ASAR – Envisat's Advanced Synthetic Aperture Radar

Building on ERS Achievements towards Future Earth Watch Missions

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Following on from the highly successful ERS-1/2 SARs, which have contributed to major scientific achievements and initiated pre-operational and commercial applications of SAR data, ESA is now ready to launch Europe's largest remote-sensing satellite to date, carrying an Advanced Synthetic Aperture Radar (ASAR).

The ASAR is an all-weather, day-and-night high-resolution radar-imaging instrument. Compared with the ERS SAR, it features extended observational capabilities, three new modes of operation and improved performances. The ASAR system has been designed to provide continuity with ERS SAR, but also to extend the range of measurements through the exploitation of its various operating modes and the development of new algorithms and data products. The Envisat ground segment will allow the generation of near-real-time and off-line precision images to satisfy the needs of the scientific, institutional and commercial data users.

The mission

The Envisat mission is an important element in providing the long-term, continuous data sets that are so crucial for addressing environmental and climate issues. At the same time, it will further promote the transfer of applications of remote-sensing data from experimental to pre-operational and operational exploitation.

The mission has both 'global' and 'regional' objectives, with the corresponding need to provide data to scientific and applications users on various time scales. Important contributions by ASAR to the global mission include:
– measuring sea-state conditions at various scales
– mapping ice-sheet characteristics and dynamics
– mapping sea-ice distribution and dynamics
– detecting large-scale vegetation changes
– monitoring natural and man-made pollution over the oceans.

ASAR is set to make a major contribution to the regional mission by providing continuous and reliable data sets for applications such as:
– offshore operations in sea ice
– snow and ice mapping
– coastal protection and pollution monitoring
– ship traffic monitoring
– agriculture and forest monitoring
– soil-moisture monitoring
– geological exploration
– topographic mapping
– predicting, tracking and responding to natural hazards
– surface deformation.

Some of the regional objectives (sea-ice applications, marine pollution, maritime traffic, hazard monitoring, etc.) require near-real-time data products (within a few hours from sensing) generated according to user requests. Some others (e.g. agriculture, soil moisture, etc.) require fast turn-around data services (within a few days). The remainder can be satisfied with offline data delivery. As well as ASAR satisfying specific operational and commercial requirements, there will be major systematic data-collection programmes to build up archives for scientific research purposes.

Land
As a result of observing the land surface with the ERS SARs, a large number of land applications have emerged, several based on

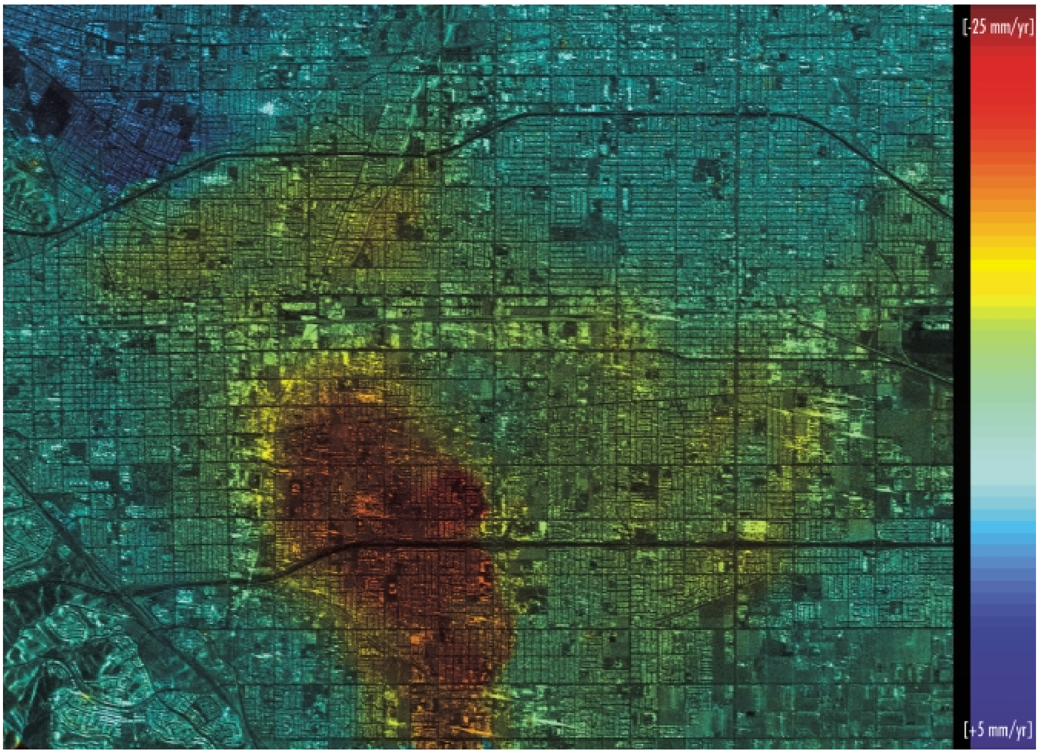


Figure 1. ERS-SAR interferometry estimated displacement over POMONA using the permanent-scatterers technique: June 1992 to January 1999 (courtesy of Politecnico di Milano, Italy)

important developments in the field of SAR interferometry. SAR data are being used for agricultural monitoring, forest mapping, geological exploration and flood mapping, while INSAR measurements of topography and small topographic changes are making major contributions to environmental risk assessment involving earthquakes and land subsidence.

ASAR has extended observational capabilities in comparison to the ERS SAR, providing SAR mission continuity as well as benefiting from the results from ERS and other SAR missions. Operating in concert with other Envisat-1 instruments MERIS and AATSR, ASAR provides essential surface-roughness and land-cover information for the determination of land-surface processes and air/sea interaction for climate studies.

The higher frequency of coverage provided by ASAR will improve greatly the value of SAR data for hazard monitoring, because locally infrequent events such as earthquakes, volcanic eruptions, floods and fires, require intensive observation over short periods. The beam steering mode will also permit (at least) 3-day repeat observations of certain localised events at high spatial resolution. Table 1 shows the average revisit frequency per 35-day orbit

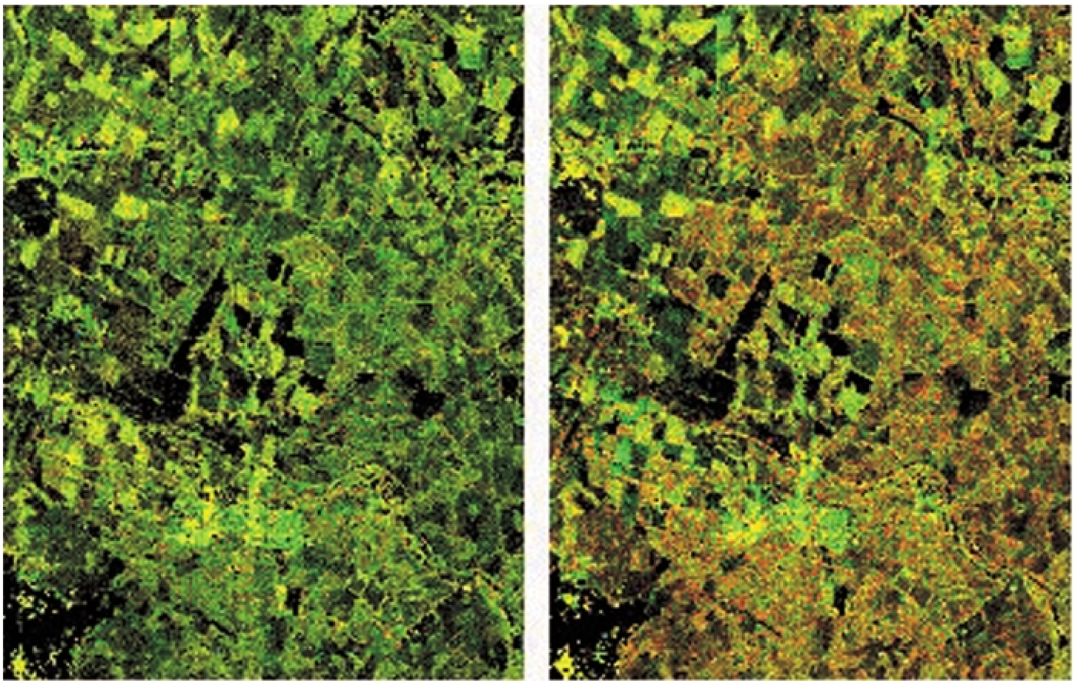


Figure 2. Dual-polarisation SAR images of Thetford Forest (UK), from the SIR-C mission. Left image: HH (green) and VV (red). Right image: HH (green) and HV (red) (courtesy of GEC-Marconi, UK)

cycle as function of latitude and incidence angle (descending tracks only).

The potential value of the Global Monitoring mode is indicated by previous work carried out over land, using the ERS wind scatterometer at 25 km spatial resolution. For local land-cover mapping, ASAR high-resolution products will continue the role already established for ERS SAR in complementing conventional optical images from other satellites, particularly under poor solar-illumination conditions or in cloudy areas. The new features of ASAR include image acquisitions at multiple incidence angles and with dual polarisation, which will open up new possibilities in land-cover classification from SAR.

Ocean and ice

The original focus of the ERS missions was ocean and ice monitoring, and there has been an impressive range of scientific investigations in oceanography, polar science, glaciology and climate research which will be supported by ASAR. These include measurements of ocean surface features (currents, fronts, eddies, internal waves), directional ocean-wave spectra, sea-floor topography, snow cover and ice-sheet dynamics. Operational systems have been developed for mapping sea ice, oil-slick monitoring and ship detection.

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

The ASAR Wave mode combined with a new algorithm called ‘inter-look cross-spectral processing’, whereby information on the wave propagation direction is computed from pairs of single-look images separated in time by typically a fraction of the dominant wave period, will provide meteorological users with wave directional and geophysical parameters and wind parameters.

Recently, investigations have shown that it is possible to derive wind-speed estimates from SAR data (see Fig. 3). The ASAR Wide Swath mode is of interest in this respect because of its large coverage area and the short revisit period.

Instrument operation

Measurement principle

The radar antenna beam illuminates the ground to the side of the satellite. Due to the satellite’s motion, each target element remains within the illumination beam for a period known as the ‘integration time’. As part of the on-ground processing, the complex echo signals received during this integration time are added coherently. This process is equivalent to a long antenna – so-called ‘synthetic aperture’ – illuminating the target. This synthetic aperture is equal to the distance the satellite has travelled during the integration time.

The along-track (equivalent to the azimuth in the ground processing) resolution obtainable with the SAR principle is half the physical antenna length. The resolution achieved can be

Incidence Angle	Latitude 0°	45°	60°	70°
No Constraints	5	7	11	16
± 5°	3	4	6	9
± 2°	1	1.4	2	3
Exact Repeat	1	1	1	1

Table 1. Average revisit cycle per 35-day orbit as a function of latitude and incidence-angle variation, illustrating ASAR revisit time capability (descending path only)

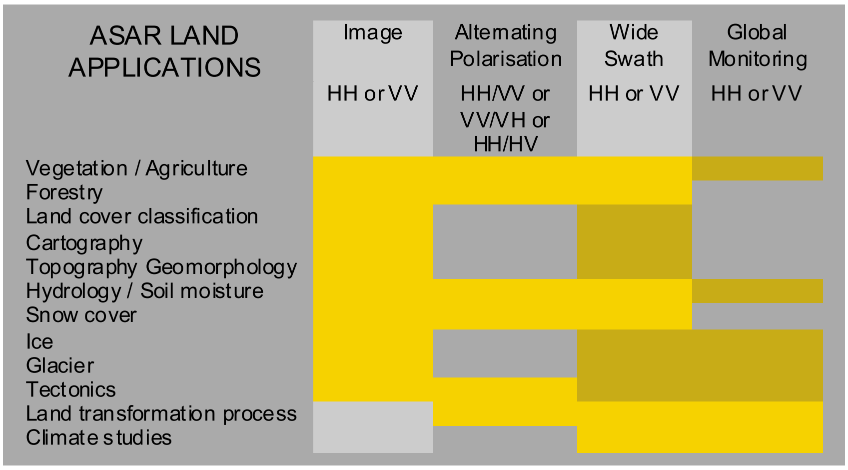


Table 2. ASAR modes and land-application themes (lighter colour indicates primary applications)

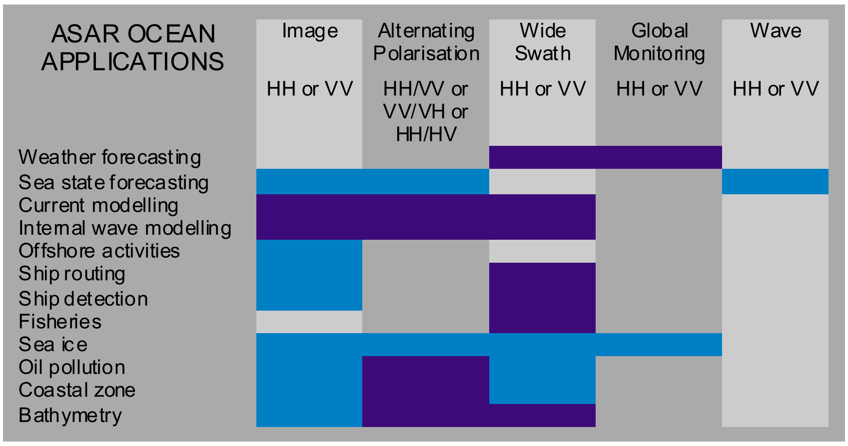


Table 3. ASAR modes and ocean-application themes (lighter colour indicates primary applications)

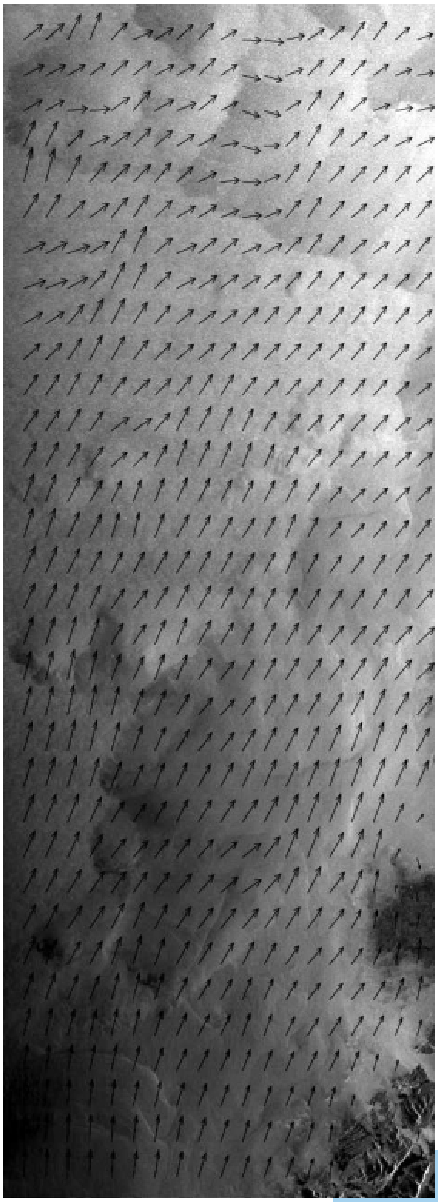


Figure 3. Wind-field estimate from ERS-2 SAR data (courtesy of Norut, Norway)

traded off against other image quality parameters (such as the radiometric resolution).

The across-track or range resolution is a function of the transmitted radar bandwidth. Pulse compression techniques are used to improve the performance taking into account the instrument's peak power capability. The fact that the end-to-end system works coherently means that both the amplitude and the phase relationships between the complex trans-mitted and received signals are maintained throughout the instruments and the processing chain.

Operating modes

The ASAR instrument is designed to provide a large degree of operational flexibility. The main instrument parameters can be selected by ground command for each of the five operational modes:

– The Image mode generates high-spatial-resolution data products (30 m for precision images) selected from the total of seven available swaths located over a range of incidence angles spanning 15 to 45 deg.

– The Wave mode generates vignettes of 5 km by 5 km, spaced 100 km along-track. The position of the vignette can be selected to alternate between any two of the seven swaths.

– The Wide Swath and Global Monitoring modes are based on the ScanSAR technique using five sub-swaths, and they generate wide-swath products (400 km) with spatial resolutions of 150 and 1000 m, respectively.

These four modes may be operated in one of two polarisations, either HH or VV (the letter first indicates the polarisation of the transmit signal – H for horizontal, V for vertical – and the second the polarisation of the receive signal).

– The Alternating Polarisation mode provides two simultaneous images from the same area in HH and VV polarisations, HH and HV or VV and VH, with the same imaging geometry as the Image mode and similarly high spatial resolution.

The ASAR instrument

The ASAR instrument consists of two main elements: the Central Electronics Sub-Assembly (CESA) and the Antenna Sub-Assembly (ASA).

The active antenna contains 20 tiles with 16 sub-arrays, each equipped with a transmit/ receive (T/R) module. The instrument is driven by the Control Sub-System (CSS), which provides the command and control interface to

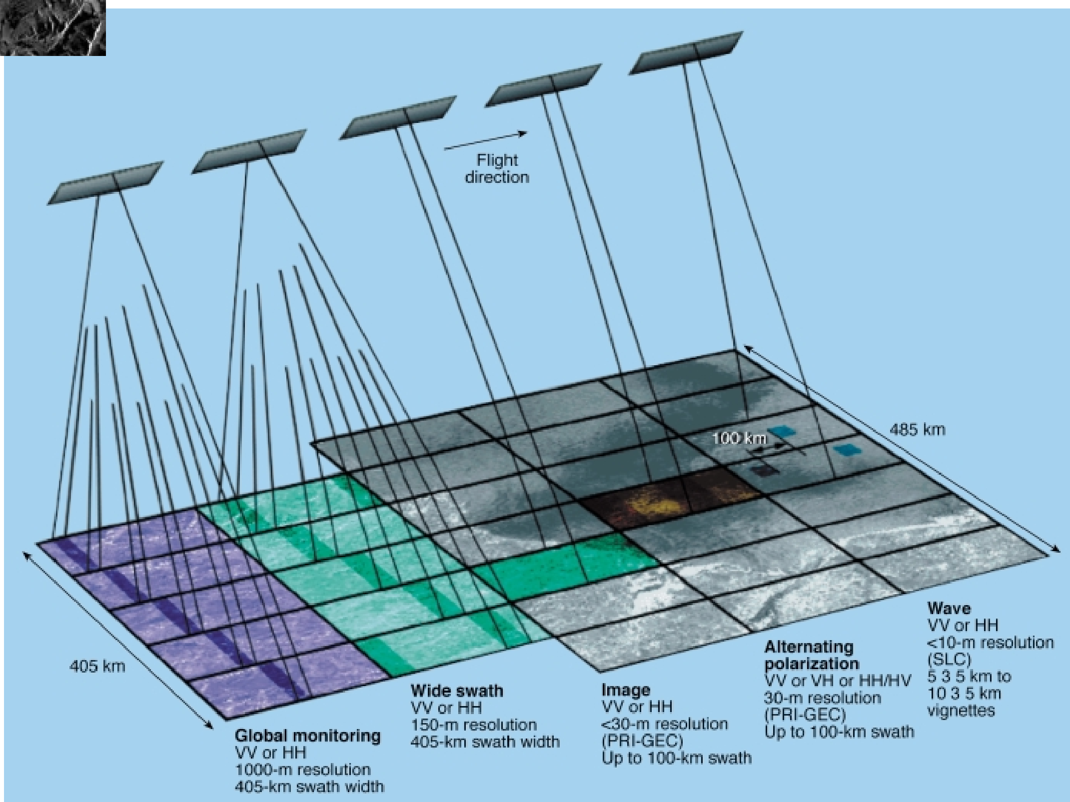


Figure 4. The ASAR operating modes

the spacecraft, manages the distribution of the operational parameters (such as transmit pulse characteristics and antenna beam-set), and generates the instrument operation time line.

The transmit pulse characteristics are set in the Data Sub-System (DSS), the output of which is an up-chirp pulse centred on the IF carrier (124 MHz). In the RF Sub-System (RF S/S) the pulse is up-converted to the RF frequency (5.331 GHz) and amplified. The signal is then passed to the Tile Sub-System (TSS) through a waveguide distribution network (RFPF) and subsequently, within the tile, to each individual T/R module using a microstrip corporate feed. The T/R modules apply phase and gain characteristics according to the pre-selected beam settings transferred from the Control Sub-System and stored in the Tile Control Interface Unit (TCIU).

In receive, the RF-echo signal follows the reciprocal path down to the Data Sub-System, where the raw science data are generated and provided to the spacecraft interface.

Central Electronics Sub-Assembly

The CESA is in charge of generating the transmitted chirp, converting the echo signal into measurement data, as well as controlling and monitoring the whole instrument. Compared to ERS-1 and ERS-2, which use Surface Acoustic Wave (SAW) devices for analogue chirp generation and on-board range compression, ASAR uses digital technologies for on-board chirp generation and data reduction for temporary storage associated with on-ground range compression. A fundamental advantage of using digital chirp generation is the inherent flexibility of such a design, which allows for chirp versatility in terms of pulse duration and bandwidth, thus accommodating efficiently the various requirements associated with the high number of available operational modes and swaths of the instrument.

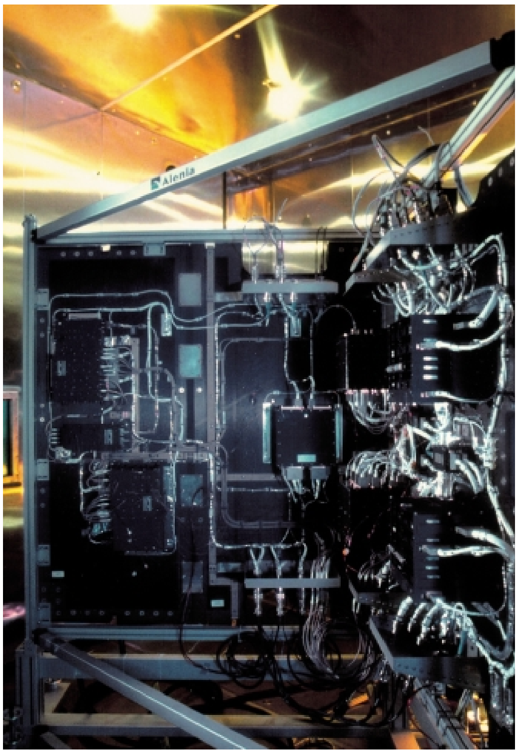


Figure 5. ASAR CESA flight model during thermal testing (courtesy of Alenia, Italy)

At reception, the echo signal is first filtered and down-converted in the RF Sub-System, then demodulated into the I & Q components of the carrier. These two signals are then both digitised into 8-bit samples. If required, it is then possible to perform digital decimation of the

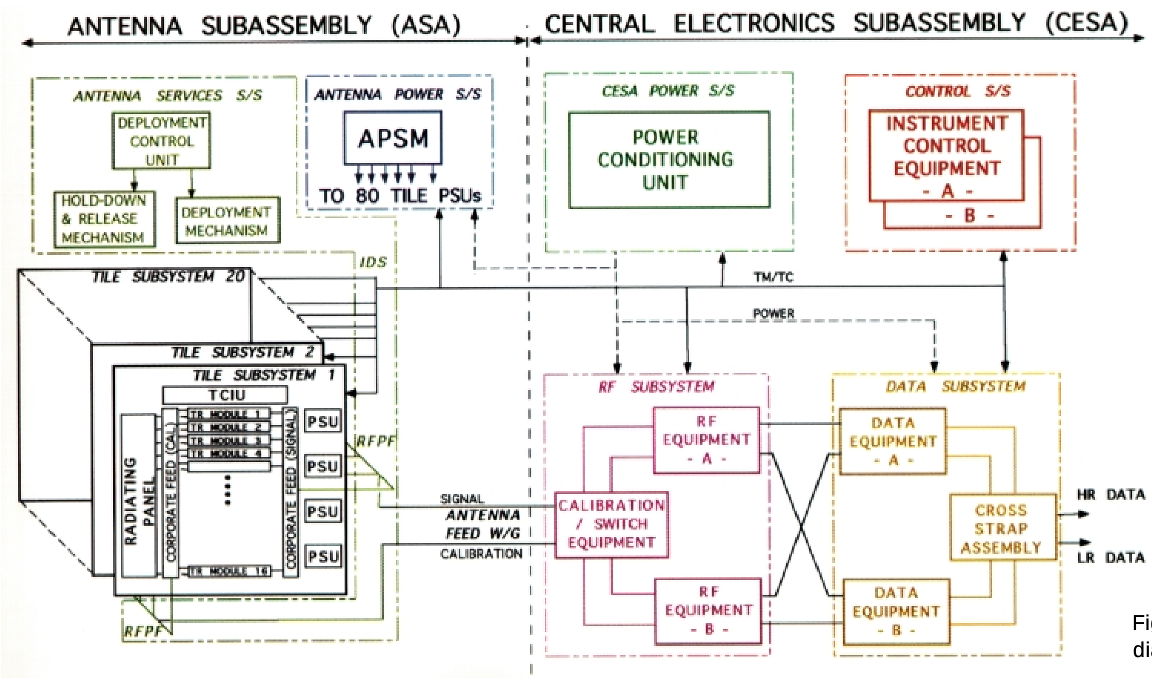


Figure 6. ASAR functional diagram

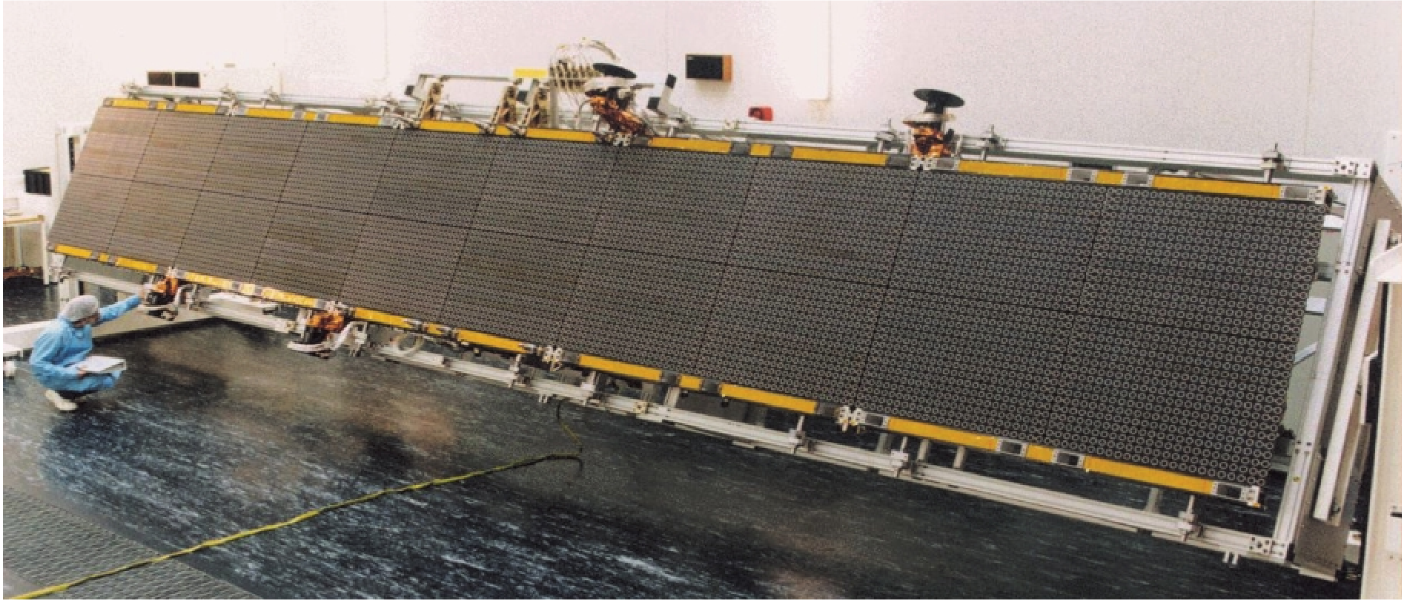


Figure 7. Flight model of the ASAR antenna (courtesy of Matra Marconi Space, UK)

samples, in order to reduce the data stream, such as in Global Monitoring mode where the transmit bandwidth is low. Following this decimation, a Flexible Block Adaptive Quantiser (FBAQ) compression scheme is applied to the echo samples.

The FBAQ allows the data rate to be maintained within data-transmission requirements without degrading the image quality. This is achieved by using a compression algorithm optimised to the statistics of the radar signal. The FBAQ ASIC that has been developed can be operated in three ways: compression according to the FBAQ algorithm (8 to 4, 3 or 2 bits), bypass or noise (fixed exponent), depending on the type of data to be processed.

In order to optimise raw data transfer, the data equipment also contains science memory, where the echo samples are temporarily stored before their transmission to the on-board recorders.

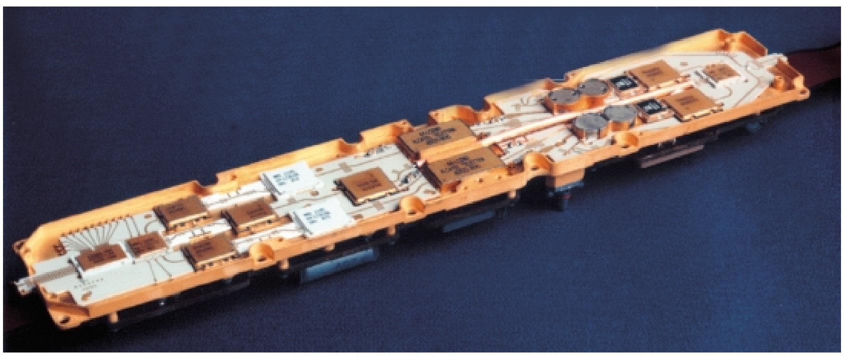
Active phased-array antenna

The ASAR active antenna is a 1.3 m x 10 m phased array. The antenna consists of five 1.3 m x 2 m panels which are folded for launch. Each panel is formed by four 0.65 m x 1 m tiles mounted together. The Antenna Sub-Assembly is divided into three sub-systems: the Antenna Services Sub-System (ASS), the Tile Sub-System (TSS) and the Antenna Power Switching and Monitoring Sub-System (APSM).

The antenna is based on a mechanical structure consisting of five rigid Carbon-Fibre-Reinforced Plastic (CFRP) frames and two RF distribution networks of CFRP waveguides running in parallel along the five panels. In launch configuration, the five panels are stowed folded over the fixed central one, and held together by eight hold-down and release mechanisms (HRMs). Each HRM consists of a retractable telescopic tube levered by a secondary mechanism based on non-pyrotechnic technology (kevlar cable and thermal knife).

After release, the panels deploy sequentially around four hinge lines by using stepper motors. Latching is performed by the eight built-in latches to achieve the final antenna planarity of ±4 mm in orbit. Each of the 20 tiles is a self-contained, full-operating sub-system which includes four Power Supply Units (PSUs), a Tile Control Interface Unit (TCIU), two microstrip RF distribution corporate feeds and 16 sub-arrays of 24 dual-polarised low-loss dispersion-free radiating elements. Each sub-array is connected to a T/R module, with independent connections for the two polarisations. The 16 sub-arrays are mounted together, although thermally and mechanically decoupled, on a radiating panel, which provides both structural and thermal integrity to the tile. The TCIU provides the control functions within the Tile. It performs the local control of the T/R modules, transfers data and interfaces to the Control Sub-System.

Figure 8. The ASAR T/R module (courtesy of Alcatel, France)



Parameter	Unit	Image	Alternating Polarisation	Wide Swath	Global Monitoring	Wave
Polarisation		VV or HH	VV/HH, HH/HV, or VV/VH	VV or HH	VV or HH	VV or HH
Spatial resolution (az. x ra.)	m			150 x 150	950 x 980	
* except swath IS1	m	28 x 28*	29 x 30*			28 x 30 *
Radiometric Resolution	dB	1.5	2.5	1.5 to 1.7	1.4	1.5
Point Target Ambiguity Ratio						
- azimuth	dB	26 to 30	19 to 28	22 to 29	27 to 29	27 to 30
- range	dB	32 to 46	26 to 41	26 to 34	25 to 32	31 to 46
Distributed Target Ambiguity Ratio						
- azimuth	dB	23 to 25	18 to 25	20 to 25	25 to 28	23 to 25
- range	dB	17 to 39	17 to 39	17 to 31	17 to 31	21 to 48
Radiometric Stability	dB	0.32 to 0.40	0.50 to 0.55	0.32 to 0.42	0.46 to 0.53	0.55 to 0.60
Noise Equivalent σ_0	dB	-20 to -22	-19 to -22	-21 to -26	-32 to –35	-20 to -22

Table 4. ASAR performance summary

Each of the 320 T/R modules consists of two (H & V) transmit chains and one common receive chain. For calibration purposes, a coupler (-24 dB) has been implemented at the output of the module to the antenna. For an active antenna, the amplitude and phase characteristics of the T/R modules vary principally as a function of temperature. To handle this, the instrument includes a scheme to compensate for drifts over the temperature range. To this end, the temperature of each T/R module is monitored and utilised by the TCIU to compensate the amplitude and phase settings. This scheme provides the antenna with a high degree of stability.

Qualification of new technologies

In order to guarantee the required operational flexibility and performance, a number of new technologies, processes and components needed to be developed and qualified (from the hybrid line for RF components, to GaAs foundry, parallel-gap welding, etc.).

Performances

The inherent principle of the Synthetic Aperture Radar impedes the direct measurement of ASAR instrument performances on the ground. The selected alternative is computation of the instrument performance characteristics from measurable lower level parameters throughout the various stages of instrument testing.

In the case of ASAR, due to the large number of operating modes and measurement capabilities, the verifications of instrument performances have resulted in an extensive test programme. It has also allowed the determination of an optimal combination of parameters in order to achieve the best overall performance across all operating configurations.

The predicted end-of-life performances for the ASAR instrument are summarised in Table 4. These figures have been derived assuming a worst-case scenario and demonstrate that the Envisat ASAR mission objectives can indeed be fulfilled.

Instrument calibration

ASAR, unlike the ERS AMI-SAR, is an active antenna and any instabilities in gain and phase characteristics will therefore distort the elevation beam patterns and can contribute

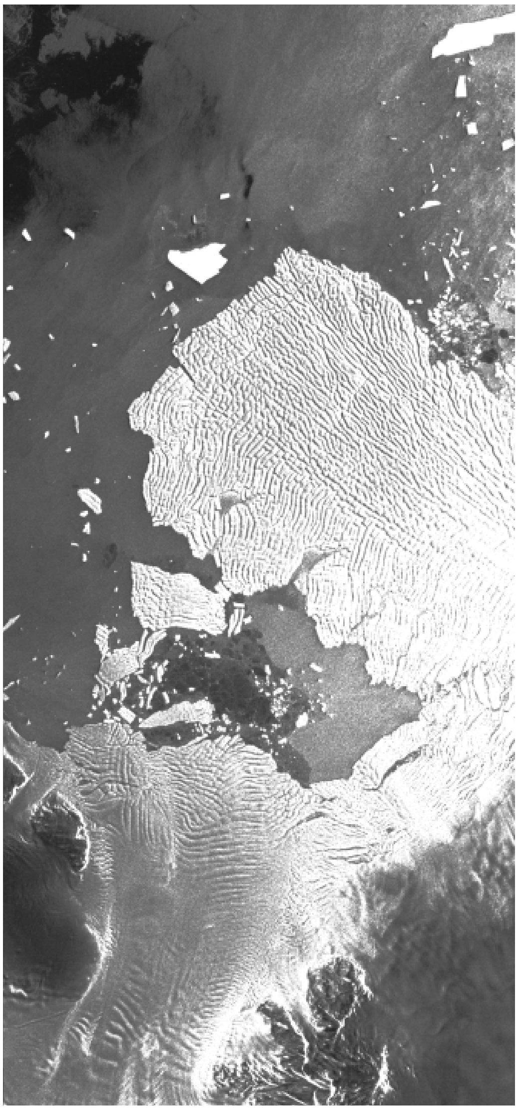


Figure 9. An Image mode medium-resolution product, showing the Walgreen Coast, Antarctica (from ERS raw data)

to radiometric errors in the SAR image. For this reason, a sophisticated scheme for the ASAR's radiometric calibration has been selected, composed of three elements: internal calibration, external calibration and external characterisation.

Internal calibration
The objectives of the ASAR instrument internal calibration are to derive the instrument's internal path transfer function and to perform noise calibration.

During normal operation in any of the ASAR measurement modes, a sequence of calibration pulses is interleaved with normal radar pulses. These pulses characterise the active array in both transmit and receive, on a row-by-row basis.

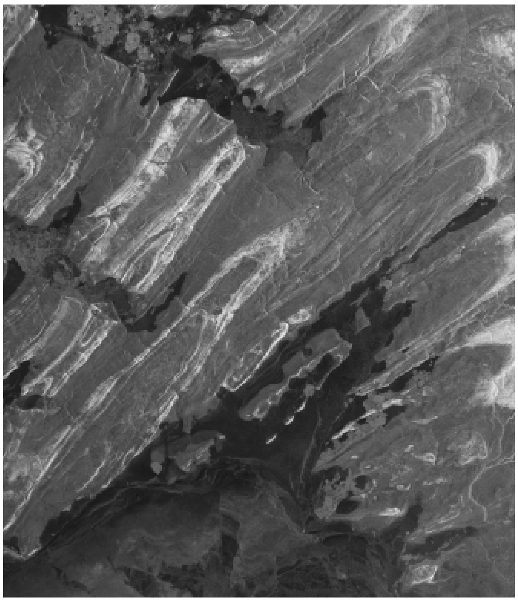


Figure 10. An Image mode precision product, showing Bathrust Island, Canada (from ERS raw data)

As well as providing internal calibration during the measurement modes, the ASAR includes a special 'module stepping' mode, in which individual T/R module characteristics can be measured. It can be used to investigate T/R module failures and ageing effects. In this mode, only one module is activated at a time in either transmit or receive.

The internal calibration scheme also includes measurements of the instrument noise level. They are taken during the initial calibration sequences at the beginning of a mode. In the modes that have natural gaps in their imaging sequence (i.e. wide-swath and global monitoring modes), noise measurements are also made during nominal operation throughout the mode.

External calibration
The objective of the external calibration is to derive the overall scaling factor. The successful methodology developed for ERS will be re-used for ASAR.

To this end, four high-precision transponders have been developed, characterised by a 0.08 dB stability and 0.13 dB accuracy. These transponders will be deployed in Flevoland (NL) across the ASAR swath and observed several times during each orbital cycle of 35 days.

Images acquired over suitable regions of the Amazonian rain forest will also be used to derive the in-flight elevation antenna patterns. Absolute calibration factors derived from transponder measurements and across-swath corrections derived from the radar equation will be used to calibrate the final image product.

For the wide-swath mode using the ScanSAR technique, the external calibration approach will be similar to the one used for the narrow-swath mode.

External characterisation
The ASAR has a dedicated External Characterisation mode to monitor all those elements that are outside the internal calibration loop, as well as the calibration loop itself.

In this mode, planned to be operated every 6 months, a sequence of pulses sent by each antenna row in turn is detected by the antenna calibration loop and simultaneously recorded on the ground by a special receiver built into the ASAR calibration transponder. The data recorded in the transponder and that down-linked from the instrument are compared in the ground processor to reveal the relative phase and amplitude of the pulse from each row. These relative amplitudes and phases are used to characterise the row of radiating sub-arrays and the calibration path of the row.

ASAR ground processor
The development of the ASAR processor is based on the following driving concepts:

- The need for users to have identical products irrespective of the processing facility.
- The need to broaden the range of products whilst ensuring the quality of the ERS SAR high-resolution products.
- The capability to cope with the large amount of products to be generated.
- The ability to generate continuous medium and low-resolution products along the orbit (stripline processing, without radiometric or geometric discontinuity).

Following the above concepts, ESA has developed a single ASAR processor able to

Mode and Product Name	Nominal Resolution (m)	Pixel spacing (m)	Coverage (km)	Product ENL
IM precision IMP	30 x 30	12.5 x 12.5	56-100 x 100	3.9
IM single look IMS	9slant x 6	natural	56-100 x 100	1
IM geocoded IMG	30 x 30	12.5 x 12.5	100 x 100	3.9
IM medium resolution IMM	150 x 150	75 x 75	56-100 x 100	40
IM browse IMB	900 x 900	225 x 225	56-100 x 100	80
AP precision APP	30 x 30	12.5 x 12.5	56-100 x 100	1.9
AP single look APS	9slant x 12	natural	56-100 x 100	1
AP geocoded APG	30 x 30	12.5 x 12.5	100 x 100	1.9
AP medium resolution APM	150 x 150	75 x 75	56-100 x 100	50
AP browse APB	900 x 900	225 x 225	56-100 x 100	75
WS medium resolution WSM	150 x 150	75 x 75	400 x 400	12
WS browse WSB	1800x1800	900 x 900	400 x 400	57-62
WV imagette & cross spectra WVI	9slant x 6	natural	5x5 to 10x5	1 n/a
WV cross spectra WVS	-	-	5x5 to 10x5	n/a
GM image GM1	1000 x 1000	500 x 500	400 x 400	12
GM browse GMB	2000 x 2000	1000x1000	400 x 400	18-21

Table 5. ASAR products, coverages and qualities

handle data from any of the ASAR modes in near-real-time and off-line. This processor will be installed at the ESA Payload Data Handling Stations (Kiruna in Sweden and ESRIN, Frascati, in Italy), at the Envisat Processing and Archiving Centres (PACs), and at the national stations offering ESA ASAR services. The use of a single processor will ensure product consistency for the users, independent of the ESA processing centre selected (same format and processing algorithm) and will simplify product validation and future product upgrade cycles.

One of the key new features of the ASAR processor is the ability to generate medium-resolution (150 m) and low-resolution (1 km) products with their corresponding browse images in stripline without geometric or radiometric discontinuity. The stripline image products represent processed data from an entire acquisition segment of up to 10 minutes for Image, Alternating Polarisation and Wide Swath modes and up to a complete orbit for Global Monitoring mode. The user can select any segment in the processed stripline.

The processor computes the replica of the transmitted pulse from the calibration-pulse measurements, the row patterns as characterised on-ground and the external characterisation data. The constructed replica tracks variations in the transmit and receive chains and is used to determine the range reference function for range-compression processing.

The ground processor includes a Doppler Centroid Estimator with a specified accuracy of 50 Hz for Image and Wave modes as for ERS and 25 Hz in the ScanSAR modes in order to limit radiometric errors in azimuth.

The ASAR processor will be used to ensure the systematic processing in near-real-time of all received high-rate data to generate medium-resolution and browse products. All Wave mode or Global Monitoring mode data will also be systematically processed in near-real-time.

Furthermore, the ASAR processor will allow high-resolution products to be processed from Image or Alternating Polarisation acquisitions (Precision Image, Single Look Complex or Ellipsoid Geocoded products) in near-real-time or off-line, depending on user requests. The accompanying figures show examples of a Precision Image and a Medium Resolution Product.

The different products, their coverages and qualities are summarised in Table 5.

Data collection and user services

The ASAR instrument modes of operation can be divided into two categories:

- Low-data-rate modes (Global Monitoring and Wave) with an operational capability of up to 100% of the orbit. Both modes are systematically recorded on-board and the on-board recorder is dumped every orbit when visible from an ESA station.
- High-data-rate modes (Image, Alternating Polarisation and Wide Swath) with a maximum operating time of 30 min per orbit (including the ability to operate for up to 10 min in eclipse).

Compared to ERS, the Envisat mission offers improved data recording and transmission capabilities for the ASAR high-data-rate modes:

- 12 minutes of on-board recording
- real-time transmission X-band in visibility of ground stations

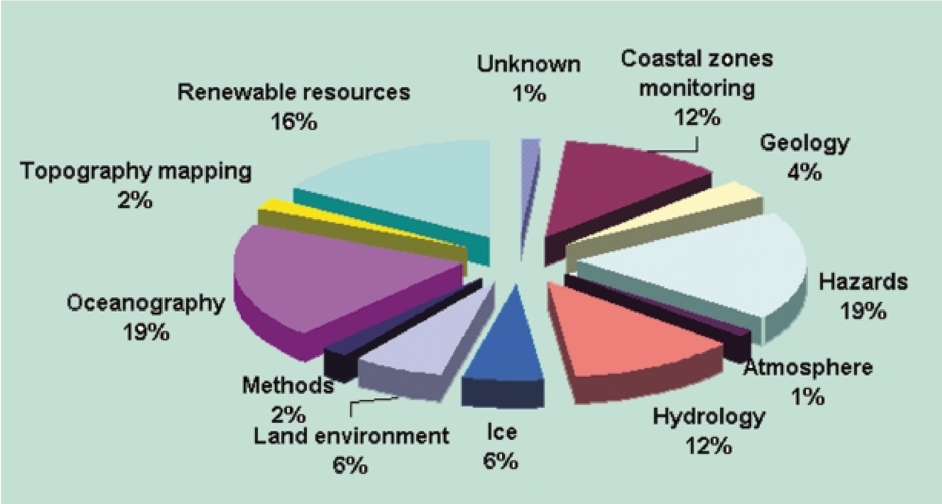


Figure 11. Distribution of ASAR Announcement of Opportunity projects across the different application fields

– real-time transmission or recorded data dump in visibility of ESA X-band ground stations or via ESA data-relay satellite Artemis using Ka-band links.

The instrument will be operated according to the following strategy:
– In response to user requests for Category 2 use (commercial applications).
– In response to user requests for Category 1 use (scientific and demonstration projects).
– For backgound acquisition, including reference data archive build-up as well as routinely planned data acquisitions (e.g. Wave mode over oceans).

All ASAR high-rate data acquired by ESA facilities will be systematically processed in near-real-time to generate medium-resolution products (~150 m) and browse products. The browses will be available on line via the Envisat User Service. The Envisat Ground Segment will provide a unified service to the users with access – once they are registered – to the full range of ESA services and products.

Users' requests will be supported for inventory searching on already acquired data, as well as for data requiring future acquisitions. Users who have ordered Envisat products will be kept informed of the status and progress of their orders: from acceptance, planning of instrument operation, data-taking, processing and through to product delivery.

Data use for science and applications

The Envisat Announcement of Opportunity (AO) for data exploitation was issued in December 1997, with a deadline for the submission of proposals of end-May 1998. A total of 674 proposals have been accepted, 376 of which involve the use of ASAR (71% science, 24% commercial and 5% Cal/Val). Figure 11 shows the distribution of the ASAR projects across the different fields of application.

Most of the AO proposals involve the use of multiple ASAR operating modes. There is no clear preference for specific swaths or specific polarisations, and different polarisation combinations are requested for all modes. Interferometry is a component of 38% of the projects.

Conclusions

The ASAR instrument is characterised by extensive flexibility, thanks to its five operating modes, the ability to operate in Horizontal and Vertical polarisations, the wide range of elevation angles covered, and the possibility to shape the antenna beam in both transmit and in receive by individually controlling the amplitude and phase of each of the 320 transmit/receive modules.

In order to achieve the required performance and operational flexibility, many new technologies, processes and components have been qualified.

All acquired data will be processed (either in near-real-time or off-line) within the ESA Ground Segment by a single design of processor, to ensure product consistency irrespective of the processing centre. A large number of ASAR products will be routinely produced by ESA and made available to users.

The large number of applications that the instrument will be capable of supporting, illustrated by the responses to the Announcement of Opportunity, qualifies ASAR as a precursor of future Earth Watch missions.

The ASAR instrument test campaign was completed in early February 2000. CESA was subsequently delivered to ESTEC in Noordwijk (NL) and mounted on the Envisat spacecraft. The ASAR antenna was delivered a month later and integrated onto the spacecraft in early March.

Acknowledgements

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