european space agency

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agence spatiale européenne

number 65

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european space agency

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European Space Organisations: the European Space Research Organisation (ESRO) and the European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO). The Member States are Austria, Belgium, Denmark, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. Finland is an Associate Member of the Agency. Canada is a Cooperating State.

In the words of the Convention: The purpose of the Agency shall be to provide for and to promote, for exclusively peaceful purposes, co-operation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems.

(a) by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
(b) by elaborating and implementing activities and programmes in the space field;
(c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
(d) by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

The Agency is directed by a Council composed of representatives of Member States. The Director General is the chief executive of the Agency and its legal representative.

The Directorate of the Agency consists of the Director General; the Inspector General; the Director of Scientific Programmes; the Director of Observation of the Earth and its Environment; the Director of the Telecommunications Programme; the Director of Space Transportation Systems; the Director of the Space Station and Microgravity Programme; the Director of ESTEC; the Director of Operations and the Director of Administration.

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

THE EUROPEAN SPACE RESEARCH AND TECHNOLOGY CENTRE (ESTEC), Noordwijk, Netherlands.

THE EUROPEAN SPACE OPERATIONS CENTRE (ESOC), Darmstadt, Germany

ESRIN, Frascati, Italy.

Chairman of the Council: Prof. F. Carassa

Director General: J.-M. Luton.

agence spatiale européenne

L'Agence Spatiale Européenne est issue des deux Organisations spatiales européennes qui l'ont précédée — l'Organisation européenne de recherches spatiales (CERS) et l'Organisation européenne pour la mise au point et la construction de lanceurs d'engins spatiaux (CECLES) — dont elle a repris les droits et obligations. Les Etats membres en sont: l'Allemagne, l'Autriche, la Belgique, le Danemark, l'Espagne, la France, l'Irlande, l'Italie, la Norvège, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. La Finlande est membre associé de l'Agence. Le Canada beneficie d'un statut d'Etat coopérant.

Selon les termes de la Convention: l'Agence a pour mission d'assurer et de développer, à des fins exclusivement pacifiques, la coopération entre Etats européens dans les domaines de la recherche et de la technologie spatiales et de leurs applications spatiales, en vue de leur utilisation à des fins scientifiques et pour des systèmes spatiaux opérationnels d'applications:

(a) en élaborant et en mettant en oeuvre une politique spatiale européenne à long terme, en recommandant aux Etats membres des objectifs en matière spatiale et en concertant les politiques des Etats membres à l'égard d'autres organisations et institutions nationales et internationales;
(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;
(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications.
(d) en élaborant et en mettant en oeuvre la politique industrielle appropriée à son programme et en recommandant aux Etats membres une politique industrielle cohérente.

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Le SIEGE de l'Agence est à Paris.

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LE CENTRE EUROPEEN DE RECHERCHE ET DE TECHNOLOGIE SPATIALES (ESTEC), Noordwijk, Pays-Bas.

LE CENTRE EUROPEEN D'OPERATIONS SPATIALES (ESOC), Darmstadt, Allemagne.

ESRIN, Frascati, Italie

Président du Conseil: Prof. F. Carassa

Directeur général: J.-M. Luton.

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Preface

It has become increasingly apparent that mankind faces a number of potentially very serious problems of an environmental nature, including climatic changes due to the greenhouse effect, ozone depletion, etc. Observation of the Earth from space is one of the keys to achieving a better understanding of the Earth as a system, and this is vital if we are to make a comprehensive assessment of the influence of man's activities on the environment.

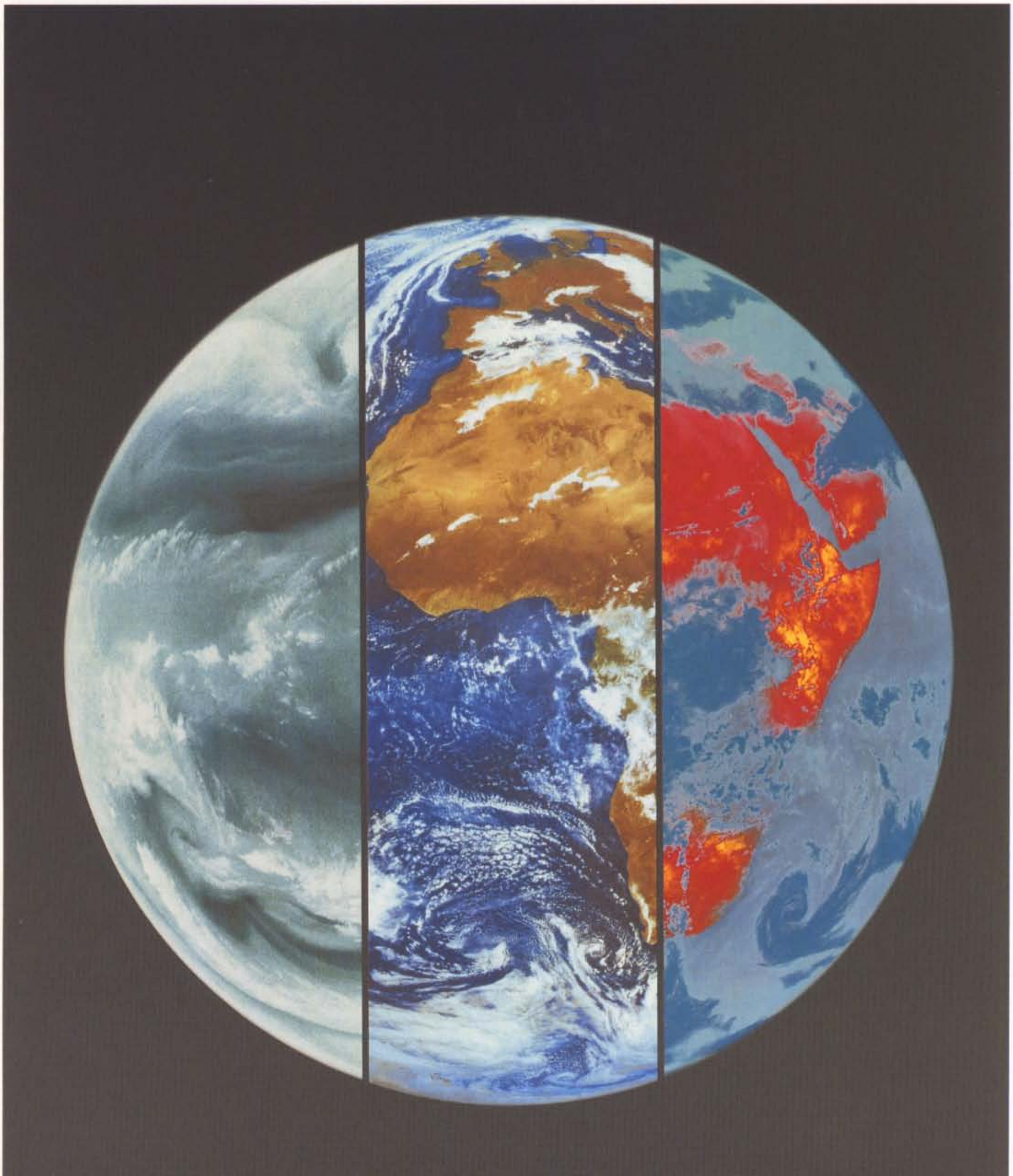
Observation of the Earth and its environment has formed part of the European Space Agency's activities since the start of its Meteosat operations in the late 1970s. In the near future, the all-weather satellites ERS-1 and ERS-2 – the latter a follow-on mission to ERS-1 – will provide, over a period of several years, better opportunities for monitoring and understanding the Earth's environment.

The future plans of the Agency envisage: a solid-Earth gravity-research mission; assistance to EUMETSAT in the development of a second-generation Meteosat with improved capabilities; and a series of polar-orbit missions designed to provide a wide range of observations of the Earth which, inter alia, are particularly important for assessing environmental issues.

A timely world-wide commitment to the goal of implementing a permanent system for Earth observation is highly desirable, in order to consolidate the considerable efforts needed by national and other agencies to develop the necessary technical and scientific infrastructure for the full exploitation of the great potential that would be provided by such a system.

The forthcoming launch of ERS-1 represents a major milestone in attaining this goal and in the quest for more information concerning the evolution of our planet.

J.-M. Luton
Director General
ESA, Paris



Introduction

P. Goldsmith
Director of Observation of the Earth and Its Environment, ESA, Paris

The ESA Earth-Observation Programme
Observation of the Earth and its environment from space encompasses an extremely broad range of disciplines, including: meteorology, atmospheric physics, chemistry and dynamics, climatology, oceanography, glaciology, land processes, environmental factors and those of the solid Earth. In addition, the degree of maturity of the endeavours in any one of theses fields can range anywhere from research, to demonstration, to pre-operation, to operation, to commercial application.

This spread leads to a necessity to fly many different instruments in space, suitably grouped on appropriate flight platforms. In most cases, the long-term continuity of data is also essential for climatology and environmental-change detection, leading to the requirement to sustain the capability for periods of a decade or more by replacing the individual spaceborne systems every few years as each comes to the end of its foreseen lifetime.

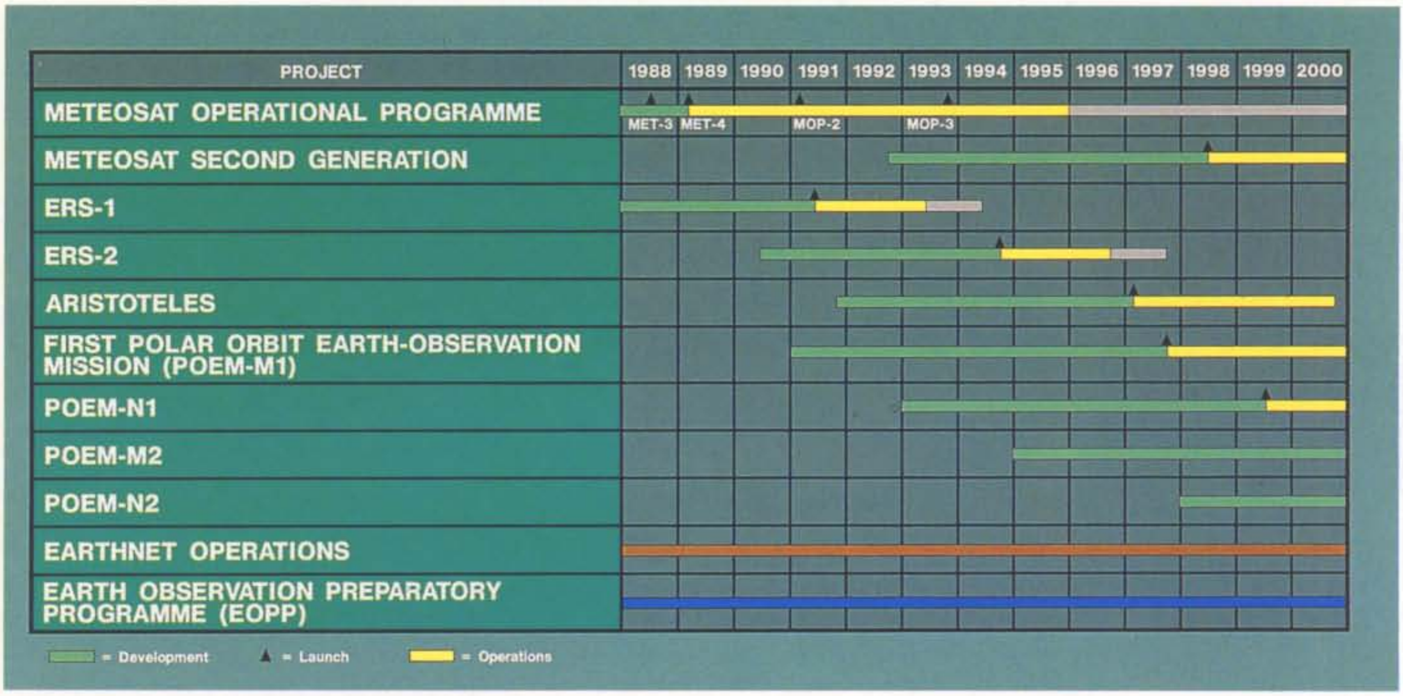
ESA's present Earth-Observation Programme addresses a part of this broad range of disciplines and in some areas already provides for this essential continuity of data. The Agency's plans and strategy for the future envisage a broadening of the Programme to enable the wide range of data essential for better understanding, monitoring, protecting and controlling our Planet, its environment and its resources to be obtained. The ESA Programme is seen as an important contribution to the overall international cooperative effort to monitor and understand the Earth's environmental system.

What has been achieved so far?
Although the subject of the Earth and its environment has recently come under the intense spotlight of World interest, the building up of the necessary infrastructure to be able to collect and analyse the requisite global information cannot be established overnight. What has ESA achieved so far?

The Meteosat Programme
This Programme is Europe's contribution to the World Weather Watch. Meteosat is one of the ring of five geostationary meteorological satellites stationed above the equator. It occupies the spot over the prime meridian and images the same part of the Earth's disc on a continuous basis once every 30 min in three spectral bands – the visible, the thermal infrared, and a water-vapour absorption band.

The first Meteosat was launched in November 1977, the second in June 1981, and the third in June 1988. The success of the Agency's Pre-operational Meteosat Programme led to the formation of the European Meteorological Satellite Organisation EUMETSAT, on whose behalf ESA is constructing, launching and operating three further spacecraft, in the framework of the 'Meteosat Operational Programme'. The first spacecraft in this series, MOP-1, was launched in March 1989; MOP-2 is scheduled for launch in February 1991, and MOP-3 in 1993. Together they will provide an operational service to the European meteorological community through 1995.

For some time now, Meteosat images have been a familiar sight to viewers of the nightly television weather forecasts. However, many more products are routinely generated from the visible, infrared and water-vapour images taken every 30 min, including:
- cloud-motion vectors for deriving wind fields
- sea-surface temperatures
- cloud-top height maps
- cloud analyses
- upper-tropospheric humidity data
- climate data sets.



The Earthnet Programme

With the advent of remote-sensing satellites in the 1970s, the potential role and importance of observing the Earth's land mass, oceans, ice and atmosphere from space became increasingly recognised. To ensure that European users could have access to these important new data sets, ESA established its Earthnet Programme in 1977.

The Earthnet Programme is responsible for acquiring, pre-processing, cataloguing, archiving and distributing data from Earth-observation satellites. It operates receiving stations at, or has arrangements with Member States to acquire data from, Kiruna (Sweden), Fucino (Italy), Maspalomas (Spain), Tromso (Norway) and Gatineau (Canada), and acquires and handles data from a variety of satellites, such as the Landsat series, MOS-1, Nimbus-7, Spot, the NOAA series and Tiros-N. Thanks to arrangements with Member States, it has also acquired data in the past via Oakhanger (UK), Oberpfaffenhofen (Germany), Lannion (France) and from the earlier satellites Seasat and HCMM (Heat-Capacity Mapping Mission).

It is envisaged that Earthnet will be responsible for the ground payload-data-handling functions for future missions, in particular the ESA missions ERS-1 and -2, and the Polar-Orbit Earth-Observation Missions (POEMs).

The Earthnet Programme Office (EPO) is located at the Agency's ESRIN establishment in Frascati, Italy. The data collected from the various spacecraft are distributed through a network of a so-called 'National Points of Contact' situated in each country. Earthnet's data sales have increased year by year, and a large spectrum of users, from research establishments to government agencies, and also firms in the private sector, are already being served.

The first European Remote-Sensing Satellite – The next step

Both global and repetitive observations are needed in order to monitor, and hence to provide a better understanding of, our environment. The requirements are very wide-ranging and Earth observation from space may be the only viable and cost-effective means of acquiring much of the necessary input data for climate models, and for monitoring the Earth's surface conditions on local, regional and global scales.

Due for launch in Spring 1991 into a Sun-synchronous orbit, ERS-1, with its unique set of all-weather microwave instruments, and with an expected operational lifetime of between two and three years, will make a substantial contribution to the scientific study of our environment. It represents the forerunner of a new generation of such space missions planned for the 1990s.

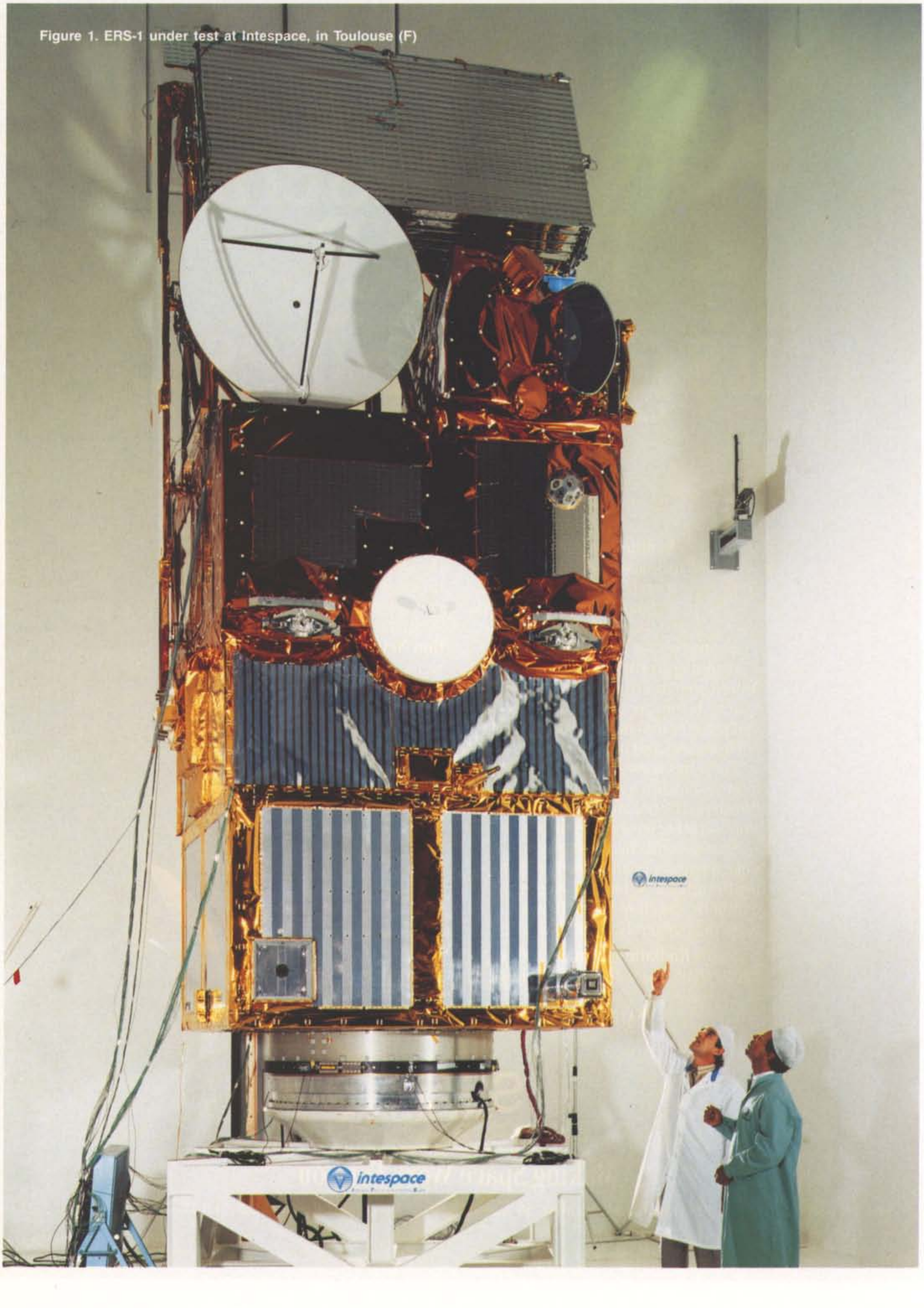


Figure 1. ERS-1 under test at Intespace, in Toulouse (F)

ERS-1 Ready for Launch

J.J. Burger
ESA Directorate for Observation of the Earth and Its Environment,
ESTEC, Noordwijk, The Netherlands

Introduction

The data from meteorological and imaging satellites, together with the increasingly sophisticated processing and interpretation of these data, have led to an ever-growing recognition of their value and benefit. In Europe, this process has been aided by the establishment of the Agency's Earthnet Programme in 1976, which further facilitated the acquisition and use of these satellite data by the European user community.

Useful as data from visible and infrared observations from space have proved to be, such observations are affected by clouds and can only be made under relatively clear weather conditions. They cannot therefore always be made when or as frequently as desired. Furthermore, not all geophysical parameters of interest on or near the Earth's surface can be 'seen', even under clear-sky conditions, via measurements in the visible or infrared regions of the spectrum. This has led to a recognition of the importance of all-weather remote-sensing techniques, utilising the microwave part of the spectrum – a band that penetrates clouds and can function at night as well as during the day.

The first studies in this vein were initiated by the Agency in the 1970s, focussing initially on high-resolution all-weather spaceborne imaging radars – so-called 'Synthetic-Aperture Radars' (SARs) – and then on different types of satellite missions in order to address the varied user requirements more explicitly. This led also to studies of further instruments, such as the Radar Altimeter and the Wind Scatterometer, and to the establishment in 1979 of the Agency's Optional Remote-Sensing Preparatory Programme to initiate development of the critical technologies required for such missions.

Convergence to the specific objectives and configuration of the first ESA Remote-Sensing Satellite, ERS-1, resulted in the adoption by the ESA Council, in 1981, of the corresponding Enabling Resolution for an optional ERS-1 Programme. The detailed definition (Phase-B) effort was undertaken during 1982 and 1983, leading in 1984 to the establishment of the Phase-C/D/E programme for the satellite's development, construction and exploitation.

The ERS-1 mission

The ERS-1 Programme not only includes the development, launch and operation of the satellite, but also the development and setting-up of a Ground Segment that will allow maximum use to be made of the acquired data for research and pre-operational applications.

The ERS-1 satellite will fly several instruments in order to achieve its mission objectives.

The Active Microwave Instrument (AMI) consists of a Synthetic-Aperture Radar (SAR) and a Wind Scatterometer. The SAR can operate in so-called 'Image Mode' for the acquisition of wide-swath, all-weather images over the oceans, polar regions and land. The AMI can also be operated in SAR 'Wave Mode', which will produce 5 km x 5 km images at regular intervals for the derivation of the lengths and directions of ocean waves. The Wind Scatterometer will employ three separate antennas for the measurement of sea-surface wind speed and direction.

The Radar Altimeter (RA) will provide accurate measurements of sea-surface elevation, significant wave heights, sea-surface wind speeds and various ice parameters.

The Along-Track Scanning Radiometer and Microwave Sounder (ATSR-M) combines sensors for the measurement of sea-surface temperature, cloud-top temperature and cloud cover, and atmospheric water vapour.

The Precise Range and Range-Rate Equipment (PRARE) is included for the accurate determination of the satellite's position and orbit characteristics, and for precise position determination for points on the ground (i.e. geodetic fixing).

Finally, a Laser Retro-Reflector (LRR), which will allow measurement of the satellite's position and orbit via the use of Laser-Ranging Stations on the ground, completes the payload.

Figure 2. Fast-delivery processing facility at the Kiruna ground station in Sweden

Details of the individual instruments and the associated mission objectives are given in the accompanying articles.

The platform to support this payload has been based on the design developed previously for the French Spot satellite programme. This platform will provide the basic attitude and orbit control for ERS-1 in its Sun-synchronous polar orbit, with three-axis stabilisation compatible with the instrument requirements. The power system is designed to provide 1.8 kW from the solar array (even after two years in orbit) when in sunlight, and to provide energy from its four 24 Ah batteries when in eclipse.

The satellite and its instruments will be commanded and controlled via the platform's On-Board Data-Handling System and associated S-band communications links. A dedicated Instrument Data-Handling and Transmission System has also been developed, which will allow the 100 Mbit/s data stream from the SAR to be transmitted directly to the ground stations. It will also allow the so-called 'low-bit-rate data' from all other instruments to be recorded onboard for a complete orbit at a rate of 1 Mbit/s. These recorded data can then be transmitted to the ground once every orbit during a station overpass at a rate of 15 Mbit/s.

The resulting ERS-1 satellite weighs 2400 kg and, once in orbit, with its antennas and solar array deployed, will measure 12 x 12 x 2.5 m, making it the largest and most sophisticated free-flying satellite built so far in Europe.

Many of the data to be acquired have potential operational applications, and the ERS-1 Programme therefore requires that a number of data products be derived and made available to users within just 3 h of observation. This means that the Ground Segment not only requires a Mission Management and Control Centre, which has been set up at ESOC in Darmstadt (Germany), and a Tracking, Telemetry and Command Station, which is located at Kiruna in Sweden, but also a sophisticated payload data-handling facility. The latter is being centrally coordinated from the ERS-1 facilities at the Earthnet Programme Office at ESRIN in Frascati (Italy).

Acquisition of the low-bit-rate payload data and the necessary processing to produce the 'Fast-Delivery Products' will be conducted at the ESA stations in Kiruna (Sweden), Fucino (Italy), Gatineau (Canada) and Maspalomas (Canary Islands). Data acquisition and fast-delivery processing of SAR data will take place at the ESA stations in Kiruna and Fucino, as well as at many additional national stations. Last but not least, offline data processing and archiving will take place at four 'Processing and Archiving Facilities' (PAFs). Adequate data-dissemination systems will therefore be available from the outset to ensure efficient provisioning of the data to users (further details can be found elsewhere in this Bulletin).

The Programme's development

The satellite and fast-delivery-product processors have been developed by an industrial consortium led by Dornier, as Prime Contractor. Their task has involved 104 distinct contracts with 60 companies in 14 countries, selected to participate in the Programme on the basis of their particular areas of expertise. The Mission Management and Control Centre and the Kiruna Tracking, Telemetry and Command Station have been developed by industry under ESOC's management, whilst the development of the other elements of the Ground Segment has been under the management of the Earthnet Programme Office. Overall Programme management has been provided by the ERS-1 Project Office at ESTEC. Ensuring the proper development scenario within the available budget and schedule constraints required not only the establishment of, and rigorous adherence to, strict management procedures throughout the Programme, but also the devoted efforts of many staff working cooperatively throughout Europe.

The ERS-1 platform is based on the Spot platform as mentioned earlier, but several significant modifications have had to be introduced so as to support the ERS-1 payload adequately. Considerable assistance was obtained from the French Space Agency CNES, in terms of both expertise and the provision of hardware to assist in a cost-effective verification of the ERS-1 satellite's design. On the payload side, the development effort has included such elements as the carbon-fibre SAR antenna, the various high-power amplifiers and travelling wave tubes, very accurate chirp generators and surface acoustic-wave devices. New radiation-hardened memories have also been introduced, to counter cosmic-ray-induced single-event upsets.

In order to test the ERS-1 hardware fully, the Programme has included the development of a multipaction test facility and a special planar-scanner facility with which to measure the antenna characteristics accurately, as well as additions and modifications to existing facilities to allow a proper radio-frequency compatibility test on the satellite and a thermal-balance test on the payload.

Now, in the last quarter of 1990, the results of development and characterisation tests, life tests on limited-lifetime items, system tests on the structural, engineering and flight models, the ground-segment system verification tests, and the reviews conducted throughout the development programme at subsystem and system level, have brought us to the point where ERS-1 is approaching launch readiness. The current schedule foresees an Ariane-4 launcher carrying ERS-1 into orbit on 3 May 1991.

Once the spacecraft has separated from the launcher, ESOC will take over its control during the early-orbit phase. After deployment of the spacecraft's solar array and antennas, the in-orbit check-out and commissioning phase will begin. The first data from the instruments and the associated fast-delivery products are expected just a few weeks after the launch, although full validation and calibration of the data coming from ERS-1 will take several months. The subsequent routine operations are foreseen to last for several years.

Conclusion

The reception of data from ERS-1 will add a new dimension to our studies of the Earth and its environment as an integrated system. It will be possible to pursue many new scientific and operational objectives that are not feasible with existing satellite systems. ERS-1 will provide essential data for addressing a wide range of environmental questions, such as ocean/atmosphere interaction, ocean circulation and transfer of energy, the mass balance of the Arctic and Antarctic ice sheets, coastal-dynamics processes, pollution and land-use changes. The rapid availability of the data products will allow significant contributions to be made to operational meteorology, sea-state forecasting, and the monitoring of sea-ice distribution for shipping and offshore activities.

This major step forward has been made possible only through the devoted efforts and cooperation of hundreds of European engineers and scientists, in industry, in research and national institutes, and within ESA itself. These efforts, together with those of the researchers who will work with the data from ERS-1 and its follow-up missions, will doubtless prove instrumental in our achieving a better understanding and more astute management of our planet, its climate, and its resources.

The ERS-1 Mission Objectives

G. Duchossois
Directorate for the Observation of the Earth and Its Environment, ESA, Paris

ERS-1: A multi-disciplinary mission
The first European Remote-Sensing Satellite is the forerunner of a new generation of space missions planned for the 1990s, which promises to make a substantial contribution to the scientific study and understanding of our environment. It will use advanced microwave (radar) techniques that will allow global measurements to be made and imaging to take place regardless of cloud and sunlight conditions. Such techniques have been used previously only by the short-lived Seasat mission in 1978, and during brief Space-Shuttle experiments in 1981 and 1984. In addition, ERS-1 will undertake the measurement of many parameters not covered by existing satellite systems, including those of sea state, sea surface winds, ocean circulation and sea and ice levels, as well as all-weather imaging of ocean, ice and land. It will also measure the sea's surface temperature with greater accuracy than any of the current space systems.

Significantly, much of the data will be collected from remote areas such as the polar regions and the southern oceans, for which little comparable information is yet available.

The ERS-1 mission will provide the data that are needed to address a wide range of pressing environmental problems, thereby contributing to:

- improved representation of ocean–atmosphere interactions in climate models;
- major advances in our knowledge of ocean circulations and the transfer of energy;
- more reliable estimates of the mass balance of the Arctic and Antarctic ice sheets;
- better monitoring of dynamic coastal processes and pollution; and
- improved detection and management of land-use change and cover.

The ERS-1 System has also been designed to satisfy operational requirements for data products needed within a few hours of the observations being made, allowing it to make significant contributions to operational meteorology, sea-state forecasting and monitoring of sea-ice distribution – all being important for shipping and offshore activities. High resolution radar imaging of the Earth's surface will also provide unique data sets for land-resource management, including both renewable and non-renewable resources.

Last but not least, thanks to its altimetric and precise tracking data, ERS-1 will provide very valuable information for the understanding of the Earth's interior and for geodetic applications.

Environmental objectives
There is increasing concern that man's activities are starting to affect the sensitive thermodynamic and ecological balance of our planet. One of the most crucial of these effects is the increase in the atmosphere's carbon-dioxide concentrations due to the burning of fossil fuels and deforestation. It has been predicted that mean global temperatures may rise by as much as 2–3°C over the next 50 years, accompanied by major shifts in regional weather and vegetation patterns. This would lead to a partial melting of the polar ice caps, with many densely populated areas becoming inundated by rising sea levels.

These major problems confronting mankind can only be addressed effectively if we can understand the complexities of our global environment to a much greater degree than we do at present. Complex interactions have to be unravelled in order to fully understand the processes that are involved, and this requires thorough investigation of the physical behaviour of the atmosphere, oceans, ice and land-surface cover. The magnitude and rate of change of many of the processes involved cannot yet be reliably measured, let alone predicted.

This concern about our environment has attracted the attention of decision-makers and politicians at the highest levels, as witnessed by the establishment in 1988 of the Inter-Governmental Panel of Climate Change (IPCC) set up by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP). This Panel, and more particularly its Working Group I, has been given the tasks of assessing available scientific information on climate change and the latter's environmental and socio-economic impacts, and of formulating response strategies. At the second World Climate Conference, held at the end of October 1990 in Geneva (CH) and attended by Ministers and other representatives from 137 countries and from the European Community, the importance was stressed of:

'a major international observational and research effort to strengthen the knowledge-base on climate processes and human interactions, and to provide the basis for operational climate monitoring and prediction'.

It was also acknowledged that both global and repetitive observations are needed to resolve the broad range of space and time scales involved in the monitoring and preservation of the environment.

These requirements are very wide ranging, and Earth observation from space may be the only viable and cost-effective means of acquiring much of the input data needed for climate models, and for monitoring our planet's surface conditions on local, regional and global scales.

The Greenhouse Effect

Current numerical and theoretical climate models allow prediction of the effects of further increases in the so-called 'greenhouse gases' (carbon dioxide, methane, ozone, etc). Without actions to reduce the emission of these gases, global warming is predicted to reach 2 to 5°C over the next century (Fig. 1), a rate of change unprecedented in the past 10 000 years. This warming is expected to be accompanied by a sea level rise of 65 cm (plus or minus 35 cm) by the end of the next century (Fig. 2).

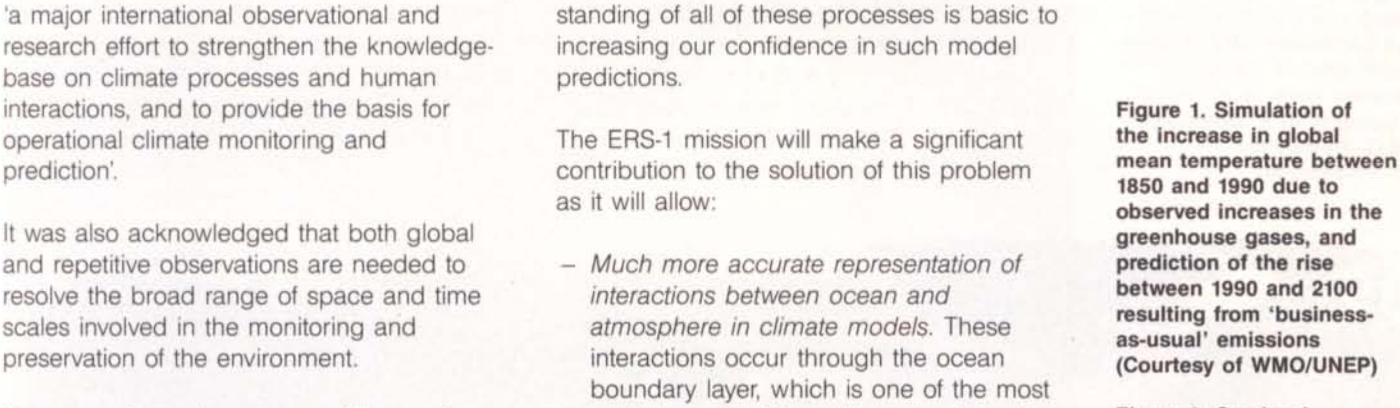
However, these predictions must be treated with great caution as the models used do not contain an adequate representation of the full Earth–atmosphere system. In particular, very sensitive assumptions are made about the exchange of heat, moisture and momentum between the planet's surface and the atmosphere and the associated cloud radiation feedback. Improved understanding of all of these processes is basic to increasing our confidence in such model predictions.

The ERS-1 mission will make a significant contribution to the solution of this problem as it will allow:

- *Much more accurate representation of interactions between ocean and atmosphere in climate models.* These interactions occur through the ocean boundary layer, which is one of the most variable parts of the global climate system on diurnal, seasonal and inter-annual time scales. Surface wind stress and very precise sea-surface temperature measurements, made continuously and on a

Figure 1. Simulation of the increase in global mean temperature between 1850 and 1990 due to observed increases in the greenhouse gases, and prediction of the rise between 1990 and 2100 resulting from 'business-as-usual' emissions (Courtesy of WMO/UNEP)

Figure 2. Sea-level rise predicted to result between now and the year 2100 from 'business-as-usual' emissions (Courtesy of WMO/UNEP)



global basis by ERS-1's sensors, will significantly improve our estimates and understanding of the heat, moisture and momentum transfers that are taking place.

- *A major advance in our knowledge of ocean circulation, its variability and the associated energy transfers.* Today's ocean-circulation modelling is much less advanced than that for atmospheric circulation, and improvement of these ocean models (particularly on the mesoscale) is of paramount importance because the ocean transports great quantities of heat horizontally in currents, gyres, eddies, etc. The meridional heat flux carried by the oceans is comparable to that carried by the atmosphere, larger in the tropics and smaller in higher latitudes.

The large-scale ocean-circulation gyres and strong boundary currents (such as the Gulf Stream) are primarily driven by, or result from, the forcing of wind stress on the sea surface. The unique surface-wind-stress data provided by ERS-1 and the accurate determination of the ocean surface topography and of its temporal variability (of the order of a few tens of centimetres over horizontal distances of hundreds of kilometres!) derived from the combined use of the very precise (centimetre-level) altimetric and tracking data, will lead to a better understanding of ocean dynamics.

ERS-1 has, in fact, been acknowledged as a critical element in implementation of the World Ocean Circulation Experiment (WOCE), which is by far the largest and most ambitious international undertaking within the World Climate Research Programme.

- *Better monitoring of polar regions, in particular the Arctic and Antarctic ice sheets and sea-ice-covered areas.* A substantial volume of the World's fresh water is stored in the Antarctic and Greenland ice sheets. In addition to land ice, there is a highly variable zone of relatively thin sea-ice which covers 10% of the Northern Hemisphere and 13% of the Southern Hemisphere. The seasonal variability in sea-ice cover can be as great as 25% in the Arctic and 75% in the Antarctic. Monitoring of the areal extent, surface elevation, surface temperature and surface roughness of ice-covered regions is therefore very important in order to study possible ice-sheet responses to global warming due to the greenhouse effect.

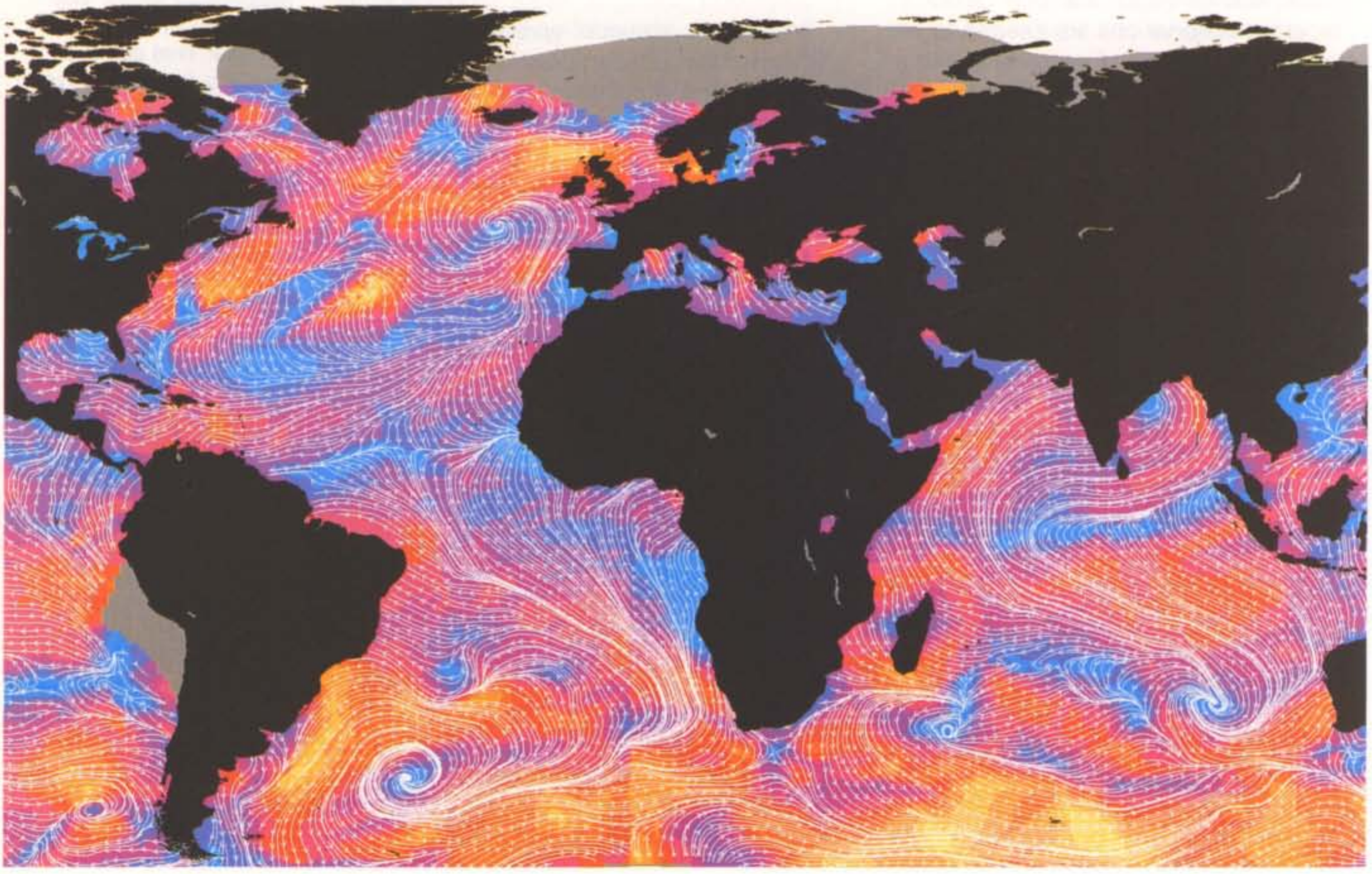


Figure 3. Surface wind field over the Atlantic on 14 September 1978, derived from satellite (Seasat) scatterometer data (Courtesy of P. Woiceshyn, M.G. Wurtele & S. Peteherych)

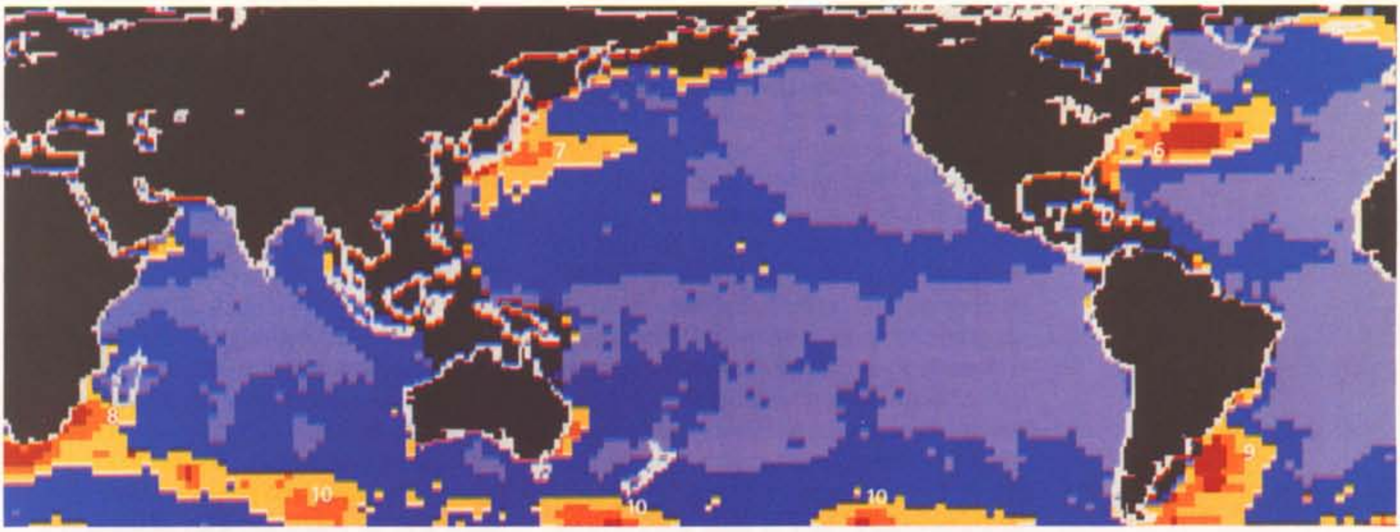


Figure 4. Variations in mean sea level during a four-week period in Sept./Oct. 1978, as measured by Seasat. The largest variations of up to 25 cm, shown in red, are associated with strong flows such as the Gulf Stream (6), Kuroshio (7), Agulhas (8), Falklands (9) and Antarctic Circumpolar (10) Currents (Courtesy of NASA)

Figure 5. A large iceberg, some 150 km long and 35 km wide, in the Antarctic Ocean adjacent to the Ross Ice Shelf (Image courtesy of EOS)

As for the ocean-circulation studies, ERS-1 will be one of the main sources of space data for large international polar-ocean and ice-cap research programmes.

- *The regular monitoring of land-surface processes on a global scale, and in particular the vegetation cover.*
  The measurement of such land-surface parameters as surface roughness, surface temperature and soil moisture is essential to describe the energy exchange between surface and atmosphere, as well as the change in surface characteristics that affect this energy exchange, which in turn affects the climate.

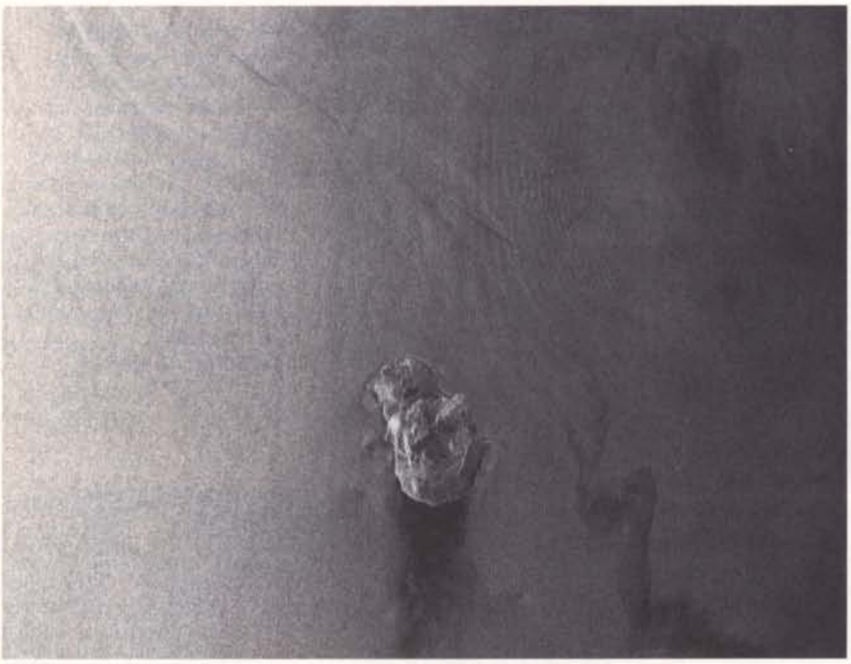


Figure 6. Seasat image taken on 19 August 1978 of Pantelleria Island, approx. 100 km southeast of Sicily, showing a large oil slick, towards the bottom right corner (Courtesy of DFVLR and ESA Earthnet)

- *The monitoring of changing land-use patterns*, such as the conversion of tropical forest to agriculture (deforestation problem in Amazonia, Southeast Asia, etc.) and of range land to intense cultivation, which are a major human influence on our global environment.
  The all-weather imaging capability offered by ERS-1 will be of paramount importance to geographical zones where quasi-permanent cloud cover strongly limits, or even prevents the use of optical sensors.

Coastal processes and surface pollution

Along many coasts, the coastline and bottom configuration is continually changing because of a combination of natural forces and man-made modifications. The monitoring of such dynamic processes (e.g. erosion, sedimentation, coastal currents, estuarine fronts and circulation) by exploiting ERS-1 data is important not only for the protection of coastal environments, but also for economic reasons (maintenance of safe navigation channels, civil-engineering activities, conservation of fishing grounds, etc.). The application of SAR data to coastal bathymetry has already been demonstrated with Seasat, where it was shown able to detect the surface expression of submarine features to significant depths.

Tanker accidents resulting in oil spills at sea can have major consequences for the local marine environment as well as their immediate financial implications vis-a-vis fishing activities, tourism, etc. ERS-1 will provide important data both for detecting oil slicks and for predicting their paths and hence their potential threat to sensitive shore areas.

Disaster assessement

Disasters occur suddenly and unexpectedly in various forms and on various time scales. Typical examples are fires, earthquakes, floods, landslides, hail storms, hurricanes, tornadoes, cyclones, avalanches, heavy snow falls, and volcanic eruptions. In view of the tremendous toll that such disasters take each year in terms of human life and material damage throughout the World, it is imperative that disaster managers and government authorities have access to as much relevant information as possible during each of the critical phases of their work (pre-disaster mitigation, disaster-response and post-disaster recovery activities). Insurance companies already use satellite data to assess the damage caused by both natural and man-made disasters.

It is recognised that satellites often serve to complement field surveys, aircraft reconnaissance and ground-data collection platforms in obtaining the requisite information, but in many disaster situations satellite imagery offers the best, and often the only means of obtaining critical information sufficiently quickly.

ERS-1 will offer a unique all-weather sensing capability that is essential for disaster observation, since many such events are the direct result of adverse weather conditions and/or occur in naturally very cloudy areas (e.g. in tropical/equatorial zones).

Contributions to operational forecasting and derived applications

ERS-1's ability to deliver products related to important geophysical ocean and ice parameters on a global basis and in near-real-time will allow it to make a significant contribution to established operational systems for forecasting weather, sea-state and ice conditions, with subsequent benefits to operational/commercial activities conducted offshore and/or in ice-infested areas.

Operational meteorology

Operational meteorology will benefit substantially from ERS-1, which will help to overcome several of the deficiencies of the current meteorological observing network, notably:

- the lack of wind observations near the sea surface
- the lack of sea-state observations
- the poor accuracy of sea-surface-temperature measurements.

It will also enhance our data on cloud fields and atmospheric water contents, as well as providing information on sea-ice distribution, on which several meteorological services advise. Some of these data will be of great relevance to both climate and forecast models.

Wind observations near the Earth's surface are one of the basic inputs to forecasting models. Lack of such data significantly degrades the model's performance. These problems will be exacerbated as model resolution increases. It is therefore a matter of great concern that, over vast areas of the globe and notably over the oceans, data coverage is at the best sparce if not totally lacking. This problem is particularly severe in the vast oceanic areas of the Southern Hemisphere, but also occurs in the Northern Hemisphere due to a reduction in the number of weather ships. The availability of data on the surface wind/wave/temperature fields will make a significant contribution to the removal of this deficiency.

These data will have an impact not only on the existing 'atmospheric' forecasting models, but also on the next generation of models which will be ocean–atmosphere coupled. The successful coupling of ocean and atmosphere is essential if the reliability of longer-term forecasts is to be enhanced. The performance of current models is limited by artificial boundary conditions imposed at the sea surface. Here also, improved information on sea state is vital. Observations of both wind and waves are essential. ERS-1 will provide the data needed and will also allow the validation and tuning of such models, thanks to its coherent microwave sensor package. This will provide the mutually supportive information on surface winds (strengths and directions) and waves (significant wave height, mean-square wave slope and spectral distribution) necessary to reconstruct the space/time history of the wave and wind field.

The other crucial input is sea-surface temperature, which is essential for estimating transfers of energy, moisture and heat between ocean and atmosphere. Errors in the estimation of these quantities significantly degrade the performance of forecasting models. Without data from ERS-1, it would not be possible to capitalise on improvements in ability to parameterise such

Figure 7. Wind reports from commercial shipping during the three-day period 31 October–3 November 1990. Each dot represents one wind-speed/direction report. During a similar period, the ERS-1 Wind Scatterometer will be able to make almost 1 000 000 individual measurements, uniformly distributed over all of the World's oceans (Courtesy of the European Centre for Medium-Range Weather Forecast)

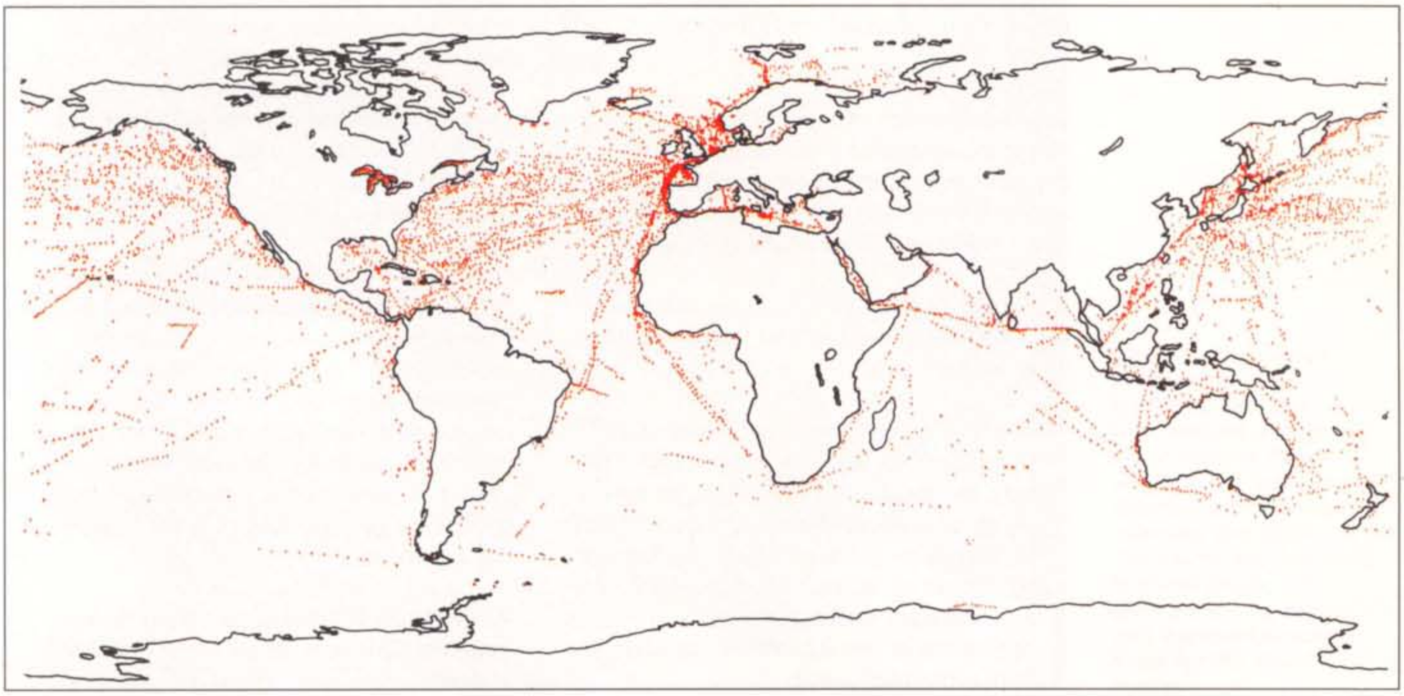


Figure 8. Radar image taken by Seasat on 15 September 1978 of the Atlantic Ocean to the west of the Shetland Islands (N. Scotland). Large swell waves, with wavelengths of some 200 m, emanating from an Atlantic storm are clearly apparent (Courtesy of NASA)

transfers. The current observing network does not meet requirements in that in-situ observations from ships and buoys have the accuracy but not the geographic coverage, while observations from existing satellites have the coverage but not the accuracy. ERS-1's observations, corrected for atmospheric effects, will certainly have the necessary accuracy and their use should lead to an improvement in model predictions. It will also make a significant contribution to observations of cloud fields and aerosol layers.

The development of techniques for assimilating the new data into models and the improvement of ocean–atmosphere interaction in models is already in progress in many operational forecasting centres.

A number of commercial activities will benefit from improved weather and sea-state information, including:

- Offshore exploration for and exploitation of gas and oil fields, for which ERS-1 will help to provide improved statistics on winds and waves (frequency, height, etc.) for engineering-design purposes (e.g. for oil platforms), as well as improved weather and sea-state forecasts for the planning of operations at sea (platform installation, field exploitation, etc.).
- Ship routing, through reducing sailing times on the main trade routes (fuel savings) by optimising courses and improving safety (reduction in hull damage, cargo damage, marine insurance costs, catastrophic ship losses, etc.).
- Fishing activities, by increasing both efficiency and safety in fishing operations.

Operational ice-forecasting

The tools needed to gather information on ice and the models to predict its motion are not yet commonly available on an operational basis. Current meteorological satellites can provide a significant amount of ice information but, in the case of optical sensors only as long as there are no clouds present, or with a coarse ground resolution in the case of (passive) microwave sensors. The all-weather, high-resolution, day-and-night sensing capability of the ERS-1 active microwave instruments will be particularly useful in those parts of the World frequently obscured by clouds or fog, or shadowed in darkness (polar night) for long periods. The integration of its data into ice dynamic models should produce a major improvement in the predictive capabilities so essential to such industrial activities as shipping, offshore oil and gas exploration and production, fishing, surveillance, and search-and-rescue operations in high-latitude regions (Bering, Beaufort, Labrador, Barents and Baltic Seas, the Gulf of Botnia, Greenland Coast, etc.).

Contributions to resource management

Mankind's demand for resources continues to increase dramatically as the World's population grows and as living standards improve, to the point where the balance between supply and demand is becoming critical in some areas. It is therefore essential to obtain resource information that is both accurate and timely if we are to monitor, and manage the use of, the Earth's renewable and non-renewable resources correctly.

Remote-sensing data from the Landsat and Spot satellites have already provided very promising and encouraging results for a variety of land applications. However, these satellites rely on optical instrumentation to provide high-resolution multispectral radiance data from the Earth's surface. With its SAR data, ERS-1 will provide a unique all-weather microwave sensing capability for resource management.

Applications that will benefit from its multitemporal SAR data, used either alone or in combination with optical data, include:

- renewable resources: monitoring of crops, vegetation, forests, water resources
- non-renewable resources: geological mapping, mineral resources, drainage patterns
- land-use planning and cartography.

Many of these applications are particularly important for Developing Countries, where the primary base for their economic development lies in their natural resources. At a time of World food and energy shortages and of spreading environmental deterioration, it is vitally important to monitor the changing condition of their natural domain in order to accurately forecast crop yields, detect erosion of land and pollution of water, recognise alterations in land use, and to observe many other critical aspects of environmental change.

Contributions to understanding of the solid Earth
ERS-1 will provide very valuable information for both solid-Earth research studies and applications through the combined use of its altimetric and precise tracking data. These data will be used, for example, for:

- determination of the geoid, and particularly the oceanic geoid: Local and regional oceanic geoid information will be used for geophysical studies of the oceanic lithosphere (e.g. tectonic, thermal and mechanical structure) and of the convection in the Earth's mantle.

- determination of ocean-surface variability, topography and currents: Measurement of the variation of the ocean surface from a unique zero reference level will provide the basis for monitoring ocean-circulation features with high resolution.

- precise orbit determination: The provision of precise satellite position data is essential for numerous applications, such as the monitoring of the integrity of large civil-engineering structures and the establishment or improvement of geodetic networks.

- precise relative geodetic positioning.

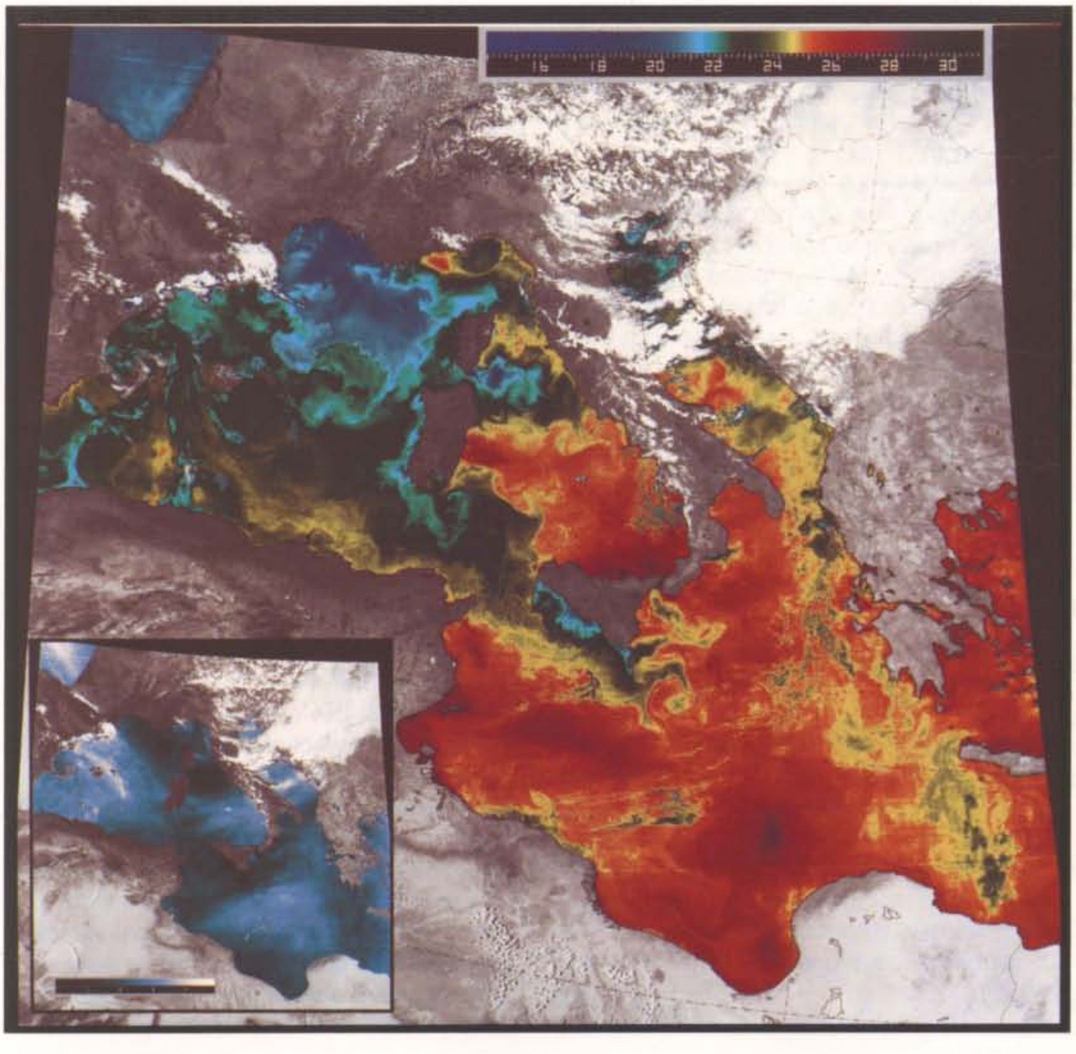


Figure 9. Sea-surface temperature of the Mediterranean on 5 August 1987, derived from radiometer imagery (NOAA AVHRR). The inset shows differences in atmospheric humidity. The ERS-1 Processing and Archiving Facilities (PAFs) will generate similar products with improved accuracy levels for the World's oceans

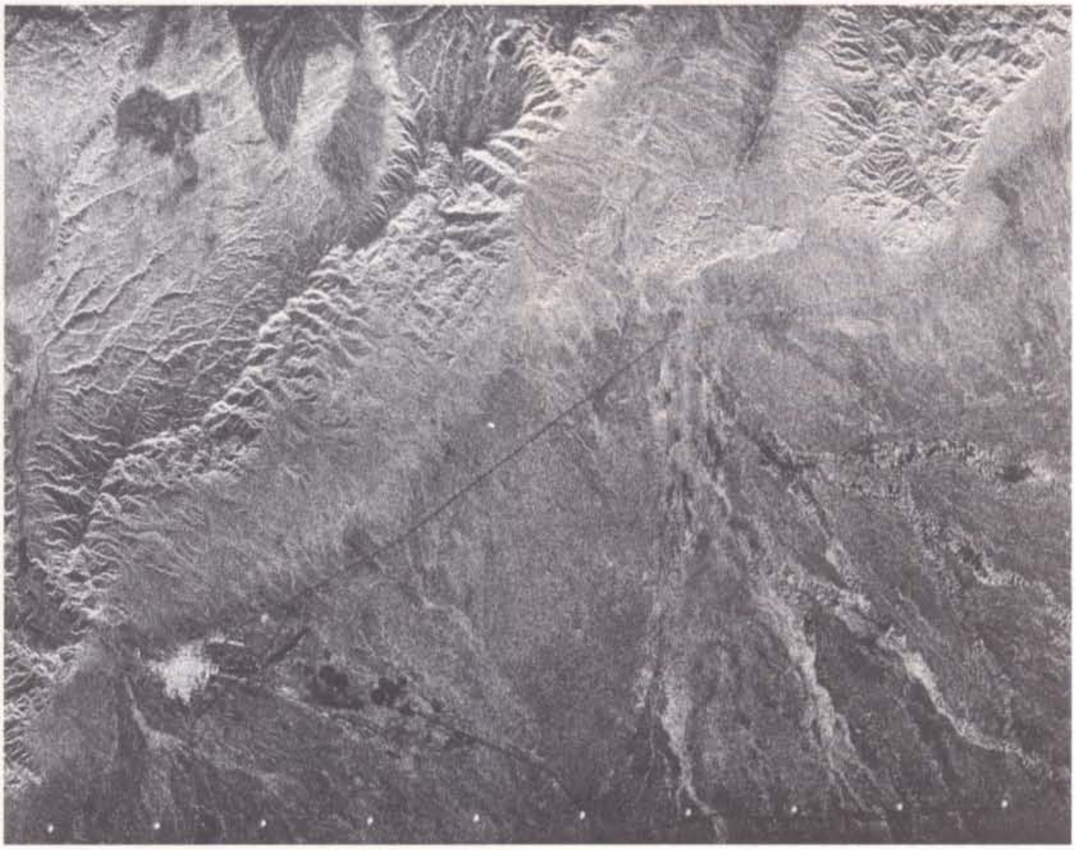


Figure 10. Radar image (SIR-A, L-band) of an area in Argentina to the east of the Andes, taken in 1981. It is mainly arid grassland and scrub crossed by dissected sedimentary ridges. There is some sparse agriculture around the town of La Rioja, shown by the circular irrigation patterns, and elsewhere

Table 1 — Relation between ERS-1 instruments and mission objectives

	AMI (SAR + Scatt.)	ATSR	RA	PRARE	Laser Reflectors
Greenhouse Effect					
— Ocean – Atmosphere Interactions	X	X			
— Ocean Circulation/ Dynamics	X	X	X	X	X
— Ice Processes	X	X	X		
— Land Processes	X	X			
— Cloud/Radiation Processes		X			
Disaster Assessment	X	X			
Solid Earth			X	X	X
Operational Meteorology	X	X	X		
Land Resources	X	X	X		
Snow/Ice Applications	X	X	X		
Coastal Management/ Engineering Applications	X	X	X		
Offshore Applications (ship traffic routing, oil exploration and exploitation, fishing, etc.)	X	X	X		
Hazard Monitoring	X	X	X		

Hence, the positioning capabilities of ERS-1 are likely to make a considerable contribution to our understanding of the structure and dynamics of the Earth's crust and interior, and to the study of tectonic-plate movements.

Contribution to the development of operational systems

The development and implementation of operational remote-sensing systems is a major objective for ESA, and it is believed that truly commercial undertakings will follow if successful operational applications can justify continuity of remote-sensing measurements over long periods and on global scales. This was clearly stated in the Declaration establishing the ERS-1 Programme and further stressed in the Ministerial Resolution on the European Long-Term Space Plan adopted in The Hague in November 1987.

In the previous sections, a number of operational domains to be addressed with ERS-1 have been described. With the recent approval of ERS-2 by the ESA Council in June 1990, it is hoped to achieve a gradual transfer of applications from experimental or pre-operational status to operational exploitation. Already with ERS-1, which is seen as an experimental/pre-operational system, preparatory activities for later quasi-operational

Figure 11. Radar image (SIR-A, L-band) of an area northeast of the city of Asuncion in 1981. The hatched pattern on the left represents typical Amazonian deforestation (the light tones are high forested areas). There is also deforestation further east, on some of the lower valley sides (dark tones) adjacent to the network of small access roads

exploitation of ERS-type data have been initiated. The considerable efforts and investments made in this context are based on the expected guarantee of continuity to be provided first by the successive ERS-1 and ERS-2 missions, and later by the Polar Platforms in the second half of the 1990s.

The various user communities have also begun preparing in earnest for operational use of ERS-type data, the following being just some examples:

- *the meteorological community*, which is developing techniques for assimilating asynoptic data into their numerical weather and sea-state forecasting models, tuning and improving the quality of these models and, as a consequence, improving the resulting predictions for the benefit of subsequent applications to industrial offshore and coastal activities;

- *the ice community*, for which SAR imagery is essential to identify ice features under all weather conditions for a number of important commercial activities such as oil research/exploitation and ship routing in ice-infested waters;

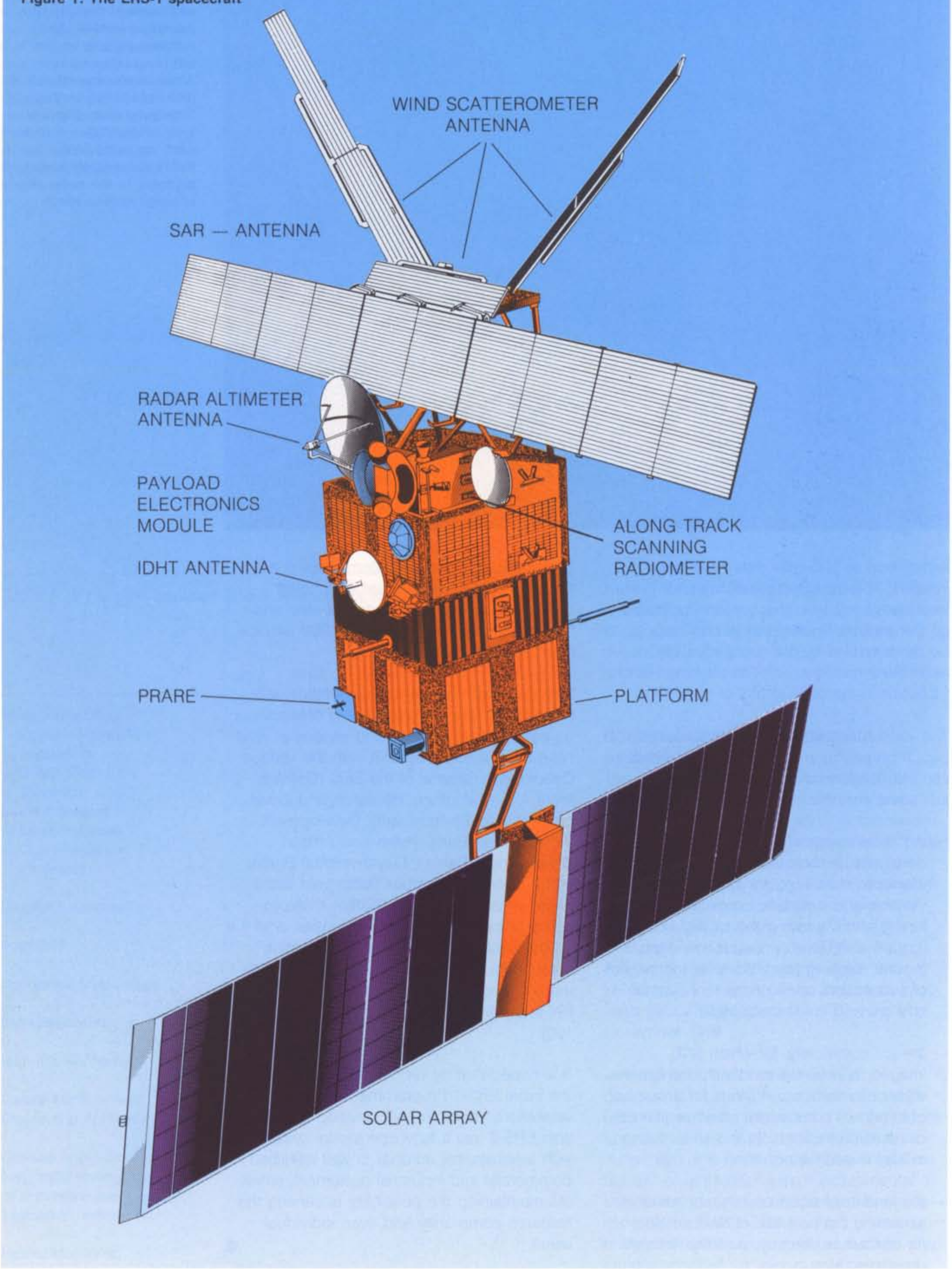
- *the land-application community*, which is assessing the potential of SAR imagery for agriculture, forestry, land-use, mineral resources, etc.

Elsewhere, operational systems based on the use of SAR imagery are also being developed for the surveillance of ship and fishing activities, etc., within the 200 nautical mile territorial exclusion zone.

Strong coordination and collaboration with the relevant user communities is obviously an essential prerequisite and various actions have been initiated by ESA with the various Directorates General of the EEC (Development Aid, Agriculture, Research and Development, and Environment), Development Banks (World Bank, Asian and African Development Banks), Governmental Bodies in the Agency's Member States with local/regional/national responsibilities, meteorological offices, ice-forecasting centres, and the private sector (e.g. oil companies, mining companies, etc.). ERS-1 is also expected to make a major European contribution to the ISY and 'Mission to Planet Earth' (see page 100).

It is hoped that by proceeding in this way, the initial ERS-1 Programme, with its large scientific component, will develop gradually with ERS-2 into a fully operational system with a substantial number of well-identified commercial and industrial customers, whilst still maintaining the possibility of serving the research community and even individual users.

Figure 1. The ERS-1 spacecraft



The ERS-1 Spacecraft and Its Payload

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The first European Remote-Sensing Satellite, ERS-1, was conceived in the late seventies and early eighties as an orbiting platform that would be capable of measuring the Earth's atmospheric and surface properties both with a high degree of accuracy and on a global scale. The primary scientific objective behind acquiring these data is to increase our understanding of the interaction between the Earth's atmosphere and the oceans, with the aim of deepening our knowledge of climate and improved global climate modelling. Other major benefits to be derived from ERS-1 data include: improved weather and sea-state forecasting and 'nowcasting', ice-coverage measurements, and the monitoring of pollution, dynamic coastal processes, and changes in land use.

In order to be able to make all of these measurements, and to provide them globally, at all times of day and regardless of cloud conditions, the principal constituents of the ERS-1 payload are active microwave instruments, or radars. To achieve the global coverage required, ERS-1 will be placed into a polar orbit with a mean altitude of about 780 km. From this altitude powerful radar pulses are needed, to provide sufficient illumination of the Earth's surface to produce detectable echo signals. Large antennas are needed on the spacecraft to pick up the returning signals.

Consequently, the satellite has to be very large, and weighs about 2.3 tons. The ERS-1 payload alone weighs approximately 1000 kg and will consume about 1 kW of electrical power when in full operation. The antennas, once deployed, will be up to 10 m long; the main payload support structure has a 2 m x 2 m base and is some 3 m high. To

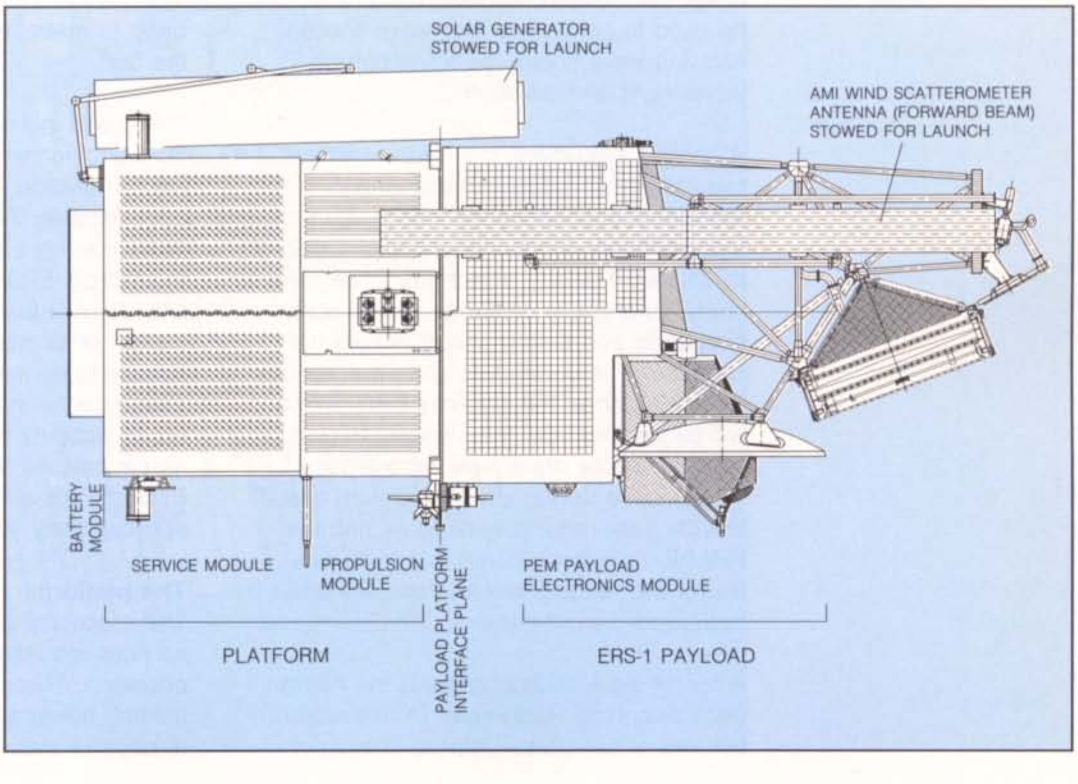


Figure 2. The major modules of the ERS-1 satellite

support the payload by providing electrical power, attitude and orbit control, as well as overall satellite operational management, a platform module – derived from the French national Spot programme – is attached to the payload. This module is roughly equivalent in size to the payload itself and is equipped with a deployable 12 m x 2.4 m solar array.

When the main development contract started, in 1984, the satellite was far larger and more complex than any that had been flown previously by ESA. A comparison between Meteosat and ERS-1, for example, shows that the latter is 7.5 times heavier, transmits 750 times more bits of data per second, and has nine active onboard computers, while Meteosat had none.

The largest of the sensors, the Active Microwave Instrument (AMI) will be capable, in its imaging mode, of producing highly detailed radar images of a 100 km strip on the Earth's surface. This mode is also known as the Synthetic Aperture Radar or 'SAR' mode. Because this mode will consume a large amount of energy and produce a vast amount of data, which cannot be stored on board, it will only be used regionally, for periods of approximately 10 min per orbit. The same instrument has alternative global measurement modes, namely the 'Wind (or Scatterometer) Mode', in which the wind speed and direction at the sea-surface can be measured over a 500 km swath, and a 'Wave Mode', which will provide small radar images at 200 km intervals. These can be used to generate ocean-wave spectra, showing wave energy as a function of wavelength and direction.

A second instrument, the Radar Altimeter, will provide highly precise measurements of the satellite's height above the ocean, ice and land surfaces. The successful exploitation of these height data – which are to be used to study, amongst other things, global ocean circulation and height profiles across the ice caps – is dependent upon precise determination of the satellite's orbit, which will be derived from the onboard tracking systems. These are a laser retroreflector – a passive device used by ground-based satellite laser-ranging systems – and the PRARE instrument, which is a two-way microwave ranging system that uses small, dedicated ground stations.

A further payload instrument is the Along-Track Scanning Radiometer (ATSR), which consists of two parts. Detailed images of the sea surface will be made by an infrared scanning radiometer, which will allow extremely precise measurements of sea-surface temperature. The other part is a passive microwave radiometer, which will be used to determine the water-vapour content of the vertical column of the Earth's atmosphere passing beneath the satellite.

The large amounts of data from these instruments will be transmitted to the ground via the Instrument Data-Handling and Transmission (IDHT) Subsystem. This includes two high-capacity onboard tape recorders to store the data being gathered whilst the satellite is outside the visibility of the various ground stations.

The orbit

ERS-1 will be placed into a Sun-synchronous polar orbit, highly inclined to the equator, giving the satellite visibility of all areas of the Earth as the planet rotates beneath its orbit. The inclination will be such that the precession of the orbit, caused by the nonspherical components of the Earth's gravity field, will exactly oppose the annual revolution of the Earth around the Sun. Consequently, the orbital plane will always maintain its position relative to the Sun, crossing the equator with the descending node at about 10:30 am local time. The constant illumination conditions throughout the year that this will provide are advantageous for the ATSR. It also has benefits for the satellite design, in that, for example, the solar array only needs to rotate about one axis, normal to the plane of the orbit, in order to maintain its correct alignment with the Sun.

The orbital inclination required to achieve Sun-synchronism is a weak function of satellite altitude. For ERS-1's mean altitude of approximately 780 km, it needs to be about 98.5°, making it a so-called 'retrograde' orbit. In practice, ERS-1 will be able to change its altitude by a few kilometres, allowing the pattern of its orbital tracks over the Earth's surface to be made to repeat itself exactly after a certain number of days. The three orbital patterns that are planned will have repeat periods of 3 d, 35 d and 176 d. Each individual orbit in the pattern will last approximately 100 min.

The platform

The spacecraft platform provides the major services required for satellite and payload operation. These include attitude and orbit control, power supply, monitoring and control of payload status, telecommunication with

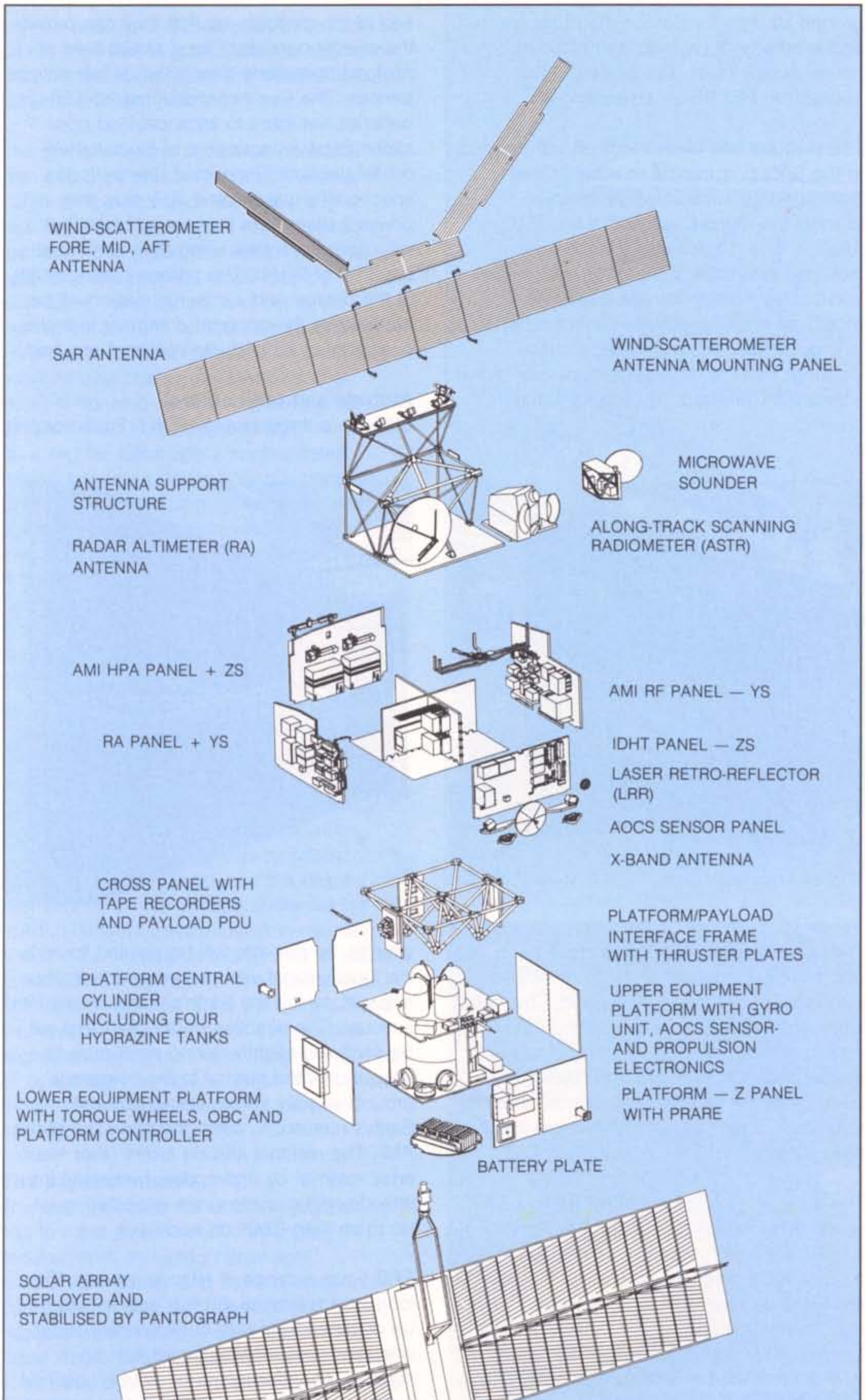


Figure 3. Exploded view of the ERS-1 satellite

ground stations for telecommand reception and telemetry of payload and platform housekeeping data. The platform also houses the PRARE as a passenger.

The platform has been modified with respect to the Spot programme in which it was developed as a multimission concept, to meet the unique needs of the ERS-1 mission. The major modifications have included extension of the solar-array power and battery energy-storage capability, modification of the attitude-control subsystem to provide yaw steering and geodetic pointing, and the development of new software for payload management and control.

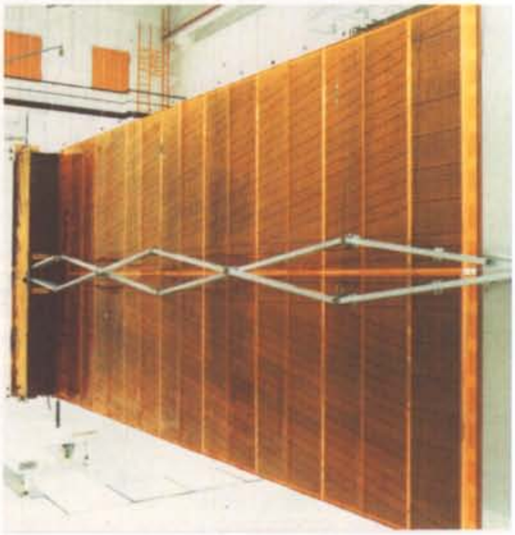


Figure 4a. Front side of the ERS-1 solar array (Photo. Aerospatiale)

Figure 4b. Rear of the array showing the pantograph deployment mechanism

The solar array's performance had to be appreciably increased to support ERS-1's power-hungry microwave payload. This has been achieved firstly by increasing the array's effective area (and corresponding power) by about 66%, to approximately 24 m^2, and secondly by using more efficient solar cells, which will produce about 12% more power.

The solar array consists of two 5.8 m x 2.4 m wings, manufactured from flexible reinforced Kapton, on which are mounted a total of 22 260 solar cells. The two wings will be deployed by means of a pantograph mechanism, and the whole array will rotate through 360° with respect to the satellite during each orbit in order to maintain its Sun pointing.

During the 66 min sunlit phase of each orbit, this array will provide electrical power to all of the onboard systems. It will also charge the spacecraft's batteries, located in a cylindrical compartment at the solar-array end of the platform, so that they can provide the energy necessary for a similar level of payload operations during the 34 min eclipse periods. The four nickel-cadmium (NiCd) batteries are sized to allow payload operations to be independent of the satellite's orbital position. Connected directly to the spacecraft's unregulated 30 V bus, they will power it during the fourteen eclipses that will occur each day, using their combined capacity of 96 Ah. The precise management of the charge and discharge cycles will be handled by the onboard computer, with the possibility of ground intervention if required.

Attitude and orbit control

ERS-1 is a three-axis-stabilised, Earth-pointing satellite. Its yaw axis will be pointed towards the local vertical with respect to a reference ellipsoid, taking the Earth's oblate shape into account. The direction of the pitch axis will be oscillated slightly during each orbit to keep it oriented normal to the composite ground velocity vector, taking account of the Earth's rotation, to assist the operation of the AMI. The residual attitude errors (after static-error removal by appropriate biasing of the attitude-control system) are expected to be no more than 0.06° on each axis.

ERS-1 has a range of attitude sensors. The long-term reference in pitch and roll will be obtained from one of two continuously operating, redundant infrared horizon sensors. The yaw reference will be obtained once each orbit from one of two redundant narrow-field Sun sensors aligned to point at the Sun as the satellite crosses the day/night terminator. The short-term and rate reference will be obtained from an inertial platform, with a pack of three gyroscopes, and again each has a redundant backup. Finally, there are two wide-field Sun-acquisition sensors for use in the initial stages of attitude acquisition, and in safe mode, when the satellite is Sun- rather than Earth-pointing.

The primary means of attitude control is provided by a set of momentum wheels (large flywheels), which are nominally at rest. They can be spun in either direction, exchanging angular momentum with the satellite in the process. It will also be possible, if there should turn out to be permanent torques on the satellite due, for instance, to radiation pressure on the solar array, to bias one or more wheels to a nominal nonzero speed. Angular momentum will also need to be dumped from the wheels on a regular basis and a sophisticated system has been devised for this purpose. ERS-1's onboard computer contains a simple model of the Earth's magnetic field, and is also able to control the current in a pair of orthogonal magnetic coils. These coils, called 'magneto-torquers', will generate torques by interacting with the Earth's geomagnetic field. Using a servo loop and the built-in field model, the spacecraft's onboard computer will continuously adjust the magneto-torquers to keep the wheel speed close to the nominal values.

ERS-1 has a number of monopropellant-type thrusters, aligned about the spacecraft's three primary axes, in which hydrazine dissociates exothermically as it is passed over a hot-platinum catalyst. They will be used in different combinations to maintain and modify the satellite's orbit and to adjust its attitude during non-nominal operations. This will normally be done by using pairs of thrusters to provide in-plane thrust when slightly changing the orbital height or speed, or by turning it in yaw to obtain out-of-plane thrust when slightly modifying the orbital inclination.

The payload module

The mechanical structure of the payload has to meet a number of challenging requirements, including rather tight mechanical-stability and thermal-isolation constraints. It was also foreseen that the payload would need to be disassembled many times, and this had to be considered in its basic design. There are two main parts to the payload module, the Payload Electronics Module (PEM) and the Antenna Support Structure (ASS), for which different design solutions were adopted.

The PEM is an aluminium face-sheet/honeycomb structure supported by nine

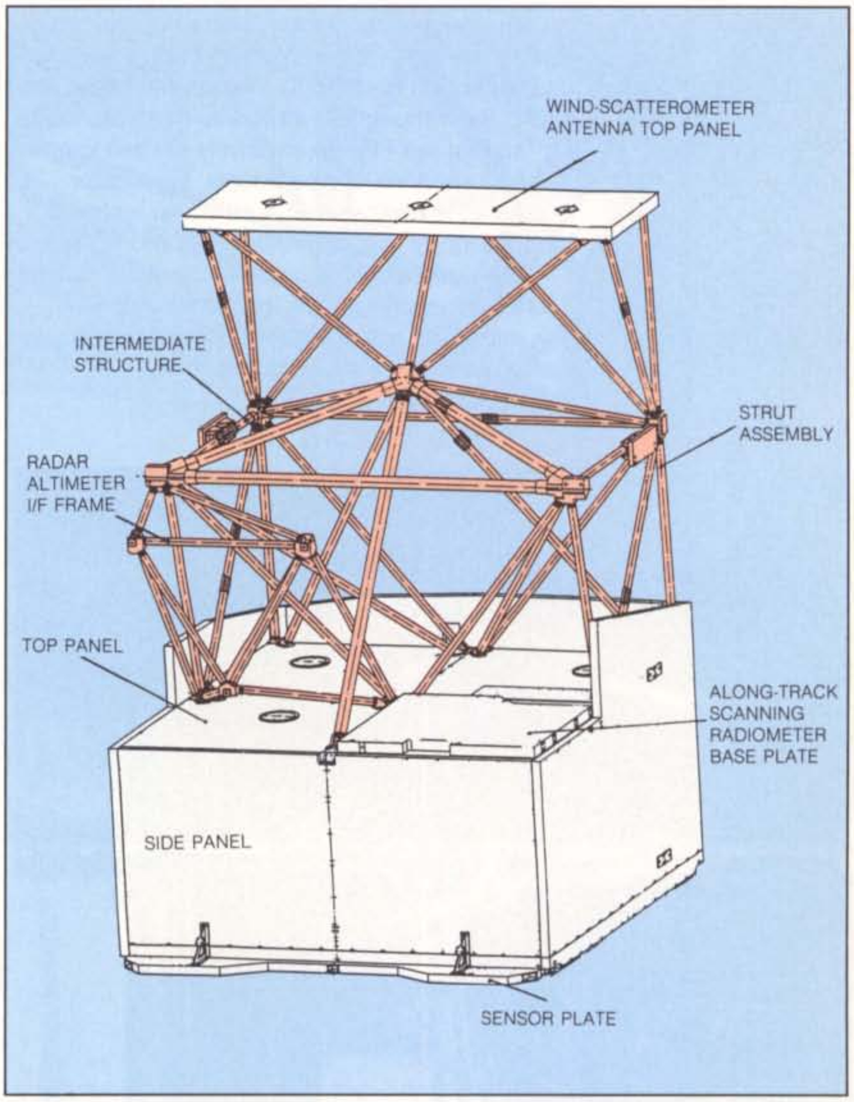


Figure 5a. The ERS-1 payload support structure, showing the box-like Payload Electronics Module (PEM) structure and the complex strut assembly of the Antenna Support Structure (ASS)

Figure 5b. Side view showing the Antenna Support Structure (ASS) prior to antenna integration

internal vertical titanium beams (titanium was selected for its low thermal conductivity and expansion coefficient). The central beam lies at the intersection of two internal cross-walls, so that the PEM is effectively divided into four separate compartments. Each outer panel is dedicated to a particular instrument, to simplify integration logistics, and is fixed to the vertical beams by close-tolerance bushes and titanium screws. This construction minimises settling effects due to vibration and ensures good structural-assembly repeatability.

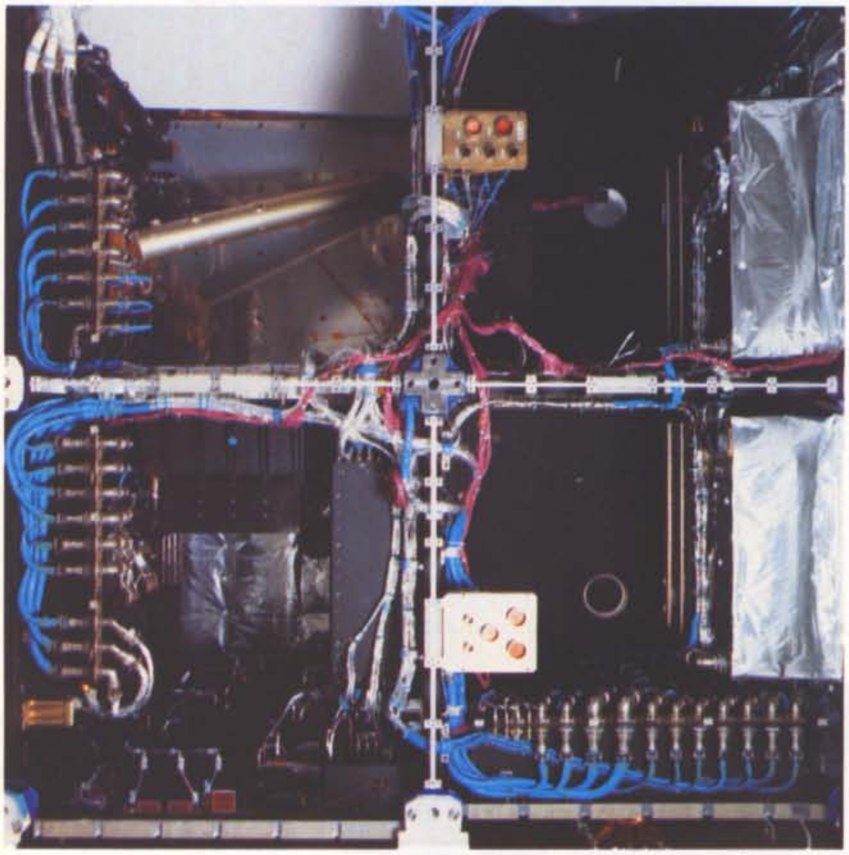


Figure 6. Interior of the Payload Electronics Module (PEM), showing its division into four compartments (the large pipe at top left was used to provide cooling air during ground testing)

The payload is separated from the platform by a non-load-bearing electromagnetic (EMC) shield. An aluminium-honeycomb panel closes the opposite end of the structure, stabilising the beams and providing the interface to the ASS at the beam locations. These provide a load path from the ASS to the platform.

It was clear that the integration programme would involve many separations between the PEM and the platform and so a system of tapered dowels and shims was developed to ensure repeatability of assembly. To facilitate the connection and disconnection of the instrument panels to and from the main harness, there are large connector brackets attached to the lower parts of the panels, with simple covers.

The ASS, requiring structural stiffness whilst minimising thermal distortion, has been manufactured primarily from high-modulus carbon-fibre-reinforced plastic (CFRP) tubes, with titanium being used for all the highly loaded structural elements such as nodes, strut end-fittings, and interface brackets.

The lower part of the assembly consists of five tripods, three of which provide support points for the SAR antenna and two intermediate support points for the upper assembly. These tripods are also connected to each adjacent node. The CFRP sandwich plate at the top, which carries the Scatterometer antennas, is supported by three further tripods attached to the intermediate points and the SAR central point. The Altimeter's antenna is attached at three node points by a triangulated strut system.

This intricate, highly stable assembly was challenging in terms of design, manufacture and integration. This is amply illustrated by the central titanium node, which interfaces to ten high-tolerance struts without inducing built-in stresses.

ERS-1's thermal-control system is basically a passive design, complemented by an active heater system. The thermal-control approach complements the modular overall design of the satellite, the payload, platform and battery compartment being thermally insulated from one other as far as practicable, allowing separate analysis and testing. The individual modules are also insulated from the external environment by multi-layer insulation blankets, except for the radiators. The latter are covered mainly with materials of low solar absorptance and high infrared emittance, which reject the internally dissipated energy. These radiator areas have been optimised for the extreme hot and cold operating conditions that will be encountered in nominal Earth-pointing attitude, and during the Sun-pointing safe mode in which the payload would be inert. A heat pipe is used to transfer heat from the ATSR to one of the radiators.

High heat fluxes in the payload electronics module are spread over larger areas by local skin thickening of honeycomb side panels or by constant-conductance heat pipes embedded in these panels.

Active heater systems, which are fully redundant during nominal operations and partially redundant in safe mode, provide autonomous thermal control to cope with periods of limited ground contact. The heater systems themselves will be controlled predominantly by onboard software in nominal modes and by thermostats in safe mode, or in failure cases when the onboard computer is not available. An anomaly-management system is triggered by failures in the heater systems and/or out-of-range equipment temperatures. It decides on the appropriate corrective action, which can be to switch to redundant heater branches and/or to switch off the payload.

All software parameters used for control or surveillance can be enabled, inhibited or updated by ground command, providing a high degree of flexibility for coping with a variety of unforeseen events or conditions.

On-board command and control

ERS-1 carries a significant number of software packages run by different processors spread throughout the platform and the payload. In the platform, the On-Board Computer (OBC) runs the so-called 'Centralised Flight Software', which is a small software package (44 kwords) incorporating all the basic functions needed to conduct the mission in an optimal fashion. In addition, each payload component (AMI, RA, ATSR and IDHT, described in more detail below) contains its own decentralised 'Instrument Control Unit' (ICU). These five computers are linked by the On-Board Data-Handling (OBDH) bus, and communicate with each other via a high-level packetised protocol. The PRARE, as a platform passenger, is not a user of the OBDH bus.

This set of interdependent computers fulfils a critical requirement. ERS-1 is an extremely complex satellite, with a great many modes, parameters and logical conditions to be set and respected throughout each orbit. It is required to have 24 h autonomy, and this could only be achieved by providing intelligent payload elements controlled by a capable central computer. A basic concept in this philosophy is the 'macrocommand', a coded instruction expanded and acted upon by the ICU. In this way the ICU relieves the OBC of many detailed tasks related to internal instrument configuration and operations.

It has been a primary requirement that all of the onboard processors be reprogrammable in flight, and many of the operating characteristics are controlled by tables of variable parameters. Commands are provided for manipulation of these tables to enable major changes in the operating characteristics to be easily achieved.

Figure 7. Part of the Antenna Support Structure (ASS), with antennas removed

The main functions of the OBC flight software are:

- to take the spacecraft from launch to operational configuration, by automatically sequencing such events as the firing of pyrotechnic cable-cutters and unfolding antennas;

- to manage the spacecraft in orbit, operating the platform subsystems and managing the overall payload. This includes overall power regulation, power distribution and thermal control of the platform subsystems, the PEM and the antennas. The Attitude and Orbit Control System (AOCS) will also be piloted by the OBC flight software;

- to monitor the spacecraft, in order to detect and neutralise any critical failure and thereby preserve the mission. In the case of serious failure, the flight software will autonomously reconfigure the faulty platform subsystem to the redundant hardware, or switch-down any payload instrument that shows anomalous behaviour. Should the reconfiguration fail, the spacecraft will be put into a so-called 'safe mode', in which the payload will be switched off, the solar array parked in the canonical position, and the satellite placed in a Sun-pointing attitude, awaiting further intervention from the ground;

- to allow mission pre-programming from the ground. The OBC flight software can memorise up to 16 orbits' worth of macrocommands for scheduled transmission to the various payload instruments, usually when the satellite is out of ground coverage. This mechanism can also be used to achieve temporary attitude (e.g. roll–tilt) effects;
- to report to the ground. Every second, the S-band telemetry link will transmit 256 bytes of data obtained by the OBC flight software, either on the real-time status of the platform and payload, or from dedicated memory areas where the significant event history has been recorded. The flight software can also support trouble-shooting via S-band telemetry, in that it is able to access and transmit the contents of all the computer memories onboard the satellite.

The ICUs run software packages whose functionality depends on the particular instrument that they serve, but there is some commonality. The common ICU tasks are:
- interfacing between the OBDH bus and the instrument hardware, receiving macrocommands and providing packetised telemetry, so-called 'ICU Formats';
- executing macrocommands, by putting the instrument into the appropriate mode to perform commands sent from the ground;
- monitoring sensors within the instruments in order to detect any critical failure, and if necessary switching the instrument to 'standby mode';
- reporting to the ground by the telemetry of 'ICU Formats' consisting of real-time data (sensor measurements, science-data samples, software variables, etc.) or data recorded to trace the history of the instrument (mode transitions, anomalies, etc.).

The other functions of the ICUs are related to scientific data conditioning/processing, and are therefore more specific to each instrument. Both the AMI and RA ICUs interface with scientific computers, known as the 'Scatterometer Electronics' and 'Signal-Processor Sub-Assembly' (SPSA), respectively. The AMI ICU manages a large memory buffer which accommodates the data originating from the sampling of the radar echo in SAR and Wave modes, while the IDHT ICU manages the tape recorders.

There are two types of time-management functions to be carried out onboard, namely the scheduling of events and the time-stamping of measurements. All timing will be referenced to a clock maintained by the OBC, providing time signals with 4 ms resolution and correlated with UTC (Universal Time Coordinated) by the Kiruna ground station. Events will be scheduled by associating a time with each macrocommand.

The time-stamping of measurements, known as 'datation', will also be performed by the ICUs, which will write the appropriate binary time code, transcribed from the ICU clock, into the secondary header of each source (data) packet.

Deployments

Several spacecraft units will be deployed during the first few orbits after ERS-1's separation from the launch vehicle, a period known as the 'Launch and Early-Orbit Phase', or 'LEOP'. They include the S-band telemetry antenna and solar-array arm and panel on the platform, and the SAR antenna, fore and aft Scatterometer antennas and ATSR antenna on the payload. In designing these deployments and their sequencing, a number of constraints had to be observed:
- Dynamic: The sequence of deployments is driven primarily by the results of a shock analysis, which showed that the SAR antenna could be deployed with the solar array already out, but the array drive mechanism had to be locked. This also applies to the Scatterometer antennas, but they could also be deployed after the drive-mechanism release if need be.
- Timing: The SAR and Scatterometer antennas must be deployed after the AOCS fine-pointing mode has been achieved, which is at most 2000 s after separation. The SAR deployment will take 18 min, and the Scatterometer antennas 8.5 min each.
- Visibility: The critical deployment phases must take place in visibility of one of the seven ground stations participating in the LEOP.
- Power: During the LEOP, the battery depth-of-discharge must not exceed 60%. Before solar-array deployment, the spacecraft has to rely entirely on its batteries, which would be 60% discharged after three orbits. Once the solar array is deployed, but not yet rotating, a short battery-charging cycle will be possible, thereby raising their operating limit to twenty orbits.
- Thermal: The payload elements must be maintained within their survival temperature limits, despite the need to use as

Figure 8. Nominal operations sequence for the Launch and Early-Orbit Phase (LEOP)

NO	EVENT DEFINITION
1	SEPARATION
2	S2 ANTENNA DEPLOYMENT
3	ATSR ANTENNA DEPLOYMENT
4	SOLAR GENERATOR ARM DEPLOYMENT
5	SOLAR GENERATOR PANEL DEPLOYMENT
6,7	SAR ANTENNA DEPLOYMENT
8,9	SCATTEROMETER ANTENNA DEPLOYMENT

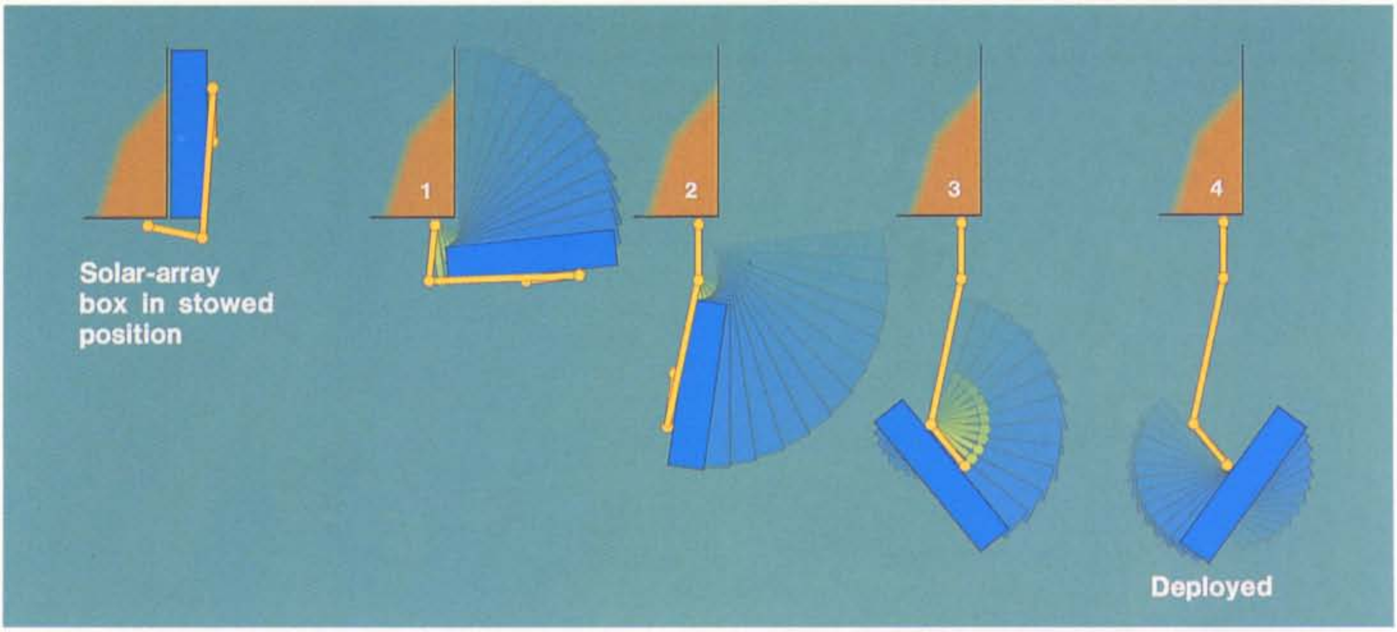


Figure 9a. Deployment sequence of the solar-array arm

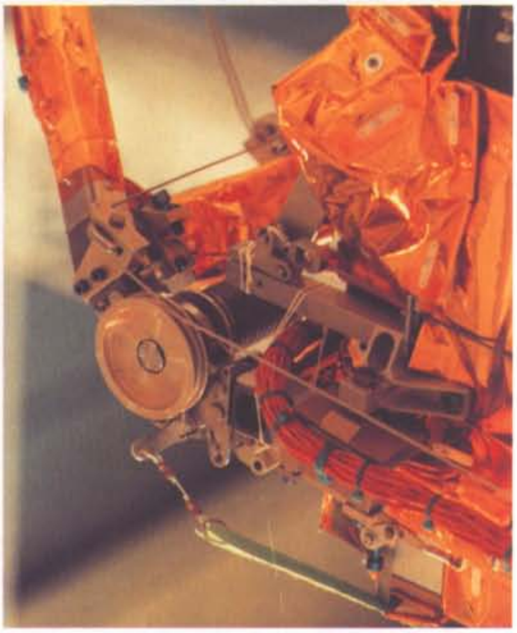


Figure 9b. One of the spring drives for solar-array arm deployment

little power as possible. During the first orbit, therefore, low-level heaters will be switched on during the day only. There are also potential thermal difficulties at some orbital positions if the active face of the deploying SAR antenna is exposed to the Sun.

All of the deployments will be controlled by the OBC, some via a pyrotechnic activation sequence triggered by the separation from the launcher, and some via time-tagged macrocommands. These macrocommands will be loaded into the OBC before launch and will thus be executed at times independent of the actual time of launch during the 4 min window. To maintain synchronism between these two types of deployment, the macrocommand queue can be updated very shortly after separation from the launcher, when ERS-1 will be visible from the Wallops ground station, on the USA's east coast. There will also be a possibility of updating from Fairbanks, in Alaska, or Perth, in Australia.

The S-band telemetry (S2) and ATSR microwave antennas will be released by pyros 5 s and 8 s after separation, respectively. Spring drives will then rotate them into their latched positions in just a few seconds. Next the solar-array arm's deployment will begin with a pyro-release firing, less than a minute after separation, the further deployment requiring no additional commands and being mechanically sequenced and driven by spring forces. Deployment of the solar-array panels themselves will not start until about 45 min after separation, when ERS-1 will be visible from Perth. The deployment will again be passive, with the two panels being pulled out of their container by spring-driven pantographs.

The SAR-antenna deployment will start 75 min after separation, in visibility of the Santiago de Chile ground station. The two antenna wings each have spring-driven and motor-driven phases and the whole sequence will be initiated by firing a pyro to release six lever clamps holding the folded antenna in launch configuration.

The Scatterometer antennas will be deployed immediately after the SAR antenna. They are stowed at the sides of the PEM for launch, and will also be released by pyro firing. Each antenna deployment involves a single motor-driven rotational movement.

Finally, after 2 1/4 h and 1 1/4 orbits, when

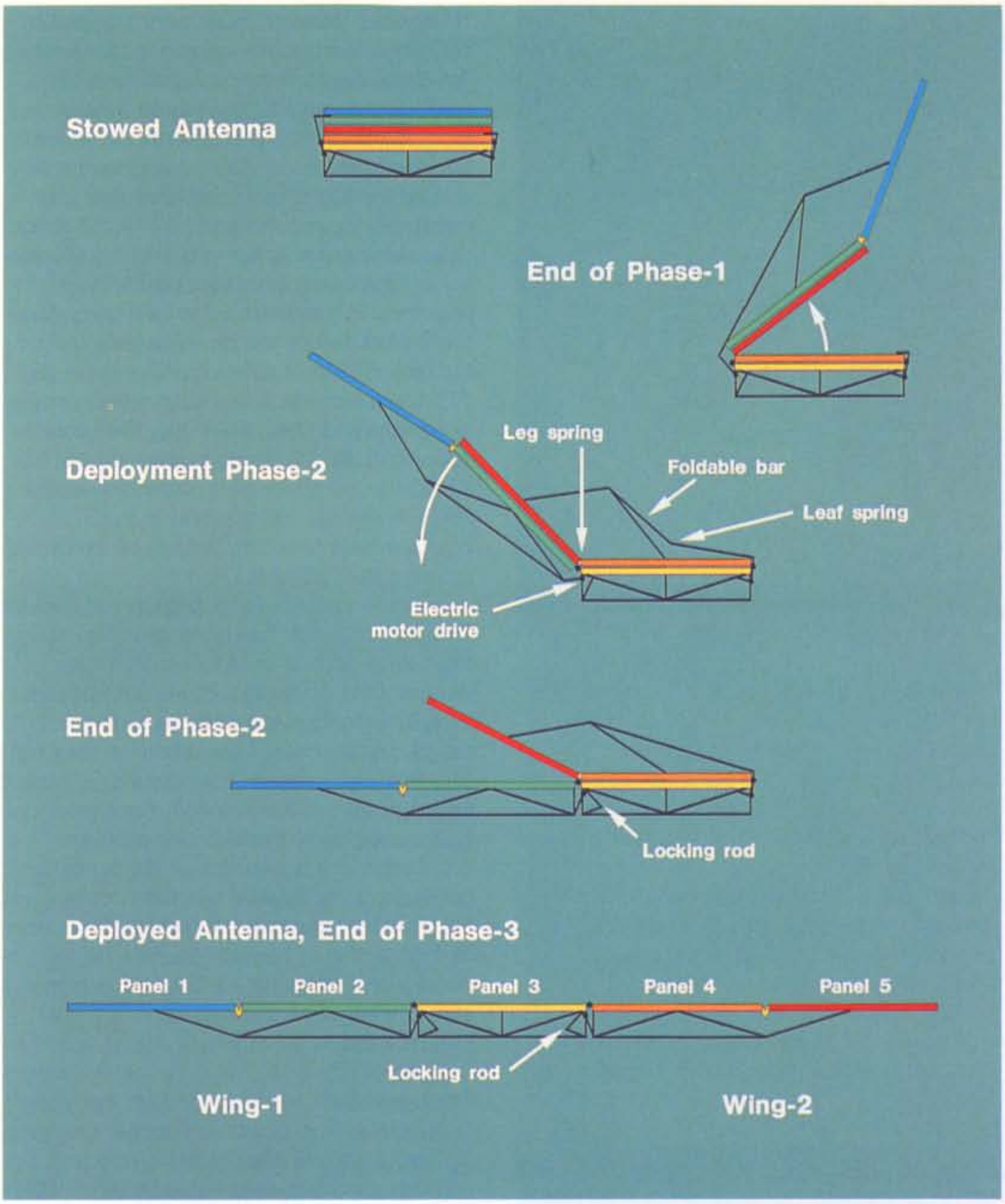
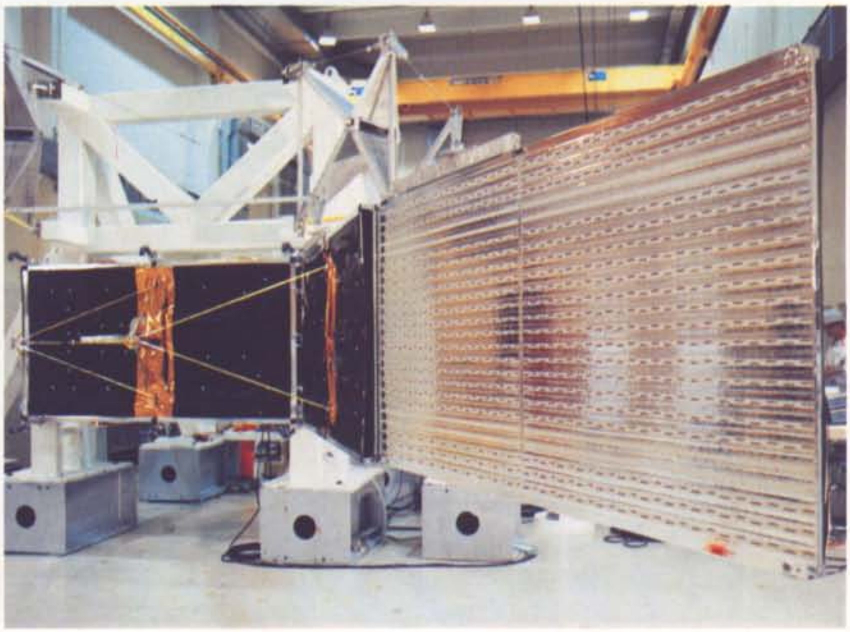


Figure 10a. Deployment sequence of the SAR antenna

Figure 10b. The SAR antenna photographed during deployment testing, showing the rear structure and support struts



the Sun is directly overhead, the solar array will be rotated into position.

Instrument data-handling and telemetry
ERS-1 has two telemetry systems. The platform's needs will be served by a classical-type Telemetry, Telecommand and Control (TTC) system operating at S-band. This low-rate (2 kbit/s) system will be used to transmit the ICU formats for housekeeping purposes. Because of the high bit rates involved, the science data cannot use this link and the payload therefore includes a so-called 'Instrument Data Handling and Transmission' (IDHT) system. This will allow real-time transmission of AMI Image-Mode data, providing a regional service to local ground stations and global recording and telemetry of the other sensors.

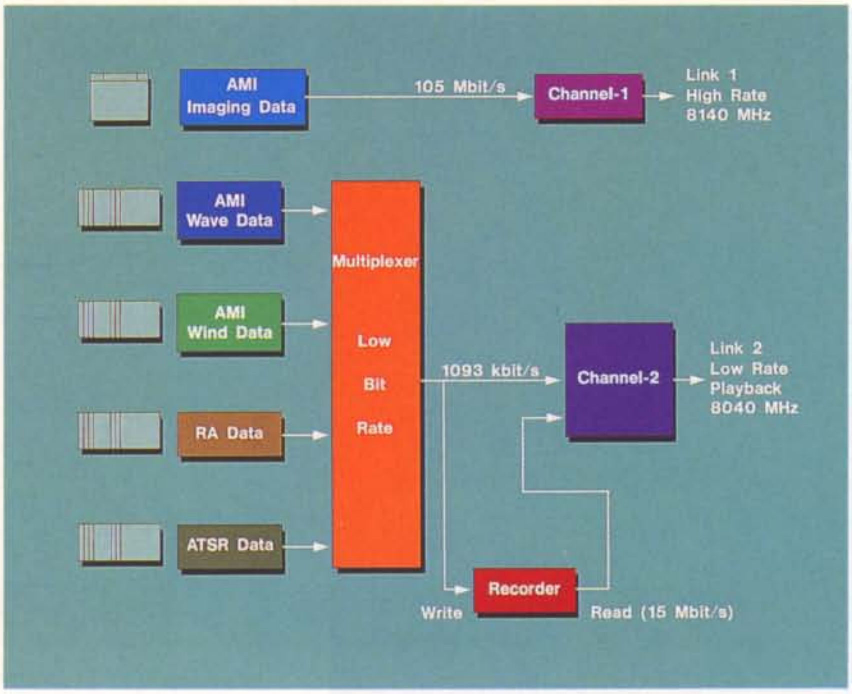


Figure 11. Block diagram of the X-band science data-transmission system (IDHT)

The instruments will generate data in the form of 'source packets', which constitute a logical division of telemetry data from the instrument point of view. However, these will not be the fundamental unit as far as transmission to the ground is concerned, for which a further division into 'transport frames' will be made. The latter are smaller than source packets and, in addition to pieces of source packets, will contain synchronisation and transmission error-control information. The source-packet structure will then be reassembled from transport frames at the ground stations.

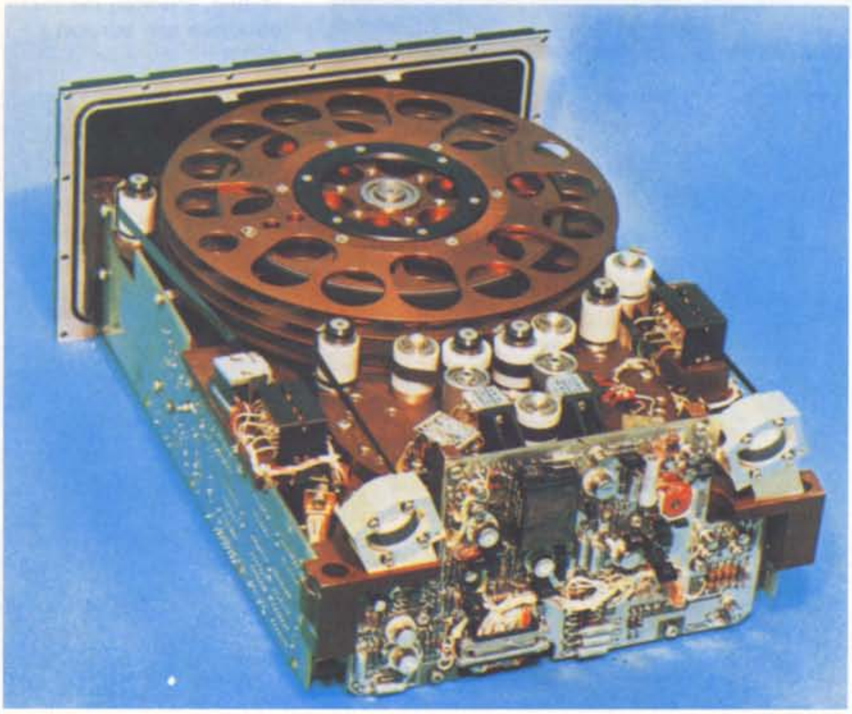


Figure 12. One of the two 6.5 Gbit tape recorders, which holds 3000 ft of 1/4-inch tape

Three data streams will be transmitted from the IDHT. The first will contain the high-rate data from the AMI Image Mode, with auxiliary data and a copy of the S-band telemetry data, at a total rate of 105 Mbit/s. This channel has an X-band link dedicated to it. The other sensors will have their data combined, again with a copy of the S-band data and satellite ephemeris information, into a (comparatively) low-rate data channel, operating at 1.1 Mbit/s, which will be continuously recorded by the onboard tape recorder. This recorder will be replayed at 13.6 times recording speed (in reverse order to save rewind time) when over the ground stations, to form a second data channel, at 15 Mbit/s. It will share the second X-band link with the live transmission of the combined low-rate data, which will constitute the third data stream.

The tape recorder has been designed to store a full orbit of continuous 1.1 Mbit/s low-rate data on 3000 ft of 1/4-inch magnetic tape, leading to a total data recording capacity of 6.5 Gbit. When performing a data dump to high-latitude ground stations, such as the primary Kiruna station, the spacecraft's solar array might cause a brief occultation of the link, due to the system geometry. On passes when this occurs, the onboard command scheduling will include a stop in playback before the occultation, a slight rewinding of the tape, and a reactivation of playback mode after the occultation.

The modulation scheme used for the high-rate channel is quadrature phase-shift keying, called 'QPSK', which allows four distinct states per clock cycle and makes it possible to transport two bits of information per cycle. This will reduce the radio-frequency bandwidth required for transmission by a factor of two compared with a simpler modulation scheme. The low-rate link will use unbalanced quadrature phase-shift keying, or 'UQPSK', to modulate the 15 Mbit/s recorder dump and the convolutionally encoded real-time data onto a single link. If there are no recorder dump data, bi-phase-shift keying (BPSK) will be used for the real-time data.

Immediately before and after recorder playback, the link will be automatically switched between BPSK and UQPSK operation, with minimum impact on the real-time data stream. The ERS-1 ground demodulators have been designed to accommodate this mode switching automatically.

The fact that the X-band transmission was required to have a minimum power-level fluctuation during the satellite pass led to the design of a shaped-beam antenna able to compensate for losses at low satellite elevation angles, when the distance to the ground station is long, and the attenuation due to the atmosphere's water content is high. To achieve this, the antenna reflector is shaped so that its radiation pattern compensates for the inverse-square-law variation in received power with distance as the satellite passes across the sky at the ground station. The polarisation of the radiated energy is rotated to compensate for Faraday rotation due to the Earth's ionosphere.

The IDHT is physically located on the Earth-facing panel of the PEM, with the tape recorders mounted inside on one of the cross-walls.

The scientific instruments

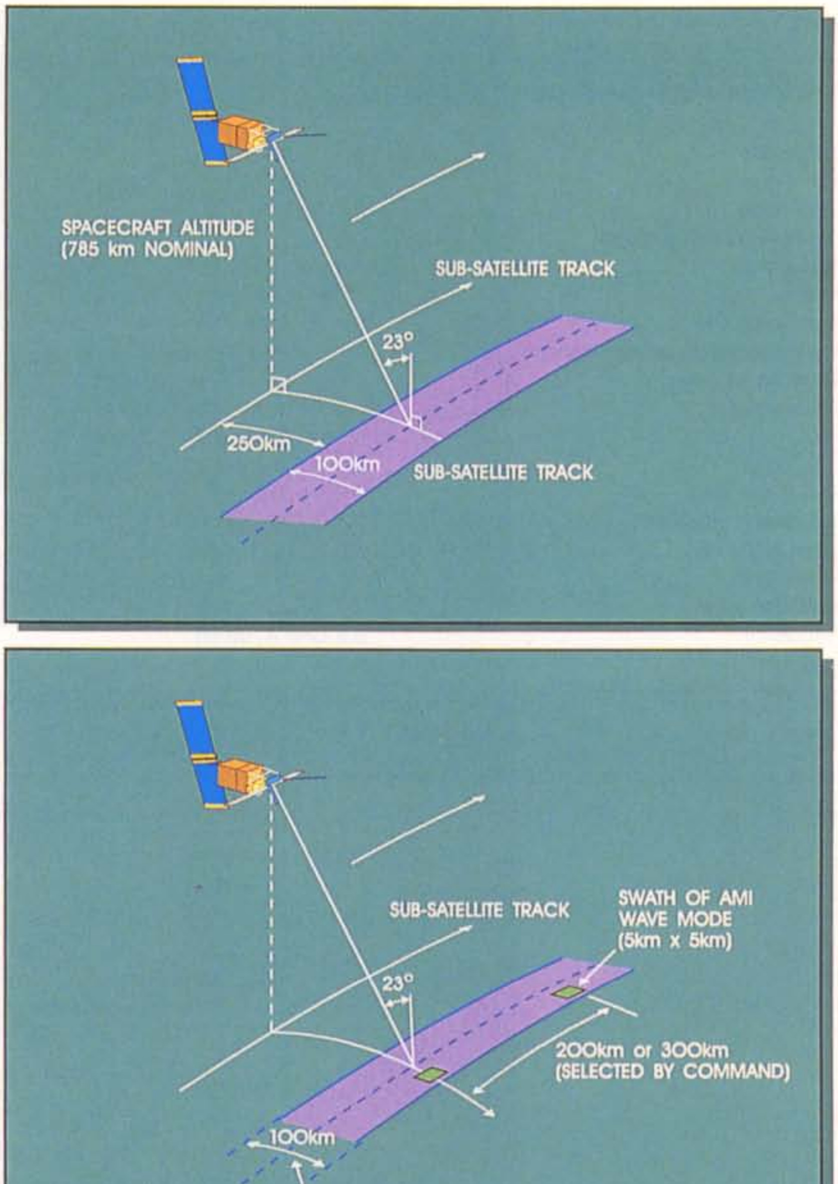
The Active Microwave Instrument (AMI)

Two separate radars are incorporated within the AMI, a Synthetic-Aperture Radar (SAR) for 'Image and Wave Mode' operation, and a scatterometer for 'Wind Mode' operation. The operational requirements are such that each mode needs to be able to operate independently, but the Wind and Wave Modes are also capable of interleaved operation, in so-called 'Wind/Wave Mode'.

In Image Mode, the SAR will obtain strips of high-resolution imagery 100 km in width to the right of the satellite track. The 10 m long antenna, aligned parallel to the flight track, will direct a narrow radar beam onto the Earth's surface over the swath. Imagery will be built up from the time delay and strength of the return signals, which depend primarily on the roughness and dielectric properties of the surface and its range from the satellite.

The SAR's high resolution in the range direction is achieved by phase coding the transmit pulse with a linear chirp, and compressing the echo by matched filtering. Range resolution is obtained from the travel time. Azimuth resolution is achieved by recording the phase as well as the amplitude of the echoes along the flight path. The set of echoes over a flight path of about 800 m will be processed (on the ground) as a single entity, giving an azimuth resolution equivalent to a real aperture 800 m in length. This is the 'synthetic aperture' of the radar.

Operation in Image Mode excludes the other AMI operating modes, and power



Figures 13a–c. SAR geometry for Image, Wave and Wind Modes

Table1

AMI Image-Mode (SAR) Characteristics

Bandwidth	15.55 ± 0.1 MHz
PRF range	1640—1720 Hz in 2 Hz steps
Long pulse	37.12 ± 0.06 μs
Compressed pulse length	64 ns
Peak power	4.8 kW
Antenna size	10 m × 1 m
Polarisation	Linear-Vertical (LV)
Analogue/digital complex sampling	18.96 million samples/s
Sampling window	296 μs (99 km telemetred swath)
Quantisation	5I, 5Q if range compression on ground (nominal 6I, 6Q if range compression on board)
Spatial resolution	30 m × 30 m
Radiometric resolution	2.5 dB at $\sigma_0 = -18$ dB
Swath stand-off	250 km to the side of the orbital track
Swath width	100 km
Incidence angle	23° at mid-swath
Frequency	5.3 GHz (C-band)
Data rate	<105 Mbit/s

AMI Wave-Mode Characteristics

Wave direction	0—180° (180° ambiguity)
Wave length	100—1000 m
Accuracy	direction ± 20° length ± 25%
Spatial sampling	5 km × 5 km every 200—300 km, programmable anywhere within the SAR swath
Incidence angle	23°
Frequency	5.3 GHz (C-band)
Polarisation	Linear-Vertical (LV)

AMI Wind-Mode Characteristics

Wind direction range	0—360°
Accuracy	± 20°
Wind speed range	4—24 m/s
Accuracy	2 m/s or 10%
Spatial resolution	50 km
Grid spacing	25 km
Swath stand-off	200 km to side of orbital track
Swath width	500 km
Frequency	5.3 GHz ± 200 kHz
Polarisation	Linear-Vertical
Peak power	4.8 kW

	Mid	Fore	Aft
Incidence angle range (approx.)	16—42°	22—50°	22—50°
Antenna length	2.3 m	3.6 m	3.6 m
Dynamic range	—	42 dB	—
Pulse length	70 μs	130 μs	130 μs
No. of pulses per 50 km	256	256	256
Radiometric resolution	8.5%	9.7%	9.7%
Detection bandwidth	25 kHz	25 kHz	25 kHz
Sampling scheme		Complex I/Q 8 bits each	
Return-echo window duration	2.46 ms	3.93 ms	3.93 ms

considerations limit operating time to a maximum of 10 min per orbit. The data rate of 100 Mbit/s is far too high to allow onboard storage, so images will only be acquired within the reception zone of a suitably equipped ground station.

Wave-Mode operation of the SAR will provide 5 km x 5 km images at intervals of 200 km along track, which can then be interpreted to provide wave spectra. The relatively low data rate allows onboard data storage, and thus a global sampling of wave spectra will be obtained.

The Wind Mode will use three antennas to generate radar beams looking 45° forward, sideways, and 45° backwards with respect to the satellite's flight direction. These beams will continuously illuminate a 500 km-wide swath as the satellite moves along its orbit, and each will provide measurements of radar backscatter from the sea surface on a 25 km grid. The result will be three independent backscatter measurements for each grid point, obtained using the three different viewing directions and separated by a short time delay. As the backscatter depends on the wind speed and direction at the ocean surface, it will be possible to calculate the surface wind speed and direction by using these 'triplets' within a mathematical model.

The AMI electronics cover two full 2 m x 1 m side panels of the PEM. In addition, the calibration unit is mounted on one of the cross-walls inside the PEM, the switch matrix and its controller are on the top panel, and the four antennas, one of the most characteristic elements of the ERS-1 satellite, on the ASS.

The largest of the AMI antennas is the SAR antenna, with a radiating area of 10 m x 1 m. It is a slotted waveguide array made of metallised CFRP. The antenna itself is subdivided into ten electrical and five mechanical panels. Its planarity across its 10 m length will be better than ±1.5 mm when in orbit.

The three Scatterometer antennas are made of aluminium alloy. Like the SAR antenna, they are slotted-waveguide arrays, and each is subdivided electrically into two panels. The central unit, measuring 2.3 m x 0.34 m, contains eight waveguides, while the fore and aft arrays, measuring 3.6 m x 0.25 m, each contain six waveguides.

All of the antennas are designed for vertical polarisation.

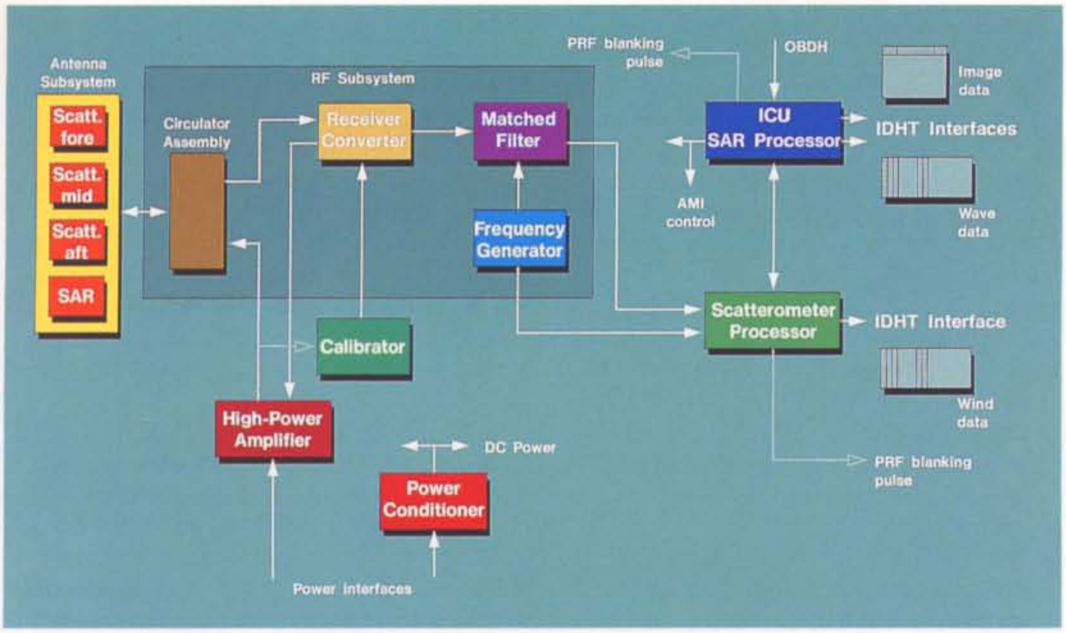


Figure 14. Functional block diagram of the Active Microwave Instrument (AMI)

The AMI Electronics

The RF-subsystem units, covering half of a panel in the spacecraft, contain all the electronics needed to generate the transmit pulses and to amplify and filter the received signals.

The IF Radar contains a transmit and a receive section. The transmit section, in Image Mode, generates a linearly chirped pulse of 15.8 MHz bandwidth and 37.2 μs length. This pulse is generated by gating the 123 MHz output of the Frequency Generator into a short pulse and applying it to a dispersive delay line. At the output of the delay line, the pulse is amplified and cut to the correct length of 37.2 μs. In Wind Mode, the transmit pulse is generated by the Scatterometer Electronics, and the IF Radar acts only as an amplifier.

The Up- and Down-Converters are contained in a single unit. The upconverter converts the output signals of the IF Radar to 5.3 GHz and amplifies them to a level of about 250 mW, required for the input of the High-Power Amplifier (HPA).

The two redundant units of the HPA occupy one complete panel; each consists of a large power conditioner unit (EPC), a travelling-wave-tube amplifier, an output isolator, and an output filter. The latter two elements are located on the outside of the panel. The HPA amplifies the input signals to output levels of about 5000 W.

The output signal from the HPA arrives at the Circulator Assembly, or switch matrix, on the top panel of the PEM. This matrix of ferrite circulators switches the signal coming from the HPA to any of the four antennas and on the return path directs the receive signal from the chosen antenna into the receive chain.

The waveguides from the switch matrix to the four antennas are lightweight CFRP units with a rectangular cross section of 4 cm x 2 cm, internally metallised. They are rigidly connected to the SAR antenna and the mid scatterometer antenna, while the connection to the deployable fore and aft antennas is by choke flanges, without a fixed connection.

The receive echo arrives at the receive part of the IF Radar, via the circulator assembly, the receiver shutter – which safeguards the sensitive low-noise receiver against transmission pulse leakage – and the down-converter. In nominal operation, the IF Radar works for both SAR and Scatterometer mode as an amplifier and filter stage. In SAR mode, however, onboard range compression can be commanded from the ground, which then switches the signal through an inverse dispersive delay line, compressing the echo pulses by a factor of about 590. Depending on the mode of operation, the output is fed to the SAR Processor or the Scatterometer Electronics.

The SAR Processor filters the signal and down-converts it to baseband. After analogue-to-digital conversion, auxiliary data are added, then the data are buffered and delivered to the IDHT for transmission to the ground. The SAR Processor additionally functions as the AMI's ICU. The Scatterometer Electronics also has two tasks. It filters and digitises the Wind Mode echoes and transfers them to the IDHT for transmission to ground. It also controls the AMI during Wind-Mode operation.

The echoes from the fore and aft antennas have rather a high Doppler shift, which varies from approximately 70 kHz to 150 kHz across the swath. This Doppler spread would prevent narrow-band filtering to reduce noise. The Scatterometer Electronics therefore, while the echoes are coming in, changes the local oscillator frequency according to the expected instantaneous Doppler shifts. This acts as Doppler compensation. This is also applied to the mid echoes, but here the required compensation is small.

Apart from providing a sample of the transmitted signal into the receiver for calibration purposes, the other task of the Calibration Unit is to delay a SAR transmit pulse and feed it back to the IF branch of the receiver. This signal is used as a replica of the chirped transmit pulse for on-ground range compression in the ground processor, as an alternative to the onboard range compression mentioned earlier. On-ground range compression is, in fact, the nominal operating mode.

The Radar Altimeter (RA)

The Radar Altimeter is a nadir-pointing pulse radar designed to make precise measurements of the echoes from ocean and ice surfaces. It has two measurement modes, optimised for measurements over ocean and ice, respectively. In the so-called 'Ocean Mode', the echo characteristics of interest are:

- Time delay with respect to the transmitted pulse. This provides the measure of altitude.
- Slope of the echo leading edge, which is related to the height distribution of reflecting facets and thus to the ocean wave height.
- The power level of the echoed signal, which depends on small-scale surface roughness and thus on wind speed.

The radar echoes over ice sheets, particularly the rough surfaces at the continental margins, show much greater variances in shape than oceanic echoes. In order to maximise the data return in these areas, the 'Ice Mode' includes three features designed to improve its 'robustness'. The range window width is increased by a factor of 4, which also degrades precision by a similar amount. A simplified height tracking loop greatly improves the ability to keep the echo in the range window, though it cannot distinguish the leading edge of the signal. Finally, the tracker is more agile.

In the Ice Mode, as in the Ocean Mode, the telemetered data stream contains the effective height of the range window, and the digitised echo waveform within this window. These allow ground-processing to retrieve topographic information. The returned power level is also telemetered.

The effective pulse width is 3 ns, which is equivalent to about 45 cm in two-way range. The radar is said to be 'pulse-width-limited' because not all of the target is illuminated simultaneously by the short pulse, and the received power is controlled by the illumination.

Over ocean surfaces, the distribution of the heights of reflecting facets is gaussian or near-gaussian, and the echo waveform has a characteristic shape that can be described analytically. It is a function of the standard deviation of the distribution, which is closely related to the ocean wave height.

Different echo waveforms occur over ice surfaces. Over sea ice, there is generally a strong specular component, while the rough topography of continental ice sheets at the margins leads to complex return waveforms. In central ice sheet areas, the height distribution becomes more regular and echoes similar to ocean returns are observed.

Real echoes are composed of the sums of signals from many point scatterers, each with individual phase and amplitude. To reduce uncertainties in the determination of pulse characteristics, the Radar Altimeter averages pulses together to reduce this statistical effect.

The constraints of available peak transmitter power and required pulse width determined that a pulse-compression technique be used to spread the required energy over time, allowing reduced peak power (see panel overleaf).

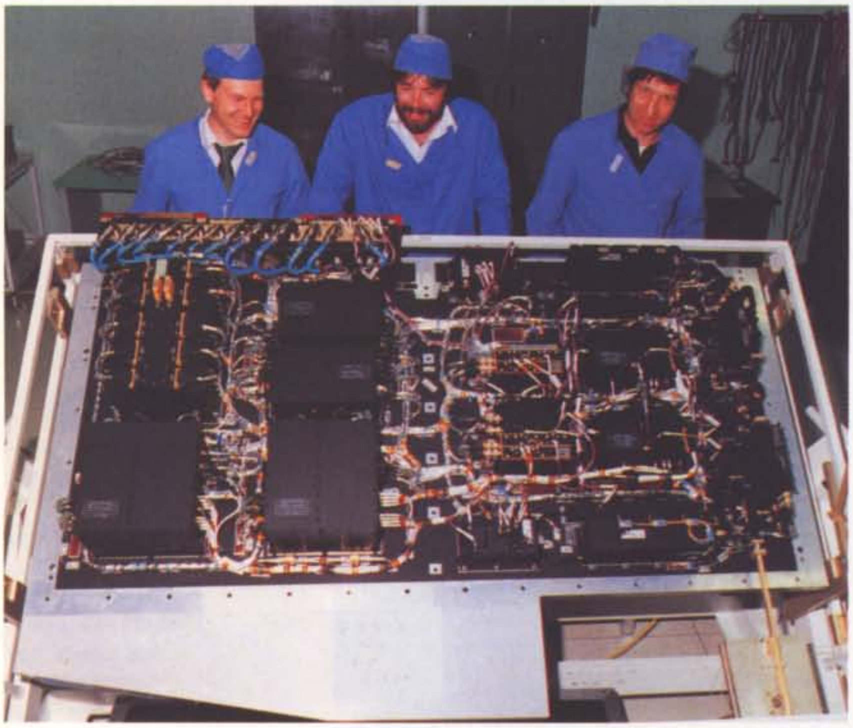


Figure 15. The Radar Altimeter panel during instrument-level testing

Table 2. Radar Altimeter (RA) characteristics

Frequency	13.8 GHz
Pulse length	20 μs
Pulse rept. frequency	1020 Hz
Chirp bandwidth	330 MHz (sea)
	82.5 MHz (ice)
Transmit power	55 W peak
Antenna diameter	1.2 m
Height noise	3 cm at 8 m wave height
Mass	96 kg
DC power	130 W

The RA Electronics

The Chirp Generator – which is based on Surface Acoustic Wave (SAW) devices – is triggered at a fixed rate of almost 1020 Hz. The chirps pass through a 20 µs SAW delay line used to separate transmit and receive chirps during calibration. After up-conversion to the transmit frequency, they are amplified by the High-Power Amplifier, a 50 W Travelling Wave Tube (TWT). The pulses pass via the Front-End Electronics (FEE), which is an arrangement of circulators and the calibration coupler, to the antenna, a front-fed paraboloid.

Returning echoes arrive, via the antenna, FEE, and Low-Noise Amplifier (LNA), at the Microwave Receiver. When the echo is expected to return, the chirp generator is re-triggered and a second chirp generated. During the up-conversion and multiplication process, a slight frequency offset is introduced, and this becomes the first Intermediate Frequency (IF). This local oscillator chirp is mixed with the received echo in the 'deramping mixer' in the microwave receiver. A series of tones is thus generated, centred on the first IF.

The microwave receiver is a dual-conversion system, and after conversion to baseband the in-phase (I) and quadrature (Q) signals are passed to the Signal Processor Sub-Assembly, or SPSA. The next important stage, inside the SPSA, is the spectrum analyser where the spectrum of the tones is found. This spectrum exactly represents the time structure of the echo waveform in 64 points at an equivalent spacing of 3.03 ns. The average power spectrum over fifty successive pulses is formed, and finally this information is used by the parameter estimator. This step is essential in order to provide the estimate of when the next echo is expected to return, for the chirp re-triggering. As an indication of the need for this estimate, the full bandwidth of the spectrum analyser is equivalent to a height window of about 30 m in the ocean mode. The maximum height rate is about 30 m/s; if the height estimate were not continually updated, the signal could be completely lost in about 1 s.

Sometimes the echo can be lost though, for example as a result of passing over some topographic surface such as mountains. In this case the acquisition mode is automatically entered. This is a sophisticated multi-stage scheme, partially relying on dedicated hardware processing, which virtually guarantees getting any trackable surface into the tracking mode range window in just over 1 s.

The parameter estimator is a microcomputer, within the SPSA. It is used in acquisition and tracking modes. In ocean and ice tracking, it is running software tracking loops which follow the signal characteristics. In the ocean mode, there are three main loops to track echo time-delay (height), leading-edge slope and echo power. The error signals used as input to these loops are derived from adaptive discriminators.

The time delay and echo power loop are also used in the Ice Mode, though the error signals are derived from different discriminators. Because of the reduced chirp bandwidth, the spectral points are spaced at 12.12 ns intervals, leading to a range window of about 115 m.

Internal open-loop calibration is performed every few minutes. This procedure is very fast (about 100 ms). The transmitted signal is coupled into the receiver through an attenuator, and analysis of the received signal is performed on the ground to determine the delay around the system. The major item omitted by this scheme is the Ultra-Stable Oscillator (USO), which provides the echo timing. This calibration is obtained by broadcasting the USO frequency via the IDHT to enable measurements to be made on the ground.

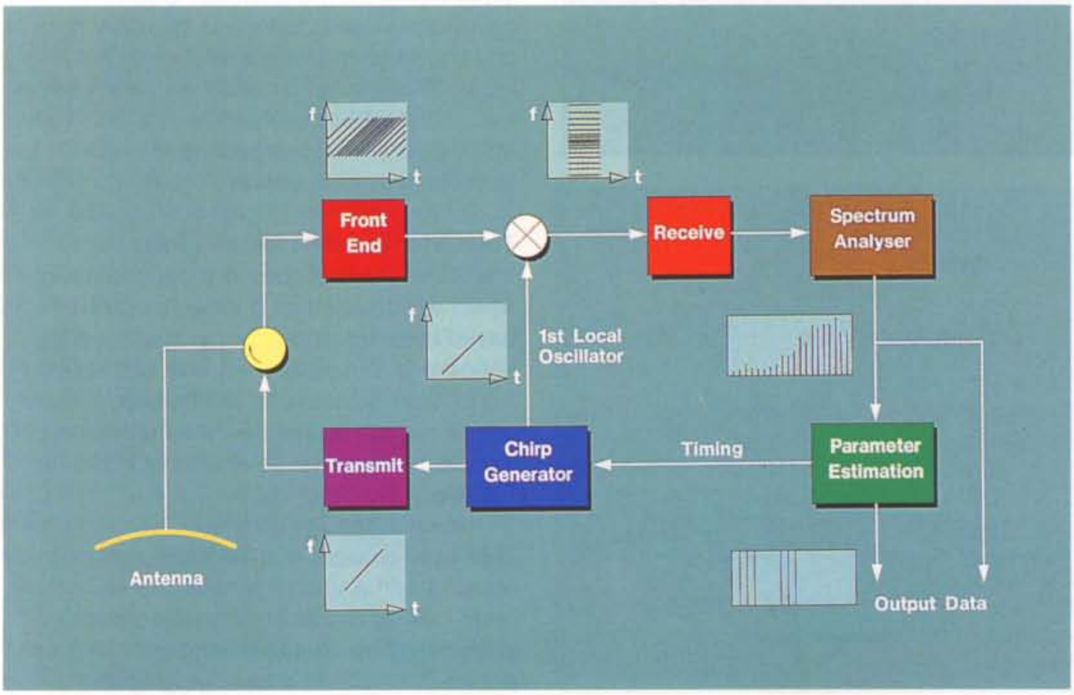


Figure 16. Schematic of the Radar Altimeter's operating principle. The signal at various points is shown as a frequency/time plot

The Along-Track Scanning Radiometer and Microwave Sounder (ATSR-M)

The ATSR-M consists of two instruments, an Infrared Radiometer (IRR) and a Microwave Radiometer (MWR).

The primary objective of the IRR is to measure the global Sea-Surface Temperature (SST) for climate-research purposes. Its absolute accuracy will be better than 0.5 K when averaged over areas of 50 km x 50 km, assuming that 20% of pixels within the area are cloud-free. For the cloud-free pixels, of 1 km x 1 km, the relative accuracy will be about 0.1 K.

To achieve these objectives, the IRR was designed as an imaging radiometer with four co-registered channels with wavelengths of 1.6, 3.7, 11 and 12 μm, defined by beam splitters and multilayer interference filters. The Instantaneous Field of View (IFOV) at the nadir on the Earth's surface is a 1 km x 1 km square, which is imaged onto the detectors via a f/2.3 paraboloidal mirror. These detectors, fixed onto a Focal-Plane Assembly, are cooled to 80 K by a Stirling-cycle cooler in order to reduce their background noise to an acceptable level.

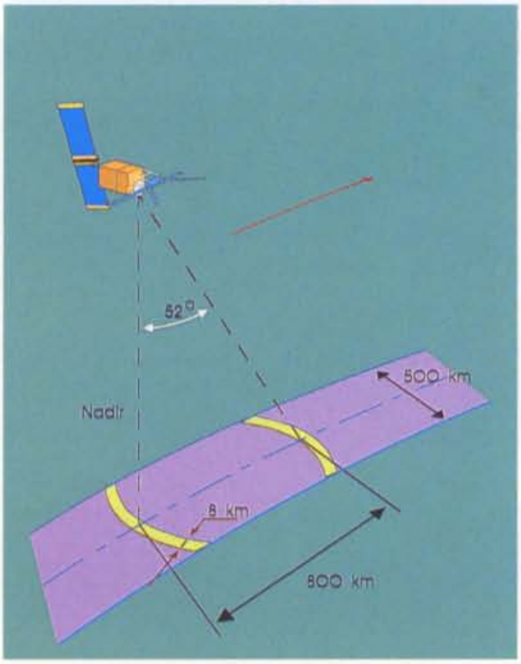


Figure 17. Measurement principle of the Along-Track Scanning Radiometer (ATSR)

Table 3. Along-Track Scanning Radiometer (ATSR) Characteristics

IR Radiometer	
Swath width	500 km
Spectral channels	1.6, 3.7, 11 and 12 μm
Spatial resolution	1 km × 1 km (at nadir)
Radiometric resolution	<0.1 K
Predicted accuracy	0.5 K over a 50×50 km^2 with 80% cloud cover
Conical scanning	
Microwave Sounder	
Channels	23.8 & 36.5 GHz
Instantaneous field of view	20 km
Near-nadir pointing	

The IFOV will be scanned over the Earth's surface by a rotating plane mirror in such a way that it gives two Earth views, namely a 0° or nadir, and a 57° or forward, view. The rotation period will be 150 ms and the scan will be subdivided into 2000 pixels of 75 μs each. In order to calibrate the optical and electrical signal chain, two black bodies (one hot and one cold) within the IRR will be scanned during the rotation. After onboard data compression, a packet of 960 pixels – 555 nadir-view and 371 forward-view pixels, and 16 hot and 16 cold black-body pixels – will be transmitted to ground, together with housekeeping and datation. Extensive on-ground data processing will then permit retrieval of the IRR final product, namely the Sea-Surface Temperature (SST).

The main objective of the ATSR Microwave Sounder will be to measure the atmospheric integrated water content (vapour and liquid) in order to compute the most problematic part of the tropospheric path delay in the Radar Altimeter's signals.

The MWR has two channels, operating at 23.8 and 36.5 GHz, each with a bandwidth of 400 MHz. The instrument will be nadir-viewing, using an offset antenna that will deploy shortly after the spacecraft's separation from the launcher. Onboard calibration will be performed by a sky horn pointing to cold space, and internal hot loads. The acquisition cycle will be synchronised to the ATSR scan occurrence and the MWR data will be merged into the IRR packets described above.

The Laser Retro-Reflector (LRR)

The Laser Retroreflector is a passive device which will be used as a target by ground-based laser ranging stations. The operating principle is to measure the time of a round trip of laser pulses reflected from an array of corner cubes mounted on the Earth-facing side of the spacecraft's Payload Electronics Module.

This array consists of a hemispherical housing with an arrangement of one nadir-looking corner cube in the centre, surrounded by an angled ring of eight corner cubes. This will allow laser ranging for satellite passes in the range of 0–360° azimuth and 30 to 90° elevation at the ground.

The Precise Range and Range-rate Equipment (PRARE)

The PRARE is a satellite tracking system which will perform two-way microwave range and range-rate measurements to ground-based transponder stations with high precision. Signal-propagation effects will be compensated by two-frequency measurements, for ionospheric refraction, and ground-station collection of meteorological data for tropospheric refraction.

Two signals will be transmitted to ground, one at S-band (2.2 GHz) and one at X-band (8.5 GHz) frequencies (both signals modulated with the pseudo-random noise code). The ground station will receive the two simultaneously emitted signals with a slight time difference and will determine the time delay. This will provide a measure of the ionospheric refraction taking place in the atmosphere.

The received signals will be demodulated and a coherent regenerated copy of the X-band (7.2 GHz) sequence will be retransmitted to the satellite, where the two-way travel time and the two-way Doppler measurements will be carried out, so that the range and range-rate can be determined. Two-way measurements will be possible for up to four stations simultaneously via so-called 'code multiplexing'.

Both the space-to-ground and ground-to-space links will have additional capacity for data transmission at low bit rates. Control codes and broadcast ephemerides for ground-station operation will be transmitted in the downlink, and calibration data, ionospheric-measurement results and meteorological ground data will be included in the uplink. All measurement data will be stored inside the PRARE itself, in 64 kbyte of RAM, and dumped during the next available ground-station pass.

Development and testing

The main development phase of the ERS-1 Programme (Phase-C/D) was started in December 1984. An initial assembly, integration and test programme was devised relying on a classical sequence of three full-size spacecraft models:

- Structural Model
- Engineering Model, using the Spot engineering-model platform, and
- Flight Model.

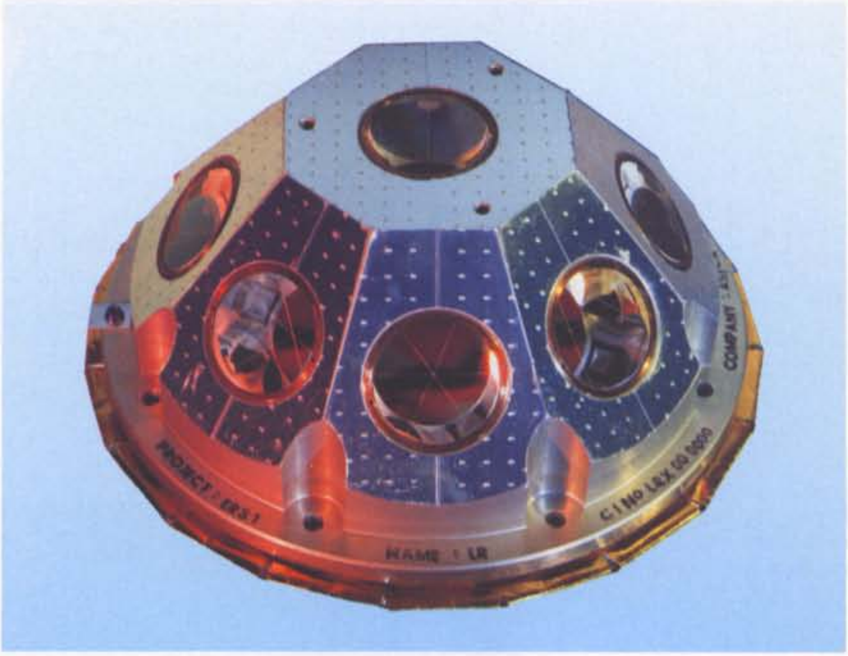


Figure 18. The Laser Retro-Reflector (LRR). Each corner cube is individually made, to compensate for satellite motion in reflecting incident laser energy back exactly along its incoming path

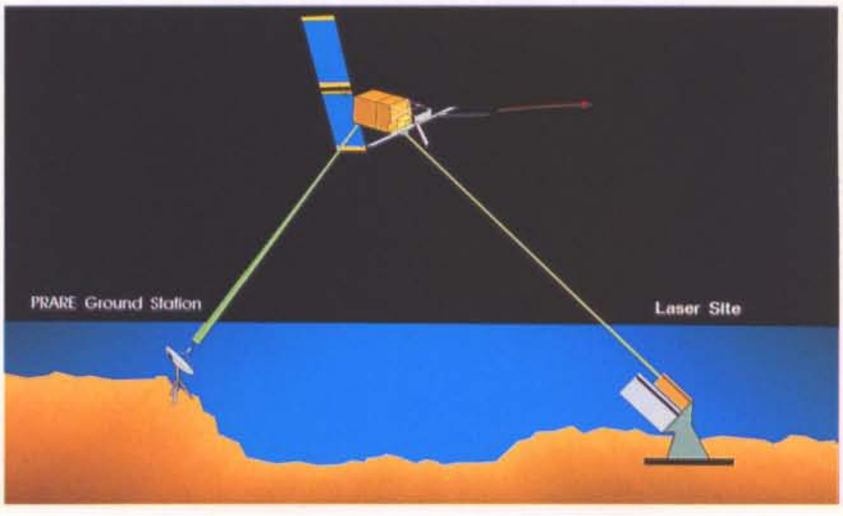
Table 4. Laser Retro-Reflector (LRR) Characteristics

Wavelength	350—800 nm optimised for 532 nm
Efficiency	≥ 0.15 end-of-life
Reflection coefficient	≥ 0.80 end-of-life
Field of view	elev. half-cone angle 60° azimuth 360°
Diameter	≤ 20 cm

Table 5. PRARE Characteristics

Up-link	7225.296 MHz 10 Mbit/s PSK (10 MHz bandwidth)
Ground transponder	60 cm parabolic dish 2 W transmit power
Down-link	8489 MHz 10 Mbit/s PSK (10MHz bandwidth), 1 W transmit power
Satellite antennas	Crossed dipoles at X- and S-bands
Ranging accuracy	5—10 cm (predicted)

Figure 19. PRARE and Laser-retroreflector range measurement



The model philosophy finally adopted differed significantly from this (see panel) as a result of various difficulties encountered during the development programme.

The Structural Model programme was completed first, in 1987, without major deviations from the baseline. It included the normal vibration and acoustic testing, as well as a static strength test of the payload on the CESTA centrifuge in Bordeaux (F). This was the only facility in Europe large enough to test the ERS-1 payload, which is at the limit of even its capabilities.

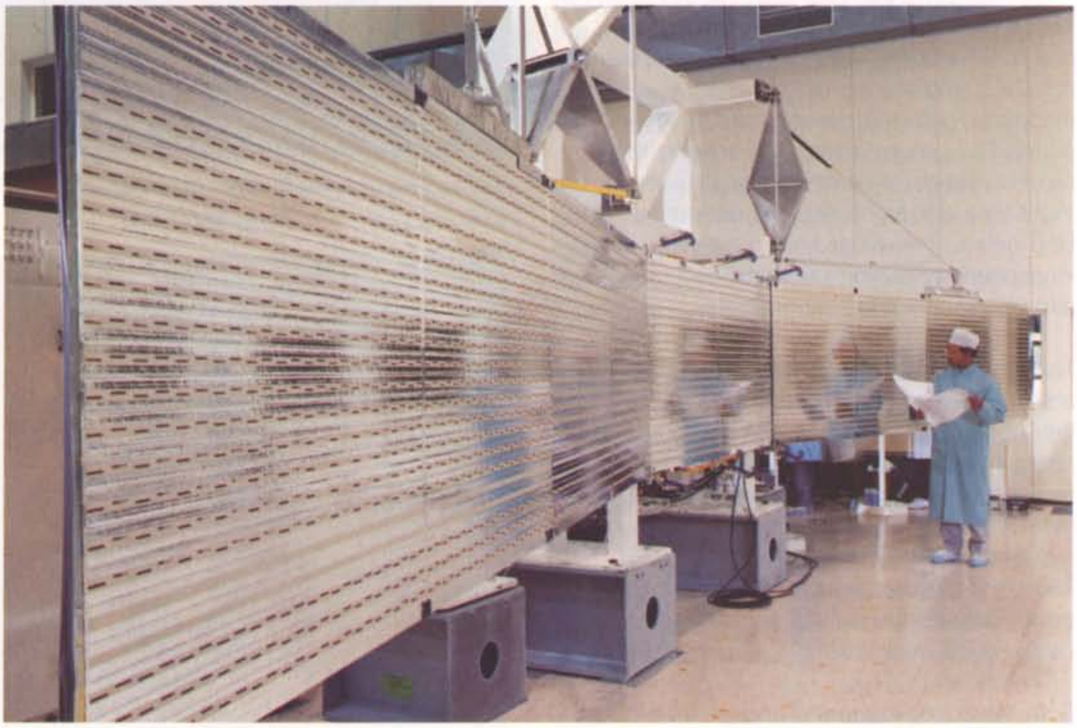


Figure 20. The SAR antenna during deployment testing

Integration of the Engineering Model payload began late due to serious development problems with a number of the onboard instruments. The most significant of these was with the AMI SAR Processor, a complex unit designed to handle command and control, and scientific data at up to 100 Mbit/s.

The project also experienced difficulties with integrating the Electrical Ground-Support Equipment (EGSE) necessary to test the payload. The EGSE occupies a floor area of about 100 m^2 and is in fact much more complex than the payload that it is used to test, so it is perhaps not surprising that problems were encountered.

Once all the instruments had been delivered, and the EGSE made to work, the remainder of the Engineering Model payload programme was completed on schedule.

This included a three-week thermal-balance test in the Large Space Simulator at ESTEC, in Noordwijk (NL). The only surprise concerned the temperature of the ATSR, which was running some 15 K too hot, which would have degraded its performance in orbit. The problem was traced to the thermal modelling of the complex obscurations of its thermal view to deep space. The solution was to fit a long heat pipe to a radiator surface, and this modification has since been incorporated in the Flight Model payload.

The next important test phases were conducted with the so-called 'Flight-Engineering Model (FEM) Satellite', namely a test to prove the compatibility of the payload with the flight software loaded into the platform's onboard computer, and the Radio-Frequency Compatibility (RFC) test, which was a first in Europe.

In the early stages of the ERS-1 Programme, this RFC test was the subject of intense debate. Clearly, with active onboard radars producing field strengths of up to 100 V/m in the vicinity of electronics boxes, and with a sensitive microwave radiometer located less than 2 m from the SAR antenna, the question 'Would it all work together?' needed to be addressed very seriously.

Calculations had shown that the coupling between receivers and transmitters onboard would be fatally compromised by even the smallest reflections from any building in which the RFC test was conducted. At first,

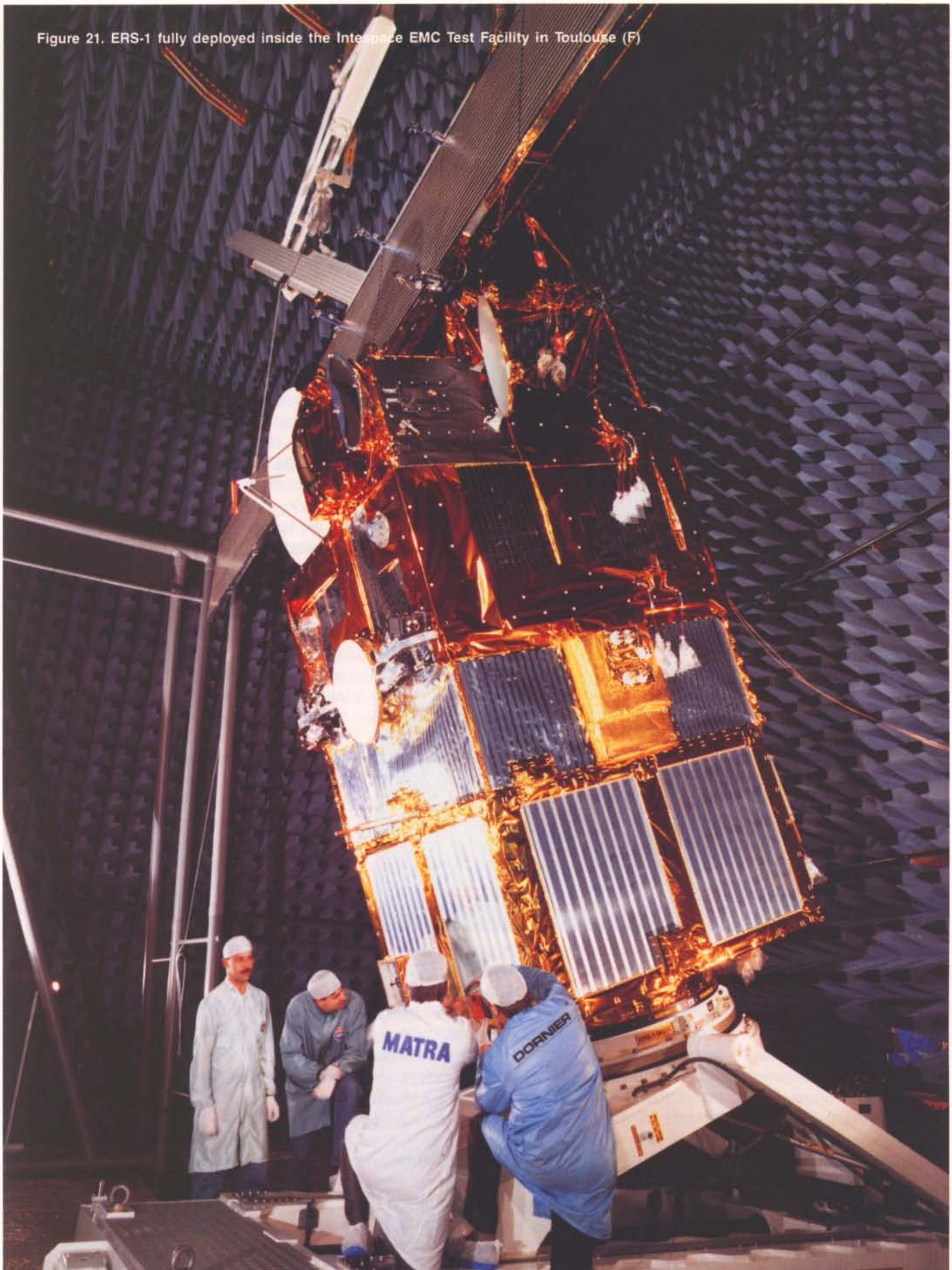


Figure 21. ERS-1 fully deployed inside the Intespace EMC Test Facility in Toulouse (F)

therefore, it was proposed to conduct the test with the deployed satellite lying on its back outdoors, using a giant roll-on/roll-off cover much like those used to protect cricket pitches during rain.

As the date for testing grew closer, the unpleasantness of exposing even Engineering Model hardware to the elements provoked a re-examination of these plans. A set of reflection measurements were made to decide between testing inside an inflatable plastic tent (like a portable tennis hall) or in a normal EMC anechoic chamber. It was subsequently decided to enlarge the EMC Chamber at Intespace in Toulouse (F) to accommodate the deployed satellite. At the same time a technique was devised, using the redundant transmit and receive chains of the instruments, to demonstrate not only a go/no-go result for the test, but actually to quantify RF margins.

Figure 22. The ERS-1 payload during thermal-balance/thermal-vacuum testing. The antennas were fitted with heaters to simulate Earth-emitted radiation

The test itself was conducted in late 1989, with surprising results. There was no detectable disturbance of the satellite by the transmitters. Performance was so similar to that with the power dissipated in EGSE that some hours were spent just to make sure that the transmitters really were transmitting. In the event, the margin test was cancelled.

Fortunately for the overall programme duration, delivery of the Flight Model instruments did not slip as much as that of the Engineering Model units. The Flight Model payload was finally shipped to Matra in March 1990, with the Flight Model SAR Processor following some six weeks later. The test programme included a further compatibility test between the payload and the onboard software, which had by now completed its validation programme. The various antennas were then installed and aligned.

Vibration and acoustic testing were then carried out to demonstrate, successfully, that the ERS-1 satellite would not be adversely affected by the vibration and noise induced by the launch vehicle. This was followed by a deployment test, under onboard software control, of the SAR and Scatterometer antennas, using special 'zero-gravity' rigs to simulate a realistic deployment.

In the late summer of 1990 the Flight Model satellite was de-coupled and the payload subjected to a further three-week thermal-balance/thermal-vacuum test. The primary purpose of this was to validate the in-orbit thermal predictions and to provide a realistic simulation of the in-orbit environment under which the payload will have to operate. This also reconfirmed the performance of the heat-pipe modification to the ATSR.

This sequence of satellite mechanical and payload thermal tests allowed an intensive post-vibration-test checkout of the platform without affecting the satellite critical path.

Finally, in October 1990, the flight platform was delivered to ESTEC for final integrated checkout, an extended three-week operations test with ESOC, packing, and shipment to the launch range.

The ERS Ground Segment

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Introduction
The European Remote-Sensing Programme is designed as an end-to-end system to serve a large variety of users with a wide range of response-time and applications requirements, as discussed in the companion article titled 'The ERS-1 Mission Objectives'.

The first ERS mission, built around the launch of the first spacecraft ERS-1, is considered pre-operational in nature, and is therefore expected to demonstrate the ability of such remote-sensing systems to provide valuable Earth-observation data from space platforms to many categories of user, ranging from the real-time operators involved in meteorological, oceanographic and environmental applications, to long-term research groups working offline.

The ERS-1 system is also intended to demonstrate some commercial capabilities of the Programme, insofar as a part of the operational costs could be covered by funds recovered by commercialising certain ERS products in appropriate ways and by affording direct access to the satellite telemetry.

The ERS Ground Segment concept
In order to respond to the very challenging mission objectives, the ERS Ground Segment – i.e. the ensemble of facilities charged with the acquisition, processing, distribution and archiving of the satellite data and of the derived products – has required a complicated systems approach (Fig. 1). Its structure is based on establishing a reasonable balance between centralised and distributed facilities, with the dual aims of optimising the overall system resources and putting at the disposal of the ERS Programme the relevant expertise already available within the participating countries.

Several factors have had a definitive influence on the ERS Ground Segment architecture.

Firstly, the institutional definition of responsibilities at the various ESA Establishments has influenced the sharing of the various tasks, and consequently also the implementation of various facilities. Satellite planning and control functions, including the remote control of the Salmijaervi (Kiruna) station, are the responsibility of the Mission Management and Control Centre at the European Space Operations Centre (ESOC), in Darmstadt (D). Similarly, the user-interface and payload-data-exploitation functions have been implemented within the ERS Central Facility at ESRIN, in Frascati (I), by the Earthnet Programme Office.

Secondly, the structure of the Ground Segment encompasses solutions adopted to resolve many technical constraints. For instance, the characteristics of the ERS Space Segment as a multi-sensor payload in quasi-polar Sun-synchronous orbit have imposed the implementation of a network of ground stations, not only to allow the acquisition around the World of high-rate Synthetic-Aperture Radar (SAR) data (for which only direct readout is possible), but also to permit the dumping to the ground once per orbit of onboard-recorded low-rate Scatterometer, Radar-Altimeter and Along-Track Scanning Radiometer data before they are overwritten by the next orbit's data (see below).

Moreover, specific user requirements have called for the implementation of ad-hoc processing tools at the ground stations operated by or for ESA, and of fast-delivery services to furnish the user centres quickly with selected data products – specifically geophysical products on a global scale for timely assimilation into forecasting models, and SAR images to allow the monitoring of shipping, oil spills, etc.

Other constraints stem more from administrative and political considerations, and relate, for example, to the Agency's own Industrial Policy drawn up by its Member States, or to the national focus on specific fields of scientific activity pursued by the countries participating in the Programme. In that context, industrial choices have determined certain technical solutions in terms, for instance, of a particular hardware configuration or software implementation. Also, the emphasis given by each Processing and Archiving Facility (PAF) to the various ERS-1 data products correlates directly in many cases with the traditions in certain scientific domains of the national organisation(s) managing each Facility.

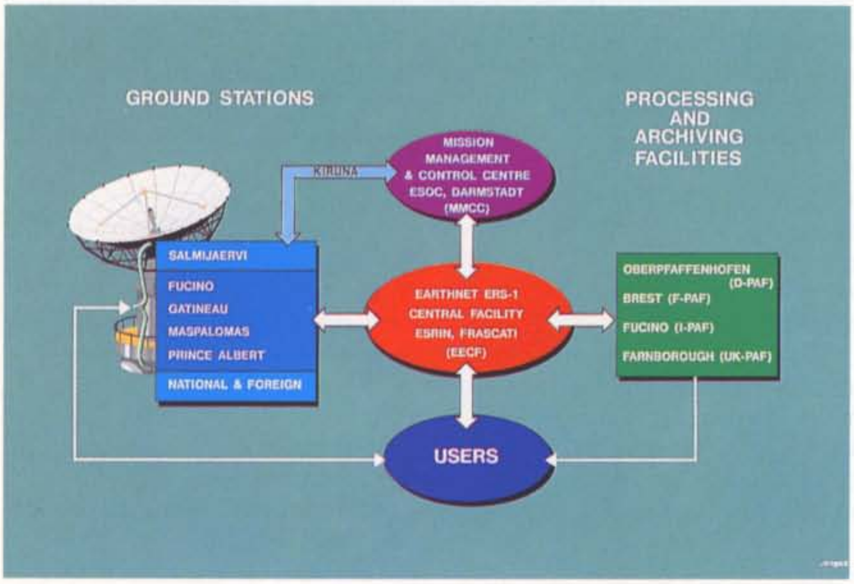


Figure 1. The overall ERS Ground Segment configuration

In addition, an important feature of the ERS system concept is that the various user interfaces are considered key Ground Segment components. In practice, the ERS Central User Service will constitute the primary user gateway to the system, a function supported by online access being implemented at the ERS Central Facility. Similarly, the ERS system output will be available directly to the user communities, either via the quick delivery of selected products to nationally nominated User Centres for operational applications, or via offline delivery to individual end users from the PAFs.

Finally, it has to be stressed that the complexity of the ERS Ground Segment has required a high level of automation. The various facilities and the system interfaces in particular have been implemented so as to allow automatic handling of the data flow during nominal routine operations, with a high number of checks for coherence and consistency. Human intervention will still be required for specific tasks such as the resolution of conflicts between the requirements of different users for payload sensing.

Overall, the ERS Ground Segment has been implemented as a distributed set of specialised facilities with centralised key functions for monitoring and control, and can truly be considered a pilot for future Polar Platform missions. In the following paragraphs, its various elements and their functions are described from the user's perspective.

The Misson Management and Control Centre (MMCC)

Historically, all of the tasks associated with a satellite's launch, its injection into orbit, and its monitoring and control have been carried out at a dedicated ESA Establishment, namely ESOC in Darmstadt, and the ERS MMCC has also been located there. It will serve the following functions (described in more detail in the companion article on 'The Control and Monitoring of ERS-1'):

- monitoring and control of the spacecraft and its payload, including correct execution of the operations plan uplinked to the satellite on a daily basis
- monitoring and control of the Salmijaervi (Kiruna) ground station, including both the satellite-telemetry acquisition and telecommand uplinking, and the fast-delivery-processing elements
- generation of the detailed mission operations plans, based on the satellite status and onboard resources and the payload-exploitation plans received from the Central Facility
- system-software maintenance for the spacecraft and the Salmijaervi station
- generation of the predicted orbit, needed to prepare the operations plan for the satellite and ground stations, calculation of the actual (restituted) orbit, and overall flight-dynamics services.

The MMCC is linked to the Central Facility by a high-speed fully redundant link, and the two Centres together constitute the heart of the ERS Ground Segment. The MMCC is also directly connected to the Salmijaervi station, which is essential to the satellite monitoring and control operations.

The Earthnet ERS Central Facility (EECF)

Another key consideration in the building up of the ERS Ground Segment was the idea of concentrating together in one facility the main functions for driving the system services for the user community. Within the

ESA Directorate for the Observation of the Earth and Its Environment, the Earthnet Programme Office has been entrusted with developing that facility to support the user requirements spelled out in the ERS-1 Programme Declaration.

The EECF constitutes the user interface to the ERS System for the scientific and applications communities, and one of its main tasks is to ensure efficient exploitation of the ERS payload data vis-a-vis the mission objectives. The EECF is located at ESRIN, in Frascati.

The Central Facility is meant to be the ERS focal point for any entity outside ESA, and is therefore the external users' gateway to the ERS System. In that respect, the EECF staff work in close cooperation with the ERS Mission Manager at ESA Headquarters in Paris, with the Project Team based at ESTEC in Noordwijk (NL), and with the MMCC staff at ESOC (D).

The EECF will drive the operations of most of the Ground Segment facilities to various degrees. Not only will it provide activity schedules to the ground stations and to the processing and archiving centres, but its input in the form of so-called 'Payload Exploitation Plans' (PEPs) will allow the MMCC to establish the detailed satellite operating schedule by incorporating the payload sensing requirements proposed by the users, with any possible conflicts already resolved.

From the user's viewpoint, the EECF offers a set of system services that will afford ERS customers an insight not only into the global catalogue of ERS data products, but also into the payload-operations schedule for future sensing activities. In fact, an ERS Global Activity Plan (GAP) will be accessible online around the clock. This Plan, which will be routinely updated with the results of each mission-planning session at the MMCC, will show the planned sequence of operations for the various onboard instruments throughout the satellite's lifetime. This will allow the users to plan their deployment of ground resources and instruments well in advance, although in many cases final confirmation of the exact time sequence of specific events will not be possible until a few days beforehand.

The EECF provides three main services to the ERS Programme (Fig. 2): the Central User Service, the Interface Subset and the Product-Control Service. Each will be addressed briefly here to allow a better appreciation of their importance within the ERS Ground Segment to fulfilment of the mission objectives and the optimum exploitation of ERS data.

The Central User Service (CUS)
The CUS embraces a variety of functions dedicated to providing a user-friendly interface between the ERS-1 System and its users, including catering for users' needs in terms of information and products, and translating those needs into system operating plans and product orders.

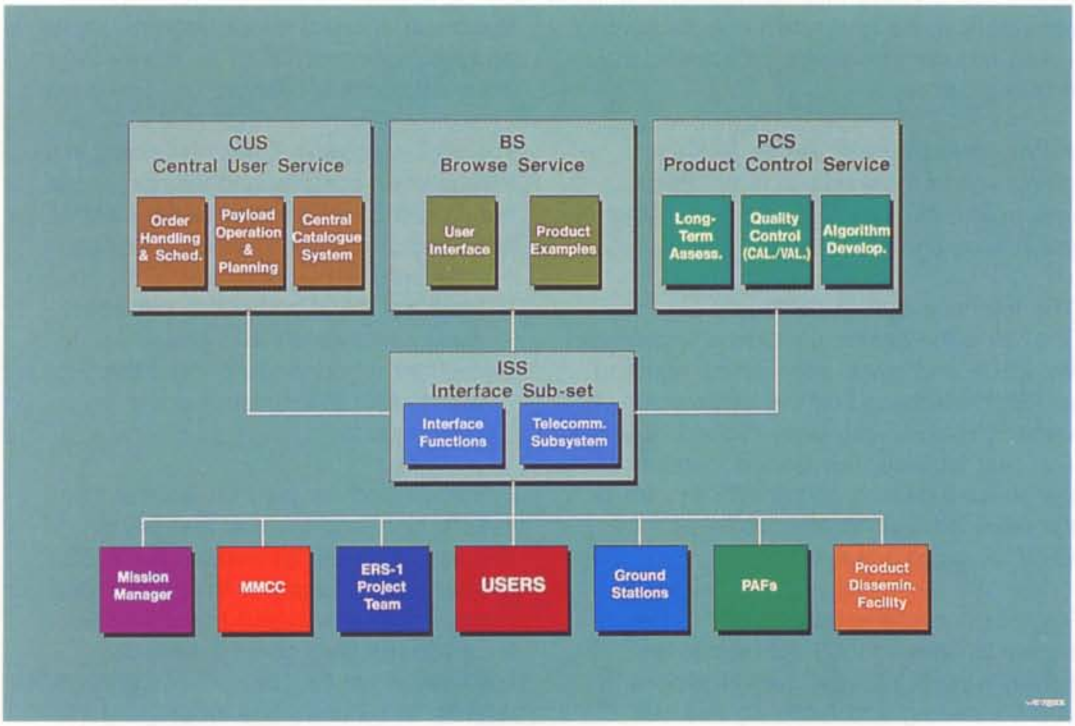


Figure 2. The Earthnet ERS Central Facility (EECF) and its services

It has to be stressed that, in the overall context of the ERS Programme, the term 'user' is applied in a very broad sense, ranging from the individual customer to the Announcement of Opportunity investigators, to the pilot projects for the operational demonstration of applications, to national programmes set up by the countries participating in the ERS Programme. ESA itself will also be a 'user' of the ERS System, whenever special operations are scheduled for calibration and validation, or observations are planned to exploit the system in the absence of specific user requirements.

In order to support these tasks, the CUS system includes:

- an online worldwide central catalogue of ERS-acquired data and derived products and the online Global Activity Plan (GAP) for payload operations
- online tools for accepting and handling user requests for ERS data products
- tools for planning the payload instrument operations, on the basis of user requirements, mission objectives and system constraints
- facilities for monitoring and controlling data acquisition, processing, archiving and distribution activities carried out by the ERS Ground Segment elements.

The dialogue with the ERS users will be handled primarily via the online terminals, but a 'Help and Order Desk' is also available at the EECF to process letters, telexes, telefaxes and phone calls, and electronic-mail connections are already in place. It will also help users to clarify their requirements where necessary, or suggest alternative solutions if their requirement cannot be satisfied as initially proposed.

A Browse Facility will also be available, giving visitors local access to the EECF system and demonstrating the ERS System's capabilities and products.

The Interface Subset (ISS)
The ISS is the technical interface between the EECF and any external entity, handling all EECF interfaces and the telecommunications links with the other Ground Segment and user facilities. The ISS will therefore be the physical gateway to the ERS System for the users, who will communicate with the EECF by logging-in to it.

Via the connections with the other operational facilities, the ISS will receive the activity reports from the ground stations and Processing and Archiving Facilities, and will despatch the product orders to those facilities. The low-bit-rate fast-delivery products generated at the ground stations will also be collected by the ISS for further routing to their final destinations. The products will be stored and will remain at the EECF for a certain time, to allow other authorised users to pick them up. In the context of data dissemination, the ISS will also handle the re-formatting of these products in World Meteorological Organisation (WMO) code (BUFR), and their delivery using the WMO file-transfer protocol (X.25) to the regional telecommunications hub of the Italian Meteorological Service in Rome, for further distribution to the European Meteorological Offices, and to NOAA in the USA for operational purposes.

To ensure a high-reliability operational environment, the CUS and ISS hardware is mutually redundant (i.e. each can serve as a backup for the other).

The Product-Control Service (PCS)
The PCS carries out another set of essential tasks assigned to the EECF, namely those associated with the monitoring and control of ERS data-product quality. The latter is of prime importance from the users' point of view, and for many applications it is possibly even more important that the quantity of data gathered. It is also fundamental to ESA for assessing the compliance of the system's performance with system specifications, and for assessing instrument behaviour and related margins, and therefore represents vital feedback for future programmes. This will be particularly true for ERS-1, as the forerunner of future space platforms equipped with active-microwave radars for the observation of the Earth and its environment.

The implementation of this philosophy in the PCS involves complex and delicate coordination of the various Ground Segment facilities in a number of areas, including:

- development of algorithms
- maintenance of application software
- quality assessment and control
- calibration and validation activities
- assessment of long-term sensor performance.

In that connection, the PCS facilities also include high- and low-rate Fast-Delivery Processing chains, as installed at the ESA ground stations, together with SAR and Scatterometer Verification Mode Processors, a SAR Image Geocoding System as implemented at the German PAF (though installed in a stand-alone mode), and the so-called 'ArMor' system for storing and handling in-situ data collected by ground instrumentation during the ESA-sponsored calibration and validation campaigns ('ArMor' means 'the sea' in the dialect of Brittany, where the ERS Oceanographic PAF is located).

Daily analysis reports generated by the various Ground Segment facilities will be routinely collected and scrutinised by the PCS. The latter will also perform limited sampling processing as required to carry out the above tasks. Similarly, any new product proposed for operational implementation will be assessed by the PCS.

The ERS ground stations

Besides the centres for monitoring and control, the ERS Ground Segment includes the ground stations required to ensure that the satellite telemetry data are correctly acquired along the orbits. ERS-1's quasi-polar Sun-synchronous orbit and the need for direct readout of the SAR telemetry have dictated the geographical locations of these ground stations around the World (Fig. 3).

The ERS ground stations can be classified into two categories:
- ESA Network
- national and foreign facilities.

Although strictly speaking not part of the ERS Ground Segment, the PRARE and Laser Tracking Stations will also be discussed below.

The ESA Network has been set up to ensure the acquisition of the global data from the low-rate instruments, taking into account their storage onboard on an orbit-by-orbit basis, and the acquisition of the high-rate data primarily over Europe.

The Network includes six ground stations, located at Salmijaervi (Kiruna, Sweden), Villafranca (Spain), Fucino (Italy), Maspalomas (Canary Islands, Spain), Gatineau (Canada), and Prince Albert (Canada).

Except for Salmijaervi, better known as Kiruna, which is fully dedicated to ERS operations, the stations of the ESA Network are owned by national entities and are operated as multi-mission stations, playing host to ESA facilities for the ERS operations (Fig. 4).

The sharing of tasks and responsibilities between these stations takes into account the technical constraints related to the high- and low-rate payload data (see companion article on 'The ERS-1 Spacecraft and Its Payload'):

- Salmijaervi
  - Satellite tracking and telecommanding
  - Global Low Bit Rate (LBR) (i.e. real-time and onboard-tape-recorder data dumping)
  - Regional SAR over North Pole area and Northern and Central Europe.
- Villafranca
  - Backup station for satellite tracking and telecommanding.

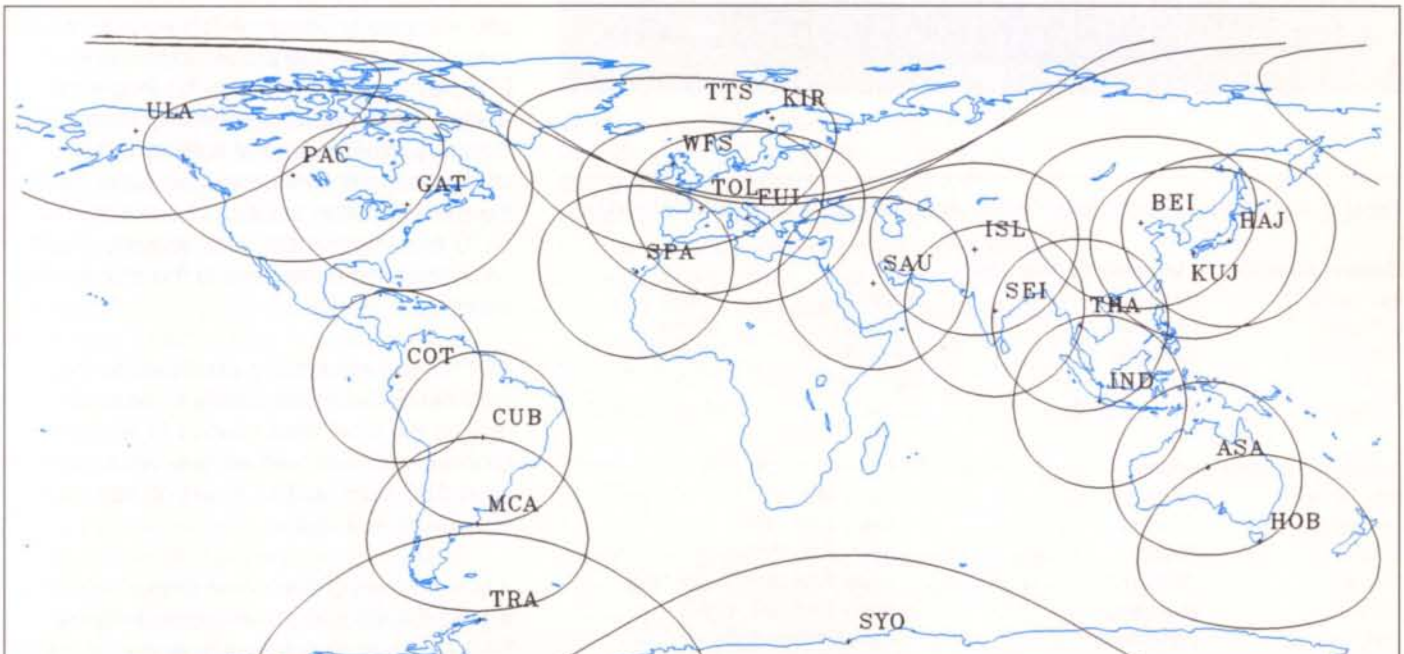


Figure 3. The planned ERS-1 ground stations and their coverages

- Fucino
  - Regional SAR over the Mediterranean area and Central and Southern Europe
  - Regional LBR over the Mediterranean area.
- Maspalomas
  - Global LBR
  - Regional SAR over Northwest Africa and the Eastern Atlantic Ocean.
- Gatineau
  - Global LBR.
- Prince Albert
  - Global LBR.

Figure 4. The ESA multi-mission antenna at the Telespazio facility in Fucino (I)

Table 1 — Ground stations planned to acquire ERS-1 SAR telemetry data

Stations scheduled to be ready by May 1991			
Fairbanks	(Alaska)	Hyderabad	(India)
Cotopaxi	(Ecuador)	Kumamoto	(Japan)
Gatineau	(Canada)	Prince Albert	(Canada)
Tromso	(Norway)	West Freugh	(UK)
O'Higgins	(Antarctica, D)	Syowa	(Antarctica, J)
Status of the other stations			
Hatoyama	(Japan)	— ready Mid-1991	
Aussaguel	(France)	— ready End-1991	
Cuiaba	(Brazil)	— ready End-1991	
Bangkok	(Thailand)	— ready End-1991/Begin 1992	
Hobart	(Australia)	— ready End-1991 (TBC)	
Pari-Pari	(Indonesia)	— implementation started (TBC)	
Riyadh	(Saudi Arabia)	— pending	
Islamabad	(Pakistan)	— pending	

The Salmijaervi—Fucino—Maspalomas station suite will acquire the European and Northwest-African SAR telemetry data, whilst the Salmijaervi—Maspalomas—Gatineau—Prince Albert combination will allow complete dumping of the LBR onboard-recorded data for the daily global coverage.

All the stations in the ESA Network, except Villafranca, will not only acquire the ERS instrument telemetry and store it on archiving media, but will also process the payload data to generate the so-called 'Fast-Delivery (FD) Products' and put them at the disposal of nationally nominated centres within 3 h of the observation being made.

In addition to the ESA Network, some national (i.e. belonging to countries participating in the ERS-1 Programme) and some foreign (i.e. belonging to non-participating countries) ground stations have been or will be built around the World, or existing stations upgraded, to acquire ERS SAR telemetry.

The current situation is summarised in Table 1 (not an exhaustive list). Of particular importance are the Antarctic ERS facilities installed at the Syowa and O'Higgins bases by Japan and Germany, respectively, as they will allow the acquisition of repetitive sets of SAR data in areas of high scientific and applicational interest, covering more than two thirds of the southern polar region.

A prerequisite for the acquisition of ERS SAR data by a national or foreign ground station is the conclusion of a Memorandum of Understanding (MOU) between ESA and the operating body. These MOUs address issues meant to ensure the proper exploitation of ERS data, and in particular the long-term storage and retrieval of telemetry data. If the '10 years after the end of satellite lifetime' storage commitment cannot be supported by the ground-station facilities in question, the MOU requires that the data be sent, stored on a compatible medium, to the PAF for final handling.

All ERS ground stations are linked to the Earthnet ERS Central Facility in order to receive the input data needed to acquire, process, distribute and archive (as applicable) ERS data, and to report on station operations and status.

It is worth noting that some ground stations, e.g. Fairbanks and the associated Alaska SAR Facility, can act as a focal point for ERS user requests both for payload operations and data processing. The requests received for sensing will be routinely forwarded to the EECF in Frascati.

In the framework of the ERS Ground Segment, it is important to mention also the PRARE and Laser Tracking Stations, whose operations will be very important for the precise calculation of ERS-1's orbit.

The German PRARE instrument is designed to provide high-precision satellite tracking, particularly in regions where clouds or fog can frequently jeopardise the laser measurements. The PRARE ground stations are basically coherent and re-generative transponders (Fig. 5). The associated PRARE Ground Control Segment is located primarily in Germany. The Command Station in Stuttgart will handle the data flow to and from the satellite. The orbit predictions and the station interrogation plan will be prepared and uplinked to the spacecraft by the Master Station in Oberpfaffenhofen, within the framework of the German PAF. The calibration site is located in Wettzell. A second PRARE dumping station is located at Tromso, in Norway. Each PRARE user ground station will receive system parameters, including accurate orbital predictions, from the Master Station via the satellite itself or normal telex links. Very good PRARE station coverage will be achieved soon after the ERS-1 launch, with some 30 stations participating around the World, several of them located in the Southern Hemisphere.

The Laser Tracking Stations operating today around the World are already organised into networks, and the station operators are used to the routine exchange of data with a high degree of international collaboration, the latter being even more active with the opening of the borders with Eastern Europe. Many stations are in the process of upgrading their equipment to deliver improved performance and accuracy. ESA has made a small contribution to these efforts by sponsoring the implementation of a software package that will allow the station operators themselves to extract the normal orbital points, thereby allowing the exact orbit parameters to be established more quickly.

Although the Laser Tracking Stations are not formally part of the ERS Ground Segment, through the substantial help of the German Geodetic Institute cooperative agreements have been reached with that community. Station operators in the EUROLAS, NASA, Soviet, Japanese, Chinese and other networks have been very cooperative, resulting in a very interesting scenario for the accurate tracking of ERS-1, particularly in view of the planned cross-comparison campaigns with the Topex/Poseidon mission.

Management of the ERS-1 tracking activities resides with the German PAF, where the PRARE and laser-tracking data will be stored.

The ERS Processing and Archiving Facilities (PAFs)
At the time when the ERS-1 Ground Segment was being defined, it became apparent that very specialised expertise in several domains was needed to ensure efficient exploitation of the data generated by an advanced Earth-observation mission like ERS-1. That fact led some ESA Member States to propose the implementation of facilities dedicated to particular scientific and applications domains, based on the existence in those countries of groups/institutes already internationally recognised in these fields. As a consequence, four Member States suggested joint national/ESA endeavours, which came to be known as 'Processing and Archiving Facilities', or 'PAFs'.

Figure 5. A PRARE user station (Photo. courtesy of Dornier)

These four PAFs are located and managed as follows:

- F-PAF in Brest, France, managed by the Institut Francais pour l'Exploitation de la Mer (IFREMER)
- UK-PAF in Farnborough, UK, managed by the Royal Aerospace Establishment (RAE)

- D-PAF in Oberpfaffenhofen, Germany, managed by the Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR) (Fig. 6).
- I-PAF in Matera, Italy, managed by the Agenzia Spaziale Italiana (ASI)(Fig. 7).

The French PAF's management scheme also involves the Centre National d'Etudes Spatiales (CNES) and the Direction de la Meteorologie Nationale (DMN). The German PAF is supported by the Remote-Sensing Unit of the University of Zurich (CH), and by the Institute for Image Processing and Computer Graphics in Graz (A).

Although the PAFs are joint national/ESA facilities, with the Agency contributing an average of 15–20% of the total investment, ESA retains overall management, coordination and harmonisation responsibility, in order to ensure a coherent Ground Segment approach and full implementation of ESA's data policy, and in practice the Agency will fund most of the routine operations.

Figure 6. The German ERS Processing and Archiving Facility (photo courtesy of DLR)

The PAF environment is intended to serve as the focal point for the scientific and technical expertise, particularly in the areas of algorithm development and quality assurance. In fact, these facilities were never meant to support massive generation of offline products with a high throughput, but rather to concentrate on a reduced number of high-quality precision products. They are also intended to function for up to 12 years after ERS-1's launch, with the aim of providing a dynamically updated learning forum, whereby some products will be improved, others will be discarded, and new ones will be introduced.

The main tasks allocated to the PAFs today are:
- long-term telemetry-data archiving and retrieval capabilities
- generation and distribution of offline geophysical products
- support to ESA for sensor-data calibration, geophysical-data validation, and long-term sensor performance evaluation.

Each PAF will receive ERS telemetry data from the ESA ground stations and will ensure their long-term archiving. In addition, the PAFs will generate, deliver, distribute and archive ERS data products. Results of ground campaigns and conventional data will be also collected, corrected, formatted and stored at the PAFs (correction and formatting are not applicable in all cases). Activity reports will be sent regularly to the EECF.

The users cannot address themselves directly to the PAFs, except in the case of

Figure 7. The Italian ERS Processing and Archiving Facility (photo courtesy of ASI)

availability of an online database such as that at the French PAF; they must apply to the EECF, which will forward their requests to the PAFs in the form of product orders.

As noted above, the PAFs are also intended to act as focal points within each country for the development of new algorithms, in order to put the experience gathered in data utilisation to good use. Consequently, the ESA ERS Product Specification Document (the main ERS-1 products are listed in Table 2) will be dynamically updated as the missions progress. Three major product categories are foreseen:
- Fast-Delivery Products
- PAF Baseline Products, for which agreed specifications exist, and which are verifiable in quality and properly validated
- PAF Experimental Products, with good potential, but whose quality cannot be adequately verified today.

In effect, one of the PAF activities during the evolution of the ERS Ground Segment will be to demonstrate the possibility of experimental products becoming 'baseline', if they prove to meet the necessary quality and validation requirements. This is, however, likely to be a lengthy process, which could mean some products becoming available only in time for the ERS-2 or Polar-Platform missions.

In this context, some additional products might be considered for inclusion sooner

Table 2 — ESA ERS-1 products

Product	Name
SAR Annotated Raw Data	ERS-1.SAR.RAW*
SAR Fast-Delivery Image	ERS-1.SAR.UI16*
SAR Single-Look Complex Image	ERS-1.SAR.SLC*
SAR Precision Image	ERS-1.SAR.PRI*
SAR Ellipsoid Geocoded Image	ERS-1.SAR.GEC*
SAR Terrain Geocoded Image	ERS-1.SAR.GTC
SAR Wave Imagette Fast-Delivery Spectrum	ERS-1.SWM.UWA*
SAR Wave Complex Imagette	ERS-1.SWM.CIT*
SAR Wave Imagette Precision Spectrum	ERS-1.SWM.IPS*
Wind-Scatterometer Fast-Delivery Product	ERS-1.WSC.UWI*
De-aliased Offline Wind Fields	ERS-1.WSC.WNF*
Altimeter Fast-Delivery Product	ERS-1.ALT.URA*
Altimeter Ocean Intermediate Product	ERS-1.ALT.OIP*
Altimeter Ocean Product	ERS-1.ALT.OPR*
Altimeter Waveform Foundation Product	ERS-1.ALT.WFP*
Altimeter Land-Ice Product	ERS-1.ALT.LIR
Altimeter Sea-Ice Product	ERS-1.ALT.SIP
Sea-Surface Height	ERS-1.ALT.SSH(*)
Sea-Surface Topography	ERS-1.ALT.TOP(*)
Oceanic Geoid	ERS-1.ALT.OGE(*)
PRARE Ionospheric Refraction Data	ERS-1.PRA.ION*
Preliminary Orbit	ERS-1.ORB.PRL*
Precise Orbit	ERS-1.ORB.PRC(*)
ERS-1 Gravity Model n-th Generation	ERS-1.ORB.EGM(n)(*)
ATSR Raw IR Data	ERS-1.ATS.RIR
ATSR Raw MW Data	ERS-1.ATS.RMW
ATSR Corrected IR Data	ERS-1.ATS.CIR
Sea-Surface Temperature Map	ERS-1.ATS.SST
Precise Sea-Surface Temperature Map	ERS-1.ATS.PST
Microwave Brightness Temperature	ERS-1.ATS.MBT
Water-Vapour/Liquid-Water Content	ERS-1.ATS.VLC

* Product ready at launch date.
(*) Processing ready at launch date. Actual product generation requires a long period of data gathering.

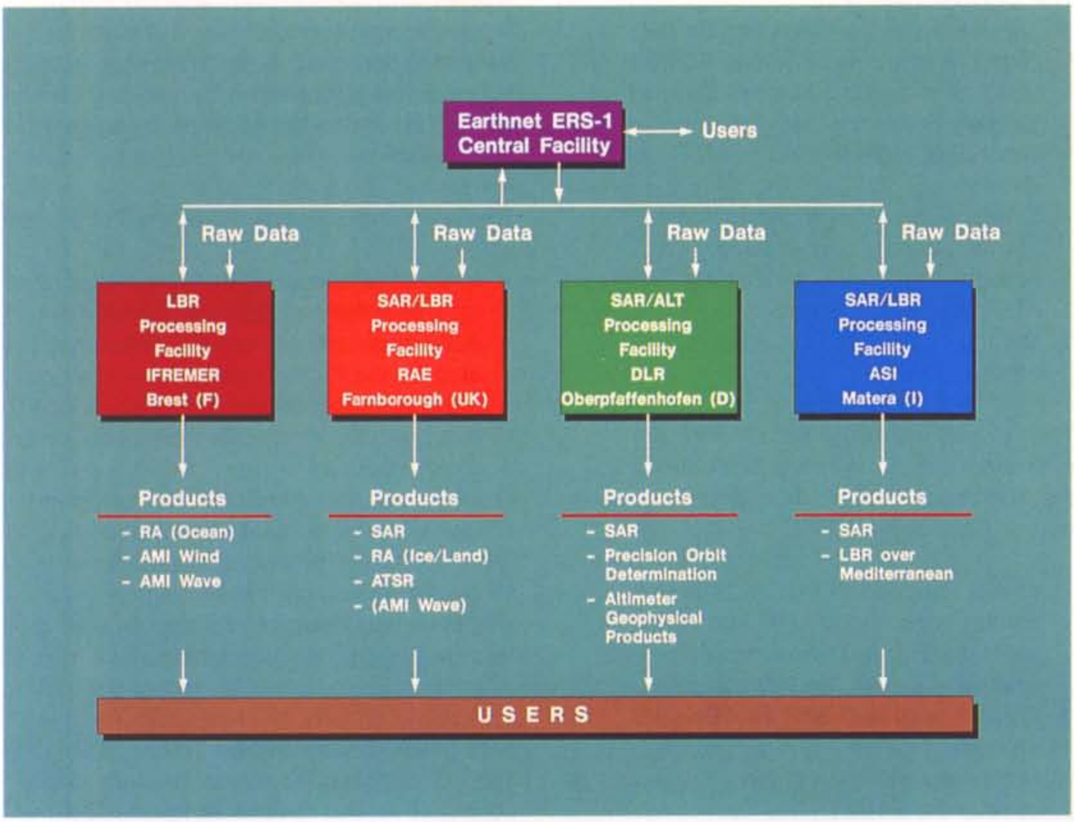


Figure 8. The responsibilities and products of the four ERS Processing and Archiving Facilities (PAFs)

or later in the fast-delivery set generated at the ESA ground stations. The ATSR Near-Real-Time Sea-Surface Temperature global product, developed by the ATSR Principal Investigator's team at the Rutherford-Appleton Laboratory (UK), in cooperation with the Tromso Satellite Station (Norway) and the Royal Aerospace Establishment (UK), is one such example. In this case a one-year assessment study will be made before the product can be put forward as a new Fast-Delivery Product candidate for the ESA Network.

As already mentioned, the sharing of tasks and responsibilities among the four PAFs is related both to their qualifying national skills or interests, and the harmonisation (by ESA) needed to avoid substantial duplication (Fig. 8).

Emphasis at the French PAF is on ocean-data products, and the traditional activities at IFREMER are oriented largely to oceanography and ocean cultures. CNES's specialised contribution lies in the field of processing algorithms for instrument data, with their particular experience in radar altimetry. The DMN will prepare meteorological wind-field data, mainly to support wind-ambiguity removal for the Scatterometer. The IFREMER operational centre in Brest, called CERSAT, will be fully commissioned at the beginning of the satellite's lifetime.

The CERSAT roles are:
- primary archiving of low-bit-rate data (Wave, Scatterometer, Radar Altimeter and Wind) over oceans, and associated Fast-Delivery Products
- secondary archiving of the ATSR global dataset
- acting as primary processing centre for low-bit-rate data over oceans
- acting as secondary processing centre for ATSR Microwave Sounder data
- storage of relevant ESA-provided campaign data.

The fields of interest of the UK PAF are mainly concerned with the radar altimetry, the exploitation of SAR data, and the passive optical radiometry (ATSR).

The tasks assigned to the UK PAF are:
- primary archiving of SAR and ATSR telemetry and processed data (the latter when applicable), low-bit-rate data over ice and land, and SAR Fast-Delivery Products
- secondary archiving of low-bit-rate data (to backup the F-PAF)
- serving as primary processing centre for SAR, and low-bit-rate data (incl. ATSR) over ice and land
- acting as the secondary processing centre for Wave data products.

Two major activities will be performed at the German PAF:
- SAR processing and geocoding
- orbit and geoid calculations.

A comprehensive system is being set up at the D-PAF for this last task, which is also able to collect PRARE and Laser Tracking inputs from anywhere in the World. The current implementation of the multi-sensor SAR processor is based on the ESA SAR Verification Mode Processor. The Zurich and Graz teams have made valuable contributions in the course of the geocoding tasks.

The tasks allocated to the German PAF are the following:
- primary archiving of telemetry data acquired by the German Antarctic station at O'Higgins, D-PAF products, ERS-1 PRARE and Laser Tracking data
- serving as primary processing centre for SAR precision and geocoded image data, higher level Altimetry products and precision orbit calculations.

The Italian PAF implementation work is focussing mainly on the processing of SAR images, and the compliance of the EMMA-2 processor with specifications has already been demonstrated. Some studies on other potential activities, related for instance to geocoding and radar altimetry, have also been initiated.

The tasks to be carried out by the Italian PAF are:
- regional archiving of SAR and low-bit-rate data (telemetry, processed fast-delivery data) acquired over the Mediterranean area by the Fucino station
- regional processing of SAR and low-bit-rate products for the Mediterranean area.

The links between the EECF and the PAFs will carry product orders, parameters for processing, and precise orbit and satellite information, while operations (archiving, processing and distribution) reports will be provided by the PAFs to the EECF.

ERS product distribution

The ERS Product Distribution System will consist of various facilities at transmission and reception sites, and of satellite and surface telecommunications links.

The present scenario includes:
- a low-rate baseline network making use of public land lines
- a high-rate satellite link, operating at some 2 Mbit/s.

As mentioned earlier, the low-rate Fast-Delivery Products generated by the ground stations of the ESA Network will be centralised at ESRIN (on the ISS) and re-distributed to the nationally Nominated Centres and to the GTS RTH in Rome via standard land lines. The alternative of using a satellite link at low rate, e.g. 64 kbit/s, for quick dissemination, at least in Europe, is also being considered.

The definition of the high-rate component is the result of protracted technical and administrative discussions during which many factors had to be analysed, including system availability, system performance, security and control, investment and running costs, agreements with the PTTs in each country, etc. The appropriate industrial setup has been identified and the associated contractual and technical work is currently in progress.

The system configuration includes two uplink stations, at the Salmijaervi (Kiruna) and Fucino ground stations, where the SAR Fast Delivery images will be generated. The EECF will make use of ESRIN scheduling, monitoring and control functions. The satellite link can be provided using ECS/SMS services. Control messages and reports will be delivered via land lines. As in the case of the low-rate system, each country participating in the ERS Programme will select one (or more) Nominated Centre(s) to which the data will be distributed. These Centres will then be responsible for ensuring that the incoming data are appropriately re-routed to the final national destinations.

Conclusion

The ERS Ground Segment has been designed to support several user communities worldwide engaged in a wide variety of applications and with a wide range of time constraints. In order to achieve this goal, the user interface and the monitoring and control functions have been centralised, but the various archival/retrieval and processing tasks have been allocated to distributed facilities with the aim of drawing upon the best national expertise, as proposed by some of the participating countries.

As a forerunner of the Polar Platforms, the ERS System will provide its users with an unprecedented number of specialised and general-purpose services, in preparation for the future need to be able to handle very large quantities of individual instrument and multisensor data. In this respect, therefore, the ERS Ground Segment architecture can be considered the prototype 'core' for the advanced Earth-observation missions of the future.

How ERS Data Will Flow

Several different types of data will be circulating within the ERS Ground Segment:

- status and activity reports
- operating schedules
- processing parameters and orbit data
- product orders
- raw and processed data products
- administrative messages.

The overall data flow within the Ground Segment is shown schematically in the accompanying figure, where the various classes of ground systems are also indicated: the two Control Centres, namely the Earthnet ERS Central Facility (EECF) and the Mission Management and Control Centre (MMCC), the four Processing and Archiving Facilities (PAFs), the ERS Ground Stations (GS) and the User Facilities.

Users can access the ERS services at the EECF, located at ESRIN in Frascati (Rome, Italy), where its Central User Service (CUS) allows the ERS Global Activity Plan (GAP) for instrument observations to be consulted. The GAP is to be built up from the user requests, taking into account the satellite's capabilities and the status of the Ground-Segment facilities, and the resolution of any conflicts arising from the overall mission objectives, user-priority rules and technical constraints.

If users cannot find an already-planned observation that suits their needs in the GAP, they can submit a sensing request. The user can also ask the CUS for a specific ERS product, either as a copy of an existing product from the ERS Catalogue, or as a product to be generated from the ERS Product List.

The two Control Centres (MMCC and EECF) have a hot line between them, via which calibration data and satellite parameters will be regularly exchanged. At the EECF, a preferred Payload Exploitation Plan (PEP) will be routinely generated by the GAP and sent to the MMCC, representing the user observation-requirement input to the Mission Planning System.

At the MMCC, a Detailed Mission Operations Plan will be generated from the PEP, based on the actual status of both the satellite and the onboard power resources, and sent to the EECF. The daily operating schedules for the satellite and the Salmijaervi station will also be prepared at the MMCC and sent to that station for execution. Orbital parameters are to be calculated from the previous orbits, with a prediction for the next ones, and sent both to the EECF and the Salmijaervi station. Key processing parameters are also to be provided.

At the EECF, the above information will be used to update the GAP and to prepare the schedules and the required inputs for all of the other ground stations.

As it moves along its orbit, the ERS spacecraft will be tracked by both PRARE (Precise Range and Range-Rate Equipment) and laser stations. The PRARE Master Station at the German Processing and Archiving Facility (PAF) will routinely collect all the data passing through the satellite from the many PRARE stations around the World. Similarly, the ERS data generated by the laser tracking stations of the national and international networks will also be collected via land-lines at the German PAF. Both sets of data will be used immediately for accurate orbit calculations.

The satellite instrumentation observes the Earth and its environment by executing the operational schedule, and the sensed data will be telemetered together with auxiliary information to the ground. The high-rate data stream (SAR) requires direct readout, and therefore it cannot be used other than when an authorised ERS station is within visibility of the spacecraft. The low-rate data, on the other hand, are to be stored onboard the satellite on an orbit-by-orbit basis, and dumped once per orbit when in sight of a station in the ESA Network.

At the ground stations, the acquired telemetry is to be stored on high-density media, and in many instances it will also be processed locally (except at Prince Albert, where there will be only low-rate data acquisition, to ensure global coverage). The Fast-Delivery Processing chain of the ESA Network will generate a set of so-called 'FD Products' every orbit, which are to be sent to the users immediately, before the next orbit, via the rapid data-distribution systems. The FD Products are also to be stored on cassette support media. Reports from the ground stations will be used at the EECF to monitor system performance and to update the ERS Central Catalogue.

To assist the FD processing of the Wind-Scatterometer data, meteorological-forecast grid data will be received four times per day at ESA's European Space Operations Centre (ESOC) in Darmstadt (D) from the European Centre for Medium-Range Weather Forecast (ECMWF) in Reading (UK), and distributed to both the Salmijaervi station and the EECF for further dissemination to the rest of the ESA Network.

The telemetry data stored on high-density media will be sent to the PAFs for long-term archiving, and for the generation of off-line products. The tapes containing high-rate telemetry will be sent directly to the PAFs. The low-rate tapes will be sent to Fucino (I), where they will be copied at the Low-Rate Data Transcription Facility (LRDTF) onto optical disks. Only the latter will be delivered to the PAFs. The FD Product cassettes will also be sent to the PAFs for archiving, and copying to users as required. The movement of the support media around the Ground Segment will be controlled by the EECF.

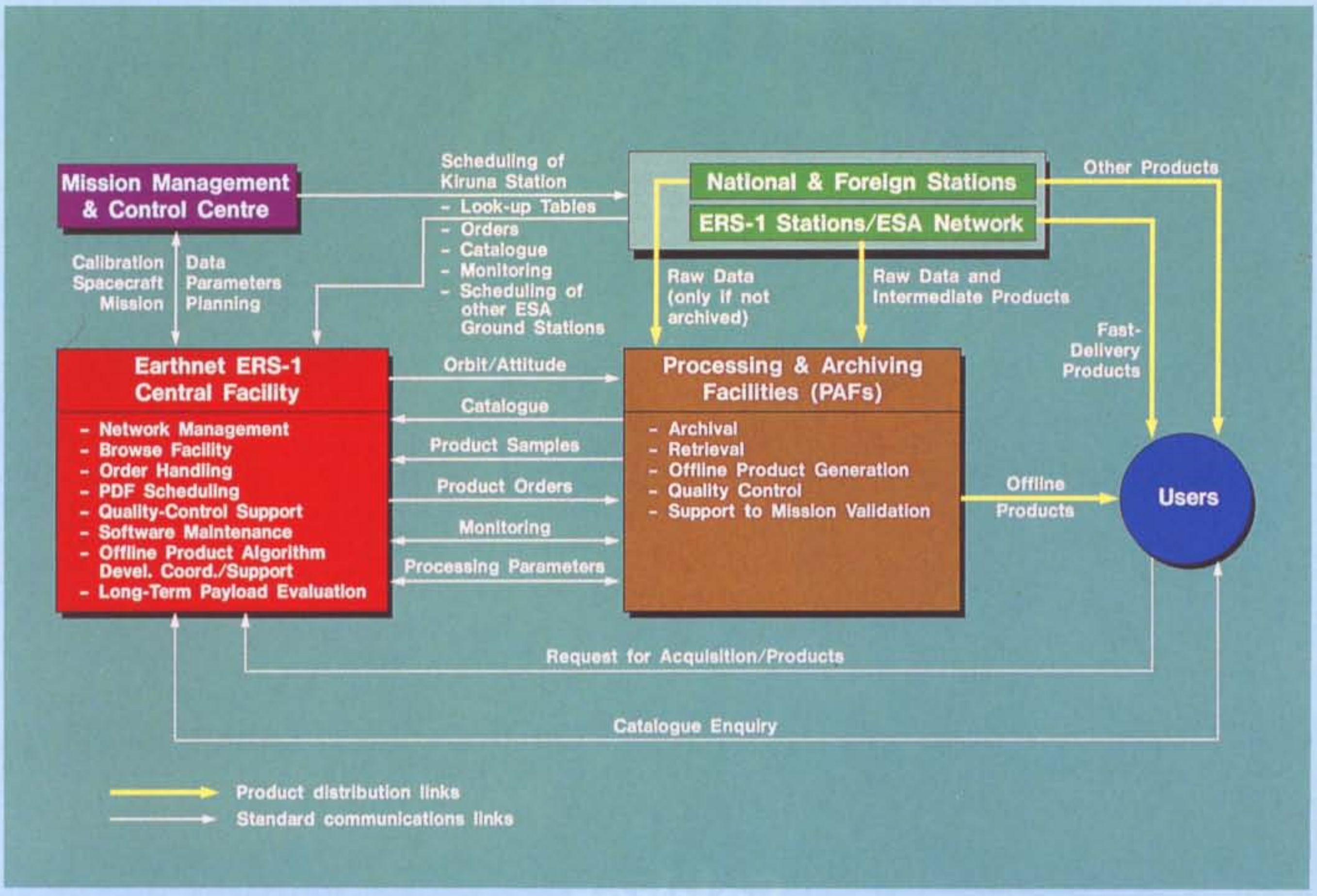


Figure 1. ERS Ground Segment data flow

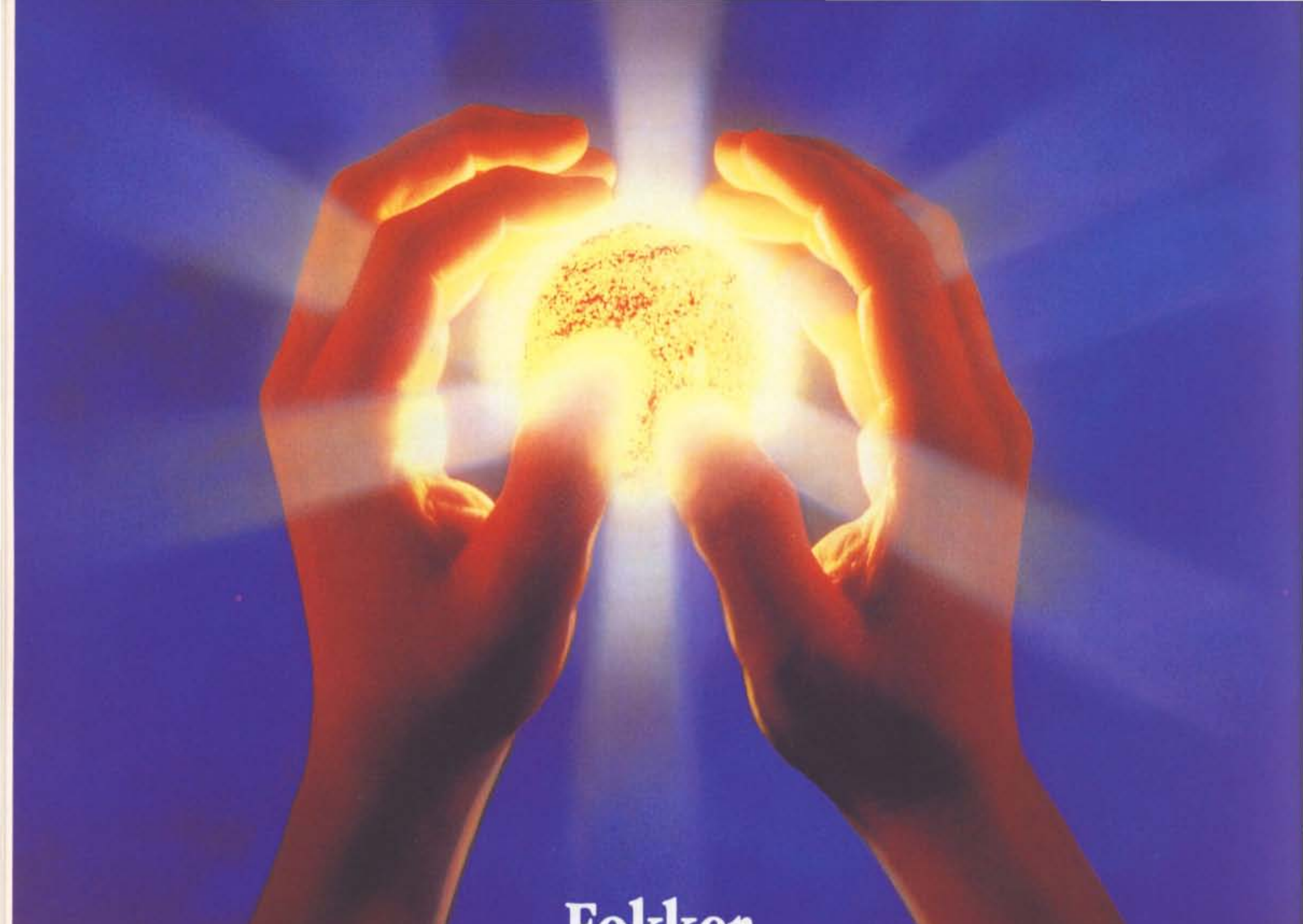
The many national and foreign ground stations around the World are also linked to the EECF, although in the case of the Japanese and German Antarctic stations in particular the link is not direct. Satellite-ephemeris and some processing parameters will be forwarded routinely by the EECF, and station reports fed back to it. In some cases, these stations will serve as focal points for their national ERS users: they will collect the user requests and make a first analysis of the observations required, with a view to resolving any conflicts and optimising data-acquisition schemes. These sets of requests will then be forwarded to the EECF for incorporation into the mission planning system. If a particular ground station cannot ensure long-term archiving of the raw data, it will send a copy of the SAR telemetry acquired to the PAFs, as required by the EECF.

Upon receipt of the storage media from the ground stations and successful completion of the archiving operations, archiving reports will be sent by the PAFs to the EECF. Those reports, which will include some information on the quality of the data, are to be used at the EECF for further updating of the ERS Catalogue. The PAF processing activity will involve two main approaches: the systematic processing of global datasets, such as altimetry and geodetic products and Wind-Scatterometer data over large pre-selected areas; and processing on user demand of SAR scenes and other offline products. The systematic processing also foresees the establishment of an online oceanographic databank at the French PAF in Brest, which will be accessible directly to ERS users authorised to do so by the EECF.

Product orders will be issued by the EECF based on user requests and PAF activity reports fed back there for system-monitoring and catalogue-updating purposes. The PAF products will then be delivered directly to users.

Campaigns will be carried out for calibration and validation purposes and in-situ data will be gathered at specially equipped test sites and by mobile platforms like aircraft and ships. Data gathered in ESA-sponsored campaigns will be stored at the EECF, while other in-situ data are to be stored at the PAFs themselves.

From the user's viewpoint, therefore, the EECF is the gateway to the ERS System and its services. The ERS products ordered will be delivered either via the Fast-Delivery Product service, directly from the PAFs, or from other ground facilities, depending on specific agreements and ERS Data Policy.



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The Processing and Exploitation of ERS-1 Payload Data

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The data emanating from the ERS-1 satellite will be generated by a set of instruments that differ substantially in individual concept. Their outputs will therefore be quite different in format, content and physical meaning, and they will be destined for use in a wide range of scientific and applications domains. As a consequence, a considerable variety of processing and information-extraction techniques will need to be applied for their efficient exploitation. The data distribution methods are also critical in that the data must reach particular users centres within given – and in many cases very short – time scales.

The ERS-1 mission will certainly be one of the most demanding Earth-observation missions yet flown in terms of data rates, instrument complement (number and complexity), multiplicity of applications (multi-disciplinarity), corresponding complexity of processing algorithms, requirements for archival and retrieval of important data sets, as well as for real-time distribution of a limited subset of products. Never previously has the role of the Ground Segment been so critical to the fulfilment of the mission objectives and hence the overall success of the mission.

Special attention has therefore been devoted to the design of the ERS-1 Ground Segment to ensure that the users will be provided with comprehensive and timely information about the availability of data sets, and more generally to provide them with good overall visibility of both satellite and payload operations and the Ground-Segment data-handling process.

Table 1. Scientific and applications disciplines with a potential interest in ERS-1 data

- Calibration studies
- Ocean studies
- Sea-ice studies
- Glaciology
- Meteorology
- Forestry
- Agriculture and soils
- Hydrology
- Cartography
- Geology
- Climatology
- Geodesy and geophysics

Primary ERS-1 scientific and applications goals

The ERS-1 mission has been prepared in close cooperation with several different user communities, and their relevant requirements duly taken into account in designing the overall system.

Early in the ERS-1 Programme, ESA issued an Announcement of Opportunity, aimed at stimulating proposals for the exploitation of the data, in both the scientific and applications domains. Several hundred replies were received, of which about 200 were retained, covering all of the instruments and most of the science and application areas initially foreseen for the mission. Whilst the response was outstanding from a scientific point of view, the applications domains were less well represented.

It was therefore decided to issue a second call for proposals, this time strictly related to projects in the relevant application domains, as so-called 'pilot' or 'demonstration' projects. The replies to this second call are currently being collected and collated.

We will focus here on the main categories of application and scientific activities covered by the replies to the first of the two calls for proposals, and the Mission Plan that has been devised to meet the associated requirements.

Though many of the proposals received for data exploitation are multi-disciplinary in nature, they can be roughly subdivided into the groups listed in Table 1. These various disciplines call for a variety of instrument performances, product characteristics, and delivery procedures.

The ERS-1 data-exploitation scheme

The overall Ground Segment is described in detail elsewhere in this Bulletin. We will concentrate here on the roles that the ERS-1 data will play in the various disciplines and, where appropriate, on the specific requirements that the latter impose.

The various ERS-1 products that will be

available, and their basic characteristics, are also discussed in the companion article on the Ground Segment.

Domains exploiting ERS-1 data

Calibration and validation studies
These consist of studies and research work aimed at:
- validating the performances of the ERS-1 instruments
- providing calibration parameters for these instruments
- validating the resulting products from a geophysical viewpoint.

To a large extent these activities consist of experiments conducted over specially equipped sites, with the participation of other facilities (airborne instruments, ships and buoys, ground-based instrumentation, etc.). They should take place mainly during the system commissioning phase (i.e during the first three months). With the present launch date (mid-May 1991), the activities related to the validation of wind and wave parameter measurements will take place in the October to December 1991 time frame, when the climatology of the site should allow measurements under a wide range of weather conditions.

The calibration and validation activities proposed with the Announcement of Opportunity have been incorporated as far as possible into this initial exercise which will involve the deployment of facilities in the Adriatic (Radar Altimeter), The Netherlands (SAR), Southern Spain (Wind Scatterometer), the North Sea, the US-Canada East Coast and the Caribbean (Wind and Wave measurements).

These calibration and validation experiments will require swift data circulation to the centres of expertise supporting them, both in Europe and in North America. Correlation of ERS-1 data with ground and sea measurements will also require particular attention. Several campaigns have and are being carried out in order to ensure the necessary coordination among all the data sources and the teams in charge of the data analysis.

The calibration and validation activities will not stop after this initial period, but are planned to be continued throughout the ERS-1 mission. They will be supported by the Product Control Service at ESRIN, in Frascati (I), which will ensure access to both the data gathered during the commissioning phase and those collected subsequently, either as part of ad hoc campaigns or in the course of routine monitoring activities, covering both satellite and instrument performances.

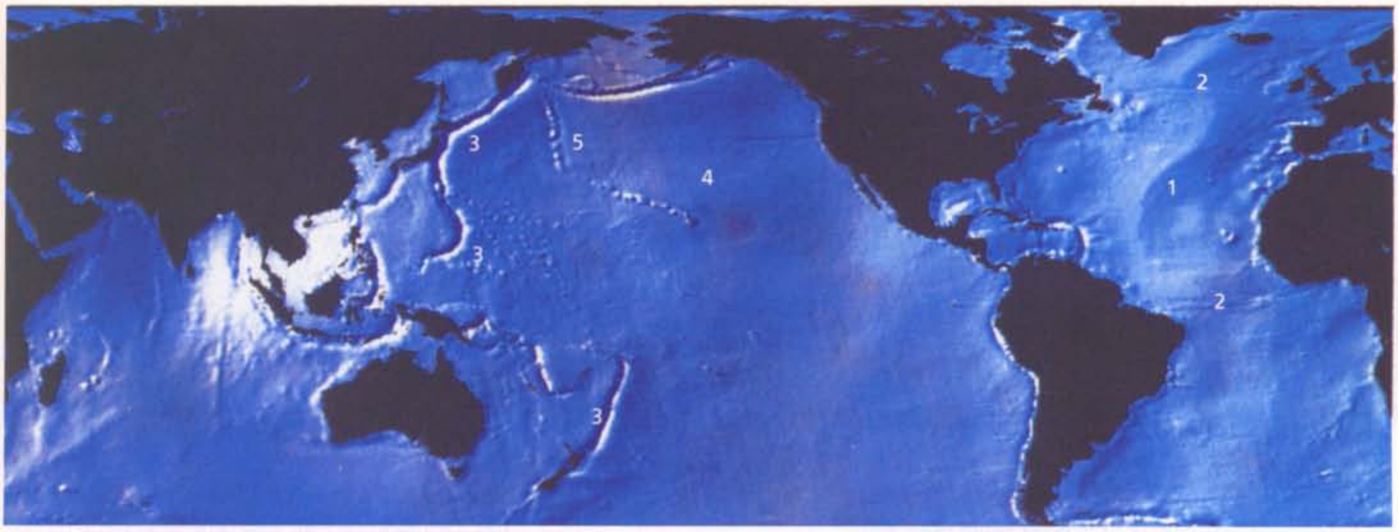
Ocean studies
The investigations and experiments covering oceanic phenomena can be subdivided somewhat artificially into five domains:

(i) Investigations of ocean wave patterns and related phenomena
These cover:
- The investigation of the exact interaction mechanism between the microwave radiation and the ocean surface.
- The development and dynamics of wave systems both in open oceans and in coastal waters and enclosed or semi-enclosed seas, such as the Mediterranean Sea.
- The climatology of ocean-wave systems.
- The relationships between wind and wave systems under various conditions.

A few investigations will address the use of wave measurements from ERS-1 instruments in operational applications, such as ship routing, and the sizing of oil-rig structures.

(ii) Sea-surface/subsurface topography studies
ERS-1's Radar Altimeter will allow detailed study of the topography of the ocean surface, of its variations over different time scales, and of the reference mean sea surface. Together with the Synthetic Aperture Radar (SAR), it will also allow correlation of features on the oceanic surface with sub-surface features, particularly in shallow waters.

(iii) Ocean circulation; thermodynamic features and heat fluxes
The Radar Altimeter will also allow studies of ocean-circulation features on a global scale. This will be particularly important in areas not systematically monitored by ships and other more traditional survey facilities. Particular attention is being devoted by ERS-1 Investigators to the study of mesoscale features in such areas as the Southern Oceans, East Australian Current, Indian Ocean, Antarctic Circum-Polar Current, Pacific Equatorial and Eastern Boundary Current. Specific experiments will address ocean-circulation features over continental shelves, tidal features, and circulation in the Mediterranean basin. Use will be made of SAR data whenever possible (i.e. in visibility of ground stations) in these studies. The injection of ERS-1 data into ocean-circulation models, on various scales, is also an important component of these studies.

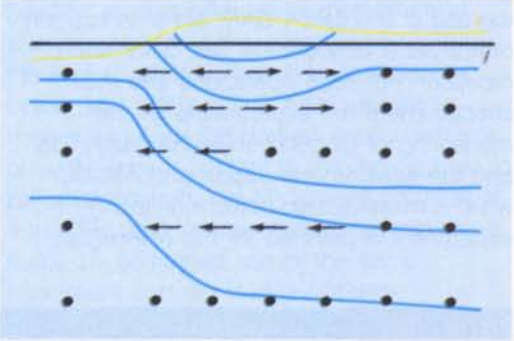


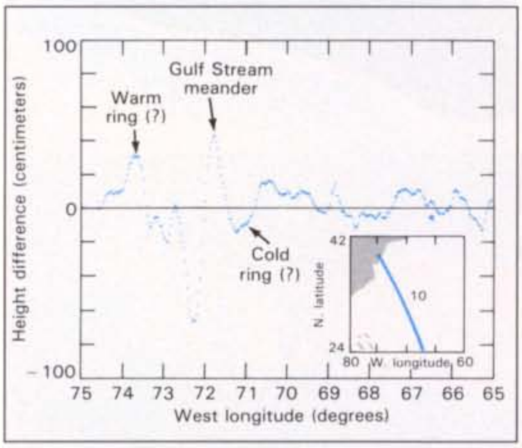
Finally, several experiments are planned to investigate the applicability of measurements from ERS-1 instruments (including in particular the Along-Track Scanning Radiometer) for the detection of thermal features in the ocean, their relation to ocean circulation, and to heat fluxes and heat exchanges with the atmosphere.

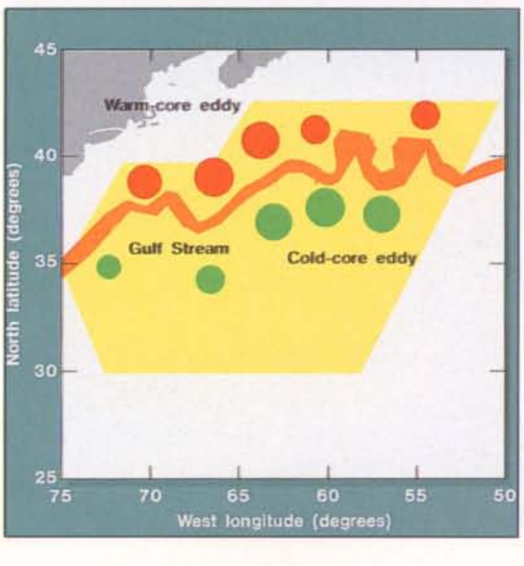
The data from ERS-1 will contribute to very large international undertakings within the framework of the World Climate Research Programme. One important element of this Programme is the World Ocean-Circulation Experiment (WOCE), which represents the first attempt to consider the global pattern of ocean currents, and to describe the World's oceans as a continuous fluid system interacting with the Earth's atmosphere.

Global ocean circulation is a crucial interactive component of our climatic system, and one without which no reliable assessment can be made of the long-term sensitivity of climate to external influences, like man-made modifications to the environment. The WOCE is designed to provide the database for the empirical description required to support long-term climate modelling.

The data system on-board ERS-1 and on the ground has been expressly designed to support the investigations and the pre-operational requirements of these and other disciplines: the data from the low-bit-rate sensors (all except SAR) will be recorded on one of the two onboard recorders (the second being kept as a backup) and played back while in visibility of one of the ESA stations. This will ensure global or quasi-global coverage of the World's oceans. The data played back will be processed at the ground stations, and the resulting products (wind vectors, wave patterns, wave heights,







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2 **Figure 1. Topography of the ocean floor reflected in that of the surface. (Courtesy of NASA)**
This Seasat-derived relief map reveals the Mid-Atlantic Ridge (1) and associated fracture zones (2); the Kuril, Marianas and Tonga trenches (3); the Hawaiian Islands chain (4); and the older Emperor seamount chain (5)

3 **Figure 2. Schematic cross-section of the Gulf Stream, with the current flowing perpendicular to the plane of the page. The coloured lines are contours of equal water density. Line *l* represents a level surface and line *s* the actual sea surface**
(From H. Stommel, The Gulf Stream, Cambridge Univ. Press, 1966)

Figure 3. Height differential along a radar-altimeter ground track. The Gulf Stream meander is
4 **evident, as are possible warm and cold rings on either side.**
(Courtesy of E.B. Dobson)

Figure 4. A sample mesoscale product map derived from Geosat altimeter data products. It shows the locations and characteristics of mesoscale ocean features, which will also be derived from ERS-1 Radar Altimeter data
(From M. Lybanon & R.L. Crout, Johns Hopkins APL Tech. Digest, No. 2, 1987)

etc.) made available for distribution within 3 h of acquisition, allowing them to be used by operational entities.

(iv) Coastal processes
These experiments address the evolution of coastal morphologies in relation to oceanic processes, currents, tides and wave systems. The SAR will be the primary instrument for these studies, although the close relationship to be established with meteorological and oceanographic features requires a thorough exploitation of the whole ERS-1 payload complement.

(v) Human operations at sea: oil pollution, ship detection, etc.
A limited number of investigations address the use of the ERS-1 SAR, either in support of human endeavours at sea or for the monitoring of such operations and their effects. There are experiments for the monitoring of oil pollution in the North Sea and the seas around Japan and Alaska, while a massive ship-traffic monitoring experiment is planned for the Norwegian Sea. Support to service providers in the North Sea will be attempted through the derivation of information from SAR data on oceanic fronts, oil pollution and coastal bathymetry. Most of these experiments will require the real-time availability of SAR data. Their success will further justify the need for very fast SAR processing and analysis systems, and for real-time SAR data transmission, which contributes to the complexity of the Ground Segment.

Figure 5. Aircraft C-band SAR image taken off the coast of Newfoundland in March 1987, during the Labrador Ice Margin Experiment (LIMEX). (From L. McNutt et al., AGU EOS Trans., No. 23, June 1988)
The image has been colour coded, with dark blue for smooth, possibly flooded ice, light blue for rough ice, and pink shades for ice broken into small cakes. The pink/blue front near the centre of the image is a shear zone. Other shear is apparent along pink lines within the pack, while the ice at the coast is almost stationary

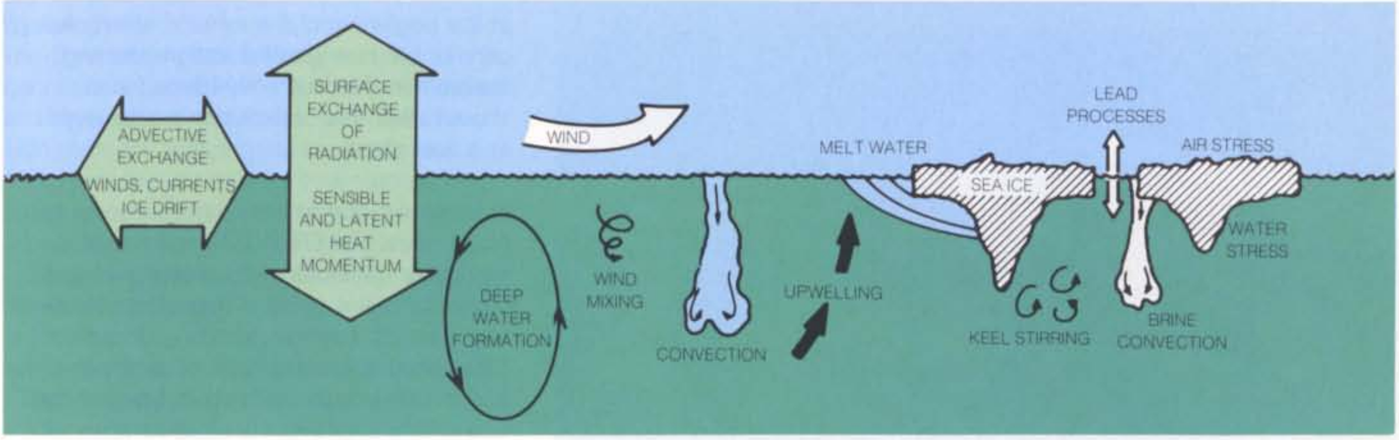
Sea-ice studies

The exploitation of SAR data in studies related to the mapping and monitoring of sea ice has been one of the main drivers for the inclusion of that instrument in ERS-1's payload. The response from the scientific and applications community has been correspondingly high, resulting both in a number of individual experiments and in important coordinated efforts involving several experiments.

Most of these experiments are being coordinated within the framework of the PIPOR (Programme for International Polar-Ocean Research) Group. The main areas of interest – linked to the availability of ground stations for SAR data acquisition – are the Baltic Sea, the Greenland Sea, the Barents and Nansen Seas, the Labrador Sea, the Beaufort, Chukchi and Bering Seas, the Weddell Sea, various Antarctic seas within the coverage of the available ground stations (Syowa, O'Higgins, etc.), the Okhotsk Sea around Northern Japan and the seas around Alaska. Attempting a gross categorisation of the planned investigations leads to the identification of four groups:

- the ice-mapping, ice-extent monitoring and ice-classification studies. These also include monitoring of ice dynamics and a few exercises on iceberg monitoring
- the monitoring of the complex interactions between ice and open water in the so-called 'Marginal Ice Zone'
- strictly linked to the previous ones, the studies on the air–sea–ice interactions in polar waters, the related heat fluxes and the complex climatic implications of such phenomena
- finally, the ice-monitoring activities in support of operational applications in polar ice-infested waters.

All of these investigations rely on common tools, the same additional supporting information, and represent complementary inputs to the understanding of the complex dynamic processes taking place in polar waters, whether or not they are covered by



ice. They also rely upon the prompt availability of data to the investigators and to the operational entities. Again everything possible has been foreseen in the ERS-1 System to make this feasible and to further demonstrate that the timely availability of satellite-acquired data is a key factor to their usefulness in most operational domains.

Glaciology

Two instruments in the ERS-1 payload are of particular importance to the monitoring of the status and evolution of permanent ice sheets extending over land surfaces (Antarctic, Greenland, and Alaska glaciers): the SAR and the Radar Altimeter. This group of studies addresses the topographic mapping of the main ice sheets of our planet, their dynamics, in terms of both displacement and mass balance, and their long-term climatic implications. These studies do not generally require rapid access (few hours) to the data; rather they require the collection of systematic and coherent data sets at fixed intervals (e.g. at six-monthly intervals), which will also allow the study of seasonal variations in the ice parameters.

Meteorology

The main contribution of ERS-1 to meteorology will be provided by the wind-vector data sets derived from the Wind Scatterometer. Additional data sets available will include the wind-speed data from the Radar Altimeter, and the sea-surface temperatures from the ATSR. It is also planned to introduce wave data from the SAR and the Radar Altimeter into meteorological models in order to improve weather predictions.

The primary investigations therefore address the problem of correctly assimilating the satellite data into these models, and assessing their impact on the accuracy of predictions. Some investigations also aim at direct validation of the empirical model that is used in the derivation of the wind vectors from the backscattering coefficients measured by the Scatterometer.

Specific studies address evaporation and energy balance at the ocean surface, and the exchange of carbon dioxide between ocean and atmosphere. Also relevant to meteorology are the derived measurements of water-vapour content in the atmosphere to be obtained from the Microwave Sounder of the ATSR, and the rain measurements to be made by combined use of the same instrument and the Radar Altimeter.

The use of ERS-1 data in the context of operational meteorological forecasting imposes very stringent data-delivery requirements due to the strict deadlines

Figure 6. Schematic representation of air–sea–ice interaction (Courtesy of P. Lemke)

Figure 7. The circles represent the areas for which the three northern ERS-1 ground stations of Kiruna, Gatineau and Fairbanks will allow the acquisition of SAR data. The larger circles correspond to the acquisition masks for 2° minimum antenna elevation, and the inner circles to 5° elevation. The dashed rectangles represents the main ice experiment sites for the ERS-1 mission

Figure 8. Antarctic ice sheets show large variations in altitude which can be mapped by ERS-1's Radar Altimeter

of the operational centres. The ERS-1 acquisition and processing facilities are therefore connected to the meteorological operational network, and the necessary data sets will be provided within 3 h of acquisition.

Forestry

Appropriate use of the SAR instrument in the monitoring of forests is dependent upon correct understanding of the interaction of the instrument's microwave radiation with the particular composite target constituted by the forest canopy, the branches and trunks of the trees, and the underlying soil. Several investigations will attempt to address this problem.

The monitoring of the overall status of the forest, in terms of the health of its component species, is also linked to a correct understanding of the microwave interaction, though in this case it is empirically more feasible to arrive at statistically valid statements.

Finally, ERS-1 will certainly make it easier to assess forest extent via systematic mapping operations, allowing the surface area covered and its variations, particularly as a consequence of man-induced destructive processes such as pollution, burning, felling, and uncontrolled agricultural practices, to be reliably determined.

Important international programmes are planned in the course of ERS-1's lifetime with the objective of assessing both the status and evolution of the main forest ecosystems of the World. The availability of an adequate set of ground stations will certainly allow this objective to be achieved for the South American tropical forest in the Amazonian Basin. The possibility of systematically covering the Southeast Asian tropical forests at the beginning of the mission seems less certain, but new ground stations coming available in the 1992–1994 time frame should allow this objective to be achieved at a later stage.

In all cases, due to its being unaffected by cloud cover, the ERS-1 SAR will make an invaluable contribution by allowing integral coverage of the areas of interest over specific time periods, thereby providing consistent data sets that can be used as a reference for and in combination with other types of data.

Agriculture and soils

The above-mentioned need for a correct understanding of the interaction between the satellite's microwave radiation and the vegetation cover and underlying soil is also important for this discipline. Attempts will be made to verify models of this interaction using the ERS-1 SAR.

The need for classification inherent in the assessment of land use and crop yield will naturally lead to the combined use of SAR data and data from optical sensors (e.g. Spot and Landsat). Several studies address the methodology required for combining these datasets; others attempt the validation of the interaction models and their improvement; still others have the objective of deriving information on vegetation water content and on soil moisture content from SAR data.

Though none of the studies described strictly requires a fast turnaround time for the processed data, some of the applications in the crop-yield-forecasting domain may benefit from a response time of the order of one day.

Once again the ERS-1 Ground Segment is designed to ensure prompt delivery of these data to operational centres (less than 12 h initially, and gradually reducing to 3 h in the course of the mission, as requirements increase).

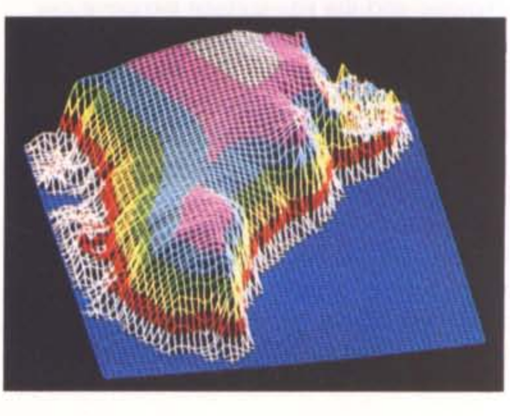


Figure 9. Three-dimensional surface-elevation map of Southern Greenland produced from 110 days of retracked Geosat radar-altimetry data (500 m colour contours). (From H.J. Zwally et al., Johns Hopkins APL Tech. Digest, No. 2, 1987)

Hydrology

The Synthetic Aperture Radar's ability to discriminate between wet (and water) bodies and dry surfaces makes it a very suitable instrument for hydrological applications. This capability is exploited in a number of investigations which address:

- the determination of snow and ice properties in mountainous areas, and run-off forecasting
- the use of satellite data in the management of water resources and in hydrological studies
- the study of wetland conditions and of soil moisture conditions.

Cartography

Using SAR data for cartographic applications requires that they be accurately corrected from a geometric viewpoint, and arranged in accordance with an appropriate geographic reference. This will enable them to be merged with information from other sensors, both airborne and spaceborne, and with ground-collected information, thereby taking maximum advantage of the SAR's all-weather sensing capability.

While the ERS-1 Ground Segment already includes the ability to generate precision-corrected SAR images, several investigations address the methodology to be used for such corrections, and for incorporating SAR data into geographic information systems. A first application of this methodology will result in a radar map of Germany.

Geology

Detection of geological features is a well-demonstrated application of Synthetic Aperture Radars. Specific investigations address the problems of mineral exploration, fault mapping, and volcanic structures.

Climatology

Many of the research and investigative activities mentioned in the previous sections are relevant to the establishment and verification of the relative importance of variables and parameters that may impact on climatic effects and of their interrelationships. Oceanographic investigations, ice-sheet and sea-ice research activities, meteorological contributions, change assessment of land surfaces and land cover, and measurements of hydrological parameters, all bear witness to the enormous potential of the ERS-1 system for monitoring climatic parameters and climate trends, on both a regional and a global scale. The continuity of the measurement process with the availability of the ERS-2 satellite, and hopefully of the new generation of platforms later in the decade, which will provide consistent and compatible data sets, will allow the buildup of longer time series of measurements that should be more meaningful from a climatic viewpoint.

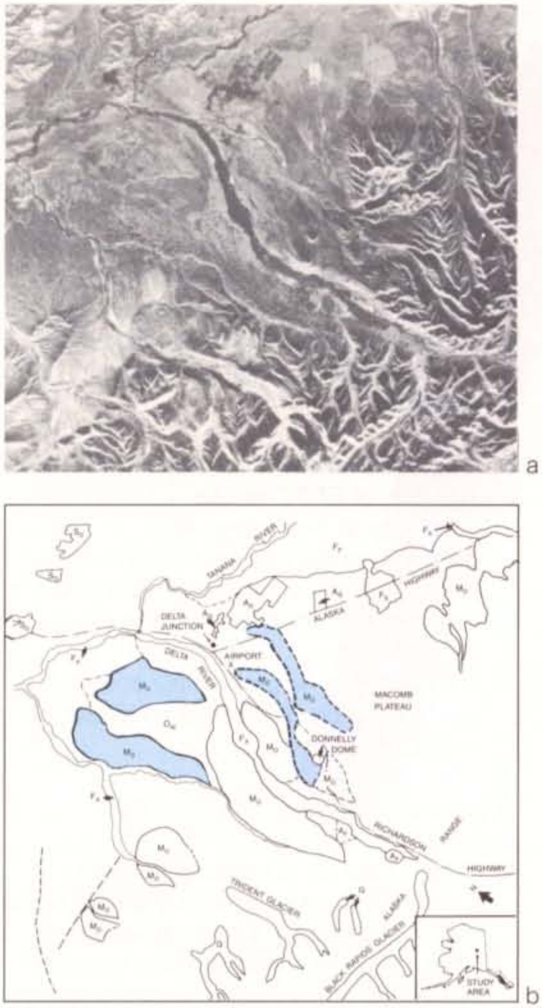


Figure 10
(a) Seasat SAR image taken on 4 August 1978 of the Delta Junction area of Alaska, showing moraines and other geological features

(b) Map of geological units observable in the SAR imagery

(From NASA/JPL Publication 89-14)

Geodesy and geophysics

ERS-1's Radar Altimeter and PRARE equipment provide a unique opportunity for research activities in geodesy, geodynamics, geoid determination, and orbit determination, and many of the proposed investigations address these topics. The large number of PRARE stations that will be deployed testifies to the interest generated within the solid-Earth community by the ERS-1 mission.
A number of ground-based laser stations, which will exploit the satellite's onboard laser retro-reflectors, will also assist in the orbit-determination process and in the derivation of geodetic parameters.

Overall investigative plan and anticipated results

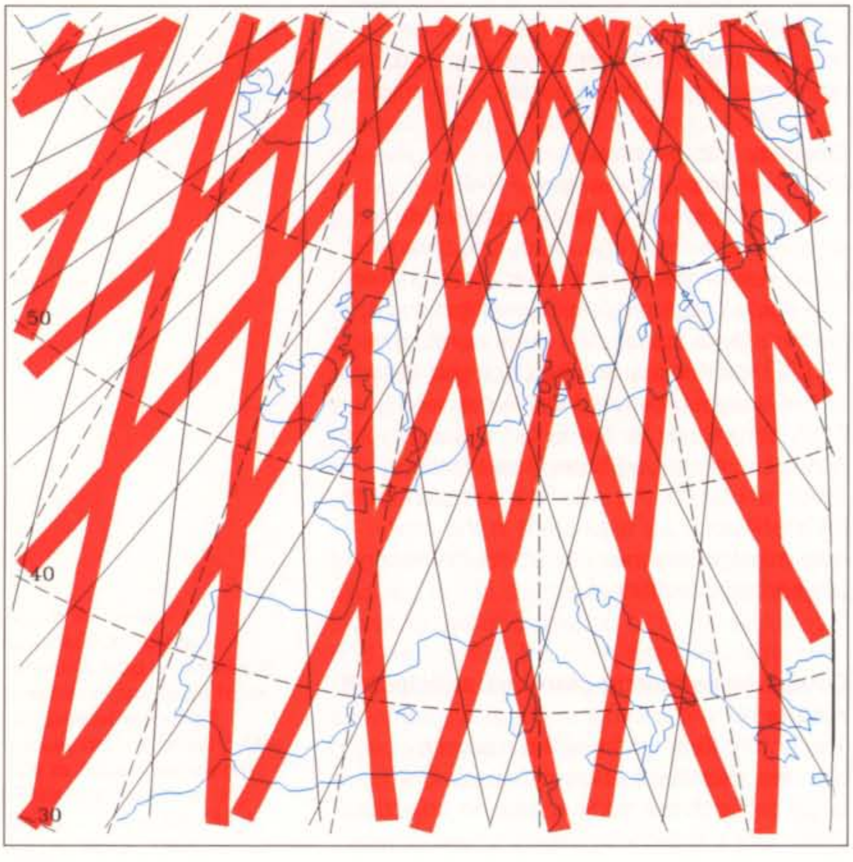
The anticipated results of the research activities described above correspond in large part with the original mission objectives. The major discrepancy lies in the domination of the scientific research topics and the substantial lack as yet of specifically application-oriented activities.

The multiplicity of investigations and their different characteristics imply an appropriate distribution of efforts both before and during the mission. Data will not be available for all investigators in all domains from the beginning of the mission; some will require months or years to be completed, while others will require a particular orbital configuration (see next section).

Two main Workshops are foreseen for the presentation of ERS-1 results:
- A first one in September 1992 dedicated to the presentation of initial results from the commissioning phase, the first multidisciplinary phase, and the first ice phase.
- A second one, approximately one year later, for the presentation of all available investigative results.

In general, it is hoped that the ERS-1 payload will:
- demonstrate an operational capability in a number of disciplines. This should be particularly true for the Wind-Scatterometer data for meteorological forecasts. The ATSR, SAR wave data and Radar-Altimeter wind and wave data are also candidates for assimilation into meteorological modelling and forecasting processes. SAR data, integrated into various types of geographical information systems, will contribute to the systematic long-term monitoring of coastal processes, forest extent and conditions, cartography, land use, land ice and snow extent and conditions, and to the assessment of the impact of human activities on natural systems. SAR data will also be used, from the outset of the mission, for operational ice monitoring and ship-traffic monitoring; ATSR data should provide useful support to fishing activities;
- provide an essential contribution in a number of scientific fields such as ocean topography, ocean circulation, geodesy and geodynamics, sea-ice dynamics, sea-ice formation processes, air–sea interaction processes, and microwave interactions with the Earth's surface;
- constitute an important milestone in the build-up of long time series of data for the understanding of the evolution of climate and major ecosystems. The ERS-1 and -2 mission sequence will provide coherent and compatible data sets over a period of four to six years and on very large spatial scales. This should serve to demonstrate the invaluable contribution that space-based instruments can make to the monitoring of the Earth's systems in advance of the larger platforms coming on stream at the end of the century.

Figure 11. ERS-1 SAR (red tracks) and Radar Altimeter (black lines) coverage for Europe using the 3 day repeat cycle fixed to Venice (Italy) for the satellite commissioning phase



Together with the other missions being flown in the same time frame (e.g. Landsat, Spot, J-ERS, Radarsat), ERS-1 and ERS-2 will offer a unique opportunity to explore the technical and logistical problems related to the establishment of international data systems in support of environmental research and modelling, climate modelling, etc. This will require important efforts for the definition and testing of the necessary methodologies, for example in terms of data access, data exchange, information extraction and exchange data merging.

Mission planning

The complexity of the ERS-1 mission, which effectively consists of a combination of several different missions, requires a very careful approach when planning the mission operations. The different disciplines, which have been mentioned in the previous paragraphs, often have conflicting requirements in terms of spacecraft orbit, instrument operations, and data acquisition.

ERS-1's features include the possibility of changing its orbital configuration in two ways:

- By changing the orbit itself by a few kilometres in altitude, thus varying the repeat cycle, i.e. the number of days between two consecutive descending overpasses of the same point on the Earth's surface. With these orbital adjustments, this repeat cycle can be varied from 3 days to several hundred days. In the actual Mission Plan, 3, 35 and 176 days are the selected repeat cycles.

- By rotating the satellite body around its velocity vector (so-called 'roll-tilt mode'), the angle at which all instruments look at the Earth can be varied. This will allow experimention with the Synthetic Aperture Radar at an incidence angle of 35°, instead of the standard 23°, thereby permitting analysis of a totally different set of signatures from objects on the Earth's surface, including in particular vegetation.

In addition, owing to the different characteristics of the various instruments, and in particular their power consumptions and data rates, a number of practical constraints have to be respected in planning the mission operations. Examples of these constraints include:

- The SAR can only be operated for an average of 10 min per orbit, of which a maximum of 2 min may be during eclipse. It must be operated within visibility of a ground data-acquisition station as its data cannot be recorded on board.
- The SAR and the Wind Scatterometer cannot be operated simultaneously.
- All low-bit-rate instrument data can be recorded by the onboard tape recorders. Their capacity is such that the recorder in use must ideally be played back and the data transmitted to a ground station every orbit.

The Mission Plan subdivides ERS-1's lifetime into a series of time periods with different orbital characteristics, objectives and priorities. It also establishes rules for the allocation of resources (SAR in particular) to the various mission components and for solving conflicts between incompatible requirements, whilst fully respecting operational constraints.

Taking into account the different mission objectives, and attempting to satisfy them in a quasi-optimal way in the course of ERS-1's lifetime, has led to the definition of seven phases of activity during the mission:

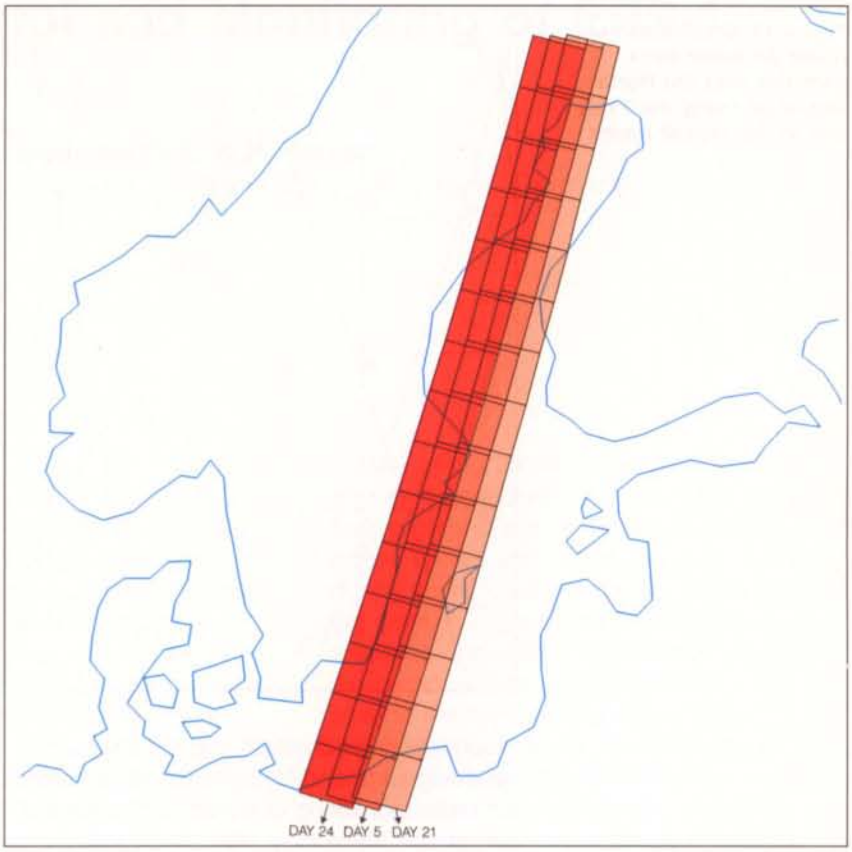


Figure 12. Overlapping SAR image coverage with a 35 day repeat cycle. All parts of the Baltic Sea are imaged four times during the 35 days

Phase 0: Orbit acquisition, initial switch-on and functional check-out. This will last about 2 weeks.

Phase 1: The 'commissioning phase', using a 3 day repeat cycle, with the positioning of the subsatellite tracks ensuring an overpass of the Radar-Altimeter calibration site in the Adriatic Sea off Venice (I). This phase is dedicated to calibration of the ERS-1 instruments and validation of the derived data products. The orbital pattern selected is also compatible with the SAR and Scatterometer calibration sites, and with those sites selected for geophysical validation of wind and wave products. This phase will last about three months, from end May to end August 1991.

Phase 2: The first multi-disciplinary phase. This will have a repeat cycle of 35 days, which will ensure full Earth coverage with the SAR. This phase will serve as a preparation for the second, much longer, multi-disciplinary phase. It will permit the collection of the first complete SAR datasets over areas of interest (Europe first), and within the visibility of available ground stations (several non-European ground stations will not yet be in operation). It will also enable initial scientific experiments, both with SAR and with other instruments (particularly the Radar Altimeter),

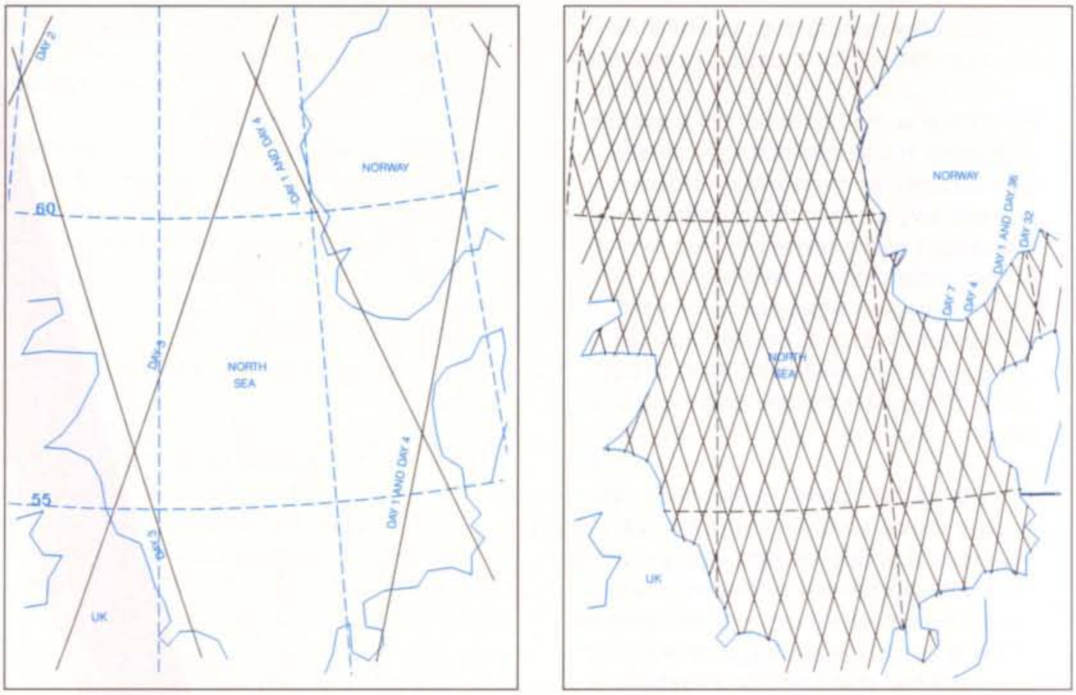


Figure 13. Comparison of Radar Altimeter track densities over the North Sea when using the 3 day and 35 day repeat cycles

though its short duration and the season (end-August to end-December) will not allow full-scale monitoring of dynamic phenomena (vegetation, hydrology, etc.).

Phase 3: The first ice phase. A 3 day repeat cycle has been selected for this phase in order to allow frequent re-visiting of critical ice areas (important experiments will take place in the Baltic Sea and Gulf of Bothnia in particular, as well as in the Labrador sea) in the Northern Hemisphere, and of the whole Arctic Basin in general. This phase will last 3 months.

Phase 4: The second multi-disciplinary phase. This phase, lasting 21 months, from the beginning of April 1992 to the end of 1993, using an orbit with a 35 day repeat cycle, will support the whole range of SAR applications and scientific research objectives. It will allow the monitoring of renewable resources and dynamic phenomena in general, over longer time scales and with full coverage of the areas of interest, always within the visibility of available ground stations (more should be operational at this stage). In addition, the high track density offered by this orbital configuration will be exploited for a more accurate estimation of the geoid with the Radar Altimeter, and for the study of meso-scale features in the open ocean. During this phase, tentatively in the first half of April 1992, the spacecraft will operate for 2 weeks in the 'tilted mode', thus allowing the collection of SAR data sets, using an incidence angle of 35°, over a number of sites of special interest.

Phase 5: The second ice phase. This will be a repetition of the first, 2 years later, from January to March 1994, with identical characteristics.

Phase 6: The geodetic phase. The orbit will have a 176 day repeat cycle, and the specific objectives will be the determination of the reference marine geoid plus high-density topographic mapping of land surfaces and ice sheets, using the Radar Altimeter in both cases. The operation of the other instruments should continue as during Phase 4.

The Control and Monitoring of ERS-1

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Introduction

For ERS-1, ESOC will fulfil its traditional role of controlling and monitoring this ESA satellite. However, the ERS-1 mission is such that the ground facilities required to execute this task are by no means traditional. In practice, they encompass several new elements, the design of which has presented the engineers involved with several new technical challenges. These challenges having been successfully met, the ERS-1 control and monitoring facilities are now 'ready for launch', and the operations staff trained, enthusiastic and 'raring to go'!

To date, the operations for some twenty-eight satellites have been conducted from the European Space Operations Centre (ESOC), since its establishment more than twenty years ago. The early missions, with operational lifetimes of typically two to five years, were relatively modest in their requirements for ground-segment facilities to satisfy the demands of the users of the satellite data. Future missions, on the other hand, are tending towards very complex ground segments in direct proportion to increasing complexity in the space hardware and have, in general, considerably longer operational lifetimes. ERS-1 lies somewhere in between these extremes. Although its planned operational lifetime is just two years, the space and ground systems needed are very complex, with a wide distribution of responsibilities. Moreover, the control and monitoring facilities have been designed with an eye to the future, i.e. ERS-2 and the planned series of polar-orbiting Earth observation missions utilising the Columbus Polar Platform.

A 'day' in the two-year life of ERS-1 will last 100 min, divided roughly into 70 min of sunlight and 30 min of darkness, as the satellite orbits about 750 km above the Earth's surface, in a Sun-synchronous polar orbit. ERS-1 will circle the Earth 14 times per day, at a speed relative to its surface of 7 km/s, taking 25 min to progress from the equator to the North Pole. It will be visible from a ground station located anywhere on the Earth's surface for only 4 to 12 min during each 100 min orbit, depending on the azimuth angle of the satellite with respect to the station. These short passes, the continuous eclipse/sunlight cycle with attendant thermal and battery-charging implications, the power demands of the active microwave instrumentation on board, the high data rates generated, and the need to deliver fast-delivery products to users within 3 h of onboard measurement, have all acted as drivers in the design of the ground segment.

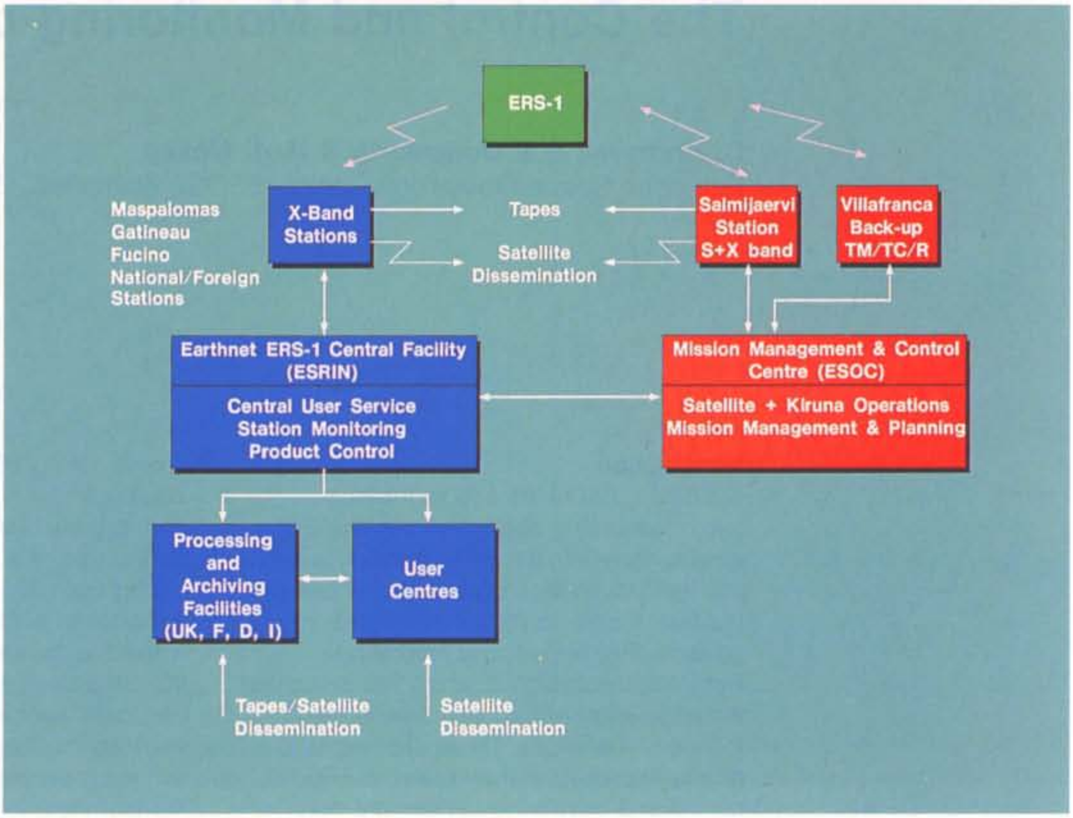
The ERS-1 control and monitoring facilities at the Mission Management and Control Centre at ESOC (Fig. 1) have been developed based on the following programme milestones and timetable:

Requirements definition:	1985/1986 (1.5 yr)
Design and development:	1987/8/9 (3 yr)
Integration and system testing:	1990/91 (1.5 yr)
Launch:	May 1991

Early days

Typically, activities associated with establishing the ground facilities to support a space mission start some six to seven years before the launch, and ERS-1 has been no exception. Not only are 'standard' facilities (modified as appropriate) re-used, but the demands of a specific mission, and particularly ERS-1 with its low polar orbit, present the additional challenge of implementing new and unique features within the existing infrastructure to provide a coherent system to support the mission. For ERS-1, these new features include:

Figure 1. The ERS-1 Ground Segment



- A ground station at Salmijaervi (Kiruna) in Northern Sweden (Fig. 2), some 200 km north of the Arctic Circle, as the prime ERS-1 station for S-band tracking, telemetry reception and telecommanding, X-band data reception and the generation of fast-delivery (FD) products.

- A control and monitoring philosophy for the satellite and Salmijaervi station appropriate to ERS-1's short ground passes and based upon the use of automatic schedules, which will pre-programme the operations of the station and the satellite in a coordinated, user-requirement-driven manner, some 24 h in advance.

- The complexity of the space segment with, for example, 17 onboard intelligent processors (compared with five on Exosat) and the associated complexity of the ground software needed to control the system.

- The interface to the user community via the Earthnet ERS-1 Central Facility (EECF), located at ESRIN, in Frascati (I).

- The high data rates generated by the onboard instrumentation, e.g. 105 Mbit/s of real-time Synthetic-Aperture Radar (SAR) data, 1 Mbit/s of real-time instrument data, and 15 Mbit/s of playback data from onboard tape recorders.

In designing the ERS-1 control and monitoring facilities, the overall mission aims of global coverage for ocean/ice monitoring and regional land/ice SAR imaging must be satisfied within the design drivers and new features identified above, at the same time minimising and simplifying the interfaces in the overall system. Thus, the functions of telecommanding (TC), telemetry (TM) and ranging (R), can be executed only during the short Salmijaervi station passes. Satellite operations and the closely-correlated station operations have therefore been automated and will be executed from 24 h schedules prepared at the MMCC from many different inputs. These schedules include the satellite (i.e. platform and payload) operations schedule itself, the Salmijaervi schedules for data acquisition, processing and distribution, and scheduling information for all other X-band ground stations. The following table illustrates the relative complexity of the ERS-1 operations compared with other missions:

	ERS-1	Spot-1	Marecs-A
Commands/day (approx.)	1000	50	50
Total commands (approx.)	2250	500	250
Telemetry parameters (approx.)	5750	500	300

The kernel of the ERS-1 control and monitoring facilities is the MMCC software, which contains all the coding necessary for mission planning, mission management, telecommanding, telemetry processing, performance assessment, communications and operator displays. This software, involving over half a million lines of code, is implemented on fully redundant ERS-1-dedicated computer systems.

A multi-staged approach has been adopted in the design, with five distinct software deliveries, each one a working system offering increasing levels of functionality from a basic telemetry/telecommand level to the final system with all facilities. This enabled the users (Operations Department) to work at a very early programme-development stage with a usable system in order to carry out interface tests with the other subsystems and the satellite. This in turn avoided a first coming-together of many separately developed elements at a late, and inevitably critical, phase in the Programme. As a consequence, development and delivery of the satellite simulator took place in time for early testing of the five stages of MMCC software.

Flight-dynamics services are usually provided for orbit determination and prediction, satellite-attitude monitoring and command generation, and manoeuvre support. ERS-1 requires a more complex service than normal in this respect and the system has been designed for maximum autonomy, to be able to cope with a difficult Launch and Early Orbit Phase (LEOP), short visibility periods, and rapid event sequences. Accurate modelling for air drag and gravity will enable ESOC to provide an orbit determination of sufficient accuracy (approx. 60 m along-track) as input for the various ERS user research programmes aimed at very accurate orbit-characteristic determinations (using PRARE and laser data).

Private ESA telecommunications networks will link the MMCC with the other elements of the ERS-1 ground system, including the additional facilities being established for the critical LEOP period, and will provide the necessary security against unauthorised access.

Simulations of the LEOP and other routine and critical aspects of the mission are being carried out in the last four months prior to launch in order to train the operations personnel thoroughly in all the procedural activities related to mission success.

Figure 2. The Salmijaervi ground station near Kiruna, in Northern Sweden

Getting ready for launch

Five days before launch, ESOC will prepare the final set of commands to be loaded into the satellite prior to lift-off. These crucial commands will specify the positions of the Sun and Moon relative to the Earth as parameters for the onboard Attitude and Orbit Control Subsystem (AOCS) to allow it to measure the satellite's attitude.

A simulation of the countdown and lift-off operations will take place two days before launch, involving the complete Ground Segment and the Launch Control Centre at Kourou, in French Guiana. Successful completion of this last simulation will confirm that the launch team in Kourou, the ground stations, and the control team in Darmstadt are fully prepared.

It has taken many months of preparation, and negotiation with our international partners in space operations, to bring the network of stations to a state of readiness for the first week of ERS-1 operations. NASA, NOAA, and the Centro de Estudios Espaciales (University of Chile) have made ground stations at Wallops Island (Virginia), Fairbanks (Alaska) and Santiago (Chile) available to ESOC, to complement ESA's own stations in Kourou, Kiruna (Sweden), Villafranca (Spain) and Perth (W. Australia) (Fig. 3). These seven stations are required to give the satellite control team the necessary visibility of the critical events that will occur during the LEOP operations.

Figure 3. The seven ground stations to be used during the Launch and Early Orbit Phase (LEOP)

Each pass over a ground station will last on average about 10 min, but can be much shorter if the satellite is 'seen' close to the ground station's horizon. The choice of ground station and the sequence of events onboard the satellite has been carefully harmonised both to allow critical events to be monitored as they take place, and to be able to take overriding control in the unlikely event of an onboard anomaly.

LEOP operations

The LEOP, although short, is a highly critical period during which the consequences of failures onboard the satellite can range from a partial loss of capability to total loss of the mission. In addition, the ground-segment operations for this critical phase for ERS-1 are very complex, and a large operations team will therefore be formed specifically for this period. Technical support will be provided by Project and Industry experts, who will monitor events from the ESOC Project-Support Room. Flight-dynamics support, for orbit determination, AOCS commanding and deployment monitoring, will be provided from a Dedicated Control Room (DCR) adjacent to the Main Control Room.

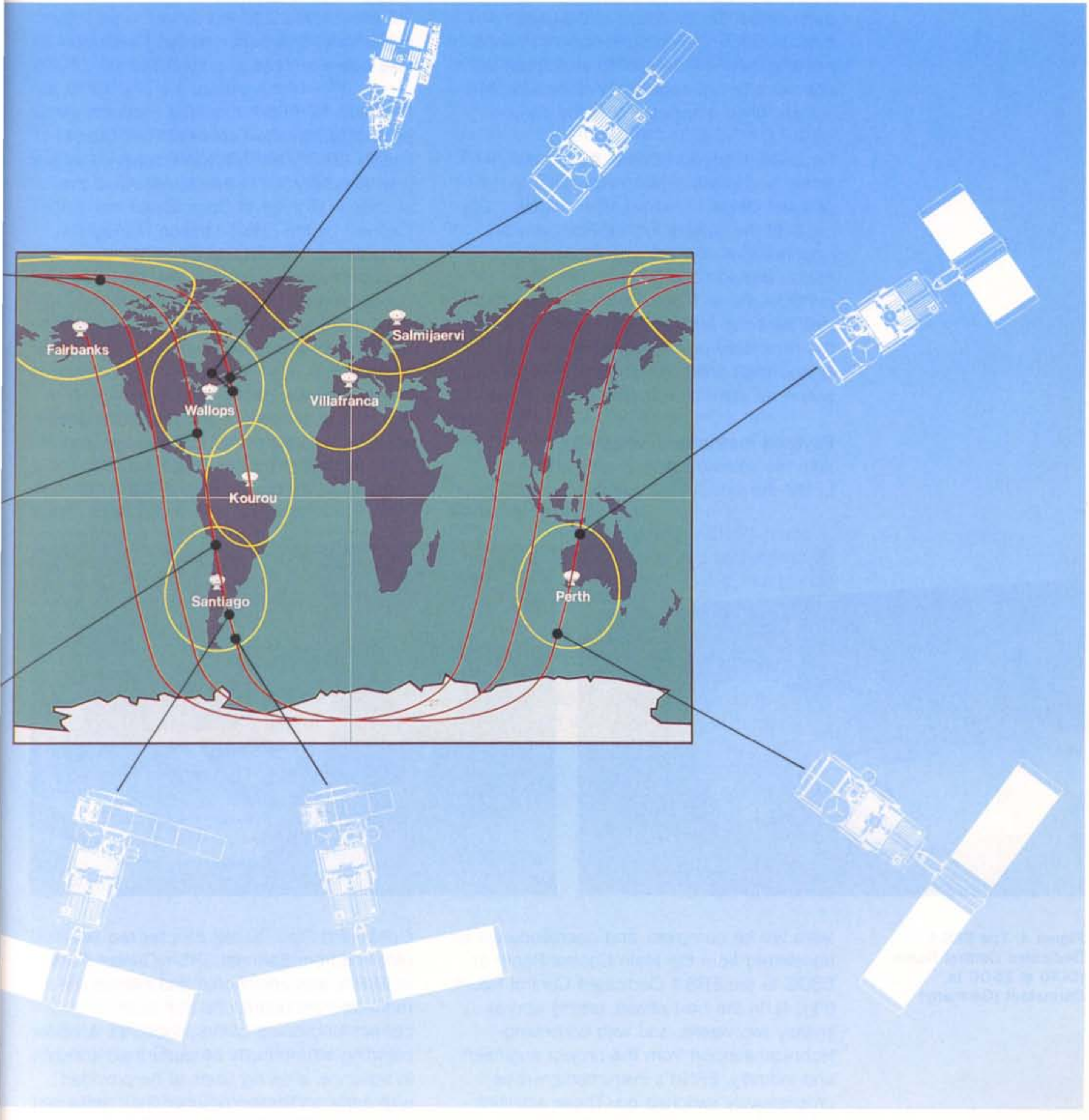
The satellite will be operated from work stations in the Main Control Room by the Spacecraft Operations Manager, four Systems Engineers and two Spacecraft Controllers, based on flight-control procedures that have been carefully developed, tested and applied throughout ground-system integration and verification. The operations of the communications network and ground stations will be managed by the Ground Operations Manager, and controlled by two Ground Configuration Controllers. Overall control will reside with the Operations Director, who will be in continuous contact with the ERS-1 Project Manager in Kourou.

Into orbit

Activities at the launch site will be followed at ESOC from about 8 h before launch, when the onboard software will be loaded and telemetry generation will start. Telemetry data will be routed via the ground station at Kourou to Darmstadt. Two hours before lift-off, the prime operations team will take their positions and make the last-minute checks on the control system and Ground Segment. Shortly before the launch window opens, the Operations Director at ESOC will confirm the 'Readiness of the Ground Segment for Launch' to the Launch Director in Kourou, thereby allowing the countdown to continue.

The exact moment of lift-off within the 4 min launch window will be immediately transmitted via ESOC to each of the ground stations, so that their antennas can be precisely programmed to track the satellite.

ERS-1's S-band transmitter will be on during launch, so that telemetry can be received at the Kourou and Wallops Island stations during the ascent phase. The uplink connection will be established before the satellite's separation from the Ariane launcher's third stage, allowing commanding to start without delay. Twenty seconds after that separation,



the Control Centre is authorised to command the satellite, and will, if necessary, start by making corrections to the time-tags of the payload antenna-deployment commands stored onboard.

The following significant events will then occur in quick succession (Fig. 3):

- deployment of the second S-band antenna
- deployment of the ATSR-payload antenna
- deployment of the solar-array arm
- attitude stabilisation in thruster-controlled Earth-pointing mode
- deployment of the solar-array panels
- deployment of SAR-antenna wings 1 and 2
- deployment of the Wind Scatterometer's fore and aft antennas
- release of the solar-array drive mechanism
- rotation of the solar array
- release of the reaction wheels, via ground command
- entry into wheel-controlled fine-pointing mode, via ground command.

Trajectory measurements will be made at every opportunity during station coverage, so that the spacecraft's orbit can be reliably determined. On the basis of the latest determination, new ground-station antenna-pointing data will be sent to all stations to ensure optimum acquisition of the satellite's signals when it appears over the horizon.

Recovery procedures have been prepared, tested and practised for nearly twenty different failure scenarios. The first two orbits of the satellite will provide several opportunities for intervention from a ground station should such a need arise. The principal aim in this period will be to ensure that the solar array has deployed to provide the necessary power, which in turn will extend the period available for any recovery action needed, by a further twenty orbits.

Payload instrument switch-on

With the satellite safely in orbit after the LEOP, the work of the extended operations team will be complete, and operations will be transferred from the Main Control Room at ESOC to the ERS-1 Dedicated Control Room (Fig. 4). In the next phase, lasting approximately two weeks, and with continuing technical support from the project engineers and industry, ERS-1's instruments will be progressively switched on. These activities will be conducted using the Salmijaervi (Sweden) and Villafranca (Spain) stations.

Figure 4. The ERS-1 Dedicated Control Room (DCR) at ESOC in Darmstadt (Germany)

The completion of instrument switch-on will mark a shift in the operations from a pre-determined engineering-driven sequence to a regime governed by the mission-planning system and tailored to user requirements, known as 'routine operations'.

Routine operations

The routine phase will begin with satellite-commissioning operations, for the calibration and validation of the payload instruments and the ground-processing systems that will provide the ERS-1 products to the user community. This commissioning exercise will take between three and six months.

Requests for ERS-1 data and products will be handled by the Earthnet ERS-1 Central Facility (EECF) at ESRIN in Frascati (I), where their feasibility within the framework of the so-called 'High-Level Operations Plan' (defined by the ERS-1 Mission Manager in consultation with the users) will be checked. Accepted requests will then be allocated a priority and forwarded to the Mission Management and Planning Office (MMPO) at ESOC for scheduling.

The MMPO will be responsible for the planning of spacecraft and Ground Segment activities and the overall coordination and management of the mission. It will be responsible for producing the ERS-1 'Mission Operations Plan', based on user requests received from Earthnet ERS-1 Central Facility at ESRIN and operational and manoeuvre requests from operations staff to ensure correct functioning of the spacecraft. Mission planning will normally be performed a month in advance, allowing users to be provided with early notification of when their requested data will be gathered. In exceptional cases, such as where expensive, long-lead-time resources, e.g. ships and manpower, are being allocated by a user in support of requested data or products, even longer term planning will be possible. Similarly, a facility will be provided to allow rapid reaction to emergency situations, such as hurricanes, large-scale flooding or pollution monitoring, with such an operation normally being schedulable at 24 h notice, and within just a few hours under exceptional circumstances.

Every morning, before the first acquisition of ERS-1 by the Salmijaervi station at 06.00 h, the MMPO will verify the operations planned for the next 24 h based on the latest orbital information and the availability of mission resources, and will update the Mission Operations Plan to reflect any minor changes that might be necessary. At the same time, this plan will be translated into command schedules for the spacecraft and Ground Segment.

These operations schedules will automatically be made available to the EECF for scheduling X-band stations, the MMCC satellite command system for uplinking and the Salmijaervi command system for acquisition, processing and dissemination at Salmijaervi. The satellite command system will automatically track the progress of the onboard execution of the schedule and will only permit the uplinking of those commands for which space is available in the onboard computer memory. The spacecraft controller will be able to 'top-up' the schedule to maintain 24 h of advance programming. Typically 1000 commands per day will be uplinked to control the satellite, the vast majority of which will be destined for the payload.

The Salmijaervi station will 'see' ERS-1 ten times per day, between approximately 6 am and midnight. During each pass, the satellite's health will be checked from the telemetry, its trajectory will be measured, and the onboard schedule will be loaded. Instrument data, both real-time and recorded, will be downlinked and captured on four high-data-rate recorders.

Between passes (approx. 90 min), the tape-recorded data will be processed to generate the 'Fast-Delivery Products' for rapid dissemination to users. Copies of the recorded data will be dispatched by mail to the Processing and Archiving Facilities for offline evaluation.

The satellite's longer term performance will be evaluated from stored telemetry data and ancillary information such as the telecommand history, using ESOC's 'Spacecraft Performance Evaluation System' (SPES). A typical routine application of this invaluable diagnostic tool will be day-by-day monitoring of the power available for instrument operations, providing the system engineers and mission planners with the data needed for optimum battery charge/discharge management.

Mission performance will be monitored using the 'Payload Evaluation System' (PLEVAL). This system will allow the subtle changes in instrument operating characteristics that can occur with time to be detected and reacted to quickly, thereby ensuring continued high-quality data acquisition.

To ensure coherency throughout the complex ERS-1 system, the mission-management system at ESOC provides for overall configuration control for both the satellite and the data-processing facilities. It will record all software changes and changes in lookup data tables and parameters used both onboard the spacecraft and throughout the Ground Segment. In addition, it will maintain the updated operations plan, reflecting the actual operations performed and system configuration used, to enable users to identify the exact conditions under which their data was collected.

Conclusion

ESOC is ready to support the ERS-1 mission and has developed, integrated and tested on schedule the most complex set of interrelated control and monitoring functions of any satellite operated to date by the Agency. In addition to achieving operational readiness for the ERS-1 launch, the system has also been designed with future missions in mind, and can form the basis of similar systems for future Earth-observation missions and, possibly, other ESA satellite programmes also.

ERS-1 Calibration and Validation

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The basic measurements to be made by ERS-1's instruments are sensor measurements of the following engineering quantities:

- radar backscattering from the Earth's surface (AMI, RA)*
- time delay between transmission and echo reception (RA)
- infrared emission from the Earth's surface and the atmosphere (ATSR)
- microwave emission from the Earth's surface and the atmosphere (ATSR/M)
- satellite range and range-rate (PRARE).

It is from these *engineering* quantities that the *geophysical* data products will be derived, such as surface wind fields over the ocean, significant wave height, and directional ocean-wave spectra. As a consequence, the calibration and validation of the ERS-1 payload will take place in two distinct stages.

Firstly the *engineering calibration* will be carried out, which is defined as the process of converting spacecraft payload telemetry into engineering units within known limits of accuracy and precision; e.g. radar backscattering coefficient (m^2/m^2), antenna brightness temperature (K) and time delay (s). Engineering calibration is achieved via inherent instrument stability, the use of internal references to compensate for system variations caused mainly by temperature variations and ageing, and the use of external references such as specially designed radar transponders or carefully selected 'targets of opportunity'.

* AMI = Active Microwave Instrumentation
RA = Radar Altimeter
ATSR = Along-Track Scanning Radiometer
ATSR/M = Microwave Sounder
PRARE = Precise Range and Range-rate Equipment

The second step will be *geophysical calibration*, the process of converting engineering quantities (e.g. radar backscattering) into geophysical units (winds and waves), within known limits of accuracy and precision. This conversion takes place in the ERS-1 ground processors and uses models to relate the engineering quantities to the geophysical quantities of interest.

ESA sponsored a number of C-band campaigns between 1983 and 1986 in which twenty institutes from six ESA Member States, Canada and the United States participated. The main goal was to provide data for constructing an empirical vertically polarised C-band radar model. This model was to cover the whole range of operating conditions specified for the ERS Scatterometer. Flights involving typically ten circles were made, measuring the radar echoes over a range of incidence angles between 15 and 65°. Emphasis was placed on radar-system calibration and on comprehensive measurements and logging of ambient sea and air conditions. Measurements were carried out in the German Bight, off the coast of Brittany, and in the Mediterranean, in the Straits of Gibraltar and Sicily. The data gathered during these C-band campaigns consist of scatterometer and surface measurements defining surface wind speed and direction, as well as ocean-wave conditions.

The ESA-sponsored airborne scatterometer campaigns produced data sets showing good self- and mutual-consistency, a direct consequence of the simultaneous use of more than one radar, and the emphasis on calibration and surface support measurements. On the basis of these data, a vertical-polarisation radar-echo model was constructed which has been used in the design and performance assessment of the ERS-1 Scatterometer.

Nevertheless, these models cannot be determined with sufficient accuracy before launch, and in-situ measurements of wind and waves concurrent with ERS-1 overpasses will be necessary to calibrate or 'tune' them.

Engineering calibration of the Active Microwave Instrumentation

The basic engineering measurement made by the AMI is that of radar backscattering coefficient (σ, m^2/m^2). In Image and Wave Mode, the AMI works as a Synthetic-Aperture Radar (SAR) and produces 30 m-resolution images. In Wind Mode, it functions as a real-aperture radar and produces three 50 km-resolution images virtually simultaneously for three different look directions.

To achieve engineering calibration, the AMI ground processors use pre-launch information about the instrument, such as its electronic gain and antenna patterns, ERS-1 orbit information, and in-flight measurements of, for example, instrument noise. Variations in electronic gain are corrected for by adjusting the processor gain according to the in-flight response from the internal calibration unit. Antenna gain corrections are derived from transponder over-flights, which will be repeated frequently during the ERS-1 commissioning phase.

Three ESA transponders (Fig. 1) located in Flevoland (The Netherlands) will be used for calibration of the AMI Image and Wave Modes and three transponders in the south of Spain for the AMI Wind Mode. Flevoland is located at about 52° N and is therefore re-visited several times during the 35-day repeat orbit, thus providing good temporal resolution for calibration and performance monitoring. This area, which will also be covered by ERS-1 during the commissioning phase, consists of some 97 000 hectares of land reclaimed from the former 'Zuiderzee'. Because of its characteristic geometry, with relatively large-scale agriculture, the lack of relief, and the availability of many well-surveyed control points, the area has often been used for radar remote-sensing experiments and calibrations in the past (Fig. 2).

In Spain, one of the transponders is located near a rocket-launching site operated by INTA, in Arenosillo. The second one is placed on the roof of the computer centre of the University of Malaga, and the third is mounted on the roof of a school in Adra.

Figure 1. ERS Scatterometer transponder during testing at ESTEC in Noordwijk (NL)

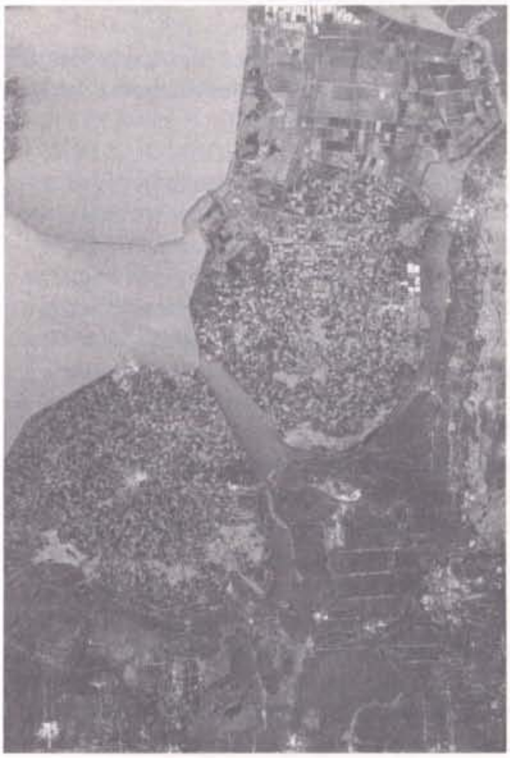


Figure 2. Flevoland SAR calibration site as seen by Seasat in 1978

The residual errors after radiometric calibration have been analysed in detail. The current prediction is that ERS-1's overall absolute radiometric accuracy for the Image Mode will be 0.7 dB (or ±9%), for the Wave Mode 0.5 dB, (or ±6%) and for the Wind Mode 0.5 dB (or ±6%).

Engineering calibration of the Radar Altimeter

Pre-launch testing, characterisation and 'calibration' of the Radar Altimeter has been performed with the aid of a Return-Signal Simulator (Fig. 3). This echo generator was attached to the Altimeter in place of the antenna, making it possible to test the instrument's performance with fully realistic echo signals. The echoes can represent ocean or any other surface, and can include realistic 'speckle effects' or simpler 'ideal echoes'. This test system was operated at the full pulse-repetition rate of the radar and was also able to simulate the acquisition sequence.

The height measurements from the Radar Altimeter will have a long-term stability of the order of 5 cm. An overall system calibration to this level is not possible prior to launch because of difficulties in calibrating the test equipment to the required accuracy. It is thus necessary to establish a calibration of the system bias in-orbit. Historically, this task has been performed twice before, for the Geos-3 and Seasat satellites, and bias values of the order of 0.5 m were found.

Of the many potential calibration techniques available, the best-known is the classical 'Bermuda method', in which the satellite overflies a laser-ranging system located on a small island. This was done for Seasat in 1978, but it is not without its difficulties, particularly when a calibration at the 5 cm level or better is required. It had been proposed that some of the potential problems could be overcome by moving the reference laser from an island to an offshore platform, but finding a platform large enough to support a laser system in European waters would essentially mean the North Sea. This region is considered unfavourable because of the likelihood of bad weather and high waves.

A different approach has therefore been adopted which makes maximum use of existing European facilities and capitalises on the density of existing satellite laser-ranging (SLR) stations in Europe.

The overall scenario is illustrated in Figure 4. The satellite will make a northward pass over a small research platform, owned by CNR and used for oceanographic measurements, about 14 km offshore from Venice (Fig. 5). It is fixed to the sea-bed in about 16 m of water in a part of the Adriatic free from significant dynamic sea-surface changes. The area has negligible currents, small and well-modelled tides, and only rarely, under storm conditions, is there appreciable wind set-up of the water surface. All of this is important because the satellite cannot be guaranteed to fly directly over the tower. Due to air-drag effects on its orbit, the satellite's ground track can vary by up to 1 km from the nominal one. The actual surface slope must be known in order to refer back to the reference platform's position. A further

Figure 3. ERS Radar-Altimeter Electrical Ground-Support Equipment (EGSE) during its acceptance testing, at Selenia Spazio (I)

Figure 4. Calibration of the Radar Altimeter by comparing measured height over the Northern Adriatic with laser-ranging measurements from an array of laser stations

contribution to this surface slope stems from the detailed geoid in the area, which has already been well measured by several different techniques.

The satellite will be tracked from several satellite laser-ranging sites simultaneously. Figure 4 shows the fixed sites at Grasse (F), Graz (A), Matera (I), Wettzell (D) and Zimmerwald (D). In addition, a new mobile laser-ranging site (Fig. 6) has been established in the Euganei Hills, south of Padova. These six lasers provide a network surrounding the Venice platform, with a favourable topology.

In addition to this network, two dedicated PRARE stations are assumed, one to be co-located with the Venice laser, and the other on the tower itself. Other PRARE stations are already foreseen at Wettzell, Stuttgart and Oberpfaffenhofen, in Germany, for the baseline PRARE calibration/validation and operations (see below).

As the main reference point for the sea-level determination, the Venice platform will be equipped with a number of measurement facilities. Some of these are permanent fixtures, like a tide gauge, wave-measurement sensors, etc., while others will be specially installed for the purpose, such as a microwave radiometer to measure atmospheric water vapour.

An extensive analysis of the errors to be expected during the calibration campaign has already been performed. Those of a random nature, varying from pass to pass, will be reduced by averaging the results over the duration of the campaign. The results of the analysis have shown that the Altimeter bias determination may be in error by up to about 5 cm at the end of the campaign, which is a significant improvement over the pre-launch value.

Engineering calibration of the Along-Track Scanning Radiometer

The ATSR instrument has been tested and calibrated in a specially-designed space simulator and test facility (Fig. 7) at the Department of Atmospheric, Oceanic and Planetary Physics of Oxford University (UK). While there, the instrument was subjected to a series of tests covering field-of-view determination, radiometric calibration, thermal-vacuum temperature cycling, and thermal-balance tests, in addition to standard instrument checkouts.

The ATSR was bolted to a 'PEM simulator', which was maintained at the predicted in-orbit temperature of the Payload Electronics Module (PEM) surface, to which the instrument will be attached. An Earth-shine plate simulated infrared and reflected solar radiation from the Earth, and a drum baffle (maintained at the same temperature as the Earth-shine plate) shielded the instrument from radiation from the inside of the test chamber at room temperature. Finally, a cold-box, surrounding the remaining four sides of the instrument, simulated the integrated thermal/reflected couplings to space.

Figure 5. The CNR Oceanographic Research Platform off the Italian Coast, near Venice

Two external calibration targets (one positioned in each of ATSR's two viewing directions) were mounted on the Earth-shine plate. Since the instrument was to be calibrated at all positions around the scan, the whole Earth-shine plate assembly (which weighed about 1/4 t) was able to rotate by ±50° about its central position.

The temperature of the external targets could be controlled between 243 and 310 K, thus covering the required sea-surface and warm cloud-top temperature ranges. Using this experimental set-up and the full range of external target temperatures, it was possible to calibrate the ATSR for a variety of thermal environments, positions around the scan, detector temperatures and on-board black-body temperatures. Furthermore, the linearity of each channel, the consistency between the different channels, and possible radiometric leaks were also investigated. In addition, one of the external targets had the facility to be cooled by liquid nitrogen to allow a low-radiance calibration. measurement.

Figure 6. The mobile laser-ranging station, MTLRS-2, in Sicily in December 1990, from where it was transferred to the Venice site

To meet its scientific objective of measuring sea-surface temperature to better than 0.3 K, the ATSR has to measure brightness temperature in the infrared to better than 0.1 K. The radiometric tests showed that this was achieved over the entire sea-surface temperature range, with no scan-dependent strays or biases.

The commissioning phase will begin approximately two days after the satellite's launch and is expected to last for three months. Initially, only brief functional checks will be carried out on the ATSR, including a fairly short period of cooler operation, to avoid condensation onto the detectors of outgassing products from plastics, etc. After about two weeks in orbit, this problem should be less severe and longer periods of cooler operation will begin. A full checkout of the Microwave Radiometer will be possible in this period as it does not require the cooler to be switched on. After the detectors have been cooled to normal operating temperature, a range of checks will be carried out to verify instrument performance and to optimise certain parameters.

A full functional check of the ATSR sub-systems will only be possible once the detectors have been cooled to normal operating temperature. Apart from the basic power and hardware functions, these checks will look closely at the on-board black-body and cooler performances and will verify the software-control functions and science-data generation.

Primary calibration of the IRR instrument will be achieved with two on-board black bodies which will stabilise at temperatures of around 263 K and 303 K, respectively. The black-body temperature is measured accurately by platinum-resistance thermometers, and each black body is seen once per scan of the optical system. The 1.6 micron (near-infrared) channel will be calibrated by observing ground features that have known albedos. One such site is the White Sands Missile Range in New Mexico, which will need to be observed in sunlight when cloud is absent. The exact site used will depend on the final choice of orbit and will not be known until nearer the launch date. Drift and noise in the near-infrared channel can be assessed from data taken at night.

Calibration of the thermal channels involves close observation of the on-board black-body performance and the thermal environment within the instrument. A comparison can then be made with the performance of the detectors during the ground calibration, and any necessary corrections made. The way in which each channel responds to sharp changes in ground temperature will be found from data collected over cloud/sea and sea/land boundaries.

Instrument tests on the Microwave Sounder (ATSR/M) will be performed at the beginning of the commissioning phase and several times during the satellite's lifetime. They will include:

- a survey of the instrument stability with time (gain, internal temperatures, horns)

- checking of the sky-horn measurements during one special orbit
- examination of antenna-pointing and sidelobe-contamination effects.

Validations of brightness temperature will be performed twice during the commissioning phase and several times during the satellite's lifetime. Observed brightness temperatures will be compared with those computed using a radiative transfer model applied to meteorological fields (ECMWF model analyses) at co-located points (two weeks' worth of data).

The validation of geophysical data will be based essentially on the comparison of calculated water-vapour contents with observations from radio-sonding (provided by the French Meteorological Office). This will be done twice during the commissioning phase and occasionally during the satellite's lifetime, in order to sample all possible meteorological conditions.

The liquid-water measurements cannot be validated, except by using aircraft profiles in clouds, and this problem is the subject of further studies.

Other validations will be performed using available data such as the Special Sensor Microwave Imager products (from the SSMI instruments flown on NOAA operational satellites), and ground-based microwave radiometer data (campaign planned in August 1991 with CNES's 'Portos' radiometer).

Engineering calibration of the Precise Range and Range-rate Equipment (PRARE)

Although the PRARE space segment and ground tracking units contain facilities for the determination of hardware-related calibration parameters for each measurement interval, there is also a strong requirement for a calibration procedure to monitor the overall performance of the tracking measurements against the most precise laser systems, and to tie the PRARE observations into the internationally accepted standard of laser tracking measurements.

The calibration procedure selected is based on comparative measurements to the ERS-1 satellite from the two tracking systems, laser and PRARE, installed adjacent to each other on the Wettzell tracking-station site, in Bavaria (D). This station has extensive experience of co-location campaigns for stationary and mobile laser systems.

It is planned to conduct an intensive calibration campaign during the ERS-1 commissioning phase in order to derive the most reliable calibration parameters and to use the co-location setup during the subsequent exploitation phase to monitor the system's behaviour.

The calibration experiment will be executed jointly by the PRARE experimenter team from the Deutsches Geodätisches Forschungsinstitut and Institut für Navigation, Universität Stuttgart, and the Institut für Angewandte Geodäsie in Frankfurt, which operates the Wettzell station.

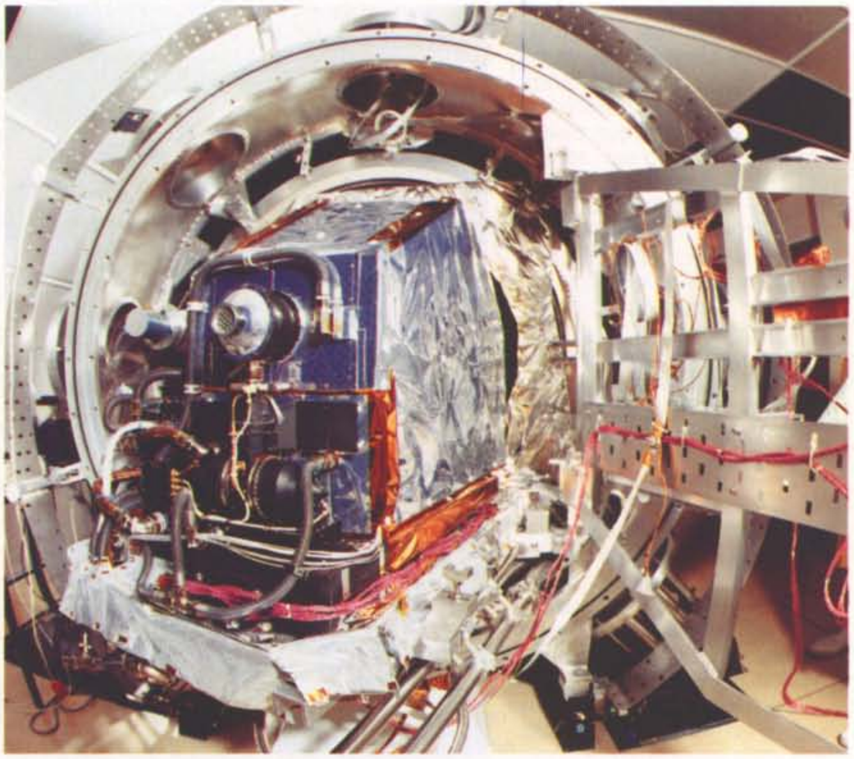


Figure 7. The ATSR in the space-simulator test facility at Oxford University (UK)

Before the start of the ERS-1 mission a new, upgraded laser system will be available capable of:

- satellite tracking with an accuracy of ±1 cm
- lunar tracking with an accuracy of ±3 cm.

A water-vapour radiometer will also be available before the start of the ERS-1 mission.

Satellite laser-ranging systems nowadays comply with high accuracy standards. By using simple passive retro-reflector ground targets, they can be reliably calibrated in a straightforward manner and their measurements, in contrast to microwave ranging, do not depend on the ionospheric conditions, and are much less influenced by the difficult-to-model water-vapour content of the troposphere. Consequently, they make an

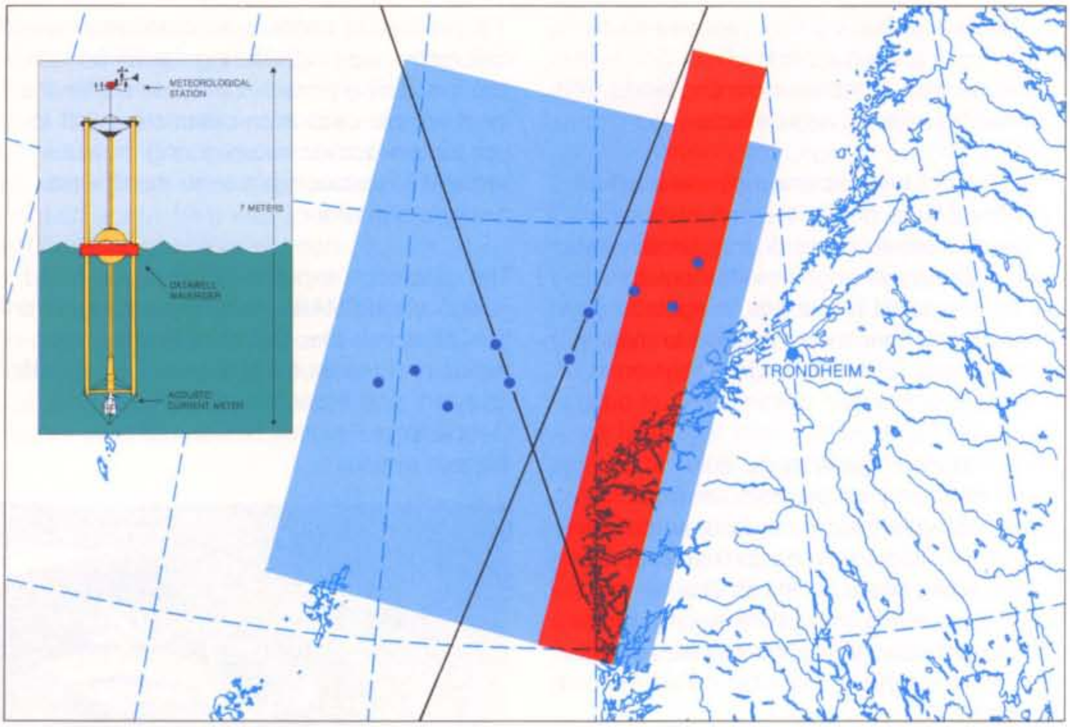


Figure 8. Norwegian geophysical validation site showing the positions of buoys and coverage zones for SAR Image Mode and Wind Scatterometer (only one pass shown). The inset shows a wind and omnidirectional-wave buoy

extremely good reference system for the calibration of the PRARE. However, they are susceptible to loss of data due to cloud or haze effects, and a laser-ranging installation is relatively large and involves a significant infrastructure, in contrast to the PRARE.

Geophysical calibration of ERS-1

The geophysical data products produced routinely by the ERS-1 instruments will include the speed and direction of the surface winds over the ocean and the directional spectrum of the ocean waves derived from radar backscattering measurements from the AMI, and the significant wave height and the surface wind speed derived from the radar echo signals measured by the Radar Altimeter.

The models used to convert radar signals into the above wind and wave parameters will be checked and, where necessary, modified by comparing the satellite-derived estimates with the analysis fields derived from meteorological and oceanographic models on both a regional and a global scale. This activity is being carried out in cooperation with the European Centre for Medium-Range Weather Forecasting (ECMWF) and the major Meteorological Offices in Europe. A large database will be built up from routine in-situ observations by ships and buoys and co-located satellite observations. This data set will be available for making a quality assessment of the ERS-1 wind and wave products and for detailed analysis of the ERS-1 interpretation models on a global scale.

In addition, a dedicated field campaign will be conducted at an ocean site off the Norwegian Coast, near Trondheim (Fig. 8).

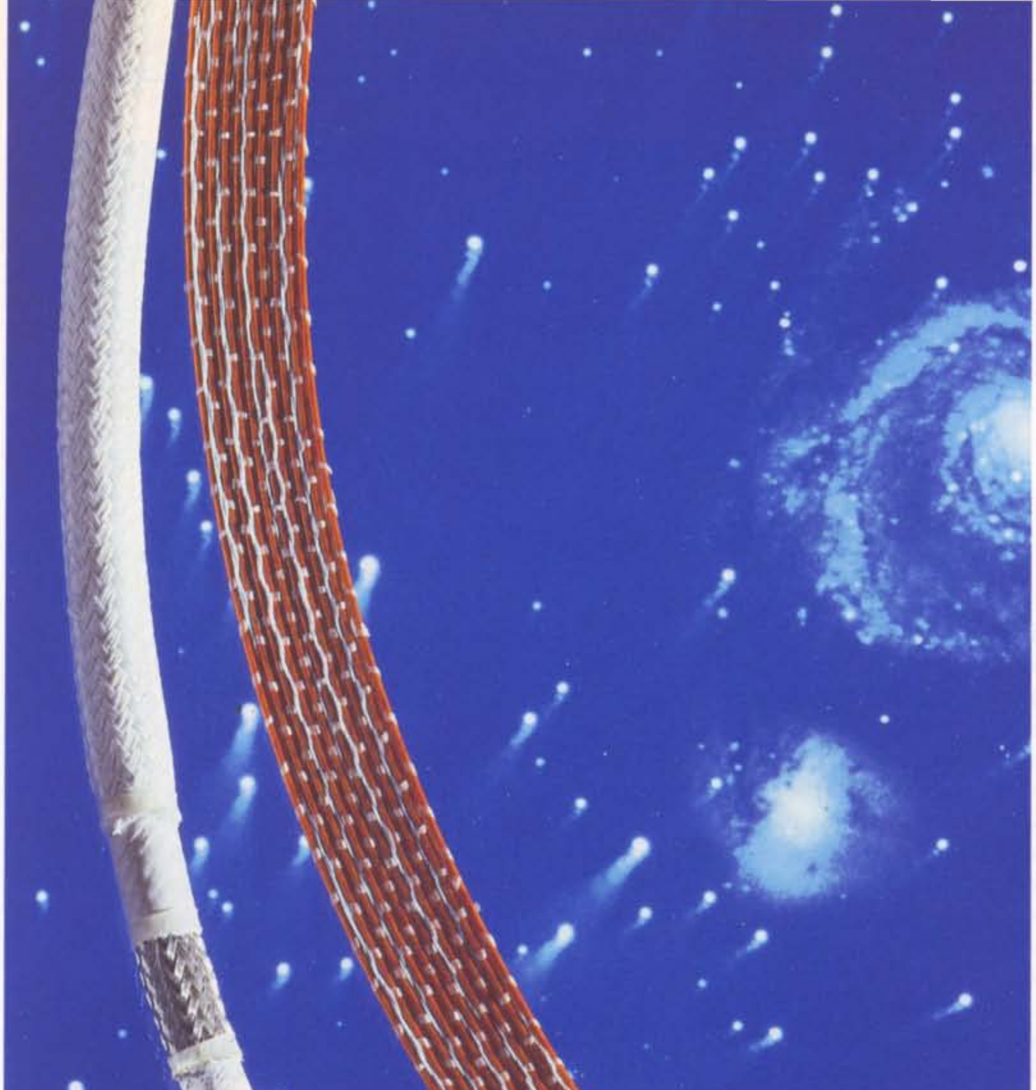
An array of meteorological buoys will be deployed there for measuring wind speed, wind direction and significant wave height during the ERS-1 overpasses.

Low-flying aircraft will also be used to make complementary wind-vector measurements. These aircraft will also carry airborne radars to verify both the wind-retrieval and the ocean-wave imaging models used for ERS-1 data.

Research vessels will be used for in-situ wind and wave measurements, and the shipborne radars will image the ocean surface during ERS-1 overpasses to determine the ocean wave field.

Similar surface measurements and airborne observations are planned in collaboration with non-European organisations in Canada, the USA and Australia.

Simulations indicate that, after a three-month geophysical calibration period, sufficient data will be available to determine and verify the geophysical performance of the operational ERS-1 wind and wave retrieval models.



Industrial Cooperation on ERS-1

H. Ege
Dornier GmbH, Friedrichshafen, Germany

The proposal phase

Discussions in Friedrichshafen in the Spring of 1982 resulted in Dornier being invited to submit a proposal for the main development phase (Phase-C/D) of the ERS-1 Programme, which represented a challenge of an exceptional nature to Industry, the Agency and the User Community. Dornier submitted their proposal, based on their earlier Phase-B (design phase) studies, in September 1983, on behalf of the Industrial Team shown in Figure 1.

This Industrial Team, with Dornier as the Prime Contractor, ensured a high degree of expertise for the Programme, with maximum European and Canadian involvement, to meet the end-to-end performance called for in the Request for Proposal and the stated mission objectives, namely:
- the collection of data for scientific use, and
- the dissemination of ocean data for later commercial application.

One of the problems at that time was to fulfil the geographical distribution laid down in the Request for Quotation (RFQ), because of a number of ERS-1's particular features, including:

- the use of a Spot derivative for the platform, built mainly by French industry
- the lack at that time of readily-available knowhow to cope with the extreme complexity of the payload- and ground-segment tasks
- the need to include key technologies sponsored by the Agency or national authorities in the ERS-1 Programme.

This problem of optimising the geographical distribution was addressed by providing, on the basis of a competitive bidder list, several proposals allowing the submission of four alternative price/geographical-distribution scenarios, as per Table 1 (each of these alternatives being a compromise in terms of geographical distribution, overall cost and technical complexity).

The negotiation phase

The difficult situation resulting from the geographical-distribution problem also resulted in a delay in the subscription to the Programme by the ESA Delegations, and made it necessary to bridge the period from September 1983 to December 1984 with extended Phase-B and pre-Phase-C/D activities. The overriding goal remained one of optimising prices and meeting both the geographical and technical requirements without unduly jeopardising parameters such as schedule and other basics mentioned above. During this period, major rearrangements in the work-sharing were made which finally optimised the geographical distribution, enabling the Agency to achieve a sufficient subscription by Delegations for the Programme to receive the go-ahead.

Aside from the completion of the Baseline Requirements Documentation, authorisation to proceed with the ERS-1 Phase-C/D activities required the finalisation of both price and contract negotiations. The Prime Contractor's efforts in this respect, with the support of the Agency, resulted in negotiated contracts for more than 70 different tasks with more than 50 contractors in all the European countries, as well as Canada.

The Main Contract was signed on 24 October 1986 in Friedrichshafen by Dornier's management and ESA's Director General at that time, Prof. Reimar Lüst.

The Industrial Team that emerged at the end of the negotiation phase is shown in Figure 2. The negotiated prices led to the geographical distribution shown in Figure 3.

The implementation phase

In order to underpin the extensive inter-

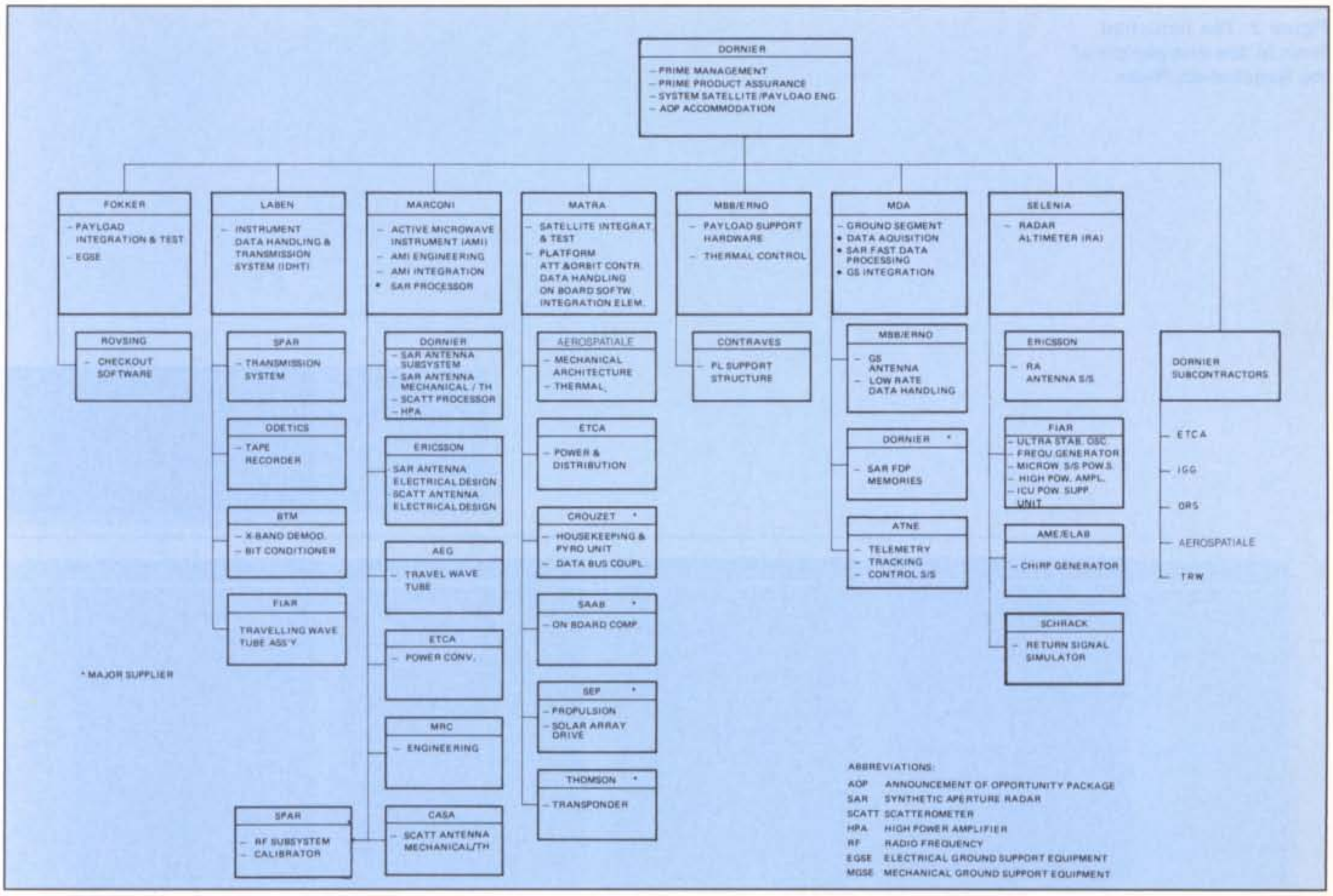


Figure 1. Composition of the Industrial Consortium in September 1983

national industrial participation in the ERS-1 Programme resulting from the earlier phases, and to foster similar cooperation in the future, a Memorandum of Understanding (MOU) was signed by the major participating companies in the various European countries and Canada.

During the regular management-board meetings of the companies that were signatories to the MOU, programme status and the corrective actions needed to rectify any problems identified were constant agenda items. This pragmatic approach, together with the very good relationship established between the various project teams working on ERS-1, has contributed greatly to the success of this complex industrial endeavour.

The technical performance of the Industrial Team was monitored by ESA by means of both regular meetings at various levels and by the holding of nine formal System Reviews:

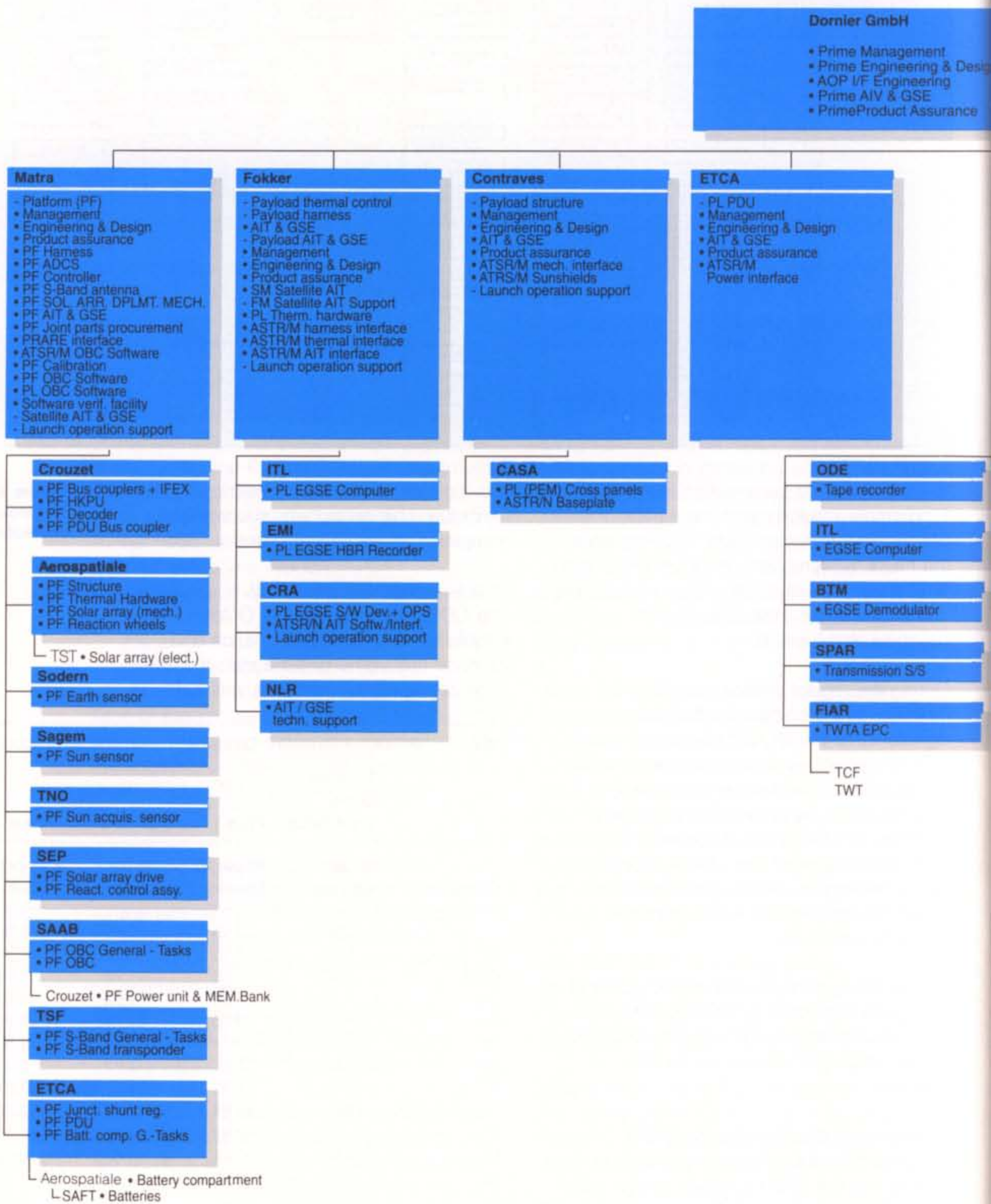
Development Baseline Review (DBR)
The objective of this Review was both to ensure that the ERS-1 baseline design met the performance and interface requirements, and to verify that the project documentation allowed release of the Engineering-Model hardware. This review was successfully completed at the end of October 1985.

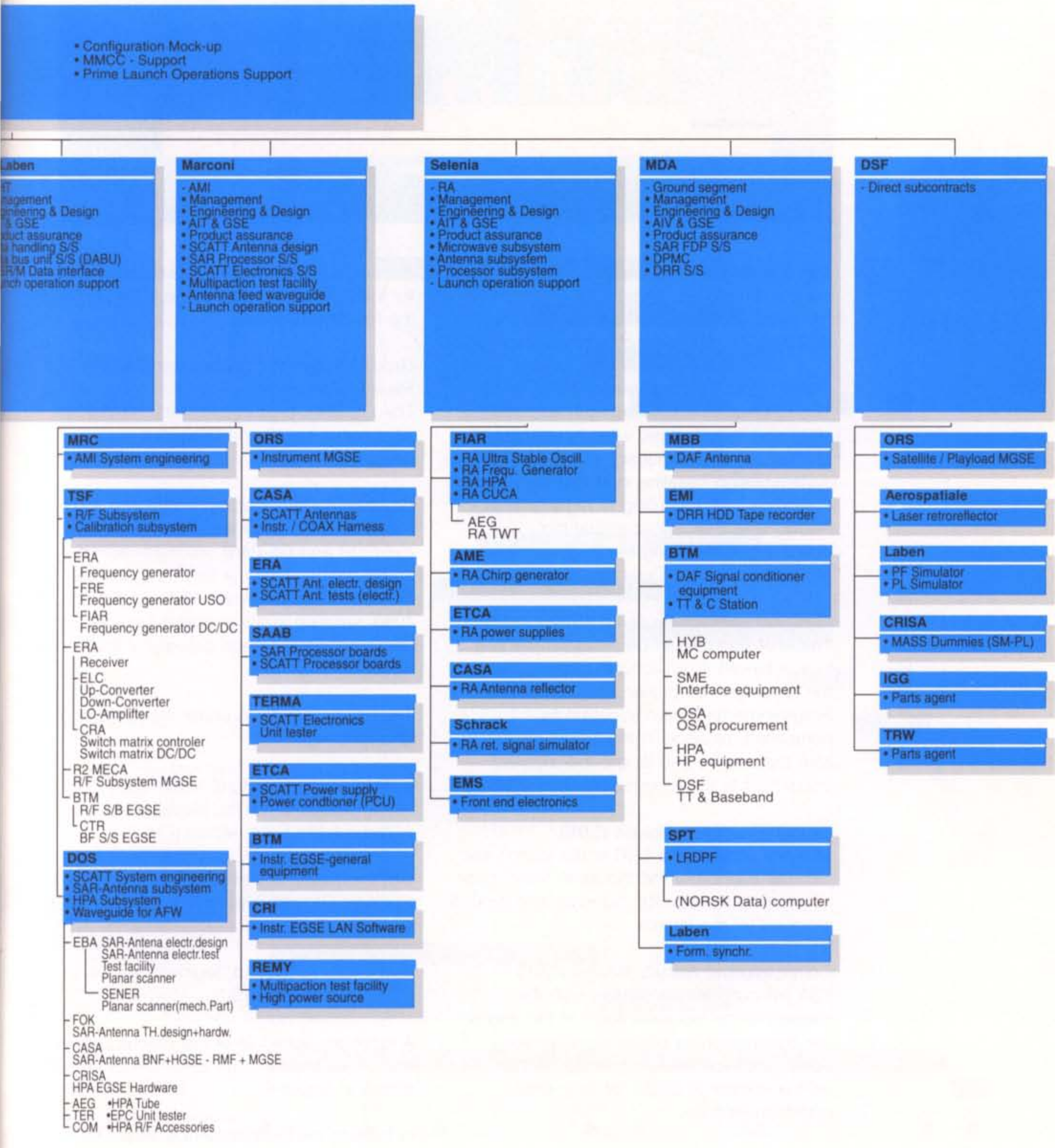
Critical Design Review (CDR)
The CDR, performed in late October 1987, established that: the performance and interface requirements were met; the Engineering-Model hardware was ready to

Table 1. The four alternative geographical-distribution/cost scenarios

	Nominal share (ESA-RFQ)	Price I	Price II	Price III	Price IV
Country	% per Country	% per Country	% per Country	% per Country	% per Country
	0.50	0.95	0.98	0.98	1.00
B	3.70	2.15	2.22	2.94	3.01
CDN	7.50	11.56	11.73	9.69	9.92
CH	1.70	1.58	1.62	1.64	1.67
D	24.00	29.80	29.73	28.84	29.45
DK	1.50	0.74	0.77	1.60	1.64
SP	3.80	1.67	1.72	2.04	2.09
F	20.00	17.75	17.07	17.89	17.55
UK	14.00	13.04	13.20	13.18	13.49
I	11.00	12.92	13.07	11.95	10.70
N	1.50	0.64	0.66	0.66	0.67
NL	5.00	3.25	3.17	3.76	3.85
S	3.90	1.42	1.46	2.20	2.26
USA	—	2.45	2.52	2.56	2.62

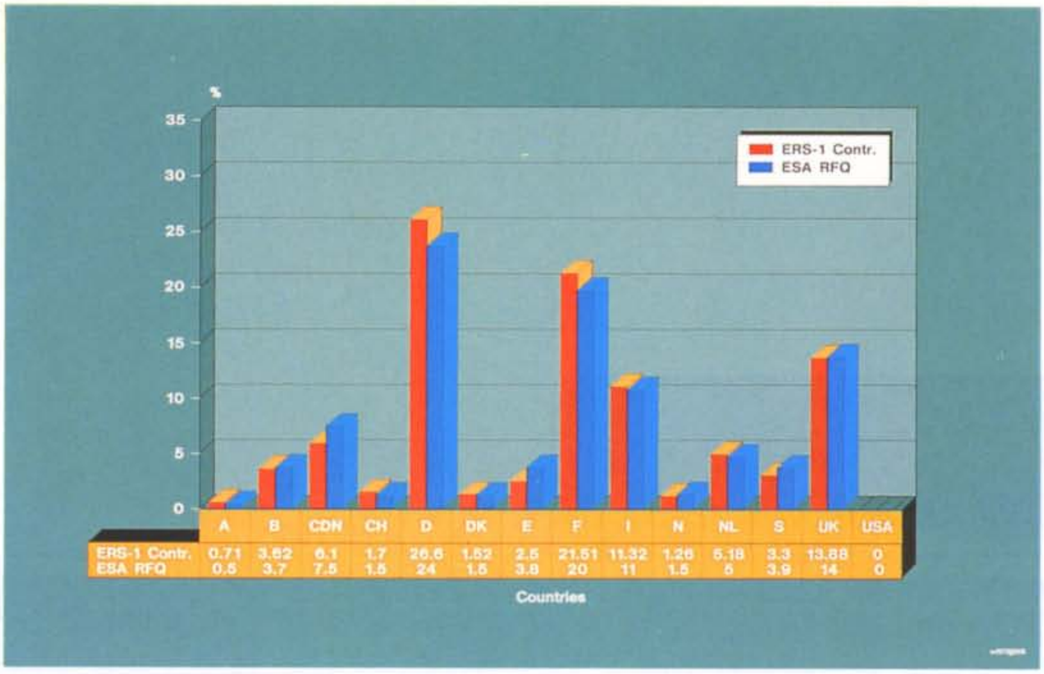
Figure 2. The Industrial Team at the completion of the Negotiation Phase





• Configuration Mock-up
• MMCC - Support
• Prime Launch Operations Support
Laben
nagement
neering & Design
& GSE
duct assurance
handling S/S
bus unit S/S (DABU)
R/M Data interface
nch operation support
Marconi
- AMI
• Management
• Engineering & Design
• AIT & GSE
• Product assurance
• SCATT Antenna design
• SAR Processor S/S
• SCATT Electronics S/S
• Multipaction test facility
• Antenna feed waveguide
- Launch operation support
Selenia
- RA
• Management
• Engineering & Design
• AIT & GSE
• Product assurance
• Microwave subsystem
• Antenna subsystem
• Processor subsystem
- Launch operation support
MDA
- Ground segment
• Management
• Engineering & Design
• AIV & GSE
• Product assurance
• SAR FDP S/S
• DPMC
• DRR S/S
DSF
- Direct subcontracts
MRC
• AMI System engineering
TSF
• R/F Subsystem
• Calibration subsystem
ERA
Frequency generator
FRE
Frequency generator USO
FIAR
Frequency generator DC/DC
ERA
Receiver
ELC
Up-Converter
Down-Converter
LO-Amplifier
CRA
Switch matrix controler
Switch matrix DC/DC
R2 MECA
R/F Subsystem MGSE
BTM
R/F S/B EGSE
CTR
BF S/S EGSE
DOS
• SCATT System engineering
• SAR-Antenna subsystem
• HPA Subsystem
• Waveguide for AFW
EBA SAR-Antena electr.design
SAR-Antenna electr.test
Test facility
Planar scanner
SENER
Planar scanner(mech.Part)
FOK
SAR-Antenna TH.design+hardw.
CASA
SAR-Antenna BNF+HGSE - RMF + MGSE
CRISA
HPA EGSE Hardware
AEG •HPA Tube
TER •EPC Unit tester
COM •HPA R/F Accessories
ORS
• Instrument MGSE
CASA
• SCATT Antennas
• Instr. / COAX Harness
ERA
• SCATT Ant. electr. design
• SCATT Ant. tests (electr.)
SAAB
• SAR Processor boards
• SCATT Processor boards
TERMA
• SCATT Electronics
Unit tester
ETCA
• SCATT Power supply
• Power condtioner (PCU)
BTM
• Instr. EGSE-general
equipment
CRI
• Instr. EGSE LAN Software
REMY
• Multipaction test facility
• High power source
FIAR
• RA Ultra Stable Oscill.
• RA Frequ. Generator
• RA HPA
• RA CUCA
AEG
RA TWT
AME
• RA Chirp generator
ETCA
• RA power supplies
CASA
• RA Antenna reflector
Schrack
• RA ret. signal simulator
EMS
• Front end electronics
MBB
• DAF Antenna
EMI
• DRR HDD Tape recorder
BTM
• DAF Signal conditioner
equipment
• TT & C Station
HYB
MC computer
SME
Interface equipment
OSA
OSA procurement
HPA
HP equipment
DSF
TT & Baseband
SPT
• LRDPF
(NORSK Data) computer
Laben
• Form. synchr.
ORS
• Satellite / Playload MGSE
Aerospatiale
• Laser retroreflector
Laben
• PF Simulator
• PL Simulator
CRISA
• MASS Dummies (SM-PL)
IGG
• Parts agent
TRW
• Parts agent

Figure 3. Geographical distribution following the Negotiation Phase



start the payload and platform assembly, integration and test phase; the Flight-Model hardware was ready for release; and the Structural Model was technically acceptable.

Qualification Results Review (QRR)
The QRR was held towards the end of June 1989 and its objectives were to establish the correctness and adequacy of the satellite system-design baseline, and that the documentation was according to requirements. Additionally, ESA declared that the obligations concerning the Engineering-Model Payload were met.

Flight Acceptance Review (FAR)
The FAR was held in December 1990 and fully achieved its objectives, showing that the Assembly, Integration and Verification Programme had been successfully completed, resulting in the formal release to ship the satellite and its ground-segment equipment to the launch site.

Launch-Readiness Review (LRR)
ESA will conduct the LRR at the launch site, with the support of the Industrial Team, prior to readying the satellite, launcher and ground segment for the launch.

Commissioning Results Review (CRR)
ESA will conduct this Review with the support of the Industrial Team at the end of the commissioning phase (approximately three months after launch). Its goal will be the release of ERS-1 for its in-orbit operational phase.

Aside from the above dedicated satellite reviews, additional reviews were performed for the Kiruna Ground Segment, as part of the Industrial Contract:

Ground-Segment Development Baseline Review (GS-DBR)
The GS-DBR, held in mid-1985, resulted in approval of the Kiruna Station's baseline design.

Ground-Segment Critical-Design and Provisional-Acceptance Reviews (GS-CDR and GS-PAR)
These reviews took the form of a number of dedicated design reviews during 1987 and 1988, resulting in the successful completion, acceptance-testing and delivery of the Kiruna Station in May 1989.

The deliverable items under the terms of the Contract are:

- the satellite Structural Model (SM)
- the satellite Electrical Model (EM)
- the satellite Flight Model (FM)

with dedicated spares and mechanical and electrical Ground-Support Equipment (GSE), and

- the Kiruna Ground Segment, specially developed for ERS-1.

A summary schedule of the various phases and major events of the ERS-1 Programme is shown in Figure 4.

In fulfilling the Development Contract for ERS-1, the Industrial Consortium encountered the 'normal' technical and managerial problems to be expected with such a challenging Programme. The approach of having integration and testing done by separate contractors at different locations certainly added to these difficulties. The willingness and ability to cooperate of all the parties involved – both the Industrial and the ESA Teams – have therefore been critical factors in ensuring the Programme's success. They will also stand the Industrial Team in good stead for the equally successful development and testing of ERS-2.

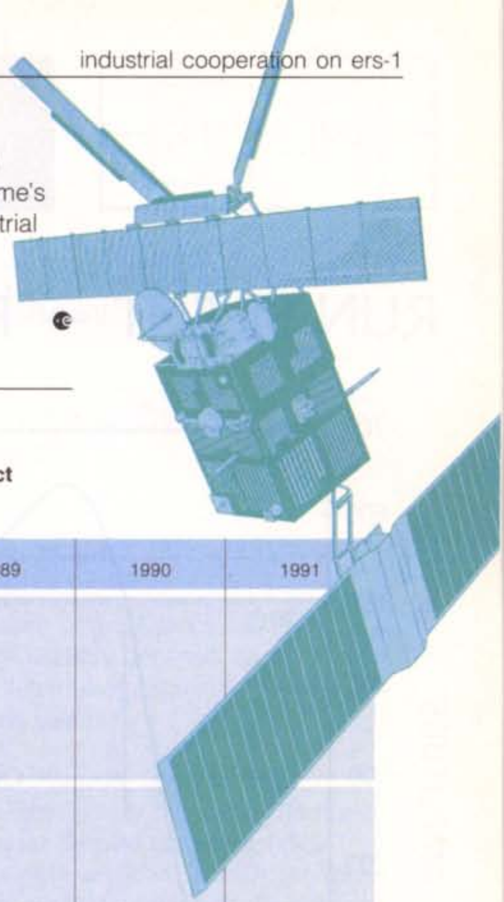
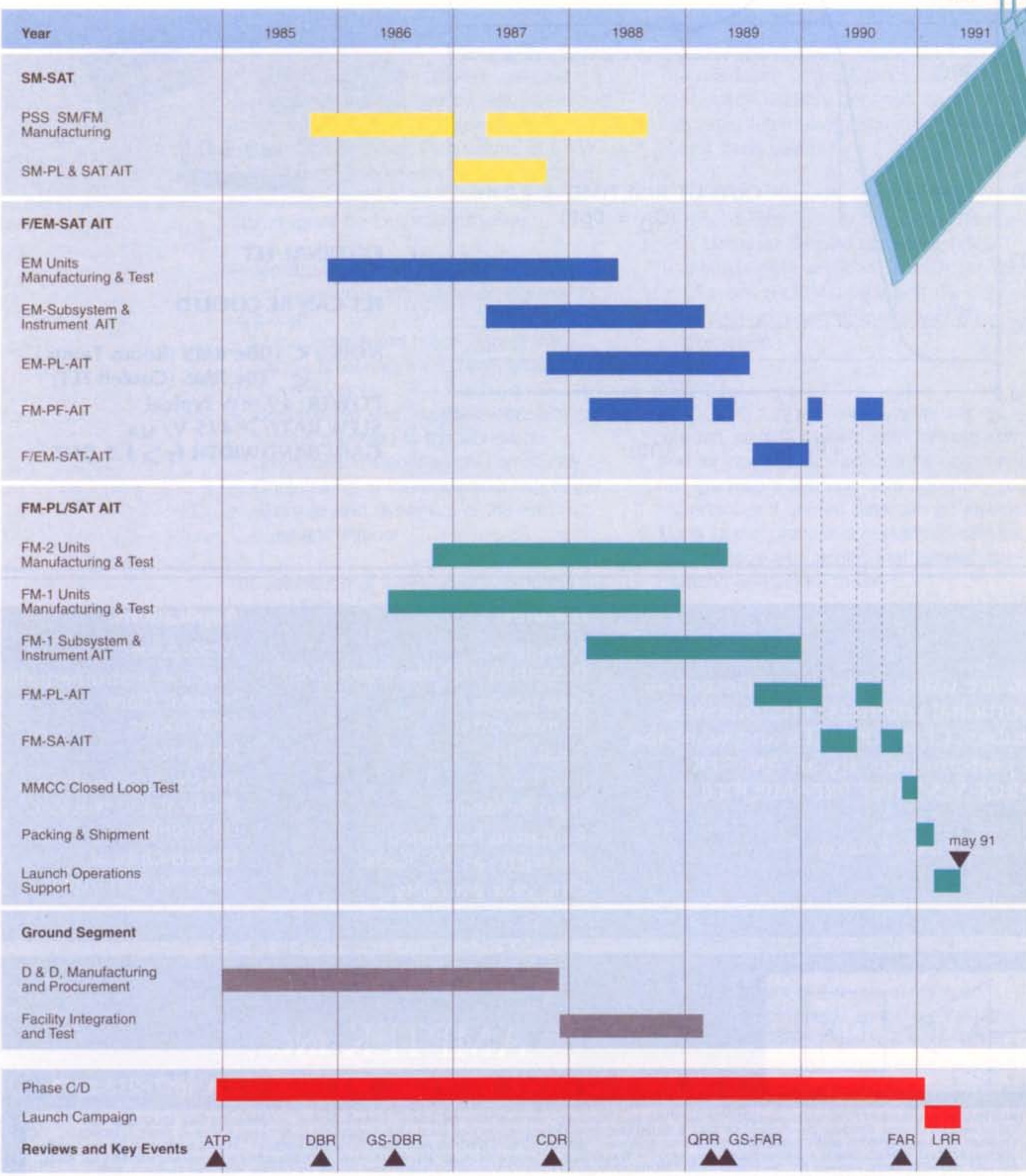


Figure 4. Summary schedule showing the main Reviews, and key events in the industrial contract



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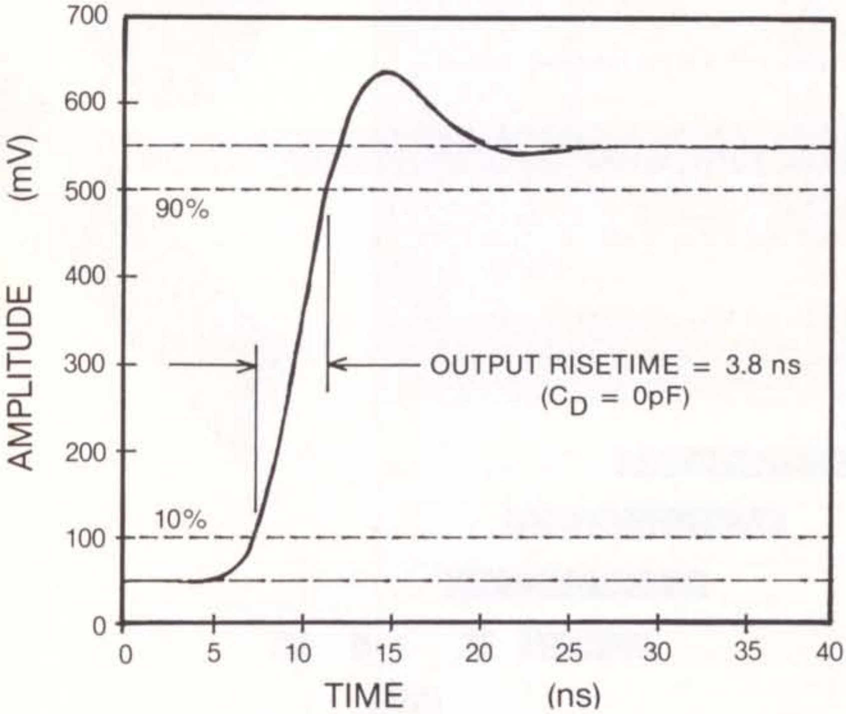

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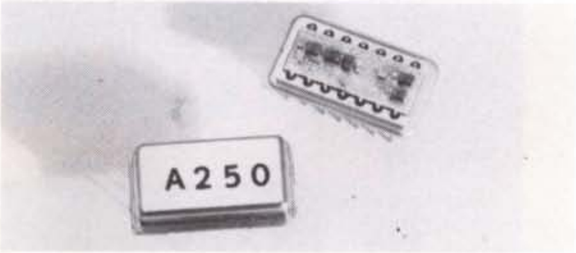

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ERS-2 and Beyond

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In 1988, following consultations with the user community, the Agency elaborated and presented: 'The Objectives and Strategy for the Earth-Observation Programme of ESA'. This Strategy document proposed that the future ESA Earth-Observation Programme should focus on four major themes:

- Monitoring of the Earth's environment on various scales, from local or regional to global.
- Management and monitoring of the Earth's resources, both renewable and non-renewable.
- Continuation and improvement of the service provided to the worldwide operational meteorological community.
- Contributing to the understanding of the structure and dynamics of the Earth's crust and interior.

The realisation of these objectives forms the basis of ESA's Earth-Observation Programme. They are based on the recognition that there are major problems, many of which are only just being recognised, associated with the well-being of mankind on an Earth with limited resources and with increasing demands on those resources. These can only be addressed effectively if the complexities of the global Earth system are understood to a much greater degree than at present. Better observations are fundamental to this requirement.

Given that these issues are of concern to all of the World's nations, they call for well-coordinated international cooperation. No one nation can afford to develop and operate the complex space systems and ground infrastructure necessary to realise the objectives. ESA's Earth-Observation Programme recognises this by seeking collaboration and taking full account of other Earth-observation programmes that are either in progress or are currently being planned.

The realisation of the Agency's Earth-observation strategy depends on an integrated future programme consisting of four main elements:

- an ERS-1 follow-on mission (ERS-2)
- a solid-Earth gravity mission (Aristoteles)
- a Meteosat Second Generation (MSG)
- a series of Polar-Orbit Earth-Observation Missions (POEMs) providing the continuity of data so essential to many of the objectives.

ERS-2

Whilst ERS-1 is seen as a major step forward, its full potential both for research and for operational applications can only be fully realised if the long-term continuity of its important and unique data can be assured. Many of the processes relevant to climate studies have time scales that exceed the duration of a single mission.

A follow-on satellite to ERS-1 has therefore been approved for launch in 1994. Together with ERS-1, this should provide continuity of data from 1991 until the advent of the Polar-Orbit Earth-Observation Missions in 1997. It will also give the various operational communities the chance to fully capitalise on the capabilities of the ERS satellites.

ERS-2, however, is not conceived as just a 'carbon copy' of ERS-1, but will also add an important new capability, that of a Global Ozone Monitoring Experiment (GOME) to address an area of growing concern, namely atmospheric chemistry (Fig. 1). This instrument is a medium-resolution (0.2 nm) spectrometer spanning the ultraviolet to visible regions of the spectrum. It will observe ozone and some related species in both the troposphere and the stratosphere of our planet.

Aristoteles

The internal structure and dynamics of the

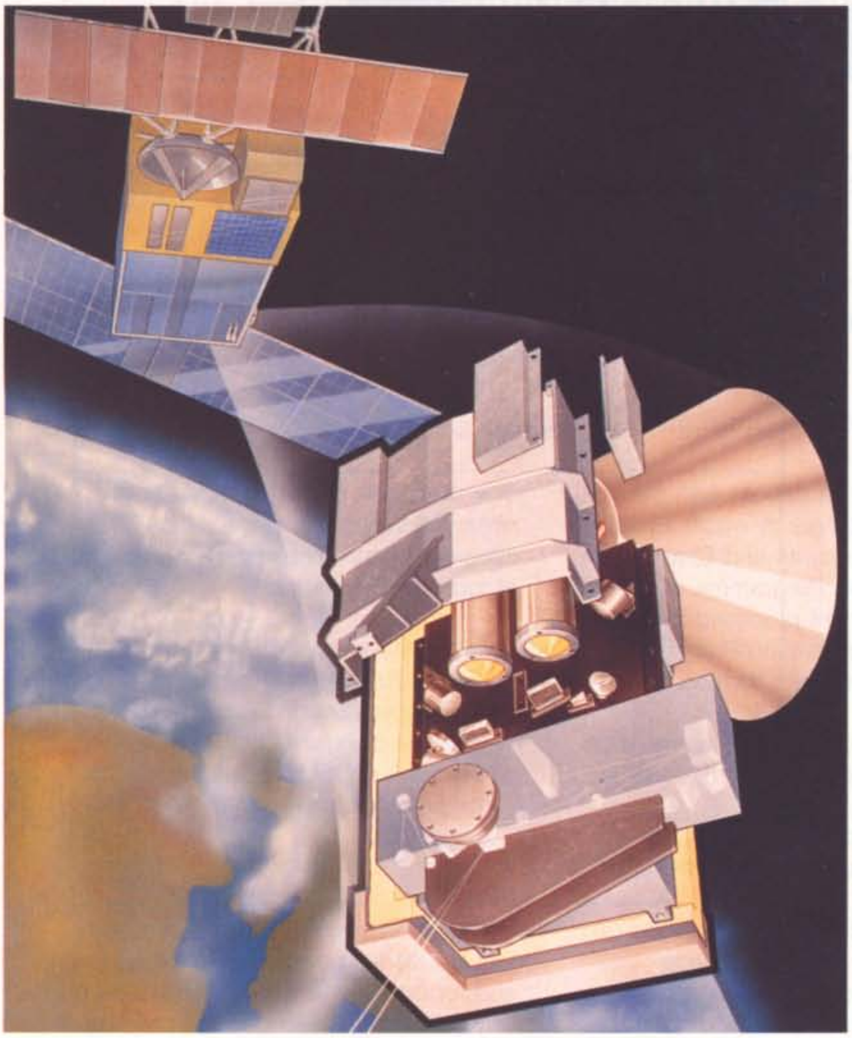


Figure 1. Artist's concept of the GOME package for ERS-1 (preliminary design study only)

Earth's interior, which are not as yet fully understood, are reflected in the fine structure of its gravity field, but this too has not yet been sufficiently well determined for this purpose. A precise geoid is a pre-requisite for the monitoring of the ocean currents, which are themselves the vehicle responsible for the very large poleward transport of the tropical heat input from the Sun.

This transport of heat, in turn, has a major influence on our climate. It is also a pre-requisite for connecting height systems and monitoring sea-level changes on a global basis. Satellite altimetry for measuring and monitoring ocean topography depends on accurate orbitography, where the main error is due to gravity-field uncertainties. An improved knowledge of the gravity field would therefore be a substantial step towards our achieving a better understanding of the Earth, and its climate, as a system.

Since the Earth's gravity field changes slowly, it only needs to be determined precisely relatively infrequently to aid areas such as those singled out above. The results would remain valid for quite some time to come.

However, since the majority of the Earth is covered by oceans, land-based gravity-measurement techniques are of little value globally. This argument applies to the Earth's magnetic field also, with the difference that this field shows variations on shorter time scales too.

Aristoteles is conceived as just such a mission dedicated to a precise determination of the Earth's gravity and magnetic fields (Fig. 2). The measuring instruments foreseen are a gradiometer (a set of micro-accelerometers for determining the gravity-gradient tensor) and a magnetometer package.

By flying at a relatively low altitude (around 200 km), Aristoteles will be able to measure even shorter wavelength components of the field. Its near-polar orbit – selected to provide near-global, precise gravity data – will result in the accuracy required for these different areas of need being achieved within a mission duration of some six months. The orbit will also be well-suited to measurement of the fine structure of the Earth's magnetic field.

Aristoteles is foreseen as a new programme start, involving cooperation with NASA, with a launch in the 1997 time frame.

Meteosat Second Generation

The Meteosat Operational Programme is intended to provide an operational service to the European meteorological community through 1995, with a possible extension to around the end of the century. However, studies are already in hand directed towards the development of a so-called 'Meteosat Second Generation', for launch in the second half of the 1990s, conceived as a joint programme between ESA and EUMETSAT.

Such a new series of satellites would not only continue to provide the present types of data and products, but improve on them and possibly add new capabilities. The current baseline, while retaining the basic concept of a spin-stabilised satellite, envisages significant improvements to its imaging capabilities, coupled with higher data rates and an improved operating capability. The possibility of including small scientific experiments is also being considered.

The Polar-Orbit Earth-Observation Missions

To address the four themes underlying the Agency's Earth-observation strategy, global data sets – in many cases spanning decades – are required. These data must cover a wide range of disciplines as the themes generally straddle traditional lines of demarcation. Moreover, given the synergism between both the disciplines themselves and the instruments necessary to realise the objectives, missions will generally have to be broader in scope and carry more instruments than has been the case in the past.

Consideration of the implications of trying to meet the above criteria led the Agency to conclude that it could make a major contribution to the basic objectives of its Earth-Observation Programme by implementing a series of polar missions based on the Columbus Polar Platform that it is currently developing.

Such platforms have an expected lifetime of about 4.5 years and a payload-carrying capability of the order of 1700 kg; in other words more than twice that of ERS-1. Moreover, they are modular in nature and are therefore capable of supporting missions whose payload requirements range from about 1000 kg to 2400 kg. The first Polar Platform is currently planned for launch in 1997.

As an optimum implementation strategy for the polar orbit, it is proposed to deploy two series of on-going missions in a so-called 'dual-orbit continuous scenario' (Fig. 3).

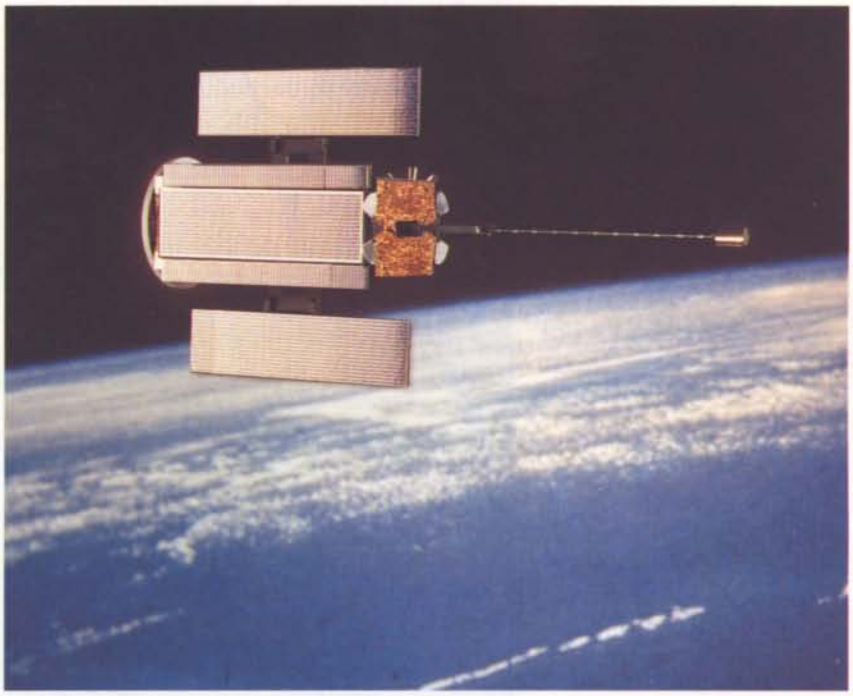


Figure 2. Aristoteles in orbital configuration (artist's impression)

The instruments embarked on each line will address a subset of the overall objectives and disciplines, synergistically grouped into coherent missions for which an optimal orbit could be chosen.

In the figure, two separate lines of Polar Platforms are distinguished, namely the 'M-series' (EPOP-M1, EPOP-M2, etc.) and the 'N-series' (EPOP-N1, EPOP-N2, etc.), each of which focusses on a different set of primary mission objectives: the M-series on

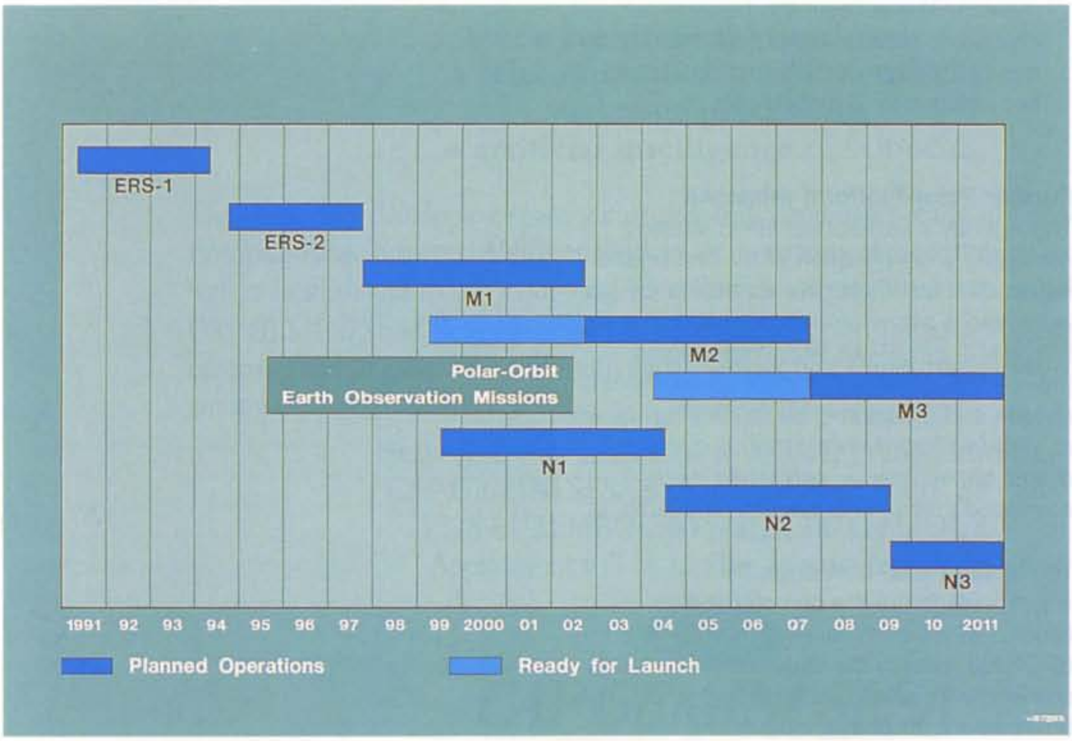


Figure 3. Continuity of Earth-observation data from polar orbit

meteorology–atmosphere–ocean–ice, and the N-series on land-resources–atmosphere. Together they span the overall objectives of the Earth-Observation Programme, and both are environmentally oriented.

The missions will employ Sun-synchronous orbits with a morning descending node and different (optimised) orbit altitudes in the range 700–850 km for each line of Platforms. They are also intended to complement missions planned by other space agencies, notably those of NASA which also envisages flying two series of polar platforms.

The First Polar-Platform Mission (EPOP-M1)

EPOP-M1 is envisaged as a meteorology–atmosphere–ocean–ice mission with its payload containing three main elements:

- Operational instruments: similar to those currently flying on the NOAA Tiros-N polar-orbiting operational meteorological satellites, i.e. sounders and imagers plus data collection.
- Core-facility instruments: large-facility instruments which would be developed by ESA. They include a Synthetic-Aperture Radar (SAR), a scatterometer, a radar altimeter, an ocean-colour monitor, and a chemistry instrument.
- Announcement-of-Opportunity (AO) instruments: a set resulting from an AO for the first polar-orbit mission has been selected for possible inclusion on that mission. These cover the fields of chemistry, radiation and positioning, and are intended to complement the other two categories of instruments.

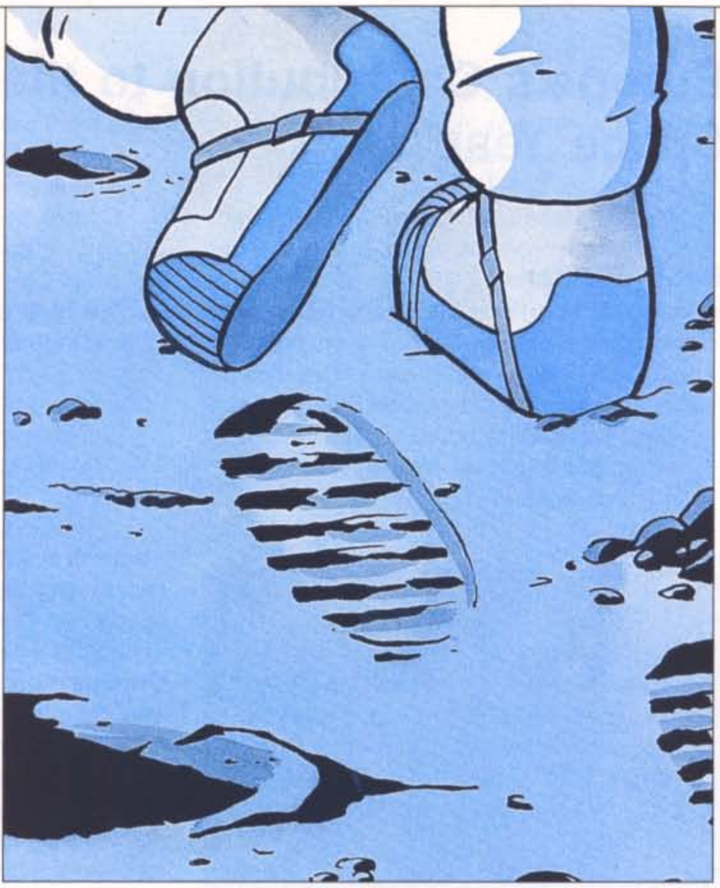
Further Polar-Platform missions

The Agency's Earth-observation strategy envisages a continuation of the first mission, beyond the first Platform's end-of-life, by launching a series of satellites known as EPOP-M2, EPOP-M3, etc. These would provide the continuity of data so essential for climate and environmental monitoring, as well as allowing improvements to be made in overall capabilities as and when more advanced instruments become available.

The strategy also envisages the implementation of the complementary second series of missions (i.e. EPOP-N1, EPOP-N2, etc.) in the dual-orbit continuous scenario with a land, atmosphere and environment emphasis, addressing particularly those areas that cannot be covered by the other series. Some of these capabilities could conceivably ultimately become 'commercial'. The candidate instruments for the N-series Platforms include advanced synthetic-aperture radars.

The broad range of disciplines that would be covered by the variety of instruments on such series of Polar Platform missions would allow the continuous monitoring of our environment. The resulting improved understanding of the Earth as a system, as well as the monitoring of changes in, for example, climate, ozone concentration, sea level, ice caps, etc., would be of fundamental importance to mankind in formulating a strategy to protect and ultimately save his environment.

The polar platform missions planned by the USA, and those envisaged towards the end of the century by Japan, would complement those proposed by ESA and further enhance the prospect of providing global, internationally coordinated observations, and thereby improving man's ability to observe, understand and monitor his planet.



Europe's Contribution to the International Space Year

B.R.K. Pfeiffer
Head of ESA's ISY Office, ESTEC, Noordwijk, The Netherlands

Introduction

The International Space Year (ISY) 1992 is a worldwide initiative to enhance international collaboration in the field of space research and to increase public awareness of the contribution of space technology to a better understanding of the Earth's environment. The results of the ERS-1 mission, to be launched in 1991, will form a significant part of the European contribution to the International Space Year and its main theme, 'Mission to Planet Earth'.

Objectives of the International Space Year

The International Space Year will be celebrated in 1992, the 500th anniversary of the discovery of America by Christopher Columbus and the 35th anniversary of the International Geophysical Year (IGY) which has had a great impact on the preparation and planning of global space research.

The ISY initiative has been welcomed by the United Nations and was formally endorsed at a meeting of the UN General Assembly in December 1989.

The main theme of the International Space Year (ISY) is 'Mission to Planet Earth' (MTPE). Activities are therefore focussed on the monitoring of all facets of our planet's environment, aiming at a better understanding of the important changes and the fundamental phenomena and processes that govern the behaviour of the Earth's environment.

In addition to remote-sensing with spaceborne instruments and the corresponding scientific applications research, the ISY also includes extra-terrestrial research and manned space activities. These concern for example the interaction of the Earth's atmosphere and magnetosphere with solar activity and interplanetary research in general. The other elements in the framework of the ISY are microgravity and life sciences research in space.

Organisation

The ISY activities are organised and coordinated by the Space Agency Forum on the International Space Year (SAFISY), which currently has twenty-eight members and eight affiliate members. Europe is represented by eleven of the ESA Member States, as well as the European Community, Eumetsat and ESA itself.

The Forum is supported by three Panels of Experts, one for each of the following disciplines:

- Earth Science and Technology,
- Education and Applications,
- Space Science,

whose task is to propose to SASIFY scientific projects for international collaboration.

To provide public relations support for the scientific and applications activities, two Associations have been created:

- the US ISY Association in Washington DC
- the European ISY Association (EURISY) in Paris, France.

In general, ISY activities rely on voluntary contributions from its members and affiliates. Each specific undertaking is led by one or two members who already have significant activity in that area, and then complemented by contributions from other members active in the same field. Lead agencies provide complementary funding to fill, where necessary, identified gaps in the proposed research and applications.

The Earth Science and Technology Panel

This Panel has proposed a total of 12 projects, suggested by international

experts, which have been accepted by SAFISY. These 12 projects address the most important problems of the global change of our environment, falling into two categories:
- Space Data for Global Change and Global Information System Tests
- Global Change Outreach (aiming to reach, with global information, the political decision makers and the general public).

Space Data for Global Change and Global Information System Tests (Category-1):
- Global consequences of Land Cover Change (LCC)
- Enhanced Greenhouse Experiment Detection Experiment (GEDEX)
- Ocean Variability and Climate (OVC)
- Polar Stratospheric Ozone (PSO)
- Productivity of the Global Ocean (PGO)
- World Forest Watch (WFW)
- Global Sea Surface Temperature (GSST)
- Polar Ice Extent (PIE)
- Global Satellite Image Mapping (GSIM)
- Space Disaster Mitigation (SDM).

Europe (ESA and its Member States) contributes to all Category-1 projects. Eight of the above ten Working Groups are jointly led by European national organisations (6) or ESA (2). ESA's contributions are closely linked to the results from the forthcoming ERS-1 mission, thus the two ESA-led Working Groups are 'Ocean Variability and Climate' and the 'Polar Ice Extent'.

The information on global sea state gathered by ERS-1 will be used in global climate models in which the ocean–atmosphere interaction is one of the key parameters. Furthermore, ERS-1 will allow for a real-time ice-monitoring demonstration during the winter of 1991/1992 as a major ISY event.

Global Change Outreach (Category-2):
- Global Change (Electronic) Encyclopedia (GCE)
- Global Change Atlas (GCA).

Several Working Group meetings have already taken place and the implementation of these two projects, led by Canada and Austria respectively, is well advanced. Europe is contributing to both these projects. There are also firm plans by some SAFISY members to add a third Global Change Outreach project which will be entitled 'Global Change Video' (GCV).

The Education and Applications Panel
The Education and Applications Panel is co-chaired by NASA and the French National Space Agency, CNES. At its first meeting a total of 39 projects were proposed, far greater than the number of Earth Science and Technology proposals.

The aim is to introduce the results of Earth monitoring and space science related to environmental research into the education process. Emphasis is being given to world-wide training in remote-sensing applications to promote the use of these new techniques and to enable less-developed countries to participate in application projects currently being undertaken all over the world by the more developed SAFISY member countries.

Education and Applications activities are covered under two themes:

Theme A: Training in Remote-Sensing Applications, guided by CNES, with 12 projects proposed in the following fields:
- Vegetation resources: monitoring and management
- Geology: natural hazards
- Urban and environmental planning.

Theme B: Space and Education, guided by NASA, with 27 projects proposed in the following areas:

- Earth observation in education
- Space science in education
- Space communications in education.

Many of the Theme-A projects are linked to existing bilateral or multilateral ventures in South-East Asia, the Pan-Amazonian region, semi-arid and tropical zones, as well as in highly industrialised countries. A number of the Theme-B projects have similar forerunners and do not require a large investment. However, the process of finalising the list of projects and identifying their lead and contributing organisations has not yet been completed.

The Space Science Panel

The activities of the Earth Science and Technology Panel are largely concerned with the Mission to Planet Earth. It is acknowledged, however, that environmental conditions on Earth can be influenced by physical phenomena within our planet's wider environment, those of the magnetosphere and the heliosphere beyond. A third Panel – on Space Science – has therefore been set up by the International Committee on Space Research (COSPAR).

The Space Science Panel of Experts met during the COSPAR meeting in June 1990 in The Hague and again in San Francisco in early December 1990. A number of proposals for international collaboration to be considered by the SAFISY members have been prepared. These proposals fall into three categories:

- to undertake investigations that clearly demonstrate the value to environmental science of research in the following areas:
  - magnetospheric and heliospheric physics
  - the structure and physical state of the Sun and our other solar system companions
  - the problems associated with living and working in space
- to take action to improve the timely and efficient acquisition, processing and distribution of data, as well as to demonstrate the feasibility of such action
- to bring the results of space-science research to the widest possible public audience.

Special events in 1992

The ISY activities will culminate in a number of special events at which the results of the joint international science and applications research will be presented. As with the International Geophysical Year, the ISY will also discuss problems and trends for future research and provide recommendations from key expert panels.

Special events in 1992 will include panel sessions with media and key political figures, as well as exhibitions related to the 'Mission to Planet Earth' theme. Events in preparation or under consideration include:

- an ISY Conference on the 'Earth and Space Science Data Information Systems', in Pasadena, California, USA, 11–14 February 1992
- a European ISY Conference on 'Space in the Service of the Changing Earth' in Munich, Germany, 30 March – 4 April
- an ISY Conference on 'World Forest Watch' in Sao Paulo, Brazil, 26–29 May
- a 'World Space Congress' in Washington DC, USA, 28 August – 9 September
- an Asian/Pacific ISY Conference on 'Remote Sensing in Densely Populated Areas of the Earth' (to be confirmed), possibly in Japan.

The most important event for Europe will be the European ISY Conference, jointly organised by the European Community, ESA and Germany, the latter hosting the Conference.

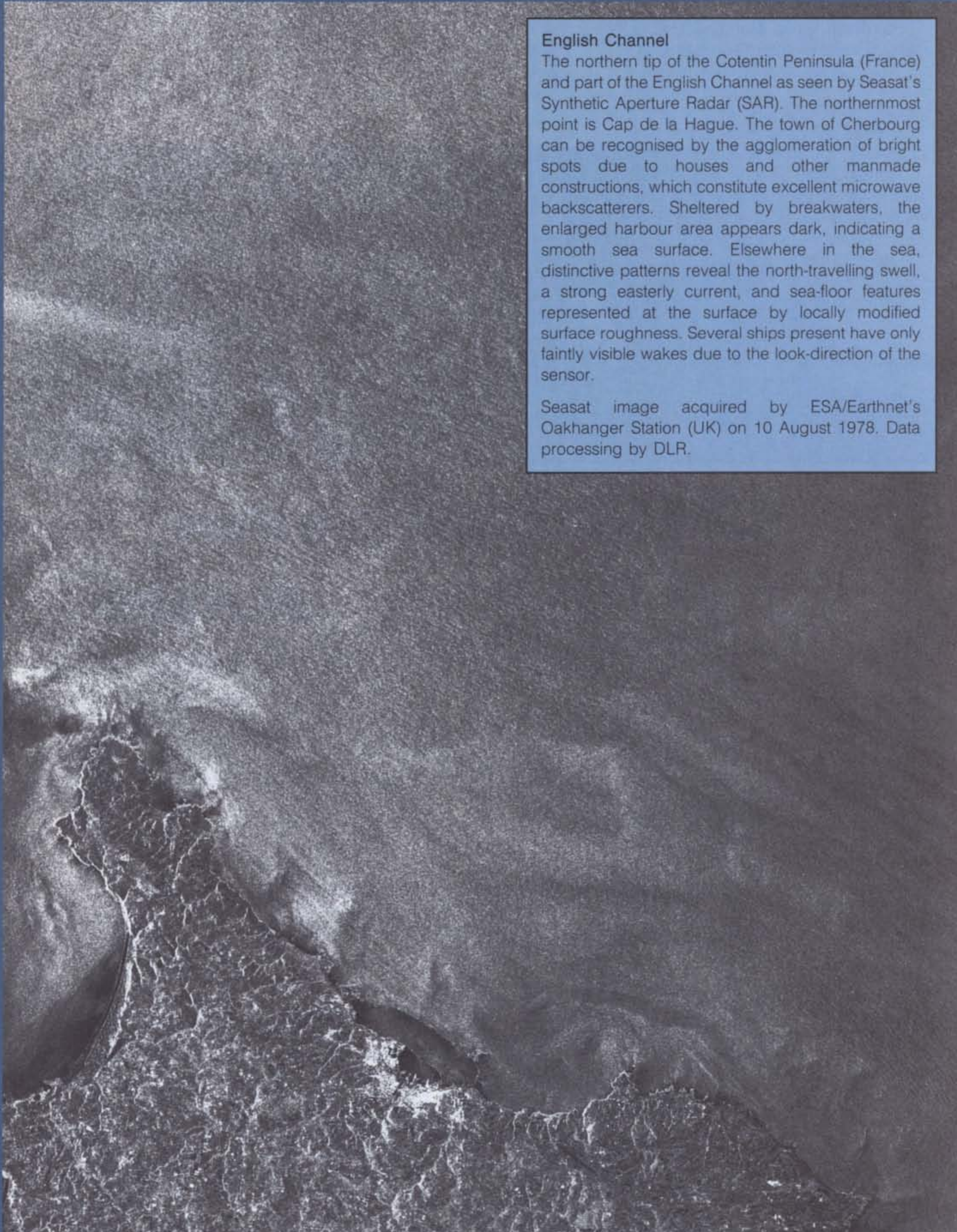
As part of the build-up to 1992, there will be a number of earlier events, for example the EURISY Symposium on 'The Earth's Environment – an Assessment from Space', Venice, Italy, 10–11 April 1991.

Conclusions

ISY projects will serve to demonstrate the possibilities of space techniques to increase our understanding of the Earth's environmental processes and to emphasise the need for continuous global monitoring from space.

Preparations for 1992 are already well advanced, in particular for the Earth Science and Technology projects which were defined very early. Through its growing involvement in environmental research, Europe is making a major contribution towards the success of this truly international collaborative effort.

Focus

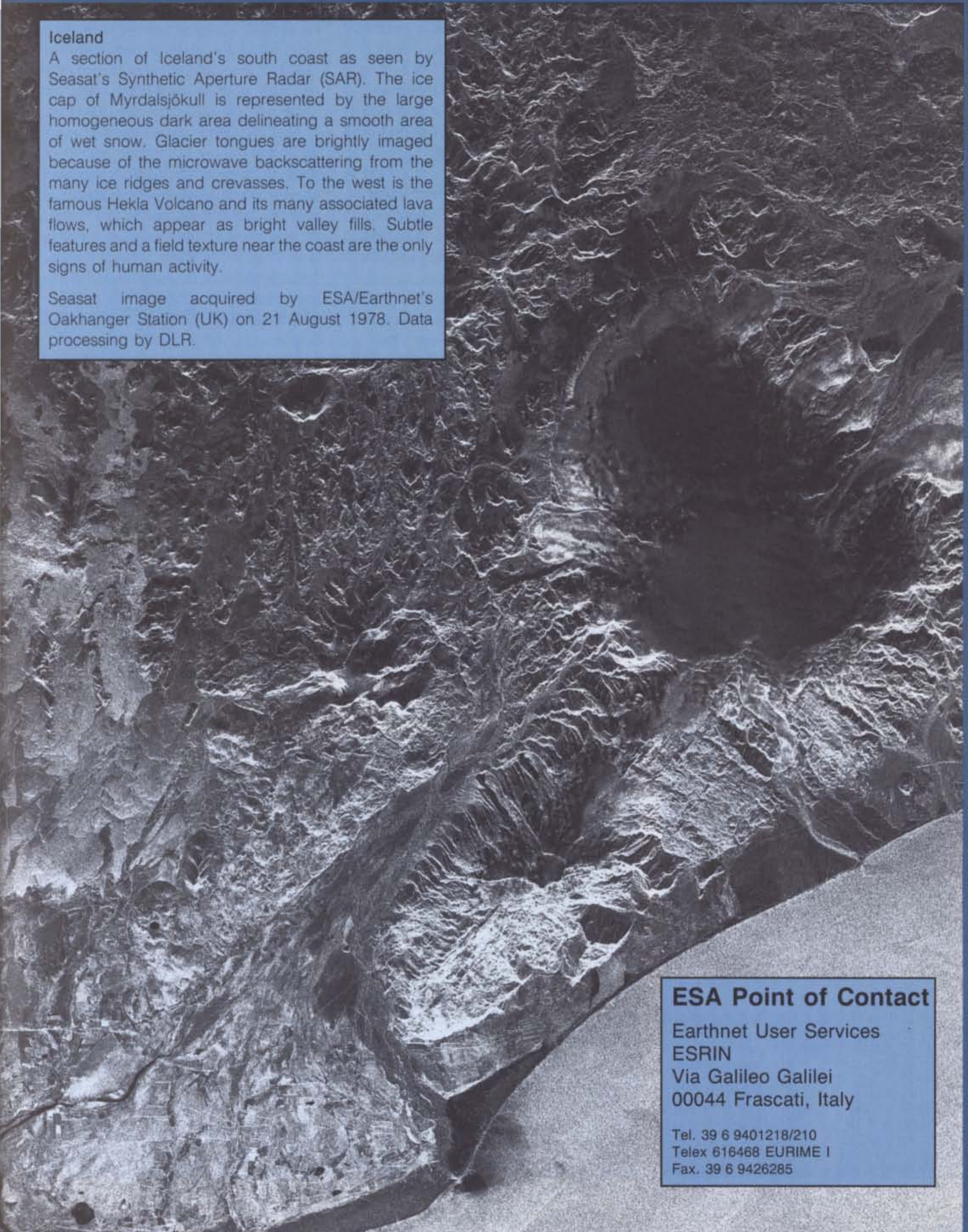


English Channel

The northern tip of the Cotentin Peninsula (France) and part of the English Channel as seen by Seasat's Synthetic Aperture Radar (SAR). The northernmost point is Cap de la Hague. The town of Cherbourg can be recognised by the agglomeration of bright spots due to houses and other manmade constructions, which constitute excellent microwave backscatterers. Sheltered by breakwaters, the enlarged harbour area appears dark, indicating a smooth sea surface. Elsewhere in the sea, distinctive patterns reveal the north-travelling swell, a strong easterly current, and sea-floor features represented at the surface by locally modified surface roughness. Several ships present have only faintly visible wakes due to the look-direction of the sensor.

Seasat image acquired by ESA/Earthnet's Oakhanger Station (UK) on 10 August 1978. Data processing by DLR.

Earth



Iceland

A section of Iceland's south coast as seen by Seasat's Synthetic Aperture Radar (SAR). The ice cap of Myrdalsjökull is represented by the large homogeneous dark area delineating a smooth area of wet snow. Glacier tongues are brightly imaged because of the microwave backscattering from the many ice ridges and crevasses. To the west is the famous Hekla Volcano and its many associated lava flows, which appear as bright valley fills. Subtle features and a field texture near the coast are the only signs of human activity.

Seasat image acquired by ESA/Earthnet's Oakhanger Station (UK) on 21 August 1978. Data processing by DLR.

ESA Point of Contact

Earthnet User Services
ESRIN
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00044 Frascati, Italy

Tel. 39 6 9401218/210
Telex 616468 EURIME I
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In Brief

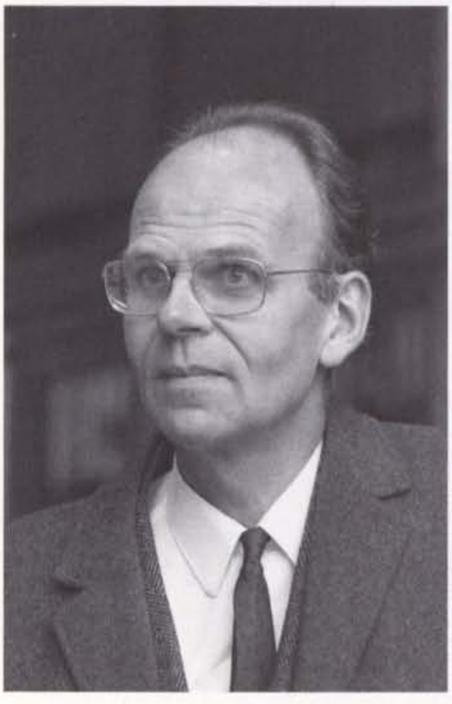
Leon van Hove, 1924 – 1990: A Great European Scientist

R.M. Bonnet, Director of Scientific Programmes, ESA

Leon van Hove was the Chairman of ESA's Science Programme Committee (SPC) from July 1984 until July 1987 when he was succeeded by Prof. K. Fredga. He died on 2 September 1990, only 18 months after a special symposium organised at CERN on the occasion of his 65th Birthday.

Leon van Hove was above all a great physicist. He was Director General for Research of CERN between 1976 and 1980 (at that time CERN had two DGs, one for Research and one for Administration). He joined CERN in 1961 when Viktor Weisskopf invited him to leave his post in Utrecht to head the Theory Division at CERN. In 1971 he was invited by Prof. R. Lüst to succeed Werner Heisenberg as President of the Max-Planck Institute for Physics and Astrophysics in Münich, but he declined, accepting, however, to chair the Directorate Committee of the Institute. He returned full-time to CERN in 1976.

During his directorship at CERN, crucial decisions were taken which determined its future activities. In that period the proton-antiproton collider was built, and the experiments began that led to the discovery of the Z^0 and W^+ particles, for which C. Rubbia and S. van der Meer were awarded the Nobel Prize in 1983. It was also during his mandate that the proposal for the electron-proton collider was formulated.



Leon van Hove played a key role in ESA's Space Science Programme. In 1983, following the suggestion of G. Setti he was invited to join the Survey Committee, chaired by J. Bleeker, whose task was to formulate ESA's Long-Term Space Science Plan, which in 1984 was christened the Horizon 2000 Programme. The idea was to incorporate in the Committee physicists who could strengthen the relationship between the space physics and particle physics communities. Our choice could not have been better. Leon van Hove played his role magnificently and, in spite of the different and very often new character of this field of science for him, participated fully in the discussions and in the elaboration of the Programme.

We benefited on many occasions from his profound scientific knowledge, his remarkable critical judgement and his ability to assess rapidly the quality of any new idea and any new project. He helped on many occasions in the making of final and often difficult decisions. When the Survey Committee held its last meeting in May/June 1984 in Venice, it was Leon van Hove who suggested, after the first three cornerstones of the programme had been agreed, i.e., the X-ray and submillimetric observatories and the mission to return pristine material from asteroids or comets, now better known as XMM, FIRST and Rosetta respectively, that a fourth cornerstone be created incorporating both the Cluster and Soho projects together in a unique Solar – Terrestrial Physics Programme.

His remarkable neutrality and his perfect knowledge of our Programme led me to ask him to become Chairman of the Science Programme Committee in July 1984. To my great satisfaction he accepted and chaired that Committee until 1987. His ability as a chairman rapidly became apparent. He was tough but left no aspect of any issue untouched. He wanted to be sure that all problems had been analysed, whether they were of a scientific, political or simply human nature. He systematically pushed the reasoning on all aspects of problems, leaving no stone unturned. He was tough but he was also modest, as he demonstrated when he declined the offer to chair the Space Science Advisory Committee, arguing that his knowledge of the science of space missions was not good enough.

Leon van Hove was very keen to analyse rationally and in more depth the convergence between particle physics and cosmology and astrophysics. In this respect he played a key role in the institutionalisation of the now famous CERN/ESO Symposium. His great power of synthesis has been always a source of inspiration in this domain. At the Bologna Symposium in 1988, he made special mention of the Exosat and Giotto results, the first for the discovery of the Quasi-Periodic Objects and the second for the brilliant results and discoveries made on

Halley's Comet. Those of us who shared these moments with him cannot forget his almost child-like pleasure in watching the launch of Giotto in 1985 in Kourou. Nor can we forget his emotion during the ceremony at the Vatican when His Holiness the Pope greeted the four space agencies involved in the space missions to Halley. He was invited to attend the launch of the Hubble Space Telescope in April 1990 but he had to decline, being already severely ill.

As well as being a great scientist, Leon was a great European. Of Belgian origin, he was fluent in French, Flemish, German and English and held several teaching positions in different countries, in particular in The Netherlands. He was of course invited to many international conferences and lectured in many summer schools. He was a man of great culture and enjoyed music and literature immensely. His hospitality was also legendary. He was a profoundly honest and a very modest person. Having attained the highest position at CERN, he was content to return to science as a basic scientist, occupying a modest office in the Theoretical Physics Division.

At ESA, Leon van Hove will be remembered for his positive and constructive contribution to space science. The Horizon 2000 Programme, which he contributed so richly to establish, bears the mark of his ideas and his judgement. Indeed no other scientist could better strengthen the links between space and fundamental physics.

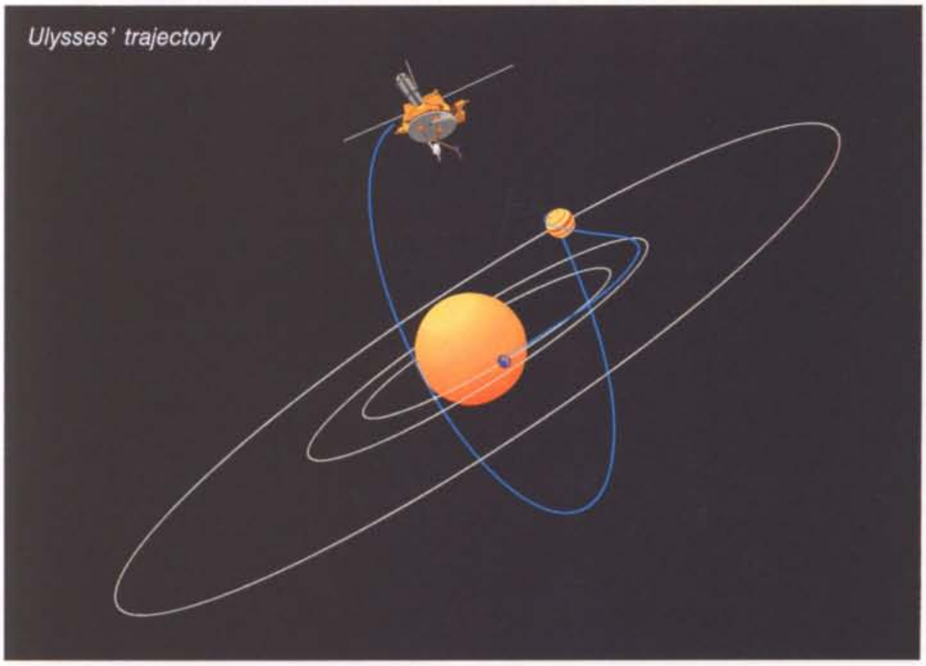
We cannot hide our great sadness at his departure. We would like to express to his wife, his son and his colleagues not only our deep sense of loss but the feeling that space science in Europe has been strengthened thanks to his dedication to his work and to science, and to his European spirit.

Ulysses Fully Operational

Ulysses is now fully commissioned and operational. As of 17 January the spacecraft, in excellent condition with all subsystems and experiments working nominally, was about 126 million km from Earth en route for Jupiter. At that distance its radio signals were taking over six minutes to reach the NASA Deep-Space Network ground stations.

Early in November Ulysses developed a nutation ('wobble') problem which was thought to be attributable to solar heating of the 7.5 m axial boom. ESA and NASA engineers correctly predicted that the nutation would decrease of its own accord as the spacecraft travelled further away from the Sun. By the third week of December the geometry of Ulysses' trajectory was such that the axial boom was completely in the shadow of the spacecraft and the problem disappeared. Onboard control strategies have now been developed to control the nutation, should it recur later in the mission.

With the commissioning of the spacecraft complete, the routine phase of the mission has begun. Meanwhile, at the first Ulysses' Science Working Team meeting since the launch on 6 October, which was held at JPL, USA, on 15 to 17 January, experimenters declared themselves extremely happy with the first scientific results.


Ulysses' trajectory

ESA Delegation to Poland

The Agency has entered into discussions with the Polish Academy of Sciences and a bi-lateral meeting was recently held in Warsaw. The ESA delegation, led by Prof. R. Bonnet, ESA's Director of Scientific Programmes, was welcomed to Warsaw on 27 November by Prof. R. Galazka, Chairman of the Committee for Space Research, leading the Polish delegation.

The ESA delegation also met with Prof. J. Janowski, Deputy Prime Minister and Minister for Research and Development, and Prof. L. Kuznicki, Vice-President of the Polish Academy of Sciences.

Both parties indicated a desire to develop mutual cooperation in the research and peaceful use of space. The Polish delegation expressed its wish to become more involved in ESA activities. Both parties agreed that the first step of this gradual process would be the negotiation of a Cooperative Agreement. Possible areas of cooperation could include: telecommunications (use of Olympus, VSAT ground stations and land mobile systems); earth-observation pilot projects in particular utilising ERS-1; and expansion of existing contacts in the space science disciplines.

Ariane's First Launch of the Year

On 15 January at 23:10:49 h GMT Ariane Flight 41, an Ariane 44 L with four liquid propellant strap-on boosters, lifted off from the ELA-2 launch complex in Kourou, French Guiana. Its two passengers, Italsat-1, the Italian Space Agency's first telecommunications satellite, and Eutelesat-II F2, the second of Eutelsat's new-generation of telecommunications satellites, were successfully placed into geostationary transfer orbit.

The next launch, carrying MOP-2, ESA's second operational meteorology satellite, and Astra-1b for the Société Européenne des Satellites, Luxembourg, is scheduled for 21 February. The Arianespace order book currently stands at 34 satellites to be launched over the next four years.

ESOC Supports the Italsat-1 Mission

ESOC, the Agency's Operations Control Centre in Darmstadt, Germany, had been asked by the Italian Space Agency (ASI) to be responsible for the Launch and Early-Orbit Phase (LEOP) of the Italsat-1 mission.

The Estrack network is providing full telemetry, tracking and command support. First signals were received via the Malindi ground station 22 minutes after launch and the partial deployment of the solar arrays was completed two hours later. The first apogee engine firing was on 17 January, and the second on 19 January.

The ESOC team will remain responsible for mission operations until Italsat is on station at 13.2° East, when the spacecraft will be handed over to Telespazio, Fucino. Once in-orbit testing has been completed in July, the satellite will be used for experimental and pre-operational telecommunications activities.

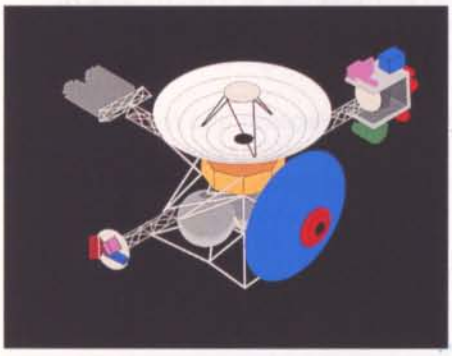
Italsat-1

Cassini/Huygens MOU Signed

ESA and NASA have recently signed the Memorandum of Understanding (MOU) on their joint Cassini mission to explore the planet Saturn and its largest moon, Titan.

The mission has two main elements; a NASA-built Orbiter will circle the planet itself, while ESA's Huygens probe will descend through Titan's atmosphere to land on the surface. A full description of the scientific objectives of the mission was given in ESA Bulletin No. 55, pp. 24–30.

As set out in the MOU, a Titan-IV expendable rocket will launch the composite spacecraft within a narrow launch window in April 1996. The launch window is critical because Cassini will rely on three gravity-assist manoeuvres, one at the Earth and one at Jupiter, to swing it on towards its final target.



Chinese Delegation Visits ESA Headquarters

Representatives of ESA and its Member States received a delegation from the Government of the People's Republic of China on 14 December 1990 at the Agency's Headquarters in Paris, for exploratory talks on the international provision of launch services.

The Chinese delegation was led by Mr Sun Jiadong, President of the Commission for Science and Technology of the Aerospace Industry Ministry. In greeting the Chinese delegation, Mr J-M. Luton, ESA's Director General, emphasised the major advances that had been achieved worldwide in developing launcher technology. Ensuring equitable international exploitation of that technology is a difficult task, but one that has to be faced. The first step is communication, thus the exploratory talks were to be welcomed, a feeling reiterated by both leaders at the close of the meeting.

The History of ESA

Towards the end of last year, a five-year project was initiated to write the history of ESA. The Project Director will be Dr John Krige, who has spent the last eight years writing the history of CERN. He will be assisted by Prof. M. De Maria of the University of Rome and Prof. A. Russo of the University of Palermo. Originally physicists by training, they have both worked on the history of cosmic-ray physics. Prof. Russo has also made a detailed study on the decision to launch the Cos-B satellite, through which he first came into contact with ESA.

In a feasibility study, presented to ESA in June 1990, the three historians postulated that the time was now ripe to write a history of the Agency. The Organisation has come of age, and its success is a tribute to those who established it, exemplifying European scientific, technological, industrial and political cooperation. It is therefore appropriate that a well-documented study be made of the sometimes difficult trail which has been blazed over the last thirty years, all the more so since many of the pioneers are still alive and able to contribute documents and personal reminiscences to the researchers.

An added advantage for the historians is that the Agency has recently decided to transfer its archives up to 1975 to the historial archives of the European Economic Community in Florence. Here an able team, under the direction of Dr K. Jaitner, has already classified the material and placed key information for accessing it into a powerful database.

The proximity of the archives, and the advantages of being integrated into an intellectual community interested in the postware reconstruction of Europe, were the key considerations behind the idea that the Project Leader should be based at the European University Institute in Florence. Dr Krige will be attached to the Department of History and Civilisation for the next five years. In this time the team has undertaken to produce a short, richly-illustrated account of ESA's history to coincide with its 30th birthday in 1994, and a substantial, two-volume scholarly account of the story of its birth and development from about 1957, when Sputnik was launched, to 1987, the Ministerial-level Conference in The Hague.

In the course of 1991 and 1992 the team will conduct about 50 in-depth oral history interviews with key figures and collect documents and photographs to build up the archives.

Anyone who has valuable or unusual documents and photographs of relevance to the history of the Agency is invited to contact:

Dr G.J. Krige
Department of History and Civilisation
European University Institute
Via dei Roccettini 9
Badia Fiesole
Florence
Italy

Tel: 55.50921

The Euroavia Design Contest

The European Association of Aerospace Students, Euroavia, together with ESA/ESTEC, Dornier GmbH and other companies, has launched the Euroavia Design Contest. This educational project will give 25 aerospace students selected from all over Europe the chance to study, in a summer-school type environment, how a satellite is designed and built. Five senior space engineers will lead a two-week configuration study on a small scientific satellite in April this year.

A very important aim of this project is to emphasise the necessity for European cooperation in space, exemplified by the Ariane, Columbus and Hermes programmes. The engineers from ESA and Dornier and the students will form a multinational working group that will have to cooperate closely to achieve results.

Interested students are invited to write a paper (maximum length ten A4 pages) on a space-related subject of their choice. The subject could be technical or scientific, or address management or political aspects.

More information may be obtained from:

Euroavia Design Contest Team
Attn: Cristian Bank
Pffaffenwaldring 27
D-7000 Stuttgart 80
Germany

Phone: 49.711.685.2319
Fax: 49.711.685.3706

ESOC Provides Information on Re-entry of Salyut-7/Kosmos-1686

Salyut-7/Kosmos-1686 is expected to re-enter the Earth's atmosphere around 6 February and ESOC, the Agency's operations centre in Darmstadt, Germany, is involved in the multi-agency attempts to predict more accurately the time and place of the re-entry.

The 20-tonne Salyut-7 space station, launched in 1982, was joined in 1985 by Kosmos-1686, of similar mass. The two cylindrical spacecraft are connected to each other along the main longitudinal axis. According to the Soviet News Agency TASS, the orbital decay caused by atmospheric drag can no longer be compensated by orbit-raising manoeuvres, and an uncontrolled re-entry is expected. Though much of the combined spacecraft is likely to disintegrate, some fragments could reach the Earth's surface.

Using information from NASA and from the German Research Establishment for Applied Science (FGAN) in Wachtberg-Werthhoven, Germany, predictions of the time and place of re-entry are being made by ESOC and passed to national authorities in the ESA Member States.

The current estimate is 6 February ±4 days, between 51.7°N and 51.7°S; closer to the re-entry date the predictions will become more accurate.

4th European Symposium on

SPACE ENVIRONMENTAL CONTROL SYSTEMS

Florence, Italy, 21–25 October 1991

with the participation of Aeritalia and Selenia Spazio

Contact: Mr. J.-F. Redor, ESA/ESTEC (YC), 2200 AG Noordwijk, The Netherlands. Fax: (31) 1719-12142.
Or: Mr. G. Rum, ASI, Viale Regina Margherita 202, 00198 Rome, Italy. Fax: (39) 647 67 267.

Programmes under Development and Operations / Programmes en cours de réalisation et d'exploitation

In Orbit / En orbite

	PROJECT	1991 – 1997	COMMENTS
SCIENTIFIC PROGRAMME	IUE		
	HIPPARCOS		OPERATIONAL 3 YEARS
	SPACE TELESCOPE		LAUNCHED 12 APRIL 1990
	ULYSSES		LAUNCHED OCTOBER 1990
APPLICATIONS PROGRAMME	MARECS-A		LEASED TO INMARSAT FOR 10 YEARS
	MARECS-B2		LEASED TO INMARSAT FOR 10 YEARS
	METEOSAT-3		LIFETIME 3 YEARS
	METEOSAT-4 (MOP-1)		LIFETIME 5 YEARS
	ECS-1		EXTENDED LIFETIME
	ECS-2		LIFETIME 7 YEARS
	ECS-4		LIFETIME 7 YEARS
	ECS-5		LIFETIME 7 YEARS
	OLYMPUS-1		LAUNCHED 12 JULY 1989

Under Development / En cours de réalisation

	PROJECT	1991 – 1997	COMMENTS
SCIENTIFIC PROGRAMME	SOLAR TERRESTRIAL SCIENCE PROG. (STSP)	SOHO; CLUSTER	LAUNCHES SOHO JULY 1995 CLUSTER DEC. 1995
	ISO		LIFETIME 1.5 YEARS
	HUYGENS		TITAN DESCENT DEC. 2002
COMMS PROG.	DATA RELAY SATELLITE (DRS)	PHASE 1; PHASE 2	SYSTEM OPERATIONAL 1996
	ARTEMIS		READY FOR LAUNCH MID-1994
EARTH OBSERV. PROGRAMME	ERS-1		
	ERS-2		
	EARTH OBS. PREPAR. PROG. (EOPP)		EXTENSION OPEN FOR SUBSCRIPTION
	METEOSAT OPS. PROG.	MOP-2; MOP-3	
SPACE ST. & PLATF. PROG.	MICROGRAVITY	EURECA; D2; IML-2	
	EURECA		READY FOR LAUNCH DEC. 1991
	COLUMBUS	PHASE 2	3 YEAR INITIAL DEVELOPMENT PHASE
SPACE TRANSPORT PROG.	ARIANE-4		
	ARIANE-5		FIRST FLIGHT APRIL 1995
	HERMES		3 YEAR INITIAL DEVELOPMENT PHASE
TECH. PROG.	IN-ORBIT TECHNOL. DEMO. PROG. (PH-1)		SEVERAL DIFFERENT CARRIERS USED

: DEFINITION PHASE — > PREPARATORY PHASE — ▨ MAIN DEVELOPMENT PHASE — # STORAGE — ◊ HARDWARE DELIVERIES

— INTEGRATION — ✝ LAUNCH/READY FOR LAUNCH — • OPERATIONS — → ADDITIONAL LIFE POSSIBLE — ✧ RETRIEVAL

Hipparcos

Le satellite Hipparcos continue à bien fonctionner et des données scientifiques de haute qualité sont recueillies pendant environ 70% du temps, soit environ 17 heures par jour. D'après ce que l'on sait actuellement du comportement des réseaux solaires et de la consommation de gaz pour la commande d'orientation, on prévoit maintenant pour le satellite une durée de vie opérationnelle d'environ trois ans (à compter au lancement). L'analyse des données progresse également de façon satisfaisante, les différentes tâches de traitement présentant un bon degré d'harmonie et de cohérence. Les activités ont été centrées jusqu'ici sur la validation du logiciel et l'étalonnage des instruments. La première phase de l'analyse systématique des données devrait normalement commencer début 1991. Suffisamment de données ont été entre temps engrangées pour permettre de dresser avec une précision d'environ 5 millisecondes d'arc le catalogue des 120 000 étoiles, ce qui représente une énorme avancée quantitative et qualitative par rapport aux données précédemment disponibles sur la position des étoiles.

Olympus

Voilà maintenant plus d'un an que le satellite Olympus-1 est en orbite. Il continue de bien fonctionner; ses quatre charges utiles donnent satisfaction et fournissent différents services de télécommunications à un nombre toujours croissant d'utilisateurs. L'éventail de ses possibilités a été démontré au cours d'une série d'émissions en direct organisées à l'occasion du congrès de la Fédération internationale d'Astronautique (IAF) qui s'est tenue à Dresde en octobre 1990.

La charge utile de radiodiffusion directe émet pratiquement vingt heures par jour sur le canal européen et quinze sur le canal italien. BBC Enterprises, opérationnelle depuis septembre 1990, utilise le faisceau européen pour diffuser un programme essentiellement composé de nouvelles, d'informations générales et de documentaires. En octobre, la RAI a officiellement annoncé le démarrage, sur le canal Raisat du faisceau italien, de programmes de télé-enseignement, d'émissions récréatives et d'intérêt général.

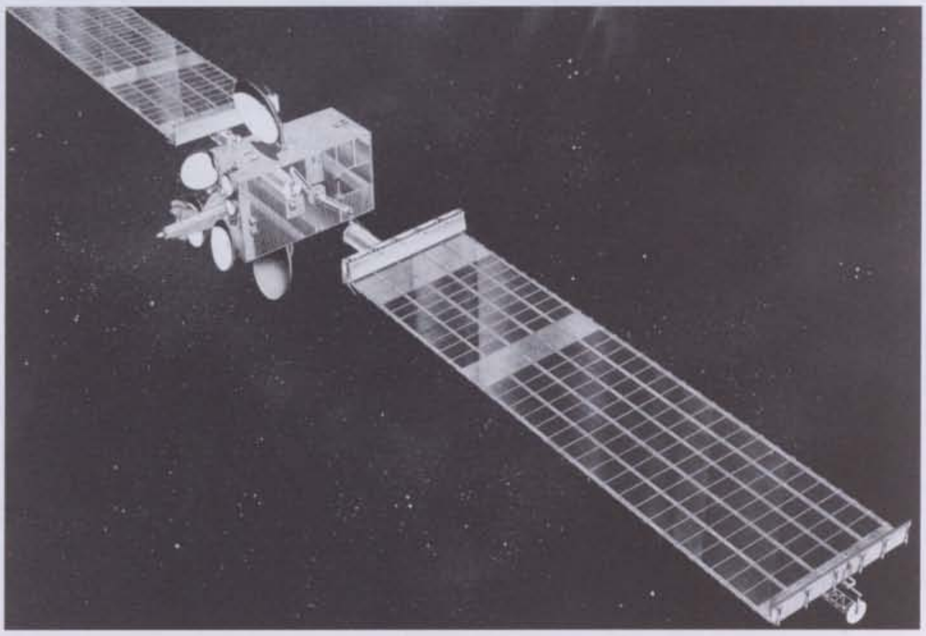
La charge utile des services spécialisés continue de susciter l'intérêt d'une large gamme d'utilisateurs. Au Royaume-Uni, Polytechnic South-West a décidé de poursuivre la diffusion de son programme destiné aux écoles et lycées pendant une deuxième année scolaire. A noter: la retransmission en direct du lancement de la sonde Ulysse et la diffusion régulière de bulletins d'information sur la région du Golfe pour la télévision et les sociétés de télédiffusion par satellite.

Pendant le congrès IAF, la charge utile 20/30 GHz a permis de démontrer le fonctionnement du système CODE (Expérience en coopération sur les données d'Olympus) avec lequel des données ont été échangées entre un terminal à très petite ouverture (VSAT) installé à Dresde et les établissements de l'ESRIN et de l'ESTEC. Le système CODE a commencé en décembre 1990 à assurer un service opérationnel pilote de connexion de réseaux de données à distance dont les prihcipaux utilisateurs seront au nombre de cinq. L'expérience de commutations directes inter-établissements (DICE) à des fins de téléconférence a fait l'objet d'une démonstration satisfaisante avec un réseau trois points lors du congrès IAF. Ce système sera opérationnel en janvier 1991. La Deutsche Bundespost et le FTZ sont au nombre des autres utilisateurs qui ont commencé à émettre au moyen de l'expérience d'accès multiple par répartition dans le temps avec commutation à bord.

Le programme Olympus de référence comprenait l'approvisionnement d'un ensemble complet d'équipements destinés à la construction d'un satellite de réserve en cas d'échec du lancement ou de défaillance prématurée en orbite. L'industrie étudie à l'heure actuelle des propositions de mission commune avec des agences extérieures afin d'utiliser ce matériel dans le cadre d'une mission Olympus-F2. Il a en outre été soumis une proposition officielle de lancement d'Olympus-F2 lors de l'un des vols de qualification d'Ariane-5.

Télescope spatial

La caméra pour objets faiblement lumineux (FOC) qui fonctionne de manière impeccable est le premier instrument dont les vérifications en orbite ont été achevées. Les études mises en route par la NASA et l'ESA sur les moyens de redonner aux instruments leur qualité de fonctionnement d'origine en dépit de l'aberration sphérique du Télescope ont permis de dégager quelques principes prometteurs. La solution à laquelle vont actuellement les préférences consisterait à équiper la FOC et les deux spectographes d'une optique



Olympus

Hipparcos

Hipparcos operations continue to run well, with high-quality scientific data being acquired about 70% of the time, i.e. for about 17 hours per day. An operational satellite lifetime of about three years (from launch) is now predicted from the currently known behaviour of the solar arrays and the utilisation of the attitude control gas. Data-analysis activities are also proceeding well, with a good level of agreement and consistency being achieved between the various processing tasks. Activities have so far concentrated on software validation and instrument calibration.

It is expected that the first phase of the routine data analysis will begin early in 1991. Meanwhile, sufficient data have been archived to allow the construction of the 120 000 star catalogue to a positional accuracy of about 5 milli-arcsec, an enormous advance on the quantity and quality of stellar positional data previously available.

Olympus

The Olympus-1 satellite is now in its second year in orbit. It has continued to work well with all of its four payloads operating satisfactorily, providing services to an ever-increasing number of users. The range of capabilities was demonstrated by a series of live transmissions during the International Astronautical Federation Meeting (IAF) at Dresden in October last year.

The Direct-Broadcast payload is providing nearly twenty hours of transmissions daily on the European channel and fifteen hours on the Italian channel. BBC Enterprises became operational in September 1990, using the European beam, with their programme consisting mainly of news, current affairs and documentaries. In October RAI officially announced the start on the Italian beam of their Raisat channel which provides distance-learning, entertainment and general-interest items.

The Specialised-Services payload continues to have a wide range of users. Polytechnic South-West (UK) have maintained their programmes for schools and educational establishments for a second academic year. Other major events have included live transmissions of the launch of the Ulysses spacecraft and regular newscasts from the Gulf region for television and satellite television companies.

The 20/30 GHz payload provided demonstrations at the IAF of the Cooperative Olympus Data Experiment (CODE) system. Data was exchanged between a Very Small Aperture Terminal (VSAT) in Dresden and the ESRIN and ESTEC establishments. A pilot operational service of CODE, connecting remote data networks, started in December 1990 with about five core users. The Direct Inter-Establishment Communications Experiment (DICE) also demonstrated its teleconferencing capabilities at the IAF. The operational phase will start in January 1991. Other users of the payload have included the Deutsche Bundespost/FTZ who have started transmissions in their SS-TDMA experiment.

The baseline Olympus Programme included a complete set of equipment for a back-up spacecraft in the event of a launch or early in-orbit failure. Proposals for a joint mission with outside Agencies to use this hardware for an Olympus-F2 mission are being studied by Industry. An associated proposal to launch Olympus-F2 on one of the Ariane-5 qualification flights has been formally submitted.

HST

The Faint-Object Camera (FOC) has been operating flawlessly and was the first instrument to complete orbital verification. Studies initiated by NASA and ESA on how to recover the original performance of the instruments affected by the Telescope's spherical aberration have established some promising concepts. The most favoured solution is to deploy corrective optics in front of the FOC and the two spectrographs via a pseudo-instrument to be installed in place of the High-Speed Photometer. The Corrective Optics ST Axial Replacement (COSTAR) unit would contain an optical bench which, after insertion into the HST, would be deployed and swing the corrective optics out in front of the other instruments. Consideration is being given to installing COSTAR during the next scheduled HST maintenance mission, planned for June 1993.

The ESA-provided solar arrays have been providing more than their specified power. This, together with the lower-than-anticipated power consumption of HST has resulted in a healthy power margin.

Attitude-control disturbances affecting the Telescope pointing are, however, apparent and are believed to be due to the solar array. They are of two types. The first occurs at day/night and night/day transitions and is believed to be initiated by the solar-array bi-stem booms bending, due to thermal gradients across them. The second occurs during the sunlit part of the orbit and is believed to be due to stick/slip rotation of the solar-array blanket stowage drum as it compensates for the differential expansion of the blanket and boom. Investigation of both of these phenomena is still underway, but design changes are already being developed to reduce or eliminate these effects. These design changes will be considered for inclusion on the second solar array, which is in an advanced state of manufacture at BAe Bristol, UK. Exchanging the solar arrays during the next HST maintenance mission is being considered. In the meantime a modification to the HST attitude-control software is being developed by NASA to reduce the effects of the disturbances.

STSP

Soho

The Soho Phase-B, with Matra as the Prime Contractor, is proceeding as scheduled and without any major problems.

Major activities have been the continuation of system/subsystem engineering and preparation of the Phase-C/D proposal. The Request for Quotations for Phase C/D was issued on 7 September 1990 with a deadline of 30 November. The Matra Phase-C/D offer, incorporating the subcontractor elements, was received on schedule and evaluation will be completed by the end of January. The next major milestones will be the Science Programme Committee (SPC) and Industrial Policy Committee (IPC) *correctrice montée à l'intérieur d'un instrument factice qui viendrait remplacer le photomètre rapide. Le COSTAR (Corrective Optics ST Axial Replacement) comporterait un banc optique qui, après insertion dans le HST, serait déployé de façon à interposer l'optique correctrice sur le chemin optique des autres instruments. On envisage actuellement de procéder à l'installation du COSTAR lors de la prochaine mission de maintenance du HST, prévue pour juin 1993 .*

La puissance délivrée par les réseaux solaires que l'ESA a fournis est supérieure aux spécifications, ce qui, joint à la consommation électrique du HST inférieure aux prévisions, donne une confortable marge de puissance. Des perturbations d'orientation que l'on pense dues au réseau solaire affectent toutefois de façon sensible le pointage du Télescope. Ces perturbations sont de deux sortes: les premières, observées lorsque le satellite passe de la nuit au jour orbital et inversement, seraient déclenchées par la flexion du support du réseau solaire sous l'effet des différences de température de part et d'autre; les autres, observées dans la partie éclairée de l'orbite, seraient dues à des à-coups du tambour de la nappe du réseau solaire lorsqu'il compense l'expansion différentielle de la nappe par rapport au tube de soutien. Ces deux phénomènes sont toujours à l'étude mais on met d'ores et déjà au point des modifications de conception destinées à réduire ou supprimer ces effets. Ces modifications seront éventuellement appliquées au deuxième réseau solaire dont la fabrication chez BAe, à Bristol (Royaume-Uni), est assez avancée. Il est envisagé de procéder à l'échange des réseaux solaires à l'occasion de la prochaine mission de maintenance prévue pour le HST. La NASA prépare entre temps une modification du logiciel de commande d'orientation du HST destinée à atténuer les effets des perturbations.

STSP

Soho

La phase B du projet Soho continue de se dérouler sous la conduite de Matra conformément au calendrier prévu, sans difficulté majeure.

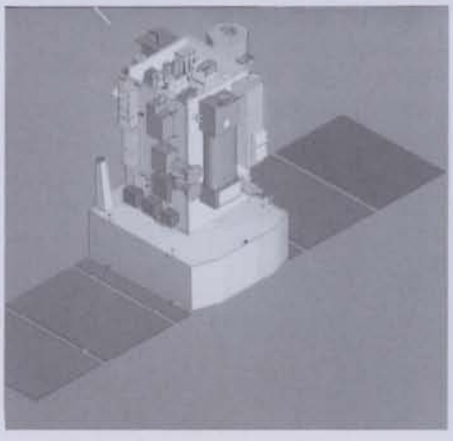
Les travaux ont essentiellement porté sur la poursuite de l'ingénierie système/sous-système et la préparation de la proposition de phase C/D. La demande de prix de phase C/D a été faite le 7 septembre 1990, avec comme date limite le 30 novembre 1990. Matra a remis dans les délais son offre de phase C/D incluant les éléments relatifs aux sous-traitants, dont l'évaluation sera achevée fin janvier. La prochaine grande étape sera celle de l'approbation par le SPC et par l'IPC de l'exécution de la phase C/D du programme STSP d'ensemble. On procède actuellement à l'allégement des impératifs techniques et à l'évaluation attentive des facteurs dont dépendent les coûts.

Les bilans système de masse, de puissance et autres ont été passés au crible: les marges sont suffisantes pour le démarrage de la prochaine phase. La propreté particulaire et chimique, d'une importance critique pour la qualité de fonctionnement de la charge utile, reçoit toute l'attention de l'ESA, des chercheurs principaux et de l'industrie.

La revue de conception au niveau système est prévue pour début avril, date à laquelle la conception du système sera figée. D'ici là, les résultats des revues de conception des sous-systèmes auront été incorporés dans la conception du système.

Les travaux relatifs à la charge utile de Soho ont bien progressé. La définition des interfaces des expériences a considérablement avancé et tous les documents s'y rapportant ont été mis à jour. Des revues intermédiaires de la conception des expériences sont actuellement conduites en Europe et aux Etats-Unis.

La structure industrielle a été soigneusement mise au point, avec le projet Cluster, de façon à réaliser un équilibre acceptable sur le plan du retour géographique, des coûts et des performances techniques. Le coup d'envoi a été donné pour tous les contractants chargés des sous-systèmes.



SOHO configuration study

Etude de configuration de SOHO

Coopération entre l'ESA et la NASA

Des réunions portant sur le détail des interfaces ont eu lieu ou ont été prévues entre l'ESA et la NASA et leurs contractants respectifs en vue de contrôler l'ensemble des interfaces: recherches scientifiques, lanceur, opérations et fourniture du satellite.

Cluster

La phase B3 du projet a démarré à la mi-septembre conformément aux plans, tous les contractants sous-système engageant les travaux de conception détaillée qui ont débouché sur les revues de conception des sous-systèmes fin 1990. En partant des revues sous-système, la conception système de référence a pu être consolidée en vue du démarrage de la phase C/D.

Compte tenu des liens étroits des projets Soho et Cluster dans le cadre du programme scientifique sur les relations Soleil – Terre, il a été convenu de prolonger la phase B du projet Cluster jusqu'à la mi-avril 1991 de façon à la faire coïncider avec celle du projet Soho. Pour les sous-systèmes critiques dont la conception de référence aura été approuvée, les activités de développement et de fabrication commenceront en février dans le cadre d'une phase C/D anticipée. La date d'achèvement du contrat industriel prévue pour fin mars 1995 sera de la sorte maintenue en dépit du démarrage tardif de la phase C/D complète.

L'évaluation de la proposition du maître d'oeuvre pour la phase C/D se poursuit et sera achevée fin janvier.

La revue de conception au niveau système est prévue pour début février, date à laquelle la conception du système sera figée. D'ici là, les résultats des revues de conception des sous-systèmes auront été incorporés dans la conception du système.

approval for the implementation of Phase C/D of the overall STSP Programme. The technical requirements are being streamlined and cost drivers are being carefully assessed.

The mass, power and other system budgets have been carefully scrutinised and sufficient margin exists for a start of the next Phase. The particles and chemical cleanliness, because of their critical influence on payload performance, are receiving much attention from ESA, the Principal Investigators and Industry.

The System Design Review is scheduled for early April, at which time the system design will be frozen. The results of the sub-system design reviews will have been incorporated into the system design by then.

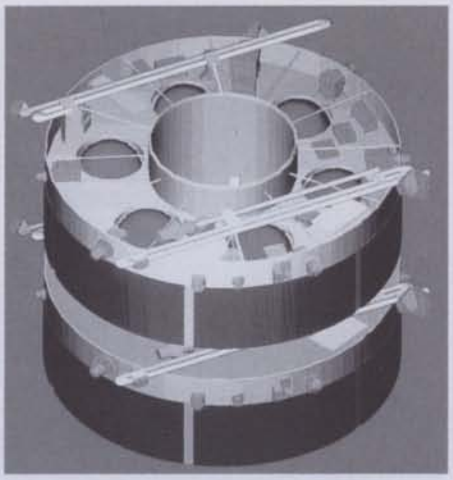
The Soho payload is well advanced. The experiment interface definition has progressed considerably and all experiment interface documents are being kept up to date. Experiment intermediate design reviews are currently being held in Europe and the United States.

The composition of the industrial team has been carefully constructed, together with the Cluster project, in order to achieve an acceptable balance of geographical return, cost and technical performance. The kick-off of all subsystem contracts has taken place.

ESA/NASA cooperation
Detailed interface meetings between ESA and NASA, and their respective contractors have taken place, planned in order to control the integrity of the interfaces; this includes scientific investigations, launcher, operations and the provision of spacecraft hardware.

Cluster
Phase B3 of the project was initiated on schedule in mid-September 1990, culminating in sub-system design reviews at the end of the year. From the sub-system reviews, the system-design baseline has been consolidated in preparation for the start of Phase C/D.

Because of the close ties between Soho and Cluster under the Solar-Terrestrial Science Programme, it was agreed to extend the Cluster Phase-B to mid-April 1991 to coincide with that of Soho. For



Cluster configuration study

Etude de configuration de Cluster

critical sub-systems with an agreed design baseline, development and manufacturing activities will commence in February under an advanced Phase C/D. The completion date for the industrial contract of the end of March 1995 will thus be maintained despite the later start of the full Phase C/D.

Evaluation of the Prime Contractor proposal for Phase C/D is still on-going and will be completed by the end of January.

The System Design Review is scheduled for early February, at which time the system design will be frozen. By then the results of the sub-system design reviews will have been incorporated into the system design.

All the intermediate design reviews on the payload were completed towards the end of 1990 and the interface definition has been frozen in preparation for the start of Phase C/D.

Responses to the Announcement of Opportunity for the Cluster Science Data System were received on time at the end of December and evaluation is expected to be completed by the end of February. Responses were received from most of the participating European countries and from Hungary and China. The latter two will be considered for associate participation within the Science Data System.

No formal confirmation has been received for the Ariane-5 Apex launch configuration but Cluster should be compatible with both the scheduled launches A501 and A502. Formal notification of the launch configuration is not now expected before mid-1991.

ISO

The first models of the four scientific instruments were tested for mutual compatibility as a combined scientific payload in a laboratory cryostat at liquid-helium temperature. The tests demonstrated that these very complex instruments work well not only together but also with the ground-support test equipment that is to be re-used later during satellite system testing and flight operations.

The manufacturing of flight-model scientific instruments is proceeding well. Special efforts have been made to solve the problems of the very advanced detector electronics of the Isophot instrument. All flight model detectors are now acceptable and Isophot is on course, working to an accelerated schedule.

Satellite-hardware development is progressing well. All electrical-subsystem qualification units are in testing and flight-model manufacture is well underway. Efforts are being made to accelerate the testing of the attitude-control subsystem which threatens the schedule. Recent testing revealed that the liquid-helium tank of the payload module leaks excessively and that the tank may be too flexible. Possible corrective measures have been identified and are being studied in detail. Testing of the qualification-model telescope at the Institut d'Astrophysique de Liège demonstrated that image quality and alignment is maintained down to liquid-helium temperatures.

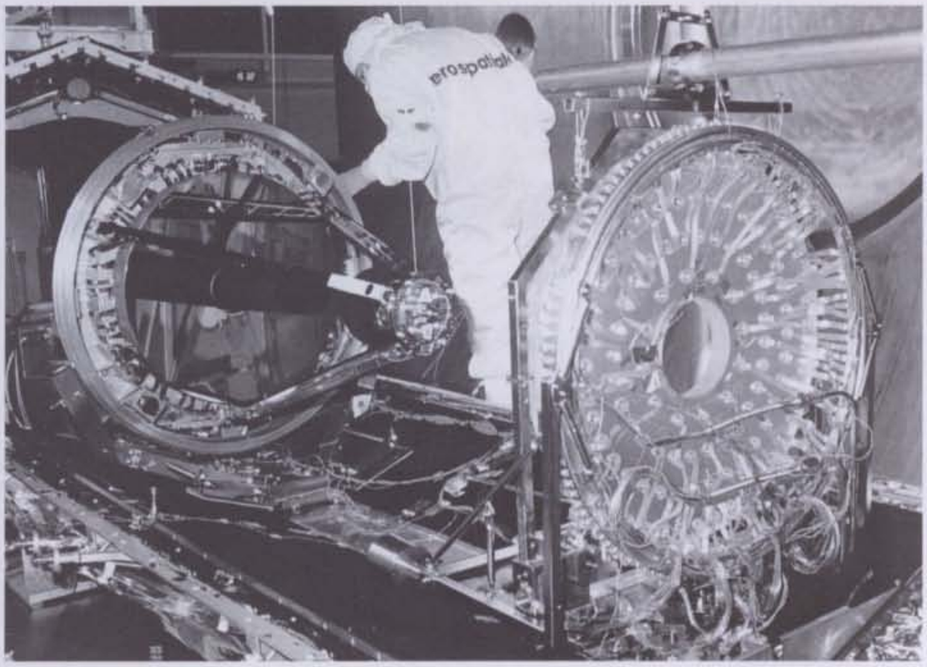
The observatory ground-segment design is proceeding with high momentum. It has become very complex and an effort is now underway to simplify it prior to the ground-segment design review, which has been rescheduled for January/February 1991.

The project schedule is geared to the May 1993 launch date. The final contract for the satellite was signed at

Toutes les revues intermédiaires de la conception touchant la charge utile ont été achevées vers la fin de 1990 et la définition des interfaces a été figée en préparation de la phase C/D.

L'Exécutif a reçu en temps utile, fin décembre 1990, les réponses à l'avis d'offre de participation lancé pour le système de données scientifiques de Cluster; les évaluations devraient normalement être achevées pour fin février. Ces réponses provenaient de la plupart des pays européens participants ainsi que de la Hongrie et de la Chine. Il sera envisagé d'associer ces deux derniers pays aux activités dans le cadre du système de données scientifiques de Cluster.

La configuration de lancement Ariane 5 Apex n'a pas reçu de confirmation officielle, mais Cluster devrait être compatible avec l'un et l'autre des lancements prévus A501 et A502. La notification officielle de la configuration de lancement n'est pas maintenant attendue avant la mi-1991.



Maquette de qualification de télescope ISO en cours de préparation en vu de vérifier la qualité de l'image à l'Institut d'Astrophysique de Liège, en Belgique

ISO qualification model telescope under preparation for image quality and alignment testing at the Institut d'Astrophysique Liège, Belgium

ISO

Les premiers modèles des quatre instruments scientifiques ont subi des essais dans un cryostat de laboratoire maintenu à la température de l'hélium liquide pour vérifier s'ils sont compatibles entre eux. Il en ressort que ces instruments très complexes fonctionnent bien ensemble ainsi qu'en liaison avec les équipements expérimentaux de soutien au sol qui seront réutilisés ultérieurement pour les essais système du satellite et pour les opérations en vol.

La fabrication des modèles de vol des instruments scientifiques se poursuit normalement. Des efforts particuliers ont été faits pour résoudre le problème de l'électronique extrêmement complexe du détecteur de l'instrument Isophot. Tous les détecteurs des modèles de vol sont maintenant jugés acceptables et les travaux se poursuivent à un rythme accéléré.

La réalisation du matériel du satellite avance bien. Tous les éléments de qualification des sous-systèmes électriques sont en cours d'essai et la fabrication des modèles de vol est en bonne voie. Des efforts sont faits pour accélérer les essais du sous-système de commande d'orientation qui risque de causer des retards. Les essais conduits récemment ont révélé que le réservoir d'hélium liquide du module de charge utile n'était pas suffisamment étanche, peut-être en raison de sa trop grande souplesse. Plusieurs moyens d'y remédier ont été dégagés et sont à l'étude. Les essais du modèle de qualification du télescope menés à l'Institut d'Astrophysique de Liège ont montré que la qualité des images et l'alignement optique restaient constants jusqu'à la température de l'hélium liquide.

La conception du secteur sol de l'observatoire avance rapidement. Ce secteur étant devenu très complexe, on s'efforce actuellement d'en simplifier l'architecture avant la revue de conception dont la date a été reportée à janvier-février 1991.

Le calendrier du projet est compatible avec la date de lancement, fixée à mai 1993. Le contrat final de réalisation du satellite a été signé le 13 septembre 1990 à la Direction centrale de l'ESA par le Professeur Reimar Lüst, Directeur général sortant, et par M. Henri Martre, Président Directeur général d'Aérospatiale (voir Bulletin ESA no. 64, page 111).

DRS

On a procédé à l'étude et à la définition détaillées des satellites du système de relais de données (DRS) au titre du contrat de phase B1 et ces activités ont été poursuivies dans le cadre du contrat de phase B1X. La phase B1 a pris fin en juillet 1990 et la phase B1X sera achevée en janvier 1991.

Les principales caractéristiques du DRS de référence sont restées inchangées au cours de ces deux phases. Le système DRS comprendra deux satellites opérationnels en orbite géosynchrone, respectivement à 44° ouest et à 59° est. Chaque satellite DRS peut desservir simultanément deux véhicules spatiaux utilisateurs par des liaisons RF totalement opérationnelles, soit en bande S (2 GHz), soit en bande Ka (23/26 GHz), ainsi qu'un autre véhicule spatial utilisateur au moyen d'une liaison optique pré-opérationnelle. La capacité maximale pour chaque type de liaison est la suivante: en bande S, 1 Mbit/s en liaison aller à destination du satellite utilisateur et 6 Mbit/s en liaison retour à partir de celui-ci; en bande Ka, 25 Mbit/s en liaison aller et 610 Mbit/s en liaison retour; en liaison optique, 64 kbit/s aller et 50 Mbit/s retour.

ESA Headquarters on 13 September 1990 by Prof. R. Lüst, ESA's outgoing Director General, and Mr H. Martre, President and Director General of Aerospatiale (see ESA Bulletin no. 64, p. 111).

DRS

Detailed study and definition of the Data-Relay System (DRS) satellites was performed under the Phase-B1 contract and has continued under the Phase-B1X contract. Phase-B1 finished in July 1990 and Phase-B1X will finish in January 1991.

The main characteristics of the baseline DRS have remained unchanged during both phases. The DRS will consist of two operational satellites in geosynchronous orbit, at 44°W and 59°E respectively. Each DRS satellite can simultaneously service two user spacecraft with fully operational RF links in either S-band (2 GHz) or Ka-band (23/26 GHz) and one user spacecraft with a pre-operational optical link. The maximum capacity of each type of link will be for S-band 1 Mbit/s on the forward link to the user spacecraft and 6 Mbit/s on the return link; for Ka-band 25 Mbit/s on the forward and 610 Mbit/s on the return link; and for the optical band 64 kbit/s on the forward and 50 Mbit/s on the return link.

The main outputs from Phases-B1 and B1X are a complete set of system and subsystem specifications, a satellite system and subsystem design and development plan and draft equipment specifications.

The ground segment was studied, with emphasis on the architecture of the management and operation of the system and also on the design of user earth stations.

These activities bring to an end the Data-Relay Preparatory Programme and further activities will take place within the Development Programme. This was approved in mid-1990 as an element of the Data-Relay and Technology Mission (DRTM) Programme and will be split into two phases. The Request for Proposals for satellite activities in the first phase of the Development Programme has been issued to the Prime Contractor Selenia Spazio, and the proposal is expected in January 1991. The main activities will be the finalisation of all equipment specifications and all the technical work required to prepare an implementation proposal.

Artemis

The Technology Mission element of the DRTM was approved and fully subscribed in 1990. This element includes the Artemis satellite and the SILEX optical-link activities.

The Artemis satellite will demonstrate advanced technologies in the payload and platform areas. These comprise phased arrays for S-band data-relay services, optical inter-orbit links for data-relay services, spot beams and a highly flexible payload for L-band land-mobile services in Europe, and ion propulsion for station-keeping.

The satellite has been studied in detail and a number of equipment items have been identified as critical from a technology point-of-view. These items will be breadboarded and contractors have been selected for each on the basis of open competition. Most of the breadboard contracts are underway.

The detailed definition and design of the satellite has started with Selenia Spazio as Prime Contractor. This activity comprises all the technical work needed to submit a proposal to ESA for the implementation of the satellite.

The SILEX optical payload will demonstrate optical data-relay communications between the Artemis satellite and a terminal installed on the Spot-4 Low-Earth-Orbiting (LEO) observation satellite. The Invitation-to-Tender for the final design of the system and the development of the LEO terminal has been issued.

ERS

ERS-1

The payload flight model successfully passed thermal vacuum and solar exposure tests in the Large Space Simulator facility at ESTEC and has been integrated with the platform into the ERS-1 satellite. A full integrated system test was completed in November with satisfactory results. Preparations for the second part of the system-validation tests in closed loop with the Mission Management Control Centre are progressing as planned.

The programme schedule has been adapted in line with a launch date in May 1991, as now offered by Arianespace.

The Flight Acceptance Review (FAR) process started on 18 December.

Ground-segment activities are concentrating on final integration and verification testing before launch, a challenging task given the size and complexity of the ERS-1 system.

ERS-2

Technical kick-off and configuration baseline review meetings have been held with all contractors to ensure the coordinated start of industrial activities.

Phase-B of the Global Ozone Monitoring Experiment (GOME) is progressing well, while contracts for the procurement of the Precise Rate and Ranging Equipment (PRARE-2) and the Along-Track Scanning Radiometer (ATSR) were concluded in December.

EOPP

Aristoteles

In view of possible ESA/NASA cooperation on the Aristoteles mission, a dedicated Launch System Study was kicked-off at ESTEC in July. This study, carried out by Aeritalia, consists of a first cursory assessment of the implications of a dedicated launch by a Delta II. Development and testing of the breadboard model of the Gradio calibration mechanism has been carried out by TPD (NL). Pre-development activity on the Gradio accelerometer proper is continuing with ONERA. Programme preparation contacts with NASA have included:

- preparation for an ESA/NASA Aristoteles Workshop in Italy, expected to involve key members of the scientific community from both the ESA Member States and the United States;

Les principaux résultats obtenus à l'issue des phases B1 et B1X sont un ensemble complet de spécifications aux niveaux système et sous-systèmes, un plan de conception et de développement du satellite aux niveaux système et sous-systèmes et un projet de spécifications en matière d'équipements.

On a procédé à l'étude du secteur sol en mettant l'accent sur l'organisation de la gestion et de l'exploitation du système, ainsi que sur la conception des stations sol utilisatrices.

Ces activités mettent fin au Programme préparatoire de relais de données; d'autres auront lieu dans le cadre du Programme de développement. Ce dernier a été approuvé à la mi-1990 en tant qu'élément du Programme de mission de technologie et de relais de données (DRTM) et sera exécuté en deux phases. La demande de proposition portant sur les activités au titre de la première phase du Programme de développement du satellite a été envoyée au contractant principal Selenia Spazio, qui doit donner sa réponse en janvier 1991. Les activités porteront principalement sur la mise au point finale de toutes les spécifications relatives aux équipements et de l'ensemble des activités techniques nécessaires à la préparation d'une proposition de mise en oeuvre.

Artemis

Le Programme de mission de technologie, élément du DRTM, a été approuvé et entièrement souscrit en 1990. Cet élément porte sur le satellite Artemis et sur les activités relatives aux liaisons optiques SILEX.

Le satellite Artemis fera la démonstration de technologies de pointe en matière de charge utile et de plate-forme, comprenant des réseaux à commande de phase pour les services de relais de données en bande S, des liaisons optiques inter-orbitales pour les services de relais de données, des faisceaux étroits et une charge utile à grande souplesse d'utilisation pour le service mobile terrestre européen en bande L, ainsi qu'une propulsion ionique pour le maintien à poste.

Le satellite a fait l'objet d'une étude détaillée, qui a recensé un certain nombre de composants critiques sur le plan technologique. Ces composants seront réalisés sous forme de montages tables, pour lesquels des contractants ont été choisis par appel d'offres concurentiel. La plupart des contrats correspondants sont en cours d'exécution.

La définition et la conception détaillées du satellite ont commencé sous l'égide de Selenia Spazio. Ces activités comprennant l'ensemble des tâches techniques nécessaires à la présentation d'une proposition à l'ESA pour la mise en oeuvre du satellite.

La charge utile optique SILEX fera une démonstration de relais de données par liaison optique entre le satellite Artemis et un terminal installé à bord du satellite d'observation Spot-4 sur orbite terrestre basse (LEO). L'appel d'offres portant sur la conception définitive du système et la mise au point de ce terminal LEO a été lancé.

ERS

ERS-1

Le modèle de vol de la charge utile a donné satisfaction lors des essais d'exposition au rayonnement solaire et au vide thermique dans le grand simulateur spatial de l'ESTEC. Il a été intégré à la plate-forme pour constituer le satellite ERS-1. Un essai du système, mené à bien en novembre après son intégration complète, a donné des résultats satisfaisants. La préparation de la deuxième partie des essais de validation du système en circuit fermé avec le Centre de contrôle de gestion de la mission progresse conformément au calendrier.

Le calendrier du programme a été modifié en fonction du mois de mai 1991 proposé par Arianespace pour le lancement.

Les activités de la revue de recette de vol (FAR) ont commencé; la réunion de la commission d'examen a commencé le 18 décembre 1990.

Les activités relatives au secteur sol portent principalement sur les derniers essais d'intégration et de vérification avant lancement, tâches exigeantes étant donné la taille et la complexité du système ERS-1.

ERS-2

Les réunions de mise en route et de revue de la configuration de référence se sont déroulées en présence de l'ensemble des contractants afin d'assurer la coordination du début des activités industrielles.

La phase B de l'expérience GOME (expérience de surveillance de l'ozone à l'échelle du globe) progresse de façon satisfaisante et l'on a conclu en décembre les contrats d'approvisionnement de l'équipement de mesure précise de distance et de vitesse (PRARE-2) ainsi que du radiomètre à balayage le long de la trace (ATSR).

EOPP

Aristoteles

Dans la perspective d'une éventuelle coopération ESA/NASA à la mission Aristoteles a eu lieu en juillet la mise en route de l'étude d'un système de lancement particulier. Cette étude, réalisée par Aeritalia, consiste en une première évaluation de l'incidence qu'aurait sur la mission l'utilisation d'un lanceur Delta II. TPD (NL) a procédé à la mise au point et aux essais du montage table du mécanisme d'étalonnage de l'instrument Gradio. Des activités de pré-développement de l'accéléromètre Gradio proprement dit se poursuivent à l'ONERA. La préparation du programme avec la NASA s'est notamment traduite sous les formes suivantes:

- *préparation de l'Atelier ESA/NASA sur Aristoteles qui doit se tenir en Italie et auquel devraient participer des scientifiques éminents tant américains qu'européens;*
- *tenue d'une série de réunions destinées à consolider progressivement la définition de l'interface technique et programmatique ESA/NASA et à préparer un Mémorandum d'accord ESA/NASA relatif à Aristoteles.*

Météosat de deuxième génération (MSG)

Des progrès continuent d'être faits en ce qui concerne la définition avec Eumetsat des missions Météosat de deuxième génération.

TPD (NL) a terminé l'étude de l'imageur haute résolution dans le visible. Eumetsat s'étant décidé pour un satellite stabilisé

— a series of meetings progressively firming up the definition of the technical and programmatic interface between ESA and NASA and to prepare a joint ESA/NASA Aristoteles Memorandum of Understanding (MOU).

Meteosat Second Generation (MSG)
Progress continues to be made with Eumetsat towards the definition of the Meteosat Second-Generation missions.

The High-Resolution Visible Imager study by TPD (NL) has been completed. Following the decision by Eumetsat to proceed with a spin-stabilised satellite, work on the technology of the spin-stabilised imaging instrument has been initiated for using charge-coupled device detectors in a time-delay integration mode.

In view of the major impact at satellite level of the antenna types and the overall antenna configuration, ITTs have been issued for parallel studies to investigate the many possible new and alternative antenna types prior to starting the overall Phase-A Study.

Following the Eumetsat Council decision in early June and the Eumetsat Workshop on Nowcasting held at Reading in mid-July 1990, the feasibility of satisfying the new requirements for both imaging and instability monitoring within a single instrument on a spinning satellite has been investigated. Further preparation of Phase-A activities is being pursued with Eumetsat concerning other aspects of the mission in the context of their Second-Generation Meteosat Advisory Technical Committee (SGATC) and other working meetings.

Polar-Orbit Mission
The extension of Phase-A of the first Polar Mission, in direct negotiation with Dornier as Prime Contractor, has been kicked-off successfully. Efforts are being made not only at technical level but also at programmatic level to harmonise the contents of the PPF and POEM-1 programmes.

The ESA/Eumetsat Joint Working Group, created to investigate the most effective means of meeting the operational meteorological requirements through cooperation with ESA, has completed its report. This recommends flying the meteorological operational instruments as a (key) part of the payload on a continuing series of Polar Platforms as the most cost-effective approach for Eumetsat.

The Earth Observation and Space Science Announcement of Opportunity instrument proposals have been evaluated further both scientifically and technically. Two alternative instrument complements have been recommended by the Peer Review Board for further consideration.

The Declaration for the Preparatory Programme for the First Polar Orbit Earth Observation Programme to use the Polar Platform was finalised by Potential Participants and opened for subscription.

Campaigns
The mission requirements for the European Lidar Airborne Campaign (ELAC) have been established and the campaign was carried out in October 1990.

EOPP Extension
A revised Declaration for extending the EOPP Programme up to 1996 was unanimously approved at the Earth Observation Programme Board meeting in November.

Meteosat

MOP-2 is scheduled for launch on Ariane Flight 42 on 21 February.

During the latter part of last year, the spacecraft successfully completed testing following improvements to prevent image anomalies similar to those seen on MOP-1.

The flight-acceptance review was held in November, clearing the way for shipment of the spacecraft to the Kourou launch site in early December. This marked the start of the launch campaign.

A ground-segment readiness review was held at ESOC in November. The Board found ESOC ready to support the launch and early operations as scheduled.

In October 1990, the image anomaly observed in late 1989 during Meteosat-4 (MOP-1) operations returned and required switching to a redundant chain. Operations are continuing with this unit. A few anomalies are seen each day, but are being removed by software.

In preparation for the Meteosat Transitional Programme (MTP), procurement of critical components has started with Tecnologica (E) and ANT (D).

Earthnet

The acquisition, archiving and, as applicable, processing and distribution of data from Landsat, Spot, MOS and Tiros continue to be performed regularly. Tiros data from the Niamey Agrhymet and from the Italian Antarctica stations have been transferred to Frascati for archiving and distribution.

Negotiations for the renewal of the data-distribution agreement with Eurimage have started, as well as preparatory activities for upgrading the stations for Landsat-6.

The distribution of data to the 36 experimenters of the 1989 ESA/JRC Maestro-1 SAR flight campaign has been completed. Operational archiving on optical disk of data available at EPO-Frascati and JRC-Ispra has been initiated as part of the OCEAN project.

ERS-1
Final integration and testing has commenced for many of the ground facilities that will support the acquisition, processing, distribution and archiving of ERS-1 data.

The Earthnet ERS-1 central facility in Frascati progresses well: the core of the central user service has been installed and the interface subset supporting the external interfaces and telecommunications is ready for installation. The high-rate and low-rate fast-delivery processing chains of the product control service have been commissioned, together with the SAR verification-mode processor and the modules for the quality assessment of SAR data products. The product control service system that will handle and store in-situ data, collected during ESA calibration and validation campaigns, has been implemented.

par rotation, des travaux ont été engagés sur la technologie de l'instrument imageur dans le cadre d'une stabilisation de ce type afin d'utiliser des détecteurs équipés de dispositifs à transfert de charge en mode intégration différée.

Compte tenu de la forte incidence qu'exerce sur le satellite le type de l'antenne et sa configuration globale, des appels d'offres ont été lancés afin d'étudier en parallèle, avant d'engager l'étude globale de phase A, les nombreux types nouveaux d'antennes qui pourraient être utilisés.

A la suite de la décision que le Conseil d'Eumetsat a prise début juin et de l'atelier Eumetsat sur les prévisions à très court terme qui s'est tenu à Reading à la mi-juillet 1990, on étudie la possibilité de répondre aux nouveaux impératifs de fourniture de capacités d'imagerie et de surveillance des instabilités au moyen d'un seul instrument dans le contexte d'une stabilisation par rotation. En ce qui concerne les autres aspects de la mission, la préparation des activités de phase-A se poursuit avec Eumetsat dans le cadre du Comité technique consultatif pour la deuxième génération de satellites Météosat (SGATC) et d'autres réunions de travail.

Mission sur orbite polaire

L'extension de la phase A de la première mission sur orbite polaire, qui a fait l'objet de négociations de gré à gré avec Dornier, contractant principal, a démarré sans encombre. Des efforts ont été faits non seulement au niveau technique mais également au niveau programmatique en vue d'harmoniser le contenu des programmes PPF et POEM-1.

Le groupe de travail commun ESA/Eumetsat, constitué pour rechercher la façon la plus efficace de répondre aux impératifs de météorologie opérationnelle dans le cadre d'une coopération avec l'Agence, a soumis son rapport. Il y recommande la formule qu'il juge la plus économique pour Eumetsat c'est-à-dire l'emport d'instruments de météorologie opérationnelle qui constitueraient une partie (clef) de la charge utile de toute une série de plates-formes polaires.

L'évaluation des propositions d'instruments faisant suite aux Avis d'offre de participation dans le domaine des sciences spatiales et de l'observation de la Terre s'est poursuivie au plan scientifique et technique. Le groupe d'examen paritaire a recommandé deux ensembles différents d'instruments pour complément d'examen.

Les Participants potentiels au programme préparatoire de la première mission d'observation de la Terre à partir de l'orbite polaire au moyen de la plate-forme polaire ont mis la dernière main à la Déclaration correspondante qui est maintenant ouverte à la souscription.

Campagnes

Les impératifs de mission relatifs à la Campagne européenne de détection par lidar aéroporté (ELAC) ont été établis et la campagne s'est déroulée en octobre 1990.

Extension de l'EOPP

Une Déclaration révisée en vue de l'extension du programme EOPP jusqu'en 1996 a été approuvée à l'unanimité lors de la réunion de novembre 1990 du Conseil directeur du Programme d'observation de la Terre.

Météosat

Le lancement de MOP-2 est fixé à fin février 1991 sur le vol Ariane 42.

Au deuxième semestre 1990, le véhicule spatial a subi avec succès les essais faisant suite aux améliorations apportées pour prévenir l'apparition d'anomalies de l'image semblables à celles qui se sont présentées sur MOP-1.

La revue de recette pour le vol qui s'est déroulée en novembre a laissé la voie libre à l'expédition du véhicule spatial sur le site de lancement en décembre marquant ainsi le début de la campagne de lancement de Kourou.

Une revue d'aptitude du secteur sol s'est tenue à l'ESOC en novembre. La commission a déclaré l'ESOC apte à assurer le soutien des phases de lancement et de début de fonctionnement en orbite aux dates convenues.

En octobre 1990, les anomalies de l'image observées l'an dernier pendant le fonctionnement de Météosat-4 (MOP-1) ont recommencé à se produire de sorte qu'il a fallu recourir à une chaîne redondante. L'exploitation se poursuit avec cette unité. Les quelques anomalies enregistrées chaque jour sont éliminées au moyen d'un logiciel adéquat.

L'approvisionnement des composants critiques a commencé auprès de Tecnologica (E) et ANT (D), en préparation du Programme Météosat de Transition (MTP).

Earthnet

L'acquisition et l'archivage ainsi que le traitement et la distribution à la demande des données de Landsat, Spot, MOS et Tiros se poursuivent régulièrement. Les données Tiros de la station Agrhymet de Niamey et de la station italienne de l'Antarctique ont été transférées à Frascati pour archivage et distribution.

Les négociations ont été engagées pour le renouvellement de l'accord avec Eurimage de distribution des données tandis que démarraient les activités préparatoires de mise à niveau des stations pour l'acquisition des données de Landsat-6.

Les 36 expérimentateurs ont reçu toutes les données recueillies au cours de la campagne de vol SAR Maestro-1 menée en 1989 par l'ESA et le CCR. L'archivage opérationnel sur disque optique des données accessibles à l'EPO-Frascati et au CCR-Ispra a commencé dans le cadre du projet OCEAN.

ERS-1

Pour nombre de moyens sol qui serviront au soutien de l'acquisition, du traitement, de la distribution et de l'archivage des données d'ERS-1, les travaux d'intégration finale et d'essai ont commencé.

La réalisation de l'installation centrale ERS-1 d'Earthnet à Frascati se poursuit normalement: le coeur du service central des utilisateurs a été mis en place et le

The Fucino, Maspalomas, Gatineau and Prince Albert ground stations are being upgraded ready for implementation of the ESA network in March 1991. Discussions have been held with several national ground station agencies on Memoranda of Understanding and associated technical aspects related to the acquisition and handling of ERS-1 SAR data. Implementation of the fast-delivery product distribution networks is almost complete, including the link to the meteorological network.

Development of the four Processing and Archiving Facilities (PAFs) is progressing, with emphasis on those core elements required at launch. Preparations for acceptance-testing of various PAF components have been completed.

The second general assembly of the ERS-1 Announcement of Opportunity Principal Investigators was held at ESTEC on 10–12 October 1990.

Eureca

In September the Eureca system successfully completed its electromagnetic compatibility (EMC) tests. Tests on mission sequence, data stress and hardware-to-software compatibility were started subsequently and are well underway.

The flight acceptance review is planned for April 1991 and Industry and ESA are currently concentrating on finalising the system verification and safety documentation needed for this.

The Shuttle cargo integration review held at NASA's Johnson Space Centre in October did not identify any incompatibility problems in Eureca sharing this flight with four other payloads.

The latest NASA Shuttle manifest shows 14 February 1992 as the earliest launch date and 19 September 1992 as the earliest retrieval date for Eureca.

Selection of the payload is now being planned for the second launch of Eureca, tentatively scheduled for September 1994.

Space Station Freedom/Columbus

Laboratories

The Preliminary Requirements Review (PRR) and Flight Configuration Reviews (CRs) for the Attached Laboratory and the Free Flyer were conducted over the period July to mid-August 1990. At the conclusion of the PRR, the general quality and completeness of the specifications was judged to be adequate for the purpose of preparing the Phase C/D proposal. The proposed configuration baselines presented at the CRs were judged to meet the Executive's technical requirements, as specified in the Requests for Quotations (RFQs).

The achievement of this major technical milestone established the configuration baselines for the revalidated space segment industrial proposal for the two laboratories.

Nearly all the updated major ESA/NASA Level-2 joint technical requirements have been formally approved by ESA, these requirements now being in line with the RFQ requirements. ESA has also made an initial assessment of the additional changes proposed in the framework of NASA's Resources Reduction Board.

ESA has been participating in the Level-1 and Level-2 meetings arranged by NASA in the period November 1990 – January 1991 to respond to the US Congress' request for a '90-day' redesign exercise. The impact on Columbus is being assessed in preparation for the selection of a new Space Station configuration early in 1991.

In the framework of proposal revalidation, and in order to achieve a 'cost-optimised' overall space segment development schedule, the launch date for the Free Flyer has now been put back by six months, giving the following launch dates for the two elements:

- Attached Laboratory: third quarter of 1997
- Free-Flying Laboratory: first quarter of 1999.

The Phase C/D revalidated proposal for the two manned elements was delivered to ESA on 30 November 1990 and is now under evaluation. The separate proposal for the docking/berthing activities will be submitted during the first half of 1991.

Industry's Preliminary Authorisation-to-Proceed-2 (PATP-2) Slice-2 proposal, covering the period July 1990 – June 1991

Unité de vol d'Eureca sur sa structure d'intégration à MBB/ERNO, Bremen

Eureca flight unit on its integration stand at MBB/ERNO, Bremen

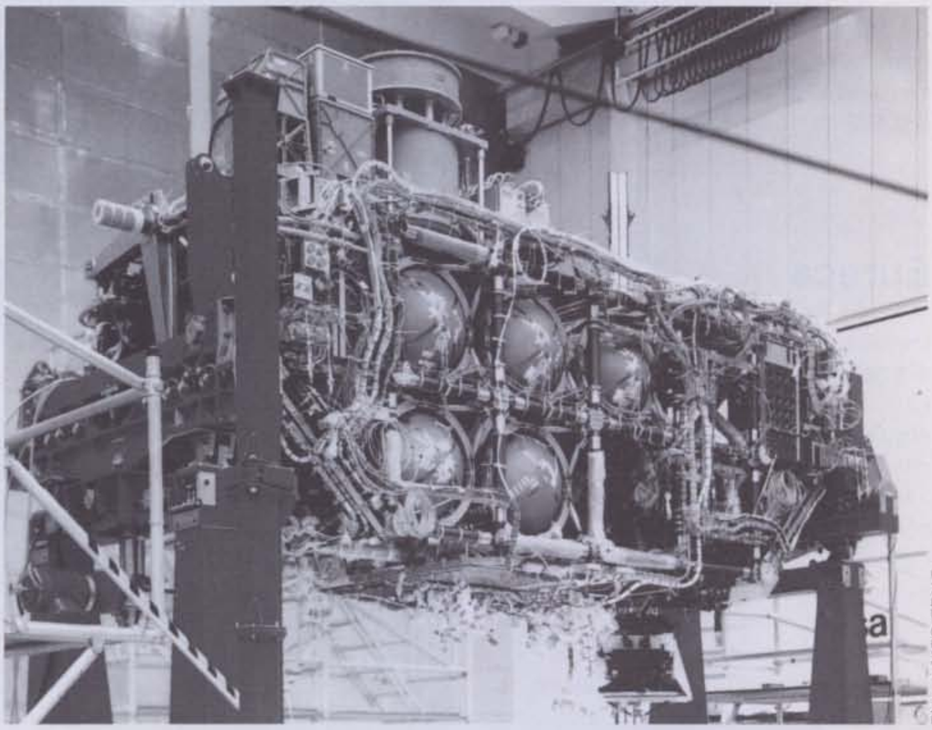


Photo: MBB/ERNO

sous-ensemble d'interface nécessaire aux liaisons extérieures et aux télécommunications est prêt à être installé. Les chaînes de traitement des données à livraison rapide à haut et faible débit du service de contrôle des produits ont été réceptionnées ainsi que le processeur de vérification des données du SAR et les modules d'évaluation de qualité des produits de données du SAR. Le système du service de contrôle des produits qui gérera et stockera les données in-situ recueillies pendant les campagnes d'étalonnage et de validation de l'ESA a été mis en oeuvre.

Les stations sol de Fucino, Maspalomas, Gatineau et Prince Albert sont mises à hauteur en vue de l'entrée en service du réseau ESA en mars 1991. Des entretiens ont eu lieu avec plusieurs entités nationales responsables de stations sol au sujet des Mémorandums d'Accord et des aspects techniques liés à l'acquisition et à la gestion des données du SAR. La mise en oeuvre des réseaux de distribution des produits à livraison rapide est en passe de se terminer, y compris en ce qui concerne la liaison avec le réseau météorologique.

La réalisation des quatre Installations de traitement et d'archivage (PAF) se poursuit, notamment en ce qui concerne les éléments centraux nécessaires lors du lancement. Les préparatifs des essais de recette des divers composants des PAF sont terminés.

La deuxième assemblée générale des chercheurs principaux responsables des instruments AO d'ERS-1 s'est déroulée à l'ESTEC du 10 au 12 octobre 1990.

Eureca

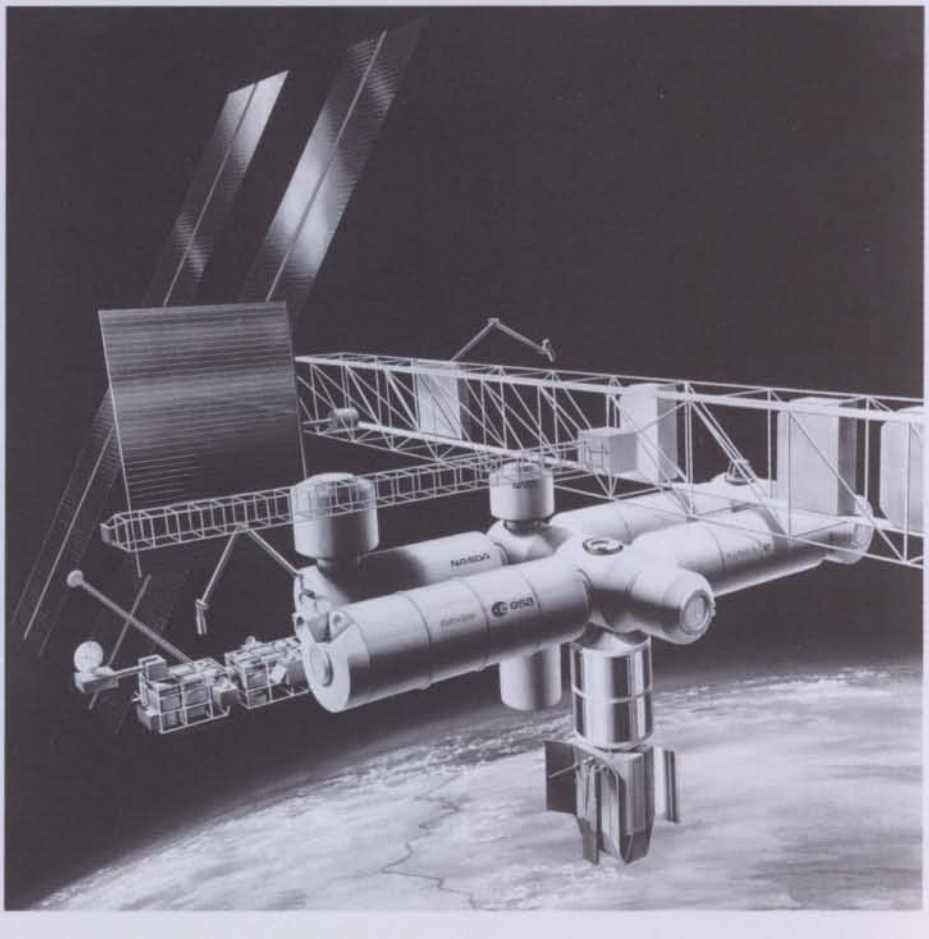
En septembre, les essais de compatibilité électromagnétique (EMC) du système Eureca ont été menés à bien. On a ensuite procédé à des essais sur le déroulement de la mission, les délais de transmission des données et la compatibilité entre le matériel et le logiciel, qui sont maintenant bien avancés.

L'examen de recette pour le vol est prévu en avril 1991; les industriels et l'ESA s'attachent actuellement à établir la version définitive de la documentation sur la vérification et la sécurité du système, qui doit être produite à cette occasion.

La revue d'intégration de la cargaison de la Navette, qui a eu lieu en octobre au Centre spatial Johnson de la NASA, n'a fait apparaître aucun problème de compatibilité en ce qui concerne Eureca, qui doit partager ce vol avec quatre autres charges utiles.

D'après le dernier manifeste de la Navette publié par la NASA, les dates les plus proches retenues pour le lancement d'Eureca et sa récupération sont respectivement le 14 février et le 19 septembre 1992.

Le choix de la charge utile est en cours de préparation pour le second lancement d'Eureca, provisoirement fixé au mois de septembre 1994.



Artist's impression of Space Station Freedom/Columbus

Vue d'artiste de station spatiale Freedom et de Columbus

Station spatiale Freedom/Columbus

Laboratoires

La revue préliminaire des impératifs (PRR) et les revues de configuration de vol ont été exécutées pour le Laboratoire raccordé et pour le Module autonome au cours de la période de juillet à la mi-août 1990. En conclusion de la PRR, il a été jugé que les spécifications présentaient la qualité générale et l'exhaustivité voulues pour la préparation de la proposition de phase C/D. Les configurations de référence proposées lors des revues de configuration de vol ont été jugées conformes aux impératifs techniques de l'ESA spécifiés dans les demandes de prix.

Le franchissement de cette étape technique majeure a marqué l'établissement des configurations de référence pour la proposition industrielle de secteur spatial revalidée touchant les deux laboratoires.

Les principaux impératifs techniques communs ESA/NASA de niveau 2 actualisés, maintenant en accord avec les impératifs des demandes de prix, ont and superseding the Slice-1 extension, was submitted to ESA in early September.

Concerning the Columbus ground segment, the studies of the Central Mission Control Centre (CMCC) and the Manned Space Laboratory Control Centre (MSLCC) have been initiated and Requirement Reviews for the Attached Laboratory Centre (ALC) and the Free-Flyer Centre (FFC) were conducted in September/October 1990. Workshops on Communications and the Network Management Centre (NMC) have also been held.

On the utilisation side, the Statement of Work for the User Support Organisation (USO) Phase-2 has been elaborated and an industrial proposal for a User Ground Station has been received.

NASA's crew-training scheme proposal has been reviewed. In the period mid-September to mid-October 1990, the Isolation Study for the European Manned Space Infrastructure (ISEMSI) was conducted at the NUTEC facilities near Bergen, Norway (see ESA Bulletin no. 64, p.112).

Polar Platform

The updated Phase C/D Proposal for development of the Columbus Polar Platform was submitted by Industry in October 1990.

It consolidates the technical baseline following the detailed changes made in various areas and includes updated and new top-level specifications and budgets, together with consolidated design information. The Proposal also provides a firm basis for the development approach (including a revised model philosophy) and the schedule of the Programme. The financial proposal will form the basis of the Polar Platform part of the overall Columbus documentation, which will be presented to the Delegations.

The Proposal has been accepted for evaluation and is under intensive review by the ESA evaluation team.

Commitment for funding has been released to Industry in order to cover the period until July 1991, which marks the start of Phase C2/D of the Columbus programme.

TDP

Experiments

A Gallium Arsenide Solar Array (GaAs) experiment consisting of two patches of 2×4 cm solar cells with soldered interconnectors will be flown on-board the Tubsat microsatellite. The critical design review for a complete solar array panel with welded interconnectors, destined for launch aboard STRV-1, is scheduled for early 1991.

The Solid-State Micro-Accelerometer flight unit is scheduled to be shipped to the launch site by early 1991.

Manufacturing of the Attitude Sensor Package unit is in progress. The experiment's compatibility with the Space Shuttle has been verified by a data-handling test at NASA's Goddard Space Flight Center.

A critical test in the Collapsible Tube Mast bridging phase is foreseen for early 1991. The final design of the Metal Deposition In-Orbit experiment and the Two-Phase Flow experiment preliminary design review have both successfully been completed.

A breadboard model of the Atomic Oxygen Detector has completed functional tests.

ESA/NASA cooperative experiments

The decision to proceed with Phase-C/D of the In-Flight Contamination Experiment is still pending the CTM critical test results.

Flight opportunities

The Get-Away Special launch of the Solid State Microaccelerometer experiment (G-21) on-board STS-40 has been shifted to May 1991. The Tubsat micro-satellite carrying the GaAs patches will be launched in May 1991 'piggy-back' to ERS-1. The Hitchhiker-G launch of the Attitude Sensor Package experiment is now foreseen for the second half of 1992, on board STS-50.

The STRV-1 launch, carrying the Gallium Arsenide Solar Array Panel, is scheduled for June 1992, while the Bremsat microsatellite, carrying the Atomic Oxygen Detector, is scheduled for launch at the end of 1992 on-board the D-2 mission.

TDP Next-Phase Preparation

The Programme content will be finalised in January 1991 with the aim of starting in the second half of 1991.

été officiellement approuvés dans leur quasi-totalité par l'ESA. L'Agence a également procédé à une première évaluation des modifications additionnelles proposées dans le cadre des activités de la Commission de réduction des ressources de la NASA.

De novembre 1990 à janvier 1991, l'ESA a participé aux réunions des niveaux 1 et 2 organisées par la NASA pour l'opération de remaniement de la conception 'de 90 jours' demandée par le Congrès des Etats-Unis. Les incidences relatives à Columbus sont en cours d'évaluation en vue de la sélection, début 1991, d'une nouvelle configuration pour la Station spatiale.

Dans le cadre de la revalidation de la proposition et en vue d'établir un calendrier d'ensemble optimal sur le plan des coûts pour la réalisation du secteur spatial, la date de lancement du module autonome vient d'être reportée de six mois, les dates de lancement des deux éléments étant désormais les suivantes:
- *Laboratoire raccordé: troisième trimestre 1997*
- *Laboratoire autonome: premier trimestre 1999.*

Remise à l'ESA le 30 novembre 1990, la proposition revalidée de phase C/D relative aux deux éléments habités est en cours d'évaluation. La proposition distincte relative aux activités d'accostage/amarrage sera soumise au cours du premier semestre 1991.

La demande d'Autorisation préliminaire d'engagement des travaux numéro 2 (PATP-2)/tranche 2 formulié par l'industrie couvrant la période de juillet 1990 à juin 1991, qui annule et remplace la prolongation de la tranche 1, a été soumise à l'ESA début septembre.

En ce qui concerne le secteur sol Columbus, les études relatives au Centre de contrôle principal des missions et au Centre de contrôle des laboratoires spatiaux habités ont été mises en route et les revues des impératifs touchant le Centre du Laboratoire raccordé et le Centre du Laboratoire autonome se sont déroulées en septembre-octobre 1990. Des ateliers sur les télécommunications et le Centre de gestion du réseau ont également eu lieu.

Dans le domaine de l'utilisation, le descriptif des travaux relatif à la phase 2 de l'Organisation de soutien des utilisateurs a été élaboré et l'industrie a fait une offre pour une station sol d'utilisateurs.

La proposition de la NASA touchant la formation des équipages a été examinée. De la mi-septembre à la mi-octobre 1990, une étude a été conduite dans les installations du NUTEC situées près de Bergen, en Norvège, sur les réactions de l'homme à l'isolement, dans la perspective de la mise en oeuvre de l'infrastructure spatiale européenne habitée (cf. ESA Bulletin no. 64 p. 112).

Plate-forme polaire

L'industrie a soumis en octobre 1990 la proposition actualisée de phase C/D relative à la réalisation de la plate-forme polaire Columbus.

Cette proposition consolide la base de référence technique à la suite des modifications détaillées apportées dans divers domaines et comprend des bilans et spécifications au plus haut niveau actualisés ou nouveaux ainsi que des informations sur le concept consolidé.

Cette proposition donne également une assise solide aux principes de réalisation (y compris aux principes de modélisation révisés) et fixe le calendrier du programme. La proposition financière constituera la base de la partie de la documentation Columbus relative à la plate-forme polaire qui sera présentée aux délégations.

Cette proposition a été acceptée pour évaluation et l'équipe d'évaluation de l'ESA la soumet actuellement à un examen approfondi.

L'ESA s'est engagée à financer les activités de l'industrie pendant la période allant jusqu'à juillet 1991 qui marque le début de la phase C2/D du programme Columbus.

TDP

Expériences

Une expérience de réseau solaire à l'arséniure de gallium (GaAs), comprenant deux groupes de photopiles de 2 × 4 cm à interconnecteurs soudés, sera embarquée sur le microsatellite Tubsat. La revue critique de définition, qui portera sur un panneau solaire complet à interconnecteurs soudés destiné à être lancé sur STRV-1, doit avoir lieu début 1991.

L'unité de vol du micro-accéléromètre à état solide doit être expédiée au site de lancement début 1991.

La fabrication de l'ensemble de détecteurs d'orientation se poursuit. La compatibilité de cette expérience avec la Navette spatiale a été vérifiée au moyen d'un essai de traitement de données au Centre spatial Goddard de la NASA.

Un essai critique du mât à tube enroulable (CTM) est prévu début 1991 dans le cadre de la phase relais. La conception définitive de l'expérience de dépôt métallique en orbite a été menée à bien, de même que la revue préliminaire de conception de l'expérience d'écoulement diphasique.

Des essais de fonctionnement ont été exécutés sur un montage table du détecteur d'oxygène atomique.

Expériences en coopération ESA/NASA

En ce qui concerne l'expérience de contamination en vol, on attend toujours les résultats de l'essai critique du CTM pour décider du passage à la phase C/D.

Occasions de vol

Le lancement de l'expérience de micro-accéléromètre à état solide (G-21), qui doit faire l'objet d'un vol spécial sur STS-40, a été reporté à mai 1991. Le microsatellite Tubsat emportant les éléments GaAs sera lancé en mai 1991 comme passager auxiliaire d'ERS-1. Le lancement Hitchhiker-G de l'ensemble de détecteurs d'orientation est maintenant prévu pour le second semestre 1992 à bord de STS-50.

Le lancement au panneau solaire à l'arséniure de gallium sur STRV-1 est prévu en juin 1992, tandis que le microsatellite Bremsat, qui emportera le détecteur d'oxygène atomique, doit être lancé fin 1992 dans le cadre de la mission D-2.

Préparation de la phase suivante du TDP

Le contenu du programme sera définitivement fixé en janvier 1991 pour un démarrage au second semestre 1991.

Publications

The documents listed have been issued since the last publications announcement in the Bulletin. Requests for copies should be made in accordance with the Table and using the Order Form inside the back cover of this issue.

ESA Journal

The following papers have been published in ESA Journal Vol. 14, No. 4:

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NAVIGATION OF ERS-1 ALONG-TRACK SCANNING RADIOMETER (ATSR) IMAGES
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INVESTIGATIONS INTO MULTIPACTOR BREAKDOWN IN SATELLITE MICROWAVE PAYLOADS
WOODE A J & PETIT J

ESA Special Publications

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BURKE W R (ED)

ESA SP-312 // 310 PAGES
SPACE & SEA, PROC INT COLLOQUIUM, PARIS, FRANCE, 24–26 SEPTEMBER 1990 (JANUARY 1991)
LANDEAU J (ED)

ESA SP-314 // 426 PAGES
FROM GROUND-BASED TO SPACE-BORNE SUB-MILLIMETRE ASTRONOMY, PROC INT COLLOQUIUM, LIEGE, BELGIUM, 3–5 JULY 1990 (DECEMBER 1990)
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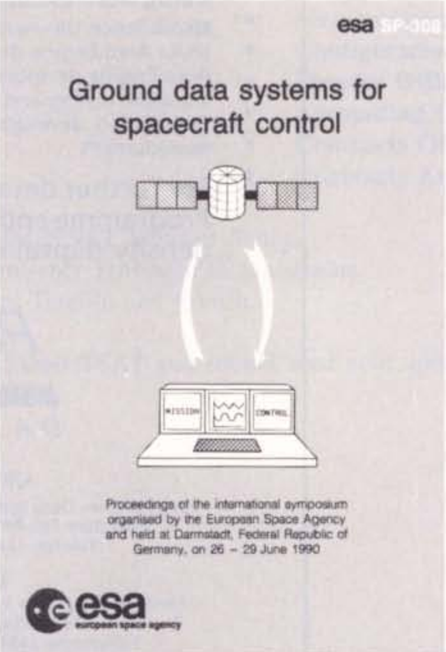
GUYENNE T D (ED)



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