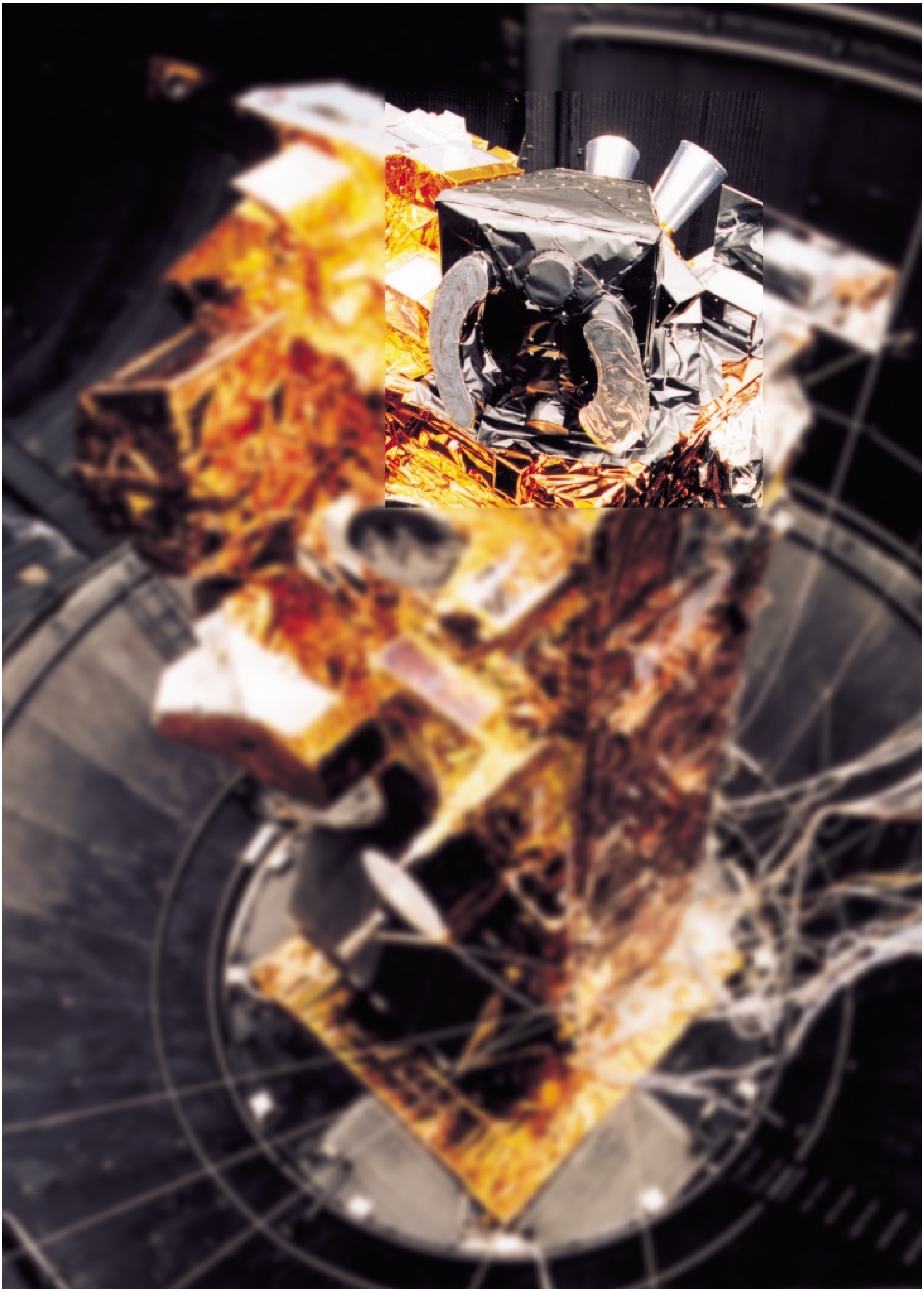

AATSR: Global-Change and Surface-Temperature Measurements from Envisat

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The Advanced Along-Track Scanning Radiometer (AATSR) onboard ESA's Envisat spacecraft is designed to meet the challenging task of monitoring and detecting climate change. It builds on the success of its predecessor instruments on the ERS-1 and ERS-2 satellites, and will lead to a 15+ year record of precise and accurate global Sea-Surface Temperature (SST) measurements, thereby making a valuable contribution to the long-term climate record.

The exceptionally high radiometric accuracy and stability of AATSR data are achieved through a number of unique features. A comprehensive pre-launch calibration programme, combined with continuous in-flight calibration, ensures that the data are continually corrected for sensor drift and degradation. A further innovative feature providing substantial advantages over traditional nadir-viewing instruments is the use of a 'dual-view' technique offering improved atmospheric correction. The accuracies achieved with this configuration are further enhanced by using low-noise infrared detectors, cooled to their optimum operating temperature by a pair of Stirling-cycle coolers.

With its high-accuracy, high-quality imagery and channels in the visible, near-infrared and thermal wavelengths, AATSR data will support many applications in addition to oceanographic and climate research, including a wide range of land-surface, cryosphere and atmospheric studies.

Introduction

The monitoring and detection of global climate change is one of the great challenges for modern satellite observing systems. The Advanced Along-Track Scanning Radiometer (AATSR) is one of the Announcement of Opportunity (AO) instruments on ESA's Envisat platform due for launch in mid-2001. It is funded jointly by the UK Department of the Environment, Transport and the Regions (DETR), the Australian Department of Industry, Science and Resources (DISR), and the UK Natural Environment Research Council (NERC) and is the most recent in a series of instruments designed and developed to measure SST to the high levels of accuracy (better than 0.3K ±1 sigma limit) and precision required for monitoring climatic trends and for research into climate prediction.

The AATSR follows ATSR-1, launched on ESA's ERS-1 satellite in July 1991 and ATSR-2, launched on ERS-2 in April 1995. Together, this family of instruments will establish a unique fifteen-year record of global Sea-Surface Temperature (SST) at a level of accuracy previously unprecedented in this field.

As an imaging spectrometer, the (A)ATSR system builds on the multi-channel approach to SST retrieval developed from the NOAA Advanced Very-High-Resolution Radiometer (AVHRR) missions, but offers considerable advantages over other sensors in the form of the unique sensitivity and stability of its calibration. This is achieved through the use of several innovative features, including:

- An along-track scanning technique that provides observations of the same point on the Earth's surface from two different viewing angles, for improved atmospheric correction.
- Continuous onboard calibration of the thermal channels against two stable, high-accuracy black-body calibration targets.
- An onboard visible calibration system for the visible and near-infrared channels (first introduced on ATSR-2).
- Low-noise infrared detectors, cooled by a pair of Stirling-cycle coolers.
- A rigorous pre-launch calibration programme.

As with ATSR-1 and ATSR-2, AATSR has been designed primarily to provide data for the monitoring and investigation of global warming and climate change. However, it will also offer valuable data for a wide range of other applications in the fields of oceanography, land-surface studies and atmospheric science.

Heritage

The (A)ATSR series of instruments have shown a gradual progression from research tool to operational observing system. All of the instruments have a common heritage, although certain aspects of instrument design have evolved as more data bandwidth, mass and power have become available from the host satellite.

ATSR-1 was an experimental scientific instrument, developed by a consortium of research institutes in the UK and Australia. It offered three thermal and one near-infrared channel, and was aimed specifically at oceanographic and climatological research. ATSR-1 had a design life of two years, but was still capable of providing accurate SST measurements when the ERS-1 platform ceased to function in early March 2000.

ATSR-2 had similar specifications to ATSR-1, but was enhanced to include three visible and near-infrared channels, plus associated on-board calibration system, to extend the mission objectives to include land applications. The possibility of combining the data from these wavelengths with the original thermal channels also offered new opportunities for innovative studies of clouds and atmospheric particulates. ATSR-2 is still operational as of November 2000.

AATSR will provide continuity of the dataset established by ATSR-1 and ATSR-2. It will offer the same combination of visible, near-infrared and thermal channels as ATSR-2, with the added advantage that the improved data rates available on Envisat will provide global coverage at the highest (12-bit) digital resolution for all channels.

The ERS-1 and ERS-2 tandem mission in the period between the launch of ATSR-2 and the end of ATSR-1 operations provided valuable data for the cross-calibration of the two instruments. An overlap period between ERS-2 and Envisat will offer similar opportunities for cross-calibration.

Mission objectives

Global SST is a key geophysical parameter required for climate research and work in this field requires accurate long-term measurements of SST, to allow the detection of very small changes (typically 0.3 K) over large geographic scales.

The primary use for (A)ATSR data will be as input to climate models, with the overall objective of identifying and quantifying human influences on global climate change. The data will be particularly valuable for studying phenomena such as the El Niño Southern Oscillation, in monitoring global warming due to the greenhouse effect, and in the investigation of ocean–atmosphere heat transfer. The particular advantage offered by the (A)ATSR data set is the continuous provision of global, self-consistent SST measurements. Measurements from buoys and ships of opportunity provide similar surface observations, but can be sparsely distributed and are prone to measurement inconsistencies. The ‘bulk’ temperature measurements they provide can also differ by several tenths of a degree from the true ‘skin’ temperature. With the addition of the visible channels, the mission objectives have also been extended to include additional scientific goals in the areas of vegetation monitoring and cloud and aerosol studies.

The main objectives of the AATSR mission can be summarised as follows:

- To extend the precise, high-accuracy data set of global SST started by ATSR-1, and continued with ATSR-2.
- To provide high-quality images of Top-Of-the-Atmosphere (TOA) Brightness Temperature (BT), at 1 km resolution, covering all parts of the globe except the polar caps.
- To enable scientific studies of ocean dynamics, land-surface properties, and the properties of clouds to be carried out through the use of these data.

Scientific requirements

SST

Due to the very high level of accuracy and precision necessary for global climate-change detection and measurement, the AATSR instrument and ground processing system are required to produce SST retrievals routinely with an absolute accuracy of better than 0.3 K, globally, both for a single sample and when averaged over areas of 0.5° longitude by 0.5° latitude, under certain cloud-free conditions (i.e. >20% cloud-free samples within each area).

For a warming trend of 0.25 K per decade and an SST data set spanning at least 10 – 15 years, a stability of 0.1 K per decade is needed to be able to detect the change with any confidence. To be of maximum use in climate research, the AATSR SST data must therefore be quality-assessed and validated with ground measurements, both during instrument commissioning and on a routine basis, to prevent undetected instrument drift or changing atmospheric conditions from obscuring any climate drift.

These high-level scientific requirements give rise to a number of more detailed requirements dictating instrument design.

Primary sensing wavelengths
AATSR has thermal-infrared channels at 3.7, 11 and 12 micron. SST is calculated using the 11 and 12 micron channels during the day, and the 11, 12 and 3.7 micron channels during the night.

The ocean surface emits infrared radiation; the peak of the emission signal is at around 10 micron. The spectral region between 10 and 13 micron is a suitable window with both low atmospheric absorption and good radiance sensitivity to small changes in SST. The AATSR 11 and 12 micron channels were chosen to exploit these conditions. The 3.7 micron channel was selected to provide an additional channel at night. Measurements in the 3–5 micron window are affected by reflected solar radiation during the day, but show very high radiometric sensitivity at night.

Atmospheric correction
Atmospheric correction of remotely sensed upwelling radiances is a subject of great importance. Given the overall global SST accuracy requirement, it is important to account precisely for the contribution of atmospheric absorption and emission to the upwelling radiances.

It is recognised from work with AVHRR data that measurements of upwelling radiances in two thermal channels will allow an accurate assessment of atmospheric effects, as the two channels will be affected differently by the atmospheric effects. Consequently, AATSR provides corrections for the effects of the atmosphere on the SST retrievals through the use of multiple thermal channels in the retrieval. However, the strict demands placed on the accuracy of AATSR SST retrievals require further improvements to atmospheric correction. These can be made by making two observations of the same ocean surface through different atmospheric path lengths. As a result, AATSR employs a novel ‘dual-view’ technique to achieve the best possible atmospheric correction.

Cloud clearing
The key to meeting the overall SST accuracy requirements is effective cloud clearing. This can be achieved with reference to a visible channel during the daytime (when cloud will be bright compared to the sea surface) or at night by looking for large differences between different channel combinations, or in the properties of, and relationships between, measured Brightness Temperatures (BT’s) expected for clear conditions. AATSR has a visible channel at 1.6 micron which is used primarily for cloud clearing. On ATSR-1 and -2, this was the only visible channel available, both day and night. For AATSR, any of the visible channels could be used, but the 1.6 micron channel is particularly good for phase discrimination between ice and water clouds.

Sampling distance and Instantaneous Field of View (IFOV)
The overall SST accuracy requirement has been set on the basis that 20% of samples need to be cloud-free over a 0.5° by 0.5° cell. For adequate noise reduction through averaging of individual sample values, a minimum of 500 samples should be cloud-free. In the limiting scenario of 80% cloud cover, this requires a total of 2500 samples, which for a 50 km x 50 km cell gives a sample size of 1 km. The AATSR sampling distance has therefore been set at 1 km at nadir. Research with previous sensors has also shown that 1 km is a reasonable compromise between data volume and spatial resolution for SST feature mapping. In terms of land applications, a 1 km sampling distance is good for mapping and monitoring on large scales, whilst providing adequate discrimination of land-surface types. To allow the cloud-clearing algorithms to work successfully at the edges of cloud masses, co-alignment of the AATSR channel IFOVs is also required to 0.1 of the sampling distance.

Calibration and characterisation requirements
To retrieve SST from the AATSR detector signals, the spectral response and IFOV of the channels need to be measured prior to launch. In order to meet the strict accuracy requirements, a pre-launch end-to-end radiometric calibration of the instrument has to be performed. In-orbit radiometric calibration will also play an important part in ensuring the long-term stability of AATSR SST measurements over the mission lifetime. To achieve this, the instrument carries two high-precision black-body targets, each of which is viewed during every scan to provide accurate in-orbit calibration of the thermal channels.

Land and atmospheric research
Work using Landsat and AVHRR data has shown the value of global monitoring of land, especially vegetation, at moderate resolution (i.e. ~1 to 4 km) and using certain combinations of bands. AATSR has three visible/near-infrared channels at 0.55, 0.67 and 0.87 micron, designed specifically for remote-sensing applications over land. However, an important instrument design requirement was that these channels be added in such a way as to avoid

compromising the primary SST measurement requirements. Whilst not originally designed for this purpose, the AATSR thermal channels complement these visible channels and have proved useful for land-based studies in such domains as improved global monitoring of burning vegetation and retrieval of Land Surface Temperature (LST).

In order to cope with all possible normal variations in brightness over the Earth's surface without saturation whilst maximising the precision of the measurements, the gain and offset of the visible channels are selectable in flight. These channels have a signal-to-noise ratio of 20:1 at 0.5% spectral albedo and measure top-of-the-atmosphere radiances to an absolute accuracy of 5% over the entire range.

The AATSR reflection channels also undergo a pre-launch calibration, including IFOV and spectral-response measurements. Nevertheless, for long-term monitoring of land parameters, it is important to have confidence in the stability of the sensing system. Thus, an in-orbit calibration system for the visible channels is also included.

The AATSR instrument

The AATSR Flight Model (FM) instrument is shown in Figure 1. Figure 2 shows the instrument with the main features highlighted. In operation, infrared and visible radiation is reflected from a scan mirror mounted on the scan mechanism, onto a paraboloid mirror. The beam is then focused and reflected into the infrared and visible Focal-Plane Assemblies (FPAs), where detectors convert the radiant energy into electrical signals. The low-level signals from the FPA are then amplified by a signal pre-amplifier, before being digitised and passed on to other systems on the satellite to transmit them back to the Earth.

The AATSR instrument consists of the following discrete items represented in the functional block diagram in Figure 3:

- The instrument itself, known as the Infrared-Visible Radiometer.
- The Instrument Electronics Unit, providing the signal channel processing function, the scan-mirror drive control and temperature-sensor conditioning. The Black-Body

Figure 1. The AATSR flight-model instrument

Figure 2. Main features of the AATSR instrument

Figure 3. AATSR functional block diagram

Figure 4. AATSR viewing geometry

Figure 5. Operation of the AATSR inclined-plane scan mirror to achieve two views of the Earth's surface

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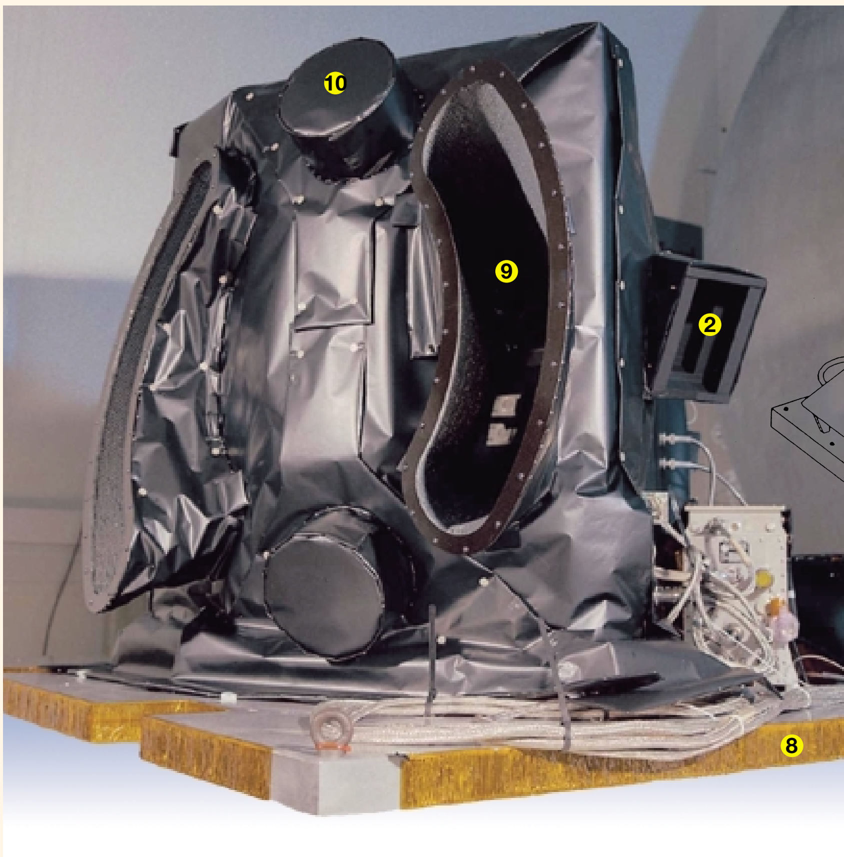

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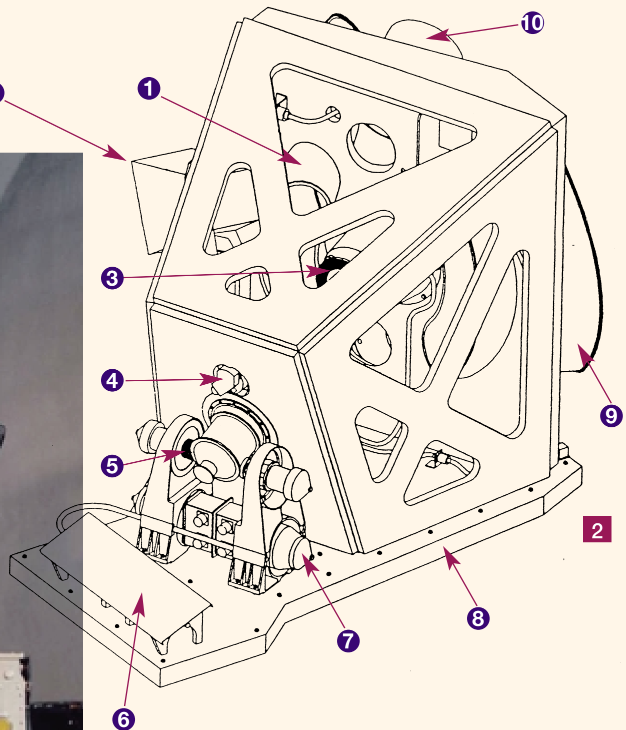

Electronics Unit is mounted on top, and provides the control of the black-body heaters and collects temperature-sensor data.
- The Cooler Control Unit, which provides the control function for the Stirling-cycle coolers.
- The Digital Electronics Unit (DEU) for instrument control and data-formatting functions.
- The Instrument Harness, which electrically connects the above items.

Spectral characteristics

The spectral channels offered by AATSR are summarised in Table 1. The selection of the thermal channels has been optimised to minimise the effect of the atmosphere on the observations. Their wavelengths are similar to those of AVHRR, which has provided operational values of SST, albeit at somewhat lower levels of accuracy, for nearly 30 years. However, unlike AVHRR, the AATSR thermal channels are supplemented by a channel at a wavelength of 1.6 micron, which was introduced for daytime cloud identification, but which also has the potential for water-ice discrimination in cloud fields.

Table 1. ATSR-2 and AATSR spectral channels (the first three channels listed were not present in ATSR-1)

Channel	Centre Wavelength	Bandwidth	Primary Application
0.55 µm	0.555 µm	20 nm	Chlorophyll
0.66 µm	0.659 µm	20 nm	Vegetation Index
0.87 µm	0.865 µm	20 nm	Vegetation Index
1.6 µm	1.61 µm	0.3 µm	Cloud Clearing
3.7 µm	3.70 µm	0.3 µm	SST
11 µm	10.85µm	1.0 µm	SST
12 µm	12.00 µm	1.0 µm	SST

Along-track scanning

The (A)ATSR instruments are unique in their use of along-track scanning to offer a dual view of the Earth's surface. The AATSR viewing geometry is shown in Figure 4. The dual view is achieved by rotating an inclined-plane scan mirror in front of a reflecting telescope, thus performing a conical scan of the instrument IFOV (Fig. 5). The resulting conical scan is arranged to view 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° (the forward view) and then at

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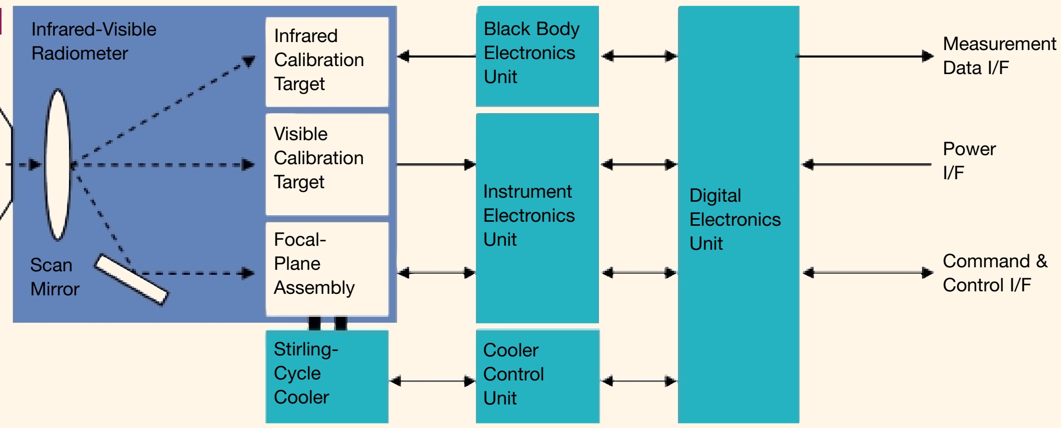

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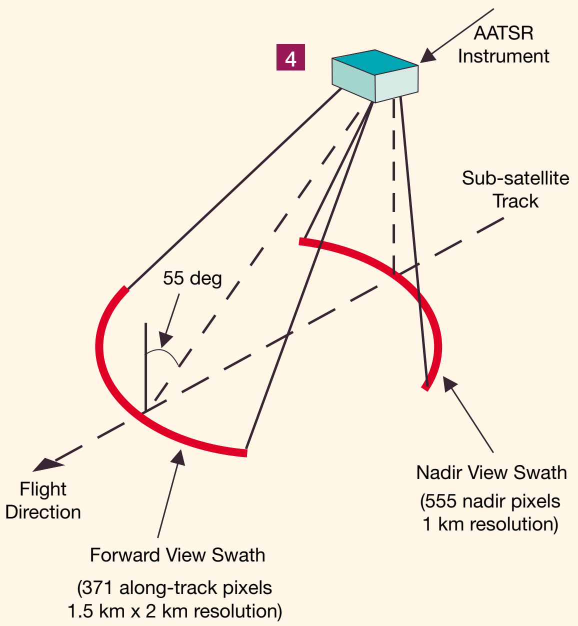

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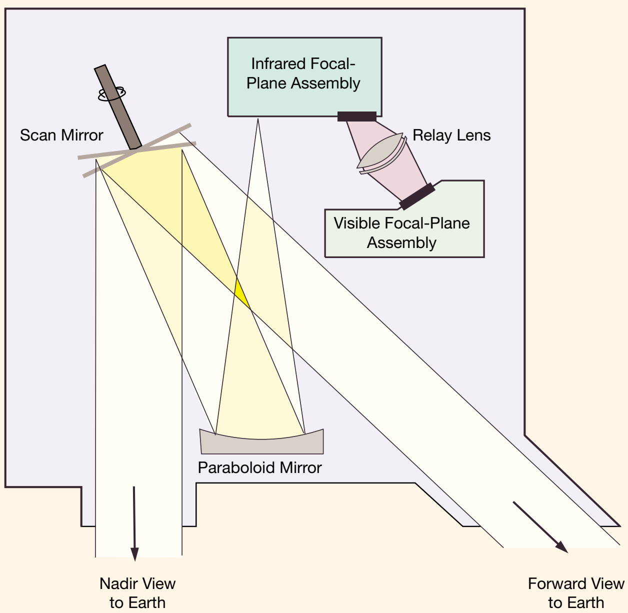


an angle close to vertical (the nadir view) as the satellite moves forward. These observations are separated in time by 150 sec, or approximately 1000 km on the ground, at the sub-satellite point.

The field of view comprises two 500 km-wide curved swaths, with 555 pixels across the nadir swath and 371 pixels across the forward swath. The nominal IFOV (pixel) size is 1 km^2 at the centre of the nadir swath and 1.5 km^2 at the centre of the forward swath. The scan cycle is repeated 6.6 times per second, and the sub-satellite point on the Earth's surface moves forward by 1 km (i.e. one pixel) during each scan cycle.

Coolers

Another unique feature of the (A)ATSR design is the use of closed-cycle mechanical coolers to maintain the thermal environment necessary for optimal operation of the infrared detectors. The FPA for the thermal- infrared wavelength region is cooled to about 80 K, whilst the other is maintained at ambient temperature. ATSR-1 was the first environmental sensor to carry such a cooler into space, and AATSR will include a commercial version of the cooler provided by the Prime Contractor, Astrium Ltd. (UK).

On-board calibration

The AATSR scan cycle allows the detectors to view a sequence of five elements, as shown in Figure 6. These are the along-track Earth view, a hot black-body target, the visible calibration unit, the nadir Earth view, and a cold black-body target. The two black-body calibration targets observed between the Earth-views are critical to the radiometric quality of the AATSR thermal data. These black bodies use a design concept specially developed for ATSR-1 and are basically cylindrical cavities with non-reflecting interior coatings, good insulation and a temperature monitoring system designed for high accuracy, high precision and low drift. The targets are designed to achieve exceptional stability and uniformity and are located in a thermal environment in which they provide extremely stable radiometer reference sources.

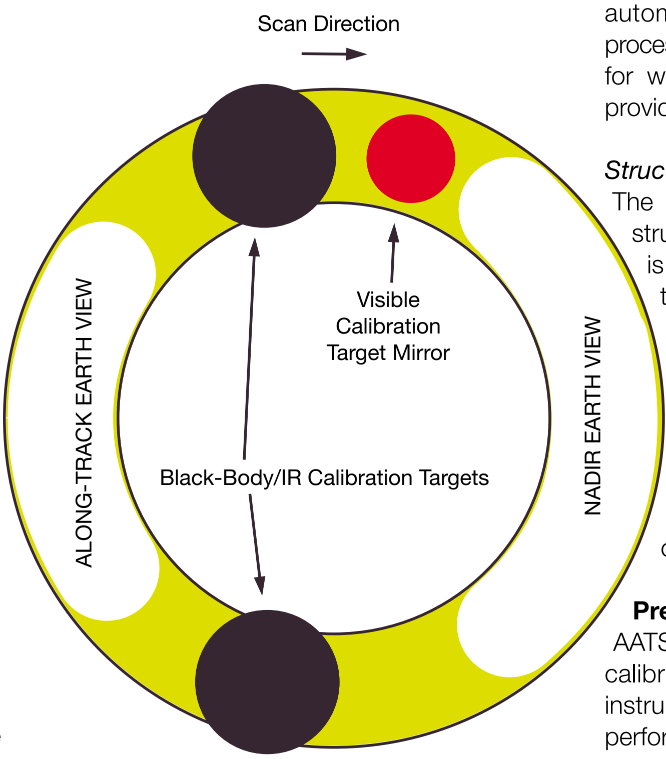


Figure 6. The AATSR scan cycle

One black body 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 enclosure (~256 K), just below the expected range of marine scene temperatures. The two black bodies therefore span the full range of expected SSTs. As a result, AATSR can be regarded as a near-ideal radiometer. The infrared calibration is applied automatically during the ground processing, so that users are provided with fully calibrated BTs or SSTs.

For the visible and near-infrared channels, a different calibration philosophy is adopted. Here AATSR employs a visible calibration system whereby once per orbit, as the satellite approaches sunrise, a brief view of the Sun is obtained, through a special aperture in the instrument. This illuminates a diffusing plate made of Russian opal tile, from which the scattered light enters the detector field of view at a suitable point in the scan cycle. Calibration of the visible channels will be performed automatically for AATSR, during ground processing. This is an improvement over ATSR-2, for which visible calibration coefficients were provided to users off-line.

Structure

The instrument is housed in a carbon-fibre structure and most of the instrument volume is taken up by the empty space required by the conical scanning geometry. The two Earth views, at different incidence angles, are defined by two large curved apertures in the Earth-facing side of the instrument. These are shielded by large baffles (Fig. 1), which prevent the entry of direct sunlight into the optical enclosure and are the most prominently visible parts of the instrument.

Pre-launch calibration

AATSR has undergone a rigorous pre-launch calibration programme to characterise the instrument and ensure that the very strict performance criteria are met. The calibration of the 12, 11 and 3.7 micron channels was verified using high-accuracy external black bodies, the characterisation of which can be traced back to international standards. Measurements were taken over a range of target temperatures from 210 to 315 K and corrections derived for detector non-linearity. Overall, the AATSR BTs were found to be within 30 mK of the target temperatures. The AATSR visible channels have also undergone a detailed laboratory calibration, to ensure that all instrument performance requirements are met.

Operations

Unlike ATSR-2, AATSR does not have special limited-sampling modes, which were necessary owing to data-rate restrictions on ERS-2. When in operation, data from all of AATSR's channels will be available all of the time at full 12-bit digitisation. The only routine interruption to the data flow will occur when the cooled detectors are warmed up to ambient temperature to remove any condensation that may have been deposited at low temperatures (a process known as outgassing). Calibration of the thermal channels is not affected by this condensation, as the view of the black bodies is subject to the same phenomenon, and so the effect is calibrated out.

Outgassing periods last about two days and occur at intervals of approximately three months. Information about such outgassing events is made available to users in advance. No useful thermal-channel data are collected during these periods. The operation of the visible and near-infrared detectors is unaffected by this warming, although consideration should be given to the accuracy of their calibration during this time.

Products and algorithms

Data from the Envisat low-bit-rate instruments, of which AATSR is one, will be acquired globally on a continuous basis and will be stored on-board for subsequent transmission to the ground. This will take place once per orbit, when the satellite is within range of selected ESA ground stations. Near Real Time (NRT) products will be generated at Payload Data-Handling Stations (PDHSs) co-located within the acquisition stations. The same data will also be sent to a dedicated Processing and Archiving Centre (PAC) for the archiving, processing and delivery of off-line products. The NRT processing will be exactly the same as the off-line processing, except for the quality of the auxiliary data files used.

The suite of AATSR products is summarised in Table 2. As for all Envisat instruments, the interface for browsing and ordering these products will be via the PDS User Service Facility (USF), accessible via the World Wide Web.

After reception on the ground, the stream of raw instrument source packets is converted into a Level-0 product. This consists of a chronological sequence of records, each containing a single instrument source packet, with each source packet representing one instrument scan. Associated header and quality information are also added to the product at this stage. From Level-0, the data processing is split into two further distinct steps, leading to the generation of first Level-1b (calibrated, geolocated radiances) and then Level-2 (single-pass geophysical quantities) products. It is these higher level products that will routinely be available to users.

Table 2. Summary of AATSR data products

Product ID	Name	Description	Approx. Size (Mbyte/orbit)
ATS_NL__0P	Level-0 Product	- Instrument source-packet data	490
ATS_TOA_1P	GBTR	- Full-resolution top of atmosphere BT/reflectance for all channels and both views - Product-quality data, geolocation data, solar angles and visible calibration coefficients	729
ATS_NR__2P	GST	- Full-resolution nadir-only and dual-view SST over sea - Full-resolution 11 µm BT and Normalised Difference Vegetation Index (NDVI) over land - Product-quality data, geolocation data and solar angles	126
ATS_AR__2P	AST	- Spatially averaged ocean, land and cloud parameters - Spatially averaged top-of-atmosphere BT/reflectance	63
ATS_MET_2P	Meteo. Product	- SST and averaged BT for all clear sea pixels, 10 arcmin cell, for meteo. users	5
ATS_AST_BP	Browse Product	- Three-band colour-composite browse image derived from Level-1b product. 4 km x 4 km sampling	4

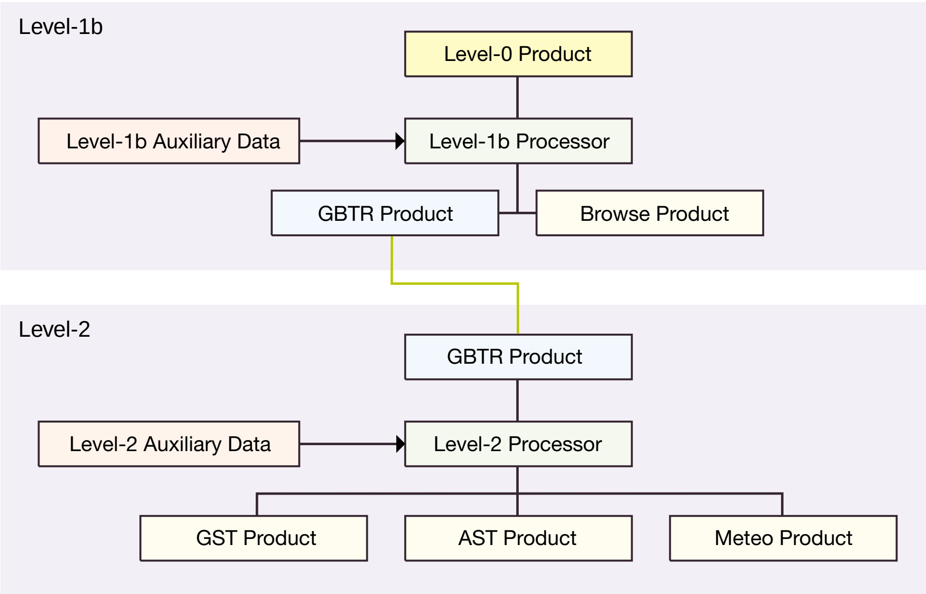


Figure 7. Relationship between the AATSR products and processing levels

Figure 7 summarises the relationship between the AATSR products and processing levels.

Level-1b products and processing

The Level-1b Gridded Brightness Temperature/ Reflectance (GBTR) comprises calibrated and geolocated images of BT for the three infrared channels, or reflectance for the near-infrared and visible channels, together with cloud and land identification. This is used as the starting point for processing to higher level geophysical products. The Level-1b processing steps are shown as a flow chart in Figure 8.

Following the unpacking and validation of the science and auxiliary data contained within the source packets, calibration parameters describing the relationship between pixel count and radiance for the three infrared channels are calculated. These are determined from the black-body pixel counts and the black-body temperatures within the auxiliary data. Look-up tables are used for the conversion of temperature to radiance. The calibration data for the visible channels, which are obtained once per orbit, are also unpacked and new calibration parameters for the visible channels are calculated and written out into an annotation data set.

Signal calibration uses the calibration coefficients to convert the science data in each channel to units of BT or reflectance, as appropriate. In the case of the infrared channels, look-up tables for the conversion of radiance to BT are used. For the visible channels, calibrated reflectances are calculated directly (the visible calibration parameters used are derived from an earlier orbit and found in an auxiliary data file).

Geolocation makes use of orbit-propagation software in conjunction with available satellite-orbit state vectors to determine the position on the Earth's surface of each instrument pixel. The data are then regridded onto a rectangular grid to correct for the curved lines of the AATSR conical scan, using the pixel co-ordinates derived at the geolocation stage. The same grid is used for both the nadir and forward-view images to achieve the colocation of the two images.

The regridding process may lead to gaps in the image, particularly in the forward view where the density of instrument pixels is lower than the density of points on the image grid; therefore, a cosmetic fill process is applied at this stage. Finally, land-flagging and cloud-clearing algorithms are applied to the images to distinguish between land and sea pixels, and to identify those regions of the image containing cloud.

Figure 9 indicates the wide variety of applications for which the AATSR Level-1b product can be used, including studies of the oceans, the land surface, the cryosphere, and the atmosphere.

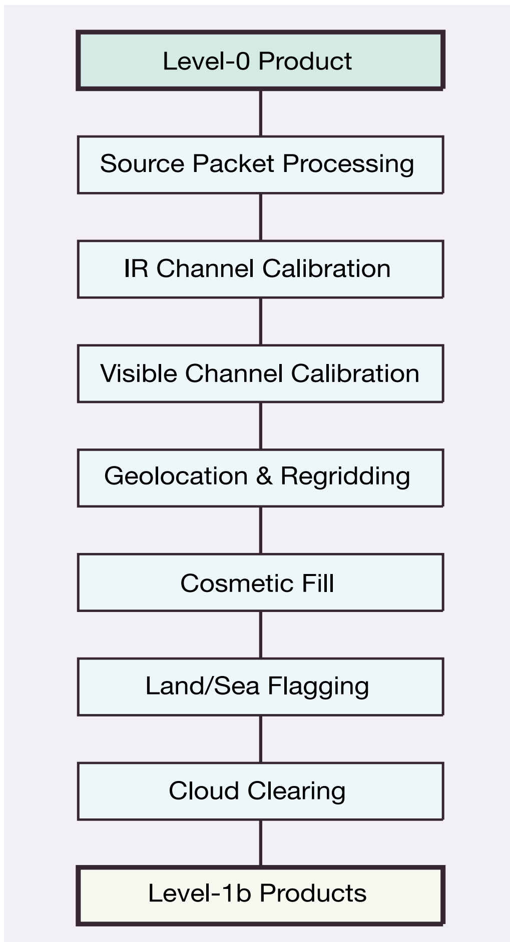
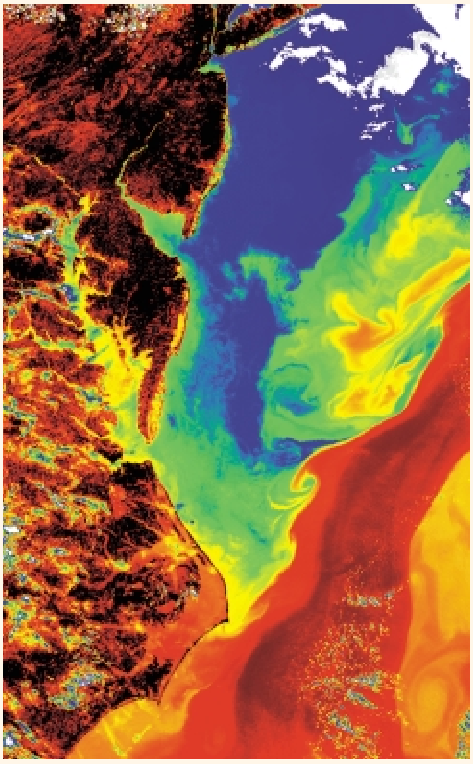


Figure 8. The AATSR Level-1b processing steps



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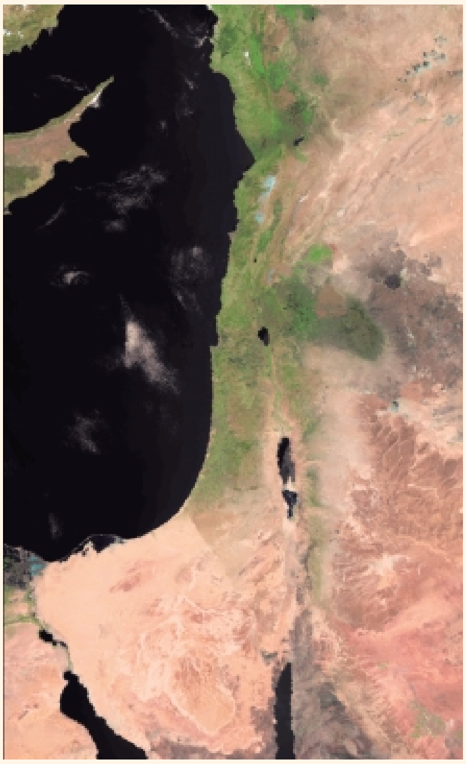

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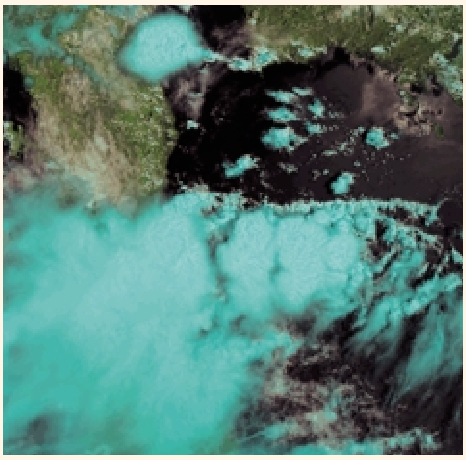

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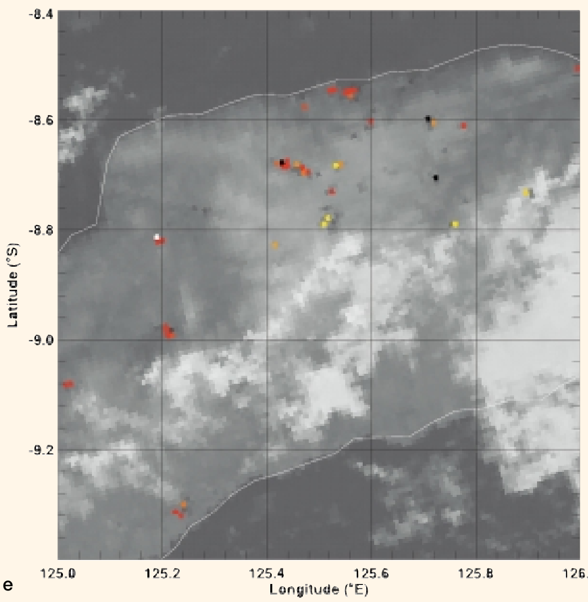
Figure 9 a to f. Applications of (A)ATSR Level-1b data

(a) A false-colour daytime ATSR-2 image (11 micron channel) of the US Eastern Seaboard, from New York, in the north to Pamlico Sound, North Carolina, in the south. Hot areas are black and red, while cool areas are white and blue. The Gulf Stream is clearly apparent at the bottom right. The image is a good example of structures on a wide range of spatial scales, and typifies the clarity and radiometric discrimination of ATSR imagery.
(b) A false-colour, daytime ATSR-2 image (0.55, 0.67 and 0.87 micron) showing Cyprus, Israel and the Sinai Peninsula. The border between Israel and the Sinai is visible due to changes in vegetation, resulting from differences in land-use patterns.
(c) A 12 micron ATSR-2 thermal image showing the break-up of the Ross Ice Shelf in the Antarctic. A large 300 km x 40 km iceberg can be seen breaking away from the main ice sheet.
(d) An image of the Malay Peninsula (1.6, 0.87 and 0.67 micron bands) showing a line of strong convection (across the centre of the image), and a gust-front.
(e) An ATSR near-real-time thermal image. Fires in the villages and towns of East Timor can be clearly identified.
(f) A daytime, 11 micron image of the Lascar volcano in northern Chile, showing two eruption columns. The ATSR stereo-view and atmospheric profile information can be used to calculate the heights of the columns. The insert shows an emplaced pyroclastic flow deposit, which saturates the 11micron channel. In this image, the coldest pixels appear white.



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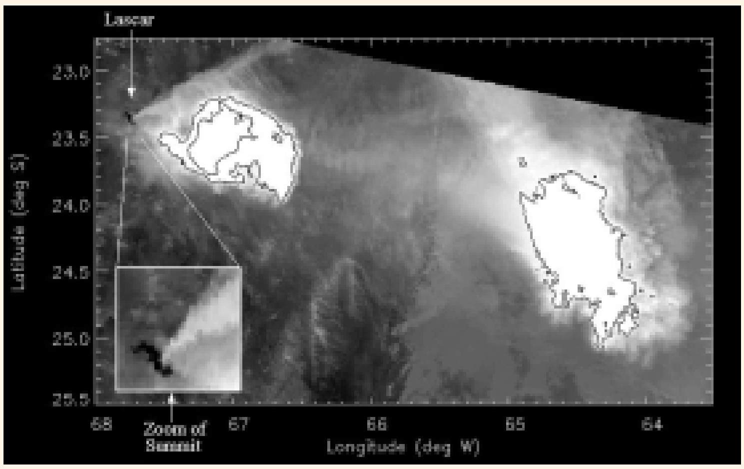

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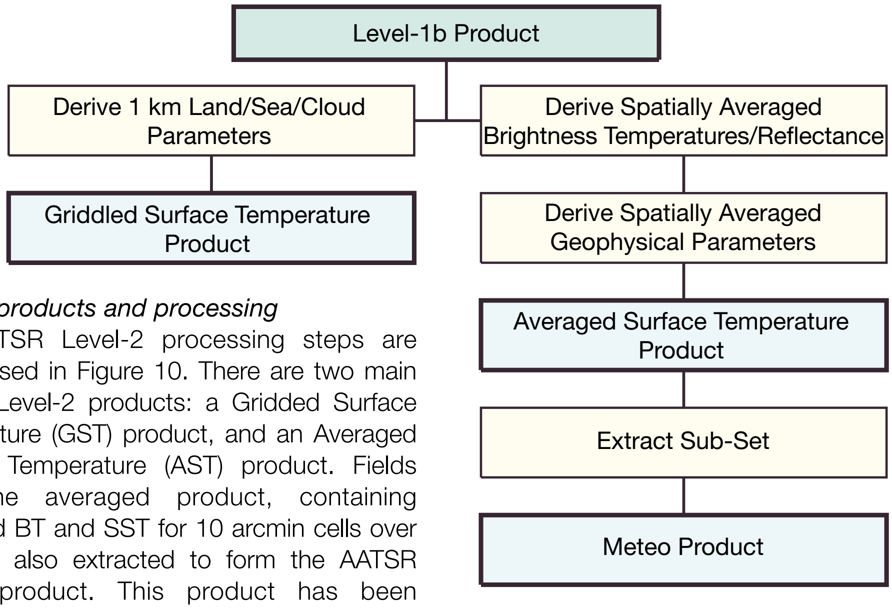

Figure 10. The AATSR Level-2 processing chain

Level-2 products and processing
The AATSR Level-2 processing steps are summarised in Figure 10. There are two main AATSR Level-2 products: a Gridded Surface Temperature (GST) product, and an Averaged Surface Temperature (AST) product. Fields from the averaged product, containing averaged BT and SST for 10 arcmin cells over sea, are also extracted to form the AATSR Meteo product. This product has been specifically designed for use by meteorological agencies in near-real-time.

Level-2 Gridded Surface Temperature
The GST product provides geophysical products over the ocean and land at 1 km resolution. This product is aimed at users interested in land and ocean applications requiring high-precision measurements at the full resolution, and will be available in multiples of the 512 km x 512 km minimum scene size, up to a maximum of one complete orbit.

SSTs are derived using the 11 and 12 micron channels for daytime data, and the 11, 12 and 3.7 micron channels for night-time data. For each pixel, two results are obtained whenever possible, one using the combined nadir and forward views and the other using the nadir view alone. The SSTs are calculated using a pre-defined set of retrieval coefficients. These are derived from a forward model representing a variety of different SSTs and atmospheric states.

Table 3. Contents of the AATSR AST product

- Averaged nadir-only and dual-view SST for cloud-free pixels over sea, plus associated parameters such as standard deviation of the mean and the number of pixels contributing to the average.
- Mean LST (currently the 11 micron BT) and NDVI for cloud-free pixels over land.
- Mean BT of the coldest 25% of cloudy pixels in the cell (as an estimate of CTT), and percentage cloud cover for each cell.
- Averaged BT/top-of-atmosphere reflectance in all channels for both cloudy and clear pixels over sea and land. (This will be particularly useful for users wishing to develop their own global algorithms and those wishing to reprocess global data sets.)

Currently, the 11 micron nadir-view BT is returned in the nadir-only field as an estimate of Land Surface Temperature (LST). A dedicated LST algorithm may be added in the future. Normalised Difference Vegetation Index (NDVI) values are calculated using the nadir 0.67 and 0.87 micron channels and returned in the combined view field. In cloudy conditions, the 11 micron BT is returned in the nadir field, as a placeholder for Cloud-Top Temperature (CTT). The combined field has been reserved for Cloud-Top Height (CTH), but this field is currently set to zero.

Level-2 Averaged Surface Temperature
The AST product contains spatially averaged SST, land and cloud parameters. Several different types of averaged measurement are offered within the same product (50 and 17 km^2 grid cells or half-degree and 10 arcmin cells) allowing users to select the most suitable data set for their needs.

The contents of the AST product include the fields listed in Table 3. The AST product will be disseminated on a full-orbit basis and is intended for global monitoring activities. Figure 11 shows spatially averaged, global SST imagery, derived from ATSR data.

It is important to note that the (A)ATSR instruments return SST measurements for the ocean's 'skin' (commonly taken to be the water layer within 0.1 mm of the surface). The AVHRR instruments also record emission from the skin, but the subsequent processing scheme uses a method of regressing the satellite observations to buoy measurements of 'bulk' SSTs, which can introduce a bias into this data set.

Algorithm heritage
ATSR-1 and ATSR-2 data are processed by the SADIST (Synthesis of ATSR Data Into Surface

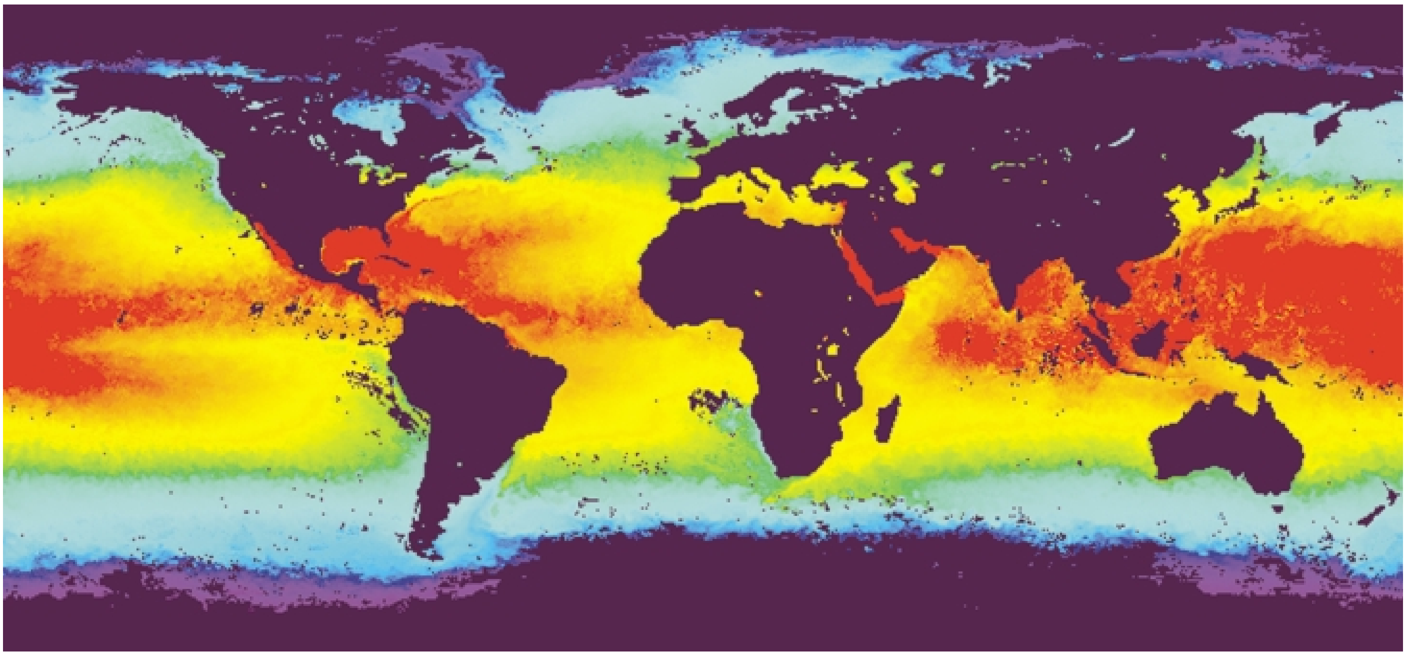

Figure 11. Spatially averaged, global SST imagery derived from ATSR data. The temperatures are represented on a scale from purple/blue (coldest) through green to red (warmest). To the east of the USA, a thin tongue of warm water can be seen stretching northwards, which is the Gulf Stream

Temperatures) processor developed by the Rutherford Appleton Laboratory (RAL). This software has been re-engineered for AATSR to allow it to be integrated within the wider Envisat PDS architecture. Algorithms from the SADIST processor have been re-used wherever possible to maintain consistency across the three missions, although AATSR products will also provide a number of enhancements. These include: the use of more accurate ellipsoidal, rather than spherical geometry within the regridding scheme; a change in the along-track sampling of the image grid from a fixed spacing of 1 km to sampling equally spaced in time; use of the Envisat tools for time correlation, orbit propagation and geolocation to ensure coherence between all Envisat instruments; operational calibration of the AATSR visible channels; the inclusion of a latitude and longitude topographic correction over land; and the introduction of NDVI over land.

Conclusions

As the third in the series of instruments, AATSR will fulfil an important scientific function within the Envisat mission. Its primary objective will be to provide continuity in the long-term data set of accurate global SST which, at the time of the Envisat launch, will be of nearly ten years' duration. It will also provide a rich source of thermal, visible and near-infrared imagery for other applications over oceans and land. As part of the wider Envisat payload, it will also offer unique opportunities for the synergistic use of AATSR data with other instruments, and particularly with the MERIS sensor.

AATSR offers the unique capabilities of continuous onboard calibration of both the infrared and visible channels, cooled detectors and along-track scanning, combined with rigorous pre-launch calibration and post-launch validation. These all combine to offer exceptionally high-quality data sets, not only over the ocean, but in all areas of environmental research.

AATSR also offers the advantage of being the third in a series of similar instruments. The length, consistency and accuracy of the SST data set, which only a series of instruments such as the ATSRs can offer, is of prime importance to climate-change research. In addition, considerable skill and expertise in instrument design, operations, data processing and data exploitation have been built up over the years in support of these missions. The AATSR programme has set itself an ambitious target of improving on a data set already in existence and of quite a high standard. Nevertheless, over the years the (A)ATSR instrument's position as the most accurate current measuring system for SST has strengthened with the improvements in both the instruments and the data-processing systems, long-term performance monitoring and comprehensive SST validation programmes.

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