The Commissioning Phase and the Calibration/Validation Activities

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Envisat is designed to provide measurements of the atmosphere, ocean, land and ice over a five-year period. After the launch, a six-month Commissioning Phase is foreseen. This first period is dedicated to instrument switch-on and in-flight calibration and to the first validation of the Envisat products. There is general consensus that the calibration and especially the validation activities represent a long-term effort, which extends far beyond the duration of the Commissioning Phase and gradually shifts into algorithm improvement. The Commissioning Phase is the period that ESA has available to check out and verify the complete data chain (instruments and ground-processing algorithms) before releasing the Envisat data to the wide user community. At the end of the Commissioning Phase, the data quality is guaranteed by the Agency.

In addition to ESA and its industrial partners in the Envisat Consortium, many other companies and research institutes are contributing to the calibration and validation programme. A major contribution is being made by the Principal Investigators of approved proposals submitted to ESA in response to the worldwide 'Announcement of Opportunity for the Exploitation of Envisat Data Products' issued in 1998. Teams have been formed in which the various participants are working side-by-side to achieve the ambitious calibration and validation programme objectives.

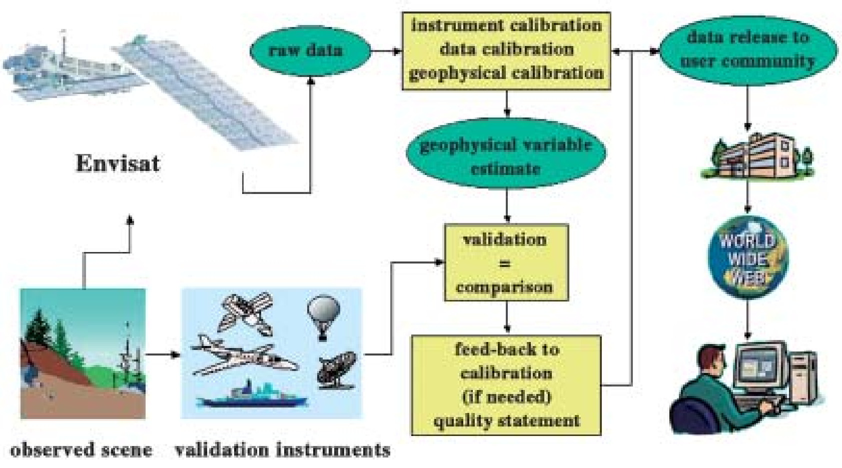


Figure 1. The Envisat calibration/validation concept

Calibration and validation defined

Following internationally agreed definitions, instrument and data calibration involves both pre-launch and post-launch measurements to fully characterise the payload instruments, and subsequent activities to configure the ground processors to provide calibrated (Level-1b) data products (e.g. radiance, reflectance, transmittance, radar backscattering coefficient, radar-echo time delay). Geophysical calibration and validation is a process whereby geophysical data products (Level-2) are derived from the Level-1 data products and checked against independent (in-situ) measurements of the relevant geophysical variables. These include atmospheric variables (temperature, pressure, atmospheric constituents, aerosol and cloud parameters), marine variables (ocean surface wind and waves, ocean colour, sea-surface temperature) and land variables (vegetation index, land surface temperature, pressure and reflectance). For each geophysical data product, a number of different in-situ measurements have to be made by ground-based, airborne and balloon-borne instruments. In addition, comparisons with other satellites and analyses based on data assimilation models will be made.

After the Commissioning Phase, the validation programme will make a quality assessment of the Envisat geophysical data products and will recommend re-calibration and algorithm development as appropriate. The overall concept of the process is illustrated in Figure 1.

Objectives, co-ordination and schedule

The Envisat Payload Data Segment (PDS) will routinely produce an unprecedented large number of products (both the Level-1b geo-located and calibrated engineering parameters, and the Level-2 geo-located geophysical products). ESA is committed to deliver products to the wide user community starting six months after launch, at the end of the

Commissioning Phase. Within this six-month period, the objective is to achieve full calibration of all Level-1b data products and a preliminary validation of the Level-2 products. In order to achieve this challenging objective, the following working teams have been formed:

- ASAR Calibration and Validation Team
- MERIS Calibration Team
- AATSR Calibration Team
- MERIS and AATSR Validation Team (MAVT)
- MIPAS Calibration and Algorithm Verification Team
- GOMOS Calibration and Algorithm Verification Team
- SCIAMACHY Calibration and Algorithm Verification Team
- Atmospheric Chemistry Validation Team (ACVT), responsible for validation of GOMOS, MIPAS and SCIAMACHY Level-2 products
- RA-2 Calibration Team
- RA-2/MWR Cross-Calibration and Validation Team (CCVT)
- Precise Orbit Determination Team (POD).

The necessary expertise is represented in the teams by ESA staff, the Expert Support Laboratories who designed the retrieval algorithms, some instrument contractor representatives (mainly in the calibration teams), and Principal Investigators leading the selected calibration/validation projects resulting from the Announcement of Opportunity.

The schedule for the initial calibration and validation activities is shown in Figure 2. The process starts just after launch with the switch-on of the different payload instruments. This phase has a limited duration and aims at verifying the functionality and operability of the various instruments from the ground. It will be completed at different times for the different instruments. As soon as the functional checkout of each instrument is completed, the calibration and validation activities will start for that instrument, consisting of three main components:

- Instrument in-flight calibration and Level-1b ground-processor verification.
- Level- 2 algorithm verification and data-product assessments.
- Geophysical campaigns and independent validation assessments.

These activities follow each other in a logical sequence. A calibrated and stable instrument configuration is required to properly assess the quality of the retrieval of the geophysical quantities, in order to avoid instrument biases and drifts being interpreted as geophysical signals. Some interdependency among these activities exists, as outlined in the schedule in Figure 2. At the beginning, the focus is on the in-flight calibration of the instrument and on its re-characterisation. This is followed by a first verification of the Level-1b processing chain.

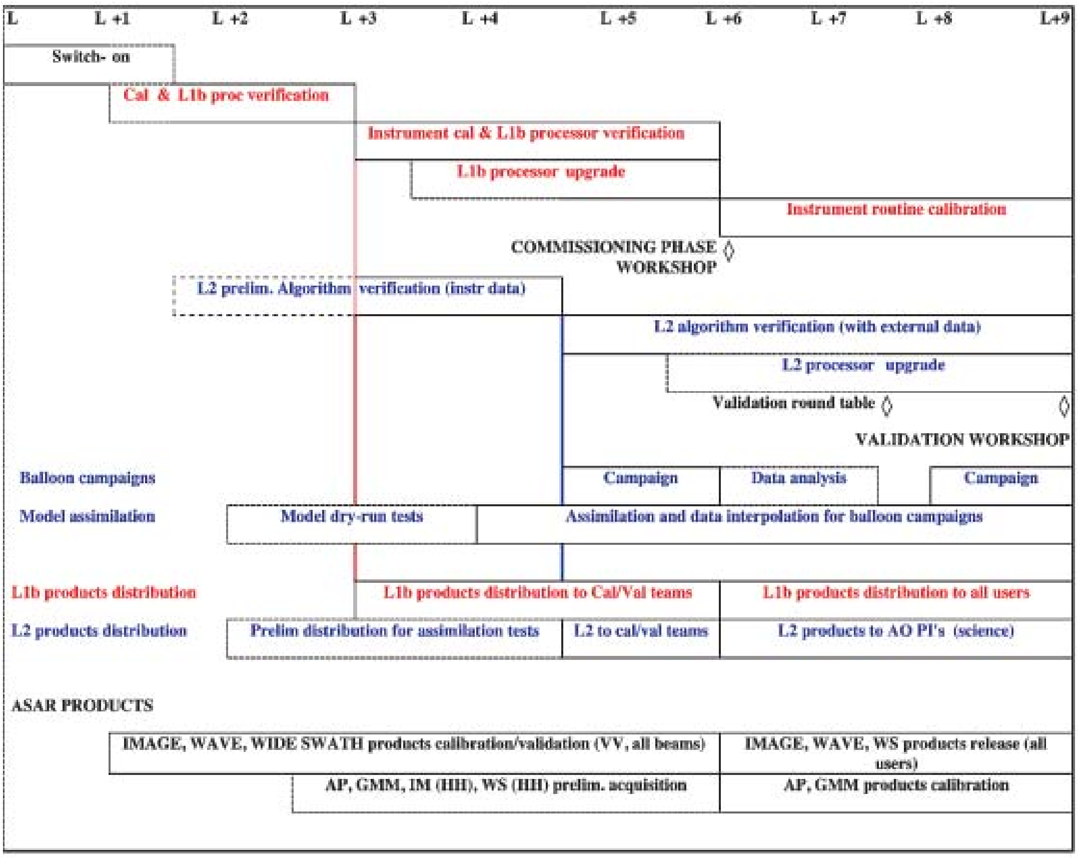


Figure 2. Schedule for the Envisat calibration/ validation activities and product release

Three months after launch, this phase will be completed and Level-1b data can be reliably used by the Investigators and ESLs working on the verification of the Level-2 processing chain. In the remaining three months, the parameters used in the Level-1b processing chain need to be adjusted following in-orbit characterisation of the payload instruments. It is anticipated that at the end of the Commissioning Phase the first upgrade of the Level-1b ground processor will take place. Reprocessing of the Level-1b data acquired during the Commissioning Phase is likely to be needed (as a consequence of the Commissioning-Phase activities and processor update) and can then be initiated. The routine calibration phase begins at launch + 6 months.

The Level-2 algorithm verification starts after the provision of the first Level-1b data at launch + 3 months. This will initially mainly consist of processor-behaviour checks based on the detailed analysis of the intermediate processing results on real data, and will not involve external data coming from geophysical campaigns. This activity is the first in-orbit verification of the pre-launch processor tests, which were based on a limited set of simulated data generated using highly sophisticated instrument simulators. After a few weeks of operation in orbit, an immense amount of real data will be available to verify the processor behaviour: It is expected that this data will reveal a lot of interesting features that might necessitate processor adjustments.

At launch + 4.5 months, the first phase of the Level-2 algorithm verification will be completed, the Level-2 products will be distributed to the whole validation community, and the geophysical validation campaigns will commence. The Level-2 algorithm verification can now benefit from external data from campaigns, model assimilation runs, and comparisons with other satellites' data. This activity extends beyond the end of the Commissioning Phase and culminates in the Validation Workshop, 9 months after the launch. The aim is to be able to assess the quality of the geophysical data by this time.

The validation activities will continue after the Workshop, with algorithm improvements in particular still taking place.

As shown in Figure 2, the schedule for the ASAR calibration/validation activities is slightly different because of the complexity of the instrument's calibration and the limited geophysical products derived from this instrument (only the Level-2 wind/wave product). The quality of a large number of ASAR products needs to be assessed. By the end of the Commissioning Phase, all ASAR products (VV polarisation, for all beams/incidence angles) derived from the Image Mode, from the Wave Mode and from the Wide-Swath Mode will be verified. Distribution of these products to the general user community will start as soon as each product has been successfully verified. The remaining ASAR products (Global Monitoring Mode and Alternating Polarisation Mode products) will be released no later than 9 months after launch.

Calibration activities

The calibration activities to be carried out in orbit consist of:

– platform calibration
– instrument calibration, and
– processor calibration.

The platform calibration relates to the verification and optimisation of parameters that control support functions for the payload, such as the characterisation of the orbit characteristics, of instrument pointing, and of the X-, Ka- and S-band communication links.

The performance of each of the individual instruments will be verified and the control parameters optimised. Of particular importance is the characterisation of the instrument response to temperature variations and ageing (instabilities and drifts). During the first weeks, periodic re-calibration of the instrument may be required. Most instruments have special operational modes for calibration and the data resulting from these have to be analysed. These data will be used to generate updated coefficients and tables for use in the ground processors.

The ground processors for the various instruments are part of the Payload Data Segment. The PDS is an operational production chain, designed to continuously handle a large amount of data. Each processor has been designed in a modular way, such that its configuration parameters are in an external file (auxiliary product) and may be changed. The processor settings will be optimised during the Commissioning Phase and subsequent changes will then be kept to a minimum in order to guarantee product continuity.

As part of the calibration activities, proper instrument control parameters have to be generated. The resulting instrument command tables will be sent to the Flight Operations Segment (FOS) to be used in the creation of the operational macro-commands to be uploaded to Envisat.

For the implementation of the above functions, dedicated hardware and software has been developed, independently of the operational data-processing chain, known as the Instrument Engineering Calibration Facility (IECF). The structure of the IECF provides the necessary flexibility; new algorithms can be added and existing ones may be modified and tested relatively quickly. The IECF will incorporate results from new analyses that will allow the calibration performance and product quality to be improved.

Validation activities

Since it is the objective of validation to compare the Envisat Level-2 data products routinely generated and archived within the Payload Data Segment with independent measurements of the relevant quantities, the validation activities consist of:
- organising data-acquisition campaigns for independent geophysical measurements
- setting up a facility for the collection, quality control and archiving of correlative data
- analysing correlative data in conjunction with Envisat data and formulating quality statements and recommendations for further work.

Figure 3. Launch of a balloon from Kiruna, in Sweden, for geophysical validation

Geophysical validation is far from a trivial problem. The requirements and the methods to be used were the subject of a long scientific debate, particularly for the atmospheric-chemistry instruments. Another complication has been the international nature of the exercise, with the participation of a large number of organisations, institutes and individual scientists. Therefore, a long preparation process was necessary. Currently, the campaign and analysis plans are defined and the various agreements and contracts are being finalised.

While all Envisat products will be stored in the PDS, all data from the various validation campaigns will be held in a central data-storage facility established at the Norwegian Institute for Air Research (NILU). NILU will provide access to correlative measurements from sensors on-board satellites, aircraft, balloons and ships, as well as from ground-based instruments and underwater devices and numerical models, such as that of the European Centre for Medium-range Weather Forecasting (ECMWF). This facility will be particularly relevant to the atmospheric-chemistry sensors and to MERIS. Two types of data will be stored in the NILU database, fixed-point and transect data. The latter will only be provided for inclusion in the database for selected times that correspond to the satellite overpasses. All data provided to NILU for inclusion in the database will be in HDF v4.1 r3 format. Envisat data will not be stored in the NILU database, but will be accessible via the PDS.

The first analysis of the Level-2 data products has to be done in a short time. The requirement is to arrive at a preliminary quality assessment 9 months after launch, at the time of the Validation Workshop. In some cases, there will be very limited time available for comparisons between validation-campaign data and Envisat data (Fig. 2). However, the time pressure comes from the requirement to establish confidence in the new data products as soon as possible, as this is a prerequisite for applications development and data exploitation.

Pre-launch preparations

It follows from the previous paragraphs that a large amount of preparatory work is required to achieve the calibration and validation goals. Obviously, the in-orbit programme relies on the successful completion of all pre-launch instrument and platform testing, as well as the development work on the ground segment. In addition, major efforts were necessary by ESA, as well as the supporting institutes and scientists, to develop software tools for analysing Envisat data products in a relatively short time.

In addition to the development of analysis tools, dedicated devices were developed for calibration, such as radar transponders, and for validation, such as airborne equipment and atmospheric lidars. Fortunately, in the latter case the Envisat project could benefit in many instances from the development of instrumentation during the last few years in the framework of scientific campaigns not directly related to Envisat. In view of the time pressure on the calibration and validation, detailed procedures have been established for the various teams, down to the individual assignments, the tools to be used, the pass/fail criteria, the detailed schedule, and the interactions between the different players.

Well in advance of the launch, a series of rehearsal exercises involving all facilities (NILU, IECF, PDS) and tools are scheduled to test the procedures, communication and analysis methods. These will facilitate remedial actions where required. These rehearsal exercises are supported by simulated Envisat products.

Calibration and validation activities for individual instruments

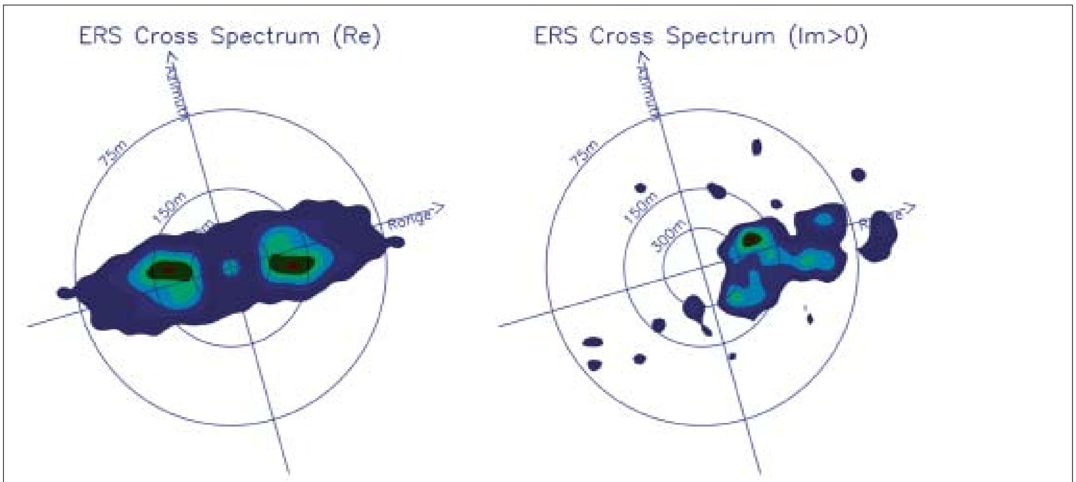
ASAR

The ASAR instrument calibration concept is built on the well-established methodology developed for ERS. It is based on measurements acquired over precision calibration transponders deployed in the Netherlands for absolute calibration, and over the Amazonian rain forest for antenna-pattern characterisation. In addition, a special calibration subsystem onboard will support the in-flight instrument characterisation and facilitate the monitoring of any gain variations in the active antenna. Needless to say, this task is more of a challenge for ASAR than it was for ERS because ASAR has a total of eight beams, five different operational modes and up to four polarisation combinations.

The validation of ASAR's Level-2 wind/wave product will involve local comparisons with in-situ measurements and global comparison through assimilation of Envisat data into numerical weather-prediction models.

MERIS

The in-flight instrument calibration of MERIS will use the onboard sunlit calibration diffuser plates. These have been characterised, using a dedicated optical bench, to an absolute accuracy of better than 1%. A round-robin exercise (involving NASA) will ensure consistency of BRDF measurements at various laboratories and consequently will provide traceability across different missions.



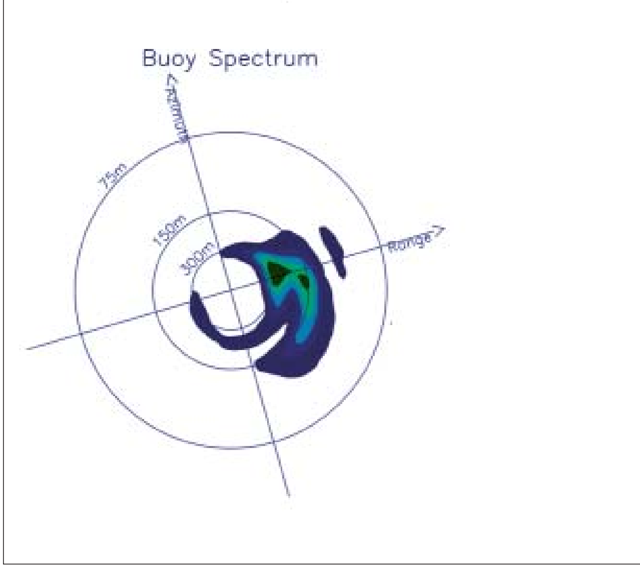


Figure 4. Simulated ASAR wave product based on ERS data

Figure 5. A SAR calibration transponder

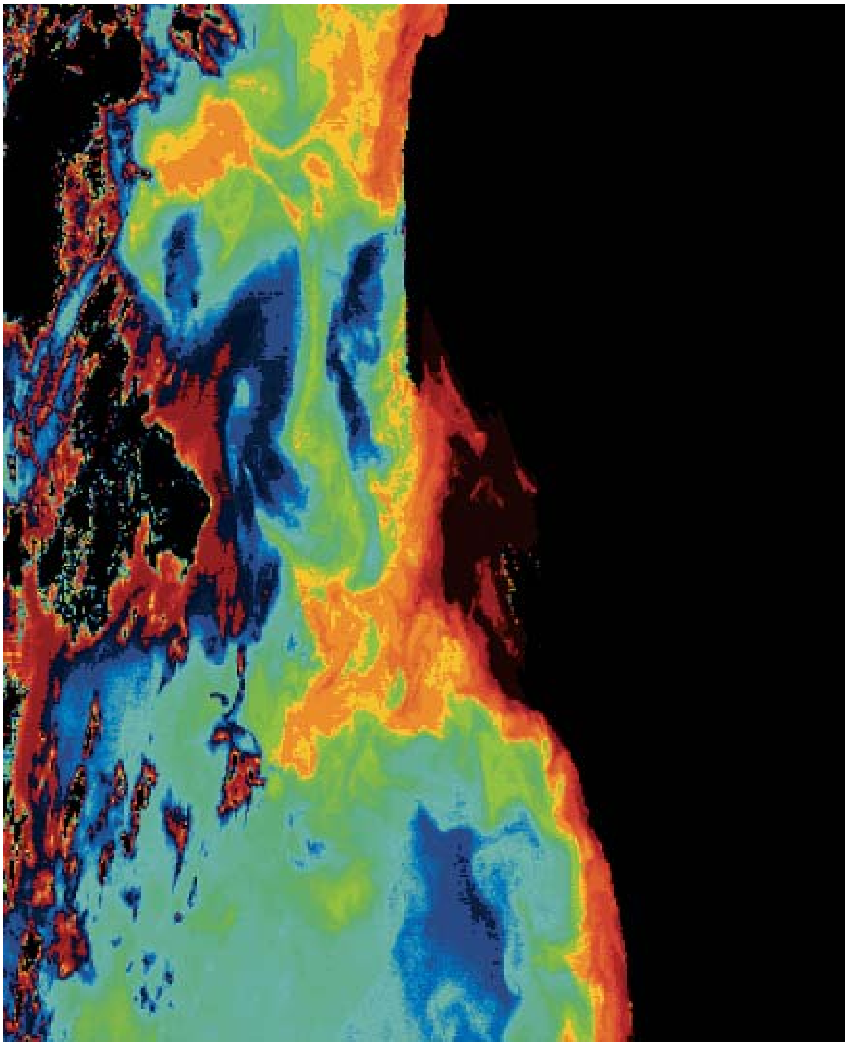


Figure 6. SeaWiFs Level-2C chlorophyll product for an area south of the Canary Islands, off the west coast of Africa

Validation of Top of the Atmosphere (TOA) radiances measured by MERIS will be achieved by comparison with TOA radiance values determined through a number of vicarious calibration methods:
- simultaneous in-situ measurements of natural targets
- analysis of Rayleigh scattering over clear water
- analysis of Sun glint
- data acquisition over stable deserts sites; the BRDF of these sites has been initially characterised using field equipment complemented by bi-directional TOA measurements from several spaceborne sensors
- simultaneous acquisition by other sensors.

Proposals to validate MERIS ocean-colour products for open ocean and coastal waters involve the installation of optical buoys, in-situ data collection during research cruises, and instrumentation on-board third-party vessels.

AATSR

AATSR is a self-calibrating instrument. It has an on-board calibration system, which involves the use of two specially designed and highly stable blackbody reference targets (for the thermal channels), and a diffusely reflecting target that is illuminated once per orbit (for the visible and near-infrared channels). Calibration of the instrument, as such, after launch is not required. There will, however, be specific activities to check and characterise the instrument post-launch, plus algorithm verification whereby the data-processing algorithms are verified and fine-tuned.

The core validation programme for AATSR has the following aims:
- to determine whether the AATSR instrument is returning an acceptable global skin sea-surface temperature (SSST ± 0.3 K)
- to make an initial assessment of the quality of the AATSR SST data products at a limited number of international sites during different seasons; making timely use of any tandem ATSR-2/AATSR mission will facilitate the determination of any bias between their measurements (and AVHRR).

The core validation activities for SST fall under three measurement types:
- *Broad Scale*: comparison with SST analysis fields, and the systematic review of buoy data.

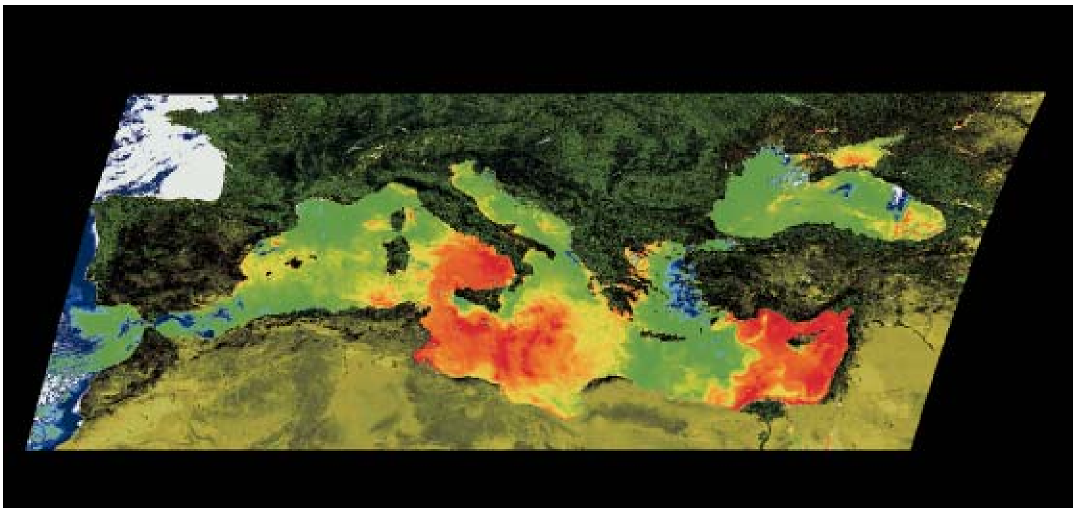


Figure 7. Daytime sea-surface temperature of the Mediterranean in August 1997 from ATSR data

- *Moderate Accuracy*: autonomous measurements on ships of opportunity.
- *High Accuracy:* precision measurements.

Atmospheric-chemistry instruments
Calibration and validation requirements for the atmospheric-chemistry calibration and validation teams relate to both Level-1 products (transmittance, irradiances, radiances, reflectances and polarisation measurements) and Level-2 products (trace-gas columns and profiles, aerosol and cloud detection). Correlative measurements will be acquired by ground-based and sonde instruments, balloon sensors, aircraft sensors and through comparison with other satellite data. Activities involving algorithm verification are also to be carried out. In addition to the campaigns and field measurement comparison (generally characterised by a high accuracy, but restricted to single points), validation analyses will strongly benefit from the use of assimilation models. These models combine localised ingestion of actual observations with knowledge of the dynamics of the atmosphere, and allow the estimation of concentrations at locations and/or times where no observations are available. Whilst all three atmospheric-chemistry instruments aboard Envisat measure overlapping sets of trace-gas species, inter-comparisons between the sensors will initially be used for the identification of large deviations and consistency checking, and not for accuracy assessment or algorithm tuning.

The calibration and validation activities relating to the atmospheric-chemistry instruments are organised within seven working groups:

- three instrument-specific subgroups, responsible for the in-flight instrument calibration and for the verification of the Level-1b and Level-2 processors
- four subgroups (which are non-instrument-specific and are organised according to validation technique) that will perform associated validation activities.

The validation groups will use a combination of different techniques to validate the instruments both globally and at single locations. Several sites located at various latitudes have been selected for aircraft and balloon campaigns. Measurements of atmospheric constituents will be performed during several seasons, by means of large balloons, small balloons and high-altitude aircraft.

The aim of data-assimilation techniques is the combination of theoretical models and sparse measurements for the forecasting or analysis of the state of the atmosphere. The assimilation efforts will be organised into two main activities:

- *Assimilations into Numerical Weather Prediction (NWP) Models:* these will be performed by operational meteorological entities such as the European Centre for Medium-range Weather Forecasting (ECMWF) and others.
- *Assimilations into Chemical Transport Models (CTM):* these are applied more in a research mode and, contrary to the NWP models, do represent the details of the atmospheric chemistry.

Networks of ground-based instruments and sonde launch sites will provide a suite of correlative measurements covering a wide range of geophysical conditions. The aim is to generate a large number of data sets for inter-comparison with GOMOS, MIPAS and SCIAMACHY Level-2 products. A large number of different measurement instruments and techniques will be used, including lidars, spectrometers and radiometers.

Figure 8. The Russian high-altitude M-55 aircraft considered for validation campaigns

Figure 9. A Brewer spectrophotometer

RA-2 and MWR

The RA-2 altimeter is intended to contribute to the continuation of an uninterrupted series of sea-level and ice-sheet elevation measurements that was started with ERS-1 in 1991. To fully exploit these measurements, it is necessary to determine the range bias and drift of the instrument, both to provide an absolute reference for the time series and to distinguish between instrumental artefacts and significant geophysical signals. To satisfy these needs, the required accuracy for the absolute range calibration is 1 cm for the bias and 1 mm/year for the drift. An experiment has been designed to achieve this effectively by making use of the northwestern Mediterranean Basin as a reference surface (Fig. 10).

Measurement of the vertical-incidence backscatter coefficient, sigma-0, by radar altimeters has largely been used for the determination of wind-speed over the ocean. The models applied are empirical and so it has been sufficient to perform relative calibration between missions. These are traced back to GEOS-3 and it is shown that there is an uncertainty in the absolute calibration of sigma-0, for all altimeters, of more than 1 dB. Recently, new applications of the altimeter sigma-0 measurement have been proposed, such as physically based models of sea-state bias and wave period, which require an absolute measure of sigma-0 to an accuracy of 0.2 dB. In response to this requirement, a plan for the absolute calibration of the RA-2 sigma-0 has been developed. By relative calibration, this absolute calibration may then be extended to all other altimeters. The measurement technique makes use of a dedicated transponder (developed by ESA). Acquisition of individual echoes (special RA-2 mode without onboard pre-averaging) will be commanded over the transponder.

The objectives of the Envisat RA-2 and MWR cross-calibration and validation are:

- Geophysical processing algorithm verification: verify algorithms, tune processing parameters.
- Validation of RA-2/MWR near-real-time and off-line products: validate parameters in the geophysical data record and estimate their accuracy.
- Relate calibration coefficients (bias and slope) with error estimates against ERS-2 and other altimetric missions of the three main measured parameters – range/height

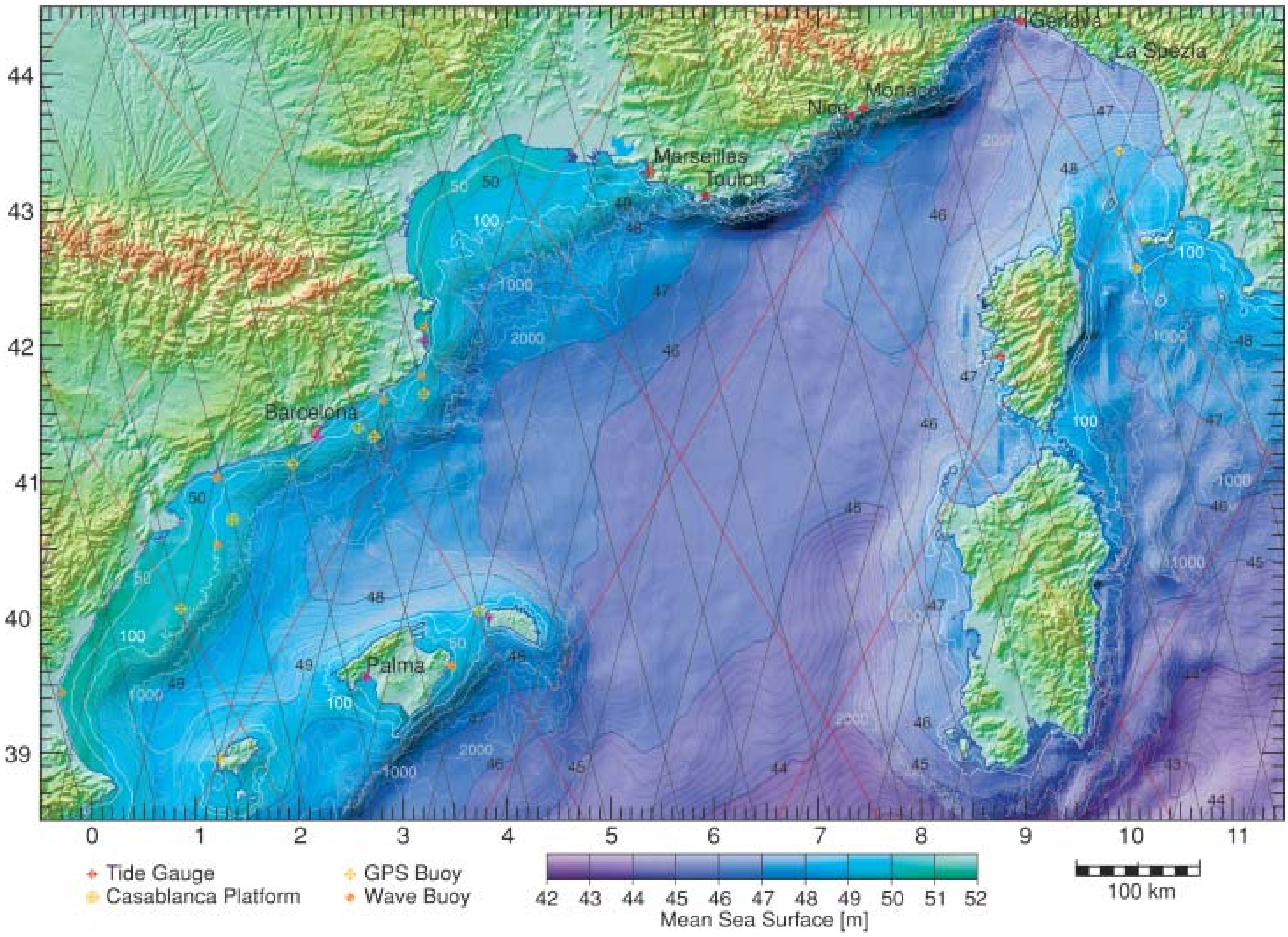


Figure 10. The northwestern Mediterranean Basin used as reference surface for the Radar Altimeter absolute range calibration (the Envisat ground tracks are shown)

wave height and sigma-0/wind.
- Validation of the absolute sigma-0 (absolutely calibrated via transponder).
- Validation of MWR brightness temperatures and water vapour by comparison with in-situ measurements and with ERS MWR.
- Long-term drift detection.

Inter-calibration, or so-called ‘cross-calibration’, is the determination of relative biases between the measurements of different altimeters. Two altimetric systems will be compared through their global geophysical data products. The strength of the technique lies in the huge number of globally distributed measurements processed. The permanent tide-gauge network will provide an estimation of drift that is complementary to the relative bias obtained from cross-calibration based on altimetry alone. Relative calibration will unify the ERS and Envisat data sets. A relative calibration between ERS-2 and ERS-1 was performed during the ERS-2 Commissioning Phase. Relative biases between Envisat and Jason, Topex/Poseidon and Geosat Follow-On will also be estimated.

The Microwave Radiometer (MWR) will be verified by monitoring temperature and gain variation, and radiometric count range. The parameters to be calibrated are the brightness temperature of each channel, the wet tropospheric Altimeter path delay, and water vapour and liquid-water content. This will be done by:
- comparison with shipborne radiosondes
- comparison with coincident simulated brightness temperature from ECMWF meteorological fields
- comparison with other radiometers, and especially with the ERS-2 MWR.

Precise Orbit Determination (POD)

ESA will produce several types of satellite orbits for Envisat depending on the information available at the time of the orbit determination. Obviously, the predicted orbit information available prior to the actual data take is less accurate than the so-called ‘restituted orbit’ derived afterwards taking into account actual flight parameters. Orbit determination based on the measurements made by the DORIS instrument is even more precise. The intention is to nominally have these DORIS orbits in, respectively, the Fast Delivery Products, the Interim Geophysical Data Products (IGDPs) and the Geophysical Data Products (GDPs), which are composed of the corrected measurements of the Altimeter and Microwave Radiometer instruments. A POD Working Team has been formed which will compute and check the orbits operationally, and external experts will validate the orbit system and products. Activities to conduct the orbit verification will include three important tasks:
- pre-launch verification of the POD project orbit software and procedures
- assessment of POD models and standards
- post-launch orbit accuracy validation and verification.

ERS-1/2 and Topex/Poseidon have provided opportunities for geodesists to develop the so-called ‘short-arc techniques’ that are based on a geometric evaluation of the orbits using data from dense satellite laser-ranging networks. This also is a task of the POD team and will prove very useful for the Mediterranean area, where extensive calibration and validation activities will be performed.

Conclusions

The approach to the calibration of the Envisat Instruments, to the verification of the on-ground processing chains, and to the validation of the Envisat-derived geophysical quantities has been presented. The Agency is committed to deliver the Envisat data to the general user community starting six months after the satellite’s launch. The calibration and validation activities have been organised in order to achieve this objective. The size and the complexity of the mission represent a major challenge to all involved.

Acknowledgements

This article is based on the Envisat Calibration and Validation Plan, compiled by the calibration and validation teams. This document is available on the ESA Envisat web site in PDF format. For more information on Envisat, please visit http://envisat.esa.int.