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Envisat – Europe's Earth-Observation Mission for the new Millennium

ESA Applications Directorate, Envisat Department

The main objective of the Envisat programme is to endow Europe with an enhanced capability for the remote sensing of the Earth from space, increasing Europe's capacity to take part in the study and monitoring of the Earth and its environment. Its primary objectives are:

- *to ensure the continuity of the observations started with the ERS satellites, including those obtained using radar-based observations*
- *to provide for the enhancement of the ERS mission, notably its ocean and ice missions, by improving the quality of the measurements*
- *to extend the range of the geophysical parameters observed to meet the need to increase knowledge of the factors determining the environment*
- *to make a significant contribution to environmental studies, notably in the areas of atmospheric chemistry and ocean studies (including marine biology).*

These are coupled with two secondary objectives:

- *to allow more effective monitoring and management of the Earth's resources*
- *to better understand solid Earth processes.*

Envisat is carrying a package of instruments to observe the Earth and its atmosphere from space in a synergetic fashion, addressing crucial matters such as global warming, climate change, ozone depletion and ocean and ice monitoring. As such, it will be a major contributor to the global study and monitoring of the Earth and its environment as expressed by international cooperative programmes such as the International Geosphere and Biosphere Programme (IGBP) and the World Climate Research Programme (WCRP).

In this Issue

European Space Agency
Agence spatiale européenne

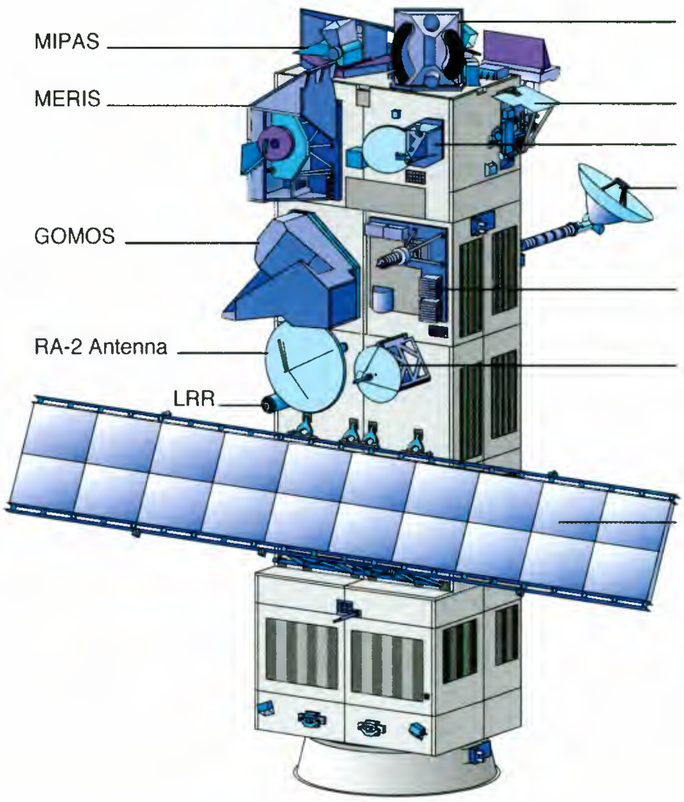
Mission & System

The main Envisat mission objectives are:
- to ensure the continuity of the observations provided by ERS-1/2, with improved accuracy
- to extend the range of the observed geophysical quantities to include the atmosphere (through three instruments, MIPAS, GOMOS and Sciamachy) and the marine biology (with MERIS).

The Envisat system consists of two main elements:
- the Satellite and
- the Ground Segment.

As a complement to the direct X-bands links between the satellite and the ground, Envisat will also utilise a Ka-band link with the Artemis Data Relay Satellite for instrument data recovery.

The satellite will be launched from the Kourou Space Centre in French Guyana by an Ariane-5 launch vehicle. The launch is scheduled for May 2000 with a design lifetime of five years.



② *Envisat satellite and payload.*

The satellite & the payload
The Envisat satellite is composed of the payload complement and the Polar Platform on which the instruments are mounted.

The payload comprises a set of ESA-Developed Instruments (EDI's) complemented by Announcement-of-Opportunity Instruments (AOI's).

ESA-Developed Instruments (EDI's)
- MERIS (Medium-Resolution Imaging Spectrometer)
- MIPAS (Michelson Interferometric Passive Atmospheric Sounder)
- ASAR (Advanced Synthetic Aperture Radar)
- GOMOS (Global Ozone Monitoring by Occultation of Stars)
- RA-2 (Radar Altimeter 2)
- MWR (Microwave Radiometer)
- LRR (Laser Retro-Reflector).

Announcement-of-Opportunity Instruments (AOI's) (Fig. 2)
- Sciamachy (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography)
- AATSR (Advanced Along-Track Scanning Radiometer)
- DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite).

Part of the instruments is focussed on ensuring the continuity of the data acquired by the ERS-1/2 missions: ASAR, AATSR, RA-2 with its supporting instrumentation (MWR, DORIS and LRR), with improved accuracy and coverage.

The observation of the ocean and coastal waters (with the retrieval of marine biology constituent information) is the primary objective of the MERIS instrument.

The ability to observe the atmosphere, following on from the GOME instrument on ERS-2, is significantly enhanced by three instruments on Envisat which offer complementary measurement capabilitites:
- observation of a large quantity of atmospheric species by analysis of the absorption lines through the atmosphere
- characterisation of the atmospheric layers as well as total column content by complementary limb and nadir observations.

These instruments operate over a wide range of the electromagnetic spectrum, from centimetre waves to ultraviolet.

The orbit
To fulfil its mission objectives, the orbit selected for the Envisat satellite is sun synchronous, with a mean altitude of 800 km and a descending node mean local solar time of 10:00 am.

The selected orbit provides a 35-day repeat cycle with the same ground track as ERS-2.

This orbit will be maintained so as to ensure that the deviation of the actual

Semi-major axis:	7159.5 km
Mean altitude:	799.8 km
Inclination:	98.55°
Repeat cycle:	35 days
No. of orbits in 1 cycle:	501
Reference ascend. node:	0.1335° E
Desc. node mean local solar time:	10.00

Table 1. Characteristics of the orbit.

ground track is kept within 1 km of the reference orbit track and the mean local solar time is maintained within 1 minute.

The satellite

Envisat will be the largest free-flying and probably the most complex satellite ever built in Europe. Ten instruments, accommodated on the Polar Platform, compose its payload.

The Polar Platform itself is constituted by two major modules:

- the <u>Service Module (SM)</u> accommodates most of the satellite support subsystems such as:
  - power generation, storage and distribution
  - Attitude & Orbit Control System (AOCS)
  - communication in S-band
  - support structure and launcher interface.

  The SM is derived from the concept and design of the Spot MkII service module with a number of important new developments (in particular new solar array and new structure).

- the <u>Payload Module (PLM)</u> carries the instruments and the payload dedicated support subsystems:
  - instrument control and data handling
  - instrument data recording with 3 tape recorders and one solid-state recorder
  - communication in X- and Ka-bands
  - power distribution
  - support structure and thermal control.

Table 2 Comparison of Envisat and ERS-2.

	Envisat-1	ERS-2
Launch mass	8140 kg	2510 kg
Payload mass	2145 kg	710 kg
Solar array power (EOL)	6500 W (After 4 years)	1940 W (After 3 years)
Instruments	10	5

This modular approach facilitates parallel development and integration of the Service and Payload Modules and allows for an efficient satellite AIT programme where only a minimum of system level activities are needed for final verification.

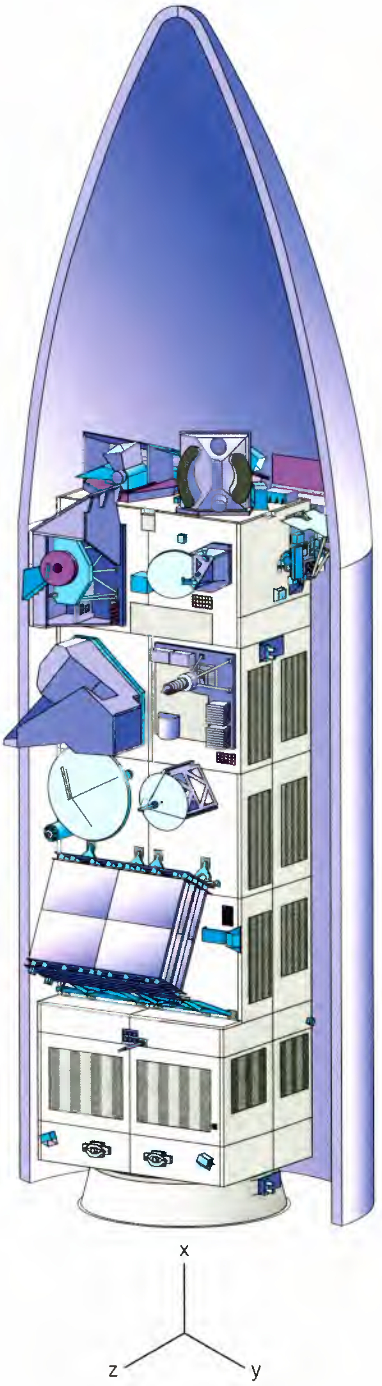
The major driver for the Envisat satellite configuration has been the need to maximise the payload instrument mounting area and to meet very different and stringent viewing requirements whilst staying within the constraints of the Ariane-5 fairing and interfaces.

This configuration concept provides a large, modular construction, with sufficient Earth-facing mounting surface for payload instruments and an anti-sun face, free of occultation by satellite subsystem equipment. In-flight, the spacecraft longitudinal (*X*) axis is normal to the orbit plane, the *Y*-axis is closely aligned to the velocity vector and the *Z*-axis is Earth-pointing.

To meet the payload requirements, the average power supply to the instrument complement is almost 2 kW, and the data transmission rate capability as high as 400 Mbps.

The most demanding instrument in terms of mass, volume and power resources is the ASAR with an antenna of ~700 kg, while six other large instruments also share the satellite resources with masses ranging between from 100 to more than 300 kg.

Table 2 summarises the overall Envisat satellite characteristics (in terms of mass and power compared to ERS-2).



③ *Envisat satellite and payload in launch configuration.*

The ground segment

The Ground Segment is split into two major elements:

- the Flight Operation Segment (FOS) which manages and controls the mission
- the Payload Data Segment (PDS) which receives and processes the data produced by the instruments

④ *Envisat model at Farnborough Air Show (4 September 1998).*

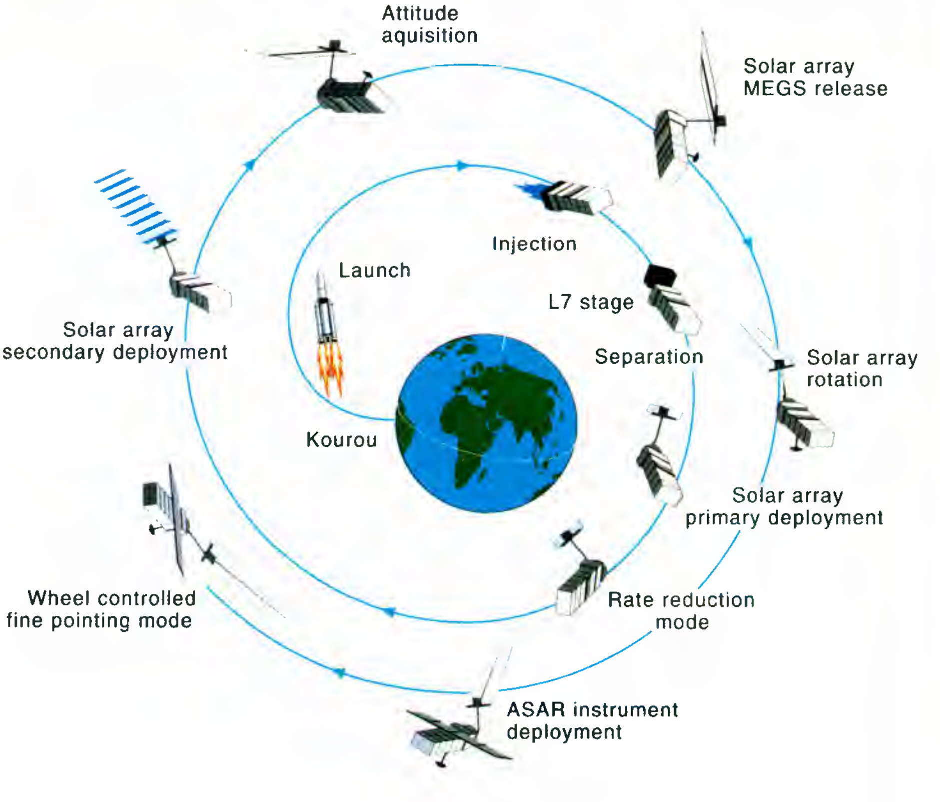
and disseminates and archives the generated products. Furthermore, it provides a single interface to the users to allow optimum utilisation of the system resources in line with the users' needs.

Flight Operation Segment (FOS)
The FOS is composed of the Flight Operations Control Centre (FOCC), located at ESOC, Darmstadt (D), and the associated command and control stations. It provides control of the satellite through all mission phases:
- satellite operation planning
- mission planning interface with Artemis
- command & control of the satellite, up-loading of operation schedules on a daily basis via the TT&C station at Kiruna-Salmijarvi (north Sweden).

Furthermore the FOCC will support:
- satellite configuration and performance monitoring
- software maintenance for PPF and payload elements
- orbit prediction, restitution and maintenance.

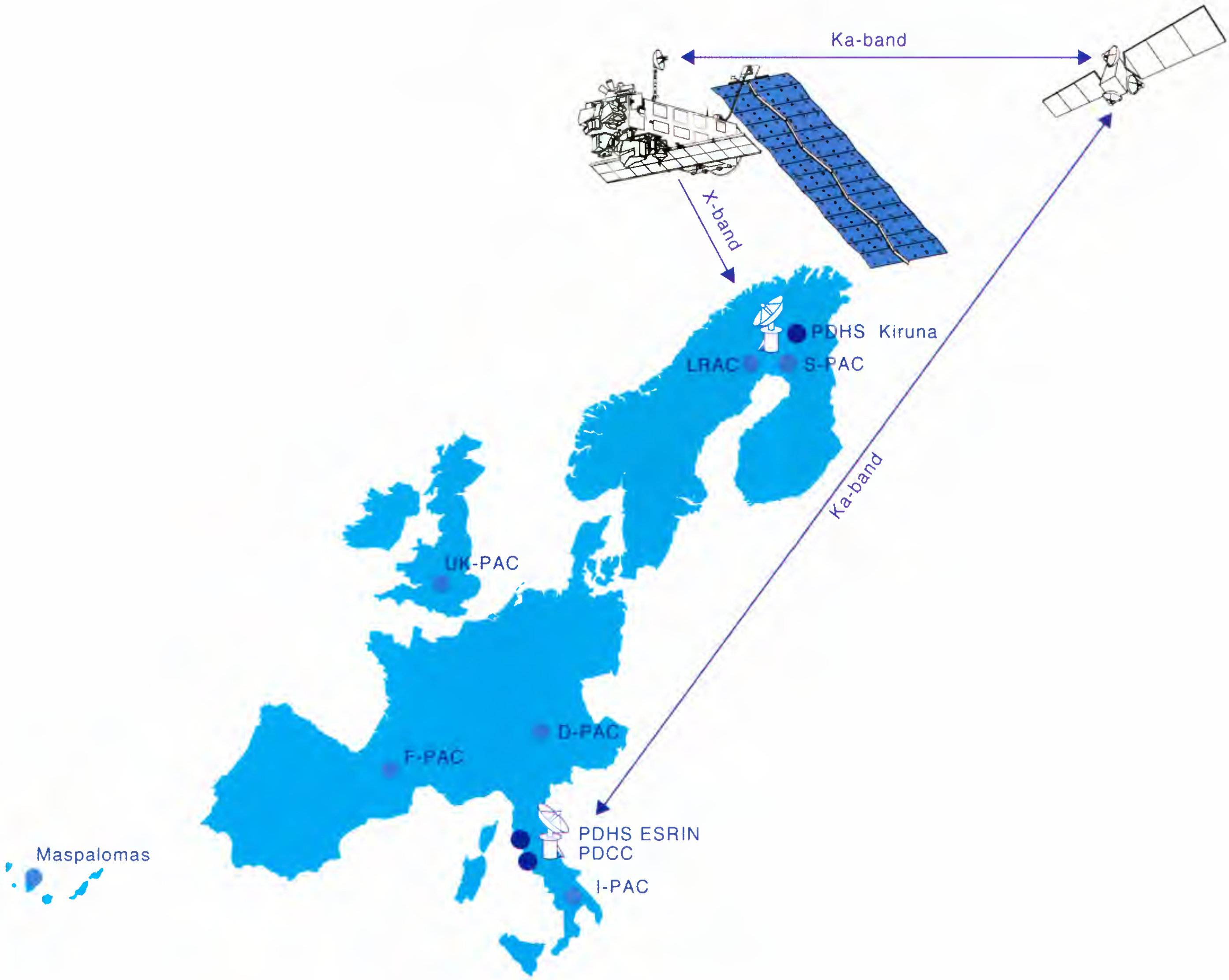
Satellite command and control will nominally be performed using S-band via the Kiruna ground station. During the launch and early orbit phase (LEOP), Kiruna will be complemented by an LEOP TT&C station network providing coverage of critical events. [Fig. 5]

⑤ *Envisat launch and early orbit phase sequence.*



Payload Data Segment (PDS)
The PDS comprises all those elements which are related to payload data acquisition, processing, archiving as well as those concerning the user interfaces and services. The PDS will thus provide: (Fig. 6 and Table 3)
- all payload data acquisition for the global mission
- all regional data acquisition performed by ESA stations
- processing and dissemination of ESA near-real-time (NRT) products within three hours from data sensing
- data archiving, processing and delivery of ESA off-line products with support of Processing & Archiving Centres (PAC's)
- interfaces with the national and foreign stations authorised to receive Envisat-1 regional data
- interfaces to the users from order handling to product delivery.

The PDS centres and stations will be co-ordinated by the Payload Data Control Centre (PDCC) located at ESRIN, Frascati (I). The PDCC will interface with the FOCC for all mission planning activities.



⑥ *Envisat Payload Data Segment centres.*

The PDS ESA stations include:

- a Payload Data Handling Station (PDHS-K) providing X-band data reception and located at Kiruna Salmijarvi;
- a Payload Data handling Station (PDHS-E) located at Esrin and receiving via an User Earth Terminal (UET) the data relayed via Artemis in Ka-band;
- a Payload Data Acquisition Station (PDAS) receiving X-band data and located in Fucino (Italy).

Approach to mission operations

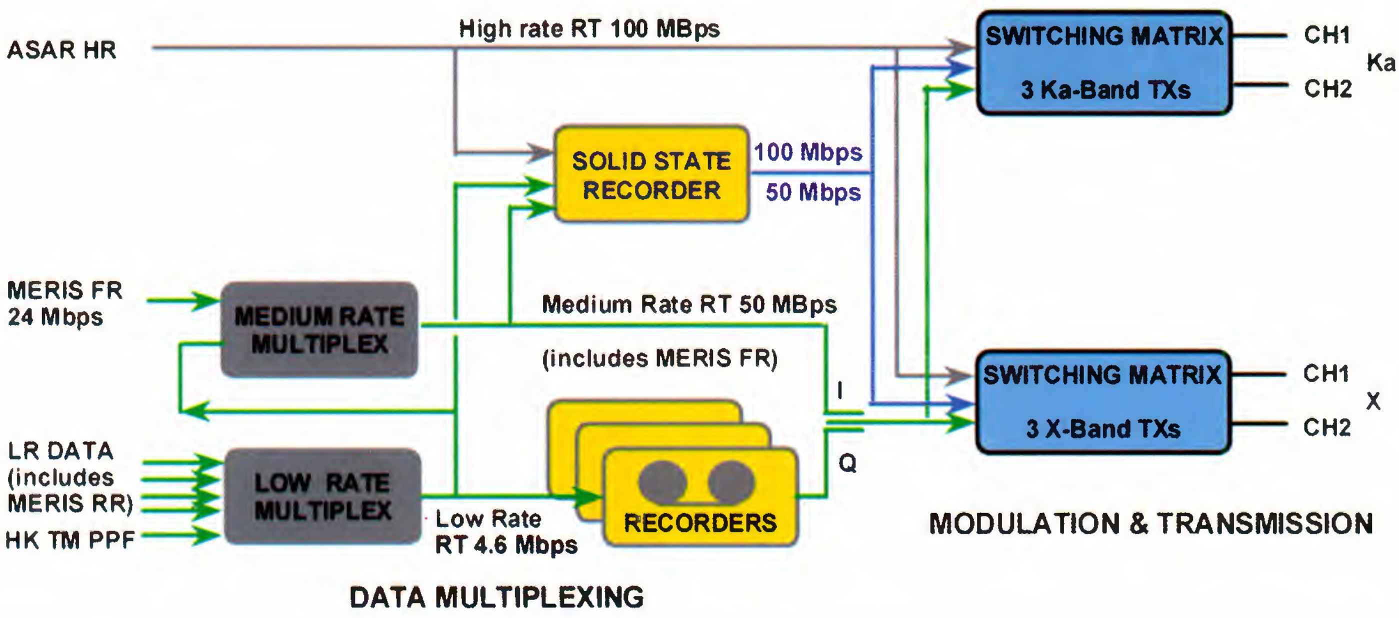
The mission objectives imply global and regional operations to provide both global and regional data to the user communities on various time-scales.

Global operations

The Global Operations cover those instruments and instrument modes which are operated systematically and for which operations are not governed by specific user requests but by the user community's need to get a continuous and coherent global dataset.

Table 3. Processing & Archiving Centres (PAC) assignments.

ASAR High Rate	to be shared between UK-PAC, D-PAC and I-PAC
MERIS Full Resolution	to be shared between UK-PAC, I-PAC and Maspalomas station
ALTIMETRY & ASAR WAVW	located at F-PAC
ATMOSPHERE CHEMISTRY	located at D-PAC (with FMI Finland for GOMOS)
AATSR	located at UK-PAC
MERIS Reduced Resolution	located at S-PAC (Kiruna-Salmijärvi)



⑦ *Satellite data, multiplexing, recording and transmission system.*

Regional operations
The Regional Operations cover those instruments and instrument modes which are not operated systematically but are governed by specific user requests. The resulting datasets correspond in general to the high-rate modes of ASAR and MERIS. All Regional Operations data acquired by the ESA PDS will be systematically processed at medium-resolution and browse level. High-resolution products will be provided in response to user requests.

Data recovery
The onboard recording system is composed of:
- 3 Tape Recorders (TR), 30 Gbits capacity each
- 1 Solid-State Recorder (SSR), 60 Gbits (EOL) capacity. (Fig. 7)

The TR record the data from the low-rate operating modes of the instruments (corresponding to Global Operations).

The SSR can record ASAR high-rate data or MERIS full-resolution data as well as low-rate data in parallel with any of these two data streams.

All instruments contributing to the global mission deliver data at rates compatible with the on-board TR capability. Therefore, for the low-rate global data, the nominal strategy is to record the data and to perform one tape dump per orbit via either the Artemis link (with data reception at the UET of ESRIN) or a direct X-band link with data reception at Kiruna. In both cases, the tape dump is performed at 50 Mbit/s and completed in less than 10 minutes. This strategy will permit the distribution to users of global near-real-time (NRT) products within less than 3 hours of observation.

The regional mission includes the imaging modes of the ASAR (single swath or Scansar wide swath), and MERIS, in its 250 m full-resolution mode. These data, acquired on a regional basis, can be either recorded on-board using the SSR or transmitted directly via the X-band and/or Ka-band data down links

The satellite is capable of providing simultaneous operation of the X-band and Ka-band channels. For the regional mission, it permits data acquisition by an X-band regional station in parallel with Ka-band operation via Artemis and reception at the ESA UET.

For recovery of the Global Mission, the nominal scenario is based on equal workload sharing between the Kiruna station and the ESRIN UET. Each station will receive daily a sequence of about seven consecutive orbits of tape recorder data dumps. All received data will be systematically processed in near-real time and the corresponding products disseminated to the users.

Whenever a request for regional mission operation is requested, the mission management control system will plan the instrument operation and the corresponding data recovery. The nominal scenario is to downlink the data in X-band to the two ESA stations of Kiruna and Fucino for data reception within their coverage (European coverage). Data outside this coverage will be acquired using the SSR or via the Artemis link, within the Artemis coverage limits. Direct X-band down link will be planned when requested by duly authorised national or foreign stations.

The Payload

ASAR

The Advanced Synthetic Aperture Radar (ASAR) is a high-resolution, wide-swath imaging radar instrument that can be used for site specific investigations as well as land, sea ice and ocean monitoring and surveillance.

Compared to the ERS-1/2 Active Microwave Instrument (AMI) the ASAR is a significantly advanced instrument employing a number of new technological developments, where the replacement of the passive radiator array of the AMI by an active phased array antenna system using distributed elements is the most challenging one. The resulting attractive improvements are the capability to provide more than 400 km wide swath coverage using Scansar techniques and the alternating polarisation feature allowing scenes to be imaged simultaneously in vertical (V) and horizontal (H) polarisation or a combination of both. (Table 4)

	Image	Wide Swath	Alternating/ Cross Polarization	Wave	Global Monitoring
Polarization	VV or HH	VV or HH	VV/HH, VV/VH or HH/HV	VV or HH	VV or HH
Spatial Resolution along-track across-track	 ≤ 30 m ≤ 30 m (~4 looks)	 ≤ 150 m ≤ 150 m (~12 looks)	 ≤ 30 m ≤ 30 m (~2 looks)	 ≤ 10 m ≤ 10 m (single look)	 ≤ 1000 m ≤ 1000 m (>7 looks)
Radiometric Resolution	≤ 2.5 dB	≤ 2.0 dB	≤ 3.6 dB	≤ 2.3 dB	≤ 1.6 dB
Swath Width	up to 100 km	≥ 400 km	up to 100 km	5 km vignette	≥ 400 km
Ambiguity Ratio (Point) along-track across-track	 ≥ 27 dB ≥ 30 dB	 ≥ 24 dB ≥ 24 dB	 ≥ 21 dB ≥ 25 dB	 ≥ 27 dB ≥ 30 dB	 ≥ 26 dB ≥ 24 dB
Ambiguity Ratio (Distrib.) along-track across-track	 ≥ 23 dB ≥ 13 dB	 ≥ 22 dB ≥ 13 dB	 ≥ 20 dB ≥ 13 dB	 ≥ 23 dB ≥ 17 dB	 ≥ 23 dB ≥ 13 dB
Radiometric Accuracy (3б)	≤ 1.6 dB	≤ 1.5 dB	≤ 2.0 dB	≤ 2.2 dB	≤ 1.8 dB
Centre Frequency			5.331 GHz		
Pulse Repet. Frequ.			1650 to 2100 Hz		
Chirp Bandwidth			up to 16 MHz		
Antenna Size			10 m x 1.3 m		
Operation		up to 30 min/orbit		Rest of orbit	
Data Rate	≤ 100 Mbit/s	≤ 100 Mbit/s	≤ 100 Mbit/s	0.9 Mbit/s	0.9 Mbit/s
Mass			830 kg		
Power	1365 W	1200 W	1395 W	647 W	713 W

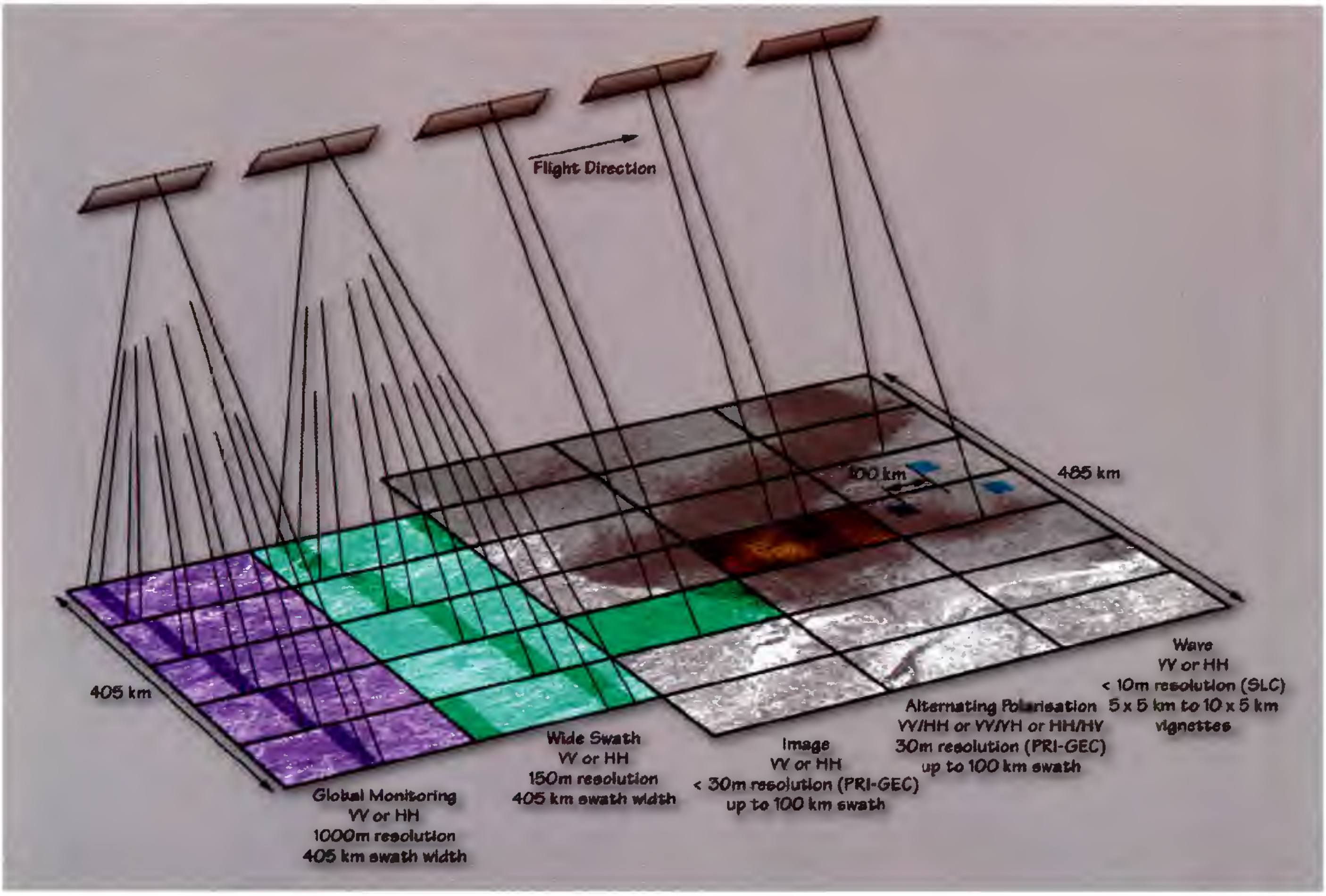
Table 4. ASAR instrument parameters.

The instrument is designed to operate in the following principal operating modes:
- image
- wide swath
- alternating polarisation mode
- wave
- global monitoring.

In image mode the ASAR gathers data from relatively narrow swaths (100 km within a viewing area of ~485 km) with high spatial resolution (30 m), whereas in wide swath mode using scansar techniques a much wider stripe (~400 km) is imaged with lower spatial resolution (150 m). The alternating/cross polarisation mode provides imaging in VV/HH, HH/HV and VV/VH polarisation of the same scene with a spatial resolution equal to image mode but reduced radiometric resolution. In wave mode, ASAR measures the change in radar backscatter from the sea surface due to ocean surface waves. In this mode, images of 5 x 5 km are taken over the ocean at a distance of 100 km. In global monitoring mode a wide swath (~ 400 km) is imaged with low spatial resolution (1 km).

In order to maintain the in orbit performance of the instrument, both internal and external calibration are planned. External calibration can be made by observing a reference target (natural target and/or radar transponder) on the ground for each mode, swath, and polarisation state. Internal calibration is intended to compensate for changes in the overall gain of the instrument. This is achieved by regular calibration loop measurements including both the central electronics and the Transmit/Receive (T/R) modules housed in the antenna. (Fig. 8)

⑧ *ASAR transmit/receive module (Photo Alcatel Space).*



⑨ *ASAR operating modes.*

⑩ *ASAR antenna during deployment test (Photo MMS).*

The ASAR instrument is a phased-array radar with T/R-modules arranged across the antenna, such that by adjusting individual module phase and gain, the transmit and receive beams may be steered and configured. The active antenna (Fig. 10) contains 20 tiles with 16 T/R modules each.

ASAR general operation strategy

ASAR offers, by exploiting the combinations of polarisation and incidence angles, 37 different and mutually exclusive high rate operating modes in high and medium (wide swath) resolution (Fig. 9). Wave mode and global monitoring mode (whose data are recovered together with the data from the Global Operations), are also mutually exclusive with respect to all the other modes. All modes will be operated in response to user requests, except for wave mode. Requests for the collection of Strategic Datasets will be entered directly by ESA

ASAR wave mode
Wave mode operation will be routinely planned over open oceans and large seas. The default setting (incidence angle and polarisation) at the beginning of the mission will be the same as the ERS wave mode, but with spacing of vignettes at 100 instead of 200 km. Experiment campaigns to evaluate other ASAR wave operating modes (varying incidence angle and polarisation) will be decided in co-ordination with the operational entities using the data and with interested scientists.

Global monitoring mode (GMM)
While GMM operations may be triggered by user requests, it is anticipated that most of the GMM operations will be defined as part of the collection of strategic datasets, this mode being mainly designed for observing/monitoring global processes.

High-rate modes (wide-swath and image modes)
To help the user in defining a request inducing future acquisitions, the approach for allowing access and assigning the various modes will be as follows:

- default ASAR HR modes will be offered to the user according to applications and/or geographic areas
- if stringent revisiting requirements are expressed, several look angles may be used to satisfy the request. The user will then be notified that his request can be satisfied only with a set of observations at different incidence angles
- user requests for interferometric pairs, using ASAR Image Mode, will be supported for both inventory searches on already acquired data as well as for ordering data requiring future acquisitions.

All ASAR high-rate data acquired by ESA facilities will be systematically processed in near-real time to generate medium-resolution products (~150 m) and browse products. Browse products will be available on line.

MERIS
The Medium-Resolution Imaging Spectrometer (MERIS) addresses the needs of three disciplines:

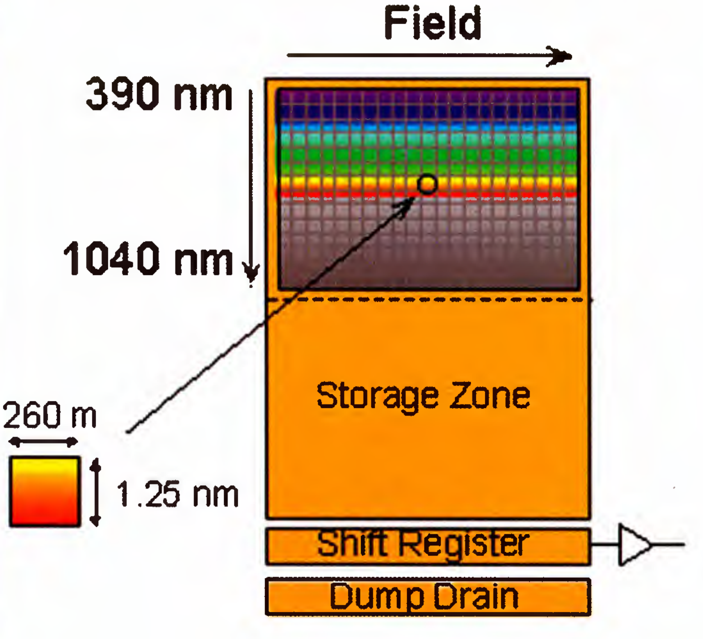
- primarily bio-geo-chemical oceanography (assessment of surface optical properties and water constituent concentrations in open oceans and coastal waters),
- secondarily, atmospheric observations(cloud/water vapour and aerosols) and
- land vegetation observations.

MERIS is a 'push-broom' instrument and measures the solar reflected radiation from the Earth's surface and from clouds through the atmosphere in the visible and near infrared range during daytime. The 1150 km wide swath is covered by 5 identical cameras having slightly overlapping fields of view. Each camera images an across-track stripe of the Earth's surface onto the entrance slit of an imaging optical grating spectrometer.

This entrance slit is imaged through the spectrometer onto a 2-dimensional CCD array, thus providing spatial and spectral information simultaneously (Fig. 11).

The spatial information along-track is determined by the push-broom principle via successive readouts of the CCD-array. MERIS operates at full resolution (FR with 300 m res. at nadir). The data are spatially averaged on board to produce a separate data stream at reduced resolution (RR with 1200 m resolution at nadir). The two data streams are available in parallel on board.

(11) *MERIS detector (CCD). The useful image covers a zone of 740 pixels across track (spatial resolution at nadir: 260 m) by 520 pixels in the spectral domain (resolution 1.25 nm).*



The instrument is optimised for absolute and relative radiometric performances. In particular, sun calibration through a diffuser plate will be performed at regular interval. In addition, MERIS is fully programmable: each band is selectable in position and width by ground command.

General operation strategy

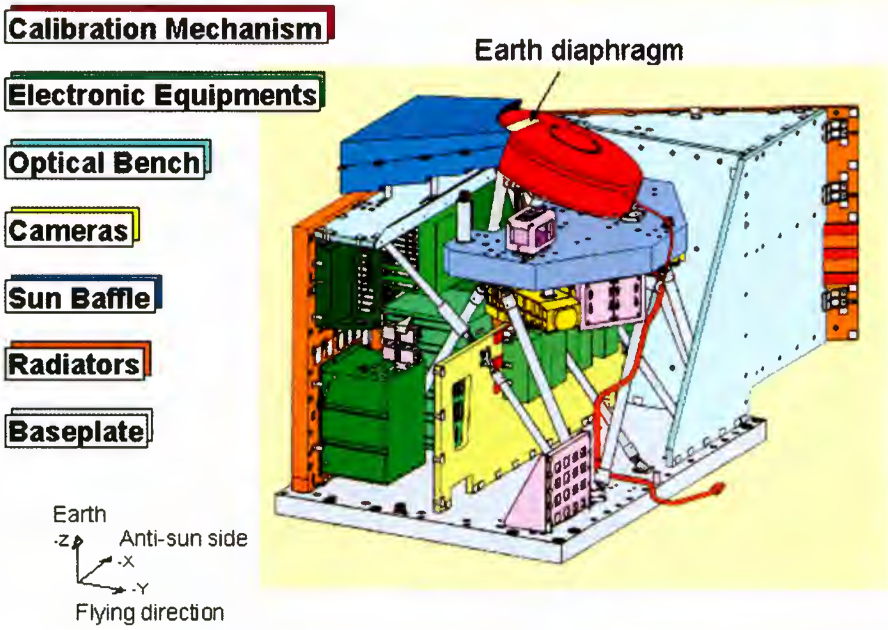
Measuring modes of MERIS can be used only out of eclipse and when the sun zenith angle at the sub-satellite point is below 80°, corresponding to about 43% of the orbit. This applies to both RR and FR modes. The RR mode will be operated systematically within this solar constraint and data recorded on board as part of the Global Mission operation. The FR data will be transmitted only when required to satisfy either user requests or the collection of strategic datasets.

MERIS will be operated with a fixed set of bands, recommended by the Scientific Advisory Group (SAG) and frozen before launch. The level-2 ESA products are being developed and will be validated for this set of bands. It will be possible to use alternative band sets for experiment campaigns of a few weeks duration.

No.	Band centre (nm)	Bandwidth (nm)	Application
1	412.5	10	Yellow substance and turbidity
2	442.5	10	Chlorophyll absorption maximum
3	490	10	Chlorophyll and other pigments
4	510	10	Turbidity, suspended sediment and red tides
5	560	10	Chlorophyll, suspended sediment
6	620	10	Suspended sediment
7	665	10	Chlorophyll absorption
8	681.25	7.5	Chlorophyll fluorescence, red edge
9	705	10	Aerosol, red edge transition
10	753.75	7.5	Oxygen absorption reference band, vegetation
11	760	2.5	O_2 absorption R-branch
12	775	15	Aerosol, vegetation
13	865	20	Aerosol
14	890	10	Water vapour, vegetation
15	900	10	Water vapour

Table 5. Nominal MERIS spectral bands

(12) *MERIS 3-D diagram.*



(13) *MERIS flight model.*

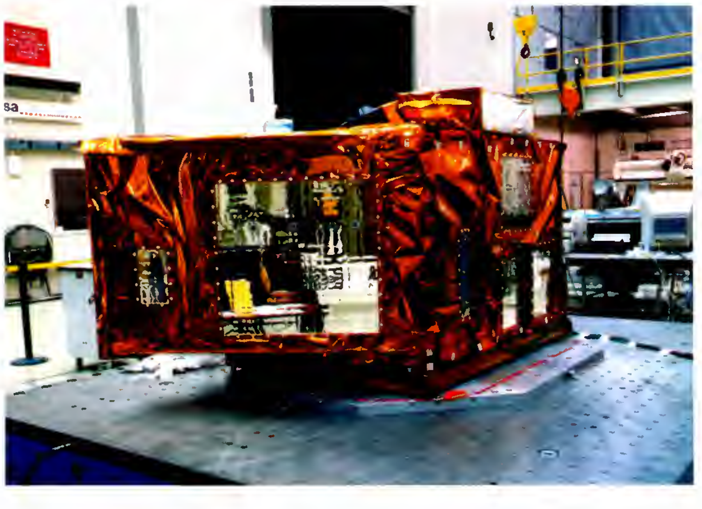
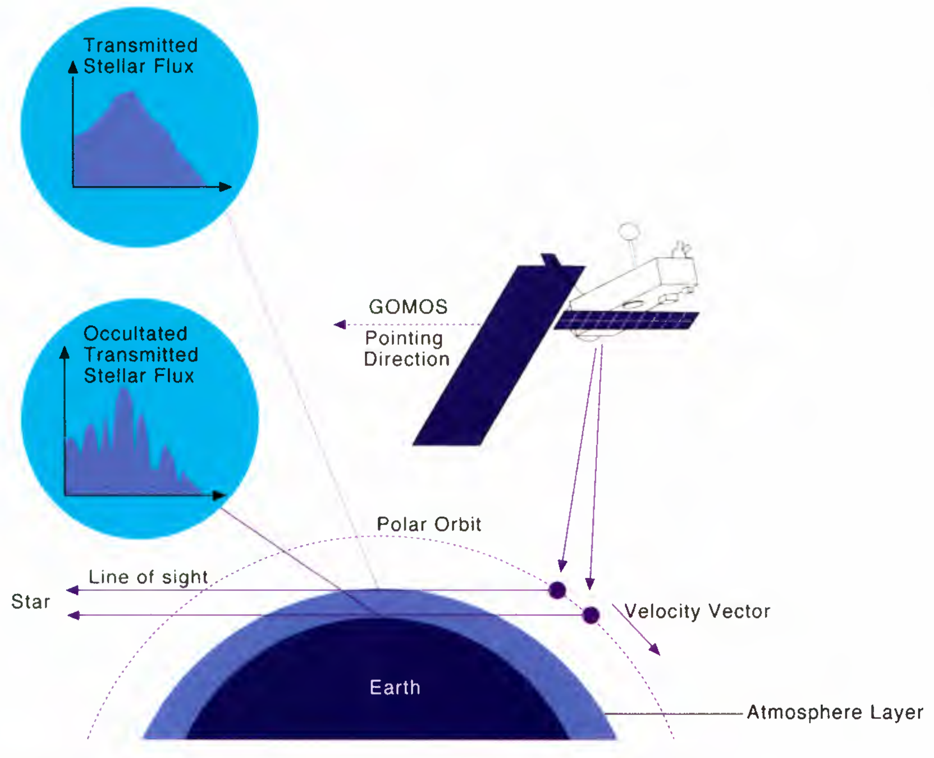


Table 6. MERIS instrument parameters.

Spectral Range	390...1040 nm
Spectral Sampling Interval	1.25 nm
Spectral Bands	15, centre frequencies programmable
Spectral Bandwidth	1.25...25 nm, programmable
Instrument Field of View	68.5°, equivalent 1150 km swath
Absolute Localisation Accuracy	< 2000 m
Solar Reflectance abs. Accuracy	< 2%
Measurement Modes	full resolution: 0.25 km x 0.25 km at nadir reduced resolution: 1 km x 1 km at nadir
Polarization Sensitivity	< 0.5%
Error of Spectral Position	< 1 nm
Radiometric Resolution	15 µW/ (m2 . sr . nm) at 865 nm (10 nm bandwith, reduced resolution)
Dynamic Range	~ 40 dB
Operation	during day time
Data Rate	24 Mb/s full resolution, 1.6 Mb/s reduced resolution
Mass	207 kg
Power	148 W average



⑭ *GOMOS measurement principle.*

GOMOS has been designed to measure trace gas concentrations and other atmospheric parameters in the 20-100 km altitude range (Fig. 14).

The instrument accommodates an UV-visible and a near-IR spectrometer fed by a telescope which has its line of sight orientated towards the target star by means of a steerable mirror (Fig. 15). The instrument then tracks the star and observes its setting behind the atmosphere. Additional measurements provided by two fast photometers allow correcting the spectral data from the high-frequency component introduced by the atmospheric scintillations.

The 930 nm band of the near-infrared spectrometer allows to derive vertical profiles of water vapour, which is an important stratospheric constituent. From the 760 nm band of this spectrometer, the vertical temperature profile can be retrieved which adds useful data for the extraction of the ozone concentration profile and for its long term trend monitoring.

GOMOS

Ozone depletion in the stratosphere has been recognised as a very critical factor affecting our environment. Accurate means to monitor and consequently understand the relevant chemical processes in the Earth's atmosphere are urgently required.

GOMOS has therefore been proposed for the Envisat Mission. The instrument enables simultaneous monitoring of ozone and other trace gases as well as temperature distributions in the stratosphere. The overall instrument performance (coverage, spatial and spectral resolution and accuracy) is far superior to previous systems such as SAGE I/II and will therefore improve significantly global monitoring of stratospheric ozone.

About 25 stars having visual magnitude brighter than 2 can routinely be observed at different longitudes from each orbit. With 14.3 orbits/day, GOMOS will produce as much data as a global network of 360 ground stations. The instrument is typically commanded to observe a sequence of up to 50 stars which are repeatedly observed on sequential orbits.

Table 7. GOMOS instrument parameters

	Channel	Spectral Range	Spectral Resolution
Optical Performance Parameters	UV-VIS	250 - 675 nm	1.2 nm
	IR 1	756 - 773 nm	0.2 nm
	IR 2	926 - 952 nm	0.2 nm
	PHOT 1	650 - 700 nm	broadband
	PHOT 2	470 - 520 nm	broadband
Altitude Range	20 km - 100 km		
Vertical Resolution	1.7 km		
Operation	continuously over full orbit		
Data Rate	222 kb/s		
Mass	163 kg		
Power	146 W		

⑮ *GOMOS flight model.*

From the spectral analysis, spatial as well as seasonal and long-term temporal information can be derived. As a result detailed maps and trends for various atmospheric constituents and parameters under investigation can be obtained.

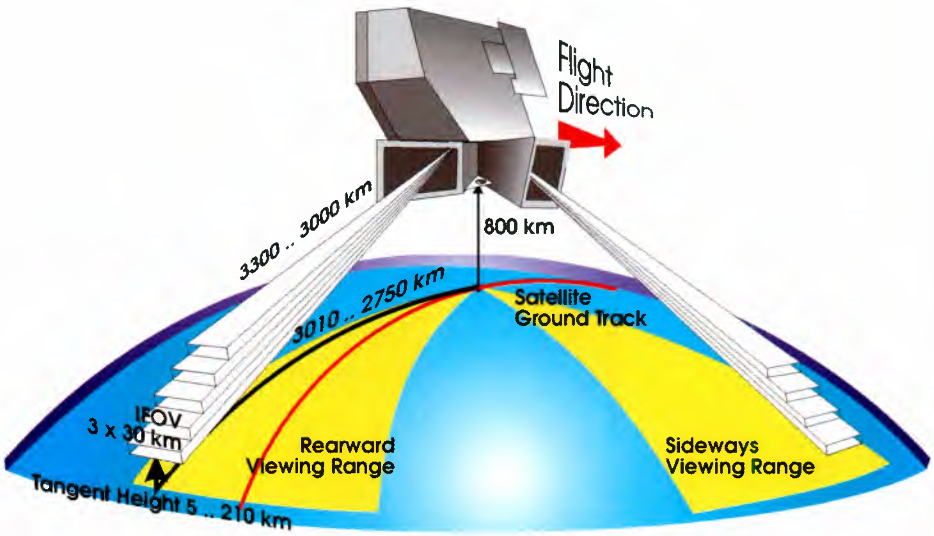
The excellent performance of GOMOS stems from
- the self-calibrating measuring scheme by detecting a star's spectrum outside and through the atmosphere
- the drift and background compensating measurement algorithms introduced by the use of 2-dimensional array detectors, which allow stellar and background spectra to be recorded simultaneously.

As a result, the spectra can therefore be corrected for background and detector dark current contributions. Successive recordings of stellar spectra outside and through the atmosphere allow any long-term changes in spectral emission characteristics as well as drifts in sensor spectral sensitivity to be compensated.

Thus, from simple relative measurements, high stability is obtained. Over a 5-year mission period, ozone level changes below the actual depletion rate can be detected.

<u>Operation plan</u>
GOMOS will observe stars according to an observation sequence defined – in cooperation with scientific experts – several months in advance.

This star sequence will be optimised to make best use of the potential visible stars, taking into account the occultation geometry and the combination of observed spectra according to their merits for extraction of the various atmospheric species.



(16) *MIPAS viewing geometry.*

MIPAS
MIPAS is a high-resolution Fourier transform infrared spectrometer designed to measure concentration profiles of various atmospheric constituents on a global scale. It will observe the atmospheric emissions from the Earth horizon (limb) in the mid-infrared region (4.15 - 14.6 µm) providing global observations of photochemically interrelated trace gases in the middle atmosphere, in the tropopause and in the upper troposphere (Fig. 16). These data will contribute to the development of a better understanding in the following research areas:
- Stratospheric Chemistry: global ozone problem, polar stratospheric chemistry,
- Global Climatology: global distribution of climate relevant constituents,
- Atmospheric Dynamics: transport exchange between troposphere and stratosphere,
- Upper Tropospheric Chemistry: correlation of gas distribution with human activities.

The instrument is designed to allow the simultaneous measurement of more than 20 relevant trace gases, including the complete NOy family and several CFCs. The atmospheric temperature as well as the distribution of aerosol particles, tropospheric cirrus clouds and stratospheric ice clouds (including polar stratospheric clouds) are further

Instrument $NESR_0$	between 50 nW cm^{-2}sr^{-1}/cm^{-1} at 685 cm^{-1} and 4.2 nW cm^{-2}sr^{-1}/cm^{-1} at 2410 cm^{-1}
Radiometric Accuracy	2 . $NESR_0$ + 2 % to 5 % of source radiance depending on wavelength
Spectral Coverage	685 cm^{-1} to 2410 cm^{-1}
Spectral Resolution	< 0.035 cm^{-1}
Spectral Stability Goal	< 0.001 cm^{-1} over 1 day
Elevation Scan Range	between 5 km to 150 km tangential height
Azimuth Scan Range	between 80° - 110° and 160° - 195° w.r.t. flight direction
Line of Sight Pointing Knowledge	< 1.8 km in tangential height
Line of Sight Stability	< 500 m/4 s in tangential height
Detectors Oper. Temperature	65 K - 75 K
Operation	continuously over full orbit
Data Rate	533 kb/s; Raw Data Mode 8 Mb/s
Mass	320 kg
Power	195 W

Table 8. MIPAS instrument parameters.

important parameters which can be derived from MIPAS observations.

The data are obtained with complete global coverage, for all seasons and independent on illumination conditions, allowing measurement of the diurnal variation of trace species.

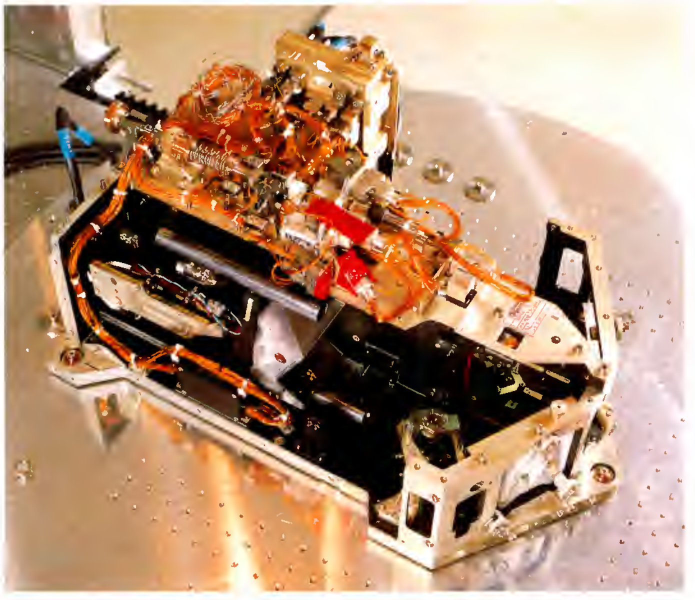
The atmospheric emissions will be measured at the horizon of the Earth (limb) over a height range of 5 to 150 km. This observation geometry allows the maximum measurement sensitivity and a good profiling capability to be achieved.

The MIPAS data products are calibrated high-resolution spectra which are derived on ground from the transmitted interferograms. From these spectra, geophysical parameters such as trace gas concentrations, temperature profiles, mixing ratios, are retrieved to establish global maps of atmospheric constituents in geophysical coordinates.

MIPAS will perform measurements in either of two pointing regimes: rearwards within a 35° wide viewing range in the anti-flight direction and sideways within a 30° wide range on the anti-sun side. The rearward viewing range will be used for most measurements, since it provides a good Earth coverage including the polar regions. The sideways range is important for observations of special events, like volcanic eruptions, trace gas concentrations above major traffic routes or concentration gradients across the dawn/dusk border.

In nominal measurement mode, MIPAS will make series of measurements at different tangent heights by performing elevation scan sequences with a duration of 75 s in the rearward viewing range. Such an elevation scan sequence comprises typically 16 interferometers sweeps (Fig. 17 & 18).

Radiometric calibration will be performed using two measurements:
- gain calibration approximately once per week, applying a two-point calibration method, where radiances from deep space and an internal blackbody are recorded in sequence;
- offset calibration, prior to every elevation scan sequence, in order to correct for the instrument self-emission.



(17) *MIPAS interferometer (Photo Dormer).*

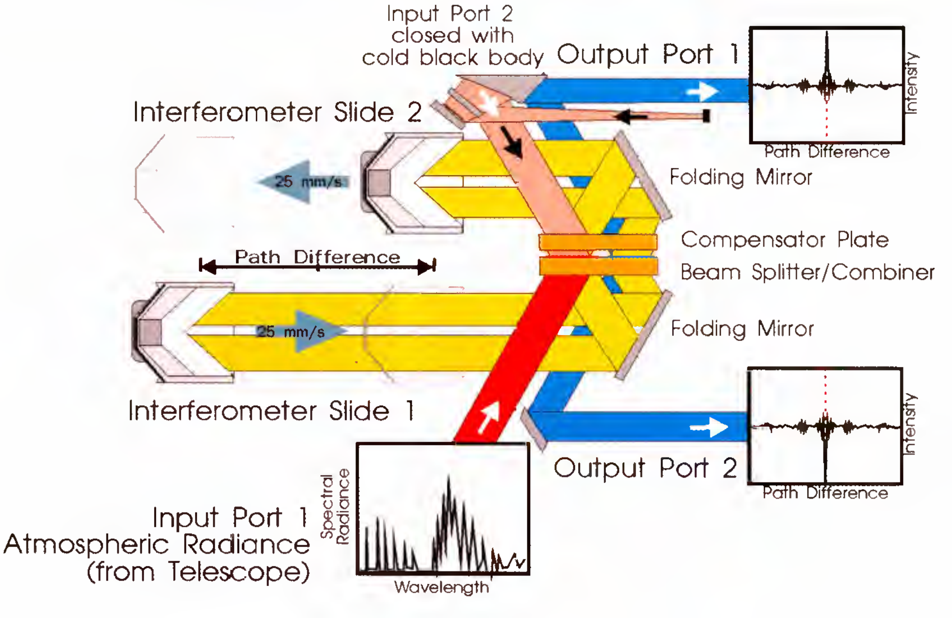
Another calibration mode will be required for the in-flight determination of the line-of-sight pointing direction, which is based on the observation of stars crossing the instrument field of view and subsequent correlation of the actual with the predicted time of star crossing.

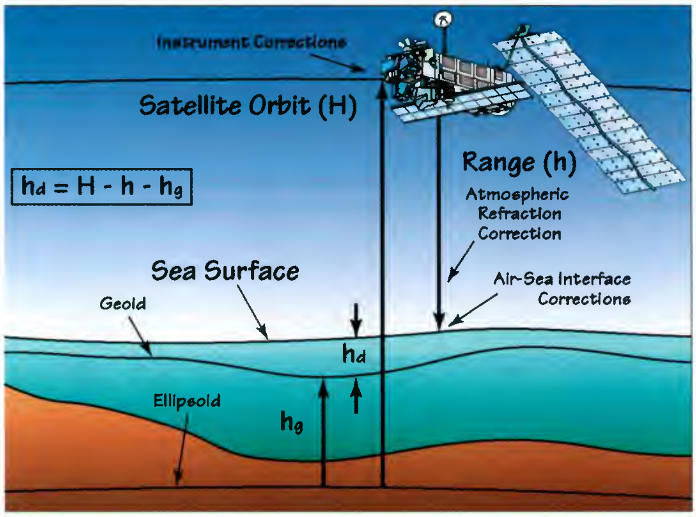
Operation strategy

MIPAS nominal operation mode is a background limb observing mode repeating all along the orbit the same limb scan sequence. This routine operation will be interrupted for line of sight calibration at regular interval of a few weeks, for a few orbits duration.

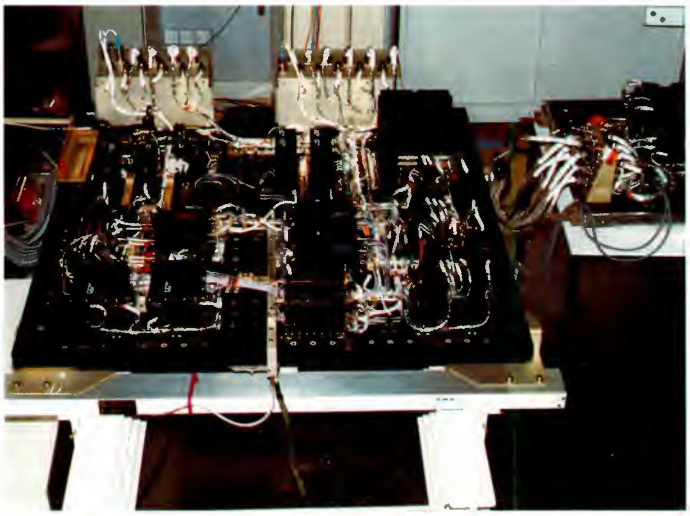
MIPAS allows monitoring of special events (e.g. volcanic eruption) in a specific side-looking mode. Requests for observations of such special events will be dealt with as occasional deviations authorised by the Mission Management authority.

(18) *Interferometer operating principle.*





(19) *RA-2 measurement principle.*



(20) *Radar Altimeter-2 flight model (Photo Alenia).*

Radar Altimeter-2
The RA-2 is a dual-frequency (Ku- and S-band) altimeter derived from the ERS-1/2 Radar Altimeters, providing improved measurement performance and new capabilities.

The main objectives of the RA-2 are the high-precision measurements of the time delay, the power and the shape of the reflected radar pulses for the determination of the satellite height and the Earth surface characteristics (Fig. 19).

Operating over oceans, these measurements are used to determine the ocean surface topography, thus supporting studies of ocean circulation, bathymetry, gravity anomalies and marine geoid characteristics.

The on-ground processing of the radar echo power and shape enables the determination of wind speed and significant wave height in the observed sea area, contributing to weather and sea state forecasting.

Furthermore, RA-2 is able to map and monitor sea ice and polar ice sheets.

The new features of RA-2 enable it to extend its measurements of altitude and reflectivity over land. The measurements will be used for the determination of Earth surface elevation, geological structure and surface characteristics.

The RA-2 design includes an auto-adaptive tracker with 3 bandwidths (automatic switching between the three in correspondence to the characteristics of the surface with corresponding height resolution). As a result, measurements over ocean are carried out with improved accuracy at the highest resolution. Over land, ice and at the boundaries, the tracking is maintained at the heighest possible resolution compatible with the topographic variations.

Accurate altitude measurements over the ocean carried out by RA-2 at the main frequency of 13.575 GHz are affected by fluctuations in ionospheric characteristics. Measurements at a second frequency channel of 3.2 GHz enable corrections for this error (Fig. 20-21).

Simultaneously to the tracking, and without any loss of scientific data, the instrument performs periodically an internal calibration. For this, the transmit

	Range	Accuracy
Altitude	764 km to 825 km	< 4.5 cm (highest res.)
Backscatter Coefficient	-10 dB to +50 dB	< 0.4 dB (bias) < 0.2 dB (residual)
Waveheight	0.5 m to 20 m	< 5 % or 0.25 m
Measurement Datation	+/- 100 µs wrt. UTC	
Operating Frequency	13.575 GHz (Ku-band) 3.2 GHz (S-band)	
Bandwidth	320 MHz & 80 MHz & 20 MHz & CW (Ku-band) 160 MHz (S-band)	
Pulse Repetition Frequency	1795.33 Hz (for Ku-band) 448.83 Hz (for S-band) interleaved operation	
Pulse Width IF Bandwidth	20 ms 6.4 MHz	
Operation Data Rate Mass Power	continuously over full orbit 100 kb/s 110 kg 161 W	

Table 9. Radar Altimeter-2 instrument parameters.

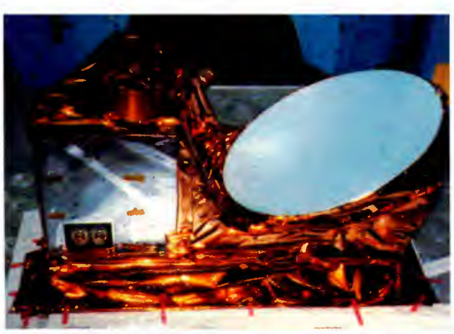
(21) *Radar Altimeter flight model.*

pulse is coupled into the receiver: the signal is processed as the normal radar echo signals are. The point target response of the instrument is calculated, thus indicating all residual errors and distortions in the transmit/receive path of the instrument (except the antenna which has to be characterised on ground).

By ground command and in parallel to the nominal collection of echo waveforms, which are averaged on board at 19 Hz rate, RA-2 has also the unique feature to be able to record streams of non-averaged 'individual' waveforms. These will be exploited on ground to better understand the physics of the scattering process.

On ground, four different re-tracking algorithms (each one tailored to a particular surface type, namely ocean, sea ice, ice caps and ice boundaries) will be run in parallel on all surfaces.

(22) *Microwave Radiometer (Photo Alenia).*



The ocean algorithm, in particular, allows the extraction of precise satellite altitude, wind speed and significant wave height information using the water vapour content in the troposphere measured by the MWR.

<u>Operation</u>
Thanks to the auto-adaptive tracker mode, the instrument will be continuously operated in the nominal measurement mode.

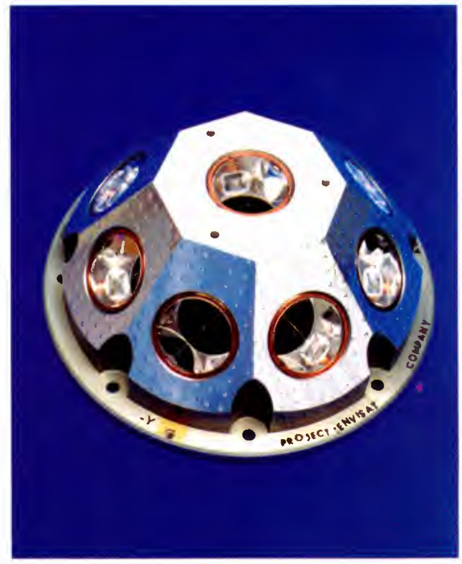
Microwave Radiometer (MWR)
The main objective of the MWR is the measurement of atmospheric humidity as supplementary information for tropospheric path correction of the RA signal, which is influenced both by the integrated atmospheric water vapour content and by liquid water. In addition, MWR measurement data are useful for the determination of surface emissivity and soil moisture over land, for surface energy budget, investigations to support atmospheric studies and for ice characterisation.

The MWR instrument on-board Envisat is a derivative of the radiometers used on the ERS-/2 satellites. It is a dual-channel, nadir pointing Dicke-type radiometer, operating at 23.8 and 36.5 GHz frequencies (Fig. 22).

In order to eliminate Earth's irradation, differential measurements at two frequencies have to be performed. The optimal frequency setting is achieved by using one frequency at the maximum and one at the minimum attenuation. The selected frequencies are the results

Table 10. Microwave Radiometer instrument parameters.

Operating Frequencies	23.8 GHz (K-band) 36.5 GHz (Ka-band)
Dynamic Range	3 K ... 300 K
Absolute Radiometric Accuracy	better 3 K
Operation	Continuously over full orbit
Data Rate	16.7 kb/s
Mass	25 kg
Power	23 W



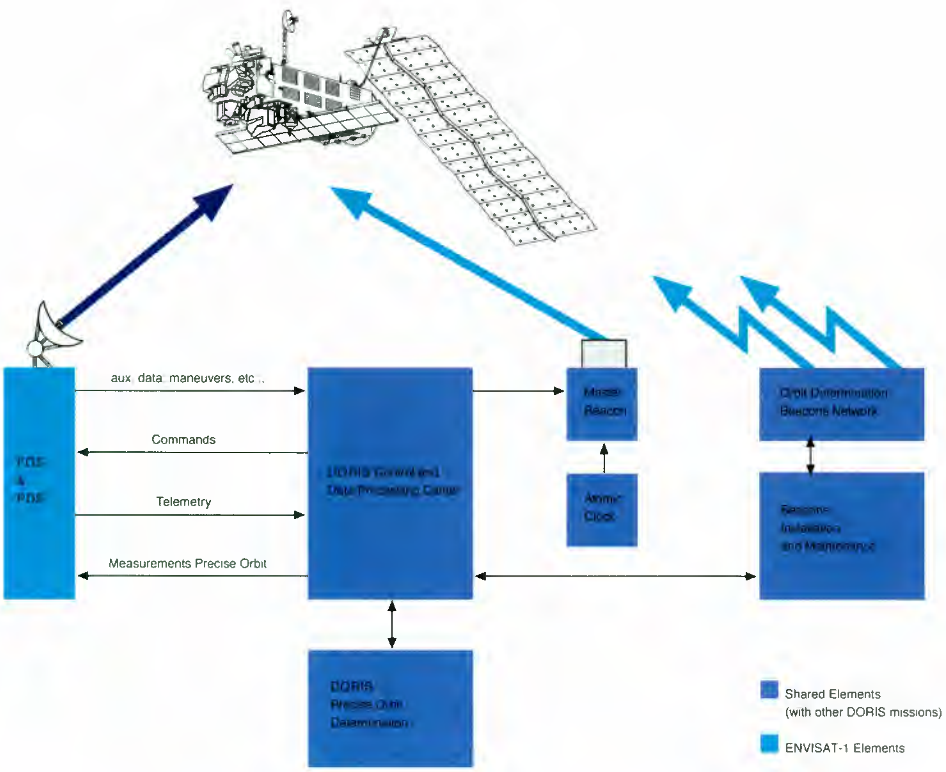
(23) *Laser-Retro Reflector (Photo Aerospatiale)*

of a trade-off between antenna size required to cover an horizontal area on the Earth surface comparable to the RA-2 illuminated area and the maximum sensitivity to water vapour change in the troposphere.

Retrieval of antenna and brightness temperature values from measurement data is accomplished by ground processing. This considers ground calibration data, antenna characteristics and in-orbit characterisation data.

Laser Retro-Reflector (LRR)
An LRR will be mounted on the nadir panel close to the RA-2 antenna to support satellite ranging and RA-2 altitude measurement calibration. The LRR is a passive device which will be used as a reflector by ground based laser ranging stations using high power pulsed lasers (Fig. 23).

The operating principle is to measure on ground the time of a round trip of laser pulses reflected from an array of corner-cubes mounted on the Earth-facing side of the satellite. The corner-cubes are designed to reflect the incident laser beam back directly, making the reflected beam parallel to the incident beam within a few arcseconds.



㉕ *DORIS system block diagram.*

DORIS

DORIS is a microwave doppler tracking system used for precise orbit determination with an accuracy in the order of centimeters. In conjunction with the radar altimeter, DORIS contributes to improve the accuracy of the measurements of the spatial and temporal ocean surface topography changes and the variations in ice coverage. In addition, data are provided to:

- help in the understanding of the dynamics of the solid Earth
- monitoring glaciers, landslides and volcanoes
- improve the modelling of the Earth gravity field and of the ionosphere.

Table 11. DORIS instrument parameters.

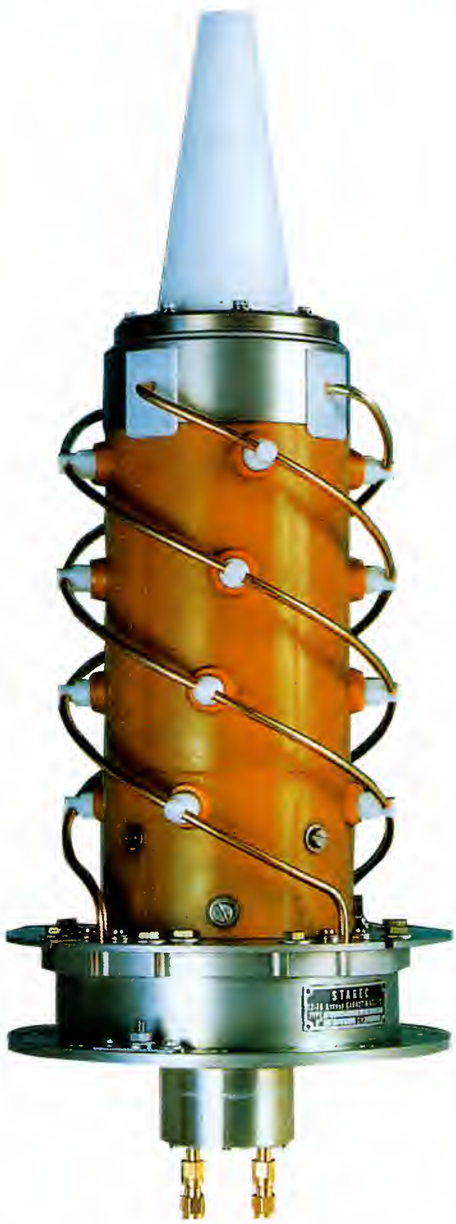
Measurement Frequency	
for Doppler Measurement	2.03625 GHz
for Ionospheric Correction	401.25 MHz
Position Accuracy	
Real-Time	1 m
Restituted	0.05 m radial
Velocity Accuracy	
Real-Time	< 2.5 mm/s
Restituted	0.4 mm/s
Operation	continuously over full orbit
Data Rate	16.7 kb/s
Mass	91 kg (incl. ICU)
Power	42 W

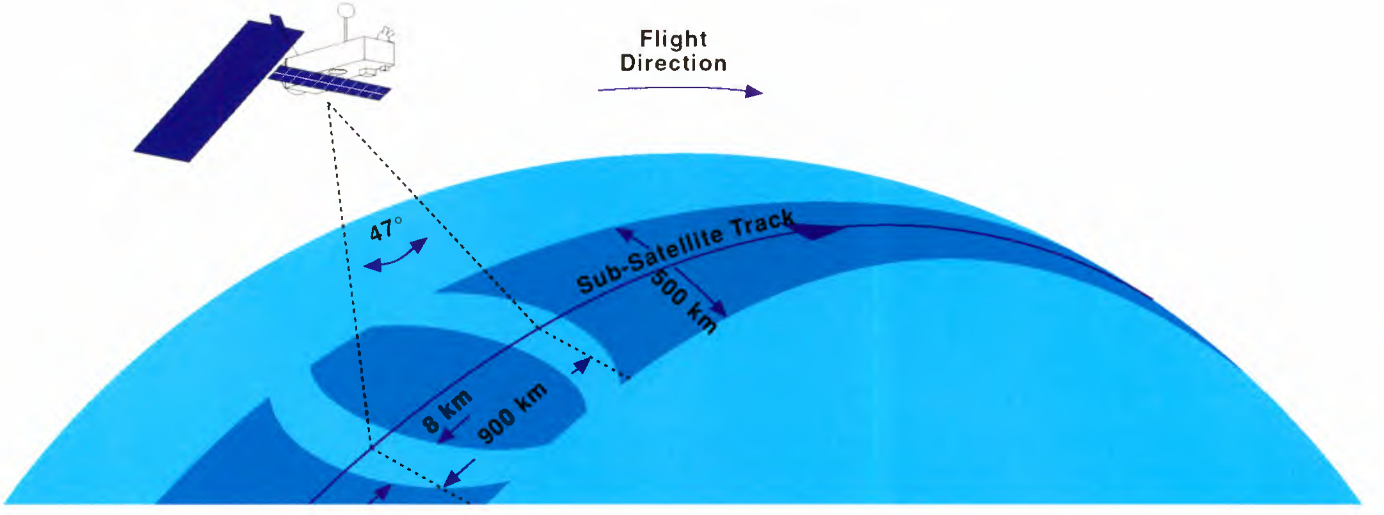
The DORIS system comprises the onboard instrument, a beacon network and the DORIS Control & Data Processing Centre.

DORIS is based upon the accurate measurement of the doppler shift of radiofrequency signals transmitted from ground beacons and received on board the spacecraft. Measurements are made at the two frequencies: 2.03625 GHz for precise doppler measurement and 401.25 MHz for correction of the propagation delay in the ionosphere.

Onboard measurements of the doppler shift are performed every 7 to 10 seconds. Resulting radial velocity values (accuracy in the order of 0.4 mm/s) are used on ground in combination with a dynamic model of the satellite trajectory to perform a precise orbit determination with an accuracy better than 5 cm in altitude. These orbit data are availble within a month. The delay is mainly due to the availability of external data, such as the solar flux. The doppler measurements are also processed on board to obtain real-time orbit data, with less accuracy, but available for use in the near-real time processing at the ESA PDS stations (Fig. 24-25).

㉔ *DORIS omnidirectional antenna (Photo CNES)*





26 *AATSR viewing geometry.*

AATSR

The primary scientific objective of the AATSR is to establish a continuity of the ATSR-1 and ATSR-2 datasets of precise Sea-Surface Temperature (SST), thereby ensuring the production of a unique 10-year near-continuous dataset at the levels of accuracy required (0.5 K or better) for climate research and for the community of operational as well as scientific users developed through the ERS-1/2 missions.

The second objective is to perform quantitative measurements over land surfaces. The land and cloud measurements objectives will be met through the use of an additional focal plane assembly, which will lead to indications of vegetation biomass, vegetation moisture, vegetation health and growth stage.

The visible channels will also contribute to the measurement of cloud parameters, like water/ice discrimination and particle size distribution.

The SST is one of the most stable of several key geophysical variables which, when determined globally, contribute to the characterisation of the state of the Earth's climate. The precise measurement of small changes in SST provides an indication of quite significant changes in ocean/atmosphere heat transfer rate, especially in the tropics; also it is known that small amplitude anomalies occurring in specific areas are sometimes associated with massive atmospheric perturbations, leading to widespread and damaging changes in the global weather system.

For example, the El Niño anomaly in the tropical East Pacific is associated with a reversal of the atmospheric 'Walker circulation'. This in turn creates widespread perturbations to the global weather system. The exact causal relationships between such phenomena are not fully understood but a significant El Niño event can evolve from an SST anomaly of 2-3 K and therefore the ability to detect, for example, a 10% change in the anomaly field will require measurements of the accuracy provided by the series of the (A)ATSR instruments.

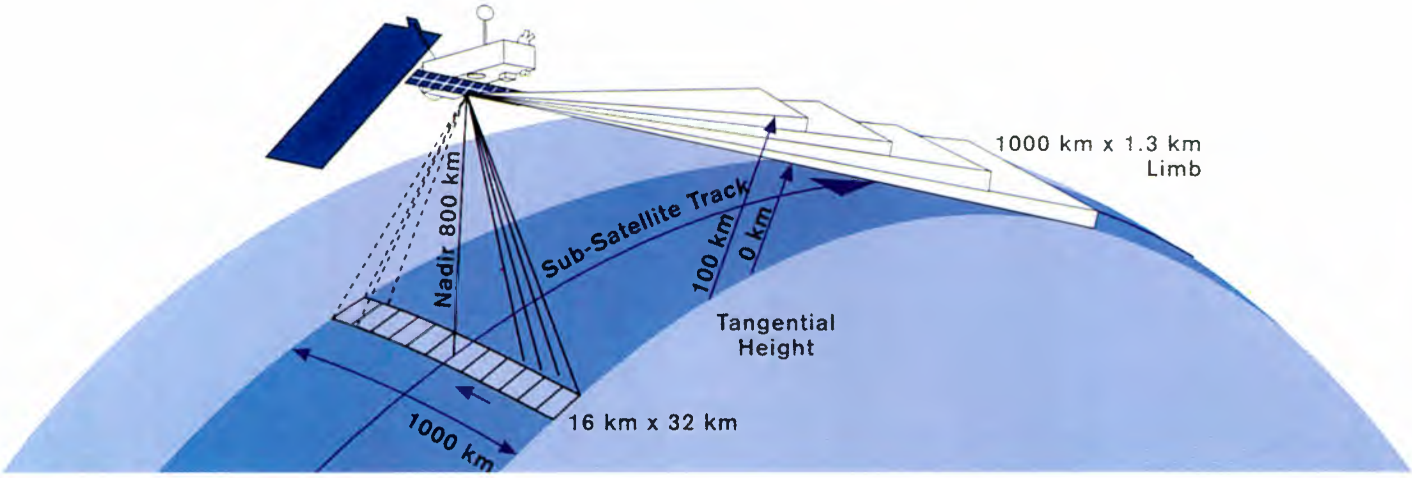
The principle of removing atmospheric effects in the measurements by viewing the sea surface from two different angles is the basis of the family of (A)ATSR instruments.

As with the AATSR inrared channels, the measurement philosophy with the visible channels is to develop and exploit a capability for making accurate quantitative measurements of radiation from the Earth's surface, using an onboard calibration system for radiometric accuracy, also using a two-angle viewing technique to obtain accurate atmospheric corrections.

The most important two visible channels are centered on 0.865 micron and 0.67 micron and will provide measurements of Vegetation Index in a similar way as AVHRR. The AATSR has the capability for making global measurements with 1x1 km resolution at nadir. An additional visible channel at 0.55 micron is also incorporated to indicate, from the chlorophyll content, the growth stage and the health of vegetation (Fig.26).

Spectral Channels	
Infrared	1.6 µm, 3.7 µm, 10.85 µm, 12 µm
Visible	0.555 µm, 0.67 µm, 0.865 µm
Spatial Resolution	1 km x 1 km
Radiometric Resolution	0.1 K
SST Accuracy	better 0.5 K
Swath Width	500 km
Operation	continuously over full orbit
Data Rate	625 kb/s
Mass	101 kg
Power	100 W

Table 12. AATSR instrument parameters.



(27) *Sciamachy viewing geometry.*

Sciamachy
The primary scientific objective of the 'Scanning Imaging Absorption Spectrometer for Atmospheric Cartography' is the global measurement of various trace gases in the troposphere and stratosphere, which are retrieved by the instrument by observation of the transmitted, backscattered and reflected radiation from the atmosphere in the 240-2400 nm wavelength range. The large wavelength range is also ideally suited for the determination of aerosols and clouds. The nadir and limb viewing strategy of Sciamachy yields total column values as well as profiles for trace gases and aerosols in the stratosphere. This enables, in addition, estimates of global trace gas and aerosol content and distribution in the lower stratosphere and troposphere.

The measurements obtained will enable the investigation of a wide range of phenomena which influence atmospheric chemistry:
- in the troposphere: biomass burning, pollution, artic haze, forest fires,dust storms, industrial plumes
- in the stratosphere: ozone chemistry, volcanic events and solar proton events.

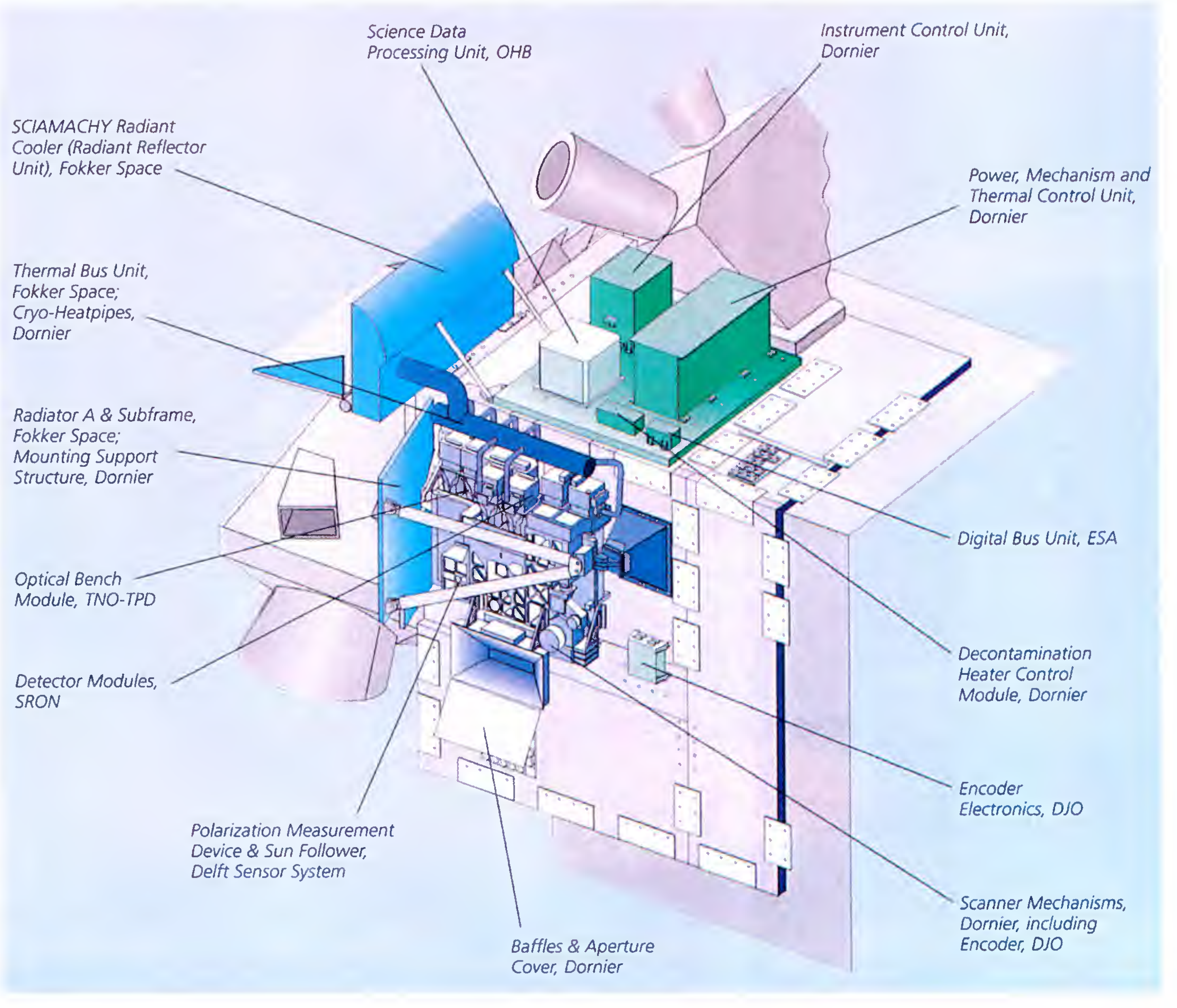
Table 13. Sciamachy instrument parameters.

	Channel	Spectral Range	Spectral Resolution
High Resolution Channels	1	240-314 nm	0.24 nm
	2	309-405 nm	0.26 nm
	3	394-620 nm	0.44 nm
	4	604-805 nm	0.48 nm
	5	785-1050 nm	0.54 nm
	6	1000-1750 nm	1.48 nm
	7	1940-2040 nm	0.22 nm
	8	2265-2380 nm	0.26 nm
Polarisation Measurement Devices (broadband)	PMD 1 to 7	310-2380 nm	67 to 137 nm (channel dependent)
Altitude Range	10 km-100 km depending on measurement mode		
Vertical Resolution	2.4 km-3 km depending on measurement mode		
Operation	continuously over full orbit		
Data Rate	400 kb/s nominal; 1867 kb/s real time mode		
Mass	198 kg		
Power	122 W		

In order to achieve the scientific objectives, measurements are performed by observing the atmosphere under different viewing angles. In nadir mode, the global distribution (total column values) of the atmospheric trace gases and aerosols will be observed. Additionally, cloud measurements are obtained. In this mode, the instrument is scanning across-track, with a swath width of ± 50 km with respect to the sub-satellite track. To obtain the altitude distribution of trace gases, Sciamachy performs observations in limb over an altitude range of 100 km, with a vertical resolution of 3 km. Starting at Earth horizon, the atmosphere is scanned tangentially over a 1000 km wide swath. After each azimuth scan, the elevation is increased until the maximum altitude of 100 km is reached (Fig.27).

Differential optical absorption spectroscopy (DOAS) is applied in Sun and Moon occultation measurements, where the Sun or the Moon are tracked, or a vertical scan over the complete Sun/Moon surface is performed. The obtained spectra can then be compared with suitable calibration spectra to yield the differential absorption of the atmosphere.

In Sciamachy optical assembly, the light from the atmosphere is fed by the scanner unit, consisting of an azimuth and an elevation scanner into the telescope which directs it onto the



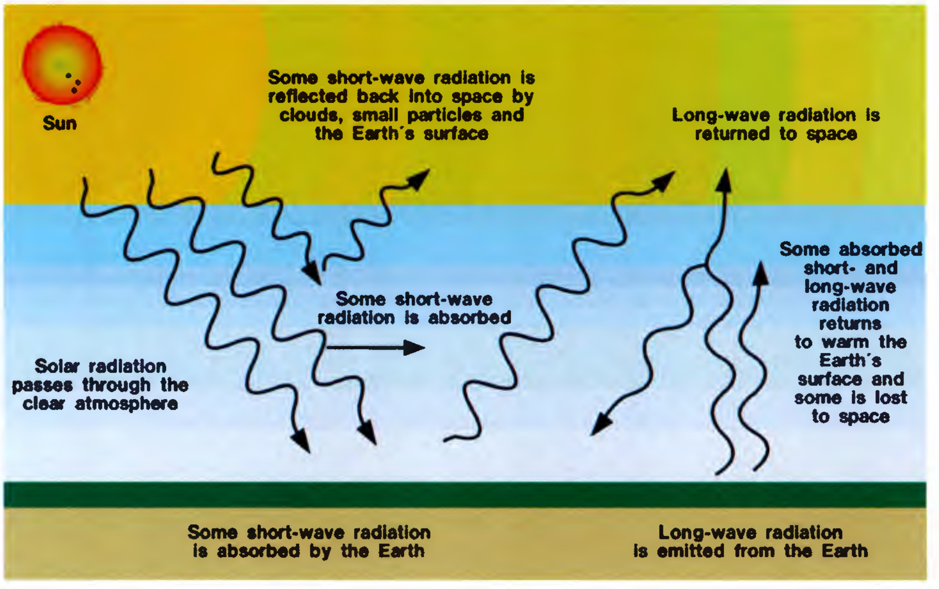
28 *Sciamachy instrument components.*

entrance slit of the spectrometer. The spectrometer contains a pre-disperser which separates the light into three spectral bands followed by a series of dichroïc mirrors which further divide the light into a total of eight channels. A grating is located in each channel to diffract the light into a high-resolution spectrum which is then focused onto eight detectors. The pre-disperser serves also as a Brewster window to separate polarised light, a part of which is sensed by the polarisation measurement device (PMD). The output of the PMD is later used to correct for the polarisation effects. Each spectrometer channel is equipped with a detector module, whose output digital signal is recorded and transmitted to ground (Fig. 28).

Operation

Sciamachy operates continuously on the basis of a template defined on an orbit by orbit basis. The nominal template defines interleaved nadir and limb observations, plus sun occultation during the corresponding orbit visibility segment. Moon occultation, sub-solar and in-flight calibration and monitoring measurements complement the nominal measurements based on pre-defined mission scenarios. Seasonal effects will cause regular changes.

Alternative scenarios (e.g. limb only, nadir only, different spatial resolutions) may be required in the course of the mission. The requests for modifications of the mission scenario will be dealt with as occasional deviations by the Envisat mission management.



(29) *The greenhouse effect.*

The Applications

Atmosphere

Satellite remote sensing provides a unique way of monitoring the complex and dynamic processes that occur in the atmosphere. Since the future of the human race is critically dependent on the long-term variability of the atmosphere, great efforts are being made to understand the many processes involved. In response to this, researchers develop models of the atmosphere as a mechanism whereby chemical reactions and physical changes in the atmosphere can be placed in context within the overall Earth system.

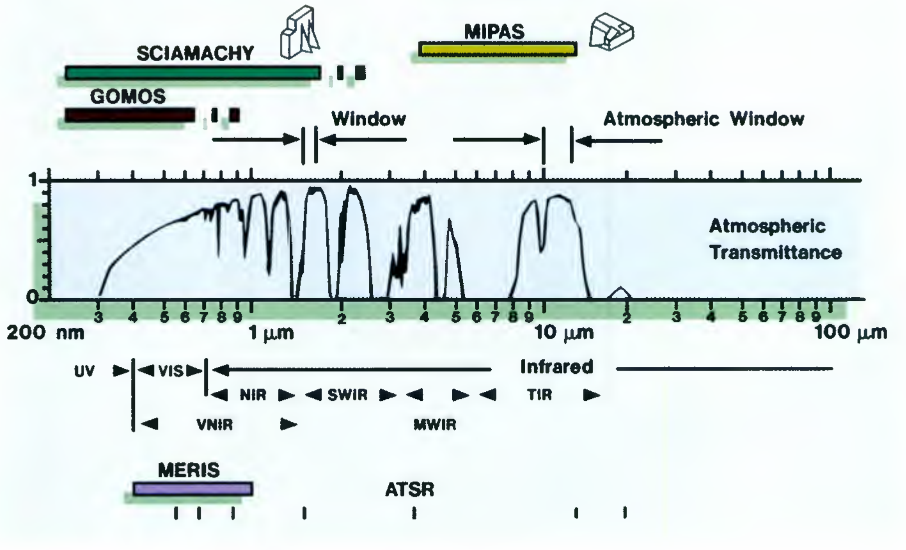
Such models require large amounts of data describing the spatial and temporal variability of the Earth's atmosphere at different locations and altitudes around the globe, taking account of diurnal, seasonal and longer-term cycles. Sources, reservoirs and sinks of critical trace gases all need to be described. Satellite remote sensing provides a powerful set of techniques for acquiring these data to sustain models of the atmosphere, especially where information is required on a global scale and within a short time span.

Many of the factors affecting the global environment are related to changes in the chemical composition of the atmosphere. The results of these changes include: the enhanced greenhouse effect, increase in the levels of ultraviolet-B radiation reaching the Earth's surface, acidification and reduced transparency. The atmosphere is very dynamic, both in terms of chemical composition and associated radiative properties and also in the way it transports materials around the globe, providing a link between land and ocean. The key role of the atmosphere in the maintenance of the Earth's environment emphasises the need to conduct research, to understand properly the processes involved and to monitor long-term changes.

As a result of man's activities, which have become progressively more significant over the last century, large quantities of carbon, chlorine, nitrogen and sulphur compounds have been injected into the atmosphere and are disrupting the natural equilibrium which had become established. Whilst long term change has always been a feature of the atmosphere, it has become apparent that it is the increased rate of change, brought about by man's activities, which is having such a potentially detrimental effect on the Earth's system.

The reduction in stratospheric ozone concentrations over Europe since 1960 is the direct result of the use of ozone depleting chemicals such as refrigerants, industrial cleaners, foaming agents and those in fire extinguishers. Conversely, pollution at the Earth's surface has led to increased levels of tropospheric ozone, particularly over industrial areas, with consequent threats to human health. No other chemical in the troposphere has a concentration which is so close to being toxic.

(30) *Different wavelengths of Envisat instruments.*



Sensor	Product Type
GOMOS	Vertical concentration profiles of O_3, NO_2, NO_3, O_2, H_2O, (OClO and BrO during ozone hole conditions), aerosol extinction coefficients, temperature, atmospheric turbulence, polar stratospheric clouds, (noctilucent clouds).
MIPAS	Vertical concentration profiles of around 20 relevant trace gases including primary species: O_3, H_2O, CH_4, N_2O and HNO_3, also temperature, distribution of aerosols, tropospheric cirrus and stratospheric ice clouds (including polar stratospheric clouds).
SCIAMACHY	Vertical concentration profiles of - in the troposphere: O_3, O_4, N_2O, NO_2, CO, CO_2, H_2O, CH_4, (HCHO, SO_2, in polluted conditions) in the stratosphere: O_3, O_2, O_4, NO, NO_2, CO, CO_2, H_2O, CH_4, volcanic eruption: SO_2 and Ozone hole conditions: OClO, ClO. Aerosol parameters, cloud measurements, pressure and temperature measurements.
MERIS	Aerosol optical thickness and type, cloud reflectance, cloud top height, water vapour column abundance.
AATSR	Cloud parameters: cloud type, water/ice discrimination and particle size distribution, aerosol distribution.
MWR	Water vapour and liquid water content of atmosphere.

Table 14. Atmospheric constituents measured by Envisat instruments.

The greenhouse effect, shown in Figure 29, concerns the warming of the troposphere by increasing concentrations of the so-called greenhouse gases (carbon dioxide, methane, nitrous oxide, ozone and others). This warming occurs because the greenhouse gases are transparent to incoming solar radiation, but absorb infrared radiation from the Earth that would otherwise escape from the atmosphere into space. The greenhouse gases then re-radiate some of this heat back towards the surface of the Earth. The rise in carbon dioxide as a result of industrialisation, is primarily responsible for the enhanced greenhouse gas effect. Current carbon dioxide levels are more than double pre-industrial levels and are the focus of international efforts to reduce emissions and offset the consequences of changed climate patterns, sea level rise, effects on hydrology, threats to ecosystems and land degradation.

The amount of water vapour in the atmosphere is an important component of the Earth's climate system. It varies considerably in response to variations in temperature and relative humidity and acts as an energy carrier, redistributing energy around the planet. Water vapour has a large radiative effect and is the most important greenhouse gas. Water, in the form of clouds, liquid or ice, modifies the radiation reaching the surface and thereby strongly influences the surface energy flux. The role of clouds in the climate system is poorly understood and this undermines the overall validity of modelling and prediction activities. Research into the influence of water vapour and clouds is needed in order that anthropogenic effects can be isolated from long term natural climate variations.

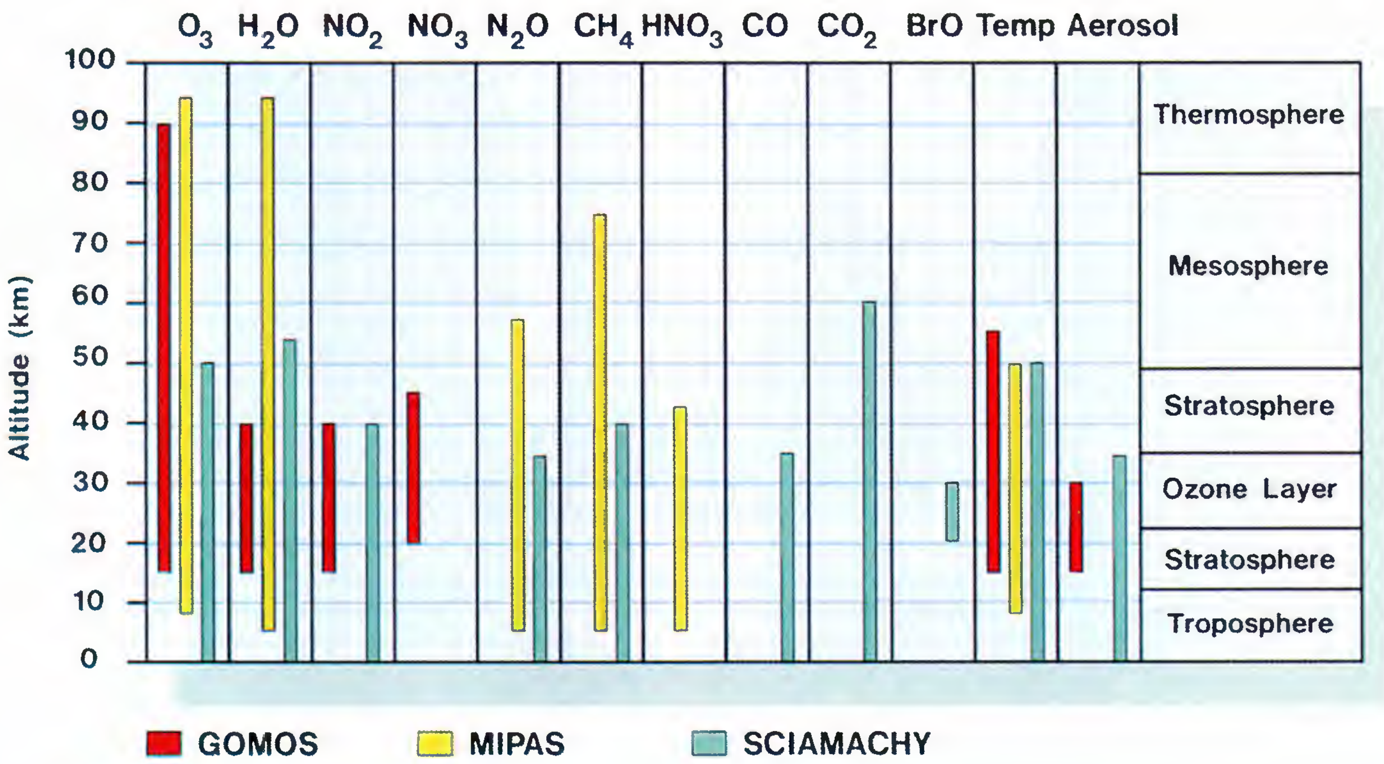
The rising concentration of methane in the atmosphere since the beginning of the 19th Century is mainly due to changing agricultural practice, waste disposal, deforestation and mining. About 80% of the gas is produced by decomposition in rice paddies, swamps, the intestines of grazing animals and by tropical termites. The levels of methane have risen by 11% since 1978. The oxidation processes, which remove methane from the atmosphere, can be impaired by other emissions, principally those of man-made carbon monoxide, but also by natural hydrocarbons from plants. Up to 40% of the rise in methane concentration is ascribed to this reduction in the natural rate of its chemical decay.

Three instruments on Envisat (GOMOS, MIPAS and Sciamachy) are dedicated to providing information about the atmosphere, but others (MERIS, AATSR and MWR) also contribute. Figure 30 provides a comparison of these instruments in terms of the wavelengths at which they acquire data.

The interaction of individual gas species in the atmosphere with incoming solar (or stellar) radiation takes place at specific wavelengths within the electromagnetic spectrum. The fact that the shapes of these absorption features and the wavelength regions where they occur are different for each molecule, is the feature which is exploited in producing the required data. The effectiveness of the instruments is strongly influenced by their spectral resolution and the strategies adopted to acquire data from the atmosphere; supported by a high emphasis on calibration.

Table 14 provides a list of atmospheric constituents which can be measured by each of the instruments. A particular strength is the emphasis on providing measurements of atmospheric constituents according to altitude, which is more valuable for understanding the processes involved than total column measurements.

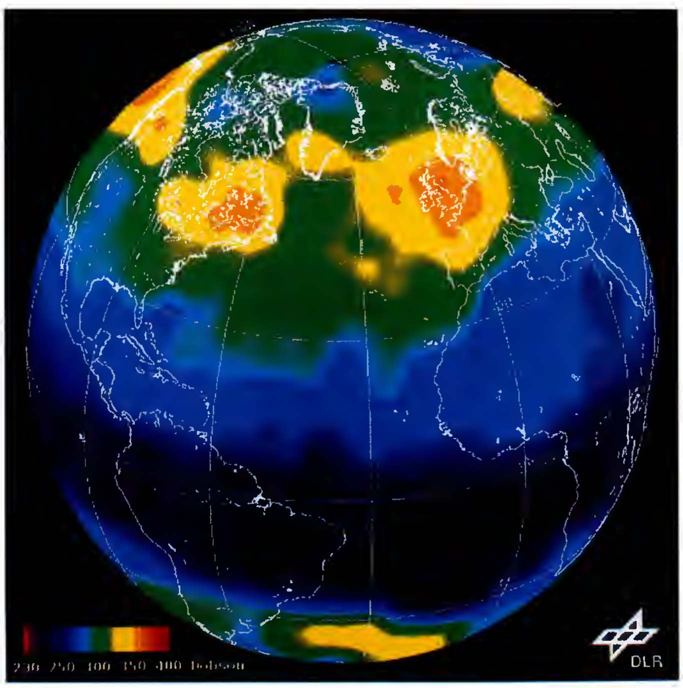
Figure 31 shows the altitude ranges over which the different constituents will be measured by GOMOS, MIPAS and Sciamachy, and also illustrates the extent of the overlapping coverage. The presence of multiple atmospheric sensors on Envisat provides the opportunity for mutual geophysical validation activities and the generation



(31) *Altitudinal ranges over which the different atmospheric constituents are measured by GOMOS, MIPAS and Sciamachy.*

of high-quality and long-term datasets which can be used with confidence for studying changes in the structure and composition of the Earth's climate.

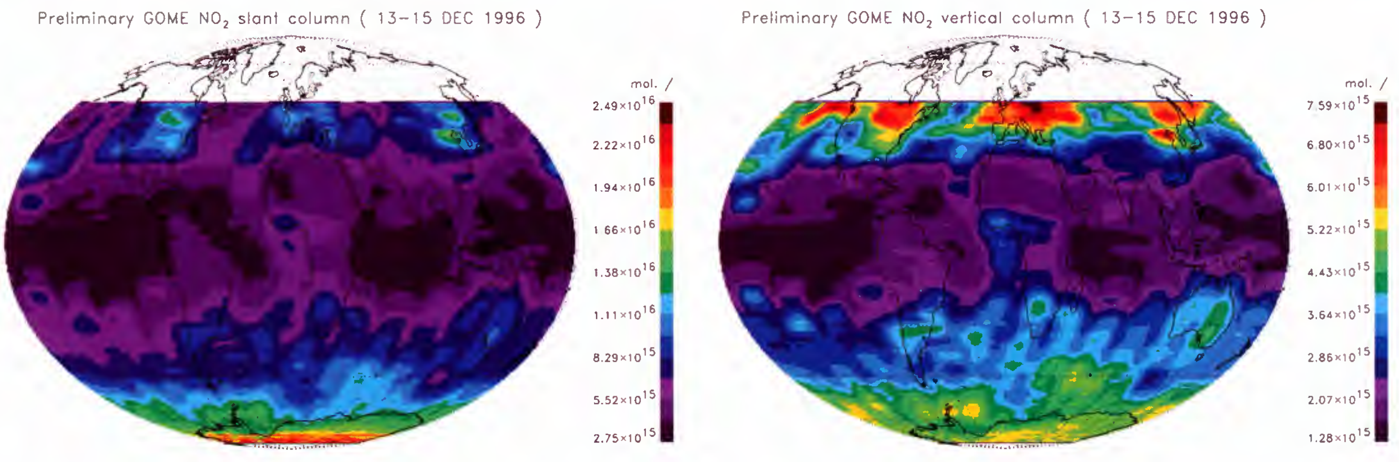
Whilst a large amount of research effort is focused on the issue of ozone depletion, it is not realistic to dissociate this from other chemical and physical processes in the stratosphere. The distribution and concentration of water vapour, for example, is directly related to ozone destruction. The reduction of the concentration in the ozone layer in the upper atmosphere, which protects living cells from UV-B radiation, has provided the clearest example of the impact of anthropogenic activity on the Earth's atmosphere. Prior to this, a state of natural equilibrium had been achieved within the biosphere. One of the results of this process was the production of a stratospheric ozone layer providing protection from the Sun's harmful ultraviolet radiation.



(32) *Global map derived from GOME data (5-7 July 1996). (Courtesy DLR Oberpfaffenhofen).*

Figure 32 shows a global map from GOME and provides an indication of the type and quality of data which will be acquired from Sciamachy.

In order to model the ozone destruction processes, it is important to relate the measurements to altitude. Total column measurements have value with regard to the amount of harmful UV radiation reaching the ground surface. However, vertical profiles of ozone concentration are needed to derive information about the creative and destructive processes involved. The main atmospheric sensors on Envisat will routinely provide data on constituents, resolved by height with vertical resolutions between 1.7 and 3 km.



33 *Global NO_2 levels derived from GOME measurements. (Courtesy: R. Hoogen, IFE, Bremen, Germany).*

It is also clear that the limb sounders onboard Envisat will provide data in much better vertical resolution than GOME, which is limited to nadir viewing.

GOMOS, MIPAS and Sciamachy all produce data relevant to stratospheric chemistry, including the detection of those chemicals involved in ozone depletion and the presence of associated phenomena such as polar stratospheric clouds.

Monitoring the troposphere provides further insights into the nature of human interaction with the atmosphere. Critical issues within the troposphere include the description of cloud types, temperature profiles, water vapour profiles, amounts of methane and other man-made pollutants released.

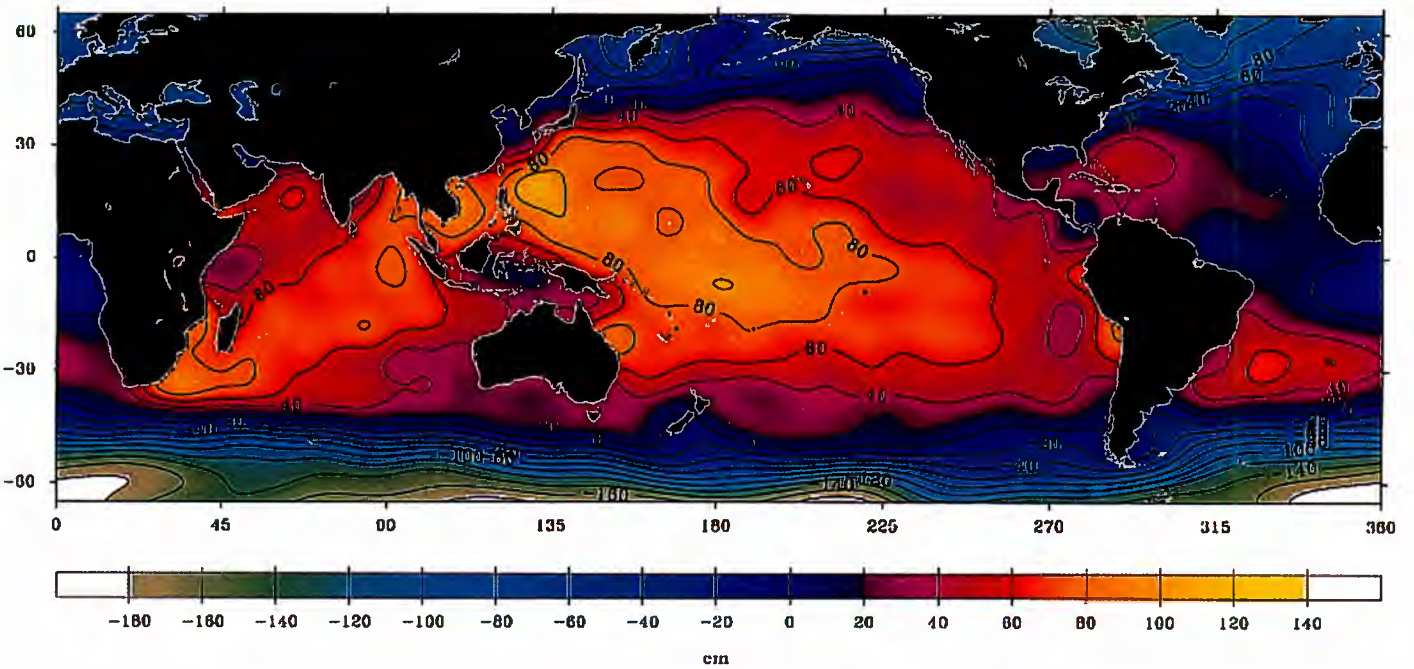
In the lower troposphere, increase in ozone is a major concern, brought about by increased levels of nitrogen oxides and hydrocarbons. Whilst mostly associated with industrial activities in the northern hemisphere, elevated tropospheric ozone levels also occur in the Southern Hemisphere as a consequence of biomass burning. Although it is clear that the levels of carbon and nitrogen in the atmosphere are increasing as a result of man's activities, more information is needed to help model the processes involved. Such information will provide support for a variety of studies including, for example, the effect of higher levels of carbon and nitrogen in the atmosphere on plant growth, due to increased atmospheric fertilisation. Figure 33 shows global NO_2 levels derived from GOME measurements.

Sensors onboard Envisat will provide information about clouds, temperature and pressure, in support of data produced by operational meteorological satellites. The provision of near real time data is especially relevant in this context. Data from Envisat sensors will contribute to medium term forecasts through the incorporation of these data into operational models.

MIPAS will provide data relevant to upper tropospheric chemistry and will support the analysis of NO emissions from aircraft exhaust in air corridors. Sciamachy is a particularly capable instrument for acquiring data from the lower part of the troposphere and has the potential to detect biomass burning, biogenic emissions, pollution incidents over populated regions, production of oxides of nitrogen by lightning, Arctic haze, forest fires, dust storms and industrial plumes. In nadir viewing, O_2, O_4, and CO_2 absorption will provide estimates of cloud top height.

There is evidence to suggest that in recent decades there have been long term changes in aerosol loading in the stratosphere. For example, amounts of sulphate aerosol in the stratosphere increased significantly in 1991 and 1992 as a result of the 1991 eruption of Mount Pinatubo. GOME data have been analysed to produce estimates of SO_2 loading of the atmosphere, for example from the eruption of the Nyamuragira volcano in Zaïre. Whilst there is a good relationship between the degree of aerosol loading and volcanic events, an upward trend has been detected in background levels.

The impact of aerosols on the Earth's radiation budget is both direct, through scattering and absorption, and indirect, through the modification of cloud properties. In both cases, aerosols in the stratosphere seem to have a cooling effect with regard to the Earth's radiation budget. Sulphate aerosol loading in the mid-latitudes has also been correlated with ozone trends in mid-latitude and polar regions, through a modification of the concentration of gases involved in ozone depletion. However, the extent to which aerosols influence the Earth's climate has been difficult to assess since aerosols vary a great deal in terms of size, shape and chemical composition. Satellite borne sensors have the potential to improve knowledge of the origin, dynamics and fate of aerosols, through their ability to monitor the whole globe within very short data capture repeat cycles. Critical to the determination of aerosol types is the wavelength dependence of extinction coefficients in the visible and near infrared parts of the spectrum.



(34) *Global ocean topography derived from ERS-1 RA data. (Courtesy B. Tapley & C. Shum, Univ. of Texas at Austin, USA).*

The use of space-borne instruments to measure aerosols in the stratosphere is well established. The SAGE (Stratospheric Aerosol and Gas Experiment) series of instruments have demonstrated the concept and share features with the atmosphere sensors onboard Envisat, with GOMOS in particular. Several of the instruments onboard Envisat will be capable of making aerosol measurements with sufficient spectral coverage to determine size distribution and composition. GOMOS and MIPAS will make observations of the distribution and structure of the stratospheric aerosol layers. Moreover, the ability of MIPAS to acquire data perpendicularly to its flight direction, will strengthen its ability to record aerosol injections into the stratosphere from volcanic eruptions. Sciamachy will provide further information about aerosols through its ability to make polarisation measurements, and its large spectral coverage. MERIS has the capability to evaluate aerosol properties including aerosol path radiance, optical thickness and type. Data from ATSR-1 and -2 have been used to map stratospheric aerosol distribution and this capability will continue with AATSR.

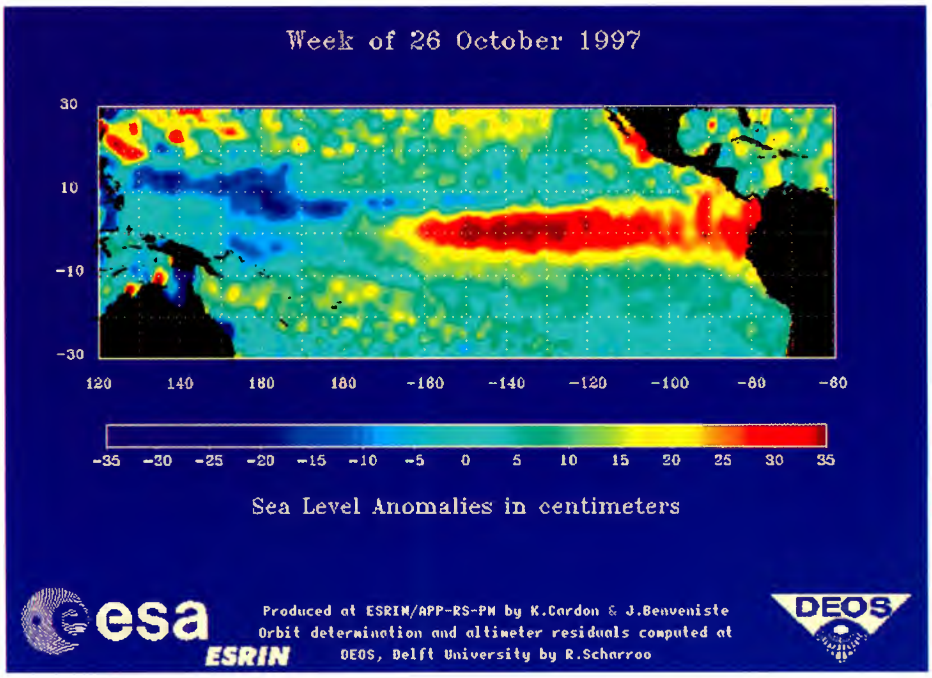
Oceans

The ocean exerts a major influence on the Earth's meteorology and climate through its interaction with the atmosphere. Understanding the transfer of moisture and energy between ocean and atmosphere is therefore a scientific priority. Better observations are needed, to improve the accuracy of forecasts for weather, marine conditions and climatic change.

Earth observation satellites have revolutionised the study of the ocean. They now provide detailed repetitive measurements over remote areas of the world, where previously there were only a limited number of (isolated) observations from ships and buoys. Microwave instruments, including SARs and radar altimeters, have a remarkable sensitivity to the roughness and height of the ocean surface, enabling the detection of ocean currents, fronts and internal waves, oil slicks and ships, as well as accurate measurement of sea level changes, wave height and wind speed. Optical instruments provide measurements of ocean colour and temperature, which are important indicators of phytoplankton, yellow substance (Gelbstoff) and suspended sediments.

Envisat, by including advanced SAR, radar altimeter, ocean-colour and ocean-temperature instruments together on the same platform, offers particularly exciting opportunities for synergetic measurements over the oceans. It will provide an improvement in measurement capability compared with ERS, together with possibilities for many new geophysical measurements. The simultaneous combination of MERIS ocean-colour measurements with both AATSR sea-surface temperature, and ASAR sea-surface roughness is particularly promising.

Our knowledge of the ocean's central role in modifying climate, through its large heat capacity and transport mechanisms and the complexity of its interactions with the atmosphere and cryosphere, is insufficient for the accurate prediction of climate change (as a result of fluctuations in natural or anthropogenic forcings). For example, it is known that at least half of the excess energy input (i.e. the incoming solar radiation minus the infrared radiation to space) in tropical areas is carried towards the poles by the oceans, the other half being transported by the atmosphere. Quantitative estimates are coarse however and predictions of how such fluxes would be modified by



35 *Sea-level anomalies observed by ERS-2 Radar Altimeter during the strong El Niño event in 1997 (Courtesy P. Scharro, Delft University of Technology and K. Cardon & J. Benveniste, ESRIN).*

'enhanced greenhouse forcings' are even coarser. The World Climate Research Programme (WCRP) includes very large oceanographic research programmes, such as WOCE and CLIVAR, focusing on this issue.

These programmes rely heavily on the availability of satellite altimetry data such as provided by the Geosat, Topex/Poseidon and ERS-1/2 missions. Figure 34 shows global ocean topography data derived from ERS-1. Several satellites, operating in unison, allow the very precise, regular and quasi-global measurement of dynamic sea surface heights.

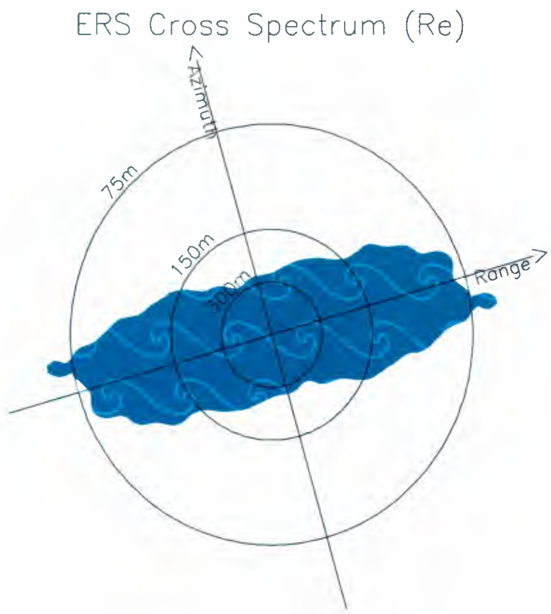
As most changes in ocean surface currents which have timescales of a few days or longer result in geostrophic balance, gradients of the sea surface 'dynamic topography', (i.e. the sea level above the geoid) as derived from radar altimetry can be employed almost directly as proxy surface current information. Unlike *in situ* measurements, altimeter measurements are global, synoptic and can be repeated for many years, and they are related to ocean processes and currents within the whole water column. They can also be assimilated directly into ocean and climate numerical models. During the last decade, the technique of radar altimetry has become fully developed, enabling routine, very precise, quasi-global measurements of sea level to be obtained. Analysis of almost 4 years of Topex/Poseidon and ERS altimetric data has provided observations of the ocean dynamic topography at an absolute accuracy of 3-4 cm [*Le Traon, Mitchum*].

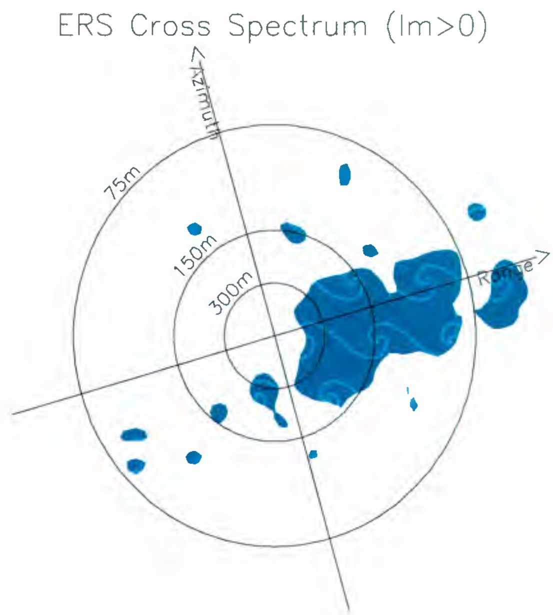
One important practical application concerns the study of the El Niño Southern Oscillation phenomenon in the Pacific Ocean. Figure 35 shows an excellent example of how centimetric sea-level anomalies observed by the ERS-2 Radar Altimeter have detected an El Niño event. Normally the effect of the easterly trade winds is to produce a higher sea level on the western side of the Pacific, with an associated strong upwelling of nutrient-rich cold waters on the eastern side. However, during an El Niño event, the trade winds weaken, there is an eastwards flow of warm surface waters, a rise in sea level by up to 30 cm on the eastern side and an interruption in the upwelling of nutrient-rich waters. Fish die or migrate to higher latitudes and rainfall patterns change dramatically, causing heavy rain and floods on the west coast of South America and drought in Australia and Southeast Asia.

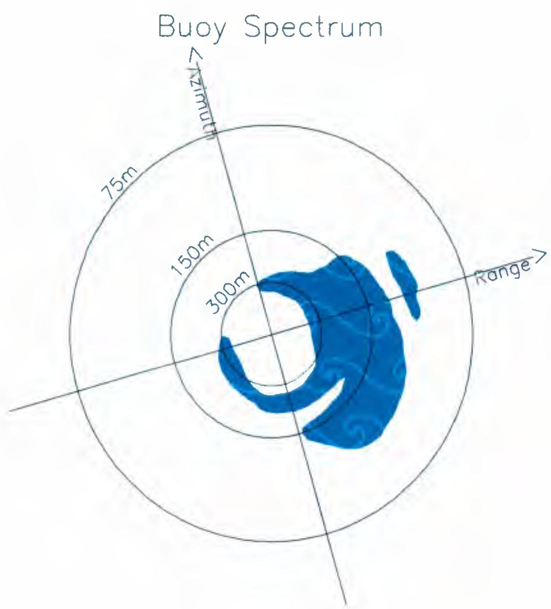
As far as data assimilation is concerned, model error statistics are essential in order to perform reliable predictions. In order to estimate these, models must be run for long periods (i.e. 10 years or more) and with a continuous data flow. It is therefore essential that continuity of the high-precision altimeter systems is ensured.

It is not possible to optimise the sampling of any single satellite mission to observe all oceanic processes and regions. The sampling problem must be thought of in terms of complementarity. The overlapping of ERS-1/2 on a 35-day orbit, and the 10-day orbit of Topex/Poseidon in 1993 and from 1995, provides such an example: the mesoscale features and high-latitude areas are adequately observed by the former, but the latter provides better coverage of the fast-varying tropics, large-scale disturbances and western boundary currents. The coverage provided by the ERS RA and the Envisat-1 RA-2 altimeters will continue to be vital for the study of mid-latitude mesoscale eddies and the impacts of high-latitude ocean and ice on seasonal and inter-annual climate predictability.

The RA-2 instrument offers improved measurement accuracy in comparison with the ERS RA, particularly with the improved tracker and through the use of DORIS data for more precise orbit determination. The second frequency channel at 3.2 GHz will enable height measurement corrections of the ionospheric effects on the signal. The near real-time products will include both this ionospheric correction and the tropospheric path correction using measurements from the MWR. Measurement accuracy after all geophysical corrections will be better than 3 cm in ocean mode.







36 *Simulated ASAR wave mode spectrum. (Courtesy NORUT IT, Norway).*

Major features of the interaction between the ocean and the atmosphere are the creation of waves and ocean currents by surface winds. Wind and wave data are needed for climatological research, as inputs to meteorological models and for sea state forecasting in support of marine operations.

Envisat has two instruments, ASAR and RA-2, which will provide observations of surface waves and winds over the ocean. The ASAR wave mode will collect imagettes of minimum size 5 x 5 km, similar to the ERS AMI wave mode, spaced 100 km along-track in either HH or VV polarisation. The position of the imagette across track can be selected to be either constant or alternating between two across-track positions over the full swath width.

ERS wave mode products are based on image spectra (frequency and direction) estimated from SAR intensity imagettes using standard Fourier transform techniques. These products are therefore symmetric, with a 180° propagation direction ambiguity. Techniques have been developed involving the use of wave model predictions to solve the ambiguity problem, though this can be subject to error when opposite or near opposite wave components exist.

For ASAR, this problem will be solved by using a new wave product preserving the phase and a new algorithm called 'inter-look cross spectral processing', whereby information on the wave propagation direction is computed from pairs of single-look images separated in time by typically a fraction of the dominant wave period. Figure 36 shows a simulated ASAR wave mode Spectrum, with the top left plot being the cross spectrum real part (symmetric and equivalent to an ERS product), and the top right plot the new imaginary part (asymmetric giving wave propagation direction). In this example, the output from the new algorithm is seen to correspond with the wave direction provided by buoy measurements, as shown in the lower plot.

Recently, investigations have shown that it is possible to derive wind speed estimates from SAR, in particular when wind directional patterns such as wind streaks are visible in the images. The ASAR global monitoring mode is of interest in this respect because of the large area coverage and the frequent revisit.

The RA-2 will provide a measure of the significant wave height through the distortion of the mean shape of the return pulse and an estimate of the wind speed based on its intensity. The earlier return from the wave crests and the retarded return from the wave troughs leads to a broadening of the return pulse which can be directly related to the significant wave height. In order to determine the mean pulse shape, several hundred pulses need to be averaged, giving one wave height measurement about every 7 km along the satellite track.

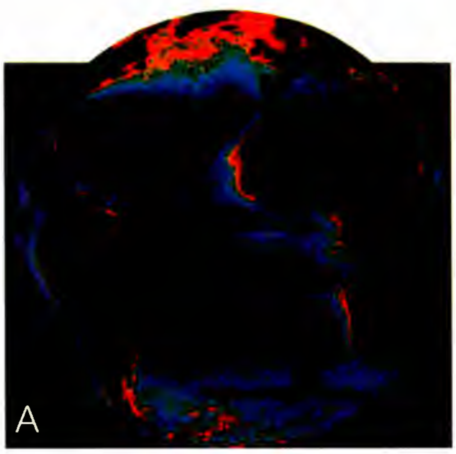
The wealth of wave height data available from the ERS RA has had a large influence on wave modelling, and has also stimulated the development of wave height assimilation techniques. One of the principal motivations for developing the third generation wave model (WAM) was to provide a state-of-the art model for the assimilation of global data from satellites for improved wind and wave field analysis and forecasting. Presently, the WAM model is in use at a number of meteorological centres (NCEP, Washington; FNMOC, Monterey; BMRC, Melbourne; ECMWF, Reading; DNMI, Oslo) and altimeter wave height data are assimilated at UKMO, Bracknell and at ECMWF, Reading.

Sea-state forecasting for ship routing has been an important commercial application of ERS data, and this will continue, using data from the RA-2 and ASAR.

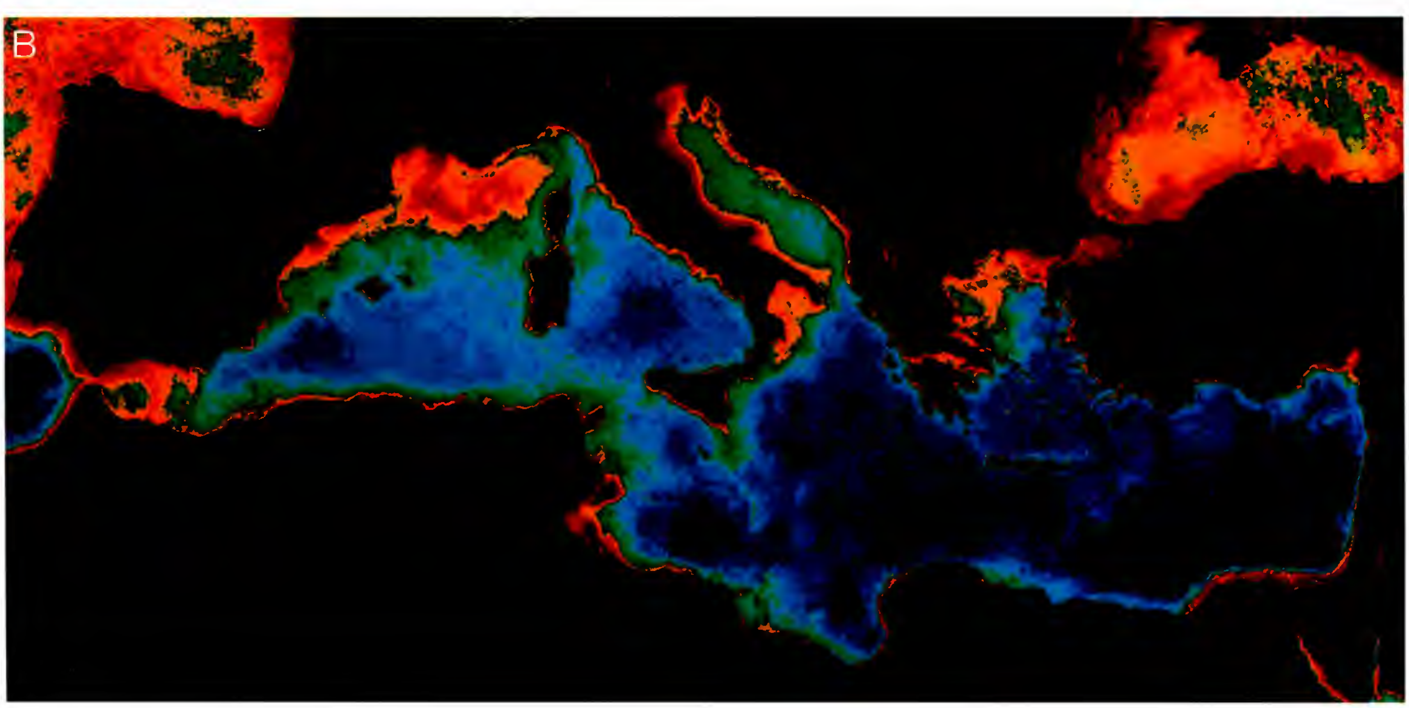
There remain major uncertainties about the amount of carbon stored in the ocean and the biosphere, and about the fluxes between these reservoirs and the atmosphere. In particular there is an important need for better information on the spatial distribution of biological activity in the upper ocean and its temporal variability, especially in the case of oceanic phytoplankton biomass, which has an important role in fixing CO_2 through photosynthesis. In the upper layers of the open ocean, chlorophyll concentration is the most convenient index for phytoplankton abundance and this can be measured using the visible part of the spectrum.

It is of paramount importance to estimate the basin and global-scale variability in the concentration of chlorophyll in the upper ocean. The images of the global distribution of these pigments, derived from data taken by the coastal zone scanner (CZCS) on board the US Nimbus-7 spacecraft, have revolutionised the way biological oceanographers view the oceans. For the first time, the blooming of the ocean basins in spring has been observed, as has the extent of the enriched areas associated with the coastal ocean." (see IGBP Report No. 12: *A study of Global Change*, 1990).

Although CZCS, launched in 1978, was intended as a one-year proof-of-concept mission, the sensor continued to transmit data over selected oceanic test sites until early 1986. Figure 37 shows examples of CZCS chlorophyll maps of the Earth and of the Mediterranean Sea.



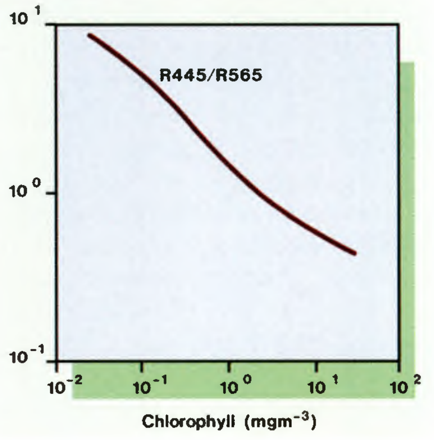
(37) *CZCS chlorophyll maps of the Earth (A) and of the Mediterranean Sea (B). (Courtesy ESA/JRC Ocean Project).*



Remotely sensed information about global ocean colour is now again available, firstly from the OCTS instrument on the Japanese ADEOS mission, from the NASA SeaWifs satellite launched in August 1997 and from the MOS instrument on IRS-3. MERIS will provide data continuity with improved spectral and spatial performance. This results from the use of several near infrared channels to perform atmospheric corrections and several narrow visible channels to compute radiance values.

Phytoplankton abundance varies from less than 0.03 mg/m^3 in oligotrophic waters (i.e. waters poor in nutrients and therefore in phytoplankton), up to about 30 mg/m^3 in eutrophic waters (i.e. in nutrient rich waters, supporting high biomass). Ocean colour responds in a non-linear way to these large changes in chlorophyll content. It is conveniently depicted by the ratio of blue to green radiation backscattered by the ocean, with the ratio which is most sensitive based on wavelengths of 445 and 565 nm. It varies within a range of 1 to 20 for the types of pigments considered, and decreases, almost linearly, with the logarithm of the concentration (Fig. 38).

The design of MERIS is driven by the radiometric, spectral and spatial requirements of ocean colour observations, with the aim of identifying 30 classes of pigment concentration over the naturally occurring range. However, since the radiances recorded at the satellite within the visible part of the spectrum are dominated by the atmospheric signal associated with Rayleigh and aerosol scattering and the contribution of the water-leaving radiance to the signal amounts to a few percent in most cases, the sensitivity is essentially determined by the aerosol load. The atmospheric correction is based on the data from several IR channels, and an extrapolation of this estimate towards the shorter wavelengths. This extrapolated atmospheric contribution is then subtracted from the total signal recorded by the sensor, to obtain the water signal.



38 *Ocean colour as a function of chlorophyll content.*

MERIS will provide global coverage every three days. Over the oceans it will be operated in a reduced resolution (RR) mode, acquiring data at 1200 m resolution at the sub-satellite point, with a swath of about 1150 km. If higher spatial resolution is required a 300 m full resolution (FR) mode is available, which is aimed primarily at coastal water and land studies.

The **coastal regions** are the most populated areas in the world and coastal waters are highly affected by human activities. These marine ecosystems are subject to bio-geochemical forcing, due to the influx into the coastal seas of pollutants from rivers and the atmosphere, which inhibit or stimulate marine productivity. In addition, large amounts of agricultural and industrial pollutants and sewage are discharged into these waters.

Continuous long-term observations of coastal waters, which cover more than three million square kilometres, is most important for climate impact studies and for environmental monitoring. Remote sensing measurements from satellite are the only available means for providing us with a synoptic view of such large areas of water.

The major water constituents, which determine the marine and estuarine ecology and the bio-geochemical budget and whose concentration and distribution can be determined by optical remote sensing, are suspended matter, phytoplankton and Gelbstoff.

Suspended matter is defined as a combination of:
- inorganic particles and detritus, present due to re-sedimentation and advection processes
- atmospheric inputs
- dead material of plankton

Gelbstoff consists of various polymerised dissolved organic molecules which are formed by the degradation products of organisms. These originate in brackish and underground water as well as in extraordinary plankton blooms. All these constituents have different optical properties, but there are similarities in their spectral scattering and absorption coefficients.

The upward radiance at any visible wavelength is composed of contributions from all these substances. Suspended matter usually enhances the upward radiances through reflection within the visible spectrum, while Gelbstoff reduces these radiances mainly in the blue.

To convert from the optical properties of the water constituents, used in the radiative transfer model, to pigment or suspended matter concentration units, robust algorithms have been developed with global applicability. The accuracy of derived oceanic properties depends strongly on the precision of the atmospheric correction procedure.

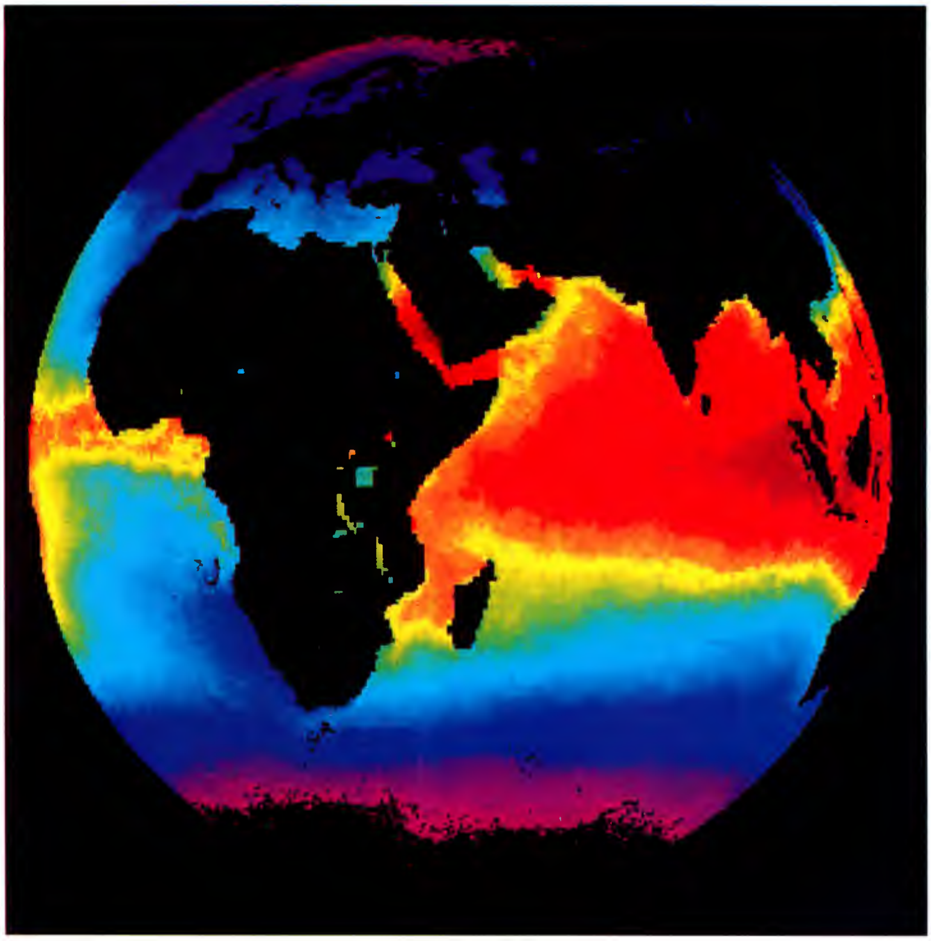
The development of inverse modelling techniques for the interpretation of MERIS measurements is an ongoing process. For monitoring coastal regions world wide, precise multispectral radiances, with contemporary optical and concentration measurements of the water constituents, are needed. As well as the chlorophyll concentration and several atmospheric parameters, planned geophysical products include total suspended matter and yellow substance concentration.

Sea-surface temperature (SST) is a sensitive indicator of global climate change. This is due to the thermal inertia of the oceans, which has the effect of damping out short-term variations in the climate. In order to capitalise on the oceans as an indicator of climate change it is necessary to acquire global measurements of SST to a high level of accuracy and compile these over a long period of time, e.g. a minimum of 10 years. The ATSR series of instruments which have flown on ERS-1/2 and now on Envisat as AATSR, provide both the necessary accuracy, within 0.3 K, and the long-term data continuity (Fig. 39).

The contribution of AATSR data has to be seen in the context of the collection of SST measurements which have been compiled over the past 150 years using a variety of measurement techniques. AATSR data provide the opportunity to validate existing models using an unbiased external source and thereby increase the confidence which can be placed in long-term assessments of climate change.

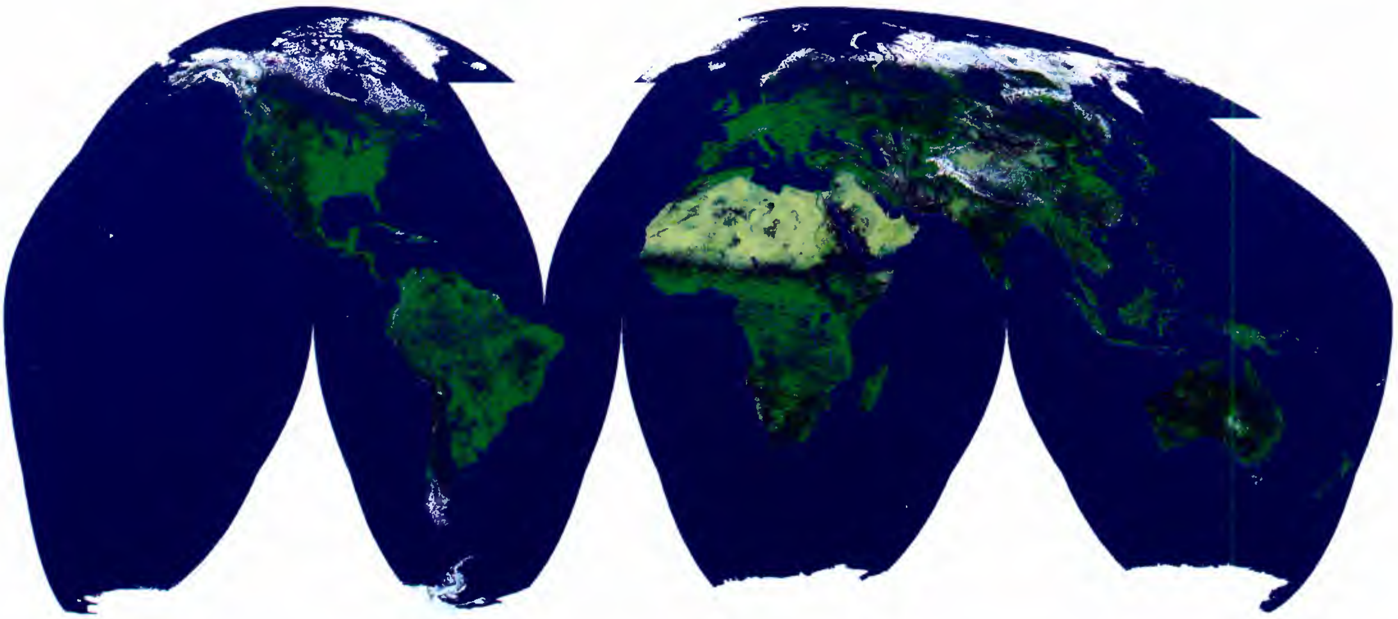
Interactions between the atmosphere and the circulation of currents around the globe involve the transfer of vast amounts of energy which can only be effectively monitored by remote sensing from space. AATSR will continue to increase knowledge of the processes reflecting the way in which the oceans, as reservoirs of heat, dominate the weather systems which are critical to life on the planet. A good example is the El Niño anomaly in the tropical east Pacific, where a change in atmospheric circulation is reflected in the pattern of SST distribution in this area. In addition to changes in the local and global climate, there are more specific impacts of El Niño, for example, the way the economic life style of populations in adjacent countries is affected through the wholesale displacement of fishing grounds. The accuracy of AATSR data makes it a unique source of information for this type of research.

Sea surface temperature information helps resolve many phenomena associated with the ocean circulation, such as mesoscale eddies, meanders, coastal currents and up-welling.



(39) *One year average of sea surface temperature derived from ATSR (Courtesy RAL, UK).*

AATSR data are applicable to research into fishing as a global source of nutrition for an ever expanding human population. The propensity of fish to be found at fronts between warm water and cold upwelling water containing food sources, demonstrates the value of SST measurements derived from AATSR. Moreover, the analysis of SST trends can be of assistance in deriving information on the migration of marine species. Pre-operational fishery support systems have been developed, for example ESA SeaShark for processing SeaWiFS and AVHRR data.



40 *Global land cover map derived from 1-km AVHRR data. (Courtesy IGBP Global Land Cover Project).*

Land

The Earth's land surface is a critical component of the Earth system as it carries over 99% of the biosphere. It is the location of most human activity and it is therefore on land that human impacts on the Earth are most visible. Within the biosphere, vegetation is critical as it supports the bulk of human and animal life and largely controls the exchanges of water and carbon between the land and the atmosphere.

Observations of the land surface by Envisat will allow the characterisation and measurement of vegetation parameters, surface water and soil moisture, surface temperature, elevation and topography. Global scale measurements (1-km resolution) will provide critical datasets for improved climate models, in particular estimates of albedo, vegetation productivity and land surface fluxes.

Envisat also provides managers of local natural resources with a capability to monitor their land with detailed (selective) observations on a monthly basis. In particular, ASAR provides 30-m spatial resolution multi-look images for monitoring economically important land units, such as agricultural fields and forest compartments. Natural resources can also be monitored at global and regional scales every few days using the low resolution imaging of MERIS, AATSR and the ASAR global mode.

The relatively high frequency of global coverage provided by Envisat is also of great value for hazard monitoring, in which locally infrequent events such as earthquakes, volcanic eruptions, floods and fires, require intensive observation over short periods. The beam steering mode of ASAR (in conjunction with its independence from cloud and illumination conditions) will also permit (at least) 3-day repeat observation of certain localised events at high spatial resolution. Whilst locally rare, certain natural hazards are frequent events on a global scale, thus they can have substantial effects on climate, especially large vegetation fires and volcanic dust clouds. Hazard monitoring is therefore an important component of the Envisat mission.

A major scientific uncertainty in global change research is the cycling of carbon in the Earth system. It is well known that CO_2 contributes to the greenhouse effect and that over the last few centuries increased human activity, especially the burning of fossil fuels and deforestation, have resulted in an increase in the release of CO_2 into the upper atmosphere. Much of the estimated anthropogenic CO_2 emission cannot currently be accounted for, indeed there is an order of magnitude uncertainty in the global carbon budget. Critical to this carbon accounting activity is global vegetation monitoring. Figure 40 shows a global land cover product derived from 1-km AVHRR data. The narrow bands of MERIS will make it possible to derive more accurate global maps and more effective vegetation indices than have previously been available. From physically based vegetation indices it is then possible to retrieve key variables in modelling plant productivity (and thus carbon sequestration), surface-atmosphere gas exchanges and energy transfers at the land surface

The potential value of global monitoring mode is indicated by previous work carried out over land, using the ERS wind scatterometer at 50 km spatial resolution.

For local land-cover mapping, ASAR high-resolution products will continue the role already established for ERS SAR in complementing conventional optical images from other satellites, particularly under poor solar illumination conditions or in cloudy areas.

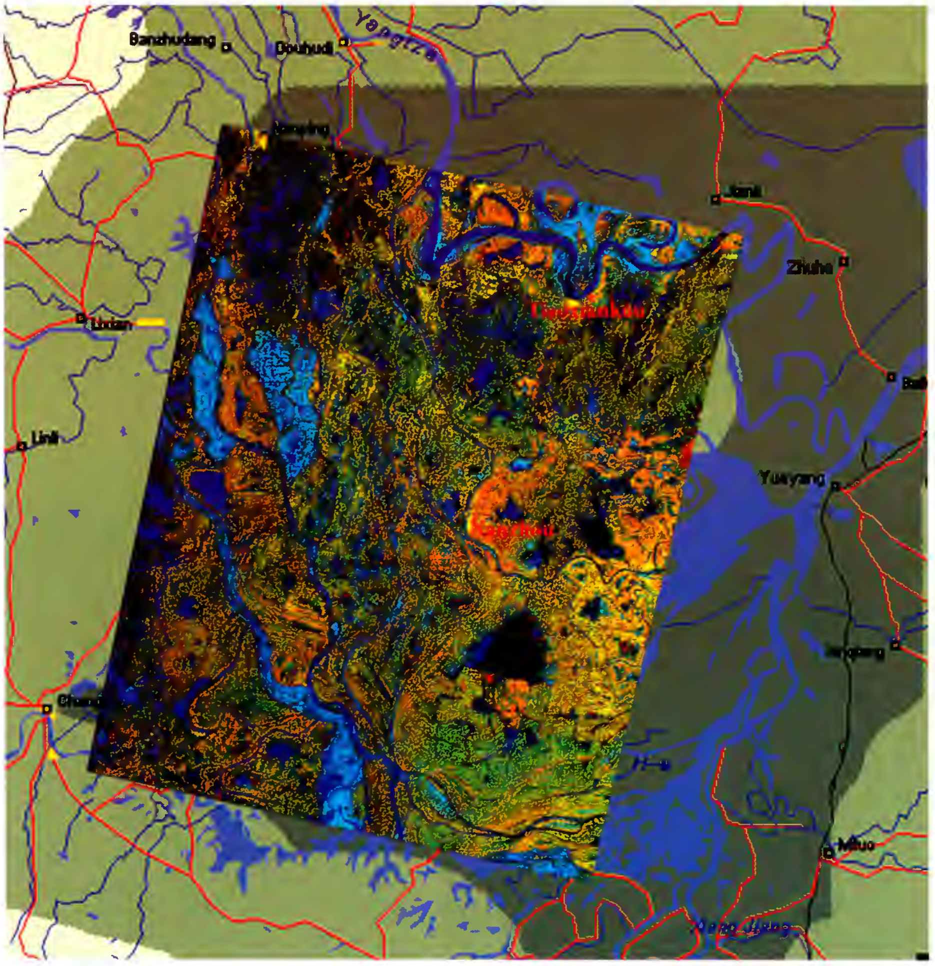
The new features of ASAR include image acquisitions at multiple incidence angles and with dual polarisation, which will open up new possibilities in land-cover classification from SAR.

Hydrology in particular will benefit from Envisat, as detailed spatial and temporal information on a wide range of land surface parameters is required in order to run physically based models and management scenarios (Fig. 41). Major variables which can be derived from Envisat observations include land surface temperature, vegetation state, soil moisture, surface roughness and terrain. Much hydrological modelling is based on gridded data at around 1 km. Because of its narrower bands and improved radiometry, MERIS may be better suited for providing vegetation parameters for hydrology than other instruments such as AVHRR. Some hydrological applications require information on snow cover distribution and snow-water equivalent. Research is required on how to derive these variables from ASAR data at high incidence angles, particularly in mountainous terrain.

Physical relationships link the land surface temperature (LST) to the evapotranspiration of vegetation canopies. Earth observation provides a unique source for global LST measurement.

It is expected that AATSR will make a significant contribution to the measurement of LST to the required accuracy of, typically, 1 K. The AATSR LST algorithm will rely only on nadir AATSR split window radiances

Envisat will have a range of capabilities for determining land surface elevation (ASAR and RA-2) as well as changes in elevation over time.



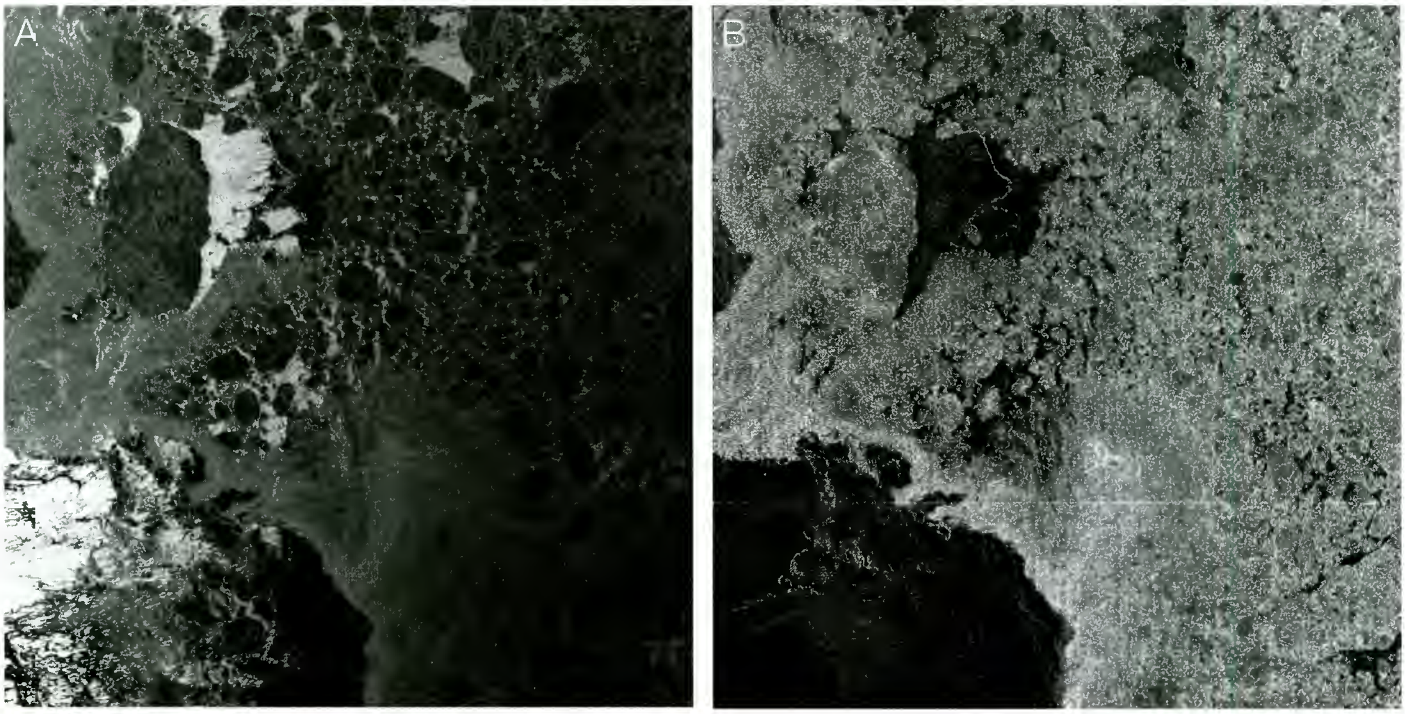
41 *Floods along the Yangze River in China in August 1998 as shown by ERS SAR multitemporal dataset (processed by DLR).*

Cryosphere

The ERS satellites have already proved the all weather capability of SAR and radar altimetry for collecting data at high latitudes and have, for example, produced the first reliable high-resolution coverage of sea ice regions.

The long-term monitoring of sea ice extent and thickness in Arctic and Antartic regions, provides a sensitive indicator of climate change. In addition, the seasonal and annual sea ice changes influence the Earth's albedo and fresh water cycle in the shorter term. It is necessary to monitor sea ice at a global level for climate change studies and also, more locally, to advance understanding of the processes involved. Information about sea ice is also required to satisfy operational needs for navigation, offshore operations and weather forecasting.

The Envisat sensors will ensure the continuity of data supply following on from those onboard ERS, with the exception of the scatterometer derived sea ice field. ERS has shown how SAR images can distinguish different ice types and map leads, polynyas, shear zones, landfast ice, drifting ice and the location of the ice edge. ASAR provides certain advanced capabilities which enhance its performance for sea ice monitoring. The lower resolution modes will open up new possibilities for applications requiring large area coverage and more frequent revisits. The sea-ice edge is also better determined using higher incidence angle data which are available from the ASAR. Wide Swath Mode and Global Monitoring Mode, will both provide near

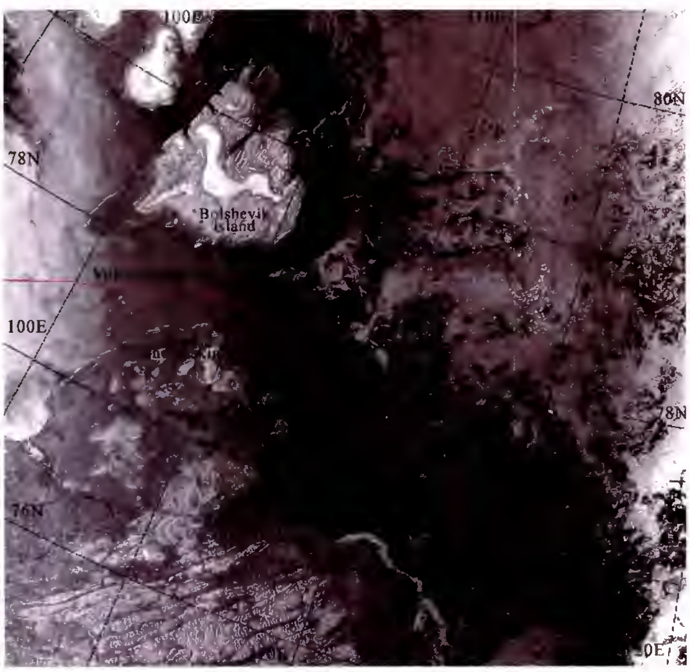


42 *Comparison of ERS-2 VV polarisation (A) and Radarsat HH polarisation (B).*

daily revisit capability of wide swaths (400 km) of sea ice in polar regions.

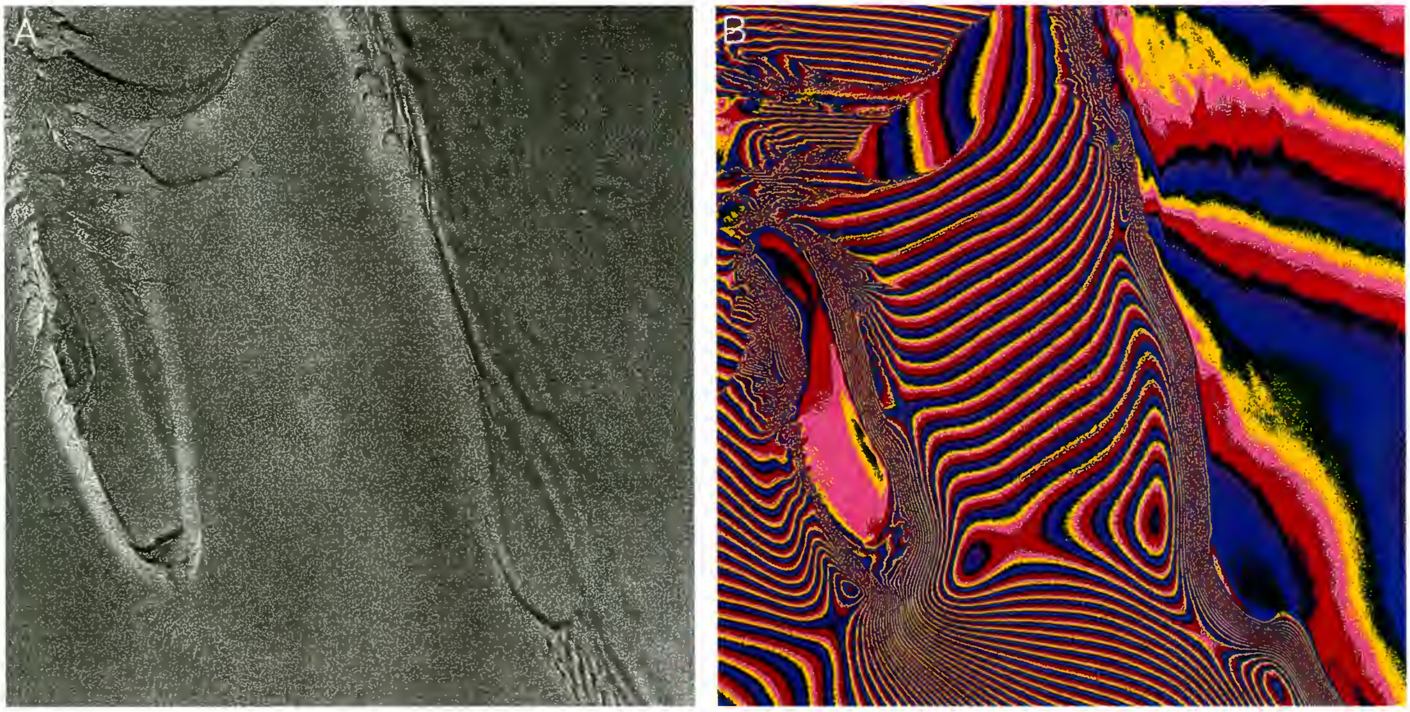
Research effort will be necessary to determine the optimum choice of polarisation for specific elements of sea ice monitoring. At present it is believed that cross polarisations (i.e. HV or VH) will be particularly useful for mapping ice topography (ridging and rafted ice) and that this mode is also likely to give improved ice type discrimination. As shown in Figure 42, comparisons between ERS (VV polarisation) and Radarsat (HH polarisation) have already demonstrated the different information content of the two channels which will be acquired simultaneously with ASAR.

Earth observation data in operational ice monitoring services. Operational demonstrations of the use of ERS and Radarsat data have been implemented for many ice covered regions. Individual ice floes and specific features can be recognised through analysis of consecutive SAR images. Advanced image processing and interpolation techniques can retrieve the motions of sea ice. This type of information will, together with meteorological data, provide the locations where leads may be expected to open or dense ice pack develop.



43 *Ship routing in sea ice along the Siberian coast with ship track shown in red. (Courtesy NERSC Bergen, Norway, Radarsat data, CSA 1997).*

The use of SAR images from satellites is playing an increasingly important role in operational sea ice monitoring. In 1995 the ICEWATCH project - the first joint project within Earth observation between the Russian Space Agency (RKA) and ESA - was initiated. The overall objective of the project is to implement satellite monitoring by combined use of ERS SAR, RKA Okean SLR and other remote sensing data, to support sea ice navigation in the Northern Sea Route, offshore industry and environmental studies (Fig. 43). The project also includes a plan for a SAR receiving station in Siberia. The rationale for the project was practical as well as scientific.



44 SAR interferometry results in monitoring ice sheet motion in the Antarctica. (A) ERS-1 SAR image showing the Ice Rise to the left and Berkner Island on the right. (B) Interferogram with the fringes generated by dynamic effects: rise and fall of ocean tide and seaward of the ice movement (toward top of the image). (Courtesy University of Stuttgart, Institut für Angewandte Geodäsie Frankfurt, Germany, and British Antarctic Survey, UK).

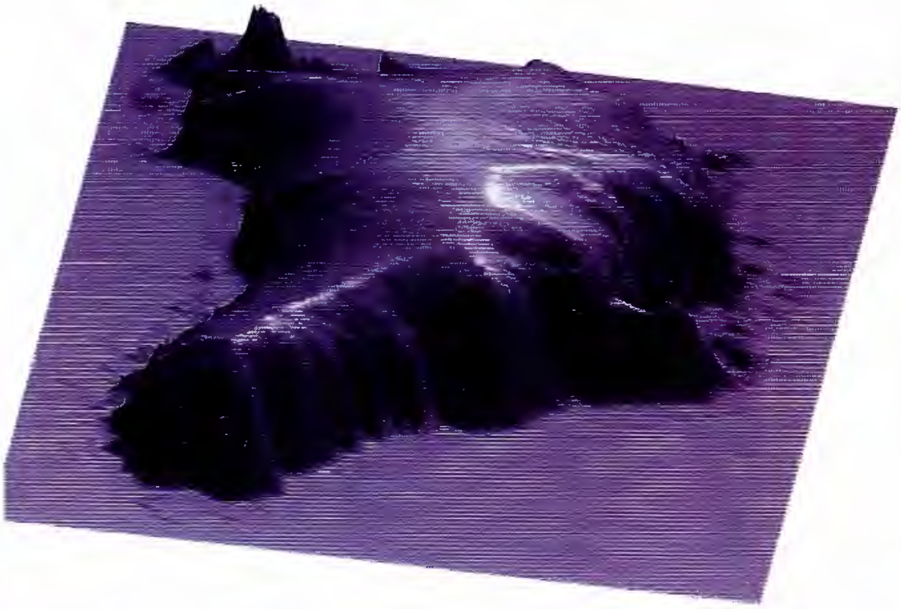
- Ships traversing the Northern Sea Route along the Siberian coast need good knowledge of ice conditions on a daily basis, as well as long term, for safe and efficient navigation.
- Oil exploration and production facilities in areas such as the Eastern Barents and the Kara Sea areas will require both reliable and timely monitoring and forecasts of sea ice behaviour.
- Fishing vessels need daily updating of accurate ice maps in order to operate in ice edge regions throughout the year.
- Monitoring of Arctic sea conditions is essential to provide an early indicator of global climate change, which is predicted to become most severe in polar regions.

The dual-frequency RA-2 not only provides data continuity with the ERS radar altimeters, in terms of measuring ice sheet elevation and extent, but also has new capabilities which make possible the more precise geographical determination of sea ice margins. This is achieved principally through autonomous selection by the instrument of the tracking window. When the radar echo is about to move out of the tracking window, due to a change in land surface elevation, the window is broadened to re-capture it. This enables the uninterrupted collection of data over the boundaries between different surfaces.

Change in the global sea level is related to climate change and global warming. The contribution of polar ice sheets to changes in sea level continues to be an area for research, elements of which are focusing on time series measurements of changes to floating and grounded ice in Antarctica and Greenland. Models have been constructed which relate the state of the polar ice sheets to climatic parameters. These attempt to determine how future climate change will cause the polar ice sheets to grow or shrink, and include allowances for the feedback from the changing ice sheets in terms of their influence on the atmosphere and ocean.

Models are also used to predict changes in sea level, salinity and global circulation as a result of ice sheet change. Ice sheets that are grounded below sea level are particularly sensitive to changes in mass balance. Retreat of floating ice shelves in front of the grounded ice may accelerate the mass transport across the grounding line and thus initiate a disintegration process. In order to improve the level of knowledge it is necessary to collect long term data sets describing ice sheet elevation, ice sheet dynamics, change of mass flux across the grounding line and surface properties (snow cover, ablation, melt line and ice-free areas).

Within the ERS programme, multi-temporal sequences of SAR images and radar interferometric techniques have provided a completely new dimension for studies of ice dynamics, enabling flow velocity fields to be derived. For example, Figure 44 shows SAR interferometry results monitoring ice sheet motion in Antarctica. The mapping of ice motion by comparing images one year apart can also provide useful information on ice boundary zones.



45 *Topographic map of Greenland Ice sheet produced from ERS-1 RA data. (Courtesy Mullard Space Science Laboratory, Univ. College London, UK).*

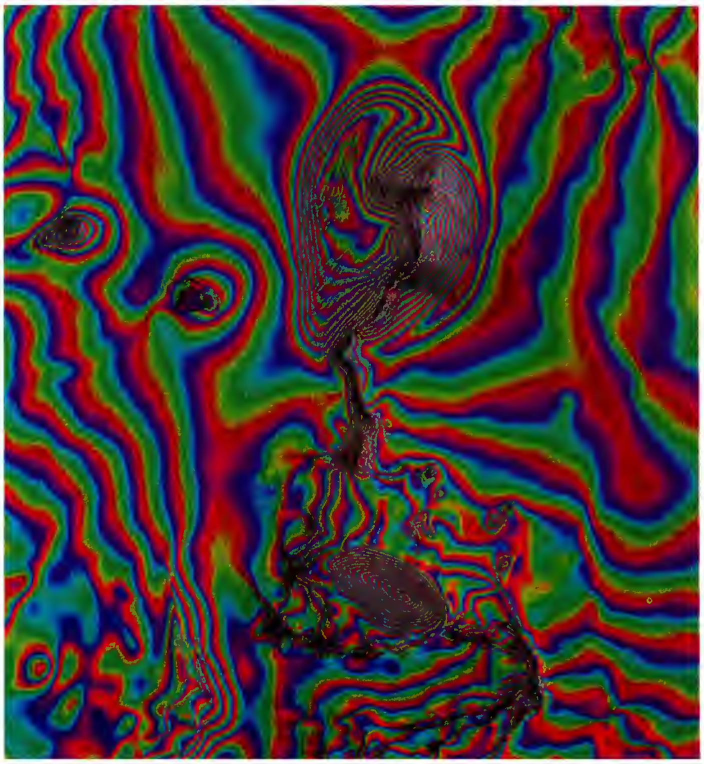
The new acquisition modes of ASAR, especially Alternating Polarisation Mode, will provide more information relating to surface characteristics and the structure of the snow pack as it varies across the ice sheet. AATSR will be able to provide accurate temperature measurements of the surface of ice sheets which provide further insights into local climatology and an indicator of long term global climate change.

The ERS RA had a special mode for mapping ice sheet topography and investigating volume changes. For example, Figure 45 is an RA topographic map of Greenland. On Envisat, RA-2 will have improved performance due to the window tracking algorithm, and changes in the onboard processing which makes the instrument tolerant to changes in surface topography.

Temperate glaciers and small ice sheets are also sensitive indicators of climate change, more particularly in a regional context. Most of the world's glaciers are in retreat and have been for the past century or so. Glacial melt water is an important component of the hydrological cycle in the mountainous areas where glaciers are to be found. In order to understand the relationship between climate change and glacial advance and retreat it is necessary to model the mass balance and dynamics of glaciers and their departure from equilibrium, according to the various inputs driving the change, including snow accumulation and ablation.

ERS SAR data have already provided significant information on the changes which take place as snow compacts and changes to ice, within an annual cycle. By analysing successive years of data it is possible to infer climate change by monitoring critical boundaries between ice and melting snow at the end of the summer melt season. Similarly, by mapping the frontal extent of glaciers on a regular basis, made feasible by using space-borne radar sensors, long term and increasingly valuable data sets can be compiled, which represent trends in global climate change.

SAR interferometry has been used to monitor the changes which take place in a glacier and the relative velocities of the components involved. Figure 46 provides an excellent example of how mapping surface topography can provide information on glacial processes. In this case, the effects of sub-glacial volcanic activity could be quantified in terms of the volume of melt water.



46 *Interferogram from ERS Tandem data, of part of the Vatnajokull Glacier, Iceland, May 1997. (Courtesy Institut für Meteorologie und Geophysik, Innsbruck, Austria).*

Products, Calibration & Validation

Data Products

A comprehensive list of ESA products has been established and approved as part of the Ground Segment concept. This list includes the following type of products:

- Level 0 products, time ordered Instrument Source Packets formatted as PDS products
- Level 1b products, geolocated and calibrated engineering parameters
- Level 2 products, geolocated geophysical quantities.

To ensure coherency of data product definitions and formatting through all the PDS, as well as to define an approach valid for both near-real-time and offline products, the Agency has established precise product guidelines and organised a clear distinction between:

- the product definition and processing algorithm development assigned to a set of Expert Support Laboratories (ESL's, constituted by several research centres and university labs) and supporting industries
- the PDS Instrument Processor implementation assigned to the PDS consortium and based on product and algorithm detailed definition documents provided by the ESLs and supporting industries.

This approach, co-ordinated by the Agency, has been so far very successful:

- commonality between NRT and offline algorithms has been confirmed, the product formats and processing algorithms are identical, the main difference is in the quality of the auxiliary data available at processing time
- the Instrument Processors being implemented in the PDS are compatible with both NRT and offline product generation
- the same processors will be used in all PDS centres and stations, ensuring constant product quality for users, co-ordinated upgrades and configuration control throughout the operation lifetime of the mission.

The programme commits to generate engineering and geophysical products from the observations performed by the Envisat-1 satellite instruments. It implies that the following activities are performed prior to the launch:

- product definition and processing algorithm development and implementation;
- generation of test data and use of Instrument System Simulators;
- instrument characterisation;
- preparation of the in-orbit calibration;
- preparation of the level 2 product validation.

In the following activities ESA is responsible of all tasks related to the ESA Developed Instruments (EDIs). For the Announcement-of-Opportunity Instruments (AOIs), all activities are the responsibility of the AOI providers, ESA implementing the AOI provided processing algorithms in the PDS operational chains.

In-flight Calibration

The in-flight calibration requires processing of data acquired via:

- use of instrument internal calibration loops, the instrument carrying its own stimuli
- use of instrument external well characterised stimuli, natural targets (i.e. stars, rain forest, deserts or ice sheets) or specific artificial targets (i.e. ASAR transponders).

The corresponding results will be processed off-line in the Instrument Engineering Calibration Facility (IECF), specifically equipped for handling these data and for generating the calibration tables to be delivered to the PDS for the corresponding level 1B processing chains.

Level 2 Algorithm Validation

The level 2 processing algorithms use numerous models to convert engineering quantities into geophysical parameters (i.e. absorption lines into atmospheric species, brightness temperatures into surface temperatures, radar cross section return echo into wind or wave). Wherever possible these models are being validated using the experience acquired before Envisat launch, using in particular data acquired in-flight (when available) or airborne campaign data.

During Envisat in-orbit commissioning, it is planned to use two approaches in parallel:

- pre-assimilation of level 2 products by operational centres (i.e. meteo centres)
- comparison with in situ data on specially equipped campaign sites.

These two approaches have been shown to be complementary and extremely powerful in the ERS-1/2 missions:

- the in situ data provide precise measurements within the constraints of well identified sites
- the pre-assimilation of data products provides comparison with operationally used models, this product analysis, on a global scale, permits potential physical problems in the overall behaviour of the instrument processing algorithm to be highlighted.

Preparation for in-orbit commissioning

As shown above, the provision of level 1B and level 2 products to users requires the setting up of a comprehensive list of complementary activities in parallel with the satellite development phase. These activities aim at preparing the in-orbit Commissioning Phase: all processing chains have to be operable with corresponding mechanisms for updating the tuneable parameters (Look-up tables for the level 1B calibration parameters and for the level 2 model validation parameters). Within the 6 months duration of the Commissioning Phase, the calibration activities will permit to deliver level 1B products.

The validation of the level 2 products shall be such that, by the end of this phase, products will start to be delivered to the users. It can be anticipated that, for the instruments derived from the ERS missions, the product validation can be completed by the end of the Commissioning Phase. For the completely new instruments, it is expected that, while the commissioning will not be completed, the products will start being released to the users with warnings concerning error bars on some of the level 2 products. The validation of these products will be completed after end of the Commissioning Phase.

Calibration/Validation throughout the Operation Phase
At the end of the Commissioning Phase, the mission will enter in its Operation Phase. This phase is at present planned for 4 and half years duration and financed accordingly.

The monitoring of the products and the corresponding calibration and validation will be maintained throughout the Operation Phase. The Agency will continue the operation of the tools, software and external calibration sites, necessary to monitor the calibration of the EDIs. For product validation, ESL activities (including centres ensuring routine assimilation or comparison with models/in situ data) will be maintained and will evolve as deemed necessary to support the agency in this task.

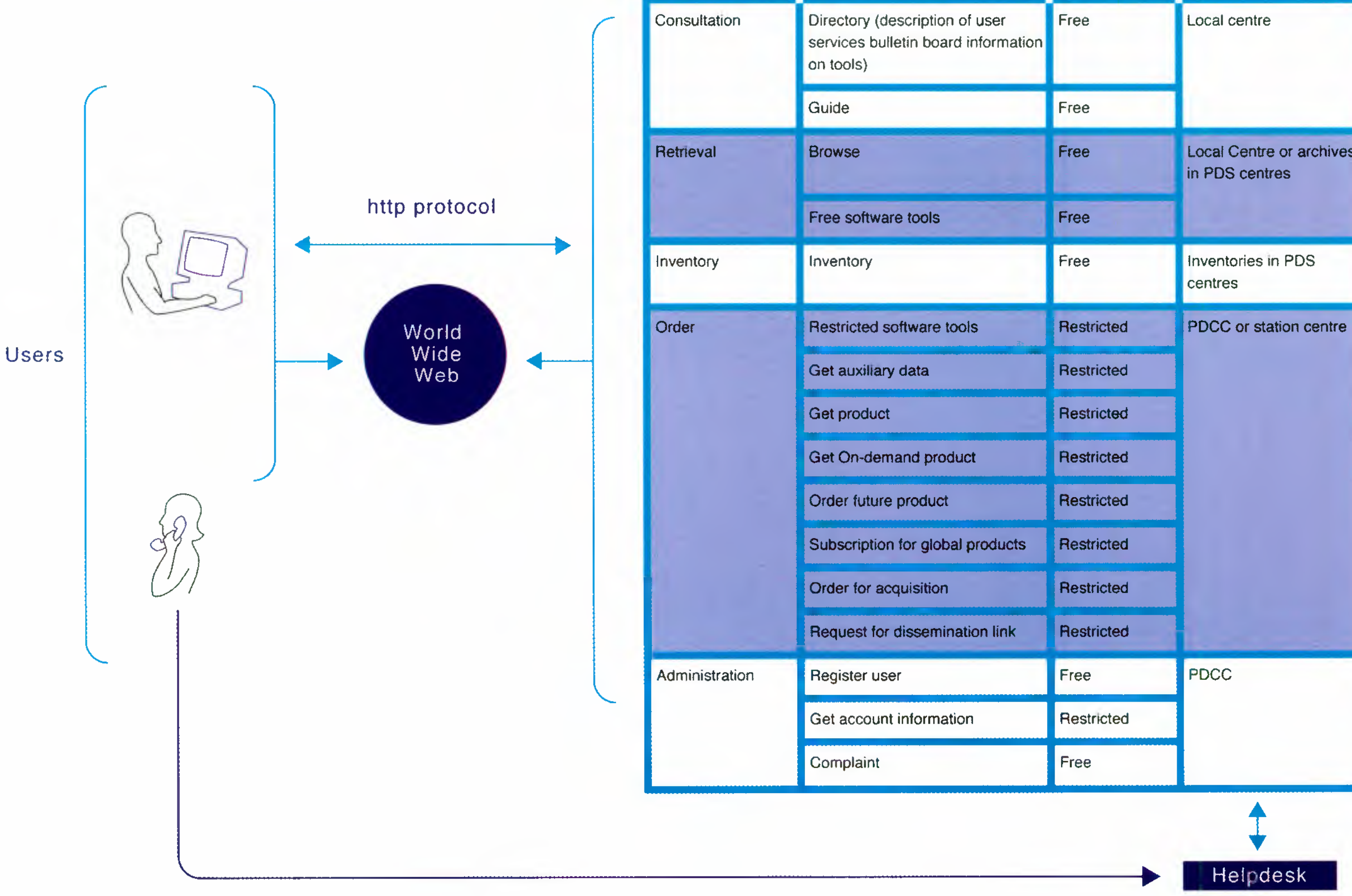
Data & User Services

Data Policy

The objectives of the Envisat data policy are to maximise the beneficial use of data and to stimulate a balanced development of science, public utility and commercial applications, consistent with the mission objectives. The Envisat data policy is based on the concept of 'use' of the data; its definitions, principles and the way they are applied depend on the use which is made of the data and not on the specific user or user entity. Two categories of use are defined:

Category 1 use : Research and applications development use in support of the mission objectives, including research on long-term issues of Earth system science, research and development in preparation for future operational use, certification of receiving stations as part of the ESA functions, and ESA internal use. In particular, for this category of users, an Announcement of Opportunity for the Exploitation of the Envisat data has been released by the Agency in December 1997 (see Appendix for a preliminary analysis of the offers received).

(47) *List of user services accessible via the Web.*



Services Types	Services	Services Availability	Centre providing services
Consultation	Directory (description of user services bulletin board information on tools)	Free	Local centre
	Guide	Free	
Retrieval	Browse	Free	Local Centre or archives in PDS centres
	Free software tools	Free	
Inventory	Inventory	Free	Inventories in PDS centres
Order	Restricted software tools	Restricted	PDCC or station centre
	Get auxiliary data	Restricted	
	Get product	Restricted	
	Get On-demand product	Restricted	
	Order future product	Restricted	
	Subscription for global products	Restricted	
	Order for acquisition	Restricted	
	Request for dissemination link	Restricted	
Administration	Register user	Free	PDCC
	Get account information	Restricted	
	Complaint	Free	

Category 2 use : All other uses which do not fall into category 1, including operational and commercial use.

The data policy introduces the concept of 'distributing entities' appointed by ESA with the task of marketing services based on Envisat data and of developing the market. Operational requirements for category 2 use will be submitted to the PDS through these distributing entities.

The User Services

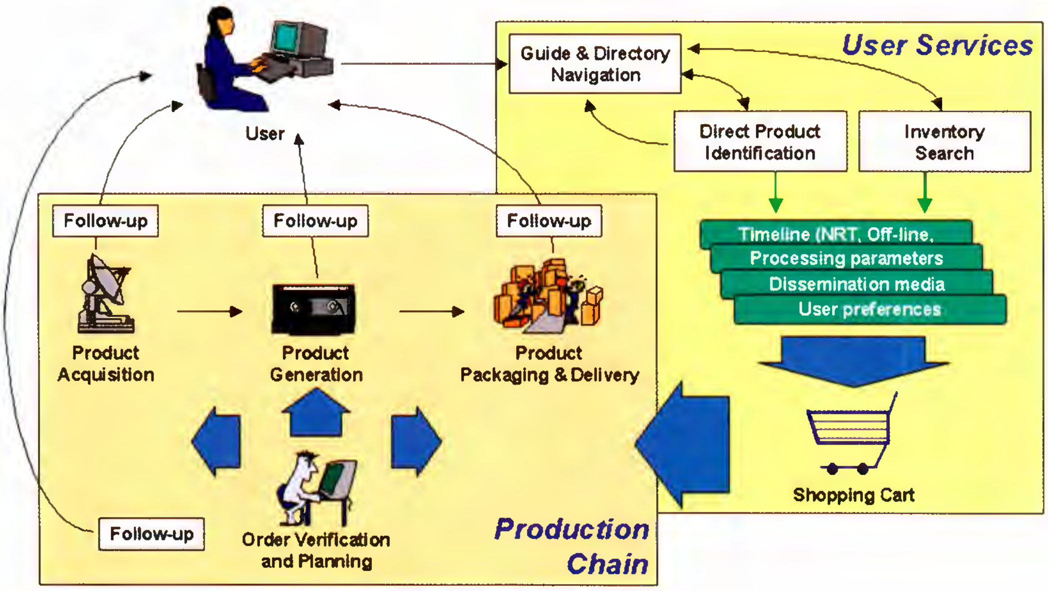
The main objective of the Envisat-1 system is to provide the required products to the users.

The PDS will provide, via its User Services accessible on Internet, an interface to the user community, registering data requests and organising the acquisition, processing and delivery of the corresponding products (Fig. 47).

The ground segment concept and architecture will provide a unified service to the users with access, once the user is registered, to the full range of services provided by the PDS centres and stations offering ESA services (Fig 48).

From the user's point of view, the services offered will provide:
- a decentralised system offering an homogeneous and consistent suite of services accessible via Internet in a transparent way (without the need to know where the data inventory nor the data are physically located)
- on line ordering of the products available and their delivery via electronic links or physical media according to size of product and network capabilities available
- systematic dissemination on electronic links (ground and satellite links) of NRT global data and for on-request dissemination of NRT high-resolution regional products
- offline product distribution on physical media
- ordering of products implying satellite data acquisitions to be planned by the PDCC
- support of the Help Desk and Order Desk located at the PDCC (Fig. 49).

48 User Earth terminal antenna at ESRIN.



49 User Service order follow-up.

Programme Development Status

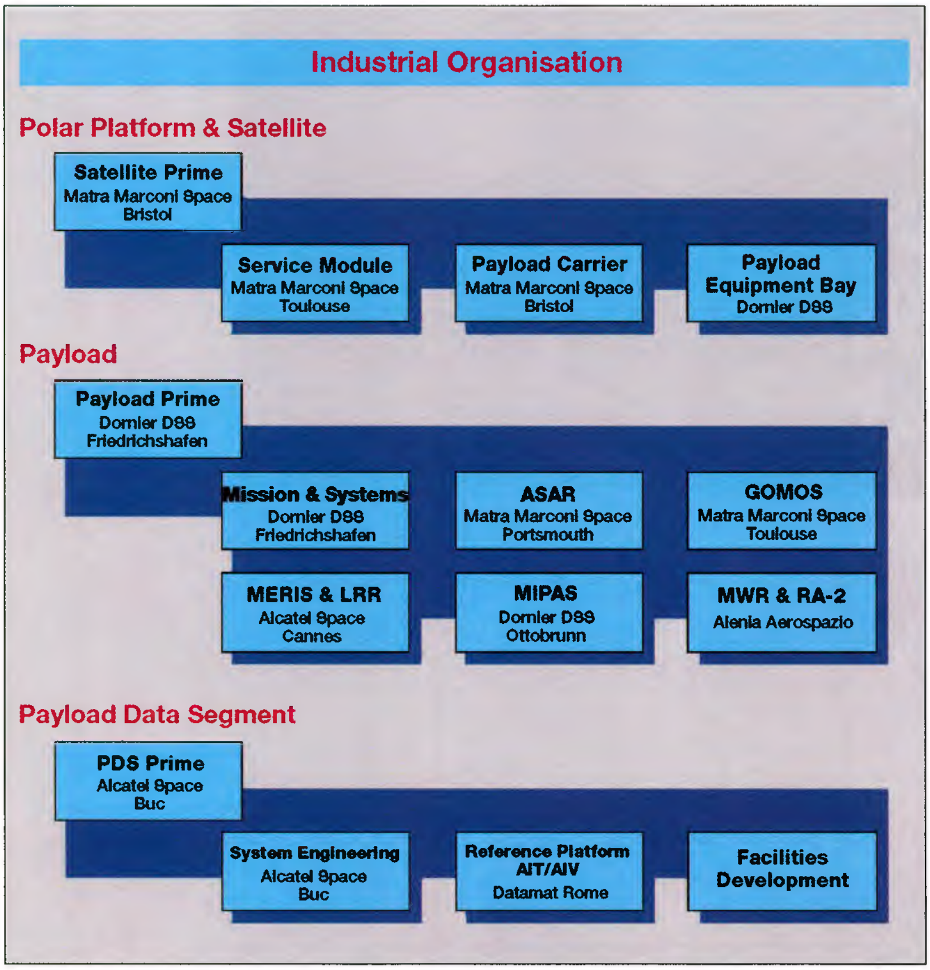


Table 15. Development Status

The Envisat Programme is constituted by three main development branches:

- the Polar Platform (PPF)
- the Instruments
- the Ground Segment (PDS)

each being developed under the responsibility of an industrial Prime Contractor, namely, Matra-Marconi Space for the PPF, Dornier for the Instruments, Alcatel Space (formerly Thomson-CSF) for the PDS. The industrial organisation is shown in Table 15.

Polar Platform
The development is basically completed. The original multimission concept has been tailored to the mission. Qualification of mechanical aspects has been achieved on the satellite structural model of which the test programme was completed in early 1997. The engineering model (EM) of the payload module was delivered in mid-1997 and assembled with EM instruments or instrument simulators and then coupled with the flight model service module (Fig. 50).

This model, which is in the final testing stages, has permitted to validate the design, performance and operation of the complete satellite and the coherence of internal interfaces, in particular with the instruments. Minor problems encountered have been resolved on the flight model hardware.

The flight model service module was integrated, tested and delivered in early 1997. The flight model payload module is currently being assembled in MMS (Bristol) with the integration of flight model instruments starting in the autumn of 1998.

System level tests (thermal, vibration, etc.) will be executed in the ESTEC test facilities prior to shipment to Kourou for the launch campaign.

Payload
To meet the demanding mission requirements, the Envisat instruments are characterised by a high level of technological innovation. Preceded by the delivery of structural-thermal models and then by the delivery (between mid-97 and mid-98) of the various engineering models (to prove the concept, the interfaces and the payload operations), the flight models of the instruments are curently being delivered for integration on the FM satellite. The last delivery, ASAR antenna, is planed for mid-1999.

Ground Segment
The Payload Data Segment (PDS) is currently in the integration phase. The overall schedule includes a first delivery (V1 version) by end 1998 and completion of the on-site acceptance (V2 version) in the second half of 1999.

The Flight Operations Segment (FOS) is entering the integration phase. The first system validation test was successfully performed in spring 98, validating the command and control of the spacecraft platform. The second system validation test (checking the command & control of the payload equipment bay) is scheduled for end 98/early 99.

(50) *Polar Platform engineering model at Bristol in September 1998 (Photo MMS-B).*

Conclusion

With its launch planned for mid-2000 and a design lifetime of 5 years, Envisat will be a multidisciplinary mission continuing and extending the science and application objectives of the ERS-1/2 missions. The number and the quality of the instruments embarked together with the Polar Platform design and capability allow to bring an unprecedented wealth of data for European and worldwide users. As such Envisat is part of a coherent European Earth Observation Programme ensuring the long-term provision of continuous datasets, essential for addressing environmental and climatological issues, as well as aiming at the promotion of application and commercial use of Earth Observation data.

The Envisat development will have equally advanced very significantly the technology and the industrial capability of the European industry involved in the Satellite and Ground Segment Programmes.

For further information on Envisat-1, please visit our Web site at: http://envisat.estec.esa.nl

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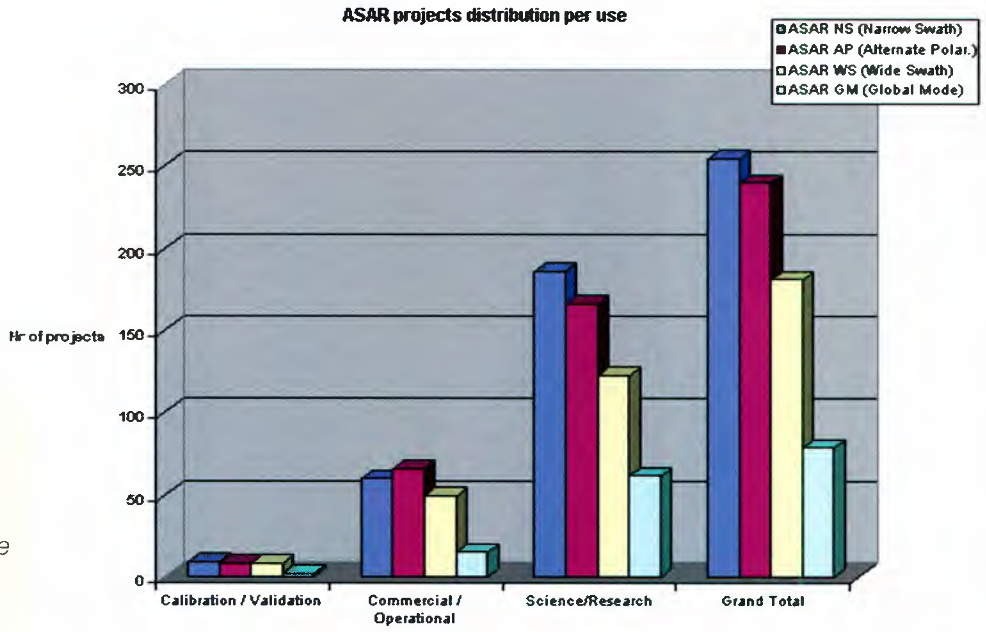
Appendix

Announcement of Opportunity for the Exploitation of Envisat data

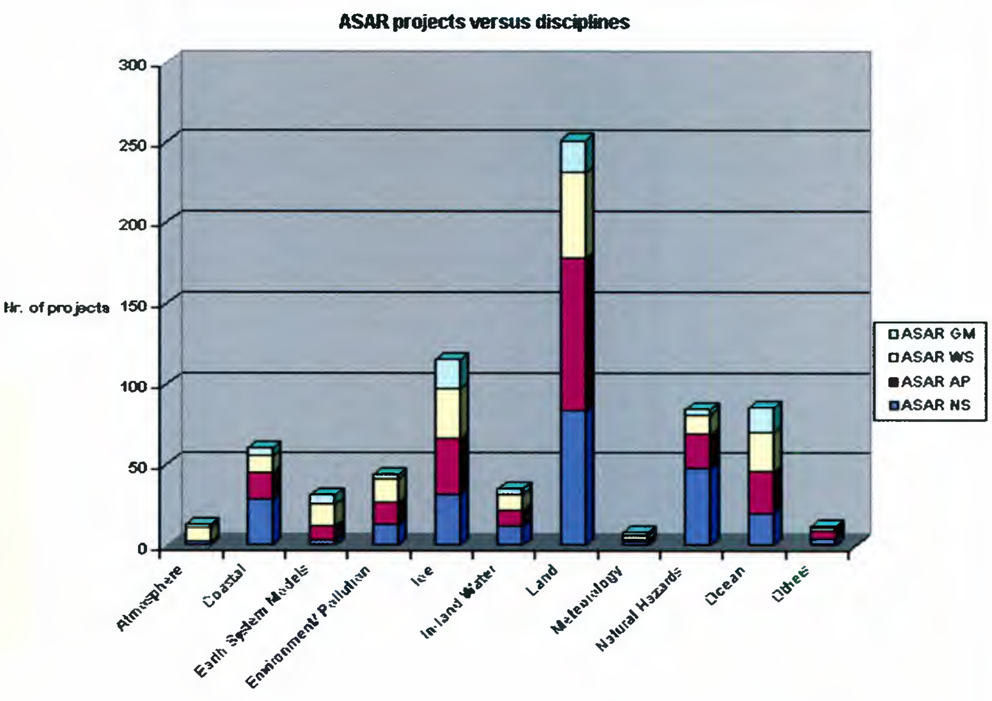
The Announcement of Opportunity for the exploitation of the data from the Envisat mission was issued in December 1997 and the deadline for submission of the projects was 31 May 1998. The proposed projects look at Envisat as a multidisciplinary source of data for earth science and applications.

More than 740 proposals were received from more than 50 countries. It can well be said that the number of replies is well in line with the technical and financial commitments of the countries funding the Envisat Programme through the European Space Agency.

More striking of all, the wide spectrum of the proposed projects helps in underlining further some unique characteristics of the Envisat mission:



① *ASAR submitted projects versus three main categories of use: calibration/validation, science & research, commercial & operational demonstrations. These categories are subdivided per ASAR operating modes.*



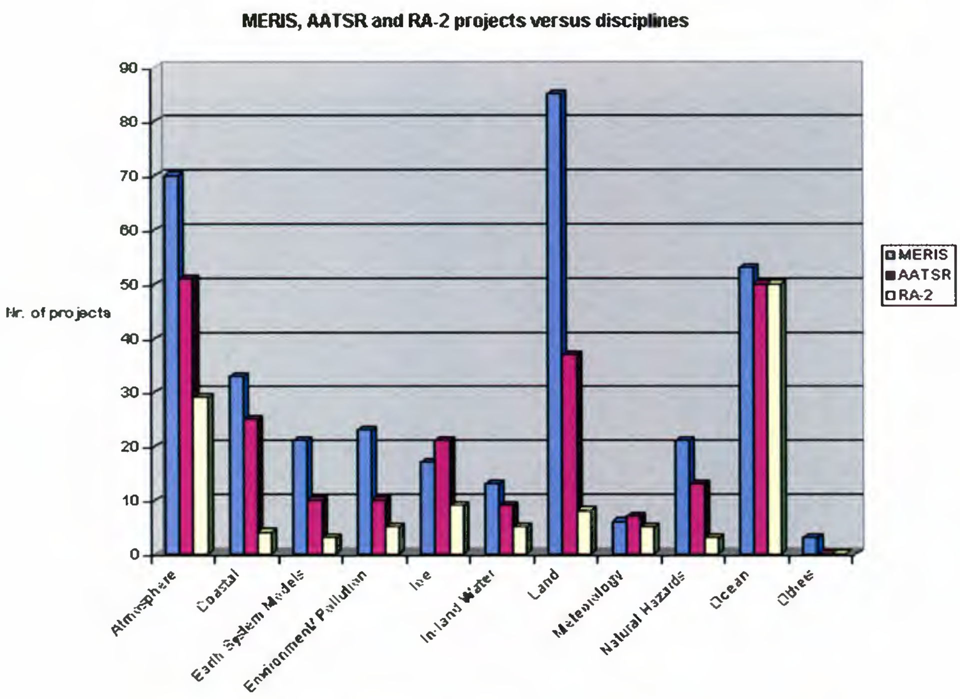
② *Distribution of the ASAR submitted projects versus 11 main science/application disciplines. It illustrates the multidisciplinary potentials as well as the interest for the various operation modes offered by the ASAR.*

- **Multidisciplinary aspect of the payload**
Envisat is providing data and services in support virtually of all earth science disciplines; it provides also new opportunities to perform demonstration projects for potential operational and commercial applications; finally, in a number of domains it will provide data for commercial and operational projects.

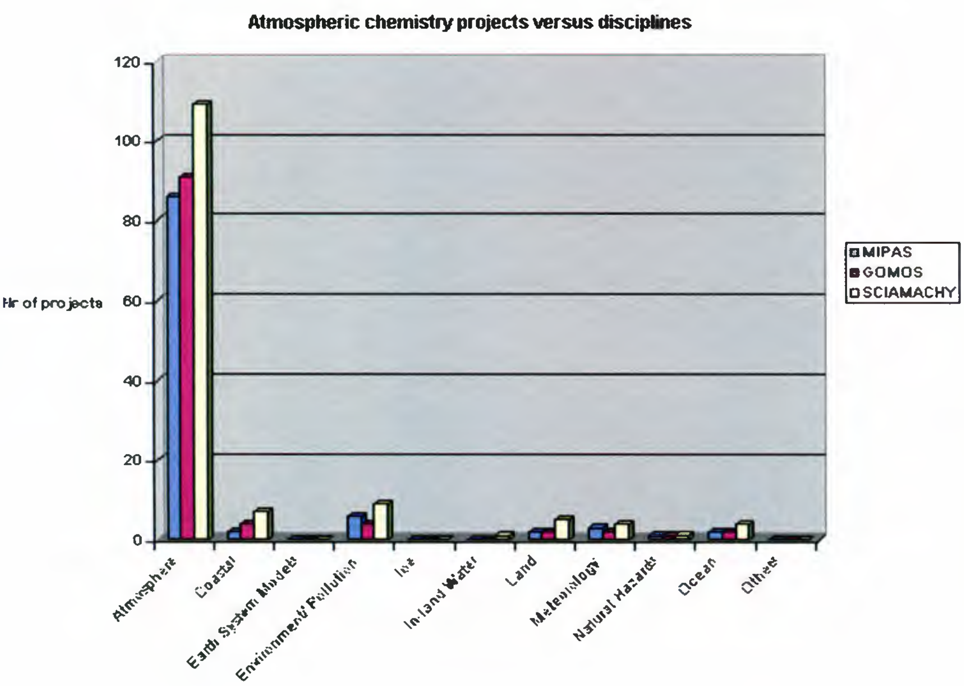
- **Synergy of the payload elements**
In several ways the Envisat instruments complement and complete each other, thus providing virtually custom-tailored datasets to the projects using them.

- **Long-term continuity**
The succession of the two ERS missions and now of Envisat provides long data series (10 to 15 years) essential for studying the long-term behaviour of critical components of the earth system.

- **Schedule**
The evaluation of the projects submitted in reply to the Envisat announcement of opportunity will be completed by December 1998, and the project leaders will be informed by end January 1999. ESA plans to organise meetings of the selected projects in fall 1999.



③ *Distribution of submitted projects making use of MERIS, AATSR, RA-2 versus 11 main science/application disciplines. Most projects making use of several instruments, the synergy between instrument is very well illustrated in this figure.*



④ *Distribution of submitted projects making use of the atmospheric instruments (GOMOS, MIPAS and Sciamachy) versus 11 main science/ application disciplines. Note that while most projects concentrate on atmosphere, as expected, some intend to demonstrate the interaction with other disciplines.*

In Memoriam
Bob Pfeiffer

It is with the deepest regret that we have to inform the Space and Earth Observation Communities that Dr. Burkhard (Bob) Pfeiffer, Envisat Programme Manager at ESA, passed away on 10 September 1998, aged 64.

Born on 15 June 1934 in Münster, Germany, Dr. Pfeiffer spent the last 22 years of his professional career at ESA as a Programme Manager responsible for the development of several of the most challenging Agency programmes of the time, such as Spacelab, ERS and Envisat. Prior to that he was the German Project Manager for the Franco-German Symphonie satellite. He combined a tenacious and highly effective management ability with an exceptional sense of duty and innate authority that left an indelible impression on those with whom he worked. He made it his business to ensure that the programme under his responsibility should have a successful outcome, no matter how difficult the circumstances, always responding to any situation in a typically positive manner. By nature a very disciplined and orderly person, he would fight energetically to surmount any obstacle that appeared to threaten his programme and would spare no effort in this respect.

After attending schools in Amberg, Nürnberg and Fürth, Dr. Pfeiffer studied at the Universities of Würzburg and the Swiss Federal Polytechnic in Zürich where he was the recipient of various degrees (Diplom Physiker, Doctorat Electronique, Dr. Sc. Nat. Physik). He started his professional career in 1961 as a Research Assistant at Zürich Polytechnic. In 1969 he joined the GfW (Gesellschaft für Weltraumforschung) as Deputy Head of the Technology Department. The following year he moved to the German Ministry of Research (BMFT), where he accepted a senior position within the Symphonie programme.

After the successful launch of Symphonie, he joined ESA in 1976 as Head of the Space Transport Systems Department. Soon afterwards, on 1 February 1977, Dr. Pfeiffer took over as Project Manager of Spacelab at the start of the equipment construction phase. He led this programme through to its first successful launch on 28 November 1983. In 1983, he was appointed Head of the Earth Observation Programme Department and in that capacity he was in charge until 1989 of several major projects, among them the highly successful ERS-1 Programme.

In the period 1989-1992, he became Head of the International Space Year and Space Awareness Office. In this capacity he was the ESA focal point for the related activities, contributing to the promotion of widespread interest in Earth observation from space.

In 1992 Dr. Pfeiffer took over responsibility for the development of Envisat (comprising the Polar Platform project and the development of the first mission payload), one of the most challenging satellite projects yet undertaken by ESA. He led this project successfully, overcoming the many obstacles and difficulties inherent in a project of this size, until September 1997 when his health began to fail. A short time before his death, when he felt that his health was finally improving after a period in hospital, he returned to the office to gradually resume his duties. People who had the chance to meet him during this period were struck by Bob Pfeiffer's optimism and stubborn determination to carry on as if nothing had happened. This was just one mark of the determination, natural modesty, and deep sense of optimism that guided Bob Pfeiffer in all his dealings.

His many former colleagues, team members and professional acquaintances will remember him with a deep sense of esteem, respect and friendship in the years to come. He is survived by his wife Eva and three daughters.

Record of Images

A supplement to EOQ 60
October 1998

ERS Products and Services from ESRIN

Cordoba Ground Station

A coverage from Amazonia to Tierra del Fuego

One of the main objectives of Argentina's National Space Plan, managed by CONAE (Comisión Nacional de Actividades Espaciales) is the promotion of the use and application of satellite data. To this purpose CONAE's Cordoba Ground Station serves as a main centre for acquisition and pre-processing of satellite images.

The Station is located some 35 km southwest Cordoba city, lat. 31°31'30.8" S, long. –64°27'48.9" W, amidst tourist zones of the Province of Cordoba, on the South America central meridian. This location, together with a very low level horizon mask, allows an acquisition coverage area reaching the central region of Brazil to the north, a significant part of Peru, Bolivia, Paraguay, Chile, Uruguay, Tierra del Fuego and beyond to the south.

How is it organised?

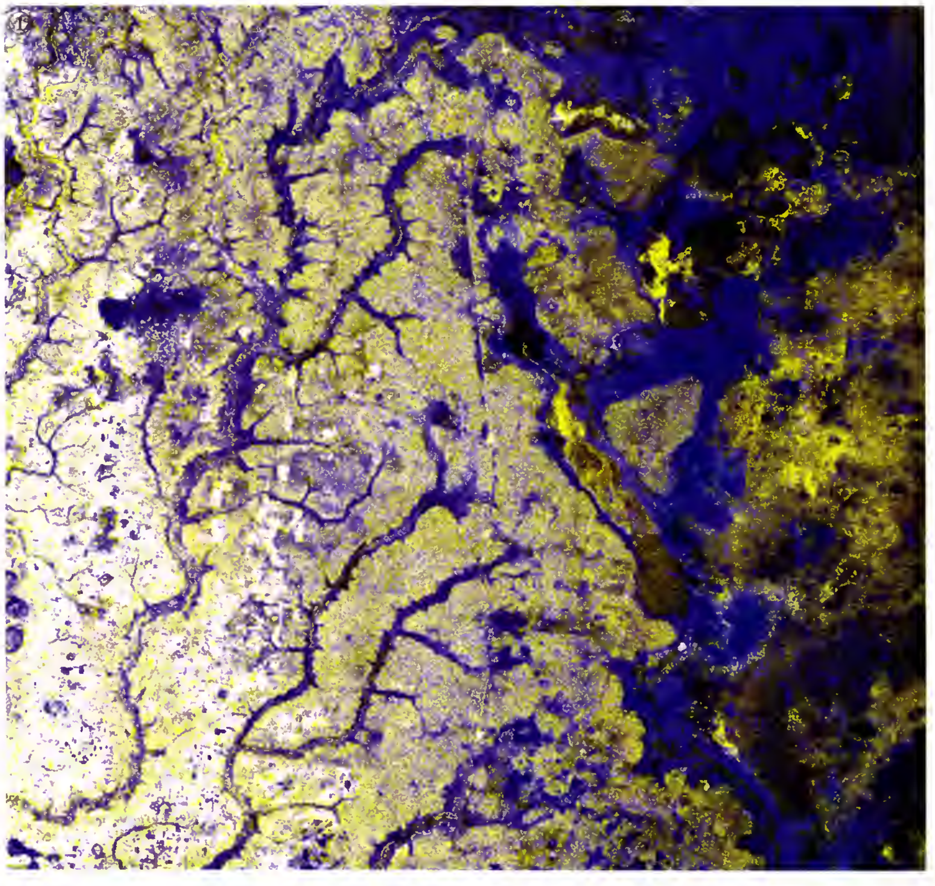
The system for the acquisition and pre-processing of satellite data consists of a direct ingestion and processing system running on Silicon Graphics platforms. Real-time satellite data are stored in a RAID unit and then transcribed off-line onto DLT tape, generating the data Archive, the Catalogue and the Browser.

12 computers running in a fast-Ethernet network are used for quality control, generation of products that need special off-line processing and CD burning or Exabyte tape reading, and a Jukebox unit for medium-term storage of products.

Through an agreement between CONAE and the DLR, a DLR mobile station was installed at the site and was connected to both the DLR and CONAE direct ingestion systems. The site preparation work began in September '96 and the installation of the hardware and software was completed just before Christmas '96. The DLR antenna and associated systems were installed and the first images downloaded by mid-January 1997.

Regular daily acquisition, archiving and cataloguing of Landsat data, as well as acquisition, archiving and cataloguing of ERS-1&2 passes on behalf of DLR and for test purposes with the CONAE-ACS system started in early March 1997.

Multitemporal image of an area affected by the flooding in the Paraná, Iguazú and Uruguay basins. The colour image is a layer stack of 2 ERS-2 SAR products, processed in CONAE, the first one of October '97 (prior to the flooding) and the second of April '98 (when the water reached the highest level). In RGB the first product went to the blue channel and the second to the green and red ones. Accordingly, grey areas correspond to places with identical response to the radar signal (no changes), blue extents show water bodies that appeared during the flooding and yellow or dark yellow patches indicate muddy areas (soil or running waters). Along the image one can see a highway running north to south cut from place to place by the calamity.



General view of Cordoba ground station, located within the Centro Espacial Teófilo Tabanera (CETT).

Which missions are supported?
The system at Cordoba ground station has the capability of acquiring and pre-processing Landsat-TM, ERS-1&2 images at all pre-processing levels, in CEOS and Fast Format, recorded on CD-ROM as a main support media. An important experience was the ERS-1&2 tandem mission that took place in September-October 1997. A significant part of ERS data was acquired and stored during that 40-day campaign.

Just before Christmas 1997 a remarkable improvement in the quality level of the station operation occurred when CONAE installed a 7.3 m Datron antenna with a much higher sensitivity and the capability of operating both in auto-tracking and programmed modes.

Also, an agreement was signed for the acquisition and recording of Spot-1/2 images on behalf of Spot Image, and this activity began at the same time the new antenna was installed. One result from this agreement is a complete catalogue of Spot images of Argentina available at the station, as well as important images from other regions outside the country within the Cordoba coverage area.

The capabilities of the station system can be assessed by the short time (in the order of 30 s) required to switch from tracking and acquisition of a satellite to a different one. In several occasions this has made possible to leave a Landsat TM data acquisition at an intermediate point switching to acquire an ERS (or Spot) pass (which are frequently rather short), and to resume the Landsat data acquisition afterwards.

Monitoring floods
As a part of the El Niño meteorological anomalies, unusual strong flooding has occurred throughout the basins of the Paraná, Iguazú and Uruguay rivers in the period extending from late 1997 until almost mid-1998. The flooding reached a peak level in April 1998 and strongly affected the life of the inhabitants and the environment of vast areas, particularly the eastern regions of Argentina located among these rivers and in zones close to them.

This situation posed important and urgent requirements of information needed for monitoring the status and evolution of the affected areas. The satellite images acquired and pre-processed at Cordoba Ground Station made a significant contribution to the information needed in those critical times. An emergency plan was implemented in which images were acquired and pre-processed in a very short time, and within hours these products were handed to government agencies, which used them in their task of monitoring and evaluating the flood effects.

It has to be noted that, as it is usually the case in such situations, earth observation with passive sensors was strongly limited by cloud cover over the regions of interest. That limitation was solved by the acquisition of the ERS SAR data, which provided images and good quality information of the affected regions, even when they were covered by clouds.

Current status and prospects
In addition to the infrastructure of Cordoba Ground Station described above, a TT&C station has also been installed in the same premises to be used for operating CONAE's satellites. In addition, another 13 m Datron antenna and related equipment are to be installed within the Station premises early next year. This new system will have TT&C and acquisition and pre-processing satellite data capabilities.

General view of the station's operation room.

Envisat Countdown

As a continuation of the introduction to Envisat published in previous issues (no. 58 and 59), a standard Payload Data Handling Station (PDHS) is presented below.

SYSTEM FUNCTIONS

CENTRE FUNCTIONS	Products Generation (Acquisition, Demultiplexing, Processing)	Products Administration (Archiving, Dissemination)	User Services (Access to service, Production Inventory)	Supervision (System Supervision, S/C Supervision)	Support to production (Product control, Engineering support)
PDHS	Acquisition of X-band, Ka-Band signals; Generation of NRT products	Rolling Archive; Dissemination of NRT products	Providing services to users	Planning, M&C of PDHS activities and ressources	
LRAC	Cleaning and consolidation of LBR products	Archiving of LBR Lev 0 & 1b products; Products dissemination	Providing services to internal users	Planning, M & C of LRAC activities and ressources	
PDCC		SW, Browses Archiving; Products dissemination	Providing services to users; Administration & Coordination of user services	Planning, M & C of PDCC activities and ressources; Planning, M & C of System Mission and ressources. Interface with FOS	Monitoring of products quality; Engineering support to PDS activities
PACs	Generation of higher level products	Archiving of generated products; Products dissemination	Providing services to users	Planning, M & C of PAC activities and ressources	

①

PDS main functions

What are the PDS facilities?
The Envisat-1 Payload Data Segment facilities are recalled in Figure 1 (see *EOQ* No.59). All centres and stations are built from the same group of facilities, by selecting specific elements to meet particular requirements.

How is a PDHS configured?
Amongst the various Payload Data Handling Stations, the PDHS's located at ESRIN, Italy and in Kiruna, Sweden acquire measurement data down-loaded by the spacecraft (respectively in Ka and X bands), process it and disseminate products, according to the Payload Data Control Centre (PDCC) directives. A short-term rolling archive is provided. Local services are also offered to the users.

The operations strategy is defined at the PDCC. The corresponding instructions are passed to the Centre Monitoring and Control (CMC) of each PDHS.

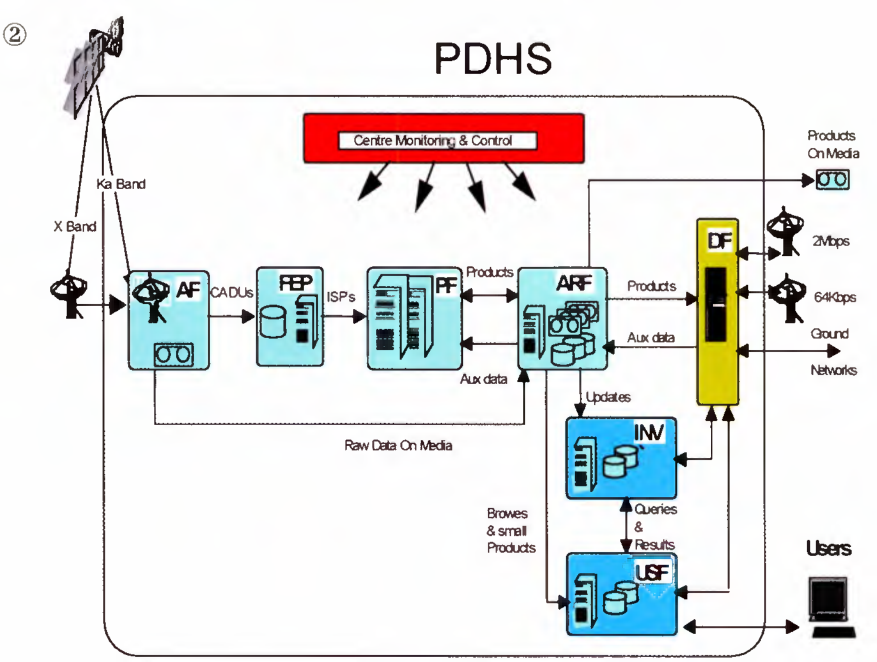
At the beginning of the pass (period corresponding to the acquisition of the measurement data for a single orbit), all production facilities as well as the archiving and dissemination facilities receive the instruction from the CMC for the operations to be performed.

The Acquisition facility (AF) acquires satellite signal, using Ka or X band. It sends raw data CADUs to the Front-End Processor (FEP), and records them simultaneously on computer-compatible media for back up.

The FEP assembles the Instrument Source Packets (ISPs) to be delivered to the Processing Facility (PF). The PF,

Overview of the architecture of a PDHS

②



which comprises the Processing Facility Host Structure (PFHS) and the Instrument Processor Facilities (IPFs), generates *near-real-time products* from the ISPs using auxiliary data provided by the Archiving Facility (ARF).

The ARF stores the generated products in the on-line archive, and sends associated products information to update the Inventory Facility (INV).

In parallel, the Dissemination Facility (DF) retrieves products from the ARF and disseminates them by network to the users according to the instructions provided by the PDCC.

At any time, users can query the INV trough the Users Services Facility (USF), and ask, for example, for on-line delivery of browsers or small products.

The Envisat Products Generation will be presented in the next issue.

More details on Envisat can be found at **http://envisat.estec.esa.nl/**

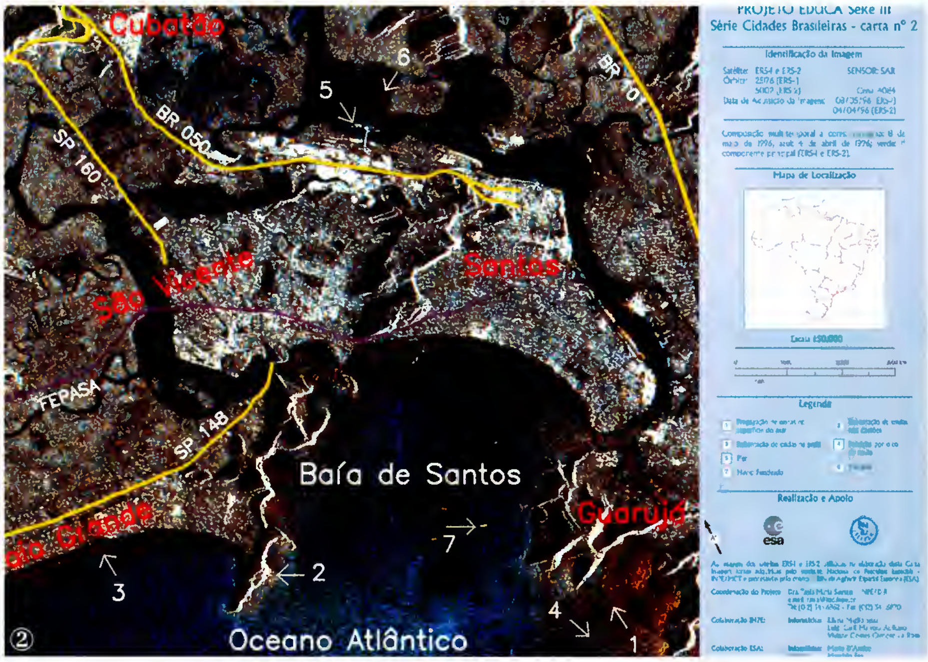
In brief

ERS in Brazil

An ESA stand was set up by ESRIN in Santos, Brazil on the occasion of a series of Latin-American events:

- Segunda Jornada Latino-Americana en Sensoriamento Remoto por Radar: Técnicas de Processamento de Imagens (11-12 Sept.)
- Seminário de Educação – ISPRS/SBSR 98 (13 Sept.)
- IX Simpósio Brasileiro de Sensoriamento Remoto (14-18 Sept.)

Maurizio Fea from ESRIN welcoming Dr. Marcio Nogueira Barbosa, Director General of INPE, at the ESA stand, where a large variety of ERS SAR images, the El Niño poster and Meteosat pictures of South America were displayed.



This poster, created by INPE with the co-operation of ESRIN on this occasion, shows a SAR image of the city of Santos, Brazil, where the main transportation network has been overlaid and the main environmental features are indicated.

Supplement to Earth Observation Quarterly

This supplement to EOQ is published four times a year by ESA Publications Division. It is distributed free of charge to all readers who wish to be informed on the ERS products and services avaible at ESRIN, Frascati.

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Layout & Prepress: Eva Ekstrand

Request for futher information on ERS products and services, and for free subscription to this *Supplement*, should be addressed to:

ERS Help Desk
via Galileo Galilei, CP. 64
0044 Fracati, Italy
Tel: +39.6.94180.777
E-mail: irshelp@mail.esrin.esa.it

Recent ERS campaigns

- Ulan Bator (Mongolia), 10 May-10 Aug. 98 : ERS-1 & 2 Tandem data acquired
- Bishkek (Kyrgystan), 6 Aug.-30 Sept. 98 : ERS-1 & 2 Tandem data acquired.

With these two campaigns, the remaining gaps in the global ERS land coverage are filled (e.g. Caspian Sea, etc.)

Eurimage Training Course

17-20 November 1998 : Seminar on land use & land cover applications of ERS SAR and other complementary spaceborne sensors.

For further information, please contact: Aldo Argentieri
Tel: +39-6-941.80947; fax:...6772
e-mail: argentieri@eurimage.it

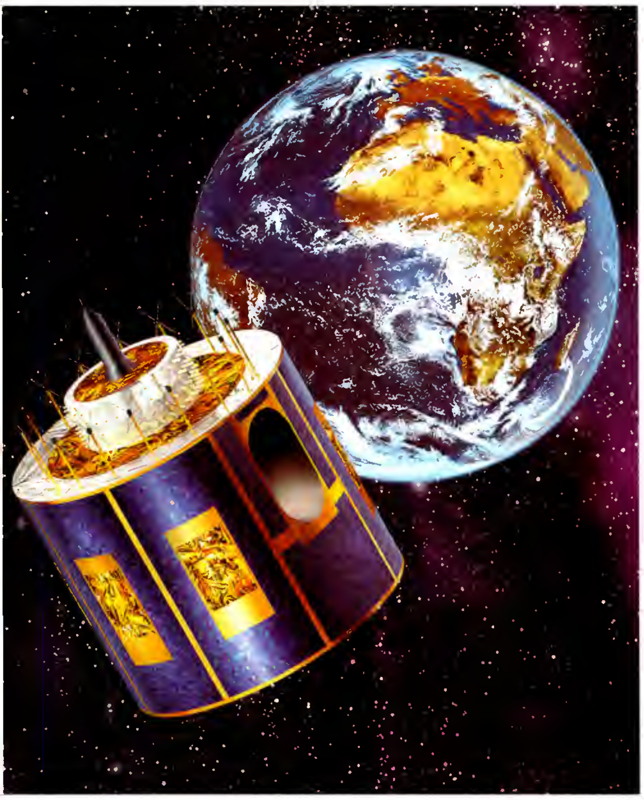
Joint ESA-EUMETSAT Research Announcement of Opportunity for Meteosat Second Generation (MSG-RAO)

Advance Notification

Meteosat Second Generation (MSG) is a meteorological geostationary satellite programme developed in co-operation between the European Space Agency (ESA) and the European Organisation for the Exploitation of European Meteorological Satellites (EUMETSAT), to primarily serve the needs of the European operational meteorological user community, which is represented by EUMETSAT. Such needs include continuity of the current geostationary service, and the MSG system design therefore builds upon the Meteosat heritage.

Due to the evolution of meteorological requirements, MSG is also very innovative, and its SEVIRI imager will provide about twenty times more information than its Meteosat predecessor. Its original combination of 12 spectral channels, including the 3 Meteosat channels, will offer new and sometimes unique capabilities to characterise clouds, surfaces and the stability of the atmosphere, with improved thermal IR calibration, radiometric performances and imaging frequency. The three-satellite programme will provide observations over a period of at least 12 years, starting after the commissioning of MSG-1, nominally in April 2001. More information on the MSG system will be made available through the following Web sites:

http://www.eumetsat.de
http://www.esrin.esa.it/esa/progs/eo.html



The novel MSG features will create new opportunities outside the meteorological operational user community, in particular for research users in several domains of Earth Sciences. Also many research challenges will have to be met in order to extract as much as possible information from the observations, as early as possible in the operational phase of the programme. In this context, ESA and EUMETSAT came to the conclusion that a Research Announcement of Opportunity is the most appropriate approach to stimulate the use and evaluation of MSG data for research purposes. It will also help to establish early, structured, constructive and mutually beneficial interactions and feedback between the research and the operational meteorological user communities. Such interactions are in particular expected to contribute to an improved mutual understanding of the requirements of both user communities, and, on that basis, to stimulate their further co-operation and the evolution of the EUMETSAT MSG data services in response to such needs.

Therefore, considering that the MSG development activities are now well advanced, with the first launch foreseen in October 2000, ESA and EUMETSAT are pleased to announce their intention to release a joint MSG Research Announcement of Opportunity (MSG-RAO).

The purpose of the MSG-RAO will be to select, through a formal Peer Review process, up to 50 Research Investigations and Investigator Teams, aimed at demonstrating the value of the mission to innovative research in areas such as hydrology and land surface processes, atmospheric, oceanographic and climate research. The restriction of the number of Investigator Teams to be selected is deemed necessary to keep the interaction process manageable and productive. The RAO will also solicit demonstration of innovative MSG products and of their relevance to European and African users, and original contributions to calibration and validation, to be integrated into the MSG calibration and validation plan. The combined use of data from SEVIRI and from the GERB (Geostationary Earth Radiation Budget) broad band radiometer to be flown as an AO instrument at least on MSG-1, e.g. for calibration, will also be encouraged. The complementary use of data from any of ESA's Earth Observation satellites (in particular ERS-1/2 and/or Envisat) in synergy with data from MSG will be welcomed, in the understanding that emphasis is expected to be given to research based on data from the latter.

The MSG-RAO, addressed worldwide to scientific organisations and institutes, will be released in early 1999, after approval of EUMETSAT and ESA Delegate Bodies, with a closing date for mid 1999. The information package will include supporting documentation about the MSG system and operations, the list of products expected from the MSG Ground Segment and the science plans for SEVIRI and GERB. Evaluation and notification of successful investigators is foreseen at the end of 1999.

It should be noted that no EUMETSAT or ESA funding will be available to support the selected investigations, which should rely on external resources from national or international research programmes and organisations. Therefore, this advance notification invites the potential investigators to plan for the preparation of their proposals and to initiate discussions with potential co-investigators, and, when appropriate, to seek financial support from national and international research programmes, in compliance with the relevant annual budget and evaluation cycles.

The selected Investigators will have access without charge to all real-time and archived MSG data and products agreed to be necessary for the purpose of their investigations. This access will be subject to a licence agreement with EUMETSAT or one of its Exclusive Licensing Agents. The Investigators will be responsible for their own receiving equipment. Access to any necessary complementary data from ESA Earth Observation satellites will be granted by and cleared through ESA.

The Investigators will be invited to participate in a series of workshops or Conferences jointly organised by EUMETSAT and ESA involving the selected Research Investigators, the contributors to the Calibration and Validation Plan and the operational meteorological services contributing to an EUMETSAT-driven MSG Early Operational Evaluation Plan. The first workshop will take place after the selection of the Investigator Teams, in mid 2000, and will be dedicated to the transfer of updated information on MSG, and to the presentation of the various MSG Plans.

32nd ESLAB Symposium Remote Sensing Methodology for Earth Observation & Planetary Exploration

Gerhard Schwehm (*Solar System Division*) & Evert Attema (*Earth Sciences Division*)

The 32nd ESLAB Symposium took place from 15 to 18 September at ESTEC. The main aim of the symposium was to bring together specialists from the different areas in remote sensing (imaging, spectroscopy and passive and active microwave techniques) from both Earth Observation and Planetary Exploration to discuss instrument requirements and related future technology development issues.

For the first time in the series of ESLAB Symposia, ESAís Solar System Division and the recently incorporated Earth Sciences Division of the Space Science Department wanted to jointly create a forum where scientists and engineers could come together to discuss, across the borders, future trends and to develop strategies for new instrumentation for missions that have to be implemented very efficiently within tight budgetary constraints.

The meeting was opened by ESA's Director of Scientific Programme, Dr. R.M. Bonnet, who welcomed the participants and described the new requirements for instrument development and miniaturisation of sensors for faster implementation of missions, warranting however, the capability to stay at the forefront of scientific and technological research. This was followed by overviews of technology research strategies in the Agency and of user requirements in the European Union. A. Peacock provided an excellent review on how the Technology Development Programme has to be focused on specific scientific goals. This was demonstrated by examples of Astrophysics missions. In the keynote address, Dr. Southwood discussed programmatics and future strategies in Earth Observation and Planetary Science.

About 90 participants from universities, research institutes, industry and the Agency took active part in the meeting to learn from their colleagues from different areas of research, who do not come together very often to exchange ideas. At the end of the meeting the participants agreed that the new set-up of the symposium had provided an unique opportunity to approach similar problems from a different point of view. It was a fruitful experience, partly of an educational nature and certainly stimulating new ideas. It was suggested to organise similar meetings in the future, perhaps more focused on a particular field, such as spectroscopy or microwave techniques. The objective of these meetings would be to establish priorities for technological research, instrument development and for future missions in Earth Observation and Planetary Exploration.

The set up of this symposium was new, but it turned out that it is rewarding to approach similar problems from different points of view, it is both educational and stimulates new ideas. There was a common agreement that it would be worthwhile to continue such meetings, perhaps focused on one area like imaging or microwave techniques, to define the areas, the instrument developers and the Agency specific development strategies. The Symposium Proceedings, containing all the invited and contributed papers, will be published shortly as ESA-SP423.

Oxford/RAL Spring School in Quantitative Earth Observation

8-16 April 1999, Oxford, UK

The Rutherford Appleton Laboratory (RAL) and the University of Oxford (OU) are holding a joint Spring School in Quantitative Earth Observation, hosted by the University sub-department of Atmospheric, Oceanic & Planetary Physics from 8 to 16 April 1999. The aim is to provide post-graduate students and researchers in the atmospheric, oceanographic & geological sciences with a concise, quantitative introduction to current data-analysis and inverse modelling techniques. We particularly encourage the participation of researchers who are involved in modelling geophysical systems or working on mission design and instrumentation but who are not currently focusing on quantitative exploitation of observational data. Specialists in data-analysis and inverse modelling should also find the interdisciplinary nature of the school stimulating.

Core lecture courses will include Principles of Geophysical Data Analysis (M. Allen, RAL/OU), Atmospheric Remote Sensing (C. Rodgers, OU & B. Kerridge, RAL), the Oceanic Inverse Problem (T. Haine, OU), Inverse Problems in Seismology (S. Das, OU), Model-data Comparison in Climate Research (R. Washington, OU) and Nonlinear Analysis of Geophysical Systems (L. Smith, OU).

Specialist guest lectures will be given by B. Ripley (OU) on Pattern recognition & neural networks; J. Eyre (UK Met. Office) on Use of satellite data in numerical weather prediction; C. Frankignoul (U. Pierre & Marie Curie, Paris) on Causal interference in the observation of coupled systems; J. Woodhouse (OU) on Global seismic tomography; and G. Hegerl (JISAO/U. Washington) on Detection and attribution of anthropogenic climate change.

There will be a program of computer practicals, to allow participants to apply selected techniques to real-world problems.

The cost of the school will be £400, plus £390 for 8 nights full-board accommodation in St. Johns College, Oxford. Financial support is available for a limited number of NERC-supported students and researchers. Further details may be obtained from Sue Clelland, Space Science Dept., RAL, Chilton, Didcot, OX11 0QX, UK. Fax: 44-1235-445848. e-mail: S.Clelland@rl.ac.uk URL: http://www.ssd.rl.ac.uk/news/EOSchool/ Application deadline: 31 Jan. 1999.

Conferences 1998-99

5-7 October – ESTEC, Noordwijk, NL
Workshop on **Emerging Scatterometer Applications: from Research to Operations**
Sponsors : ESA, Eumetsat
Contact : Eva Oriol-Pibernat, ESA Paris
tel: +33-1-5369 7726; fax: ... 7674
e-mail: eoriol@hq.esa.fr
or: Jochen Kerkmann, Eumetsat
tel: +49-6151-807514; fax: ... 807555
e-mail: kerkmann@eumetsat.de

19-20 October – Athens, Greece
Space Techniques for Environmental Management in the Mediterranean
Sponsors : Eurisy, Hellenic Space Res. & Technology Committee
Contact : Eurisy Secretariat
17-21 rue de Javel
75015 Paris, France
tel: +33-1-4575.0007; fax: ... 4579.9008
e-mail: eurisy@micronet.fr

21-23 October – ESTEC, Noordwijk, NL
2nd Intl. Workshop on **Retrieval of Bio- and Geo-physical Parameters from SAR Data for Land Applications**
Sponsor : ESA
Contact : Maurice Borgeaud, ESTEC
tel: +31-71-565.4830; fax: ... 4999
e-mail: maurice@xe.estec.esa.nl

23-27 November – Singapore
1st Euro-Asian Space Week on Space Cooperation
Sponsors : ESA, Nat. Univ. Singapore, RIET, Spotimage-Asia, Arianespace...
Contact : Ms. Valerie Hood, ESA HQ
tel: +33-1-5369.7443; fax: ... 7627
e-mail: vhood@esa.hq.fr
or : Prof. Hock Lim, Director CRISP, National University of Singapore
tel: +65-874-3220, fax: +65-775-7717
e-mail: phylimh@leonis.nus.sg

8-16 April 1999 – Oxford, UK
Spring School in Quantitative Earth Observation
Sponsors : Rutherford Appleton Lab., Univ. Oxford, UK NERC EO Programme
Contact : Sue Clelland, Space Sci. Dept, RAL, Chilton, OX11 0QX, UK
Fax: 44-1235-445848. e-mail: S.Clelland@rl.ac.uk – URL:http://www.ssd.rl.ac.uk/news/EOSchool/

27-29 April 1999 – Singapore
Oceanography International 99 Pacific Rim – New Regional Senior Buyers' Programme
Sponsors: Tropical Marine Science Inst., Maritime & Port Authority of Singapore, Sgp. Trade Dept. Board, Soc. for Underwater Technology, Oceanography Soc., WMO & Hydro International
Contact: Spearheads Exhibitions Ltd., Ocean House, 50 Kingston Road
New Malden, Surrey KT3 3LZ, UK
tel: 44-181.949.9222; fax: ...8186/8168
http://www.spearhead.co.uk
e-mail: oi99@spearhead.co.uk

26-28 May 1999 – Strasbourg, France
4th ISU Symp. on **International Space Station: Creating New Opportunities**
Contact: Patrick French, International Space University, Bld. Gonthier d'Andernach, 67400 Illkirch, France
tel: 33-03.8865.5454; fax: ... 5447
e-mail: french@isu.isunet.edu

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SP-434 : Image Processing Techniques
Proceedings of the 2nd Latino-American Seminar on Radar Remote Sensing, Santos, SP, Brazil, 11-12 Sept. 1998
(200 pages, Oct. 1998, 75 Dfl).

SP-423 : Remote Sensing Methodology for Earth Observation and Planetary Exploration
Proc. of the 32nd ESLAB Symposium, ESTEC, 15-18 Sept. 1998
(~ 220 p., Oct. 1998, 100 Dfl).

SP-424 : Emerging Scatterometer Applications From Research to Operations
Proc. of an International Workshop, ESTEC, 5-7 October 1998
(~ 300 p., Nov. 1998, 100 Dfl).

SP-441 : Retrieval of Bio- & Geo-physical Parameters from SAR Data for Land Applications
Proc. of an International Workshop, ESTEC, 21-13 October 1998
(~ 650 p., Dec. 1998, 150 Dfl).