CEOS coordinates civil spaceborne observations of the Earth. Participating agencies strive to address critical scientific questions and to harmonise satellite mission planning to address gaps and overlaps.

CEOS has three primary objectives in pursuing this goal:

- to optimise benefits of spaceborne Earth observations through cooperation of its Members in mission planning and in development of compatible data products, formats, services, applications and policies;
- to serve as a focal point for international coordination of space-related Earth observation activities;
- to exchange policy and technical information to encourage complementarity and compatibility of observation and data exchange systems.

CEOS Earth Observation Handbook www.eohandbook.com

CEOS

COMMITTEE ON EARTH OBSERVATION SATELLITES

Earth Observation Handbook

esa

www.eohandbook.com

CEOS Secretariat

Europe/Africa

ESA – European Space Agency
8-10, rue Mario Nikis
75738 Paris Cedex 15
France

+33 1 5369 7707 (voice)
+33 1 5369 7286 (fax)

huw.hopkins@esa.int

EUMETSAT – European Organisation for the Exploitation of Meteorological Satellites

Am Kavalleriesand 31
64295 Darmstadt
Germany

+49 6151 807 603 (voice)
+49 6151 807 555 (fax)

dwilliams@eumetsat.de

North and South America

NASA – National Aeronautics and Space Administration
300 E Street, SW
Washington, DC 20546
USA

+1 202 358 1622 (voice)
+1 202 358 2798 (fax)

devon.carroll@nasa.gov

NOAA – National Oceanic and Atmospheric Administration
1335 East-West Highway
20910-3226 Silver Spring, MD
USA

+1 301 713-2024 (voice)
+1 301 713-2032 (fax)

brent.smith@noaa.gov

Asia Pacific

MEXT/JAXA
Ministry of Education, Culture, Sports, Science and Technology / Japan Aerospace Exploration Agency
Earth Observation Research Center (EORC)
Harumi Triton Square X-tower 23F
1-8-10 Harumi, Chuoku, Tokyo, JAPAN

+81 3 6221 9139 (voice)
+81 3 6221 9180 (fax)

ceos-jpn@jaxa.jp
ishida.chu@jaxa.jp

Researched and written by:

Symbios Communications

www.symbioscomms.com

Designed and produced by:

beaucroft

www.beaucroft.co.uk

Contents

Foreword

It gives me great pleasure, on behalf of the Committee on Earth Observation Satellites (CEOS), to present the 2005 Edition of the CEOS Earth Observation Handbook, prepared by the European Space Agency (ESA).

The report presents the main capabilities of satellite Earth observations, their applications, and a systematic overview of present and planned Earth observation satellite missions and their instruments. It also explores society's increasing need for information on our planet. As humanity exceeds the planet's capacity to sustain us, such information is playing a vital role in understanding, monitoring, managing and mitigating key Earth System processes. This is true on a global scale, in support of improved global environmental governance and the underlying conventions and treaties (such as the Kyoto Protocol), and on regional and national scales, as countries adapt competitively to shrinking reserves of natural resources and to the basic needs of expanding populations. Earth System information may be considered as the essential foundation for sustainable development policies aimed at ensuring our continued health and prosperity.

The nature of climate change issues presents special challenges in terms of the need for global information and data on key planetary indicators – which can provide the information required for governments and policy makers to make well-informed decisions. Recognising that no single country can satisfy all of the observational requirements which are necessary for monitoring of the Earth System, governments are taking steps to harmonise and integrate their observing networks and satellite observing systems to be able to address common problems of global concern.

2005 marks a milestone in this co-operation process with the establishment of an international mechanism to manage the implementation of a Global Earth Observation System of Systems (GEOSS) – which represents a political commitment to move toward development of "a comprehensive, coordinated, and sustained Earth observation system".

Such ambitions are inconceivable without the measurement capabilities offered by the Earth observation satellite programmes being planned by the world's space agencies. The major aim of CEOS is to achieve international coordination in the planning of these programmes and to maximise utilisation of their data – in order to effectively address the most critical requirements.

I hope that the CEOS Earth Observation Handbook will continue to serve as a valuable reference source for a variety of readers, including those with needs in Earth System research, and decision-makers in political and socio-economic sectors. I further hope that it can help improve optimisation of the overall observation strategy, which is central to our future success.

Volker Liebig
Director of Earth Observation Programmes
European Space Agency

Introduction

The 2005 CEOS Earth Observation Handbook explores society's increasing need for information on our planet, being the essential foundation for sustainable development policies aimed at ensuring our continued health and prosperity in the face of man-made climate change, population growth, and degradation of our natural environment.

It explains the important role of Earth observation satellite programmes in fulfilling those information needs. It presents the current status and plans for future Earth observation satellite programmes of governments world-wide, through their national and regional space agencies, and describes how the data and information which they supply relate to some of society's most pressing needs for information on Earth System processes and our interaction with them.

The role of the Committee on Earth Observation Satellites (CEOS), as the body with responsibility for co-ordination of government-funded satellite programmes world-wide, is explained, including in relation to plans now underway for implementation of a Global Earth Observation System of Systems (GEOSS).

It is hoped that this report will prove to be a valuable source of information concerning the possible application and value of the data and information from Earth observation satellites. It should be of interest to a wide range of groups: those with responsibility for national/international development policy; those responsible for programmes with requirements for observations to enable understanding of our environment and its processes; and those needing information for decision-making in many socio-economic sectors.

It is further hoped that this report will be of educational value, helping to explain some of the techniques and technologies underlying satellite Earth observation and making the subject as accessible as possible to the lay-person who would like to investigate further.

As an up-to-date and comprehensive compilation of CEOS agency plans, the report provides a handy reference source of information on current and future civil Earth observation programmes. It also provides details of points of contact within CEOS and lists relevant internet information sources for those requiring more information.

Part I of the Handbook discusses the Earth System and highlights current concerns and trends (section 1). It explains the ongoing development of the GEOSS (section 2) and the important role for satellite Earth observations and for CEOS (section 3). Future challenges are discussed in section 4.

Part II presents a number of case studies (section 5) to illustrate the use of Earth observation satellites supporting the provision of information for societal benefit in key areas.

Part III of the Handbook summarises Earth observation satellite capabilities and plans, including a description of the various types of satellite missions and instruments and their applications (section 6). For those interested in particular measurements (e.g. of 'ozone' or 'ocean temperature'), section 7 provides details of 26 different parameters and the plans for their observation during the coming decades. Sections 8 & 9 contain catalogues of satellite missions and instruments respectively.

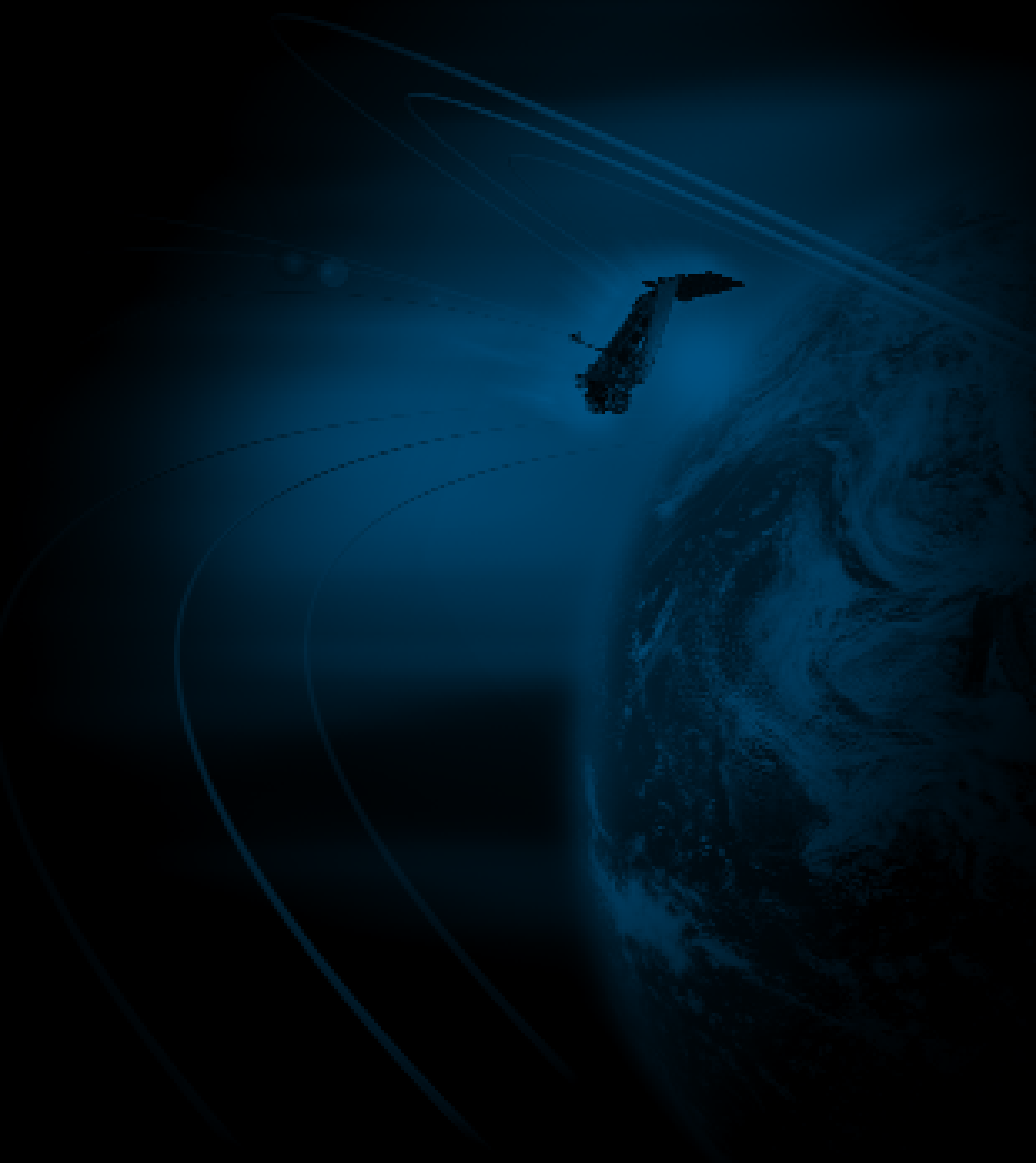
The annexes include:

A Further information on CEOS

B CEOS involvement in IGOS

C Abbreviations

Part I: Global environmental issues & the role for Earth observations



1 What on Earth is going on?

1.1 Introduction

Parts II and III of this document explain the capabilities and contribution of more than 150 satellites planned by space agencies around the world over the next 15 years. The majority of these are dedicated to the study of different aspects of the Earth System, and in particular climate change science.

The planning and funding of these missions is the responsibility of individual governments, based on their strategic assessments of national priorities and user community needs.

Through the Committee on Earth Observation Satellites (CEOS), member agencies respond to the necessity for international cooperation and harmonisation in future efforts, driven by a need for a common understanding of the state of our environment and future information priorities. Coordination through CEOS is particularly important given the lead times involved in planning and launching Earth observation satellite missions and the need for timely information to anticipate the most pressing environmental issues that will face future generations. This section presents a brief discussion of the context for these efforts, including:

- a discussion of humankind's impact on the Earth System and the consequent global changes (in part based upon the IGBP Science Report: 'Global Change and the Earth System: A planet under pressure' (2001));
- scientific predictions for the future, based on climatic trends, and estimates of human population growth and consumption patterns (in part based upon the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), 'Climate Change 2001');
- the beginnings of global environmental governance: the importance of Earth System science for the development of our understanding of global change and mitigation of its effects, and the necessity for observations of the Earth as baseline information for future decision-making aimed at sustainable development (in part based on 'A Guide to World Resources 2002-2004' by UNDP, UNEP, World Bank, and the World Resources Institute).

1.2 Humankind's interaction with nature

Not so long ago, our planet Earth seemed infinitely large in its extent and capacity to support human life and lifestyles. Distances seemed huge, news travelled slowly, and our imaginations were fired by rare images of exotic peoples and unspoilt and remote countries – abundant in natural beauty and resources. In 2005, the Earth feels like a much smaller place. Modern communications and transportation have shrunk distances, the daily news is a global bulletin, and we communicate with, and consume and trade products and services supplied by, people and countries from around the globe – without so much as a second thought.

Until very recently in the history of Earth, humans and their activities have been an insignificant force in the dynamics of the Earth System. From the start of the industrial revolution more than 200 years ago, developed nations have achieved ever greater prosperity and higher living standards. Combined with a six-fold increase in the global human population within those 200 years, these factors have resulted in significantly increased resource consumption, evident in agriculture and food production, industrial development, energy use and urbanisation.

Some facts are slow to be absorbed and accepted by a generation unaccustomed to associating environmental factors with lifestyle and consumer choices. But today it is a reality that humankind has begun to match and even exceed nature in terms of changing the biosphere and impacting other facets of Earth System functioning.

The magnitude, spatial scale, and pace of human-induced changes to our atmosphere, oceans, geology, chemistry, and biodiversity are unprecedented and are so pervasive and profound that they affect the Earth on a global scale in complex, interactive and accelerating ways. We now have the capacity to alter the Earth System in ways that threaten the very processes and components upon which humans depend – not simply requiring some adjustments in society, but so far-reaching in impact that human existence may be radically and irreversibly altered.

The speed of these changes is in the order of decades to centuries, not the centuries-to-millenia pace of comparable change in the natural dynamics of the Earth System. In other words, changes that normally happen in geologic time are happening during the lifetime of a human being:

- in a few generations humankind is in the process of exhausting fossil fuel reserves that were generated over several hundred million years;
- human action has transformed almost half of the Earth's land surface with significant consequences for biodiversity and climate;
- more than half of all accessible freshwater is used directly or indirectly by humankind;
- concentrations of several climatically important greenhouse gases, in addition to CO_2 and CH_4, have substantially increased in the atmosphere;
- coastal and marine habitats are being dramatically altered; 50% of mangroves have been removed and wetlands have shrunk by one-half;
- extinction rates are increasing sharply in marine and terrestrial ecosystems around the world;
- the Earth is now in the midst of its first great extinction event caused by the activities of a single biological species (humankind).

In 2002, a report on the state of world resources (published by the UN Development and Environment Programmes, World Bank, and World Resources Institute) indicated an 'overwhelming human dependence on rapidly deteriorating ecosystems' – the systems that support all life on Earth.

In brief, the ways in which we meet basic human needs (such as water, food, shelter, health, employment) of the 6.4 billion people inhabiting the Earth at present, have a critical impact on our environment – at all scales. In particular, the affluence of the developed world and our appetite for consumer goods for entertainment, for mobility, for communication and a broad range of goods and services, is placing significant demands on global resources.

Our Dependence and Impact on Ecosystems

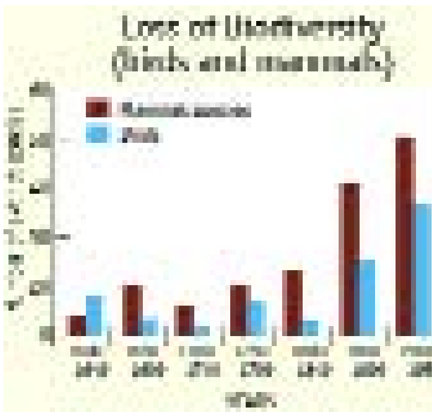
Annual value of global agricultural production	$1.3 trillion
Percentage of global agricultural lands showing soil degradation	65%
Population directly dependent on forests for survival	350 million
Decline in global forest cover since pre-agricultural times	50%
Population dependent primarily on fish for protein	1 billion
Percentage of global fisheries over-fished or fished at their biological limit	75%
Percentage of world population living in water-stressed river basins	41%
Percentage of normal global river flow extracted for human use	20%
Percentage of major river basins strongly or moderately fragmented by dams	60%
Percentage of Earth's total biological productivity diverted to human use	40–50%

1.3 The Earth's Signs

There is increasing evidence to suggest that the functioning of the Earth System is changing in response to human activities. This 'global change' includes, but is not limited to, climate change.

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established to bring together the world's leading scientists to conduct rigorous surveys of the latest technical and scientific literature on climate change. The IPCC summarised the main effects of human activity on our climate as follows:

- the composition of the atmosphere has changed since the industrial era, with increased concentrations of greenhouse gases due primarily to fossil-fuel burning and land-use change: since 1750, concentrations of carbon dioxide have increased by 31%, methane by 151% and nitrous oxide by 17%; it is believed that present carbon dioxide concentrations are unprecedented in the past 420,000 years;
- land and oceans have warmed: global average surface temperature has increased by about 0.6°C during the 20th century;
- globally, it is very likely that the 1990s were warmer than at any time in the last 1000 years;
- precipitation patterns have changed;
- the frequency, persistence and magnitude of El Niño events has increased;



UNEP

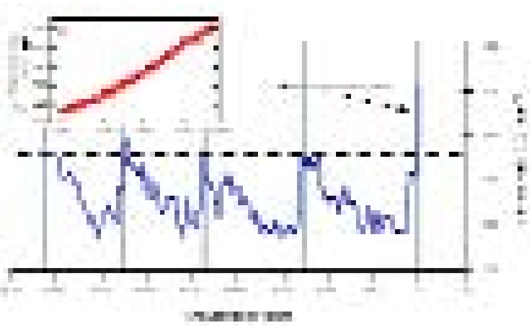
- global average sea level has risen over the last century: tide gauge data indicate a global average rise of 10-20cm, attributed to thermal expansion of the oceans and melting of the polar ice caps and glaciers.

The Earth's climate does vary naturally as a result of interactions between the ocean and the atmosphere, changes in the Earth's orbit, fluctuations in energy received from the sun and volcanic eruptions. However, the best scientific knowledge and evidence available suggests that the Earth System has recently moved well outside the range of natural variability exhibited over at least the last half million years. The nature of changes now occurring simultaneously in the global environment, their magnitudes and rates, are unprecedented in human history, and probably in the history of the planet.

The main human influence on global climate is likely to be emissions of greenhouse gases such as carbon dioxide (CO_2) and methane. At present, about 6.5 billion tonnes of CO_2 are emitted globally each year, mostly through burning coal, oil and gas for energy. Changes in land use mean a further net annual emission of 1-2 billion tonnes of CO_2. Increasing concentrations of these greenhouse gases in the atmosphere over the last 200 years have trapped more energy in the lower atmosphere, altering global climate.

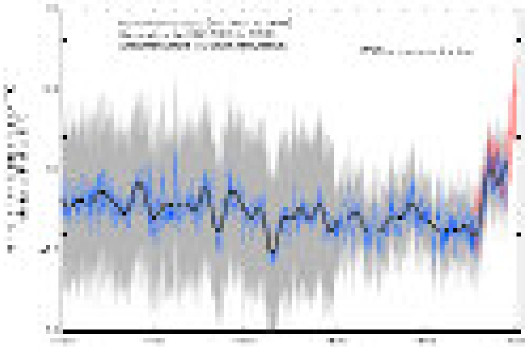
The IPCC's 2001 Third Assessment Report on the scientific basis for climate change reported that "an increasing body of observations gives a collective picture of a warming world and other changes in the climate system". The report concludes that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities".

IGBP (GLOBAL CHANGE AND THE EARTH SYSTEM)



Recent human influence on the carbon cycle

IPCC THIRD ASSESSMENT REPORT, TECHNICAL SUMMARY OF WG1 REPORT



Variations in Earth's surface temperature for the past 1000 years

1.4 Future Trends

In the summer of 2003, an extreme drought and heat wave hit Europe. This had enormous adverse social, economic and environmental effects, such as the premature deaths of up to 30,000 vulnerable people (particularly the elderly), the destruction of large areas of forests by fire, and effects on water ecosystems and glaciers. It caused power cuts, transport restrictions and decreased agricultural production. The losses are estimated to exceed 13 billion euros. Global change, it seems, is already with us, and the IPCC has predicted that this trend will accelerate:

- greenhouse gas emissions due to fossil fuel burning are virtually certain to be the dominant influence on trends in atmospheric greenhouse gas concentrations in the coming century;

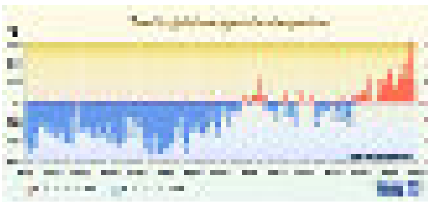
- assuming a 'business as usual' scenario in which greenhouse gas emissions continue to rise, the global average surface temperature is expected to rise between 1.4°C and 5.8°C: this rate of warming is without precedent in at least the last 10,000 years;

- this warming is likely to have profound effects on precipitation patterns and occurrence of extreme weather events;

- global mean sea-level is projected to rise by between 9cm and 88cm in the coming century: tens of millions of people are projected to be at risk of being displaced by sea level rise.

Increases in human population (estimated to increase by 50% over the next 50 years), increases in resource consumption by society, and changes in technology and socio-political organisations, are expected to accelerate these changes to our environment.

The need to feed this expanding human population requires that crop yields increase by over 2% annually throughout the next three to four decades. Significant land-use change is anticipated – resulting from intensification of agriculture in areas that are already cropped, and conversion of forests and grasslands into



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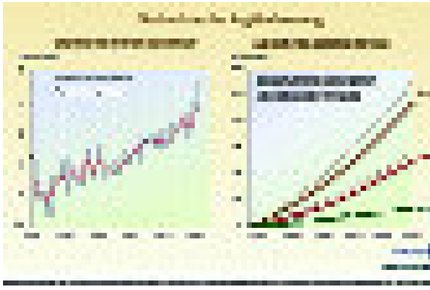

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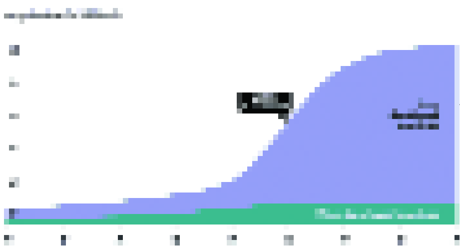

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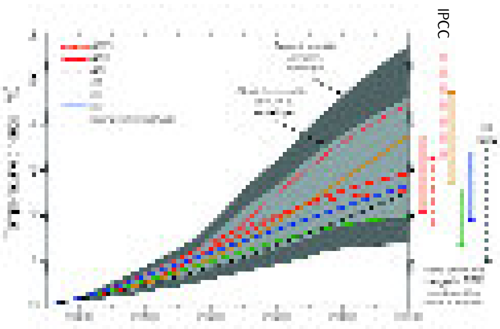


IPCC

Climate models predict surface temperature rise in the next century

cropping systems. Strong links between land cover and climate (including in relation to exchange of greenhouse gases, the radiation balance of the Earth surface, and exchange of heat between the land surface and atmosphere) suggest that land-use change may be one of the most significant components of global change in the coming century.

Significant uncertainties remain. Despite employing sophisticated global computer models capable of determining climate sensitivity to drivers such as greenhouse gas concentrations or land-use change, we do not yet know where critical thresholds may lie. Nor can we say if, when and how the increasing human enterprise will propel the Earth System towards and across the boundaries to different states of the global environment. Scientists have proposed a number of ‘tipping points’ – such as the North Atlantic Current, the Asian monsoon, the West Antarctic Ice Sheet, and the forests of the Amazon basin – which, if subjected to stress, could trigger large-scale, rapid and cascading changes across the entire planet.

1.5 Global environmental governance

Humanity is already ‘managing the planet’, but in an unconnected and haphazard way driven ultimately by individual and group needs and desires. The Earth System is being pushed beyond its natural operating domain and the global management challenges involved in the achievement of a sustainable future are unprecedented.

Widespread public awareness of the ‘environment’ dates back to the 1960s and 1970s, born from concerns such as air and water pollution, use of pesticides, and disasters such as the first catastrophic oil spill from a supertanker. Many governments established environment ministries and environmental protection agencies in the 1970s, leading to new consideration of environmental issues and demands for environmental information. Industry too became more environmentally aware, with the realisation of new trends in consumer behaviour and due to the introduction of new legislation and environmental regulations.

Environmental governance is a global endeavour, however, and requires global solutions beyond the mandate of individual governments. Over the last two decades, the prospect that the global climate could change as a result of human influence has generated widespread concern. An unprecedented co-operative global response has developed as a result, including:

- **international decision-making and policy measures:** Governments and national and regional agencies are pursuing increased political and legal obligations to address Earth System-related topics of global concern. Such obligations are often encapsulated within international treaties, whose signatories have explicit requirements placed upon them;
- **collaboration in scientific research and assessment:** including the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 by the World Meteorological Organisation (WMO) and the UN Environment Programme (UNEP). The IPCC acts as the source of technical advice to the United Nations Framework Convention on Climate Change (UNFCCC).

There are several examples of far-sightedness on the part of governments as nations have struggled to assemble a coherent system of global environmental governance in response to increasing environmental awareness: e.g. the Montreal Protocol (on protection of the ozone layer) and the Convention on International Trade in Endangered Species (CITES). There are in fact 500 or so international environmental agreements now in effect, of which about 150 are global treaties. But environmental trend indicators suggest that our prodigious efforts at environmental diplomacy have largely failed to make serious headway against the world's most pressing environmental challenges.

Basic principles of good global environmental decision-making were pioneered at the Rio Earth Summit in 1992, where 172 nations endorsed environmental governance principles when they signed the Rio Declaration on Environment and Development, a charter of 27 principles meant to guide the world community toward sustainable development. The World Summit on Sustainable Development (Johannesburg, 2002) reviewed the progress of the previous 10 years and initiated new commitments on: expanding access to water and sanitation, energy, improving agricultural yields, managing toxic chemicals, protecting biodiversity and improving ecosystem management - not only by governments, but also by NGOs, intergovernmental organizations and businesses, who launched over 300 voluntary initiatives. The problem in applying these good governance practices is not their novelty, but the fact that they profoundly challenge traditional government institutions and economic practices.

The challenge is further complicated politically, by the mismatch in timing between the environmental and political/electoral impact, and by the fact that only though international action – commonly agreed and commonly implemented – can the problem be addressed, since profound structural and economic re-engineering will be involved for participating nations. Disparities between developed and developing countries will emerge and nations may seek competitive advantage in the process. Such teething problems have all been apparent in the definition and implementation of treaties such as the Kyoto Protocol to the UNFCCC which imposes binding limits on greenhouse gas emissions by developed countries relative to their 1990 levels.

One of the challenges is the difficulty of agreement on specific targets, their enforcement and the financing of that enforcement. A more systemic problem is that current environmental agreements have arisen in an ad hoc and largely uncoordinated fashion as each new environmental problem – acid rain, ozone depletion, global warming – has entered the public consciousness. They reflect a single-issue approach toward environmental stewardship and have not sprung from an integrated perspective that sees the common drivers of environmental decline.

At the international level, there is rhetorical commitment to the goals of sustainable development and participatory decision-making. However, there is far less commitment to localising these goals in national policies and decision-making practices. There is a fundamental reluctance in our societies to shoulder the domestic political and financial costs to make global environmental treaties enforceable.

1.6 Global science for global sustainability

Just as science and technology has given us the evidence to measure the danger of climate change, so it can help us find safety from it. Earth System science is the key to implementing any approach towards good planetary management, providing us with the necessary insights into the feasibility, risks, trade-offs and timeliness of any strategy considered.

The nature of climate change issues presents special challenges in terms of the need for global information and data on key planetary indicators, which can provide the information required for governments and policy makers to make well-informed decisions. Recognising that no single country can satisfy all of the observational requirements that are necessary for monitoring of the Earth System, governments are taking steps to harmonise and integrate their observing networks and satellite observing systems to be able to address common problems of global concern.

This document discusses the need for observations of planet Earth and its environment and highlights the opportunities presented by Earth observation satellite systems to produce information for decision-making.

If the best current scientific expertise is correct in predicting the future impacts of human-induced climate change and the likelihood that such changes are, if anything, likely to accelerate with an expanding human population in the coming century – then such information will become increasingly vital; providing an essential foundation for the development of ethics of global governance and strategies for sustainable Earth System management that will define how humankind adapts in future to the expected global change.

IPCC: www.ipcc.ch

Planet under pressure: www.igbp.kva.se

World Resources Institute: www.wri.org

World population: www.prb.org

UNEP: www.unep.org

2 Towards a Global Earth Observation System of Systems (GEOSS)

2.1 Why observe the Earth?

An improved understanding of the Earth System – of its weather, climate, oceans, land, geology, natural resources, ecosystems, and natural and human-induced hazards – is essential if we are to better predict and mitigate against the expected global changes and the impacts on human civilisation.

Data collected and information created from Earth observations constitute critical inputs to the exploration of sustainable management of the Earth – providing evidence for informed decision-making, supporting the science that underpins strategies for global environmental governance, and for monitoring our progress on all geographical scales.

The significance of Earth observations in our future decision-making processes is apparent in both:

- **the long term:** where high-quality information must be gathered continuously over many years in support of vital climate studies to:
  - *observe and characterise the current climate;*
  - *detect climate change, determine the rate of change and assist in attributing the causes of change;*
  - *identify the climate changes resulting from human activities;*
  - *validate climate models and assist in prediction of the future climate;*
  - *understand and quantify impacts of climate change on human activities and natural systems.*
- **the short term:** where better information on every-day activities that support human existence will be a vital component of the global strategy for adaptation to a world with a rapidly increasing population, depleting natural resources, and experiencing the possible consequences of human-induced climate change; regions, countries, and industries can all be expected to be striving for improved efficiency and international competitiveness in agricultural production, freshwater management, land use management, atmospheric emissions control, natural resources exploration and management – including forests and fossil fuels, as well as in the prediction and mitigation of more frequent extreme weather events and natural disasters.

This information will be required on all scales – from local to global. We can anticipate that it might be used by intergovernmental bodies for decision-making and global governance to ensure sustainability, and also more locally as countries, regions, and industries compete for larger shares of smaller reserves of natural resources in order to support their growing populations and economic ambitions. Such information takes many forms, spanning data on population, demographics, economics, and environmental indicators. Observations of planet Earth itself, of man's environment, might be regarded as the most important of all, as the context for all decisions.

Earth observing systems help to provide data in support of a wide range of information needs, on Earth parameters which are central to:

- **improved understanding:** with a multitude of global scale observations contributing to research into Earth System processes;
- **evidence:** Earth observations support the formulation of authoritative scientific advice – which is vital for governments when deciding to fund mitigation measures in response to global change, to react to impending crises in resource shortages, or to participate in agreements or conventions which require costly changes in national consumption patterns;
- **monitoring and compliance:** we might expect to see increasing emphasis on international policy measures and treaties such as the Kyoto Protocol emerging in the future; Earth observations will play an essential role in monitoring such agreements, ensuring that countries meet their legal obligations in relation to challenges like reductions in fossil fuel emissions, or pollution dumping.

  The economic implications of such agreements can be enormous for countries and highly visible and public measures to deter 'cheating' will be an important part of their success;
- **management and mitigation:** in support of increased efficiency in providing basic resources for future generations and in predicting and countering the worst effects of severe weather and natural disasters.

The beneficiaries will be a broad range of global user communities, including: national, regional, and local decision-makers; organisations responsible for the implementation of international conventions and treaties; business, industry, and service sectors; scientists and educators; and, of course, every inhabitant of planet Earth.

2.2 The GEO Initiative

In what might be considered as a first step towards establishment of the Earth observations component of a far-sighted scheme for global environmental governance, high-level officials from 33 countries, from the European Commission, and from 21 international organisations involved in Earth observations, convened in Washington DC, USA on 31st July 2003 to attend the 'First Earth Observation Summit'.

Recalling the urgent need expressed by the World Summit on Sustainable Development (WSSD – Johannesburg 2002) for coordinated observations relating to the state of the Earth, these governments and organisations adopted a Declaration signifying a political commitment to move toward development of "a comprehensive, coordinated, and sustained Earth observation system".

The Summit established the ad hoc intergovernmental Group on Earth Observations (GEO), co-chaired by the European Commission, Japan, South Africa and the United States of America, and tasked it with the development of an initial 10-Year Implementation Plan by February 2005. The 2nd EO Summit (Tokyo, April 2004) developed a 'Framework Document' to guide this process.

The Plan will define the operating principles, institutions and commitments relating to the establishment of a Global Earth Observation System of Systems (GEOSS). The Group envisages that GEOSS will be:

- **comprehensive**, by including observations and products gathered from all components required to serve the needs of participating members;
- **coordinated**, in terms of leveraging resources of individual contributing members to accomplish this system, whose total capacity is greater than the sum of its parts;
- **sustained**, by the collective and individual will and capacity of participating members.

GEOSS will be a distributed system of systems, building step-by-step on current cooperation efforts among existing observing and processing systems within their mandates, while encouraging and accommodating new components. Participating members will determine ways and means of their participation in GEOSS.

Nine topics were identified on which there was agreement that clear societal benefits could be derived from a coordinated global observation system:

- reducing loss of life and property from natural and human-induced **disasters**;
- understanding environmental factors affecting **human health** and well being;
- improving management of **energy resources**;
- understanding, assessing, predicting, mitigating, and adapting to **climate** variability and change;
- improving water resource management through better understanding of the **water cycle**;
- improving **weather** information, forecasting, and warning;
- improving the management and protection of terrestrial, coastal, and marine **ecosystems**;
- supporting sustainable **agriculture** and combating desertification;
- understanding, monitoring, and conserving **biodiversity**.

It is anticipated that each societal benefit area will evolve over time and that others may be added in due course.

The rationale for GEOSS is that collective action is needed to bring operational observing systems in line with the requirements for addressing a range of issues of concern to society; and that we are currently not getting full value from the substantial investment (of the order of tens of billions of euros per year in total) already made in Earth observation. This results from the lack of systematic implementation, coordination, data exchange and attention to information systems that meet user needs.

The global, comprehensive, integrated and sustained effort outlined in the GEOSS 10-Year Implementation Plan aims to address such shortcomings in the following ways:

- **agreements on system interoperability and data sharing:** thereby increasing the number and type of observations available for analysis, as well as their spatial and temporal coverage, while only marginally increasing the cost of data provision. GEOSS provides a mechanism through which partial or full data sharing can be negotiated and a technical process by which it can be achieved;
- **collective optimisation of the observation strategy:** using cooperation to avoid redundancies in sampling, and gaining synergies and cost savings by using observational infrastructure for multiple purposes;
- **cooperative gap filling:** for example, in overcoming national difficulties in justifying certain observations for local benefit, and ensuring monitoring of regions outside the territory of individual nations (such as the open oceans and Antarctica);

- **commitments to observational adequacy and continuity:** a fundamental commitment to continuation of observations at an acceptable level of accuracy and coverage is essential for realisation of all the benefits envisaged for GEOSS.

The ad hoc GEO process is scheduled to conclude its work with the 3rd EO Summit, to be held in Brussels, where it is expected that an international mechanism (to be known as GEO - without the ad hoc) will be established to take forward an agreed 10-Year Implementation Plan and to serve as a focus for cooperation efforts.

The First Earth Observation Summit

Declaration of the Earth Observation Summit

We, the participants in this Earth Observation Summit held in Washington, DC, on July 31, 2003:

Recalling the World Summit on Sustainable Development held in Johannesburg that called for strengthened cooperation and coordination among global observing systems and research programmes for integrated global observations;

Recalling also the outcome of the G-8 Summit held in Evian that called for strengthened international cooperation on global observation of the environment;

Noting the vital importance of the mission of organizations engaged in Earth observation activities and their contribution to national, regional and global needs;

Affirm the need for timely, quality, long-term, global information as a basis for sound decision making. In order to monitor continuously the state of the Earth, to increase understanding of dynamic Earth processes, to enhance prediction of the Earth System, and to further implement our environmental treaty obligations, we recognize the need to support:

(1) Improved coordination of strategies and systems for observations of the Earth and identification of measures to minimize data gaps, with a view to moving toward a comprehensive, coordinated, and sustained Earth observation system or systems;

(2) A coordinated effort to involve and assist developing countries in improving and sustaining their contributions to observing systems, as well as their access to and effective utilization of observations, data and products, and the related technologies by addressing capacity-building needs related to Earth observations;

(3) The exchange of observations recorded from in situ, aircraft, and satellite networks, dedicated to the purposes of this Declaration, in a full and open manner with minimum time delay and minimum cost, recognizing relevant international instruments and national policies and legislation; and

(4) Preparation of a 10-year Implementation Plan, building on existing systems and initiatives, with the Framework being available by the Tokyo ministerial conference on Earth observations to be held during the second quarter of 2004, and the Plan being available by the ministerial conference to be hosted by the European Union during the fourth quarter of 2004.

To effect these objectives, we establish an ad hoc Group on Earth Observations and commission the group to proceed, taking into account the existing activities aimed at developing a global observing strategy in addressing the above. We invite other governments to join us in this initiative. We also invite the governing bodies of international and regional organizations sponsoring existing Earth observing systems to endorse and support our action, and to facilitate participation of their experts in implementing this Declaration.

(Adopted 31 July 2003)

GEO Members

- Algeria
- Argentina
- Australia
- Belgium
- Belize
- Brazil
- Cameroon
- Canada
- Central African Republic
- Chile
- China
- Croatia
- Cyprus
- Denmark
- Egypt
- Finland
- France
- Gabon
- Germany
- Greece
- Guinea-Bissau
- India
- Indonesia
- Iran
- Ireland
- Israel
- Italy
- Japan
- Kazakhstan
- Latvia
- Luxembourg
- Mali
- Mexico
- Morocco
- Mozambique
- Nepal
- Netherlands
- New Zealand
- Nigeria
- Norway
- Portugal
- Republic of the Congo
- Republic of Korea
- Russian Federation
- South Africa
- Spain
- Sudan
- Sweden
- Switzerland
- Thailand
- Ukraine
- United Kingdom
- United States
- Uzbekistan

GEO Participating Organisations

- ADIE
- CCAD/SICA
- CEOS
- ECMWF
- EEA
- ESA
- EUMETNET
- EUMETSAT
- European Commission
- FAO
- FDSN
- GCOS
- GEO Secretariat
- GOOS
- GTOS
- IAG
- ICSU
- IEEE
- IGBP
- IGFA
- IGOS-P
- IISL
- IOC
- ISCGM
- ISDR
- POGO
- UNCBD
- UNCCD
- UNEP
- UNESCO
- UNFCCC
- UNOOSA
- WCRP
- WMO
- World Bank (IBRD)

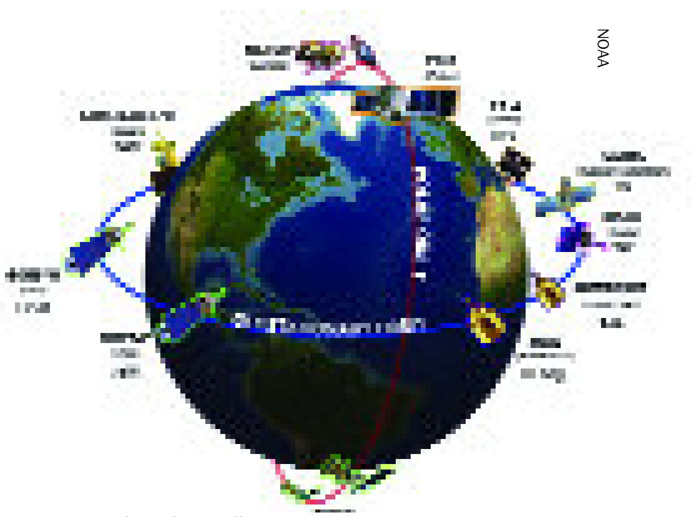
2.3 Existing observing systems

As a 'system of systems' GEOSS will encompass a broad range of existing and planned networks of satellite-borne and Earth-based sensors, including ocean buoys, weather stations and atmospheric radiosondes – providing important parameters relating to land, ocean, and atmospheric processes. It has long been recognised that the range of observations, many of which are global, needed to understand and monitor Earth System processes and to assess the impact of human activities cannot be satisfied by a single programme, agency, or country. The main Earth observing networks are therefore typically international collaborative programmes by nature, and include:

World Weather Watch

The best known of these networks may be the World Weather Watch (WWW) of the World Meteorological Organization (WMO). The WWW is a unique achievement in international cooperation, providing a truly world-wide operational system to which virtually every country in the world contributes, every day of every year, for the common benefit of humankind.

The Global Observing System (GOS) of the WWW - which includes around 10,000 stations on land providing observations near the Earth's surface, at least every three hours, of meteorological parameters such as atmospheric pressure, wind speed and direction, air temperature and relative humidity – ensures that every country has all the information available to generate weather analyses, forecasts and warnings on a day-to-day basis. The most obvious benefits of the GOS are the safeguarding of life and property through the forecasting, detection and warning of severe weather phenomena such as local storms, tornadoes, and tropical cyclones. GOS provides observational data for agricultural management, aviation safety,



NOAA

Operational weather satellites

meteorology and climatology, including the study of global change. These observations also provide an international database of upper air observations for research purposes.

22 Global Atmosphere Watch (GAW) stations world-wide supplement these observations with information on ozone, other greenhouse gases, solar radiation, UV, and other atmospheric and meteorological parameters.

The Global Observing Systems

Within the last decade, the Global Observing System of the World Weather Watch has been complemented by the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS) to produce a set of Global Observing Systems integrating in-situ and remotely sensed data from a range of international, regional and national observing systems and networks, with each focusing on a major component of the Earth System. The Global Climate Observing System (GCOS) has also been planned and initiated to integrate the observing needs for climate purposes.

GOOS: GOOS is a permanent global system for observations, modelling and analysis of marine and ocean variables to support operational ocean services worldwide. GOOS will provide accurate descriptions of the present state of the oceans, including living resources; continuous forecasts of the future conditions of the sea; and the basis for forecasts of climate change. GOOS is capitalising on existing ocean observing systems, such as:

- The TAO/TRITON array: comprises 70 moored buoys in the Tropical Pacific Ocean, which since its completion in 1994 has enabled real-time collection of high quality oceanographic and surface meteorological data for monitoring, forecasting, and understanding of climate swings associated with El Niño and La Niña. Data and graphic displays from the TAO/TRITON array are updated every day, and the data are freely available to the research community, operational forecasting community, and the general public.
- The Global Sea Level Observing System (GLOSS): an international programme coordinated by the Intergovernmental Oceanographic Commission (IOC) for the establishment of high quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research. The main component of GLOSS is the 'Global Core Network' (GCN) of 290 sea level stations around the world for monitoring long term trends and accelerations in global sea level.

There are numerous other contributors to GOOS, including: voluntary observing ships providing measurements of upper ocean and meteorological parameters; the Global Temperature and Salinity Profile Programme; and the Global Coral Reef Monitoring Network.

GTOS: GTOS is a programme for observations, modelling, and analysis of terrestrial ecosystems to support sustainable development. GTOS facilitates access to information on terrestrial ecosystems so that researchers and policy makers can detect and manage global and regional environmental change.

To achieve this GTOS is working towards the establishment of a "system of networks", formed by linking existing terrestrial monitoring sites and networks as well as planned satellite remote sensing systems. Thematic networks have been established for ecology, glaciers, and permafrost, and a hydrology network is in progress.

Since the sustainable development of forest resources is regarded as one of the most pressing environmental issues of our time, GTOS has established a panel on Global Observations of Forest Cover and Land Cover Dynamics (GOFC-GOLD) which aims to improve the quality and availability of observations of forests at regional and global scales and to produce useful, timely and validated information products from these data for a wide variety of users.

The Global Terrestrial Network (GT-Net) links the world's terrestrial research networks together. It serves as a framework for network managers to explore areas of common interest, harmonize research efforts and share data, information and experience.

GCOS: GCOS was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. It is co-sponsored by WMO, the IOC, the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). GCOS is intended to be a long-term, user-driven operational system capable of providing the comprehensive observations required for monitoring the climate system, for detecting and attributing climate change, for assessing the impacts of climate variability and change, and for supporting research toward improved understanding, modelling and prediction of the climate system. It addresses the total climate system including physical, chemical and biological properties, and atmospheric, oceanic, hydrologic, cryospheric and terrestrial processes.

GCOS does not itself directly make observations nor generate data products. It stimulates, encourages, coordinates and otherwise facilitates the taking of needed observations by national or international organisations in support of their own requirements as well as of common goals. It provides an operational framework for integrating, and enhancing as needed, observational systems of participating countries and organisations into a comprehensive system focussed on the requirements for climate issues.

GCOS builds upon, and works in partnership with, other existing and developing observing systems such as the Global Ocean Observing System, the Global Terrestrial Observing System, and the Global Observing System and Global Atmospheric Watch of the WMO.

The Integrated Global Observing Strategy Partnership

The Integrated Global Observing Strategy Partnership (IGOS-P) was established in June 1998 by a formal exchange of letters among the 13 founding Partners for the definition, development and implementation of the Integrated Global Observing Strategy (IGOS). The principal objectives of the IGOS are to address how well user requirements are being met by the existing mix of observations, including those of the global observing systems, and how they could be met in the future through better integration and optimisation of remote sensing (especially space-based) and in-situ systems.

The IGOS serves as guidance to those responsible for defining and implementing individual observing systems. Implementation of the Strategy, like the establishment and maintenance of the components of an integrated global observing system, lies with those governments and organisations that have made relevant commitments, for example, within the governing councils of the observing systems' sponsors.

To aid the development of the Strategy, the Partners have adopted an incremental "Themes" approach based on perceived priorities. The Ocean Theme was the first IGOS Theme report to be approved and published – in January 2001. Since then a number of other Themes have been developed, or are in progress:

- Global Carbon Cycle;
- Geo-hazards;
- Global Water Cycle;
- Atmospheric Chemistry;
- Coastal Zones/Coral Reefs;
- Land;
- Cryosphere.

The IGOS Themes represent a strong foundation in international cooperation for the future efforts of GEOSS. Further information on IGOS-P and the IGOS Themes is presented in annex B.

GEO: earthobservations.org

World Weather Watch:
www.wmo.ch/web/www/www.html

The Global Observing Systems:
www.gos.udel.edu

GCOS: www.wmo.ch/web/gcos/gcoshome.html

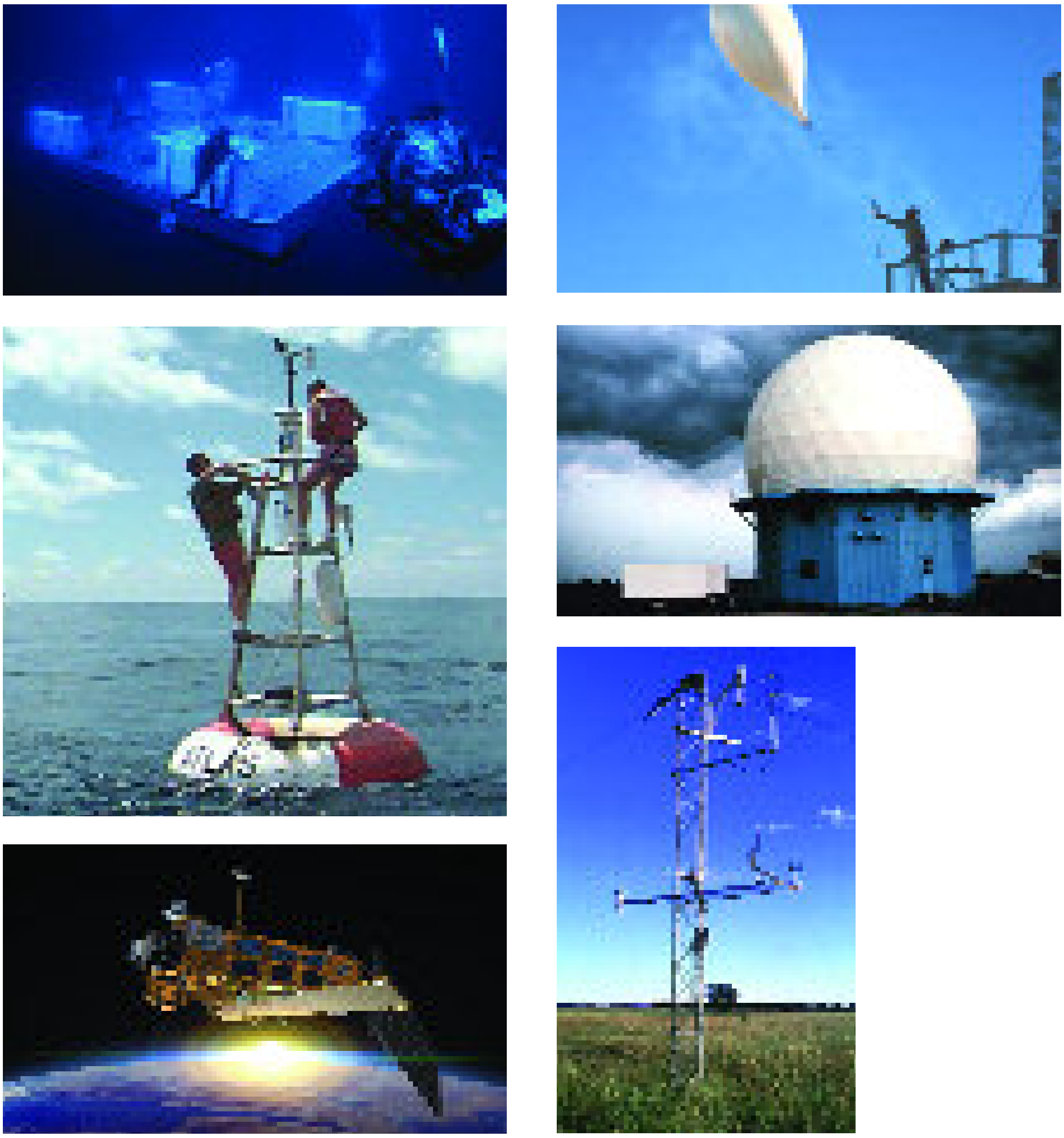
GOOS: ioc.unesco.org/goos

GTOS: www.fao.org/gtos

The IGOS Partnership: www.igospartners.org

Earth observation: www.esa.int/export/esaEO
earthobservatory.nasa.gov

The science of remote sensing:
rst.gsfc.nasa.gov/start.html



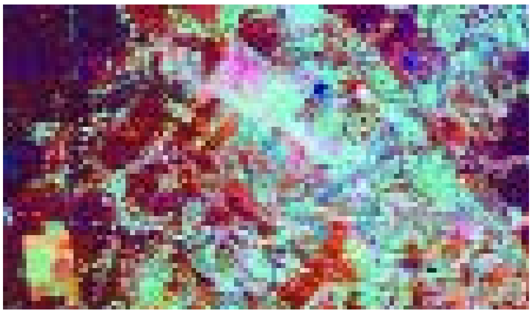
A multitude of in-situ and space-based sensors contribute to Earth observations

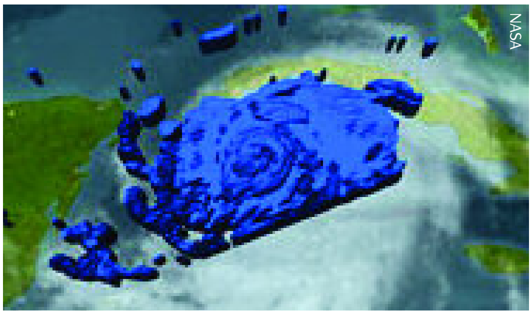
IGOS Theme Reports

3 The important role of satellite Earth observations – and CEOS

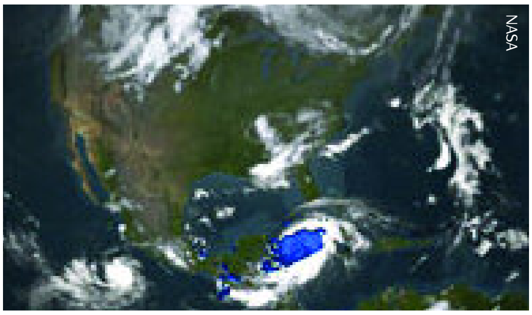
3.1 Satellite Earth observations

Since the first TV images of the Earth from space were transmitted by the TIROS-1 satellite back in 1960, humankind has recognised the benefits of this unique and global perspective of our home planet. There are currently 68 Earth observation satellite missions operating, and around 100 more missions, carrying over 300 instruments, planned for operation during the next 15 years or so by the world's civil space agencies. An increasing number of commercial Earth observation satellites, which are funded, launched, and operated by industry, are also emerging to address important spatial information markets.





Space-based remote sensing observations of the atmosphere-ocean-land system have evolved substantially since the first operational weather satellite systems were launched. Over the last decade Earth observation satellites have proven their capabilities to accurately monitor nearly all aspects of the total Earth System on a global basis; a capability unmatched by ground-based systems that are limited to land areas and cover only about 30% of the planetary surface. Currently, satellite systems monitor the evolution and

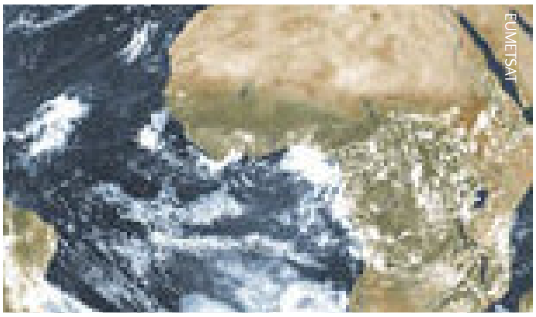


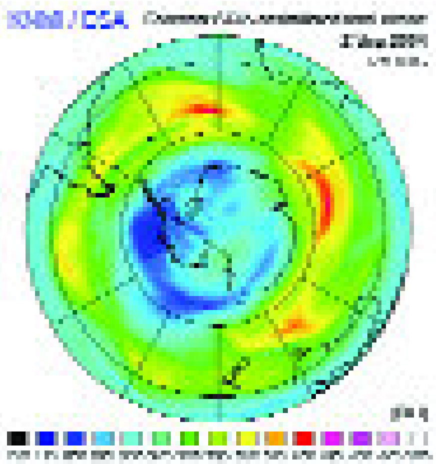
impact of the El Niño, weather phenomena, natural hazards, and extreme events such as floods and droughts, vegetation cycles, the ozone hole, solar fluctuations, changes in snow cover, sea ice and ice sheets, ocean surface temperatures and biological activity, coastal zones and algal blooms, deforestation, forest fires, urban development, volcanic activity, tectonic plate motion, and others. These various observations are used extensively in real-time decision-making and in the strategic planning and management of industrial, economic, and natural resources.

The proliferation of Earth observation satellites reflects their unique abilities and benefits, such as:

- inherent wide area observation capability: offering synoptic views of large-scale phenomena, and placing in-situ measurements in the global context required for the observation of many environmental and climatic phenomena;
- non-intrusive observations: allowing collection of data to take place without compromising national sovereignty in the way that ground-based measurements or airborne remote sensing might; this is an advantage in the context of use within international environmental treaties;
- uniformity: in that the same sensor may be used at many different places in the world (some of which are inaccessible, making in-situ measurements infeasible);
- rapid measurement capability: allowing sensors to be targeted at any point on Earth, including remote and hostile areas;
- continuity: with single sensors or series of sensors providing long time series of data suitable for climate studies.

Present-day applications of satellite data are widespread and cover research, operational and commercial activities. On a global scale, space-based systems make a considerable contribution to the collection of data required for climate change research, in providing high-quality, consistent, global datasets over long time periods for use in understanding the climate system, detection of potential anthropogenic change, validating climate models, and predicting future change.





Satellites are capable of obtaining global spatial coverage, particularly over the vast expanses of the oceans, sparsely populated land areas (e.g. deserts, mountains, forests, and polar regions), and the mid and upper troposphere and stratosphere. Satellites provide unique measurements of solar output, the Earth's radiation budget, vegetation cover, ocean biomass productivity, atmospheric ozone, stratospheric water vapour and aerosols, greenhouse gas distributions, sea level and ocean interior, ocean surface conditions and winds, weather, and tropical precipitation, among others.

Earth observation satellite applications are not limited to meteorology, climate and environmental studies; Earth observation satellites deliver information to a broad range of sectors, providing significant economic, societal, and humanitarian benefits as a result, including:

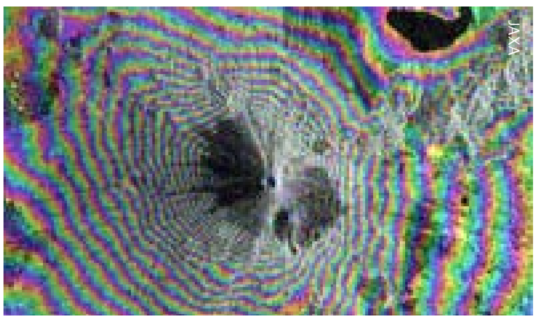
- agriculture and forestry services utilise satellite data to provide, amongst other products, mapping information, crop health statistics, yield predictions, harvest optimisation, and estimated rainfall amount;
- resource mapping utilising very high resolution satellite data, when combined with conventional survey techniques, provides information needed to locate both renewable and non-renewable resources, such as mineral deposits, and a cost-effective means of mapping large, sometimes inaccessible regions;
- hazard monitoring and disaster assessment schemes are in place which incorporate satellite data to provide wide area coverage of, amongst other things, volcano plumes and areas stricken by drought or earthquake;
- commercial fishing industries routinely utilise satellite-derived fishing assessments to optimise their operations;
- ocean wave and current information is used by offshore exploration companies and shipping to improve operational safety and route-planning;
- mapping and urban planning agencies exploit satellite imagery for generation of maps and digital elevation models.

3.2 CEOS

What is CEOS?

CEOS is the Committee on Earth Observation Satellites, created in 1984 in response to a recommendation from a Panel of Experts on Remote Sensing from Space, under the aegis of the Economic Summit of Industrialised Nations Working Group on Growth, Technology and Employment.

CEOS was established to provide coordination of the Earth observations being provided by satellite missions – recognising that no single programme, agency, or nation can hope to satisfy all of the observational requirements which are necessary for improved understanding of the Earth System. Since its establishment, CEOS has provided a broad framework for international coordination on spaceborne Earth observation missions.



What does CEOS contribute?

CEOS strives to facilitate the necessary harmonisation and achieve maximum cost-effectiveness for the total set of space-based observation programmes of member countries and agencies.

CEOS has established three primary objectives in pursuing this goal:

- to optimise benefits of spaceborne Earth observations through cooperation of its Members in mission planning and in development of compatible data products, formats, services, applications and policies;
- to serve as a focal point for international coordination of space-related Earth observation activities;
- to exchange policy and technical information to encourage complementarity and compatibility of observation and data exchange systems.

The work of CEOS spans the full range of activities required for proper international coordination of Earth observation programmes and maximum utilisation of their data, and ranges from the development of detailed technical standards for data product exchange, through to the establishment of high level interagency agreements on common data principles for different application areas – such as global climate change and environmental monitoring.

Who participates in CEOS?

CEOS membership comprises most of the world's civil agencies responsible for Earth observation satellite programmes – amounting to 24 Members in 2005. CEOS also has 20 Associates, comprising:

- governmental organisations that are international or national in nature and that are developing Earth observing satellite programmes or significant supporting ground facility programmes;

CEOS On-line

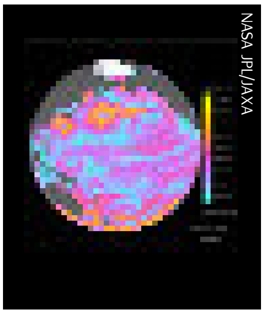
- other existing satellite coordination groups and scientific or governmental bodies that are international in nature and currently have a significant programmatic activity that supports CEOS objectives.
- The full list of Members and Associates is shown in the tables on pages 18 and 19.

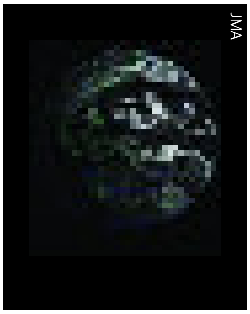
How does CEOS operate?

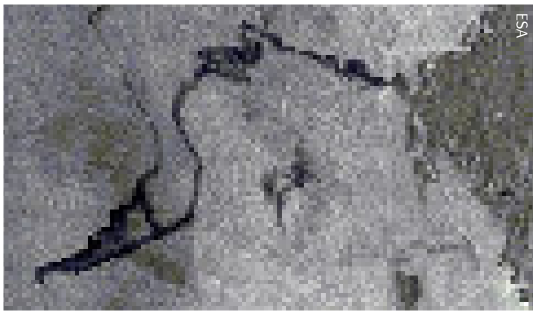
CEOS is managed by Plenary, at which CEOS Principals meet annually. The CEOS Plenary determines policy, reviews progress on the projects and activities being undertaken, and sets the agenda of activities for the upcoming year. The Chair of CEOS rotates at the annual Plenary.

The work of CEOS is conducted within its various working groups. Coordination throughout the year is maintained through a permanent Secretariat maintained by the European Space Agency (ESA) jointly with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the National Aeronautics and Space Administration (NASA) jointly with the National Oceanic and Atmospheric Administration (NOAA) of the USA, and the Ministry of

17th CEOS Plenary participants, Colorado Springs, November 2003







Education, Culture, Sports, Science and Technology (MEXT) jointly with the Japan Aerospace Exploration Agency (JAXA).

CEOS, IGOS-P and GEO

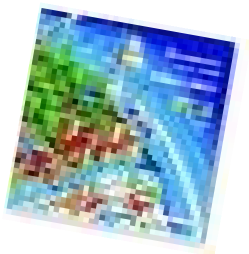
CEOS was one of the founding Partners that established the Integrated Global Observing Strategy Partnership. The principal objectives of the Integrated Global Observing Strategy are to address how well user requirements are being met by the existing mix of observations, including those of the global observing systems, and how they could be met in the future through better integration and optimisation of satellite remote sensing and in-situ systems.

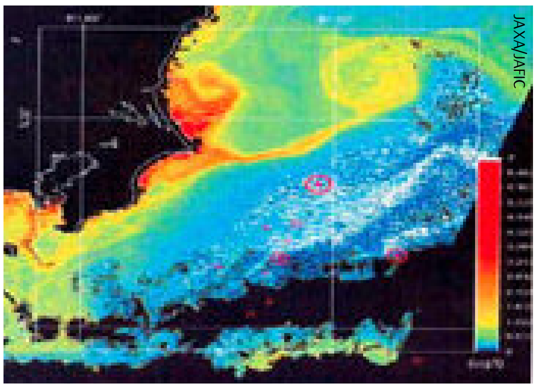
Strengthened links between space-based and Earth-based observing systems, and with scientific and environmental policy-making processes, provide compelling motivation for CEOS to take an active role in IGOS-P activities, and CEOS has embraced the concept of an IGOS as a valuable initiative which perfectly complements its own set of objectives.

By working together, CEOS agencies are in a position to plan their Earth observation programmes with the minimum of unnecessary overlap and to devise joint strategies for addressing serious gaps in their observation capabilities. As GEO evolves (see section 2), CEOS expects to extend its efforts to support the space observation aspects of its Implementation Plan for a global system of systems.

More information

Further information on the membership, structure, activities, and achievements of CEOS is provided in Annex A of this document.





Organisation		Country / Countries
ASI	Agenzia Spaziale Italiana	Italy
BNSC	British National Space Centre	United Kingdom
CAST	Chinese Academy of Space Technology	China
CNES	Centre National d'Etudes Spatiales	France
CONAE	Comisión Nacional de Actividades Espaciales	Argentina
CSA	Canadian Space Agency	Canada
CSIRO	Commonwealth Scientific and Industrial Research Organisation	Australia
DLR	Deutsches Zentrum für Luft- und Raumfahrt	Germany
EC	European Commission	Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom
ESA	European Space Agency	Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom. (Luxembourg and Greece anticipated to become full members during 2005. Canada, Hungary and Czech Republic are Cooperating States of ESA)
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom. (plus 9 cooperating states: Slovak Republic, Hungary, Poland, Croatia, Republic of Serbia and Montenegro, Slovenia, Romania, Czech Republic and Latvia)
INPE	Instituto Nacional de Pesquisas Espaciais	Brazil
ISRO	Indian Space Research Organsation	India
KARI	Korea Aerospace Research Institute	Korea
MEXT/JAXA	Ministry of Education, Culture, Sports, Science and Technology / Japan Aerospace Exploration Agency	Japan
NASA	National Aeronautics and Space Administration	United States of America
NASRDA	National Space Research and Development Agency	Nigeria
NRSCC	National Remote Sensing Center of China	China
NSAU	National Space Agency of Ukraine	Ukraine
ROSHYDROMET	Russian Federal Service for Hydro-meteorology and Environment Monitoring	Russia
ROSKOSMOS	Russian Federal Space Agency	Russia
SNSB	Swedish National Space Board	Sweden
USGS	United States Geological Survey	United States of America

CEOS Membership

Organisation		Country / Countries
CCRS	Canada Centre For Remote Sensing	Canada
CRI	Crown Research Institute	New Zealand
ESCAP	Economic and Social Commission of Asia and the Pacific	UN
FAO	Food and Agriculture Organization	UN
GCOS	Global Climate Observing System	International Programme
GISTDA	Geo-Informatics and Space Technology Development Agency	Thailand
GOOS	Global Ocean Observing System	International Programme
GTOS	Global Terrestrial Observing System	International Programme
ICSU	International Council for Science	International Programme
IGBP	International Geosphere-Biosphere Programme	International Programme
IOC	Inter-governmental Oceanographic Commission	UNESCO
IOCCG	International Ocean Colour Coordinating Group	International Programme
ISPRS	International Society for Photogrammetry and Remote Sensing	International Programme
NRSC	Norwegian Space Centre	Norway
OSTC	Federal Office for Scientific, Technical and Cultural Affairs	Belgium
SAC/CSIR	Satellite Applications Centre/Council for Scientific and Industrial Research	South Africa
UNEP	United Nations Environment Programme	UN
UNOOSA	United Nations Office of Outer Space Affairs	UN
WCRP	World Climate Research Programme	UN
WMO	World Meteorological Organization	UN

CEOS Associates

CEOS: www.ceos.org

Earth Observation Handbook: www.eohandbook.com

CEOS Newsletter:
www.ceos.org/pages/newsletter.html

CEOS Annual Report:
www.ceos.org/pages/annual_reports.html

CEOS Brochure:
www.ceos.org/pdfs/CEOS_Bro2004e.pdf

CEOS CD-ROM:
http://ceos.cnes.fr:8100/html/cd00.htm

CEOS Database:
alto-stratus.wmo.ch/sat/stations/SatSystem.html

For CD-ROM copies of CEOS Database:
dhinsman@wmo.int

IGOS Partnership: www.igospartners.org

4 Future challenges: from science to services

As humanity exceeds the planet's capacity to sustain us, the measurement capabilities offered by Earth observation satellites will play an increasingly important role in understanding, monitoring, managing and mitigating key Earth System processes. This is true on a global scale – in support of far-sighted attempts to improve global environmental governance, and on regional and national scales – as countries adapt competitively to shrinking reserves of natural resources, and to the basic needs of expanding populations.

Without these capabilities we would have insufficient information for future Earth System sciences studies, which depend on data-intensive computer models, we would have insufficient evidence with which to inform our decision-making on policies aimed at sustainable development, and we would have no way of checking the effectiveness of our adaptation strategies in terms of the trends of key global environmental parameters. Earth-based measurement systems alone cannot provide the synoptic global picture which is required.

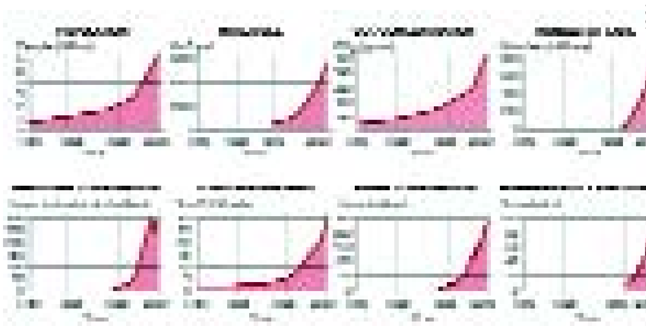
Around 170 Earth observation satellite missions (hosting over 340 different observing instruments) are being funded by the world's space agencies in the coming years in response to the most pressing Earth System information needs – as expressed by the international, science, policy, and operational monitoring communities. These missions also respond to more immediate needs in relation to a variety of economic, social, and environmental concerns, including: weather services, agricultural efficiency and yield optimisation, fisheries management, mapping, hazard monitoring and disaster response, ship routing and safety, national security, pollution monitoring, resource exploration and protection, urban planning, insurance business support, and others.

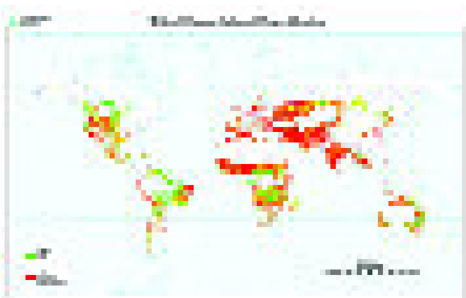
CEOS is recognised internationally as having the responsibility for the coordination and planning of government-funded Earth observation satellite missions. The scale of the information demand, and the scale of the planned information supply (involving satellite programmes of more than 30 countries), makes such coordination an increasingly complex, but increasingly essential undertaking if we are to maximise the transfer of benefits to society and ensure supply of vital Earth System information for current and future generations.

To achieve this goal, within the framework of the proposed GEOSS, CEOS and its partners will face a number of challenges:

Accelerating the transition from science-focused missions to operational services: Many Earth observation satellite programmes, even those providing vital information on long term climate indicators and trends, are still derived from research projects – and as such lack access to continuity and stability in funding and staffing. Only by being seen to provide operational, essential services to society – such as those provided by satellite meteorology – can future programmes ensure appropriate consideration in government planning processes. This operational status, whereby information is provided on a routine and long term basis without interruption, is now being demanded by a broader range of user groups, including those involved in ocean monitoring, ozone and UV monitoring, carbon cycle studies, pollution alerting, and food security, amongst others.

Improved optimisation of the overall observation strategy: Despite the best efforts of both the space and in-situ observations communities, the current observation networks and future plans remain far from ideal. Large parts of the globe are under-sampled; there is substantial redundancy in some observations resulting from lack of coordination; and entire topics of vital interest to society are missing crucial observations taken on a sustained basis. The IGOS Partnership has demonstrated that an integrated observation strategy is both more effective and more efficient than stand-alone strategies. More specific coordination will be essential in the coming decades, linked to the early planning and financing processes of individual countries and agencies. This coordination must include: mechanisms for

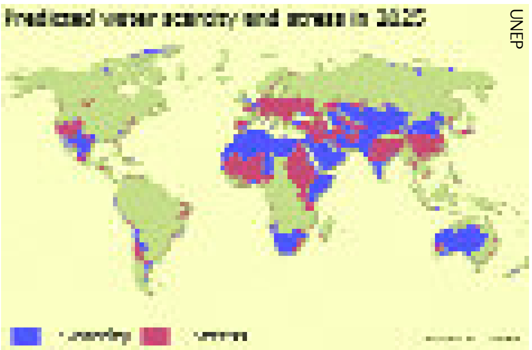

IGBP

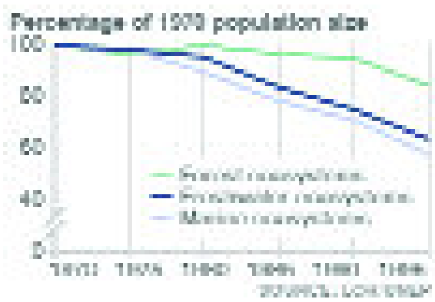


Risk of human-induced desertification

strengthened links between satellite and in-situ observation systems; more multi-use Earth observation systems, derived from co-ordination of requirements of different user communities in order to exploit efficiencies in their synergies and commonalities; and creative mechanisms for sharing costs and benefits so that all countries – large or small, developed or developing – might contribute to, and participate in, a global cooperative effort, in ways which, individually, many nations might otherwise be unable to achieve or justify.

Increased uptake and utilisation of Earth observation data for maximum overall benefit: It is a fact that much more data is collected than used by those who need it, because it is hard or costly to access, or may be in a form that is difficult to interpret, compare with existing sources, or is of uncertain quality. CEOS has identified improved data utilisation as a future priority for action, including: enhancing data delivery systems to ensure optimal access; new mechanisms and technical means for data sharing and exchange; improving our ability to compare and integrate different data sources so as to maximise their utility; provision of supporting education, training and capacity building to guarantee the necessary expertise for data exploitation.





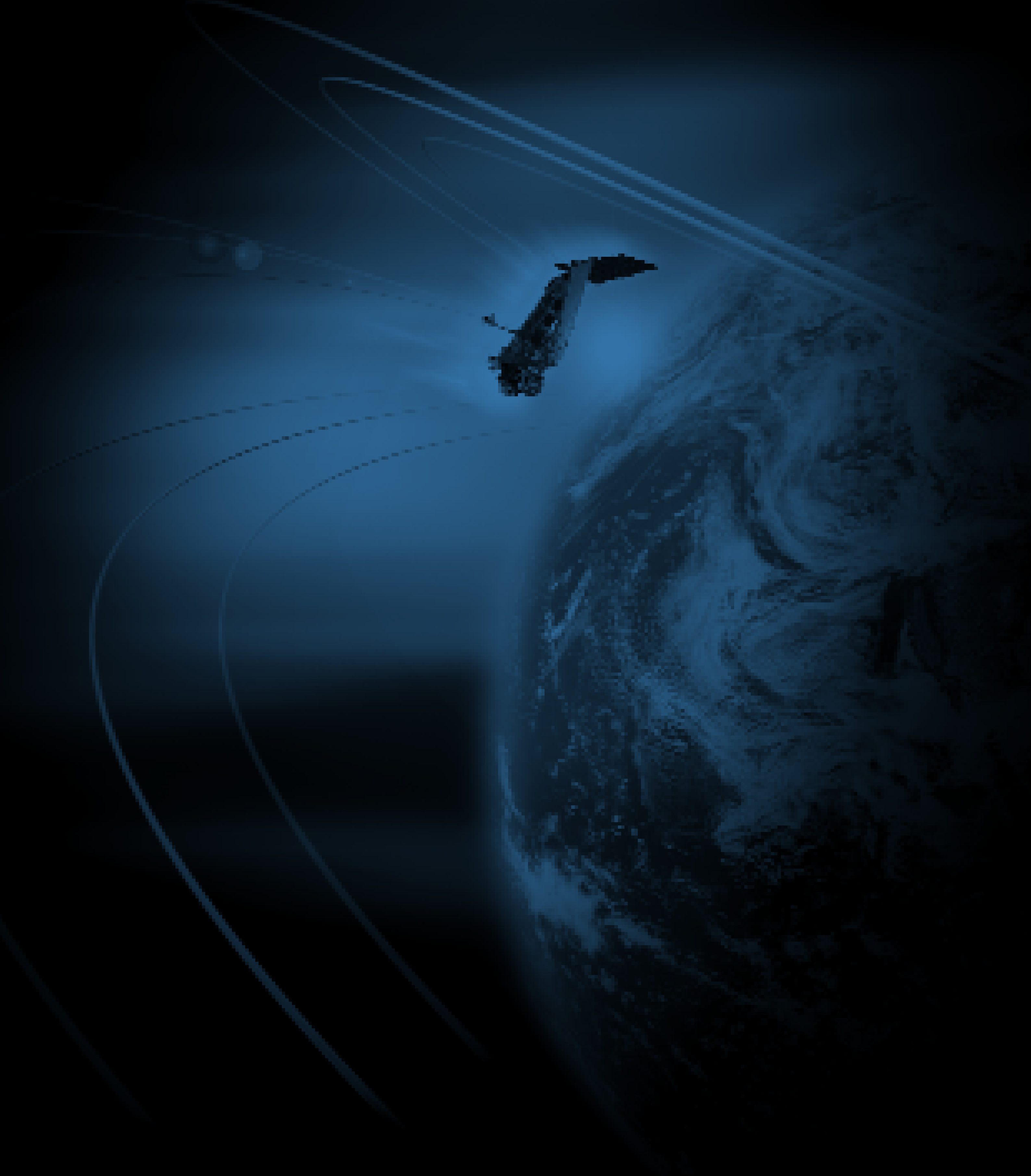
UNEP's Living Planet Index – a measure of biodiversity changes in different ecosystems since 1970

Ensuring continuity of future observations: None of the above actions are meaningful without a fundamental commitment to continuation of observations at an acceptable level of accuracy and coverage. The IPCC predicts that, should the current decline in observational networks continue, we may have less information on the Earth System in future decades than in the final decades of the 20th century. Recognising the need for coordination of Earth observation satellite programmes, CEOS will aim to ensure continuity, consistency, and inter-comparability of the priority measurements throughout the coming decades – consistent with the requirements of climate studies for trend monitoring and change detection.

Strengthening partnerships between observation planners and global environmental governance frameworks: International political will is a prerequisite to any successful solution to global environmental issues which span political borders. Although international cooperation on environmental issues is still in its infancy, progress on major issues is being achieved. However, public concern over man-made climate change will demand further progress during the 21st century – especially on managing fossil fuel emissions and the global carbon cycle. Providing the information required by decision-makers who represent our countries in the legal and political processes that develop international policies, and by the agencies which monitor compliance and impact of these policies, must be a priority for future observation programmes, including those of CEOS and its Members. CEOS will therefore seek to strengthen partnerships with relevant global environmental governance bodies as they develop, including: those with responsibility for implementation of the GEOSS 10-year Plan; the secretariats of international treaties and conventions relating to Earth's environment and sustainable development (such as the UNFCCC, and the UN Commission for Sustainable Development (CSD); the IPCC, recognised as the main source of assessment advice to these bodies) – to ensure that future satellite missions reflect their priorities for Earth System information.

The progress of the GEO initiative of the last two years has elevated political awareness of, and participation in, international cooperation in the planning of future Earth observations to meet society's needs. CEOS has 20 years experience as an Earth observation international coordination body and provides GEOSS with a ready-made and proven mechanism for coordination of space agencies and their programmes.

Part II: Case studies – information for societal benefit



5 Case studies

5.1 Introduction

Part I highlighted a range of environmental issues and challenges which face our 'planet under pressure' in the 21st century, including those arising from climate change and expected increase in human population.

This section highlights how Earth observation satellite programmes support both the information needs of the main Earth System challenges and more immediate needs for information in the social, economic, and environmental domains.

5.2 Contents

Within the GEOSS Implementation Plan, nine topics are identified where clear societal benefits could be derived from a coordinated global observation system:

- reducing loss of life and property from natural and human-induced **disasters**;
- understanding environmental factors affecting **human health** and well being;
- improving management of **energy resources**;
- understanding, assessing, predicting, mitigating, and adapting to **climate** variability and change;
- improving water resource management through better understanding of the **water cycle**;
- improving **weather** information, forecasting,and warning;
- improving the management and protection of terrestrial, coastal, and marine **ecosystems**;
- supporting sustainable **agriculture** and combating desertification;
- understanding, monitoring, and conserving **biodiversity**.

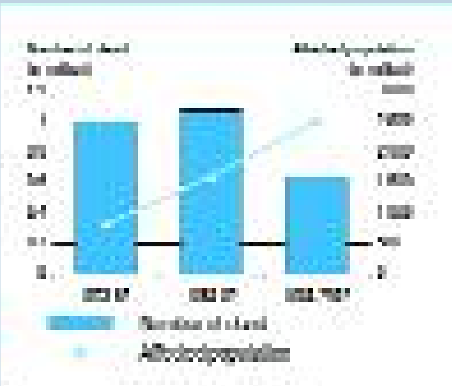
The potential role for Earth observations from satellites in each of these areas is presented here in Part II. In each case, the issues affecting society and the anticipated future consequences are discussed. (Note that ecosystems and biodiversity are addressed together in a single case study.) The need for information and the role of Earth observation satellites is explained, including an indication of future plans.

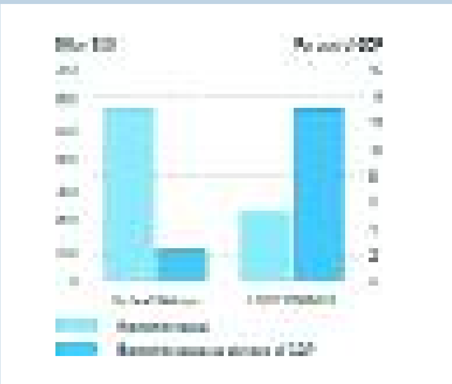
Disaster Mitigation

Human and economic losses due to natural disasters continue to increase despite best efforts undertaken by communities, governments and international support organisations. Data for 2003 from reinsurance companies report the occurrence of around 700 'disasters', with over 50,000 people killed, almost five times as many as in the previous year (11,000); such a high number of victims has only been recorded four times since 1980. Economic losses rose to over US$60 billion (in 2002: US$55 billion). Swiss Re, the world's second largest insurer, has estimated that the economic costs associated with hazards resulting from global warming alone could increase to US$150 billion each year in the coming decade.

Economic and human impacts of disasters 1973-2002

UNISDR





Developing countries are disproportionately affected, with their losses rising to about five times higher per unit of GDP than for the rich countries, sometimes exceeding years of hard-won and desperately needed economic development. Natural disasters should be recognised as a major obstacle to sustainable development.

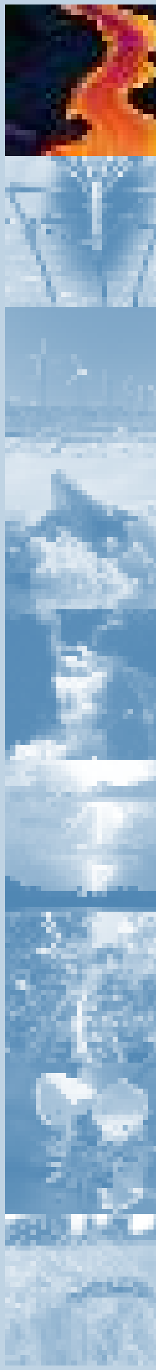
The natural hazards which lead to these disasters with the potential to create loss to humans and to their welfare include: floods, typhoons, tsunamis, hurricanes and cyclones, earthquakes, tornadoes, volcanic eruptions, landslides, subsidence, drought, and wildfires – coupled with a wide range of pollution and other events that are at least partially human induced, and secondary disasters such as disease outbreaks that commonly follow floods or earthquakes.

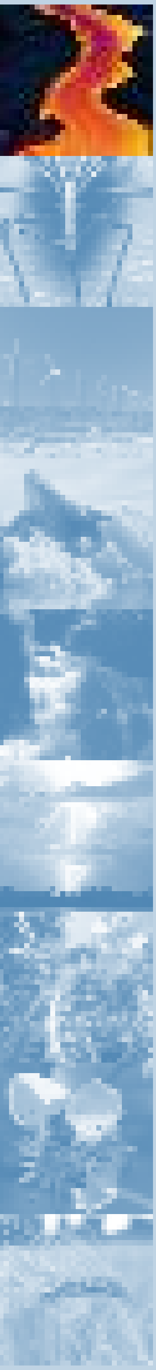
A wide variation in the number and intensity of such natural hazards is normal and to be expected – but the events of the last few decades suggest that there may be an upward trend caused by human activities, including growing numbers living in areas affected by disasters. Many scientists believe that the recent upsurge of weather-related natural disasters is the product of increased global warming. There were three times as many great natural disasters in the 1990s as in the 1960s, while disaster costs increased more than nine-fold in the same period. The reason for the upward trend in loss of life and wealth is apparent; ninety per cent of disaster victims worldwide live in developing countries, where poverty and population pressures force growing numbers of poor people to live in harm's way – on flood plains, in earthquake-prone zones and on unstable hillsides.

Disaster mitigation information

Natural disasters cannot be prevented, but their social and economic impacts can be reduced through effective disaster management programmes. Disaster management involves a series of information-intensive activities:

- disaster knowledge and prevention: including activities aimed at the avoidance or reduction of risks, through the evaluation of the characteristics of hazards, such as their probability of occurrence, severity and location, as well as the vulnerability of life and property to such hazards;
- disaster preparedness and forecasting: activities that reflect the readiness of the public to cope with a specific hazard; actions taken in response to an ongoing or impending hazard; actions such as hazard forecasting, warning and prediction;
- emergency response, recovery and reconstruction: activities undertaken immediately before and after the onset of a hazard to reduce the effects of a disaster





after it occurs; assessment of the extent and severity of the damage; relief measures such as delivering food, health care and other sustenance; implementation of remedial and reconstruction measures.

Hazards are characterised by information on geology, tectonics, seismicity, regimes of rivers and their water basins, amount & characteristics of fuel, local meteorological conditions, terrain and topography. Vulnerability depends highly on the location of residential areas and urban centres and assets such as hospitals, schools, plants, road and utility networks, and the likely effect of a given disaster.

Meteorological forecasts are essential to prediction and warning of hurricanes, floods and fires. So far no reliable prediction system is available for earthquakes, although warnings may be issued for volcanoes and tsunamis. Evacuation plans and similar measures are triggered accordingly and their efficiency is conditioned heavily by available information on settlements, roads, etc.

Disaster reduction and risk management has moved rapidly up the policy agenda of affected governments and the international community. This trend has led to the adoption of the International Strategy for Disaster Reduction (ISDR) by governments to promote implementation of the recommendations emanating from the International Decade for Natural Disaster Reduction (IDNDR, 1990-1999). The World Conference on Disaster Reduction (WCDR), Kobe, Japan (January 2005) is a milestone event to increase the profile of disaster risk reduction in development planning and practice.

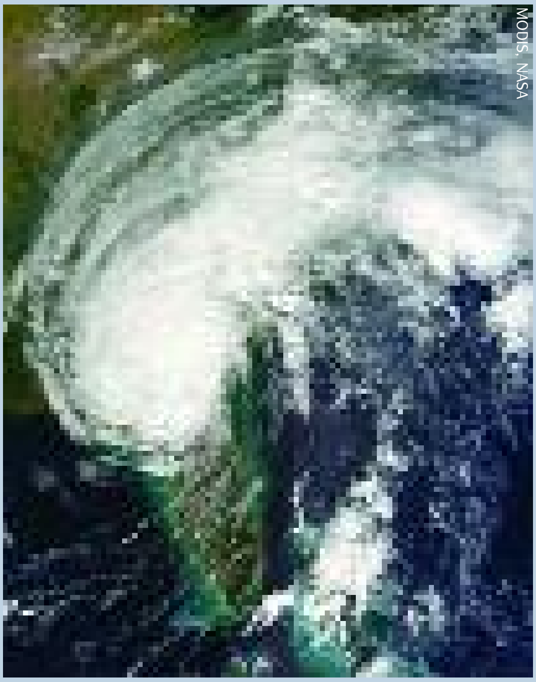
The role of Earth observation satellites

Increasingly, data derived from Earth observation satellites is being used to contribute to the information requirements of different phases of disaster mitigation programmes.

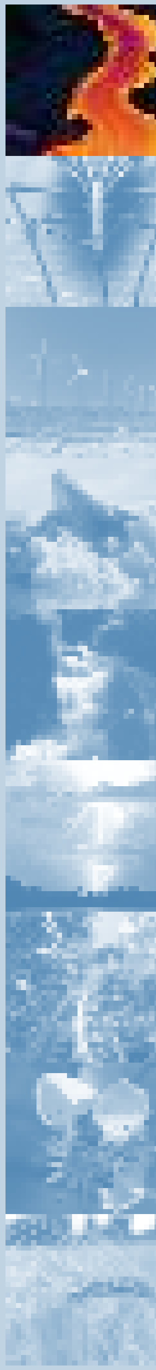
Weather satellites, have been used for more than 40 years to support forecasting of intensive weather hazards such as tropical cyclones, severe storms, and flash flooding. Today, many countries operate weather satellites, coordinating their activities to benefit an international user community through organisations such as WMO. Derived products are produced routinely several times per day, many of them focused on particular hazard events. Tracking sequences of tropical cyclone images from geostationary satellites as well as storm intensities and atmospheric winds derived from these images provide information for forecasting landfall – where and when. Recent integration of experimental products, such as ocean surface winds from scatterometer instruments and moisture or rainfall from microwave instruments, has improved these forecasts.

Forecasts and warnings for other severe storms utilise products also derived from sequences of images from geostationary satellites. Flash flood forecasts are improved with the integration of precipitation estimates derived from analysis of cloud imagery, and severe storm index sequences are utilised for warnings of severe storms such as tornadoes.

By allowing society time to prepare for or avoid an impending hazard, such forecasting and early warning systems incorporating satellite data have dramatically reduced deaths, injuries, property damage and other economic losses.



Tropical Storm Jeanne on 27th September, 2004



In recent years, Earth observation satellites have demonstrated their utility in providing data for a wide range of applications in disaster management. These include the mapping and monitoring of hydrological and seismic hazards, variables affecting climate and weather, land use, the extent of damage due to volcanic eruptions, oil spills, forest fires, the spread of desertification, and the forecasting of floods and droughts. Information from satellites is often combined with other relevant data in geographic information systems (GIS) in order to carry out risk assessment and help identify areas at risk.

Some of these capabilities are shown in the table overleaf.

Although Earth observation satellites have demonstrated their considerable potential in supporting a range of disaster management activities, space agencies have recognised that further steps are necessary to persuade the disaster management community to assimilate these new technologies into their operations. Further, to meet the needs of such a diverse range of hazards and their often critical timescales for information, the space agencies decided to pool the satellite resources of different countries more effectively for the benefit of the international community.

International Charter on Space and Major Disasters: The aim of this charter, initiated by the French (CNES) and European (ESA) space agencies, is "to supply during periods of crisis, to States or communities whose population, activity or property are exposed to an imminent risk, or are already victims, of natural or technological disasters, data providing a basis for critical information for the anticipation and management of potential crises". CSA (Canada), ISRO (India), and CONAE (Argentina) are also party to the charter. Since the Charter became operational on 1st November 2000, authorised civil defence organisations may enlist support from space by calling a telephone number, 24 hours a day, 365 days a year. Rescue and civil defence bodies of the country to which the participating agencies belong are registered authorised users. Civil protection authorities of other countries may also submit requests by contacting their sister organisations through existing cooperation mechanisms.

The Charter has proven to be a highly effective and practical mechanism for delivering applications of Earth observation satellite data to those in society in most dire need. The Charter has been activated over 55 times since its inception, and continues to support several events monthly in response to calls for assistance from countries all around the globe.

UNOSAT: UNOSAT is a consortium of UN agencies, remote sensing service companies and space agencies, and is supported by a number of CEOS Members and their national governments. UNOSAT's objectives are to facilitate the planning and monitoring processes of local authorities, local technicians, development project managers and humanitarian field operators working in coordination with or within the framework of UN activities, on issues such as disaster management, risk prevention, peace keeping operations, post-conflict reconstruction, environmental rehabilitation and social and economic development.

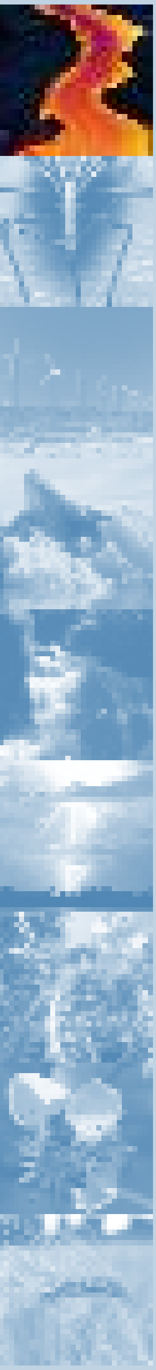
ESA

The International Disasters Charter has been activated more than 55 times since November 2000 to supply Earth observation satellite data to crisis-struck regions

ESA

UNOSAT aims to encourage, facilitate, accelerate and expand the use of accurate geographic information derived from EO-satellite imagery by professionals involved in achieving vulnerability reduction, crisis management and recovery as well as sustainable development at the local level.

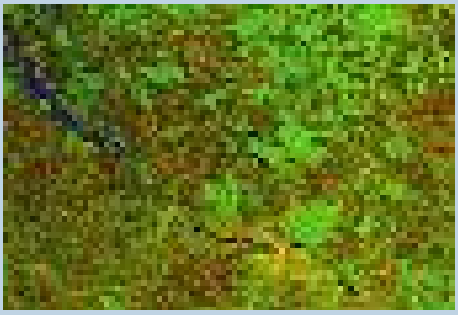
RESPOND: RESPOND is an alliance of European and international organisations working with the humanitarian community to improve access to maps, satellite imagery, and geographic information. RESPOND is a five-year staged programme providing: guaranteed access to global mapping; access to an archive of detailed base mapping, imagery and thematic mapping; and access to rapid assessment maps for major crisis. RESPOND is one of the services initiated under the GMES (Global Monitoring for Environment and Security)



initiative of ESA and the European Commission. Since 2004, the RESPOND consortium has been collaboratively producing products for the Sudan Darfur Crisis.

The reports of the CEOS Disaster Management Support Group provide excellent references on the use of Earth observation for disaster management:

SERTIT



SERTIT/ESA

Satellite imagery of flood extent is increasingly used to target response operations: examples are shown for Sudan/Darfur, August 2004 and for the River Elbe, August 2002

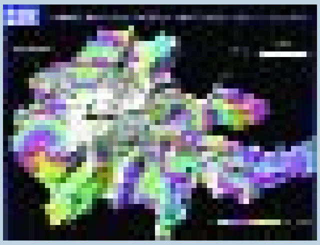
Future challenges

There are a number of obstacles to the increased use of Earth observation satellite data in disaster mitigation applications – both institutional and technical.

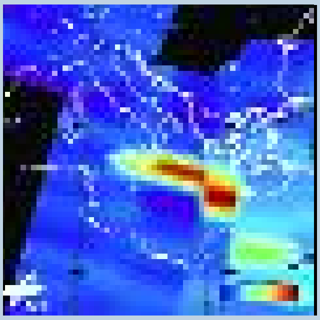
Institutionally, it is recognised that there must be greater cooperation between satellite-operating agencies, between these agencies and the commercial sector, and between all data providers and the disaster management community. This cooperation is essential if we are to achieve the scale and speed of response which is required to face diverse and time-critical disasters. In order to promote wider acceptance and use of space systems by disaster management users, the space and services communities must create the appropriate tools and continue to promote a mutual understanding and dialogue between the disaster management and space sectors.

Technically, we can expect to see future efforts aiming at providing satellite-derived information more rapidly and at higher spatial resolutions, consistent with the needs of many disaster management applications. A number of new capabilities can also be expected, including:

- improved spatial and temporal resolution of storm tracking from geostationary satellites, combined with new atmospheric wind measurements (from planned lidar instruments) and with ocean surface wind measurements (from scatterometers), to provide more accurate early warning services;
- operational tectonic strain-mapping and surface deformation monitoring techniques in support of earthquake and volcano warning systems;
- more precise precipitation measurements and modelling results as important inputs for flood warnings;
- a trend towards broad compatibility of satellite-derived information with the GIS employed to aid disaster management programmes.



DLR



USGS

Interferometric SAR techniques may be used to monitor fault motions and strain. 9 Volcanic Ash Advisory centres world-wide use ash cloud data from satellites to ensure aviation safety.

UN International Strategy for Disaster reduction: www.unisdr.org

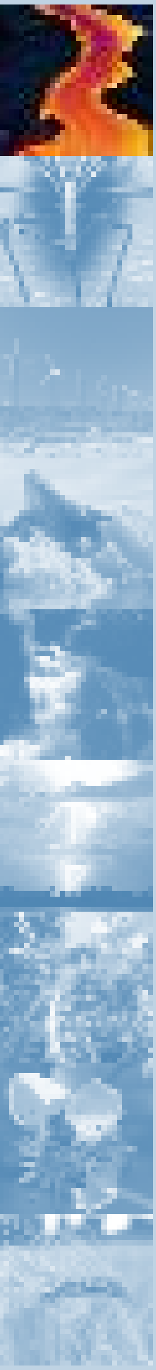
Disasters Charter: www.disasterscharter.org

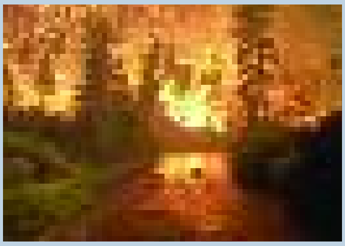
UNOSAT: www.unosat.org

RESPOND: www.respond.eu.com

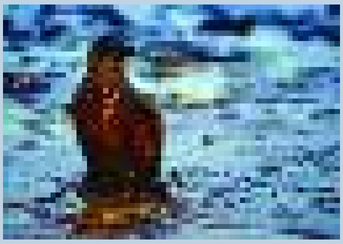
CEOS DMSG information server: disaster.ceos.org

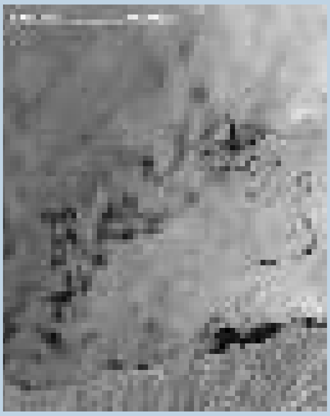
Hazard	Use of EO satellites
Hurricanes & tornadoes	Weather satellites are used extensively for detection and tracking of storms and contribute effectively to the forecasting capability. Recent satellite missions providing more detailed and frequent measurements of sea surface wind speed and tropical rainfall mapping have significantly improved forecasts.
Volcanic eruptions & earthquakes	In-situ systems and Global Positioning System (GPS) satellites provide valuable information on seismic and volcanic activity. EO satellites provide complementary data in support of disaster mitigation and response: interferometry techniques of radar sensors are used to monitor fault motions and strain, and signs of Earth surface deformation and topographic changes. Very high resolution sensors are used to map damage assessment, direct response efforts, and aid reconstruction planning. Satellite data is the primary information source employed by the 9 Volcanic Ash Advisory Centres operational world-wide which issue volcanic ash cloud warnings, an essential information source for international aviation safety.
Wildfires	A number of satellites now contribute routinely to each stage of wildfire hazard management world-wide, including: fire risk mapping using land cover and fire fuel assessments, moisture data, digital elevation maps, and meteorological information – all derived from satellite; fire detection and early warning; fire monitoring and mapping; burned area assessment.
Oil spills	Synthetic Aperture Radar (SAR) data is used as the basis for ocean surveillance systems for oil slick detection, to provide enforcement and monitoring capabilities to deter pollution dumping. The SAR data is processed within 1-2 hours of the satellite overpass and used by pollution control authorities to cue aircraft surveillance. Surveillance systems are currently operational in Norway, and Denmark, and under trial in the Netherlands, Germany, and the UK. SAR data and optical data are also used to develop information in support of major coastal oil spills, to assist in mapping pollution extent and managing the response.
Drought	Currently, multichannel and multi-sensor data sources from geostationary satellites and polar orbiting satellites are used routionely for determining key monitoring parameters such as: precipitation intensity, amount, and coverage, atmospheric moisture and winds. Instruments with spectral bands capable of measuring vegetative biomass are also used operationally for drought monitoring. The Famine Early Warning System (FEWS) in Africa, for example, exploits operational use of satellite technology to reduce the incidence of famine in sub-Saharan Africa by monitoring the agricultural growing season. Monitoring is carried out through "greenness maps" derived every 10 days from the AVHRR instrument, and from rainfall estimates.
Floods	Earth observation satellites are used for the development of flood impact prediction maps, contributing measurements of landscape topography, land use, and surface wetness for use in hydrological models. Weather satellites provide key information on rainfall predictions to assist flood event forecasting. Since optical observations are hampered by the presence of clouds, SAR missions (which can achieve regular observation of the earth's surface, even in the presence of thick cloud cover) are frequently used to provide near real-time data acquisitions in support of flood extent mapping.





US firefighters and land managers are using NASA's MODIS data to combat wildfires





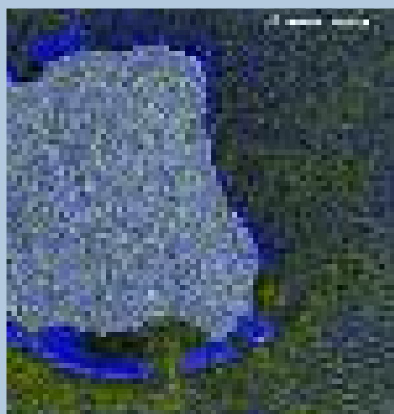
A crippled tanker carrying around 67,000 tons of oil split in half off the northwest coast of Spain on Nov. 19 2002, threatening one of the worst environmental disasters in history.

Within the framework of the International Disasters Charter ESA provided satellite images almost daily since 17 November from its ERS and Envisat spacecraft in support of relief efforts.

STOP PRESS: December 2004 Tsunami

The recent tragedy striking the coastlines of the Indian Ocean has highlighted the benefits of international cooperation in Earth Observation for the management of disaster relief, while demonstrating the scope for improved cooperation in the future. Immediately after the first tsunami struck in the Eastern Indian Ocean the International Charter on Space and Major Disasters was invoked by three different agencies. India activated the Charter for access to data over its own territory, the UN Office of Outer Space Affairs activated in relation to Indonesia and Thailand while the French Civil Protection Agency opened the Charter for the case of Sri Lanka.

As a result, data have been acquired from many satellite sources since immediately after the event, including ESA's Envisat, ERS and Proba satellites, the French SPOT series, Canada's Radarsat, the USGS Landsat and India's IRS series together with very high resolution data from the IKONOS and Quickbird series supported through the German Space Agency DLR and NASA respectively. Satellite data from before the disaster have also made a major contribution by providing a historical analysis baseline. All data have given to the relief agencies in the field, with higher-level derived information being developed and made available by image processing and value-adding agencies. The main benefit of the data has been to allow an immediate assessment of the extent of the damage in those areas where local information is either impossible or difficult to access, and to give a more general overview of the affected areas.



This Envisat ASAR multitemporal composite image highlights coastal destruction - including damaged coral reefs - on North Sentinel Island, part of the Andaman Islands in the Bay of Bengal. The colour in the image comes from combining two separate ASAR images acquired on different dates in order to highlight differences between them. The yellow (combining red and green) is matched to a 3 June 2004 acquisition while the blue is matched to a post-tsunami acquisition on 30 December 2004.

Human Health and Well-Being

Part of the improvement in human life expectancy achieved during the last century may be attributed to our improved understanding of environmental influences on our health and well-being. Contributing factors include improved sanitation, cleaner water and air, and more effective understanding of (and control of) the sources and means of transmission of disease.

The GEOSS Implementation Plan (described in Section 2) outlines a vision for Earth observing systems to make a significant contribution to continued improvements in human health in both developed and developing countries, through implementation of a system of remote sensing and in-situ observations integrated through assimilation and modelling tools with census data on health. The outputs would identify environmental conditions, health hazards, and at risk populations, and establish epidemiological associations between measurable environmental parameters, chronic and infectious diseases, and health conditions.

Environmental datasets can be powerful tools in support of research, epidemiology, health care planning and delivery, and public health alerts. For example, by linking weather and air quality data, air quality forecasts can help protect those at risk from air pollution episodes – such as asthmatics and the elderly. And by connecting the environmental requirements of pathogens with weather and other data, it is possible to predict outbreaks of infectious diseases such as malaria, and to reduce the impact and/or severity of the outbreak. Remotely sensed land-use data can support monitoring of water quality and allow communities to better target in-situ water quality monitoring and remedial efforts. Better UV-B measurements and warning systems will help contribute to reductions in the incidence of skin cancer and cataracts around the world.

Such observations, delivered in a sustained and timely fashion, can bring a focus to predictive and preventative aspects of health, particularly with respect to environmental hazards such as pollutants. At a global level, the availability of remotely sensed and in-situ environmental data offers promise of powerful new tools for the discovery of early indicators of health hazards – alerting the community and providing time for hazard avoidance or disease mitigation.

The role of Earth observation satellites

Earth observation satellite data has the potential to supply information on a range of important health-related parameters. These measurements are of particular value: where alternative in-situ measurement networks are not available in support of public health programmes (notably in many developing countries), and for wide-area monitoring as the basis for forecasting and alerting services.

Current health-related applications of satellite data include:

- detection of environmental factors associated with disease-vector habitats and human transmission risk;
- monitoring of air and water quality measures.

Examples of these applications are discussed below.

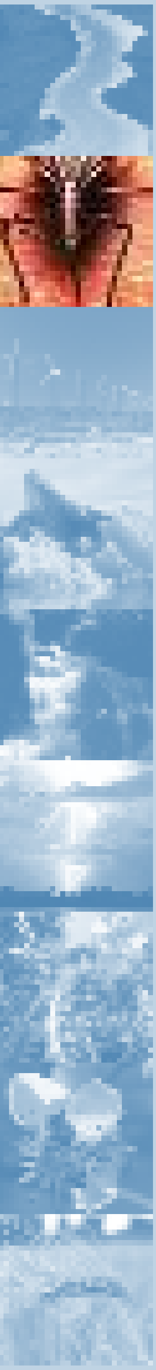
ESA's HUMAN project supplies satellite data to Medecins Sans Frontieres (MSF) in Nicaragua.

Aid workers are using imagery of crowded slums to analyse infections by Chagas disease on a house by house basis and to implement effective control and monitoring programmes on the ground.

Disease Early Warning Systems

Since the 1970s, researchers have been studying the potential of Earth observation satellite data in geographic information systems (GIS) for disease early warning primarily in 'landscape epidemiology' applications.

Landscape epidemiology involves the identification of geographical areas where disease is transmitted. By knowing the vegetation and geologic conditions necessary for the maintenance of specific pathogens in nature, one can use the landscape to identify the spatial and temporal distribution of disease risk. Key environmental elements, including elevation, temperature, rainfall, and humidity, can influence the presence, development, activity, and longevity of pathogens, vectors, reservoirs of infection, and their interactions with humans.



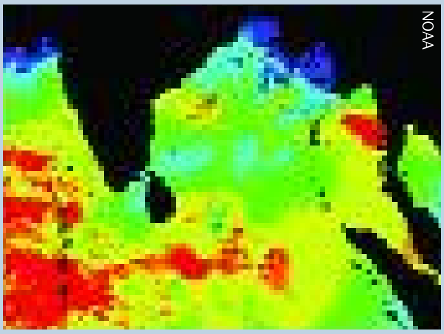
Most of these studies have focused on the derivation of vegetation cover, landscape structure, and water bodies. These factors are important because the distribution of vegetation types integrates the combined impact of rainfall, temperature, humidity, topographic effects, soil, water availability, and human activities. Nearly all vector-borne diseases are linked to the vegetated environment during some aspect of their transmission cycle.

NASA's Center for Health Applications of Aerospace Related Technologies (CHAART) has undertaken a review documenting research undertaken in public health projects involving the world's major diseases that are thought to have environmental components that can be monitored using remotely sensed data. These include: Chagas' disease, cholera, dengue fever, filariasis, hantavirus pulmonary syndrome, leishmaniasis, lyme disease, malaria, river blindness, plague, Rift Valley fever, schistosomiasis, trypanosomiasis (sleeping sickness), and yellow fever. Projects to map the vectors of these diseases by satellite have been trialled in a wide range of countries, including: Belize, Benin, Gambia, Kenya, Mexico, Senegal, and USA.

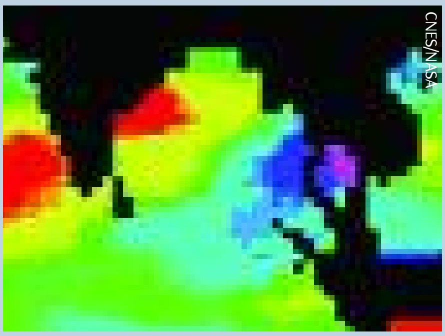
It is not only landscape parameters that are of value in this context. Links have been established between outbreaks of cholera in India and Bangladesh and oceanic conditions in the Bay of Bengal – including anomalies in sea surface height, temperature, and concentrations of chlorophyll and phytoplankton. Data from AVHRR, SeaWiFS, and Topex-Poseidon (amongst other sources) have been used in support of these assessments.

Datasets used to model the temporal patterns of cholera outbreaks in Bangladesh.

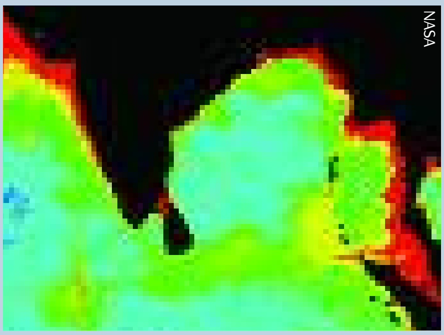
A AVHRR image of the mouth of the Ganges and the Bay of Bengal. Vegetation is shown in shades of red and water in shades of blue.



B Sea surface temperature data, derived from AVHRR



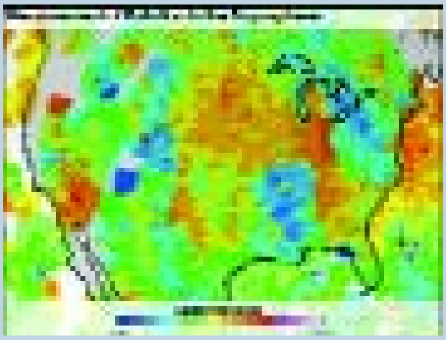
C Sea surface height data, derived from TOPEX-Poseidon

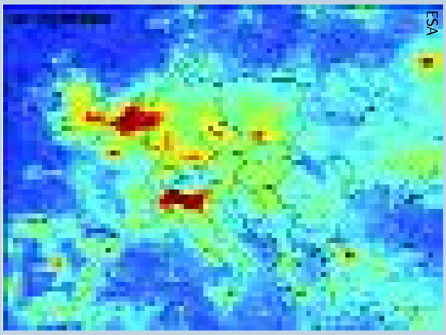


D SeaWiFS image showing chlorophyll concentrations

Air quality monitoring

Global monitoring of the atmosphere is one of the most significant contributions of environmental satellites to the study of the Earth's climate and its changes. The capabilities of the latest generation of atmospheric monitoring sensors are also enabling satellites to provide measurements at a finer (local) spatial scale, and at lower levels of the atmosphere, down to ground level – which is most relevant to public health alerts.





Carbon Monoxide pollution in North America measured by MOPITT (CSA) and nitrogen dioxide pollution in Europe measured by SCIAMACHY (ESA)

A number of sensors – including MOPITT (providing measurements of carbon monoxide and methane in the troposphere), TES (carbon monoxide, methane, HNO_3), and GOMOS, MIPAS, and SCIAMACHY (on the ENVISAT spacecraft) are providing new and powerful streams of information on air quality and composition of potential benefit to public health. Environmental protection and public health agencies are studying how to incorporate such information into their operations and warning systems – through projects such as IDEA (Infusing Satellite Data into Environmental Air Quality Applications), which combines the assets of NASA and the US Environmental Protection Agency (EPA) with NOAA's weather information in order to improve the EPA's decision-making tools with satellite observations for better air quality forecasts.

In Europe, ESA is participating in the establishment of the GMES (Global Monitoring for Environment and Security) Atmosphere Service – which will provide information on the ozone layer, UV-exposure on the ground, air pollution and climate change. These services are directed at the needs for information on environment and climate by public authorities, governmental agencies, the general public, and industry.

Respiratory illnesses are on the rise across the developed world. Tainted air around urban centres – originating from power generation, industry or traffic – is a well-known problem, but difficult to solve. Space-based instruments trace otherwise invisible plumes of waste chemicals as they move through the air, providing maps of their concentrations in three dimensions. Such data can be used to provide daily forecasts of meteorological fields and air pollution – valuable additions to the monitoring undertaken by fixed-location stations on the ground.

Future challenges

Many applications are at a research or pre-operational stage. Improved utilisation of satellite data for the benefit of human health will require a combination of:

- making better use of the capabilities that are currently available, including improved linkages between data providers and healthcare communities; capacity building in developing countries to ensure the means and understanding for use of the data; better integration of satellite data with existing datasets to exploit its full potential; and
- translation of the new and planned measurement capabilities from scientific prospects into operational services, including through adequate modelling and analysis capabilities in order to derive the essential information; adequate spatial and temporal coverage will continue to be a challenge.

CHAART: geo.arc.nasa.gov/sge/health/chaart.html

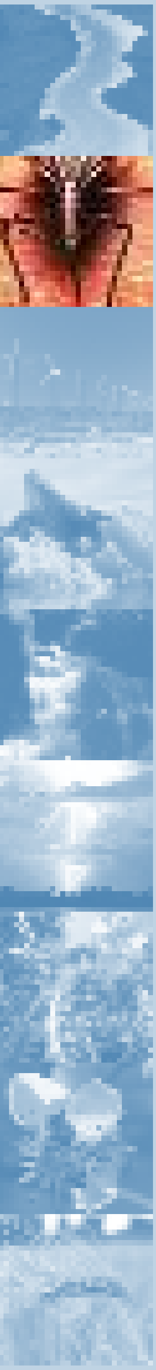
WHO Roll Back Malaria: www.rbm.who.int

NASA's IDEA: earthobservatory.nasa.gov/Study/IDEA

East Africa Rift Valley Fever: edcintl.cr.usgs.gov/riftvalleysa.html

ESA: www.esa.int/export/esaCP/Protecting.html

GMES PROMOTE: www.knmi.nl/samenw/promote

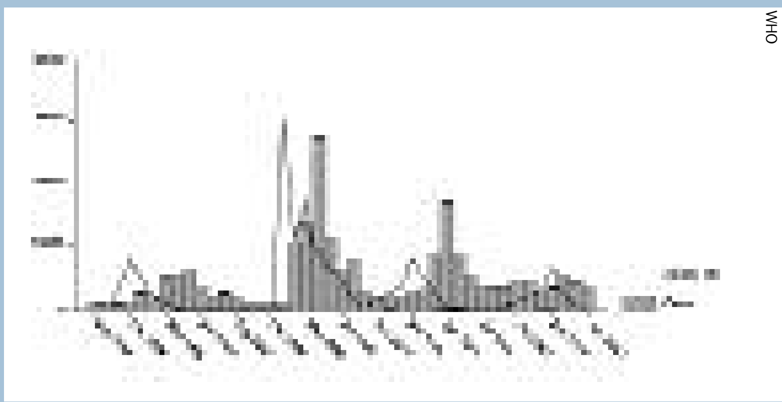


Malaria Early Warning Systems

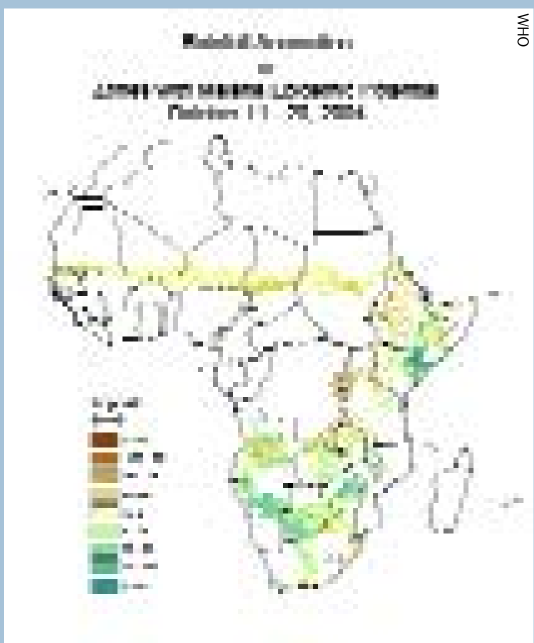
The 'Roll-Back Malaria' programme of the World Health Organization (WHO) has implemented a number of Malaria Early Warning Systems (MEWS) intended to facilitate timely responses that will prevent and contain malaria epidemics. MEWS comprise forecasting, early warning, and early detection. Forecasting usually refers to seasonal climate forecasts; early warning refers to the monitoring of meteorological conditions such as rainfall and temperature; and early detection is based on routine clinical surveillance.

WHO has supported development of simple tools to monitor epidemic risks in marginal transmission areas based on anomalies in rainfall and temperature identified from satellite observations. Rainfall is one of the major factors influencing malaria transmission in semi-arid and desert-fringe areas of Africa. Epidemics may occur after excessive rains, usually with a lag time of several weeks during which mosquito vector populations and malaria infections gradually increase. Epidemics following drought and poor food security conditions can be especially severe.

Risks are displayed on maps which are updated every 10 days and can be freely accessed via the WHO/RBM web site. MEWS are generally performing well in southern Africa, and studies have started in Ethiopia, Kenya, Uganda, the United Republic of Tanzania, and Sudan. Decision-tree models are being constructed and validated. Work remains to be done to better involve staff from meteorological services in joint ventures with ministries of health to regularly compile and evaluate data and disseminate warnings to communities.



Number of inpatient malaria cases in selected hospitals in Namibia, compared measurements of 'cold cloud duration' - a satellite-derived proxy for rainfall



Energy Resource Management

Energy underpins all aspects of the economic and social development policy in all countries. It is an input universally required by every segment of economy and society, and equally needed in both developed and developing countries.

The energy sector covers a wide range of activities such as oil and gas exploration, extraction and production, transportation, and electricity generation, transport and distribution. The optimal management of this diverse, global, trillion-dollar industry - which includes the non-renewable resources of oil and gas as well as renewable resources such as solar, wind, biomass and hydropower generation is a critical concern to all nations.

Energy resource management decisions are the basis for economic growth, ecologically responsible use of resources, and human health and security. According to the International Energy Agency, worldwide energy demand over the next thirty years is expected to double, with the bulk of this increase occurring in large, rapidly developing countries – such as India and China. By 2030, global energy demand is expected to exceed supply by 20%. At the same time, existing reserves of traditional fuels from fossil sources may diminish and new reserves will be more difficult to find and exploit commercially. Environmental awareness of the global warming effects of use of fossil fuels may lead to greater reliance on renewable energy sources – which are themselves sensitive to weather and climate phenomena.

Major issues for the energy industry include fuel supply, type, and sustainability, as well as power efficiency, reliability, security, safety and cost effectiveness. Nations need reliable and timely information in order to manage the risks associated with uncertainty in supply, demand, and market dynamics. This requires sound management practices and strategies, by both industry and government.

The role of Earth observation satellites

The energy industry is already an important user of information from Earth observation satellites:

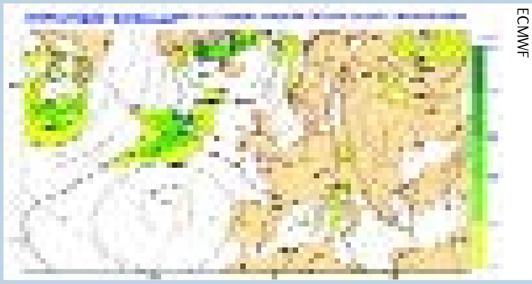
- weather data is vital in estimations of both the supply and demand for electricity;
- satellites play an important role in support of exploration, extraction, and safe transportation of the world's oil and gas reserves – which are being sought in increasingly remote and hostile areas of the planet;
- satellite observations have a central role in the detection and observation of climatic trends due to changing atmospheric composition.

Some examples of the roles for satellite Earth observations in the global energy sector are outlined below.

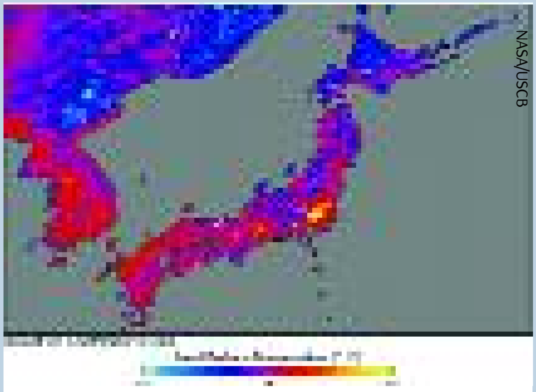
Forecasting the demand for electricity

The electrical grid 'blackouts' in northern USA and Canada in August 2003 were an extreme example of the effects of miscalculating the demand for electricity. The outage affected some 50 million people and losses were estimated at between $5.8bn and $11.8bn. It occurred during summer peak seasonal energy use periods when air conditioning demand was in full force – and demonstrates the important influence of environmental conditions on society's daily demand for electricity.

The electric power industry relies heavily on projected demand requirements for the buying, selling and trading of electric power. Weather information is a necessary

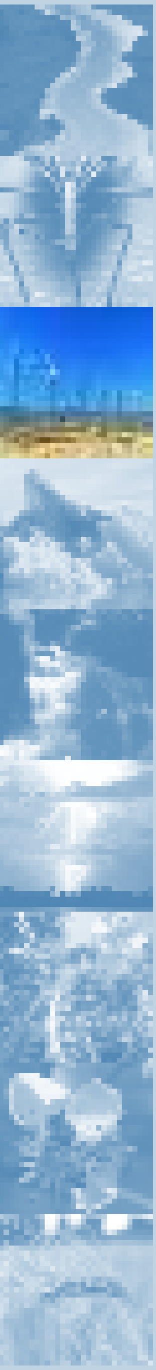


ECMWF



NASA/USCB

Weather forecasts are vital for electricity demand forecasting. Meteorologists noted a record-breaking hot summer in Japan in 2004 – with 68 days reaching more than 30°C. Urban heat island conditions are increasing demand for air conditioning and placing stress on electrical supply systems.



component of the industry's supply forecasting process. Companies make or purchase forecasts of electricity demand ranging from a few hours ahead to many days ahead. The electric power industry values these demand forecasts and the models that produce them. Energy managers base critical operational decisions upon them.

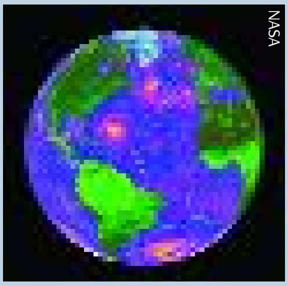
Operational meteorological satellites play an important role in the generation of the short term and seasonal weather forecast products that are employed in the power industry. Everyday forecasts of temperature, humidity, precipitation and wind speed, and warnings of severe weather events such as hurricanes, droughts and heat waves, all have value in the prediction of how many electrical appliances each of us will use in the course of our typical day. Getting the forecast wrong means generating either too much or too little energy, and profits are lost in either case. Energy sector meteorologists have suggested that, in the USA, imperfect forecasts can have an impact on the electricity generation industry by as much as US$1Mn per degree (fahrenheit) per day.

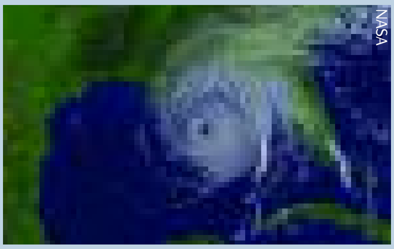
Weather forecasting improvements from the introduction of new and advanced satellites are therefore of significant value to that industry. It has been estimated that the economic benefit to the US supply industry resulting from improvements included in the GOES-R mission alone would amount to US$451Mn in 2015. This benefit would be realised in the form of savings primarily from improved load forecasts, and better real time weather information.

Direct observation of environmental conditions can also play an important role in ensuring electricity supply. Utilities and energy trading companies often use satellite imagery data on snow accumulation to predict snowmelt and therefore the energy potential of hydroelectric dams. Longer term supply and infrastructure planning also depends on predictions of urban growth. Wide field-of-view sensors such as those on Landsat and SPOT have been used specifically for this purpose.

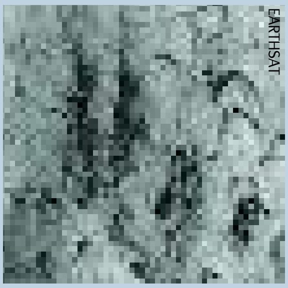
Oil and gas

Earth observationn imagery is used extensively by exploration companies in support of their search for new oil and gas reserves – both on land and at sea. Instruments such as ASTER on NASA's Terra satellite are specifically designed to support geologists gathering information on remote and poorly mapped regions of the world and to supply information on the geological and tectonic features – which the trained interpreter can exploit, in association with seismic data, to optimise exploration efforts.





Satellite observations of weather formations, sea surface winds, and wave heights are essential for safe offshore operations



Satellite imagery is routinely used in exploration of offshore oil basins – including through oil 'seep' detection

Satellite data is used for prospecting for undersea hydrocarbon deposits. Research by oil companies in the 1990s demonstrated that over 75% of the world's oil-bearing basins contain surface seeps – which form a thin slick on the sea surface above, visibly changing the water's reflective qualities. Searches for these naturally occurring oil slicks can be undertaken using boats and aircraft – but these are time-consuming and costly and may require access rights, and alert competitors to potential resources.

Synthetic Aperture Radar satellites offer the oil industry an effective, low-cost technique for reducing source risk in high-cost exploration environments such as the new deep frontier basins This is due to their ability to image surface oil seeps remotely with wide swath coverage (typically 100-200km wide scenes) and at low cost.

Moreover, satellite data does not compromise national sovereignty and can provide multi-temporal coverage data over any area of the globe. Time-series data can provide the location for follow-up surface sampling from which key geochemical information on the reservoired oil can be obtained ahead of drilling.

Oil and gas drilling increasingly takes place on the open seas – operations which are particularly vulnerable to severe storms. This vulnerability was apparent in the 2004 hurricane season when oil output from platforms in the Gulf of Mexico, the largest domestic source of oil for the USA, was reduced by about 25-30% of its usual daily rate. Oil prices increased sharply as a result – on fears of supply security. Marine forecasts are essential in the offshore drilling business and for oil pipeline management, providing information on sea-state conditions, wind, wave, surface temperature, and extreme events such as severe storms and hurricanes. Satellite observations are often the only source of such information out at sea and are invaluable in managing offshore operations – and therefore in ensuring security of oil supply.

The same benefits are enjoyed by ocean-going supertankers that transport much of the world's oil and gas supplies. Active microwave sensors on satellites such as ERS, ENVISAT, and QUICKSCAT provide homogeneous, global measurements of sea surface winds and wave height which are used by meteorologists in their marine forecast models. These models are used in support of offshore operations and for ship route optimisation. The same instruments have helped improve forecasting of the landfall – where and when – of impending hurricanes. This can now typically be predicted to within 400km, up to 2-3 days in advance. The goals of NASA's Earth Science Enterprise call for improving this capability to within 100km by 2010.

Environmental and climate impacts of global fossil fuel use can be expected to come under increasing scrutiny in the 21st century, as nations explore more sustainable energy policies and try to limit greenhouse gas emissions. The role of Earth observation satellites in this domain is the subject of the following case study on Climate.

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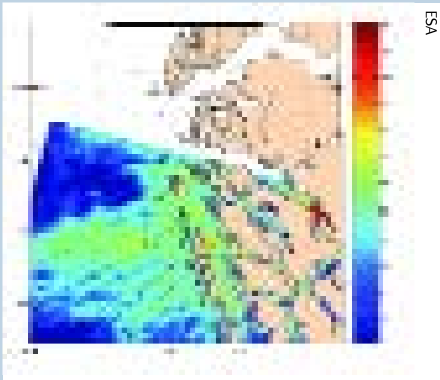


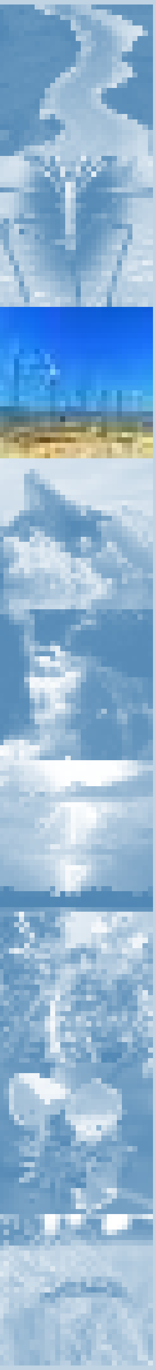
ESA

Coastal wind mapping using radar satellites

NREL

EUMETSAT

Solar irradiance map



Alternative energy sources

Real opportunity exists for information from Earth observations to contribute to the optimisation of renewable energy systems for power production, and to contribute to the provision of information for optimal integration of traditional and renewable energy supply systems into electric power grids.

Energy sources such as solar, wind, and wave power, offer environmentally-friendly alternatives to fossil fuels but are particularly sensitive to environmental conditions. These energy sources are intermittent, and their availability depends largely on local climate and weather.

Local climate data on cloud cover, solar irradiance, and on wind/wave speed and direction – combined with other environmental parameters such as land elevation and land cover models – are vital elements in developing a strategy for the location and operation of solar, wind, and wave power facilities.

Geostationary satellites have been used experimentally as a tool in resource assessment for solar energy for a number of years. The HELIOSAT-3 project, financed by the European Commission, aims to exploit Meteosat data to support the solar energy community in its efforts to increase the efficiency and cost-effectiveness of solar energy systems and thereby improve the viability of solar energy. The project aims to provide high spatial and temporal solar irradiance data as well as information on the distributions of sunlight by angle of incidence and spectral band.

SAR, scatterometer, and altimeter data from satellites are also used to support the mapping of wind energy in offshore and near-coastal regions to identify potential wind turbine sites.

Future advances

Increasing fuel prices and sensitivity to national fossil fuel emissions will ensure ever-increasing importance of the efficiency of our power generation industries. In the medium term, progress and improvement of energy resources management activities using satellite Earth observations will be largely related to the improvement of short-term to medium-term (up to 8-10 days) weather predictions as well as progress in seasonal to inter-annual climate forecasts.

The new generation of operational meteorology satellites will enable the range of deterministic forecasts to be extended to 15 days. Predictions of high-impact weather will also see improvement – up to 5 days ahead for flash floods, storms and blizzards, 10 days for plain floods, and 15 days or beyond for droughts, heat waves and severe cold spells.

Operational weather systems will be extended to provide daily global analyses of greenhouse gases, and monthly estimates of the sources and sinks of CO_2.

International Energy Agency: www.iea.org

The Kyoto Protocol: unfccc.int/resource/convkp.html

European Centre for Medium-Range Weather Forecasts: www.ecmwf.int

ARGOSS: www.argoss.nl

Wind and wave forecasts for offshore operations and ship routing; earth.esa.int/applications/data_util/hrisk/ssf/ssf.htm

Satellites for oil and mineral exploration: www.npagroup.co.uk/oilandmineral/index.htm

Heliosat-3 project: www.heliosat3.de

Climate Change

A global concern

In New York on 9th May 1992, the UN Framework Convention on Climate Change (UNFCCC) was adopted; to date, the most significant global legal framework for international action to address climate change. By the start of 2005, 186 countries and the European Community had become Parties to the Convention.

The ultimate objective of this Convention is to achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic (man-made) interference with the climate system.

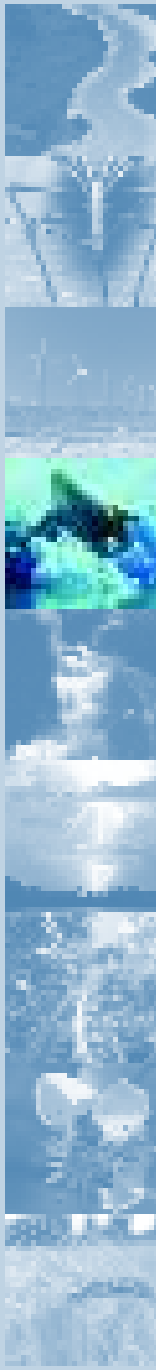
The UNFCCC was strengthened at a meeting of the Conference of the Parties (COP) to the Convention in December 1997, where a legal instrument – named the Kyoto Protocol – was adopted. The Protocol subjects industrialised countries to legally-binding targets to limit their greenhouse gas emissions. These targets add up to a total reduction of 5% in greenhouse gas emissions from 1990 levels, for the five-year period 2008-2012. By November 2004, 127 countries had ratified the protocol; in order to enter into force, the Protocol is required to be ratified by 55 Parties to the Convention, including enough major industrialised Parties to account for at least 55% of the total carbon dioxide emissions by industrialised countries in 1990. This participation target was achieved when Russia ratified the treaty in late 2004 – and the Kyoto protocol became a legally binding agreement.

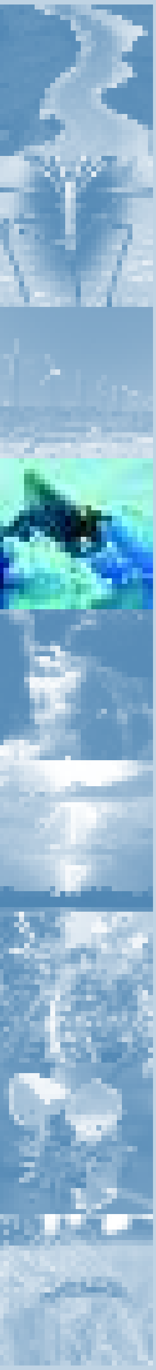
National commitments under the Kyoto Protocol were not offered lightly. The necessary reductions in greenhouse gas emissions will require changes in the way in which countries generate energy, provide transportation, and manage land use – issues which are all fundamental to future economic development. However, the necessary impetus to meet these challenges is the alarming realisation, based on the best available scientific assessment, that human activities are already affecting the Earth's climate, and that the emission of greenhouse gases is the primary cause.

The term 'climate change' usually refers to changes in the climate system, notably a global warming trend caused by emissions of greenhouse gases that create a 'human-induced greenhouse effect.' The most important of these gases is carbon dioxide (CO_2), which comes mainly from the burning of fossil fuels such as oil, gasoline, natural gas and coal. Other important greenhouse gases include methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFCs).

The Intergovernmental Panel on Climate Change (IPCC) projects that greenhouse gas emissions due to fossil fuel burning are almost certain to be the dominant influence on trends in atmospheric greenhouse gas concentrations in the coming century and that with a 'business as usual' scenario, the global average surface temperature is expected to rise between 1.4°C and 5.8°C. This rate of warming is most likely without precedent in at least the last 45,000 years. Scientists anticipate profound consequences for sea level (a rise of 9-88cm in the 21st century), precipitation patterns and extreme weather, with consequent impacts on a wide range of ecological functions and human activities essential for individual and societal well-being.

PHILIPPE REKACEWICZ, VITAL CLIMATE GRAPHICS, UNEP-GRID ARENDAL, NORWAY, 2000





The International Response

The relevant international communities are collaborating on an unprecedented global scale in order to observe, model, and understand the underlying Earth System processes and to implement policy measures to avert the worst effects of the 'business as usual' scenario. The main policy initiative is the Kyoto Protocol.

The Kyoto Protocol sets limits on the emission of six main greenhouse gases:

- carbon dioxide (CO_2);
- methane (CH_4);
- nitrous oxide (N_2O);
- hydrofluorocarbons (HFCs);
- perfluorocarbons (PFCs);
- sulphur hexafluoride (SF_6).

Some specified activities in the land-use change and forestry sector (namely, afforestation, deforestation and reforestation) that emit or remove carbon dioxide from the atmosphere are also covered. All changes in emissions, and in removals by so-called 'sinks' (absorbers), are considered equivalent for accounting purposes.

The Protocol also establishes three innovative 'mechanisms', known as 'joint implementation', 'emissions trading', and the 'clean development mechanism', which are designed to help Parties reduce the costs of meeting their emissions targets by achieving or acquiring emission reductions more cheaply in other countries than at home. The clean development mechanism also aims to assist developing countries to achieve sustainable development by promoting environmentally-friendly investment in their economies from industrialised country governments and businesses.

Fossil fuel emissions and deforestation play major roles in climate change

Fluxtowers monitor exchanges of CO_2, water vapour and energy between land and atmosphere

The role for satellite Earth observations

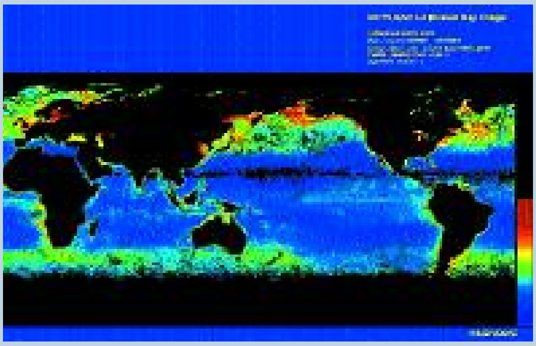
For adaptation to be effective, governments as well as the private sector need information about past and current climate conditions, their variability and extremes, as well as sound projections of future conditions, not only on a year-over-year basis but for many decades into the future. The World Climate Research Programme (WCRP) was established in 1980 to co-ordinate international research in this domain, in order to determine the extent to which climate can be predicted and the extent of human influence on climate.

The climate system responds to both external forcings and to perturbations of internal processes; it is important that we can track climate change and variability in a way that causes can be determined, trends and variability predicted, and appropriate adaptation and mitigation strategies defined for implementation.

The Global Climate Observing System (GCOS), in consultation with its partners, has developed a plan which identifies the observations of the 'essential climate variables' required by the Parties to the United Nations Framework Convention on Climate Change (UNFCCC). These key Earth System parameters are shown in the table on the next page and include measurements of land, sea, ice, ocean, and atmosphere.

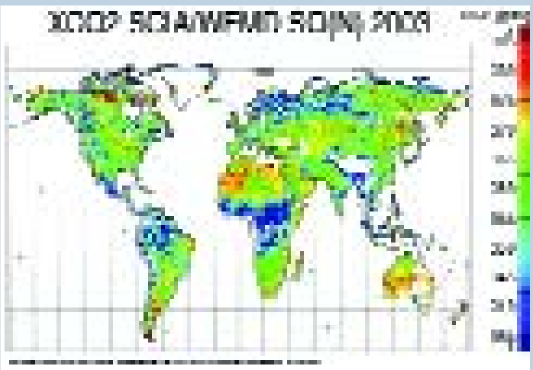
The GCOS Implementation Plan notes that this will require terrestrial, oceanic, and atmospheric observations from both in-situ and remote sensing platforms, which then must be transformed into products and information through analysis and integration in both time and space. Global observing systems for climate will comprise instruments at ground stations as well as on ships, buoys, floats, ocean profilers, balloons, samplers, aircraft, and satellites, since no single technology or source can provide all the needed information. Of these, in the future, Earth observation satellites providing global coverage and well calibrated measurements will become '*the single most important contribution to global observations for climate*'.

Since the dominant influence on future greenhouse gas trends is widely agreed to be the emission of CO_2 from fossil fuel burning, an improved understanding of the global carbon cycle has become a policy imperative for the forthcoming decades, both globally and for individual countries. The focus of this case study on climate change is therefore on observations of the carbon cycle – a global concern. It should be noted that there are many other, equally significant, aspects of climate monitoring – including those which highlight the results of climate change as well as the causes. These include the water cycle and water resources, and the cryosphere. Both topics are the subject of individual IGOS Themes, and the cryosphere will be the focus for the planned International Polar Year in 2007-2008.



JAXA/EORC

Satellite ocean colour sensors provide important information on the ocean's role in the carbon cycle



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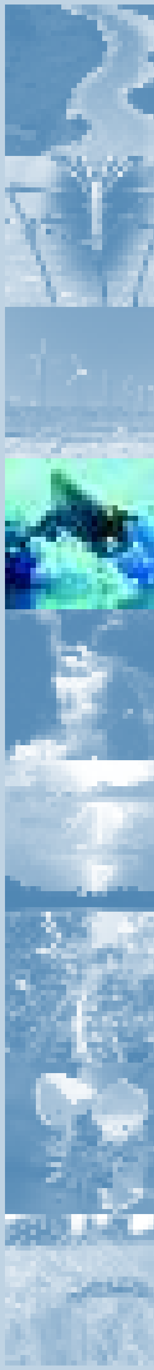
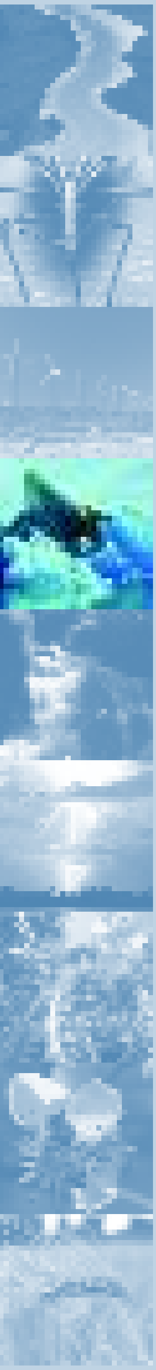
NASA JPL

The Orbiting Carbon Observatory

Satellites already deliver global estimates of CO_2 concentrations in our atmosphere





Domain	Essential Climate Variables
Atmospheric (over land, sea, and ice)	Surface: Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour. Upper-air: Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties. Composition: Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases, Aerosol properties.
Oceanic	Surface: Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure. Sub-surface: Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.
Terrestrial	River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Biomass, Fire disturbance.

Observing the Carbon Cycle

The global carbon cycle connects the three major components of the earth system: the atmosphere, oceans, and land. In each domain, large pools of readily exchangeable carbon are stored in various compartments ('pools' or 'sinks' and 'sources'). Large amounts of carbon ('fluxes') are transferred between the pools over various time periods, from daily to annual and much longer. Although some of the fluxes are very large, the net change over a given time period need not be. For many centuries prior to the industrial revolution, the carbon pools were more or less in equilibrium, and the net transfer was close to zero for the planet as a whole.

The major changes have occurred following the development of agriculture and industry, with the accelerated transfer from the geological (fossil fuels) and terrestrial pools to the atmosphere. Because of the connections among pools, the increased atmospheric carbon concentration affects the other connected pools in oceans and on land. The processes governing the fluxes between the pools take place at various rates, from daily to centennial and longer.

The UNFCCC and the Kyoto Protocol represent the first attempt by mankind, acting collaboratively across the world, to manage, at least partly, a global element cycle of the Earth System – the global carbon cycle. The Kyoto Protocol recognises the role of terrestrial systems as carbon sinks and sources, and it provides a basis for developing future 'emission trading arrangements' that involve forests and potentially other ecosystems. Understanding of the pathways through which the anthropogenic CO_2 is absorbed from the atmosphere and into ecosystems (thus offsetting a portion of the anthropogenic emissions) is fragmentary and incomplete. These factors and dependencies make the quantification and study of the carbon cycle very challenging to model, observe, and predict.

This challenge requires the support of a coordinated set of international activities – scientific research (including modelling), observation, and assessment. Assessment is perhaps the most advanced, with the pioneering work of the IPCC providing the scientific assessment required for the policy action. In terms of scientific research, the International Geosphere-Biosphere Programme (IGBP) has recently joined forces with the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP) to build an international framework for integrated research on the carbon cycle (called the Global Carbon Project).

Observations of the global carbon cycle, including the land, oceans, and atmosphere compartments of the cycle, are being co-ordinated within the IGOS Partnership, by the Integrated Global Carbon Observations (IGCO) Theme (see annex B for more on IGOS Themes).

The IGCO Theme will build on a number of carbon cycle observation initiatives at the Earth's surface that are underway or planned, including:

- global networks of atmospheric greenhouse gas measurement stations (such as GLOBALVIEW CO_2)and the WMO World Data Center for Greenhouse Gases (Tokyo);
- global networks of measurement tower sites that monitor the exchanges of CO_2, water vapour, and energy between terrestrial ecosystems and atmosphere; e.g. the FLUXNET system has over 260 tower sites operating on a long-term and continuous basis;
- measurement ships and arrays of buoys, including the TAO array in the equatorial Pacific.

Data from Earth observation satellites provide the only global, synoptic view of key measures of the carbon cycle and form an essential and central part of the envisaged integrated observation strategy planned within IGCO.

The major applications include:

- global mapping of land cover use, land cover change, and vegetation cover characteristics that are important to full carbon accounting – using sensors such as AATSR, AVHRR, Landsat TM/ETM/ETM+ and MODIS and carried out through the Global Observation of Forest Cover and Land Cover (GOFC-GOLD) project initiated by CEOS;
- seasonal growth characteristics, including important parameters such as fraction of absorbed photosynthetically active radiation and Leaf Area Index (LAI) are generated on a global scale (e.g. by AVHRR, MODIS, MERIS, and SPOT VEGETATION);
- fire detection and burn scar mapping: in many regions of the world, fires are the most significant disturbance of vegetation and drive large inter-annual variations in carbon emissions from ecosystems; large fires in forests and grasslands are detected and mapped from space using thermal and optical sensors (radar sensors also show promise for burn mapping);
- combinations of satellite measurements of parameters such as ocean chlorophyll, dissolved organic matter, and pigment composition and physical measurements from satellite of ocean waves, winds, and temperature are used to derive three main contributions for the study of ocean carbon:
- quantifying upper ocean biomass and ocean primary productivity;
- providing a synoptic link between the ocean ecosystem and physical processes;
- quantifying air-sea CO_2 flux.

Another key role for satellites relates to monitoring of the Kyoto Protocol's 'carbon trading' mechanisms, especially the Clean Development Mechanism (CDM). Existing archives of high resolution satellite imagery (e.g. from Landsat and SPOT) provide the capacity for determining eligibility of CDM reforestation projects by confirming compliance with the Kyoto Protocol's rule that any proposed forestry project must be able to prove that the site "did not contain forest on 31st December 1989". The same technologies can also provide the geographically explicit land use data for national inventory reports concerning carbon sinks, and provide important information in trade-offs and conflicts between mitigation/adaptation carbon initiatives involving land use, land-use change and forestry, and long-term sustainable development strategies.

Future challenges

Within the next few years, scientists are hopeful of an extraordinary and unique revolution in global monitoring of atmospheric CO_2 concentrations, sources, and sinks – with the benefit of space-based high-precision measurements of column-integrated CO_2 molecular density with global, frequent coverage.

The precision requirements for such measurements are extremely taxing – requiring concentrations as low as 0.3% (1 ppm) to be achieved in order to accurately characterise carbon sources and sinks. But a number of new missions, specifically dedicated to this challenge, are being planned to provide the first such data. NASA will launch the Orbiting Carbon Observatory (OCO) in 2007. This 2-year mission is seen as a pathfinder for future long-term CO_2 monitoring missions – and will use measurements of reflected sunlight in the short-wave infrared to provide global, high-precision measurements of the column-integrated CO_2 mixing ratio. A second satellite, launched by JAXA, also aims to provide information on CO_2. GOSAT (Greenhouse gas Observing Satellite) will be operational from 2008.

In the interim, scientists continue to make advances in the retrieval of CO_2 information from atmospheric sounding instruments on the NOAA polar orbiting satellites, and from atmospheric chemistry instruments such as SCIAMACHY on ENVISAT.

Part of the future challenge will be to support a monitoring system that is suitably accurate, robust, and sustained to effectively support the implementation and policing of treaties such as the Kyoto Protocol – since cold, hard evidence may on occasion be required to ensure their enforcement. For Earth observation satellites this will require a move from research to operational status to support international policy frameworks.

The necessary co-ordination of the relevant satellite missions will be undertaken by the Committee on Earth Observation Satellites (CEOS) including through their participation in the IGCO Theme. Part III of this document summarises the various plans of the world's space agencies.

Global Carbon Cycle: whrc.org/carbon/index.htm

UNFCCC and Kyoto Protocol: http://www.unfccc.de

Climate change science: www.climatechangesolutions.com

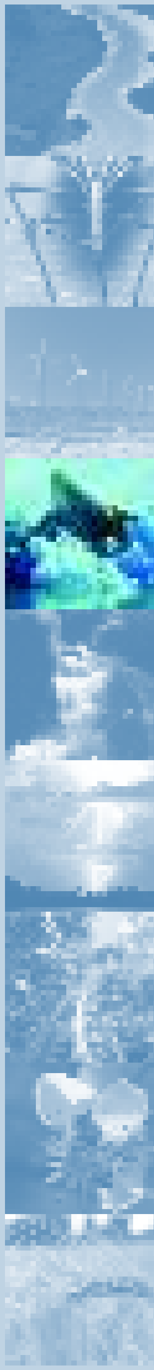
Global Carbon Project: www.globalcarbonproject.org

IGCO Theme: ioc.unesco.org/igospartners/Carbon.htm

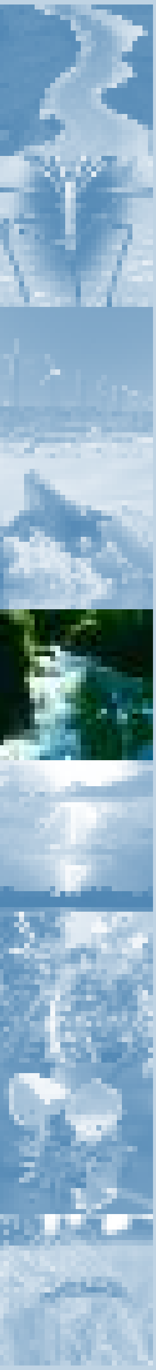
OCO: oco.jpl.nasa.gov

GOSAT: www.jaxa.jp/missions/projects/sat/eos/gosat/index_e.html

EO and modelling carbon fluxes: edc.usgs.gov/carbon_cycle/FluxesResearchActivities.html



Water resource management



An essential resource

Of all the water present on our planet, only 2.5% is fresh, and only 0.007% is readily available to people via rivers, lakes, and reservoirs. Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment, and management of this resource is expected to emerge as one of the greatest challenges facing mankind during the 21st century. Despite significant improvements in recent decades, over one billion people still lack access to safe water, and nearly two billion lack safe sanitation. An estimated 10,000 people die every day from water and sanitation-related diseases, and thousands more suffer from a range of debilitating illnesses. The impact of inadequate water and sanitation services falls primarily on the world's poor.

Humans currently appropriate more than half of accessible freshwater run-off, and this amount is expected to increase significantly in the coming decades. A substantial amount, 70%, of the water currently withdrawn from all freshwater resources is used for agriculture. With the world's population set to increase significantly by 2050, the additional food required to feed future generations will put further pressure on fresh water resources. According to recent global water assessments, around 70% of the future world population will face water shortages and 16% will have insufficient water to grow their basic food requirement by 2050. Future management of freshwater resources will be complicated by the uncertainties in rainfall patterns introduced by climate change, with observations and models suggesting increased frequency and intensity in both extreme precipitation and drought events – depending on the region.

The combination of increased scarcity of global water resources, and increased uncertainties in the Earth's water cycle, has added urgency to the need to improve predictions of rainfall and water resources by developing an integrated water cycle observing system, and by extending our understanding of the physical basis of the climate system driven by the water cycle.

Observing and understanding the water cycle

In all, the Earth's water content is about 1.39 billion cubic kilometres and the vast bulk of it, about 96.5%, is in the global oceans. Approximately 1.7% is stored in the polar icecaps, glaciers, and permanent snow, and another 1.7% is stored in groundwater, lakes, rivers, streams, and soil. Finally, a thousandth of 1% exists as water vapour in the Earth's atmosphere.

Because water continually evaporates, condenses, and precipitates, with evaporation on a global basis approximately equalling global precipitation, the total amount of water vapour in the atmosphere remains approximately the same over time. This movement of water, in a continuous circulation from the ocean to the atmosphere to the land and back again to the ocean is termed the global water cycle, and is at the heart of the

ESA

The Earth's water cycle

Irrigation for agriculture dominates human use of available water.

New satellite techniques for measurement of soil moisture will help to account for this element of the water cycle.

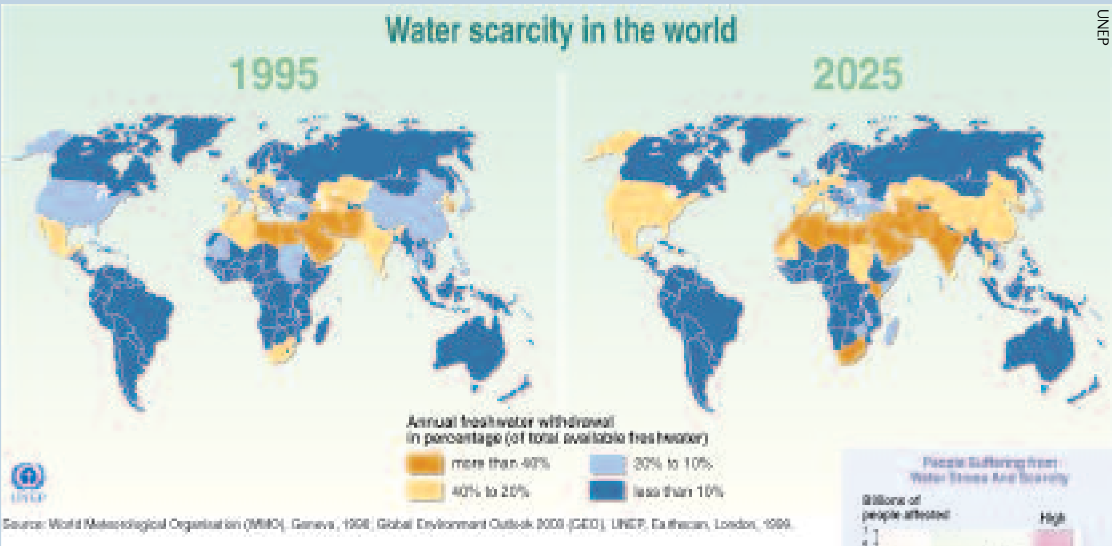
Earth's climate system, affecting every physical, chemical, and ecological component. Amongst the highest priorities in Earth science and environmental policy issues confronting society are the potential changes in global water cycle due to climate change. Climate changes may profoundly affect atmospheric water vapour concentrations, clouds, and precipitation patterns. Many uncertainties remain, however, as illustrated by the inconsistent results given by current climate models regarding the future distribution of precipitation.

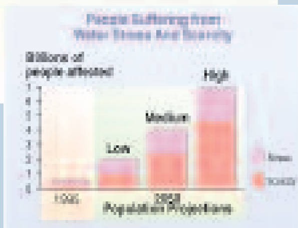
Better predictions of water cycle behaviour are needed for:

- monitoring climate variability and change;
- effective water management through better provision of information inputs to decision support tools;
- sustainable development of the world's water resources requiring knowledge of trends and long-term projections of the intensity of the global water cycle;
- improved weather forecasts and monthly to seasonal climate predictions – including for mitigation against drought and flood.

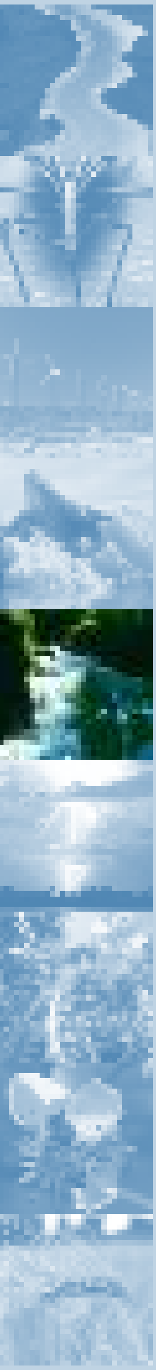
Such capabilities will require improved understanding of a range of complex processes, such as:

- evaporation processes from the global ocean (which account for as much as 87% of the water present in the atmosphere);
- land surface hydrologic processes which govern evapotranspiration and the partitioning of rainfall between re-evaporation, storage in the soil, and run-off to rivers;
- relationships between global climate and regional weather systems which govern clouds and rainfall;
- the science of clouds, and how they lead to precipitation.





Water stress and scarcity will increase globally due to population increases and climate changes



Given the complex and global nature of the water cycle, this understanding can only be achieved if scientists are equipped with long-term data to characterise the behaviour of the Earth System with regards to a range of key parameters, including:

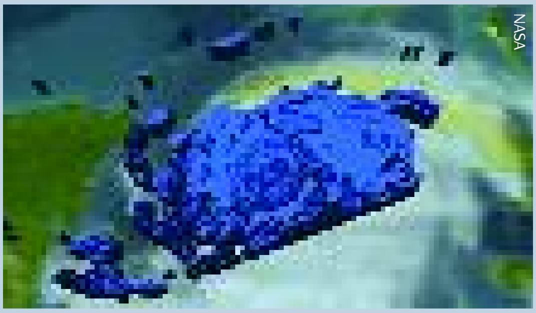
- global precipitation: precipitation is the most significant aspect of climate change from the perspective of human interests and the health of ecosystems;
- atmospheric temperature and water vapour: since water vapour is the Earth's primary greenhouse gas and contributes significantly to uncertainties in projections of future global warming, it is critical to understand how it varies in the Earth System;
- sea surface temperature and ocean salinity: as a significant measure of air-sea fluxes;
- soil moisture and snow accumulation: to assess the freshwater budget of land and ocean.

In large parts of the world, the collection and dissemination of water-related information has been in decline in recent years. In order to strengthen cooperation amongst countries in gathering the necessary information, the WMO, in association with the World Bank, established the World Hydrological Cycle Observing System (WHYCOS) in 1993. WHYCOS is based on a global network of reference stations, which transmit hydrological and meteorological data in near real-time, via satellites, to national and regional centres.

A number of international scientific research programmes have been developed to address the key challenges relating to the global water cycle – most notably under the auspices of the World Climate Research Programme, including:

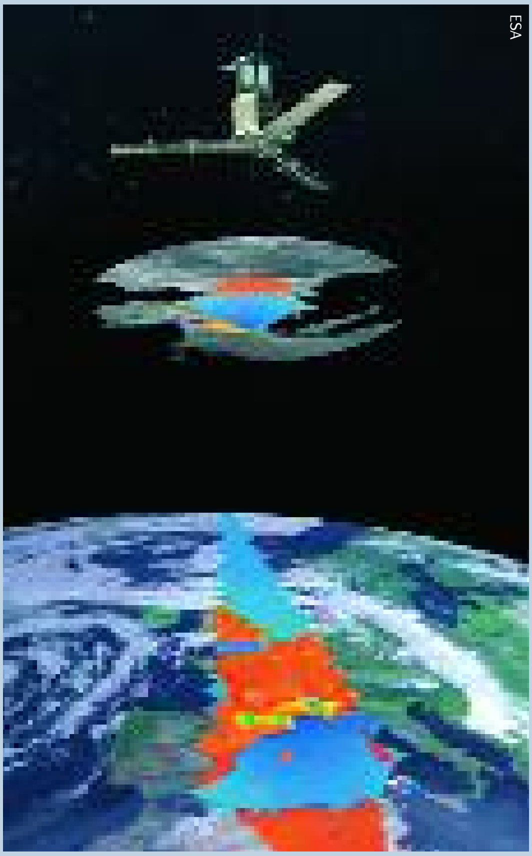
- GEWEX: The Global Energy and Water Cycle Experiment whose scientific focus includes studies of atmospheric and thermodynamic processes that determine the global hydrological cycle and water budget and their adjustment to global changes such as the increase in greenhouse gases and land use change;
- CLIVAR: "Climate Variability and Predictability" is the main focus in WCRP for studies of climate variability.

The main forum for co-ordination of the supporting observation programmes – including those of the satellite and in-situ measurement communities, is the Integrated Global Water Cycle Observations Theme (IGWCO) of the IGOS Partnership. IGWCO provides a framework for guiding international decisions regarding priorities and strategies for the maintenance and enhancement of Water Cycle observations so they will support the most important applications and science goals, including the provision of systematic observations of trends in key hydrologic variables.



On the morning of 15th September 2004, the TRMM satellite captured a 3-D look inside Hurricane Ivan – providing unique information on the structure of rainfall inside the storm as Ivan approached landfall

HYDROS will deliver the first global views of the Earth's soil moisture content and freeze/thaw state



Novel measurements of soil moisture and ocean salinity will be provided by SMOS

The role of Earth observation satellites

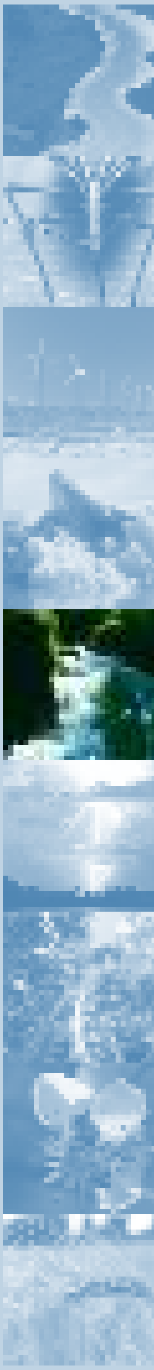
Earth observation satellites play a major role in the provision of information for study and monitoring of the water cycle and represent an important element of the observation strategy defined within IGWCO – the first element of which is the CEOP project (Co-ordinated Enhanced Observing Period), which is taking the opportunity of the simultaneous operation of key satellites of Europe, Japan, and USA, and the GEWEX Continental-scale Experiments, during a multi-year period to generate new data sets of the water cycle.

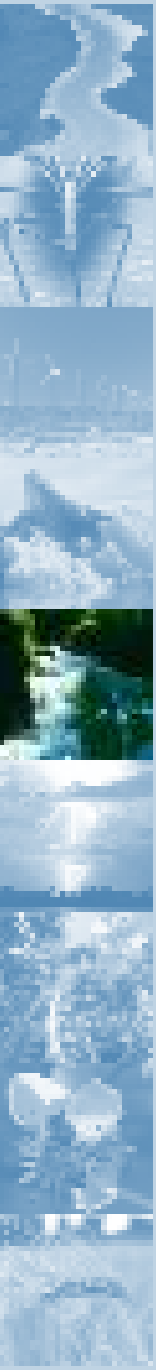
Atmospheric temperature and water vapour data are provided operationally by polar orbiting meteorological satellites. Sea surface temperature measurements are also provided by these satellites, by Envisat (AATSR), and by the Terra and Aqua missions (MODIS). Ocean wind measurements are also provided by these missions – and by NASA's QuikSCAT which acquires all-weather, high-resolution measurements of near-surface winds over 90% of the global oceans on a daily basis.

Precipitation is clearly a key parameter, but given the high temporal and spatial variability of precipitation it is a fundamentally difficult parameter to measure. Until recently, visible/infrared images from geostationary meteorological satellites provided the best source of information from satellite – with indirect but frequent estimates of rainfall derived from measurements of cloud top temperature. The advent of the Tropical Rainfall Mapping Mission (TRMM of NASA/JAXA) in 1997 provided a breakthrough in the provision of 3-D information on rainfall structure and characteristics.

NASA, JAXA, and ESA will collaborate to follow-up the success of TRMM and will launch the Global Precipitation Mission (GPM) from 2009. GPM aims to provide precipitation measurements on a global basis with sufficient quality, Earth coverage, and sampling to improve prediction of the weather, the Earth's climate, and specific components of the global water cycle. GPM design involves a large 'core' platform equipped with both passive and active microwave instruments and a number of smaller satellites large enough to ensure a repeat observation cycle of approximately 3 hours.

Recognising the central role of the water cycle to our understanding of the Earth System and climate change, the world's space agencies are operating or developing a number of new missions aimed at addressing key water cycle issues. These include the Aqua mission (NASA), Cloudsat (NASA), EarthCare (ESA/JAXA), Cryosat (ESA), and Megha-Tropiques (CNES/ISRO) (which will study water cycle and energy exchanges in the tropical belt). Revolutionary new measurement capabilities – such as the provision of information on soil moisture and ocean salinity – will be provided in future by missions such as SMOS (ESA), HYDROS (NASA), and Aquarius (CONAE/NASA).





Following the 2002 Johannesburg World Summit on Sustainable Development, ESA launched the TIGER Initiative - focusing on the use of space technology for water resource management in Africa and providing concrete actions to match the Resolutions.

Future challenges

New technologies for measuring, modelling, and organising data on the Earth's water cycle offer the promise of deeper understanding of water-cycle processes and of how management decisions may affect them. Earth observation satellites will provide synoptic, high-resolution measurement coverage that is unprecedented in the geophysical sciences. The challenges to be faced in utilisation of these new capabilities include:

- converting satellite measurements into useful parameters that can be applied in scientific models, and that can be inter-compared and inter-calibrated among the different satellite missions;
- development of assimilation methodologies to integrate satellite and in-situ observations;
- capacity building, particularly in developing countries – so that those countries in most dire need of water information have the means of access, analysis, and understanding required for maximum benefit;
- providing consistent and accurate data over many years in order to detect the trends necessary for climate change studies;
- succeeding in the technology developments aimed at accurately measuring key parameters from space for the first time – including soil moisture and ocean salinity.

To complement the satellite data, existing ground-based measurement networks and systems must continue operating to obtain current data that can be compared meaningfully with past records.

Water vapour observation from geostationary satellite

Water Cycle:
earthobservatory.nasa.gov/Library/Water

World Bank Water Page:
www.worldbank.org/html/fpd/water

World Water Forum: www.worldwaterforum.org

WMO Hydrology & Water Resources Programme:
www.wmo.ch/web/homs/hwrpframes.html

CEOP: www.ceop.net

IGWCO: ioc.unesco.org/igospartners/Water.htm

GEWEX: www.gewex.org

SMOS: www.esa.int/export/esaLP/smos.html

Aqua: aqua.nasa.gov

TRMM:
www.jaxa.jp/missions/projects/sat/eos/trmm/index_e.html

HYDROS: hydros.gsfc.nasa.gov

Weather forecasting

"Know yourself and know your enemy, and victory is guaranteed. Know the terrain and know the weather, and you will have total victory."

Chinese philosopher Sun Tzu, 4th century BC

Today, as throughout history, many aspects of our lives are governed by the weather. Our well-being and prosperity depends on it, civilisations have prospered or struggled because of it and its direct impact on many social and economic sectors – including public health, agriculture, energy, construction, transportation, tourism, recreation, ecosystems and biodiversity. Of particular consequence are severe weather events, such as hurricanes, tornadoes, flash floods, blizzards, heat waves, droughts, and poor air quality episodes – which impact every nation on Earth and which lead to the loss of tens of thousands of lives annually.

The economic and social benefits of accurate weather forecasts are immense and include improved efficiencies in agricultural systems, optimised planning of energy supply and distribution, and of course ensuring public safety.

The art of weather forecasting began with early civilisations using reoccurring astronomical and meteorological events to help them monitor seasonal changes in the weather. With the formation of regional and global meteorological observation networks in the nineteenth and twentieth centuries, more data became available for observation-based weather forecasting.

As weather and climate know no national boundaries, international cooperation at a global scale is essential for weather forecasting and for sharing its benefits. Established in 1950, the World Meteorological Organization (WMO) became the specialised agency of the United Nations for meteorology (weather and climate), operational hydrology and related geophysical sciences. WMO provides the framework for such international cooperation – with a membership of 187 Member States and Territories.

Numerical weather prediction and observations

Modern weather forecasting techniques use sophisticated, computer-intensive models of the atmosphere. These models obtain an objective forecast of the future state of the atmosphere by solving a set of equations that describe the evolution of variables (such as temperature, wind speed, humidity and pressure) that define its state. The process begins by analysing the current state of the atmosphere – taking a previous short range forecast and using observations to amend this forecast so that the best guess of the current true state of the atmosphere is obtained. A computer model is then run to produce a forecast.

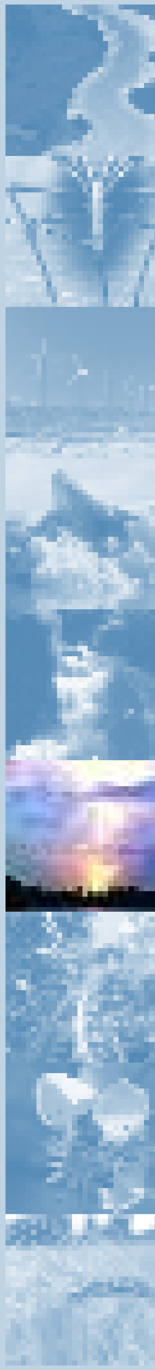
All numerical models of the atmosphere are based upon the same set of governing equations, but may differ in the approximations and assumptions made in the application of these equations, how they are solved and also in the representation of physical processes.

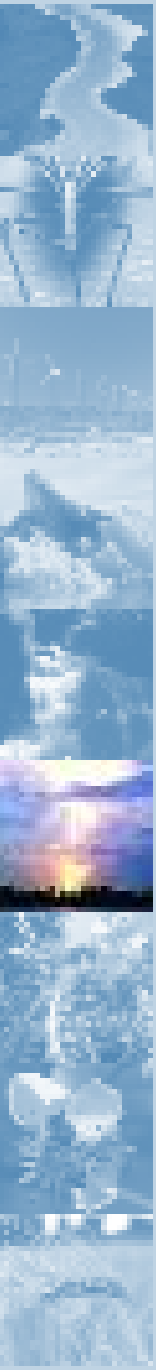
Observations are crucial inputs to these Numerical Weather Prediction (NWP) models. Weather bureaus receive many thousands of observations each day and these are processed, quality controlled, and monitored. Sources include surface data from weather stations, ships, and buoys, as well as radiosondes, aircraft, and satellites. These observations need to be incorporated, or assimilated, into the numerical models so that the information that they contain can be usefully exploited in making the forecasts.

The essential role of Earth observation satellites

Modern technology, particularly computers and weather satellites, and the availability of data provided by coordinated meteorological observing networks, has resulted in enormous improvements in the accuracy of weather forecasting. Satellites, in particular, have given forecasters routine access to observations and data from remote areas of the globe. On 1st April 1960, the polar-orbiting satellite TIROS-1 was launched. Although the spacecraft operated for only 78 days, meteorologists worldwide were ecstatic over the pictures of the Earth and its cloud cover that TIROS relayed back to the ground.

The first picture of Earth from a weather satellite, taken by the TIROS-1 satellite on April 1, 1960. Although primitive in comparison with the images we now receive from satellites, this first picture was a major advance.





Over the past 40 years, satellite sensor technology has advanced enormously. In addition to providing visual images, satellites can also provide data that allow calculation of numerous atmospheric and environmental variables – including temperature and moisture profiles. This is done using a variety of instruments, among them atmospheric sounders, which measure quantities at various levels in atmospheric columns. The data retrieved from spaceborne sounder measurements can be utilised in a similar way as that from radiosonde observations – with the major advantage that the satellite data are more complete spatially, filling in gaps between weather ground stations, which often are hundreds or even thousands of kilometres apart.

Geostationary and polar-orbiting orbits for weather satellites

USA, Europe, Russia, China, Japan amongst others contribute satellites to the Global Observing System of WMO

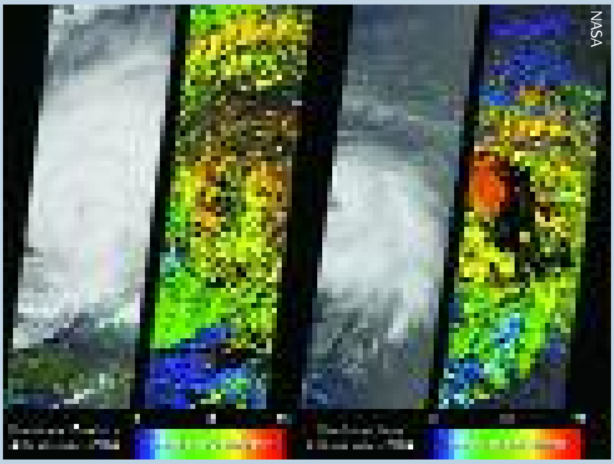
Today, the global system of operational meteorological satellites includes a constellation which is evenly spaced around the equator in geostationary orbit, and at least two further satellites in near-polar orbits. The geostationary satellites fly at an altitude of about 36,000km and each has the capability to provide almost continuous imagery and communications support over a wide region of the planet. Each satellite can generate full earth disc images covering nearly one quarter of the Earth's surface, day and night.

The polar orbiting satellites fly in much lower orbits, typically at around 850 km. Each polar satellite can typically observe the entire planet twice in each 24-hour period, with better resolution than the geostationary satellites.

These missions provide a wide range of valuable data used for weather forecasting and warnings, including:

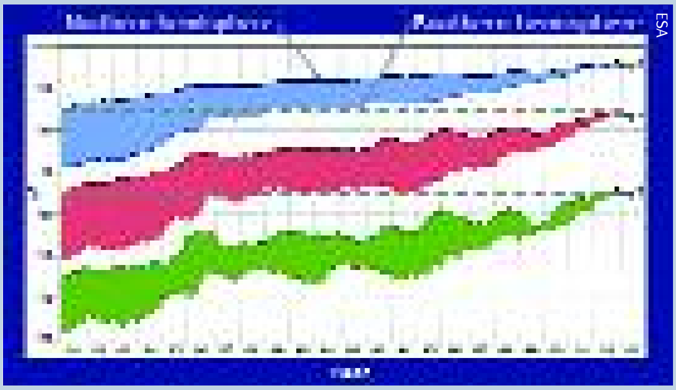
- **visible and infra-red imagery of the Earth's surface and atmosphere:** such imagery is usually the only means of obtaining continually updated quantitative information about cloud over a wide area, and is used to determine the movement of the atmosphere – providing the main source of wind information for NWP models; infrared imagery can also be used to determine cloud top temperature, and from this estimates derived of rainfall in tropical regions;
- **atmospheric humidity and temperature profiles:** atmospheric sounder instruments generally make passive measurements of the IR or microwave radiation emitted by the atmosphere – from which vertical profiles of humidity and temperature may be obtained – which are at the heart of daily weather forecasts using NWP models and have improved forecasts significantly;
- **ozone concentration profiles:** developments are under way to add satellite measurements of ozone (from sounder instruments) as a new NWP model variable – primarily for use as a tracer for information on wind;
- **sea surface temperature estimates:** which are required for low level cloud diagnosis (and their discrimination from the sea background) as well as for seasonal to inter-annual forecasts – especially in the tropics;
- **precipitation and liquid water:** microwave imagers and sounders on satellite missions provide information on precipitation, and represent the only potential information source of their kind over the oceans – although accurate measurements are difficult to achieve and validation is difficult;
- **sea surface winds:** the strength, direction and circulation patterns of the surface wind is of great importance for meteorology and climate studies – including for helping to define storm centres, and for detecting patterns associated with inter-seasonal climate variations such as the El Niño/Southern Oscillation (ENSO), which affects the weather over large parts of the planet; until recently the only source of surface wind data over the oceans were reports from ships, mostly concentrated in a few shipping lanes; since the launch of satellite wind scatterometers a huge quantity of high resolution wind data over the oceans has been available, proving of great value to NWP models and other applications.

In addition to the data from operational satellite series – which are planned, operated, and funded on a

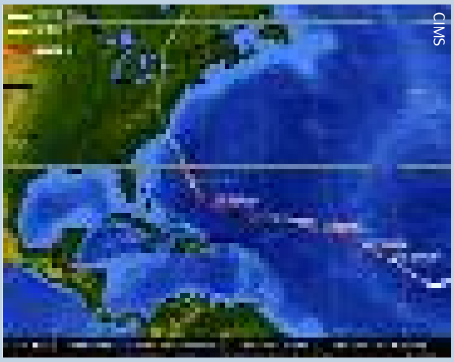


2-D cloud height maps generated by MISR on the Terra spacecraft

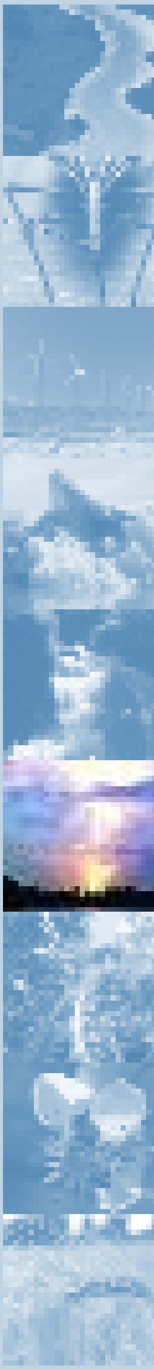
QuikSCAT image of winds on the surface of the Pacific Ocean on 8th January 2004

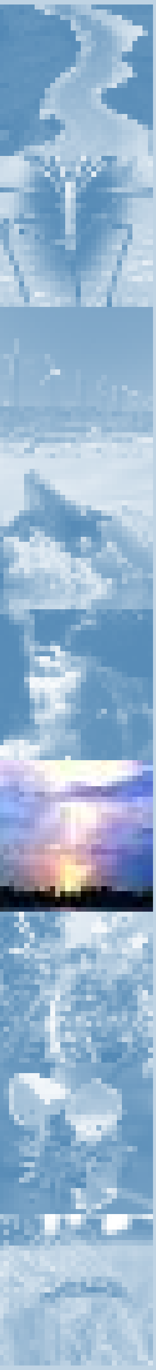


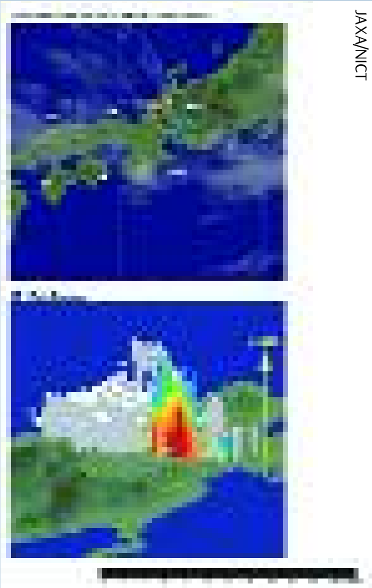
The impact of satellite observations on weather forecast accuracies during the 1980's and 1990's is evident in this chart – particularly for the Southern hemisphere where weather stations are relatively sparse (% scale is the evolution of annual mean forecast skill for the European Centre or Medium Range Weather Forecasting)



Satellite imagery is an everyday feature of TV weather forecasts. The early warnings they provide of hurricanes and severe storms can help save lives and property (images show track of Hurricane Isabel, Sept 2003)







The Precipitation Radar (PR) on TRMM observed the heavy rain in Fukui, Japan on 18th July 2004 which claimed several lives. The 4-D data gave insight into the storm structure and showed that the rain fell from as high as 13 km.

continuous basis as essential public services – the world's space and weather agencies are cooperating to explore the introduction of new satellite-derived information streams into the weather forecasting systems. For example, scientists have used the sensors on the joint US-Japan TRMM mission to peer inside the tropical thunderstorms associated with hurricanes in an attempt to understand which parts of a hurricane produce rainfall and why. Most importantly to people endangered by hurricanes, such satellite missions are adding to the knowledge required to precisely predict the path and intensity of these storms.

Future developments

Planners of the Global Earth Observation System of Systems (GEOSS) described in Part I, have outlined a vision where every country will have the weather information needed to virtually eliminate loss of life and to reduce property damage from severe weather events. The aim is to have a society where weather forecasts are fully used in decision support systems to improve economic efficiency and productivity, as well as environmental protection, through improved longer-range predictions available in probabilistic terms.

The GEOSS Implementation Plan calls for an end-to-end weather information system that provides, to decision makers around the world, timely, reliable and actionable information. This system will have improved in-situ and space-based observations of critical parameters, coordinated and exchanged globally. These will provide input to improved NWP models, with advanced physics capabilities, providing accurate (in location and time) forecasts of severe weather events to new or strengthened regional and local warning centres, allowing rapid and tailored notification to local authorities responsible for protecting people and property.

Given the importance of weather observations, a significant number of the future missions planned by CEOS agencies over the next decade have the objective of providing either improved operational observations for meteorology or new research capabilities. These will include:

- finer spatial, temporal, and spectral measurements of atmospheric parameters, allowing more accurate determinations of parameters such as temperature and moisture; this data – from missions such as Aqua (NASA), METOP (EUMETSAT), and NPOESS (NOAA) is expected to lead to substantial improvements in the accuracy of mid- and long-range weather forecasts;
- the introduction of new series of polar orbiting missions to complement the current NOAA series: the METOP series (EUMETSAT) will be launched from late 2005 and the FY-3 series (China) soon afterwards;
- new capabilities for monitoring precipitation and cloud properties: by 2007, a constellation of satellites will be in place (comprising Aqua, Aura, CALIPSO, Cloudsat, PARASOL, and OCO) and will fly in orbital formation to gather data needed to evaluate and improve the way clouds are represented in global models; the Global Precipitation Mission (GPM) will provide global observations of precipitation every three hours; and Megha-Tropique (a French-Indian cooperation) will collect data on rain over the tropical oceans;
- soil moisture measurements: which are important for initialisation of NWP models will be provided by SMOS (ESA) and HYDROS (NASA);
- global three-dimensional wind-fields: direct measurements will be made from space for the first time in 2007 by the ADM Aeolus mission (ESA) – with the aim of improving weather forecasting and climate research.

There will be significant challenges in developing models and assimilation techniques to make full use of these new capabilities in operational forecasting systems.

NWP: www.metoffice.com/research/nwp

WMO: www.wmo.int

NOAA: www.noaa.gov

EUMETSAT: www.eumetsat.de

Conserving Ecosystems and Biodiversity

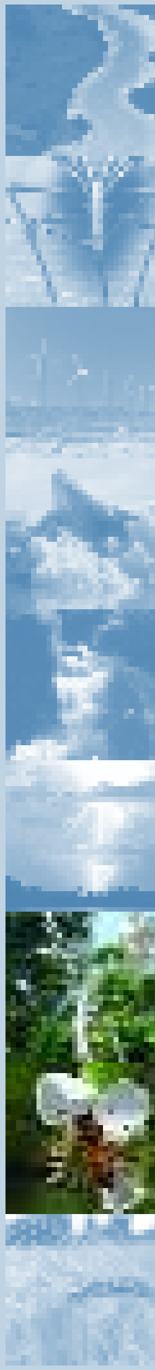
The crucibles of life on Earth

Based on our current understanding of the cosmos, the biosphere, which provides for the needs of life on our planet, is the feature that makes Earth unique in the Universe. The number of ecosystems, and the strength and biodiversity within those ecosystems, are two of the leading measures of the health and vitality of the Earth's biosphere. Distributed over numerous and remote locations on Earth, the variety of ecosystems is striking and includes: rain forests, boreal forests, grasslands, wetlands, alpine, tundra, deserts, coastal regions, fresh water, and salt water systems. Each of these ecosystems supports the biodiversity that ensures the vibrancy of life on Earth – and their interactions form a sacred balance that has allowed life on Earth to form, evolve, and adapt to ever-changing environmental conditions.

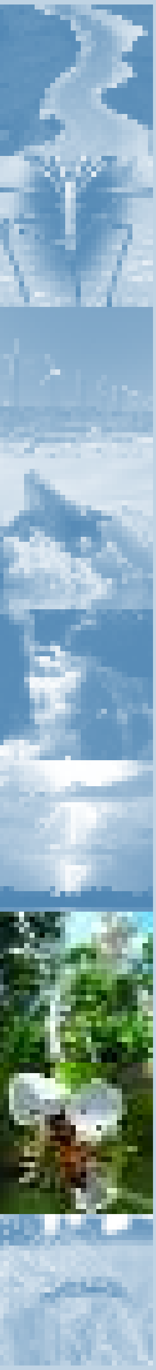
Ecosystems provide the resources needed to support life on Earth and have a great impact on our wellbeing: both physical and economic, individual and national. The richness and biodiversity of Earth's ecosystems provide people with food and nutrition, pharmaceutical drugs and herbal remedies, renewable resources and protection from weather, and cyclically replenished resources like fresh air and fresh water. It is not difficult to draw connections between the health and robustness of Earth's ecosystems, and the health and robustness of the natural species (including humans) they support – and by extension their strong links to our economic prosperity. The stark reality, however, as discussed in Part I of this document, is that all available indicators point to an 'overwhelming human dependence on rapidly deteriorating ecosystems' – the systems that support all life on Earth:

In 1971 an inter-governmental treaty established the Ramsar Convention on Wetlands, establishing a framework for the stewardship and preservation of wetlands. 138 national signatories are obliged to report on the state of listed wetlands they are responsible for.

The GlobWetland Project is producing satellite-derived and geo-referenced products including inventory maps and digital elevation models of wetlands to assist with Ramsar reporting requirements.

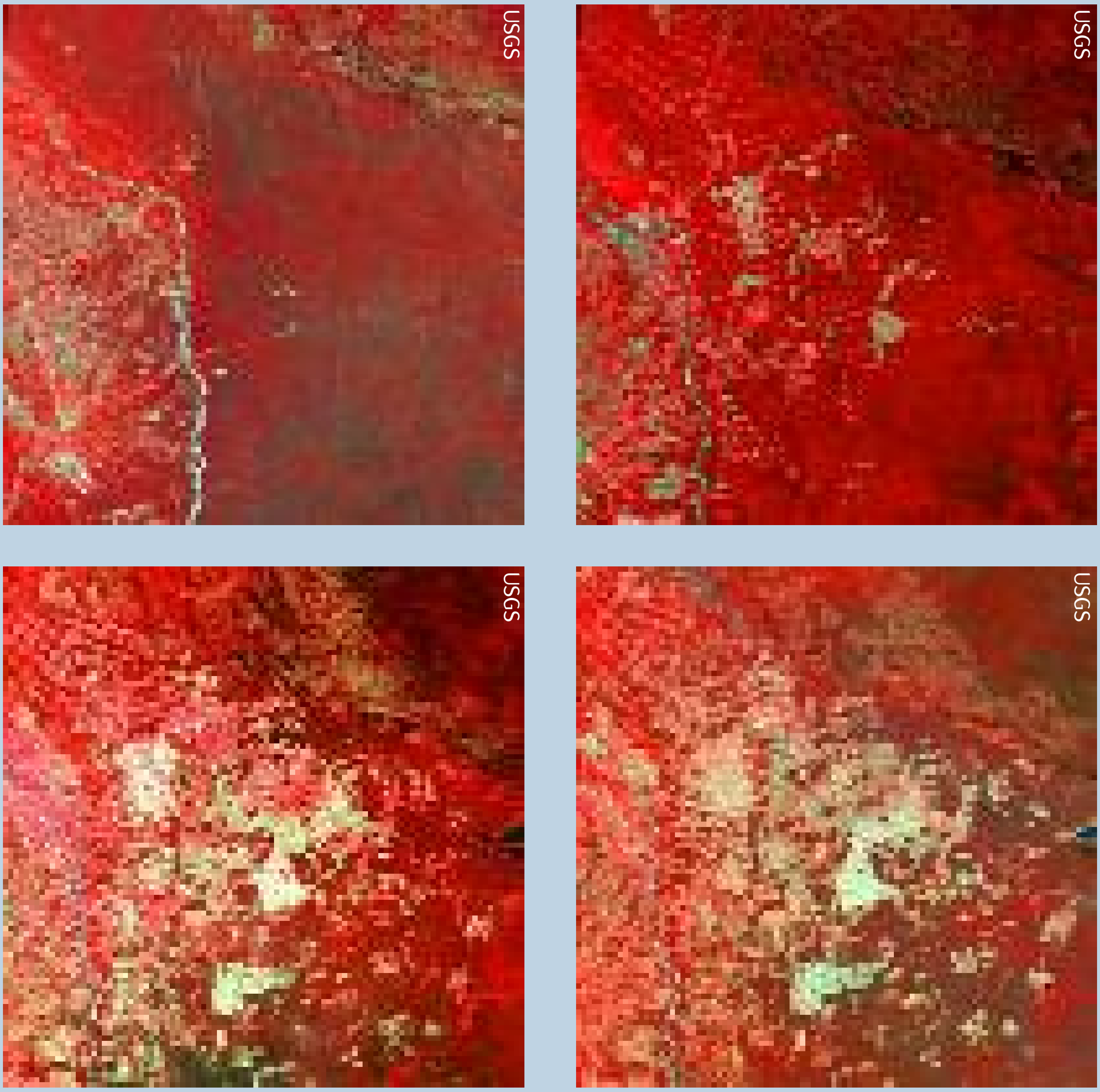


Conservation International has identified 25 biodiversity 'hotspots' that contain 44% of all plant species and 35% of all land vertebrate species – despite accounting for just 1.4% of the Earth's land area



- human action has transformed almost half of the Earth's land surface;
- coastal and marine habitats are being dramatically altered; 50% of mangroves have been removed and wetlands have shrunk by one-half;
- extinction rates are increasing sharply in marine and terrestrial ecosystems around the world;
- 1 in 6 humans depends on fish for protein needs, yet 75% of the world's fisheries are over-fished or fished at their biological limit;
- 41 of every 100 people live in water-stressed river basins;
- some 350 million people are directly dependent on forests for their survival, with global forest cover declining by 46% since pre-agricultural times.

Better understanding and management of future changes in Earth's ecosystems and biodiversity are necessary to ensure their essential benefits are enjoyed by future generations. More information on the various ecosystems and their extent, on their complex interactions, their response to local and global environmental changes, and on their capacity to sustain biodiversity is needed to develop this understanding and to provide the evidence needed to guide scientific study, inform public opinion, and support cooperative protection measures, e.g. through international conservation treaties.



Landsat time series (1975, 1992, 2000, 2002) images of large scale deforestation in the Amazon. Such images have raised global awareness of deforestation

The role for Earth observation satellites

The challenge of conserving our precious ecosystems and biodiversity is compounded by their distribution around the globe, the fact that they often span national boundaries, and by their remoteness. This is where remote sensing technologies such as Earth observation satellites can play a significant role.

Some scientists are using remote-sensing technology to better understand relationships between species and the places they live. Satellites' ability to routinely observe even the most remote areas can make biologists' search for important species and habitats quicker and easier – particularly in remote or hazardous areas where access may be hazardous or prohibitively expensive.

Current and planned Earth observing missions offer a broad range of monitoring capabilities of value to conservation efforts – from monitoring the rate of land use change each year for farmland or urban growth, to the frequency and severity of air pollution events, to increased ocean temperatures in sensitive coral habitats.

Improvements in spatial resolution are enabling more and more specific, local information to be derived – and in some rare cases, high resolution satellites can directly observe (particularly large) species on the ground. Mostly though, environmental data or images from satellites offer indirect but invaluable information about species and their habitat including environmental, biological, and physical information – topography, rainfall, forest cover – that reveal where species are likely to be found and the nature of possible extinction threats. Satellite imagery is proving to be an extremely compelling way to show politicians and land managers what is going on and how land has changed.

During the last few years, there has been rapid adoption and use of data from several Earth observation satellites – including Landsat, SPOT, ENVISAT, RADARSAT, Terra and others by NGOs (e.g. The Nature Conservancy, Global Forest Watch of the World Resources Institute, Conservation International). Their analyses are primarily related to conservation, especially in relation to biodiversity. The results of this work have led to several definitive analyses of land cover change in many parts of the world including Mozambique, the boreal forests of northern Eurasia, Indonesia, Cameroon, and several countries in South America.

These and other projects have exploited the ability of multi-spectral electro-optical and radar satellite sensors to detect land cover change, determine vegetation abundance, discriminate vegetation types, and detect and map invasive species. Such data is valuable in charting the main environmental factors which researchers believe drive patterns of biodiversity: vegetation growth, habitat structure, and climate. New capabilities of 'hyper-spectral' sensors (which provide more unique identification information on chemical composition of vegetation and land cover materials) and of 'vegetation canopy lidars' (which can map the 3-D vegetation structure in an ecosystem) will further add to the wealth of data from satellites used in conservation studies.

While these new technologies and techniques offer a far greater range of information than has ever been possible before, there are still challenges to using satellite data effectively. For starters, remote sensing data need to be validated, or compared with other sources of information to see if there is agreement. Such 'ground-truth' information might come from ground-based sensors, higher-resolution remote-sensing sources, like aerial photographs, or researchers in the field. Affordability and ease of access of the best satellite data available are further issues to be addressed if we are to make full use of their potential.

Millenium Ecosystem Assessment: www.millenniumassessment.org

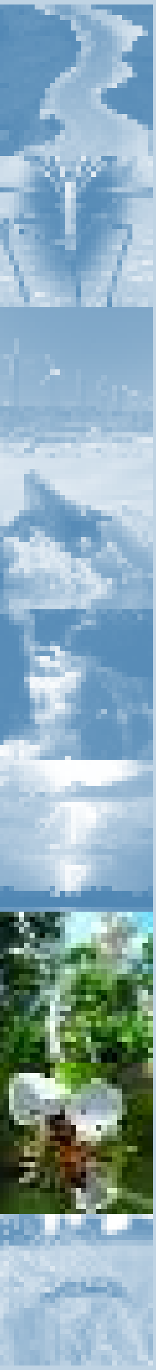
Global Biodiversity Forum: www.gbf.ch

Conservation International: www.biodiversityhotspots.org

ESA's application programmes: www.esa.int/export/esaEO

Case studies of remote sensing for conservation: earthobservatory.nasa.gov/Study/Conservation

Environmental Monitoring and Information System, Africa: edcintl.cr.usgs.gov/dataportaldata.html



Space technologies to support the World Heritage Convention

Surveillance of the Gorilla Habitat (SOGHA) is the first outcome of an agreement signed in 2001 between the European Space Agency (ESA) and the United Nations Educational, Scientific and Cultural Organisation (UNESCO) to use remote sensing and other space technologies to monitor World Heritage Sites.

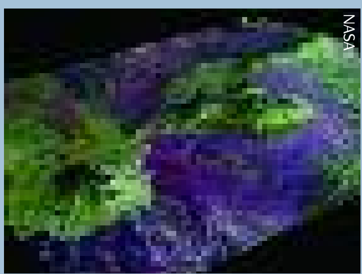
Lulenga, an eleven-year-old mountain gorilla, chews part of the roughly 30 pounds of foliage he eats daily in Congo's Virunga National Park. Lulenga has led his group since his father was killed by poachers in 1995.

There are about 600 mountain gorillas left in the world, most of whom thrive in this relatively small volcanic forest habitat preserved by the park, which overlaps into the neighbouring countries Rwanda and Uganda.

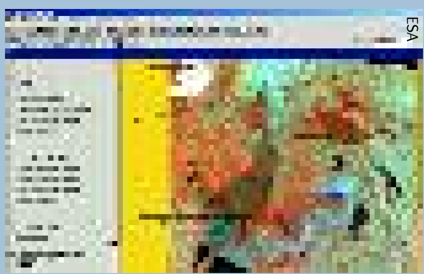
UNESCO together with the involved countries has recognised the mountain gorilla habitat – and specifically the area included in the Virunga National Park in the Congo, bordering Rwanda and Uganda, and the Bwindi Impenetrable National Park in Uganda – to be World Heritage Sites. But these habitats are increasingly coming under pressure as regional conflicts cause an influx of refugees. Clearing forest land for agriculture or fuel, and poaching for food have reduced the living space left for the gorillas. That is why the WHC has classified the sites in the Congo as World Heritage sites in danger.

Wildlife workers on the ground are limited in their monitoring capacity because these habitats total more than eight hundred thousand hectares, with long boundaries across extremely inaccessible and seldom-mapped terrain. As a result, UNESCO and ESA agreed to begin a pilot scheme using satellite data to monitor the changes of land use in the gorilla habitats and to identify possible environmental indicators.

Radar instruments on board satellites such as ESA's ERS-2 and Envisat can pierce through the near-total cloud cover of the rainforest to identify illegal forest clearance or settlements, data that can be integrated with visible imagery from satellites and with ground observations provided by organisations working in the area – before being supplied to local authorities.



Satellite-derived elevation map



Multiple satellite and in-situ data sources, combined with local knowledge and gorilla sightings are combined in the project GIS

In this transfrontier region of Uganda, Rwanda, and the Democratic Republic of Congo, the volcanic highlands of the Virungas shelter the last 600 plus mountain gorillas in the world. Photo: Courtesy of International Gorilla Conservation Program (IGCP) a coalition of AWF, WWF and FFI.

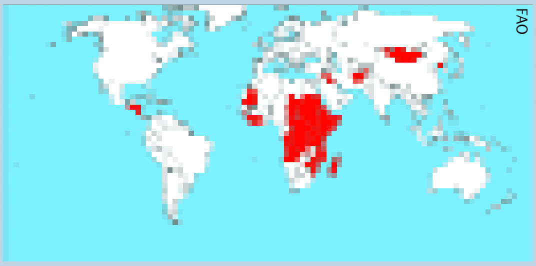
Sustainable agriculture

Feeding 10 billion people

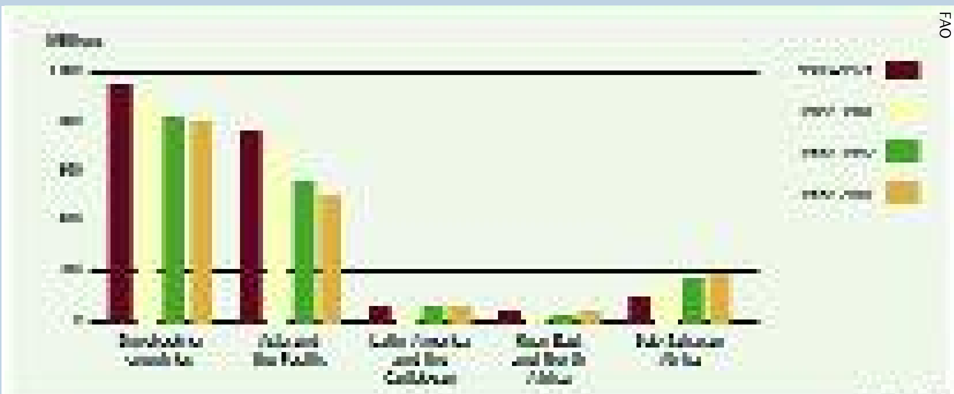
The FAO (Food and Agriculture Organization of the United Nations) estimates the number of undernourished people in the world at over 840 million – mostly living in developing countries of the Asian-Pacific and sub-Saharan Africa regions. Above all other goals that are the focus of international cooperation among countries, the eradication of famine might be considered to be the most universally supported. The United Nations Millennium Declaration, adopted by the world's leaders at the Millennium Summit of the United Nations in 2000, captured the aspirations of the international community for the new century. It spoke of a world united by common values and striving with renewed determination to achieve decent standards of living for every man, woman and child. The first of the eight agreed 'Millennium Development Goals' is to "Eradicate extreme poverty and hunger" – with the specific target of reducing by half the number of undernourished people by 2015.

FAO statistics suggest that some progress is being made towards this target – with the global incidence of malnourishment being reduced from 28% in the early 1980s to 17% in the early 2000s. However, as a result of global population growth, the decline in actual numbers of undernourished people has been slower; and the decline appears to have slowed in recent years. Malnutrition, and even starvation, will therefore remain a fact of life, and death, for hundreds of millions of people on Earth for the foreseeable future.

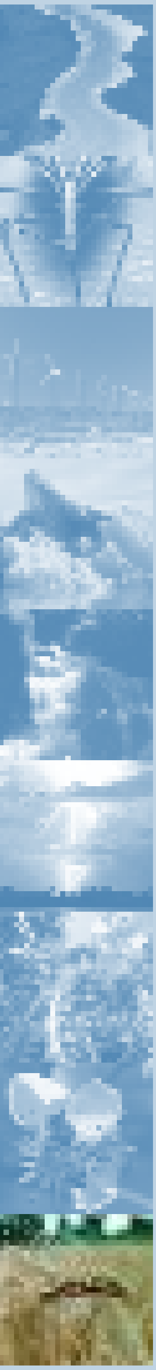
The challenge of sustainable food production is heightened by the expected global population expansion – increasing from around six billion to between nine and ten billion people by 2050. To meet the associated food demand, crop yields will need to increase, consistently, by over 2% every year through this period. Despite advances in technology, increasing food production must lead to intensification of agriculture in areas that are already cropped, and conversion of forests and grasslands into cropping systems. Much of the latter will occur in semi-arid regions and on lands that are marginally suitable for cultivation, increasing the risk of soil erosion, accelerated water use, and further land degradation. The resulting land-use changes are anticipated to make agriculture one of the most significant components of global change over the next century.



Countries facing food emergencies, Oct 2004



Number of undernourished people in developing countries, by region



Information needs

Global agricultural production systems must be enhanced, well maintained, and reliable if we are to routinely meet the food requirements of the Earth's projected 10 billion inhabitants beyond 2050 – and sustainable development practices, consistent with protection of biodiversity and ecosystems, are seen as the key. Such practices require a broad range of information on all scales. Parameters of importance include:

- land-cover, land-use, and vegetation state;
- crop yield, land degradation, and desertification;
- soil characteristics such as fertility and moisture levels;
- freshwater availability including from rainfall, fluxes in small water bodies, and groundwater resources;
- total irrigated area;
- population distribution, production intensity, and food provision.

This data is required at various (from local to global) scales and requires fusion of multiple datasets quantifying both the physical state of the land and socio-economic parameters. Such information will help provide food producers with: information on changes in land usage and productivity, improved market supply and demand forecasts, and seasonal and inter-annual action plans - taking account of seasonal forecasts and predictions of major climatic events such as El Niño.

The hope is that, with more detailed and timely information available on the state of crops and their growing environment, parties in the agricultural sector will improve their capacity to make informed decisions regarding sustainable agricultural practices:

- improving yields and increasing food security, by reducing susceptibility to climatic variations, extreme weather events and natural hazards; whilst
- making optimum use of the precious natural resources required to produce food, and protecting ecosystems and biodiversity;

so that the needs of present and future generations can be addressed.

The role of Earth observation satellites

In 2005, Earth observation satellites are in routine use for a broad range of agricultural applications.

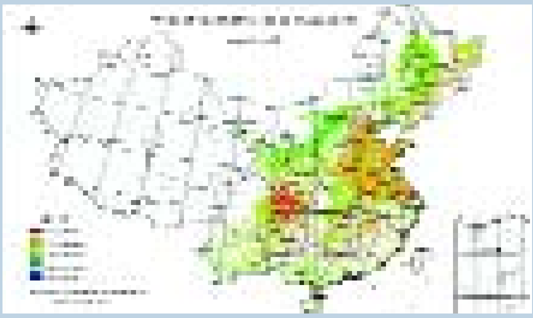
In developed countries, where producers are often sophisticated users of agricultural and meteorological information, satellite data is widely used in many "agri-business" applications. Remote sensing techniques play an important role in crop identification, acreage and production estimation, disease and stress detection, soil and water resources characterisation, and also provide

inputs for crop-yield and crop-weather models, integrated pest management, watershed management, and agro-meteorological services.

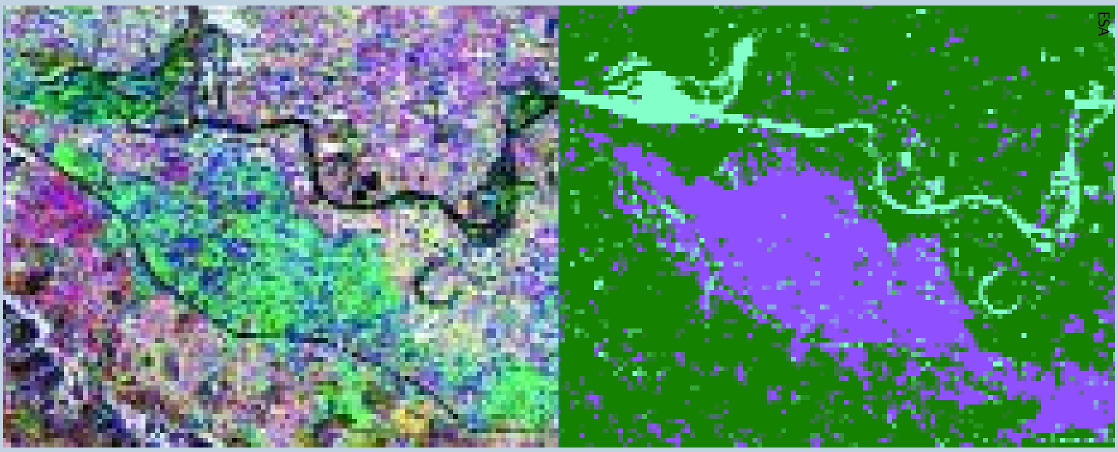
Multi-spectral imagery from the Landsat and SPOT satellite series might be regarded as the most widely exploited data for agricultural applications over the last few decades. By providing frequent, site-specific insights into crop conditions throughout the growing season, such satellite data products have helped growers and other agriculture professionals to efficiently manage crop production risks, thereby increasing crop yields while minimising environmental impacts.

With the advent of high accuracy global satellite navigation systems (such as GPS and Galileo) installed on farm machinery, new capabilities are being developed which allow the possibility of automated operations like tillage, planting, fertilizer applications, pesticide/herbicide spraying, irrigation, harvesting and other mechanised cultural operations – all optimised with the aid of geo-spatial information provided by imaging satellites.

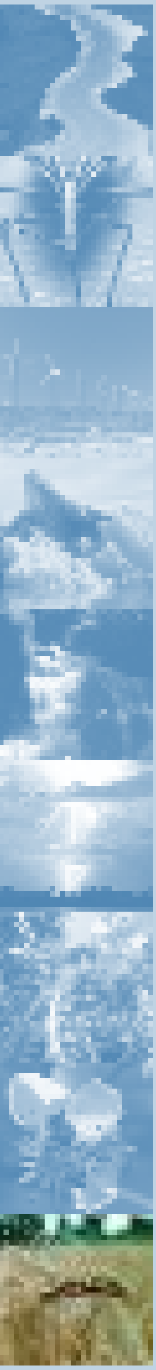
The latest generation of multi-spectral, hyper-spectral, and synthetic aperture radar (SAR) sensors – combined with improved models for interpretation of their data for various crops and environmental parameters – are increasing the scope and capabilities of Earth observing satellites in support of agricultural businesses. A number of commercial satellite missions (e.g. RapidEye (Germany) and Tuyuan (China)), dedicated exclusively to (and funded by) crop monitoring and yield forecasting, will be launched within the next 3 years – and a sizable industry of service companies is emerging to exploit such missions.

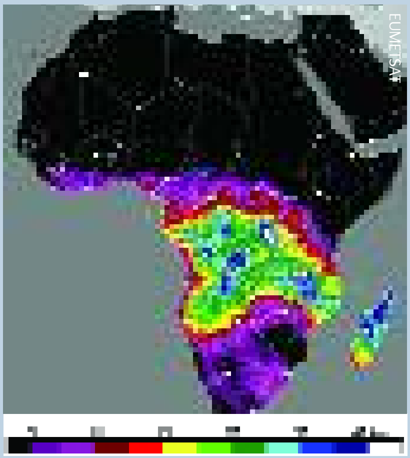


China's State Food Bureau has developed an "agriculture information monitoring system" using several Earth observation satellite data sources

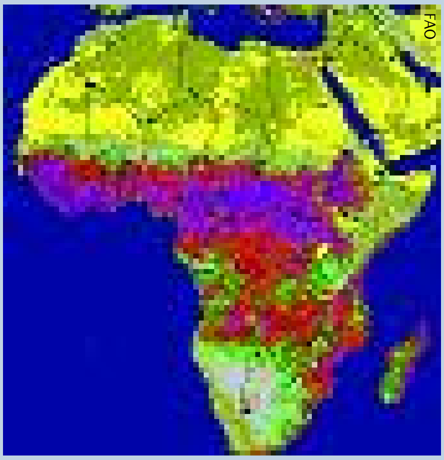


Radar imagery is used to classify rice fields in Thailand and to provide simple estimates of acreage





Rainfall estimates are derived from cold cloud duration maps such as this one from METEOSAT



NDVI (vegetation) map as utilised by FAO

Earth observation data is also used by government agencies in developed countries, typically on large scales – in support of market forecasting, generation of statistics, and in development and enforcement of agricultural policies, including in relation to the payment of subsidies to farmers for growing (or not growing) certain crops. (See the article on the MARS programme of the European Commission.)

In developing countries, government agencies and international organisations – with responsibility for advice on development decisions and for food security – are exploiting Earth observation data as a management tool in decision-making processes. For example, the government of India has been actively exploring the use of spaceborne remote sensing data for crop acreage estimation and production since the early 1980s. These projects have been expanded to provide national level forecasts – including through use of all-weather microwave data (from synthetic aperture radar sensors such as RADARSAT) for monitoring of rice crops in the cloudy and wet monsoon season.

Similar state-funded projects are underway in China. China is a large country with 1.2 billion people and a per capita cultivated land area of just one third of the world average. Grain production is a national priority for agricultural development, and is an important influence on China's sustainable development, modernisation, and food security for the population. The government needs timely and accurate grain production information for agricultural management and market decision making. Remote sensing techniques play an important role in crop identification, acreage and production estimation, disease and stress detection, soil and water resources characterisation, and also provide inputs for crop-yield and crop-weather models, integrated pest management, watershed management, and agro-meteorological services.

FAO is a key player in establishing the link between Earth observation data and product suppliers and the communities of users at all levels. FAO has a well established and structured mechanism for interacting with farmers, national agencies, and international agencies. It also has direct cross links to work on ecosystems and biodiversity. FAO's Global Information and Early Warning System (GIEWS) on Food and Agriculture collects data from four different satellite systems to monitor various crop seasons throughout the world:

- rainfall estimates are derived from cold cloud duration images of Africa (METEOSAT) and Asia (GMS); archives dating back to 1988 allow analysts to pinpoint anticipated droughts based on seasonal norms;
- Normalised Difference Vegetation Index (NDVI) products from the AVHRR sensor provide an indication of the vigour and extent of vegetation cover – and can help monitor crop conditions;
- the VEGETATION instrument on-board the SPOT-4 satellite provides data at 1km resolution – suitable for crop monitoring at sub-national levels.

One of the main causes of food insecurity is drought. FAO and other international bodies utilise satellite data sources operationally to help identify drought-prone areas, and then to monitor changing drought risks and conditions. Pests, too, are a major cause of food insecurity, particularly through their direct effects on crop yield and harvests (see the example on the 2004 locust plague in Africa).

Future challenges

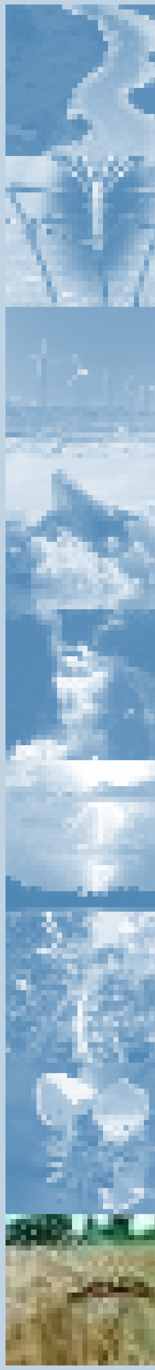
Current Earth observation satellites have the capability to supply many agricultural information needs – for both developed and developing countries. In the case of developing countries, there is a need to ensure that those who might benefit most from this kind of information, are suitably equipped with the knowledge and equipment to effectively apply it for long-term benefit. This will require investment in capacity-building for training and infrastructure projects.

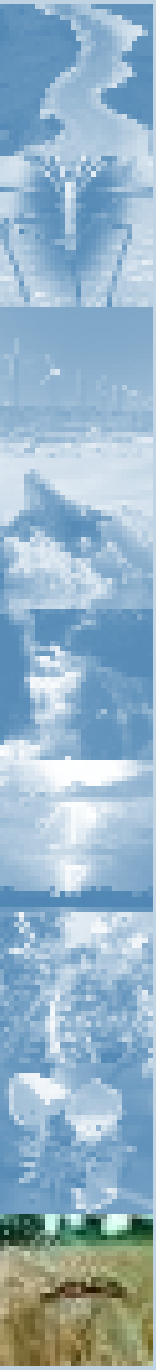
FAO report that the capacity to use Earth observation data is generally weakest in Africa and that sustainability of institution-building initiatives remains problematic. Needs highlighted by FAO include:

- increased co-ordination between national satellite programmes in developed countries and their counterpart development assistance programmes;
- stronger links between ground observations in developing countries and related satellite observations by developed countries;
- better understanding of developing country user needs for Earth observation data in the agricultural and rural sectors – more assessments are needed.

To ensure maximum value from the data in agricultural applications in both the developed and developing world, further attention must be paid to:

- improvements in product development, validation, and continuity of data sources, in particular of high (5m) and medium (30-40m) resolution satellite systems such as LANDSAT and SPOT;
- improved data archiving and access;
- integration of data collection, management, and assimilation;
- strengthened links between in-situ data gathering networks and satellite programmes to assist product validation such as land cover, land use, crop production, and cultivated area.





MARS: Monitoring Agriculture though Remote Sensing techniques

MARS (Monitoring Agriculture through Remote Sensing techniques) is a long term project that has provided technical support and expertise to the European Commission's Directorate General for Agriculture (DG VI) over several decades.

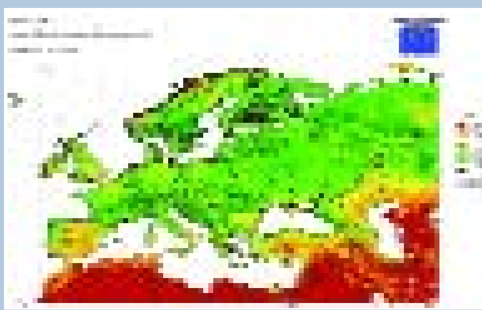
The programme supports decision-making at the European level – providing statistical input to the implementation of the EC's Common Agricultural Policy (CAP) and other activities of the Directorate General for Agriculture.

MARS has developed and implemented new methods and tools specific to agriculture using remote sensing, including:

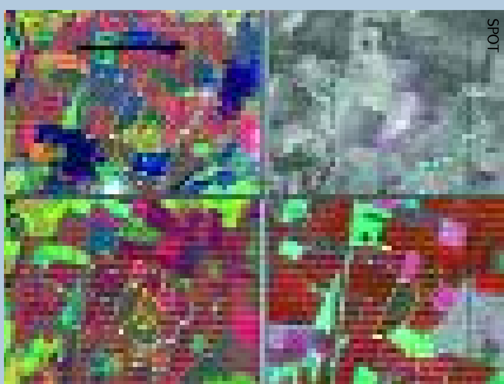
- anti-fraud measures: measures to combat fraud related to the implementation of the CAP; remote sensing is used in validating farmers' declarations of planted crops and acreages, and in optimising allocation of agri-environmental subsidies;

- crop and yield monitoring: crop yield monitoring with agro-meteorological models and low resolution remote sensing methods, and area estimates using high resolution data combined with ground surveys.

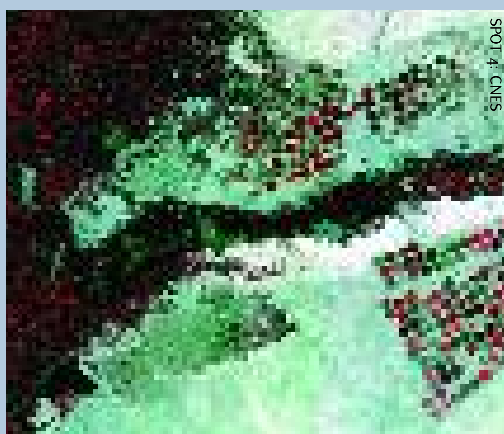
The main goal of the MARS project is to monitor weather and crop conditions during the current growing season and to estimate final crop yields for Europe by harvest time. To facilitate the monitoring and estimation, tools ranging from remote sensing techniques to agro-meteorological models are applied. A range of remote sensing data has been exploited in the project – including from the NOAA polar orbiting series (AVHRR), Landsat, SPOT, and ERS/ENVISAT.



EC



SPOT



SPOT 4: CNES

Yield monitoring and area estimating products from the MARS programme

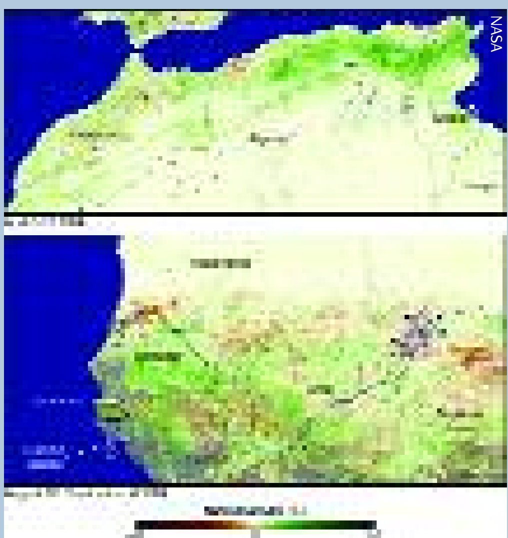
North-West Africa's locust plague of 2004

A wet winter and spring settled over north-western Africa in 2004 and the dry Sahel bloomed with life. As the desert turned green, the plentiful water nourished more than vegetation. Buried in the sandy soils were the eggs of desert locusts, waiting to absorb moisture and hatch. This year, there was enough water and vegetation to support large populations of young locusts and, by late summer, several large swarms had developed.

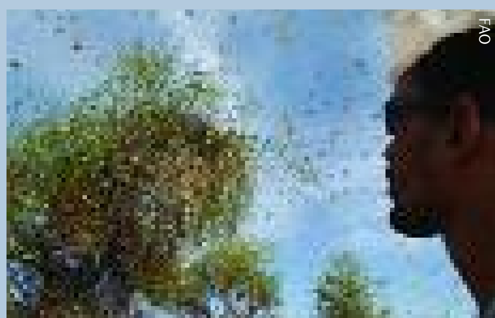
Swarms can contain as many as 80 million locusts per square kilometre and may cover several square kilometres. An adult locust can eat its own weight in food every day (about two grams) which means that, according to the FAO, a small part of a typical swarm can eat as much food as 2,500 people in a single day. At these rates, the locusts consume most vegetation in their path and then must migrate to find new sources of food.

The locust emergency in 2004 began as three separate outbreaks in 2003 in Mauritania, Mali, and Niger. While locusts can't be seen in satellite imagery, the conditions that support them are clearly visible. The image shows how vegetation differed from previous years. The image is a composite of Normalized Difference Vegetation Index (NDVI) data collected between April 6 and April 13, 2004. Green areas indicate that there was more vegetation in the region than the average of the past four years. Not surprisingly, these areas correlate well with the early breeding grounds of the locusts near the interface between dry desert land and wetter coastal land.

The satellite data also shows where locust swarms can migrate to find food, by indicating where food is available. In the lower image, a composite of data collected between August 28 and September 4, 2004, pockets of green in southern Mauritania, Senegal, Mali, and Burkina Faso suggest where the locusts may be finding food and breeding. Information from FAO showed that these were indeed the areas where the locusts were concentrated at the time. Mauritania's national food security authority expected to lose up to 75% of the cereal crop as a result of the plague.



MODIS imagery was used to assist FAO's Desert Locust Information Service predict migration paths of the 2004 plague in Africa



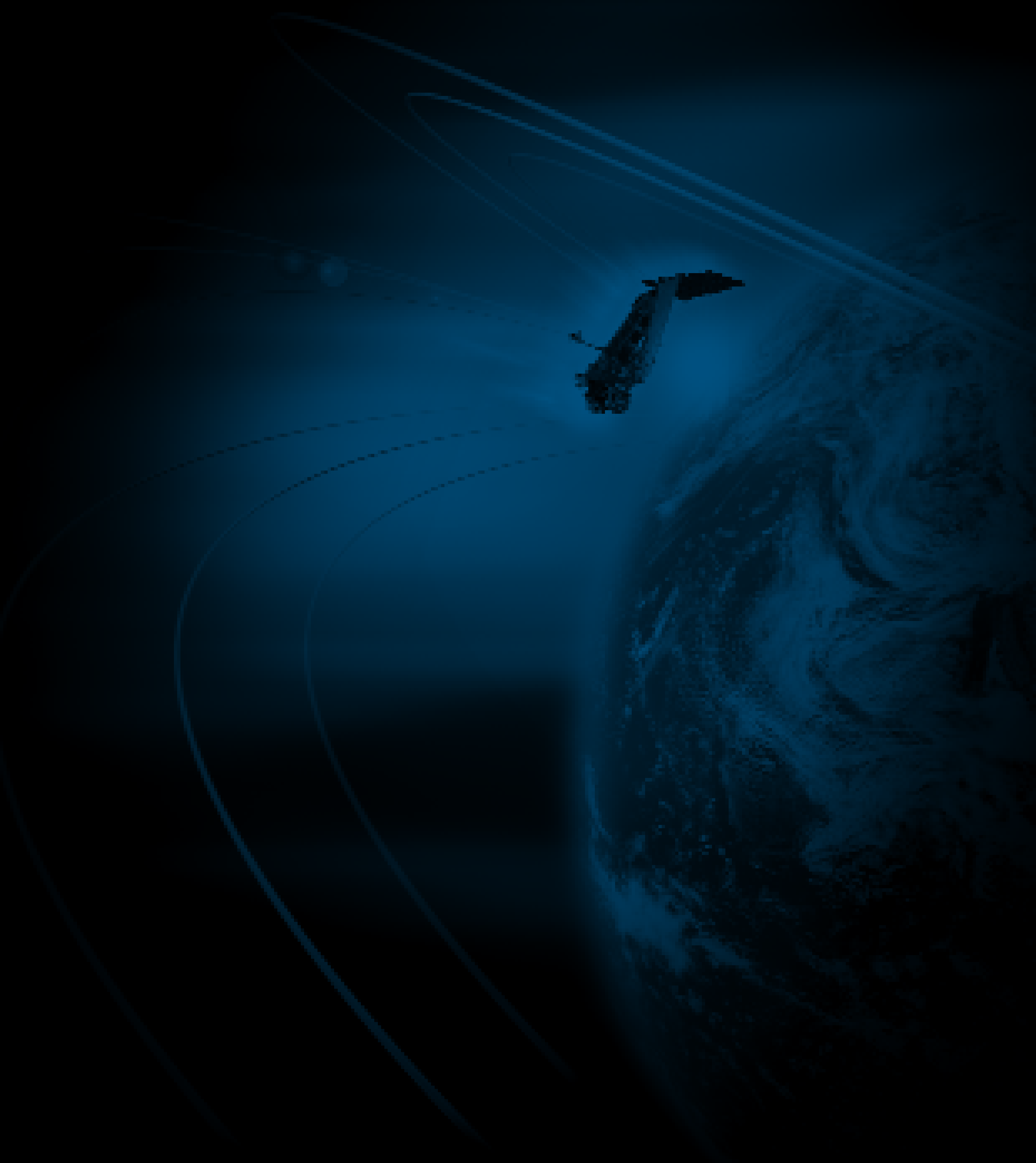
FAO & GIEWS: www.fao.org/giews/english/index.htm

ARTEMIS: metart.fao.org/default.htm

Locust Watch: www.fao.org/news/global/locusts/locuhome.htm

The MARS programme: www.marsop.info

Part III: Earth observation satellite capabilities & plans



6 Capabilities of Earth observation satellites

A variety of instruments are flown on space missions, employing various measurement technologies and techniques – both active and passive sensing, utilising a wide range of the electromagnetic spectrum.

CEOS agencies are operating or planning around 170 satellites with an Earth observation mission over the next 15 years. These satellites will carry over 340 different instruments.

This sustained investment by the space agencies will ensure the provision of information of unique value in both public and commercial spheres, derived from the measurements being undertaken of a diverse range of geophysical parameters and phenomena.

Public awareness of the applications of Earth observation satellites tends to focus on meteorology, and the knowledge that data from meteorological satellites is used on a daily basis for the Numerical Weather Prediction models which drive our weather forecasting capabilities. Meteorology is certainly one of the most established disciplines for application of Earth Observation satellite data, with satellite-derived information being used operationally by weather services world-wide. Dedicated meteorological satellites have been in operation providing continuous coverage of much of the globe for many years.

In reality, only 60, or around a third of the missions planned for the next 15 years, could be described as having meteorology as a primary objective. The other 110 missions will be applied to a diverse range of research, operational and commercial activities. Given the significance of the issues, and the unique role of satellite Earth observations, many will be dedicated to different aspects of climate or environmental studies. Others will be employed to assist decision-making in strategic planning and management of industrial, economic, and natural resources, including the provision of information required for sustainable development strategies.

Increased frequency of satellite measurements, improved satellite and sensor technology, and easier access and interpretation of Earth observation data have all contributed to increased demand for satellite data, and to the reality of new operational services being established in the near future for several domains, including monitoring of key oceanic and atmospheric parameters.

Information on the various missions and instruments, their capabilities and their applications is given in sections 8 (missions) and 9 (instruments).

For ease of discussion, the different instruments listed in section 9 may be considered under the following categories.

Instrument categories

- Atmospheric chemistry instruments
- Atmospheric temperature and humidity sounders
- Cloud profile and rain radars
- Earth radiation budget radiometers
- High resolution optical imagers
- Imaging multi-spectral radiometers (vis/IR)
- Imaging multi-spectral radiometers (passive microwave)
- Imaging microwave radars
- Lidars
- Multiple direction/polarisation instruments
- Ocean colour instruments
- Radar altimeters
- Scatterometers
- Gravity, magnetic field, and geodynamic instruments

Plans for future missions and instruments include entirely new types of measurement technology, such as hyper-spectral sensors, cloud radars, lidars, and polarimetric sensors providing new insights into key parameters of soil moisture and ocean salinity. Several new gravity field missions aimed at more precise determination of the marine geoid are also planned. Importantly, every effort is being made to assure continuity of existing key measurements – for the generation of long-term datasets. Agency plans also reveal that future priorities will include: disaster management, studies of key Earth System processes, including the water cycle, carbon cycle, cryosphere, and the role of clouds and aerosols in global climate change.

The following section gives a brief discussion of the different types of instruments which feature on Earth observation satellite missions, including: a list of the relevant instruments for each type from the full catalogue in section 9; a description of the operational characteristics; and pointers to the key applications. Information on specific measurement parameters is given in section 7.

Atmospheric chemistry instruments

Description

'Atmospheric chemistry instruments' is used here to describe a range of different types of instruments using various techniques, and different parts of the electromagnetic spectrum, to undertake measurements of composition of the atmosphere. Each atmospheric gas is characterised by its 'absorption' and 'emission' spectra which describe how the molecules respond to different frequencies of radiation. Remote sensing instruments exploit these 'signatures' to provide information on atmospheric composition, using measurements over a range of wavelengths, between UV and microwave.

Atmospheric absorption tends to be dominated by water vapour, carbon dioxide, and ozone, with smaller contributions from methane and other trace gases. Relatively broadband instruments can be used for measurements of the dominant gases, but high spectral resolution sensors are needed to make measurements of other species, since they produce weaker signals, and these must be discriminated from the signals from more abundant gases.

These instruments are typically operated in either:

– nadir-viewing mode: looking directly down to measure the radiation emitted or scattered in a small sold angle centred around a measurement point on the Earth – with resulting high spatial resolution in the horizontal direction, but limited vertical resolution; or

– limb-viewing mode: scanning of positions beyond the horizon to observe paths through the atmosphere at a range of altitudes – providing high vertical resolution (few km) and limited horizontal resolution (10's of kms) – and particularly useful for studying the middle atmosphere.

Emission or absorption spectra can be studied in limb-viewing mode. One approach – known as occultation – uses known astronomical bodies (such as the sun and stars) as well characterised target sources and measures the effect of the Earth's atmosphere on the radiation reaching the satellite to determine atmospheric composition.

Applications

The earliest atmospheric chemistry instruments were deployed to help international understanding of stratospheric ozone depletion, and succeeded in producing startling and convincing evidence of the growth of the Antarctic ozone hole. Many of the current and planned instruments continue to provide more sophisticated and accurate information on ozone chemistry in the atmosphere, including relating to gases and radicals which impact on the ozone cycle.

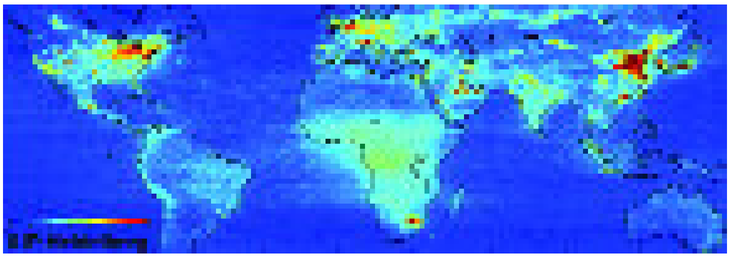
In addition to ozone measurements, instruments are now available which offer information on a range of different trace gases, including key greenhouse gases and chemically active gases which affect the environment. The capability to provide a global picture of the atmosphere, and how it is changing on a daily, seasonal and geographical basis is ensuring demand for these instruments in a wide range of applications, including: pollution monitoring; climatology, including studies of the carbon cycle and support to policy-making processes such as the Kyoto Protocol; volcanic eruption monitoring; and operational meteorology.

The trend towards improved measurement resolutions and accuracies, profiling measurements (rather than total column measurements), and extended capability in the Upper Troposphere/Lower Stratosphere (UTLS) will further extend the value of these instruments in the coming years for monitoring air quality and modelling atmospheric processes.

Current & planned instruments

- ACE-FTS
- APS
- EPIC
- GHG Sensor
- GOME
- GOME-2
- GOMOS
- HALOE
- HiRDLS
- HRDI
- IASI
- MAESTRO
- MASTER
- MIPAS
- MLS
- MOPITT
- OCO
- OMI
- OMPS
- OP
- OSIRIS
- SABER
- SAGE II
- SAGE III
- SBUV/2
- SCIAMACHY
- SFM-2
- SMR
- TES
- TOM
- WINDII

Atmospheric transmittance and radiance for UV to IR regions



A global air pollution (nitrogen dioxide) map produced by SCIAMACHY on ENVISAT

ACE-FTS: www.ace.uwaterloo.ca

GOMOS/MIPAS/SCIAMACHY: envisat.esa.int/instruments/index.html

IASI: smsc.cnes.fr/IASI/

HIRDLS/MLS/OMI/TES: eos-aura.gsfc.nasa.gov/instruments/

Atmospheric temperature and humidity sounders

Current & planned instruments

- AIRS
- AMSU-A
- AMSU-B
- ATMS
- CHAMP GPS Sounder
- CMIS
- CrIS
- Geomicrowave sounder
- GIFTS
- GOLPE
- GPS receiver
- GPSDR
- GRAS
- HIRS/2
- HIRS/3
- HIRS/4
- HSB
- IASI
- IKFS-2
- IMWTS
- IRAS
- ISAMS
- MASTER
- MHS
- MIPAS
- MIRAS
- MIVZA
- MLS
- MSU
- MTVZA
- MTVZA-OK
- MWHS
- MWR (BNSC)
- MWTS
- Radiomet
- ROSA
- SABER
- SAPHIR
- SMR
- Sounder
- Sounder (INSAT)
- SSM/T-1
- SSM/T-2
- SSMIS
- SSU
- TRSR

Description

Atmospheric sounders generally make passive measurements of the distribution of IR or microwave radiation emitted by the atmosphere, from which vertical profiles of temperature and humidity through the atmosphere may be obtained. Oxygen or carbon dioxide is usually used as a 'tracer' for the estimation of temperature profiles since they are relatively uniformly distributed throughout the atmosphere, and hence atmospheric temperature sounders often measure radiation at wavelengths emitted by these gases. For humidity profiling, either IR or microwave wavelengths specific to water vapour are used. Most measurements are conducted in nadir viewing mode.

Sounders are able to estimate profiles of temperature and humidity by identifying radiation coming from different levels in the atmosphere. This is achieved by observations of the spectral broadening of an emission line, a phenomenon which is primarily caused by intermolecular collisions with other species, and which decreases with atmospheric pressure (and therefore is a function of altitude).

Microwave sounders have the ability to sound through cloud and hence offer nearly all-weather capability; their spatial resolution (both vertical and horizontal) is generally lower than that of the IR instruments. IR sounders are routinely used to provide temperature profiles from a few km altitude to the top of the atmosphere with a temperature accuracy of 2-3K, a vertical resolution of around 10km, and a horizontal resolution of between 10 and 100km.

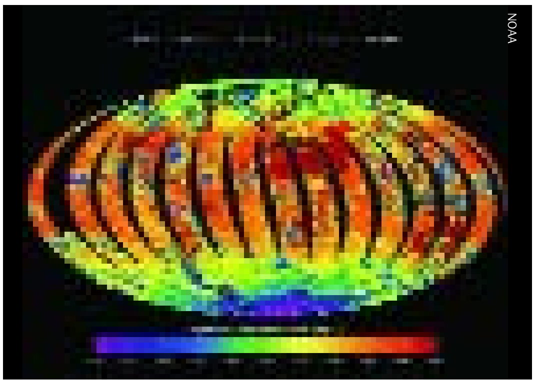
The next generation of sounders, combining IR (IASI, CrIS) and MW (MHS, CMIS, ATMS) capabilities will feature: improved accuracy of humidity and temperature measurements (of order 10% accuracy for humidity and below 1K for temperature); better spatial resolution (to 1km); and improved capabilities in the upper atmosphere.

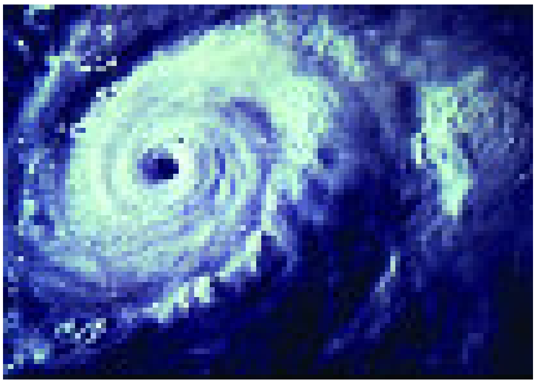
Observations of how the signals from Global Positioning Satellites (GPS) are affected as they travel through the atmosphere will be increasingly exploited using a technique known as GPS occultation. This technique is used to determine profiles of the pressure, temperature, and humidity and will provide complementary information.

Applications

Since the launch of the first weather satellites in the 1960's, atmospheric sounders have provided valuable global observations of the atmosphere, even in the remotest areas. In 1969, the first temperature profile information estimated from satellite measurements was introduced into the Numerical Weather Prediction (NWP) models which are at the heart of daily weather forecasts; even in those early days the new satellite measurements improved forecasts significantly for many areas.

Today, atmospheric sounders are used to infer a wide range of key atmospheric parameters on an operational basis (mostly on polar orbiting satellites), and their data is used by NWP models in their raw form to such an extent that the satellite measurements are a vital and integral part of the global observing systems for operational meteorology. The same data is used on a longer term basis for studies of extended range weather and climate forecasting, and detection of climate change, including man-made climate change.





Atmospheric sounders provide crucial inputs to weather forecasting systems

AMSU: amsu.cira.colostate.edu/

HIRS: www2.ncdc.noaa.gov/docs/klm/html/c3/sec3-2.htm

NWP: www.metoffice.gov.uk/research/nwp/numerical/index.html

Weather forecasting: www.usatoday.com/weather/wforcsto.htm

GPS radio occultation: op.gfz-potsdam.de/champ/docs_CHAMP/GRL_2001_wickert.pdf

Cloud profile and rain radars

Description

These instruments are predominantly based on active microwave radar systems. Cloud profile radars use very short wavelength (mm) radar (typically 94GHz) to detect scattering from non-precipitating cloud droplets or ice particles thereby yielding information on cloud characteristics such as moisture content and base height. A 94GHz cloud profiling radar has the unique property that it is able to penetrate ice clouds with negligible attenuation and provide a range-gated profile of cloud characteristics.

Rain radars use centimetric radiation to detect backscatter from water drops and ice particles in precipitating clouds, and to measure the vertical profile of such particles. One of the key challenges with rain radars is suppressing the return from the Earth's surface clutter, which is inevitably much stronger than the rain echo. Recent instruments however, can map the 3-D distribution of precipitating water and ice in a relatively narrow swath (around 200km) along the track of a low altitude satellite and thereby infer more precise estimates of instantaneous rainfall.

The Precipitation Radar (PR) on the Tropical Rainfall Measuring Mission launched in 1997 (with the mission just recently terminating in early 2005) was the first radar in space with the capability to measure rainfall. PR provided three-dimensional maps of storm structure, and invaluable information on the intensity and distribution of rain, rain type, and storm depth.

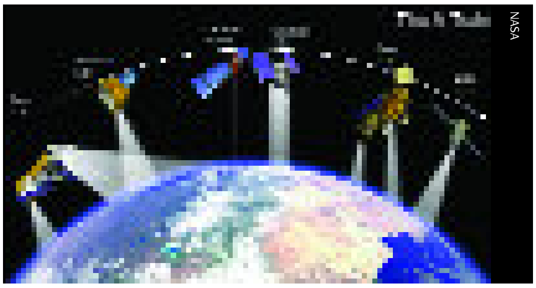
To date, there has been no cloud radar flown in space, but advanced instruments on planned missions (eg NASA's Cloudsat, Mar 2005) will use advanced radar to 'slice' through clouds to see their vertical structure, providing a completely new observational capability from space. These instruments will be the first to study clouds on a global basis, and to look at their structure, composition and effects. From 2009, the Global Precipitation Measurement (GPM) mission - an international co-operative programme - will provide more frequent and complete sampling of the Earth's precipitation using a constellation of satellites.

Applications

Measurements from cloud radar will give information on cloud type and amount, and more importantly on cloud profile (currently not measured), information which is required both for improving numerical weather prediction and for climate studies. Scientists believe that some of the main uncertainties in climate model simulation are due to the difficulties in adequately representing clouds and their radiative properties. Satellite observations are planned to address this issue.

TRMM has demonstrated that spaceborne rain radars can provide a unique source of information on liquid water and precipitation rate - since the ground based rain radars used at present have limited coverage over the oceans. The global precipitation datasets derived from TRMM have proven to be valuable tools for climatologists. Information on tropical rainfall and extreme events such as hurricanes is of particular importance, since more than two thirds of global rainfall is in the Tropics, and is a primary driver of global atmospheric circulation.

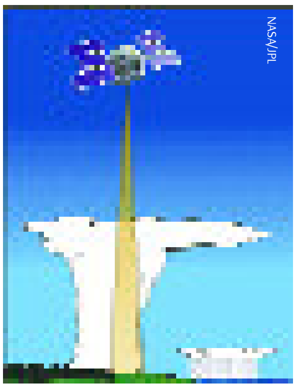
The gap between termination of the TRMM mission (early 2005) - and availability of the new information anticipated from GPM (no earlier than 2009) is of concern to scientists studying the Earth's global water cycle.



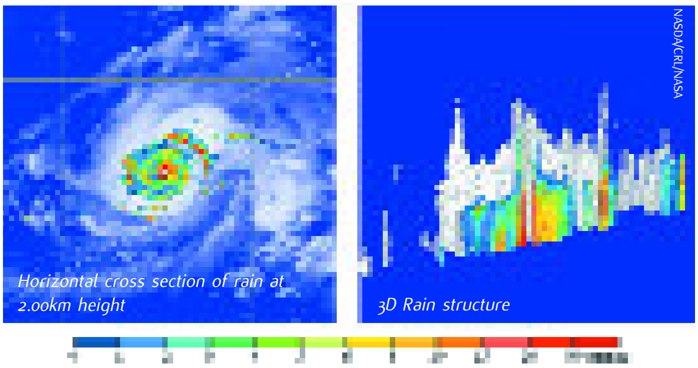
CloudSat will fly in orbital formation as part of a constellation of satellites including Aqua, Aura (multi-sensor platforms that are a part of NASA's Earth Observing System), CALIPSO (a NASA-CNES lidar satellite), PARASOL (a CNES satellite carrying a polarimeter), and OCO (NASA's CO_2 measurement mission)

Current & planned instruments

- Cloud sensor
- CPR
- CPR (Cloudsat)
- DPR
- IGPM rain radar



The CloudSat radar will penetrate into and through clouds, yielding a new capability that fills a critical gap in existing and planned observations



The Precipitation Radar on TRMM provided new insights into the 3-D rain structure of storms

CPR (Cloudsat): cloudsat.atmos.colostate.edu/cs4a.html

Precipitation radar: trmm.gsfc.nasa.gov/overview_dir/pr.html

GPM: gpm.gsfc.nasa.gov/index.html

Earth radiation budget radiometers

Current & planned instruments

- ACRIM II
- ACRIM III
- CERES
- ERBE
- ERBS
- GERB
- IKOR-M
- KGI-4C
- NISTAR
- PREMOS
- ScaRaB
- SIM
- SODISM
- SOLSTICE
- SOVAP
- SUSIM (UARS)
- TIM
- TSIS

Description

The Earth's radiation budget is the balance between the incoming radiation from the sun and the outgoing reflected and scattered solar radiation plus the thermal infrared emission to space. A number of instruments contribute to measurements of these parameters; the discussion here focuses on those instruments specifically designed to study radiation budget as their sole or primary mission.

In general, different instruments are used to measure the different components of the radiation budget:

– broadband radiometers: to cover the full range of incoming solar radiation (0.2 – 4.0μm) and to monitor the long-wave emitted Earth radiation (3 – 50μm);

– short-wave radiometers: to measure the reflected short-wave radiation from the Earth.

The instruments offer high radiometric accuracy to provide accurate absolute measurements (~ 1 Wm^{-2} is needed). Most radiometers have a narrow field of view and are used to measure the radiance in a particular direction. Using this, together with information on the angular properties of the radiation, the radiation flux may be obtained. Advanced instruments have a directional capability and channels which allow study of the anisotropy and polarisation characteristics of the radiation fluxes.

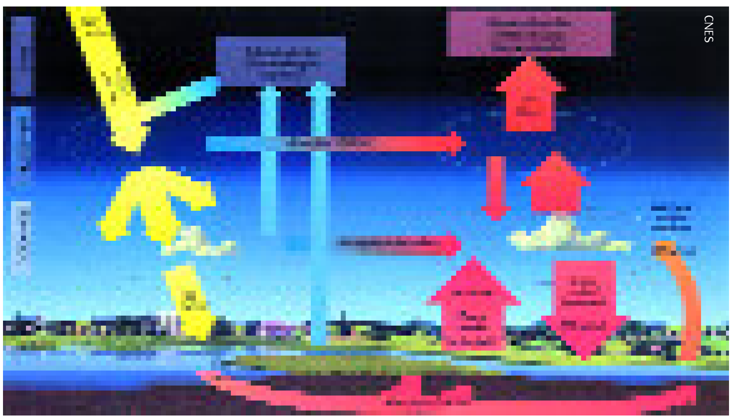
NISTAR (DSCOVR mission), which will be placed in orbit (in 2008) at the Lagrange point L1 (the point between the Earth and the Sun at which the gravitational pull of each is cancelled out), will be the first instrument capable of providing continual observations over the key measurement angle range for the entire Earth and will supplement low Earth orbit and geosynchronous orbit observations.

The new generation of geostationary satellites (eg the Meteosat Second Generation series with GERB on-board) will measure the shortwave and longwave radiation from the Earth every 15 minutes, and will provide much needed improvements in temporal sampling.

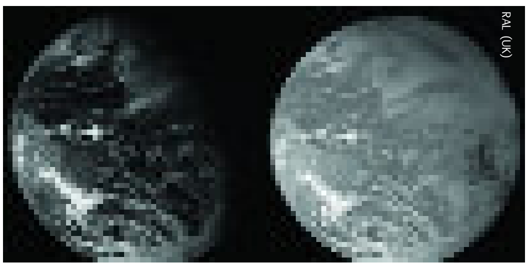
Applications

Solar radiant energy is a major driver of the Earth's climate. The reflection, absorption, and re-emission of that energy is done through a complex system of clouds, aerosols, atmospheric constituents, oceans, ice and land surfaces. Variations in this complex system are the source of changes in the Earth's radiation balance. While the input of energy from the sun is well understood, the amount of radiation leaving the Earth through this complex system is not. Thus, the models that assimilate all of the known characteristics of the Earth, its atmosphere, and the best measurements of the net radiation energy budget, have different predictions. It is theorised that as much as 25% of the anticipated global warming of the earth may be solar in origin. In addition, seemingly small (0.5%) changes in the total solar irradiance (TSI) output of the sun over a century or more may cause significant climatological changes on earth.

Earth radiation budget radiometers offer a unique contribution to understanding of the budget, together with its relationship to global warming such as that resulting from the greenhouse effect. In addition, information from these instruments is of interest in studies of clouds (to investigate cloud radiation forcing, for example) and albedo. Planned measurements will have unprecedented accuracy (0.1%) and precision (relative changes of 0.03%) – which is necessary for detecting the small changes in Earth's radiances that correspond to the incremental changes in our climate system that could be of major importance for humankind far into the future.



The Earth energy budget – the numbers indicate the average energy fluxes over one year, at a global scale



First GERB images taken on 12 December 2002, showing total radiances (left) and short wave radiances (right). The GERB instrument will enable environment experts for the first time to study the radiation balance at the top of the atmosphere, its changes over a given period and its potential influence on the climate.

NISTAR: science.hq.nasa.gov/missions/satellite_53.htm

Radiation budget science: earthobservatory.nasa.gov/Library/SORCE/

PICARD: smsc.cnes.fr/PICARD

TIM/SIM/SOLTICE: earthobservatory.nasa.gov/Library/SORCE/sorce_06.html

GERB: www.sstd.rl.ac.uk/gerb

ACRIM: acrim.jpl.nasa.gov

High resolution optical imagers

Description

High resolution optical imagers provide detailed images of the Earth's surface. In general, these are nadir-viewing instruments with a horizontal spatial resolution in the range 10 to 100m, and swath widths of order 100km. In the past few years, high resolution sensors have emerged with spatial resolution in the range 1-5m. An increasing number of government-funded and private sector-funded sensors with sub-5m resolution are planned for the coming years.

High resolution imagers are, in general, panchromatic and multispectral sensors with spectral bands in the visible and IR range, which are simultaneously recorded. This increases the information content that may be derived from the imagery (including the ability for land cover classification) and allows corrections to be made, for example, for the effects of atmospheric water vapour on the measured surface parameters. In order to reduce atmospheric absorption and to increase image quality, the operating wavelengths of these instruments are selected to coincide with atmospheric windows.

Use of these sensors can be limited by weather conditions, since they are unable to penetrate thick cloud, rain or fog – typically being restricted to fair weather, daytime-only operation. Some have pointing capability which enables imagery of specified areas to be acquired more frequently.

Many countries, including developing countries, have and/or are planning high resolution optical imaging programmes. Future trends will include a greater number of sampling channels, and improved spectral and spatial resolution. More instruments will also become available that are capable of producing stereo images from data collected on a single orbit, ie along track, as opposed to across track whereby stereo images are acquired from different passes.

Applications

High resolution optical imagers are amongst the most widely applied of Earth observation satellite instruments, finding application in, for example:

– agriculture: definition of crop type and area, Crop inventory, yield prediction;

– natural hazards: damage assessment;

– geological mapping;

– urban planning: land cover mapping; topographic mapping; urban development monitoring;

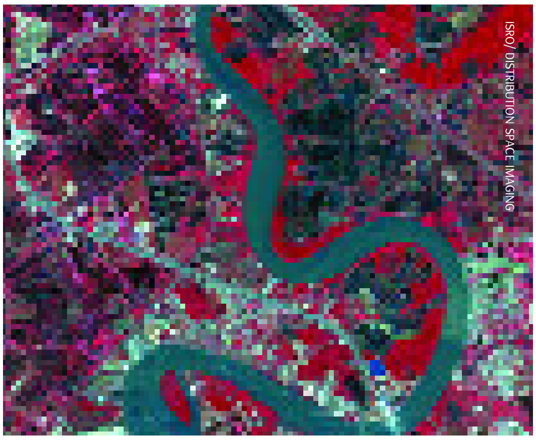
– cartography: map generation and updating; generation of digital elevation models;

– environmental planning and monitoring.

Current & planned instruments

ALI
ASTER
AVNIR-2
AWiFS
CCD (CBERS)
CCD (HJ, HY)
DMC Imager
EOC
ETM+
HRG
HR-PAN
HRS
HRTC
HRV
HRVIR
IR-MSS
IRS
LISS-III
LISS-IV
MBEI
MIREI
MSC
MSI
MSS
MSU-EU
PAN
PAN (Cartosat-1)
PAN (GISTDA)
Pleiades HR
PRISM
TM
TOPSAT
telescope
WFI

SPOT 5 launched in May 2002 features imaging sensors with 2.5m resolution. This image is of Rome.



A town in Thailand imaged by the LISS IV sensor on ISRO's Resourcesat-1

ALOS (AVNIR-2 & PRISM): www.jaxa.jp/missions/projects/sat/eos/alos/index_e.html

SPOT: www.spotimage.fr

Landsat: landsat.usgs.gov

CBERS: www.cbers.inpe.br/en/index_en.htm

TOPSAT: www.qinetiq.com/home/case_studies/security/security2.html

Imaging multi-spectral radiometers (vis/IR)

Current & planned instruments

AATSR
ABI
ATSR-2
AVHRR/2
AVHRR/3
CCD camera
CIA
CZI
Geoton-L1
GLI follow-on
HES
HRMS
HSC
HSI (HJ-1A)
HSMS
HSRS
HSS
HSTC
HYC
Hyperion
IIR
Imager (INSAT)
Imager
IMAGER/MTSAT-1R
IMAGER/MTSAT-2
IR (HJ-1B)
IR Camera (SAOCOM)
IVISSR (FY-2)
Klimat
LAC
MERIS
MERSI
MMRS
MOC
MODIS
MR-2000M1
MS (GISTDA)
MSS (Roskosmos)
MSU-GS
MSU-M
MSU-MR
MSU-SM
MUX
MVIRI
NIRST
OBA
OEA
OLS
OSMI
PSA
PSS
RDSA
SEVIRI
SPECTRA
TIS (CONAE)
VEGETATION
VHRR
VIIRS
VIRR
VISSR (GMS-5)
WAOSS-B
WFC
WFI-2
WiFS

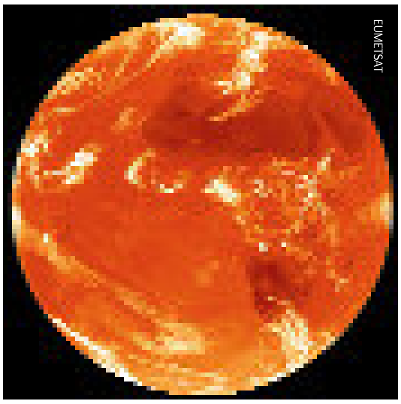
Description

Visible/IR imaging multi-spectral radiometers are used to image the Earth's atmosphere and surface, providing accurate spectral information at spatial resolutions of order 100m up to several km, and with a swath width generally in the range several hundred to a few thousand km.

Sensing usually occurs in multiple narrow, precisely calibrated spectral channels. These instruments cannot penetrate cloud or rain and hence are predominantly limited to clear weather observations.

The information obtained from these instruments is often complemented by that from atmospheric sounders, since in deriving parameters such as surface temperatures, atmospheric effects such as absorption must be taken into account.

Recent developments include improvements in spatial resolution, in some cases, equivalent to those of high resolution imagers, and in spectral resolution and radiometric accuracy. Planned hyperspectral instruments will be able to simultaneously acquire imagery in many tens of wavebands which should significantly improve the quality of land cover and land use information derived from satellite imagery.



Weather satellite data, such as these images from EUMETSAT and from China's FY satellite, are an essential input to todays weather forecasting systems

Applications

Measurements from these multi-spectral radiometers operating in IR and visible bands may be used to infer a wide range of parameters, including information on sea and land surface temperatures, snow and sea ice cover, and Earth surface albedo. These instruments may also make measurements of cloud cover and cloud-top temperatures, and measurements of the motion vectors of clouds made by radiometers on geostationary satellites may be used in order to derive tropospheric wind estimates.

Visible/IR radiometers are an important source of data on processes in the biosphere, providing information on global-scale vegetation and its variations on subseasonal scales which allow monitoring of natural, anthropogenic, and climate-induced effects on land ecosystems. Classification and seasonal monitoring of vegetation types on a global basis allows modelling of primary production (the growth of vegetation that is the base of the food chain) and terrestrial carbon balances. Such information is of great value in supporting the identification of drought areas and provides early warning on food shortages.

This spectacular 'blue marble' image is the most detailed true-colour image of the entire Earth to date, produced in early 2002 using data from MODIS

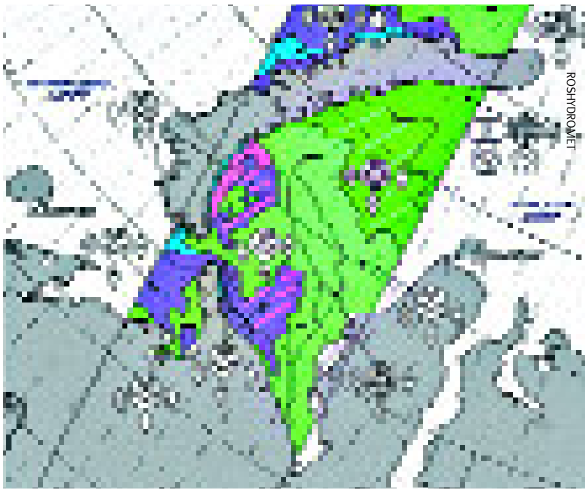
AVHRR: edcwww.cr.usgs.gov/glis/hyper/guide/avhrr
SEVIRI (METEOSAT): www.esrin.esa.it/msg/pag4.html
IMAGER (GOES): noaasis.noaa.gov/NOAASIS/ml/imager.html
MODIS: modis.gsfc.nasa.gov
VEGETATION: vegetation.cnes.fr

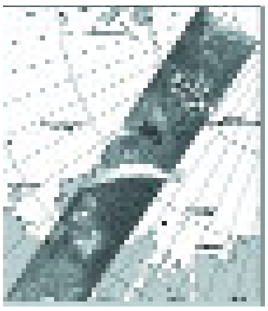
Imaging multi-spectral radiometers (passive microwave)

Description

Operating at microwave wavelengths, these instruments have the advantage of cloud penetration and hence all weather capability. Channels within 1 to 40GHz and 80 to 100GHz are used to get day/night information on the Earth's surface, having the advantage over visible/IR radiometers of the ability to probe the dielectric properties of a surface or to penetrate certain surfaces – especially useful with vegetation and soil. Channels between 50 and 60GHz are used for deriving atmospheric parameters.

As with other imaging radiometers, although these instruments offer accurate spectral information, their spatial resolution is poor. At 90GHz, the spatial resolution is typically 5km, and for the lower frequencies it is of order tens of kilometres – poorer than that of their visible or infra-red counterparts. As a consequence, they are most used for global rather than regional or local analysis, although some instruments are used to correct measurements from other sensors, rather than for imaging applications. These include the microwave radiometers on the ERS and Topex-Poseidon series satellites, which are used to estimate and correct for atmospheric water vapour content in the column through which altimetric readings are being taken.



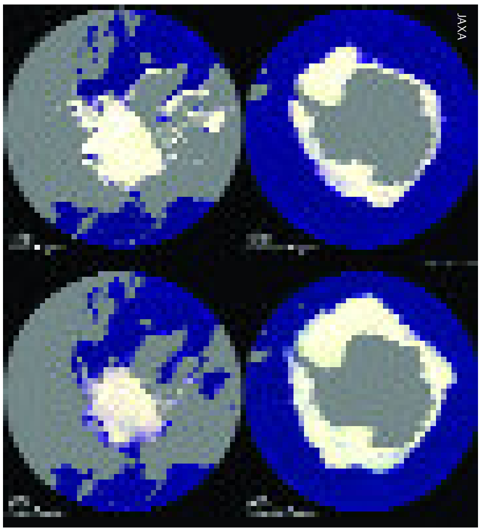


Passive microwave and radar data from Russian satellites is used operationally to generate vital sea ice map products

Applications

Measurements from these instruments may be used to infer a range of parameters. One of their primary uses (often in conjunction with other instruments) is snow and ice mapping – due in part to their capability for cloud penetration. Current applications of passive microwave radiometer data include operational forecasting and climate analysis, and the prediction of sea ice concentration, extent and ice type. Passive microwave radiometers are also used to provide cloud liquid water content information.

These instruments can also supply information on soil moisture content, which is a key surface parameter in agriculture, hydrology, and climatology, and provides a measure of vegetation health. They are also capable of contributing some information on ocean salinity, which is important to our understanding of ocean circulation.



JAXA's AMSR-E instrument can monitor changes in polar sea ice extent – which influence the balance of global head and radiation

Current & planned instruments

- AMSR follow-on
- AMSR-E
- Aquarius
- ATSR/M
- CMIS
- GMI
- IGPM radiometer
- JMR
- KMSS
- MADRAS
- MIRAS (SMOS)
- MSMR
- MWR (BNSC)
- MWR (CONAE)
- MWRI
- RM-08
- SSM/I
- TMR

AMSR-E: sharaku.eorc.nasda.go.jp/AMSR/index_e.htm

CMIS: www.ipo.noaa.gov/Technology/cmis_summary.html

IMAGER (GOES): www.ipo.noaa.gov/Technology/cmis_summary.html

MWR: earth.esa.int/rootcollection/ee04.10075/ERS1.5.html

SSM/I: dmsp.ngdc.noaa.gov/html/sensors.html

Imaging microwave radars

Current & planned instruments

AMI/SAR/Image
AMI/SAR/wave
ASAR
ASAR (image mode)
ASAR (wave mode)
BISSAT
L-band SAR
L-SAR
PALSAR
RLSBO
SAR (RADARSAT)
SAR (RADARSAT-2)
SAR (RISAT)
SAR (ROSHYDROMET)
SAR (SAOCOM)
SAR 2000
S-band SAR
TerraSAR-X

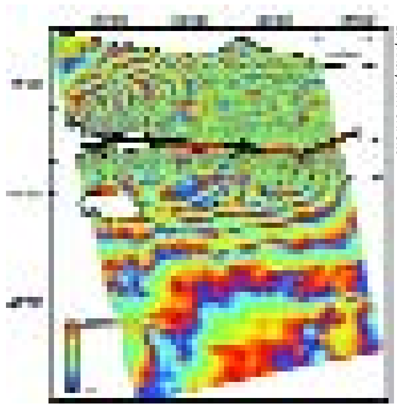
Description

These instruments transmit at frequencies of around 1 to 10GHz and measure the backscattered signals to generate microwave images of Earth's surface at high spatial resolutions (between 10m and 100m) and with a swath width of around 100km. Both synthetic aperture radars (SARs) and some real aperture side-looking imaging radar systems fall into this category. The images produced have a similar resolution to those from high resolution optical imagers, but radars have the capability to 'see' through clouds providing data on an all weather, day/night basis.

SARs also have the ability to penetrate vegetation and to sample surface roughness and surface dielectric properties. They may also be used to obtain polarisation information and although the operating wavelength is in general fixed for a given radar, radars operating at a variety of wavelengths (typically L-, C- and X-band) are and will be available during the next decade

The beam shape and direction of new generation SARs enable imagery to be acquired from many points on the Earth more frequently. Multipolarised SARs (such as ASAR on ENVISAT) enable land cover to be classified more accurately and will provide quantitative data on biophysical parameters such as soil moisture and biomass.

A number of bistatic radar system concepts (such as BISSAT) are under study. A bistatic radar is a system that operates with separated transmitting and receiving antennae. Since a number of large active radar missions are foreseen for the coming decade, there is the opportunity to use relatively small satellite missions, with passive payloads, flying in formation with one of these missions in order to gather the backscatter information.



An interferogram created using pairs of images taken by the ERS-2 SAR, showing surface deformation or changes that may have occurred during and after the 17 August 1999 Izmit, Turkey earthquake. Each of the colour contours represents 28 mm of motion towards the satellite, or about 70mm of horizontal motion.

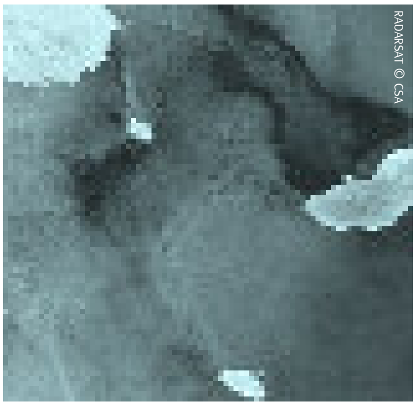
Applications

Although a variety of backscatter measurements may be taken by imaging radars, interpretation of these measurements is a complex and, in some cases, still developing science. However, significant advances in a number of areas and a number of SAR applications are now fully operational.

Backscatter from the ocean can be used to deduce surface waves, to detect and analyse surface features such as fronts, eddies, and oil slicks, and to detect and track ships. Operational wave and sea ice forecasting is also an important near real-time application of SAR data.

Land images may be used to infer information on vegetation type and cover, and are therefore of use in forestry and agriculture – the ability of SARs to penetrate cloud cover makes them particularly valuable in rainforest studies, and also in resource monitoring applications. The information obtained from such images depends upon the characteristics (eg wavelength) of the probing radiation – under certain conditions, for example, some penetration of vegetation may be feasible. Such imagery is often used in order to complement visible/IR multi-spectral imagery by, in effect, providing an additional microwave channel. One of the most important current applications of imaging radars, however, is in all-weather measurements of snow and ice sheets, from which information on topography, texture and motion may be inferred; flood detection is another proven capability of SAR.

A technique known as interferometry is used to record the phase shift between 2 SAR images recorded at slightly different times, thereby providing accurate information on the motion of surfaces and targets and allowing large scale 3-D topographical images to be produced. Similar stereo images may be produced using conventional SAR images taken on adjacent orbits. Differential SAR interferometry is valuable for detection of ground movements at millimetre/sub-millimetre level and of interest in the context of tectonic and volcanic hazard studies, and in studies of subsidence in urban areas.



RADARSAT data was used to assist oil spill clean-up in the Galapagos islands

ASAR: envisat.esa.int/instruments/asar/index.html

PALSAR: www.ersdac.or.jp/palsar/palsar_E.html

RADARSAT: www.rsi.ca/products/sensor/radarsat/radarsat1.asp

Terrasarr-X: www.eid.dlr.de/tsx/start_en.htm

Lidars

Description

Lidars, or LIght Detection And Ranging instruments, measure the radiation that is returned either from particles in the atmosphere or from the Earth's surface when illuminated by a laser source. Compared with radar, the shorter wavelengths used in a lidar allow greater detail to be observed, but cannot penetrate optically thick layers such as clouds.

There are a number of different types of lidar instrument:

– the backscatter lidar, in which the laser beam backscattered, reflected or re-radiated by the target gives information on the scattering and extinction coefficients of the various atmospheric layers being probed;

– the differential absorption lidar which analyses the returns from a tuneable laser at different wavelengths to determine densities of specific atmospheric constituents as well as water vapour and temperature profiles;

– Doppler lidar which measures the Doppler shift of the light backscattered from aerosol particles transported by the wind, thereby allowing the determination of wind velocity;

– the ranging and altimeter lidar which provides accurate measurements of the distance from a reference height to precise locations on the Earth's surface.

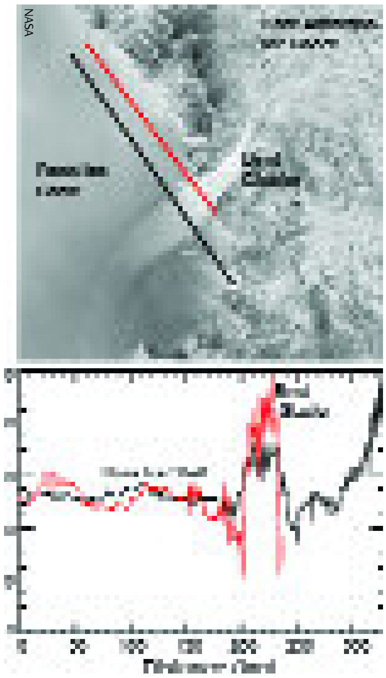
The first satellite-borne lidar is flying on the ICESat mission launched in January 2003 to study the decadal variations of ice thickness. Further lidars will be flown by NASA (CALIPSO) and ESA (Future Missions) to study cloud and aerosol properties. A Doppler lidar will be flown on the ESA ADM-Aeolus mission scheduled for launch in 2007 to provide 3-D wind profiles.

Doppler Wind Lidar principle: The lidar emits a laser pulse towards the atmosphere, then collects, samples, and retrieves the frequency of the backscattered signal. The received signal frequency is Doppler-shifted from the emitted laser due to the spacecraft, Earth, and wind velocity. The lidar measures the wind projection along the laser line-of-sight, using a slant angle versus nadir.

Applications

The different types of lidar may be used to measure a diverse range of parameters. Ranging and altimeter lidars may be used to provide surface topography information, for example on ice sheet height and land altitude. Missions planned within the next few years will undertake to determine the mass balance of the polar ice sheets and their contributions to global sea level change; others will focus on study of the vegetation canopy structure and provide unique data sets including estimations of global biomass and carbon stocks, and fractional forest cover.

Multifrequency ranging lidars with probe wavelengths in the visible and near IR will be used to measure aerosol height distributions and cloud height. Differential absorption and backscatter lidar may be used to measure cloud properties over an extended swath width, and Doppler lidars may be used to measure 3-D winds. This capability for measuring clear air winds (ie in the absence of clouds or winds above clouds) is of particular importance since it will correct a major deficiency in wind-profiling of the current global meteorological observing systems. Instruments such as ESA's ALADIN on ADM-Aeolus will provide wind profile measurements to establish significant advances in atmospheric modelling and analysis.



Byrd Glacier, shown in a radar image (top), is the largest outlet glacier draining ice from the East Antarctic Ice Sheet. Two ICESat profiles across the glacier are shown. With time, ICESat's measurements of small changes in elevations of the ice sheets, glaciers, and ice shelves will provide information on whether ice discharge into the ocean is increasing or decreasing and thus influencing sea level.

Current & planned instruments

- ALADIN
- ATLID
- CALIOP
- GLAS

ALADIN: www.esa.int/export/esaLP/aeolus.html

ATLID: www.esa.int/export/esaLP/earthcare.html

GLAS: icesat.gsfc.nasa.gov

CALIOP: www-calipso.larc.nasa.gov

Multiple direction/polarisation instruments

Current & planned instruments

- AATSR
- ATSR-2
- HYDROS
- MIRAS (SMOS)
- MISR
- POLDER-P
- SPECTRA

Description

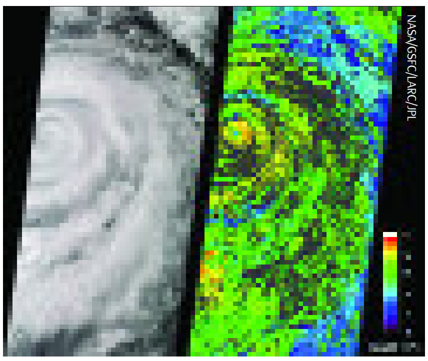
Advances in satellite instrumentation have resulted in a general trend towards multi-functional capabilities in many types of sensors - resulting in instruments with the capability to operate using different viewing modes and angles, and multiple polarisations. The latest SAR instruments demonstrate this trend. The category of 'multiple direction/polarisation instruments' is used here however to describe instruments which are custom-built for observing, as their primary function, directional or polarisational characteristics of the target's signature (either visible/IR or microwave), as a means of deriving geophysical information.

Multi-directional radiometers can make observations of the diffused or emitted radiation from a particular element of the Earth's surface or clouds from more than one incidence angle. In this way, information on anisotropies in the radiation may be identified. The emphasis in these instruments is on spectral rather than spatial information with the result that the detection channels, which typically span the visible to the IR, are precisely calibrated and the spatial resolution is usually of order 1km.

Polarimetric radiometers are used for applications in which radiative information is embedded in the polarisation state of the transmitted, reflected or scattered wave. Some polarimetic radiometers also have a multi-directional capability so that directional information can be determined.

Applications

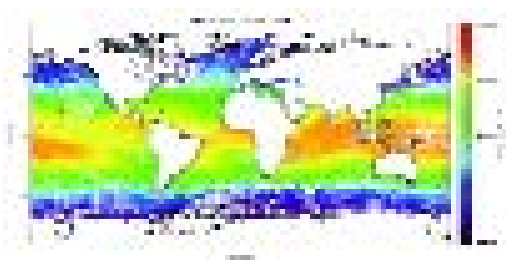
Using IR channels, multiple-angle viewing capabilities are used to achieve accurate corrections for the effects of (variable) atmospheric absorption and therefore to infer precise temperature values, for example, of sea and land surfaces. Multi-directional radiometers are also capable of measuring cloud cover and cloud top temperature together with atmospheric water vapour and liquid water content.



Hurricane Juliette, captured by MISR on 26th September 2001. On the left is a true-color image, on the right is cloud-top height field derived using automated computer processing of the data from multiple MISR cameras.

In the visible and near IR spectrum, these instruments allow for improved measurements of the scattering properties of particles such as aerosols, and for the angular characteristics of the various contributions to the Earth radiation budget, including surface albedo, to be measured. They also enable accurate measurement of parameters such as Normalised Difference Vegetation Indices (NDVI) which are used to assess vegetation state and crop yield at regional and global scales. MISR, currently flying on NASA's Terra mission is providing new types of information for scientists studying Earth's climate, such as the partitioning of energy and carbon between the land surface and the atmosphere, and the regional and global impacts of different types of atmospheric particles and clouds on climate.

Polarisation information is used to infer a variety of parameters, including the size and scattering properties of liquid water, cloud particles and aerosols, as well as additional information on the optical thickness and phase of clouds. Polarimetric radiometers also provide information on the polarisation state of the radiation backscattered from the Earth's surface which supplements measurements obtained from other land and sea imaging instruments. Such measurements are of interest in a range of applications from investigations of albedo and reflectance to agriculture and the classification of vegetation. ESA's SMOS mission planned for launch in 2007 will use an L-band (1.4 GHz) dual polarisation microwave interferometer to measure estimates of soil moisture (a key variable for numerical weather and climate models) and ocean salinity (important for ocean circulation models).



AATSR and its predecessors ATSR-1 and ATSR-2 have undertaken over 13 years of Sea Surface Temperature measurements with the accuracy required for climate research

MISR: www-misr.jpl.nasa.gov

AATSR: envisat.esa.int/instruments/aatsr

SMOS: www.esa.int/export/esaLP/smos.html

HYDROS: hydros.gsfc.nasa.gov

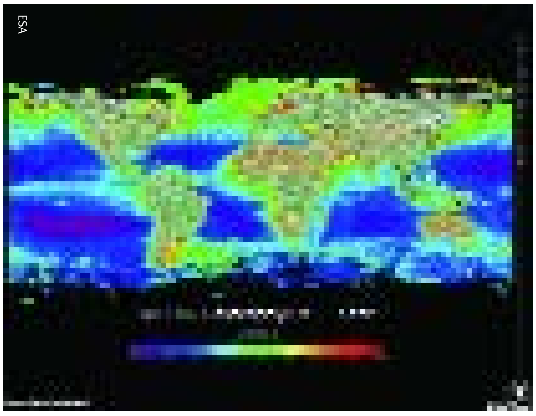
Ocean colour instruments

Description

Ocean colour radiometers and imaging spectrometers measure the radiance leaving marine waters in the visible and near IR spectrum in the range 400-800nm, where the colour is characterised by the constituents of the water, typically phytoplankton, suspended particulate material and dissolved compounds. Differences in the intensity of light received in the different bands give information on the concentration of a variety of substances present in the ocean.

These instruments have very narrow detection channels, around 10nm wide, to measure fine spectral details. The spatial resolution of these instruments is typically 0.3 to 1km. The more recent ocean colour instruments have improved spatial, spectral and radiometric resolution. The trend towards multi-channel, multi-purpose sensors, such as MODIS and MERIS, is resulting in more instruments with an 'ocean colour' capability, amongst their many other applications.

Significant calibration and validation activities and algorithm development for ocean colour instruments continues – particularly with respect to measuring ocean productivity.

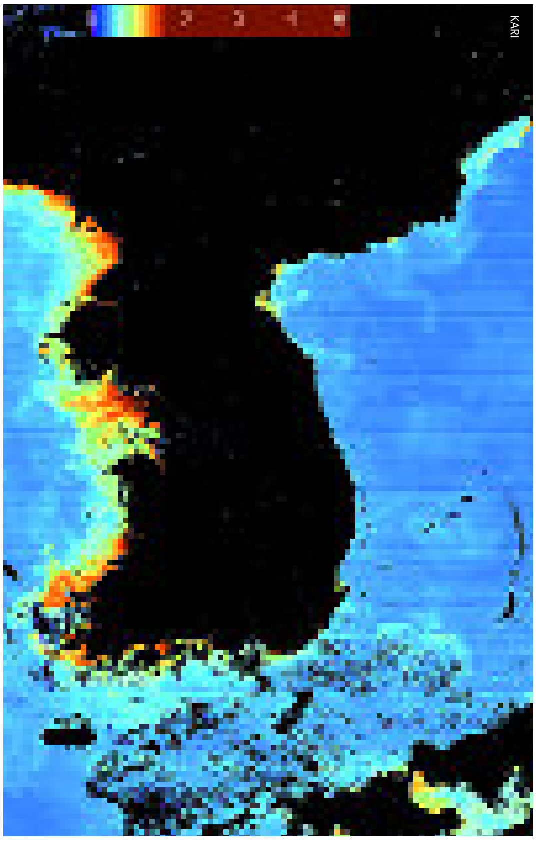


Global ocean chlorophyll measurements derived from MERIS

Applications

The colour of the oceans as seen from space is an indirect measurement of ocean biomass and its associated productivity, via phytoplankton pigment concentration (chlorophyll). These parameters are of considerable oceanographic and climatological significance as oceanic productivity 'drives' the air-to-sea exchange of biogenic greenhouse gasses (eg CO_2).

Ocean colour imagery can also be used to guide fishing fleets to biologically-rich areas. Other data that may be inferred from ocean colour measurements includes information about suspended matter (useful in coastal studies), biological productivity, marine pollution and coastal-zone water dynamics (eddies, currents, etc).



Ocean colour sensors such as OSMI (KOMPSAT-1) can provide valuable information for coastal studies

Current & planned instruments

- COCTS
- GLI follow-on
- MERIS
- MODIS
- MSS-BIO
- OCM
- OSMI
- VIIRS

MERIS: envisat.esa.int/instruments/meris

MODIS: modis.gsfc.nasa.gov

Ocean colour sensors: www.ioccg.org/sensors_ioccg.html

VIIRS: www.ipo.noaa.gov/technology/viirs_summary.html

Radar altimeters

Current & planned instruments

- ALT
- POSEIDON-1 (SSALT-1)
- POSEIDON-2 (SSALT-2)
- POSEIDON-3
- RA
- RA-2
- SIRAL
- TOPEX

Description

Radar altimeters are non-imaging radar sensors which use the ranging capability of radar to measure the surface topographic profile parallel to the satellite track. They provide precise measurements of a satellite's height above the ocean and, if appropriately designed, over land/ice surfaces by measuring the time interval between the transmission and reception of very short electromagnetic pulses.

To date, most spaceborne radar altimeters have been wide-beam (pulse-limited) systems operating from low Earth orbits. Such altimeters are useful for relatively smooth surfaces such as oceans and low relief land surfaces, but are less effective over high relief continental terrain as a result of the large radar footprint.

ESA's CryoSat mission will provide an instrument for the ice sheet interiors, the ice sheet margins, for sea ice and other topography, with three-mode operation:

– conventional pulse-limited operation for the ice sheet interiors (and oceans if desired);

– synthetic aperture operation for sea ice;

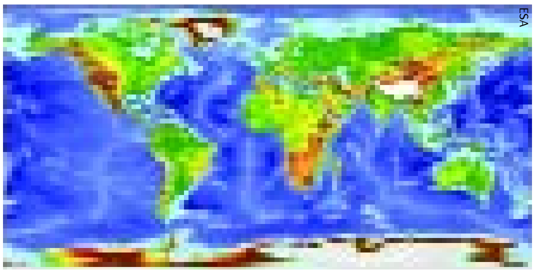
– dual-channel synthetic aperture/interferometric operation for ice sheet margins.

Successful exploitation of the height data is dependent upon precise determination of the satellite's orbit. A number of precision radar altimetry 'packages' are available which contain:

– a high precision radar altimeter (with basic measurement accuracy in the range 2cm to 4cm);

– a means of correction for errors induced in the height measurements by variations in the amount of water vapour along the path (for example, by means of a microwave atmospheric sounder or radiometer);

– a high precision orbit determination system (typically based on GPS, the DORIS beacon/satellite receiver system and/or a lidar tracking system).



The world as seen by radar altimeters

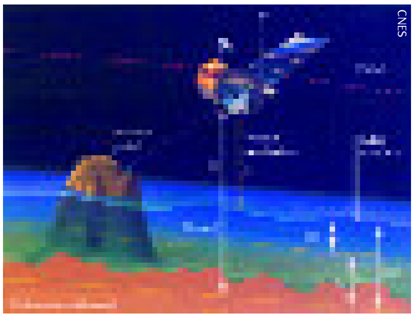
Applications

A variety of parameters may be inferred using the information from radar altimeter measurements. These parameters include: time-varying sea surface height (ocean topography), the lateral extent of sea ice and the altitude of large icebergs above sea-level, and the topography of land and ice sheets and even that of the sea floor. Topographical maps of the structure of the Arctic sea floor have not only revealed new mineral deposits, but they also provide new insights into how a large part of the ocean basin was formed some hundred million years ago.

Observations by current and future radar altimeters of trends in the ice masses of the Earth are of principal importance in testing of the predicted thinning of Arctic sea ice due to global warming, and will quantify the extent to which the Antarctic and Greenland ice sheets have contributed to the global rise in sea level. New generation radar altimeters are also providing useful information for the monitoring of inland waters (rivers and lakes levels) - as demonstrated by RA-2 on ENVISAT.

Satellite altimetry also provides information which is of use in mapping sea surface wind speeds and significant wave heights. Precision ocean altimetry applications for sea level monitoring and ocean circulation studies depend on more accurate, independent measurements of the geoid – derived from the instruments described in the 'gravity field' category.

The new generation of current and future instruments will provide more frequent data coverage and faster access to observations for incorporation into ocean circulation and wave forecast models used to generate marine information products.



Radar altimeters measure the distance between the satellite and the sea surface (E). The distance between the satellite and the reference ellipsoid (S) is derived by using the Doppler effect associated with signals emitted from marker points on the Earth's surface as the satellite orbits overhead. Variations in sea surface height (SS, ie S-E), are caused by the combined effect of the geoid (G) and ocean circulation (dynamic topography, DT).

JASON-1: www.jpl.nasa.gov/missions/current/jason-1.html

TOPEX/POSEIDON: topex-www.jpl.nasa.gov/

RA-2: envisat.esa.int/instruments/ra2

SIRAL: www.esa.int/export/esaLP/cryosat.html

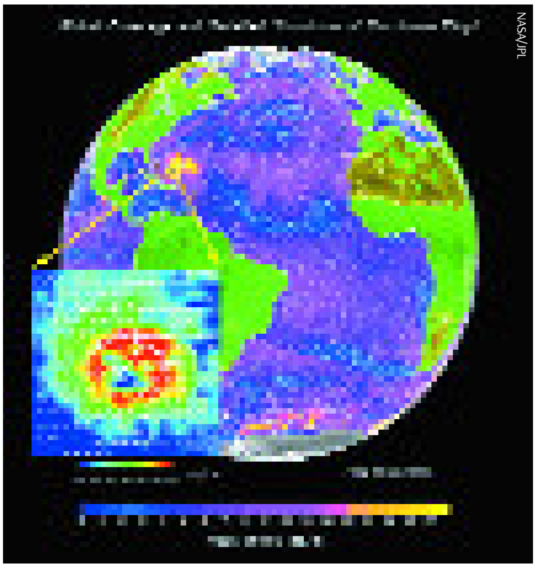
Scatterometers

Description

A scatterometer transmits radar pulses and receives backscattered energy, the intensity of which depends on the roughness and dielectric properties of a particular target. Scatterometers were originally designed to measure oceanic surface winds, where the amount of backscatter depends on two factors – the size of the surface ripples on the ocean, and their orientation with respect to the propagation direction of the pulse of radiation transmitted by the scatterometer. The first is dependent on wind stress and hence wind speed at the surface, while the second is related to wind direction. Hence measurements by such scatterometers may be used to derive both wind speed and direction.

These instruments aim to achieve high accuracy measurements of wind vectors (speed and direction) and resolution is of secondary importance (they generally produce wind maps with a resolution of order 25-50km). Because scatterometers operate at microwave wavelengths, the measurements are available irrespective of weather conditions.

Spaceborne scatterometers have provided continuous synoptic microwave coverage of the Earth for nearly a decade, starting with the ERS series, NSCAT on ADEOS, and more recently SeaWinds on QuikSCAT. The ERS and NSCAT instruments employed a fan-beam (multi-incidence) wind retrieval technique, whereas QuikSCAT employs a conically scanning (fixed incidence) technique. Increases in swath width capability of scatterometers now mean that a single instrument can provide around 90% coverage of global oceans on a daily basis.



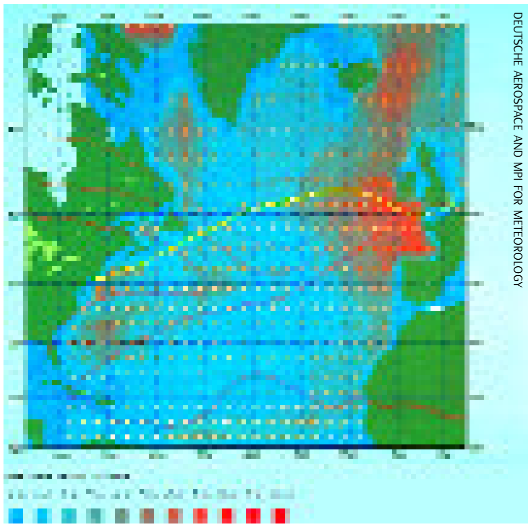
Scatterometer data can measure the horizontal wind speed and direction over sea surfaces. NSCAT data was used in September 1999 to monitor the size and movement of Hurricane Floyd.

Applications

Information from scatterometers provides a unique source of data on sea surface wind speed and direction which has important applications in weather and wave forecasting and the investigation of climate models and elaboration
of marine wind climate. The assimilation of scatterometer data into atmospheric forecasting models greatly improves the description of cyclonic features which are so important in predicting future weather patterns.

Beyond the original ocean winds mission of scatterometers, a large number of new unforeseen terrestrial and sea ice applications has emerged, including: the measurement of sea ice extent and concentration; snow accumulation; regional-scale monitoring of ice shelves, rainforests and deserts. The daily global coverage of scatterometers in the polar regions and ability to discriminate sea ice, ice sheets, and icebergs, despite the poor solar illumination and frequent cloud cover of the polar regions, make them excellent instruments for large-scale systematic observations of polar ice.

Scatterometer measurements will be undertaken operationally by ASCAT on the METOP series from late 2005.



The ERS scatterometer has been used to optimise trans-Atlantic ship routing, steering ships clear of storms (in red above)

Current & planned instruments

- AMI/scatterometer
- Aquarius
- ASCAT
- Scatterometer (ISRO)
- Scatterometer (JAXA)
- SeaWinds

ASCAT: www.eumetsat.de/en/area2/cgms/ap10-17.htm

AMI: earth.esa.int/rootcollection/ee04.10075/ERS1.3.html

Aquarius: aquarius.gsfc.nasa.gov

SeaWinds: winds.jpl.nasa.gov/missions/quikscat/index.cfm

Gravity, magnetic field, and geodynamic instruments

Description

This 'category' of instruments is used here to describe a variety of sensors and supporting systems used to derive information on either the Earth's gravity field, magnetic field, or geodynamic activity.

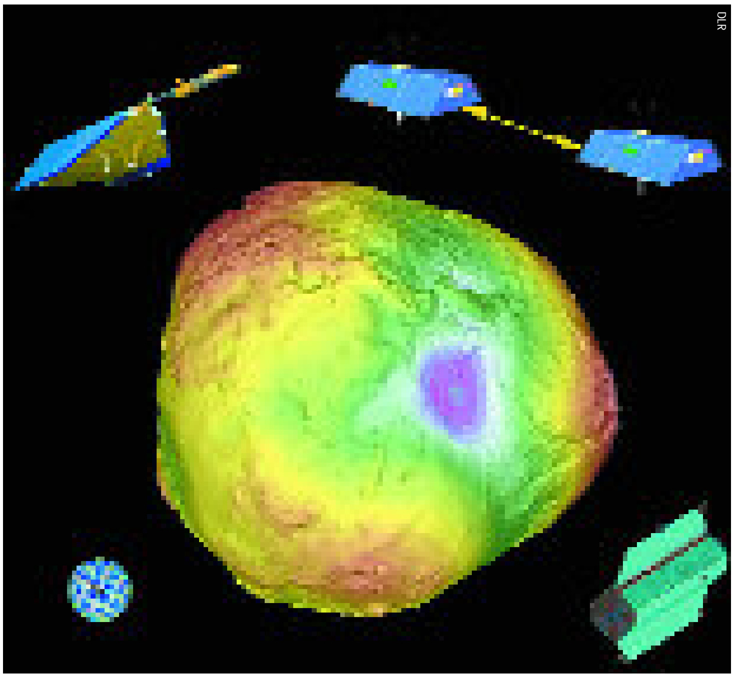
Gravity field measurements from space rely on one of three techniques:

– use of single or multiple accelerometers on one or more satellites to derive gravity or gravity gradient information;

– precise satellite orbit determination (using satellite to ground navigation systems such as GPS and satellite laser ranging systems), and separation of satellite motion induced by the Earth's gravitational force alone, from other forces (such as solar radiation and aerodynamic drag);

– satellite to satellite tracking (eg by GPS or microwave link) to measure relative speed variations of two satellites induced by gravitational force.

Satellite-borne magnetometers provide information on strength and direction of the internal and external Earth's magnetic field and its time variations.



LAGEOS, CHAMP, GRACE, GOCE all provide new insights into Earth's gravity field

Applications

Gravity field measurements from space provide the most promising advances for improved measurement of the 'geoid' and its time variations. The geoid is the surface of equal gravitational potential at mean sea level, and reflects the irregularities in the Earth's gravity field at the Earth's surface due to the inhomogeneous mass and density distribution in the Earth's interior.

More accurate models of the static mean geoid and its temporal variability are vital for:

– a precise marine geoid, needed for the quantitative determination, in combination with satellite altimetry, of absolute ocean currents and their transport of heat and other properties;

– a unified global height reference system for the study of topographic processes, including the evolution of ice-sheets and land-surface topography;

– new understanding of the physics of the Earth´s interior;

– estimates of the thickness of the polar ice sheets and its variations – through combination of bedrock topography derived from gravity measurements and ice-sheet surface topography from altimetry;

– estimates of the mass/volume redistribution of freshwater in order to further understand the hydrological cycle;

– improved understanding of post-glacial rebound processes on a global scale.

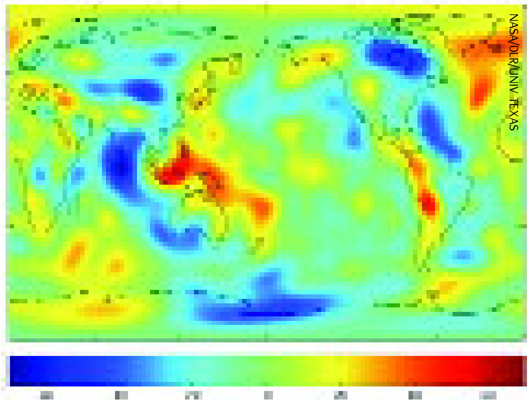
Magnetic field measurements are also valuable in a range of applications, including navigation systems, resource exploration drilling, spacecraft attitude control systems, assessments of the impact of 'space weather' caused by cosmic particles, and in earthquake prediction studies (eg by the DEMETER mission).

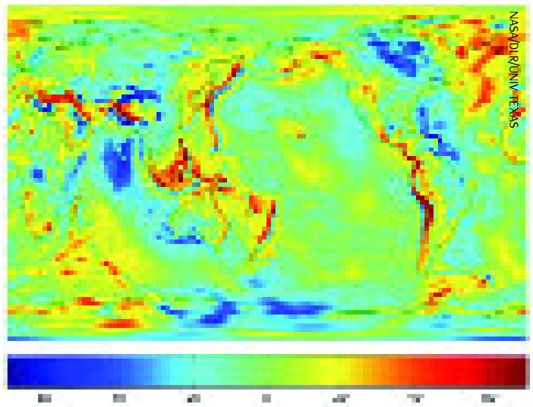
The precision location capabilities of satellite laser ranging and other systems (such as DORIS and GPS), sometimes in combination with interferometric SAR (INSAR), are applied in support of studies of crustal deformation, tectonic movements, and Earth's spin rate.

CHAMP: op.gfz-potsdam.de/champ/index_CHAMP.html

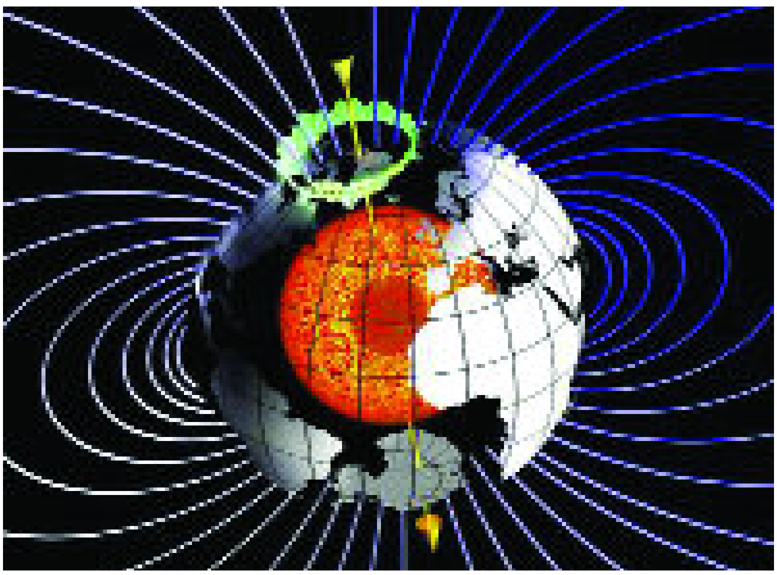
GRACE: www.csr.utexas.edu/grace

GOCE: www.esa.int/export/esaLP/goce.html





Prior to GRACE, the long-wavelength part of the Earth's gravity field from space was determined from various tracking measurements of Earth orbiting satellites. Only broad geophysical features of the Earth's structure could be detected. The lower image shows the final detail available after just 1 year of GRACE data.



Current & planned instruments

Gravity

- ACC
- CHAMP gravity package
- EGG
- HAIRS

Magnetic field

- ASM
- CHAMP magnetometry package
- EFI
- Fluxgate magnetometer
- GGAK-E
- GGAK-M
- GID-12T
- IMSC
- Magnetometer (NOAA)
- MMP
- PEM
- Plasma-Mag
- RBE
- SESS
- SSJ/4
- SSJ/5
- SSM
- STR
- Variant
- VFM

Precision orbit

- ARGOS
- CHAMP GPS Sounder
- DORIS
- DORIS-NG
- EGG
- GOLPE
- GPS (ESA)
- GPS receiver
- GPSDR
- GRAS
- INES
- IST
- Laser reflectors
- Laser reflectors (ESA)
- LRA
- LRA (LAGEOS)
- ROSA
- RRA
- TRSR

7 Earth observation plans: by measurement

7.1 Introduction

At the start of 2005, there are 68 satellites operating (annex A) and providing important data about the Earth and its environment, helping us to develop our understanding of the basic Earth System and of human influences on it. These data cover measurements of a very wide range of geophysical parameters, spanning the whole spectrum of the environment including atmosphere, land, oceans, and ice and snow. This section considers some of the key observations contributed by EO satellites, as indicated in the table.

Measurement categories

ATMOSPHERE
- Aerosols
- Atmospheric humidity fields
- Atmospheric temperature fields
- Atmospheric winds
- Cloud particle properties and profile
- Cloud type, amount and cloud top temperature
- Liquid water and precipitation rate
- Ozone
- Radiation budget
- Trace gases (excluding ozone)

LAND
- Albedo and reflectance
- Landscape topography
- Soil moisture
- Vegetation
- Surface temperature (land)
- Multi-purpose imagery (land)

OCEAN
- Ocean colour/biology
- Ocean topography/currents
- Ocean surface winds
- Surface temperature (ocean)
- Ocean wave height and spectrum
- Multi-purpose imagery (ocean)

SNOW AND ICE
- Ice sheet topography
- Snow cover, edge and depth
- Sea ice cover, edge and thickness

GRAVITY AND MAGNETIC FIELDS
- Gravity, magnetic and geodynamic measurements

This list is not comprehensive, but does include many key measurements of interest to the main user groups of Earth observation satellite data, and describes a significant part of the capability of current and planned instruments.

The CEOS/WMO Database contains considerably more detail on the expected performance of the various CEOS agency missions and on the specifications of the requirements for certain applications and users. For example, the CEOS/WMO Database provides information on more than 120 different geophysical measurements. See below for contact details for access to the CEOS/WMO Database.

This section identifies the satellite instruments which primarily contribute data for any particular measurement from the list above and indicates the plans for future provision of that measurement over the next 15 years. Measurement continuity is a key requirement in many areas, for example in providing confidence to sustain public and commercial investment in operational applications of Earth observation data. It is also of paramount importance for the generation of long term datasets required for global environmental programmes and for climate change studies. This section identifies the prospects for achieving that continuity given the programmes and plans that exist in 2005 – whether it may be provided by a single series of satellites dedicated to a particular measurement, or whether users of that measurement must look to various satellite missions planned by different agencies world-wide to satisfy their information requirements.

The need for this continuity, and to ensure that the measurements by different agencies from different countries can be inter-compared and calibrated requires a significant degree of coordination in mission planning and data provision. Harmonisation and maximum cost-effectiveness for the total set of space-based observation programmes is the objective of CEOS. Harmonisation of the space-based and in-situ observational resources is the aim of IGOS (see annex B). The IGOS Partnership provides a forum for establishing the performance and timing necessary from CEOS agency missions in order to satisfy the information requirements of the IGOS Themes, and of international programmes such as the Global Climate Observing System (GCOS), Global Ocean Observing System (GOOS), the Global Terrestrial Observing System (GTOS), the World Climate Research Programme (WCRP), and the International Geosphere-Biosphere Programme (IGBP).

For CD-ROM copies of CEOS Database:
dhinsman@.wmo.int

7.2 Overview

Current areas of strength of the Earth observation satellites providing data today include:

- Atmospheric chemistry measurements, including of ozone, are being provided by instruments on NASA's Aura and Terra missions and by ESA's Envisat;

- Atmospheric humidity and temperature profiles are routinely provided for operational meteorology by the NOAA and DMSP series polar orbiting satellites and by a number of meteorological geostationary satellites;
- Atmospheric winds (through cloud tracking), cloud amount and tropical precipitation estimates are provided for most of the globe by the geostationary meteorological satellite series Meteosat, GOES, GMS, FY-2, and INSAT/Kalapana;
- Multi-purpose imagery for both land and sea is being collected by both high resolution optical and synthetic aperture radar (SAR) instruments for use in environmental, public, and commercial applications. Optical sensors include AVHRR on the NOAA polar orbiters and those on Terra, SPOT, Landsat, and IRS series. SAR sensors include those on the ERS/Envisat and RADARSAT series. Future missions and increasing spatial resolution will ensure improved data collection and application opportunities;
- Sea surface temperature information is being generated by data from existing meteorological satellites and from instruments on the Aqua/Terra and the ERS/Envisat series. Future plans should provide continuity. Satellites are now also making consistent and continuous measurements of other important oceanographic parameters such as ocean topography, ocean currents, and sea surface winds – such as from QuikSCAT, Jason-1, and Envisat;
- Sea ice and ice sheet extent are being measured by a range of missions (including ICESat) and continuity is planned (eg by Cryosat, ALOS, and Terrasar-X).

Future missions will feature a new generation of technology and techniques to enable Earth observation satellites to extend their contribution, including:

- a significant increase in information about the chemistry and dynamics of the atmosphere, including: long term global measurements of concentrations of ozone and many other trace and greenhouse gases; information on the role of clouds in climate change; the ability to better map cloud cover and precipitation - including over the oceans; measurements of 3-D atmospheric winds without the need for cloud tracking; global aerosol distributions; and extended coverage of atmospheric measurements into the troposphere to allow improved pollution monitoring. Just as significantly, existing measurement capabilities for many key parameters, such as atmospheric humidity and temperature, will have greatly improved accuracy and spatial resolution. A variety of novel instruments will be used - such as cloud and rain radars, and lidar instruments proposed for future missions;
- Improved repeat coverage, resolution, and accuracy of many oceanographic measurements, including ocean surface winds, and ocean colour and biology;
- New capabilities for determination of soil moisture and ocean salinity – starting with ESA's SMOS mission;
- New information on global land surface processes, through use of increased number of spectral bands, and multi-directional and polarisational capabilities of future imaging sensors;
- Estimates of global biomass and carbon stocks, and estimates of mass balance of the polar ice sheets and their contributions to global sea level change – from innovative new lidar systems;
- Improved measurements of global ocean currents, based on data from altimeters and gravity field instruments – such as GRACE and GOCE.

We can expect the exact plans to change as space agency programmes evolve to keep pace with accepted scientific and political priorities for information on the Earth System – including the influence of the processes initiated by the Ad-hoc Group on Earth Observations (GEO - discussed in detail in Part I of this document).

7.3 Measurement timelines

For each measurement category listed in section 7.1, a brief discussion is given below of the significance of that measurement, together with an indication of the present and future measurement capabilities of satellite observations. This description is supported by two timeline diagrams spanning the period 2005-2020, indicating the instruments contributing to that measurement and the missions on which they are expected to fly.

The first timeline shows missions that are either:

- Current: where at least the prototype has been launched, and financing is approved for the whole series; or
- Approved: where financing is available for the whole series, the prototype is fully defined, the development is in phase C/D.

The second shows missions which are not yet approved - rather they are:

- Planned: financing is available up to the end of phase B, financing of the full series is being considered; or
- Considered: conceptual studies and phase A have been completed, financing of phase B is in preparation.

Of course, all missions have a degree of uncertainty. This description of mission status reflects information available from the relevant agencies at the time of compilation. If the month of the launch of a planned mission has not been specified the timeline is shown to commence at the beginning of the planned year of launch. Note also that missions currently operating beyond their planned life are shown as operational until the end of 2005 unless an alternative date has been proposed.

The timelines in this section represent a qualitative analysis of the provision of data from Earth observation satellites in terms of a number of key geophysical measurements and the requirement for those measurements in different disciplines.

Atmosphere

Aerosols

Aerosols are tiny particles suspended in the air. The majority are derived from natural phenomena such as volcanic eruptions, but it is estimated that some 10% are generated by human activities such as burning of fossil fuels. The majority of aerosols form a thin haze in the lower atmosphere and are regularly washed out by precipitation; the remainder are found in the stratosphere where they can remain for many months or years. Scientists have yet to quantify accurately the relative impacts on climate of natural aerosols and those of human origin, and are unsure as yet whether aerosols are warming or cooling the Earth. Predicting the rate and nature of future climate change requires this understanding.

The IPCC identifies further information on aerosols as a priority requirement and highlights a particular need for additional systematic, integrated and sustained observations, including observations of the spatial distribution of greenhouse gases and aerosols. The Integrated Global Atmospheric Chemistry Observations (IGACO) Theme of the IGOS Partnership aims to provide a framework ensuring continuity and spatial comprehensiveness of the full spectrum of atmospheric chemistry observations, including the monitoring of atmospheric composition parameters related to climate change and environmental conditions. The IGACO Theme Report (available from www.igospartners.org) was finalised in May 2004 and provides a comprehensive overview of current and future satellite measurements for tropospheric and stratospheric aerosols The report states, in particular, that "satellite observations of aerosol optical properties have progressed to a point where they range from pre-operational to operational, although there are demonstration-mode instruments on a number of research satellites".

Reliable information on aerosols is also required by applications outside the study of the climate system. For example, accurate and timely warnings of the presence of airborne dust and ash - such as that arising from desert dust clouds and volcanic eruptions - is important to the safety of airline operations. A worldwide volcanic ash monitoring system, which is dependent on satellite observations, is in place to provide real time advice to pilots.

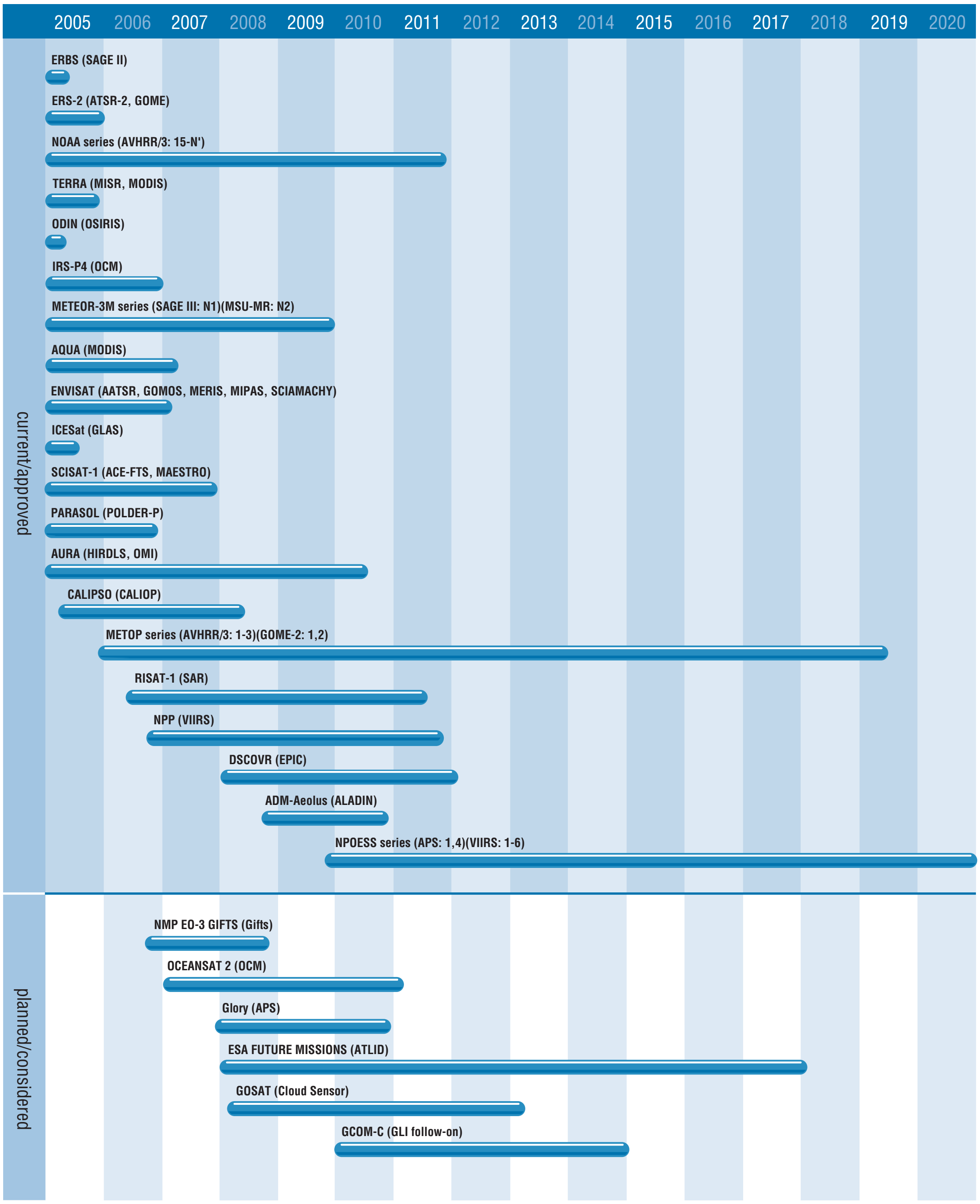
Measuring the distribution of aerosols through the depth of the atmosphere is technically difficult, particularly in the troposphere, and previously, techniques using instruments such as AVHRR and ATSR were limited to producing estimates of vertically-integrated total amounts, mainly over oceanic regions.

Measurements over land are difficult (due to both persistent cloud cover and to the high value, and variability, of land surface reflectance) but the new generation of multi-directional or polarimetric instruments - such as AATSR, MISR and APS (planned) - can provide detailed information. Today, MODIS, MERIS and MISR offer better optical depth at different frequencies from which aerosol particle sizes, particularly over oceans, may be inferred. The development of active instruments such as ATLID, and laser altimeter sensors, including GLAS on ICESat (in orbit since January 2003), should yield much improved measurement capability. In 2005, CALIPSO will fly a 3-channel lidar (designed specifically to provide vertical profiles) and passive instruments in formation with Aqua, Aura (both already in operation), Parasol and CloudSat to obtain coincident observations of radiative fluxes and atmospheric state. This comprehensive set of measurements is essential for accurate quantification of global aerosol and cloud radiative effects.

Limb-sounding instruments such as ACE-FTS, SCIAMACHY, GOMOS, and HIRDLS provide data principally on the upper troposphere and stratosphere with high vertical resolution, but relatively poor horizontal resolution (typically of the order of a few hundred km).

AVHRR/3 on the NOAA and METOP series will continue current limited capabilities to provide estimates of total column aerosol amounts over the ocean, and SEVIRI on MSG will have similar capabilities, but with increased temporal resolution. AVHRR/3 will be replaced by a more capable visible and infrared imager, called VIIRS, on the NPOESS series of satellites, starting with the preparatory NPP mission in 2006. VIIRS will acquire high resolution atmospheric imagery and generate a variety of applied products including some giving information on atmospheric aerosols.

Aerosols



2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
current/approved
ERBS (SAGE II)
ERS-2 (ATSR-2, GOME)
NOAA series (AVHRR/3: 15-N')
TERRA (MISR, MODIS)
ODIN (OSIRIS)
IRS-P4 (OCM)
METEOR-3M series (SAGE III: N1)(MSU-MR: N2)
AQUA (MODIS)
ENVISAT (AATSR, GOMOS, MERIS, MIPAS, SCIAMACHY)
ICESat (GLAS)
SCISAT-1 (ACE-FTS, MAESTRO)
PARASOL (POLDER-P)
AURA (HIRDLS, OMI)
CALIPSO (CALIOP)
METOP series (AVHRR/3: 1-3)(GOME-2: 1,2)
RISAT-1 (SAR)
NPP (VIIRS)
DSCOVR (EPIC)
ADM-Aeolus (ALADIN)
NPOESS series (APS: 1,4)(VIIRS: 1-6)
planned/considered
NMP EO-3 GIFTS (Gifts)
OCEANSAT 2 (OCM)
Glory (APS)
ESA FUTURE MISSIONS (ATLID)
GOSAT (Cloud Sensor)
GCOM-C (GLI follow-on)

Atmosphere

Atmospheric humidity

The observations for atmospheric humidity are a core requirement for weather forecasting and are largely dealt with in the framework of the Coordinating Group for Meteorological Satellites (CGMS). A wide range of sensors are available and these are improved as technology allows. In broad terms the challenges are to improve vertical resolution of observations, overcome cloud problems and improve the ability to process sounding data over land.

The 3 dimensional field of humidity is a key variable for global weather prediction (NWP) models that are used to produce short- and medium-range forecasts of the state of the troposphere and lower stratosphere. Polar satellites provide information on tropospheric humidity with global coverage, good horizontal resolution and acceptable accuracy, but with poor vertical resolution

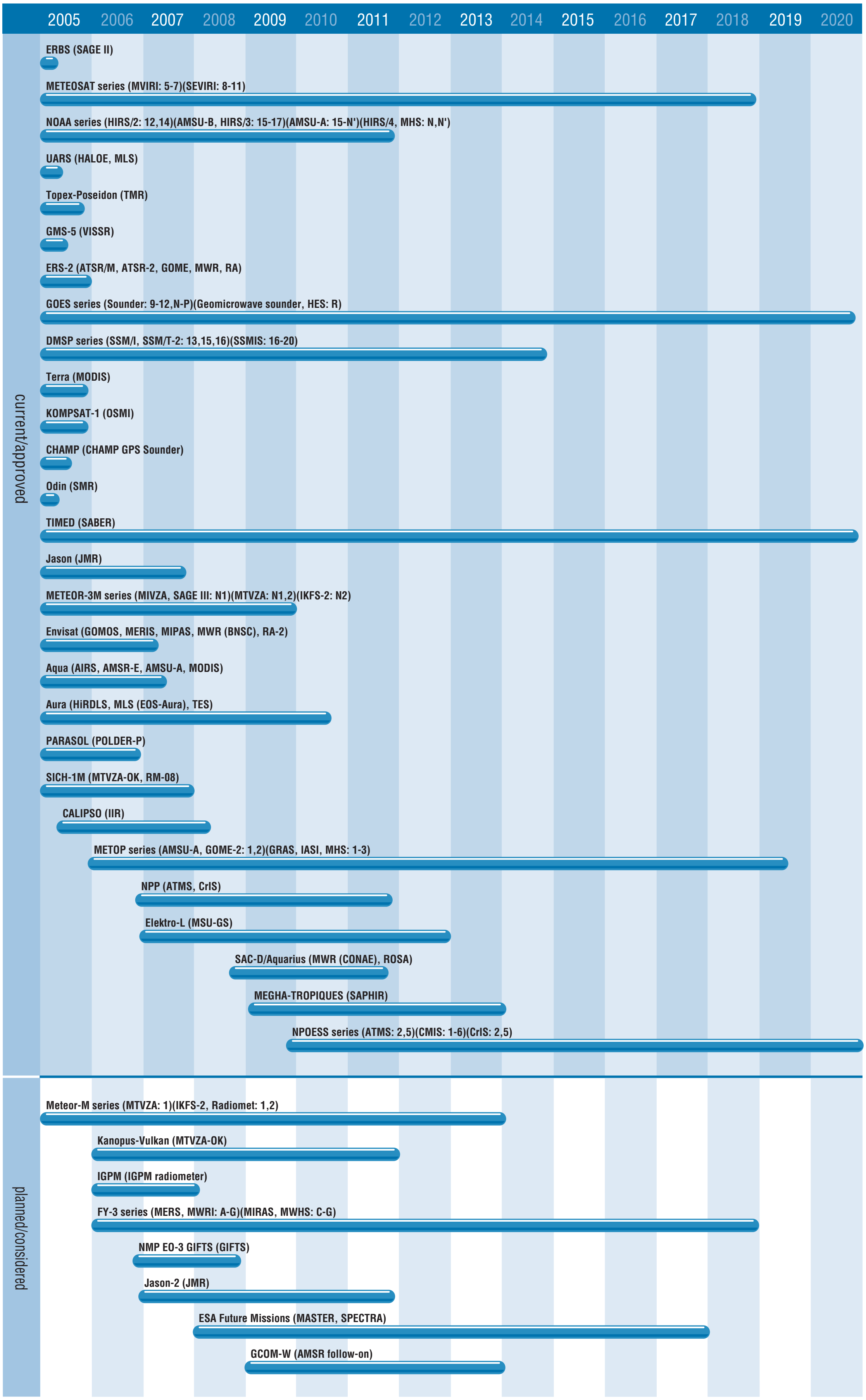
In the case of observations for regional NWP models, polar and geostationary satellites provide estimates of total column water vapour accurate to within 10-20%. Enough information is collected to infer moisture concentration within several thick layers vertically, with good horizontal resolution. Vertical resolution is marginal for mesoscale prediction, and the infrared information is available only for cloud-free fields of view.

Until recently, performance in cloudy areas was poor, but the new microwave measurements from AMSU offer substantial improvements. Geostationary infrared soundings are also helping to expand coverage in some regions by making measurements on repeat timescales of fifteen minutes to one hour and thus creating more cloud-free observations. Over oceans, coverage is currently supplemented by information on total column water vapour from microwave imagers.

Humidity measurements for weather forecasting are assured continuity through the operations of the METOP, NOAA, and NPOESS series, which in future will feature instruments with improved accuracy and resolution, a number of which will be common to the different satellites (such as AMSU-A, HIRS/4, and MHS). The DMSP series sounders will also provide continuity. NPOESS will feature the combination of the CRiS interferometer and ATMS sounder to derive accurate humidity profiles. This data will be supplemented by instruments on Aqua (AIRS+, AMSR-E, AMSU-A), Aura (HiRDLS, MLS, TES), and the FY-3 series (MWHS), amongst others.

Satellite sounding data are currently under-utilised over land, but progress in data interpretation is expected in the near future. Radio-occultation measurements using the GPS constellation is complementing other systems by providing information on the humidity profile in the lower troposphere.

Atmospheric humidity



Atmosphere

Atmospheric temperature

As with humidity, atmospheric temperature data are a core requirement for weather forecasting and are addressed within the CGMS framework. The data are used for NWP, for monitoring inter-annual global temperature changes, for identifying correlations between atmospheric parameters and climatic behaviour, and for validating global models of the atmosphere.

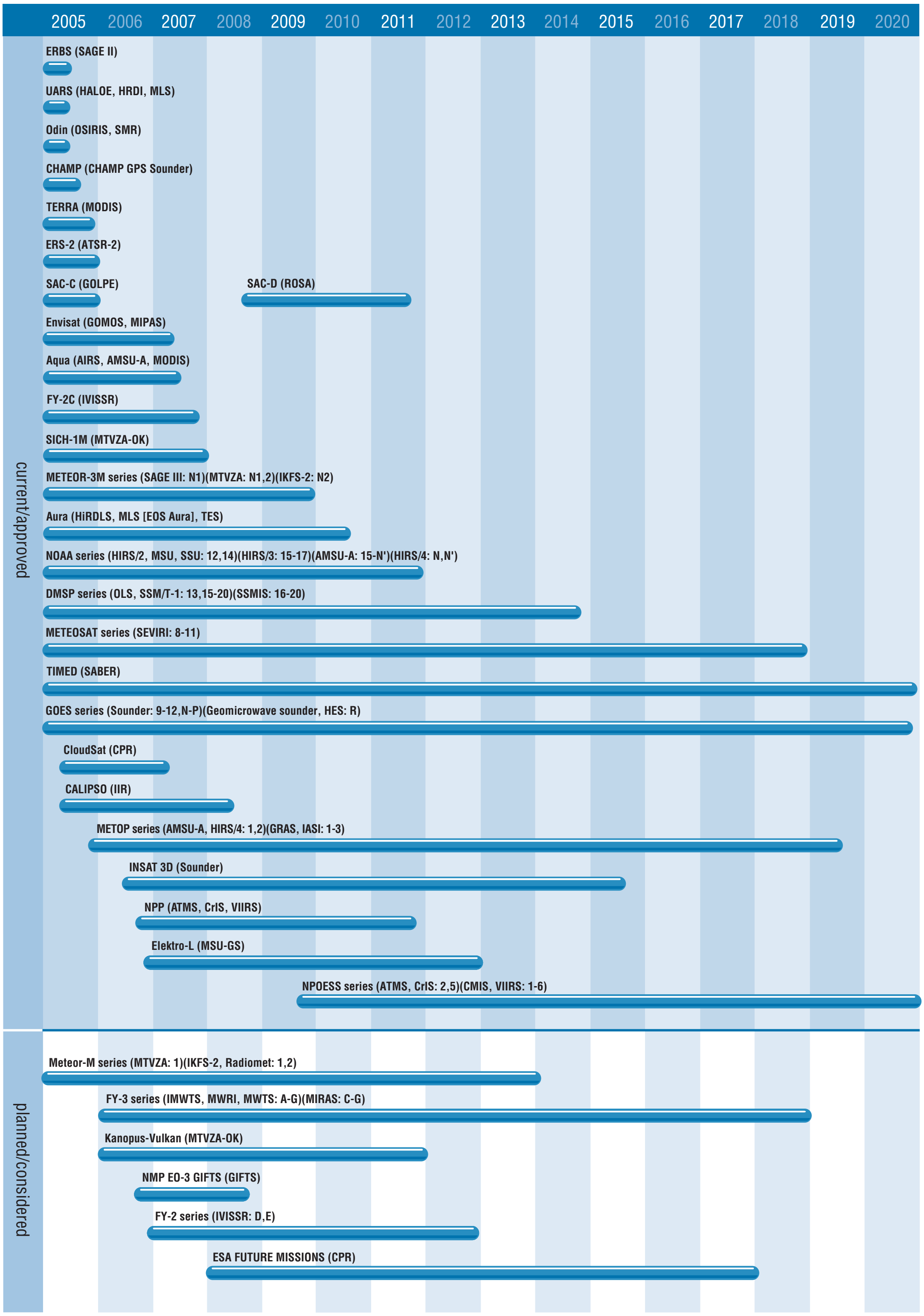
Data on atmospheric temperature is derived partly from satellite observations. For global NWP, polar satellites provide information on temperature with global coverage, good horizontal resolution and acceptable accuracy, but improvements in vertical resolution are needed. Performance in cloudy areas has been poor, but the new microwave measurements such as AMSU have provided substantial improvements. As in the case of humidity profiles, the Aqua, METOP, NOAA, and NPOESS missions offer comparable improvements in vertical resolution for measuring atmospheric temperature (using AIRS+, AMSU-A, CrIS, HIRS, IASI, MSU).

For regional NWP, polar orbiting satellites provide information on temperature with acceptable accuracy and good horizontal resolution, but with marginal temporal frequency and vertical resolution for mesoscale prediction. Advanced radiometers or interferometers planned for future satellites should improve on the vertical resolution and accuracy of current radiometers.

Geostationary satellites provide frequent radiance data, but their use over land is hindered because of the difficulty in estimating surface emissivity. In nowcasting, the temperature and humidity fields are particularly useful for determining atmospheric stability for predicting precipitation type, the amount of frozen precipitation, and convective storms. As with humidity profiles, nowcasting predictions using atmospheric temperature data will benefit from hourly geostationary infrared soundings (such as from the GOES and MSG series).

The combination of the HIRS/3 and AMSU instruments on the NOAA and METOP series allows improved information, sufficient to infer temperature within several thick layers in the vertical. On the METOP series, IASI will also be used with other instruments to deliver comparable sounding capacity. CrIS on the NPOESS series, which will replace HIRS, is designed to enable retrievals of atmospheric temperature profiles at 1K accuracy for 1km layers in the troposphere. The GRAS instrument on METOP will provide temperature information of high accuracy and vertical resolution in the stratosphere and upper troposphere (helping to improve analyses around the tropopause). Its information will thus be complementary to that provided by the passive sounding instruments on METOP. China's FY-2 series of satellites FY-2C, D & E), feature improved measurements from October 2004 with the addition of new spectral channels to their IVISSR instrument.

Atmospheric temperature



Atmosphere

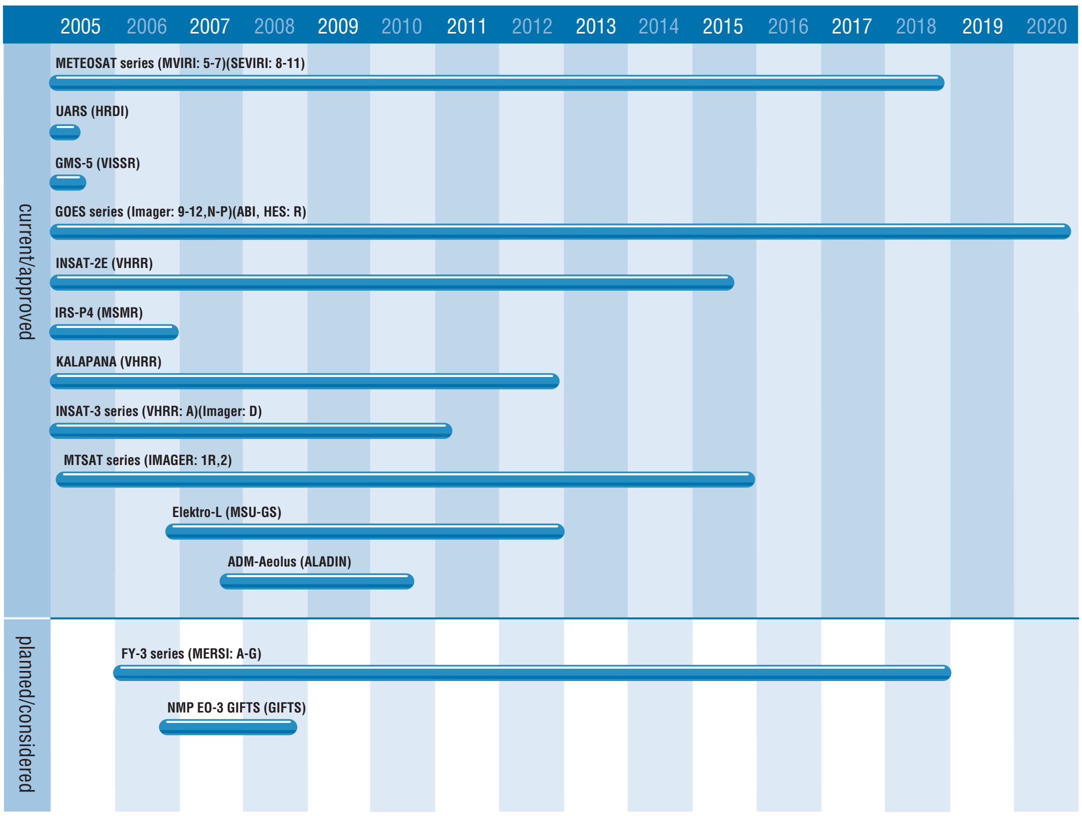
Atmospheric winds

Measurements of atmospheric winds are of primary importance to weather forecasting, and as a variable in the study of global climate change as well as in a number of applications such as aviation flight planning. Horizontal wind may be inferred by motion vectors or by humidity tracers in geostationary imagery. While substantial information can be derived by these methods the quality is not homogeneous and vertical resolution is poor. Planned instruments for geostationary satellites promise improved information, but the limited vertical resolution and the problems of accurate height assignment of winds will remain areas to be improved.

For global NWP models, wind profile information - mostly overland - is available mainly from radiosondes. Doppler wind lidar technology is being developed to provide 3D winds of acceptable coverage and vertical resolution, but there are significant technical problems and thick cloud is a limitation. Geostationary imagers offer wind profile information by cloud tracking and in cloud-free areas through tracking of highly-resolved features in the water vapour channels. In the lower atmosphere, coverage may be supplemented in future by tracking ozone features in satellite imagery. Regional NWP models also rely heavily on radiosondes (overland) and aircraft (over ocean and over the poles) for atmospheric wind profile measurements, but would benefit from improved satellite data. In nowcasting, single level satellite wind information is sufficiently available over low and mid-latitudes to provide acceptable horizontal and temporal coverage, but vertical coverage is marginal and accuracy is acceptable to marginal.

At present, geostationary multi-channel visible and infrared imagers such as IMAGER, MVIRI and VISSR are used to measure cloud and water vapour motion vectors from which tropospheric wind estimates may be derived. Atmospheric motion vectors generated from SEVIRI imagery on MSG provide improved data in terms of coverage, spatial and temporal resolution, and accuracy of both wind vectors and height assignment. Though valuable, because they offer wind information in areas of the world where otherwise there would be none, atmospheric wind vectors are only single level observations and are only available where there are suitable image features to be tracked. NASA will be demonstrating the technology for an advanced sounder generating wind information with GIFTS in 2006.

In the longer term, laser instruments such as Doppler lidars offer the promise of directly measuring clear air winds. Although such active instruments will provide high accuracy and vertical resolution, the coverage offered by polar missions such as that planned for ALADIN is likely to be limited.



Cloud particle properties and profile

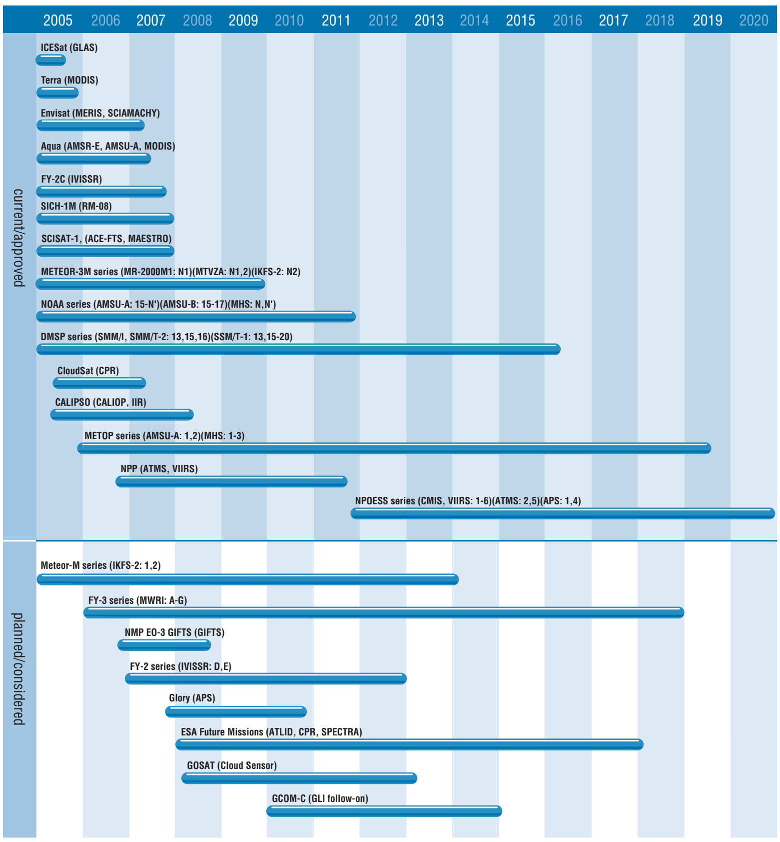
A key to predicting climate change is to observe and understand the global distribution of clouds, their physical properties, such as thickness and droplet size, and their relationship to regional and global climate. Whether a particular cloud will heat or cool the Earth's surface depends on several factors, including the cloud's altitude, its size, and the make-up of the particles which form the cloud.

Because clouds change rapidly over short time and space intervals, they are difficult to quantify. Full 3-D observations of cloud structure from space are still in development, with the first sensors expected with a few years on NASA (CloudSat) and ESA missions. These missions will be capable of measuring the vertical structure of a large fraction of clouds and precipitation - from very thin cirrus clouds to thunderstorms producing heavy precipitation.

Currently, basic information on the structure of clouds (ie determination of whether water or ice particles are present) is being obtained from microwave instruments such as AMSR-E on Aqua. MODIS and MISR on Terra also provide observations which enable estimates of cloud droplet size to be made. These measurements are important for climate purposes as the structure of clouds (particle size and phase) greatly affects their optical properties and hence their albedo. Together with cloud top temperatures, information on the 3-D structure of clouds can be used as a basic tool for the real time surveillance of features such as thunderstorms. Study of these parameters through the life cycle of a storm allows researchers to develop useful short term forecasting criteria.

Additional phase information will also be available from polarimetric radiometers such as POLDER. However, the users' requirements for cloud data are unlikely to be met until data from instruments such as ATLID or the cloud radars become available.

In a fine example of international co-operation, from April 2005 a multiple satellite constellation comprising CloudSat, Aqua, Aura, CALIPSO and PARASOL will fly in orbital formation with the goal of gathering data needed to evaluate and improve the way clouds are represented in global models, and to develop a more complete knowledge of their poorly understood role in climate change and the cloud-climate feedback. CloudSat will maintain a tight formation with CALIPSO, with a goal of overlapping measurement footprints at least 50% of the time. CALIPSO will carry a dual-wavelength polarisation-sensitive lidar that provides high resolution vertical profiles of aerosols and clouds. CloudSat and CALIPSO will maintain a somewhat looser formation behind Aqua - which carries a variety of passive microwave, infrared, and optical instruments.



Atmosphere

Cloud type, amount and cloud top temperature

The study of clouds, where they occur, and their characteristics, play a key role in the understanding of climate change. Low, thick clouds primarily reflect solar radiation and cool the surface of the Earth. High, thin clouds primarily transmit incoming solar radiation; at the same time they trap some of the outgoing infrared radiation emitted by the Earth and radiate it back downward, thereby warming the surface of the Earth. The Earth's climate system constantly adjusts in a way that tends toward maintaining a balance between the energy that reaches the Earth from the sun and the energy that goes back from Earth back out to space. This process is known as Earth's 'radiation budget'. The components of the Earth system that are important to the radiation budget are the planet's surface, atmosphere and clouds.

The IPCC point out that even the most advanced climate models cannot yet simulate all aspects of climate, and that there are particular uncertainties associated with clouds and their interaction with radiation and aerosols.

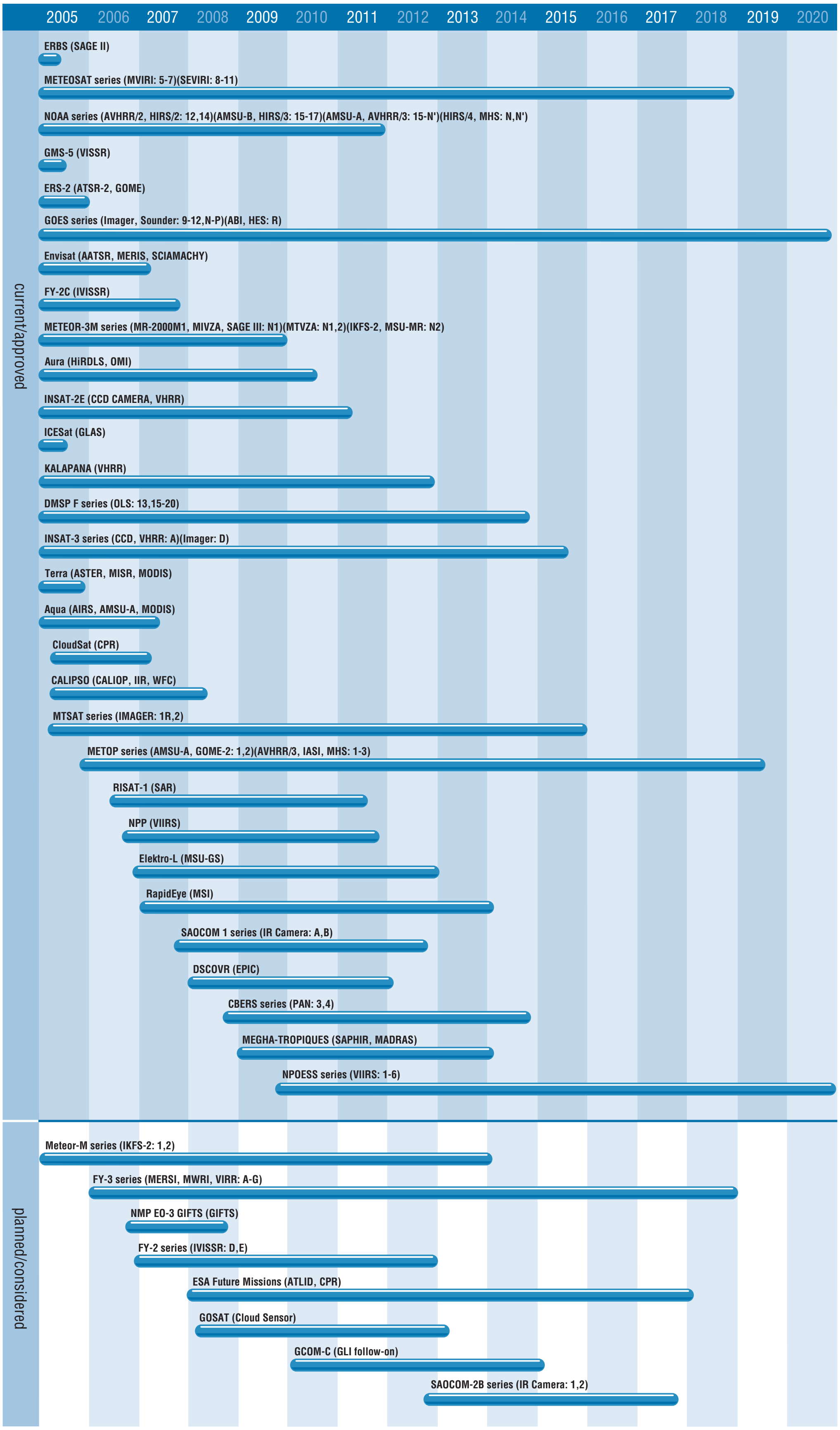
Weather forecasters are able to draw on a range of satellite data on clouds in devising models and in making forecasts. For both global and regional NWP models, satellite instruments offer detailed information on cloud coverage, type, growth and motion. The coverage is global from polar orbiting satellites and - with the exception of high latitudes - global from geostationary satellites. Infrared imagers and sounders can provide information on cloud cover and cloud top height of good horizontal and temporal resolution. Microwave imagers and sounders give information on cloud liquid water, cloud ice and precipitation. Microwave information is valuable for regional mesoscale models which have sophisticated parameterisation of cloud physics. In the context of nowcasting and very short range forecasting, meteorological satellite data are well suited to monitoring the rapid development of precipitation-generating systems in space and time.

In the field of climate research, the MODIS and MISR spectro-radiometers on the Terra mission are enabling viewing of cloud features at higher resolutions than previously. MODIS is taking measurements to allow more precise determination of the contribution which clouds make to the 'greenhouse' warming of the Earth. MISR is observing angles at which sunlight is reflected from clouds. These observations are critical in support of new research on the radiative properties of clouds. On the same Terra mission, the ASTER radiometer, measuring visible and infrared wavelengths, will complement the other instruments by providing high resolution views of specific targets of interest.

For weather forecasting, satellite instruments will continue to offer a wealth of useful information on clouds. HIRS, AMSU-A, MHS and IASI on polar orbiting missions will offer improved information on clouds. Geostationary imagers and sounders (on MSG, GOES, Elektro-L, INSAT, MTSAT and FY-3 series) will contribute to retrieval of information about cloud cover, cloud top temperature, cloud top pressure and cloud type, and will be close to meeting regional NWP modeling needs for these variables. Retrievals will not only comprise the temperature and moisture profiles, but also fractional cloud cover, cloud top height, cloud top pressure, surface temperature and surface emissivity - from both infrared and microwave soundings.

The increased use of imager data to determine the cloud amount will improve the performance and the number of retrieved profiles. In general, IASI will increase sounding performance to a level very significant for regional NWP. On the NPOESS series of satellites, parameters that may be derived from VIIRS will include cloud cover.

Cloud type, amount and cloud top temperature



Atmosphere

Liquid water and precipitation rate

Water forms one of the most important constituents of the Earth's atmosphere and is essential for human existence. The global water cycle is at the heart of the Earth's climate system, and better predictions of its behaviour are needed for monitoring climate variability and change, weather forecasting, and sustainable development of the world's water resources. A better understanding of the current distribution of precipitation, and of how it might be affected by climate change, is vital in support of accurate predictions of regional drought or flooding.

Information on liquid water and precipitation rate is used for initialising NWP models. For global NWP a variety of satellites provide complete global coverage, but they present two major challenges: firstly, the satellite sensors (such as visible/IR imagers on geostationary weather satellites) typically observe quantities (such as cloud height and cloud top temperature) related to precipitation, and algorithms must be developed to get the best estimates from each particular sensor; and secondly, the mix of available data is constantly changing in space and time.

Microwave imagers and sounders (eg AMSR-E) offer information on precipitation of marginal horizontal and temporal resolution, and acceptable to marginal accuracy (though validation is difficult). Satellite-borne rain radars (eg on the recently-ended TRMM mission, and on CloudSat), together with plans for constellations of microwave imagers, offer most potential for improved observations. For regional NWP, no satisfactory precipitation estimates are available from satellites at present, although satellites are the only potential source of information over the oceans. Geostationary satellites do provide vital information on the location of tropical cyclones.

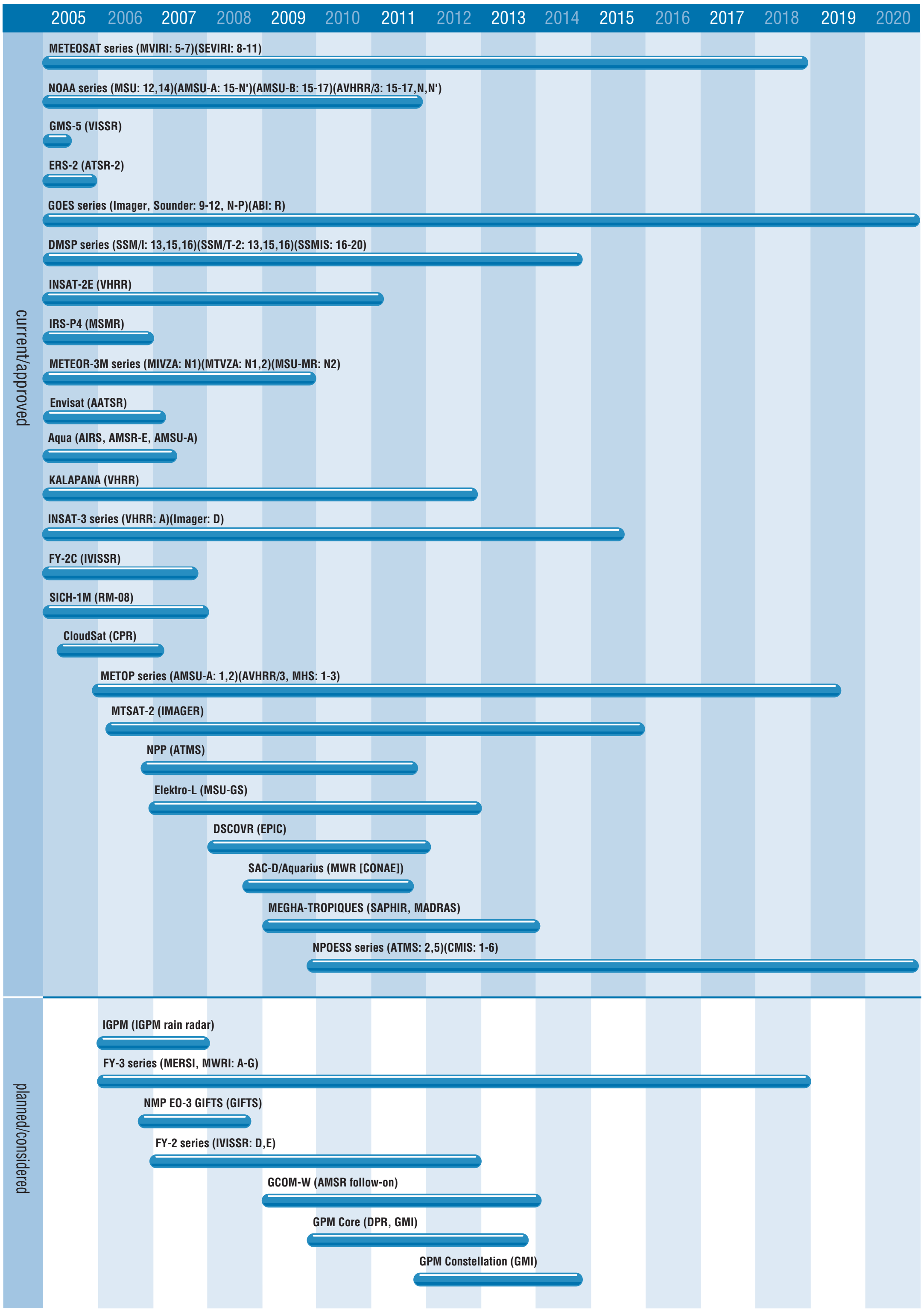
Increasing amounts of useful microwave data - such as from the TRMM mission - are becoming available. TRMM was dedicated to studying tropical and sub-tropical rainfall and carried the first spaceborne precipitation radar, NASDA's PR instrument, and also NASA's TMI microwave imager. Data from PR and TMI have provided new insights into the internal composition of tropical thunderstorms associated with hurricanes. NASA, JAXA and ESA plan to continue this collaboration in future to develop the Global Precipitation Measurement mission (GPM) for launch from 2009; the GPM constellation of satellites will provide global observations of precipitation every three hours to help develop the understanding of the global structure of rainfall and its impact on climate. The recently approved CNES-ISRO mission Megha-Tropiques will provide further measurements of tropical rainfall; MADRAS, a passive multi-frequency radiometer, will collect data on rain over the oceans.

The CMIS microwave imager/sounder on NOAA's NPOESS missions will be sensitive to various forms of water and moisture in the atmosphere and clouds, and will provide an 'all weather' measurement capability.

Future coordination of these various satellite programmes, as well as the efforts of the in-situ measurement community, will be addressed by the Integrated Global Water Cycle Observations Theme (IGWCO) of the IGOS Partnership. The first element of IGWCO is a 'Coordinated Enhanced Observing Period (CEOP)' which is taking the opportunity of the simultaneous operation of key satellites of Europe, Japan, and USA to generate new data sets of the water cycle.

The IGWCO Theme report is available from www.igospartners.org. This document represents a comprehensive overview of the state-of-the-art in water cycle observations and formulates recommendations for an international work programme to better understand, monitor and predict water processes.

Liquid water and precipitation rate



Atmosphere

Ozone

Ozone (O_3) is a relatively unstable molecule, and although it represents only a tiny fraction of the atmosphere, ozone is crucial for life on Earth. Depending on its location ozone can protect or harm life on Earth. Most ozone resides in the stratosphere, where it acts as a shield to protect Earth's surface from the sun's harmful ultraviolet radiation. In the troposphere, ozone is a harmful pollutant which causes damage to lung tissue and plants. Man-made chemicals and weather conditions over Antarctica combine to deplete stratospheric ozone concentrations during the winter months there. The total amount of O_3 in the troposphere is estimated to have increased by 36% since 1750, due primarily to anthropogenic emissions of several O_3-forming gases.

Developments are under way to add ozone as a new NWP model variable, primarily to allow ozone observations to be used to act as a tracer for information on wind. More detail on ozone issues is presented in the case study in Part II of this document.

Satellite instruments have for many years provided data measuring interactions within the atmosphere that affect ozone, and soon more advanced instruments will be in orbit to collect more detailed measurements, increasing knowledge of how human activities are affecting Earth's protective ozone layer.

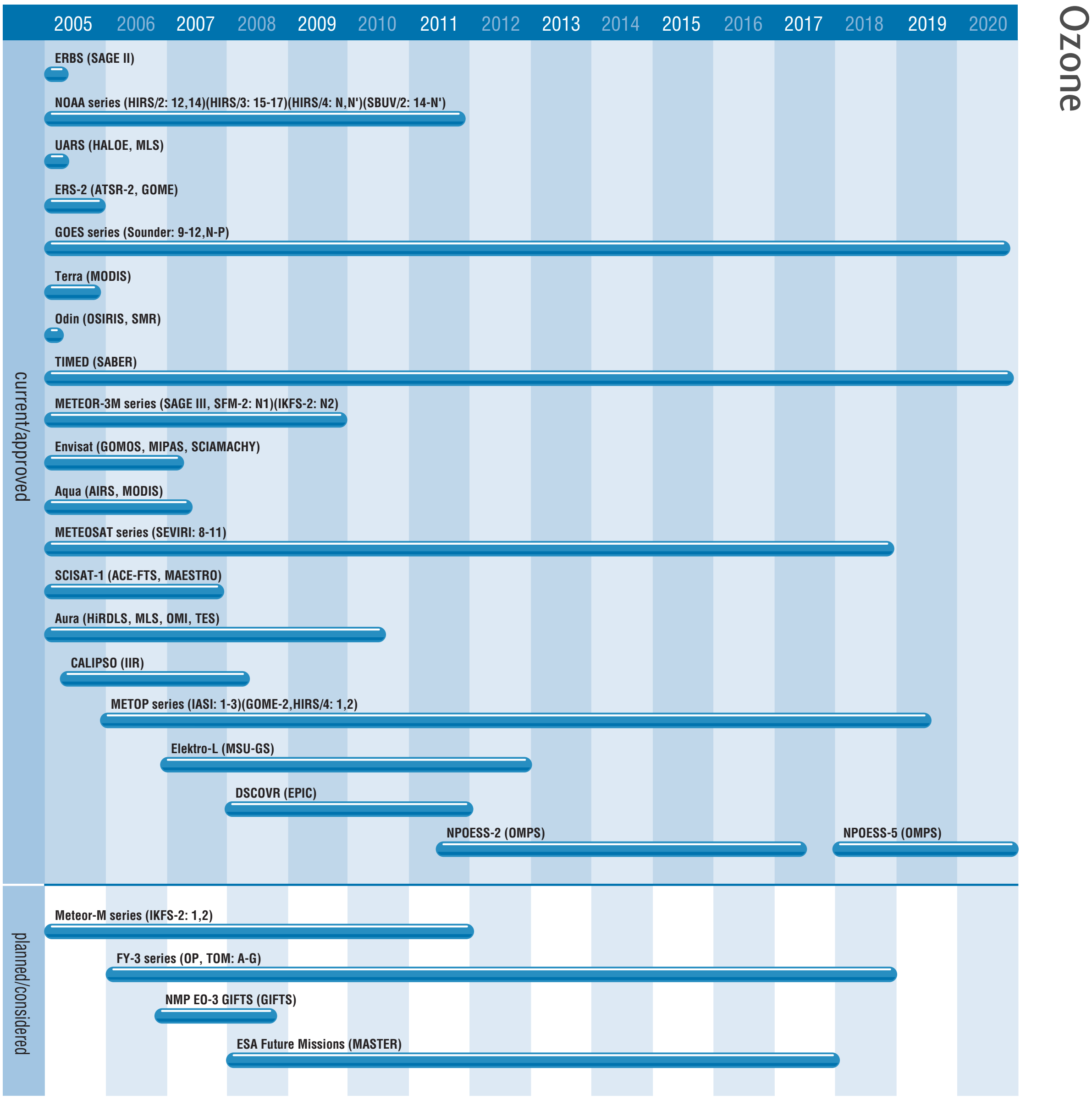
Total column measurements of ozone have been provided by NASA's TOMS and NOAA's SBUV instruments over long periods. Stratospheric ozone profiles have also been measured by instruments such as HALOE & MLS (UARS mission), GOME (ERS-2), and SAGE III (part of the International Space Station payload).

Since launch in March 2002, GOMOS and SCIAMACHY on ESA's Envisat mission have provided improved observations of the concentration of ozone in the stratosphere and trace gases.

A wide range of instruments dedicated to, or capable of, ozone measurements are planned for the next decade. On the recently launched Aura mission, HIRDLS, OMI, and MLS study and monitor atmospheric processes which govern stratospheric and mesopheric ozone, and continue the TOMS record of total ozone measurements. TES on Aura is used to create three dimensional maps of ozone concentrations in the troposphere.

IASI and GOME-2 on the METOP series will provide information on both total column ozone and on vertical profile. The Ozone Profiler on China's FY-3 series will contribute further data continuously from 2006. In the longer term (from 2011), NOAA's Ozone Mapping and Profiler Suite (OMPS) will collect data to permit the calculation of the vertical and horizontal distribution of ozone in the atmosphere.

The IGOS theme on atmospheric chemistry observations (IGACO) has developed a strategy for the integrated provision of chemistry observations (and associated meteorological parameters) required to realise the theme objectives, including the monitoring of atmospheric composition parameters related to climate change.


Ozone
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ERBS (SAGE II)
NOAA series (HIRS/2: 12,14)(HIRS/3: 15-17)(HIRS/4: N,N')(SBUV/2: 14-N')
UARS (HALOE, MLS)
ERS-2 (ATSR-2, GOME)
GOES series (Sounder: 9-12,N-P)
Terra (MODIS)
Odin (OSIRIS, SMR)
TIMED (SABER)
METEOR-3M series (SAGE III, SFM-2: N1)(IKFS-2: N2)
Envisat (GOMOS, MIPAS, SCIAMACHY)
Aqua (AIRS, MODIS)
METEOSAT series (SEVIRI: 8-11)
SCISAT-1 (ACE-FTS, MAESTRO)
Aura (HiRDLS, MLS, OMI, TES)
CALIPSO (IIR)
METOP series (IASI: 1-3)(GOME-2,HIRS/4: 1,2)
Elektro-L (MSU-GS)
DSCOVR (EPIC)
NPOESS-2 (OMPS)
NPOESS-5 (OMPS)
planned/considered
Meteor-M series (IKFS-2: 1,2)
FY-3 series (OP, TOM: A-G)
NMP EO-3 GIFTS (GIFTS)
ESA Future Missions (MASTER)

Atmosphere

Radiation budget

The Earth's radiation budget is the balance within the climate system between the energy that reaches the Earth from the sun and the energy that returns from Earth to space. Satellite measurements offer a unique means of assessing the Earth's radiation budget. The goal of such measurements is to determine the amount of energy emitted and reflected by the Earth. This is necessary to understand the processes by which the atmosphere, land and oceans transfer energy to achieve global radiative equilibrium, which in turn is necessary to simulate and predict climate.

Systematic observations of the Earth system energy balance components are noted by the IPCC as being of key importance in narrowing the uncertainties associated with the climate system. In addition to these continuous global measurements of the radiation budget which are necessary both to estimate any long term climatic trends and shorter term variations overlying these trends, measurements on a regional scale are useful to understand better the dynamics of certain events or phenomena and to assess the effect of climate change, for example on agriculture and urban areas.

In general, three types of measurements are currently possible:

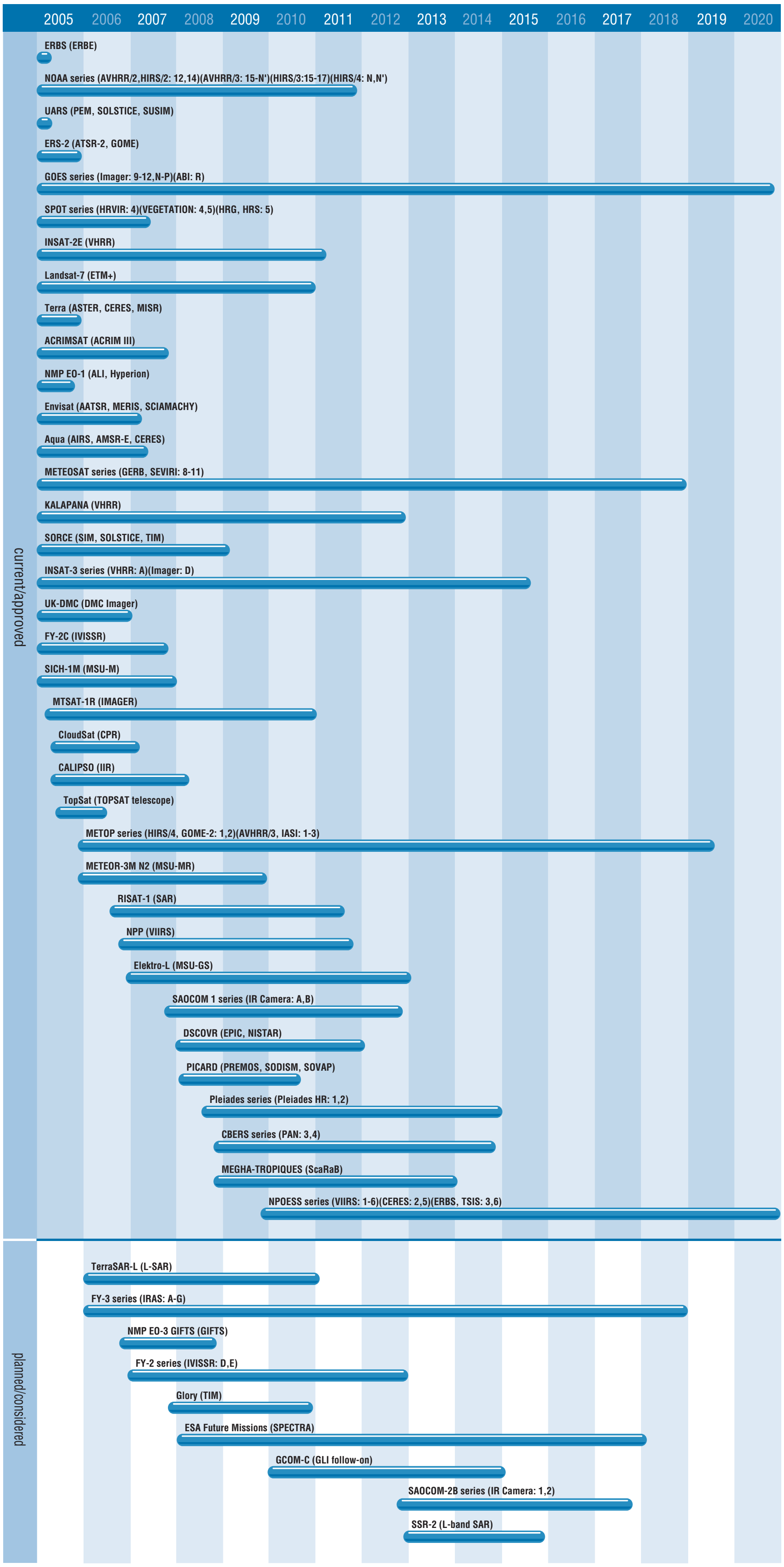
- the shortwave and longwave radiation budget at the top of the atmosphere;
- the shortwave radiation budget at the Earth's surface;
- the total incoming broadband radiation flux.

NASA has, since the mid sixties, been measuring the net radiation with the ERBE, ACRIM, and CERES sensors. The MISR spectroradiometer (also on Terra with CERES) provides data on top of the atmosphere, cloud and surface hemispheric albedos and aerosol opacity. Continuity of Total Solar Irradiance (TSI) measurements is now assured by the launch of the SORCE mission at the beginning of 2003, carrying 4 instruments (TIM, SOLSTICS, SIM, XPS) operating over the 1nm-2000nm waveband and measuring over 95% of spectral contribution to TSI.

NISTAR on the DSCOVR mission (from 2008) will measure reflected solar energy and radiant power emitted by the sunlit Earth in the UV, Visible, and IR bands from an orbit optimized to continuously achieve the critical viewing angle.

An increasing number of radiation budget measurements are featuring on operational meteorology missions, including: GERB (on METEOSAT-8 operating since September 2002 and measuring shortwave and longwave radiation every 15 minutes); TSIS and ERBS (on NPOESS); continued narrow-band information from the HIRS, AVHRR, and VIIRS instruments.

Radiation budget



Atmosphere

Trace gases (excluding ozone)

Trace gases other than ozone may be divided into three categories:

- greenhouse gases affecting climate change;
- chemically aggressive gases affecting the environment (including the biosphere);
- gases and radicals impacting on the ozone cycle, thereby affecting both climate and environment.

The presence of trace gases in the atmosphere can have a significant effect on global change as well as potentially harmful local effects through increased levels of pollution. The chemical composition of the troposphere in particular is changing at an unprecedented rate - the rate at which pollutants from human activities are being emitted into the troposphere is now thought to exceed that from natural sources (such as from volcanic eruptions).

The IPCC notes large increases in atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) since the industrial era and suggests that emissions of CO_2 due to fossil fuel burning are virtually certain to be the dominant influence on the trends in atmospheric CO_2 concentration during the 21st century. They consider that reductions in greenhouse gas emissions and the gases that control their concentration would be necessary to stabilise radiative forcing.

Measurements from satellite sensors have already made an important contribution to the recognition that human activities are modifying the chemical composition of both the stratosphere and the troposphere, even in remote regions.

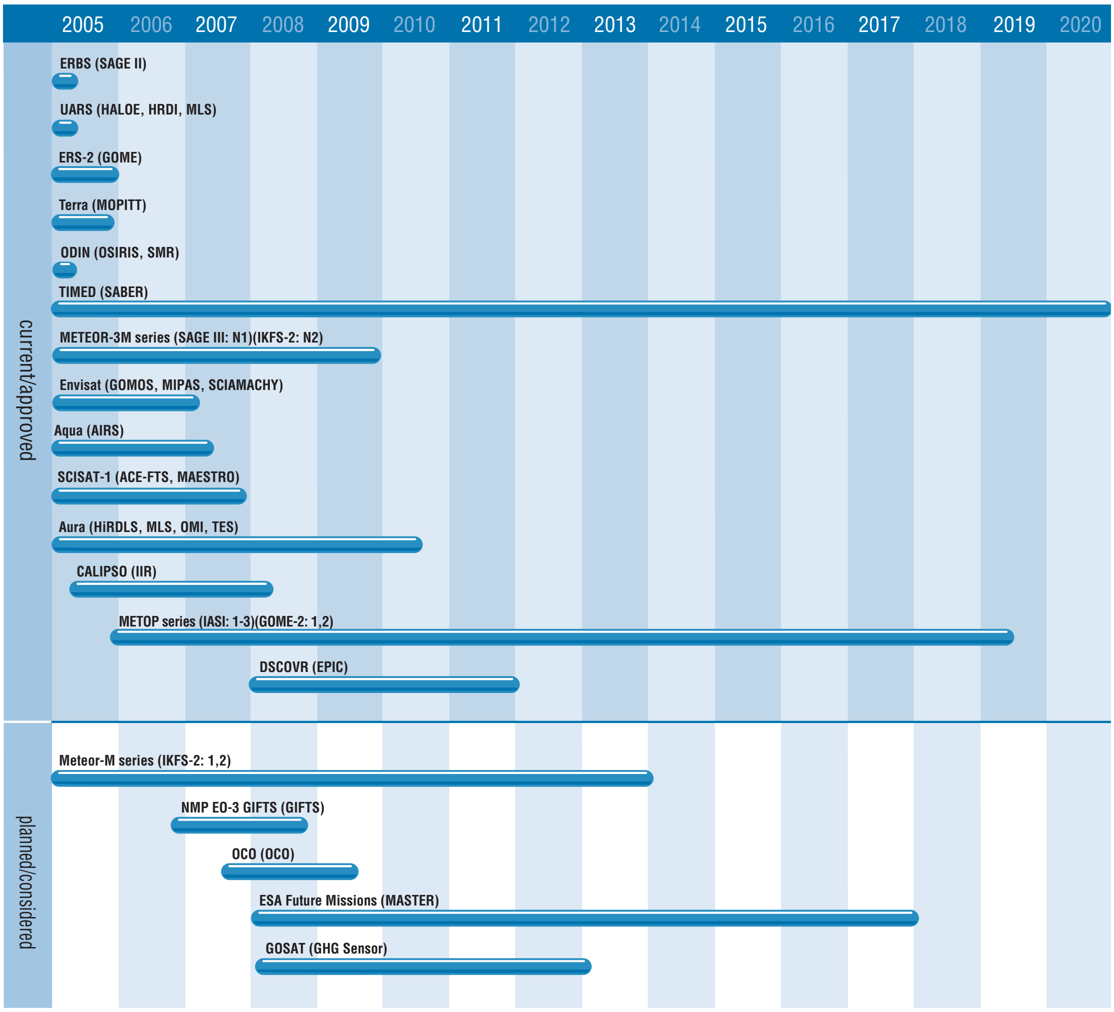
A variety of instruments provide measurements on the concentration of trace gases. In general, high spectral resolution is required to detect absorption, emission and scattering from individual species. Some instruments offer measurements of column totals, ie integrated column measurements, whilst others provide profiles of gas concentration through the atmosphere (usually limited to the upper troposphere and stratosphere using limb measurements).

To date, the instruments on UARS, launched in 1991 have provided the most significant source of data on trace gases and have been vital for studies of stratospheric chlorine chemistry, stratospheric tracer-tracer correlation, tropospheric water vapour, the chemistry of the wintertime Arctic lower stratosphere, and tropospheric aircraft exhaust studies.

The last few years have seen the arrival of new and significant capabilities, with advanced instruments on Terra (MOPITT - providing global measurements of carbon monoxide and methane in the troposphere), and Envisat (GOMOS, MIPAS, SCIAMACHY - providing profiles of trace gases through the stratosphere and troposphere). On NASA's Aura mission, HiRDLS, an infrared limb-scanning radiometer, carries out soundings of the upper troposphere, stratosphere and mesosphere to determine concentrations of trace gases, with horizontal and vertical resolutions superior to those previously obtained. On the same mission MLS measures concentrations of trace gases for their effects on ozone depletion, TES provides a primary input to a database of 3D distribution on global, regional and local scales of gases important to tropospheric chemistry, and OMI continues the TOMS record for atmospheric parameters related to ozone chemistry and climate. JAXA's GOSAT mission (from 2008) and EUMETSAT's METOP series (from late 2005) are also expected to make significant contributions to observations of trace gases.

The IGOS IGACO Theme for observations of atmospheric chemistry has considered all relevant chemical species to properly interpret the observations and intends to monitor the research required to improve understanding of Earth processes so that air quality evolutions can be predicted.

Trace gases (excluding ozone)



Land

Albedo and reflectance

Albedo is the fraction of solar energy that is reflected back from Earth to space. Measurements of albedo are essential for climate research studies and investigations of the Earth's energy budget. Different parts of the Earth have different albedos. For example, ocean surfaces and rain forests have low albedos, which means that they reflect only a small portion of the sun's energy. Deserts, ice and clouds, however, have high albedos; they reflect a large portion of the sun's energy. The high albedo of ice helps to insulate the polar oceans from solar radiation. Over the whole surface of the Earth, about 30% of incoming solar energy is reflected back to space. Because a cloud usually has a higher albedo than the surface beneath it, clouds reflect more shortwave radiation back to space than the surface would in the absence of the cloud, thus leaving less solar energy available to heat the surface and atmosphere. Hence, this 'cloud albedo forcing', taken by itself, tends to cause a cooling or 'negative forcing' of the Earth's climate.

Surface albedo can be estimated from shortwave, broadband or multi-spectral radiometer measurements with good horizontal resolution. Current measurements of albedo and reflectance are obtained primarily using multi-spectral imagers such as AATSR, AVHRR, and sensors on SPOT, Landsat, and some geostationary satellites.

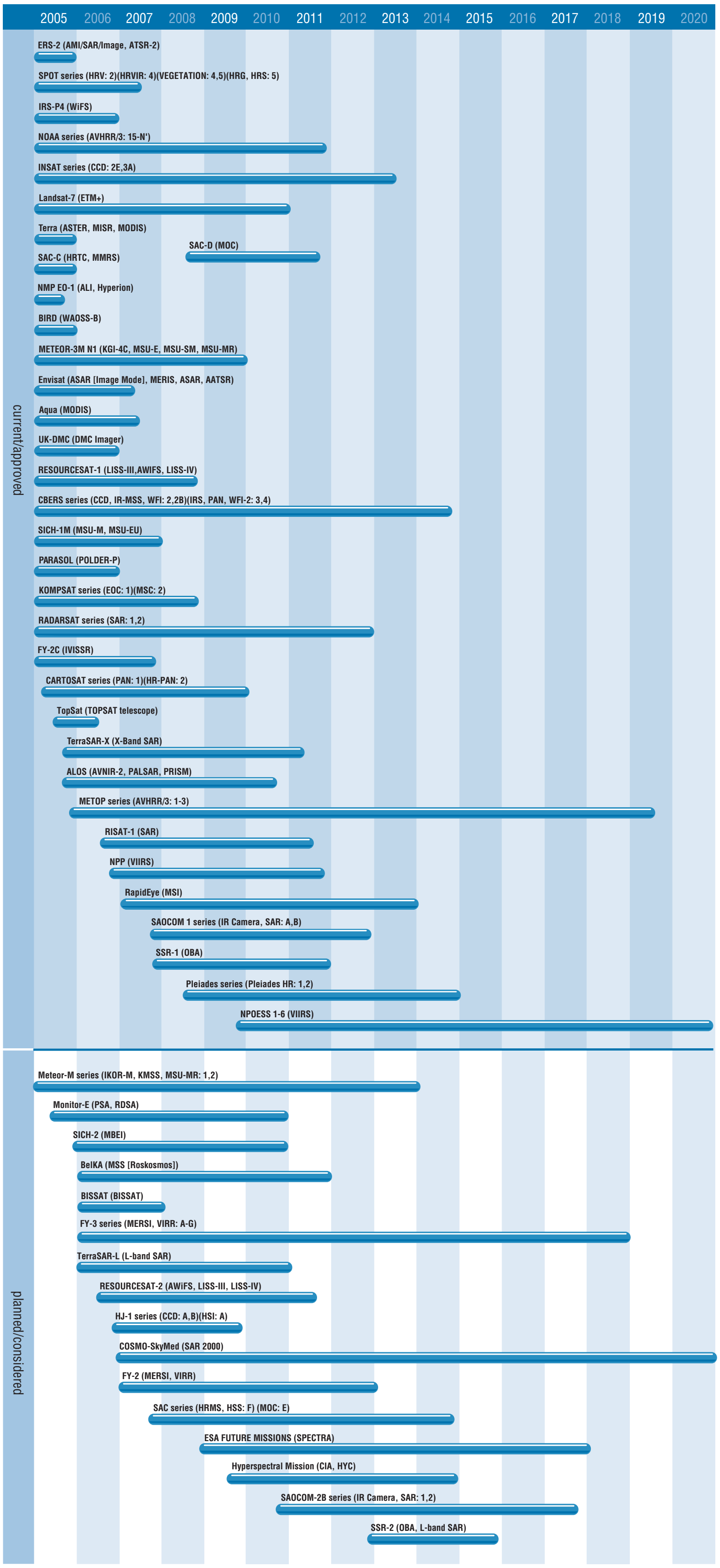
Clouds, aerosols and atmospheric gases affect the accuracy achievable, which is currently marginal to acceptable, but should become good as progress is made in interpreting data from high-resolution, multi-spectral instruments. Surface conditions (moisture, surface vegetation, snow cover etc) strongly affect albedo and high quality ground truth data is necessary in support of satellite measurements. Better understanding of the reflectance properties of different surfaces and more accurate aerosol data (to correct atmospheric effects) is needed to improve surface reflectance measurements.

As aerosol concentration increases within a cloud, more cloud drops form. Since the total amount of condensed water in a cloud does not change much, the average drop becomes smaller. This has two consequences - clouds with smaller drops reflect more sunlight and such clouds last longer. Both effects increase the amount of sunlight that is reflected to space without reaching the surface.

The Terra spacecraft is yielding greater knowledge of such cloud/aerosol effects - with MODIS and MISR providing data on cloud features, and ASTER providing complementary high spatial resolution measurements. Terra's data will provide new insights into how clouds modulate the atmosphere and surface temperature. Further multi-directional and polarimetric instruments (eg POLDER) should also provide measurements leading to better estimates of albedo.

New sensors, such as GERB and SEVIRI (on the MSG missions, starting with METEOSAT-8), provide improved capabilities for measuring surface albedo; improved sounder performance will yield more information on the infrared surface emissivity spectrum; multi-spectral imaging sensors such as AVHRR/3, VEGETATION, IVISSR and AWIFS will provide global visible, near infrared and infrared imagery of clouds, the ocean surface, land surface, and vegetation.

Albedo and reflectance



Land

Landscape topography

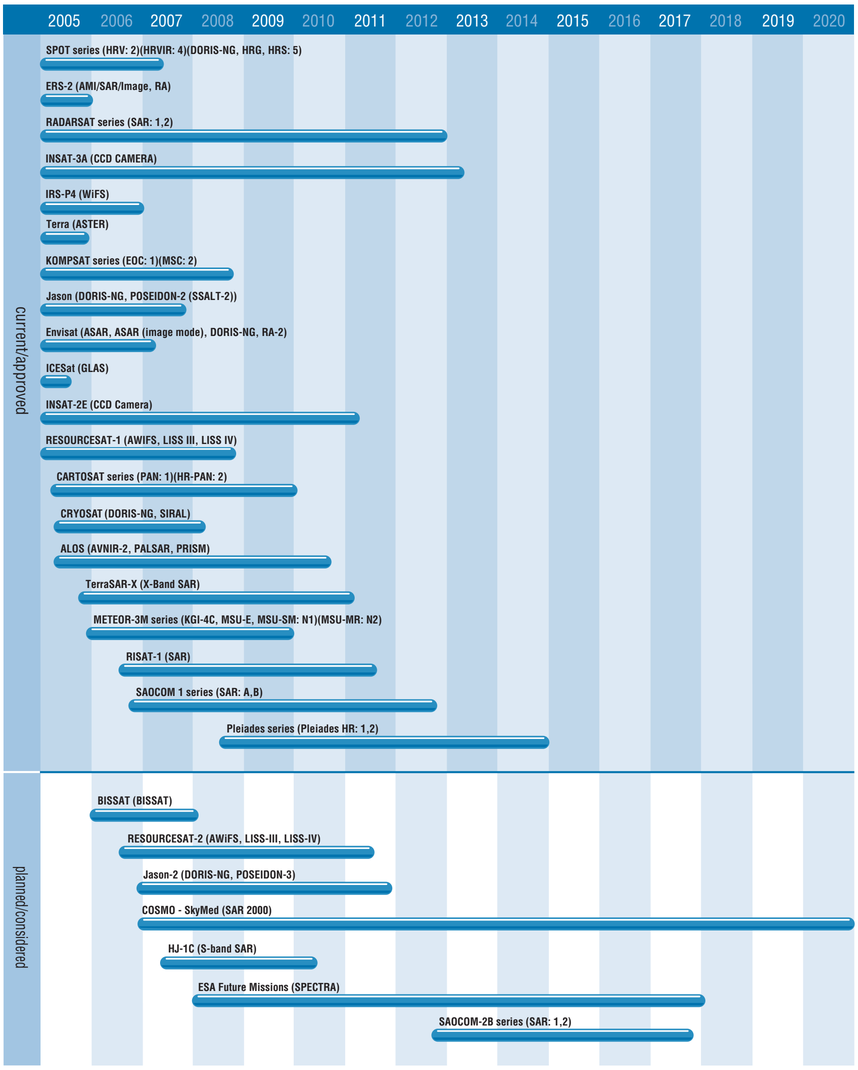
Many modelling activities in Earth and environmental sciences, telecommunications and civil engineering increasingly require accurate, high-resolution and comprehensive topographical databases with, where relevant, indication of changes over time. The information is also used by, amongst others, land-use planners for civil planning and development; by hydrologists to predict the drainage of water and where floods are likely, especially in coastal areas. In their Third Assessment Report, 'Climate Change 2001', the IPCC predicts that global mean sea level may rise as much as 88cm by the end of the 21st century, compared to a rise of between 10 and 25cm, estimated during the 20th century. Potentially, sea level rise will have disastrous impacts on large, populous, low-lying coastal cities and deltaic areas such as Bangladesh - which may suffer severe flooding.

Satellite techniques offer a unique, cost-effective and comprehensive source of landscape topography data. At present, most information is obtained primarily from multi-band optical imagers and synthetic aperture radar (SAR) instruments with stereo image capabilities. The pointing capability of some optical instruments allows the production of stereo images from data gathered on single (eg by ASTER) or multiple (eg by SPOT series) orbits - which are then used to create digital elevation maps which give a more accurate depiction of terrain.

SARs can also be used in interferometric mode to detect very small changes in topography and have important applications in monitoring of volcanoes, landslides, earthquake displacements, and urban subsidence. Current missions include Envisat and RADARSAT-1. JAXA's ALOS mission planned for 2005 is significant since it carries both high precision optical and SAR topographic mapping instruments.

Radar altimeters can also provide coarse topographic mapping over land, and have been supplemented by a new generation of laser altimeters - such as GLAS (ICESat) which can provide landscape topography products with height accuracies of order 50-100cm, depending on slope.

The role of these satellites, and their importance in mitigating geo-hazards such as earthquakes, landslides, and volcanic eruptions, is the focus of the IGOS Geo-hazards Theme. The Geo-hazards Theme report is available from www.igospartners.org.



Soil Moisture

Soil moisture plays a key role in the hydrological cycle. Evaporation rates, surface run-off, infiltration and percolation are all affected by the level of moisture in the soil. Soil moisture monitoring at scales from small catchments to large river basins is important for drought analysis, crop yield forecasting, irrigation planning, flood protection and forest fire protection. There is a pressing need for measurements of soil moisture for applications such as crop yield predictions, identification of potential famine areas, irrigation management, and monitoring of areas subject to erosion and desertification, and for the initialisation of NWP models.

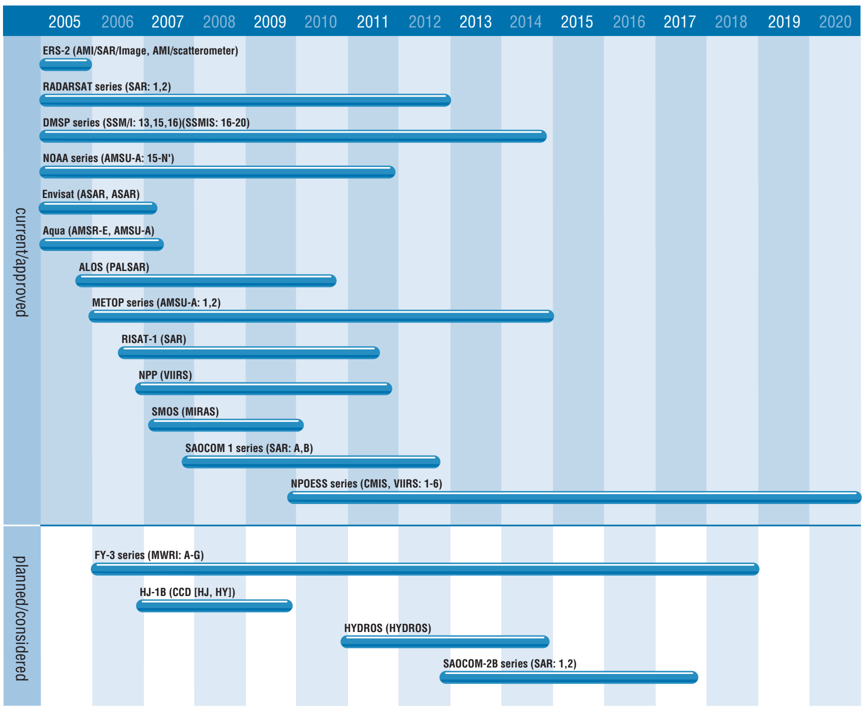
Direct measurement of soil moisture from space is difficult. Most of the active and passive microwave instruments will provide some soil moisture information for regions of limited vegetation cover. However, under many conditions remote sensing data are inadequate, and information regarding moisture depth remains elusive. While recent studies have successfully demonstrated the use of infrared, passive microwave, and non-SAR sensors to obtain soil moisture information, the potential of active microwave remote sensing based on SAR instruments remains largely unrealised. The main advantage of radar is that it provides observations at a high spatial resolution of tens of metres compared to tens of kilometres for passive satellite instruments such as radiometers or non-SAR active instruments such as scatterometers. The main difficulty with SAR imagery is that soil moisture, surface roughness, and vegetation cover all have an important and nearly equal effect on radar backscatter. These interactions make retrieval of soil moisture possible only under particular conditions such as bare soil or surfaces with low vegetation or complex modelling to 'subtract' contributions/effects of vegetation.

An appropriate instrument for measurements of soil moisture would appear to be the passive microwave radiometer, although some success has been achieved by radar - despite the complications of analysing the signals reflected from the ground. Microwave radiation emitted at the ground can be monitored to infer estimates of soil moisture. Passive microwave sensors can be used to do this based on detection of surface microwave emissions, although the signal is very small. Reliable data (high signal to noise ratio) need to be taken over a large area - which introduces the problem of understanding how to interpret the satellite signal since it consists of reflected radiation from many different soil types.

SAR data currently provide the main source of information on near-surface (10-15cm) soil moisture - for example ASAR on ESA's Envisat mission provides data from which soil moisture information can be inferred, and a project using ASAR data is planned to produce maps of seasonal soil moisture patterns at the regional scale for two European river basins.

AMSR-E on Aqua provides a variety of information on water content by measuring weak radiation from the Earth's surface. NOAA's conical microwave imager/sounder, CMIS, will provide environmental data including indications of soil moisture.

The first mission likely to satisfy requirements for observing soil moisture from space for the primary applications of hydrologic and meteorological models will be ESA's SMOS (Soil Moisture and Ocean Salinity Mission), carrying the MIRAS (Microwave Imaging Radiometer using Aperture Synthesis) passive L-band 2-D interferometer (from 2007). The approval of the NASA HYDROS mission for soil moisture measurement (launch date around 2010) will allow cross-comparison of results.



Land

Vegetation

Changes in land cover are important sources of global environmental change and have implications for ecosystems, biogeochemical fluxes and the global climate. Land cover change affects climate through a range of factors from albedo through to emissions of greenhouse gases from the burning of biomass.

Deforestation inter alia increases the amount of carbon dioxide (CO_2) and other trace gases in the atmosphere. When a forest is cut and burned to establish cropland and pastures, the stored carbon joins with oxygen and is released into the atmosphere as CO_2. The IPCC notes that about three-quarters of the anthropogenic emissions of CO_2 to the atmosphere during the past 20 years was due to fossil fuel burning. The rest was predominantly due to land use change, especially deforestation.

IGOS has set up an Integrated Global Carbon Observation (IGCO) Theme (report available from www.igospartners.org) to develop a flexible, robust strategy for international global carbon observations over the next decade. A key component of IGCO is terrestrial carbon observations aimed at the determination of terrestrial carbon sources and sinks with increasing accuracy and spatial resolution. The IPCC has highlighted an improved understanding of carbon dynamics as vital in tackling one of the biggest environmental problems facing humanity. The IGCO work will be an essential input to the implementation of of the United Nations Framework Convention on Climate Change (UNFCCC), particularly on the role of natural sinks in meeting targets under the UNFCCC Kyoto Protocol.

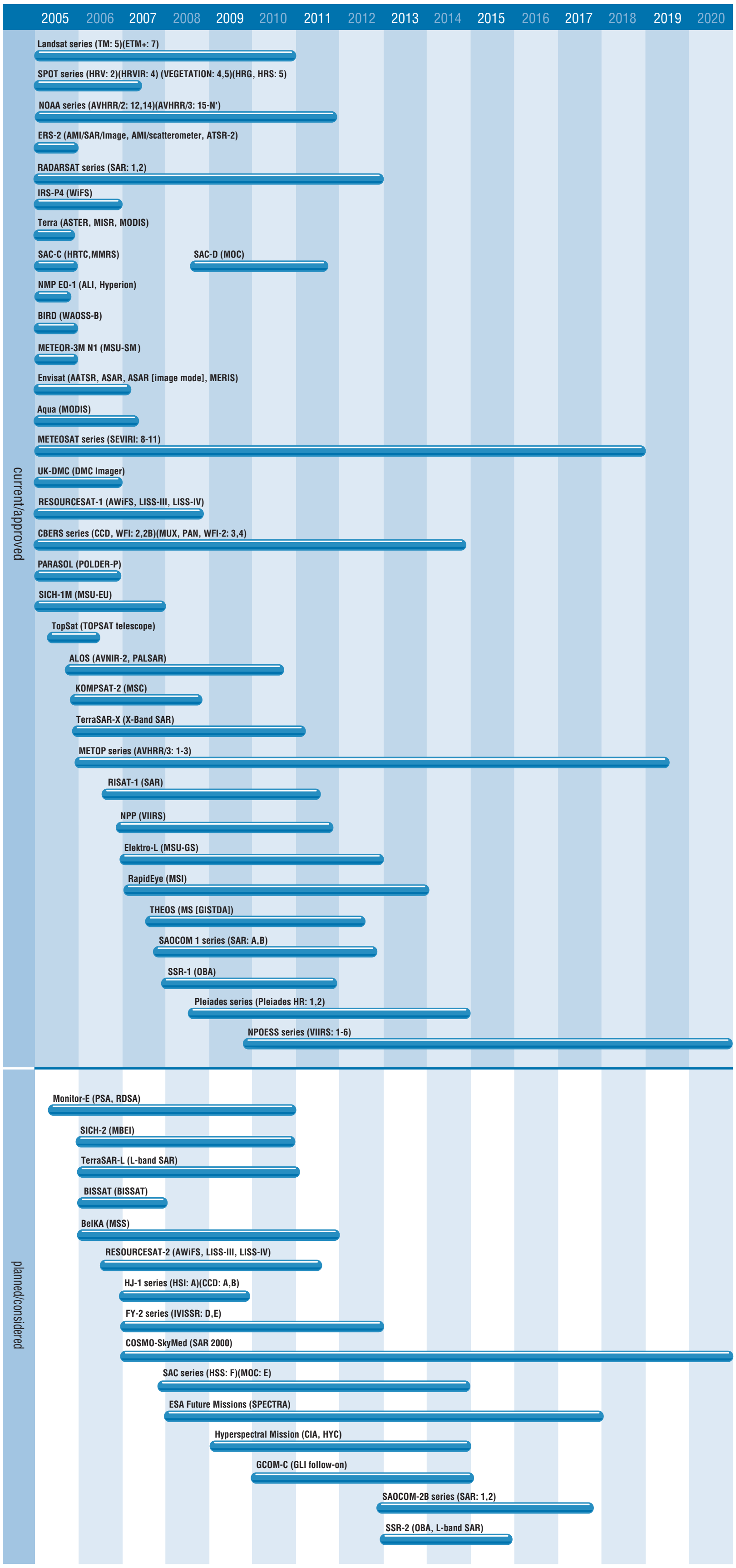
Satellite observations allow scientists to track two key elements of Earth's vegetation - the 'Leaf Area Index' (LAI) and the 'Fraction of absorbed Photosynthetically Active Radiation' (FPAR). LAI is defined as the one-sided green leaf area per unit ground area in broadleaf canopies, or as the projected needleleaf area per ground unit in needle canopies, and FPAR is the fraction of photosynthetically active radiation absorbed by vegetation canopies. Both LAI and FPAR are data necessary for understanding how sunlight interacts with the Earth's vegetated surfaces.

Multiple types of satellite observations are used in agricultural applications. Satellite imagery provides information which can be used to monitor quotas and to examine and assess crop characteristics and planting practice - information on crop condition, for example, may also be used for irrigation management. In addition, data may be used to generate yield forecasts which in turn may be used to optimise the planning of storage, transport and processing facilities. Classification and seasonal monitoring of vegetation types on a global basis allows the modelling of primary production - the growth of vegetation that is the base of the food chain - which is of great value in monitoring global food security.

A number of radiometers provide measurements of vegetation cover, including AVHRR/3,MODIS, MERIS and the purpose-designed VEGETATION instrument. These instruments are helping production of global maps of surface vegetation for modelling of the exchange of trace gases, water and energy between vegetation and the atmosphere. Multi-directional and polarimetric instruments (such as MISR and POLDER) will provide more insights into corrections of land-surface images for atmospheric scattering and absorption and sun-sensor geometry, which will allow better calculation of vegetation properties.

Synthetic aperture radars (SARs) are used extensively to monitor deforestation and surface hydrological states and processes. The ability of SARs to penetrate cloud cover and dense plant canopies make them particularly valuable in rainforest and high-latitude boreal forest studies.

Instruments such as ASAR, SAR (RADARSAT), and PALSAR will provide data for applications in agriculture, forestry, land cover classification, hydrology and cartography amongst others.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SPOT series (HRV: 2)(HRVIR: 4) (VEGETATION: 4,5)(HRG, HRS: 5)
NOAA series (AVHRR/2: 12,14)(AVHRR/3: 15-N')
ERS-2 (AMI/SAR/Image, AMI/scatterometer, ATSR-2)
RADARSAT series (SAR: 1,2)
IRS-P4 (WiFS)
Terra (ASTER, MISR, MODIS)
SAC-C (HRTC,MMRS)
SAC-D (MOC)
NMP EO-1 (ALI, Hyperion)
BIRD (WAOSS-B)
METEOR-3M N1 (MSU-SM)
Envisat (AATSR, ASAR, ASAR [image mode], MERIS)
Aqua (MODIS)
METEOSAT series (SEVIRI: 8-11)
UK-DMC (DMC Imager)
RESOURCESAT-1 (AWiFS, LISS-III, LISS-IV)
CBERS series (CCD, WFI: 2,2B)(MUX, PAN, WFI-2: 3,4)
PARASOL (POLDER-P)
SICH-1M (MSU-EU)
TopSat (TOPSAT telescope)
ALOS (AVNIR-2, PALSAR)
KOMPSAT-2 (MSC)
TerraSAR-X (X-Band SAR)
METOP series (AVHRR/3: 1-3)
RISAT-1 (SAR)
NPP (VIIRS)
Elektro-L (MSU-GS)
RapidEye (MSI)
THEOS (MS [GISTDA])
SAOCOM 1 series (SAR: A,B)
SSR-1 (OBA)
Pleiades series (Pleiades HR: 1,2)
NPOESS series (VIIRS: 1-6)
planned/considered
Monitor-E (PSA, RDSA)
SICH-2 (MBEI)
TerraSAR-L (L-band SAR)
BISSAT (BISSAT)
BelKA (MSS)
RESOURCESAT-2 (AWiFS, LISS-III, LISS-IV)
HJ-1 series (HSI: A)(CCD: A,B)
FY-2 series (IVISSR: D,E)
COSMO-SkyMed (SAR 2000)
SAC series (HSS: F)(MOC: E)
ESA Future Missions (SPECTRA)
Hyperspectral Mission (CIA, HYC)
GCOM-C (GLI follow-on)
SAOCOM-2B series (SAR: 1,2)
SSR-2 (OBA, L-band SAR)

Land

Surface temperature (land)

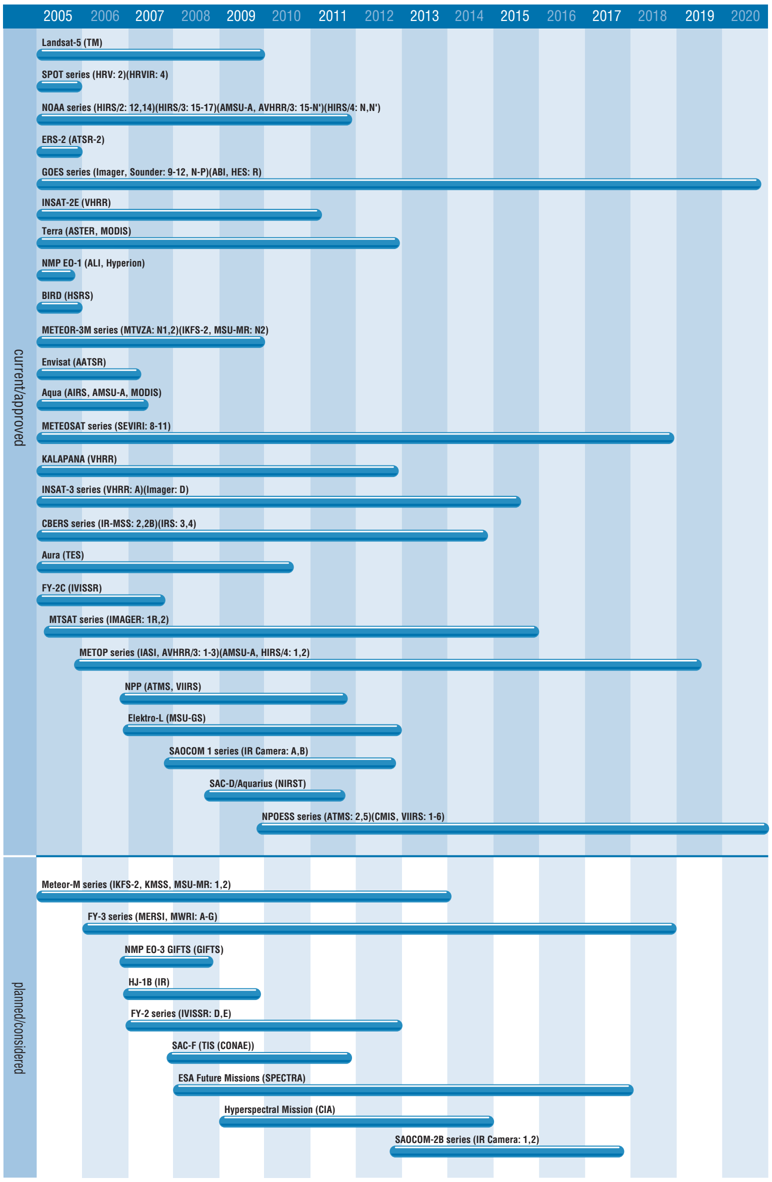
As one of the key parameters in the physics of land surface dynamics, land surface temperature (LST) is a good indicator of the energy balance at the Earth's surface. On a global scale, data on LST are used in conjunction with measurements of albedo as an input to climate change models, and to validate the surface physics elements of NWP models. On a local scale, surface temperature imagery may be used to refine techniques for predicting ground frost and to determine the warming effect of urban areas (urban heat islands) on night-time temperatures. In agriculture, temperature information may be used, together with models, to optimise planting times and to provide timely warnings of frost.

Measurements of surface temperature patterns may also be used in studies of volcanic and geothermal areas, and for forest fire detection and resource exploration.

Land surface temperature measurements are made using the thermal infra-red channel of medium/high resolution multi-spectral imagers in low Earth orbit. In addition, visible/infra-red imagers on geostationary satellites also provide useful information (with the advantage of very high temporal resolution). However, difficulties remain in converting the apparent temperatures as measured by these instruments into actual surface temperatures - variations due to atmospheric effects, and vegetation cover, for example, require compensation using additional imagery/information.

A number of capable sensors are currently operating or planned which will provide land surface temperature data including advanced sounders (IASI, HIRS/4) on operational meteorological platforms. On the NPOESS missions, VIIRS will combine the radiometric accuracy of AVHRR with the high spatial resolution of the DMSP's OLS instrument, and the CMIS imager/sounder will measure thermal microwave emissions from land surfaces.

The Hot Spot Recognition Sensors (HSRS) on BIRD (launched 2001) has already demonstrated its value as a purpose-built fire detection instrument.



Multi-purpose imagery (land)

The spatial information which can be derived from satellite imagery is of value in a wide range of applications - particularly when combined with spectral information from multiple bands of a sensor. Satellite Earth observation is of particular value where conventional data collection techniques are difficult, such as in areas of inaccessible terrain, and can provide cost and time savings in data acquisition - particularly over large areas.

At regional and global scales, low resolution instruments with wide coverage capability and imaging sensors on geostationary satellites are routinely exploited for their ability to provide global scale data on land cover and vegetation. Land cover change detection is an important source of global environmental change and has profound implications for ecosystems, biochemical fluxes and climate. Instruments on satellites with wide and frequent coverage provide data useful for spin-off applications. AVHRR on NOAA's polar orbiting satellite series was originally intended only as a meteorological satellite system, but has subsequently been used in a multitude of diverse applications.

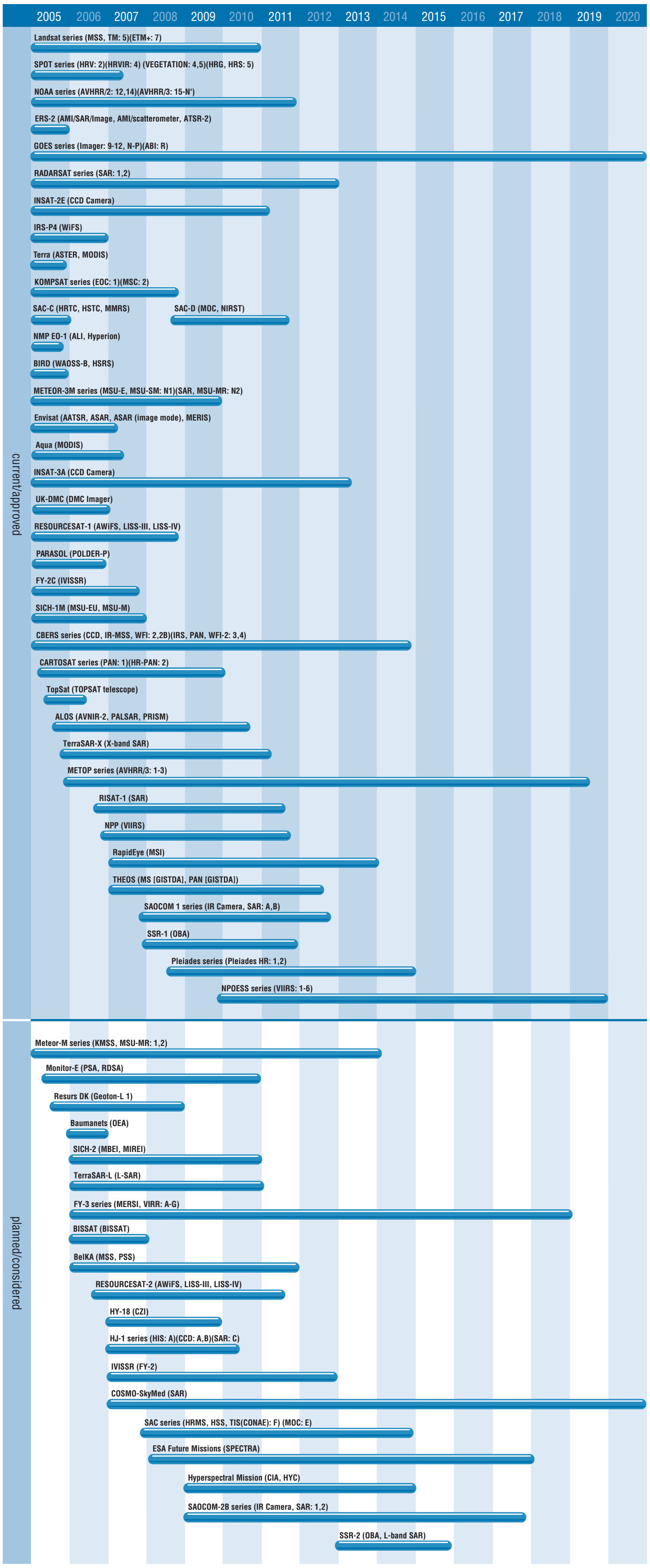
On national and local scales, the higher spatial resolution requirements for information mean that high resolution imaging sensors, such as on SPOT, Landsat, and IRS series, and imaging radars - such as on ERS, Envisat and RADARSAT, are most useful. Such sensors are routinely used as practical sources of information for:

- agriculture: monitoring, precision farming and production forecasting;
- resource exploration and management eg forestry;
- geological surveying: mineral exploration and identification;
- hydrological applications: such as flood monitoring;
- civil mapping and planning: cartography, infrastructure and urban management;
- coastal zone monitoring including oil spill detection and monitoring;
- topographic mapping, generation of DEMs.

SAR data are particularly useful in monitoring and mapping floods because they are available even in the presence of thick cloud cover. Instruments of RADARSAT, Envisat and (from 2005) ALOS, continue to provide improved capabilities in this field. Such multi-incidence, high resolution SAR systems will also be useful for landslide inventory maps and earthquake mitigation. Moreover InSAR techniques can be used to document deformation and topographic changes preceding, and caused by, volcanic eruptions. Volcanic features have distinctive thermal characteristics which can be detected by thermal imagery, such as that provided by the ASTER radiometer flying on Terra. The IGOS Geo-hazards Theme report is the definitive reference on the value of satellite Earth observation for such applications. Future SAR instruments will continue to be important for land imagery because of their all weather day and night observing capability and high spatial resolution (1-3 metres) such as will be provided by Radarsat-2, COSMO-SKYMED and TerraSAR-X.

Higher performance radiometers such as AVNIR-2 and PRISM on ALOS will enhance land observing technology and provide improved data products. In general, future sensors will benefit from a greater number of sampling channels. NOAA's VIIRS instrument for instance will have multi-channel imaging capabilities and will combine the radiometric accuracy of AVHRR with the high spatial resolution of the OLS flown on DMSP missions.

Land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INSAT-2E (CCD Camera)
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Terra (ASTER, MODIS)
KOMPSAT series (EOC: 1)(MSC: 2)
SAC-C (HRTC, HSTC, MMRS)
SAC-D (MOC, NIRST)
NMP EO-1 (ALI, Hyperion)
BIRD (WAOSS-B, HSRS)
METEOR-3M series (MSU-E, MSU-SM: N1)(SAR, MSU-MR: N2)
Envisat (AATSR, ASAR, ASAR (image mode), MERIS)
Aqua (MODIS)
INSAT-3A (CCD Camera)
UK-DMC (DMC Imager)
RESOURCESAT-1 (AWiFS, LISS-III, LISS-IV)
PARASOL (POLDER-P)
FY-2C (IVISSR)
SICH-1M (MSU-EU, MSU-M)
CBERS series (CCD, IR-MSS, WFI: 2,2B)(IRS, PAN, WFI-2: 3,4)
CARTOSAT series (PAN: 1)(HR-PAN: 2)
TopSat (TOPSAT telescope)
ALOS (AVNIR-2, PALSAR, PRISM)
TerraSAR-X (X-band SAR)
METOP series (AVHRR/3: 1-3)
RISAT-1 (SAR)
NPP (VIIRS)
RapidEye (MSI)
THEOS (MS [GISTDA], PAN [GISTDA])
SAOCOM 1 series (IR Camera, SAR: A,B)
SSR-1 (OBA)
Pleiades series (Pleiades HR: 1,2)
NPOESS series (VIIRS: 1-6)
planned/considered
Meteor-M series (KMSS, MSU-MR: 1,2)
Monitor-E (PSA, RDSA)
Resurs DK (Geoton-L 1)
Baumanets (OEA)
SICH-2 (MBEI, MIREI)
TerraSAR-L (L-SAR)
FY-3 series (MERSI, VIRR: A-G)
BISSAT (BISSAT)
BelKA (MSS, PSS)
RESOURCESAT-2 (AWiFS, LISS-III, LISS-IV)
HY-18 (CZI)
HJ-1 series (HIS: A)(CCD: A,B)(SAR: C)
IVISSR (FY-2)
COSMO-SkyMed (SAR)
SAC series (HRMS, HSS, TIS(CONAE): F) (MOC: E)
ESA Future Missions (SPECTRA)
Hyperspectral Mission (CIA, HYC)
SAOCOM-2B series (IR Camera, SAR: 1,2)
SSR-2 (OBA, L-band SAR)

Ocean

Ocean colour/biology

Remote sensing measurements of ocean colour (ie the detection of phytoplankton pigments) provide the only global-scale focus on the biology and productivity of the ocean's surface layer. Phytoplankton are microscopic plants that live in the ocean, and like terrestrial plants, they contain the pigment chlorophyll, which gives them their greenish colour. Different shades of ocean colour reveal the presence of differing concentrations of sediments, organic materials and phytoplankton. The ocean over regions with high concentrations of phytoplankton will appear as certain shades, from blue-green to green, depending on the type and density of the phytoplankton population there. From space, satellite sensors can distinguish even slight variations in colour, to which the human eye is not sensitive.

Ocean biology is important not only for understanding ocean productivity and biogeochemical cycling, but also because of its impact on oceanic CO_2 and the flux of carbon from the surface to the deep ocean. Over time, organic carbon settles in the deep ocean - a process referred to as the 'biological pump'. CO_2 system measurements, integrated with routine ocean colour and ecological/biogeochemical observations, are critical for understanding of the interactions between oceanic physics, biology, chemistry and climate. CO_2 measurements are also important for making climate forecasts, and for satisfying the needs of climate conventions.

At a local scale, satellite observations of ocean colour, usually in conjunction with sea surface temperature measurements, may be used as an indication of the presence of fish stocks. Measurements may also be used to monitor water quality and to give an indication of the presence of pollution by identifying algal blooms.

Measurements of ocean colour are particularly important in coastal regions where they can be used to identify features indicative of coastal erosion and sediment transfer.

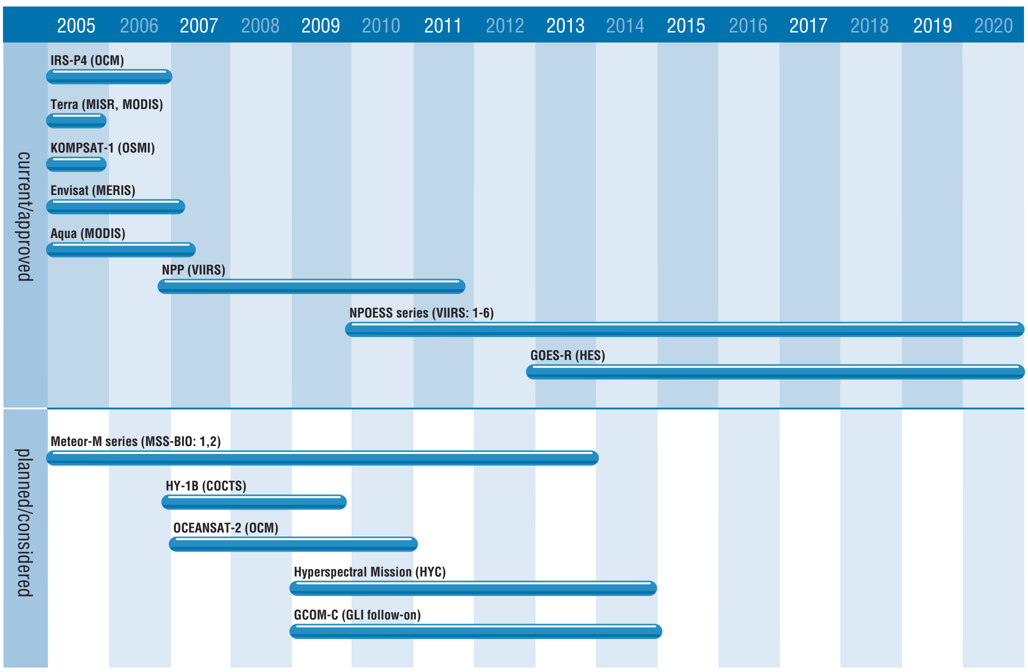
IGOS set up an Ocean Theme in 1999 to develop a strategy for an observing system serving research and operational oceanographic communities and other users. Building on the CEOS Ocean Biology and GODAE Projects, the Ocean Theme Team published its final report in January 2001 - available from www.igospartners.org. This brought together information on:

- the variety of needs for global ocean observations;
- the existing and planned observing systems;
- the planning commitments required to ensure long-term continuity of the observations.

Ocean colour measurements from space are the focus of the International Ocean Colour Coordinating Group (http://www.ioccg.org/).

In recent years there has been a steady flow of ocean colour data from instruments such as OCTS, SeaWiFs, OCM, MODIS, and MERIS. As the timeline shows, a number of current missions will end in the near future. Information available on agency plans indicate that future continuity may be provided by Oceansat-2 (India), HY-1C (China) and others.

Beyond these research missions, NOAA is developing VIIRS for its NPOESS missions. A visible/infrared sensor, VIIRS will have an operational capability for ocean colour observations and a variety of derived ocean colour products. The NPOESS preparatory programme will deploy prototypes of VIIRS in the 2006-2007 time frame.



Ocean

Ocean topography/currents

Ocean surface topography data contains information that has significant practical applications in such fields as the study of worldwide weather and climate patterns, the monitoring of shoreline evolution, and the protection of ocean fisheries. Ocean circulation is of critical importance to the Earth's climate system. Ocean currents transport a significant amount of energy from the tropics towards the poles leading to a moderation of the climate at high latitudes. Thus knowledge of ocean circulation is central to understanding the global climate. Circulation can be deduced from ocean surface topography, which may be readily measured using satellite altimetry. However, altimeters will only provide the geostrophic part of ocean currents unless the geoid is known more accurately, in which case it is then possible to measure large scale permanent ocean currents.

Using satellite altimetry, large scale changes in ocean topography, such as those in the tropical Pacific, may be observed. During an El Niño event, the westward trade winds weaken and warm, nutrient-poor water occupies the entire tropical Pacific Ocean. During the following La Niña the trade winds are stronger and cold, and nutrient-rich water occupies much of the tropical Pacific Ocean.

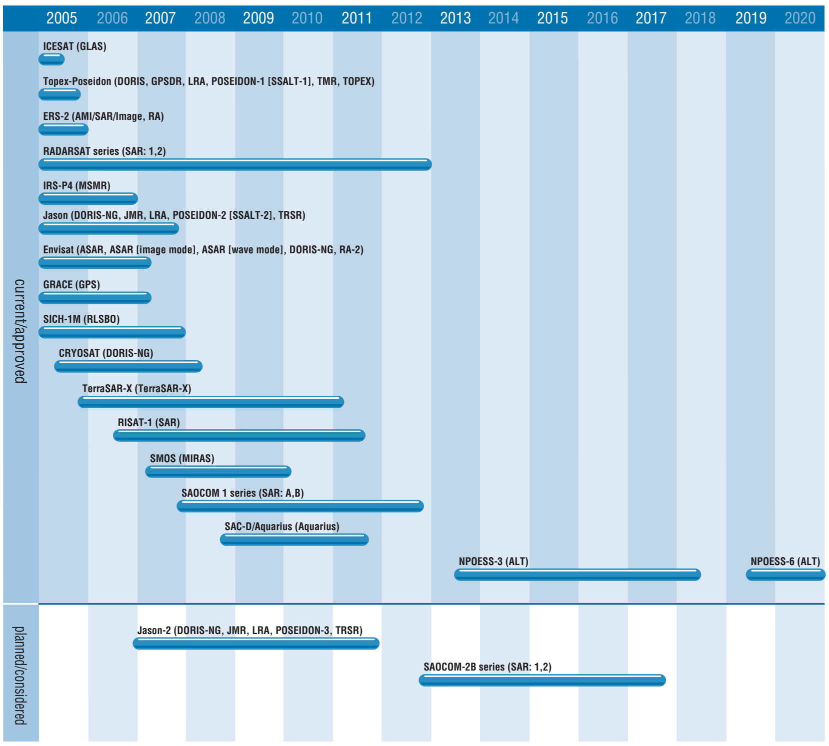
On a local scale, topographic information from satellites may be used in support of off-shore exploration for resources, oil spill detection and for optimising pipeline routing on the sea floor.

The TOPEX/POSEIDON and ERS missions have demonstrated that satellite altimetry may be utilised in a wide range of ocean research such as planetary waves, tides, global sea level change, seasonal-to-interannual climate prediction, defence, environmental prediction and commercial applications. TOPEX/POSEIDON can measure the height of ocean surface directly under the satellite with an accuracy of 4-5cms. The Jason-1 mission, launched in late 2001, is a follow-on to TOPEX/POSEIDON and aims to:

- provide a 5-year view of global ocean topography;
- increase understanding of ocean circulation and seasonal changes;
- improve forecasting of climate events like El Niño;
- measure global sea-level change;
- improve open ocean tide models;
- provide estimates of significant wave height and wind speeds over the ocean.

Information on ocean circulation may also be obtained indirectly from features such as current and frontal boundaries in SAR imagery, and by using differences in ocean temperature or ocean colour as observed by visible and infrared imagers.

In their Final Report, in early 2001, the IGOS Ocean Theme Team identified a long-term need for continuity of a high-precision mission (eg the JASON series) and a polar-orbiting altimeter (eg the ERS and Envisat series) to enhance temporal/spatial coverage of the global ocean. Planning of Jason-2 and of an altimeter on selected satellites of the NPOESS series will contribute to this objective.



Ocean surface winds

High resolution vector wind measurements at the sea surface are required in models of the atmosphere, ocean surface waves, and ocean circulation. They are proving useful in enhancing marine weather forecasting through assimilation into NWP models and in improving understanding of the large-scale air-sea fluxes which are vital for climate prediction purposes. Accurate wind vector data affect a broad range of marine operations, including offshore oil operations, ship movement and routing. Such data also aid short-term weather forecasting and the issue of timely weather warnings.

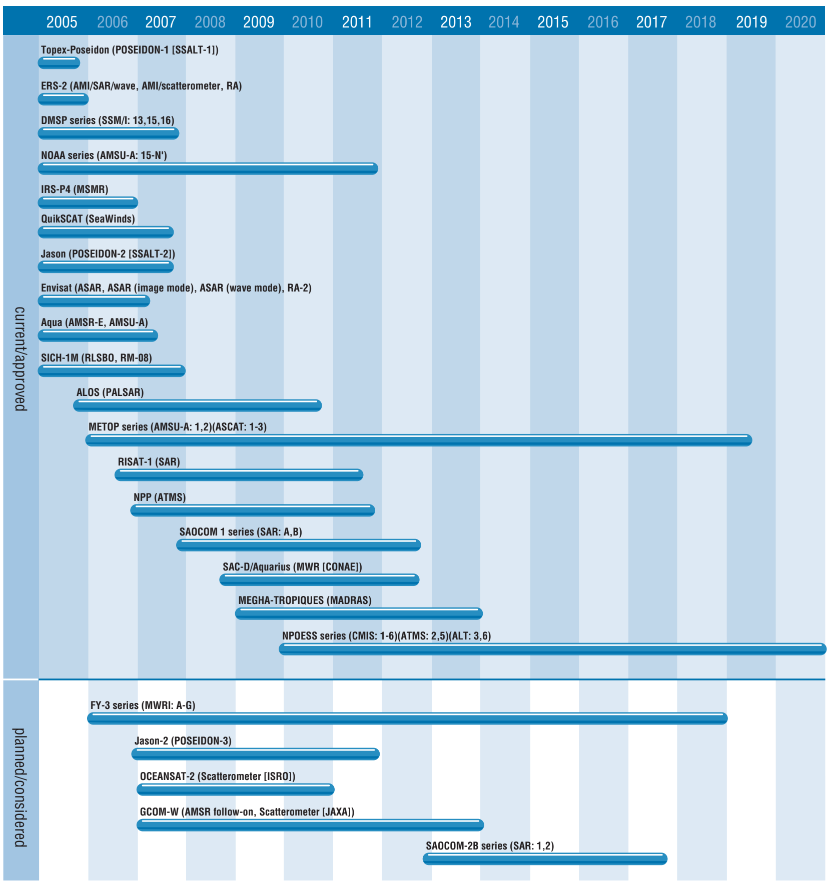
Polar orbiting satellites provide information on surface wind with global coverage, good horizontal resolution and acceptable accuracy, though temporal frequency is marginal for regional mesoscale forecasts. They provide useful information in two ways:

- scatterometers provide dense observations of wind direction and speed along a narrow swath, although the most recent and planned scatterometers provide better coverage via broader swaths (90% global coverage daily); scatterometers have made a positive impact in predicting marine forecasting, operational global NWP and climate forecasting;
- passive microwave imagers provide information on wind speed only.

The single swath scatterometer on ERS-2 and the broad swath scatterometer on QuickSCAT currently provide adequate coverage. QuickSCAT, launched in 1999, carries the SeaWinds scatterometer that measures near surface wind speed and direction in all weather and cloud conditions. Global coverage by a broad swath scatterometer will be provided by ASCAT on the METOP missions. Developed by ESA as a follow-on from the 'wind mode' of the AMI on the ERS series, ASCAT will be used primarily for global measurement of sea surface wind vectors and will be able to provide quasi-global coverage within 24 hours. AMSR-E on Aqua also provides data on sea surface wind speed.

The operational NPOESS missions, will use the CMIS instrument, which employs a passive microwave approach for collecting data on sea surface winds.

In recent years, the ability to detect and track severe storms has been dramatically enhanced by the advent of weather satellites. Data from SeaWinds is augmenting traditional satellite images of clouds by providing direct measurements of surface winds enabling better determination of a storm's location, direction, structure and strength.



Ocean

Surface temperature (ocean)

Ocean surface temperature (often known as 'sea surface temperature', SST) is one of the most important boundary conditions for the general circulation of the atmosphere. The ocean exchanges vast amounts of heat and energy with the atmosphere and these air/sea interactions have a profound influence on the Earth's weather and climate patterns. SST is also very sensitive to changes in ocean circulation, as demonstrated time and again by the El Niño-Southern Oscillation (ENSO) cycle. A major research goal is the development of an increased understanding of the links between SST and all the above processes. This will only be achieved through a more precise and comprehensive set of SST measurements.

Satellite remote sensing provides the only practical means of developing such a dataset. In-situ data, predominantly from ships of opportunity and from networks of moored and drifting buoys are limited in coverage whereas satellites offer the potential for surveying the complete ocean surface in just a few days. The in-situ data have a key role to play in calibrating the satellite data and in providing information needed for deriving bulk temperatures.

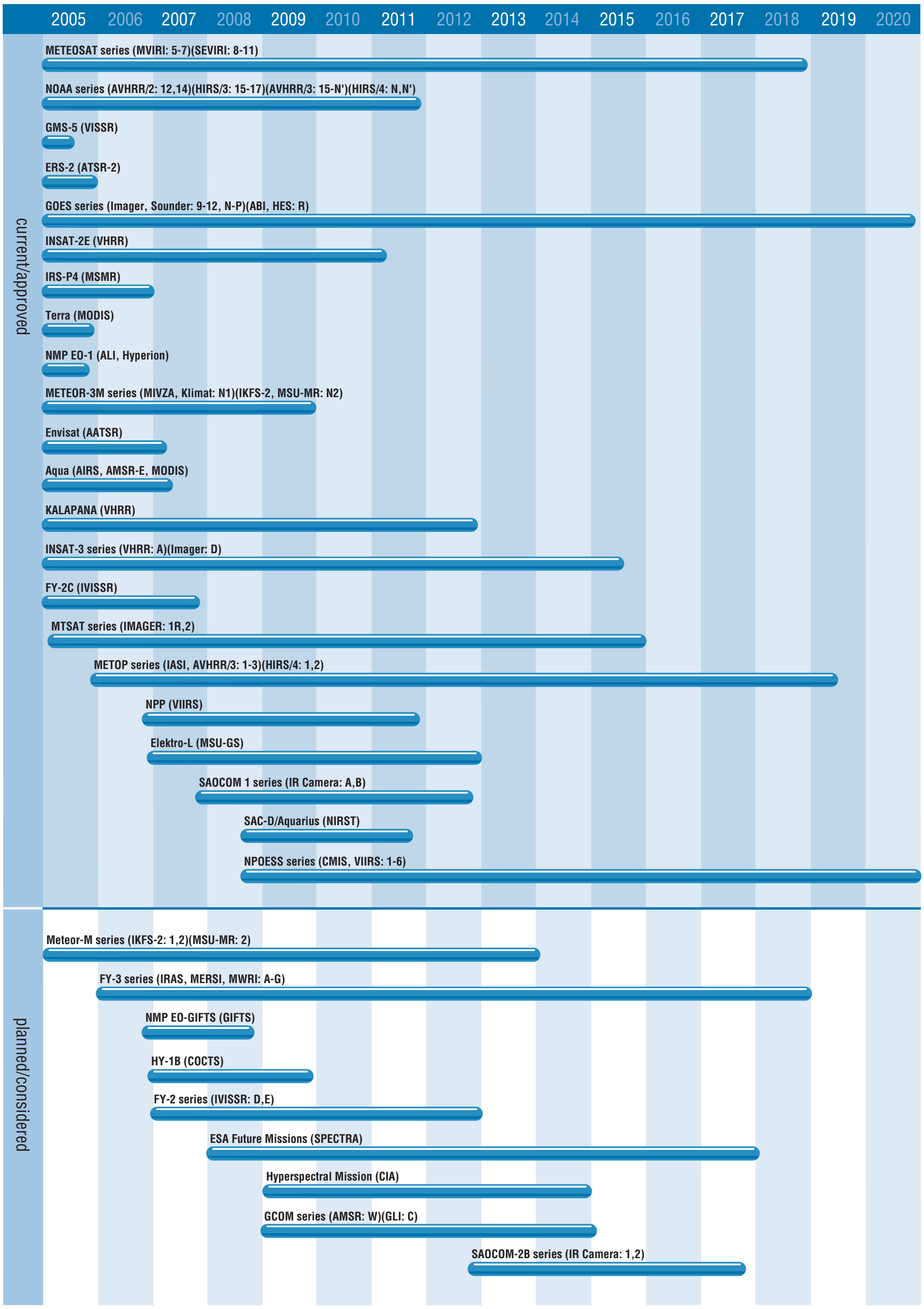
Instruments on polar satellites provide information with global coverage, good horizontal and temporal resolution and accuracy for short to medium-range NWP, except in areas that are persistently cloud-covered. Accurate SST determinations, especially in the tropics, are important for seasonal to inter-annual forecasts. The advent of high spectral resolution infrared sounders will enable separation of surface emissivity and temperature, and the accuracy of the SST product is expected to improve into the acceptable range.

Geostationary imagers with split window measurements are also helping to expand the temporal coverage by making measurements hourly and thus creating more opportunities for finding cloud-free areas and characterising any diurnal variations (known to be up to 4K in cloud-free regions with relatively calm seas). For regional NWP, skin sea-surface temperature is inferred with acceptable horizontal resolution from polar satellites, while geostationary satellites complement information with better temporal resolution.

A range of instruments with thermal bands are being used for SST measurements. Visible/infrared imagers such as AVHRR, AATSR, and MODIS currently provide the main source of SST data, with AATSR and MODIS providing better accuracy (0.25–0.3K) – but AVHRR giving greater coverage, enabling it to track ocean currents, and to monitor ENSO phenomena through its larger swath width. The Aqua mission, which includes MODIS along with AIRS+ and AMSR provides oceanographers with further precise information and the ability to remove atmospheric effects. NOAA's VIIRS and CMIS instruments on the planned NPOESS missions will provide capabilities to produce higher resolution and more accurate measurements of SST than currently available from AVHRR. Future sources of SST data include: AMSR-E on Aqua; the SEVIRI and IASI instruments on the METEOSAT-8/MSG and METOP missions respectively.

Reviewing supply of SST observations, the IGOS Ocean Theme Team was reassured about continuity of SST data from operational meteorological satellites, but noted that continuity beyond the Envisat mission for the AATSR class of instrument was not assured and urged consideration of how AATSR-class instruments could be introduced into operational systems.

Surface temperature (ocean)



Ocean

Wave height and spectrum

The state of the sea and surface pressure are two features of the weather that are important to commercial use of the sea (eg ship routing, warnings of hazards to shipping, marine construction, off-shore drilling installations and fisheries). Information on surge height at the coast is key to the protection of life and property in coastal habitats.

Measurements of wave height and spectrum are also used by oceanographers to investigate large-scale ocean features such as fronts and eddies and to construct and verify models of these phenomena. The processes behind these phenomena are complex and detailed measurements are vital to improving understanding. These data are also important for climate purposes as they are needed for the correct representation of turbulent air-sea fluxes.

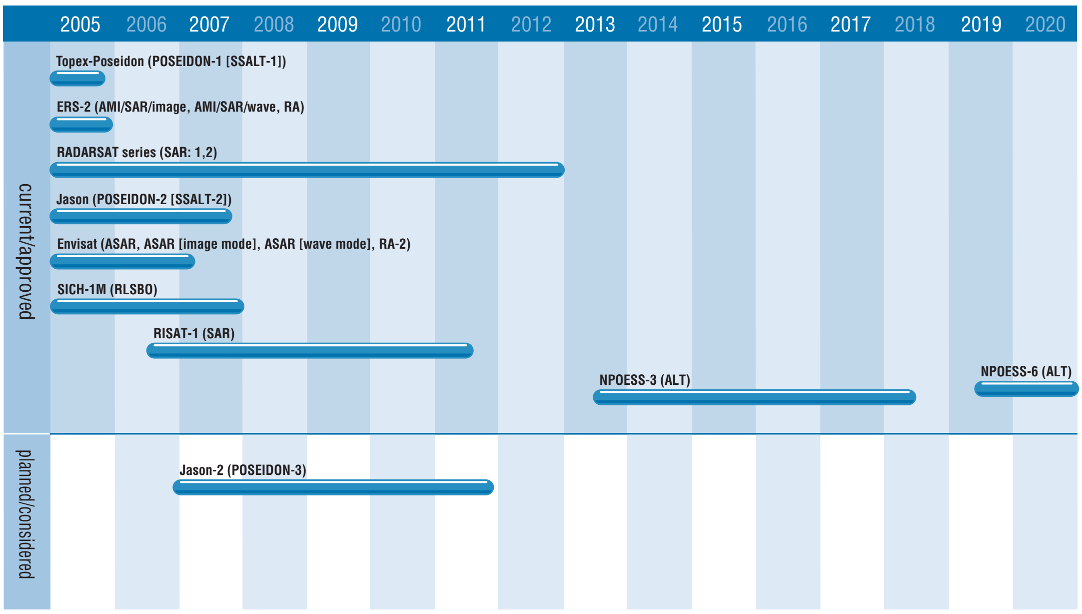
Wave height is influenced by wind speed and direction over water. In the nowcasting context, ocean wave models are driven by NWP predictions of surface wind. However, errors in waves generated at large distances can accumulate. Improvements in forecasts, especially of long wavelength swell, can be achieved by assimilating observations from different sources. These are currently available from isolated buoys and from satellite altimeter and scatterometer data. In the absence of direct observations, initial wave state is deduced from the wind history. This is currently available over the sea from isolated buoys and from low-Earth-orbiting satellite scatterometer and microwave instruments.

For global NWP, ships and buoys provide observations of acceptable frequency and acceptable to marginal accuracy, but coverage is marginal or absent over large areas of the ocean. Altimeters on polar satellites provide information on significant wave height with global coverage and good accuracy, but horizontal/temporal coverage is marginal. Information on the 2D wave spectrum is provided by SAR instruments with good accuracy, but marginal horizontal/temporal resolution.

SAR instruments can accurately measure changes in ocean waves and winds, including wavelength and the direction of wave fronts, regardless of cloud, fog or darkness. The AMI SAR on ERS-2 has been operating in both wave and image mode, and the ASAR on Envisat continues to provide the ERS wave mode products, but with improved quality. PALSAR on JAXA's ALOS mission will provide data on sea surface wind and wave spectrum required for oil spill analysis and for studies of coastal topography-air-sea interaction. The ScanSAR wave data supplied by RADARSAT will continue to be provided by RADARSAT 2.

Information from radar altimeters is limited to data on significant wave height. The altimeter on the Jason 1 mission, for example, provides such information.

In their January 2001 Report, the IGOS Ocean Theme Team recognised that SAR instruments currently provide information about the properties of the sea surface and the wave spectrum. Nevertheless the Team noted limitations to its use operationally and called for further development of these capabilities.



Multi-purpose imagery (ocean)

In addition to the specific ocean measurement observations discussed in previous sections, a number of sensors are capable of providing a range of ocean imagery from which useful secondary applications can be derived.

High resolution radiometers such as AVHRR, AATSR, and VIIRS have multi-channel imaging capabilities to support the acquisition and generation of a variety of applied products including visible and infrared imaging of hurricanes. They provide observations of large scale ocean features, using variations in water colour and temperature to derive information about large scale circulation, currents, river outflow and water quality. Such observations are relevant to activities such as ship routing, coastal zone monitoring, toxic algal bloom detection, management of fishing fleets and sea pollution monitoring.

High to medium resolution imaging sensors such as MERIS are better suited to observations of coastal zone areas and can provide information on sedimentation, bathymetry, erosion phenomena and aquaculture activity.

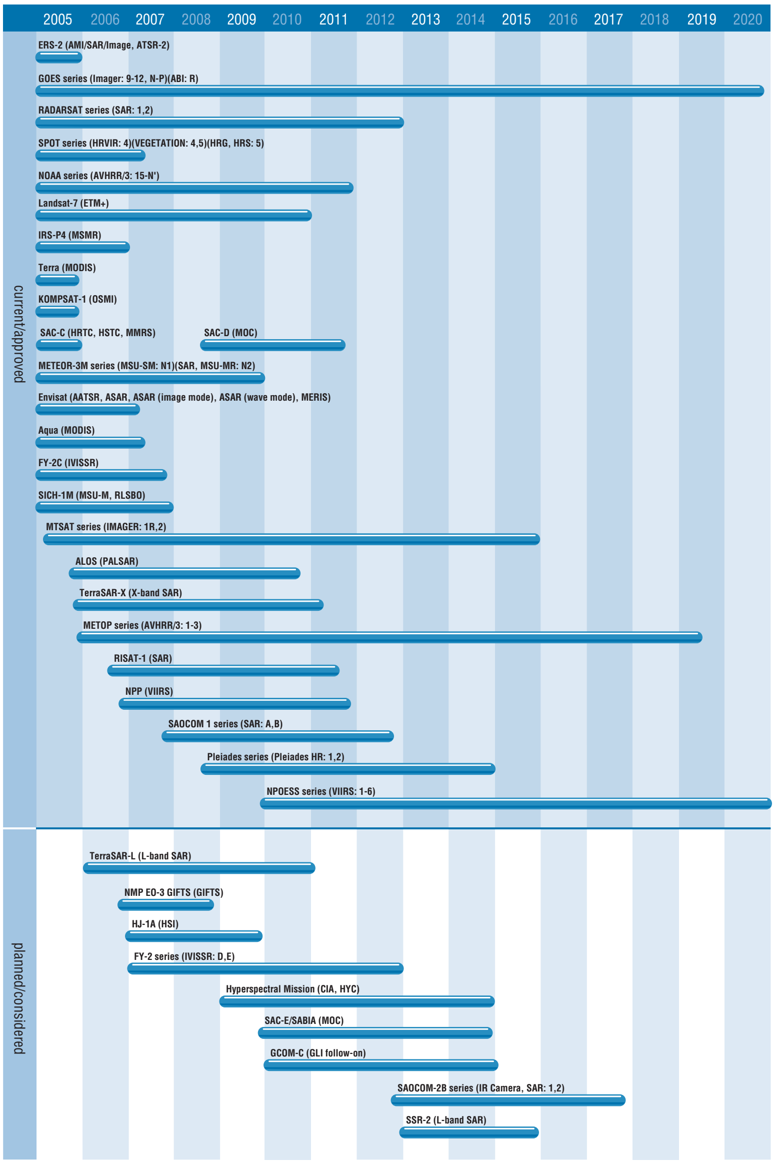
In addition, SAR instruments such as RADARSAT, ASAR and (from 2005) PALSAR provide a valuable all-weather, day and night source of information on oceanographic features including fronts, eddies and internal waves. SAR imagery is also useful for:

– pollution monitoring - notably oil spill detection;

– ship detection - useful to rescue services, port authorities, custom and immigration services;

– coastal change detection - topography mapping;

– bottom topography mapping, valuable for resource exploration and pipeline routing.



Snow and ice

Ice sheet topography

The state of the polar ice sheets and their volumes are both indicators and causes of climate change. Consequently it is important to monitor and study them in order to investigate the impact of global warming and to forecast future trends. The IPCC expects that ice sheets will continue to react to climate warming and contribute to sea level rise for thousands of years after climate has been stabilised. They note that:

- climate models indicate that the local warming over Greenland is likely to be one to three times the global average;
- ice dynamic models suggest that melting of the West Antarctic ice sheet could contribute up to 3 metres of sea level rise over the next 1000 years, but such results are strongly dependent on model assumptions regarding climate change scenarios, ice dynamics and other factors.

Satellite remote sensing allows observations of the changes in the shape of ice sheets, and identification of the shape and size of large icebergs that have detached from the ice sheet.

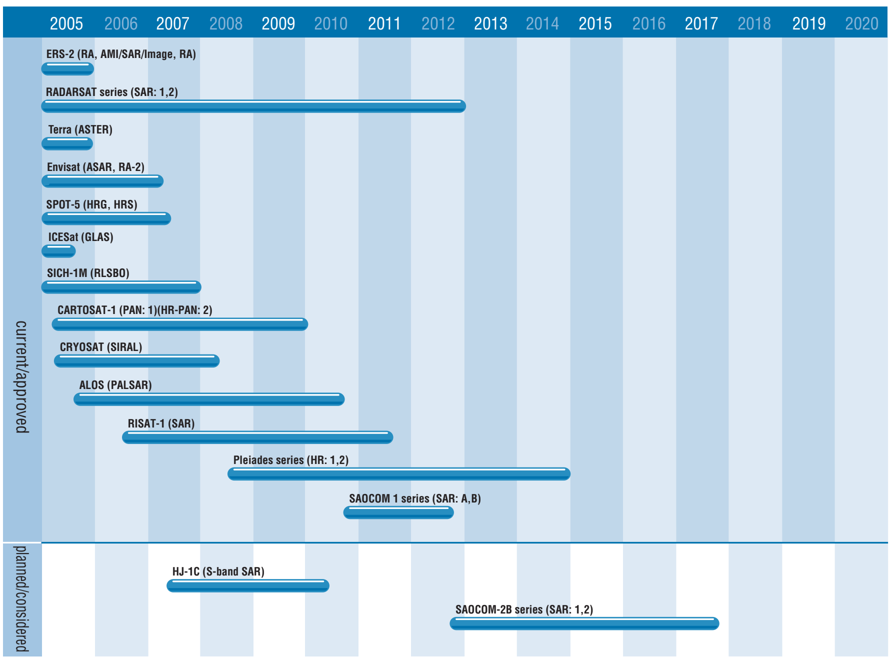
SAR instruments are one source of data on the polar ice sheets. RADARSAT provides routine surveillance of polar regions, and has created the first high resolution radar images of Antarctica - enabling detection of changes in the polar ice sheet and improved understanding of the behaviour of the Antarctic glacier. The AMI instrument on ESA's ERS 2 mission has been collecting data on the polar ice to assist derivation of indicators of climate change, and ASAR on the Envisat mission will continue to provide data on polar ice topography.

Analysis of interferometric measurements by PALSAR, together with observations by the AVNIR-2 instrument on JAXA's ALOS mission, will contribute to understanding the ice sheet mass balance and glacier variation in the South Pole and in Greenland.

Altimeters provide useful data on ice sheet topography. While many have high vertical resolution, their limited horizontal resolution means that their observations over smoother, near-horizontal portions of ice sheets are of greatest value. The RA-2 instrument on Envisat is providing improved mapping of icecaps.

Given the significance of information on changes in the continental ice sheets, two missions dedicated to their study have been developed: NASA's ICESat (launched Jan 2003) and ESA's Cryosat (from Mar 2005). ICESat is already providing measurements of revolutionary accuracy and detail about the elevation of ice sheets and the elevation structure of land surfaces. CryoSat will provide an instrument for the ice sheet interiors, the ice sheet margins, for sea ice and other topography, with three-mode operation:

- conventional pulse-limited operation for the ice sheet interiors (and oceans if desired);
- synthetic aperture operation for sea ice;
- dual-channel synthetic aperture/interferometric operation for ice sheet margins.



Snow cover, edge and depth

Regular measurements of terrestrial snow are important because snow dramatically influences surface albedo, thereby making a significant impact on the global climate; as well as influencing hydrological properties and the regulation of ecosystem biological activity. In its Third Assessment Report, 'Climate Change 2001', the IPCC found that - on the evidence of satellite data - there was likely to have been a decrease of about 10% in the extent of snow cover since the late 1960's.

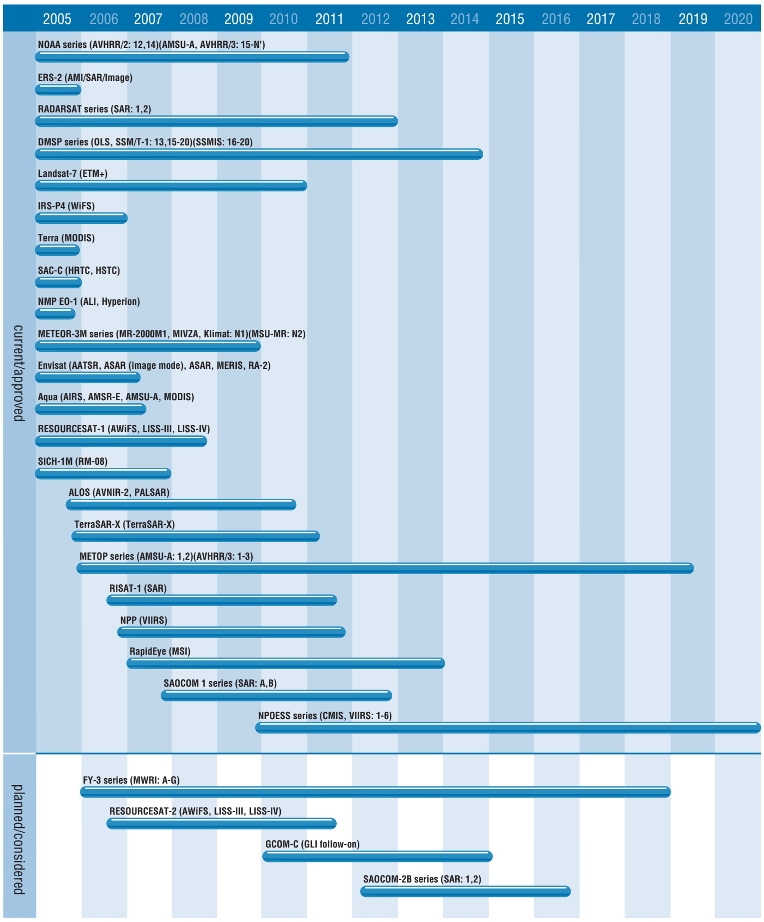
Snow forms a vital component of the water cycle. In order to make efficient use of meltwater run-off, resource agencies must be able to make early predictions of the amount of water stored in the form of snow. Coverage area, snow water equivalent, and snowpack wetness are the key parameters to be determined in this process.

Snow cover information has a range of additional applications such as in agriculture for detecting areas of winterkill, resulting from lack of snow cover to insulate plants from freezing temperatures. Locally, monitoring of snow parameters is important for meteorology, and for enabling warnings of when melting is about to occur - which is crucial for hydrological research and for forecasting the risk of flooding.

A range of different instrument types can contribute to measurements of snow. Visible/near-infrared satellite imagery provides information of good horizontal and temporal resolution and accuracy on snow cover in the day-time in cloud-free areas. AVHRR provides snow cover information and this will be continued in the future by VIIRS. MODIS data are being used to monitor the dynamics of large area (greater than 10km^2) snow and ice cover and, on a weekly basis, to report the maximum area covered by both. The resulting snow maps should be available within 48 hours of MODIS data collection.

Passive microwave instruments such as SSM/I, AMSR, and CMIS will have all-weather and day/night monitoring capability and will be able to estimate the thickness of dry snow up to about 80cm deep.

Data from RADARSAT and ERS-2 have shown the usefulness of SAR remote sensing techniques to determine snow area extent and to monitor the physical conditions of snow. RADARSAT 2, Envisat, and ALOS will provide continuity of such snow information.



Snow and ice

Sea ice cover, edge and thickness

Sea ice modulates planetary heat transport by insulating the ocean from the cold polar atmosphere and by modulating the thermohaline circulation of the world ocean through processes in deep-water. Moreover, the high albedo of ice insulates the polar oceans from solar radiation. Time series of sea-ice concentration data are also critical for identifying inter-annual and decadal fluctuations that could point to the existence of significant changes in oceanic and atmospheric circulation at high latitudes. The motion of sea ice creates patterns of ice convergence and divergence that play a critical role in determining energy and momentum fluxes between the ocean and atmosphere at high latitudes.

Near real-time delivery of data tracking the continually changing nature of ice field conditions provides operational sea ice charts for use by:

– shipping to avoid damage, delay and to reduce fuel costs;

– offshore drilling companies;

– maritime insurance companies;

– government environmental regulatory bodies.

Ice cover and type may be determined using visible/infra-red sensors which are currently available (AVHRR, AATSR etc). Observations provided by microwave instruments on polar satellites also offer good horizontal and temporal resolution and acceptable accuracy. The data now produced are being used to generate wide-area sea ice motion and deformation products for the north polar region and similar products are being planned for the south polar region. Systematic global observation of sea-ice extent and concentration, inferred from passive imaging microwave radiometry, has already produced a 20-year record of global sea ice concentration.

Improved microwave imagery from multi-spectral radiometers such as AMSR (on Terra) provide all weather operation coupled with good coverage.

High resolution synthetic aperture radars such as on Envisat and RADARSAT offer the best source of data, and again have the important advantage of all-weather day/night operation. Data from these instruments provides information on the nature, extent and drift of ice cover and is used not only for status reports, but also for ice forecasting and as an input for meteorological and ice drift models. JAXA's PALSAR radar will contribute to methodological development of extensive sea ice monitoring and, using polarimetric data, will improve the accuracy of sea ice classification.

Low resolution scatterometer observations are also used to retrieve information on sea ice extent and concentration in all weather conditions, during day or night.

Current radar altimeters provide some information on ice thickness, but more accurate measurements have been provided since the launch of ICESat in 2003 (and are expected from Cryosat from March 2005).

In its January 2001 Report, the IGOS Ocean Team stated that:

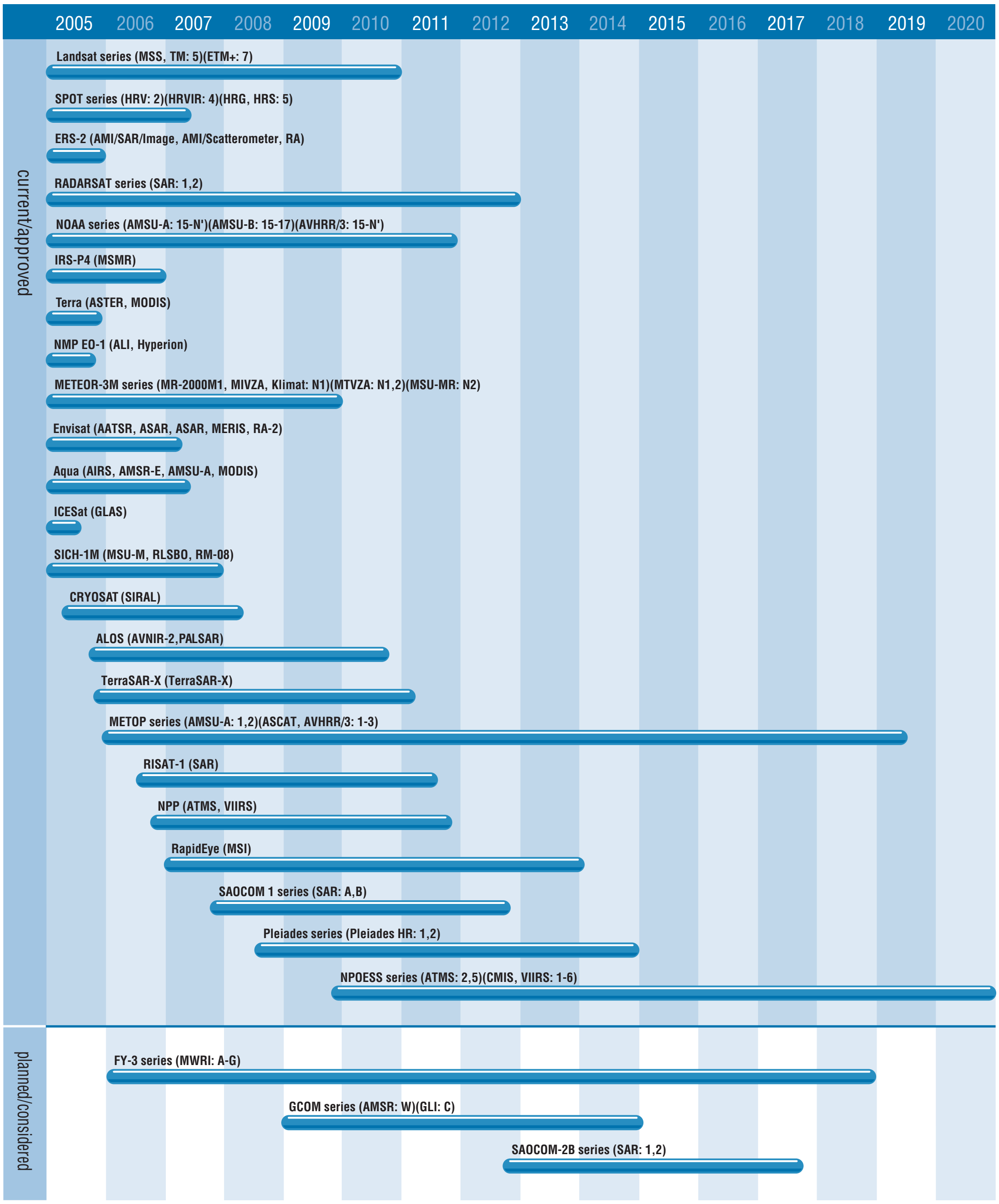
– ERS/Envisat offer an Arctic coverage service since 1991;

– RADARSAT has provided SAR coverage of the majority of the Arctic every few days since 1996;

– JAXA's AMSR-E radiometer on Aqua and operational sensors such as the DMSP SSM/I and NOAA CMIS on NPOESS missions will ensure continuity of the global sea ice concentration in the near term;

– continuation of RADARSAT/Envisat class radar-equipped missions is important in providing complementary high resolution data to further elucidate sea ice processes.

Sea ice cover, edge and thickness



Gravity and magnetic fields

Gravity, magnetic, and geodynamic measurements

Not all near-Earth measurements undertaken by satellite observations are discussed in this document, since the focus here is on land, sea, and air parameters; but many more are observed on a routine basis, including measurements of the space environment and solar activity, amongst others. Of particular note are measurements of the Earth's gravity field, magnetic field, and geodynamic activity.

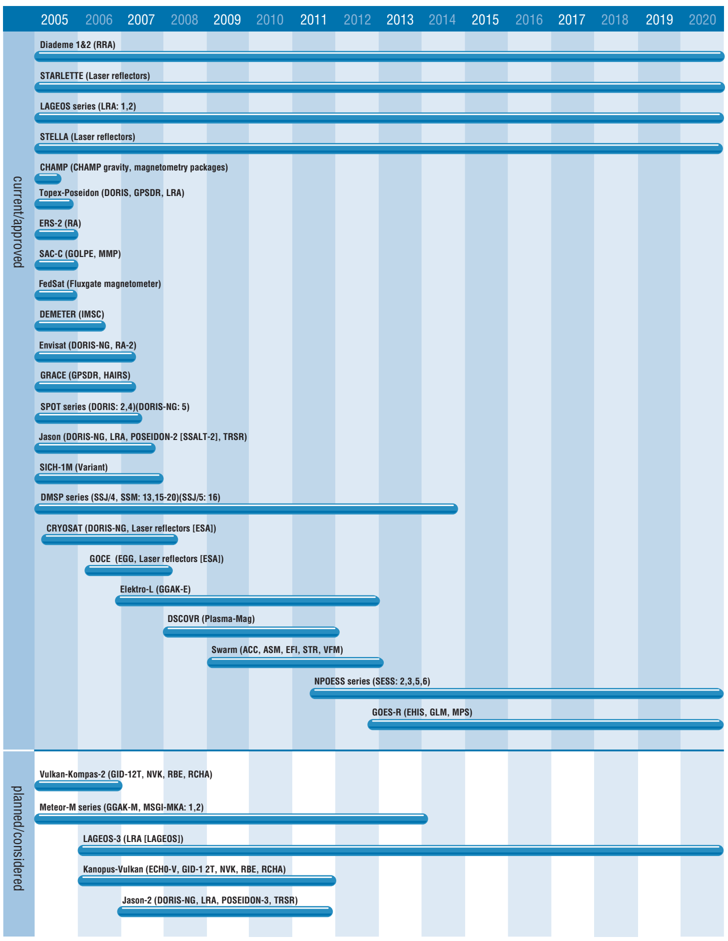
Gravity field measurements from space provide the most promising advances for improved measurement of the 'geoid' and its time variations. The geoid is the surface of equal gravitational potential at mean sea level, and reflects the irregularities in the Earth's gravity field at the Earth's surface due to the inhomogeneous mass and density distribution in the Earth's interior. Such measurements are vital for quantitative determination, in combination with satellite altimetry, of absolute ocean currents, improving global height references, estimates of the thickness of the polar ice sheets and its variations and estimates of the mass/volume redistribution of freshwater in order to further understand the hydrological cycle.

Gravity field measurement packages on satellites often utilise combinations of different instrument types in order to derive the necessary information: single or multiple accelerometers; precise satellite orbit determination systems; and satellite to satellite tracking systems.

DLR's CHAMP gravity package has been providing new information on the Earth's gravity field since 2000. Two new missions, one launched by NASA in 2002 (the twin satellite GRACE) and one planned by ESA (GOCE, in 2006), will provide new and unique models of the Earth's gravity field and its variability over time, allowing determination of the geoid to 1cm accuracy.

A number of Earth missions, including Australia's Fedsat launched in 2002, have carried sensors to study the electromagnetic environment of spacecraft. Satellite-borne magnetometers provide information on strength and direction of the internal and external Earth's magnetic field and its time variations The CHAMP mission makes such measurements - which are of value in a range of applications, including navigation systems, resource exploration drilling, spacecraft attitude control systems, and assessments of the impact of 'space weather'.

Further missions are underway or planned for more in-depth, dedicated studies of magnetic field - including: DEMETER (launched June 2004) which is investigating links between earthquakes and magnetic field variations; and SWARM (from 2009) which aims to provide the best ever survey of the geomagnetic field and its temporal evolution, and gain new insights into improving our knowledge of the Earth's interior and climate.



8 Catalogue of satellite missions

8.1 Introduction

This section gives details of the satellite missions of CEOS members and of the CEOS/WMO database from which much of the data in this handbook is derived.

Nearly all information contained in this catalogue has been gathered from and verified by CEOS agencies but it should be noted that the launch date and duration of some planned missions is uncertain (eg due to changes in funding or policy, changes in requirements, etc) hence, the accuracy of timelines relating to these missions cannot be guaranteed. If the month of the launch of a planned mission has not been specified the timeline is shown to commence at the beginning of the planned year of launch. It should also be noted that missions currently operating beyond their planned life are shown as operational until the end of 2005 unless an alternative date has been proposed.

The catalogue of CEOS agency EO satellite missions is arranged both chronologically by launch date and alphabetically by mission name. For each of the missions, the following information is supplied:

Mission name and agency	Mission acronym Full mission name Agency acronym
Status	Current: at least the prototype has been launched, and financing is approved for the whole series Approved: financing is available for the whole series, the prototype is fully defined, the development is in phase C/D Planned: financing is available up to the end of phase B, financing of the full series is being considered Considered: conceptual studies and phase A have been completed, financing of phase B is in preparation
Key dates	Launch date Estimated end of life date
Primary applications	Of those measurements discussed in section 7
Instructions	A list of instruments on board the mission from the catalogue in section 9
Orbit details	Type of orbit Altitude Period Inclination Repeat cycle LST: Local Solar Time – the time of satellite equator overpass Longitude (for geostationary orbits) Ascending/descending: whether the satellite crosses the equator in a northbound (ascending) or southbound (descending) direction
URL	For further information via internet

8.2 Recent events

Five missions were launched by CEOS agencies during 2004:

Mission	Agency	Launch date
DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions)	CNES	29 June 2004
Aura (formerly EOS Chemistry)	NASA	15 July 2004
FY-2C Geostationary Meteorological Satellite	NRSCC	19 October 2004
PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a LIDAR)	CNES	18 December 2004
SICH-1M	NSAU/ ROSKOSMOS	24 December 2004

STOP PRESS: The NASA/JAXA Tropical Rainfall Measuring Mission (TRMM) was removed from the Handbook tables due to plans for its completion in late 2004. It has just been announced that the mission will continue until May 2005.

No fewer than 23 missions are planned for launch before the end of 2005:

Mission	Agency	Launch
Meteor-M No1	ROSHYDROMET/ ROSKOSMOS	Jan 2005
Vulkan-Kompas-2	ROSKOSMOS	Jan 2005
MTSAT-1R (Multi-functional Transport Satellite)	JMA	Feb 2005
CARTOSAT-1 (Indian Remote Sensing Satellite – P5)	ISRO	Mar 2005
CRYOSAT (CryoSat (Earth Explorer Opportunity Mission))	ESA	Mar 2005
NOAA-N (National Oceanic and Atmospheric Administration – N)	NOAA	Mar 2005
GOES-N (Geostationary Operational Environmental Satellite – N)	NOAA	Apr 2005
Monitor-E	ROSKOSMOS	Apr 2005
CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations)	NASA / CNES	Apr 2005
CloudSat	NASA	Apr 2005
DMSP F-17 (Defense Meteorological Satellite Program F-17)	NASA	Apr 2005
TopSat (Optical Imaging Satellite)	BNSC	May 2005
METEOSAT-9 (Meteosat Second Generation-2)	EUMETSAT	Jun 2005
Resurs DK	ROSKOSMOS	Jun 2005
ALOS (Advanced Land Observing Satellite)	JAXA	Sep 2005
KOMPSAT-2 (Korea Multi-Purpose Satellite 2)	KARI	Oct 2005
TerraSAR-X	DLR	Oct 2005
METEOR-3M N2	ROSHYDROMET/ ROSKOSMOS	Dec 2005
METOP-1 (Meteorological Operational Polar Satellite – 1)	EUMETSAT	Dec 2005
Baumanets	ROSKOSMOS	Dec 2005
CARTOSAT-2	ISRO	Dec 2005
RADARSAT-2 (Radar satellite-2)	CSA	Dec 2005
SICH-2	NSAU	Dec 2005

8.3 Current missions

68 different Earth observation satellite missions are estimated to be currently operating (January 2005). Many of these comprise series of missions planned to provide the continuity which is essential for many observations and applications. The principal satellite series are highlighted below:

Geostationary meteorological satellites:
There is a world-wide network of operational geostationary meteorological satellites which provide visible and infra-red images of the Earth's surface and atmosphere. Countries/regions with current geostationary operational meteorological satellites are the USA (GOES series), Europe (METEOSAT series), Japan (GMS series), India (INSAT and Kalapana series), and China (FY series). Russia will follow-on from the previous GOMS series by launching the first satellite in the Elektro-L series in 2006.

Crustal motion and gravitational field series:
A number of small satellite missions designed to measure the Earth's crustal motion and the Earth's gravitational field have been launched – since as long ago as 1967. The space segment typically comprises corner cube laser retroreflectors and the ground segment is a global network of transportable laser sites. The design life of the space segment is many thousands of years. These missions include the Diademe and Starlette series (CNES) and the LAGEOS series (NASA & ASI). More recently, missions such as CHAMP (DLR) and GRACE (NASA) have been launched to provide high precision measurements of the Earth's gravitational field.

DMSP series:
The long-term meteorological programme of the US Department of Defense (DoD) – with the objective of collecting and disseminating worldwide atmospheric, oceanographic, solar-geophysical, and cloud cover data on a daily basis.

NOAA polar orbiters:
The current series of operational polar orbiting meteorological satellites is provided by NOAA. Two satellites are maintained in polar orbit at any one time, one in a "morning" orbit and one in an "afternoon" orbit. The series provides a wide range of data of interest, including sea surface temperature, cloud cover, data for land studies (notably the AVHRR sensor) , temperature and humidity profiles and ozone concentrations.

TOPEX/POSEIDON and JASON series:
These satellites form a joint NASA/CNES precision radar altimetry mission to measure ocean topography and hence, the speed and direction of ocean currents.

ERS & Envisat series:
ERS-1 was launched by ESA in July 1991, ERS-2 in April 1995, and Envisat in March 2002. This series

concentrates on global and regional environmental issues, making use of active microwave techniques that enable a range of measurements to be made of land, sea and ice surfaces independent of cloud cover and atmospheric conditions. In addition, the ATSR/AATSR instruments on these missions provides images of the surface or cloud top and the GOME instrument on ERS-2 provides measurements of ozone levels. ERS-1 and ERS-2 operated in tandem for around 1 year in 1995 and 1996 providing data for topographic applications such as differential interferometry. Envisat features a range of new sensors for land surface and atmospheric studies.

IRS series:
The Indian IRS satellites (which include the RESOURCESAT and CARTOSAT missions) provide high resolution imagery in a range of visible and infra-red bands. Their primary objectives are in support of agriculture, disaster management, land and water resource management. Latest in the series was RESOURCESAT-1 (IRS-P6) launched in October 2003.

METEOR series:
Roshydromet maintains these missions – mainly for operational meteorological purposes. Other applications include experimental measurement of ozone and Earth radiation budget.

RADARSAT series:
launched in November of 1995, RADARSAT provides researchers and operational users with a range of SAR data products which are used for marine applications such as ship routing, and ice forecasting as well as land applications such as resource management and geological mapping. Data continuity will be ensured through the proposed launch of RADARSAT-2.

SPOT and Landsat series:
The SPOT satellites (lead agency CNES), and the Landsat satellites (lead agency USGS) provide high resolution imagery in a range of visible and infra-red bands. They are used extensively for high resolution land studies. Data from these satellites is supplemented by availability of very high resolution imagery (up to 1m) from various commercial satellites.

CBERS series:
A joint mission series of China and Brazil, aimed at environmental monitoring and Earth resources. The latest in the series was launched in October 2003.

KOMPSAT series:
Korean missions aimed at cartography, land use and planning and ocean and disaster monitoring – starting from December 1999.

NASA's EOS missions:
Carrying the latest advanced sensors and each mission dedicated to investigation of particular Earth System issues – including the Terra, Aqua and Aura missions. NASA has also launched a number of missions aimed at developing understanding of the sun's influence on our climate, and its variability – including the ACRIMSAT, SORCE, and TIMED programmes.

8.4 Future missions

Current plans supplied by CEOS agencies estimate that of order 100 new satellite missions will be launched for operation between 2005 and 2020. The next few years mark a significant era for satellite Earth observations, with **half** of these new missions to be launched by April 2007.

These new programmes will ensure continuity of key measurements, provide improved resolutions and accuracies, and introduce several exciting new capabilities. Some of the highlights are described below:

Gravity and magnetic field studies:
The GRACE and GOCE missions are dedicated to providing more precise measurements of the geoid, while DEMETER (currently in orbit), Kanopus-Vulkan, and Vulkan-Kompas-2 will study links between electromagnetic fields and earthquake predictability.

Polar ice cap studies:
Given, the significance of information on changes in the continental ice sheets, two missions have been dedicated to their study: NASA's ICESat (already launched Jan 2003) and ESA's Cryosat (Mar 2005).

Cloud properties and climate links:
By April 2005, a multiple satellite constellation will be in place (comprising CloudSat, Aqua, Aura, CALIPSO and PARASOL) and will fly in orbital formation to gather data needed to evaluate and improve the way clouds are represented in global models, and to develop a more complete knowledge of their poorly understood role in climate change and the cloud-climate feedback.

Operational meteorology:
The current geostationary programmes will continue operationally. With the launch of the METOP series late in 2005, EUMETSAT and NOAA will share responsibility for the provision of polar orbiting meteorological satellites. The NOAA series of satellites will evolve to become NPOESS, featuring more advanced sensors and new capabilities. China will also operate the FY-3 series of polar orbiting satellites from early 2006.

Atmospheric studies:
New data on the chemistry and dynamics of the Earth's atmosphere will be gathered by missions from many countries, including the recently launched Aura (USA), as well as future missions such as GOSAT and GCOM (Japan). ADM-Aeolus (ESA) will provide new information on winds.

Radiation budget:
Continuity and new capabilities are provided by NASA's SORCE (launched in 2003) and DSCOVR (early 2008) missions, by the PICARD mission (early 2008) of CNES,

and by operational meteorology missions, such as the MSG and NPOESS series.

Ocean observations:
Continuity and improvements in many current measurements have been assured with the launch of missions such as Envisat and Aqua. SMOS (2007) and SAC-D/Aquarius (2008) are worthy of special note – since they will provide new capabilities for measurements of ocean salinity. Ocean surface wind and topography measurements – pioneered by the Topex-Poseidon and ERS missions – will be continued operationally by sensors on the METOP and NPOESS series.

Land surface observations:
A range of different sensors are planned for land surface observations, including advanced SAR systems such as ALOS and TerraSAR-X & –L. SMOS will measure soil moisture from 2007.

Hyperspectral observations:
A new generation of sensors is emerging, featuring 100's of different spectral bands, and with the capability – using spectral-libraries - to remotely sense the chemical composition of surfaces. Such sensors (including on ASI's 'Hyperspectral Mission' and China's 'HJ-1A') are expected to provide new and exciting capabilities for Earth observation of land, sea, and atmosphere.

8.5 CEOS/WMO Database

The information presented in the CEOS Handbook is a much condensed summary of the information provided in the CEOS/WMO Database. This database contains extensive information on the capabilities of both satellite and in-situ observing system capabilities, and relates them in some detail to the requirements of key user programmes. The database is maintained by WMO in co-operation with ESA.

The database was established to support planning of future observing systems, with the primary aim of improving the extent to which space system capabilities meet user requirements for observations. Although many possible uses have been identified for the database, its structure and level of detail are designed primarily to assist in the assessment of conformance between users' requirements for observations and the potential capability of the space segments of satellite systems. To this end, the following information is included in the Database:

- from the user communities ("Users"), a summary of their observational requirements, as available to CEOS through its partnerships with many user communities;
- from the in situ observing system operators and space agencies ("Providers"), a summary of the potential performances of their in situ and satellite instruments, expressed in the same terms as the user requirements;
- instrument and mission descriptions sufficiently detailed to support the evaluation of their performances;
- programmatic information to permit assessment of service continuity aspects.

Those interested in obtaining a copy of the database (available as an MS Access stand-alone application on CD-ROM) for more detailed investigation are encouraged to contact Dr Don Hinsman at WMO:

dhinsman@wmo.int

http://alto-stratus.wmo.ch/sat/stations/SatSystem.html

The information contained in the Earth Observation Handbook is also available on-line at the following address, and contains searchable tables of missions and instruments with internal hyperlinks for ease of navigation:

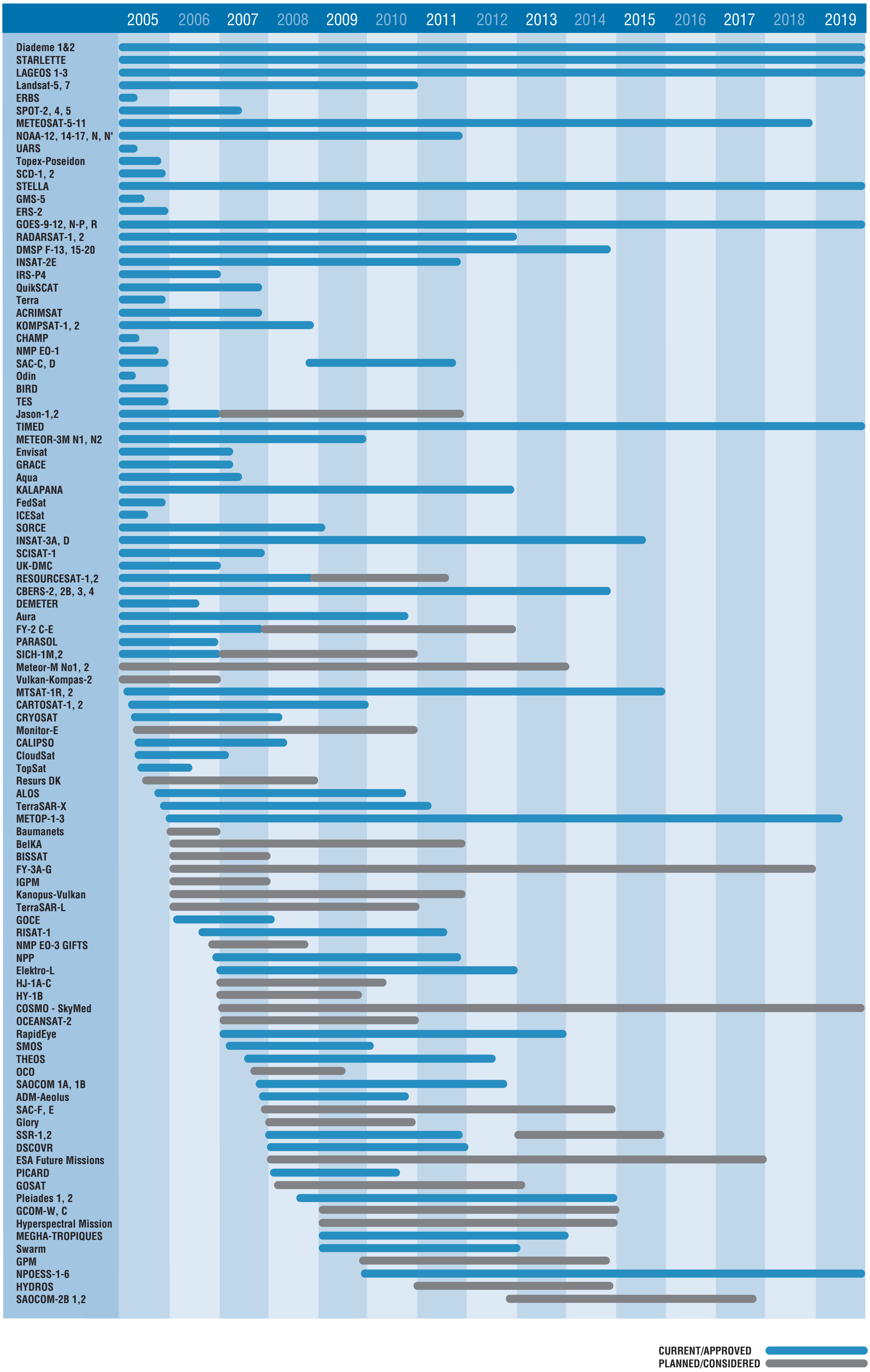
www.eohandbook.com

List of satellite missions (by year and sponsoring agency)

Launch Year	EO Satellite Mission (and sponsoring agency)
1967	Diademe 1&2 (CNES)
1975	STARLETTE (CNES)
1976	LAGEOS-1 (NASA)
1984	Landsat-5 (USGS) ERBS (NASA)
1990	SPOT-2 (CNES)
1991	METEOSAT-5 (EUMETSAT) NOAA-12 (NOAA) UARS (NASA)
1992	Topex-Poseidon (NASA / CNES) LAGEOS-2 (NASA / ASI)
1993	SCD-1 (INPE) STELLA (CNES)
1993	METEOSAT-6 (EUMETSAT)
1994	NOAA-14 (NOAA)
1995	GMS-5 (JAXA / JMA) ERS-2 (ESA) GOES-9 (NOAA) RADARSAT-1 (CSA)
1997	DMSP F-13 (NOAA) GOES-10 (NOAA) METEOSAT-7 (EUMETSAT)
1998	SPOT-4 (CNES) NOAA-15 (NOAA) SCD-2 (INPE)
1999	INSAT-2E (ISRO) Landsat-7 (USGS) IRS-P4 (ISRO) QuikSCAT (NASA) DMSP F-15 (NOAA) Terra (NASA) ACRIMSAT (NASA) KOMPSAT-1 (KARI)
2000	GOES-11 (NOAA) CHAMP (DLR) NOAA-16 (NOAA) NMP EO-1 (NASA) SAC-C (CONAE)
2001	Odin (SNSB) GOES-12 (NOAA) BIRD (DLR) TES (ISRO) Jason (NASA / CNES) TIMED (NASA) METEOR-3M N1 (ROSHYDROMET / ROSKOSMOS)
2002	Envisat (ESA) GRACE (NASA) Aqua (NASA) SPOT-5 (CNES) NOAA-17 (NOAA) METEOSAT-8 (EUMETSAT) KALAPANA (ISRO) FedSat (CSIRO / CRCSS)

Launch Year	EO Satellite Mission (and sponsoring agency)
2003	ICESat (NASA) SORCE (NASA) INSAT-3A (ISRO) SCISAT-1 (CSA) UK-DMC (BNSC) RESOURCESAT-1 (ISRO) DMSP F-16 (NOAA) CBERS-2 (CAST / INPE)
2004	DEMETER (CNES) Aura (NASA) FY-2C (NRSCC) PARASOL (CNES) SICH-1M (NSAU / ROSKOSMOS)
2005	Meteor-M No1 (ROSHYDROMET / ROSKOSMOS) Vulkan-Kompas-2 (ROSKOSMOS) MTSAT-1R (JMA) NOAA-N (NOAA) GOES-N (NOAA) CARTOSAT-1 (ISRO) CRYOSAT (ESA) Monitor-E (ROSKOSMOS) CALIPSO (NASA / CNES) CloudSat (NASA) DMSP F-17 (NOAA) TopSat (BNSC) METEOSAT-9 (EUMETSAT) Resurs DK (ROSKOSMOS) ALOS (JAXA) KOMPSAT-2 (KARI) TerraSAR-X (DLR) METEOR-3M N2 (ROSHYDROMET / ROSKOSMOS) METOP-1 (EUMETSAT) Baumanets (ROSKOSMOS) CARTOSAT-2 (ISRO) RADARSAT-2 (CSA) SICH-2 (NSAU)
2006	BelKA (ROSKOSMOS) BISSAT (ASI) FY-3A (NRSCC) IGPM (ASI) Kanopus-Vulkan (ROSKOSMOS) LAGEOS-3 (NASA / ASI) TerraSAR-L (BNSC) MTSAT-2 (JMA) GOCE (ESA) INSAT-3D (ISRO) RESOURCESAT-2 (ISRO) RISAT-1 (ISRO) NMP EO-3 GIFTS (NASA) CBERS-2B (CAST / INPE) NPP (NOAA) Elektro-L (ROSHYDROMET / ROSKOSMOS) HJ-1A (CAST) HJ-1B (CAST) HY-1B (CAST) Jason-2 (NASA / CNES) COSMO - SkyMed (ASI) FY-2D (NRSCC) FY-3B (NRSCC)

Launch Year	EO Satellite Mission (and sponsoring agency)
2007	Meteor-M No2 (ROSHYDROMET / ROSKOSMOS) OCEANSAT-2 (ISRO) RapidEye (DLR) SMOS (ESA) GOES-O (NOAA) HJ-1C (CAST) THEOS (GISTDA) OCO (NASA) SAOCOM 1A (CONAE) ADM-Aeolus (ESA) DMSP F-18 (NOAA) SAC-F (CONAE) Glory (NASA) SSR-1 (INPE)
2008	DSCOVR (NASA) ESA Future Missions (ESA) PICARD (CNES) GOSAT (JAXA) METEOSAT-10 (EUMETSAT) Pleiades 1 (CNES) SAC-D/Aquarius (CONAE / NASA) SAOCOM 1B (CONAE) GOES-P (NOAA) CBERS-3 (CAST / INPE) NOAA-N' (NOAA) FY-3C (NRSCC)
2009	GCOM-W (JAXA) Hyperspectral Mission (ASI) MEGHA-TROPIQUES (CNES / ISRO) Swarm (ESA) DMSP F-19 (NOAA) GPM Core (NASA) SAC-E/SABIA (CONAE) NPOESS-1 (NOAA) FY-2E (NRSCC) METOP-2 (EUMETSAT) Pleiades 2 (CNES)
2010	GCOM-C (JAXA) GPM Constellation (NASA) HYDROS (NASA) FY-3D (NRSCC)
2011	NPOESS-2 (NOAA) DMSP F-20 (NOAA) CBERS-4 (CAST / INPE) METEOSAT-11 (EUMETSAT)
2012	SAOCOM-2B (2) (CONAE) GOES-R (NOAA) SSR-2 (INPE) FY-3E (NRSCC)
2013	NPOESS-3 (NOAA) SAOCOM-2B (1) (CONAE)
2014	METOP-3 (EUMETSAT) FY-3F (NRSCC)
2015	NPOESS-4 (NOAA)
2016	FY-3G (NRSCC)
2018	NPOESS-5 (NOAA)
2019	NPOESS-6 (NOAA)


2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
Diademe 1&2
STARLETTE
LAGEOS 1-3
Landsat-5, 7
ERBS
SPOT-2, 4, 5
METEOSAT-5-11
NOAA-12, 14-17, N, N'
UARS
Topex-Poseidon
SCD-1, 2
STELLA
GMS-5
ERS-2
GOES-9-12, N-P, R
RADARSAT-1, 2
DMSP F-13, 15-20
INSAT-2E
IRS-P4
QuikSCAT
Terra
ACRIMSAT
KOMPSAT-1, 2
CHAMP
NMP EO-1
SAC-C, D
Odin
BIRD
TES
Jason-1,2
TIMED
METEOR-3M N1, N2
Envisat
GRACE
Aqua
KALAPANA
FedSat
ICESat
SORCE
INSAT-3A, D
SCISAT-1
UK-DMC
RESOURCESAT-1,2
CBERS-2, 2B, 3, 4
DEMETER
Aura
FY-2 C-E
PARASOL
SICH-1M,2
Meteor-M No1, 2
Vulkan-Kompas-2
MTSAT-1R, 2
CARTOSAT-1, 2
CRYOSAT
Monitor-E
CALIPSO
CloudSat
TopSat
Resurs DK
ALOS
TerraSAR-X
METOP-1-3
Baumanets
BelKA
BISSAT
FY-3A-G
IGPM
Kanopus-Vulkan
TerraSAR-L
GOCE
RISAT-1
NMP EO-3 GIFTS
NPP
Elektro-L
HJ-1A-C
HY-1B
COSMO - SkyMed
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SMOS
THEOS
OCO
SAOCOM 1A, 1B
ADM-Aeolus
SAC-F, E
Glory
SSR-1,2
DSCOVR
ESA Future Missions
PICARD
GOSAT
Pleiades 1, 2
GCOM-W, C
Hyperspectral Mission
MEGHA-TROPIQUES
Swarm
GPM
NPOESS-1-6
HYDROS
SAOCOM-2B 1,2
CURRENT/APPROVED
PLANNED/CONSIDERED

List of satellite missions (chronological)

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
ACRIMSAT (Active Cavity Radiometer Irradiance Monitor) **NASA**	Currently being flown	20 Dec 99	01 Oct 07	Will sustain long-term solar luminosity database by providing measurements of total solar irradiance and the solar constant	ACRIM III	Type: Sun-synchronous Altitude: 716 km Period: 90 mins Inclination: 98.13 deg Repeat cycle: LST: 1050 Longitude (if geo): Asc/desc: Ascending URL: acrim.jpl.nasa.gov
ADM-Aeolus (Atmospheric Dynamics Mission (Earth Explorer Core Mission)) **ESA**	Approved	15 Oct 07	15 Oct 10	Will provide wind profile measurements for global 3-D wind field products used for study of atmospheric dynamics, including global transport of energy, water, aerosols, and chemicals	ALADIN	Type: Sun-synchronous Altitude: 408 km Period: Inclination: 96.99 deg Repeat cycle: 7 days LST: Longitude (if geo): Asc/desc: TBD URL: www.esa.int/export/esaLP/aeolus.html
ALOS (Advanced Land Observing Satellite) **JAXA**	Approved	01 Sep 05	01 Sep 10	Cartography, digital terrain models, environmental monitoring, disaster monitoring, civil planning, agriculture and forestry, Earth resources, land surface	AVNIR-2, PALSAR, PRISM	Type: Sun-synchronous Altitude: 692 km Period: 98.7 mins Inclination: 98.16 deg Repeat cycle: 3 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: alos.jaxa.jp/index-e.html
Aqua (Aqua (formerly EOS PM-1)) **NASA**	Currently being flown	04 May 02	04 May 07	Atmospheric dynamics/water and energy cycles, cloud formation, precipitation and radiative properties, air/sea fluxes of energy and moisture, sea ice extent and heat exchange with the atmosphere. Option of 705km or 438km orbit altitude.	AIRS, AMSR-E, AMSU-A, CERES, HSB, MODIS	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2 deg Repeat cycle: 16 days LST: 1330 Longitude (if geo): Asc/desc: Ascending URL: eos-pm.gsfc.nasa.gov
Aura (Aura (formerly EOS Chemistry)) **NASA**	Currently being flown	15 Jul 04	15 Jul 10	Chemistry and dynamics of Earth's atmosphere from the ground through the mesosphere.	HiRDLS, MLS (EOS-Aura), OMI, TES	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2 deg Repeat cycle: 16 days LST: 1345 Longitude (if geo): Asc/desc: Ascending URL: aura.gsfc.nasa.gov
Baumanets **ROSKOSMOS**	Planned	05 Dec 05	31 Dec 06	Experimental satellite for data transmission, remote sensing, and spacecraft management.	OEA	Type: Sun-synchronous Altitude: 700 km Period: Inclination: 98 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.federalspace.ru
BelKA **ROSKOSMOS**	Planned	01 Jan 06	31 Dec 11	Regular imaging of terrestrial sites in visible and near IR ranges with high spatial resolution	MSS (Roskosmos), PSS	Type: Sun-synchronous Altitude: 505 km Period: Inclination: 97.4 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.federalspace.ru

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
BIRD (Bi-spectral Infrared Detection) **DLR**	Currently being flown	22 Oct 01	31 Dec 05	Small satellite mission with technical and scientific objectives (Study of thermal processes on the Earth surface)	HSRS, WAOSS-B	Type: Sun-synchronous Altitude: 572 km Period: Inclination: 97.8 deg Repeat cycle: LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.fire.uni-freiburg.de/iffn/tech/tech_9.htm
BISSAT ((Bistatic SAR mission)) **ASI**	Considered	01 Jan 06	01 Jan 08	Evaluation of bistatic radar cross section of natural and man-made targets, image classification, land surface. Receive-only satellite in formation with main mission COSMO-Skymed	BISSAT	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD
CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) **NASA / CNES**	Approved	15 Apr 05	15 Apr 08	Measurements of aerosol & cloud properties for climate predictions, using a 3 channel lidar and passive instruments in formation with Aqua and CloudSat for coincident observations of radiative fluxes and atmospheric state	CALIOP, IIR, WFC	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2 deg Repeat cycle: LST: 1330 Longitude (if geo): Asc/desc: Ascending URL: www-calipso.larc.nasa.gov/
CARTOSAT-1 (Indian Remote Sensing Satellite - P5) **ISRO**	Approved	15 Mar 05	01 Jul 09	High precision large-scale cartographic mapping of 1:10000 scale and thematic applications (with merged XS data) at 1:4000 scales	PAN (Cartosat-1)	Type: Sun-synchronous Altitude: 630 km Period: 97.178 mins Inclination: 97.87 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
CARTOSAT-2 **ISRO**	Approved	31 Dec 05	01 Jan 10	High precision large-scale cartographic mapping of 1:10000 scale and thematic applications (with merged XS data) at 1:4000 scales	HR-PAN	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
CBERS-2 (China Brazil Earth Resources Satellite - 2) **CAST / INPE**	Currently being flown	22 Oct 03	18 Aug 07	Earth resources, environmental monitoring, land surface	CCD (CBERS), DCS (CAST), IR-MSS, WFI	Type: Sun-synchronous Altitude: 778 km Period: 100.26 mins Inclination: 98.5 deg Repeat cycle: 26 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/ & www.cbers.inpe.br/en/programas/cbers1-2.htm

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
CBERS-2B (China Brazil Earth Resources Satellite - 2B) **CAST / INPE**	Approved	20 Oct 06	20 Oct 08	Earth resources, environmental monitoring, land surface	CCD (CBERS), DCS (CAST), IR-MSS, WFI	Type: Sun-synchronous Altitude: 778 km Period: Inclination: 98.5 deg Repeat cycle: 26 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/ & www.cbers.inpe.br/en/programas/cbers1-2.htm
CBERS-3 (China Brazil Earth Resources Satellite - 3) **CAST / INPE**	Approved	20 Oct 08	20 Oct 11	Earth resources, environmental monitoring, land surface	DCS (CAST), IRS, MUX, PAN, WFI-2	Type: Sun-synchronous Altitude: 778 km Period: 100.26 mins Inclination: 98.5 deg Repeat cycle: 26 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/ & www.cbers.inpe.br/en/programas/cbers3-4.htm
CBERS-4 **(China Brazil Earth Resources Satellite - 4)** **CAST / INPE**	Approved	20 Oct 11	20 Oct 14	Earth resources, environmental monitoring, land surface	DCS (CAST), IRS, MUX, PAN, WFI-2	Type: Sun-synchronous Altitude: 778 km Period: 100.26 mins Inclination: 98.5 deg Repeat cycle: 26 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/ & www.cbers.inpe.br/en/programas/cbers3-4.htm
CHAMP (Challenging Mini-Satellite Payload for Geophysical Research and Application) **DLR**	Currently being flown	15 Jul 00	15 Jul 05	Gravity field, Precise geoid, Magnetic field, Atmospheric physics	CHAMP GPS Sounder, CHAMP gravity package (Accelerometer+GPS), CHAMP magnetometry package (1 Scalar + 2 Vector Magnetometer)	Type: Inclined, non-sunsynchronous Altitude: 470 km Period: Inclination: 87 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: op.gfz-potsdam.de/champ/index_CHAMP.html
CloudSat (CloudSat) **NASA**	Approved	15 Apr 05	15 Feb 07	CloudSat will use advanced radar to "slice" through clouds to see their vertical structure, providing a completely new observational capability from space. One of first satellites to study clouds on global basis. Will fly in formation with Aqua and CALIPSO.	CPR (Cloudsat)	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2 deg Repeat cycle: LST: 1335 Longitude (if geo): Asc/desc: Ascending URL: cloudsat.atmos.colostate.edu/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
COSMO - SkyMed (COnstellation of small Satellites for Mediterranean basin Observation) **ASI**	Planned	31 Dec 06	31 Dec 20	Environmental monitoring, surveillance and risk management applications, environmental resources management, maritime management, earth topographic mapping, law enforcement, informative / science applications	SAR 2000	Type: Sun-synchronous Altitude: 619 km Period: 97.86 mins Inclination: Repeat cycle: 16 days LST: 600 Longitude (if geo): Asc/desc: Ascending URL: www.alespazio.it/program/tlr/cosmo/cosmo.htm
CRYOSAT (CryoSat (Earth Explorer Opportunity Mission)) **ESA**	Approved	31 Mar 05	31 Mar 08	A radar altimetry mission to determine variations in the thickness of the Earth's continental ice sheets and marine ice cover. Primary objective is to test the prediction of thinning arctic ice due to global warming	DORIS-NG, Laser reflectors (ESA), SIRAL	Type: Inclined, non-sunsynchronous Altitude: 717 km Period: Inclination: 92 deg Repeat cycle: 369 days LST: Longitude (if geo): Asc/desc: TBD URL: www.esa.int/export/esaLP/cryosat.html
DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions)	Approved	29 Jun 04	29 Jun 06	Micro-satellite to study; ionospheric disturbances related to seismic activity, ionospheric disturbances related to human activity, pre and post-seismic effects in the ionosphere, global information on the Earth's electromagnetic environment	IAP, ICE, IDP, IMSC, ISL	Type: Sun-synchronous Altitude: 800 km Period: Inclination: Repeat cycle: LST: 1030 Longitude (if geo): Asc/desc: TBD URL: smsc.cnes.fr/DEMETER/index.htm
Diademe 1&2 **CNES**	Currently being flown	15 Feb 67	31 Dec 50	Geodetic measurements using satellite laser ranging	RRA	Type: Inclined, non-sunsynchronous Altitude: 1200 km Period: 108 mins Inclination: 40 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/diademe
DMSP F-13 (Defense Meteorological Satellite Program F-13) **NOAA**	Currently being flown	01 Mar 97	30 Sep 05	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide atmospheric, oceanographic, solar-geophyscial, and cloud cover data on a daily basis. (Primary operational satellite)	OLS, SSB/X-2, SSIES-2, SSJ/4, SSM, SSM/I, SSM/T-1, SSM/T-2, SSZ	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.7 deg Repeat cycle: LST: 1812 Longitude (if geo): Asc/desc: Ascending URL: dmsp.ngdc.noaa.gov/dmsp.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
DMSP F-15 (Defense Meteorological Satellite Program F-15) **NOAA**	Currently being flown	12 Dec 99	30 Sep 06	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis. (Primary operational satellite)	OLS, SSB/X-2, SSIES-2, SSJ/4, SSM, SSM/I, SSM/T-1, SSM/T-2, SSZ	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.9 deg Repeat cycle: LST: 2029 Longitude (if geo): Asc/desc: Ascending URL: dmsp.ngdc.noaa.gov/dmsp.html
DMSP F-16 (Defense Meteorological Satellite Program F-16) **NOAA**	Approved	15 Oct 03	15 Oct 07	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis.	OLS, SSB/X-2, SSIES-2, SSIES-3, SSJ/4, SSJ/5, SSM, SSM/I, SSM/T-1, SSM/T-2, SSMIS, SSULI, SSUSI, SSZ	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.9 deg Repeat cycle: LST: 2132 Longitude (if geo): Asc/desc: Ascending URL: dmsp.ngdc.noaa.gov/dmsp.html
DMSP F-17 (Defense Meteorological Satellite Program F-17) **NOAA**	Approved	15 Apr 05	01 Jun 08	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis.	OLS, SSIES-3, SSJ/5, SSM, SSM/T-1, SSMIS, SSULI, SSUSI	Type: Sun-synchronous Altitude: 850 km Period: 101 mins Inclination: 98.7 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: dmsp.ngdc.noaa.gov/dmsp.html
DMSP F-18 (Defense Meteorological Satellite Program F-18) **NOAA**	Approved	15 Oct 07	15 Oct 10	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis.	OLS, SSIES-3, SSJ/5, SSM, SSM/T-1, SSMIS, SSULI, SSUSI	Type: Sun-synchronous Altitude: 850 km Period: 101 mins Inclination: 98.7 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: dmsp.ngdc.noaa.gov/dmsp.html
DMSP F-19 (Defense Meteorological Satellite Program F-19) **NOAA**	Approved	15 Apr 09	15 Apr 12	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis.	OLS, SSIES-3, SSJ/5, SSM, SSM/T-1, SSMIS, SSULI, SSUSI	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.7 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: dmsp.ngdc.noaa.gov/dmsp.html
DMSP F-20 (Defense Meteorological Satellite Program F-20) **NOAA**	Approved	15 Oct 11	15 Oct 14	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis.	OLS, SSIES-3, SSJ/5, SSM, SSM/T-1, SSMIS, SSULI, SSUSI	Type: Sun-synchronous Altitude: 850 km Period: 101 mins Inclination: 98.7 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: dmsp.ngdc.noaa.gov/dmsp.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
DSCOVR (formerly Triana) **NASA**	Approved	01 Jan 08	01 Jan 12	Continuously observes the sunlit Earth (full disk) – transmitting an image every 15 minutes for distribution by internet. Studies how solar radiation affects climate. Will be positioned at the Langrange point between Earth and sun.	EPIC, NISTAR, Plasma-Mag	Type: TBD Altitude: 1500000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: triana.gsfc.nasa.gov/home/www-pm.larc.nasa.gov/triana.html
Elektro-L (Geostationary Operational Meteorological Satellite - 2) **ROSHYDROMET / ROSKOSMOS**	Approved	01 Dec 06	31 Dec 12	Hydrometeorology, climatology, disaster management, space environment, ice and snow, land surface, space environment, data collection and communication.	DCS (ROSHYDROMET), GGAK-E, MSU-GS	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -76 Asc/desc: N/A URL: sputnik1.infospace.ru/
Envisat (Environmental Satellite) **ESA**	Currently being flown	01 Mar 02	01 Mar 07	Physical oceanography, land surface, ice and snow, atmospheric chemistry, atmospheric dynamics/water and energy cycles	AATSR, ASAR, ASAR (image mode), ASAR (wave mode), DORIS-NG, ENVISAT Comms, GOMOS, MERIS, MIPAS, MWR (BNSC), RA-2, SCIAMACHY	Type: Sun-synchronous Altitude: 782 km Period: 100.5 mins Inclination: 98.52 deg Repeat cycle: 35 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: envisat.esa.int/
ERBS (Earth Radiation Budget Satellite) **NASA**	Currently being flown	05 Oct 84	30 Apr 05	Earth radiation budget measurements.	ERBE, SAGE II	Type: Inclined, non-sunsynchronous Altitude: 585 km Period: 96.3 mins Inclination: 57 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: asd-www.larc.nasa.gov/erbe/erbs.html
ERS-2 (European Remote Sensing satellite - 2) **ESA**	Currently being flown	21 Apr 95	31 Dec 05	Earth resources plus physical oceanography, ice and snow, land surface, meteorology, geodesy/gravity, environmental monitoring, atmospheric chemistry	AMI/SAR/Image, AMI/SAR/wave, AMI/scatterometer, ATSR/M, ATSR-2, ERS Comms, GOME, MWR (BNSC), RA	Type: Sun-synchronous Altitude: 782 km Period: 100.5 mins Inclination: 98.52 deg Repeat cycle: 35 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.esa.int/export/esaEO/SEMGWH2VQUD_index_0_m.html
ESA Future Missions **ESA**	Considered	01 Jan 08	01 Jan 18	Physical Oceanogreaphy, land surface, ice and snow, atmospheric dynamics/water and energy cycles	ATLID, CPR, MASTER, SPECTRA	Type: TBD Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: www.esa.int/export/esaLP/index.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
FedSat (Federation Satellite) **CSIRO / CRCSS**	Currently being flown	14 Dec 02	14 Dec 05	Communications, data relay, near Earth environment, upper atmospheric physics, meteorology	Communications payload (Ka and UHF band), Fluxgate magnetometer, GPS receiver	Type: Sun-synchronous Altitude: 803 km Period: 101 mins Inclination: 98.6 deg Repeat cycle: LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.crcss.csiro.au/
FY-2C (FY-2C Geostationary Meteorological Satellite) **NRSCC**	Currently being flown	19 Oct 04	19 Oct 07	Meteorology and environmental monitoring. Data collection and redistribution	IVISSR (FY-2)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: TBD URL:
FY-2D (FY-2D Geostationary Meteorological Satellite) **NRSCC**	Planned	31 Dec 06	31 Dec 09	Meteorology and environmental monitoring. Data collection and redistribution	IVISSR (FY-2)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: TBD URL:
FY-2E (FY-2E Geostationary Meteorological Satellite) **NRSCC**	Planned	31 Dec 09	31 Dec 12	Meteorology and environmental monitoring. Data collection and redistribution	IVISSR (FY-2)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: TBD URL:
FY-3A (FY-3A Polar-orbiting Meteorological Satellite) **NRSCC**	Planned	01 Jan 06	01 Jan 08	Meteorology and environmental monitoring. Data collection and redistribution	IRAS, MERSI, MWRI, MWTS, OP, TOM, VIRR	Type: Sun-synchronous Altitude: 890 km Period: Inclination: Repeat cycle: 98.728 deg LST: 1010 Longitude (if geo): Asc/desc: Descending URL:
FY-3B (FY-3B Polar-orbiting Meteorological Satellite) **NRSCC**	Planned	31 Dec 06	31 Dec 08	Meteorology and environmental monitoring. Data collection and redistribution	IRAS, MERSI, MWRI, MWTS, OP, TOM, VIRR	Type: Sun-synchronous Altitude: 890 km Period: Inclination: Repeat cycle: 98.728 deg LST: 1010 Longitude (if geo): Asc/desc: Descending URL:
FY-3C (FY-3C Polar-orbiting Meteorological Satellite) **NRSCC**	Planned	31 Dec 08	31 Dec 10	Meteorology and environmental monitoring. Data collection and redistribution	IMWTS, IRAS, MERSI, MIRAS, MWHS, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: 890 km Period: Inclination: Repeat cycle: 98.728 deg LST: 1010 Longitude (if geo): Asc/desc: Descending URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
FY-3D (FY-3D Polar-orbiting Meteorological Satellite) **NRSCC**	Planned	31 Dec 10	31 Dec 12	Meteorology and environmental monitoring. Data collection and redistribution	IMWTS, IRAS, MERSI, MIRAS, MWHS, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: 890 km Period: Inclination: Repeat cycle: 98.728 deg LST: 1010 Longitude (if geo): Asc/desc: Descending URL:
FY-3E (FY-3E Polar-orbiting Meteorological Satellite) **NRSCC**	Planned	31 Dec 12	31 Dec 14	Meteorology and environmental monitoring. Data collection and redistribution	IMWTS, IRAS, MERSI, MIRAS, MWHS, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: 890 km Period: Inclination: Repeat cycle: 98.728 deg LST: 1010 Longitude (if geo): Asc/desc: Descending URL:
FY-3F (FY-3F Polar-orbiting Meteorological Satellite) **NRSCC**	Planned	31 Dec 14	31 Dec 16	Meteorology and environmental monitoring. Data collection and redistribution	IMWTS, IRAS, MERSI, MIRAS, MWHS, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: 890 km Period: Inclination: Repeat cycle: 98.728 deg LST: 1010 Longitude (if geo): Asc/desc: Descending URL:
FY-3G (FY-3G Polar-orbiting Meteorological Satellite) **NRSCC**	Planned	31 Dec 16	31 Dec 18	Meteorology and environmental monitoring. Data collection and redistribution	IMWTS, IRAS, MERSI, MIRAS, MWHS, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: 890 km Period: Inclination: Repeat cycle: 98.728 deg LST: 1010 Longitude (if geo): Asc/desc: Descending URL:
GCOM-C (Global Climate Observation Mission-C) **JAXA**	Considered	01 Jan 10	01 Jan 15	Atmospheric and terrestrial observation	GLI follow-on	Type: Sun-synchronous Altitude: 800 km Period: Inclination: Repeat cycle: LST: 1330 Longitude (if geo): Asc/desc: Descending URL:
GCOM-W (Global Climate Observation Mission-W) **JAXA**	Considered	01 Jan 09	01 Jan 14	Sea surface observation	AMSR follow-on, Scatterometer (JAXA)	Type: Sun-synchronous Altitude: 800 km Period: Inclination: Repeat cycle: LST: 1330 Longitude (if geo): Asc/desc: Descending URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Glory **NASA**	Planned	01 Dec 07	01 Dec 10	Concentration and nature of both natural and anthropogenic aerosols (BC, sulfates, etc.) with accuracy and coverage sufficient for quantification of the aerosol effect on climate, the anthropogenic component of this effect, and the long-term change of this effect caused by natural and anthropogenic factors	APS, TIM	Type: Sun-synchronous Altitude: 824 km Period: 101 mins Inclination: 1030 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL:
GMS-5 (Geostationary Meteorogical Satellite - 5) **JAXA / JMA**	Currently being flown	18 Mar 95	01 Jun 05	Meteorology	DCS (JAXA), GMS Comms, VISSR (GMS-5)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -140 Asc/desc: N/A URL: spaceinfo.jaxa.jp/db/kaihatu/eisei/eisei_e/gms_5_e.html
GOCE (Gravity Field and Steady-State Ocean Circulation Explorer (Earth Explorer Core Mission)) **ESA**	Approved	15 Feb 06	15 Feb 08	Research in steady-state ocean circulation, physics of Earth's interior and levelling systems (based on GPS). Will also provide unique data set required to formulate global and regional models of the Earth's gravity field and geoid.	EGG, GPS (ESA), Laser reflectors (ESA)	Type: Sun-synchronous Altitude: 250 km Period: Inclination: 96.5 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: www.esa.int/export/esaLP/goce.html
GOES-9 (Geostationary Operational Environmental Satellite - 9) **NOAA**	Currently being flown	23 May 95	15 Jan 05	Meteorology (primary mission), search and rescue, space environment monitoring, data collection, platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, WEFAX	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 255 Asc/desc: N/A URL: www.oso.noaa.gov/goes/
GOES-10 (Geostationary Operational Environmental Satellite - 10) **NOAA**	Currently being flown	25 Apr 97	15 Jan 06	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, WEFAX	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 135 Asc/desc: N/A URL: www.oso.noaa.gov/goes/
GOES-11 (Geostationary Operational Environmental Satellite - 11) **NOAA**	Currently being flown	03 May 00	15 Jul 11	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, WEFAX	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 103 Asc/desc: N/A URL: www.oso.noaa.gov/goes/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
GOES-12 (Geostationary Operational Environmental Satellite - 12) **NOAA**	Currently being flown	23 Jul 01	15 Jan 11	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, SXI, WEFAX	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 75 Asc/desc: N/A URL: www.oso.noaa.gov/goes/
GOES-N (Geostationary Operational Environmental Satellite - N) **NOAA**	Approved	14 Apr 05	14 Apr 17	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, SXI, WEFAX	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 75 Asc/desc: N/A URL: www.oso.noaa.gov/goes/
GOES-O (Geostationary Operational Environmental Satellite - O) **NOAA**	Approved	07 Apr 07	07 Apr 19	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, WEFAX	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 75 Asc/desc: TBD URL: www.oso.noaa.gov/goes/
GOES-P (Geostationary Operational Environmental Satellite - P) **NOAA**	Approved	15 Oct 08	15 Oct 20	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, SXI, WEFAX	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 135 Asc/desc: TBD URL: www.oso.noaa.gov/goes/
GOES-R (Geostationary Operational Environmental Satellite - R) **NOAA**	Approved	31 Oct 12	31 Oct 20	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	ABI, EHIS, EUVS, Geomicrowave sounder, GLM, HES, Magnetometer (NOAA), MPS, SGPS, SXI, SXS	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 135 Asc/desc: URL: www.osd.noaa.gov/goes_R/index.htm
GOSAT (Greenhouse gases Observing Satellite) **JAXA**	Planned	01 Feb 08	01 Feb 13	Observation of Greenhouse gases	Cloud Sensor, GHG Sensor	Type: Sun-synchronous Altitude: 666 km Period: 98 mins Inclination: 98 deg Repeat cycle: 3 days LST: Longitude (if geo): Asc/desc: TBD URL: www.jaxa.jp/missions/projects/sat/eos/gosat/index_e.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
GPM Constellation (Global Precipitation Measurement Mission Constellation spacecraft) **NASA**	Planned	01 Nov 10	01 Nov 14	Study of global precipitation, evaporation, and cycling of water are changing. The mission comprises a primary spacecraft with active and passive microwave instruments, and a number of 'constellation spacecraft with passive microwave instruments.	GMI	Type: Inclined, non-sunsynchronous Altitude: 600 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: gpm.gsfc.nasa.gov/
GPM Core (Global Precipitation Measurement Mission Core spacecraft) **NASA**	Planned	01 Nov 09	01 Nov 13	Study of global precipitation, evaporation, and cycling of water are changing. The mission comprises a primary spacecraft with active and passive microwave instruments, and a number of 'constellation spacecraft with passive microwave instruments	DPR, GMI	Type: Inclined, non-sunsynchronous Altitude: 400 km Period: Inclination: 65 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: gpm.gsfc.nasa.gov/gpm.gsfc.nasa.gov/
GRACE (Gravity Recovery and Climate Experiment) **NASA**	Currently being flown	17 Mar 02	01 Mar 07	Extremely high precision gravity measurements for use in construction of gravity field models	GPS (GRACE), HAIRS	Type: Inclined, non-sunsynchronous Altitude: 400 km Period: 94 mins Inclination: 89 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: www.csr.utexas.edu/grace/
HJ-1A (Disaster and Environment Monitoring and Forecast Small Satellite A) **CAST**	Planned	01 Dec 06	01 Dec 09	Disaster and Environment Monitoring and Forecast	CCD (HJ, HY), HSI (HJ-1A)	Type: Sun-synchronous Altitude: 649 km Period: Inclination: 97.9 deg Repeat cycle: 31 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/
HJ-1B **(Disaster and Environment Monitoring and Forecast Small Satellite B)** **CAST**	Planned	01 Dec 06	01 Dec 09	Disaster and Environment Monitoring and Forecast	CCD (HJ, HY), IR (HJ-1B)	Type: Sun-synchronous Altitude: 649 km Period: Inclination: 97.9 deg Repeat cycle: 31 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/
HJ-1C (Disaster and Environment Monitoring and Forecast Small Satellite B) **CAST**	Planned	01 May 07	01 May 10	Disaster and Environment Monitoring and Forecast	S-band SAR	Type: Sun-synchronous Altitude: 499 km Period: Inclination: 97.3 deg Repeat cycle: 31 days LST: 600 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
HY-1B (Ocean color satellite B) **CAST**	Planned	01 Dec 06	01 Dec 09	Detecting ocean color and sea surface temperature	COCTS, CZI	Type: Altitude: 798 km Period: Inclination: 98.6 deg Repeat cycle: 7 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.cast.cn/
HYDROS (Hydrosphere State) **NASA**	Planned	01 Dec 10	01 Dec 14	Measure soil moisture content and freeze-thaw state	HYDROS	Type: Sun-synchronous Altitude: 670 km Period: Inclination: 98 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: hydros.gsfc.nasa.gov/
Hyperspectral Mission (Hyperspectral Earth Observer) **ASI**	Considered	01 Jan 09	31 Dec 14	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils	CIA, HYC	Type: Sun-synchronous Altitude: 620 km Period: 97 mins Inclination: 91.87 deg Repeat cycle: 16 days LST: 1000 Longitude (if geo): Asc/desc: Descending URL: www.ifac.cnr.it/ot/hyperspectral_workshop_2004.html
ICESat (Ice, Cloud, and Land Elevation Satellite) **NASA**	Currently being flown	12 Jan 03	30 Jun 05	Monitors mass balance of polar ice sheets and their contribution to global sea level change. Secondary goals: cloud heights and vertical structure of clouds/aerosols; roughness, reflectivity, vegetation heights, snow-cover.	GLAS	Type: Inclined, non-sunsynchronous Altitude: 600 km Period: 97 mins Inclination: 94 deg Repeat cycle: 183 days LST: Longitude (if geo): Asc/desc: N/A URL: icesat.gsfc.nasa.gov/
IGPM **ASI**	Considered	01 Jan 06	01 Jan 08	To detect and measure rain and snowfall, to demonstrate the feasibility of high quality measurements of light rain and snow from space	IGPM radiometer, IGPM rain radar	Type: Sun-synchronous Altitude: 510 km Period: Inclination: Repeat cycle: LST: 1430 Longitude (if geo): Asc/desc: TBD URL:
INSAT-2E (Indian National Satellite - 2E) **ISRO**	Currently being flown	03 Apr 99	04 Mar 11	Meteorology, data collection and communication, search and rescue	CCD camera, VHRR	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -83 Asc/desc: TBD URL: www.isro.org/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
INSAT-3A (Indian National Satellite - 3A) **ISRO**	Currently being flown	10 Apr 03	10 Apr 13	Meteorology, data collection and communication, search and rescue	CCD camera, VHRR)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -94 Asc/desc: TBD URL: www.isro.org/
INSAT-3D (Indian National Satellite - 3D) **ISRO**	Approved	01 Jul 06	01 Jul 15	Meteorology, data collection and communication, search and rescue	Imager (INSAT), Sounder (INSAT)	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -83 Asc/desc: TBD URL: www.isro.org/
IRS-P4 (OCEANSAT-1) **ISRO**	Currently being flown	26 May 99	31 Dec 06	Ocean biology, physical oceanography	MSMR, OCM, WiFS	Type: Sun-synchronous Altitude: 720 km Period: 99.31 mins Inclination: 98.28 deg Repeat cycle: 2 days LST: 1215 Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
Jason (Ocean surface topography) **NASA / CNES**	Currently being flown	07 Dec 01	01 Oct 07	Physical oceanography, geodesy/gravity, climate monitoring, marine meteorology	DORIS-NG, JMR, LRA, POSEIDON-2 (SSALT-2), TRSR	Type: Inclined, non-sunsynchronous Altitude: 1336 km Period: 112.4 mins Inclination: 66 deg Repeat cycle: 10 days LST: Longitude (if geo): Asc/desc: N/A URL: topex-www.jpl.nasa.gov/mission/jason-1.html
Jason-2 (also known as OSTM) (Ocean Surface Topography Mission) **NASA / CNES**	Planned	07 Dec 06	07 Dec 11	Physical oceanography, geodesy/gravity, climate monitoring, marine meteorology	DORIS-NG, JMR, LRA, POSEIDON-3, TRSR	Type: Inclined, non-sunsynchronous Altitude: 1336 km Period: 112.4 mins Inclination: 66 deg Repeat cycle: 10 days LST: Longitude (if geo): Asc/desc: N/A URL: topex-www.jpl.nasa.gov/mission/mission.html
KALAPANA (Meteorological satellite) **ISRO**	Currently being flown	09 Dec 02	09 Dec 12	Meteorological applications	VHRR	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -83 Asc/desc: TBD URL: www.isro.org/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Kanopus-Vulkan **ROSKOSMOS**	Planned	01 Jan 06	31 Dec 11	Hydrology, hydrometeorology, monitoring man-made and natural accidents, research into short-term forecasting of earthquakes	ECHO-V, GID-12T, MTVZA-OK, NVK, RBE, RCHA	Type: Sun-synchronous Altitude: 700 km Period: Inclination: 97 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.federalspace.ru
KOMPSAT-1 (Korea Multi-Purpose Satellite 1) **KARI**	Currently being flown	21 Dec 99	21 Dec 05	Cartography, land use and planning, disaster monitoring, Global marine resource and environmental monitoring, ocean contamination and chlorophyll detection	EOC, OSMI	Type: Sun-synchronous Altitude: 685 km Period: 98.5 mins Inclination: 28 deg Repeat cycle: 1050 days LST: Longitude (if geo): Asc/desc: Ascending URL: kompsat.kari.re.kr/english/index.asp
KOMPSAT-2 (Korea Multi-Purpose Satellite 2) **KARI**	Approved	01 Oct 05	01 Oct 08	Cartography, land use and planning, disaster monitoring	MSC	Type: Sun-synchronous Altitude: 685 km Period: 98.5 mins Inclination: 28 deg Repeat cycle: 1050 days LST: Longitude (if geo): Asc/desc: Ascending URL: kompsat.kari.re.kr/english/index.asp
LAGEOS-1 (Laser Geodynamics Satellite - 1) **NASA**	Currently being flown	04 May 76	04 May 16	Geodesy, crustal motion and gravity field measurements by laser ranging	LRA (LAGEOS)	Type: Inclined, non-sunsynchronous Altitude: 6000 km Period: 225 mins Inclination: 110 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/lagoes.html
LAGEOS-2 (Laser Geodynamics Satellite - 2) **NASA / ASI**	Currently being flown	22 Oct 92	22 Oct 32	Geodesy, crustal motion and gravity field measurements by laser ranging	LRA (LAGEOS)	Type: Inclined, non-sunsynchronous Altitude: 5900 km Period: 223 mins Inclination: 52 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/lagoes.htmlNASA\NASA_Agency_Missions1x2.doc
LAGEOS-3 (Laser Geodynamics Satellite - 3) **NASA / ASI**	Planned	01 Jan 06	01 Jan 46	Geodesy, crustal motion and gravity field measurements by laser ranging. Launch TBD - dates given are for illustration only.	LRA (LAGEOS)	Type: Inclined, non-sunsynchronous Altitude: 5900 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: www.laeff.esa.es/eng/laeff/activity/lageos3.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Landsat-5 **USGS**	Currently being flown	01 Mar 84	31 Dec 09	Earth resources, land surface, environmental monitoring, agriculture and forestry, disaster monitoring and assessment, ice and snow cover	Landsat Comms, MSS, TM	Type: Sun-synchronous Altitude: 705 km Period: 98.9 mins Inclination: 98.2 deg Repeat cycle: 16 days LST: 945 Longitude (if geo): Asc/desc: Descending URL: landsat7.usgs.gov/
Landsat-7 **USGS**	Currently being flown	15 Apr 99	31 Dec 10	Earth resources, land surface, environmental monitoring, agriculture and forestry, disaster monitoring and assessment, ice and snow cover	ETM+, Landsat Comms	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2 deg Repeat cycle: 16 days LST: 1000 Longitude (if geo): Asc/desc: Descending URL: landsat7.usgs.gov/
MEGHA-TROPIQUES **CNES / ISRO**	Approved	01 Jan 09	01 Jan 14	Study of the inter-tropical zone and its convective systems (water and energy cycles).	MADRAS, SAPHIR, ScaRaB	Type: Sun-synchronous Altitude: 867 km Period: 100 mins Inclination: 20 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL:
METEOR-3M N1 **ROSHYDROMET / ROSKOSMOS**	Currently being flown	10 Dec 01	31 Dec 05	Hydrometeorology, climatology, land surface, physical oceanography, heliogeophysics and space environment, sounding of the atmosphere, agriculture.	KGI-4C, Klimat, MIVZA, MR-2000M1, MSTE-5E, MSU-E, MSU-SM, MTVZA, SAGE III, SFM-2	Type: Sun-synchronous Altitude: 1018 km Period: 105.3 mins Inclination: 99.6 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: sputnik1.infospace.ru/
METEOR-3M N2 **ROSHYDROMET / ROSKOSMOS**	Approved	01 Dec 05	31 Dec 09	Hydrometeorology, climatology, land surface, physical oceanography, heliogeophysics and space environment, data collection, sounding of the atmosphere, agriculture	DCS (ROSHYDROMET), IKFS-2, KMSS, MSGI-MKA, MSU-MR, MTVZA, SAR (ROSHYDROMET),	Type: Sun-synchronous Altitude: 1024 km Period: 105.3 mins Inclination: 99.6 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: sputnik1.infospace.ru/
Meteor-M No1 **ROSHYDROMET / ROSKOSMOS**	Planned	01 Jan 05	01 Jan 12	Meteorology, hydrology, climate and environmental monitoring	GALS-M, GGAK-M, IKFS-2, IKOR-M, KMSS, MSGI-MKA, MSS-BIO, MSU-MR, MTVZA, Radiomet, RIMS-M, SKL-M	Type: Sun-synchronous Altitude: 835 km Period: Inclination: 98.8 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.federalspace.ru

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Meteor-M No2 **ROSHYDROMET / ROSKOSMOS**	Planned	01 Jan 07	01 Jan 14	Meteorology, hydrology, climate and environmental monitoring	GALS-M, GGAK-M, IKFS-2, IKOR-M, KMSS, MSGI-MKA, MSS-BIO, MSU-MR, MTVZA, Radiomet, RIMS-M, SKL-M	Type: Sun-synchronous Altitude: 835 km Period: Inclination: 98.8 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.federalspace.ru
METEOSAT-5 **EUMETSAT**	Currently being flown	02 Mar 91	31 Dec 05	Meteorology, climatology, Atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase	METEOSAT Comms, MVIRI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -63 Asc/desc: N/A URL: umetsat.de/en/dps/news/spacecraft.html
METEOSAT-6 **EUMETSAT**	Currently being flown	20 Nov 93	01 Jun 08	Meteorology, climatology, Atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase	METEOSAT Comms, MVIRI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 9 Asc/desc: N/A URL: www.eumetsat.de/en/dps/news/spacecraft.html
METEOSAT-7 **EUMETSAT**	Currently being flown	03 Sep 97	01 Jun 09	Meteorology, climatology, Atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase	METEOSAT Comms, MVIRI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/mtp/index.html
METEOSAT-8 (Meteosat Second Generation-1) **EUMETSAT**	Currently being flown	13 Aug 02	13 Aug 09	Meteorology, climatology, Atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase	GERB, MSG Comms, SEVIRI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html
METEOSAT-9 (Meteosat Second Generation-2) **EUMETSAT**	Approved	01 Jun 05	01 Jun 12	Meteorology, climatology, Atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase	GERB, MSG Comms, SEVIRI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
METEOSAT-10 (Meteosat Second Generation-3) **EUMETSAT**	Approved	01 Jun 08	01 Jun 15	Meteorology, climatology, Atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase	GERB, MSG Comms, SEVIRI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html
METEOSAT-11 (Meteosat Second Generation-4) **EUMETSAT**	Approved	01 Dec 11	01 Dec 18	Meteorology, climatology, Atmospheric dynamics/water and energy cycles. Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase	GERB, MSG Comms, SEVIRI	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html
METOP-1 (Meteorological Operational Polar Satellite - 1) **EUMETSAT**	Approved	01 Dec 05	01 Dec 10	Meteorology, climatology	AMSU-A, ARGOS, ASCAT, AVHRR/3, GOME-2, GRAS, HIRS/4, IASI, MCP, MHS, S&R (NOAA)	Type: Sun-synchronous Altitude: 840 km Period: 101.7 mins Inclination: 98.8 deg Repeat cycle: 5 days LST: 930 Longitude (if geo): Asc/desc: Descending URL: www.eumetsat.de/en/area4/topic2.html
METOP-2 (Meteorological Operational Polar Satellite - 2) **EUMETSAT**	Approved	31 Dec 09	31 Dec 14	Meteorology, climatology	AMSU-A, ARGOS, ASCAT, AVHRR/3, GOME-2, GRAS, HIRS/4, IASI, MCP, MHS, S&R (NOAA), SEM (POES)	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: 930 Longitude (if geo): Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic2.html
METOP-3 (Meteorological Operational Polar Satellite - 3) **EUMETSAT**	Approved	01 Jun 14	01 Jun 19	Meteorology, climatology	AMSU-A, ARGOS, ASCAT, AVHRR/3, GOME-2, GRAS, HIRS/4, IASI, MCP, MHS	Type: Sun-synchronous Altitude: 840 km Period: 101.7 mins Inclination: 98.8 deg Repeat cycle: 5 days LST: 930 Longitude (if geo): Asc/desc: Descending URL: www.eumetsat.de/en/area4/topic2.html
Monitor-E **ROSKOSMOS**	Planned	01 Apr 05	31 Dec 10	Agriculture and forestry, hydrology, environmental monitoring, hydrometeorology, ice and snow, land surface, meteorology	PSA, RDSA	Type: Sun-synchronous Altitude: 540 km Period: Inclination: 97.5 deg Repeat cycle: LST: 540 Longitude (if geo): Asc/desc: TBD URL: www.federalspace.ru

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
MTSAT-2 (Multi-functional Transport Satellite) **JMA**	Approved	01 Feb 06	31 Dec 15	Meteorology, aeronautical applications	IMAGER/MTSAT-2, MTSAT Comms	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -140 Asc/desc: N/A URL:
NMP EO-1 (New Millenium Program Earth Observing-1) **NASA**	Currently being flown	21 Nov 00	30 Sep 05	Land surface, earth resources	ALI, Hyperion, LAC	Type: Sun-synchronous Altitude: 705 km Period: 99 mins Inclination: 98.2 deg Repeat cycle: 16 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: eo1.gsfc.nasa.gov/
NMP EO-3 GIFTS (New Millenium Program EO-3 - Geosynchronous Imaging Fourier Transform Spectrometer) **NASA**	Considered	01 Oct 06	01 Oct 08	Continuous observation of atmospheric temperature, water vapour content and distribution, and the concentration of certain other atmospheric gases as a function of altitude over time - providing a new way to observe weather and the changing atmosphere.	GIFTS	Type: Geostationary Altitude: 36000 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -83 Asc/desc: N/A URL: nmp.jpl.nasa.gov/eo3/index.html
NOAA-12 (National Oceanic and Atmospheric Administration - 12) **NOAA**	Currently being flown	14 May 91	31 Dec 05	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, space environment, solar flux analysis, search and rescue	ARGOS, AVHRR/2, HIRS/2, MSU, NOAA Comms, SEM (POES), SSU	Type: Sun-synchronous Altitude: 850 km Period: 101.3 mins Inclination: 98.5 deg Repeat cycle: LST: 449 Longitude (if geo): Asc/desc: Descending URL: www.oso.noaa.gov/poes/
NOAA-14 (National Oceanic and Atmospheric Administration - 14) **NOAA**	Currently being flown	30 Dec 94	31 Dec 05	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, space environment, solar flux analysis, search and rescue	ARGOS, AVHRR/2, HIRS/2, MSU, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES), SSU	Type: Sun-synchronous Altitude: 850 km Period: 102.1 mins Inclination: 99.1 deg Repeat cycle: LST: 1752 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/
NOAA-15 (National Oceanic and Atmospheric Administration - 15) **NOAA**	Currently being flown	01 May 98	31 Dec 06	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, space environment, solar flux analysis, search and rescue	AMSU-A, AMSU-B, ARGOS, AVHRR/3, HIRS/3, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES)	Type: Sun-synchronous Altitude: 813 km Period: 101.4 mins Inclination: 98.6 deg Repeat cycle: LST: 708 Longitude (if geo): Asc/desc: Descending URL: www.oso.noaa.gov/poes/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
NOAA-16 (National Oceanic and Atmospheric Administration - 16) **NOAA**	Currently being flown	21 Sep 00	31 Dec 06	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue	AMSU-A, AMSU-B, ARGOS, AVHRR/3, HIRS/3, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES)	Type: Sun-synchronous Altitude: 870 km Period: 102 mins Inclination: 98.8 deg Repeat cycle: LST: 1354 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/
NOAA-17 (National Oceanic and Atmospheric Administration - 17) **NOAA**	Approved	10 Mar 05	30 Nov 08	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue	AMSU-A, ARGOS, AVHRR/3, HIRS/4, MHS, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES)	Type: Sun-synchronous Altitude: 870 km Period: 102.1 mins Inclination: 98.75 deg Repeat cycle: LST: 1400 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/
NOAA-N **(National Oceanic and Atmospheric Administration - N)** **NOAA**	Approved	11 Feb 05	30 Nov 08	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue	AMSU-A, ARGOS, AVHRR/3, HIRS/4, MHS, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES)	Type: Sun-synchronous Altitude: 870 km Period: 102.1 mins Inclination: 98.75 deg Repeat cycle: LST: 1400 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/
NOAA-N' (National Oceanic and Atmospheric Administration - N') **NOAA**	Approved	30 Nov 08	01 Dec 11	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue	AMSU-A, ARGOS, AVHRR/3, HIRS/4, MHS, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES)	Type: Sun-synchronous Altitude: 870 km Period: 102.1 mins Inclination: 98.75 deg Repeat cycle: LST: 1400 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/
NPOESS-1 (National Polar-orbiting Operational Environmental Satellite System - 1) **NOAA**	Approved	30 Nov 09	01 Nov 15	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	A-DCS, APS, CMIS, SARSAT, VIIRS	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.75 deg Repeat cycle: 2130 days LST: Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/
NPOESS-2 (National Polar-orbiting Operational Environmental Satellite System - 2) **NOAA**	Approved	30 Jun 11	01 Jun 17	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	A-DCS, ATMS, CERES, CMIS, CrIS, OMPS, S&R (NOAA), SARSAT, SESS, VIIRS	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.75 deg Repeat cycle: 1330 days LST: Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
NPOESS-3 (National Polar-orbiting Operational Environmental Satellite System - 3) **NOAA**	Approved	04 Jun 13	09 Jun 18	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	A-DCS, ALT, CMIS, ERBS, S&R (NOAA), SARSAT, SESS, TSIS, VIIRS	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.75 deg Repeat cycle: 1730 days LST: Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/
NPOESS-4 (National Polar-orbiting Operational Environmental Satellite System - 4) **NOAA**	Approved	01 Nov 15	06 Nov 20	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	A-DCS, APS, CMIS, SARSAT, SESS, VIIRS	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.75 deg Repeat cycle: 2130 days LST: Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/
NPOESS-5 (National Polar-orbiting Operational Environmental Satellite System - 4) **NOAA**	Approved	01 Jan 18	01 Jun 23	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	A-DCS, ATMS, CERES, CMIS, CrIS, OMPS, S&R (NOAA), SARSAT, SESS, VIIRS	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.75 deg Repeat cycle: 1330 days LST: Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/
NPOESS-6 (National Polar-orbiting Operational Environmental Satellite System - 4) **NOAA**	Approved	09 May 19	01 May 24	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection.	A-DCS, ALT, CMIS, ERBS, S&R (NOAA), SARSAT, SESS, TSIS, VIIRS	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 98.75 deg Repeat cycle: 1730 days LST: Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov/
NPP (NPOESS (National Polar-orbiting Operational Environmental Satellite System) Preparatory Project) **NOAA**	Approved	31 Oct 06	26 Oct 11	Meteorological, climatic, terrestrial, and oceanographic applications; global and regional environmental monitoring. (Joint mission with NASA)	ATMS, CrIS, OMPS, VIIRS	Type: Sun-synchronous Altitude: 833 km Period: 101 mins Inclination: 1030 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL: jointmission.gsfc.nasa.gov/
OCEANSAT-2 (Ocean satellite-2) **ISRO**	Planned	01 Jan 07	01 Jan 11	Ocean and atmosphere applications	OCM, Scatterometer (ISRO)	Type: Sun-synchronous Altitude: 720 km Period: 99.31 mins Inclination: 98.28 deg Repeat cycle: 2 days LST: 1200 Longitude (if geo): Asc/desc: Descending URL: www.isro.org/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
OCO (Orbiting Carbon Observatory) **NASA**	Planned	01 Aug 07	01 Aug 09	High resolution carbon dioxide measurements to characterize sources and sinks on regional scales and quantify their variability over the seasonal cycle	OCO	Type: Sun-synchronous Altitude: 705 km Period: 98.8 mins Inclination: 98.2 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: essp.gsfc.nasa.gov/oco/index.html
Odin **SNSB**	Currently being flown	20 Feb 01	30 Mar 05	Atmospheric research, stratospheric ozone chemistry, mesospheric ozone science, summer mesospheric science	OSIRIS, SMR	Type: Sun-synchronous Altitude: 590 km Period: 97.6 mins Inclination: 97.8 deg Repeat cycle: LST: 1800 Longitude (if geo): Asc/desc: Ascending URL: www.ssc.se
PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a LIDAR) **CNES**	Approved	18 Dec 04	18 Dec 06	Micro-satellite with the aim of characterisation of the clouds and aerosols microphysical and radiative properties, needed to understand and model the radiative impact of clouds and aerosols.	POLDER-P	Type: Sun-synchronous Altitude: 700 km Period: 98.8 mins Inclination: Repeat cycle: LST: 1200 Longitude (if geo): Asc/desc: TBD URL: smsc.cnes.fr/PARASOL/index.htm
PICARD **CNES**	Approved	06 Jan 08	01 Aug 10	Simultaneous measurements of solar diameter, differential rotation, solar constant, and variability	PREMOS, SODISM, SOVAP	Type: TBD Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: www-projet.cst.cnes.fr:8060/PICARD/index.html
Pleiades 1 **CNES**	Approved	01 Jul 08	01 Jul 13	Cartography, land use, risk, agriculture and forestry, civil planning and mapping, digital terrain models, defence	Pleiades HR	Type: Sun-synchronous Altitude: 694 km Period: Inclination: Repeat cycle: 26 days LST: 1015 Longitude (if geo): Asc/desc: Descending URL: smsc.cnes.fr/PLEIADES/Fr/index.htm
Pleiades 2 **CNES**	Approved	31 Dec 09	31 Dec 14	Cartography, land use, risk, agriculture and forestry, civil planning and mapping, digital terrain models, defence	Pleiades HR	Type: Sun-synchronous Altitude: 694 km Period: Inclination: Repeat cycle: LST: 1015 Longitude (if geo): Asc/desc: Descending URL: smsc.cnes.fr/PLEIADES/Fr/index.htm

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
QuikSCAT (Quick Scatterometer) **NASA**	Currently being flown	19 Jun 99	01 Oct 07	Acquires accurate, high-resolution, global measurements of sea-surface wind vectors in 1 to 2 day repeat cycles for studies of tropospheric dynamics and air-sea interaction processes, including air-sea momentum transfer. End of life date TBD	SeaWinds	Type: Sun-synchronous Altitude: 803 km Period: 101 mins Inclination: 98.6 deg Repeat cycle: LST: 600 Longitude (if geo): Asc/desc: Ascending URL: winds.jpl.nasa.gov/missions/quikscat/index.cfm
RADARSAT-1 (Radar satellite-1) **CSA**	Currently being flown	04 Nov 95	31 Dec 05	Environmental monitoring, physical oceanography, ice and snow, land surface	RADARSAT DTT, RADARSAT TTC, SAR (RADARSAT)	Type: Sun-synchronous Altitude: 798 km Period: 100.7 mins Inclination: 98.594 deg Repeat cycle: 24 days LST: 1800 Longitude (if geo): Asc/desc: Ascending URL: www.space.gc.ca/csa_sectors/earth_environment / radarsat/default.asp
RADARSAT-2 (Radar satellite-2) **CSA**	Approved	31 Dec 05	31 Dec 12	Environmental monitoring, physical oceanography, ice and snow, land surface	SAR (RADARSAT-2)	Type: Sun-synchronous Altitude: 798 km Period: 100.7 mins Inclination: 98.6 deg Repeat cycle: 24 days LST: 1800 Longitude (if geo): Asc/desc: Ascending URL: www.space.gc.ca/csa_sectors/earth_environment /radarsat2/default.asp
RapidEye (RapidEye) **DLR**	Approved	01 Jan 07	01 Jan 14	System of 5 satellites for cartography, land surface, digital terrain models, disaster management, environmental monitoring.	MSI	Type: Sun-synchronous Altitude: 600 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.rapideye.de/
RESOURCESAT-1 (Resource satellite-1) **ISRO**	Currently being flown	01 Oct 03	01 Oct 08	Natural Resources Management; Agricultural applications; Forestry	AWiFS, LISS-III, LISS-IV	Type: Sun-synchronous Altitude: 817 km Period: 102 mins Inclination: 98.72 deg Repeat cycle: 26 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
RESOURCESAT-2 (Resource satellite-2) **ISRO**	Planned	01 Jul 06	01 Jul 11	Natural Resources Management; Agricultural applications; Forestry	AWiFS, LISS-III, LISS-IV	Type: Sun-synchronous Altitude: 817 km Period: 102 mins Inclination: 98.72 deg Repeat cycle: 26 days LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Resurs DK **ROSKOSMOS**	Planned	01 Jun 05	31 Dec 08	Agriculture and forestry, hydrology, environmental monitoring, hydrometeorology, ice and snow, land surface, meteorology	Arina, Geoton-L1, Pamela	Type: Inclined, non-sunsynchronous Altitude: 480 km Period: Inclination: 70.4 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: sputnik1.infospace.ru/
RISAT-1 (Radar Imaging Satellite) **ISRO**	Approved	01 Jul 06	01 Jul 11	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils - especially during cloud season	SAR (RISAT)	Type: Sun-synchronous Altitude: 586 km Period: 96.5 mins Inclination: 12 deg Repeat cycle: 600 days LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
SAC-C **CONAE**	Currently being flown	21 Nov 00	31 Dec 05	Earth Observation, studies the structure and dynamics of the Earth's surface, atmosphere, ionosphere and geomagnetic field	GOLPE, HRTC, HSTC, ICARE, INES, IST, MMP, MMRS, WTE	Type: Sun-synchronous Altitude: 705 km Period: 98 mins Inclination: 98.2 deg Repeat cycle: 9 days LST: 1015 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAC-D/Aquarius **CONAE / NASA**	Approved	11 Sep 08	11 Sep 11	Earth observation studies; measurement of ocean salinity; emergency management	Aquarius, HSC, ICARE, MWR (CONAE), NIRST, ROSA, SODAD	Type: Sun-synchronous Altitude: 705 km Period: 98 mins Inclination: 98.2 deg Repeat cycle: 9 days LST: 1015 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAC-E/SABIA **CONAE**	Planned	21 Nov 09	01 Dec 14	Food production; environmental monitoring; inner coastal and water quality	MOC	Type: Sun-synchronous Altitude: 705 km Period: 98 mins Inclination: 98.2 deg Repeat cycle: 9 days LST: 1015 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAC-F **CONAE**	Planned	21 Nov 07	01 Dec 11	Earth observation studies; emergency management; landscape epidemiology	HRMS, HSMS, HSS, TIS (CONAE)	Type: Sun-synchronous Altitude: 705 km Period: 98 mins Inclination: 98.2 deg Repeat cycle: 9 days LST: 1015 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
SAOCOM 1A **CONAE**	Approved	01 Oct 07	01 Oct 11	Earth Observation and Emergency management with an L-band SAR	IR Camera (SAOCOM), SAR (SAOCOM)	Type: Sun-synchronous Altitude: 629 km Period: 96 mins Inclination: 98 deg Repeat cycle: 16 days LST: 600 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAOCOM 1B **CONAE**	Approved	01 Oct 08	01 Oct 12	Earth Observation and Emergency management with an L-band SAR	IR Camera (SAOCOM), SAR (SAOCOM)	Type: Sun-synchronous Altitude: 629 km Period: 96 mins Inclination: 98 deg Repeat cycle: 16 days LST: 600 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAOCOM-2B (1) **CONAE**	Planned	01 Oct 13	01 Oct 17	Earth Observation and Emergency management with an L-band SAR	IR Camera (SAOCOM), SAR (SAOCOM)	Type: Sun-synchronous Altitude: 629 km Period: 96 mins Inclination: 98 deg Repeat cycle: 16 days LST: 600 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SAOCOM-2B (2) **CONAE**	Planned	01 Oct 12	01 Oct 16	Earth Observation and Emergency management with an L-band SAR	IR Camera (SAOCOM), SAR (SAOCOM)	Type: Sun-synchronous Altitude: 629 km Period: 96 mins Inclination: 98 deg Repeat cycle: 16 days LST: 600 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar/
SCD-1 (Data Collecting Satellite 1) **INPE**	Currently being flown	09 Feb 93	01 Dec 05	Data collection and communication	DCP (SCD)	Type: Inclined, non-sunsynchronous Altitude: 750 km Period: 100 mins Inclination: 25 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: www.inpe.br/programas/mecb/default.htm
SCD-2 (Data Collecting Satellite 2) **INPE**	Currently being flown	22 Oct 98	01 Dec 05	Data collection and communication	DCP (SCD)	Type: Inclined, non-sunsynchronous Altitude: 750 km Period: 100 mins Inclination: 25 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: www.inpe.br/programas/mecb/default.htm

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
SCISAT-1 (SCISAT-I/ACE) **CSA**	Currently being flown	12 Aug 03	20 Dec 07	To improve our understanding of the depletion of the ozone layer, particularly over Canada and the Arctic	ACE-FTS, MAESTRO	Type: Sun-synchronous Altitude: 650 km Period: Inclination: 74 deg Repeat cycle: 15 days LST: Longitude (if geo): Asc/desc: TBD URL: www.space.gc.ca/scisat1
SICH-1M **NSAU / ROSKOSMOS**	Approved	24 Dec 04	31 Dec 07	Physical Oceanography, Hydrometeorology, Land Observation	MSU-EU, MSU-M, MTVZA-OK, RLSBO, RM-08	Type: Inclined, non-sunsynchronous Altitude: 650 km Period: 98 mins Inclination: 82.5 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL:
SICH-2 **NSAU**	Planned	31 Dec 05	31 Dec 10	Land Observation	MBEI, MIREI	Type: Sun-synchronous Altitude: 668 km Period: 98 mins Inclination: 98 deg Repeat cycle: 4 days LST: 1050 Longitude (if geo): Asc/desc: TBD URL:
SMOS (Soil Moisture and Ocean Salinity (Earth Explorer Opportunity Mission)) **ESA**	Approved	15 Feb 07	15 Feb 10	Overall objectives are to provide global observations of two crucial variables for modelling the weather and climate, Soil Moisture and Ocean Salinity. It will also monitor the vegetation water content, snow cover and ice structure.	MIRAS (SMOS)	Type: Sun-synchronous Altitude: 756 km Period: Inclination: 98.45 deg Repeat cycle: 165 days LST: 600 Longitude (if geo): Asc/desc: Ascending URL: www.esa.int/export/esaLP/smos.html
SORCE (Solar Radiation and Climate Experiment) **NASA**	Currently being flown	25 Jan 03	25 Jan 09	Continues the precise, long-term measurements of total solar irradiance at UV and VNIR wavelengths. Daily measurements of solar UV. Precise measurements of visible solar irradiance for climate studies.	SIM, SOLSTICE, TIM, XPS	Type: Inclined, non-sunsynchronous Altitude: 600 km Period: Inclination: 40 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: lasp.colorado.edu/sorce/
SPOT-2 (Satellite Pour l'Observation de la Terre - 2) **CNES**	Currently being flown	22 Jan 90	31 Dec 05	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring	DORIS, HRV	Type: Sun-synchronous Altitude: 832 km Period: 101 mins Inclination: 98.7 deg Repeat cycle: 26 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.spotimage.fr/html/_167_224_229_.php

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
SPOT-4 (Satellite Pour l'Observation de la Terre - 4) **CNES**	Currently being flown	24 Mar 98	31 Dec 05	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring	DORIS, HRVIR, VEGETATION	Type: Sun-synchronous Altitude: 832 km Period: 101 mins Inclination: 98.7 deg Repeat cycle: 26 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.spotimage.fr/html/_167_224_229_.php
SPOT-5 (Satellite Pour l'Observation de la Terre - 5) **CNES**	Currently being flown	04 May 02	04 May 07	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring	DORIS-NG, HRG, HRS, VEGETATION	Type: Sun-synchronous Altitude: 832 km Period: 101 mins Inclination: 98.7 deg Repeat cycle: 26 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: www.spotimage.fr/html/_167_224_229_.php
SSR-1 (Remote Sensing Satellite 1) **INPE**	Approved	01 Dec 07	01 Dec 11	Earth resources, environmental monitoring, land surface	OBA	Type: Inclined, non-sunsynchronous Altitude: 905 km Period: 103.2 mins Inclination: 0 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: www.inpe.br/programas/mecb/default.htm
SSR-2 (Remote Sensing Satellite 2) **INPE**	Planned	01 Dec 12	01 Dec 15	Earth resources, environmental monitoring, land surface	L-band SAR, OBA	Type: Inclined, non-sunsynchronous Altitude: 905 km Period: 103 mins Inclination: 0 deg Repeat cycle: 16 days LST: Longitude (if geo): Asc/desc: TBD URL: www.inpe.br/programas/mecb/default.htm
STARLETTE **CNES**	Currently being flown	06 Feb 75	31 Dec 50	Geodesy/gravity Study of the Earth's gravitational field and its temporal variations	Laser reflectors	Type: Inclined, non-sunsynchronous Altitude: 812 km Period: 104 mins Inclination: 49.83 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:
STELLA **CNES**	Currently being flown	30 Sep 93	31 Dec 50	Geodesy/gravity Study of the Earth's gravitational field and its temporal variations	Laser reflectors	Type: Inclined, non-sunsynchronous Altitude: 830 km Period: 101 mins Inclination: 98 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Swarm (Earth's Magnetic Field and Environment Explorer; Constellation of three satellites) **ESA**	Approved	01 Jan 09	01 Jan 13	To provide the best ever survey of the geomagnetic field and its temporal evolution, and gain new insights into improving our knowledge of the Earth's interior and climate.	ACC, ASM, EFI, GPS (ESA), STR, VFM	Type: Inclined, non-sunsynchronous Altitude: 450 km Period: Inclination: 87.4 deg Repeat cycle: LST: 600 Longitude (if geo): Asc/desc: URL: www.esa.int/export/esaLP/swarm.html
Terra (formerly EOS AM-1) **NASA**	Currently being flown	18 Dec 99	18 Dec 05	Atmospheric dynamics/water and energy cycles, Atmospheric chemistry, Physical and radiative properties of clouds, airland exchanges of energy, carbon and water, vertical profiles of CO and methane vulcanology	ASTER, CERES, MISR, MODIS, MOPITT	Type: Sun-synchronous Altitude: 705 km Period: 99 mins Inclination: 98.2 deg Repeat cycle: 16 days LST: 1030 Longitude (if geo): Asc/desc: Descending URL: terra.nasa.gov/
TerraSAR-L (TerraSAR L band) **BNSC**	Considered	01 Jan 06	01 Jan 11	SAR imagery in support of agriculture, forestry etc.	L-SAR	Type: TBD Altitude: 660 km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: www.infoterra-global.com/terrasar.html
TerraSAR-X (TerraSAR X band) **DLR**	Approved	27 Oct 05	01 Mar 11	Cartography, land surface, civil planning and mapping, digital terrain models, environmental monitoring.	TerraSAR-X	Type: Sun-synchronous Altitude: 514 km Period: 94.85 mins Inclination: 97.4 deg Repeat cycle: 11 days LST: 1800 Longitude (if geo): Asc/desc: Ascending URL: www.terrasar.de/
TES (Technology Experimental Satellite) **ISRO**	Currently being flown	22 Oct 01	31 Dec 05	For demonstrating many satellite technologies for future Cartosat satellites		Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL: www.isro.org/
THEOS (Thailand Earth Observation System) **GISTDA**	Approved	01 Jul 07	01 Jul 12	Earth Resources, Land surface and Disaster Monitoring, Civil Planning	MS (GISTDA), PAN (GISTDA)	Type: Sun-synchronous Altitude: 822 km Period: 101 mins Inclination: 98.7 deg Repeat cycle: 35 days LST: 1000 Longitude (if geo): Asc/desc: Descending URL: www.gistda.or.th

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics mission) **NASA**	Currently being flown	07 Dec 01	07 Dec 20	Investigates the influences of the sun and humans on the least explored and understood region of the Earth's atmosphere - the mesosphere and lower thermosphere/ ionosphere (MLTI)	SABER	Type: Inclined, non-sunsynchronous Altitude: 625 km Period: Inclination: 74.1 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.timed.jhuapl.edu/
Topex-Poseidon (Topographic Experiment/Poseidon) **NASA / CNES**	Currently being flown	10 Aug 92	01 Oct 05	Physical oceanography, geodesy/gravity	DORIS, GPSDR, LRA, POSEIDON-1 (SSALT-1), TMR, TOPEX	Type: Inclined, non-sunsynchronous Altitude: 1336 km Period: 112.4 mins Inclination: 66 deg Repeat cycle: 10 days LST: Longitude (if geo): Asc/desc: N/A URL: topex-www.jpl.nasa.gov/mission/tp-launch.html
TopSat (Optical Imaging Satellite) **BNSC**	Approved	01 May 05	01 May 06	Prototype low-cost high-resolution imager	TOPSAT telescope	Type: Sun-synchronous Altitude: 600 km Period: Inclination: 98 deg Repeat cycle: LST: 1030 Longitude (if geo): Asc/desc: TBD URL: www.qinetiq.com/industries/space/ spacecraft_technology/case_study_topsat/index.asp
UARS (Upper Atmosphere Research Satellite) **NASA**	Currently being flown	15 Sep 91	30 Apr 05	Atmospheric chemistry (middle to upper atmosphere), atmospheric dynamics/water and energy cycles. HALOE, HRDI, MLS, PEM instruments still functioning. End date TBD.	ACRIM II, CLAES, HALOE, HRDI, ISAMS, PEM, SOLSTICE, SUSIM (UARS), WINDII	Type: Inclined, non-sunsynchronous Altitude: 585 km Period: 95.9 mins Inclination: 57 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: umpgal.gsfc.nasa.gov/uars-science.html
UK-DMC (UK Disaster Monitoring Constellation) **BNSC**	Currently being flown	27 Sep 03	31 Dec 06	Medium resolution visible imager for support of disaster management	DMC Imager	Type: TBD Altitude: 785 km Period: Inclination: 98.2 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: TBD URL: www.sstl.co.uk/index.php?loc=113
Vulkan-Kompas-2 **ROSKOSMOS**	Planned	01 Jan 05	31 Dec 06	Monitoring of Earth's seismic activity for earthquake and volcanic eruption forecasting	DRF, GID-12T, NVK, RBE, RCHA	Type: Inclined, non-sunsynchronous Altitude: 500 km Period: Inclination: 79 deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.federalspace.ru

9 Catalogue of satellite instruments

This section contains an alphabetical list of all instruments on the missions listed in section 8. For each instrument the following information is given:

Instrument name	Instrument acronym Full instrument name
Missions	A list of missions that the instrument is expected to fly on
Status	Short description of the status of the instrument (eg whether being developed or currently operational)
Type	Instrument type – using the categories outlined in section 6
Measurements/ applications	Primary measurements and applications of the instrument
Technical characteristics	Waveband Spatial resolution Swath width Accuracy

The descriptions of waveband adopt the following conventions for defining which parts of the spectrum are measured:

Frequency		Acronym	Wavelength range	
Region	**Sub-region**		**from**	**to**
Ultraviolet		UV	~0.01μm	~0.40μm
Visible		VIS	~0.40μm	~0.75μm
Infrared	Near Infrared	NIR	~0.75μm	~1.3μm
	Short Wave Infrared	SWIR	~1.3μm	~3.0μm
	Mid Wave Infrared	MWIR	~3.0μm	~6.0μm
	Thermal Infrared	TIR	~6.0μm	~15.0μm
	Far Infrared	FIR	~15.0μm	~0.1cm
Microwave		MW	~0.1cm	~100cm

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
AATSR Advanced Along-Track Scanning Radiometer BNSC	Envisat	Operational	Imaging multi-spectral radiometers (vis/IR) & Multiple direction/ polarisation radiometers	Measurements of sea surface temperature, land surface temperature, cloud top temperature, cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content	Waveband: VIS - NIR: 0.555, 0.659, 0.865µm,SWIR: 1.6µm, MWIR: 3.7µm, TIR: 10.85, 12µm Spatial resolution: IR ocean channels: 1km x 1km, Visible land channels: 1km x 1km Swath width: 500 km Accuracy: Sea surface temperature: <0.5K over 0.5 deg x 0.5 deg (lat/long) area with 80% cloud cover Land surface temperature: 0.1K (relative)
ABI Advanced Baseline Imager NOAA	GOES-R	Approved	Imaging multi-spectral radiometers (vis/IR)	Measures cloud cover, atmospheric radiance, winds, atmospheric stability, rainfall estimates. Used to provide severe storm warnings/ monitoring day and night (type, amount, storm features)	The GOES-R Project is in the formulation phase. The satellite will comprise improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.
ACC Accelerometer ESA	Swarm	Operational	Gravity & Space environment	Measures the non-gravitational accelerations, caused for example by air-drag, winds, Earth albedo and solar radiation pressure acting on the satellites. In-situ air density measurements together with magnetic data can be used to obtain new insights on the geomagnetic forcing of the upper atmosphere.	Waveband: N/A Spatial resolution: 0.1nm/s2 Swath width: N/A Accuracy: 0.1nm/s2
ACE-FTS Atmospheric Chemistry Experiment (ACE) mission CSA	SCISAT-1	Operational	Atmospheric chemistry	Objective is to measure and understand the chemical processes that control the distribution of ozone in the Earth's atmosphere, especially at high altitudes.	Waveband: SWIR - TIR: 2 - 5.5 µm, 5.5 - 13 µm ($0.02cm^{-1}$ resolution) Spatial resolution: Swath width: Accuracy:
ACRIM II Active Cavity Radiometer Irradiance Monitor NASA	UARS	Not operational	Earth radiation budget radiometer	Measurements of solar luminosity and solar constant. Data used as record of ime variation of total solar irradiance, from extreme UV through to infra-red	Waveband: UV-FIR:1nm-50µm Spatial resolution: Not applicable Swath width: Not applicable Accuracy: Measures integrated flux of solar radiation to <0.1%
ACRIM III Active Cavity Radiometer Irradiance Monitor NASA	ACRIMSAT	Operational	Earth radiation budget radiometer	Measurements of solar luminosity and solar constant. Data used as record of time variation of total solar irradiance, from extreme UV through to infra-red	Waveband: UV - MWIR: 0.15 - 5 µm Spatial resolution: 5 deg FOV Swath width: 55 mins per orbit of full solar disk data Accuracy: 0.1% of full scale
A-DCS ARGOS-Data Collection System NOAA	NPOESS-1, NPOESS-2, NPOESS-3, NPOESS-4, NPOESS-5, NPOESS-6	Being developed	Data collection	Data collection and communication system for receiving and retransmitting data from ocean and land-based remote observing platforms/transponders	The Argos DCS is a data collection relay system and not an Earth observing instrument.

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
AIRS Atmospheric Infra-red Sounder NASA	Aqua	Operational	Atmospheric temperature and humidity sounders	High spectral resolution measurement of temperature and humidty profiles in the atmosphere. Long-wave Earth surface emissivity. Cloud diagnostics. Trace gas profiles. Surface temperatures.	Waveband: VIS - TIR: 0.4 - 1.7µm, 3.4 - 15.4µm, Has approximately 2382 bands from VIS to TIR Spatial resolution: 1.1 degree (13X13 Km at nadir) Swath width: +/-48.95 degrees Accuracy: Humidity: 20%, Temperature: 1K
ALADIN Atmospheric Laser Doppler Instrument ESA	ADM-Aeolus	Prototype	Lidars	Primary objective is to provide wind profile measurements for an improved analysis of global 3-D wind fields. Measures Doppler shift information from molecules and particles advected by the wind	Waveband: UV: 355nm Spatial resolution: 50km (footprint: 70m) Swath width: Accuracy: $0.5ms^{-1}$(0 to 2km), $1ms^{-1}$(2 to 16km), $2ms^{-1}$ (above 16km)
ALI Advanced Land Imager NASA	NMP EO-1	Operational	High resolution optical imagers	Measurement of Earth surface reflectance. Will validate new technologies contributing to cost reduction and increased capabilities for future missions. ALI comprises a wide field telescope and multispectral and panchromatic instrument	Waveband: 10 bands: VIS&NIR: 0.480-0.690µm, 0.433-0.453µm, 0.450-0.515µm, 0.525-0.605µm, 0.630-0.690µm, 0.775-0.805µm, 0.845-0.890µm, 1.200-1.300µm, SWIR: 1.550-1.750µm, 2.080-2.350µm Spatial resolution: PAN: 10m, VNIR&SWIR: 30m Swath width: 37km Accuracy: SNR @ 5% surf refl Pan:220, Multi 1: 215, Multi 2: 280, Multi 3: 290, Multi 4:240, Multi 4':190, Multi 5':130, Multi 5:175, Multi 7:170 (prototype instrument exceeds ETM+ SNR by a factor of 4 - 8)
ALT Altimeter NOAA	NPOESS-3, NPOESS-6	Being developed	Radar altimeters	Obtains precise altimeter height measurements over world's oceans	Waveband: 13.6 and 5.3 GHZ Spatial resolution: Along track 15km Swath width: 15km Accuracy: SST height 4cm
AMI/SAR/Image Active Microwave Instrumentation. Image Mode ESA	ERS-2	Operational	Imaging microwave radars	All-weather images of ocean, ice and land surfaces. Monitoring of coastal zones, polar ice, sea state, geological features, vegetation (including forests), land surface processes, hydrology.	Waveband: Microwave: 5.3 GHz, C band, VV polarisation, bandwidth 15.5 ± 0.06 MHz Spatial resolution: 30m Swath width: 100km Accuracy: Landscape topography: 3m, Bathymetry: 0.3m, Sea ice type: 3 classes
AMI/SAR/wave Active Microwave Instrumentation. Wave mode ESA	ERS-2	Operational	Imaging microwave radars	Provides measurements of ocean wave spectra	Waveband: Microwave: 5.3GHz (C-band), VV polarisation Spatial resolution: 30m Swath width: Accuracy: Sea surface wind speed: 3m/s, Significant wave height: 0.2m

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
AMI/scatterometer Active Microwave Instrumentation. Wind mode ESA	ERS-2	Operational	Scatterometers	Provides measurements of wind fields at the ocean surface, wind direction (range 0-360 deg), wind speed (range 1m/s - 30m/s)	Waveband: Microwave: 5.3GHz (C-band), VV polarisation Spatial resolution: Cells of 50km x 50km at 25km intervals Swath width: 500km Accuracy: Sea surface wind speed: 3m/s, Sea ice type: 2 classes
AMSR follow-on Advanced Microwave Scanning Radiometer follow-on JAXA	GCOM-W	Prototype	Imaging multi-spectral radiometers (passive microwave)	Provides measurements of water vapour, cloud liquid water, precipitation, winds, sea surface temperature, sea ice concentration, snow cover, soil moisture	Waveband: Microwave: 6.925, 10.65, 18.7, 23.8, 36.5, 50.3, 52.8, 89.0 GHz Spatial resolution: 5-50km (dependent on frequency) Swath width: 1600km Accuracy: Sea surface temparature: 0.5K, Sea ice cover: 10%, Cloud liquid water: 0.05kg/m2, Precipitation rate: 10%, Water vapour: 3.5kg/m2 through total column, Sea surface wind speed 1.5m/s
AMSR-E Advanced Microwave Scanning Radiometer-EOS JAXA (NASA)	Aqua	Prototype	Imaging multi-spectral radiometers (passive microwave)	Provides measurements of water vapour, cloud liquid water, precipitation, winds, sea surface temperature, sea ice concentration, snow cover and soil moisture	Waveband: Microwave: 6.925, 10.65, 18.7, 23.8, 36.5, 89.0 GHz Spatial resolution: 5-50km (dependent on frequency) Swath width: 1445km Accuracy: Sea surface temparature: 0.5K, Sea ice cover: 10%, Cloud liquid water: 0.05kg/m2, Precipitation rate: 10%, Water vapour: 3.5kg/m2 through total column, Sea surface wind speed 1.5m/s
AMSU-A Advanced Microwave Sounding Unit-A NOAA (BNSC)	Aqua, METOP-1, METOP-2, METOP-3, NOAA-15, NOAA-16, NOAA-17, NOAA-N, NOAA-N'	Operational	Atmospheric temperature and humidity sounders	Provides all weather night-day temperature sounding to an altitude of 45km	Waveband: Microwave: 15 channels, 23.8-89.0GHz Spatial resolution: 48km Swath width: 2054km Accuracy: Temperature profile: 2K, Humidity: 3kg/m2, Ice & snow cover: 10%
AMSU-B Advanced Microwave Sounding Unit-B NOAA (BNSC)	NOAA-15, NOAA-16, NOAA-17	Operational	Atmospheric temperature and humidity sounders	Provides all weather night-day humidity sounding	Waveband: Microwave: 89GHz, 150GHz, 183.3± 1.0 GHz (2bands), 183.3± 3.0 GHz (2bands), 183.3± 7.0 GHz (2bands) Spatial resolution: 16km Swath width: 2200km Accuracy: Humidity profile: 1kg/m2,
APS Aerosol Polarimetry Sensor NOAA	Glory, NPOESS-1, NPOESS-4	Proposed	Atmospheric chemistry	Global distribution of natural and anthropogenic aerosols for quantification of the aerosol effect on climate, the anthropogenic component of this effect, and the long-term change of this effect caused by natural and anthropogenic factors	Waveband: Microwave: 89GHz, 150GHz, 183.3± 1.0 GHz (2bands), 183.3± 3.0 GHz (2bands), 183.3± 7.0 GHz (2bands) Spatial resolution: 16km Swath width: 2200km Accuracy: Humidity profile: 1kg/m2,

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
Aquarius NASA (CONAE)	SAC-D/ Aquarius	Proposed	Imaging multi-spectral radiometers (passive microwave) & Scatterometers	The Aquarius mission will measure global sea surface salinity with unprecedented resolution. The instruments include a set of three radiometers that are sensitive to salinity (1.413 GHz; L-band). The scatterometer corrects for the ocean's surface roughness.	Waveband: L Band (1.413-1.260 GHz Spatial resolution: 100km Swath width: 300km Accuracy: . 2 psu
ARGOS CNES (NASA)	METOP-1, METOP-2, NOAA-12, NOAA-14, NOAA-15, NOAA-16, NOAA-17, NOAA-N, NOAA-N'	Operational	Data collection & Precision orbit	Provides location data by Doppler measurements	The Argos DCS is a data collection relay system and not an Earth observing instrument.
Arina ROSKOSMOS	Resurs DK		Space Environment	Space particle detection experiment	Arina is an instrument for observation of solar magnetosphere variations of charged particle fluxes.
ASAR Advanced Synthetic-Aperture Radar ESA	Envisat	Operational	Imaging microwave radars	Provides all weather images of ocean, land and ice for monitoring of land surface processes, sea and polar ice, sea state, and geological and hydrological applications. Has 2 stripmap modes (Image and Wave (for ocean wave spectra)) and 3 ScanSAR modes	Waveband: Microwave: C-band, with choice of 5 polarisation modes (VV, HH, VV/HH, HV/HH, or VH/VV) Spatial resolution: Image, wave and alternating polarisation modes: approx 30m x 30m, Wide swath mode: 150m x 150m, Global monitoring mode: 950mm x 950m Swath width: Image and alternating polarisation modes: up to 100km, Wave mode: 5km, Wide swath and global monitoring modes: 400km or more Accuracy: Radiometric resolution in range: 1.5-3.5 dB, Radiometric accuracy: 0.65 dB
ASAR (image mode) Advanced Synthetic Aperture Radar (Image mode) ESA	Envisat	Operational	Imaging microwave radars	Provides all weather images of ocean, land and ice for monitoring of land surface processes, sea and polar ice, sea state, and geological and hydrological applications	See above.
ASAR (wave mode) Advanced Synthetic Aperture Radar (Wave mode) ESA	Envisat	Operational	ASAR (wave mode) Advanced Synthetic Aperture Radar (Wave mode) ESA	Provides measurements of ocean wave spectra	See above.

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
ASCAT Advanced Scatterometer EUMETSAT (ESA)	METOP-1, METOP-2, METOP-3	Being developed	Scatterometers	Provides sea ice cover, sea ice type and wind speed over sea surface measurements. Air pressure over ocean, Polar ice contours, Ice/snow imagery, Soil moisture	Waveband: Microwave: C Band, 5.256Ghz Spatial resolution: Hi-res mode: 25-37km, Nominal mode: 50km Swath width: Continuous Accuracy: Wind speeds in range 4-24m/s: 2m/s and direction accuracy of 20deg
ASM Absolute Scalar Magnetometer ESA (CNES)	Swarm	Being developed	Magnetic field	The objective of the Absolute Scalar Magnetometer (ASM) is to calibrate the vector field magnetometer (VFM) to maintain the absolute accuracy in the multi-year geomagnetic field mission	Waveband: N/A Spatial resolution: 0.016pT Swath width: N/A Accuracy: 0.3nT
ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer METI (Japan) (NASA)	Terra	Operational	High resolution optical imagers	Surface and cloud imaging with high spatial resolution, stereoscopic observation of local topography, cloud heights, volcanic plumes, and generation of local surface digital elevation maps. Surface temperature and emissivity	Waveband: VIS&NIR: 3 bands in 0.52-0.86µm, SWIR: 6 bands in 1.6-2.43µm, TIR: 5 bands in 8.125-11.65µm Spatial resolution: VNIR: 15m, stereo: 15m horizontally and 25m vertical, SWIR: 30m, TIR: 90m Swath width: 60km Accuracy: VNIR and SWIR: 4% (absolute), TIR: 4K, Geolocation: 7m
ATLID ATmospheric LIDar ESA	ESA Future Missions	Prototype	Lidars	Provides measurements of cloud top heights, aerosol properties, troposphere height, vertical distribution of cloud, boundary layer height	Waveband: UV: 355nm Spatial resolution: footprint: 30m Swath width: Nadir Accuracy: Detection of cirrus cloud with optical thickness 1 with 15% error
ATMS Advanced Technology Microwave Sounder NOAA (NASA)	NPOESS-2, NPOESS-5, NPP	Approved	Atmospheric temperature and humidity sounders	Collects microwave radiance data that when combined with the CrIS data will permit calculation of atmospheric temperature and water vapor profiles	Waveband: Microwave: 22 bands, 23-184 GHz Spatial resolution: 5.2 deg - 1.1 deg Swath width: 2300 km Accuracy: 0.75 K - 3.60 K
ATSR/M CNES	ERS-2	Operational	Imaging multi-spectral radiometers (passive microwave)	Part of the ATSR payload on board ERS1 and ERS2	See ATSR-2.
ATSR-2 Along Track Scanning Radiometer - 2 BNSC (CSIRO)	ERS-2	Operational	Imaging multi-spectral radiometers (vis/IR) & Multiple direction/ polarisation radiometers	Provides measurements of sea surface temperature, land surface temperature, cloud top temperature and cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content	Waveband: VIS-SWIR: 0.65, 0.85, 1.27, and 1.6µm, SWIR-TIR: 1.6, 3.7, 11 and 12µm, Microwave: 23.8, 36.5GHz (bandwidth of 400MHz) Spatial resolution: IR ocean channels: 1km x 1km, Microwave near-nadir viewing: 20km instantaneous field of view Swath width: 500km Accuracy: Sea surface temperature to <0.5K over 0.5 deg x 0.5 deg (lat/long) area with 80% cloud cover, Land surface temperature: 0.1K

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
AVHRR/2 Advanced Very High Resolution Radiometer/2 NOAA	NOAA-12, NOAA-14	Operational	Imaging multi-spectral radiometers (vis/IR)	Provides measurements of land and sea surface temperature, cloud cover, snow and ice cover, soil moisture and vegetation indices. Data also used for volcanic eruption monitoring	Waveband: VIS: 0.58-0.68μm, NIR: 0.725-1.1μm, MWIR: 3.55-3.93μm, TIR: 10.3-11.3μm, 11.5-12.5μm Spatial resolution: 1.1km Swath width: 3000km approx Accuracy:
AVHRR/3 Advanced Very High Resolution Radiometer/3 NOAA	METOP-1, METOP-2, METOP-3, NOAA-15, NOAA-16, NOAA-17, NOAA-N, NOAA-N'	Operational	Imaging multi-spectral radiometers (vis/IR)	Provides measurements of land and sea surface temperature, cloud cover, snow and ice cover, soil moisture and vegetation indices. Data also used for volcanic eruption monitoring	Waveband: VIS: 0.58-0.68μm, NIR: 0.725-1.1μm, SWIR: 1.58-1.64μm, MWIR: 3.55-3.93μm, TIR: 10.3-11.3μm, 11.5-12.5μm Spatial resolution: 1.1km Swath width: 3000km approx, Ensures full global coverage twice daily Accuracy:
AVNIR-2 Advanced Visible and Near Infra-red Radiometer type 2 JAXA	ALOS	Being developed	High resolution optical imagers	High resolution multi-spectral imager for land applications which include environmental monitoring, agriculture and forestry, disaster monitoring	Waveband: VIS: 0.42-0.50μm, 0.52-0.60μm, 0.61-0.69μm, NIR: 0.76-0.89μm Spatial resolution: 10m Swath width: 70km Accuracy:
AWiFS Advanced Wide Field Sensor ISRO	RESOURCE-SAT-1, RESOURCE-SAT-2	Operational	High resolution optical imagers	Vegetation and crop monitoring, resource assessment (regional scale), forest mapping, land cover/ land use mapping, and change detection	Waveband: VIS: 0.52-0.59 & 0.62-0.68μm, NIR:0.77-0.86μm, SWIR: 1.55-1.7μm Spatial resolution: 55m Swath width: 730km Accuracy: 10 bit data
BISSAT Bissat Passive Radar ASI	BISSAT	TBD	Imaging microwave radars	Evaluation of bistatic radar cross section of natural and man-made targets, image classification, land surface. Passive instrument flown with main SAR mission	Waveband: Microwave: X-band (passive) Spatial resolution: Swath width: Accuracy:
CALIOP Cloud-Aerosol Lidar with Orthogonal Polarization NASA	CALIPSO	Approved	Lidars	Two-wavelength, polarization lidar capable of providing aerosol and cloud profiles and properties	Waveband: 532 nm (polarization-sensitive), 1064 nm, VIS - NIR Spatial resolution: Vertical sampling: 30 m, 0 – 40 km Swath width: 333 m along-track Accuracy: 5% (532 nm)
CCD (CBERS) High Resolution CCD Camera CAST (INPE)	CBERS-2, CBERS-2B	Operational	High resolution optical imagers	Provides measurements of cloud type and extent and land surface reflectance, and used for global land surface applications	Waveband: VIS: 0.45-0.52μm, 0.52-0.59μm, 0.63-0.69μm, NIR: 0.77-0.89μm, PAN: 0.51-0.71μm Spatial resolution: 20m Swath width: 113km Accuracy:
CCD (HJ, HY) CCD camera CAST	HJ-1A, HJ-1B		High resolution optical imagers	Land surface applications	Waveband: 0.43-0.90μm Spatial resolution: 30m Swath width: 360km (per set)700km (two sets) Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
CCD camera ISRO	INSAT-2E, INSAT-3A	Operational	Imaging multi-spectral radiometers (vis/IR)	Cloud and Vegetation monitoring	Waveband: VIS: 0.62-0.68µm, NIR: 0.77-0.86µm, SWIR: 1.55-1.69µm Spatial resolution: 1X1km Swath width: Normal: 6000km (N-S) X 6000km (E-W) anywhere on earth disc, Program: 6000km (N-S) X (n X 300) km (E-W) : n and number of frames programmable Accuracy:
CERES Cloud and the Earth's Radiant Energy System NASA	Aqua, NPOESS-2, NPOESS-5, Terra	Operational	Earth radiation budget radiometer	Long term measurement of the Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface; provision of an accurate and self-consistent cloud and radiation database	Waveband: 3 channels: 0.3-5 µm, 0.3 - 100 µm, 8-12 µm, UV-FIR Spatial resolution: 20km Swath width: Accuracy: 0.5%, 1%, 1% (respectively for the 3 channels)
CHAMP GPS Sounder GPS TurboRogue Space Receiver (TRSR) NASA (DLR)	CHAMP	Operational	Atmospheric temperature and humidity sounders & Precision orbit	Temperature and water vapour profiles	Uses GPS frequencies for sounding of temperature and water profiles of the atmosphere. CHAMP provides temperature profiles in the troposphere up to the middle stratosphere, and water vapour profiles in the troposphere only.
CHAMP gravity package (Accelerometer+GPS) STAR Accelerometer CNES (DLR)	CHAMP	Operational	Gravity	Earth gravity field measurements	Since the advent of CHAMP, the first in a series of low-altitude satellites being almost continuously and precisely tracked by GPS, a new generation of long-wavelength gravitational geopotential models have been derived.
CHAMP magnetometry package (1 Scalar + 2 Vector Magnetometer) Overhauser Magnetometer and Fluxgate Magnetometer DLR	CHAMP	Operational	Magnetic field	Earth gravity field measurements	A high performance Fluxgate magnetometer set measuring the three components of the ambient magnetic field in the instrument frame combined with a star camera determining the attitude of the assembly with respect to a stellar frame and a Overhauser scalar magnetometer serving as magnetic reference.
CIA Advanced Hyperspectral camera ASI	Hyperspectral Mission		Imaging multi-spectral radiometers (vis/IR)	Pancromatic and Hyperspectral data for complex land ecosystem studies	Waveband: HYC spectral range + MIR and TIR channels Spatial resolution: Improved (wrt HYC) resolution PAN 2-3m Swath width: Greater swath Accuracy:
CLAES Cryogenic Limb Array Etalon Spectrometer instrument NASA	UARS	Not operational	Earth radiation budget radiometer	Measures many of the chemical species which are involved in stratospheric chemistry as well as global distribution of statospheric aerosols	Waveband: SWIR: 3.5µm, 6µm, TIR: 8µm, 12.7µm Spatial resolution: Vert 2.8km, Horiz 480km Swath width: 50.7km vert limb Accuracy: 20%, 3K
Cloud Sensor Cloud and aerosol sensor JAXA	GOSAT		Cloud profile and rain radars	Will contribute to GOSAT main mission of CO2 profile measurement - which requires detection and removal of contaminating signals from clouds and aerosols	No data yet available.

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
CMIS Conical-scanning Microwave Imager/Sounder NOAA	NPOESS-1, NPOESS-2, NPOESS-3, NPOESS-4, NPOESS-5, NPOESS-6	Being developed	Imaging multi-spectral radiometers (passive microwave) & Atmospheric temperature and humidity sounders	Collects microwave radiometry and sounding data. Data types include atmospheric temperature and moisture profiles, clouds, sea surface winds, and all-weather land/water surfaces.	Waveband: Microwave: 190Ghz Spatial resolution: 15-50km depending on frequency Swath width: 1700km Accuracy: Temperature Profiles to 1.6K, water vapor 20%
COCTS Ocean colour scanner CAST	HY-1B	Being developed	Ocean colour instruments	Ocean chlorophyll, Ocean yellow substance absorbance, Sea-ice surface temperature	Waveband: B1: 0.402-0.422, B2: 0.433-0.453, B3: 0.480-0.500, B4: 0.510-0.530, B5: 0.555-0.575, B6: 0.660-0.680, B7: 0.740-0.760, B8: 0.845-0.885, B9: 10.30-11.40, B10: 11.40-12.50µm Spatial resolution: 1.1km Swath width: 3083km Accuracy:
Communications payload (Ka and UHF band) CSIRO	FedSat	Operational	Communications		Waveband: up 313.55MHz, down 400.4MHz
CPR Cloud Profiling Radar ESA	ESA Future Missions	Prototype	Cloud profile and rain radars	Measures cloud characteristics including base height	Waveband: Microwave: 94GHz Spatial resolution: 750m Swath width: nadir only Accuracy: 98% detection of radiatively significant ice cloud
CPR (Cloudsat) Cloud Profiling Radar NASA	CloudSat	Approved	Cloud profile and rain radars	Primary goal is to provided data needed to evaluate and improve the way clouds are represented in global climate models. Measures vertical profile of clouds	Waveband: Microwave: 94Ghz Spatial resolution: Vertical: 500m, Cross-track: 1.4km, Along-track: 2.5km Swath width: Instantaneous Footprint < 2km Accuracy: Cloud liquid water content<=50%; ice water content within +100%, -50%; detect all single layer clouds with optical depth>=1.0
CrIS Cross-track Infrared Sounder NOAA (NASA)	NPOESS-2, NPOESS-5 NPP	Prototype	Atmospheric temperature and humidity sounders	Daily measurements of vertical atmospheric distribution of temperature, moisture, and pressure	Waveband: MWIR-TIR: 3.92-4.4µm, 5.7-8.62µm, 9.1-14.7µm, 1300 spectral channels Spatial resolution: IFOV 14km diameter, 1km vertical layer resolution Swath width: 2200km Accuracy: Temperature profiles: to 0.9K, Moisture profiles: 20-35%, Pressure profiles: 1%
CZI Coast region imager CAST	HY-1B	Being developed	Imaging multi-spectral radiometers (vis/IR)	Coastal Zone monitoring and environmental applications	Waveband: B1: 0.433-0.453, B2: 0.555-0.575, B3: 0.655-0.675, B4: 0.675-0.695_m Spatial resolution: 250m Swath width: 500km Accuracy:
DCP (SCD) Data Collecting Platform Transponder INPE	SCD-1, SCD-2	Operational	Data collection	Environmental data collection from ground based data collecting platforms	Data collection and relay system.

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
DCS (CAST) Data Collecting System Transponder (CAST) CAST	SCD-1, SCCBERS-2, CBERS-2B, CBERS-3, CBERS-4D-2	Operational	Data collection	Data collection and communication	Data collection and relay system.
DCS (JAXA) Data Collection System (JAXA) JAXA	GMS-5	Prototype	Data collection	Data Collection System, Receives in-situ data from data collection platforms worldwide and transmits to ground station	Data collection and relay system.
DCS (NOAA) Data Collection System (NOAA) NOAA	GOES-9, GOES-10, GOES-11, GOES-12, GOES-N, GOES-O, GOES-P, GOES-R	Operational	Data collection	Collects data on temperature (air/water), atmospheric pressure, humidity and wind speed/direction, speed and direction of ocean and river currents	Data collection and relay system.
DCS (ROSHYDROMET) Data Collection System ROSHYDROMET (ROSKOSMOS)	Elektro-L, METEOR-3M N2	Operational	Data collection	Collects data on temperature (air/water), atmospheric pressure, humidity and wind speed/direction, speed and direction of ocean and river currents	Data collection and relay system.
DMC Imager Disaster Management Constellation Imager BNSC	UK-DMC	Operational	High resolution optical imagers	Visible and NIR imagery in support of disaster management	Waveband: VIS and NIR Spatial resolution: 32m Swath width: 2 beams of 300km Accuracy:
DORIS Doppler Orbitography and Radio-positioning Integrated by Satellite CNES	SPOT-2, SPOT-4, Topex-Poseidon	Operational	Precision orbit	Orbit determination	Waveband: Spatial resolution: Swath width: Accuracy: Orbit error ~2.5cm
DORIS-NG Doppler Orbitography and Radio-positioning Integrated by Satellite-NG CNES	CRYOSAT, Envisat, Jason, Jason-2 (also known as OSTM), SPOT-5	Operational	Precision orbit	Precise orbit determination Real time onboard orbit determination (navigation)	Waveband: 401.25MHz, 2036.25MHz Spatial resolution: Swath width: FOV :130 degrees Accuracy: Orbit error ~1cm
DPR Dual-frequency Precipitation Radar JAXA (NASA)	GPM Core	TBD	Cloud profile and rain radars	Measures rain rate classified by rain and snow, in latitudes up to 70 degrees	Waveband: Microwave: 13.6 GHz (Ku band) and 35.5 GHz (Ka band) Spatial resolution: Range resolution: 4-5 km Horizontal Swath width: 245 km (Ku-band), 100km (Ka band) Accuracy: rainfall rate 0.2mm/h
DRF ROSKOSMOS	Vulkan-Kompas-2		Space Environment	Space radiation and ultraviolet measurements	Waveband: UV: 0.2-0.35µm, Ee>30keV, Ep>7keV Spatial resolution: Swath width: Accuracy:
ECHO-V ROSKOSMOS	Kanopus-Vulkan		Space Environment	Space particle detection experiment	Waveband: Ee 3-30MeV, Ee 30-100MeV Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
EFI Electric Field Instrument ESA (CSA)	Swarm	Being developed	Gravity & Space environment	Measures ion density, drift velocity and electric field	Waveband: N/A Spatial resolution: 0.3mV/m Swath width: N/A Accuracy: <3mV/m
EGG 3-Axis Electrostatic Gravity Gradiometer ESA	GOCE	Being developed	Gravity & Precision orbit	The main objective of EGG is to measure the 3 components of the gravity-gradient tensor (ie gradiometer data)	Designed specifically for determining the stationary gravity field. The measured signal is the difference in gravitational acceleration at the test-mass location inside the spacecraft caused by gravity anomalies from attracting masses of the Earth.
EHIS Energetic Heavy Ion Sensor NOAA	GOES-R	Approved	Space Environment	Space particle detection	The GOES-R Project is in the formulation phase. The satellite will comprise improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.
ENVISAT Comms Communications package on ENVISAT ESA	Envisat	Operational	Communications	Communication package onboard ENVISAT series satellites	Data communication only.
EOC Electro-Optical Camera KARI	KOMPSAT-1	Operational	High resolution optical imagers	High resolution stereo imager for land applications of cartography and disaster monitoring	Waveband: Panchromatic VIS: 0.51-0.73µm Spatial resolution: 6.6m Swath width: 17km Accuracy:
EPIC Earth PolyChromatic Imaging Camera NASA	DSCOVR	Proposed	Atmospheric chemistry	Measures ozone amounts, aerosol amounts, cloud height and phase, hotspot land properties, and UV radiation estimates at the Earth's surface	Waveband: UV-NIR: 0.317-0.905µm 10 bands Spatial resolution: 8km Swath width: Accuracy:
ERBE Earth Radiation Budget Experiment (non-scanner) NASA	ERBS	Operational	Earth radiation budget radiometer	Radiation budget measurements - Total energy of Sun's radiant heat and light, Reflected solar radiation, Earth emitted radiation	Waveband: UV-FIR Spatial resolution: Narrow: 250km; Wide: 1000km Swath width: Medium and wide earth views Accuracy: Shortwave- 15%, Longwave- 5%
ERBS Earth Radiation Budget Sensor NOAA	NPOESS-3, NPOESS-6	TBD	Earth radiation budget radiometer	Measures Earth radiation gains and losses on regional, zonal and global scales	Waveband: 0.3-50µm Spatial resolution: 25km Swath width: 2200Km Accuracy: DLR/DSR10 watts/m2 net solar 3w/m2OLR 5w/m2
ERS Comms Communication package for ERS ESA	ERS-2	Operational	Communications	Communication package onboard ERS series satellites	Data communication only.

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
ETM+ Enhanced Thematic Mapper Plus USGS	Landsat-7	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures surface radiance and emittance, land cover state and change (eg vegetation type). Used as multi-purpose imagery for land applications	Waveband: VIS-TIR: 8 channels: 0.45-12.5µm, Panchromatic channel: VIS 0.5-0.9µm Spatial resolution: Pan: 15m, Vis-SWIR: 30m, TIR: 60m Swath width: 185km Accuracy: 50-250m systematically corrected geodetic accuracy
EUVS Extreme Ultraviolet Sensor NOAA	GOES-R	Approved	Other	Solar EUV radiation is a dominant energy source for the upper atmosphere and the ionizing radiation produces the ionosphere. Solar variability at these wavelengths is one of the primary drivers of thermospheric/ ionospheric variability. EUVS will measure this radiation	The GOES-R Project is in the formulation phase. The satellite will comprise improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.
Fluxgate magnetometer CRCSS	FedSat	Approved	Magnetic field	Measures electrical currents and perturbations in the Earth's magnetic field in the range 0.1Hz to 1kHz	A high precision instrument designed to measure magnetic fields at all latitudes at an 800 km altitude over a range of ±65,000 nT.
GALS-M Galactic space rays detector ROSHYDROMET	Meteor-M No1, Meteor-M No2	TBD	Space Environment	Space environment monitoring	Waveband: protons fluxes density > 600 MeV Spatial resolution: Swath width: Accuracy:
Geomicrowave sounder NOAA	GOES-R	Approved	Atmospheric temperature and humidity sounders	For geo oribit, will provides atmospheric soundings and data on atmospheric stability and thermal gradient winds	The GOES-R Project is in the formulation phase. The satellite will comprise improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.
Geoton-L1 ROSKOSMOS	Resurs DK		Imaging multi-spectral radiometers (vis/IR)	Natural resource surveying, environmental monitoring	Waveband: 0.5-0.8µm Spatial resolution: 1-3m Swath width: 28.3-42km Accuracy:
GERB Geostationary Earth Radiation Budget EUMETSAT (ASI)	METEOSAT-8, METEOSAT-9, METEOSAT-10, METEOSAT-11	Operational	Earth radiation budget radiometer	Measures long and short wave radiation emitted and reflected from the Earth's surface, clouds and top of atmosphere. Full Earth disk, all channels in 5 mins	Waveband: UV-MWIR: 0.32-4.0µm, UV-FIR: 0.32-30µm Spatial resolution: 44.6km x 39.3km Swath width: Full Earth disk Accuracy: Emitted radiation: 0.12-1.3 W/m2, Reflectance: 1%
GGAK-E Heliogeophysical hardware complex ROSKOSMOS	Elektro-L		Magnetic field & Space environment	Electromagnetic field measurements	Electro-L carries an array of solar and magnetic sensors providing data on solar activity and radiation levels needed for near-earth environment forecasts.
GGAK-M Heliogeophysical hardware complex ROSKOSMOS	Meteor-M No1, Meteor-M No2		Magnetic field & Space environment	Electromagnetic field measurements	A complex of heliogeophysical instruments

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
GHG Sensor Greenhouse gases observing sensor JAXA	GOSAT	TBD	Atmospheric chemistry	This mission is in response to the Kyoto Protocol - and aims to observe Green House Gases (GHGs) including CO2 with 1% relative accuracy in sub-continental spatial resolution and to identify the GHGs sources and sinks in conjunction with data from ground instruments	No data yet available.
GID-12T ROSKOSMOS	Kanopus-Vulkan, Vulkan-Kompas-2		Magnetic field & Space environment	Electromagnetic field measurements	Waveband: 1200MHz, 1600MHz Spatial resolution: Swath width: Accuracy:
GIFTS Geosynchronous Imaging Fourier Transform Spectrometer NASA	NMP EO-3 GIFTS	Proposed	Atmospheric temperature and humidity sounders	Measures temperature, water vapour, tracer winds, chemical composition with high spatial and temporal resolution for considerable improvements in weather observations and air quality monitoring. Tests next-generation met observing systems.	Waveband: MWIR-TIR: 1724 channels in the bands 4.45-6.06µm and 8.85-14.6µm Spatial resolution: Visible: 1km x 1km, IR: 4km x 4km Swath width: Full Earth disk Accuracy:
GLAS Geoscience Laser Altimeter System NASA	ICESat	Operational	Lidars	Provision of data on ice sheet height/thickness, land altitude, aerosol height distributions, cloud height and boundary layer height	Waveband: VIS-NIR: Laser emits at 1064nm (for altimetry) and 532nm (for atmospheric measurements) Spatial resolution: 66m spots separated by 170m Swath width: N/A Accuracy: Aerosol profile: 20%, Ice elevation: 20cm, Cloud top height: 75m, Land elevation: 20cm, geoid: 5m
GLI follow-on Global Imager follow-on JAXA	GCOM-C	Prototype	Imaging multi-spectral radiometers (vis/IR) & Ocean colour instruments	Measures water vapour, aerosols, cloud cover, cloud top height/temp, ocean colour, sea surface temperature, land surface temparature, glacier extent, icebergs, sea ice and snow cover, photosynthetically active radiation, vegetation type and land cover	Waveband: VIS&NIR: 23 bands (380-830nm), NIR-SWIR: 6 bands (1050-2215nm), MWIR-TIR: 7 bands (3.75-11.95µm) Spatial resolution: 1km for 28 bands, 250m for 6 bands Swath width: 1600km Accuracy: Specific humidity profile: 0.5g/m2 through total column, Surface temp 0.4-0.5K, Cloud top temp: 0.5K, Cloud cover: 3%, Cloud top height: 0.5km, Ice and snow cover: 5%
GLM GEO Lightning Mapper NOAA	GOES-R	Approved	Lightning imager		The GOES-R Project is in the formulation phase. The satellite will comprise improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
GMI GPM Microwave Imager NASA	GPM Constellation, GPM Core	Proposed	Imaging multi-spectral radiometers (passive microwave)	Measures rainfall rates over oceans and land, combined rainfall structure and surface rainfall rates with associated latent heating. Used to produce three hour, daily, and monthly total rainfall maps over oceans and land	Waveband: Microwave: 10.65, 19.4, 21.3, 37, and 85.5 GHz Spatial resolution: Horizontal: 36 km cross-track at 10.65 GHz (required - Primary Spacecraft, goal - Constellation Spacecraft); 10 km along-track and cross-track (goal - Primary Spacecraft) Swath width: 800km (Primary Spacecraft) 1300 km (Constellation Spacecraft) Accuracy: NEDT 0.5 K - 1.0 K
GMS Comms Communications package on GMS JAXA (JMA)	GMS-5	Prototype	Communications	Communication package onboard GMS series satellites	Data communication only.
GOES Comms Communications package on GOES NOAA	GOES-9, GOES-10, GOES-11, GOES-12, GOES-N, GOES-O, GOES-P, GOES-R	Prototype	Communications		Data communication only.
GOLPE GPS Occultation and Passive reflection Experiment NASA	SAC-C	Operational	Precision orbit & Atmospheric temperature and humidity sounders	Measurements of atmospheric effects on GPS signals, and precise positioning information to assist gravitational measurements	Waveband: Uses GPS frequencies. Spatial resolution: Swath width: Accuracy: 0.05 K or better appears attainable
GOME Global Ozone Monitoring Experiment ESA	ERS-2	Prototype	Atmospheric chemistry	Measures concentration of O3, NO, NO2, BrO, H2O, O2/O4, plus aerosols and polar stratospheric clouds, and other gases in special conditions	Waveband: UV-NIR: 0.24-0.79µm (resolution 0.2-0.4nm) Spatial resolution: Vertical: 5km (for O3), Horizontal: 40 x 40 km to 40 x 320 km Swath width: 120-960km Accuracy:
GOME-2 Global Ozone Monitoring Experiment - 2 EUMETSAT (ESA)	METOP-1, METOP-2, METOP-3	Prototype	Atmospheric chemistry	Measurement of total column amounts and stratospheric and tropospheric profiles of ozone. Also amounts of H20, NO2, OCIO, BrO, SO2 and HCHO	Waveband: UV-NIR: 0.24-0.79µm (resolution 0.2-0.4nm) Spatial resolution: Horizontal: 40 x 40 km (960km swath) to 40 x 5 km (for polarization monitoring) Swath width: 120-960km Accuracy: Cloud top height: 1km (rms), Outgoing short wave radiation and solar irradiance: 5W/m2, Trace gas profile: 10-20%, Specific humidity profile: 10-50g/kg
GOMOS Global Ozone Monitoring by Occultation of Stars ESA (CNES)	Envisat	Operational	Atmospheric chemistry	Provides stratospheric profiles of temparature and of ozone, NO2, H20, aerosols and other trace species	Waveband: Spectrometers: UV-Vis: 248-371nm & 387-693nm,NIR: 750-776nm & 915-956nm, Photometers: 644-705nm & 466-528nm Spatial resolution: 1.7km vertical Swath width: Not applicable Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
GPS (ESA) GPS receiver ESA	GOCE, Swarm	TBD	Precision orbit	Satellite positioning	Used for precision satellite positioning only – not an Earth observing instrument.
GPS (GRACE) Global Positioning System Receiver NASA	GRACE			Microwave: 1227.60MHz, 1575.42MHz	Used for precision satellite positioning only – not an Earth observing instrument.
GPS receiver CRCSS	FedSat	Operational	Precision orbit & Atmospheric temperature and humidity sounders	Sounding data for study of physics of upper atmosphere, and water vapour, temparature and refractivity profiles	Waveband: Spatial resolution: 1 sample every 30 secs Swath width: Accuracy:
GPSDR GPS Demonstration Receiver CONAE (NASA)	Topex-Poseidon	Operational	Precision orbit & Atmospheric temperature and humidity sounders	Provides precise continuous tracking data of satellite to decimeter accuracy	Used for precision satellite positioning only – not an Earth observing instrument.
GRAS GNSS Receiver for Atmospheric Sounding EUMETSAT (ESA)	METOP-1, METOP-2, METOP-3	Prototype	Atmospheric temperature and humidity sounders & Precision orbit	GNSS receiver for atmospheric temperature and humidty profile sounding	Waveband: Spatial resolution: Vertical: 150m (trophosphere) and 1.5km (stratosphere), Horizontal: 100km approx (troposphere), 300km approx (stratosphere) Swath width: Altitude range of 5-30km Accuracy: Temperature sounding to 1K rms
HAIRS High Accuracy Inter-satellite Ranging System NASA	GRACE	Operational	Gravity	Ranging instrument between the 2 GRACE spacecraft - to derive Earth gravity field measurements	Waveband: Microwave: K Band, Ka Band Spatial resolution: Swath width: Accuracy: 10 microns total at twice per revolution
HALOE Halogen Occultation Experiment NASA	UARS	Operational	Atmospheric chemistry	Provides data on vertical distributions of hydrofluoric and hydrochloric acids, methane, water vapour and members of the nitrogen family. It also provides atmospheric temperature versus pressure profiles from observations of carbon dioxide	Waveband: channels between 2.4µm - 10µm, SWIR - TIR Spatial resolution: 2km-4km Swath width: Accuracy: HCL: 12-24%, HF: 15-27%, CH4: 6-27%, NO: 14-30%, H2O: 14-30%, O3: 9-25%, NO2: 9-21%: Temperature: 3-5K, Aerosol Extinction: < 30%
HES Hyperspectral Environmental Suite NOAA	GOES-R	Approved	Imaging multi-spectral radiometers (vis/IR)	Will sense emitted thermal energy and reflected solar energy from sampled areas of the Earth's surface and atmosphere. These data are used to compute vertical profiles of temperature and moisture, surface and cloud-top temperatures, and winds, and provide information about the Earth surface and oceans	The GOES-R Project is in the formulation phase. The satellite will comprise improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
HiRDLS High Resolution Dynamics Limb Sounder NASA (BNSC)	Aura	Approved	Atmospheric chemistry	Measures atmospheric temperature, concentrations of ozone, water vapour, methane, NOx, N2O, CFCs and other minor species, aerosol concentration, location of polar stratospheric clouds and cloud tops	Waveband: TIR: 6.12-17.76µm (21 channels) Spatial resolution: Vertical: 1km, Horizontal: 10km Swath width: Accuracy: Trace gas: 10%, Temparature: 1K, Ozone: 10%
HIRS/2 High Resolution Infra-red Sounder/2 NOAA	NOAA-12, NOAA-14	Operational	Atmospheric temperature and humidity sounders	Measures atmospheric temperature, concentrations of ozone, water vapour, methane, NOx, N2O, CFCs and other minor species, aerosol concentration, location of polar stratospheric clouds and cloud tops	Waveband: VIS-TIR: 0.69-14.95µm (20 channels) Spatial resolution: 20.3km Swath width: 2240km Accuracy:
HIRS/3 High Resolution Infra-red Sounder/3 NOAA	NOAA-15, NOAA-16, NOAA-17	Operational	Atmospheric temperature and humidity sounders	Provides atmospheric temperature profiles and data on cloud parameters, humidity soundings, water vapour, total ozone content, and surface temperatures	Waveband: VIS-TIR: 0.69-14.95µm (20 channels) Spatial resolution: 20.3km Swath width: 2240km Accuracy:
HIRS/4 High Resolution Infra-red Sounder/4 NOAA	METOP-1, METOP-2, METOP-3, NOAA-N, NOAA-N'	Operational	Atmospheric temperature and humidity sounders	Provides atmospheric temperature profiles and data on cloud parameters, humidity soundings, water vapour, total ozone content, and surface temperatures. Same as HIRS/3, with 10km IFOV	Waveband: VIS-TIR: 0.69-14.95µm (20 channels) Spatial resolution: 20.3km Swath width: 2240km Accuracy:
HRDI High Resolution Doppler Imager NASA	UARS	Operational	Atmospheric chemistry	Daytime wind measurements below 50km from Doppler shifts of molecular oxygen absorption lines. Day and night wind measurements above about 60km from Doppler shifts of neutral and ionised atomic oxygen emission lines. Also measures temperature	Waveband: 0.557-0.776µm Spatial resolution: Vertical (limb): 4km, Horizontal (limb): 80km Swath width: 5 to 100km (vertical coverage) Accuracy: Vector winds in the stratosphere, mesosphere and lower thermosphere during the day, and the lower thermosphere at night to an accuracy of 5 m/s
HRG High Resolution Geometry CNES	SPOT-5	Operational	High resolution optical imagers	High resolution multispectral mapper. 2 HRG instruments on this mission can be processed to produce simulated imagery of 2.5m. Images are 60km x 60km in size	Waveband: VIS: B1:0.50-0.59µm, B2: 0.61-0.68µm, NIR: B3: 0.79-0.89µm, SWIR: 1.50-1.75µm, Panchromatic: 0.49-0.69µm Spatial resolution: Panchromatic: 2, 5m, Multispectral: 10m Swath width: 60km (1 instrument), 117km (2 instruments). Same as SPOT 4 with off-track steering capability (±27 deg) Accuracy:
HRMS High Resolution Multi-spectral Scanner CONAE	SAC-F	Approved	Imaging multi-spectral radiometers (vis/IR)		Waveband: Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
HR-PAN High Resolution Panchromatic Camera ISRO	CARTOSAT-2	Prototype	High resolution optical imagers	High resolution stereo images for large scale (better than 1:0000) mapping applications, urban applications, GIS ingest	Waveband: VIS: 0.5-0.75µm Spatial resolution: 1 m Swath width: 12 km Accuracy:
HRS High Resolution Stereoscopy CNES	SPOT-5	Operational	High resolution optical imagers	High resolution stereo instrument	Waveband: Panchromatic: VIS 0.49-0.69µm Spatial resolution: Panchromatic: 10m, Altitude: 15m Swath width: 120km Accuracy:
HRTC High Resolution Panchromatic Camera CONAE	SAC-C	Operational	High resolution optical imagers	High resolution eath imagery to complement MMRS on the same mission	Waveband: VIS-NIR: 400-900nm Spatial resolution: 35m Swath width: 90km Accuracy:
HRV High Resolution Visible CNES	SPOT-2	Operational	High resolution optical imagers	2 HRV instruments on this mission provide 60km x 60km images for a range of land and coastal applications	Waveband: VIS: B1:0.5-0.59µm, B2:0.61-0.68µm, NIR: B3:0.79-0.89µm, Panchromatic: VIS 0.51-0.73µm Spatial resolution: 10m (panchromatic) or 20m Swath width: 117km (ie 60km + 60km with 3km overlap) - steerable up to ±27 deg off-track Accuracy:
HRVIR High Resolution Visible and Infra-red CNES	SPOT-4	Operational	High resolution optical imagers	2 HRVIR instruments on this mission provide 60km x 60km images for a range of land and coastal applications	Waveband: VIS: B1: 0.50-0.59µm, B2: 0.61-0.68µm, NIR: 0.79-0.89µm, SWIR: 1.58-1.75µm, Panchromatic:(B2) 0.61-0.68µm Spatial resolution: 10m (0.64µm) or 20m Swath width: 117km (ie 60km + 60km with 3km overlap). Steerable up to ±27 deg off-track Accuracy:
HSB Humidity Sounder/Brazil INPE (NASA)	Aqua	Not operational	Atmospheric temperature and humidity sounders	Humidity soundings for climatological and atmospheric dynamics applications	Waveband: Microwave: 5 discreet channels in the range of 150-183 MHz Spatial resolution: 13.5km Swath width: 1650km Accuracy: Temperature: 1.0-1.2k coverage of land and ocean surfaces, Humidity: 20%
HSC High Sensitivity Camera CONAE	SAC-D/ Aquarius	Approved	Imaging multi-spectral radiometers (vis/IR)		Waveband: PAN: VIR-NIR: 450-900 nm Spatial resolution: 200-300m Swath width: > 700 km Accuracy:
HSI (HJ-1A) Hyper Spectrum Imager CAST	HJ-1A	Being developed	Imaging multi-spectral radiometers (vis/IR)	Hyperspectral imaging	Waveband: 0.45-0.95µm Spatial resolution: 100m Swath width: 50km Accuracy:
HSMS High Swath Multi-spectral Scanner CONAE	SAC-F	Approved	Imaging multi-spectral radiometers (vis/IR)		Waveband: Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
HSRS Hot Spot Recognition System DLR	BIRD	Operational	Imaging multi-spectral radiometers (vis/IR)	Hot spot Detection (vegetation fires, volcanic activities, burning oil wells or coal seams	Waveband: MWIR: 3.4-4.2µm, TIR: 8.4-9.3µm Spatial resolution: 370m Swath width: 190km Accuracy:
HSS Hyper-spectral Scanner CONAE	SAC-F	Approved	Imaging multi-spectral radiometers (vis/IR)	Hyperspectral imaging	Waveband: Spatial resolution: Swath width: Accuracy:
HSTC High Sensitivity Technological Camera CONAE	SAC-C	Operational	Imaging multi-spectral radiometers (vis/IR)	Provides data to Monitor forest fires, electrical storms and geophysical studies of aurora borealis	Waveband: PAN: VIS-NIR: 450-850nm Spatial resolution: 250m Swath width: 900km Accuracy:
HYC HYperspectral Camera ASI	Hyperspectral Mission	TBD	Imaging multi-spectral radiometers (vis/IR)	Pancromatic and Hyperspectral data for complex land ecosystem studies	Waveband: VIS-NIR:400-900 nm, 400-1000nm; SWIR: 900-2500nm; Spectral resolution 10 nm, 220 bands Spatial resolution: PAN: 5m ; VNIR-SWIR:20m; Swath width: 20 Km Accuracy:
HYDROS NASA	HYDROS	Proposed	Multiple direction/ polarisation radiometers	Microwave measurement of soil moisture and freeze/thaw timeline	Waveband: 1.26 GHz for the radar and 1.41 GHz for the radiometer and will be capable of both horizontal and vertical polarizations Spatial resolution: Radar 3km&10km, Radiometer 40km Swath width: 1000km Accuracy:
Hyperion Hyperspectral Imager NASA	NMP EO-1	Operational	Imaging multi-spectral radiometers (vis/IR)	Hyperspectral imaging of land surfaces	Waveband: VIS-NIR: 400-1000nm; NIR-SWIR: 900-2500nm; 10nm spectral resolution for 220 bands Spatial resolution: 30m Swath width: 7.5km Accuracy: SNR @ 10% refl target: vis 10-40 swir 10-20
IAP Instrument for plasma analysis CNES	DEMETER	Operational	Space Environment	Density, temperatures, speeds of major ions	Waveband: Spatial resolution: Swath width: Accuracy: Ion density: +5%, Temperature +5%, Speed +5%
IASI Infra-red Atmospheric Sounding Interferometer CNES (EUMETSAT)	METOP-1, METOP-2, METOP-3	Being developed	Atmospheric temperature and humidity sounders & Atmospheric chemistry instruments	Measures tropospheric moisture and temperature, column integrated contents of ozone, carbon monoxide, methane, dinitrogen oxide and other minor gases which affect tropospheric chemistry. Also measures sea surface and land temperature	Waveband: MWIR-TIR: 3.4-15.5µm with gaps at 5µm and 9µm Spatial resolution: Vertical: 1-30km, Horizontal: 25km Swath width: 2052km Accuracy: Temperature: 0.5-2K, Specific humidity: 0.1-0.3g/kg, Ozone, trace gas profile: 10%

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
ICARE Influence of Space Radiation on Advanced Components CNES	SAC-C, SAC-D/ Aquarius	Operational	Space Environment	Improvement of risk estimation models on latest generation of integrated circuits technology	Will measure high energy radiation environment, trapped particle intensities and energy distribution and correlate them with advanced electronic components degradation. ICARE will be able to conduct regular environment characterization campaigns for ten days every six months and exceptional ones during solar events.
ICE Instrument for Electric Field CNES	DEMETER	Operational	Space Environment	Electric field	Waveband: DC to 3MHz Spatial resolution: Swath width: Accuracy: DC field +3mV/m
IDP Instrument For Plasma Detection CNES	DEMETER	Operational	Space Environment	Energy spectrum of electrons	Waveband: Spatial resolution: Swath width: Accuracy:
IGPM radiometer IGPM microwave radiometer ASI	IGPM	TBD	Imaging multi-spectral radiometers (passive microwave)	Global water and energy cycle	No data available yet.
IGPM rain radar ASI	IGPM	TBD	Cloud profile and rain radars	Global water and energy cycle	No data available yet.
IIR Imaging infrared radiometer CNES	CALIPSO	TBD	Imaging multi-spectral radiometers (vis/IR)	Radiometer optimized for combined IIR/lidar retrievals of cirrus particle size	Waveband: TIR: 8.7, 10.5, and 12.0 μm (08.μm resolution) Spatial resolution: 1km Swath width: 64km Accuracy: 1K
IKFS-2 Fourier spectrometer ROSHYDROMET	METEOR-3M N2, Meteor-M No1, Meteor-M No2	TBD	Atmospheric temperature and humidity sounders	Atmospheric temperature and humidity sounding and radiation budget assessment	Waveband: 5-15μm, 1300 spectral channels Spatial resolution: Swath width: 2500km Accuracy: 1K
IKOR-M The modernized measuring instrument of short-wave reflected radiation ROSKOSMOS	Meteor-M No1, Meteor-M No2		Earth radiation budget radiometer		Waveband: Spatial resolution: Swath width: Accuracy:
Imager NOAA	GOES-9, GOES-10, GOES-11, GOES-12, GOES-N, GOES-O, GOES-P, GOES-R	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures cloud cover, atmospheric radiance, winds, atmospheric stability, rainfall estimates. Used to provide severe storm warnings/ monitoring day and night (type, amount, storm features)	Waveband: GOES 8-12; N,O,P: VIS: 1 channel (8 detectors), IR: 4 channels: 3.9, 6.7, 10.7 and 12μm, GOES 12-Q: VIS: 1 channel (8 detectors), IR: 4 channels: 3.9, 6.7, 10.7 and 13.3μm Spatial resolution: 1km in visible 4km in IR (8km for 13.3μm band (water vapour)) Swath width: Full Earth disk Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
Imager (INSAT) ISRO	INSAT-3D	TBD	Imaging multi-spectral radiometers (vis/IR)	Cloud cover, severe storm warnings/monitoring day and night (type, amount, storm features), atmospheric radiance winds, atmospheric stability rainfall	Waveband: VIS: 0.55-0.75µm, SWIR: 1.55-1.7µm, MWIR: 3.80-4.00µm, 6.50-7.00µm, TIR: 10.2-11.3µm, 11.5-12.5µm Spatial resolution: 1x1km (VIS & SWIR), 4x4km (MWIR, TIR), 8x8km (in 6.50-7.00µm) Swath width: Full Earth disc and space around, Normal Frame (50 deg. N to 40 deg. S and full E-W coverage), Program Frame (Programmable, E-W Full coverage) Accuracy:
IMAGER/MTSAT-1R Imager/MTSAT JMA	MTSAT-1R	Prototype	Imaging multi-spectral radiometers (vis/IR)	Measures cloud cover, cloud motion, cloud height, water vapour, rainfall, sea surface temparature and Earth radiation	Waveband: VIS-SWIR: 0.55-0.90µm, MWIR-TIR: 3.5-4µm, 6.5-7µm, 10.5-11.3µm, 11.5-12.5µm Spatial resolution: Visible: 1km, TIR: 4km Swath width: Full Earth disk every hour Accuracy:
IMAGER/MTSAT-2 Imager/MTSAT JMA	MTSAT-2	Prototype	Imaging multi-spectral radiometers (vis/IR)	Measures cloud cover, cloud motion, cloud height, water vapour, rainfall, sea surface temparature and Earth radiation	Waveband: VIS-SWIR: 0.55-0.90µm, MWIR-TIR: 3.5-4µm, 6.5-7µm, 10.5-11.3µm, 11.5-12.5µm Spatial resolution: Visible: 1km, TIR: 4km Swath width: Full Earth disk every hour Accuracy:
IMSC Instrument Search Coil Magnetometer CNES	DEMETER	Operational	Magnetic field	Magnetic field	Waveband: 10Hz - 17.4kHz Spatial resolution: Swath width: Accuracy:
IMWTS Improved MicroWave Temperature Sounder NRSCC (CAST)	FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Approved	Atmospheric temperature and humidity sounders	Atmospheric temperature soundings for meteorological applications	Waveband: Microwave: 50-57GHz (4channels) Spatial resolution: 50km Swath width: ±48° Accuracy:
INES Italian Navigation Experiment ASI	SAC-C	Operational	Precision orbit	Composed of GPS Tensor and GNSS Lagrange Receiver to perform navigation experiment on precise orbit determination	Precision positioning only – not an Earth observing instrument.
IR (HJ-1B) Infrared Camera CAST	HJ-1B	Being developed	Imaging multi-spectral radiometers (vis/IR)	Global environmental applications	Waveband: 0.75~1.10, 1.55~1.75, 3.50 ~3.90, 10.5 ~12.5µm Spatial resolution: 300m (10.5~12.5_m), 150m (the other bands) Swath width: 720km Accuracy:
IR Camera (SAOCOM) CONAE	SAOCOM 1A, SAOCOM 1B, SAOCOM-2B (1), SAOCOM-2B (2)	Being developed	Imaging multi-spectral radiometers (vis/IR)	Fires monitoring	Waveband: NIR-TIR Spatial resolution: 200m Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
IRAS InfraRed Atmospheric Sounder NRSCC (CAST)	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Approved	Atmospheric temperature and humidity sounders	Atmospheric sounding for weather forecasting	Waveband: VIS-TIR: 0.65-14.95µm (26 channels) Spatial resolution: 1.254km Swath width: ±49.5º Accuracy:
IR-MSS Infrared Multispectral Scanner CAST (INPE)	CBERS-2, CBERS-2B	Operational	High resolution optical imagers	Used for fire detection, fire extent and temperature measurement	Waveband: VIS-NIR: 0.5-1.1µm, NIR-SWIR: 1.55-1.75µm, 2.08-2.35µm, TIR: 10.4-12.5µm Spatial resolution: Visible, NIR, SWIR: 78m, TIR: 156m Swath width: 120km Accuracy:
IRS CAST (INPE)	CBERS-3, CBERS-4	Operational	High resolution optical imagers	Used for fire detection, fire extent and temperature measurement	Waveband: VIS-NIR: 0.5-1.1µm, NIR-SWIR: 1.55-1.75µm, 2.08-2.35µm, TIR: 10.4-12.5µm Spatial resolution: Visible, NIR, SWIR: 78m, TIR: 156m Swath width: 120km Accuracy:
ISAMS Improved Stratospheric and Mesospheric Sounder instrument NASA	UARS	Not operational	Earth radiation budget radiometer	Concentrations of nitrogen chemical species, ozone, water vapour, methane, and carbon monoxide. Aerosols. Atmospheric temperature	Waveband: SWIR-TIR: 4.6-16.6µm Spatial resolution: vert 2.6km, horiz: 18km Swath width: 65km Accuracy:
ISL Langmuir probes CNES	DEMETER	Operational	Space Environment	Density of the plasma and electron temperature	Waveband: Spatial resolution: Swath width: Accuracy: Relative ion and electron density <5%, Absolute temperature <5%, Potential 10mV Ion direction +15°
IST Italian Star Tracker ASI	SAC-C	Operational	Precision orbit	Test of a fully autonomous system for attitude and orbit determination using a star tracker	Precision positioning only – not an Earth observing instrument.
IVISSR (FY-2) Improved Multispectral Visible and Infra-red Spin Radiometer (5 channels) NRSCC (CAST)	FY-2C, FY-2D, FY-2E	Approved	Imaging multi-spectral radiometers (vis/IR)	Meteorological	Waveband: VIS-TIR: 0.55-0.9, 10.3-11.3, 11.5-12.5, 6.5-7.0, 3.5-4.0µm (5 channels) Spatial resolution: 1.4km, 5km Swath width: Accuracy:
JMR JASON Microwave Radiometer NASA	Jason, Jason-2 (also known as OSTM)	Operational	Imaging multi-spectral radiometers (passive microwave))	Provides altimeter data to correct for errors caused by water vapour and cloud-cover. Also measures total water vapour and brightness temperature	Waveband: Microwave: 18.7GHz, 23.8GHz, 34GHz Spatial resolution: 41.6km at 18.7GHz, 36.1km at 23.8GHz, 22.9km at 34GHz Swath width: 120 deg cone centred on nadir Accuracy: Total water vapour: 0.2g/sq cm, Brightness temperature: 0.15 K

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
KGI-4C Module for Geophysical Measurements ROSHYDROMET	METEOR-3M N1	Prototype	Earth radiation budget radiometer	Measures particle flux and electromagnetic emissions	Waveband: Electron flux density range: 0.15-3.2MeV, proton flux density range: 5- 90MeV, Protons density of energy more that 600 MeV (5-10 channels) Spatial resolution: 8-12km Swath width: 3100km Accuracy: 1.6K
Klimat Scanning IR radiometer ROSHYDROMET	METEOR-3M N1	Operational	Imaging multi-spectral radiometers (vis/IR)	Provides images of cloud, ice and snow. Measures sea surface temperature	Waveband: TIR: 10.5-12.5µm Spatial resolution: 0.45km x 0.9km Swath width: 1300km Accuracy:
KMSS Medium range multi-spectral scanner ROSHYDROMET (ROSKOSMOS)	METEOR-3M N2, Meteor-M No1, Meteor-M No2	Operational	Imaging multi-spectral radiometers (passive microwave)	Moderate resolution imaging applications	Waveband: Microwave:0.45-0.50, 0.535-0.575, 0.63-0.68, 0.76-0.9µm Spatial resolution: 70m Swath width: 1000-1200km Accuracy:
LAC Laser Atmospheric Corrector NASA	NMP EO-1	Operational	Imaging multi-spectral radiometers (vis/IR)	Corrects high spatial resolution multispectral imager data for atmospheric effects	Waveband: 256 bands, NIR-SWIR: 0.89-1.58µm Spatial resolution: 250m Swath width: 185km Accuracy:
Landsat Comms Communications package for Landsat USGS	Landsat-5, Landsat-7	Operational	Communications		Data communications only.
Laser reflectors CNES	STARLETTE, STELLA	Operational	Precision orbit	Measures distance between the satellite and the laser tracking stations	24cm sphere covered in 60 retro-reflectors
Laser reflectors (ESA) Laser reflectors ESA	CRYOSAT, GOCE	TBD	Precision orbit	Measures distance between the satellite and the laser tracking stations	Cluster of 9 laser reflectors provide orbit determination with cm accuracy using laser ground stations.
L-band SAR INPE	SSR-2	Proposed	Imaging microwave radars	Microwave imaging of land and ice for use in environmental monitoring, agriculture and forestry, disaster monitoring, Earth resource management and interferometry	Waveband: Spatial resolution: Swath width: Accuracy:
LISS-III Linear Imaging Self Scanner - III ISRO	RESOURCE-SAT-1, RESOURCE-SAT-2	Operational	High resolution optical imagers	Data used for vegetation type assessment, resource assessment, crop stress detection, crop production forecasting, forestry, land use and land cover change	Waveband: VIS: Band 2: 0.52-0.59µm, Band 3: 0.62-0.68µm, NIR: Band 4: 0.77-0.86µm, SWIR: Band 5: 1.55-1.75µm Spatial resolution: Bands 2, 3 & 4: 23.5m, Band 5: 70.5m Swath width: 140km Accuracy:
LISS-IV Linear Imaging Self Scanner - IV ISRO	RESOURCE-SAT-1, RESOURCE-SAT-2	Operational	High resolution optical imagers	Vegetation monitoring, improved crop discrimination, crop yield, disaster monitoring and rapid assessment of natural resources	Waveband: VIS: 0.52-0.59µm, 0.62-0.68µm, NIR: 0.77-0.86µm, Spatial resolution: 5.8m Swath width: 70km Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
LRA Laser Retroreflector Array NASA (ASI)	Jason, Jason-2 (also known as OSTM), Topex-Poseidon	Operational	Precision orbit	Provides baseline tracking data for precision orbit determination and/or geodesy. Also for calibration of radar altimeter bias. Several types used on various missions. (ASI involved in LAGEOS 2 development)	The LRA is an array of mirrors that provide a target for laser tracking measurements from the ground. By analyzing the round-trip time of the laser beam, we can locate very precisely where the satellite is on its orbit.
LRA (LAGEOS) Laser Retroreflector Array NASA (ASI)	LAGEOS-1, LAGEOS-2, LAGEOS-3	Being developed	Precision orbit	Provides baseline tracking data for precision geodesy. Also for calibration of radar altimeter bias. Several types used on various missions. (ASI involved in LAGEOS 2 development)	The LAGEOS satellites are passive vehicles covered with retro-reflectors designed to reflect laser beams transmitted from ground stations. Accuracy: 2cm overhead ranging
L-SAR L-Band SAR BNSC	TerraSAR-L	Prototype	Imaging microwave radars	L-Band Sar for agriculture and forestry	Waveband: Microwave: L-band (2GHz) Spatial resolution: 5m Swath width: 10-200km depending on mode Accuracy:
MADRAS CNES	MEGHA-TROPIQUES	Operational	Imaging multi-spectral radiometers (passive microwave)	Studies precipitation and clouds properties	Data not yet available.
MAESTRO Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation CSA	SCISAT-1	Operational	Atmospheric chemistry	Will aid in the SCISAT-1 overall mission of increasing our understanding of the chemical processes involved in the depletion of the ozone layer	Waveband: UV-NIR: 0.285 to 1.03um (1-2nm spectral resolution) Spatial resolution: Approx 1km vertical Swath width: Accuracy:
Magnetometer (NOAA) NOAA	GOES-R	Approved	Magnetic field	Measures magnitude and direction of Earth's ambient magnetic field in three orthogonal directions in an Earth referenced coordinate system. Will provide a map of the space environment that controls charged particle dynamics in the outer region of the magnetosphere	The GOES-R Project is in the formulation phase. The satellite will comprise improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.
MASTER ESA	ESA Future Missions	TBD	Atmospheric temperature and humidity sounders & Atmospheric chemistry instruments	Data for study of exchange mechanisms between stratosphere/troposphere, and information for studies on global change. Measures upper troposphere/ lower stratosphere profiles of O3, H2O, CO, HNO3, SO2, N2O, pressure and temperature	Waveband: Microwave: 199-207, 296-306, 318-326, 342-348GHz Spatial resolution: 3km Swath width: Accuracy: 199-207GHz channel: 1K, Other channels: 1.5K, 50MHz resolution, 0.3 secs integration time
MBEI Multi-band Earth Imager NSAU	SICH-2	Approved	High resolution optical imagers	Multispectral scanner images of land surface	Waveband: VIS-NIR: 0.50-0.885µm, VIS: 0.50-0.59, 0.605-0.68µm, NIR: 0.785-0.885µm Spatial resolution: 7.8m Swath width: 46.6km pointable ±35° from nadir Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
MCP Meteorological Communications Package (MCP) EUMETSAT	METOP-1, METOP-2, METOP-3	TBD	Communications	Meteorological Communications Package (MCP) onboard METOP series satellites	Data communication only.
MERIS Medium-Resolution Imaging Spectrometer ESA	Envisat	Operational	Imaging multi-spectral radiometers (vis/IR)	Main objective is monitoring marine biophysical and biochemical parameters. Secondary objectives are related to atmospheric properties such as cloud and water vapour and to vegetation conditions on land surfaces	Waveband: VIS-NIR: 15 bands selectable across range: 0.4-1.05µm (bandwidth programmable between 0.0025 and 0.03µm) Spatial resolution: Ocean: 1040m x 1200 m, Land & coast: 260m x 300m Swath width: 1150km, global coverage every 3 days Accuracy: Ocean colour bands typical S:N = 1700
MERSI Moderate Resolution Spectral Imager NRSCC (CAST)	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Approved	Imaging multi-spectral radiometers (vis/IR)	Measures surface temperature and cloud and ice cover. Used for snow and flood monitoring and surface temperature	Waveband: VIS-TIR: 0.47-12.5µm (20 channels) Spatial resolution: 250m-1.1km Swath width: 3200km Accuracy:
METEOSAT Comms Communications package for METEOSAT EUMETSAT	METEOSAT-5, METEOSAT-6, METEOSAT-7	Prototype	Communications	Communication package onboard METEOSAT series satellites	Data communication only.
MHS Microwave Humidity Sounder EUMETSAT	METOP-1, METOP-2, METOP-3, NOAA-N, NOAA-N'	Prototype	Atmospheric temperature and humidity sounders	Provides atmospheric humidity profiles, cloud cover, cloud liquid, water content, ice boundaries and precipitation data	Waveband: Microwave: 89, 166GHz and 3 channels near 183Ghz Spatial resolution: Vertical: 3-7km, Horizontal: 30-50km Swath width: 1650km Accuracy: Cloud water profile: 10g/m2, Specific humidity profile: 10-20%
MIPAS Michelson Interferometric Passive Atmosphere Sounder ESA	Envisat	Operational	Atmospheric chemistry instruments & Atmospheric temperature and humidity sounders	Provides data on stratosphere chemistry (global/polar ozone), climate research (trace gases/clouds), transport dynamics, tropospheric chemistry. Primary/secondary species: O3, NO, NO2, HNO3, N2O5, ClONO2, CH4	Waveband: MWIR-TIR: between 4.15 and 14.6µm Spatial resolution: Vertical resolution: 3km, vertical scan range 5-150km, Horizontal: 3km x 30km, Spectral resolution: 0.035 lines/cm Swath width: Accuracy: Radiometric precision: 685-970cm-1: 1%, 2410 cm-1: 3%
MIRAS Multichannel Infrared Atmospheric Sounder NRSCC (CAST)	FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Prototype	Imaging multi-spectral radiometers (passive microwave)	Atmospheric sounding for weather forecasting	No data available
MIRAS (SMOS) 2-D Passive L-Band Microwave Interferometer ESA	SMOS	Proposed	Multiple direction/polarisation radiometers & Imaging multi-spectral radiometers (passive microwave)	Objective is to demonstrate observations of sea surface salinity and soil moisture in suport of climate, meteorology, hydrology, and oceanography applications.	Waveband: Microwave: L-Band 1.41GHz (based on MIRAS concept) Spatial resolution: Requirements: Soil moisture: 30km (desired), Sea surface salinity: 200km (desired) Swath width: 934km (at 756km altitude), allowing a 3 day revisit time at the equator Accuracy: Radiometric accuracy: 3.5K for land, 2.5K for sea

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
MIREI Middle IR Earth Imager NSAU	SICH-2	Approved	High resolution optical imagers	Scanner images of land surface	Waveband: NIR: 1.55-1.7µm Spatial resolution: 39.5m Swath width: 55.3 km pointable ±35° from nadir Accuracy:
MISR Multi-angle Imaging SpectroRadiometer NASA	Terra	Operational	Multiple direction/ polarisation radiometers	Provides measurements of global surface albedo, aerosol and vegetation properties. Also provides multi-angle bidirectional data (1% angle-to-angle accuracy) for cloud cover and reflectances at the surface and aerosol opacities. Global and local modes	Waveband: VIS: 0.44, 0.56, 0.67µm, NIR: 0.86µm Spatial resolution: 275m, 550m or 1.1km, Summation modes available on selected cameras/bands: 1x1, 2x2, 4x4, 1x4. 1 pixel = 275m x 275m Swath width: 360km common overlap of all 9 cameras Accuracy: 0.03% hemispherical albedo, 10% aerosol opacity, 1-2% angle to angle accuracy in bidirectional reflectance
MIVZA Microwave scanning radiometer ROSHYDROMET	METEOR-3M N1	Prototype	Atmospheric temperature and humidity sounders	Microwave radiometer for humidity sounding of atmosphere	Waveband: Microwave:22-94 GHz, 5 channels Spatial resolution: 25-100km Swath width: 1500m Accuracy:
MLS Microwave Limb Sounder NASA	Aura	Operational	Atmospheric temperature and humidity sounders & Atmospheric chemistry instruments	Provides data on emissions of chlorine monoxide, water vapour and ozone. Data also used for determination of atmospheric pressure and temperatures as a function of altitude from observations of molecular oxygen emissions	Waveband: 118GHz, 190GHz, 240GHz, 640GHz, 2.5THz Spatial resolution: Measurements are performed along the sub-orbital track, and resolution varies for different parameters; 5 km cross-track x 500 km along-track x 3 km vertical are typical values. Swath width: 1.5 km vertical x 3 km cross-track x 300 km along-track at the limb tangent point Accuracy: Depends on measurement
MMP Magnetic Mapping Payload CONAE (DSRI (Denmark))	SAC-C	Operational	Magnetic field	Measurement of the Earth's magnetic field with a vector and a scalar magnetometer	Waveband: Scalar (SHM) 1nTeslaVectorial 3-5 nT Spatial resolution: Res angular 20 sec arc Swath width: Vector 0.5 nT Accuracy:
MMRS Multispectral Medium Resolution Scanner CONAE	SAC-C	Operational	Imaging multi-spectral radiometers (vis/IR)	Applications related to agriculture, environment, forestry, hydrology, oceanography, mineralogy and geology, desertification, contamination and protection of ecosystems.	Waveband: VIS-NIR: 480 - 500nm, 540-560nm, 630-690nm, 795-835nm, SWIR: 1550-1700nm Spatial resolution: 175m Swath width: 360kmAccuracy:
MOC Multi-spectral Optical Camera CONAE	SAC-E/SABIA	Approved	Imaging multi-spectral radiometers (vis/IR)		Waveband: Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
MODerate-Resolution Imaging Spectroradiometer NASA	Aqua, Terra	Operational	Imaging multi-spectral radiometers (vis/IR) & Ocean colour instruments	Data on biological and physical processes on the surface of the Earth and in the lower atmosphere, and on global dynamics. Surface temperatures of land and ocean, chlorophyll fluorescence, land cover measurements, cloud cover (day and night)	Waveband: VIS-TIR: 36 bands in range 0.4-14.4µm Spatial resolution: Cloud cover: 250m (day) and 1000m (night), Surface temperature: 1000m Swath width: 2330km Accuracy: Long wave radiance: 100nW/m2, Short wave radiance: 5%, Surface temperature of land: <1K, Surface temperature of ocean: <0.2K, Snow and ice cover: 10%
MOPITT Measurements Of Pollution In The Troposphere CSA	Terra	Prototype	Atmospheric chemistry	Measurements of greenhouse gases (CO, methane) in the troposhere	Waveband: SWIR-MWIR: 2.3, 2.4 and 4.7µm Spatial resolution: CO profile: 4km vertical, 22 x 22km horizontal, CO, CH4 column: 22x22km horizontal Swath width: 616km Accuracy: Carbon monoxide (4km layers): 10%, Methane column: 1%
MPS Magnetospheric Particle Sensor NOAA	GOES-R	Approved	Space Environment	Studies of natural radiation hazard to humans at high altitudes and in space, as well as risk assessment and warning of episodes of surface charging, deep dielectric charging, and single event upset of satellite systems	The GOES-R Project is in the formulation phase. The satellite will comprise improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.
MR-2000M1 Scanning visible radiometer ROSHYDROMET	METEOR-3M N1	Prototype	Imaging multi-spectral radiometers (vis/IR)	TV camera images of cloud, snow and ice	Waveband: VIS-NIR: 0.5-0.8µm Spatial resolution: 1.5km Swath width: 3100km Accuracy:
MS (GISTDA) Multi spectral imager GISTDA	THEOS	Approved	Imaging multi-spectral radiometers (vis/IR)	Land surface applications	Waveband: 0.45-0.52, 0.53-0.60, 0.62-0.69, 0.77-0.90µm Spatial resolution: 15m Swath width: 90km Accuracy:
MSC Multi-Spectral Camera KARI	KOMPSAT-2	Being developed	High resolution optical imagers	High resolution imager for land applications of cartography and disaster monitoring	Waveband: VIS-NIR: 0.50-0.92µm, VIS: 0.45-0.52µm, 0.52-0.60µm, 0.63-0.69µm, NIR: 0.76-0.90µm Spatial resolution: Pan: 1m, VNIR: 4m Swath width: 15km Accuracy:
MSG Comms Communications package for MSG EUMETSAT	METEOSAT-8, METEOSAT-9, METEOSAT-10, METEOSAT-11	Being developed	Communications	Communication package onboard MSG series satellites	Data communication only.
MSGI-MKA Spectrometer ROSHYDROMET	METEOR-3M N2, Meteor-M No1, Meteor-M No2	TBD	Other	Geoactive corpuscular emissions measurements	The MSGI-MKA instrument features four channels for the measurement of the following parameters: Electron fluxes in the energy range of 0.1-15 keV (high-sensitivity channel); Ion (proton) fluxes in the energy range of 0.1-15 keV (high-sensitivity channel); Electron fluxes in the energy range of 0.1-15 keV (low-sensitivity channel); Monitoring of integral electron fluxes with a threshold energy of 40 keV. The Field of View is 10º x 10º for each channel (3) and 20º x 20º for the integral electron flux.

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
MSI Multi Spectral Imager DLR	RapidEye	Approved	High resolution optical imagers	High resolution images with short observing cycle for commercial and scientific applications	Waveband: 4 VIS + 1 NIR band: 440-510nm, 520-590nm, 630-685nm, 690-730nm, 760-850nm Spatial resolution: 6.5m Swath width: 78km Accuracy: 2-3%
MSMR Multifrequency Scanning Microwave Radiometer ISRO	IRS-P4	Operational	Imaging multi-spectral radiometers (passive microwave)	Sea state and meteorological parameter monitoring (sea surface temperature, surface wind speed, water vapour over ocean and liquid water content of the cloud)	Waveband: Microwave: 6.6, 10.6, 18 and 21GHz Spatial resolution: 40m at 21GHz to 120m at 6.6GHz, Wind speed: 75 x 75km, Sea surface temperature: 146 x 150km Swath width: 1360km Accuracy: Sea surface temparature: 1.5K, Sea surface wind speed: 1.5 m/s
MSS Multispectral Scanner USGS	Landsat-5	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures surface radiance. Data mostly used for land applications	Waveband: 0.5-1.1µm Spatial resolution: 82m Swath width: 185km Accuracy:
MSS (Roskosmos) Multispectral film-making system ROSKOSMOS	BelKA		Imaging multi-spectral radiometers (vis/IR)	Land surface applications	Waveband: VIS-NIR: 0.54-0.6, 0.63-0.69, 0.69-0.72, 0.75-0.86µm Spatial resolution: 12m Swath width: 20km Accuracy:
MSS-BIO Polyzonal scanning system of bioefficiency of sea water areas ROSKOSMOS	Meteor-M No1, Meteor-M No2		Ocean colour instruments	Ocean biology applications	Waveband: 0.43-0.48, 0.5-0.58, 0.6-0.68, 0.7-0.9, 2.0-2.3µm Spatial resolution: 60-100m Swath width: 520km Accuracy:
MSTE-5E Multichannel system of geoactive measurements ROSHYDROMET	METEOR-3M N1	TBD	Other	Geoactive Emission Measurements	Waveband: Ions energetic spectrum: 0.1 – 15 keV, 3 channels, Energy of electrons: 0.05 – 20 keV and more than 40 keV, 4 channels Spatial resolution: Swath width: Accuracy:
MSU Microwave Sounding Unit NOAA	NOAA-12, NOAA-14	Operational	Atmospheric temperature and humidity sounders	Provides temperature sounding through cloud up to 20km in altitude	Waveband: 4 channels: 50.3 to 57.95 GHz Spatial resolution: 109.3 km Swath width: 2348 km Accuracy:
MSU-E Multispectral high resolution electronic scanner ROSHYDROMET	METEOR-3M N1	Operational	Imaging multi-spectral radiometers (vis/IR)	Multispectral scanner images of land surface and ice cover	Waveband: VIS: 0.5-0.6, 0.6-0.7µm, NIR: 0.8-0.9µm Spatial resolution: 35-45m Swath width: 45km for one scanner, 80km for two scanners (pointable ±30 deg from nadir) Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
MSU-EU Multi-Spectral Radiometer with High Resolution NSAU	SICH-1M	Being developed	High resolution optical imagers	Multispectral scanner images of land surface	Waveband: VIS: 0.5-0.6, 0.6-0.7µm, NIR: 0.8-0.9µm Spatial resolution: Visible: 24x34m Swath width: 48km or 105km; pointable ±30° from nadir Accuracy:
MSU-GS Multispectral scanning imager-radiometer ROSHYDROMET	Elektro-L	TBD	Imaging multi-spectral radiometers (vis/IR)	Measurements of cloud cover, cloud top height, precipitation, cloud motion, vegetation, radiation fluxes, convection, air mass analysis, cirrus cloud discrimination, tropopause monitoring, stability monitoring, total ozone and sea surface temparature	Waveband: VIS: 0.5-0.65, 0.65-0.8µm, NIR: 0.9µm, SWIR: 1.5µm, MWIR: 3.5-4.01µm, TIR: 5.7-7.0, 8-8.7, 9.7, 10.2-11.2, 11.2-12.5µm Spatial resolution: 1km (at SSP) for visible and 4 km for IR channels Swath width: Full Earth disk Accuracy:
MSU-M Multi-Spectral Low Resolution Scanning System NSAU	SICH-1M	Prototype	Imaging multi-spectral radiometers (vis/IR)	Provide images of ocean surface and ice sheets	Waveband: VIS: 0.5-0.6, 0.6-0.7µm, NIR: 0.7-0.8, 0.8-1.1µm Spatial resolution: 1.7km x 1.8km Swath width: 1930km Accuracy:
MSU-MR Images of clouds, snow, ice and land cover ROSHYDROMET	METEOR-3M N2, Meteor-M No1, Meteor-M No2	TBD	Imaging multi-spectral radiometers (vis/IR)	Images of clouds, snow, ice and land cover	Waveband: Visible: 0.5-0.7µm, NIR: 0.7-1.1µm, SWIR: 1.6-1.8µm, MWIR: 3.5-4.1µm, TIR: 10.5-11.5µm, 11.5-12.5µm Spatial resolution: 1km Swath width: 3000km Accuracy: VIS: 0.5%, IR: 0.1K
MSU-SM Multi-Spectral Medium Resolution Scanning System ROSHYDROMET	METEOR-3M N1	TBD	Imaging multi-spectral radiometers (vis/IR)	Images of clouds, snow, ice and land cover	Waveband: VIS: 0.5-0.7µm, NIR: 0.7-1.1µm Spatial resolution: 225m Swath width: 2250km Accuracy:
MTSAT Comms Communications package for MTSAT JMA (JAXA)	MTSAT-1R, MTSAT-2	Prototype	Communications		Data communication only
MTVZA Scanning microwave radiometer ROSHYDROMET	METEOR-3M N1, METEOR-3M N2, Meteor-M No1, Meteor-M No2	Prototype	Atmospheric temperature and humidity sounders	Provision of atmospheric temparature and humidity profiles	Waveband: Microwave:18.7-183 GHz, 52-55 GHz, 19 channels Spatial resolution: 12x22km to 75x136km Swath width: 2200km Accuracy:
MTVZA-OK Scanning microwave radiometer ROSHYDROMET	Kanopus-Vulkan, SICH-1M	Approved	Atmospheric temperature and humidity sounders	Multi-Spectral Scanner Images of Earth Surface	Waveband: MW: 6.9, 10.6, 18.7, 23.8, 31.5, 36.7, 42, 48, 52.3-57.0, 89, 183.32 GHz, VIS: 0.37-0.45, 0.45-0.51, 0.58-0.68, 0.68-0.78µm, MWIR:3.55-3.93µm Spatial resolution: MW: 12-260km, VIS: 0.96km, MWIR:1.1km Swath width: MW: 2000km VIS: 1280km, MWIR: 1850km Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
MUX Multispectral CCD Camera CAST (INPE)	CBERS-3, CBERS-4	Being developed	Imaging multi-spectral radiometers (vis/IR)	Earth resources, environmental monitoring, land use	Waveband: Spatial resolution: 20m Swath width: Accuracy:
MVIRI METEOSAT Visible and Infra-Red Imager EUMETSAT (ESA)	METEOSAT-5, METEOSAT-6, METEOSAT-7	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures cloud cover, motion, height, upper tropospheric humidity and sea surface temperature	Waveband: VIS-NIR: 0.5-0.9μm, TIR: 5.7-7.1μm (water vapour), 10.5-12.5μm Spatial resolution: Visible: 2.5km, Water vapour: 5km (after processing), TIR: 5 km Swath width: Full Earth disk in all three channels, every 30 minutes Accuracy: Cloud top height: 0.5km, Cloud top/ sea surface temperature: 0.7K, Cloud cover 15%
MWHS MicroWave Humidity Sounder NRSCC (CAST)	FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Approved	Atmospheric temperature and humidity sounders	Meteorological applications	Waveband: Microwave: 150-183GHz (5channels) Spatial resolution: 15km Swath width: ±48º Accuracy:
MWR (BNSC) Microwave Radiometer BNSC	Envisat, ERS-2	Operational	Imaging multi-spectral radiometers (passive microwave) & Atmospheric temperature and humidity sounders	To provide multispectral analysis of hydrological, oceanographic, land use and meteorological parameters. Global imager & SST. Ocean colour	Waveband: Microwave: 23.8 and 36.5GHz Spatial resolution: 20km Swath width: 20km Accuracy: Temparature: 2.6K
MWR (CONAE) Microwave radiometer CONAE	SAC-D/ Aquarius	Approved	Imaging multi-spectral radiometers (passive microwave)	The Aquarius mission will measure global sea surface salinity with unprecedented resolution. The instruments include a set of three radiometers that are sensitive to salinity (1.413 GHz; L-band). The scatterometer corrects for the ocean's surface roughness	Waveband: Ka Band (23.8 and 36.56 GHz) Spatial resolution: 400km Swath width: 300km Accuracy: 5K
MWRI MicroWave Radiation Imager NRSCC (CAST)	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Approved	Imaging multi-spectral radiometers (passive microwave)	Meteorological applications	Waveband: 10.65-89GHz (10channels) Spatial resolution: 15-80km Swath width: 1400km Accuracy:
MWTS MicroWave Temperature Sounder NRSCC (CAST)	FY-3A, FY-3B	Approved	Atmospheric temperature and humidity sounders	Meteorological applications	Waveband: Microwave: 50-57GHz (4channels) Spatial resolution: 50km Swath width: ±48º Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
NIRST New Infrared Sensor Technology CONAE	SAC-D/ Aquarius	Approved	Imaging multi-spectral radiometers (vis/IR)	Fire area, Fire Temperature, Volcanic ash	Waveband: 3.5-4.5µm, 10.5-11.5µ, 11.5-12.5µm Spatial resolution: 150m Swath width: Normal mode: 75km, Accessible swath width: 700km Accuracy:
NISTAR NIST Advanced Radiometer NASA	DSCOVR	Approved	Earth radiation budget radiometer	Measures radiance output from the sunlit Earth over a broad spectrum (UV and VIS reflected and IR emitted) to detect energy balance changes in support of climate studies	Waveband: UV-FIR: 0.2-100µm, 0.2-4µm, 0.7-4µm, 0.3-1µm Spatial resolution: Swath width: Full Earth disk Accuracy: Total Earth reflected and emitted power to within 0.1%
NOAA Comms Communications package for NOAA NOAA	NOAA-12, NOAA-14, NOAA-15, NOAA-16, NOAA-17, NOAA-N, NOAA-N'	Prototype	Communications		Data communication only.
NVK Low-frequency wave complex ROSKOSMOS	Kanopus-Vulkan, Vulkan-Kompas-2		Other	Geomagnetic applications related to volcanoes and earthquakes	Waveband: 1Hz - 25kHz Spatial resolution: Swath width: Accuracy:
OBA Observador Brasileiro da Amazonia INPE	SSR-1, SSR-2	Approved	Imaging multi-spectral radiometers (vis/IR)	Used for fire extent detection and temperature measurement, coastal and vegetation monitoring, land cover and land use mapping	Waveband: VIS: 0.45-0.50µm, 0.52-0.57µm, 0.63-0.69µm, NIR: 0.76-0.90µm, MWIR: 3.4-4.2µm Spatial resolution: VIS-NIR: 100m, MIR: 300m Swath width: 2200km (equatorial belt from latitude 5N to 15S) Accuracy:
OCM Ocean Colour Monitor ISRO	IRS-P4, OCEANSAT-2	Operational	Ocean colour instruments	Ocean colour information, coastal zone monitoring, land resources monitoring	Waveband: VIS-NIR: 0.40-0.88µm (8 channels) Spatial resolution: 236m x 360m Swath width: 1440km Accuracy:
OCO Orbiting Carbon Observatory NASA	OCO		Atmospheric chemistry	Precise global maps of carbon dioxide (CO2) in the Earth's atmosphere. Scientists will analyse OCO data to improve our understanding of the natural processes and human activities that regulate the distribution of CO2 in the atmosphere	The Orbiting Carbon Observatory (OCO) is a single instrument consisting of three high resolution grating spectrometers that flies on a dedicated spacecraft. Each spectrometer detects the intensity of radiation within a very specific narrow band at Near Infrared (NIR) wavelengths.
OEA Optical-electronic equipment ROSKOSMOS	Baumanets		Imaging multi-spectral radiometers (vis/IR)		Waveband: 0.5-0.9µm Spatial resolution: 50m Swath width: 100km Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
OLS Operational Linescan System NOAA (US DoD)	DMSP F-13, DMSP F-15, DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19	Operational	Imaging multi-spectral radiometers (vis/IR)	Day and night cloud cover imagery	Waveband: VIS-NIR: 0.4-1.1μm, TIR: 10.0-13.4μm, and 0.47-0.95μm Spatial resolution: 0.56km (fine), 5.4km (stereo products) Swath width: 3000km Accuracy:
OMI Ozone Measuring Instrument NASA (NIVR (Netherland))	Aura	Operational	Atmospheric chemistry	Mapping of ozone columns, key air quality components (NO2, SO2, BrO, OClO and aerosols), measurements of cloud pressure and coverage, global distribution and trends in UV-B radiation	Waveband: UV: 270-314nm & 306-380nm, VIS: 350-500nm Spatial resolution: 13km x 24km or 36km x 48km depending on the product. Also has zoom modes (13km x 13km) for example for urban pollution detection Swath width: 2600km Accuracy:
OMPS Ozone Mapping and Profiler Suite NOAA	NPOESS-2, NPOESS-5, NPP	Being developed	Atmospheric chemistry	Measures total amount of ozone in the atmosphere and the ozone concentration variation with altitude	Waveband: Nadir Mapper: UV 0.3-0.38μm, Nadir profiler: UV 0.25-0.31μm, Limb soundings: UV-TIR 0.29-10μm Spatial resolution: Mapper: 50km, Profiler: 250km, Limb: 1km vertical Swath width: Mapper: 2800km, Profiler: 250km, Limb: 3 vertical slits along track +/- 250km Accuracy: Total Ozone: 15 Dobson units. Profile Ozone: 10% between 15 and 60km, 20% between Tropopause and 15km
OP Ozone Profiler NRSCC (CAST)	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Being developed	Atmospheric chemistry	Ozone chemistry measurements	Waveband: UV Spatial resolution: 200km Swath width: Accuracy:
OSIRIS Optical Spectrograph and Infra-Red Imaging System CSA	Odin	Prototype	Atmospheric chemistry	Detects aerosol layers and abundance of species such as O3, NO2, OClO, and NO. Consists of spectrograph and IR imager. Measures temperature for altitudes above 30km	Waveband: Spectrograph: UV-NIR: 0.28-0.80μm, IR Imager, NIR: 1.26μm, 1.27μm, 1.52μm Spatial resolution: Spectrograph 1km at limb, Imager 1km in vertical Swath width: N/A, but measures in the altitude range 5-100 km Accuracy: Depends on species
OSMI Ocean Scanning Multispectral Imager KARI	KOMPSAT-1	Operational	Imaging multi-spectral radiometers (vis/IR) & Ocean colour instruments	Ocean color measurements for biological oceanography	Waveband: VIS: 0.412μm, 0.443μm, 0.490μm, 0.555μm, NIR: 0.765μm, 0.865μm Spatial resolution: 1km Swath width: 800km Accuracy:
PALSAR Phased Array type L-band Synthetic Aperture Radar JAXA (METI (Japan))	ALOS	Being developed	Imaging microwave radars	High resolution microwave imaging of land and ice for use in environmental monitoring, agriculture and forestry, disaster monitoring, Earth resource management and interferometry	Waveband: Microwave: L-Band 1270MHz Spatial resolution: Hi-res: 7-44m or 14-88m (depends on polarisation and looks), ScanSAR mode: <100m, Polarimetry 24-88m Swath width: High resolution mode: 70km, Scan SAR mode: 250-360km, Polarimetry: 30km Accuracy: Radiometric: ±1dB

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
Pamela ROSKOSMOS	Resurs DK		Space Environment	Measures the energy spectrum of antiprotons and positrons in the cosmic radiation. Will allow significant comparisons between competing models of antimatter production in our galaxy	PAMELA consists of a time-of-flight / trigger system, transition radiation detector, a magnetic spectrometer with silicon tracking, an anticoincidence system, a silicon-tungsten imaging electromagnetic calorimeter, a shower-tail catcher and a neutron counter.
PAN Panchromatic and multispectral imager CAST	CBERS-3, CBERS-4	Being developed	High resolution optical imagers	Provides measurements of cloud type and extent and land surface reflectance, and used for global land surface applications	Waveband: VIS: 0.52-0.59µm, 0.63-0.69µm, NIR: 0.77-0.89µm, PAN: 0.51-0.85µm Spatial resolution: 5m panchromatic and 10m multispectral Swath width: 60 km Accuracy:
PAN (Cartosat-1) Panchromatic sensor ISRO	CARTOSAT-1	Operational	High resolution optical imagers	High resolution stereo images for study of topography, urban areas, development of DTM, run-off models etc. Urban sprawl, forest cover/timber volume, land use change	Waveband: Panchromatic VIS: 0.5-0.75µm Spatial resolution: 2.5m Swath width: Accuracy:
PAN (GISTDA) Panchromatic imager GISTDA	THEOS	Approved	High resolution optical imagers	Land surface applications	Waveband: 0.45-0.90µm Spatial resolution: 2m Swath width: 22km Accuracy:
PEM Particle Environment Monitor NASA	UARS	Operational	Magnetic field	PEM measures UV and charged particle energy inputs: determines type, amount, energy and distribution of charged particles injected into Earth's thermosphere, mesosphere and stratosphere	There are four PEM 'instruments', AXIS, HEPS, MEPS, and VMAG. Their purpose is to provide quantitative measurements of both local and global energy inputs into the Earth's atmosphere by charged particles and Joule dissipation – via measurements of x-rays, charged particles, and the magnetic field.
Plasma-Mag NASA	DSCOVR	Proposed	Magnetic field & Space environment	Sun-viewing instrument to measure the solar wind and magnetic field parameters. Also serves as early-warning for solar-event storms that could damage satellites and equipment on Earth	Plasma-Mag contains a triaxal fluxgate magnetometer that will investigate solar- wind magnetic fields with a sensitivity level of better than 0.1nT.
Pleiades HR High Resolution Optical Imaging CNES	Pleiades 1, Pleiades 2		High resolution optical imagers	Cartography, land use, risk,agriculture and forestry, civil planning and mapping, digital terrain models, defense	Waveband: 4 bands:Near IR, Red, Green, Blue Spatial resolution: <1m Swath width: in vertical: 20km Accuracy:
POLDER-P POLarization and Directionality of the Earth's Reflectances (PARASOL version) CNES	PARASOL	Approved	Multiple direction/polarisation radiometers	Measures polarization, and directional and spectral characteristics of the solar light reflected by aerosols, clouds, oceans and land surfaces	Waveband: VIS-NIR: 0.490, 0.670 and 0.865µm at 3 polarisations, and 0.49, 0.565, 0.763, 0.765, 0.91µm, and 1.02µm with no polarisation Spatial resolution: 5.5km x 5.5km Swath width: 1600km Accuracy: Radiation budget, land surface, Reflectance: 2%

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
POSEIDON-1 (SSALT-1) Positioning Ocean Solid Earth Ice Dynamics Orbiting Navigator (Single frequency solid state radar altimeter) CNES	Topex-Poseidon	Operational	Radar altimeters	Nadir viewing sounding radar for provision of real-time high precision sea surface topography, ocean circulation and wave height data	Waveband: Microwave: Ku-band (13.575GHz) Spatial resolution: Swath width: Accuracy:
POSEIDON-2 (SSALT-2) Positioning Ocean Solid Earth Ice Dynamics Orbiting Navigator (Single frequency solid state radar altimeter) CNES	Jason	Operational	Radar altimeters	Nadir viewing sounding radar for provision of real-time high precision sea surface topography, ocean circulation and wave height data	Waveband: Microwave: Ku-band (13.575GHz), C-band (5.3GHz) Spatial resolution: Basic measurement: 1/sec (6km along track), Raw measurement: 10/sec (600m along track) Swath width: On baseline TOPEX/POSEIDON orbit (10 day cycle): 300km between tracks at equator Accuracy: Sea level: 3.9cm, Significant waveheight: 0.5m, Horizontal sea surface wind speed: 2m/s
POSEIDON-3 Positioning Ocean Solid Earth Ice Dynamics Orbiting Navigator (Single frequency solid state radar altimeter) CNES	Jason-2 (also known as OSTM)	Operational	Radar altimeters	Nadir viewing sounding radar for provision of real-time high precision sea surface topography, ocean circulation and wave height data	Waveband: Microwave: Ku-band (13.575GHz), C-band (5.3GHz) Spatial resolution: Basic measurement: 1/sec (6km along track), Raw measurement: 10/sec (600m along track) Swath width: On baseline TOPEX/POSEIDON orbit (10 day cycle): 300km between tracks at equator Accuracy: Sea level: 3.9cm, Significant waveheight: 0.5m, Horizontal sea surface wind speed: 2m/s
PREMOS PREcision Monitoring of Solar variability CNES	PICARD	TBD	Earth radiation budget radiometer	Solar UV and visible flux in selected wavelength bands	Waveband: UV: 230nm, 311nm, 402nm; VIS: 548 nm Spatial resolution: Swath width: Accuracy:
PRISM Panchromatic Remote-sensing Instrument for Stereo Mapping JAXA	ALOS	Being developed	High resolution optical imagers	High resolution panchromatic stereo imager for land applications which include cartography, digital terrain models, civil planning, agriculture and forestry	Waveband: VIS-NIR: 0.52-0.77µm (panchromatic) Spatial resolution: 2.5m Swath width: 35km (triplet stereo observations), 70km (nadir observations) Accuracy:
PSA Panchromatic film-making equipment ROSKOSMOS	Monitor-E		Imaging multi-spectral radiometers (vis/IR)	High resolution thematic mapping, agriculture and forestry	Waveband: VIS-NIR: 0.51-0.85µm Spatial resolution: 8m Swath width: 90/730km Accuracy:
PSS Panchromatic film-making system ROSKOSMOS	BelKA		Imaging multi-spectral radiometers (vis/IR)	High resolution mapping, environmental, and resource survey applications	Waveband: VIS-NIR: 0.52-0.85µm Spatial resolution: 3.2m Swath width: 23km Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
RA Radar Altimeter ESA	ERS-2	Operational	Radar altimeters	Measures wind speed, significant wave height, sea surface elevation, ice profile, land and ice topography, and sea ice boundaries	Waveband: Microwave: Ku-band: 13.8GHz Spatial resolution: Footprint is 16-20km Swath width: Accuracy: Wave height: 0.5m or 10% (whichever is smaller) Sea surface elevation: better than 10cm
RA-2 Radar Altimeter - 2 ESA	ERS-2	Operational	Radar altimeters	Measures wind speed, significant wave height, sea surface elevation, ice profile, land and ice topography, and sea ice boundaries	Waveband: Microwave: 13.575Ghz (Ku-Band) & 3.2GHz (S-Band) Spatial resolution: Swath width: Accuracy: Altitude: better than 4.5cm, Wave height: better than 5% or 0.25m
RADARSAT DTT X band (downlink of payload) CSA	RADARSAT-1	Operational	Communications		Data communication only.
RADARSAT TTC S band (Tracking, Telemetry and Command) CSA	RADARSAT-1	Operational	Communications		Data communication only.
Radiomet ROSKOSMOS	Meteor-M No1, Meteor-M No2		Atmospheric temperature and humidity sounders	Atmospheric sounding for weather forecasting	Waveband: 3cm, 32cm Spatial resolution: Swath width: Accuracy:
RBE ROSKOSMOS	Kanopus-Vulkan, Vulkan-Kompas-2		Magnetic field & Space environment	Geomagnetic applications related to volcanoes and earthquakes	Waveband: 150MHz, 400MHz Spatial resolution: Swath width: Accuracy:
RCHA ROSKOSMOS	Kanopus-Vulkan, Vulkan-Kompas-2		Other	Geomagnetic applications related to volcanoes and earthquakes	Waveband: 50kHz -15MHz Spatial resolution: Swath width: Accuracy:
RDSA ROSKOSMOS	Monitor-E		Imaging multi-spectral radiometers (vis/IR)	Thematic mapping, agriculture and forestry	Waveband: VIS-NIR: 0.54-0.59, 0.63-0.68, 0.79-0.9μm Spatial resolution: 20/40m Swath width: 160/890km Accuracy:
RIMS-M Mass-spectrometer ROSHYDROMET	Meteor-M No1, Meteor-M No2	TBD	Other	Ion composition in upper atmosphere	Waveband: 1-4 a.e.m., 5-20 a.e.m Spatial resolution: Swath width: Accuracy:
RLSBO Side looking microwave radar ROSKOSMOS (NIIRI)	SICH-1M	Prototype	Imaging microwave radars	Provides images of ocean surface and ice sheets	Waveband: Microwave: 0.8cm Spatial resolution: 25x25km Swath width: 550km Accuracy: 3K temperature sensitivity"

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
RM-08 Scanning Microwave Radiometer ROSHYDROMET (NSAU)	SICH-1M	Prototype	Imaging multi-spectral radiometers (passive microwave)	Passive microwave images of ocean surface and ice sheets	Waveband: Microwave: 0.8cm Spatial resolution: 25x25km Swath width: 550km Accuracy: 3K temperature sensitivity
ROSA formerly called Lagrange ASI	SAC-D/ Aquarius	TBD	Precision orbit & Atmospheric temperature and humidity sounders	GPS Receiver. Including specialized version equipped with limb sounding antenna and dedicated signal tracking capability for metereological, climate and space weather applications	Uses observations of GPS satellite occultations in order to supply information about the atmosphere temperature, pressure and water vapour content.
RRA Retroreflector Array CNES	Diademe 1&2		Precision orbit	Satellite laser ranging for geodynamic measurements	The RRA consist of 2 flattened truncated cones with 77 cube corners per cone for a total of 144 cube corners.
S&R (GOES) Search and Rescue NOAA	GOES-9, GOES-10, GOES-11, GOES-12, GOES-N, GOES-O, GOES-P, GOES-R	Prototype	Other	Satellite and ground based system to detect and locate aviators, mariners, and land-based users in distress	Communications payload.
S&R (NOAA) Search and Rescue Satellite Aided Tracking NOAA	METOP-1, METOP-2, NOAA-14, NOAA-15, NOAA-16, NOAA-17, NOAA-N, NOAA-N'	Operational	Other	Satellite and ground based system to detect and locate aviators, mariners, and land-based users in distress	Communications payload.
SABER Sounding of the Atmosphere usingBroadband Emission Radiometry NASA	TIMED	Operational	Atmospheric temperature and humidity sounders & Atmospheric chemistry instruments	SABER provides measurements of the mesosphere and lower thermosphere globally to support investigations into the fundamental processes governing the energetics, chemistry, dynamics, and transport of the atmospheric region extending from 60 km to 180 km	Waveband: NIR-FIR: 1.27µm - 17µm (10 channels) Spatial resolution: 2km vertical resolution Swath width: Accuracy:
SAGE II Stratospheric Aerosol and Gas Experiment-II NASA	ERBS	Operational	Atmospheric chemistry	Profiles of ozone, aerosols, NO2, and water vapor. Data suitable for atmospheric chemistry, ozone trend, and climate studies	Waveband: 7 channels, UV-NIR: 0.385 - 1.02 µm Spatial resolution: 0.75 km Swath width: N/A Accuracy: O3- 4%, Aerosol – 1%, NO2 – 15%, H2O- 20% in lower stratosphere

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
SAGE III Stratospheric Aerosol and Gas Experiment-III NASA (ROSKOSMOS)	METEOR-3M N1	Operational	Atmospheric chemistry	Profiles of ozone, water vapor, NO2, NO3, OCIO, aerosols, temperature and pressure for atmospheric chemistry and climate studies using a 809 element CCD-based grating spectrometer and discrete photodiode channel at 1550 nm	Waveband: UV-NIR: 0.29-1.55µm Spatial resolution: 1-2km vertical resolution Swath width: N/A Accuracy: Temperature: 2K, Ozone: 6%, Humidity: 3-10%, Aerosol and trace gases: 5-10%
SAPHIR CNES (ISRO)	MEGHA-TROPIQUES	Approved	Atmospheric temperature and humidity sounders	Cross-track sounder with the objective of measuring water vapour profiles in the troposphere in six layers from 2-12km altitudes	Waveband: Microwave: 183.3GHz (6 channels) Spatial resolution: 10km Swath width: Accuracy:
SAR (RADARSAT) Synthetic Aperture Radar (CSA) C band CSA	RADARSAT-1	Operational	Imaging microwave radars	Provides all-weather images of ocean, ice and land surfaces. Used for monitoring of coastal zones, polar ice, sea ice, sea state, geological features, vegetation and land surface processes	Waveband: Microwave: C band: 5.3GHz, HH polarisation Spatial resolution: Standard: 25 x28 m (4 looks), Wide beam (1/2):48-30 x 28m/ 32-25 x 28m (4 looks), Fine resolution: 11-9 x 9m (1 look), ScanSAR (N/W): 50 x 50m/ 100 x 100m (2-4/4-8 looks), Extended (H/L): 22-19x28m/ 63-28 x 28m (4 looks) Swath width: Standard: 100km Wide: 150km Fine: 45km ScanSAR Narrow: 300km ScanSAR Wide: 500km Extended (H): 75km Extended (L): 170kmWide: 150km Fine: 45km ScanSAR Narrow: 300km ScanSAR Wide: 500km Extended (H): 75km Extended (L): 170km Accuracy: Geometric distortion: < 40m, Radiometric: 1.0dB
SAR (RADARSAT-2) Synthetic Aperture Radar (CSA) C band CSA	RADARSAT-2	Being developed	Imaging microwave radars	Provides all-weather images of ocean, ice and land surfaces. Used for monitoring of coastal zones, polar ice, sea ice, sea state, geological features, vegetation and land surface processes	Waveband: Microwave: C band 5.405 GHz: HH, VV, HV, VH polarisation - includes fully polarimetric imaging modes, and left- and right-looking capability Spatial resolution: Standard: 25 x28 m (4 looks), Wide beam (1/2):48-30 x 28m/ 32-25 x 28m (4 looks), Fine resolution: 11-9 x 9m (1 look), ScanSAR (N/W): 50 x 50m/ 100 x 100m (2-4/4-8 looks), Extended (H/L): 22-19x28m/ 63-28 x 28m (4 looks), Ultrafine: 3m Swath width: Standard: 100km (20-49deg), Wide beam (1/2): 165km/ 150km (20-31/ 31-39deg), Fine resolution: 45km (37-48deg), ScanSAR (W): 510km (20-49deg), Extended (H/L): 75km/170km (50-60/ 10-23deg), Ultrafine: 10-20km Accuracy: Geometric distortion: < 40m, Radiometric: 1.0dB

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
SAR (RISAT) ISRO	RISAT-1	Proposed	Imaging microwave radars	Radar backscatter measurements of land, water and ocean surfaces for applications in soil moisture, crop applications (under cloud cover), terrain mapping etc	Waveband: C-Band (5.350 Ghz) Spatial resolution: 3-6m (FRS-1), 9-12m (FRS-2), 25/50m (MRS/CRS) Swath width: 10km (HRS), 30km (FRS-1/FRS-2), 120/240km (MRS/CRS) Accuracy:
SAR (ROSHYDROMET) Synthetic Aperture Radar ROSHYDROMET (ROSKOSMOS)	METEOR-3M N2	Operational	Imaging microwave radars	Provides all-weather images of ocean, ice and land surfaces. Used for monitoring of coastal zones, polar ice, sea ice, sea state, geological features, vegetation and land surface processes	No data available.
SAR (SAOCOM) Synthetic Aperture Radar (CONAE) CONAE	SAOCOM 1A, SAOCOM 1B, SAOCOM-2B (1), SAOCOM-2B (2)	Being developed	Imaging microwave radars	Land and Ocean Emergencies	Waveband: Microwave: L-Band SAR 1.275 GHz Spatial resolution: 10x10m - 100x100m Swath width: Accuracy: 70m
SAR 2000 Multi-Mode Synthetic Aperture Radar ASI	COSMO - SkyMed	TBD	Imaging microwave radars	All weather images of ocean, land and ice for monitoring of land surface processes, ice, environmental monitoring, risk management, environmental resources, maritime management, earth topographic mapping	Waveband: Microwave: X-band, with choice of 4 polarisation modes (VV, HH, VV/HH, HV/HH). Spatial resolution: Single polarisation mode; Stripmap: few metres, ScanSAR: from few tens to several tens of metres; Frame: resolution: order of the m Two polarisation mode·PING PONG: few metres Swath width: Single polarisation modes: Stripmap (tens of km), ScanSAR (hundreds of km), Frame (spot width several tens km2) Two polarisation modes: PING PONG (several tens of km) Accuracy:
SARSAT Search and Rescue Satellite Aided Tracking NOAA	NPOESS-1, NPOESS-2, NPOESS-3, NPOESS-4, NPOESS-5, NPOESS-6	TBD	Data collection	Satellite and ground based system to detect and locate aviators, mariners, and land-based users in distress	Waveband: UHF 406.0 MHZ
S-band SAR S-band Synthetic Aperture Radar CAST	HJ-1C	Being developed	Imaging microwave radars	All weather microwave 3-D images	Waveband: Spatial resolution: 20m (4looks) Swath width: 100km Accuracy: 3dB
SBUV/2 Solar Backscattter Ultra-Violet Instrument/2 NOAA	NOAA-14, NOAA-15, NOAA-16, NOAA-17, NOAA-N, NOAA-N'	Operational	Atmospheric chemistry	Provides data on trace gases including vertical profile ozone, and solar irradiance and total ozone concentration measurements	Waveband: UV: 0.16-0.4µm (12 channels) Spatial resolution: 170km Swath width: Accuracy: Absolute accuracy: 1%

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
ScaRaB Scanner for Earth's Radiation Budget CNES (NPO "PLANETA")	MEGHA-TROPIQUES	Operational	Earth radiation budget radiometer	Measures top-of-atmosphere shortwave radiation (0.2-4.0µm) and total radiation (0.2-50µm). Two additional narrow-band channels (0.5-0.7µm and 11-12µm) allow cloud detection and scene identification	Waveband: VIS window channel: 0.5-0.7µm, Solar channel UV-SWIR: 0.2-4µm, Total channel UV-FIR: 0.2-50µm, Thermal window channel: 10.5-12.5µm Spatial resolution: 60km Swath width: 2200km Accuracy: Absolute: ± 2.5W/m2/sr, Relative: ± 0.7W/m2/sr
Scatterometer (ISRO) ISRO	OCEANSAT-2	TBD	Scatterometers	Mainly for wind measurements	Under definition.
Scatterometer (JAXA) Scatterometer JAXA	GCOM-W	TBD	Scatterometers	Ocean surface wind measurements	Under definition.
SCIAMACHY Scanning Imaging Absorption Spectrometer for Atmospheric Chartography ESA	Envisat	Operational	Atmospheric chemistry	Measures middle atmosphere temperature. Provides tropospheric and stratospheric profiles of O2, O3, O4, CO, N2O, NO2, CO2, CH4, H2O, and tropospheric and stratospheric profiles of aerosols and cloud altitude	Waveband: UV-SWIR: 240-314, 309-3405, 394-620, 604-805, 785-1050, 1000-1750, 1940-2040 and 2265-2380nm Spatial resolution: Limb vertical 3 x 132km, Nadir horizontal 32 x 215km Swath width: Limb and nadir mode: 1000km (max) Accuracy: Radiometric: <4%
SeaWinds NASA (JAXA)	QuikSCAT	Operational	Scatterometers	Measurement of surface wind speed and direction; lost power on-orbit in October 2003	Waveband: Microwave: 13.402 GHz Spatial resolution: 25 km Swath width: 1600 km Accuracy: Speed: 2-3.5 m/s Direction: 20 deg
SEM (GOES) Space Environment Monitor NOAA	GOES-9, GOES-10, GOES-11, GOES-12, GOES-N, GOES-O, GOES-P, GOES-R	Operational	Space Environment	Used for equipment failure analysis, solar flux measurement, solar storm warning, and magnetic and electric field measurement at satellite	The SEM System consists of a three-axis vector magnetometer, an Energetic Particle Sensor (EPS) and associated High-Energy Proton and Alpha Detector (HEPAD), and an X-Ray Sensor (XRS). This set of instruments is designed to provide real-time measurement of solar activity, the charged particle environment, and the Earth's magnetic field at synchronous orbit.
SEM (POES) Space Environment Monitor NOAA	METOP-2, NOAA-12, NOAA-14, NOAA-15, NOAA-16, NOAA-17, NOAA-N, NOAA-N'	Operational	Space Environment	Used for equipment failure analysis, solar flux measurement, solar storm warning, and magnetic and electric field measurement at satellite	The SEM consists of two separate sensor units: the Total Energy Detector (TED) and the Medium Energy Proton and Electron Detector (MEPED). The TED senses and quantifies the intensity in the sequentially selected energy bands. The particles of interest have energies ranging from 0.05 keV to 20 keV. The MEPED senses protons, electrons, and ions with energies from 30 keV to levels exceeding 6.9 MeV.
SESS Space Environmental Sensor Suite NOAA	NPOESS-2, NPOESS-3, NPOESS-4, NPOESS-5, NPOESS-6	Being developed	Space environment & Magnetic field	Measures characteristics of auroral boundary, auroral energy deposition, auroral imagery, electric field, electron density profile, geomagnetic field, in-situ plasma fluctuations, ionosphere scintillation. Data aids future space system design	Multiple sensors to measure auroral characteristics, geomagnetic field, electron density profile, and total electron content, 10-km vertical resolution from 60 km to 3000 km.

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
SEVIRI Spinning Enhanced Visible and Infra-Red Imager EUMETSAT (ESA)	METEOSAT-8, METEOSAT-9, METEOSAT-10, METEOSAT-11	Prototype	Imaging multi-spectral radiometers (vis/IR)	Measurements of cloud cover, cloud top height, precipitation, cloud motion, vegetation, radiation fluxes, convection, air mass analysis, cirrus cloud discrimination, tropopause monitoring, stability monitoring, total ozone and sea surface temparature	Waveband: VIS: 0.56-0.71µm, 0.5-0.9µm (broadband),NIR: 0.74-0.88µm,SWIR 1.5-1.78µm, SWIR: 3.48-4.36µm, TIR: 5.35-7.15µm, 6.85-7.85µm, 8.3-9.1µm, 9.38-9.94µm, 9.8-11.8µm, 11-13µm, 12.4-14.46µm Spatial resolution: 1km (at SSP) for one broadband visible channel HRV, 5km (at SSP) for all other channels Swath width: Full Earth disk Accuracy: Cloud cover: 10%, Cloud top height: 1km, Cloud top temparature: 1K, Cloud type: 8 classes, Surface temparature: 0.7-2.0K, Specific humidity profile: 10%, Wind profile (horizontal component): 2-10m/s, Long wave Earth surface radiation: 5W/m2
SFM-2 UV limb spectrometer ROSHYDROMET	METEOR-3M N1	Operational	Atmospheric chemistry	Global ozone monitoring	Waveband: UV-VIS: 0.2-0.51µm (4 channels) Spatial resolution: Swath width: Accuracy:
SGPS Solar and Galactic Proton Sensor NOAA	GOES-R	Approved	Space Environment	Studies natural radiation hazard to humans at high altitudes and in space, as well as risk assessment and warning of episodes of surface charging, deep dielectric charging, and single event upset of satellite systems	The GOES-R Project is in the formulation phase. The satellite will comprise improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.
SIM Spectral Irradiance Monitor NASA	SORCE	Operational	Earth radiation budget radiometer	Measures solar spectral irradiance in the 200-2000nm range	Waveband: UV-SWIR: 200-2000nm Spatial resolution: Swath width: Accuracy:
SIRAL SAR Interferometer Radar Altimeter ESA	CRYOSAT	Being developed	Radar altimeters	Objective is to observe ice sheet interiors, the ice sheet margins, for sea ice and other topography	Waveband: Microwave: 13.575GHz (Ku-Band) Spatial resolution: Range resolution 45cm, along-track resolution 250m Swath width: Footprint 15km Accuracy: Arctic sea-ice: 1.6cm/year for 300kmx300km cells, Land ice (small scale): 3.3cm/year for 100km x 100km cells, Land ice (large scale): 0.17cm/year for Antarctica size area
SKL-M Solar ray spectrometer ROSHYDROMET	Meteor-M No1, Meteor-M No2	TBD		Proton flux density	Waveband: 2, 4, 6 and > 6 MeV, 30, 50, 100, 300 and > 300 MeV Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
SMR Submillimetre Radiometer SNSB	Odin	Operational	Atmospheric chemistry instruments & Atmospheric temperature and humidity sounders	Measures global distributions of ozone and species of importance for ozone chemisty, ClO, HNO3, H2O, N2O, (HO2, H2O2). Measures temperature in the height range 15-100km	Waveband: Microwave: 118.7GHz + 4 bands in the region 480-580GHz: Tunable measures 2-3 x 1GHz regions at a time Spatial resolution: Vertical resolution 1.5-3km, along track 600km Swath width: Altitudes of 5-100km Accuracy: 2-40% depending on species and altitude
SODAD Orbital System for an Active Detection of Debris CNES	SAC-D/ Aquarius	Approved	TBD	Space Debris	Instrument for the measurement of the properties of micrometeorites and space debris.
SODISM SOlar Diameter Imager and Surface Mapper CNES	PICARD	TBD	Earth radiation budget radiometer	Measures diameter and differential rotation of the sun - a whole Sun imager	Waveband: UV: 230nm, VIS: 548nm, Active regions: 160nm plus Lyman alpha detector Spatial resolution: Swath width: Accuracy:
SOLSTICE SOLar STellar Irradiance Comparison Experiment NASA	SORCE, UARS	Operational	Earth radiation budget radiometer	Provides data on UV and charged particle energy inputs, and on time variation of full-disk solar UV spectrum. Measures solar UV radiation (115 to 430nm) with resolution of 0.12nm. Compares solar UV output with UV radiation of stable bright blue stars	Waveband: UV: 115-180nm & 170-320nm Spatial resolution: Swath width: Accuracy: 1%
Sounder NOAA	GOES-9, GOES-10, GOES-11, GOES-12, GOES-N, GOES-O, GOES-P, GOES-R	Operational	Atmospheric temperature and humidity sounders	Provides atmospheric soundings and data on atmospheric stability and thermal gradient winds	Waveband: GOES 8-12; N,O,P: VIS-TIR: 19 channels Spatial resolution: 10km Swath width: Horizon to horizon Accuracy:
Sounder (INSAT) ISRO	INSAT-3D	TBD	Atmospheric temperature and humidity sounders	Atmospheric soundings, atmospheric stability, thermal gradient winds	Waveband: SWIR: 3.74-4.74µm, MWIR: 6.51-11.03µm, TIR: 12.02-14.71µm, VIS: 0.55-0.75µm Spatial resolution: 10x10 km Swath width: Full (Full Earth disc sounding), Program (Options provided for for Sector Scans) Accuracy:
SOVAP SOlar Variability Picard radiometer CNES	PICARD	Being developed	Earth radiation budget radiometer	Total solar irradiance measurements	Waveband: Total irradiance Spatial resolution: Swath width: Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
SSB/X-2 Special Sensor Gamma Ray Particle Detector NOAA (US DoD)	DMSP F-13, DMSP F-15, DMSP F-16	Operational	Space Environment	Detects the location, intensity, and spectrum of X-rays emitted from the Earth's atmosphere	Array-based system.
SSIES-2 Special Sensor Ionospheric Plasma Drift/Scintillation Meter NOAA (US DoD)	DMSP F-13, DMSP F-15, DMSP F-16	Operational	Space Environment	Measurement of the ambient electron density and temperatures, the ambient ion density, and ion temperature and molecular weight	Consists of an electron sensor (Langmuir probe) and an ion sensor mounted on a 2.5 meter boom. The ion sensor is a planar aperture, planar collector sensor oriented to face the spacecraft velocity vector at all times. In addition to the Langmuir probe and planar collector, has a plasma drift meter and a scintillation meter.
SSIES-3 Special Sensor Ionospheric Plasma Drift/Scintillation Meter NOAA (US DoD)	DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	TBD	Space Environment	Measurement of the ambient electron density and temperatures, the ambient ion density, and ion temperature and molecular weight	Consists of an electron sensor (Langmuir probe) and an ion sensor mounted on a 2.5 meter boom. The ion sensor is a planar aperture, planar collector sensor oriented to face the spacecraft velocity vector at all times. In addition to the Langmuir probe and planar collector, has a plasma drift meter and a scintillation meter.
SPECTRA Surface Processes and Ecosystem Changes Through Response Analysis ESA	ESA Future Missions	Prototype	Imaging multi-spectral radiometers (vis/IR) & Multiple direction/ polarisation radiometers	Data for study of land surface processes	Waveband: VIS-SWIR: 450-2350 nm and TIR: 10.3-12.3 micron Spatial resolution: Spatial sampling interval approx 50m, along track pointing ±30 deg Swath width: 50km Accuracy:
SSJ/4 Special Sensor Precipitating Plasma Monitor NOAA (US DoD)	DMSP F-13, DMSP F-15, DMSP F-16	Operational	Magnetic field	Measurement of transfer energy, mass, and momentum of charged particles through the magnetosphere-ionosphere in the Earth's magnetic field	Consists of four electrostatic analyzers that record electrons and ions between 30 eV and 30 KeV as they flow past the spacecraft toward the Earth. The instruments "look" toward the satellite zenith.
SSJ/5 Special Sensor Precipitating Plasma Monitor NOAA (US DoD)	DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	TBD	Magnetic field	Measurement of transfer energy, mass, and momentum of charged particles through the magnetosphere-ionosphere in the Earth's magnetic field	Consists of four electrostatic analyzers that record electrons and ions between 30 eV and 30 KeV as they flow past the spacecraft toward the Earth. The instruments "look" toward the satellite zenith.
SSM Special Sensor Magnetometer NOAA (US DoD)	DMSP F-13, DMSP F-15, DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	Operational	Magnetic field	Measures geomagnetic fluctuations associated withMeasures geomagnetic fluctuations associated with solar geophysical phenomena. With SSIES and SSJ provides heating and electron density profiles in the ionosphere	A triaxial fluxgate magnetometer
SSM/I Special Sensor Microwave Imager NOAA (US DoD)	DMSP F-13, DMSP F-15, DMSP F-16	Operational	Imaging multi-spectral radiometers (passive microwave)	Measures atmospheric, ocean and terrain microwave brightness temperatures to provide: sea surface winds, rain rates, cloud water, precipitation, soil moisture, ice edge, ice age	Waveband: Microwave: 19.35, 22.235, 37, 85 GHz Spatial resolution: 15.7km x 13.9km to 68.9 x 44.3km (depends on frequency) Swath width: 1400km Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
SSM/T-1 Special Sensor Microwave Temperature Sounder NOAA (US DoD)	DMSP F-13, DMSP F-15, DMSP F-16, DMSP F-18, DMSP F-19, DMSP F-20	Operational	Atmospheric temperature and humidity sounders	Measures Earth's surface and atmospheric emission in the 50-60GHz oxygen band	Waveband: Microwave: 7 channels in the 50-60GHz range Spatial resolution: 174km diameter beam Swath width: 1500km Accuracy:
SSM/T-2 Special Sensor Microwave Water Vapor Sounder NOAA (US DoD)	DMSP F-13, DMSP F-15, DMSP F-16	Operational	Atmospheric temperature and humidity sounders	Water Vapour profiler	Waveband: Microwave: 91.6, 150, 183.31 (3 channels) (Total 5 channels) Spatial resolution: approx 48km Swath width: 1500km Accuracy:
SSMIS Special Sensor Microwave Imager Sounder NOAA (US DoD)	DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	Operational	Atmospheric temperature and humidity sounders	Measures thermal microwave radiation. Global measurements of air temp profile, humidity profile, ocean surface winds, rain overland/ocean, ice concentration/age, ice/snow edge, water vapour/clouds over ocean, snow water content, land surface temperature	Waveband: Microwave: 19 - 183GHz (24 frequencies) Spatial resolution: Varies with frequency: 25x17km to 70X42km Swath width: 1700km Accuracy:
SSU Stratospheric Sounding Unit NOAA	NOAA-12, NOAA-14	Operational	Atmospheric temperature and humidity sounders	Provides temperature profiles in stratosphere, top-of-atmosphere radiation from 25km to 50km altitude	Waveband: 669.99, 669.63 and 669.36/cm (carbon dioxide) Spatial resolution: 147.3km at nadir Swath width: ±40 deg scan Accuracy:
SSULI Special Sensor Ultraviolet Limb Imager NOAA	DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	TBD	Space Environment	Measures vertical profiles of the natural airglow radiation from atoms, molecules and ions in the upper atmosphere and ionosphere	SSULI makes measurements from the extreme ultraviolet (EUV) to the far ultraviolet (FUV) (80nm-170nm with 1.5 nm resolution). Uses a spectrograph fed by a mirror capable of scanning below the satellite horizon from 10-27 deg, every 90 seconds (which gives a vertical slice of Earth's atmosphere from 750-50km in altitude).
SSUSI Special Sensor Ultraviolet Spectrographic Imager NOAA	DMSP F-16, DMSP F-17, DMSP F-18, DMSP F-19, DMSP F-20	TBD	Space Environment	Monitors the composition and structure of the upper atmosphere and ionosphere, as well as auroral energetic particle inputs, with spectrographic imaging and photometry	A scanning imaging spectrograph whose field-of-view is scanned from horizon to horizon and a nadir-looking photometer system. The SIS produces simultaneous multispectral images over the spectral range 115-180nm.
SSZ NOAA (US DoD)	DMSP F-13, DMSP F-15, DMSP F-16	Operational	Space Environment	Laser threat detector	The SSZ is a static Earth viewing sensor, monitoring electro magnetic radiation.
STR Star Tracker ESA	Swarm	Operational	Precision orbit	Precise satellite orbit and attitude determination	Waveband: N/A Spatial resolution: <1arcsec Swath width: N/A Accuracy: <0.7arcsec
SUSIM (UARS) Solar Ultraviolet Irradiance Monitor NASA	UARS	Operational	Earth radiation budget radiometer	Provides data on UV and charged particle energy inputs, and on time variation of full-disk solar UV spectrum	Waveband: UV: 0.12-0.4μm Spatial resolution: Not applicable Spectral resolution: 0.15nm Accuracy: 1% Swath width: Looks at sun

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
SXI Solar X-ray Imager NOAA (USAF)	GOES-12, GOES-N, GOES-P, GOES-R	Prototype	Space Environment	Obtains data on structure of solar corona. Full disk imagery also provides warnings of geomagnetic storms, solar flares, and information on active regions of sun and filaments	Waveband: GOES 12,N,P: X-Ray 0.6-6.0nm bandpass Spatial resolution: Swath width: FWHM of ~10 arcsec Accuracy:
SXS Solar X-Ray Sensor NOAA	GOES-R	Approved	Space Environment	Studies of natural radiation hazard to humans at high altitudes and in space, as well as risk assessment and warning of episodes of surface charging, deep dielectric charging, and single event upset of satellite systems.	The GOES-R Project is in the formulation phase. The satellite will comprise improved spacecraft and instrument technologies, which will result in more timely and accurate weather forecasts, and improve support for the detection and observations of meteorological phenomena that directly affect public safety, protection of property, and ultimately, economic health and development.
TerraSAR-X X-Band Synthetic Aperture Radar DLR	TerraSAR-X	Approved	Imaging microwave radars	High resolution images for monitoring of land surface and coastal processes and for agricultural, geological and hydrological applications	Waveband: 9.65GHz, 300MHz bandwidth, all 4 polarisation modes Spatial resolution: Spotlight: 1,2m x 1-4m Stripmap: 3m x 3-6m ScanSAR: 16m x 16m Swath width: Spotlight: 5-10km x 10 km, Stripmap: 30 km, ScanSAR: 100 km Accuracy:
TES Tropospheric Emission Spectrometer NASA	Aura	Operational	Atmospheric chemistry	3-D profiles on a global scale of all infra-red active species from surface to lower stratosphere. Measures greenhouse gas concentrations, tropospheric ozone, acid rain precursors, gas exchange leading to stratospheric ozone depletion	Waveband: SWIR-TIR: 3.2-15.4µm Spatial resolution: In limb mode: 2.3km vertical resolution. In down-looking mode: 50km x 5km (global), 5km x 0.5km (local) Swath width: Limb mode: global: 50km x 180km, local: 5km x 18km Accuracy: Ozone: 20ppb, Trace gases: 3-500ppb
TIM Total Irradiance Monitor NASA	Glory, SORCE	Operational	Earth radiation budget radiometer	Measurement of total solar irradiance directly traceable to SI units with an absolute accuracy of 0.03% abd relative accuracy of 0.001% per year	Waveband: Spatial resolution: Swath width: Looks at the sun every orbit, providing 15 measurements per day Accuracy:
TIS (CONAE) Thermal IR Scanner CONAE	SAC-F	Approved	Imaging multi-spectral radiometers (vis/IR)		Data not available
TM Thematic Mapper USGS	Landsat-5	Operational	Imaging multi-spectral radiometers (vis/IR)	Measures surface radiance and emittance, lands cover state and change (eg vegetation type). Used as multipurpose imagery for land applications	Waveband: 0.45-12.50µm Spatial resolution: VIS-SWIR, 30m; TIR: 120m Swath width: 185km Accuracy:

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
TMR TOPEX Microwave Radiometer NASA	Topex-Poseidon	Operational	Imaging multi-spectral radiometers (vis/IR)	Provides altimeter data to correct for errors caused by water vapour and cloud-cover. Also measures total water vapour and brightness temperature	Waveband: Microwave: 18GHz, 21GHz, 37GHz Spatial resolution: 44.7km at 18GHz, 37.4km at 21GHz, 23.6km at 37GHz Swath width: 120 deg cone centred on nadir Accuracy: Total water vapour: 0.2g/sq cm, Brightness temperature: 0.3 K
TOM Total Ozone Mapper NRSCC (CAST)	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Being developed	Atmospheric chemistry	Ozone chemistry measurements	Waveband: UV Spatial resolution: 50km Swath width: Accuracy:
TOPEX TOPEX NASA Radar Altimeter NASA	Topex-Poseidon	Operational	Radar altimeters	Measurement of global ocean surface topography	Waveband: Microwave: 126 GHz and 5.3 GHz Spatial resolution: Swath width: 6km Accuracy: 2.4cm
TOPSAT telescope BNSC	TopSat	Prototype	High resolution optical imagers	Experimental medium-resolution imaging satellite supporting a range of possible land applications	Waveband: Panchromatic VIS: 0.5-0.75μm. 3-band multi-spectral. Spatial resolution: 2.5m pan. 5m multi-spectral. Swath width: 10km-MS, 15km-Pan Accuracy:
TRSR Turbo-Rogue Space Receiver NASA	Jason, Jason-2 (also known as OSTM)	TBD	Precision orbit & Atmospheric temperature and humidity sounders	Provides precise continuous tracking data of satellite to decimeter accuracy	Waveband: L-band:1228 and 1575MHz Spatial resolution: Not applicable Swath width: Not applicable Accuracy:
TSIS Total Solar Irradiance Sensor NOAA	NPOESS-3, NPOESS-6	Being developed	Earth radiation budget radiometer	0.2- 2 micron solar spectral irradiance monitor	Waveband: UV-SWIR: 0.2-2μm Spatial resolution: Swath width: Accuracy: 1.5w/m2
Variant ROSKOSMOS	SICH-1M		Magnetic field	Studies of the ionosphere	Payload package which includes: an electric probe, a wave probe, a Rogovsky coil, a Faraday cup, a fluxgate magnetometer, and a data acquisition unit.
VEGETATION CNES (EEC)	SPOT-4, SPOT-5	Operational	Imaging multi-spectral radiometers (vis/IR)	Data of use for crop forecast and monitoring, vegetation monitoring, and biosphere/ geosphere interaction studies	Waveband: Operational mode: VIS: 0.61-0.68μm, NIR: 0.78-0.89μm, SWIR: 1.58-1.75μm, Experimental mode: VIS: 0.43-0.47μm Spatial resolution: 1.15km at nadir - minimal variation for off-nadir viewing Swath width: 2200km Accuracy:
VFM Vector Magnetometer ESA	Swarm	Operational	Magnetic field	The VFM is the prime instrument of the Swarm mission. It will provide ultra linear and low-noise measurements of the Earth's magnetic field vector components	Waveband: N/A Spatial resolution: <0.1nT Swath width: N/A Accuracy: <0.5nT/15days

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
VHRR Very High Resolution Radiometer ISRO	INSAT-2E, INSAT-3A, KALAPANA	Operational	Imaging multi-spectral radiometers (vis/IR)	Cloud cover, rainfall, wind velocity, sea surface temperature, outgoing longwave radiation, reflected solar radiation in spectral band 0.55-0.75µm, emitted radiation in 10.5-12.5µm range	Waveband: VIS: 0.55-0.75µm, NIR: 5.7-7.1µm, TIR: 10.5-12.5µm Spatial resolution: 2km in visible, 8km in IR Swath width: Full Earth disk every 30 minutes Accuracy:
VIIRS Visible/Infrared Imager Radiometer Suite NOAA (NASA)	NPOESS-1, NPOESS-2, NPOESS-3, NPOESS-4, NPOESS-5, NPOESS-6, NPP	Approved	Imaging multi-spectral radiometers (vis/IR)	Global observations of land, ocean, and atmosphere parameters: cloud/weather imagery, sea-surface temperature, ocean colour, land surface vegetation indices	Waveband: VIS - TIR: 0.4-12.5µm (22 channels) Spatial resolution: 400m-1.6km Swath width: 3000km Accuracy: SST 0.35K
VIRR Multispectral Visible and Infra-red Scan Radiometer (10 channels) NRSCC (CAST)	FY-3A, FY-3B, FY-3C, FY-3D, FY-3E, FY-3F, FY-3G	Being developed	Imaging multi-spectral radiometers (vis/IR)	Multispectral Visible and Infra-red Scan Radiometer	Waveband: Spatial resolution: 1.1km Swath width: 3200km Accuracy:
VISSR (GMS-5) Visible and Infra-red Spin Scan Radiometer (GMS-5) JAXA (JMA)	GMS-5	Operational	Imaging multi-spectral radiometers (vis/IR)	Data used for cloud type and motion detection wind. Also measures sea surface temperature and atmospheric water vapour	Waveband: VIS: 0.55-0.9µm, TIR: 6.5-7, 10.5-11.5, 11.5-12.5µm Spatial resolution: Visible: 1.25km, TIR: 5km Swath width: Full Earth disk in all channels, every 1 hour Accuracy:
WAOSS-B Wide-Angle Optoelectronic Stereo Scanner DLR	BIRD	Operational	Imaging multi-spectral radiometers (vis/IR)	Vegetation and Cloud coverage	Waveband: VIS: 600-670nm, NIR: 840-900nm Spatial resolution: 185m Swath width: 533km Accuracy:
WEFAX Weather Facsimile NOAA	GOES-9, GOES-10, GOES-11, GOES-12, GOES-N, GOES-O, GOES-P, GOES-R	Operational	Communications	Weather Facsimile	Data communications
WFC Wide Field Camera NASA	CALIPSO	Approved	Imaging multi-spectral radiometers (vis/IR)	Acquires high spatial resolution imagery for meteorological context	Waveband: VIS: 620 to 670 nm Spatial resolution: 125m Swath width: 60km Accuracy:
WFI Wide Field Imager CAST (INPE)	CBERS-2, CBERS-2B	Operational	Imaging multi-spectral radiometers (vis/IR)	Earth resources, environmental monitoring, land use	Waveband: VIS: 0.63-0.69µm, NIR: 0.77-0.89µm Spatial resolution: 258m Swath width: 890km Accuracy: 0.3pixels

Instrument & agency (& any partners)	Missions	Status	Type	Measurements & applications	Technical characteristics
WFI-2 Wide Field Imager 2 CAST (INPE)	CBERS-3, CBERS-4	Operational	Imaging multi-spectral radiometers (vis/IR)	Earth resources, environmental monitoring, land use	Waveband: VIS: 0.45-0.52, 0.52-0.59, 0.63-0.69, 0.77-0.89µm Spatial resolution: 73m Swath width: Accuracy:
WiFS Wide Field Sensor ISRO	IRS-P4	Operational	Imaging multi-spectral radiometers (vis/IR)	Vegetation monitoring, environmental monitoring, drought monitoring, snow melt run-off forecasting, global green cover assessment, agro-climatic regional planning	Waveband: VIS: 0.62-0.68µm NIR: 0.77-0.86µm SWIR: 1.55-1.7µm (IRS P3 only) Spatial resolution: 188m Swath width: 810km Accuracy:
WINDII CNES (NASA)	UARS	Not operational	Atmospheric chemistry	Day and night wind measurements between 80km and 300km altitude. Measures atmospheric temperature and concentration of emitting species. WINDII is no longer operational on UARS	Waveband: Visible-NIR:0.55-0.78µm Spatial resolution: Vertical: 2km Horizontal: 25km Swath width: 70-310km Accuracy: Wind speed: 10m/s
WTE Whale Tracker Experiment CONAE	SAC-C	TBD	Data collection	Environmental data collection system	Data communication
XPS XUV Photometer System NASA	SORCE	Operational	Other	Objective is to measure the extreme UV solar irradiance from 1-35nm	Waveband: UV: 1-35nm Spatial resolution: Swath width: Accuracy:

A Further information on CEOS

A.1 Overview

The Committee on Earth Observation Satellites (CEOS) was created in 1984, in response to a recommendation from a Panel of Experts on Remote Sensing from Space, under the aegis of the Economic Summit of Industrialised Nations Working Group on Growth, Technology and Employment. This group recognized the multidisciplinary nature of satellite Earth observation and the value of coordination across all proposed missions.

CEOS combined the previously existing groups for Coordination on Ocean Remote-Sensing Satellites (CORSS) and Coordination on Land Observation Satellites (CLOS), and established a broad framework for coordinating all spaceborne Earth observation missions.

A.2 Purpose

CEOS coordinates civil spaceborne observations of the Earth. Participating agencies strive to address critical scientific questions and not to plan satellite missions which unnecessarily overlap each other.

CEOS has three primary objectives in pursuing this goal:

- to optimise benefits of spaceborne Earth observations through cooperation of its Members in mission planning and in development of compatible data products, formats, services, applications and policies;
- to serve as a focal point for international coordination of space-related Earth observation activities;
- to exchange policy and technical information to encourage complementarity and compatibility of observation and data exchange systems.

A.3 Participants

Members: Governmental organisations that are international or national in nature and are responsible for a civil spaceborne Earth observations program currently operating, or at least in Phase B or equivalent of system development, will be eligible for membership in CEOS.

Associates: CEOS Associates are either:

- Governmental organisations that are international or national in nature and currently have a civil space-segment activity in Phase A/pre-Phase A or equivalent of system development, or a significant ground-segment activity that supports CEOS objectives; or
- Other existing satellite coordination groups and scientific or governmental bodies that are international in nature and currently have a significant programmatic activity that supports CEOS objectives.

A.4 CEOS Plenary

Currently, 23 space agencies along with 20 other national and international organisations participate in CEOS planning and activities. Participating agencies meet in Plenary annually, with activities and coordination occurring throughout the year. The Plenary reviews progress on the various projects and activities being undertaken within CEOS. The Chair of CEOS rotates at the annual Plenary. The CEOS Chair for 2005 is the British National Space Centre (BNSC). For 2006, the Comision Nacional de Actividades Espaciales (CONAE), of Argentina, will undertake CEOS Chairmanship.

A.5 CEOS Secretariat

A permanent Secretariat, chaired by the current CEOS host organisation, provides most of the coordination between plenary sessions and is maintained by:

- the European Space Agency (ESA) jointly with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT);
- the National Aeronautics and Space Administration (NASA) jointly with the National Oceanic and Atmospheric Administration (NOAA) of the United States;
- the Ministry of Education, Culture, Sports, Science and Technology (MEXT) jointly with the Japan Aerospace Exploration Agency (JAXA);

and is chaired by the current CEOS host organisation in support of the CEOS Plenary. As part of the ongoing contribution to CEOS Secretariat activities, ESA is responsible for the CEOS Handbook, NASA for the CEOS Annual Report and WWW site content, and MEXT/JAXA for the CEOS Newsletter, Brochure and maintenance of the WWW site.

A.6 CEOS Working Groups

Working Group on Calibration and Validation (WGCV): The objectives of the WGCV are to enhance coordination and complementarity, to promote international cooperation and to focus activities in the calibration and validation of Earth observations for the benefit of CEOS Members and the international user community. WGCV addresses sensor specific calibration/validation and geophysical parameter/derived products validation. WGCV meets approximately every nine months. The subgroups of WGCV are as follows:

- The Infrared and Visible Optical Sensors Subgroup;
- The Microwave Sensors Subgroup;
- The SAR Subgroup;
- The Terrain Mapping Subgroup;
- The Land Product Validation Subgroup
- The Atmospheric Chemistry Subgroup.

http://wgcv.ceos.org

Working Group on Information Systems and Services (WGISS): The objective of WGISS is to facilitate data and information management and services for users and data providers in dealing with global, regional, and local issues. In particular, it addresses the capture, description, processing, access, retrieval, utilisation, maintenance and exchange of spaceborne Earth observation data and supporting ancillary and auxiliary data and information, enabling improved interoperability and interconnectivity of information systems and services. WGISS meets approximately every six months.

The two subgroups of WGISS are the 'Technology & Services', and the 'Projects and Applications' Subgroups. WGISS has started a new initiative called the WGISS Test Facility which offers a framework for partnership with selected international science and EO projects to test and develop information systems and services to meet their requirements. The Global Observation of Forest Cover (GOFC) international science project was the first test of this concept. More recent implementations include WTF-CEOP – which aims to provide assistance to the CEOP (Coordinated Enhanced Observing Period) science community in the development of data services associated with satellite data integration.

http://wgiss.ceos.org

Working Group on Education and Training (WGEdu): The CEOS Working Group on Earth Observation, Education, Training, and Capacity Building (WGEdu) has developed a Strategy for EO Education and Training in order to establish an effective coordination and partnership mechanism among CEOS agencies and institutions offering education and training around the world. The key objective of the strategy is to facilitate activities that substantially enhance international education and training in Earth System Science and the observation techniques, data analysis and interpretation required for its use and application to societal needs. The Group has developed a CEOS Education portal to provide easy access to data sets available for these purposes.

http://wgedu.ceos.org

A.7 Strategic Implementation Team

CEOS has established a Strategic Implementation Team (SIT) with the responsibility to address the composition and function of the space component of an IGOS. (Further details in annex B). The SIT provides a forum where the heads of space agencies can meet to develop agreements on programme commitments - in order to address gaps or overlaps in mission planning.

In 2005, the SIT is Chaired by JAXA. ESA will commence their 2-year chairmanship late in 2005.

A.8 Further information on CEOS activities

Refer to **www.ceos.org**

Or contact the nearest member of the CEOS Secretariat:

Europe:
ESA
8-10, rue Mario Nikis
75738 Paris Cedex 15
France

+33 1 5369 7707 (voice)
+33 1 5369 7286 (fax)
huw.hopkins@esa.int

EUMETSAT
Am Kavalleriesand 31
64295 Darmstadt
Germany

+49 6151 807 603 (voice)
+ 49 6151 807 555 (fax)
dwilliams@eumetsat.de

United States:
NASA
300 E Street, SW
Washington, DC 20546
USA

+1 202 358 1622 (voice)
+1 202 358 2798 (fax)
devon.carroll@nasa.gov

NOAA
1335 East-West Highway
20910-3226 Silver Spring, MD
USA

+1 301 713 2024 (voice)
+1 301 713 2032 (fax)
brent.smith@noaa.gov

Japan:
MEXT*/JAXA
Earth Observation Research Center (EORC)
Harumi Triton Square X-tower 23F
1-8-10 Harumi, Chuoku, Tokyo, JAPAN

+81 3 6221 9139 (voice)
+81 3 6221 9180 (fax)
ceos-jpn@jaxa.jp
ishida.chu@jaxa.jp

* *MEXT: Ministry of Education, Culture, Sports, Science and Technology*

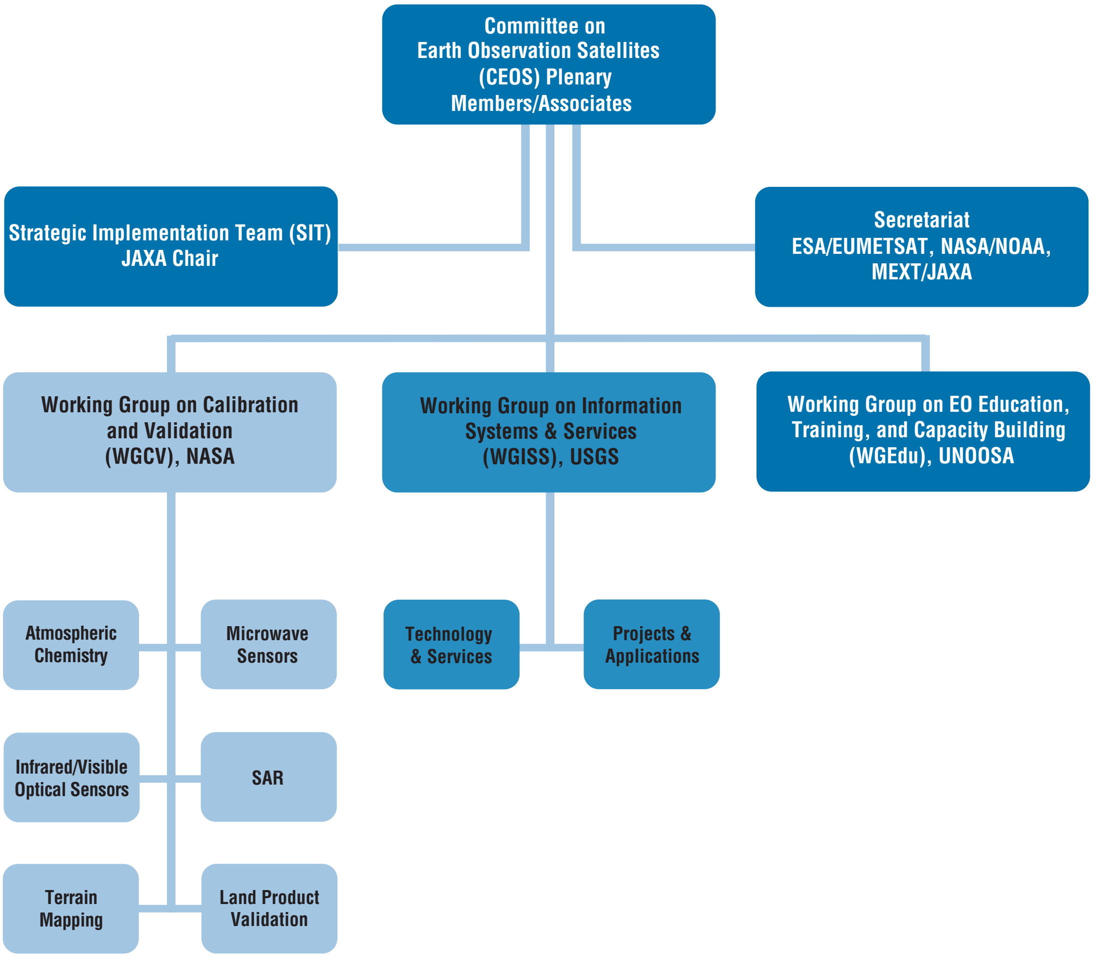
The CEOS Newsletter supplements the latest information available on-line about CEOS and is distributed internationally on a 6-monthly basis. Subscription requests should be sent to:

Ms Kazuko Misawa

RESTEC
+81 3 5561 4547 (voice)
misawa@restec.or.jp

CEOS History

Plenary	Year	Venue	Host
1st Plenary	1984	Washington, DC, USA	NOAA
2nd Plenary	1986	Frascati, Italy	ESA
3rd Plenary	1988	Ottawa, Canada	CSA
4th Plenary	1990	São José dos Campos, Brazil	INPE
5th Plenary	1991	Washington, DC, USA	NASA/NOAA
6th Plenary	1992	London, UK	BNSC
7th Plenary	1993	Tsukuba, Japan	MEXT/NASDA
8th Plenary	1994	Berlin, Germany	DARA
9th Plenary	1995	Montreal, Canada	CSA
10th Plenary	1996	Canberra, Australia	CSIRO
11th Plenary	1997	Toulouse, France	CNES
12th Plenary	1998	Bangalore, India	ISRO
13th Plenary	1999	Stockholm, Sweden	EUMETSAT
14th Plenary	2000	Rio de Janeiro, Brazil	INPE
15th Plenary	2001	Kyoto, Japan	MEXT/NASDA
16th Plenary	2002	Frascati, Italy	ESA
17th Plenary	2003	Colorado Springs, USA	NOAA
18th Plenary	2004	Beijing, PR China	NRSCC
19th Plenary	2005	London, UK	BNSC
20th Plenary	2006	Argentina	CONAE



CEOS Structure

B CEOS involvement in IGOS

B.1 The IGOS Partnership

The Integrated Global Observing Strategy Partnership (IGOS-P) was established in June 1998 by a formal exchange of letters among the 13 founding Partners for the definition, development and implementation of the Integrated Global Observing Strategy (IGOS). The principal objectives of the IGOS are to address how well user requirements are being met by the existing mix of observations, including those of the global observing systems, and how they could be met in the future through better integration and optimisation of remote sensing (especially space-based) and in situ systems.

The IGOS serves as guidance to those responsible for defining and implementing individual observing systems. Implementation of the Strategy, i.e. the establishment and maintenance of the components of an integrated global observing system, lies with those governments and organisations that have made relevant commitments, for example, within the governing councils of the observing systems' sponsors. To aid the development of the Strategy, the Partners have adopted an incremental "Themes" approach based on perceived priorities.

The IGOS brings together the major Earth and space-based systems for global environmental observations of the atmosphere, oceans and land in a strategic planning process, in order to facilitate the necessary harmonisation and achieve maximum cost-effectiveness for the total set of observations. The relevant observing systems encompass a broad range of different networks of satellite-borne and Earth-based sensors, including ocean buoys, weather stations and atmospheric radiosondes. IGOS recognises that many of these observing systems are in need of improvements, some lack the necessary long-term continuity, and all require strengthened links between the space-based and Earth-based components, as well as between the observing programmes and the processes of scientific and environmental policy-making which define the information priorities.

B.2 Membership

The IGOS-P brings together the efforts of a number of international bodies concerned with the observational component of global environmental issues, both from a research and a long-term operational programme perspective. The partners are:

- **the Global Observing Systems:** Within the last decade, the Global Observing System of the World Weather Watch (WWW/GOS) and the Global Atmosphere Watch (GAW) have been complemented by the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS) to produce a set of Global Observing Systems integrating in-situ and remotely sensed data, with each focusing on a major component of the Earth System. The Global Climate Observing System (GCOS) has also been planned and initiated to integrate the observing needs for climate purposes;
- **the international agencies which sponsor the Global Observing Systems:** The Global Observing Systems are sponsored by a number of international agencies: Food and Agriculture Organization (FAO), International Council for Science (ICSU), Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO) and World Meteorological Organization (WMO);
- **the Committee on Earth Observation Satellites (CEOS):** CEOS coordinates the efforts of space agencies worldwide in the planning of Earth observation satellite missions and their applications;
- **the International Group of Funding Agencies for Global Change Research (IGFA):** National research funding agencies and ministries involved in programming and funding of global change research collaborate in IGFA;
- **the international global change research programmes:** The World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP) are key international frameworks for nations and institutions to cooperate in undertaking research into broad planetary environmental issues and in the funding of such research.

Other organisations prepared to contribute to the development of IGOS may be welcomed as Partners in future and several already contribute to the development and implementation of the various IGOS Themes. The Partnership provides a continuing mechanism to oversee the development of IGOS. The IGOS-P Secretariat ensures continuity in the process, provides a focus for external interfaces, and helps to promote the visibility of the IGOS-P in key arenas, such as the environmental conventions.

B.3 IGOS Themes

The IGOS Partners recognise that it is not practical to attempt to define a comprehensive global system that would in a single step satisfy all needs for environmental information. Rather, they have adopted a process - The IGOS Themes - which allows for the coherent definition and development of an overall global strategy for observing selected fields of common interest among a group of the Partners. Selection of the Themes is based on an assessment of the relevant scientific and operational priorities for overcoming deficiencies in information, as well as analysis of the state of development of relevant existing and planned observing systems.

In early 2005, the status of the IGOS Theme is as follows:

Theme	Lead agencies	Status
Ocean	GOOS/NASA	In implementation
Geo-hazards	UNESCO/ESA	In implementation
Carbon Cycle	IGBP	In implementation
Water Cycle	WCRP	In implementation
Atmospheric Chemistry	WMO	In implementation
Coastal	GOOS/GTOS	In implementation
Land	GTOS	In definition
Cryosphere	WCRP/ESA	In definition

B.4 CEOS involvement in IGOS

CEOS has embraced the concept of an Integrated Global Observing Strategy as a valuable initiative which perfectly complements its own set of objectives, and which may be adopted by CEOS to derive greater benefit from operating and planned observing systems. Through working together, CEOS agencies are in a position to plan their Earth observation programmes with the minimum of unnecessary overlap and to devise joint strategies for addressing serious gaps in their observation capabilities.

Strengthened links between space-based and Earth-based observing systems, and with scientific and environmental policy-making processes provide compelling motivation for CEOS to take an active role in IGOS Partnership activities. To reflect the significance of IGOS work, and notably the progress of the IGOS Themes within its efforts, CEOS established a Strategic Implementation Team (SIT) – which has the responsibility to address the composition and function of the space component of an IGOS.

On a Theme by Theme basis, the SIT takes the lead role in defining the requirements for, and capabilities of, existing and planned satellite-based observing systems for specific measurements and applications for consideration in IGOS-P.

B.5 Further information on IGOS

Extensive information on the activities of the IGOS Partnership can be found on the WWW site.

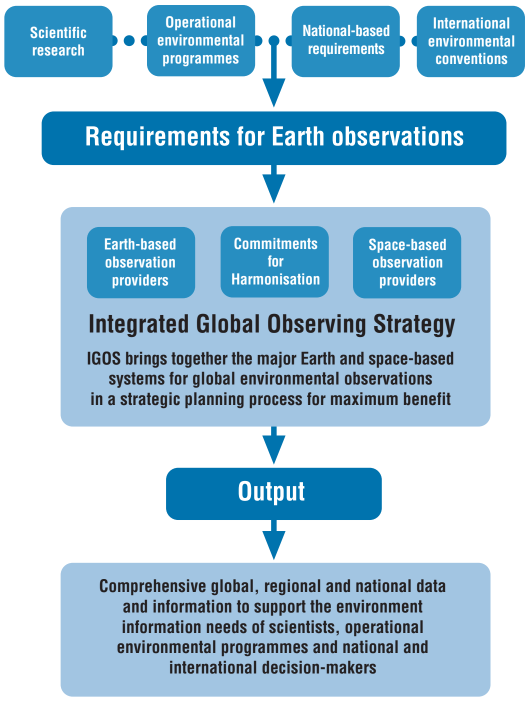
www.igospartners.org

The IGOS brochure also contains the latest information on each of the IGOS Themes and full contact information for the Theme Teams:

ioc.unesco.org/igospartners/docs/brochure/IGOSbrochureJuly03.pdf

You can also register to receive copies of the IGOS Bulletin, distributed periodically by CNES:

Carole.Deniel@cnes.fr



International community urges the establishment of the strategy for integrated global observations

AGENDA 21 OF THE UNITED NATIONS CONFERENCE ON THE ENVIRONMENT AND DEVELOPMENT (1992)

(d) Improvement of methods of data assessment and analysis

"40.9 Relevant international organisations should develop practical recommendations for co-ordinated, harmonised collection and assessment of data at the national and international levels."

THE NINTH SESSION OF THE COMMISSION ON SUSTAINABLE DEVELOPMENT (CSD9: APRIL 2001)

Decision 9/2 (Atmosphere)

"8. The commission emphasises the importance of:
(d) Encouraging relevant international organisations especially the United Nations specialised agencies, to jointly plan and implement a **strategy for integrated global observations** to monitor the Earth's atmosphere."

Decision 9/4 (Information for Decision-making and Participation)

"The commission; ...
(d) Urges strengthened co-operation among global observing systems and research programmes for **integrated global observations** taking into account, the need for sharing, among all countries, of valuable data such as ground based observation data and satellite remote sensing data."

C Abbreviations

ASI	Agenzia Spaziale Italiana
BNSC	British National Space Centre
CAST	Chinese Academy of Space Technology
CCRS	Canada Centre for Remote Sensing
CEOP	Coordinated Enhanced Observing Period
CEOS	Committee on Earth Observation Satellites
CFCs	chlorofluorcarbons
CGMS	Coordinating Group for Meteorological Satellites
CLIVAR	Climate Variability and Predictability
CNES	Centre National d'Etudes Spatiale
CONAE	Comisión de Actividates Espaciales
COP	Conference of the Parties
CRI	Crown Research Institute
CSA	Canadian Space Agency
CSD	United Nations Commission for Sustainable Development
CSIR	Satellite Applications Centre (SAC)/ Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital Elevation Model
DLR	Deutsches Zentrum für Luft-und Raumfahrt
DMSG	Ad Hoc Working Group on Disaster Management Support
DoD	US Department of Defense
EC	European Commission
ENSO	El Niño-Southern Oscillation
EO	Earth Observation
ESA	European Space Agency
ESCAP	Economic and Social Commission of Asia and the Pacific
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organization
FIR	Far Infra-Red
FPAR	Fraction of absorbed Photosynthetically Active Radiation
GCOS	Global Climate Observing System
GEO	Ad-hoc Group on Earth Observations
GEWEX	The Global Energy and Water Cycle Experiment
GFMC	Global Fire Monitoring Center
GIS	Geographic Information Systems
GISTDA	Geo-Informatics and Space Technology Development Agency
GLOSS	Global Sea Level Observing System
GOOS	Global Ocean Observing System
GPS	Global Positioning Satellites
GTOS	Global Terrestrial Observing System
ICSU	International Council for Science
IDNDR	International Decade for Natural Disaster Reduction
IGACO	The Integrated Global Atmospheric Chemistry Observations
IGBP	International Geosphere-Biosphere Programme
IGCO	Integrated Global Carbon Observation
IGCO	Integrated Global Carbon Observations
IGOS	Integrated Global Observing Strategy
IGOS-P	Integrated Global Observing Strategy Partnership
IHDP	International Human Dimensions Programme
INPE	Instituto Nacional de Pesquisas Espaciais

IOC	Inter-governmental Oceanographic Commission
IOCCG	International Ocean Colour Coordinating Group
IPCC	International Panel on Climate Change
IPCC	Intergovernmental Panel on Climate Change
IR	Infra-Red
ISDR	International Strategy for Disaster Reduction
ISPRS	International Society for Photogrammetry and Remote Sensing
ISRO	Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
KARI	Korea Aerospace Research Institute
KNMI	Royal Netherlands Meteorological Institute
LIDAR	LIght Detection And Ranging instruments
LST	Local Solar Time
MEXT	Ministry of Education, Culture, Sports, Science and Technology
MWIR	Medium Wave Infra-Red
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NDVI	Normalised Difference Vegetation Indices
NGOs	Non-governmental organisations
NIR	Near Infra-Red
NOAA	National Oceanic and Atmospheric Administration
NRSC	Norwegian Space Centre
NRSCC	National Remote Sensing Center of China
NSAU	National Space Agency of Ukraine
NWP	Numerical Weather Prediction
OSTC	Federal Office for Scientific, Technical and Cultural Affairs
ROSHYDROMET	Russian Federal Service for Hydrometeorology and Environment Monitoring
ROSKOSMOS	Russian Aviation and Space Agency
SAR	Synthetic Aperture Radar
SIT	Strategic Implementation Team
SNSB	Swedish National Space Board
SST	Sea surface temperature
SWIR	Short-wave Infra-Red
TCO	Terrestrial Carbon Observations
TIR	Thermal Infra-Red
TSI	Total solar irradiance
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNOOSA	United Nations Office of Outer Space Affairs
USGS	United States Geological Survey
UV	Ultra-Violet
VIS	Visible
WCRP	World Climate Research Programme
WGCV	Working Group on Calibration and Validation
WGEdu	Working Group on Earth Observation Education, Training, and Capacity Building
WGISS	Working Group on Information Systems and Services
WMO	World Meteorological Organization
WWC	World Water Council
WWW	World Wide Web