

Envisat

The Envisat Mission and System

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Introduction

The Envisat satellite is composed of the payload complement and the Polar Platform (PPF) on which the instruments are mounted. It carries a package of ten multi-disciplinary instruments to observe the Earth and its atmosphere from space in a synergistic fashion, offering unprecedented opportunities in environmental monitoring and operational Earth observation. It addresses 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 endeavours such as the International Geosphere-Biosphere Programme (IGBP) and the World Climate Research Programme (WCRP).

The Envisat mission is designed to provide synergistic measurements over:

- oceans
- land
- ice caps
- atmosphere

thereby offering capabilities for global monitoring as well as precise local/regional observations, supporting in particular pollution and disaster monitoring. In this respect, Envisat responds very well to the recent European Commission initiative for the Global Monitoring of our Environment and Security (GMES) and will provide the basic data products needed for developing the required applications and services.

With the successful completion of the Envisat development programme and the satellite's imminent launch by an Ariane-5 from Kourou (Fr. Guiana) this autumn, the European space community is demonstrating its ability to develop advanced Earth-observation instruments meeting challenging performance requirements, and thereby confirming its leading role in Earth observation.

The satellite and its payload

The Envisat satellite is composed of the payload complement and the Polar Platform (PPF) on which the instruments are mounted (Fig. 1). Its orbit will be Sun-synchronous, with the same repeat cycle as that of ERS-2. The two orbits will be phased to have the same ground track, with Envisat preceding ERS-2 by half an hour.

The payload

The payload comprises a set of ESA-Developed Instruments (EDIs) complemented by Announcement-of-Opportunity Instruments (AOIs) developed on a national basis.

While our planet, throughout its long history, has undergone a natural evolution in its physical characteristics, it is now recognised that our growing human activities can directly affect our environment. An increasing population and expanding development demands are placing heavy stresses upon the finite resources of the Earth's system. There is also an increased awareness of the human and economic impact of the variability of our environment, particularly when facing natural disasters such as floods, earthquakes or volcanic eruptions. This growing concern has resulted in international agreements aimed at monitoring and minimising manmade environmental damage.

For the monitoring of environmental changes, the major contribution from satellites through their systematic observation of the Earth is now fully acknowledged. They offer both global observations for worldwide environmental needs and regional observations to support local environmental monitoring. Continuity of these observations is of paramount importance to identify and separate seasonal variations from long-term trends. The main objective of the Envisat programme is therefore to endow Europe with an enhanced capability for the remote sensing of the Earth from space. It significantly increases Europe's capacity to take part in the study and monitoring of the Earth and its environment, following the very successful ERS-1 and ERS-2 missions.

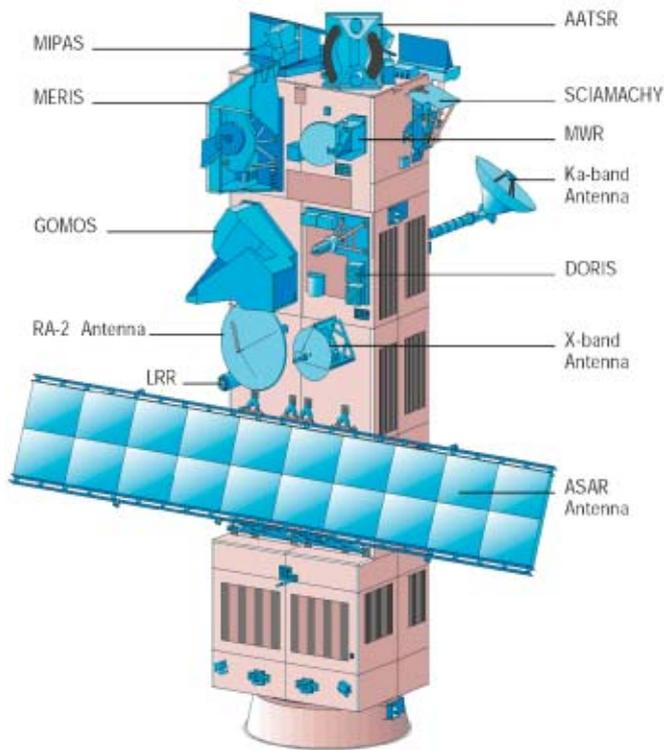


Figure 1. The main characteristics of the Envisat satellite

The EDIs are:

- 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), and
- LRR (Laser Retro-Reflector).

Figure 2. The contributions of the different Envisat instruments to the meeting of mission objectives

Instruments	Disciplines									
	ASAR	GOMOS	RA-2	MERIS	MIPAS	MWR	LR	SCIAMACHY	DORIS	AATSR
Atmosphere										
Radiative Fluxes										
Aerosols										
Land										
Ocean										
Turbidity										
Marine Geoid										
Ice										

Dimensions

- Launch configuration: length 10.5 m
envelope diameter 4.57 m
- In-Orbit Configuration: 26 m × 10 m × 5 m

Mass: Total satellite 8140 kg
(Payload 2050 kg)

Solar array power: 6.5 kW (EOL)

Average power demand:	Sun (watts)	Eclipse (watts)
Payload	1700	1750
Satellite	3275	2870

Launch vehicle: Ariane-5 (single launch)

Orbit: Sun-synchronous, 800 km mean altitude
35-day repeat cycle
10:00 descending node mean local solar time

The AOIs are:

- SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography)
- AATSR (Advanced Along-Track Scanning Radiometer), and
- DORIS (Doppler Orbitography and Radio-positioning Integrated by Satellite).

Part of the instrument complement is focussed on ensuring continuity of the data acquired by the ERS instruments – ASAR, AATSR and RA-2 with its supporting instrumentation (MWR, DORIS and LRR) – with improved accuracy and coverage. Observation of the oceans and coastal waters (with the retrieval of marine-biology constituent information) is the primary objective of the MERIS instrument. ASAR brings a new dimension to the applications and services already pioneered with the ERS Synthetic-Aperture Radar (SAR), by offering different incidence angles at high resolution, dual polarisation, wide-swath medium resolution, as well as an enhanced wave mode. The ability to observe the atmosphere, following on from the GOME instrument on ERS-2, is significantly enhanced by three instruments on Envisat that offer complementary measurement capabilities in terms of limb and nadir observations for a large variety of trace-gas concentrations and profiles through their specific absorption features.

The synergy of these ten instruments as a function of mission objectives is illustrated in Figure 2, demonstrating the comprehensive capabilities of Envisat for observing our planet's land masses, oceans, ice caps and atmosphere.

The satellite

The Envisat satellite is composed of two major elements: the Polar Platform and the instrument suite constituting the Earth-observation payload. A major driver for the overall satellite configuration has been the need to maximise the mounting area for the payload instruments and to meet their viewing requirements, whilst staying within the constraints of the Ariane-5 fairing and interfaces. The Polar Platform is a large modular construction comprising two major assemblies, the Service Module and the Payload Module (Fig. 3).

The *Service Module (SM)* provides the basic satellite functions of power generation, storage and distribution, attitude and orbit control, S-band telemetry and telecommand communication, and data handling for the overall satellite-control functions. The SM is based on the concept and design of the Spot-4 service module, but with a number of important new developments, particularly in the mechanical design area.

The *Payload Module (PLM)* consists of the Payload Carrier (PLC) and the Payload Equipment Bay (PEB). The PLC provides mounting surfaces of 6.4 m x 2.75 m for the payload instruments and associated electronics. The payload-dedicated support systems are mounted in the PEB. The payload support functions include instrument control and data handling, X-band and Ka-band communications, power distribution, mechanical support and thermal control.

The payload capabilities versus mission objectives

The payload complement addresses four major areas:

- radar imaging, with ASAR
- optical imaging over oceans, coastal zones and land, with MERIS and AATSR
- observation of the atmosphere, with GOMOS, MIPAS and SCIAMACHY
- altimetry, with RA-2, supported by MWR, LRR and DORIS.

Radar imaging

The Advanced Synthetic-Aperture Radar (ASAR)

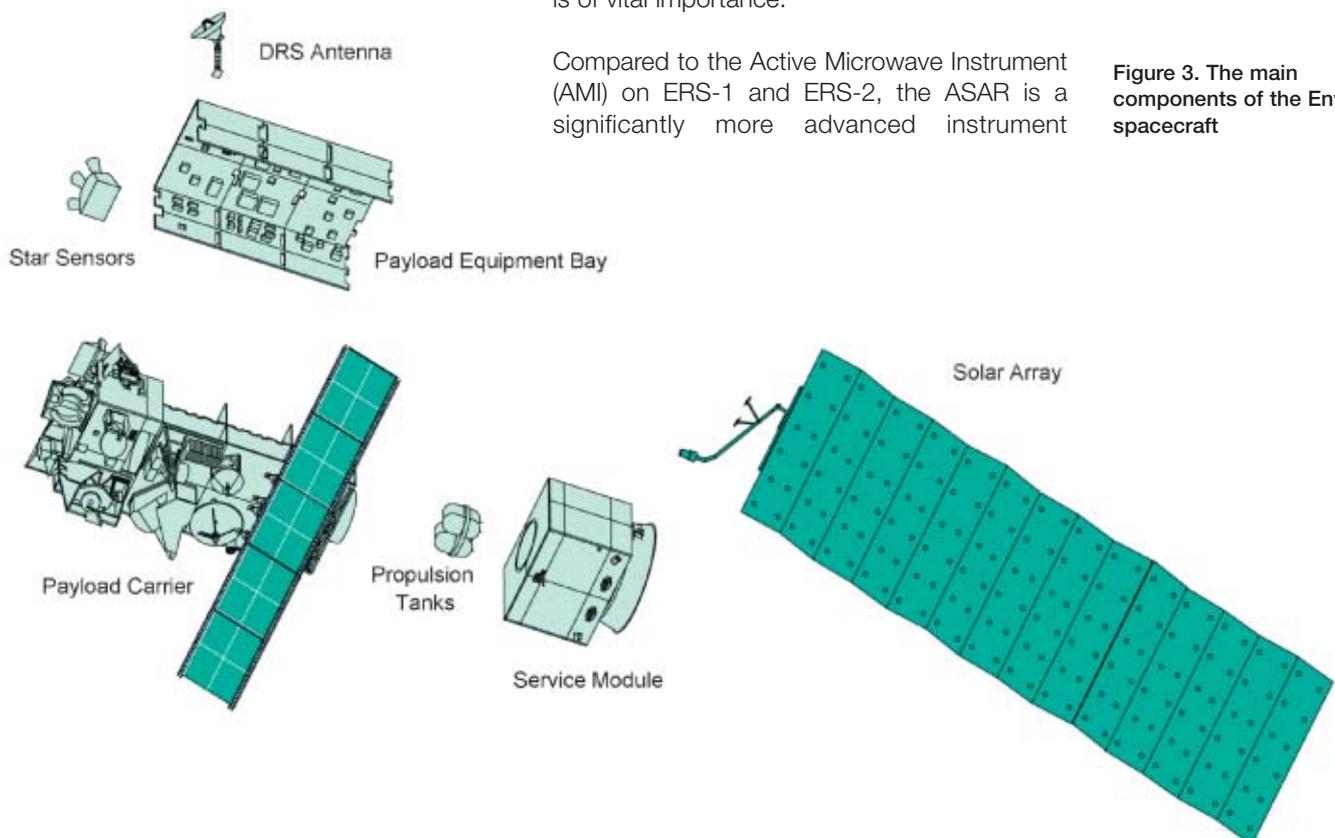
The ASAR is a high-resolution, wide-swath imaging radar instrument. Its main objective is to monitor the Earth's environment and to collect information on:

- ocean-wave characteristics
- sea-ice extent and motion
- snow and ice extent
- surface topography
- land-surface properties
- surface soil moisture and wetland extent
- deforestation, and extent of desert areas
- disaster monitoring (floods, earthquakes, etc).

The major advantage of using a SAR instrument for these Earth-observation tasks is its ability to take images independent of weather conditions, cloud coverage and solar illumination. Considering in particular observations of disasters like floods, which usually happen during persistent adverse weather conditions, this weather independence is of vital importance.

Compared to the Active Microwave Instrument (AMI) on ERS-1 and ERS-2, the ASAR is a significantly more advanced instrument

Figure 3. The main components of the Envisat spacecraft



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 was the most challenging one. The resulting improvements include the ability 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.

The ASAR instrument is designed to operate in the following principal modes:

- image
- wide swath
- wave
- alternating polarisation
- global monitoring.

The observing geometries of these different modes are illustrated in Figure 4.

In image mode, the ASAR gathers data from relatively narrow swaths (100 km within a viewing area of approx. 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).

In wave mode, the ASAR measures the change in radar backscatter from the ocean due to

surface waves. Wave spectra are extracted from 5 km x 5 km imagerettes taken over the ocean at 100 km intervals. The alternating-polarisation mode provides imaging of a scene with alternating polarisation during transmission and reception. The spatial resolution is equal to that of the image mode. In global-monitoring mode, a wide swath (400 km) is imaged with 1000 m spatial resolution.

The low data rates in wave and global-monitoring mode are recorded all around the satellite's orbit, while the high-data-rate modes are operated upon user request. The radar images obtained by ground processing of the ASAR data will allow the generation of enhanced products suited to applications over land surfaces, ocean and coastal regions, and ice zones.

Optical imaging over oceans, coastal zones and land

These observation capabilities are offered by two complementary instruments: MERIS and AATSR.

The Medium-Resolution Imaging Spectrometer (MERIS)

MERIS addresses the needs of three disciplines, primarily oceanographic but also atmospheric and land observations. Complemented by the RA-2 and AATSR instruments, it provides a unique synergistic mission for

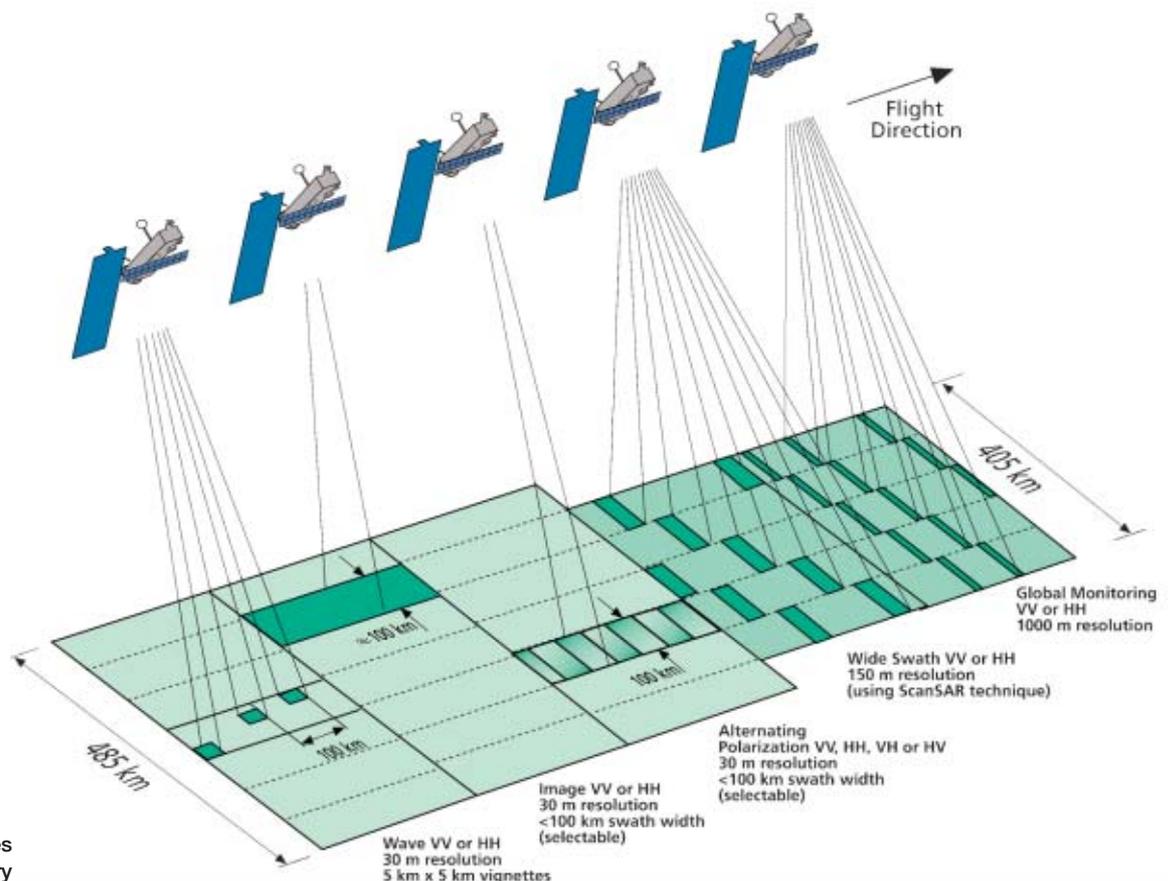


Figure 4. The ASAR modes and observation geometry

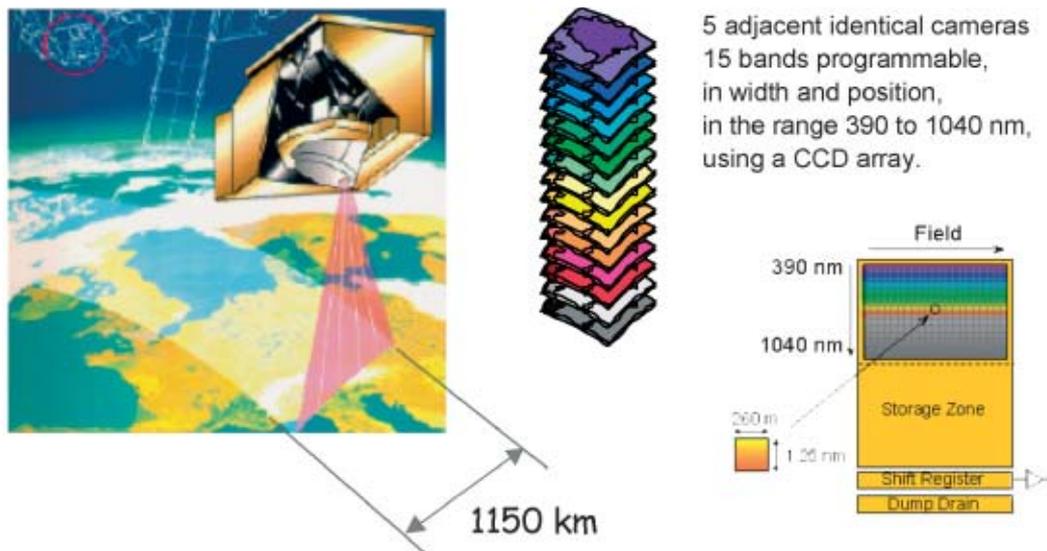


Figure 5. The operating principle of MERIS

bio/geophysical characterisation of the oceans and coastal zones, and thus for global climatological and environmental studies and monitoring.

MERIS is a push-broom instrument measuring the solar radiation reflected from the Earth's surface and from clouds in the visible and near-infrared range (390 – 1040 nm). The 1150 km-wide swath is provided by five identical adjacent cameras (Fig. 5). 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 two-dimensional CCD array, thereby providing spatial and spectral information simultaneously.

MERIS features a high degree of flexibility. Fully programmable on-board processing allows the selection of up to 15 different spectral bands in the 1.25 – 30 nm range. The spatial information along-track is determined by the push-broom principle via successive read-outs of the CCD-array. Full-spatial-resolution observations, i.e. 250 m at nadir, will be made over coastal zones and land surfaces. Reduced-spatial-resolution data, achieved by the on-board combination of 4 x 4 adjacent pixels across-track and along-track, resulting in a resolution of approximately 1000 m at nadir, will be generated and recorded onboard over the full Sun-illuminated segment. The instrument is optimised for absolute and relative radiometric performances, featuring regular updating of calibration parameters applied on-board via dedicated calibration hardware to achieve long-term stability.

The instrument data will be processed on the ground to provide spectral images of the Earth corrected for atmospheric influences. These data will be used for the generation of large-scale maps for, for example:

- ocean pigment concentrations
- ocean phytoplankton biomass production (a major factor in the carbon cycle)
- coastal-water monitoring
- clouds and water vapour, and
- vegetation status and distribution.

The Advanced Along-Track Scanning Radiometer (AATSR)

The prime objective of the AATSR is to establish continuity of the ERS ATSR-1 and -2 data sets of precise Sea-Surface Temperature (SST), thereby ensuring the production of a unique 15 year near-continuous data set at the levels of accuracy required (0.3 K or better) for climate research and for the operational and scientific user communities already established with the ERS-1 and -2 missions.

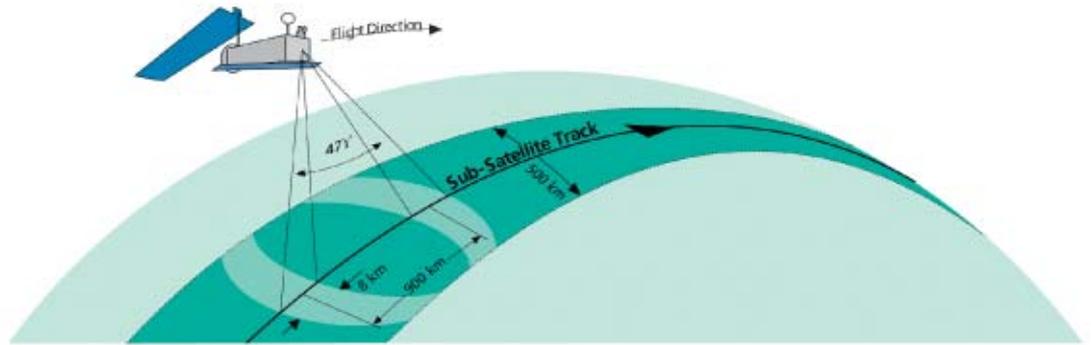
The second objective is to obtain precise land-vegetation measurements, through observations in three visible channels, exploiting the improved visible-wavelength atmospheric correction that will be achievable with the AATSR's two-angle view, thus providing estimates of:

- vegetation biomass
- vegetation moisture
- vegetation health and growth stage.

The above parameters will be used to derive Global Vegetation Indices. The visible channels will also be used to measure cloud parameters like water/ice discrimination and particle size distribution.

The AATSR field of view comprises two 500 km-wide curved swaths, with pixel sizes of 1 km x 1 km at the centre of the nadir swath and 1.5 km x 2 km at the centre of the forward swath. The two views result from the instrument's conical scanning mechanism (Fig. 6). As the two views of the same scene are taken through different atmospheric path

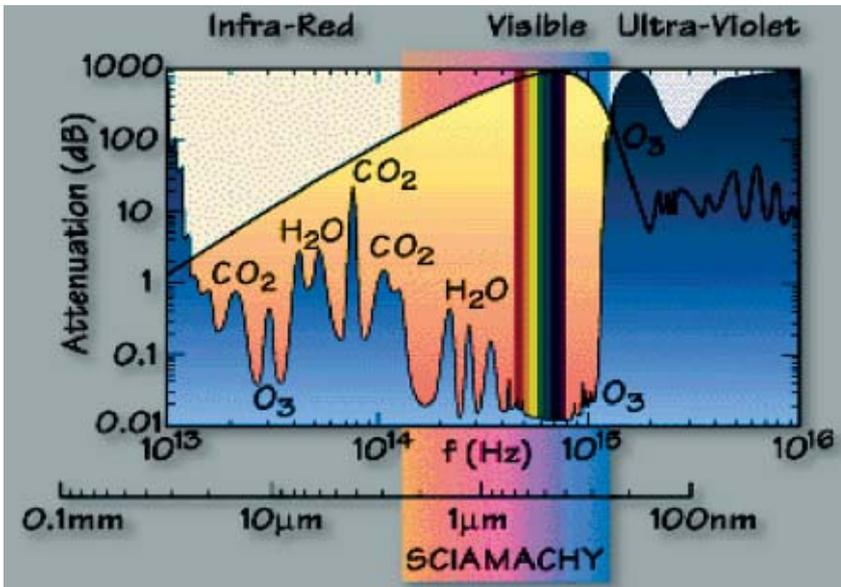
Figure 6. The AATSR viewing geometry



lengths, it is possible to calculate a correction for the effect of atmospheric absorption.

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

Figure 8. Trace-gas absorption lines



objectives will be met through the use of thermal-infrared channels (centred on 1.6, 3.7, 10.7 and 12 μm), identical to those on ATSR-1 and -2.

The visible channels will provide accurate quantitative measurements of radiation from the Earth's surface, using an on-board calibration system for basic radiometric accuracy, and a two-angle viewing technique to obtain accurate atmospheric corrections. The two most important visible channels, at 0.67 and 0.87 μm, provide measurements of Vegetation Index, and the additional channel at 0.55 μm supports the determination of the state of vegetation (chlorophyll content).

Observation of the atmosphere

Three instruments are dedicated to observation of the atmosphere: GOMOS, MIPAS and SCIAMACHY. Their complementarity for observing primary trace gases is illustrated in Figure 7. Whilst using different observation techniques, all three instruments rely upon analysis of the specific absorption lines created by the gases in the observed spectra (Fig. 8)

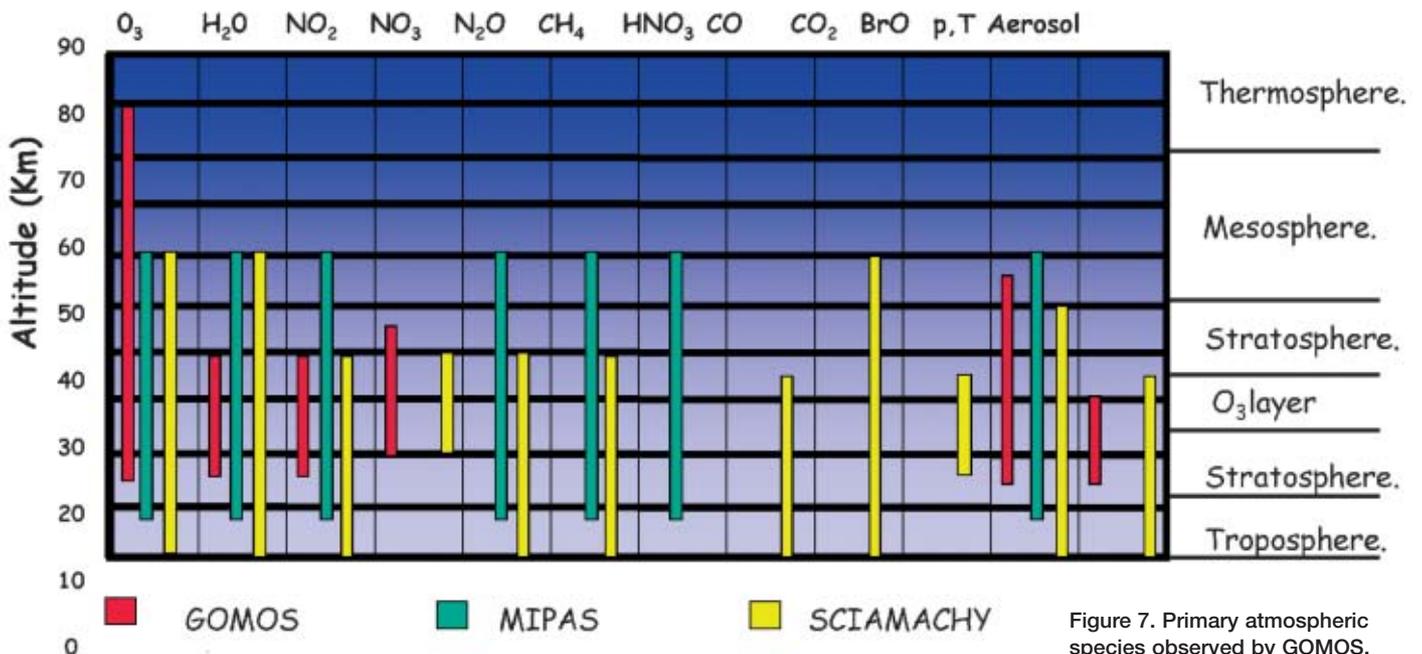


Figure 7. Primary atmospheric species observed by GOMOS, MIPAS and SCIAMACHY

Global Ozone Monitoring by Occultation of Stars (GOMOS)

The GOMOS instrument has been designed to enable simultaneous monitoring of ozone and other trace gases, as well as aerosol and temperature distributions in the stratosphere. It also supports the analysis of atmospheric turbulences. Trace-gas concentrations and other atmospheric parameters will be measured at altitudes between 20 and 100 km with a vertical resolution of approximately 1.7 km.

The instrument accommodates a UV-visible and a near-infrared spectrometer fed by a telescope which has its line of sight orientated towards the target star by means of a steerable mirror. The instrument then tracks the star and observes its setting behind the atmosphere (Fig. 9).

GOMOS will be operated continuously over the full Envisat orbit. About 25 stars brighter than $M_V = 2$ can be observed routinely at different longitudes from each orbit. The GOMOS instrument will produce as much data as a global network of 360 ground stations. The instrument will typically be commanded to observe a sequence of up to 50 stars repeatedly during sequential orbits.

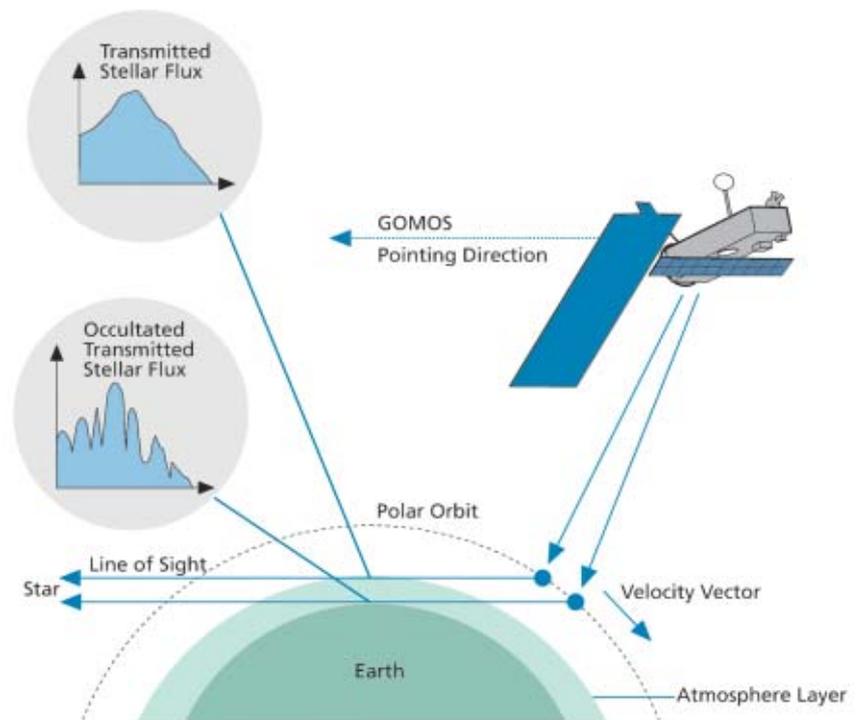
The excellent performance of the GOMOS instrument stems from:

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

As a result, the spectra are easily corrected for background or stray-light and detector dark-current contributions. Thus, high stability is obtained from simple relative measurements. Over a five-year mission period, ozone-level changes as low as 0.05% per year can be detected, which is far below the depletion rate expected from model calculations.

Michelson Interferometer for Passive Atmospheric Sounding (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 atmospheric emissions from the Earth's horizon (limb) in the mid-infrared region (4.15–14.6 micron), providing global observations of photo-chemically interrelated trace gases in the middle atmosphere and upper troposphere.



These data will contribute to the development of a better understanding in the following research areas:

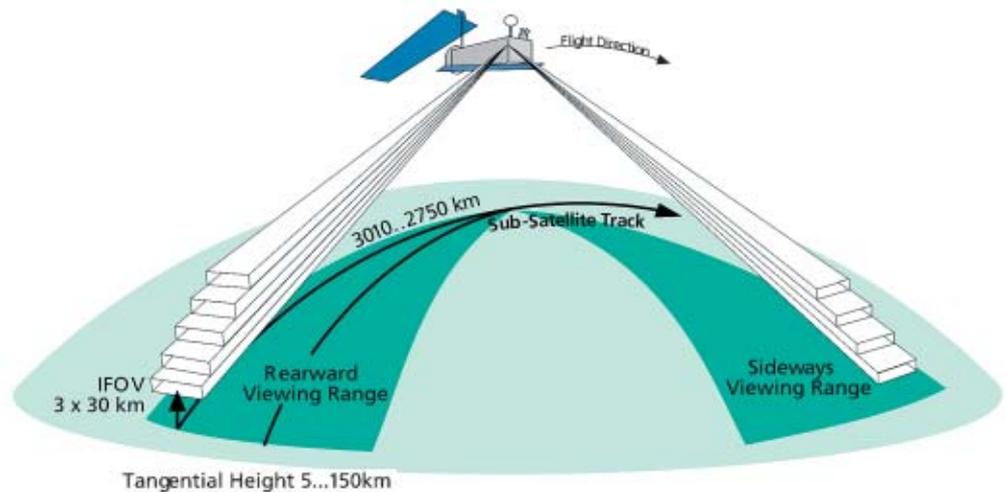
- Stratospheric Chemistry: global ozone problem, polar stratospheric chemistry.
- Global Climatology: global distribution of climate-relevant constituents.
- Atmospheric Dynamics: stratospheric transport exchange between troposphere and stratosphere.
- Upper Tropospheric Chemistry: correlation of gas distribution with human activities.

The instrument is designed to allow simultaneous measurement of more than 20 relevant trace gases, including the complete NO_y family and several CFCs. Atmospheric temperature as well as the distributions of aerosol particles, tropospheric cirrus clouds and stratospheric ice clouds (including polar stratospheric clouds) are other important parameters that can be derived from MIPAS observations. These data will be obtained over the complete orbit, for all seasons and independent of illumination conditions, allowing measurement of the diurnal variations of the trace species. Atmospheric emissions will be measured at the Earth's horizon (limb) over a height range of 5 – 150 km. This observation geometry provides maximum measurement sensitivity and allows a good profiling capability to be achieved.

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

Figure 9. GOMOS observing principle

Figure 10. The MIPAS viewing geometry



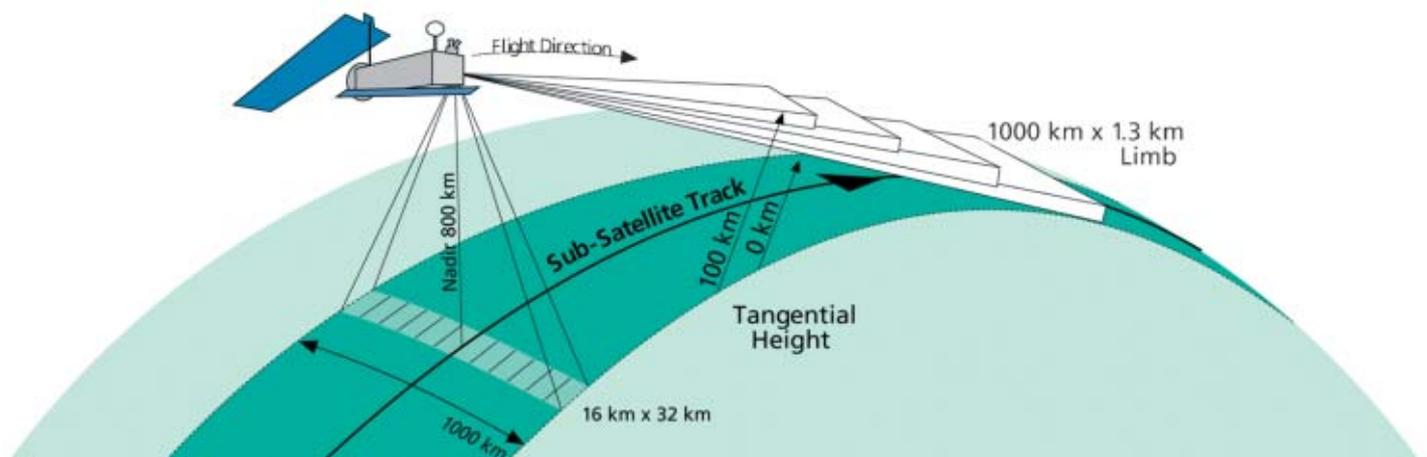
viewing range on the anti-Sun side (Fig. 10). The rearward viewing range will be used for most measurements, since it provides good Earth coverage, including the polar regions. The sideways range is important for observations of special events, like volcanic eruptions, trace-gas concentrations above heavily polluted areas, or concentration gradients across the dawn/dusk boundary.

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

Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY)

The primary scientific objective of SCIAMACHY is the global measurement of various trace gases in the troposphere and stratosphere, which are retrieved from the instrument by observing the transmitted back-scattered and reflected radiation from the atmosphere in the wavelength range 240 – 2400 nm. This large range is also ideally suited for the determination of aerosols and clouds.

Figure 11. The SCIAMACHY viewing geometry



The nadir- and limb-viewing strategy for SCIAMACHY (Fig. 11) 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 from SCIAMACHY will enable the investigation of a wide range of phenomena that influence atmospheric chemistry:

- in the troposphere: biomass burning, pollution, Arctic haze, dust storms and industrial plumes
- in the stratosphere: ozone chemistry, volcanic events and solar-proton events.

The scientific objectives are achieved by observing the atmosphere under different viewing angles. In nadir viewing mode, the global distribution (total column values) of atmospheric trace gases and aerosols will be observed. Cloud measurements will also be obtained. In this mode, the instrument is scanning across-track, with a swath width of ± 500 km with respect to the sub-satellite track. To obtain the altitude distribution of trace gases, SCIAMACHY performs limb observations over an altitude range of 100 km, with a vertical

resolution of 3 km. Nadir and limb observations are then interleaved to obtain dual observations over the 1000 km swath width.

Differential Optical Absorption Spectroscopy is applied in Sun and Moon occultation measurements, where either the Sun or Moon is tracked or a vertical scan over the complete solar or lunar surface is performed. The spectra obtained can then be compared with suitable calibration spectra to yield the differential absorption of the atmosphere.

The Altimetry mission

The Altimetry mission is fulfilled by the Radar Altimeter (RA-2), supported by three other instruments:

- the Microwave Radiometer, to correct for the wet-path atmospheric contribution
- the Laser Retro-Reflector, to allow precise ranging by ground laser stations and hence calibration of the RA-2 altitude
- the DORIS system (on-board receiver and on-ground beacon network), to provide a high-accuracy orbit.

Radar Altimeter 2 (RA-2)

RA-2 is derived from the ERS-1 and -2 Radar Altimeters, providing both improved measurement performance and new capabilities. The main objectives are the high-precision measurement of the time delay, power and shape of the reflected radar pulses to determine the satellite height and Earth-surface characteristics (Fig. 12). When operating over oceans, these measurements will be used to determine the ocean topography, thus supporting research into ocean-circulation, sea-floor and marine-geoid characteristics. The processing of the radar echo power and shape

enables the determination of wind speed and significant wave height in the observed sea area, thereby also supporting weather and sea-state forecasting. In addition, RA-2 is able to map and monitor sea ice and polar ice sheets.

The new features of RA-2 enable it to extend the measurements of altitude and reflectivity over land. They will be used for the determination of surface elevation, geological structure and surface characteristics. RA-2 transmits radio-frequency pulses, which propagate at approximately the speed of light. The time elapsed from the transmission of a pulse to the reception of its echo reflected from the Earth's surface is proportional to the satellite's altitude. The magnitude and shape of the echoes contain information on the characteristics of the surface that caused the reflection.

On board the satellite, RA-2 measures the power level and time position of the samples from the earliest part of the echoes from ocean, ice and land surfaces. This is achieved using one of the new features on RA-2: a model-free tracker in the on-board signal processor that keeps the radar echoes within the sampling window. Window position and resolution are controlled by algorithms developed to suit the tracking conditions. Adaptive height-resolution operation is implemented by selecting the bandwidth of the transmitted pulses. As a result, measurements over the ocean are carried out at the highest resolution. Tracking is maintained over land, ice or during transitions from one kind of surface to another, sometimes by accepting a certain degradation in height resolution. Accurate altitude measurements over the ocean at the main frequency of

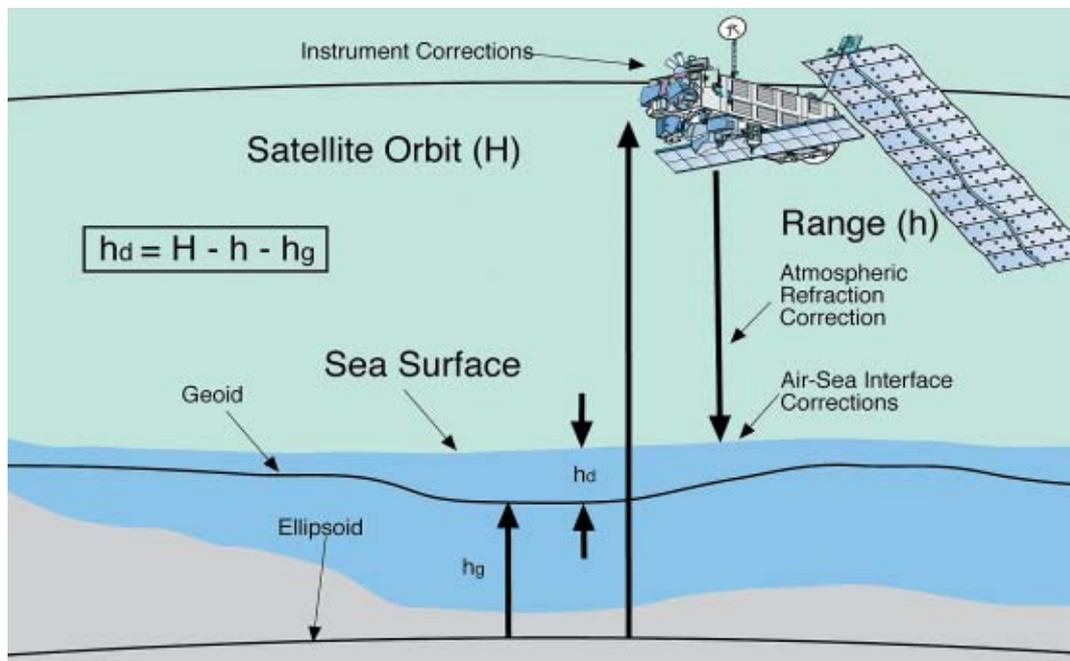


Figure 12. RA-2 derived height measurements

13.575 GHz are affected by fluctuations in the ionosphere beneath the satellite, but measurements in a second channel at 3.2 GHz enable those errors to be corrected.

The Laser Retro-Reflector (LRR)

The Laser Retro-Reflector (a passive device composed of nine reflective corner cubes) is mounted on the nadir-pointing face of the satellite close to the RA-2 antenna. An identical design was flown on the ERS satellites. The LRR will be used as a reflector by ground-based laser-ranging stations to provide precise ranging data, which will be correlated with RA-2 and DORIS data for calibration purposes.

The Microwave Radiometer (MWR)

The MWR's main role is the measurement of atmospheric humidity as supplementary information for tropospheric path correction of the Radar Altimeter signal, which is influenced both by the integrated atmospheric water-vapour content and by liquid water. In addition, MWR measurement data will be useful for the determination of surface emissivity and soil moisture over land, for the surface-energy budget investigations to support atmospheric studies, and for ice characterisation.

The MWR instrument is a derivative of the radiometers used on the ERS-1 and -2 satellites. It is a dual-channel, nadir-pointing Dicke-type radiometer, operating at frequencies of 23.8 and 36.5 GHz. Differential measurements have to be performed at two frequencies in order to eliminate the Earth's radiation.

Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS)

DORIS is an orbit-determination system that provides satellite orbit data with accuracies in the order of centimetres. In conjunction with the Radar Altimeter, DORIS will contribute to climatology studies by measuring spatial and temporal ocean-surface topography changes and variations in ice coverage.

DORIS is based upon the accurate measurement of the Doppler shifting of radio-frequency signals transmitted from ground beacons and received on-board the satellite. Measurements are made at two frequencies: at 2.03625 GHz for precise Doppler measurements, and at 401.25 MHz for ionospheric correction of the propagation delay.

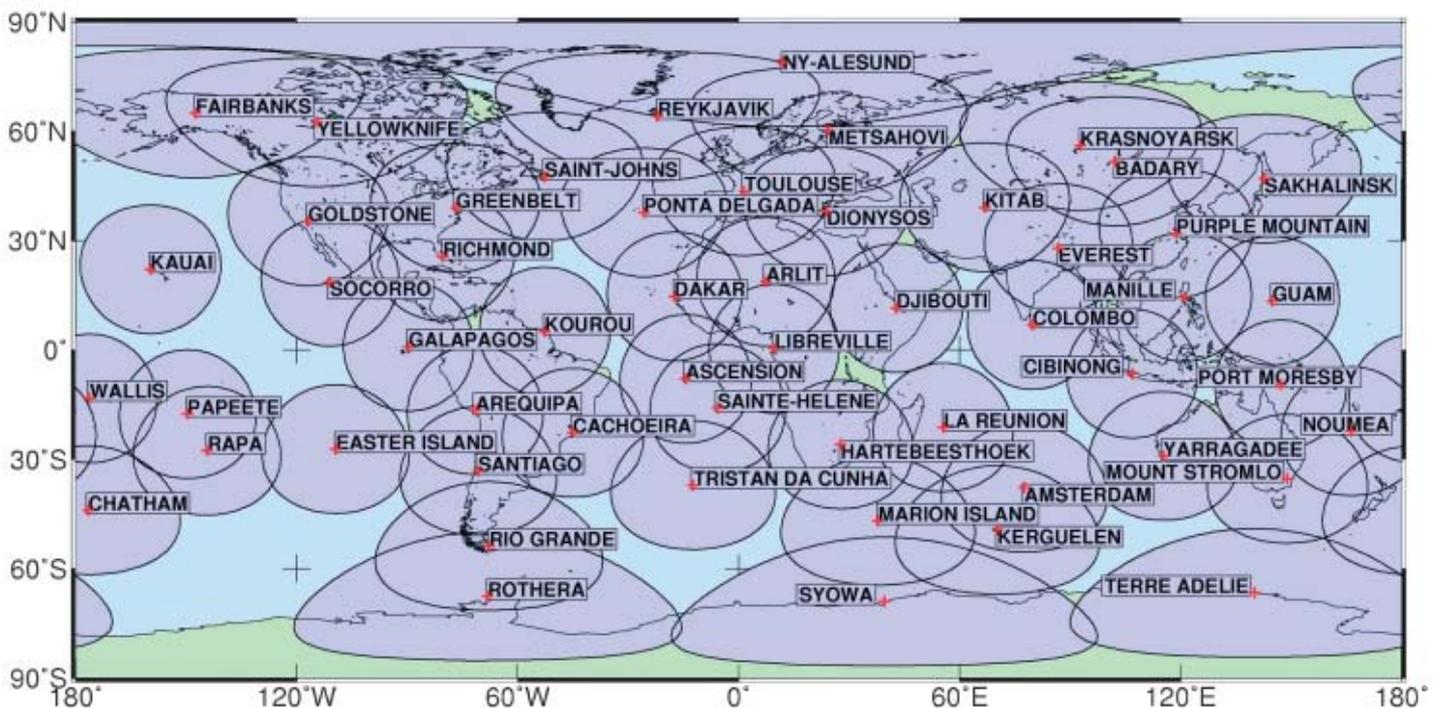
DORIS will allow the determination of Envisat's position with an accuracy of better than 0.05 m radially, and its velocity with an accuracy of better than 0.4 mm/s. The DORIS system comprises the on-board instrument, a beacon network, the DORIS Control and Data Processing Centre and a network of more than 55 ground beacons deployed around the world (Fig. 13).

The mission-operations scenario

Payload data recording and transmission

Envisat has both global and regional mission objectives. The regional mission is constituted by the ASAR operating in its high-rate modes and MERIS in its full-resolution mode. These data will be acquired on a regional basis to meet specific user requests, as well as to build

Figure 13. The DORIS ground-beacon network



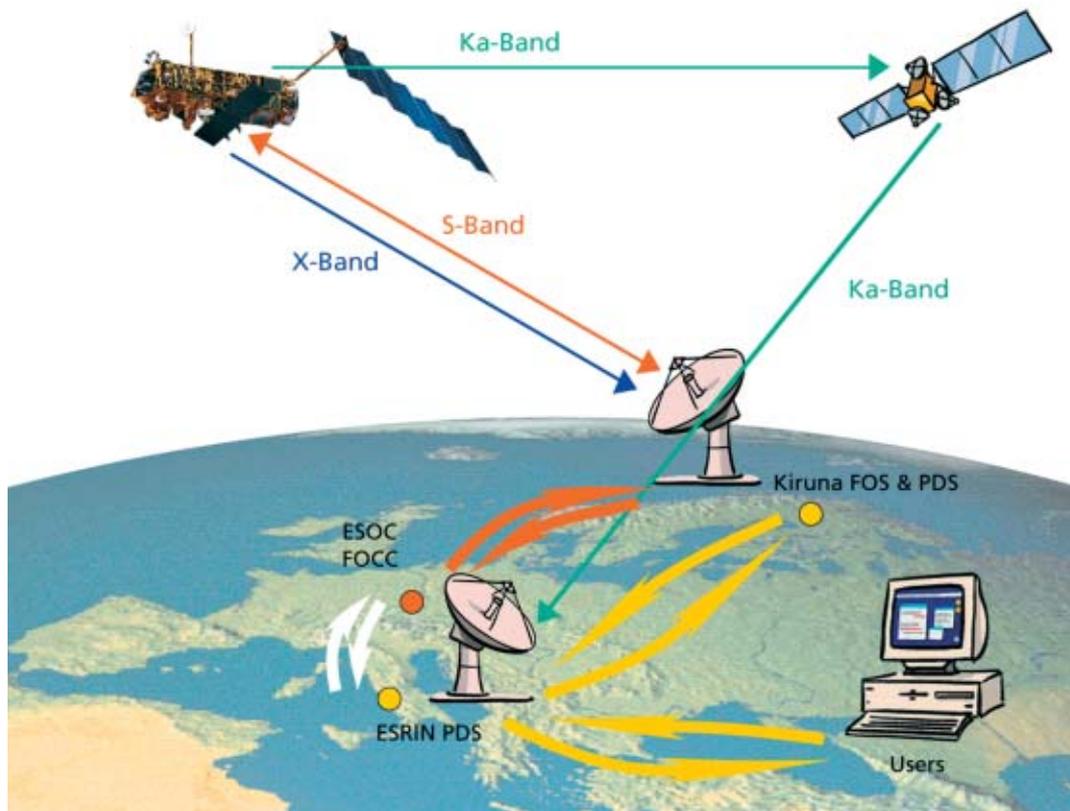


Figure 14. The Envisat system

up a reference data archive, following a background data-acquisition plan. All other instruments, including the low-rate modes of ASAR and MERIS, constitute the global mission, with instruments operated on a continuous basis around the orbit (for the MERIS low-resolution mode, this is limited to the 43 min Sun-illuminated part of the orbit).

For payload data recovery, Envisat is equipped with direct X-band links to ground stations as well as with Ka-band links relayed via ESA's geostationary data-relay satellite Artemis. The requirement for global coverage implies the use of on-board data storage, and so the satellite is equipped with two 70 Gbit solid-state recorders, and a 30 Gbit tape recorder as a backup. The solid-state recorders will permit:

- Complete global data collection (the 4.5 Mbps composite data stream), with data dumping once per orbit when in view of an ESA station (X-band at Kiruna, or Artemis satellite data-relay link to ESRIN).
- Recording of ASAR and MERIS high-rate data on a regional basis, when not within X-band station or Artemis visibility.

To downlink the stored data within the minimum ground-contact time, playback rates of 50 and 100 Mbps are provided. For the downlinking of the different categories of measurement data, the following channels (each transmitting 100 Mbps) are available:

- one X-band channel used for recorder dumps and the real-time transmission of MERIS full-resolution data

- one X-band channel for ASAR high-rate measurement data, or alternatively high-rate dumping of recorded regional data.
- two Ka-band channels, with the same data allocation as for X-band, for transmissions via Artemis.

Payload data-recovery scenarios

There are two data-recovery scenarios:

- the baseline scenario, sharing the workload equally between the Kiruna station, receiving the X-band links, and ESRIN, receiving the Ka-band links relayed via Artemis
- the back-up scenario, in case of unavailability of Artemis, making use of X-band links only, but ensuring full data recovery via the Kiruna station (for 9 to 10 orbits per day) and the Svalbard station (for the remaining 4 to 5 orbits per day).

In both scenarios, recorded-data dumps will be performed only in visibility of the ESA stations, and X-band direct transmission of regional data will only be provided in visibility of stations having a valid licence. Both scenarios allow the global as well as the regional mission objectives to be fulfilled.

The Ground Segment

The Ground Segment, which provides the means and resources needed to efficiently manage and control the satellite operations and the provision of user services, has two major elements:

- the Flight Operations Segment (FOS)
- the Payload Data Segment (PDS).

Flight Operations Segment (FOS)

The FOS is composed of the Flight Operations Control Centre (FOCC), located at ESOC in Darmstadt (D), and the associated command and control stations. It will control the satellite throughout all mission phases, including:

- satellite operations planning
- mission planning interface with Artemis
- command and control of the satellite
- up-loading of operation schedules on a daily basis via the TT&C station at Kiruna-Salmijärvi.

Furthermore, the FOCC will support:

- satellite configuration and performance monitoring
- software maintenance for the spacecraft and payload elements
- orbit prediction, restitution and maintenance.

Satellite command and control will nominally be performed using the two command and control stations of Kiruna-Salmijärvi and Svalbard. The Kiruna-Salmijärvi station is the primary control station for 9 to 10 consecutive orbits per day, and the remaining 4 to 5 orbits per day will be accessed via the Svalbard station. For the Launch and Early Orbit Phase (LEOP), 7 extra stations will supplement the network to ensure good coverage of the critical events (Fig. 15).

The FOCC prepares the satellite operation plans based upon a fixed strategy defined for the global mission, and operation requests received from the Payload Data Control Centre (PDCC) for the regional mission. It also plans

the Artemis-related operations and interfaces with the Artemis mission-planning facilities.

The FOC facilities are based on an upgrade of ESOC's well-proven SCOS-1B system used for the two ERS missions. This upgrade has been performed with successive deliveries allowing a stepwise acceptance and validation process. A satellite simulator, emulating Envisat's on-board software, supports operational-procedure validation and FOCC operator training. The flight-dynamics software, derived from the ORATOS system already in use for ERS, has been upgraded to support star-tracker control and monitoring. The orbit-prediction, orbit-restitution and orbit-control/manoeuvre-planning activities will be performed as for ERS, with the same software and in-orbit control strategy.

Payload Data Segment (PDS)

The PDS comprises all of those elements related to payload data acquisition, processing and archiving, as well as those concerning the user interfaces and services. It will thus provide:

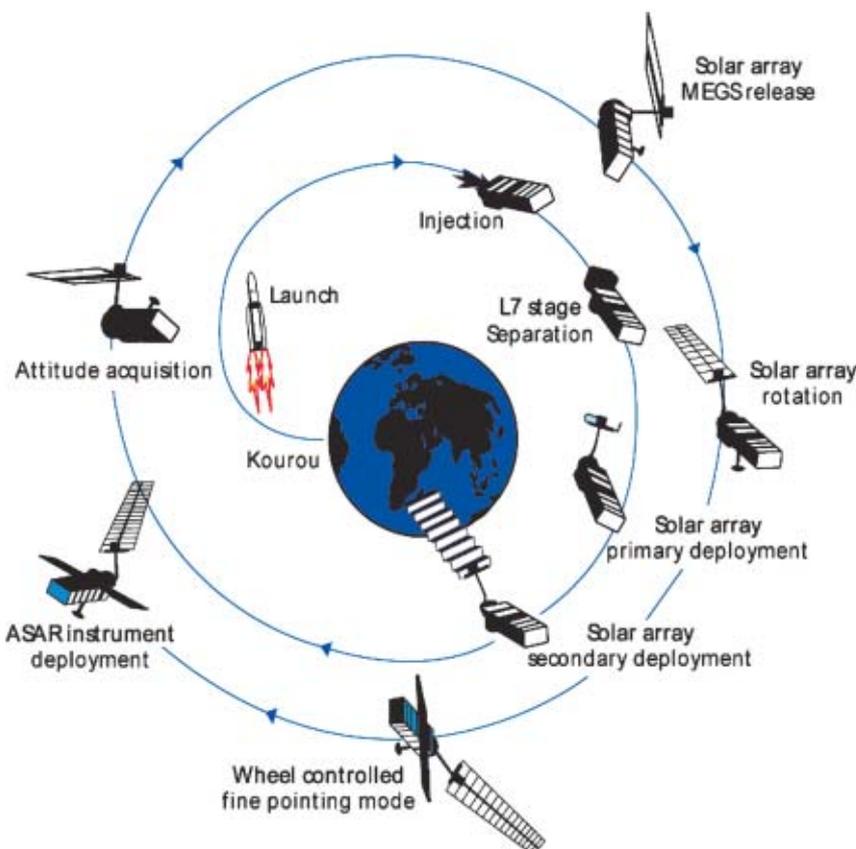
- all payload data acquisition for the global mission
- regional data acquisition performed by ESA stations
- processing and delivery of ESA Fast Delivery Products
- data archiving, processing and delivery of ESA offline products, with the support of the Processing and Archiving Centres (PACs)
- interfaces with national and foreign stations acquiring regional data
- interfaces to the user, ranging from order handling to product delivery.

The PDS centres and stations will be coordinated by the PDCC located at ESRIN, in Frascati (I). The PDCC will interface with the FOCC for all mission-planning activities. The PDS ESA stations include:

- the Payload Data Handling Station (PDHS-K), located at Kiruna-Salmijärvi (S), providing X-band data reception
- the PDHS-E, located at ESRIN, receiving via a User Earth Terminal (UET) data relayed by Artemis (Fig. 16)
- the Payload Data Acquisition Station (PDAS), located at Fucino (I), providing direct X-band data reception for the regional mission and offering, together with the Kiruna station, coverage of Europe and the Mediterranean basin.
- the PDHS-S, located at Svalbard (N) and used when Artemis is not available, to complement the Kiruna PDHS for ensuring the recovery of all payload data dumps.

The PDCC builds up satellite observation scheduling based upon user requests, and

Figure 15. LEOP critical events



provides it to the FOCC for satellite operations planning. With its four stations, the PDS acquires all payload data directly, or in deferred mode via on-board recorder data dumps. They are processed in Near Real Time (NRT), to provide users with a complete suite of products within 3 h of an observation being made. For this purpose, all operating strategies, with or without Artemis, ensure that the data stored on-board are dumped every orbit within the visibility of one of the ESA PDS stations. For providing offline products, the PDS relies on the Processing and Archiving Centres (PACs), implemented with national funding by the Participating States. The ESA PDS centres and stations are being provided via a single Envisat PDS procurement action, led by Alcatel.



Figure 16. The Artemis User Earth Terminal antenna at ESRIN, in Frascati (I)

Offline Centres providing Level-1b and -2 Products

LRAC	Low-Rate Archiving Centre for all Level-1b global mission products	at Kiruna-Salmijarvi (S)
D-PAC	All atmospheric products (with FMI for GOMOS) and ASAR*	at DLR, Oberpfaffenhofen (D)
F-PAC	RA-2, MWR and Doris Orbit products	at CNES, Toulouse (F)
I-PAC	ASAR and MERIS FR products*	at ASI, Matera (I)
E-PAC	MERIS FR products*	at Maspalomas (E)
S-PAC	MERIS RR products, co-located with the LRAC	at Kiruna-Salmijarvi (S)
UK-PAC	AATSR and ASAR*	at NRSC, Farnborough (UK)

* For ASAR and MERIS FR, archive and offline services are shared between several PACS

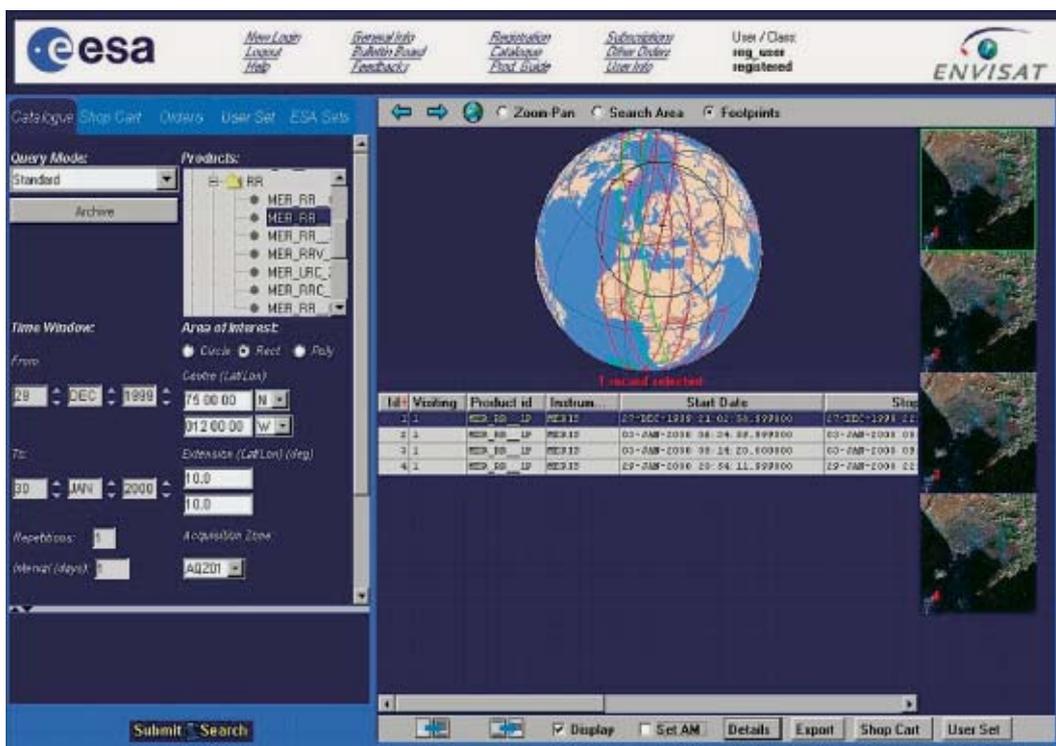


Figure 17. A typical user screen

Since the PACs are providing offline ESA products based upon the same processing algorithms as the NRT products, the PACs are requested to use the facilities developed for the PDS. These facilities are made available to them as generic elements, with each PAC procuring its computer hardware setup, on which the generic elements are installed, to build up the specific configuration required to fulfil its assigned tasks. With this approach the users get, for each instrument, a single suite of coherent NRT and offline products. ESA is committed to guarantee, with the support of Expert Support Laboratories (ESLs), continuous calibration and validation of the PDS products throughout the mission's lifetime, as well as processing-algorithm upgrades as required. Consequently, only one set of processors will be maintained and upgraded, ensuring coherency of all the user PDS services, whilst at the same time minimising the corresponding overall maintenance costs.

User services

The user services offer, via Internet:

- a unified user interface, search mechanism and ordering interface, without the need to know where the data are physically stored, since all stations and centres are linked by a PDS internal network (ordering of products requiring specific data acquisition will be routed to the PDCC)
- on-line browsing for all imaging instruments and the possibility of obtaining direct on-line delivery of small products
- ordering on a subscription basis for the systematic delivery of selected product type(s) in NRT or off-line.

The Internet user screen is illustrated in Figure 17.

The on-line product data dissemination will benefit from the use of ground lines as well as of

a dedicated Data Dissemination System via satellite over Europe, offering a sustained rate of 2 Mbps, 24 hours per day, for data reception by very small DVB terminals.

PDS products and validation activities

ESA is committed to provide, with the PDS, a complete suite of Level-1b products and a comprehensive set of Level-2 products. Level-1b products are geo-located data products providing engineering quantities directly derived from the instruments: radiance, reflectance, transmittance, polarisation, radar back-scattering values, and radar echo-time delay. These products are presented as images for ASAR, MERIS and AATSR.

All Level-1b products will be calibrated during the in-orbit Commissioning Phase. Various techniques will be involved, using on-board calibration devices and/or specific modes of the instruments to observe targets in the sky (Sun, Moon, stars) or on the Earth (natural stable targets, like deserts or tropical forests, as well as specially developed targets like transponders or radar corner-reflectors).

Level-2 products will provide geophysical variables obtained by processing the Level-1b products further using validated geophysical algorithms. Level-2 products will provide quantitative values for atmospheric variables (temperature, pressure, atmospheric constituents, aerosol and cloud parameters) as well as marine variables (ocean surface winds and waves, ocean and coastal-zone water constituents, sea-surface temperature), and land variables (vegetation indices, temperatures, pressures and reflectances).

For each geophysical data product, a specific validation is required. It will be performed by correlating the obtained data products with various in-situ measurements using ground-based, airborne and balloon-borne instruments. In addition, comparisons will be performed with other satellite data as well as analyses based on the use of data assimilation models (meteorology, climatology, etc.).

Samples of these products (Fig. 18) have already been produced and distributed to the users for familiarisation purposes.

Before the end of the Commissioning Phase, all of the Level-1b products will be released as calibrated products. Most of the Level-2 products will be released with notification to the user of the corresponding confidences and error bars. For products obtained from Envisat instruments having an ERS heritage, the

Figure 18. PDS data-product samples already produced



validation will be performed within 6 months of launch. That for the novel instruments such as MERIS and the three atmospheric instruments will take somewhat longer.

Data policy

The Envisat Data Policy, illustrated in Figure 19, defines two categories of use:

- Category-1 use: for research and applications development
- Category-2 use: for operational and commercial use.

For Category-1 use, 700 proposals, including 130 proposals to support product validation, have been selected in response to an Announcement of Opportunity issued by ESA in 1998. Category-1 users will be served directly by the ESA PDS. For Category-2 users, two worldwide distributors have been selected: SARCOM, led by Spot Image, and EMMA, led by Eurimage. Some niche distributors have also applied for specific licences, in accordance with the provisions laid down in the approved Envisat Data Policy. The PDS services and data products will be available to all distributors.

Conclusion

With the Envisat Programme, European space industry and the scientific community supporting the Programme are reinforcing Europe's position at the leading edge of Earth-observation technology and services, following up the successful ERS missions. Given its sheer size, the Envisat development programme has required the involvement of almost all of Europe's space industries in the development of numerous advanced technologies, particularly for the payload.

The mission is attracting very great interest in the Earth-science community, both at European level and worldwide. This was demonstrated conclusively by the response to the Announcement of Opportunity for Envisat data exploitation and the large involvement of scientists in the preparation of the product-validation activities for the in-orbit commissioning phase.

Ariane-5 is set to inject Envisat directly into its Sun-synchronous orbit in Autumn 2001. After the few weeks required to get the satellite and its payload operational and to set up the various data-recovery links, the main challenge remaining will be to complete the Commissioning Phase and to achieve, within its tight schedule, the timely availability of the engineering calibrated and geophysically

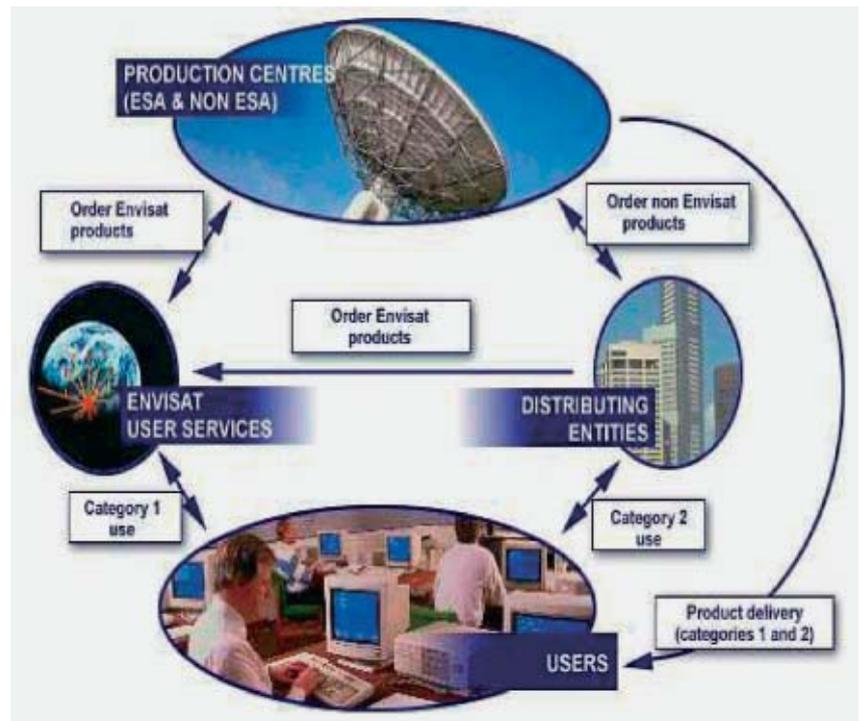


Figure 19. The Envisat Data Policy's implementation

validated data products. Envisat should then respond very well to the high expectations of the users and provide them with reliable data products for at least the nominal five-year lifetime of the satellite.

Acknowledgement

The extremely ambitious development of the Envisat space segment has been successfully achieved thanks to the skilled and sustained support received, over almost ten years, from the European space industry teams led by Astrium Ltd. And Astrium GmbH.

Thanks also go to Alcatel Space for leading the challenging development and integration of the Payload Data Segment (PDS), which is the most comprehensive Earth-observation ground segment ever built. This venture would not have succeeded without the brilliant contributions of the Expert Support Laboratories, all over Europe and in Canada, in developing the processing algorithms for the instrument products implemented in the PDS.

Finally, my great thanks go to the ESA teams at ESTEC, ESOC and ESRIN for their dedication to the Envisat Programme and their great team spirit. The availability and complementary expertise of these teams has been essential to the achievements so far, as well as for the challenging tasks that still lie ahead with the final launch preparations and the planned in-orbit activities.