MATCHING DEMAND AND SUPPLY FOR EARTH OBSERVATION DATA AND INFORMATION

THE USE OF EO DATA FOR POLICY SUPPORT AND ENVIRONMENTAL APPLICATIONS IN THE EU

A report of a study undertaken as part of the

EUFOREO Thematic Network

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ACKNOWLEDGEMENTS

The authors gratefully acknowledge the many project partners from the 4[th] and 5[th] Framework Programme who gave up their time to contribute to this study. It is nevertheless important to recognise that the opinions presented in this report – though in some cases attributed to individual projects – are in fact the *interpretations* of the authors. The authors thus take sole responsibility for all the views and opinions expressed herein.

THE EUFOREO THEMATIC NETWORK

The purpose of the EUFOREO (*EUropean FORum on EO use for Environment and Security*) Thematic Network (TN) is to develop the case for the efficient implementation of EU and national policies for Environment and Security, through the use of Earth Observation. In so doing, it will accompany and to support GMES in the present initial phase and assist in building the GMES Action Plan. EUFOREO has the role to providing the views of GMES significant stakeholders on GMES organisation and implementation through the involvement of a wide European range of participants, including final users. EUFOREO participants include 18 members, among which: ESA, JRC, EUMETSAT, EARSC and EUROSPACE, National Space Agencies, Research Institutions, Space and Service Companies. Eight EU Member States are directly represented. The present Study on "MATCHING DEMAND AND SUPPLY FOR EO DATA AND INFORMATION" is the first deliverable of the Thematic Network.

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EXECUTIVE SUMMARY

1. Introduction

1.1 This report presents results of a study of the EUFOREO Thematic Network – the aim of which is to develop and establish the case for more efficient use of Earth observation (EO) data in support of EU policy development and implementation.

1.2 Both the EUFOREO Thematic Network more generally, and this study in particular, have been motivated by recognition that EO data are not yet being used to their maximum capability for policy support in the EU.

1.3 The specific aims of this project were to thus explore the factors that act to deter or hinder use of EO data, and to identify ways in which these obstacles could be mitigated or overcome.

2. Methods

2.1 The study covered three main areas of application:

Land resources – including land use, land cover, terrestrial ecology, surface hydrology, soils, geology and topography;

Air and climate – including air quality/atmospheric pollution, climate, meteorology and tropospheric/stratospheric processes and chemistry;

Oceans and large lakes – including oceanic circulation, marine resources, marine pollution and limnology.

2.2 Research focused on the results and experience provided by 4th and 5th Framework Programme projects. Final (and interim) reports from more than 70 projects (undertaken between 1993 and the present) were reviewed; follow-up interviews were held with more than 40 partners from over 30 projects; and workshops were held with representatives from 35 projects. Additional information was also gathered from other relevant studies and from literature reviews.

3. Results

3.1 The three areas of application considered differ in terms of the characteristics of their users, the types of application for which EO data are needed, and their specific data needs. The land resource area, for example, is characterised by a large number of potential users (e.g. local authorities), with mainly local interests and well-established and routine usage of (and access to) a wide range of traditional data sets. Users in the oceanic field, however, tend to operate at a regional-global scale, be more research (rather than application) focused, and to have access to fewer alternative data sources. The air/climate field tends to be intermediate between these two extremes.

3.2 In all three areas, however, it is evident that EO data have enormous potential for both research and policy support, for example:

- As a source of data on the extent and condition of the environment
- For monitoring both long- and short-term change in the environment
- As a source of proxy data in other areas of application (e.g. health, social policy)
- As a basis for stratification for environmental sampling and monitoring
- As a basis for spatial interpolation and transformation of environmental and other data
- As a framework for environmental and other (e.g. social, health, socio-economic) modelling
- As an aid to data integration and visualisation

3.3 It is also evident that the 4th and 5th FP projects have achieved a great deal, both in generating and validating new data sets at local to international level, and in developing and testing new analysis tools (including techniques for data collection, processing, modelling, visualisation and interrogation).

3.4 Nevertheless, it is clear that adoption of EO technologies for routine applications in the areas of policy and environmental management is still only partially developed. To some extent this is not surprising, for the technology is still new, and as other recent developments in information technology have shown (e.g. GIS), it can take many years for full adoption to be achieved.

3.5 The factors hindering adoption of EO data and technologies are complex, and are to a great extent data-, user- and application-specific. Four main sets of issues can, however, be defined: attitudes to information amongst potential data users, awareness about EO technology and data products, the utility (or fitness-for-purpose) of available EO data, and the obtainability of EO data.

Attitudes to information

3.6 Attitudes to information are important because they determine the willingness of potential users to make use of EO and other data. It is clear that, despite the growing power and availability of information technology, not all policy-makers and environmental managers have an information-based approach to their responsibilities. In a small, but significant, number of cases, some prefer to rely on their professional judgement and experience and tend to eschew the use of independent information.

3.7 Attitudes to information are also shaped, in many cases, by the regulatory environment. The existence of legislation often acts as a strong motivation to collect and make use of information – and it thus encourages the use of EO data. However, where these legislative needs are already served by more traditional forms of monitoring and reporting, EO data may not be seen as relevant. In the case of development control, for example, EO data only tend to be used where formal inspection mechanisms do not operate effectively.

3.8 In some cases, also, EO is seen as a 'last resort' data source – i.e. one that is used only when other, traditional forms of data have failed. In these cases, EO may have to confront – and be judged in terms of its performance with – only the more challenging tasks. This may set EO data at a disadvantage when they are compared with other data sources.

Technology and product awareness

3.9 Many potential users remain somewhat unaware of EO technology, and of what EO data have to offer. Knowledge about the technology is often confined to a small number of individuals in user organisations; when these leave (as they often do, because of their enhanced employability), knowledge of the technology leaves with them.

3.10 The expectations of users are in some cases negative, because of unsuccessful previous experience with EO data (and perhaps because of professional jealousies). In the past, this has sometimes been exacerbated by the tendency of EO data and service providers to raise false expectations by 'overselling' their products.

3.11 The lack of readily available sample EO data sets or demonstration materials (e.g. packaged with GIS or with other data sets) also contributes to this limited product awareness amongst potential users.

3.12 There is a tendency for EO data to be (mistakenly) perceived as less accurate than other, traditional data sources. In part this is because – in contrast to other sources of data – the accuracy of EO data is routinely reported. The misconception sometimes exists, therefore, that these traditional data sources are error-free.

Fitness-for-purpose

3.13 One of the most important factors limiting the perceived utility of EO data in many situations is the spatial resolution of the data. The problems of scale and resolution are especially important in the land resource area because of the spatial heterogeneity of the landscape in Europe: this typically comprises a complex mosaic of patches and transitional forms. Mapping or monitoring these requires data at a higher resolution than that achievable from most EO sources.

3.14 Traditionally, these data needs have often been served by aerial photography or field survey and monitoring. These thus provide the benchmark for data specifications.

3.15 For national and EU-wide applications, on the other hand, there is a need for data of intermediate scale, covering the whole area of interest; these data, too, are often lacking.

3.16 Problems with the availability of multi-temporal EO data also create obstacles in many cases. Multi-temporal data are needed both to aid classification (e.g. of land cover) and to detect change; however, gaps in time series data often occur because of cloud cover and sensor failure. These add to the cost and difficulty of data acquisition, and may limit data use.

3.17 Repeat intervals for most (especially high resolution) EO data are too long to allow reliable monitoring of short-term events or processes (e.g. fires, disasters, pollution episodes).

3.18 In the long-term, changes in EO technology and data specifications make it difficult to maintain consistent time series, and may hinder or prevent comparisons and change detection.

3.19 In the land resource area, especially, the use of EO data is also limited by the need to apply pre-defined typologies (e.g. land use classes, habitat types) which cannot always be discriminated clearly using EO techniques. Many-to-many relationships between the classes definable from EO data, and those required for policy purposes, make it difficult to extract useful information.

Obtainability

3.20 Problems of accessing and obtaining EO data are cited most frequently as the main obstacle to data use. In particular, access facilities (such as Web browsers and portals) are often seen as cumbersome, complex and unnecessarily inconsistent.

3.21 Metadata on EO data are also seen as poor in many cases: problems include lack of, incomplete and misleading metadata (e.g. on cloud cover, data formats). These problems relate both to the *discovery* metadata needed to find out about, and carry out an initial assessment of, EO data, and the *access* metadata needed actually to acquire and use them.

3.22 Data delivery times – and supporting service quality – achieved by many providers are frequently seen as inadequate compared to the service quality given by traditional data suppliers.

3.23 Although costs of EO data have generally been reduced in recent years, for many users they are still seen as a deterrent. Problems of cost are especially acute for small users, with limited (and often annually set) data budgets. Costs are considered to be especially high when compared to aerial photography and other, traditional data sets, which may be available under preferential purchasing arrangements (e.g. service level agreements). Costs can also be a constraint where large data sets are required (e.g. for pan-European or global studies). However, compared to some forms of traditional data collection (e.g. ship-based oceanic surveys or fixed-site air pollution monitoring) EO data may be relatively cheap.

4. Conclusions and recommendations

4.1 The study has confirmed that EO technologies have enormous potential as sources of data and as analytical frameworks for both research and policy on the environment. It is also evident that the FP projects have made important contributions to EO science in this area, both through the generation of new data sets and by the development and testing of analysis methods and tools.

4.2 As yet, however, EO data are not achieving their full potential in these areas. In part the problems relate to the technical limitations and complexity of EO data; more generally, however, they derive from the low levels of EO expertise and awareness of potential users, and the poor understanding of user needs by data providers and the EO service sector. As a consequence, an effective market for EO data has not yet emerged.

4.3 To resolve these problems, the following priorities need to be addressed:

1. *Developing a wider suite of EO-derived data products, better matched to existing user needs, and able to offer ready-made data for new users*, e.g. through EU funding to help develop key data sets; closer involvement of EU Directorates and agencies in EO-based research projects, in order to strengthen the European value of the data products; greater emphasis on the role of EO service providers in developing and marketing customised data products

2. *Improving understanding of user needs*, e.g. through workshops and seminars aimed to bring together EO (and other) data providers, service organisations and end users in order to specify more clearly user needs and what EO (and other) data can provide; improved dissemination of the products of FP project results, and other developments, to raise user awareness; development and wide dissemination of demonstration products and sample data sets (including via the Web); training sessions and hands-on experience for end-users/

3. *Developing more flexible and user-friendly analysis tools,* e.g. through research in to improved modelling methods, statistical data analysis, and systems for data integration and linkage between EO data and other data sources.

4. *Improving systems for data access, evaluation and acquisition*, e.g. by providing better discovery and access metadata, development of co-ordinated browsers/ portals, more comprehensive documentation, application of more consistent data formats and standards, adoption of less 'elitist' attitudes by data providers and service organisations.

5. *Developing fair and appropriate pricing policies for key user communities,* e.g. through the establishment of preferential purchasing arrangements (e.g. 'service-level agreements') for key user groups, and provision of introductory/trial data on favourable terms.

6. *Recognising the validity and value of EO data in policy and legislation*, e.g. through inter-comparability and calibration studies to demonstrate and quantify the equivalence between EO-derived and traditional data; recognition in new or existing EU Directives and national legislation of the role of EO as a data source; definition of policy classifications and typologies in terms of EO capabilities

7. *Funding for EO development studies*, i.e. action to reverse the current bias in FP funding towards EO technology (and against product development and operation) by targeting FP projects at more generic users, who have the capability to act as leaders in adoption and use of the project outcomes; increased emphasis in FP projects to effective dissemination of the results to the wider community of users; provision of follow-up/extension funding to help take the outputs from FP ensuring greater emphasis in both FP and follow-up studies on mechanisms projects to an operational state

1. Aims

This report presents results from a study on the obstacles to the use of Earth observation (EO) data in Europe. The study represents a sub-project of the EUFOREO Thematic Network, which itself aims to develop the case for more efficient use of EO data in the implementation of EU and national policies.

The study therefore derives from the hypothesis that EO data are less extensively or effectively used than they might be. The challenge, if this is true, is to explain why it is so. The aims of this study are thus:

- to define the scientific, technical/operational and institutional obstacles which act to restrict the use of EO data for policy-related purposes in the EU, and the production of environmental information in general;
- to identify the measures needed to enhance and improve the effectiveness of EO data for policy support.

2. Study design and methods

The study is structured in relation to three themes or application sectors:

- Land, including land use, land cover, terrestrial ecology, surface hydrology, soils, geology and topography;
- Air, including air quality/atmospheric pollution, climate, meteorology and tropospheric/stratospheric processes and chemistry;
- Oceans and lakes, including oceanic circulation, marine resources, marine pollution and limnology.

In order to explore obstacles to EO data usage in each of these sectors, consideration was initially given to developing a model of the EO data stream and, based on this, of the key decision processes and determinants affecting data usage. This involved a combination of brainstorming by the study team, a review of relevant literature (including results of previously published and unpublished studies of EO and other environmental data usage), and consultation with other experts in environmental data supply and exploitation.

This model was then tested in three ways. Firstly, a review was undertaken of relevant research and development (R&D) and concerted action (CA) projects, funded under the 4th Framework Programme (4th FP), between 1993 and 1998. Final (and where appropriate interim) reports of these studies were obtained and reviewed.

Secondly, a series of detailed case studies was undertaken, through follow-up with individual projects. In these, contact was made both with project leaders and, through them, with a number of project partners from the user community. Interviews were held either face-to-face or by telephone, and supplementary information gathered where appropriate by written communication or questionnaire. In some instances, these case studies were supplemented by experience from other non-4th FP projects.

Thirdly, a workshop was held with project leaders from 4th and 5th Framework Programme projects, in Brussels, on 11-13th September 2001, at which these same issues were explored. The forthcoming proceedings of this workshop will provide more analytical and detailed information to complement the present study.

It should be noted that the focus on 4th and 5th FP projects in this study inevitably leads to bias in the types of issues that are encountered, the types of users involved, and their experience of dealing with these problems. Most FP studies are attempting to develop or apply new methods and applications and thus are often endeavouring to stretch the available data to their limits, and possibly to use the EO data for purposes for which they were not originally designed. Research studies such as those in the Framework Programme consequently tend to confront problems that would not be faced by more routine applications, and to suffer a higher failure rate; at the same time, because they are exploratory studies, they also have more flexibility and greater opportunity to adjust their methods and approach than do routine applications for policy or management purposes. Finally, the techniques are often applied by experts in their field and so do not always highlight problems that may be encountered by more "casual" users. As a result, these studies do not necessarily provide a wholly representative picture of the obstacles and issues faced by EO users (and especially non-users) in less research-orientated fields.

It should also be noted that, by concentrating on the *obstacles* to EO data usage, this study inevitably presents a somewhat negative picture, that does not do justice to the undoubted potential and numerous positive outcomes of EO usage in the research and policy field. We have attempted to redress this where possible, by drawing attention to some of these achievements, but the inherent bias in the report needs to be recognised.

3. The potential of EO data

Two precepts increasingly underlie environmental policy and management, at all levels from the local to the international. Action should be well informed, so that appropriate interventions can be made, where and when they are needed, in a cost-effective way; and decision-making should be transparent, so that actions can be properly audited and assessed, and stakeholders can have insight into the decisions that affect them or for which they pay.

In Europe, these precepts have been motivated by, and reflected in, various developments in recent years: for example by the gathering impetus of environmental policy and its expansion of policy into new areas, by the growing requirement of accountability (which implies the ability to track and evaluate policy impacts), by the consequent need to link more closely decision-making (and related information) at different policy scales, by increasing demands for public information, and by the growing use of indicators to meet these various needs. Implementation of these precepts also has far-reaching implications, not least in terms of information demand and information supply. Together, they imply the need for information both *for* policy and *about* policy.

Despite the many advances that have occurred in information technology and information science in recent decades, meeting this need remains a major challenge. On the demand side, data needs are highly variable, both from place to place (reflecting different priorities and policy imperatives) and over time (in response to changing policy agendas). Many information needs are also case-dependent; they require specific data, focused on specific issues, and formatted in a particular way, if they are to be fit for the intended purpose. On the supply side, data collection is expensive and time-consuming, and can rarely be justified in advance of a recognised need. Most data collection exercises are also designed and developed for specific purposes, so the routine data collected for one application are often not easily transferable to other uses. Over time, therefore, an almost inevitable mismatch tends to evolve between the routine data available for policy support, and the needs of the user. This mismatch is especially acute in new areas of policy concern or where new policy initiatives are being developed, for in these cases the lag between demand and supply can rarely be immediately bridged. It is likely to be particularly problematic where information is needed at high spatial resolution (i.e. for small spatial units) across a large geographic area, and/or for high temporal resolution (i.e. short averaging times) over long durations, since in these cases data need to be both detailed and consistent over extensive areas and long periods of time.

In the face of this information deficit, Earth observation (EO) data would seem to have particular potential. Since the launch of the early Landsat satellites, in 1972, enormous investments have been made in Earth observation systems, and today there are 30 or more instruments providing regular observation of all or a large part of Europe (Table 1). These provide measurements across a wide range of bandwidths and wavelengths, at a variety of resolutions and orbit frequencies. They thus generate data capable of detecting an enormous variety of surface and subsurface characteristics of the land, as well as atmospheric and marine conditions.

> The potential of EO data to address issues of environmental policy concern has been extensively reported, both through demonstration and research projects. Important applications include natural resource prospecting and management, emergency preparedness and hazard management, land use management and planning, pollution monitoring and modelling, biodiversity management and conservation, meteorological forecasting and climatology, environmental law, and risk assessment. Many other, non-environmental applications can also be recognised – for example in relation to economic and social policy, health protection, regional development, humanitarian assistance and national security. Numerous regional, national and international programmes have therefore been initiated to collect and use EO data on a routine basis in these various areas of concern.

Against this background, it may be expected that EO data have now become firmly established as a policy tool, at all levels of application. Whilst the use of EO data has expanded in recent years, however, the uptake of EO technology has been slower than has previously been anticipated, and in many potential areas of application usage of EO data remains undeveloped. This situation poses a number of important questions that merit attention. Why, for example, has uptake of EO data been so tardy? Has the potential of EO data been overestimated? Are there problems with the way the data are made available to users? Are users unaware of the potential which the data offer? Or are users in some way deterred from using the data, for example because of their cost or technical complexity? In the light of these questions, we might further ask whether the huge investment in EO systems has been worthwhile, and how this investment should be directed in the future?

The answers to all these questions also have wider relevance. Understanding what determines the uptake of EO data may also help us to understand how other information technologies may evolve or best be developed as a basis for policy support. It is these questions that we address in this study.

Table 1 Examples of EO satellites currently operational over Europe

a) Optical Data

Data Type	*Mission*	*Pan Resolution*	*MS Resolution (m)*	*Swath Width (km)*
High-Resolution	QuickBird (launch 10/01)	1 m	4	22
	Ikonos	1 m	4	11
	KVR 1000 (Kosmos)	2-3 m	-	40
	Eros	1.8m	-	12
	Spot	-	20	80
Mid-Resolution	LANDSAT 7 ETM+	15 m	30-60	185
	LANDSAT 4 & 5 TM	-	30-120	185
	JERS-1 OPS	-	18	75
	IRS-1C PAN	5.8 m	-	71
	IRS-1C LISS III	-	23 and 70	142
	TK-350 (Kosmos)	10 m	-	200
Low-Resolution	LANDSAT 1 - 5 MSS	-	80	185
	RESURS-O1	-	170-600	600
	IRS-1C WIFS	-	188	810
	SeaWiFS	-	1100	2801
	MODIS	-	1000	
	TIROS/ AVHRR (NOAA)	-	1000	3000
	Meteosat	2500 m	5000	1/3 earth

b) Radar Data

Mission	*Band*	*Frequency*	*Polarisation*	*Incidence Angle*	*Resolution (m)*	*Swath Width (km)*
ERS-1/2 (SAR)	C-Band	5.3 GHz	VV	23° at mid-swath	30	100
Radarsat	C-Band	5.3 GHz	HH	10° - 59°	8-100	50-500
JERS-1 SAR	L-Band	1.275 GHz	HH	35° off nadir	18	75

4. Determinants of EO data usage

4.1 The EO data stream

EO data comprise radiometric data about the surface (and near subsurface) of the Earth, obtained through the use of satellite or airborne sensors. As such, these data take many forms. They may be generated by different sensors, borne on different carriers, and operating under a wide range of different conditions. Between their initial generation and ultimate use – i.e. as they pass through the 'EO data stream' – they also undergo many different processes and transformations, including:

- *geo-rectification* to match them to a defined geography or model grid;
- *formatting* to translate them into a usable data structure;
- *classification* to convert them into interpretable measurement scales;
- *modelling* and *analysis* to derive secondary information; and
- *linkage* to other data sets.

Many different EO data products may therefore be developed, more or less customised to the needs of specific users. Many different individuals and organisations may also be involved within the process, including:

- *source data providers* – the EO organisations responsible for collecting and initial processing of the data;
- *primary data analysts* – normally technical people, with expertise in the specific data and ways of manipulating them (e.g. remote sensing experts);
- *secondary data analysts* – often non-experts in terms of EO data, but with other relevant specialist expertise (e.g. GIS experts, statisticians); and
- *end users* – such as decision-makers or others who have relatively limited understanding of the data, but require the information that can be extracted from the data to help them in their work.

These various groups of actors within the EO data stream are not single and homogenous communities. Instead, they vary in both identity and character from one application sector to another. This is especially true of the end users, who often represent markedly different user communities, with different information needs, different technical skills, and working in different administrative and scientific environments. These differences, in turn, tend to create the needs for specific levels and types of analytical support; as a result, they tend to draw upon rather different groups of data analysts. For these reasons, the character of the EO data stream, and of its key actors, tends to vary between different areas of application – including those considered here. Table 2 presents a generalised summary of the end user communities, and their implications for the EO data stream, in the three application areas investigated here.

4.2 The EO data decision process

With the recent explosion of information availability – and the increasing demand for information to support policy – growing attention has been given to the process of data selection and utilisation in recent years. Much of this has been directed at the technologies of data search and retrieval (e.g. Ambite *et al.* 2001). Theoretical advances have also come from the general field of decision analysis (e.g. von Winterfeldt and Edwards 1986), marketing (e.g. Casimir 1999), risk management (e.g. Lin *et al.* 1999), project development (Riis 1999) and spatial data modelling (e.g. de Bruin *et al.* 2001). Many of these, however, have focused on a relatively narrow aspect of the data selection process – in particular on the effects of uncertainty and error in the data on optimum selection of data sources. These see successful information strategies as those which maximise benefits (or benefit-cost ratios) in the presence of uncertainty. While many studies have considered the costs or benefits in essentially monetary or economic terms (Casimir 1999, Forsyth 1997), Riis (1999) defines the 'value of information' in terms of

Table 2. Characteristics of end users in the three application sectors, and their implications for EO data needs

	Land resources	Air/climate	Oceans/lakes
Main users	Local authorities, statutory countryside agencies, research groups, utility companies, emergency services, insurance companies	Local, regional and national authorities, international agencies, climate, weather forecasting and air pollution monitoring research groups	Local, regional and national authorities, international agencies, climate forecasting, disaster management groups. Environmental consultants. Ship and military operators.
Number or (potential) users	Large	Medium	Medium
Size of user organisations	Small-medium	Variable from small to large	Medium-large
Types of application	Very varied, including resource mapping and management, policy compliance, regional planning, environmental impact assessment, state of environment reporting/auditing, indicator development and reporting, emergency preparedness and risk assessment, public awareness, education	Well focused on air quality, climate and meteorology	Varied application but focused on a small range of data products. Environmental impact, state of environment reporting (change), risk assessment, fisheries, ship routing, pollution management, mixing zone studies, coastal erosion, carbon cycle budgets.
Scale of operation	Mainly local-national	From local and regional to global	Broad – local to oceanic-global
Types of information required	Map-based, multivariate (classified) – e.g. on land cover types	Both map-based, multivariate and parameter-based, univariate data	Multivariate and univariate, parameter-based data.
Availability of alternative data sources	Extensive and well-established	Broad and well-established	Extensive but not globally established. Expensive.
Level of EO data experience	Varied but often limited	Varied but often limited	Growing.
Implications for EO data needs	Need for customised, high resolution, pre-processed data which can be linked to a wide range of pre-existing data sets	Need for high resolution and multi-temporal, pre-processed data, which can discriminate between subtle and complex features	Need for data products to known precision at multi-time/space scales.

the potential 'reward or risk' of success or failure of a project, while de Bruin *et al.* (2001) apply the concept of 'expected value of control' – i.e. the net value (positive or negative) of being able to control how an uncertainty within any decision is resolved. Increasingly, Bayesian statistics and Monte Carlo methods are used to model the decision process, and provide a means of seeking optimum solutions.

The assessment of these various costs and benefits can usefully be presented as a 'decision-tree'. de Bruin *et al.* (2001) and Riis (1999), for example, both present examples of decision-trees using formal, statistical assessment methods. At each branch in the tree, the potential user makes choices between different data sources, or different options, based on their assessment of the expected net value of the information. In practice, however, the choice to use, or not to use, EO data is rarely likely to be made by such explicit assessment methods. Instead, decision-making about data sources tends to be a far more contingent process – dependent on the characteristics of both the data themselves and the user, but also influenced by short-term considerations of convenience and feasibility, as well as by preference and chance. The data decision process is thus more complex, more inter-dependent, and more entangled than these simple decision trees imply. Indeed, in many ways, the selection of data can be seen as analogous to innovation and adoption strategies. Theories of these processes (e.g. Hagerstrand 1967) recognise four main links within the chain leading to adoption. In relation to EO data these are that:

1. the potential users must recognise an unfulfilled need for information;
2. they must be aware of the existence of EO data as a potential data source;
3. the EO data must be deemed fit for the intended purpose;
4. the potential users must be able to obtain the data in an appropriate form, within an appropriate timescale and at an appropriate cost.

Failure of any one of these links is likely to preclude the use of EO data.

Figure 1 presents a general model of the EO data decision process, based on this rationale. As this shows, each of these links involves a wide range of considerations. On the demand side, these relate to the needs and capabilities of the user; on the supply side they reflect the characteristics of the data and the supply mechanism. Demand-side considerations are determined ultimately by two main factors – the roles and responsibilities of the organisation, and the availability of other (alternative or complementary) data sets. Supply-side considerations are driven largely by the initial purpose of the EO data (and hence the satellite and sensor characteristics) and by the marketing and dissemination strategies of the data suppliers.

As Figure 1 also implies, supply-side and demand-side factors do not operate in isolation, but converge at each decision point. Thus the level of product awareness of the users depends not just on their degree of involvement in the EO community, but also on the quality and availability of 'discovery metadata' (information about the EO data that can help users to learn about their existence and make a preliminary assessment of their utility). The perceived fitness for purpose of the EO data, in turn, depends not only on the inherent properties of the EO data, but on how well these meet the information needs of the users. Equally, it is the costs and complexity of the EO data products and the data acquisition process, set against the users' financial resources and expertise, that determine the capability of the users to obtain and apply the data for that purpose. Moreover, the

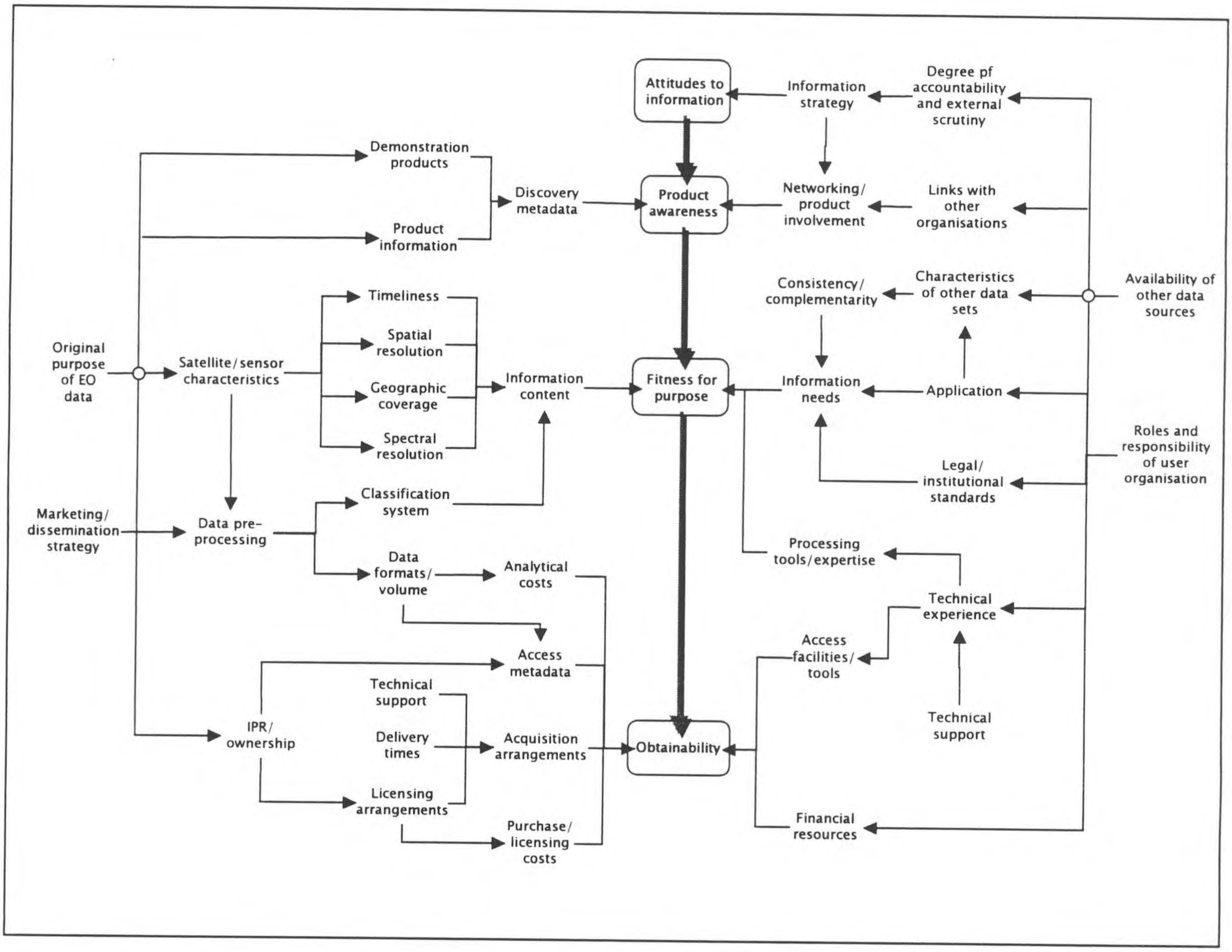

Figure 1. A model of key factors influencing EO data selection and use

choices inherent in this process are not made about EO data in isolation, but involve comparisons with alternative data sources, and judgements alongside complementary data sources.

The contingent nature of the data decision process (e.g. its dependence on the needs of specific users and specific applications) means that the model presented in Figure 1 will not fit every circumstance. Different factors will operate in different situations, and the balance between them will also change from case to case. It does, however, provide a framework within which to consider obstacles to EO data usage. In the following sections, it is therefore used to compare and contrast experiences in the three thematic areas covered by this study: land resources, air and climate, and oceans and large lakes.

5. Land resources

5.1 EO data users in the land resource sector

The potential user community of EO data in the area of land resources is extremely diverse. The traditional division into local, regional, national and international scales does not work very effectively, because of the often shared interests across these different levels. But the fulcrum lies at the national scale: above this, EO data often feed into international initiatives; below this, national data and national regulations often provide the framework within which more local data must nest and in which more local actors (who are ultimately responsible for implementing EU and national policies) must work.

At the national scale, looking upward, EO data are already relatively well established, in part, perhaps, because many of these users have few alternative data sources available to them. In particular, at this scale, EO data provide the most extensive and most consistent data sources available. Examples of the application include initiatives on habitat protection (e.g. for Natura 2000), resource assessment and management (e.g. for forest yield prediction in the USA), for monitoring of policy compliance (e.g. the MARS project in the EU), for modelling of the impacts of climate change (e.g. work by IIASA), analysis and prediction of food aid requirements (e.g. the work in Africa of US-AID) and modelling of vector borne diseases (e.g. the MARA programme in Africa). In the EU, one of the most successful and widely used EO products in this context is the CORINE land cover map, which not only provides pan-European data on land cover but also acts as a co-ordinating framework within which to compile national land cover data sets. Nevertheless, the EO user community at this level is inherently small, and in the EU probably amounts to no more than a hundred or so active groups.

At national level, looking downwards, the range of potential users is much greater. They include mapping agencies, local authorities, countryside organisations, national park authorities, archaeological and heritage organisations, public utilities, the emergency services, insurance companies, tourism and travel agencies, and farmers and land managers. Within these organisations and areas of interest, EO data can provide information not just on land cover and land use, but also on the distribution and quality of specific natural and semi-natural habitats; on soil types, soil erosion, soil quality and soil pollution; on crop yields and management; on the built environment, associated infrastructure and the extent and quality of the housing stock; and on a wide diversity of other environmental and social indicators.

It is this latter group of users that has been most widely represented in the 4th Framework Programmes. The character of these users also poses distinct challenges to the use of EO data. As Table 2 indicates, they are characterised by:

their large number;

their relatively small organisational size;

- their diversity of interests;

- their access to, and use of, a wide range of alternative data sources.

Many of these organisations (e.g. local authorities and emergency services) are also inherently reactive in operation. Their data needs are thus often temporary and difficult to predict. Even if the type of data required can be foreseen, exactly where they will be needed cannot easily be predicted, and may depend on exogenous events such as development applications, industrial accidents or chance discoveries to initiate data collection and use. Often, these organisations also work within a relatively tightly controlled and regulated framework, within which data needs and data typologies are predefined. In these cases data are needed not just to manage and support day-to-day activities, but also to report upwards and to demonstrate compliance with national or other policy.

Most applications are also concerned not so much with single parameters or environmental indicators, but higher levels of classification, for example on land cover types, habitats, soil types, rock types or landscapes. Classification into these synoptic and often pre-defined categories is therefore an important part of EO data use. Related to this is the spatial and structural complexity of land resource features, especially in the EU. This means that patch sizes of many features, for example, are small; many occur as complex mosaics; and many are transitional in character. Dealing with these complexities is not unique to EO data, but it does pose specific challenges.

Without doubt these various use characteristics have acted to limit the uptake and application of EO data within the land resource community, and are reflected in the experiences of projects both in the 4th Framework Programme and elsewhere.

5.2 Data sources

As part of this study, information was gathered from 26 4th and 5th Framework Programme projects (Annex 1). Final reports from 16 of these were read and reviewed in detail, selected to provide a wide range of interests, applications and user types. From these, 11 projects were chosen for more detailed follow-up, including face-to-face or telephone interviews with project leaders and, in so far as they were available, representatives of user partners. Subsequently, representatives of 13 projects also took part in a workshop organised by the Research Directorate in Brussels (11-12 September 2001).

In addition, information was gathered through three cognate studies with which the author was involved:

1. an investigation of information needs and strategies in the national parks of England and Wales (Briggs *et al.* 1996);

2. a review of user needs and experiences in relation to the national Countryside Survey 2000 project in Great Britain (Haines Young *et al.* 2001);

3. a PhD thesis on information sources and needs for countryside management in Great Britain supervised by the author (Tantram 2001).

5.3 Obstacles to EO data usage in the land resource sector

5.3.1 Attitudes to information

Attitudes to information amongst the user community in the area of land resources vary greatly. Though most of these organisations operate in an environment that implies the need for information – for example, as a basis for priority setting, for day-to-day management, to monitor performance, to communicate with the public – and many make routine use of data, some still seem to eschew the use of the available data. In a study of a range of organisations concerned with countryside and habitat management in the UK, for example, Tantram (2001) noted:

> "In many cases, decisions on policy and management do not appear to be information-driven.... In many cases, objective setting and policy formulation were neither a response to, nor based on, information, but were apparently a product largely of historical precedent intermixed with 'professional' judgement.

Attitudes to data in these organisations seem to be based less on explicit evaluation of data needs and the available data sources, than on considerations of internal power, convenience, and professional pride. EO data, perhaps more than most, suffer from these attitudes, since by their very nature they are alien to the experience and training of many professionals. They are thus seen as a threat to this specialist expertise.

Attitudes to data are also affected by the regulatory environment. On the one hand, the existence of policy and regulation acts as a major spur to information use, including EO data. On the other hand, users tend to trust other forms of data (e.g. field-based reporting) more than they do EO data, perhaps because they have greater control over their collection and interpretation. In many cases, also, EO data are seen as difficult to verify, and have not yet been accepted as valid sources of information by the regulatory or overseeing bodies – for example in the way that national topographic data or field-based ecological data are for planning processes. This also inhibits the ability of statutory bodies to use EO data in their core business. As a result, in a well-regulated environment, where policies are well-enforced, EO data tend not to be used, for reliable data come through formal registration, inspection and reporting procedures. Conversely, where regulatory systems are not well established, EO data are seen to provide a valuable means of checking on compliance. Opportunities to use EO data in relation to development planning in the UK and Denmark are therefore seen as limited; in Italy and Greece, however, their potential for monitoring unplanned housing and tourism development is considerable (PLAINS, ISOLE). Partly as a result of these factors, the use of EO data is still in its infancy in many of these organisations: Tantram (2001) thus found that levels of usage of EO data in the statutory countryside agencies were small compared to either field-based data and aerial photography.

5.3.2 Users' awareness and expectations

Generalisations about user awareness of, and perceptions about, EO data cannot easily be made in the land resource sector, because of the diversity of this user community. Because of the relatively limited use of EO data in this sector, perceptions are also often based on limited first-hand experience. Significantly, however, Tantram (2001) found that perceived strengths of land cover data (i.e. EO and related aerial photographic data) in the statutory countryside agencies greatly exceeded their perceived weaknesses, and that stronger views were held about these data than most other types of data.

Where EO data have been used, there is also some tendency for biases to develop in perceptions and expectations. In particular, users seem to expect higher standards of accuracy in relation to EO data, because of different reporting cultures. While it is common practice, for example, to report levels of classification success for EO data, similar performance measures are relatively rarely quoted for field-based data. This leads to a serious misconception about the relative accuracies of EO and other types of land data. Typically, for example, EO users report classification accuracies in the order of 80%; to the uninitiated this might seem rather poor, but in reality it probably matches (or even exceeds) that achieved by many field-based surveys in which sampling errors and observer bias may be present, though unrecorded. In the UK, for example, Cherrill and McClean (1999) found considerable categorical variations due to observer error for the field-based Phase 1 surveys used to classify vegetation. Work conducted for the BSBI monitoring scheme found bias in botanical surveys associated with the recording behaviour of botanists and systematic error related to recording methods. These biases did not necessarily affect the overall validity of survey results, but were highly relevant when the data were combined with data from other sources (Rich and Woodruff 1992). Clearly, errors thus exist in traditional ecological field survey, but the description and quantification of these errors is not common and is rarely explicit. This may lead to a spurious concept of survey accuracy amongst users – and an inappropriately negative view of EO data.

One of the most important factors in this context is the availability of alternative data sources on land resources. As a result, many users do not have to rely on EO data; many, indeed, have already established use of other data types (e.g. field survey, aerial photography). This has various implications. In many cases it means that users have preconceived ideas about the required performance from EO data: they need to match, or in many cases surpass, the performance of the data currently used (surpass, because there is often a considerable cost – for example in converting archive data, in purchasing new software an in training staff – in changing from one data source to another). In other cases, it seems that users may only turn to EO data as a last resort: to resolve problems that other, more traditional data sets have not yet reached – for example, identification and mapping of detailed habitats/landscape features, or tourist impacts (e.g. footpath erosion, ski-piste condition). This means that EO data are in many cases being given some of the most challenging problems, for which they are not necessarily adapted (PLAINS, SNOW-TOOLS).

Another important factor in relation to user awareness and expectations – and ultimately their ability to access and use EO data – is the level of expertise of users. The EO field is relatively young, and as yet expertise in EO methods and technology has not spread widely into user organisations. As a result, understanding of the potential of EO data, and their limits, is not well established, nor is experience in how to analyse and interpret the data. Multi-spectral data provide especially difficult challenges for non-experts in this respect, so that user organisations are likely to need their own in-house specialists if they are to make effective use of EO data (e.g. APERTURE). This undoubtedly acts as a continuing constraint on the adoption of EO data. As the ENFORMA project noted, however, 'results from the test districts, as well as from other districts where satellite data is being used, show that the basic experiences quickly can become sufficient'.

Whether or not this experience is sufficient to allow users to maintain their use of EO data beyond the limits of the development project is nevertheless far less certain. The problems are twofold. First, without the continuing guidance and support of EO experts, users may find that they lack the time, resources or motivation to pursue their development and use. Second – and often more crucially – the number of staff with EO experience in many user organisations remains small. When these staff leave, as they often do (for turnover of specialist staff in the land resource area seems to be relatively high), the EO experience goes with them (e.g. PLAINS). Significantly, relatively few of the specific users involved in the 4th FP projects examined here could be contacted for this reason.

5.3.3 Fitness-for-purpose

The fitness-for-purpose of EO data in the land resource sector is influenced by a number of factors, including the spatial resolution and scale of the available data, the timeliness of the data and availability of multi-temporal data, the classification systems used and their compatibility with (and ease of linkage to) other data sets.

Spatial resolution and scale

Spatial resolution is an especially important issue in the land resource area, for high resolutions are often demanded by users. In some cases – with use of high resolution EO data, with careful analysis ('cautious handling of the "thresh-hold" button') and where relatively clearly-defined land cover types are to be defined – these demands can be met satisfactorily. In the ENFORMA project, for example, a spatial resolution of 30-metres was found to be suitable in locating clear-cut forest patches, in detecting broad-leaved tree growth, and estimating the actual forest area. In many cases, however, users are concerned with small, complex and ill-defined land features, and in these cases the challenge to the EO data is more severe.

Problems are especially acute in relation to habitat data, for across much of the EU habitats occur as a complex mosaic of often small and remnant habitat patches, set within a relatively intensively used agricultural landscape. The modal area of saltmarsh habitats in the UK, for example, is only 3 ha; that of lowland heathland only 0.1ha (Tantram 2001). Such areas imply the need for a spatial resolution of no worse than 10 metres for detailed mapping purposes. These habitats are also likely to vary considerably in terms of structure, composition and state depending on local environmental conditions (e.g. soil type, drainage, slope angle, aspect) and land use (both current and historical). In addition, the pressures acting on any habitat patch are likely to vary depending on local circumstances, such as the type or intensity of land use in the surrounding area. The resilience of most habitat patches to these pressures is also dependent to a large extent upon their specific characteristics (e.g. size, shape) and their connectivity to other habitats that might act as sources for key species. Furthermore, many management and policy decisions are focused on questions of habitat change rather than stock or quality at a single point in time. Data on change are especially vulnerable to problems of scale and resolution, since change is often small (relative to the initial stock or state of the habitat) and subtle, and because measurement of change usually depends on the ability to compare data sets from different survey periods: the errors in the change data are thus a product of the errors in the two source data sets.

As a consequence, and not surprisingly, EO data are often seen to be wanting. In the PLAINS project, for example, interests included mapping and monitoring of footpath erosion and mapping of rare habitats, neither of which could readily be met by the use of the affordable EO data. In the ENFORMA project, where the aim was to map detailed forest management features, a spatial resolution of about 1 metre was required: against this EO data could not match the performance of traditional high resolution aerial photography or field survey. Problems such as these become especially acute in areas of complex terrain, both because patch sizes tend to be smaller and because of the added difficulties created by surface slope and shadows. Because of these, use of EO data to map detailed surface features in the ASTERIMOS and APERTURE projects was less successful in the Greek study area than in flatter Spanish study area. Similar problems were also reported by the PRIMAVERA study, where an added challenge was the use of local stone for building material, making accurate discrimination between buildings and bare rock difficult. The CALIS project concluded that EO data provided sufficient spatial resolution for analysis of micro-meteorological features (frost, drought, heat excess) at the scale of administrative regions but were too coarse for individual, field-by-field analysis.

These problems of spatial resolution are not absolute or unavoidable; in part they are a product of the (often enforced) choice of EO data made in the projects. High resolution EO data are becoming available (e.g. Ikonos) but delays in the launch of these satellites, difficulties in obtaining the data, the often high cost of high resolution data and the significant problems involved in storage and processing of the high volumes of data involved have deterred their use in the 4th FP projects investigated here (see below). As these data become more available, if access arrangements improve and if costs of data acquisition are reduced, constraints of spatial resolution may be relaxed. Advances in methods for EO data analysis, such as the image segmentation techniques used in the UK Land Cover Map 2000 (Groom *et al.* 1996), also offer enhanced capability for detailed feature discrimination and mapping.

Timeliness and multi-temporality

Problems of temporal resolution and the availability of suitable time series data (multi-temporality) are severe in many land resource applications. Multi-temporal data are often needed for the accurate classification of land cover, and are even more important for monitoring change in land resources. A major issue in this context, oft repeated especially in more northern and western areas, is cloud cover. In the ENFORMA project, for example, 6 months of data collection were necessary to provide a whole cloud free coverage of Sweden (900 scenes) in 1999. In the CS2000 project in the UK, initial plans to use Landsat imagery only from a single year (1998) had to be revised because of problems of cloud cover, and the survey period extended for a further year. Even then, data were lacking for ca. 3% of the land area of Great Britain, requiring the patching in of scenes from earlier years.

Where real-time data are needed – e.g. for monitoring of pollution events, forest fires or volcanic activity – the long repeat intervals for many satellites (especially those providing higher resolution data) also limits the utility of the available EO data (PRIMAVERA). Problems similarly occur due to the short – and diminishing – data archive periods (e.g. SPOT, DMSP, NOAA) which create difficulties in gaining access to historic data (ENFORMA, MANTLE). This is especially important for many land resource applications, where long series of data may be necessary to detect change or provide accurate measures of trends.

Sensor or transmission failures also continue to be problems in terms of providing multi-temporal EO data. ERS 1, for example, is no longer operational and ERS2 is on a 35 day orbit, which is insufficient for many applications. Equally the variable gain sensor on the DMSP-OLS has been misaligned for some months, preventing the collection of fine resolution night-time data. In the case of the MANTLE project, this created the need to adjust the survey period, and meant that contemporaneous ground survey could not be undertaken. This implies the need for more satellites of the same type to provide greater choice of data and backup for data failures.

In the long term, additionally, changes in satellite sensors, and more especially developments in classification systems and analytical methods, mean that comparisons of temporal sequences are often difficult. This is especially problematic for routine monitoring of long-term habitat or land cover change over wide (e.g. national or EU) areas: the cost and complexity of analysis, and the relatively slow rates of change, mean that repeat intervals for such surveys are often long – typically in the order of 10 years. The dynamic nature of EO science means that substantial technological developments can occur within timescales of this magnitude. The choice may therefore be either to use out-dated and sub-optimal methods in order to ensure consistency with past surveys, or to improve the survey methods but lose direct comparability with previous data. The latter approach has been taken in producing the Land Cover Map 2000, as part of the UK Countryside Survey: as a result, changes compared to the previous survey (Countryside Survey 1990) cannot easily be assessed.

Classification systems

Classification issues possibly present one of the most intractable problems in relation to EO data in the land resource sector. As noted earlier, classification is inherent in many land resource applications, and in a large percentage of cases these classifications are pre-defined: either by legislation (e.g. the EU Habitats Directive) or by previous practice (e.g. by national soil classifications or pre-existing vegetation classifications). Data extracted from EO sources thus have to be fitted to these prior classifications.

The problem is probably most acute in relation to habitat and land cover data, for here many different policy- and practice-related classifications exist, few of which have been established on the basis of EO data. In the UK, for example, as many as six commonly used vegetation classifications are in common use – NVC, Phase1, BAP, ITE land classes, CS Reporting classes, Habitats Directive – only the last of which is rooted in EO data. The Phase 1 habitat classification, in contrast, uses a mixture of land cover and land use characteristics for categorical definition, while the National Vegetation Classification (NVC), depends upon detailed floristic and frequency occurrence data recorded from field survey. The reality, of course, is more complex than any of these classifications can portray: rather than existing as discrete, monothetic features, most habitats occur as composite, transitional and highly variable entities, which all but defy classification. Not surprisingly, therefore, matching these different classifications is extremely difficult, and many-to-many relationships often occur when attempts are made to relate classifications developed on the basis of EO data to those derived from policy or other sources.

Tantram (2001) gives the following example, in relation to the field-based classification used in the Countryside Survey 1990 (CS90) and the Landsat-derived Land Cover Map of Great Britain 1990 (LCMGB):

> "Taking the example of woodland, the CS90 category 'broadleaved woodland' relates to both 'deciduous' and 'coniferous' categories in LCMGB and the CS90 category 'conifer woodland' includes elements of both 'coniferous' and 'marsh/rough grass' categories in LCMGB. The marsh/rough grass category is included because the satellite signature for young coniferous plantations is influenced by the land cover type the plantation is on, before canopy closure, and therefore cannot be distinguished within a generalised classification. By contrast, a field-based survey can distinguish such types because further structural, compositional and land use characteristics can be used to define class membership. Therefore, even if the signatures produced from the original Thematic Mapper data are consistently assigned according to their spectral signature, there can still be mismatches between field- and land cover-based data. In practice, this detection-based leakage into other reporting categories will also be dependent, in some cases, upon context. The adjacent land cover may affect the signature of detection and other scattered features may contaminate the overall spectral signature, giving rise to mismatches in classification."

In many cases, therefore, EO data provide only partial discrimination of the habitat types of interest. In the MANHUMA study, for example, they were found to give reliable detection for only a few wetland classes, and to be especially poor at detecting forested and scrub-shrub wetlands. These problems are especially severe where EO data are being applied in areas which have been previously neglected (e.g. because of their remoteness) – areas for which, in many ways, EO data are especially important. In these cases, little may be known about the discriminatory features of different habitat types, and suitable field-based information by which to validate or calibrate the EO data may not be available. There is thus a need for more sharing of experience between studies and users, in order to provide better guidance on how to interpret EO data in different areas and environments – i.e. on 'how to get the most out of data sets in different regions such as mountainous, wetland, dry land areas or different climate zones' (PRIMAVERA).

Linkage to other data sets

In terms of land cover data especially, the ability to link EO to other data is essential. Linkage to topographic data is an almost universal requirement, in order to provide a means of georeferencing and integration with other, map-based data. In many applications, however, there is also a need to link the EO data to field-based survey data, especially where the interest is in the 'quality' as opposed to 'stock' of land resources. Another important motive for data linkage – and ostensibly one of the main functions of EO data – is to provide a means of stratification that can allow sample data from field surveys to be extrapolated across the wider landscape.

Problems of data linkage occur for a number of reasons, especially inconsistencies between the classification systems (see above). The ambiguities (overlaps and underlaps) between the different classification systems exert a major limitation on the ability to use EO data as a basis for stratification. Backwards compatibility of EO data is also problematic in some cases, because of changes in the processing techniques and – to a lesser extent – the EO technology, as noted above. This makes it difficult – or in some cases impossible – to derive reliable change statistics.

Effective linkage, and therefore interpretation and application, of EO data is also constrained in some instances by inadequacies in, or the lack of, the relevant exogenous data sets (ISLA, PRIMAVERA). A particularly common problem is the presence of inconsistencies and gaps in the key fields needed to match data sets, such as site references, co-ordinates or names (ISLA) – a problem which, it may be noted, is not confined to linkage with EO data, but equally affects almost any spatial matching of data sets (e.g. Briggs *et al.* 2001).

A further problem (certainly not limited to EO data) is the wide variety of geographic zone systems used to map and report data on land resources. Individual applications might, for example, involve the use of data variously described in terms of points (e.g. soil sample data or vegetation quadrats), irregular areas (soil types, habitat types, farm holdings, administrative areas etc), and regular grids (e.g. modelled data on acid deposition). Integrating all these data in a consistent way (e.g. to examine potential impacts of acid deposition on sensitive habitats) requires the ability to transform data between these different zone systems. In this context, however, EO data would seem to have a specific advantage, which is perhaps not yet being tapped. By providing high resolution data, over wide geographic areas, EO offers the capability for data stratification and interpolation, as a basis for spatial transformation and integration. Uses of EO data for this purpose were illustrated in a recent Eurostat-funded study on the use of GIS techniques for spatial staitistical data (Huntings plc and University College Northampton 1999).

5.3.4 Obtainability

Difficulties in obtaining EO data – within the prevailing time and resource constraints – are cited more often than any other issue as an obstacle to data usage in the land resource sector. Important problems include the inadequacies of the access arrangements, data formats and costs.

Access arrangements

Problems of access to EO data dog many potential users in the land resource sector. In part, this derives from the relative inexperience of users: in few of the 4th FP studies reviewed here did users have prior experience of EO data, and relatively rarely were they directly involved in data selection and acquisition. (Partly, also, this may reflect the way in which FP projects are developed and designed: the requirement to develop closely justified, well-founded proposals, often in a relatively short time, tends to preclude the involvement of users in extensive debate about alternative data sources. Instead, partners may have to accept a ready-made project proposal and study protocol.) More generally, however, it is due to the perceived and actual complexities of access procedures. In many studies, even where experienced users have been involved, major problems and delays are often encountered in acquiring EO data, especially where these involve new or non-standard queries.

In the MANTLE project, for example, it took more than 4 months to acquire EU coverage of DMSP-OLS data, despite prior confirmation by the data providers that they were available. Reasons for the delay included staff shortages and computer problems in the provider's institution. Delays of over 4 months were also reported in obtaining the high resolution KVR1000 data in the ASTERIMOS and APERTURE projects, and when obtained the data were of poor quality due to scratches on the film. Whilst Web-based portals should provide the answer to these problems, the Web presence of EO data providers is still seen as very primitive and user unfriendly. For example, it is reported to take six weeks or more to acquire Landsat data from Infoterra via the Web. The large number of different Web browsers also makes searching for, and evaluation of, EO data sources difficult: one solution would be the availability of a single, powerful and reliable tool that could search all the available portals.

Copyright is also a major problem with some EO data, especially Ikonos and the US data sources: one respondent noted that IPR constraints on the use of US data make operational use almost impossible.

Metadata

Metadata are likewise widely criticised. Amongst the more experienced, there is a tendency to dismiss these as irrelevant: the attitude of one respondent was that if you needed to use the metadata you were probably already lost! Where data sets need to be merged and linked (e.g. in a GIS), where they need to be transformed and processed in some way (e.g. to convert them to different projections), and above all where pre-processed data are being used, reliable and understandable metadata are paramount. Errors in these metadata can then be costly, as clearly demonstrated (in a different context) by the experience of integrating the soil map of Europe into the CORINE information system (Briggs *et al.* 1989). Yet standards for metadata are weak, and often not applied. One interviewee, for example, noted that the CEO metadata protocol is widely promoted, yet 48 out of 50 members do not follow these protocols in their own data headers! In the case of Ikonos, users suspect that gaps in metadata sets are designed to 'hide' problems with sensor. Particular problems also tend to occur in relation to cloud cover and image quality: metadata do not always provide reliable information on the extent to which images are obscured by clouds, scratches or other data drop-outs, with the result that users may waste time and resources obtaining coverage which is then unusable. The report of the EUROP-LIFELINES study, for example, gives the following cautionary tale:

> "In this project... we faced large discrepancies between schedule and reality. It was for instance planned... to use the following pairs of Landsat TM for the processing as offered by the data provider: Date 1 - 20.08.92 and 29.08.92; date 2.1 - 20.06.84 and 27.06.84.... Date 2.1 could not be used since the satellite data quality was distort(ed) for more than 50%.... Our first alternative for Date 2.2 again could not be used since we faced unacceptable cloud coverage plus data dropouts and distortions even though the data provider's metadata indicated cloud coverage 0%! A second alternative of data finally

was used although there were more clouds than desired..... These satellite images were also full of data dropouts and distortions which caused extra work to fix the data sets. "

These inadequacies in the available metadata are all the more severe because of the lack of centralisation of both the EO data and the ancillary data needed to aid their interpretation and use. In the ISLA study, for example, difficulties were experienced in Greece because many of the crucial data were available (if at all) only in analogue form, so could not easily be searched or captured, and tended to be scattered across a number of different organisation, no-one knowing exactly what data were available or where.

Data formats

Data formats are significant obstacles to the use of EO data, especially where data undergo numerous stages of processing and analysis. In these cases, the range of different data formats and headers generated by the wide range of software used can make it nearly impossible to combine data sets. One interviewee commented that, as a result, many of the impressive 'screenshots' included in reports are often made using glue and scissors rather than by computerised integration and overlay of the various data sets!

Problems are also most acute with new satellites, because of the need to adapt software and geocoding processes to the new formats. These difficulties are exacerbated when the metadata provided lack relevant details (see above); in these cases, trial-and-error methods may have to be used to convert and integrate data sets (e.g. ENFORMA).

The often inconsistent choices of data formats made by data providers similarly cause difficulties. NASA, for example, is now using .hdf, while Spot uses .bil data formats: .hdf, especially, is not a commercial format, and this creates problems for reading the data into conventional software – commercial companies, especially, cannot afford to waste time and money to experiment with different and non-standard formats until they are able to read them into their software packages.

Cost

Costs are a major issue in selecting EO data in the land resource area, for a number of reasons: many of the user organisations are relatively small and run on low budgets; many applications are unique, making economies of scale (e.g. by re-use or mass purchase of data difficult); and the area is relatively data-rich, so that EO data have to compete with a range of other data sources. For many users this influences not only whether or not to use EO data, but also which EO sources to use. In some cases, the consequence is that users adopt cheaper sources which may not be optimal for the application. Because of its cost advantage, Landsat imagery is often used; higher resolution satellite images, or specialist data products such as SPOT Thema, are as expensive as airborne material, so where more high resolution data are needed, aerial images are often preferred (ENFORMA, PLAINS).

In other data fields, such as topographic data, cost constraints have often been addressed by facilities for consortium purchase (e.g. by different departments/authorities or key groups of users). In the case of EO data, the market has not yet developed to this extent: within any organisation the number of people aware of EO data is often small, and there is little commonality of perceived need; data providers have also not yet taken substantial strides to establish the types of service level agreement operated, for example, by some national geographical institutes. Indeed, the concern of at least one user was that monopolisation of data provision in Europe (e.g. through Infoterra/Astrium) will lead to the adoption of even less competitive pricing policies for EO data, while providers of aerial photography data may be persuaded to offer 'dumping' prices for their data as competition from EO data develops.

The structure and funding arrangements of EU FP projects are also widely seen as important constraints in this context (PLAINS, ISLA, CALIS, ENFORMA, MANHUMA). The research-focused and time-bound nature of these projects, for example, tends to leave a resource vacuum at the end of the project, when the data products should, ideally, be further developed and operationalised by the end users. In practice, lack of accessible resources within the user organisations, accompanied by suspicion about new and untried techniques, often mean that users have little opportunity to advance the technology. The need would seem to be for some form of bridging or extension funding that can be used to establish the use of the EO technologies and data products in the user organisations, and thence to disseminate the knowledge more widely within the user community.

5.3.5 Implications

EO data have clearly had an important impact in the area of land resources. While this effect has perhaps been greatest in relation to broad-scale applications, the use of EO data at the regional and local scale is also increasing. An enormous, latent potential nevertheless remains to be exploited.

Table 3 summarises the key obstacles to the use of EO data identified by, or encountered within, the land resource projects reviewed in this study. As this shows, experiences vary from one project to another, reflecting not only the different topics covered, but also the different geographic areas and users involved. Direct comparisons between projects or issues cannot be made, because no allowance is included in this table for the *degree* of obstacle that each of these might represent. Nevertheless, a number of issues are repeatedly noted, including the problems of metadata and access tools, spatial resolution, multi-temporality, costs and FP funding arrangements.

Several implications arise from these findings. One derives from the diverse nature of this sector. Because of this, the demand for EO data is also varied and difficult to satisfy. Whilst some core, basic data products are likely to be needed, at least by large groups within this sector (e.g. data on land cover, soil moisture, topography), much of the demand is for customised data products, targeted at individual applications and needs. In this sector, therefore, perhaps more than most, the service community has an especially important role to play, adapting and customising EO data to meet users' needs. There is also likely to be a particular need for analysis tools, that can help users process and adapt their own data according to need. In any event, both the service sector and the source data providers need to understand this market well, if they are to serve it effectively. This implies much closer communication between all three sets of actors – data providers, service providers and users – than has so far been achieved. A wide range of demonstration and tutorial products is also needed to extend awareness about these various tools, data products and services across this varied market. FP projects have an important role to play in all these areas – namely to help develop the generic data products, the analysis tools and the demonstration materials.

Table 3. Key issues identified by 4th FP land resource projects

	APERTURE	ASTERIMOS	CALIS	CARTESIAN	CEREAL-YES	ENFORMA	EOPOLE	EUROP-LIFELINES	HIGH-SCAN	ISLA	ISOLE	MANHUMA	PLAINS	PRIMAVERA	MANTLE*
User expectations/ attitudes										X	X		X	X	
Data delivery times	X	X				X						X			X
Metadata/ access tools	X					X	X	X				X	X	X	X
Spatial resolution	X	X	X			X				X		X	X	X	X
Multi-temporality						X		X		X		X			X
Classification systems												X	X	X	
Analysis tools						X									
Ancillary data/ data linkage										X				X	
Data formats												X		X	
Copyright						X	X			X				X	
Users' expertise	X							X					X	X	
Costs	X	X				X	X	X		X			X		
FP funding arrangements			X							X	X	X	X	X	

*Notes: * 5th FP project*

A second implication concerns the way in which EO data are made available within this sector. Comparison with other recent developments in data provision and information technology in this field is valuable here – for example, in the provision of spatial data for GIS applications. In these cases, adoption was initially slow and piecemeal, in much the same way as it has been for EO data. Once the technologies became established, however, rapid growth occurred (Rhind 1992, Worrall 1994). Important factors instigating this breakthrough were their acceptance as valid sources of data by the regulatory and officiating bodies, and the provision of suitable data products by the supply companies (e.g. by GIS vendors and mapping agencies). As yet, neither of these have materialised in relation to EO data. Another important factor in the area of spatial data and GIS has also been the development of relatively strong and powerful standards. In the case of map data, these were often set by national mapping agencies or through legislation (e.g. in terms of planning data). In the case of GIS technologies, standards have emerged to a great extent because of the domination of the market by a few lead companies (notably ESRI). In the EO arena, these forces for coherence do not yet exist. A further crucial development in this context has been the establishment of favourable purchasing arrangements for core users – for example, the service level agreements available to local authorities for digital map data. Given the cost constraints faced by many users in the land resource area, the availability of similar arrangements for EO data is likely to be crucial.

A third issue concerns the way in which FP projects are designed and funded. There is a tendency – not explicitly acknowledged, perhaps, but implicit in many studies – that the requirement of these projects to involve end users results in a degree of 'tokenism': users take part more to make up the necessary project team than actually to tackle real, user-defined problems. In other words, users are bolted on to the science, rather than the science being defined to address user needs. Related to this is the problem that many users (especially those in the public sector) face in post-project development and maintenance of EO data products. In the absence of any continuation funds from the project, and lacking sufficient internal resources, many users have little choice but to let the outcomes from the project lapse. Some form of funding for follow-up work to translate the project outputs into operational products seems to be vital.

6. Air quality and climate

6.1 EO data users in the air quality and climate sector

EO data are widely used in both the air quality and climate sectors. In the air quality area, for example, the potential user community is relatively focused and well structured across the EU, with the strongest applications occurring at the local/regional scale – the scale of responsibility for air quality monitoring and management throughout the majority of the EU. The main end user organisations are thus the authorities with competence for air quality monitoring and management, along with universities and research institutes. The applications of more "academic" nature, however, tend to be focused on large-scale, interregional projects, which attempt to exploit the potential hidden in EO data for innovative integrated applications to the global environment.

In climatology and meteorology, likewise, EO data have had a profound impact. Instead of having to infer the varying state of weather and climate systems from a few discrete and widely scattered observations, meteorological and climatological researchers can now exploit the capabilities offered by EO data. In this area, the users comprise a well established community of scientists/experts in the research field of atmospheric remote sensing, serving both the international organizations (e.g. ECMWF) and national organisations (e.g. MET-Office, Meteo France, KNMI, university research groups etc) responsible mainly for weather forecasting and weather-climate observing.

The main activities of these organisations are twofold:

- *Operational* - for providing day-to-day services and information on weather forecasting in all spatial and temporal scales and
- *Research*, on atmospheric and climate studies.

In addition, these organisations play an important role in national and international policy by acting as the interface between scientists and both governments and the general public.

A marked gap nevertheless continues to exist in the degree of involvement with, or use of, EO technology amongst the many organizations involved in meteorology and climatology. On the one hand, most research projects funded by the EU have been driven by remote sensing experts, with the intention of providing reliable, spatially and temporally continuous information to assist the operational, research and policy-related activities of their organisations. On the other hand, many similar organisations continue to operate far from this technological and scientific front line (e.g. Hellenic National Meteorological Service). Though aware of the potential benefits offered by EO data, they have not been active participants in any of the 4th and 5th Framework Programme projects examined here, and in many cases still rely on more traditional or conventional methodologies.

Users in the air and climate sector are characterised by a combination of features that distinguish them from those in the areas of land resources and oceans/large lakes. These include their:

- relatively restricted number (well identified user community);
- varied size, ranging from small (for local applications) to large (for regional and international applications);
- focus on air quality and on understanding the mechanisms controlling atmospheric processes and climate;
- access to, and use of, a wide range of alternative data sources.

These organisations are both reactive and proactive in operation. Local authorities tend to be reactive to regulatory requirements, in that they need to provide cost-effective responses to environmental problems and pressures. National authorities, however, tend to be proactive in planning the national, and contributing to the international, regulatory framework governing air quality monitoring and management at all levels. Their data requirements are thus rather easily predictable and well understood, albeit not necessarily by the community of EO data suppliers. These organisations also work within a relatively tightly controlled and regulated framework, within which data needs and data typologies are predefined. In these cases data are needed not just to manage and support day-to-day activities, but also to report upwards and to demonstrate compliance with national or international policy.

Most applications are concerned with specific environmental indicators, such as air quality, cloud parameters, atmosphere visibility and, related to the last of these, the effects of atmospheric aerosol haze. Even so, classification of EO data into classes that meet the reporting requirements of these indicators can be rather cumbersome and is still an issue for applied research. Related to this is the spatial and structural complexity of land resource features that affect air quality and climatic variation, especially in the EU. As in the area of land resources, this results in a need for high resolution, multi-temporal EO data with the power to discriminate between subtle and often complex features.

These various use characteristics have again acted to limit the uptake and application of EO data within the atmospheric studies community, and are reflected in the experiences of projects both in the 4th Framework Programme and elsewhere.

6.2 Data sources

As part of this study, 16 reports from 4th Framework Programme projects were examined in detail. These were selected to provide a representative set of interests, applications and user types from the ca. 27 projects for which project reports were available (Annex 1). From these, 3 projects from the air quality area were chosen for more detailed follow-up, including telephone interviews with project leaders and, most importantly, representatives of user partners. A further 19 projects were also involved in the workshop organised in Brussels by the Research Directorate on 12-13th September 2001.

In addition, information was gathered through a previous cognate study by Smith Engineering with which the author was familiar.

6.3 Obstacles to EO data usage in the air quality and climate sector

6.3.1 Attitudes to information

The attitude to information in the user community in the area of air quality (and to a lesser extent climate) is very positive. Most of the organisations involved in this sector operate in an environment that implies the need for information, not only as a basis for priority setting and for day-to-day management of air quality, but also as a basis for monitoring their performance, and to communicate with and disseminate information to the public. Many make routine use of EO data for these purposes.

As in the area of land resources, however, the use of EO data has not yet been universally accepted by the regulatory or overseeing bodies – for example in the way that ground-based air quality monitoring data or field-based specific environmental observations are for monitoring and planning purposes. This also inhibits the ability of statutory bodies to use EO data in their core business. Partly as a result, the use of EO data is still in its infancy in many of these organisations, much as is the case in their use for land resources monitoring and management.

6.3.2 Users' awareness and expectations

For many applications in the air and climate sector, 'ground-truthing' is an important requirement. This is considered necessary to demonstrate comparability or equivalence between the data provided from EO, and those obtained from conventional ground-based sources: it reflects the user expectations, created through long-time use of these more conventional datasets, that only ground data provide 'true' measures of the environmental conditions of interest. There is also a tendency for users to turn to EO data only when conventional methods have failed. As a result, attitudes to EO data are in some cases rather blinkered, and various possible applications of EO data have in some cases been overlooked: e.g. their use in –

quantification and mapping of detailed air quality features in both large geographic areas and at very high spatial resolution,

- land zoning based on air quality characterisation – including challenging problems such as the identification of the link between air quality or climate change and vegetation health (ICAROS),

- forecasting of extreme air pollution incidents based on a combination of climatic and air quality data derived through EO (ICAROS),
- detailed and computationally cost-effective determination of emission inventories in widely varying landscape settings (IMPRESAREO)).

As in other policy areas, the perceived utility of EO data is also affected by the regulatory environment. In the air quality area, for example, the Air Quality Framework Directive foresees the possibility that competent authorities and regulators use methods other than ground-based pollutant sampling and chemical analysis to monitor air quality. Further work is, however, required by the technical groups drafting the "daughter" directives to include EO-derived information processing methods in the armament of air quality monitoring legislation. At the same time, there is a tendency for many users to be somewhat distrustful of EO data in this context. Other forms of data (e.g. ground-based monitoring) therefore tend to be seen as the 'golden mean' against which EO data are judged and, except where applied as part of Community and national legislations on air quality, EO data so far tend to be used only as an additional, exogenous information source for regulatory enforcement (e.g. to provide independent cross-checking of the methods conventionally used by competent authorities), or as surrogate to ground-based methods when reliable and extensive air quality data are lacking.

If the EO field is also relatively young, its application to air quality and climate studies is even younger – it has emerged only timidly since 1995. User organisations naturally lack technical staff with EO-relevant expertise. Even when these staff exist, they are usually not conversant with EO applications for atmospheric monitoring (air quality and/or climate studies). The lack of specialised staff increases significantly the real cost of EO data use for public administrations. In this kind of organisation, which represents a large slice of the end user group, EO data processing competence is considered marginal. Usually the organisations outsource this kind of work, externalising at the same time the direct knowledge of the potential of EO data for everyday use or strategic planning. This problem is exacerbated when public administrations tackle complex problems requiring the use of integrated tools or which need the integration of different tools and datasets, such as air quality management. In these cases, when the use of the data processing tools change, the administration cannot even pose the right questions technically to define the issue, let alone find the appropriate solutions involving EO data.

The above analysis highlights the need for specialised training, targeted towards the technical staff of user organisations. According to the managers consulted in this study, a combination of specialised seminars and a period of collaboration and hands-on training is necessary to provide the necessary skills to the staff of end users. This also implies that public administrations would be more actively involved in pilot applications at the regional level (the most appropriate spatial scale to demonstrate the high potential and cost-effectiveness of EO data), especially in the field of air quality.

6.3.3 Fitness-for-purpose

Spatial resolution

As noted earlier, spatial resolution is a crucial issue in relation to data in the air quality field: for most applications the need is for data that are both of high resolution and also give wide geographical coverage. Especially where combined use of several satellite platforms is possible, these demands may be met satisfactorily. In the ICAROS project, for example, a spatial resolution of 30-metres was found to be suitable in making estimates of pollution aerosol loading in the atmosphere with a grid of 500 m cell length. This level of spatial resolution is more than appropriate for air pollution loading estimates at the trans-urban and regional scale and it outperforms most medium- to large-scale pollution transport models. (In this context it is noteworthy that the latter are the most advanced tools explicitly referred to in the relevant Community legislation, though most competent authorities in the EU use tools of a much lower level of spatial and temporal resolution.) In many cases, however, users are concerned with small-scale urban problems of air quality, where complex landscape and local effects have made it difficult for EO data to contribute significantly to the understanding of spatial patterns of air pollution. The very high esolution data currently available from instruments on board satellites such as Ikonos-2 are likely to provide an effective (although not necessarily cost-effective) answer to this problem.

A major hurdle to the efficient use of EO data for air quality and climate monitoring is the differences between the spatial resolution of the EO-derived information relevant to atmospheric processes (e.g. aerosol optical thickness, cloud parameters, etc.) and the EO-derived ancillary information, such as land use and land cover classification, surface roughness etc. On many occasions, for example, the potential of EO data to derive very fine information on atmospheric parameters has been hampered by the its inability to produce equally fine information on land morphology that is necessary for the subsequent processing of the information.

Classification systems

Compared to the land resource area (where interest is often in land cover typology) information needs in the air and climate sector focus on more univariate of parameter-based measures. Where classification of EO data is required, it is primarily for the purpose of land use or source activities, needed as inputs to air quality, emission or climate models. These typically use pre-existing (and often socio-economic) classifications: one example is the land use/cover classification used for the determination of emission inventories according to the CORINE AIR methodology of the EEA (IMPRESAREO). In other cases, specific classification schemes have had to be devised to allow the use of new information, previously unforeseen in the existing legislation or in established methodologies. This is the case in the ICAROS project, where a new scheme for classification of atmospheric aerosol loading was conceived to match the requirements of air quality monitoring legislation at Community level. Finally, DECAIR has attempted to face the problem of non-matching classifications among the different datasets used in air quality monitoring and to provide an automatic procedure for the conversion of data into the appropriate format and classification scheme in order to allow communication and information exchange between different data sources.

In conclusion, EO data classification does not seem to be a major obstacle to the use of EO data for air quality and climate monitoring and modelling. Further work, however, needs to be done to improve international standardisation and encourage wider acceptance of the data by users, especially in relation to standards for the GIS-based linkage of EO and ancillary datasets.

Linkage to other data sets

In terms of air quality and climate data especially, the ability to link EO to other data is essential. Topographic data, for example, provide a basis for georeferencing and important inputs to air quality and climate models. In air quality and climate applications there is also a need to link the EO data to ground-based monitoring data, especially where the interest is in operational monitoring as opposed to long-term management of air quality. Another important motive for data linkage is to provide a means of validation that can allow sample data from field campaigns to be extrapolated across a wider control area. This is how the ICAROS team used EO data to derive statistical correlations between EO-derived indicators of environmental pressure and actual environmental loading measurements over the whole region of Lombardy in northern Italy. Atmospheric pollution measurements were obtained through field campaigns over a shorter range, the data were benchmarked against validated EO data, and the statistical correlations were extrapolated to the rest of the region and cross-checked again versus both independent ground-based air quality measurements and EO-derived air pollution indicators.

Problems of data linkage occur for a number of reasons, including inconsistencies between the classification systems. As in the area of land resources, ambiguities between different classification systems may be a major limitation while reliable and comprehensive data validation in the air quality and climate area would need the availability of both ground-based and EO-derived data types in a synchronised way. Ground-based air quality monitoring data, however, have a different time reference to satellite-derived information. These temporal inconsistencies need to be resolved if EO data are to provide a reliable data source in the air and climate sector. Access to non-EO-derived types of data must also be timely if data are to be used for real-time monitoring of air quality or climatic events.

Quality assurance of 'ground-truth' data is another major problem for the use of EO in air quality and climate monitoring and modelling. On more than one occasion, quality assurance of ground-based networks has not been sufficient to provide an adequate basis for validation of EO data. This is a serious problem which acts to reduce the confidence of users in EO data as part of integrated information systems on air quality and climate. To resolve the issue, information fusion algorithms, providing mutual validation of EO and ground-based environmental information, need to be developed.

As in any rapidly changing area of technology, backwards compatibility of EO data can also be problematic in some cases. Nevertheless, EO data still provide probably the best available tool for retrospective assessment of air quality trends on a large scale using archived data.

6.3.4 Obtainability

Data availability

Raw data availability – i.e. the existence of adequate geographic and temporal coverage – continues to be a significant issue in many areas of application. Reported problems relate less to the total absence of data than to gaps in the data that do exist. One of the most serious sources of data loss in this context is cloud cover. In the ICAROS project, for example, it was hardly possible to derive a whole cloud free picture of French Guiana even though SPOT, Landsat and NOAA data archives over the last ten years were consulted in the study.

Another major hurdle to the use of EO data in atmospheric processes is the rapid dynamics of these processes compared to the orbit of high spatial resolution sensors around Earth. This makes the coupled use of several sensors on board different satellite systems a necessity, but consequently adds to the difficulties faced by data providers and information processing centres. Development of EO-derived information processing platforms with the capability to deal with several complementary satellite systems should be a top priority for specialised software developers and EO data/service providers, supported appropriately by RTD funds.

Access arrangements

Problems of access to EO data plague the air and climate sector just as they do the area of land resources, particularly where end-users are concerned. In the case of local, regional or national authorities responsible for air quality management, the relative lack of technical staff with the experience necessary to handle appropriately EO data exacerbates these difficulties. Given the strong competition of other information sources (with which most users are more familiar), the complex access procedures characterised by EO-derived environmental information are a major barrier and require serious streamlining.

In many projects in the air quality and climate studies sector, moderate to significant delays to the final delivery of the EO data to their user were encountered. These problems occurred even when experienced users were involved. Web-based EO data acquisition is hampered by the sometimes unreliable service. Web-based portals are still of poor quality and content (compared to other portals of similar kind), making even experienced users turn to more conventional acquisition procedures. The whole EO data procurement cycle needs revamping in order to meet the rising demands for integrated environmental information utilising EO data.

Metadata

Metadata quality and format are equally important. Several projects in the air quality and climate sector have met with delays in data processing, partially due to errors or inappropriate formatting of metadata. Standards for metadata are weak, and often not applied. A serious effort should be made to develop robust and detailed standards for EO metadata, and the data provider industry should be invited to commit voluntarily to reliable enforcement of the standards.

Data formats

Air quality research and operational management calls for the combined use of several types and classes of data. Differing data formats pose significant hurdles to the widespread use of EO data, given the amount of processing and analysis they undergo. The different formats and headers generated by the broad array of processing software can make the fusion of EO-derived information with other data types cumbersome and, sometimes, practically impossible. The DECAIR project was designed to face exactly this problem through an automated procedure for converting different data sets and making them interoperable using various software tools. This procedure is now available on the Web. Its use is, however, still limited to the project team. The ICAROS team opted for a different approach: it developed its computational platform on the basis of open software architecture to allow users the maximum degree of freedom in choosing data processing software.

Further support to the development of these two and other similar procedures will be required if incompatible formatting amongst different EO data is to be resolved.

Cost

Cost is not a major issue in selecting EO data in the air quality and climate area. All users reviewed in this study or otherwise are aware of the availability, fitness and real operational cost of EO data use and do not see cost as a significant impediment to their use.

Atmospheric research, be it on climate or air quality, demands a large variety of data, including significant amounts of analytical data, derived from highly expensive ground-based instrumentation. Financial cost is thus a major constraint to the organisation of field campaigns and it has been reported as having been a significant factor in the design of the field experiments accompanying EO data retrieval in the projects reviewed. Air quality monitoring and management to date is also heavily dependent on ground-based monitoring networks. The spatial configuration, typology and, ultimately, the overall performance and effectiveness of these networks is equally strongly influenced by cost constraints.

The cost of ground-based — i.e. conventional — monitoring is about ten times the cost of the EO data used in the 4th FP-funded projects. EO data thus provide a relatively affordable alternative and the opinion of all end-users is that cost is currently not a limiting constraint to the use of EO data in the atmospheric studies field. In a number of interviews, however, it was made clear that that appropriate pricing policies would have to be enacted by EO data providers. Such policies should target specific user groups, possibly based on data acquisition volume and frequency, as well as intended end use. They could, for instance, give special support to the multiple end uses of EO data that characterise the *modus operandi* of public administrations.

6.3.5 Implications

As in the land resources sector, the obstacles to the use of EO data for air quality and climate studies need to be put in perspective. Most users are aware of the potential EO data have in the atmospheric studies area, although they probably fail to exploit this potential to the fullest. The reasons lie in the obstacles identified above. These issues, however, act only as inhibitors to the extended use of EO-derived atmospheric information, not as preventing factors. The challenge is to establish the best means of communication between the EO and the end-user communities, so that EO data can satisfy the real needs of the users. This might entail a potential shift in the core activity of EO data companies from *data provision* to *integrated service delivery*.

What most end users long for is a reliable, cost-effective environmental service, which, empowered with EO-derived information, can outperform the conventional environmental monitoring practices in terms of spatial reliability, measurement objectivity, timeliness and cost-effectiveness. The provision of integrated environmental service requires functional assimilation of EO data with complementary data sets. It further needs operational integration of data acquisition, retrieval, delivery, and processing procedures effectively to couple EO-derived data with ground-based and modelling data.

'Entry' activities supporting the enhanced penetration of EO data into the air quality and climate information market should therefore:

(a) include public administrations and other targeted user organisations in pilot applications at the regional scale; and,

(b) involve staff training, comprising hands-on development of the technical skills required to reside at user organisations, in order for them to be able to continue using EO data in their everyday work without the need of specialised consultancy services (i.e. user capacity building) after the training period is over.

At the same time, the following two extreme positions need to be avoided:

(a) to consider the use of EO data immature and discard them;

(b) to presume that EO data can give answers to everything in the atmospheric studies field. The delusion following the inevitable failure of any attempt advocating EO data as a *panacea* for environmental information can be detrimental. Experience shows that the weight of negative experiences thus cdreated can only be overcome only with tremendous effort, far beyond that which EO data providers can offer.

Finally, the EO community needs fully to demonstrate (and disseminate evidence of) the evolving functionality and potential of EO data. Key initiatives should include the organisation of public events highlighting success stories to date and, more importantly, trends in EO data/service features for the next ten years. In other words, a more structured approach to the identification of the market for EO data needs to be followed and communicated to the user organisations.

In terms of thematic priorities, emphasis should be given to the development of integrated tools needed to tackle complex environmental issues rather than the development of tools maximising the use of EO data. Users are looking for the best solution to their problem, not the best way to increase the use of EO information. Hence, EU-funded RTD projects should be geared towards meeting environmental challenges (where appropriate with the use of EO data), not refining the provision of satellite-based information for its own sake.

In conclusion, EO data can give a synoptic view of atmospheric processes over large areas with specific applications in air quality and climate studies. They can complement and support the streamlining of ground-based monitoring towards globally cost-effective solutions. They can also be a tool for stakeholder participation and communication/ dissemination of information that does not suffer from the inevitable biases characterising ground-based measurements. To overcome the obstacles identified above, however, will require a deliberate and comprehensive data policy. This will need to include concerted action between the EO industry, the EO research community, and international RTD funding organisations, such as the EC, in the context of the 6th RTD framework programme.

7. Oceans and lakes

7.1 EO data users in the marine and limnology sector

The users of EO data for land resources are a mature community who are restricted by their very diversity – each user needs different information from the same data resources, so defining a standard product is in many cases difficult. The air quality and climate users are a newer and burgeoning community whose requirements are quite focused, with clear end products. The users of EO data for oceanography and limnology sit comfortably alongside these two communities: they comprise a well-established network of experts, and research into the science of marine remote sensing is also well established. More importantly EO data are now routinely used as a tool along with *in-situ* data and model output to provide a holistic view of the marine environment. If anything, EO and model data have highlighted shortcomings in the *in-situ* observation programmes and technologies which need addressing, but are beyond the scope of this report.

Whilst heated debates will continue as to the subtleties of bio-geophysical outputs from EO data amongst the research community, the information needs for the user are more straightforward. EO data have the potential to provide data outputs of wave height, dynamic topography (medium-large scale circulation patterns), sea surface winds, sea surface temperature, turbidity, phytoplankton density (and potentially type) and CDOM (coloured dissolved organic matter). The information requirements are, however, substantive. These data are required over spatial scales of 100m to global, and on time resolutions/spans of a few hours to tens of years; as such oceanographic users are the largest volume users of EO data and information. In addition data assimilation is a major problem in its own right – synergistic data use has formed the core of modern oceanographic investigation and EO data forms an important tool alongside *in-situ* data and models.

The main hurdles are in turning these synergistic data sources into information, and EO is by no means the poor partner. *In-situ* data are, for the user, very expensive and spatially very limited. The cost of *in-situ* measurement also means that longevity can be prohibitive. However, detailed discrimination of water quality parameters, dynamic features and depth variability can be very good. EO techniques compliment *in-situ* techniques very well, and mixed with predictive models satisfies most users' end needs.

The study highlighted a number of issues in the remote sensing community but one (perhaps not surprising) observation is that having too many experts involved in an operational programme can actually remove the end users from the cognitive chain rather than enlighten them. To date most science programmes have been driven by remote sensing experts who have a clear focus of pushing the boundaries and improving precision. The effect of this is that an inexperienced end user becomes embroiled in the detail and becomes confused and unclear as to the usefulness of the information. An expert will become concerned for example about errors in phytoplankton measurement of 5-10%, describing the output as unsatisfactory. The end user will pick up on this dissatisfaction rather than the fact that the end product is better than the order of magnitude estimate previously available without the benefit of EO information.

The heavy involvement of experts has also meant that there is limited pressure on space agencies to standardise (and adhere to) data formats – experts will generally find a way around formatting problems. Experts are, of course, essential to maintain cutting edge discoveries and improved algorithms, but for the end user a new path of information needs to be investigated. The space agencies need to consider a more operational relationship with end users and this will require funding beyond the usual 2 year pilot scheme.

The other key issue from the marine side is the longevity of funded programmes. The evidence is clear that, whilst most achieve their goals, few if any have continued to operational status. This has been in part due to lack of sufficient funds for a longer time period, which ultimately means that the pilot funding does not represent value for money. Europe is littered with exciting data bases and methodologies which have not quite reached maturity and lie dormant, probably now (for Framework 4) beyond recovery.

7.2 Data Sources

As part of this study, 12 reports from the 4th/5th framework projects were examined in detail. These formed a good cross section of projects covering a range of end user needs and aspirations. From these eight were chosen for a more detailed in person interview (complete) and two for telephone interviews (pending). Those responsible for using the data were contacted in most cases - in two the relevant people had moved out of the field! A further 5 projects were consulted as part of the workshop organised in Brussels by the Research Directorate, on 12-13 September 2001. In addition data were gathered through two further global programmes - EUROGOOS and GODAE - both linked and aimed at provision of global monitoring information. The draft report was presented to the September workshop and issues discussed over the two day period. The results of these discussions are encompassed in this final report.

7.3 Obstacles to EO data usage in marine science and limnology

7.3.1 Attitudes to information

In general, attitudes towards the use of EO data in the marine sector are favourable. However, many specialists involved with routine use of EO data pointed out that even they found it difficult to keep track of what sensors were available, what data they produced and where those data could be found (or, more specifically, most readily found). The generalised preconceptions regarding EO data were that they are known to work in theory, but problems concerned with cloud cover (passive systems), stability of final output, and the precision of the final products had to be acknowledged.

Many of the users within the ocean research community have prior knowledge of EO data and possible applications. There are, however, other theoretical users of level 3 products gained from EO data, such as coastal defence programmes, coastal tourism, fisheries management and flood warning authorities. Many, if not most, of the 4th FP projects were conducted by those who already had detailed knowledge of EO data, and so the attitudes to the applications of EO data within these alternative areas has been difficult to gauge. It is expected that the initial enquiries about EO usage from these areas would be directed to those institutions with prior knowledge. Further investigation into this may well reveal a different, and less positive, attitude to the use of EO data within marine and freshwater associated fields.

It is helpful that EO data usage within ocean research has been a common tool for at least 10 years, and so has already achieved a degree of respectability and reliability. This research community is still the major end user of EO data and is likely to remain so. As with any tool, however, the validity of the results is only as good as the calibration, validation and the accompanying auxiliary information regarding data quality. It is generally accepted that EO data will never be able to act as stand alone information, as they will always require *in-situ* validation. There are perceived gaps in these *in-situ* data and as much effort is needed to develop new and more relevant *in-situ* measurement campaigns and techniques in order to fulfil these shortfalls. Nevertheless, the synoptic view of the global oceans EO data offer cannot, as yet, be matched by any other technique.

It is worthwhile pointing out at this juncture that few of the 4^{th} FP projects produced a final operational product/tool that is still being utilised. Of those projects considered in this review, only OILWATCH was operational as the review was published, having proved its viability as a commercial tool during the funded stage. If EO data are to be used and exploited more fully, it may be necessary to incorporate a more business-orientated objective within any future funded work.

7.3.2 Obtainability

Accessibility

Accessibility of data was an area where major concerns were displayed. Ease of accessibility, knowledge of what data could be found where, access to processed as opposed to raw data, and the often complex forms that require completion before data can be accessed are amongst the prohibitive areas concerning accessibility. Accessibility also appears to become more complex as the data provider institutions become larger. Specific access problems were mentioned regarding ESA (CLEAN SEAS and COLORS), though dealing directly with receiving stations was efficient and quick. CLEAN SEAS also found that, once accessed, it was difficult to automate the data in order to get a routine supply – a concern that PML (Plymouth Marine Laboratory, UK) remote sensing group has addressed for their customers/end users. Accessibility of data within OILWATCH was not a problem as the data came from the ground station run by QinetiQ, (DERA), who were also the product providers. Whilst this implies that greater use should be made of the ground stations, the experience was only successful because of the close working relationship between the data user and provider at the ground station. It was indicated that the following improvements may prove beneficial:

- easy access to data sets and catalogues via the Internet, giving both open and restricted access dependant upon the user;
- ground stations producing (standardised) final products, not solely images but information, which can be readily available to potential users;
- standardisation of the complex array of systems/algorithms used at present;
- establishment of a meta-database giving guidance to anyone who may wish to enquire about the use of EO data, the information they need regarding access and

confidentiality issues, access restrictions, locations of databases, contact points for those databases and auxiliary data concerning interpretation and limitations of the data sets;

- easy access to long time series of simple .jpeg images which, for many users, may be a satisfactory initial starting point.

The proposed approach is one that is most closely aligned to that which NASA currently offers EO users.

Delivery of data

It appears that where organisations/project teams approach ESA or other main agencies, there is a considerable delay in receiving the data requested, as experienced by COLORS, CLEAN SEAS and COASTLOOC, whereas those groups that knew of a "back door" method of accessing data achieved timely deliveries. COASTLOOC required the information at the end of the main project work, in order to superimpose the *in-situ* data collected; therefore the delay in receiving the data was acceptable. For many short-term projects, however, this delay cannot be tolerated. PML remote sensing group appear to be very efficient, managing to deliver pre-processed data of specified products to end users within hours, thereby achieving the real time data sets that many research projects ideally require, as seen in OMEX. A different example is provided by CLEAN SEAS: the NRSC–ATSR data experienced huge production delays and, when they did arrive, failed to deliver the products requested. Yet the same team found fewer problems by going to the receiving stations directly, while RAIDS managed to refine the service and processing schedule as required. OILWATCH was able to issue first alerts regarding oil spills to its customers within 90 minutes of the satellite beginning its pass, again because the ground station processed the data directly. This appears to demonstrate a definite change in attitude to the end user between the main agencies and the smaller data centres. This can be seen in the way that project partners with principle investigator (PI) status receive their data. Within the data delivery system, PI status can be viewed as secondary to other data requests, and therefore projects do not receive the near real time data sets that they require.

To achieve such prompt delivery there appear to be a number of requirements.

- Primarily there needs to be recognition that the end user is vitally important, and that service standards must therefore be foremost. The technology is there to "serve" the end user, not the other way round.

- Links between the satellite, the receiving station, the processing group and the final end user must be faster and more efficient. The "expert" end user is used to having to pick data mid-flow for urgent applications – the universal end user is not.

- Automated processing of known product requirements is essential, with the flexibility to adapt and incorporate new product requests.

- Possible consideration should be given as to the feasibility of three parallel data streams, offering: a) access to raw data immediately for those with the appropriate software capabilities; b) basic pre-processed data within hours; or c) level 2 products of high accuracy within days for those projects reliant on reducing all possible sources of errors. This type of parallel data streaming can already be seen with regard to altimetry data; effort should therefore be focused upon evolution and expansion of the current system as opposed to implementation of a new one.

- Further exploitation should be made of the ground stations, and their role within the processing and data delivery service strengthened, unless a more efficient link can be established with faster data delivery from the central agencies.

Archiving and databases

The main concern in relation to archiving and database access was that data obtained from now obsolete sensors may be lost when the knowledge base connected with those sensors is not satisfactorily archived. This would have an affect on the archived baselines and trends available. It is generally accepted amongst those questioned that an archive system is essential, as is a cataloguing scheme for the EO data. Formats for such archives for certain data products are described in projects such as CEVEX and many of the NASA data handling manuals. Strict adherence to these, or very clear information on departures from these, is essential.

Robert Freeman, of QinetiQ, felt that there were enough substantial websites to negate the need for another database to be set up, but what does seem to be required is the need to standardise the quality of the data held (to the highest possible level).

Ground level support systems

There is still perceived to be quite a serious gap in the ground level support for the EO data and potential users. There has been major financial investment into the technological side (it costs hundreds of millions of Euros to put some of these systems into space), but full exploitation of the data gained cannot be accomplished without financial investment at ground level. Lack of funding for ground support often means that EO data cannot be regarded as value for money from the end users standpoint. Key needs are thus for:

- an increase in the human resources devoted to data exploitation;
- opportunities for vicarious calibration to enhance payback.

Formats

The area of data formats is one which causes many problems for the user – and still relates to data output rather than the sensors themselves. One group (involving an experienced remote sensing specialist) mentioned an occasion when SAR data were received from ESA, which took a week to decode, despite having (or perhaps as the result of) a 40 page accompanying booklet! This experience was mirrored in many of the conversations regarding the difficulties of using EO data received from space agencies. CLEAN SEAS felt that the ease of data format interpretation was dependent on the level of pre-existing knowledge within the team. Therefore those organisations with knowledge of EO formats are usually able to utilise the information contained, but for the vast majority of potential users within the broader reaches of environmental monitoring data formats represent a major stumbling block. According to BADC, approximately one third of most project time is currently taken up by trying to decipher ever-changing data formats. This issue thus needs to be seriously addressed if the use of EO data is to become attractive to those organisations that do not readily have access to remote sensing specialists, and do not have the funding available to incorporate what may therefore be seen as an additional cost. A system that offers pre-processed data, and more importantly *information*, is much more accessible.

The QinetiQ representative expressed an opinion that there can sometimes be too much importance placed on the implementation of new technology, and that keeping information data delivery simple is the most efficient way of enabling the greatest number of users the least number of data usage problems. OILWATCH also experienced problems regarding the formatting software when EOS, the manufacturers of the software, ceased business. This raises issues regarding not only the formats and software that are used, but also their sustainability long term, and the implications faced if that software should become unavailable at a future date.

In addition, the formatting of data needs to ensure comparability and compatibility between data sets. The concerns over data formatting not only encompass the form in which the data is delivered to the end user, but also the formats in which those data are later archived and managed. To these ends, issues that need to be addressed include:

- evolution of generic data formats and archiving structures within the data delivery system from the agency to the end user: whilst .hdf, for example, is a "standard" format, some data providers are more standard than others! This standard needs to be adhered to by all providers, EO, in-situ and models;
- possible standardisation of the basic oceanographic products, such as SST, chlorophyll, wind and wave climate, via utilisation of generic algorithms;
- simple standardised explanations regarding data extraction and limitations for those users not well versed in EO data – ideally with a means to import data to standard "MS type" products.

At the September meeting, this issue of data formats was raised. Discussions had been established with the EUROGOOS group and protocols proposed that most providers were happy to adhere to, from *in-situ*, model and third level EO product stage. Ironically the only two organisations that were still in disagreement (or at least required more discussion) were EUMETSAT (who were close to agreement) and ESA (who were not).

Funding

The issue of funding was considered from two perspectives – funding of research projects themselves by the EC, and the funding into the technology and data management side. On the project side it was the general view that the EC were not overtly steering projects to utilise EO data, and that any encouragement to access these data was necessary in order to produce the end products required by a more general consumer community.

This was not the story, however, when considering the issue of whether to fund EO technology or to invest in ground based activities aimed at utilising the data gained from that technology. Once example, cited by Dr. Bryan Lawrence, was that of ENVISAT. Approximately £20 million was invested into the technology by the UK, and yet no fund has been set up by any UK organisation in order fully to exploit the products of this major financial investment. It was apparent that a lack of funding at this level was resulting in a communication problem between the initial data provider and the end user. To this end the following issues need to be addressed:

- eliminate the financial bias towards the technological side of EO;
- provide additional funding within projects to enable full exploitation of the data sets currently being gathered;
- provide funding in order to establish ground-based data management centres, possibly linked to operational institutes, devoted to full exploitation of the data being gathered;
- fund smaller nationally-based projects in order to build up levels of expertise, which can then more fully support the larger international projects.

Cost

Costs could feasibly be a problem as identified in land applications, but many of the processing/delivery organisations, such as PML, have agreements that enable free access to data if the user is UK-based. It was pointed out by Peter Miller, however, that for other non-eligible organisations, if the free access announcements made by ESA were missed, or if equivalent national data authorities did not exist, then costs could become a problem. This was experienced by the CLEAN SEAS project, which was financially limited in terms of the number of SAR images used. As stated earlier, marine users require large numbers of images in order to resolve the tidal/oceanic dynamics of the environment in which they operate. In general, however, the issues regarding costs did not inhibit use of EO data in the projects reviewed, though this experience may not extend to commercial users who do not benefit from the purchasing agreements currently available to the scientific community. Robert Freeman, of QinetiQ, for example, believed that costs were a major issue, especially within the commercial area.

Clearly costs are always likely to be an issue in any area of research or application. The key question to be addressed is how those costs are borne. As long as the customers are expected to pay heavily for images, data and information, EO data usage will never achieve their full potential. Possible improvements to this situation could be:

- contracting service providers, funded by the EC/ESA, to supply "free" data;
- increasing the number of satellites available and therefore possibly reducing costs to the end users through competition.

In discussion at the September meeting it was broadly accepted that EO data are ultimately there for the public good in the marine environment and as such should be funded by governments. A number of commercial companies were involved in the discussions and they saw little problem in data being freely and openly available to all. Any benefit to SMEs would come through using the data in value added products.

7.3.3 Other Obstacles

A number of other, generally lesser issues were also raised by the 4th FP projects reviewed here. These included spatial resolution, geographic coverage and the risk of hiatuses in time series data resulting from gaps between funded projects. Spatial resolution was generally considered to be adequate for most applications, with data commonly providing resolutions of ~300m, sufficient for most studies of open seas. Detailed research, especially in the coastal area, however, requires higher resolution. Improvements in spatial resolution may therefore help to expand use of EO data to a wider set of users. In much the same way, geographical coverage is generally considered adequate, but can always be improved – in which case it may also open up new areas of application.

An additional concern, voiced by Jim Aiken (PML), was not the lack of new technology, but the lack of operational technology currently transmitting data. Reduced satellite numbers can lead to reduction in temporal coverage, which can in turn reduce the viability of the EO data. Robert Freeman, similarly raised the issue of sensor longevity, and sensor orbits: both of these issues could, and do, impact on the effective temporal and spatial resolution of EO data.

8. Conclusions and recommendations

This study has demonstrated the wide range of factors that can act as obstacles to the uptake and use of EO data for policy purposes in the EU. These include factors relating primarily to the attitudes to information of the end users, the levels of awareness about EO data products and technology amongst potential users; the fitness-for-purpose of EO data (due, for example, to issues of spatial resolution, multi-temporality and information content); and the obtainability of the data (as a result of problems of access arrangements, metadata, formats, cost). Together with a range of other, often serendipitous factors, these combine to influence whether or not potential users choose EO data and if so how and to what extent they are used.

These various obstacles to the use of data must nevertheless be placed in perspective. The focus in this study has – by necessity – been on the *obstacles* to use of EO data, rather than the advantages and successes. The 4th and 5th FP projects investigated here are also not fully representative of the wider situation of EO data usage, especially for routine, policy-related applications. Routine applications necessarily require reliable and 'risk-free' data and methods. Good research projects, on the other hand, are likely to court problems and partial failure because they are designed to work at the frontiers of knowledge and capability. In spite of this, there is clear evidence of the successes of newer 5th FP projects building on the experiences of the 4th FP. Many of the shortcomings experienced in the earlier programme are thus being well targeted in the 5th FP.

In reality, the situation is far from wholly problematic. EO data clearly have a major role to play in both research and policy – not just as a source of environmental data in their own right, but also as a basis for environmental modelling, environmental stratification and sampling, and as an aid to spatial transformation, data visualisation and data interrogation. It is also evident, across almost all the studies examined here, that the Framework Programmes continue to produce high quality research, that makes major contributions to policy through the provision of new data sets, by adding value to existing data, and by providing new and often powerful tools for data analysis. The challenge in most cases is to find ways of translating this research into routine operational use, across the wider community of users. This highlights the need for funding mechanisms for post-project development of products, and for effective strategies to disseminate project outcomes to users.

Partly as a result of the efforts of FP projects, awareness amongst users about the potential of EO data is undoubtedly increasing, and use of these data is expanding. Many of the problems, where they occur, can be – and are – overcome; they merely act to inhibit, rather than prevent, the use of EO data. An exceptionally wide range of potential users also exists across (and in some cases within) the various application sectors who between them have immense expertise: the challenge, in many cases, is to connect with these users in a way which can exploit this experience and begin to satisfy their needs. Uptake of EO data may in some cases appear slow, but it important to remember the strong inertias that exist in any user community: users are rarely free to adopt new technologies, however well informed and willing they might be.

The picture to emerge from this study is therefore mixed. EO data certainly do have enormous potential and are becoming more widely used in the policy arena. But adoption is still patchy and relatively slow, and in many cases EO-derived information is not yet seen as competitive with more traditional data sources. Especially from the perspective of the end-user, many barriers to the use of EO data also persist. Consequently, the full potential of EO data has yet to be exploited.

Use of EO data for its own sake clearly has no merit. Across all the areas reviewed here, however, it is evident that greater use of EO data could be greatly beneficial. It would provide new information, improved consistency of this information, enhanced repeat rates, and – in many cases – lower costs of data acquisition. (These same benefits would also extend to many other areas of potential application, not considered here, such as social, economic, regional and health policy.) Efforts to encourage the use of EO data are therefore worthwhile. On the basis of the evidence gathered in this project, these efforts need to focus on seven main sets of action:

1. *Developing a wider suite of EO-derived data products, better matched to existing user needs, and able to offer ready-made data for new users*

   If existing users are to be better served, and new users encouraged, there is a need for a wider range of 'off-the-shelf' or readily available 'made-to-order' data products. These include both generic data sets, designed to provide basic data for wide groups of users at a variety of scales, and customised data products and services, targeted at specialist users. Important actions should include

   - EU funding to help develop key data sets
   - closer involvement of EU Directorates and agencies in EO-based researchg projects, in order to strengthen the European value of the data products
   - greater emphasis on the role of EO service providers in developing and marketing customised data products

2. *Improving understanding of user needs*

If data providers and the service sector are to meet user needs, the users must appreciate more clearly what EO can offer and how they might take advantage of EO data, while the providers need to recognise the nature of the users' needs and the operational constraints within which users work. This implies far closer communication between providers, service organisations and users. Important actions should include:

- workshops and seminars aimed to bring together EO (and other) data providers, service organisations and end users in order to specify more clearly user needs and what EO (and other) data can provide
- improved dissemination of the products of FP project results, and other developments, to raise user awareness
- development and wide dissemination of demonstration products and sample data sets (including via the Web)
- training sessions and hands-on experience for end-users

3. *Developing more flexible and user-friendly analysis tools*

The wide range of user needs cannot always be met directly by data providers or service organisations; in-house development of EO products by end-users is often necessary, and this need will increase as user communities expand. To support such development (and also to strengthen the role of the service organisations) there is a need for a range of new, and more integrated, analysis tools. Important areas for development include:

- modelling methods
- statistical data analysis
- systems for data integration and linkage between EO data and other data sources.

4. *Improving systems for data access, evaluation and acquisition*

Difficulties in accessing EO data and derived data products continue to be one of the main barriers to wider EO data usage. The main focus for action here lies with data providers and service organisations. Priorities include:

- providing better discovery and access metadata
- development of co-ordinated browsers/portals
- more comprehensive documentation
- application of more consistent data formats and standards
- adoption of less 'elitist' attitudes by data providers and service organisations

5. *Developing fair and appropriate pricing policies for key user communities*

To compete with more traditional data sources, and to be realistic alternatives within the funding constraints of many users, EO data need to be available on a comparable financial basis to these competing data sets. This requires the provision, for example, of:

- preferential purchasing arrangements (e.g. 'service-level agreements') for key user groups
- introductory/trial data on favourable terms

6. *Recognising the validity and value of EO data in policy and legislation*

Legislation continues to be one of the main motives for information use, and one of the key determinants of what data are used in any situation. As yet, EO data have only rarely been explicitly accepted as valid data in policy and regulatory legislation. Increased attention needs to be given to the value of EO data in such legislation. To this end important actions include:

- inter-comparability and calibration studies to demonstrate and quantify the equivalence between EO-derived and traditional data
- recognition in new or existing EU Directives and national legislation of the role of EO as a data source
- definition of policy classifications and typologies in terms of EO capabilities

7. *Funding for EO development studies*

The current bias in FP funding towards EO technology (and against product development and operation) needs to be reversed. Funding needs to be provided to support post-project development and application of EO data products within user organisations. At the same time it is important it needs to be recognised that the development of EO data and tools from a research to an operational stage often takes a long time – the time limited nature of FP projects makes it difficult to complete this development within a single project. Consideration should thus be given to:

- targeting FP projects at more generic users, who have the capability to act as leaders in adoption and use of the project outcomes
- increased emphasis in FP projects to effective dissemination of the results to the wider community of users
- provision of follow-up/extension funding to help take the outputs from FP ensuring greater emphasis in both FP and follow-up studies on mechanisms projects to an operational state.

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ANNEX 1 - REVIEWED PROJECTS

A. Land resources

Project	Title	Description	User groups	Area	Interviewees
APERTURE	Environmental typological space facilitating the implementation of European legislation	Mapping and classification of Europe according to international, European and national environmental legislation	Ministries of agriculture in Hellas, Spain and Portugal; Department of Environment, UK	Greece, Spain, Portugal, UK	I. Nicolaou A. Ganas D. Rokos N. Spiropoulos
ASTERIMOS	Application of space technology to environmental aspects of surface mining – a surface mining decision system	To demonstrate how Earth Observation from satellites can be used within the decision process relation to surface mining activities	Mining and metallurgical companies;	Greece, Spain	A. Ganas N. Spiropoulos
BALANS	Planning and management in the Baltic Sea region with land information from EO	Use of EO data for planning and environmental management in the Baltic region		Baltic region	B. Olsen (Workshop 1)
CALIS	Calamities information system	To evaluate the extent to which Earth observation from satellites can be used to help monitor and assess agricultural damage caused by drought, storm and frost.	Public administration in agriculture, insurance companies, farmer unions	France, Spain	D. Aifantopoulou
CARTESIAN	A cost effective application of remote sensing to environmental aspescts of ski region monitoring and management information system	To examine how space technology can provide a cost-effective assistance in the environmental monitoring and maintenance of ski regions, and to develop a monitoring and management system which supports their sustainable development	Skiing industry, Nature conservationsists	Switzerland, France, Austria	
CEREAL-YES	Cereal yield estimation system	To investigate the use of high resolution satellite imagery and crop growth models to produce reliable, timely and objective predictions of cereal yields	Regional government Agricultural administrations	Spain, UK	
ELDAS	Development of a European land data assimilation	To improve models of soil moisture as a basis for flood, drought and discharge modelling, and	Private companies		B. van den Hurk (Workshop 1)

	system to predict floods and droughts	as a stress indicator for nature and biodiversity			
ENFORMA	Integration of EO- data in enforcing national legislation for environmental forest management	To improve the effectiveness of national forest authorities in monitoring forestry activities, particularly with regards to sustainable, environmentally sensitive management	Forestry authorities	Sweden, Finland, Austria	M. Rosengreen A. Persson J. Uuttera W. Luckel
EOBEM	Earth observation for woodlands, shrublands and grassland – biomass estimate and management	Use of EO data for mapping grassland, shrubland and woodland biomass production, and to determine whether these data can match ground survey methods in terms of their accuracy and cost-effectiveness	National park administrations Game conservancy agencies Forest managers	Italy, Greece, UK	C. Terranova (Workshop 1)
EON2000 / EON2000 +	Earth observation for Natura 2000/Natura 2000 +	Development of a habitat monitoring system for environmental applications	Environmental agencies Resource managers WWF	Europe	A. Lamb (Workshop 1)
EOPOLE	Earth observation data policy in Europe	To evaluate the impacts of data policy on the uptake of EO satellite data and to recommend future policy changes where appropriate	Decision makers in EO policies	EU	R. Harris
EPN	European Phenological Network	Thematic network, aimed at improving understanding of phonological processes in Europe		Europe	A. van Vleit (Workshop 1)
EUROP-LIFELINES	Sustainable development of European life lines	To prove the benefit of remote sensing for environmental planning and support of decision makers in planning, implementing and monitoring European Life Lines.	Decision makers in environmental planning Nature conservation bodies	Germany, Spain, Austia	
HIGH-SCAN	Assessing forest stand attributes by integrated use of high-resolution satellite imagery and laser scanner	To explore and test methods for the integrated use of high-resolution satellite imagery and laser scanner for small-area forest inventory and mapping at the retrieval of several forest attributes (volume, species, tree height, density, age, soil, crown area and boundaries)	Forest authorities	Finland, Austria, Germany, Switzerland	
ISLA	Land and water management in Mediterranean	To develop and test a user-driven pre-operational application to	Island water managers	Spain,, Greece	H. Kontoes D.

	islands using earth observation data	support water managers in their decision-making activities			Aifantopoulou
ISOLE	Island satellite observation system for local exploitation	Monitoring and assessment of the human induced pollution of two pilot (island) coastal environments	Island administrations	Italy, Greece	M. Petrakis
MANHUMA	Utilisation of earth observation for the management and conservation of humid areas	To demonstrate how EO data and information products can contribute to the management of wetland resources	Nature conservation agencies	France, Germany, UK	R. Harris, M. Sties, S. Clandillon F. Ribbes (Workshop 1)
MANTLE	Mapping night-time light emissions for policy support in Europe	To assess the use of night time light emission data as a tool for mapping and modelling indicators for policy support	Regional planning agencies	UK, Italy, Greece, Denmark, France-Belgium border region; EU	G. Deane P. Smyth
PELCOM	Pan-European Land Cover Monitoring	Development of a 1km resolution land cover map for the whole of Europe	European and national environmental agencies Climate modellers Emission modellers	Europe	M. Wachowicz (Workshop 1)
PLAINS	Prototype landscape assessment information system	Integration of EO data within the decision making processes in the tourism sector	National Association of estate agents Local authorities Tourism agencies	UK, Germany, Italy	G. Deane P. Smyth W. Cudlipp (Workshop 1)
POSITIVE	Phenological observations and satellite data (NDVI): trends in the vegetation cycle in Europe	Develop and assess the use of EO for the analysis of phonological processes in Europe			A. Menzel (Workshop 1)
PRIMAVERA	Parks resources information system management via environmental remotely sensed data analysis	To support Park Resources Information Management via environmental remotely sensed data analysis	National and regional park administrations Park management	Greece, Italy, UK	I. Keramitsoglou M. Petrakis K.Fabbri (Workshop 1)
SCANNET	Scandinavian/ North European network of terrestrial field stations	Thematic Network project aimed at establishing a research network to assess variations in system sensitivity and responses to environmental change in		Scandinavia	M. Johansson (Workshop 1)

		the Arctic region			
SNOW-TOOLS	Research and development of remote sensing methods with a main focus on snow hydrology	The development of generic methods for correction and interpretation of optical and microwave data	Meteorological authorities responsible for water resources management	Finland and mountain-ous areas in Norway	
SPIN	Spatial indicators for European nature conservation	Development of spatial indicators for European nature conservation at local and broader scales	Nature conservation authorities		S. Weiers (Workshop 1)

B. Air and climate

Project	Title	Description - Objectives	User groups	Area	Interviewees
AIMWATER	Analysis, investigation and monitoring of water resources for management of multi-purpose reservoirs	AIMWATER demonstrates how multi-purpose reservoir management could be improved through integration of EO data in commonly used decision-support hydrological models.	Hydrological modellers and reservoir operation engineers; specialists in RS and hydrological applications; and authorities responsible for reservoir management.	Seine basin in France	
ALPMON	Inventory of alpine-relevant parameters for an alpine monitoring system using remote sensing data	The alpine environment, is exposed to considerable environmental threat.This is due to an aggressive development drive in the past, huge numbers of tourists as well as environmental damage.	The Alpine Convention, natural resources and environmental managers in the Alps. Tourists also benefit from an environment that is better managed.	Alpine landscapes	
BALANS	Planning and management in the Baltic sea region with land information from EO	BALANS aims to produce and test a seamless, homogeneous land cover database for the Baltic Sea drainage basin, based upon medium-resolution satellite data. The database is envisaged to have a maximum resolution in the order of 250 meters, and will provide land cover information and derived products in several broad and some more detailed classes.	Authorities and inter-governmental initiatives responsible for resources management and monitoring in the Baltic countries, as well as transboundary projects.	The Baltic Sea drainage basin.	
CLAUS	Cloud Archive User Service	Clouds have a significant effect on climate, while their distribution in time and space is a consequence of the prevailing climate. The objective of CLAUS is to improve the parameterisation of climate models by comparing their output with data assembled from various satellite sources	Climate modellers and the meteorological community	Global	During Workshop 2
CIRAMOSA					During Workshop 2
CLIMAP	Climate and environmental monitoring with GPS atmospheric	The advent of radio occultation techniques applied to signals from GPS satellites has proved to be a very promising	Climate modellers	Not applicable	During Workshop 2

	profiling	approach for accurate measurements of temperature and humidity profiles up through the atmosphere. CLIMAP aims to establish and evaluate a pilot system for climate and environmental monitoring based on atmospheric profiling with GPS radio occultation data			
CLIWA-NET	Cloud liquid water network	CLIWA-NET focuses on observations of cloud liquid water and vertical structures, and evaluation/improvement of parameterisations. A prototype of a European cloud observing system will be established. CLIWA-NET co-ordinates the use of existing, mostly operational, ground-based microwave radiometers and profiling instruments. The network data will be integrated with satellite estimates of cloud water.	Climate modellers	Not applicable	During Workshop 2
COVERAL	Cloud retrieval validation experiment	Gather unique datasets, from which a better understanding of microwave interaction with clouds can be deduced; to verify, and potentially improve algorithms which retrieve cloud parameters from current and future space-based passive microwave instruments; to provide a quantitative validation of Liquid Water Path (LWP) accuracy, as derived from existing satellite sensors and retrieval algorithms.	Experts in climate monitoring, weather and climate prediction modelling	Great Britain	
CLOUDMAP	Cirrus and contrail cloud-top-maps from satellites for weather forecasting and climate change analysis	The overall objective of CLOUDMAP is to provide cloud-top parameters (heights, amounts, types, wind-fields) to weather forecasters and global climate modellers to improve their ability to improve forecasts and quantify the impact of natural and anthropogenic changes upon the environment	Weather forecasters and global climate modellers	Europe and the North Atlantic	During Workshop 2
CLOUD-NET					During

					Workshop 2
CLOUDS	Mission study of "CLOUDS" – a cloud and radiation monitoring satellite	The overall objective of CLOUDMAP is to provide cloud-top parameters (heights, amounts, types, wind-fields) to weather forecasters and global climate modellers to improve their ability to improve forecasts and quantify the impact of natural and anthropogenic changes upon the environment	Industries specialised in space instrumentation and systems, and end users involved in climate and weather prediction	Global	During Workshop 2
COSE	Compilation of atmospheric observations in support of satellite measurements over Europe	The objective of COSE is to provide the EO user community with a validated, consistent and well-documented data set of mainly stratospheric constituent columns and/or profiles, by co-ordination of ground-based observations at existing stations in Europe. The data set builds on past and ongoing time series	Atmospheric research groups, in particular satellite experiment teams, and databases	Europe	
ERA-40		The main objective is to promote the use of global analyses of the state of the atmosphere, land and surface conditions over the period			During Workshop 2
DECAIR	Development of an Earth observation data converter with application to air quality forecast	The improvement of atmospheric air quality models by providing them with high quality input data derived from EO. It is intended to develop a demonstrator (the DECAIR prototype), used in a pre-operational context on two application sites	Two levels of users can be identified: model-users (i.e. scientists from companies and research institutions) who need input data for their simulation models (meteorological, topographic and emission data); and end-users (i.e. local authorities, health/traffic decision-makers) who need atmospheric and air quality models for scenario analysis and forecast on European urban areas	The urban areas of Berlin (D) and Madrid (E).	
DUACS	Developing use	Develop new applications	The climate	Global	

	of altimetry for climate studies	of altimetry in the field of climate modelling and forecasting by making climate specialists familiar with altimetry and by demonstrating the usefulness of altimetry for various applications, including seasonal climate forecasting.	modelling and forecasting community		
EOPOLE	Earth observation data policy and Europe	The study of a new satellite mission to provide accurate, comprehensive, consistent and frequent information on clouds and radiation to be used for the purpose of improved climate and weather forecasting	EO data policy-makers in EU Member States, environmental policy advisers and decision makers, major EO user programmes, national and international space agencies, academic researchers	Europe	
EURAINSAT	European satellite rainfall analysis and monitoring at the geostationary scale				During Workshop 2
EUROCS	European cloud systems	To improve the treatment of cloud systems in global and regional climate models	UK Meteorological Office		During Workshop 2
EUROTRMM	Exploitation of TRMM data for an improved weather and climate Forecast				Workshop 2
FLOODGEN	Flood risk reduction by space borne recognition of indicators of excess runoff generating areas	The objective of FLOODGEN is to assess regional risk of runoff using reliable, existing RS and GIS techniques and to propose new tools to help the joint management of catchment basins.	Regional authorities and the EC DG VI (Agriculture)	Europe	
GERB					During Workshop 2
ICAROS	Integrated computational assessment via remote Earth observation system	The development of an interactive computational environment that allows the integration and assimilation of different data types including RS observations, ground air quality measurements, and advanced	a. Regional Plan for Air Quality in Lombardy, b. ASM Brescia SpA	Italy, France	D. Sarigiannis: Scientific Coordinator G.VOLTA: Technical Director, Regional Plan for Air Quality

		atmospheric modelling for the minimisation of the uncertainty in decision-making regarding air pollution control and abatement in the urban environment.			in Lombardy And D. Zambelli, A. Bonetti
IMRESAREO	Improving the spatial resolution of air emission inventories using Earth observation data	IMPRESAREO aims to demonstrate how satellite imagery can improve the spatial resolution of air emission inventories, so that air pollution predictions for urban areas can be undertaken more cost-effectively	The environmental assessment industry (commercial consultancies, research organisations) which produces air quality management tools to help national and local authorities improve air quality	Italy, UK, Finland	A.GIUDICI: Responsible for Air Emissions in Regione Lombardia
MAGIC	Meteorological applications of global positioning system integrated column water vapour measurements in the Western Mediterranean	The broad aim of the project is to examine the scope for the improved use of techniques taken from machine vision in the analysis of the latest generation of VHSR imagery from RS platforms.	The remote sensing community and the industrial users of advanced visual processing algorithms	Europe	
MAUVE	Design and assessment of global, European and regional scale UV irradiance maps based on satellite data and ground measurements	The main objective of MAUVE is to establish maps of surface UV radiation, derived from satellite data, as a recognised source of information for a variety of applications including climatology studies, documentation of potential environmental changes and risk assessment for human health	The European atmospheric and climate research communities, experts involved in environmental research and assessment, dermatologists	Global and Europe at higher spatial resolution	
MAVIRIC	Machine vision in remotely sensed image comprehension	The broad aim of the project is to examine the scope for the improved use of techniques taken from machine vision in the analysis of the latest generation of VHSR imagery from RS platforms.	The remote sensing community and the industrial users of advanced visual processing algorithms	Europe	
MSRS	Multispectral high resolution system	MSRS is a multi-spectral high-resolution system, designed to meet the requirements of current and future EO users.	Various including: advanced agricultural and vegetation monitoring; water resources and	Global	

			quality management; oceanic and coastal zone monitoring and surveillance; hazard warning, risk management and damage assessment.		
PACE					During Workshop 2
REFIR	Radiation explorer in the far infra-red	REFIR is a feasibility study of a novel instrument that measures spectral radiance in the Far Infra-Red (FIR) from space. The proposed REFIR instrument would be used to provide knowledge important for climate and meteorology.	The climatologic and meteorological community. REFIR should contribute in a very synergistic way to work planned by ESA, EUMETSAT and NASA.	Not Applicable	During Workshop 2
SNOW-TOOLS	Research and development of remote sensing methods with a main focus on snow hydrology	The development of generic methods for correction and interpretation of optical and microwave data.	The meteorological community and the authorities responsible for water resources management.	Finland and in mountainous areas in Norway	
SODA	Studies of ozone distribution based on assimilated satellite measurements	The objective of SODA is to develop the technique of data assimilation to generate a database with a consistent description of the dynamics and the ozone distribution in the atmosphere.	Atmospheric scientific community (chemical, dynamical and radiation aspects), plus weather prediction modellers.	Global	
VIRTEM	Validation of IASI radiative transfer: experiments and modelling	VIRTEM is designed to thoroughly prepare the meteorological community for the launch of IASI.	Atmospheric scientists and the NWP communities	Global	During Workshop 2
WAVEFRONT	GPS/water vapour experiment for regional operational trials	WAVEFRONT aims to demonstrate that GPS can be used to estimate Integrated Precipitable Water Vapour (IPWV). D water vapour distribution	Meteorological and climatological communities	Europe	During Workshop 2

C. Oceans and large lakes

Project	Title	Description	User Groups	Area	Interviewee
CASOTS	Combined action to study the Ocean's	To enhance the work of individual groups within the EU through collaboration in the study of the ocean thermal skin	Research organisations	Europe and North Atlantic	I. Robinson

	thermal skin	measurements			
CEVEx	Concentration on European validation experiments for coastal / shelf water remote sensing	Provide better assessment of Cal / val methods, in-situ measurement protocols, processing and archiving tools.	Research community	Europe and Atlantic	J. Aiken S.Boxall M Wernand
CLEAN SEAS	Clean Seas: European marginal seas – A study of pollution monitoring from space	Evaluate the contribution that EO can make to the routine surveillance of pollution in the marine environment	European Environment Agency and Meditteranean regional governments	Europe (Meditterane an and Baltic)	H. Snaith
COASTLOOC	Coastal surveillance through observation of Ocean colour	Develop the necessary tools for exploiting the new potential from ocean colour technique		Europe	M. Babin
COLORS	Coastal region long-term measurements for colour remote sensing development and validation	Development and assessment to retrieve remote sensing atmospheric and marine products	Research community and Cal/Val	Europe and N.E. Atlantic	J. Aiken S. Boxall
GANES	Global assimilation applied to modelling of European shelf seas	Utilisation of EO and oceanic in-situ data to enhance the effectiveness of predictive models in near-coastal waters.	Research/global climate change	Global	D. Webb
ICAMS	The Integrated Coastal Analysis Monitoring System	Integration of multi-parameter EO data with in-situ measurement to monitor turbidity, temperature, chlorophyll and primary production.	Commercial end user targeted	Eastern Mediterrane an and Irish Sea	-
NEUROSAT		The use of Neural Networks to estimate and analyse atmospheric and oceanographic parameters from EO data - primarily wind vectors from ERS1/2 and N.Scat data.	French Hydrographic Service and Meteo, France	Europe	-
OILWATCH		Operational spill monitoring service based on the use of space-borne SAR data.		Europe	R. Freeman
OMEX	Ocean Margin Exchange	To study biogeochemical fluxes and processes	Research community	Global	P. Miller
RESSAC	Remote sensing support for analysis of	To introduce EO methodologies and techniques to the Israel Min. of Env. in order to	Israeli Ministry of the Environment.	Eastern Mediterrane an	

	coasts	provide new tools in support of its activites related to environmental planning I coastal regions.			
SALMON	Satellite remote sensing for lake monitoring	Multisensor approach to monitor lake-environments and improve the management of the resource.	Swedish Met and Hydro. Service, Local Water Authority in Italy, Finish Forestry Inst.	Italy, Finland, Sweden	

Also consulted: Dr. Bryan Lawrence – BADC