The Optical Imaging Instruments and Their Applications: AATSR and MERIS

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The global mission of AATSR and MERIS will make a major contribution towards our understanding of the role of the oceans and ocean productivity in the climate system and will also enhance our ability to model and forecast change. The availability of these two complementary sensors on the same platform also offers new opportunities for the synergistic use of data in multi-disciplinary oceanographic and climate studies.

MERIS is primarily dedicated to observing oceanic biology and marine water quality through observations of water colour. However, it will also make contributions to atmospheric and land-surface-related studies. Similarly, the main role of AATSR is to provide detailed Sea Surface Temperature maps, and yet it also provides the capability to measure a range of parameters for cloud microphysics, plus surface temperatures and various vegetation indices over land. Data from these instruments are therefore applicable to a wide range of environmental application.

Introduction

The Medium-Resolution Imaging Spectrometer (MERIS) to be launched on-board Envisat will provide a unique European remote-sensing capability for observing oceanic biology and marine water quality through global observations of ocean colour (Fig. 1), and will provide continuity with other ocean-colour sensors such as Sea-WiFS and MODIS. The Advanced Along-Track Scanning Radiometer (AATSR) will provide continuity with similar ATSR instruments flown on ERS-1 and 2, thereby ensuring the production of a near-continuous, 15-year dataset of Sea-Surface Temperatures (SSTs) at an unprecedented accuracy level of 0.3 K or better (Fig. 2).

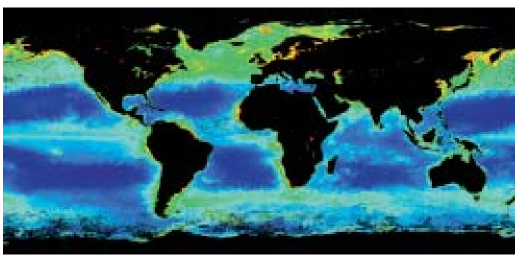


Figure 1. A SeaWiFS image of the global seasonal average of chlorophyll pigment concentration (courtesy of NASA/GSFC and Orbimage)

Biogenic material in our oceans accounts for a large portion of their carbon pick-up, playing a major role in the Earth's carbon cycle and therefore our climate. SST is one of the most stable of several geographical variables which, when determined globally, characterise the state of the Earth's climate system. Phytoplankton concentrations in the oceans, responsible for the latter's primary production, therefore need to be known with a high degree of accuracy for their adequate prediction through modelling. Furthermore, accurate knowledge of marine water constituent concentrations has become mandatory for the assessment of the water quality in marine ecosystems. In parallel, precise measurement of small changes in SST will provide an indication of significant variations in ocean/atmosphere heat-transfer rates and their impact on our physical climate.

AATSR and MERIS are both passive optical imaging instruments measuring radiation reflected and emitted from the Earth's surface. AATSR has four channels in the visible/near-infrared wavelengths and three in the thermal-infrared region (Table 1). MERIS has 15 channels in the visible and near-infrared (Table 2). The overlap between the instrument bands, and the complementary measurements they provide over ocean and land, creates novel opportunities for the synergetic use of data in many fields of study.

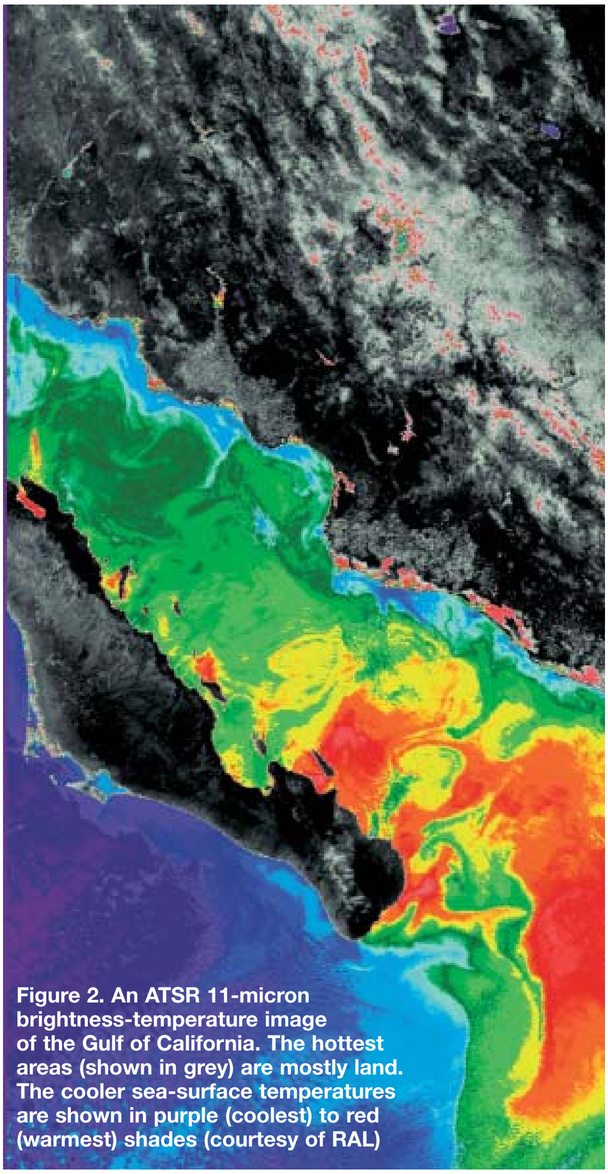


Figure 2. An ATSR 11-micron brightness-temperature image of the Gulf of California. The hottest areas (shown in grey) are mostly land. The cooler sea-surface temperatures are shown in purple (coolest) to red (warmest) shades (courtesy of RAL)

Table 1. AATSR spectral channels

Channel (µm)	Bandwidth (nm)	Primary Application
0.55	20 nm	Chlorophyll
0.66	20 nm	Vegetation Index
0.87	20 nm	Vegetation Index
1.6	0.3 µm	Cloud Clearing
3.7	0.3 µm	SST
11	1.0 µm	SST
12	1.0 µm	SST

Table 2. MERIS spectral channels

Channel (µm)	Bandwidth (nm)	Primary Application
412.5	10	Yellow substance, turbidity
442.5	10	Chlorophyll absorption maximum
490	10	Chlorophyll, other pigments
510	10	Turbidity, suspended sediment, red tides
560	10	Chlorophyll reference, suspended sediment
620	10	Suspended sediment
665	10	Chlorophyll absorption
681.25	7.5	Chlorophyll fluorescence
708.75	10	Atmospheric correction, red edge
753.75	7.5	Oxygen absorption reference
760.625	3.5	Oxygen absorption R-branch
778.75	15	Aerosols, vegetation
865	20	Aerosols correction over ocean
885	10	Water-vapour absorption reference
900	10	Water-vapour absorption, vegetation

The instruments

AATSR

The AATSR (Fig. 3) is the third in a series of similar instruments that use the same innovative features to provide high-accuracy measurements of SST for use in studies of global climate change. The exceptional sensitivity and stability of calibration of these instruments, coupled with the dual-view technique for atmospheric correction, allows measurements of SST to an accuracy of ± 0.3K. These high-quality image data also contribute to a wide range of other scientific studies related to the land surface, atmosphere, clouds, oceans, and the cryosphere.

The first Along-Track Scanning Radiometer (ATSR) was carried on ESA's ERS-1 mission, which operated between July 1991 and March 2000. The second instrument, ATSR-2, followed on ERS-2 in April 1995 and is still operating. The AATSR on Envisat is one of the Announcement of Opportunity (AO) Instruments and has been developed and

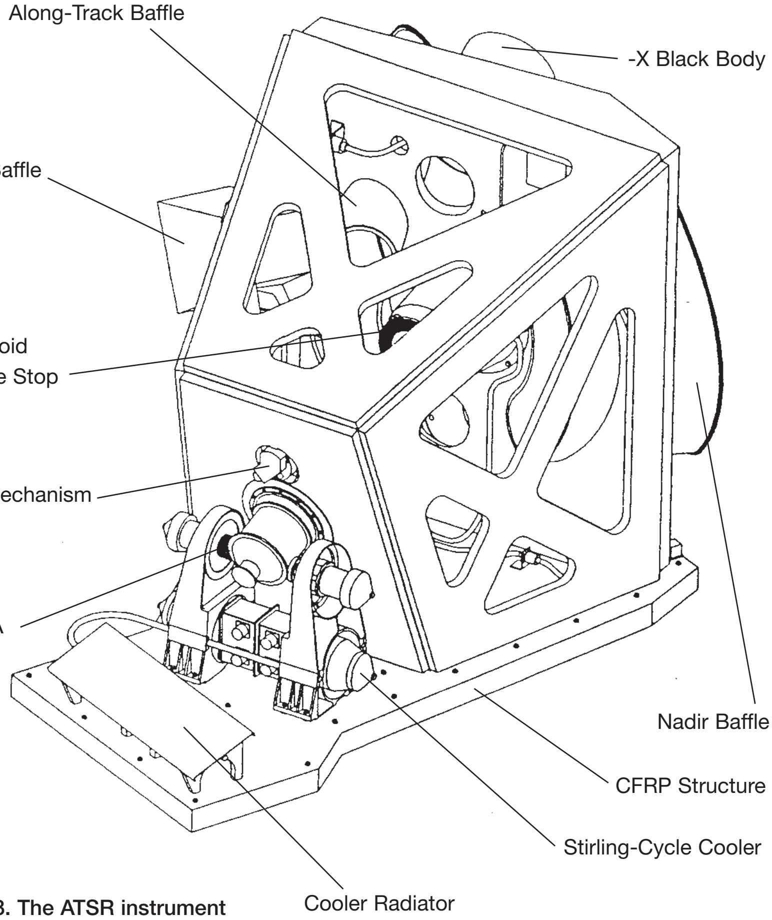


Figure 3. The ATSR instrument

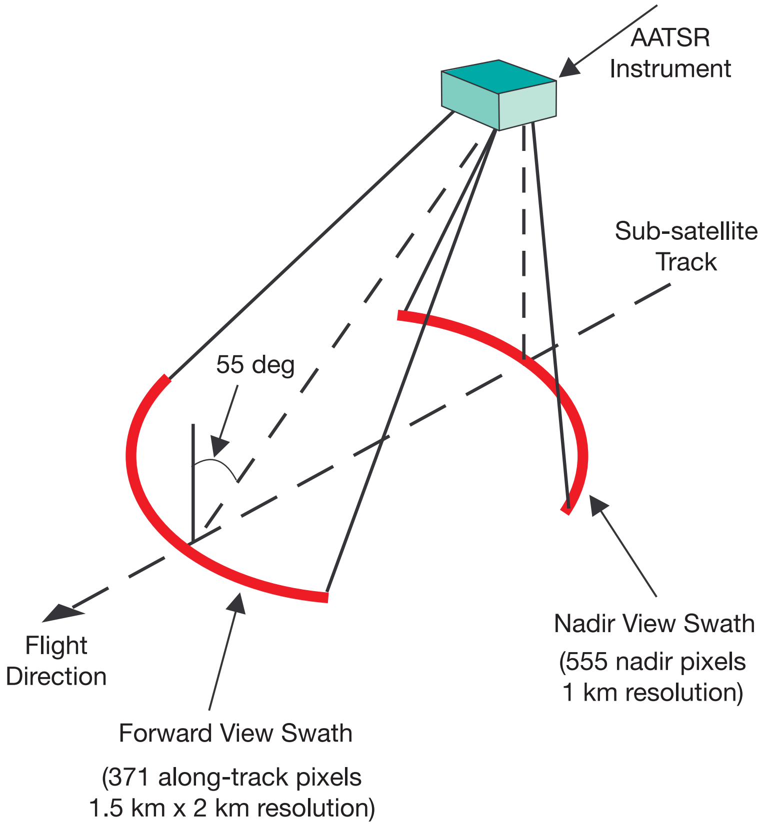


Figure 4. The AATSR viewing geometry (courtesy of RAL)

procured by the UK Department of the Environment, Transport and the Regions (DETR), in partnership with the Australian Department of Industry, Science and Resources (DISR) and the UK Natural Environment Research Council (NERC).

The (A)ATSR instruments are unique in their use of 'along-track scanning' to improve atmospheric correction. Two views of the same point on the Earth's surface are obtained in quick succession at two different angles through the intervening atmosphere. By viewing the same point in this way through different atmospheric paths, it is possible to estimate and correct for the effect of atmospheric absorption. The AATSR viewing geometry is shown in Figure 4. A conical scan projects downwards and ahead in the along-track direction, allowing each point on the Earth's surface to be viewed in turn, first at an angle of 55 deg (the forward view) and then at an angle close to the vertical (the nadir view) as the satellite moves forward. The two curved swaths are approximately 500 km wide, and the nominal size of each pixel within the scan is 1 km.

Figure 5. MERIS flight model during integration at Alcatel Space Industries in Cannes (F)

Other key features of the instruments are their low-noise detectors, high-quality calibration and long-term stability. The exceptional sensitivity and stability of calibration is achieved not only by extensive pre-launch calibration, but also through the use of state-of-the-art on-board calibration targets. The instrument carries two black-body targets, which are viewed once per scan. One is maintained at a temperature of about 305 K, just above the maximum temperature expected to be observed over marine scenes. The other is unheated and floats at a temperature close to the ambient temperature of the instrument (~256 K), just below the expected range of marine scene temperatures. The two black bodies therefore span the full expected range of SSTs. As a result, the AATSR can be regarded as a near-ideal radiometer. The use of infrared detectors, cooled to their near-optimal operating temperature by a Stirling-cycle mechanical cooler, further contribute to the overall accuracy of the AATSR's thermal measurements.

Over land, the AATSR visible channels need to cope with all possible normal variations in brightness over the Earth's surface without saturation, whilst maximising the precision of the measurements. To achieve this, the gain and offset of the visible channels is selectable in flight. Calibration of the visible and near-infrared channels is also achieved once per orbit by viewing the Sun through a special Visible Calibration Unit.

MERIS

MERIS is a sensor operated in a push-broom mode and looking in the vertical plane (Fig. 5). It consists of five identical cameras arranged in a fan-shaped configuration yielding a large field of view of 68.5°, or a swath of 1150 km. This modular design has been chosen to ensure high optical image quality over such a large field of view.

MERIS data will be of interest for both global observation and for detailed studies on a regional scale. Full Resolution (FR) data with a 300 m ground resolution at the sub-satellite point is intended for coastal-zone and land monitoring. Reduced Resolution (RR) data at 1200 m, combined with the 1150 km swath that gives global Earth coverage in three days, will be used for large-scale studies.

MERIS operates in 15 spectral bands in the 390–1040 nm range of the visible/near-infrared spectrum. The band positions, bandwidths and gains are programmable in flight. The spectral bandwidths can be adjusted between 1.25 and 30 nm, depending upon the width of the feature to be observed and the amount of energy needed in a band to perform an adequate observation.

The optical signal from the bio-chemical activity in the ocean is strongest in the visible wavelengths. It decreases in the near-infrared, where atmospheric perturbation dominates. MERIS takes advantage of this property by measuring the atmospheric signal at two wavelengths in the infrared (where the ocean is considered to be ‘dark’) and extrapolating this information to the visible wavelengths; the atmosphere’s contribution can then be subtracted from the top-of-atmosphere signal. Outstanding radiometric accuracy is imperative for this correction because, in the visible, 90% of the signal reaching the sensor originates from the atmosphere and only 10% from the ocean. This high accuracy will be achieved by on-board calibration using a Sun-illuminated diffuser plate, in addition to radiometric gain factors, allowing the adequate quantisation of very faint signals from the ocean.

Calibration will be carried out on average once every two weeks, as the spacecraft flies over the south orbital pole and the Sun illuminates the on-board calibration device. MERIS will acquire data whenever illumination conditions are suitable, namely in the day zone of the orbit where the Sun incidence angle is less than 80° at the sub-satellite point.

Instrument inter-calibration

Despite the use of on-board calibration systems, the calibration of each instrument can drift with time and general exposure to the space environment. Both immediate and long-term changes in the performance of the visible channels of both instruments will therefore be monitored as part of the Envisat Calibration and Validation Programme. Since three spectral bands of MERIS coincide with the broader visible AATSR channels, their respective evolutions will be compared. This will not only help to maintain and improve the quality of the calibration of each instrument, but will also open the way for the generation of blended records of the same geophysical parameters logged by the two sensors.

Applications

The primary mission objectives for MERIS are observation of the colour of the open ocean and of marine coastal zones. These objectives have subsequently been extended to the observation of cloud and land properties. Similarly, the AATSR mission objectives have been extended beyond SST retrieval, as its high-quality image data are being used in an increasingly wide range of different EO applications. Table 3 summarises the main MERIS and AATSR products and their respective applications.

Oceans

SST and climate research

The Earth’s climate is subject to a great range of variability, both natural and man-induced. Probably the most serious change seen in recent years has been the increase in global temperature, possibly linked to the concentrations of carbon dioxide released into the atmosphere from the burning of fossil fuels. Climate models predict that this increase in carbon dioxide will cause an increase in global temperatures, although the exact scale and pattern of this effect is unclear.

Owing to its relative stability, Sea-Surface Temperature is a particularly important geophysical parameter for the understanding of climate change and the heat exchange between the oceans and the atmosphere. By measuring SST to an overall accuracy of better than 0.3 K (Fig. 6), the AATSR will provide an invaluable dataset on a global scale, which will be accurate enough for detailed climate studies. Measurements from buoys and ships provide similar surface observations, but they can only be sparsely distributed and are prone to measurement inconsistencies; hence the increasing importance of satellite-derived measurements.

Figure 6. ATSR global SST image from ATSR-2, June 1999 (courtesy of RAL)

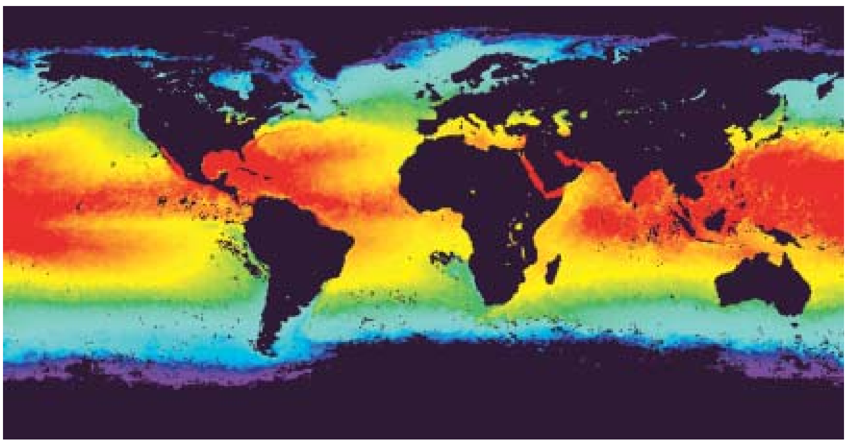


Table 3. AATSR and MERIS products and applications

Product	Parameter	Application
	AATSR	
Gridded Brightness Temperature/Reflectance	12, 11 and 3.7 µm TOA BT	Ocean, land, cloud, atmosphere and cryosphere
	0.55, 0.66, 0.87 and 1.6 µm TOA Reflectance	Ocean, land, cloud, atmosphere and cryosphere
Gridded Surface Temperature (1 km)	SST	Ocean and climate research
	NDVI	Vegetation
	LST (currently 11 µm BT)	Land and climate research
	CTT (currently 11 µm BT)	Cloud
	CTH (currently set to zero)	Cloud
Averaged Surface Temperature (10 arcmin, 30 arcmin, 17 km and 50 km cells)	Mean SST	Ocean and climate research
	Mean LST	Land and climate research
	Mean NDVI	Vegetation
	Mean TOA BT 12, 11 and 3.7 µm	Ocean, land, cloud and atmosphere.
	Mean TOA Reflectance 0.55, 0.66, 0.87 and 1.6 µm	Ocean, land, cloud and atmosphere
	Average CTT	
	MERIS	
L1B a) Full Resolution b) Reduced Resolution	Radiance	
Reference L2 a) Full Resolution b) Reduced Resolution	Surface reflectance (land and ocean)	Land. sea and climate research
	Chlorophyll	Carbon cycle, oceanography
	Yellow Substance	Carbon cycle, local applications
	Suspended matter	Carbon cycle, local applications
	Water vapour	Climate research, weather prediction
	Cloud albedo	Climate research
	Cloud optical thickness	Climate research , weather prediction
	Cloud top pressure	Climate research, weather prediction
	MERIS Vegetation Index	Land research

SST data are also useful for studies on a regional scale. For example, SST is a particularly sensitive indicator of El Niño events. This phenomenon occurs when the normal equilibrium of the oceanic and atmospheric conditions throughout the Southern Hemisphere is disturbed by a weakening of the trade winds, causing warming in the tropical Pacific. These El Niño events produce an eastwards flow of warm surface water, a rise in sea level, an interruption in the up-welling of nutrient rich waters, and significant changes in weather throughout the region. Fish die or migrate to higher latitudes, and rainfall patterns change dramatically, with heavy rains and floods on the western coast of South America and droughts in Australia and Southeast Asia. The exact origin of this phenomenon is not well-understood. However, ability to predict the onset and severity of these events can go some way to preparing for and alleviating their effects.

Open ocean

Major uncertainties still remain about the amount of carbon stored in the oceans and the biosphere, and about the fluxes between these reservoirs and the atmosphere. In particular, there is a need for better information on the spatial distribution of biological activity in the upper ocean and its variability over time. Because phytoplankton biomass (Fig. 7) plays a important role in fixing CO_2 in the upper layers of the ocean through photosynthesis, the monitoring of chlorophyll concentration provides the most convenient measurement of its abundance.

The presence of algae, by changing the absorption properties of water, can affect the heating rate of the upper layers of the ocean, modify the depth of the ocean's mixed layer, and influence the seasonal thermocline regime. As a result, ocean colour is rapidly becoming part of dynamical oceanography and it is certainly possible that, within the lifetime of Envisat, the inclusion of chlorophyll data in ocean models will begin to play a role in medium-range weather forecasting.

Over open oceans, MERIS will not only deliver measurements of water-leaving radiance at a range of wavelengths, but will also provide products representing algal pigment concentration, sediment in suspension, dissolved organic matter and radiation available for photo-synthesis. These products, which will be largely compatible with those derived by other sensors (Sea-WiFS, Modis, Polder II, etc.), will provide temporal and spatial continuity with other missions.

Coastal waters

Coastal regions are some of the most heavily populated in the world and are greatly affected by human activities. Pollutants from rivers and the atmosphere enter the marine ecosystem at this point, disturbing the natural marine productivity. Satellite measurements are ideal for monitoring the environment over such diverse areas.

Once again, the water-leaving radiance measured by MERIS can be used to derive suspended sediment, phytoplankton and dissolved organic-matter concentrations (Fig. 8), which are the major water constituents that control marine and estuarine ecology.

In addition to well-known applications of local, but extremely important, practical interest (such as monitoring the quality of coastal waters, sediment transport, assistance to fishing, and protection of fish and shell farms), MERIS will also provide the first global dataset allowing the exploration of continental-margin carbon fluxes on a global scale.

Synergistic use of ocean data

Envisat will offer data on winds and waves from the Advanced Synthetic Aperture Radar (ASAR), ocean topography from the Radar Altimeter 2 (RA-2), SSTs from AATSR and ocean colour from MERIS, all from the same platform. It will therefore offer unprecedented opportunities for synergistic measurements over the oceans. As an example, data from the first Radar Altimeter have been usefully combined with ATSR-2 SST data to record the rise in both the temperature and height of the sea surface associated with El Niño events. The availability of ocean-colour and SST data co-located both spatially and temporally will also provide a unique dataset for general ocean bio/geophysical characterisation. This is particularly significant, as simultaneous

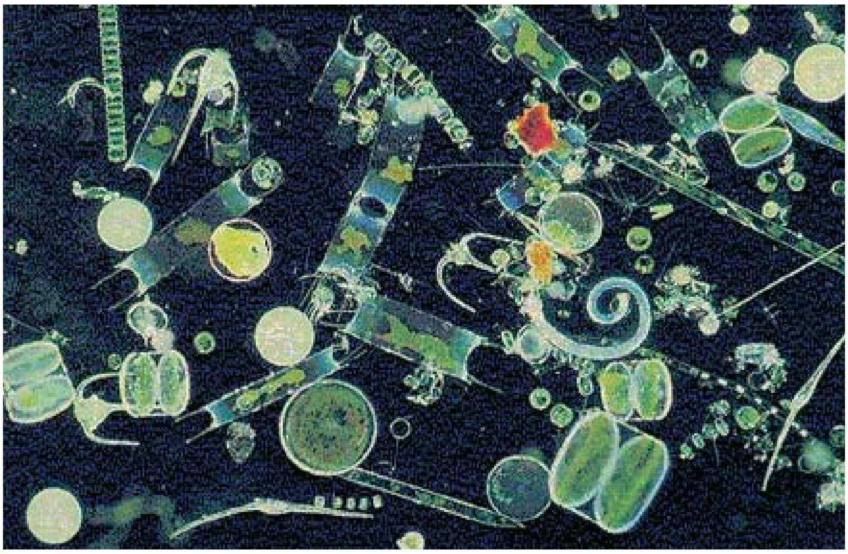


Figure 7. Phytoplankton (courtesy of N. Nichols)

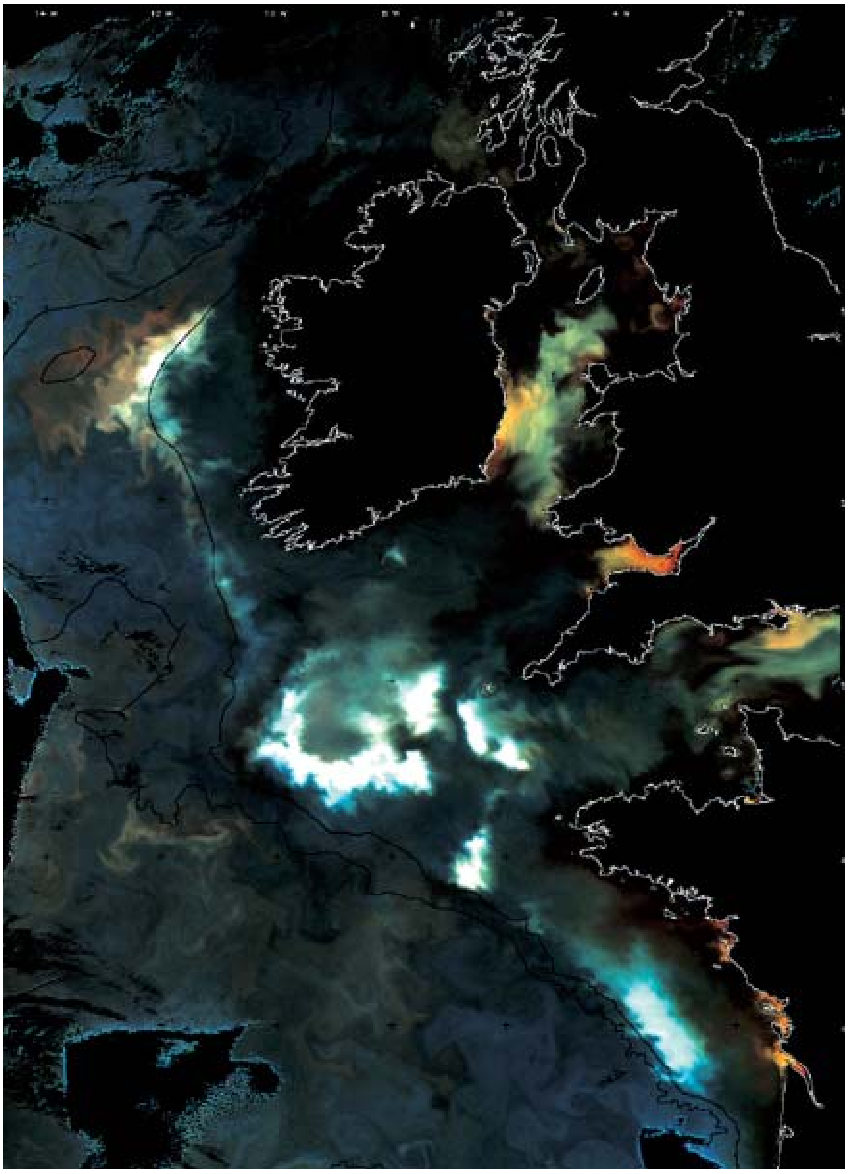


Figure 8. SeaWiFS image of the coastal waters around the United Kingdom on 18 May 1998 (colour composite of 555, 510 and 443 nm bands as red, green and blue, respectively, produced with SeaAPS software). The data were received by the Dundee Satellite Receiving Station (copyright Orbital Imaging Corps and NASA/SeaWiFS)

measurements of comparable spatial resolution at optical and thermal-infrared wavelengths have never previously been available on a routine basis.

Satellite observations can also be combined with a wide range of other data sources. For example, the Clean Seas Project co-ordinated the work of a number of major European research centres in France, Germany, Italy, Spain, Sweden and the United Kingdom in a programme designed to evaluate the contribution that present and future satellite-surveillance systems can make to the monitoring of marine pollution.

The project combined data from a wide range of sources, including low-resolution meteorological satellite data, high-resolution ocean-colour and radar satellite data, and in-situ measurements of meteorological data, to study particular occurrences of algal blooms. The dataset for this project included ATSR imagery in the 0.55 micron channel (Fig. 9) and images from the SeaWiFS instrument, similar to MERIS.

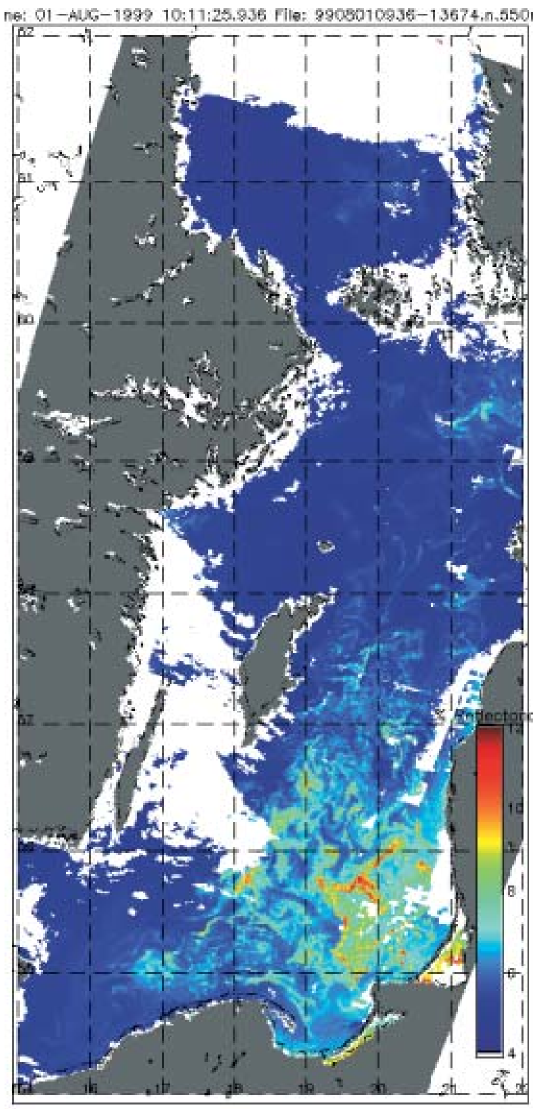


Figure 9. An ATSR 0.55 micron channel image showing algal bloom extent in the Baltic Sea (courtesy of Clean Seas Project)

Land

Issues such as the influence of surface conditions on atmospheric circulation, water circulation and carbon cycling are at the core of a better understanding of climate processes. Data products from sensors such as MERIS and AATSR, which represent the ratio of radiation in the near-infrared and red wavelengths (e.g. normalized difference vegetation index) are primarily useful to locate vegetation and estimate its amount. Novel experimental products are expected to provide a measure of the boundary position between chlorophyll absorption in the red and leaf scattering in the near-infrared (i.e. red edge) to estimate both chlorophyll concentration and vegetation condition.

It is also a priority to provide data on the spectral structure of the land surface. This data will be obtained by recording wavelengths related to the phenomena of interest, such as chlorophyll concentration, leaf senescence, moisture content and iron content. Of particular interest for the land community is the combination of high spectral and coarse spatial resolution in a frequent repetitive coverage, which is provided by both MERIS and AATSR.

Global land-cover monitoring

Within the biosphere, vegetation is critical, as it not only supports the bulk of human and animal life, but also controls the exchange of water and carbon between the land and the atmosphere.

Spatial and temporal models of the biosphere are currently being developed to study the mechanics of such complex systems, in order to predict their behaviour under changing environmental conditions. These models are based on physical and biophysical relationships, needing validated results on a regular basis from space-borne sensors. Repetitive accurate physical measurements are necessary in order to quantify surface processes and to improve the understanding of vegetation seasonal dynamics and responses to environmental stress. Instrumental to this is the ability to understand the surface structure of vegetation and soils. In this context, the surface bi-directional reflectance distribution function has also to be analysed in data with a high repeat rate and a comparably large swath, enabling the investigation of a target under varying illumination conditions. Surface spectral bi-directional reflectance can be calculated after normalisation to the solar irradiance and atmospheric corrections. Such a high-quality dataset can then be efficiently calibrated against ground data such as leaf-area index, biomass, soil background, etc. A vegetation

Figure 10. Monthly MERIS Global Vegetation Index for June 1998, derived from SeaWiFS images (courtesy of JRC/SAI/GVM)

Figure 11. An ATSR-1 image showing the extent of de-forestation in Brazil (courtesy of RAL)

index has also been specifically developed for MERIS, giving rise to improved quantitative estimates of the vegetation status and its condition.

The top-of-atmosphere reflectances offered by AATSR and MERIS can also be used in other ways over land. 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 (Fig.10). They will also contribute towards the construction of the accurate albedo maps needed as boundary conditions in meteorological prediction models. Estimates of vegetation parameters such as land-cover type, leaf-area index and biomass concentration can also be derived from the basic reflectances.

Forestry

The Earth's forests play an important role in absorbing carbon dioxide from the planet's atmosphere, and their destruction will contribute to the Greenhouse Effect. On a local scale, deforestation has had dramatic effects on the climate, and the combination of reduced rainfall and soil erosion severely limits the agricultural use of the cleared land, with consequent economic repercussions.

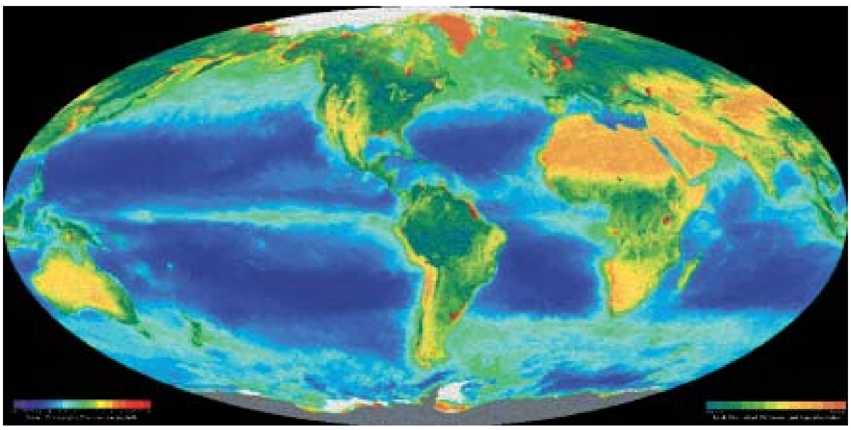
AATSR and MERIS will provide improved capabilities for global and regional forest inventory. For example, clear evidence of the anthropogenic origin of forest destruction can be seen in the ATSR imagery in Figure 11. Regular linear inroads into the forest can be seen, and large cleared areas stand out among the surrounding vegetation. Ground-based estimates of the scale and rate of deforestation are notoriously inaccurate and rapidly become outdated, but satellite images provide a reliable and convenient method for the long-term global monitoring of this phenomenon.

Synergy

The attribute of synchronised observations from two different instruments will be equally valuable for vegetation studies over land. Although the visible/near infrared bands on AATSR are not as narrow as those on MERIS, there is potential for the superior atmospheric correction offered by the dual views to assist in improving estimates of bi-directional reflectance for crop growth and other models. AATSR will offer the added advantage of complementary observations in the thermal channels over land that, whilst not originally designed for this purpose, have proved useful for studies of burning vegetation and the retrieval of land-surface temperature.

Ocean-colour data and information on land vegetation can also be combined to provide views of the whole Earth biosphere (Fig. 12).

Figure 12. Biosphere globe derived from SeaWiFS images (courtesy of NASA/GSFC and Orbimage)



Clouds and atmosphere

Cloud parameters

Figure 13 shows a night-time, 11 micron, false-colour image of typhoon Saomai over the East China Sea, heading north towards the Korean Peninsula. In addition to providing information on the basic location, extent and structure of clouds, data from different AATSR channels can be combined to estimate various properties of the cloud field. These include:

– optical depth, which is broadly related to the vertical dimension of the cloud
– phase, which determines whether the cloud contains ice or water
– particle size, which is the effective radiative dimension of the cloud particles, and pressure, which reflects the cloud-top pressure or altitude.

Thanks to the possibility of using narrow spectral bands, MERIS also provides information about cloud amount, cloud type, cloud albedo and cloud-top height, to complement the top-of-atmosphere radiance data. These datasets are of particular value for the validation of the models of radiative transfer in the presence of clouds used in general-circulation models of the atmosphere.

The unique conical scanning mechanism used by the AATSR instrument and the resulting dual view of the Earth also provide a natural stereoscopic view of cloud fields. The stereo view allows discrimination of the different layers and structures within the cloud. The dual view can also be exploited to estimate cloud-top height. By matching sub-scenes from the nadir and forward images, the relative displacement of objects in the two images can be found. Combined with knowledge of the pointing geometry of the two views, this leads to an estimate of the object's height above sea level.

Aerosols

MERIS has the ability to evaluate aerosol properties, including optical thickness and type. Data from ATSR-1 and ATSR-2 have also been used to map stratospheric aerosol distribution, a capability continued with AATSR.

Aerosol optical thickness and aerosol type will be determined over open oceans. The MERIS ground segment will also attempt to perform an aerosol correction over turbid (coastal) waters. This will lead to marine directional reflectances at the air/sea interface, which will be important for deriving other local and regional applications.

MERIS also possesses two channels in the near-infrared dedicated to the measurement of pressure by differential absorption of O_2. This allows the discrimination of optically thick aerosols from clouds. This is particularly important in the tropics, where low cloud cover makes the large absorbing aerosol loads from tropical deserts (Fig. 14) a prime contributor to the radiative forcing of the atmosphere. The aerosol product will be provided systematically and will help resolve the uncertainties associated with the modelling of the radiative forcing of mineral dust. The presence in the same product of aerosol, algal pigment and cloud data is also expected to further the search for correlations between these different parameters over the oceans.

Figure 13. ATSR image of Typhoon Saomai

Aerosol properties will also be estimated by MERIS over land, but only over patches of dense dark vegetation. The retrieval of aerosols over land is a very difficult task for an instrument operating in the visible and near-infrared. Aerosol optical thickness and type can only be retrieved over limited land cover types, such as dense forests, the reflectance of which has to be known with confidence. It also requires some a-priori assumptions about the refractive index of the aerosol. Consequently, this will be provided as an experimental product.

Water vapour
The MERIS water-vapour product is a measurement of the concentration of water vapour found in the total atmospheric column. This product is of particular interest over land where the signal, and consequently the precision of this product, is expected to be particularly high. It will also be provided over water surfaces and clouds. Good water-vapour retrieval is also expected over ocean regions affected by Sun-glint. This product will be delivered to ECMWF for assimilation into meteorological models to improve weather forecasting.

Cryosphere
Changes in global sea level are at present related mostly to the global warming of the climate, through the thermal dilatation of the oceans. However, the contribution of the melting of polar ice sheets to rises in sea level is also becoming an important area of research, with particular focus on time-series measurements of changes in floating and grounded ice in Antarctica and Greenland.

AATSR will provide frequent observations of the Antarctic region, coverage of a large proportion of the coastline on a daily basis, and total coverage of the region every three days. Large icebergs, several kilometres or more across, can be identified in the images (Fig. 15) and their dimensions determined. These data provide the basic information needed for an assessment of their spatial distribution, of their calving, breakage and melting rates, and of their movement.

The icebergs represent a major component of the mass discharge from the Antarctic ice sheet, and hence of its overall mass budget. The other large, but poorly known, component of the mass discharge occurs through melting from the base of the floating ice.

Hazard monitoring
Volcanoes
Volcanoes represent serious natural hazards, particularly in developing countries where large populations gather on the highly fertile volcanic soils close to active volcanoes, and where monitoring activities are most limited. The logistics associated with monitoring the vast number of potentially active volcanoes is also a problem.

Satellite remote sensing provides the opportunity to augment traditional monitoring methods. This is particularly true of the ATSR instruments, which will view all of Earth's terrestrial volcanoes once every three days under night-time conditions, which is the ideal time to monitor their thermal activity and detect any eruptive activity (Fig. 16).

Forest fires
Large vegetation fires are a major source of atmospheric pollutants and fire is a key

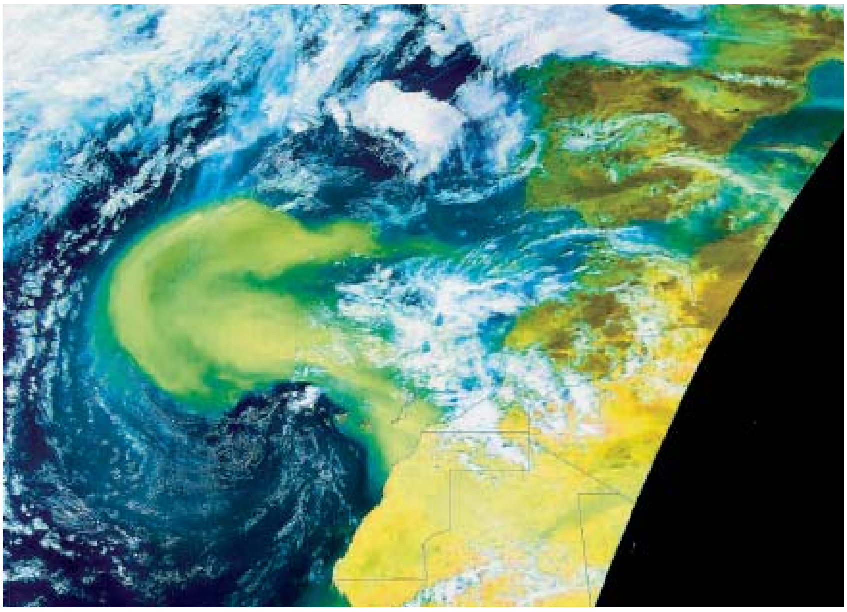


Figure 14. SeaWiFS image of a Saharan dust storm over the Atlantic Ocean west of Morocco, on 28 February 2000 (courtesy of NASA/GSFC and Orbimage)

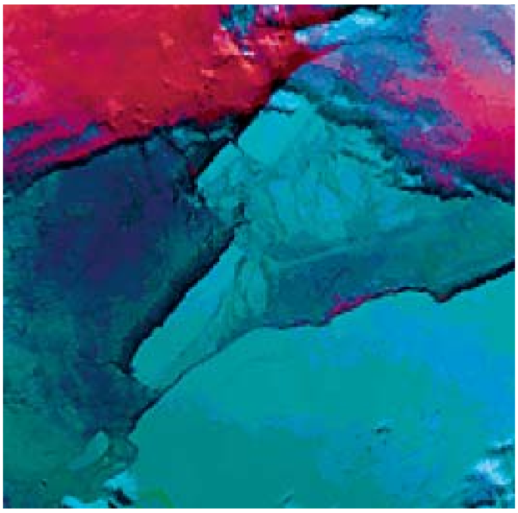


Figure 15. An ATSR-2 image of the B-15 iceberg as it broke away from the Ross Ice Shelf (courtesy of RAL)

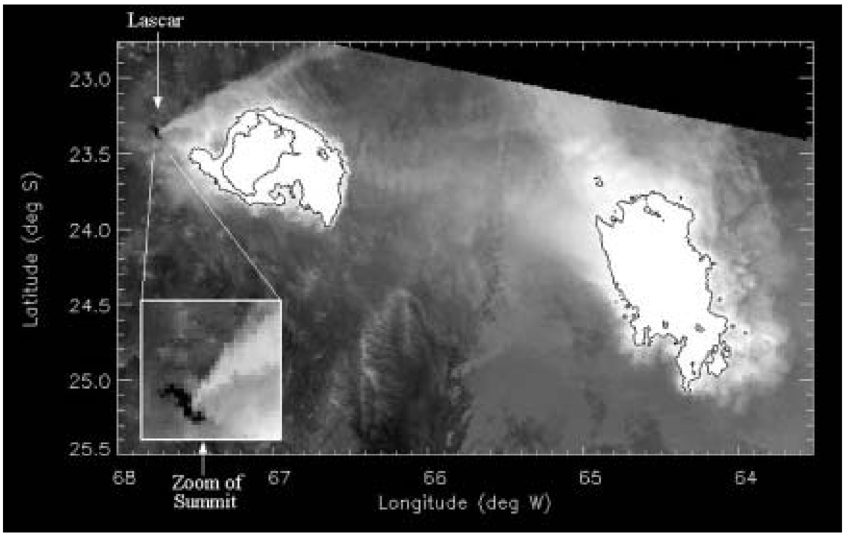


Figure 16. ATSR daytime 11-micron image of the Lascar Volcano, in Northern Chile (courtesy M. Wooster, Kings College London)

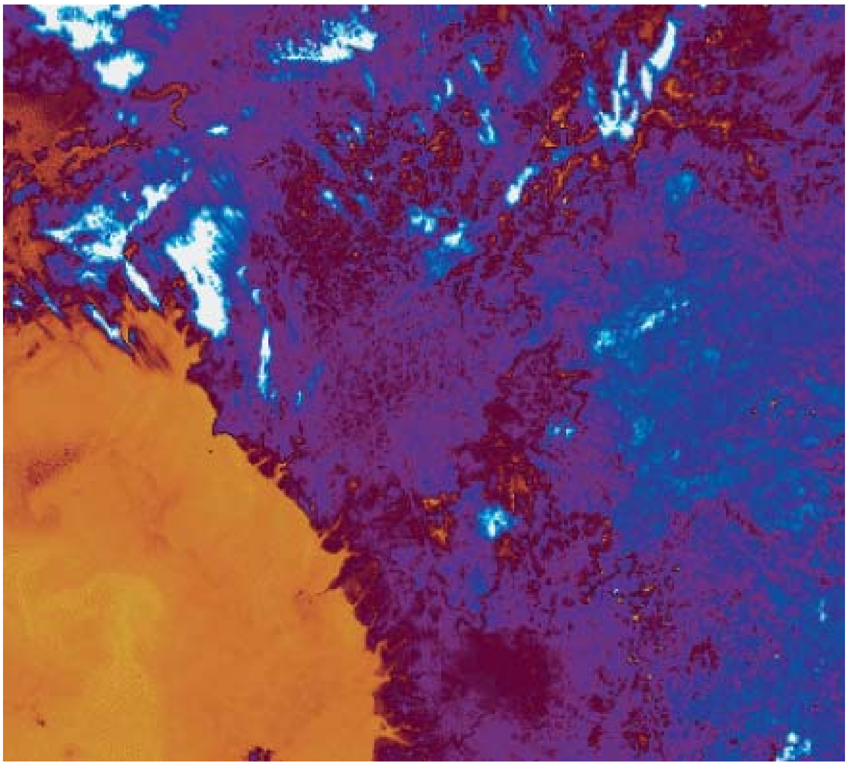


Figure 17. An ATSR night-time image of the West African Coast. The large yellow area is the Atlantic Ocean. The cooler land appears red, and bush fires can be seen as small yellow spots (courtesy of RAL)

Figure 18. SeaWiFS image of smoke plumes over the Gulf of Mexico on 5 June 1998 (courtesy of NASA/GSFC and Orbimage)

indicator of anthropogenic activity and biomass destruction. In some ecosystems, fire is a natural and beneficial land-management tool, but in others it is a major hazard requiring careful monitoring.

ATSR-2 has already demonstrated a capability for detecting fires at night using the 3.7 micron channel (Fig. 17). Visible-channel images from both the AATSR and MERIS will also be useful for detecting smoke plumes (Fig. 18). Time series of images of this kind are particularly valuable for determining the distribution and spread of fires throughout a region, and have also been used to create a global fire atlas.

Conclusion

Both MERIS and AATSR, with their moderate pixel size and large-area imaging abilities, will have an enormous range of potential local, regional or global applications on time scales ranging from days to years. The products to be routinely produced from these instruments have been identified by experts as the most important, globally measurable parameters on which further applications can be built. In addition, the potential for exploitation of AATSR and MERIS data will be underpinned by a rigorous calibration and validation programme that will be undertaken by ESA and the instrument science teams.

The main application of both optical sensors will be in the measurement of biological and physical variables of the ocean, in particular sea-surface temperature and the amount of phytoplankton. This is expected to lead to new insights into the global carbon cycle and processes that shape our climate. Furthermore, the extended objectives of both instruments will be directed to the understanding of atmospheric variables associated with clouds, water vapour and aerosols, with a view to atmosphere and climate modelling. Finally, the global monitoring of land cover and attendant estimates of the state of vegetation or biomass are also important parameters that will contribute to biogeochemical models applied to dynamic processes of global ecosystems and climatic variations.

In the context of growing concern about the future evolution of our climate and the devastation of the natural environment by mankind, MERIS and AATSR will provide data of unique quality and of crucial importance for understanding the mechanisms that control or amplify climate variability, for the improvement of weather forecasts as well as for a rational use of the Earth's resources.