The ENVISAT Calibration and Validation Approach

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1. Abstract

Envisat is ESA ‘s advanced Earth observing satellite to be launched in October 2001 and is designed to provide measurements of the atmosphere, ocean, land and ice over a five-year period. After the launch and the switch-on period a six-month commissioning phase is foreseen for instrument calibration and geophysical validation. In addition to ESA and its industrial partners in the Envisat consortium many other companies and research institutes contribute to the calibration and validation programme under ESA contract as expert support laboratories (ESLs). A major contribution is also made by the Principal Investigators of approved proposals submitted to ESA in response to a world-wide “*Announcement of Opportunity for the Exploitation of the Envisat Data Products*” in 1998. Working teams have been formed in which the different participants work side by side to achieve the objectives of the calibration and validation programme. This paper presents the plans and the approach adopted for the co-ordination of this ambitious programme.

2. Calibration and Validation

Following internationally agreed definitions Instrument and data calibration involves pre-launch and post-launch measurements to fully characterise the payload instruments and subsequent activities to configure the ground processors to provide calibrated (level1b) data products (radiance, reflectance, transmittance, polarisation, 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 color, sea surface temperature) and land variables (vegetation index, 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.

3. Objectives, Co-ordination and Schedule

The Envisat Payload Data Segment (PDS) will routinely produce an unprecedented large number of products (both Level 1b - i.e. geo-located and calibrated engineering parameters - and Level 2 - i.e. geo-located geophysical products). ESA is engaged to deliver products to the wide users' community starting six months after launch at the end of the Commissioning Phase. The objective is to achieve full calibration of all level 1b data products and a preliminary validation of the level 2 data products. In order to achieve this challenging objective the following working teams have been formed:

- ASAR Calibration and Validation Team,
- MERIS Calibration team,
- MERIS & AATSR Validation Team (MAVT)
- MIPAS Calibration team,
- GOMOS Calibration team,
- SCIAMACHY Calibration team,

- Atmospheric Chemistry Validation Team (ACVT), responsible for the validation of the GOMOS, MIPAS and SCIAMACHY,
- RA-2/MWR Calibration team,
- RA-2/MWR Cross-Calibration & Validation team (CCVT),
- Precise Orbit Determination Team (POD).

The necessary expertise is represented in the teams by ESA staff, Expert Support Laboratories who designed retrieval algorithms, 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 of the initial calibration and validation activities is depicted in Fig.1. The process starts with the switch-on of the different payload instruments followed by full in-flight calibration and re-characterisation of the instruments. In parallel the Level 1b processors have to be verified and its parameters 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 have been taken place and the routine calibration phase can begin.

At the level 2 processing the initial algorithm verification starts after the provision of the first level 1b data at that time without full calibration. This will initially consist mainly in consistency checks and will not involve external data. As level 2 will become available validation activities will commence based on external data from campaigns, model assimilation runs and other satellites. After the six month commissioning phase an additional period of three months is required to prepare for the first quality statement regarding the level 2 geophysical data products. As shown in the figure, the schedule for ASAR is slightly different because of the complexity of the instrument calibration.

Data distribution will initially be to the members of the calibration and validation teams only but at the end of the commissioning phase general data distribution will begin.

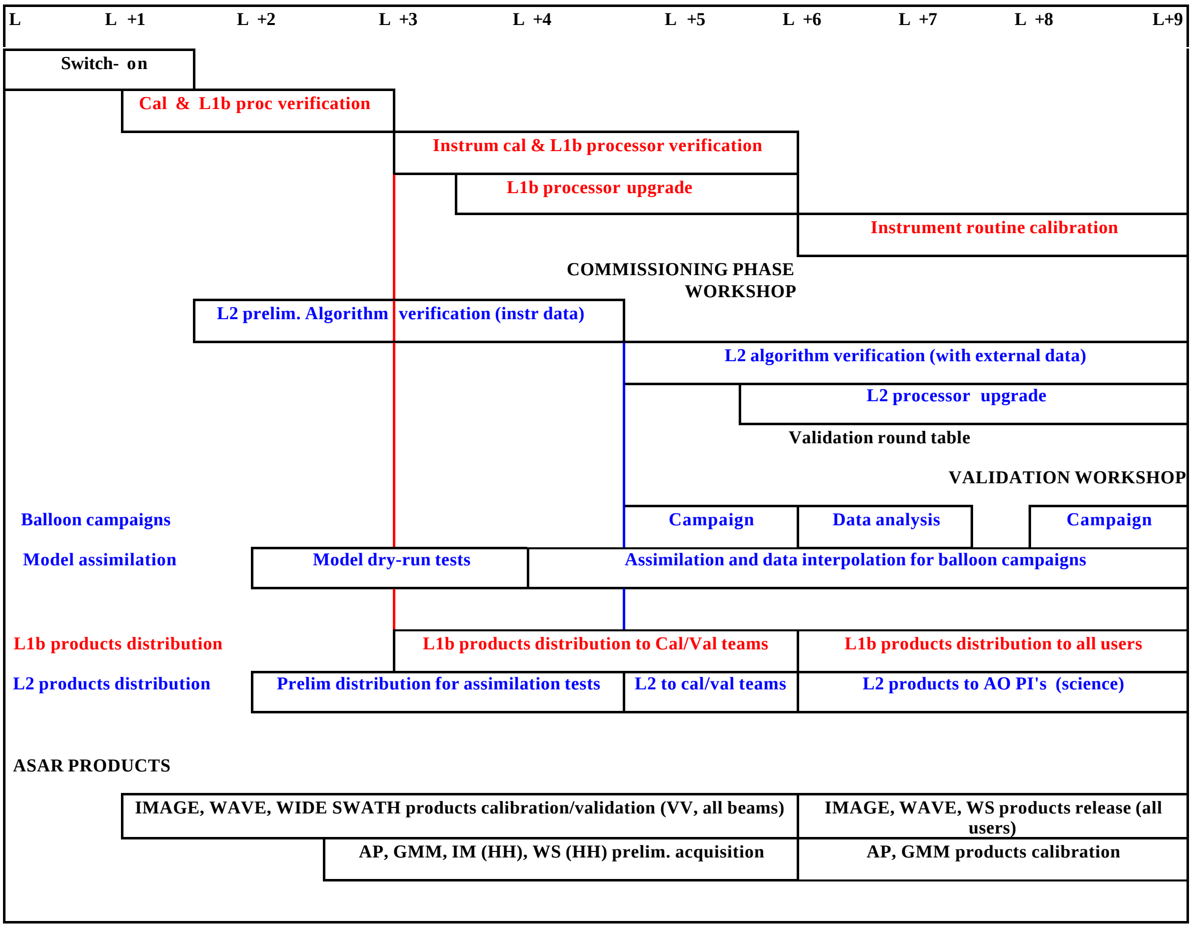

Fig. 1: Schedule for Envisat's calibration / validation activities and the product release

4. Calibration Activities

The Calibration activities to be carried out in orbit consist of

- platform calibration
- instrument calibration
- 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 will be 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 calibration modes of operation and the data resulting from these have to be analysed. These 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 (aux product) and may be changed. The processor setting 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 independent of the operational data processing chain. This is 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.

5. Validation Activities

Since it is the objective of validation to compare the Envisat level 2 data products routinely generated and archived in the Payload Data Segment to independent measurements of the relevant quantities, the validation activities consist of

- organising data acquisition campaigns for independent geophysical measurements
- setting up of a facility for collection, quality control and archiving of correlative data
- analysing correlative data in conjunction with Envisat data and formulate quality statements and recommendations for further work

Geophysical validation is far from a trivial problem. The requirements and the methods to be used were subject of a long scientific debate particularly for the atmospheric chemistry instruments. Another complication has been the international nature of the exercise with participation by 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.

The data coming from the various validation campaigns will be held within a central data storage facility established at the Norwegian Institute for Air Research (NILU) in Norway. NILU will provide access to correlative measurements from sensors on-board satellites, aircraft, balloons and ships, as well as from ground-based instruments and under-water devices and numerical models, such as that of the 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. Transect data will only be provided for inclusion in the database for selected times which correspond to the satellite overpass. 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 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 nine months after launch at the validation workshop. In some cases there will be very limited time available for comparisons between validation campaign data and Envisat data (see Fig.1). However the time pressure comes from the requirement to gain confidence in the new data products as soon as possible as this is a prerequisite for application development and data exploitation.

6. Pre-launch Preparation

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 by the supporting institutes and scientists to develop software tools for analysing Envisat data products in a relative 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 are established for the various teams, down to individual assignments, the tools to be used, the pass-fail criteria, the detailed schedule and interaction 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.

7. Calibration and Validation Activities for Individual Instruments

7.1. 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 (Fig. 2) deployed in the Netherlands for absolute calibration and over the Amazonian rainforest for antenna pattern characterisation. In addition a special calibration subsystem on board will support the in-flight instrument characterisation and facilitate monitoring any gain variations in the active antenna. Needless to say that this task is more of a challenge for ASAR than it was for ERS because ASAR has a total of eight beams, five different modes and up to four polarisation combinations

Fig. 2: ASAR Calibration Transponder

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 in numerical weather prediction models (Fig. 3).

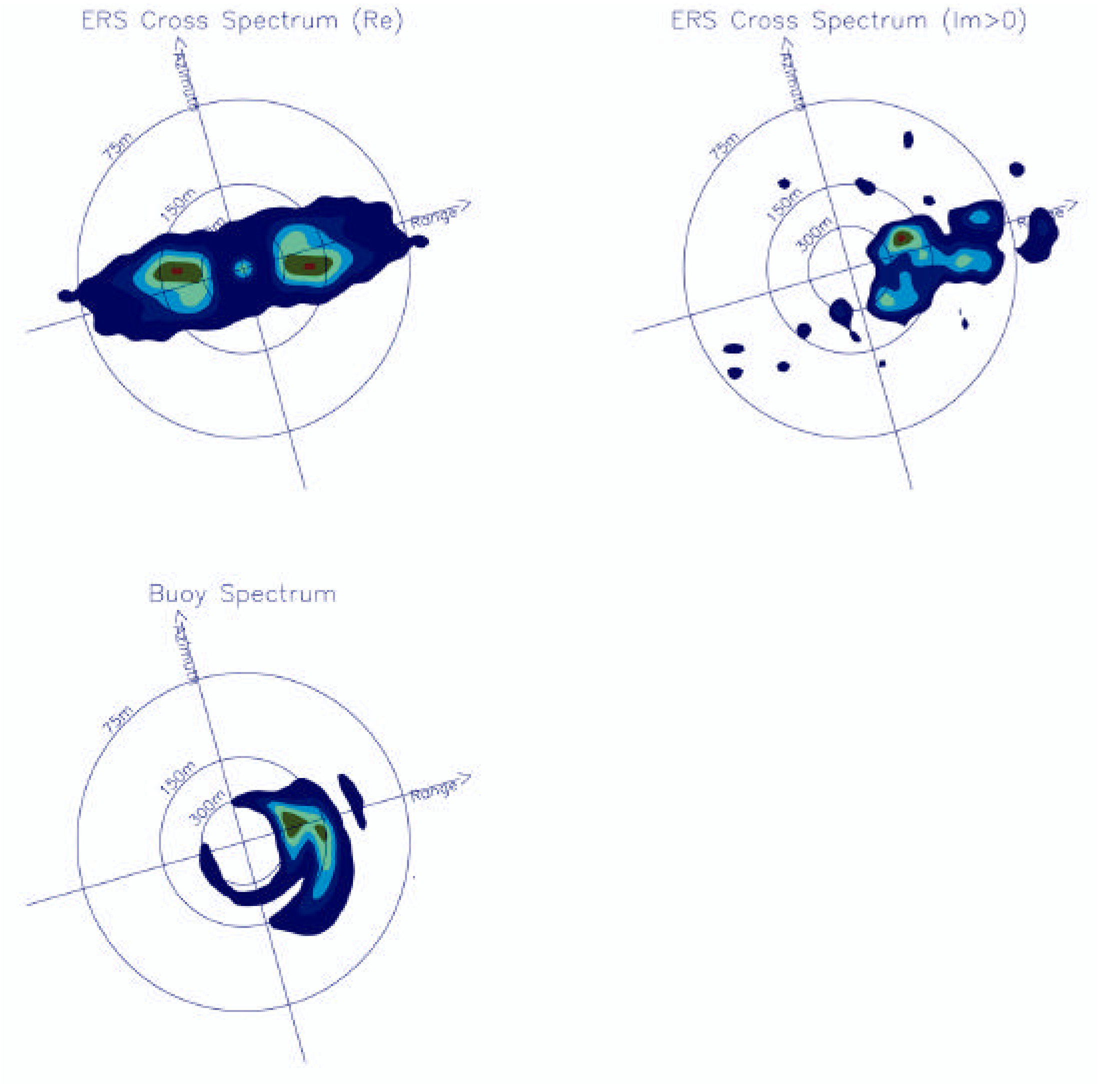

Fig. 3: Simulated ASAR Wave Product based on ERS Data

7.2. MERIS

The in-flight instrument calibration of MERIS will use the on-board sun-lit 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 provide traceability across different missions.

Validation of Top of the Atmosphere (TOA) radiance 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 bidirectional 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.

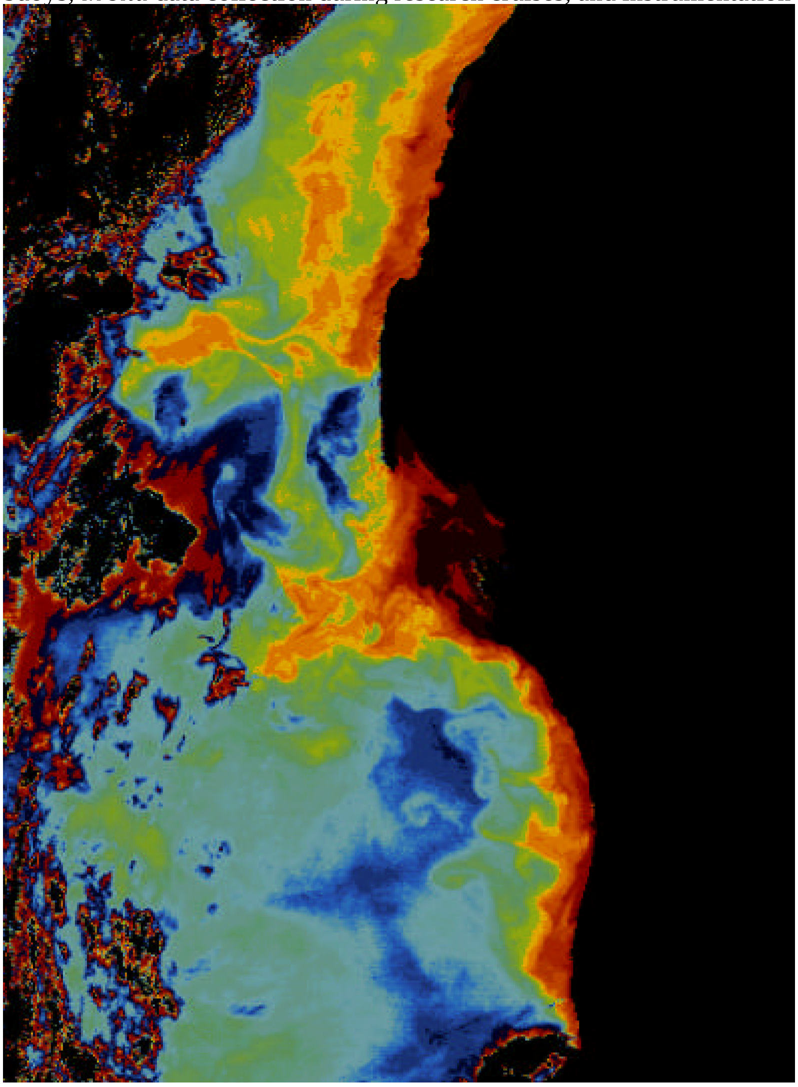

Fig. 4: SeaWiFs level 2C Chlorophyll product located south of the Canary Islands off the west coast of Africa

7.3. 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 NIR channels). As such, calibration of the instrument after launch is not required. There will, however, be specific activities to check and characterise the instrument post-launch, plus algorithm verification where 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 Sea Surface temperature (SST) data products (Fig. 5) in a limited number of international sites and seasons. Making timely use of any tandem ATSR2/AATSR mission, this should include the determination of any bias difference between the measurements made by AATSR and those made by ATSR2 (and AVHRR).

The core validation activities for sea surface temperature (SST) are summarised into three measurement types:

- Broad Scale: Comparison with SST analysis fields, and the systematic review of buoy data,
- Moderate Accuracy: Autonomous measurements on ships of opportunity,
- High Accuracy: Precision measurements.

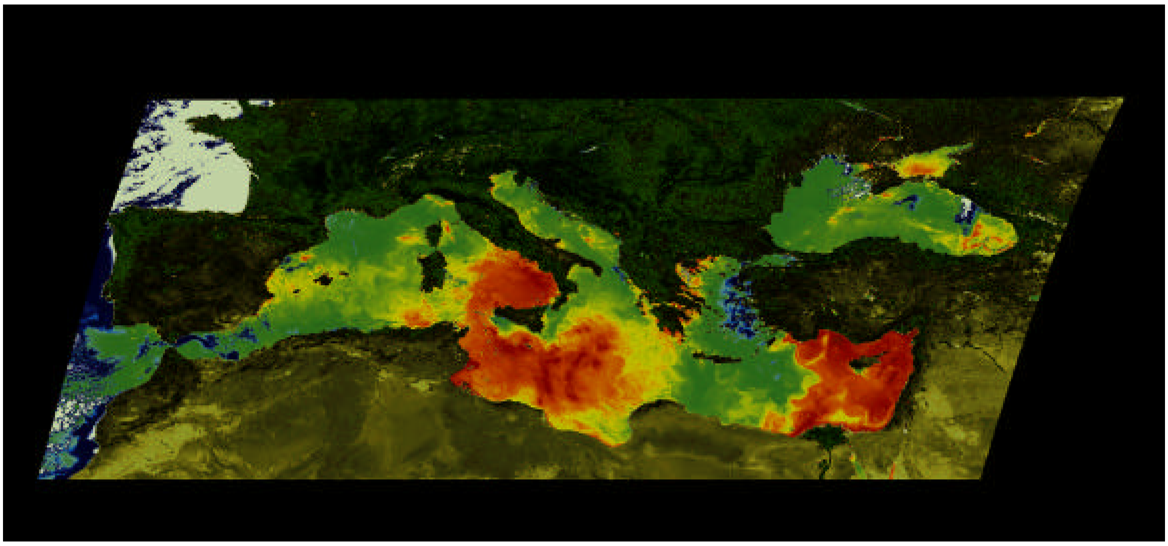

Fig.5: Daytime Sea Surface Temperature of the Mediterranean Sea for August 1997 from ATSR Data

7.4. ATMOSPHERIC CHEMISTRY INSTRUMENTS

Calibration and validation requirements for the atmospheric chemistry calibration and validation teams relate to L1 products (transmittance, irradiances, radiances, reflectances and polarisation measurements), and to L2 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 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 housed on-board Envisat measure overlapping sets of trace gas species, inter-comparisons between the sensors will only be used for the identification of deviations and long-term consistency checking, and not for assessment of accuracy or algorithm tuning.

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

- three instrument-specific subgroups, responsible for the in-flight instrument calibration and for the verification of the L1b and L2 processors
- four subgroups (which are non-instrument specific) 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. Measurement 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 forecast or analysis of the state of the atmosphere. The assimilation efforts will be organised into two main activities.

- Assimilation 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).
- Assimilation 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 aims are to generate a large number of data sets for inter-comparison with GOMOS, MIPAS and SCIAMACHY L2 products. A large number of different measurement instruments and techniques will be used, including lidars, spectrometers and radiometers.

7.5. RA-2 & MWR

The RA-2 altimeter is intended to contribute to the continuation of an uninterrupted series of measurements of sea level and ice-sheet elevation that was started by 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 making use of the north-western Mediterranean basin as a reference surface (fig. 6).
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 used 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 (under development by ESA). Acquisition of individual echoes (special RA-2 mode without on board 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, wave height and sigma0/wind,
- Validation of the absolute sigma0 (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.

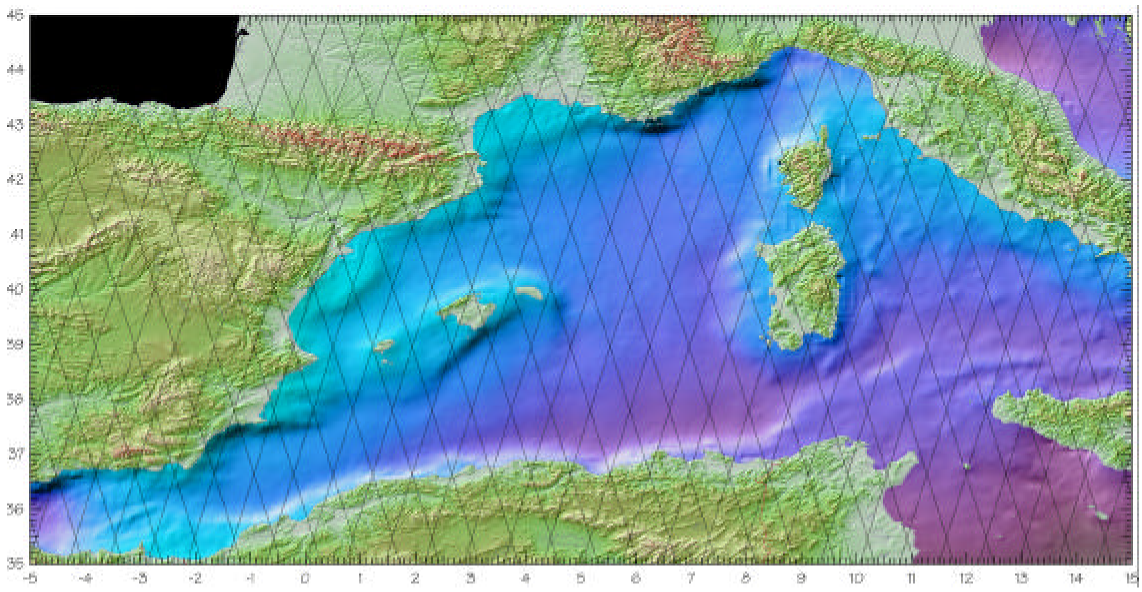

Fig. 6: The north-western Mediterranean basin used as reference surface for the Radar Altimeter absolute range calibration (the Envisat ground tracks are shown).

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. A relative calibration between ERS-2 and ERS-1 was performed during for the commissioning phase of ERS-2. 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.

7.6. Precise Orbit Determination

ESA will produce several types of satellite orbits for Envisat dependent 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 taken by the DORIS instrument is even more precise. The intention is to nominally have these DORIS orbits respectively in the Fast delivery Products, in the Interim Geophysical Products (IGDRs), and in the Geophysical products (GDRs), 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.

TOPEX/POSEIDON and ERS-1/2 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 over the Mediterranean area where extensive calibration and validation activities will be performed.

8. 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 launch. The Calibration and Validation activities have been organised such to be able to reach this objective. The size and the complexity of the mission represent a major challenge to all involved.

Acknowledgements
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The document is available on the ESA Envisat web site in PDF format.
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