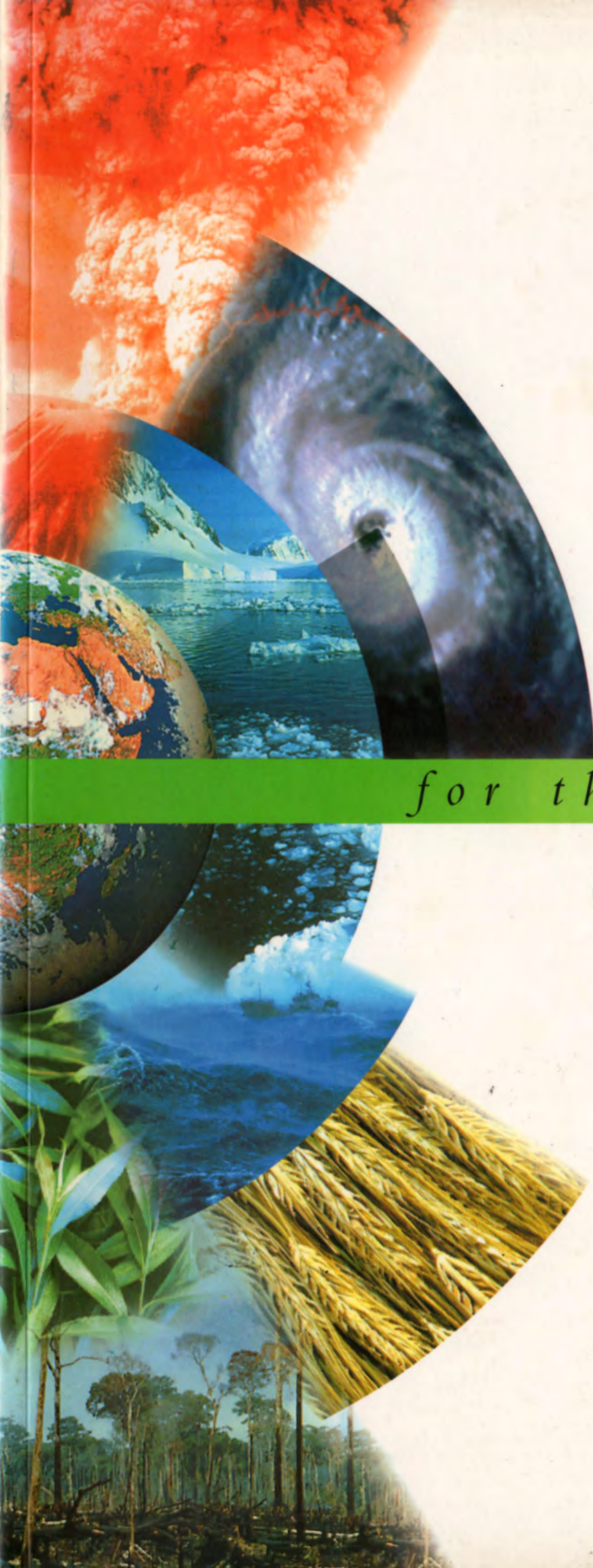

CEOS

COMMITTEE ON EARTH OBSERVATION SATELLITES

Coordination for the next decade

1995 CEOS Yearbook

esa
european space agency

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Committee on Earth Observation Satellites: Coordination for the next decade (1995 CEOS yearbook)

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Contents

Foreword

CEOS – the Committee on Earth Observation Satellites – is an organisation which aims to achieve international coordination in the planning of satellite missions for Earth observation and to maximise the utilisation of data from these missions worldwide. Recognising the global benefit of the cooperation and coordination promoted by CEOS, the European Space Agency (ESA) became a founder member in 1984, and continues to play an active role – including support to the permanent Secretariat.

It therefore gives me great pleasure to present this report, prepared by ESA on behalf of CEOS, which details the current status and plans for future Earth observation satellite missions. It describes how the data and information which they supply relate to worldwide needs for information on Earth System processes – in support of a range of significant objectives of national and international concern.

This report provides a valuable source of information concerning the possible application of data from Earth observation satellites. I hope that it will be of interest to a wide range of groups. This includes those responsible for programmes with requirements for observations to enable understanding of our environment and to provide information for decision-making in many socio-economic sectors, ranging from global climate research programmes to national resource management programmes.

As CEOS enters its second decade, I am confident that it will continue to achieve the coordination which is essential to meet efficiently the needs of the full range of users and to guarantee comprehensive information on the Earth System, for present and future generations.

Jean-Marie Luton
Director General
European Space Agency

1 Introduction

1.1 THE INCREASING NEED FOR OBSERVATIONS OF THE EARTH

It is recognised that, today, the effects of growing population and economic development are placing heavier and expanding demands and stresses upon the finite resources of the Earth System, through for example:

- increasing consumption of many natural resources, such as food stocks, water, minerals, oil, gas, and other materials;
- environmental pollution of land, sea, and air;
- large-scale changes in land use through urbanisation and deforestation;
- the possibility of anthropogenic global climate change.

At the same time there is increased awareness of the human and economic significance of the natural variability of the Earth System, particularly with regard to the effects of extreme events – manifested through natural disasters such as floods and earthquakes.

Despite growing concern and scrutiny of these effects, our efforts to meet global human needs mean that future development cannot be halted, rather, it must become sustainable and less environmentally destructive – so that today's development does not undermine the development and environment needs of future generations.

Factors pertinent to sustainable development cover virtually all human activities. In order to understand these factors and their complex inter-relationships, more information is required on the social, economic and environmental spheres of human activity. In the broadest sense, observations are required to provide basic data on all these areas. Such data underpin advances in understanding of the basic Earth System and of human influences on it.

Although the primary concerns of governments may relate to the needs of national development, many of the relevant issues are global in nature. For example, local atmospheric pollution may affect the global climate system. The worldwide concern over the requirement for sustainable development has been reflected in the formulation of a number of international agreements, many of which explicitly call for systematic observations of the Earth to increase our understanding of its processes and our ability to monitor them. Notable among these agreements are:

- Agenda 21 and the work of the UN Commission on Sustainable Development;
- the Framework Convention on Climate Change;
- the International Convention to Combat Desertification;
- the Biodiversity Convention;
- the Vienna Convention and its Montreal Protocol.

Concern over the costs of the most extreme effects of the Earth System has also been recognised through the United Nations declaration of the 1990s as the International Decade for Natural Disaster Reduction.

This document focuses on the need for observations of the environment, both: worldwide environmental needs which call for observations with global coverage; and regional, national, and local needs in support of specific environmental and development issues. These observations, comprising a number of different geophysical measurements, are required on a variety of temporal and spatial scales, determined on a measurement-by-measurement basis and depending on the uses of the data.

For observations relating to the global system, long time series of data are often essential; a combination of previously recorded data must be coupled with contemporary observations to provide a consistent database. Many years of ozone observations were required, for example, to establish convincingly that ozone levels were being depleted and that governments should agree to protocols limiting the release of chemicals which were decreasing ozone to potentially harmful levels. Similarly, the Framework Convention on Climate Change is, at least partly, motivated by the careful 30-year observational record of carbon dioxide, begun during the International Geophysical Year.

Regional, national, and local observations are required, *inter alia*, to: enable increased understanding of national environmental issues and improved resource management; to inform national decision-making in environmentally-sensitive socio-economic sectors including water, energy, agriculture, forestry, fisheries, construction, transportation and the retail and leisure industries; and to provide information for natural disaster warning and mitigation. An important area of concern for governments, particularly within developing countries and countries with economies in transition, is their ability to prepare for and respond to extreme environmental events such as flooding, drought and earthquakes.

The required observations, be they local, regional or global, can be made using a variety of measuring techniques and platforms. In general, a combination of in-situ observations (for example, measurements from weather stations and ships) and a variety of sensors mounted on space platforms are able to provide useful data. Both kinds of data must be adequately calibrated and quality controlled, effectively disseminated and archived to provide comprehensive information on the Earth System, for both present and future generations.

1.2 OPPORTUNITIES FROM SPACE

The observational requirements arising from the need to understand more fully the Earth System, and provide services based on that increased understanding, are wide ranging, involving many different measuring techniques and associated data processing systems. No single agency is in a position to provide the complete range of information.

Earth observation satellites provide an important source of information. Over the next 15 years the world's civil space agencies plan approximately 80 missions carrying over 200 different instruments, providing measurements of many parameters of interest to those studying the Earth's environment*. These planned missions will provide a significant increase in data and information over the satellites currently flying and, supported by complementary *in-situ* observations, offer the prospect of global coverage for a range of valuable measurements. However, some missions are still uncertain regarding funding, launch dates and payloads and only a few are planned as operational systems to maintain continuous, consistent measurements over long periods of time.

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 the successful applications of satellite Earth observation data is given 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 operational satellite measurements of both surface and upper air winds and atmospheric temperature fields. Due to model and observational improvements, the accuracy of recent 5 day forecasts is much better than the 2 day forecasts in the mid 1970s and recent 7 day forecasts are as accurate as the 5.5 day forecasts available in 1980;
- *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.

It is clear that satellite data have many potential applications and that already there exist a number of satellite-based instruments providing valuable information. Earth observation satellites have the potential to both:

- assist future development, for example by providing information to improve natural resource exploration and recovery techniques; and
- enable management of that development in a sustainable way, by providing global monitoring capabilities which allow better understanding of Earth System processes and improved assessments of development impact – such as depletion of stocks or quality of natural resources.

Coordination of international satellite-related activities in order to meet efficiently the needs of the full range of users is a vital consideration. Indeed, as an extension of the G-7 Economic Summit process, the Committee on Earth Observation Satellites (CEOS) was formed in 1984 to provide such coordination.

International investment in satellite platforms and instruments and the associated ground segments is already substantial (amounting to many hundreds of millions of US$ per annum). A higher scale of investment is planned over the coming decade and CEOS will continue to play a key role in coordinating these investments, through its principal objectives outlined in section 2, in order to ensure full realisation of the benefits of this truly international activity.

1.3 SCOPE AND CONTENTS OF THIS REPORT

The information contained within this report details the current status and plans for future Earth observation satellite missions and describes how the data and information which they supply relate to worldwide needs for information on Earth System processes – in support of significant objectives of national and international concern. The approach which has been adopted has been to illustrate the contributions from satellites in providing a range of different geophysical measurements.

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 technology behind 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 definitive reference source for information on current and future Earth observation programmes.

Section 2 gives an overview of the organisation, activities, and achievements of CEOS. The capabilities of satellites in providing Earth observations are discussed in section 3 – including information on the different types of missions and instruments which are planned. Section 4 relates the measurements of these instruments to the need for Earth observations – notably those needs relating to global environment programmes.

The annexes include:

A catalogue of satellite missions
B catalogue of satellite instruments
C CEOS membership details
D CEOS Affiliate agencies and programmes
E abbreviations
F points of contact

* 1994 CEOS Dossier: Satellite Missions and Instruments; Ground Segment and Data Products; Relevance of Satellite Missions to Global Environmental Programmes

† CEOS Special Report on Successful Applications of EO Satellite Data, Pilot Version, July 1994, presented to the 1994 CEOS Plenary by STA/NASDA

2 CEOS: Coordination for the next decade

2.1 OVERVIEW

The Committee on Earth Observation Satellites (originally named the International Earth Observation Satellite Committee, IEOSC) was created in 1984, in response to a recommendation from a panel of experts on Satellite Remote Sensing 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 observations and the value of coordinating international mission plans. CEOS has since established a broad framework for coordination across all spaceborne Earth observation missions.

CEOS has three primary objectives:

- to optimize the benefits of spaceborne Earth observations through cooperation 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 coordination of space-related Earth observation activities, including those related to global change;
- to exchange policy and technical information to encourage complementarity and compatibility among spaceborne Earth observation systems currently in service or development, 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 (annex C) 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.

International user organisations, such as the World Climate Research Programme and the United Nations Environment Programme have Affiliate status (annex D) and governmental organisations that are international or national in nature and have significant ground segment activity can apply to become Observers.

2.2 STRUCTURE AND ACTIVITIES

Structure

The work of CEOS spans the full range of activities required for proper international coordination of Earth observation programmes and maximum utilisation of their data, and ranges from the development of detailed technical standards for data product exchange, through to the establishment of high level interagency agreements on common data 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 worldwide, and to review progress on the various projects and activities being undertaken within the CEOS working groups and task forces.

The working level organisation of CEOS is shown in figure 2-1.

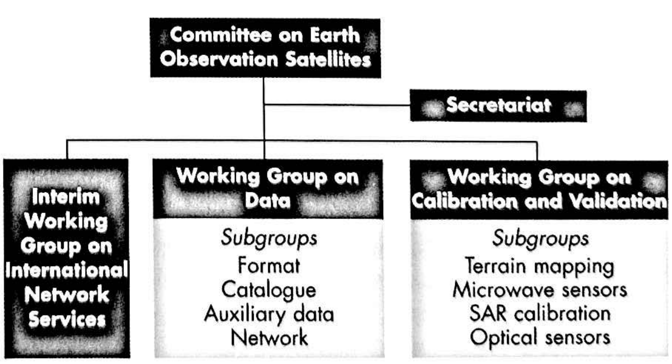


Figure 2-1 Current CEOS organisation

There are currently two standing working groups:

the Working Group on Data (WGD) which has the goal of coordinating and standardising all aspects of EO data management and has subgroups tasked with addressing:

- compatible approaches to data formatting (Format Subgroup);
- international catalogue system interoperability (Catalogue Subgroup);
- coordination of issues related to auxiliary data (Earth data which are complementary to satellite Earth observation data) (Auxiliary Data Subgroup);
- optimisation and improvement of data networks for use by CEOS agencies and their users (Network Subgroup);

the Working Group on Calibration and Validation (WGCV) which provides a focus for coordination and cooperation in activities related to calibration and validation of Earth observations, and has the following subgroups:

- Terrain Mapping Subgroup;
- Microwave Sensors Subgroup;
- SAR Calibration Subgroup;
- Infrared and Visible Optical Sensors Subgroup.

In addition, recognising the need to keep pace with technological developments, CEOS has recently established an Interim Working Group on International Network Services to help define the best way ahead for CEOS agencies to address the issue of cooperation in future high speed global networks for Earth observation data and their associated user services. CEOS is currently considering how best to execute such initiatives in terms of future working group structure.

CEOS places great emphasis upon the communication between the providers of satellite Earth observation data (the space agencies) and users of the data – represented in CEOS by the Affiliate agencies, which include agencies interested in global environmental research and operational monitoring. To enhance this communication, CEOS has held periodic User Requirements Workshops – as a means of reporting the data needs of these agencies and exploring how well they can be met by satellite Earth observations. Such workshops have been held in the spring of each year for the last three years and have been successful in developing a better dialogue and mutual understanding concerning the capabilities of satellites and how they can contribute to the requirements of user programmes.

Activities

The CEOS Dossier

As CEOS enters its second decade, it is now recognised as the main international forum for the coordination of Earth observation satellite programmes and for interaction of the space agencies with users worldwide. The CEOS Dossier has proved to be a key means of achieving this coordination and user interaction. The CEOS Dossier is a compendium of the programmes and plans of the space agencies over the next 15 years, and contains comprehensive details of mission schedules, instrument characteristics and measurement capabilities. The Dossier comprises 3 volumes:

- Volume A: Missions and Instruments;
- Volume B: Ground Segment and Data Products – a guide to the reception and processing facilities available worldwide and details of the various data products available to users, plus information on CEOS working groups and their activities;
- Volume C: The Relevance of Satellite Missions to Global Environmental Programmes, contains a detailed comparison of the provision of data arising from agency plans (reported in Volume A) with the requirements specified by the Affiliate agencies. The analysis is arranged by principal

measurements, such as sea surface temperature, and attempts to identify areas where there are either gaps or overlaps in satellite data provision with a view to assisting in the rationalisation of international plans.

The CEOS Dossier was first produced in 1992 and has been updated and widely distributed each year since, including production of a condensed version for the UNCED Conference in Rio de Janeiro in June 1992. An interactive database version was produced in 1994 to enable searching of the Volume A Dossier and to enable users to identify data sources which might meet their data needs.

The CEOS Dossier is now recognised as the definitive reference guide to international Earth observation programmes and plans, and provides a basis for analysis as to how well these plans meet user requirements.

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 worldwide.

The CEOS International Directory Network (IDN) provides on-line access to information on scientific data held worldwide. The IDN is truly multi-disciplinary and spans datasets in:

- Earth sciences;
- space physics;
- solar physics;
- planetary science;
- astronomy and astrophysics.

The IDN offers information on several thousand relevant data sets, plus details of data centres worldwide, campaigns and projects, and satellites and instruments.

The heart of the IDN consists of 3 coordinating nodes (held by NASA (USA), NASDA (Japan), and ESA (Europe)) which provide duplicate databases of directory information on-line for open access. Each coordinating node has a number of regional cooperating 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 cooperating nodes throughout each region.

The CEOS Infosys is an on-line information service, available via the Internet's World Wide Web, which provides comprehensive and up-to-date information on CEOS activities and also provides an initial gateway to the many on-line services offered worldwide by CEOS agencies.

Further details on how to access the IDN and CEOS Infosys are given in annex F.

Recognising the need to provide users with access to Earth observation data which is as simple and as comprehensive as possible, CEOS working groups have undertaken a number of experiments on interoperability of on-line user services, such as catalogues and imagery browse systems, with the vision of realising a system which would enable simple access to data resources held anywhere in the world. Prototype services are already in place.

Data exchange and utilisation

With a view to promoting maximum utilisation of Earth observation data collected worldwide, CEOS agencies have developed principles for the exchange of data in support of the key areas of global change research and operational environment use for public benefit. These principles elaborate on the CEOS Terms of Reference which state that: 'Members must have a continuing activity in spaceborne Earth observations, intended to operate and provide non-discriminatory and full access to data that will be made available to the international community'. The mechanisms behind these principles are currently being tested in the context of the International Geosphere-Biosphere Programme (IGBP) through a pilot project to exchange high-resolution image data between agencies.

There are very many other CEOS initiatives, undertaken by the working groups – ranging from: the standardisation of data product calibration and validation procedures; the development of glossaries of technical terms; to the development of data format standards, and the improvement of inter-agency network connectivity – which have been aimed at simplifying and standardising exchange and use of satellite data.

Promotion of EO applications

Reflecting the broad range of application interests of CEOS agencies, a pilot version of the "CEOS Special Report on Successful Applications of EO Satellite Data" was produced during 1994. The aims of the report were:

- to provide a guide to the successful utilisation of satellite EO data in various application projects;
- to identify and quantify the derived benefits;
- to identify implications for future projects.

The pilot report 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.

A full version of the CEOS Special Report will be produced during 1995.

2.3 EMERGING INITIATIVES

Change is one feature which is common to our understanding of the Earth System, to the status of technology which we use to observe it, and to the understanding and working practices of the scientists and decision-makers charged with monitoring and advising on the state of that system. CEOS agencies are mindful of the need to be responsive to these changes and a five year strategy for CEOS was drafted during 1994 which will be reviewed and revised on an annual basis.

A number of the more recent initiatives emerging from CEOS are discussed below.

International Network Services

Recognising the need for a coordinated approach in achieving an international Earth observing system, CEOS has already taken steps towards coordination in the development of the observing satellites in order to provide complementary data. To maximise the utilisation of the data collected by these satellites it will be necessary to achieve a corresponding degree of international coordination in the provision of the systems which disseminate and enable access to that data. The interconnectivity of available global networks and interoperability of network services are key factors in achieving this objective.

CEOS agencies are in the process of defining a strategy for the use of a global network infrastructure and standard network services – with the emphasis on the provision of user services and encouraging wider utilisation of EO data through wider and easier access on the 'information superhighway'.

Developing Countries Initiative

It is generally recognised that, although there have been many demonstrations of the value of EO satellites in application to development issues such as food production, resource management and environment characterisation, there has been insufficient effort applied to the transfer of that knowledge to developing countries. Similarly, the potentially valuable role of developing countries contributing to global climate and environmental observations has not been explored sufficiently.

In order to start to address these issues, a CEOS Workshop on Developing Country Activities was convened in Brazil in 1994. As a result of that meeting, CEOS is developing a strategy to create and maintain an indigenous capability which 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.

Task Force on CEOS Planning and Analysis

Developing the dialogue between the Member space agencies and the Affiliate user agencies is an important priority for CEOS and significant efforts have already been made through the CEOS Dossier to compare the provision of data from satellites with the user programme requirements. The logical conclusion of this exercise is to identify how future international Earth observation programmes might be modified to avoid gaps and overlaps in the provision of data and to achieve the measurement characteristics which are required (such as the necessary accuracy and frequency).

A Task Force on CEOS Planning and Analysis was established last year to further develop this process and will report to the 1995 CEOS Plenary on its findings.

3 Capabilities of Earth observation

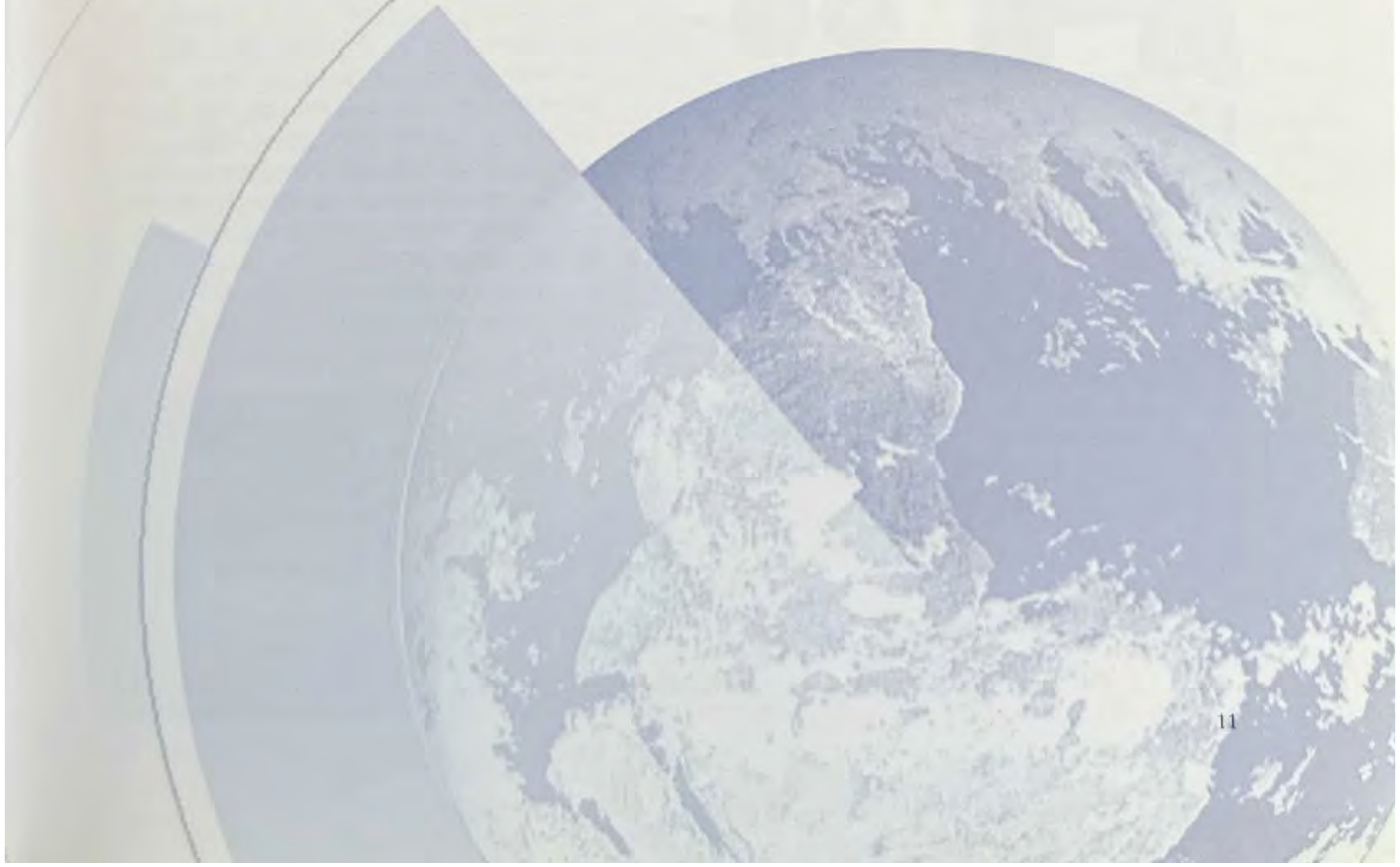
A variety of instruments are flown on space missions, employing both active and passive sensing technology, covering a wide range of the electromagnetic spectrum. These instruments provide a wealth of information on a diverse range of geophysical parameters and phenomena; information which is of value to different disciplines, such as:

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

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 worldwide. 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 environmental monitoring, resource management, agriculture and forestry operations, and disaster mitigation. 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. This information is proving to be of direct benefit in both public and commercial spheres. This trend can be expected to continue, given the increase in the number of missions dedicated to specific applications and the improvements in sensing technology and techniques – such as higher spatial resolution and in data access capabilities.

CEOS agencies are planning more than 80 missions for operation over the next 15 years, carrying over 200 different instruments – providing measurements of many parameters of interest to those studying the Earth's environment. 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
Polarimeter radiometers
Radar altimeters
Wind scatterometers

This list is derived from the various instrument types considered by the CEOS Affiliate agencies in identifying possible data sources to satisfy their requirements. There are of course other schemes for classifying the different types of Earth observing instruments which can be used. For example, imaging and non-imaging (profiling) classes of sensors can be identified, as follows:

- imaging instruments:
  active types: imaging radars and wind scatterometers;
  passive types: multichannel imagers and radiometers;
- profiling instruments:
  active types: profiling radars and lidars, and altimeters;
  passive types: passive sounders.

The future plans include several different types of mission for these instruments: some being demonstrators of new and potentially valuable technology (such as cloud radars and lidars) and others being continuous series of satellites designed to provide long term data sets (such as the NOAA polar orbiter series). Annex A tabulates the specific missions and their objectives.

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 4.

ATMOSPHERIC CHEMISTRY INSTRUMENTS

Description

Atmospheric trace gases may be observed by detecting the characteristic radiation from their absorption, emission or scattering 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, typically between the UV and microwave.

Relatively broad-band radiometers may be used to detect the strong bands observed from ozone. For most other trace gases, however, high spectral resolution spectrometers are required since only very weak lines are produced, and these are generally embedded in the continuum of lines of 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 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 100 km. Limb viewing allows measurements either in emission or in absorption mode. Occultation (absorption) techniques may rely either on the sun or other stars as the radiation source.

Atmospheric chemistry instruments can detect and monitor the impact of volcanic eruptions in the atmosphere.

Applications

Measurements from atmospheric chemistry instruments are for the first time providing a truly global picture of the atmosphere and how it is varying on a daily and seasonal basis – information which has application 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 aggressive gases which affect the environment, and other gases and radicals impacting on the ozone cycle and which therefore affect both climate and the environment.

In the future, the spatial measurement resolution of these instruments is likely to increase. In addition, an extension of the measurements towards the lower atmosphere will allow for improved pollution monitoring capabilities.

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

The GOME spectrometer mapping ozone.

Description

IR and microwave atmospheric sounders provide accurate spatial information on the distribution of radiation emitted by the atmosphere from which vertical profiles of temperature and humidity though 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 – since this broadening is caused by intermolecular collisions with other species, it decreases with atmospheric pressure, and hence the radiation received at the instrument with a wavelength close to the centre of the emission line will originate in the upper atmosphere, whilst that well away from line centre 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 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 MW bands in the water spectrum are used. Although microwave sounders offer the ability of being able to sound through cloud and hence offer all weather capability, their spatial resolution (both vertical and horizontal) is generally lower than that of the IR instruments. IR sounders are routinely used to provide temperature profiles from a few km altitude to the top of the atmosphere with a temperature accuracy of 2-3K, a vertical resolution of around 10 km and a horizontal resolution of between 10 and 100 km.

Applications

Although most sounders are carried on polar orbiters, a few sounders are also carried on the geostationary weather 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 also contribute information on the total column, or precipitable, water vapour content of the atmosphere, and on atmospheric discontinuities and instability indexes.

Satellites can provide global perspectives of Earth system processes – such as this map of surface temperatures generated from IR and microwave sounder data.

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

CLOUD PROFILE AND RAIN RADARS

Description

These instruments are 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 200 km) along the track of a low altitude satellite and thereby infer 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 is due to be flown on board the Tropical Rainfall Measuring Mission (TRMM) mission will be the first spaceborne rain radar. Cloud radars are still in a state of development, and the earliest operational system is likely to be flown on a future ESA mission.

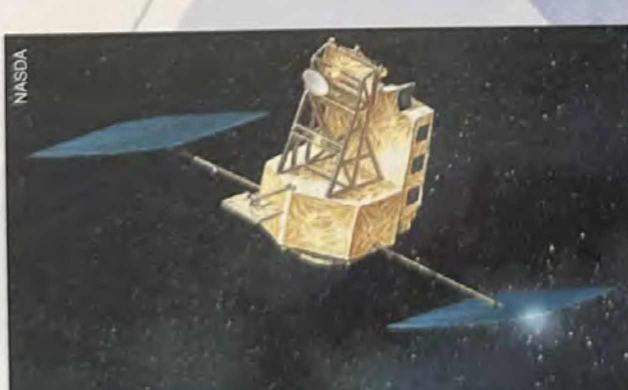
Applications

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. Information on 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 obviously have limited coverage over the oceans. The availability of an extensive tropical 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.

TOKAI UNIV

Tropical clouds play an important role in global climate.



TRMM will measure precipitation in tropical regions from 1997.

EARTH RADIATION BUDGET RADIOMETERS

Description

These instruments provide measurements of the various components of the Earth's radiation budget. The instruments are precisely calibrated and offer a high radiometric accuracy, thereby allowing 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:

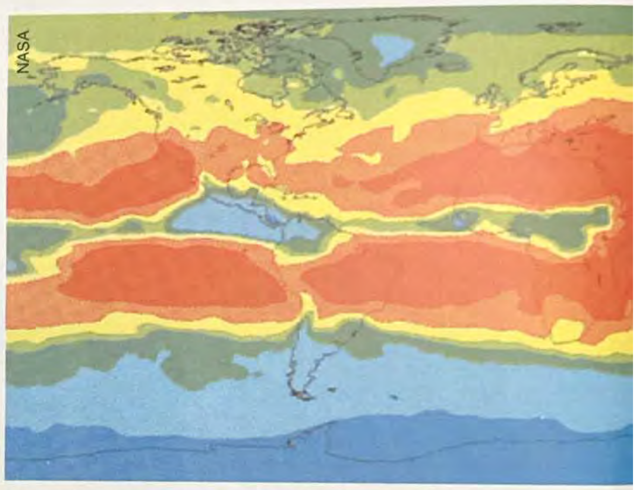
- broad band radiometers are used to cover the full range of incoming solar radiation (0.2 – 4.0 microns) and to monitor the long-wave emitted Earth radiation (3 – 50 microns) – this range may be covered either by two single channels, or by a series of narrower band channels;
- short wave radiometers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

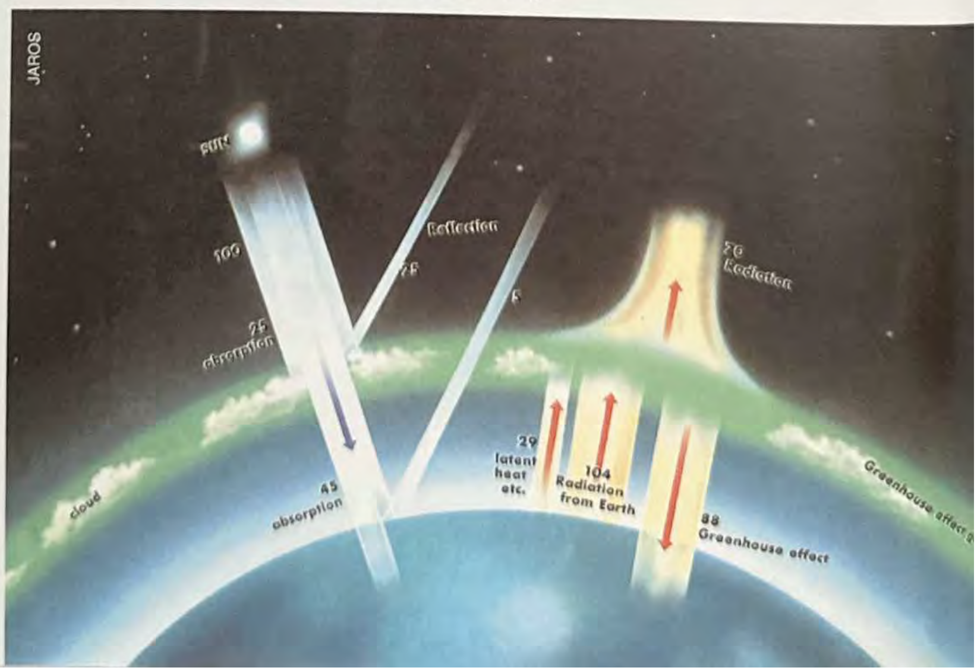
Application

The Earth's radiation budget is an important forcing function behind change. Earth radiation budget radiometers offer a unique contribution to our 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 indirect 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

The Earth's radiation budget.



HIGH RESOLUTION IMAGERS

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 100 km. The instruments 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.

There is a wide range of examples of this category of instrument – many countries have had 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 addition, instruments will become available capable of producing stereo images from data collected on a single orbit (at present the production of stereo images requires data from different passes).

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.

The high resolution and stereo capabilities of some EO sensors can be exploited in geographic information systems for civil planning and mapping applications.

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

INSTRUMENT CATALOGUE

ASTER
AVNIR
AVNIR-2
CCD camera
ETM+
HRG
HR PAN
HRV
HRVIR
IIS camera
IR multi-scanner
KFA-1000
KFA-200
KFA-3000
LISS I
LISS II
LISS III
MESSR
MK-4
MK-4M
MOMS-2P
MSS
MSU-E
MSU-E1
MSU-E2
MSU-V
OPS
PAN
SILVA
Spectro-radiometer medium resolution
TIR spectro-radiometer
TM
WFI camera

IMAGING MULTI-SPECTRAL RADIOMETERS (VISIBLE/IR)

INSTRUMENT CATALOGUE

Geostationary orbit
- BTVK
- IMAGER
- Multispectral Visible and IR Scan Radiometer
- MVIRI
- SEVIRI
- VHRR
- VISSR

Low Earth orbit
- AATSR
- ATSR
- ATSR-2
- AVHRR/2
- AVHRR/3
- GLI
- Klimat
- Klimat-2
- MERIS
- MODIS
- MOS
- MR-2000
- MR-2000M
- MR-900
- MR-900B
- MSR (RSA)
- MSU-M
- MSU-S
- MSU-SK
- OCTS
- PRISM
- SROSM
- TV camera
- UV-visible spectrometer
- VEGETATION
- VIRS
- VTIR
- WiFS

Description

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

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

Future developments are likely to result in improvements both in the spatial resolution and radiometric accuracy of these instruments.

Applications

Measurements from these multi-spectral radiometers operating in the IR and visible 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 allow 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 have also been important sources of ocean colour data, although more specialist instrument types are emerging (see later) for precise ocean colour measurements.

Images from geostationary satellites are a common feature of today's TV weather bulletins and form a vital component in operational forecasting.

AVHRR sensor imagery has been used to monitor vegetation growth to assist food security programmes

IMAGING MULTI-SPECTRAL RADIOMETERS (MICROWAVE)

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. Other advantages over visible/IR radiometers include the ability to probe the dielectric properties of the surface and to penetrate vegetation and, to a lesser extent, the Earth's surface. As with other imaging radiometers, emphasis is on accurate spectral rather than spatial information. Indeed, the spatial resolution of the images produced by these microwave radiometers (typically of order a few km) is generally poorer than that of their shorter wavelength counterparts.

There are, as yet, few operational examples of these instruments.

Applications

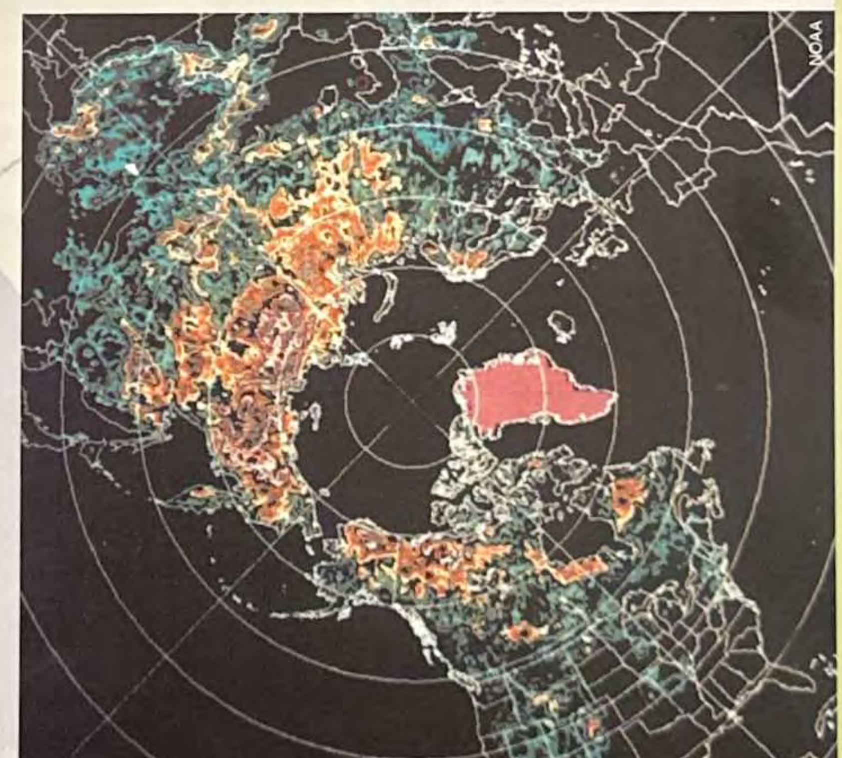
Measurements from the imaging microwave radiometers may be used to infer a range of parameters. Snow and ice mapping (often in conjunction with other instruments) has become one of the primary uses of these instruments, due in part to their capability for cloud penetration. These instruments are also 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.

INSTRUMENT CATALOGUE

AMR
AMSR
IKAR-D
IKAR-N
IKAR-P
MIMR
MR-0.8
MSR
MWR
MZOAS
R-400
TMI
TRASSER-O



Snow and ice cover maps of the entire Northern Hemisphere can be created from microwave radiometer imagery.

INSTRUMENT CATALOGUE

- AMI - SAR image and wave modes
- ASAR
- RLSBO
- SAR (RADARSAT)
- SAR (JERS-1)
- SAR (SICH-1)
- SAR-3
- SAR-10
- SAR-70
- SLR-3
- Travers SAR
- VSAR

Description

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

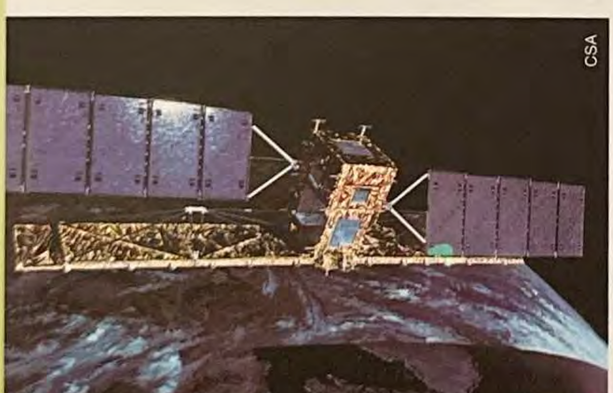
Interferometric SARs record the phase shift between 2 images recorded at slightly different times, thereby providing accurate information on the motion of surfaces and targets and allowing large scale 3-D topographical images to be produced. Stereo images may be produced using conventional SAR images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

Applications

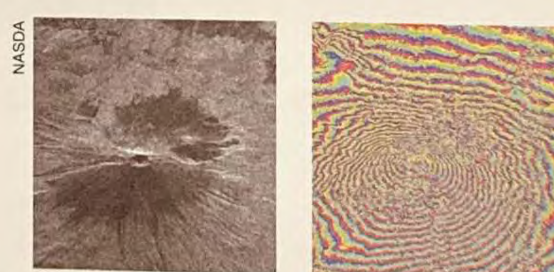
Although a variety of backscatter measurements may be taken by imaging radars, interpretation of these measurements is a complex and developing science. Significant advances in a number of areas and operational applications are emerging.

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. Analysis of the backscatter spectrum also allows information on wave spectra to be obtained. Operational sea ice forecasting is an important and growing application of SAR data.

Land images can be used to infer vegetation type and cover, and are therefore of use in forestry and agriculture – the ability of SARs to penetrate cloud cover and dense plant canopies makes them particularly valuable in rainforest studies, and also in resource monitoring applications. Information from SAR may also be used to measure soil moisture content. One of the most important current application 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.



RADARSAT will be launched in 1995 and will provide SAR data for the next five years



SAR and interferometic image of Mt. Fuji – demonstrating application of SAR for the generation of precise topographical data

SAR measurements have revealed many interesting oceanographic phenomena -such as these internal waves in the Mediterranean Sea.

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:

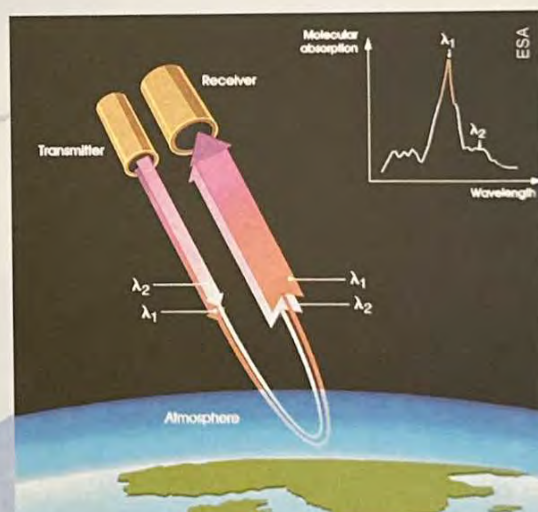
- the backscatter lidar, in which the laser beam backscattered, reflected or re-radiated by the target gives information on the scattering and extinction coefficients of the various atmospheric layers being probed;
- the differential absorption lidar which analyses the returns from a tuneable laser at different wavelengths to determine densities of specific atmospheric constituents as well as water vapour and temperature profiles;
- Doppler lidars which measure 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 spaceborne lidars, although some experiments have been flown on the Space Shuttle, and several instruments are planned for missions in the near future.

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) 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)

Atmospheric features detectable by Lidar as a function of latitude

INSTRUMENT CATALOGUE
ALADIN
ALISSA
ATLID
Balkan-2 lidar
GLAS

MULTI-DIRECTIONAL RADIOMETERS

Description

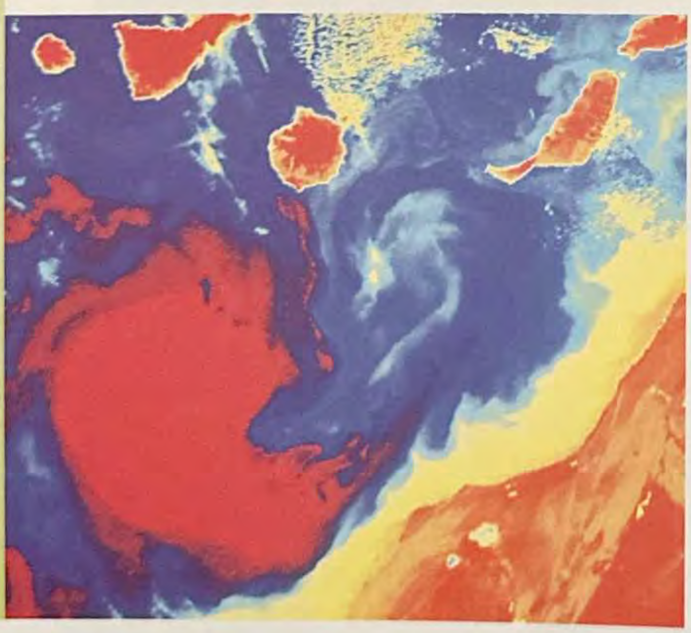
Multi-directional radiometers are able to make observations of the diffused or emitted radiation from a particular element of the Earth's surface or clouds from more than one incidence angle. In this way, information on anisotropies in the radiation may be identified. The emphasis in these instruments 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 a km.

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

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, they 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, 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.



ESA, RAL

Accurate measurements of global sea surface temperature using multi-directional radiometers such as ATSR are of great value in climate change detection.

OCEAN COLOUR RADIOMETERS

Description

Ocean colour radiometers are a special case of imaging multi-spectral radiometers which make very sensitive measurements of the intensity of radiation present in a restricted range of wavelengths corresponding to that characteristic of ocean features. Typically, bands in the visible and near IR spectrum in the range 0.4 to 0.8 microns are sampled. Differences in the intensity of light received in the different bands gives information on the concentration of different substances present in the ocean.

These instruments have very narrow detection channels, just several nanometres wide, to measure fine spectral details.

Horizontal spatial resolution is generally low (at best of order 1 km), but swath widths of many hundreds of km allow large scale images of the ocean to be generated. Future developments may result in ocean colour radiometers with a much improved spatial resolution, which would be particularly useful for local studies.

Applications

The colour of the oceans as seen from space is an indirect measurement of the ocean biomass, via phytoplankton pigment concentration (chlorophyll). This parameter is of considerable oceanographic and potential climatological significance, and may also be used to guide fishing fleets to nutrient-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).

USNMFS

Fishing fleet management benefits from ocean colour information provided by Earth observation satellites.

Ocean colour instruments provide valuable wide-area information on water quality and biology.

POLARIMETER RADIOMETERS

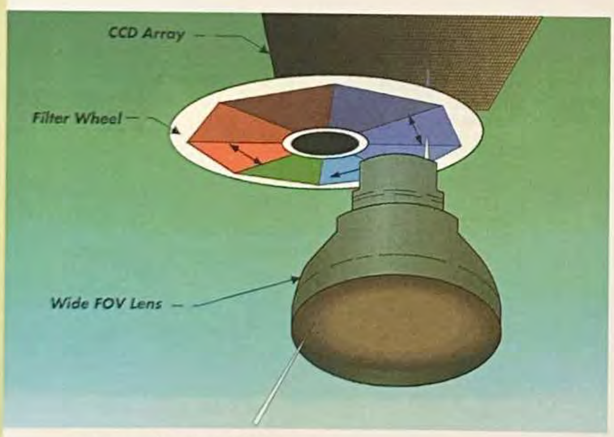
Description

Polarimeter radiometers form another special category of imaging radiometer. They are used for applications in which the key 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. Polarimeter 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 polarimeter radiometers have a multi-directional capability so that directional information can also be determined. There are as yet few examples of this category of instrument.

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.

Polarimeter 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 investigations of albedo and reflectance, agriculture, and the classification of vegetation.



CNES

Concept for the POLDER instrument to be launched in 1996.

Description

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

To date, most spaceborne radar altimeters have been wide-beam systems operating from low Earth orbits. Such altimeters are useful for relatively smooth surfaces such as oceans, but are less effective 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 2 to 4 cm);
- 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).

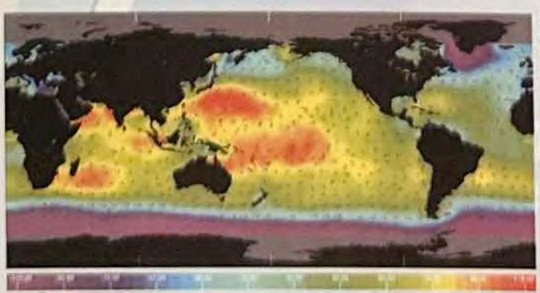
Applications

Parameters which can be inferred from radar altimeter measurements include: the topography of the ocean surface; the lateral extent of sea ice and the altitude of ice bergs 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, 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 velocity field and significant wave heights.

CNES

Altimetry satellites, tide-gauge networks, and land and satellite-based geodetic location systems are vital for accurate, long-term continuous monitoring of sea level.



NASA

TOPEX/POSEIDON has provided valuable information on dynamic topography of the world's oceans.

INSTRUMENT CATALOGUE

ALT

RA

RA-2

SSALT

SSALT-2

WIND SCATTEROMETERS

INSTRUMENT CATALOGUE

- AMI (scatterometer mode)
- ASCAT
- NSCAT
- RLSBO with scatterometer
- Sea Winds

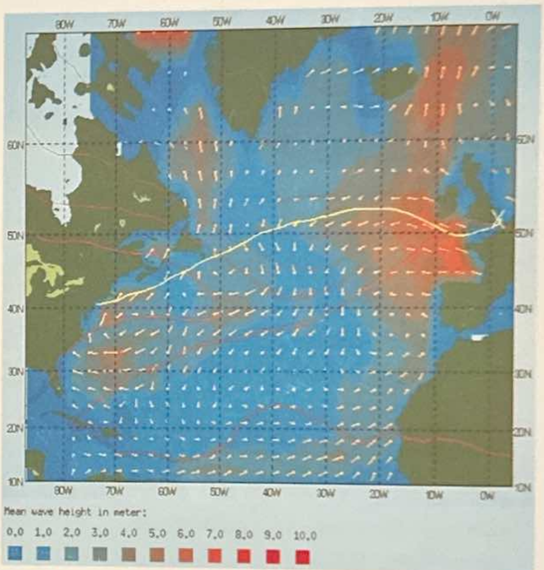
Description

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 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 50 km). Because these scatterometers operate at microwave wavelengths, the measurements are available irrespective of weather conditions.

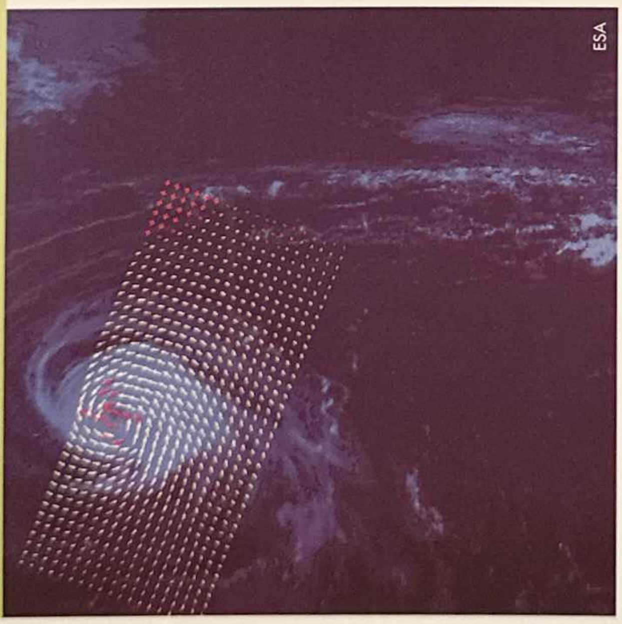
Applications

Information from wind scatterometers provides a unique source of data on sea surface wind speed and direction which has important applications in 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, tundra, and deserts.



Deutsche Aerospace and MPI for Meteorology.

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



Wind speeds of over 15m/sec were mapped near the eye of Hurricane Emily in 1993 by ERS-1.

4 Future provision of data

4.1 INTRODUCTION

There are over twenty satellites currently flying (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 geophysical parameters which span the whole spectrum of the environment including atmosphere, land, ice and snow, and oceans. Some of the key observations contributed by EO satellites can be considered within 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

This list is derived from the definition of requirements undertaken by the CEOS Affiliate agencies. Although those requirements relate primarily to global environmental programmes, the above measurements are relevant to many applications on many different scales.

A number of these measurements are routinely provided by today's satellites, and future missions planned by CEOS agencies will provide continuity and enhanced capabilities – and with them a clearer understanding of our environment.

This section identifies the satellite sources of data for any particular measurement requirement from the list above and indicates the potential 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 continuity or high volumes of data at any time will need to look to various satellite missions, planned by different agencies worldwide. As such, a significant degree of coordination in mission planning and data provision is required between these data providers to ensure that reliable data sources are guaranteed.

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 data sets required for the global environmental programmes of agencies such as the World Meteorological Organisation (WMO), the International Council of Scientific Unions (ICSU), the Intergovernmental Oceanographic Commissions (IOC), the United Nations Environment Programme (UNEP) and Food and Agriculture Organisation (FAO) and Office of Outer Space Affairs (UNOOSA). These programmes are major international, interagency initiatives such as the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), the World Climate Research

Programme (WCRP), and the International Geosphere-Biosphere Programme (IGBP). All of these programmes are affiliated to CEOS which provides the forum for an ongoing liaison between the environmental agencies and the space agencies with a view to: developing a common dialogue between data providers and data users; communicating user requirements; and ultimately harmonising international Earth observation plans to provide a strategy which will provide the information to satisfy global needs and to ensure maximum return – in terms of data utilisation – from the resources invested in support of Earth observing space missions.

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

4.2 OVERVIEW

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

- Chemistry and dynamics of the stratosphere are currently being studied using data from the NASA UARS mission. UARS is providing a global picture of the stratosphere and its diurnal and seasonal variations.
- Atmospheric humidity and temperature profiles are routinely provided for operational meteorology by the NOAA polar orbiting satellites.
- Atmospheric winds (through cloud tracking), cloud amount, and tropical precipitation estimates, are provided for most of the globe by the geostationary meteorological satellite series Meteosat, GOES, GMS, 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, ATSR, those on SPOT, Landsat, Resource, and IRS series; SAR sensors include those on the ERS series and JERS-1. Further future missions and increasing sensor resolution will ensure improved data collection and application opportunities.
- Sea surface temperature information is being generated by data from existing meteorological satellites and from instrumentation on the ERS series. Future plans, including the ADEOS series, 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. Contributing satellites include Topex/Poseidon and the ERS series.

- Sea ice and ice sheet extent are being measured by a range of missions and continuity is planned – notably through RADARSAT due for launch in 1995.

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 instrumentation – such as the Precipitation Radar featured on TRMM and the concept demonstrators for cloud and rain radars and doppler lidar instruments proposed for future missions.
- Improved repeat coverage of many oceanographic measurements, plus new capabilities in measuring ocean colour and biology – starting with SeaStar in 1995.
- 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 the ADEOS and EOS-AM series will also provide new data for studies of the Earth surface.

4.3 MEASUREMENT TIMELINES

For each measurement category listed in section 4.1, 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 1995-2010 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 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.

Note also that the instrument timelines for *ESA Future Missions* refer to candidate ESA missions following on from ENVISAT in 2003 and do not suggest specific plans for missions or instruments over that period.

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. Information on instrument measurement capabilities is based on data supplied by the relevant space agency. Statements regarding adequacy of measurements are generally with regard to global environmental/climate change programme requirements – as expressed by the CEOS affiliate agencies.

AEROSOLS

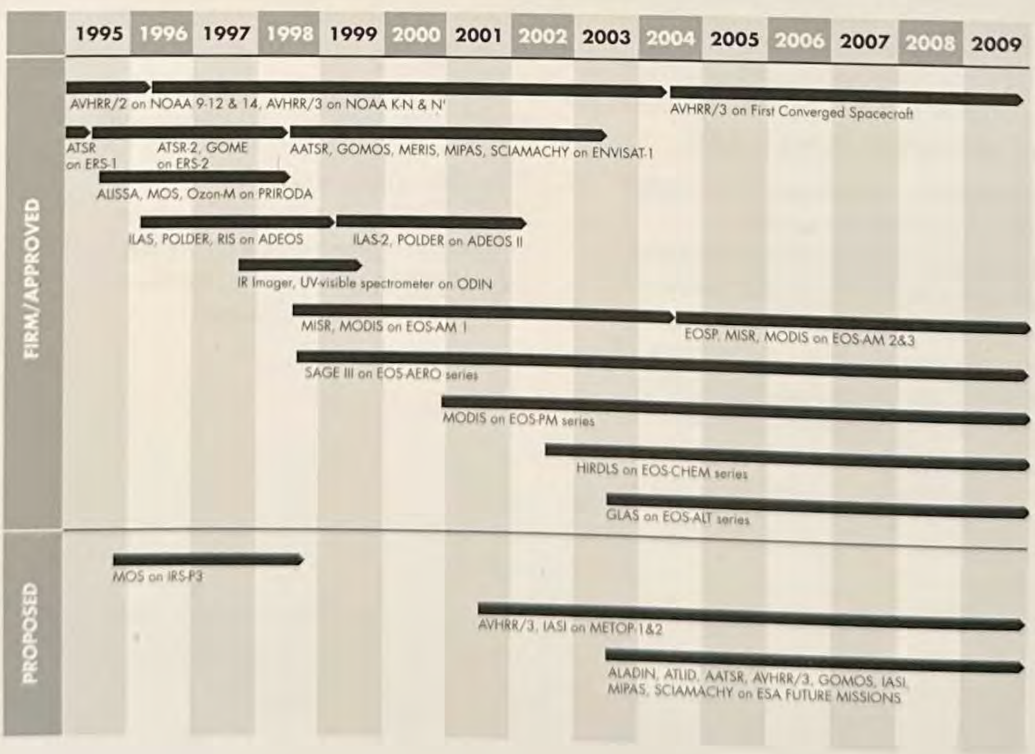
The concentration and distribution of aerosols, eg dust or sulphate particles, in the atmosphere is of great significance for the study of the climate system. Their presence directly affects the absorption and transmission of solar radiation and hence alters the energy balance of the Earth system. In 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 current techniques using 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. MODIS, MISR and MERIS 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 ATSR-2 (and its successors), MISR, EOSP and POLDER also provide more detailed information (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).



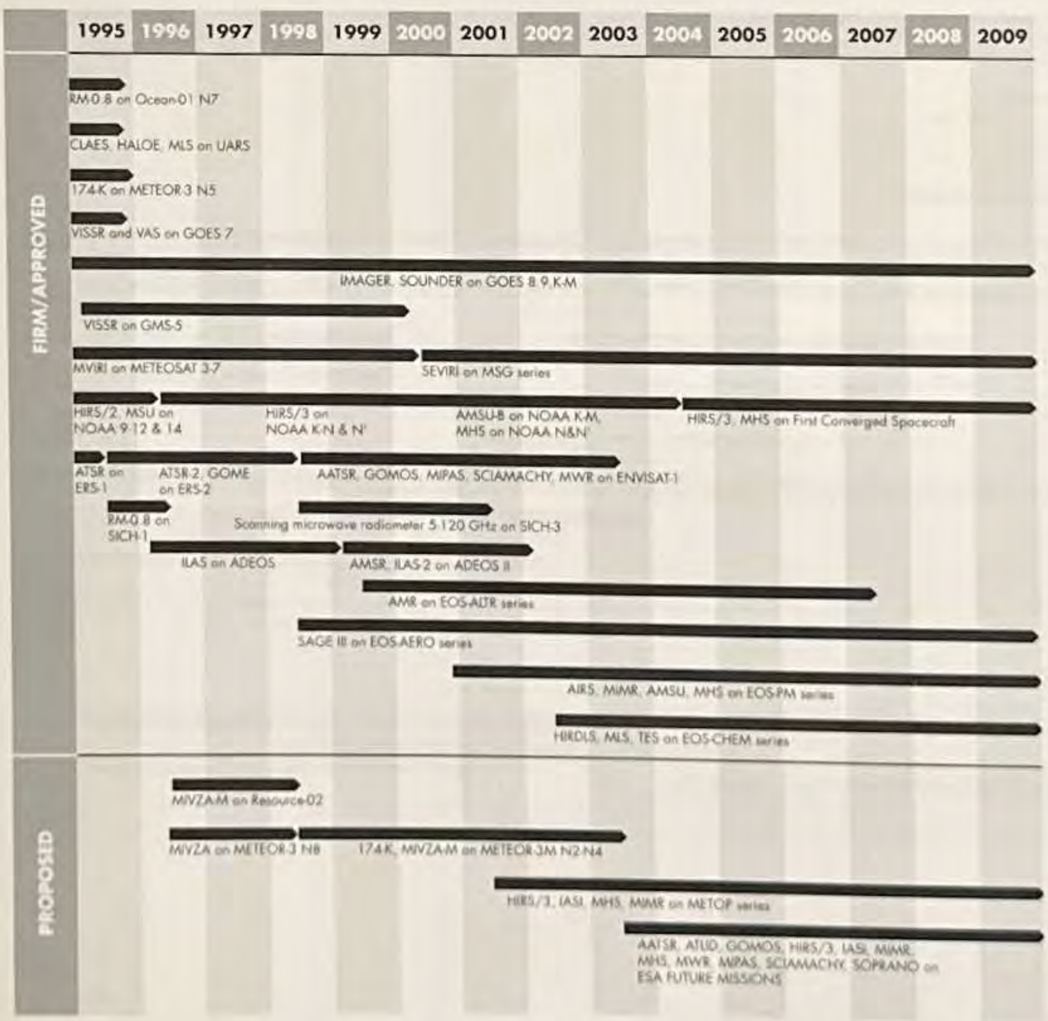
ATMOSPHERIC HUMIDITY FIELDS

Measurements of atmospheric humidity are needed for many applications. Used together with vertical temperature soundings, humidity profiles are useful for supplementing conventional observations as inputs to global 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 required 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. A 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.



Atmosphere

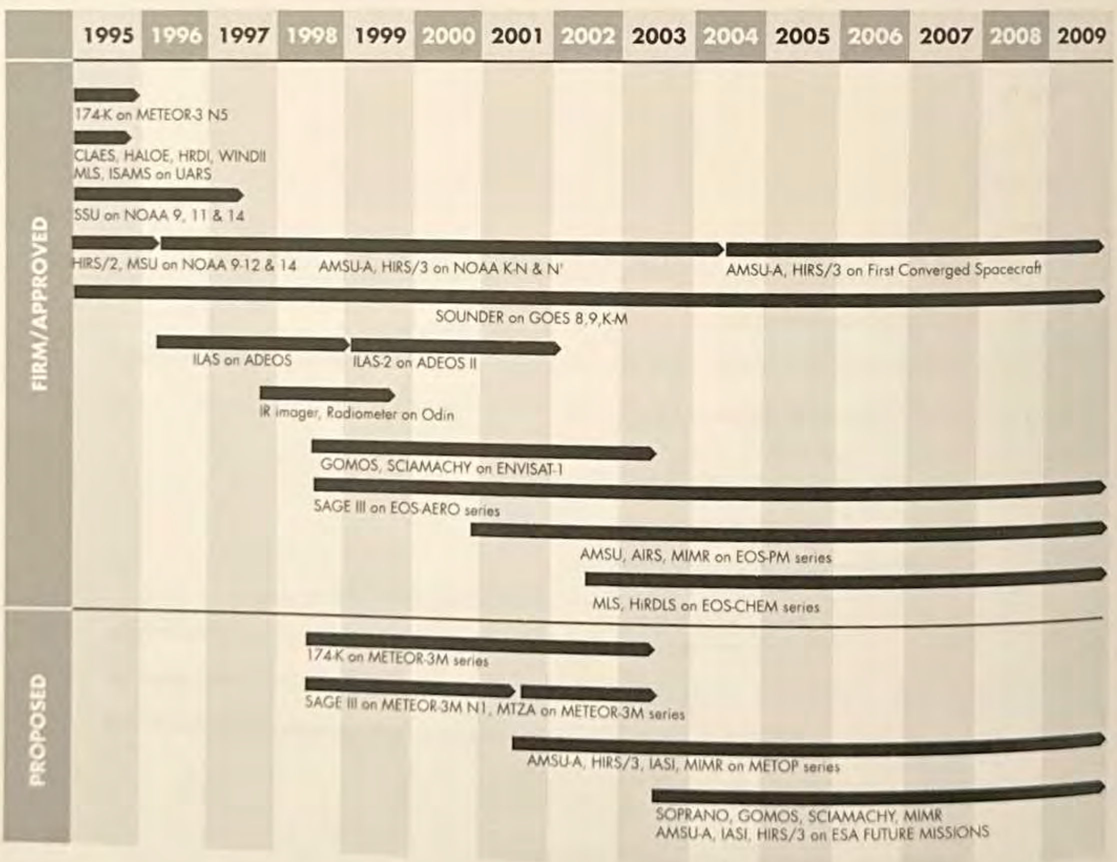
ATMOSPHERIC TEMPERATURE FIELDS

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 numerical 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 – a process combining satellite and in-situ observations together with model predictions of temperature and associated variables. Current research is aimed at utilising multi-spectral radiances, rather than retrieved temperatures profiles, in the 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 10-100 km 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 and 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.



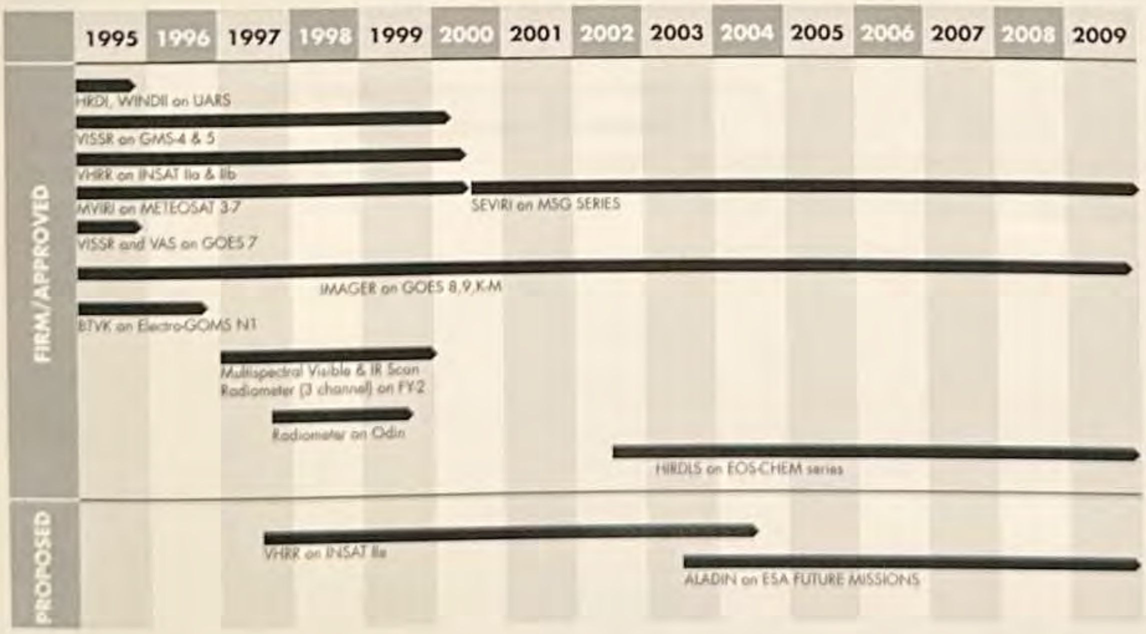
ATMOSPHERIC WINDS

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. Atmospheric winds are a key meteorological parameter. 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. Atmospheric winds at high latitudes 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 relatively 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 these 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 section.

Atmosphere



CLOUD TYPE, AMOUNT AND CLOUD TOP TEMPERATURE

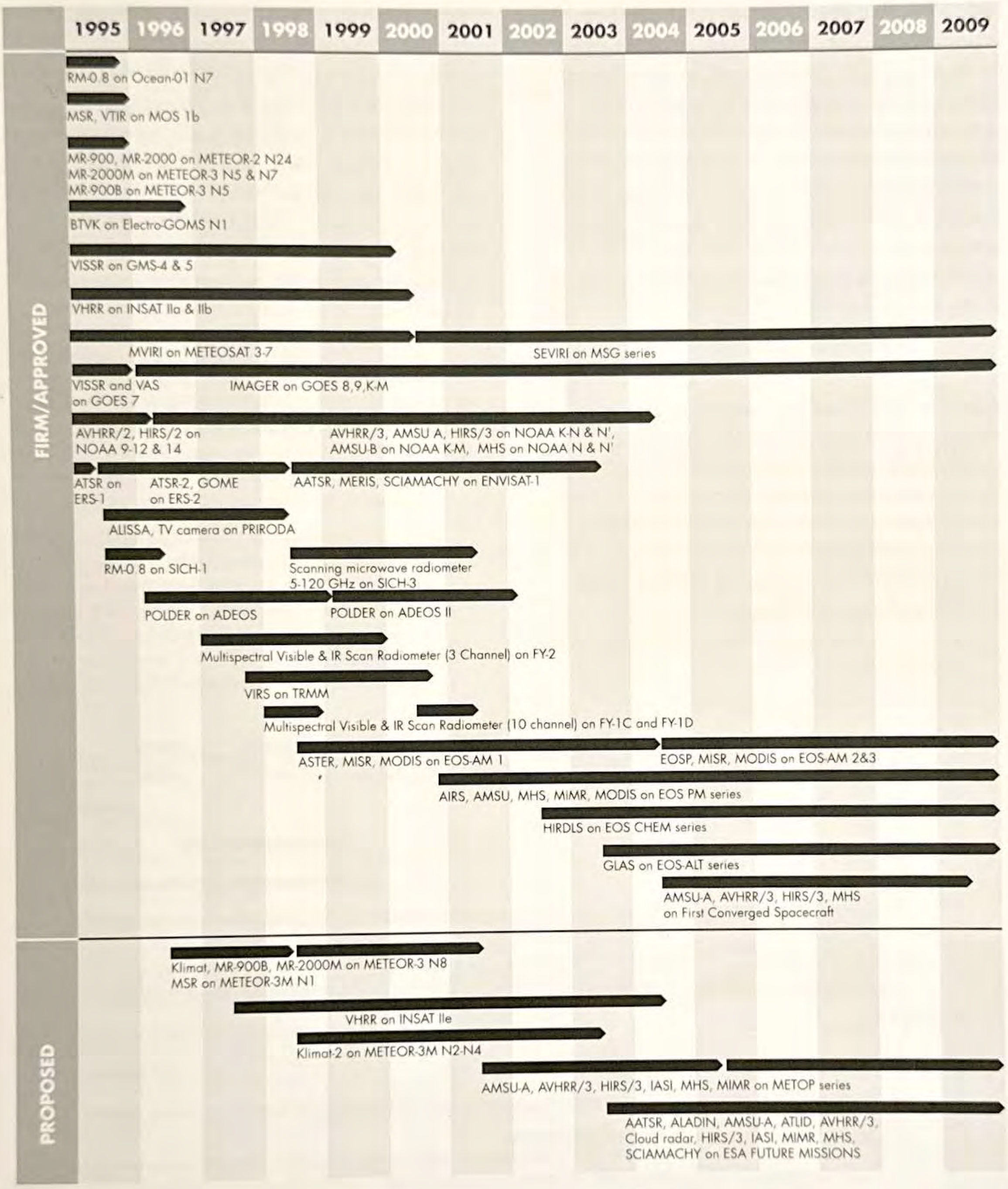
Better understanding of the role of clouds in climate has been identified as one of the highest priorities for further research since the potential feedback effect of clouds is a major source of uncertainty in predictions of greenhouse warming (see, for example, the assessment of the Intergovernmental Panel on Climate Change). 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 by 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 and imagery from geostationary satellites will be greatly enhanced with the new generation of instruments such as MODIS, MERIS, EOSP, MISR and POLDER, 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.

Atmosphere



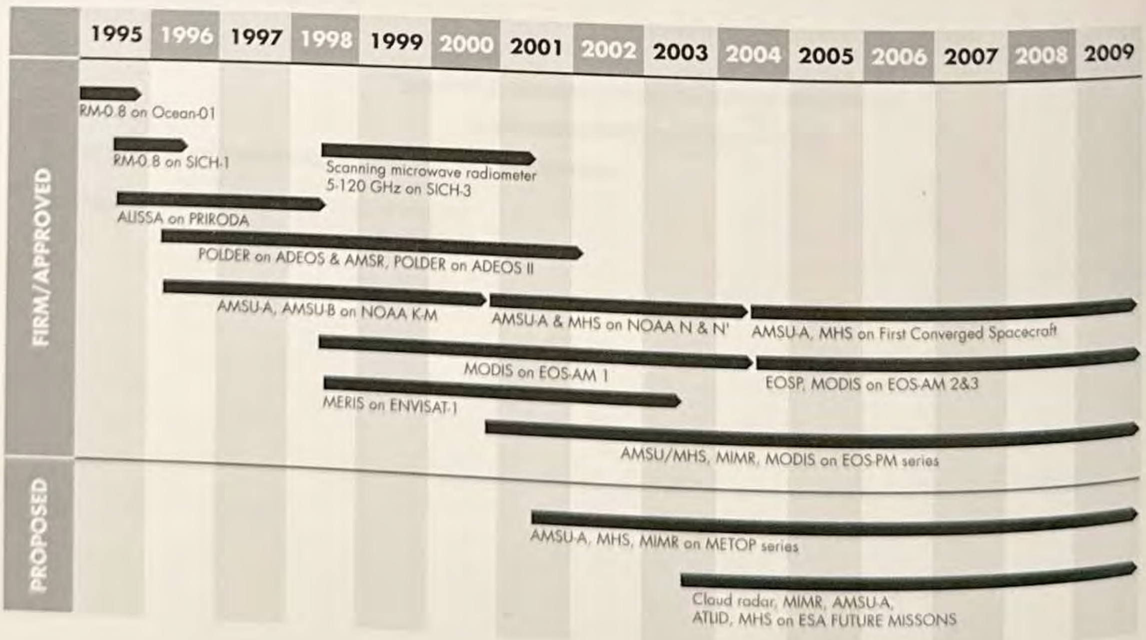
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
FIRM/APPROVED
RM-0.8 on Ocean-01 N7
MSR, VTIR on MOS 1b
MR-900, MR-2000 on METEOR-2 N24
MR-2000M on METEOR-3 N5 & N7
MR-900B on METEOR-3 N5
BTVK on Electro-GOMS N1
VISSR on GMS-4 & 5
VHRR on INSAT IIa & IIb
MVIRI on METEOSAT 3-7
SEVIRI on MSG series
VISSR and VAS on GOES 7
IMAGER on GOES 8,9,K-M
AVHRR/2, HIRS/2 on NOAA 9-12 & 14
AVHRR/3, AMSU A, HIRS/3 on NOAA K-N & N', AMSU-B on NOAA K-M, MHS on NOAA N & N'
ATSR on ERS-1
ATSR-2, GOME on ERS-2
AATSR, MERIS, SCIAMACHY on ENVISAT-1
ALISSA, TV camera on PRIRODA
RM-0.8 on SICH-1
Scanning microwave radiometer 5-120 GHz on SICH-3
POLDER on ADEOS
POLDER on ADEOS II
Multispectral Visible & IR Scan Radiometer (3 Channel) on FY-2
VIRS on TRMM
Multispectral Visible & IR Scan Radiometer (10 channel) on FY-1C and FY-1D
ASTER, MISR, MODIS on EOS-AM 1
EOSP, MISR, MODIS on EOS-AM 2&3
AIRS, AMSU, MHS, MIMR, MODIS on EOS PM series
HIRDLS on EOS CHEM series
GLAS on EOS-ALT series
AMSU-A, AVHRR/3, HIRS/3, MHS on First Converged Spacecraft
PROPOSED
Klimat, MR-900B, MR-2000M on METEOR-3 N8
MSR on METEOR-3M N1
VHRR on INSAT IIe
Klimat-2 on METEOR-3M N2-N4
AMSU-A, AVHRR/3, HIRS/3, IASI, MHS, MIMR on METOP series
AATSR, ALADIN, AMSU-A, ATLID, AVHRR/3, Cloud radar, HIRS/3, IASI, MIMR, MHS, SCIAMACHY on ESA FUTURE MISSIONS

CLOUD PARTICLE PROPERTIES AND PROFILE

Full 3D observations of cloud structure are at very early stages of development, with probably another decade of development required before sensors are in orbit that will go some way to meeting users' requirements. In the nearer term, basic information on the structure of clouds (ie determination of whether there are water or ice particles) can be obtained from future microwave instruments such as MIMR and 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 above), information on the 3D structure of clouds (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 and its successors should also be able to make this type of measurement. As discussed above, in the slightly longer term, microwave radiometers such as MIMR and AMSR will provide some cloud phase information. Additional phase information will also be available from polarimeter radiometers such as POLDER and EOSP. However, the users' requirements are unlikely to be met until data from a cloud radar profiler is available.



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. Hence observations of the spatial and temporal distribution of precipitation over the globe are essential to assist in modelling and predicting patterns of possible global change as well as for operational weather forecasting. 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 reliable 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 also 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 contribute to measurements 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 MIMR and 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 will provide data principally over the tropics and although this region is of particular interest, there is likely to remain a requirement for coverage of polar regions at high spatial resolution.

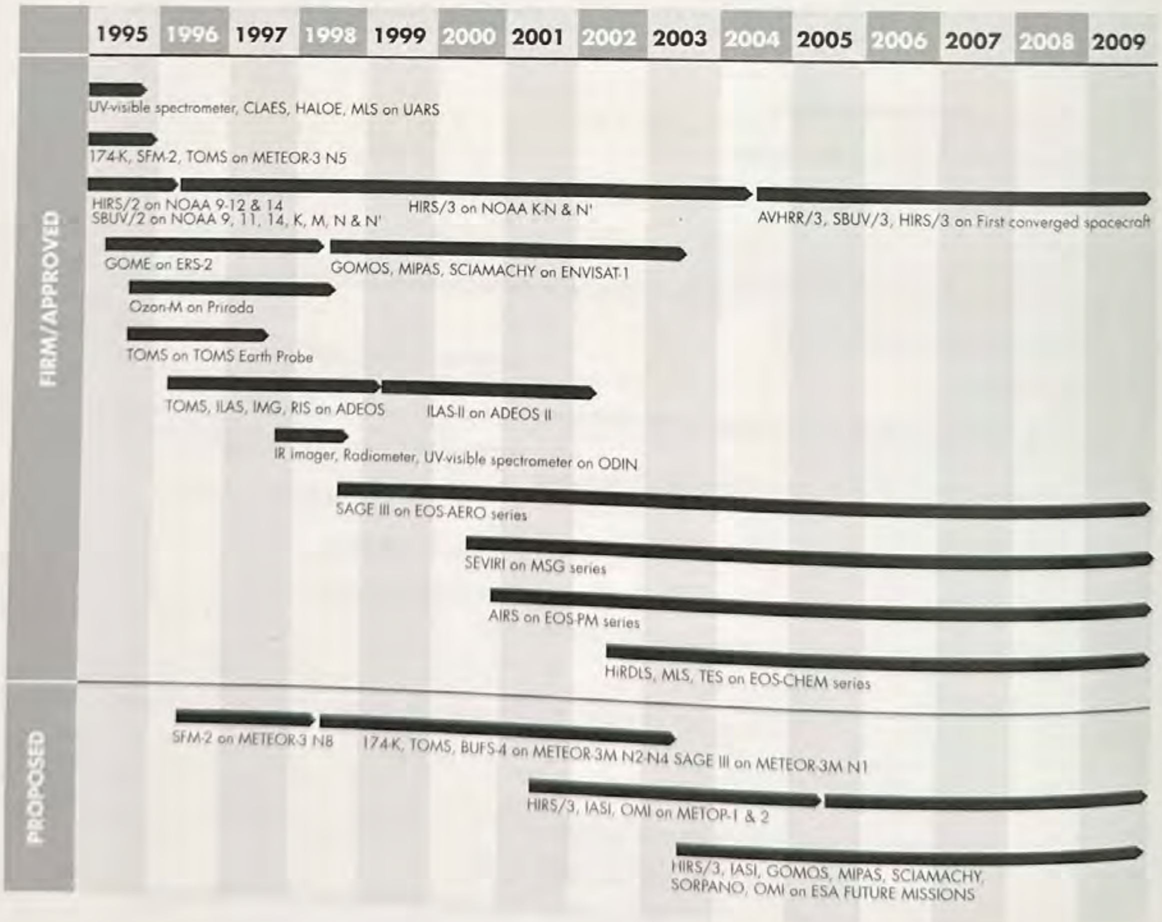
Given the very high temporal and spatial variability of precipitation it is a fundamentally difficult parameter to measure. All remote sensing techniques require high quality ground truth data for calibration purposes. Indeed it is likely that for the foreseeable future, the best datasets will comprise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

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 other missions since, and SBUV on the NOAA polar orbiters.

Stratospheric ozone profiles are currently measured using the suite of instruments including CLAES on UARS. In the near future, measurements from GOME (recently launched) IMG and ILAS will become available and these will be joined later by measurements from the various ESA and EOS missions. Tropospheric ozone profile measurements will also improve with measurements from SCIAMACHY, MIPAS and HIRDLS covering the upper troposphere and above. Profiles from the Earth's surface (a region of the atmosphere not covered at present) will be provided in the longer term by TES. Future sounders such as IASI and AIRS will also provide useful information on total ozone observations.

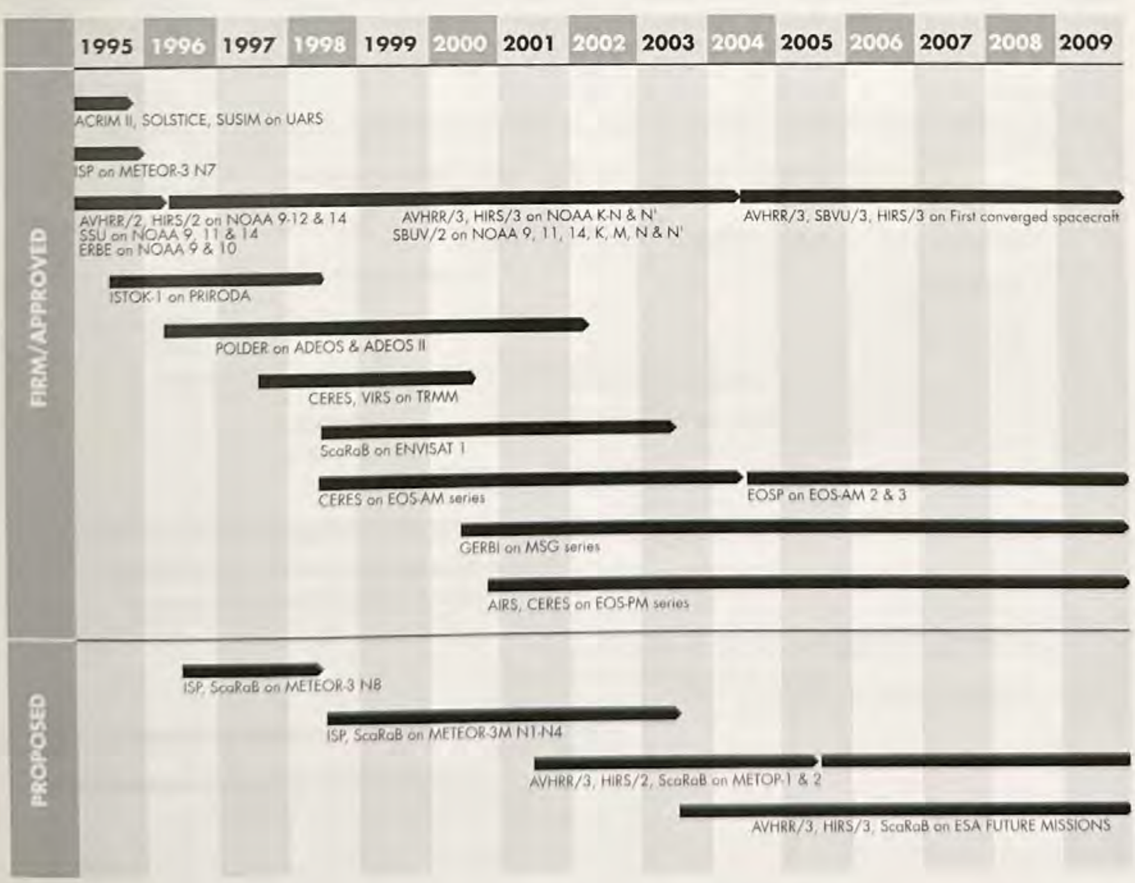


RADIATION BUDGET

Satellite measurements offer a unique way 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 sheets, which may be used to monitor and assess the effects of global warming.

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 way to meet these requirements is currently a research topic. It should also noted that it is not possible to measure directly, on global scales, the radiative imbalance deemed to lead to global warming (as this would require a measuring 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. At present, some information is being obtained from the narrow band HIRS and AVHRR instruments. In the near future, measurement capability will be enhanced by POLDER on ADEOS and the CERES sensors on the EOS series. The broadband radiometer planned for flight on MSG (GERBI) will allow "perfect" temporal sampling with a radically different viewing geometry to complement the information available from polar orbiting satellites.

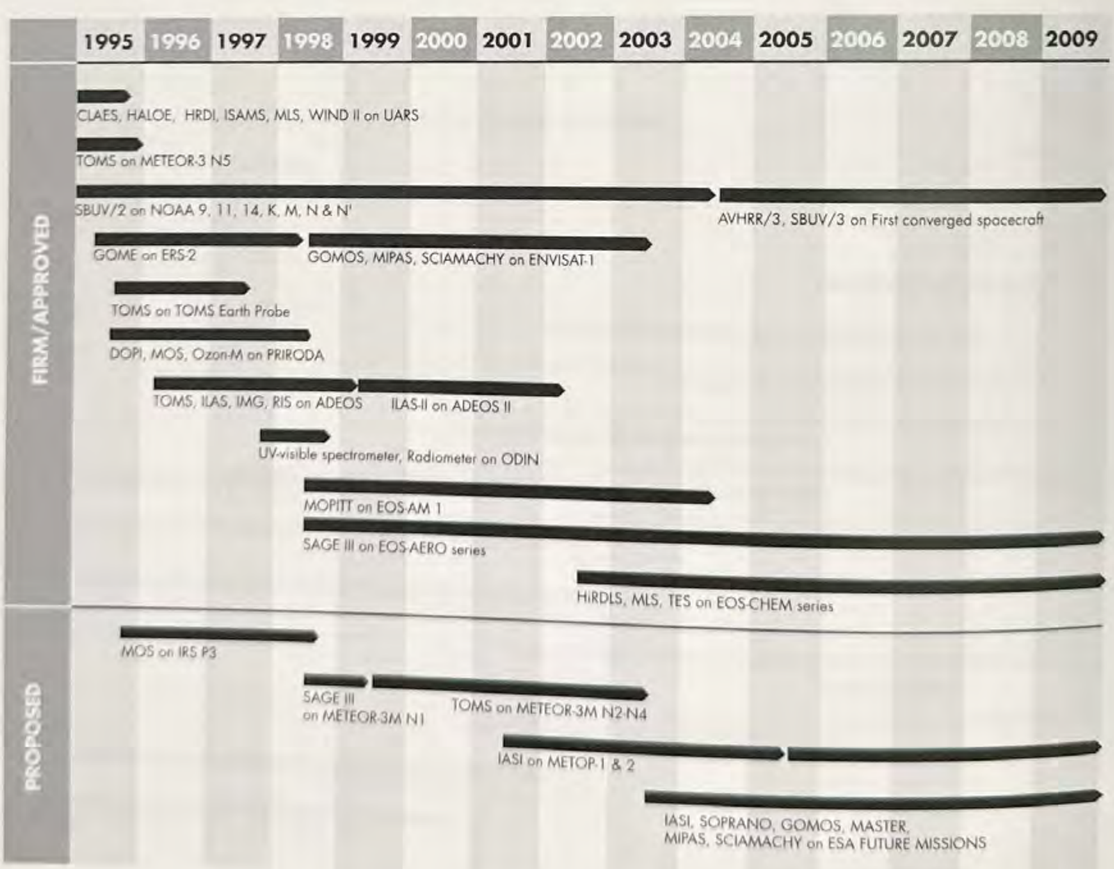


TRACE GASES (EXCLUDING OZONE)

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 gas 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 much research.

A variety of instruments are available to provide measurements on the concentration of trace gases. In general, high spectral resolution is required to detect the absorption, emission, or scattering from individual species. Some instruments offer measurements of column totals, ie integrated column measurements, 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). At present, the instruments on UARS provide the main source of this type of data (with other instruments available on ERS-2 (GOME) and planned for the ADEOS and EOS series). In the future, measurements should improve as instruments such as TES will become available to provide profiles of a number of trace gases through the troposphere, and MIPAS and SCIAMACHY will profile the upper troposphere and above.



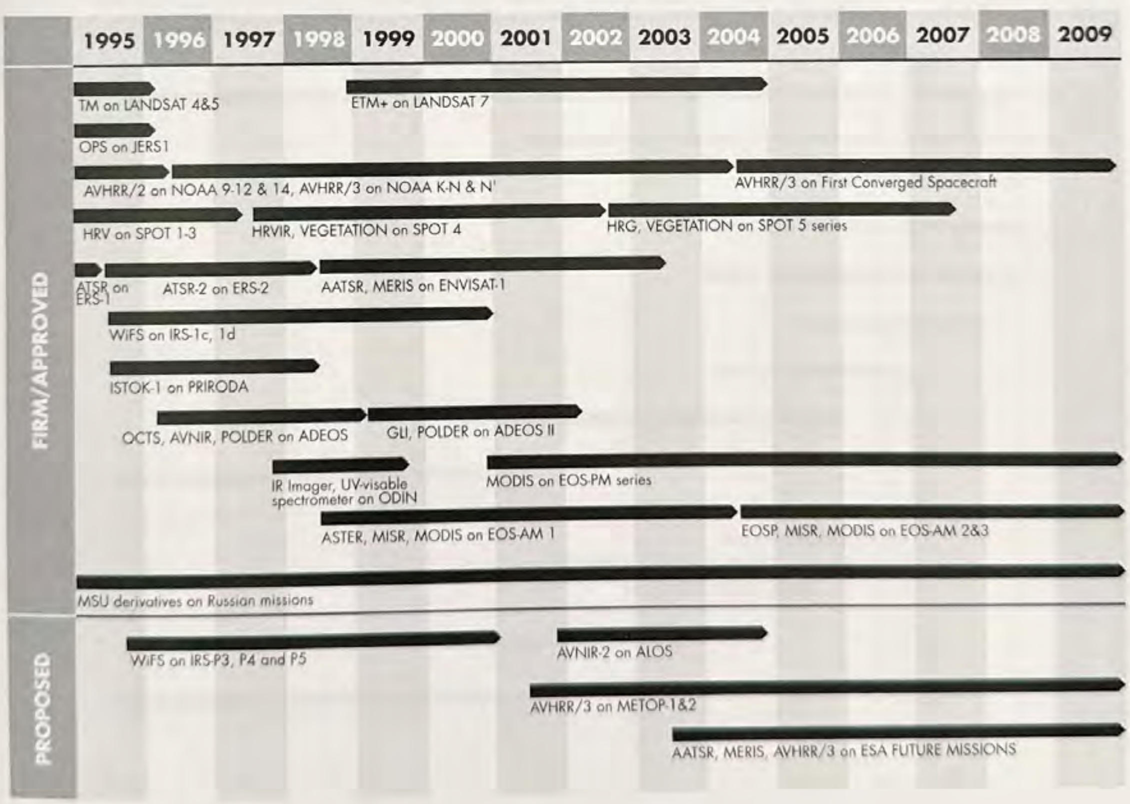
ALBEDO AND REFLECTANCE

Quantitative measurements of albedo are essential for climate research studies and investigations of the Earth's energy budget. Albedo and reflectance 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 albedo 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 which depends on, amongst other things, the anisotropy of the surface and the solar position. Detailed in-situ experiments are still required to enable adequate parameterisations 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 above) to enable atmospheric effects to be correctly subtracted when measuring surface reflectance properties.

Measurements of albedo may also be used for monitoring the sensitivity of satellite radiometers: routine survey of radiance measurements over selected targets of high albedo in clear sky regions allows 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, SPOT and LANDSAT. Geostationary sensors can also contribute information. However, many of these measurements are inadequate for climate research since instrument calibration is insufficiently accurate, and more work is required on algorithms to extract global information on surface albedo. Future measurements using multi-directional radiometers such as MISR and AATSR will allow measurement of the directional nature of surface reflectance, and polarimetric sensors such as POLDER should also increase understanding.

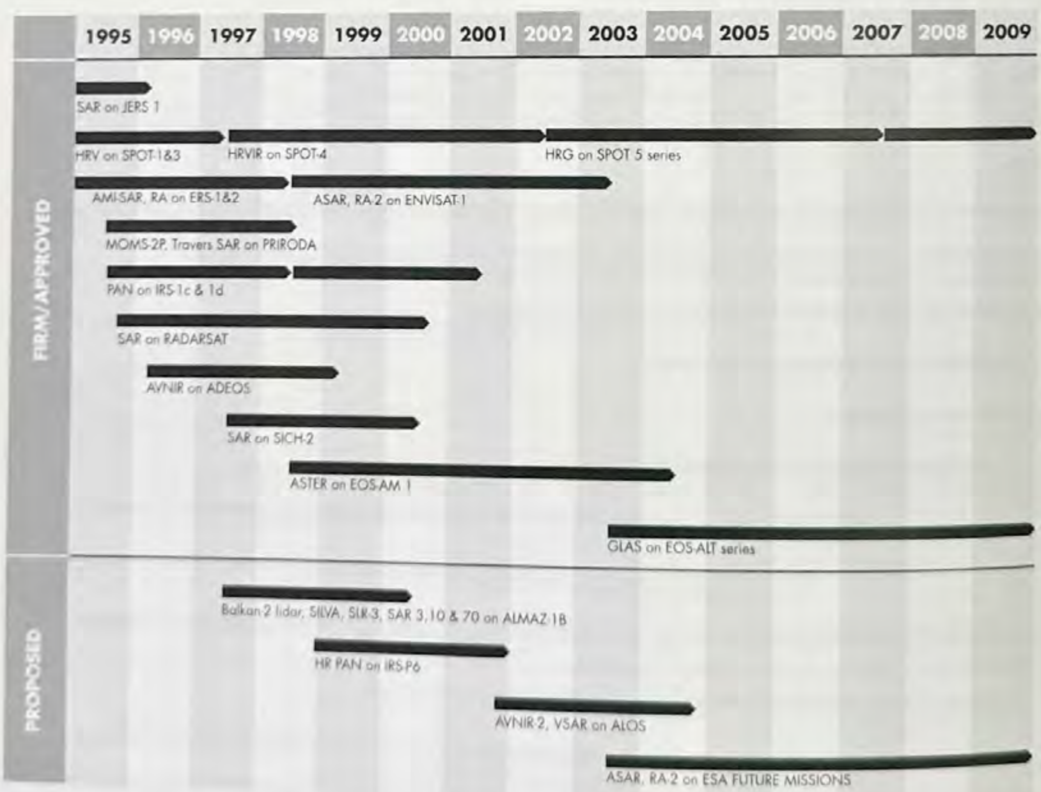


LANDSCAPE TOPOGRAPHY

Many modelling activities in Earth and environmental sciences increasingly require accurate, high resolution and comprehensive topographical databases with, where relevant, some 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 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 avoid loss of life and property; interferometric techniques may also be used to measure landslides, and earthquake displacements. 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 visible imagers and SAR instruments. Good results are obtained from stereo optical instruments and SARs which have a stereo image capability. The pointing of SPOT, for example, allows the production of stereo images from data gathered on different orbits which are used to create digital elevation maps which give a more accurate depiction of terrain. SARs may 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 run-off, 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 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, although some success has been achieved using radar – despite the complications of analysing the the signals reflected from the ground. Passive microwave sensors can also be used to infer information based upon surface surface microwave emissions, although the signal is very small. Reliable (high signal to noise ratio) data need to be taken over a large area – which introduces the problem of understanding how to interpret the satellite signal since it comes 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, 1.4 GHz), except under very dry conditions.

SAR data currently provide the main source of information, giving information on near-surface soil moisture to a depth of 5 cm 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. Soil moisture is a very 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. Data will also be able to be derived from passive microwave instruments such as MIMR and 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

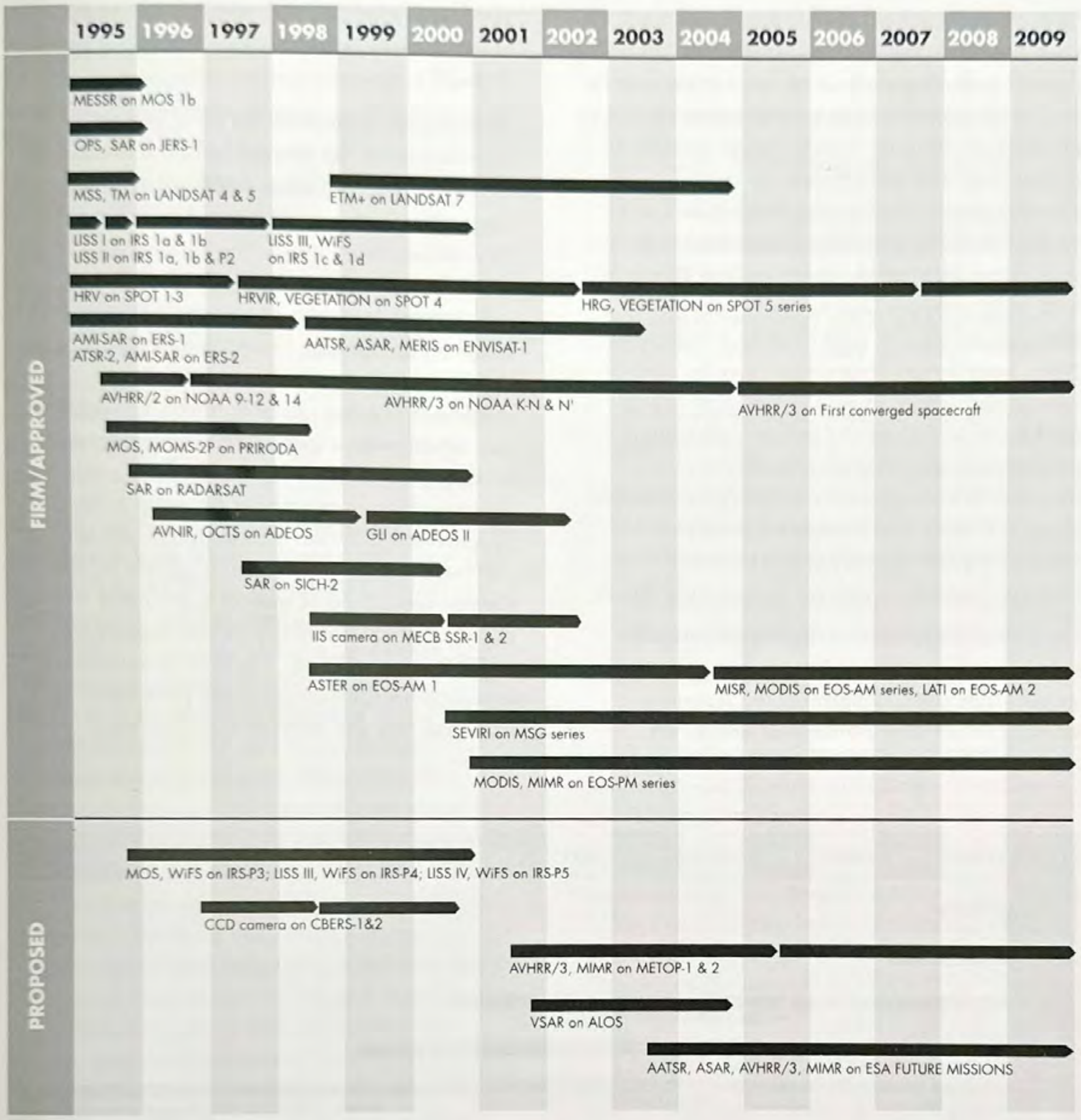
Changes in land cover are an important source of global environmental change and have implications for ecosystems, biogeochemical fluxes and the global climate. Land cover change affects climate through a range of factors from albedo (desertification, for example, results in changes in albedo which itself alter 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 carbon dioxide from the atmosphere which in turn may contribute to a better understanding of the part vegetation plays in modifying the effects of man-made carbon dioxide. However, for these detailed studies, the resolution requirements 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 allow 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. Other 'local' applications of EO data include locust plague control – imagery is used to monitor vegetation growth in areas susceptible to locust swarms and to thereby identify areas to be pre-emptively sprayed – and to determine the possible extent of drought-threatened areas.

There is also significant potential for the use of EO data 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 been felled. 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 resolution information is obtained from mapping radars such as SAR, although the global coverage and temporal resolution offered by current and planned radar sensors is limited.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MESSR on MOS 1b
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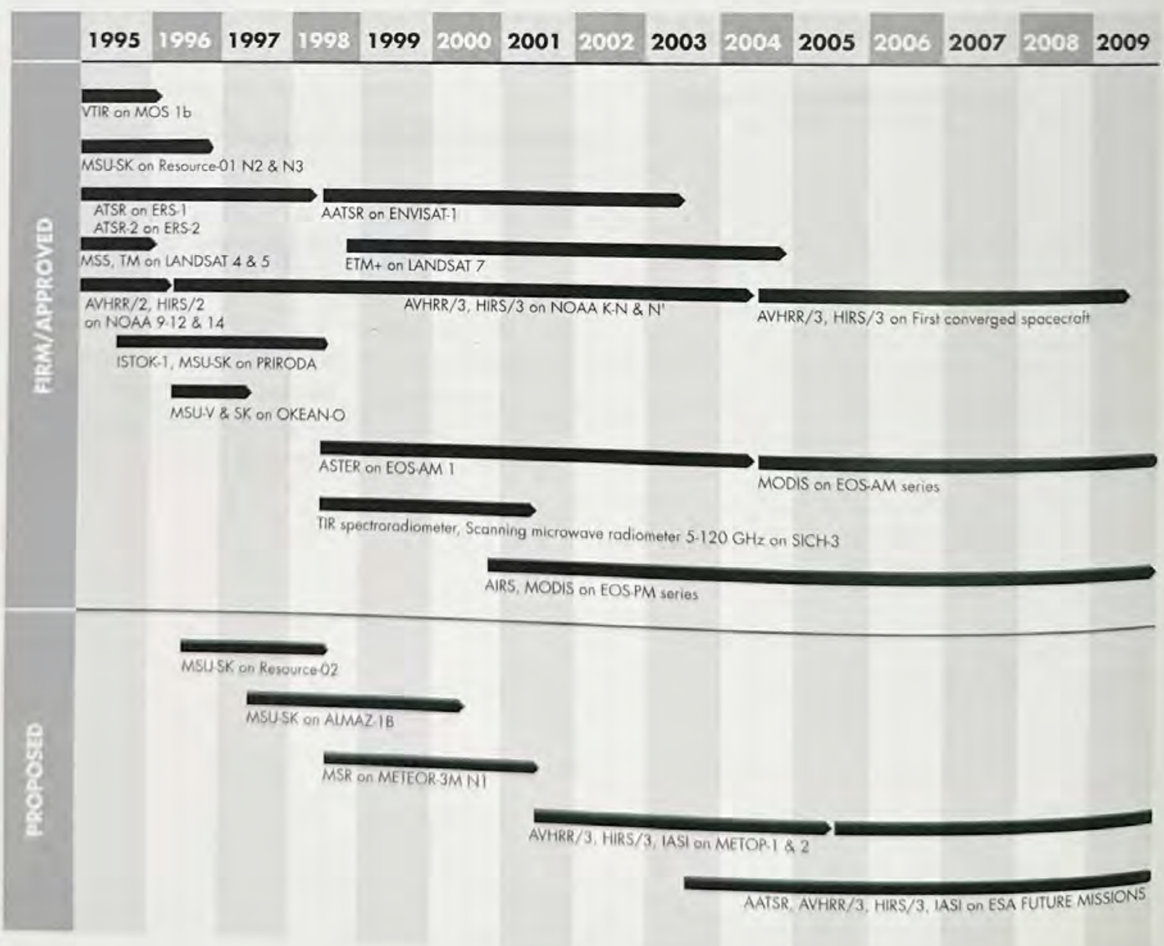
ETM+ on LANDSAT 7
LISS I on IRS 1a & 1b
LISS II on IRS 1a, 1b & P2
LISS III, WiFS on IRS 1c & 1d
HRV on SPOT 1-3
HRVIR, VEGETATION on SPOT 4
HRG, VEGETATION on SPOT 5 series
AMI-SAR on ERS-1
ATSR-2, AMI-SAR on ERS-2
AATSR, ASAR, MERIS on ENVISAT-1
AVHRR/2 on NOAA 9-12 & 14
AVHRR/3 on NOAA K-N & N'
AVHRR/3 on First converged spacecraft
MOS, MOMS-2P on PRIRODA
SAR on RADARSAT
AVNIR, OCTS on ADEOS
GLI on ADEOS II
SAR on SICH-2
IIS camera on MECB SSR-1 & 2
ASTER on EOS-AM 1
MISR, MODIS on EOS-AM series, LATI on EOS-AM 2
SEVIRI on MSG series
MODIS, MIMR on EOS-PM series
PROPOSED
MOS, WiFS on IRS-P3; LISS III, WiFS on IRS-P4; LISS IV, WiFS on IRS-P5
CCD camera on CBERS-1&2
AVHRR/3, MIMR on METOP-1 & 2
VSAR on ALOS
AATSR, ASAR, AVHRR/3, MIMR on ESA FUTURE MISSIONS

SURFACE TEMPERATURE (LAND)

Measurements of land surface temperature are again important inputs for a range of studies. On a global scale, data on land surface temperature is 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 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 from a range of instruments 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, there remain difficulties 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 resolution offered by the current generation of sensors is poor and will be improved with the advent of new sensors such as ASTER on EOS-AM. The next generation of sounding instruments on board polar-orbiting platforms will also provide improved data.



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.

On the 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:

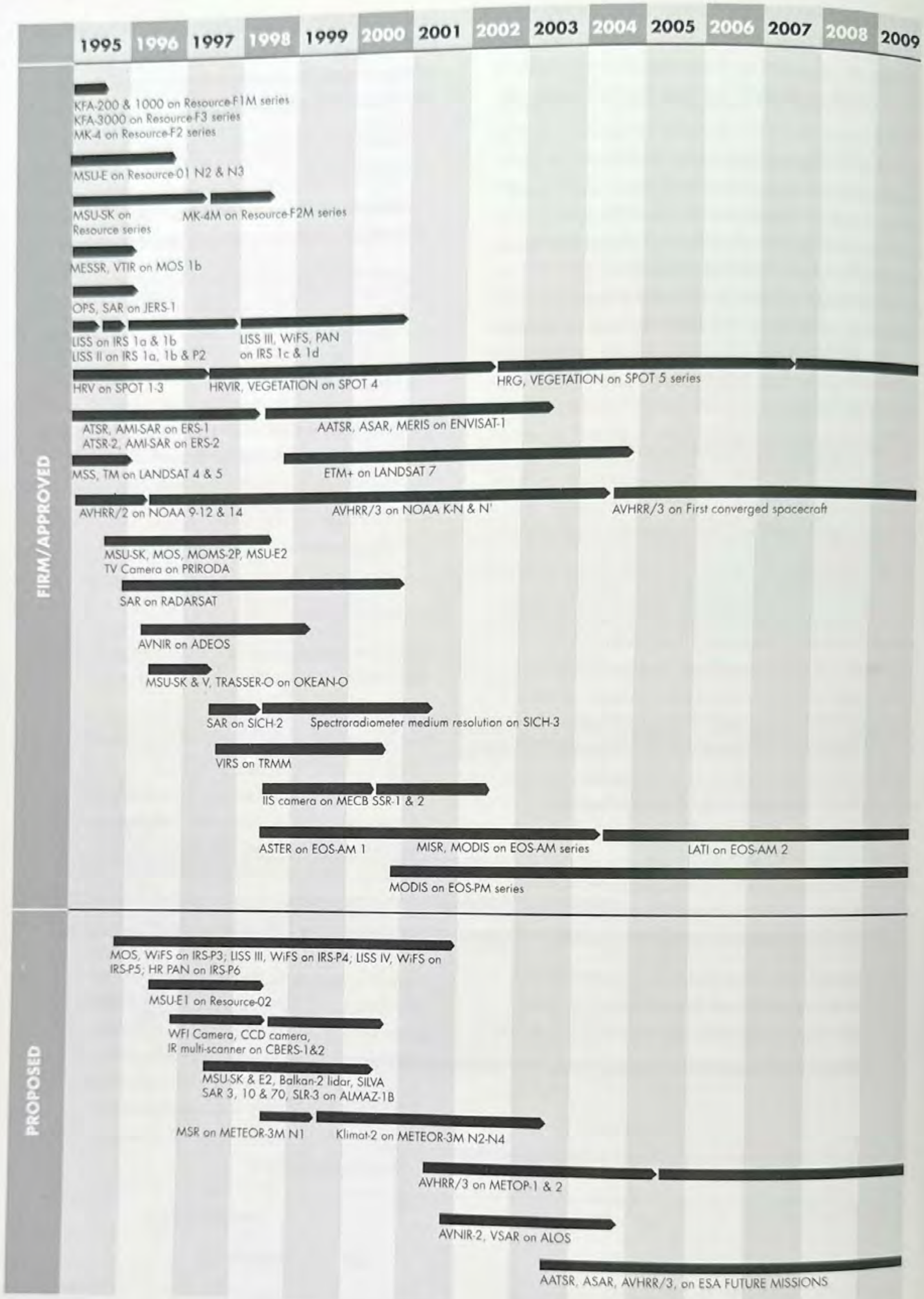
- agriculture: monitoring, prediction, and management;
- resource exploration and management – for example in forestry, and in mineral deposits;
- geological surveying: identifying geological structures and sub-surface geometry (when combined with geophysical survey data), for identifying minerals, water 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 accretion.

High resolution imagery can also be used for land cover classification and change detection on the 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 the different future sensors, for example for better discrimination.

Land

MULTI-PURPOSE IMAGERY (LAND)

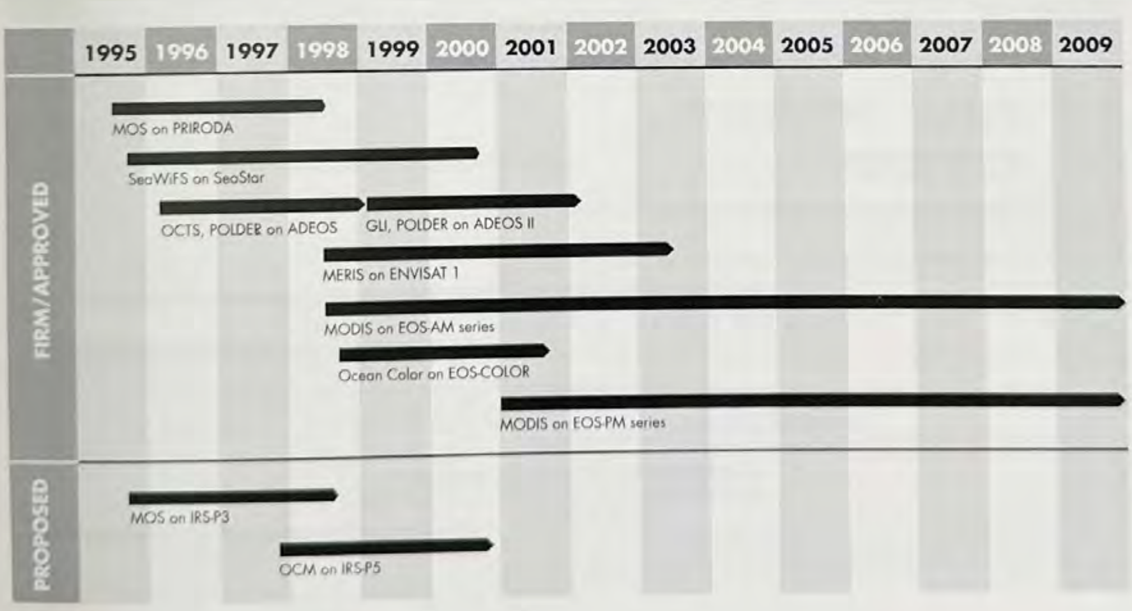


OCEAN COLOUR/BIOLOGY

Measurements of ocean colour give 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 carbon dioxide into other compounds, thereby acting as a biological pump absorbing some of the carbon dioxide released into the atmosphere by fossil fuels. A more fundamental understanding of biological cycles is thus essential in quantifying human impacts on the global biosphere.

On a local scale, satellite observations of ocean colour 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 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 transport.

The launch of SeaWiFS will provide a critical source of data that has 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 – thus, to some extent, alleviating the problem that satellite-based ocean colour data can only be acquired during daylight hours in cloud-free areas. 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 OCTS, MODIS and MERIS.



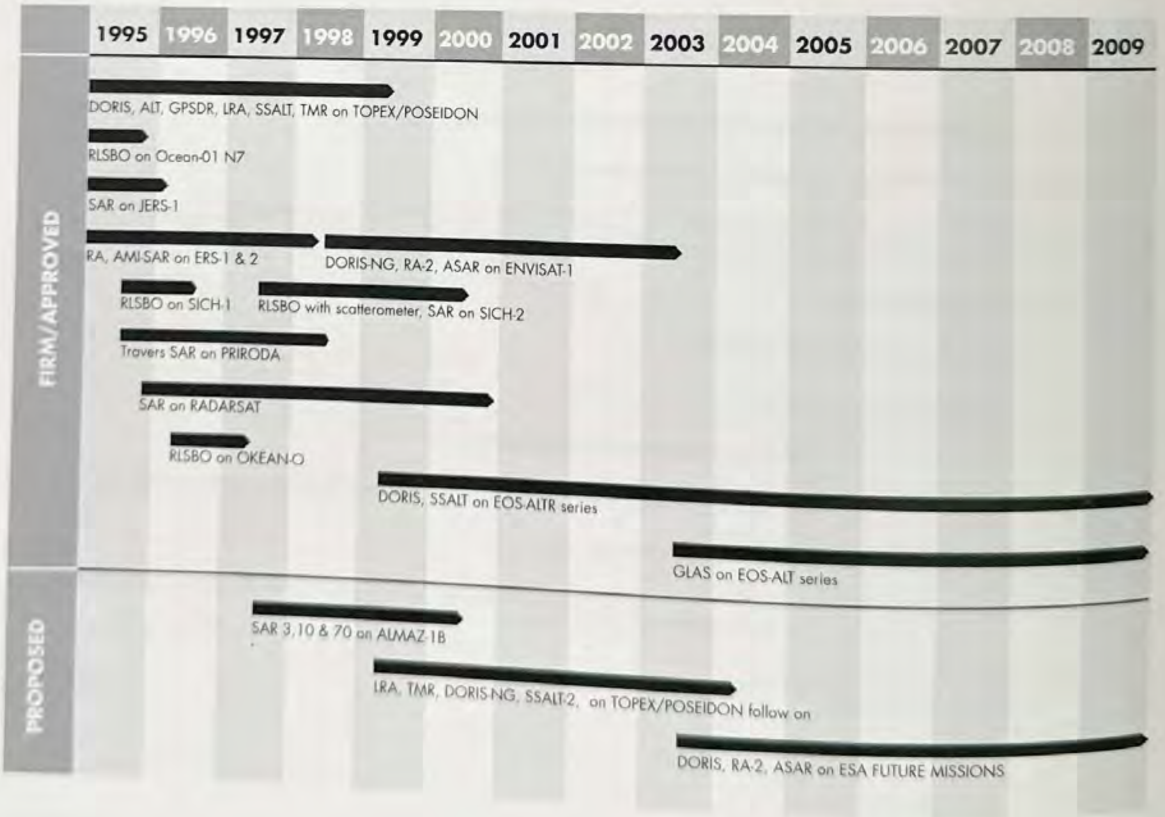
OCEAN TOPOGRAPHY/CURRENTS

Ocean circulation plays an important role in the Earth's climate system. Ocean currents move a significant amount of energy from the tropics towards the poles leading to a moderation of the climate at high altitudes. Thus an understanding of the ocean circulation is central to understanding the global climate. Circulation can be deduced from ocean 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 the El Niño event 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 level, topographic information from satellites may be used in support of off-shore exploration for resources and for optimising pipe-line routing on the sea bed.

Altimeter packages, such as those on the ERS series and on TOPEX/POSEIDON, are capable of measuring ocean topography to better than 10 cm. The TOPEX/POSEIDON platform comprises a dual frequency altimeter which allows corrections to be made for ionospheric delays. Future instruments include the package based on SSALT on EOS-ALT. 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. 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.

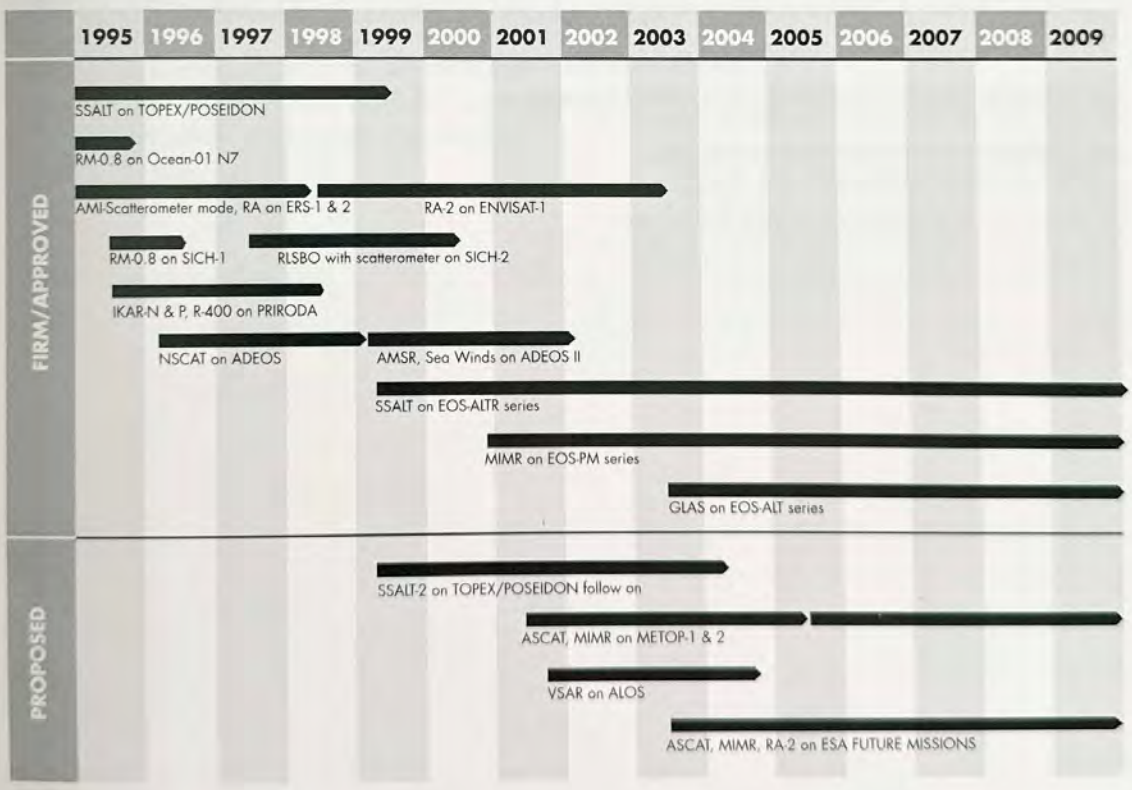


SEA SURFACE WINDS

Consistent sea surface wind data of high quality and high temporal resolution are required for 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 wind currents 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 instrument is limited, however, since they have a single sided field of view, and hence coverage will be greatly improved when scatterometers such as NSCAT on ADEOS and Sea Winds on ADEOS II become operational (as they have dual sided swaths). Measurements of wind speed (but not direction) may also be derived from altimeters such as ALT and RA, and from passive microwave imaging radiometers such as the future MIMR.

Ocean



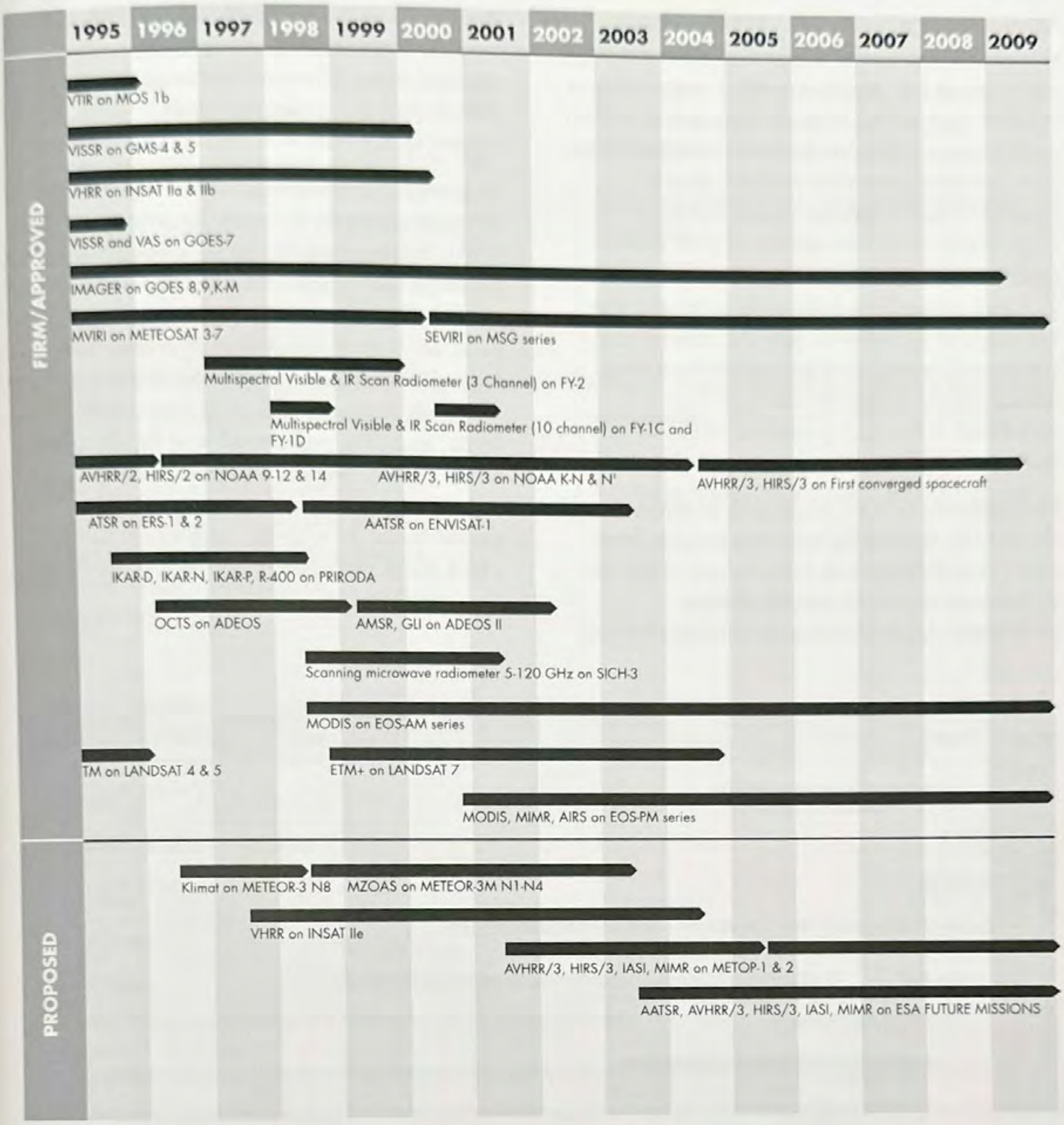
SURFACE TEMPERATURE (SEA)

Measurements of sea surface temperature (SST) are the key to understanding a variety of 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 key indicators of environmental change, both those transient in nature such as the El Niño, 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 – in-situ 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 a variety of mesoscale ocean features such as eddies and fronts, an understanding of which is vital to creating local ocean models.

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



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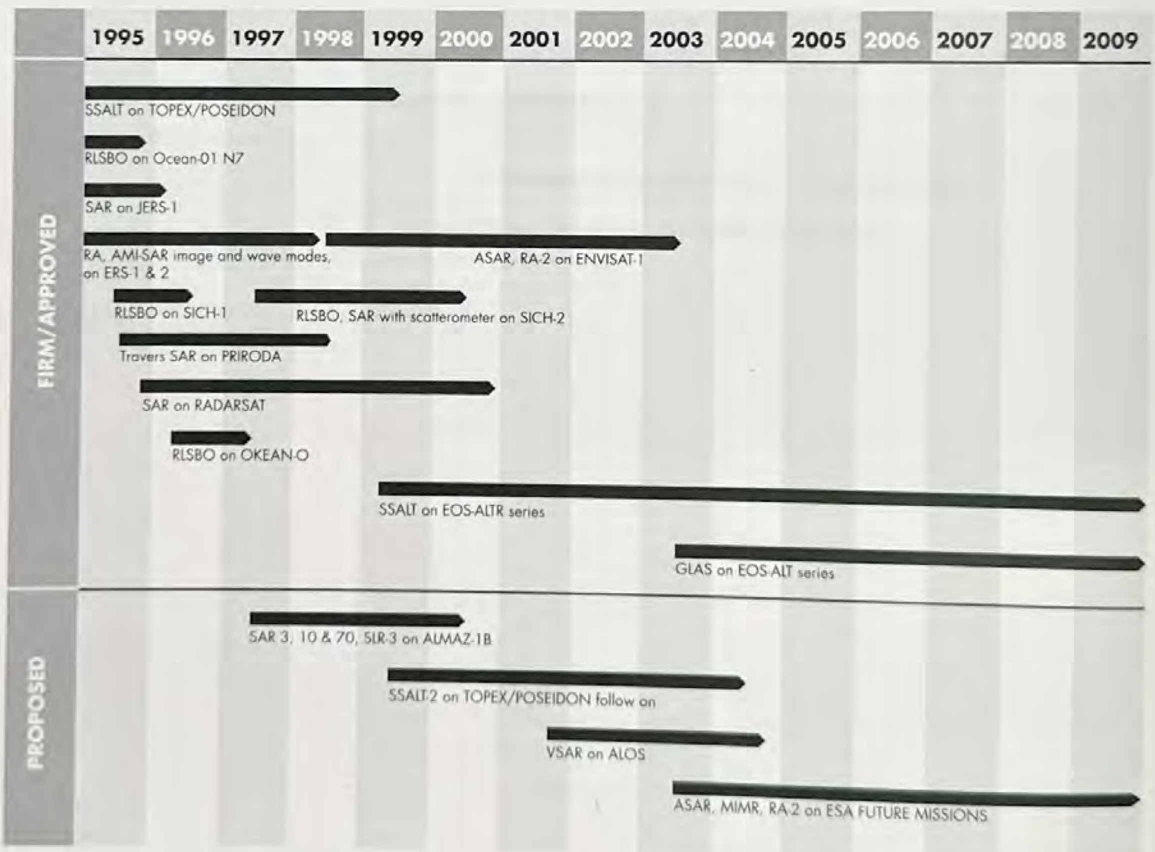
VTIR on MOS 1b
VISSR on GMS-4 & 5
VHRR on INSAT IIa & IIb
VISSR and VAS on GOES-7
IMAGER on GOES 8,9,K-M
MVIRI on METEOSAT 3-7
SEVIRI on MSG series
Multispectral Visible & IR Scan Radiometer (3 Channel) on FY-2
Multispectral Visible & IR Scan Radiometer (10 channel) on FY-1C and FY-1D
AVHRR/2, HIRS/2 on NOAA 9-12 & 14
AVHRR/3, HIRS/3 on NOAA K-N & N'
AVHRR/3, HIRS/3 on First converged spacecraft
ATSR on ERS-1 & 2
AATSR on ENVISAT-1
IKAR-D, IKAR-N, IKAR-P, R-400 on PRIRODA
OCTS on ADEOS
AMSR, GLI on ADEOS II
Scanning microwave radiometer 5-120 GHz on SICH-3
MODIS on EOS-AM series
TM on LANDSAT 4 & 5
ETM+ on LANDSAT 7
MODIS, MIMR, AIRS on EOS-PM series
PROPOSED
Klimat on METEOR-3 N8
MZOAS on METEOR-3M N1-N4
VHRR on INSAT IIe
AVHRR/3, HIRS/3, IASI, MIMR on METOP-1 & 2
AATSR, AVHRR/3, HIRS/3, IASI, MIMR on ESA FUTURE MISSIONS

WAVE HEIGHT AND SPECTRUM

Measurements of ocean wave height and 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 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 wave length 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.



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 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, and customs and immigration;
- coastal change detection – through topography monitoring;
- bottom topography mapping: which has value in resource exploration and pipeline routing.

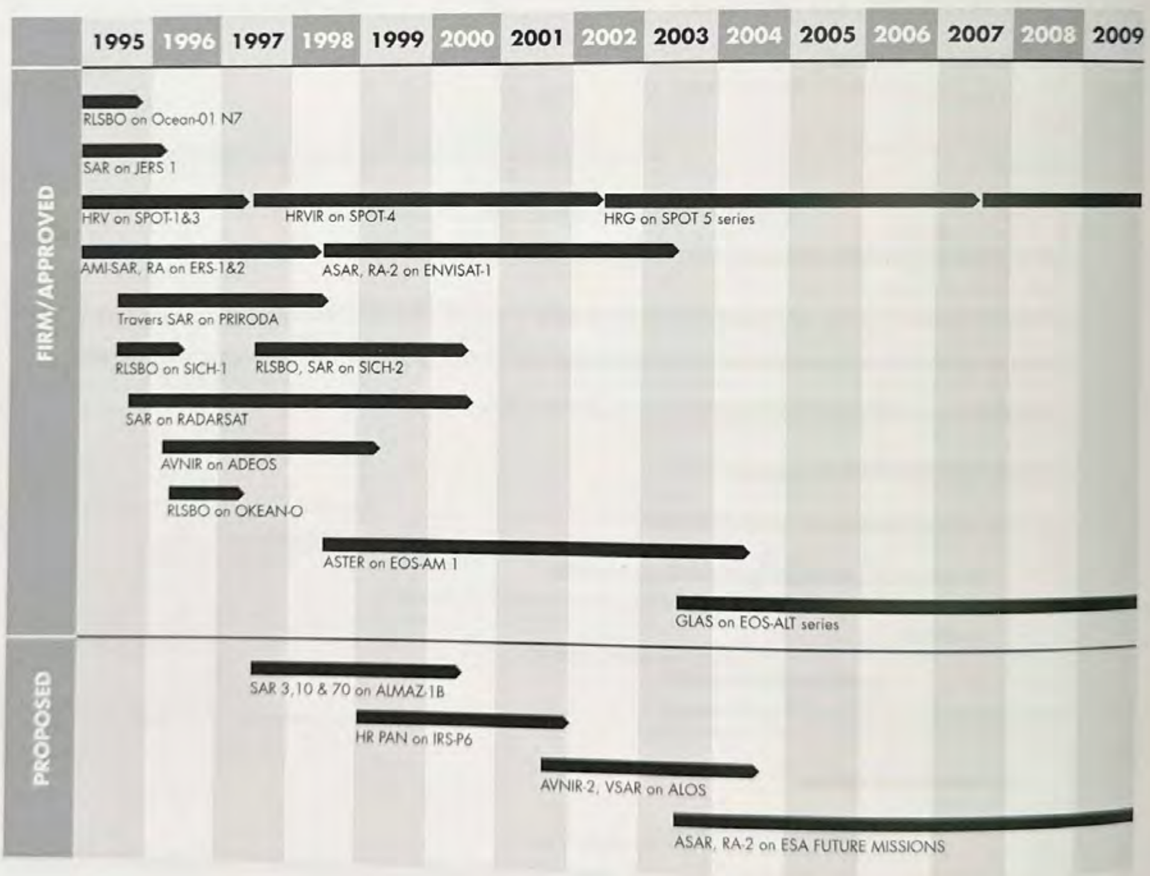
ICE SHEET TOPOGRAPHY

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 analyse 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 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 (or 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 laser altimeters such as GLAS on EOS-ALT with a high (~70m) horizontal resolution should be able to detect much sharper changes in topography.

Some high resolution instruments such as ASTER and SAR 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 accuracy.

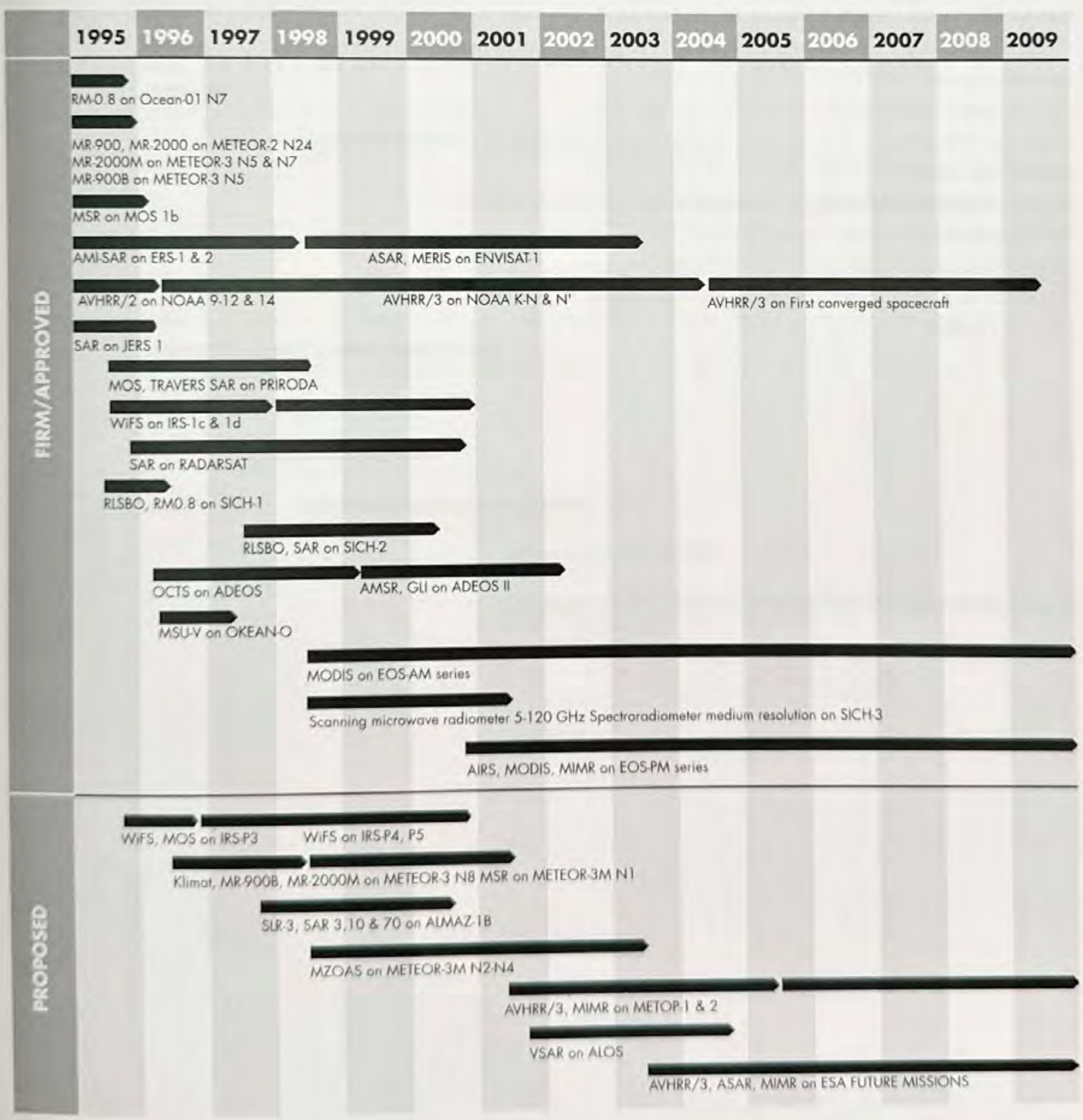


SNOW COVER, EDGE AND DEPTH

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 quantitative information on 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 which results when grain planted in 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 MIMR and 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 can 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).



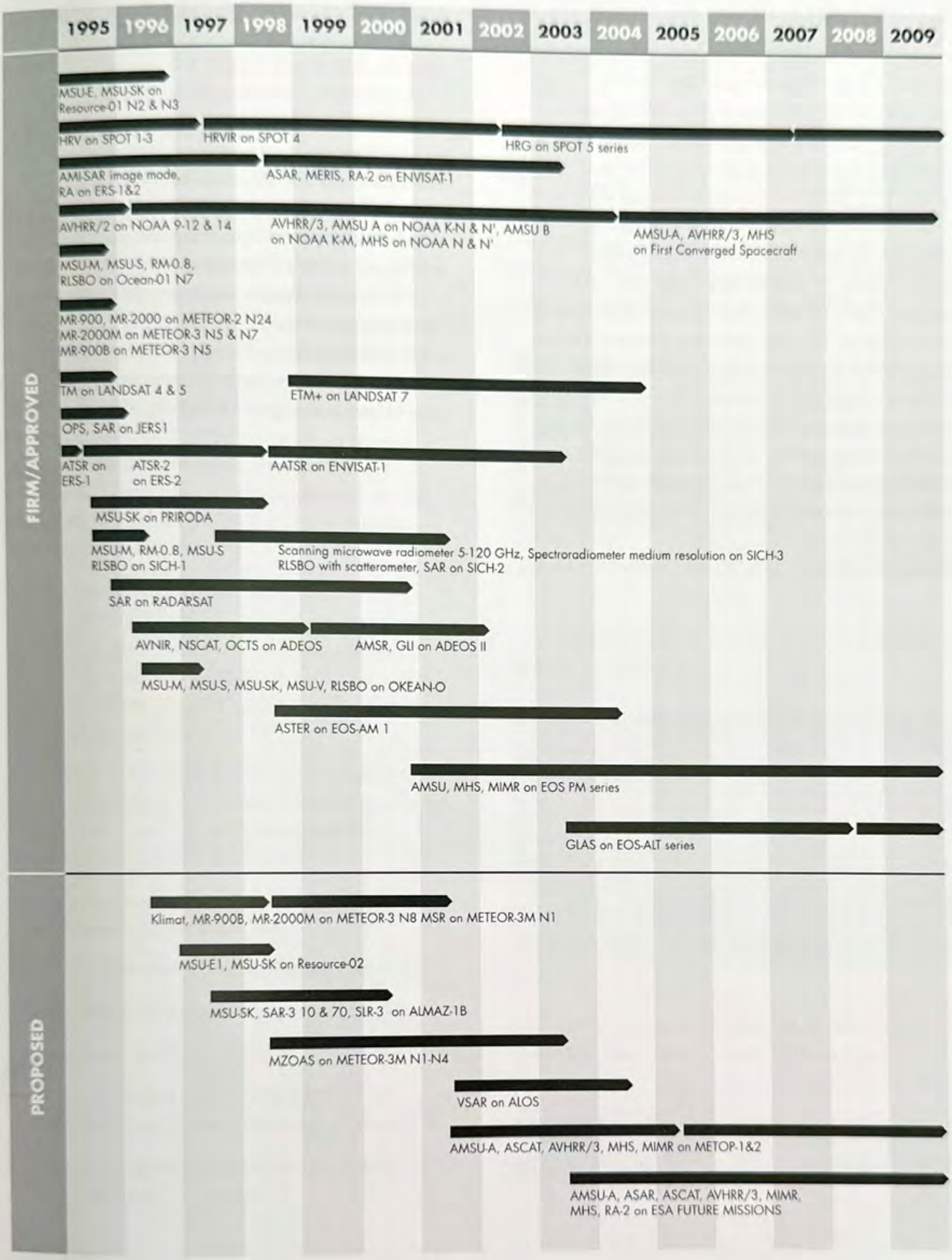
SEA ICE COVER, EDGE AND THICKNESS

Satellite Earth observation can provide information on ice cover, 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 off-shore 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-infiltrated areas enveloped in darkness for long periods.

Information on the position, extent and thickness of ice cover is also of interest for monitoring of changes in the polar caps which have a strong relationship with the global climate, both through their high albedo and elevated topography, and also through their potential to change significantly global sea levels through mass exchange with the oceans. Sea ice data are important climatologically due to, amongst other things, 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). In the future, microwave imagery from multi spectral radiometers such as MIMR and 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.

Synthetic aperture radars such as RADARSAT, AMI on the ERS series, and SAR on JERS-1 are a key 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.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HRV on SPOT 1-3
HRVIR on SPOT 4
HRG on SPOT 5 series
AMI-SAR image mode, RA on ERS-1&2
ASAR, MERIS, RA-2 on ENVISAT-1
AVHRR/2 on NOAA 9-12 & 14
AVHRR/3, AMSU A on NOAA K-N & N', AMSU B on NOAA K-M, MHS on NOAA N & N'
AMSU-A, AVHRR/3, MHS on First Converged Spacecraft
MSU-M, MSU-S, RM-0.8, RLSBO on Ocean-01 N7
MR-900, MR-2000 on METEOR-2 N24
MR-2000M on METEOR-3 N5 & N7
MR-900B on METEOR-3 N5
TM on LANDSAT 4 & 5
ETM+ on LANDSAT 7
OPS, SAR on JERS1
ATSR on ERS-1
ATSR-2 on ERS-2
AATSR on ENVISAT-1
MSU-SK on PRIRODA
MSU-M, RM-0.8, MSU-S RLSBO on SICH-1
Scanning microwave radiometer 5-120 GHz, Spectroradiometer medium resolution on SICH-3
RLSBO with scatterometer, SAR on SICH-2
SAR on RADARSAT
AVNIR, NSCAT, OCTS on ADEOS
AMSR, GLI on ADEOS II
MSU-M, MSU-S, MSU-SK, MSU-V, RLSBO on OKEAN-O
ASTER on EOS-AM 1
AMSU, MHS, MIMR on EOS PM series
GLAS on EOS-ALT series
PROPOSED
Klimat, MR-900B, MR-2000M on METEOR-3 N8 MSR on METEOR-3M N1
MSU-E1, MSU-SK on Resource-02
MSU-SK, SAR-3 10 & 70, SLR-3 on ALMAZ-1B
MZOAS on METEOR-3M N1-N4
VSAR on ALOS
AMSU-A, ASCAT, AVHRR/3, MHS, MIMR on METOP-1&2
AMSU-A, ASAR, ASCAT, AVHRR/3, MIMR, MHS, RA-2 on ESA FUTURE MISSIONS

4.4 COORDINATION IN DATA PROVISION

Sections 3 and 4 above have discussed a multiplicity of instrument types which are currently in orbit or are planned for Earth observation satellite missions over the next 15 years. The timeline diagrams indicate that, in the case of some measurements, a number of missions planned worldwide will operate concurrently to supply data. This does not suggest that there is a high degree of inefficiency or overlap in the data provision planned among the CEOS agencies for these measurements. Rather, the different missions are planned to evaluate different techniques, and to satisfy various requirements on regional, national and global scales with very different needs for sampling, spatial resolution, and accuracy.

High levels of investment in Earth observation satellites are planned internationally over the coming decade and CEOS will continue to play a key role in coordinating these investments, in order to ensure full realisation of the benefits of this truly international activity. Where some redundancy or gaps in mission planning are identified,CEOS agencies will continue to develop the process of information exchange, and analysis of mission plans against user requirements – achieving the coordination which is essential to efficiently meet the needs of the full range of users, and to guarantee comprehensive information on the Earth System, for both present and future generations.

A Catalogue of satellite missions

A.1 INTRODUCTION

This section gives details of the satellite missions of CEOS members. Key events of 1994-95 are identified and changes to mission plans that have occurred since production of the 1994 CEOS dossier are cited. Those missions that are currently in service are then briefly described, and a chronogramme spanning the period 1995-2010 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.

It should be noted that although the chronogramme identifies many missions, there are uncertainties associated with the planned missions (changes in funding or policy, changes in requirements etc) and hence not all of these can be guaranteed.

The annex is concluded with a set of tables in which all missions are detailed 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 (type, altitude, period, repeat);
- instrument suite;
- primary mission application areas corresponding to those discussed in section 4.

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

A.2 EVENTS OF 1994-95

The September 1994 update to the CEOS dossier listed 18 Earth observation missions scheduled for launch during the remainder of 1994 and 1995. Of these, at the time of writing eight missions have been successfully launched:

IRS P2 (ISRO)	launched October 1994
Ocean-01 N7 (Russia)	launched October 1994
Electro-GOMS N1 (Russia)	launched November 1994
Resource-01 N3 (Russia)	launched November 1994
NOAA 14 (NOAA J) (NOAA)	launched December 1994
GMS-5 (NASDA)	launched March 1995
ERS-2 (ESA)	launched April 1995
GOES 9 (GOES J) (NOAA)	launched May 1995

Further missions now planned for launch before the end of 1995 are:

TOMS Earth Probe (NASA)
SeaStar (NASA)
SICH-1 (NSAU)
RADARSAT (CSA)
INSAT IIc (ISRO);
IRS 1c (ISRO);
IRS P3 (ISRO);
MECB SCD-2 (INPE);
PRIRODA (Russia, on MIR space station).

Two missions originally planned for this period have now been delayed until 1996 or later:

OKEAN-O (NSAU)	delayed until May 1996;
FY-2 (China)	delayed until 1996/97.

A number of in-service Earth observation platforms were due to complete their missions (extended missions in some cases) during 1994 or early 1995, but continue to supply data beyond their expected lifetime:

METEOR-2 series (Russia);
LANDSAT 5 (NOAA);
SPOT 1 and 2 (CNES);
MOS 1b (NASDA);
ERS-1 (ESA);
UARS (NASA);
JERS-1 (NASDA);
MECD SCD-1 (INPE).

LANDSAT 4 was taken out of service and is now in standby mode. METEOSAT 3 is now due to be deorbited at the end of 1995.

A.3 CHANGES TO FUTURE PLANS

The table of satellites in section A.4 lists the missions which are planned for launch between 1995 and 2010.

The most significant recent changes to these plans are:

- RADARSAT-2 (CSA) – follow-on to RADARSAT-1 – funding has been approved by the Canadian Government and will ensure continuity of data. RADARSAT-3 is in the planning stages and the payload may differ, based upon experience gained from RADARSAT-1 and 2;
- the EOS-AERO series (NASA) will be implemented beginning with a flight in 1998 on a Russian Meteor 3M satellite;
- the EOS-ALT series (NASA) has been separated into two missions: a radar (EOS-ALTR) series and a laser (EOS-ALT) series;
- the status of EOS-COLOR (NASA) has been changed to a flight of opportunity and is on hold pending the launch of SeaStar;
- the introduction of the ODIN mission (Sweden) for astronomy/aeronomy, planned for launch in October 1997.

There are numerous detailed changes to the launch dates of future missions and to the planned instruments. These details may be found in section A.5.

A.4 CURRENT MISSIONS

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

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. In addition, the ATSR instrument on these missions provides images of the surface or cloud top. The GOME instrument on ERS-2 provides atmospheric chemistry measurements.

Geostationary meteorological satellites: There is a world-wide network of operational geostationary meteorological satellites which provides 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, including the recently launched GMS-5), India (INSAT 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.

JERS-1: The aim of JERS-1 is to observe the Earth using optical sensors and a high resolution synthetic aperture radar. Land surveys and monitoring of various resources are the main application areas of this satellite.

LAGEOS I and II: 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 10000 years.

Landsat and SPOT: The US operated Landsat and French operated SPOT satellites provide high resolution imagery in a range of visible and infra-red bands. They are used extensively for high resolution land studies.

METEOR series: The Russians maintain two or three satellites in orbit at any time (such as the recently launched METEOR-3 N7), mainly for operational meteorological purposes. Other applications include experimental measurement of ozone and Earth radiation budget. This series has now been supplemented by the GOMS meteorological mission.

MOS 1b: The main purpose of this Japanese satellite is to establish the fundamental technologies for Earth observation and to carry out practical observations of the Earth, primarily of the ocean. Its sensors operate in the visible, near infra-red, thermal infra-red and microwave bands.

NOAA polar orbiters: The current series of operational polar orbiting meteorological satellites is provided by NOAA and now includes NOAA 14. 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.

Okean series: Russia maintains a continuous series of measurements of oceanographic and hydrometeorological parameters with, in general, one or two satellite launches per year.

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

SCD-1: This Brazilian satellite receives environmental data gathered on the ground and transmits it to other locations.

TOPEX/POSEIDON: This is a joint NASA/CNES precision radar altimetry mission to measure ocean topography and hence speed and direction of ocean currents.

UARS: Launched in September 1991 by NASA, this provides a comprehensive platform for the study of middle atmosphere chemistry and physics.

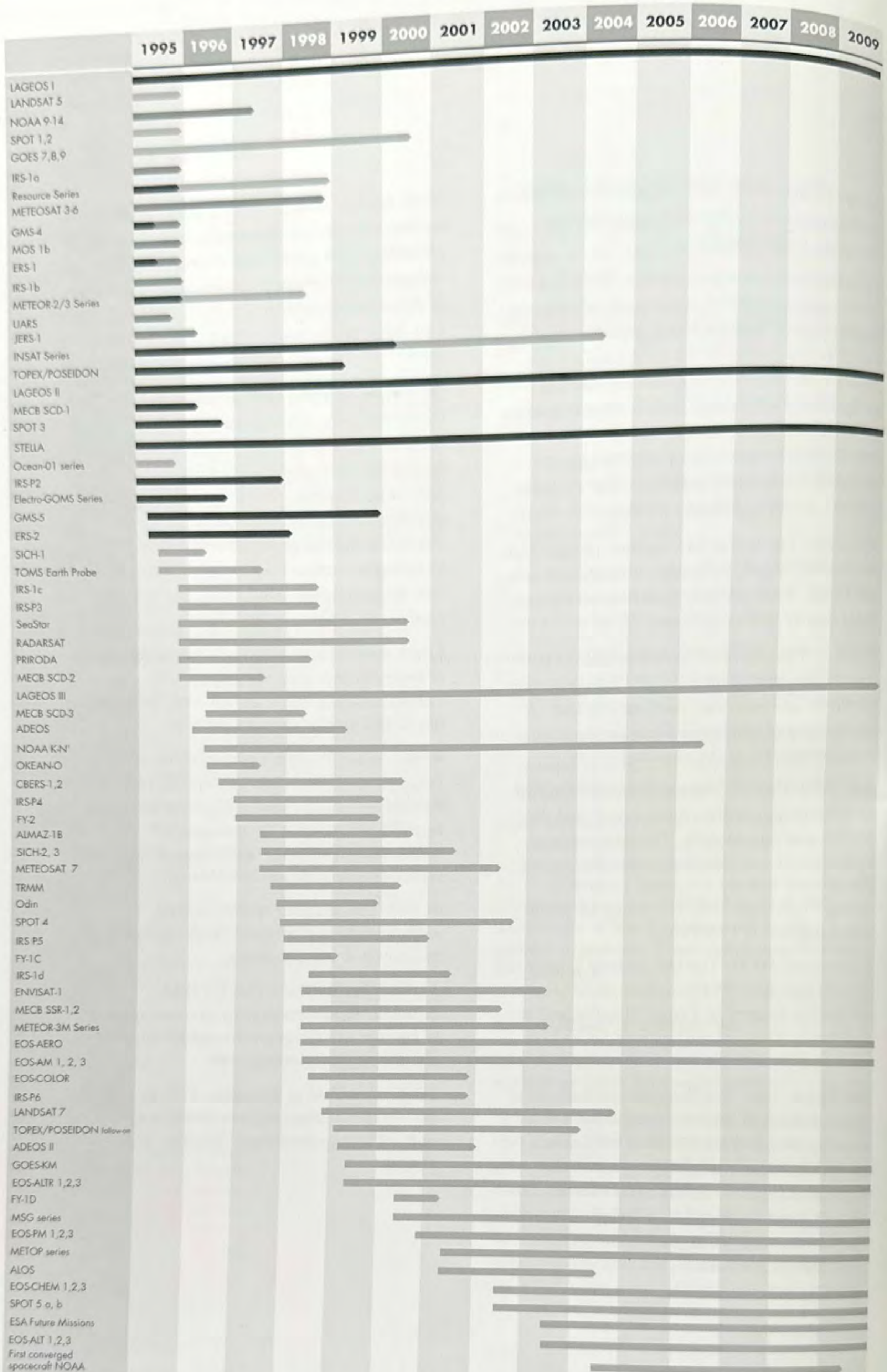

Figure A.1 Mission summary diagram

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
Resource-01 N2 (Russia)	In service	April 1988 7 years 8 months	Near polar, sun synchronous 98 deg, 670km	MSU-E, MSU-SK	Agriculture and forestry, hydrology, environmental monitoring, crop and soil monitoring, forest and tundra fires, pollution monitoring
METEOSAT 3 (EUMETSAT)	In service	June 1988 7 years 6 months	Geostationary	MVIRI	Meteorology, climatology
NOAA 11 (NOAA)	In service	September 1988 7 years 3 months	Polar sun synchronous, pm crossing, 850km	ARGOS, AVHRR/2, HIRS/2, MSU, S&R, SSU, SBUV/2	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 & rescue
METEOSAT 4 (EUMETSAT)	In service	March 1989 6 years 9 months	Geostationary	MVIRI	Meteorology, climatology
GMS-4 (NASDA)	In service	September 1989 6 years 3 months	Geostationary	VISSR	Meteorology
SPOT 2 (CNES)	In service	January 1990 6 years	Sun synchronous, 830km, 101 mins, 26 days	DORIS 2xHRV	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring
MOS 1b (NASDA)	In service	February 1990 6 years	Sun synchronous, 909km, 103 mins, 17 days	DCS, MESSR, MSR, VTIR	Earth resources (ocean), agriculture and forestry, environmental monitoring
METEOSAT 5 (EUMETSAT)	In service	March 1991 5 years	Geostationary	MVIRI	Meteorology, climatology
NOAA 12 (NOAA)	In service	May 1991 4 years 7 months	Polar sun synchronous, am crossing, 820km	ARGOS, AVHRR/2, HIRS/2, MSU, SEM	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 & rescue

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
LAGEOS 1 (NASA)	In service	May 1976 10000 years	101 deg, 6000km	Laser cornercube relectors	Geodesy, crustal motion and gravity field measurements by laser ranging
LANDSAT 5 (NOAA)	In service	March 1984 11 years 9 months	Near polar sun synchronous, crossing 0930 LST, 705 km, 99 mins, 16 days	MSS, TM	Land surface, Earth resources
NOAA 9 (NOAA)	In service	December 1984 11 years	Polar sun synchronous, pm crossing, 350km	ARGOS, AVHRR/2, ERBE, HIRS/2, MSU, S&R, 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 & rescue
SPOT 1 (CNES)	In service	February 1986 10 years	Sun synchronous, 830km, 101 mins, 26 days	2 x HRV	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring
NOAA 10 (NOAA)	In service	September 1986 9 years 3 months	Polar sun synchronous, am crossing, 820km	ARGOS, AVHRR/2, ERBE, HIRS/2, MSU, S&R, SEM	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 & rescue
GOES 7 (NOAA)	In service	February 1987 8 years 10 months	Geostationary	DCS, S&R, SEM, WEFAX, VISSR and VAS	Meteorology plus atmospheric dynamics, land surface, space environment, search and rescue, data collection platform, data gathering, WEFAX (weather facsimile)
IRS 1a (ISRO)	In service	March 1988 7 years 9 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

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
ERS-1 (ESA)	In service	July 1991 3 years 10 months	Near circular, sun synchronous, 782-785km, 100 mins, 3, 35, 176 days	AMI – SAR image mode, AMI – SAR wave mode, AMI - Scatterometer mode, ATSR, RA	Earth resources plus physical oceanography, ice and snow, land surface, meteorology, geodesy/gravity, environmental monitoring
IRS 1b (ISRO)	In service	August 1991 4 years 5 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
METEOR-3 N5 (Russia)	In service	August 1991 4 years 4 months	Near polar, 81-83 deg, 1200km, 109.4 mins	174-K, MR-2000M, MR-900B, RMK-2, SFM-2, TOMS	Agriculture and forestry, atmospheric dynamics/water and energy cycles, climatology, environmental monitoring, hydrology, hydrometeorology, ice and snow, land surface, meteorology, space environment
UARS (NASA)	In service	September 1991 4 years	57 deg inclination, 600km, 97 mins, 36 days	ACRIM II, CLAES, HALOE, HRDI, ISAMS, MLS, 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 4 years	Sun synchronous, 568km, 96 mins, 44 days	OPS, SAR	Earth resources land surface
INSAT IIa (ISRO)	In service	July 1992 7 years	Geostationary	BSS & FSS transponders, DRT-S&R, VHRR	Meteorology, data collection and communication, search and rescue
TOPEX/ POSEIDON (NASA)	In service	August 1992 5-7 years	non sun-synchronous, oceanography, 66 deg, circular, 1336km, 112 mins 26sec, 9 days 22 hours, ground track repeatability within 1km	ALT, DORIS GPSDR, LRA, SSALT, TMR	Physical geodesy/gravity
LAGEOS II	In service	October 1992 10000 years	52 deg, 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

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
INSAT IIb (ISRO)	In service	July 1993 7 years	Geostationary	BSS & FSS transponders, DRT-S&R, VHRR	Meteorology, data collection and communication, search and rescue
METEOR-2 N24 (Russia)	In service	August 1993 2 years	82.5 deg inclination, 900km, 102.5 mins	MR-2000, MR-900, RMK-2	Land surface, physical oceanography, atmospheric dynamics/water and energy cycles
SPOT 3 (CNES)	In service	September 1993 3 years	Sun synchronous, 830km, 101 mins, 26 days	DORIS 2x HRV POAM 2	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring
STELLA (CNES)	In service	September 1993 10000 years	Circular, 98 deg, 830km	Laser reflectors	Geodesy/gravity study of the Earth's gravitational field and its temporal variations
METEOSAT 6 (EUMETSAT)	In service	November 1993 5 years	Geostationary	MVIRI	Meteorology, climatology
Resource-F1 M series (Russia)	In service	1994 1 year	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 (Russia)	In service	1994 1 year	82.3 deg, 240km, 89.22 mins, 16 days	MK-4	Land surface, physical oceanography
Resource-F3 series (Russia)	In service	1994 1 year	82.3 deg, 240, 275, 340km 89.22 mins, 14 days	KFA-3000	Cartography (land and ocean) 1:25000 and below
METEOR-3 N7 (Russia)	In service	January 1994 2 years	near polar, 81-83 deg, 1200km 109.4 mins	ISP, MR-2000M, PRARE, RMK-2	Agriculture and forestry, atmospheric dynamics/ water and energy cycles, hydrology, hydrometeorology, ice and snow, land surface, meteorology, space environment
GOES 8 (NOAA)	In service	April 1994 5 years	Geostationary	DCS, IMAGER, S&R, 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
Ocean-01 N7 (Russia)	In service	October 1994 1 year	Near polar 82.6 deg, 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
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
Electro-GOMS N1 (Russia)	In service	November 1994 2 years	Geostationary over 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 (Russia)	In service	November 1994 2 years	Near polar, sun synchronous 98 deg, 670km	MSU-E, MSU-SK	Agriculture and forestry, hydrology, environmental monitoring, hydrometeorology, ice and snow, land surface, meteorology
NOAA 14 (NOAA)	In service	December 1994 2 years 6 months	Near polar, sun synchronous, am crossing, 850km, 101.5 mins	ARGOS, AVHRR/2, HIRS/2, MSU, S&R, SSU, SBUV/2, SEM,	Meteorology, climatology, 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 & rescue
MECB SCD-2 (INPE)	Firm/ approved	1995 2 years	25 deg inclination, 750km, 100 min	DCP	Data collection and communication
GMS-5 (NASDA)	In service	March 1995 5 years	Geostationary	VISSR	Meteorology
ERS-2 (ESA)	In service	April 1995 3 years	Sun synchronous, 785km	AMI-SAR image mode, AMI – SAR wave mode, AMI - Scatterometer mode, ATSR-2, GOME, PRARE, RA	Earth resources plus physical oceanography, ice and snow, land surface, meteorology, geodesy/gravity, environmental monitoring, atmospheric chemistry

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
GOES 9 (NOAA)	In service	In service from May 1995 (yet to be tested)	Geostationary	DCS, IMAGER, S&R, WEFAX, SEM, SOUNDER	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX
INSAT IIc (ISRO)	Firm/ approved	Mid-1995 7 years	Geostationary	BSS&FSS transponders, DRT-S&R	Data collection and communication, search and rescue
SICH-1 (NSAU)	Firm/ approved	July 1995 1 year	82.5 deg inclination, 650km, 98 mins	KONDOR-2, MSU-M, MSU-S, RLSBO, RM-0.8	Physical oceanography, hydrometeorology
TOMS Earth Probe (NASA)	Firm/ approved	9 August 1995 2 years	Sun synchronous, 670-690km, 98 mins	TOMS	Atmospheric chemistry ozone and sulphur dioxide measurements
IRS 1c (ISRO)	Firm/ approved	September 1995 3 years	Sun synchronous, 817km, 101.35	LISSIII, PAN WiFS	Land surface, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils
IRS P3 (ISRO)	Proposed	September 1995 3 years	Sun synchronous, 817km, 101.35 mins	MOS, WiFS, X-ray astronomy payload	Land surface, agriculture and forestry regional geology, land use studies, water resources, vegetation studies, coastal studies and soils
SeaStar (NASA)	Firm/ approved	September 1995 5 years	Polar sun synchronous, crossing 1200h, descending, 705km, 99 mins, 2 days	SeaWiFS	Ocean biology/ocean colour, physical oceanography
RADARSAT (CSA)	Firm/ approved	September 1995 5 years	Dawn-dusk, 98.6 deg inclination, ascending crossing, 1800h, 793km-821km, 7&3 day subcycles, 24 days	SAR	Environmental monitoring, physical oceanography ice and snow, land surface
PRIRODA (Russia)	Firm/ approved	December 1995 3 years	MIR space station, 51.6 deg, 380-420km	ALISSA, DOPI, IKAR-D, IKAR-N, IKAR-P, ISTOK-1, MOMS-2P, MOS, MSU-E2, MSU-SK, 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

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
INSAT IId (ISRO)	Firm/ approved	1996 7 years	Geostationary	BSS & FSS transponders, DRT-S&R	Data collection and communication, Search and Rescue
LAGEOS III (ASI)	Proposed	1996 10000 years	70 deg, 5900km	Laser cornercube reflectors	Geodesy, crustal motion and gravity field measurements by laser ranging
MECB SCD-3 (INPE)	Firm/ approved	1996 2 years	25 deg inclination, 750km, 100 min	DCP	Data collection and communication
METEOR-3 N8 (Russia)	Proposed	1996 2 years	Near polar, 81-83 deg, 1200km, 110 mins	ISP, Klimat, MIVZA, MR-2000M, MR-900B, RMK-2, ScaRaB, SFM-2	Land surface, agriculture and forestry, climatology, hydrology, hydrometeorology, ice and snow, meteorology, space environment
Resource-02 (Russia)	Proposed	1996 2 years	Near polar, sun synchronous 98 deg, 670km	MIVZA-M, MSU-E1, MSU-SK	Land surface, physical oceanography
ADEOS (NASDA)	Firm/ approved	February 1996 3 years	Sun synchronous, 796.75km, 100.92 mins, 41 days	AVNIR, ILAS, IMG, NSCAT, OCTS, POLDER, RIS, TOMS	Physical oceanography, atmospheric dynamics/water and energy cycles, atmospheric chemistry
NOAA K (NOAA)	Firm/ approved	April 1996 2 years 6 months	Near polar sun synchronous, pm crossing, 825-850km	AMSU-A, AMSU-B, ARGOS, AVHRR/3, HIRS/3, S&R (NOAA), SBUV/2, SEM	Meteorology
OKEAN-O (NSAU)	Firm/ approved	May 1996 1 year	Near polar, sun synchronous 98 deg, 670km, 98 mins	DELTA-2, KONDOR-2, MSU-M, MSU-S, MSU-SK, MSU-V, R-225, R-600, RLSBO, TRASSER-O	Agricultue and forestry, hydrology, environmental monitoring crop and soil monitoring, forest and tundra fires, pollution monitoring, oceans
CBERS 1 (INPE)	Proposed	October 1996 2 years	Sun synchronous, crossing 1030h, 778km, 100 min, 26 days	CCD camera, DCP, IR multi-scanner, WFI camera	Environmental data collection, space environment, environmental monitoring, land surface
IRS P4 (ISRO)	Proposed	End 1996 3 years 101 mins 22 days approx	Sun synchronous, 800km approx	LISS III WIFS	Agriculture and forestry, cartography, disaster warning, earth resources, environment monitoring, land surfaces
FY-2 (China (CMA))	Firm/ approved	1996/97 3 years	Geostationary 105 deg East	Multispectral Visible & IR Scan Radiometer (3 channel)	Meteorology and environmental monitoring data collection and redistribution

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
ALMAZ-1B (Russia)	Proposed	1997 3 years	Circular, 73 deg, 400km, 92 mins	Balkan-2 lidar, MSU-E2, MSU-SK, SAR-10, SAR-3, SAR-70, SILVA, SLR-3, SROSM	Agriculture and forestry, cartography, oceans
SICH-2 (NSAU)	Firm/ approved	1997 3 years	Near polar, sun synchronous 98 deg, 670km, 98 mins	RLSBO with scatterometer, SAR	Agriculture and forestry, hydrology, environmental monitoring crop and soil monitoring, forest and tundra fires, pollution monitoring
INSAT IIe (ISRO)	Proposed	1997 7 years	Geostationary	BSS & FSS transponders, DRT-S & R, VHRR	Land surface
Resource-F2 M series (Russia)	Firm/ approved	1997	82.3 deg, 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.
METEOSAT 7 (EUMETSAT)	Firm/ approved	June 1997 5 years	Geostationary	MVIRI	Meteorology, climatology
TRMM (NASA)	Firm/ approved	August 1997 3 years	35 deg inclination, 350km	CERES, LIS, PR, TMI, VIRS	Atmospheric dynamics/ water and energy cycles
Odin (SNSB)	Firm/ approved	October 1997 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
SPOT 4 (CNES)	Firm/ approved	December 1997 5 years	Sun synchronous, 830km, 101 mins, 26 days	DORIS 2xHRVIR, VEGETATION POAM3	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring
NOAA L (NOAA)	Firm/ approved	December 1997 2 years 6 months	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, 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
IRS P5 (ISRO)	Proposed	End 1997 3 years	Sun synchronous, 800 km, approx 101 mins 22 days repeat	LISS IV, OCM, WIFS (125m)	Agriculture and forestry disaster warning, Earth resources, environmental monitoring, hydrology land surface, ocean biology/ocean colour
FY-1C (China (CMA))	Firm/ approved	1997/98 1 year	Polar, sun synchronous, 870km, 102.3 min, 14 days	Multispectral Visible & IR Scan Radiometer (10 channel)	Meteorology environmental monitoring
CBERS 2 (INPE)	Proposed	1998 2 years	Sun synchronous, crossing 1030h, 778km, 100 mins, 26 days	CCD Camera, DCP, IR multi-scanner, WFI camera	Environmental data collection, space environment, optical remote sensing of the Earth
ENVISAT 1 (ESA)	Firm/ approved	1998 5 years	Sun synchronous polar, 780-820km, 100.59 mins, 35 days	AATSR, ASAR, DORIS-NG GOMOS, MERIS, MIPAS, MWR, RA-2, ScaRaB, SCIAMACHY	Physical oceanography, land surface, ice and snow, atmospheric chemistry, atmospheric dynamics/water and energy cycles
MECB SSR-1 (INPE)	Firm/ approved	1998 2 years	Sun synchronous, 640km, 4 days	IIS camera	Land surface, environmental monitoring
METEOR-3M N1 (Russia)	Proposed	1998 3 years	Near polar, sun synchronous, 1000km	ISP, KGI-4, MSR (RSA), MTZA, MZOAS, SAGE III, ScaRab	Agriculture and forestry, climatology, hydrology, hydrometeorology, ice and snow, land surface, meteorology, space environment
METEOR-3M N2 (Russia)	Proposed	1998 3 years	Near polar, sun snchronous 98 deg, 900km	174-K, BUFS-4, ISP, KGI-4, Klimat-2, MIVZA-M, MTZA, MZOAS, ScaRab, TOMS	Land surface, physical oceanography, atmospheric dynamics/water and energy cycles, space environment
SICH-3 (NSAU)	Firm/ approved	1998 3 years	Near polar, sun synchronous 98 deg, 670km, 98 mins	KONDOR-2, Scanning microwave radiometer 5-120GHz, Spectroradiometer medium resolution, TIR spectroradiometer	Agriculture and forestry, hydrology, environmental monitoring crop and soil monitoring, forest and tundra fires, pollution monitoring
EOS-AM 1 (NASA)	Firm/ approved	June 1998 6 years	Polar sun synchronous, crossing 1030h, 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

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
IRS 1d (ISRO)	Firm/ approved	mid 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
EOS-AERO 1 (NASA)	Firm/ approved	mid 1998 3 years	Near polar, sun synchronous, (METEOR-3M NI orbit), 1000km	SAGE III	Atmospheric chemistry tropospheric and stratospheric aerosol properties
EOS-COLOR (NASA)	Firm/ approved (flight of opportunity on hold pending launch of Sea WIFS in 1995)	October 1998 3 years	TBC	Ocean color	Ocean biology, role of oceans in global carbon and biogeochemical cycles
LANDSAT 7 (NASA)	Firm/ approved	December 1998 6 years	Polar sun synchronous, crossing equator 0945-1015h, 705km, 98 mins, 233 orbits/ cycle, 16 days	ETM+	Land surface, Earth resources
IRS P6 (ISRO)	Proposed	End 1998 3 years	Sun synchronous, approx 700km, approx 101mins	HR PAN	Cartography, civil planning, digital terrain models
TOPEX/ POSEIDON follow-on	Proposed	1999 5 years	EOS-ALTR 1 orbit 66 deg, 1336km, 10 day	DORIS-NG, LRA, SSALT-2, TMR GPSDR (option)	Physical oceanography, geodesy/gravity climate monitoring, operational marine meteorology (real time service)
METEOR-3M N3 (Russia)	Proposed	1999 3 years	Near polar, sun synchronous 98 deg, 900km	174-K, BUFS-4, ISP, KGI-4, Klimat-2, MIVZA-M, MTZA, MZOAS, ScaRaB, TOMS	Land surface, physical oceanography, atmospheric dynamics/water and energy cycles, space environment
ADEOS II (NASDA)	Firm/ approved	February 1999 3 years	Circular sun synchronous (local sun time 10:30±30 min), approx 802.9km, approx 101 mins, 4 days (57 revisit)	AMSR, ARGOS DCS, GLI, ILAS-II, POLDER, Sea Winds	Atmospheric dynamics/ water and energy cycles, land surface, physical oceanography

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
EOS-ALTR 1 (TOPEX/ POSEIDON follow on) **(NASA)**	Firm/ approved	March 1999 3 years	66 degree inclination, 1336km, 113 mins, 10 days	AMR, DORIS SSALT	Physical oceanography, gravity fields, ocean altimetry and circulation
GOES K (NOAA)	Firm/ approved	April 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
NOAA M (NOAA)	Firm/ approved	April 1999 2 years 6 months	Near polar sun synchronous, pm crossing, 825-850km	AMSU-A, AMSU-B, ARGOS, AVHRR/3, HIRS/3, S&R SBUV/2, SEM	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 & rescue
FY-1D (China (CMA))	Firm/ approved	2000 1 year	Polar, sun synchronous, 870km, 102.3 min, 14 days	Multispectral Visible & IR Scan Radiometer (10 channel)	Meteorology environmental monitoring
MECB SSR-2 (INPE)	Firm/ aproved	2000 2 years	Sun synchronous, 640km, 4 days	IIS camera	Land surface, environmental monitoring
METEOR-3M N4 (RUSSIA)	Proposed	2000 3 years	Near polar, sun synchronous 98 deg, 900km	174-K, BUFS-4, ISP, KGI-4, Klimat-2, MIVZA-M, MTZA, MZOAS, ScaRaB, TOMS	Land surface, physical oceanography, atmospheric dynamics/ water and energy cycles, space environment
MSG 1 (EUMETSAT)	Firm/ approved	2000 6 years	Geostationary	GERBI, SEVIRI	Meteorology, climatology, atmospheric dynamics/ water and energy cycles
GOES L (NOAA)	Firm/ approved	April 2000 5 years	Geostationary	DCS, IMAGER, S&R,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
EOS-PM 1 (NASA)	Firm/ approved	December 2000 5 years	Polar sun synchronous, crossing 1330h, ascending, 705km, 99 mins	AIRS, AMSU, CERES, MHS, MIMR, MODIS	Atmospheric dynamics/ water and energy cycles cloud formation, precipitation and radiative propeties, air/sea fluxes of energy and moisture, sea ice extent and heat exchange with the atmosphere
NOAA N (NOAA)	Firm/ approved	December 2000 2 years 6 months	Near polar sun synchronous, 825-850km	AMSU-A, ARGOS, AVHRR/3, HIRS/3, MHS S&R, SBUV/2, SEM	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 & rescue
EOS-AERO 2 (NASA)	Firm/ approved	2001 3 years	Near polar, sun synchronous, 1000km (METEOR-3 orbit)	SAGE III ARGOS	Atmosheric chemistry, tropospheric and stratospheric aerosol properties
METOP 1 (EUMETSAT)	Proposed	2001 5 years	Polar, sun synchronous, approx 800km	AMSU-A, ASCAT, AVHRR/3, HIRS/3, IASI, MHS, MIMR, OMI, ScaRaB, SEM	Meteorology, climatology
ALOS (NASDA)	Proposed	August 2001 3 years	Sun synchronous, approx 700km, approx 45 days	AVNIR-2, DCS, VSAR	Advanced land observing satellite. civil planning, data collection and communication, digital terrain models, environmental monitoring, disaster monitoring
EOS-CHEM 1 (NASA)	Firm/ approved	2002 5 years	Polar sun synchronous, 705km, 99 mins	HiRDLS, MLS, TES	Atmospheric chemistry atmospheric dynamics/ water and energy cycles
MSG 2 (EUMETSAT)	Firm/ approved	2002 6 years	Geostationary	GERBI, SEVIRI	Meteorology, climatology, atmospheric dynamics/ water and energy cycles
SPOT 5a (CNES)	Firm/ approved	2002 5 years	Sun synchronous, 830km, 101 mins, 26 days	DORIS-NG 3xHRG VEGETATION	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
ESA Future Missions (ESA)	Proposed	2003 10 years	Near polar and Sun synchronous, 1000km possibly other LEOs	ALADIN, AMSU-A, ASAR, ASCAT, ATLID, AVHRR/3, Cloud radar, DORIS-NG GOMOS, HIRS/3, IASI, MASTER, MERIS, MHS, MIMR, MIPAS, MWR, PRISM, OMI, RA-2, Rain radar, ScaRaB, SCIAMACHY, SEM, SOPRANO	Physical oceanography, land surface, ice and snow, atmospheric chemistry, atmospheric dynamics/water and energy cycles
EOS-ALT 1 (NASA)	Firm/ approved	July 2003 3 years	94 degree inclination, 705km, 90 mins, n/a	GLAS	Physical oceanography, geodesy/gravity, land surface, ocean altimetry and circulation, ice sheet mass balance, geological features
NOAA N' (NOAA)	Firm/ approved	December 2003 2 years 6 months	Near polar sun synchronous, pm crossing, 825-850km	AMSU-A, ARGOS, AVHRR/3, HIRS/3, MHS, S&R, SBUV/2, SEM	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 & rescue
EOS-AERO3 (NASA)	Firm/ approved	2004 3 years	Near polar, sun synchronous,	SAGE III	Atmospheric chemistry, troposheric and statosphric aerosol properties
First Converged Spacecraft (NOAA)	Firm/ approved	2004 5 years	Near polar sun synchronous, pm crossing, 825-850km	AMSU-A, ARGOS AVHRR/3, HIRS/3, MHS, S&R SBUV/3, SEM	Meteorology, climatology and other environmental applications
EOS-ALTR 2 (NASA)	Firm/ approved	March 2004 3 years	66 degree inclination, 1336km, 113 mins, 10 days	AMR DORIS, SSALT	Physical oceanography, gravity fields, ocean altimetry and circulation
GOES M (NOAA)	Firm/ approved	April 2004 5 years	Geostationary	DCS, IMAGER, S&R, SEM, SOUNDER, SXI, 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
EOS-AM 2 (NASA)	Firm/ approved	June 2004 6 years	Polar sun synchronous, crossing 1030h, descending, 705km, 99 mins, 16 days	CERES, EOSP, LATI, MISR, MODIS	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
EOS-CHEM 2 (NASA)	Firm/ approved	2005 5 years	Polar sun synchronous, 705km, 99 mins	HiRDLS, MLS, TES	Atmospheric chemistry atmospheric dynamics/ water and energy cycles
METOP-2 (EUMETSAT)	Proposed	2005 5 years	Polar, sun synchronous, approx 800km	AMSU-A, ARGOS ASCAT, AVHRR/3, HIRS/3, IASI, MHS MIMR, OMI, ScaRaB, SEM	Meteorology, climatology
MSG 3 (EUMETSAT)	Firm/ approved	2006 6 years	Geostationary	GERBI, SEVIRI	Meteorology, climatology, atmospheric dynamics/ water and energy cycles
EOS-PM 2 (NASA)	Firm/ approved	December 2006 5 years	Polar sun synchronous, crossing 1330h, ascending, 705km, 99 mins	AIRS, AMSU, CERES, MHS, MIMR, MODIS	Atmospheric dynamics/ water and energy cycles cloud formation, precipitation and radiative propeties, air/sea fluxes of energy and moisture, sea ice extent and heat exchange with the atmosphere
EOS-AERO4 (NASA)	Firm/ approved	2007 3 years	Near polar, sun synchronous,	SAGE III	Atmospheric chemistry, troposheric and statosphric aerosol properties
SPOT 5b (CNES)	Firm/ approved	2007 5 years	Sun synchronous, 830km, 101 mins, 26 days	DORIS-NG, 3xHRG VEGETATION	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring
EOS-ALT 2 (NASA)	Firm/ approved	July 2008 3 years	94 degree inclination, 705km, 90 mins, n/a	GLAS	Physical oceanography, geodesy/gravity, land surface, ocean altimetry and circulation, ice sheet mass balance, geological features

Mission (Agency)	Status	Launch date/ Duration	Orbit details	Instruments	Primary application areas
EOS–AERO 5 (NASA)	Firm/ approved	2010 3 years	Near polar, sun synchronous,	SAGE III	Atmospheric chemistry, troposheric and statosphric aerosol properties
EOS-ALTR 3 (NASA)	Firm/ approved	March 2010 3 years	66 degree inclination, 1336km, 113 mins, 10 days	AMR , DORIS, SSALT	Physical oceanography, gravity fields, ocean altimetry and circulation
EOS-AM 3 (NASA)	Firm/ approved	June 2010 6 years	Polar sun synchronous, crossing 1030h, descending, 705km, 99 mins, 16 days	CERES, EOSP, MISR, MODIS	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
EOS-PM 3 (NASA)	Firm/ approved	December 2012 5 years	Polar sun synchronous, crossing 1330h, ascending, 705km, 99 mins	AIRS, AMSU, CERES, MHS MIMR, MODIS	Atmospheric dynamics/ water and energy cycles cloud formation, precipitation and radiative propeties, air/sea fluxes of energy and moisture, sea ice extent and heat exchange with the atmosphere
EOS-ALT 3 (NASA)	Firm/ approved	July 2013 3 years	94 degree inclination, 705km, 90 mins, n/a	GLAS	Physical oceanography, geodesy/gravity, land surface, ocean altimetry and circulation, ice sheet mass balance, geological features
EOS-CHEM 3 (NASA)	Firm/ approved	2014 5 years	Polar sun synchronous, 705km, 99 mins	HiRDLS, MLS, TES	Atmospheric chemistry atmospheric dynamics/ water and energy cycles

B Catalogue of satellite instruments

B.1 INTRODUCTION

This annex contains an alphabetical list of all instruments. For each instrument, the following information is given:

- the mission(s) that the instrument is expected to fly on (mission details may be found in annex A);
- the measurements that the instrument can make;
- the technical characteristics of the instrument.

B.2 SATELLITE INSRUMENTS (ALPHABETICALLY)

Instrument	Mission(s)	Measurements/application	Technical characteristics
174-K	METEOR-3 N5, METEOR-3M N2, METEOR-3M N3, METEOR-3M N4	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), 11.10µm (transparent), 9.6µm (ozone) Spatial resolution: 42km Accuracy: Duty cycle: 100% Swath width: 1000km Data rate:
AATSR Advanced Along Track Scanning Radiometer	ENVISAT 1	Sea surface tempeature, land surface temperature, cloud top temperature and cloud cover, aerosols, vegetation,	Waveband: Visible, NIR: 0.555, 0.659, 0.865µm, SWIR: 1.6µm, TIR: 3.7, 10.85 and 12µm Spatial resolution: IR ocean channels: 1km x 1km Land visible 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 tempeature: 0.1K relative Duty cycle: 100% Swath width: 500km Data rate: 1Mbps
ACRIM Active Cavity Radiometer Irradiance Monitor	EOS flights of opportunity	Will sustain long term solar luminosity database total solar irradiance, solar constant	Waveband: UV-FIR: 1nm-1mm Spatial resolution: Not applicable Accuracy: 0.1% Duty cycle: 100% (daylight only) Swath width: Not applicable Data rate: 1kbps
ACRIM II Active Cavity Radiometer Irradiance Monitor	UARS	Maintains a long-term solar luminosity database and dataset on solar constant. Time variation of total solar irradiance, extreme UV through infra-red	Waveband: UV-FIR: 1nm-1,000µm 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
AIRS Advanced Infra-red Sounder	EOS-PM 1, EOS-PM 2, EOS-PM 3	Temperature/humidity sounding	Waveband: Visible – SWIR: 0.4-1.7µm TIR: 3.4-15.4µm Spatial resolution: Vertical: 1km, Horizontal: 13.5km 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: 1.44Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
ALADIN Atmospheric Laser Doppler Instrument	ESA Future Missions	Wind component in clear air, cloud top heights, vertical distribution of cloud, aerosol properties, troposphere height, boundary layer height	Waveband: One band in the 9.11-10.59μm range (TIR) 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 lidar	PRIRODA	Cloud altimetry, boundary layer, aerosols, cloud top altitude, aerosol backscatter	Waveband: visible: 532nm 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 Dual 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 and 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 (and forests), land surface processes, hydrology, digital elevation models, interferometry	Waveband: Microwave: 5.3GHz, C band, VV polarisation, bandwidth 15.5±0.06MHz Spatial resolution: 30m Accuracy: Duty cycle: 10% nominal Swath width: 100km Data rate: 105Mbps
AMI-SAR wave mode	ERS-1, ERS-2	Ocean wave spectra wave direction: 0-180 deg with 180 deg ambiguity to ±20 deg wave length: 100m to 1000m to ±25%	Waveband: Microwave: 5.3GHz, C band, VV polarisation Spatial resolution: 30m Accuracy: 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 Data rate: 370kbps
AMI Scatterometer mode	ERS-1, ERS-2	Wind fields at the ocean surface wind direction range 0-360 deg wind speed in the range 1m/s to 30m/s	Waveband: Microwave: 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

Instrument	Mission(s)	Measurements/application	Technical characteristics
AMR	EOS-ALTR 1, EOS-ALTR 2, EOS-ALTR 3	Total water vapour, brightness temperature	Waveband: Microwave: 18, 21 and 37GHz Spatial resolution: 44.6knm at 18GHz, 37.4km at 21GHz, 23.5km at 37GHz Accuracy: Total water vapour 0.2g/square cm Brightness temperature: 1K Duty cycle: 100% Swath width: 120 deg cone centred on nadir Data rate: 125bps
AMSR Advanced Microwave Scanning Radiometer	ADEOS II	Water vapour, precipitation, winds, sea surface temperature, snow and ice cover	Waveband: Microwave: 6.9, 10.65, 18.7, 23.8, 36.5, 50.3, 52.8, 89.0GHz Spatial resolution: 5-50km (dependent upon frequency) Accuracy: target is 1K Duty cycle: 100% Swath width: 1600km Data rate: approx 130kbps
AMSU Advanced Microwave Sounding Unit	EOS-PM 1, EOS-PM 2, EOS-PM 3	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	ESA Future Missions, First Converged Spacecraft, METOP 1, METOP 2, NOAA K, NOAA L, NOAA M, NOA N, NOAA N'	All weather, night-day temperature sounding to an altitude of 45km	Waveband: Microwave: 23.8, 31.4, 50.3-57.3 and 89GHz Spatial resolution: 50km at nadir Accuracy: Duty cycle: 100% Swath width: Approximately 2200km (±48.3 deg) Data rate: 2.2kbps
AMSU-B Advanced Microwave Sounding Unit B	NOAA K, NOAA L, NOAA M	All weather, night-day humidity profiles	Waveband: Microwave: 89, 157 and three channels close to 183GHz Spatial resolution: 15km at nadir Accuracy: Duty cycle: 100% Swath width: Approximately 2200km (±48.3 deg) Data rate: 4kbps
ARGOS	First Converged Spacecraft, NOAA 9, NOAA 10, NOAA 11, NOAA 12, NOAA 14, NOAA K, NOAA L, NOAA M, NOAA N, NOAA N'	Location by doppler measurements	Waveband: collection): ±01004Mhz Uplink (data 401.650 Mhz down link: 470 Mhz 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:

Instrument	Mission(s)	Measurements/application	Technical characteristics
ASAR Advanced Synthetic Aperture Radar	ENVISAT 1, ESA Future Missions	All weather images of ocean, land and ice applications, oonitoring of land surface processes, sea and polar ice, sea state, geology, hydrology	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: 1.5-3.5dB Radiometric accuracy: 0.65dB Duty cycle: 20% Swath width: Image and alternating polarisation modes: up to 100km, Wave mode: 5km, Wide swath and global monitoring modes: 40km Data rate:
ASCAT Advanced Scatterometer	ESA Future Missions METOP 1, METOP 2	Surface wind over the sea	Waveband: C band Spatial resolution: 25km Accuracy: Duty cycle: 100% Swath width: 2 x 500km Data rate:
ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer	EOS-AM 1	Surface and cloud imaging with high spatial resolution, stereo-scopic observation of local topography, cloud heights, volcanic plumes, and generation of local surface digital elevation maps. Surface temperature and emissivity	Waveband: 3 visible and NIR channels (0.5-0.9μm), 6 SWIR channels (1.6-2.5μm), 5TIR channels (8.0-12.0μm) Spatial resolution: VNIR: 15m, Stereo: 15m horizontally and 25m vertical, SWIR: 20m, TIR: 90m Accuracy: VNIR and SWIR: 4% (absolute) TIR: 1-2k 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. Accesses any point on the globe once every 16 days. Data rate: Average/peak: 8.3/ 89.2Mbps
ATLID Atmospheric Lidar	ESA Future Missions	Cloud top heights, aerosol properties, troposphere height, vertical distribution of cloud, boundary layer height	Waveband: NIR: 1064nm Spatial resolution: Shot spacing: <50km, footprint: 100m (at nadir) Accuracy: Height: ±100m Duty cycle: Swatch width: ±350km (±23.5 deg) Data rate: 1Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
ATSR Along Track Scanning Radiometer and Microwave Sounder	ERS-1	Sea surface temperature, land surface temperature, cloud top temperature and cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content	Waveband: SWIR-TIR channels: 1.6, 3.7, 11 and 12μm Microwave channels: 23.8 and 36.5GHz with bandwidth of 400MHz Spatial resolution: IR: 1km x 1km instantaneous field of view at nadir, conical scan Sea surface temperature 50 x 50km 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 and Microwave Sounder	ERS-2	Sea surface temperature, land surface temperature, cloud top temperature and cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content	Waveband: 4 SWIR-TIR channels: 1.6, 3.7, 11.0 and 12μm. 4 Visible/ Reflected channels: 0.65, 0.85, 1.27 and 1.6μm. Microwave channels: 23.8GHz, 36.5GHz with a bandwidth of 400MHz Spatial resolution: IR ocean channels: 1km x 1km Microwave near nadir viewing 20km instantaneous field of view Accuracy: Sea surface tempeature 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	Land and sea surface temperature, marine oil pollution mapping, cloud cover and precipitation, volcanic eruption monitoring, snow and ice cover, soil moisture, vegetation index	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 (ssp). Compressed Global Area Coverage (GAC) data recorded at 4km resolution Accuracy: Data cycle: 100% Swath width: 3000km (approximate), 55.4 deg scan off nadir Data rate: 66.54kbps for GAC, 665.4kbps for HRPT

Instrument	Mission(s)	Measurements/application	Technical characteristics
AVHRR/3 Advanced Very High Resolution Radiometer	ESA Future Missions, First Converged Spacecraft, METOP 1, METOP 2, NOAA K, NOAA L, NOAA M, NOAA N, NOAA N'	Land and sea surface temperature, marine oil pollution mapping, cloud cover and precipitation, volcanic eruption monitoring, snow and ice cover, soil moisture, vegetation index	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: 1.1km (ssp). 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
AVNIR Advanced Visible and Near Infra-red Radiometer	ADEOS	High resolution land and coastal zone imaging	Waveband: Visible: 0.42-0.50μm, 0.52-6-0.60μm, 0.61-0.69μm, 0.52-0.69μm (panchromatic), NIR: 0.76-0.89μm Spatial resolution: Multi-band: 16m Panchromatic band: 8m Accuracy: Duty cycle: 33% Swath width: 80km Data rate: Multi-band: 60Mbps Panchromatic band: 60Mbps
AVNIR-2 Advanced Visible and Near Infra-red Radiometer	ALOS	High resolution panchromatic mapper	Waveband: Visible: 3 bands 0.42-0.69μm Panchromatic: 0.52-0.77μm NIR: 0.76-0.89μm Spatial resolution: Panchromatic band: 2.5m Multi-spectral bands: 10-15m Accuracy: Duty cycle: Swath width: 35km panchromatic 70km multi-spectral Data rate: 240Mbps (panchromatic after data compression) 120Mbps (multi-spectral after data compression)
Balkan-2 lidar	ALMAZ-1B		Waveband: Visible: 532nm Spatial resolution: 3-10m altitude (lidar mode), 0.5-1.0m altitude (range-finding mode). 40 seconds of arc for radiation Accuracy: 15-30% Duty cycle: Programmable Swath width: ±10 deg from nadir Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
BRK	Electro-GOMS N1		Waveband: Spatial resolution: Accuracy: Duty cycle: Initiated every 30 mins Swath width: Data rate: 2.56Mbps
BSS & FSS transponders	INSAT IIa, INSAT IIb, INSAT IIc, INSAT IId INSAT IIe	Data collection and communication	Waveband: BSS operates in 2 channels in S-band; FSS operates in 18 channels in INSAT in Ku-band Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:
BTVK	Electro-GOMS N1	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: Duty cycle: 24-48 times per day Swath width: 13500km Data rate:
BUFS-4 backscatter spectrometer	METEOR-3M N2, METEOR-3M N3, METEOR-3M N4	Atmospheric ozone content profiles	Waveband: UV: 250-350nm (12 channels) Spatial resolution: 3 x 3 deg Accuracy: 2% Duty cycle: 100% Swath width: 3100km Data rate:
CCD camera	CBERS 1, CBERS 2	Vegetation monitoring	Waveband: Visible-NIR: 0.45-0.52µm, 0.52-0.59µm, 0.63-0.69µm, 0.77-0.89µm, 0.51-0.71µm Spatial resolution: 19.5m at nadir Accuracy: <0.3 pixels Duty cycles: International access open to all participating stations, limited to 20 minutes per revolution Swath width: 113km Data rate: 53Mbps per channel (2 channels)
CERES Clouds and Earth's Radiant Energy System	EOS-AM1, EOS-AM 2, EOS-AM 3, EOS-PM 1, EOS-PM 2, EOS-PM 3 TRMM	Global maps of the Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface measures longwave and shortwave infra-red radiation using thermistor bolometers to determine the Earth's radiation budget	Waveband: UV-SWIR: 0.3-5.0µm, TIR: 8.12µm, UV-FIR: 0.3-50µm Spatial resolution: 21km at nadir Accuracy: 2% shortwave radiance, 1% longwave radiance Duty cycle: 100% Swath width: Limb to limb Data rate: 20kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
CLAES Cryogenic Limb Array Etalon Spectrometer	UARS	Concentrations of nitrogen and chlorine families, ozone, water vapour, methane, carbon dioxide (measurements at 3.5 to 12.7μm). carbon dioxide measurements used to determine atmospheric temperature as a function of altitude. Simultaneous measurements at 20 altitudes between 10 and 60km	Waveband: SWIR: 3.5μm, 6μm, TIR: 8μm, 12.7μm Spatial resolution: Vertical: 2.8k, Horizontal: 480km Accuracy: 20%, 3K (mid-stratosphere) Duty cycle: long term: 80%, daily: 96% Swath width: 50.7km vertical limb coverage Data rate: 3kbps
Cloud radar	ESA Future Missions	Cloud characteristics including base height	Waveband: 78 or 94GHz Spatial resolution: TBD Accuracy: Duty cycle: 100% Swath width: TBD Data rate:
DCP Data Collection Platform Transponder	CBERS 1, CBERS 2, MECB SCD-1, MECB SCD-2, MECB SCD-3	Data collection	Waveband: Not applicable Spatial resolution: Accuracy: Duty cycle: Operates only over Brazil/China Swath width: Data rate:
DCS Data Collection System	GOES 7, GOES 8, GOES 9, GOES K, GOES L, GOES M ADEOS II, ALOS, MOS 1b	Data Collection Service - temperatures (air/water), atmospheric pressure, humidity and wind speed/direction, speed and direction of ocean and river currents	Waveband: Spatial resolution: Not applicable Accuracy: Not applicable Duty cycle: 100% Swath width: Not applicable Point measurements specific to platform locaton Data rate: Not applicable
DELTA-2	OKEAN-0		Waveband: Microwave: 7.0, 13.0, 22.5, 36.5GHz (2polarisation) Accuracy: Duty cycle: 100% Swath wirth: 2600km
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-NG Doppler Orbitography and Radio Positioning Integrated by Satellite	ENVISAT, SPOT 5a SPOT 5a follow-on ESA future missions Topex/Poseidon follow-on	Precise orbit determination. real time onboard orbit determination (navigation)	Waveband: Dual frequency Doppler 2036.25MHz and 401.25MHz Spatial resolution: One measurement every 10 seconds Accuracy: 0.3mms on Doppler measurement, <2-4 cm on the satellite altitude, <2 cm on ground beacon absolute positioning, 5m RMS real time onboard orbit determination on the 3D component Duty cycle: 100% operating network visibility >70% (from orbit) Swath width: Not applicable Data rate: <100bps

Instrument	Mission(s)	Measurements/application	Technical characteristics	
DORIS Doppler Orbitography and Radio Positioning Integrated by Satellite	EOS-ALTR 1, EOS-ALTR 2, EOS-ALTR 3, SPOT 2, SPOT 3, SPOT 4, TOPEX/POSEIDON	Precise orbit determination	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Dual frequency Doppler 2036.25MHz and 401.25MHz 0.3mm/s onemeasurement every 10 seconds <2-4cm RMS on the satellite altitude; <2cm RMS on ground beacon absolute position 100% operating network visibility >80% Not applicable
DRT-S&R	INSAT IIa, INSAT IIb, INSAT IIc, INSAT IId INSAT IIe,	Data collection and communication, search and rescue	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Duty rate:	
EOSP Earth Observing and Scanning Polarimeter	EOS-AM 2, EOS-AM 3	Atmospheric corrections for clear-sky ocean and land observations, cloud and aerosol propeties global maps of radiance (to 5%) and linear polarisation (to 0.2%). global aerosol distribution and optical thickness in the troposphere and stratosphere. Optical thickness and phase of clouds	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible-SWIR: 0.41-2.25μm 10km at nadir 5% spectral bidirectional reflection distribution function 0.2% polarisation 100% Limb to limb scan (±65 deg) Average/peak: 44/88kbps
ERBE Earth's Radiation Budget Experiment	NOAA 9, NOAA 10	Earth radiation gains and losses on regional, zonal and global scales	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible 0.5-0.7μm, TIR: 10.5-12.5μm, UV-SWIR: 0.2-4.0μm, UV-FIR: 0.2-50μm 200-250km at the Earth's surface for non scanning radiometer, 50km at nadir for scanning radiometer 100% 3000km
ETM+ Enhanced Thematic Mapper	LANDSAT 7	Surface radiance and emittance land cover state and change eg vegetation type	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible-TIR: 0.45-12.5μm (8 spectral bands including 1 panchromatic band between 0.52 and 0.90μm) Panchromatic band: 15m Visible, NIR and SWIR: 30m TIR: 60m 5% 30% 185km. 16 days 150Mbps
GERBI Geostationary Earth Radiation Budget Instrument	MSG 1, MSG 2, MSG 3	Total radiation	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	UV-SWIR: 0.2-4μm SWIR-FIR: 4-50μm 48km at SSP Full disc every 15 mins-1 hour Full Earth Disc

Instrument	Mission(s)	Measurements/application	Technical characteristics
GLAS Geoscience Laser Altimeter System	EOS-ALT 1, EOS-ALT 2, EOS-ALT 3	Ice sheet height/thickness (10cm precision), land altitude, aerosol height distributions, cloud height, boundary layer height	Waveband: Visible-HIR: 0.532μm and 1.064μm Spatial resolution: Along track: 70m spots separated by 188m Accuracy: Ice elevation: 10cm, Cloud top height: 75m, Land elevation: 50cm (3 degree slope) Duty cycle: 50% average, 100% capability Swath width: Nadir viewing Data rate: <200kbps
GLI Global Imager	ADEOS II	Ocean colour, sea surface temperature	Waveband: Visible-HIR: 22 channels SWIR: 5 channels TIR: 2 channels Spatial resolution: TIR channels: 1km Some visible/NIR channels: 250m Accuracy: TBD Duty cycle: 100% (approx 50% for some visible/NIR channels) Swath width: 1600km Data rate: 1km mode: approx 4Mbps, >50m mode: approx 60Mbps, 6km subsample mode for direct UHF transmission to local users: approx 16kbps
GOME Global Ozone Monitoring Experiment	ERS-2	O3, NO, NO2, BrO, H2), O2/O4, plus aerosols and polar stratospheric clouds, other gases in special conditions	Waveband: UV-NIR 0.24-0.79μm (resolution 0.2 to 0.4nm) Spatial resolution: Vertical: 5km (for O3) Horizontal: 40 x 40 km to 40 x 320km Accuracy: Duty cycle: 100% Swath width: 120 to 960km Data rate: 40kbps
GOMOS Global Ozone Monitoring by Occultation of Stars	ENVISAT 1, ESA Future Missions	Stratospheric profiles of ozone, NO2, H20 and aerosols plus some other trace species, temperature profiles	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: 220kbps
GPSDR GPS Demonstration Receiver	TOPEX/POSEIDON follow on (option)	Precise continuous tracking of TOPEX/POSEIDON with decimeter accuracy	Waveband: 1227.6MHz and 1575.4HMz Spatial resolution: 0.1m Accuracy: 4cm on satellite altitude Duty cycle: 100% Swath width: Data rate: 700bps
HALOE Halogen Occultation Experiment	UARS	Vertical distributions of hydrofluoric and hydrochloric acids as well as methane, water vapour and members of the nitrogen family. Atmospheric temperature versus pressure profiles from observations of carbon dioxide.	Waveband: SWIR: 2.43μm, 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

Instrument	Mission(s)	Measurements/application	Technical characteristics
HiRDLS High Resolution Dynamics Limb Sounder	EOS-CHEM 1, EOS-CHEM 2, EOS-CHEM 3	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: 6.12µm-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: 5-10% mixing ratio absolute accuracy Duty cycle: 100% Swath width: 6 profiles across 2000-3000km Data rate: 50kbps average, 1000kbps peak
HIRS/2 20 channel High Resolution Infra-red Sounder	NOAA 9, NOAA 10, NOAA 11, NOAA 12, NOAA14	Atmospheric temperature profiles, cloud parameters, humidity soundings, water vapour, total ozone content, 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/3 High Resolution Infra-red Sounder	ESA Future Missions, First Converged Spacecraft, METOP 1, METOP 2, NOAA K, NOAA L, NOAA M, NOAA N, NOAA N	Atmospheric temperature profiles, cloud parameters, humidity soundings, water vapour, total ozone content, 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
HR PAN	IRS P6	High resolution stereo images for large scale (better than 1:10000) application	Waveband: panchromatic (visible region) Spatial resolution: 2.5m Accuracy: Duty cycle: Swath width: 10km Data rate:
HRDI High Resolution Doppler Imager	UARS	Daytime wind measurements below 50km from Doppler shifts of molecular oxygen absorption lines. Day and night above about 60km from doppler shifts of neutral and and ionised atomic oxygen emission lines. Also measures temperature.	Waveband: Visible-NIR: 557.0-775.6nm 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	SPOT 5a and SPOT 5b	Images 60km x 60km or 60km x 80km	Waveband: Visible: 550, 610-680, 640nm NIR-SWIR: 0.78-0.89µm, 0.85µm, 1.5-1.7µm Panchromatic: 500-750nm Spatial resolution: Panchromatic: 5m Multispectral: 10m Accuracy: Duty cycle: Daylight coverage only Swath width: 60km(one instrument)/ 117km (two instruments) / 174km (three instruments) Same as SPOT 4 with off-track steering capability (±27 deg) Data rate: >50Mbps for 3 instuments

Instrument	Mission(s)	Measurements/application	Technical characteristics
HRV High Resolution Visible	SPOT 1, SPOT 2, SPOT 3	Images 60km x 60km	Waveband: Visible: 500-590, 610-680nm, NIR: 790-890nm, Panchromatic: 510-730nm 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
HRVIR High Resolution Visible and Infra-red	SPOT 4	Images 60km x 60km	Waveband: Visible: 500-590nm, 610-680nm, NIR: 790-890nm, SWIR: 1.5-1.7μm Spatial resolution: 10m (640nm) or 20m Accuracy: Duty cycle: Daylight coverage only (world wide coverage using on board tape rcorder) 100% in daylight. 26 day 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: 25 Mbps each instrument
IASI Infra-red Atmospheric Sounding Inferfero-meter	ESA Future Missions, METOP 1, METOP 2	Tropospheric moisture and temperature, column integrated contents of ozone, carbon monoxide, methane, dinitrogen oxide and other minor gases which affect tropospheric chemistry. Sea surface and land temperature	Waveband: SWIR-TIR: 3.4-15.5μm with gaps at 5μm and 9μm Spatial resolution: Horizontal: 18km, Vertical: 1-3km Accuracy: Duty cycle: 100% Swath width: 2230km Data rate: 1.5Mbps
IIS camera	MECB SSR-1, MECB SSR-2	Vegetation monitoring	Waveband: Visible: 0.63-0.69μm NIR: 0.77-0.89μm Spatial resolution: 200m Accuracy: Duty cycle: Operates only over Brazilian territory Swath width: 755km Data rate: 1.2kbps
IKAR-D	PRIRODA	Investigations of ocean-atmosphere system sea surface temperature, wind speed, precipitable water content, cloud liquid water content, rain rate	Waveband: Microwave: 0.3, 1.35 and 2.25cm Spatial resolution: 5, 15 and 26km respectively (at 400km altitude) Accuracy: 5-7% Duty cycle: A few orbits, on several occasions Swath width 420km (at 400km altitude) Data rate: 8kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
IKAR-N	PRIRODA	Investigations of ocean-atmosphere system sea surface temperature, wind speed, precipitable water content, cloud liquid water content, rain rate	Waveband: Microwave: 0.3, 0.8, 1.35 2.25 and 6.0cm Spatial resolution: 60-70km (at 400km altitude) Accuracy: Duty cycle: A few orbits, on several occasions Swath width: 750km (at 400km altitude) Data rate: 1kbps
IKAR-P	PRIRODA	Inestigations of ocean-atmosphere system, sea surface temperature, wind, speed, precipitable water content, cloud liquid water content, Rain rate	Waveband: Microwave: 2.25cm (3 chan) 6.0cm (5 chan) Spatial resolution: 75km (at 400km altitude) Accuracy: Duty cycle: A few orbits, on several occasions Swath width: 750km (at 400km altitude) Data rate: 1kbps
ILAS Improved Limb Atmospheric Spectro-meter	ADEOS	Measures minor species in high latitude areas, in the altitude range 10-60km (O3, CH4, NO2, N2O, H2O, CFC12, HNO3, aerosols, temperature, pressure)	Waveband: Visible: 0.753-0.784μm, TIR: 6.2-11.8μm Spatial resolution: Infra-red: 13km x 2km (at the tangent point) Visible: 2km x 2km Accuracy: Duty cycle: Every occultation Swath width: Not applicable Data rate: 0.5Mbps
ILAS-II Improved Limb Atmospheric Spectro-meter	ADEOS II	Measures minor species in high latitude areas, in the altitude range 10-60km (O3, CH4, NO2, N2O, H2O, CFC11, HNO3, pressure)	Waveband: 2 visible bands: 0.753-0.784μm 3 TIR bands: 7.14-11.76μm, 2-8μm, 12.80-12.83μm Spatial resolution: IR: 13 x 2km Visible: 2 x 2km Accuracy: 5% (1% for ozone) Duty cycle: Every occultation Swath width: Not applicable Data rate: 0.5Mbps
IMAGER	GOES 8, GOES 9, GOES K, GOES L, GOES M	Cloud cover, severe storm warnings/monitoring day and night (type, amount, storm features), atmospheric radiance winds, atmospheric stability rainfall,	Waveband: GOES I-L: 8 visible detectors (1- channel), and 4 IR channels: 3.9, 6.7, 10.7 & 20μm. GOES M: 8 visible detectors (1- channel), and 4 IR channels: 3.9, 6.7, 10.7 and 13.3μm. Spatial resolution: occasions1km in visible 4km in 4 IR bands Accuracy: Improved Earth location accuracy from 10km to between 2-4km Duty cycle: 100% Swath width: Horizon to horizon Data rate: 2.11Mbps (GVAR - replaces Mode-AAA for GOES I-M)

Instrument	Mission(s)	Measurements/application	Technical characteristics
IMG Interferometric Monitor for Greenhouse Gases	ADEOS	Carbon dioxide, methane, dinitrogen oxide and other greenhouse gases	Waveband: SWIR-TIR: 3.3-14.5μm (spectral resolution 0.1/cm) Spatial resolution: 0.6 x 0.6 deg Accuracy: Duty cycle: Continuous for 4 days out of 14 (TBD) Swath width: 32km Data rate: 0.9Mbps
IR imager	Odin		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
IR multi-scanner	CBERS 1, CBERS 2		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: 77.8m, TIR: 156m Accuracy: Duty cycle: International access open to all participating stations, limited to 20 minutes per revolution Swath width: 19.5km Data rate: 6.13Mbps
ISAMS Improved Stratospheric and Mesospheric Sounder	UARS	Concentrations of nitrogen chemical species, ozone, water vapour, methane and carbon monoxide. Concentrations of aerosol. Atmospheric temperature as a function of altitude from observations of carbon dioxide	Waveband: SWIR-TIR: 4.6-16.6μm Spatial resolution: Vertical (limb): 2.6km, Horizontal (limb): 18km Accuracy: Duty cycle: Swath width: 65km (vertical limb coverage) Data rate: 1.25kbps
ISP	METEOR-3 N7, METEOR-3 N8, METEOR-3M N1, METEOR-3M N2, METEOR-3M N3, METEOR-3M N4	Solar radiation flux	Waveband: UV-FIR; 0.1-100μm Spatial resolution: 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 on 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

Instrument	Mission(s)	Measurements/application	Technical characteristics
KFA-1000	Resource-F1M series	Photography of land and ocean surfaces	Waveband: Visible-NIR: 570-800nm 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: 600-700nm 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 (1:25000 and below)	Waveband: Visible: 600-700nm 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 N1, METEOR-3M N2, METEOR-3M N3, METEOR-3M N4	Particle flux, electromagnetic emissions	Waveband: Spatial resolution: Accuracy: Duty cycle: 100% Swath width: Data rate:
Klimat	METEOR-3 N8	Images of cloud, ice and snow, Sea surface temperature	Waveband: TIR: 10.5-12.5μm Spatial resolution: 3 x 3km (at nadir) Accuracy: Duty cycle: 100% Swath width: 3100km Data rate:
Klimat-2	METEOR-3M N2, METEOR-3M N3, METEOR-3M N4	Global and local observations of land	Waveband: Visible-NIR: 0.65-1.0μm, TIR: 10.5-12.5μm Spatial resolution: 1km Accuracy: Duty cycle: Programmable Swath width: 3000km Data rate:
KONDOR-2	Ocean-01 N7, OKEAN-O, SICH-1, SICH-3		Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: 600km coverage Data rate: 200bps
Laser cornercube reflectors	LAGEOS I, LAGEOS II, LAGEOS III	Distance between the satellite and the laser tracking stations	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
Laser reflectors	STELLA	Distance between the satellite and the laser tracking stations	Waveband: Spatial resolution: Accuracy: Duty cycle: Passive satellite Tracking in visibility of any laser station Swath width: Data rate:
LATI	EOS-AM 2	Earth resources (renewable and non-renewable) including civil planning and mapping, vegetation type, surface radiance and emittance, landcover state and change	Waveband: Visible – TIR: 0.45-12.5 (number of spectral bands, including 1 panchromatic band between 0.52 and 0.90) to be decided. Spatial resolution: 15m in panchromatic band 30m in visible, NIR and SWIR 60m in TIR (may be deleted) Accuracy: 5% Swath width: 185m (may be achieved with 2 instruments) 16 day revisit time Data rate: 150Mbps (TBD)
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: Field of view: 80x80 deg Data rate: 6kbps
LISS I Linear Imaging Self Scanning System	IRS 1a, IRS 1b	National projects include mapping of land use/land cover, forest cover, ground water prospective zones, coastal zones, wastelands, crop acreage and production estimation for wheat, rice, sorghum, cotton, groundnut, tobacco etc. Also Integrated mission for sustainable development	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 time is 22 days for individual satellite, 11 days effectively for IRS 1a/1b together Data rate: 5.2Mbps
LISS II Linear Imaging Self Scanning System	IRS 1a, IRS 1b, IRS P2	National projects include mapping of land use/and cover, forest cover, ground water prospective zones, coastal zones, wastelands, crop acreage and production estimation for wheat, rice, sorghum, cotton, groundnut, tobacco etc. Also integrated mission for sustainable development	Waveband: Visible: 0.46-0.52µm, 0.52-0.59µm, 0.62-0.68µm NIR: 0.77-0.86µm Spatial resolution: 36.25m (32m x 37m IRS P2) Accuracy: Duty cycle: Daylight coverage 100% Swath width: IIA and IIB: 74km each (145km together)– revisit time is 22 days for individual satellite, 11 days effectively for IRS1a/1b together; 132km with 24 day revisit time IRS P2 Data rate: 2 x 10.4Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
LISS III Linear Imaging Self Scanning System	IRS 1c, IRS 1d IRS P4	Land and water resources management, crop protection, pest control, crop production forecasting, forest type mapping, species diversity assessment, integrated resource mapping, environmental impact assessment. Leaf area indices, green biomass, forest cover, area under each species, carrying capacity, land use change, land capability	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 time is 24 days Data rate: 42.45Mbps
LISS IV Linear Imaging Self Scanning System	IRS P5	High resolution multi-spectral mapper	Waveband: Visible (green – red), NIR, SWIR Spatial resulution: ~10m Accuracy: Duty cycle Swath width: 40km, 22 day revisit Data rate: 70mbps
LRA Laser Retroreflector Array	TOPEX/POSEIDON, TOPEX/POSEIDON follow-on	Provides baseline tracking data for precision orbit determination and calibration of radar altimeter bias	Waveband: Spatial resolution: Accuracy: 2cm overhead ranging Duty cycle: 100% Swath width: Data rate:
MASTER	ESA Future Missions	Exchange mechanisms between stratosphere and troposphere complementary information for studies on global change upper troposphere/lower stratosphere profiles of O3, H2O, CO, HNO3, SO2, N2O, pressure, 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 bio-chemical parameters. Secondary objectives are related to atmospheric properties such as cloud and water vapour and to vegetation conditions on land surfaces	Waveband: 15 bands (width programmable between 0.0025μm and 0.03μm) selectable across the spectral range of 0.4μm to 1.05μm (Vis-NIR) 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 aboe 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
MESSR Multispectral Electronic Self Scanning Radiometer	MOS 1b	Atmospheric and oceanic measurements high resolution imaging	Waveband: Visible: 0.51-0.59μm, 0.61-0.69μm NIR: 0.73-0.80μm, 0.80-1.10μm Spatial resolution: 50m Accuracy: Duty cycle: Swath width: 100km (200km when both camera systems are operating) Data rate: 9Mbps
MHS Microwave Humidity Sounder	EOS-PM 1, EOS-PM 2, EOS-PM 3, ESA Future Missions, First Converged Spacecraft, METOP 1, METOP 2, NOAA N, NOAA N'		Waveband: Microwave: 89GHz, 166GHz and 3 channels at 183.3GHz Spatial resolution: Horizontal: 13.5km at nadir Accuracy: 89GHz: ±0.9; 150GHz: ±0.9; 183.3GHz: ±1.0, ±3.0 and ±7.0. Duty cycle: 100% Swath width: 1650km Data rate: 4.2kbps
MIMR Multi frequency Imaging Microwave Radiometer	EOS-PM 1, EOS-PM 2, EOS-PM 3, ESA Future Missions, METOP 1, METOP 2	Precipitation, cloud liquid water content, water vapour, Sea surface winds, sea surface temperature, sea ice (boundary), snow cover, soil moisture, Ice sheets, permafrost, sea ice (concentration, type, extent)	Waveband: Microwave: 6.8 to 90GHz Spatial resolution: 7-85km Accuracy: Duty cycle: 100% Swath width: 1600km Data rate: 100kbps
MIPAS Michelson Interferometric Passive Atmosphere Sounder	ENVISAT 1, ESA Future Missions	Chemistry of stratosphere (global and polar ozone), climate research (global distribution of trace gases and clouds), transport dynamics, tropospheric chemistry. O3, NO, NO2, HNO3, N2O5, ClONO2, CH4, H2O, N20. target species (detection to be investigated) are: HNO4, COF2, HOCl, CFCs, CO, OCS, aerosols, clouds, C2H2, C2H4, SF6	Waveband: IR band between 4.15 and 14.6μm Spatial resolution: Vertical resolution: 3km, vertical scan range 5-100km Horizontal: 30km x 300km, 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, EOS-AM 2, EOS-AM 3	Global maps of planetary and surface albedo, aerosol and vegetation properties, top of atmosphere, cloud and surface angular reflectance functions radiometrically calibrated images in global and local modes. multi-angle bidirectional data (1% angle-to-angle accuracy) for cloud cover and reflectances at the surface. aerosol opacities	Waveband: Visible: 0.44μm, 0.56μm, 0.67μm NIR: 0.86μm Spatial resolution: 240m, 480m, 960m or 1.93km 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 Data rate: Average/peak: 3.3/9.0Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
MIVZA	METEOR-3 N8	Humidity sounding	Waveband: Microwave: 1.5, 0.86, 0.32cm Spatial resolution: 20-80km Accuracy: Duty cycle: 100% Swath width: 1500km Data rate:
MIVZA-M	METEOR-3M N2, METEOR-3M N3, METEOR-3M N4, Resource-02	Total atmospheric humidity sounding	Waveband: Microwave, 20, 35, 94GHz (5 channels) Spatial resolution: 80, 55, 20km respectively Accuracy: Duty cycle: 100% Swath width: 1500km Data rate:
MK-4	Resource-F2 series	Photography of land and ocean surfaces in 4 out of 6 channels	Waveband: Visible-NIR: 435-680nm, 460-510nm, 515-565nm, 640-690nm, 610-750nm, 810-860nm 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:
MK-4M	Resource-F2M series	Photography of land and ocean surfaces in 4 spectral channels	Waveband: Visible-NIR: 640-690nm, 520-560nm, 610-760nm, 810-870nm 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, EOS-CHEM 2, EOS-CHEM 3	Lower stratospheric temperature, concentration of H2O, O3, ClO, HCl, OH, HNO3, N2O and SO2	Waveband: 5 spectral bands centered at 215GHz, 310GHz, 640GHz and 2.5THz with a spectral resolution of 1MHz Spatial resolution: Vertical: 1.5km (2.5THz) to 4.0km (215GHz) Horizontal: 10km Accuracy: Duty cycle: 100% Swath width: Limb scan 2.5-62.5km Limb to limb Data rate: 100kbps
MLS (UARS) Microwave Limb Sounder	UARS	Emissions of chlorine monoxide, water vapour and ozone (4.8, 1.64 and 1.46mm). Determination of atmospheric pressure and temperatures as a function of altitude from observations of molecular oxygen emissions	Waveband: Microwave: 63, 183 and 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-AM 2, EOS-AM 3, EOS-PM 1, EOS-PM 2, EOS-PM 3	Biological and physical processes-global dynamics and processes on the surface of the Earth and in the lower atmosphere. Surface temperatures of land and ocean, chlorophyll fluorescence. Land surface cover measurements (vegetation and snow). Cloud cover by day and night. Cloud properties, aerosol properties	Waveband: Visible-TIR: 36 bands between 0.4 and 14.4µm Spatial resolution: Cloud cover: 250m (day) and 1000m (night) Surface temperature: 1000m Accuracy: Surface temperature of land: <1K Surface temperature of ocean: <0.2K Duty cycle: 100% Swath width: 2300km at 110 deg deg). Provides daylight reflection and day/ night emission spectral imaging of any point on the Earth at least every two days. Data rate: 2.5-11Mbps (average 6.2Mbps)
MOMS-2P Modular Optoelectronic Multispectral Scanner	PRIRODA	The instrument can be operated in 4 different modes: 1) full stereo with high resolution, 2) multi-spectral, all four bands, 3) high resolution and 3 spectral bands, 4) 2 multispectral bands plus fore and aft stereo	Waveband: MS:4 Visible-NIR channels: 440-505, 530-575, 645-680, 770-810nm HR and ST: Panchromatic:520-760nm 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 end 1995 Swath width: MS: 92-105km, HR: 44-50km, ST: 88-105km, Revisit: approx 14 days Data rate: Up to 100Mbps without compression
MOPITT Measurements of Pollutants in the Troposphere	EOS-AM 1	Measurement of greenhouse gases (CO, methane) in the troposphere	Waveband: 2.3,2.4,4.7µm Spatial resolution: CO profile: 22x22km horizontal, 4km vertical CO, CH4 column: 22x22km horizontal Accuracy: Carbon monoxide: 10% Methane: 2% Duty cycle: 100% Swath width: swath ±25 degrees about nadir, revisit 4 days Data rate: 25kbps continuous
MOS Modular Optoelectronic Scanning Spectrometer (A and B)	IRS P3, PRIRODA	Spectral analysis of O2 absorption in the NIR band, vegetation index, condition of soil and vegetation	Waveband: MOS-A: NIR: 755-768nm (4 channels) MOS-B: Visible-NIR: 408-1010nm (13 bands) MOS-C: SWIR: 1600nm Spatial resolution: MOS-A: 2.52km 2.87km, MOS-B: 720 x 850m, MOS-C: 1000x720m Accuracy: Radiometric: <1% Duty cycle: 10% Swath width: ~200km Data rate: 3.9 Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
MR-2000	METEOR-2 N24	Images of cloud, snow and ice	Waveband: Visible-NIR: 0.5-0.8μm Spatial resolution: 1km (at nadir) Accuracy: Duty cycle: 100% Swath width: 2600km Data rate:
MR-2000M	METEOR-3 N5, METEOR-3 N7, METEOR-3 N8	Images of cloud, snow and ice	Waveband: Visible-NIR: 0.5-0.8μm Spatial resolution: 0.7 x 1.4km (at nadir) Accuracy: Duty cycle: 5-7 viewing periods each day Swath width: 3100km Data rate:
MR-900	METEOR-2 N24	Images of cloud, snow and ice	Waveband: Visible-NIR: 0.5-0.8μm Spatial resolution: 2km (at nadir) Accuracy: Duty cycle: 100% Swath width: Scan angle 90 deg (2100km) Data rate:
MR-900B	METEOR-3 N5, METEOR-3 N8	Images of cloud, snow and ice	Waveband: Visible-NIR: 0.5-0.8μm Spatial resolution: 2 x 1km (at nadir) Accuracy: Duty cycle: Real-time programmable Swath width: 2600km Data rate:
MSR (NASDA) Microwave Scanning Radiometer	MOS 1b	Sea ice, snow cover, atmospheric water vapour (over oceans), liquid water content (over oceans)	Waveband: Microwave: 23.8GHz and 31.4GHz Spatial resolution: 23.8GHz: 32km, 31.4GHz: 23km Accuracy: Duty cycle: 100% Swath width: 320km Data rate: 2kbps
MSR (RSA)	METEOR-3M N1	Imaging multi-spectral (visible, IR) radiometer	Waveband: 4 bands: 0.5-0.7 (visible), 0.8-1.0 (NIR) and 10.4-11.3 and 11.5-12.5μm (TIR) Spatial resolution: 1km Accuracy: Visible – NIR: 0.003μm TIR: 0.15K Duty cycle: 100% Swath width: 2700km Data rate: 1.3Mbps
MSS Multi-spectral Scanning System	LANDSAT 4, LANDSAT 5	Surface radiance	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

Instrument	Mission(s)	Measurements/application	Technical characteristics	
MSU	NOAA 9, NOAA 10, NOAA 11, NOAA 12, NOAA 14	Temperature sounding through cloud up to 20km in altitude	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Microwave: 50.3GHz, 53.74GHz, 54.96GHz, 57.95GHz 105km 100% 2348km 320bps
MSU-E	Resource-01 N2, Resource-01 N3	Images of land surface and ice cover	Waveband: Spatial resolution: Accuracy: Duty cycle Swath width: Data rate:	Visible: 0.5-0.6μm, 0.6-0.7μm, NIR: 0.8-0.9μm 45m (at nadir) 4% radiometric accuracy Programmable 45m for one scanner, 80km for two scanners (pointable ±30 deg from nadir) 11.5Mbps (3 channels)
MSU-E1	Resource-02	Images of land surface and ice cover	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible: 0.5-0.6μm, 0.6-0.7μm, NIR: 0.8-0.9μm 25m (at nadir) 4% radiometric accuracy Programmable 45km for one scanner, 80km for two scanners (pointable ±30 deg from nadir) 11.5Mbps (3 channels)
MSU-E2	ALMAZ-1B, PRIRODA		Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible: 0.5-0.6μm, 0.6-0.7μm, NIR: 0.8-0.9μm 10m (at nadir) 4% radiometric accuracy Programmable 2 x 24km 11.5Mbps (3 channels)
MSU-M	Ocean-01 N7 PRIRODA	Images of ocean surface and ice sheets	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible: 0.5-0.6μm, 0.6-0.7μm, NIR: 0.7-0.8μm 0.8-1.1μm 1x1.7km 30mins max continuous operation 1900km
MSU-S	Ocean-01 N7 OKEAN-O, SICH-1	Images of ocean surface and ice sheets	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible: 0.5-5-0.7μm, NIR: 0.7-1.0μm 345m 100% 1280km

Instrument	Mission(s)	Measurements/application	Technical characteristics
MSU-SK	ALMAZ-1B, OKEAN-O, PRIRODA, Resource-01 N2, Resource-01 N3, Resource-02	Images of land surface and ice cover	Waveband: Visible: 0.5-5-0.6µm, 0.6-0.7µm, NIR: 0.7-0.8µm, 0.8-1.1µm, TIR: 10.3-11.8µm, Spatial resolution: visible-NIR: 170m, TIR600m Accuracy: 4% radiometric accuracy Duty cycle: Programmable Swath width: 600km Data rate: 11.5Mbps (5 channels)
MSU-V	OKEAN-O,	Images of ice and snow and land use assessment	Waveband: Visible: 0.45-0.52µm, 0.52-0.62µm, 0.62-0.74µm, NIR: 0.79-0.90µm 0.9-1.1µm, SWIR: 1.55-1µm 2.1-2.35µm , TIR: 10.3-12.6µm Spatial resolution: visible-: 50m, NIR 50-250m TIR: 100m Accuracy: Duty cycle: 100% Swath width: Data rate: 5.12Mpbs – 1.28Mbps
MTZA	METEOR-3M N1, METEOR-3M N2, METEOR-3M N3, METEOR-3M N4	Atmospheric temperature profiles	Waveband: Microwave: 20, 35, 52.28, 52.85, 53.33, 54.4, 55.45, 56.968, 94GHz (15 channels) Spatial resolution: 80-20km Accuracy: Duty cycle: 100% Swath width: 1500km Data rate:
Multi-spectral Visible & IR Scan Radiometer (10 channel)	FY-1C, FY-1D	Imaging multi-spectral radiometer	Waveband: 10 channels: (4 vis, 3 NIR, 1 SWIR, 2 FIR): 0.58-0.68µm 1.58-1.68µm 0.84-0.89µm 0.43-0.48µm 3.55-3.93µm 0.48-0.53µm 10.3-11.3µm 0.53-0.58µm 11.5-12.5µm 0.90-0.965µm Spatial resolution: 1.1km Accuracy: Duty cycle: 100% Swath width: 3200km Data rate: 1.3308Mbps
Multi-spectral Visible & IR Scan Radiometer (3 channel)	FY-2	Cloud cover, ice, snow and flood monitoring surface temperature	Waveband: Visible-NIR: 0.55-1.05µm TIR: 6.2-7.6µm, 10.5-12.5µm Spatial resolution: 1.25km (visible), 5km (IR and water vapour) Accuracy: Duty cycle: 100% Swath width: Full earth disc Data rate: raw data 14Mbps S-VISSR 0.66Mbps
MVIRI METEOSAT Visible and Infra-red Imager	METEOSAT 3, METEOSAT 4, METEOSAT 5, METEOSAT 6 METEOSAT 7	Cloud cover, motion, height upper tropospheric humidity values, sea surface temperature	Waveband: Visible-NIR: 0.5 to 0.9µm TIR: 5.7 to 7.1µm (water vapour), 10.5 to 12.5µm Spatial resolution: Visible: 2.5km Water vapour: 5km (after processing) TIR: 5km Accuracy: Duty cycle: Full Earth in all three channels, every 30 minutes Swath width: Full Earth Disc Data rate: 333kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
MWR Microwave Radiometer	ENVISAT 1, ESA Future Missions	Atmospheric humidity	Waveband: Microwave: 23.8 and 36.5GHz Spatial resolution: 20km Accuracy: 2.6K Duty cycle: 100% Swath width: 20km Data rate: 0.5kbps
MZOAS	METEOR-3M N1, METEOR-3M N2, METEOR-3M N3, METEOR-3M N4	Effective temperature and liquid water content of ocean surface, cloud, snow	Waveband: Microwave: 6, 11, 19, 22, 35, 94GHz (10 channels) Spatial resolution: 160, 80, 40, 36, 22, 9km respectively Accuracy: Duty cycle: 100% Swath width: 1500km Data rate:
NSCAT NASA Scatterometer	ADEOS	Surface wind speed and direction	Waveband: Microwave: 14GHz Spatial resolution: 50km. Location accuracy: 25km (absolute), 10km (relative) Accuracy: Surface wind speed: 2m/s (wind speed 3-20m/s); 10% (wind speed 20-30m/s) Direction: 20 deg Duty cycle: 100% Swath width: 1200km – covers 90% of ocean every 2 days Data rate: 2.9kbps
Ocean Color	EOS-COLOR	Ocean colour and biology	Waveband: Visible-NIR: 0.402-0.885μm; global coverage every 2 days. Spatial resolution: Local area coverage: 1.1km Global area coverage: 4.5km Accuracy: Radiometric accuracy <5% absolute Duty cycle: 100% in daylight Swath width: 2800km (±58.3 deg) Data rate:
OCM	IRS P5	Ocean colour in visible and NIR region	Waveband: 8 bands in visible/NIR Spatial resolution: 500m Accuracy: Duty cycle: Swath width: Data rate:
OCTS Ocean Colour and Temperature Scanner	ADEOS	Sea surface temperature ocean primary productivity, interaction between the ocean and the atmosphere and environment conditions studies	Waveband: Visible: 0.402-0.422, 0.433-0.453, 0.479-0.501 0.511-, 0.529, 0.555-0.575, 0.660-0.680μm. NIR: 0.745-0.785, 0.845-0.885μm. SWIR: 3.55-3.88μm. TIR: 8.25-8.80, 10.3-11.4, 11.4-12.7μm Spatial resolution: 700m
OHM	Future NOAA polar orbiters	Earth magnetic field measurement	Waveband: static field Spatial resolution: Accuracy: 0.5nT Duty cycle: continuous Swath width: Data rate: 1 per second

Instrument	Mission(s)	Measurements/application	Technical characteristics
OMI Ozone Monitoring Instrument	METOP 1,2 ESA Future Missions	Ozone	Waveband: Spatial resolution: Accuracy: Duty cycle: Data rate:
OPS Optical Sensor	Future NOAA	Earth magnetic field measurements	Waveband: Static field Spatial resolution: Accuracy: 0.5 nT Duty cycle: continuous Swath width: Data rate: 1 per second
Ozon-M	PRIRODA	Atmospheric turbidity, 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: 0.02-0.07μm Duty cycle: A few orbits, on several occasions Swath width: Data rate: 2 x 25 angular minutes
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. Urban sprawl, forest cover/ timber volume, land use change	Waveband: Panchromatic: 0.5-0.75μm Spatial resolution: 5.8m Accuracy: Duty cycle: Daylight coverage only Swath width: 70km mosaic Revisit time is 5 days (with steerability) Data rate: 84.9Mbps
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 3keV to 100keV, HEPS: electrons from 0.04MeV to 5.0MeV, protons from 0.07MeV to 150MeV, MEPS: electrons and protons from 1eV to 32keV, VMAG: three-axis magnetic field from -65000nT to +65000nT Spatial resolution: AXIS: horizontal ~60km, vertical ~5km, HEPS: horizontal ~30km, vertical ~5kmMEPS: horizontal ~15km, vertical ~5km, VMAG: horizontal ~1.5km, vertical ~5km Accuracy: AXIS: 1 count in 8 sec ± Poisson static value [sqrt(n)], HEPS: 1 count in 4 sec ± Poisson static value [sqrt(n)], MEPS: 1 count in 57 msec ± Poisson static value [sqrt(n)], VMAG: 2nT ± 1nT Duty cycle: 100% Swath width: Data rate: 3.5kbps
POAM 2	SPOT 3		
POAM 3	SPOT 4		

Instrument	Mission(s)	Measurements/application	Technical characteristics
POLDER Polarisation and Directionality of the Earth's Reflectance	ADEOS, ADEOS II	Measurement of polarization, directional and spectral characteristics of the solar light reflected by aerosols, clouds, oceans and land surfaces	Waveband: Visible-NIR: 0.443, 0.670 & 0.865µm (at 3 polarisations) and 0.443, 0.49, 0.565, 0.763, 0.765 & 0.91µm (no polarisation) Spatial resolution: 6km x 6km (nadir) Accuracy: Expected accuracy of measurement: 2-3% Duty cycle: 50% max Swath width: 2400km (across track) x 1800km (along track) Data rate: 0.9Mbps
PR Precipitation Radar	TRMM	Rainfall rate 0.7mm/h at storm top (not yet verified) observable range: from surface to approx 15km altitude	Waveband: Microwave: 13.796GHz and 13.802GHz Spatial resollution: Range resolution: 250m (not yet verified) Horizontal resolution: 4.3km at nadir Accuracy: Duty cycle: Swath width: 215km (scanned every 0.6s) Data rate: 93.5kbps
PRARE Precise Range and Rate Equipment	ERS-2, METEOR-3 N7	Precise evaluation of altimeter measurements geodetic and geodynamic research pseudo-noise coded ranging and doppler shift measurements	Waveband: X and S bands Spatial resolution: Not applicable Accuracy: Duty cycle: Not applicable Swath width: Not applicable Data rate: 4kbps
PRISM Process Research by an Imaging Space Mission	ESA Future Missions	Land surface processes	Waveband: Visible-SWIR: 0.45-2.35µm at 10-12nm resolution TIR: 3.5-4.1µm (1 band) TIR: 8 x 12µm (3 bands) Spatial resolution: Spatial sampling interval approx 50m, Along and across track pointing ±30 deg Accuracy: Visible, NIR, SWIR: typical S:N is 200:1 TIR: NETD approx 0.01K Duty cycle: Swath width: 50km Data rate: <100Mbps by data selection/compression
R-225	OKEAN-O		Waveband: Microwave: 13.3GHz (2.25cm) (2 polarisation) Spatial resolution: 130km Accuracy: Duty cycle: 100% Swath width: Data rate:
R-400	PRIRODA	Investigations of ocean-atmosphere system sea surface temperature, wind speed, precipitable water conent, cloud liquid water content, 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

Instrument	Mission(s)	Measurements/application	Technical characteristics
R-600	OKEAN-O		Waveband: Microwave: 4.9GHz (6cm) (2 polarisation) Spatial resolution: 130km Accuracy: Duty cycle: 100% Swath width: Data rate:
RA Radar Altimeter	ERS-1, ERS-2	Wind speed, significant wave height, sea surface elevation, Ice profile, land and ice topography, sea ice boundaries	Waveband: 13.8GHz, K band 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, ESA Future Missions	Wind speed, significant wave height, sea surface topography, ice profile, land and ice topography, sea ice boundaries	Waveband: K band: 13.575GHz, S band: 3.2GHz 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: 64/100kbps
Radiometer	Odin		Waveband: 3 Microwave bands: 119, 486-502, 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	Rain rate, height of melting layer	Waveband: Spatial resolution: Global: 100km x 100km Vertical: 0.5-1km (goals) Accuracy: Duty cycle: TBD Swath width: TBD Data rate:
RIS Retroreflector In Space	ADEOS	Ozone, fluorocarbons, carbon dioxide, CH4 and other minor species	Waveband: Uses wavelengths between 0.4 and 14μm Spatial resolution: A few km/column amount (dependent on target species) Accuracy: Duty cycle: Every pass over the ground station (visibility permitting) Swath width: Not applicable Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics
RLSBO	Ocean-01 N7, OKEAN-O, SICH-1	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:
RLSBO with scatterometer	SICH-2	Images of ocean surface and ice sheets	Waveband: Microwave: 3.2cm Spatial resolution: 0.8 x 1.6km Accuracy: Duty cycle: 15 min maximum continuous operation Swath width: 2 x 700km Data rate:
RM-0.8	Ocean-01 N7, SICH-1	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	METEOR-2 N24, METEOR-3 N5, METEOR-3 N7, METEOR-3 N8	Data on electron and proton fluxes	Waveband: Spatial resolution: Accuracy: Duty cycle: 100% Swath width: Data rate:
RMS	Electro-GOMS N1	Fluxes of charged particles and EM radiation, magnetic field	Waveband: Spatial resolution: Not applicable Accuracy: Duty cycle: 100% Swath width: Not applicable Data rate:
S&R (GOES) Search and Rescue	GOES 7, GOES I, GOES J, GOES K, GOES L, GOES M	Search and rescue	Waveband: Uplink: 406MHz, Downlink: 1544.5MHz Spatial resolution: Not applicable Accuracy: Not applicable Duty cycle: 100% Swath width: Not applicable Data rate: Not applicable
S&R (NOAA) Search and Rescue	First Converged Spacecraft, NOAA 9, NOAA 10, NOAA 11, NOAA 14, NOAA K, NOAA L, NOAA M, NOAA N, NOAA N'	Search and rescue	Waveband: Uplink: 121.5, 243, 406MHz, Downlink:1544.5MHz Spatial resolution: Not applicable Accuracy: Not applicable Duty cycle: 100% Swath width: Not applicable Data rate: Not applicable
SAGE III Stratospheric Aerosol and Gas Experiment	EOS – AERO1 – 5, EOS flights of opportunity, METEOR-3M N1	Profiles of ozone, water vapour, NO_2, OClO, aerosols, temperature and pressure	Waveband: UV-NIR: 0.29 – 1.55µm Spatial resolution: 1-2km in the vertical Accuracy: 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

Instrument	Mission(s)	Measurements/application	Technical characteristics
SAR Synthetic Aperture Radar	RADARSAT	All weather images of ocean, ice and land surfaces monitoring of coastal zones, polar ice, sea ice, sea state, geological features, vegetation, land surface processes	Waveband: C band – 5.3GHz, HH polarisation Spatial resolution: Standard: 25m x 28m, Wide beam (1/2): 48-30m x 28m/ 32-25m x 28m, Fine resolution: 11-9m x 9m, ScanSAR (N/W): 50m x 50m/ 100m x 100m, Extended (H/L): 22m-19m x 28m/ 63m-28m x 28m Accuracy: Geometric distortion: <40m, Radiometric: 1.0dB Standard: 4 looks, Wide beam (1/2): both 4 looks, Fine resolution: 1 look, ScanSAR (N/W): 2-4/4-8 looks, Extended (H/L): both 4 looks 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), Scan-SAR (W): 510km (20-49deg), Extended (H/L): 75km/170km (50-60/ 10-23deg) Data rate: 85-105Mbps by X-band downlink
SAR Synthetic Aperture Radar	JERS 1	High resolution imaging	Waveband: Microwave: 1.275GHz Spatial resolution: 18m x 18m Accuracy: Duty cycle: Swath width: 75km Data rate: 60Mbps
SAR Synthetic Aperture Radar	SICH-2	All weather radar data for geology, cartography, geophysics, statistics, ecology	Waveband: Microwave: 23cm Spatial resolution: 10-50m Accuracy: Duty cycle: 100% Swath width: 40km (detailed), 80-120km (survey) Data rate:
SAR-10 Synthetic Aperture Radar	ALMAZ-1B	All weather radar data	Waveband: Microwave: 9.6cm Spatial resolution: 5-7m (detailed), 15m (intermediate), 15-40m (survey) Accuracy: Contrast sensitivity: 2-2.25dB (left side), 1-1.5dB (right side) Duty cycle: Programmable Swath width: 30-55km (detailed), 60-70km (intermediate), 120-170km (survey). Resight swath 330km Data rate: Survey: 104-288Mbps, Intermediate: 354-740Mbps, Detailed: 172-582Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
SAR-3 Synthetic Aperture Radar	ALMAZ-1B	All weather radar data	Waveband: Microwave: 3.5cm Spatial resolution: 5-7m Accuracy: Contrast sensitivity: 2-3dB Duty cycle: Programmable Swath width: 20-35km. Resight swath 330km Data rate: 116-370Mbps
SAR-70 Synthetic Aperture Radar	ALMAZ-1B	All weather radar data	Waveband: Microwave: 70cm Spatial resolution: 20-40m Accuracy: Contrast sensitivity: 1dB Duty cycle: Programmable Swath width: 120-170km. Resight swath 330km Data rate: 172-488Mbps
SBUV/2 Solar Backscatter Ultra-Violet instrument	NOAA 9, NOAA 11, NOAA 14, NOAA K, NOAA M, NOAA N, NOAA N'	Trace gases including ozone distribution, solar irradiance measurements, total ozone concentration measurement in the atmosphere to an absolute accuracy of 1%	Waveband: 100-400nm, 252-340nm Spatial resolution: 170km Accuracy: Duty cycle: 100% Swath width: Nadir pointing Data rate: 320bps
SBUV/3 Solar Backscatter Ultra-Violet instrument	First Converged Spacecraft	Trace gases including ozone distribution, solar irradiance measurements, total ozone concentration measurement in the atmosphere to an absolute accuracy of 1%	Waveband: Spatial resolution: 170km Accuracy: Duty cycle: 100% Swath width: Nadir pointing Data rate: 320bps
Scanning microwave radiometer 5-120GHz	SICH-3	Thermal mapping (land and sea), humidity, precipitable water, atmospheric phenomena	Waveband: Microwave: 6, 10, 18, 22, 37, 90GHz Spatial resolution: 80 x 110km, 50 x 70km, 35 x 50km, 27 x 35km, 15 x 21km, 6 x 6km respectively Accuracy: 6, 10GHz: 1K; 18, 22, 37GHz: 0.15K; 90GHz: 0.3K Duty cycle: Swath width: 1000km Data rate: 100kbps
ScaRaB Scanner for Earth's Radiation Budget	ENVISAT 1, ESA Future Missions, METOER-3 N8 METEOR-3M N1, METEOR-3M N2, METEOR-3M N3, METEOR-3M N4, METOP 1, METOP 2	Top of atmosphere shortwave radiation (0.2-4μm) and total (0.2-50μm) radiation. Two additional narrow band channels (0.5 to 0.7μm and 11 to 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: abs: ±2.5W/m2/sr, rel: ±0.7W/m2/sr Duty cycle: Programmable Swath width: 2200km Data rate: 1kbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
SCIAMACHY Scanning Imaging Absorption Spectrometer for Atmospheric Cartography	ENVISAT 1, ESA Future Missions	Middle atmosphere temperature tropospheric and stratospheric profiles of O2, O3, O4, CO, N2O, NO2, CO2, CH4, H2O. In stratosphere NO column, HF, BrO, ClO, OClO. In troposphere HCHO, SO2, NO3 tropospheric and stratospheric profiles of aerosols, cloud altitude	Waveband: UV-SWIR: 240-295, 290-405, 400-605, 590-810, 790-1055, 1000-1700, 1980-2020, 2265-2380nm Spatial resolution: Limb vertical 3km Nadir horizontal 32 x 215km Accuracy: Duty cycle: 100% Swath width: Limb mode: 600km, Nadir mode: 1000km Data rate: 400-1900Mbps (mode-dependent)
Sea Winds	ADEOS II	Surface wind speed and direction	Waveband: Operates at 13.402GHz Spatial resolution: 50km resolution Accuracy: 15km (rms) Duty cycle: 100% Swath width: 90% of the oceans in 2 days Data rate:
SeaWiFS Sea viewing Wide Field Sensor	SeaStar	Ocean colour and biology	Waveband: Visible-NIR: 0.402-0.422μm, 0.433-0.453μm, 0.480-0.5μm, 0.5-0.52μm, 0.545-0.565μm, 0.66-0.68μm, 0.745-0.785μm, 0.845-0.885μm Spatial resolution: 1.1km (local) and 4.4km (global) at nadir Accuracy: 5% (absolute radiometric accuracy) Duty cycle: 100% on daylit Earth Swath width: 1500-2800km Data rate: 665kbps
SEM Space Environment Monitor	ESA Future Missions, First Converged Spacecraft, GOES 7, GOES 8, GOES 9, GOES K, GOES L, GOES M, METOP 1, METOP 2, NOAA 9, NOAA 10, NOAA 12, NOAA 14, NOAA K, NOAA L, NOAA M, NOAA N, NOAA N'	Solar activity and energy deposited by solar particles, solar storm warning	Waveband: Spatial resolution: Not applicable Accuracy: Duty cycle: 100% Swath width: Not applicable Data rate: 160bps
SEVIRI Spinning Enhanced Visible and Infra-red Imager	MSG 1, MSG 2, MSG 3	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, sea surface temperature	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, 8.3-9.1μm, 9.8-11.8μm, 11.0-13.0μm, 5.35-7.15μm, 6.85μm – 7.85μm, 9.46-9.94μm, 13.04-13.76μm Spatial resolution: 1km (at SSP) for one broadband visible channel HRV 3km (at SSP) for all other channels Accuracy: Duty cycle: Full disc every 15 minutes Swath width: Full Earth Disc Data rate: 2.8Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
SFM-2 spectrometer to measure direct solar radiation	METEOR-3 N5, METEOR-3 N8	Ozone profile measurements	Waveband: UV: 260-400nm Spatial resolution: 40 x 10 deg Accuracy: Duty cycle: 100% Swath width: Data rate:
SILVA	ALMAZ-1B	Height data	Waveband: Visible-NIR: 0.5-0.6, 0.6-0.7, 0.7-0.8, 0.58-0.8μm Spatial resolution: 2.5-4m Accuracy: Photogrammatical distortion: 0.015% Duty cycle: Programmable Swath width: 80km. Resight swath ±300km Data rate: 560Mbps (1 channel)
SLR-3 Side Looking Radar	ALMAZ-1B	All weather radar data	Waveband: Microwave: 3.5cm Spatial resolution: 190-250m range, 1200-2000m azimuth Accuracy: Contrast sensitivity: 2-3dB Duty cycle: Programmable Swath width: 450km Data rate: 116-370Mbps
SOLSTICE Solar/Stellar Irradiance Comparison Experiment	UARS	UV and charged particle energy inputs, time variation of full-disc solar UV spectrum. Measurements of solar UV radiation (115 to 430nm) with resolution of 0.12nm. Compares solar UV output with UV radiation of stable bright blue stars for calibration	Waveband: UV: 115-430nm (0.12nm and 0.25nm bands for sun, 5nm and 10nm bands for stars) Spatial resolution: Not applicable Accuracy: better than 5% Duty cycle: 100% Swath width: Not applicable Data rate: 0.25kbps
SOLSTICE II Solar/Stellar Irradiance Comparison Experiment	EOS flights of opportunity	Improve understanding of the changes in the photochemistry, dynamics and energy balance of the middle atmosphere. Solar UV irradiance, solar radiation penetration, radiation fields	Waveband: UV: 5-440nm (5 channels) Spectral resolution: 0.2nm to 0.0015nm Spatial resolution: Not applicable Accuracy: Photometric accuracy 5% absolute, 1% relative Duty cycle: 74% Swath width: Full solar disc Data rate: 5-8kbps
SOPRANO Sub-millimetre Observation of Processess in the Absorption Noteworthy for Ozone	ESA Future Missions	Temperature profiles and trace gases in the upper troposphere to mesosphere including ClO, O3, HCl, NO, BrO as first priority. HOCl, CH3Cl, H2O, N2O, HO2, HNO3 as second priority.	Waveband: Sub mm: a) 499.4-505.0GHz b) 624.5-626.6GHz and 628.2-628.7GHz c) 730.5-732.0GHz 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 res, 0.3 secs integration time Duty cycle: 100% Swath width: 10-50km tangent height range Data rate: 0.5Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
SOUNDER	GOES 8, GOES 9, GOES K, GOES L, GOES M	Atmospheric soundings atmospheric stability thermal gradient winds	Waveband: Visible, SWIR, TIR Spatial resolution: 10km (improved resolution from 14km to 10km) Accuracy: Duty cycle: 100% Swath width: Horizon to horizon Data rate: 40kbps (inc in GVAR)
Spectro-radiometer medium resolution	SICH-3	Images of ice and snow and land use assessment	Waveband: Visible: 0.4-0.7μm, NIR-SWIR: 0.8-2.4μm Spatial resolution: 10-40m Accuracy: Duty cycle: 100% Swath width: 160-200km coverage within a possible 600km swath Data rate: 32-64Mbps
SROSM	ALMAZ-1B	Temperature data	Waveband: Visible-TIR: 0.4-12.5μm Spatial resolution: 600m Accuracy: <5% Duty cycle: Programmable Swath width: Scan field: 2 x 100km Data rate: 2.4Mbps (11 channels)
SSALT-2	TOPEX/POSEIDON follow-on	Satellite-ocean distance and by products: wave height, wind speed	Waveband: Ku band, C band Spatial resolution: Basic measurement: 1/sec (6km along track) Raw measurement: 10/sec (600m along track) Accuracy: 2cm RMS for instantaneous 1/sec Ku band measurement 2.5cm RMS for instantaneous 1/sec combined (Ku and C band) measurements 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
SSALT TOPEX/ POSEIDON	TOPEX/POSEIDON	Satellite-ocean distance and by-products: wave height, wind speed	Waveband: Microwave 13.65GHz Spatial resolution: 2km antenna footprint Basic measurement: 1/sec (6km along track Raw measurement: 20/sec (300m along track) Accuracy: 2cm typical Duty cycle: 10% due to antenna sharing with NASA altimeter. 100% duty cycle capability. Subsequent assessment resulted in continuation of 10% operation for remainder of mission. Swath width: 10 day cycle 300km between tracks at equator Data rate: 1.3kbps in operational mode 12kbps in calibration mode

Instrument	Mission(s)	Measurements/application	Technical characteristics
SSALT (EOS-ALT radar series)	EOS-ALTR 1, EOS-ALTR 2, EOS-ALTR 3	Satellite-ocean distance and by-products: wave height, wind speed	Waveband: Microwave 5.3GHz, 13.65GHz Spatial resolution: 5km Accuracy: 2cm in height typical Duty cycle: Swath width: Not applicable, measurements are performed only at ssp Data rate: 1.375kbps
SSU Stratospheric Sounder Unit	NOAA 9, NOAA 11, NOAA 14	Temperature profiles in stratosphere, top of atmosphere radiation (from 25km to 50km in altitude)	Waveband: 3 bands: 669.99, 669.63, 669.36cm-1 (carbon dioxide) Spatial resolution: 147.3km at nadir Accuracy: Duty cycle: 100% Swath cycle: ±40 deg scan Data rate: 0.48kbps
SUSIM Solar Ultraviolet Irradiance Monitor	UARS	UV and charged particle energy inputs, time variation of full-disc solar UV spectrum. Measures solar UV radiation (0.12 to 4μm) with resolution of 0.15nm	Waveband: UV: 0.12-0.4μm (0.15nm bands) Spatial resolution: Not applicable Accuracy: 1% Duty cycle: Swath width: Looks at sun Data rate: 2kbps
SXI Solar X-ray Imager	GOES M	Solar coronal structure, full disc imagery, geomagnetic storm warning, solar flares, active regions on sun, 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, EOS-CHEM 2, EOS-CHEM 3	3D profiles on a global scale of all infra-red active species from surface to lower stratosphere grenhouse gas concentrations, tropospheric ozone, acid rain precursors, gas exchange leading to stratospheric ozone depletion. Species measurements include NOx, CH4, CO, SO2, CFCs and halons	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: 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 Data rate: Average/peak: 3.24/ 19.5Mbps
TIR spectro-radiometer	SICH-3		Waveband: SWIR-TIR: 3.0-13.0μm Spatial resolution: 20-60m Accuracy: Duty cycle: 100% Swath width: 100-150km coverage within a possible 600km swath Data rate: 16-32Mbps

Instrument	Mission(s)	Measurements/application	Technical characteristics
TM Thematic Mapper	LANDSAT 4, LANDSAT 5	Surface radiance, plus higher resolution mapping	Waveband: Visible: 0.45-0.52μm, 0.52-0.6μm, 0.6-0.69μm, NIR: 0.76-0.9μm, 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
TMI - TRMM Microwave Imager	TRMM	Data related to rainfall rates over oceans – less reliable over land. Data used with and supported by data from PR instrument. Surface rainfall rates with associated latent heating. Monthly total rainfall maps over ocean. Data also used with and supported by data from PR instrument to produce combined rainfall structure.	Waveband: Microwave: 10.7GHz, 19.4GHz, 21.3GHz, 37GHz, 85.5GHz Spatial resolution: 5km to 41km depending on frequency used Accuracy: Duty cycle: Swath width: 790km Data rate: 8.8kbps
TMR TOPEX Microwave Radiometer	TOPEX/POSEIDON, TOPEX/POSEIDON follow-on	Correct altimeter data for errors due to water vapour and cloud-cover effects, total water vapour brightness temperature (1K accuracy)	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 Data rate: 125bps
TOMS Total Ozone Mapping Spectrometer	ADEOS, METEOR-3 N5, METEOR-3M N2, METEOR-3M N3, METEOR-3M N4, TOMS Earth Probe	Extends long term dataset on ozone, long term changes and trends detailed maps of Antarctic ozone hole and Arctic ozone, sulphur dioxide	Waveband: UV: 0.3086, 0.3125, 0.3175, 0.3223, 0.3312 and 0.36μm Spatial resolution: Nadir: 47 x 47km, Average: 62 x 62km, IFOV: 3 deg Accuracy: Ozone trend measurement capacity goal is 0.1% yearly Duty cycle: up to 100% Swath width: 3100km Data rate: 7kbps
TRASSER-O	OKEAN-O		Waveband: Microwave Spatial resolution: Accuracy: Duty cycle: 100% Swath width: Data rate:
Travers SAR	PRIRODA	Vegetation canopy type and state, soil moisture, land topograpy, 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

Instrument	Mission(s)	Measurements/application	Technical characteristics
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
UV-visible spectro-meter	Odin		Waveband: UV: beyond 280nm Visible: up to 800nm Spectral resolution: 1-2nm Spatial resolution: Vertical: 1km Horizontal: 40km Accuracy: Spectral resolution 1-2nm Duty cycle: 50% maximum (half of mission for astronomy) Swath width: Data rate: 11Mbyte/orbit (approx)
VEGETATION	SPOT 4, SPOT 5a, SPOT 5b,	Crop forecast and monitoring vegetation monitoring biosphere/geosphere interaction studies	Waveband: Operational: Visible: 0.61-0.68μm, NIR: 0.78-0.89μm, SWIR: 1.58-1.75μm Experiment: Visible: 0.43-0.47μm Spatial resolution: 1km throughout swath Accuracy: Duty cycle: 100% in daylight Swath width: 2200km Data rate:
VHRR	INSAT IIa, INSAT IIb INSAT IIe	Cloud cover, rainfall, wind velocity, sea surface temperature, outgoing longwave radiation, reflected solar radiation in spectral band 0.55-0.75μm, emitted radiation in 10.5-12.5 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 disc once every 30 minutes Swath width: Full Earth disc Data rate: 526.5kbps
VIRS	TRMM	Data will 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: 1.6μm, 3.75μm, TIR: 10.8μm, 12μm Spatial resolution: 2km at nadir Accuracy: Duty cycle: Swath width: 720km (45 deg either side of track) Data rate: 50kbps
VISSR (GMS4) Visable and Infra-red Spin Scan Radiometer	GMS-4	Clouds, cloud motion winds, sea surface temperature	Waveband: Visible: 0.5-0.75μm TIR: 10.5-12.5μm Spatial resolution: Visible: 1.25km, Infra-red: 5km Accuracy: Duty cycle: Full Earth in all channels, every 1 hour Swath width: Full Earth disc Data rate:

Instrument	Mission(s)	Measurements/application	Technical characteristics	
VISSR (GMS5) Visible and Infra-red Spin Scan Radiometer	GMS-5	Clouds, cloud motion winds, sea surface temperature, atmospheric water vapour	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible: 0.55-0.9μm TIR: 0.5-7.00μm, 10.5-11.5μm, 11.5-12.5μm Visible: 1.25km Infra-red: 5km Full Earth in all channels, every 1 hour Full Earth disc
VISSR and VAS (GOES-7) Visible and Infra-red Scanning Radiometer	GOES 7	Severe storm warnings/ monitoring day and night atmospheric soundings (temperature, moisture) visible and IR imagery of Earth surface, atmosphere and cloud cover, rainfall estimates	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Imaging: 1 visible (0.55-0.75μm), with 1 IR at 11.0μm plus 2 other IR, selectable from 3.9, 6.7, 7.3, 12.7 and 13.3μm Sounder: 1 visible and 12 IR (3.9 to 14.7μm) Visible: 1km, IR: 7 and 14km 100% Horizon to horizon 2.11Mbps (Mode-AAA)
VSAR	ALOS	High resolution imaging	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	1.2GHz Range: 10m (slant range) Azimuth: 5m (1 look) ±1dB 70km (high resolution mode) 250km (low resolution mode) 240Mbps (max)
VTIR Visible and Thermal Infra-red Radiometer	MOS 1b	Clouds, sea surface temperature	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible: 0.5-0.7μm TIR: 6.0-7.0μm, 10.5-11.5μm, 11.5-12.5μm Visible: 900m, TIR: 2700m 1500km 0.8Mbps
WEFAX	GOES 7, GOES 8, GOES 9, GOES K, GOES L, GOES M	Retransmission of narrow-band WEFAX data to existing small ground based APT receiving stations (transponder) low resolution transponded data	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Frequency: 1691MHz Not applicable Not applicable 100% Not applicable Not applicable
WFI camera Wide Field Imager	CBERS 1, CBERS 2		Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible: 0.63-0.69μm NIR: 0.77-0.89μm 258m 0.3 pixels International access open to all participating stations, limited to 20 minutes per revolution 890km 1.1Mbps (8/6 compressed)

Instrument	Mission(s)	Measurements/application	Technical characteristics	
WiFS Wide Field Sensor	IRS 1c, IRS 1d, IRS P3, IRS P4	Global change, environmental research, drought monitoring, snow melt run-off forecasting, global green cover assessment, agro-climatic regional planning. Albedo, photosynthetic active radiation, snow cover, vegetation cover, global production potential	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible: 0.62-0.68μm NIR: 0.77-0.86μm, SWIR: 1.55 – 1.75μm (IRS P3, P4 only) 188m daylight coverage 100% 774km (1c, 1d), 804km (P3, P4) Revisit time is 5 days 2 Mbps
WIFS (125m) Wide Field Sensor	IRS P5	Wide field multi-spectral image	Waveband: Spatial resolution: Horizontal: Accuracy: Duty cycle: Swath width: Data rate:	Visible: red region, NIR, SWIR approx 125m 750km, 5 day revisit time 7Mbps
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 tempeature and concentrations of emitting species	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	Visible-NIR: 0.55-0.78μm Vertical: 2km, Horizontal: 25km Wind speed: 10m/s 100% 70-310km 2kbps
X-ray astronomy payload	IRS P3	Study of time variability and spectral characteristics of cosmic X-ray sources	Waveband: Spatial resolution: Accuracy: Duty cycle: Swath width: Data rate:	 40kbps

C CEOS membership

This annex lists, alphabetically, the organisations that comprise CEOS.

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 (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	National Aeronautics and Space Administration (NASA) National Oceanic and Atmospheric Administration (NOAA)

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

Food and Agriculture Organization (FAO)
Global Climate Observing System (GCOS)
Global Ocean Observing System (GOOS)
International Council of Scientific Unions (ICSU)
International Geosphere-Biosphere Programme (IGBP)
Intergovernmental 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 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:

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

D.2 FOOD AND AGRICULTURE ORGANISATION OF THE UNITED NATIONS (FAO)

The Food and Agriculture Organisation of the United Nations is the lead Specialised Agency within the UN family in the fields of renewable natural resources, nutrition, food and agriculture, including fisheries and forestry. 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, for example, is used in the assessment and monitoring of tropical forest cover, and as part of the FAO's Global Information and Early Warning System on Food and Agriculture, the FAO Africa Realtime 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 for new applications.

FAO provides advisory services to member countries on applications of remote sensing techniques, including the execution of pilot projects; assistance in the formulation of projects that include a remote sensing component; and 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 landcover 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. Coordination of remote sensing applications within FAO is done by its Environmental Information Management Service (formerly the FAO Remote Sensing centre).

D.3 GLOBAL CLIMATE OBSERVING SYSTEM (GCOS)

The Global Climate Observing System (GCOS) was established in 1990 by the WMO, the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environmental Programme (UNEP) and the International Council of Scientific Unions (ICSU) in order to address the problems of climate change by providing comprehensive information on the total climate system. Its specific objectives are to meet the needs for:

- climate system monitoring, climate change detection, and response monitoring of the impacts of, and the response to, climate change, especially in terrestrial ecosystems;

- data for application to national economic development;
- research towards improved understanding, modelling and prediction of the climate system.

The GCOS Plan, developed in 1994 in close cooperation with the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS), defines an Initial Operational System which will be composed of existing observational components, enhancements and augmentations to these components, and a comprehensive data system. The observational requirements and design objectives of GCOS are currently being defined by the Joint Scientific and Technical Committee (JSTC). In addition, the GCOS Space Plan is being co-ordinated with both research and operational satellite programmes. Key issues for the GCOS include a requirement for high quality and representative data, long-term continuity of observations (although some parameters need not be continuously observed), and ready access to a database that appropriately combines space-based and surface based 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, and, as an Affiliate of CEOS, the GCOS will make recommendations and suggest its priorities to CEOS for specific satellite missions, instruments and ground-based systems as appropriate.

D.4 GLOBAL OCEAN OBSERVING SYSTEM (GOOS)

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

GOOS is conceived as 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 will utilise 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.5 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 interdisciplinary issues which none of them could handle alone.

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

- by initiating, designing and coordinating major international, interdisciplinary research programmes, such as the International Geosphere-Biosphere Programme (IGBP);
- by creating interdisciplinary 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 break 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, science and technology in developing countries, 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 intergovernmental 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.6 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 selects from the broad array of subjects that comprise the science of the Earth System those questions that are deemed to be of greatest importance in contributing to the understanding of the changing nature of the global environment on time scales of decades to centuries; that most affect the biosphere; that are most susceptible to human perturbations; and 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 specific needs for global monitoring, including observation from space. Long term (of order 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 the planet 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.7 INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (IOC)

The IOC coordinates 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 Ocean Services Station 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 contribution to that programme, the IOC is embarking 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 system 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 impacts 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.

D.8 UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP)

Satellite data are used for many activities of UNEP, notably by the Global Environment Monitoring System (GEMS) and the Global Resource Information Database (GRID). GEMS is a programme to acquire the data needed for the management of the environment at global, regional and local levels. It includes monitoring programmes in the fields of atmosphere and climate (background air pollution, acid rain, stratospheric ozone, climate), environmental pollution (urban air, surface waters, food, nuclear radiation) and renewable resources (tropical forests, land degradation, oceans, ecological monitoring, biological diversity). Although for some specific issues regional data may be used, the global aspect is predominant for many activities. GEMS' specific Earth observation data requirements are: (i) global coverage, (ii) temporal dynamics of data, (iii) manageable data volumes, (iv) simple and reliable sensors, and (v) reasonable costs of data.

GRID is a world-wide system and service to users of Earth environmental data. Through its many collaborating centres, GRID provides access to existing broad scale, public domain Earth observation data and other existing geo-referenced environmental data which can be linked with remote sensing data. In addition, the GRID system provides support of geographical information and image processing systems for users from the international science and development communities and brokers training through appropriate international and regional bodies.

Other UNEP activities such as the Desertification Control Programme Activity Centre (DC/PAC), Oceans and Coastal Areas Programme Activity Centre (OCA/PAC), Terrestrial Ecosystems Branch (TEB), and Support Measures (SM) also use satellite Earth observation data. The data requirements of 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 observations by satellites.

D.9 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 promotion of greater cooperation in space science and technology, greater exchange of data, information and staff, and the stimulation of facilities for space technology in developing countries.

SAP conducts training courses, workshops and seminars on a wide range of space and remote sensing topics. As follow-up activities to these, OOSA has been implementing several projects aimed at an improved utilisation of Earth observation data by developing countries. For example, in collaboration with ESA a number of projects have been established providing data to institutions in Africa, Latin America and the Caribbean with the aim of improving the capability of these institutions to effectively utilise Earth observation data in support of on-going or already approved projects and programmes in areas of capacity building, economic and social improvement or where governments have made commitments for sustainable development or preservation of the environment.

A current priority of the Programme is the establishment of regional Centres for Space Science and Technology Education at existing institutions in each region covered by the United Nations Economic Commissions. The Programme is also playing a leading role in establishing a satellite-based information system, the Cooperative Information Network (COPINE), that will link remote sensing and environment centres in the participating African countries to acquisition stations, processing and archiving facilities located in Europe as well as in Africa with the initial aim of improving the collection, transmission distribution and exchange of information.

An International Space Information Service is to be established within OOSA, initially consisting of a directory of sources of information and data services, to provide direction upon request to accessible data banks and information sources.

D.10 WORLD CLIMATE RESEARCH PROGRAMME (WCRP)

The WCRP was established in 1979 as a joint undertaking of the ICSU and WMO to determine to what extent climate can be predicted and the extent of man's influence on climate. IOC is also a co-sponsor of the WCRP since 1993. To achieve its goals, the WCRP requires a quantitative understanding of the four major components of the physical climate system, namely:

- the global atmosphere;
- the world oceans;
- the cryosphere, which comprises the continental ice sheets, ice caps, glaciers, sea ice and snow cover;
- the land surface with its surface and ground water flow systems.

Three major projects have been instituted to investigate climate change processes:

- The Tropical Ocean and Global Atmosphere (TOGA) project to study the interactions between the tropical ocean and global atmosphere which are the principal mode of climatic variation from year to year.
- The World Ocean Circulation Experiment (WOCE) to assemble, for the first time, almost

simultaneous observations of all oceans, as a basis for the development of mathematical models of global ocean circulation and heat transport.

- The Global Energy and Water Cycle Experiment (GEWEX) to determine the fluxes of water and energy globally using both observations and computational models.

Planned projects include the Climate Variability and Prediction Research Programme (CLIVAR) aimed at improving the understanding of the coupled dynamics of the global ocean-atmosphere system, and the Arctic Climate System Study (ACSYS) which includes a basin-wide study of the Arctic ocean and a basic monitoring programme for the Greenland ice sheet.

D.11 WORLD METEOROLOGICAL ORGANIZATION (WMO)

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 Forty Fifth 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 CBS Working Group on Satellites 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 most useful synthesis and would be very useful to WMO programmes and planning as well as to space agencies.

Lists of parameters to be observed and quality of observations 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. Whilst making reference to the original list for details, ECSAT made an attempt to consolidate a "short list" which, for the purpose of being handed to satellite planners (for instance, those space agencies represented at CEOS), might be much more useful than the voluminous original information, which does not clearly discriminate what should be expected from satellites versus what is more appropriate for ground-based global observing system.

The requirements as determined by ECSAT were expressed in terms of geophysical parameters, which were what the end user needed. Data quality must be specified at the same time as data requirement, in order to prevent misunderstandings on 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 was 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, 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.

The Working Group 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 data base of requirements that retains their heritage, so that the ownership and responsibility for continued verification are clear.

The Working Group also agreed that it will: 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, i.e., 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.

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
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
CCRS	Canada Centre for Remote Sensing
CEOS	Committee on Earth Observation Satellites
CFC	Chlorofluorocarbon
CLIVAR	Climate Variability and Prediction Research Programme
CNES	Centre National d'Etudes Spatiales (French Space Agency)
CRI	Crown Research Institute (New Zealand)
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DARA	Deutsche Agentur für Raumfahrt-Angelegenheiten (German Space Agency)
DIAL	Differential Absorption Lidar
DMSP	Defense Meteorological Satellite Programme
EC	European Community
ECSAT	Executive Council Panel of Experts on Satellites
EO	Earth Observation
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organisation
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
GPCP	Global Precipitation Climatology Project
GPS	Global Positioning System
GTOS	Global Terrestrial Observing System
ICSU	International Council of Scientific Unions
IDN	International Directory Network
IEOSC	International Earth Observation Satellite Committee
IGAC	International Global Atmosphere Chemistry Project
IGBP	International Geosphere-Biosphere Programme
IGOSS	Integrated Ocean Services Station System
INPE	Instituto Nacional de Pesquisas Espaciais (Brazilian Space Agency)

IOC	Intergovernmental Oceanographic Commission
IR	Infra-Red
ISCCP	International Satellite Cloud Climatology Project
ISRO	Indian Space Research Organisation
JGOFS	Joint Global Ocean Flux Study
JSTC	Joint Scientific and Technical Committee
LOICZ	Land-Ocean Interactions in the Coastal Zone
MW	Microwave
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)
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
OSTC	Federal Office for Scientific, Technical and Cultural Affairs (Belgium)
PAC	Programme Activity Centre
PAGES	Past Global Changes
RAL	Rutherford Appleton Laboratory
ROSHYDROMET	Russian Federal Service for Hydrometeorology and Environment Monitoring
RSA	Russian Space Agency
SAR	Synthetic Aperture Radar
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 (Japan)
SWIR	Short Wave Infra-Red
TBC	To be confirmed
TEB	Terrestrial Ecosystems Branch
TIR	Thermal Infra-Red
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UNOOSA	UN Office of Outer Space Affairs
UV	Ultra-Violet
WCRP	World Climate Research Programme
WGCV	Working Group on Calibration and Validation
WGD	Working Group on Data
WGSAT	Working Group on Satellites
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment

F Points of contact

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

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A considerable amount of information is also available on-line via the CEOS Infosys (see section 2). The Infosys also provides a gateway to various on-line resources provided by CEOS agencies worldwide – including extensive information on data products, image samples, catalogues, and other services to help users understand the capabilities of Earth observation satellites and how they might fulfil their data and information needs.

The CEOS Infosys is available on the World Wide Web at:

http://ceos.esrin.esa.it/Cceosinfo

Information on specific Earth science data set 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 initial point of contact might be through one of the regional coordinating nodes at:

NASA
World Wide Web:
http://gcmd.gsfc.nasa.gov

Telnet:
telnet gcmd.gsfc.nasa.gov (192.107.190.77)
Username: GCDIR

ESA
World Wide Web:
http://gds.esrin.esa.it/CEURO_IDN_HP

Telnet:
telnet epocat.esrin.esa.it (192.106.252.160)
Username: ESAPID

NASDA
Telnet:
telnet nsaeoc.eoc.nasda.go.jp (133.56.72.1)
Username: NASDADIR

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