Research Activities in Response to the Envisat Announcement of Opportunity

Y-L. Desnos, F. Palazzo*, P. Regner, C. Zehner, J. Benveniste & M. Doherty
Earth-Observation Applications Department, ESA Directorate of Earth and Environment Monitoring from Space, ESRIN, Frascati, Italy

Since the launch of ERS-1 in 1991, ESA has issued several Announcements of Opportunity (AOs) for scientific research and application development using ERS satellite data. A total of more than 1000 projects proposed by scientific investigators from around the world have been selected and accepted. The outcomes of the various AO projects have been presented at ESA-organised Symposia and Workshops and published in the scientific literature. The Envisat AO, issued in December 1997, led to the selection of 674 proposals in support of scientific research, application development and calibration and validation. This is the largest and most diverse AO ever issued by ESA in the Earth-observation field.

Introduction

Over the last ten years, ESA has released six Announcements of Opportunity to exploit ERS and now Envisat satellite data, with the goal of fostering scientific knowledge and our understanding of the Earth's environment. The primary objectives of all of the AOs were to support scientific research, stimulate the development of algorithms and products, and to support application demonstrations. In addition, they facilitated the transfer of scientific results into sustainable applications/services and supported the transfer of technology. By signing the ESA Terms and Conditions, the project leaders of the accepted AO proposals agreed to generate regular reports on their project's progress. As a result, the achievements of the ERS-1 and ERS-2 mission projects have been published in more than 8000 papers or articles (Fig. 1), covering all of the Earth-sciences disciplines.

The exciting results provided from past AOs, together with Envisat mission's ability to make significant contributions to environmental studies, generated a massive response to the first Envisat AO. The new sensors onboard Envisat will, in fact, open new perspectives for research dealing with atmospheric chemistry (GOMOS, MIPAS, SCIAMACHY) ocean colour and marine biology (MERIS), and will consolidate ongoing research in all of the other scientific disciplines, ensuring continuity with the ERS observations. The overview of worldwide participation in the ERS and Envisat AOs in Figure 2, shows that the number of accepted Envisat projects is more than double those for the third ERS AO.

The Envisat Announcement of Opportunity

In October 1998, the results of the review of the 734 proposals submitted in response to the

* SERCO SpA support to ESRIN

Figure 1. Striking results from the use of ERS-1/ERS-2 data

first Envisat AO were presented to the ESA Earth Observation Programme Board, formalising the final acceptance of 674 proposals (the list of accepted proposals is available on the Web at http://esa-ao.org/accepted.pdf)

Proposals had been submitted from more than 40 different countries, covering the three main categories defined in the AO, namely:

- Scientific Research
- Application Development and Demonstration
- Calibration and Geophysical Validation of Envisat Data Products.

The division of the accepted proposals into these categories reveals that the large majority (64%) fall within the scientific domain, 18% address the calibration and validation of Envisat products, and 18% deal with application development and demonstration. The majority of the proposals (70%) originate from ESA Member States (Fig. 3), but with noticeably strong participation from several other countries: the USA (87 proposals), Canada (23 proposals), and Asia (51 proposals).

The interdisciplinary character of the Envisat mission is highlighted by the Earth-sciences disciplines identified in the AO proposals in Figure 4. For example, its data will be extensively used in studies dealing with oceanography, the atmosphere, renewable resources, and environmental hazards.

In the past, the traditional Earth sciences have tended to treat questions related to environmental monitoring as separate disciplines using only one type of data. The Envisat mission will provide global and synoptic observations of different kinds of processes at different spatial and spectral resolutions at exactly the same time. This will enable researchers to identify, characterise and monitor a wide range of environmental phenomena better than ever before, and it will provide the opportunity for geophysical-validation activities. An example of simultaneous coverage by ASAR, AATSR and MERIS is shown in Figure 5.

From a preliminary statistical analysis of the data requirements of the accepted Envisat AO scientific projects, it is clear that the synergistic use of sensors will be a main issue in the case of atmosphere, ocean, coastal-zone and land environment studies. In some projects related to coastal-zone and ocean monitoring, land applications and atmosphere, the synergistic use of data from up to six instruments is envisaged. As shown in Figure 6, specific clusterings of instruments can be identified in almost all of the application fields.

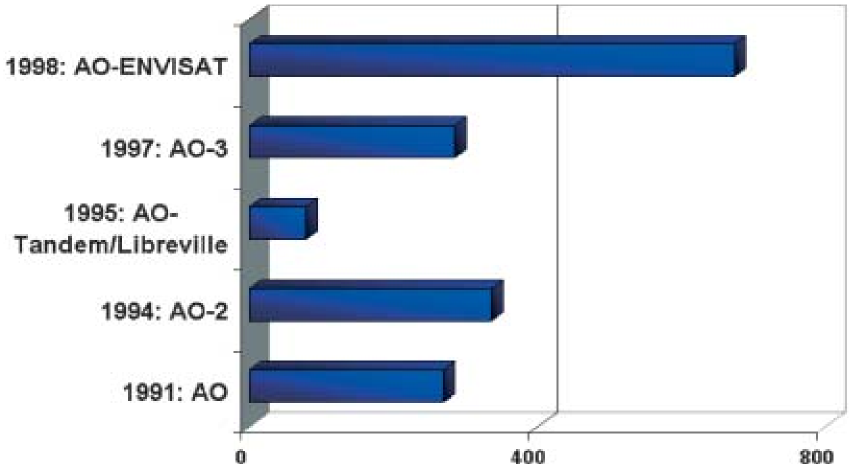


Figure 2. The acceptance statistics for the ERS and Envisat Announcements of Opportunity (AOs)

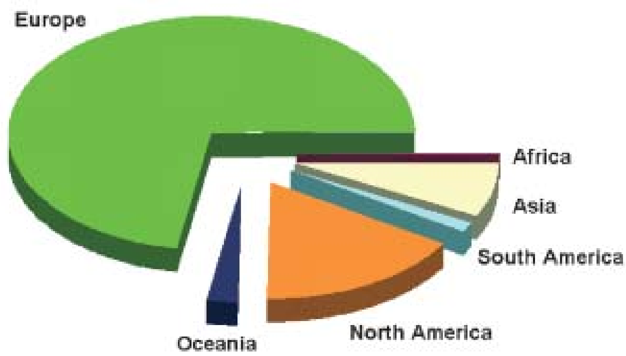


Figure 3. The geographical distribution of the accepted Envisat proposals

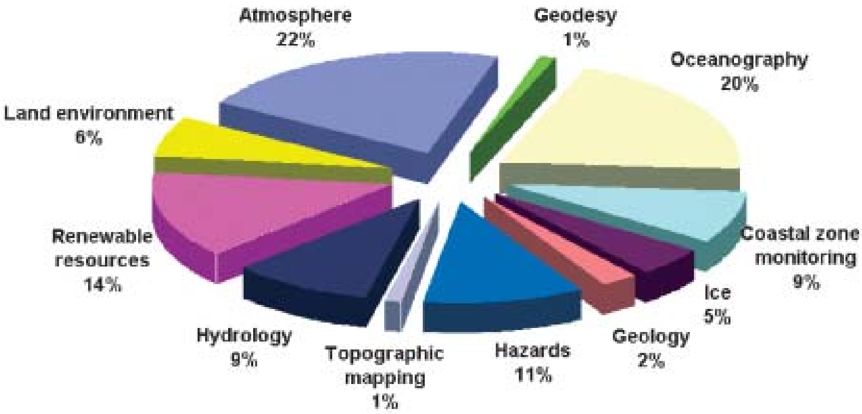


Figure 4. Thematic distribution of the accepted Envisat scientific projects

The number of scientific projects per two instrument sensor combination is shown in Table 1. For instance, three of Envisat's instruments, namely GOMOS, MIPAS, and SCIAMACHY, are dedicated to providing information on the chemical composition of the atmosphere and the concentration and distribution of greenhouse gases and aerosols. ERS provided several examples of synergies between different instruments; for example, by the combination of ATSR hot spots with GOME nitrogen-dioxide measurements, the local biomass-burning emission sources and the volume and dynamics of the emitted air pollution can be studied. The follow-on

Table 1. Scientific projects: number of projects per instrument combination

	ASAR	MERIS	AATSR	ASAR WAVE	RA2/MWR	MIPAS	GOMOS	SCIAMACHY	DORIS
ASAR	259								
MERIS	140	217							
AATSR	89	125	154						
ASAR WAVE	16	16	17	22					
RA-2/MWR	43	47	57	14	77				
MIPAS	5	11	11	0	4	59			
GOMOS	4	14	8	0	3	48	62		
SCIAMACHY	7	22	22	0	5	52	51	73	
DORIS	14	2	4	1	7	0	0	0	20

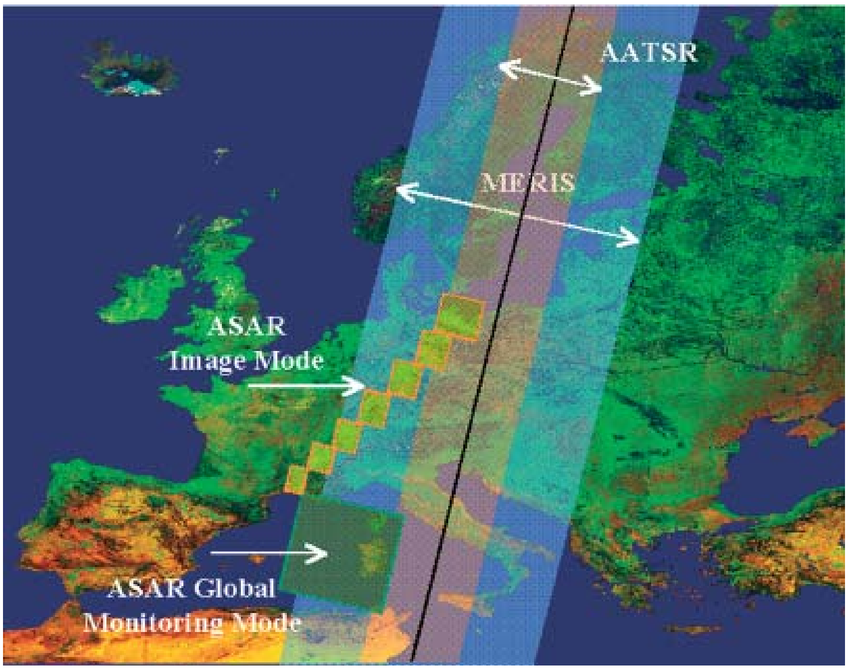


Figure 5. Synergistic observation capabilities of ASAR, MERIS and AATSR (with the satellite ground track in black)

instruments on Envisat – SCIAMACHY and AATSR – will provide the possibility to further develop their synergy, especially in terms of the derivation of new cloud/aerosol products (Fig. 7).

The synergistic use of sensors is envisaged in the case of oceanographic studies, such as MERIS, AATSR and RA-2/MWR, or the synergy between ASAR WAVE and RA2-MWR, which was successfully pioneered with ERS SAR WAVE and RA data. The provision of optical and microwave information taken simultaneously will benefit land studies, by improving land-use and land-cover classifications.

The monitoring of changes in environmental processes requires frequent repeat observations on regional to global scales. The succession of the two ERS missions and now Envisat (with its advanced and new

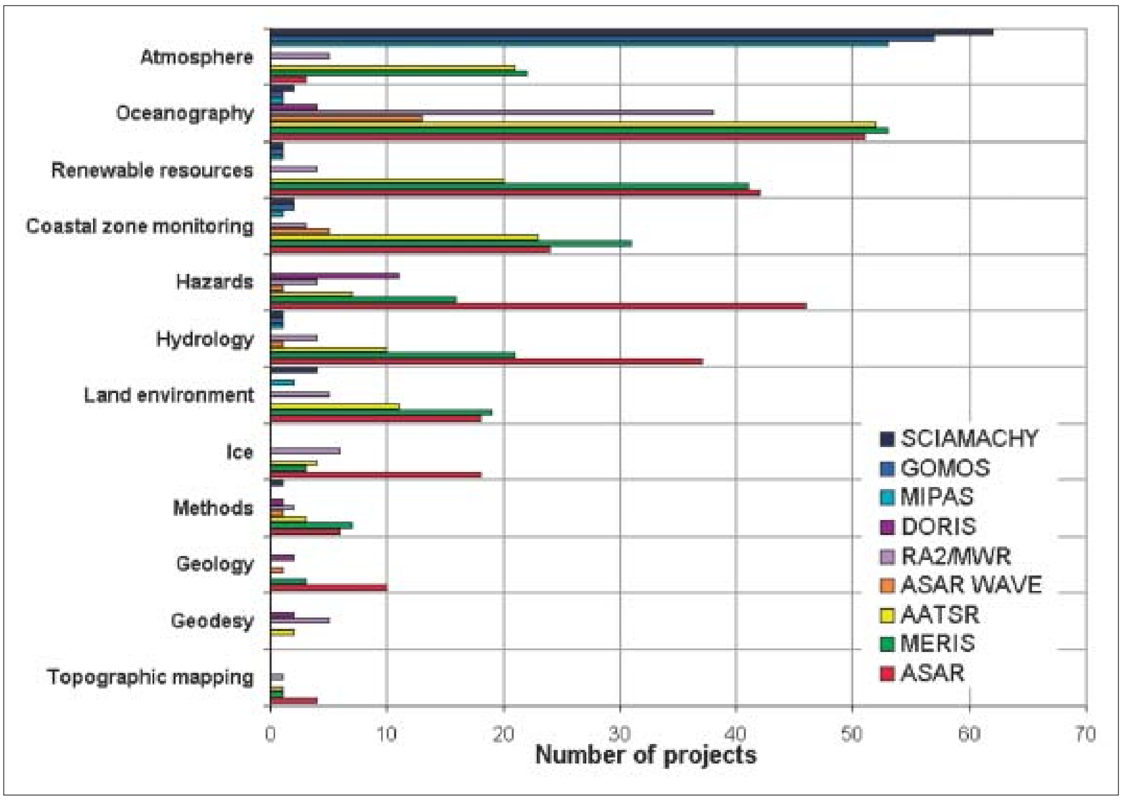


Figure 6. The scientific projects and their requested sensors

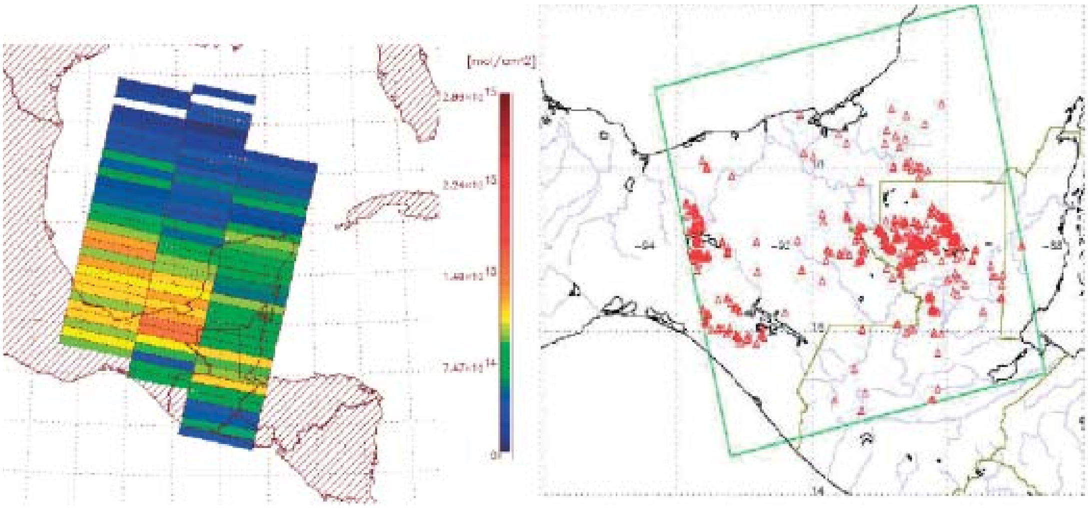


Figure 7. Forest fires in Mexico, monitored by instruments on-board ERS-2 to assess the extent and duration of the air pollution caused. Left: nitrogen-dioxide plume caused by biomass-burning over the Gulf of Mexico, measured by GOME on 13 May 1998. Right: ATSR-2 hot-spot measurements over Latin America on 13 May 1998 (Images processed at ESRIN)

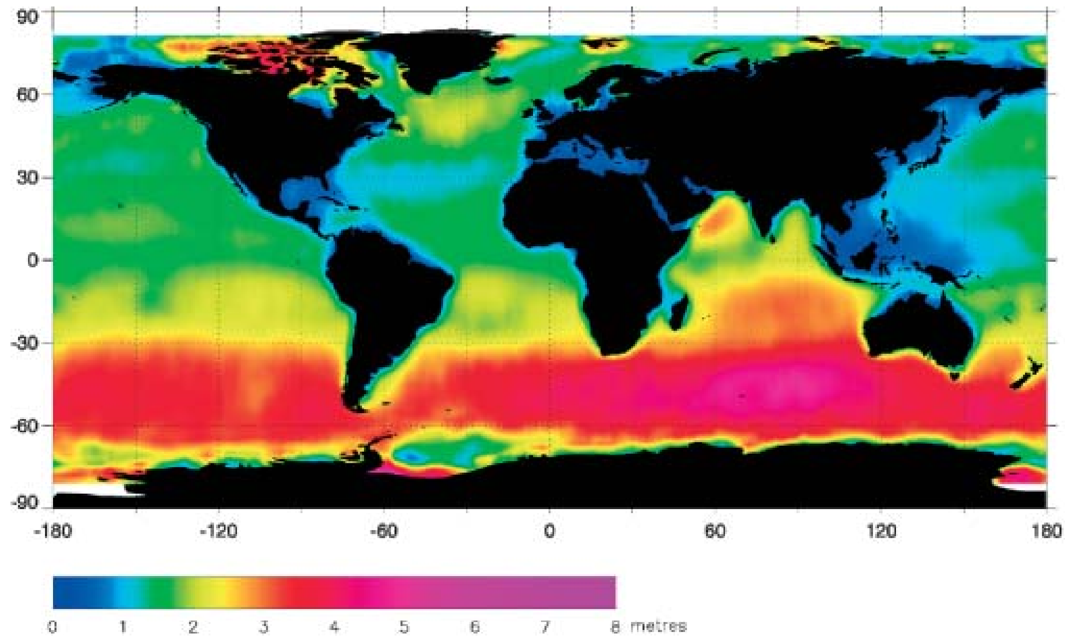
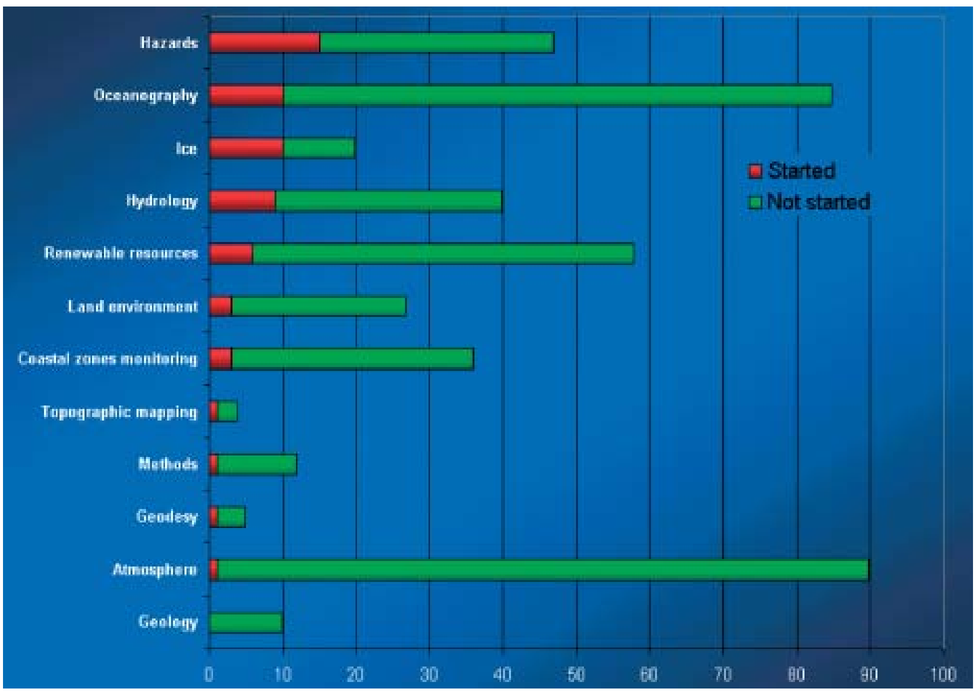


Figure 8. Map of Northern Hemisphere summer-averaged global significant wave heights from the ERS-2 Altimeter OPR final precision product. Note the high waves in the Roaring Forties and the Howling Fifties (southern winter). Seasonal mapping of the global wave field allows the monitoring of climatological trends (Image processed at ESRIN)

Figure 9. Envisat AO scientific projects already started



instruments) provides continuity of the observations relevant for oceans (Fig. 8), the cryosphere, land- and sea-surface temperatures, and ozone. Envisat products will permit the continuation of studies related to such processes as global warming, land-cover changes, and changes in the marine environment.

Data continuity is an issue for many projects: 38% of the accepted Envisat scientific projects plan to request ERS data, and to date 60 projects have already started using ERS data (Fig. 9).

Envisat will measure a large number of environmental parameters on local to global scales, and will offer new opportunities to obtain a comprehensive understanding of the

Earth as an integrated, dynamic system. The major research areas addressed by the scientific community in their proposals can be classified into the categories shown in Table 2.

Atmosphere

This category addresses the understanding of the chemical composition of, and the processes occurring in, the Earth's atmosphere. Measurements performed by Earth-observation satellites (in combination with ground-based measurements) during recent decades indicate two changes in the Earth's atmosphere: an increase in global average temperature and a decrease in global ozone concentration.

Human activities are believed to be responsible for these effects due to the emission of both greenhouse gases and chlorofluorocarbons (CFCs) into the atmosphere. Greenhouse gases (like water vapour, carbon dioxide and

Table 2. Breakdown of the Envisat scientific projects showing the different topics being studied, by main theme and sub-theme

Theme	Sub-theme
Atmosphere	• Atmospheric constituents: retrieval and geophysical results - 29 • Clouds, aerosols, surface parameters - 22 • UV radiation, Air pollution - 3 • Trend analysis, Assimilation - 21 • Chemistry models - 16
Oceanography	• Wind-waves - 6 • Primary production (Geochemistry, Fisheries, SST) - 25 • Ocean dynamics (Circulation, Sea-level, NRT) - 20 • Sea-features (Ship detection, Air-sea features) - 13 • Sea-ice - 17
Geodesy	• Geodesy - 5
Coastal-zone monitoring	• Bathymetry mapping - 2 • River discharge mapping - 7 • Coastal protection and change monitoring (algae blooms, erosion assessment, water pollution...) - 30
Ice	• Ice-sheet mapping - 5 • Ice-sheet dynamics - 15
Hydrology	• Snow melt - 8 • Soil moisture - 16 • Wetlands - 10 • Run-off - 4 • Water cycle - 2
Renewable resources	• Agriculture - 11 • Vegetation - 14 • Forestry - 16 • Land cover mapping - 17
Land environment	• Environment (Mapping, Urban, Climatology, Global change...) - 17 • Land surface temperature - 7 • Desertification - 3
Geology	• Geological mapping - 4 • Archaeology - 2
Hazards	• Earth motion (Subsidence, Crust motion) - 10 • Earthquakes - 14 • Volcanoes - 11 • Floods - 3 • Landslides and Soil erosion - 5 • Various hazards - 7
Topographic mapping	• DEM - 5
Methods	• Algorithm development, Software development, Product development, Validation -12

methane) allow short-wave radiation to enter, but block the outgoing long-wave radiation, thereby warming the air in the atmosphere. Such gases are produced by the burning of fossil fuels (coal, oil, and natural gas for heating and electricity; gasoline for transportation), de-forestation, cattle ranching, and rice farming. Some of the impacts of global warming may include stronger storms, migration of agricultural zones, spreading of tropical diseases, melting of glaciers and ice caps and increases in pollution levels. CFCs (used for refrigeration, solvents, and aerosol propellant) stay in the atmosphere for a long time (e.g. CFC-11 ~50 years) and deplete the ozone in the stratosphere. When this occurs, the atmosphere's ability to block ultraviolet radiation is diminished. This UV radiation might have an impact on the human immune responses and could cause infectious diseases, the induction of skin cancers, particularly basal-cell carcinomas and melanoma, and eye diseases, especially cataracts. International protocols (Montreal 1987, Kyoto 1997) were signed by the leading industrial countries to reduce the emission of trace gases responsible for ozone destruction and global warming. Global measurements from satellites provide a very good means of monitoring them.

ERS AO projects using GOME measurements (Fig. 10) on the one hand enabled new research topics (e.g. trace-gas retrieval in the troposphere, improving insight into the variability of stratospheric ozone), and on the other developed the basis for such future applications as the monitoring of air pollution due to natural and industrial processes, and UV radiation monitoring to assess the impact of ozone depletion on human health and the weather.

The Envisat atmospheric payload consisting of the GOMOS, MIPAS and SCIAMACHY instruments will measure a series of trace-gas constituents with new techniques, enabling a continuation and essential extension (e.g. retrieval of greenhouse gases, development of commercial services) of the work started on ERS with GOME.

Coastal zones, oceanography and geodesy

This segment is directed at improving the understanding of the complex marine dynamics and bio-geochemical cycles. The ocean is the major regulator of heat transfer on the planet (e.g. deep-water formation in the Arctic affects temperature differences between Europe and Canada) and so monitoring the ocean's circulation and its surface temperature is crucial for climate-trend monitoring. Climate change and its impact on Europe can be understood, and hence modelled and predicted, by monitoring the energy and latitudinal position of the Gulf stream and their trends.

Almost all living creatures in the oceans depend directly or indirectly on phytoplankton, which uses photosynthesis to convert light energy and raw materials (e.g. nitrogen, oxygen, water and carbon dioxide) into food ('primary production'). Since many countries depend on fish for food and commerce, understanding the processes that affect the ocean's primary production is important from both the economic and conservation viewpoints.

MERIS will provide a wealth of ocean-colour data and derived marine parameters which, when used in synergy with other geophysical parameters such as ocean currents (RA-2/MWR, DORIS), sea-surface temperatures (AATSR), or wind fields and wave spectra (RA-

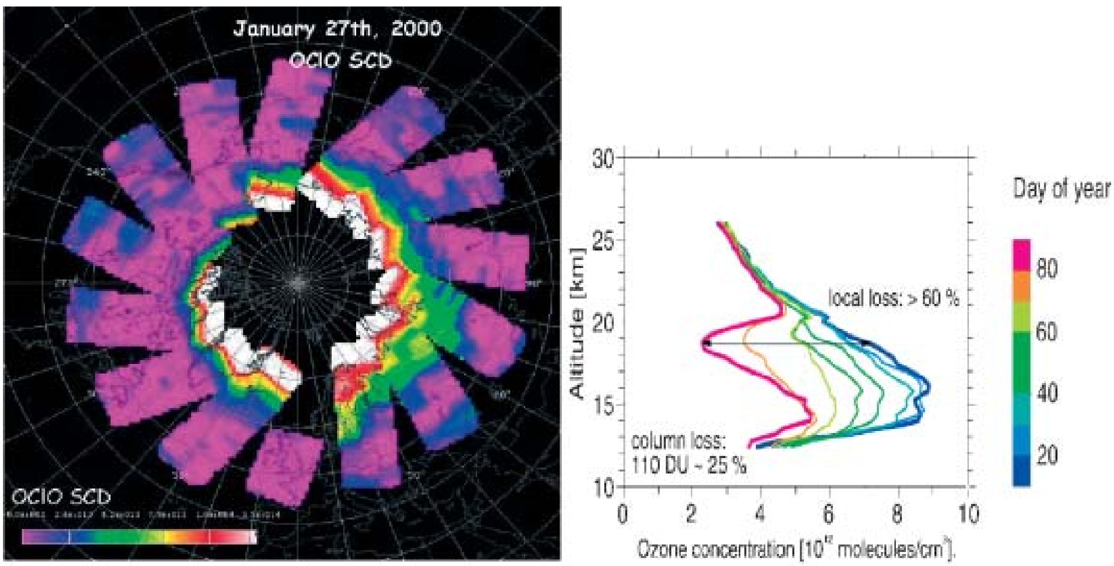


Figure 10. Left: Chlorine activation measured by the ERS GOME instrument over the Arctic on 27 January 2000 (Image courtesy of Univ. of Heidelberg). Right: Up to 60% ozone loss in the lower stratosphere in March 2000 over the Arctic (Image courtesy of NILU)

2/MWR, ASAR), provide a unique source from which a better understanding of the processes that determine the spatial and temporal distribution of biomass can be derived. Special emphasis is placed on the coastal zones, which are affected by intense and diverse activities with consequential environmental impacts for fishing, fish farming, industry of all types, release of sewage, pollution by trace metals and organic compounds, eutrophication by terrestrial fertilizers, tourism and marine traffic. Coastal waters are characterised by highly dynamic processes with complicated patterns of fronts and upwelling areas, rapid changes in concentrations of water constituents, and interactions between land and sea on a wide range of temporal and spatial scales. MERIS has been specifically designed for the mapping of concentrations of water constituents, notably suspended particulate matter, phytoplankton, and yellow substance.

Data obtained from the Radar Altimeter will offer the scientists working in the field of geodesy an opportunity to develop, test and refine models of the altimetric geoid and the Earth's gravity field. The Altimetry NRT service will be drastically improved for Envisat thanks to the development of high-quality algorithms for the NRT processor and of improved NRT orbit solution thanks to the on-board DORIS navigator. This will support international programmes to experiment with NRT oceanographic data assimilation for ocean forecasting.

The ERS AO projects have produced valuable results in terms of weather forecasting, detection and measurement of events such as the El Niño (Fig. 11), bathymetric applications, coastal-zone mapping, ship routing, ocean tides, assimilation of high-resolution data into regional models, and the extraction of parameters for information services like oil-spill detection, sea-ice monitoring or sea-state alarms.

Hydrology and ice

This segment studies the factors that control the global hydrologic cycle. Emphasis is placed on the reservoirs and fluxes of water, their coupling with plant life and biogeochemical cycles, and the definition of the impacts of modern agriculture and industry.

Extreme hydro-meteorological events such as storms, floods and droughts are a global threat to human life, infrastructure, water resources and the environment. Research work is directed to the effects of sea and land ice, run-off, and interactions between the vegetation, soil and topographic characteristics of the land surface and the components of the hydrologic cycle. With the novel tracking capabilities of Envisat's second-generation Altimeter, the levels of most of the Earth's rivers can be monitored with unprecedented accuracy.

ERS AO projects have allowed the grounding lines of glaciers to be defined and unprecedented ice-top and ice-velocity maps to be generated. Envisat will provide a new capability for the continued monitoring of ice caps and further mapping of areas such as Greenland and Antarctica.

Renewable resources, land environment and geology

For information needs related to changes in vegetation, de-forestation, desertification, wetlands, biomass-burning and greenhouse-gas reservoirs, the combination of the ASAR, MERIS and AATSR sensors constitutes a unique source of valuable information to support global and regional monitoring activities. Land-cover change will have an important influence on hydrology, global bio-geochemical cycles, and climate. Global estimates of the net flux of carbon due to land-

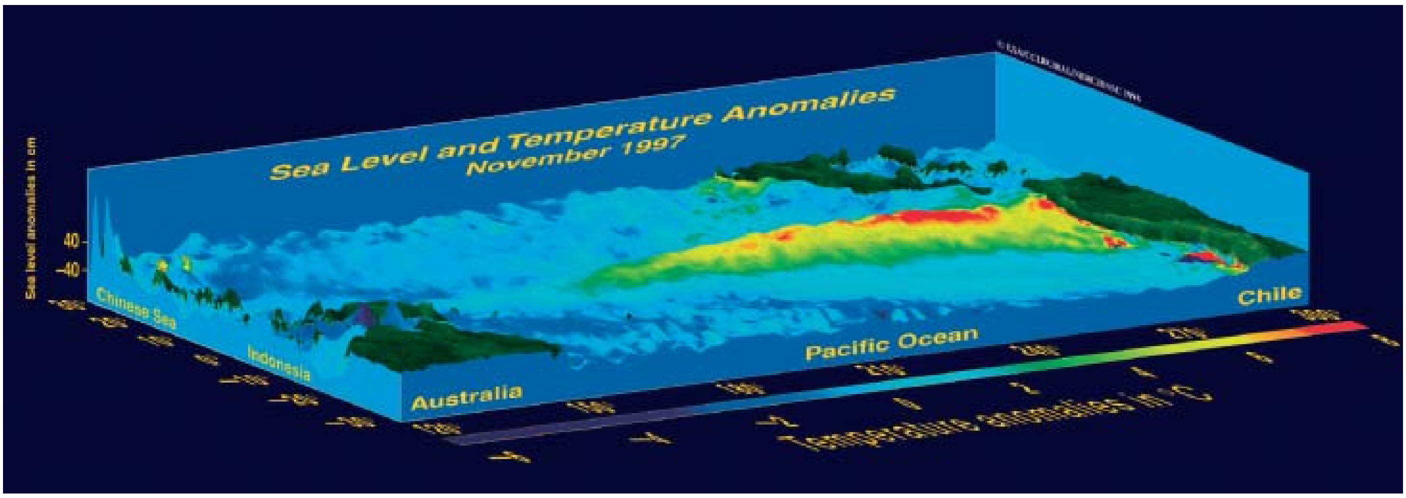


Figure 11. The El Niño has been monitored and studied with the sensors onboard the ERS missions (RA and ATSR). Envisat will pursue this monitoring to provide early detection and a better understanding of this phenomenon (Image processed at ESRIN)

cover change have been made in the last decade, yet the estimates for geologic and terrestrial biosphere carbon reservoirs are still not reliable enough to support an international policy. To develop a comprehensive analysis of green-house-gas emissions, land-cover and land-cover-change analyses will have to be coupled with efforts to obtain better ancillary data on carbon in vegetation and soils.

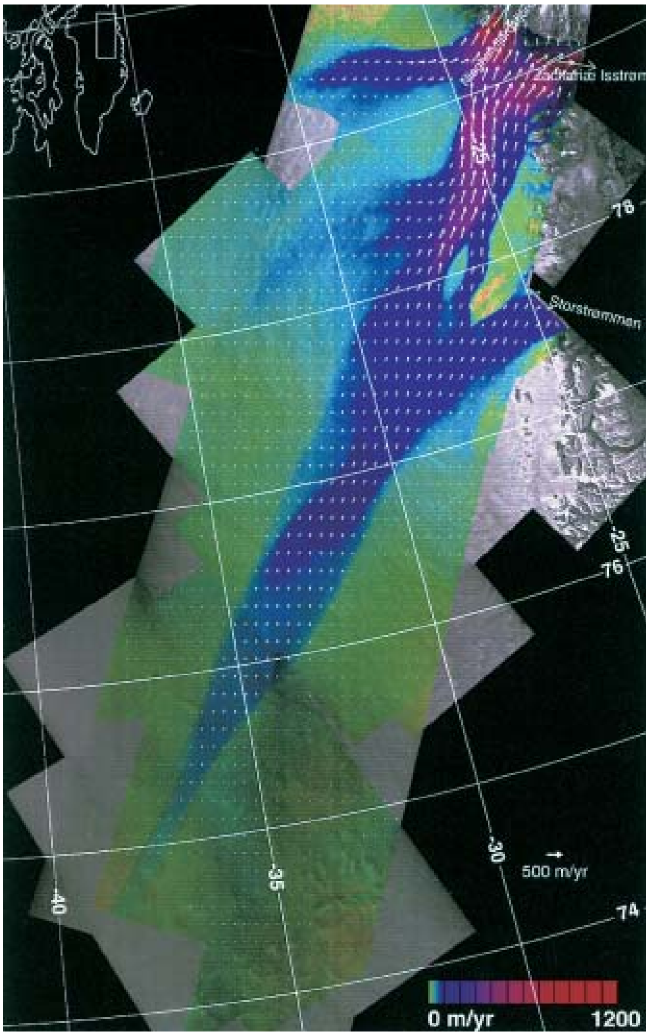
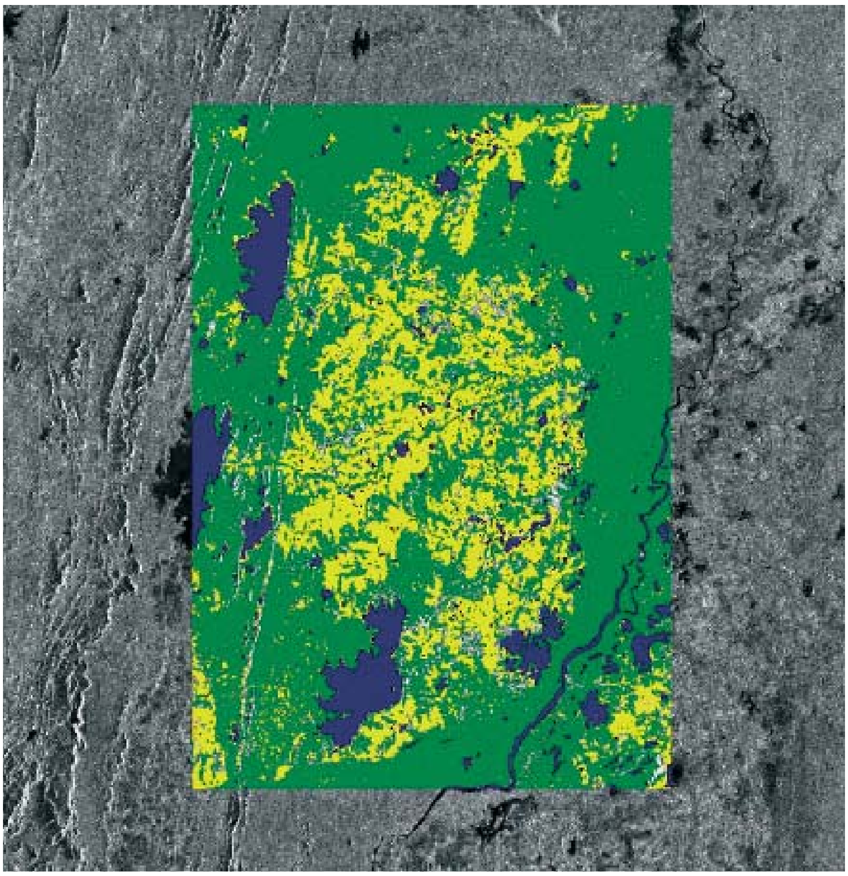


Figure 12. Ice-velocity mosaic of a Greenland glacier derived from ERS SAR interferometry (Image courtesy of Johan Mohr, DRCS)

Farmers trying to decide what crops to plant for the next season, urban planners shaping policy on the direction in which their city should grow, and emergency planning organisations charged with taking appropriate steps against floods or droughts, are just three of the groups that need better predictions of future conditions at the Earth's surface.

ERS data acquired as a result of the most recent AO were used for crop mapping (rice, cereals, sugar beet, etc.) and the derivation of area-based statistics, for the mapping of de-forestation, and for environmental studies. The higher incidence angles and dual-polarisation data from Envisat's ASAR (Fig. 13) will further improve the potential for forestry applications. Use of low incidence angles enhances the sensitivity to biomass, whereas the use of high incidence angles improves mapping of deforestation, and the dual polarisation will improve the discrimination of forest types.

Figure 13. Map of rice fields (yellow) in Sri Lanka, derived from ERS SAR data. Envisat's ASAR, with its different viewing angles and polarisation capabilities, will allow further improvements and provide the possibility to obtain precise rice maps (Image courtesy of University of Zurich)



Another major issue of public concern and significant economic consequence is water management and water quality, whether for drinking purposes or ecological sustainability. Direct waste discharge, water abstraction, changes in land use, urbanisation, atmospheric pollution and, possibly, climate change all threaten to reduce the quality of this most vital resource. Envisat's data can provide base, topographic, and land-use maps for water-quality monitoring and hydrological modelling.

Hazards and topography

Hazard studies have received growing attention from the Earth-observation community in recent years due to the dramatic consequences of natural and man-made disasters for populations world-wide. Ecosystems are threatened by natural hazards such as floods, droughts, earthquakes, or wind storms, man-made pollutants resulting from

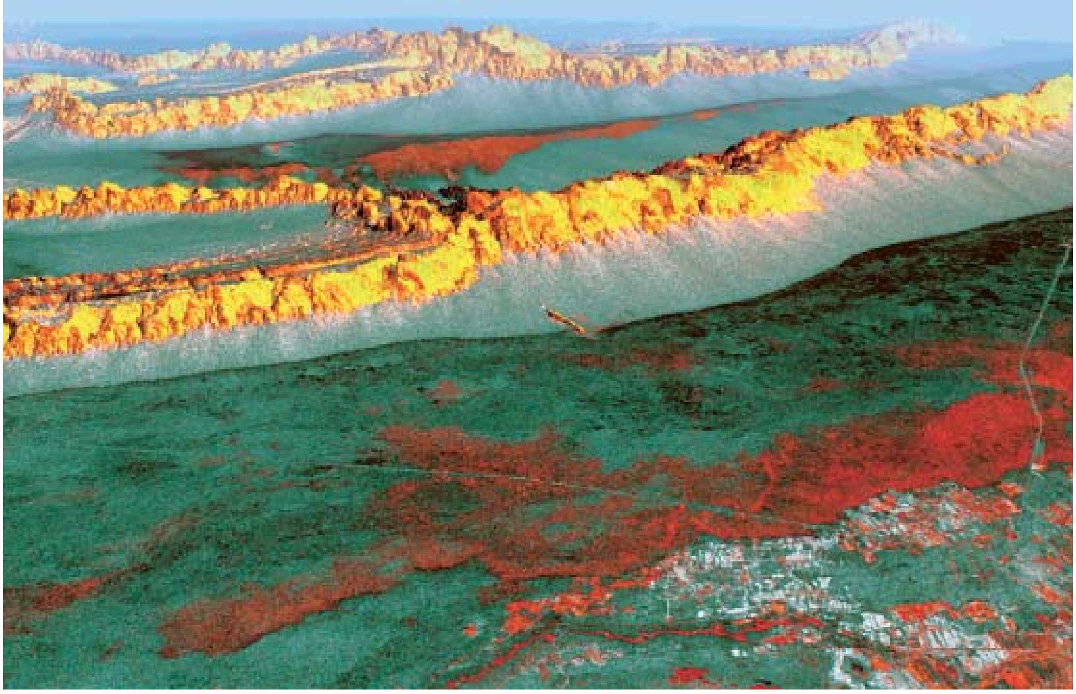


Figure 14. 3D image of the Bachu region, in western China, derived from ERS data. ASAR will provide similar images using the radargrammetry technique, combining data acquired at high and low incidence angles (Image courtesy of DLR)

waste discharges, and careless acts by man such as uncontrolled de-forestation leading to loss of bio-diversity. Research activities are directed at increasing the understanding of how episodic processes such as rainfall run-off, dust storms, volcanism, and earthquakes on the one hand, and human actions on the other, can have an impact on the Earth's surface.

The latest achievements of the AO projects are related to the refinement of InSAR techniques: very large active fault structures, such as the San Andreas fault, are being measured using ERS SAR interferometry; seismic deformations are being quantified; and some work has been done to monitor volcanic deformations and estimate the amount of magma contained in the chamber via comparison with theoretical models. The exploitation of interferometry for the quantification of land subsidence is almost operational, and new results could be obtained in terms of land-slide monitoring. The derivation of flood maps from SAR data is another almost operational application.

Figure 15. The ESA Earth-Observation Projects website (http://projects.esa-ao.org)

The new interferometric capabilities provided by the ASAR sensor, such as the various incidence angles or the improved revisit cycle, will benefit all previous applications. Also, topographic studies conducted by means of interferometry (Fig. 14), which are already benefiting from the combination of ascending and descending orbits and from data provided by ERS-2's Altimeter, will exploit such advanced instrument capabilities. Synergistic use of MERIS data will provide value-added information on land-cover or atmospheric artefacts.

ESA support to Project Leaders

All information submitted by the Project Leader to ESA is available to the Project Correspondent, an ESA expert appointed to follow closely a number of projects in a given discipline or geographical area. The Correspondent is the ESA focal point with whom not only to raise technical matters, specific to individual projects, but also to discuss broader issues related to progress in the research and development, science and application domains.

ESA is supporting quick publication/promotion of the interesting results from its AO-driven scientific projects. It has opened the EO Projects website (http://projects.esa-ao.org), where Project Leaders can publish their project's latest achievements as 'Hot News' (Fig. 15). Search facilities such as browsing by application, instrument, country, test site, Project Leader's name, institute, project title, objective or other keywords will allow all users to retrieve information about the on-going EO projects. The website also has a private area where all reports, materials or publications produced can be stored and submitted on-line to ESA by the Project Leader.

Thematic workshops and conferences
In the exploitation phase of the Envisat mission, the Agency together with its Project Correspondents, will organise a number of thematic workshops that will give the Project Leaders the opportunity to present the results of their current AO research project activities and to discuss the state-of-the art in their respective Earth-sciences disciplines. Position papers, progress reports on on-going projects, and demonstrations of running application prototypes will constitute the main form of communication in these workshops. One of the primary objectives is to foster the development of cross-disciplinary and cross-regional research activities and to encourage the development of innovative research ideas leading to new research projects or application developments.

Good examples of more recent ESA-organised (and co-organised) work-shops that were well received by the research community are: Fringe (November 1999, Liege), the CEOS SAR subgroup (October 1999, Toulouse), the ATSR Workshop (June 1999, ESRIN), and ESAMs (January 1999, ESTEC). These workshops have been complemented by ESA Symposia (Fig. 16) like the ERS-Envisat Symposium held in October 2000 in Gothenburg (S), which attracted a large audience and was reported upon in ESA Bulletin No. 105.

Beyond the AOs: the new Earth-Observation Data Policy
The possibility of conducting scientific research using ESA-provided data continues beyond the Envisat AO. The new Data Policy, applicable for ERS and Envisat, allows proposals to be submitted at any time, beyond the fixed dates normally imposed by an Announcement of Opportunity. Having been approved by ESA's Earth-Observation Programme Board (PB-EO), it aims to maximise the beneficial use of EO data from both the ERS and Envisat satellites and to stimulate a balanced development of scientific, public-utility and commercial applications.

Under the new Data Policy, the conditions of data distribution for ESA EO data are directly related to the category of use. Two different categories have been 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.

Category 2 Use: All other users who do not fall into Category-1, including operational and commercial use.

Under the new Data Policy, some 48 Category-1 projects are already in progress, and 22 further projects are under evaluation. Further information can be found on the ESA EO Projects website at: http://projects.esa-ao.org.

Figure 16. The Proceedings of recent ESA thematic workshops and conferences, available on CD-ROM from ESA Publications Division

Conclusions
The Envisat mission provides Europe with a unique and unprecedented tool to improve our understanding of the Earth and its environment. The work of the scientists within the framework of the ESA AOs is the core process for answering the scientific questions and fostering the development of new applications in the field of Earth observation. The fact that the new Data Policy allows one to submit new proposals to ESA at any time will further increase flexibility for accessing Envisat data for scientific use. The Agency's coordinated support to the Project Leaders through the 'Correspondent' scheme should further sustain the development of science and focus the applications for EO data.