

Earth Observation Handbook

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Contents

Foreword

Introduction

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

1	CEOS	2
2	21st century Earth: Our environment.....	6
3	The importance of Earth observations	11
4	Future challenges	16

Part II: Case studies – information for global decision-making

5	Case studies	20
	Counting on Carbon	21
	Water resources	25
	Observations of the ocean	29
	The Ozone layer – catastrophe averted?	33
	Managing natural disasters	37

Part III: Earth observation satellite capabilities & plans

6	Capabilities of Earth observation satellites	44
7	Earth observation plans: by measurement	60
8	Catalogue of satellite missions	101
9	Catalogue of satellite instruments	128

Annexes

A	Further information on CEOS	157
B	CEOS involvement in IGOS	161
C	Abbreviations.....	164
D	Image credits	166

Foreword



2002 is a significant year in terms of our consideration of the state of our environment, the impact of our activities on it, and the consequences for future generations. The Johannesburg Summit 2002 – the World Summit on Sustainable Development – will bring together tens of thousands of participants, including heads of State and Government, national delegates and leaders from non-governmental organisations (NGOs), businesses and other major groups to focus the world's attention and direct action toward meeting difficult challenges, including improving people's lives and conserving our natural resources in a world that is growing in population, with ever-increasing demands for food, water, shelter, sanitation, energy, health services and economic security.

The expected global changes to the Earth system and the associated impacts on human civilisation will make information on our environment increasingly vital for the effective and sustainable future management of the Earth. We can anticipate that this information might be used by intergovernmental bodies for decision-making and global governance to ensure sustainability, and also more locally as countries, regions, and industries compete for larger shares of smaller reserves of natural resources in order to support their growing populations and economic ambitions. Observations of planet Earth itself, of our environment, might be regarded as the most important information of all, as the context for all decisions.

The current ambitions for greatly enhanced understanding, monitoring, management and mitigation of key Earth system processes will be possible only with the measurement capabilities offered by the Earth observation satellite programmes being planned by the world's space agencies. The major aim of the Committee on Earth Observation Satellites (CEOS) is to achieve international coordination in the planning of Earth observation satellite missions and to maximise the world-wide utilisation of data from these missions. This role includes participation in the activities of the Integrated Global Observing Strategy Partnership (IGOS-P), to ensure that future space-based observing systems and Earth-based observing systems will be suitably harmonised to address the most critical requirements.

It gives me great pleasure, on behalf of CEOS, to present the 2002 Edition of the CEOS Handbook, prepared by the European Space Agency (ESA) – as the Chair Agency of CEOS in 2002. The report presents the main capabilities of Earth observation satellites and their major current and future applications, and a systematic overview of present and planned Earth observation satellite missions and their instruments.

I hope that the CEOS Handbook will continue to serve as a valuable reference source for a variety of users, including those with needs in Earth system research, and decision-makers in political and socio-economic sectors. I further hope that it can assist the harmonisation of our efforts on a global scale, which is central to our future success.

A handwritten signature in dark ink, reading "José Achache". The signature is fluid and cursive, with the first name "José" and last name "Achache" clearly distinguishable.

Prof. José Achache
Director of Earth Observation Programmes
European Space Agency
CEOS Chairman (2002)

Introduction

The 2002 CEOS Handbook explores the need for information on our planet. Information which is essential for making decisions, defining policies, and implementing management strategies to ensure mankind has a sustainable future on Earth – resistant to impacts of man-made climate change, population growth, and increasing development.

It explains the important role of Earth observation satellite programmes in fulfilling those information needs. It presents the current status and plans for future Earth observation satellite programmes of governments world-wide, through their national and regional space agencies, and describes how the data and information which they supply relate to world-wide needs for information on Earth system processes – in support of significant objectives of national and international concern.

The role of the Committee on Earth Observation Satellites (CEOS), as the body with responsibility for co-ordination of these satellite programmes, is explained, including the CEOS role within the Integrated Global Observing Strategy Partnership (IGOS-P), to ensure that future space-based observing systems and Earth-based observing systems will be suitably harmonised to address the most critical requirements.

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

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

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

Part I of the Handbook provides an explanation of CEOS (section 1). It discusses global environmental issues (section 2) and the role of Earth observations (section 3). Future challenges are discussed in section 4.

Part II presents a number of case studies (section 5) to illustrate the use of Earth observation satellites supporting the provision of information for global governance.

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

The annexes include:

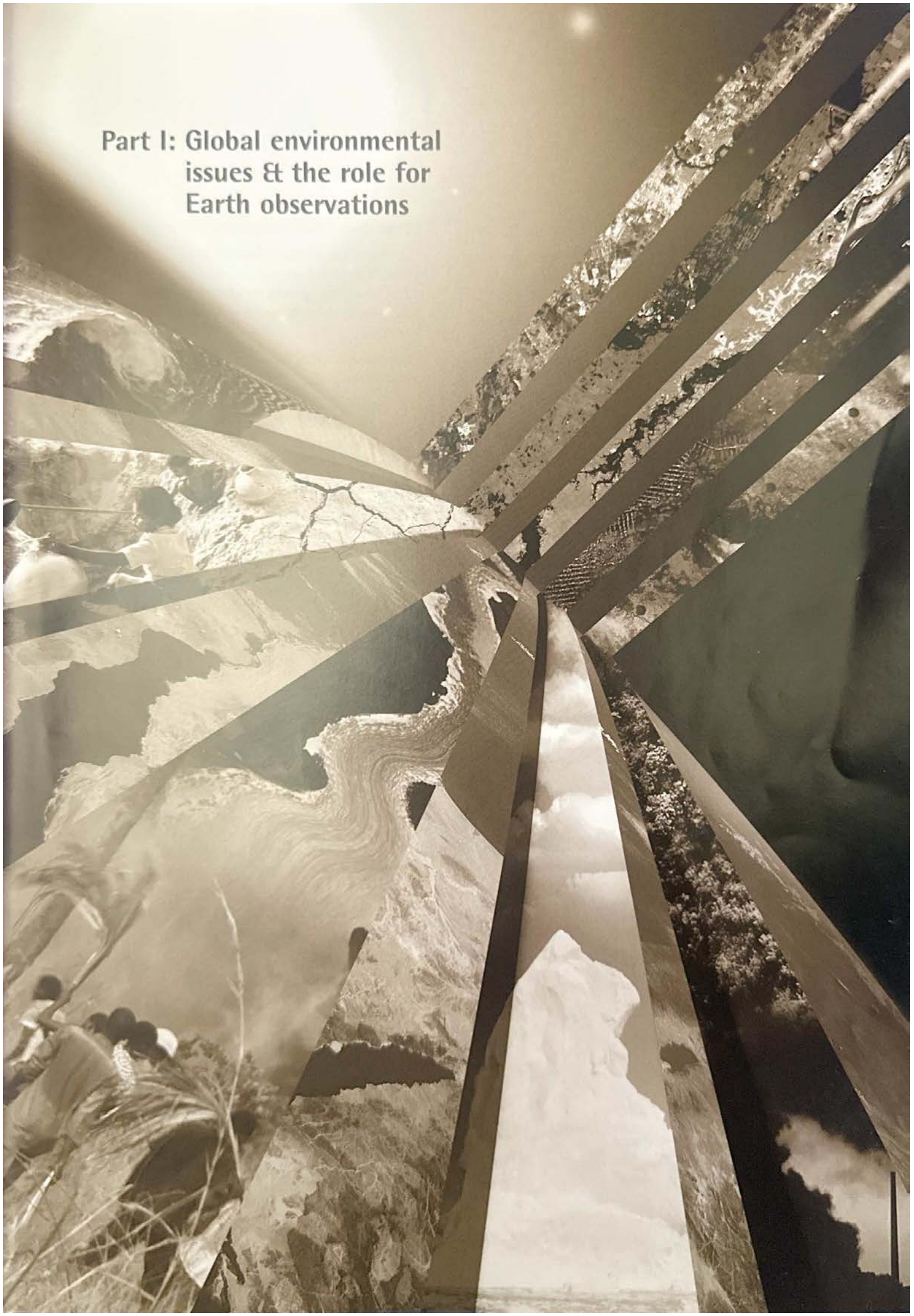
A Further information on CEOS

B CEOS involvement in IGOS

C Abbreviations

D Image credits

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



1 CEOS



What is CEOS?

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

Since its establishment, CEOS has provided a broad framework for international coordination on spaceborne Earth observation missions.

Why coordinate Earth observation satellites?

Earth observation satellites are recognised as the sole or primary source of data for a wide range of operational and commercial applications, scientific studies, and policy needs – such as in the monitoring of international environmental treaties. Part I of this document describes some examples of their importance in areas such as future management of freshwater resources, and improving understanding of the global carbon cycle.

Many of the relevant issues are global in nature and require global solutions beyond the mandate and resources of individual governments. Large numbers of geophysical measurements are required – often with different spatial and temporal resolutions and accuracies. No single programme, agency, or nation can hope to satisfy all of the observational requirements which are necessary for improved understanding of the Earth system.

CEOS was established to provide coordination of the Earth observations being provided by satellite missions.

What does CEOS contribute?

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

CEOS has established three primary objectives in pursuing this goal:

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

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

Who participates in CEOS?

CEOS membership comprises most of the world's civil agencies responsible for Earth observation satellite programmes – amounting to 23 Members in 2002.

CEOS also has 20 Associates, comprising:

- governmental organisations that are international or national in nature and that are developing Earth observing satellite programmes or significant supporting ground facility programmes;
- other existing satellite coordination groups and scientific or governmental bodies that are international in nature and currently have a significant programmatic activity that supports CEOS objectives.

The full list of Members and Associates is shown in the tables on pages 3 and 4.

How does CEOS operate?

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

The work of CEOS is conducted within its various working groups. Coordination throughout the year is maintained through a permanent Secretariat maintained by the European Space Agency (ESA), the National Aeronautics and Space Administration (NASA) jointly with the National Oceanic and Atmospheric Administration (NOAA) of the USA, and the Ministry of Education, Culture, Sports, Science and Technology (MEXT) jointly with the National Space Development Agency of Japan (NASDA).

CEOS involvement in IGOS-P

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

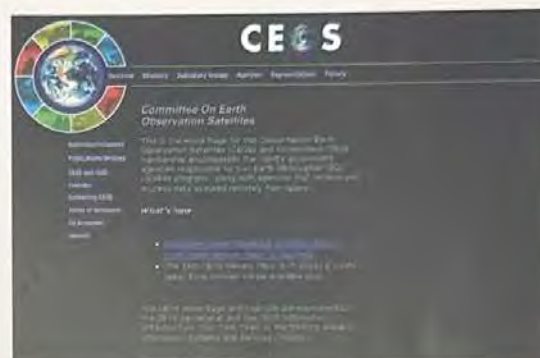
CEOS has embraced the concept of an IGOS as a valuable initiative which perfectly complements its own set of objectives, and which may be adopted by CEOS to derive greater benefit from operating and planned observing systems. Through working together, CEOS agencies are in a position to plan their Earth observation programmes with the minimum of unnecessary overlap and to devise joint strategies for addressing serious gaps in their observation capabilities.

Strengthened links between space-based and Earth-based observing systems, and with scientific and environmental policy-making processes provide compelling motivation for CEOS to take an active role in IGOS-P activities.

More information

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

CEOS involvement in IGOS-P is explained in annex B.



Organisation		Country / Countries
ASI	Agenzia Spaziale Italiana	Italy
BNSC	British National Space Centre	United Kingdom
CAST	Chinese Academy of Space Technology	China
CNES	Centre National d'Etudes Spatiales	France
CONAE	Comisión de Actividades Espaciales	Argentina
CSA	Canadian Space Agency	Canada
CSIRO	Commonwealth Scientific and Industrial Research Organisation	Australia
DLR	Deutsches Zentrum für Luft-und Raumfahrt	Germany
EC	European Commission	Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, United Kingdom
ESA	European Space Agency	Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom
INPE	Instituto Nacional de Pesquisas Espaciais	Brazil
ISRO	Indian Space Research Organisation	India
KARI	Korea Aerospace Research Institute	Korea
MEXT/NASDA	Ministry of Education, Culture, Sports, Science and Technology / National Space Development Agency of Japan	Japan
NASA	National Aeronautics and Space Administration	United States of America
NRSCC	National Remote Sensing Center of China	China
NSAU	National Space Agency of Ukraine	Ukraine
NOAA	National Oceanic and Atmospheric Administration	United States of America
ROSHYDROMET	Russian Federal Service for Hydro-meteorology and Environment Monitoring	Russia
ROSAVIAKOSMOS	Russian Aviation and Space Agency	Russia
SNSB	Swedish National Space Board	Sweden
USGS	United States Geological Survey	United States of America

CEOS Membership.

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

CEOS Associates.

CEOS: www.ceos.org

UN International Strategy for Disaster Reduction: www.unisdr.org/

CEOS Newsletter: nasda.ceos.org/ceosnews_menu_e.html

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

CEOS Brochure: www.ceos.org/pages/pub.html

CEOS CD-ROM: ceos.cnes.fr:8100/cdrom-00b2/astart.htm

IGOS Partnership: www.igospartners.org

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

For CD-ROM copies of CEOS Database:
hinsman_dif@gateway.wmo.ch

2 21st century Earth: Our environment

2.1 Introduction

Part III of this document provides details of more than 150 satellites with an Earth observation mission planned by CEOS agencies over the next 15 years – the majority of which will be dedicated to different aspects of climate or environmental studies.

CEOS does not have responsibility for defining the climate or environmental priorities to be addressed by these missions. Planning and funding of missions remains the responsibility of individual agencies, based on their own government policies, strategic assessments, and user community requirements.

CEOS agencies recognise and respond to the necessity for international co-operation efforts to harmonise these various plans to be founded on a common understanding of the state of our environment and future information priorities – particularly given the lead times involved in planning and launching Earth observation missions, and the need to anticipate the most pressing environmental issues which will face future generations.

This section presents a brief discussion of the context for these efforts, including:

- a discussion of global changes to the Earth system (based upon the IGBP Science Report: 'Global Change and the Earth system: A planet under pressure' (2001));
- the impact of these changes and the possible consequences for the future (based upon the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), 'Climate Change 2001');
- the trend towards increased international co-operation and the need for observations of planet Earth in order to produce information for decision-making

2.2 Planet under pressure

Throughout history, mankind has adapted to the natural variability of the Earth system and its climate. Until very recently in the history of the Earth, humans and their activities have not featured as a significant force in the dynamics of the Earth system; but today, mankind has begun to match and even surpass the forces of nature in changing key Earth system processes.

Variability and change, both short and long term, are natural realities of the Earth system, from forces such as variation in the sun's energy output, and volcanic eruptions which spew dust and gases into the atmosphere and scatter incoming sunlight.

Over the past two centuries, both the human population and the economic wealth of the world have grown rapidly. These two factors have increased resource consumption significantly, evident in agriculture and food production, industrial development, energy production and urbanisation.

Human activities are now so pervasive and profound in their consequences that they too affect the Earth on a global scale in complex, interactive and accelerating ways; humans now have the capacity to alter the Earth system in ways that threaten the very processes and components upon which humans depend. The speed of these changes is on the order of decades to centuries, not the centuries to millennia pace of comparable change in the natural dynamics of the Earth system:

- in a few generations mankind is in the process of exhausting fossil fuel reserves that were generated over several hundred million years;
- almost half of the Earth's land surface has been transformed by direct human action, with significant consequences for biodiversity, nutrient cycling, soil structure and biology, and climate;
- more than half of all accessible freshwater is used directly or indirectly by mankind, and underground water resources are being depleted rapidly in many areas;
- the concentrations of several climatically important greenhouse gases, in addition to CO₂ and CH₄, have substantially increased in the atmosphere;
- coastal and marine habitats are being dramatically altered; 50% of mangroves have been removed and wetlands have shrunk by one-half;
- about a quarter of recognised marine fisheries are over exploited or already depleted, and almost a half more are at their limit of exploitation;
- extinction rates are increasing sharply in marine and terrestrial ecosystems around the world;
- the Earth is now in the midst of its first great extinction event caused by the activities of a single biological species (mankind).

2 21st century Earth: Our environment

Around 6 billion people inhabit the globe at present. All share basic human needs, such as the demand for water, food, shelter, community health and employment. The ways in which these needs are met are critical determinants of the environmental consequences at all scales. In the developed world, affluence, and more importantly the demand for consumer goods for entertainment, for mobility, for communication and a broad range of goods and services, is placing significant demands on global resources. Between 1970 and 1997, the global consumption of energy increased by 84%, and consumption of materials also increased dramatically.

2.3 Facing the consequences

There is now strong evidence that human activities are affecting Earth's environment at the global scale. Increasingly strong evidence suggests that the functioning of the Earth system is changing in response. While impacts of human activities have long been apparent at the local level, we are now seeing global-scale impacts – with the first 'wake-up call' being concern in the early 1970's that the Earth's protective ozone layer in the atmosphere was vulnerable to damage by the release of certain chemicals, such as CFCs – and further warnings of changing climate due to changes in the composition of the atmosphere.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to bring together leading scientists from all over the world to conduct rigorous surveys of the latest technical and scientific literature on climate change. Their 2001 Third Assessment Report on the scientific basis for climate change reported that "an increasing body of observations gives a collective picture of a warming world and other changes in the climate system". The report concludes that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities".

The IPCC summarises the main effects of human activity on our climate as follows:

- the land and oceans have warmed: global average surface temperature has increased by about 0.6°C over the 20th century;
- globally, it is very likely that the 1990's were warmer than at any time in the last 1000 years;
- precipitation patterns have changed;

- the frequency, persistence and magnitude of El Niño events has increased;
- human activities have changed the composition of the atmosphere since the industrial era, with increased concentrations of greenhouse gases due primarily to fossil fuel burning and land-use change: since 1750, concentrations of carbon dioxide have increased by 31%, methane by 151%, and nitrous oxide by 17%; it is believed that present carbon dioxide concentrations are unprecedented in the past 420,000 years. The best scientific knowledge and evidence available suggests that the Earth system has moved well outside the range of natural variability exhibited over the last half million years at least. The nature of changes now occurring simultaneously in the global environment, their magnitudes and rates, are unprecedented in human history, and probably in the history of the planet.

2.4 The future

The Third Assessment Report of the IPCC makes the following projections:

- greenhouse gas emissions due to fossil fuel burning are virtually certain to be the dominant influence on trends in atmospheric greenhouse gas concentrations in the coming century;
- assuming a 'business as usual' scenario in which greenhouse gas emissions continue to rise, the global average surface temperature is expected to rise between 1.4°C and 5.8°C: this rate of warming is without precedent in at least the last 45,000 years;
- this warming is likely to have profound effects on precipitation patterns and occurrence of extreme weather events;
- global mean sea level is projected to rise by between 9cm and 88cm in the coming century: tens of millions of people are projected to be at risk of being displaced by sea level rise.

These accelerating changes to the Earth's environment are being fuelled by growth in the human population, by the increasing level of resource consumption by human societies and by changes in technology and socio-political organisations.

Perhaps one of the most significant components of global change over the next three or four decades will be changes in land-use – driven largely by the need to feed the expanding human population, expected to increase by almost one billion people per decade for the next three decades at least.

To meet the associated food demand, crop yields will need to increase, consistently, by over 2% every year through this period. Despite advances in technology, increasing food production must lead to intensification of agriculture in areas which are already cropped, and conversion of forests and grasslands into cropping systems. Much of the latter will occur in semi-arid regions and on lands which are marginally suitable for cultivation, increasing the risk of soil erosion, accelerated water use, and further land degradation.

Concurrent with the expanding population, technological and economic advances will lead to an increase in per capita consumption of resources, with the most likely scenario being the continued strong increase in global change drivers such as land-use change and changes in atmospheric composition.

2.5 International response

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

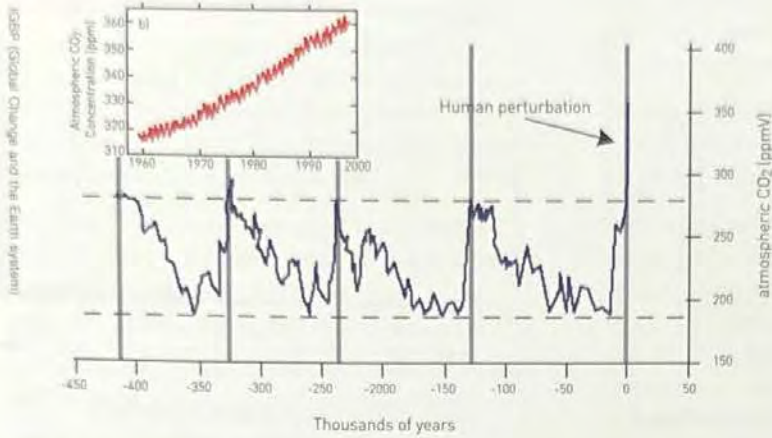
Many of the relevant issues are global in nature and require global solutions beyond the mandate of individual governments. Over the last two decades, the prospect that the global climate could change as a result of human influence has generated widespread concern. An unprecedented co-operative global response has developed as a result, including:

- **international decision-making and policy measures:** governments and national and regional agencies are pursuing increased political and legal obligations to address Earth system topics of global concern. Such obligations are often encapsulated within international treaties, whose signatories have explicit requirements placed upon them;
- **collaboration in scientific research and assessment:** including the establishment of the IPCC in 1988 by the World Meteorological Organisation (WMO) and the UN Environment Programme (UNEP). The IPCC acts as the source of technical advice to the United Nations Framework Convention on Climate Change (UNFCCC) as does the Subsidiary Body for Scientific and Technological Advice (SBSTA);
- **information sharing:** the nature of climate change issues presents special challenges in terms of the need for global datasets on key planetary indicators – which can provide the information necessary so that governments and policy makers can make well-informed decisions; recognising that no single country can satisfy all of the observational requirements which are necessary for monitoring of the Earth system, governments are taking steps to harmonise and integrate their observing networks and satellite observing systems to be able to address common problems of global concern.

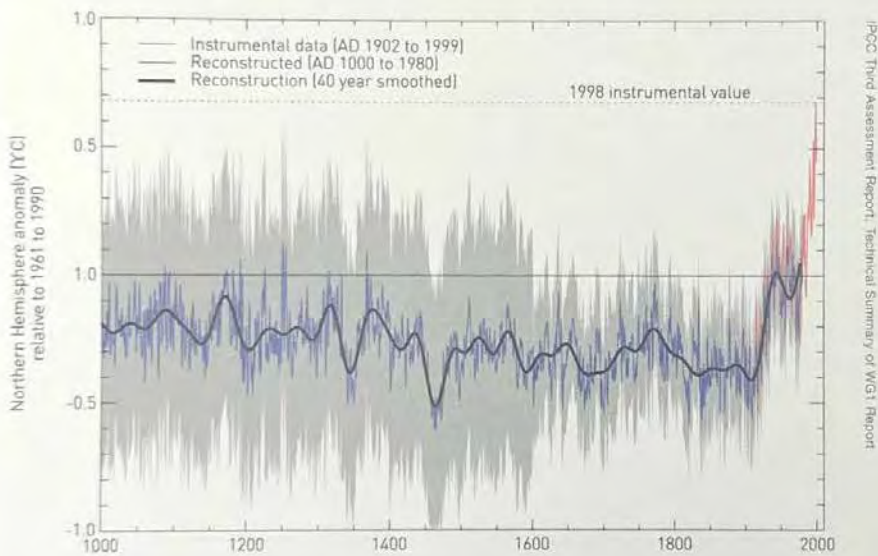
This document discusses the need for observations of planet Earth and its environment and highlights the opportunities presented by Earth observation satellite systems to produce information for decision-making.

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

2 21st century Earth: Our environment



Recent human influence on the carbon cycle.



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

Planet under Pressure:

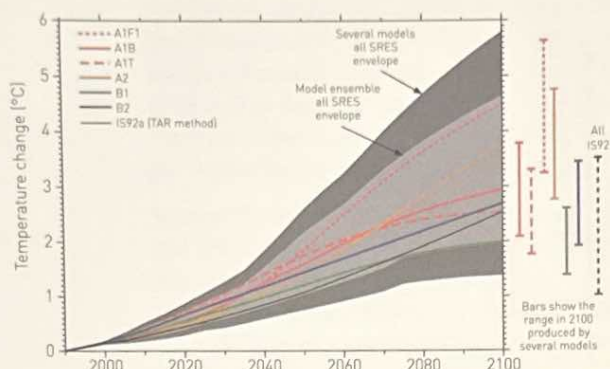
www.igbp.kva.se/cgi-bin/php/frameset.php

IPCC: www.ipcc.ch

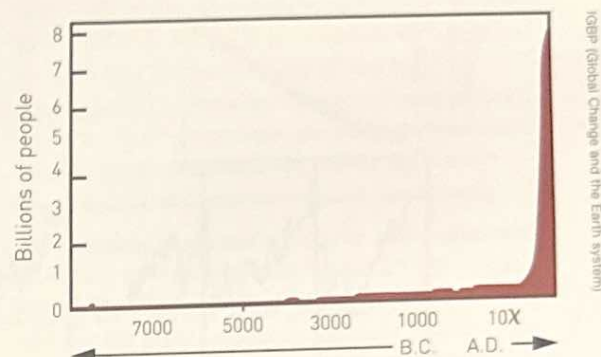
World population: www.prb.org

WMO: www.wmo.ch

2 21st century Earth: Our environment



Climate models predict surface temperature rise in the next century.



Human population is increasing dramatically.

Major environmental treaties

- **Agenda 21 and the UN Commission for Sustainable Development (1992):** Agenda 21 is a blueprint for sustainable development into the 21st century. Its basis was agreed during the 'Earth Summit' at Rio in 1992, and signed by 179 Heads of State and Government.
- **The UN Framework Convention on Climate Change (UNFCCC - 1992):** The UNFCCC provides a framework for future agreement and action to regulate levels of greenhouse gas concentrations in the atmosphere, so as to avoid the occurrence of climate change on a level that would impede sustainable economic development, or compromise initiatives in food production. **The Kyoto Protocol (1997)** to the UNCCC commits parties to legally-binding targets to limit their greenhouse gas emissions, adding up to a total reduction of at least 5% from 1990 levels on average during the five-year period 2008-2012.
- **The UN Convention to Combat Desertification (1992):** The Desertification Convention aims to combat desertification and to mitigate the effects of drought through the establishment of long-term integrated strategies.
- **The Convention on Biological Diversity (1992):** Aims to conserve biological diversity, promote the sustainable use of its components, and encourage equitable sharing of the benefits arising out of the utilisation of genetic resources.
- **The Montreal Protocol of the Vienna Convention on the Protection of the Ozone Layer (1987):** The Montreal Protocol sets out specific legal obligations in the form of timetables for the progressive reduction and/or elimination of the production and consumption of certain ozone-depleting substances.
- **The United Nations Convention on the Law of the Sea (1982):** Which proposes a comprehensive new legal regime for the sea and oceans and, as far as environmental provisions are concerned, to establish material rules concerning environmental standards as well as enforcement provisions dealing with pollution of the marine environment.
- **The Convention on Long-range Transboundary Air Pollution (1979):** Which aims to protect man and his environment against air pollution and endeavours to limit and, as far as possible, gradually reduce and prevent air pollution, including long-range transboundary air pollution.
- **The International Convention for the Prevention of Pollution from Ships (MARPOL) (1973/1978):** MARPOL is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes and covers pollution by oil, chemicals, harmful substances in packaged form, sewage and garbage.

3 The importance of Earth observations

3.1 Why observe the Earth?

The expected global changes to the Earth system and the associated impacts on human civilisation will make information on our environment increasingly vital for the effective and sustainable future management of the Earth. This is true in both:

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

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

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

- **improved understanding:** with a multitude of global scale observations contributing to research into Earth system processes;
- **evidence:** Earth observations support the formulation of authoritative scientific advice – which is vital for governments when deciding to fund mitigation measures in response to global change, to react to impending crises in resource shortages, or to participate in agreements or conventions which require costly changes in national consumption patterns;
- **monitoring and compliance:** we might expect to see increasing emphasis on international policy measures and treaties such as The Kyoto Protocol emerge in future; Earth observations will form an essential role in monitoring such agreements, ensuring that countries meet their legal obligations in relation to challenges like reductions in fossil fuel emissions, or pollution dumping;
The economic implications of such agreements can be enormous for countries and highly visible and public measures to deter 'cheating' will be an important part of their success;
- **management and mitigation:** in support of increased efficiency in providing basic resources for future generations and in predicting and countering the worst effects of severe weather and natural disasters.

3.2 The status of Earth observing programmes

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

World Weather Watch

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

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

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

The Global Observing Systems

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

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

- The TAO/TRITON array: of 70 moored buoys in the Tropical Pacific Ocean, which since its completion in 1994 has enabled real-time collection of high quality oceanographic and surface meteorological data for monitoring, forecasting, and understanding of climate swings associated with El Niño and La Niña. Data and graphic displays from the TAO/TRITON array are updated every day, and the data are freely available to the research community, operational forecasting community, and the general public.
- The Global Sea Level Observing System (GLOSS): an international programme coordinated by the Intergovernmental Oceanographic Commission (IOC) for the establishment of high quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research. The main component of GLOSS is the 'Global Core Network' (GCN) of 287 sea level stations around the world for monitoring long term trends and accelerations in global sea level.

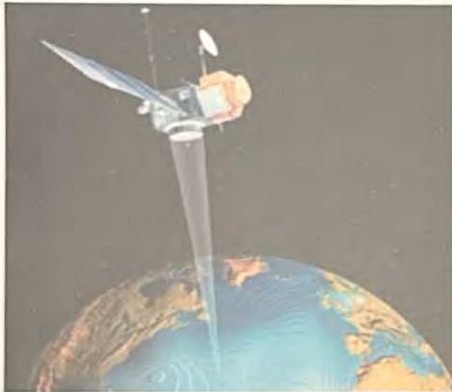
There are numerous other contributors to GOOS, including: voluntary observing ships providing measurements of upper ocean and meteorological parameters; the Global Temperature and Salinity Profile Programme; and the Global Coral Reef Monitoring Network.

GTOS: GTOS aims to provide the scientific and policy making community with access to the data necessary to manage the change in the capacity of terrestrial ecosystems to support sustainable development. To achieve this GTOS is working towards the establishment of a 'system of networks', formed by linking existing terrestrial monitoring sites and networks as well as planned satellite remote sensing systems. Thematic networks have been established for ecology, glaciers, and permafrost, and a hydrology network is in progress.

3 The importance of Earth observations



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



Since the sustainable development of forest resources is regarded as one of the most pressing environmental issues of our time, GTOS has established a panel on Global Observations of Forest Cover (GOFC) which aims to provide regional and global datasets containing information on location of different types of forests; major changes in forests resulting from logging, agricultural conversion, fire, and other environmental stresses.

GTOS, in collaboration with a number of partners, has also developed the Terrestrial Carbon Observations (TCO) initiative which responds to the need by the policy and scientific communities for improved knowledge of the role of the terrestrial carbon sources and sinks. It aims to provide information on the spatial and temporal distribution of carbon sources and sinks in the terrestrial biosphere using data obtained through systematic ground and satellite-based observations.

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

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

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

IGOS-P: The Integrated Global Observing Strategy Partnership

Earth observations from satellite have revolutionised human perspectives and understanding of the planet and are highly complementary to those collected on or near the Earth's surface by in-situ systems - such as ocean buoys or weather stations. In-situ measurements may be necessary for some high accuracy local observations, for the calibration of observations made by satellite and for models of the Earth system. Satellites are often necessary for the provision of synoptic, wide-area information required to put in-situ measurements in the global context required for the observation of many environmental and climatic phenomena.

In order to facilitate the necessary harmonisation and achieve maximum cost-effectiveness for the total set of space-based and in-situ observations the IGOS Partnership was established in June 1998 by a formal exchange of letters among the 13 founding Partners for the definition, development and implementation of an Integrated Global Observing Strategy (IGOS). IGOS brings together the major Earth and space-based systems for global environmental observations of the atmosphere, oceans and land in a strategic planning process.

The IGOS Partners recognise that many of their respective observing systems are in need of improvements. Some lack the necessary long-term continuity, and all require strengthened links between the space-based and Earth-based components, as well as between the observing programmes and the processes of scientific and environmental policymaking which define the information priorities.

Further information on IGOS-P is presented in annex B.

3.3 Satellite Earth observations

Since the first TV images of the Earth from space were transmitted by the TIROS-1 satellite back in 1960, mankind has recognised the benefits of this unique and global perspective of our home planet. There are currently over 60 Earth observation satellite missions operating, and around 90 more missions, carrying over 300 instruments, planned for operation during the next 15 years or so by the world's civil space agencies. An increasing number of commercial Earth observation satellites, which are funded, launched, and operated by industry, are also emerging to address important spatial information markets.

Space-based, remote sensing observations of the atmosphere-ocean-land system have evolved substantially since the first operational weather satellite systems were launched. Over the last decade Earth observation satellites have proven their capabilities to accurately monitor nearly all aspects of the total Earth system on a global basis; a capability unmatched by ground-based systems that are limited to land areas and cover only about 30% of the planetary surface. Currently, satellite systems monitor the evolution and impact of the El Niño, weather phenomena, natural hazards, and extreme events such as floods and droughts, vegetation cycles, the ozone hole, solar fluctuations, changes in snow cover, sea ice and ice sheets, ocean surface temperatures and biological activity, coastal zones and algae blooms, deforestation, forest fires, urban development, volcanic activity, tectonic plate motions, and others. These various observations are used extensively in real-time decision-making and the strategic planning and management of industrial, economic, and natural resources.

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

- inherent wide area observation capability: offering synoptic views of large-scale phenomena, and placing in-situ measurements in the global context required for the observation of many environmental and climatic phenomena;
- non-intrusive observations: allowing collection of data to take place without compromising national sovereignty in the way that ground-based measurements or airborne remote sensing might; this is an advantage in the context of use within international environmental treaties;

3 The importance of Earth observations

- uniformity: in that the same sensor may be used at many different places in the world (some of which are inaccessible, making in-situ measurements infeasible);
 - rapid measurement capability: allowing sensors to be targeted at any point on Earth, including remote and hostile areas;
 - continuity: with single sensors or series of sensors providing long time series of data which is suitable for climate studies.
- hazard monitoring and disaster assessment schemes are in place which incorporate satellite data to provide wide area coverage of, amongst other things, volcano plumes and areas stricken by drought or earthquake;
 - commercial fishing industries routinely utilise satellite-derived fishing assessments to optimise their operations;
 - ocean wave and current information is used by offshore exploration companies and shipping to improve operational safety and route-planning;
 - mapping and urban planning agencies exploit satellite imagery for generation of maps and digital elevation models.

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

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

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

- agriculture and forestry services utilise satellite data to provide, amongst other products, mapping information, crop health statistics, yield predictions, harvest optimisation, and estimated rainfall amount;
- resource mapping utilising very high resolution satellite data, when combined with conventional survey techniques, provides information needed to locate both renewable and non-renewable resources, such as mineral deposits, and a cost-effective means of mapping large, sometimes inaccessible regions;

CEOS is recognised as the most important framework for coordination across all spaceborne Earth observation missions. CEOS also plays an important role within the IGOS Partnership to ensure that future space-based observing systems and Earth-based observing systems will be suitably harmonised to address the most critical requirements.

Further information on CEOS is presented in annex A of this document.

The case studies presented in Part II highlight the importance of Earth observations, in particular satellite observations, in providing essential information to address some of the key issues facing mankind at the start of the 21st century.

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

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

The IGOS Partnership: www.igospartners.org/

The Committee on Earth Observation Satellites:
www.ceos.org

Earth observation: www.esa.int/export/esaSA/earth.html
earthobservatory.nasa.gov/

The science of remote sensing:
ceos.cnes.fr:8100/cdrom-00b2/ceos1/science/science.htm

UNESCO: www.unesco.org/

ICSU: www.icsu.org/

GLOSS: www.pol.ac.uk/psmsl/programmes/gloss.info.html

TAO/TRITON: www.pmel.noaa.gov/tao/

GOFC: www.gofc.org

4 Future challenges

The current ambitions for greatly enhanced understanding, monitoring, management and mitigation of key Earth system processes will be possible only with the measurement capabilities offered by the Earth observation satellites programmes being planned by the world's space agencies. Many of the sophisticated computational models on which these studies depend will otherwise simply not have sufficient information to provide the necessary insights. Measurements of in-situ stations, buoys radiosondes, aircraft and ship based instruments cannot provide the synoptic global picture required to understand the Earth system.

The full significance of the satellite observations being gathered, and of those planned for the coming years is probably still to be fully appreciated or exploited. Information on climatic and environmental trends is increasingly valuable - in line with the expected increase in the impacts of man-made climate change, accelerated in the 21st century by population growth and increasing development.

Around 150 Earth observation satellite missions (with over 300 instruments onboard) are planned for operation over the coming 15 years in response to the main Earth system challenges defined by the international, science, policy and operational monitoring communities. These missions also respond to more immediate needs for information in the social, economic, and environmental domains, including: meteorological services, mapping, urban planning, disaster mitigation, agriculture and fisheries management, resource exploration, pollution monitoring, ship routing and safety, and others.

Careful planning and coordination of these programmes is essential if we are to ensure supply of the information required by current and future generations. For Earth observation satellite missions funded by governments, this coordination is already being provided by CEOS - recognised internationally as having this responsibility. This coordination will eventually span the space segment (satellite systems), ground segment (reception, processing, and distribution centres), the associated science, and information service development.

To achieve this goal, CEOS, with its partners, must respond to a number of challenges:

Providing continuity of data: The IPCC predicts that, should the current decline in observational networks continue, we may have less information on the Earth system in future decades than in the final decades of the 20th century. Recognising the need for coordination of Earth observation satellite programmes, CEOS will aim to ensure continuity, consistency, and inter-comparability of the priority measurements throughout the coming decades - consistent with the requirements of climate studies for trend monitoring and change detection.

Responding to broad demand for operational measurements in fields other than meteorology: Key meteorological parameters are provided by satellite and in-situ systems on an operational basis to the relevant user communities; forecasts of local precipitation, wind, temperature, and cloudiness are a feature of daily life. This operational status, whereby information is provided on a routine and long term basis without interruption, is now being demanded by a broader range of user groups, including those involved in ocean monitoring, ozone and UV monitoring, carbon cycle studies, pollution alerting, and food security, amongst others. CEOS recognises the need to work with the relevant users - including through participation in the IGOS Partnership - to establish the requirements, and a strategic planning process for the necessary satellite missions, in-situ observations, as well as supporting modelling and information processing efforts.

The need for strengthened links between satellite and in-situ observation systems: Satellite observations must continue to strengthen links with in-situ observation systems which provide: measurements unobtainable from space; measurements complementary to those from space; and validation of satellite measurements. CEOS proposes to place particular emphasis on this challenge in the coming years, through its involvement in the IGOS Partnership, to ensure the planning of the required operational observation systems. Work is already underway in the domains of ocean monitoring, atmospheric chemistry, global carbon cycle, global water resources, and coral reefs within the IGOS Themes. These areas are regarded as particular priorities.

4 Future challenges



Strengthening partnerships between observation planners and international treaties:

As demonstrated by the possibility of our 'lucky escape' from stratospheric ozone depletion, international political will is a prerequisite to any successful solution to global environmental issues which span political borders.

Whilst international co-operation on environmental issues is still in its infancy, progress on major issues is being achieved. However, public concern over man-made climate change will demand further progress during the 21st century – especially on managing fossil fuel emissions and the global carbon cycle.

Providing the information required by decision-makers who represent our countries in the legal and political processes which develop international policies, and by the agencies which monitor compliance and impact of these policies, must therefore be a priority for future observation programmes, including those of CEOS and its Members. CEOS will therefore seek to strengthen partnerships with the secretariats of international treaties and conventions relating to Earth's environment and sustainable development – including the Conference of the Parties to the UNFCCC, and the UN Commission for Sustainable Development (CSD).

CEOS will also seek to build dialogue with the IPCC, recognised as the main source of assessment advice to these bodies – to ensure that future satellite missions reflect their priorities for Earth system information.

Simplifying access and maximising use:

Recognising the diversity of existing and potential users of Earth observation satellite data and their various levels of technological development, CEOS will endeavour to develop simplified means of access and utilisation for the information contained within the data products from satellites; this should maximise both the data value across a broad range of sectors and the cost-benefit of the government investment in the observation systems.

**Part II: Case studies – information
for global decision-making**



5 Case studies

5.1 Introduction

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

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

5.2 Contents

In order to illustrate the importance of Earth observations from satellite, five case studies are presented:

- global carbon cycle;
- water resources;
- ocean observations, including of El Niño;
- ozone monitoring;
- managing natural disasters.

In each case, the issues affecting society and the anticipated future consequences are discussed. The need for information and the role of Earth observation satellites is explained, including an indication of future plans.

Counting on Carbon

A global concern

In New York on 9th May 1992, the UN Framework Convention on Climate Change (UNFCCC) was adopted; to date, the most significant global legal framework for international action to address climate change. By the start of 2002, 186 countries and the European Community had become Parties to the Convention.

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

The UNFCCC was strengthened at a meeting of the Conference of the Parties (COP) to the Convention in December 1997, where a legal instrument – named The Kyoto Protocol – was adopted. The Protocol subjects industrialised countries to legally-binding targets to limit their greenhouse gas emissions. These targets add up to a total reduction of 5% in greenhouse gas emissions from 1990 levels, for the five-year period 2008-2012. By the start of 2002, 84 countries had signed; in order to enter into force, the Protocol will have to be ratified by 55 Parties to the Convention, including enough major industrialised Parties to account for at least 55% of the total carbon dioxide emissions by industrialised countries in 1990.

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

The term 'climate change' usually refers to changes in the climate system, notably a global warming trend caused by emissions of greenhouse gases that create a 'human-induced greenhouse effect.' The most important of these gases is carbon dioxide (CO₂), which comes mainly from the burning of fossil fuels such as oil, gasoline, natural gas and coal. Other important greenhouse gases include methane (CH₄), nitrous oxide (N₂O), ozone (O₃), and chlorofluorocarbons (CFCs).

As noted in Part I of this document¹:

- in 2001 the IPCC suggested that human activity is impacting on our climate, manifested as: changed atmospheric composition; global warming of land and oceans; changed precipitation patterns; increasing frequency of severe weather events, including those attributed to El Niño;
- the IPCC projects that greenhouse gas emissions due to fossil fuel burning are almost certain to be the dominant influence on trends in atmospheric greenhouse gas concentrations in the coming century and that with a 'business as usual' scenario, the global average surface temperature is expected to rise at a rate which is most likely without precedent in at least the last 45,000 years. Scientists anticipate profound consequences on sea level rise, precipitation patterns and extreme weather, with consequent impacts on a wide range of ecological functions and human activities essential for individual and societal well-being.

The International Response

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

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

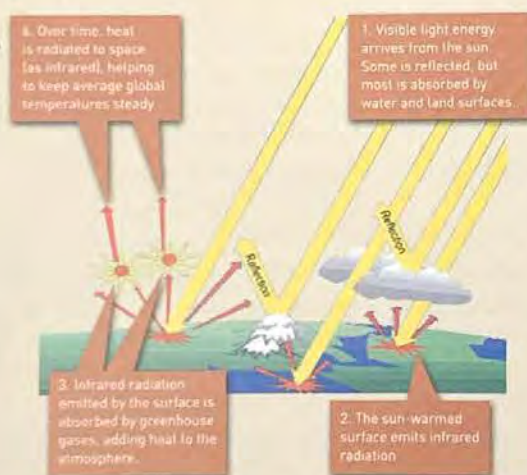
- carbon dioxide (CO₂);
- methane (CH₄);
- nitrous oxide (N₂O);
- hydrofluorocarbons (HFCs);
- perfluorocarbons (PFCs);
- sulphur hexafluoride (SF₆).

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

¹Based upon the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Climate Change 2001



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



The greenhouse effect.

The Global carbon cycle

Since the dominant influence on future greenhouse gas trends is widely agreed to be the emission of CO_2 from fossil fuel burning, an improved understanding of the global carbon cycle has become a policy imperative for the forthcoming decades, both globally and for individual countries.

The global carbon cycle connects the three major components of the earth system: the atmosphere, oceans, and land. In each domain, large pools of readily exchangeable carbon are stored in various compartments ('pools' or 'sinks' and 'sources'). Large amounts of carbon ('fluxes') are transferred between the sinks and sources over various time periods, from daily to annual and much longer. Although

some of the fluxes are very large, the net change over a given time period need not be. For many centuries prior to the industrial revolution the carbon sinks and sources were more or less in equilibrium, and the net transfer was close to zero for the planet as a whole.

The major changes have occurred following the development of agriculture and industry, with the accelerated transfer from the geological (fossil fuels) and terrestrial pools to the atmosphere. Because of the connections among pools, the increased atmospheric carbon concentration affects the other connected pools in oceans and on land.

The Kyoto Protocol recognises the role of terrestrial systems as carbon sinks and sources, and it provides a basis for developing future 'emission trading arrangements' that involve forests and potentially other ecosystems. Understanding of the pathways through which the anthropogenic CO_2 is absorbed from the atmosphere and into ecosystems (thus offsetting a portion of the anthropogenic emissions) is fragmentary and incomplete. These factors and dependencies make the quantification and study of the carbon cycle very challenging to model, observe, and predict.

Observing the carbon cycle

The UNFCCC and the Kyoto Protocol represent the first attempt by mankind, acting collaboratively across the world, to manage, at least partly, a global element cycle of the Earth system – the global carbon cycle.

This challenge requires the support of a coordinated set of international activities – scientific research (including modelling), observation, and assessment. Assessment is perhaps the most advanced, with the pioneering work of the IPCC providing the scientific assessment required for the policy action. In terms of scientific research, the International Geosphere-Biosphere Programme (IGBP) has recently joined forces with the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP) to build an international framework for integrated research on the carbon cycle (a project called Carbon 21).

5 Case studies – Counting on Carbon

A key element of international carbon activities – an integrated strategy for the observation of the global carbon cycle, including the land, oceans, atmosphere compartments of the cycle, is being coordinated by the IGOS Partnership, within the Integrated Global Carbon Observations (IGCO) Theme (see annex B for more on IGOS Themes).

A broad range of observations of important atmospheric, oceanic, and terrestrial parameters are required to: support future policy-making with evidence of trends; monitor the legal commitments undertaken within the Kyoto Protocol or future treaties; improve scientific understanding of the underlying processes. The same observations are important requirements for sustainable development and resource management.

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

- global networks of atmospheric greenhouse gas measurement stations (such as GLOBALVIEW CO₂), and the WMO World Data Center for Greenhouse Gases (Tokyo);
- global networks of measurement tower sites that monitor the exchanges of CO₂, water vapor, and energy between terrestrial ecosystems and atmosphere; eg the FLUXNET system has over 150 tower sites operating on a long-term and continuous basis;
- measurement ships and arrays of buoys, including the TAO array in the equatorial Pacific.

The role of Earth observation satellites

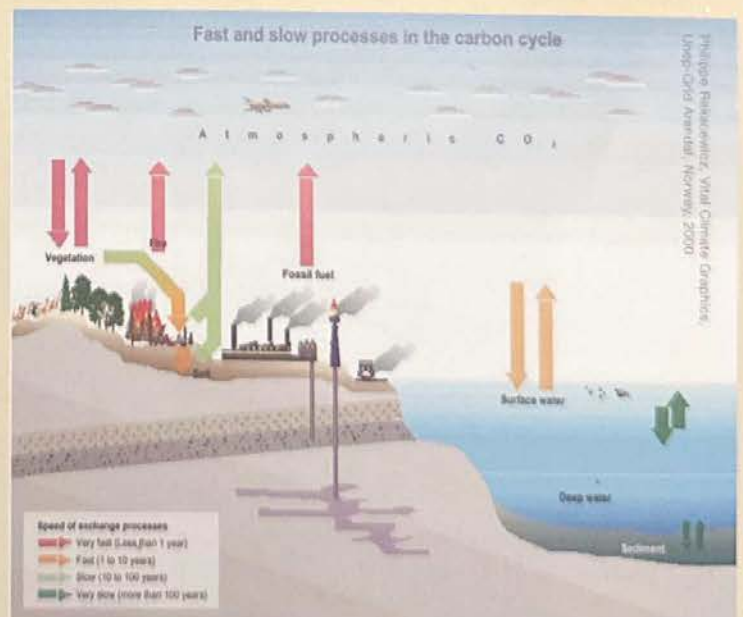
Data from Earth observation satellites provide the only global, synoptic view of key measures of the carbon cycle, and form an essential and central part of the envisaged integrated observation strategy planned within IGCO.

The major applications include:

- global mapping of land cover use, land cover change, and vegetation cover characteristics which are important to full carbon accounting – using sensors such as AATSR, AVHRR, ETM+ and MODIS and carried out through the Global Observation of Forest Cover (GOFC) project initiated by CEOS;

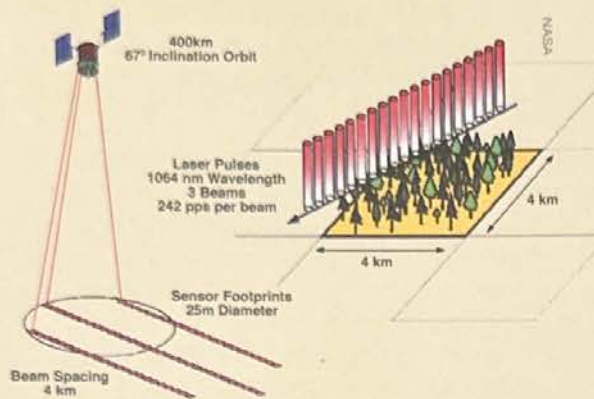
- seasonal growth characteristics, including important parameters such as Leaf Area Index (LAI) are generated on a global scale (eg by AVHRR);
- fire detection and burn scar mapping; in many regions of the world, fires are the most significant disturbance of vegetation and drive large inter-annual variations in carbon emissions from ecosystems; large fires in forests and grasslands are detected and mapped from space using thermal and optical sensors (radar sensors also show promise for burn mapping);
- combinations of satellite measurements of parameters such as ocean chlorophyll, dissolved organic matter, and pigment composition and physical measurements from satellite of ocean waves, winds, temperature are used to derive three main contributions for the study of ocean carbon;
 - quantifying upper ocean biomass and ocean primary productivity;
 - providing a synoptic link between the ocean ecosystem and physical processes;
 - quantifying air-sea CO₂ flux.

The most challenging aspect of observing the carbon cycle from space is the development of instruments for monitoring total column CO₂ concentration with complete coverage.

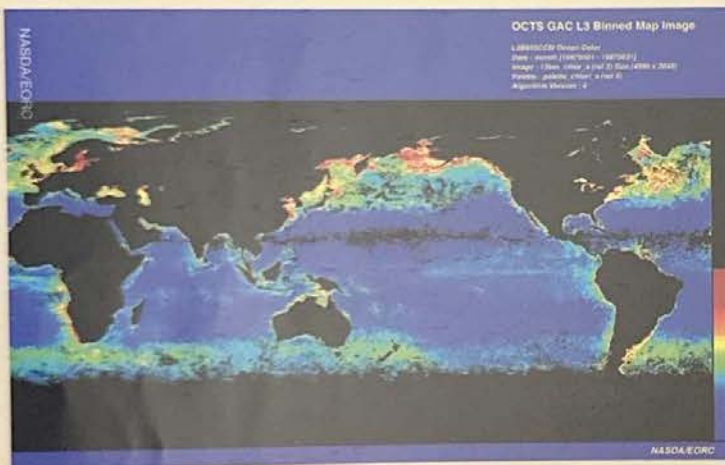


Fast and slow processes in the carbon cycle.

5 Case studies – Counting on Carbon



Future instruments such as VCL will provide new insights into global vegetation characteristics and biomass.



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



Fluxtowers monitor exchanges of CO₂, water vapour, and energy between land and atmosphere.

Future challenges

Future challenges relating to the global carbon cycle include:

- institutional: the continuing need for mechanisms for its management which are acceptable to all countries;
- scientific: improved understanding of the global carbon cycle is vital, including the ability to observe changes in carbon cycle dynamics;
- ensuring continuity of Earth observations.

Future plans for next generation Earth observation satellites include:

- a move from research to operational status for key observations, to support international policy frameworks, and to maintain the necessary continuity;
- development of future measurement capabilities: eg measurements of global vegetation characteristics and biomass, using lidar (laser radar instruments, such as NASA's proposed Vegetation Canopy Lidar – VCL) and new multi-directional, multi-spectral instruments (such as SPECTRA planned by ESA);
- measurement of atmospheric CO₂ concentration from space, globally in a comprehensive and consistent way.

The necessary coordination of the relevant satellite missions will be undertaken by CEOS including through their participation in the IGC Theme. Part III of this document summarises the various plans of the world's space agencies.

Global Carbon Cycle:

www.whrc.org/science/carbon/carbon.htm

UNFCCC and Kyoto Protocol: www.unfccc.de

Climate change science:

www.climatechangesolutions.com/english/science/default.htm

GOFC: www.gofc.org

Globalview: www.cmdl.noaa.gov/ccgg/globalview/

Fluxnet: daac.ornl.gov/FLUXNET/

SPECTRA mission:

www.esa.int/export/esaLP/ASE12YNW9SC_futuremissions_0.html

VCL mission: www.geog.umd.edu/vcl/

Water resources

An essential resource

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

Humans currently appropriate more than half of accessible freshwater run-off, and this amount is expected to increase significantly in the coming decades. A substantial amount, 70%, of the water currently withdrawn from all freshwater resources is used for agriculture. With the world's population set to increase by 65% (3.7 billion) by 2050, the additional food required to feed future generations will put further enormous pressure on fresh water resources. According to recent global water assessments, around 70% of the future world population will face water shortages and 16% will have insufficient water to grow their basic food requirement by 2050. Future management of freshwater resources will be complicated in future by the uncertainties in rainfall patterns introduced by climate change, with observations and models suggesting increased frequency and intensity in both extreme precipitation and drought events – depending on the region.

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

Observing and understanding the Water Cycle

Water is everywhere on Earth and is the only known substance that can naturally exist as a gas, liquid, and solid within the relatively small range of air temperatures and pressures found at the Earth's surface. In all, the Earth's water content is about 1.39 billion cubic kilometres and the vast bulk of it, about 96.5%, is in the global oceans. Approximately 1.7% is stored in the polar icecaps, glaciers, and permanent snow, and another 1.7% is stored in groundwater, lakes, rivers, streams, and soil. Finally, a thousandth of 1% exists as water vapour in the Earth's atmosphere.

Because water continually evaporates, condenses, and precipitates, with evaporation on a global basis approximately equalling global precipitation, the total amount of water vapour in the atmosphere remains approximately the same over time. This movement of water, in a continuous circulation from the ocean to the atmosphere to the land and back again to the ocean is termed the global water cycle, and is at the heart of the Earth's climate system, affecting every physical, chemical, and ecological component. Amongst the highest priorities in Earth science and environmental policy issues confronting society are the potential changes in global water cycle due to climate change. Climate changes may profoundly affect atmospheric water vapour concentrations, clouds, and precipitation patterns. Many uncertainties remain, however, as illustrated by the inconsistent results given by current climate models regarding the future distribution of precipitation.

Better predictions of water cycle behaviour are needed for:

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



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

- evaporation processes from the global ocean (which account for 80% of the water present in the atmosphere);
- land surface hydrologic processes which govern evapotranspiration and the partitioning of rainfall between re-evaporation, storage in the soil, and run-off to rivers;
- relationships between global climate and regional weather systems which govern clouds and rainfall;
- the science of clouds, and how they lead to precipitation.

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

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

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

A number of international scientific research programmes have been developed to address the key challenges relating to the global water cycle – most

notably under the auspices of the World Climate Research Programme, including:

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

The role of Earth observation satellites

Earth observation satellites play a major role in the provision of information for study and monitoring of the water cycle. Atmospheric temperature and water vapour data is provided operationally by polar orbiting meteorological satellites. Sea surface temperature measurements are also provided by these satellites, and by the European ERS and Envisat missions. Ocean wind measurements are also provided by these missions – and by NASA's QuikSCAT which acquires all-weather, high-resolution measurements of near-surface winds over 90% of the global oceans on a daily basis.

Precipitation is clearly a key parameter, but given the high temporal and spatial variability of precipitation it is a fundamentally difficult parameter to measure. Until recently, visible/infrared images from geostationary meteorological satellites provided the best source of information from satellite – with indirect but frequent estimates of rainfall derived from measurements of cloud top temperature. The advent of the Tropical Rainfall Measuring Mission (TRMM of NASA/NASDA) in 1997 provided a breakthrough in the provision of 3-D information on rainfall structure and characteristics. NASA and NASDA and other international partners will continue this collaboration in future to develop the Global Precipitation Mission (GPM) for launch in the latter half of this decade; the GPM constellation of satellites – including potential contributions from USA, Japan, Europe, France, India and China – will provide global observations of precipitation every three hours to help develop the understanding of the global structure of rainfall and its impact on climate and the Earth's habitability.

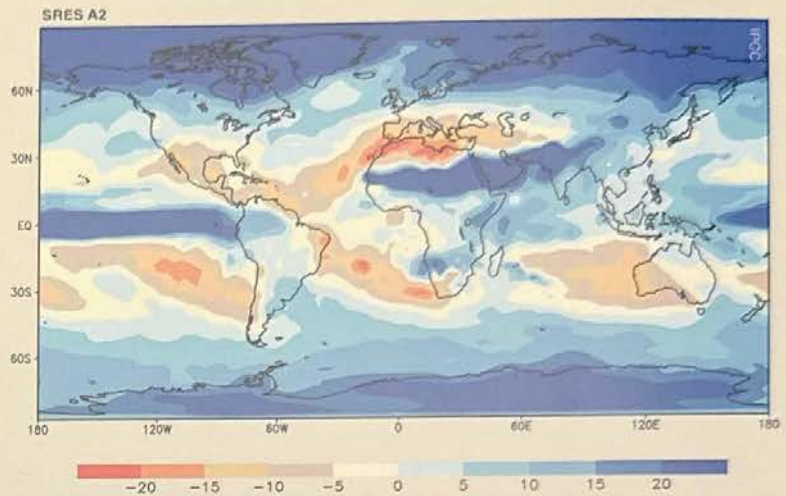
Recognising the central role of the water cycle to our understanding of the Earth system and climate

5 Case studies – Water resources

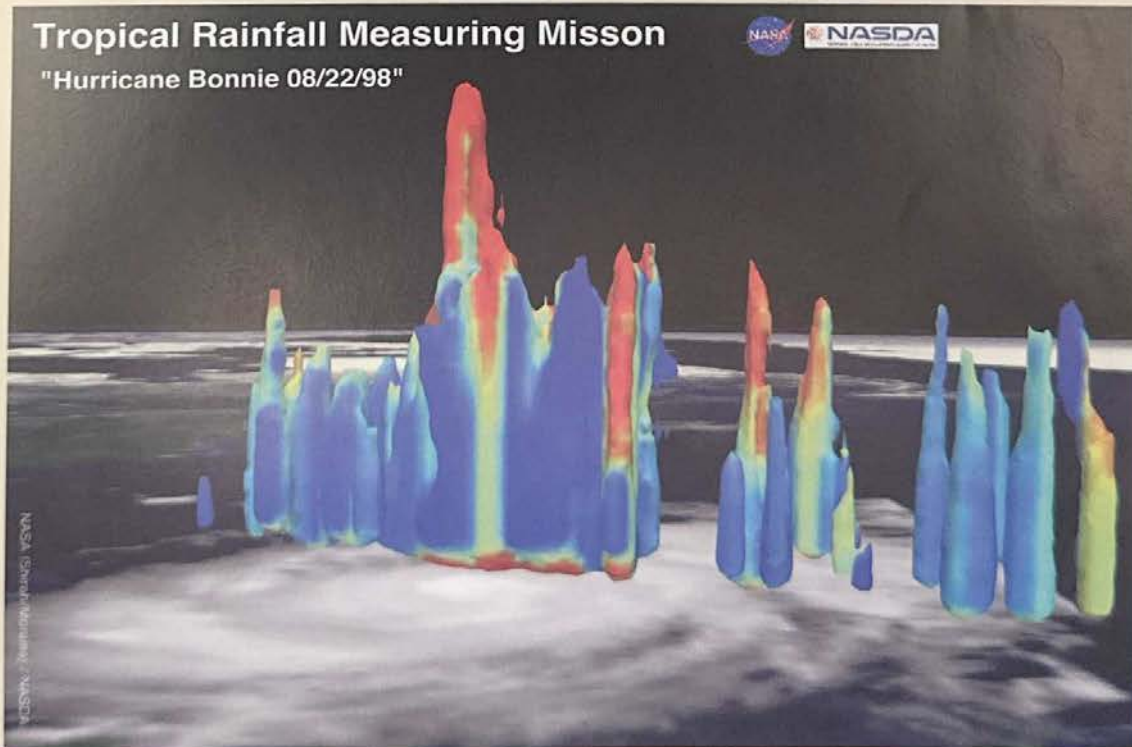
change, the world's space agencies are operating or developing a number of new missions aimed at addressing key scientific objectives. These include the Aqua mission (NASA), Cloudsat (NASA), EarthCare (ESA/ NASDA), and Cryosat (ESA). Revolutionary new measurement capabilities – such as the provision of information on soil moisture and ocean salinity – will be provided in future by missions such as SMOS (ESA) and Hydros (NASA).

Further information on these programmes can be found in Part III of this document.

In order to ensure the coordination which is necessary among these many satellite programmes, and the efforts of the in-situ measurement community, the IGOS Partnership is developing an Integrated Global Water Cycle Observations Theme (IGWCO). The IGWCO theme will provide a framework for guiding international decisions regarding priorities and strategies for the maintenance and enhancement of Water Cycle observations so they will support the most important applications and science goals, including the provision of systematic observations of trends in key hydrologic variables. The first element of IGWCO will be a 'Coordinated Enhanced Observing Period (CEOP)' which is taking the opportunity of



Climate models suggest some areas of the Earth will become drier, and others wetter – with increased frequency and intensity in both extreme precipitation and drought events.



The TRMM mission provided revolutionary 3-D information from space on rainfall structure.



the simultaneous operation of key satellites of Europe, Japan, and USA during the period 2001–2004 to generate new data sets of the water cycle.

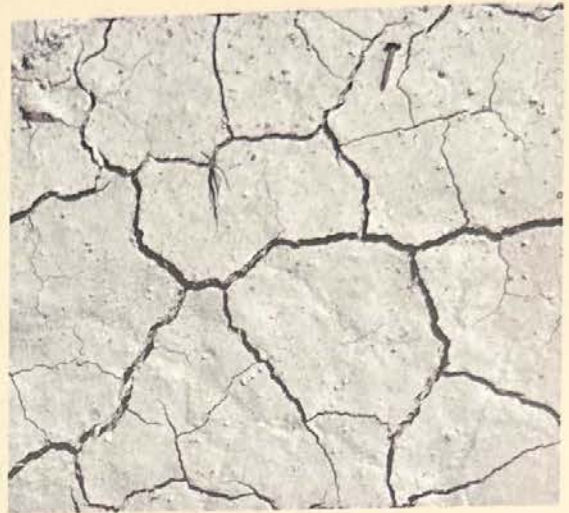
Future challenges

The impacts of water cycle variability on human society are very real and well recognised. However, the issue has not – until quite recently – received the corresponding attention on the global environmental agenda. At the Rio Summit for example in 1992, water resources were not a particularly prominent issue – with issues such as deforestation and biodiversity having a far higher profile. The balance has, to an extent, been redressed through the importance given to freshwater issues by the United Nations Commission for Sustainable Development (CSD) and in the 1997 UN General Assembly Special Session – which contained calls for greater concerted efforts. A number of world bodies – such as the World Water Council (WWC) have since been established to consider water issues, and The World Water Forum planned for 2003 in Japan is potentially a major milestone in addressing water problems at the international level.

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

- converting satellite measurements into useful parameters which can be applied in scientific models, and which can be inter-compared and inter-calibrated among the different satellite missions;
- providing consistent and accurate data over many years in order to detect the trends which are necessary for climate change studies;
- succeeding in the technology developments aimed at accurately measuring key parameters from space for the first time – including soil moisture and ocean salinity.

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



70% of the future world population will face water shortages by 2050.

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

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

World Water Council: watercouncil.org/

World Water Forum: www.worldwaterforum.org/

WCRP: www.wmo.ch/web/wcrp/wcrp-home.html

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

CEOP: monsoon.t.u-tokyo.ac.jp/ceop/index.html

SMOS: www.esa.int/export/esaLP/ESAMBA2VMOC_sm0s_0.html

EarthCare:
www.esa.int/export/esaLP/ASESMYNW9SC_futuremissions_0.html

Aqua: eos-pm.gsfc.nasa.gov/

TRMM: www.eorc.nasda.go.jp/TRMM/index_e.htm

Observations of the ocean

Ocean planet

Earth is an ocean planet – 70% of its surface is covered by ocean. The ocean plays a critical role in establishing global climate and is inextricably linked to the atmosphere in creating the natural fluctuations of our climate system:

- the ocean is the 'heat engine' of the planet – global ocean circulation, together with the atmosphere, constitutes the mechanism by which solar energy received in the tropics is re-distributed to the entire planet;
- the state of the ocean influences climate and the energy and water cycles, and thereby affects agriculture, and water and energy supplies;
- the ocean also affects the intensity of hurricanes and tropical cyclones, which can cause billions of dollars in property damage and alter the economic fortunes of peoples in affected areas;
- the El Niño/La Niña phenomenon of the tropical Pacific widely impacts normal weather patterns in many regions and can have profound economic consequences (some bad, some good);
- the ocean, through atmospheric exchange, plays an important part in the global carbon cycle – and is therefore inextricably linked to global change processes.

The ocean has always been critical to the success of human civilisation; some 30% of the world's population now live within 100km of the coasts, and humans have depended on the ocean for food and economic growth for hundreds of years.

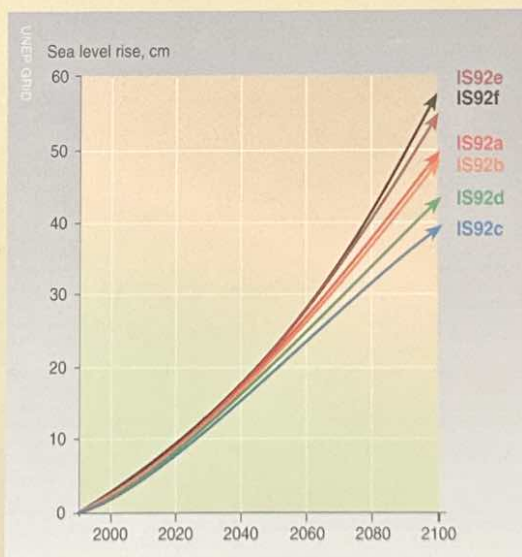
- in the technically developed Group of Seven countries, marine resources and services contribute, on average, 5% of GNP or about \$600 billion per annum (1991);
- the world fish catch is 80-90 million tonnes/year (worth approximately \$70 billion), and provides about 20% of the world protein supply. For large parts of the world population, particularly in East and Southeast Asia, fish constitute the most important source of animal protein;
- ocean transport is the most inexpensive way of trading bulk goods. The result is that about 90% of the world's trade involves transit via the ocean – and the volume is expected to double over the next decade.

World production of offshore oil and gas was worth \$135 billion in 1990, amounting to 20% of world hydrocarbon production. Operations continue to venture into deeper waters – at depths of up to 2000 metres.

Ocean observations

In the coming years, the need to understand and forecast the oceans and their resources is going to increase significantly – and on time-scales that permit relevant and effective management decision-making. Scientists will require a range of data for assimilation into numerical models to provide analyses of a range of ocean phenomena and climate-related processes:

- understanding the dynamics of ocean circulation will require systematic measurements of ocean currents at least weekly, but also spanning decades, commensurate with the characteristic time scales of anomalies such as El Niño, The North Atlantic Oscillation, and the Pacific Decadal Oscillation;
- global, precise, long-term measurements of ocean temperature are of key importance for studies of the Earth's energy balance, for understanding how the ocean regulates weather and climate, and for the provision of indicators of the El Niño event;
- the mean level of the oceans must be monitored precisely for decades to come, for use in climate models – which have suggested a future rise in ocean levels due to global change – and to allow mitigation planning by low-lying countries;
- more accurate information is needed on the concentration, position, extent, and thickness of sea ice for monitoring of changes in the polar regions, which have a strong relationship to global climate;



Using estimates of climate sensitivity and ice melt parameters, and various fossil fuel emission scenarios (known as IS92), models have projected an increase in global mean sea level of between 13 and 94cm in this century.



- the ocean is the largest mobile reservoir of carbon on decadal to millennial time-scales, and is estimated to absorb between 30–40% of the CO₂ added to the atmosphere. Assessments of the effectiveness of any measures taken to reduce carbon emissions will ultimately be judged by their long-term effect on atmospheric CO₂ levels, which in turn requires a understanding and monitoring the ocean carbon cycle and long-term storage changes;
- a suite of biological, chemical, and physical parameters must be monitored to understand, predict and manage potential climate change effects on the abundance, diversity, and productivity of marine populations, including fisheries.

The continued migration of people to coastal communities, the increasing volume of commodities transported by sea, the exploitation of sea-based mineral and oil reserves in deeper water, the creation of offshore facilities, rising sea-levels threatening to overwhelm present coastal protection systems, increasing pollution of coastal waters caused by increased use of nitrogen-based fertilisers, national security, and the need to sustain and protect marine fisheries will also force us to pay much more attention to the open ocean and coastal seas over the next century. Minimising loss of life and property, and avoiding environmental degradation and disasters requires significant improvements in the ocean information which is available to decision-makers in addressing issues of public concern such as:

- frequency and intensity of hurricanes and storm surges;
- pollution (eg nitrates, oil, and industrial chemicals from land affecting water quality and public health);
- oil spills and other marine accidents;
- dumping and waste disposal, including radioactive waste;
- loss of amenities due to coastal development, and urbanisation;
- coastal erosion and loss of coastal ecosystems;
- degradation of coral reefs and mangrove forests;
- increases in toxic algal blooms;
- exhaustion of fish stocks, degradation of biodiversity in the ocean, and wildlife conservation;
- safety of passenger and cargo ships, ferries and offshore operators.

Recognition of the increasing need for comprehensive measurements in the marine environment led in the 1990's to the formation of the Global Ocean Observing System (GOOS) – a permanent global system for observations, modelling and analysis of marine and ocean variables to

support operational ocean services worldwide. The vision guiding the development of GOOS is one of a world where the information needed by governments, industry, science and the public to deal with marine related issues, including the effects of the ocean upon climate, is supported by a unified global network to systematically acquire, integrate and distribute oceanic observations, and to generate analyses, forecasts and other useful products.

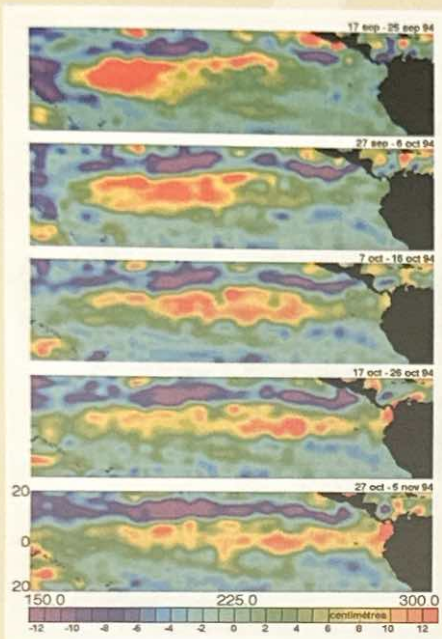
GOOS capitalises on a range of existing ocean observing systems, including meteorological stations on land, remote sensing from space, a mixture of fixed and floating data-gathering instrument arrays, and observations from ships.

The importance of Earth observation satellites

Satellite remote sensing has revolutionised observation of the oceans in many ways, providing synoptic views of a range of key parameters. Some of the most significant achievements and their applications are:

- the provision of long term sea surface temperature data to the high accuracy required for climate studies (the same data is also used on a daily basis to assist the management of fishing fleet operations); satellite remote sensing provides the only practical means of developing such a dataset – in-situ data are extremely limited in coverage and predominantly confined to shipping lanes whereas satellites offer the potential for surveying the entire ocean surface in just a few days;
- satellite altimetry is the main source of data being used to monitor large scale changes in ocean circulation and the mean level of the oceans – such as those related to El Niño; on a local scale, topographic information from satellites is used in support of off-shore exploration for resources and for optimising cable and pipeline routing on the sea floor;
- sea surface winds: satellites now acquire all-weather, high-resolution measurements of near-surface winds over global oceans; this information is used to improve weather forecast models and climate applications, and is particularly valuable for short-term severe weather warnings and for ship-routing;
- ocean biology: ocean colour data from satellites is now being collected for every square kilometre of cloud-free ocean every 48 hours; this data provides information on concentrations of types and quantities of marine phytoplankton (microscopic marine plants) and will help develop understanding of the oceans' role in the global carbon cycle, as well as other biogeochemical cycles.

5 Case studies – Observations of the Ocean



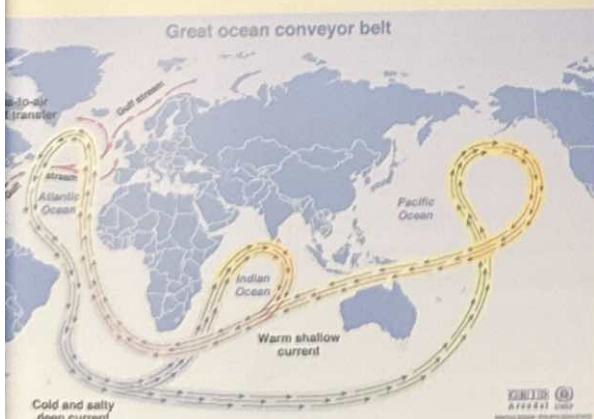
NASA/CNES

Satellite altimetry and temperature measurements now provide unprecedented foresight of El Niño's arrival.



NASA

Sea surface temperature records from satellite provide crucial indicators of global change.



UNEP GRID

Global ocean circulation is the 'heat engine' of the planet – re-distributing solar energy received in the tropics to the entire planet.

Future challenges

Ocean observing systems must rise to a number of challenges in the 21st century in order to keep pace with the demand for information on the ocean's role in climate change, and on parameters to assist its sustainable management for use in transportation, resource exploration, recreation, and fisheries.

These challenges include organisational and institutional issues related to: coordinating efforts among providers/users of ocean/climate services; developing applications and infrastructure to deliver them to users; delivering information products for decision-making that are responsive to user needs.

Part III of this document summarises the various plans of the world's space agencies over the coming decades in providing satellite missions for critical ocean observations. To be effective, improved techniques for assimilation of data from these missions will be necessary. Satellite data will also have to be integrated better with in-situ observations; in-situ sensors provide invaluable validation information for satellites, as well as measurements deep below the ocean surface, which satellites cannot.

Future plans for next generation Earth observation satellites include:

- maintaining crucial continuity and calibration of key measurements – such as sea surface temperature, ocean winds, and ocean colour – over long timescales in support of climate studies;
- development and proving of remote sensing technologies to provide measurements of the depth of the ocean mixing layer, and of sea surface salinity – a key variable in determining ocean density, which drives ocean circulation and thus impacts climate;
- provision of improved measurements on sea ice extent, type, and thickness – allowing scientists to determine the mass balance of the polar ice sheets and their contributions to global sea level change;
- missions for accurate global and high-resolution determination of the Earth's gravity field – which is prerequisite for better understanding of ocean surface currents and heat transport.

These developments, and others, have been determined as priorities for the way ahead by the Ocean Theme studies of the IGOS Partnership.



Watching from space for El Niño

El Niño is an anomalous oceanographic and atmospheric event in the equatorial Pacific Ocean that usually occurs every three to seven years and is characterised by an increase in the sea-surface temperature in the eastern equatorial Pacific Ocean. El Niño is thought to be responsible for anomalous climatic conditions spanning most of the globe. Many of the resulting impacts of El Niño are negative, causing drought, famine, and floods. But some are positive, like the decrease in hurricanes along the Atlantic margin of the USA in El Niño years. It is not uncommon for an El Niño winter to be followed by a La Niña one – characterised by unusually cold ocean temperatures in the Equatorial Pacific – and where climate patterns and worldwide effects are, for the most part, the opposite of those produced by El Niño.

The El Niño of 1997-98 has been attributed with property damage of more than US\$ 33 billion, disrupted weather patterns around the world, and an estimated 2100 deaths. But the 1997-98 El Niño was also significant as being the first El Niño for which researchers were able to predict the worst impacts months in advance – allowing flood or drought warnings to be issued to the threatened countries. The first announcements of a possible El Niño were as early as April 1997 and a few months later detailed predictions were available for many regions.

After the surprise devastation of the 1982-83 El Niño event, climate experts intensified efforts to understand how the process works globally. Governments invested in observing systems to monitor the particular conditions in the Pacific that trigger El Niño.

By the time the 1997-98 El Niño started to emerge, scientists had several new and powerful observing systems on the look out for the tell-tale signs:

- precision altimetry instruments on the US/French Topex/Poseidon satellite, providing vital information on sea surface height;
- the Tropical Atmosphere Ocean (TAO) array of 70 moored buoys spanning the equatorial Pacific since 1984 providing measurements of water temperature, wind, air temperature, and humidity;
- complementary measurements, such as ocean surface temperature from other satellite missions;
- much improved computer models integrating satellite and in situ data to provide improved forecasts.

Thanks to this range of valuable data sources and ability to produce high-level integrated information products, climate scientists now have information of unprecedented range and accuracy, which has enabled them to confirm and expand their theories about what occurs both during normal weather patterns and during sea changes that herald the periodic – and inevitable – arrivals of El Niño and La Niña.

There is a consensus among climate scientists that El Niños have become more frequent and progressively warmer over the past century. In the past 98 years there have been 23 El Niños and 15 La Niñas. Of the century's ten most powerful El Niños, four – the four strongest – have occurred since 1980.

Whatever the future may bring, the world need never again be taken completely off guard by El Niño or La Niña, thanks to the unprecedented foresight that Earth observing systems and climate science has made possible.

Ocean and climate:

earthobservatory.nasa.gov/Library/OceanClimate/

Future precise gravity missions:

www.esa.int/export/esaLP/ESAYEK1VMOC_goce_0.html

GOOS: ioc.unesco.org/goos/

El Niño and La Niña: www.pmel.noaa.gov/tao/el_nino/nino-home.html

Altimetry and ocean topography by satellite:

www.jason.oceanobs.com/html/portail/general/welcome_uk.php3

TAO array: www.pmel.noaa.gov/tao/

IGOS Ocean theme report:

ioc.unesco.org/igospartners/IGOS-Oceans-Final-0101.pdf

The Ozone layer – catastrophe averted?

The big issue

Ozone (O_3) is very rare in our atmosphere, averaging about three molecules of ozone for every 10 million air molecules. Although it represents only a tiny fraction of the atmosphere, ozone is crucial for life on Earth.

Close to Earth in the troposphere (the atmospheric layer from the surface up to about 10km), ozone is a harmful pollutant that causes damage to lung tissue and plants. Most ozone (about 90%) resides in the stratosphere (a layer of the atmosphere between 10 and 40km above us), where it acts as a shield (strongest at about 25km altitude on average) to protect Earth's surface from the sun's harmful ultraviolet radiation (UV-B), filtering out the high energy radiation below $0.29\mu m$ and allowing only a small amount to reach the Earth's surface. The ozone in this region is commonly known as the ozone layer. The consequences of damage to this protective layer, and subsequent increases in UV-B radiation include risks of eye damage, skin cancer, and adverse effects on marine and plant life.

Throughout the 1970's and 1980's, scientists began first to suspect, and then to detect, a steady thinning of the ozone layer – accompanied by increases in the amount of UV-B reaching the Earth's surface. Scientific concern turned to public alarm when, in 1985, the British Antarctic Survey announced the detection of the first Antarctic ozone 'hole' – a sharp decline in stratospheric ozone concentrations over most of Antarctica for several months during the southern hemisphere spring; subsequent studies using satellite data recorded depleting ozone levels over Antarctica growing worse with each passing year.

It is now known that the ozone layer over Antarctica thins to between 40% and 55% of its pre-1980 level with up to 70% deficiency in short time periods, and at some altitudes, ozone destruction is almost total. In September 1998, the Antarctic ozone hole reached a record size of 25 million km^2 , or two and half times the size of Europe.

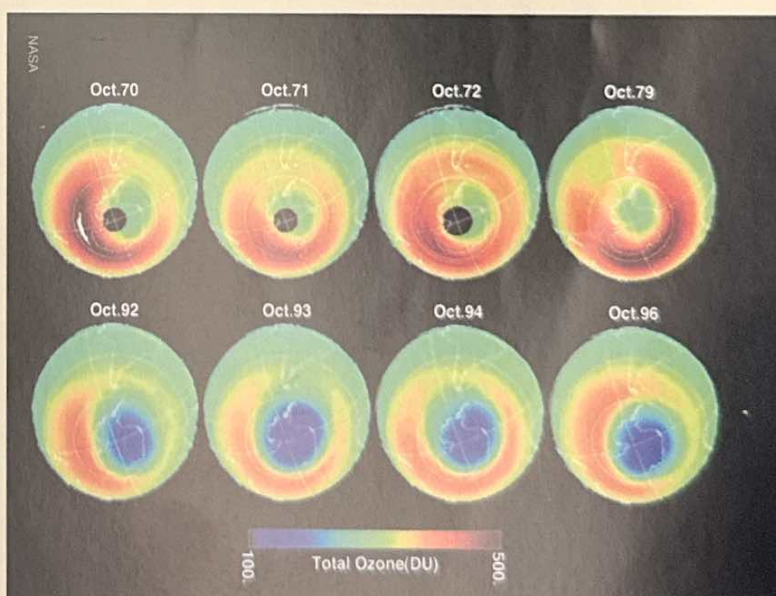
Moreover, there is the potential of ozone losses occurring in the Arctic. Recently observed Arctic ozone losses have reached levels that are becoming comparable to Antarctic losses. The large Arctic losses observed over the last decade cannot be explained adequately by current atmospheric

models. This inability to quantitatively explain present-day ozone losses undercuts the ability to predict ozone losses and, ultimately, ozone recovery in a future atmosphere containing increased concentrations of greenhouse gases.

The response

The scientific evidence, accumulated over several decades by the international research community, showed that human-produced chemicals were responsible for the observed depletions of the ozone layer. These ozone-depleting substances, such as halocarbons or chlorofluorocarbons (CFCs) contain various combinations of the chemical elements chlorine, fluorine, bromine, carbon and hydrogen. Substances like CFCs had grown to be extremely popular for use as coolants, solvents, sterilants, and aerosol propellants, amongst other applications. When released into the lower atmosphere, through the use of an aerosol spray for example, they diffuse up into the stratosphere and react in a process which involves destruction of ozone molecules.

Faced with the strong possibility that CFCs and similar compounds could cause serious ozone depletion, policy makers from around the world signed the Montreal Protocol treaty in 1987, limiting CFC production and usage. By 1992, the



With each passing year over the last few decades, ozone concentrations over the South Pole have grown less during the months of September and October. These images show the progression of the ozone 'hole', as measured by the TOMS and SBUV instruments.



growing scientific evidence of ozone loss prompted diplomats to strengthen the Montreal Protocol. The revised treaty called for a complete phase out of CFC production in developed countries by 1996. As a result, most CFC concentrations are slowly decreasing around the globe – with production having fallen by 95% in industrialised countries.

The latest research suggests that the Montreal Protocol is working. The abundance of ozone-depleting substances in the lower atmosphere peaked in 1994 and has now started to decline. As a result, the ozone layer is expected to recover slowly over the next 50 years.

The importance of Earth observation satellites

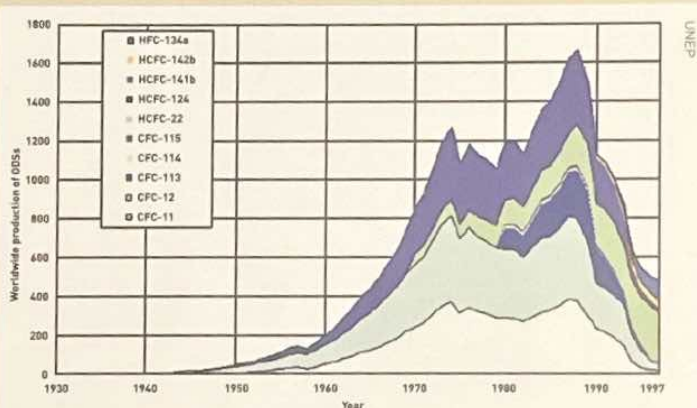
Since the 1920's, ozone has been measured by ground-based instruments. Scientists place instruments at locations around the globe to measure the amount of ultraviolet radiation getting through the atmosphere at each site. From these measurements, they calculate the concentration of ozone in the atmosphere above that location. These data, although invaluable for learning about ozone, are not able to provide an adequate picture of global ozone concentrations.

The amount and distribution of ozone molecules in the atmosphere varies greatly over the globe, and scientists observing ozone fluctuations over just one spot could not know whether a change in local ozone levels meant an alteration in global ozone levels, or simply a fluctuation in the concentration over that particular spot. Satellites have given scientists the ability to overcome this problem because they provide a picture of what is happening daily over the entire Earth.

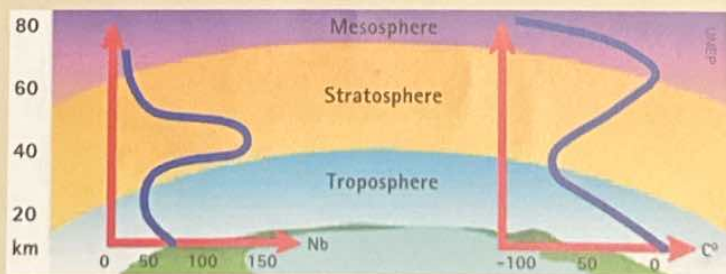
Satellite observations of atmospheric ozone date back to the late 1970's, to the launch of the TOMS (Total Ozone Mapping Spectrometer) and SBUV (Solar Backscatter Ultraviolet) instruments. These instruments have since been complemented by long term measurements by US and European satellite series, and by missions of Russia and Japan. Re-analysis of the early satellite data proved instrumental in providing the scientific evidence necessary to support the case for the international political response which emerged in the 1980's, and more recent missions have proved essential in long term mapping of the ozone depletion trends, and in gathering the data required for a better understanding of the underlying atmospheric science.

Increasingly, satellite instrumentation is capable of more advanced measurements of ozone parameters – such as profiles of ozone concentration through the atmosphere (as opposed to just the total 'column' amount), as well as information on a range of other trace gases which help ozone chemistry studies. Such data is now being used as the basis for operational information services for the public and science community alike.

The UV Forecasting service of the Royal Netherlands Meteorological Institute (KNMI) – in collaboration with the European Space Agency (ESA) – is one example; this uses data from ESA satellites to



The growth in concentrations of the major ozone-depleting chemicals in the atmosphere has slowed after a peak in 1994.



The thin layer of ozone in the stratosphere is at its thickest between about 20-40km up. It also accumulates near the ground in the troposphere, where it is a troublesome pollutant.

5 Case studies – The Ozone layer – catastrophe averted?

provide ozone profile and UV measurement indices within hours of collection, and can cover the entire globe within just 3 days. Such information is becoming a routine and essential part of our daily diet of weather information as awareness increases of the dangers of exposure to excessive sun.

Future challenges

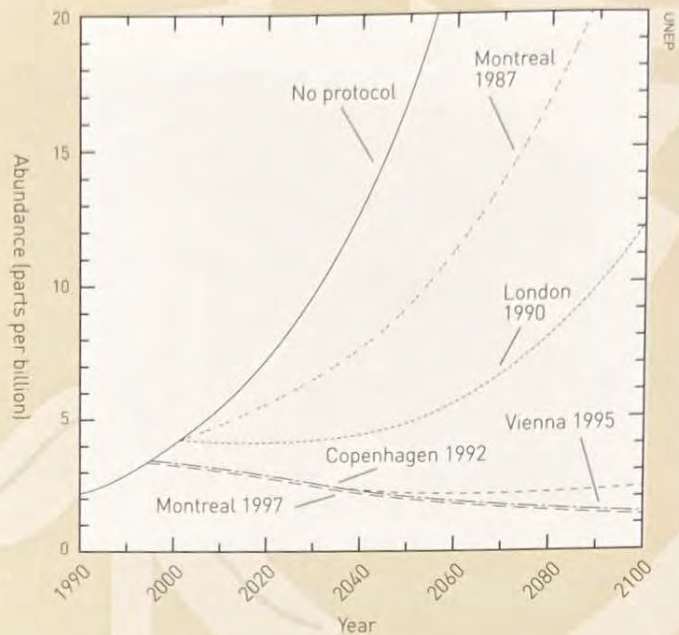
Although not yet conclusive, there are some symptoms of a very slow recovery of the ozone layer – and that a global environmental catastrophe may have been averted. The detection of the damage, its characterisation by Earth observation satellites and supporting ground stations, and mobilisation of a relatively swift political response might be regarded as a scientific success story.

Yet there is no room for complacency. The trend to recovery in the ozone layer is both slow, recent, and inconclusive. Atmospheric science is complex and much remains to be learned about the processes that affect ozone. To create accurate models, scientists must study simultaneously all of the factors affecting ozone creation and destruction. Moreover, they must study these factors continuously, over many years, and over the entire globe. Earth observation satellites will provide the main source of information for these studies.

Part III of this document summarises the various plans of the world's space agencies over the coming decades in providing satellite missions in support of this global responsibility. To be effective, data from these missions must be inter-comparable, and provide the precision, consistency, and long-term accuracy required for scientific studies of climate.

Earth observation satellites must also rise to a number of new and emerging dimensions to the ozone issue, including:

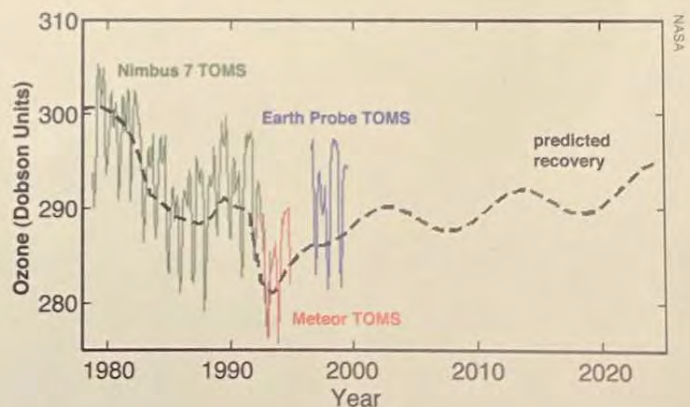
- the link between ozone layer depletion and global warming: cooling in the stratosphere due to climate change is expected to promote the same ozone-depleting effect in the Northern hemisphere as that which leads to the Antarctic ozone holes;
- tropospheric pollution: research is showing that air quality, and the presence of pollutants (including ozone), is a global issue – and that pollution hotspots can affect air quality in far flung places, due to intercontinental transport; and pollution itself may have further impact on climate.



Effect of the international agreements on ozone-depleting stratospheric chlorine/bromide.

Improved measurement capabilities in the troposphere, and higher resolution profiling capabilities of planned satellite instruments are expected to contribute significantly to study of these problems.

The necessary coordination of the relevant satellite missions will be undertaken by CEOS including through their participation in the Integrated Global Atmospheric Chemistry Observations (IGACO) Theme of the IGOS Partnership – which aims to integrate both space-based and in-situ measurements of key atmospheric parameters.

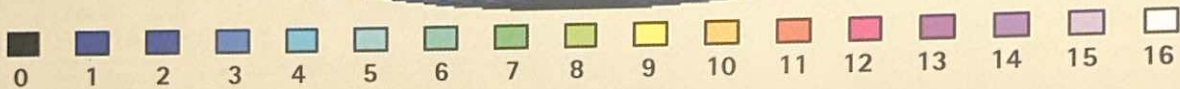
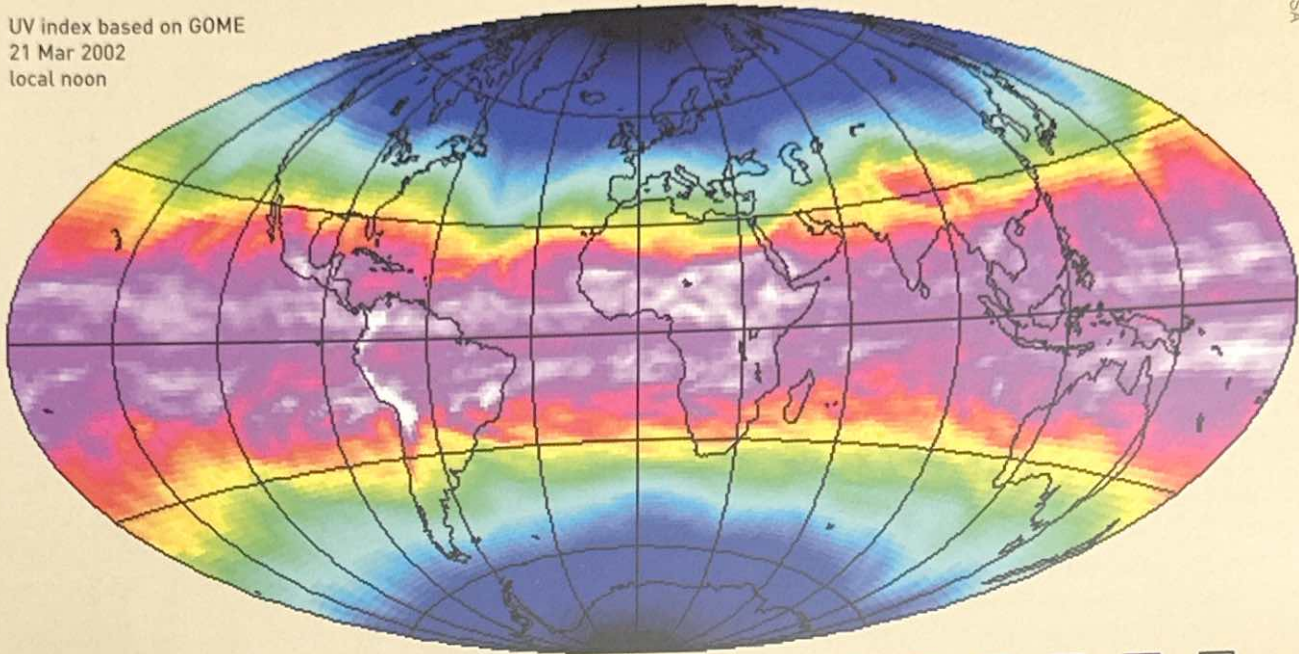


Global average ozone.

5 Case studies – The Ozone layer – catastrophe averted?

KNMI/ESA

UV index based on GOME
21 Mar 2002
local noon



UV index forecasts derived from satellite data are an increasingly common feature of our everyday weather forecast information.

Ozone science, major initiatives – the UNEP

Ozone Secretariat:

www.unep.org/ozone/index-en.shtml

Ozone depletion FAQ:

www.al.noaa.gov/WWWHD/pubdocs/Assessment98.html

Online ozone textbook:

see.gsfc.nasa.gov/edu/SEES/strat/class/S_class.htm

Satellite Earth observations of ozone:

earthobservatory.nasa.gov/Library/Ozone/

www.esa.int/export/esaSA/ESAHRQQSTC_earth_0.html

Operational UV forecasting service:

www.esa.int/export/esaSA/ESAS3RUM5JC_earth_0.html

Managing natural disasters

On average each year, natural disasters around the world leave 4 million people homeless, injure another 900,000 people and kill 128,000 people. These disasters also cause many billions of dollars of property damage. In 1991 and 1992 alone, property damage amounted to US\$100 billion. A single event, Hurricane Andrew, caused US\$25 billion of damage in the southern part of the United States of America in 1992. It has been estimated that, in the same year, the world economy lost more money (US\$62 billion) from natural disasters in the less developed countries than it spent on development aid (US\$60 billion). Natural disasters should be recognised as a major obstacle to sustainable development.

The natural or human-induced hazards which lead to these disasters with the potential to create loss to humans and to their welfare include: floods, typhoons, hurricanes and cyclones, earthquakes, tornadoes, volcanic eruptions, landslides, drought, and wildfires.

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

Disaster management information

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

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

- emergency response, recovery and reconstruction: activities taken immediately before and after the onset of a hazard to reduce the effects of a disaster after it occurs; assessment of the extent and severity of the damage; relief measures such as delivering food, health care and other sustenance; implementation of remedial and reconstruction measures.

Hazards are characterised by information on geology, tectonics, seismicity, regimes of rivers and their water basins, amount and characteristics of fuel, local meteorological conditions, terrain and topography. Vulnerability derives very much from the location of assets such as urban centers and more precisely hospitals, schools, plants, road and utility networks, and the likely effect of a given disaster.

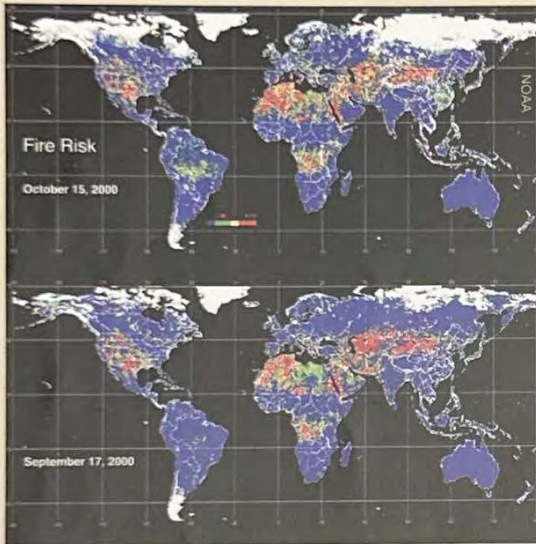
Meteorological forecasts are essential to prediction and warning of hurricanes, floods and fires. So far no reliable prediction system is available for earthquakes, although warnings may be issued for volcanoes and tsunamis. Evacuation plans and similar measures are triggered accordingly and their efficiency is conditioned heavily by available information on settlements, roads, etc. This is exemplified in areas which are frequently affected by disasters such as hurricanes (hundreds of thousands of citizens were evacuated during Hurricane Floyd's visit to US coasts).

An efficient response requires accurate and rapid knowledge of the location and intensity of damage. Information on roads, bridges, utility networks, critical infrastructure such as hospitals or airports is essential. The same type of information, coupled with knowledge of hazards, will help reconstruction planning, to assist avoidance of dangerous areas.





Disaster reduction and risk management has moved rapidly up the policy agenda of affected governments and the international community. This trend has led to the adoption of the International Strategy for Disaster Reduction (ISDR) by governments to promote implementation of the recommendations emanating from the International Decade for Natural Disaster Reduction (IDNDR, 1990-1999). The aim of the ISDR is to mobilise Governments, UN-agencies, regional bodies, private sector and civil society to unite efforts in building resilient societies by developing a culture of prevention and preparedness. Amongst other actions, ISDR calls for action on the information required to: reduce human vulnerability; plan urban development strategies; monitor environmental risk factors and land use; and develop global, regional, national and local early warning systems.



A range of data sources, including a number of satellite sources, are used to generate fire risk maps.

The role of Earth observation satellites

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

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

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

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

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

Some of these capabilities are shown in the table.

5 Case studies – Managing natural disasters

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



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

DMSG: The Disaster Management Support Group of CEOS was established in 1997, with the objective of supporting natural and technological disaster management on a worldwide basis by fostering improved utilisation of



World-wide Volcanic Ash Advisory Centres use satellite data to support volcanic ash cloud warnings for aviation.

existing and planned EO satellite data. The DMSG serves as a forum to identify, and interact with, current and potential users of space-derived data as one of the tools to deal with disasters. DMSG includes specialist teams addressing different types of hazards and has developed substantial on-line resources: <http://disaster.ceos.org>

International Charter on Space and Major Disasters: The aim of this Charter, initiated by the French (CNES), European (ESA) and Canadian (CSA) space agencies is "to supply during periods of crisis, to States or communities whose population, activity or property are exposed to an imminent risk, or are already victims, of natural or technological disasters, data providing a basis for critical information for the anticipation and management of potential crises". ISRO (India), and NOAA (USA) also participate in the Charter. Since the Charter became operational on November 1st 2000, authorised civil defence organisations may enlist support from space by calling a telephone number, 24 hours a day, 365 days a year. Rescue and civil defence bodies of the country to which the participating agencies belong are registered authorised

users. Civil protection authorities of other countries may also submit requests by contacting their sister organisations through existing co-operation mechanisms.

<http://www.disasterscharter.org>

Office of Outer Space Affairs, Committee on Peaceful Uses of Outer Space: The COPUOS Programme on Space Applications (PSA) works to improve the use of space science and technology for the economic and social development of all nations, in particular developing countries. Under the Programme, the Office conducts training courses, workshops, seminars and other activities on applications such as disaster management. The PSA, working closely with DMSG and the Charter, is focusing on defining and transferring technology-based solutions by holding Regional Workshops on the Use of Space Technology for Disaster Management.

Future challenges

There are a number of obstacles to the increased use of Earth observation satellite data in disaster management applications – both institutional and technical. Institutionally, it is recognised that there must be greater co-operation between satellite-operating agencies, between these agencies and the commercial sector, and between all data providers and the disaster management community. This co-operation is essential if we are to achieve the scale, frequency of measurements, and speed of response, which are required to face diverse and time-critical disasters.

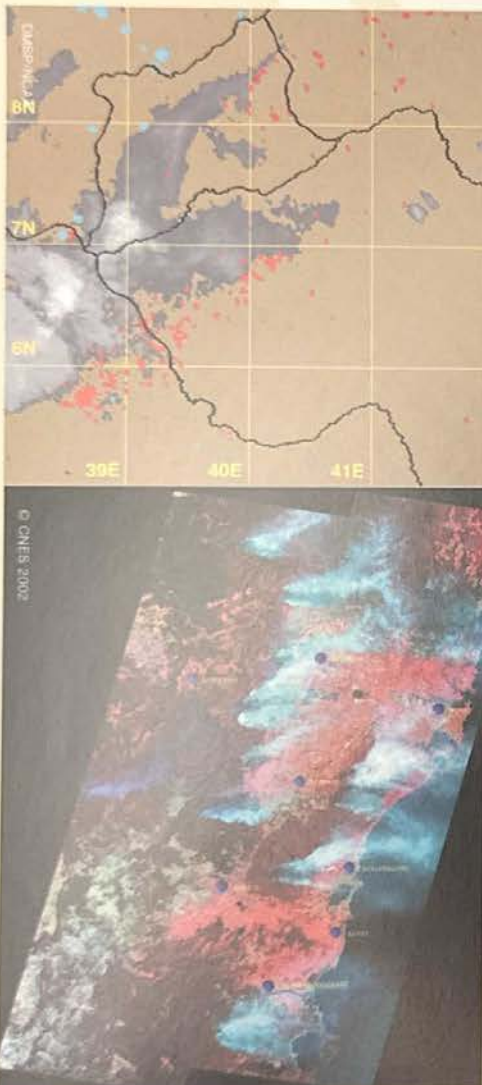
There is a general reluctance among the disaster management community to assimilate new technologies and information quickly, due to concern for introducing new, unproven technology into operational programs, and due to the lack of products and services tailored to their needs. In order to promote wider acceptance and use of space systems by disaster management users, the space and services communities must create the appropriate tools and continue to promote a mutual understanding and dialogue between the disaster management and space sectors.

Technically, we can expect to see future efforts aiming at

5 Case studies – Managing natural disasters

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

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



Fighting fire with fire information

The Global Fire Monitoring Center (GFMC) was established in Freiburg, Germany in 1998 to serve as an international co-ordination centre for the provision of near-real time and archived information on forest fires, land-use fires, and smoke pollution at a global level. This information is provided to decision makers at national and international levels in support of the evaluation of fire situations or precursors of fire which potentially endanger humans or may negatively affect the environment.

The GFMC serves as an operational global portal to facilitate rapid access to a range of fire imagery and data collected from Earth observation satellites. This information has been used effectively by fire fighting teams in many of the major international fire disasters of recent years, including the bush fires near Sydney, Australia in early 2002, and the fires in the mountain forests of Ethiopia in February – April 2000. In the latter case, the use of AVHRR and DMSP satellite imagery helped to develop support for the assembly of a significant multinational fire-fighting team and to plan their response.

Sample images from DMSP (Ethiopia) and SPOT (Australia) used to target fire-fighting efforts.

All about Natural Disasters: www.natural-disasters.com

UN International Strategy for Disaster Reduction:
www.unisdr.org/

CEOS DMSG Information Server: disaster.ceos.org/

GFMC: www.ruf.uni-freiburg.de/fireglobe/

ARTEMIS: metart.fao.org/default.htm

FEWS: www.fews.net/

Volcanic Ash Alerts: www.ssd.noaa.gov/VAAC/gen-info.html

Norwegian Oil Spill Surveillance System:
www.tss.no/services/

Part III: Earth observation
satellite capabilities
& plans



6 Capabilities of Earth observation satellites

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

CEOS agencies are operating or planning more than 150 satellites with an Earth observation mission over the next 15 years. These satellites will carry over 300 different instruments.

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

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

In reality, only 60, or around 40% of the 150 missions planned for the next 15 years, could be described as having meteorology as a primary objective. The other 90 missions will be applied to a diverse range of research, operational and commercial activities. Given the significance of the issues, and the unique role of satellite Earth observations, many will be dedicated to different aspects of climate or environmental studies. Others will be employed to assist decision-making in strategic planning and management of industrial, economic, and natural resources, including the provision of information required for sustainable development strategies.

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

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

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

Instrument categories

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

Plans for future missions and instruments include entirely new types of measurement technology, such as cloud radars, lidars, and polarimetric sensors providing new insights into key parameters of soil moisture and ocean salinity. Several new gravity field missions aimed at more precise determination of the marine geoid are also planned. Importantly, every effort is being made to assure continuity of existing key measurements – for the generation of long-term datasets.

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

Atmospheric chemistry instruments

Description

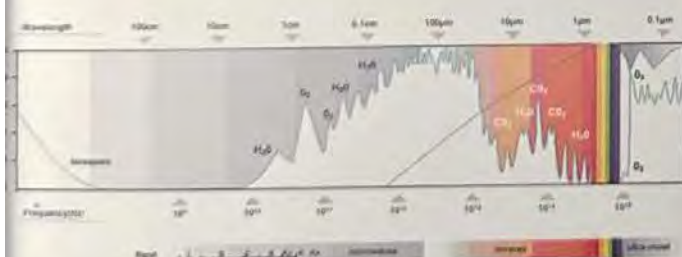
'Atmospheric chemistry instruments' is used here to describe a range of different types of instruments using various techniques, and different parts of the electromagnetic spectrum, to undertake measurements of composition of the atmosphere. Each atmospheric gas is characterised by its 'absorption' and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

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

These instruments are typically operated in either:

- nadir-viewing mode: looking directly down to measure the radiation emitted or scattered in a small solid angle centred around a measurement point on the Earth - with resulting high spatial resolution in the horizontal direction, but limited vertical resolution; or
- limb-viewing mode: scanning of positions beyond the horizon to observe paths through the atmosphere at a range of altitudes - providing high vertical resolution (few km) and limited horizontal resolution (10's of kms) - and particularly useful for studying the middle atmosphere.

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



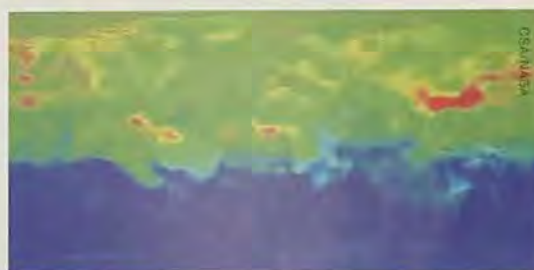
Atmospheric transmittance and radiance for UV to IR regions.

Applications

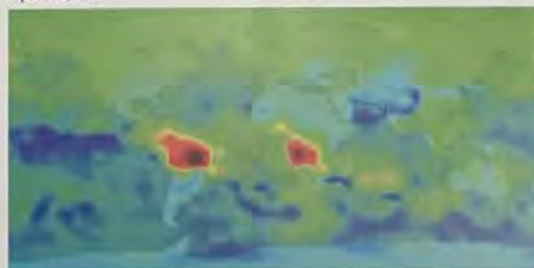
The earliest atmospheric chemistry instruments were deployed to help international understanding of stratospheric ozone depletion, and succeeded in producing startling and convincing evidence of the growth of the Antarctic ozone hole. Many of the current and planned instruments continue to provide more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

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

The trend towards improved measurement resolutions, profiling measurements (rather than total column measurements), and extended capability in the lower atmosphere will further extend the value of these instruments in the coming years for monitoring air quality and modeling atmospheric processes.



April 30, 2000



October 30, 2000

First Global Carbon Monoxide (Air Pollution) Measurements produced by MOPITT on NASA's Terra satellite.

Instrument catalogue

ACE-FTS
APS
COALA
EPIC
GOME
GOME-2
GOMOS
HALOE
HIRDLS
HRDI
IASI
ILAS-II
MAESTRO
MASTER
MIPAS
MLS (EOS-Aura)
MOPITT
OMI
OMPS
OP
OPUS
OSIRIS
SAGE II
SAGE III
SBUV/2
SBUV/3
SCIAMACHY
SFM-2
SMR
SOFIS
SOPRANO
SWIFT
TES
TOM
TOMS
WINDII

ACE-FTS: www.ace.uwaterloo.ca/index.html

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

IASI: www.projet.cst.cnes.fr/8060/IASI/

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

TOMS: jwocky.gsfc.nasa.gov/

Atmospheric temperature and humidity sounders

Instrument catalogue

AIRS
AMSU-A
AMSU-B
ATMS
CHAMP GPS
Sounder
CMIS
CrIS
GIFTS
GRAS
HIRS/2
HIRS/3
HIRS/4
HSB *
IASI
IKFS-2
IMWAS
IR Sounder
IRAS
MASTER
MHS
MIPAS
MIRAS
MIVZA
MLS
MLS/EOS-Aural
MSU
MTVZA
MTVZA-OK
MWAS
MWS
MWR
MWR-2
PFS
RFTS
SAPHIR
SMR
Sounder
Sounder (INSAT)
SSM/T-1
SSM/T-2
SSMIS
SSU

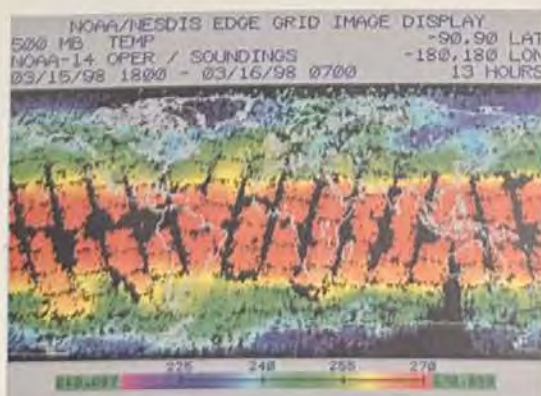
Description

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

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

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

Future sounders will feature: improved accuracy of humidity and temperature measurements (of order 10% accuracy for humidity and below 1K for temperature); better spatial resolution (to 1km); and improved capabilities in the upper atmosphere.



Atmospheric sounders provide crucial inputs to weather forecasting systems.

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

Applications

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

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



AMSU: amsu.cira.colostate.edu/

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

NWP: www.met-office.gov.uk/research/nwp/numerical/index.html

Weather forecasting: www.usatoday.com/weather/wforcast0.htm

GPS radio occultation:

op.gfz-potsdam.de/champ/docs_CHAMP/GRL_2001_wickert.pdf

Cloud profile and rain radars

Description

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

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

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

To date, there has been no cloud radar flown in space, but instruments on planned NASA (Cloudsat) and ESA/NASDA (EarthCARE) missions planned for launch in this decade will use advanced radar to 'slice' through clouds to see their vertical structure, providing a completely new observational capability from space. These instruments will be the first to study clouds on a global basis, and to look at their structure, composition and effects.



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

Applications

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

TRMM has demonstrated that spaceborne rain radars can provide a unique source of information on liquid water and precipitation rate – since the ground based rain radars used at present have limited coverage over the oceans. The global precipitation datasets derived from TRMM have proven to be valuable tools for climatologists. Information on tropical rainfall 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.

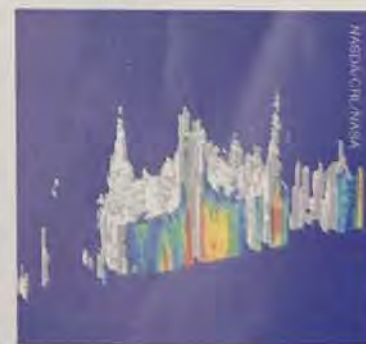


CloudSat will fly in orbital formation as part of a constellation of satellites including Aqua, Aura (multi-sensor platforms that are a part of NASA's Earth Observing System), CALIPSO (a NASA-CNES lidar satellite), and PARASOL (a CNES satellite carrying a polarimeter).

Horizontal cross section of rain at 2.00km height



3D Rain structure



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

CPR [Cloudsat]: cloudsat.atmos.colostate.edu/cs4a.html

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

EarthCARE:

www.esa.int/export/esaLP/ESA_JLJUWSC_futuremissions_0.html

TRMM: www.eorc.nasda.go.jp/TRMM/index_e.htm

Instrument catalogue

PR
CPR
CPR (Cloudsat)

Earth radiation budget radiometers

Instrument catalogue

ACRIM III
CERES
ERBE
ERBS
GERB
ISP
KGI-4C
NISTAR
PREMOS
RTER
ScaRaB/MV2
SIM
SODISM
SOLSTICE
SOVAP
SUSIM (UARS)
TIM
TSIS

Description

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

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

- broadband radiometers: to cover the full range of incoming solar radiation (0.2 – 4.0 μ m) and to monitor the long-wave emitted Earth radiation (3 – 50 μ m);
- short-wave radiometers: to measure the reflected short-wave radiation from the Earth.

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

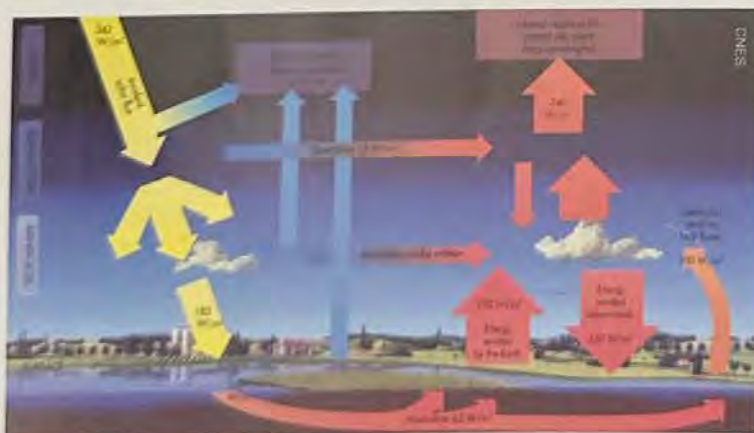
NISTAR, which will be placed in orbit at the Lagrange point L1 (the point between the Earth and the Sun at which the gravitational pull of each is cancelled out), will be the first instrument capable of providing continual observations over the key measurement angle range for the entire Earth and will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

Future geostationary satellites will measure the shortwave and longwave radiation from the Earth every 15 minutes, and will provide much needed improvements in temporal sampling.

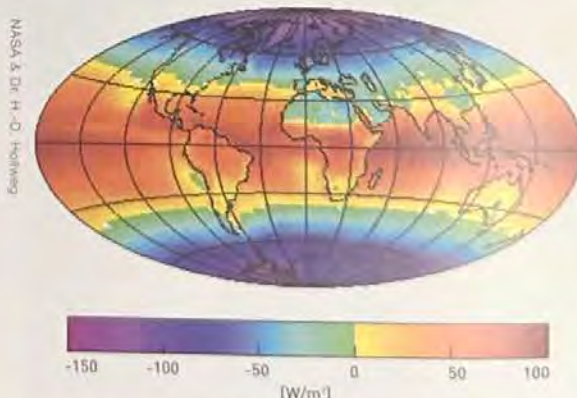
Applications

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

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



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



Sensors such as ERBE have measured the Earth's Net Radiation Budget over long periods (1985-1989 in this sample data).

NISTAR: trana.gsfc.nasa.gov/instruments/nistar.htm

Radiation budget science:

trana.gsfc.nasa.gov/instruments/radiation.htm

TIM/SIM/SOLSTICE: lasp.colorado.edu/sorce/

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

ACRIM: acrim.jpl.nasa.gov/

High resolution optical imagers

Description

High resolution optical imagers provide detailed images of the Earth's surface. In general, these are nadir-viewing instruments with a horizontal spatial resolution in the range 10 to 100m, and swath widths of order 100km. In the past few years, high resolution sensors have emerged with spatial resolution in the range 1-5m. Many of these sensors are operated as fully commercial ventures; an increasing number of government-funded sensors with sub-5m resolution are planned for the years from 2003.

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

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



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

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

Applications

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

- agriculture: definition of crop type and area, Crop inventory, yield prediction;
- natural hazards: damage assessment;
- geological mapping;
- urban planning: land cover mapping; topographic mapping; urban development monitoring;
- cartography: map generation and updating; generation of digital elevation models;
- environmental planning and monitoring.



Instrument catalogue

ALI
ASTER
AVNIR-2
AWIFS
CCD
DMC Imager
EOC
ETM+
HRG
HR-PAN
HRS
HRTC
HRVIR
Hycam
IR-MSS
LISS I
LISS II
LISS-III
LISS-IV
Multispectral high resolution scanner
MSC
MSU-E
MSU-EU
OEK DZZ WR
PAN
PAN MUX
PRISM (ALOS)
SU-UMS
SU-VR
TM
TOPSAT
telescope
VNIR
WFI



2002 FIFA Soccer World Cup main stadium in Seoul City: images from Korea's EOC sensor.

ALOS (AVNIR-2 & PRISM): alos.nasda.go.jp/index-e.html

PAN: www.eurimage.com/Products/irs.shtml

SPOT: www.spot.com/

Landsat: landsat7.usgs.gov/

CBERS: www.inpe.br/programas/cbers/english/index.html

TOPSAT:

www.qinetiq.com/industries/space/spacecraft_technology/case_study_topsat/index.asp

Imaging multi-spectral radiometers (vis/IR)

Instrument catalogue

AATSR
Atmospheric
Corrector
ATSR-2
AVHRR/2
AVHRR/3
CCD Camera
CHRIS
GLI
HSRS
HYC
Hyperion
IR camera
(SAOCOM)
IIR
Imager
Imager (INSAT)
IMAGER/MTSAT-1R
IMAGER/MTSAT-2
IVISSR (FY-2)
Klimat
MADRAS
MERIS
MMRS
MODIS
MR-2000M1
MR-900B
MSU-GS
MSU-M
MSU-MR
MSU-SK
MSU-SM
MSU-UM
MSU-V
MVIRI
MVIRS
MVISR (10
channels)
OBA
OLS
OSMI
REI
SEVIRI
SPECTRA
TIR
TRASSER
VEGETATION
VHRR
VIIRS
VIRR
VIRS
VISSR (FY-2)
VISSR (GMS-5)
WAOSS-B
WFC
WIFS

Description

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

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

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

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



Weather satellite data, such as these images from EUMETSAT and from China's FY-1B satellite, are an essential input to today's weather forecasting systems.

Applications

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

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



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

AVHRR: edcwww.cr.usgs.gov/glis/hyper/guide/avhrr

MVIRI (METEOSAT): www.eumetsat.de/en/area2/cgms/ap10-02.htm

IMAGER (GOES): noaa.nas.nasa.gov/NOAA515/ml/imager.html

MODIS: modis.gsfc.nasa.gov/

GLI: sharaku.eorc.nasda.go.jp/GLI/index.html

VEGETATION: vegetation.cnes.fr/

Imaging multi-spectral radiometers (passive microwave)

Description

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

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

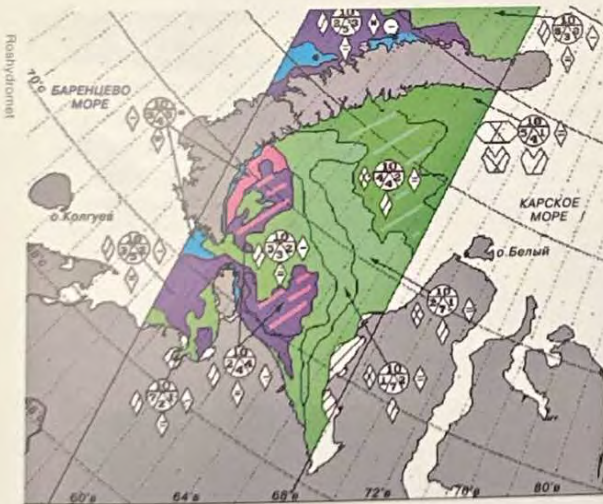
Applications

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

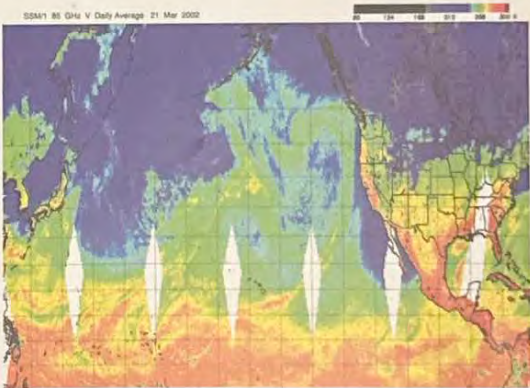
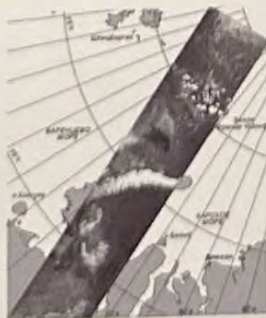
These instruments can also supply information on soil moisture content, which is a key surface parameter in agriculture, hydrology, and climatology, and provides a measure of vegetation health. They are also capable of contributing some information on ocean salinity, which is important to our understanding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

Instrument catalogue

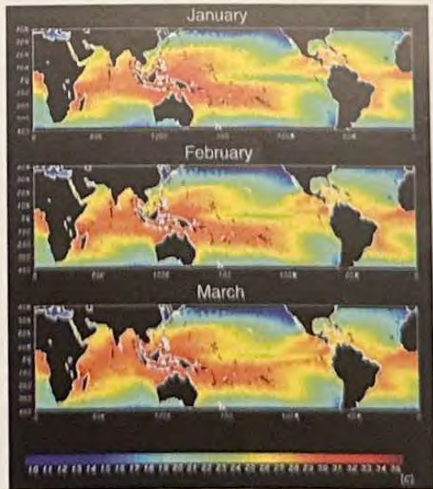
AMSR
AMSR-E
ATSR/M
CMIS
DELTA-2D
IGPM
JMR
MIRAS
MSMR
MWR
MWR-2
MWRI
R-600
RM-08
SSM/I
TMI
TMR



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



Sensors such as SSM/I provide valuable inputs to weather forecasting models.



Mean monthly sea surface temperature measurements (1999) derived from TMI on TRMM.

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

CMIS: www.ipc.noaa.gov/cmris.html

MWR: envisat.estec.esa.nl/instruments/mwr/

SSM/I: www.ngdc.noaa.gov/dmsp/descriptions/dmsp_sensors.html

Imaging microwave radars

Instrument catalogue

AMI/SAR/Image
AMI/SAR/wave
ASAR
ASAR
(image mode)
ASAR
(wave mode)
BISSAT
L-SAR
PALSAR
RLSBO
SAR
(RADARSAT)
SAR
(RADARSAT-2)
SAR (RISAT)
SAR 2000
X-Band SAR

Description

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

SARs also have the ability to penetrate vegetation and to sample surface roughness and surface dielectric properties. They may also be used to obtain polarisation information and although the operating wavelength is in general fixed for a given radar, radars operating at a variety of wavelengths are available.

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

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



Envisat's ASAR instrument is the first permanent space-based radar to incorporate dual-polarisation capabilities – which improves the capability to classify different types of terrain. This image from April 2002 shows the Russian port of Archangel and nearby seas infested with ice floes.

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

PALSAR: www.eorc.nasda.go.jp/ALOS/about/palsar.htm

RADARSAT: www.rsi.ca/index.htm

COSMO Skymed:

www.alespazio.it/program/tlr/cosmo/cosmo.htm

Applications

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

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

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

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

Several scientific activities and new applications are foreseen using bistatic SAR data.



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

Lidars

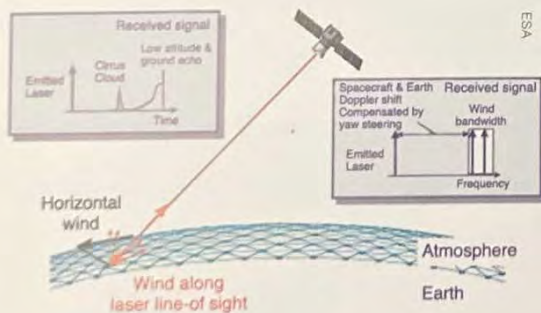
Description

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

There are a number of different types of lidar instrument:

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

The first satellite-borne lidars are expected to fly on the NASA VCL and ICESat missions within the next few years.



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

Applications

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

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

Instrument catalogue

ALADIN
ATLID
GLAS
Lidar (Calipso)
MBLA
WALES



GLAS on ICESat will provide data on ice-sheet topography from late 2002.

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

VCL: www.geog.umd.edu/vcl/

GLAS: www.csr.utexas.edu/glas/

CALIPSO: essp.gsfc.nasa.gov/calipso/

Multiple direction/polarisation instruments

Instrument catalogue

AATSR
ATSR-2
MIRAS
MISR
POLDER
POLDER-P
SPECTRA

Description

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

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

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

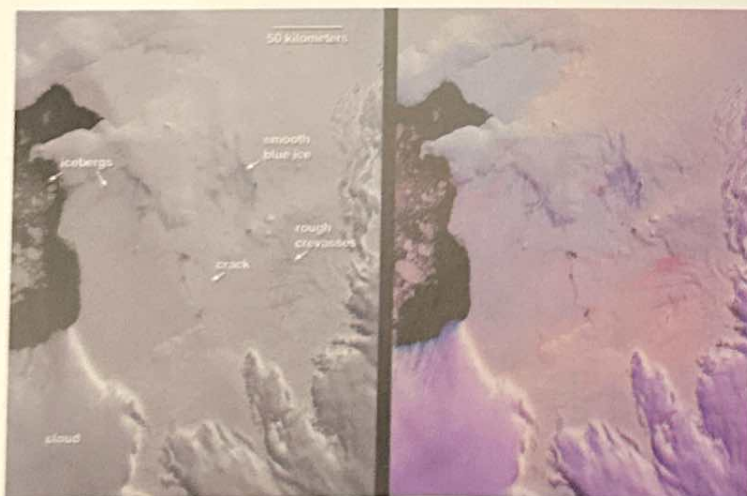
Applications

Using IR channels, multiple-angle viewing capabilities are used to achieve accurate corrections for the effects of (variable) atmospheric absorption and therefore to infer precise temperature values, for example, of sea and land

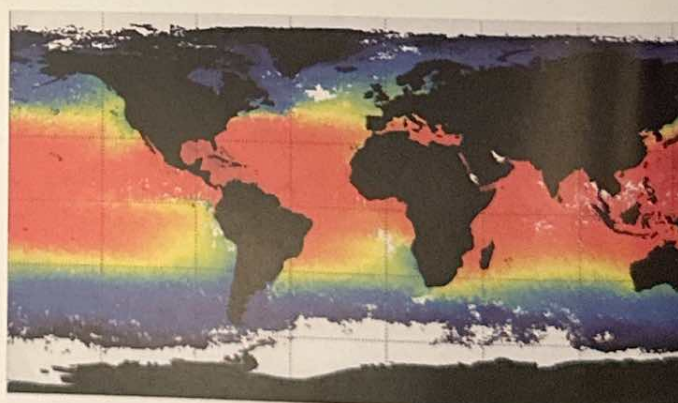
surfaces. Multi-directional radiometers are also capable of measuring cloud cover and cloud top temperature together with atmospheric water vapour and liquid water content.

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

Polarisation information is used to infer a variety of parameters, including the size and scattering properties of liquid water, cloud particles and aerosols, as well as additional information on the optical thickness and phase of clouds. Polarimetric radiometers also provide information on the polarisation state of the radiation backscattered from the Earth’s surface which supplements measurements obtained from other land and sea imaging instruments. Such measurements are of interest in a range of applications from investigations of albedo and reflectance to agriculture and the classification of vegetation. ESA’s SMOS mission planned for launch in 2005 will use a dual polarisation interferometer to measure estimates of soil moisture (a key variable for numerical weather and climate models) and ocean salinity (important for ocean circulation models).



These two MISR images of Pine Island Glacier in Antarctica revealed a 25km long crack that created a large iceberg. The views from MISR also reveal differences in the ice sheet’s surface texture, highlighting surface fractures and enabling distinction of rough crevasses from smooth blue ice. In the multi-angle composite (right) colour variations indicate differences in the angular reflectance properties of the scene – with the smoother ice appearing dark purple instead of orange.



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

MISR: www-misr.jpl.nasa.gov/

AATSR: envisat.estec.esa.nl/instruments/aatsr/

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

Ocean colour instruments

Description

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

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

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



Ocean colour data is used routinely to guide fishing fleets to biologically-rich areas.

Applications

The colour of the oceans as seen from space is an indirect measurement of ocean biomass and its associated productivity, via phytoplankton pigment concentration (chlorophyll). These parameters are of considerable oceanographic and climatological significance as oceanic productivity 'drives' the air-to-sea exchange of biogenic greenhouse gasses (eg CO₂).

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



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

Instrument catalogue

GLI
MODIS
MOS
OCM
OSMI
SeaWiFS
VIIRS
VNIR

GLI: sharaku.eorc.nasda.go.jp/GLI/

MERIS: envisat.estec.esa.nl/instruments/meris/

MODIS: modis.gsfc.nasa.gov/

OCM: www.ioccg.org/general/ocm/ocm.html

OSMI: kompsat.kari.re.kr/english/index.asp

VIIRS: www.ipo.noaa.gov/viirs.html

Radar altimeters

Instrument catalogue

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

Description

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

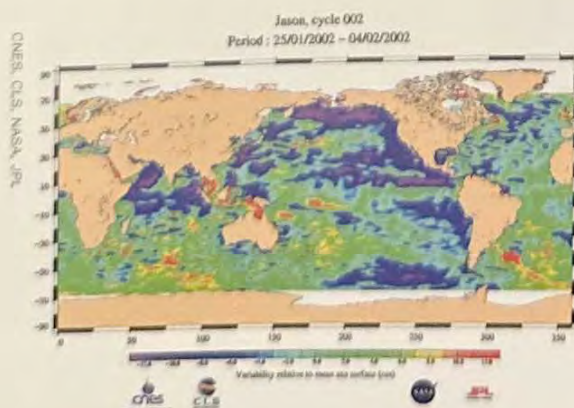
To date, most spaceborne radar altimeters have been wide-beam (pulse-limited) systems operating from low Earth orbits. Such altimeters are useful for relatively smooth surfaces such as oceans, but are ineffective over high relief continental terrain as a result of the large radar footprint.

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

- conventional pulse-limited operation for the ice sheet interiors (and oceans if desired);
- synthetic aperture operation for sea ice;
- dual-channel synthetic aperture/interferometric operation for ice sheet margins.

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

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



In January 2002, Jason-1 began to generate its first science products on its mission to monitor global climate interactions between the sea and the atmosphere - providing continuity from Topex-Poseidon.

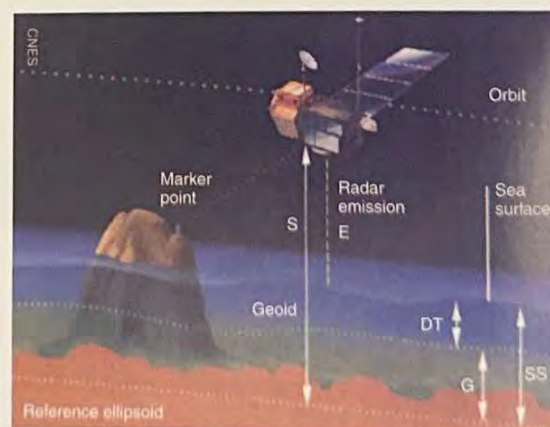
Applications

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

Future observations by radar altimeters of trends in the ice masses of the Earth are of principal importance in testing of the predicted thinning of Arctic sea ice due to global warming, and will discover the extent to which the Antarctic and Greenland ice sheets have contributed to the global rise in sea level.

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

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



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

JASON-1: sealevel.jpl.nasa.gov/mission/jason-1.html

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

RA-2: envisat.estec.esa.nl/instruments/ra2/

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

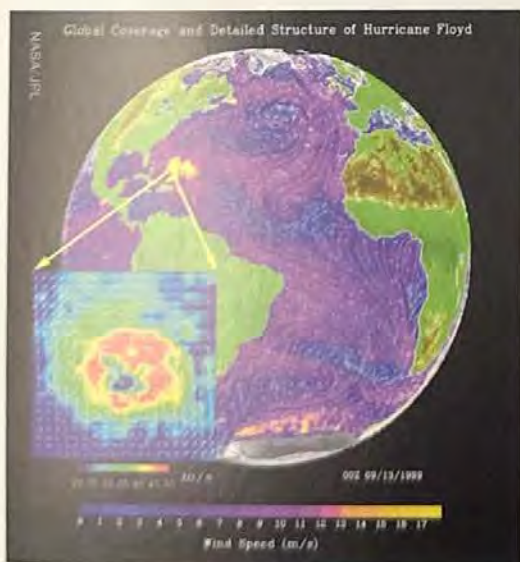
Scatterometers

Description

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

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

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



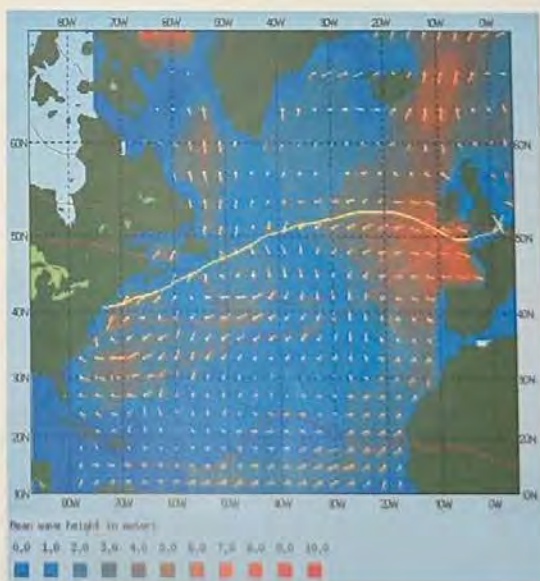
Scatterometer data can measure the horizontal wind speed and direction over sea surfaces. NSCAT data was used in September 1999 to monitor the size and movement of Hurricane Floyd.

Applications

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

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

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



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

Instrument catalogue

AMR/scatterometer
ASCAT
Scatterometer
(ISRO)
SCATTEROMETER
SeaWinds

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

AMR: earth.esa.int/ers/ers04_144

SeaWinds: winds.jpl.nasa.gov/missions/quikscat/quikindex.html

Gravity, magnetic field, and geodynamic instruments

Description

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

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

- use of single or multiple accelerometers on one or more satellites to derive gravity or gravity gradient information;
- precise satellite orbit determination (using satellite to ground navigation systems such as GPS and satellite laser ranging systems), and separation of satellite motion induced by the Earth's gravitational force alone, from other forces (such as solar radiation and aerodynamic drag);
- satellite to satellite tracking (eg by GPS or microwave link) to measure relative speed variations of two satellites induced by gravitational force.

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

Applications

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

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

- a precise marine geoid, needed for the quantitative determination, in combination with satellite altimetry, of absolute ocean currents and their transport of heat and other properties;
- a unified global height reference system for the study of topographic processes, including the evolution of ice-sheets and land-surface topography;
- new understanding of the physics of the Earth's interior;
- estimates of the thickness of the polar ice sheets and its variations - through combination of bedrock topography derived from gravity measurements and ice-sheet surface topography from altimetry;
- estimates of the mass/volume redistribution of freshwater in order to further understand the hydrological cycle;
- improved understanding of post-glacial rebound processes on a global scale.

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

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



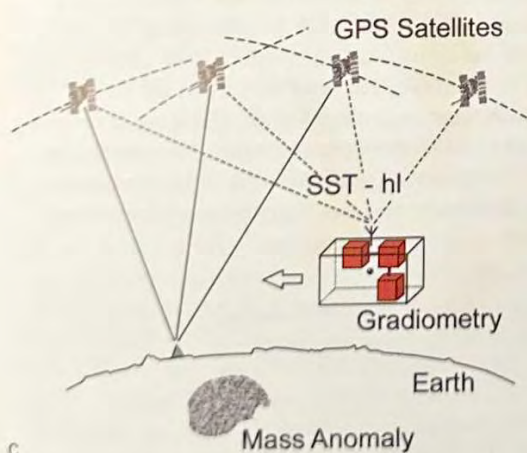
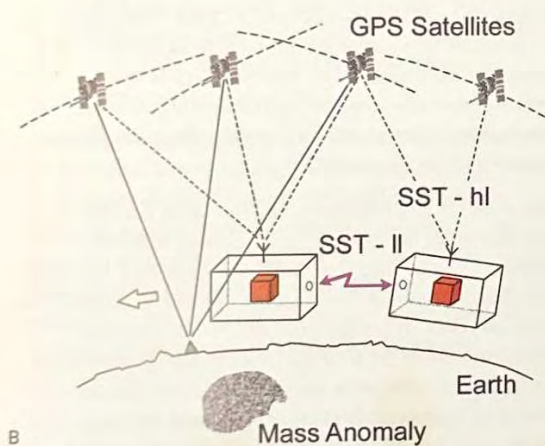
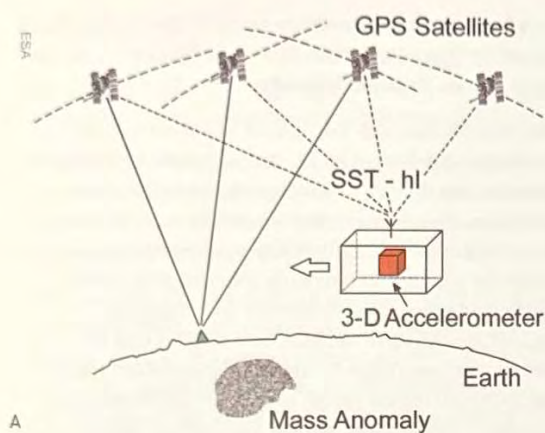
LAGEOS, CHAMP, GRACE, GOCE all provide new insights into Earth's gravity field.

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

GRACE: essp.gsfc.nasa.gov/grace/

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

FEDSAT: www.crcss.csiro.au/fedsat1.htm



Concept of satellite-to-satellite tracking in the high-low mode (SST-hl). A low Earth orbiter is tracked by the high orbiting navigation satellites, relative to a network of ground stations. Non-gravitational forces on the low orbiter are measured by accelerometry; b). Concept of satellite-to-satellite tracking in the low-low mode (SST-ll) combined with SST-hl. The relative motion between two low orbiters following each other in the same orbit at a distance of a few hundred kilometres is measured by an inter-satellite link; c). Concept of satellite gradiometry combined with SST-hl. The second-order derivative of the gravitational potential of the Earth is measured in a low orbiting satellite by differential accelerometry.

Instrument catalogue

Gravity

CHAMP gravity package
(Accelerometer+GPS)
EGG
HAIRS

Magnetic field

CHAMP magnetometry package
(1 Scalar+2 Vector Magnetometer)
EMA
Fluxgate magnetometer
IMSC
LP/ RPA
MMP
PDA
PEM
Plasma-Mag
SESS
SSJ/4
SSJ/5
SSM

Precision orbit

CHAMP GPS Sounder
DORIS
DORIS-NG
GPS
GPS receiver
GPSDR
Laser reflectors
Laser reflectors (ESA)
LRA
LRA (LAGEOS)
RRA
TRSR

7 Earth observation plans: by measurement

7.1 Introduction

In 2002, there are over 60 satellites operating (annex A) and providing important data about the Earth and its environment, helping us to develop our understanding of the basic Earth system and of human influences on it. These data cover measurements of a very wide range of geophysical parameters, spanning the whole spectrum of the environment including atmosphere, land, oceans, and ice and snow. This section considers some of the key observations contributed by EO satellites, as indicated in the table.

Measurement categories

ATMOSPHERE

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

LAND

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

OCEAN

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

SNOW AND ICE

Ice sheet topography
Snow cover, edge and depth
Sea ice cover, edge and thickness

GRAVITY AND MAGNETIC FIELDS

Gravity, magnetic and geodynamic measurements

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

The CEOS Database contains considerably more detail on the expected performance of the various CEOS agency missions and on the specifications of the requirements for certain applications and users. For example, the CEOS

Database provides information on more than 120 different geophysical measurements. See below for contact details for access to the CEOS Database.

This section identifies the satellite instruments which primarily contribute data for any particular measurement from the list above and indicates the plans for future provision of that measurement over the next 15 years. Measurement continuity is a key requirement in many areas, for example in providing confidence to sustain public and commercial investment in operational applications of Earth observation data. It is also of paramount importance for the generation of long term datasets required for global environmental programmes and for climate change studies. This section identifies the prospects for achieving that continuity given the programmes and plans that exist in 2002 – whether it may be provided by a single series of satellites dedicated to a particular measurement, or whether users of that measurement must look to various satellite missions planned by different agencies world-wide to satisfy their information requirements.

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

For CD-ROM copies of CEOS Database:
hinsman_d@gateway.wmo.ch

7.2 Overview

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

- Atmospheric chemistry measurements, including of ozone, are being provided by the NASA TOMS instrument on the TOMS Earth Probe, by CSA's MOPITT instrument on Terra, and by OSIRIS on Odin. Significant new capabilities became available in March 2002 when ESA's Envisat mission was launched with several advanced instruments;

7 Earth observation plans – by measurement

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

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

- A significant increase in information about the chemistry and dynamics of the atmosphere, including: long term global measurements of concentrations of ozone and many other trace and greenhouse gases; information on the role of clouds in climate change; the ability to better map cloud cover and precipitation – including over the oceans; measurements of 3-D atmospheric winds without the need for cloud tracking; global aerosol distributions; and extended coverage of atmospheric measurements into the troposphere to allow improved pollution monitoring. Just as significantly, existing measurement capabilities for many key parameters, such as atmospheric humidity and temperature, will have greatly improved accuracy and spatial resolution. A variety of novel instruments will be used – such as cloud and rain radars, and lidar instruments proposed for future missions;
- Improved repeat coverage, resolution, and accuracy of many oceanographic measurements, including ocean surface winds, and ocean colour and biology;
- New capabilities for determination of soil moisture and ocean salinity – starting with ESA's SMOS mission;

- New information on global land surface processes, through use of increased number of spectral bands, and multi-directional and polarisational capabilities of future imaging sensors;
- Insights into vegetation canopy structure, estimates of global biomass and carbon stocks, and estimates of mass balance of the polar ice sheets and their contributions to global sea level change – from innovative new lidar systems, including those on future ESA and NASA missions;
- Improved measurements of global ocean currents, based on data from altimeters and gravity field instruments – such as GRACE and GOCE.

We can expect the exact plans to change as space agency programmes evolve to keep pace with accepted scientific and political priorities for information on the Earth system.

7.3 Measurement timelines

For each measurement category listed in section 7.1, a brief discussion is given below of the significance of that measurement, together with an indication of the present and future measurement capabilities of satellite observations. This description is supported by two timeline diagrams spanning the period 2002–2018, indicating the instruments contributing to that measurement and the missions on which they are expected to fly.

The first timeline shows missions that are either:

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

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

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

Of course, all missions have a degree of uncertainty. This description of mission status reflects information available from the relevant agencies at the time of compilation. If the month of the launch of a planned mission has not been specified the timeline is shown to commence at the beginning of the planned year of launch. Note also that missions currently operating beyond their planned life are shown as operational until the end of 2002 unless an alternative date has been proposed.

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

Atmosphere

Aerosols

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

The IPCC identifies further information on aerosols as a priority requirement and highlights a particular need for additional systematic, integrated and sustained observations, including observations of the spatial distribution of greenhouse gases and aerosols. The Integrated Global Atmospheric Chemistry Observations (IGACO) Theme of the IGOS Partnership will aim to provide a framework ensuring continuity and spatial comprehensiveness of the full spectrum of atmospheric chemistry observations, including the monitoring of atmospheric composition parameters related to climate change and environmental conditions. A first report from the IGACO Team is scheduled for the end of 2002.

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

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

Measurements over land are difficult (due to both persistent cloud cover and to the high value, and variability, of land surface reflectance) but the new generation of multi-directional or polarimetric instruments – such as AATSR, MISR and APS (planned) – can provide detailed information. Today, MODIS, MERIS and MISR offer better optical depth at different frequencies from which aerosol particle sizes, particularly over oceans, may be inferred. The development of active instruments such as ATLID, and laser altimeter sensors, including GLAS, should yield much improved measurement capability. In 2004, CALIPSO will fly a 3 channel lidar and passive instruments in formation with Aqua and CloudSat to obtain coincident observations of radiative fluxes and atmospheric state. This comprehensive set of measurements is essential for accurate quantification of global aerosol and cloud radiative effects.

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

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

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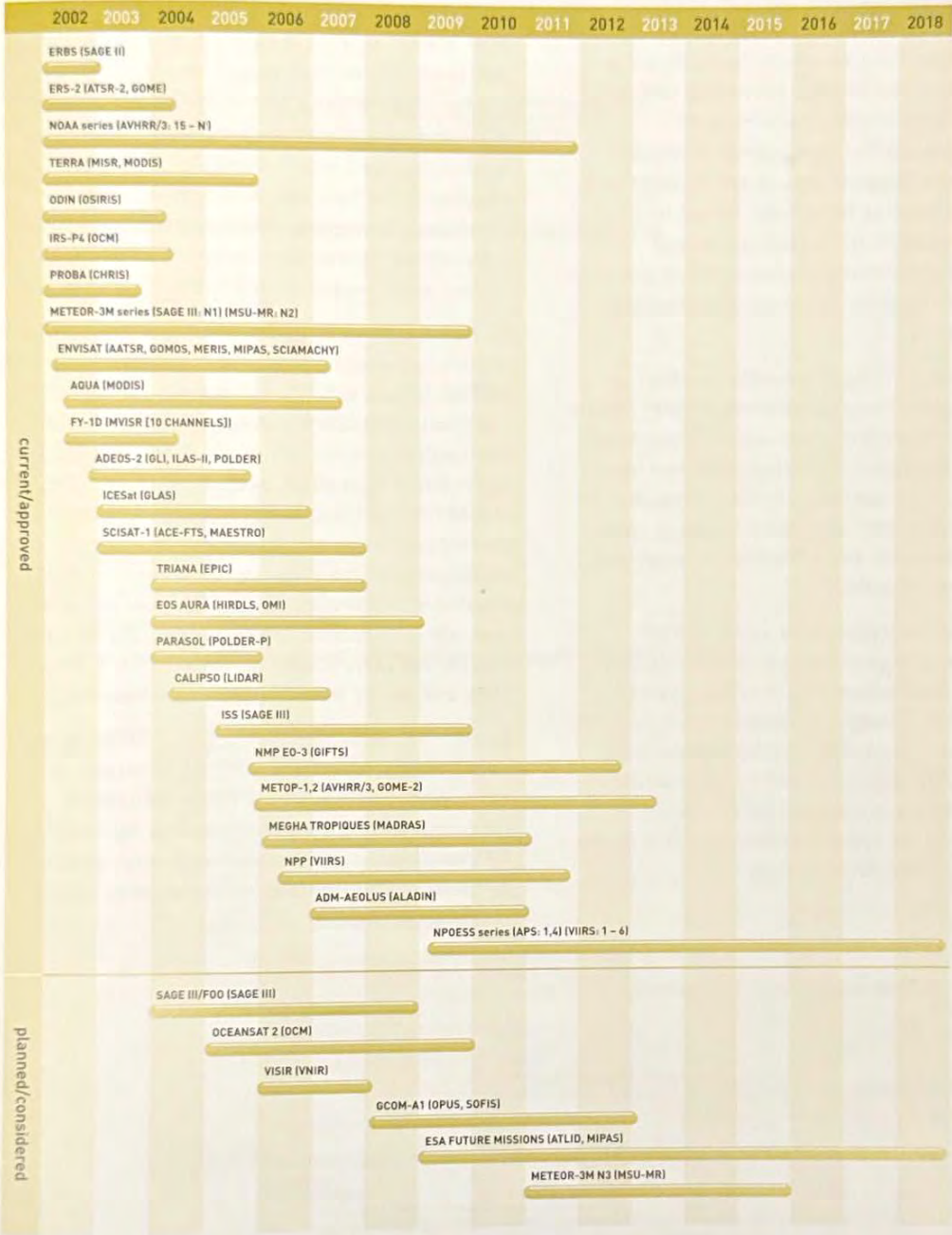
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7 Earth observation plans – by measurement

Aerosols



Atmosphere



Atmospheric humidity

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

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

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

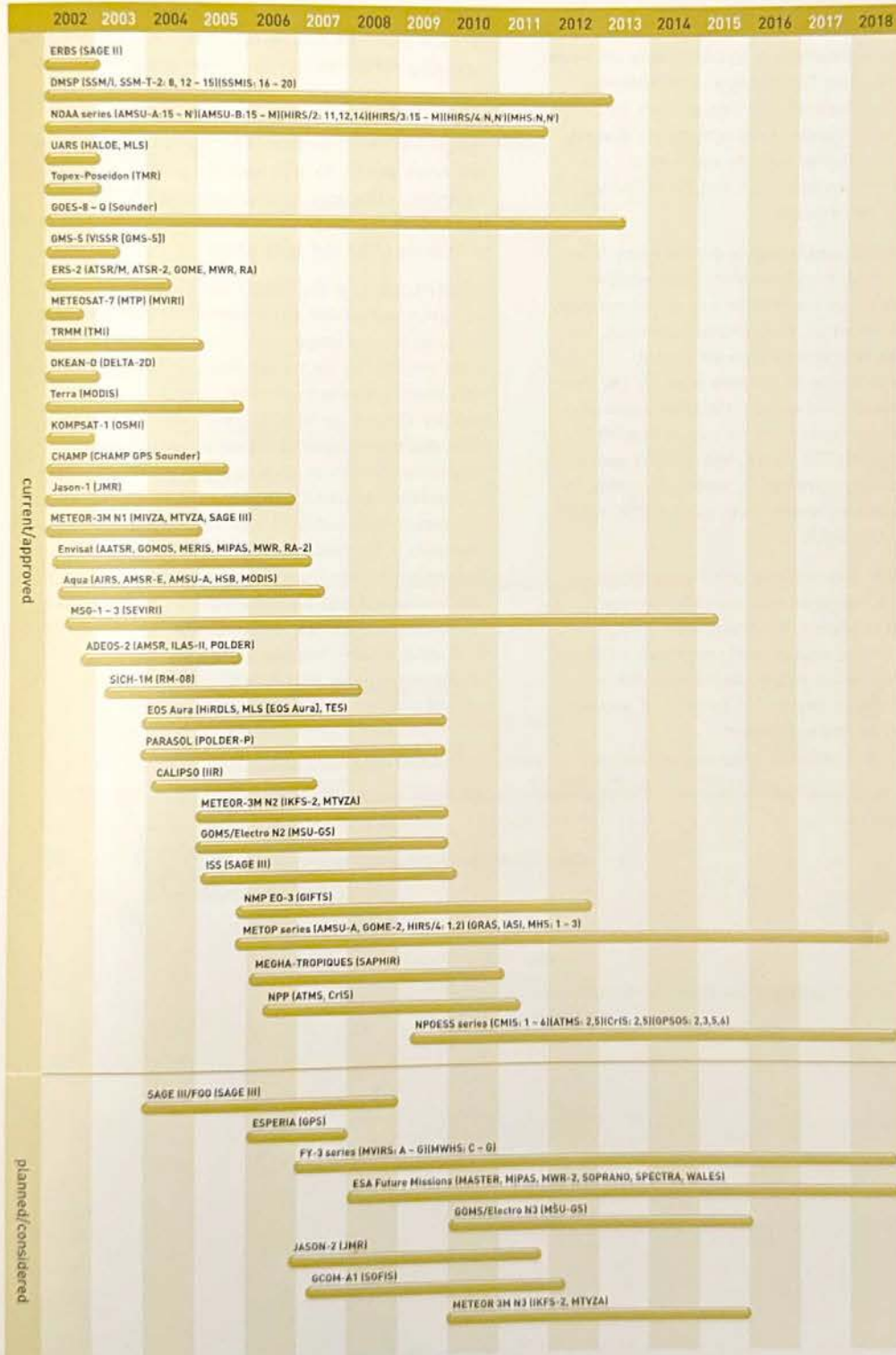
Until recently, performance in cloudy areas was poor, but the new microwave measurements from AMSU offer substantial improvements. Geostationary infrared soundings are also helping to expand coverage in some regions by making measurements on repeat timescales of fifteen minutes to one hour and thus creating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

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

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

7 Earth observation plans – by measurement

Atmospheric humidity



Atmosphere



Atmospheric temperature

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

Data on atmospheric temperature is derived partly from satellite observations. For global NWP, polar satellites provide information on temperature with global coverage, good horizontal resolution and acceptable accuracy, but improvements in vertical resolution are needed.

Performance in cloudy areas has been poor, but the new microwave measurements such as AMSU have provided substantial improvements. As in the case of humidity profiles, the Aqua, METOP, NOAA, and NPOESS missions offer comparable improvements in vertical resolution for measuring atmospheric temperature (using AIRS+, AMSU-A, CrIS, HIRS, IASI, MSU).

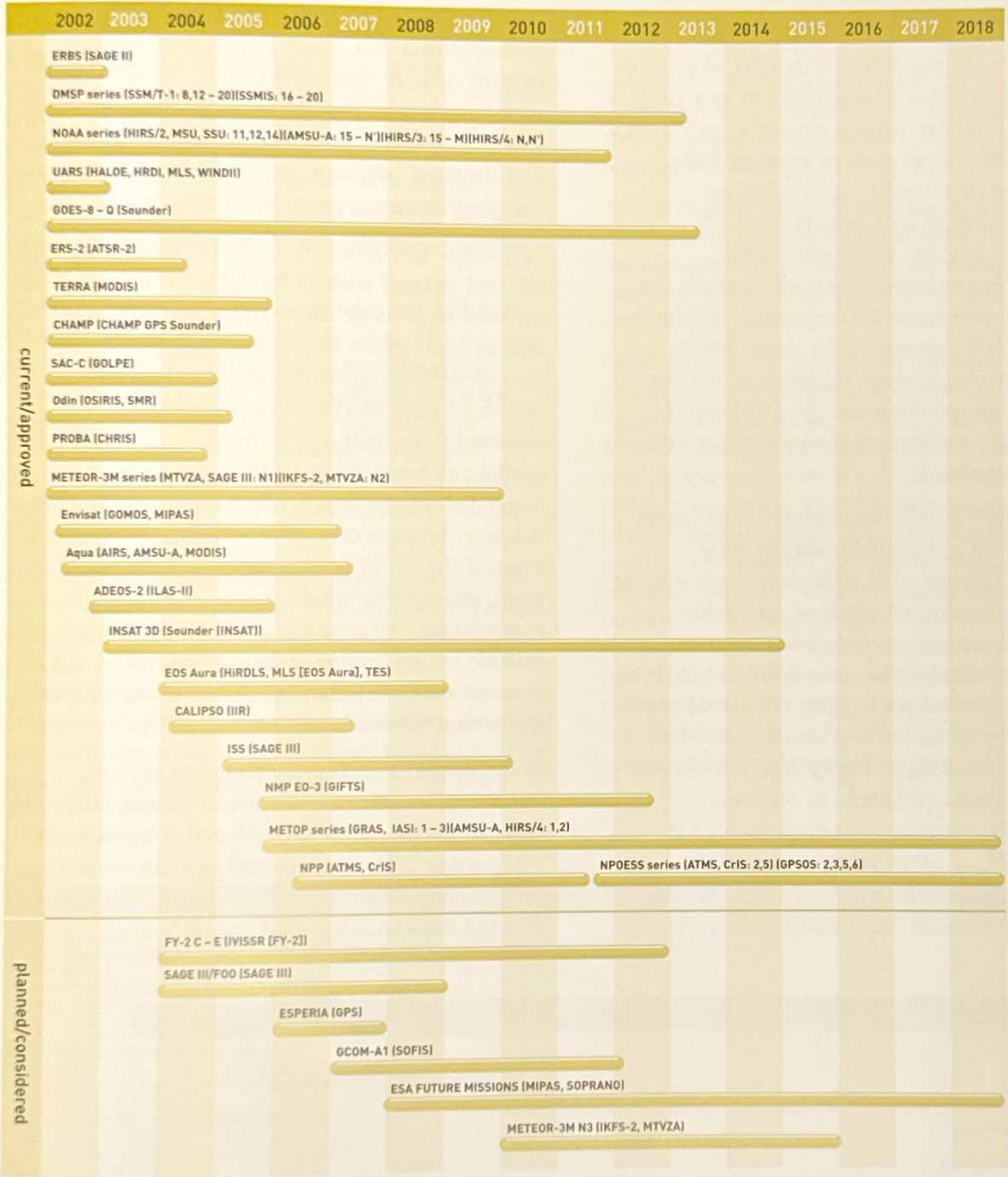
For regional NWP, polar orbiting satellites provide information on temperature with acceptable accuracy and good horizontal resolution, but with marginal temporal frequency and vertical resolution for mesoscale prediction. Advanced radiometers or interferometers planned for future satellites should improve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

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

The combination of the HIRS/3 and AMSU instruments on the NOAA and METOP series allows improved information, sufficient to infer temperature within several thick layers in the vertical. On the METOP series, IASI will also be used with other instruments to deliver comparable sounding capacity. CrIS on the NPOESS series, which will replace HIRS, is designed to enable retrievals of atmospheric temperature profiles at 1K accuracy for 1km layers in the troposphere. The GRAS instrument on METOP will provide temperature information of high accuracy and vertical resolution in the stratosphere and upper troposphere (helping to improve analyses around the tropopause). Its information will thus be complementary to that provided by the passive sounding instruments on METOP. China's FY-2 series of satellites, will feature improved measurements from 2003 with the addition of new spectral channels to their IVISSR instrument.

7 Earth observation plans – by measurement

Atmospheric temperature



Atmosphere



Atmospheric winds

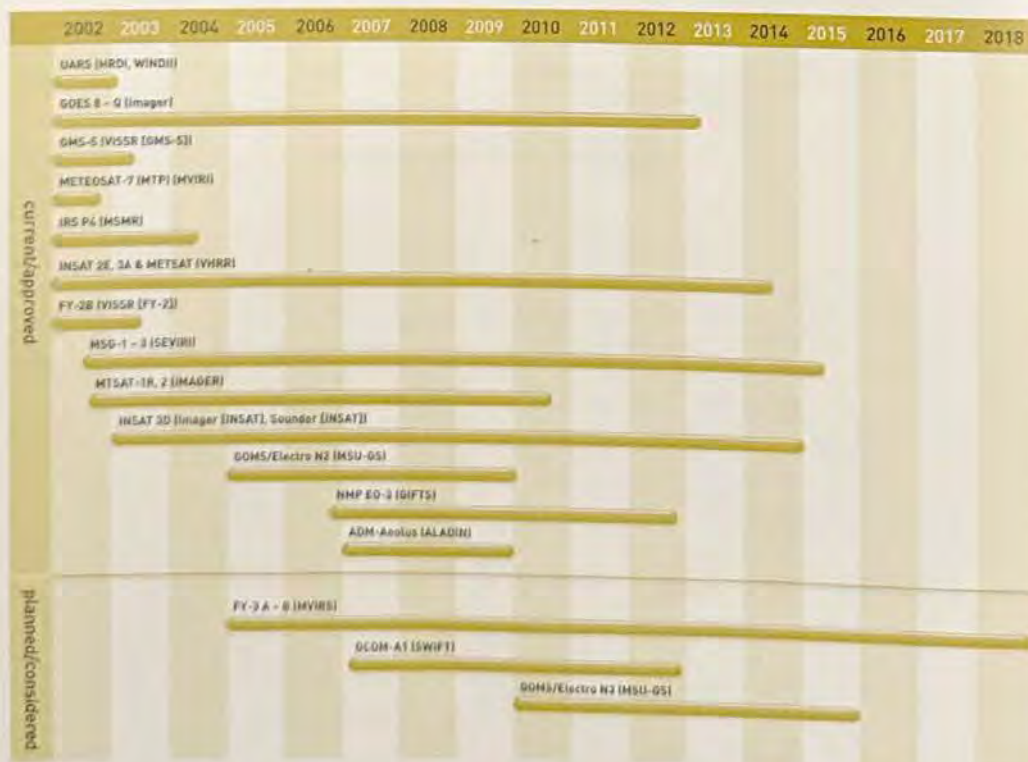
Measurements of atmospheric winds are of primary importance to weather forecasting, and as a variable in the study of global climate change as well as in a number of applications such as aviation flight planning. Horizontal wind may be inferred by motion vectors or by humidity tracers in geostationary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

For global NWP models, wind profile information – mostly overland – is available mainly from radiosondes. Doppler wind lidar technology is being developed to provide 3D winds of acceptable coverage and vertical resolution, but there are significant technical problems and thick cloud is a limitation. Geostationary imagers offer wind profile information by cloud tracking and in cloud-free areas through tracking of highly-resolved features in the water vapour channels. In the lower atmosphere, coverage may be supplemented in future by tracking ozone features in satellite imagery. Regional NWP models also rely heavily on radiosondes (overland) and aircraft (over ocean and

over the poles) for atmospheric wind profile measurements, but would benefit from improved satellite data. In nowcasting, single level satellite wind information is sufficiently available over low and mid-latitudes to provide acceptable horizontal and temporal coverage, but vertical coverage is marginal and accuracy is acceptable to marginal.

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

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



7 Earth observation plans – by measurement

Cloud particle properties and profile

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

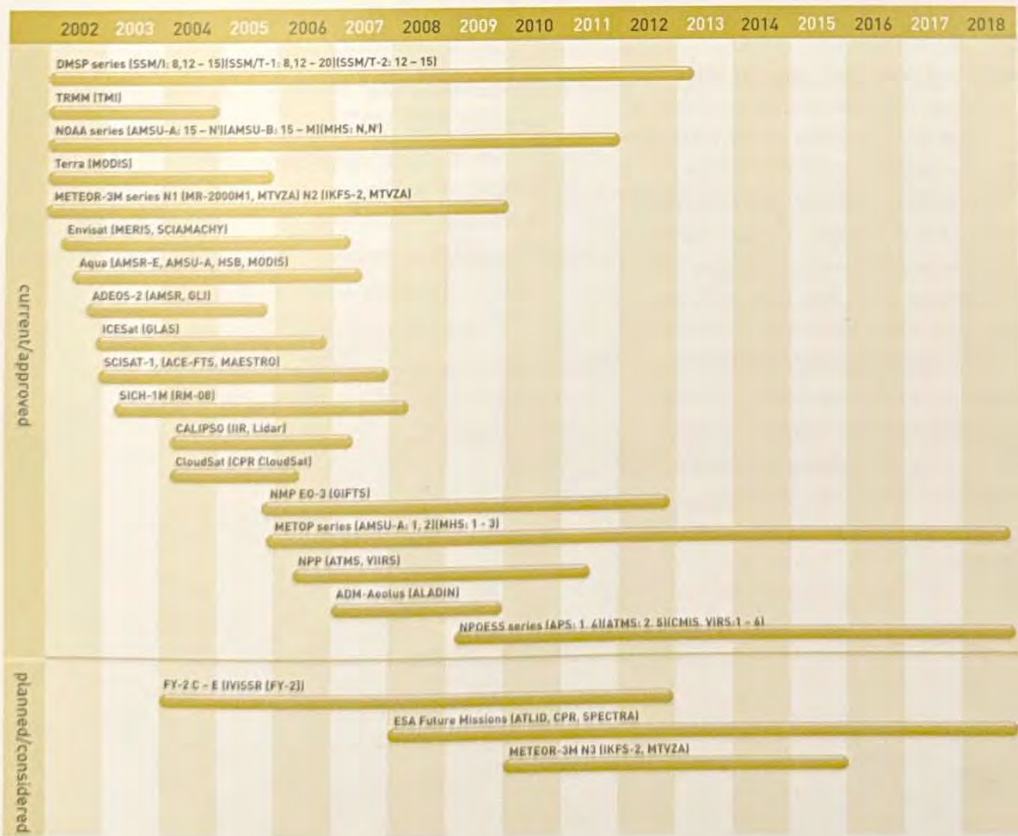
Because clouds change rapidly over short time and space intervals, they are difficult to quantify. Full 3-D observations of cloud structure from space are still in development, with the first sensors expected with a few years on NASA (CloudSat) and ESA missions. These missions will be capable of measuring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

Currently, basic information on the structure of clouds (ie determination of whether water or ice particles are present) is being obtained from microwave instruments such as AMSR-E, MODIS and MISR on Terra also provide observations which enable estimates of cloud droplet size to be made. These measurements are important for climate purposes as the structure of clouds (particle size and phase) greatly affects their optical properties and hence

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

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

In a fine example of international co-operation, from 2006 a multiple satellite constellation comprising CloudSat, Aqua, Aura, CALIPSO and PARASOL will fly in orbital formation with the goal of gathering data needed to evaluate and improve the way clouds are represented in global models, and to develop a more complete knowledge of their poorly understood role in climate change and the cloud-climate feedback. CloudSat will maintain a tight formation with CALIPSO, with a goal of overlapping measurement footprints at least 50% of the time. CALIPSO will carry a dual-wavelength polarisation-sensitive lidar that provides high resolution vertical profiles of aerosols and clouds. CloudSat and CALIPSO will maintain a somewhat looser formation behind Aqua – which carries a variety of passive microwave, infrared, and optical instruments.



Atmosphere



Cloud type, amount and cloud top temperature

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

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

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

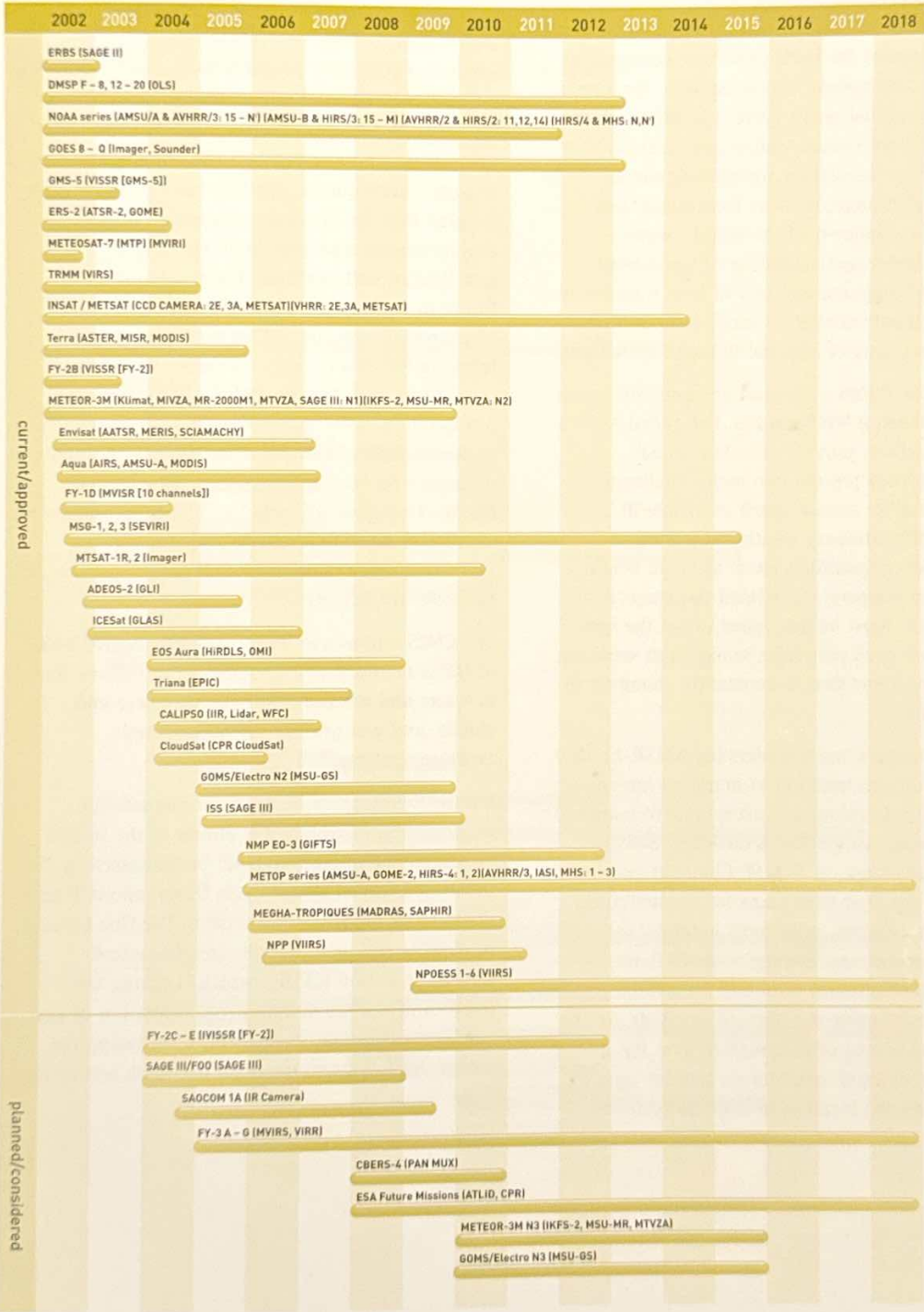
In the field of climate research, the MODIS and MISR spectro-radiometers on the Terra mission are enabling viewing of cloud features at higher resolutions than previously. MODIS is taking measurements to allow more precise determination of the contribution which clouds make to the 'greenhouse' warming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

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

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

7 Earth observation plans – by measurement

Cloud type, amount and cloud top temperature



Atmosphere



Liquid water and precipitation rate

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

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

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

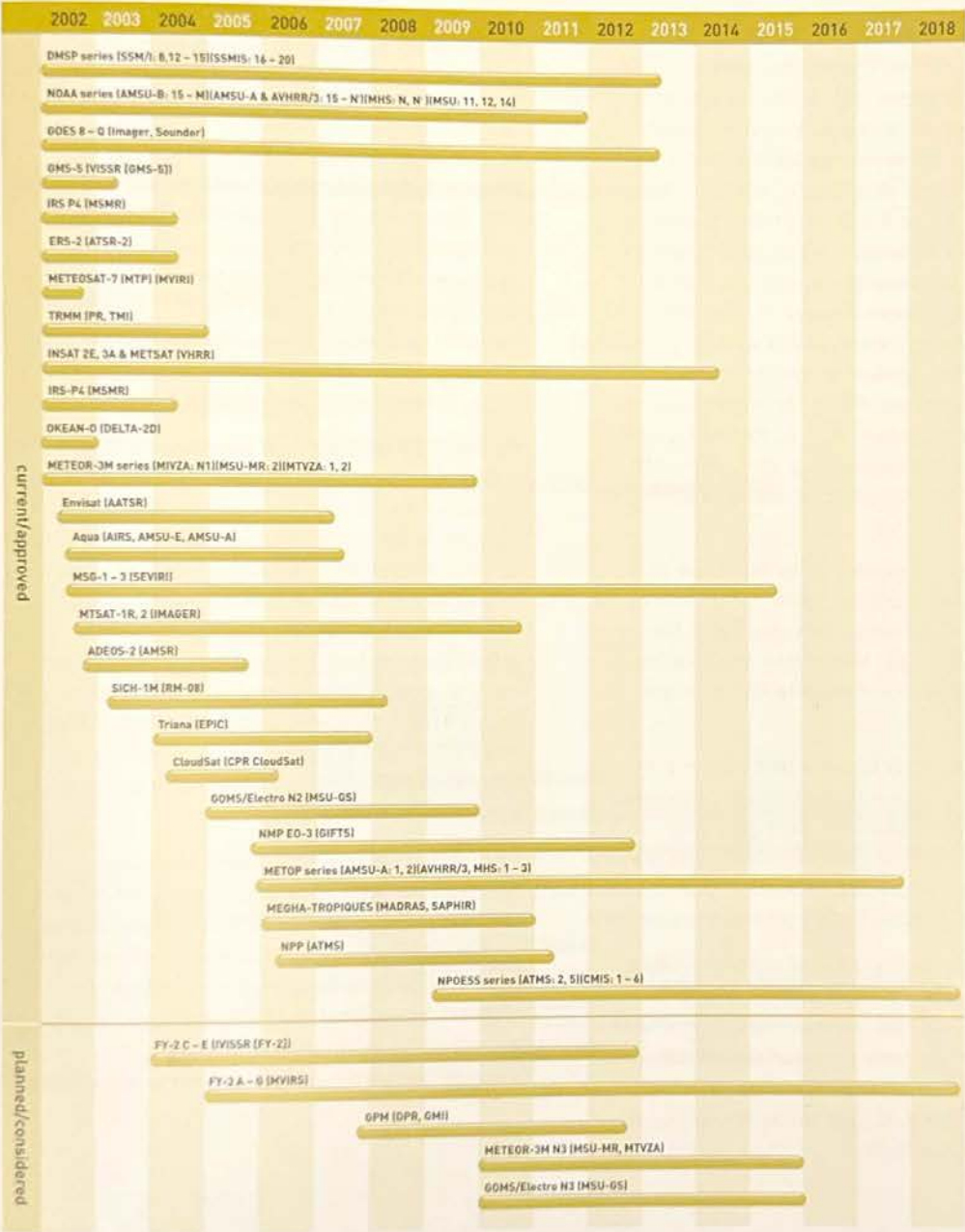
Increasing amounts of useful microwave data – such as from the TRMM mission – are becoming available. TRMM is dedicated to studying tropical and sub-tropical rainfall and carries the first spaceborne precipitation radar, NASDA's PR instrument, and also NASA's TMI microwave imager. Data from PR and TMI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

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

Future coordination of these various satellite programmes, as well as the efforts of the in-situ measurement community, will be addressed by the Integrated Global Water Cycle Observations Theme (IGWCO) of the IGOS Partnership. The first element of IGWCO will be a 'Coordinated Enhanced Observing Period (CEOP)' which is taking the opportunity of the simultaneous operation of key satellites of Europe, Japan, and USA during the period 2001–2004 to generate new data sets of the water cycle.

7 Earth observation plans – by measurement

Liquid water and precipitation rate



Atmosphere

Ozone

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

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

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

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

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

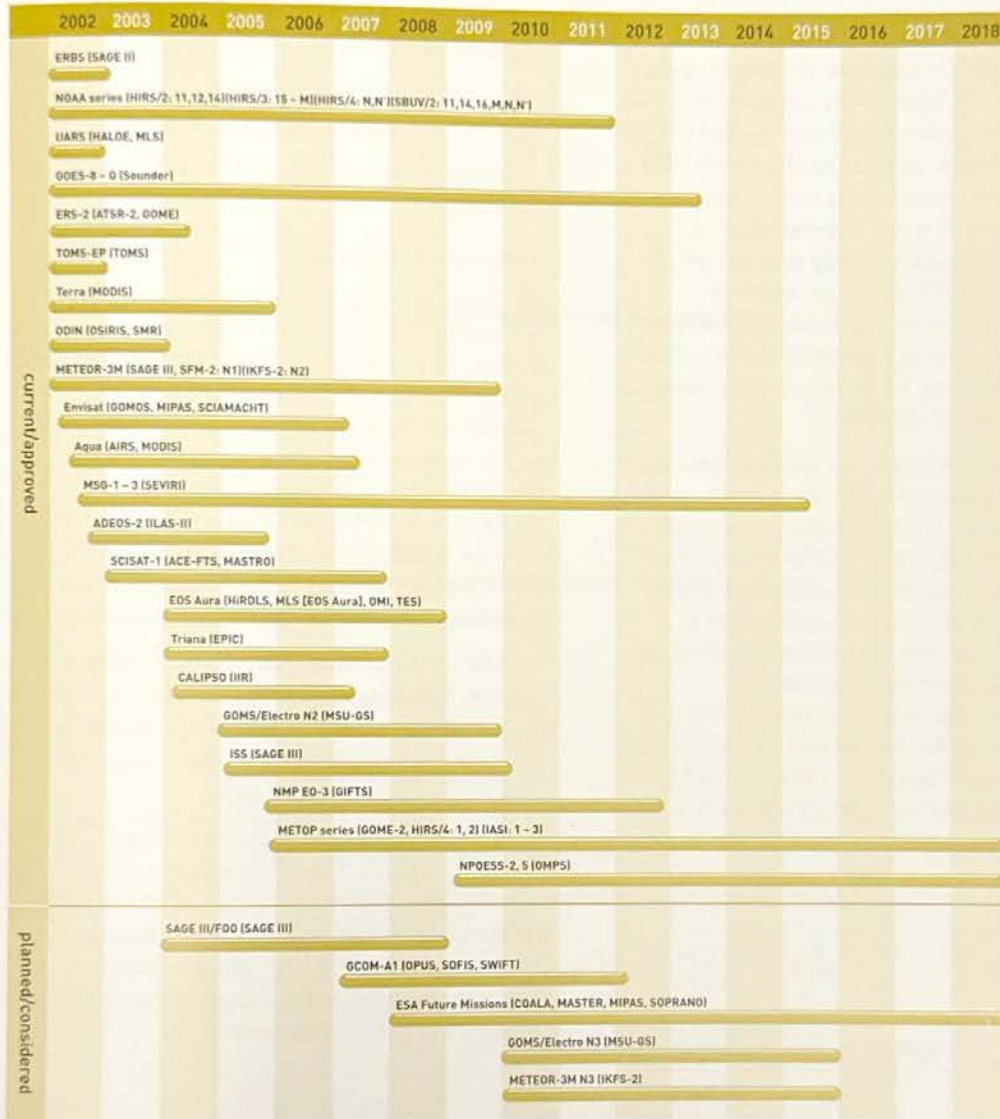
A wide range of instruments dedicated to, or capable of, ozone measurements are planned for the next decade. On the Aura mission, HIRDLS, OMI, and MLS will study and monitor atmospheric processes which govern stratospheric and mesospheric ozone, and will continue the TOMS record of total ozone measurements.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

On NASDA's GCOM-A1 mission, the OPUS and SOFIS instruments will observe trace gases such as ozone and CFCs; ILAS-II on ADEOS II will monitor changes in the stratosphere triggered by emissions of CFCs and measure the vertical profiles of species related to ozone depletion phenomena. IASI and GOME-2 on the METOP series will provide information on both total column ozone and on vertical profile. In the longer term (from 2011), NOAA's Ozone Mapping and Profiler Suite (OMPS) will collect data to permit the calculation of the vertical and horizontal distribution of ozone in the atmosphere.

The IGOS theme on atmospheric chemistry observations (IGACO) will build upon the report of the CEOS Ozone 'Pathfinder' Project and develop a strategy for the integrated provision of chemistry observations (and associated meteorological parameters) required to realise the theme objectives, including the monitoring of atmospheric composition parameters related to climate change.

7 Earth observation plans – by measurement

Ozone



Atmosphere



Radiation budget

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

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

In general, three types of measurements are currently possible:

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

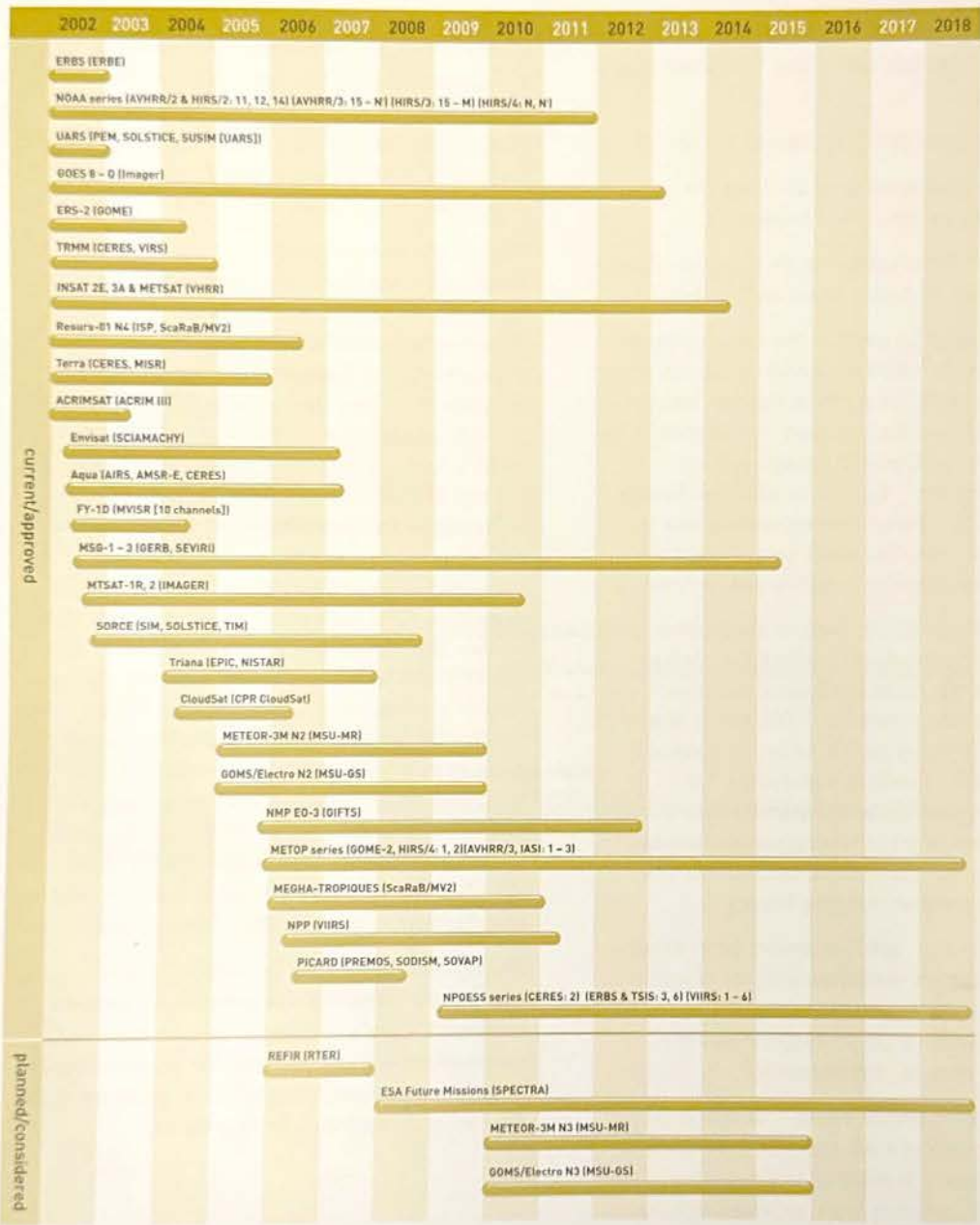
NASA has for some time been measuring the net radiation with the ERBE, ACRIM, and CERES sensors. The MISR spectroradiometer (also on Terra with CERES) provides data on top of the atmosphere, cloud and surface hemispheric albedos and aerosol opacity. Continuity of Total Solar Irradiance (TSI) measurements is assured in future by the launch of the SORCE mission in late 2002, carrying 4 instruments (TIM, SOLSTICS, SIM, XPS) operating over the 1nm-2000nm waveband and measuring over 95% of spectral contribution to TSI.

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

An increasing number of radiation budget measurements will feature on operational meteorology missions, including: GERB (on MSG, measuring shortwave and longwave radiation every 15 minutes); TSIS and ERBS (on NPOESS); continued narrow-band information from the HIRS, AVHRR, and VIIRS instruments.

7 Earth observation plans – by measurement

Radiation budget



Atmosphere



Trace gases (excluding ozone)

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

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

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

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

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

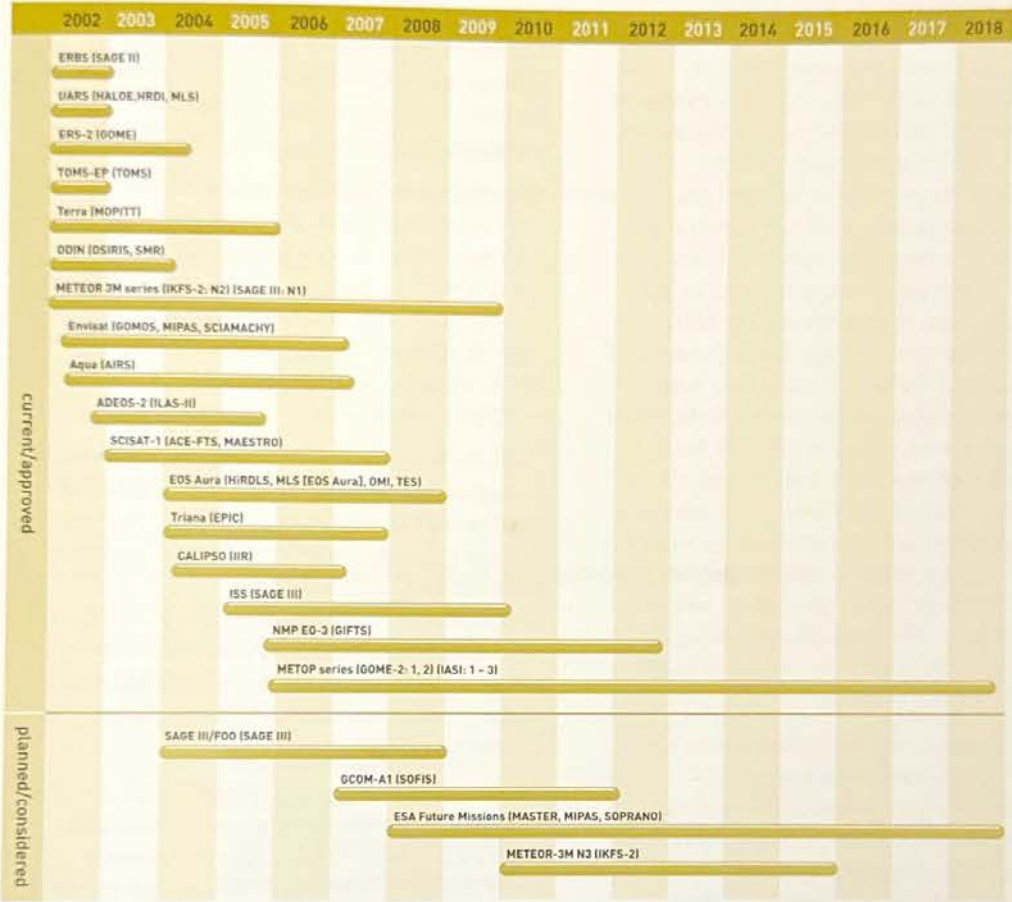
A variety of instruments provide measurements on the concentration of trace gases. In general, high spectral resolution is required to detect absorption, emission and scattering from individual species. Some instruments offer measurements of column totals, ie integrated column measurements, whilst others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

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

The last few years have seen the arrival of new and significant capabilities, with advanced instruments on Terra (MOPITT – providing global measurements of carbon monoxide and methane in the troposphere), and Envisat (GOMOS, MIPAS, SCIAMACHY – providing profiles of trace gases through the stratosphere and troposphere). On NASA's Aura mission (from 2004) HIRDLS, an infrared limb-scanning radiometer, will carry out soundings of the upper troposphere, stratosphere and mesosphere to determine concentrations of trace gases, with horizontal and vertical resolutions superior to those previously obtained. On the same mission MLS will measure concentrations of trace gases for their effects on ozone depletion, TES will provide a primary input to a database of 3D distribution on global, regional and local scales of gases important to tropospheric chemistry, and OMI will continue the TOMS record for atmospheric parameters related to ozone chemistry and climate. NASDA's GCOM-A1 mission and EUMETSAT's METOP series are also expected to make significant contributions to observations of trace gases.

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

7 Earth observation plans – by measurement



Trace gases (excluding ozone)

Land



Albedo and reflectance

Albedo is the fraction of solar energy that is reflected back from Earth to space. Measurements of albedo are essential for climate research studies and investigations of the Earth's energy budget.

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

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

Clouds, aerosols and atmospheric gases affect the accuracy achievable, which is currently marginal to acceptable, but should become good as progress is made in interpreting data from high-resolution, multi-spectral instruments. Surface conditions (moisture, surface vegetation, snow cover etc) strongly affect albedo and high quality ground truth data is necessary in support of satellite

measurements. Better understanding of the reflectance properties of different surfaces and more accurate aerosol data (to correct atmospheric effects) is needed to improve surface reflectance measurements.

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

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

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

7 Earth observation plans – by measurement



Land



Landscape topography

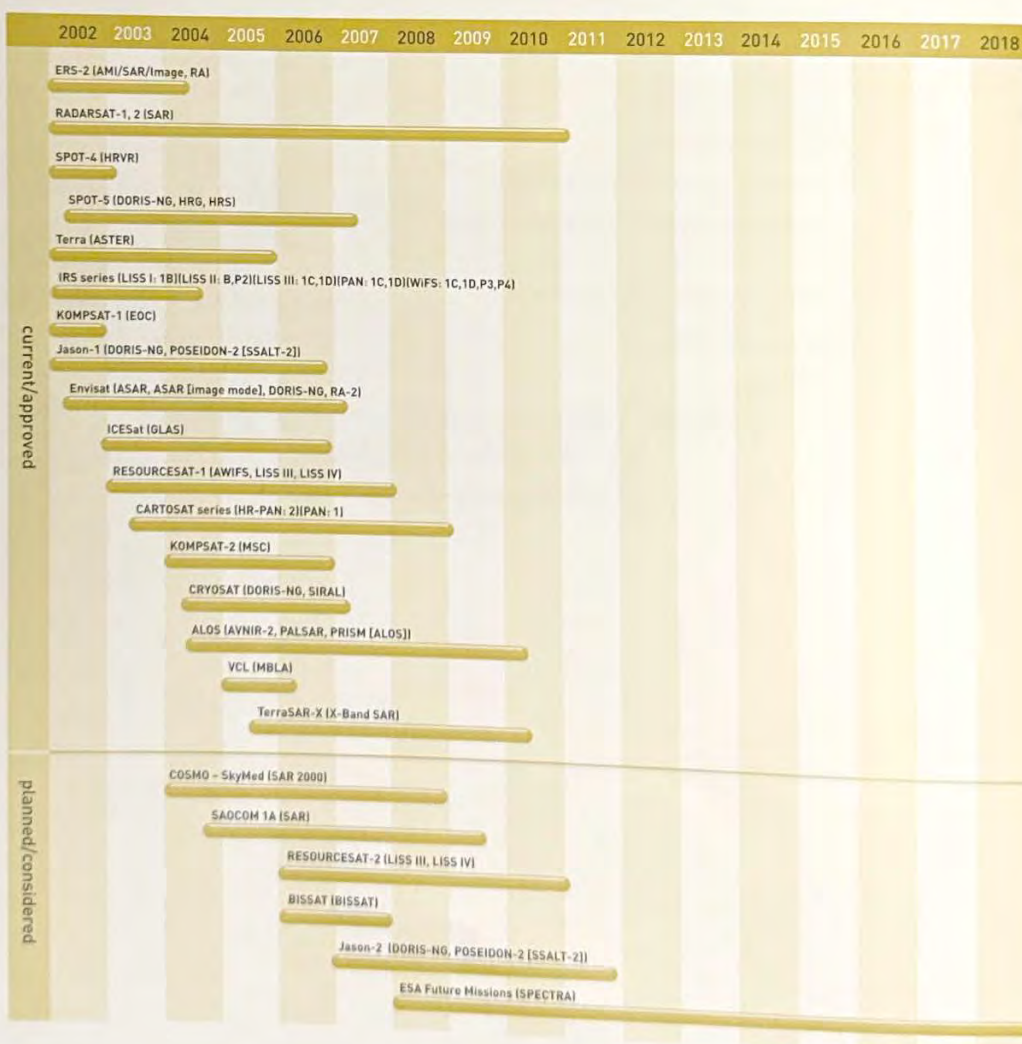
Many modelling activities in Earth and environmental sciences, telecommunications and civil engineering increasingly require accurate, high-resolution and comprehensive topographical databases with, where relevant, indication of changes over time. The information is also used by, amongst others, land-use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

Satellite techniques offer a unique, cost-effective and comprehensive source of landscape topography data. At present, most information is obtained primarily from multi-band optical imagers and synthetic aperture radar (SAR) instruments with stereo image capabilities. The

pointing capability of some optical instruments allows the production of stereo images from data gathered on single (eg by ASTER) or multiple (eg by SPOT series) orbits – which are then used to create digital elevation maps which give a more accurate depiction of terrain.

SARs can also be used in interferometric mode to detect very small changes in topography and have important applications in monitoring of volcanoes, landslides, earthquake displacements, and urban subsidence. Current missions include Envisat and RADARSAT-1. NASDA's ALOS mission planned for 2004 is significant since it carries both high precision optical and SAR topographic mapping instruments.

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



Soil Moisture

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

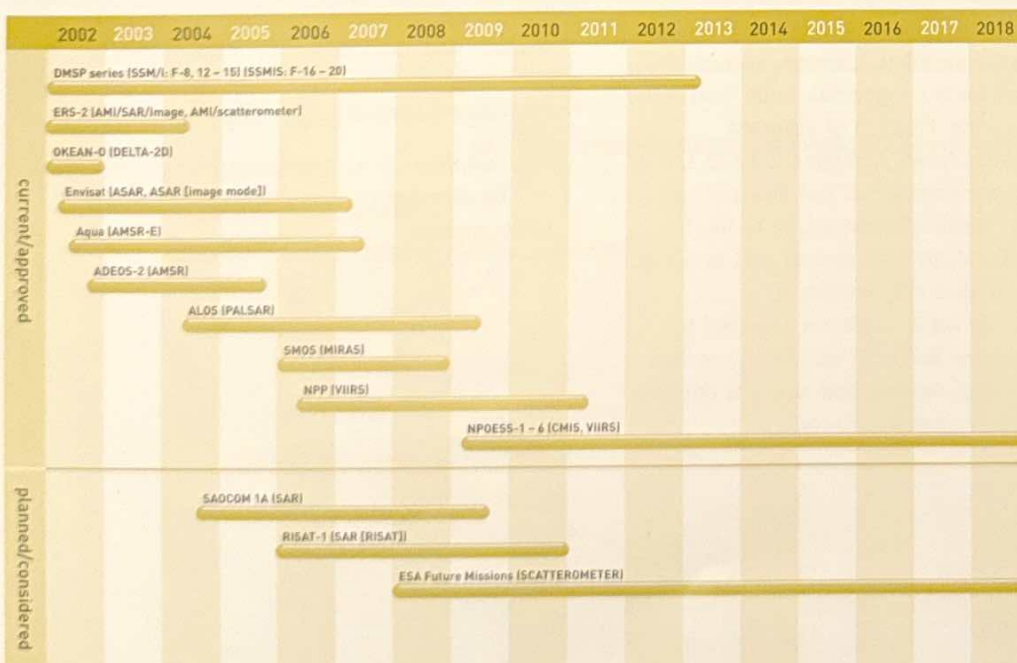
Direct measurement of soil moisture from space is difficult. Most of the active and passive microwave instruments will provide some soil moisture information for regions of limited vegetation cover. However, under many conditions remote sensing data are inadequate, and information regarding moisture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

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

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

AMSR on Aqua and ADEOS-2 missions will provide a variety of information on water content by measuring weak radiation from the Earth's surface. NOAA's conical microwave imager/sounder, CMIS, will provide environmental data including indications of soil moisture.

The first mission likely to satisfy requirements for observing soil moisture from space for the primary applications of hydrologic and meteorological models will be ESA's SMOS (Soil Moisture and Ocean Salinity Mission), carrying the MIRAS (Microwave Imaging Radiometer using Aperture Synthesis) passive L-band 2D-interferometer (from 2005).



Land



Vegetation

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

Deforestation *inter alia* increases the amount of carbon dioxide (CO₂) and other trace gases in the atmosphere. When a forest is cut and burned to establish cropland and pastures, the stored carbon joins with oxygen and is released into the atmosphere as CO₂. The IPCC notes that about three-quarters of the anthropogenic emissions of CO₂ to the atmosphere during the past 20 years was due to fossil fuel burning. The rest was predominantly due to land use change, especially deforestation.

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

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

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

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

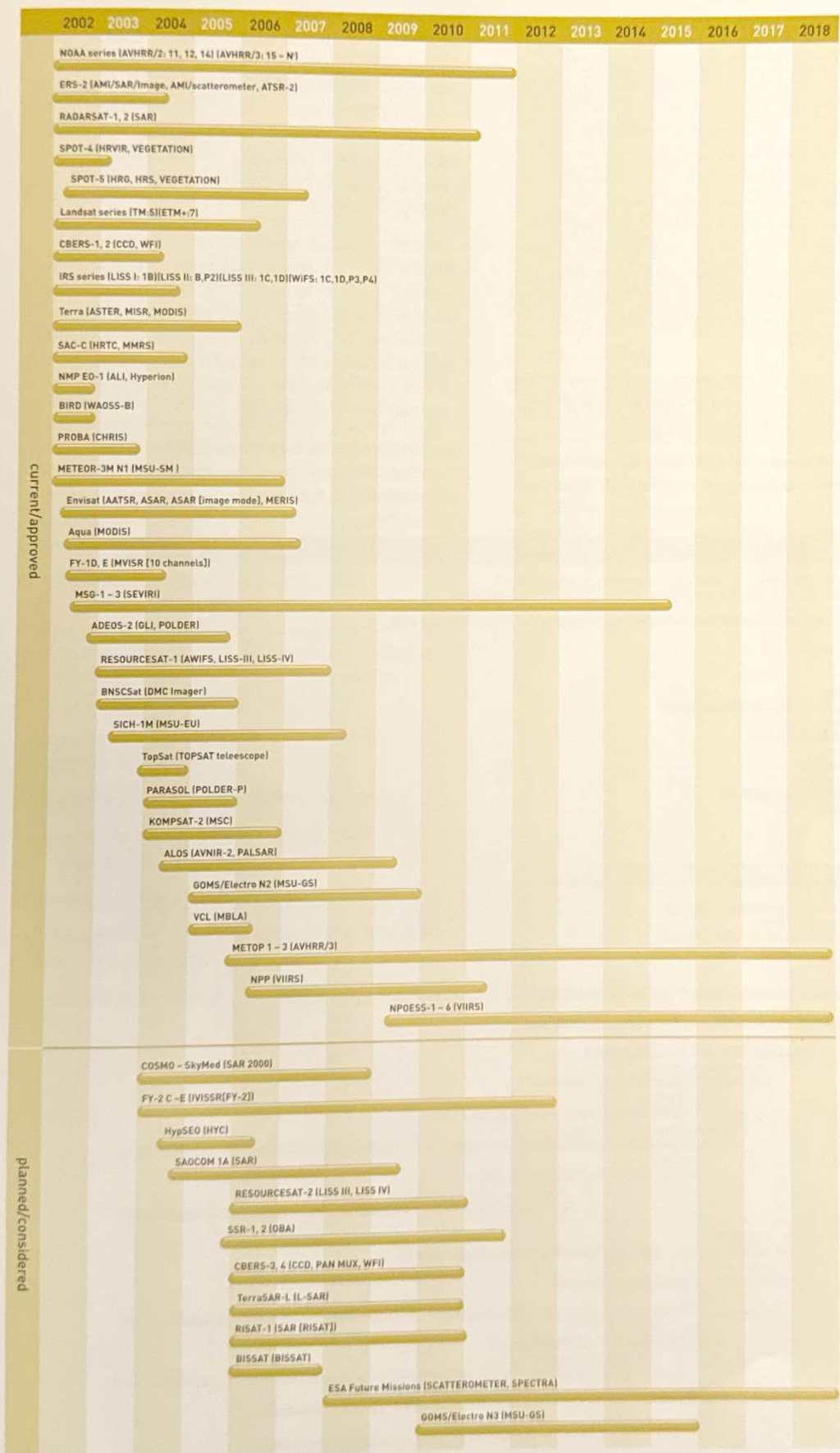
Synthetic aperture radars (SARs) are used extensively to monitor deforestation and surface hydrological states and processes. The ability of SARs to penetrate cloud cover and dense plant canopies make them particularly valuable in rainforest and high-latitude boreal forest studies.

Instruments such as ASAR, RADARSAT, and PALSAR will provide data for applications in agriculture, forestry, land cover classification, hydrology and cartography amongst others.

New information on vegetation canopy structure will be obtained from the Vegetation Canopy Lidar mission.

7 Earth observation plans – by measurement

Vegetation



Land



Surface temperature (land)

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

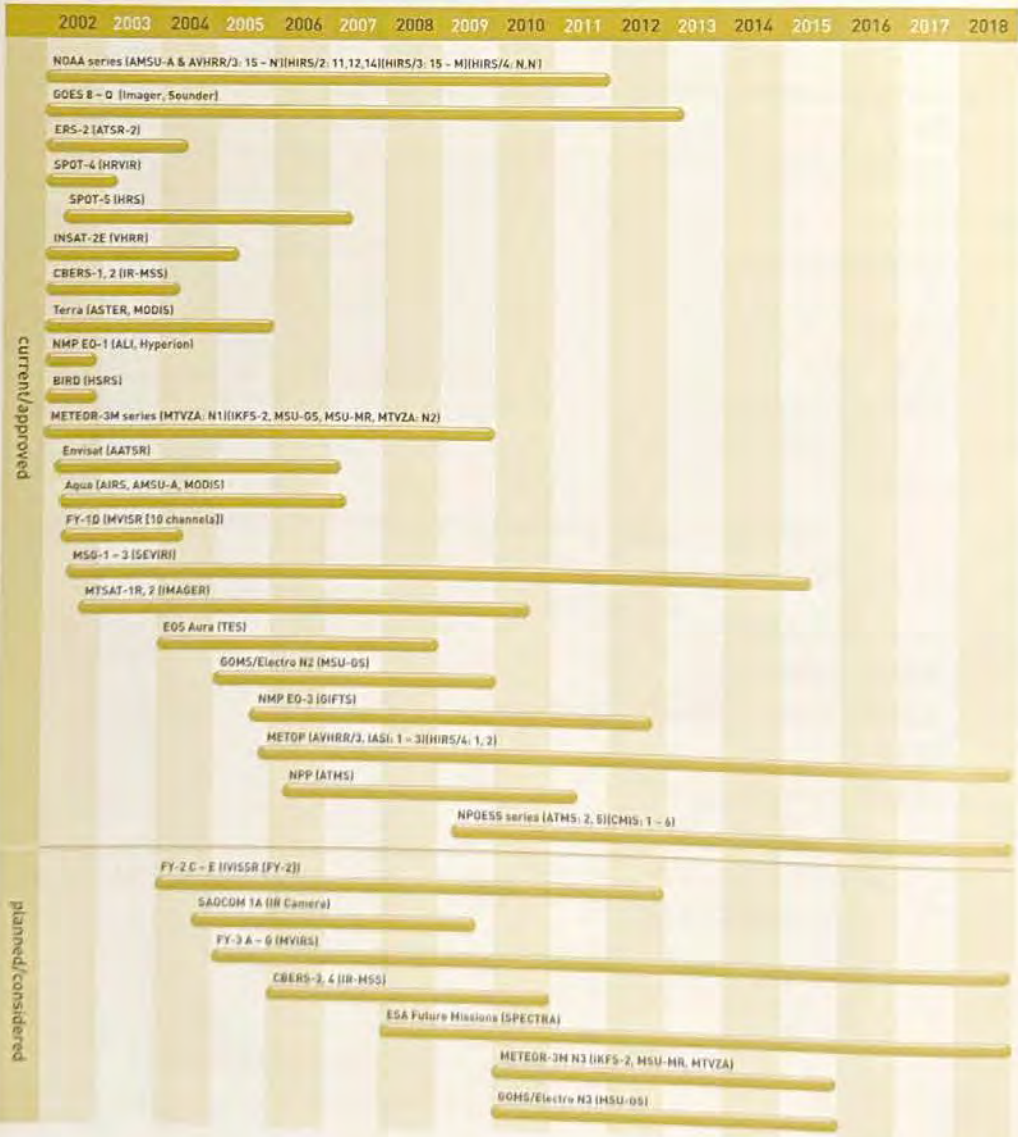
Measurements of surface temperature patterns may also be used in studies of volcanic and geothermal areas, and for forest fire detection and resource exploration.

Land surface temperature measurements are made using the thermal infra-red channel of medium/high resolution

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

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

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



7 Earth observation plans – by measurement

Multi-purpose imagery (land)

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

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

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

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

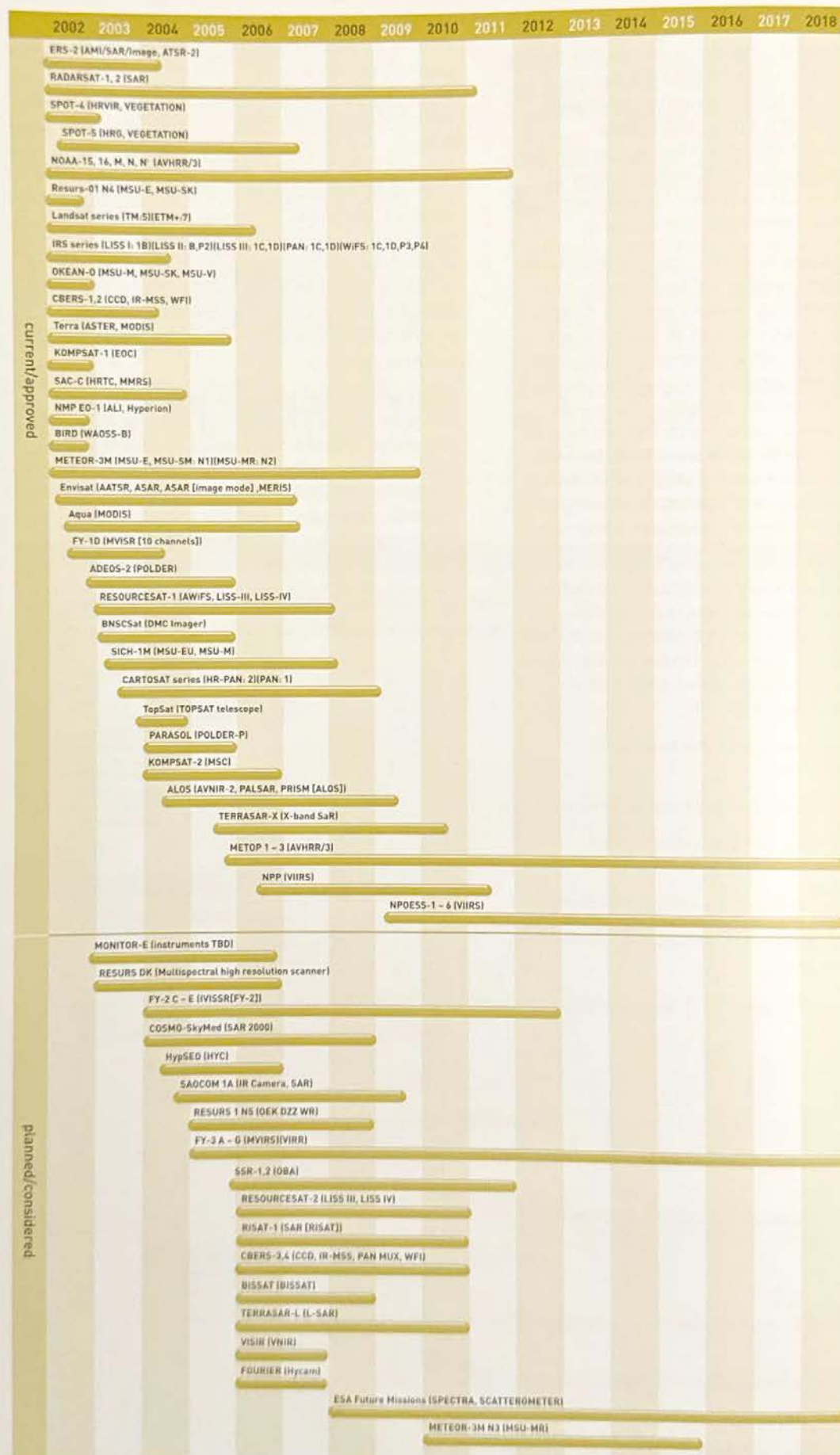
SAR data are particularly useful in monitoring and mapping floods because they are available even in the presence of thick cloud cover. Instruments of RADARSAT, Envisat and ALOS will continue to provide improved capabilities in this field. Such multi-incidence, high resolution SAR systems will also be useful for landslide inventory maps. Moreover InSAR techniques can be used to document deformation and topographic changes preceding, and caused by, volcanic eruptions. Volcanic features have distinctive thermal characteristics which can be detected by thermal imagery, such as that provided by the ASTER radiometer flying on Terra. Future SAR instruments will continue to be important for land imagery because of their all-weather day and night observing capability.

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

Land



Multi-purpose imagery (land)



Ocean

Ocean colour/biology

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

Ocean biology is important not only for understanding ocean productivity and biogeochemical cycling, but also because of its impact on oceanic CO₂ and the flux of carbon from the surface to the deep ocean. Over time, organic carbon settles in the deep ocean – a process referred to as the 'biological pump'. CO₂ system measurements, integrated with routine ocean colour and ecological/biogeochemical observations, are critical for understanding of the interactions between oceanic physics, biology, chemistry and climate. CO₂ measurements are also important for making climate forecasts, and for satisfying the needs of climate conventions.

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

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

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

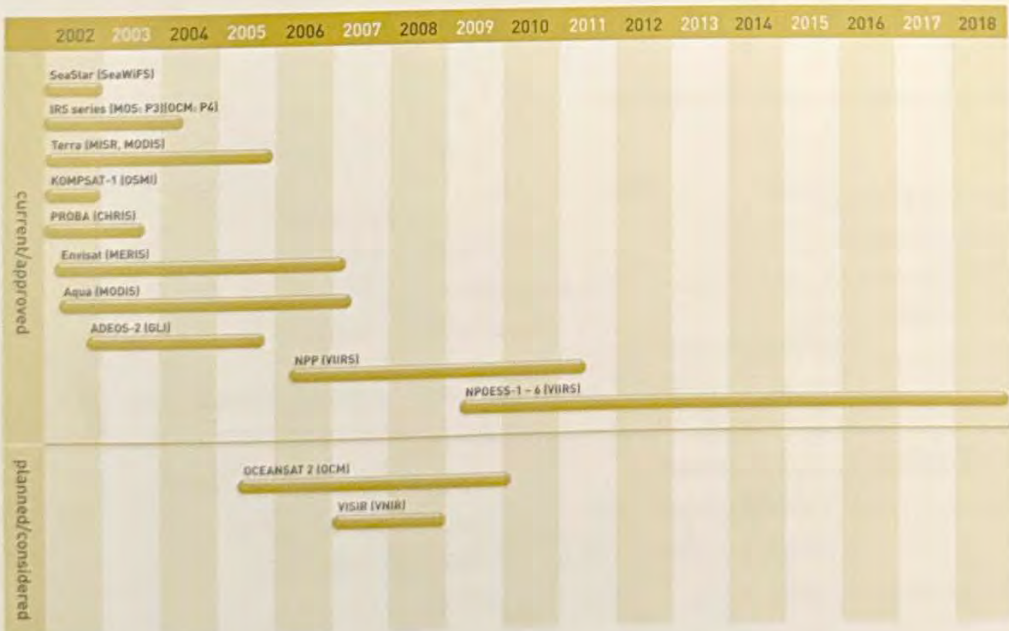
- the variety of needs for global ocean observations;
- the existing and planned observing systems;
- the planning commitments required to ensure long-term continuity of the observations.

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

In recent years there has been a steady flow of ocean colour data from instruments such as OCTS, SeaWiFS, OCM, MODIS, and MERIS. By the end of 2002, additional data will be available from:

- GLI on ADEOS-2: 15 of its 36 spectral bands will be dedicated to ocean colour;
- MODIS on Aqua: 9 of its 36 bands of visible and infrared data will be available for ocean colour applications.

Beyond these research missions, NOAA is developing VIIRS for its NPOESS missions. A visible/infrared sensor, VIIRS will have an operational capability for ocean colour observations and a variety of derived ocean colour products. The NPOESS preparatory programme will deploy prototypes of VIIRS in the 2004-2005 time frame.



Ocean



Ocean topography/currents

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

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

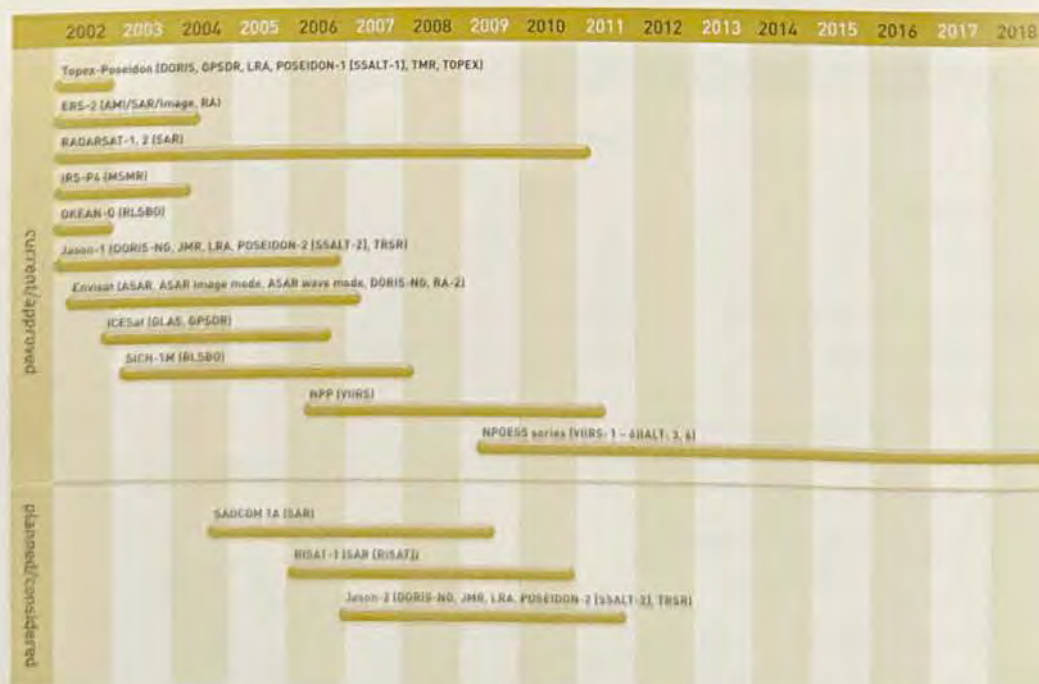
On a local scale, topographic information from satellites may be used in support of off-shore exploration for resources, oil spill detection and for optimising pipeline routing on the sea floor.

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

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

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

In their Final Report, in early 2001, the IGOS Ocean Theme Team identified a long-term need for continuity of a high-precision mission (eg the JASON series) and a polar-orbiting altimeter (eg the ERS and Envisat series) to enhance temporal/spatial coverage of the global ocean.



7 Earth observation plans – by measurement

Ocean surface winds

High resolution vector wind measurements at the sea surface are required in models of the atmosphere, ocean surface waves, and ocean circulation. They are proving useful in enhancing marine weather forecasting through assimilation into NWP models and in improving understanding of the large-scale air-sea fluxes which are vital for climate prediction purposes. Accurate wind vector data affect a broad range of marine operations, including ship movement and routing. Such data also aid short-term weather forecasting and the issue of timely weather warnings.

Polar orbiting satellites provide information on surface wind with global coverage, good horizontal resolution and acceptable accuracy, though temporal frequency is marginal for regional mesoscale forecasts. They provide useful information in two ways:

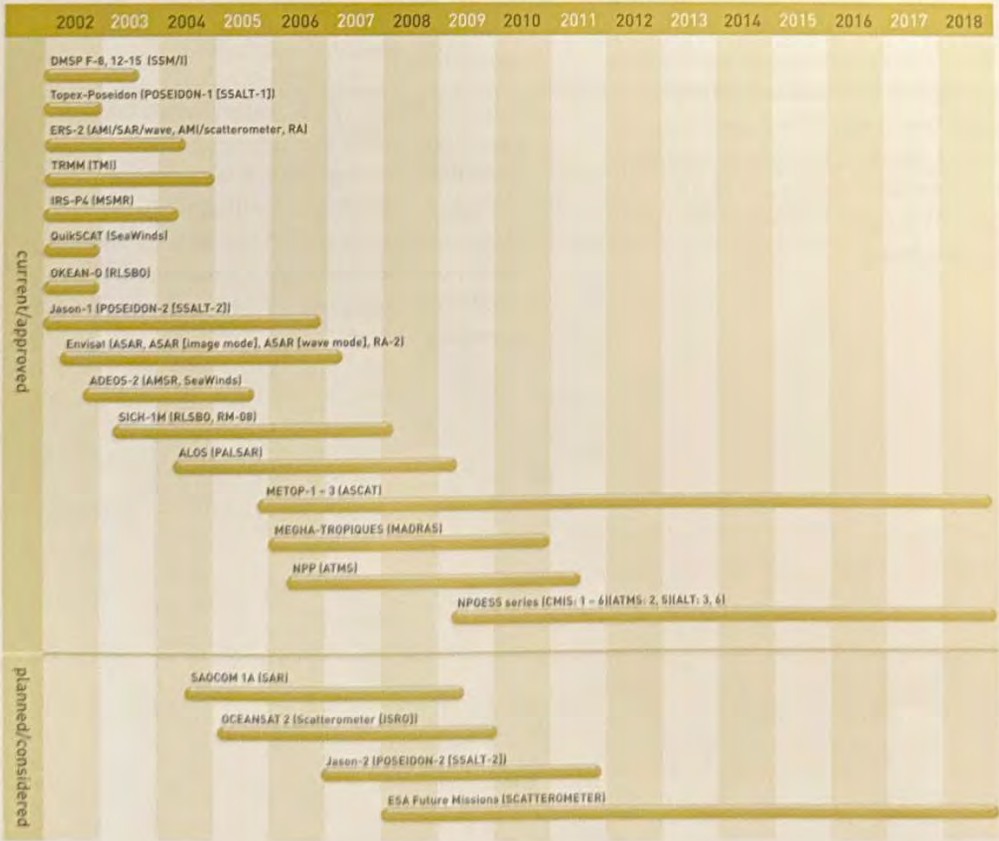
- scatterometers provide dense observations of wind direction and speed along a narrow swath, although the most recent and planned scatterometers provide better coverage via broader swaths (90% global coverage daily); scatterometers have made a positive impact in predicting marine forecasting, operational global NWP and climate forecasting;
- passive microwave imagers provide information on wind speed only.

The single swath scatterometer on ERS-2 and the broad swath scatterometer on QuickSCAT currently provide coverage. QuickSCAT, launched in 1999, carries the SeaWinds scatterometer that measures near surface wind speed and direction in all weather and cloud conditions. Global coverage by two broad swath scatterometers will be effected by the planned launches of SeaWinds on ADEOS-2 and ASCAT on the METOP missions. Developed by ESA as a follow-on from the ‘wind mode’ of the AMI on the ERS series, ASCAT will be used primarily for global measurement of sea surface wind vectors and will be able to provide quasi-global coverage within 24 hours. AMSR on Aqua and ADEOS-II will also provide data on sea surface wind fields.

The operational NPOESS missions, will use the CMIS instrument, which employs a passive microwave approach for collecting data on sea surface winds.

In recent years, the ability to detect and track severe storms has been dramatically enhanced by the advent of weather satellites. Data from SeaWinds is augmenting traditional satellite images of clouds by providing direct measurements of surface winds enabling better determination of a storm’s location, direction, structure and strength.

In their January 2001 Report, the IGOS Ocean Theme Team noted possible future gaps in scatterometer ocean surface wind coverage and efforts are underway to consider solutions to ensure continuity.



Ocean



Surface temperature (ocean)

Ocean surface temperature (often known as 'sea surface temperature', SST) is one of the most important boundary conditions for the general circulation of the atmosphere. The ocean exchanges vast amounts of heat and energy with the atmosphere and these air/sea interactions have a profound influence on the Earth's weather and climate patterns. SST is also very sensitive to changes in ocean circulation, as demonstrated time and again by the El Niño-Southern Oscillation (ENSO) cycle. A major research goal is the development of an increased understanding of the links between SST and all the above processes. This will only be achieved through a more precise and comprehensive set of SST measurements.

Satellite remote sensing provides the only practical means of developing such a dataset – in-situ data, predominantly from ships of opportunity and from networks of moored and drifting buoys are limited in coverage whereas satellites offer the potential for surveying the complete ocean surface in just a few days. The in-situ data have a key role to play in calibrating the satellite data and in providing information needed for deriving bulk temperatures.

Instruments on polar satellites provide information with global coverage, good horizontal and temporal resolution and accuracy for short to medium-range NWP, except in areas that are persistently cloud-covered. Accurate SST determinations, especially in the tropics, are important for seasonal to inter-annual forecasts. The advent of high spectral resolution infrared sounders will enable separation of surface emissivity and temperature, and the accuracy of the SST product is expected to improve into the acceptable range.

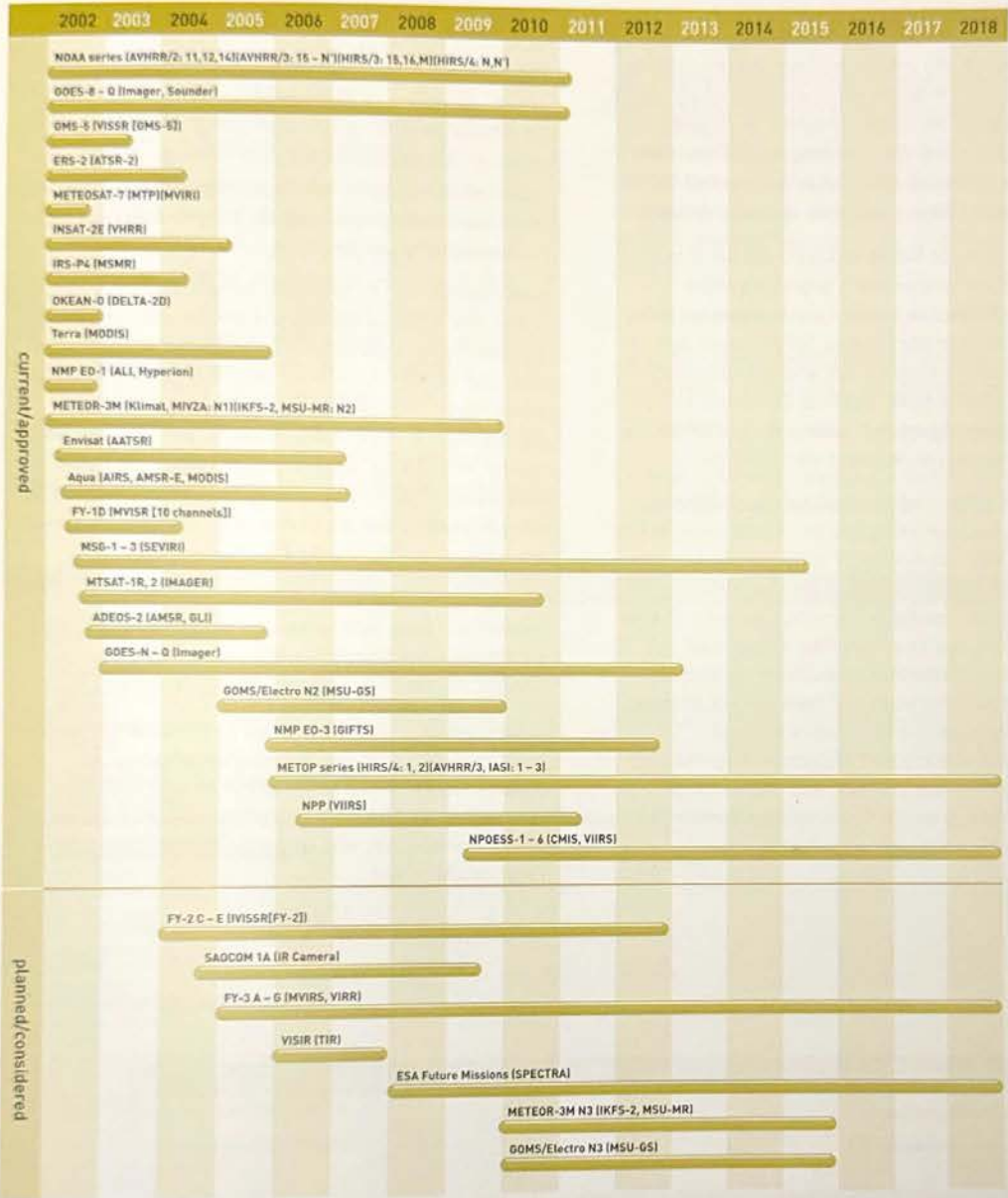
Geostationary imagers with split window measurements are also helping to expand the temporal coverage by making measurements hourly and thus creating more opportunities for finding cloud-free areas and characterising any diurnal variations (known to be up to 4K in cloud-free regions with relatively calm seas). For regional NWP, skin sea-surface temperature is inferred with acceptable horizontal resolution from polar satellites, while geostationary satellites complement information with better temporal resolution.

A range of instruments with thermal bands may be used for SST measurements. Visible/infrared imagers such as AVHRR, AATSR, and MODIS currently provide the main source of SST data, with AATSR and MODIS providing better accuracy (0.25–0.3K) – but AVHRR giving greater coverage, enabling it to track ocean currents, and to monitor ENSO phenomena through its larger swath width. The Aqua mission, which includes MODIS along with AIRS+ and AMSR provides oceanographers with further precise information and the ability to remove atmospheric effects. NOAA's VIIRS and CMIS instruments on the planned NPOESS missions will provide capabilities to produce higher resolution and more accurate measurements of SST than currently available from AVHRR. Future sources of SST data include: AMSR and GLI on NASDA's ADEOS-2 mission; the SEVIRI and IASI instruments on the MSG and METOP missions respectively.

Reviewing supply of SST observations, the IGOS Ocean Theme Team was reassured about continuity of SST data from operational meteorological satellites, but noted that continuity beyond the Envisat mission for the AATSR class of instrument was not assured and urged consideration of how AATSR-class instruments could be introduced into operational systems.

7 Earth observation plans – by measurement

Surface temperature (ocean)



Ocean



Wave height and spectrum

The state of the sea and surface pressure are two features of the weather that are important to commercial use of the sea (eg ship routing, warnings of hazards to shipping, marine construction, off-shore drilling installations and fisheries). Information on surge height at the coast is key to the protection of life and property in coastal habitats.

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

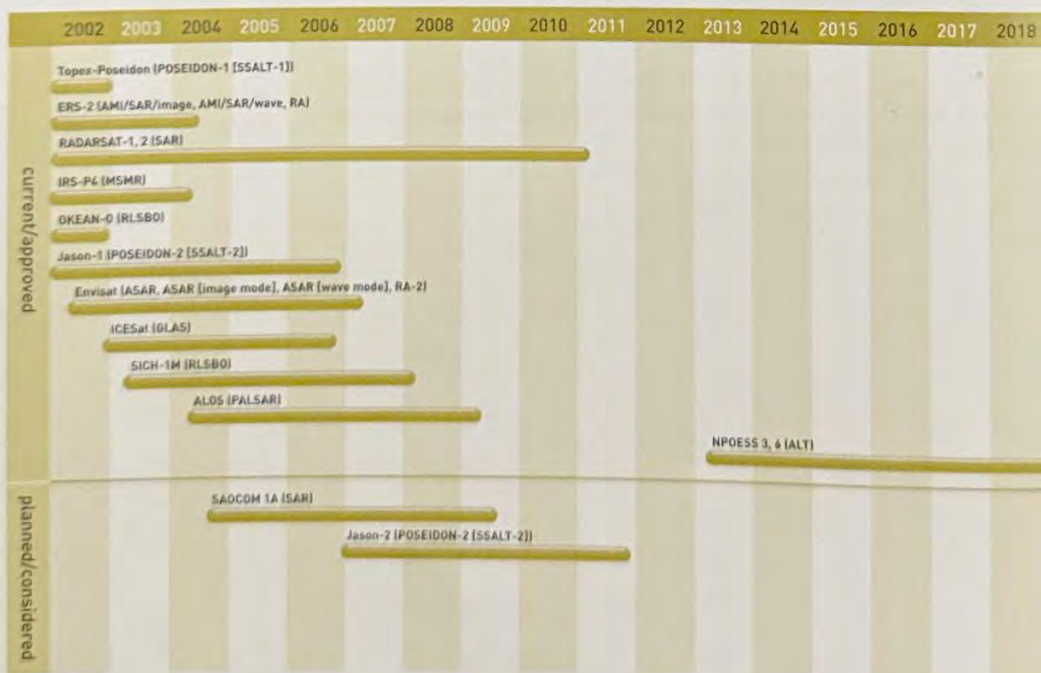
Wave height is influenced by wind speed and direction over water. In the nowcasting context, ocean wave models are driven by NWP predictions of surface wind. However, errors in waves generated at large distances can accumulate. Improvements in forecasts, especially of long wavelength swell, can be achieved by assimilating observations from different sources. These are currently available from isolated buoys and from satellite altimeter and scatterometer data. In the absence of direct observations, initial wave state is deduced from the wind history. This is currently available over the sea from isolated buoys and from low-Earth-orbiting satellite scatterometer and microwave instruments.

For global NWP, ships and buoys provide observations of acceptable frequency and acceptable to marginal accuracy, but coverage is marginal or absent over large areas of the ocean. Altimeters on polar satellites provide information on significant wave height with global coverage and good accuracy, but horizontal/temporal coverage is marginal. Information on the 2D wave spectrum is provided by SAR instruments with good accuracy, but marginal horizontal/temporal resolution.

SAR instruments can accurately measure changes in ocean waves and winds, including wavelength and the direction of wave fronts, regardless of cloud, fog or darkness. The AMI SAR on ERS 2 has been operating in both wave and image mode, and the ASAR on Envisat continues to provide the ERS wave mode products, but with improved quality. PALSAR on NASDA's ALOS mission will provide data on sea surface wind and wave spectrum required for oil spill analysis and for studies of coastal topography-air-sea interaction. The ScanSAR wave data supplied by RADARSAT will continue to be provided by RADARSAT 2.

Information from radar altimeters is limited to data on significant wave height. The altimeter on the Jason 1 mission, for example, provides such information.

In their January 2001 Report, the IGOS Ocean Theme Team recognised that SAR instruments currently provide information about the properties of the sea surface and the wave spectrum. Nevertheless the Team noted limitations to its use operationally and called for further development of these capabilities.



7 Earth observation plans – by measurement

Multi-purpose imagery (ocean)

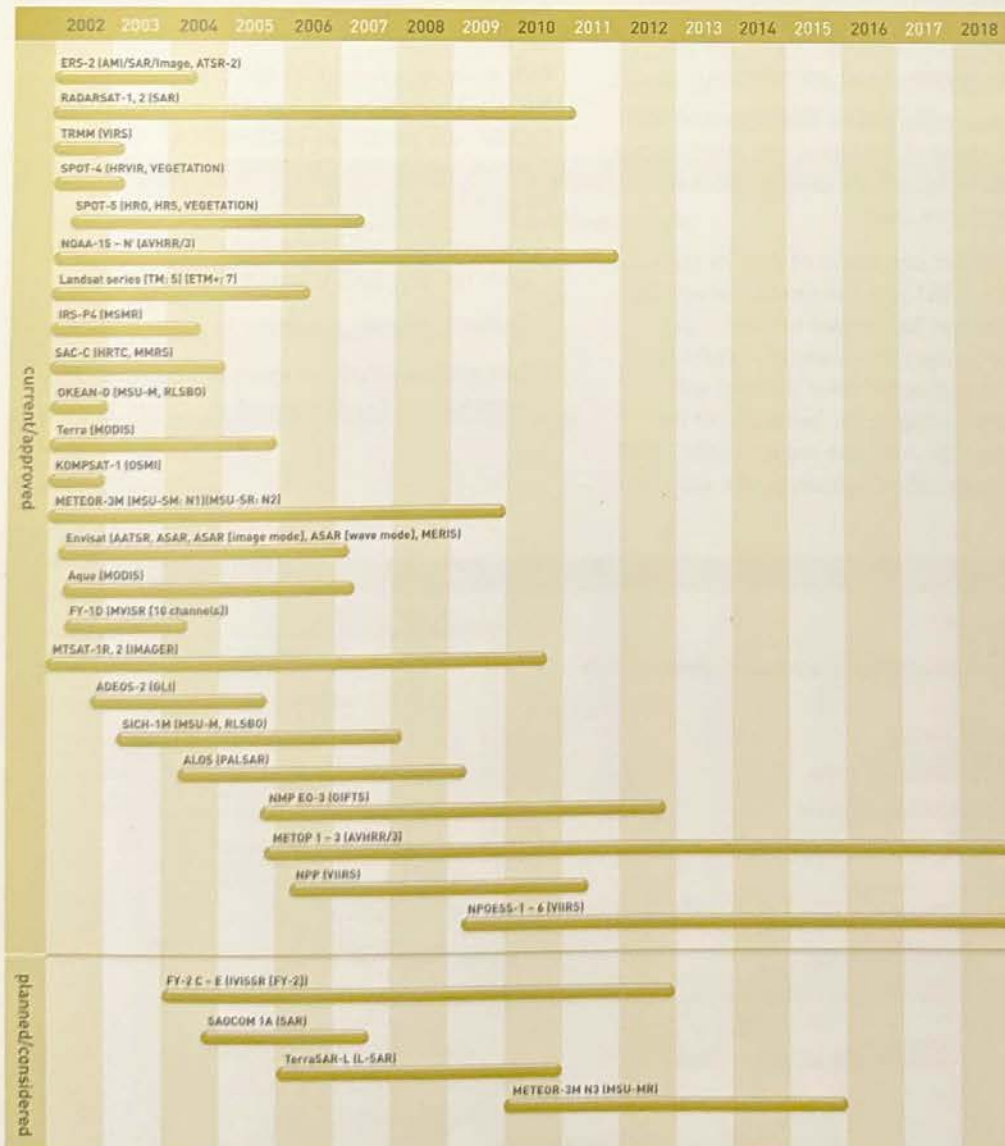
In addition to the specific ocean measurement observations discussed in previous sections, a number of sensors are capable of providing a range of ocean imagery from which useful secondary applications can be derived.

High resolution radiometers such as AVHRR, AATSR, and VIIRS have multi-channel imaging capabilities to support the acquisition and generation of a variety of applied products including visible and infrared imaging of hurricanes. They provide observations of large scale ocean features, using variations in water colour and temperature to derive information about large scale circulation, currents, river outflow and water quality. Such observations are relevant to activities such as ship routing, coastal zone monitoring, toxic algal bloom detection, management of fishing fleets and sea pollution monitoring.

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

In addition, SAR instruments such as RADARSAT, ASAR and PALSAR provide a valuable all-weather, day and night source of information on oceanographic features including fronts, eddies and internal waves. SAR imagery is also useful for:

- pollution monitoring – notably oil spill detection;
- ship detection – useful to rescue services, port authorities, custom and immigration services;
- coastal change detection – topography mapping;
- bottom topography mapping, valuable for resource exploration and pipeline routing.



Snow and ice



Ice sheet topography

The state of the polar ice sheets and their volumes are both indicators and causes of climate change. Consequently it is important to monitor and study them in order to investigate the impact of global warming and to forecast future trends. The IPCC expects that ice sheets will continue to react to climate warming and contribute to sea level rise for thousands of years after climate has been stabilised. They note that:

- climate models indicate that the local warming over Greenland is likely to be one to three times the global average;
- ice dynamic models suggest that melting of the West Antarctic ice sheet could contribute up to 3 metres of sea level rise over the next 1000 years, but such results are strongly dependent on model assumptions regarding climate change scenarios, ice dynamics and other factors.

Satellite remote sensing allows observations of the changes in the shape of ice sheets, and identification of the shape and size of large icebergs that have detached from the ice sheet.

SAR instruments are one source of data on the polar ice sheets. RADARSAT provides routine surveillance of polar regions, and has created the first high resolution radar images of Antarctica – enabling detection of changes in the polar ice sheet and improved understanding of the behaviour of the Antarctic glacier. The AMI instrument on ESA's ERS 2 mission has been collecting data on the polar ice

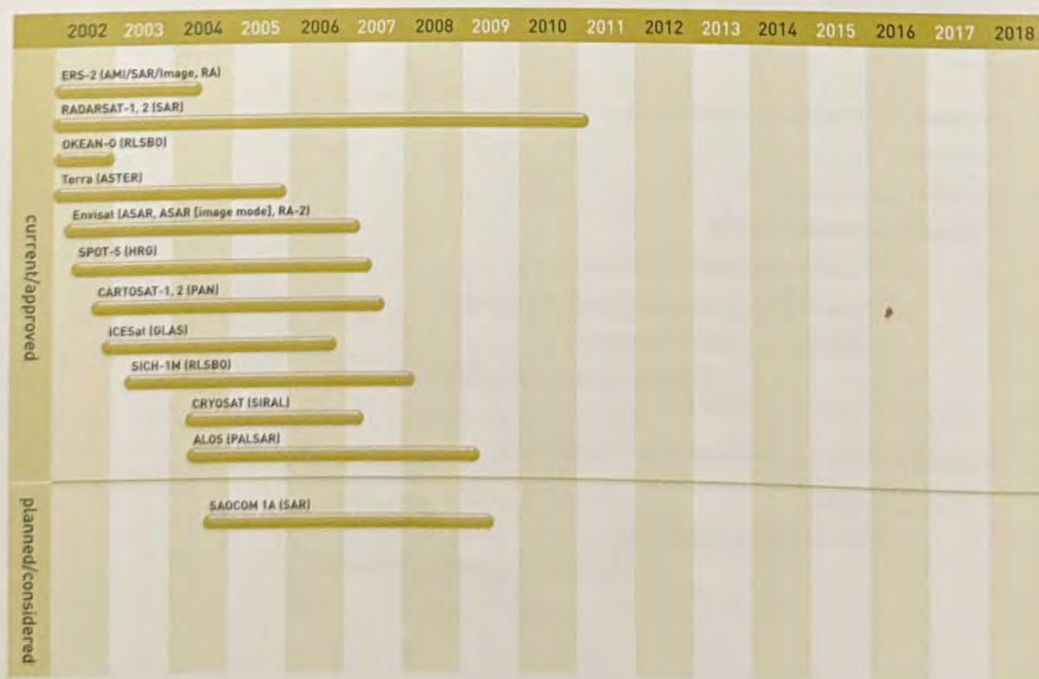
to assist derivation of indicators of climate change, and ASAR on the Envisat mission will continue to provide data on polar ice topography.

Analysis of interferometric measurements by PALSAR, together with observations by the AVNIR-2 instrument on NASDA's ALOS mission, will contribute to understanding the ice sheet mass balance and glacier variation in the South Pole and in Greenland.

Altimeters provide useful data on ice sheet topography. While many have high vertical resolution, their limited horizontal resolution means that their observations over smoother, near-horizontal portions of ice sheets are of greatest value. The RA-2 instrument on Envisat is providing improved mapping of icecaps.

Given the significance of information on changes in the continental ice sheets, two missions dedicated to their study are planned for the coming decade: NASA's ICESat (late 2002) and ESA's Cryosat (2004). CryoSat will provide an instrument for the ice sheet interiors, the ice sheet margins, for sea ice and other topography, with three-mode operation:

- conventional pulse-limited operation for the ice sheet interiors (and oceans if desired);
- synthetic aperture operation for sea ice;
- dual-channel synthetic aperture/interferometric operation for ice sheet margins.



7 Earth observation plans – by measurement

Snow cover, edge and depth

Regular measurements of terrestrial snow are important because snow dramatically influences surface albedo, thereby making a significant impact on the global climate; as well as influencing hydrological properties and the regulation of ecosystem biological activity. In its Third Assessment Report, 'Climate Change 2001', the IPCC found that – on the evidence of satellite data – there was likely to have been a decrease of about 10% in the extent of snow cover since the late 1960's.

Snow forms a vital component of the water cycle. In order to make efficient use of meltwater run-off, resource agencies must be able to make early predictions of the amount of water stored in the form of snow. Coverage area, snow water equivalent, and snowpack wetness are the key parameters to be determined in this process.

Snow cover information has a range of additional applications such as in agriculture for detecting areas of winterkill, resulting from lack of snow cover to insulate plants from freezing temperatures. Locally, monitoring of snow parameters is important for meteorology, and for enabling warnings of when melting is about to occur –

which is crucial for hydrological research and for forecasting the risk of flooding.

A range of different instrument types can contribute to measurements of snow. Visible/near-infrared satellite imagery provides information of good horizontal and temporal resolution and accuracy on snow cover in the day-time in cloud-free areas. AVHRR provides snow cover information and this will be continued in the future by VIIRS. MODIS data are being used to monitor the dynamics of large area (greater than 10km²) snow and ice cover and, on a weekly basis, to report the maximum area covered by both. The resulting snow maps should be available within 48 hours of MODIS data collection.

Passive microwave instruments such as SSM/I, AMSR, and CMIS will have all-weather and day/night monitoring capability and will be able to estimate the thickness of dry snow up to about 80cm deep.

Data from RADARSAT and ERS-2 have shown the usefulness of SAR remote sensing techniques to determine snow area extent and to monitor the physical conditions of snow. RADARSAT 2, Envisat, and ALOS will provide continuity of such snow information.



Snow and ice



Sea ice cover, edge and thickness

Sea ice modulates planetary heat transport by insulating the ocean from the cold polar atmosphere and by modulating the thermohaline circulation of the world ocean through processes in deep-water. Moreover, the high albedo of ice insulates the polar oceans from solar radiation. Time series of sea-ice concentration data are also critical for identifying inter-annual and decadal fluctuations that could point to the existence of significant changes in oceanic and atmospheric circulation at high latitudes. The motion of sea ice creates patterns of ice convergence and divergence that play a critical role in determining energy and momentum fluxes between the ocean and atmosphere at high latitudes.

Near real-time delivery of data tracking the continually changing nature of ice field conditions provides operational sea ice charts for use by:

- shipping to avoid damage, delay and to reduce fuel costs;
- offshore drilling companies;
- maritime insurance companies;
- government environmental regulatory bodies.

Ice cover and type may be determined using visible/infra-red sensors which are currently available (AVHRR, AATSR etc). Observations provided by microwave instruments on polar satellites also offer good horizontal and temporal resolution and acceptable accuracy. The data now produced are being used to generate wide-area sea ice motion and deformation products for the north polar region and similar products are being planned for the south polar region. Systematic global observation of sea-ice extent and concentration, inferred from passive imaging microwave radiometry, has already produced a 20-year record of global sea ice concentration.

Improved microwave imagery from multi-spectral radiometers such as AMSR (on Terra and ADEOS-II) provide all weather operation coupled with good coverage.

High resolution synthetic aperture radars such as on Envisat and RADARSAT offer the best source of data, and again have the important advantage of all-weather day/night operation. Data from these instruments provides information on the nature, extent and drift of ice cover and is used not only for status reports, but also for ice forecasting and as an input for meteorological and ice drift models. NASDA's PALSAR radar will contribute to methodological development of extensive sea ice monitoring and, using polarimetric data, will improve the accuracy of sea ice classification.

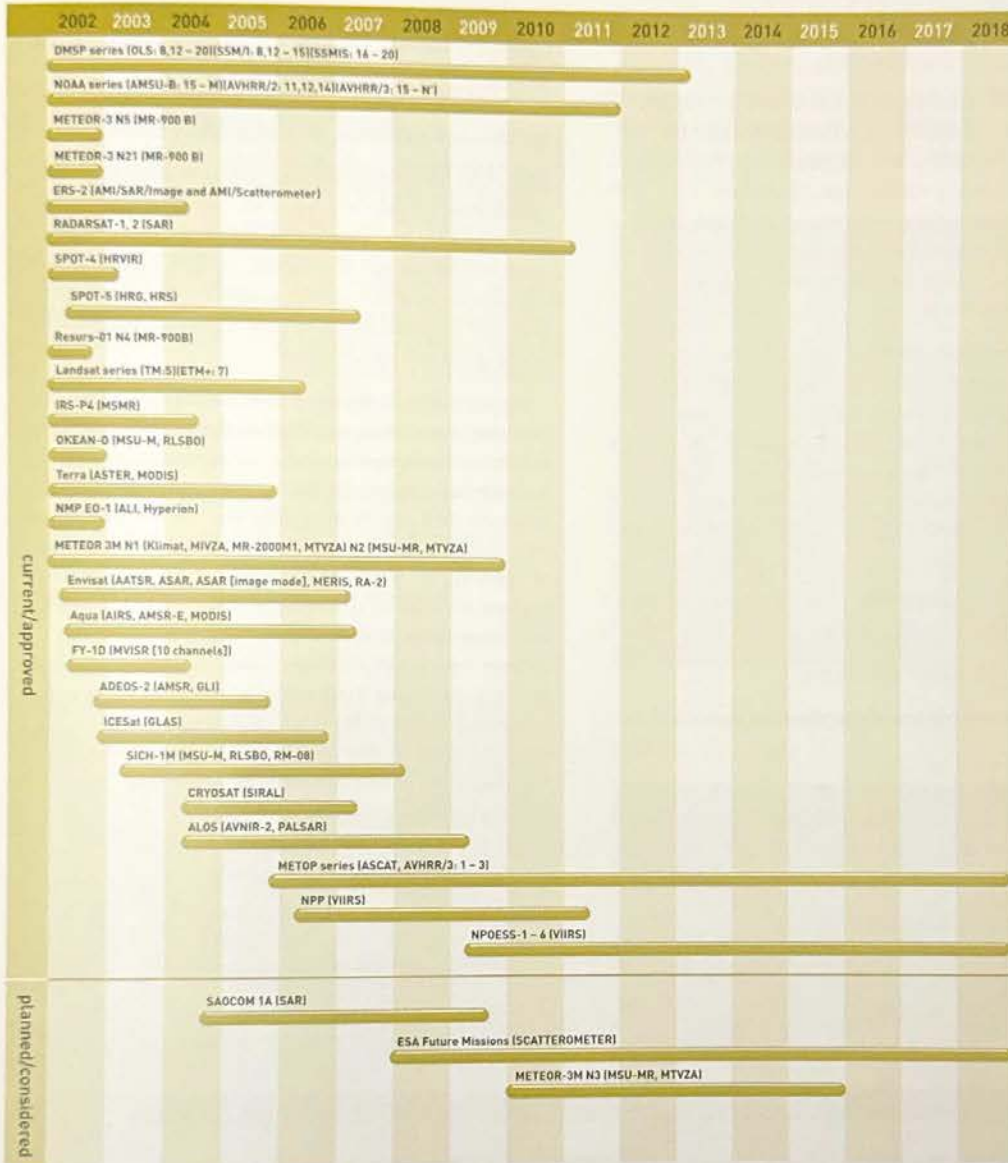
Low resolution scatterometer observations are also used to retrieve information on sea ice extent and concentration in all weather conditions, during day or night.

Current radar altimeters provide some information on ice thickness, but more accurate measurements will be available with the launch of ICESat and Cryosat.

In its January 2001 Report, the IGOS Ocean Team stated that:

- ERS/Envisat offer an Arctic coverage service since 1991;
- RADARSAT has provided SAR coverage of the majority of the Arctic every few days since 1996;
- NASDA's AMSR radiometer on Aqua and ADEOS-II missions and operational sensors such as the DMSP SSM/I and NOAA CMIS on NPOESS missions will ensure continuity of the global sea ice concentration in the near term;
- continuation of RADARSAT/Envisat class radar-equipped missions is important in providing complementary high resolution data to further elucidate sea ice processes.

7 Earth observation plans – by measurement



Sea ice cover, edge and thickness

Gravity and magnetic fields



Gravity, magnetic, and geodynamic measurements

Not all near-Earth measurements undertaken by satellite observations are discussed in this document, since the focus here is on land, sea, and air parameters; but many more are observed on a routine basis, including measurements of the space environment and solar activity, amongst others. Of particular note are measurements of the Earth's gravity field, magnetic field, and geodynamic activity.

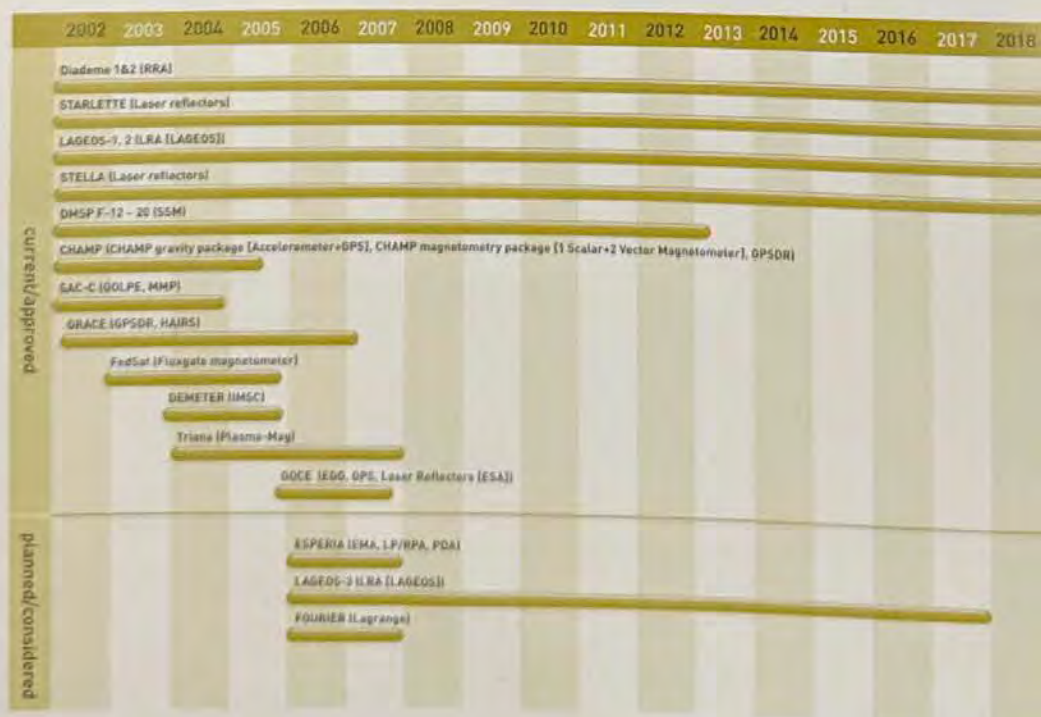
Gravity field measurements from space provide the most promising advances for improved measurement of the 'geoid' and its time variations. The geoid is the surface of equal gravitational potential at mean sea level, and reflects the irregularities in the Earth's gravity field at the Earth's surface due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

- quantitative determination, in combination with satellite altimetry, of absolute ocean currents;
- improving global height references;
- estimates of the thickness of the polar ice sheets and its variations;
- estimates of the mass/volume redistribution of freshwater in order to further understand the hydrological cycle.

Gravity field measurement packages on satellites often utilise combinations of different instrument types in order to derive the necessary information: single or multiple accelerometers; precise satellite orbit determination systems; and satellite to satellite tracking systems.

DLR's CHAMP gravity package has been providing new information on the Earth's gravity field since 2000. Two new missions, one launched by NASA in 2002 (the twin satellite GRACE) and one planned by ESA (GOCE, in 2005), will provide new and unique models of the Earth's gravity field and its variability over time, allowing determination of the geoid to 1cm accuracy.

A number of Earth missions have carried sensors to study the electromagnetic environment of spacecraft. Satellite-borne magnetometers provide information on strength and direction of the internal and external Earth's magnetic field and its time variations. The CHAMP mission makes such measurements – which are of value in a range of applications, including navigation systems, resource exploration drilling, spacecraft attitude control systems, and assessments of the impact of 'space weather'. The coming decade will see further missions planned for more in-depth, dedicated studies of magnetic field – including Australia's FedSat in late 2002, and a number of missions aimed at investigating links between earthquakes and magnetic field variations (DEMETER, 2003 and ESPERIA, 2006).



8 Catalogue of satellite missions

8.1 Introduction

This section gives details of the satellite missions of CEOS members and of the CEOS database from which much of the data in this handbook is derived.

Nearly all information contained in this catalogue has been gathered from and verified by CEOS agencies but it should be noted that the launch date and duration of some planned missions is uncertain (eg due to changes in funding or policy, changes in requirements, etc) hence, the accuracy of timelines relating to these missions cannot be guaranteed. If the month of the launch of a planned mission has not been specified the timeline is shown to commence at the beginning of the planned year of launch. It should also be noted that missions currently operating beyond their planned life are shown as operational until the end of 2002 unless an alternative date has been proposed.

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

Mission name and agency	Mission acronym Full mission name Agency acronym
Status	Current: at least the prototype has been launched, and financing is approved for the whole series Approved: financing is available for the whole series, the prototype is fully defined, the development is in phase C/D Planned: financing is available up to the end of phase B, financing of the full series is being considered Considered: conceptual studies and phase A have been completed, financing of phase B is in preparation
Key dates	Launch date Estimated end of life date
Primary applications	Of those discussed in section 7
Instruments	A list of instruments on board the mission from the catalogue in section 9
Orbit details	Type of orbit Altitude Period Inclination Repeat cycle LST: Local Solar Time – the time of satellite equator overpass Longitude (for geostationary orbits) Ascending/descending: whether the satellite crosses the equator in a northbound (ascending) or southbound (descending) direction
URL	For further information via internet

8.2 Recent events

2002 marks a significant year for new Earth observation satellite missions. At the time of writing, a total of 18 missions had been planned for launch by the end of the year; of those, 5 had already been launched and are in service:

Mission	Agency	Launch date
Envisat (Environmental Satellite)	ESA	1/03/2002
GRACE (Gravity Recovery and Climate Experiment)	NASA	17/03/2002
Aqua	NASA	4/05/2002
SPOT-5 (Satellite Pour L'Observation de la Terre – 5)	CNES	4/05/2002
FY-1D (Polar-orbiting Meteorological Satellite)	NRSCC	15/05/2002

Those missions planned for launch before the end of 2002 are:

Mission	Agency	Launch date
NOAA-M	NOAA	June 2002
INSAT-3A	ISRO	June 2002
MSG-1 (Meteosat Second Generation-1)	EUMETSAT	Aug 2002
CBERS-2 (China Brazil Earth Resources Satellite – 2)	CAST/INPE	Aug 2002
MTSAT-1R (Multi-functional Transport Satellite)	JMA	Sept 2002
DMSP F-16 (Defense Meteorological Satellite Program F-16)	NOAA	Oct 2002
SORCE (Solar Radiation and Climate Experiment)	NASA	Nov 2002
FedSat (Australian 100 year Federation Satellite)	CRCSS	Nov 2002
ADEOS-2 (Advanced Earth Observing Satellite – 2)	NASDA	Nov 2002
ICESat (Ice, Clouds, and Elevation Satellite)	NASA	Dec 2002
SCISAT-1	CSA	Dec 2002
MONITOR-E	ROSAVIKOSMOS	Dec 2002
METSAT	ISRO	Dec 2002

8.3 Current missions

68 different Earth observation satellite missions are estimated to be currently operating (June 2002). Many of these comprise series of missions planned to provide the continuity which is essential for many observations and applications. The principal satellite series are highlighted below:

Geostationary meteorological satellites:

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

DMSP series:

The long-term meteorological programme of the US Department of Defense (DoD) – with the objective of collecting and disseminating worldwide atmospheric, oceanographic, solar-geophysical, and cloud cover data on a daily basis.

NOAA polar orbiters:

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

METEOR series:

Roshydromet maintains two or three satellites in orbit at any time mainly for operational meteorological purposes. Other applications include experimental measurement of ozone and Earth radiation budget.

ERS and Envisat series:

ERS-1 was launched by ESA in July 1991, ERS-2 in April 1995, and Envisat in March 2002. This series concentrates on global and regional environmental issues, making use of active microwave techniques that enable a range of measurements to be made of land, sea and ice surfaces independent of cloud cover and atmospheric conditions. In addition, the ATSR/AATSR instruments on these missions provides images of the surface or cloud top and the GOME instrument on ERS-2 provides measurements of ozone levels. ERS-1 and ERS-2 operated in tandem for around 1 year in 1995 and 1996 providing data for topographic applications such as differential interferometry. Envisat features a range of new sensors for land surface and atmospheric studies.

RADARSAT series:

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

SPOT and Landsat series:

The SPOT satellites operated by French, Swedish and Belgian space agencies, and the Landsat satellites operated by USGS provide high resolution imagery in a range of visible and infra-red bands. They are used extensively for high resolution land studies. Data from these satellites is supplemented by availability of very high resolution imagery (up to 1m) from various commercial satellites.

IRS series:

The Indian IRS satellites provide high resolution imagery in a range of visible and infra-red bands. Their primary objectives are national mapping of various resources. The series was supplemented by IRS-P4 (for ocean colour studies) in May 1999.

CBERS series:

A joint mission series of China and Brazil, aimed at environmental monitoring and Earth resources. The latest in the series was launched in April 2002.

KOMPSAT series:

Korean missions aimed at cartography, land use and planning and ocean and disaster monitoring – starting from December 1999.

TOPEX/POSEIDON and JASON series:

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

NASA's EOS missions:

Carrying the latest advanced sensors and each mission dedicated to investigation of particular Earth system issues – including the Terra and Aqua missions.

LAGEOS series:

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

8.4 Future missions

Current plans supplied by CEOS agencies estimate that of order 90 new satellite missions will be launched for operation between mid-2002 and 2018. The next few years mark a significant era for satellite Earth observations, with half of these new missions to be launched before the end of 2005.

These new programmes will ensure continuity of key measurements, provide improved resolutions and accuracies, and introduce several exciting new capabilities. Some of the highlights are described below:

Gravity and magnetic field studies:

The GRACE and GOCE missions are dedicated to providing more precise measurements of the geoid, while DEMETER and ESPERIA will study links between electromagnetic fields and earthquake predictability.

Polar ice cap studies:

Given the significance of information on changes in the continental ice sheets, two missions dedicated to their study are planned for the coming decade: NASA's ICESat (late 2002) and ESA's Cryosat (2004).

Cloud properties and climate links:

By 2006, a multiple satellite constellation will be in place (comprising CloudSat, Aqua, Aura, CALIPSO and PARASOL) and will fly in orbital formation to gather data needed to evaluate and improve the way clouds are represented in global models, and to develop a more complete knowledge of their poorly understood role in climate change and the cloud-climate feedback.

Operational meteorology:

The current geostationary programmes will continue operationally. With the launch of the METOP series in 2005, EUMETSAT and NOAA will share responsibility for the provision of polar orbiting meteorological satellites. The NOAA series of satellites will evolve to become NPOESS, featuring more advanced sensors and new capabilities. China will also operate the FY-3 series of polar orbiting satellites from late 2004.

Atmospheric studies:

New data on the chemistry and dynamics of the Earth's atmosphere will be gathered by missions from many countries, including ADEOS-2 and GCOM-A1 (Japan), EOS Aura (USA), and SCISAT-1 (Canada). ADM-Aeolus (Europe) will provide new information on winds.

Radiation budget:

Continuity and new capabilities will be provided by NASA's SORCE (late 2002) and Triana missions (launch TBD), and by operational meteorology missions, such as the MSG and NPOESS series.

Ocean observations:

Continuity and improvements in many current measurements are assured with the launch of missions such as Envisat, Aqua and ADEOS-2 in 2002. SMOS is worthy of special note – since it will provide new capabilities for measurements of ocean salinity from 2006.

Land surface observations:

A range of different sensors are planned for land surface observations, including advanced SAR systems such as ALOS and TerraSAR. From 2005, VCL will provide innovative new data on the vegetation canopy structure. SMOS will measure soil moisture from 2006.

8.5 CEOS Database

The information presented in the CEOS Handbook is a much condensed summary of the information provided in the CEOS Database. This database contains extensive information on the capabilities of both satellite and in-situ observing system capabilities, and relates them in some detail to the requirements of key user programmes. The database is maintained by WMO.

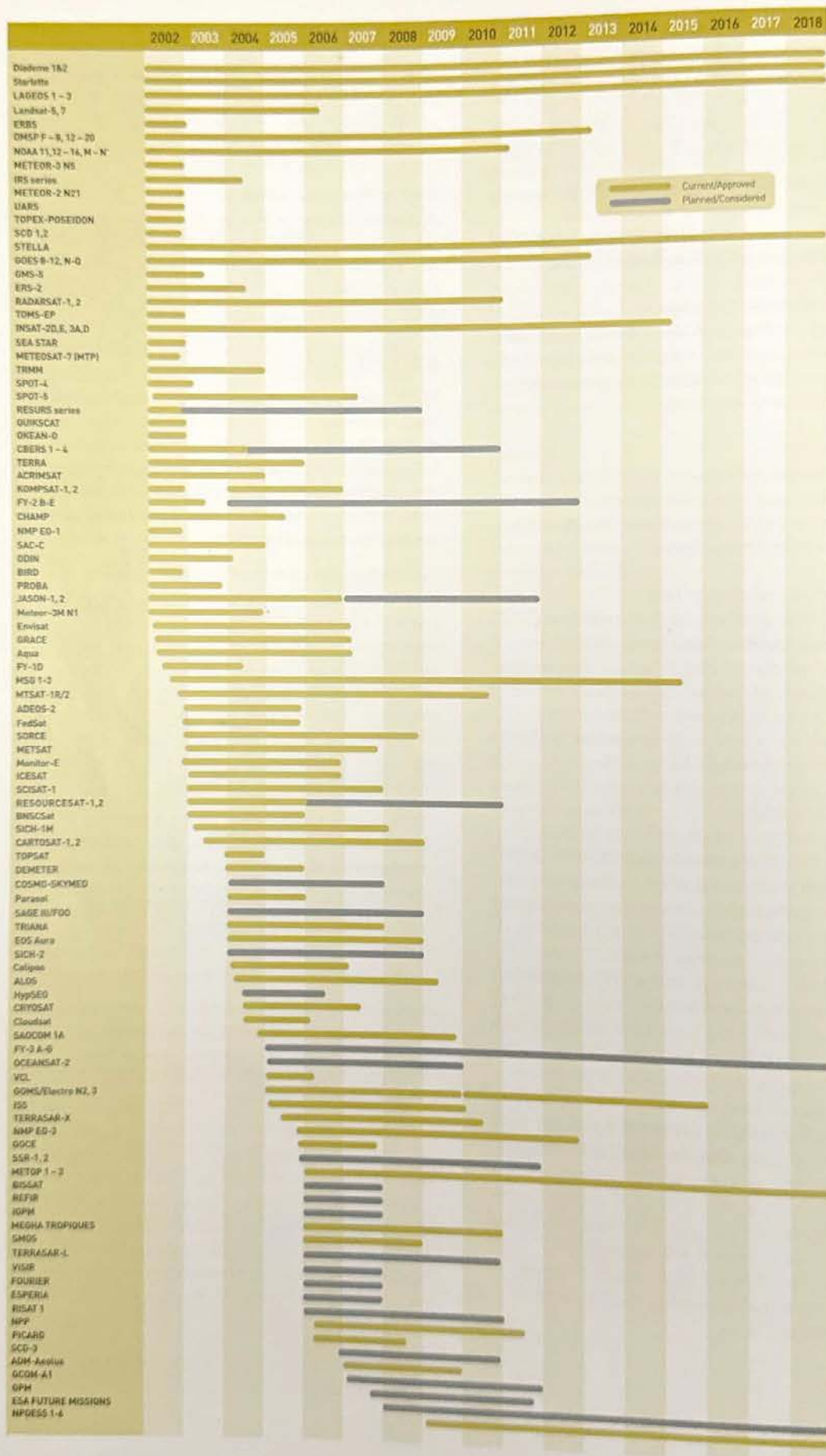
The database was established to support planning of future observing systems, with the primary aim of improving the extent to which space system capabilities meet user requirements for observations. Although many possible uses have been identified for the database, its structure and level of detail are designed primarily to assist in the assessment of conformance between users' requirements for observations and the potential capability of the space segments of satellite systems. To this end, the following information is included in the Database:

- from the user communities ('Users'), a summary of their observational requirements, as available to CEOS through its partnerships with many user communities;
- from the in-situ observing system operators and space agencies ('Providers'), a summary of the potential performances of their in-situ and satellite instruments, expressed in the same terms as the user requirements;
- instrument and mission descriptions sufficiently detailed to support the evaluation of their performances;
- programmatic information to permit assessment of service continuity aspects.

Those interested in obtaining a copy of the database (available as an MS Access stand-alone application on CD-ROM) for more detailed investigation are encouraged to contact Dr Don Hinsman at WMO:

hinsman_d@gateway.wmo.ch

<http://alto-stratus.wmo.ch/sat/stations/SatSystem.html>



List of satellite missions (chronological)

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Diadème 1&2 CNES	Currently being flown	15-Feb-67	31-Dec-50	Geodetic measurements using satellite laser ranging	RRA	Type: Inclined, non-sunsynchronous Altitude: 584-1733km Period: 108mins Inclination: 40deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: galileo.crl.go.jp/ilsr/diademe.html
STARLETTE CNES	Currently being flown	6-Feb-75	31-Dec-50	Geodesy/gravity Study of the Earth's gravitational field and its temporal variations	Laser reflectors	Type: Inclined, non-sunsynchronous Altitude: 812km Period: 104mins Inclination: 49.83deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
LAGEOS-1 (Laser Geodynamics Satellite-1) NASA	Currently being flown	4-May-76	4-May-16	Geodesy, crustal motion and gravity field measurements by laser ranging	LRA (LAGEOS)	Type: Inclined, non-sunsynchronous Altitude: 6000km Period: 225mins Inclination: 110deg Repeat cycle: LST: Longitude (if geo): Asc/desc:
Landsat-5 USGS	Currently being flown	01-Mar-84	31-Dec-04	Earth resources, land surface, environmental monitoring, agriculture and forestry, disaster monitoring and assessment, ice and snow cover	TM, (MSS non-functional)	Type: Sun-synchronous Altitude: 705km Period: 99mins Inclination: 98.2deg Repeat cycle: 16days LST: 09:45 Longitude (if geo): Asc/desc: Descending URL: landsat7.usgs.gov or edc.usgs.gov
ERBS (Earth Radiation Budget Satellite) NASA	Currently being flown	5-Oct-84	1-Jan-03	Earth radiation budget measurements	ERBE, SAGE II	Type: Inclined, non-sunsynchronous Altitude: 585km Period: 96.3mins Inclination: 57deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.earth.nasa.gov/missions/ref_web/erbs.htm
DMSP F-8 (Defense Meteorological Satellite Program F-8) NOAA	Currently being flown	1-Jun-87	31-Aug-03	The long-term meteorological programme of the US Department of Defense (DoD) – with the objective to collect and disseminate worldwide atmospheric, oceanographic, solar-geophysical, and cloud cover data on a daily basis. (Primary operational satellite)	OLS SSB/X, SSM/I, SSM/T-1	Type: Inclined, Sun-synchronous Altitude: 830km Period: 101mins Inclination: 98.7deg Repeat cycle: LST: 05:55 Longitude (if geo): Asc/desc: Descending URL: www.ngdc.noaa.gov/dmsp/dmsp.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
NOAA-T1 (National Oceanic and Atmospheric Administration -11) NOAA	Currently being flown	24-Sep-88	31-Aug-03	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis	NOAA Comms, ARGOS, S&R (NOAA), HIRS/2, AVHRR/2, SBUV/2, SSU, MSU	Type: Inclined, Sun-synchronous Altitude: 845km Period: 101.9mins Inclination: 99.1deg Repeat cycle: 0.5days LST: 22:37 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/
NOAA-12 (National Oceanic and Atmospheric Administration -12) NOAA	Currently being flown	14-May-91	31-Aug-03	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis	ARGOS, AVHRR/2, HIRS/2, MSU, NOAA Comms, SEM (POES)	Type: Sun-synchronous Altitude: 850km Period: 101.3mins Inclination: 98.5deg Repeat cycle: LST: 04:49 Longitude (if geo): Asc/desc: Descending URL: www.oso.noaa.gov/poes/
METEOR-3 N5 Roshydromet	Currently being flown	15-Aug-91	31-Dec-02	Currently limited operation only MR-900B instrument is working! Hydrometeorology, climatology, land surface, physical oceanography, heliogeophysics, data collection	MR-900B	Type: Inclined, non-sunsynchronous Altitude: 1200km Period: 109mins Inclination: 82.5deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: sputnik1.infospace.ru
IRS-1B (Indian Remote Sensing Satellite - 1B) ISRO	Currently being flown	28-Aug-91	31-Aug-02	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils	LISS-I, LISS-II	Type: Sun-synchronous Altitude: 904km Period: 101mins Inclination: 99deg Repeat cycle: 26 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL:
METEOR-2 N21 Roshydromet	Currently being flown	31-Aug-91	31-Dec-02	Currently limited operation only 1 instrument working! Hydrometeorology, climatology, land surface, physical oceanography, heliogeophysics, data collection	MR-900B	Type: Inclined, non-sunsynchronous Altitude: 109km Period: 109mins Inclination: 82.5deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: sputnik1.infospace.ru
UARS (Upper Atmosphere Research Satellite) NASA	Currently being flown	15-Sep-91	31-Dec-02	Atmospheric chemistry (middle to upper atmosphere), atmospheric dynamics/water and energy cycles. HALOE, HRDI, MLS, PEM instruments still functioning. End date TBD	HALOE, HRDI, MLS, PEM, SOLSTICE, SUSIM (UARS), WINDII	Type: Inclined, non-sunsynchronous Altitude: 585km Period: 96.7mins Inclination: 57deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: daac.gsfc.nasa.gov/CAMPAIGN_DOCS/UARS_project.html
Topex-Poseidon NASA/JNES	Currently being flown	10-Aug-92	31-Dec-02	Physical oceanography, geodesy/gravity	DORIS, GPSDR, LRA, POSEIDON-1 (SSALT-1), TMR, TOPEX	Type: Inclined, non-sunsynchronous Altitude: 1336km Period: 112mins Inclination: 66deg Repeat cycle: 10days LST: Longitude (if geo): Asc/desc: N/A URL: topex-www.jpl.nasa.gov/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
LAGEOS-2 (Laser Geodynamics Satellite - 2) NASA	Currently being flown	22-Oct-92	22-Oct-32	Geodesy, crustal motion and gravity field measurements by laser ranging	LRA (LAGEOS)	Type: Inclined, non-sunsynchronous Altitude: 5900km Period: 223mins Inclination: 52deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
SCD-1 (Data Collecting Satellite 1) INPE	Currently being flown	09-Feb-93	01-Dec-02	Data collection and communication	DCP (SCD)	Type: Inclined, non-sunsynchronous Altitude: 750km Period: 100mins Inclination: 25deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.inpe.br/programas/mecb/default.htm
STELLA CNES	Currently being flown	30-Sep-93	31-Dec-50	Geodesy/gravity Study of the Earth's gravitational field and its temporal variations	Laser reflectors	Type: Inclined, non-sunsynchronous Altitude: 830km Period: 101mins Inclination: 98deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL:
GOES-8 (Geostationary Operational Environmental Satellite - 8) NOAA	Currently being flown	13-Apr-94	31-Aug-03	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, WEFAX	Type: Geostationary Altitude: Period: Inclination: 0.09deg Repeat cycle: LST: Longitude (if geo): 75 Asc/desc: URL: www.oso.noaa.gov/goes/
DMSP F-12 (Defence Meteorological Satellite Program F-12) NOAA	Currently being flown	01-Aug-94	31-Aug-03	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide atmospheric, oceanographic, solar-geophysical, and cloud cover data on a daily basis	OLS, SSB/X-2, SSIES-2, SSJ/4, SSM, SSM/I, SSM/T-1, SSM/T-2	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.7deg Repeat cycle: LST: 19.29 Longitude (if geo): Asc/desc: Ascending URL: www.ngdc.noaa.gov/dmsp/dmsp.html
IRS-P2 (Indian Remote Sensing Satellite - P2) ISRO	Currently being flown	15-Oct-94	31-Mar-03	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils	LISS-II	Type: Sun-synchronous Altitude: 904km Period: 103mins Inclination: 98deg Repeat cycle: 22 days LST: 10:15 Longitude (if geo): Asc/desc: Descending URL:
NOAA-14 (National Oceanic and Atmospheric Administration - 14) NOAA	Currently being flown	30-Dec-94	31-Aug-03	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis	ARGOS, AVHRR/2, HIRS/2, MSU, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES), SSU	Type: Sun-synchronous Altitude: 850km Period: 102.1mins Inclination: 99.1deg Repeat cycle: LST: 17:52 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/
GMS-5 (Geostationary Meteorological Satellite - 5) JMA/NASDA	Currently being flown	18-Mar-95	01-Jun-03	Meteorology	DCS (NASDA), GMS Comms, VISSR (GMS-5)	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): ~140 Asc/desc: N/A URL: www.nasda.go.jp/sat/gms/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
ERS-2 [European Remote Sensing Satellite - 2] ESA	Currently being flown	21-Apr-95	30-Jun-04	Earth resources plus physical oceanography, ice and snow, land surface, meteorology, geodesy/gravity, environmental monitoring, atmospheric chemistry	AMI/SAR/Image, AMI/SAR/wave, AMI-scatterometer, ATSR/M, ATSR-2, ERS Comms, GOME, MWR, RA	Type: Sun-synchronous Altitude: 782km Period: 100.5mins Inclination: 98.52deg Repeat cycle: 35days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.esa.int/export/esaSA/GGGWBR8RVDC_earth_0.html
GOES-9 [Geostationary Operational Environmental Satellite - 9] NOAA	Currently being flown	23-May-95	31-Aug-03	Meteorology (primary mission), search and rescue, space environmental monitoring, data collection, platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, WEFAX	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 105 Asc/desc: N/A URL: www.oso.noaa.gov/goes/
RADARSAT-1 CSA	Currently being flown	04-Nov-95	01-Nov-03	Environmental monitoring, physical oceanography, ice and snow, land surface	SAR (RADARSAT)	Type: Sun-synchronous Altitude: 798km Period: 100.7mins Inclination: 98.594deg Repeat cycle: 24days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.space.gc.ca/csa_sectors/earth_environment/radarsat/default.asp
IRS-1C [Indian Remote Sensing Satellite - 1C] ISRO	Currently being flown	28-Dec-95	28-Dec-02	Land surface, agriculture and forestry regional geology, land use studies, water resources, vegetation studies, coastal studies and soils, cartography, digital terrain models	LISS-III, PAN, WiFS	Type: Sun-synchronous Altitude: 817km Period: 101.35mins Inclination: 98.6deg Repeat cycle: 24 days LST: 10:50 Longitude (if geo): Asc/desc: Descending URL:
IRS-P3 [Indian Remote Sensing Satellite - P3] ISRO	Currently being flown	21-Mar-96	31-Mar-03	Ocean biology, physical oceanography, land surface, agriculture and forestry, water resources, vegetation and coastal studies	MOS, WiFS, X-ray astronomy payload	Type: Sun-synchronous Altitude: 817km Period: 101.35mins Inclination: 98.7deg Repeat cycle: 24 days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL:
TOMS-EP [Total Ozone Mapping Spectrometer Earth Probe] NASA	Currently being flown	02-Jul-96	01-Jan-03	Atmospheric Chemistry, Ozone and sulphur dioxide measurements. End date TBD	TOMS	Type: Sun-synchronous Altitude: 740km Period: 104.4mins Inclination: 98.365deg Repeat cycle: LST: 11:10 Longitude (if geo): Asc/desc: Ascending URL: jwocky.gsfc.nasa.gov/ep/toms/ep.html
DMSP F-13 [Defense Meteorological Satellite Program F-13] NOAA	Currently being flown	01-Mar-97	31-Aug-03	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide atmospheric, oceanographic, solar-geophysical and cloud cover data on a daily basis	OLS, SSB/X-2, SSIES-2, SSJ/4, SSM, SSM/I, SSM/T-1, SSM/T-2, SSZ	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.7deg Repeat cycle: LST: 18:12 Longitude (if geo): Asc/desc: Ascending URL: www.ngdc.noaa.gov/dmsp/dmsp.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
DMSP F-14 (Defense Meteorological Satellite Program F-14) NOAA	Currently being flown	04-Apr-97	31-Aug-03	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide atmospheric, oceanographic, solar-geophysical, and cloud cover data on a daily basis.	OLS, SS8/X-2, SSIES-2, SSJ/4, SSM, SSM/I, SSM/T-1, SSM/T-2, SSZ	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.7deg Repeat cycle: LST: 20.29 Longitude (if geo): Asc/desc: Ascending URL: www.ngdc.noaa.gov/dmsp.html
INSAT-2D (Indian National Satellite - 2D) ISRO	Currently being flown	06-Apr-97	01-Jan-03	Meteorology, data collection and communication, search and rescue	BSS & FSS transponders, DRT-S&R, INSAT Comms	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): -74 Asc/desc: URL:
GOES-10 (Geostationary Operational Environmental Satellite - 10) NOAA	Currently being flown	25-Apr-97	31-Aug-03	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS INOAAI, GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, WEFAX	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 135 Asc/desc: URL: www.oso.noaa.gov/goes/
SeaWiFS NASA	Currently being flown	01-Aug-97	31-Dec-02	Ocean-colour data, ocean biology and ecology, phytoplankton concentrations and growth, pollution, algal bloom monitoring	SeaWiFS	Type: Sun-synchronous Altitude: 705km Period: 99mins Inclination: 98.2deg Repeat cycle: 16days LST: 12.00 Longitude (if geo): Asc/desc: Descending URL: www.xs4all.nl/~carlkop/seawif.html
METEOSAT-7 (MTP) (Meteosat Transition Programme) EUMETSAT	Currently being flown	03-Sep-97	30-Sep-02	Meteorology, climatology	METEOSAT Comms, MVIRI	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/mtp/index/html
IRS-1D (Indian Remote Sensing Satellite - 1D) ISRO	Currently being flown	29-Sep-97	29-Sep-04	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils	LISS-III, PAN, WIFS	Type: Sun-synchronous Altitude: 817km Period: 101mins Inclination: 98.6deg Repeat cycle: 24 days LST: 10.50 Longitude (if geo): Asc/desc: Descending URL:
TRMM (Tropical Rainfall Measuring Mission) NASA/JAXA	Currently being flown	27-Nov-97	31-Dec-04	Atmospheric dynamics/water and energy cycles	CERES, LIS, PR, TMI, VIRS	Type: Inclined, non-sunsynchronous Altitude: 350km Period: 91mins Inclination: 35deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.eorc.nasda.go.jp/TRMM/index_e.htm
SPOT-4 (Satellite Pour l'Observation de la Terre - 4) CNES	Currently being flown	24-Mar-98	01-Mar-03	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring	DDRIS, HRVIR, VEGETATION	Type: Sun-synchronous Altitude: 832km Period: 101mins Inclination: 98.7deg Repeat cycle: 26days LST: 10.30 Longitude (if geo): Asc/desc: Descending URL: www.spot.com/home/system/introsat/welcome.htm

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
NOAA-15 (National Oceanic and Atmospheric Administration - 15) NOAA	Currently being flown	01-May-98	31-Aug-03	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, space environment, solar flux analysis, search and rescue	AMSU-A, AMSU-B, ARGOS, AVHRR/3, HIRS/3, NOAA Comms, S&R (NOAA), SEM (POES)	Type: Sun-synchronous Altitude: 813km Period: 101.4mins Inclination: 98.6deg Repeat cycle: LST: 07:08 Longitude (if geo): Asc/desc: Descending URL: www.oso.noaa.gov/poes/
Resurs-D1 N4 Rosavakosmos	Currently being flown	10-Jul-98	31-Aug-02	Environmental monitoring, agriculture and forestry, hydrology, hydrometeorology, ice and snow, land surface, agriculture, disaster management. Currently only providing data from MR-900B instrument	ISP, MR-900B, MSU-E, MSU-SK, RMK-2, ScaRaB/M/MV2	Type: Sun-synchronous Altitude: 850km Period: 101mins Inclination: 98.75deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: sputnik1.infospace.ru
SCD-2 (Data Collecting Satellite 2) INPE	Currently being flown	22-Oct-98	01-Dec-02	Data collection and communication	DCP (SCD)	Type: Inclined, non-sunsynchronous Altitude: 750km Period: 100mins Inclination: 25deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.inpe.br/programas/mecb/default.htm
INSAT-2E (Indian National Satellite - 2E) ISRO	Currently being flown	04-Mar-99	04-Mar-11	Meteorology, data collection and communication, search and rescue	BSS & FSS transponders, DRT-S&R, INSAT Comms	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): -83 Asc/desc: URL:
Landsat-7 USGS	Currently being flown	15-Apr-99	15-Apr-04	Land surface, Earth resources	ETM+, LANDSAT Comms	Type: Sun-synchronous Altitude: 705km Period: 99mins Inclination: 98.2deg Repeat cycle: 16days LST: 10:00 Longitude (if geo): Asc/desc: Descending URL:
IRS-P4 (OCEANSAT-1) ISRO	Currently being flown	26-May-99	26-May-04	Ocean biology, physical oceanography	MSMR, OCM, WIFS	Type: Sun-synchronous Altitude: 720km Period: 99.31mins Inclination: 98.28deg Repeat cycle: 2days LST: 12:15 Longitude (if geo): Asc/desc: URL:
QuikSCAT (QuikSCAT/Sea Winds) NASA	Currently being flown	19-Jan-99	01-Jan-03	Acquires accurate, high-resolution, global measurements of sea-surface wind vectors in 1 to 2 day repeat cycles for studies of tropospheric dynamics and air-sea interaction processes, including air-sea momentum transfer. End of life date TBD	SeaWinds	Type: Sun-synchronous Altitude: 803km Period: Inclination: 98.6deg Repeat cycle: LST: 06:00 Longitude (if geo): Asc/desc: Ascending URL: winds.jpl.nasa.gov/missions/quikscat/quikindex.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
OKEAN-O ROSHYDROMET	Currently being flown	17-Jul-99	31-Dec-02	Oceanography, agriculture and forestry, hydrology, environmental monitoring, crop and soil monitoring, forest and tundra fires, pollution monitoring	DELTA-2D, KONDOR-2, MSU-M, MSU-SK, MSU-V, R-600, RLSBO, TRASSER	Type: Sun-synchronous Altitude: 670km Period: 98mins Inclination: 98deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL: sputnik1.infospace.ru
CBERS-1 (China Brazil Earth Resources Satellite-1) CASTANPE	Currently being flown	14-Oct-99	01-Dec-02	Earth resources, environmental monitoring, land surface	CCD, DCP, IR-MSS, WFI	Type: Sun-synchronous Altitude: 778km Period: 100.26mins Inclination: 98.5deg Repeat cycle: 26days LST: 10:50 Longitude (if geo): Asc/desc: Descending URL: www.inpe.br/programas/cbers/english/index.html
DMSP F-15 (Defense Meteorological Satellite Program F-15) NOAA	Currently being flown	12-Dec-99	31-Aug-03	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide atmospheric, oceanographic, solar-geophysical, and cloud cover data on a daily basis. [Primary operational satellite]	OLS, SSIES-2, SSJ/4, SSM, SSM/I, SSM/T-1, SSM/T-2, SSZ	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.9deg Repeat cycle: LST: 20:29 Longitude (if geo): Asc/desc: Ascending URL: www.ngdc.noaa.gov/dmsp/dmsp.html
Terra (formerly EOS AM-1) NASA	Currently being flown	18-Dec-99	18-Dec-05	Atmospheric dynamics/water and energy cycles, Atmospheric chemistry, Physical and radiative properties of clouds, air-land exchanges of energy, carbon and water, vertical profiles of CO and methane volcanology	ASTER, CERES, MISR, MODIS, MOPITT	Type: Sun-synchronous Altitude: 705km Period: 99mins Inclination: 98.2deg Repeat cycle: 16days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: terra.nasa.gov/
ACRIMSAT (Active Cavity Radiometer Irradiance Monitor) NASA	Currently being flown	20-Dec-99	01-Jan-05	Will sustain long-term solar luminosity database by providing measurements of total solar irradiance and the solar constant	ACRIM III	Type: Sun-synchronous Altitude: 716km Period: Inclination: 98.13deg Repeat cycle: LST: 10:50 Longitude (if geo): Asc/desc: Ascending URL: acrim.jpl.nasa.gov
KOMPSAT-1 (Korea Multi-Purpose Satellite 1) KARI	Currently being flown	21-Dec-99	21-Dec-02	Cartography, land use and planning, disaster monitoring, Global marine resource and environmental monitoring, ocean contamination and chlorophyll detection	EOC, OSMI	Type: Sun-synchronous Altitude: 685km Period: 98.5mins Inclination: Repeat cycle: 28days LST: 10:50 Longitude (if geo): Asc/desc: Ascending URL: kompsat.kari.re.kr/english/index.asp
GOES-11 (Geostationary Operational Environmental Satellite - 11) NOAA	Currently being flown	03-May-00	03-May-05	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, WEFAX	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 103 Asc/desc: N/A URL: www.oso.noaa.gov/goes/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
FY-2B (FY-2B Geostationary Meteorological Satellite) NRSSC	Currently being flown	25-Jun-00	30-Jun-03	Meteorology and environmental monitoring Data collection and redistribution	VISSR (FY-2)	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): ~105 Asc/desc: URL:
CHAMP (Challenging Mini-Satellite Payload for Geophysical Research and Application) DLR	Currently being flown	15-Jul-00	15-Jul-05	Gravity field, Precise geoid, Magnetic field, Atmospheric physics	CHAMP GPS Sounder, CHAMP gravity package (Accelerometer, GPS), CHAMP magnetometry package (1 Scalar+2 Vector Magnetometer), GPSDR	Type: Inclined, non-sunsynchronous Altitude: 470km Period: Inclination: 87deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: op.gfz-potsdam.de/champ/index_CHAMP.html
NOAA-16 (National Oceanic and Atmospheric Administration - 16) NOAA	Currently being flown	21-Sep-00	01-Jun-04	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue	AMSU-A, AMSU-B, ARGOS, AVHRR/3, HIRS/3, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES)	Type: Sun-synchronous Altitude: 870km Period: 102mins Inclination: 98.8deg Repeat cycle: LST: 13:54 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/
NMP EO-1 (New Millennium Program EO-1) NASA	Currently being flown	21-Nov-00	21-Nov-02	Land surface, earth resources	ALI, Atmospheric Corrector, Hyperion	Type: Sun-synchronous Altitude: 705km descending in formation with Landsat-7 Period: 99mins Inclination: 98.2deg Repeat cycle: 16days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: eo1.gsfc.nasa.gov/miscPages/home.html
SAC-C (CARTOSAT) ISRO	Currently being flown	21-Nov-00	01-Dec-04	Earth Observation, studies the structure and dynamics of the Earth's surface, atmosphere, ionosphere and geomagnetic field	GOLPE, HRTC, HSTC, ICARE, INES, IST, MMP, MMRS, WTE	Type: Sun-synchronous Altitude: 705km Period: 98mins Inclination: 98.2deg Repeat cycle: 9days LST: 10:15 Longitude (if geo): Asc/desc: Descending URL: www.CONAE.gov.ar
Odin SIS	Currently being flown	20-Feb-01	20-Feb-04	Atmospheric research, stratospheric ozone chemistry, mesospheric ozone science, summer mesospheric science	OSIRIS, SMR	Type: Sun-synchronous Altitude: 625km Period: 97.6mins Inclination: 97.8deg Repeat cycle: LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.ssc.se/ssd/ssat/odin.html and www.snsb.se
GOES-12 (Geostationary Operational Environmental Satellite - 12) NOAA	Currently being flown	23-Jul-01	23-Jul-06	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, S&R (GOES), SEM (GOES), Sounder, SXI, WEFAX	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 90 Asc/desc: N/A URL: www.oso.noaa.gov/goes/

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
BIRD (Bi-spectral Infrared Detection small satellite) DLR	Currently being flown	22-Oct-01	31-Oct-02	Small satellite mission with technical (infrared push-broom sensors, on-board data processing) and scientific (Study of thermal processes on the Earth surface) objectives	HSRS, WAOSS-B	Type: Sun-synchronous Altitude: 572km Period: Inclination: 97.8deg Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: spacesensors.dlr.de/SE/bird/
PROBA (Project for On-Board Autonomy) ESA	Currently being flown	22-Oct-01	22-Oct-03	PROBA is a technology experiment to demonstrate the on-board autonomy of a generic platform suitable for small scientific or application missions. A number of earth observation instruments are included	CHRIS	Type: Sun-synchronous Altitude: 560-670km Period: 96.9mins Inclination: 97.9deg Repeat cycle: 16days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.chris-proba.org.uk/ & www.estec.esa.nl/www/ES/PROBA.html
Jason-1 NASA/CNES	Currently being flown	07-Dec-01	07-Dec-06	Physical oceanography, geodesy/gravity, climate monitoring, marine meteorology	DORIS-NG, JMR, LRA, POSEIDON-2 (SSALT-2), TRSR	Type: Inclined, non-sunsynchronous Altitude: 1336km Period: 122.4mins Inclination: 66deg Repeat cycle: 10days LST: Longitude (if geo): Asc/desc: N/A URL: irs.gsfc.nasa.gov/irs/jason1.html
METEOR-3M NI Rostov-based Russian mission	Currently being flown	10-Dec-01	31-Dec-04	Hydrometeorology, climatology, land surface, physical oceanography, heliogeophysics and space environment, sounding of the atmosphere, agriculture. (Expected operational during 2002)	KGI-4C, Klimat, MIVZA, MR-2000M1, MSGI-5EI, MSU-E, MSU-SM, MTVZA, SAGE III, SFM-2	Type: Sun-synchronous Altitude: 1018km Period: 105.3mins Inclination: 99.6deg Repeat cycle: days LST: 09:25 Longitude (if geo): Asc/desc: Ascending URL: sputnik1.infospace.ru
Envisat (Environmental Satellite) ESA	Currently being flown	01-Mar-02	01-Mar-07	Physical oceanography, land surface, ice and snow, atmospheric chemistry, atmospheric dynamics/water and energy cycles	AATSR, ASAR, ASAR (image model), ASAR (wave model), DORIS-NG, ENVISAT Comms, GOMOS, MERIS, MIPAS, MWR, RA-2, SCIAMACHY	Type: Sun-synchronous Altitude: 782km Period: 100.5mins Inclination: 98.52deg Repeat cycle: 35days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: envisat.esa.int
GRACE (Gravity Recovery and Climate Experiment) NASA	Currently being flown	17-Mar-02	01-Mar-07	Extremely high precision gravity measurements for use in construction of gravity field models	GPSR, HAIRS	Type: Inclined, non-sunsynchronous Altitude: 300-500km Period: Inclination: 89deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.csr.utexas.edu/grace/
Aqua NASA	Currently being flown	04-May-02	04-May-07	Atmospheric dynamics/water and energy cycles, cloud formation, precipitation and radiative properties, air-sea fluxes of energy and moisture, sea ice extent and heat exchange with the atmosphere. Option of 705km or 438km orbit altitude	AIRS, AMSR-E, AMSU-A, CERES, HSB, MODIS	Type: Sun-synchronous Altitude: 705km Period: 98.8mins Inclination: 98.2deg Repeat cycle: 16days LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: aqua.gsfc.nasa.gov/menu.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
SPOT-5 [Satellite Pour l'Observation de la Terre - 5] CNES	Currently being flown	04-May-02	04-May-07	Cartography, land surface, agriculture and forestry, civil planning and mapping, digital terrain models, environmental monitoring	DORIS-NG, HRG, HRS, VEGETATION	Type: Sun-synchronous Altitude: 832km Period: 101mins Inclination: 98.7deg Repeat cycle: 26days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.spotimage.fr/home/system/future/spot5/welcome.htm
FY-1D [FY-1D Polar- orbiting Meteorological Satellite] NRSCC	Currently being flown	15-May-02	31-May-04	Meteorology, Environmental monitoring	MVISR (10 channels)	Type: Sun-synchronous Altitude: 863km Period: 102.3mins Inclination: 98.8deg Repeat cycle: LST: 09:00 Longitude (if geo): Asc/desc: Descending URL:
INSAT 3A [Indian National Satellite - 3A] ISRO	Approved	01-Jun-02	01-Jun-14	Meteorology, data collection and communication, search and rescue	CCD camera, VHRR	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 93.5 Asc/desc: URL:
NOAA-M [National Oceanic and Atmospheric Administration - M] NOAA	Approved	25-Jun-02	01-Mar-06	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue	AMSU-A, AMSU-B, ARGOS, AVHRR/3, HIRS/3, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES)	Type: Sun-synchronous Altitude: 833km Period: 101.4mins Inclination: 98.75deg Repeat cycle: LST: 10:00 Longitude (if geo): Asc/desc: Descending URL: www.oso.noaa.gov/poes/
MSG-1 [Meteosat Second Generation-1] EUMETSAT	Approved	13-Aug-02	13-Aug-09	Meteorology, climatology, Atmospheric dynamics/water and energy cycles	GERB, MSG Comms, SEVIRI	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html
CBERS-2 [China Brazil Earth Resources Satellite - 2] CAST/NPE	Approved	18-Aug-02	18-Aug-07	Earth resources, environmental monitoring, land surface	CCD, DCP, IR-MSS, WFI	Type: Sun-synchronous Altitude: 778km Period: 100.26mins Inclination: 98.5deg Repeat cycle: 26days LST: 10:50 Longitude (if geo): Asc/desc: Descending URL: www.inpe.br/programas/cbers/english/index.html
MTSAT-1R [Multi- functional Transport Satellite] JMA	Approved	01-Sep-02	01-Sep-07	Meteorology, aeronautical applications	IMAGER/MTS AT-1R, MTSAT Comms	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): -140 Asc/desc: N/A URL:
DMSP F-16 [Defense Meteorological Satellite Program F-16] NOAA	Approved	06-Oct-02	01-Aug-05	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis	OLS, SSIES-3, SSJ/S, SSM, SSM/T-1, SSMIS, SSULI, SSUSI	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.9deg Repeat cycle: LST: 21:32 Longitude (if geo): Asc/desc: Ascending URL: www.ngdc.noaa.gov/dmsp/dmsp.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
ADEOS-2 [Advanced Earth Observing Satellite - 2] NASA	Approved	01-Nov-02	01-Nov-05	Atmospheric dynamics/water, carbon and energy cycles Land surface Physical oceanography	ADEOS Comms, AMSR, GLI, ILAS-II, POLDER, SeaWinds	Type: Sun-synchronous Altitude: 803km Period: 101mins Inclination: 98.6deg Repeat cycle: 4days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.nasa.gov/ip/sat/adeos2/
FedSat [Australian 100 year Federation Satellite] CRCS 124	Approved	01-Nov-02	01-Nov-05	Communications, data relay, near Earth environment, upper atmospheric physics, meteorology	Communications payload (Ka and UHF band), Fluxgate magnetometer, GPS receiver	Type: Sun-synchronous Altitude: 803km Period: 101mins Inclination: 98.6deg Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: www.crcss.csiro.au
SORCE [Solar Radiation and Climate Experiment] NASA	Approved	01-Nov-02	01-Nov-08	Continues the precise, long-term measurements of total solar irradiance at UV and VNIR wavelengths. Daily measurements of solar UV. Precise measurements of visible solar irradiance for climate studies	SIM, SOLSTICE, TIM, XPS	Type: Inclined, non-sunsynchronous Altitude: 600km Period: Inclination: 40deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: http://lasp.colorado.edu/sorce/
METSAT (SRG)	Approved	01-Dec-02	01-Dec-07	Meteorological applications	VHRR	Type: Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
Monitor-E Rosaviskosmos	Approved	01-Dec-02	01-Dec-05	Agriculture and forestry, hydrology, environmental monitoring, hydrometeorology, ice and snow, land surface, meteorology	TBC	Type: Altitude: 540km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
ICESat [Ice, Clouds, and Elevation Satellite] NASA	Approved	15-Dec-02	15-Dec-06	Monitors mass balance of polar ice sheets and their contribution to global sea level change. Secondary goals: cloud heights and vertical structure of clouds/aerosols; roughness, reflectivity, vegetation heights, snow-cover	GLAS, GPSDR	Type: Inclined, non-sunsynchronous Altitude: 600km Period: 97mins Inclination: 94deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: icesat.gsfc.nasa.gov/
SCISAT-1 [sciasat-1] CSA	Approved	20-Dec-02	20-Dec-07	To improve our understanding of the depletion of the ozone layer, particularly over Canada and the Arctic	ACE-FTS, MAESTRO	Type: Sun-synchronous Altitude: 650km Period: Inclination: 74deg Repeat cycle: 15days LST: Longitude (if geo): Asc/desc: URL: www.space.gc.ca/scisat1
RESOURCESAT-1 (SRG)	Approved	01-Jan-03	01-Jan-08	Natural Resources Management, Agricultural applications, Forestry	AWiFS, LISS-III, LISS-IV	Type: Sun-synchronous Altitude: 817km Period: 102mins Inclination: 98.72deg Repeat cycle: 26days LST: 10:30 Longitude (if geo): Asc/desc: Descending URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
BNSCSat [Disaster Monitoring Constellation] BNSC	Approved	01-Jan-03	01-Jan-06	Medium resolution visible imager for support of disaster management	DMC Imager	Type: TBD Altitude: 700km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.sstl.co.uk/missions/
INSAT 3D [Indian National Satellite - 3D] ISRO	Approved	01-Jan-03	01-Jan-15	Meteorology, data collection and communication, search and rescue	Imager (INSAT), Sounder (INSAT)	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 83 Asc/desc: URL:
Resurs DK Resursniks	Planned	01-Jan-03	31-Dec-06	Agriculture and forestry, hydrology, environmental monitoring, hydrometeorology, ice and snow, land surface, meteorology	Multispectral high resolution scanner	Type: Sun-synchronous Altitude: 670km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
GOES-N [Geostationary Operational Environmental Satellite - N] NOAA	Approved	07-Jan-03	07-Jan-08	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, SEM (GOES), S&R (GOES), Sounder, SXI, WEFAX	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: www.oso.noaa.gov/goes/
SICH-1M NSAU	Approved	01-Mar-03	01-Mar-08	Physical Oceanography, Hydrometeorology, Land Observation	MSU-EU, MSU-M, MTVZA-OK, RLSBO, RM-08	Type: Sun-synchronous Altitude: 650km Period: 98mins Inclination: 82.5deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
CARTOSAT-1 ISRO	Approved	01-Jun-03	01-Jan-08	Cartography, digital terrain models, civil planning, resource and cadastre management	PAN	Type: Sun-synchronous Altitude: 630km Period: 94.44mins Inclination: 97.44deg Repeat cycle: LST: 09:30 Longitude (if geo): Asc/desc: Descending URL:
DEMETER [Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions] CNES	Approved	01-Dec-03	01-Dec-05	Micro-satellite to study: ionospheric disturbances related to seismic activity, ionospheric disturbances related to human activity, pre and post-seismic effects in the global information on the Earth's electromagnetic environment	IAP, ICE, IDP, IMSC, ISL	Type: Sun-synchronous Altitude: 800km Period: Inclination: Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: TBD URL: www-project.cst.cnes.fr/8060/DEMETER/index/html
TopSat [Optical Imaging Satellite] BNSC	Approved	01-Dec-03	01-Dec-04	Prototype low-cost high-resolution imager	TOPSAT telescope	Type: Sun-synchronous Altitude: 600km Period: Inclination: 98deg Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: URL: www.qinetiq.com/industries/space/spacecraft_technology/case_study_topsat/index.asp

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
COSMO-SkyMed (Constellation of small Satellites for Mediterranean basin Observation) ASI	Planned	31-Dec-03	31-Dec-08	Environmental monitoring, surveillance and risk management applications, environmental resources management, maritime management, earth topographic mapping, law enforcement, informative/science applications	SAR 2000	Type: Sun-synchronous Altitude: 619km Period: 97.86mins Inclination: Repeat cycle: 16days LST: 06:00 Longitude (if geo): Asc/desc: Ascending URL: www.alespazio.it/program/tlr/cosmo/cosmo.htm
FY-2C (FY-2C Geostationary Meteorological Satellite) NRSCC	Planned	31-Dec-03	31-Dec-06	Meteorology and environmental monitoring Data collection and redistribution	IVISSR (FY-2)	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: URL:
EOS Aura (Earth Observing System - Aura) NASA	Approved	01-Jan-04	01-Jan-09	Chemistry and dynamics of Earth's atmosphere from the ground through the mesosphere	HIRDLS, MLS (EOS-Aura), OMI, TES	Type: Sun-synchronous Altitude: 705km Period: 98.8mins Inclination: 98.2deg Repeat cycle: 16days LST: 13:45 Longitude (if geo): Asc/desc: Ascending URL: aura.gsfc.nasa.gov/
KOMPSAT-2 (Korea Multi-Purpose Satellite 2) KARI	Approved	01-Jan-04	01-Jan-07	Cartography, land use and planning, disaster monitoring	MSC	Type: Sun-synchronous Altitude: 685km Period: 98.5mins Inclination: Repeat cycle: 28days LST: 10:50 Longitude (if geo): Asc/desc: Ascending URL: komsat.kari.re.kr/english/index.asp
PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a LIDAR) CNES	Approved	01-Jan-04	01-Jan-06	Micro-satellite with the aim of characterisation of the clouds and aerosols microphysical and radiative properties, needed to understand and model the radiative impact of clouds and aerosols	POLDER-P	Type: Sun-synchronous Altitude: 700km Period: Inclination: Repeat cycle: LST: 12:00 Longitude (if geo): Asc/desc: URL: www-projet.cst.cnes.fr:8060/PARASOL/index.html
SAGE III/FOO (SAGE III flight of opportunity) NASA	Planned	01-Jan-04	01-Jan-09	Stratospheric Aerosols and Gas Monitoring. A flight of opportunity is being sought for the SAGE III instrument	SAGE III	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www-sage3.larc.nasa.gov/
SICH-2 NSAU	Considered	01-Jan-04	01-Jan-09	Physical Oceanography, Hydrometeorology, Land Observation	MSU-UM, SU-UMS, SU-VR	Type: Sun-synchronous Altitude: 650km Period: 98mins Inclination: 98deg Repeat cycle: LST: 10:50 Longitude (if geo): Asc/desc: URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
Triana NASA	Approved	01-Jan-04	01-Jan-08	Continuously observes the sunlit Earth (full disk) - transmitting an image every 15 minutes for distribution by internet. Studies how solar radiation affects climate. Will be positioned at the Lagrange point between Earth and sun. Launch date TBD	EPIC, NISTAR, Plasma-Mag	Type: TBD Altitude: Lagrange 1km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: triana.gsfc.nasa.gov/home/
DMSP F-17 (Defence Meteorological Satellite Program F-17) NOAA	Approved	01-Feb-04	01-Jun-07	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis	OLS, SSIES-3, SSJ/5, SSM, SSM/T-1, SSMIS, SSULI, SSUSI	Type: Sun-synchronous Altitude: 850km Period: 101mins Inclination: 98.7deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.ngdc.noaa.gov/dmsp/dmsp.html
RADARSAT-2 CSA	Approved	01-Mar-04	01-Feb-11	Environmental monitoring, physical oceanography, ice and snow, land surface	SAR (RADARSAT-2)	Type: Sun-synchronous Altitude: 798km Period: 100.7mins Inclination: 98.6deg Repeat cycle: 24days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.space.gc.ca/csa_sectors/earth_environment/radarsat2/default.asp
CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) NASA/CNES	Approved	01-Apr-04	01-Apr-07	Measurements of aerosol and cloud properties for climate predictions, using a 3 channel lidar and passive instruments in formation with Aqua and CloudSat for coincident observations of radiative fluxes and atmospheric state	IIR, Lidar, WFC	Type: Sun-synchronous Altitude: 705km - formation with Aqua Period: Inclination: 98.2deg Repeat cycle: LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www-essp3.larc.nasa.gov/outreach.html
CRYOSAT (CryoSat (Earth Explorer Opportunity Mission)) ESA	Approved	01-Apr-04	01-Apr-07	A radar altimetry mission to determine variations in the thickness of the Earth's continental ice sheets and marine ice cover. Primary objective is to test the prediction of thinning arctic ice due to global warming	DORIS-NG, Laser reflectors (ESA), SIRAL	Type: Inclined, non-sunsynchronous Altitude: 720km Period: mins Inclination: 92deg Repeat cycle: days LST: Longitude (if geo): Asc/desc: TBD URL: www.esa.int/export/esaLP/cryosat.html
CloudSat NASA	Approved	01-Apr-04	01-Apr-06	CloudSAT will use advanced radar to 'slice' through clouds to see their vertical structure, providing a completely new observational capability from space. One of first satellites to study clouds on global basis. Will fly in formation with Aqua	CPR (CloudSat)	Type: Sun-synchronous Altitude: 705km in formation with Aqua Period: Inclination: 98.2deg Repeat cycle: LST: 13:35 Longitude (if geo): Asc/desc: Ascending URL: www.earth.nasa.gov/missions/ref_web/mcloud.htm

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
GOES-O (Geostationary Operational Environmental Satellite - O) NOAA	Approved	01-Apr-04	01-Apr-09	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, SEM (GOES), S&R (GOES), Sounder, WEFAX	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 75 Asc/desc: URL: www.oso.noaa.gov/goes/
ALOS (Advanced Land Observing Satellite) NASDA	Approved	01-Jun-04	01-Jun-09	Cartography, digital terrain models, environmental monitoring, disaster monitoring, civil planning, agriculture and forestry, Earth resources, land surface	AVNIR-2, PALSAR, PRISM (ALOS)	Type: Sun-synchronous Altitude: 692km Period: 98.7mins Inclination: 98.16deg Repeat cycle: 46days LST: 10.30 Longitude (if geo): Asc/desc: Descending URL: www.nasda.go.jp/sat/alos/
NOAA-N (National Oceanic and atmospheric Administration - N) NOAA	Approved	01-Jun-04	01-Mar-08	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue	AMSU-A, ARGOS, AVHRR/3, HIRS/4, MHS, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES)	Type: Sun-synchronous Altitude: 870km Period: 102.1mins Inclination: 98.75deg Repeat cycle: LST: 14.00 Longitude (if geo): Asc/desc: Ascending URL: www.oso.noaa.gov/poes/
CARTOSAT-2 ISRO	Approved	01-Jun-04	01-Jan-09	High precision large-scale cartographic mapping of 1:10000 scale and thematic applications (with merged XS data) at 1:4000 scales	HR-PAN	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL:
HypSEO (Hyperspectral Earth Observer) ASI	Planned	30-Jun-04	03-Jun-06	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils	HYC	Type: Sun-synchronous Altitude: 620km Period: 97mins Inclination: 91.87deg Repeat cycle: 16days LST: 10.00 Longitude (if geo): Asc/desc: Descending URL: gpm.gsfc.nasa.gov/
SAOCOM 1A CONAE	Approved	01-Oct-04	01-Oct-09	Emergency management with an L-band SAR	IR Camera (SAOCOM), SAR (SAOCOM)	Type: Sun-synchronous Altitude: 629km Period: 96mins Inclination: 98deg Repeat cycle: 17days LST: 18.00 Longitude (if geo): Asc/desc: Descending URL: www.conae.gov.ar
DMSP F-18 (Defense Meteorological Satellite Program F-18) NOAA	Approved	01-Nov-04	01-Feb-09	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis	OLS, SSIES-3, SSJ/5, SSM, SSM/T-1, SSMIS, SSULI, SSUSI	Type: Sun-synchronous Altitude: 850km Period: 101mins Inclination: 98.7deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.ngdc.noaa.gov/dmsp/dmsp.html
FY-3A (FY-3A Polar-orbiting Meteorological Satellite) NRSCC	Planned	31-Dec-04	31-Dec-06	Meteorology and environmental monitoring, Data collection and redistribution	IRAS, MVIRS, MWAS, MWRI, DP, TOM, VIRR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
VCL (Vegetation Canopy Lidar) NASA	Approved	01-Jan-05	01-May-06	Aim is to characterise the 3-D structure of the Earth. Objectives are: land cover characterisation for terrestrial ecosystem and climate modelling; global reference data set of topographic spot heights, transects. Launch date TBD	GP5DR, MBLA	Type: Inclined, non-sunsynchronous Altitude: 390-410km Period: Inclination: 67deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: essp.gsfc.nasa.gov/vcl/
Resurs 1 N5 Rosaviakosmos	Planned	01-Jan-05	31-Dec-08	Environmental monitoring, agriculture and forestry, hydrology, hydrometeorology, ice and snow, land surface, agriculture, disaster management	OEK DZZ WR	Type: Sun-synchronous Altitude: 680km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
GDMS/Electro N2 (Geostationary Operational Meteorological Satellite -2) Roshydromet	Approved	01-Jan-05	31-Dec-09	Hydrometeorology, climatology, disaster management, space environment, ice and snow, land surface, space environment, data collection and communication	BRK, MSU-GS, RMS	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): -76 Asc/desc: URL: sputnik1.infospace.ru/
METEOR-3M N2 Roshydromet	Approved	01-Jan-05	31-Dec-09	Hydrometeorology, climatology, land surface, physical oceanography, heliogeophysics and space environment, data collection, sounding of the atmosphere, agriculture	BRK, GALS-M, IKFS-2, IR Sounder, MSGI-MKA, MSU-MR, MTVZA, RIMS-M, SKL-M	Type: Sun-synchronous Altitude: 1024km Period: 105.3mins Inclination: 99.6deg Repeat cycle: LST: 10:50 Longitude (if geo): Asc/desc: Ascending URL: sputnik1.infospace.ru
OCEANSAT-2 ISRO	Planned	01-Jan-05	01-Jan-10	Ocean and atmosphere applications	OCM, Scatterometer (ISRO)	Type: Sun-synchronous Altitude: 720km Period: 99.31mins Inclination: 98.28deg Repeat cycle: 2days LST: 12:00 Longitude (if geo): Asc/desc: Descending URL:
MSG-2 (Meteosat Second Generation-2) EUMETSAT	Approved	23-Jan-05	23-Jan-12	Meteorology, climatology, Atmospheric dynamics/water and energy cycles	GERB, MSG Comms, SEVIRI	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html
ISS (International Space Station) NASA	Approved	01-Feb-05	01-Feb-10	Various applications, including platform for EO sensors. Dates here refer to SAGE III instrument on ISS	SAGE III	Type: Inclined, non-sunsynchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: spaceflight.nasa.gov/station/
TerraSAR-X (TerraSAR-X band) DLR	Approved	01-Jul-05	30-Jun-10	Cartography, land surface, civil planning and mapping, digital terrain models, environmental monitoring	X-Band SAR	Type: Sun-synchronous Altitude: 515km Period: 94.85mins Inclination: 97.4deg Repeat cycle: 11days LST: 18:00 Longitude (if geo): Asc/desc: Ascending URL: www.infoterra-global.com/terrasar.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
MTSAT-2 [Multi-functional Transport Satellite] JMA	Approved	01-Sep-05	01-Sep-10	Meteorology, aeronautical applications	IMAGER/MTS AT-2, MTSAT Comms	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): -140 Asc/desc: N/A URL:
EO-3 [GIFTS] [New Millennium Program EO-3 (GIFTS)] NASA	Approved	01-Nov-05	01-Nov-12	Continuous observation of atmospheric temperature, water vapour content and distribution, and the concentration of certain other atmospheric gases as a function of altitude over time - providing a new way to observe weather and the changing atmosphere	GIFTS	Type: Geostationary Altitude: Geo Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: nmp.jpl.nasa.gov/eq3/index.html
GOCE [Gravity Field and Steady-State Ocean Circulation Explorer [Earth Explorer Core Mission]] ESA	Approved	01-Dec-05	01-Dec-07	Research in steady-state ocean circulation, physics of Earth's interior and levelling systems (based on GPS). Will also provide unique data set required to formulate global and regional models of the Earth's gravity field and geoid	EGG, GPS (ESA), Laser reflectors (ESA)	Type: Sun-synchronous Altitude: 250km Period: Inclination: 96.5deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.esa.int/export/esaLP/goce.html
METOP-1 [Meteorological Operational Polar Satellite - 1] EUMETSAT	Approved	01-Dec-05	01-Dec-10	Meteorology, climatology	AMSU-A, ARGOS, ASCAT, AVHRR/3, GOME-2, GRAS, HIRS/4, IASI, MCP, MHS, S&R (NOAA)	Type: Sun-synchronous Altitude: 840km Period: 101.7mins Inclination: 98.8deg Repeat cycle: 5days LST: 09:00 Longitude (if geo): Asc/desc: Descending URL: www.eumetsat.de/en/area4/topic2.html
SSR-1 [Satélite de Sensoriamento Remoto] INPE	Planned	01-Dec-05	01-Dec-09	Earth resources, environmental monitoring, land surface	OBA	Type: Inclined, non-sunsynchronous Altitude: 905km Period: 103mins Inclination: 0deg Repeat cycle: LST: Longitude (if geo): Asc/desc: N/A URL: www.inpe.br/programas/mecb/default.htm
BISSAT [Bistatic SAR mission] ASI	Considered	01-Jan-06	01-Jan-08	Evaluation of bistatic radar cross section of natural and man-made targets, image classification, land surface. Receive-only satellite in formation with main mission (eg COSMO-Skyrmid or ENVISAT)	BISSAT	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
CBERS-3 [China Brazil Earth Resources Satellite - 3] CAST INPE	Considered	01-Jan-06	01-Jan-09	Earth resources, environmental monitoring, land surface	CCD, DCP, IR-MSS, PAN MUX, WFI	Type: Sun-synchronous Altitude: 778km Period: 100.26mins Inclination: 98.5deg Repeat cycle: 27days LST: 11:50 Longitude (if geo): Asc/desc: Descending URL: www.inpe.br/programas/cbers/english/index.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
ESPERIA (Earthquake investigations by Satellite and Physics of the Environment Related to the Ionosphere and Atmosphere) ASI	Considered	01-Jan-06	01-Jan-08	Study of perturbations in the atmosphere and ionosphere caused by electromagnetic waves, short term earthquake prediction	EMA, GPS, LP/RPA, PDA	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
FOURIER ASI	Considered	01-Jan-06	01-Jan-08	Atmospheric physics, radiative properties, climate change	Hycam, Lagrange, PFS	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
RESOURCESAT 2	Planned	01-Jan-06	01-Jan-11	Natural Resources Management: Agricultural applications; Forestry	AWiFS, LISS-III, LISS-IV	Type: Sun-synchronous Altitude: 817km Period: 102mins Inclination: 98.72deg Repeat cycle: 26 days LST: Longitude (if geo): Asc/desc: Descending URL:
IGPM ASI	Considered	01-Jan-06	01-Jan-08	Global water and energy cycle	IGPM	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
LAGEOS-3 (Laser Geodynamics Satellite -3) NASA/ASI	Planned	01-Jan-06	01-Jan-46	Geodesy, crustal motion and gravity field measurements by laser ranging. Launch TBD - dates given are for illustration only	LRA (LAGEOS)	Type: Inclined, non-sunsynchronous Altitude: 5900km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.laefr.esa.es/eng/laeff/activity/lageos3.html
MEGHA-TROPIQUES CNES/ISRO	Approved	01-Jan-06	01-Jan-11	Study of the inter-tropical zone and its convective systems (water and energy cycles)	MADRAS, SAPHIR, ScaRaB/MV2	Type: Sun-synchronous Altitude: 867km Period: 100mins Inclination: 20deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Descending URL: www.cnes.fr/espace_pro/communiqués/cp2001/5_17_va.html
REFIR (Radiation Explorer in the Far IR) ASI	Considered	01-Jan-06	01-Jan-08	Study of radiation processes for climate change, study of water vapour feedback processes and gaseous forcing	REI, RFTS, RTER	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.refir.org/
SMOS (Soil Moisture and Ocean Salinity (Earth Explorer Opportunity Mission)) ESA	Approved	01-Jan-06	01-Jan-09	Overall objectives are to provide global observations of two crucial variables for modelling the weather and climate: Soil Moisture and Ocean Salinity. It will also monitor the vegetation water content, snow cover and ice structure	MIRAS	Type: Sun-synchronous Altitude: 755km Period: Inclination: 98.43deg Repeat cycle: LST: 06:00 Longitude (if geo): Asc/desc: Ascending URL: www.esa.int/export/esaLP/smos.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
TerraSAR-L (TerraSAR L band) BNSC	Considered	01-Jan-06	01-Jan-11	SAR imagery in support of agriculture, forestry etc.	L-SAR	Type: TBD Altitude: 660km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.infoterra-global.com/terrasar/html
VISIR ASI	Considered	01-Jan-06	01-Jan-08	Ocean Colour, Sea surface Temperature, columnar content of Atmospheric aerosol particles, bio-geo-chemical fluxes through vegetation, air sea fluxes of energy, hydrological analysis	TIR, VNIR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
RISAT 1 (Radar Imaging Satellite) ISRO	Planned	01-Jan-06	01-Jan-11	Land surface, agriculture and forestry, regional geology, land use studies, water resources, vegetation studies, coastal studies and soils - Specially during cloud season	SAR (RISAT)	Type: Sun-synchronous Altitude: 586km Period: 96.5mins Inclination: Repeat cycle: 12 days LST: 06:00 Longitude (if geo): Asc/desc: Descending URL:
GOES-P (Geostationary Operational Environmental Satellite - P) NOAA	Approved	01-Apr-06	01-Apr-11	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, SEM (GOES), S&R (GOES), Sounder, SXI, WEFAX	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.oso.noaa.gov/goes/
NPP (NPOESS Preparatory Project) NOAA/ESA	Approved	01-Jun-06	01-Jun-11	Meteorological, climatic, terrestrial and oceanographic applications; global and regional environmental monitoring	ATMS, CrIS, VIIRS	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: Repeat cycle: LST: 10:30 Longitude (if geo): Asc/desc: Descending URL: jointmission.gsfc.nasa.gov/
PICARD CNES	Approved	01-Jun-06	01-Aug-08	Simultaneous measurements of solar diameter, differential rotation, solar constant and variability	PREMOS, SODISM, SOVAP	Type: TBD Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
SCD-3 (Data Collecting Satellite 3) INPE	Planned	01-Dec-06	01-Dec-10	Data collection and communication	DCP (SCD)	Type: Inclined, non-synchronous Altitude: 1100km Period: 107mins Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.inpe.br/programas/mecb/delaolt.htm
Jason-2 NASA/CNES/ NOAA/ JAMSTEC	Planned	07-Dec-06	07-Dec-11	Physical oceanography, geodesy/gravity, climate monitoring, marine meteorology	DORIS-N6, JMR, LRA, POSEIDON-2 (SSALT 2), TRSR	Type: Inclined, non-synchronous Altitude: 1336km Period: 122.4mins Inclination: 66deg Repeat cycle: 10days LST: Longitude (if geo): Asc/desc: N/A URL: jira.gsfc.nasa.gov/trg/jason1.html

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
FY-2D (FY-2D Geostationary Meteorological Satellite) NRSDC	Planned	31-Dec-06	31-Dec-09	Meteorology and environmental monitoring. Data collection and redistribution	IVISSR (FY-2)	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: URL:
FY-3B (FY-3B Polar-orbiting Meteorological Satellite) NRSDC	Planned	31-Dec-06	31-Dec-08	Meteorology and environmental monitoring. Data collection and redistribution	IRAS, MIRS, MWAS, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
ADM-Aeolus (Atmospheric Dynamics Mission [Earth Explorer Core Mission]) ESA	Approved	01-Jan-07	01-Jan-10	Will provide wind profile measurements for global 3-D wind field products used for study of atmospheric dynamics, including global transport of energy, water, aerosols and chemicals	ALADIN	Type: Inclined, Sun-synchronous Altitude: 408km Period: Inclination: 96.99deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.esa.int/export/esaLP/aeolus.html
GCOM-A1 (Global Change Observation Mission) NASDA	Considered	01-Feb-07	01-Feb-12	Understanding of ozone and greenhouse gas circulation to assist prediction of ozone layer and atmospheric composition variabilities	OPUS, SDFIS, SWIFT	Type: Inclined, non-sunsynchronous Altitude: 650km Period: 98mins Inclination: 70deg Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
DMSP F-19 (Defense Meteorological Satellite Program F-19) NOAA	Approved	01-Jun-07	01-Sep-10	The long-term meteorological programme of the US Department of Defense (DoD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis	OLS, SSIES-3, SSJ/5, SSM, SSM/T-1, SSMIS, SSULI, SSUSI	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.7deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.ngdc.noaa.gov/dmsp/dmsp.html
GPM (Global Precipitation Measurement Mission) NASA/NASDA	Planned	01-Nov-07	01-Nov-12	Study of global precipitation to improve climate, weather, and global water cycle/hydrological predictions. The mission comprises a primary spacecraft with active and passive microwave instruments and a number of constellation spacecraft with passive microwave instruments	DPR, GMI	Primary Satellite Type: Inclined Altitude: ~400km Period: Inclination: 65 degrees Repeat Cycle: Constellation Satellite Type: Sun-synchronous Altitude: ~600km Period: Inclination: Repeat cycle: LST: Asc/desc: URL: gpm.gsfc.nasa.gov
SSR-2 (Satellite de Sensoriamento Remoto 2) INPE	Considered	01-Dec-07	01-Dec-11	Earth resources, environmental monitoring, land surface	OBA	Type: Inclined, non-sunsynchronous Altitude: 905km Period: 103mins Inclination: 0deg Repeat cycle: 16days LST: Longitude (if geo): Asc/desc: URL: www.inpe.br/programas/mecb/default.htm

Mission	Status	Launch date	EDL date	Applications	Instruments	Orbit details & URL
CBERS-4 (China Brazil Earth Resources Satellite -4) CAST/INPE	Considered	01-Jan-08	01-Jan-11	Earth resources, environmental monitoring, land surface	CCD, DCP, IR-M5S, PAN MUX, WFI	Type: Sun-synchronous Altitude: 778km Period: 100.26mins Inclination: 98.5deg Repeat cycle: 28days LST: 12:50 Longitude (if geo): Asc/desc: Descending URL: www.inpe.br/programas/cbers/english/index.html
ESA Future Missions ESA	Considered	01-Jan-08	01-Jan-18	Physical Oceanography, land surface, ice and snow, atmospheric dynamics/water and energy cycles	ATLID, COALA, CPR, MASTER, MIPAS, MWR-2, SCATTERO- METER, SOPRANO, SPECTRA, WALES	Type: TBD Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
NOAA-N' (National Oceanic and Atmospheric Administration - N') NOAA	Approved	01-Mar-08	01-Dec-11	Meteorology, agriculture and forestry, environmental monitoring, climatology, physical oceanography, Volcanic eruption monitoring, ice and snow cover, total ozone studies, space environment, solar flux analysis, search and rescue	AMSU-A, ARGOS, AVHRR/3, HIRS/4, MHS, NOAA Comms, S&R (NOAA), SBUV/2, SEM (POES)	Type: Sun-synchronous Altitude: 870km Period: 102.1mins Inclination: 98.75deg Repeat cycle: LST: 14:00 Longitude (if geo): Asc/desc: Ascending URL: www.noaa.gov/poes/
GOES-Q (Geostationary Operational Environmental Satellite - Q) NOAA	Approved	01-Apr-08	01-Apr-13	Meteorology (primary mission), search and rescue, space environment monitoring, data collection platform, data gathering, WEFAX	DCS (NOAA), GOES Comms, Imager, SEM (GOES), S&R (GOES), Sonder, WEFAX	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.noaa.gov/goes/
MSG-3 (Meteosat Second Generation-3) EUMETSAT	Approved	01-Jun-08	01-Jun-15	Meteorology, climatology, Atmospheric dynamics/water and energy cycles	GERB, MSG Comms, SEVIRI	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): 0 Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic1.html
FY-3C (FY-3C Polar-orbiting Meteorological Satellite) NIRX	Planned	31-Dec-08	31-Dec-10	Meteorology and environmental monitoring. Data collection and redistribution	IMWAS, IRAS, MIRAS, MVIRS, MWHs, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
DMSP F-20 (Defence Meteorological Satellite Program F-20) NOAA	Approved	01-Feb-09	01-Apr-13	The long-term meteorological programme of the US Department of Defense (DOD) - with the objective to collect and disseminate worldwide cloud cover data on a daily basis	OLS, SSIES-3, SSJ/5, SSM, SSM/T-1, SSMIS, SSULI, SSUSI	Type: Sun-synchronous Altitude: 850km Period: 101mins Inclination: 98.7deg Repeat cycle: LST: Longitude (if geo): Asc/desc: Ascending URL: www.ngdc.noaa.gov/dmsp/dmsp.html
NPOESS-1 (National Polar-orbiting Operational Environmental Satellite System - 1) NOAA	Approved	01-Apr-09	01-Jan-15	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection	A-DCS, APS, CMIS, SARSAT, VIIRS	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.75deg Repeat cycle: LST: 21:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
FY-2E (FY-2E Geostationary Meteorological Satellite) NRSCC	Planned	31-Dec-09	31-Dec-12	Meteorology and environmental monitoring Data collection and redistribution	VISSR (FY-2)	Type: Geostationary Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): -105 Asc/desc: URL:
GOMS/Electro N3 (Geostationary Operational Meteorological Satellite - 3) Roshydromet	Planned	01-Jan-10	31-Dec-15	Hydrometeorology, climatology, disaster management, space environment, ice and snow, land surface, space environment, data collection and communication	BRK, MSU-G5	Type: Geostationary Altitude: 36000km Period: Inclination: Repeat cycle: LST: Longitude (if geo): -76 Asc/desc: URL: www.sputnik1.infospace.ru/
METEOR-3M N3 Roshydromet	Planned	01-Jan-10	31-Dec-15	Hydrometeorology, climatology, land surface, physical oceanography, heliogeophysics and space environment, data collection, sounding of the atmosphere, agriculture	BRK, GALS-M, IKFS-2, MSGI-MK1, MSU-MR, MTVZA, RIMS-M, SKL-M	Type: Sun-synchronous Altitude: 1000km Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL: www.sputnik1.infospace.ru
METOP-2 (Meteorological Operational Polar Satellite - 2) NASA	Approved	30-Jun-10	30-Jun-15	Meteorology, climatology	AMSU-A, ARGOS, ASCAT, AVHRR/3, GOME-2, GRAS, HIRS/4, IASI, MCP, MHS, S&R (NOAA), SEM (POES)	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: 09:30 Longitude (if geo): Asc/desc: N/A URL: www.eumetsat.de/en/area4/topic2.html
FY-3D (FY-3D Polar-orbiting Meteorological Satellite) NRSCC	Planned	31-Dec-10	31-Dec-12	Meteorology and environmental monitoring Data collection and redistribution	IMWAS, IRAS, MIRAS, MVIRS, MWHS, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
NPOESS-2 (National Polar-orbiting Operational Environmental Satellite System - 2) NOAA	Approved	01-Jun-11	01-Jan-17	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection	A-DCS, ATMS, CERES, CMIS, CrIS, GPSOS, OMP5, SARSAT, SESS, VIIRS	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.75deg Repeat cycle: LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov
FY-3E (FY-3E Polar-orbiting Meteorological Satellite) NRSCC	Planned	31-Dec-12	31-Dec-14	Meteorology and environmental monitoring Data collection and redistribution	IMWAS, IRAS, MIRAS, MVIRS, MWHS, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:

Mission	Status	Launch date	EOL date	Applications	Instruments	Orbit details & URL
NPOESS-3 (National Polar-orbiting Operational Environmental Satellite System - 3) NOAA	Approved	01-Apr-13	01-Sept-18	Meteorological, climatic, terrestrial, oceanographic and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection	A-DCS, ALT, CMIS, CrIS, ERBS, GP50S, S&R (NOAA), SARSAT, SESS, TSIS, VIIRS	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.75deg Repeat cycle: LST: 17:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov
FY-3F (FY-3F Polar-orbiting Meteorological Satellite) NRSCC	Planned	31-Dec-14	31-Dec-16	Meteorology and environmental monitoring Data collection redistribution	IMWAS, IRAS, MIRAS, MIRS, MWS, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
NPOESS-4 (National Polar-orbiting Operational Environmental Satellite Systems - 4) NOAA	Approved	01-Jan-15	01-Jun-20	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection	A-DCS, APS, CMIS, SARSAT, VIIRS	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.75deg Repeat cycle: LST: 21:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov
METOP-3 (Meteorological Operational Polar Satellite - 3) EUMETSAT	Approved	30-Jun-15	30-Jun-20	Meteorology, climatology	ARGOS, ASCAT, AVHRR/3, GRAS, IASI, MCP, MHS	Type: Sun-synchronous Altitude: 840km Period: 101.7mins Inclination: 98.8deg Repeat cycle: 5days LST: 09:30 Longitude (if geo): Asc/desc: Descending URL: www.eumetsat.de/en/area4/topic2/html
FY-3G (FY-3G Polar-orbiting Meteorological Satellite) NRSCC	Planned	31-Dec-16	31-Dec-18	Meteorology and environmental monitoring Data collection and redistribution	IMWAS, IRAS, MIRAS, MIRS, MWS, MWRI, OP, TOM, VIRR	Type: Sun-synchronous Altitude: Period: Inclination: Repeat cycle: LST: Longitude (if geo): Asc/desc: URL:
NPOESS-5 (National Polar-orbiting Operational Environmental Satellite System - 4) NOAA	Approved	01-Jan-17	01-Jun-22	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection	A-DCS, ATMS, CMIS, CrIS, GP50S, OMPS, SARSAT, SESS, VIIRS	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.75deg Repeat cycle: LST: 13:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov
NPOESS-6 (National Polar-orbiting Operational Environmental Satellite System - 4) NOAA	Approved	01-Sep-18	01-Jan-24	Meteorological, climatic, terrestrial, oceanographic, and solar-geophysical applications; global and regional environmental monitoring, search and rescue, data collection	A-DCS, ALT, CMIS, ERBS, GP50S, SARSAT, SESS, TSIS, VIIRS	Type: Sun-synchronous Altitude: 833km Period: 101mins Inclination: 98.75deg Repeat cycle: LST: 17:30 Longitude (if geo): Asc/desc: Ascending URL: www.npoess.noaa.gov

9 Catalogue of satellite instruments

9.1 Introduction

This section contains an alphabetical list of all instruments on the missions listed in section 8. For each instrument the following information is given:

Instrument name	Instrument acronym Full instrument name
Missions	A list of missions that the instrument is expected to fly on
Type	Instrument type - using the categories outlined in section 6
Measurements/ applications	Primary measurements and applications of the instrument
Technical characteristics	Waveband Spatial resolution Swath width Accuracy

The descriptions of waveband adopt the following conventions for defining which parts of the spectrum are measured:

Frequency		Acronym	Wavelength range	
Region	Sub-region		from	to
Ultraviolet		UV	~0.01 μ m	~0.40 μ m
Visible		VIS	~0.40 μ m	~0.75 μ m
Infrared	Near Infrared	NIR	~0.75 μ m	~1.3 μ m
	Short Wave Infrared	SWIR	~1.3 μ m	~3.0 μ m
	Mid Wave Infrared	MWIR	~3.0 μ m	~6.0 μ m
	Thermal Infrared	TIR	~6.0 μ m	~15.0 μ m
	Far Infrared	FIR	~15.0 μ m	~0.1cm
Microwave		MW	~0.1cm	~100cm

List of satellite instruments (alphabetical)

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
AATSR Advanced Along-Track Scanning Radiometer	Envisat	Imaging multi-spectral radiometer (vis/IR)	Measurements of sea surface temperature, land surface temperature, cloud top temperature, cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content	Waveband: VIS-NIR: 0.555, 0.659, 0.865µm, SWIR: 1.6µm, MWIR: 2.7µm, TIR: 10.85, 12µm Resolution: IR ocean channels: 1km x 1km Visible land channels: 1km x 1km Swath: 500km Accuracy: Sea surface temperature: <0.5K over 0.5 deg x 0.5 deg [lat/long] area with 80% cloud cover, Land surface temperature: 0.1K [relative]
ACE-FTS Atmospheric Chemistry Experiment [ACE] mission	SCISAT-1	Atmospheric Chemistry instrument	Objective is to measure and understand the chemical processes that control the distribution of ozone in the Earth's atmosphere, especially at high altitudes	Waveband: SWIR-TIR: 2-5.5µm, 5.5-13µm [0.02cm-1 resolution] Resolution: Swath: Accuracy:
ACRIM III Active Cavity Radiometer Irradiance Monitor	ACRIMSAT	Earth radiation budget radiometer	Measurements of solar luminosity and solar constant. Data used as record of time variation of total solar irradiance, from extreme UV through to infra-red	Waveband: UV-MWIR: 0.15-5µm Resolution: 5deg FOV Swath: 55 mins per orbit of full solar disk data Accuracy: 0.1% of full scale
A-DCS ARGOS-Data Collection System	NPOESS-1,2,3,4,5,6	Other	Data collection and communication system for receiving and retransmitting data from ocean and land-based remote observing platforms/transponders	Waveband: Resolution: Swath: Accuracy:
ADEOS Comms Communications package for ADEOS	ADEOS-2	Other		Waveband: Resolution: Swath: Accuracy:
AIRS Atmospheric Infra-red Sounder	Aqua	Atmospheric sounder [IR or microwave]	High spectral resolution measurement of temperature and humidity profiles in the atmosphere. Long-wave Earth surface emissivity. Cloud diagnostics. Trace gas profiles. Surface temperature	Waveband: Vis-TIR: 0.4 - 1.7µm, 3.4 - 15.4µm Has approximately 2382 bands from Visual to TIR Resolution: 1.1 degree [13X13Km at nadir] Swath: +/-48.95 degrees Accuracy: Humidity: 20%, Temperature: 1K
ALADIN Atmospheric Laser Doppler Instrument	ADM - Aeolus	Lidar	Primary objective is to provide wind profile measurements for an improved analysis of global 3-D wind fields. Measures Doppler-shift information from molecules and particles advected by the wind	Waveband: UV: 355nm Resolution: Swath: Accuracy:
ALI Advanced Land Imager	NMP EQ-1	High resolution imager	Measurement of Earth surface reflectance. A prime objective is to validate new technologies contributing to cost reduction and increased capabilities for future land imaging missions. ALI comprises a wide field telescope and multispectral and panchromatic instrument	Waveband: 10 bands: VIS&NIR: 0.480-0.690µm, 0.433-0.453µm, 0.450-0.515µm, 0.525-0.605µm, 0.630-0.660µm, 0.775-0.805µm, 0.845-0.890µm, 1.200-1.300µm, SWIR: 1.550-1.750µm, 2.090-2.350µm Resolution: PAN: 10m, VNIR&S WiR: 30m Swath: 37km Accuracy: SNR @ 5% surf refl: Pan:220, Multi: 1: 215, Multi 2: 280, Multi 3: 290, Multi 4:240, Multi 4': 190, Multi 5: 130, Multi 5: 175, Multi 7: 170 [prototype instrument exceeds ETM+ SNR by a factor of 4 - 8]
ALT Altimeter	NPOESS-3,6	Radar altimeter	Obtains precise altimeter height measurements over world's oceans	Waveband: Resolution: Swath: Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
AMI/SAR/ Image Active Microwave Instrumentation, Image Mode	ERS-2	Imaging radar	All-weather images of ocean, ice and land surfaces. Monitoring of coastal zones, polar ice, sea state, geological features, vegetation (including forests), land surface processes, hydrology	Waveband: Microwave: 5.3GHz, C band, VV polarisation, bandwidth 15.5 ± 0.06 MHz Resolution: 30m Swath: 100km Accuracy: Landscape topography: 3m, Bathymetry: 0.3m, Sea ice type: 3 classes
AMI/ scatterometer Active Microwave Instrumentation Wind mode	ERS-2	Scatterometer	Provides measurements of wind at the ocean surface, wind direction (range 0-360 deg), wind speed (range 1m/s - 30m/s)	Waveband: Microwave: 5.3GHz (C-band), VV polarisation Resolution: Cells of 50km x 50km at 25km intervals Swath: 500km Accuracy: Sea surface wind speed: 3m/s, Sea ice type: 2 classes
AMSR Advanced Microwave Scanning Radiometer	ADEOS-2	Imaging multi-spectral radiometer (microwave)	Provides measurements of water vapour, cloud liquid water, precipitation, winds, sea surface temperature, sea ice concentration, snow cover, soil moisture	Waveband: Microwave: 6.925, 10.65, 18.7, 23.8, 36.5, 50.3, 52.8, 89.0GHz Resolution: 5-50km (dependent on frequency) Swath: 1600km Accuracy: Sea surface temperature: 0.5K, Sea ice cover: 10%, Cloud liquid water: 0.05kg/m ² , Precipitation rate: 10%, Water vapour: 3.5kg/m ² through total column, Sea surface wind speed 1.5m/s
AMSR-E Advanced Microwave Scanning Radiometer-EOS	EOS Aqua	Imaging multi-spectral radiometer (microwave)	Provides measurements of water vapour, cloud liquid water, precipitation, winds, sea surface temperature, sea ice concentration, snow cover and soil moisture	Waveband: Microwave: 6.925, 10.65, 18.7, 23.8, 36.5, 89.0GHz Resolution: 5-50km (dependent on frequency) Swath: 1445km Accuracy: Sea surface temperature: 0.5K, Sea ice cover: 10%, Cloud liquid water: 0.05kg/m ² , Precipitation rate: 10%, Water vapour: 3.5kg/m ² through total column, Sea surface wind speed 1.5m/s
AMSU-A Advanced Microwave Sounding Unit-A	NOAA-15, 16, M, N, N', METOP-1, 2 Aqua	Atmospheric sounder (IR or microwave)	Provides all weather night-day temperature sounding to an altitude of 45km	Waveband: Microwave: 15 channels, 23.8-89.0GHz Resolution: 48km Swath: 2054km Accuracy: Temperature profile: 2K, Humidity: 3kg/m ² , Ice & snow cover: 10%
AMSU-B Advanced Microwave Sounding Unit-B	NOAA-15, 16, M	Atmospheric sounder (IR or microwave)	Provides all weather night-day humidity sounding	Waveband: Microwave: 89GHz, 150GHz, 183.3±1.06GHz (2bands), 183.3±3.0GHz (2bands), 183.3±7.0 GHz (2bands) Resolution: 16km Swath: 2200km Accuracy: Humidity profile: 1kg/m ²
APS Aerosol Polarimeter Sensor	NPOESS-1, 4	Atmospheric Chemistry instrument	Measures aerosol optical thickness, particle size and refractive index and cloud particle size distribution	Waveband: 9 channels Resolution: Swath: Accuracy:
ARGOS ARGOS	NOAA-11, 12, 14, 15, 16, M, N, N', METOP-1, 2, 3	Other	Provides location data by Doppler measurements	Waveband: Resolution: Swath: Accuracy:
ASAR Advanced Synthetic Aperture Radar	Envisat	Imaging radar	Provides all weather images of ocean, land and ice for monitoring of land surface processes, sea and polar ice, sea state, and geological and hydrological applications. Has 2 stripmap modes (Image and Wave (for ocean wave spectra)) and 3 ScanSAR modes	Waveband: Microwave: C-band, with choice of 5 polarisation modes (VV, HH, VV/HH, HV/HH, or VH/VV) Resolution: Image, wave and alternating polarisation modes: approx 30m x 30m Wide swath mode: 150m x 150m Global monitoring mode: 950m x 950m Swath: Image and alternating polarisation modes: up to 100km Wave mode: 5km Wide swath and global monitoring modes: 400km or more Accuracy: Radiometric resolution in range: 1.5-3.5 dB, Radiometric accuracy: 0.65 dB

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
ASCAT Advanced Scatterometer	METOP-1, 2, 3	Scatterometer	Provides sea ice cover, sea ice type and wind speed over sea surface measurements. Air pressure over ocean, Polar ice contours, Ice/snow imagery, Soil moisture	Waveband: Microwave: C Band, 5.256GHz Resolution: Hi-res mode: 25-37km, Nominal mode: 50km Swath: Continuous Accuracy: Wind speeds in range 2-24m/s-2m/s and direction accuracy of 20 deg
ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer	Terra	High resolution imager	Surface and cloud imaging with high spatial resolution, stereoscopic observation of local topography, cloud heights, volcanic plumes, and generation of local surface digital elevation maps. Surface temperature and emissivity	Waveband: VIS&NIR: 3 bands in 0.52-0.84µm SWIR: 6 bands in 1.6-2.43µm TIR: 5 bands in 8.125-11.65µm Resolution: VNIR: 15m, stereo: 15m horizontally and 25m vertical; SWIR: 30m TIR: 90m Swath: 60km Accuracy: VNIR and SWIR: 4% (absolute) TIR: 4K Geolocation: 7m
ATLID Atmospheric LiDAR	ESA Future Missions	Lidar	Provides measurements of cloud top heights, aerosol properties, troposphere height, vertical distribution of cloud, boundary layer height	Waveband: NIR: 1.064µm Resolution: Shot spacing: <50km, footprint: 100m (at nadir) Swath: 350km Accuracy: Aerosol profile: 10%
Atmospheric Corrector Atmospheric Corrector	NMP EO-1	Imaging multi-spectral radiometer (vis/IR)	Corrects high spatial resolution multispectral imager data for atmospheric effects	Waveband: 256 bands; NIR-SWIR: 0.89-1.58µm Resolution: 250m Swath: 185km Accuracy:
ATMS Advanced Technology Microwave Sounder	NPOESS-2, 5, NPP	Atmospheric sounder (IR or microwave)	In conjunction with CrIS, global observations of temperature and moisture profiles at high temporal resolution. Advanced technology version of the current AMSU-A/B with similar performance	Waveband: Microwave: 22 channels, 23.8 - 183.1+/-7GHz Resolution: Swath: Accuracy:
ATSR/M ATSR/M	ERS-2	Imaging multi-spectral radiometer (microwave)	Microwave channels of ATSR	Waveband: 23.8, 36.5GHz Resolution: Swath: Accuracy:
ATSR-2 Along Track Scanning Radiometer - 2	ERS-2	Imaging multi-spectral radiometer (vis/IR)	Provides measurements of sea surface temperature, land surface temperature, cloud top temperature and cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content	Waveband: VIS-SWIR: 0.65, 0.85, 1.27, and 1.6µm SWIR-TIR: 1.6, 3.7, 11 and 12µm Microwave: 23.8, 36.5GHz (bandwidth of 400MHz) Resolution: IR ocean channels: 1km x 1km, Microwave near-nadir viewing: 20km instantaneous field of view Swath: 500km Accuracy: Sea surface temperature to <0.5K over 0.5 deg x 0.5 deg (lat/long) area with 80% cloud cover Land surface temperature: 0.1K
AVHRR/2 Advanced Very High Resolution Radiometer/2	NOAA-11, 12, 14	Imaging multi-spectral radiometer (vis/IR)	Provides measurements of land and sea surface temperature, cloud cover, snow and ice cover, soil moisture and vegetation indices. Data also used for volcanic eruption monitoring	Waveband: VIS: 0.58-0.68µm, NIR: 0.725-1.1µm, MWIR: 3.55-3.93µm, TIR: 10.3-11.3µm, 11.5-12.5µm Resolution: 1.1km Swath: 3000km approx Accuracy:
AVHRR/3 Advanced Very High Resolution Radiometer/3	NOAA-15,16,M,N,N+ METOP-1,2,3	Imaging multi-spectral radiometer (vis/IR)	Provides measurements of land and sea surface temperature, cloud cover, snow and ice cover, soil moisture and vegetation indices. Data also used for volcanic eruption monitoring	Waveband: VIS: 0.58-0.68µm, NIR: 0.725-1.1µm, SWIR: 1.58-1.64µm, MWIR: 3.55-3.93µm, TIR: 10.3-11.3µm, 11.5-12.5µm Resolution: 1.1km Swath: 33000km approx. Ensures full global coverage twice daily Accuracy:
AVNIR-2 Advanced Visible and Near Infra-red Radiometer type 2	ALOS	High resolution imager	High resolution multi-spectral imager for land applications which include environmental monitoring, agriculture and forestry, disaster monitoring	Waveband: VIS: 0.43-0.50µm, 0.53-0.60µm, 0.61-0.69µm, NIR: 0.76-0.89µm Resolution: 10m Swath: 70km Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
AWiFS Advanced Wide Field Sensor	RESOURCESAT-1	High resolution imager	Vegetation and crop monitoring, resource assessment (regional scale), forest mapping, land cover/land use mapping and change detection	Waveband: VIS: 0.52-0.59 & 0.62-0.68 μ m, NIR: 0.77-0.86 μ m, SWIR: 1.55-1.7 μ m. Resolution: 55m Swath: 700km Accuracy: 10 bit data
BISSAT Bissat Passive Radar	BISSAT	Imaging radar	Evaluation of bistatic radar cross section of natural and man-made targets, image classification, land surface. Passive instrument flown with main SAR mission	Waveband: Microwave: X-band (passive) Resolution: Swath: Accuracy:
BRK	GOMS/Electro N2,3 METEOR-3M N2,3	Other	Data collection and communication	Waveband: Resolution: Swath: Accuracy:
BSS & FSS transponders	INSAT-2D, E	Other	Data collection and communication	Waveband: Resolution: Swath: Accuracy:
CCD High Resolution CCD Camera	CBERS-1, 2, 3, 4	High resolution imager	Provides measurements of cloud type and extent and land surface reflectance, and used for global land surface applications	Waveband: VIS: 0.45-0.52 μ m, 0.52-0.59 μ m, 0.63-0.69 μ m, NIR: 0.77-0.89 μ m, PAN: 0.51-0.71 μ m. Resolution: 20m Swath: 113km Accuracy:
CCD camera	INSAT 2E, 3A	Imaging multi-spectral radiometer (vis/IR)	Cloud and Vegetation monitoring	Waveband: VIS: 0.62-0.68 μ m, NIR: 0.77-0.86 μ m, SWIR: 1.55-1.69 μ m. Resolution: 1 x 1km Swath: Normal: 6000km (N-S) X 6000km (E-W) anywhere on earth disc, Program: 6000km (N-S) X 1n X 300km (E-W) : n and number of frames programmable Accuracy:
CERES Cloud and the Earth's Radiant Energy System	Terra, Aqua, TRMM, NPOESS-2	Earth radiation budget radiometer	Long term measurement of the Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface; provision of an accurate and self-consistent cloud and radiation database	Waveband: 3 channels: 0.3-5 μ m, 0.3-100 μ m, 8-12 μ m. Resolution: 20km Swath: Accuracy: 0.5%, 1%, 0.3% (respectively for the 3 channels)
CHAMP GPS Sounder GPS TurboRogue Space Receiver (TRS)	CHAMP	Atmospheric sounder (IR or microwave)	Atmospheric sounding, temperature and water vapour profiles	Waveband: Resolution: Swath: Accuracy:
CHAMP gravity package (Accelerometer +GPS) STAR Accelerometer	CHAMP	Gravity field or geodynamic	Earth gravity field measurements	Waveband: Resolution: Swath: Accuracy:
CHAMP magnetometry package (1 Scalar+2 Vector Magnetometer) Overhauser Magnetometer (OVM) and Fluxgate Magnetometer (FGM)	CHAMP	Magnetic field	Earth magnetic field measurements	Waveband: Resolution: Swath: Accuracy:
CHRIS Compact High Resolution Imaging Spectrometer	PROBA	Imaging multi-spectral radiometer (vis/IR)	Supports a range of land, ocean and atmospheric applications, including agricultural science, forestry, environmental science, atmospheric science and oceanography	Waveband: Vis-NIR: 400nm-1050nm (63 spectral bands at a spatial resolution of 36m, or 18 bands at full spatial resolution (18m)) Resolution: 36m or 18m depending on wavebands selected Swath: 14km Accuracy: 5/N 200 @ target albedo of 0.2, 12 bits digitisation

Instrument	Mission(s)	Type	Measurements /Application	Technical characteristics
CIMS Conical-scanning Microwave Imager/ Sounder	NPOESS-1, 2, 3, 4, 5, 6	Imaging multi-spectral radiometer (microwave)	Collects microwave radiometry and sounding data. Data types include atmospheric temperature and moisture profiles, clouds, sea surface winds, and all- weather land/water surfaces	Waveband: Microwave: 1-250GHz Resolution: 15-50km depending on frequency Swath: Accuracy:
COALA Calibration for Ozone through Atmospheric Limb Acquisitions	ESA Future Missions	Atmospheric Chemistry instrument	Atmospheric ozone profiles	Waveband: Resolution: Swath: Accuracy:
Communications payload (Ka and UHF band)	FedSat	Other	Communications	Waveband: Resolution: Swath: Accuracy:
CPR (CloudSat) Cloud Profiling Radar	CloudSat	Cloud profiler and/or rain radar	Primary goal is to provide data needed to evaluate and improve the way clouds are represented in global climate models. Measures vertical profile of clouds	Waveband: Microwave: 94GHz Resolution: Vertical: 500m, Cross-track: 1.4km, Along-track: 2.5km Swath: Instantaneous Footprint < 2km Accuracy:
CPR Cloud Radar	ESA Future Missions	Cloud profiler and/or rain radar	Measures cloud characteristics including base height	Waveband: Microwave: 78 or 94GHz Resolution: Swath: Accuracy:
CrIS Cross-track Infrared Sounder	NPOESS-2, 5, NPP	Atmospheric sounder (IR or microwave)	Daily measurements of vertical atmospheric distribution of temperature, moisture and pressure	Waveband: MWIR-TIR: 3.92-4.64µm, 5.7- 8.62µm, 9.1-15.3µm, 1300 spectral channels Resolution: IFOV 14km diameter, 1km vertical layer resolution Swath: 2300km Accuracy: Temperature profiles: to 0.9K Moisture profiles: 20-35% Pressure profiles: 1%
DCP (SCD) Data Collecting Platform Transponder	SCD-1, 2, 3	Other	Data collection and communication	Waveband: Resolution: Swath: Accuracy:
DCP Data Collecting Platform Transponder	CBERS-1, 2, 3, 4	Other	Data collection and communication	Waveband: Resolution: Swath: Accuracy:
DCS (NASDA) Data Collection System (NASDA)	GMS-5	Other	Data collection	Waveband: Resolution: Swath: Accuracy:
DCS (NOAA) Data Collection System (NOAA)	GOES 8-Q	Other	Collects data on temperature (air/water), atmospheric pressure, humidity and wind speed/direction, speed and direction of ocean and river currents	Waveband: Resolution: Swath: Accuracy:
DELTA-2D Multispectral microwave scanning radiometer	OKEAN-O	Imaging multi- spectral radiometer (microwave)	Scanning microwave radiometer for measurement of emissive microwave radiation at atmosphere/ sea surface interface	Waveband: Microwave: 0.8cm, 1.35cm, 2.2cm, 4.3cm Resolution: 20km-100km depending on frequency Swath: 1100km Accuracy: 0.1-0.15K error
DMC Imager Disaster Management Constellation Imager	BNCSAT (DMC)	High resolution imager	Visible and NIR imagery in support of disaster management	Waveband: VIS and NIR Resolution: 32m Swath: 2 beams of 300km Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
DORIS Doppler Orbitography and Radio-positioning Integrated by Satellite	SPOT-4 Topex-Poseidon	Gravity field or geodynamic	Orbit determination	Waveband: Resolution: Swath: Accuracy:
DORIS-NG Doppler Orbitography and Radio-positioning Integrated by Satellite-NG	Jason-1, 2, Envisat, SPOT-5, CRYOSAT	Gravity field or geodynamic	Precise orbit determination Real time onboard orbit determination (navigation)	Waveband: Resolution: Swath: Accuracy:
DPR Dual-frequency Precipitation Radar	GPM	Cloud profiler and/or rain radar	Measures rain rate classified by rain and snow, in latitudes up to 70 degrees	Waveband: Microwave: 13.6GHz (Ku band) and 35.5GHz (Ka band) Resolution: Range resolution: 4-5km Horizontal Swath: 245km (Ku-band), 100km (Ka band) Accuracy: rainfall rate 0.2mm/h
DRT-S&R	INSAT-2E, D	Other	Relay of search and rescue information	Waveband: Resolution: Swath: Accuracy:
EGG 3-Axis Electrostatic Gravity Gradiometer	GOCE	Gravity field or geodynamic	The main objective of EGG is to measure the 3 components of the gravity-gradient tensor (ie gradiometer data)	Waveband: Resolution: Swath: Accuracy:
EMA Electric, Magnetic, fields Analyser	ESPERIA	Magnetic field	Study of perturbations in the atmosphere and ionosphere caused by electromagnetic waves, short term earthquake prediction	Waveband: Resolution: Swath: Accuracy:
ENVISAT Comms Communications package on ENVISAT	Envisat	Other	Communications	Waveband: Resolution: Swath: Accuracy:
EOC Electro-Optical Camera	KOMPSAT-1	High resolution imager	High resolution stereo imager for land applications of cartography and disaster monitoring	Waveband: Panchromatic VIS: 0.51-0.73µm Resolution: 6.6m Swath: 17km Accuracy:
EPIC Earth PolyChromatic Imaging Camera	Triana	Atmospheric Chemistry instrument	Measures ozone amounts, aerosol amounts, cloud height and phase, hotspot land properties and UV radiation estimates at the Earth's surface	Waveband: UV-NIR: 0.317-0.905µm 10 bands Resolution: 8km Swath: Accuracy:
ERBE Earth Radiation Budget Experiment	ERBS	Earth radiation budget radiometer	Radiation budget measurements - Total energy of Sun's radiant heat and light, Reflected solar radiation, Earth emitted radiation	Waveband: Sunview: NIR-FIR: 0.2-3.5µm, 0.2-50.0µm; Channel 5: 0.2-50.0µm Earth view: 0.2-50.0µm Resolution: 1000km sun, 40km earth Swath: Full sun and full earth views Accuracy:
ERBS Earth Radiation Budget Sensor	NPOESS-3, 6	Earth radiation budget radiometer	Measures Earth radiation gains and losses on regional, zonal and global scales	Waveband: Resolution: Swath: Accuracy:
ERS Comms Communication package for ERS	ERS-2	Other	Communications	Waveband: Resolution: Swath: Accuracy:
ETM+ Enhanced Thematic Mapper+	Landsat-7	High resolution imager	Measures surface radiance and emittance, land cover state and change (eg vegetation type). Used as multi-purpose imagery for land applications	Waveband: VIS-TIR: 8 channels: 0.45-12.5µm, Panchromatic channel: VIS 0.5-0.9µm Resolution: Pan: 15m, Vis-SWIR: 30m, TIR: 60m Swath: 185km Accuracy: 50-250m systematically corrected geodetic accuracy

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
Fluxgate magnetometer	Fedsat	Magnetic field	Measures electrical currents and perturbations in the Earth's magnetic field in the range 0.1Hz to 1kHz	Waveband: Resolution: Swath: Accuracy:
GALS-M <i>Galactic space rays detector</i>	METEOR-3M N2,3	Other	Space environment monitoring	Waveband: Protons fluxes density > 600 MeV Resolution: Visible: 1.25km, TIR: 5km Swath: Full Earth disk in all channels, every 1 hour Accuracy:
GERB Geostationary Earth Radiation Budget	MSG-1, 2, 3	Earth radiation budget radiometer	Measures long and short wave radiation emitted and reflected from the Earth's surface, clouds and top of atmosphere. Full Earth disk, all channels in 5 mins	Waveband: UV-MWIR: 0.32-4.0µm UV-FIR: 0.32-30µm Resolution: 44.6km x 39.3km Swath: Full Earth disk Accuracy: Emitted radiation: 0.12-1.3 W/m2, Reflectance: 1%
GIFTS Geostationary Imaging Fourier Transform Spectrometer	NMP EO-3	Atmospheric sounder (IR or microwave)	Measures temperature, water vapour, tracer winds, chemical composition with high spatial and temporal resolution for considerable improvements in weather observations and air quality monitoring. Tests next-generation met observing systems	Waveband: MWIR-TIR: 1724 channels in the bands 4.45-6.06µm and 8.85-14.6µm Resolution: Visible: 1km x 1km, IR: 4km x 4km Swath: Full Earth disk Accuracy:
GLAS Geoscience Laser Altimeter System	ICESat	Lidar	Provision of data on ice sheet height/thickness, land altitude, aerosol height distributions, cloud height and boundary layer height	Waveband: VIS-NIR: Laser emits at 1064nm (for altimetry) and 532nm (for atmospheric measurements) Resolution: 66m spots separated by 170m Swath: Accuracy: Aerosol profile: 20%, Ice elevation: 20cm, Cloud top height: 75m, Land elevation: 20cm, Geoid: 5m
GLI Global Imager	ADEOS-2	Imaging multi-spectral radiometer (vis/IR)	Measures water vapour, aerosols, cloud cover, cloud top height/temp, ocean colour, sea surface temperature, land surface temperature, glacier extent, icebergs, sea ice and snow cover, photosynthetically active radiation, vegetation type and land cover	Waveband: VIS&NIR: 23 bands (380-830nm), NIR-SWIR: 6 bands (1050-2215nm), MWIR-TIR: 7 bands (3.75-11.95µm) Resolution: 1km for 28 bands, 250m for 6 bands Swath: 1600km Accuracy: Specific humidity profile: 0.5g/m2 through total column, Surface temp 0.4-0.5K, Cloud top temp: 0.5K, Cloud cover: 3%, Cloud top height: 0.5km, Ice and snow cover: 5%
GMI GPM Microwave Imager	GPM Primary and Constellation Satellites	Imaging multi-spectral radiometer (microwave)	Measures rainfall rates over oceans and land, combined rainfall structure and surface rainfall rates with associated latent heating. Used to produce three hour, daily, and monthly total rainfall maps over oceans and land	Waveband: Microwave: 10.65, 19.4, 21.3, 37, and 85.5GHz Resolution: Horizontal: 36km cross-track at 10.65GHz (required - Primary Spacecraft, goal - Constellation Spacecraft), 10km along-track and cross-track (goal - Primary Spacecraft) Swath: 800km (Primary Spacecraft) 1300km (Constellation Spacecraft) Accuracy: NEDT 0.5 K - 1.0 K
GMS Comms Communications package on GMS	GMS-5	Other	Communications	Waveband: Resolution: Swath: Accuracy:
GOES Comms Communications package on GOES	GOES 8-0	Other	Communications	Waveband: Resolution: Swath: Accuracy:
GOLPE Ops Occultation and Passive reflection Experiment	SAC-C	Other	Measurements of atmospheric effects on GPS signals and precise positioning information to assist gravitational measurements	Waveband: Resolution: Swath: Accuracy:
GOME Global Ozone Monitoring Experiment	ERS-2	Atmospheric Chemistry instrument	Measures concentration of O3, NO, NO2, BrO, H2O, O2/O4, plus aerosols and polar stratospheric clouds, and other gases in special conditions	Waveband: UV-NIR: 0.24-0.79µm (resolution 0.2-0.4nm) Resolution: Vertical: 5km (for O3) Swath: Horizontal: 40 x 40km to 40 x 320km Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
GOME-2 Global Ozone Monitoring Experiment - 2	METOP-1, 2	Atmospheric Chemistry instrument	Measurement of total column amounts and stratospheric and tropospheric profiles of ozone. Also amounts of H ₂ O, NO ₂ , OClO, BrO, SO ₂ and HCHO	Waveband: UV-NIR: 0.24-0.77µm [resolution 0.2-0.4nm] Resolution: Horizontal: 40 x 40km [960km swath] to 40 x 5km [for polarization monitoring] 120-960km Swath: Cloud top height: 1km [rms], Outgoing short wave radiation and solar irradiance: 5W/m ² , Trace gas profile: 10-20%, Specific humidity profile: 10-50g/kg
GOMOS Global Ozone Monitoring by Occultation of Stars	Envisat	Atmospheric Chemistry instrument	Provides stratospheric profiles of temperature and of ozone, NO _x , H ₂ O, aerosols and other trace species	Waveband: Spectrometers: UV-Vis: 248-371nm & 387-693nm, NIR: 750-776nm & 915-956nm, Photometers: 644-705nm & 466-528nm Resolution: 1.7km vertical Swath: Not applicable Accuracy:
GPS receiver	Fedsat	Gravity field or geodynamic	Sounding data for study of physics of upper atmosphere and water vapour, temperature and refractivity profiles	Waveband: Resolution: 1 sample every 30 secs Swath: Accuracy:
GPS GPS receiver	ESPERIA	Gravity field or geodynamic	Study of perturbations in the atmosphere and ionosphere caused by electromagnetic waves, short term earthquake prediction	Waveband: Resolution: Swath: Accuracy:
GPS (ESA)	GOCE	Gravity field or geodynamic	Satellite positioning	Waveband: Resolution: Swath: Accuracy:
GPSDR GPS Demonstration Receiver	TopeX-Poseidon, VCL, GRACE, ICESat, SAC-A, CHAMP	Gravity field or geodynamic	Provides precise continuous tracking data of satellite to decimeter accuracy	Waveband: Resolution: Swath: Accuracy:
GPSOS Global Positioning System Occultation Sensor	NPOESS-2, 3, 5, 6	Other	Monitors signals from 24 GPS satellites that circle the Earth to help characterise ionospheric density profiles and atmospheric pressure, temperature and humidity profiles	Waveband: Resolution: Swath: Accuracy:
GRAS GNSS Receiver for Atmospheric Sounding	GOCE, METOP-1, 2, 3	Atmospheric sounder (IR or microwave)	GNSS receiver for atmospheric temperature and humidity profile sounding	Waveband: Resolution: Vertical: 150m (troposphere) and 1.5km (stratosphere), Horizontal: 100km approx (troposphere), 300km approx (stratosphere) Swath: Altitude range of 5-30km Accuracy: Temperature sounding to 1K rms
HAIRS High Accuracy Inter-satellite Ranging System	GRACE	Gravity field or geodynamic	Ranging instrument between the 2 GRACE spacecraft - to derive Earth gravity field measurements	Waveband: Microwave: K Band, Ka Band Resolution: Swath: Accuracy: 10 microns total at twice per revolution
HALOE Halogen Occultation Experiment	UARS	Atmospheric Chemistry instrument	Provides data on vertical distributions of hydrofluoric and hydrochloric acids, methane, water vapour and members of the nitrogen family. It also provides atmospheric temperature versus pressure profiles from observations of carbon dioxide	Waveband: SWIR: 2.43µm, TIR: 10.25µm Resolution: Vertical (limb): approx 4.5km Horizontal (limb): about 300km along limb tangent path Swath: 6-150km (vertical limb coverage) Accuracy: 10-30%
HiRDLS High Resolution Dynamics Limb Sounder	EOS - Aura	Atmospheric Chemistry instrument	Measures atmospheric temperature, concentrations of ozone, water vapour, methane, NO _x , N ₂ O, CFCs and other minor species, aerosol concentration, location of polar stratospheric clouds and cloud tops	Waveband: TIR: 6.12-17.76µm (21 channels) Resolution: Vertical 1km, Horizontal: 10km Swath: Accuracy: Trace gas: 10%, Temperature 1K, Ozone: 10%

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
HIRS/2 High Resolution Infra-red Sounder/2	NOAA-11, 12, 14	Atmospheric sounder (IR or microwave)	Provides vertical profiles of temperature, humidity, and ozone. Measures atmospheric temperature, concentrations of ozone, water vapour, methane, NO _x , N ₂ O, CFCs and other minor species, aerosol concentration, location of polar stratospheric clouds and cloud tops	Waveband: VIS-TIR: 0.69-14.95µm (20 channels) Resolution: 20.3km (IFOV and ground sample) Swath: 2240km Accuracy:
HIRS/3 High Resolution Infra-red Sounder/3	NOAA-15,16,M	Atmospheric sounder (IR or microwave)	Provides atmospheric temperature profiles and data on cloud parameters, humidity soundings, water vapour, total ozone content, and surface temperatures	Waveband: VIS-TIR: 0.69-14.95µm (20 channels) Resolution: 20.3km (IFOV and ground sample) Swath: 2240km Accuracy:
HIRS/4 High Resolution Infra-red Sounder/4	NOAA-N,N', METOP-1,2	Atmospheric sounder (IR or microwave)	Provides atmospheric temperature profiles and data on cloud parameters, humidity soundings, water vapour, total ozone content, and surface temperatures. Same as HIRS/3, with 10km IFOV	Waveband: VIS-TIR: 0.69-14.95µm (20 channels) Resolution: 10km (IFOV) and 20.3km ground sample Swath: 2240km Accuracy:
HRDI High Resolution Doppler Imager	UARS	Atmospheric Chemistry instrument	Daytime wind measurements below 50km from Doppler shifts of molecular oxygen absorption lines. Day and night wind measurements above about 60km from Doppler shifts of neutral and ionised atomic oxygen emission lines. Also measures temperature	Waveband: Visible-NIR: 0.557-0.776µm Resolution: Vertical (limb): 4km Horizontal (limb): 80km Swath: 5 to 100km (vertical coverage) Accuracy: Daytime wind measurements: 5m/s or better Day and night: 15m/s or better
HRG HRG	SPOT-5	High resolution imager	High resolution multispectral mapper. 2 HRG instruments on this mission can be processed to produce simulated imagery of 2.5m. Images are 60km x 60km in size	Waveband: VIS: 0.55, 0.61-0.68, 0.64µm, NIR-SWIR: 0.78-0.89µm, 0.85µm, 1.5-1.7µm, Panchromatic: 0.5-0.75µm Resolution: Panchromatic: 5m, Multispectral: 10m Swath: 60km (1 instrument), 117km (2 instruments). Same as SPOT 4 with off-track steering capability (±27 deg) Accuracy:
HR-PAN High Resolution Panchromatic Camera	CARTOSAT-2	Hi resolution imager	High resolution stereo images for large scale (better than 1,0000) mapping applications, urban applications, GIS ingest	Waveband: VIS: 0.5-0.75µm Resolution: 1m Swath: 12km Accuracy:
HRS High Resolution Stereoscope	SPOT-5	High resolution imager	High resolution stereo instrument	Waveband: Panchromatic: VIS 0.49-0.69µm Resolution: Panchromatic: 10m, Altitude: 15m Swath: 120km Accuracy:
HRTC High Resolution Panchromatic Camera	SAC-C	High resolution imager	High resolution earth imagery to complement MMR5 on the same mission	Waveband: VIS-NIR: 400-900nm Resolution: 35m Swath: 90km Accuracy:
HRVIR High Resolution Visible and Infra-red	SPOT-4	High resolution imager	2 HRVIR instruments on this mission provide 60km x 60km images for a range of land and coastal applications	Waveband: VIS: 0.50-0.59µm, 0.61-0.68µm NIR: 0.79-0.89µm, SWIR: 1.5-1.7µm Resolution: 10m (0.64µm) or 20m Swath: 117km (ie 60km + 60km with 3km overlap). Steerable up to ±27 deg off-track Accuracy:
HSB Humidity Sounder/Brazil	Aqua	Atmospheric sounder (IR or microwave)	Humidity soundings for climatological and atmospheric dynamics applications	Waveband: Microwave: 5 discrete channels in the range of 150-183MHz Resolution: 13.8km Swath: 1680km Accuracy: Temperature: 1.0-1.2K coverage of land and ocean surfaces; Humidity: 20%
HSRS Hot Spot Recognition Sensor	BIRD	Imaging multi- spectral radiometer (vis/IR)	Detection of hot spots (forest fires, volcanic activities, burning oil wells or coal seams)	Waveband: MWIR: 2.4-4.2µm, TIR: 8.5-9.3µm Resolution: 370m Swath: 190km Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
HSTC High Sensitivity Technological Camera	SAC-C	Other	Provides data to monitor forest fires, electrical storms and geophysical studies of aurora borealis	Waveband: 450-850nm PAN-VIR Resolution: 250m Swath: 990km Accuracy:
HYC Hyperspectral Camera	HypSE0	Imaging multi-spectral radiometer (vis/IR)	Panchromatic and Hyperspectral data for complex land ecosystem studies	Waveband: VIS-NIR: 400-900nm, 400-1000nm, SWIR: 900-2500nm; Spectral resolution 10nm, 220 bands Resolution: PAN: 5m; VNIR-SWIR: 20m Swath: 20km Accuracy:
Hycam Hyperspectral Camera	FOURIER	High resolution imager	Atmospheric physics, radiative properties, climate change	Waveband: VIS-NIR: 0.4-1.1µm Resolution: Swath: Accuracy:
Hyperion Hyperspectral Imager	NMP EO-1	Imaging multi-spectral radiometer (vis/IR)	Hyperspectral imaging of land surfaces	Waveband: TVIS-NIR: 400-1000nm; NIR-SWIR: 900-2500nm; 10nm spectral resolution for 220 bands Resolution: 30m Swath: 7.5km Accuracy: SNR @ 10% refl target: vis 10-40 swir 10-20
IAP Instrument for plasma analysis	DEMETER	Other	Density, temperatures, speeds of major ions	Waveband: Resolution: Swath: Accuracy:
IASI Infra-red Atmospheric Sounding Interferometer	METOP-1, 2, 3	Atmospheric sounder (IR or microwave)	Measures tropospheric moisture and temperature, column integrated contents of ozone, carbon monoxide, methane, dinitrogen oxide and other minor gases which affect tropospheric chemistry. Also measures sea surface and land temperature	Waveband: MWIR-TIR: 3.4-15.5µm with gaps at 5µm and 9µm Resolution: Swath: Vertical: 1-30km, Horizontal: 25km Accuracy: Temperature: 0.5-2K, Specific humidity: 0.1-0.3g/kg, Ozone, trace gas profile: 10%
ICARE Influence of Space Radiation on Advanced Components	SAC-C	Other	Improvement of risk estimation models on latest generation of integrated circuit technology	Waveband: Resolution: Swath: Accuracy:
ICE Instrument for Electric Field	DEMETER	Other	Electric field	Waveband: DC to 3MHz Resolution: Swath: Accuracy:
IDP Instrument for Plasma Detection	DEMETER	Other	Energy spectrum of electrons	Waveband: Resolution: Swath: Accuracy:
IGPM IGPM microwave radiometer	IGPM	Imaging multi-spectral radiometer (microwave)	Global water and energy cycle	Waveband: Resolution: Swath: Accuracy:
IIR Imaging infrared radiometer	CALIPSO	Imaging multi-spectral radiometer (vis/IR)	Radiometer optimized for combined IIR/lidar retrievals of cirrus particle size	Waveband: TIR: 8.7, 10.5, and 12.0µm (0.8µm resolution) Resolution: 1km Swath: 64km Accuracy: 1K
IKFS-2 Fourier spectrometer	METEOR-3M N2.3	Atmospheric sounder (IR or microwave)	Atmospheric temperature and humidity sounding and radiation budget assessment	Waveband: 5-15µm, 1300 spectral channels Resolution: Swath: 2500km Accuracy: 1K
ILAS-II Improved Limb Atmospheric Spectrometer II	ADEOS-2	Atmospheric Chemistry instrument	Measures minor trace gas species at high latitudes, in the altitude range 10-60km (O ₃ , CH ₄ , NO ₂ , N ₂ O, H ₂ O, CFC11, HNO ₃ , ClONO ₂ , N ₂ O ₅ , aerosols, temperature, pressure)	Waveband: VIS: 0.753-0.784µm, MWIR-TIR: 3.0-5.7µm, 6.21-11.76µm, 12.78-12.85µm Resolution: Vertical: 1km, Temperature, aerosols, pressure: 2km (horiz), ClONO ₂ : 21.7km (horiz), Others: 13km (horiz) Swath: Accuracy: Temperature: 0.2K, Pressure: 1%, Aerosol: 2%, Ozone: 3-5%, Other trace gases: 2-25%

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
Imager	GOES-8, 9, 10, 11, 12, N, O, P, Q	Imaging multi-spectral radiometer (vis/IR)	Measures cloud cover, atmospheric radiance, winds, atmospheric stability, rainfall estimates. Used to provide severe storm warnings/ monitoring day and night (type, amount, storm features)	Waveband: GOES 8-11: VIS: 1 channel (8 detectors), IR: 4 channels: 3.9, 6.7, 10.7 and 12µm, GOES 12-Q: VIS: 1 channel (8 detectors), IR: 4 channels: 3.9, 6.7, 10.7 and 13.3µm Resolution: 1km in visible 4km in IR (8km for 13.3µm band [water vapour]) Swath: Full Earth disk Accuracy:
Imager (INSAT)	INSAT-3D	Imaging multi-spectral radiometer (vis/IR)	Cloud cover, severe storm warnings/monitoring day and night (type, amount, storm features), atmospheric radiance winds, atmospheric stability rainfall	Waveband: VIS: 0.55-0.75µm, SWIR: 1.55-1.7µm, MWIR: 3.80-4.00µm, 6.50-7.00µm, TIR: 10.2-11.3µm, 11.5-12.5µm Resolution: 1x1km (VIS & SWIR), 4x4km (MWIR, TIR), 8x8km (in 6.50-7.00µm) Swath: Full Earth disc and space around, Normal Frame (50 deg. N to 40 deg S and full E-W Full coverage) Accuracy:
IMAGER/ MTSAT	MTSAT-1R, 2	Imaging multi-spectral radiometer (vis/IR)	Measures cloud cover, cloud motion, cloud height, water vapour, rainfall, sea surface temperature and Earth radiation	Waveband: VIS-SWIR: 0.55-0.80µm, MWIR-TIR: 3.5-4µm, 6.5-7µm, 10.3-11.3µm, 11.5-12.5µm Resolution: Visible: 1km, TIR: 4km Swath: Full Earth disk every hour Accuracy:
IMSC Instrument Search Coil Magnetometer	DEMETER	Other	Magnetic field	Waveband: 400Hz - 10kHz Resolution: Swath: Accuracy:
IMWAS Improved Microwave Atmospheric Sounder	FY-3C, D, E, F, G	Atmospheric sounder (IR or microwave)		Waveband: Microwave: 19.35-89.00GHz (8 channels) Resolution: Swath: Accuracy:
INES Italian Navigation Experiment	SAC-C	Other	Composed of GPS Tensor and GNSS Lagrange Receiver to perform navigation experiment on precise orbit determination	Waveband: Resolution: Swath: Accuracy:
INSAT Comms Communications package for INSAT	INSAT-2D,E	Other		Waveband: Resolution: Swath: Accuracy:
IR Camera (SAOCCOM)	SAOCCOM 1A	Imaging Multispectral Radiometer (IR)	Fires monitoring	Waveband: NIR-TIR Resolution: 200m Swath: TBD Accuracy: TBD
IRAS Infrared Atmospheric Sounder	FY-3A, B, C, D, E, F, G	Atmospheric sounder (IR or microwave)	Atmospheric sounding for weather forecasting	Waveband: VIS - TIR: 0.65-14.95µm (26 channels) Resolution: 14km Swath: Accuracy:
IR-MSS Infrared Multispectral Scanner	CBERS-1, 2, 3, 4	High resolution imager	Used for fire detection, fire extent and temperature measurement	Waveband: VIS-NIR: 0.5-1.1µm, NIR-SWIR: 1.55-1.75µm, 2.08-2.35µm Resolution: TIR: 10.4-12.5µm Visible, NIR, SWIR: 78mm TIR: 156m Swath: 120km Accuracy:
ISL Langmuir probes	DEMETER	TBC	Density of the plasma and electron temperature	Waveband: Resolution: Swath: Accuracy:
ISP	Resurs-O1 N4	Earth radiation budget radiometer	Measures solar radiation flux	Waveband: UV-FIR: 0.2-50µm Resolution: Swath: Accuracy: 0.01% (mean day accuracy)

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
IST Italian Star Tracker	SAC-C	Other	Test of a fully autonomous system for attitude and orbit determination using a star tracker	Waveband: Resolution: Swath: Accuracy:
IVISSR (FY-2) Improved Multispectral Visible and Infrared Scan Radiometer (5 channels)	FY-2 C, D, E	Imaging multi-spectral radiometer (vis/IR)	Meteorological	Waveband: Vis + TIR: 0.5-12.5µm (5 channels) Resolution: 1.4km Swath: Accuracy:
JMR JASON-1 Microwave Radiometer	Jason-1, 2	Imaging multi-spectral radiometer (microwave)	Provides altimeter data to correct for errors caused by water vapour and cloud-cover. Also measures total water vapour and brightness temperature	Waveband: Microwave: 18.7GHz, 23.8GHz, 34GHz Resolution: 41.6km at 18.7GHz, 36.1km at 23.8GHz, 22.9km at 34GHz Swath: 120 deg cone centred on nadir Accuracy: Total water vapour: 0.2g/sq cm, Brightness temperature: 0.15 K
KGI-4C	METEOR-3M N1	Earth radiation budget radiometer	Measures particle flux and electromagnetic emissions. Electron flux density range: 0.15-2.0MeV, proton flux density range: 5- 90MeV, gamma ray flux density range: 0.1-1.0MeV	Waveband: Resolution: Swath: Accuracy:
Klimat Scanning IR radiometer	METEOR-3M N1	Imaging multi-spectral radiometer (vis/IR)	Provides images of cloud, ice and snow. Measures sea surface temperature	Waveband: TIR: 10.5-12.5µm Resolution: 0.45km x 0.9km Swath: 1300km Accuracy:
KONDOR-2 Data collection and transmission system	OKEAN-O	Other	Data collection and retransmission	Waveband: Resolution: Swath: Accuracy:
Lagrange LABEN GNSS Receiver for Advanced Navigation, Geodesy and Experiments	FOURIER	Other	GPS Receiver. Including specialised version equipped with limb sounding antenna and dedicated signal tracking capability for meteorological, climate and space weather applications	Waveband: Resolution: Swath: Accuracy:
Laser reflectors (IESA)	CRYOSAT, GOCE	Gravity field or geodynamic	Measures distance between the satellite and the laser tracking stations	Waveband: Resolution: Swath: Accuracy:
Laser reflectors Laser reflectors	STELLA, STARLETTE	Gravity field or geodynamic	Measures distance between the satellite and the laser tracking stations	Waveband: Resolution: Swath: Accuracy:
Lidar Lidar	CALIPSO	Lidar	High resolution vertical profiles of aerosols and clouds	Waveband: VIS & NIR: 532nm and 1064nm Nd:YAG laser Resolution: Horizontal: 333m, Vertical: 30m Swath: Accuracy:
LIS Lightning Imaging Sensor	TRMM	Other	Global distribution and variability of total lightning. Data can be related to rainfall to study hydrological cycle	Waveband: NIR: 0.7774µm Resolution: 4km Swath: FOV: 80 x 80 deg Accuracy: 90% day and night detection probability
LISS-I Linear Imaging Self Scanner - I	IRS-1B	High resolution imager	Provides data for: monitoring land use/land cover, forest cover, coastal zones and wastelands; identification of prospective ground water zones; and crop acreage and production estimation for wheat, rice, sorghum, cotton, groundnut, tobacco, etc.	Waveband: VIS: 0.46-0.52µm, 0.52-0.59µm, 0.62-0.68µm, NIR: 0.77-0.86µm Resolution: 72.5m Swath: 148km Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
LISS-II Linear imaging Self Scanner - II	IRS-1B, IRS-P3	High resolution imager	Data used for vegetation type assessment, resource assessment, crop stress detection, crop production forecasting, forestry and for monitoring land use and land cover change	Waveband: VIS: 0.44-0.52µm, 0.52-0.59µm, 0.62-0.68µm, NIR: 0.77-0.86µm Resolution: 32 x 37m Output sampled to 3.6m compatible to IRS-1A/1B Swath: 132km Accuracy:
LISS-III Linear Imaging Self Scanner - III	IRS-1C, O RESOURCESAT-1, 5	High resolution imager	Data used for vegetation type assessment, resource assessment, crop stress detection, crop production forecasting, forestry, land use and land cover change	Waveband: VIS: Band 2: 0.52-0.59µm, Band 3: 0.62-0.68µm, NIR: Band 4: 0.77-0.86µm, SWIR: Band 5: 1.55-1.75µm Resolution: Bands 2, 3 & 4: 23.5m, Band 5: 70.5m Swath: 140km Accuracy:
LISS-IV Linear Imaging Self Scanner - IV	RESOURCESAT-1, 2	High resolution imager	Vegetation monitoring, improved crop discrimination, crop yield, disaster monitoring and rapid assessment of natural resources	Waveband: VIS: 0.52-0.59µm, 0.62-0.68µm NIR: 0.77-0.86µm Resolution: 5.8m Swath: 70km Accuracy:
LP/RPA Langmuir Probe and Retarding Potential Analyser	ESPERIA	Magnetic field	Study of perturbations in the atmosphere and ionosphere caused by electromagnetic waves, short term earthquake prediction	Waveband: Resolution: Swath: Accuracy:
LRA Laser Retroreflector Array	TOPEX-POSEIDON, Jason-1, 2, LAGEOS-1, 2, 3	Gravity field or geodynamic	Provides baseline tracking data for precision orbit determination and/or geodesy. Also for calibration of radar altimeter bias. Several types used on various missions	Waveband: Resolution: Swath: Accuracy: 2cm overhead ranging
L-SAR L-Band SAR	TerraSAR-L	Imaging radar	L-Band Sar for agriculture and forestry	Waveband: Microwave: L-band (2GHz) Resolution: 5m Swath: 10-200km depending on mode Accuracy:
MADRAS	MEGHA-TROPIQUES	Imaging multi-spectral radiometer (vis/IR)	Measures precipitation and cloud properties. 89 & 157GHz channels permit detection of convective rain regions over land and sea. Lower frequencies used over oceans for measuring cloud liquid water and precipitation	Waveband: Microwave: 18.7GHz, 23.8GHz, 36.5GHz, 89GHz, 157GHz Resolution: Swath: Accuracy:
MAESTRO Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation	SCISAT-1	Atmospheric Chemistry instrument	Will aid in the SCISAT-1 overall mission of increasing our understanding of the chemical processes involved in the depletion of the ozone layer	Waveband: UV-NIR: 0.285 to 1.03µm [1-2nm spectral resolution] Resolution: Approx 1km vertical Swath: Accuracy:
MASTER	ESA Future Missions	Atmospheric sounder (IR or microwave)	Data for study of exchange mechanisms between stratosphere/troposphere, and information for studies on global change. Measures upper troposphere/ lower stratosphere profiles of O3, H2O, CO, HNO3, SO2, N2O, pressure and temperature	Waveband: Microwave: 199-207, 296-306, 318-326, 342-349GHz Resolution: 3km Swath: Accuracy: 199-207GHz channel: 1K, Other channels: 1.5K, 50MHz resolution, 0.3 secs integration time
MBLA Multi-Beam Laser Altimeter	VCL	Lidar	Pulsed lidar for continuous global remote sensing of tree canopy height, vertical distribution of intercepted surfaces in the canopy, and ground topography elevations	Waveband: NIR: Nd:YAG lasers operating at 1064nm Resolution: 25m footprint diameter Swath: 8km Accuracy: Elevation: +/-1m in low slope terrain, Vegetation height: +/-1m
MCP Meteorological Communications Package (MCP)	METOP-1, 2, 3	Other	Communications	Waveband: Resolution: Swath: Accuracy:

Instrument	Mission(s)	Type	Measurements / Application	Technical characteristics
MERIS Medium-Resolution Imaging Spectrometer	Envisat	Imaging multi-spectral radiometer (vis/IR)	Main objective is monitoring marine biophysical and biochemical parameters. Secondary objectives are related to atmospheric properties such as cloud and water vapour and to vegetation conditions on land surfaces	Waveband: VIS-NIR: 15 bands selectable across range: 0.4-1.05µm (bandwidth programmable between 0.0025 and 0.03µm) Resolution: Ocean: 1040m x 1200m, Land & coast: 260m x 300m Swath: 1150km, global coverage every 3 days Accuracy: Ocean colour bands typical S-N = 1700
METEOSAT Comms Communications package for METEOSAT	METEOSAT-3, 4, 5, 6, 7	Other	Communications	Waveband: Resolution: Swath: Accuracy:
MHS Microwave Humidity Sounder	NOAA-N,N', METOP-1,2,3	Atmospheric sounder (IR or microwave)	Provides atmospheric humidity profiles, cloud cover, cloud liquid, water content, ice boundaries and precipitation data	Waveband: Microwave: 89, 166GHz and 3 channels near 183GHz Resolution: Vertical: 37km, Horizontal: 30-50km Swath: 1650km Accuracy: Cloud water profile: 10g/m ² , Specific humidity profile: 10-20%
MIPAS Michelson Interferometric Passive Atmosphere Sounder	Envisat, ESA Future Missions	Atmospheric Chemistry instrument	Provides data on stratosphere chemistry (global/polar ozone), climate research (trace gases/ clouds), transport dynamics, tropospheric chemistry. Primary/ secondary species: O ₃ , NO, NO ₂ , HN0 ₃ , N ₂ O ₅ , ClONO ₂ , CH ₄	Waveband: MWIR-TIR: between 4.15 and 14.6µm Resolution: Vertical resolution: 3km, vertical scan range 5-150km Horizontal: 3km x 30km Spectral resolution: 0.035 lines/cm Swath: Accuracy: Radiometric precision: 685-970 cm ⁻¹ : 1%, 2410 cm ⁻¹ : 3%
MIRAS Multichannel Infrared Atmospheric Sounder	FY-3 C, D, E, F, G	Atmospheric sounder (IR or microwave)		Waveband: Resolution: Swath: Accuracy:
MIRAS Microwave Imaging Radiometer using Aperture Synthesis	SMOS	Multi-direction / polarisation instruments	Objective is to demonstrate observations of sea surface salinity and soil moisture in support of climate, meteorology, hydrology, and oceanography applications	Waveband: Microwave: L-Band 1.41GHz (based on MIRAS concept) Resolution: Science requirements: Soil moisture: 10km (desired), Sea surface salinity: 20km (desired) Swath: Science requirements: Soil moisture: 10km (desired), Sea surface salinity: 20km (desired) Accuracy: Desired radiometric accuracy: 1K for land, 0.5K for sea
MISR Multi-angle Imaging Spectro Radiometer	Terra	Multi-direction / polarisation instruments	Provides measurements of global surface albedo, aerosol and vegetation properties. Also provides multi-angle bidirectional data (1% angle-to-angle accuracy) for cloud cover and reflectances at the surface and aerosol opacities. Global and local modes	Waveband: VIS: 0.44, 0.56, 0.67µm, NIR: 0.86µm Resolution: 275m, 550m or 1.1km, Summation modes available on selected cameras/bands: 1x1, 2x2, 4x4, 1x4, 1 pixel = 275m Swath: 360km common overlap of all 9 cameras Accuracy: 0.03% hemispherical albedo, 10% aerosol opacity, 1-2% angle to angle accuracy in bidirectional reflectance
MIVZA MIVZA	METEOR-3M N1	Atmospheric sounder (IR or microwave)	Microwave radiometer for temperature sounding of atmosphere	Waveband: Microwave: 1.5, 0.86, 0.32cm Resolution: 1500m Swath: Accuracy:
MLS (EOS-Aura) Microwave Limb Sounder (EOS-Aura)	EOS-Aura	Atmospheric sounder (IR or microwave)	Measures lower stratospheric temperature and concentration of H ₂ O, O ₃ , ClO, HCl, OH, HNO ₃ , N ₂ O and SO	Waveband: Microwave: 118, 190, 240, 640GHz & 2.5THz Resolution: 3km x 300km horizontal x 1.2km vertical Swath: Limb scan 2.5 - 62.5km Limb to limb Accuracy: Temperature: 4K, Ozone: 50%
MLS Microwave Limb Sounder (JARS)	JARS	Atmospheric sounder (IR or microwave)	Provides data on emissions of chlorine monoxide, water vapour and ozone. Data also used for determination of atmospheric pressure and temperatures as a function of altitude from observations of molecular oxygen emissions	Waveband: Resolution: Swath: Accuracy:

Instrument	Mission(s)	Type	Measurements /Application	Technical characteristics
MMP Magnetic Mapping Payload	SAC-C	Magnetic field	Magnetic Field Measurement of the Earth's magnetic field with a vector and a scalar magnetometer	Waveband: 2 arcsec and 1 nT Resolution: Swath: Accuracy:
MMRS Multispectral Medium Resolution Scanner	SAC-C	Imaging multi-spectral radiometer (vis/IR)	Applications related to agriculture, environment, forestry, hydrology, oceanography, mineralogy and geology, desertification, contamination and protection of ecosystems	Waveband: VIS-NIR: 480 - 500nm, 540-560nm, 630-690nm, 795-835nm, SWIR: 1550-1700nm Resolution: 175m Swath: 360km Accuracy:
MODIS Moderate-Resolution Imaging Spectro radiometer	Terra, Aqua	Imaging multi-spectral radiometer (vis/IR)	Data on biological and physical processes on the surface of the Earth and in the lower atmosphere, and on global dynamics. Surface temperatures of land and ocean, chlorophyll fluorescence, land cover measurements, cloud cover (day and night)	Waveband: VIS-TIR: 36 bands in range 0.4-14.4µm Resolution: Cloud cover: 250m (day) and 1000m (night), Surface temperature: 1000m Swath: 2330km Accuracy: Long wave radiance: 100nW/m ² , Short wave radiance: 5%, Surface temperature of land: <1K, Surface temperature of ocean: <0.2K, Snow and ice cover: 10%
MOPITT Measurements of Pollution in the Troposphere	Terra	Atmospheric Chemistry instrument	Measurements of greenhouse gases (CO, methane) in the troposphere	Waveband: SWIR-MWIR: 2.3, 2.4 and 4.7µm Resolution: CO profile: 4km vertical, 22 x 22km horizontal, CO, CH ₄ column: 22x22km horizontal Swath: 616km Accuracy: Carbon monoxide (4km layers): 10%, Methane column: 1%
MOS Modular Opto-electronic Scanner	IRS-P3	Ocean colour radiometer	Provides data for spectral analysis of O ₂ absorption in the NIR band, vegetation and indices and vegetation condition and soil assessment	Waveband: NIR: 755-768nm (4 bands), VIS-NIR: 408-1010nm (13 bands), SWIR: 1600nm Resolution: 1570m, 525m, 645m Swath: 200km (approximately) Accuracy: Radiometric: < 1%
MR-2000M1	METEOR-3M N1	Imaging multi-spectral radiometer (vis/IR)	TV camera images of cloud, snow and ice	Waveband: VIS-NIR: 0.5-0.8µm Resolution: 0.7 x 1.4km Swath: 3100km Accuracy:
MR-900B Scanning visual band telephotometer	METEOR-3 N5 METEOR-2 N21 Resurs-01 N4	Imaging multi-spectral radiometer (vis/IR)	TV camera images of cloud, snow and ice	Waveband: VIS-NIR: 0.5-0.8µm Resolution: 2 x 1km Swath: 2600km Accuracy:
MSC Multi-Spectral Camera	KOMPSAT-2	High resolution imager	High resolution imager for land applications of cartography and disaster monitoring	Waveband: VIS-NIR: 0.5-0.92µm, VIS: 0.45-0.52µm, 0.52-0.6µm, 0.63-0.69µm NIR: 0.76-0.9µm Resolution: Pan: 1m, VNIR: 4m Swath: 15km Accuracy:
MSG Comms Communications package for MSG	MSG-1, 2, 3	Other	Communications	Waveband: Resolution: Swath: Accuracy:
MSG1-5EI Multichannel System for Geosynchronous Emission Measurements	METEOR-3M N1	Other	Geosynchronous Emission Measurements	Waveband: Ions energetic spectrum: 0.1 - 15 keV, 3 channels, Energy of electrons: 0.05 - 20 keV and more than 40 keV, 4 channels Resolution: Swath: Accuracy:
MSG1-MKA Spectrometer	METEOR-3M N2,3	Other	Geosynchronous corpuscular emissions measurements	Waveband: Resolution: Swath: Accuracy:
MSMR Multifrequency Scanning Microwave Radiometer	IRS-P4	Imaging multi-spectral radiometer (microwave)	Sea state and meteorological parameter monitoring (sea surface temperature, surface wind speed, water vapour over ocean and liquid water content of the cloud)	Waveband: Microwave: 6.6, 10.6, 18 and 21GHz Resolution: 40m at 21GHz to 120m at 6.6GHz Wind speed: 75 x 75km, Sea surface temperature: 146 x 150km Swath: 1360km Accuracy: Sea surface temperature: 1.5K Sea surface wind speed: 1.5 m/s

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
MSU Microwave Sounding Unit	NOAA-11, 12, 14	Atmospheric sounder (IR or microwave)	Provides temperature sounding through cloud up to 20km in altitude	Waveband: Microwave: 50.3, 53.74, 54.96 and 57.95GHz Resolution: 105km Swath width: 2348km, +/-47.4 deg scan Accuracy:
MSU-E Multispectral high resolution electronic scanner	Resurs-O1 N4, METEOR-3M N1	High resolution imager	Multispectral scanner images of land surface and ice cover	Waveband: VIS: 0.5-0.6µm, 0.6-0.7µm NIR: 0.8-0.9µm Resolution: 35-45m Swath: 45km for one scanner, 80km for two scanners (pointable ±30 deg from nadir) Accuracy:
MSU-EU Multi-Spectral Radiometer with High Resolution	SICH-1M	High resolution imager	Multispectral scanner images of land surface	Waveband: VIS: 0.5-0.6µm, 0.6-0.7µm (scanning radiometer), NIR: 0.8-0.9µm Resolution: Visible: 24x34m Swath: 48km or 105km; pointable ±30° from nadir Accuracy:
MSU-GS Multispectral scanning imager- radiometer	GOMS/Electro N2, 3	Imaging multi-spectral radiometer (vis/IR)	Measurements of cloud cover, cloud top height, precipitation, cloud motion, vegetation, radiation fluxes, convection, air mass analysis, cirrus cloud discrimination, tropopause monitoring, stability monitoring, total ozone and sea surface temperature	Waveband: Visible: 0.5-0.65µm, 0.65-0.8µm (broadband), NIR: 0.9µm, SWIR: 1.5µm, MWIR: 3.5-4.01µm TIR: 5.7-7.0µm, 8µm, 8.7µm, 9.7µm, 10.2-11.2µm, 11.2-12.5µm, 13.4µm Resolution: 1km (at SSP) for visible and 4km for IR channels Swath: Full Earth disk Accuracy:
MSU-M Multi-Spectral Low Resolution Scanning System	SICH-1M OKEAN-0	Imaging multi-spectral radiometer (vis/IR)	Provides images of ocean surface and ice sheets	Waveband: VIS: 0.5-0.6, 0.6-0.7µm NIR: 0.7-0.8, 0.8-1.1µm Resolution: Visible: 1.7x1.8km Swath: 1930km Accuracy:
MSU-MR Images of clouds, snow, ice and land cover	METEOR-3M N2,3	Imaging multi- spectral radiometer (vis/IR)	Images of clouds, snow, ice and land cover	Waveband: Visible: 0.5-0.7µm, NIR: 0.7-1.1µm, SWIR: 1.6-1.8µm, MWIR: 3.5-4.1µm, TIR: 10.5-11.5µm, 11.5-12.5µm Resolution: 1km Swath: 3000km Accuracy: VIS: 0.5%, IR: 0.1K
MSU-SK Multispectral medium resolution conical scanner	Multispectral medium resolution conical scanner	Imaging multi- spectral radiometer (vis/IR)	Multispectral scanner images of land surface and ice cover	Waveband: Resolution: Swath: Accuracy:
MSU-SM Multi-Spectral Medium Resolution Scanning System	METEOR-3M N1	Imaging multi- spectral radiometer (vis/IR)	Images of clouds, snow, ice and land cover	Waveband: Visible: 0.5-0.7µm, NIR: 0.7-1.1µm Resolution: 225m Swath: 2250km Accuracy:
MSU-UM Visible Multi-Spectral Radiometer	SICH-2	Imaging multi-spectral radiometer (vis/IR)		Waveband: VIS-NIR: 0.52-0.90µm (3 channels) Resolution: Swath: Accuracy:
MSU-V Multispectral high resolution conical scanner	OKEAN-0	Imaging multi- spectral radiometer (vis/IR)		Waveband: Resolution: Swath: Accuracy:
MTSAT Comms Communications package for MTSAT	MTSAT-1R, 2	Other	Communications	Waveband: Resolution: Swath: Accuracy:
MTVZA Scanning microwave radiometer	METEOR-3M N1,2	Atmospheric sounder (IR or microwave)	Provision of atmospheric temperature and humidity profiles	Waveband: Microwave: 18.7-183GHz, 52-550GHz, 19 channels Resolution: 12-75km Swath: 2400km Accuracy:

Instrument	Mission(s)	Type	Measurements /Application	Technical characteristics
MTVZAOK Scanning microwave radiometer	SICH-1M	Atmospheric sounder (IR or microwave)	Multi-Spectral Scanner Images of Earth Surface	Waveband: Microwave: 6.9 (V,H), 10.6 (V,H), 18.7 (V,H), 23.8 (V), 31.5 (V,H), 36.7 (V,H), 42 (V,H), 48 (V,H), 52.3-57.0 (V,H), 91 (V,H), 183.31GHz VIS: 0.37-0.45, 0.45-0.51, 0.58-0.68, 0.68-0.78µm IR: 10.4-11.5, 11.5-12.6µm Resolution: Microwave: 12x200km Visible: 1.1 or 4.0km IR: 1.1 or 4.0km Swath: 2000km Accuracy:
Multispectral high resolution scanner	Resurs DK	High resolution imager	Research of Earth natural resources, cartography	Waveband: VIS-NIR: 0.5-0.6, 0.6-0.7, 0.7-0.8, 0.58-0.8µm Resolution: Panchromatic band 1.8 m, Narrow spectral bands 3.5 -4.5m Swath: 48.5km Accuracy:
MVIRI METEOSAT Visible and Infrared Imager	METEOSAT 7 (MTP)	Imaging multi-spectral radiometer (vis/IR)	Measures cloud cover, motion, height, upper tropospheric humidity and sea surface temperature	Waveband: TVIS-NIR: 0.5-0.9µm, TIR: 5.7-7.1µm (water vapour), 10.5-12.5µm Resolution: VIS-NIR: 0.5-0.9µm, TIR: 5.7-7.1µm (water vapour), 10.5-12.5µm Swath: Full Earth disk in all three channels, every 30 minutes Accuracy: Cloud top height: 0.5km, Cloud top/ sea surface temperature: 0.7K, Cloud cover 15%
MVIRS Moderate Resolution Visible and Infrared Imaging Spectro radiometer	FY-3 A, B, C, D, E, F, G	Imaging multi-spectral radiometer (vis/IR)	Measures surface temperature and cloud and ice cover. Used for snow and flood monitoring and surface temperature	Waveband: VIS-TIR: 0.47-12.5µm [20 channels] Resolution: Swath: Accuracy:
MVISR (10 channels) Multispectral Visible and Infrared Scan Radiometer (10 channels)	FY-1 C, D	Imaging multi-spectral radiometer (vis/IR)	To provide multispectral analysis of hydrological, oceanographic, land use and meteorological parameters. Global imager & SST Ocean colour	Waveband: 10 channels: VIS: 0.43-0.48µm, 0.48-0.53µm, 0.53-0.58µm, 0.58-0.68µm, NIR: 0.84-0.89µm, NIR-SWIR: 0.90-0.965µm, 1.58-1.68µm, 3.55-3.93µm, TIR: 10.3-11.3µm, 11.5-12.5µm Resolution: 1.1km Swath: 3200km Accuracy:
MWAS Microwave Atmospheric Sounder	FY-3 A, B	Atmospheric sounder (IR or microwave)	Meteorological applications	Waveband: Microwave: 19.35-89.0GHz (8 channels) Resolution: Swath: Accuracy:
MWHS MicroWave Humidity Sounder	FY-3 C, D, E, F, G	Atmospheric sounder (IR or microwave)	Meteorological applications	Waveband: Microwave: 19.35-89.0GHz (8 channels) Resolution: Swath: Accuracy:
MWR MicroWave Radiometer	ERS-2, Envisat	Imaging multi-spectral radiometer (microwave)	To provide multispectral analysis of hydrological, oceanographic, land use and meteorological parameters	Waveband: Microwave: 23.8 and 36.5GHz Resolution: 20km Swath: 20km Accuracy: Temperature: 2.6K
MWR-2 MicroWave Radiometer-2	ESA Future Missions	Imaging multi-spectral radiometer (microwave)	To provide multispectral analysis of hydrological, oceanographic, land use and meteorological parameters	Waveband: Resolution: Swath: Accuracy:
MWRI MicroWave Radiation Imager	FY-3 A, B, C, D, E, F, G	Imaging multi-spectral radiometer (microwave)		Waveband: Resolution: Swath: Accuracy:
NISTAR NIST Advanced Radiometer	Triana	Earth radiation budget radiometer	Measures radiance output from the sunlit Earth over a broad spectrum (UV and VIS reflected and IR emitted) to detect energy balance changes in support of climate studies	Waveband: UV-FIR: 0.2-100µm, 0.2-4µm, 0.7-4µm, 0.3-1µm Resolution: Swath: Full Earth disk Accuracy: Total Earth reflected and emitted power to within 0.1%

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
NOAA Comms Communications package for NOAA	NOAA-11,12,14,15,16,M,N,N'	Other	Communications	Waveband: Resolution: Swath: Accuracy:
OBA Observador Brasileiro da Amazonia	SSR-1, 2	Imaging multi-spectral radiometer (vis/IR)	Used for fire extent detection and temperature measurement, coastal and vegetation monitoring, land cover and land use mapping	Waveband: VIS: 0.45-0.50µm, 0.52-0.57µm, 0.63-0.69µm, NIR: 0.76-0.90µm, MWIR: 3.4-4.2µm Resolution: VIS-NIR: 100m, MIR: 300m Swath: 2200km (equatorial belt from latitude 5N to 15S) Accuracy:
OCM Ocean Colour Monitor	IRS-P4,OCEANSAT 2	Ocean colour radiometer	Ocean colour information, coastal zone monitoring, land resources monitoring	Waveband: VIS-NIR: 0.40-0.88µm (8 channels) Resolution: 236m x 360m Swath: 1440km Accuracy:
OEK DZZ WR High resolution electron-optical complex for Earth remote sensing	Resurs-01 N5	High resolution imager	Research of Earth natural resources, cartography	Waveband: PAN (VIS-NIR) 0.45-0.9µm, Narrow bands: VIS: 0.43-0.47µm, 0.51-0.59µm, 0.61-0.69µm, VIS-NIR: 0.7-0.8µm, NIR: 0.8-0.9µm, 0.8-1.1µm Resolution: Panchromatic band 1.0 m, Narrow spectral bands 2.0m Swath: 30km Accuracy:
OLS Operational Linescan System	DMSP F-8, 12, 13, 14, 15, 16, 17, 18, 19, 20	Imaging multi-spectral radiometer (vis/IR)	Day and night cloud cover imagery	Waveband: VIS-NIR: 0.4-1.1µm, TIR: 10.0-13.4µm, and 0.47-0.95µm Resolution: 0.56km (fine), 5.4km (stereo products) Swath: 3000km Accuracy:
OMI Ozone Measuring Instrument	EOS Aura	Atmospheric Chemistry instrument	Mapping of ozone columns, key air quality components (NO ₂ , SO ₂ , BrO, OCIO and aerosols), measurements of cloud pressure and coverage, global distribution and trends in UV-B radiation	Waveband: UV: 270-314nm & 306-380nm, VIS: 350-500nm Resolution: 13km x 24km or 36km x 48km depending on the product. Also has zoom modes (13km x 13km) for example for urban pollution detection Swath: 2600km Accuracy:
OMPS Ozone Mapping and Profiler Suite	NPOESS-2, 5	Atmospheric Chemistry instrument	Measures total amount of ozone in the atmosphere and the ozone concentration variation with altitude	Waveband: Nadir Mapper: UV 0.3-0.38µm, Nadir profiler: UV 0.25-0.31µm, Limb soundings: UV-TIR 0.29-10µm Resolution: Mapper: 50km, Profiler: 250km, Limb: 1km vertical Swath: Mapper: 2800km, Profiler: 250km, Limb: 3 vertical slits along track +/- 250km Accuracy:
OP Ozone Profiler	FY-3A, B, C, D, E, F, G	Atmospheric Chemistry instrument	Ozone measurements	Waveband: Resolution: Swath: Accuracy:
OPUS Ozone and Pollution Measuring Ultraviolet Spectrometer	GCOM-A1	Atmospheric Chemistry instrument	Primary objective of measuring global total column ozone on a daily basis. Also measures volcanic SO ₂ , aerosols, NO ₂ ,HCHO,BrO and stratospheric OCIO, plus cloud top heights	Waveband: UV-VIS: 0.306-0.420µm [228 channels - with a resolution of 0.5-0.7nm] Resolution: 20km Swath: 2500km Accuracy: Total ozone 5% nominal (2% after calval with a precision of 2%)
OSIRIS Optical Spectrograph and Infrared Imaging System	Odin	Atmospheric Chemistry instrument	Detects aerosol layers and abundance of species such as O ₃ , NO ₂ , OCIO, and NO. Consists of spectrograph and IR imager. Measures temperature for altitudes above 30km	Waveband: Spectrograph: UV-NIR: 0.28-0.80µm, IR Imager, NIR: 1.26µm, 1.27µm, 1.52µm Resolution: Spectrograph 1km at limb, Imager 1km in vertical Swath: N/A, but measures in the altitude range 5-100km Accuracy: Depends on species
OSMI Ocean Scanning Multispectral Imager	KOMPSAT-1	Imaging multi-spectral radiometer (vis/IR)	Ocean colour measurements for biological oceanography	Waveband: VIS : 0.412µm, 0.443µm, 0.490µm, 0.555µm, NIR: 0.765µm, 0.865µm Resolution: 1km Swath: 800km Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
PALSAR Phased Array type L-Band Synthetic Aperture Radar	ALOS	Imaging radar	High resolution microwave imaging of land and ice for use in environmental monitoring, agriculture and forestry, disaster monitoring, Earth resource management and interferometry	Waveband: Microwave: L-Band 1270MHz Resolution: Hi-res: 7-44m or 14-88m (depends on polarisation and looks). ScanSAR mode: <100m, Polarimetry 24-88m Swath: High resolution mode: 70km, Scan SAR mode: 250-360km Polarimetry: 30km Accuracy: Radiometric: $\pm 1\text{dB}$
PAN Panchromatic sensor	IRS-1C,D, CARTOSAT-1	High resolution imager	High resolution stereo images for study of topography, urban areas, development of DTM, run-off models etc. Urban sprawl, forest cover/timber volume, land use change	Waveband: Panchromatic VIS: 0.5-0.75 μm Resolution: 5.8m (2.5m on CARTOSAT-1) Swath: 70km at nadir (30km each camera on CARTOSAT) Accuracy: CARTOSAT: 5m elevation discrimination
PAN MUX Panchromatic and multispectral imager	CBERS-3, 4	High resolution imager	Provides measurements of cloud type and extent and land surface reflectance and used for global land surface applications	Waveband: VIS: 0.52-0.59 μm , 0.63-0.69 μm NIR: 0.77-0.89 μm , PAN: 0.51-0.85 μm Resolution: 5m panchromatic and 10m multispectral Swath: 60km Accuracy:
PDA Particle Detector Analyser	ESPERIA	Magnetic field	Study of perturbations in the atmosphere and ionosphere caused by electromagnetic waves, short term earthquake prediction	Waveband: Resolution: Swath: Accuracy:
PEM Particle Environment Monitor	UARS	Magnetic field	PEM measures UV and charged particle energy inputs: determines type, amount, energy and distribution of charged particles injected into Earth's thermosphere, mesosphere and stratosphere	Waveband: Resolution: Swath: Accuracy:
PFS Planetary Fourier Spectrometer	FOURIER	Atmospheric sounder (IR or microwave)	Atmospheric physics, radiative properties, climate change	Waveband: NIR-FIR: 1.2-45 μm Resolution: Swath: Accuracy:
Plasma-Mag Plasma-Mag	Triana	Magnetic field	Sun-viewing instrument to measure the solar wind and magnetic field parameters. Also serves as early-warning for solar-event storms that could damage satellites and equipment on Earth	Waveband: Resolution: Swath: Accuracy:
POLDER POLarization and Directionality of the Earth's Reflectances	ADEOS-2	Multi-direction / polarisation instruments	Measures polarisation, and directional and spectral characteristics of the solar light reflected by aerosols, clouds, oceans and land surfaces	Waveband: VIS-NIR: 0.443, 0.670 and 0.865 μm at 3 polarisations, and 0.443, 0.49, 0.565, 0.763, 0.765 and 0.91 μm with no polarisation Resolution: 6km x 7km Swath: 2400km (across track) x 1800km (along track) Accuracy: Radiation budget, land surface, Reflectance: 2%
POLDER-P POLarization and Directionality of the Earth's Reflectances (PARASOL version)	PARASOL	Multi-direction / polarisation instruments	Measures polarization, and directional and spectral characteristics of the solar light reflected by aerosols, clouds, oceans and land surfaces	Waveband: VIS-NIR: 0.490, 0.670 and 0.865 μm at 3 polarisations, and 0.49, 0.565, 0.763, 0.765, 0.91 μm , and 1.02 μm with no polarisation Resolution: 5.5km x 5.5km Swath: 1600km Accuracy: Radiation budget, land surface, Reflectance: 2%
POSEIDON-1 (SSALT-1) Positioning Ocean Solid Earth Ice Dynamics Orbiting Navigator (Single frequency solid state radar altimeter)	Topex-Poseidon	Radar altimeter	Nadir viewing sounding radar for provision of real-time high precision sea surface topography, ocean circulation and wave height data	Waveband: Microwave 13.65GHz Resolution: 2km antenna footprint Basic measurement: 1/sec (6km along track) Raw measurement: 20/sec (300m along track) Swath width: 10 day cycle 300km between tracks at equator Accuracy: Sea level: 4cm Significant waveheight: 0.5m Horizontal sea surface wind speed: 2m/s

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
POSEIDON-2 (SSALT-2) Positioning Ocean Solid Earth Ice Dynamics Orbiting Navigator (Single frequency solid state radar altimeter)	Jason-1, 2	Radar altimeter	Nadir viewing sounding radar for provision of real-time high precision sea surface topography, ocean circulation and wave height data	Waveband: Microwave: Ku-band (13.575GHz), C-band (5.3GHz) Resolution: Basic measurement: 1/sec (6km along track), Raw measurement: 10/sec (600m along track) Swath: On baseline TOPEX/POSEIDON orbit (10 day cycle): 300km between tracks at equator Accuracy: Sea level: 3.9cm, Significant waveheight: 0.5m, Horizontal sea surface wind speed: 2m/s
PR Precipitation Radar	TRMM	Cloud profiler and/or rain radar	Measures precipitation rate of clouds in tropical latitudes	Waveband: Microwave: 13.796 and 13.802GHz Resolution: Range resolution: 250m Horizontal resolution: 4.3km at nadir Swath: 215km (scanned every 0.6 secs) Observable range: from surface to approx 15km altitude Accuracy: Rainfall rate 0.7mm/h at storm top
PREMOS PREcision Monitoring of Solar variability	PICARD	Earth radiation budget radiometer	Solar UV and visible flux in selected wavelength bands	Waveband: UV: 230nm, 402nm; VIS: 548nm Resolution: Swath: Accuracy:
PRISM (ALOS) Panchromatic Remote-sensing Instrument for Stereo Mapping	ALOS	High resolution imager	High resolution panchromatic stereo imager for land applications which include cartography, digital terrain models, civil planning, agriculture and forestry	Waveband: VIS-NIR: 0.52-0.77µm (panchromatic) Resolution: 2.5m Swath: 35km (triplet stereo observations), 70km (nadir observations) Accuracy:
RA Radar Altimeter	ERS-2	Radar altimeter	Measures wind speed, significant wave height, sea surface elevation, ice profile, land and ice topography and sea ice boundaries	Waveband: Microwave: Ku-band: 13.8GHz Resolution: Footprint is 16-20km Swath: Accuracy: Wave height: 0.5m or 10% (whichever is smaller) Sea surface elevation: better than 10cm
RA-2 Radar Altimeter - 2	Envisat	Radar altimeter	Measures wind speed, significant wave height, sea surface elevation, ice profile, land and ice topography, and sea ice boundaries	Waveband: Microwave: 13.575GHz (Ku-Band) & 3.20GHz (S-Band) Resolution: Swath: Accuracy: Altitude: better than 4.5cm, Wave height: better than 5% or 0.25m
REI REFIR Embedded Imager	REFIR	Imaging multi-spectral radiometer (vis/IR)	Study of radiation processes for climate change, study of water vapour feedback processes and gaseous forcing	Waveband: TIR: 10.5-12.5µm Resolution: Swath: Accuracy:
RFTS REFIR Fourier Transform Spectrometer	REFIR	Imaging atmospheric sounder (IR or microwave)	Study of radiation processes for climate change, study of water vapour feedback processes and gaseous forcing	Waveband: TIR-FIR: 9-100µm Resolution: Swath: Accuracy:
RIMS-M Mass- spectrometer	METEOR-3M N2,3	Other	Ion composition in upper atmosphere	Waveband: Resolution: Swath: Accuracy: 1-4 a.e.m., 5-20 a.e.m
RLSBO Side looking microwave radar	SICH-1M OKEAN-O	Imaging radar	Provides images of ocean surface and ice sheets	Waveband: Microwave: 3.0cm Resolution: 1.3 x 2.5km or 1.3x 2.8km Swath: 450km Accuracy:
RM-08 Imaging Microwave Radiometer	SICH-1M	Imaging multi-spectral radiometer (microwave)	Passive microwave images of ocean surface and ice sheets	Waveband: Microwave: 0.8cm Resolution: 25 x 25km Swath: 550km Accuracy: 3K temperature sensitivity
RMS Radiation measurement system	GOMS/Electro N1,2	Other	Measures flux of charged particles and EM radiation and Earth's magnetic field	Waveband: Resolution: Swath: Accuracy:
RRA Retroreflector Array	Diadème-1, 2	Gravity field or geodynamic	Satellite laser ranging for geodynamic measurements	Waveband: Resolution: Swath: Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
RTER REFIR total energy radiometer	REFIR	Earth radiation budget radiometer	Study of radiation processes for climate change, study of water vapour feedback processes and gaseous forcing	Waveband: MWIR-FIR: 3-30µm Resolution: Swath: Accuracy:
S&R (GOES) Search and Rescue	GOES 8-12, N-Q	Other	Satellite and ground based system to detect and locate aviators, mariners, and landbased users in distress	Waveband: Resolution: Swath: Accuracy:
S&R (NOAA) Search and Rescue Satellite Aided Tracking	NOAA-11,14,15,16,M,N,N', METOP-1,2	Other	Satellite and ground based system to detect and locate aviators, mariners, and landbased users in distress	Waveband: Resolution: Swath: Accuracy:
SAGE II Stratospheric Aerosol and Gas Experiment-II	ERBS	Atmospheric Chemistry instrument	Profiles of ozone, water vapour, NO ₂ , OClO, aerosols	Waveband: 7 channels, UV-NIR: 0.385 - 1.02µm Resolution: 0.5km Swath: Accuracy:
SAGE III Stratospheric Aerosol and Gas Experiment-III	ISS, Meteor-3M N1	Atmospheric Chemistry instrument	Profiles of ozone, water vapour, NO ₂ , OClO, aerosols, temperature and pressure	Waveband: UV-NIR: 0.29-1.55µm (9 channels) Resolution: 1-2km vertical resolution Swath: Accuracy: Temperature: 2K, Ozone: 6%, Humidity: 3-10%, Aerosol and trace gases: 5-10%
SAPHIR SAPHIR	MEGHA-TROPIQUES	Atmospheric sounder (IR or microwave)	Cross-track sounder with the objective of measuring water vapour profiles in the troposphere in six layers from 2-12km altitudes	Waveband: Microwave: 183.3GHz Resolution: 10km Swath: Accuracy:
SAR (RISAT)	RISAT-1	Imaging radar	Radar backscatter measurements of land, water and ocean surfaces for applications in soil moisture, crop applications (under cloud cover), terrain mapping etc	Waveband: C-Band (5.350GHz) Resolution: 1-2m (HRS), 3-6m (FRS-1), 9-12m (FRS-2), 25/50m (MRS/CRS) Swath: 10km (HRS), 30km (FRS-1/FRS-2), 120/240km (MRS/CRS) Accuracy:
SAR (RADARSAT) Synthetic Aperture Radar (CSA) C band	RADARSAT-1	Imaging radar	Provides all-weather images of ocean, ice and land surfaces. Used for monitoring of coastal zones, polar ice, sea ice, sea state, geological features, vegetation and land surface processes	Waveband: Microwave: C band: 5.3GHz, HH polarisation Resolution: Standard: 25 x 28m (4 looks), Wide beam (1/2): 48-30 x 28m/ 32-25 x 28m (4 looks), Fine resolution: 11-9 x 9m (1 look), ScanSAR (N/W): 50 x 50m/ 100 x 100m (2-4/4-8 looks), Extended (H/L): 22-19x28m/ 63-28 x 28m (4 looks) Swath: Standard: 100km, Wide: 150km, Fine: 45km, ScanSAR Narrow: 300km, ScanSAR Wide: 500km, Extended (H): 75km, Extended (L): 170km Accuracy: Geometric distortion: < 40m, Radiometric: 1.0dB
SAR (RADARSAT-2) Synthetic Aperture Radar (CSA) C band	RADARSAT-2	Imaging radar	Provides all-weather images of ocean, ice and land surfaces. Used for monitoring of coastal zones, polar ice, sea ice, sea state, geological features, vegetation and land surface processes	Waveband: Microwave: C band 5.405GHz: HH, VV, HV, VH polarisation includes fully polarimetric imaging modes, and left- and right-looking capability Resolution: Standard: 25 x 28m (4 looks), Wide beam (1/2): 48-30 x 28m/ 32-25 x 28m (4 looks), Fine resolution: 11-9 x 9m (1 look), ScanSAR (N/W): 50 x 50m/ 100 x 100m (2-4/4-8 looks), Extended (H/L): 22-19x28m/ 63-28 x 28m (4 looks) Ultrafine: 3m Swath: Standard: 100km (20-49deg), Wide beam (1/2): 165km/ 150km (20-31/ 31-39deg), Fine resolution: 45km (37- 48deg), ScanSAR (W): 510km (20-49deg), Extended (H/L): 75km/170km (50-60/ 10-23deg) Ultrafine: 10-20km Accuracy: Geometric distortion: < 40m, Radiometric: 1.0dB

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
SAR (SAOCOM) SAOCOM 1A	SAOCOM 1A	Imaging radar	Land and Ocean Emergencies	Waveband: Microwave L-Band SAR 1.275GHz Resolution: 10x10m – 100x100m Swath: Accuracy: 70m
SAR 2000 Multi-Mode Synthetic Aperture Radar	COSMO - Skymed	Imaging radar	All weather images of ocean, land and ice for monitoring of land surface processes, ice, environmental monitoring, risk management, environmental resources, maritime management, earth topographic mapping	Waveband: Microwave: X-band, with choice of 4 polarisation modes (VV, HH, VV/HH, HV/HH) Resolution: Single polarisation mode: Stripmap: few metres, ScanSAR: from few tens to several tens of metres; Frame resolution: order of metres Two polarisation modes: PING PONG: few metres Swath: Single polarisation modes: Stripmap (tens of km), ScanSAR (hundreds of km), Frame (spot width several tenskm ²) Two polarisation modes: PING PONG (several tens ofkm) Accuracy:
SARSAT Search and Rescue Satellite Aided Tracking	NPOESS-1, 2, 3, 4, 5, 6	Other	Satellite and ground based system to detect and locate aviators, mariners, and land-based users in distress	Waveband: Resolution: Swath: Accuracy:
SBUV/2 Solar Backscatter Ultra-Violet Instrument/2	NOAA-11, 14, 16, M, N, N'	Atmospheric Chemistry instrument	Provides data on trace gases including vertical profile ozone, and solar irradiance and total ozone concentration measurements	Waveband: UV: 0.16-0.47µm (12 channels) Resolution: 170km Swath: Accuracy: Absolute accuracy: 1%
ScaRaB/MV2 Scanner for Earth's Radiation Budget	Resource-01 N4, MEGHA-TROPICS	Earth radiation budget radiometer	Measures top-of-atmosphere shortwave radiation (0.2-4.0µm) and total radiation (0.2-50µm). Two additional narrow-band channels (0.5-0.7µm and 11-12µm) allow cloud detection and scene identification	Waveband: VIS window channel: 0.5-0.7µm, Solar channel UV-SWIR: 0.2-4µm, Total channel UV-FIR: 0.2-50µm, Thermal window channel: 10.5-12.5µm Resolution: 60km Swath: 2200km Accuracy: Absolute: ± 2.5W/m ² /sr, Relative: ± 0.7W/m ² /sr
Scatterometer (ISRO)	OCEANSAT-2	Scatterometer	Mainly for wind measurements	Waveband: Resolution: Swath: Accuracy:
SCATTEROMETER	ESA Future Missions	Scatterometer	Ocean, land, ice applications	Waveband: Resolution: Swath: Accuracy:
SCIAMACHY Scanning Imaging Absorption Spectrometer for Atmospheric Cartography	Envisat	Atmospheric Chemistry instrument	Measures middle atmosphere temperature. Provides tropospheric and stratospheric profiles of O ₂ , O ₃ , O ₄ , CO, N ₂ O, NO ₂ , CO ₂ , CH ₄ , H ₂ O, and tropospheric and stratospheric profiles of aerosols and cloud altitude	Waveband: UV-SWIR: 240-314, 309-3405, 394-620, 604-805, 785-1050, 1000-1750, 1940-2040 and 2265-2380nm Resolution: Limb vertical 3 x 132km, Nadir horizontal 32 x 215km Swath: Limb and nadir mode: 1000km (max) Accuracy: Radiometric: <4%
SeaWiFS Sea-Viewing Wide Field-of-View Sensor	SeaStar	Ocean colour radiometer	Provides data on aerosols and ocean colour and biology	Waveband: VIS-NIR: 0.402-0.422µm, 0.433-0.453µm, 0.48-0.5µm, 0.5-0.52µm, 0.545-0.565µm, 0.66-0.68µm, 0.745-0.785µm and 0.845-0.885µm Resolution: 1.1km (local) and 4.4km (global) at nadir Swath: 1500-2800km Accuracy: 5% (absolute radiometric accuracy)
SeaWinds SeaWinds	QuickSCAT, ADEOS-2	Scatterometer	Measurement of surface wind speed and direction	Waveband: Microwave: 13.402GHz Resolution: 25km Swath: 1600km Accuracy: Speed: 2-3.5 m/s Direction: 20 deg
SEM (GOES) Space Environment Monitor	GOES-8, 9, 10, 11, 12, H, O, P, Q	Other	Used for equipment failure analysis, solar flux measurement, solar storm warning, and magnetic and electric field measurement at satellite	Waveband: Resolution: Swath: Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
SEM (POES) Space Environment Monitor	NOAA-12, 14, 16, M, N, N' METOP-2	Other	Used for equipment failure analysis, solar flux measurement, solar storm warning, and magnetic and electric field measurement at satellite	Waveband: Resolution: Swath: Accuracy:
SESS Space Environmental Sensor Suite	NP0ESS-2, 3, 5, 6	Magnetic field	Measures characteristics of auroral boundary, auroral energy deposition, auroral imagery, electric field, electron density profile, geomagnetic field, in-situ plasma fluctuations, ionosphere scintillation. Data aids future space system design	Waveband: Resolution: Swath: Accuracy:
SEVIRI Spinning Enhanced Visible and Infrared Imager	MSG-1, 2, 3	Imaging multi-spectral radiometer (vis/IR)	Measurements of cloud cover, cloud top height, precipitation, cloud motion, vegetation, radiation fluxes, convection, air mass analysis, cirrus cloud discrimination, tropopause monitoring, stability monitoring, total ozone and sea surface temperature	Waveband: VIS: 0.56-0.71µm, 0.5-0.9µm (broadband), NIR: 0.74-0.88µm, SWIR: 1.5-1.78µm, SWIR: 3.48-4.36µm, TIR: 5.35-7.15µm, 6.85-7.85µm, 8.3-9.1µm, 9.38-9.94µm, 9.8-11.8µm, 11-13µm, 12.4-14.46µm Resolution: 1km (at SSP) for one broadband visible channel HRV, 5km (at SSP) for all other channels Swath: Full Earth disk Accuracy: Cloud cover: 10%, Cloud top height: 1km, Cloud top temperature: 1K, Cloud type: 8 classes, Surface temperature: 0.7-2.0K, Specific humidity profile: 10%, Wind profile (horizontal component): 2-10m/s, Long wave Earth surface radiation: 5W/m²
SFM-2 UV limb spectrometer	METEOR-3M N1	Atmospheric Chemistry instrument	Global ozone monitoring	Waveband: UV-Visible: 0.2-0.51µm (4 channels) Resolution: Swath: Accuracy:
SIM Spectral Irradiance Monitor	SORCE	Earth radiation budget radiometer	Measures solar spectral irradiance in the 200-2000nm range	Waveband: UV-SWIR: 200-2000nm Resolution: Swath: Accuracy:
SIRAL SAR Interferometer Radar Altimeter	CRYOSAT	Radar altimeter	Objective is to observe ice sheet interiors, the ice sheet margins, for sea ice and other topography	Waveband: Microwave: 13.575GHz (Ku-Band) Resolution: range resolution 45cm, along-track resolution 250m Swath: Footprint 15km Accuracy: Arctic sea-ice: 1.6cm/year for 300kmx300km cells; Land ice (small scale): 3.3cm/year for 100km x 100km cells, Land ice (large scale): 0.17cm/year for Antarctica size area
SKL-M Solar ray spectrometer	METEOR-3M N2,3	Other	Proton flux density	Waveband: 2, 4, 6 and > 6 MeV, 30, 50, 100, 300 and > 300 MeV Resolution: Swath: Accuracy:
SMR Submillimetre Radiometer	Odin	Atmospheric sounder (IR or microwave)	Measures global distributions of ozone and species of importance for ozone chemistry, ClO, HNO ₃ , H ₂ O, N ₂ O, (HO ₂ , H ₂ O ₂) Measures temperature in the height range 15-100km	Waveband: Microwave: 118.7GHz + 4 bands in the region 480-580GHz; Tunable, measures 2-3 x 10Hz regions at a time Resolution: Vertical resolution 1.5-3km, along track 600km Swath: Altitudes of 5-100km Accuracy: 2-40 % depending on species and altitude
SODISM Solar Diameter Imager and Surface Mapper	PICARD	Earth radiation budget radiometer	Measures diameter and differential rotation of the sun - a whole Sun imager	Waveband: UV: 230nm, VIS: 548nm, Active regions: 160nm plus Lyman alpha detector Resolution: Swath: Accuracy:
SOFIS Solar Occultation Fourier transform spectrometer for Inclined Orbit Satellite	GCOM-A1	Atmospheric Chemistry instrument	Monitors ozone and its minor constituents to obtain the global distribution of O ₃ , HNO ₃ , NO ₂ , N ₂ O, CH ₄ , H ₂ O, CO ₂ , CFC-11, CFC-12, ClONO ₂ , aerosols, pressure & temperature Provides 3-D global ozone distribution along with OPUS	Waveband: MWIR-TIR: 3.25-6.5µm, 6.5-13µm, 753-784nm Resolution: Swath: Altitudes of 5-150km Accuracy:

Instrument	Mission(s)	Type	Measurements / Application	Technical characteristics
SOLSTICE SOlar STellar Irradiance Comparison Experiment	SORCE UARS	Earth radiation budget radiometer	Provides data on UV and charged particle energy inputs, and on time variation of full-disk solar UV spectrum. Measures solar UV radiation (115 to 430nm) with resolution of 0.12nm. Compares solar UV output with UV radiation of stable bright blue stars	Waveband: UV: 115-180nm & 170-320nm Resolution: Swath: Accuracy: 1%
SOPRANO Sub-millimetre Observation of Processes in the Absorption Noteworthy for ozone	ESA Future Missions	Atmospheric Chemistry instrument	Provides temperature profiles and trace gases in the upper troposphere to mesosphere including ClO, O ₃ , HCl, NO, BrO as first priority, and HOCl, CH ₃ Cl, H ₂ O, N ₂ O, HO ₂ , HNO ₃ as second priority	Waveband: Sub-millimetre a) 499.4-505GHz b) 624.5-626.6 and 628.2-628.7GHz c) 730.5-732GHz d) 851.3-852.8GHz Resolution: Vertical: 2km at lowest level, Limb viewing instrument Swath: 10-50km tangent height range Accuracy: Band a: 2.5K, Bands b and c: 12K, Band d: 8K at 3MHz resolution, 0.3 secs integration time
Sounder	GOES-8, 9, 10, 11, 12, N, O, P, Q	Atmospheric sounder (IR or microwave)	Provides atmospheric soundings and data on atmospheric stability and thermal gradient winds	Waveband: VIS-TIR: 19 channels Resolution: 10km Swath: Horizon to horizon Accuracy:
Sounder (INSAT)	INSAT 3D	Atmospheric sounder (IR or microwave)	Atmospheric soundings, atmospheric stability, thermal gradient winds	Waveband: SWIR: 3.74-4.74µm, MWIR: 6.51-11.03µm, TIR: 12.02-14.71µm, VIS: 0.55-0.75µm Resolution: 10 x 10km Swath: Full (Full Earth disc sounding), Program (Options provided for Sector Scans) Accuracy:
SOVAP SOlar Variability Picard radiometer	PICARD	Earth radiation budget radiometer	Total solar irradiance measurements	Waveband: Total irradiance Resolution: Swath: Accuracy:
SPECTRA Surface Processes and Ecosystem Changes Through Response Analysis	ESA Future Missions	Imaging multi-spectral radiometer (vis/IR)	Data for study of land surface processes	Waveband: VIS-SWIR: 450-2350nm and TIR: 10.3-12.3 micron Resolution: Spatial sampling interval approx 50m, along track pointing ±30 deg Swath: 50km Accuracy:
SSB/X Special Sensor Gamma Ray Particle Detector	DMSP F-8	Other	Detects the location, intensity and spectrum of X-rays emitted from the Earth's atmosphere	Waveband: Resolution: Swath: Accuracy:
SSB/X-2 Special Sensor Gamma Ray Particle Detector	DMSP F-12, 13, 14	Other	Detects the location, intensity and spectrum of X-rays emitted from the Earth's atmosphere	Waveband: Resolution: Swath: Accuracy:
SSIES-2 Special Sensor Ionospheric Plasma Drift/Scintillation Meter	DMSP F-12, 13, 14, 15	Other	Measurement of the ambient electron density and temperatures, the ambient ion density, and ion temperature and molecular weight	Waveband: Resolution: Swath: Accuracy:
SSIES-3 Special Sensor Ionospheric Plasma Drift/Scintillation Meter	DMSP F-16, 17, 18, 19, 20	Other	Measurement of the ambient electron density and temperatures, the ambient ion density, and ion temperature and molecular weight	Waveband: Resolution: Swath: Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
SSJ/4 Special Sensor Precipitating Plasma Monitor	DMSP F-12, 13, 14, 15	Magnetic field	Measurement of transfer energy, mass, and momentum of charged particles through the magnetosphere-ionosphere in the Earth's magnetic field	Waveband: Resolution: Swath: Accuracy:
SSJ/5 Special Sensor Precipitating Plasma Monitor	DMSP F-16, 17, 18, 19, 20	Magnetic field	Measurement of transfer energy, mass, and momentum of charged particles through the magnetosphere-ionosphere in the Earth's magnetic field	Waveband: Resolution: Swath: Accuracy:
SSM Special Sensor Magnetometer	DMSP 12, 13, 14, 15, 16, 17, 18, 19, 20	Other	Measures geomagnetic fluctuations associated with solar geophysical phenomena. With SSIES and SSJ provides heating and electron density profiles in the ionosphere	Waveband: Resolution: Swath: Accuracy:
SSM/I Special Sensor Microwave Imager	DMSP F-8, 12, 13, 14, 15	Imaging multi-spectral radiometer (microwave)	Measures atmospheric, ocean and terrain microwave brightness temperatures to provide: sea surface winds, rain rates, cloud water, precipitation, soil moisture, ice edge, ice age	Waveband: Microwave: 19.35, 22.235, 37, 85.6GHz Resolution: 15.7km x 13.9km to 68.9 x 44.3km (depends on frequency) Swath: 1400km Accuracy:
SSM/T-1 Special Sensor Microwave Temperature Sounder	DMSP F-8, 12, 13, 14, 15, 16, 17, 18, 19, 20	Atmospheric sounder (IR or microwave)	Measures Earth's surface and atmospheric emission in the 50-60GHz oxygen band	Waveband: Microwave: 7 channels in the 50-60 GHz range Resolution: 174km diameter beam Swath: 1500km Accuracy:
SSM/T-2 Special Sensor Microwave Water Vapour Sounder	DMSP F-12, 13, 14, 15	Atmospheric sounder (IR or microwave)	Water Vapour profiler	Waveband: Microwave: 91.6, 150, 183.31 (3 channels) (Total 5 channels) Resolution: Approx 48km Swath: 1500km Accuracy:
SSMIS Special Sensor Microwave Imager Sounder	DMSP F-16, 17, 18, 19, 20	Atmospheric sounder (IR or microwave)	Measures thermal microwave radiation. Global measurements of air temp profile, humidity profile, ocean surface winds, rain overland/ocean, ice concentration/age, ice/snow edge, water vapour and clouds over ocean, snow water content, land surface temperature	Waveband: Microwave: 19 - 183GHz (24 frequencies) Resolution: Varies with frequency: 25x17km to 70x42km Swath: 1700km Accuracy:
SSU Stratospheric Sounding Unit	NOAA-11, 14	Atmospheric sounder (IR or microwave)	Provides temperature profiles in stratosphere, top-of-atmosphere radiation from 25km to 50km altitude	Waveband: 669.99, 669.63 and 669.36/cm (carbon dioxide) Resolution: 147.3km at nadir Swath: ±40 deg scan Accuracy:
SSULI Special Sensor Ultraviolet Limb Imager	DMSP F-16, 17, 18, 19, 20	Other	Measures vertical profiles of the natural airglow radiation from atoms, molecules and ions in the upper atmosphere and ionosphere	Waveband: Resolution: Swath: Accuracy:
SSUSI Special Sensor Ultraviolet Spectrographic Imager	DMSP F-16, 17, 18, 19, 20	Other	Monitors the composition and structure of the upper atmosphere and ionosphere, as well as auroral energetic particle inputs, with spectrographic imaging and photometry	Waveband: Resolution: Swath: Accuracy:
SSZ	DMSP F-13,14,15	Other	Laser threat detector	Waveband: Resolution: Swath: Accuracy:
SUSIM (UARS) Solar Ultraviolet Irradiance Monitor	UARS	Earth radiation budget radiometer	Provides data on UV and charged particle energy inputs, and on time variation of full-disk solar UV spectrum	Waveband: UV: 0.12-0.4µm (0.15nm resn) Resolution: Not applicable Swath: Looks at sun Accuracy: 1%

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
SU-UMS Stereo Radiometer with High Resolution	SICH-2	High resolution imager		Waveband: Resolution: Swath: Accuracy:
SU-VR Visible Radiometer with High Resolution	SICH-2	High resolution imager		Waveband: Resolution: Swath: Accuracy:
SWIFT Stratospheric Wind Interferometer for Transport studies	GCQM-A1	Atmospheric Chemistry instrument	Measures a mid-infrared thermal emission line of ozone in order to reach the 20-40km region in the stratosphere and to measure stratospheric winds, as well as ozone	Waveband: Resolution: Swath: Accuracy:
SXI Solar X-ray Imager	GOES-12, N, P	Other	Obtains data on structure of solar corona. Full disk imagery also provides warnings of geomagnetic storms, solar flares, and information on active regions of sun and filaments	Waveband: Resolution: Swath: Accuracy:
TES Tropospheric Emission Spectrometer	EOS Aura	Atmospheric Chemistry instrument	3-D profiles on a global scale of all infra-red active species from surface to lower stratosphere. Measures greenhouse gas concentrations, tropospheric ozone, acid rain precursors, gas exchange leading to stratospheric ozone depletion	Waveband: MWIR-TIR: 3.2-15.4µm Resolution: In limb mode: 2.3km vertical resolution. In down-looking mode: 50km x 5km (global), 5km x 0.5km (local) Swath: Limb mode: global: 50km x 180km, local: 5km x 18km Accuracy: Ozone: 20ppb, Trace gases: 3-500ppb
TIM Total Irradiance Monitor	SORCE	Earth radiation budget radiometer	Measurement of total solar irradiance directly traceable to SI units with an absolute accuracy of 0.03% and relative accuracy of 0.001% per year	Waveband: Resolution: Swath: Looks at the sun every orbit, providing 15 measurements per day Accuracy:
TIR Surface Temperature Imager	VISIR	Imaging multi-spectral radiometer (vis/IR)	Sea surface Temperature	Waveband: 11µm, 12µm Resolution: Swath: Accuracy:
TM Thematic Mapper	Landsat-5	High resolution imager	Measures surface radiance and emittance, land cover state and change (eg vegetation type). Used as multipurpose imagery for land applications	Waveband: VIS-TIR: 7 channels: 0.45-12.50µm Resolution: VIS-SWIR: 30m; TIR: 120m Swath: 185km Accuracy:
TMI TRMM Microwave Imager	TRMM	Imaging multi-spectral radiometer (microwave)	Measures rainfall rates over oceans (less reliable over land), combined rainfall structure and surface rainfall rates with associated latent heating. Used to produce monthly total rainfall maps over oceans	Waveband: Microwave: 10.7, 19.4, 21.3, 32, and 85.5GHz Resolution: Vertical: 2.5km approx Horizontal: 18km Swath: 290km Accuracy: Liquid water: 3mg/cm3, Humidity: 3mg/cm3, Ocean wind speed: 1.5 m/s
TMR TOPEX Microwave Radiometer	Topex-Poseidon	Imaging multi-spectral radiometer (microwave)	Provides altimeter data to correct for errors caused by water vapour and cloud-cover. Also measures total water vapour and brightness temperature	Waveband: Microwave: 18GHz, 21GHz, 37GHz Resolution: 44.7km at 18GHz, 37.6km at 21GHz, 23.6km at 37GHz Swath: 120 deg cone centred on nadir Accuracy: Total water vapour: 0.2g/sq cm, Brightness temperature: 0.3 K
TOM Total Ozone Mapper	FY-3 A, B, C, D, E, F, G	Atmospheric Chemistry instrument		Waveband: Resolution: Swath: Accuracy:
TOMS Total Ozone Mapping Spectrometer	TOMS EP	Atmospheric Chemistry instrument	Retrieval of ozone column measurements	Waveband: UV: 0.3086, 0.3125, 0.3175, 0.3220, 0.3312 and 0.36µm Resolution: Nadir: 39km x 39km Swath: 3100km Accuracy: 0.1%

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
TOPEX TOPEX NASA Radar Altimeter	Topex-Poseidon	Radar altimeter	Measurement of global ocean surface topography	Waveband: Microwave: 13.66GHz and 5.36GHz Resolution: Swath: 6km Accuracy: 2.3cm
TOPSAT telescope	TOPSAT	High resolution imager	Experimental high-resolution imaging satellite supporting a range of possible land applications	Waveband: Panchromatic VIS: 0.5-0.75µm 3-band multi-spectral Resolution: 2.5m pan, 5m multi-spectral Swath: 10km Accuracy:
TRASSER	OKEAN-O	Imaging multi-spectral radiometer (vis/IR)		Waveband: Resolution: Swath: Accuracy:
TRSR Turbo-Rogue Space Receiver	Jason-1, 2	Gravity field or geodynamic	Provides precise continuous tracking data of satellite to decimeter accuracy	Waveband: Resolution: Swath: Accuracy:
TSIS Total Solar Irradiance Sensor	NPOESS-3, 6	Earth radiation budget radiometer	0.2- 2 micron solar spectral irradiance monitor	Waveband: UV-SWIR: 0.2-2µm Resolution: Swath: Accuracy:
VEGETATION	SPOT-4, 5	Imaging multi-spectral radiometer (vis/IR)	Data of use for crop forecast and monitoring, vegetation monitoring, and biosphere/geosphere interaction studies	Waveband: Operational mode: VIS: 0.61-0.68µm, NIR: 0.78-0.89µm, SWIR: 1.58-1.75µm, Experimental mode: VIS: 0.43-0.47µm Resolution: 1.15km at nadir - minimal variation for off-nadir viewing Swath: 2200km Accuracy:
VHRR Very High Resolution Radiometer	INSAT-2 E, INSAT-3 A, METSAT	Imaging multi-spectral radiometer (vis/IR)	Cloud cover, rainfall, wind velocity, sea surface temperature, outgoing longwave radiation, reflected solar radiation in spectral band 0.55-0.75µm, emitted radiation in 10.5-12.5µm range	Waveband: VIS: 0.55-0.75µm, NIR: 5.7-7.1µm TIR: 10.5-12.5µm Resolution: 2km in visible, 8km in IR Swath: Full earth disk every 30 minutes Accuracy:
VIIRS Visible/Infrared Imager Radiometer Suite	NPOESS-1,2,3,4,5,6, NPP	Imaging multi-spectral radiometer (vis/IR)	Global observations of land, ocean, and atmosphere parameters: cloud/weather imagery, sea-surface temperature, ocean colour, land surface vegetation indices	Waveband: VIS - TIR: 0.6-12.5µm (22 channels) Resolution: 400m-800m Swath: 30000km Accuracy:
VIRR Multispectral Visible and Infrared Scan Radiometer (10 channels)	FY-3A, B, C, D, E, F, G	Imaging multi-spectral radiometer (vis/IR)		Waveband: Resolution: Swath: Accuracy:
VIRS Visible Infrared Scanner	TRMM	Imaging multi-spectral radiometer (vis/IR)	Data to be used in conjunction with data from CERES instrument to determine cloud radiation. Will enable 'calibration' of precipitation indices derived from other satellite sources	Waveband: VIS: 0.63µm, SWIR-MWIR: 1.6 and 3.75µm, TIR: 10.8 and 12µm Resolution: 2km at nadir Swath: 720km Accuracy:
VISSR (FY-2) Multispectral Visible and Infrared Scan Radiometer (3 channels)	FY-2A, B	Imaging multi-spectral radiometer (vis/IR)		Waveband: Resolution: Swath: Accuracy:

Instrument	Mission(s)	Type	Measurements /application	Technical characteristics
VISSR (GMS-5) Visible and Infrared Spin Scan Radiometer (GMS-5)	GMS-5	Imaging multi-spectral radiometer (vis/IR)	Data used for cloud type and motion detection wind. Also measures sea surface temperature and atmospheric water vapour	Waveband: VIS: 0.55-0.9µm; TIR: 6.5-7, 10.5-11.5, 11.5-12.5µm Resolution: Visible: 1.25km; TIR: 5km Swath: Full Earth disk in all channels, every 1 hour Accuracy:
VNIR Imaging Spectrometer	VISIR	High resolution imager	Ocean Color, columnar content of atmospheric aerosol particles bio-geo-chemical fluxes through vegetation, air-sea fluxes of energy, hydrological analysis	Waveband: VIS-NIR: 412,443,490,510,555,570,665,680,705,765,865,946nm Resolution: Swath: Accuracy:
WALES Water Vapour Lidar Experiment in Space	ESA Future Missions	Lidar	Accurate profiles of water vapour globally and at high vertical resolution, with the horizontal resolution expected for global atmospheric models	Waveband: NIR: 935nm range Resolution: Typically 100km sampling Swath: 1-2km vertical sampling Accuracy: < 5 % systematic error
WAOSS-B Wide-Angle Optoelectronic Stereo Scanner	BIRD	Imaging multi-spectral radiometer (vis/IR)	Vegetation and Cloud coverage	Waveband: 1 x VIS: 600-670nm 1 x NIR: 840-900nm Resolution: 185m Swath: 533km Accuracy:
WEFAX Weather Facsimile	GOES 8-Q	Other		Waveband: Resolution: Swath: Accuracy:
WFC Wide Field Camera	CALIPSO	Imaging multi-spectral radiometer (vis/IR)	Acquires high spatial resolution imagery for meteorological context	Waveband: VIS: 620 to 670nm Resolution: 125m Swath: 60km Accuracy:
WFI Wide Field Imager	CBERS-1, 2, 3, 4	High resolution imager	Data used for coastal and vegetation monitoring	Waveband: VIS: 0.63-0.69µm, NIR: 0.77-0.89µm Resolution: 258m Swath: 890km Accuracy: 0.3 pixels
WiFS Wide Field Sensor	IRS-1C,D,P3,P4	Imaging multi-spectral radiometer (vis/IR)	Vegetation monitoring, environmental monitoring, drought monitoring, snow melt run-off forecasting, global green cover assessment, agro-climatic regional planning	Waveband: VIS: 0.62-0.68µm NIR: 0.77-0.86µm SWIR: 1.55-1.7µm (IRS P3 only) Resolution: 188m Swath: 810km Accuracy:
WINDII Wind Imaging Interferometer	UARS	Atmospheric Chemistry instrument	Day and night wind measurements between 80km and 300km altitude. Measures atmospheric temperature and concentration of emitting species	Waveband: Visible-NIR: 0.55-0.78µm Resolution: Vertical: 2km Horizontal: 25km Swath: 70-310km Accuracy: Wind speed: 10m/s
WTE Whale Tracker Experiment	SAC-C	TBC	Tracking of Eubalean Australis and environmental data collection system	Waveband: Resolution: Swath: Accuracy:
X-Band SAR X-Band Synthetic Aperture Radar	TerraSAR-X	Imaging radar	Provides images for monitoring of land surface and coastal processes and for agricultural, geological and hydrological applications. Instrument modes: Spotlight, Stripmap, ScanSAR	Waveband: Microwave: 9.6GHz (X-band), 4 polarisation modes: HH, VV, HV, VH (selectable or twin) Resolution: Spotlight: 1,2m x 1-4m Stripmap: 3m x 3-6m ScanSAR: 16m x 16m Swath: Spotlight: 5-10km x 10km, Stripmap: 30km, ScanSAR: 100km Accuracy:
XPS XUV Photometer System	SORCE	Other	Objective is to measure the extreme UV solar irradiance from 1-35nm	Waveband: Resolution: Swath: Accuracy:
X-ray astronomy payload	IRIS-P3	Other	Study of time variability and spectral characteristics of cosmic X-ray sources	Waveband: Resolution: Swath: Accuracy:

A Further information on CEOS

A.1 Introduction

Part I of the document provides an overview of CEOS and its activities. This annex provides more details of the organisation and function of CEOS.

A.2 Participants

Members

Governmental organisations that are international or national in nature and are responsible for a civil spaceborne Earth observations program currently operating, or at least in Phase B or equivalent of system development, will be eligible for membership in CEOS.

Associates

CEOS Associates are either:

- Governmental organisations that are international or national in nature and currently have a civil space-segment activity in Phase A/pre-Phase A or equivalent of system development, or a significant ground-segment activity that supports CEOS objectives; or
- Other existing satellite coordination groups and scientific or governmental bodies that are international in nature and currently have a significant programmatic activity that supports CEOS objectives.

A full list of CEOS Members and Associates is given in section 1.

A.3 CEOS Plenary

Currently, 23 space agencies along with 20 other national and international organisations participate in CEOS planning and activities. Participating agencies meet in Plenary annually, with activities and coordination occurring throughout the year. The Plenary reviews progress on the various projects and activities being undertaken within CEOS. The Chair of CEOS rotates at the annual Plenary. The CEOS Chair for 2002 is the European Space Agency (ESA). For 2003, the National Oceanic and Atmospheric Administration (NOAA) will undertake CEOS Chairmanship.

A.4 CEOS Secretariat

A permanent Secretariat, chaired by the current CEOS host organisation, provides most of the coordination between plenary sessions and is maintained by:

- the European Space Agency (ESA);
- the National Aeronautics and Space Administration (NASA) jointly with the National Oceanic and Atmospheric Administration (NOAA) of the United States;
- the Ministry of Education, Culture, Sports, Science and Technology (MEXT) jointly with the National Space Development Agency of Japan (NASDA);

and is chaired by the current CEOS host organisation in support of the CEOS Plenary. As part of the ongoing contribution to CEOS Secretariat activities, ESA is responsible for the CEOS Handbook, NASA for the CEOS Annual Report and WWW site content, and MEXT/NASDA for the CEOS Newsletter, Brochure and maintenance of the WWW site.

A.5 CEOS Working Groups

Working Group on Calibration and Validation (WGCV)

The objectives of the WGCV are to enhance coordination and complementarity, to promote international cooperation and to focus activities in the calibration and validation of Earth observations for the benefit of CEOS Members and the international user community. WGCV addresses sensor specific calibration/validation and geophysical parameter/derived products validation. WGCV meets approximately every nine months. The subgroups of WGCV are as follows:

- The Infrared and Visible Optical Sensors Subgroup;
- The Microwave Sensors Subgroup;
- The SAR Subgroup;
- The Terrain Mapping Subgroup;
- The Land Product Validation Subgroup;
- The Atmospheric Chemistry Subgroup.

Working Group on Information Systems and Services (WGISS)

The objective of WGISS is to facilitate data and information management and services for users and data providers in dealing with global, regional, and local issues. In particular, it addresses the capture, description, processing, access, retrieval, utilisation, maintenance and exchange of spaceborne Earth observation data and supporting ancillary and auxiliary data and information, enabling improved interoperability and interconnectivity of information systems and services. WGISS meets approximately every six months.

The three subgroups of WGISS are the Access, Data and Network Subgroups. WGISS has started a new initiative called the Test Environment which offers a framework under which WGISS will work in partnership with selected international science and EO projects to test and develop information systems and services to meet their requirements. The Global Observation of Forest Cover (GOFC) international science project has been selected as a first test of this concept.

Ad Hoc Working Group on Disaster Management Support (DMSG)

The CEOS Disaster Management Support Group (DMSG) focuses on developing and refining recommendations for the application of satellite data to selected hazard areas – drought, earthquake, fire, flood, ice, landslide, oil spill, and volcanic hazards.

The DMSG has entered its final phase of work and efforts will continue in the various other groups with which it has actively collaborated and supported in the past particularly, the Integrated Global Observing Strategy (IGOS) and the development of an IGOS Geohazards Theme, the UN International Strategy for Disaster Reduction (ISDR), and UN Office of Outer Space Affairs (OOSA) in its support of the UN Committee on Peaceful Uses of Outer Space (COPUOS).

The final DMSG report contains recommendations to space agencies and preliminary emergency scenarios for each hazard area. The final report is available in hardcopy or via the group's web site:

disaster.ceos.org

Ad Hoc Working Group on Education and Training (WGEdu)

The main objective of the Ad Hoc Working Group on Education and Training (WGEdu) is to develop a plan of action for CEOS to pursue in the field of EO education and training. Towards this, the WGEdu is aiming to:

- Assess the Earth Observation education needs in developing countries;
- Assess technology trends of relevance for education and training;
- Recommend a Plan of Action for CEOS participation in Earth Observation education activities.

CEOS WGEdu has developed a Strategy for EO Education and Training to provide an overarching framework for on-going efforts of CEOS agencies and other international agencies. WGEdu is aiming to: provide an effective coordination mechanism for EO education and training efforts; to initiate specific projects of web-enabled learning; to develop a directory of education/teaching materials; and to organise annual events to focus/steer 'unified' actions for EO education and training.

A.6 Strategic Implementation Team

CEOS has established a Strategic Implementation Team with the responsibility to address the composition and function of the space component of an IGOS. (Further details in annex B).

A Further information on CEOS

A.7 Further information on CEOS activities

Refer to <http://www.ceos.org>

Or contact the nearest member of the CEOS Secretariat:

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

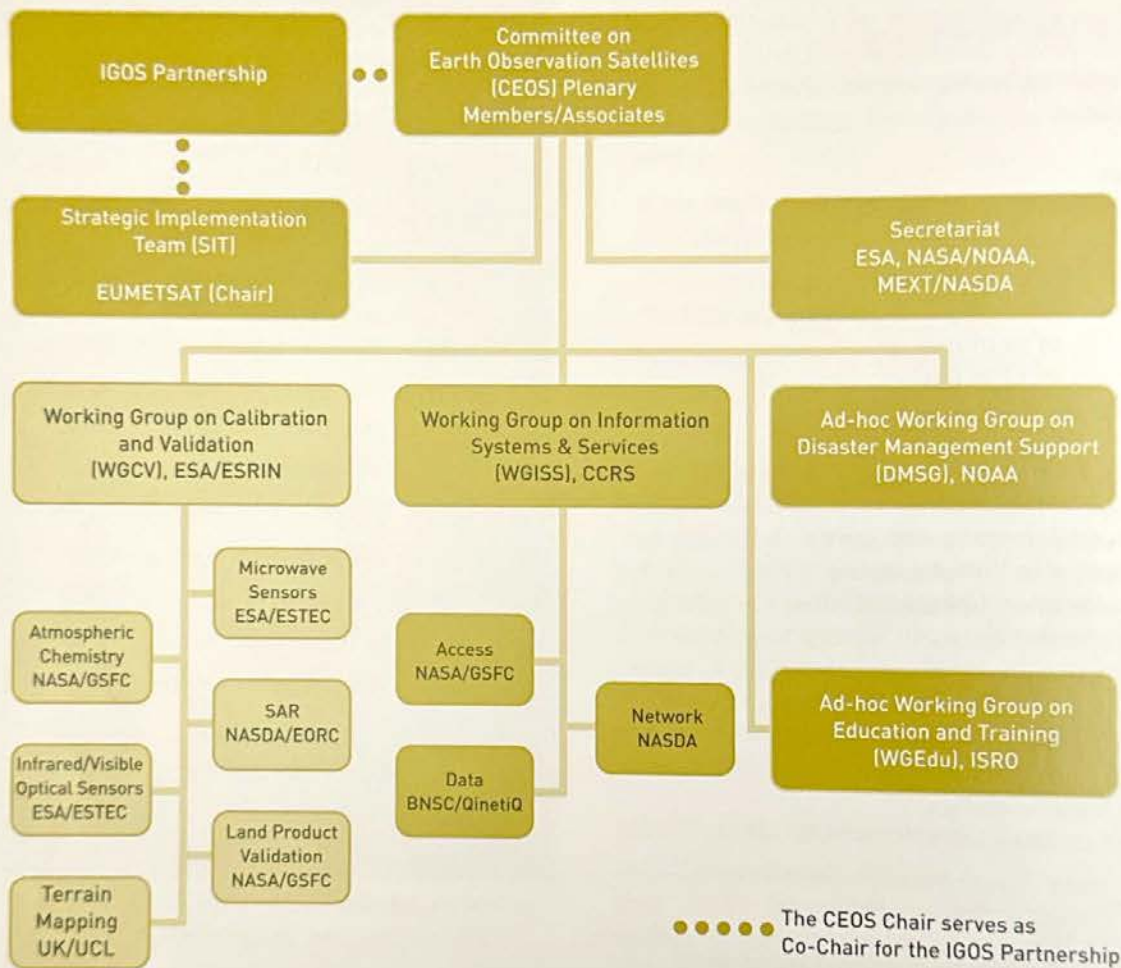
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CEOS History.

Plenary	Year	Venue	Host
1st Plenary	1984	Washington, DC, USA	NOAA
2nd Plenary	1986	Frascati, Italy	ESA
3rd Plenary	1988	Ottawa, Canada	CSA
4th Plenary	1990	São José dos Campos, Brazil	INPE
5th Plenary	1991	Washington DC, USA	NASA/NOAA
6th Plenary	1992	London, UK	BNSC
7th Plenary	1993	Tsukuba, Japan	MEXT/NASDA
8th Plenary	1994	Berlin, Germany	DARA
9th Plenary	1995	Montreal, Canada	CSA
10th Plenary	1996	Canberra, Australia	CSIRO
11th Plenary	1997	Toulouse, France	CNES
12th Plenary	1998	Bangalore, India	ISRO
13th Plenary	1999	Stockholm, Sweden	EUMETSAT
14th Plenary	2000	Rio de Janeiro, Brazil	INPE
15th Plenary	2001	Kyoto, Japan	MEXT/NASDA
16th Plenary	2002	Frascati, Italy	ESA
17th Plenary	2003	[TBD], USA	NOAA
18th Plenary	2004	[TBD], China	NRSCC

A Further information on CEOS

CEOS Structure.



B CEOS involvement in IGOS

B.1 The IGOS Partnership

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

The IGOS serves as guidance to those responsible for defining and implementing individual observing systems. Implementation of the Strategy, ie the establishment and maintenance of the components of an integrated global observing system, lies with those governments and organisations that have made relevant commitments, for example, within the governing councils of the observing systems' sponsors. To aid the development of the Strategy, the Partners have adopted an incremental 'Themes' approach based on perceived priorities.

The IGOS brings together the major Earth and space-based systems for global environmental observations of the atmosphere, oceans and land in a strategic planning process, in order to facilitate the necessary harmonisation and achieve maximum cost-effectiveness for the total set of observations. The relevant observing systems encompass a broad range of different networks of satellite-borne and Earth-based sensors, including ocean buoys, weather stations and atmospheric radiosondes. IGOS recognises that many of these observing systems are in need of improvements, some lack the necessary long-term continuity, and all require strengthened links between the space-based and Earth-based components, as well as between the observing programmes and the processes of scientific and environmental policy-making which define the information priorities.

B.2 Membership

The IGOS-P brings together the efforts of a number of international bodies concerned with the observational component of global environmental issues, both from a research and a long-term operational programme perspective. The partners are:

- the Global Observing Systems: Within the last decade, the Global Observing System of the World Weather Watch (WWW/GOS) and the Global Atmosphere Watch (GAW) have been complemented by the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS) to produce a set of Global Observing Systems integrating in-situ and remotely sensed data, with each focusing on a major component of the Earth system. The Global Climate Observing System (GCOS) has also been planned and initiated to integrate the observing needs for climate purposes;
- the international agencies which sponsor the Global Observing Systems: The Global Observing Systems are sponsored by a number of international agencies: Food and Agriculture Organization (FAO), International Council for Science (ICSU), Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO) and World Meteorological Organization (WMO);
- the Committee on Earth Observation Satellites (CEOS): CEOS coordinates the efforts of space agencies worldwide in the planning of Earth observation satellite missions and their applications;
- the International Group of Funding Agencies for Global Change Research (IGFA): National research funding agencies and ministries involved in programming and funding of global change research collaborate in IGFA;
- the International Global change research programmes: The World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP) are key international frameworks for nations and institutions to cooperate in undertaking research into broad planetary environmental issues and in the funding of such research.

Other organisations prepared to contribute to the development of IGOS may be welcomed as Partners in future. The Partnership provides a continuing mechanism to oversee the development of IGOS. The IGOS-P Secretariat ensures continuity in the process, provides a focus for external interfaces, and helps to promote the visibility of the IGOS-P in key arenas, such as the environmental conventions.

B.3 IGOS Themes

The IGOS Partners recognise that it is not practical to attempt to define a comprehensive global system that would in a single step satisfy all needs for environmental information. Rather, they have adopted a process – The IGOS Themes – which allows for the coherent definition and development of an overall global strategy for observing selected fields of common interest among a group of the Partners. Selection of the Themes is based on an assessment of the relevant scientific and operational priorities for overcoming deficiencies in information, as well as analysis of the state of development of relevant existing and planned observing systems.

The first IGOS Themes are:

- Ocean Theme (Under leadership of IOC/UNESCO and CEOS/NASA);
- Integrated Global Carbon Observations (IGCO) Theme (Under leadership of IGBP);
- Integrated Global Water Cycle Observations Theme (Under leadership of WCRP and CEOS/NASDA);
- Integrated Global Atmospheric Chemistry Observations (IGACO) Theme (Under leadership of WMO);
- Coastal Theme – starting with a Coral Reefs sub-theme (Under leadership of UNEP and CEOS/NOAA);
- Geological and Geophysical Hazards Theme (Under leadership of UNESCO and CEOS/ESA).

B.4 CEOS involvement in IGOS

CEOS has embraced the concept of an Integrated Global Observing Strategy as a valuable initiative which perfectly complements its own set of objectives, and which may be adopted by CEOS to derive greater benefit from operating and planned observing systems. Through working together, CEOS agencies are in a position to plan their Earth observation programmes with the minimum of unnecessary overlap and to devise joint strategies for addressing serious gaps in their observation capabilities.

Strengthened links between space-based and Earth-based observing systems, and with scientific and environmental policy-making processes provide compelling motivation for CEOS to take an active role in IGOS Partnership activities. To reflect the significance of IGOS work, and notably the progress of the IGOS Themes, within its efforts, CEOS established a Strategic Implementation Team (SIT) – which has the responsibility to address the composition and function of the space component of an IGOS.

On a Theme by Theme basis, the SIT takes the lead role in defining the requirements for, and capabilities of, existing and planned satellite-based observing systems for specific measurements and applications for consideration in IGOS-P.

B.5 Further information on IGOS

Extensive information on the activities of the IGOS Partnership can be found on the WWW site.

<http://www.igospartners.org/>

The IGOS brochure also contains the latest information on each of the IGOS Themes and full contact information for the Theme Teams:

<http://ioc.unesco.org/igospartners/IGOSbrochure2002.pdf>

You can also register to receive copies of the IGOS Bulletin, distributed twice a year by CNES by sending an e-mail to Dominique Fourny-Delloye at:

Dominique.Fournydelloye@cnes.fr

B CEOS involvement in IGOS



International community urges the establishment of the strategy for integrated global observations

AGENDA 21 OF THE UNITED NATIONS CONFERENCE ON THE ENVIRONMENT AND DEVELOPMENT (1992)

(d) Improvement of methods of data assessment and analysis

"40.9 Relevant international organisations should develop practical recommendations for co-ordinated, harmonised collection and assessment of data at the national and international levels."

THE NINTH SESSION OF THE COMMISSION ON SUSTAINABLE DEVELOPMENT (CSD9: APRIL 2001)

Decision 9/2 (Atmosphere)

"8. The Commission emphasises the importance of:

(d) Encouraging relevant international organisations especially the United Nations specialised agencies, to jointly plan and implement a strategy for integrated global observations to monitor the Earth's atmosphere."

Decision 9/4 (Information for Decision-making and Participation)

"The Commission; ...

(d) Urges strengthened co-operation and co-operation among global observing systems and research programmes for integrated global observations taking into account, the need for sharing, among all countries, of valuable data such as ground based observation data and satellite remote sensing data."

C Abbreviations

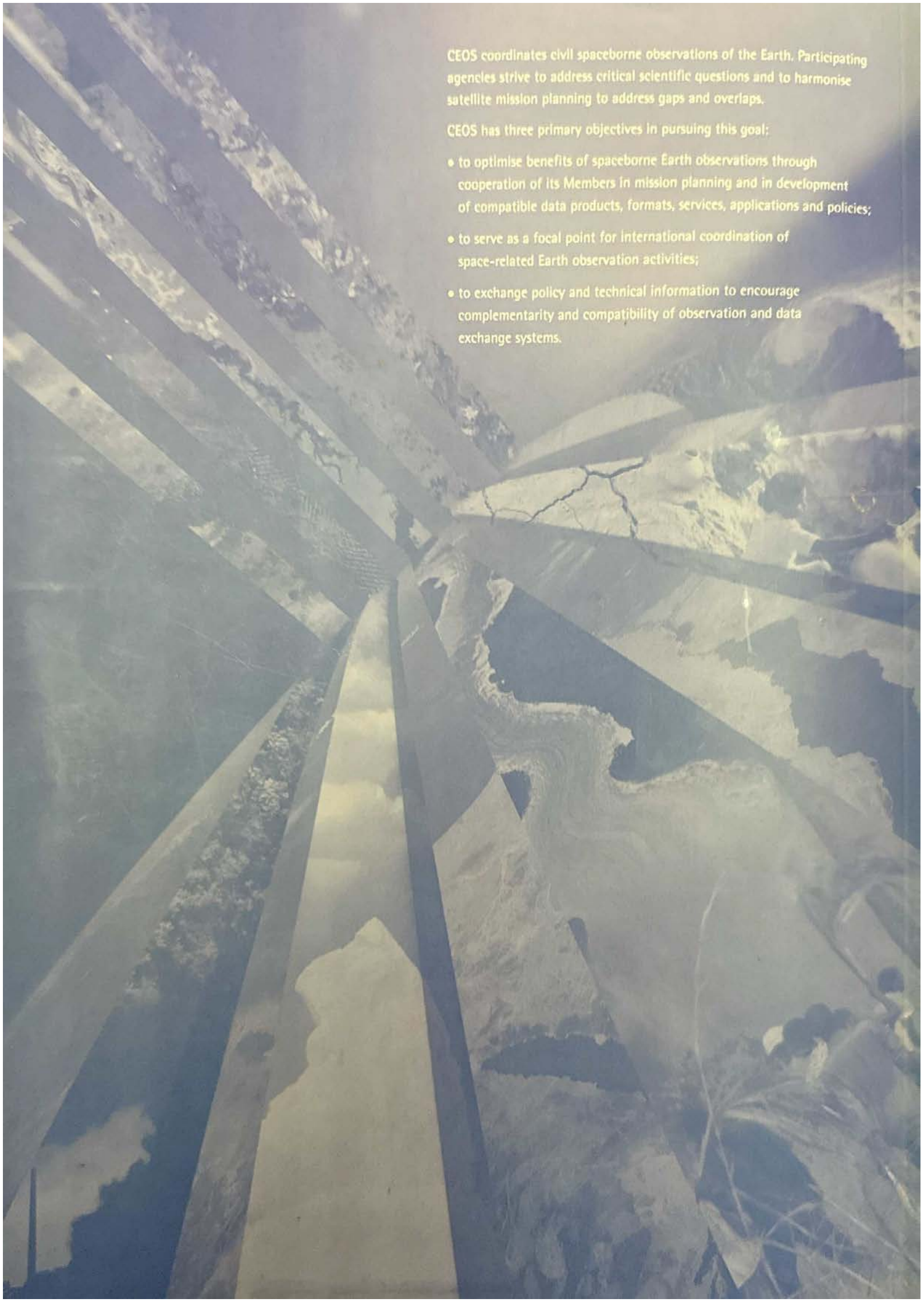
ASI	Agenzia Spaziale Italiana
BNSC	British National Space Centre
CAST	Chinese Academy of Space Technology
CCRS	Canada Centre for Remote Sensing
CEOP	Coordinated Enhanced Observing Period
CEOS	Committee on Earth Observation Satellites
CFCs	Chlorofluorocarbons
CGMS	Coordinating Group for Meteorological Satellites
CLIVAR	Climate Variability and Predictability
CNES	Centre National d'Etudes Spatiale
CONAE	Comisión de Actividades Espaciales
COP	Conference of the Parties
CRI	Crown Research Institute
CSA	Canadian Space Agency
CSD	United Nations Commission for Sustainable Development
CSIR	Satellite Applications Centre (SAC)/ Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DLR	Deutsches Zentrum für Luft-und Raumfahrt
DMSG	Ad Hoc Working Group on Disaster Management Support
DoD	US Department of Defense
EC	European Commission
ENSO	El Niño-Southern Oscillation
EO	Earth Observation
ESA	European Space Agency
ESCAP	Economic and Social Commission of Asia and the Pacific
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organization
FIR	Far Infra-Red
FPAR	Fraction of absorbed Photosynthetically Active Radiation
GCOS	Global Climate Observing System
GEWEX	The Global Energy and Water Cycle Experiment
GFMC	Global Fire Monitoring Center
GIS	Geographic Information Systems
GISTDA	Geo-Informatics and Space Technology Development Agency
GLOSS	Global Sea Level Observing System
GOOS	Global Ocean Observing System
GPS	Global Positioning Satellites
GTOS	Global Terrestrial Observing System
ICSU	International Council for Science
IDNDR	International Decade for Natural Disaster Reduction
IGACO	The Integrated Global Atmospheric Chemistry Observations
IGBP	International Geosphere-Biosphere Programme
IGCO	Integrated Global Carbon Observations
IGOS	Integrated Global Observing Strategy
IGOS-P	Integrated Global Observing Strategy Partnership
IHDP	International Human Dimensions Programme
INPE	Instituto Nacional de Pesquisas Espaciais
IOC	Intergovernmental Oceanographic Commission

IOCCG	International Ocean Colour Coordinating Group
IPCC	Intergovernmental Panel on Climate Change
IR	Infra-Red
ISDR	International Strategy for Disaster Reduction
ISPRS	International Society for Photogrammetry and Remote Sensing
ISRO	Indian Space Research Organisation
KARI	Korea Aerospace Research Institute
KNMI	Royal Netherlands Meteorological Institute
LIDAR	Light Detection And Ranging instruments
LST	Land Surface Temperature
MEXT	Ministry of Education, Culture, Sports, Science and Technology
MWIR	Medium Wave Infra-Red
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NDVI	Normalised Difference Vegetation Indices
NGOs	Non-Governmental Organisations
NIR	Near Infra-Red
NOAA	National Oceanic and Atmospheric Administration
NRSC	Norwegian Space Centre
NRSCC	National Remote Sensing Center of China
NSAU	National Space Agency of Ukraine
NWP	Numerical Weather Prediction
OSTC	Federal Office for Scientific, Technical and Cultural Affairs
ROSHYDROMET	Russian Federal Service for Hydrometeorology and Environment Monitoring
Rosaviakosmos	Russian Aviation and Space Agency
SAR	Synthetic Aperture Radar
SIT	Strategic Implementation Team
SNSB	Swedish National Space Board
SST	Sea Surface Temperature
SWIR	Short-wave Infra-Red
TCO	Terrestrial Carbon Observations
TIR	Thermal Infra-Red
TSI	Total Solar Irradiance
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNOOSA	United Nations Office of Outer Space Affairs
USGS	United States Geological Survey
UV	Ultra-Violet
VIS	Visible
WCRP	World Climate Research Programme
WGCV	Working Group on Calibration and Validation
WGEdu	Ad Hoc Working Group on Education and Training
WGISS	Working Group on Information Systems and Services
WMO	World Meteorological Organisation
WWC	World Water Council
WWW	World Wide Web

D Image credits

Section	Image	Credit
Foreword	Antonio Rodota	IMAPRESS/Patrick Gely
2	Human population	IGBP (Global Change and the Earth System)
	Carbon Cycle	IGBP (Global Change and the Earth System)
	Temperature rise	IPCC Third Assessment Report, Technical Summary of WG1 Report © IPCC
	Climate models	IPCC Third Assessment Report, Summary for Policy Makers © IPCC
Carbon case study	Carbon Cycle	Philippe Rekacewicz, Vital Climate Graphics, Unep-Grid Arendal, Norway, 2000
	VCL	NASA
	OCTS	NASDA/EORC
Water case study	Precipitation models	© IPCC 2001
	TRMM	NASA (Shirah/Morales) / NASDA
Ocean case study	Ocean circulation	UNEP GRID
	Sea level rise	UNEP GRID
	El Niño	NASA, CNES
	SST	NASA
Ozone case study	Ozone layer	UNEP
	TOMS data	NASA
	Global Ozone	NASA
	Agreements	UNEP
	UV Forecasts	KNMI/ESA
Disasters case study	DMSP	NOAA
	Sydney Fires	Image acquired 8 January 2002 by the Australian Centre for Remote Sensing (ACRES), Geoscience Australia. © CNES 2002.
	Fire product	NOAA
	Ethiopia Weather	GFMC
	Fire-fighters	Johann G. Goldammer, GFMC
	Mt Etna	ESA
	MOPITT	CSA/NASA
	Atmospheric sounder data	NOAA
	TRMM	NASDA/CRL/NASA
	Constellation	NASA
	CLOUDSAT	NASA/JPL
	Energy budget	CNES
	ERBE	NASA & Dr. H.-D. Hollweg
	World cup stadiums	KARI
	SPOT	CNES/SPOTIMAGE
	MODIS	NASA
	1km landcover map	IGBP
	Meteosat image	EUMETSAT
	FY-2 image	NRSCC
	SSM/I	NOAA

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	Russian sea ice	Roshydromet
	SAR image	ESA
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	AATSR	ESA
	MISR	NASA/JPL
	OSMI	KARI
	Radar altimetry	CNES
	Jason-1	CNES, CLS, NASA, JPL
	ERS-1	Deutsche Aerospace and MPI for Meteorology
	Quikscat	Dr. W. Timothy Liu, NASA Jet Propulsion Laboratory
	Geoid	DLR
	Tracking series	ESA



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

CEOS has three primary objectives in pursuing this goal:

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