Restricted distribution

IOC/INF-915
Paris, 27 January 1993
English only

31 MAR 1993

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
(of UNESCO)

REPORT OF THE IOC BLUE RIBBON PANEL FOR A GLOBAL OCEAN OBSERVING SYSTEM (GOOS)

THE CASE FOR GOOS

Upon the request of the Secretary of the IOC, an *ad hoc* panel of internationally-recognized experts, the Blue Ribbon Panel for GOOS, was convened at Scripps Institute of Oceanography in August 1992 to develop "The Case for GOOS". Its objective was to provide justification to political leaders and decision makers for committing national efforts to GOOS.

The report of the Panel was submitted to many individual scientists and specialists for review and comments. This report incorporates some of these comments. This report, however, does not represent a consensus of views expressed by the reviewers or the Panel.

SC-93/WS/3

CONTENTS

ANNEXES

Preface

Scientific knowledge of the sea tends to be exploited locally rather than globally. Most human use of the ocean, amounting to economic activities valued at hundreds of billions of dollars per year, lies on the peripheries: on the continental shelf, on the seabed or on the surface. Oceanographers have long believed that the effectiveness of the services supporting those activities could be greatly enhanced if they could be set in a global context. The improvements would be cost effective, and potentially save billions of dollars per year. Atmospheric weather forecasting went global in the 1970s with great benefits for its customers. It is more difficult to take that step in ocean forecasting for well understood scientific reasons, the most important being the relatively small scale of weather systems (eddies) inside the ocean. Under one storm in the atmosphere there may be several hundred storms inside the ocean. As in the atmosphere, much of the impact of oceanic weather lies in the transient jets and vertical motion at fronts embedded in the storms. These motions cause patchiness with scales of order ten kilometres in such important variables as plankton biomass, sound speed, fisheries, and surface currents.

Given the small scale events involved and the need to address not only the physics but also the chemical, biological and sedimentological aspects of dynamic variables, it is not surprising that going global has presented the oceanographer with technical problems far greater than those overcome by meteorologists during the last thirty years. It has been impossible to design a cost-effective global observing system using the traditional method in which ships lower instruments and water samplers into the ocean while on fixed station.

Since there is no prospect of a many-fold increase in the number of ships devoted to ocean monitoring, a radically new approach is needed. The solution is to exploit improved use of satellite measurements of the ocean surface, and to develop robotic tools to map the distributions deep inside the ocean in the same way as satellites (robots in space) do for the surface. They must sample not only the physical fields needed for climate prediction, but also the chemical and biological fields needed by other customers. Improved methods of *in situ* observation are also needed on the surface and in the upper layers of the ocean.

A number of automatic systems being tested in the 1990s appear to be good candidates. Moored and drifting instrument platforms are used extensively in the Tropical Ocean Global Atmosphere project (TOGA) and have a role in the World Ocean Circulation Experiment (WOCE). Long-range unmanned submersibles capable of motoring to any depth, anywhere in the ocean will be tested in the next few years and should become operational by the end of the decade. Instruments are being miniaturised and modified for automatic operation on moored, drifting or motoring platforms. Data from those instruments are increasingly being collected by satellite, when the platform surfaces or releases a floating data capsule. Acoustic remote sensing has been used to map ocean weather in critical regions and to monitor mean temperature over long range. Taken together these advances promise a portfolio of robotic tools sufficient to monitor the interior of the ocean automatically by the end of the decade. This is the reason why oceanographers believe that the time has come to design a global ocean observing system.

A technology programme is needed to develop not only cost-effective tools to sample the ocean routinely, but also effective methods to extract information from the data they collect. Even the most optimistic design for an operational GOOS does not envisage a density of samples that on their own would resolve all the transient eddies and jets that make up ocean weather and control ocean circulation. But mere contouring of observations reveals little of their latent information content. Meteorologists have shown that much more can be learnt by assimilating observations automatically into prognostic models based on the laws of

Nature. As the models are integrated forward in time they fill in the gaps between sparse observations. Such dynamical interpolation is vital for weather forecasting. Recent experience with high resolution ocean models initialised by old data archived in the World Data Centres has demonstrated that realistic simulations can also be extracted from sparse oceanographic data. That gives us confidence that a practical operational sampling scheme can support ocean simulation models so that they will describe the changing state of the ocean sufficiently accurately to be of real value.

The new observing techniques and high resolution models offer sufficient potential to justify designing a Global Ocean Observing System (GOOS). Many of the ingredients of a GOOS have already performed well in global experiments like TOGA and WOCE. But they have never been deployed together as components of an integrated observing system designed to deliver products reliably to users in a timely manner. Before embarking on an operational system it will be necessary to demonstrate the capabilities of such a combination, and to discover the best way to use each component. That will be the goal of the GOOS Pilot Experiment (GPE), an essential step towards permanent monitoring of the world ocean.

This document presents the concept definition for a global ocean observing system in five parts:

1. The Case for GOOS
2. The benefits of GOOS: Applications and products
3. Methods, science, and technology
4. The GOOS Pilot Experiment
5. Timescale, management, and costs

The document was prepared by members of the IOC Panel for GOOS, who met at Scripps Institute of Oceanography during August 1992. It was reviewed by a hundred leading oceanographers nominated by the Intergovernmental Oceanographic Commission (IOC), International Council of Scientific Unions (ICSU) and Scientific Committee on Ocean Research (SCOR). The Panel approved the revised version for publication by IOC. Their work is now completed. Further planning and promotion will be entrusted to a new Joint GOOS Scientific and Technical Committee (J-GOOS) who will use the concept definition presented in this paper as their starting point.

J D Woods
Panel Chairman
Oxford, December 1992

Executive Summary

The objectives of this report are:

(a) To define a Global Ocean Observing System which will produce descriptions and predictions of the state of the world ocean as a service to customer groups in seven main areas: Coastal Seas, Living Resources, Science and Technology, Health of the Oceans, Shipping, Defence, Climate, and Ocean Floor; and

(b) To encourage national governments to finance the planning of a Global Ocean Observing System (GOOS) by supporting the appropriate international agencies; and

(c) To encourage national governments to approve in principle the development of GOOS, especially by including planning and investment at national level, and participation in the GOOS Pilot Experiment; and

(d) To help national governments identify observational programmes, and local and regional models and data products, which would be of most benefit nationally within the framework of GOOS.

The international planning requires an initial 3 year phase costing of the order of $2m. The long term development requires a steady increase in activity nationally and internationally over a period of 15 years. The target date for a fully operational GOOS is 2007, preceded by a GOOS Pilot Experiment from 1997-2007.

There is a need for improved availability of globally consistent ocean data and information. Present oceanographic observations are carried out without long-term commitment or co-ordination between agencies and countries. Notwithstanding the excellent programmes which exist, inefficiencies result because of gaps in data, lack of delivery, lack of integration, incompatibility of data sets, lack of continuity and consistency in satellite observations, insufficient understanding of processes, and insufficient investment in data assimilation and modelling. The lack of global integration of oceanographic data is an obstacle to monitoring, understanding, and prediction of climate change, and reduces the opportunities for improving the efficiency of many marine industries and social amenities. There would probably be a gradual increase in national investments in marine data gathering in the next decade in any case, but, in the absence of GOOS, the return on this investment would be much less than that achievable with GOOS.

Existing major global marine science programmes include plans to identify the key observations which need to be continued operationally, and these recommendations will help to identify and establish the first components of GOOS to be implemented. GOOS will continue observations consistently over decades, since some of the climatic processes which need to be understood fluctuate on this timescale.

Scientific knowledge, growth in computing power, the availability of remote sensing satellites, and foreseeable improvements in marine technology demonstrate that it is now possible to design and start the progressive implementation of a permanent ocean observing system which will be cost-effective.

Marine industries, services, and social amenities depend upon information about the ocean, first for the design of structures, vessels, and equipment; and secondly for the conduct, management and operation of oil exploitation, shipping, ports, fisheries, scientific research, coastal defences, safety, control of pollution, tourism, and a host of other activities.

The global value of marine industries and services estimated in the most conservative manner is approximately $600-800bn per year.

Efficient design of marine structures, vessels and equipment depends upon knowledge of the average and extreme conditions of storm, wind, current, waves, and icing which the structure or ship will have to undergo. This implies also understanding of the possible change in those conditions, or change in climate, during the operating life of several decades. Efficient management and operation of equipment and services at sea and on the coast depends upon short and medium term prediction of the local and regional marine and atmospheric conditions, Management of the marine environment, control of pollution, and the management of living resources in the sea can be improved similarly by availability of improved data and predictions.

Improved measurement, description, and prediction of surface and subsurface ocean conditions would provide a significant increase in the efficiency of all marine and coastal activities. Each 1% increase in efficiency would produce a benefit of the order of $8bn/yr. In practice, improved predictability of the ocean would result also in improvement of atmospheric long-term weather forecasting and climate prediction through the use of coupled ocean-atmosphere models, which would produce further large economic benefits on land. Taken together the economic, social, and scientific benefits arising from continuous and permanent measurement, description, and prediction of the ocean and coastal seas justify investment now in the development of a Global Ocean Observing System (GOOS). One of the benefits from GOOS will be an improved ability to predict the natural variability of the ocean in such processes such as the El Niño Southern Oscillation (ENSO), which causes major changes in climate and fisheries production over periods of 2-5 years in countries bordering the equatorial Pacific. Data from GOOS will help to detect changes in the heat stored in the upper ocean, and its effect on possible global warming. GOOS will concentrate on the production of global data which will assist in monitoring, understanding, and forecasting events on timescales of weeks to decades. Whilst some products will be available within a few years, those related to decadal climate change will require decades of development.

In developing GOOS, oceanographers have the example of atmospheric weather forecasting which developed from regional to global data gathering and modelling in the 1970s, with great benefits to its customers. Marine and oceanic sub-surface forecasting services do exist already for some parameters in some regions, but oceanographers have not been able to exploit the advantages of global modelling because larger volumes of data are needed to describe the ocean than the atmosphere, and suitable data are not gathered on a routine basis.

Present well-proven technology and existing satellites and planned remote sensing missions are sufficient to start the planning and development of GOOS. New technology needs to be developed for some data types, and to increase data gathering rates at reduced cost. Special effort is needed to improve systems which will measure chemical and biological parameters operationally.

GOOS will be a scientifically designed, permanent, international system for gathering and processing oceanographic observations, from the global ocean and from coastal and shelf seas. Data and data products will be distributed to all nations. GOOS will operate on two spatial scales. One requirement is to provide the observation system and data delivery which is necessary to produce globally consistent data sets for ocean-atmosphere coupled modelling and other global products. This is the GOOS Global Framework. A second requirement is to interface the global data with regional and national scale activities, including regional data gathering and modelling, and special applications. At the global scale the main benefits will accrue through the study, monitoring, understanding, and prediction of global climate change and global environmental monitoring. At the regional scale the main benefits will accrue through improved operational and design data for marine industries, services, and environmental management.

GOOS will require effort to be devoted to the operational data gathering, data management and processing, and product distribution.

The development of GOOS requires the testing and operating of many existing and new technological systems in a global suite, conveying data on a strict timetable to super-computers which assimilate, and analyse the data, and then provide descriptions and forecasts of the state of the ocean and coastal seas. Global scientific programmes at present under way, or planned, (World Ocean Circulation Experiment (WOCE), Tropical Ocean Global Atmosphere project (TOGA), Joint Global Ocean Fluxes Study (JGOFS), and others) provide the basis for the design of GOOS. Work is needed in equipment specification, testing and trials, development of operational procedures, procurement of equipment and services, and progressive merging and testing parts of the whole system. Equipment, vessels, satellites, and personnel will be dedicated to the GOOS by participating nations, and will remain under national control. The Panel proposes that a 10-year GOOS Pilot Experiment should run from 1997-2007 to test and develop the operational components of data gathering, data delivery, numerical modelling and product distribution.

The GOOS Pilot Experiment will be preceded by a planning phase, and further planning will continue in parallel with the Experiment, both to take account of the experience gained, and to develop the design and implementation of the permanent observing system after 2007.

GOOS will be developed from operational and scientific data gathering systems already in place. As a result of this policy new practical data products will be generated each year from about 1995 as GOOS is developed and integrated. Early products will be based on single parameters or types of observation, such as wave conditions, sea ice, or depth to the thermocline. Later products will be based on the integration of several parameters, and will be more sophisticated. Prediction of the El Niño phenomenon is expected to be increasingly accurate in the next few years. The distribution of the interim data products will provide a continuous and increasing economic and social benefit as GOOS is developed.

Because of the phased stages of development of GOOS, each with a defined deliverable product, governments can review their commitment to the system at regular intervals.

Governments are requested to support the next 3-year planning phase of GOOS, the establishment of a GOOS Directorate, the funding of a Joint GOOS Scientific and Technical Committee, and the establishment of a GOOS Fund. Governments are also requested to indicate in principle their support for the subsequent planning phases of GOOS, and the GOOS Pilot Experiment.

The total running cost of operating GOOS after 2007 cannot be estimated accurately at this stage, and a refinement of cost estimates will be an important part of the early phases of planning. Successful operation of GOOS will depend upon a continuing body of marine research, a number of satellites, sensors, instruments, communications systems, data centres, numerical models, and data distribution systems which will also support many other applications, and produce other benefits. The summed costs of these components should not therefore be attributed wholly to GOOS. For example, the Global Climate Observing System (GCOS), Earth Observing System (EOS), and the planned Global Terrestrial Observing System (GTOS) will benefit from many of the same components. The unique costs attributable to GOOS will include the ship-borne and subsurface instruments, and some satellite missions or sensors.

It is essential that new funding for GOOS is not created by diverting funds from process-related marine scientific research programmes. Development of GOOS needs marine research, and continuing research and operations will interact beneficially.

The G7 countries at present spend about $10bn/yr on all aspects of marine and oceanographic scientific research and marine technological research. Of this approximately one eighth is dedicated to marine environmental research, monitoring, and process studies of the marine environment aimed at improving understanding and management of the sea. New expenditure to create GOOS would thus be an increase from a present baseline of the order of $1bn/yr.

A direct comparison with the World Weather Watch would indicate that the total resources to operate GOOS if they were all dedicated solely to GOOS would be equivalent to a running cost of the order of $2bn/yr. This figure should be approximately halved to account for the multiple applications of many components. Since some of the components are already planned or committed, especially the earth-observing space missions for the next ten years, the expenditure required to support GOOS will not consist entirely of new funding. The best estimate at present is that the added cost of running GOOS after the year 2007 would be approximately $1.0bn/yr. By committing resources to an integrated GOOS, governments are ensuring that the investment in national marine science and operational oceanography in the next decade will produce maximum benefit for a minimum marginal increase in investment.

The Intergovernmental Oceanographic Commission (IOC) appointed an expert Panel to advise on the design, planning, and development of GOOS. The decision to proceed with GOOS has already been supported by IOC, World Meteorological Organisation (WMO), and United Nations Environment Programme (UNEP). This Report presents the recommendations of the Panel, with the argument on economic, social, and scientific grounds justifying the investment in GOOS.

INTRODUCTION: THE CASE FOR GOOS

The ocean is important

There are 129 coastal states in the UN and 31 landlocked. For many countries marine resources and services provide 3-5% of inputs to their GNP. For a few countries the proportion is much higher. For the technically developed G7 countries the average contribution of marine resources and services is 5% of GNP, or about $600bn (1991) value added per year. For all countries together it is of the order of $800bn. Already G7 countries spend on all aspects of marine science and technology R&D of the order of $10bn per year, excluding space satellites. The G7 countries operate about 200 civilian oceanographic research ships. The vast majority of all international trade is carried by sea, with 3.5 billion tonnes of cargo transported in ships. By the year 2020 it is probable that 75% of world population will live within 60km of sea coasts and estuaries. World production of offshore oil and gas was worth $135 bn in 1990, and provides approximately 20% of world hydrocarbon production, and substantial tax revenues. World fish catch is 80-90 million tons/yr worth approximately $45bn. Thus a significant proportion of world economic activity, and a wide range of services, amenities, and social benefits depend on the sea, and are underpinned by marine research (see Annexe 3).

The workings of the ocean and the marine ecosystem revealed by research show extreme complexity and interconnectedness on many scales. Actions taken out of ignorance - even the minimalist actions of the "Precautionary Principle" - may have counter-productive effects. There is a premium in obtaining a much better understanding of the ocean. The twin treaties of the UNCED Conference already commit us to establish an adequate observing system to develop understanding, and to monitor change. Many of the processes which control the variability and change of global climate are themselves controlled by processes in the ocean. Public perceptions of risk are only eased when governments are seen to be keeping a close watch on the environment, including the ocean.

The transport of heat, water, gases and nutrients by the oceans and coastal seas largely determines the future weather, climate, and productivity of most of the earth's surface - land and sea. It is possible in principle to predict storms, floods, seasonal to inter-annual climate fluctuations, factors controlling fisheries' productivity, and the transport of pollutants with greater accuracy and further into the future than at present. In practice the ocean and coastal seas of the world are measured so infrequently and sparsely that it is not possible now to exploit this potential for economic, humanitarian, social, and scientific benefit. There are common factors in many basic data observations required, particularly sea surface temperature and salinity, plankton and nutrient distribution, sea surface winds, variations in sea level, upper ocean heat content, and the transport of heat and water horizontally and vertically around the world by ocean currents. Specific regional and local problems will require additional local observations.

Many hundreds of $bn per year of global maritime exploitation of resources and services, together with the monitoring of pollution, climate variability and change, are underpinned by more than $10bn of marine research each year. But the effectiveness of both marine economic activities and the research which supports them is reduced because actions and decisions have to be based on local observations only. Costly ocean services and research projects are inefficient because each is too localised in space and brief in time, deprived of data from adjacent areas. There is scientific uncertainty about the causes of observed phenomena, and no general information about changes and processes on the scale of ocean basins, or the whole world ocean. We know that changes in the upper ocean are connected over thousands of km, and interact with the atmosphere, and that processes vary irregularly with periods of several years to decades. The causes, mechanisms, monitoring, and hence prediction, of large scale changes in fisheries, weather, climate, ocean currents, sea temperature, wave climate, algal blooms, and storm surges, will only be understood if there is a common framework of global ocean observations, with the output data available to all countries on a common basis. The establishment of a Global Ocean Observing System (GOOS) will achieve this objective.

Investment in GOOS can improve the efficiency of marine activities and services by a few percent so that the value of benefits would be in the range of tens of $bn per year. To this should be added the benefit of improving prediction of climate variability on land, which is probably larger, but more indirect.

Definition of GOOS

The Global Ocean Observing System (GOOS) is a scientifically designed permanent, international system for gathering, processing, and analysing oceanographic observations on a consistent basis, and distributing data products. It will gather data by remote sensing, sea surface, and sub-surface instrumentation, from the open ocean, coastal and shelf seas. GOOS products will describe the state of the ocean globally at regular intervals. Data and data products will be available to all nations.

The Proposal

The establishment of GOOS has been proposed and agreed by the Intergovernmental Oceanographic Commission (IOC), World Meteorological Organisation (WMO), United Nations Environment Programme (UNEP), and Second World Climate Conference (SWCC). In this document we endorse the establishment of GOOS, define a 10-year Pilot Experiment, and propose the methodology to be tested during the 10-year Pilot Experiment.

We endorse the establishment of the Global Ocean Observing System (GOOS).

We propose that the Global Ocean Observing System be a scientifically designed, permanent, international system for gathering and processing oceanographic observations, from the global ocean, and from coastal and shelf waters. Data and data products will be distributed to all nations. During the design, development, and trial phases (1993-2007), a major experiment should be carried out to test the practical methods of operationally integrating global data gathering and data processing techniques. This will be the GOOS Pilot Experiment, from 1997-2007. Further development and up-grading will be an ongoing activity. Research results will also constitute a sector in GOOS. There will be a steady expansion of the operational sector of the system, with progressive build-up of routine, repeated, and long-term observations so as to provide cost-effective data required for operational and scientific objectives. Useful products and economic benefits will be generated during the GOOS 10-year Pilot Experiment.

We propose that GOOS shall utilise remote sensing of the ocean surface from satellites, shipborne observations, towed instrument systems, anchored moorings, drifting buoys and subsurface floats, long-range acoustic propagations through the ocean, and powered subsurface automatic vehicles. The first measurements will describe some of the physical, chemical, and biological characteristics of oceans, marginal seas, and coastal waters. Continuous observation and monitoring using consistent techniques that produce compatible data will permit the detection of trends, monitoring, and comparisons among regions, and computation of total global changes.

We propose that Governments, through national agencies and/or international agencies, support the initial 3-year phase in the design and development of a Global Ocean Observing System (GOOS), and confirm their interest or intent in supporting the first 10-year Pilot Experiment of GOOS, 1997-2007.

We propose that data products from GOOS should be in the public domain, and should be distributed on equal terms to all states for use in improving management of natural resources, operation of maritime services, improvement of safety, monitoring and management of the marine and coastal environment, and to assist governments in the fulfilment of international treaty obligations, and the monitoring of national statutory obligations.

The need for GOOS

A long term ocean observing system is needed for many reasons, and the Panel considers that a Global Ocean Observing System as defined in this document will best meet the requirements. The following are the key demands for beginning the development of GOOS now:

- The Global Climate Observing System (GCOS) requires globally consistent surface and sub-surface marine data to monitor, describe, and understand the physical and biogeochemical processes that determine ocean circulation and the effects of seasonal and decadal climate changes, and to provide the observations needed for climate predictions.

- Developing countries have strongly requested IOC to provide consistent marine scientific data and information relating to regional climate change; coastal impacts of climate change; monitoring, and predicting sea level change and its impacts; regional scale data on the marine environment relating to fisheries: and data on the long term implications of marine pollution. Whilst there is a necessary local and regional element in developing monitoring and prediction in coastal and shelf seas, understanding fluctuations on the inter-annual and decadal scale requires data gathering at the scale of ocean basins, and globally.

- Studies of the economic impact of certainty and uncertainty concerning inter-seasonal and inter-annual fluctuations of climate, agriculture, and fisheries caused by the Southern Oscillation- El Niño (ENSO) indicate that there is an economic and commercial benefit to be obtained from improving monitoring and prediction on this timescale.

- Satellite remote sensing observation of the ocean is at present only carried out in the mode of research missions or engineering trials of sensors. An organisation is needed which will negotiate with the space agencies to ensure continuity and consistency of ocean data measured from space on a decadal timescale, and meeting defined operational and scientific standards. (The IOC Committee for GOOS is an affiliate organisation to the Committee for Earth Observing Satellites (CEOS)).

- Following the Framework Convention on Climate Change and the Convention on Biodiversity, national agencies have an obligation to obtain relevant data from the ocean environment, and make the data available in the public domain. (See Annexe 1 for treaties and conventions relevant to GOOS). Only a globally co-ordinated observation system allows this to be achieved efficiently.

- Local, regional, and even international scientific and operational projects which are already funded are not as beneficial as they could be due to lack of timely submission of data, inconsistency of data in adjacent regions or projects, poor co-ordination between *in situ* activities and remote sensing from satellites, and the *ad hoc* way in which national efforts overlap or leave gaps in time and space coverage.

- Existing marine data gathering programmes are incomplete at the global scales or too inaccurate, so that it is often not possible to make conclusions which distinguish between different scientific hypotheses. There are enough missing data to perpetuate ambiguity.

- The lack of continuity in time and space of present observing programmes means that it has not been possible to establish consistent data sets of sub-surface parameters for recent decades. Expensive projects are now being started to rescue and restore old data, to try and provide consistent long term data for the past. From now on it will be more efficient to measure ocean parameters efficiently year by year, than to make unco-ordinated *ad hoc* measurements, and then try to re-create poorly sampled basin scale data sets through "data archaeology" some years later.

- National efforts to monitor, understand, and predict marine processes such as coastal erosion, migration of fisheries, relative changes of sea level, and the transport of pollutants, are prone to loss of efficiency, or even failure, due to lack of information on oceanic variability of physical and biogeochemical processes which vary on multi-year timescales, and interact with the coastal seas.

- GOOS will facilitate the services to coastal states to obtain the maximum benefit at the national level from data obtained internationally, and at the scale of ocean basins or globally. In the absence of such a provision, most countries have to rely solely on the data which they can measure themselves. This is very inefficient for most countries.

- GOOS will provide the mechanism which will allow all countries to participate in the effort of observing the ocean, secure in the knowledge that their contribution is balanced fairly in terms of the contributions of other states, and that all the resulting data are in the public domain. Participation in GOOS will assist states in the organisation of their own national programmes, and definition of their national objectives within the framework of GOOS.

- In the absence of a global planning or co-ordinating function, the sum of national observing programmes and experiments, each carried out for limited objectives, would never add up to an optimum sampling of the world ocean. GOOS will provide the planning and agreement on allocation of resources which will fill in gaps to obtain critical data which would otherwise not be measured.

- Scientists should not have to conduct repeated operational monitoring observations on science research budgets. After completion of process studies, routine observations should be funded by operational agencies, and GOOS will facilitate this transition.

- The primary products of GOOS at the global or basin scale will be data sets assembled in near real time, or at intervals related to the rate of change of the processes being observed. The primary users will be national and international agencies concerned with environmental management, climate monitoring and prediction, assessment of the impacts of global change, management and regulation of living resources in the sea, and marine pollution; additionally, there will be a secondary market through value-added firms using GOOS data to develop regional and local products providing a better service than can be obtained using local data only, and supporting the marine industries.

- Finally, it is practical and possible to design and implement GOOS now, whereas it would not have been possible 10 years ago.

Specific benefits achievable by applying the data from GOOS to different areas of activity are listed in Annexe 3.

What will investment in GOOS buy?

GOOS will provide a reliable description of the state of the world ocean, regularly up-dated, with sufficient scope, resolution, and range of variables, physical, biological, and biogeochemical, to serve as input to applications in a wide range of operations.

GOOS, through the collaboration of a range of national and international agencies, will use the most cost-effective technology for each observation, and will not be restricted to the established technology of one agency. Progressive development of operational methods for each data type will mean that the quality-controlled data needed can be obtained automatically, using increasingly unmanned systems. GOOS will be designed to gather data on a scientifically defined network so as to provide the most effective description of the ocean with the minimum number of observations. Large quantities of routine data will be available to the scientific community, freeing them to work on new research, and providing an expanded data base. The efficiency of GOOS will be enhanced if there is the opportunity to de-classify existing military oceanographic data, and to use military experience in real time data acquisition, operational marine modelling and prediction. It would be too expensive for any one country, or one sectoral interest or industry, to finance GOOS, but collaboration between the countries with the technical experience in marine science and technology will provide a wide range of benefits at an acceptable cost, without duplication.

GOOS will be designed with a core Global Framework system of well-established routine parameters, models, and intermediate data products (Fig 1.). From the data products of the GOOS Global Framework a wide range of information, services, and data products will be developed for specialised applications in support of industry, coastal protection, marine resource exploitation, safety, monitoring the marine environment, and control of pollution. The primary benefits of GOOS will accrue in the associated economic, social, and environmental Modules, not within the Framework itself. Figure 1 shows the Beneficiary Modules in rectangular boxes, and marine science itself is a beneficiary. The use of global data sets and common data systems will improve the consistency of data, and comparability between statistics and trends.

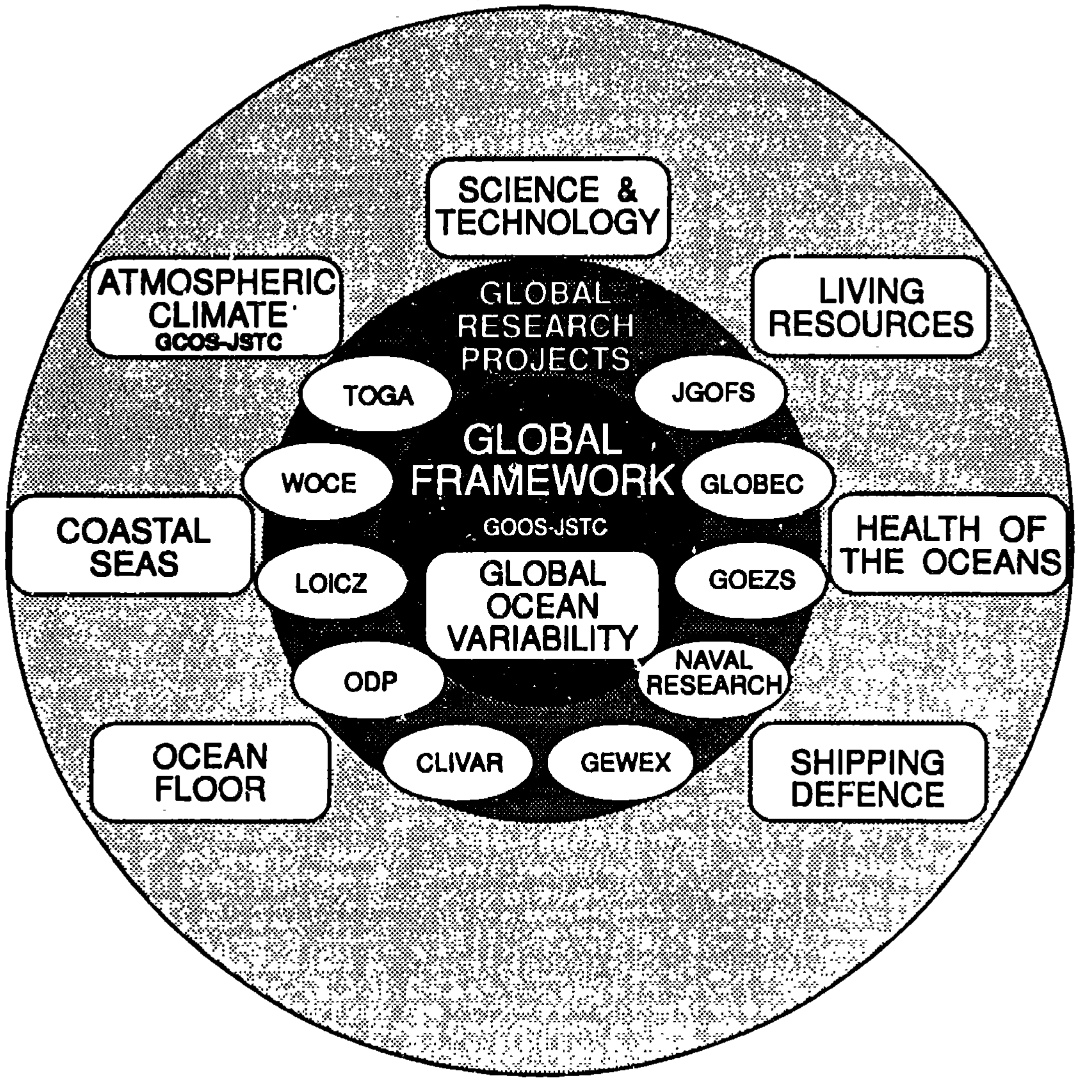

Figure 1: *The GOOS Global Framework is a system of routine global observations and, data analysis, and data products, represented by the dark inner circle of the diagram. The design, development, and evaluation of the Framework are based on the results of marine research experiments shown as white ellipses. The beneficiaries of the data provided by the GOOS Framework are the GOOS Beneficiary Modules, shown as white rectangles. The Beneficiary Module of measuring and predicting Global Ocean Variability is shown as being within the Global Framework, since the whole data set obtained by the Framework will explicitly describe that variability. This diagram is not an organogram, and does not indicate any element of managerial control of one organisation by another.*

Acronyms:

CLIVAR	Climate Variability and Predictability
GEWEX	Global Energy and Water Cycle Experiment
GLOBEC	Global Ocean Ecosystem Dynamics
GOEZS	Global Ocean Euphotic Zone Study
JGOFS	Joint Global Ocean Flux Study
LOICZ	Land-Ocean Interactions in the Coastal Zone
ODP	Ocean Drilling Program
TOGA	Tropical Oceans and the Global Atmosphere
WOCE	World Ocean Circulation Experiment

Phased development

GOOS in 1993 is at the stage of concept evaluation and feasibility study. GOOS will be developed in a controlled and accountable way by successive phases of feasibility trials, and design work, technical definition, development investment, and operational implementation. The phases of development are presented more fully later in this Report. The Phases carried out during the period 1992-2007 include the GOOS Pilot Experiment 1997-2007. Much of the work during the Pilot Experiment will consist of trials and tests with practical systems in order to establish the most efficient working methods, and to check the validity of the results. Each Phase will have a deliverable product, and Governments can assess the progress before making commitments for investment in the next Phase. During the Pilot Experiment there will be trial operational activities which will produce useful data well before the entire system is implemented. These trials will provide estimates of economic performance and improved design. See Figure 2.

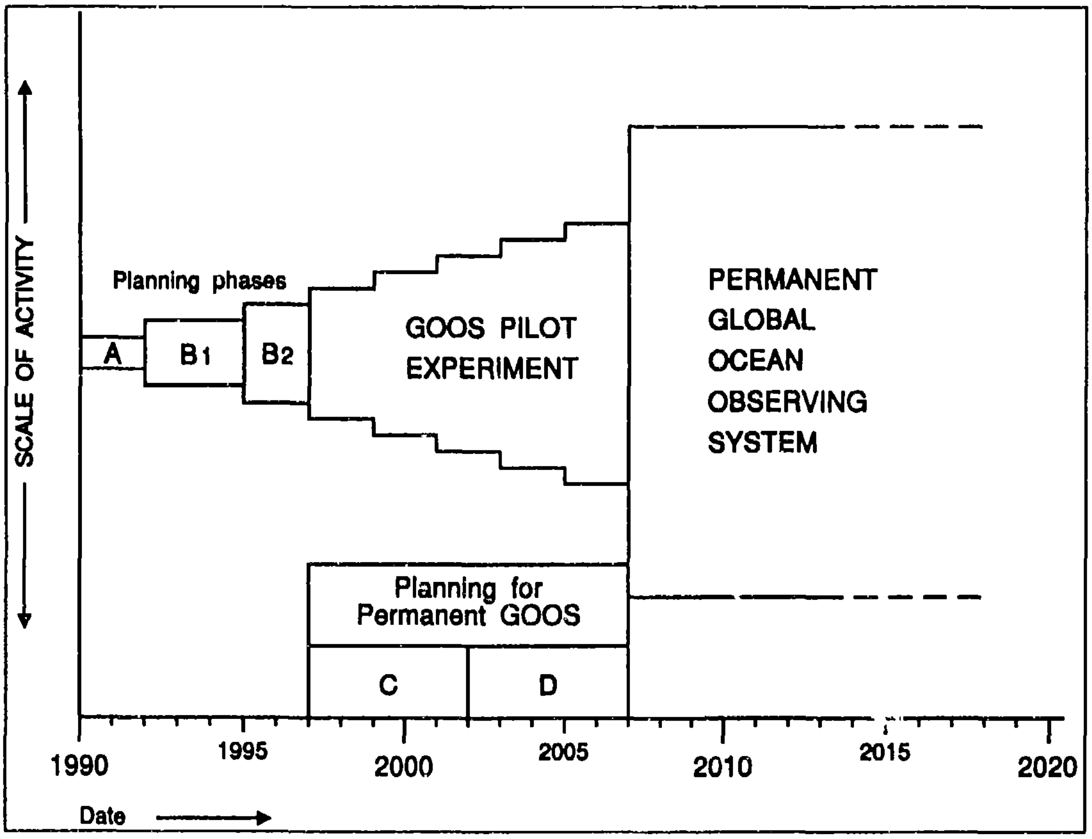

Figure 2: *Schematic diagram of the sequence of phases of planning and trials leading first to the GOOS Pilot Experiment (GPE); followed by further planning in parallel with the GPE in order to prepare implementation of the Permanent Global Ocean Observing System. (see page 27 for definition of phases)*

Is the international marine community ready to start designing GOOS?

Scientific timeliness: Scientific knowledge, sea-going skills, and experience with satellite remote-sensed data are sufficient to start designing GOOS as a core system. The rate of progress in marine science, especially through experiments such as TOGA, WOCE, JGOFS, and GLOBEC, indicates that it will be possible to design more complex parts of GOOS before the end of the decade. Cycles, oscillations, and teleconnections involving the ocean and atmosphere have been studied in recent years, including the El-Niño/Southern Oscillation (ENSO), and if these irregular cycles are to be understood and predicted, it is necessary to observe several iterations of events over a decade or more. The stamina required to maintain consistent observations on a sufficient timescale requires the establishment of a system which is effectively permanent.

Technological timeliness: Present experience with marine instrumentation, deployment systems, sensors, data logging, remote sensing, data transmission, and numerical modelling indicates that sections of an observing system could be implemented now, given adequate resources. New technology will be tested and proven during the decade of the GOOS Pilot Experiment, permitting the steady expansion of the system.

Political timeliness: The UN Convention on the Law of the Sea, the Framework Climate Convention, and the UNCED Agenda-21 stress the importance of transfer of marine data in the public domain. Universal access to a common global data set describing the ocean and marginal seas will be of benefit to coastal and maritime states, and will reduce their costs. GOOS will provide the oceanographic data needed by the Global Climate Observing System (GCOS), and the benefits arising from climate monitoring and prediction will accrue to all countries. GOOS will enhance the transfer of marine technology to Developing Countries, and enhance the management of the marine environment on a regional basis. In addition to the common global data streams produced by the GOOS Global Framework, it will be logical to develop regional emphasis with extra data specific to the problems of each region. The availability of up-to-date accurate marine data will help to reduce uncertainty about the marine environment, and avoid costly mistakes or unnecessary actions which would be more expensive.

Practical experience so far: Several countries already have practical experience at the regional scale of operational observations of the marine environment, including extended range forecasts in the range of 1 month. Experience exists in real-time data products for sea-ice condition and forecasts; fluctuations in Pacific sea level; surface and sub-surface conditions in the ENSO area; tsunamis in the Pacific; temperature and salinity in the upper ocean in the Tropical Atlantic; sea surface conditions measured by drifting buoys; and sea surface temperature, elevation, and winds, from orbiting satellites. Several navies have extensive experience in providing real time data on the upper ocean, and forecasts. On the completion of the Tropical Ocean Global Atmosphere project (TOGA) a monitoring and prediction system will probably be established for the tropical Pacific. The Integrated Global Ocean Services System of IOC and WMO provides real-time delivery of 40,000 expendable bathythermograph profiles to data centres each year.

International management and control

An Intergovernmental Committee for GOOS was established in 1992 by IOC. A Joint Scientific and Technical Committee is being set up in 1993. Papers on GOOS have been considered by G7 and the International Group of Funding Agencies for Global Change Research (IGFA). Since many of the resources needed for GOOS will be contributed by a limited number of countries, in accordance with the recommendations of the UNCED Report Agenda-21, there will need to be a GOOS Board consisting of representatives of the countries making regular major contributions or having a special interest in GOOS. Planning and co-ordination of GOOS will require a Directorate or Support Office. (See section on GOOS management, page 28-29.

Cost of planning GOOS

The Phase A Concept Evaluation for GOOS has been conducted by IOC and voluntary staff allocation by several Member States. IOC Secretariat estimates that the staff costs in IOC for Phase B1 of GOOS, Feasibility Study, Planning and Trials, will be $1.5m over the next 2 years. Several Member States have already identified research or operational activities which they wish to incorporate within GOOS. During the next 2-5 years there will be a steady increase in national activities with potential contribution to GOOS.

What needs to be done now?

- Fund GOOS Feasibility Phase B1 which will plan and prepare for the GOOS Pilot Experiment.
- Design and develop a Global Framework core of global data types in a trial observing system
- Develop local and regional models to exploit the benefits of GOOS data at the application level
- Establish a Joint GOOS Scientific and Technical Committee, supported by a GOOS Directorate.

THE BENEFITS OF GOOS: APPLICATIONS AND PRODUCTS

Annexe 3 provides an order of magnitude estimate of the possible economic value of providing marine industries and activities with data from GOOS. The benefit of implementing GOOS can be approximated by predicting that there is a small improvement of the order of 1%, or a few percent, of value resulting from the application of the data to design, operations, and management of activities which have a global value of the order of $600-800bn/yr. Examples of costs and potential benefits are given in Annexe 3. We do not wish at this stage to suggest a hard figure for the economic benefits of GOOS, other than to demonstrate that it will be many $bn/yr, whereas the marginal cost of a fully operational GOOS after 2007 will be of the order of $1.0bn/yr.

One of the benefits of GOOS, and a major application of the data produced by GOOS, is in the development and operation of coupled ocean-atmosphere models to describe, monitor, and predict climate, and climate change. GOOS will provide the ocean data for GCOS (see Annexe 6). The benefit from this will start to develop after a time lapse of the order of a decade, and major benefits after several decades. There are many other possible shorter term uses for improved descriptions and predictions of the state of the ocean, including its biological and biogeochemical processes at the basin and global scales. The same improved flow of data on upper ocean thermal structure, winds, waves, currents, and biological productivity has short and medium term applications, as well as accumulating over a decade or more to provide the basis for climate change analysis. Addition of measured variables not necessarily needed for climate research could further increase the value of the observing system to other users.

It would make this analysis simpler if we could say that there is one over-riding application for the data obtained by GOOS on all space scales and timescales. The responsibility for funding an improved observation system would then be clear-cut, falling to one, or at most two agencies at national level, one for research and one for operations. The implications of a negative decision would also be clear to the agencies concerned.

Since there are multiple potential applications of data from GOOS, the necessary focus and narrowing of immediate objectives can be achieved by identifying those global data sets and technologies which will most efficiently lead to the most valuable benefits for most applications, including climate research, at least cost.

Civil operational oceanographic agencies do not exist in most countries. To gather global data systematically and operationally from the ocean for the first time, and apply it only for climate monitoring and prediction, would be to waste potential applications of the data which would provide an earlier return on the continuing investment. There are many maritime activities which can benefit from better descriptions of the state of the ocean and coastal seas, better climatic data on annual and seasonal means and ranges, and better understanding of fluctuations and anomalies in conditions. The primary objective of GOOS is to obtain globally consistent data sets, which implies a resolution which would be coarse by the standards of coastal applications. It follows that data obtained through the Global Framework will be combined with, or supplemented by, more site-specific or region-specific observations to produce data of value to the Beneficiary Modules.

A key argument in "The Case for GOOS" is that investment in the Global Framework of GOOS will produce greater benefits across a wider range of industries and activities than could be obtained by investment of a similar sum of money directly and only in the localities where the activities are carried out.

The marine industries, services, and environmental amenities which could benefit from the use of data provided by GOOS are discussed in Annexe 3, where there is an estimate of the scale of each activity globally, and the extent to which its productivity or efficiency could be improved by the use of data from GOOS.

In Figure 1 the Beneficiary Modules are shown in the outer circle. The symbolic rectangles represent both the industrial, economic, and environmental activities as a whole, and the applied research and development which serves them. The benefits of the GOOS Global Framework will flow directly to the economic sector through specialist service organisations, and also through the applied research and development sector, where there will be further value added. There are some co-ordination programmes in the applied R&D sector to ensure that the benefits of GOOS reach the user community and these will be part of GOOS, but not part of the Global Framework.

GOOS will produce the raw data, and model outputs, for forecasts, analyses, and design criteria which will benefit the activities listed below.

Beneficiaries of GOOS:

- **Living resources**
- **Ocean floor, non-living resources**
- **Health of the oceans**
- **Coastal seas**
- **Science and technology**
- **Shipping, Defence**
- **Atmospheric climate**
- **The study of global ocean variability**

The estimates of value or benefits from each economic activity calculated in Annexe 3 are based on sales value at first landing, or value added within the industry. There have been no additional benefits included from the impact of marine products or services used in other industries. The value calculated approximates that of the raw input to the GNP. Total output benefits would be much greater than the values shown in this report, or in Annexe 3.

Descriptions, monitoring, understanding, and predictions of oceanic conditions, or the ocean-atmosphere coupled system, will benefit different industries and activities on different timescales. Figure 3 illustrates this relationship.

The present proposal does not include funding for the Modules, which have access to support from a wide range of other national and international sources, and are in any case closely related to activities of direct economic profit, or subject to agreements. In contrast, no authority at present has responsibility for the Global Framework, and it will not come into existence unless new resources and new responsibilities are created.

Accordingly, the Global Framework provides a mechanism for the acquisition, assimilation, interpretation and dissemination of data for a wide variety of applications, and transfer of the data to the Beneficiary Modules. It is anticipated that the individual Modules will be developed and funded to support the objectives of their user communities.

There are a number of scientific programme initiatives that will improve the understanding of the ocean and its processes. Many of these programmes (WOCE, LOICZ, TOGA, GLOBEC, JGOFS, CLIVAR, etc., see Fig.1) offer implicit benefits in improving the value and reliability of products from the GOOS and its Modules. These science initiatives will also enable GOOS measurements to be honed to improve their cost-effectiveness and specificity in terms of deliverables from GOOS Global Framework and the Modules.

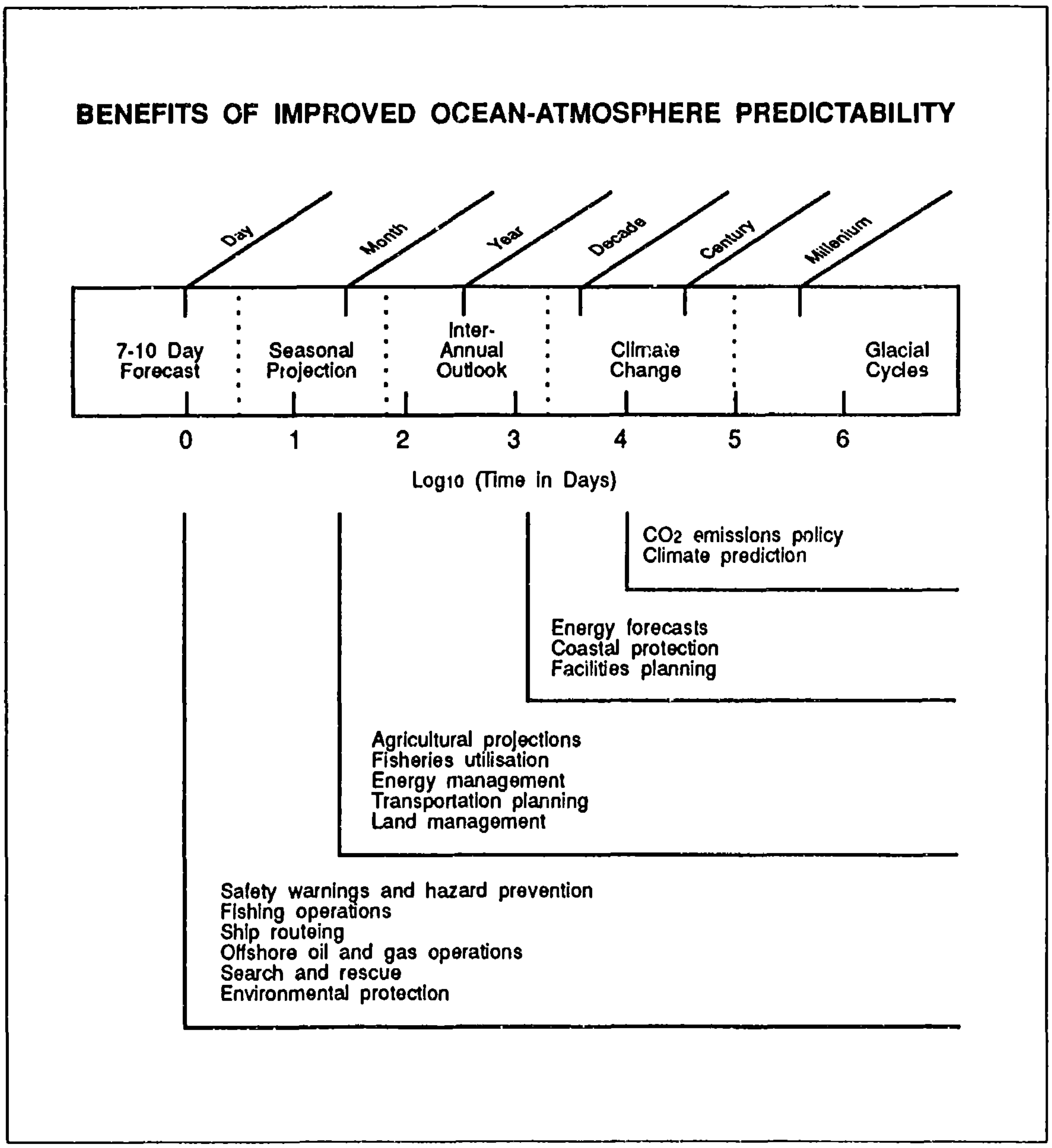

Figure 3: *The benefits of GOOS are effective over different timescales. Some information products will benefit fisheries, coastal defences, or agriculture with predictions applying to periods of a few weeks to months in advance. These products will be generated early in the GOOS Pilot Experiment. Other products and predictions will influence planning on a decadal timescale, and will take longer to develop.*

Potential products from the Global Framework of GOOS

GOOS products from the Global Framework will provide global and regional fields of ocean properties such as temperature, salinity, biological concentrations, nutrients, plankton biomass, wave spectra, ice edge, etc., at regular intervals and with consistent standards.

Potential GOOS products fall into four broad classes.

- Global scale products delivered operationally and electronically to modelling centres for assimilation into ocean basin scale models, or global coupled ocean-atmosphere models.
- Global scale products relating to one, or a small number of parameters, and delivered operationally to end users.
- Global or basin scale products delivered to regional or local modelling groups, to be combined with higher resolution data for applications.
- Data streams at any scale provided to value-added government or commercial agencies who are in business to develop higher order specialist application products.

Annexe 5 lists a range of potential products from GOOS. Several data types or products listed in Annexe 5 are already provided in part, or on a regional basis, and the experience gained from these services will be used to design the larger scale GOOS system and products.

METHODS, SCIENCE AND TECHNOLOGY

The planning, development, and progressive phased implementation of GOOS will be based on a number of general principles.

- GOOS will build on and utilise wherever possible existing systems such as the Integrated Global Ocean Service System (IGOSS); the Global Telecommunication System (GTS); the Drifting Buoy Co-operation Panel (DBCP); the International Oceanographic Data and Information Exchange system (IODE); the World Weather Watch (WWW) and the Global Sea Level Observing System (GLOSS), etc.

- GOOS will collaborate with international agencies, and their component bodies or programmes concerned with global science, or global oceanography. Relevant UN bodies include IOC, WMO and UNEP. For scientific guidance this includes ICSU.

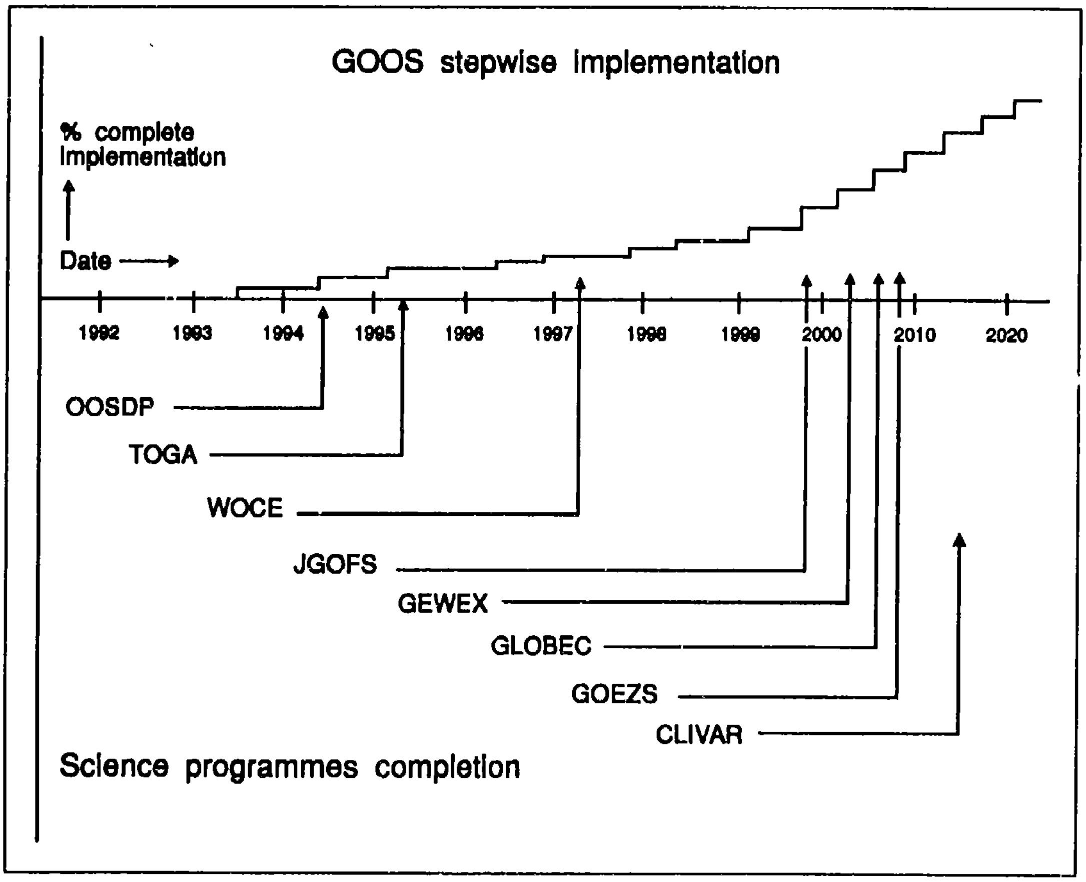

Figure 4: *Several major global scientific experiments in marine science are already under way, or are planned for later this decade. (For acronyms see Appendix 2 and box on page 22). The Ocean Observing System Development Panel (OOSDP) will report in 1994 on the design of an ocean data gathering system for climate research and prediction. The design and implementation of the GOOS Pilot Experiment will be carried out incrementally as the information becomes available. Some decisions can be made now; others depend on scientific experiments not yet completed.*

- GOOS will design and manage the observing system on the basis of the scientific knowledge and understanding of oceanographic, biological, and biogeochemical processes resulting from the major scientific research programmes such as TOGA, WOCE, JGOFS, GLOBEC, CLIVAR, etc. The stepwise development of GOOS incorporating design experience from the science programmes is illustrated in Fig.4.

- GOOS will work with groups or agencies representing the different Beneficiary Modules and areas of application of GOOS data, so as to identify and prioritise their needs more clearly. This process will result in a focused definition of the global data sets which would support most applications, including supporting research.

- GOOS will collaborate with the national and multi-national space agencies to ensure that the appropriate organisations and planning bodies are aware of the remote sensing needs of the marine science and marine operational data communities. The IOC GOOS Committee is an Affiliate Member of CEOS.

This section describes in broad terms the methods which will be used by GOOS to achieve its objectives, and the science and technology which will be needed.

Core observations for GOOS

The selection of the primary observing systems, and the core parameters which will be tested globally and implemented first for the Global Framework of GOOS, will be in response to the needs identified by different user groups and the related scientific experiments. Identification of high priority observations will depend on the sum total of benefits, and the technical possibility of meeting the demand within a reasonable timescale or cost. The Joint Scientific and Technical Committee will advise on these matters.

The observing system will have to acquire each data type with an accuracy, sampling rate, spatial coverage, and delay in delivery which is determined by the nature of the phenomenon being measured, and the use to which it will be put. Some processes will have to be measured hourly, and data delivered within 3 hours; others may only need to be measured once every three months, with the data incorporated into a model once a year. Even for the data types which are required infrequently the emphasis will be on consistency, reliability, and routine delivery by specified dates. GOOS observations will include data from the sea surface, air-sea boundary, the layer of the upper ocean which is mixed by wind and waves, sea ice, coastal and marginal seas, from the deep ocean down to depths of several km, and from the ocean floor.

This Report on "The Case for GOOS" does not pre-judge the findings and recommendations of OOSDP or other advisory bodies. As a result of the work already done by OOSDP the data requirements for an ocean climate observing system are better understood than the requirements for other applications. However, by combining the factors of availability of technology, scientific experience, and the most apparent needs of the Beneficiary Modules, it is possible to identify a range of candidate data types for the core observations or Global Framework of GOOS. The following paragraphs must not be taken as firm recommendations as to the core observations of GOOS, but are illustrative of some of the likely candidates.

Satellite remote sensing

Remote sensing is now an established technology with proven methods for measuring the topography and physical state of the ocean surface, surface winds, currents, the colour and optical properties of the upper layers, and the characteristics of sea ice. For the most accurate interpretation of some oceanographic characteristics, especially surface currents, it is also important to have very accurate determination of the earth's precise shape, or geoid, which is also measured by satellites.

The Committee of Earth Observations Satellites (CEOS) in its presentation to UNCED identified satellites carrying Synthetic Aperture Radar (SAR) as important for measuring sea ice, and the spectra of sea waves. GOOS is identified as manager and provider of the data. A variety of satellite missions are in operation or planned carrying radar altimeters which can be used to derive sea surface wave characteristics, sea surface topography and sea level change, surface currents, and the earth's geoid. Again, GOOS is listed as manager and provider of the data. GOOS will also need wind stress data which can be measured from satellites with a radar scatterometer. Sea surface temperature is measured from satellites by scanning radiometer. In 1993 the next satellite will be launched carrying sensors which scan the ocean surface to detect colour changes, and this will permit the derivation of various biological parameters. Further satellites detecting colour are planned.

Accuracy of data fields derived from remote sensing depends upon the availability of accurate *in situ* data for calibration purposes.

Space missions have planning and lead times of the order of 10-20 years. Most of the satellites, mission plans, and sensors for the rest of this decade have therefore been fixed already. To ensure the success of GOOS it is essential that the final definition of sensor characteristics and orbits of relevant missions should be responsive to the oceanographic community; that successive missions and sensors are compatible, ensuring a continuous sequence of consistent and comparable data; and that missions being planned now are managed with the needs of GOOS included in their specifications. Satellite missions must be planned to meet operational needs, as well as new science objectives.

Future satellite missions will be needed which are specifically designed to meet or include the data requirements of GOOS, and repeat missions of an operational nature will be required.

Core observations which have the greatest combination of proven experience and general application are satellite altimetry, wind scatterometry, ocean colour, and sea surface temperature determination. These would be likely candidates for a GOOS Pilot Experiment, and for eventual inclusion in the permanent system.

Recent discussions between agencies using data from existing remote sensing missions for oceanographic research and operations concluded that the most urgent step is to improve substantially the processing, handling, and development of data products for sea surface temperature, sea ice monitoring, sea surface elevation and topography, ocean colour, and wind/wave fields.

Instruments in the ocean

Observations from space give information about the sea surface, the winds at the surface, and some information on surface currents and colour to a depth of a few metres. Important processes in the ocean are determined by sub-surface currents, movement of heat and freshwater by sub-surface currents, mixing of water masses, upwelling and downwelling of water masses, oceanographic processes under sea ice and ice shelves, the transport of nutrients and oxygen by deep currents, transport and alteration of chemical compounds and species, biological interactions between species in the water, the behaviour of biological species such as feeding or migration, and the properties and movement of ocean water in contact with the sea bed at depths of several km. Measurement of these processes can only be carried out by instruments which operate in the water, or which measure by propagating sound waves through the water, or through biological or geological materials.

Surface and sub-surface data from the ocean are routinely obtained from moored or anchored instruments such as current meters, thermistor chains, or biogeochemical sensors. These technologies are available for operational applications.

Drifting instruments include surface buoys carrying temperature and meteorological sensors which transmit data ashore via communications satellites. This system is very well proven, and is being up-graded to improve accuracy and data rate. Data are centralised and processed through the Integrated Global Oceanographic Services System (IGOSS) of IOC and WMO, and archived at a Responsible National Oceanographic Data Centre. Drifting instruments can also be operated in the deep ocean, communicating acoustically, or surfacing and communicating by satellite links, e.g. ALACE floats.

The Drifting Buoy Co-operation Panel (DBCP) responds to the expressed needs of the international meteorological and oceanographic communities for data from drifting buoys, and will be integrated with GOOS.

Instruments towed by, mounted on, or launched from ships include devices to measure bathymetry, temperature, salinity, current profiles, plankton, and chlorophyll. These technologies are very well developed, but investment is needed to increase data productivity, reliability, and geographical coverage per unit cost.

Seabed and coastal instruments are used to measure tides, waves, and sediment movements. A global service already exists to collect and process sea level data from tide gauges (Global Ocean Sea Level Observing System, GLOSS), and the greatest experience has been gained in the Pacific. *In situ* oceanographic data of many types are centralised and archived by the International Oceanographic Data Exchange Committee of IOC.

In situ oceanographic instrumentation tends to suffer from low data rate, and relatively short operating life between maintenance or calibration checks. To meet the objectives of GOOS there will have to be investment in instruments with a greater degree of automation.

In order to collect observations from all depths and in all regions according to tightly prescribed sampling schemes, GOOS will benefit from long-range unmanned autonomous vehicles capable of carrying instruments to all parts of the world ocean.

A GOOS Pilot Experiment will include instruments and data types from the category of *in situ* oceanographic instrumentation.

Acoustic remote sensing

Sound is propagated over thousands of km through the ocean, and the speed of sound is largely determined by the temperature of the sea water. Acoustic Thermometry of Ocean Climate (ATOC) exploits these facts to measure the mean temperature of the ocean between points separated by thousands of km. A feasibility test has demonstrated that ATOC works over distances of up to 10,000 km. It is therefore potentially feasible to measure the average temperature of a whole ocean basin, and hence fluctuations in the average temperature. The accuracy is sufficient to detect ocean temperature changes of the magnitude associated with climate fluctuations. The use of a number of distinct sound trajectories can be used to reveal the internal structure of large ocean areas through the techniques of acoustic tomography.

Ocean floor observations

The Past Global Changes (PAGES) established core project of IGBP depends upon a wide range of indicators which contain records of the state of the environment at different dates. Sediment cores of the ocean floor provide critical data on past ocean temperature and productivity during the Ice Ages.

Deep ocean floor observations, deep sea drilling, and seismic observations provide, amongst other things, essential data on past climate characteristics during the last millions of years. One deep ocean drilling ship is already highly successful in the Ocean Drilling Programme (ODP) led by the USA, and further drilling ships are planned in Japan and Europe.

Communications and navigation

GOOS implies a greatly increased rate of data generation than in the past, with the essential requirement that most data reach processing and analysis centres within a few hours to days. Some GOOS data streams can be handled slowly, or off-line, and can use relatively low-technology transmission. Real-time data acquisition and transmission are used in military operational oceanography, in marine meteorology and near surface water temperature profiling through IGOSS, and from drifting and moored buoys using telecommunications via satellites. In the Tropical Ocean Global Atmosphere (TOGA) project real time transmission is used for a wider range of buoy data, and for acoustic current profile data from ships and buoys. Commercial developments in satellite communications are greatly increasing the capacity to transmit high data rates. Experience therefore exists to estimate and plan the communications requirements for a trial phase of GOOS, the GOOS Pilot Experiment, and ultimately a fully developed GOOS. The development of a full communications system for ocean data will require extensive operational research, procurement, and planned implementation. The technology of communications, including possibly acoustic telemetry through water, will have to be improved as GOOS is developed. Two-way communication will be required in some cases to control instrumentation and platforms.

All measurements depend critically upon accurate position fixing and navigation. Modern satellite controlled and sub-surface acoustic systems provide well-proven techniques to support the data types to be collected by GOOS. Investment will be needed to procure, operate, and maintain adequate systems, and in some cases to improve accuracy or reliability.

Sampling Strategy

The data volumes required by GOOS are a great increase on the number of measurements per year made previously in the sea, but not extraordinarily large in number when compared with some data sets already generated by satellite remote sensing and imaging over land or through the atmosphere. The sampling strategy for GOOS is dictated by the processes in the ocean which must be detected, and the needs of the computer models which assimilate the data to make descriptions and predictions. Many millions of observations are required each day, with extensive global coverage and continuing over decades.

Existing scientific experiments, combined with the analysis of OOSDP and other advisory bodies being formed to advise on GOOS modules, and the experience with present operational systems can be used to define a strategy for measurements and sampling observations. Some variables can be measured from space, others need to be measured within the water mass. There must be compatibility between the two observing methods.

Parts of the ocean need to be measured more intensively than others, and some variables need to be measured more intensively at some times of year than at other times. In general, the most economic strategy for sampling one variable over a decade will not be the same as that for another variable. In the design of GOOS we need to establish the following facts concerning data requirements:

- The variables and processes which are essential to define the state of the ocean, resolve variability, and which will reliably produce the descriptions, trends, and predictions which we need.
- The geographical extent of the ocean which must be sampled or studied for each variable to provide a data set which will not lead to unacceptable errors. Can any parts of the ocean be left out or sparsely sampled for a given variable, so as to save costs?
- Spatial and temporal sampling density for each variable so as to describe the processes, gyres, currents, fronts, plankton blooms, etc., which may be needed. The density required may vary with time of year, and geographical location.
- The accuracy and precision of measurement needed for each variable, and the accuracy of location and time required.
- The delay which can be accepted in measuring the variable, checking the quality of the data, and transmitting them to a numerical modelling centre.
- Identify possible sampling strategies which are only put into action when certain events are happening, or likely to happen. Particularly intense sampling might be initiated in an area of frequent hurricanes, the critical phase of an El-Niño cycle, an unusual monsoon, extraordinary plankton blooms, or rapid break-up of ice shelves.
- The most effective combination of observations, tracks, moorings, etc., which will provide the data sets required without additional journeys or deployments, and without critical omissions.
- Numerical tests with computer models will be carried out using different data sets so as to identify what data are redundant, and what are essential: so-called sensitivity trials.
- Instrumental techniques and tests which will ensure consistency of data between different sensors, even when technology evolves and advances.
- Old data from past decades need to be rescued and translated into computer readable formats so as to improve long time series or geographical coverage.

The previous discussion has assumed that data are numerical records obtained by instruments, and transmitted in digital form. Many useful data are also obtained as material samples, sediment cores, rocks, biological species, etc., which are analysed days or even months later. Whilst the main core of the GOOS Global Framework depends upon real-time electronic transmission of digital data, many useful facts can be derived from material samples. Sediment and ice cores contain detailed records of past climatic and biological cycles, which can be used to interpret modern processes. Biological samples which need to be identified by inspection in the laboratory, or analysed chemically, will contribute essential data on the feedbacks between physical, chemical, and biological phenomena. The Continuous Plankton Recorder (CPR) is an example of a measuring system which takes material samples, and produces numerical data later.

It would be impossible to use data generated at the rate of many millions of observations per day unless the data are assimilated automatically into models. As well as serving operational models, the raw data will also be archived for incorporation into progressively more sophisticated analyses of changes and trends through time. The accumulation of archived data permits the identification of long period cycles, and the establishment of reliable means, and average conditions for different seasons, and variability.

Data management

Data management in the GOOS Global Framework will cost approximately 20% of the total system cost, that is, of the order of $200-400m/year.

Data management includes getting the individual data sequences from the sensors into a reliable world-wide data transmission network. From there the data are assembled into quality-controlled global data sets, some of which may be used to generate single-parameter products. The bulk of data will be assimilated into global and regional models after automatic quality control, and used to produce a suite of general and specialist descriptions of the ocean (diagnostics), and a range of short-term and long-term forecasts. The "cleaned" quality-controlled data will also be compressed and archived for future use in the densest possible reliable storage media in regional and World Data Centres. The data products from the Global Framework will be distributed rapidly to regional modelling centres, so that many local and regional institutions can make use of them for routine and research objectives, possibly combined with additional local observations.

The largest data sets will come from remote sensing imaging devices such as SAR and colour sensing, but unusually large data sets will also be created by the latest generation of sub-surface oceanographic instruments which measure acoustically along sections, areas, or volumes of water, rather than at single points.

The highest data rate sensors produce thousands or even millions of numbers per second. Since there are approximately 30 million seconds in a year, we can readily calculate and compare the effect of some sensors measuring a parameter several times per second for a year; other imaging systems producing millions of pixels per second; and yet other instruments, making only a few measurements per day.

The core data volumes of GOOS Global Framework will probably consist of approximately 20-30 data types collectively producing millions of numbers of raw data per second. Some data types may be reduced in volume by computing derived parameters before the data are assimilated into models.

Data rate and volume are not the whole problem. Many of the high data rate sensors produce very consistent and reliable data from well-controlled orbits or fixed locations. Other data types may require relatively unproven sensors, a variety of sensors which have to be compared and inter-calibrated, have transmission paths which introduce errors or distortion or gaps, or have other causes for uncertainty concerning quality. These data streams will require careful checking and quality control, adding to complexity and the cost of the system.

The data management networks, communications, procedures, and models developed for GOOS will include highly standardised protocols for routine operational data streams, and more flexible or variable components which can be adapted to provide supporting services to large scientific experiments. Satellite communications links are essential.

Much of the technology, software, and experience needed to develop the data management for GOOS already exists in the areas of conventional meteorology, (IGOSS, IODE, GLOSS, WWW), military operations, commercial banking, airline operations, etc. GOOS will require an advanced system, by any standards, and the emphasis will be on design, procurement, agreements on standards, quality control, procedures, and protocols, testing and reliability, rather than innovation for its own sake. It is recognised that a major up-grading of existing systems is needed to provide a high speed global marine data network linking the key data assembly centres, modelling, and archiving centres. The data management system will have to evolve gradually as technology and requirements advance. A training programme will be needed for data managers in some countries.

Distribution of data products

Experience exists in the derivation of experimental real-time marine data products, and in some operational products, especially in the military. Regional or local services exist providing maps and plots of wave conditions, sea ice, and currents. The GOOS Pilot Experiment will require the development of skills in data communications, assembly of quality controlled data sets, assimilation into models, and the generation of standard products on a scale which has not previously been attempted in civilian oceanography. During such a trial phase data products will be designed and distributed to the applications and user communities in order to maximise the short-term benefits, and to accelerate the process of learning and designing later phases.

The scientific basis of GOOS

Scientific understanding and process studies

Scientific knowledge in 1993 is sufficient to start planning and developing the GOOS Pilot Experiment, and the longer term design of an operational GOOS. Present and future marine scientific research experiments are essential to GOOS. Scientific research, understanding of oceanographic and biogeochemical processes, provide the basis for the optimum design of GOOS. Each type of observation, temperature, plankton, current velocity, etc., requires measurement to an accuracy, time resolution, and spatial resolution, and geographical coverage which will describe the processes and variations needed to make useful models and predictions. If we take too few measurements GOOS may be ineffective; if we take too many we are wasting money. Only large scale scientific experiments will provide the necessary information for design.

Notes on the more detailed interactions between ongoing scientific research and the development of GOOS are contained in Annexe 4.

The scientific research needed to support the development and implementation of GOOS includes three categories:

(a) Scientific data and analysis needed for the selection of variables to be measured and specification of the field observations and sampling programme.

(b) Research into new types of computer numerical models, methods of automatic data quality control, assimilation of data into models, and testing and verification of the models themselves.

(c) Research into oceanographic, biological, and biogeochemical processes which will increase the understanding of the ocean, and provide checks or verification for the improvement of GOOS.

The box below lists the major marine science experiments and research programmes which are under way at present, or in an advanced planning stage. The science programmes reach completion at different dates. As the completion date approaches, the knowledge gained can be fed into the design and operation of GOOS, whilst the observation system built up for the experiment can be reviewed to see what practical equipment, moorings, drifting buoys, etc., can be converted to permanent operational status. The experiments which are most advanced, TOGA, WOCE, and JGOFS, help to define the variables and technologies which can be identified first as operational routines in GOOS.

There are gaps in the planning and co-ordination of the big science experiments, and it is not clear that all the science necessary for the design of an observing system is being carried out. On the other hand, many different global marine experiments require the same data sets, such as sea surface temperature fields, and so the development of GOOS could result in reduction of costs. Figure 4 illustrates schematically how the science programmes will feed into the design and implementation of GOOS.

TOGA:	Tropical Ocean Global Atmosphere (1985 - 1994)
WOCE:	World Ocean Circulation Experiment (1990-1997)
JGOFS:	Joint Global Ocean Fluxes Study (1991 - 2000)
GEWEX:	Global Energy Water cycle Experiment (1995 - 2000)
GLOBEC:	Global Ocean Ecosystem Dynamics (1992 - ....)
LOICZ:	Land Ocean Interaction Coastal Zone experiment (1992 - 2001)
GOEZS:	Global Ocean Euphotic Zone Study (1998 - 2005)
ODP:	Ocean Drilling Programme (1990 - 2000)
CLIVAR:	Climate Variability and Predictability Experiment (1997 - ....)

Scientific design criteria

The Ocean Observing System Development Panel (OOSDP) is an expert group co-ordinated to both GOOS and GCOS. The final Report of OOSDP is due in December 1994, and the first section on The Role of Models in an Ocean Observing System was published in 1992. OOSDP has identified as major requirements of an ocean observing system for climate studies the ability to measure the heat balance of the ocean, freshwater balance, carbon balance; water mass conversion; storage of heat, water and carbon in the ocean; the oceanic transports, and velocities.

OOSDP envisages a basic core of field measurements; model and analysis centres, the ability to assimilate 4-dimensional (time + space) data into upper ocean coupled atmosphere global models; the production of surface fields from the model output; the ability to support research both in sea-going research experiments and research models.

OOSDP will address the problem of sampling strategy, and the trade-off between different sampling options. OOSDP has only studied the data requirements for monitoring climate variability and change, but not the data required for other GOOS Modules.

The next Phase of the GOOS planning will identify existing expert groups, or establish new groups, which can advise on the scientific criteria for the other Modules. Such groups could be the IOC Committee for Global Investigation of Pollution in the Marine Environment (GIPME) for Health of the Oceans; the IOC Committee for Ocean Sciences and Living Resources for Living Resources; and the IOC Committee for Ocean Science and Non-Living Resources (OSNLR) and the Ocean Drilling Project (ODP) for the Ocean Floor. IOC has recently established a Programme on Coastal Ocean Advanced Science and Technology Studies (COASTS). GOOS will be advised by GCOS on the continuing requirements for data related to coupled ocean-atmosphere climate modelling.

UN Agencies will not serve the interests of national Defence Agencies, but, after the demise of the Cold War, it may be possible for the civilian community to learn from the experience in operational oceanographic modelling developed by navies.

The scientific criteria for gathering data to support climate modelling are the most advanced, and the criteria for gathering biological and chemical data are the least advanced. It is important to develop the criteria for data quality control, the understanding of processes, and the sampling strategy, to design the biological and biogeochemical data components for GOOS. It is also important to develop methods for making models of coastal regions more portable, and less dependent upon site-specific information.

TOGA is due to end as a scientific experiment in 1994 and an operational ENSO Prediction Programme is being established. The development of GOOS will be designed to support strongly the objectives of the ENSO Prediction Programme. The progress of ENSO Prediction is particularly important as it is the first example of progress from a large-scale ocean experiment to a routine prediction system.

Simulation and Predictability

The GOOS Global Framework will observe and record more ocean data per day or per year than has ever been observed before, and computer numerical simulation or modelling will be essential to derive plots, contoured fields and useful interpretations of the data. The internal structures and processes in the ocean are complex on a scale 10-100km, with rotating eddies, meandering currents, fronts, and overlying water masses of different densities, so that statistical smoothing or contouring of the raw data would fail to show the most important boundaries, which take the form of abrupt gradients or discontinuities in salinity, temperature, density, or velocity. Even with the most closely spaced observing scheme imaginable, it would not be possible to detect all such important features by direct measurement. Additionally, since the observations cannot all be made simultaneously so as to describe the ocean at a given moment, models constrained by the laws of physics are needed to assimilate data, into regular grids in time and space.

Different types of models will be used to assimilate the data. Some will simulate the upper ocean only, where processes occur which control the sea surface temperature and hence seasonal variations in atmospheric climate. Other models will simultaneously replicate the state of the ocean, or parts of the ocean, and the atmosphere, so-called coupled models. Models will be used to simulate and predict the condition and edge of the floating sea ice in polar regions, and special models will be run to replicate the slow changes in the deep ocean circulation from year to year.

Through experiments such as JGOFS and GLOBEC the scientific experience is being obtained to incorporate biogeochemical processes into models, and to model systems which depend upon phytoplankton productivity and grazing. By progressive stages it will be possible to develop models providing a range of biological information by the time that GOOS is operational in 2007.

The rapid evolution of computer technology guarantees that by the end of the decade computers will be able to make the computations needed, many multiples of one million million calculations per second (teraflops). Investment of effort is needed in the optimum design of models, the procedures for assimilation of data, and the iterative relationship between the reliability of models and the observing strategy.

The World Climate Research Programme was established to discover "to what extent climate is predictable". The results are not yet in, but some issues are becoming clearer. First, models of the atmosphere alone do not have predictability beyond a few weeks. Successful forecasting further into the future will depend on being able to predict how the boundary conditions of the atmosphere will change. The sea surface is crucial, including the fluxes between the ocean and atmosphere. Some progress has been made in demonstrating predictive skill in the tropical ocean, as part of the TOGA programme. That research will reveal the scope for predicting ENSO events up to months or even years ahead.

The recent development of eddy-resolving ocean Global Circulation Models (GCMs) is an important step towards exploring the limits to predictability for decadal change in the ocean, which is central to forecasting climate response to the greenhouse effect. At present, the limits to predictability are masked by uncertainty in the description of the ocean used to initialise integrations of such models. That problem is being addressed by the World Ocean Circulation Experiment, which will deliver a description of the state of the ocean in the period 1990-97. Unfortunately funding of WOCE has been less than planned, and significantly more research on this problem is required. The general issue of climate predictability is likely to become clearer over the next decade. However, solving the predictability problem will require improved documentation of the internal variability of the ocean, one of the deliverables of GOOS.

Technology development programme

The identification of a suite of instruments and data types to be included in the GOOS Pilot Experiment will be one of the tasks in Phase B1 (1993-1995). The Joint Scientific and Technical Committee will advise. A corollary of this work will almost certainly be that the existing instrumentation, even if it is adequate in practice for use by expert scientists, is not either cheap enough or reliable enough for a permanent routine observing system. This will create opportunities for industry to develop a new range of operational oceanographic instrumentation to meet GOOS requirements.

The GOOS Pilot Experiment will implement first those observing systems which can be carried out using existing proven technology. At all stages, new technologies which have been developed and tested will only be introduced operationally after extensive trials and proving.

The development of new technology, or the incorporation of technology developed elsewhere, is fundamental to GOOS. Whereas meteorology has an established range of reliable operational instruments, the majority of measuring instruments used in the ocean are designed for research purposes, and are built in small numbers to be operated by qualified scientists and technicians. National agencies, research institutes, and organisations participating in GOOS will be encouraged to identify promising new systems and technologies which would provide the necessary accuracy, reliability, and cost advantages. Developing countries will be invited to collaborate in programmes for the installation, deployment, and maintenance of instruments within the GOOS Pilot Experiment.

Equal attention needs to be given to technologies for each data type and module in GOOS. At present the technology and manufacture of proven instrumentation is most advanced to physical oceanographic parameters, and measurements at the ocean interface with the atmosphere. A special effort is needed to develop standard instruments for determining oceanic plankton distributions, their abundance, and potentially the routine measurement of algal toxicity, the measurement of marine chemical and nutrient concentrations, the measurement of contaminants and their effects on ecosystems, and methods for evaluating the characteristics of the benthic ocean. Research and development is already underway in tackling these problems.

THE GOOS PILOT EXPERIMENT

GOOS is planned to have a major operational scale of activity for launching in 2007. To be effective all the subsystems of GOOS must be tested before that date, and the experimental procedure for developing and testing the operational methods is called the GOOS Pilot Experiment.

The GOOS Pilot Experiment (GPE) will involve national and international agencies to conduct trials of the following type:-

- Deployment of different instrument systems in operational mode to compare efficiency, accuracy, data delivery, costs, etc.
- Utilisation of different data telemetry and communications carriers to establish working procedures, and compare costs and efficiency.
- Testing different data protocols and networks.
- Trials of new instrumentation systems in operational mode.
- Tests of data assimilation in models.
- Development and trials of procedures for merging *in situ* and remote sensed data.
- Distribution of test data products, and assessment of user evaluation.
- Testing of different sampling strategies as recommended by scientific and user advisory groups.
- Sensitivity trials using different sampling strategies and models.
- Collaboration between global modelling centres and regional applications groups on a test basis, with evaluation of results.
- Testing of data quality control procedures in operational timescales.
- Evaluate the economic benefit of the pilot system through case studies.

  etc.

This is not a prioritised list of activities in the GPE, but is presented to show that there is a host of tasks to be undertaken in the development of GOOS which are not themselves the objectives of scientific research. They are the means to an end. These activities cannot be planned only on paper, and then implemented in 2007. Experience must be gained in conducting these activities against delivery deadlines, and deciding as the result of practical trials which devices and procedures work.

Before the GPE starts, scientific and economic evaluation of the data types which are of highest priority will have been carried out. The GPE will be planned as a practical test of the methods to deliver the specified data. It will therefore have two objectives:

i) to serve as a practical experiment in procedures, management, communications and engineering to find the best way to create and deliver a product.

ii) to deliver the best quality data possible to scientific research groups and applications sectors, to meet the specifications which they have provided.

TIMESCALE, MANAGEMENT, AND COSTS

Timetable

The planning, development, and implementation of GOOS will require 15 years, 1992-2007. This work will proceed in parallel with, and interact with, a number of major scientific research programmes. Between 1997 and 2007 GOOS will conduct the GOOS Pilot Experiment which will be designed to test progressive implementation and operational trials of systems and methods to be used in a fully operational GOOS.

To facilitate management control, GOOS is planned in successive Phases, and at the end of each Phase an agreed review will take place of progress made, and deliverables. The Phases and dates are as follows:

1991-93: PHASE A	- Concept definition.
1993-95: PHASE B1	- Technical feasibility study, costing, and trials.
1995-97: PHASE B2	- Design and definition of GOOS Pilot Experiment (GPE).
1997-2002: PHASE C	- Implementation of GPE, and development, systems trials, implementation plan for permanent GOOS.
2002-2007 PHASE D	- Implementation of GPE, and implementation and testing of fully operational system for permanent GOOS.

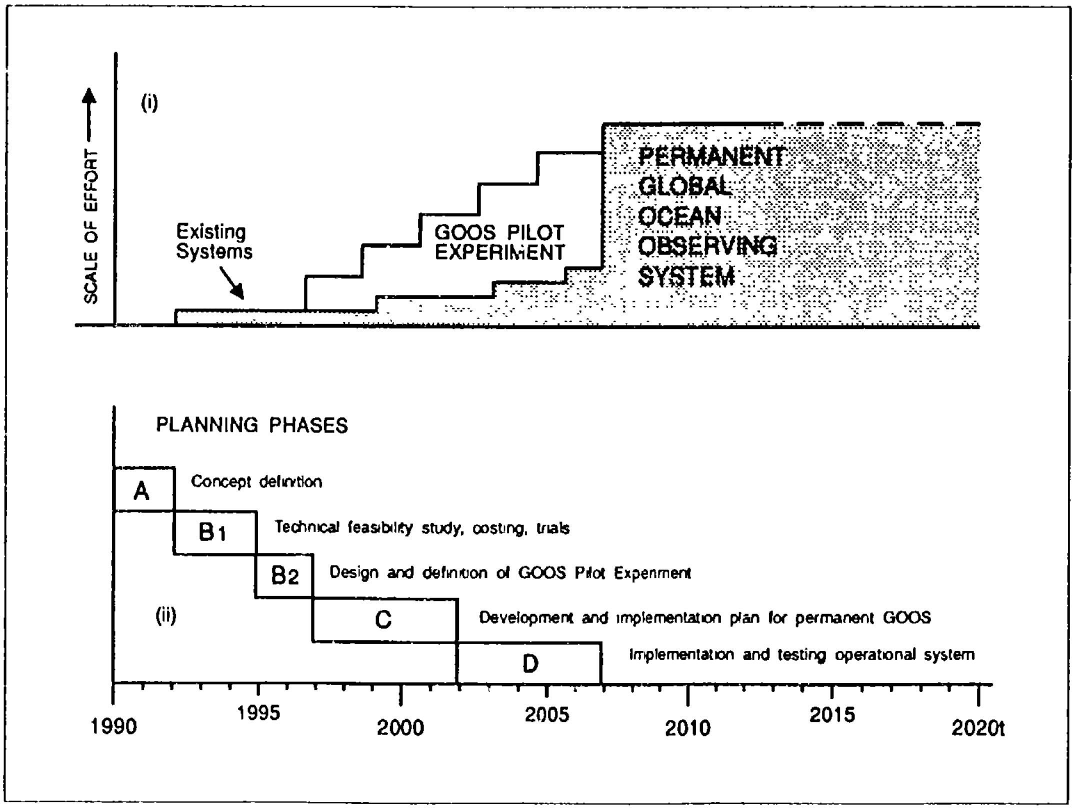

Figure 5: *Diagram illustrating (i) the relation between existing observation systems in place (e.g. GLOSS, IGOSS, DRIBU, etc.), and progressive implementation of the GPE and Permanent GOOS. In the lower panel (ii) are the phases of study and planning which support the implementation.*

Phase A has been conducted in an *ad hoc* way, collecting information from many agencies, holding meetings, circulating reports, culminating in the formation of the IOC Committee for GOOS, and the preparation of the present report, "The Case for GOOS."

Phase B1 in preparation for the GOOS Pilot Experiment will include the following work elements: Explore technical issues, problems, and solutions; prepare the first science plan for GOOS; identify sub-systems requiring feasibility trials; estimate of costs and cost profiles; estimate duration of tasks in later Phases; identify observing components which could be brought forward for early implementation or major trials in Phase B2; prepare Programme of Work for Phase B2, Design and Definition of GOOS Pilot Experiment. The relationship between the planning and the GPE is shown in Fig. 5.

To promote the implementation of GOOS it will be desirable to invite various bilateral, multilateral, and international activities as component or trial projects for GOOS, both as parts of the Global Framework, and within the Beneficiary Modules.

Management

The management of GOOS will be practical and businesslike to ensure that this complex but routine system delivers reliable cost-effective products. Several components of management and control are needed to achieve scientific integrity, international accountability, and reliable efficiency. GOOS will have the following structure:

- The IOC Intergovernmental Committee for GOOS. This Committee was established by IOC in 1992. It provides the formal intergovernmental link which will allow Member States to specify their requirements of GOOS, and to which progress reports will be presented.

- The Joint GOOS Scientific and Technical Committee. This Committee will be formed during 1993. The JSTC-GOOS will assess the scientific criteria for the design and implementation of GOOS; maintain scientific links with a range of associated bodies and international agencies; receive progress reports on the progress of GOOS; and recommend experiments or projects which would enhance the design of GOOS.

- The main source of funding for GOOS will be the technically developed countries, especially those with prolonged experience in oceanographic research and operations. The same countries, through their national agencies, will provide most of the hardware and staffing to carry out the design, trials, and implementation of GOOS. All countries can contribute to the costs of GOOS at an appropriate level in relation to their national economy A representative group of countries will become members of the GOOS Executive Board, which will not be subject to or part of a UN agency. The GOOS Executive Board will guarantee to meet the requirements of GOOS to the best of its abilities, and to place the resulting data in the international domain for the benefit of all countries, on a contractual basis.

- The GOOS Fund will be established and supervised by the Members of the GOOS Executive Board to support the costs of a GOOS Directorate, the planning and development costs of GOOS, and to support some of the trials and pilot experiments. It should be stressed that the activities, research, and specialist observations carried out by the applications modules associated with GOOS would not be financed by the GOOS Fund.

- The GOOS Directorate will be a full-time staff working on the co-ordination of the design, development, and implementation of GOOS. The Director GOOS will report to the GOOS Board and to the international agencies sponsoring GOOS, and will support the J-GOOS and the IOC Committee for GOOS.

Logistics

- GOOS will be implemented by national contributions, and the commitment of resources by national agencies, or international agencies such as Space Agencies.

- GOOS will have to develop the techniques and procedures for merging and exploiting data sets from a wide range of different satellite sensors and *in situ* instruments measuring similar parameters.

- A programme for funding or assisting the participation of developing countries will be needed.

- The activities of GOOS cannot be implemented effectively without a number of long-term contractual arrangements, and possibly international agreements, protocols, or treaties, covering issues such as access to data, access to EEZs, and prompt transmission of data in the public domain.

Transfer of data to Beneficiary Modules

The diagram in Fig 1 shows in broad terms the types of activity which will benefit from GOOS. These are illustrated by the rectangular boxes termed Beneficiary Modules.

The management structure responsible for GOOS and its Global Framework is not responsible for the application of the knowledge gained to economic activities, but is responsible for supplying the data and information which these communities need. This is a vitally important activity of GOOS. The economic, social, amenities, and environmental activities in each area are described briefly in the section on Benefits of GOOS, and Annexe 3. In this section we indicate the existing international organisations which can help to transfer the output of GOOS into the user community, and interpret the needs of the community to influence the development of GOOS.

The UN agencies, IOC, FAO, UNEP, and WMO, support a range of programmes to assist countries in using modern scientific and observational data. The programmes and committees in the best position to act as intermediaries are as follows:

Living Resources: OSLR (IOC); FAO
Ocean Floor, non-living resources: OSNLR (IOC); ODP; CCOP-SOPAC.
Health of the Oceans: GIPME (IOC); OCA/PAC (UNEP); GESAMP.
Coastal Seas: Coastal Seas Programme, GLOSS/(IOC); UNEP Regional Seas;

Science and Technology: ICSU/SCOR; IOC/C-GOOS.
Atmospheric Climate: WMO/GCOS.
Global ocean variability. WOCE; TOGA; JGOFS; GLOBEC; LOICZ; ICSU/SCOR; OOSDP.

Costs

The G7 countries at present spend about $10bn per year on all aspects of marine science and technology research. Of this about one eighth is allocated to marine environmental research, and biological, physical and chemical oceanography. There is therefore already in existence a baseline of research activity broadly related to GOOS which costs of the order of $1bn.

IOC Secretariat estimates that the administrative and staff costs in IOC for the first two years of Phase B1 will be $1.5m. The effectiveness of Phase B1 will be increased by the research and planning carried out by national offices developing national GOOS contributions, and will be supported by relevant national and international oceanographic programmes already in action, or planned.

The operational costs of a fully designed and implemented GOOS Global Framework are comparable with the costs of global atmospheric monitoring, or about $2bn/yr. GOOS is being planned and developed on the assumption that, in constant 1992 dollars, this full operational cost will be incurred by the year 2007. The operational cost of GOOS includes the launch and operating costs of remote sensing satellites: many of these have already been approved and funding committed. Approximately 30% of the costs of GOOS have therefore already been committed or planned. The existence of GOOS will ensure that the investment in the satellite systems will have a far greater total benefit than would otherwise have been the case.

The hardware, satellites, communications links, data centres etc. required by GOOS will, in some cases perform other functions as well, be shared, or leased commercially, thus minimising capital expenditure and discontinuities in spending. Some of the national programmes, ships, and other activities would in any case be funded, with or without GOOS, and little new money will be needed to ensure that the data generated are included in GOOS. The cost of GOOS in terms of new investment will therefore only be about half the cost of all the resources which are available to be used, or $1bn/yr.

The present annual cost of national and international ocean observing systems producing data which are regularly transmitted in the public domain is $70m/yr. These services form a nucleus for the development of GOOS. Many further observations are obtained in scientific research programmes. The transition from the present status of research-funded civil oceanography and a small real-time civil oceanographic service, to an operational GOOS requires both a progressive increase in funding, and a growth of responsibility in operational agencies at the national level. At every stage of the development and continued implementation of GOOS there would be a continuing scientific sector funded from research budgets as at present.

A Japanese Government estimate of the costs of GOOS, and the rate of increase of funding required, suggests parallel sectors of research, technology development, and operational trials of observing systems. The global cost, excluding satellites, is calculated to ramp up to about $1.5-2.0bn/yr by 2000, and then to remain in the range $2-3bn/yr from 2000-2010. This assumes that equipments are dedicated only to GOOS.

Phase B1 of the GOOS Pilot Experiment will prepare more detailed cost estimates of GOOS, and projected cost profiles. Provisional technical estimates based on reasonable numbers of ship sections, satellites, automated or robotic systems, fixed moorings, tomography, and costs of communications and data management, confirm that the goals of GOOS are achievable within the $1bn/yr marginal expenditure proposed. The Developed countries will have to finance the larger technical components of GOOS, but many observations will be required in shelf and coastal seas, and in the region of oceanic islands. In these areas Developing countries can participate fully in the design and implementation of GOOS

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

i) The GOOS will provide a global framework of measurements describing the state of the world ocean at regular intervals.

ii) The GOOS global framework of observations will complement the local observations currently made in support of ocean activities, greatly increasing their effectiveness.

iii) A wide range of ocean activities will benefit from the GOOS global framework of observations. The beneficiaries of GOOS can be grouped into seven user sectors:
   i. The ocean floor
   ii. Coastal seas
   iii. Atmospheric climate
   iv. Science and technology
   v. Living resources
   vi. Health of the oceans
   vii. Shipping and defence.

iv) It is scientifically and technically feasible to design and implement a Global Ocean Observing System over a period of 15 years.

v) It will be necessary to demonstrate the practical feasibility of an operational global ocean observing system in a GOOS Pilot Experiment lasting ten years. The GOOS Pilot Experiment will include the scientific design and development of a Global Framework core of permanent, consistent, global ocean observations, and operational trials of measurements, data transmission, and generation of useful data products.

vi) The costs of the GOOS Pilot Experiment and planning the operational GOOS will increase steadily over the 15-year period towards the eventual operating cost of $2bn/yr, and benefits will accrue from intermediate data products during that time.

vii) The cost of an operational GOOS will be of the order of $2bn/yr from the year 2007 onwards, of which approximately $1bn/yr represents new funding.

viii) Marine activities throughout the world have an economic input contribution to GNP of the order of $800bn/yr, and present marine research expenditure by the G7 countries is of the order of $10bn/yr. GOOS, directly and through its Beneficiary Modules, will achieve increases in efficiency and avoidance of loss equivalent to tens of $bn/yr, providing a good benefit:cost ratio.

ix) The cost of implementing GOOS permanently will be justified if the Pilot Experiment demonstrates that it is possible to improve the value of ocean activities in the seven sectors by a few percent of turnover, demonstrating through case histories an order of magnitude benefit : cost ratio.

x) GOOS products will also support scientific research aimed at improving knowledge about the sea. It will improve the effectiveness of the $10 bn/year spent on marine scientific and technological research.

xi) GOOS will provide oceanographic data to the Global Climate Observing System (GCOS). Without these data it would not be possible to predict changes in global climate.

xii) The effectiveness of GOOS in producing economic and social benefits will depend upon social and institutional factors outside GOOS, and the willingness of individuals and organisations to use and apply the data and predictions provided.

xiii) GOOS will provide substantial benefits for Developing countries, and requires their involvement.

xiv) GOOS will support both operational and scientific research observations at sea. It will provide services to oceanographic research experiments, and will include a strong research component at all times.

Recommendations

The Panel makes the following recommendations

i) Member States of IOC should fund the GOOS Feasibility Study (Phase B1) which will plan and subsequently run the 10-year GOOS Pilot Experiment from 1997-2007.

ii) A 10-year GOOS Pilot Experiment should be undertaken to demonstrate the feasibility of collecting global ocean data sets and preparing up-dated descriptions of the state of the ocean in a reliable operational manner.

iii) IOC should promote and develop research in the Beneficiary Modules using regional and local numerical models based on GOOS data, and incorporating extra data at the applications level. The Beneficiary Modules should be designed to produce economic, social, and environmental benefits.

iv) A Joint Scientific and Technical Committee for GOOS should be established, supported by a Directorate Office. The JSTC-GOOS should take responsibility for the scientific policy and design of GOOS, and organise the GOOS Pilot Experiment.

v) GOOS should promote the development of new technology which it requires, especially in the domains of instrumentation and sensors, automation of marine and subsurface instruments, robotics and untethered vehicles, data telemetry, and operational numerical modelling.

vi) GOOS should collaborate with the national and multi-national space agencies, and the Committee on Earth Observing Satellites (CEOS), to ensure a sequence of appropriate and consistent orbiting sensors to produce the necessary oceanographic data.

vii) GOOS should be developed in a series of Phases, each with an identifiable end-point and deliverable.

APPENDIX 1

Panel members

J D Woods, UK (Chairman)
N Andersen, USA
J Baker, USA
P Bernal, Chile
P G Brewer, USA
R Dickson, UK
G Kullenberg, France
J Labrousse, France
A Moura, Brazil
W Munk, USA
Noriyuki Nasu, Japan
C Wunsch, USA

Secretariat

N C Flemming, UK (Secretary)
M Bewers, Canada
M Glantz, USA
R Godin, USA

Recipients of the first draft

D M Anderson, USA
Tomio Asai, Japan
B Bayne, UK
R G V Boelens, Ireland
M Briscoe, USA
W S Broecker, USA
O Brown, USA
P Buat-Menard, France
D Cadet, France
J Calder, USA
H Charnock, UK
E Charpentier, France
R A Clarke, Canada
D H Cushing, UK
H Dahlin, Sweden
R Davis, USA
R Dawson, USA
P Delecluse, France
K Denman, Canada
P Dexter, Switzerland
T Dickey, USA
A Dickson, USA
H Dooley, Denmark
H Ducklow, USA
J C Duinker, Germany
M J Dunbar, Canada
D Farmer, Canada
J Farrington, USA
N Friligos, Greece
C J R Garrett, Canada
M Glass, France
E D Goldberg, USA
M Gorges, Kenya
J Gray, Norway
E Gross, USA
G Gross, USA
P Gurbutt, Canada
D Halpern, USA
S E Hansen, Norway
G Harris, Australia
K Hasselmann, Germany
R Hawroth, Canada
T Healy, New Zealand
R Heath, New Zealand
P Hedgecock, UK
Kenkichi Hirose, Japan
E Hoffmann, USA
G Holland, Canada
P Holligan, UK
J T Houghton,
Masayuki Inoue, Japan
G Jacques, France
M T Jones, UK
I Jones, Australia
T Joyce, USA
D Karl, USA
P Killworth, UK
P Kingston, UK
A Knap, Bermuda
D Kohnke, Germany
S Lappo, Russia
P Lasserre, France
X Le Pichon, France
G W Lennon, Australia
S Levitus, USA
R Lukas, USA
F T Mackenzie, USA
F Madelain, France
P Maladenov, New Zealand
M Martinez-Garcia, Mexico
G Maul, USA
B S McCartney, UK
I N Mccave, UK
A Mcewan, Australia
D Mclain, USA
M Mcphaden, USA
L Mee, Monaco
J Meincke, Germany
L Merlivat, France
J-F Minster, France
A Morel, France
M Mork, Norway
R Muench, USA
R E Munn, Canada
K O Munnich, Germany
L Mysak, Canada
G Needler, Canada
C Nelson, New Zealand
W Nowlin, USA
J J O'Brien, USA
L Otto, Netherlands
G Parrilla, Spain
J Parslow, Australia
R J Pentreath, UK
J C Pernetta, UK
T Platt, Canada
R T Pollard, UK
D T Pugh, UK
S Ragoonaden, Mauritius
K Richardson, Denmark
P Richardson, USA
A Robinson, USA
A Rodriguez De Leon, Spain
F Roots, Canada
B Rothschild, USA
J Sarmiento, USA
R Schmitt, USA
B Searle, Australia
G Siedler, Germany
M Sinclair, Canada
V I Smirnov, Russia
N Smith, Australia
T Spence, USA
J H Steele, USA
R W Stewart, Canada
A Stigebrandt, Sweden
Jilan Su, China
Nobuo Suginohara, Japan
Moon-Sik Suk, Korea
P K. Taylor, UK
G Topping, UK
A Colin De Verdière, France
A Vezina, Canada
B Voituriez, France
J J Walsh, USA
F Webster, USA
G Wefer, Germany
R Weller, USA
Hou Wen Feng, China
M Whitfield, UK
S Wilson, USA
J R Wilson, Canada
H Windom, USA
K Wyrtki, USA

APPENDIX 2

Acronyms

ATOC	Acoustic Thermometry of Ocean Climate
CEOS	Committee on Earth Observing Satellites
CLIVAR	Climate Variability and Predictability Experiment
COASTS	Coastal Ocean Advanced Science and Technology Studies
CPR	Continuous Plankton Recorder
DBCP	Drifting Buoy Co-operation Panel
DRIBU	WMO code for drifting buoy data distribution on the GTS
EC	European Communities
EEZ	Exclusive Economic Zone
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organisation
GCM	Global Circulation Model
GCOS	Global Climate Observing System
GEEP	Group of Experts on Effects of Pollutants
GESAMP	Group of Experts on Scientific Aspects of Marine Pollution
GEWEX	Global Energy and Water-cycle Experiment
GIPME	Global Investigation of Pollution in Marine Environment
GLOBEC	Global Ocean Ecosystem Dynamics
GLOSS	Global Sea Level Observing System
GOEZS	Global Ocean Euphotic Zone Study
GOOS	Global Ocean Observing System
GTS	Global Telecommunication System (of the WWW)
ICSU	International Council of Scientific Unions
IGAC	International Global Atmosphere Chemistry programme
IGBP	International Geosphere-Biosphere Programme
IGFA	International Group of Funding Agencies for Global Change Research
IGOSS	Integrated Global Ocean Services System
IMO	International Maritime Organization
IOC	Intergovernmental Oceanographic Commission
IPCC	International Panel on Climate Change
JGOFS	Joint Global Ocean Flux Study
J-GOOS	Joint GOOS Technical and Scientific Committee
JSTC	Joint Scientific and Technical Committee
LOICZ	Land-Ocean Interactions in the Coastal Zone
MST	Marine Science and Technology
NWP	Numerical Weather Prediction
OCA/PAC	Ocean and Coastal Areas Programme
ODP	Ocean Drilling Program
OOSDP	Ocean Observing System Development Panel
OSLR	Ocean Science in Relation to Living Resources
OSNLR	Ocean Science in Relation to Non-Living Resources
OSPARCOM	Oslo and Paris (Conventions) Commission
PAGES	Past Global Change Project
R&D	Research and Development
SAR	Synthetic Aperture Radar
SCOR	Scientific Committee on Ocean Research
SOFAR	Sound Fixing and Ranging
SWCC	Second World Climate Conference
TEMA	Training, Education and Mutual Assistance in the Marine Sciences
TOGA	Tropical Oceans and the Global Atmosphere
UNCED	United Nations Conference on Environment and Development
UNCLOS	UN Law of the Sea Convention
UNEP	United Nations Environment Programme
WCRP	World Climate Research Programme
WDC	World Data Centre
WMO	World Meteorological Organisation
WOCE	World Ocean Circulation Experiment
WWW	World Weather Watch (of WMO)
XBT	Expendable Bathythermograph

ANNEXE 1

International Treaties and agreements served by GOOS

Framework Convention on Climate Change - Article 4

All parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, shall:

(g) Promote and co-operate in scientific, technological, technical, socio-economic and other research, systematic observation and development of data archives related to the climate system and intended to further the understanding and to reduce or eliminate the remaining uncertainties regarding the causes, effects, magnitude and timing of climate change and the economic and social consequences of various response strategies;

(h) Promote and co-operate in the full, open and prompt exchange of relevant scientific, technological, technical, socio-economic and legal information related to the climate system and climate change, and to the economic and social consequences of various response strategies."

Convention on Biological Diversity - Article 7

Each Contracting Party shall, as far as possible and as appropriate, in particular for the purposes of Articles 8 and 10 [*In situ* Conservation and Sustainable Use of Components of Biological Diversity]:

(b) Monitor, through sampling and other techniques, the components of biological diversity identified pursuant to subparagraph (a) above, paying particular attention to those requiring urgent conservation measures and those which offer the greatest potential for sustainable use;

(c) Identify processes and categories of activities which have or are likely to have significant adverse impacts on the conservation and sustainable use of biological diversity, and monitor their effects through sampling and other techniques; and

United Nations Convention on the Law of the Sea - Article 268

States, directly or through competent international organizations, shall promote:

(a) the acquisition, evaluation and dissemination of marine technological knowledge and facilitate access to such information and data;

(b) the development of appropriate marine technology;

Article 270

International co-operation for the development and transfer of marine technology shall be carried out, where feasible and appropriate, through existing bilateral, regional or multilateral programmes, and also through expanded and new programmes in order to facilitate marine scientific research, the transfer of marine technology, particularly in new fields, and appropriate international funding for ocean research and development.

United Nations Conference on Environment and Development (Agenda 21) - Article 17.8

Coastal States, where necessary, should improve their capacity to collect, analyse, assess and use information for sustainable use of resources, including environmental impacts of activities affecting the coastal and marine areas. Information for management purposes should receive priority support in view of the intensity and magnitude of the changes occurring in the coastal and marine areas.

Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, Oslo, 1972 - Article 1

The Contracting Parties pledge themselves to take all possible steps to prevent the pollution of the sea by substances that are liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea.

Article 13

The Contracting Parties agree to institute, in co-operation with appropriate international organizations and agencies, complementary or joint programmes for monitoring the distribution and effects of pollutants in the area to which the Convention applies [i.e., the eastern North Atlantic ocean].

Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter, London, 1972 - Article I

Contracting Parties shall individually and collectively promote the effective control of all sources of pollution of the marine environment, and pledge themselves especially to take all practical steps to prevent the pollution of the sea by the dumping of wastes and other matter that is liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea.

Article IX

The Contracting Parties shall promote, through collaboration within the organization and other international bodies, support for those Parties which request it for:

(a) The training of scientific and technical personnel;

(b) The supply of necessary equipment and facilities for research and monitoring;

(c) The disposal and treatment of waste and other measures to prevent or mitigate pollution caused by dumping;

preferably within the countries concerned, so furthering the aims and purpose of this Convention.

National statutory obligations and legislation applying to coastal seas

Control of Pollution
Food & Environment Protection
New Chemicals Notification Scheme
Radioactive Substances
Wildlife and Countryside
Animal (Fisheries) Health
Town and Country Planning
Flood Protection
Seals
Introduction of Alien Species
National Radiological Protection Board
Carriage of Dangerous Goods at Sea
Prevention of Oil Pollution
Petroleum and Submarine Pipelines
Coastal Protection

International and Regional Treaties

Montreal Conventions/Protocols
London Dumping Convention
Paris Convention (OSPARCOM)
Oslo Convention (OSPARCOM)
MARPOLS 73/78 Convention
North Sea Conferences
Common Fisheries Policy
Marine Science & Technology R&D
Environment and Climatology R&D

EC Directives - Bathing Water
- Water Quality
- Water Quality for Shellfish Waters
- Birds
- Environmental Assessment
- Toxic Substances
- Emissions (Various)
- Discharge of Dangerous Substances
- Seals

ANNEXE 2

Recommendations for establishing GOOS

Intergovernmental Oceanographic Commission, Assembly 1989. Resolution XV-4:

Reaffirms that the Intergovernmental Oceanographic Commission is the appropriate intergovernmental organisation for the promotion, planning, and co-ordination of a global integrated ocean observing system.

Intergovernmental Panel on Climate Change, WG1, 1990:

The Key areas of scientific uncertainty are: (clouds...); oceans: the exchange of energy between the ocean and atmosphere, between the upper layers of the ocean and the deep ocean, and transport within the ocean, all of which control the rate of global climate change and the patterns of regional change; (greenhouse gases...); and (polar ice sheets...). (p.xxxi)

The main observational requirements are: (i, ii...); (iii) the establishment of a global ocean observing system to measure changes in such variables as ocean surface topography, circulation, transport of heat and chemicals, and sea-ice extent and thickness. (iv, v...). (p.xxxii).

All nations must reaffirm their commitment to observe and document the fundamental aspects of the climate system and the changes occurring with it, including:
1)...; 2) development of a global ocean and ice observing system. Satellite observations of ocean surface temperature, wind, and topography, sea-ice concentration and colour, operational upper-ocean heat and freshwater monitoring, and systematic sea-level and deep ocean measurements are required. (3...). (p.315).

The key to predicting the rate of change of the global system is to be found in observations of the ocean circulation and heat storage. (p.323).

A comprehensive ocean and ice observing system requires:
a) Satellite observations of the ocean surface temperature, wind and topography, sea ice concentration and chlorophyll content (colour), and the topography of the Antarctic and Greenland ice sheets, by an international array of space platforms in suitable orbits around the earth;
b) an international operational upper-ocean monitoring programme, to determine the time and space dependent distribution of heat and fresh water in upper ocean layers, seasonal variations and long-term trends; and
c) an international programme of systematic sea level and deep ocean measurements, at suitable time and space intervals, to determine the state of the ocean circulation, ocean volumes and transport of heat. (p.323)

Second World Climate Conference, 1990

There is an urgent need to create a Global Climate Observing System (GCOS) built upon... and based upon: (2) the establishment of a global ocean observing system (GOOS) of physical, chemical and biological measurements. (Conference Statement, C. 5-7, p.4).

The Task Group makes the following recommendations: a permanent Global Ocean Observing System for the purpose of improving predictions of climate change should be established, as recommended by IPCC WG1. (p.446).

United Nations Conference on Environment and Development, Agenda 21. 1992.

17.107: States should consider: (....) (b) Supporting the role of the IOC in co-operation with WMO, UNEP and other international organisations in the collection, analysis and distribution of data and information from the oceans and all seas, including as appropriate, through the proposed Global Ocean Observing System, giving special attention to the need for IOC to develop fully the strategy for providing training and technical assistance for developing countries through its Training, Education and Mutual Assistance (TEMA) programme.

17.114: Developed countries should provide the financing for the further development and implementation of the proposed Global Ocean Observing System.

ANNEXE 3

The economic benefits of GOOS

This annexe provides a brief review of the scale of activity in different marine sectors, and the possible improvements in management and environmental protection which could result from the application of data from GOOS.

Scientific enquiry is not a sufficient justification for investment in an operational ocean observing system on the scale of GOOS, although science would benefit. It would be difficult to justify GOOS on the basis of understanding, monitoring, and predicting climate, since substantial infrastructure would have to be developed early on, and the tangible benefits would occur after a delay of decades. Whereas new meteorological programmes can be developed by adding relatively small components of new activity to a large existing operational system with strong national agencies, the proposal to observe the ocean systematically requires the development for the first time of civilian operational marine and ocean observing systems. This is in addition to the continuing scientific research effort.

The justification for an observing system therefore requires additionally an estimate of economic, social, environmental, and amenities benefits which are likely to result from the use of the data generated by GOOS. It is not possible at this stage to predict exactly the manner in which different commercial and national bodies would use data, information, and predictions to improve the efficiency of their activities, but analogies can be drawn with the way in which the offshore oil industry, or the authorities responsible for coastal defences, or safety at sea, use climatic data and operational data to set design standards, design structures for different environments, plan sensitive operations such as heavy lifting or towing at sea, regulate fisheries, predict the dispersal of pollutants, or control the impact of toxic algal blooms.

A first step is to assess the economic scale of marine activities globally. If marine activities are an insignificant percentage of the global economy, then the economic argument falls at the first hurdle. If the scale of activities is a substantial proportion of the global economy, or of the economy of a large proportion of countries, then the improved availability of information, monitoring, and predictions concerning the marine environment which could produce an improvement in performance of the order of 1%, would produce a valuable return for the investment in GOOS.

This Annexe analyses in broad terms the economic scale of the Beneficiary Modules shown in Figure 1 of the Report: Living resources, Ocean floor and non living resources, Health of the oceans, Coastal seas, Science and technology, Shipping and Defence, Coupled Ocean-Atmosphere Climate, and Study of Global Ocean Variability.

Living Resources

Fish, shellfish, krill, mariculture, seaweed

Global sea fish catch is 80-90 million tons per year. An average cash value is about $500 per ton, suggesting a global cash value of $45bn per year. Although the cash value may be less in developing countries, there are many countries where the contribution to national diet, health, or foreign earnings is far more important than the dollar value would suggest. Fish farming, aquaculture, shellfisheries, and other products based on marine life create additional large global markets. Since many areas of the world ocean are fished intensively, and close to or exceeding the maximum sustainable catch, sound environmental data and predictions of ocean conditions are essential to aid the maintenance of sustainable catches. Over-exploitation can cause a rapid destruction of stocks and complete collapse of a regional industry. In Developed countries fishing is often an industry which provides employment in the more depressed regions, and therefore has high social importance. The value of fish used in this section is the price at first landing, not the increased value at retail, or sale in a restaurant.

The location and scale of marine fisheries are strongly influenced by physical and chemical changes in the ocean on annual to multi-decadal timescales. The dependence of the SE Pacific fisheries on the ENSO cycle is well proven. A contrasting example is that of the fluctuations in the North Atlantic cod catch off West Greenland, which were very low in the first part of this century, boomed between 1950 - 1970 to a value equivalent to more than $1bn/yr in today's currency, and then dropped almost to zero again. This was not due to mismanagement, but due to variation in the strength of the wind systems and the relatively warm Irminger Current which transports fish larvae from Iceland to West Greenland. The oceanographic evidence shows that a multi-decade fluctuation in wind and current systems on the scale of an ocean basin caused a fish stock supporting a $1bn/yr fish catch to develop and decay once during this century. Understanding and predicting such fluctuations would aid the management of fisheries in future.

Ocean floor, non-living resources

Mineral ores, oil, gas, sand and gravel, bromine, salt, coal, heavy minerals

Oil and gas are at present extracted from the continental shelves and EEZs of 41 countries, and new resources are being steadily discovered each year. The greatest depth at which hydrocarbons are being produced offshore is 752m, and reserves have been explored to water depths of 3000m. The value of oil and gas extracted from the seabed is the greatest resource benefit from the ocean in financial terms. In 1990 the production of offshore oil was 26% of the world total, with a value of approximately $112bn. The production of offshore gas was 18% of the world total, with a value of approximately $23bn. The proportional dependence of each producing region on offshore production is as follows: Middle East 19% of oil is produced offshore, and 14% of gas; for Africa, 24% of oil, and 2% of gas; for Western Europe 95% of oil and 57% of gas production; for the Americas 29% of oil and 20% of gas; for Asia and the Pacific 68% of oil and 49% of gas; Russia and Eastern Europe (approximate) 1% of oil and 1.5% of gas are produced offshore. These figures refer only to production. In terms of the economic dependence of countries or regions on offshore oil and gas, one would have to consider also the extent to which hydrocarbons are imported from the regions listed above.

The offshore oil and gas industry is supported by a huge range of service, supply, and contracting industries, providing extensive employment onshore. Offshore hydrocarbons exploration and production are very dependent upon science, technology, and accurate environmental data, both for design and operations. For example, in the Arabian Gulf it is estimated that there are $250bn of oil installations constructed within 0.5m of present sea level. In other areas of the world, structures and operations must withstand extremes of storms, waves, currents, wind, ice, hurricanes, earthquakes, tsunamis (tidal waves), and sediment scour or instability. Forecasting these events in the short term, and predicting average or extreme events in the long term, reduces costs, reduces accidents, and increases efficiency.

Other marine minerals are extracted from seas usually shallower than 100m, but deep ocean drilling and exploration by acoustic surveys and submersibles have revealed potentially economic deposits.

Health of the oceans

Prevention or control of gross pollution including by oil and radionuclides, aeolian deposited contaminants, reduction of runoff from the land and rivers containing pesticides, herbicides, nutrients, and sewage, monitoring low-level eco-toxicology, control of toxic algal blooms, control and management of waste disposal, monitoring the balance of nutrients and oxygen in the ocean

Regulation of waste disposal and contamination of coastal seas and the high seas is required at all levels of law from the UN Convention on the Law of the Sea (UNCLOS) and the London Dumping Convention, through regional agreements such as the Oslo, Paris and Helsinki conventions, to national and local laws and controls. Implementation of treaties and regulations can be very expensive, whilst neglect of critical signs of contamination or degradation can be equally expensive, whether governed by existing legislation or not. The measure of the Health of the Oceans may be indicated by the survival or death of key species, certain changes in the plankton ecosystem, effects on commercial fisheries, measured concentrations of known toxic or potentially dangerous chemicals or contaminants, or the actual incidence of sickness or death to people using marine resources or amenities.

At the local level the health of the sea may be damaged by an obvious source of waste or contaminants. But for a small sea area it is not clear what contaminants are transported into and out of the area, what are the sources of variation, and whether there are causes outside the area for observed changes in biological activity. Models are needed of regional and coastal seas to monitor and predict changes in the biological and chemical properties, in short, to predict water quality. These models in turn need data from the bordering oceans in order to link the physical and chemical driving forces to the biological processes.

It is difficult to provide a cash value for the health of the oceans, but indicative figures are available. If mismanagement of the health of the ocean damages commercial fisheries, the cumulative cost would be hundreds of $m. Damage to water quality which impacts on tourism has a similar scale. Waste disposal from land to sea by pipe or dumping for one country (UK) saves $2bn/yr compared with the cost of disposal on land. If all industrial and industrialising countries were required to reduce waste emissions to rivers and seas on this scale, the cost would be many $bn/yr.

Other sources of damage include silt and soil runoff through rivers which can destroy or damage coastal biological features such as wetlands, mangrove forests, and coral reefs. Damage to these features then creates the need for other measures for coastal protection and management.

Industries operating on the coast and offshore are subject to regulations which increase their costs. Appropriate regulations based on good science, and up-to-date monitoring and data can both protect the ocean and reduce costs. The cost to industry and governments of enforcing and complying with regulations of marine waste disposal, marine discharges, and other necessary marine environmental controls is tens of $bn/yr. A global data system would greatly increase the accuracy of assessment of damage to the sea, and thus ensure that expenditure was effective but kept to a minimum.

Coastal seas

Living and non-living resources, recreation, tourism, coastal construction and civil engineering, flood prevention, coastal defences against erosion, pipeline and cable installation, operation of ports and harbours, ensuring the health and safety of people at sea or bathing in the sea

The coastal, semi-enclosed, and shelf seas are the most intensively exploited, and are subject to the greatest stress and potentially greatest conflicts of interest. The importance of reducing or controlling the environmental stress on coastal seas has been identified as of great interest to coastal states, and has resulted in the joint UNEP-IOC-WMO Long-term Monitoring System of Coastal and Near-shore Phenomena Related to Climate Change.

International tourism globally in 1991 involved 448 million arrivals of people crossing borders for recreational purposes. Total receipts from trans-national tourism were $261bn. To a rough approximation, tourism internally within countries is of the same order of magnitude as international tourism, but world cumulative figures for individual nations have not been obtained. A very significant proportion of all tourism, both national and international is towards beaches, islands, and regions of dramatic coastal scenery. If we assume that one quarter of all tourism is oriented towards coasts and islands, the global value of this activity is of the order of $100bn/yr. For some regions and small countries tourism is almost the only source of income which can support a modern standard of living. The cash losses through single incidents, such as the algal blooms in the northern Adriatic, are measured in hundreds of $m. Oil spills, floods, extreme storm damage, or stories of local pollution can have similar costs to tourism. Maintaining a clean and healthy coastal sea, with clean beaches, is rated as the highest environmental priority by the public in many countries. Benefits globally from GOOS are in $bn/yr.

Protection of the coastline against storm waves, storm surges of sea level, possible global rising of sea level, and hurricane damage is planned more efficiently if good data are available. Oceanographic data are needed to predict regional and global trends and extremes, as well as to predict individual events. For example, the insurance claims in the USA resulting from Hurricane Hugo in 1989 were $4.2bn, and those from Hurricane Andrew in 1992 are approximately $7.3bn. The federal aid requested after Hurricane Andrew was $7.6bn, and 250,000 people were homeless. Storm surges and hurricanes striking the coasts of the Caribbean, SE Asia, and in Bangladesh have created appalling homelessness and loss of life. A fractional improvement in data and modelling the air-sea interactions which produce the very high wind velocities could result in savings of many lives and some property.

The Coastal Seas Module will include the application of global sea level data to the design of coastal defences, and the prediction of the impact of climate change and possible sea level change on the coast. Coastal erosion has been increasing on all coasts of the world during recent decades, though the cause of this is uncertain. IPCC estimate of possible sea level rise in the next 80 years is 44cm, with a broad range of uncertainty. For the USA this would mean a loss of 15,000 square km of land, and an investment of the order of $100bn cumulatively in coastal defences and dikes. This is equivalent to an annual cost of the order of $1bn. Globally the cost would be tens of $bn/yr. Low lying countries such as Egypt, Netherlands, Bangladesh, and many Pacific islands, would have to choose between sacrificing a large proportion of their national land area, or spending many $bn each on coastal defences. Coastal erosion, and flooding require a steady expenditure of many $bn/yr, and improved regional forecasting and prediction of extremes would increase the efficiency of design and maintenance, and the prevention of disasters.

Harbour works and costs related to dredging and coastal navigation amount annually to $15bn globally. These activities are subject to improvement by marine research, and to routine benefits from improved data services and predictions.

The Coastal Seas Beneficiary Module of GOOS will benefit particularly from the operation of regional and local observing systems and models run on a finer mesh than the GOOS Global Framework. These regional and local systems would be provided with global and basin scale data and predictions, which can be used to initialise the models, and provide climatic forecasts which could not be derived from local data alone. This module contains several tens of $bn/yr of activity not counted in other modules, and there is a substantial benefit from GOOS.

Science and technology

There is a continuous feedback between advancing marine science and technology (MST) on one hand, and the development of an efficient observing system on the other. Improved scientific knowledge of oceanic processes and improved instrumentation lead to improved description and forecasting of the state of the ocean; this improvement enables scientists to conduct their research more quickly and accurately by locating precisely the events and features which they need to study. The total MST R&D budget of the G7 countries is approximately $10bn/yr. Of this about 30% is spent on research related to improving or protecting the marine environment, and 10% is spent on basic research into the science of the ocean. Research activities are far more information and data intensive than most industrial and economic activities. If all MST research projects could be improved in effectiveness by 5% the improvement in performance would be worth $0.5bn/yr. Marine research carried out by developing countries usually relates to economic resources such as fisheries, and improved basin-scale data from GOOS would result in an improvement in resource utilisation and management.

The major scientific uncertainties about the ocean remain because there is no complete data set. The high resolution models which ask the key questions cannot be run accurately, tested, or checked, because there is neither synoptic data, nor enough data. A routine observing system is needed to permit the scientific solution of the key problems.

At present, the majority of unclassified subsurface ocean data are obtained as part of scientific experiments funded from national research budgets. Collectively these experiments produce a partial data set which permits some deductions about the global ocean. Insofar as economic benefits in predicting the ocean are already obtained, the operational Departments of governments are obtaining much of their information free of charge. When scientific research priorities change, the observations will cease. It is preferable that the transfer of financial responsibility to operational Departments be planned in advance.

Shipping

The tonnage of world shipping has been rising steadily by 3-8% every year since 1948, with the exception of a small decrease in tonnage from 1983-87. Total tonnage of the world fleet of registered vessels over 100 tons is 670 million tons deadweight (1992), and total cargo transported in 1987 was 3.5bn tonnes in international trade. Coastal and short voyage shipping is growing more rapidly than long distance traffic. The Developing countries account for 36% of world international sea trade tonnage; Western Europe 27%; North America 13%; and Japan 6%. The bulk of world international trade is carried by sea, and for some countries more than 90% of national imports and exports are carried by sea. Safety and efficiency of ships, and that of the harbours which support them, are subject to improvements arising from marine research, and to routine benefits from improved data services and predictions.

Defence

Military oceanography has grown steadily and effectively since the 1940s, with the objectives of improving the safety and efficiency of ships at sea, predicting coastal conditions for amphibious operations, and in particular to predict acoustic propagation in submarine warfare. Neither UN agencies, civilian research agencies, nor the objectives of GOOS itself can be influenced by military requirements, but the existence of the data produced by GOOS will have military implications. A common data set in the public domain should help to make the ocean a more transparent and peaceful environment.

At present naval forces are the major users of operational sub-surface oceanographic data. In support of submarine and anti-submarine warfare data are obtained from air-dropped instruments, moored and subsurface instruments, and from Expendable Bathythermographs (XBTs). The data are assimilated in numerical models, and used to predict the changing acoustic conditions which facilitate the screening or detection of submarines. It is probable that naval oceanographic organisations have experience of data gathering, data transmission, quality control, and the operation of numerical models, which would be useful to GOOS. Where possible, collaboration should be encouraged between civilian and declassified military oceanography. This collaboration would serve to increase efficiency and reduce costs, avoiding the necessity to invent techniques twice, and repeat mistakes.

Atmospheric climate

Atmospheric Climate: Monitoring of the global atmospheric climate is the responsibility of the Global Climate Observing System (GCOS) (see section on understanding climate). Climate prediction requires knowledge of the fluxes of heat, moisture, CO_2, other radiative trace gases, and momentum between the ocean and the atmosphere, and the horizontal and vertical transfers in the ocean. A subset of GOOS can therefore provide for GCOS the data needed to study and possibly predict atmospheric climate evolution. The Joint Scientific and Technical Committee of GCOS is in the process of defining the requirements for upper ocean observations for prediction of ENSO phenomena. The models used at present to predict El Niño events do not assimilate oceanographic data, but such models are under development.

OOSDP has stated that a prerequisite for the success of a predictive modelling endeavour is a steady flow of the necessary observational data established by the TOGA project.

The order of priority in tropical observations recommended by OOSDP is as follows: (1) surface wind stress and sea surface temperature; (2) thermal structure of the upper ocean; (3) sea level; and (4) upper ocean current. In addition, salinity measurements are needed for boundary conditions.

At present there is no observing system which could provide precipitation data or ocean sub-surface data for assimilation in global or regional numerical weather prediction models. Modern data assimilation schemes could assimilate precipitation data to modify the humidity and temperature structure of the atmosphere. A further factor which needs to be introduced is that of sea surface waves. Waves can be measured by satellite altimetry, and *in situ* techniques. It is difficult to measure precipitation over the ocean, but observational techniques are in the development stage.

A general review of surface oceanographic data required for climate monitoring and predictions in the future indicates the following, not in order of priority: sea surface temperature, sea surface salinity, precipitation, wind vector, gas exchange, significant wave height, wave spectra, sea surface elevation, sea ice extent, ice concentration, snow depth on ice, and ice velocity. These are the factors which apply on the interface between the ocean and atmosphere.

The Second World Climate Conference (1990) recommended the establishment of GCOS, which was set up by WMO in 1991. A 1992 estimate of the benefits of ENSO forecasting showed that the benefit to the USA agricultural sector alone is of the order of \$200m/yr. In very broad terms the benefits to the world community in terms of prediction of extremes of flood and drought, energy requirements, crop forecasts, etc., will be in \$bn/yr, in addition to the avoidance of hardship or death to hundreds of thousands of people. The Global Ocean Observing System, by contributing oceanographic data to GCOS, will contribute to this benefit. Long range forecasting, seasonal or annual, is not possible without subsurface oceanographic data.

The study of global ocean variability

If the atmosphere and upper ocean alone were responding to the increase in greenhouse heating and the cloud-radiation feedback operated according to current knowledge, then the surface of the Earth would already be 1 to 2°C warmer than the temperatures of the 19th century. The rate of warming of the climate is being reduced by heat transport through the upper ocean layer, or below it into the deep ocean at 1000m depth or more. Deep-ocean warming results mainly from warm water moving polewards, sinking at high latitudes, frequently in the presence of ice, and subsequently circulating in the ocean. Variability in such processes has a profound influence on the ocean itself on all scales, and hence on the coastal waters and the atmosphere, at a later date.

Thirty years ago ocean scientists assumed that the bulk of the ocean was in steady state, with annual variability in the surface layers. Measurements of currents or temperature from different years of observation were assumed to be compatible with data from previous and later years as if one were mapping the geology of a mountain range. Unexpected values were thought to be due to instrumental errors, navigational errors, or random fluctuations.

Research eventually showed that, even in the deep ocean, salinity and temperature fields varied continuously through time, and therefore the state could only be properly described by measuring the whole system more or less simultaneously, so-called synoptic measurements. Since that is clearly impossible, all real measurements are contaminated by the uncertainty that the difference between observations at two successive locations may also be due to the change in time of observation. If observing effort is concentrated into continuous measurements at one place, the scientists are uncertain as to whether their observations can be extrapolated to unmeasured areas.

The whole ocean, both the upper mixed layer that varies significantly on a seasonal cycle, and the deeper waters which vary more slowly, is now known to experience variability on many scales of time and space, with eddies, gyres, fronts, internai waves, fluctuations of sea surface topography, and extreme patchiness and variability in biological production. The objective of the GOOS Global Framework is to make the observations which will provide a description of this physical, chemical, and biogeochemical variability.

Uncertainty as to the degree of long-term change in the ocean is still extreme. It has taken many years to establish unambiguously that sea surface temperature is changing slowly on a decadal timescale. For subsurface temperature structure the data available from the North Atlantic, the most studied ocean in the world, are only just sufficient to detect a temperature change between aggregated data for the 1950s and the 1980s. For other oceans and other parameters the data are even less adequate. A recent analysis of all the data on the optical transparency of the open Pacific surface waters spanning the years 1900-1981 was used to try and estimate an increase or decrease in oceanic phytoplankton. Other long-term data sets which permit analysis of variability are those of sea level measured by tide-gauges, going back over 100 years, though only at a few locations, and the biological plankton recordings of the Continuous Plankton Recorder, back to the 1930s. In the case of the latter, the level of understanding can be shown to have improved steadily with time (see Figure 6).

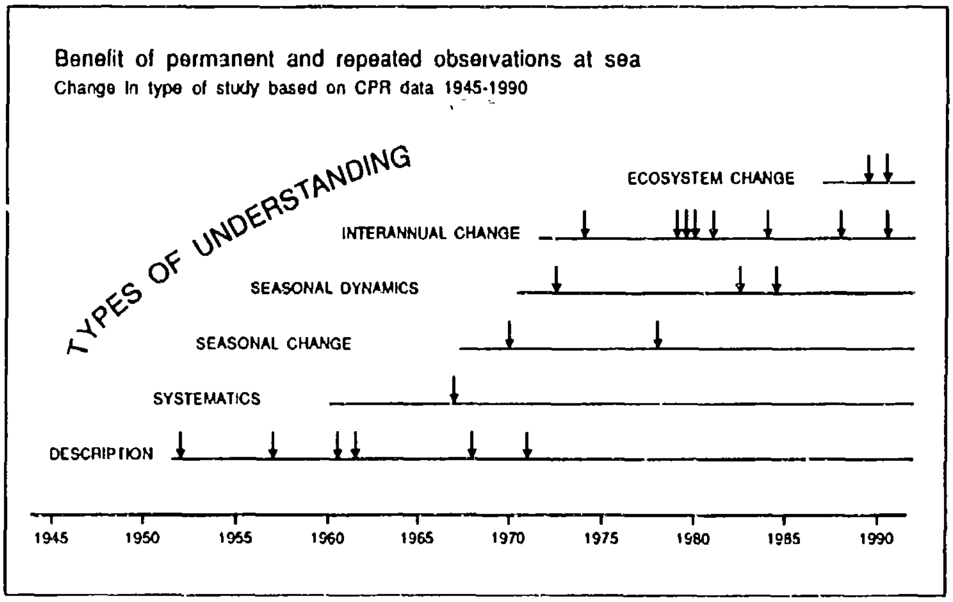

Figure 6: *As longer records of observations are built up it becomes possible to detect new types of phenomena, and make new kinds of predictions. The quality of information and predictions increases. The arrows indicate key publications of each category*

Permanent observation schemes not only reveal the temporal and spatial variability of the ocean, but also result in data sets which permit analysis of longer period processes, and hence better prediction further into the future. Improved data and predictability result in benefits over progressively greater timescales affecting different industries, as shown in Figure 3 of the report.

The measurement and modelling of the variability of the ocean itself on global and basin scale underpins all the other objectives of GOOS, and will support all the Beneficiary Modules.

Already it is clear that WOCE, designed to meet the WCRP criterion of heat fluxes to ±10 Watt/m^2, would not meet the more demanding specification posed by forecasting climate change due to the greenhouse effect (±1 Watt/m^2). A permanent monitoring system to meet those needs will require much higher annual sampling rates than have been achieved in WOCE. If the measurement errors are random, going from 10 to 1 Watt/m^2 requires a hundred-fold increase in sampling rate: from WOCE in eight years to a WOCE per month.

The GOOS Global Framework will produce a consistent global data set, repeated each year, which will for the first time provide a description of the natural spatial and temporal variability of the ocean on timescales of weeks to decades. It will in effect describe the climate of the interior of the ocean itself. The best description of the ocean will be obtained by assimilating the data into 4-dimensional numerical models which will diagnose the current state of the physics and chemistry, and produce better estimates of the continuous fields than indicated by the raw observational data.

Bibliography

Meyer, S., 1991, International Energy Statistics Sourcebook, PennWell Publishing Co., Tulsa

Basic Petroleum Data Book, 1992. American Petroleum Institute, Washington.

Oil and Gas Journal, Special Issue 1991. Worldwide Production. Pennwell Publishing Co. Tulsa.

FAO Yearbook of Fisheries Statistics.... Library.

Mosley, M.P., 1990. Pricing Natural Resources Information. Division of Water Sciences, Department of Scientific and Industrial Research, Wellington, NZ. 135pp.

Oceans of Wealth? 1989. Report of the Review Committee on Marine Industries, Science and Technology. Department of Industry, Technology and Commerce. Canberra, Australia. 188pp.

OECD, 1990. Maritime Transport. OECD, Paris, 144 pp.

Showers, V., 1989, World Facts and Figures. John Wiley and Sons. 721 pp.

HMSO, 1992. Transport Statistics Report: Merchant Fleet Statistics 1991. 82 pp.

UNCTAD, 1987. Review of Maritime trade.

Our Changing Planet, 1990. US Global Change Research Program, FY 91 Research Plan. Report by the Committee on Earth and Environmental Sciences, of the Office of Science and Technology Policy. 169 pp plus annexes.

CCMST, 1990. Marine Science and Technology in the UK. Report of the Co-ordinating Committee on Marine Science and Technology. Department of Education and Science. HMSO, London. 162 pp.

World Tourism Organisation, 1992. Trends of International Tourism in 1991. Madrid.

Woods, J.D., 1984. The World Ocean Circulation Experiment. Nature, v.314, p. 501-511.

Florida State University 1992. Workshop on the Economic Impact of ENSO Forecasts on the American, Australian and Asian Continents. August 1992. 85 pp.
NAS-NAE-IM, 1991. Policy Implications of G.eenhouse Warming. National Academy of Sciences. Washington.
Dornbusch, R., and Poterba, J.M., (Eds) 1991. Global Warming: Economic Policy Responses. MIT Press. Cambridge, Mass.
United Nations, 1992. Agenda 21. UNCED Document A/CONF.151/4 (Parts I, and II).
International Bank for Reconstruction and Development, 1992. World Development 1992: Development and the Environment. Oxford University Press, Oxford.
Houghton, J.T., Callander, B.A., and Varney, S.K., 1992. Climate Change 1992: The Supplementary Report to the IPCC Scientific Statement. WMO, UNEP. 199 pp.
IFREMER reports.

ANNEXE 4

Notes on scientific issues

The design and management of GOOS depends upon scientific understanding of marine processes, and the ability to model these processes in computers. There is an iterative connection between better understanding, resulting in better design of the observing scheme, which produces better understanding. Some additional points about the importance of science and modelling are made in this Annexe.

- Some variables and processes are much better understood than others. It is possible make some elements of GOOS operational, whilst major research is still required on others, and continues in parallel.

- Research is needed to turn theoretical knowledge into applicable technology and procedures.

- As GOOS starts to produce data and data products, the output must be verified and checked. Research will be needed to check that the descriptive and predictive models produce a good correlation with the actual state of the ocean, and to check whether the methods used have been the most efficient possible.

- Research enables GOOS to be continuously improved, and the scientific research community constitutes an important Beneficiary Module of GOOS. The routine data produced by GOOS will enable research to be planned more efficiently, which will in turn result in knowledge to improve the design of GOOS.

- In the early Phases of GOOS observations are likely to be implemented parameter by parameter, with separate global data products each based on a small number of variables. As observations of more parameters are implemented it will become possible to integrate all the variables into complex models. Research will be needed to design, test, and verify those models as GOOS progresses.

Since the observed data cannot detect or define completely the physical processes and structures which occur in the ocean, the models, controlled by the geophysical fluid dynamical equations, are needed to make the best possible description, or now-cast, of the state of the ocean at the present moment. Ideally, the models will re-construct the complex features which the raw observations miss. When models have been demonstrated to make accurate descriptions of the ocean in this way, it will be possible to make progressively ambitious runs of the computer models forward in discrete time steps to try and predict the future.

Computer simulation is further important in identifying the areas and sampling rates which are necessary for most detailed observation at sea. Firstly, the output from the computers will show the areas and times where there is the greatest complexity of spatial or temporal variation, and hence the greatest need for closely sampled data. Secondly, experiments can be conducted including or excluding particular sections of data, and comparisons made in the validity of the output. These experiments will show whether certain parts of the ocean have been under-sampled, leading to errors in interpretation, or over-sampled, leading to waste of time, money, and misallocation of effort.

ANNEXE 5

Possible data products from GOOS

- Globally consistent, long term, quality controlled data sets, made available and updated operationally, for a wide range of oceanographic parameters such as temperature, salinity, precipitation, heat flux, upper layer thickness, geostrophic currents, global sea level topography, etc., in such a way that the data can be assimilated into ocean climate models, and coupled ocean-atmosphere climate models.

- The global perspective obtained through global data sets and model outputs consistently through time should permit the early detection of the onset of non-linear events, such as formation of unusually persistent layers of low salinity water, changes of ocean circulation patterns. The same global approach maximises the chance of detecting complex patterns or 'fingerprints' which can be attributed to known causes.

- Products on an ocean basin scale, and continental marginal sea scale, which provide data on physical and chemical parameters, and data on primary and secondary productivity, for the guidance of fisheries managers and regulatory agencies.

- Global overview of data and information related to living resources and their changes which will permit the identification of trends and problems occurring on global, as opposed to regional and/or local scales, leading to co-operating efforts to analyse and address these issues.

- Ocean basis scale products of physical, chemical and biological parameters which will provide boundary conditions for coastal models.

- Global and regional data sets which will permit analysis and correlation of the factors causing harmful algal blooms.

- Coastal phytoplankton, productivity and standing crop data, based on SEAWIFS satellite measurements and *in situ* data sources.

- Integrated data products based on predictions of sea level, storm extreme events, and storm surges, related to coastal erosion and flooding.

- Global data sets related to the physical and chemical parameters determining productivity and survival of major ecosystem habitats such as coral reefs, and mangrove forests.

- Basin scale and continental shelf sea scale data sets designed to facilitate and support local modelling of estuaries and wetlands.

- Global maps and profiles of distribution of contaminants and pollutants designated as potentially dangerous for the health of the open ocean, such as PCBs, lead, plastics, and the distribution of nuclear waste.

- Distribution of nutrients, excess nutrients, and the probability of eutrophication on basin scale and continental shelf seas scale.

- Data products indicating nutrient ratios.

- Global and basin scale products showing production of methane from clathrates, and venting of methane to the atmosphere.
- Products indicating optical properties of the upper ocean, light transmission at a range of wavelengths and water depths, including the effects of possible increases in UV.
- Global and basin scale products indicating variability in ecosystems, species diversity, and environmental factors causing changes in primary productivity and fisheries.
- Trans-ocean Continuous Plankton Recorder data sets.
- Global and regional sea ice products, based on modelling and prediction including data from radar sat, SAR, wind data, sea-surface temperature, currents, upper ocean thermal balance, convection, etc.
- Improved data on ice thickness, ice front, navigability, etc.
- Global and regional predictions of icing conditions on ships' structure and rigging, based on wind, wave, spray, SST, air-temperature, etc.
- A combination of Radar Altimetry, improved geoid by the gravity field satellite 'Aristoteles', ship-borne and moored ADCP, and currents derived from dead-reckoning and GPS, and data from sea level gauges, will allow derivation of global maps showing surface geostrophic and wind-driven currents.
- Global and regional products will predict the position of western boundary currents, large scale gyres, warm and cold rings and associated currents.
- These products will be valuable in ship-routing, and in the fishing industry.
- Products could include current information with salinity and frontal data.
- Weather forecasts to ships in the prediction range 10-30 days could be improved by the inclusion of global data on upper ocean, heat flux, precipitation over the ocean, precipitation-evaporation data, etc.
- Wind-wave products are part of the routine services of meteorological offices, but enhanced observation, generated through GOOS should permit improvements in quality as well as scale coverage. The data are important in ship-routing, ship design, oil field operations, safety at sea, and design of offshore structures.
- Wind and wave products are important for the prediction of movement and dispersion of oil slicks, other hazardous spills, or nuclear contamination.
- Sea surface temperature maps, predicting temperatures and the positions of fronts are relevant to fisheries exploitation and management, and long term policy for the sustainability of fisheries.
- Additional sub-surface thermal data products are relevant in connection with mixed-layer depth and the formation of fronts.

ANNEXE 6

The contribution of GOOS to understanding Climate: Relationship between GOOS and GCOS

The establishment of a Global Ocean Observing System was recommended by the International Panel on Climate Change (IPCC) Working Group 1 in 1990, and implemented by the Intergovernmental Oceanographic Commission at its Assembly in 1991. The formation of GOOS was also recommended by the Second World Climate Conference in 1990 as part of its general recommendation for the establishment of GCOS. (See Annexe 2).

There are many reasons for establishing a Global Ocean Observing System, and one of these is the need to obtain long-term data which will help to explain and predict the variability and change of climate. The ocean contains 60 times as much carbon as the atmosphere, and fluxes of carbon dioxide, heat, and water between the atmosphere and the ocean have a long-term effect on climate. Uncertainty as to the rate at which carbon-dioxide is absorbed into the ocean is a major factor in understanding the future significance of the so-called "Greenhouse Gas Effect".

Fluxes of heat, momentum, water, and radiatively active gases between the ocean and atmosphere need to be included in coupled ocean-atmosphere models.

The Global Climate Observing System (GCOS) was established by WMO jointly with other agencies in 1991. GCOS will include observations of all the major parameters influencing climate, such as vegetation cover, the size of ice sheets, rainfall, river runoff, etc. The models and predictions generated by GCOS require an input of data from the ocean, and it is therefore important that GOOS and GCOS collaborate.

Both GCOS and GOOS are innovative in that they establish for the first time systems for routine gathering and processing of data on a global scale, encompassing a sufficient range of variables with sufficient accuracy over a long time span to detect climate change and variability.

The requirements for ocean observations and ocean data for GCOS are expected to be specified by the Joint Scientific and Technical Committee (JSTC) for GCOS, using the reports of the Ocean Observing System Development Panel (OOSDP) as appropriate. The definition of these requirements will be provided to GOOS through the IOC Committee for GOOS and the Joint GOOS Technical and Scientific Committee (J-GOOS). The requirements for data will be met by the implementation of GOOS. There should be a contractual relationship between GCOS and GOOS so as to ensure that GOOS implements the ocean observations specified by GCOS as part of its activities.

The organisations concerned with climate research are listed below:

Organisations concerned with climate

The World Climate Research Programme (WCRP was established in 1979 by the World Meteorological organisation (WMO) and the International Council of Scientific Unions (ICSU). The Intergovernmental Oceanographic Commission (IOC) joined in 1992.

The International Geosphere Biosphere Programme (IGBP) was created by ICSU in 1990, and sponsors several programmes related to ocean climate, principally the Joint Global Ocean Fluxes Study (JGOFS), and the planned Global Ocean Euphotic Zone Study (GOEZS), Past Global Changes (PAGES), and the International Global Atmosphere Chemistry Programme (IGAC).

Both WCRP and IGBP have roles as umbrella programmes or sponsors for atmospheric, oceanographic, and cryospheric global experiments.

The Global Climate Observing System (GCOS) was established by WMO at its Congress in 1991, in response to recommendations of the Second World Climate Conference, and the Intergovernmental Panel on Climate Change. IOC, UNEP, and ICSU are now co-sponsors of GCOS.