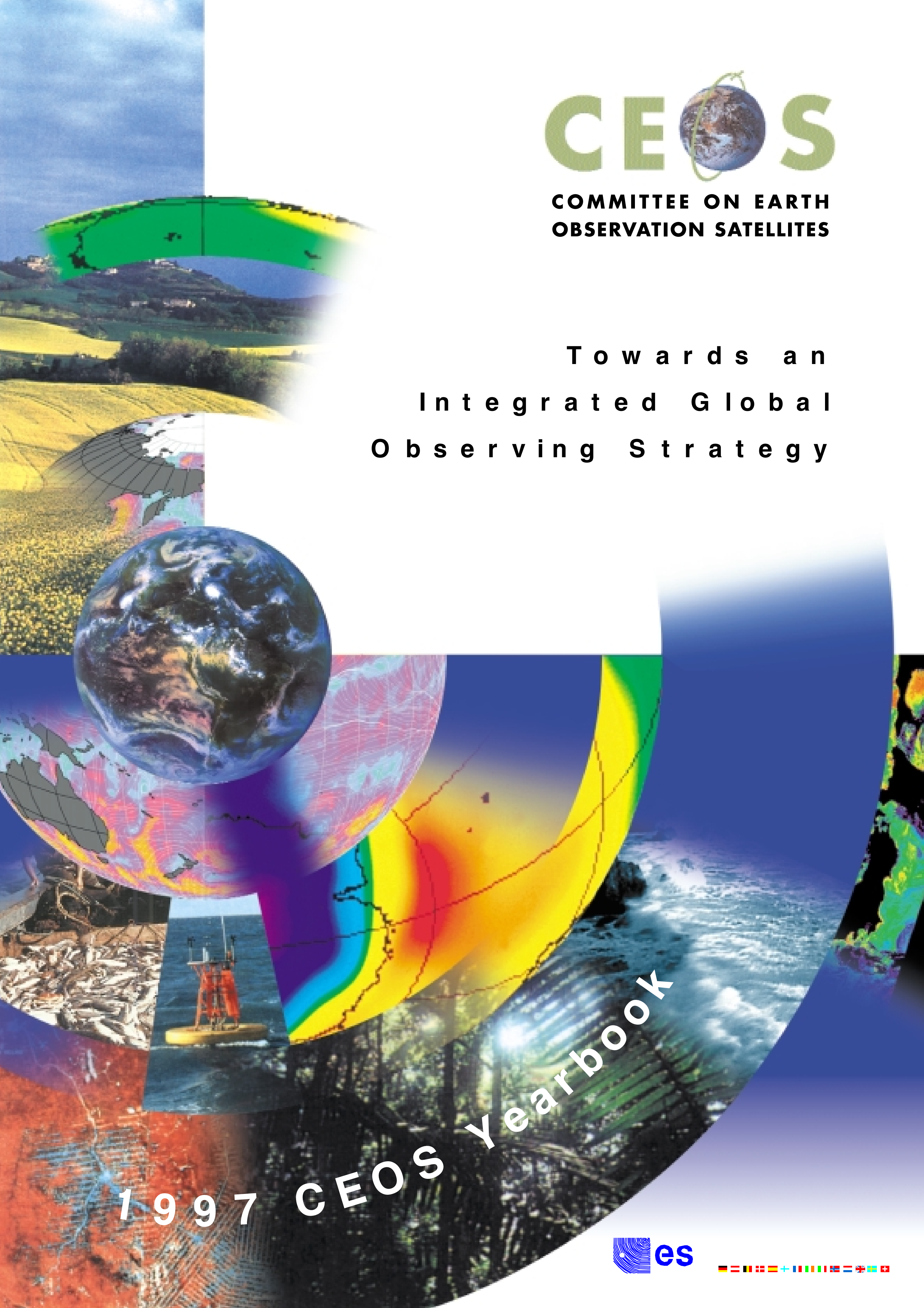
CEOS

COMMITTEE ON EARTH OBSERVATION SATELLITES

Towards an Integrated Global Observing Strategy



1997 CEOS Yearbook

esa

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Foreword


IMAPRESS/PATRICK GELY

Data from Earth Observation satellites are an important source of information for many research and operational applications at local to global scales. They help us improve our understanding of planet Earth, support its conservation through the preparation of governmental decisions on issues such as global climate change and sustainable development, and improve the quality of our lives. The major aim of the Committee on Earth Observation Satellites (CEOS) is to achieve international co-ordination in the planning of Earth Observation satellite missions and to maximize the world-wide utilisation of data from these missions.

Providing the necessary global observations requires programmes on a scale which no single nation or agency can achieve. Further, contributions from many different observing systems are required to address the diversity of users' requirements, spanning both space-borne and in-situ Earth observing systems. Recognizing this, CEOS and the International Group of Funding Agencies for global change research (IGFA), and other organisations, are pursuing the development of an Integrated Global Observing Strategy (IGOS). An IGOS will provide an over-arching strategy for observations to allow organisations involved in the collection of data to extend their contribution, and to assist user groups requiring information from these systems to specify their requirements in a synergistic way.

In light of the ongoing IGOS development it gives me great pleasure to present the 1997 CEOS Yearbook, prepared by the European Space Agency (ESA) on behalf of CEOS. The report presents the status and perspectives of the IGOS discussions, the main capabilities of Earth Observation satellites and their major current and future applications, and a systematic overview of present and planned Earth Observation satellite missions and their instruments.

This report will be a valuable source of information for a variety of users, spanning the wide range of requirements from Earth System research to decision-making in political and socio-economic sectors.
I hope that it will support the work of regional, national and international organisations responsible for planning and co-ordinating future observation programmes to meet the users' requirements in an efficient and effective way.

Antonio Rodotà
Director General
European Space Agency

1 Introduction

1.1 THE NEED FOR GLOBAL OBSERVATIONS

Increased awareness of the stresses being placed on the Earth System, often induced by human activity, has heightened the need for information on the current state of the Earth System and for enhanced capability to assess its evolution so that governments and policy makers can make well informed decisions relating to issues such as: environmental pollution; natural resource management; sustainable development; and global climate change.

Governments are primarily concerned with national development needs, but there is an increasing realisation that many of the relevant issues transcend political boundaries and are, in fact, global by nature. This realisation has resulted in increased political and legal obligations on governments and national and regional agencies to address Earth System topics of global concern. These obligations are often encapsulated within international treaties, whose signatories have explicit requirements placed upon them.

Many of these treaties call for systematic observations of the Earth to increase our understanding of its processes and our ability to monitor them:

- The UN Framework Convention on Climate Change (FCCC). As its name suggests, the FCCC provides a framework for future agreement and action to achieve "… stablisation of greenhouse gases at a level that would prevent dangerous anthropogenic interference with the climate system." The FCCC contains a commitment to promote and co-operate in systematic observations of the climate system and in the development of data archives and international co-ordination of the relevant programmes.
- The UN Convention to Combat Desertification in those Countries experiencing Serious Drought and/or Desertification, particularly in Africa. The Desertification Convention aims to combat desertification and to mitigate the effects of drought through the establishment of long-term integrated strategies, an important element of which are national action programmes, such as the strengthening of capabilities for assessment and systematic observation, including meteorological and hydrological services.
- The Montreal Protocol of the Vienna Convention on the Protection of the Ozone Layer. The Montreal Protocol sets out specific legal obligations in the form of timetables for the progressive reduction and/or elimination of the production and consumption of certain ozone-depleting substances. Whilst the obligations are in terms of imports and exports of controlled substances, the Protocol does imply that reliable measurements of the ozone layer are required in order to assess the effectiveness of the control measures.
- Agenda 21 and the UN Commission on Sustainable Development. Agenda 21 requires a range of actions to support a comprehensive climate observing system, including closer co-operation in systematic observation of the oceans, and greater use of new techniques of data collection, including satellite-based remote sensing.
- The Inter-governmental Panel on Climate Change, although not part of an international treaty, also explicitly recognises the critical need for systematic observations of the Earth's climate system.

The commitments outlined in these treaties are triggered mainly by concerns about human activities on the Earth System. These commitments require substantial economic, technical and scientific resources for their execution, and action at many levels, including significant programmes of global observations.

This document discusses the need for observations of planet Earth and its environment – both global observations, such as might be required to fulfil the needs of the treaties outlined above, and regional, national and local observations in support of specific environment, development and other issues. A large number of geophysical measurements are required whose spatial and temporal resolutions and accuracies depend on the specific application under consideration.

No single programme or agency can satisfy all of the observational requirements which are necessary for improved understanding of the Earth System. Contributions from many different observing systems will be required to address the diversity of these requirements – spanning both in-situ systems (such as ocean buoy and world-wide weather station networks) and space-borne systems. Optimal integration of these assets requires careful planning and national and international organisations are considering how to derive greater benefit from both current and planned observing systems to address common problems of global concern. In this context, the Committee on Earth Observation Satellites (CEOS) and the International Group of Funding Agencies for global change research (IGFA), together with other organisations, have initiated discussions on the development of an Integrated Global Observing Strategy (IGOS) as an objective of all agencies involved in the collection and analysis of both space-based and in-situ data. Section 3 provides an overview of the current and planned activities related to IGOS.

1.2 OPPORTUNITIES FROM SPACE

As recognised in the international treaties discussed above, Earth observation satellites provide an important and unique source of information for studies of the Earth System. There are currently over 45 missions operating, and around 70 more missions, carrying over 230 instruments, planned for operation during the next 15 years by the world's civil space agencies. These satellites are providing measurements of many parameters of interest to those studying the Earth System and the planned missions will provide a significant increase in data and information over the satellites currently in operation.

Earth observations from satellite are highly complementary to those collected by in-situ systems. In-situ measurements may be necessary for some high accuracy local observations, for the calibration of observations made by satellite and for models of the Earth System. Satellites are often necessary for the provision of synoptic, wide-area information required to put in-situ measurements in the global context required for the observation of many environmental and climatic phenomena.

In the context of use within international environmental treaties, Earth observation by satellite has further attractive features. It is non-intrusive, allowing collection of data to take place without compromising national sovereignty in the way that ground-based measurements or airborne remote sensing might. It is objective in that quantitative measurements can be made by sensors whose properties may be defined and calibrated. It is uniform in that the same sensor may be used at many different places in the world (some of which are inaccessible, making in-situ measurements infeasible) and, as noted above, it provides an inherent wide area capability, offering a synoptic view of large-scale phenomena.

Present-day applications of satellite data are widespread and cover research, operational and commercial activities. These activities are of interest in the global context and the regional, national, and local context where Earth observation data are successfully applied in support of a range of different sectors. A brief subset of successful applications of satellite Earth observation data is listed below:

- climate change research relies on operational and research systems to generate high-quality, consistent, global datasets for use in understanding the global climate system, detection of potential anthropogenic change, validation of climate models, and prediction of the impact of change;
- stratospheric chemistry, particularly related to the ozone hole, benefits from satellite information to monitor and map ozone concentrations and to assist in understanding the fundamental, underlying processes leading to ozone depletion;
- weather forecasts based on Numerical Weather Prediction (NWP) utilise, amongst other things, operational satellite measurements of both surface and upper air winds and atmospheric temperature fields;
- agriculture and forestry services utilise satellite data to provide, amongst other products, mapping information, crop health statistics, yield predictions, harvest optimisation, and estimated rainfall amount;
- resource mapping utilising very high resolution satellite data, when combined with conventional survey techniques, provides information needed to locate both renewable and non-renewable resources, such as mineral deposits, and a cost-effective means of mapping large, sometimes inaccessible regions;
- hazard monitoring and disaster assessment schemes are in place which incorporate satellite data to provide wide area coverage of, amongst other things, volcano plumes and areas stricken by drought or earthquake;
- ice monitoring with satellite data is provided as an operational service in many parts of the world affected by sea ice and results in improved safety and reduced operating costs through optimum routing for ships through ice fields;
- coastal zone management benefits from satellite information on parameters such as water quality, suspended sediment and sea surface temperature. These can be used to monitor river outflow and track oceanic features. In addition, satellites generally provide much superior sampling compared with conventional surveys;
- oceanographic applications include provision of more accurate information on likely fishing grounds (based on sea surface temperature), ocean wave forecasting for ship routing, measurement of the sea floor topography for off-shore exploration, and oil slick pollution monitoring.

International investment in satellite platforms and instruments and the associated ground segments is already substantial. More investment is planned over the coming years and CEOS will continue to play a key role in co-ordinating these investments, through its principal objectives outlined in section 2 and through partnership within an IGOS (see section 3), in order to ensure full realisation of the benefits of this truly international activity.

1.3 SCOPE AND CONTENTS OF THIS REPORT

The 1997 CEOS Yearbook presents the status and a perspective for the development of an Integrated Global Observing Strategy (IGOS). In addition, it presents the current status and plans for future Earth observation satellite missions of CEOS Members and describes how the data and information which they supply relate to world-wide needs for information on Earth System processes – in support of significant objectives of national and international concern. The report approaches the subject by clearly illustrating the contributions from satellite on a measurement-by-measurement basis.

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

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

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

Section 2 gives an overview of the organisation, activities, and achievements of CEOS. Section 3 discusses the Integrated Global Observing Strategy (IGOS) - which is an initiative of CEOS and IGFA, together with other international agencies. The capabilities of satellites in providing observations of the Earth are explained in section 4 – including information on the different types of missions and instruments which are current or are planned. Section 5 relates the measurements of these instruments to the need for observations of the Earth.

The annexes include:

A Catalogue of satellite missions

B Catalogue of satellite instruments

C CEOS membership details

D CEOS Affiliates: environmental programmes and agencies

E Abbreviations

F CEOS information on the net

G CEOS agencies on the net

2 CEOS

2.1 OVERVIEW

The Committee on Earth Observation Satellites (CEOS) was created in 1984, in response to a recommendation from a Panel of Experts on Remote Sensing from Space, under the aegis of the Economic Summit of Industrialised Nations Working Group on Growth, Technology and Employment. This group recognised the multidisciplinary nature of satellite Earth observation and the value of co-ordinating international mission plans. CEOS has since established a broad framework for co-ordination across all space-borne Earth observation missions.

CEOS has three primary objectives:

– to optimize the benefits of space-borne Earth observations through co-operation of its Members in mission planning and in the development of compatible data products, formats, services, applications, and policies;

– to aid both its Members and the international user community by, inter alia, serving as the focal point for international co-ordination of space-related Earth observation activities, including those related to global change;

– to exchange policy and technical information to encourage complementarity and compatibility among space-borne Earth observation systems currently in service or being developed, and the data received from them; issues of common interest across the spectrum of Earth observation satellite missions will be addressed.

Individual members of CEOS use their best efforts to implement CEOS recommendations in their respective Earth observation programmes.

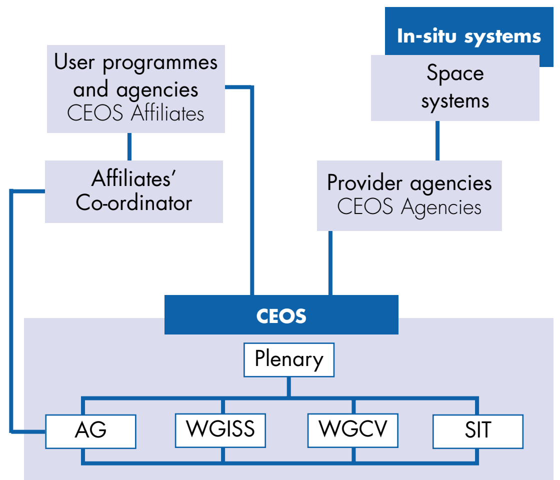
Since its inception, CEOS Membership has grown to encompass all the world's civil agencies responsible for Earth observation satellite programmes, along with agencies that receive and process data acquired remotely from space. At its 1990 Plenary meeting in Brazil, CEOS enhanced its outreach to include international user organisations - including scientific, policy, and inter-governmental groups such as the World Meteorological Organization and the Global Climate Observing System, which now have Affiliate status in CEOS (CEOS Affiliate programmes are described in Annex D). Governmental organisations that are developing a space segment or have significant ground segment activity can also to become Observers of CEOS.

2.2 CEOS STRUCTURE

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

At the highest level within CEOS, the Plenary session meets once per year and brings together all Member, Affiliate, and Observer agencies (annex C) – providing them with a valuable forum to exchange information on relevant national/regional plans and activities, to discuss the impact of relevant developments world-wide, and to review progress on the various projects and activities being undertaken within the CEOS working groups and task forces.

The current working level organisation of CEOS is shown below.



There are currently two standing working groups:

1) the **Working Group on Information Systems and Services (WGISS)** which has the goal of co-ordinating and standardising EO data management and services, addressing the needs of: data providers by assisting them to improve the efficiency of their operations and maximising the utilisation and benefit of the EO data which they gather; and data and information users by providing simpler and wider access to the resources which they require.

WGISS has subgroups tasked with:

– enabling EO data and information services to be more accessible, interoperable and usable to data providers and users world-wide through international collaboration (Access Subgroup);
– enhancing the complementarity, interoperability and standardisation of EO data and information management and services (Data Subgroup);
– fostering easier exchange of EO data and information through networks and other means, to meet the requirements of users and data providers (Network Subgroup).

More detail on the activities of WGISS and its subgroups can be obtained from: http://earth1.esrin.esa.it/wgiss

WGISS places great emphasis on the use of demonstration projects involving user groups to solve the critical interoperability issues associated with the achievement of global services.

2) to ensure the quality, accuracy and long-term confidence in EO data products the **Working Group on Calibration and Validation (WGCV)** provides a focus for co-ordination and co-operation in activities related to calibration and validation (cal-val) of Earth observations, and has the following subgroups:

– Terrain Mapping Subgroup;
– Microwave Sensors Subgroup;
– SAR Calibration Subgroup;
– Infra-red and Visible Optical Sensors Subgroup.

In 1997, the WGCV undertook a new three year work-plan, including the establishment of a new WWW homepage (http://www.eos.co.uk/ceos-calval)

One of the activities of the WGCV is to provide the science community with information on existing and planned cal-val laboratories, test sites, and field instruments. An information service is available through the WGCV Infoserver.

WGCV's current focus is validation pilot projects and collaborative efforts to identify protocols and methods for the validation of high level EO satellite data products (such as sea surface temperature, digital terrain models, etc).

At the 10th CEOS Plenary in Canberra, November 1996, a **Strategic Implementation Team (SIT)** was established to develop further and implement the space component of an overall IGOS - as well as to investigate the practical, political, and programmatic mechanisms for CEOS agencies and partners to act upon recommendations regarding correction of gaps/overlaps in observing programmes.

To provide the Plenary and the SIT with the analysis of the extent to which the existing and planned space segment missions are meeting the identified international and national user requirements, the Plenary also established an **Analysis Group (AG)** comprising both provider and user agencies. The activities of the AG are designed to build upon past work in this area undertaken by CEOS Members and Affiliates and to complement Affiliates' plans for carrying out comparative analyses of requirements versus provision so as to avoid duplication of effort. Since their establishment, both the SIT and the AG have focused their activities around specific projects which are described in more detail in section 3.

2.3 CEOS ACTIVITIES

The CEOS Dossier and its development

CEOS is widely recognised as the main international forum for the co-ordination of Earth observation satellite programmes and for the interaction of the space agencies with users world-wide. The CEOS Dossier, a precursor to this Yearbook, has proved to be a key input to this co-ordination and user interaction and was first produced in 1992.

Since that time, the dossier has been updated regularly, improved, expanded and made available in different formats. The first interactive version was made available at the 1994 CEOS Plenary in order to enable users to identify rapidly data sources which might meet their data needs.

Recognising the potential of the Dossier as a powerful tool to assist future EO mission planning on a global scale, and to optimise the investments made by CEOS Members and Affiliates, the 1994 CEOS Plenary established a CEOS Task Force on Planning and Analysis to improve and further develop the Dossier concept, primarily through an electronic database version.

The result is a comprehensive dataset of CEOS agency programmes and instrument performances and CEOS Affiliate requirements. This database is available in two forms:

- an on-line system available via the World Wide Web;
- as a PC-based system for local use;

both of which support the need for information on EO mission plans, and the need for comparison with user programme requirements to assist co-ordination in programme planning - such as in the IGOS initiative. The two versions of the database are fundamental to the work of the CEOS AG and it is using both specific implementations of the core dataset and a number of other tools to carry out its work (see section 3).

The on-line version developed by ESA, is available at http://ceos.esrin.esa.it/dossier and the PC version is available from the WMO (see annex F for contact details). Both versions of the database form the definitive reference guide to Earth observation programmes and plans of governments world-wide.

CEOS also recognises the benefits of providing a "hard-copy" condensed summary of the detailed information contained within the CEOS database (much along the lines of the original Dossier) and indeed this is contained within this Yearbook, primarily in section 5 and Annexes A and B.

More details on the development of the CEOS database can be found in Annex A.

On-line services

CEOS agencies have sponsored the development of a number of on-line network data and information services to promote awareness and education concerning satellite Earth observation, to facilitate access to information about the data available, and to maximise utilisation of that data world-wide.

The CEOS International Directory Network (IDN) provides on-line access to information on multi-disciplinary scientific data held world-wide. Its goal is to permit rapid identification and location of in-situ and remotely sensed data held by government agencies, research organisations and academic institutions.

The IDN offers information on over 5,000 relevant datasets, plus details of data centres world-wide, campaigns and projects, and satellites and instruments.

The heart of the IDN consists of 4 co-ordinating nodes (held by NASA (USA), NASDA (Japan), ESA (Europe), and UNEP) which provide duplicate databases of directory information on-line for open access. Each co-ordinating node has a number of regional co-operating nodes associated with it which provide a path for local users to access or contribute to the IDN. There are now a large number of such co-operating nodes throughout each region. The WGISS IDN task team is responsible for co-ordinating activities among the nodes to maintain, improve and expand the functions of the IDN and its greater use.

The CEOS Infosys is an on-line information service, available via the World Wide Web which provides comprehensive and up-to-date information on CEOS activities, as well as information on current and upcoming events and initiatives of interest to EO data providers and users world-wide. The CEOS Infosys incorporates the WGISS Yellow Pages - which is a world-wide directory of on-line services for EO data users, and serves as a practical guide for users and potential users as to the availability and use of on-line services for EO data (http://www.smithsys.co.uk/yp). The Yellow Pages gives practical assistance to users to enable them to navigate agency services and to access and utilise available data products. On-line services focused on the needs of developing countries are discussed later in this section.

CEOS Newsletter

The CEOS Newsletter, together with the CEOS Infosys are the primary means of disseminating information about CEOS to its agencies and the EO satellite data user community. The Newsletter provides readers with the latest information about CEOS activities and is distributed internationally to a growing number of subscribers on a 6-monthly basis. To date, 8 issues have been published which currently reach some 3,000 subscribers from CEOS and non-CEOS organisations. As part of its contribution to the CEOS secretariat, STA/NASDA prepares and distributes the newsletter which provides reports on CEOS Plenary meetings, and the activities and achievements of the CEOS working groups, IGOS developments, a calendar of events, and points of contact for further information.

CEOS Newsletter No.8 reports on: the 10th Plenary in Canberra; CEOS and IGOS - The Way Forward; and recent activities of the WGISS and WGCV Working Groups. The next issue is due to be published in September 1997.

The Newsletter is also available at the following web site:
http://www.eoc.nasda.go.jp/guide/guide/committee/ceos/ceosnews_menu_e

Subscription request details can be found in annex F.

Promotion of EO applications

In 1995, the "CEOS Special Report on Successful Applications of EO Satellite Data" was produced, which demonstrated the current level of maturity of satellite data applications and illustrated the potentially significant benefits – in social, economic and environmental terms – across a broad spectrum of sectors such as agriculture, resource management, and civil planning.

This activity was extended in 1996 through the production of a CD-ROM "Resources in Earth Observation" which featured a series of illustrative, practical case studies, plus EO datasets and information, for educational use - particularly in developing countries. The CD may be navigated using WWW browser software, allowing seamless access to the resources stored on the CD and to those on the internet which are identified in the CD.

A further development of the CD-ROM is expected to be produced during 1997 - incorporating a new range of case studies and tutorial materials for users.

2.4 EMERGING INITIATIVES

CEOS agencies are mindful of the need to be responsive to the changes in the requirements of the scientists, operational users and decision-makers which drive their planning of EO satellite mission programmes, and of the global economic and political context in which those programmes must operate.

A number of the more recent initiatives emerging from CEOS which reflect that awareness are discussed below.

IGOS - Integrated Global Observing Strategy

In conjunction with the International Group of Funding Agencies for global change research (IGFA), and other organisations, CEOS has initiated discussions concerning the development of an Integrated Global Observing Strategy (IGOS) for all agencies involved in the collection and analysis of both space-based and in-situ data. CEOS has focused its effort on addressing the space component of an IGOS, including the establishment of six prototype projects designed to demonstrate the value of working within such an integrated framework. Section 3 discusses IGOS in more detail and the work of the groups established by CEOS to develop the concept.

Private Sector Outreach

Although long pioneered and financed by governments, Earth observing satellite programmes are now entering a new era, where both commercial and governmental missions will operate - each with their own target users. 1997 is significant as the year marking the onset of several commercially financed and operated EO satellite missions - many with high resolution imagery capability (of order 1m resolution).

Recognising the need for harmonisation of the government and non-government led activities, CEOS is in the process of initiating an outreach to non-member organisations, such as regional private sector organisations, through a proposed 'dialogue partner' relationship. The practicalities of this idea are currently being explored and the concept will be more fully developed during the coming year.

Frequency allocation planning

The ongoing revolution in global telecommunications, including satellite telecommunications, is placing increasing pressure on use of the electromagnetic spectrum and on the proper allocation of frequency bands in the spectrum to ensure interference-free operation for different services.

EO satellite missions are dependent upon use of radio frequencies for the transmission of data to and from ground stations - and in the case of microwave sensors, as the basic mechanism for their remote sensing operation.

CEOS NEWSLETTER: http://www.eoc.nasda.go.jp/guide/guide/committee/ceos/ceosnews_menu_e

Recognising the need to represent the Earth observation community in bodies such as the International Telecommunications Union, and the World Radio Conference, CEOS is developing plans to identify, co-ordinate, and reflect members' interests in these international organisations. Notably, CEOS and the Space Frequency Co-ordination Group (SFCG) are now establishing mutual, informal, observer status and liaison contacts. CEOS is managing this activity and liaison through an Ad-hoc Co-ordination Group on Spectrum Management (contact details in annex F).

Developing Countries Support

The fundamental aim of CEOS in its developing country activities is to encourage the creation and maintenance of indigenous capability that is integrated into local decision-making processes – thereby enabling developing countries to obtain maximum benefit from Earth observation. Specific actions include:

- improving links and communications;
- improving access mechanisms to relevant data;
- training activities;
- scientist exchange programmes.

1997 sees the launch of the CEOS Information Locator Service (CILS) for developing countries. CILS will provide a network-based means for users in developing countries around the world to access information about satellite Earth observation, and will enable them to enter, administer and share their data and information. CILS will also contain information of special interest to developing countries and provide relevant points of contact.

With a view to improved harmonisation of efforts, CEOS is currently in the process of reviewing and documenting members' interests and resources applied in support of developing countries.

These activities will be presented in a dedicated annual report which will be submitted for the first time to the 1997 CEOS Plenary.

CILS: http://cils.dlr.de
http://cils.jrc.it
http://cils.unep.org
http://cils.eoc.csiro.au

3 The Integrated Global Observing Strategy (IGOS)

3.1 OVERVIEW

National and international organisations are considering how to derive greater benefit from both operating and planned observing systems, in support of increasing applications of global Earth observations. This assessment is occurring in an environment that demands adoption of performance measures congruent with agency needs for continuous improvement. The Committee on Earth Observation Satellites (CEOS) and the International Group of Funding Agencies for global change research (IGFA), with other organisations, have initiated and participated in international discussions with the aim of outlining possible ways to improve the integration of global observation activities.

One of the prime drivers behind the current discussion is the general acceptance that no single nation can satisfy all of its observation requirements. The need for co-operation between data-provider agencies also arises from the fact that contemporary data products often require the integration of multiple observations from multiple sources. The scarcity of financial resources is yet another compelling reason for improved co-operation.

3.2 AIMS

An Integrated Global Observing Strategy (IGOS) should be the joint product of all agencies involved in the collection and analysis of both space-based and in-situ data. For an IGOS to be successful, agencies must recognise and mutually support integration of the roles of partner organisations. Discussions on the concept of an IGOS have highlighted the need for better agency interactions, both at the national and the international level. A key characteristic will be the achievement of outcomes that are beyond the present capabilities of existing observing systems. An IGOS will provide an over-arching strategy for observations to allow organisations involved in the collection of data to extend their contribution, and assist user groups requiring information from the systems to specify their requirements in a synergistic way. An IGOS must build upon the strategies of existing international global observation programs. It should also build upon current achievements, with additional efforts being directed to focus on those areas where satisfactory international arrangements and structures do not currently exist. A successful IGOS will help nations make better decisions in the allocation of resources to meet their own priorities, by taking advantage of better international collaboration and co-operation.

3.3 PARTNERSHIP

In discussions since late 1995, CEOS has appropriately focussed its attention on the space component of an IGOS. However, it recognises that an IGOS, by its very nature, must incorporate user requirements for all sources of Earth observation data. IGFA has recognised the importance of adequate spatial and temporal resolution in global observations for global change research to facilitate improvements to the prediction of global change and to the assessment of impacts and mitigation/adaptation strategies.

A key to the initiation of activities in support of the goals of an IGOS will be the commitment of agencies with responsibilities for space-based data acquisition programs to formulate a structured, coherent set of observational strategies, which transcend national requirements. Integration of relevant non-space data should be a key element in an IGOS. A full partnership is required involving:

(1) those international, regional and national organisations with responsibilities for providing in-situ observations;

(2) space agencies;

(3) science funding agencies; and

(4) agencies with operational responsibilities.

The requirements definition for an IGOS must be user driven and address the political protocols and conventions, eg IPCC and Agenda 21, as well as programmatic support for specific research and operational activities. The detailed products and services to be developed within the concept of an IGOS will be in response to requirements specified by user communities.

CEOS, IGFA, and others have identified several high level attributes, or goals, that reflect the value of an IGOS which, whilst applicable to space data, are also valid for many aspects of non-space data:

(i) provide a framework for a coherent set of user requirements so that providers can respond to them;

(ii) reduce unnecessary duplication of observations;

(iii) assist in the improved allocation of resources between different types of observation systems;

(iv) make possible the creation of improved higher level products by facilitating the integration of multiple datasets from different agencies and national and international organisations;

(v) provide a framework for decisions on continuity and spatial comprehensiveness of key observations;

(vi) identify situations where existing international arrangements do not exist for the management and distribution of key global observations and products;

(vii) assist in the transitioning of systems from research to operational status through improved international co-operation;

(viii) provide improved understanding for Governments on the need for global observation through the presentation of an over-arching view of current system capabilities and limitations.

IGFA has joined CEOS in a Strategic Implementation Team (SIT) to progress the development of an IGOS. As Affiliates of CEOS, a number of international scientific and inter-governmental user organisations, including the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), and the Global Terrestrial Observing System (GTOS), are also participating in the SIT. The team's primary purpose is to agree on and implement a work program supported by participating organisations that reflects their capabilities, strengths and objectives, whilst demonstrating the enhanced benefits to be gained through mutual co-operation in the planning and use of integrated global observations. The work of the SIT will set the framework for the implementation of the responsibilities of each of the participating agencies.

Acutely aware that the IGOS concept does not belong to any single nation, agency or organisation, CEOS and IGFA are proposing an expanded partnership to evolve ideas on the definition, characterisation and vision of an IGOS. In particular, it is noteworthy that the Sponsors of the Global Observing Systems (G3OS, ie GCOS, GOOS and GTOS) at their first meeting, 13-14 January 1997, discussed the elements and issues that should be included in an integrated global observing strategy as an umbrella for the three Observing Systems and other international observation activities. WCRP, IGBP and other science and operational entities also have key roles to play. Integrated global observing can succeed only through the development of a synergistic partnership amongst funding agencies responsible for the provision of space-based and in-situ observations, user organisations, and user communities.

As an outcome of its first meeting in Irvine, California February 1997, the SIT, in consultation with G3OS scientists, agreed to pursue six prototype projects of international dimension designed to demonstrate the accrued value of working within an IGOS framework. Appended is a listing of the projects, together with identified (to this date) provider and user participant organisations. While the initial projects vary greatly with regard to scope, they were selected on the basis of degree of political and societal importance, the feasibility of early and tangible accomplishments, the clear need for an integrated global strategic approach and the existence of agencies willing to take the lead in developing a partnership.

The Global Ocean Data Assimilation Experiment, for example, builds upon a set of operational requirements well articulated within the global ocean community and is being developed as a high priority requirement of the GOOS/GCOS/WCRP Ocean Observations Panel for Climate. As a further example, the Upper Air Measurements Project was included in response to an invitation by the Director of the WMO World Weather Watch to the SIT. The project will investigate the planned reduction in upper-air observations due to the termination of the OMEGA navigational system, and the means to increase the quantity and quality of observations through the use of new technology from satellites, aircraft and 4-D assimilation methods.

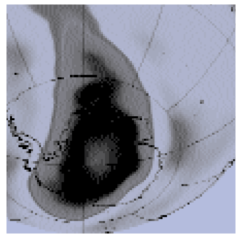
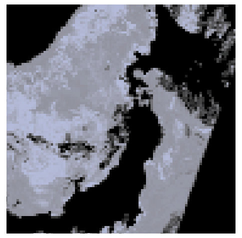
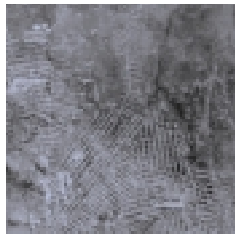
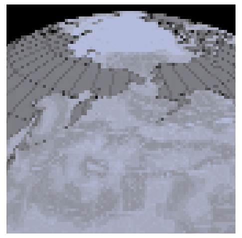
3.4 NEXT STEPS

CEOS and IGFA now propose to advance on two fronts in implementing IGOS:

(1) The SIT will refine and further develop the six prototype projects. The projects are proceeding through a series of workshops and are supported by the work program of the CEOS Analysis Group, in consultation with the Global Observing System Space Panel (GOSSP), of the G3OS. The status of the projects will be reviewed at the SIT meeting in Oxford, UK, in September 1997, and at the IGFA Plenary in October and the CEOS Plenary in November.

(2) Extend the dialogue beyond CEOS and IGFA to develop the IGOS concept and associated prototype project activities in a partnership environment involving other organisations. To achieve full partnership it is important that international science and inter-governmental user organisations, in particular the G3OS and their sponsors, as well as WCRP and IGBP, are involved in the process.

This is planned to proceed as follows: the CEOS and IGFA Chairmen have contacted senior officials of the G3OS and other science and user organisations to propose informal discussions on the IGOS concept. Informal IGOS discussion has already taken place at the invitation of the FAO, in Rome mid-May, timed with a meeting of the GTOS Steering Committee. The CEOS Chair addressed the WMO Executive Council in Geneva in mid-June on the topic of an IGOS. A further informal discussion occurred late June in Paris, hosted by GOOS/IOC and ICSU. An informal discussion amongst prospective IGOS partners was also arranged in Paris by the CEOS Chair in late June and further discussions were held in mid-September. A further opportunity to develop the partnership concept will occur in mid-September at an UNEP-hosted meeting of the G3OS Sponsors Group in Geneva.

3.5 SUMMARY OF INITIAL IGOS IMPLEMENTATION PROJECTS

GLOBAL OCEAN DATA ASSIMILATION EXPERIMENT

Issue: Need an integrated suite of remote (and direct) measurements of the ocean for real-time assimilation, interpretation, and application. The project will provide a regular, global depiction of the ocean circulation, from climate down to ocean eddy scales, consistent with the measurements and appropriate dynamic and physical constraints.

Tools Needed: Real-time satellite data stream; global in-situ observing system; assimilation to exploit integrated data stream; models and computer for production and output; high bandwidth communications

Partners: GOOS/GCOS/WCRP OOPC, CNES, ESA, NASA, EUMETSAT, NOAA, NASDA

Products/Results: Global analyses/forecasts based on limited models, data streams; global products at reduced resolution (time and space); global reports based on past remote sensing & in-situ data; global eddy-resolving analyses with reduced physics, dynamics, assimilation; some regional analyses/forecasts based on enhanced data models.

UPPER AIR MEASUREMENTS

Issue: Ground-based radiosonde observations and omega sondes are being reduced and could impact upon numerical weather prediction models.

Tools Needed: In-situ and satellite data of tropospheric winds and profiles of temperature and specific humidity.

Partners: WMO, NOAA, EC, ESA, NASA, CNES, EUMETSAT, ECMWF

Products/Results: New/improved satellite-derived products assimilated into operational models.

LONG-TERM CONTINUITY OF OZONE MEASUREMENTS

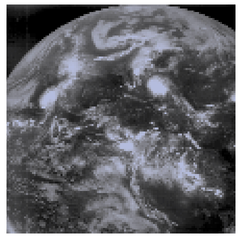
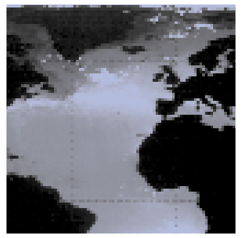
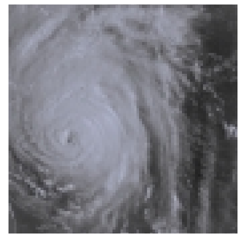
Issue: No long-term strategy for continuity of stratospheric ozone observations.

Tools Needed: Space and ground-based measurements of total ozone and vertical profiles; ground-based measurements of both ozone and spectrally resolved surface UV; space-based full daily global coverage total ozone; vertical profiles of ozone and other species, and temperature

Partners: WMO/IPCC, ESA, NASA, EUMETSAT, DARA, CNES, NOAA, NASDA, ASI, CSA/AES

Products/Results: Commitment by identified agencies to long-term total ozone and ozone vertical profile measurements and data exchange.

GLOBAL OBSERVATION OF FOREST COVER

Issue: Monitoring of forest cover and its changes is essential to a variety of issues, including land cover change, biodiversity, and renewable energy resources. There is no systematic plan for routine acquisition and analysis of data on global forest cover from optical and microwave satellites.

Tools Needed: Optical and microwave imaging satellites (already in existence and planned); acquisition stations & processing facilities

Partners: GCOS/GTOS TOPC, IGBP LUCC, FAO, CSA/CCRS, INPE, ESA, EC, NASA, CNES, EUMETSAT, ASI, NASDA, NOAA

Products/Results: Database of georeferenced high resolution data with periodic systematic coverage of all forested areas globally; periodic analysis of change on regional and global scale

LONG-TERM OCEAN BIOLOGY MEASUREMENTS

Issue: Multiple ocean colour sensors in operation and planned need co-ordinated strategy to support data needs for scientific studies of ocean biogeochemical and ecosystem processes.

Tools Needed: Satellite & in-situ observations; co-ordinated cal/val campaign

Partners: GOOS, IOC, NASDA, NASA, CSA, EC, DARA, ESA, NOAA, CNES, WGISS, WGCV

Products/Results: Internationally co-ordinated calibration/validation program to understand regional influences and variations in the ocean environment; integrated database with in-situ and satellite data; multi-sensor data streams and products.

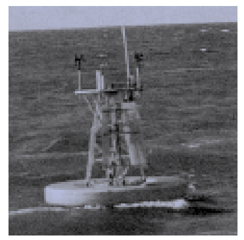
DISASTER MANAGEMENT SUPPORT

Issue: Earth observation satellite data is not being fully utilised to support disaster prediction, monitoring, and mitigation on a world-wide basis.

Tools Needed: Information systems to locate, acquire, reformat as necessary, and deliver Earth observation satellite data products rapidly to emergency response authorities; improved understanding of the requirements of emergency response authorities.

Partners: NOAA, EC, ESA, BNSC, ASI, STA/NASDA, NASA, CSA, CNES, WGISS, CCRS, Council of Europe, DARA, ESCAP, EUMETSAT, GTOS, IDNDR, INPE, RPA PLANETA, WCRP, WMO

Products/Results: Work with subset of agencies with broad geographic responsibility to develop an initial requirements and capabilities profile for the contribution of EO satellite data; and to implementation of a capabilities demonstrator.

4 Capabilities of Earth observation

A variety of instruments are flown on space missions, employing both active and passive sensing technology, covering a wide range of the electromagnetic spectrum.

These instruments provide information on a diverse range of geophysical parameters and phenomena; information which is of value to disciplines such as:

- atmospheric chemistry;
- atmospheric physics;
- oceanography;
- ocean biology;
- land studies;
- climate studies;
- solid Earth studies.

Meteorology is recognised to be the most established discipline for application of EO satellite data, with satellite-derived information being used operationally by weather services world-wide. Dedicated meteorological satellites have been in operation providing continuous coverage of much of the globe for many years.

Following in the pioneering footsteps of meteorology, a growing number of applications are finding value in the unique perspectives offered by satellite Earth observation, including agriculture, resource management, exploration, mapping and planning, and hazard monitoring and disaster assessment. Given the global data collection capabilities offered by EO satellites, many applications are of direct relevance to international issues such as climate change and sustainable development. But equally, information from EO satellites is contributing successfully to national and local needs. As a result of sustained investment by space agencies information derived from EO satellites is proving to be of direct benefit in both public and commercial spheres. This trend is highlighted by the number of missions dedicated to specific applications and the improvements in sensing technology and techniques, such as higher spatial resolution. Furthermore, developments in IT and telecommunications technology are leading to reduced EO data handling costs and enabling EO information to be exploited more widely and more effectively.

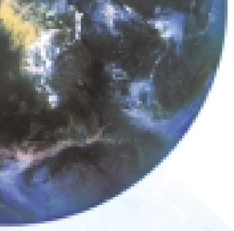
CEOS agencies are planning more than 70 missions for operation over the next 15 years, carrying over 200 different instruments - of these, some 120 will comprise instruments from existing instrument series and over 80 instruments will be new. These instruments will provide measurements of many parameters of interest to those studying the Earth's environment (see section 5 for more details). Information on these missions and instruments, their capabilities and their applications is given in annexes A and B.

For ease of discussion, the different instruments listed in annex B may be arranged into the list of categories indicated in the panel below:

INSTRUMENT CATEGORIES
Atmospheric chemistry instruments
Atmospheric sounders (IR & microwave)
Cloud profile and rain radars
Earth radiation budget radiometers
High resolution imagers
Imaging multi-spectral radiometers (vis/IR)
Imaging multi-spectral radiometers (microwave)
Imaging radars
Lidars
Multi-directional radiometers
Ocean colour radiometers
Polarimetric radiometers
Radar altimeters
Wind scatterometers

Plans for future missions and instruments include demonstrators of new and potentially valuable technology such as cloud radars and lidars. They also include the continuation of existing satellites to provide long-term datasets such as those data provided by the NOAA polar orbiter series.

The following section gives a brief discussion on the different types of instruments which feature on Earth observation missions, including a list of the relevant instruments of this type from the full catalogue in annex B, a description of the operational characteristics, and pointers to the key areas of application in each case. For further details of these application areas, the reader is referred to section 5.



Atmospheric chemistry instruments

INSTRUMENT CATALOGUE

- COALA
- DOPI
- GOME
- GOME-2
- GOMOS
- HALOE
- HiRDLS
- HRDI
- IASI
- ILAS-II
- ISTOK-1
- MASTER
- MIPAS
- MLS
- MOPITT
- Ozon-M
- SAGE III
- SBUV/2
- SCIAMACHY
- SFM-2
- SOPRANO
- TES
- TOMS
- UV-visible spectrometer
- WIND II

DESCRIPTION

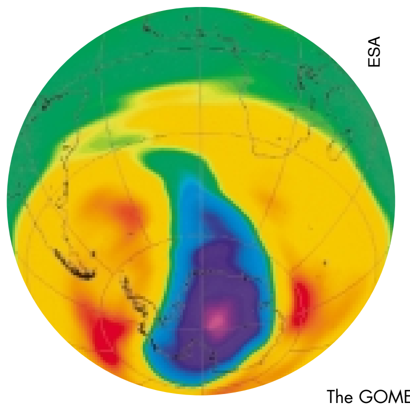
Atmospheric trace gases may be observed by detecting absorption or emission from their characteristic spectral lines. Atmospheric chemistry spectrometers and radiometers rely on this to provide information about the chemical composition of the atmosphere from passive measurements of the radiation present over a range of wavelengths, between the UV and microwave.

Relatively broad-band radiometers may be used to detect the strong bands observed from ozone. For many other trace gases, however, high spectral resolution spectrometers are required since only very weak lines are available, and these are generally embedded in the continuum of lines from more abundant gases such as water vapour and carbon dioxide.

The instruments are conventionally used in either nadir or limb-viewing mode:

- Nadir instruments look directly down at the Earth and measure the radiation emitted or scattered in a small solid angle centred about a given spot on the Earth - they typically provide high horizontal spatial resolution, but are limited in vertical resolution.

- Limb viewing instruments, by contrast, scan positions beyond the horizon so as to observe horizontal paths through the Earth's atmosphere at different altitudes - this geometry allows for very high vertical resolution, of order a few km, and is particularly useful for studying the middle atmosphere, although horizontal resolution is limited to around 300km. Limb viewing allows measurements in either emission or absorption mode. Occultation (absorption), techniques rely either on the Sun or other stars as the radiation source.



ESA

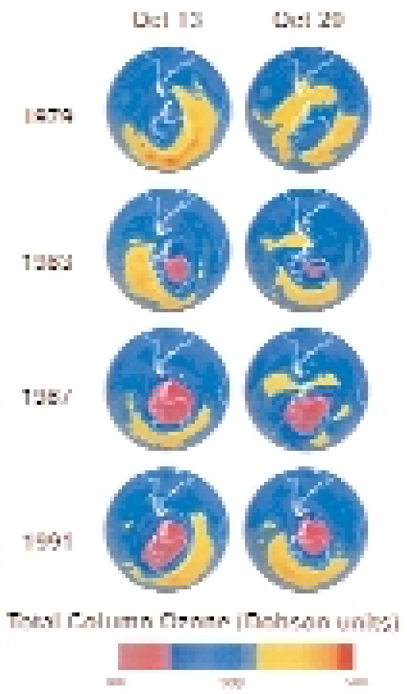
The GOME spectrometer monitors global ozone levels on a daily basis

APPLICATIONS

Measurements from atmospheric chemistry instruments are for the first time providing a global picture of the atmosphere and how it is varying on a daily, seasonal and geographical basis. These measurements have applications in a wide range of fields from monitoring emissions from volcanic eruptions through to climatology and operational meteorology.

Historically, atmospheric chemistry spectrometers and radiometers were first used to monitor stratospheric ozone levels. Increasingly, instruments are now becoming available which offer information on other trace gases, including greenhouse gases which affect climate change, chemically active gases which affect the environment, and other gases and radicals impacting on the ozone cycle which therefore affect both climate and the environment.

In the future, the vertical resolution of these instruments is likely to increase to up to 1km. In addition, an extension of the measurements towards the lower atmosphere will allow for improved pollution monitoring capabilities and modelling of atmospheric processes. Better radiometric accuracy will also be achieved through improvements to light diffusion apparatus within some instruments.



NOAA

TOMS instrument data has recorded long term observations of Antarctic ozone depletion

IASI: http://www-projet.cst.cnes.fr:8000/iasi/mission
HIRDLS: http://webserver.gsfc.nasa.gov/csfp/hirdls/hirdls
TOMS: http://jwocky.gsfc.nasa.gov

WINDII: http://www.cress.yorku.ca/windii/windii
HRDI: http://www.sprl.umich.edu/HRDI/hrdi_homepage
GOME: http://pooh.esrin.esa.it:8888/eeo/fr/eeo4.63/eeo4.96

Atmospheric sounders (IR & microwave)

INSTRUMENT CATALOGUE

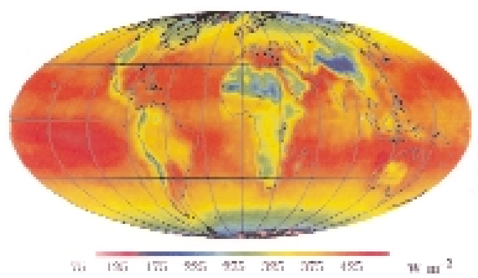
- 174-K
- AIRS
- AMSU
- AMSU-A
- AMSU-B
- GRAS
- HIRS/2
- HIRS/3
- HIRS/4
- HSB
- IASI
- IR imager
- MASTER
- MHS
- MIVZA
- MSU
- MTVZA
- MWR
- Radiometer
- SOUNDER
- SSU

DESCRIPTION

IR and microwave atmospheric sounders provide information on the distribution of radiation emitted by the atmosphere from which vertical profiles of temperature and humidity through the atmosphere may be obtained. In general, sounders operate in nadir viewing mode and perform passive measurements of the radiation only in a finite number of channels aligned with the spectral features associated with the species under observation.

Sounders are able to discriminate between radiation coming from different levels in the atmosphere by observing the spectral broadening of an emission line. This broadening, which is primarily caused by intermolecular collisions with other species, decreases with atmospheric pressure. The radiation received at the instrument with a wavelength close to the centre of the emission line will hence originate in the upper atmosphere, whilst radiation incident away from centre of the emission line will come from the lower levels in the atmosphere.

Oxygen or carbon dioxide is usually used as a tracer for temperature profiles since it is essentially uniformly distributed throughout the atmosphere, and hence temperature sounders often have a number of channels centred around the oxygen and carbon dioxide emission lines. For humidity profiling, either IR or microwave bands in the water spectrum are used. Although microwave sounders have the ability to sound through cloud and hence offer nearly all-weather capability, their spatial resolution (both vertical and horizontal) is generally lower than that of the IR instruments. IR sounders are routinely used to provide temperature profiles from a few km altitude to the top of the atmosphere with a temperature accuracy of 2 - 3 K, a vertical resolution of around 10km and a horizontal resolution of between 10 and 100km.



NOAA

Global distribution of monthly-averaged downward longwave radiation measured by HIRS - such data are used to validate outputs of weather forecast models

Future sounders such as the interferometer-based IASI are likely to benefit from improvements both in the accuracy of humidity and temperature measurements and also in the vertical spatial resolution. They shall also have better spatial resolution and upper atmospheric sounding capabilities than current instruments. Developments in on-board instrument calibration will also eliminate the need for some internal calibration checks, freeing sensors to gather more data. Future microwave sounders will provide significantly improved global soundings and information on precipitation and ice.

APPLICATIONS

Most atmospheric sounders are carried on polar orbiters although a few are carried on geostationary satellites. The comprehensive global coverage offered by these make them useful for providing inputs to daily weather forecasts. Atmospheric sounders may be used to infer a wide range of key atmospheric parameters. The temperature and humidity profiles obtained from these instruments are used for operational meteorology and to build up a comprehensive weekly, monthly and seasonal database of values. By studying this database, scientists are able to increase their understanding of the global climate which enables them not only to improve their skills for extended range weather and climate forecasting, but also helps them to understand and differentiate important man-made changes in climate from natural variations.

In addition to atmospheric profiles, these instruments may contribute information on the total column, or precipitable, water content of the atmosphere, and on atmospheric discontinuities and instabilities.

Improved understanding of climate variations gained from EO satellites can help mitigate natural disasters such as floods

AIRS: http://www-airs.jpl.nasa.gov
HIRS: http://faster.gsfc.nasa.gov/HIRS/HIRS

SOUNDER: http://www.noaa.gov/news_flash/GOES

Cloud profile and rain radars

INSTRUMENT CATALOGUE
Cloud radar
PR
Rain radar

DESCRIPTION

These instruments are predominantly based on active microwave radar systems. Cloud profile radars use very short wavelength (mm) radar to detect scattering from non-precipitating cloud droplets or ice particles thereby yielding information on cloud characteristics such as moisture content and base height. Rain radars use centimetric radiation to detect backscatter from water drops and ice particles in precipitating clouds, and to measure the vertical profile of such particles.

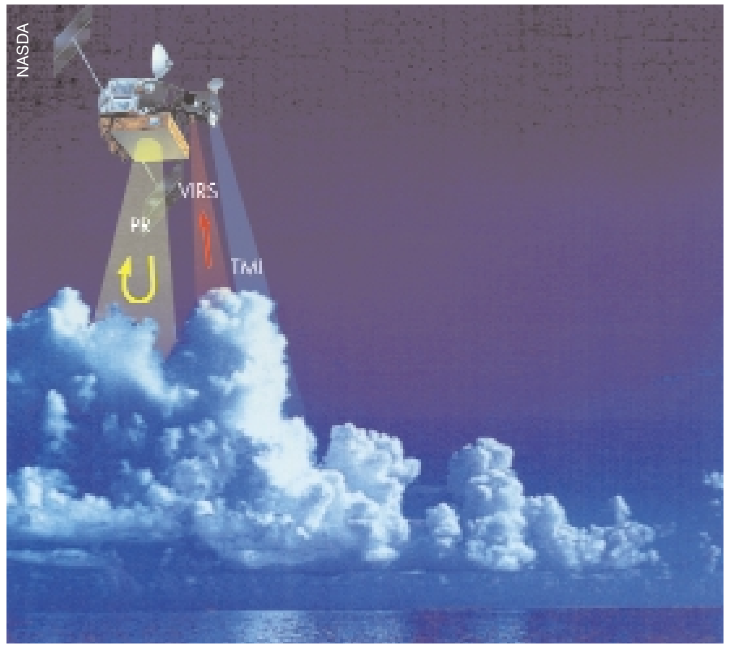
One of the key challenges with rain radars is suppressing the return from surface clutter, which is inevitably much stronger than the rain echo. Radars are now being developed, however, which can map the 3-D distribution of precipitating water and ice in a relatively narrow swath (around 200km) along the track of a low altitude satellite and thereby infer more precise estimates of instantaneous rainfall.

To date, there have been no rain or cloud profile radars flown in space. The NASDA Precipitation Radar (PR) which shall be flown on board the Tropical Rainfall Measuring Mission (TRMM) will be the first space-borne rain radar. TRMM is due to be launched in November 1997. Cloud radars are still at the development stage. Currently, research is being conducted using ground-based and airborne radars to gain a better understanding of cloud properties and their associated radar response, and it is expected that this work will form the basis for specifying a cloud radar instrument. The earliest potential cloud radars are likely to be flown on a future ESA mission.

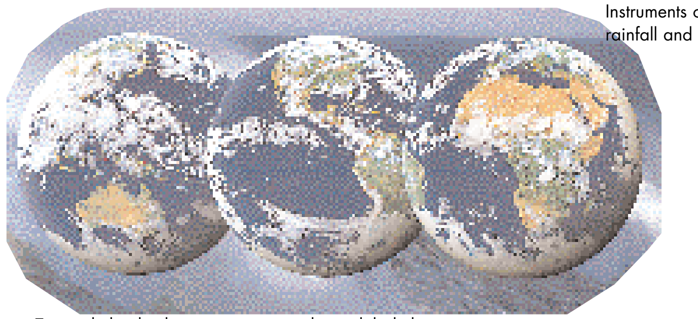
APPLICATIONS

Measurements from cloud radar will give information on cloud type and amount, and more importantly on cloud profile (currently not measured), information which is required both for improving numerical weather prediction and for climate studies. Measurements of liquid water and precipitation rate from space-borne rain radars will also provide a unique source of information, since the ground based rain radars used at present have limited coverage over the oceans. The availability of an extensive global dataset will be a valuable tool for climatologists and will have significant implications for meteorological forecasting.

Information on tropical rainfall is of particular importance, since more than two thirds of global rainfall is in the Tropics, and is a primary driver of global atmospheric circulation.



Instruments on TRMM will provide quantitative data on rainfall and cloud characteristics at tropical latitudes



Tropical clouds play an important role in global climate

PR: http://hdsn.eoc.nasda.go.jp/guide/guide/satellite/sendata/pr_e

Earth radiation budget radiometers

INSTRUMENT CATALOGUE
ACRIM
ACRIM II
CERES
ERBE
GERB
ISP-2M
ScaRaB
SFM-2
SOLSTICE
SUSIM

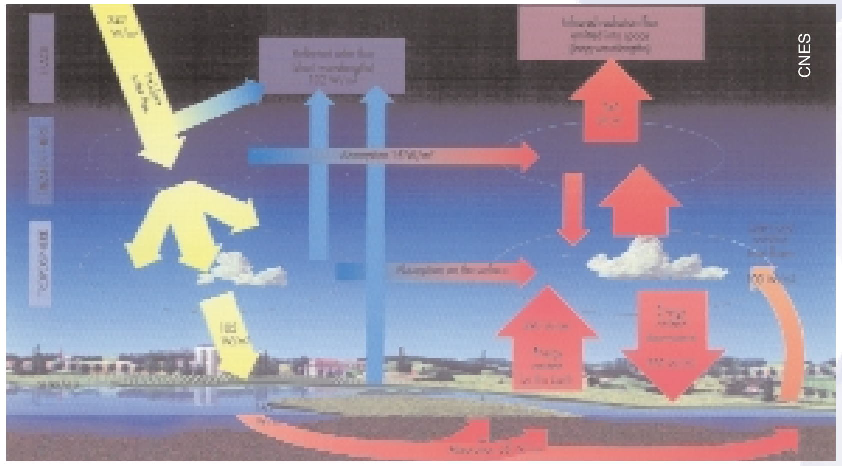
DESCRIPTION

These instruments provide measurements of the various components of the radiation budget. The instruments offer a high radiometric accuracy to allow accurate absolute measurements. Most radiometers have a narrow field of view and are used to measure the radiance in a particular direction. Using this, together with information on the angular properties of the radiation, the radiation flux may be obtained. In general, different instruments are used to measure the different components of the radiation budget:

- broad-band radiometers are used to cover the full range of incoming solar radiation (0.2 – 4.0 microns) and to monitor the long-wave emitted Earth radiation (3 – 50 microns) – this range may be covered either by two single channels, or by a series of narrower band channels;
- short wave radiometers are used to measure the reflected short-wave radiation from the Earth.

Advanced instruments have a directional capability and channels which allow study of the anisotropy and polarisation characteristics of the radiation fluxes. Other instruments measure the true total radiation flux at the satellite. Although such instruments do not require information on the shape of the radiation field, their spatial resolution is much poorer than that offered by directional radiometers.

When combined with information that is required to account for the effects of atmosphere, direct measurements made by these instruments at the top of the atmosphere also allow for investigation of radiation fluxes at the Earth's surface.

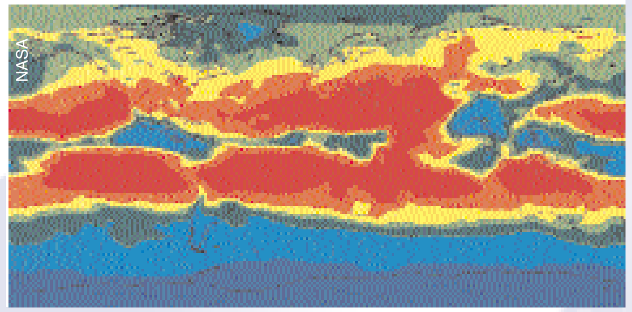


The Earth energy budget – the numbers indicate the average energy fluxes over one year, at a global scale

In the future, broad-band Earth budget radiometer data will be available from geostationary orbit offering significantly improved spatial resolution and radiometric accuracy, and more frequent data acquisition compared to current EO sources. These data will enable the development of more accurate models for converting sun radiance to top-of-atmosphere flux.

APPLICATION

The Earth's radiation budget is an important forcing function behind change. Earth radiation budget radiometers offer a unique contribution to understanding of the budget, together with its relationship to global warming such as that resulting from the greenhouse effect. In addition, information from these instruments is of interest in studies of clouds (to investigate cloud radiation forcing, for example) and albedo.



Infrared fluxes from the Earth's surface have been mapped over long periods by sensors such as ERBE

CERES: http://cirrus.larc.nasa.gov/ASDceres
SCARAB: http://w3.gkss.de/ScaRaB

SCARAB: http://www-project.cst.cnes.fr:8060/scarab/Mission
SOLSTICE: http://lasp.colorado.edu/solstice
SUSIM: http://louis14.nrl.navy.mil/susim_uars

High resolution imagers

INSTRUMENT CATALOGUE

ASTER
AVNIR-2
AWiFS
Camea
CCD camera
ETM+
Gemma
HRG
HRV
HRVIR
Imaging spectrometer
IRMSS
KFA-200
KFA-1000
KFA-3000
LATI
LISS I
LISS II
LISS III
LISS IV
MK-4
MK-4M
MOMS-2P
MSS
MSU-E
MSU-E1
MSU-E2
MSU-EU
OPS
PAN
Panchromatic sensor
PRISM (ALOS)
TM
WFI camera

DESCRIPTION

High resolution imagers provide detailed images of the Earth's surface. In general, these are nadir-viewing instruments with a horizontal spatial resolution in the range 10 to 100 m, and swath widths of order 100km. In the near future, very high resolution (VHR) imagery with a spatial resolution in the range 1m to 5m will be available from a number of commercial sources. High resolution imagers operate within the visible to IR range and typically record images simultaneously at a number of wavelengths within this range. This increases the information content that may be derived from the imagery (including the ability for classification) and allows corrections to be made, for example, for the effects of atmospheric water vapour on the measured surface parameters. In order to reduce atmospheric absorption and to increase image quality, the operating wavelengths of these instruments are selected to coincide with atmospheric windows. The instruments in this category do, however, suffer from an inability to penetrate thick cloud, rain or fog, and many are restricted to fair weather, daytime-only operation although some have pointing capability which enables imagery of specified areas to be acquired more frequently.

There is a wide range of examples of this category of instrument - many countries have and/or are planning imaging programmes. Future imagers may have a greater number of sampling channels and are likely to have improved resolution, both spectral and spatial. In 1998, instruments capable of acquiring panchromatic imagery at 1m spatial resolution and multi-spectral imagery (3-4 bands, visible/NIR) at better than 5m resolution will become operational. More instruments will also become available that are capable of producing stereo images from data collected on a single orbit, ie along track, as opposed to across track whereby stereo images are acquired from different passes. In addition, more instruments will become available with the capability of acquiring and distributing data to users nearer to real-time.

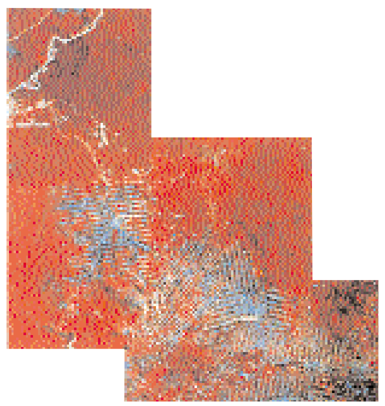
APPLICATION

The data from high resolution imagers has perhaps the widest range of application of any instrument category. Multi-purpose sea and land imagery, for example, is used to provide information on:

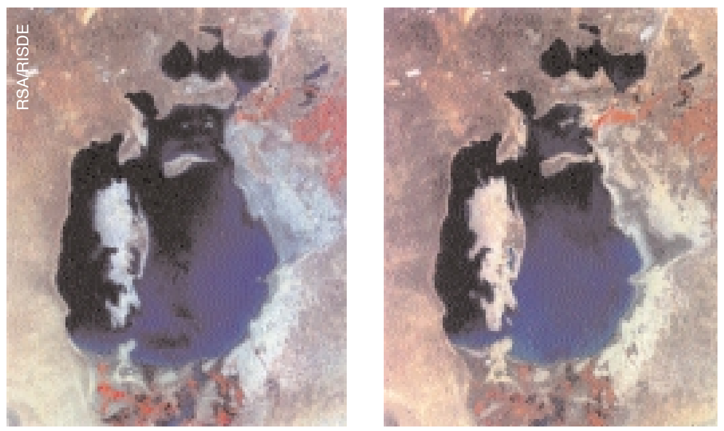
- the nature and extent of land cover, both regionally and locally;
- vegetation type and structure (for example, to identify deforestation in tropical areas or desertification);
- agriculture;
- geological mapping;
- the extension of inland water bodies, including floods;
- coastal erosion;
- mapping and cartography.

In addition, measurements from these imagers can contribute to investigations of cloud properties and extent, albedo and aerosol distribution over the oceans. Much of this information helps ecologists assess the impact of natural climate variations and human-induced activities on natural and managed ecosystems.

NASA



Mapping sensors have been used to monitor deforestation in the Amazon basin



MSU-SK images of the Aral Sea in 1993 (left) and 1996 (right) - high resolution imagery is used to detect and monitor land cover change

ALOS: http://alos.nasda.go.jp/alos/alos
ASTER: http://asterweb.jpl.nasa.gov
IRS 1c: http://www.eosat.com/EOS/irs
LANDSAT: http://geo.arc.nasa.gov/sge/landsat/l7
MOMS-2P: http://www.nz.dlr.de/moms2p
SPOT: http://www.spotimage.fr

Imaging multi-spectral radiometers (visible/IR)

DESCRIPTION

Visible/IR imaging multi-spectral radiometers are used to image the Earth's atmosphere and surface, providing accurate spectral information at lower spatial resolution than the imagers discussed in the previous section. Sensing usually occurs in multiple narrow, precisely calibrated spectral channels. The spatial resolution obtained typically varies from 100m up to several km, and the swath width is generally in the range several hundred to a few thousand km. These instrument cannot penetrate cloud or rain and hence are predominantly limited to clear weather observations.

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

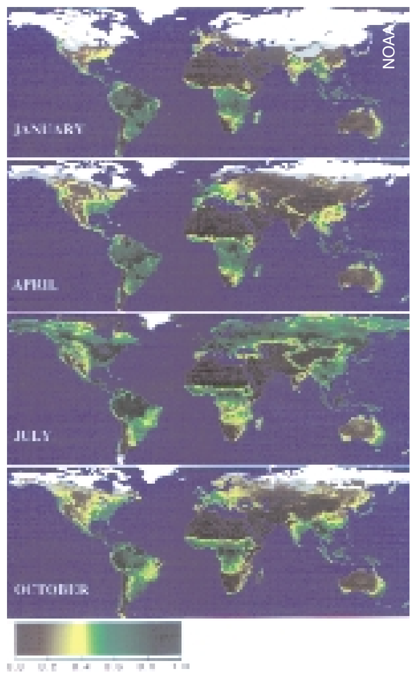
Recent developments include improvements in spatial resolution, in some cases, equivalent to those of high resolution imagers, and in spectral resolution and radiometric accuracy. Planned hyperspectral instruments will be able to simultaneously acquire imagery in many tens of wavebands which should significantly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

APPLICATIONS

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

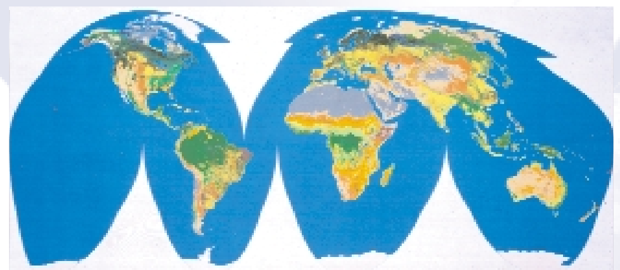
Visible/IR radiometers are an important source of data on processes in the biosphere, providing information on global-scale vegetation and its variations on sub-seasonal scales which allow monitoring of natural, anthropogenic, and climate-induced effects on land ecosystems. Classification and seasonal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

Multi-spectral radiometers are also important sources of ocean colour data, although more specialist instrument types are emerging for precise ocean colour measurements (see section on ocean colour radiometers).



Seasonal cycle of fractional greeness – polar orbiting satellites such as NOAA and METOP will provide daily global information on Earth System processes

IGBP



This landcover map shows global vegetation at 1km resolution. Multispectral imagers are an important source of inventory information for monitoring climate change

INSTRUMENT CATALOGUE

Geostationary orbit

BTVK
IMAGER (GOES)
IMAGER (MTSAT)
Multi-spectral Visible and IR Scanning Radiometer
MVIRI
SEVIRI
VHRR
VISSR

Low Earth orbit

AATSR
ATSR
ATSR-2
AVHRR/2
AVHRR/3
GIS
GLI
Klimat
MERIS
MODIS
MOS (IRS P3)
MOS (PRIRODA)
MR-2000
MR-2000M
MR-900
MR-900B
MR-900M
MS
MSR
MSU-M
MSU-S
MSU-SK
OBA
POLDER
PRISM (ESA Future missions)
TV camera
UV-visible spectrometer
VEGETATION
VIRS
VIS/IR Imager
WiFS
WS

AVHRR: http://www.esdim.noaa.gov
IMAGER (GOES): http://www.noaa.gov/news_flash/GOES
METEOSAT: http://gds.esrin.esa.it/meteosat
MODIS: http://ltpwww.gsfc.nasa.gov/MODIS/MODIS
MSR: http://hdsn.eoc.nasda.go.jp/guide/guide/satellite/satdata/mos_e
POLDER: http://earth-sciences.cnes.fr:8060/polder/Mission
VIRS: http://hdsn.eoc.nasda.go.jp/guide/guide/satellite/sendata/virs_e

Imaging multi-spectral radiometers (microwave)

INSTRUMENT CATALOGUE

- AMSR
- AMSR-E
- IKAR-D
- IKAR-N
- IKAR-P
- JMR
- MSMR
- MWR
- MZOAS
- R-225
- R-400
- RM-0.8
- TMI

DESCRIPTION

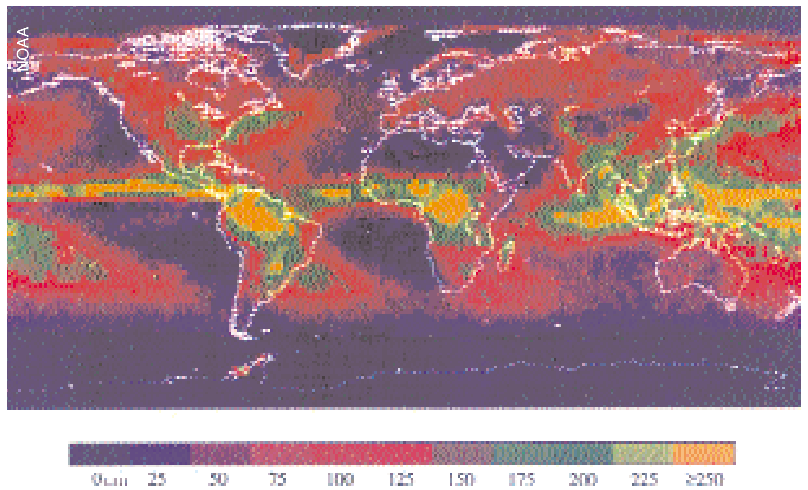
Imaging multi-spectral radiometers operate in a number of channels at microwave wavelengths, with the associated advantage of cloud penetration and hence all weather capability. Depending upon the exact frequency channels used, other advantages over visible/ IR radiometers include the ability to probe the dielectric properties of a surface or to penetrate certain surfaces - especially useful with vegetation and soil. As with other imaging radiometers, although these instruments offer accurate spectral information, their spatial resolution is poor. At 90 GHz, the spatial resolution is typically 5km, and for the lower frequencies it is of order tens of kilometres. The spatial resolution of the images produced by these microwave radiometers is generally poorer than that of their visible or infra-red counterparts. As a consequence, they are used for global rather than regional or local analysis.

APPLICATIONS

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

These instruments can also supply information on soil moisture content, which is a key surface parameter in agriculture, hydrology, and climatology, and provides a measure of vegetation health.

Imaging microwave radiometers are also capable of contributing information on ocean salinity, which is important to our understanding of ocean circulation.



Annual precipitation averaged over a 3-year period – the global coverage of satellite imagery is essential for producing global precipitation statistics

AMSR: http://www.eorc.nasda.go.jp/ADEOS-II/AMSR/amsr
MSU SK: http://www.ire.rssi.ru/priroda/MSU-SK/Msu_sk
TMI: http: //hdsn.eoc.nasda.go.jp/guide/guide/satellite/sendata/tmi_e

Imaging radars

DESCRIPTION

Imaging radars generate microwave images of a surface. Such radars generally have a high spatial resolution (between 10m and 100m) and a swath width of around 100km. Both synthetic aperture radars (SAR s) and some real aperture imaging radar systems fall into this category. The images produced have a similar resolution to those from high resolution optical imagers, but radars have the capability to "see" through clouds providing data on an all weather, day/ night basis. SAR s also have the ability to penetrate vegetation and to sample surface roughness and surface dielectric properties. They may also be used to obtain polarisation information and although the operating wavelength is in general fixed for a given radar, radars operating at a variety of wavelengths are available.

Interferometric SAR s record the phase shift between 2 images recorded at slightly different times, thereby providing accurate information on the motion of surfaces and targets and allowing large scale 3-D topographical images to be produced. Similar stereo images may be produced using conventional SAR images taken on adjacent orbits.

The beam shape and direction of future SAR s will enable imagery to be acquired from many points on the Earth more frequently. Multipolarised SAR s will enable land cover to be classified more accurately and will provide quantitative data on biophysical parameters such as soil moisture and biomass.

APPLICATIONS

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

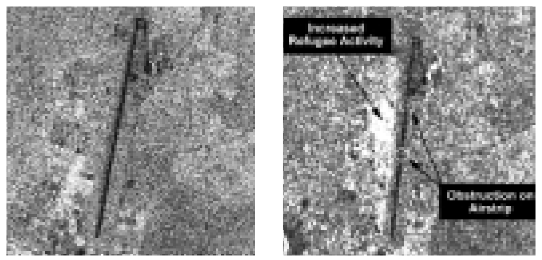
Backscatter from the ocean can be used to deduce surface waves, to detect and analyse surface features such as fronts, eddies, and oil slicks, and to detect and track ships. Operational wave and sea ice forecasting is also an important and growing near real-time application of SAR data.

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

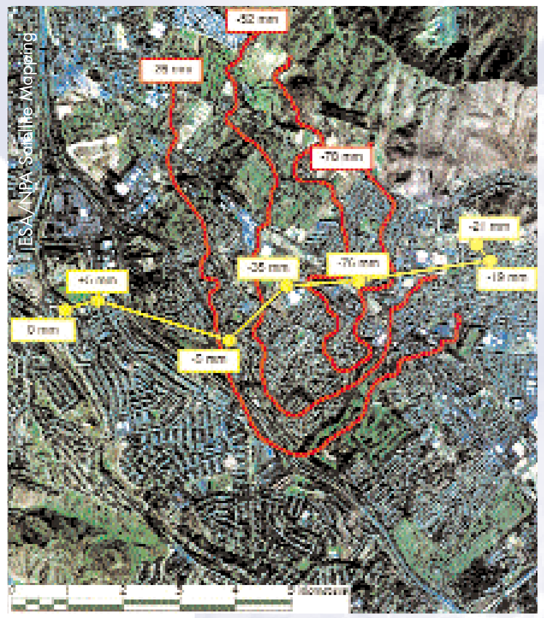
INSTRUMENT CATALOGUE

- AMI - SAR image and wave modes
- ASAR
- LightSAR
- PALSAR
- RLSBO
- SAR (ESA Future Missions)
- SAR (JERS-1)
- SAR (RADARSAT)
- Travers SAR

CCRS / RADASAT



RADARSAT imagery showing the build up of refugees around the airfield in Goma, Congo (ex Zaire), over a 10-day period. SAR imagery is an important source of data in regions frequently shrouded with clouds



ERS SAR imagery is an important source of data for interferometric applications. This example shows how SAR imagery can be used to detect and measure subsidence in urban areas

ERS SAR:
http://pooh.esrin.esa.it:8888/eeo/fr/eeo4.63/eeo4.128

JERS-1:
http://www.eoc.nasda.go.jp/guide/guide/satellite/satdata/sar_e
RADARSAT SAR: http://radarsat.space.gc.ca

Lidars

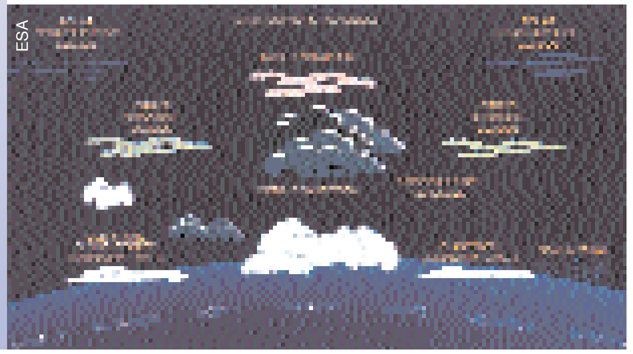
DESCRIPTION

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

There are a number of different types of lidar instrument:

- the backscatter lidar, in which the laser beam backscattered, reflected or re-radiated by the target gives information on the scattering and extinction coefficients of the various atmospheric layers being probed;
- the differential absorption lidar which analyses the returns from a tuneable laser at different wavelengths to determine densities of specific atmospheric constituents as well as water vapour and temperature profiles;
- Doppler lidar which measures the Doppler shift of the light backscattered from aerosol particles transported by the wind, thereby allowing the determination of wind velocity;
- the ranging and altimeter lidar which provides accurate measurements of the distance from a reference height to precise locations on the Earth's surface.

There are, as yet, no space-borne lidars although some experimental instruments have been flown on the Space Shuttle, and several lidars are planned for satellite missions in the near future.

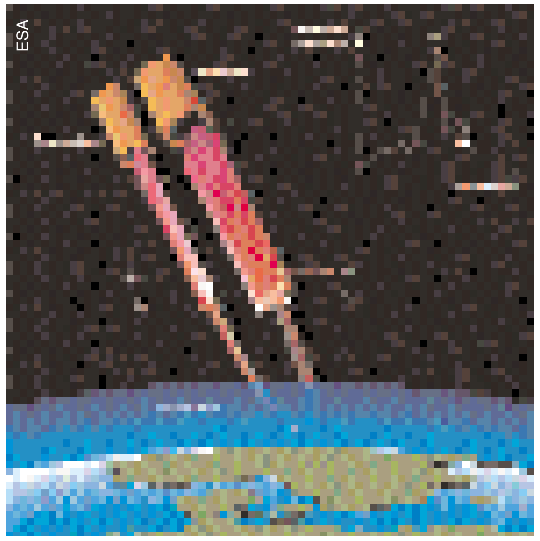


Atmospheric features detectable by Lidar as a function of latitude

APPLICATIONS

The different types of lidar may be used to measure a diverse range of parameters. Ranging and altimeter lidars may be used to provide surface topography information, for example on ice sheet height and land altitude. Multifrequency ranging lidars with probe wavelengths in the visible and near IR will be used to measure aerosol height distributions and cloud height.

Differential absorption and backscatter lidar may be used to measure cloud properties over an extended swath width, and Doppler lidars may be used to measure 3-D winds. This capability for measuring clear air winds (ie in the absence of clouds or winds above clouds) is of particular importance since it will provide a unique source of information for meteorological forecasting, with the potential for significant improvements in accuracy.



Principle of Differential Absorption Lidar (DIAL)

VCL: http://essp.gsfc.nasa.gov/vcl

Multi-directional radiometers

DESCRIPTION

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

There are as yet few instruments in this category, although a number are planned for future missions.

Future instruments will have better spatial and spectral resolution and will acquire imagery from many more angles than current instruments. The additional information contained in these data will make it possible to set limits on particle size and composition, as well as aerosol amount, measured over the ocean. The new data will also be used to derive aerosol properties.

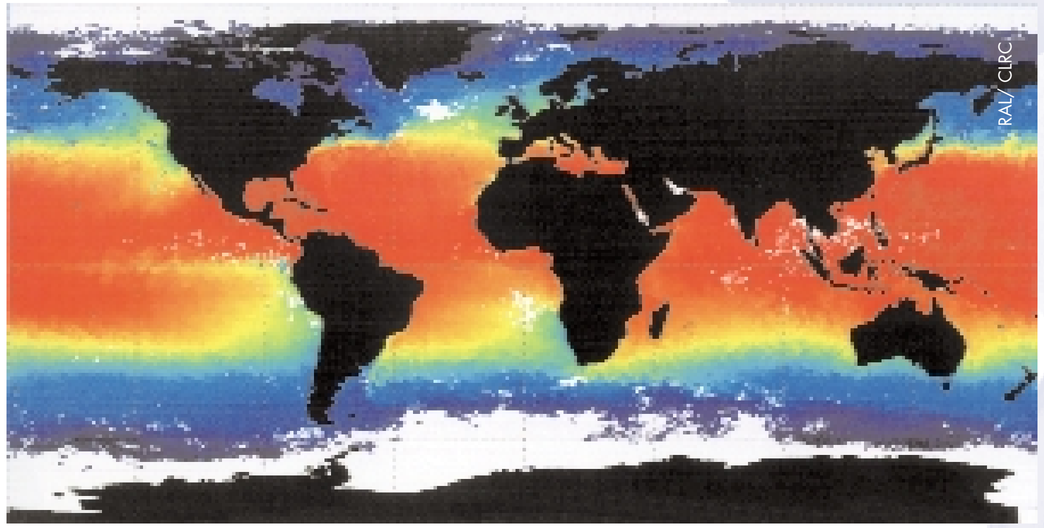
Multi-angle imaging of globally distributed cloudy regions at high resolution will enable direct validation of theoretical models and provide cloud-top height information not previously available.

APPLICATIONS

In the IR, the multiple viewing angle capability of these radiometers is used to achieve accurate corrections for the effects of (variable) atmospheric absorption and therefore to infer precise temperature values, for example, of sea and land surfaces. In addition to accurate measurements of surface temperature, multi-directional radiometers are also capable of measuring cloud cover and cloud top temperature together with atmospheric water vapour and liquid water content.

In the visible and near IR spectrum, these instruments allow for improved measurements of the scattering properties of particles such as aerosols, and for the angular characteristics of the various contributions to the Earth radiation budget, including surface albedo to be measured. They also enable accurate measurement of parameters such as Normalised Difference Vegetation Indices (NDVI) which are used to assess vegetation state and crop yield at regional and global scales.

ATSR-2 image showing dispersion of ash from Mt Ruapeliu, New Zealand - imagery such as this is a potentially important source of data for monitoring geological hazards



Global sea surface temparature map produced using ATSR-2 data - inaccuracies caused by atmospheric effects can be removed from multi-directional radiometer data enabling precise measurements to be made

ATSR/ AATSR:
http://pooh.esrin.esa.it:8888/eeo/fr/eeo4.63/eeo4.80
http://www.atsr.rl.ac.uk

POLDER: http://earth-sciences.cnes.fr:8060/polder/Mission

INSTRUMENT CATALOGUE
GLI
MERIS
MODIS
MOS (IRS P3)
OCM
POLDER
SeaWiFS

Ocean colour radiometers/Imaging spectrometers

DESCRIPTION

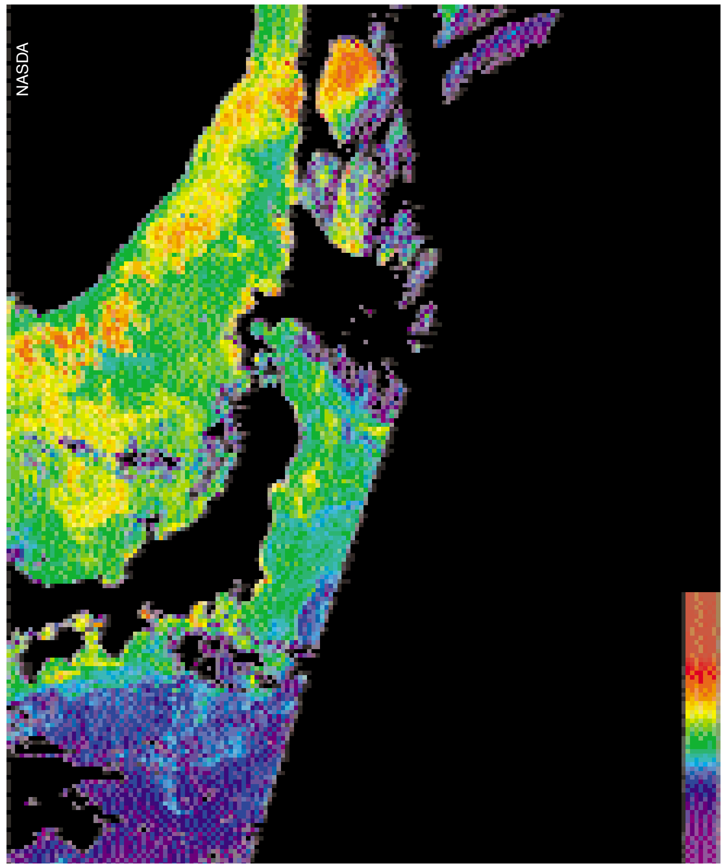
Ocean colour radiometers and imaging spectrometers measure the radiance leaving marine waters in the visible and near IR spectrum in the range 0.4 to 0.8 microns, where the colour is characterised by the constituents of the water, typically phytoplankton, suspended particulate material and dissolved compounds. Differences in the intensity of light received in the different bands gives information on the concentration of a variety of substances present in the ocean.

These instruments have very narrow detection channels, around 10 nanometres wide, to measure fine spectral details. The spatial resolution of these instruments is typically 0.3km to 1km.
Ocean colour radiometers are currently being developed which will have improved spatial, spectral and radiometric resolution compared to existing and previous instruments. Significant calibration and validation activities and algorithm development also continues – particularly with respect to measuring ocean productivity.

APPLICATIONS

The colour of the oceans as seen from space is an indirect measurement of ocean biomass and its associated productivity, via phytoplankton pigment concentration (chlorophyll). These parameters are of considerable oceanographic and climatological significance as oceanic productivity 'drives' the air-to-sea exchange of biogenic greenhouse gasses (eg CO_2). Ocean colour imagery can also be used to guide fishing fleets to biologically-rich areas. Other data that may be inferred from ocean colour measurements includes information about suspended matter (useful in coastal studies), biological productivity, marine pollution and coastal-zone water dynamics (eddies, currents, etc).

Fishermen benefit from ocean colour radiometer data which can be used to locate potential fishing grounds



Ocean colour instruments provide information on marine photosynthesis and productivity. The wide-area coverage of these instruments is important for studying ocean processes

SEAWIFS: http://seawifs.gsfc.nasa.gov/SEAWIFS
GLI: http://www.eorc.nasda.go.jp/ADEOS-II/GLI/gli

Polarimetric radiometers

DESCRIPTION

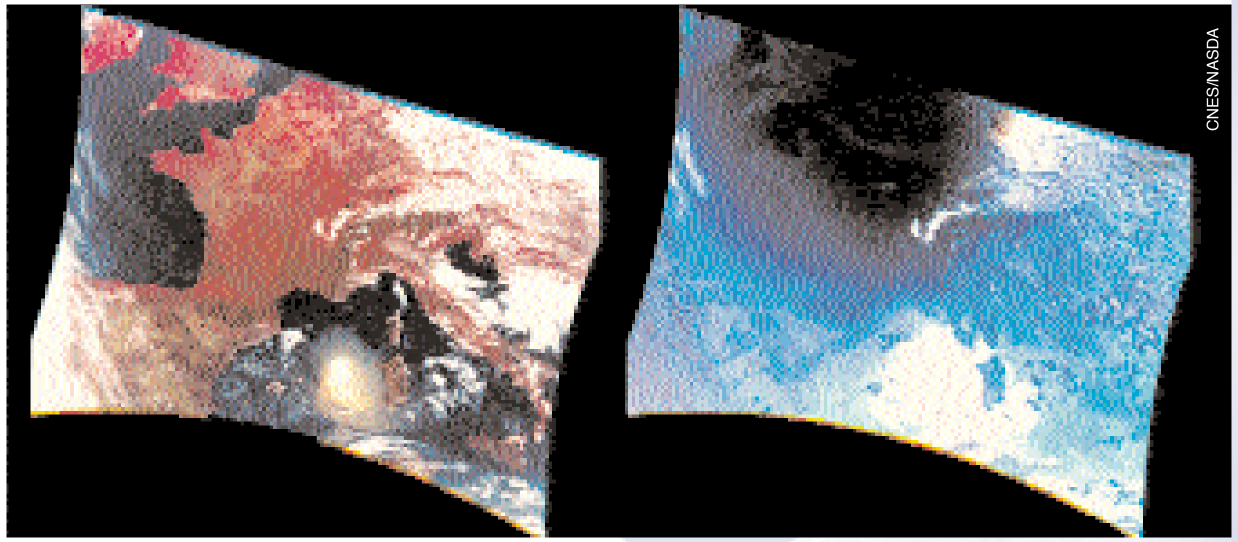
Polarimetric radiometers form a special category of imaging radiometer. They are used for applications in which radiative information is embedded in the polarisation state of the transmitted, reflected or scattered wave. This type of instrument can measure the polarisation state of the received radiation in a given waveband. Polarimetric radiometers usually operate in the visible and IR bands, and as with other radiometers, the bands used are generally precisely calibrated so that accurate spectral information is obtained. In addition, some polarimetric radiometers have a multi-directional capability so that directional information can also be determined.

APPLICATIONS

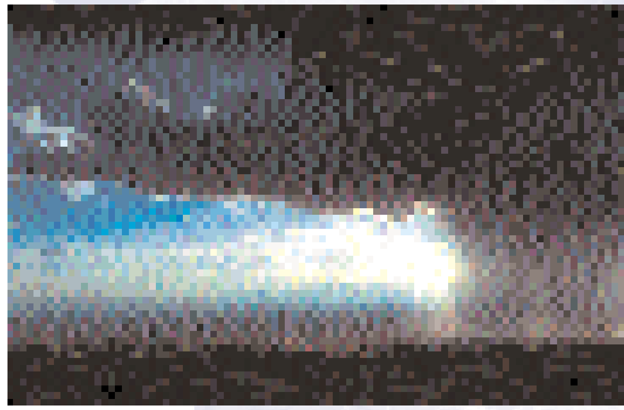
The polarisation information received by these radiometers may be used to infer a variety of parameters, including the size and scattering properties of liquid water, cloud particles and aerosols. In addition, these instruments offer the potential to provide additional information on the optical thickness and phase of clouds.

Polarimetric radiometers also provide information on the polarisation state of the radiation backscattered from the Earth's surface which supplements measurements obtained from other land and sea imaging instruments. Such measurements are of interest in a range of applications from investigations of albedo and reflectance to agriculture and the classification of vegetation.

INSTRUMENT CATALOGUE
EOSP
POLDER



POLDER is the first polarimeric radiometer to provide information on the polarisation state of radiation reflected from the Earth which enables better characterisation of the atmospheric contribution to reflectance at the top of the atmosphere and better retrieval of information on aerosols, and surface and cloud parameters



POLDER: http://hdsn.eoc.nasda.go.jp/guide/guide/satellite/sendata/polder_e
POLDER: http://earth-sciences.cnes.fr:8060/polder/Mission

Radar altimeters

INSTRUMENT CATALOGUE

- ALT
- POSEIDON/ SSALT
- POSEIDON/ SSALT-2
- RA
- RA-2
- Radar altimeter

DESCRIPTION

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

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

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

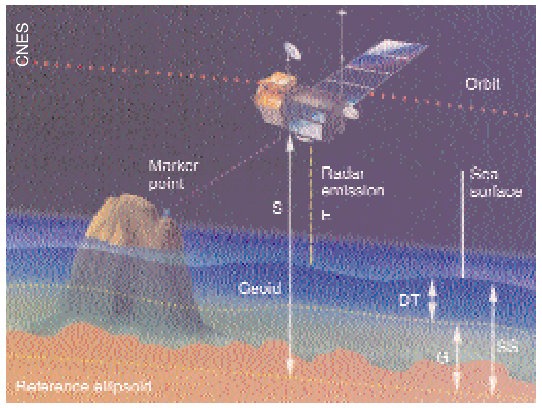
- a high precision radar altimeter (with basic measurement accuracy in the range 2cm to 4cm);
- a means of correction for errors induced in the height measurements by variations in the amount of water vapour along the path (for example, by means of a microwave atmospheric sounder or radiometer);
- a high precision orbit determination system (typically based on GPS, the DORIS beacon/ satellite receiver system and/ or a lidar tracking system).

APPLICATIONS

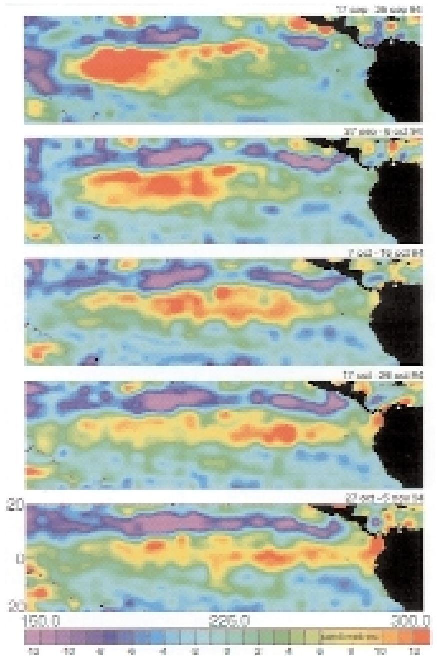
A variety of parameters may be inferred using the information from radar altimeter measurements. These parameters include: time-varying sea surface height (ocean topography), the lateral extent of sea ice and the altitude of large icebergs above sea-level, and the topography of land and ice sheets and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

Satellite altimetry also provides information which is of use in measuring the precise geoid, and in mapping the sea surface wind speed and significant wave heights.

The new generation of current and future instruments have a larger swath than past instruments enabling data to be acquired more frequently. Future instruments will also be configured to provide data in near real-time for incorporation into ocean circulation and wave forecast models used to generate marine information products.



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



TOPEX-POSEIDON data shows the elevation of the reference level of the ocean surface. Positive anomalies correspond to areas of upwelling warm water. These data assist in the prediction of El Nino events

SSALT: http://quest.arc.nasa.gov/topex/welcome
SSALT: http://topex-www.jpl.nasa.gov
POSEIDON: http://www-projet.cst.cnes.fr:8060/topex/Mission

RA: http://services.esrin.esa.it
RA: http://pooh.esrin.esa.it:8888/eeo/fr/eeo4.63/eeo4.64

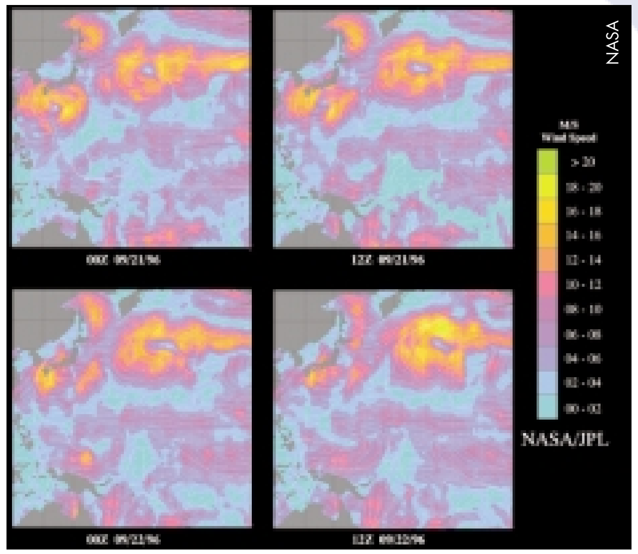
Wind scatterometers

DESCRIPTION

Wind scatterometers use accurate measurements of the radar backscatter from the ocean surface when illuminated by a microwave signal with a narrow spectral bandwidth to derive information on ocean surface wind velocity. At a given angle to the flight path of the satellite, the amount of backscatter depends on two factors – the size of the surface ripples on the ocean, and their orientation with respect to the propagation direction of the pulse of radiation transmitted by the scatterometer. The first is dependent on wind stress and hence wind speed at the surface, while the second is related to wind direction. Hence measurements by such scatterometers (which usually combine observations from at least 3 antennae with different look directions) may be used to derive both wind speed and direction.

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

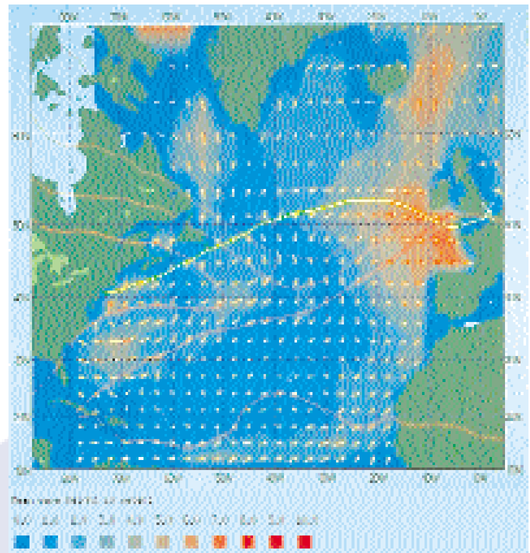
Coverage from instruments currently in orbit is limited, however, since they have a single-sided field of view. Data from the limited period of operation of the dual-sided swath instrument NSCAT on ADEOS (which failed in June 1997) is of great interest. Coverage will be greatly improved in the future with the flight of more dual-sided swath instruments.



Scatterometer data can measure the horizontal wind speed and direction over sea surfaces. NSCAT data was used in September 1996 to monitor the size and movement of Typhoons Violet and Tom in the western Pacific

APPLICATIONS

Information from wind scatterometers provides a unique source of data on sea surface wind speed and direction which has important applications in operational weather forecasting and the investigation of climate models. There are numerous other applications of this data including the optimisation of ship routes, measurement of sea ice extent and concentration, and emerging land surface applications – such as monitoring of rain forests, snow conditions, tundra, and deserts.



The ERS-1 scatterometer has been used to optimise trans-Atlantic ship routing, steering ships clear of storms (in red above)

INSTRUMENT CATALOGUE

- AMI - scatterometer mode
- ASCAT
- Sea Winds

AMI SCAT: http://pooh.esrin.esa.it:8888/eeo/fr/eeo4.63/eeo4.144

5 Future provision of data

5.1 INTRODUCTION

There are over 45 satellites currently in operation (annex A) which are providing important data about the Earth and its environment, and helping us to develop our understanding of the basic Earth System and of human influences on it. These data cover measurements of a very wide range of geophysical parameters which span the whole spectrum of the environment including atmosphere, land, oceans, and ice and snow. This section considers some of the key observations contributed by EO satellites, grouped into the measurement categories indicated in the panel:

MEASUREMENT CATEGORIES
Atmosphere
Aerosols
Atmospheric humidity fields
Atmospheric temperature fields
Atmospheric winds
Cloud type, amount and cloud top temperature
Cloud particle properties and profile
Liquid water and precipitation rate
Ozone
Radiation budget
Trace gases (excluding ozone)
Land
Albedo and reflectance
Landscape topography
Soil moisture
Vegetation
Surface temperature (land)
Multi-purpose imagery (land)
Ocean
Ocean colour/biology
Ocean topography/currents
Sea surface winds
Surface temperature (sea)
Ocean wave height and spectrum
Multi-purpose imagery (sea)
Snow and ice
Ice sheet topography
Snow cover, edge and depth
Sea ice cover, edge and thickness

The above 25 parameters are a convenient way of grouping and presenting the key measurements which are important to users (CEOS Affiliates) and about which space-based instruments are capable of, or are likely to be capable of, providing information.

The reader that is interested in a more detailed description of instrument measurement capabilities (for example, relating to individual trace gases at different heights in the atmosphere) is referred to the CEOS database (see section 2 and annex A). Over 175 distinct geophysical measurements are specified therein.

A number of the measurements specified in this document are routinely provided by today's satellites, and future missions planned by CEOS agencies will provide a further increase in data over the existing suite of missions, providing new capabilities for Earth observation - and with them a clearer understanding of our environment.

This section identifies the space-based instruments which primarily contribute data for any particular measurement requirement from the list above and indicates the potential means for continuity of that data provision over the next 15 years. In some cases, that continuity is provided by a single series of satellites planned by one agency; in other cases, users requiring long-term datasets or high volumes of data at any time will need to look to various satellite missions planned by different agencies world-wide. As such, a significant degree of co-ordination in mission planning and data provision is required between these data providers (and providers of non space-based data) to ensure that a reliable data source is guaranteed. Efficient and effective deployment of observational resources are key aims of the Integrated Global Observing Strategy (IGOS) discussed in section 3.

Measurement continuity is a key requirement in many areas, for example in providing confidence to sustain public and commercial investment in operational applications of EO data. It is also of paramount importance for the generation of long term datasets required for the global environmental programmes of agencies such as the World Meteorological Organisation (WMO), the International Council of Scientific Unions (ICSU), the Inter-governmental Oceanographic Commissions (IOC), the United Nations Environment Programme (UNEP), and Food and Agriculture Organisation (FAO) and Office of Outer Space Affairs (UNOOSA).

The programmes are major international, interagency initiatives such as the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), the Global Terrestrial Observing System (GTOS), the World Climate Research Programme (WCRP), and the International Geosphere-Biosphere Programme (IGBP). These programmes and agencies are known as CEOS Affiliates. CEOS Affiliates and Members are playing a key role in the development of an IGOS as described in section 3.

Outline descriptions of the environmental programmes and agencies which are affiliated to CEOS are given in annex D.

5.2 OVERVIEW

Current areas of strength of today's Earth observation satellites include:

- Chemistry and dynamics of the stratosphere are currently being provided by the NASA UARS mission and TOMS Earth probe, and by the GOME instrument onboard ESA's ERS-2 mission.
- Atmospheric humidity and temperature profiles are routinely provided for operational meteorology by the NOAA polar orbiting satellites and by a number of meteorological geostationary satellites (see below).
- Atmospheric winds (through cloud tracking), cloud amount and tropical precipitation estimates are provided for most of the globe by the geostationary meteorological satellite series Meteosat, GOES, GMS, INSAT and GOMS.
- Multi-purpose imagery for both land and sea is being collected by both high resolution optical and synthetic aperture radar (SAR) instruments for use in environmental, public, and commercial applications. Optical sensors include AVHRR on the NOAA polar orbiters and those on SPOT, Landsat, Resource, and IRS series. SAR sensors include those on the ERS series, RADARSAT and JERS-1. Further future missions and increasing spatial resolution will ensure improved data collection and application opportunities.
- Sea surface temperature information is being generated by data from existing meteorological satellites and from instruments on the ERS series. Future plans should provide continuity. Satellites are now also making consistent and continuous measurements of other important oceanographic parameters such as ocean topography, ocean currents, and sea surface winds - satellites providing this information include the TOPEX/POSEIDON and ERS series.
- Sea ice and ice sheet extent are being measured by a range of missions and continuity is planned.

Future missions, with new types of instruments employing a new generation of technology and techniques, will enable Earth observation satellites to make further contributions, including:

- A significant increase in information about the chemistry and dynamics of the atmosphere, including: long term global measurements of concentrations of ozone and many other trace and greenhouse gases; information on the role of clouds in climate change; the ability to better map cloud cover and precipitation - including over the oceans; measurements of 3-D atmospheric winds in the absence of clouds to track; global aerosol distributions; and extended coverage of atmospheric measurements into the troposphere to allow improved pollution monitoring. These capabilities will be provided by a variety of novel instruments - such as the Precipitation Radar (PR) featured on TRMM and the concept demonstrators for cloud and rain radars, and Doppler lidar instruments proposed for future ESA, NASA and NASDA missions.
- Global data on ocean biological parameters will become available from the recently launched SeaWiFS instrument. Lessons learnt interpreting these data, and recent data from the period of operations of the OCTS instrument on-board the ADEOS mission, will set the scene for the analysis of similar, higher resolution data from instruments on board future NASA, ESA and NASDA missions.
- Improved repeat coverage of many oceanographic measurements, plus new capabilities in measuring ocean colour and biology as discussed above.
- The potential for new information on global land surface processes, through use of increased number of spectral bands on future imaging sensors. Multi-directional and polarisational measurements from instruments on missions such as Envisat, EOS-AM and ADEOS-II will also provide new data for studies of the Earth surface .

5.3 MEASUREMENT TIMELINES

For each measurement category listed in section 5.1, a brief discussion is given below of the significance of that measurement, together with an indication of the present and future measurement capabilities. This description is supported by two timeline diagrams scanning the period 1997-2012 indicating the instruments contributing to that measurement and the missions on which they are expected to fly. The first timeline shows 'firm/approved' missions, and the second shows missions which are not yet approved - rather they are 'proposed'.

Note that all missions, except those currently flying, have a degree of uncertainty. The description of missions as firm/approved and proposed has been used to indicate the current status, as reported by the relevant agencies at the time of compilation. If the month of the launch of a planned mission has not been specified the timeline is shown to commence at the beginning of the planned year of launch. Note also that missions currently operating beyond their planned life are shown as operational until the end of 1997 unless an alternative date has been proposed.

The instrument timelines for ESA Future Missions, ie. Earth Explorer and Earth Watch missions, refer to candidate ESA missions following on from ENVISAT in 2004. In this respect, it should be noted that new instruments or derivatives of existing instruments may be considered in addition to those specified in the timelines.

The timelines in this section represent a qualitative analysis of the provision of data from Earth observation satellites in terms of a number of key geophysical measurements and the requirement for those measurements in different disciplines. Statements regarding adequacy of measurements are generally with regard to global environmental/climate change programme requirements - as expressed by the CEOS Affiliates (annex D).

Aerosols

The concentration and distribution of aerosols, eg dust or sulphate particles, in the atmosphere is of great significance for the study of the climate system. Indeed the need for more information on them and their effect is noted as one of the priority topics in the most recent Inter-disciplinary Panel on Climate Change (IPCC) scientific assessment. Their presence directly affects the absorption and transmission of solar radiation and hence alters the energy balance of the Earth System. In addition, aerosols can act as condensation nuclei around which clouds can form. Clouds strongly affect the transmission of solar energy and their distribution affects precipitation patterns. Aerosols can be chemically active and they may play a role in creating or destroying other species, including ozone, at higher altitudes.

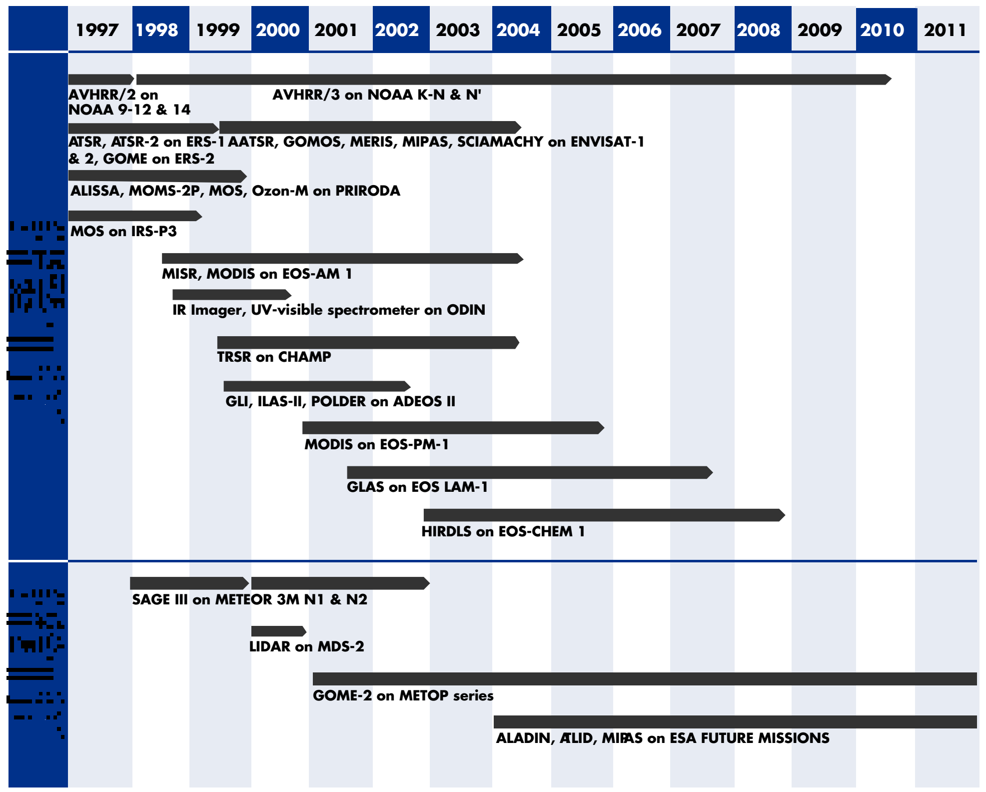
In order to understand the influence of aerosols on the climate system, predictive models are being developed which require data on aerosol distributions - principally their number, concentration and size distribution. Satellite-based sensing provides the only practical way of potentially achieving global measurements of these species.

Reliable information on aerosols is also required by applications outside of the study of the climate system. For example, accurate and timely warnings of the presence of airborne dust and ash such as that arising from desert dust clouds and volcanic eruptions is important to the aviation industry. This information is needed both for safety and economies linked with flight planning (as aircraft have to be re-routed around danger areas).

Measuring the distribution of aerosols through the depth of the atmosphere is technically difficult, particularly in the troposphere, and existing techniques using instruments such as AVHRR and ATSR are limited to producing estimates of vertically-integrated total amounts, mainly over oceanic regions. Measurements over land are difficult due to both persistent cloud clover and to the high value, and variability, of land surface reflectance. ATSR-2, however, is able to provide more detailed information (particularly over land). MODIS, MERIS, and MISR will provide a good opportunity to obtain optical depth at different frequencies from which aerosol particle sizes, predominantly over oceans, may be inferred. The new generation of multi-directional or polarimetric instruments such as AATSR, MISR and EOSP will also provide more detailed information (again particularly over land), and the development of active instruments such as ATLID, and laser altimeter sensors (including GLAS) should result in a much improved measurement capability.

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

Aerosol data are of importance in the IGOS prototype project on Long-Term Continuity of Ozone Measurements: spectral distributions are needed from the surface to the stratosphere and column optical depth is required. Such data are also needed for corrections of optical data within the Global Observations of Forest Cover project.



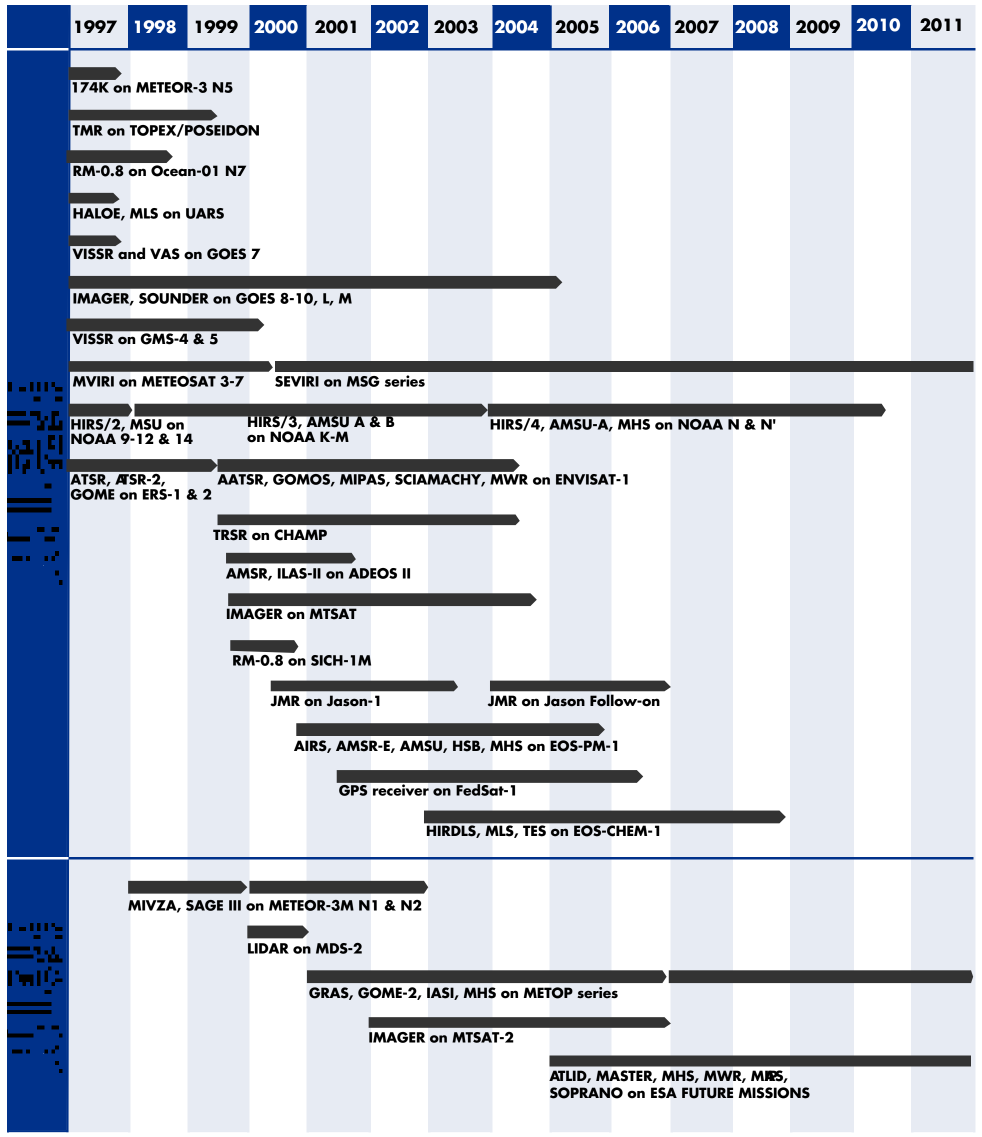
Atmospheric humidity fields

Measurements of atmospheric humidity are needed for many applications. Humidity profiles are used together with vertical temperature soundings, as inputs to Numerical Weather Prediction (NWP) models - although humidity data are not yet, in general, routinely assimilated into these models. Accurate measurement of humidity profiles is also vital to allow correction to be made for the effect of atmospheric water vapour on the signals received by a range of other EO sensors, in particular satellite altimeters. A range of sensors (in-situ and space-based) are needed in order to provide the required information - determining the optimum way to combine these data is still a research topic.

In terms of the Earth's climate, water vapour is perhaps the most important trace gas present in the atmosphere. It strongly affects the transmission of infra-red radiation and thus contributes to the greenhouse effect, and its phase changes lead to cloud formation and provides a mechanism for the transfer of latent heat between the oceans and the atmosphere. Hence measurements of the variability in time and space of relative humidity, particularly in the upper troposphere, are crucially important in understanding the climate system and in detecting any possible future changes. Long-term monitoring may also make use of humidity as a tracer of atmospheric dynamics, providing insight into changes in the large-scale circulation of the upper atmosphere.

Although current sounders such as HIRS2/MSU have provided useful measurements, time sampling is limited and the vertical resolution of the soundings is often coarse. The new generation of sounders, including the high resolution infra-red AIRS and IASI and microwave sounders, capable of sounding through cloud, such as AMSU-B and MHS, should provide greater resolution, and better all-weather operation, although temporal resolution is likely to remain a problem with a lack of advanced instruments in geostationary orbits. Further into the future, active instruments such as Differential Absorption Lidars (DIAL) will offer further significant improvements in accuracy and vertical resolution.

Atmospheric humidity fields are of primary importance for the following IGOS projects: the Long Term Continuity of Ozone Measurements project (between 500hPa and 10hPa); the Upper Air measurements project (profiles and total column); GODAE (as a correction to altimeter measurements); the Global Observations of Forest Cover project (for correction of optical data); and the Long Term Measurements of Ocean Biology project.



Atmospheric temperature fields

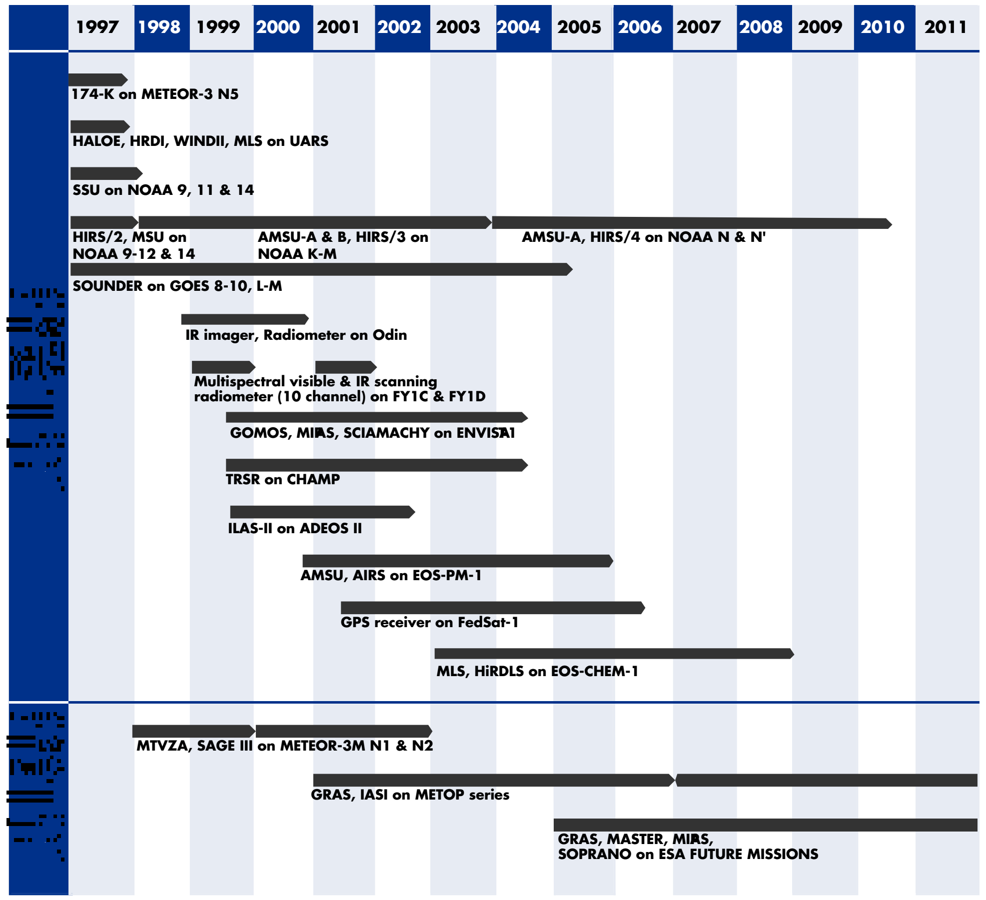
Data on atmospheric temperature are vital to a range of modelling processes associated with understanding atmospheric circulation and for Numerical Weather Prediction (NWP). Atmospheric temperature data are used for monitoring inter-annual global temperature changes, for identifying correlations between atmospheric parameters and climatic behaviour, and to validate global models of the atmosphere. They may also be used for computing the upper level wind structure (geostrophic winds) which, in turn, is a useful aid in the prediction of strong winds at the surface and warning of possible storm surges in the sea level around coasts.

Temperature data are routinely analysed through the assimilation process – whereby data from satellites are combined with in-situ observations are used together to model predictions of temperature and associated variables. Current research is aimed at utilising multi-spectral radiances, rather than retrieved temperatures profiles, in this assimilation process.

Sounders such as MSU and HIRS routinely provide profiles typically from a few km altitude to the top of the atmosphere, with a horizontal resolution of 10-100km and a temperature accuracy of a few degrees. Such accuracies and resolutions are, however, insufficient for many climate requirements, and, as with humidity sounding, global temporal resolution is limited. Infra-red sounders which currently offer the highest accuracy and horizontal and vertical resolution are restricted to clear skies operation, and hence microwave instruments (MSU and its successors) will continue to be required to provide an all weather capability. Ideally, a combination of microwave sounders for all weather operation and IR sounders for high vertical resolution information is required, both with improved vertical resolution. Future sounders such as the polar orbiting AMSU-A, AIRS, and IASI are designed to meet such requirements.

Beyond this series of passive sounders, active instruments such as DIAL will provide data of significantly higher accuracy and vertical resolution.

Atmospheric temperature profile data are of primary importance for the following IGOS projects: the Long Term Continuity of Ozone Measurements project; and the Upper Air Measurements project.



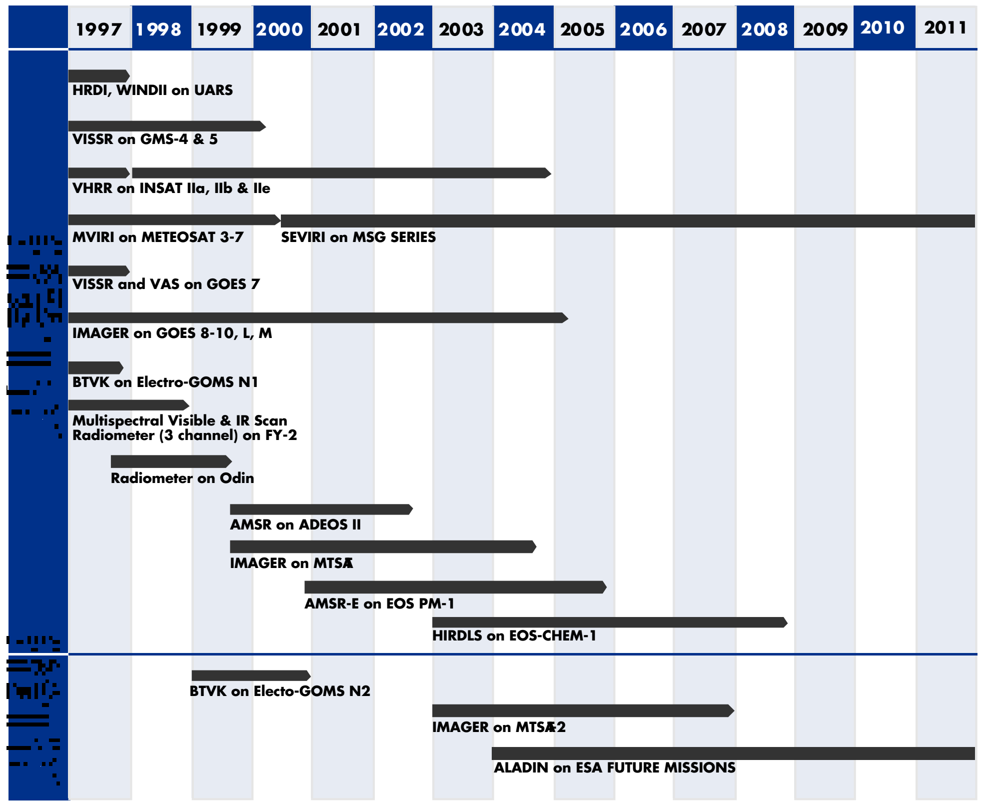
Atmospheric winds

Measurements of atmospheric winds are of primary importance not only as inputs for weather forecasting models, but also in order to study global changes. In the tropics and extra-tropics, imagery from geostationary satellites is used to infer winds from the motion of clouds (assuming that there are clouds which can be tracked). Away from the tropics, the geostrophic component of the wind can be inferred from temperature data. Reliable wind observations in the tropics are crucial as their inclusion in the NWP assimilation process strongly affects the large scale features of the tropical wind field. Accurate and timely information on winds is central to, amongst other things, aviation flight planning and the prediction of the dispersal of atmospheric pollutants.

At present, multi-channel visible and infra-red imagers on geostationary platforms such as IMAGER, MVIRI, VISSR and VAS, are used to measure cloud and water vapour motion vectors from which tropospheric wind estimates may be derived. Other tracers, such as ozone, may also be used to measure higher altitude winds. This technique suffers, however, from low vertical resolution although this may be improved by increasing the number of sampling channels. Geostrophic winds may also be derived using vertical temperature/humidity profiles from infra-red sounders such as HIRS and MSU. Future sounders (AIRS and IASI) offer the prospect of improved vertical resolution and accuracy.

In the near future, geostationary measurements will be complemented by instruments with greater resolution and more channels such as SEVIRI. In the longer term, laser instruments such as Doppler lidars offer the promise of directly measuring clear air winds. Although such active instruments will provide high accuracy and vertical resolution, the coverage offered by polar missions such as that planned for ALADIN is likely to be limited. Sea surface wind measurements are discussed later in this chapter.

Atmospheric winds are of primary importance in the following IGOS projects: the Long Term Continuity of Ozone Measurements project (between 500hPa and 10hPa); and the Upper Air Measurements project.



Cloud type, amount and cloud top temperature

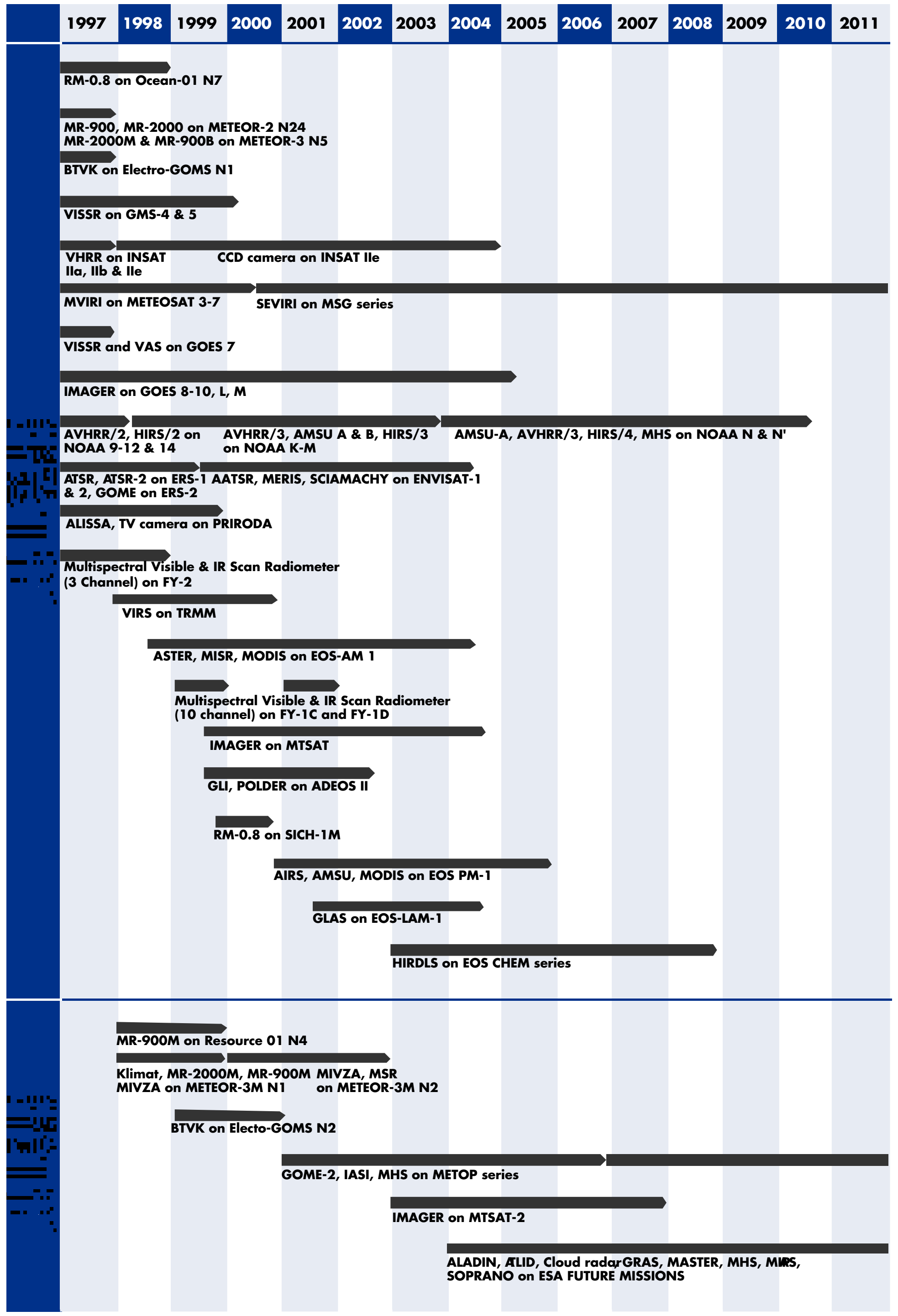
Better understanding of the role of clouds in climate has been identified as one of the highest priorities for further research since the potential feedback effect of clouds is a major source of uncertainty in predictions of greenhouse warming (see, for example, the latest assessment of the IPCC). The effects of clouds on radiative processes in the atmosphere is a key area in climate research because of the opposing but very large influences that clouds have on the short wave solar radiation and the long wave terrestrial radiation: low level cloud layers are important reflectors of solar radiation; high level cirrus clouds trap escaping long wave radiation and lead to atmospheric warming (the greenhouse effect). Measuring cloud properties is fundamentally difficult due to their extreme variability - data are therefore required with sufficient frequency to sample both diurnal and synoptic variations.

Cloud types, cloud patterns and their evolution are also among the best indicators of a wide range of atmospheric processes and so are used in investigations of climate change and for input to and validation of numerical weather and climate prediction models. Forecasters, for example, rely heavily on satellite cloud imagery in order to locate and track thunderstorms and other significant cloud structures in order to provide warnings to a range of users (aviation, shipping, and the tourist trade, for example).

Cloud top temperatures, difficult to measure using traditional observing techniques, are used indirectly in conjunction with measurements of cloud thickness to detect precipitation, information which complements that available from ground-based weather radars. Enhanced precipitation information may be used in hydrology studies, for example to improve estimates of run-off, to provide improve flood warnings and for agricultural planning

At present, measurements of cloud type, amount and top temperature are provided by the wide variety of visible, infra-red and microwave instruments in both geostationary and low Earth orbits. Reliable classification of cloud type requires accurately calibrated multi-spectral imagery. The measurements currently provided by AVHRR, ATSR/ATSR-2 and imagery from geostationary satellites will be greatly enhanced with the new generation of instruments such as MODIS, MERIS, EOSP and MISR, some of which also benefit from multi-directional and polarisation detection capabilities. Cloud height measurements will also be enhanced with the near term introduction of enhanced sounders (AIRS and IASI) and, in the longer term, when active lidar instruments such as ATLID become available.

Cloud type, amount and cloud top temperature data are of primary importance for the IGOS Upper Air Measurements project.



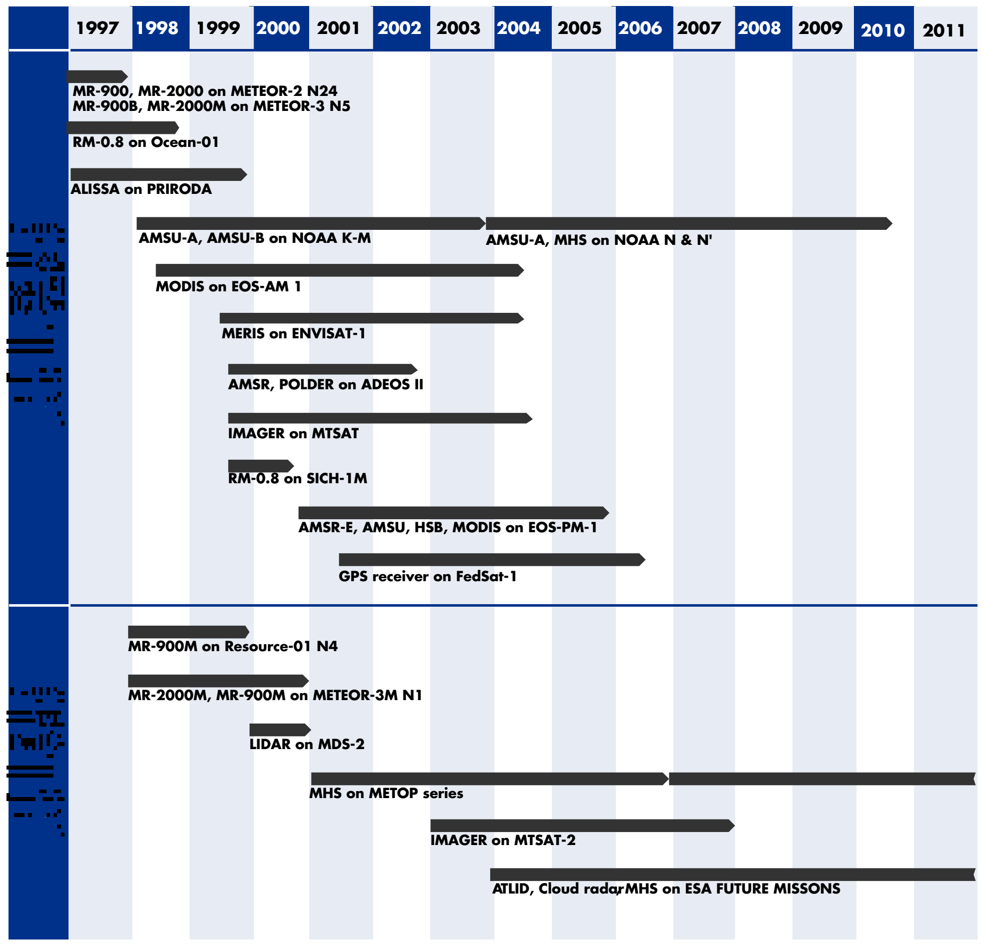
Cloud particle properties and profile

Full 3-D observations of cloud structure are at very early stages of development, with several more years before sensors are in orbit that will go some way to meeting users' requirements. In the nearer term, basic information of the structure of clouds (ie determination of whether water or ice particles are present) can be obtained from future microwave instruments such as AMSR. These measurements are important for climate purposes as the structure of clouds (particle size and phase) greatly affects their optical properties and hence their albedo.

Together with cloud top temperatures (see previous sub section), information on the 3-D structure of clouds (currently obtained from aircraft-based sensors) can be used as a basic tool for the real time surveillance of features such as thunderstorms. Study of these parameters through the life cycle of a storm allows researchers to develop useful short term forecasting criteria

The main source of information currently available is an AVHRR-derived product obtainable through ISCCP (the International Satellite Cloud Climatology Project). This product contains relatively crude information on water cloud particle size. ATSR-2 is also able to make this type of measurement. As discussed above, in the slightly longer term, microwave radiometers such as AMSR will provide some cloud phase information. Additional phase information will also be available from polarimetric radiometers such as EOSP. However, the users' requirements are unlikely to be met until data from active microwave instruments such as ATLID or cloud radars become available.

Cloud particle properties and profile data are of primary importance for the following IGOS projects: the Long Term Continuity of Ozone Measurements project (particularly Polar Stratospheric Clouds); and the Upper Air Measurements project.



Liquid water and precipitation rate

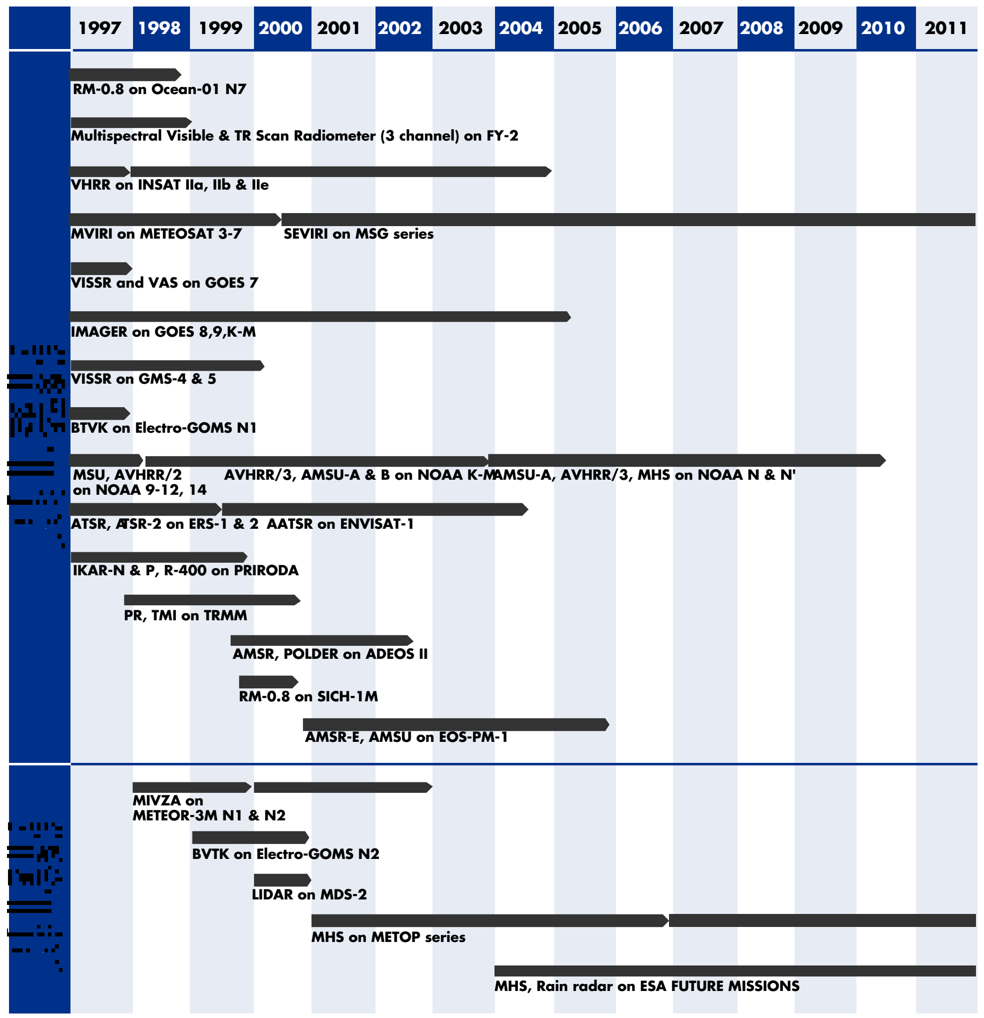
Water forms one of the most important constituents of the Earth's atmosphere and is essential for human existence. It strongly affects the climate of the Earth by providing a sink of heat energy in some locations (through evaporation and melting), and a source in others (through condensation) thus significantly changing the manner in which solar energy is redistributed across the planet. A better understanding of the current distribution of precipitation and of how it might be affected by global change is vital - with accurate predictions of likely regional drought or flooding being of high priority. The most recent IPCC assessment notes that systematic collection of information on the hydrological cycle is of key importance. Tropical rainfall comprises more than two-thirds of global rainfall and is therefore of particular interest. Satellite remote sensing is probably the only way to provide global data because of the sparsity of ground based measurements, especially over remote land regions and oceans.

Information on liquid water and precipitation rate is used for initialising numerical weather prediction models, and on a local scale, for timely planning and response. For example, information on precipitation is used in agricultural applications and near real-time information is vital for water resource management for drought alert and to manage river flow.

A large number of instruments are available which contribute to estimates of liquid water and precipitation rate, although at present there is a lack of instruments capable of making direct measurements. Visible/IR imagers on geostationary meteorological satellites provide indirect but frequent measurements of rainfall from measurements of cloud-top temperature, and some information will be obtainable from microwave imaging sensors such as AMSR (although measurements over ice are difficult).

A significant breakthrough will come with the launch of active instruments which are capable of 3-D measurements of precipitation. TRMM includes such an instrument and will provide data principally over the tropics. Although this region is of particular interest, there is likely to remain a requirement for coverage of polar regions at high spatial resolution.

Given the very high temporal and spatial variability of precipitation it is a fundamentally difficult parameter to measure. All remote sensing techniques require high quality ground truth data for calibration purposes. Indeed it is likely that for the foreseeable future, the best datasets will comprise data from many different sources (satellites, in-situ and models) – such as is underway in the Global Precipitation Climatology Project (GPCP).



Atmosphere

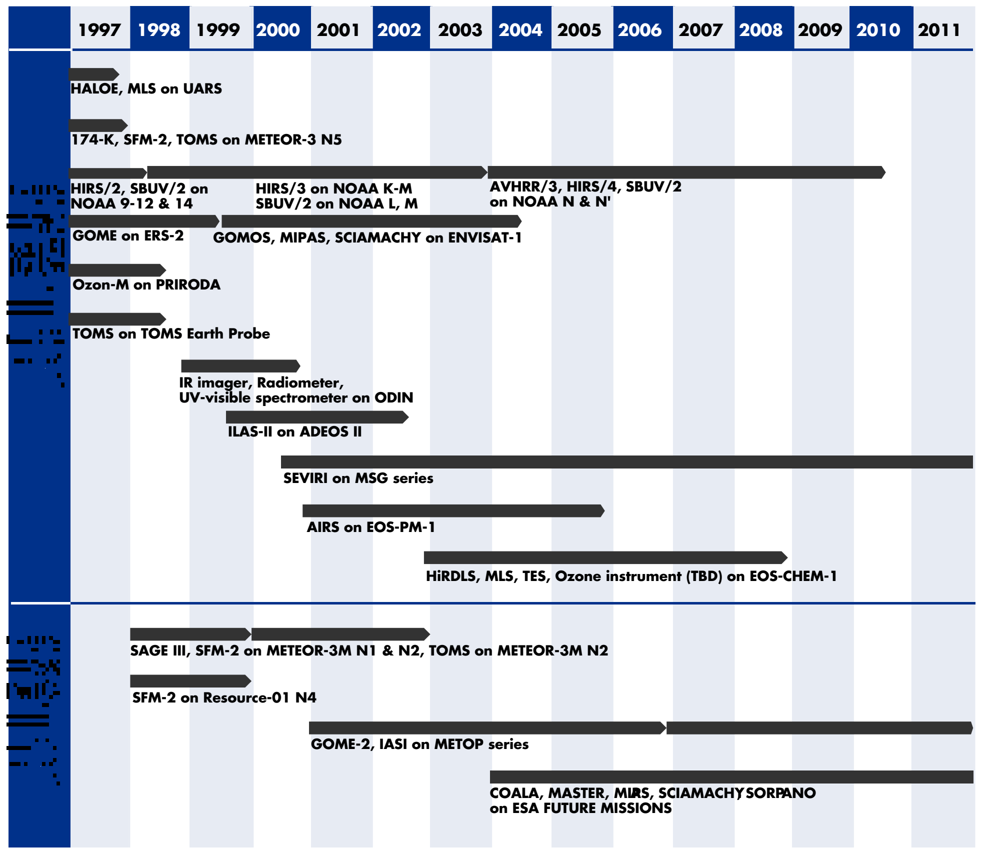
Ozone

Ozone is present in many layers of the atmosphere. The importance of the stratospheric ozone layer in shielding the Earth from incoming UV radiation has long been recognised. More recently, an increase of ozone in the troposphere has been thought to contribute to the greenhouse effect and is of concern due to its pollutant effects.

Man-made chemicals such as chlorofluorocarbons (CFCs) rising into the stratosphere act to destroy the Earth's protective ozone layer through a series of complex chemical reactions. Despite international agreements to reduce CFC emissions (established through the Montreal Protocol to the Vienna Convention), ozone depletion remains one of the most critical global environmental problems facing human kind today. The level of ozone varies seasonally, and in order to understand, model and predict the processes behind these seasonal fluctuations, satellite EO data can be used to create a database of measurements. The ozone hole has already been successfully monitored using satellite-based instruments, with an important contribution to understanding coming from the total ozone observations made by the TOMS instrument on Nimbus-7 and SBUV on the NOAA polar orbiters. GOME on ERS-2 also provides profiles of stratospheric ozone.

High resolution stratospheric ozone profiles have also been measured by instruments such as MLS, HALOE and SAGE II. In future, measurements from microwave imaging sensors such as AMSR and from various ESA (notably GOMOS) and EOS instruments will become available. Tropospheric ozone profile measurements will also improve with measurements from SCIAMACHY. MIPAS and HIRDLS will observe the upper troposphere and above. In the longer term, profiles from the Earth's surface (a region of the atmosphere not covered at present) will be provided by TES. Future sounders such as IASI and AIRS will also provide useful information on total ozone observations.

In addition to the IGOS Long Term Continuity of Ozone Measurements project, ozone data are of importance for the IGOS Upper Air Measurements project and the Global Observation of Forest Cover project (for correction of optical data).



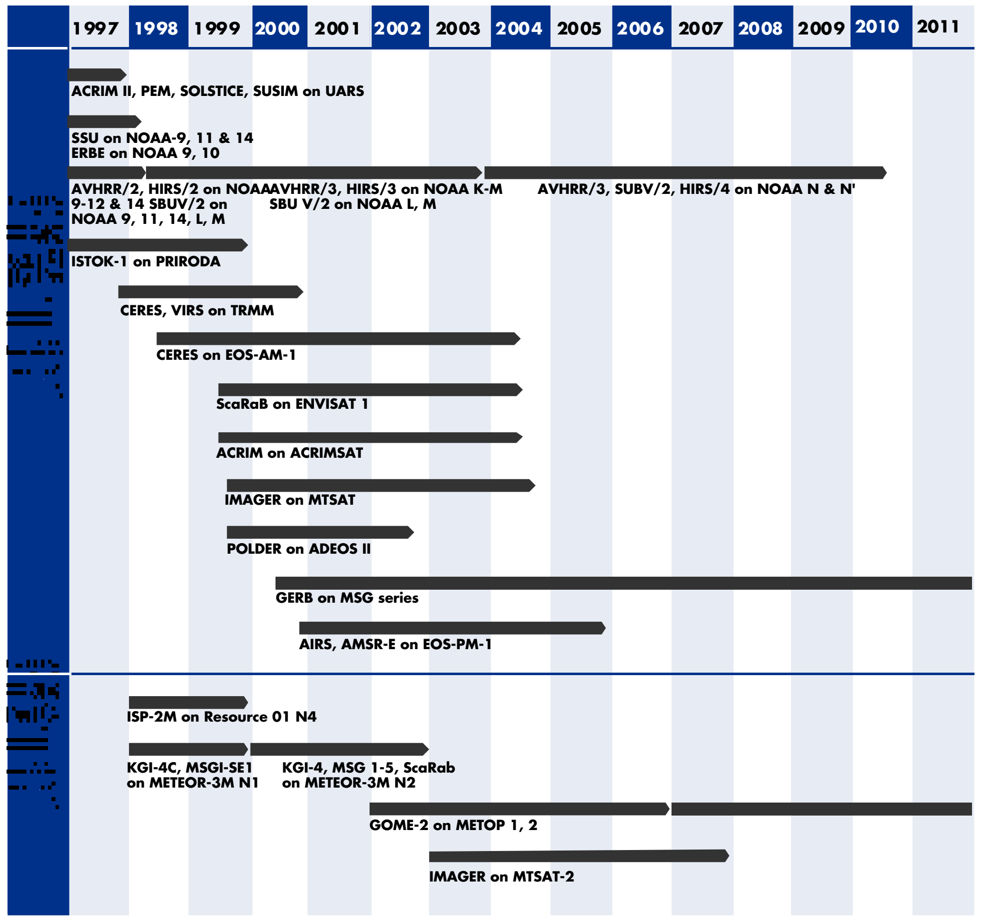
Radiation budget

Satellite measurements offer a unique means of assessing the Earth's radiation budget (ERB). The goal of such measurements is to determine the amount of energy emitted and reflected by the Earth. This is necessary to understand the processes by which the atmosphere, land and oceans transfer energy to achieve global radiative equilibrium, which in turn is necessary to simulate and predict climate. Measurements of the geographical distribution of the radiation budget, for example, reveal the energy exchanges between the different regions of the globe by oceanic currents and atmospheric circulation and may be used for validation of general circulation models. Combining information from radiation budget measurements with those from albedo measurements over the poles gives information on factors influencing the extent of the polar ice packs, which may be used to monitor and assess the effects of global warming. Systematic observations of the Earth System energy balance components are noted by the most recent IPCC scientific assessment as being of key importance in narrowing the uncertainties associated with the climate system.

In addition to these continuous global measurements of the radiation budget which are necessary both to estimate any long term climatic trends and shorter term variations overlying these trends, measurements on a regional scale are useful to understand better the dynamics of certain events or phenomena and to assess the effect of climate change for example on agriculture and urban areas.

In general, three types of measurement are currently possible: the short-wave and long-wave radiation budget at the top of the Earth's atmosphere; the short wave radiation budget at the Earth's surface; and the total incoming broad-band radiation flux. Measurements are also needed of the surface long-wave budget but the best means of meeting these requirements is currently a research topic. It is not possible to measure directly, at a global scale, the radiative imbalance deemed to lead to global warming (as this would require a measurement accuracy greater than 1 Wm^{-2} which is unlikely to be possible). Ideally, for all measurements, the radiometers should be capable of sampling diurnal fluctuations, and have a directional measurement capability. Sensors such as ERBE and ScaRaB have been the principal source of measurements, although information can also be obtained from the narrow-band HIRS and AVHRR instruments. In the near future, measurement capability will be enhanced by the CERES sensors on the EOS series and TRMM (POLDER on ADEOS also provided useful information for a limited period of time). The broad-band radiometer planned for flight on MSG (GERB) will allow "perfect" temporal sampling with a radically different viewing geometry to complement the information available from polar orbiting satellites.

The amount of Photosynthetically Active Radiation reaching the surface of the Earth is of primary importance for the following IGOS projects: the Long Term Measurements of Ocean Biology project; and the Global Observations of Forest Cover project.



Atmosphere

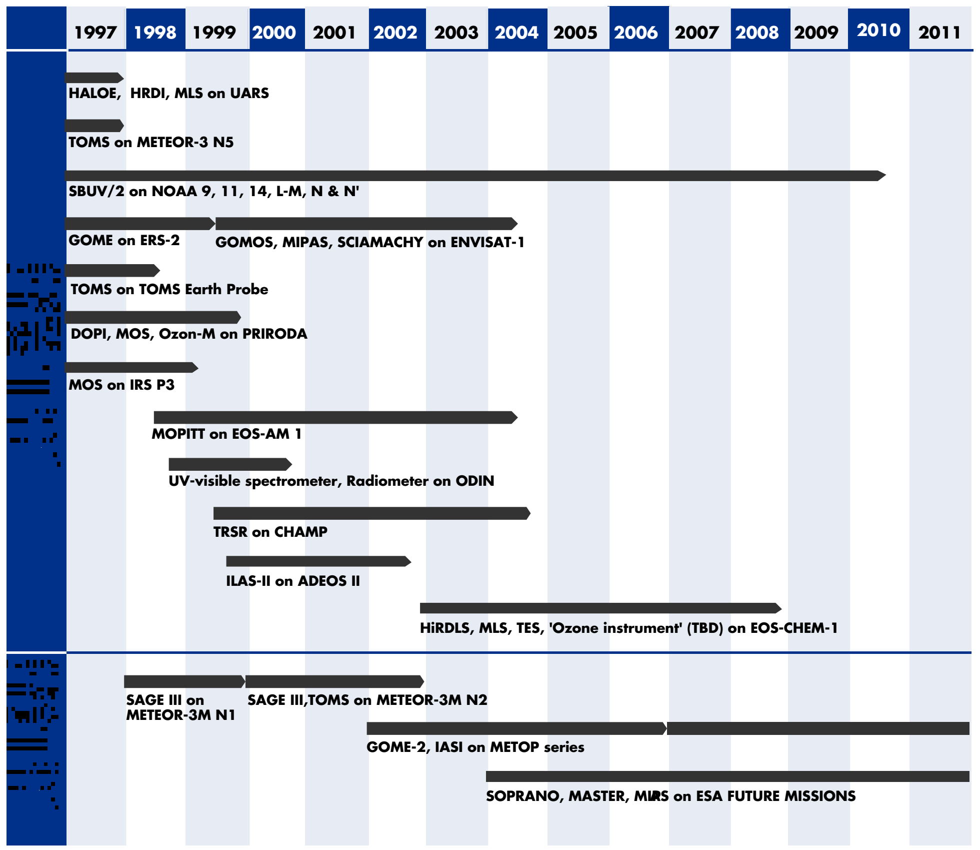
Trace gases (excluding ozone)

The presence of trace gases in the atmosphere can have a significant effect on global change as well as potentially harmful local effects through increased levels of pollution. Trace gases other than ozone may be divided into one of three categories: greenhouse gases affecting climate change; chemically aggressive gases affecting the environment (including the biosphere); and gases and radicals impacting on the ozone cycle, thus affecting both climate and environment.

The chemical composition of the troposphere in particular is changing at an unprecedented rate - the rate at which pollutants from human activities are input to the troposphere is now thought to exceed that from natural sources (such as volcanic eruptions) and is known (through measurements) to be greater than the atmosphere's natural capacity for their removal. EO measurements offer a unique source of global data on atmospheric concentrations of trace gases and have already made an important contribution to the recognition that human activities are modifying the chemical composition of both the stratosphere and the troposphere, even in remote regions. It is recognised that measurement of trace gases is vital both to monitor changes in the composition of the various layers in the atmosphere and to deduce the effects of these changes on the global climate. The selection of species which need to be monitored on a routine basis is still the subject of research.

A variety of instruments is available to provide measurements on the concentration of trace gases. In general, high spectral resolution is required to detect absorption/emission/scattering from individual species. Some instruments offer measurements of column totals, ie integrated column measurements, whilst others provide profiles of gas concentration through the atmosphere. Tropospheric profiling is in general difficult, but in the upper troposphere and stratosphere it is possible to use limb measurements to obtain high vertical resolution (but with relatively poor horizontal resolution). To date, instruments on UARS have provided the main source of this type of data (with useful data for a limited period from instruments on board ADEOS). In the future, measurements should improve as instruments on ADEOS II, Envisat and the EOS series, such as TES and SCIAMACHY, become available to provide profiles of a number of trace gases through the stratosphere and troposphere. MIPAS and HiRDLS will profile the upper troposphere and above.

Trace gas data are of primary importance for the IGOS project on Long Term Continuity of Ozone Measurements project. In particular the spectral distribution of BrO, ClO, NO_2, N_2O, HF, HCl and CH_4 is needed at altitudes above 100hPa; the spectral distribution of NO_2 is also needed down to altitudes as low as 1000hPa; and ground based column data are needed for NO_2, HF, HCL and CH_4.



Albedo and reflectance

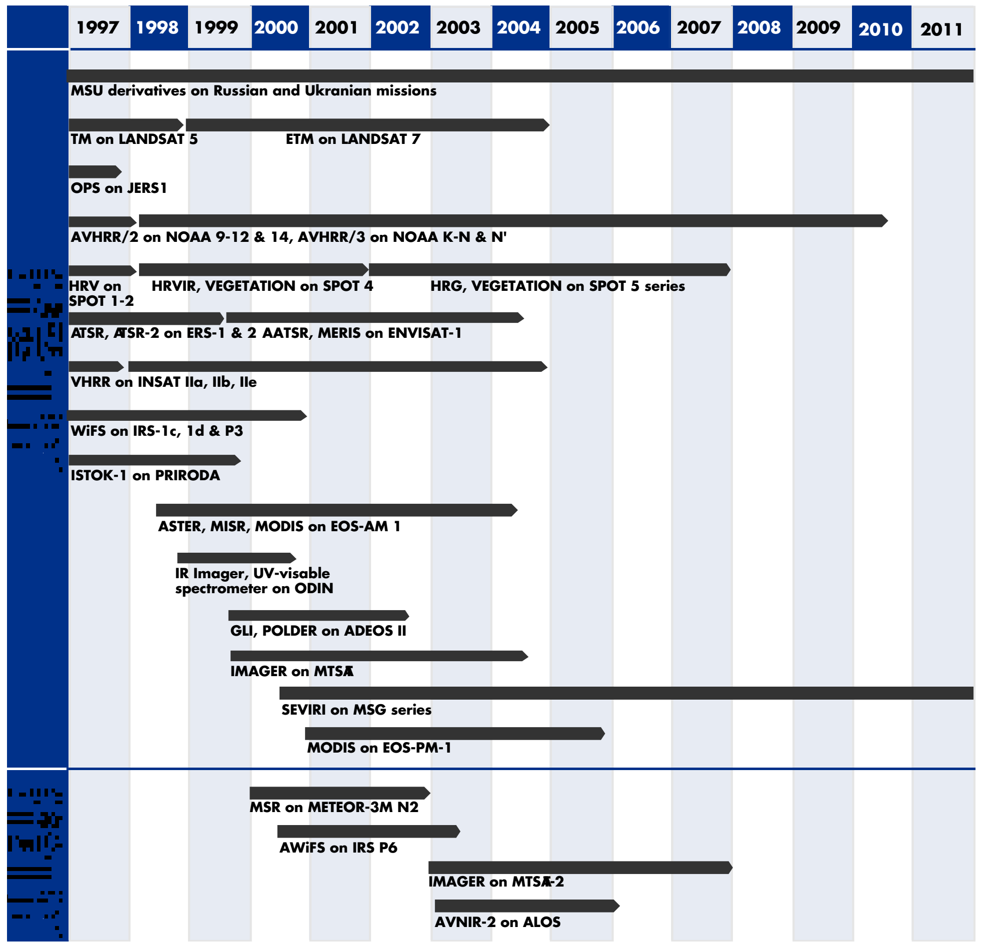
Quantitative measurements of albedo (the fraction of total solar radiation incident on a body that is reflected by it) are essential for climate research studies and investigations of the Earth's energy budget. Albedo and reflectance(the fraction of solar radiation incident on a body that is reflected by it, *at a given wavelength*) are significant drivers in the radiation budget, with about 30% of the sun's radiant energy incident on the Earth being reflected back into Space. Although most of the reflected signal is due to clouds, surface reflectance can have a significant impact on the distribution of absorbed solar radiation. In order to understand the processes occurring and to identify the effects of changes in albedo resulting from, for example, a change in land use, it is vital to establish long term datasets describing albedo and reflectance.

It is actually Bi-directional Reflectance Distribution Functions (BRDF) which are intrinsic to a particular surface. The albedo is a derived quantity that depends on, amongst other things, the anisotropy of the surface and the solar position. Detailed insitu experiments are still required to enable adequate parameterisation of surface reflectance properties such as albedo and to provide high quality ground truth data. Reliable maps of surface albedo depend on a better understanding of the BRDF of different surfaces and more accurate aerosol data (see sub section on Aerosols) to enable atmospheric effects to be corrected when measuring surface reflectance properties.

Measurements of reflectance may also be used for monitoring the sensitivity of satellite radiometers: routine surveys of radiance measurements over selected targets of high albedo in clear sky regions allows the detection of a decrease in radiometer sensitivity, and permits inter-calibration of different instruments.

Current measurements of albedo and reflectance are obtained primarily using multi-spectral imagers such as AVHRR and ATSR/ATSR-2, and sensors on SPOT and Landsat. Geostationary sensors can also contribute information. However, more work is required on algorithms to extract global information on surface albedo. Future measurements using multi-directional radiometers such as MISR and AATSR, and polarimetric radiometers such as POLDER will allow the measurement of the directional nature of surface reflectance leading to better estimates of albedo.

The amount of Photosynthetically Active Radiation reaching the surface of the Earth is of primary importance for the IGOS Global Observations of Forest Cover project.

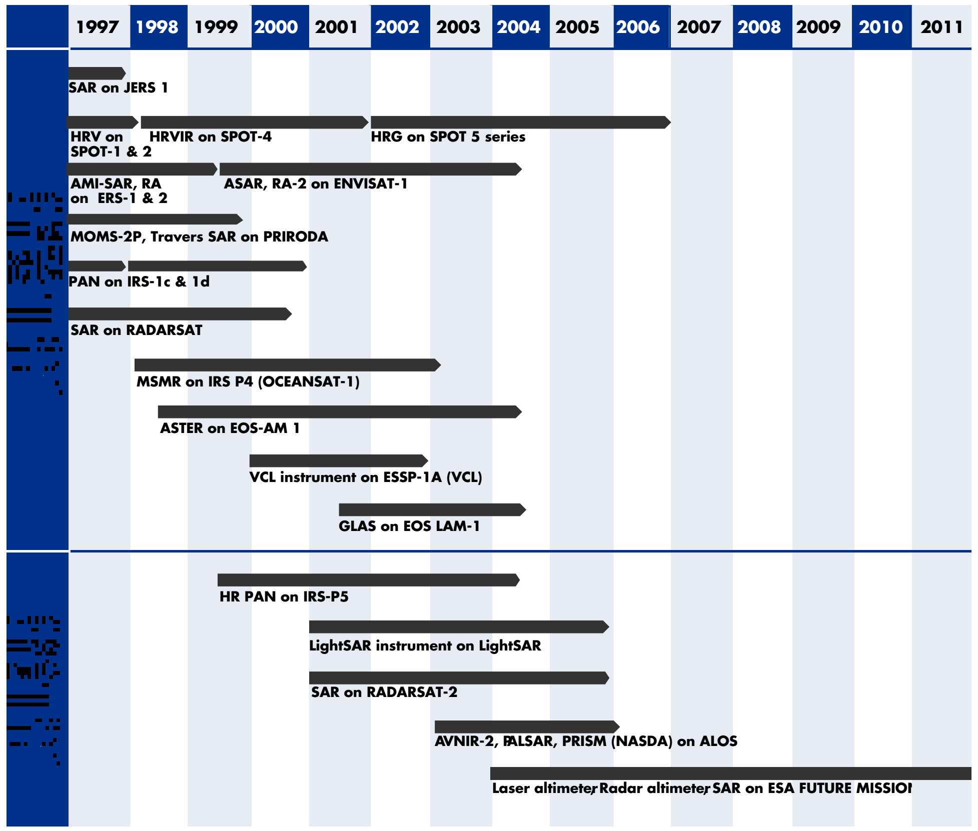


Landscape topography

Many modelling activities in Earth and environmental sciences, telecommunications and civil engineering increasingly require accurate, high resolution and comprehensive topographical databases with, where relevant, indication of changes over time. Satellite techniques offer a unique, cost-effective and comprehensive source of such data.

To date, EO has allowed localised high resolution mapping of certain regions. This information has been used, amongst others, by land-use planners for civil planning and development; by those who analyse remote sensing data (to compensate for local terrain effects on the signals received from other sensors); and by hydrologists to predict the drainage of water and where floods are likely, to observe if erosion is occurring, and to understand how vegetation receives water. In coastal areas, topographic information may be used to detect small changes in the slope of the coast which may determine whether or not communities may be susceptible to flooding. Very accurate measurements of the geometry of volcanoes (using interferometric techniques) may be used to predict eruption and potentially avoid loss of life and property. Interferometric techniques may also be used to detect landslides, earthquake displacements, and urban subsidence. In addition to local mapping, a global database of medium resolution data is being created for use in studying the flexure and rigidity of the Earth's crust, large scale crustal magnetic and gravity anomalies, and the nature of island arcs and basins.

At present, information on landscape topography is obtained primarily from multi-band optical imagers and SAR instruments. Good results have been obtained from stereo optical instruments and SARs which have a stereo image capability. The pointing capability of SPOT, for example, allows the production of stereo images from data gathered on different orbits which are then used to create digital elevation maps which give a more accurate depiction of terrain. SARs can also be used in interferometric mode to detect very small changes in topography. Future sensors such as ASTER will create stereo images from data gathered on a single orbit and will have improved resolution. Unlike present radar altimeters, which allow only for coarse topography mapping over land, future laser altimeters such as GLAS will give very precise height information, although their coverage will be limited.



Soil moisture

Soil moisture plays a key role in the hydrological cycle. Evaporation rates, surface runoff, infiltration and percolation to the water table are all affected by the level of moisture in the soil. It is therefore one of the key surface parameters in agriculture, hydrology and climatology, and in order to understand better the role of this parameter there is an urgent need for measurements of soil moisture. Such an understanding would enable models to be developed to forecast soil moisture and to simulate run-off. Potential applications include crop yield predictions including identification of potential famine areas, irrigation management, and monitoring of areas subject to erosion and desertification, and for the initialisation of NWP models. The development of a large regional database will also provide a baseline set of values against which long-term climatic measurements may be compared.

Direct measurement of soil moisture from space is difficult. The ideal instrument would appear to be the passive microwave radiometer, although some success has been achieved using radar – despite the complications of analysing the signals reflected from the ground. Passive microwave sensors can also be used to infer information based upon surface microwave emissions, although the signal is very small. Reliable data (high signal to noise ratio) need to be taken over a large area - which introduces the problem of understanding how to interpret the satellite signal since it consists of reflected radiation from many different soil types. For both active and passive sensors, the microwave signal is related to the soil moisture in the top few centimetres of soil for practical frequencies (for example, 1.4GHz), except under very dry conditions.

SAR data currently provide the main source of information on near-surface soil moisture to a depth of 5cm (but only in the absence of dense overlying vegetation). To date, the use of this information has been limited to tasks such as distinguishing between irrigated and non-irrigated fields. Determination of soil moisture from space is an active area of research and information has indirectly been obtained from other satellite observations, including visible/infra-red measurements such as those from AVHRR of land surface temperature and vegetation condition. Some data will also be able to be derived from passive microwave instruments such as AMSR and there has been some success in deriving large scale measurements from wind scatterometer data.

No timeline summary of specific contributing instruments is offered here. Rather the reader is referred to sections on land surface temperature and vegetation measurements and to the sections on imaging radars and microwave radiometers – all of which are of relevance.

Vegetation

Changes in land cover are important sources of global environmental change and have implications for ecosystems, biogeochemical fluxes and the global climate. Land cover change affects climate through a range of factors from albedo (desertification, for example, results in changes in albedo which itself alters rainfall distribution) through to emissions of greenhouse gases from the burning of biomass. As a result, quantitative information on the extent and rates of change in this cover is vital for global climate research. Used in conjunction with other data, the construction of a global index of vegetation would also enable investigation of the effects of changes in vegetation on hydrology, and of the causes of variations in land productivity.

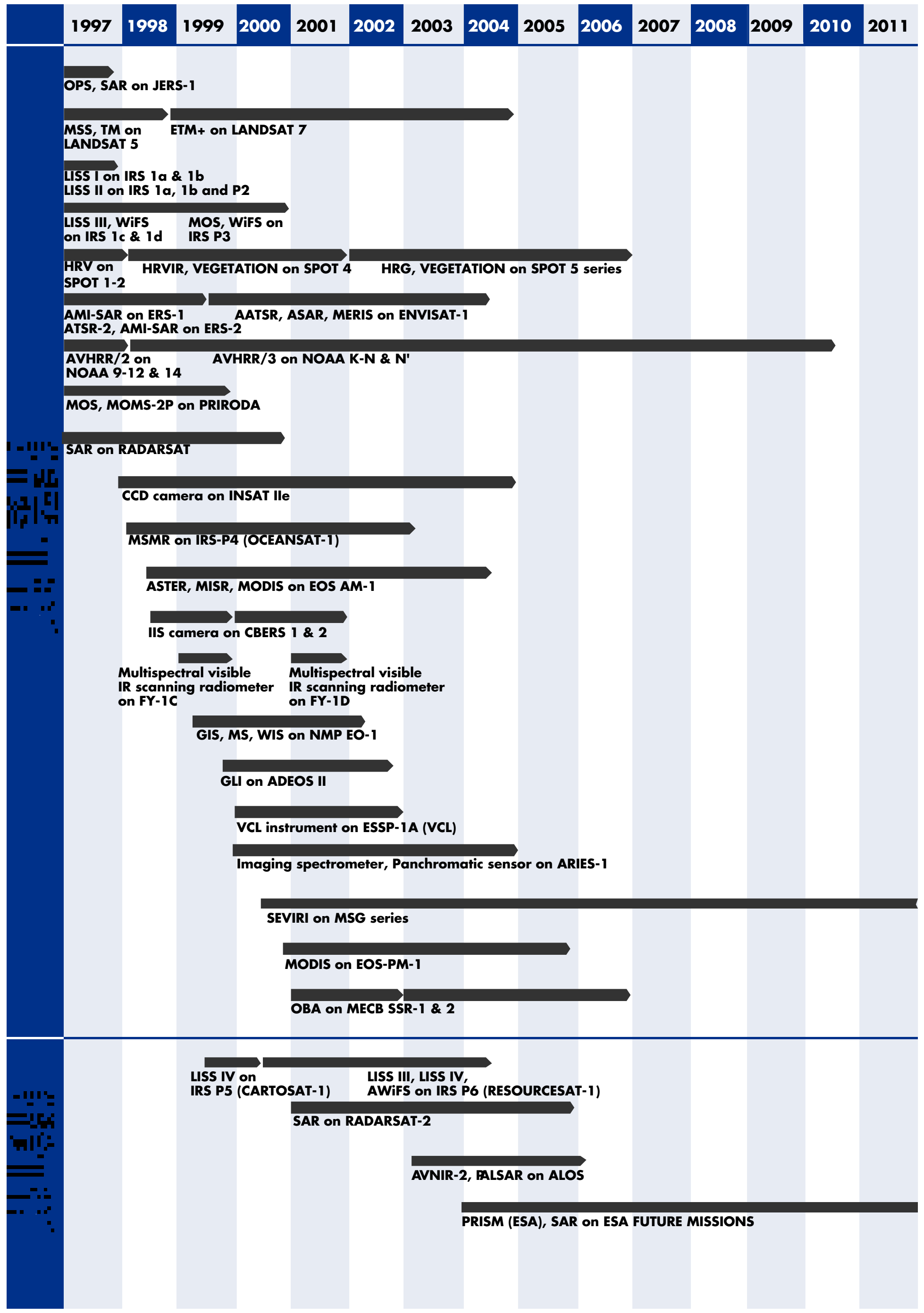
The involvement of vegetation in the carbon cycle is of key importance, and measurements of vegetation offer a means of monitoring the uptake of CO_2 from the atmosphere which in turn may contribute to a better understanding of the part vegetation plays in modifying the effects of man-made CO_2. However, the measurement requirements necessary for studying the role of vegetation in the carbon cycle, in terms of spatial, spectral and temporal resolution are, in general, only likely to be met by in-situ measuring techniques.

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

There is also significant potential for the use of EO data on vegetation in forestry. Deforestation is of widespread concern to ecologists and its impact is not yet fully understood. Forest monitoring using satellite imagery has become an increasingly important tool for investigating and controlling the exploitation of forest land, especially in the tropical rain forest regions where large areas of trees have disappeared. In rain forest areas which are frequently covered with clouds, the all-weather day/ night capability of SAR has been particularly useful.

There is a large number of medium-to-high resolution multi-spectral imagers that may be used to provide data on vegetation type. AVHRR, for example, provides routine data that have been used to derive vegetation indices. In the future, SEVIRI will offer a similar capability, and the purpose-designed VEGETATION instrument should offer improved spectral resolution and hence categorisation capability. Higher spatial and spectral resolution information will be obtained from the ESA PRISM mission and from imaging radars such as SAR, although the global coverage and temporal resolution offered by current and planned radar sensors is limited.

Data on vegetation is of primary importance to the IGOS Global Observations of Forest Cover project (eg land cover data, forest biomass data and leaf area index data).



Land

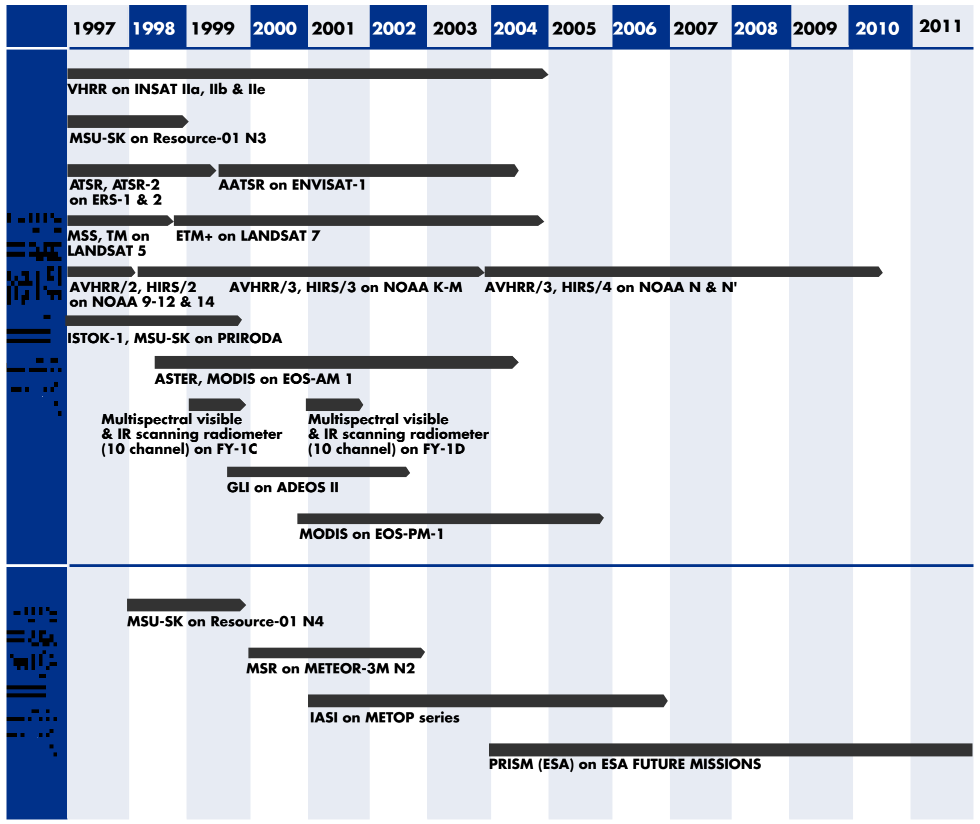
Surface temperature (land)

On a global scale, data on land surface temperature are used in conjunction with measurements of albedo as an input to climate change models. In conjunction with information on rainfall, measurements of land surface temperature may be used to derive evaporation rates which are used in investigating the water budget. In parallel with multi-purpose land imagery, surface temperatures may be used to deduce vegetation types. Land surface temperature may be used to validate the surface physics elements of NWP models. Measurements of surface temperature patterns may also be used in studies of plate tectonics to indicate areas of activity, for example along fault lines, and to monitor particular volcanic regions. Forest fire detection and resource exploration are two further applications.

On a local scale, surface temperature imagery may be used to refine techniques for predicting ground frost and to determine the warming effect of urban areas (urban heat islands) on night-time temperatures. In agriculture, temperature information may be used, together with models, to optimise planting times and to provide timely warnings of frosts.

Temperature measurements are at present provided using the thermal infra-red channel of medium/high resolution multi-spectral imagers in low Earth orbit. In addition, visible/infra-red imagers on geostationary satellites also provide useful information (with the advantage of very high temporal resolution). However, difficulties remain in converting the apparent temperatures as measured by these instruments into actual surface temperatures - variations due to atmospheric effects, and vegetation cover, for example, require compensation using additional imagery/information. The temporal and, in particular, the spatial resolutions offered by the current generation of sensors are poor and will be improved with the advent of new sensors such as ASTER and PRISM. The next generation of sounding instruments on board polar-orbiting platforms will also provide improved data.

The IGOS Global Observations of Forest Cover project requires measurements of land surface temperature in order to provide information on Fire Scar extent.



Multi-purpose imagery (land)

The measurements listed above do not alone provide a sufficiently wide or representative picture of the possible contributions from Earth observation satellites in relation to observations of land.

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

At regional and global scales, low resolution instruments with wide coverage capability - such as AVHRR, ATSR-2, and imaging sensors on geostationary satellites, are routinely exploited for their ability to provide global scale data on land cover and vegetation. Land cover change detection is an important source of global environmental change and has profound implications for ecosystems, biogeochemical fluxes and climate. Land cover change affects climate through a range of factors from albedo, through to emissions both of trace greenhouse gases such as methane and of particulates to the atmosphere resulting from biomass burning. Wide coverage land imagery is of value in many other areas, such as monitoring and mapping severe flooding events, forest fire detection in remote areas, volcano hazard alerting, drought watch and food security programmes.

On national and local scales, the higher spatial resolution requirements for information mean that high resolution imaging sensors, such as on Spot and Landsat, and imaging radars, such as on JERS-1 and ERS-1, are most useful. Such sensors can be (and routinely are) used as practical sources of information for:

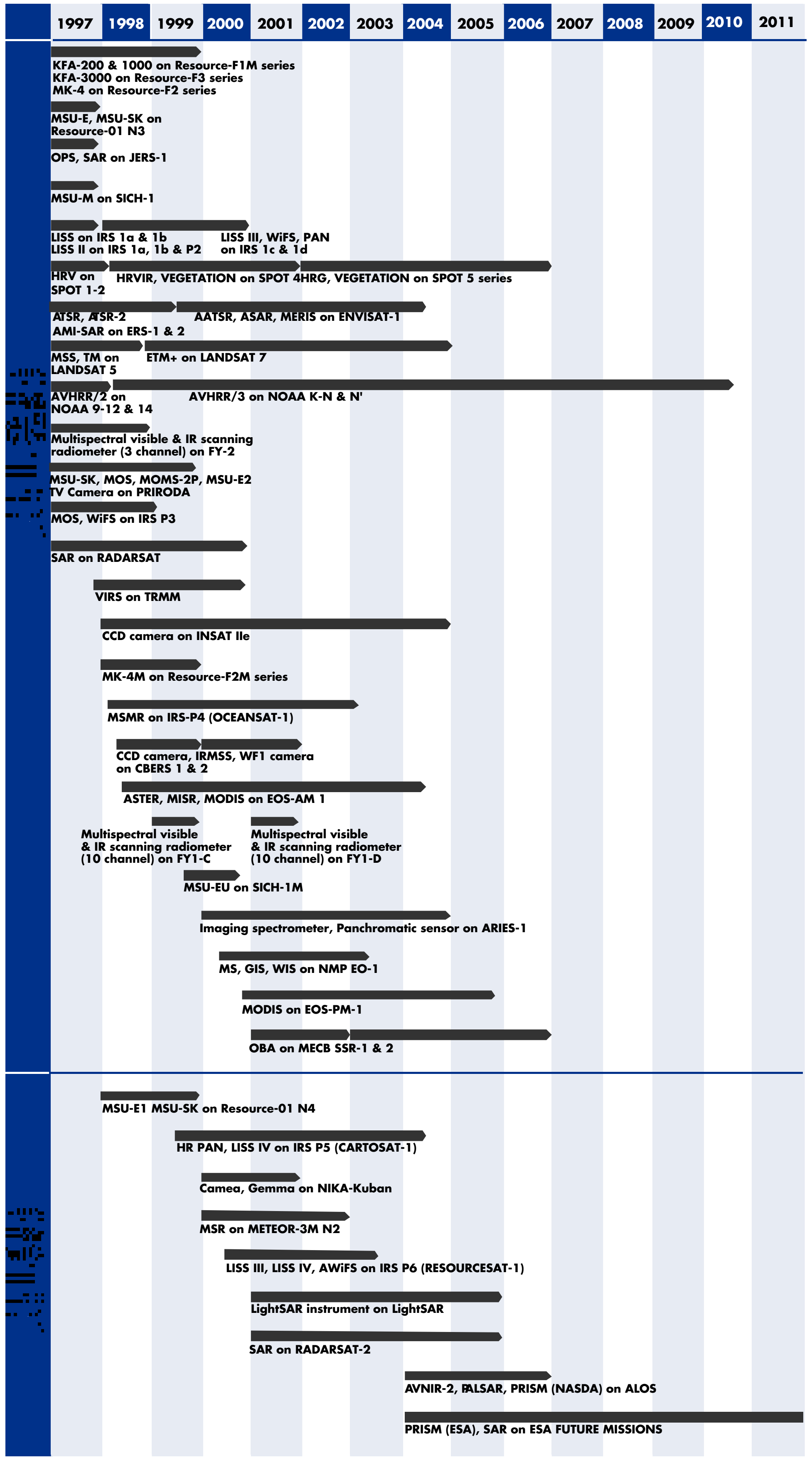
- agriculture: monitoring, production forecasting, and management;
- resource exploration and management: for example, in forestry, and in mineral deposits;
- geological surveying: identifying geological structures and sub-surface geometry (when combined with geophysical survey data), for identifying minerals, water and gas and oil deposits;
- hydrological applications: such as flood monitoring and environmental impact assessments for water diversion schemes;
- civil mapping and planning: for cartography, infrastructure and urban management etc;
- coastal zone management: monitoring erosion and deposition.

High resolution imagery can also be used for land cover classification and change detection on a local/national level.

An increasing number of missions providing multi-purpose land imagery (such as those of the USA, France, Japan, India, China and Brazil) are in operation or are planned for the next decade. Broader swath instruments designed for global coverage (such as AVHRR) will be complemented by higher resolution sensors such as MODIS and MERIS. In general, future sensors will benefit from a greater number of sampling channels. However, many of these instruments will be restricted to daylight only or clear sky operations and the all-weather day/night capability of high resolution SARs will continue to be important. Also, multi-temporal techniques are being developed to better exploit different future sensors, for example for better discrimination.

Multi-purpose land imagery is of primary importance to the IGOS Global Observations of Forest Cover project.

Land



Ocean

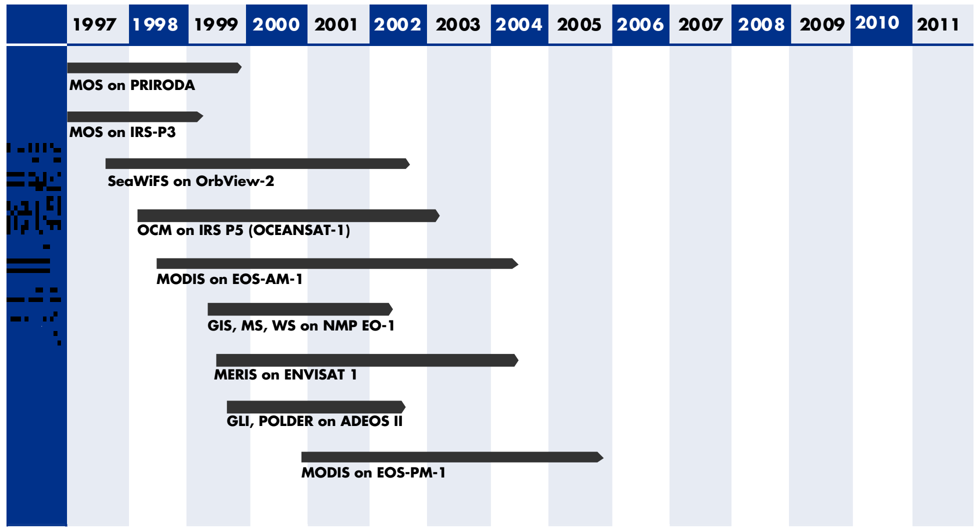
Ocean colour/biology

Measurements of ocean colour provide information on ocean biological parameters, in particular the quantity of phytoplankton present. These plants are of great importance since not only do they form the lowest level of the marine food chain, but they also play a role in many geochemical processes such as converting dissolved CO_2 into other compounds, thereby acting as a biological pump absorbing some of the CO_2 released into the atmosphere by fossil fuels. A fundamental understanding of biological cycles is thus essential in quantifying human impacts on the global biosphere.

At a local scale, satellite observations of ocean colour, usually in conjunction with sea surface temperature measurements, may be used as an indication of the presence of fish stocks. Measurements may also be used to monitor water quality and to give an indication of the presence of pollution by identifying algal blooms. Measurements of ocean colour are particularly important in coastal regions where they can be used to identify features indicative of coastal erosion and sediment transfer.

The launch of OCTS and POLDER (and their relatively brief source of data) and more recently of SeaWiFS has provided critical sources of data that have been missing since the completion of the CZCS mission (1987). In order to provide sufficient global coverage with the desired accuracy on timescales characteristic of ocean variability, techniques are needed which blend satellite and in-situ data. At present, measurements of ocean colour using the general imaging sensors of SPOT, Landsat and AVHRR are of limited use, primarily as a result of relatively low spectral resolution or radiometer sensitivity. In the future, additional capability will be provided by the new generation of narrow spectral band spectrometers such as MODIS, MERIS and GLI.

Ocean colour data are of primary importance for the following IGOS projects: GODAE; and the Long Term Measurements of Ocean biology project (particularly chlorophyll measurements).



Ocean topography/currents

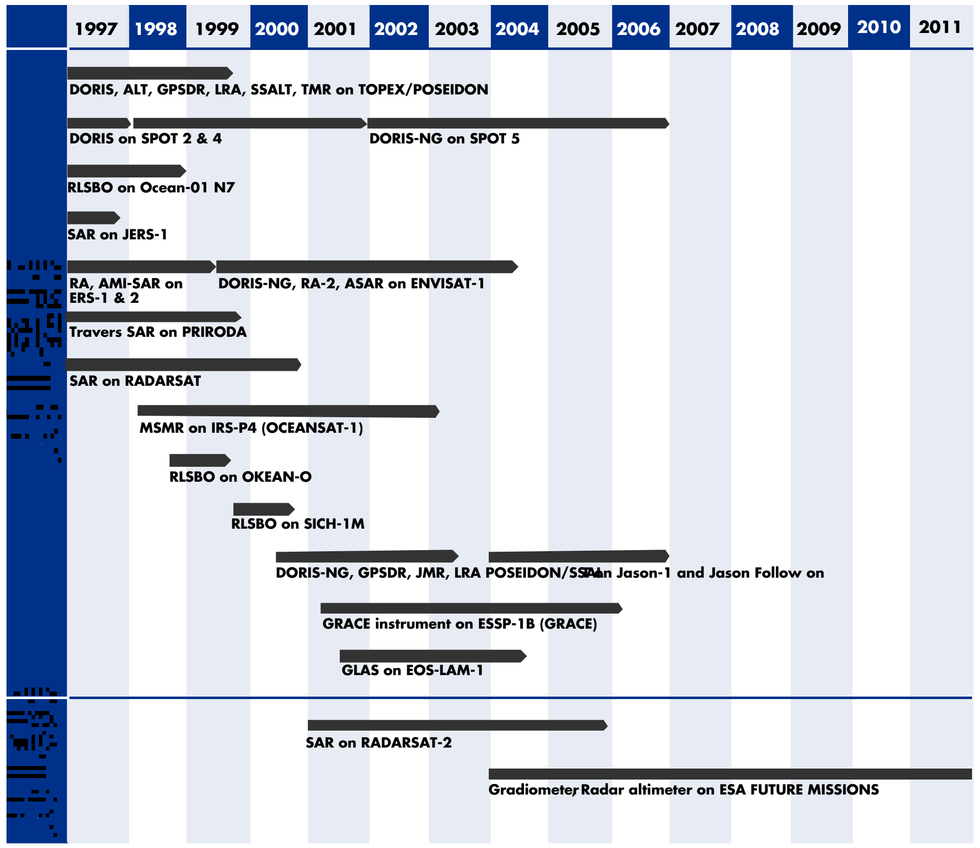
Ocean circulation is of critical importance to the Earth's climate system. Ocean currents transport a significant amount of energy from the tropics towards the poles leading to a moderation of the climate at high altitudes. Thus knowledge of ocean circulation is central to understanding the global climate. Circulation can be deduced from ocean surface topography, which may be readily measured using satellite altimetry. In fact, no other instrument is capable of providing observations of the global ocean circulation - in-situ measurements are plagued by inconsistencies in the reference level and insufficient coverage. However, altimeters will only provide the geostrophic part of ocean currents unless the geoid is known more accurately (with this information it is then possible for altimeters to measure large scale permanent ocean currents).

Using satellite altimetry, large scale changes in ocean topography, such as those in the tropical Pacific related to El Niño events may be observed, and the mean level of the oceans may be measured - information which is of particular interest to low-lying countries.

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

Altimeter packages, such as those on the ERS series and on TOPEX/POSEIDON and its successor JASON-1, are capable of measuring ocean topography to around 7cm and 3cm, respectively. The TOPEX/POSEIDON and JASON-1 platforms comprise a dual frequency altimeter which allows corrections to be made for ionospheric delays. Altimeters with large swaths (a few hundred kms across track) are under development but are unlikely to have flight opportunities for a decade or more. Information on ocean circulation may also be obtained indirectly from features such as current and frontal boundaries in SAR imagery, and by using differences in ocean temperature or ocean colour as observed by visible and infra-red imagers.

Sea surface topography data is of primary importance to the IGOS GODAE project. It is required for applications such as mesoscale variability, large scale variability, mean sea level and heat transport.



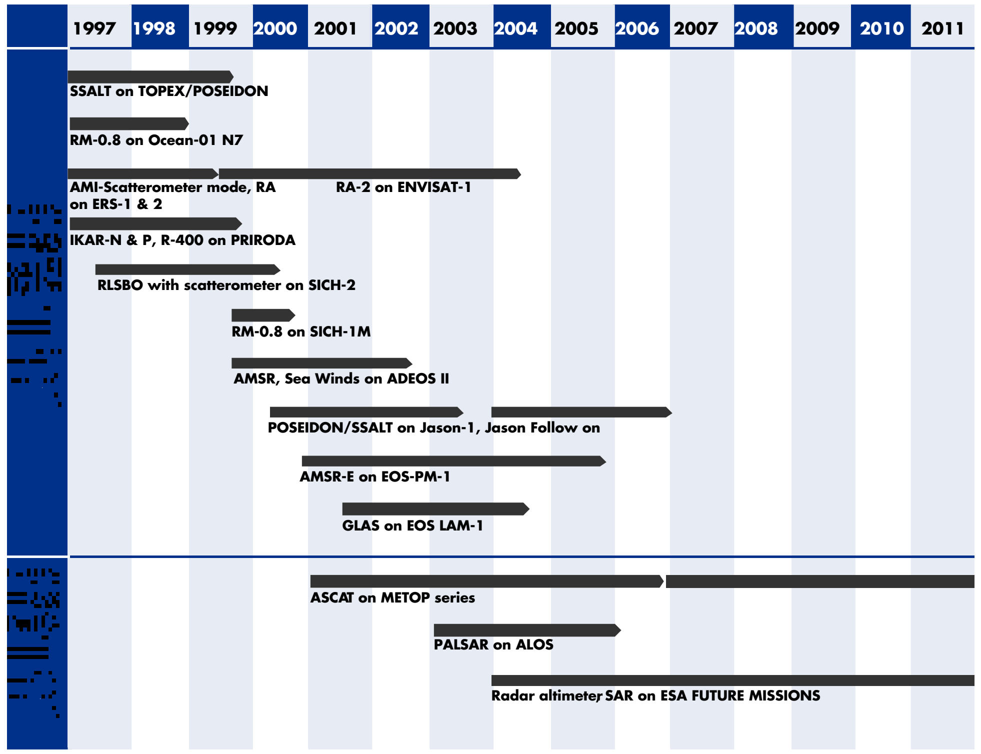
Sea surface winds

Consistent sea surface wind data of high quality and high temporal resolution are required for operational weather forecasting (through assimilation into NWP models) and to enable understanding of the large-scale air-sea fluxes which are vital for climate prediction purposes. Apart from their use in standard weather forecasting and climate applications, satellite EO data on sea surface winds are particularly valuable for short-term severe weather warnings and for ship-routing, providing a valuable source of information at sea, where no alternative data sources are available. Studies on cyclones, hurricanes and other intense wind patterns have been greatly impeded in the past by a severe lack of accurate, extensive wind data – in-situ observations are nearly impossible in these types of weather conditions, so the ability to exploit remote sensing is imperative, and scientists are now increasing their understanding and ability to predict these phenomena through the use of EO data.

The AMI active microwave scatterometers on the ERS series are the only instruments that can measure both surface wind speed and direction. The coverage from these instruments is limited, however, since they have a single-sided field of view, and hence data from the limited period of operation of the dual-sided swath instrument NSCAT on ADEOS (which failed in June 1997) is of great interest. Coverage will also be greatly improved with SeaWinds on ADEOS II and ASCAT on METOP. Measurements of wind speed (but not direction) may also be derived from altimeters such as ALT and RA/RA-2, and from passive microwave imaging radiometers such as AMSR on ADEOS II.

Recently, it has also been demonstrated that SAR data can be used to derive quantitative information on the near-surface wind field at a spatial resolution of several kilometres.

Sea surface wind data are of primary importance to the following IGOS projects: GODAE; and the Long Term Measurements of Ocean Biology project.



Ocean

Surface temperature (sea)

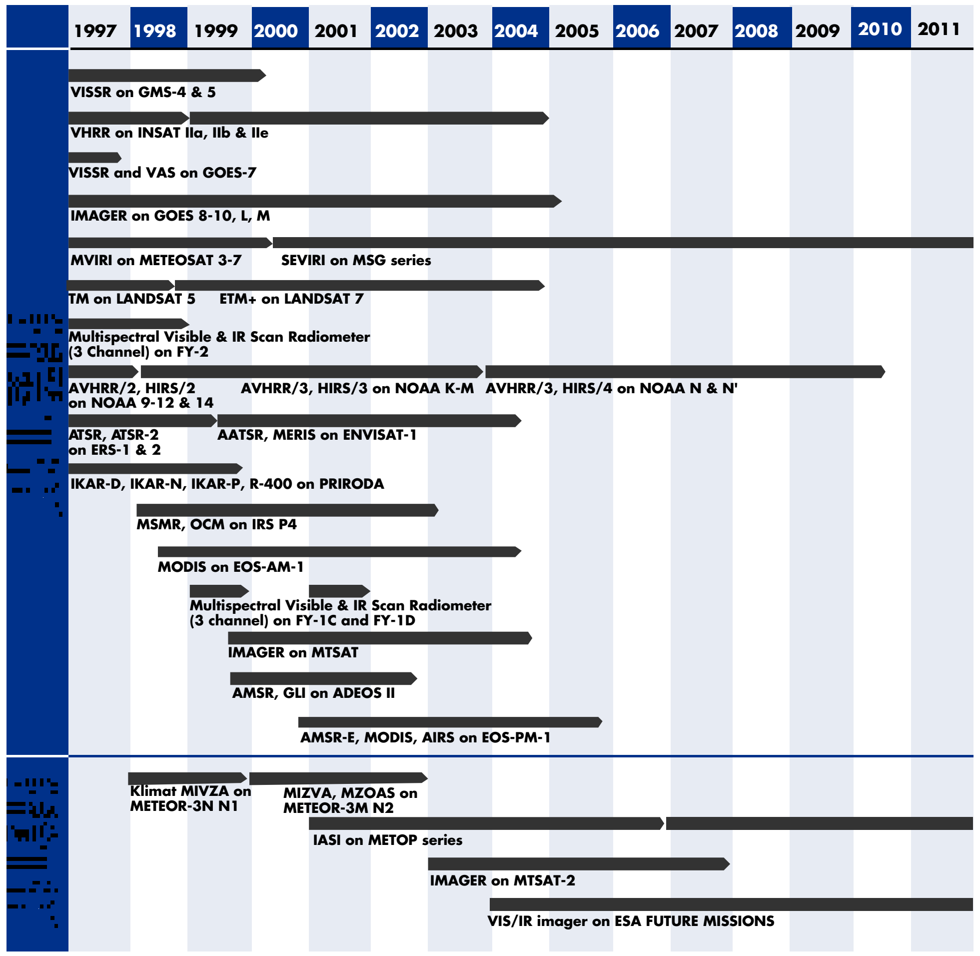
Measurements of sea surface temperature (SST) are of key importance for the studies of coupled atmosphere-ocean phenomena. Through heat exchanges at the air-sea interface, SST is a major factor in the processes underlying the surface energy balance. It is also central to the circulation of the atmosphere and oceans, and hence plays a fundamental role in regulating weather and climate. Departures from mean SSTs are also key indicators of environmental change, both those transient in nature such as the El Nino event, and those of a longer term such as rising sea levels and desertification. A major research goal is the development of an increased understanding of the links between SST and all the above processes. This will only be achieved through a more precise and comprehensive set of SST measurements. Satellite remote sensing provides the only practical means of developing such a dataset - insitu data are extremely limited in coverage and are predominately confined to shipping lanes whereas satellites offer the potential for surveying the complete ocean surface in just a few days. Nevertheless, in-situ data still have a key role to play in calibrating satellite data and in providing data needed for the conversion from skin temperatures (as measured by satellite) to bulk temperatures (as measured by conventional means).

EO data have also been used to monitor a variety of phenomena such as river outflow and the intrusion of the Gulf Stream water into coastal regions. In conjunction with ocean colour measurements, measurements of SST can be used to give improved estimates of ocean biological productivity and to monitor global phytoplankton distributions, which may themselves be used to guide fishing fleets to productive fishing grounds and to support geographic separation of coastal commercial fishing operations from the nesting and migratory pathways of protected species.

Other applications of SST measurements include the study of mixed layer dynamics, mesoscale ocean features such as eddies and fronts, and coupled physical-biochemical processes, all of which are vital for the development of process models.

A range of instruments with thermal bands may be used for SST measurement. Visible/infra-red imagers such as AVHRR and ATSR/ATSR-2 currently provide the main source of SST data, with ATSR/ATSR-2 providing better accuracy, but AVHRR provciding greater coverage (due to its larger swath width). In the future, spatial and spectral resolution will be improved with instruments such as MERIS and MODIS. Microwave sensors provide useful (although less accurate) data during cloudy conditions. AMSR in particular will ensure that future coverage and temporal requirements are met, although it will not be sufficiently accurate for climate change studies. Visible/infrared imagers on geostationary platforms can also provide 'clear-sky' data with very high temporal but relatively low spatial resolution.

Sea surface temperature data are of primary importance to the following IGOS projects: GODAE; and the Long Term Measurements of Ocean Biology project.

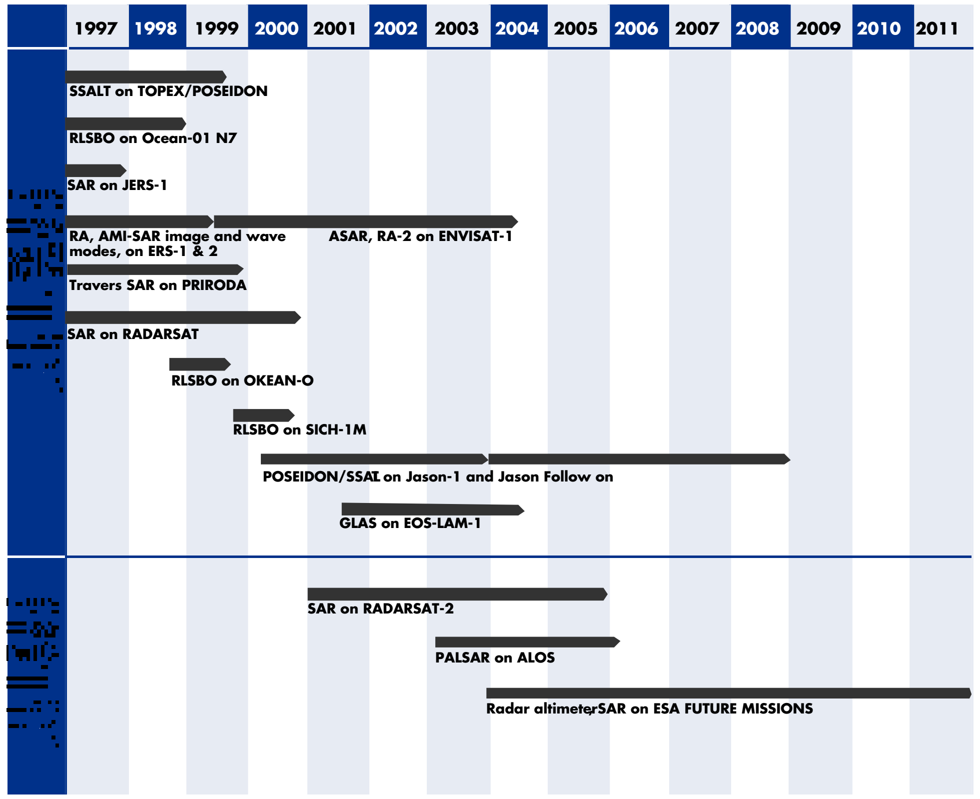


Wave height and spectrum

Measurements of ocean wave spectrum allow for the prospect of improved modelling of the conditions within storms and, together with information on wind speeds and surface temperatures, an improved understanding of the air-sea interactions involved, thereby resulting in better forecasts of the behaviour of ocean waves. Such forecasts are of great interest to a variety of marine and coastal activities, including ocean-bound shipping (to protect lives and property as well as to plan the most economical routing of ships), off-shore drilling installations (to ensure the safety of their operations) and coastal protection industries (for example to optimise harbour construction).

Measurements of wave height and spectrum are also used by oceanographers to investigate large-scale ocean features such as fronts and eddies and to construct and verify models of these phenomena. Understanding the processes behind these phenomena is difficult and detailed measurements are vital to improving understanding. These data are also important for climate purposes as they are needed for the correct representation of turbulent air-sea fluxes.

At present, information on wave heights is obtained primarily from satellite altimeters and SARs. Information from radar altimeters is limited to significant wave heights, and the resolution of these measurements is generally poor, although this should be improved with future instruments such as GLAS. SARs can accurately measure changes in ocean waves and winds, including wavelength and the directions of wave fronts, regardless of cloud, fog or darkness. In addition, by inverting SAR image spectra, ocean wave spectra may be obtained which are of particular importance in modelling ocean phenomena.



Ocean

Multi-purpose imagery (ocean)

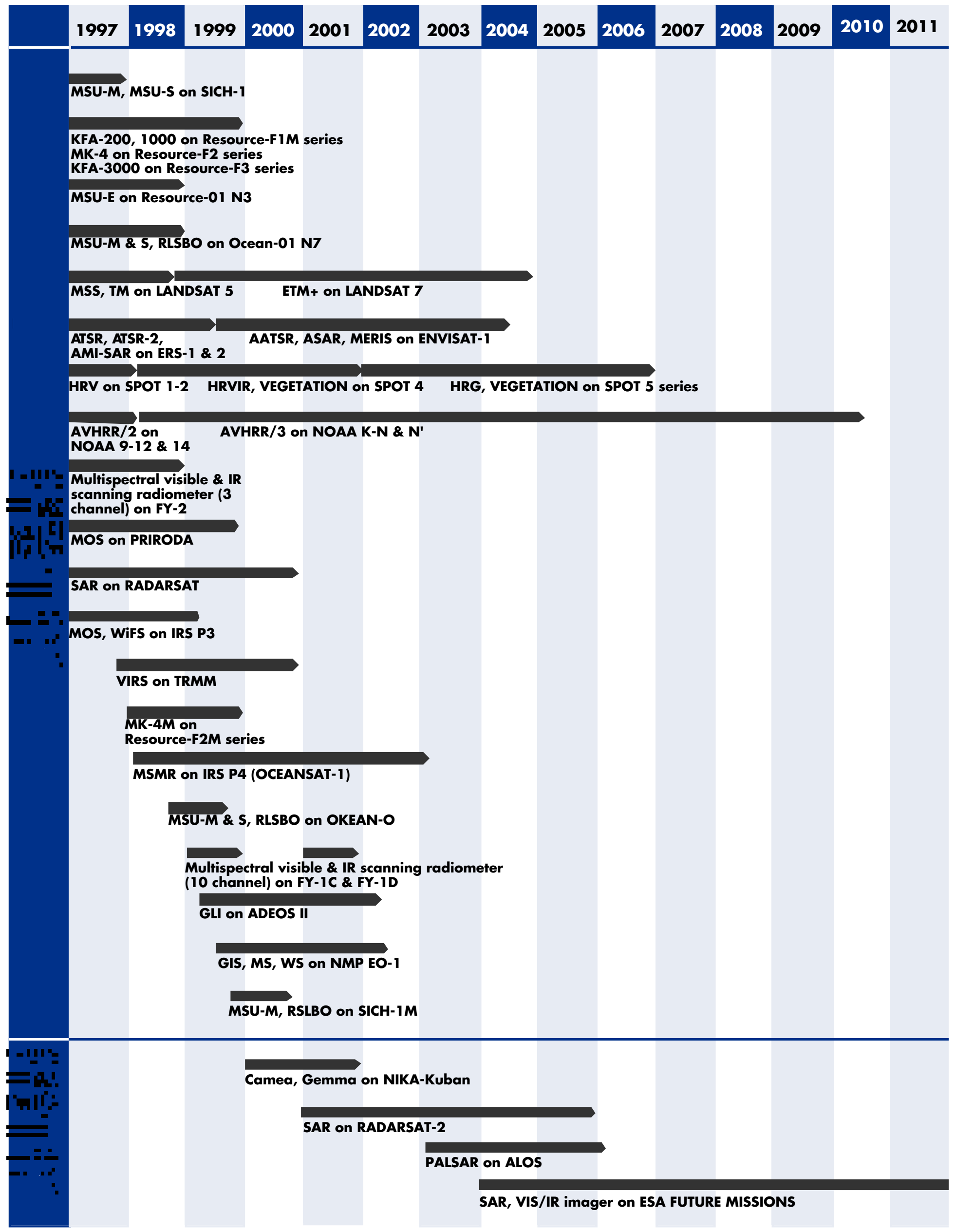
In addition to the specific ocean measurement observations discussed above, a number of sensors are capable of providing ocean imagery which is of value in various applications.

Wide area coverage sensors such as AVHRR and ATSR/ATSR-2 are suitable for observations of large scale ocean features, using variations in water colour and temperature to derive information concerning large scale circulation, currents, river outflow, and water quality. Such observations are applied to areas such as ship-routing, environmental monitoring of sensitive coastal zones, hazard assessment and management of fishing fleets.

High resolution imaging sensors are better suited to observations of coastal zone areas and can provide information on sedimentation, bathymetry, erosion phenomena, and aquaculture activity.

In addition, SARs provide a valuable and reliable all-weather source of information on oceanographic features – including fronts, eddies and internal waves. SAR imagery is also useful for:

- pollution monitoring – including oil spill detection;
- ship detection of use in the context of rescue services, port authorities, customs and immigration;
- coastal change detection – topography monitoring;
- bottom topography mapping: which has value in resource exploration and pipeline routing.



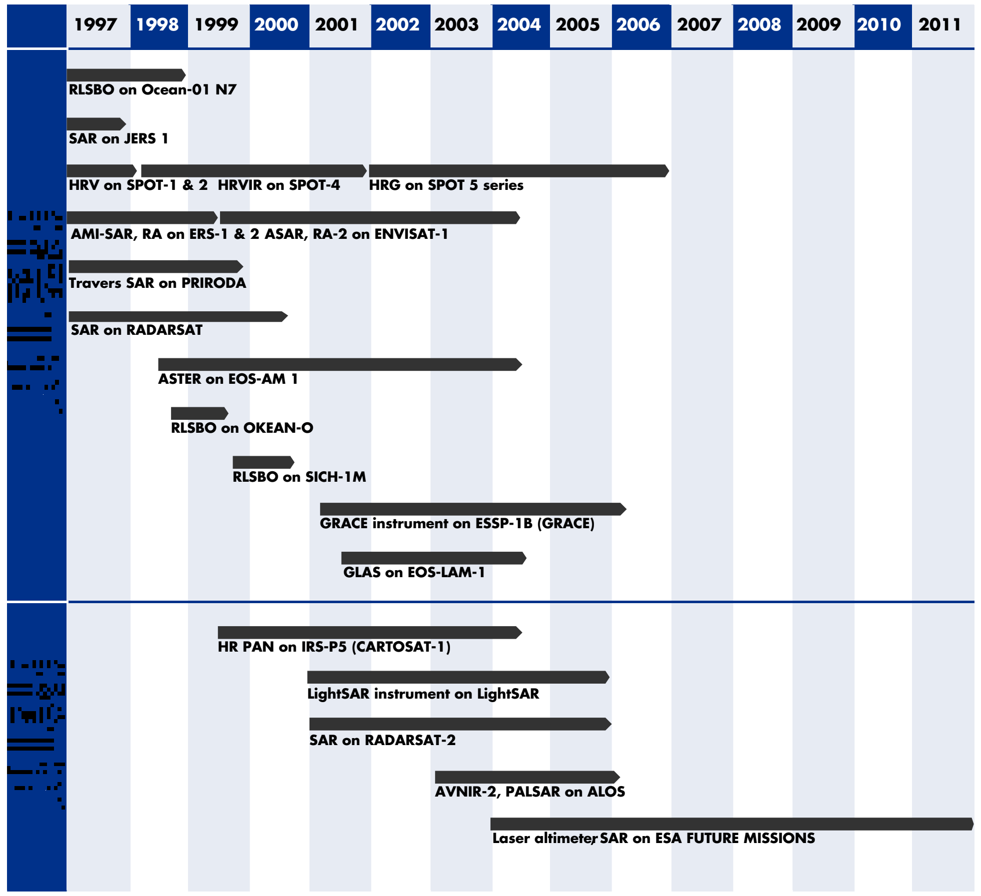
Ice sheet topography

The state of the polar ice sheets and their volumes are both indicators and causes of climate change and it is thus of great importance to monitor and study them in order to investigate the impact of global warming and to forecast future trends. Satellite remote sensing allows not only observations of the changes in shape of ice sheets, but also identification of the shape and size of large icebergs that have detached from the ice sheet.

The primary source of EO measurements of ice sheet topography comes from a range of satellite altimeters flown on both ESA and NASA/CNES missions. Although many of the altimeters have high vertical resolution (of order a few cm), their horizontal resolution is often limited and hence they are of most use over the smoother, near horizontal portions of ice sheets. The new generation of beam-limited laser altimeters such as GLAS with a high (~70m) horizontal resolution should be able to detect much sharper changes in topography.

Some high resolution instruments with a stereo viewing capability may also be used to infer topography. AMI on the ERS series, for example, has provided detailed maps of polar ice topography.

New techniques employing SAR interferometry are providing topographical information of very high precision.



Sea ice cover, edge and thickness

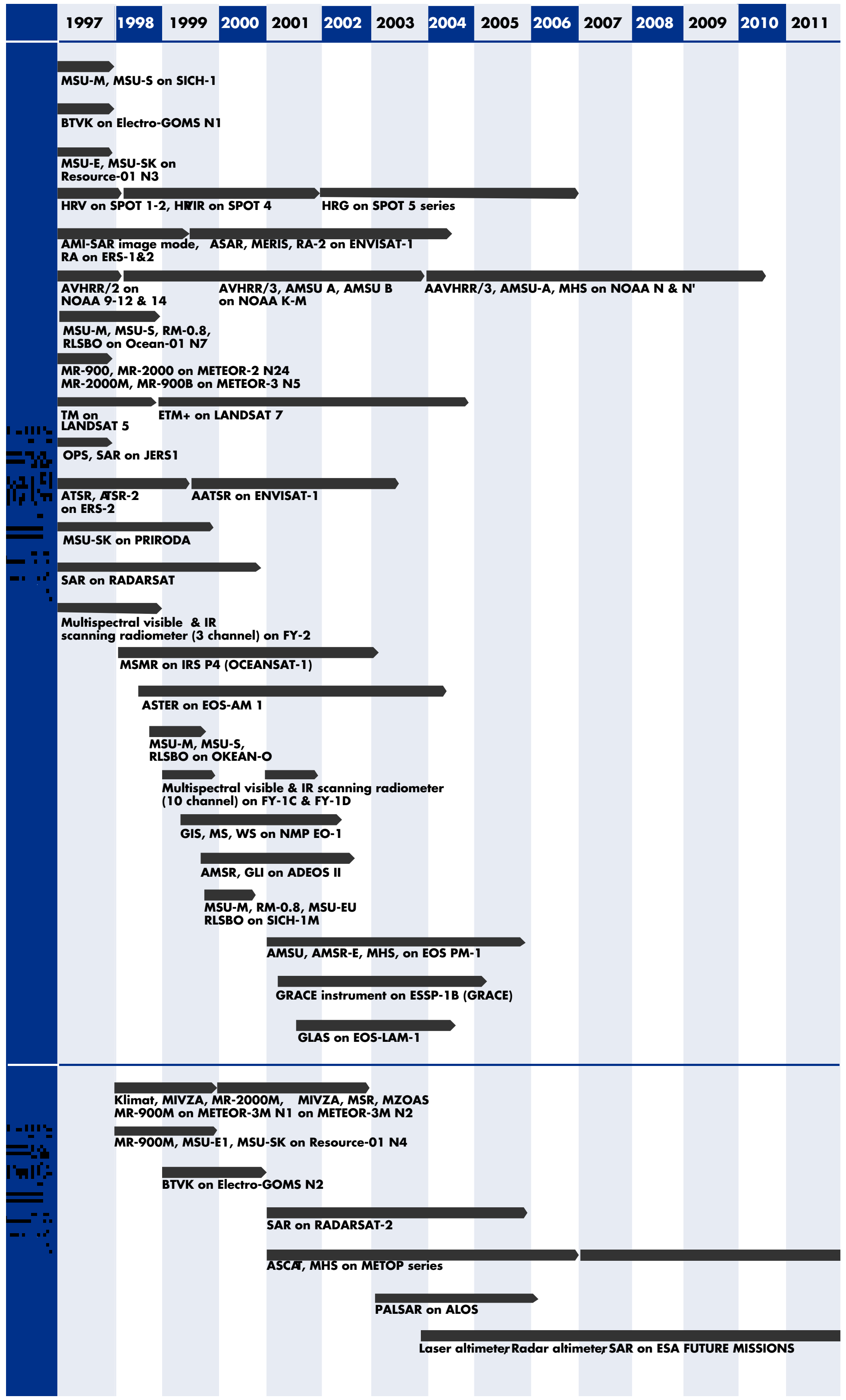
Satellite Earth observation can provide information on ice cover, ice type, ice edge and, to a lesser extent, ice thickness that would not be practically or economically achieved through conventional airborne surveys or in-situ measurements. Near real-time delivery of data tracking the continually changing nature of ice field conditions provides operational sea ice charts for use: by shipping to avoid damage, delay and to reduce fuel costs; by offshore drilling companies; by maritime insurance companies; and by government environmental regulatory bodies. The ability to map sea ice distribution and to identify ice-type in all weather conditions is of particular value to countries that have large ice-infested areas enveloped in darkness for long periods.

Information on the position, extent and thickness of sea ice cover is also of interest for monitoring of changes in the polar regions which have an strong relationship with the global climate, both through their high albedo, the effect sea ice has on ocean-air fluxes and its potential to alter the local salinity and hence dynamics of the ocean. In addition, sea ice thickness may be a sensitive indicator of possible climate change.

Ice cover and type may be determined using visible/infra-red sensors which are currently available (AVHRR, ATSR/ATSR-2). In the future, microwave imagery from multi-spectral radiometers such as AMSR will enable all weather operation coupled with good coverage. Radar altimeters provide some information on ice thickness, but more accurate measurements will require laser profilers such as GLAS.

High resolution synthetic aperture radars such as AMI on the ERS series, SAR on JERS-1, and RADARSAT offer the best source of data, and again have the important advantage of all-weather day/night operation. Data from these instruments provides information on the nature, extent and drift of ice cover and is used not only for status reports, but also for ice forecasting and as an input for meteorological and ice drift models. Low resolution scatterometer observations such as those from ERS AMI and ASCAT on METOP are also used to retrieve information on sea ice extent and concentration in all-weather conditions, during the day or night.

Sea ice cover data is of primary importance to the IGOS GODAE project.



1997 CEOS Yearbook

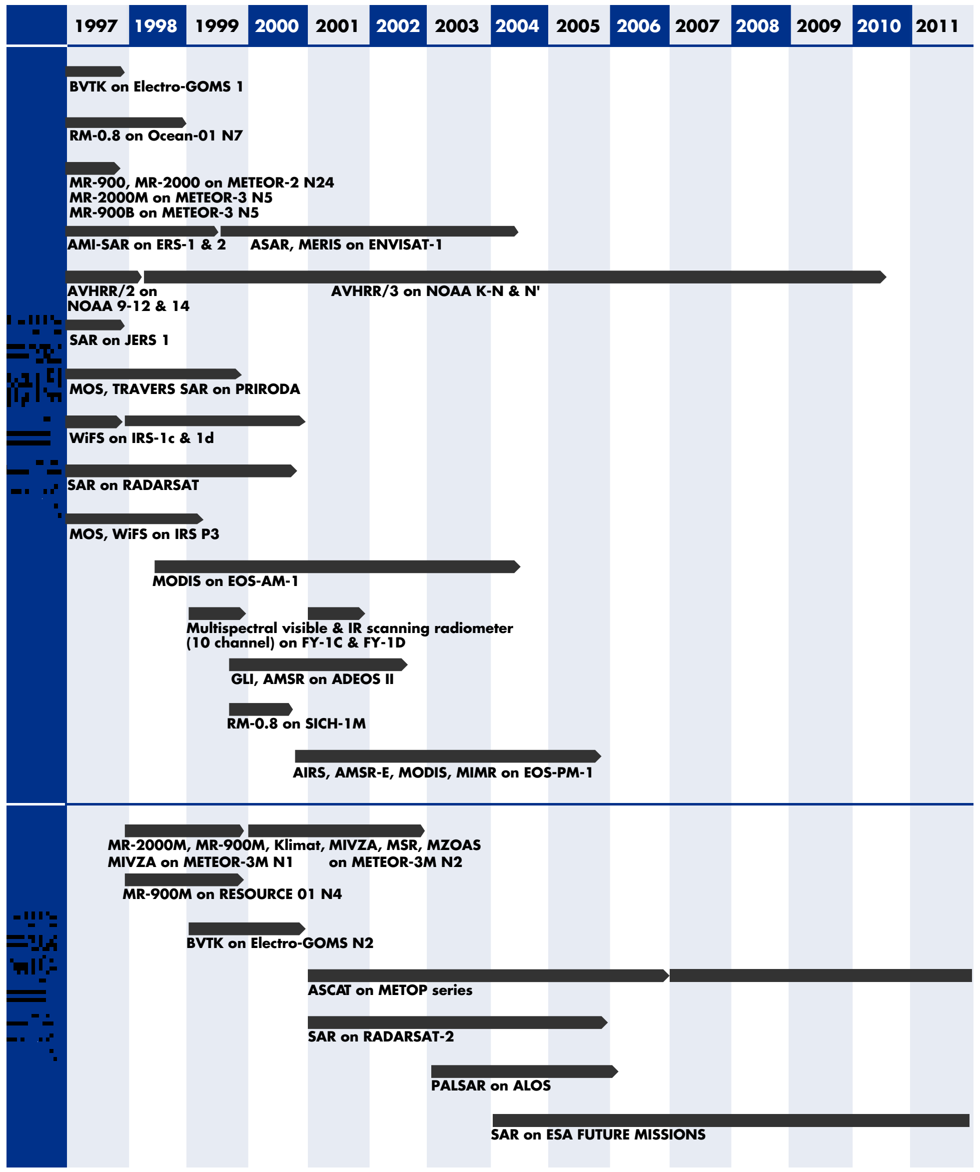
Snow cover, edge and depth

Snow cover results in marked changes in albedo and hence the radiation balance, and thus has a significant impact on the global climate. In addition, snow forms a vital component of the water cycle, and is an important source of water supply in many areas. Long-term databases of the volume, extent and depth of snow are therefore required to study and comprehend the climatic and economic impact of snow cover and to monitor climatic variations. With the availability of such information from satellite sensors, understanding of the role of snow in the global climate and hydrology processes is being improved. Snow cover and depth are important in the boundary conditions for NWP models.

Snow cover information has a range of additional applications such as in agriculture for detecting areas of winterkill; this results when grain planted in the autumn is damaged or killed because there is insufficient snow cover to insulate plants from freezing temperatures. Locally, monitoring of snow parameters thus allows warning of when melting is about to occur, which is crucial for hydrological research, for predicting run-off and in turn for forecasting the risk of flooding.

A range of different instrument types can contribute to measurements of snow. Visible, IR and microwave sensors can all be used to estimate snow cover. A more difficult measurement is snow depth. Passive microwave instruments (such as the planned AMSR) are capable of measuring snow liquid water content which, when combined with prescribed estimates of snow density, permits estimates of snow depth to be made. Active microwave instruments such as SARs offer very high resolution information on snow properties, for example SARs can distinguish between wet and dry snow (in the case of dry snow, microwave penetration also gives information on the underlying surface).

Low resolution scatterometer observations such as those from ERS AMI and ASCAT, which will be carried on METOP, are used to retrieve information on snow surface characteristics such as melting phase, in all-weather conditions, during the day or night.



A Catalogue of satellite missions

A.1 INTRODUCTION

This section gives details of the satellite missions of CEOS members and of the CEOS database from which much of the data in this yearbook is derived. Key events of 1996-97 are identified and changes to mission plans that have occurred since production of the 1995 CEOS Yearbook are cited. Those missions that are currently in service are then briefly described, and a timeline spanning the period 1997-2012 is used to identify all missions currently planned for this period. Distinction is made between missions that are currently in service and missions that are either approved or proposed. Those cases where a mission is to be extended beyond its planned lifetime are also identified.

Nearly all information contained in this annex has been gathered from and verified by CEOS agencies but it should be noted that the launch date and duration of some planned missions is uncertain (eg due to changes in funding or policy, changes in requirements, etc) hence, the accuracy of timelines relating to these missions cannot be guaranteed. If the month of the launch of a planned mission has not been specified the timeline is shown to commence at the beginning of the planned year of launch.

It should also be noted that missions currently operating beyond their planned life are shown as operational until the end of 1997 unless an alternative date has been proposed.

The annex is concluded with the full catalogue of CEOS agency EO satellite missions, arranged chronologically by launch date. For each of the missions, the following information is supplied:

- status, ie in service or planned (either firm/approved or proposed);
- launch date and expected mission duration;
- orbit details (note that the parameters given refer to: type, altitude, period, repeat cycle);
- instrument suite;
- primary mission application areas corresponding to those discussed in section 5.

Details of the instruments on these missions are listed alphabetically in annex B.

A.2 EVENTS OF 1995-97

The 1995 CEOS Yearbook listed 19 Earth observation missions scheduled for launch during the period from late 1995 to mid 1997. Of these, at the time of writing 10 missions have been successfully launched in addition to some 12 Resource series satellites:

SICH-1 (NSAU)	August 1995
RADARSAT (CSA)	November 1995
IRS 1c (ISRO)	December 1995
IRS P3 (ISRO)	March 1996
PRIRODA (Russia, on MIR space station)	April 1996
TOMS Earth Probe (NASA)	July 1996
ADEOS (NASDA)	August 1996 (no longer operating)
GOES 10 (NOAA)	April 1997
Resource-F1, F2 and F3 series satellites (RSA) – these satellites have a planned mission duration of several months. Between 1 and 3 satellites from each of these series were launched per annum during 1996 and 1997;	
OrbView-2 (NASA)	August 1997
METEOSAT 7 (EUMETSAT)	September 1997

Further missions now planned for launch before the end of 1997 are:

MECB SCD-2A (INPE)
TRMM (NASA/ NASDA)

Missions currently scheduled to be launched in 1998 comprise:

SPOT 4 (CNES)	February 1998
NOAA 15 (NOAA K) (NOAA)	February 1998
IRS P4 (ISRO)	February 1998
CBERS-1 (INPE)	May 1998
EOS AM 1 (NASA)	June 1998
OKEAN-O (NSAU)	September 1998
Odin (SNSB)	later half of 1998
LANDSAT 7 (NASA)	December 1998
MECB SCD-2 (INPE)	1998
IRS 1d (ISRO)	1998
METEOR 3M N1 (RSA)	1998

A number of in-service Earth observation satellites were due to complete their missions (extended missions in some cases) during 1996 or early 1997, but continue to supply data beyond their expected lifetime:

SPOT 1 and 2 (CNES);
ERS-1 (ESA);
MECB SCD-1 (INPE);
IRS-1a and 1b (ISRO);
UARS (NASA);
JERS-1 (NASDA);
GMS-4 (NASDA);
LANDSAT 5 (NOAA);
SICH-1 (NSAU).
Electro-GOM S N1 (RSA);
Ocean-01 (RSA);
Resource-01 N3 (ROSHYDROMET);
N5, N21 of the METEOR-2/3 series (ROSHYDROMET)

Although these missions continue to provide valuable data, in some cases their instruments are no longer fully functional.

A single mission, SPOT 1 has been recommissioned by CNES for the second time to meet users' demands for data until SPOT 4 becomes operational.

A.3 UPDATES TO FUTURE PLANS

The table of satellites in section A.6 lists *inter alia*, the missions that are planned for launch between 1997 and 2012. The most significant recent changes to these plans in 1996 and 1997 are:

- the definition of the Optimized Converged System - the US system (NPOESS) will combine the future NOAA and defence meteorological satellite series and be designed to satisfy users of meteorological data from polar orbiting satellites. A key element in the planning for the converged system is the Joint Polar System between NOAA and EUMETSAT with participation from ESA and NASA;
- merging of the planned EOS-ALTR (NASA) satellite series and the TOPEX/POSEIDON Follow On mission to form the JASON series;
- redefinition of the EOS-satellite programme (NASA) around the EOS AM, PM and CHEM series. This activity is ongoing - plans for the initial satellites in the EOS AM, PM and CHEM series remain unchanged, while plans for follow-on satellites are being reconsidered. Some instruments from other series (eg EOS AERO and COLOR) are being redeployed to other missions;
- extension of Landsat 5 operations until 1999 – after the launch of Landsat 7 – or until the satellite ceases to function normally if this event occurs sooner.

There are numerous detailed updates to the launch dates of future missions and to planned instruments. These details may be found in section A.6.

A.4 CURRENT MISSIONS

Brief descriptions of the principal current missions are listed alphabetically below.

ADEOS series: The aim of the ADEOS series is to observe the Earth using an array of optical, thermal, ocean colour and other sensors to obtain information on land, ocean and atmospheric processes. The ADEOS series also carries an experimental communication instrument (IOCS) for the study of interorbit links. The first ADEOS stopped operating unexpectedly in June 1997. ADEOS II is due for launch in 1999.

ERS series: ERS-1 was launched by ESA in July 1991; ERS-2 was launched in April 1995. This series concentrates on global and regional environmental issues, making use of active microwave techniques that enable a range of measurements to be made of land, sea and ice surfaces independent of cloud cover and atmospheric conditions. In addition, the ATSR/ATSR-2 instrument on these missions provides images of the surface or cloud top and the GOME instrument on ERS-2 provides measurements of ozone levels. ERS-1 and ERS-2 operated in tandem for around 1 year in 1995 and 1996 providing data for topographic applications such as differential interferometry.

Geostationary meteorological satellites: There is a world-wide network of operational geostationary meteorological satellites which provide visible and infra-red images of the Earth's surface and atmosphere. Countries/regions with current geostationary operational meteorological satellites are the USA (GOES series), Europe (METEOSAT series), Japan (GMS series), India (INSAT series), China (FY series) and Russia (GOMS).

IRS series: The Indian IRS satellites provide high resolution imagery in a range of visible and infra-red bands. Their primary objectives are national mappings of various resources. The series was supplemented by IRS-1c in December 1995.

LAGEOS series: These missions are designed to measure the Earth's crustal motion and the Earth's gravitational field. The space segment comprises corner cube laser retroreflectors and the ground segment is a global network of transportable laser sites. The design life of the space segment is 10,000 years.

METEOR series: RSA maintains two or three satellites in orbit at any time mainly for operational meteorological purposes. Other applications include experimental measurement of ozone and Earth radiation budget. This series is supplemented by the Electro-GOMS N1 meteorological mission which has been extended to 1998.

NOAA polar orbiters: The current series of operational polar orbiting meteorological satellites is provided by NOAA. Two satellites are maintained in polar orbit at any one time, one in a "morning" orbit and one in an "afternoon" orbit. The series provides a wide range of data of interest, including sea surface temperature, cloud cover, data for land studies, temperature and humidity profiles and ozone concentrations.

ORBVIEW-2: A satellite launched in August 1997 that carries the ocean colour radiometer SeaWiFS. OrbView-2 provides near-realtime information on aerosols, and ocean colour and biology which is used for environmental and fisheries applications.

PRIRODA: A dedicated remote sensing module on-board the MIR space station (Russia) comprising lidar, sounder and optical/IR and microwave imaging instruments. PRIRODA is an experimental platform used for the development and verification of remote sensing methods and for climatological, oceanographic and ecological applications.

RADARSAT series: launched in November of 1995, RADARSAT provides researchers and operational users with a range of SAR data products which are used for marine applications such as ship routing, and ice forecasting as well as land applications such as resource management and geological mapping. Data continuity into the next millennium will be ensured through the proposed launch of RADARSAT 2.

Resource series: Russia maintains a series of Resource satellites such as the recently launched Resource-01 N3 for land applications such as crop and soil monitoring, assessment of hydrological conditions, monitoring of forest and tundra firs and pollution monitoring.

MECB SCD series: This Brazilian satellite series receives environmental data gathered on the ground and transmits it to other locations.

SICH series: SICH-1, the first of this satellite series, is equipped with a radar imager, microwave radiometer, and low and high spatial resolution optical instruments. These satellites are designed to provide information on land, marine and sea ice phenomena, on an operational basis.

SPOT and Landsat series: The SPOT satellites operated by French, Swedish and Belgian space agencies, and the Landsat satellites operated by NOAA provide high resolution imagery in a range of visible and infra-red bands. They are used extensively for high resolution land studies. In 1997/98, US commercial satellites will provide very high resolution (better than 5m spatial resolution) imaging satellites which will broaden the range of land applications of EO data.

TOPEX/POSEIDON and JASON series: These satellites form a joint NASA/CNES precision radar altimetry mission to measure ocean topography and hence, the speed and direction of ocean currents.

A.5 CEOS DATABASE

As discussed in section 2, this Yearbook has its origins in the CEOS Dossier, first published by BNSC in 1992 and subsequently by ESA in 1993 and 1994. The CEOS Dossier Database - an electronic database version of the Dossier based on the information presented in the tables of this annex, was also produced by ESA in 1994. All of these documents had the aim of assisting in the task of determining how well the output from CEOS Members' missions met the requirements of CEOS Affiliates. The 1994 CEOS Plenary established the CEOS Task Force on Planning and Analysis to address this aim in more detail.

During its second year of activities, the Task Force was assisted by the development, at ESA ESRIN, of an on-line, relational database which was accessible via the Internet and which could be used by CEOS participants to update requirements and data provision information relevant to them. The Task Force established guidelines for the structure of the database and developed "standards" for its content in terms of the definition of variables and of the parameters used when entering Affiliates' requirements and Members' statements of provision (for example units, accuracy, resolution etc).

The WMO, one of the members of the Task Force, had already developed a stand-alone (PC-based) database of Affiliate requirements, based upon experience gathered cataloguing requirements of the various WMO Commissions over the past decade. The two database developments continued in parallel and both were used by the Task Force which presented its final report to the 1996 CEOS Plenary. Its work provided the foundation for the establishment of the CEOS Analysis Group referred to in section 2.

In January 1997, it was agreed that both versions of the database (ie on-line and stand-alone) were important and that each had its own merits. However, for the databases to be useful it was recognised that they must contain identical data from CEOS participants. Mechanisms for the input and transfer of data and for synchronisation of the two versions of the CEOS database were agreed and the first synchronised set of data in both versions of the database became available in early July 1997. The data can be read by anyone from either database but changes can only be made by authorised Member and Affiliate representatives.

Over 100 different geophysical variables are defined in the databases - atmospheric variables are further categorised into 4 "height" levels plus a vertically integrated column total. Those individuals charged with inputting data can also specify the degree of "certainty" associated with either a requirement or a statement of provision. The data within the databases is structured into different levels:

- Level 1 data includes basic identification details and summaries of satellite/ user programmes.
- Level 2 information relates to CEOS Members and contains information on the programmatic features of a series of satellites, lists the satellites in the series and reports technical features common to all satellites in the series.
- Level 3 information relates to CEOS Members and contains information on an individual satellite of a series or on a single satellite programme.
- Level 4 information details instrument characteristics needed by the user to evaluate the extent to which the instrument is suitable to fulfil the user's requirements.
- Level 5 information details requirements and performances in terms of geophysical variables.

The on-line version of the CEOS database can be accessed at http:/ / ceos.esrin.esa.it/ dossier and the PC-based version is available from WMO.

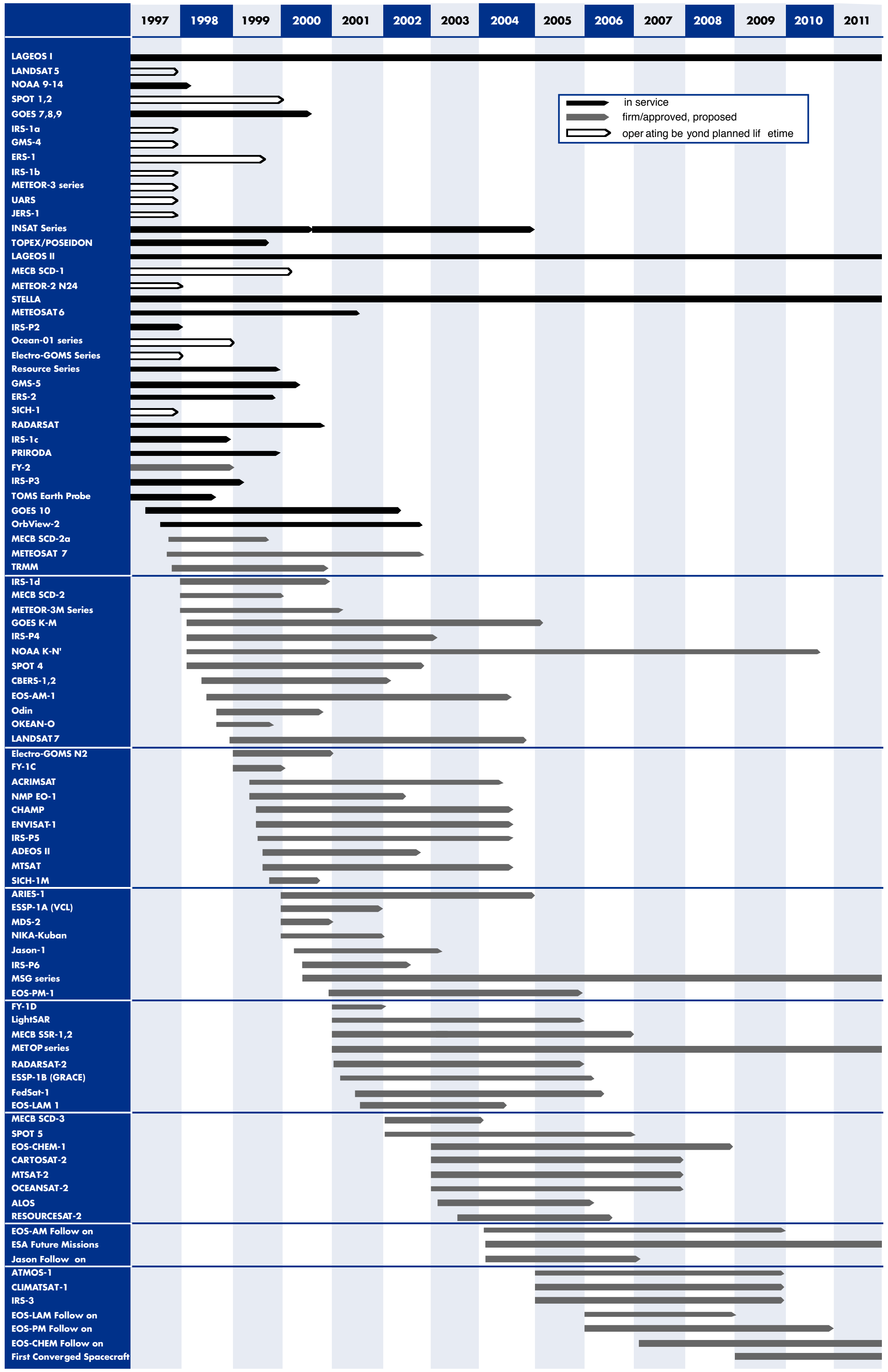


Fig A.1 Mission summary diagram

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A.6 LIST OF SATELLITE MISSIONS (CHRONOLOGICAL)

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
LAGEOS (NASA)	In service	May 1976 10,000	101 deg inclination, 6000km	Laser cornercube reflectors	Geodesy, crustal motion and gravity field measurements by laser ranging
LANDSAT 5 (NOAA)	In service	March 1984 13 years 6 months	Near polar, sun synchronous, crossing 0945h LST, 705km, 99 mins, 16 days	MSS, TM	Land surface, Earth resources
NOAA 9 (NOAA)	In service	December 1984 12 years 9 months	Polar, sun synchronous, crossing 1015h LST crossing, 843km	ARGOS, AVHRR/2, ERBE, HIRS/2, MSU, S&R (NOAA), SBUV/2, SEM, SSU	Meteorology, Agriculture and forestry, Environmental monitoring, Climatology, Physical oceanography, Volcanic eruption monitoring, ice and snow cover, ozone studies, space environment, solar flux analysis, life-saving capability through Search and Rescue
SPOT 1 (CNES)	In service	February 1986 13 years 10 months	Sun synchronous, 1031h LST, 832km, 101 mins, 26 days	HRV	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring
GOES 7 (NOAA)	In service	February 1987 10 years 7 months	Geostationary	DCS, S&R (GOES), SEM, VISSR and VAS (GOES-7), WEFAX	Meteorology, atmospheric dynamics, land surface, space environment, search and rescue, data collection, WEFAX (weather facsimile service)
IRS 1a (ISRO)	In service	March 1988 9 years 6 months	Sun synchronous, 904km, 103 mins, 22 days	LISS I, LISS II	Land surface, agriculture and forestry regional geology, land use studies, water resources, vegetation studies, coastal studies and soils
NOAA 11 NOAA	In service	September 1988 9 years	Polar, sun synchronous, pm crossing, 846km	ARGOS, AVHRR/2, HIRS/2, MSU, S&R (NOAA), SBUV/2, SEM, SSU	Meteorology, Agriculture and forestry, Environmental monitoring, Climatology, Physical oceanology, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, life-saving capability through Search & Rescue

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
UARS (NASA)	In service	September 1991 6 years	57 deg inclination, 600km, 97 mins, 36 days	ACRIM II, HALOE, HRDI, MLS (UARS), PEM, SOLSTICE, SUSIM, WINDII	Atmospheric chemistry (middle to upper atmosphere), atmospheric dynamics/water and energy cycles Research mission
JERS 1 (NASDA)	In service	February 1992 5 years 7 months	Sun synchronous, 568km, 96 mins, 44 days	OPS, SAR	Earth resources Land surface
INSAT IIa (ISRO)	In service	July 1992 9 years 1 month	Geostationary	BSS & FSS transponders, SRT-S&R, VHRR	Meteorology, data collection and communication, search and rescue
TOPEX/ POSEIDON (NASA)	In service	August 1992 7 years	Non sun-synchronous, 66 deg inclination, 1336km, 112 mins 25.8 sec, 9 days, 21 hours 58 mins 32 secs	ALT, DORIS, GPSDR, LRA, POSEIDON (aka SSALT), TMR	Physical oceanography, geodesy/gravity
LAGEOS II (NASA)	In service	October 1992 10000 years	52 deg inclination, 5900km	Laser cornercube reflectors	Geodesy, crustal motion and gravity field measurements by laser ranging
MECB SCD-1 (INPE)	In service	February 1993 3 years	25 deg inclination, 750km, 100 min	DCP	Data collection and communication
INSAT IIb (ISRO)	In service	July 1993 7 years	Geostationary	BSS & FSS transponders, SRT-S&R, VHRR	Meteorology, data collection and communication, search and rescue
METEOR-2 N24 (ROSHYDRO MET)	In service	August 1991 4 years 1 month	82.5 deg inclination, 900km, 102.5 mins	MR-2000, MR-900, RMK-2	Land surface, physical oceanography, atmospheric dynamics/water and energy cycles
STELLA (CNES)	In service	September 1993 10,000 years	Circular, 98 deg inclination, 830km	Laser reflectors	Geodesy/gravity Study of the Earth's gravitational field and its temporal variations
METEOSAT (EUMETSAT)	In service	November 1993 8 years 7 months	Geostationary	MVIRI	Meteorology, climatology

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
GOES 8 (NOAA)	In service	April 1994 5 years	Geostationary	DCS, IMAGER, S&R (GOES), SEM, SOUNDER, WEFAX	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX
IRS P2 (ISRO)	In service	October 1994 3 years	Sun synchronous, 817km, 101.35 mins	LISS II	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils
Ocean-01 N7 (ROSHYDRO MET)	In service	October 1994 4 years	Near polar, 82.6 deg inclination, 650km, 98 mins	KONDOR-2, MSU-M, MSU-S, RLSBO, RM-0.8	Agriculture and forestry, climatology, data collection and communication, hydrology, hydrometeorology, ice and snow, land surface, meteorology
Electro-GOMS N1 (RSA)	In service	November 1994 4 years	Geostationary at 76 deg East, 36000km, 24 hour	BRK, BTVK, RMS	Climatology, data collection and communication, disaster warning, hydrometeorology, ice and snow, land surface, meteorology, space environment. Continuous observation of cloud cover and Earth's surface
Resource-01 N3 (ROSHYDRO MET)	In service	November 1994 4 years	Near polar, sun synchronous 98 deg inclination, 670km	MSU-E, MSU-SK (Resource-01 N3)	Agriculture and forestry, hydrology, environmental monitoring, hydrometeorology, ice and snow, land surface, meteorology

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
NOAA 14 (NOAA)	In service	December 1994 2 years 9 months	Near polar, sun synchronous, pm crossing, 851km, 102.1 mins	ARGOS, AVHRR/2, HIRS/2, MSU, S&R (NOAA), SBUV/2, SEM, SSU	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, life-saving capability through Search and Rescue
GMS-5 (NASDA)	In service	March 1995 5 years	Geostationary	VISSR (GMS5)	Meteorology
ERS-2 (ESA)	In service	April 1995 4 years 2 months	Sun synchronous, 785km, 1030h LST descending phase, 100.5 mins	AMI – SAR image mode, AMI – SAR wave mode, AMI – Scatterometer mode, ATSR-2, GOME, MWR, PRARE, RA	Earth resources plus physical oceanography, ice and snow, land surface, meteorology, geodesy/gravity, environmental monitoring, atmospheric chemistry
GOES 9 (NOAA)	In service	May 1995 5 years	Geostationary	DCS, IMAGER, S&R (GOES), SEM SOUNDER, WEFAX	Meteorology (primary mission), search and rescue, space environment monitoring, data collection, platform, data gathering, WEFAX
SICH-1 (NSAU)	In service	August 1995 2 years 1 month	82.5 deg inclination, 650km, 98 mins	MSU-M, MSU-S	Physical oceanography, hydrometeorology
RADARSAT (CSA)	In service	September 1995 5 years	Dawn-dusk, 98.6 deg inclination, ascending crossing 1800h LST, 793km-821km, 7 & 3 day subcycles, 24 days	SAR	Environmental monitoring, physical oceanography, ice and snow, land surface

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
IRS 1c (ISRO)	In service	December 1995 3 years	Sun synchronous, 817km, 101.35 mins, 24 days	LISS III, PAN, WiFS	Land surface, agriculture and forestry regional geology, land use studies, water resources, vegetation studies, coastal studies and soils, cartography, digital terrain models
PRIRODA (RSA)	In service	December 1995 4 years	MIR space station, 51.6 deg inclination, 380-420km	ALISSA, DOPI, IKAR-D, IKAR-N, IKAR-P, ISTOK-1, MOMS-2P, MOS (PRIRODA), MSU-E2, MSU-SK (PRIRODA), Ozon-M, R-400, Travers SAR, TV camera	Agriculture and forestry, atmospheric chemistry, atmospheric dynamics/water and energy cycles, climatology, digital terrain models, meteorology, ocean biology/ocean colour, physical oceanography, space environment
FY-2 (China (CMA))	In service	1996 3 years	Geostationary at 105 deg East	Multispectral Visible & IR Scan Radiometer (3 channel)	Meteorology and environmental monitoring Data collection and redistribution
Resource-F1M series (RSA)	In service	1996 4 years	82.3 deg (1,2: near-circular, 3: elliptical), 1:235km 2:285km, 3:180-305km, 89.16 mins, 14 days	KFA-1000 KFA-200	Land surface, physical oceanography, geodesy/gravity
Resource-F2 series (RSA)	In service	1996 3 years	82.3 deg inclination, 240km, 89.22 mins, 16 days	MK-4	Land surface, physical oceanography
Resource-F3 series (RSA)	In service	1996 2 years	82.3 deg inclination, 240, 275, 340km, 89.22 mins, 14 days	KFA-3000	Cartography (land and ocean) 1:25000 and below
IRS P3 (ISRO)	In service	March 1996 3 years	Sun synchronous, 817km, 101.35 mins	MOS, WiFS, X-ray astronomy payload	Ocean biology, physical oceanography, land surface, agriculture and forestry, water resources, vegetation and coastal studies
TOMS Earth Probe (NASA)	In service	July 1996 2 years	Sun synchronous, 670-690km, 98 mins	TOMS	Atmospheric chemistry, Ozone and sulphur dioxide measurements

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
GOES 10 (NOAA)	In service	April 1997 5 years	Geostationary	DCS, IMAGER, S&R (GOES), SEM, SOUNDER, WEFAX	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX
OrbView-2 (NASA)	In service	August 1997 5 years	Polar, sun synchronous, crossing 1200h LST, descending, 705km, 99 mins, 2 days	SeaWiFS	Ocean biology/ocean colour, physical oceanography
MECB SCD-2A (INPE)	Firm/ approved	September 1997 2 years	25 deg inclination, 750km, 100mins	DCP	Data collection and communication
METEOSAT 7 (EUMETSAT)	Firm/ approved	October 1997 5 years	Geostationary	MVIRI	Meteorology, climatology
TRMM (NASA)	Firm/ approved	November 1997 3 years	35 deg inclination, 350km	CERES, LIS, PR, TMI, VIRS	Atmospheric dynamics/water and energy cycles
INSAT IIe (ISRO)	Firm/ approved	1998 7 years	Geostationary	BSS & FSS transponders, CCD camera (INSAT-IIe), DRT-S&R, VHRR	Meteorology, data collection and communication, search and rescue
IRS 1d (ISRO)	Firm/ approved	1998 3 years	Sun synchronous, 817km, 101.35 mins, 24 days	LISS III, PAN, WiFS	Land surface, agriculture and forestry regional geology, land use studies, water resources, vegetation studies, coastal studies and soils
MECB SCD-2 (INPE)	Firm/ approved	1998 2 years	25 deg inclination, 750km, 100mins	DCP	Data collection and communication
METEOR-3M N1 (RSA)	Proposed	1998 3 years	Near polar, sun synchronous, 1000km	KGI-4 C, Klimat, MIVZA, MR-2000M, MR-900M, MSGI-5EI, MTVZA, SAGE III, SFM-2	Agriculture and forestry, climatology, hydrology, hydrometeorology, ice and snow, land surface, meteorology, space environment

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
Resource-01 N4 (RSA)	Proposed	1998 2 years	Near polar, sun synchronous, 98 deg inclination 670km	ISP-2M, MR-900M, MSU-E1, MSU-SK (Resource-01 N4), RMK-2, SFM-2	Land surface, physical oceanography
Resource-F2M series (RSA)	Firm/ approved	1998 2 years	82.3 deg inclination, 240km, 89.22 mins, 14 days	MK-4M	Agriculture and forestry, cartography, civil planning, digital terrain models, earth resources, hydrology, ice and snow, land surface, ocean biology/ocean colour, physical oceanography
IRS P4 (aka OCEANSAT-1) (ISRO)	Firm/ approved	February 1998 5 years	Sun synchronous, LST noon ± 20 mins descending, 720km, 98 mins, approx 22 days	MSMR, OCM	Ocean biology, physical oceanography
NOAA K (NOAA)	Firm/ approved	February 1998 3 years	Near polar, sun synchronous, am crossing, 825-850km	AMSU-A, AMSU-B, ARGOS, AVHRR/3, HIRS/3, S&R (NOAA), SEM	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, life-saving capability through Search and Rescue
SPOT 4 (CNES)	Firm/ approved	February 1998 5 years	Sun synchronous, 830km, 101 mins, 26 days	DORIS, HRVIR, VEGETATION	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring
CBERS 1 (INPE)	Firm/ approved	May 1998 2 years	Sun synchronous, crossing 1030h LST, 778km, 100 min, 26 days	CCD camera, DCP, IRMSS, WFI camera	Earth resources, environmental monitoring, land surface

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
EOS-AM 1 (NASA)	Firm/ approved	June 1998 6 years	Polar, sun synchronous, crossing 1030h LST, descending, 705km, 99 mins, 16 days	ASTER, CERES, MISR, MODIS, MOPITT	Atmospheric dynamics/water and energy cycles, Atmospheric chemistry, Physical and radiative properties of clouds, air-land exchanges of energy, carbon and water, vertical profiles of CO and methane vulcanology
Odin (SNSB)	Firm/ approved	September 1998 2 years	Circular, polar, sun synchronous terminator orbit, 620km, 97 mins, 5 days (±100km at equator)	IR imager, radiometer, UV-visible spectrometer	Astronomy/aeronomy mission Atmospheric chemistry, atmospheric dynamics/water and energy cycles, climatology, astronomy
OKEAN-O (NSAU)	Firm/ approved	September 1998 1 year	Near polar, sun synchronous, 98 deg inclination, 670km, 98 mins	DELTA-2, KONDOR-2, MSU-M, MSU-S, R-225, RLSBO	Agriculture and forestry, hydrology, environmental monitoring, crop and soil monitoring, forest and tundra fires, pollution monitoring
LANDSAT 7 (NASA)	Firm/ approved	December 1998 6 years	Polar, sun synchronous, crossing equator 0945-1015h LST, 705km, 98 mins, 233 orbits/cycle, 16 days	ETM+	Land surface, Earth resources
Electro-GOMS N2 (RSA)	Proposed	1999 2 years	Geostationary at 76 deg East, 36000km, 24 hour	BRK, BTVK, RMS	Climatology, data collection and communication, disaster warning, hydrometeorology, ice and snow, land surface, meteorology, space environment. Continuous observation of cloud cover and Earth's surface.
FY-1C (China (CMA))	Firm/ approved	1999 1 year	Polar, sun synchronous, 870km, 102.3 mins, 14 days	Multispectral Visible & IR Scan Radiometer (10 channel)	Meteorology Environmental monitoring
GOES L (NOAA)	Firm/ approved	February 1999 5 years	Geostationary	DCS, IMAGER, S&R (GOES), SEM, SOUNDER, WEFAX	Meteorology (primary mission), search and rescue, space environment monitoring. Data collection platform, data gathering, WEFAX

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
ACRIMSAT (NASA)	Firm/ approved	May 1999 5 years	TBD	ACRIM	Will sustain long term solar luminosity database by providing measurements of total solar irradiance and the solar constant
NMP EO-1 (NASA)	Firm/ approved	May 1999 3 years	Sun synchronous, 98.2 deg inclination, 1045h LST descending phase, 705km	ALI, GIS, MS, WIS	Land surface Earth resources
CHAMP (DARA)	Firm/ approved	June 1999 5 years	Non sun synchronous, 83 deg inclination, 450km (beginning of life), 300km (end of life)	Magnetometry package (CHAMP), STAR Accelerometer, TRSR	Gravity field Precise geoid Magnetic field Atmospheric physics
ENVISAT 1 (ESA)	Firm/ approved	June 1999 5 years	Polar, 780-820km, 100.59 mins, 35 days	AATSR, ASAR, DORIS-NG, GOMOS, MERIS, MIPAS, MWR, RA-2, SCIAMACHY	Physical oceanography, land surface, ice and snow, atmospheric chemistry, atmospheric dynamics/water and energy cycles
IRS P5 (aka CARTO SAT-1) (ISRO)	Proposed	June 1999 5 years	Sun synchronous, 617km, approx 101 mins, 22 days	HR PAN, LISS IV	Cartography, digital terrain models, civil planning, resource and cadastre management
ADEOS II (NASDA)	Firm/ approved	August 1999 3 years	Circular, sun synchronous 1030h ±15mins LST, approx 802.9km, approx 101 mins, 4 days (57 revisit)	AMSR, DCS (NASDA/CNES), GLI, ILAS-II, POLDER, Sea Winds	Atmospheric dynamics/water and energy cycles Land surface Physical oceanography
MTSAT Ministry of Aeronautical Transportation, Control, Japan	Firm/ approved	August 1999 5 years	Geostationary	IMAGER (MTSAT)	Meteorology Aeronautical applications
SICH-1M (NSAU)	Firm/ approved	September 1999 1 year	82.5 deg inclination, 650km, 98 mins	MSU-EU, MSU-M, RLSBO, RM-0.8	Physical oceanography, hydrometeorology

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
NOAA L (NOAA)	Firm/ approved	December 1999 3 years	Near polar, sun synchronous, pm crossing, 825-850km	AMSU-A, AMSU-B, ARGOS, AVHRR/3, HIRS/3, S&R (NOAA), SBUV/2, SEM	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, life-saving capability through Search and Rescue
ARIES-1 (Australia)	Proposed	2000 5 years	Circular, sun synchronous, 500km	Imaging spectrometer, Panchromatic sensor	Earth resources, agriculture and forestry, water resources, vegetation studies
CBERS 2 (INPE)	Firm/ approved	2000 2 years	Sun synchronous, crossing 1030h LST, 778km, 100 mins, 26 days	CCD camera, DCP, IRMSS, WFI camera	Earth resources, environmental monitoring, land surface
ESSP-1A (aka VCL) (NASA)	Firm/ approved	2000 2 years	55 deg inclination, 390-410km	VCL	Land use, land cover, vegetation and topographic mapping
MDS-2 (NASDA)	Firm/ approved	2000 1 year	Equatorial, 30 deg inclination, 550km, 16 mins	LIDAR	Climatological data on clouds and aerosols
METEOR-3M N2 (RSA)	Proposed	2000 1 year	Near polar, sun synchronous, 98 deg inclination, 900km	KGI-4, MIVZA, MSGI-5, MSR (RSA), MTVZA, MZOAS, SAGE III, ScaRaB, SFM-2, TOMS	Land surface, physical oceanography, atmospheric dynamics/water and energy cycles, space environment
NIKA-Kuban (RSA)	Proposed	2000 2 years	81.4 deg, 248-273km	Camea, Gemma	Land surface, physical oceanography
GOES M (NOAA)	Firm/ approved	February 2000 5 years	Geostationary	DCS, IMAGER, S&R (GOES), SEM, SOUNDER, SXI, WEFAX	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX
Jason-1 (NASA)	Firm/ approved	April 2000 3 years	66 deg inclination, 1336km, 113 mins, 14 days	DORIS-NG, GPSDR, JMR (formerly AMR), LRA, POSEIDON-2 (aka SSALT-2)	Physical oceanography, geodesy/gravity, climate monitoring, marine meteorology

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
IRS P6 (aka RESOURCE SAT-1) (ISRO)	Proposed	June 2000 3 years	Sun synchronous, 817km, approx 1001 mins, approx 22 days	AWiFs, LISS III (IRS-P6), LISS IV	Agriculture and forestry, disaster warning, Earth resources, environmental monitoring, land surface, ocean biology/ocean colour
MSG 1 (EUMETSAT)	Firm/ approved	June 2000 7 years	Geostationary	GERB, SEVIRI	Meteorology, Climatology, Atmospheric dynamics/water and energy cycles
EOS-PM 1 (NASA)	Firm/ approved	December 2000 5 years	Polar, sun synchronous, crossing 1330h LST, ascending, 705km, 99 mins	AIRS, AMSR-E, AMSU, HSB, MODIS	Atmospheric dynamics/water and energy cycles, cloud formation, precipitation and radiative properties, air/sea fluxes of energy and moisture, sea ice extent and heat exchange with the atmosphere
FY-1D (China (CMA))	Firm/ approved	2001 1 year	Polar, sun synchronous, 870km, 102.3 mins, 14 days	Multispectral Visible & IR Scan Radiometer (10 channel)	Meteorology Environmental monitoring
Light SAR (NASA)	Proposed	2001 5 years	TBD	TBD	TBD
MECB SSR-1 (INPE)	Firm/ approved	2001 4 years	Equatorial, 0 deg inclination, 905km, 103 mins, 0.2 day	OBA	Earth resources, environmental monitoring, land surface
METOP 1 (EUMETSAT)	Proposed	2001 5 years	Polar, sun synchronous, at 0930h LST in descending phase, approx 840km, 101.7 mins	ASCAT, GOME-2, GRAS, IASI, MHS	Meteorology Climatology
RADAR SAT-2 (CSA)	Proposed	2001 5 years	Dawn-dusk, 98.6 deg inclination, ascending crossing 1800h LST, 793km-821km, 7 & 3 day subcycles, 24 days	SAR	Environmental monitoring, physical oceanography, ice and snow, land surface
ESSP-1B (aka GRACE) (NASA)	Firm/ approved	March 2001 5 years	83 degree inclination, initial altitude 450km	GRACE	Detection of Earth gravity field variation

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
NOAA M (NOAA)	Firm/ approved	April 2001 3 years	Near polar, sun synchronous, pm crossing, 825-850km	AMSU-A, AMSU-B, ARGOS, AVHRR/3, HIRS/3, S&R (NOAA), BUV/2, SEM	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, life-saving capability through Search and Rescue
FedSat-1 (Australia)	Firm/ approved	June 2001 5 years	Circular orbit, inclination TBD, 1000km	GPS receiver, Magnetometer and advanced communications payload	Communications, data relay, near Earth environment, upper atmospheric physics, meteorology
EOS-LAM 1 (NASA)	Proposed	July 2001 3 years	94 deg inclination, 600km, 90 mins	GLAS	Physical oceanography, geodesy/gravity, land surface, ocean altimetry and circulation, ice sheet mass balance, geological features
MECB SCD-3 (INPE)	Firm/ approved	2002 2 years	0 deg inclination, 750km, 100mins	DCP, LEO communication transponder	Data collection and communication
SPOT 5 (CNES)	Firm/ approved	2002 5 years	Sun synchronous, 830km, 101 mins, 26 days	DORIS-NG, HRG, VEGETATION	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring
EOS-CHEM 1 (NASA)	Firm/ approved	December 2002 6 years	Polar, sun synchronous, 705km, 99 mins	HiRDLS, MLS (EOS-CHEM), Ozone instrument (TBD), TES	Atmospheric chemistry Atmospheric dynamics/water and energy cycles
MSG 2 (EUMETSAT)	Firm/ approved	December 2002 7 years	Geostationary at 0 deg of longitude	GERB, SEVIRI	Meteorology, Climatology, Atmospheric dynamics/water and energy cycles
CARTO SAT-2 (ISRO)	Proposed	2003 5 years	Sun synchronous, 617km, approx 101 mins, approx 22 days	TBD	Cartography, digital terrain models, civil planning, resource and cadastre management

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
MECB SSR-2 (INPE)	Firm/ approved	2003 4 years	Equatorial, 0 deg inclination, 905km, 103 mins, 0.2 days	OBA	Earth resources, environmental monitoring, land surface
MTSAT-2 Ministry of Aeronautical Transportation, Control, Japan	Proposed	2003 5 years	Geostationary	IMAGER (MTSAT)	Meteorology, Aeronautical applications
OCEAN SAT-2 (ISRO)	Proposed	2003 5 years	Sun synchronous, 720km, approx 101 mins, approx 22 days	TBD	Ocean biology, physical oceanography
ALOS (NASDA)	Proposed	January 2003 3 years	Sun synchronous, 691km, 46 days	AVNIR-2, PALSAR, PRISM (NASDA)	Cartography, digital terrain models, environmental monitoring, disaster monitoring, civil planning, agriculture and forestry, Earth resources, land surface
RESOURCE SAT-2 (ISRO)	Proposed	June 2003 5 years	Sun synchronous, 817km, approx 101 mins, approx 22 days	TBD	Agriculture and forestry, disaster warning, Earth resources, environmental monitoring, land surface, ocean biology/ocean colour
NOAA N (NOAA)	Firm/ approved	December 2003 3 years	Near polar, sun synchronous, pm crossing, 825-850km	AMSU-A, ARGOS, AVHRR/3, HIRS/4, MHS, MHS, S&R (NOAA), SBUV/2, SEM	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, total ozone studies, ice and snow cover, solar flux analysis, space environment, life-saving capability through Search and Rescue
EOS-AM Follow-on missions (NASA)	Proposed	2004 6 years	TBD	TBD	TBD

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
ESA Future Missions (ESA)	Proposed	2004 10 years	Polar and possibly other LEOs	ALADIN, ATLID, COALA, Cloud radar, Gradio-meter, GRAS, Laser altimeter, MASTER, MHS, MIPAS, MWR, PRISM, Radar altimeter, Rain radar, SAR (ESA Future Missions), SOPRANO, VIS/IR imager	Physical oceanography, land surface, ice and snow, atmospheric dynamics/water and energy cycles
Jason Follow-on (CNES)	Proposed	2004 3 years	66 deg inclination, 1336km, 113 mins, 10 days	DORIS-NG, GPSDR, JMR (formerly AMR), LRA, POSEIDON-2 (aka SSALT-2	Physical oceanography, geodesy/gravity, climate monitoring, marine meteorology
ATMOS-1 (ISRO)	Proposed	2005 5 years	TDB	TBD	Climatology, atmospheric research
CLIMAT SAT-1 (ISRO)	Proposed	2005 5 years	TDB	TBD	Meteorology and climatology
IRS-3 (ISRO)	Proposed	2005 5 years	TDB	TBD	SAR instrument for land and marine applications
EOS-LAM Follow-on missions (NASA)	Proposed	2006 3 years	TBD	TBD	TBD
EOS-PM Follow-on missions (NASA)	Proposed	2006 5 years	TBD	TBD	TBD
METOP 2 (EUMETSAT)	Proposed	December 2006 5 years	Polar, sun synchronous, TBD	ASCAT, GOME-2, GRAS, IASI, MHS	Meteorology, Climatology
EOS-CHEM Follow-on missions (NASA)	Proposed	2007 5 years	TBD	TBD	TBD

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
MSG 3 (EUMETSAT)	Firm/ approved	June 2007 7 years	Geostationary	GERB, SEVIRI	Meteorology, Climatology, Atmospheric dynamics/water and energy cycles
NOAA N' (NOAA)	Firm/ approved	July 2007 3 years	Near polar, sun synchronous, pm crossing, 825-850km	AMSU-A, ARGOS, AVHRR/3, HIRS/4, MHS, S&R (NOAA), SBUV/2, SEM	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, solar flux analysis, space, environment, life-saving capability through Search and Rescue
First Converged Spacecraft (NPOESS) (NOAA)	Firm/ approved	2009 5 years	Near polar, sun synchronous, pm crossing, 825-850km	ARGOS, S&R (NOAA)	Meteorology, climatology and other environmental applications
METOP 3 (EUMETSAT)	Proposed	December 2010 5 years	Polar, sun synchronous, descending phase, approx 840km, 101.7 mins	ASCAT, GRAS, IASI, MHS	Meteorology, climatology

B Catalogue of satellite instruments

B.1 INTRODUCTION

This annex contains an alphabetical list of all instruments on the missions listed in Annex A. For each instrument the following information is given:

- the mission(s) that the instrument is expected to fly on;
- the measurements that the instrument can make;
- the technical characteristics of the instrument.

Secondly, instruments are listed according to basic type and within each type chronologically according to first launch opportunity.

B.2 LIST OF SATELLITE INSTRUMENTS (ALPHABETICAL)

Instrument	Mission(s)	Measurements/application	Technical characteristics
174-K	METEOR-3 N5	Provides vertical profiles of temperature, humidity and ozone	Waveband: TIR-FIR 18µm (water absorption), 13.33, 13.70, 14.24, 14.43, 14.75, 15.02µm (carbon dioxide), 11µm (transparent), 9.6µm (ozone) Spatial resolution: 42km Accuracy: Duty cycle: 100% Swath width: 1000km Data rate: 15Kbps
AATSR Advanced Along Track Scanning Radiometer	ENVISAT-1	Measurements of sea surface temperature, land surface temperature, cloud top temperature, cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content	Waveband: Visible-NIR: 0.555, 0.659, 0.865µm, SWIR: 1.6µm, TIR: 3.7, 10.85, 12µm Spatial resolution: IR ocean channels: 1km x 1km Visible land channels: 1km x 1km Accuracy: Sea surface temperature: <0.5K over 0.5 deg x 0.5 deg (lat/long) area with 80% cloud cover Land surface temperature: 0.1K (relative) Duty cycle: 100% Swath width: 500km Data rate: 1Mbps
ACRIM Active Cavity Radiometer Irradiance Monitor	ACRIMSAT	Measurements of solar luminosity and solar constant. Data used as record of ime variation of total solar irradiance, from extreme UV through to infra-red	Waveband: UV-FIR: 1nm-1µm Spatial resolution: Not applicable Accuracy: 0.007 W/m2 Duty cycle: 100% (daylight only) Swath width: Not applicable Data rate: 1Kbps
ACRIM II Active Cavity Radiometer Irradiance Monitor	UARS	Measurements of solar luminosity and solar constant.Data used as record of ime variation of total solar irradiance, from extreme UV through to infra-red	Waveband: UV-FIR:1nm-50µm Spatial resolution: Not applicable Accuracy: Measures integrated flux of solar radiation to <0.1% Duty cycle: 100% in daylight Swath width: Not applicable Data rate: 1Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
AIRS Advanced IR Sounder	EOS PM-1	Provides temperature/ humidity soundings, measurements of albedo and reflectance, radiation budget, land surface temperature, snow cover	Waveband: Visible-SWIR: 0.4-1.7µm Spatial resolution: Vertical: 1km, 1-2km temparature and humidity Horizontal: 50km temperature and humidity Accuracy: Humidity: 20% Reflectance: 3% Temperature: 1K Duty cycle: 100% Swath width: 1650km, cross field swath is ±49.5 deg Revisit capability: 2 days Data rate: 1.44Mbps
ALADIN Atmospheric Laser Doppler Instrument	ESA Future Missions	Provides measurements of wind component in clear air, cloud top heights, vertical distribution of cloud, aerosol properties, troposphere height, boundary layer height	Waveband: 1 band in the range 9.11-10.59µm Spatial resolution: 0-2km alt: 200 x 200 x 0.5km 2-10km alt: 200 x 200 x 1.0km 10-15km alt: 200 x 200 x 2.0km Accuracy: Wind velocity goals: <2m/s (0-2km alt), <6m/s (2-10km alt), <10m/s (10-15km alt) Duty cycle: 100% Swath width: 45 deg conical scan Data rate: approx 4Mbps
ALISSA L'Atmosphere par Lidar Sur Salyut	PRIRODA	Lidar instrument providing cloud altimetry, boundary layer, aerosols, cloud top altitude and aerosol backscatter data	Waveband: 0.532µm Spatial resolution: 150m vertical, 1km along track. Nadir viewing only Accuracy: Duty cycle: A few orbits, on several occasions Swath width: FOV: 0.001rad Data rate: 44Kbps
ALT Duel-frequency Radar Altimeter	TOPEX/ POSEIDON	Obtains precise altimeter height measurements over world's oceans, total ionospheric electron content is a by-product of the measurement	Waveband: Microwave: 5.3, 13.6GHz Spatial resolution: 6-7km along track Accuracy: 2.4cm altitude accuracy Duty cycle: Antenna shared with SSALT Swath width: n/a - 10 day repeat cycle Data rate: 9.2Kbps
AMI-SAR image mode	ERS-1, ERS-2	All-weather images of ocean, ice and land surfaces. Monitoring of coastal zones, polar ice, sea state, geological features, vegetation (including forests), land surface processes, hydrology. Applications also include production of digital elevation models and interferometry	Waveband: 5.3GHz (C-band), VV polarisation, bandwidth 15.5 ±0.06MHz Spatial resolution: 30m Accuracy: 10% nominal Duty cycle: Swath width: 100km Data rate: 105Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
AMI-SAR wave mode	ERS-1, ERS-2	Provides measurements of ocean wave spectra	Waveband: 5.3GHz (C-band), VV polarisation Spatial resolution: 30m Accuracy: Wave direction: 0-180 deg with 180 deg ambiguity to ±20 deg Wave length: 170m to 1000m ±25% Duty cycle: Depends upon the use of AMI for SAR images Swath width: The instrument delivers spectra derived from SAR images of the ocean surface, taken at 200km intervals, on windows of 5km x 5km or 5km x 10km Data rate: 370Kbps
AMI scatterometer mode	ERS-1, ERS-2	Provides measurements of wind fields at the ocean surface, wind direction (range 0-360 deg), wind speed (range 1m/s - 30m/s)	Waveband: 5.3GHz (C-band), VV polarisation Spatial resolution: Cells of 50km x 50km at 25km intervals Accuracy: Wind direction: ±20 deg Wind speed: ±2m/s or 10% Duty cycle: Depends upon the use of AMI for SAR images Swath width: 500km Data rate: 500Kbps
AMSR Advanced Microwave Scanning Radiometer-E	ADEOS II	Provides measurements of water vapour, cloud liquid water, precipitation, winds, sea surface temperature, sea ice concentration, snow cover, soil moisture	Waveband: Microwave: 6.9, 10.65, 18.7, 23.8, 36.5, 50.3, 52.8, 89GHz Spatial resolution: 5-50km (dependent upon frequency) Accuracy: Sea surface temparature: 0.5K Sea ice cover: 10% Could liquid water: 0.05kg/m2 Precipitation rate: 10% Water vapour: 3.5kg/m2 through total column Sea surface wind speed 1.5m/s Duty cycle: 100% Swath width: 1450km Data rate: Approx 90Kbps
AMSR-E Advanced Microwave Scanning Radiometer-E	EOS PM-1	Provides measurements of water vapour, cloud liquid water, precipitation, winds, sea surface temperature, sea ice concentration, snow cover and soil moisture	Waveband: Microwave: 6.9, 10.65, 18.7, 23.8, 36.5, 50.3, 52.8, 89GHz Spatial resolution: 5-50km (dependent upon frequency) Accuracy: Sea surface temparature: 0.5K Sea ice cover: 10% Precipitation rate: 10% Water vapour: 3.5kg/m2 through total column Cloud liquid water 0.05kg/m2 Sea surface wind speed 1.5m/s Duty cycle: 100% Swath width: 1450km Data rate: Approx 90Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
AMSU Advanced Microwave Sounding Unit	EOS PM-1	Provides measurements of total column water vapour, presence of rain, vertical temperature profiles up to 40km	Waveband: Microwave: 15 channels (23.8-89GHz) Spatial resolution: Horizontal: 40km at nadir Accuracy: Temperature retrieval: 1K Emissivity accuracy: 0.05 Duty cycle: 100% Swath width: 1650km, cross field swath is ±49.5 deg Data rate: 3.2Kbps
AMSU-A Advanced Microwave Sounding Unit A	NOAA K-N'	Provides all weather night-day temperature sounding to an altitude of 45km	Waveband: Microwave: 23.8, 31.4, 50.3-57.3, 89GHz Spatial resolution: 50km at nadir Accuracy: 2K Duty cycle: 100% Swath width: Approximately 2200km (±48.3 deg) Data rate: 3.2Kbps
AMSU-B Advanced Microwave Sounding Unit B	NOAA K-M	Provides all weather night-day humidity sounding	Waveband: 89, 150, 3 channels close to 183GHz Spatial resolution: 15km at nadir Accuracy: 2K Duty cycle: 100% Swath width: Approximately 2200km (±48.3 deg) Data rate: 3.2Kbps
ARGOS	NOAA 9-12, NOAA 14, NOAA K-N', First Converged Spacecraft (NPOESS)	Provides location data by Doppler measurements	Waveband: Uplink (data collection): 401.65MHz Downlink: 470MHz Spatial resolution: Location within 300m (30m feasible on some days) Accuracy: Duty cycle: Measurements delivered within 30 minutes or 3 hours depending on geographical location Swath width: Not applicable Data rate:
ASAR Advanced Synthetic Aperture Radar	ENVISAT 1	Provides all weather images of ocean, land and ice for monitoring of land surface processes, sea and polar ice, sea state, and geological and hydrological applications	Waveband: C-band Spatial resolution: Image, wave and alternating polarisation modes: 30m x 30m, Wide swath mode: 100m x 100m Global monitoring mode: 1km x 1km Accuracy: Radiometric resolution in range: 1.5-3.5 dB Radiometric accuracy: 0.65 dB Duty cycle: 20% Swath width: Image and alternating polarisation modes: up to 100km Wave mode: 5km Wide swath and global monitoring modes: 400km Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
ASCAT Advanced Scatterometer	METOP 1, METOP 2, METOP 3	Provides sea ice cover, sea ice type and wind speed over sea surface measurements	Waveband: C-band Spatial resolution: Horizontal: 50km Accuracy: Soil moisture: 1g per kg; Sea ice cover:.10%; Sea ice type: 4 classes; Horizontal sea surface wind speed: 3m/s Duty cycle: 100% Swath width: 2160km Revisit capability 1.5 days Data rate:
ASTER Advanced Space-borne Thermal Emission & Reflection Radiometer	EOS PM-1	Surface and cloud imaging with high spatial resolution, stereoscopic observation of local topography, cloud heights, volcanic plumes, and generation of local surface digital elevation maps. Surface temperature and emissivity	Waveband: Visible-NIR: 3 channels (0.5-0.9μm), SWIR: 6 channels (1.6-2.5μm), TIR: 5 channels (8-12μm) Spatial resolution: VNIR: 15m, stereo: 15m horizontally and 25m vertical SWIR: 20m, TIR: 90m Accuracy: VNIR and SWIR: 4% (absolute) TIR: 4K Geolocation: 7m Duty cycle: VNIR and SWIR, daylight only: 8% TIR: 16% Swath width: 60km at nadir, swath centre is pointable cross-track by ±106km for SWIR and TIR and ±314km for VNIR. Revisit capability: 16 days Data rate: Average/peak: 8.3/89.2Mbps
ATLID Atmospheric Lidar	ESA Future Missions	Provides measurements of cloud top heights, aerosol properties, troposphere height, vertical distribution of cloud, boundary layer height.	Waveband: NIR: 1.064μm Spatial resolution: Shot spacing: <50km, footprint: 100m (at nadir) Accuracy: Height: ±100m Duty cycle: Swath width: 350km (±23.5 deg) Data rate: 1Mbps
ATSR Along Track Scanning Radiometer & Microwave Sounder	ERS-1	Provides measurements of sea surface temperature, land surface temperature, cloud top temperature and cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content	Waveband: SWIR-TIR: 4 channels:1.6, 3.7, 11 and 12μm Microwave: 23.8 and 36.5GHz (bandwidth 400MHz) Spatial resolution: IR:1kmx1km instantaneous field of view at nadir, conical scan Sea surface temperature: 50x50km Microwave near nadir viewing: 20km instantaneous field of view Accuracy: Sea surface temperature to <0.5K over 0.5 deg x 0.5 deg (lat/long) area with 80% cloud cover Land surface temperature: 0.1K Duty cycle: 100% Swath width: 500km Data rate:
ATSR-2 Along Track Scanning Radiometer & Microwave Sounder	ERS-2	Provides measurements of sea surface temperature, land surface temperature, cloud top temperature and cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content	Waveband: Visible-SWIR: 0.65, 0.85, 1.27, and 1.6μm SWIR-TIR: 1.6, 3.7, 11 and 12μm Microwave: 23.8, 36.5GHz (bandwidth of 400MHz) Spatial resolution: IR ocean channels: 1km x 1km Microwave near-nadir viewing: 20km instantaneous field of view Accuracy: Sea surface temperature to <0.5K over 0.5 deg x 0.5 deg (lat/long) area with 80% cloud cover Land surface temperature: 0.1K Duty cycle: 100% Swath width: 500km Data rate: 1Mbps
AVHRR/2 Advanced Very High Resolution Radiometer	NOAA 9, NOAA 10, NOAA 11, NOAA 12, NOAA 14	Provides measurements of land and sea surface temperature, cloud cover, snow and ice cover, soil moisture and vegetation indices. Data also used for volcanic eruption monitoring	Waveband: Visible: 0.58-0.68μm, NIR: 0.725-1.1μm, SWIR: 3.55-3.93μm, TIR: 10.3-11.3μm, 11.4-12.4μm Spatial resolution: 1.1km (at nadir). Compressed Global Area Coverage (GAC) data recorded at 4km resolution Accuracy: Duty cycle: 100% Swath width: 3000km (approximate), 55.4 deg scan off nadir Data rate: 66.54Kbps for GAC, 665.4Kbps for HRPT
AVHRR/3 Advanced Very High Resolution Radiometer	NOAA K, NOAA L, NOAA M, NOAA N, NOAA N'	Provides measurements of land and sea surface temperature, cloud cover, aerosols, snow and ice cover, water on land, vegetation indices, soil moisture, and albedo. Data also used for volcanic eruption monitoring	Waveband: Visible: 0.58-0.68μm, NIR: 0.725-1.1μm, SWIR: 1.6μm, TIR: 3.55-3.93μm, 10.3-11.3μm, 11.4-12.4μm Spatial resolution: 1.1 km at nadir Accuracy: Duty cycle: 100% Swath width: 3000km approx. Scan off nadir: 55.4 deg Ensures full global coverage twice daily Data rate: 66.5Kbps for GAC, 665.4Kbps for HRPT
AVNIR-2 Advanced Visible & Near Infrared Radiometer	ALOS	High resolution multi-spectral imager for land applications which include environmental monitoring, agriculture and forestry, disaster monitoring	Waveband: Visible: 3 channels: 0.42-0.69μm NIR: 0.76-0.89μm Spatial resolution: 10m Accuracy: Radiometric accuracy <10% Duty cycle: 50% (max) Swath width: 70km Data rate: 160Mbps (max)

Instrument	Mission(s)	Measurements/application	Technical characteristics
AWiFS Advanced Wide-Field Sensor	IRS P6 (aka RESOURCESAT-1)	Vegetation and crop monitoring, resource assessment (regional scale), forest mapping, land cover/ land use mapping, and change detection	Waveband: 3 channels: Visible-SWIR Spatial resolution: 70m Accuracy: Duty cycle: Swath width: 142km (all bands) Revisit capability: 3-5 days Data rate: 10Mbps
BRK	Electro-GOMS N1, Electro-GOMS N2	Data collection and communication	Waveband: Spatial resolution: Accuracy: Duty cycle: Initiated every 30 mins Swath width: Data rate: 2.56Mbps
BSS & FSS transponders	INSAT IIa, NSAT IIb, INSAT IIe	Data collection and communication	Waveband: Visible: 0.4-0.7µm, TIR: 10.5-12.5µm Spatial resolution: Visible: 1.5km, TIR: 8km Accuracy: Visible: 3% TIR: 1K Duty cycle: 24-48 observations per day Swath width: 13,500km Data rate:
BTVK	Electro-GOMS N1, Electro-GOMS N2	Images of cloud cover, Earth's surface and snow and ice fields	Waveband: Visible: 0.4-0.7µm, TIR: 10.5-12.5µm Spatial resolution: Visible: 1.5km, TIR: 8km Accuracy: Visible: 3% TIR: 1K Duty cycle: 24-48 observations per day Swath width: 13,500km Data rate:
Camea	NIKA-Kuban	Photography of land and ocean surfaces for large scale applications (>1:25,000)	Waveband: Visible-NIR: 0.6-0.7µm Spatial resolution: 2m at an altitude of 250km using film type 48; 4m at an altitude of 250km using film type CN-18 Accuracy: 19% Duty cycle: Swath width: 0.43 of the orbit altitude Data rate:
CCD camera (INPE)	CBERS 1, CBERS 2	Vegetation monitoring	Waveband: Visible:0.45-0.52µm, 0.52-0.59µm, 0.63-0.69µm NIR: 0.77-0.89µm PAN: 0.51-0.71µm Spatial resolution: 20m at nadir Accuracy: 0.3 pixels Duty cycle: International access open to all participating stations, limited to 20 minutes per revolution Swath width: 113km Revisit capability: 26 days Data rate: 53Mbps per channel (2 channels)

Instrument	Mission(s)	Measurements/application	Technical characteristics
CCD camera (ISRO)	INSAT IIe	Provides measurements of cloud type and extent and land surface reflectance, and used for global land surface applications	Waveband: Visible:0.45-0.52µm, 0.52-0.59µm, 0.63-0.69µm NIR: 0.77-0.89µm PAN: 0.51-0.71µm Spatial resolution: 1km Accuracy: Duty cycle: Swath width: 1000km Revisit capability: sector scan-steerable Data rate: 800Kbps
Cloud radar	ESA Future Missions	Measures cloud characteristics including base height	Waveband: 78 or 94GHz Spatial resolution: TBD Accuracy: Duty cycle: 100% Swath width: TBD Data rate:
COALA	ESA Future Missions	Provides high resolution stratospheric ozone profiles	Waveband: 0.25-0.35µm, 0.42-0.675µm Spatial resolution: Vertical: 1km Accuracy: self-calibrating Duty cycle: Approx 25 profiles/orbit Swath width: Not applicable Data rate: 5Kbps
DCP Data Collection Platform transponder	CBERS 1, CBERS 2, MECB SCD-1, MECB SCD-2, MECB SCD-2A, MECB SCD-3	Data collection and communication	Waveband: Not applicable Spatial resolution: Not applicable Accuracy: Duty cycle: Operates only over Brazil and China Swath width: Data rate:
DCS (NOAA) Data Collection System	GOES 7, GOES 8, GOES 9, GOES 10, GOES L, GOES M	Collects data on temperature (air/water), atmospheric pressure, humidity and wind speed/direction, speed and direction of ocean and river currents	Waveband: Receives data from NOAA and GOES satellites at several frequencies near 402MHz Spatial resolution: Not applicable Accuracy: Not applicable Duty cycle: 100% Swath width: Not applicable. Point measurements specific to platform location Data rate: 400bps
DCS (NASDA/ CNES) Data Collection System	ADEOS II	In situ data relay	Waveband: UHF Spatial resolution: Not applicable Accuracy: Duty cycle: 100% Swath width: Not applicable Data rate: 400bps uplink 100bps or 200bps downlink

Instrument	Mission(s)	Measurements/application	Technical characteristics
DELTA-2	OKEAN-O	Scanning microwave radiometer for measurement of emissive microwave radiation at atmosphere/ sea surface interface	Waveband: Microwave: 7, 13, 22.5, 36.5GHz (2 polarisations) Spatial resolution: Accuracy: Duty cycle: 100% Swath width: 2600km Data rate:
DOPI	PRIRODA	Measurement of atmospheric optical properties in the IR range	Waveband: SWIR-FIR: 2.4-20μm Spatial resolution: Accuracy: Spectral resolution: 0.01-0.02/cm Duty cycle: A few orbits, on several occasions Swath width: FOV: 1-2 angular minutes Data rate: 0.6-1.0 interferogram/ sec
DORIS Doppler Orbitography & Radio Positioning Integrated by Satellite	SPOT 2, SPOT 4, TOPEX/ POSEIDON	Orbit determination	Waveband: Dual frequency Doppler at 401 and 2036MHz Spatial resolution: 0.3mm/s on Doppler measurement, one measurement every 10 seconds Accuracy: 0.3mm on Doppler measurement 2-4cm RMS on the satellite altitude <2cm RMS on ground beacon absolute positioning Duty cycle: 100% operating network visibility > 80% Swath width: Not applicable Data rate: 32bps
DORIS-NG Doppler Orbitography & Radio Positioning Integrated by Satellite - Next Generation	ENVISAT-1, Jason-1, Jason Follow-on, SPOT 5	Precise orbit determination Real time onboard orbit determination (navigation)	Waveband: Dual frequency Doppler at 401 and 2036MHz Spatial resolution: One measurement every 10 seconds Accuracy: 0.3mm on Doppler measurement, 2-4cm RMS on the satellite altitude, <2cm RMS on ground beacon absolute positioning, <5m RMS (on the 3D components) real time onboard orbit determination Duty cycle: 100%. Operating network visibility > 80% (from orbit) Swath width: Not applicable Data rate: <100bps
DRT-S&R	INSAT IIa, INSAT IIb, INSAT IIe	Relay of search and rescue information	Waveband: Not applicable Spatial resolution: Not applicable Accuracy: Duty cycle: Swath width: Not applicable Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
EOSP Earth Observation & Scanning Radiometer	TBD	Atmospheric corrections for clear-sky ocean and land observations, cloud and aerosol properties. Data to provide global maps of radiance and linear polarisation and information on global aerosol distribution and optical thickness in the troposphere and stratospere, and optical thickness and phase of clouds	Waveband: Visible-SWIR: 0.41-2.25μm Spatial resolution: 10km at nadir Accuracy: 5% spectral bidirectional reflectance function distribution 0.2% polarisation Duty cycle: 100% Swath width: Limb to limb scan (±65 deg) Revisit capability: 2 days Data rate: Average/peak: 44/88Kbps
ERBE Earth's Radiation Budget Experiment	NOAA 9, NOAA 10	Measures Earth radiation gains and losses on regional, zonal and global scales	Waveband: Visible: 0.5-0.7μm, UV-SWIR: 0.2-4μm, UV-FIR: 0.2-50μm, TIR: 10.5-12.5μm Spatial resolution: 200-250km at the Earth's surface for non scanning radiometer 50km at nadir for scanning radiometer Accuracy: Duty cycle: 100% Swath width: 3000km Data rate:
ETM+ Enhanced Thematic Mapper	LANDSAT 7	Measures surface radiance and emittance, land cover state and change (eg vegetation type). Used as multi-purpose imagery for land applications	Waveband: Visible-TIR: 8 channels: 0.45-12.5μm Panchromatic channel: 0.52-0.9μm Spatial resolution: Panchromatic band: 15m Visible, NIR and SWIR: 30m TIR: 60m Accuracy: 5% Duty cycle: 30% Swath width: 185km Data rate: 150Mbps
Gemma	NIKA-Kuban	Photography of land and ocean surfaces at scales of 1:100,000 and greater	Waveband: Visible-NIR: 0.5-0.54μm, 0.53-0.57μm, 0.542-0.565μm, 0.58-0.62μm, 0.61-0.68μm, 0.66-0.68μm, 0.71-0.77μm, 0.735-0.765μm, 0.81-0.87μm Spatial resolution: 3-5m at an altitude of 250km using film type 92; 6-8m at an altitude of 250km using film type CN-18 Accuracy: Duty cycle: 19% Swath width: 0.43 of the orbit altitude Data rate:
GERB Geostationary Earth Radiation Budget instrument	MSG 1, MSG 2, MSG 3	Measures long and short wave radiation emitted and reflected from the Earth's surface, clouds and top of atmosphere	Waveband: UV-SWIR: 0.2-4μm, SWIR-FIR: 4-50μm Spatial resolution: 50km at SSP Accuracy: Emitted radiation: 0.12-1.3 W/m2 Reflectance: 1% Duty cycle: Full disk every 15 minutes-1 hour Swath width: Full Earth Disk Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
GIS Grating Imaging Spectrometer	NMP EO-1	Hyperspectral measurements for land and marine applications research and development	Waveband: Visible-VNIR: VNIR: 100 channels in range 0.4-1.0µm SWIR: 133 channels in range 0.9-2.5µm Spatial resolution: Panchromatic: 10m Multispectral: 30m Accuracy: Duty cycle: Swath width: Data rate:
GLAS Geoscience Laser Altimeter System	EOS LAM-1	Provision of data on ice sheet height/thickness, land altitude, aerosol height distributions, cloud height and boundary layer height	Waveband: Visible-NIR: 0.532, 1.064µm Spatial resolution: Along track: 70m spots separated by 188m Accuracy: Ice elevation: 20cm, Cloud top height: 75m, Land elevation: 20cm, geoid: 5m Duty cycle: 50% average, 100% capability Swath width: Nadir viewing Revisit capability: 182 days Data rate: <200Kbps
GLI Global Imager	ADEOS II	Measures water vapour, aerosols, cloud cover, cloud top height and temparature, ocean colour, sea surface temperature, land surface temparature, glacier extent, icebergs, sea ice and snow cover, photosynthetically active radiation, vegetation type and land cover	Waveband: Visible-NIR: 23 channels (0.375-12.5µm), SWIR: 7 channels, TIR: 9 channels Spatial resolution: TIR: 7 channels: 1km Visible/NIR/SWIR channels: 250m-1km Accuracy: Specific humidity profile: 0.5g/m2 through total column Temparature: surface 0.4-0.5K, cloud top 0.5K Cloud cover: 3% Cloud top height: 0.5km Ice and snow cover: 5% Duty cycle: 100% (approx 50% for some visible/NIR channels) Swath width: 1600km Data rate: 1km mode: approx 4Mbps, 250m mode: approx 60Mbps 6km subsample mode for direct UHF transmission to local users: approx 23Kbps
GOME Global Ozone Monitoring Experiment	ERS-2	Measures concentration of O3, NO, NO2, BrO, H2O, O2/O4, plus aerosols and polar stratospheric clouds, and other gases in special conditions	Waveband: UV-NIR: 0.24-0.79µm (resolution 0.2-0.4nm) Spatial resolution: Vertical: 5km (for O3) Horizontal: 40 x 40 km to 40 x 320 km Duty cycle: 100% Swath width: 120-960 km Data rate: 40Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
GOME-2 Global Ozone Monitoring Experiment-2	METOP 1, METOP 2	Measures cloud top height, outgoing radiation and solar irradiance at top of atmosphere. Trace gas profiles of aerosols, ozone, humidity, and BrO2, ClO, ClONO2, NO and NO2	Waveband: UV-NIR: 0.24-0.79µm (resolution 0.2-0.4nm) Spatial resolution: Vertical: 5km Horizontal: 160km Outgoing radiation and irradiance: 250km Accuracy: Cloud top height: 1km (rms) Outgoing short wave radiation and solar irradiance: 5W/m2 Trace gas profile: 10-20% Specific humidity profile: 10-50g/kg Duty cycle: Swath width: Revisit capability 36 hours. Solar irradiance: 36 days Data rate:
GOMOS Global Ozone Monitoring by Occultation of Stars	ENVISAT-1	Provides stratospheric profiles of temparature and of ozone, NO2, H20, aerosols and other trace species	Waveband: UV-Visible: 0.25-0.675µm NIR: 0.756-0.773µm, 0,926-0.952µm Spatial resolution: Vertical: 1km Accuracy: Self-calibrating Duty cycle: 50% (for observations) night-side Swath width: Not applicable Data rate:
GPS receiver	FedSat-1	Sounding data for study of physics of upper atmoshpere, and water vapour, temparature and refractivity profiles	Waveband: Not applicable Spatial resolution: Not applicable Accuracy: Duty cycle: Swath width: Not applicable Data rate:
GPSDR GPS Demonstration Receiver	TOPEX/POSEIDON Jason-1, Jason Follow-on	Provides precise continuous tracking data of satellite to decimeter accuracy	Waveband: 1227.6MHz and 1575.4MHz Spatial resolution: 0.1m Accuracy: 4cm on satellite altitude Duty cycle: 100% Swath width: Data rate: 700bps
GRACE Gravity Recovery And Climate Experiment	ESSP-IB (aka GRACE)	Measures gravity field strength and variation	Waveband: K/Ka-band antenna, upward-looking L1/L2-band antenna Spatial resolution: Accuracy: Duty cycle: Swath width: Revisit capability: 15 days Data rate:
Gradiometer	ESA Future Missions	Provides high resolution data on geoid and derived data on time-invariant mean component of ocean currents. Also provides improved reference surface data for the world-wide height system and for vertical ice and land movements, and gravity field data for study of tectonic processes and the ocean lithosphere	Waveband: Not applicable Spatial resolution: Approx 100km Accuracy: Approx 2-5cm at 100km wavelength, < 1cm at 1000km wavelength Duty cycle: Continuous operation for 8 months Swath width: Not applicable Data rate: 1-2Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
GRAS	METOP 1, METOP 2, METOP 3	GNSS receiver for atmospheric sounding	Waveband: SWIR-TIR Spatial resolution: Vertical: 1km Horizontal: 300km Accuracy: Specific humidity profile: 10% Temparature: 1-2K Duty cycle: Swath width: Revisit capability: 5 days Data rate:
HALOE Halogen Occultation Experiment	UARS	Provides data on vertical distributions of hydrofluoric and hydrochloric acids, methane, water vapour and members of the nitrogen family. It also provides atmospheric temperature versus pressure profiles from observations of carbon dioxide	Waveband: SWIR: 2.43 µm, TIR: 10.25µm Spatial resolution: Vertical (limb): approx 4.5km Horizontal (limb): about 300km along limb tangent path Accuracy: 10-30% Duty cycle: 100% Swath width: 6-150km (vertical limb coverage) Data rate: 4Kbps
HiRDLS High Resolution Dynamics Limb Sounder	EOS CHEM-1	Measures atmospheric temperature, concentrations of ozone, water vapour, methane, NOx, N2O, CFCs and other minor species, aerosol concentration, location of polar stratospheric clouds and cloud tops	Waveband: TIR: 6.12-17.76µm Spatial resolution: Vertical: 1km Horizontal: 400km x 400km Averaging volume for each data sample is 1km vertical x 10km across x 400km along line-of-sight Accuracy: Trace gas: 10% Temparature: 1K Ozone: 10% Duty cycle: 100% Swath width: 6 profiles across 2000-3000km Data rate: 50Kbps average, 100Kbps peak
HIRS/2 High Resolution Limb Sounder	EOS CHEM-1	Measures atmospheric temperature, concentrations of ozone, water vapour, methane, NOx, N2O, CFCs and other minor species, aerosol concentration, location of polar stratospheric clouds and cloud tops	Waveband: TIR: 6.12-17.76µm Spatial resolution: Vertical: 1km Horizontal: 400km x 400km Averaging volume for each data sample is 1km vertical x 10km across x 400km along line-of-sight Accuracy: Trace gas: 10% Temparature: 1K Ozone: 10% Duty cycle: 100% Swath width: 6 profiles across 2000-3000km Data rate: 50Kbps average, 100Kbps peak
HIRS/3 High Resolution Limb Sounder	NOAA K, NOAA L, NOAA M	Provides atmospheric temperature profiles and data on cloud parameters, humidity soundings, water vapour, total ozone content, and surface temperatures	Waveband: VNIR: 0.69µm, TIR: 3.76-4.57µm, 6.72-14.95µm (20 channels) Spatial resolution: 20km at nadir Accuracy: Duty cycle: 100% Swath width: 2240km Data rate: 2.28Kbps
HIRS/4 High Resolution Limb Sounder	NOAA N, NOAA N'	Provides atmospheric temperature profiles and data on cloud parameters, humidity soundings, water vapour, total ozone content, and surface temperatures	Waveband: VNIR: 0.69µm, TIR: 3.76-4.57µm, 6.72-14.95µm (20 channels) Spatial resolution: 10km at nadir Accuracy: Duty cycle: 100% Swath width: 2240km Data rate: 2.28Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
HR PAN High Resolution Panchromatic instrument	IRS P5 (aka CARTOSAT-1)	High resolution stereo images for large scale (better than 1:10,000) applications	Waveband: Panchromatic: visible region Spatial resolution: 2.5m Accuracy: Duty cycle: Swath width: 30km Revisit capability: 26 days Data rate: 210Mbps
HRDI High Resolution Doppler Imager	UARS	Daytime wind measurements below 50km from Doppler shifts of molecular oxygen absorption lines. Day and night wind measurements above about 60km from Doppler shifts of neutral and ionised atomic oxygen emission lines. Also measures temperature	Waveband: Visible-NIR: 0.557-0.776µm Spatial resolution: Vertical (limb): 4km Horizontal (limb): 80km Accuracy: Daytime wind measurements: 5m/s or better Day and night: 15m/s or better Duty cycle: Swath width: 5 to 100km (vertical coverage) Data rate: 4.75Kbps
HRG High Resolution Geometry	SPOT 5	High resolution multispectral mapper. 2 HRG instruments on this mission can be processed to produce simulated imagery of 2.5m. Images are 60km x 60km in size	Waveband: Visible: 0.55, 0.61-0.68, 0.64µm NIR-SWIR: 0.78-0.89µm, 0.85µm, 1.5-1.7µm Panchromatic: 0.5-0.75µm Spatial resolution: Panchromatic: 5m Multispectral: 10m Accuracy: Duty cycle: Daylight coverage only Swath width: 60km (1 instrument), 117km (2 instruments). Same as SPOT 4 with off-track steering capability (±27 deg) Data rate: >50Mbps for 2 instruments
HRV High Resolution Visible	SPOT 1, SPOT 2	2 HRV instruments on this mission provide 60km x 60km images for a range of land and coastal applications	Waveband: Visible: 0.5-0.59, 0.61-0.68µm NIR: 0.79-0.89µm Panchromatic: 0.51-0.73µm Spatial resolution: 10m (panchromatic) or 20m Accuracy: Duty cycle: Daylight coverage only. World wide coverage (on board tape recorder). 26 day orbital cycle. 100% in daylight Swath width: 117km (ie 60km + 60km with 3km overlap) - steerable up to ±27 deg off-track Revisit capability (1 to 4 days at mid latitude) Data rate: 25Mbps each instrument
HRVIR High Resolution Visible & IR	SPOT 4	2 HRVIR instruments on this mission provide 60km x 60km images for a range of land and coastal applications	Waveband: Visible: 0.50-0.59µm, 0.61-0.68µm, NIR: 0.79-0.89µm, SWIR: 1.5-1.7µm Spatial resolution: 10m (0.64µm) or 20m Accuracy: Duty cycle: Daylight coverage only (world wide coverage using on board tape recorder) 100% in daylight. 26 days orbital cycle Swath width: 117km (ie 60km + 60km with 3km overlap). Steerable up to ±27 deg off-track Revisit capability: 1 to 4 days at mid-latitude Data rate: 25Mbps each instrument

Instrument	Mission(s)	Measurements/application	Technical characteristics
HSB Humidity Sounder for Brazil	EOS PM-1	Humidity soundings for climatological and atmospheric dynamics applications	Waveband: Channel 1: 150GHz Channel 2: 183.3GHz ±1GHz Channel 3: 183.3GHz ±3GHz Channel 4: 183.3GHz ±7GHz Spatial resolution: 13.5km Accuracy: Channel 1: 1K Channel 2: 1.2K Duty cycle: Swath width: 1650km Revisit capabiltiy: 2 days Data rate: 4.2Kbps
IASI Infra-red Atmospheric Sounding Interferometer	METOP 1, METOP 2, METOP 3	Measures tropospheric moisture and temperature, column integrated contents of ozone, carbon monoxide, methane, dinitrogen oxide and other minor gases which affect tropospheric chemistry. Also measures sea surface and land temperature	Waveband: SWIR-TIR: 3.4-15.5μm with gaps at 5μm and 9μm Spatial resolution: Vertical: 1-30km Horizontal: 25km Accuracy: Temparature: 0.5-2K Specific humidity: 0.1-0.3g/kg Ozone, trace gas proflie: 10% Duty cycle: 100% Observing cycle: 12 hrs Swath width: 2230km Revisit capability: 5 days Data rate: 1.5Mbps
IKAR-D	PRIRODA	Used for investigations of ocean-atmosphere system. Measures sea surface temperature, wind speed, precipitable water content, cloud liquid water content and rain rate	Waveband: Microwave: 0.8, 1.35 and 2.25cm Spatial resolution: 5, 15 and 25km respectively (at 400km altitude) Accuracy: 5-7% Duty cycle: A few orbits, on several occasions Swath width: 420km (at 400km altitude) Data rate: 8Kbps
IKAR-N	PRIRODA	Used for investigations of ocean-atmosphere system. Measures sea surface temperature, wind speed, precipitable water content, cloud liquid water content and rain rate	Waveband: Microwave: 0.8, 1.35 and 2.25cm Spatial resolution: 5, 15 and 25km respectively (at 400km altitude) Accuracy: 5-7% Duty cycle: A few orbits, on several occasions Swath width: 420km (at 400km altitude) Data rate: 8Kbps
IKAR-P	PRIRODA	Used for investigations of ocean-atmosphere system. Measures sea surface temperature, wind speed, precipitable water content, cloud liquid water content and rain rate	Waveband: Microwave 2.25cm (3 channels) and 6cm (5 channels) Spatial resolution: 75km (at 400km altitude) Accuracy: 3-5% Duty cycle: A few orbits, on several occasions Swath width: 750km (at 400km altitude) Data rate: 1Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
ILAS-II Improved Limb Atmospheric Spectrometer	ADEOS II	Measures minor trace gas species at high latitudes, in the altitude range 10-60km (O3, CH4, NO2, N2O, H2O, CFC11, HNO3, ClONO2, N2O5, aerosols, temparature, pressure)	Waveband: Visible: 0.753-0.784μm TIR: 3.0-5.7μm, 6.21-11.76μm, 12.78-12.85μm Spatial resolution: Vertical: 1km Temparature, aerosols, pressure: 2km (horiz) ClONO2: 21.7km (horiz) Others: 13km (horiz) Accuracy: Temparature: 0.2K Pressure: 1% Aerosol: 2% Ozone: 3-5% Other trace gases: 2-25% Duty cycle: Every occultation Swath width: Not applicable Data rate: 450Kbps
IMAGER (GOES)	GOES 8, GOES 9, GOES 10, GOES 11, GOES 12	Measures cloud cover, atmospheric radiance, winds, atmospheric stability, rainfall estimates. Used to provide severe storm warnings/ monitoring day and night (type, amount, storm features)	Waveband: GOES I-L: Visible: 1 channel (8 detectors), IR: 4 channels: 3.9, 6.7, 10.7 and 12μm GOES M: Visible: 1 channel (8 detectors), IR: 4 channels: 3.9, 6.7, 10.7 and 13.3μm Spatial resolution: 1km in visible 4km in IR (8km for 13.3μm band (water vapour)) Accuracy: Earth location accuracy <4km Duty cycle: 100% except during eclipse season Swath width: Horizon to horizon Data rate: 2.11 Mbps (GVAR)
IMAGER (NASDA/MT)	MTSAT, MTSAT-2	Measures cloud cover, cloud motion, cloud height, water vapour, rainfall, sea surface temparature and Earth radiation	Waveband: Visible: 0.55-0.80μm TIR: 3.5-4μm, 6.5-7μm, 10.3-11.3μm, 11.5-12.5μm Spatial resolution: Visible: 1km TIR: 4km Accuracy: Duty cycle: Full Earth disk every hour Swath width: Full Earth disk Data rate: 2.6Mbps
Imaging spectrometer	ARIES-1	Multispectral data for Earth resources, agriculture and forestry, water resources and vegetation studies	Waveband: Visible-NIR: 32 contiguous wavebands (0.6-1.1μm) SWIR: 32 contiguous wavebands (2.0-2.5μm) (Wavebands between 1.0-2.0μm for atmospheric correction and calibration - optional) Spatial resolution: 30m at nadir Accuracy: 0.4-1.1μm: minumum 600:1 SNR 2.0-2.5μm:400:1 SNR at 2.1μm Duty cycle: Programmable Swath width: 15km Data rate: 150Mbps by X-band downlink
IR imager	Odin	Atmospheric sounder measurements of albedo, aerosols, ozone and temparature profiles	Waveband: NIR: 1.26, 1.27, 1.28μm Spatial resolution: Approx 1km/pixel Accuracy: Duty cycle: 50% maximum (half of mission for astronomy) Swath width: Data rate: A few Mbyte/orbit

Instrument	Mission(s)	Measurements/application	Technical characteristics
IRMSS IR Multi-Spectral Scanner	CBERS 1, CBERS 2	Used for fire detection, fire extent and temperature measurement	Waveband: Visible-NIR: 0.5-1.1µm, NIR: 1.55-1.75µm, SWIR: 2.08-2.35µm, TIR: 10.4-12.5µm Spatial resolution: Visible, NIR, SWIR: 80m TIR: 160m Accuracy: Duty cycle: International access open to all participating stations, limited to 20 minutes per revolution Swath width: 19.5km Revisit capability: 26 days Data rate: 6.13Mbps
ISP-2M	Resource-01 N4	Measures solar radiation flux	Waveband: UV-FIR: 0.2-50µm Spatial resolution: Not applicable Accuracy: 0.01% (meanday accuracy) Duty cycle: 100% Swath width: Data rate:
ISTOK-1 Infra-red Spectrometer	PRIRODA	Spectral measurements of thermal emission of atmosphere and of underlying Earth surface at a variety of incident angles as well as measurements of transmission spectra of atmosphere while tracking the Sun	Waveband: SWIR-FIR: 4-8 and 8-16µm Spatial resolution: 0.6-2km (along track) Accuracy: Duty cycle: A few orbits, on several occasions Swath width: FOV: 6.5 x 26 angular minutes Data rate: 8Kbps
JMR (formerly AMR) Jason Microwave Radiometer	Jason-1, Jason Follow-on	Provides altimeter data to correct for errors caused by water vapour and cloud-cover. Also measures total water vapour and brightness temperature	Waveband: Microwave: 18.24 and 34GHz Spatial resolution: 45km at 18GHz, 37km at 24GHz, 24km at 34GHz Accuracy: Total water vapour: 0.2g/sq cm Brightness temperature: 1K Duty cycle: 100% Swath width: 120 deg cone centred on nadir Data rate: 125bps
KFA-1000	Resource-F1M series	Photography of land and ocean surfaces	Waveband: Visible-NIR: 0.57-0.8µm Spatial resolution: 6m at an altitude of 235km Accuracy: Duty cycle: 12% Swath width: 0.3 of the orbit altitude Data rate:
KFA-200	Resource-F1M series	Photography of land and ocean surfaces	Waveband: Visible: 0.6-0.7µm Spatial resolution: 23m at an altitude of 235km Accuracy: Duty cycle: 12% Swath width: 0.9 of the orbit altitude Data rate:
KFA-3000	Resource-F3 series	Photography of land and ocean surfaces for use at 1:25000 scale and below	Waveband: Visible: 0.6-0.7µm Spatial resolution: 3m at an altitude of 275km Accuracy: Duty cycle: 12% Swath width: 0.1 of the orbit altitude Data rate:
KGI-4	METEOR-3M N2	Measures particle flux and electromagnetic emissions	Waveband: Not applicable Spatial resolution: Not applicable. Electron flux density range: 0.15-2.0MeV, proton flux density range: 5-90MeV, gamma ray flux density range: 0.1-1.0MeV Accuracy: Duty cycle: 100% (103 mins or 1 coil) Swath width: 12 seconds Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
KGI-4 C	METEOR-3M N1	Measures particle flux and electromagnetic emissions	Waveband: Not applicable Spatial resolution: Not applicable. Electron flux density range: 0.15-2.0MeV, proton flux density range: 5-90MeV Accuracy: 0.15-0.5K Duty cycle: 100% (103 mins or 1 coil) Swath width: 12 seconds Data rate:
Klimat	METEOR-3M N1	Provides images of cloud, ice and snow. Measures sea surface temparature	Waveband: TIR: 10.5-12.5µm Spatial resolution: 3 x 3km at nadir Accuracy: Duty cycle: 100% Swath width: 3100km Data rate:
KONDOR-2	Ocean-01 N7, OKEAN-O	Data collection and communication	Waveband: Not applicable Spatial resolution: Not applicable Accuracy: Duty cycle: Passive satellites Swath width: 600km coverage Data rate: 200bps
Laser altimeter	ESA Future Missions	Provide measurements of sea ice surface roughness, thickness, ice sheet elevation and land topography	Waveband: 1.06µm Spatial resolution: 100m Accuracy: Vertical: 2cm (vertical repeatability 10cm) Duty cycle: Swath width: Not applicable Data rate: 100kbps
Laser cornercube reflectors	LAGEOS I, LAGEOS II	Provide data on Earth crust motion	Waveband: Not applicable Spatial resolution: Not applicable Accuracy: Duty cycle: Passive satellite Swath width: Not applicable Data rate: Not applicable
Laser reflectors	STELLA	Measures distance between the satellite and the laser tracking stations	Waveband: Not applicable Spatial resolution: Not applicable Accuracy: Duty cycle: Passive satellite - tracking in visibility of any laser station Swath width: Not applicable Data rate: Not applicable
LATI Landsat Advanced Technology Instrument	TBD	Provision of data for Earth resource applications (renewable and non-renewable), civil planning and mapping, vegetation type, surface radiance and emittance, landcover state and land cover change	Waveband: Visible-TIR: 0.45-12.5µm (number of spectral bands, including 1 panchromatic band between 0.52 and 0.90, to be decided) Spatial resolution: Panchromatic: 15m Visible, NIR and SWIR: 30m TIR: 60m (band may be deleted) Accuracy: 5% Duty cycle: 30% Swath width: 185km (may be achieved with 2 instruments) 16 day revisit time Data rate: 150Mbps (TBD)

Instrument	Mission(s)	Measurements/application	Technical characteristics
LEO communication transponder	MECB SCD-3		Waveband: Not applicable Spatial resolution: Not applicable Accuracy: Duty cycle: Swath width: Not applicable Data rate:
LIDAR	MDS-2	Lidar measurements of clouds and aerosols	Waveband: 0.527μm, 1.053μm, Spatial resolution: 1.5km at nadir Accuracy: 100m (altitude, cloud detection) Duty cycle: 25% (TBD) Swath width: 1.5km Data rate: 85Kbps max
Light SAR	Light SAR	All weather images of land surface features, and land and ice topography	Waveband: Microwave Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:
LIS Lightning Imaging Sensor	TRMM	Global distribution and variability of total lightning. Data can be related to rainfall to study hydrological cycle	Waveband: NIR: 0.7774μm onto a CCD array Spatial resolution: 4km at nadir Accuracy: 90% day and night detection probability Duty cycle: 100% Swath width: FOV: 80 x 80 deg Data rate: 6Kbps
LISS I Linear Imaging Self-Scanning system	IRS 1a, IRS 1b	Provides data for: monitoring land use/ land cover, forest cover, coastal zones and wastelands; identification of prospective ground water zones; and crop acreage and production estimation for wheat, rice, sorghum, cotton, groundnut, tobacco, etc	Waveband: Visible: 0.46-0.52μm, 0.52-0.59μm, 0.62-0.68μm NIR: 0.77-0.86μm Spatial resolution: 72.5m Accuracy: Duty cycle: Daylight coverage 100% Swath width: 148km Revisit capability: 22 days for individual satellite, 11 days effectively for IRS1a/1b together Data rate: 5.2Mbps
LISS II Linear Imaging Self-Scanning system	IRS 1a, IRS 1b, IRS P2	Data used for vegetation type assessment, resource assessment, crop stress detection, crop production forecasting, forestry, and for monitoring land use and land cover change	Waveband: Visible: 0.46-0.52μm, 0.52-0.59μm, 0.62-0.68μm NIR: 0.77-0.86μm Spatial resolution: 32 x 37m Output sampled to 3.6m compatible to IRS-1a/1b Accuracy: Duty cycle: All day time passes Swath width: 132km Revisit capability: 24 days Data rate: 2 x 10.4Mbps
LISS III Linear Imaging Self-Scanning system	IRS 1c, IRS 1d	Data used for vegetation type assessment, resource assessment, crop stress detection, crop production forecasting, forestry, land use and land cover change	Waveband: Visible: Band 2: 0.52-0.59μm, band 3: 0.62-0.68μm NIR: Band 4: 0.77-0.86μm SWIR: Band 5: 1.55-1.75μm Spatial resolution: Bands 2, 3 & 4: 23.5m, Band 5: 70.5m Accuracy: Duty cycle: Daylight coverage 100% Swath width: Bands 2, 3 & 4: 142km, band 5: 148km Revisit capability 24 days Data rate: 42.45 Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
LISS IV Linear Imaging Self-Scanning system	IRS P5 (aka CARTOSAT-1), IRS P6 (aka RESOURCESAT-1)	High resolution multispectral data for cartography and land applications	Waveband: Visible (green, red), NIR and SWIR Spatial resolution: About 10m Accuracy: Duty cycle: Swath width: 40km Revisit capability: 22 days Data rate: 70 Mbps
LRA Laser Retroflector Array	TOPEX/POSEIDON Jason-1, Jason Follow-on	Provides baseline tracking data for precision orbit determination and calibration of radar altimeter bias	Waveband: Not applicable Spatial resolution: Not applicable Accuracy: 2cm overhead ranging Duty cycle: 100% Swath width: Not applicable Data rate: Not applicable
Magnetometer and advanced communications payload	FedSat-1	Part of FedSat-1 payload to provide data for upper atmosphere and meteorology research	Waveband: 0.1-1.0Hz Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate: 0.8-1Kbps
Magnet-ometry package	CHAMP	Magnetometer for measuring the strength and variation of the Earth's magnetic field	Waveband: Not applicable Spatial resolution: Accuracy: Duty cycle: 100% Swath width: Data rate: 3570bps
MASTER	ESA Future Missions	Provide data for study of exchange mechanisms between stratosphere and troposphere, and complementary information for studies on global change. Measures upper troposphere/ lower stratosphere profiles of O3, H2O, CO, HNO3, SO2, N2O, pressure and temperature	Waveband: Microwave: 199-207, 296-306, 318-326, 342-348GHz Spatial resolution: 3km Accuracy: 199-207GHz channel: 1K Other channels: 1.5K, 50MHz resolution, 0.3 secs integration time Duty cycle: 100% Swath width: Not applicable Data rate: 0.5Mbps
MERIS Medium Resolution Imaging Spectrometer	ENVISAT 1	Main objective is monitoring marine biophysical and biochemical parameters. Secondary objectives are related to atmospheric properties such as cloud and water vapour and to vegetation conditions on land surfaces	Waveband: Visible-NIR: 15 bands selectable across range: 0.4-1.05μm (bandwidth programmable between 0.0025 and 0.03μm) Spatial resolution: 300m or 1200m at SSP Accuracy: Ocean colour bands typical S:N = 1700 Duty cycle: Full resolution mode (300m at SSP) up to 25% Low resolution mode (1.2km at SSP) 80% of orbit Operates only above 10 deg solar elevation Swath width: 1150km giving global coverage every 3 days Data rate: Full resolution mode (no onboard storage) 24Mbps Low resolution mode 1.7Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
MHS Microwave Humidity Sounder	METOP 1, METOP 2, METOP 3, NOAA N, NOAA N' ESA Future Missions	Provides atmospheric humidity profiles, cloud cover, cloud liquid, water content, ice boundaries and precipitation data	Waveband: Microwave:89, 166GHz and 3 channels near 183Ghz Spatial resolution: Vertical: 3-7km Horizontal: 30-50km Accuracy: Cloud water profile: 10g/m2 Specific humidity profile: 10-20% Duty cycle: 100% Swath width: 1650km Data rate: 4.2Kbps
MIPAS Michelson Interferometric Passive Atmospheric Sounder	ENVISAT 1, ESA Future Missions	Provides data on chemistry of stratosphere (global and polar ozone), climate research (global distribution of trace gases and clouds), transport dynamics, tropospheric chemistry. Primary/secondary species measured are: O3, NO, NO2, HNO3, N2O5, ClONO2, CH4	Waveband: IR bands between 4.15 and 14.6µm Spatial resolution: Vertical resolution: 3km, vertical scan range 5-100km Horizontal: 30km x 300 km Spectral resolution: 0.025 lines/cm Accuracy: Radiometric precision: 685-970 cm-1: 1%, 2410 cm-1: 3% Duty cycle: 100% Swath width: Not applicable Data rate: 620Kbps
MISR Multi-angle Imaging Spectro Radiometer	EOS AM-1	Provides measurements of global surface albedo, aerosol and vegetation properties. Also provides multi-angle bidirectional data (1% angle-to-angle accuracy) for cloud cover and reflectances at the surface and aerosol opacities	Waveband: Visible: 0.44, 0.56, 0.67µm NIR: 0.86µm Spatial resolution: 240m, 480m, 960m or 1.92km Summation modes available on selected cameras/bands: 1x1, 2x2, 4x4, 1x4. 1 pixel = 275m x 275m Accuracy: 0.03% hemispherical albedo 10% aerosol opacity 1-2% angle to angle accuracy in bidirectional reflectance Duty cycle: 50% Swath width: Unedited, nadir camera: 370km Unedited, non-nadir cameras: 408km Revisit capability: 2 days Data rate: Average/peak: 3.3/9.0Mbps
MIVZA	METEOR-3M N1, METEOR-3M N2	Microwave radiometer for temparature sounding of atmosphere	Waveband: Microwave:1.5, 0.86, 0.32cm Spatial resolution: 20-80km Accuracy: Duty cycle: 100% Swath width: 1500km Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
MK-4	Resource-F2 series	Photography of land and ocean surfaces in 4 out of 6 channels	Waveband: Visible-NIR: 0.435-0.68µm, 0.46-0.51µm, 0.515-0.565µm, 0.64-0.69µm, 0.61-0.75µm, 0.81-0.86µm Spatial resolution: 10m at an altitude of 240km, film type 30M; 14m at an altitude of 240km, film type SN-10 Accuracy: Relative photometric accuracy ±5% Duty cycle: 19% Swath width: 0.6 of the orbit altitude Data rate: Not applicable
MK-4M	Resource-F2 series	Photography of land and ocean surfaces in 4 spectral channels	Waveband: Visible-NIR: 0.52-0.56µm, 0.61-0.76µm, 0.64-0.69µm, 0.81-0.87µm Spatial resolution: 6m at an altitude of 240km, film type 92 9m at an altitude of 240km, film type SN-18 Accuracy: Relative photometric accuracy ±5% Duty cycle: 19% max Swath width: 0.6 of the orbit altitude Data rate:
MLS (EOS-CHEM) Microwave Limb Sounder	EOS CHEM-1	Measures lower stratospheric temperature and concentration of H2O, O3, ClO, HCl, OH, HNO3, N2O and SO2	Waveband: Microwave: 215, 310, 640GHz and 2.5THz Spatial resolution: Vertical: 1.5km (2.5GHz) to 4.0km (215GHz) Horizontal: 10km Spectral resolution 1MHz Accuracy: Temparature: 4K Ozone: 50% Duty cycle: 100% Swath width: Limb scan 2.5 - 62.5km Limb to limb Revisit capability: 2 days Data rate: 100Kbps
MLS (UARS) Microwave Limb Sounder	UARS	Provides data on emissions of chlorine monoxide, water vapour and ozone. Data also used for determination of atmospheric pressure and temperatures as a function of altitude from observations of molecular oxygen emissions	Waveband: Microwave: 63,183, 205GHz Spatial resolution: Vertical (limb): 4km Horizontal (limb): 400km approx Accuracy: 5-25% Duty cycle: 100% Swath width: Operating mode changed to look at 18km on limb, instead of the normal 15-85km, with full vertical scans on occasion Data rate: 1.25Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
MODIS Moderate Resolution Imaging Spectro radiometer	EOS AM-1, EOS PM-1	Provision of data on biological and physical processes on the surface of the Earth and in the lower atmosphere, and on global dynamics. Measures surface temperatures of land and ocean, chlorophyll fluorescence, land surface cover measurements (vegetation and snow), cloud cover (day and night), and cloud and aerosol properties	Waveband: Visible-TIR: 36 bands in range 0.4-14.4μm Spatial resolution: Cloud cover: 250m (day) and 1000m (night) Surface temperature: 1000m Accuracy: Long wave radiance: 100nW/m2 Short wave radiance: 5% Surface temperature of land: <1K Surface temperature of ocean: <0.2K Snow and ice cover: 10% Duty cycle: 100% Swath width: 2300km at 110 deg (±55 deg). Revisit capability: daylight reflection and day/night emission spectral imaging at least every 2 days Data rate: 2.5-11Mbps (average 6.2Mbps)
MOMS-2P Modular Opto-electronic Multispectral Scanner	PRIRODA	Provides data for topographic and land applications. Instrument can be operated in 4 different modes: 1) full stereo with high resolution 2) multispectral, all four bands 3) high resolution and 3 spectral bands 4) 2 multispectral bands plus fore and aft stereo	Waveband: MS: Visible-NIR: 0.44-0.505μm, 0.53-0.575μm, 0.645-0.68μm, 0.77-0.76μm HR & ST: Panchromatic: 0.52-0.76μm Spatial resolution: MS: 15.9-18m HR: 5.3-6m ST: 15.9-18m (within 350-400km altitude range) Accuracy: Duty cycle: 5-10 minutes of data per day on average over 18 months starting mid 1996 Swath width: MS: 92-105km, HR: 44-50km, ST: 88-105km Revisit capability: approx 14 days Data rate: Up to 100Mbps without compression
MOPITT Measurements of Pollutants in the Troposphere	EOS AM-1	Measurements of greenhouse gases (CO, methane) in the troposhere	Waveband: IR: 2.3, 2.4 and 4.7μm Spatial resolution: CO profile: 4km vertical, 22 x 22km horizontal, CO, CH4 column: 22x22km horizontal Accuracy: Carbon monoxide: 10% Methane: 2% Duty cycle: 100% Swath width: Swath ±25 degrees about nadir Revisit capability: 4 days Data rate: 25Kbps continuous
MOS **(IRS P3)** Modular Opto-electronic Scanning Spectrometer	IRS P3	Data used for spectral analysis of O2 absorption in the NIR band, Vegetation index, Condition of soil and vegetation	Waveband: MOS-A: NIR: 4 channels in range 0.755-0.768μm MOS-B: Visible-NIR: 13 channels in range 0.408-1.01μm MOS-C: SWIR: 1.6μm Spatial resolution: MOS-A: 1.6 x 1.4km MOS-B: 0.52 x 0.52km MOS-C: 0.52 x 0.64km Accuracy: Radiometric: Visible, IR: <1%, SWIR: 2% (12 bit ADC) Duty cycle: 100% Swath width: approx 200km Data rate: MOS-A: 37.5Kbps MOS-B: 121Kbps MOS-C: 18.7Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
MOS **(PRIRODA)** Modular Opto-electronic Scanning Spectrometer	PRIRODA	Provides data for spectral analysis of O2 absorption in the NIR band, vegetation indices, and vegetion condition and soil assessment	Waveband: MOS-A: NIR: 4 channels in range 0.755-0.768μm MOS-B: Visible-NIR: 13 channels in range 0.408-1.01μm Spatial resolution: MOS-A: 2.87 x 2.87km MOS-B: 0.7 x 0.65km Accuracy: Radiometric <1% (12 bit ADC) Duty cycle: 10% Swath width: MOS-A: 80.5km MOS-B: 82km Data rate: 320Kbps
MR-2000	METEOR-2 N24	TV camera images of cloud, snow and ice	Waveband: Visible-NIR: 0.5-0.8μm Spatial resolution: 1km (at nadir) Accuracy: 0.03% Duty cycle: 100% Swath width: 2600km Data rate:
MR-2000M	METEOR-3 N5, METEOR-3M N1	TV camera images of cloud, snow and ice	Waveband: Visible-NIR: 0.5-0.8μm Spatial resolution: 0.7 x 1.4km (at nadir) Accuracy: 0.03% Duty cycle: 5-7 viewing periods each day Swath width: 3100km Data rate:
MR-900	METEOR-2 N24	TV camera images of cloud, snow and ice	Waveband: Visible-NIR: 0.5-0.8μm Spatial resolution: 2km (at nadir) Accuracy: 0.03% Duty cycle: 100% Swath width: Scan angle 90 deg (2100km) Data rate:
MR-900B	METEOR-3 N5	TV camera images of cloud, snow and ice	Waveband: Visible-NIR: 0.5-0.8μm Spatial resolution: 2 x 1km (at nadir) Accuracy: 0.03% Duty cycle: 100% (programmable in real-time) Swath width: 2600km Data rate:
MR-900M	METEOR-3M N1, Resource-01 N4	TV camera images of cloud, snow and ice	Waveband: Visible-NIR: 0.5-0.8μm Spatial resolution: 2 x 1km (at nadir) Accuracy: 0.03% Duty cycle: 100% (programmable in real-time) Swath width: 2600km Data rate:
MS Multispectral Scanner	NMP EO-1	Hyperspectral measurements for land and marine applications research and development	Waveband: Panchromatic: 0.48-0.69μm Multispectral: MS-1': 0.433-0.453μm, MS-1: 0.450-0.515μm, MS-2: 0.525-0.605μm, MS-3: 0.63-0.69μm, MS-4': 0.775-0.805μm, MS-4: 0.845-0.89μm, MS-5': 1.2-1.3μm, MS-5: 1.55-1.75μm, MS-7: 2.08-2.35μm Spatial resolution: Panchromatic: 10m Mulitspectral: 30m Accuracy: Duty cycle: Swath width: Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
MSGI-5 Multi-channel system for Geoactive measurements	METEOR-3M N2	Measures charged particle flux density	Waveband: Not applicable Spatial resolution: Not applicable. Electron flux density range: 0.05-15KeV, proton flux density range: 40KeV Accuracy: Duty cycle: 100% (1 coil or 12 hrs) Swath width: 1 second of orbit Data rate:
MSGI-5EI	METEOR-3M N1	Measures charged particle flux density	Waveband: Not applicable Spatial resolution: Not applicable. Electron flux density range: 0.1-15MeV, proton flux density range: 0.1-100KeV Accuracy: Duty cycle: 100% (1 coil or 12 hrs) Swath width: 1-8 seconds of orbit Data rate:
MSMR Multispectral Microwave Scanning Radiometer	IRS P4 (aka OCEANSAT-1)	Measures microwave brightness temparature for oceanographic applications	Waveband: Microwave: 6.6, 10.6, 18 and 21GHz Spatial resolution: 40m at 21GHz to 120m at 6.6GHz Wind speed: 75 x 75km Sea surface temparature: 146 x 150km Accuracy: Sea surface temparature: 1.5K Sea surface wind speed: 1.5 m/s Duty cycle: Swath width: 1360km Revisit capability: 26 days Data rate: 5Kbps
MSR Microwave Scanning Radiometer	METEOR-3M N2	Provides multispectral (visible, IR) data for small-scale applications	Waveband: Visible-TIR: 0.5-0.7μm, 0.8-1.0μm, 10.4-11.3μm and 11.5-12.5μm Spatial resolution: 1km Accuracy: Visible-NIR: 0.5% TIR: 0.15K Duty cycle: 100% Swath width: 2700km Data rate: 1.3Mbps
MSS Multispectral Scanning System	LANDSAT 5	Measures surface radiance. Data mostly used for land applications	Waveband: Visible: 0.5-0.6μm, 0.6-0.7μm NIR: 0.7-0.8μm, 0.8-1.1μm Spatial resolution: 80m in visible and NIR channels Accuracy: Duty cycle: 30% Swath width: 185km Data rate: 15Mbps
MSU Microwave Sounding Unit	NOAA 9-12, NOAA 14	Provides temperature sounding through cloud up to 20km in altitude	Waveband: Microwave: 50.3, 53.74, 54.96 and 57.95GHz Spatial resolution: 115km Accuracy: Duty cycle: 100% Swath width: 2348km Data rate: 320bps

Instrument	Mission(s)	Measurements/application	Technical characteristics
MSU-E	Resource-01 N4	Multispectral scanner images of land surface and ice cover	Waveband: Visible: 0.5-0.6μm, 0.6-0.7μm NIR: 0.8-0.9μm Spatial resolution: 45m (at nadir) Accuracy: 4% radiometric accuracy Duty cycle: Programmable Swath width: 45km for one scanner, 80km for two scanners (pointable ±30 deg from nadir) Data rate: 11.5Mbps (3 channels)
MSU-E1	Resource-01 N4	Multispectral scanner images of land surface and ice cover	Waveband: Visible: 0.5-0.6μm, 0.6-0.7μm NIR: 0.8-0.9μm Spatial resolution: 25m (at nadir) Accuracy: 4% radiometric accuracy Duty cycle: Programmable Swath width: 45km for one scanner, 80km for two scanners (pointable ±30 deg from nadir) Data rate: 11.5Mbps (3 channels)
MSU-E2	PRIRODA	Multispectral scanner images of land surface and ice cover	Waveband: Visible: 0.5-0.6μm, 0.6-0.7μm NIR: 0.8-0.9μm Spatial resolution: 10m (at nadir) Accuracy: 4% radiometric accuracy Duty cycle: Programmable Swath width: 2 x 24km Data rate: 11.5Mbps (3 channels)
MSU-EU	SICH-1M	Multispectral scanner images of land surface	Waveband: Visible: 0.5-0.6μm, 0.6-0.7μm (scanning radiometer) NIR: 0.8-0.9μm Spatial resolution: 45m at nadir Accuracy: Duty cycle: Programmable Swath width: 45km or 90km Pointable ±30 deg from nadir Data rate: 11.5 Mbps
MSU-M	Ocean-01 N7, OKEAN-O, SICH-1, SICH-1M	Provide images of ocean surface and ice sheets	Waveband: Visible: 0.5-0.6μm, 0.6-0.7μm NIR: 0.7-0.8μm, 0.8-1.1μm Spatial resolution: 1 x 1.7km Accuracy: Duty cycle: 30 mins max continuous operation Swath width: 1900km Data rate:
MSU-S	Ocean-01 N7, OKEAN-O, SICH-1	Multispectral scanner images of ocean surface and ice sheets	Waveband: Visible: 0.55-0.7μm NIR: 0.7-1.0μm Spatial resolution: 370m Accuracy: Duty cycle: 15 mins max continuous operation Swath width: 1100km Data rate:
MSU-SK (PRIRODA)	PRIRODA	Multispectral scanner images of land surface and ice cover	Waveband: Visible: 0.5-0.6μm 0.6-0.7μm NIR: 0.7-0.8μm, 0.8-1.1μm TIR: 10.3-11.8μm Spatial resolution: Visible: 80m, IR: 300m Accuracy: 4% radiometric accuracy Duty cycle: Programmable Swath width: 300km Data rate: 11.5Mbps (5 channels)

Instrument	Mission(s)	Measurements/application	Technical characteristics
MSU-SK (Resource-01 N3)	Resource-01 N3	Multispectral scanner images of land surface and ice cover	Waveband: Visible: 0.5-0.6μm, 0.6-0.7μm NIR: 0.7-0.8μm, 0.8-1.1μm TIR: 10.4-12.6μm Spatial resolution: Visible-NIR: 170m TIR: 600m Accuracy: 4% radiometric accuracy Duty cycle: Programmable Swath width: 600km Data rate: 11.5Mbps (5 channels)
MSU-SK (Resource-01 N4)	Resource-01 N4	Multispectral scanner images of land surface and ice cover	Waveband: Visible: 0.5-0.6μm, 0.6-0.7μm NIR: 0.7-0.8μm, 0.8-1.1μm TIR: 10.3-11.8μm Spatial resolution: Visible-NIR: 170m TIR: 600m Accuracy: 4% radiometric accuracy Duty cycle: Programmable Swath width: 600km Data rate: 11.5Mbps (5 channels)
MTVZA Microwave Radiometer for temparature and humudity soundings of the Atmosphere	METEOR-3M N1, METEOR-3M N2	Provision of atmospheric temparature and humidity profiles	Waveband: Microwave: 18.7-183.31GHz Spatial resolution: 10km, 72km Accuracy: Duty cycle: 100% (12 hrs) Swath width: Data rate: 8Kbps
Multispectral Visible & IR Scan Radiometer (10 channel)	FY-1C, FY-1D	Provides multi-spectral (visible, IR) data for small-scale applications	Waveband: 10 channels: Visible: 0.430.48μm, 0.48-0.53μm, 0.53-0.58μm, 0.58-0.68μm NIR: 0.84-0.89μm SWIR-FIR: 0.90-0.965μm, 1.58-1.68μm, 3.55-3.93μm TIR: 10.3-11.3μm, 11.5-12.5μm Spatial resolution: 1.1km Accuracy: Duty cycle: 100% Swath width: 3200km Data rate: 1.3308Mbps
Multispectral Visible & IR Scan Radiometer (3 channel)	FY-2	Measures surface temparature and cloud and ice cover. Used for snow and flood monitoring and surface temperature	Waveband: Visible-NIR: 3 channels in range 0.55-1.05μm Spatial resolution: 1.25km (visible), 5km (IR and water vapour) Accuracy: Duty cycle: 100% Swath width: Full Earth disk Data rate: Raw data 14Mbps, S-VISSR 0.66Mbps
MVIRI METEOSAT Visible & IR Imager	METEOSAT 5-7	Measures cloud cover, motion, height, upper tropospheric humidity and sea surface temperature	Waveband: Visible-NIR: 0.5-0.9μm TIR: 5.7-7.1μm (water vapour), 10.5-12.5μm Spatial resolution: Visible: 2.5km Water vapour: 5km (after processing) TIR: 5 km Accuracy: Cloud top height: 0.5km Cloud top/ sea surface temparature: 0.7K Cloud cover 15% Duty cycle: Full Earth disk in all three channels, every 30 minutes Swath width: Full Earth disk Data rate: 333Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
MWR Microwave Radiometer	ENVISAT 1, ERS-1, ERS-2, ESA Future Missions	Measures atmospheric humidity	Waveband: Microwave: 23.8 and 36.5GHz Spatial resolution: 20km Accuracy: Temparature: 2.6K Duty cycle: 100% Swath width: 20km Data rate: 0.5Kbps
MZOAS Microwave Radiometer for Ocean, Atmosphere And Sounding	METEOR-3M N2	Measures effective temperature and liquid water content of ocean surface, cloud and snow	Waveband: Microwave: 6, 11, 19, 22, 35, 94GHz (10 channels) Spatial resolution: 160, 80, 40, 36, 22, 9km respectively Accuracy: Temparature: 0.05K Duty cycle: 100% Swath width: 1500km Data rate:
OBA	MECB SSR-1, MECB SSR-2	Used for fire extent detection and temparature measurement, coastal and vegetation monitoring, land cover and land use mapping	Waveband: Visible: 0.46-0.48μm, 0.63-0.69μm, NIR: 0.76-0.90μm, MIR: 2.08-2.35μm Spatial resolution: VIS-NIR: 100m MIR: 300m Accuracy: Duty cycle: Operates only over Brazilian territory Swath width: 2200km Revisit capability: 0.2 days Data rate: 0.7-1.3Kbps (1:10 data compression)
OCM	IRS P4 (aka OCEANSAT-1)	Provides chlorophyll and biological productivity measurements in oceans	Waveband: 8 bands in Visible-NIR Spatial resolution: 350m Accuracy: Temparaure: <0.1K Duty cycle: Swath width: 1500km Revisit capability: 26 days Data rate: 17.35Mbps
OPS Optical Sensor	JERS 1	High resolution land imaging data used for energy and mineral resource management, land use, agriculture and forestry, fishery and coastal monitoring, environmental protection and disaster prevention	Waveband: Visible-NIR: 0.52-0.6μm, 0.63-0.69μm, 0.76-0.86μm (stereo) Spatial resolution: 18m x 24m Accuracy: Duty cycle: Swath width: 75km Data rate: 60Mbps
Ozon-M	PRIRODA	Multispectral UV spectrometer measurements of atmospheric turbidity and trace gas concentrations	Waveband: UV: 0.26-0.30μm, 0.36-0.42μm, Visible: 0.6-0.7μm NIR: 0.91-1.05μm Spatial resolution: 1km vertical Accuracy: Spectral: 0.02-0.07μm Duty cycle: A few orbits, on several occasions Swath width: 2 x 25 angular minutes Data rate: 50Kbps
PALSAR Phased Array L-band Synthetic Aperture Radar	ALOS	High resolution microwave imaging of land and ice for use in environmental monitoring, agriculture and forestry, disaster monitoring, Earth resource management and interferometry	Waveband: Microwave: L-Band 1270MHz Spatial resolution: High resolution mode: 10m (2 looks), 20m (4 looks) Scan SAR mode: 100m Accuracy: Radiometric: ±1dB Duty cycle: 100% (max) Swath width: High resolution mode: 70km Scan SAR mode: 250-360km Data rate: 240Mbps (max)

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Instrument	Mission(s)	Measurements/application	Technical characteristics
PAN Panchromatic Sensor	IRS 1c, IRS 1d	High resolution stereo images for study of topography, urban areas, development of digital terrain models, run-off models etc. Images also used to monitor urban sprawl, forest cover/timber volume and land use change	Waveband: Panchromatic: 0.5-0.75μm Spatial resolution: 5.8m Accuracy: Duty cycle: Daylight coverage only Swath width: 70km mosaic Revisit capability 5 days (with steerability) Data rate: 84.9Mbps
Panchromatic sensor	ARIES-1	Panchromatic data for Earth resources, agriculture and forestry, water resources and vegetation studies	Waveband: 0.4-1.0μm Spatial resolution: 10m at nadir Accuracy: 0.4-1.1μm: minumum 600:1 SNR 2.0-2.5μm: 400:1SNR at 2.1μm Duty cycle: Programmable Swath width: 15km Data rate: 150Mbps by X-band downlink
PEM Particle Environment Monitor	UARS	PEM measures UV and charged particle energy inputs: determines type, amount, energy and distribution of charged particles injected into Earth's thermosphere, mesosphere and stratosphere	Waveband: AXIS: Bremsstrahlung X-rays from 3-100KeV HEPS: electrons from 0.04-5MeV, protons from 0.07-150MeV MEPS: electrons and prontons from 1eV to 32KeV VMAG: three-axis magnetic field from -65000nT to +65000nT Spatial resolution: AXIS: vertical ~5km, horizontal: ~60km HEPS: vertical ~5km, horizontal ~30km MEPS: vertical ~5km, horizontal ~15km VMAG: vertical ~5km, horizontal ~1.5km Accuracy: AXIS: 1 count in 8sec ± Poisson static value [sqrt(n)], HEPS: 1 count in 4sec ± Poisson static value [sqrt(n)], MEPS: 1 count in 57msec ± Poisson static value [sqrt(n)], VMAG: 2nT ± 1nT Duty cycle: 100% Swath width: Data rate: 3.5Kbps
POLDER Polarisation & Directionality of the Earth's Reflectance	ADEOS II	Measures polarization, and directional and spectral characteristics of the solar light reflected by aerosols, clouds, oceans and land surfaces	Waveband: Visible-NIR: 0.443, 0.670 and 0.865μm at 3 polarisations, and 0.443, 0.49, 0.565, 0.763, 0.765 and 0.91μm with no polarisation Spatial resolution: 6km x 7km Accuracy: Radiation budget, land surface Reflectance: 2% Duty cycle: 50% max Swath width: 2400km (across track) x 1800km (along track) Revisit capability: 1 day Data rate: 882Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
POSEIDON/ SSALT Solid State Altimeter	TOPEX/POSEIDON	Nadir viewing sounding radar provides high precision off-line sea surface topography, ocean circulation and wave height data	Waveband: Microwave 13.65GHz Spatial resolution: 2km antenna footprint Basic measurement: 1/sec (6km along track) Raw measurement: 20/sec (300m along track) Accuracy: Sea level: 4cm Significant waveheight: 0.5m Horizontal sea surface wind speed: 2m/s Duty cycle: 10% due to antenna sharing with NASA altimeter. 100% duty cycle capability Swath width: 10 day cycle 300km between tracks at equator Data rate: 1.3Kbps in operational mode 12Kbps in calibration mode
POSEIDON/ SSALT-2 Solid State Altimeter-2	Jason-1, Jason Follow-on	Nadir viewing sounding radar for provision of real-time high precision sea surface topography, ocean circulation and wave height data	Waveband: Ku-band, C-band Spatial resolution: Basic measurement: 1/sec (6km along track) Raw measurement: 10/sec (600m along track) Accuracy: Sea level: 3.9cm Significant waveheight: 0.5m Horizontal sea surface wind speed: 2m/s Duty cycle: Full time operation Swath width: On baseline TOPEX/POSEIDON orbit (10 day cycle): 300km between tracks at equator Data rate: 1.5Kbps in low TM rate mode 15Kbps in high TM rate mode
PR Precipitation Radar	TRMM	Measures precipitation rate of clouds in tropical latitudes	Waveband: Microwave: 13.796 and 13.802GHz Spatial resolution: Range resolution: 250m Horizontal resolution: 4.3km at nadir Accuracy: Rainfall rate 0.7mm/h at storm top (not yet verified) Duty cycle: 100% Swath width: 215km (scanned every 0.6 secs) Observable range: from surface to approx 15km altitude Data rate: 93.5Kbps
PRARE Precise Range & Rate Equipment	ERS-2	Provides precise evaluation of altimeter measurements for geodetic and geodynamic research. Also performs pseudo-noise coded ranging and doppler shift measurements	Waveband: X and S bands Spatial resolution: Not applicable Accuracy: Duty cycle: 100% Swath width: Not applicable Data rate: 10Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
PRISM (ESA) Process Research by an Imaging Space Mission	ESA Future Missions	Data for study of land surface processes	Waveband: Visible-SWIR: 0.45-2.35μm TIR: 3.5-4.1μm (1 band) TIR: 8-8.5μm, 8.5-9μm (2 bands) Spatial resolution: Spatial sampling interval approx 50m, along track pointing ±30 deg Spectral resolution: 10-12nm per channel (Visible-SWIR) Accuracy: Duty cycle: Swath width: 50km Data rate: <100Mbps by data selection/compression
PRISM (NASDA)	ALOS	High resolution panchromatic stereo imager for land applications which include cartography, digital terrain models, civil planning, agriculture and forestry	Waveband: Visible-NIR: 0.52-0.77μm (panchromatic) Spatial resolution: 2.5m Accuracy: Duty cycle: 50% (max) Swath width: 35km, 70km (wide swath mode) Data rate: 960Mbps (max)
R-225	OKEAN-O	Passive microwave measurements for investigations of ocean-atmosphere system	Waveband: Microwave: 13.3GHz (2.25cm) (2 polarisation) Spatial resolution: 130km Accuracy: Duty cycle: 100% Swath width: Data rate:
R-400	PRIRODA	Data of use for investigations of ocean-atmosphere system. Measures sea surface temperature, wind speed, precipitable water content of clouds, cloud liquid water content and rain rate	Waveband: Microwave: 4.0cm Spatial resolution: 50km (at 400km altitude) Accuracy: Duty cycle: A few orbits, on several occasions Swath width: 420km (at 400km altitude) Data rate: 1.5Kbps
RA Radar Altimeter	ERS-1, ERS-2	Measures wind speed, significant wave height, sea surface elevation, ice profile, land and ice topography,and sea ice boundaries	Waveband: K-band: 13.8GHz Spatial resolution: 7km Accuracy: Wave height: 0.5m or 10% (whichever is smaller) Sea surface elevation: better than 10cm Duty cycle: 100% Swath width: Data rate:
RA-2 Radar Altimeter	ENVISAT 1	Measures wind speed, significant wave height, sea surface elevation, ice profile, land and ice topography, and sea ice boundaries	Waveband: K band: 13.575 GHz, S band: 3.2 GHz Spatial resolution: 7km Accuracy: Wave height: 0.5m or 10% (whichever is smaller) Sea surface elevation: better than 10cm Duty cycle: 100% Swath width: Approx 3-5km Data rate: 64/100Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
Radar altimeter	ESA Future Missions	Measures sea surface roughness, thickness, ice sheet elevation, land topography, ocean topography, wind speed and significant wave height	Waveband: 94GHz Spatial resolution: Approx 300m Accuracy: Vertical: 2cm (vertical repeatability 10cm) Duty cycle: 100% Swath width: 5.6km Data rate: 2.5Mbps
Radiometer	Odin	Limb measurements of trace gases, temparature profiles and atmospheric winds	Waveband: 3 Microwave bands: 119, 486-502 and 541-580GHz Spatial resolution: Vertical: 2km Horizontal: 2km (circular beam) Accuracy: Spectral resolution 0.15 and 1.0MHz Duty cycle: Max 50% average (half of mission for astronomy) Swath width: Data rate: Approx 10Mbyte/orbit
Rain radar	ESA Future Missions	Measures rain rate and height of melting layer	Waveband: Microwave Spatial resolution: Global: 100km x 100km Vertical: 0.5-1km (goals) Accuracy: Duty cycle: TBD Swath width: TBD Data rate:
RLSBO Side-Looking Real-Aperture Radar	Ocean-01 N7, OKEAN-O, SICH-1M	Provides images of ocean surface and ice sheets	Waveband: Microwave: 3.1cm Spatial resolution: 1.5 x 2.0km Accuracy: Duty cycle: 15 mins max continuous operation, programmable Swath width: 450km Data rate:
RM-0.8	Ocean-01 N7, SICH -1M	Passive microwave images of ocean surface and ice sheets	Waveband: Microwave: 0.8cm Spatial resolution: 15 x 20km Accuracy: 0.3K temperature sensitivity Duty cycle: 15 mins max continuous operation, programmable Swath width: 550km Data rate:
RMK-2 Radiation Measurement Complex	METEOR-2 N24, METEOR-3 N5, Resource-01 N4	Provides data on electron and proton fluxes	Waveband: Spatial resolution: Not applicable Accuracy: Duty cycle: 100% Swath width: Not applicable Data rate: 100bps (N24), 4Kbps (N5)
RMS Radiation Measurement System	Electro-GOMS N1, Electro-GOMS N2	Measures flux of charged particles and EM radiation, and Earth's magnetic field	Waveband: Spatial resolution: Not applicable Accuracy: Duty cycle: 100% Swath width: Not applicable Data rate:
S&R (GOES) Search & Rescue	GOES 7, GOES 8, GOES 9, GOES L, GOES M	Relay of search and rescue information	Waveband: Uplink: around 406MHz Downlink: 1544.5MHz Spatial resolution: Not applicable Accuracy: Not applicable Duty cycle: 100% Swath width: Not applicable Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
S&R (NOAA) Search & Rescue	NOAA 9, NOAA 10, NOAA 11, NOAA 12, NOAA 14, NOAA K, NOAA L, NOAA M, NOAA N, NOAA N' First Converged Spacecraft (NPOESS)	Relay of search and rescue information	Waveband: Uplink: 121.5, 243, 406.05MHz and 406.025MHz Downlink: 1544.5MHz Spatial resolution: Not applicable Accuracy: Not applicable Duty cycle: 100% Swath width: Not applicable Data rate:
SAGE III Stratospheric Aerosol & Gas Experiment	METEOR-3M N1, METEOR-3M N2, TBD	Profiles of ozone, water vapour, NO_2, OCIO, aerosols, temperature and pressure	Waveband: UV-NIR: 0.29-1.55µm Spatial resolution: 0.5-1km in the vertical Accuracy: Temparature: 2K Ozone: 6% Humidity: 3-10% Aerosol and trace gases: 5-10% Duty cycle: During solar and lunar Earth occultation Swath width: Not applicable - looks at sun through Earth's limb Data rate: 100Kbps, 24 minutes per orbit
SAR (ESA Future Missions) Synthetic Aperture Radar	ESA Future Missions	Provides all weather images of ocean, land and ice for monitoring of land surface processes, sea and polar ice, sea state and geological and hydrological applications	Waveband: Microwave Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:
SAR (JERS-1) Synthetic Aperture Radar	JERS 1	Provides high resolution images for energy and mineral resource applications, land use, environmental protection and disaster prevention, agriculture and forestry, fisheries and coastal monitoring and SAR interferometry applications	Waveband: Microwave: 1.275GHz Spatial resolution: 18m x 18m Accuracy: Duty cycle: Swath width: 75km Data rate: 60Mbps
SAR (RADARSAT) Synthetic Aperture Radar	RADARSAT, RADARSAT-2	Provides all-weather images of ocean, ice and land surfaces. Used for monitoring of coastal zones, polar ice, sea ice, sea state, geological features, vegetation and land surface processes	Waveband: C band: 5.3GHz, HH polarisation Spatial resolution: Standard: 25 x28 m (4 looks), Wide beam (1/2):48-30 x 28m/ 32-25 x 28m (4 looks), Fine resolution: 11-9 x 9m (1 look), ScanSAR (N/W): 50 x 50m/ 100 x 100m (2-4/4-8 looks), Extended (H/L): 22-19 x28m/ 63-28 x 28m (4 looks) Accuracy: Geometric distortion: < 40m Radiometric: 1.0dB Duty cycle: 101 minute orbit, 28 minutes of SAR on time per orbit Swath width: Standard: 100km (20-49deg), Wide beam (1/2): 165km/ 150km (20-31/ 31-39deg), Fine resolution: 45km (37-48deg), ScanSAR (W): 510km (20-49deg), Extended (H/L): 75km/170km (50-60/ 10-23deg) Data rate: 85-105Mbps by X-band downlink

Instrument	Mission(s)	Measurements/application	Technical characteristics
SBUV/2 Solar Backscatter Ultra-Violet instrument	NOAA 9, NOAA 11, NOAA 14, NOAA L, NOAA M, NOAA N, NOAA N'	Provides data on trace gases including vertical profile ozone, and solar irradiance and total ozone concentration measurements	Waveband: Spatial resolution: 170km Accuracy: Absolute accuracy: 1% Duty cycle: 100% Swath width: Nadir pointing profiler Data rate: 320bps
ScaRaB Scanner for Earth's Radiation Budget	METEOR-3M N2	Measures top-of-atmosphere shortwave radiation (0.2-4.0µm) and total radiation (0.2-50µm). Two additional narrow-band channels (0.5-0.7µm and 11-12µm) allow cloud detection and scene identification	Waveband: Visible window channel: 0.5-0.7µm Solar channel: 0.2-4µm Total channel: 0.2-50µm Thermal window channel: 10.5-12.5µm Spatial resolution: 60km at nadir (42km sampling) Accuracy: Absolute: ± 2.5W/m2/sr Relative: ± 0.7W/m2/sr Duty cycle: Programmable Swath width: 2200km Data rate: 1Kbps
SCIAMACHY Scanning Imaging Absorption Spectrometer for Atmospheric Cartography	ENVISAT 1	Measures middle atmosphere temperature. Provides tropospheric and stratospheric profiles of O_2, O_3, O_4, CO, N_2O, NO_2, CO_2, CH_4, H_2O, and tropospheric and stratospheric profiles of aerosols and cloud altitude	Waveband: UV-SWIR: 240-309, 314-394, 405-604, 620-785, 805-1000, 1050-1750, 1940-2040 and 2265-2380nm Spatial resolution: Limb vertical 3 x 132km Nadir horizontal 32 x 215km Accuracy: Radiometric: <4% Duty cycle: 100% on day side Swath width: Limb and nadir mode: 1000km (max) Data rate: 400-1900Kbps (mode-dependent)
Sea Winds	ADEOS II	Measurement of surface wind speed and direction	Waveband: Operates at 13.402GHz Spatial resolution: 50km resolution Accuracy: Windspeed: 12% Wind vector: 20% Duty cycle: 100% Swath width: 90% of the oceans in 2 days Data rate:
SeaWiFS Sea-viewing Wide-Field Sensor	OrbView-2	Provides data on aerosols and ocean colour and biology	Waveband: Visible-NIR: 0.402-0.422µm, 0.433-0.453µm, 0.48-0.5µm, 0.5-0.52µm, 0.545-0.565µm, 0.66-0.68µm, 0.745-0.785µm and 0.845-0.885µm Spatial resolution: 1.1km (local) and 4.4km (global) at nadir Accuracy: 5% (absolute radiometric accuracy) Duty cycle: 100% on dayside Swath width: 1500-2800km Revisit capability: 2 days Data rate: 665Kbps
SEM Space Environment Monitor	GOES 7-9, GOES L-M, NOAA 9-12, NOAA 14, NOAA K-N'	Used for equipment failure analysis, solar flux measurement, solar storm warning, and magnetic and electric field measurement at satellite	Waveband: Spatial resolution: Not applicable Accuracy: Duty cycle: 100% Swath width: Not applicable Data rate: Magnetometer: 100bps XRS, EPS, HEPAD: 50bps

Instrument	Mission(s)	Measurements/application	Technical characteristics
SEVIRI Spinning Enhanced visible & IR Imager	MSG 1, MSG 2, MSG 3	Provides measurements of cloud cover, cloud top height, precipitation estimates, cloud motion winds, vegetation, radiation fluxes, convection monitoring, air mass analysis, cirrus cloud discrimination, tropopause monitoring, stability monitoring, total ozone and sea surface temparature	Waveband: Visible: 0.56-0.71μm, 0.5-0.9μm (broadband), NIR: 0.71-0.95μm, SWIR 1.44-1.79μm, TIR: 3.4-4.2μm, 5.35-7.15μm, 6.85-7.85μm, 8.3-9.1μm, 9.46-9.94μm, 9.8-11.8μm, 11-13μm, 13.04-13.76μm Spatial resolution: 1km (at SSP) for one broadband visible channel HRV 5km (at SSP) for all other channels Accuracy: Cloud cover: 10% Cloud top height: 1km Cloud top temparature: 1K Cloud type: 8 classes Surface temparature: 0.7-2.0K Specific humidity profile: 10% Wind profile (horizontal component): 2-10m/s Long wave Earth surface radiation: 5W/m2 Duty cycle: Full disk every 15 minutes Swath width: Full Earth disk Data rate: 2.8Mbps
SFM-2 Spectrometer to measure direct solar radiation	METEOR-3 N5, METEOR-3M N1, METEOR-3M N2, Resource-01 N4	Provides ozone profile measurements	Waveband: UV: 0.26-0.4μm Spatial resolution: 40 x 10 deg Accuracy: 4% Duty cycle: 100% Swath width: Data rate:
SOLSTICE Solar/Stellar Irradiance Comparision Experiment	UARS	Provides data on UV and charged particle energy inputs, and on time variation of full-disk solar UV spectrum. Measures solar UV radiation (115 to 430nm) with resolution of 0.12nm. Compares solar UV output with UV radiation of stable bright blue stars for	Waveband: UV: 115-430 Spatial resolution: Not applicable Accuracy: 1% Duty cycle: 100% Swath width: Not applicable Data rate: 0.25Kbps
SOPRANO Sub-millimetre Observation of Processes in the Absorption Noteworthy for Ozone	ESA Future Missions	Provides temperature profiles and trace gases in the upper troposphere to mesosphere including ClO, O3, HCl, NO, BrO as first priority, and HOCl, CH3Cl, H2O, N2O, HO2, HNO3 as second priority	Waveband: Sub-millimetre a) 499.4-505GHz b) 624.5-626.6 and 628.2-628.7GHz c) 730.5-732GHz d) 851.3-852.8GHz Spatial resolution: Vertical: 2km at lowest level Limb viewing instrument Accuracy: Band a: 2.5K, Bands b and c: 12K, Band d: 8K at 3MHz resolution, 0.3 secs integration time Duty cycle: 100% Swath width: 10-50km tangent height range Data rate: 0.5Mbps
SOUNDER	GOES 8, GOES 9, GOES 10, GOES L, GOES M	Provides atmospheric soundings and data on atmospheric stability and thermal gradient winds	Waveband: Visible-TIR: 19 channels Spatial resolution: 10km Accuracy: Duty cycle: 100% except during eclipse periods Swath width: Horizon to horizon Data rate: 40Kbps (inc in GVAR)

Instrument	Mission(s)	Measurements/application	Technical characteristics
SSU Stratospheric Sounder Unit	NOAA 9, NOAA 11, NOAA 14	Provides temperature profiles in stratosphere, top-of-atmosphere radiation from 25km to 50km altitude	Waveband: 669.99, 669.63 and 669.36/cm (carbon dioxide) Spatial resolution: 147.3km at nadir Accuracy: Duty cycle: 100% Swath width: ±40 deg scan Data rate: 0.48Kbps
STAR Accelerometer	CHAMP	Accelerometer for measuring the strength and variation of the Earth's gravity field	Waveband: Not applicable Spatial resolution: Accuracy: Duty cycle: 100% Swath width: Revisit capability: Observing cycle of 2 years Data rate: 100bps
SUSIM Solar Ultra-violet Irradiance Monitor	UARS	Provides data on UV and charged particle energy inputs, and on time variation of full-disk solar UV spectrum.	Waveband: UV: 0.12-0.4μm Spatial resolution: Not applicable Spectral resolution: 0.15nm Accuracy: 1% Duty cycle: Swath width: Looks at sun Data rate: 2Kbps
SXI Solar X-ray Imager	GOES M	Obtains data on structure of solar corona. Full disk imagery also provides warnings of geomagnetic storms, solar flares, and information on active regions of sun and filaments	Waveband: Spatial resolution: Not applicable Accuracy: Duty cycle: 100% Swath width: Not applicable Data rate: 100 bps
TES Tropospheric Emission Spectrometer	EOS CHEM-1	Provides 3-D profiles on a global scale of all infra-red active species from surface to lower stratosphere. Measures greenhouse gas concentrations, tropospheric ozone, acid rain precursors, gas exchange leading to stratospheric ozone depletion. Species me	Waveband: SWIR-TIR: 2.3-15.4μm Spatial resolution: In limb mode: 2.3km vertical resolution. In down-looking mode: 50km x 5km (global), 5km x 0.5km (local) Accuracy: Ozone: 20ppb Trace gases: 3-500ppb Duty cycle: Once per month, 100% for 4 days to achieve full global coverage <2% annually Swath width: Limb mode: global: 50km x 180km, local: 5km x 18km Revisit capability: 4 days Data rate: Average/peak: 3.24/19.5 Mbps
TM Thematic Mapper	LANDSAT 5	Measures surface radiance. Data used for wide range of applications up to 1:50,000 scale	Waveband: Visible: 0.45-0.52μm, 0.52-0.6μm, 0.63-0.69μm SWIR: 1.55-1.75μm, 2.08-2.35μm TIR: 10.4-12.5μm Spatial resolution: Visible and SWIR: 30m TIR: 120m Accuracy: Radiometric: 10%, Geometric: 500m Duty cycle: 30% Swath width: 185km Data rate: 84.9Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
TMI TRMM Microwave Imager	TRMM	Measures rainfall rates over oceans (less reliable over land), combined rainfall structure and surface rainfall rates with associated latent heating. Used to produce monthly total rainfall maps over oceans	Waveband: Microwave: 10.7, 19.4, 21.3, 37, and 85.5GHz Spatial resolution: Vertical: 2.5km approx Horizontal: 18km Accuracy: Liquid water: 3mg/cm3 Humidity: 3mg/cm3 Ocean wind speed: 1.5 m/s Duty cycle: 790km Revisit capability: 12hrs Swath width: 8.8Kbps Data rate:
TMR TOPEX Microwave Radiometer	TOPEX/POSEIDON	Altimeter data used to correct for errors caused by water vapour and cloud-cover effects. Also measures total water vapour and brightness temperature	Waveband: Microwave: 18, 21 and 37GHz Spatial resolution: 44.6km at 18GHz, 37.4km at 21GHz, 23.5km at 37GHz Accuracy: Total water vapour: 0.2g/sq cm Brightness temperature: 1K Duty cycle: 100% Swath width: 120 deg cone centred on nadir 10 day repeat cycle Data rate: 125bps
TOMS Total Ozone mapping Spectrometer	METEOR-3M N2, TOMS Earth Probe	Data extends long term dataset on ozone which is used to measure ozone concentration changes and trends, and to produce detailed maps of Antarctic ozone hole and Arctic ozone. Also measures sulphur dioxide concentration	Waveband: UV: 0.3086, 0.3125, 0.3175, 0.3223, 0.3312 and 0.36μm Spatial resolution: Nadir: 47x47km Average: 62x62km IFOV: 3 deg Accuracy: 0.1% Duty cycle: Up to 100% Swath width: 3100km Revisit capability: 1 day Data rate: 7Kbps
Travers SAR	PRIRODA	Measures vegetation canopy type and state, soil moisture, land topography and ice and sea surface roughness	Waveband: Microwave: 9.2 and 23cm Spatial resolution: 50-150m Accuracy: Duty cycle: A few orbits, on several occasions Swath width: 50km Data rate: 16Mbps per channel
TRSR Turbo Rogue Space Receiver	CHAMP	Provides data for in-orbit location of satellite for instrument data registration and correction	Waveband: L-band:1228 and 1575MHz Spatial resolution: Not applicable Accuracy: Duty cycle: 100% Swath width: Not applicable Data rate: 2500bps
TV camera	PRIRODA	Survey of cloud cover and Earth surface	Waveband: Visible-NIR: 0.6-1.1μm and 1.04μm Spatial resolution: 3.3 angular minutes Accuracy: Duty cycle: A few orbits on several occasions Swath width: FOV: 20 x 15 deg and 2 x 1 deg Data rate: 64Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
UV-visible spectrometer	Odin	Limb measurements of albedo, aerosols and trace gases	Waveband: UV-Visible: 0.28-0.8μm Spatial resolution: Vertical: 1km Horizontal: 40km Spectral resolution 1-2nm Accuracy: Duty cycle: 50% maximum (half of mission for astronomy) Swath width: Data rate: 11Mbyte/orbit (approx)
VCL Vegetation Canopy Lidar	ESSP-1A (aka VCL)	Measure leaf area index, vegetation type	Waveband: Visible-NIR Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:
VEGETATION	SPOT 4, SPOT 5	Data of use for crop forecast and monitoring, vegetation monitoring, and biosphere/ geosphere interaction studies	Waveband: Operational mode: Visible: 0.61-0.68μm NIR: 0.78-0.89μm SWIR: 1.58-1.75μm Experimental mode: Visible: 0.43-0.47μm Spatial resolution: 1.15km at nadir - minimal variation for off-nadir viewing Accuracy: Duty cycle: 100% in daylight Swath width: 2200km Revisit capability: 1 day Data rate: 3.4Mbps
VHRR Very High Resolution Radiometer	INSAT IIa, INSAT IIb, INSAT IIe	Provides data on cloud cover, rainfall, wind velocity, sea surface temperature, outgoing longwave radiation, reflected solar radiation in spectral band 0.55-0.75μm and emitted radiation in 10.5-12.5 micron range	Waveband: Visible: 0.55-0.75μm TIR: 10.5-12.5μm Spatial resolution: 2km in visible, 8km in IR Accuracy: Duty cycle: Full Earth disk once every 30 minutes Swath width: Full Earth disk Data rate: 526.5Kbps
VIRS Visible Infrared Scanner	TRMM	Data to be used in conjunction with data from CERES instrument to determine cloud radiation. Will enable 'calibration' of precipitation indices derived from other satellite sources	Waveband: Visible: 0.63μm, SWIR: 1.6 and 3.75μm, TIR: 10.8 and 12μm Spatial resolution: 2km at nadir Accuracy: Duty cycle: Swath width: 720km (45 deg either side of track) Revisit capability: 1 day Data rate: 50Kbps
VISSR (GMS4) Visible & IR Spin Scan Radiometer	GMS-4	Data used for cloud type and cloud motion detection. Also measures sea surface temperature	Waveband: Visible: 0.5-0.75μm TIR: 10.5-12.5μm Spatial resolution: Visible: 1.25km TIR: 5km Accuracy: Duty cycle: Full Earth disk in all channels, every 1 hour Swath width: Full Earth disk Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
VIS/IR Imager	ESA Future Mission	Provides imagery for oceanic applications	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:
VISSR (GMS5) Visible & IR Spin Scan Radiometer	GMS-5	Data used for cloud type and motion detection wind. Also measures sea surface temperature and atmospheric water vapour	Waveband: Visible: 0.55-0.9µm TIR: 6.5-7, 10.5-11.5, 11.5-12.5µm Spatial resolution: Visible: 1.25km TIR: 5km Accuracy: Duty cycle: Full Earth disk in all channels, every 1 hour Swath width: Full Earth disk Data rate:
VISSR and VAS (GOES-7) Visible & IR Spin Scanning Radiometer	GOES 7	Provides data for severe storm warnings/ monitoring. Also provides day and night atmospheric soundings (temparature, moisture) and data on the Earth surface, atmosphere and cloud cover and rainfall estimates	Waveband: Imaging mode: Visible: 0.55-0.75µm IR: 11µm plus 2 other channel selectable from 3.9, 6.7, 7.3 and 13.3µm Spatial resolution: Visible: 1km IR: 7 and 14km Accuracy: Duty cycle: 100% Swath width: Horizon to horizon Data rate: 2.11Mbps (Mode-AAA)
WFI camera Wide-Field Imager	CBERS 1, CBERS 2	Data used for coastal and vegetation monitoring	Waveband: Visible: 0.63-0.69µm, NIR: 0.77-0.89µm Spatial resolution: 258m Accuracy: 0.3 pixels Duty cycle: International access open to all participating stations, limited to 20 minutes per revolution Swath width: 890km Revisit capability: 5 days Data rate: 1.1Mbps (8/6 compressed)
WiFS Wide-Field Sensor	IRS 1c, IRS 1d, RS P3	Data used for drought and snow cover monitoring, snow melt run-off forecasting, and studies of albedo, photosynthetic active radiation, vegetation cover and global production potential	Waveband: Visible: 0.62-0.68µm NIR: 0.77-0.86µm SWIR: 1.55-1.7µm (IRS P3 only), 1.55-1.75µm (IRS P4 only) Spatial resolution: 188m Accuracy: Duty cycle: Daylight coverage 100% Swath width: 774km Revisit capability: 5 days Data rate: 2 Mbps
WINDII Wind Imaging Interferometer	UARS	Day and night wind measurements between 80km and 300km altitude from Doppler shift measurements of emission lines of neutral and ionised atomic oxygen, two lines of the hydroxyl molecule and molecular oxygen. Measures atmospheric temperature and concentration of emitting species	Waveband: Visible-NIR:0.55-0.78µm Spatial resolution: Vertical: 2km Horizontal: 25km Accuracy: Wind speed: 10m/s Duty cycle: 100% Swath width: 70-310km Data rate: 2Kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
WIS Wedge Imaging Spectrometer	NMP EO-1	Hyperspectral measurements for land and marine applications research and development	Waveband: NIR-A: 41 channels in range 0.4-0.66µm, NIR-B: 62 channels in range 0.6-1.0µm SWIR-A: 122 channels in range 0.9-1.6µm, SWIR-B: 96 channels in range 1.52-2.5µm Spatial resolution: Panchromatic: 10m Mulitspectral: 30m Accuracy: Duty cycle: Swath width: Data rate:
X-ray Astronomy Payload	IRS P3	Study of time variability and spectral characteristics of cosmic X-ray sources	Waveband: Spatial resolution: Not applicable Accuracy: Duty cycle: Not applicable Swath width: Not applicable Data rate: 40Kbps

C CEOS membership

This annex presents, alphabetically, by country, the agencies and organisations participating in CEOS.

COUNTRY	CEOS MEMBERS
Australia	Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Brazil	Instituto Nacional de Pesquisas Espaciais (INPE)
Canada	Canadian Space Agency (CSA)
China	Chinese Academy of Space Technology (CAST) National Remote Sensing Center of China (NRSCC)
Europe	European Commission (EC) European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) European Space Agency (ESA)
France	Centre National d'Etudes Spatiales (CNES)
Germany	Deutsche Agentur für Raumfahrt-Angelegenheiten (DARA)
India	Indian Space Research Organisation (ISRO)
Italy	Agenzia Spaziale Italiana (ASI)
Japan	Science and Technology Agency (STA) (National Space Development Agency of Japan (NASDA))
Russia	Russian Federal Service for Hydrometeorology and Environment Monitoring (ROSHYDROMET) Russian Space Agency (RSA)
Sweden	Swedish National Space Board (SNSB)
Ukraine	National Space Agency of Ukraine (NSAU)
United Kingdom	British National Space Centre (BNSC)
United States of America	National Aeronautics and Space Administration (NASA) National Oceanic and Atmospheric Administration (NOAA)

COUNTRY	CEOS OBSERVERS
Belgium	Federal Office for Scientific, Technical and Cultural Affairs (OSTC)
Canada	Canada Centre for Remote Sensing (CCRS)
New Zealand	Crown Research Institute (CRI)
Norway	Norwegian Space Centre (NSC)

CEOS AFFILIATES

Economic and Social Commission of Asia and the Pacific (ESCAP)
Food and Agriculture Organization (FAO)
Global Climate Observing System (GCOS)
Global Ocean Observing System (GOOS)
Global Terrestrial Observing System (GTOS)
International Council of Scientific Unions (ICSU)
International Geosphere-Biosphere Programme (IGBP)
Inter-governmental Oceanographic Commission (IOC)
United Nations Environment Programme (UNEP)
United Nations Office of Outer Space Affairs (UNOOSA)
World Climate Research Programme (WCRP)
World Meteorological Organisation (WMO)

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D CEOS Affiliates: environmental programmes & agencies

D.1 INTRODUCTION

This section gives a brief background description of the CEOS affiliate agencies, together with examples of their environmental programmes. The list of programmes is not exhaustive and will continue to evolve as new programmes are defined. The following agencies are considered:

- Economic and Social Commission of Asia and the Pacific (ESCAP);
- Food and Agriculture Organisation of the United Nations (FAO);
- Global Climate Observing System (GCOS);
- Global Ocean Observing System (GOOS);
- Global Terrestrial Observing System (GTOS);
- International Council of Scientific Unions (ICSU);
- International Geosphere Biosphere Programme (IGBP);
- Inter-governmental Oceanographic Commission (IOC);
- United Nations Environment Programme (UNEP);
- United Nations Office of Outer Space Affairs (UNOOSA);
- World Climate Research Programme (WCRP);
- World Meteorological Organisation (WMO).

D.2 ECONOMIC AND SOCIAL COMMISSION OF ASIA AND THE PACIFIC (ESCAP)

The Economic and Social Commission for Asia and the Pacific (ESCAP) is a regional arm of the United Nations. It is responsible for the United Nations' social and economic development activities in the Asia - Pacific region. ESCAP has 60 members and associated members, including regional developed members such as Australia, Japan and New Zealand, non regional members such as France and the United States of America. It also includes the newly-established Republics of Central Asia. ESCAP's major approach is to work closely with its member governments to address the issues related to sustainable social and economic development, as well as those issues relating to natural resources and environment management in the region.

ESCAP is instrumental in implementing Agenda 21 - a global action plan for environment and sustainable development. In order to promote the regional implementation of Agenda 21, the Regional Action Programme for Environmentally Sound and Sustainable Development 1996-2000 was adopted by ESCAP to provide a timely response to the major environmental problems identified in the 1995 report on the State of the Environment in Asia and the Pacific.

In the context of CEOS, ESCAP considers space technology as an enabling tool for implementing Agenda 21. ESCAP is enhancing regional co-ordination and co-operation in the promotion of applications of space technology for sustainable development in the Asia-Pacific region through the Regional Space Applications Programme for Sustainable Development (RESAP). RESAP is based on the Strategy for Regional Co-operation in Space Applications for Sustainable Development and the Action Plan on Space Applications for Sustainable Development in Asia and the Pacific. These were adopted by the first Ministerial Conference on Space Applications for Development in Asia and the Pacific held in Beijing in September 1994.

RESAP aims at directly assisting developing members and associate members of ESCAP in addressing urgent environmental and development problems through information exchanges, seminars and training workshops, provision of technical advice, policy studies and pilot projects. A strong regional network within RESAP has been established with the participation of more than 30 member countries.
The network consists of:

- the Inter-governmental Consultative Committee (ICC) on RESAP;
- the Regional Working Group on Remote Sensing and GIS and Satellite-based Positioning;
- the Regional Working Group on Meteorological Satellite Applications and Natural Hazards Monitoring;
- the Regional Working Group on Satellite Communication Applications;
- the Regional Working Group on Space Science and Technology Applications.

The network also has a Regional Information Service and Education/training sub-network whose activities are focused on integrating key space technologies into development planning for achieving sustainable development.

Through RESAP, ESCAP organised approximately 10 seminars/training workshops and meetings annually to promote information exchanges and transfer of knowledge. ESCAP also provides fellowship awards for remote sensing and GIS applications studies, to members with development needs. Since the Ministerial Conference, ESCAP has completed a number of studies, including the feasibility study on the establishment of an Earth Space Information Network for Asia and the Pacific (ESINAP). Currently, ESCAP is implementing the following major projects through the RESAP network:

- Harmonisation of initiatives for promoting regional co-operation in space technology applications for sustainable development in Asia and the Pacific.
- National capacity-building for sustainable environment and natural resource management through research and studies on uses of data from Japan's Advanced Earth Observing Satellite (ADEOS).
- Promoting co-operation in space technology applications with special focus on satellite-based education for human development and sustainable development in the Asia-Pacific region.
- Study on coastal zone environment management with emphasis on the mangrove ecosystem to assist in poverty alleviation.
- Promotion of applications of small satellite data in Asia and the Pacific.
- Integrated applications of remote sensing and GIS for comprehensive development planning in arid regions.
- Establishment of a meteorological disasters' database and development of associated applications.

D.3 FOOD AND AGRICULTURE ORGANISATION OF THE UNITED NATIONS (FAO)

The Food and Agriculture Organisation of the United Nations is the lead Agency within the UN family in the fields of renewable natural resources, nutrition, and food and agriculture, including fisheries and forestry. Its functions include the collection, analysis and dissemination of information, the promotion of research and education, and the provision of technical assistance to its member countries.

Satellite remote sensing is used in many of the activities of the FAO. Data from land resources satellites and meteorological satellites are used for the assessment and monitoring of tropical forest cover. As part of the FAO's Global Information and Early Warning System on Food and Agriculture, the FAO Africa Real-time Environmental Monitoring System (ARTEMIS) uses data from METEOSAT and NOAA to monitor growing conditions and vegetation development over Africa. Additional pilot projects are expected to test the suitability of remotely sensed data such as RADARSAT and ERS SAR data for new applications.

FAO provides advisory services to member countries on applications of remote sensing techniques, including the execution of pilot projects, the provision of assistance in the formulation of projects that include a remote sensing component; and the provision of technical support to FAO executed field projects, including services for the browsing, selection and ordering of satellite imagery. Examples include the new Africover project to map land cover over the whole of Africa and various activities in the mapping and monitoring of illicit crop cultivation. Furthermore, FAO organises, or participates in, remote sensing education and training activities and produces materials and workshops for decision makers. Co-ordination of remote sensing applications within FAO is done by its Environmental and Natural Resources Service (formerly the FAO Remote Sensing Centre) which also conducts all FAO activities relating to environmental information systems and Agenda 21.

D.4 GLOBAL CLIMATE OBSERVING SYSTEM (GCOS)

The Global Climate Observing System (GCOS) was established in 1992 by the World Meteorological Organisation (WMO), the Inter-governmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environmental Programme (UNEP) and the International Council of Scientific Unions (ICSU). GCOS aims to address the problems of climate change and climate variability by providing comprehensive observations of the total climate system. Its specific objectives are to insure the acquisition of data to meet the needs for:

- Climate system monitoring, climate change detection, and response monitoring especially in terrestrial ecosystems;
- Application of climate information to national economic development; and
- Research toward improved understanding, modelling, and prediction of the climate system.

A series of plans have been prepared to describe: the overall GCOS concept; the principal scientific elements for the atmosphere, ocean, and land surface; the requirements for space-based observations; and the requirement for data and information management. The GCOS plans have been developed in close co-operation with existing operational and research programmes and both the Global Ocean Observing System (GOOS) and Global Terrestrial Observing System (GTOS). GCOS has developed and implemented key elements of an Initial Operational System which is composed of currently operational components needed for climate issues, the necessary enhancements to these components for which the technology is available, and a comprehensive global data management system. The observational requirements, design objectives, and implementation guidance of GCOS have been provided by the Joint Scientific and Technical Committee (JSTC) through a number of expert panels.

Recognising the need for a comprehensive approach to formulate, implement, and oversee data and information management of the global observing systems, the Joint Scientific and Technical Committee (JSTC) of GCOS, the Inter-governmental Committee for GOOS (I-GOOS), and the Steering Committee (SC) for GTOS have established a Joint Data and Information Management Panel (JDIMP).

Insofar as is possible, the data and information management system for the global observing systems, G3OS should be developed to accommodate data and products from the various components of the global observing systems. To do so, the JDIMP should comprise a core group of members representing the variety of global observing communities and disciplines. The JDIMP should possess the expertise to understand and use global datasets, and operational and research global information management systems. The JDIMP should be a "problem solving" group, focused on resolving issues affecting the quality and maintenance of global observing system datasets, and access to them.

With regard to satellite observations, Version 1.0 of the GCOS Plan for space-based observations was published in 1995. The plan provides an initial assessment of the requirements for climate-related observations which may be made from satellites and space-based instruments, and assesses the agency programmes and plans to assess the degree to which satellites are capable of meeting the requirements. Version 2.0 of the Plan is currently being prepared by the Global Observing Systems Space Panel (GOSSP) jointly established by GCOS, GOOS, and GTOS.

Critical concerns for GCOS focus on equirements for high quality and representative observations, long-term continuity (although some parameters need not be continuously under observation), and effective user access to the database and products from them that appropriately combine space-based and in situ information.

In the near term, the planning for GCOS will continue to focus on the current capabilities for observation, in light of the requirements that are being developed for climate measurements, and on the implementation of important components.

As an Affiliate of CEOS, GCOS will develop and deliver its recommendations and suggest its priorities for specific variables, taking into account the user community needs, the capabilities of various satellite missions and instruments and available ground-based systems as appropriate.

D.5 GLOBAL OCEAN OBSERVING SYSTEM (GOOS)

At the Sixteenth Session of its Assembly in March 1991, the Inter-governmental Oceanographic Commission (IOC) confirmed its plan to pursue, as a priority, the development of a Global Ocean Observing System (GOOS) in co-operation with the World Meteorological Organization (WMO), United Nations Environment Programme (UNEP) and the International Council of Scientific Unions (ICSU).

GOOS is a global framework for systematic ocean observations: to meet the needs for forecasting climate variability and change; for assessing the health or state of the marine environment and its resources, including the coastal zone; and for supporting an improved decision-making and management process - one which takes into account potential natural and man-made changes in the environment and their effects on human health and resources. Specific GOOS modules deal with:

- monitoring and assessment of marine living resources;
- monitoring of the coastal zone environment and its changes;
- assessment and prediction of the health of the ocean; and
- marine meteorological and oceanographic services.

The climate monitoring, assessment, and prediction module of GOOS forms the ocean component of the GCOS.

GOOS utilises operational observing methods including both remote sensing and in-situ measurements. The major elements of the system include oceanographic observations and analyses, timely distribution of data and products, data assimilation into numerical models leading to predictions and capacity building within participating Member States, especially in developing countries, to develop analysis and application capability.

D.6 GLOBAL TERRESTRIAL OBSERVING SYSTEM (GTOS)

The Global Terrestrial Observing System was established in 1995 by five international organisations the Food and Agricultural Organisation of the United Nations (FAO), International Commission Scientific Unions (ICSU), United Nations Educational, Scientific and Cultural Organisation (UNESCO), United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO).

A Steering Committee (GTSC) was established to formulate the overall concept and scope of the GTOS, to plan for its implementation, and to provide continuing oversight of the system. The Steering Committee consists of 17 members from 15 different countries, including Burkina Faso, India, Columbia, Venezuela, China, and Tunisia. The GTSC will establish and update requirements, review existing programmes to assess their ability to meet these requirements, and make recommendations for enhancements or new elements, as appropriate. A Secretariat located at the FAO in Rome supports the GTSC in its efforts. To assist in these tasks, panels and working groups to address specific issues, have been, or will be established. To assure close co-operation between the Global Observing Systems (G3OS) joint panels with the Global Climate Observing System (GCOS), and the Global Ocean Observing System (GOOS) have been set up where there are common interests between them. For example, the Terrestrial Observation Panel for Climate is co-sponsored with the GCOS, and both the Joint Data and Information Management Panel and the Global Observing Systems Space-based Observation Panel are jointly sponsored by GCOS and GOOS .

The central mission of GTOS is to provide the data needed to detect, quantify, locate and give warning of changes (especially reductions) in the national or global capacity of terrestrial ecosystems (including freshwater and coastal areas) in order to support sustainable development and improvements in human welfare. Five main initial areas of interest have been identified:

1 The ability of terrestrial ecosystems to support constantly growing demand for food and agricultural products;

2 The extent to which freshwater resources will be able to meet projected demands;

3 Changes in biological diversity;

4 How terrestrial ecosystems affect and are affected by global changes such as changes in climate, forest cover, wetlands;

5 The extent to which threats are posed to terrestrial ecosystems by toxic pollutants.

An important objective of GTOS is to link scientific information with policy development. This will be achieved through equitable partnerships between data providers and users. Included in these two groups are governments, national and international scientific programmes, secretariats of international conventions related to the environment (eg Biodiversity, Climate Change and Desertification), UN agencies, non-governmental organisations and the private sector.

GTOS is directed toward specific needs and building synergies between existing global and regional observational systems. It is not directed at data collection for its own sake, and research is not its major objective. However, GTOS does collaborate with IGBP, DIVERSITAS and other organisations in the identification of appropriate sources of data and in the assembly of appropriate datasets. In this regard, GTOS co-sponsored with GCOS and GOOS, a major meeting on In situ Observations held in September 1996, in Geneva, Switzerland. As a follow up to that meeting, GTOS, GCOS and IGBP co-sponsored a meeting of representatives from major ecological networks in Guernica, Spain, in June 1997. The participants at that meeting recommended a series of steps be taken to form an initial Global Observing Systems Network (GOS -Net).

D.7 INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS (ICSU)

The International Council of Scientific Unions was created in 1931 to promote international scientific activity in the different branches of science and their applications for the benefit of humanity. Members include scientific academics/research councils and scientific unions and the complement of these two groups provides a wide spectrum of scientific expertise enabling members to address major international inter-disciplinary issues which none of them could handle alone.

The Council seeks to accomplish its role in a number of ways:

- by initiating, designing and co-ordinating major international, inter-disciplinary research programmes, such as the International Geosphere-Biosphere Programme (IGBP);
- by creating inter-disciplinary bodies which undertake activities and research programmes of interest to several member bodies - examples include Antarctic, oceanic, space and water research and problems of the environment.

In addition to these programmes and activities which seek to surpass the barriers of specialisation, several bodies set up within ICSU address matters of common concern to all scientists, such as capacity building in science, data, technology in developing countries, and ethics and freedom in the conduct of science.

The Council also acts as a focus for the exchange of ideas, the communication of scientific information and the development of scientific standards by organising conferences, congresses and symposia and publishing a wide range of newsletters, handbooks and journals. ICSU also assists in the creation of networks of scientists with similar interests and maintains close working relations with a number of inter-governmental and non-governmental organisations. Because ICSU is in contact, through its membership, with hundreds of thousands of scientists world-wide, it is being increasingly called upon to act as the spokesman for the world scientific community and as an advisor in matters ranging from ethics to the environment.

D.8 INTERNATIONAL GEOSPHERE BIOSPHERE PROGRAMME (IGBP)

In 1986, ICSU decided to launch the International Geosphere-Biosphere Programme, a study of global change. The objective of IGBP is to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth System, the changes that are occurring in this system, and the manner in which they are influenced by human activities.

IGBP is an evolving programme that addresses those questions that are deemed to be of greatest importance in contributing to the understanding of the changing nature of the global environment on a timescale of decades to centuries. In particular, IGBP addresses issues affecting the biosphere, that are most susceptible to human perturbations and those that will most likely lead to a practical, predictive capability.

The initial operational phase of the programme focuses on projects aimed at investigating seven such key questions, including 'how does global change affect global ecosystems?' (being addressed by the Global Change and Terrestrial Ecosystems (GCTE) project), 'how can our knowledge of components of the Earth System be integrated and synthesised in a numerical framework that provides predictive capacity?' (being addressed by the Global Analysis, Interpretation and Modelling (GAIM) task force).

As the research becomes formulated, attention will be focused on the specific needs for global monitoring, including observation from space. Long-term (of order of decades) satellite data will be required for three overriding reasons:

- to document precisely global scale changes in key variables in order to assess the way Earth as a whole is evolving with time;
- to measure the long term trends in the forcing functions of global change;
- to simultaneously measure several parameters to study interactive processes which regulate the Earth System.

D.9 INTER-GOVERNMENTAL OCEANOGRAPHIC COMMISSION (IOC)

The IOC co-ordinates and disseminates information and data on the state of the world's oceans. This is achieved through a number of research and support services organised in conjunction with member states and other international agencies. For example, IOC (together with WMO) supports and develops IGOSS (the Integrated Global Ocean Services System) and IOC has developed and established GLOSS (the Global Sea Level Observing System). It is also co-sponsoring WCRP.

Together with the WMO, ICSU and UNEP, the IOC is also participating in the programme to establish GCOS. As a major contributor to that programme, the IOC, together with WMO, UNEP and ICSU, has embarked on the development of GOOS, a complex system for collecting, analysing and distributing physical, chemical and biological data from the oceans. The climate-related aspects of the GOOS will be developed jointly with WMO. Coastal monitoring components will be developed with UNEP and WMO.

The IOC-UNEP programme on Global Investigations of Pollution in the Marine Environment (GIPME) concentrates on studies of pollution distribution and impact particularly in the coastal zones. It also considers the inputs of pollutants to coastal zones and open ocean areas.

GIPME and other IOC programmes may be expected to have an increasing interest in satellite data, particularly measurements of ocean parameters such as sea surface temperature, ocean currents, wind stress and biological properties.

The IOC is supporting the scientific basis for Integrated Coastal Area Management (ICAM) inter alia by emphasising the use and application of remote sensing technology in this context. Ocean colour in combination with other coastal datasets will be a particularly important component.

D.10 UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP)

Satellite data are used for many activities of UNEP and its partners, most notably by the Global Resource Information Database (GRID). GRID is a world-wide system and service for users of environmental data. Through its many co-operating centres, GRID provides access to existing broad-scale public domain Earth observation data, meta-data and other existing geo-referenced environmental data which can be linked with remote sensing data. In addition, the GRID system provides support to geographical information and image processing systems for users from the international science and development communities, and brokers training through appropriate international and regional bodies. GRID, through its various co-operators, also supports the analysis of Earth observation data for global, regional and national state of environment reporting and provides input to UNEP's Global Environment Outlook process.

UNEP's Environment and Natural Resources Information Networking (ENRIN) programme strives to strengthen the state-of-the-environment reporting capabilities in developing countries. This is achieved in part by brokering donor support for the effective application of modern environmental management tools, such as the analysis of Earth observation data and use of GIS, to improve the currency and reliability of the state-of-the-environment reporting.

The Natural Resources Branch of UNEP and its collaborators use Earth observation data from satellites for application in programmes to combat desertification and soil degradation and in the assessment and management of coastal areas. Programmes associated with UNEP's Human Health and Well-being initiative are also increasingly interested in the application of satellite Earth observation data for assessing the impact of refugees on the environment. The data requirements for these activities depend on the specific environmental problems addressed and on existing and/or new international conventions, which need to be controlled or enforced through Earth observation satellites.

UNEP further embarked on a programme of satellite communications development in 1995 in partnership with ESA, and more recently the Government of Norway, designed to improve access to and the exchange of environmental data and information for decision makers world-wide. The Mercure telecommunications system, as it is known, is a donation from six ESA member states (Austria, Belgium, Norway, Spain, Switzerland and the UK) to UNEP that will become operational in 1997, initially in 14 industrialised and developing countries. Mercure uses the Intelsat series of satellites for high speed data communications to link UNEP regional offices and other partner institutions via V-SAT terminals and, at the same time, provides the backbone for UNEPnet, an environmental internet service linked to the global Internet. UNEPnet is taking advantage of the CEOS/CILS information locator system to improve the efficiency of environmental information access and exchange on a world-wide basis.

D.11 UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS (UNOOSA) - SPACE APPLICATIONS PROGRAMME (SAP)

The United Nations Programme on Space Applications (SAP), Office for Outer Space Affairs (OOSA), is a focal point of the organisation's efforts to enhance the ability of all countries to utilise space technology for national development. The programme focuses on promoting co-operation in space science and technology, and the exchange of data, information and experience among developed and developing countries. It also fosters the development and growth of indigenous centres of space technology in developing countries, and the provision of technical advisory services on request.

Three activities constitute the priority areas for SAP. These activities include:

- technical support for the Regional Centre for Space Science and Technology Education established in India for Asia-Pacific countries. In the near future SAP shall also provide technical support to centres in Latin America, the Caribbean and in Africa, and to a network of educational and research institutions in a number of Member States of the EC region;
- establishment of COPINE - a satellite-based Co-operative Information Network System that will link several academic, research and programme application institutions, including remote sensing and environment centres in participating African countries, to acquisition stations, and processing and archiving facilities located in Europe and Africa. The initial aim of COPINE is to improve the collection, transmission, distribution and exchange of information, relating to agriculture, food security and environmental monitoring institutions in participating countries;
- provision of a focal point for international activities related to the organisation of regional preparatory meetings for UNISPACE III Conference.

SAP annually conducts six to eight training courses, workshops and conferences on different aspects of space science and technology and its applications, including remote sensing. OOSA has also implemented several projects aimed at an improving the utilisation of Earth observation data within developing countries. For example, a number of projects have been established, in collaboration with ESA, to provide data and support to institutions in Africa, Latin America and the Caribbean with the aim of improving the capability of these institutions to utilise Earth observation data in existing economic and environmental projects.

OOSA is developing a user-friendly Internet home page for itself, for the Space Applications Programme and for the benefit of the general public. Through this same home page, OOSA also serves as the co-ordinating node for accessing information on space activities of the organisations within the United Nations countries.

D.12 WORLD CLIMATE RESEARCH PROGRAMME (WCRP)

The WCRP undertaken jointly by WMO, ICSU and IOC, is a key international scientific programme aiming to develop the fundamental understanding of the physical climate system and climate processes that is needed to predict climate variations and to determine the extent of human influence on climate. The programme encompasses studies of the global atmosphere, the world oceans, sea and land ice, and the land surface which together constitute the Earth's physical climate system. Scientific activity in the WCRP is organised around a series of large-scale projects:

- The Global Energy and Water Cycle Experiment (GEWEX) to study the atmospheric processes and land-surface/atmosphere interactions that determine the global hydrological cycle and energy budget and their adjustment to changes such as the increase of greenhouse gases.

- Stratospheric Processes and their Role in Climate (SPARC) to investigate the influence of the stratosphere on climate, and the interacting chemical, dynamical and radiative processes that control stratospheric changes.
- The World Ocean Circulation Experiment (WOCE) to assemble nearly simultaneous measurements in all ocean basins and to provide, for the first time, a synoptic view of the world oceans.
- The Climate Variability and Predictability (CLIVAR) study is now the main thrust in the WCRP for exploring climate variations on a timescale of seasons to decades occurring naturally or as a result of anthropogenic effects.
- The Arctic Climate System Study (ACSYS) to investigate the role of the Arctic as an interactive component of the climate system and to assess exchanges of Arctic freshwater (or ice) with the adjoining oceans.
- Climate System Modelling to build on the advances in the other WCRP projects and to develop the comprehensive models of the climate system needed to predict natural variations and anthropogenic climate change.

D.13 WORLD METEOROLOGICAL ORGANISATION (WMO)

This section outlines the development of the WMO's satellite data requirements. The detailed satellite data requirements described in this section are followed by a description of instrument types and candidate sensors for each parameter.

Draft WMO satellite data requirements were presented at the April 1992 CEOS meeting in London, based on the report of the tenth session of the WMO Executive Council Panel of Experts on Satellites (ECSAT) which met in March 1992. Since 1992, a user dialogue has been established such that the requirements have been further refined by the Panel of Experts and presented to the WMO Executive Council as part of the Panel's final report in March 1993. The 45th WMO Executive Council was of the opinion that the "Final Report from the EC Panel of Experts on Satellites" recorded important milestones and achievements in the history of the panel. It suggested that the new Commission for Basic Systems (CBS) Working Group on Satellites should continue to update the report and its various sections as appropriate and when required. It noted that the statements of satellite data requirements, principles and definitions were a useful synthesis of requirements and would be of benefit to WMO programmes and planning, and to space agencies.

Lists of parameters to be observed and the quality of observations made have been compiled by many WMO Technical Commissions and many committees in charge of international programmes. These lists can be found in the documentation provided to ECSAT and discussed in a number of session reports. This documentation was consolidated by ECSAT into a "shortlist" which should be more useful to satellite mission planners (eg CEOS space agencies) than the voluminous original information, which does not clearly discriminate what should be expected from satellites versus what is more appropriate for groundbased global observing systems.

The requirements, as determined by ECSAT, were expressed in terms of geophysical parameters. Data quality must be specified at the same time as the data requirement, in order to prevent misunderstandings on the feasibility assessment (a data requirement cannot be considered fulfilled if the quality is insufficient for the data to have a real impact on the application). Data quality is specified in terms of horizontal resolution, vertical resolution (if applicable), frequency of the observation, and accuracy. As quality requirements are different for the different scales of application, two figures were generally quoted, namely for global scale and limited areas respectively.

The WMO Commission for Basic Systems Working Group on Satellites (CBS WGSAT) met in March 1994 and reviewed the list of WMO satellite data requirements prepared by ECSAT. The objectives of the CBS WGSAT, with regard to the satellite data requirements, were: to build upon the work of the EC Panel of Experts on Satellites (ECSAT) in collecting, collating, keeping under review, interpreting and promoting to potential providers and their agents, statements of the satellite data, products and services required by WMO Members; to reassure the user community that their needs are being properly interpreted and promoted; to assist developing countries to identify opportunities to make use of satellite data, products and services.

WGSAT agreed to accomplish these objectives: through publications and statements written for potential data, product and service providers; in the context of WMO's general requirements for space and ground based observations, by providing draft material suitable for use in maintaining and updating the Guide and Manual on the GOS; and by some form of database of requirements that retains their heritage, so that the ownership and responsibility for continued verification are clear.

WGSAT also agreed that it would: prepare a critical review of WMO requirements for satellite data, products and allied services, and of the capabilities to meet them; conduct the critical review by pursuing a "pathfinder" approach, ie, by revising requirements for data and adding requirements for products and allied services for a few, representative applications before applying the approach to capture all relevant WMO requirements; and accordingly, characterise the sources of requirements for operational meteorology and climate research.

Observational requirements were discussed at the Second Session of the CBS Working Group on Satellites (CBS WGSAT-II) held in Geneva from 15 to 19 April. The working group noted the activities that had occurred in the inter-sessional period since its first session in preparing a "critical review" of the capabilities and potential of present, planned and proposed satellite systems to fulfill the stated observational requirements of applications within WMO's approved programmes. It noted that the "critical review" followed the model proposed in the "Rolling Review of User Requirements" and utilised the format proposed by the CEOS Task Force on Long-term Planning and Analysis as well as the data contained in the WMO Secretariat databases. The group also noted the report of the Extraordinary Session of CBS held in Helsinki in 1994 which provided overall guidance to working groups on the requirements review process within WMO. The inputs to the "critical review" were:

- a statement of the combined observational requirements for applications within WMO's approved programmes, and
- an inventory of the capabilities and potential of instruments on present, planned and proposed Earthobserving satellites.

The working group then discussed a general procedure within which the users' requirements for observations and the capabilities of existing, planned and proposed observing systems to provide them would be reviewed, and through which guidance on appropriate observing systems to meet the users' requirements would be developed. There are four steps:

(1) develop user requirements,

(2) review observing system capabilities,

(3) perform a critical review, and

(4) develop guidance on feasibility of meeting requirements.

It was recommended that the user requirements should be user oriented, not system dependent. Although directed principally towards the capabilities of satellite systems to meet the observational requirements of WMO programmes, the working group noted that the proposed procedures could have wider application within WMO. Of utmost importance, was the ability to maintain heritage and the ability to provide feedback to the WMO Technical Commissions. The four components of the review process would be carried out periodically by the working group.

As part of the ongoing process of evolving WMO satellite data requirements, the working group was briefed on the relational database developed by the Secretariat that contained a description of the present requirements of the various user communities as well as a description of the expected performance of present and future satellite systems. The group fully endorsed the valuable work of the WMO Secretariat in maintaining this database on user requirements and satellite instruments and capabilities. This was recognised as a valuable data source for undertaking the periodic reviews. To ensure the database on satellite instrument capabilities was kept up to date, it was suggested that it should be updated annually after the CEOS plenary meeting based on the presentations at the meeting. The database should include a record of when the most recent update was made on each parameter. The members of the working group would have the opportunity to review the requirement and instrument database during each update.

It was agreed the requirements should be developed for the 2000-2010 time frame. During the meeting, the working group members started a review of the contents of the database on user requirements and satellite instruments. One group member was nominated to be responsible for the updated tables for each application area. It was agreed that revised tables would be sent out to experts nominated by the group for an independent review.

The working group reviewed the progress in developing a critical analysis of satellite data requirements. The analysis was performed to clarify and interpret the requirements for all WMO Programmes and would be used as input for various sources of data requirements. An overall approach adopted was the use of Order of Magnitude (OOM) to express representative requirements for selected applications. The use of OOM allowed the selected application requirements to be expressed as: a single value with a half order of magnitude range; a needed range that was a half order of magnitude range centred on the requirement; a target range that was a quarter OOM range higher; and a useful range that was a quarter OOM range lower. This approach allowed the selected applications to be expressed on a single sheet with four descriptors: a requirements summary; an assessment of instruments and missions; an assessment of systems and plans; and an overall evaluation. More detailed information for a particular application could be provided on a second sheet. Such an approach gave a clear and succinct description of the situation yet was detailed enough for most purposes and met with the approval of the working group. The principal aim of the summary sheets was to provide a clear indication to the WMO Technical Commissions and the space agencies if there were any major gaps or duplication in the satellite observing system. It would not provide a detailed analysis of a specific requirement.

A draft "Critical Review" was prepared using observational requirements in response to the WGSAT-II action item and distributed to working group members for comments. Comments highlighted a need to review the methodology by which the limits of usefulness and goals for observational requirements were met. As a result of the review, it was decided to state observational requirements in terms of goals and limit of usefulness through the use of Maximum/Minimum characteristics. Maximum and minimum figures would be provided for horizontal and vertical resolution, accuracy, observing cycle and delay of availability. Maximum implied the figure which need not be exceeded, eg a maximum horizontal resolution of 1km means that an observing system need not measure at 0.5km. Minimum implied the limit at which useful data would be added for a particular application. A methodology using Max/Min has been evaluated and provided the best manner to state requirements.

E Abbreviations

This annex provides a list of the abbreviations used in the text with the exception of satellite mission and instrument names. The reader is referred to annexes A and B respectively for these.

ACSYS	Arctic Climate System Study
AES	Atmospheric Environment Service
AG	Analysis Group
AOSIS	Alliance of Small Island States
ARTEMIS	Africa Real Time Environmental Monitoring using Imaging Satellites
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
BAHC	Biospheric Aspects of the Hydrological Cycle
BNSC	British National Space Centre
BRDF	Bi-directional Reflectance Distribution Functions
CAST	Chinese Academy of Space Technology
CBS	Commission for Basic Systems
CCRS	Canada Centre for Remote Sensing
CEOS	Committee on Earth Observation Satellites
CFC	Chlorofluorocarbon
CILS	CEOS Information Locator Service
CLIVAR	Climate Variability and Prediction Research Programme
CNES	Centre National d'Etudes Spatiales (French Space Agency)
COPINE	Co-operative Information Network System
CRI	Crown Research Institute (New Zealand)
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australian Space Research Organisation)
DARA	Deutsche Agentur für Raumfahrt-Angelegenheiten (German Space Agency)
DMSP	Defense Meteorological Satellite Programme
EC	European Commission
ECMWF	European Centre for Medium-range Weather Forecasting
ECSAT	Executive Council Panel of Experts on Satellites
ENRIN	Environment and Natural Resources Information Networking
EO	Earth observation
ESA	European Space Agency
ESCAP	Economic and Social Commission of Asia and the Pacific
ESINAP	Earth Space Information Network for Asia and the Pacific
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organisation
FCCC	Framework Convention on Climate Change
G3OS	Global Observing Systems: GCOS, GOOS, GTOS
G7	Group of Seven Industrial Nations
GAIM	Global Analysis, Interpretation and Modelling
GCOS	Global Climate Observing System
GCTE	Global Change and Terrestrial Ecosystems

GEWEX	Global Energy and Water Cycle Experiment
GIPME	Global Investigations of Pollution in the Marine Environment
GOEZS	Global Ocean Euphotic Zone Study
GOOS	Global Ocean Observing System
GOS-Net	Global Observing Systems Network
GOSSP	Global Observing System Space Panel
GPCP	Global Precipitation Climatology Project
GPS	Global Positioning System
GRID	Global Resource Information Database
GTOS	Global Terrestrial Observing System
GTSC	Global Terrestrial Steering Committee
ICAM	Integrated Coastal Area Management
ICSU	International Council of Scientific Unions
IDN	International Directory Network
IDNDR	International Decade for Natural Disaster Reduction
IEOSC	International Earth Observation Satellite Committee
IGAC	International Global Atmosphere Chemistry Project
IGBP	International Geosphere-Biosphere Programme
IGFA	International Group of Funding Agencies for global change research
IGOS	Integrated Global Observing Strategy
IGOSS	Integrated Ocean Services Station System
INPE	Instituto Nacional de Pesquisas Espaciais (Brazilian Space Agency)
IOC	Inter-governmental Oceanographic Commission
IPCC	Inter-disciplinary Panel on Climate Change
IR	Infra-Red
ISCCP	International Satellite Cloud Climatology Project
ISRO	Indian Space Research Organisation
JDIMP	Joint Data and Information Management Panel
JGOFS	Joint Global Ocean Flux Study
JRC	Joint Research Centre
JSTC	Joint Scientific and Technical Committee
LOICZ	Land-Ocean Interactions in the Coastal Zone
LST	Local sun time
LUCC	Land Use and Cover Change
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NESDIS	National Environment Satellite Data Information Service
NIR	Near Infra-Red
NOAA	National Oceanic and Atmospheric Administration
NRSCC	National Remote Sensing Center of China

NSAU	National Space Agency of Ukraine
NSC	Norwegian Space Centre
NWP	Numerical Weather Prediction
OCA	Oceans and Coastal Areas
OOM	Order of Magnitude
OOPC	Ocean Observation Panel for Climate
OOSA	Office of Outer Space Affairs
OSTC	Federal Office for Scientific, Technical and Cultural Affairs (Belgium)
PAC	Programme Activity Centre
PAGES	Past Global Changes
RESAP	Regional Space Applications Programme
ROSHYDROMET	Russian Federal Service for Hydrometeorology and Environment Monitoring
RSA	Russian Space Agency
SAR	Synthetic Aperture Radar
SC	Steering Committee
SFCG	Space Frequency Co-ordination Group
SIT	Strategic Implementation Team
SM	Support Measures
SNSB	Swedish National Space Board
SPARC	Stratospheric Processes and their Role in Climate
SST	Sea Surface Temperature
STA	Science and Technology Agency of Japan
SWIR	Short Wave Infra-Red
TBC	To be confirmed
TEB	Terrestrial Ecosystems Branch
TIR	Thermal Infra-Red
TOPC	Terrestrial Observation Panel for Climate
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UNOOSA	UN Office of Outer Space Affairs
WCRP	World Climate Research Programme
WGCV	Working Group on Calibration and Validation
WGD	Working Group on Data
WGISS	Working Group on Information Systems and Services
WGSAT	Working Group on Satellites
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWW	World-Wide Web

F CEOS information on the net

POINTS OF CONTACT

Secretariat

Further information on CEOS activities can be obtained from the CEOS Secretariat:

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CEOS comprises two standing working groups: the Working Group on Information Systems and Services (WGISS) and the Working Group on Calibration and Validation (WGCV).

WGISS

Information about the Working Group on Information Systems and Services (WGISS) can be obtained by contacting the WGISS Chair or by accessing the WGISS homepage at http:/ / earth1.esrin.esa.it/ wgiss

WGISS Chair:

Ms Helen Wood
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(until end November 1997)

Mr Takashi Moriyama
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+81 3 5401 8703 (fax)
moriyama.takashi@nasda.go.jp
(from start December 1997)

WGISS SUBGROUPS:

- Access Subgroup:
  http:/ / ceos.ccrs.nrcan.gc.ca
- Data Subgroup:
  http:/ / www.dfd.dlr.de/ CEOS/ DS/ d_ds_m
- Networks Subgroup:
  http:/ / nic.nasa.gov/ ceos-ns

WGCV

Information on the activities of WGCV can be obtained from: http:/ / www.eos.co.uk/ ceos-calval or by contacting the WGCV Chair.

WGCV Chair:

Dr Alan Belward
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WGCV SUBGROUPS:

- Terrain Mapping Subgroup:
  http:/ / www.eos.co.uk/ ceos-calval/ info/ tm
- Microwave Sensors Subgroup:
  http:/ / www.eos.co.uk/ ceos-calval/ info/ ms
- SAR Calibration Subgroup:
  http:/ / www.eos.co.uk/ ceos-calval/ info/ sar
- Infra-red and Visible Optical Sensors Subgroup:
  http:/ / www.eos.co.uk/ ceos-calval/ info/ ivos

WGCV also provides the science community with information on existing and planned cal-val laboratories, test sites, and field instruments. An information service is available from http:/ / spso.gsfc.nasa.gov/ calval/ homepage.

CEOS DATABASE

The on-line CEOS Database can be accessed at: http:/ / ceos.esrin.esa.it/ dossier

INFOSYS

Information is available on-line via the CEOS Infosys at http:/ / ceos.esrin.esa.it/ infosys

The WGISS yellow pages can be accessed at: http:/ / www.smithsys.co.uk/ yp

INTERNATIONAL DIRECTORY NETWORK (IDN)

Information on specific Earth science dataset holdings, including many satellite-related observations can be obtained from the CEOS International Directory Network (IDN – see section 2). There are many means of access to the IDN, but the initial point of contact might be through one of the regional co-ordinating nodes at:

NASA
http:/ / gcmd.nasa.gov/ ceosidn

ESA
http:/ / gds.esrin.esa.it/ CEURO_IDN_HP

NASDA
http:/ / gcmd.eoc.nasda.go.jp

UNEP
http:/ / www.grid.unep.org

For those without internet access, the IDN may be accessed via telnet at:

telnet gcmd.gsfc.nasa.gov (192.107.190.77)
Username: gcdir

CEOS INFORMATION LOCATOR SERVICE (CILS)

The CEOS Information Locator Service (CILS) can be contacted at the following points of the CILS network.

http:/ / cils.dlr.de
http:/ / cils.jrc.it
http:/ / cils.unep.org
http:/ / cils.eoc.csiro.au

NEWSLETTER

The CEOS Newsletter supplements the latest information available on-line about CEOS and is distributed internationally on a 6-monthly basis. Subscription requests should be sent to :

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misawa.kazuko@nasda.go.jp

PROMOTION OF EO APPLICATIONS

Information on the “Special Report on Successful Applications of EO Satellite Data” can be obtained by contacting Ms Kazuko Misawa (see above for contact details).

Further information about the CD-ROM entitled “Resources in Earth Observation” may be obtained by contacting:

Mr Jeff Kingwell
CSIRO
+61 2 6216 7222 (fax)
jeff.kingwell@cossa.csiro.au

A further development of the CD-ROM is expected to be produced during 1997 - incorporating a new range of case studies and tutorial materials for users. For further information contact:

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+33 5 61 27 40 13 (fax)
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IGOS

Further information about IGOS can be obtained by contacting the Chairs of the Strategic Implementation Group (SIT) and Analysis Group (AG).

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AG
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FREQUENCY ALLOCATION PLANNING

In recognition of the need to represent the Earth observation community in bodies such as the International Telecommunications Union, and the World Radio Conference, CEOS plans to identify, co-ordinate, and register members’ interests in these international issues through an Ad-hoc Co-ordination Group on Spectrum Management.

Further information on this group’s activities can be obtained by contacting:

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G CEOS agencies on the net

CEOS Members

Agenzia Spaziale Italianna (ASI)	http://www.asi.it
British National Space Centre (BNSC)	http://www.open.gov.uk/bnsc/bnschome
Canadian Space Agency (CSA)	http://www.science.sp-agency.ca
Centre National d'Etudes Spatiales (CNES)	http://www.cnes.fr
Chinese Academy of Space Technology (CAST)	
Commonwealth Scientific & Industrial Research Organisation (CSIRO)	http://www.cossa.csiro.au
Deutsche Agentur für Raumfahrt-Angelegenheiten (DARA)	http://isis.dlr.de
European Commission (EC)	http://www.sai.org
European Organisation for the Exploration of Meteorological Satellites (EUMETSAT)	http://www.eumetsat.de
European Space Agency (ESA)	http://www.esrin.esa.it
Indian Space Research Organisation (ISRO)	
Instituto Nacional de Pesquisas Espaciais (INPE)	http://www.inpe.br
National Aeronautics & Space Administration (NASA)	http://www.nasa.gov
National Oceanic & Atmospheric Administration (NOAA)	http://www.noaa.gov
National Remote Sensing Center of China (NRSCC)	
National Space Agency of Ukraine (NSAU	
National Space Development Agency of Japan (NASDA)	http://www.nasda.go.jp
Russian Federal Service for Hydrometeorology and Environment Monitoring (ROSHYDROMET)	
Russian Space Agency (RSA)	
Science & Technology Agency (STA)	http://www.sta.go.jp
Swedish National Space Board (SNSB)	

CEOS AFFILIATES

Economic and Social Commission of Asia and the Pacific (ESCAP)	http://www.un.org/DEPTS/escap
Food and Agriculture Organization (FAO)	http://www.fao.org
Global Climate Observing System (GCOS)	http://www.wmo.ch/web/gcos/gcoshome
Global Ocean Observing System (GOOS)	http://www.unesco.org/ioc/iocgoos
Global Terrestrial Observing System (GTOS)	http://www.fao.org/GTOS/default
International Council of Scientific Unions (ICSU)	http://www.Imcp.jussieu.fr/icsu/index
International Geosphere-Biosphere Programme (IGBP)	http://www.igbp.kva.se
Inter-governmental Oceanographic Commission (IOC)	http://www.unesco.org//ioc
United Nations Environment Programme (UNEP)	http://unep.unep.org
United Nations Office of Outer Space Affairs (UNOOSA)	http://www3.un.or.at/OOSA-Kiosk/index
World Climate Research Programme (WCRP)	http://www.wmo.ch/web/wrcp/wrcp-home
World Meteorological Organisation (WMO)	http://www.wmo.ch/Welcome

CEOS OBSERVERS

Federal Office for Scientific, Technical and Cultural Affairs (OSTC)	http://www.belspo.be/home_e
Canada Centre for Remote Sensing (CCRS)	http://www.ccrs.nrcan.gc.ca/ccrs/homepg
Crown Research Institute (CRI)	http://www.landcare.cri.nz
Norwegian Space Centre (NSC)	http://www.spacecentre.no

1997 CEOS Yearbook