ENVISAT

Calibration and Validation Plan

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Acronyms

AATSR	Advanced Along Track Scanning Radiometer
ACF	Absolute gain Calibration Factor
ACVT	Atmospheric Chemistry Validation Team
AERONET	Aerosol Robotic Network
AMF	Air Mass Factor
AMT	Atlantic Meridianal Transect
AO	Announcement of Opportunity
AOI	Announcement of Opportunity Instrument
ASAR	Advanced Synthetic Aperture Radar
AVHRR	Advanced Very High Resolution Radiometer
BOA	Bottom Of the Atmosphere
BRDF	Bidirectional Reflectance Distribution Function
Cal/val	Calibration / Validation
CASI	Compact Airborne Spectrographic Imager
CCD	Charge Coupled Device
CCVT	RA-2 / MWR Cross-Calibration & Validation Team
CESA	Control Electronics Sub-Assembly
CESAR	Cold Atmospheric Emission Spectral Radiometer
CHAMP	Comet Halley Active Monitoring Programme
CNES	Centre National d'Études des Télécommunications, France
COASTLOOC	COAstal Surveillance Through Observation of Ocean Colour
CORINE	Co-ordination of Information on the Environment
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTM	Chemical Transport Model
DLR	Deutsche Forschungsanstalt für Luft und Raumfahrt, Germany
DOAS	Differential Optical Absorption Spectrometer
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
ECMWF	European Centre for Medium-range Weather Forecasting
ECOC	Electrochemical Ozone Cell
EDI	ESA Developed Instrument
ELHYSA	Etude de L'HYgrométrie StrAtosphérique
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESABC	Envisat Stratospheric Aircraft and Balloon Campaign
ESL	Expert Support Laboratory
ESOC	European Space Operations Centre, Darmstadt
ESOV	Earth Map and Swaths Visualisation tool
FISH	Fast *In situ* Stratospheric Hygrometer
FOS	Flight Operations Segment
FOZAN	Fast Ozone Analyser
FTIR	Fourier-Transform Infrared Spectrometer
FTS	Fourier-Transform Absorption Spectrometer
GDR	Geophysical Data Record
GOCE	Gravity and steady-state Ocean Circulation Explorer
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of the Stars
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GUV	Ground-based Ultraviolet Radiometer
HDF	Hierarchical Data Format
HH	Horizontal Transmit – Horizontal Receive Polarisation
HV	Horizontal Transmit – Vertical Receive Polarisation
IECF	Instrument Engineering Calibration Facility
IGDR	Interim Geophysical Data Record
ILS	Instrument Lineshape

IPF	Instrument Processing Facility
IRF	Impulse Response Function
L1b	Level 1b
L2	Level 2
Lidar	Light Detection and Ranging
LOS	Line-Of-Sight
LST	Land Surface Temperature
LUT	Look-Up Table
M-AERI	Marine Atmosphere Emitted Radiance Interferometer
MAVT	MERIS & AATSR Validation Team
MERIS	Medium Resolution Imaging Spectrometer
METEOSAT	Meteorological Satellite
MGVI	MERIS Global Vegetation Index
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MISR	Multi-angle Imaging Spectrometer
MODIS	Moderate-Resolution Imagine Spectrometer
MOE	Medium Accuracy Orbit
MSG	Meteosat Second Generation
MWR	Microwave Radiometer
NASA	National Aeronautics and Space Administration, USA
NASDA	National Space Development Agency, Japan
NDSC	Network for the Detection of Stratospheric Change
NESR	Noise Equivalent Spectral Radiance
NILU	Norwegian Institute for Air Research
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
NRT	Near Real time
NWP	Numerical Weather Predication
OL	On Line
OVID	Optical Visible and near Infrared Detector
PCD	Product Confidence Data
PDS	Payload Data Segment (Envisat)
PF-ASAR	ASAR Processing Facility
PI	Principal Investigator
POD	Precise Orbit Determination
POE	Precise Orbit
POLDER	Polarisation and Directionality of Earth's Reflectances
PTU	Pressure Temperature Humidity
RA-2	Radar Altimeter-2
RAL	Rutherford Appleton Laboratory, UK
RMVT	RA-2 / MWR Validation Team
SAFIRE	Spectroscopy of the Atmosphere Far Infrared Emission
SAR	Synthetic Aperture Radar
SBUV	Solar Backscatter Ultraviolet
ScanSAR	Scanning SAR Imaging Technique (for wide swath coverage)
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SeaWiFS	Sea Wide Field-of-view Spectrometer
SLR	Satellite Laser Ranging
SOAZ	Système d'Analysis par Observations Zénithales
SODAP	Switch-On and Data Acquisition Phased
SPOT	Satellite pour l'Observation de la Terre
SSST	Skin Sea Surface Temperature
SST	Sea Surface Temperature
TBD	To Be Determined
T/R	Transmit – Receive
TOA	Top Of the Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Topography Experiment for Ocean Circulation

USF	User Service Facility
USO	Ultra Stable Oscillator
UV	Ultraviolet
VH	Vertical Transmit – Horizontal Receive Polarisation
VIS	Visible
VMR	Volume-Mixing Ratio
VV	Vertical Transmit – Vertical Receive Polarisation

List of Figures and Tables

1 Overview

The Envisat Calibration and Validation Plan defines the activities that will calibrate Envisat instruments validate its data products, particularly the Level 2 (L2) geophysical products, derived from the ESA-developed instruments (EDIs):

- Michelson Interferometer for Passive Atmospheric Sounding (MIPAS),
- Global Ozone Monitoring by Occultation of the Stars (GOMOS),
- Medium Resolution Imaging Spectrometer (MERIS),
- Advanced Synthetic Aperture Radar (ASAR),
- Radar Altimeter-2 (RA-2),
- Microwave Radiometer (MWR),

and the AO instruments (AOIs):

- Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY),
- Advanced Along Track Scanning Radiometer (AATSR),
- Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS).

Detailed information on these instruments is available from the Envisat worldwide web site: http://envisat.estec.esa.nl.

ESA issued an "Announcement of Opportunity for the Exploitation of the Envisat Data Products" in 1998. More than 740 proposals (out of which 130 deal with calibration / validation) were received from more than 50 countries. The ESA calibration / validation (cal/val) programme embodies these projects and the success of the Envisat validation relies on these important contributions.

Envisat is scheduled for launch in June 2001.
The Commissioning Phase will last for six months and will incorporate:

- The Instrument Switch-on and Data Acquisition Phase (SODAP) where the instruments operation will be verified.
- The calibration / validation activities.

A workshop will be held at the end of the Commissioning Phase. This will be followed by a Validation workshop nine months after launch. After this time, validation activities will not cease but will continue throughout the mission life of the Envisat sensors to ensure long-term validation of their products.

1.1 Organisation of the Calibration / Validation Activities

For the co-ordination of the Envisat cal/val activities, the following teams have been established:

- 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) which includes GOMOS, MIPAS and SCIAMACHY,
- RA-2/MWR Calibration team,
- RA-2/MWR Cross-Calibration & Validation team (CCVT),
- Precise Orbit Determination Team (POD).

Typical membership of the cal/val teams comprises:

- ESA staff,
- Expert Support Laboratory (ESL) members,
- An instrument contractor representative (in the calibration team),
- Selected AO cal/val project representatives (PI),
- A representative of the operational processor,
- One representative of the validation group within the relevant calibration team,
- One representative of the calibration group within the relevant validation team.

The objectives of the commissioning phase are to achieve:

- a full calibration and
- a preliminary validation

for each instrument and its products.

The calibration team activities will encompass:

- Full in-flight calibration and re-characterisation of the instrument.
- Complete verification of the Level 1b (L1b) processor (tuning of all parameters, regeneration of all L1b auxiliary products).
- A first upgrade of the Level 1b ground processor (at the end of the commissioning phase).[1]

Validation team activities will embrace:

- Level 2 (L2) algorithm verification (tuning of all processing parameters, first regeneration of all L2 auxiliary products). This is essentially performed by the ESL team and is carried out on the basis of the instrument data and the preliminary results of some validation campaigns.
- Ensuring consistent geophysical behaviour of the processor products.
- Quantifying errors within the geophysical products by the Validation Workshop (L+9m).

The schedule for Envisat's cal/val activities and product release is detailed in figure 1.1.
Figure 1.1 depicts the calibration activities (in red) and validation activities (in blue) and also highlights the major milestones.

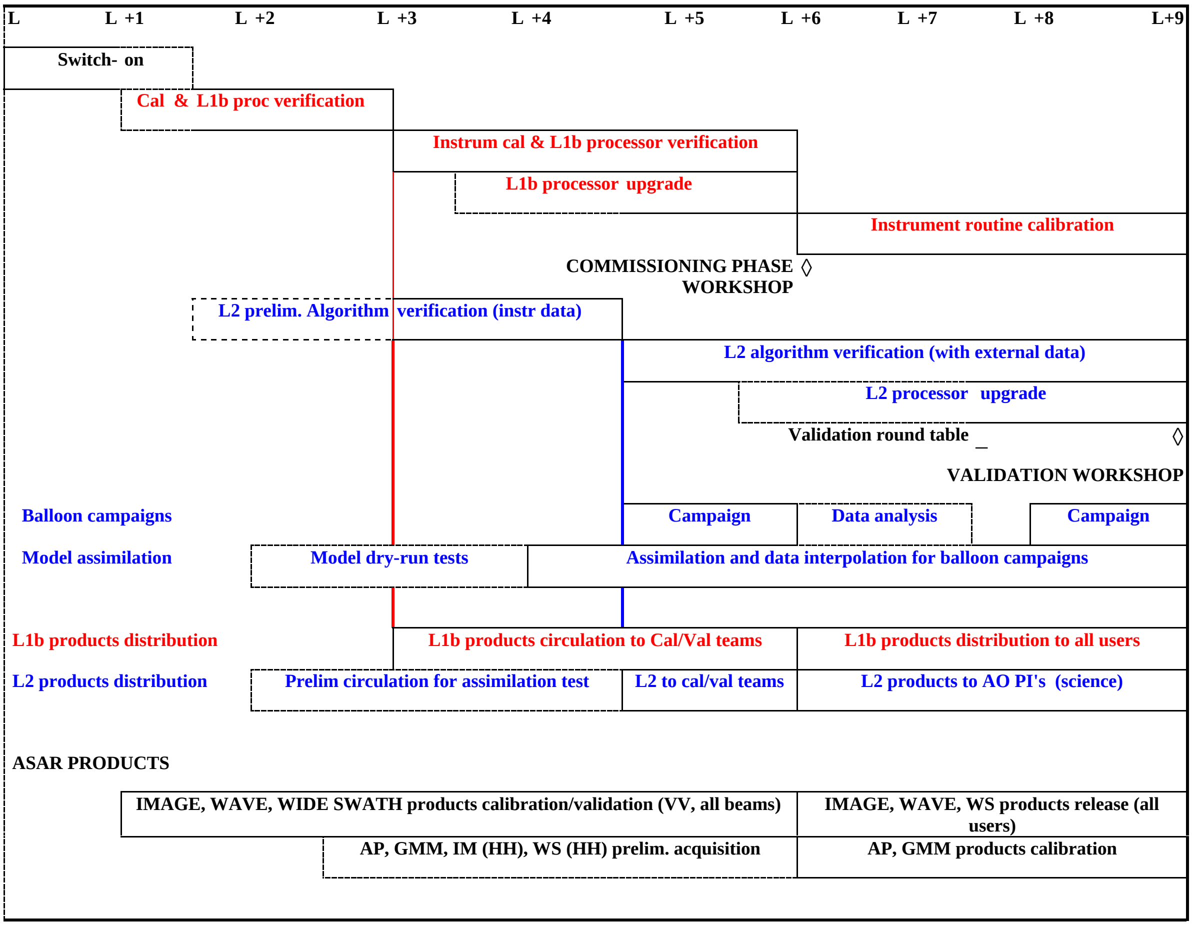

Figure 1.1: Schedule for Envisat s calibration / validation activities and the product release

[1] *It should be noted that reprocessing of data acquired during the first six months is not an objective of the commissioning phase*

By the end of the Commissioning Phase the Level 1b products will be fully verified and thus distribution to all users can begin. Routine calibration starts at the end of the Commissioning Phase. Level 2 products will have been preliminary validated only. The validation activities will have achieved the complete tuning of all processing parameters and will have verified the processor functionality. Initial distribution of these preliminary L2 products to the AO PI's (science category) will commence at the end of the commissioning phase. ASAR Image, Wave and Wide Swath products distribution (outside the ASAR Cal-Val team) starts at the end of the Commissioning Phase.

- By the Validation Workshop at Launch + 9m, the Level 2 products preliminary validation will have been consolidated. A first regeneration of the Level 2 auxiliary products will have been achieved and error bars for all Level 2 products will have been estimated and reported. Distribution to all users of all Level 2 products will start at Launch+9m (immediately after the Validation Workshop). ASAR AP and GMM products will also be released at this time.

1.2 Organisation of the Validation Campaigns

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. NILU will provide documentation describing the facility and how users gain access to the database to retrieve or upload data, and the formats to be used. Particular attention will be given to the quality control of such data. Envisat data products are stored within the PDS and will not be held at NILU. Users will be able to connect with the database to add or retrieve data according to their requirements. Access to such a range of data will strengthen the statistical significance of the results and increase the chances of detecting errors in the processing algorithms.

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 although other correlative satellite data will be included to facilitate their comparison with data acquired for the Envisat mission.

1.2.1 Instrument Engineering Calibration Facility

The Calibration activities will be centred on the Instrument Engineering Calibration Facility (IECF). Data acquired by the various instruments in calibration modes are not processed by the processors within the Payload Data Segment, but are processed by the IECF.
The main functions of the IECF are:

- Platform calibration and performance monitoring. This includes activities relating to a specific platform or those common across all instruments. Activities will involve the characterisation of the orbit characteristics, of instrument pointing, and of the X-, Ka- and S- band links.
- Instrument calibration and performance monitoring. The instrument performance will be verified, the parameter evolution monitored with respect to temperature, ageing (instabilities and drifts) and any other driving parameters (if applicable), and periodic recalibration of the instrument biases will be performed. Other activities will include the analysis of calibration mode data and thus the generation of updated coefficients and tables, and the production of regular reports on the instrument status.
- Auxiliary Data Product generation (to PDS). The IECF is the source of all auxiliary products needed for the PDS processing chain (with the sole exception of on-line auxiliary data such as the orbit and the ECMWF meteo prediction and analysis fields). These products can either be imported by the IECF from an external supplier (e.g. from the SOST team in the case of the SCIAMACHY calibration) or generated by the IECF itself (for the EDIs).
- Optimisation of PDS instrument processor set-up parameters. 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 will be optimised during the commissioning phase and subsequent changes will then be kept to a minimum in order to guarantee product continuity.
- Instruments control table generation (to FOS). The computation of most instrument parameters (like the alpha and beta values for the RA-2 on-board tracker) will be performed by the IECF. The resulting instrument command table will be sent to the FOS (ESOC) to be used in the creation of the operational macrocommands to be uploaded to Envisat.

The structure of the IECF provides the necessary flexibility; new algorithms can be added and existing ones may be modified and tested. The IECF will incorporate results from new analyses that will allow the calibration performance and product quality to be improved. Conversely, care will be taken to maintain continuity in the product quality during the operational phase.

1.3 Rehearsal

In order to test validation procedures, a rehearsal will take place in autumn 2000. Emphasis will be placed on data transfer procedures, including the use of the NILU facility. In addition, the rehearsal will provide the opportunity to test software tools developed by team members. The rehearsal objectives are summarised as follows:
- Test communications channels,
- Test validation data handling software,
- Verify data quality control procedures,
- Generate overpass tables, observation plans, and detailed measurement schedules using ESA and local tools,
- Check login procedures with NILU,
- Test uploading of data to NILU,
- Test downloading of correlative data from NILU,
- Test downloading of Envisat data from the USF,
- Test Envisat data handling software provided by ESA,
- Test local data analysis tools and facilities,
- Test reporting procedures and tools and generate a test report,
- Evaluate and report on the performance of all data-transfer tools and facilities,
- Prepare a review of the performance of all teams and components,
- Formulate recommendations for improvements.

1.4 ESA Provided Software Tools

A suite of software will be made available to the user community and distributed free of charge via the worldwide web and together with the data products themselves.
EnviView is a software package that can be run under all common operating systems (Solaris, Windows and Mac OS) and has the capability to view all Envisat products.
ESOV is a tool for the display of the orbit tracks and the swath position that is useful to compute the coverage and overpass opportunity of any given location..

1.4.1 EnviView

EnviView is a platform independent software tool that is capable of reading all Envisat products. It includes basic 'quick look' visualisation capabilities and also the facility to extract data, or subsets of data, for post-processing. Also included is an option to convert the data from PDS to HDF 4.1 r3 format, useful for comparison with data held in the NILU database, which are also stored in this version of HDF or as a bridge to applications able to handle the HDF format. EnviView also includes the detailed structure and format definition of the Envisat products.

1.4.2 ESOV

The Earth Map and Swaths Visualisation tool (ESOV) is a collection of software functions that perform accurate computations of mission related parameters for the Envisat and for ERS. The use of this software will assist the scientific investigator in the planning of data acquisition designed to coincide with the overpasses of Envisat and also of other satellites. ESOV contains information and detailed predictions of the satellites' orbit, indicating when and over what stretch of the ground or ocean the images will be acquired.

1.5 Calibration / Validation Documents

The following documentation will be produced as part of the calibration and validation activities:

PRE-LAUNCH

- Envisat Calibration and Validation Plan (this document)
- Calibration and Validation Management Plan that will cover organisational aspects and the team composition.
- Calibration and Validation Implementation Plans of which there will be one per team. These contain detail plans of the activities to be carried out by the team (down to individual assignments), of the tool used, of the pass/fail criteria, etc.

POST-LAUNCH

- *Calibration and Validation Reports* (at the end of the Commissioning Phase and at the Validation Workshop) detailing the results-of the planned activities. There will be one report per team.
- *Calibration and Validation Achievements Report*. A draft of this document will be available by the commissioning phase workshop and the final version will be complete by the validation workshop.

2 ASAR

The ASAR 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 rainforest, for antenna pattern characterisation. In addition, special calibration loops have been installed to monitor any gain variations in the active antenna.

The ASAR cal/val plan is divided into three sections that describe the methods for calibration and validation of the instrument, the processing facility and the Wave mode products.

2.1 Calibration

The instrument calibration comprises all measures to characterise and to monitor the ASAR flight hardware. This includes:

- Internal calibration,
- Antenna pattern characterisation,
- Gain calibration,
- In-flight evaluation of performance parameters.

2.1.1 Internal Calibration

A very comprehensive system for internal monitoring is necessary to be able to derive the transfer function of the internal path. Using this information, it is possible to make corrections for the transfer function in the ground processor and to monitor any ageing or eventual failure of a particular transmit/receive (T/R) module.

There are individual calibration paths to each of the 320 T/R modules and calibration can also be carried out on a row-by-row basis for each of the 32 rows. Calibration pulses (fig. 2.1) are included in the instrument's timeline during imaging and consist of:

1. A transmit calibration pulse - P1 / P1a ,
2. A receive calibration pulse - P2,
3. A central electronics calibration pulse - P3.

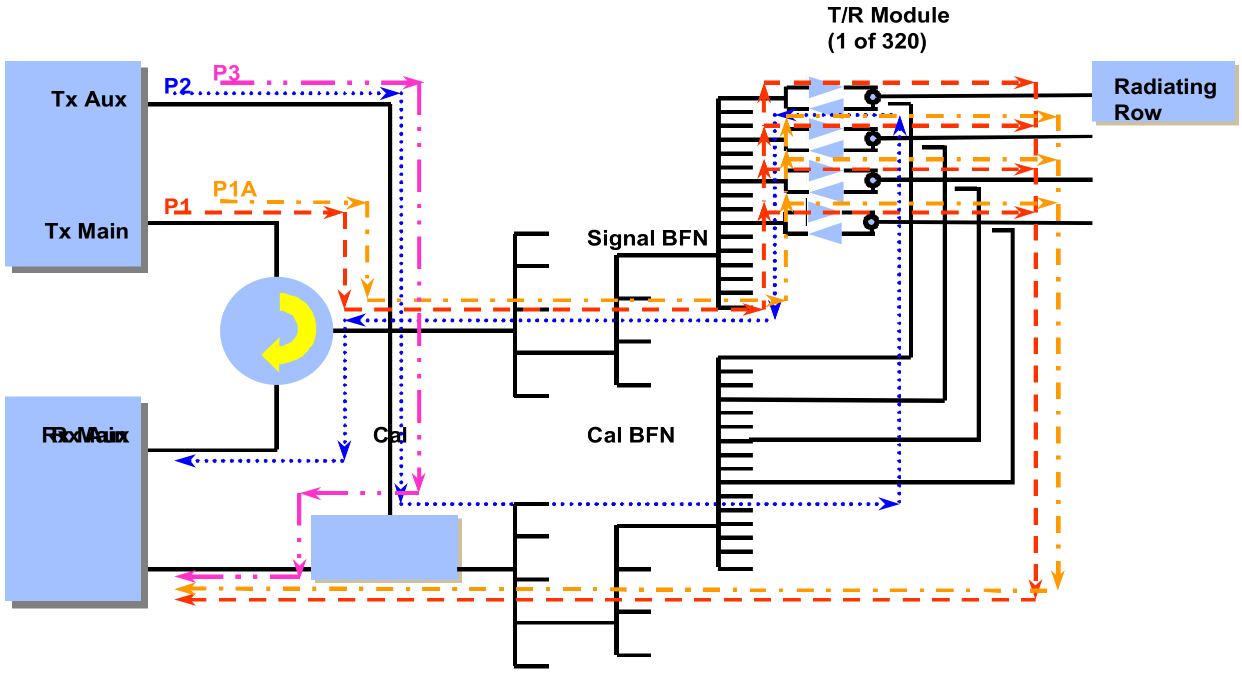

Figure 2.1: ASAR Calibration Pulse Diagram

1. Transmit Calibration Pulse

- P1 (representative of T/R module load)

Since T/R modules of the four adjacent rows share the same power supply, the ten modules of the “wanted” row are set to their nominal phase and amplitude settings. The phase of the modules of the three “unwanted” rows are set so that their combined contribution out of the calibration network is nominally zero; this minimises their interference to the measurement of the wanted row.

- P1a

A second type of transmit pulse is added in order to characterise the residual parasitic contribution of the three unwanted rows during P1. During P1a, the three unwanted rows are set as for P1 and the previously wanted row is switched off. Even though the load conditions on the power supplies are not exactly representative, the small error introduced into the estimation of P1a is negligible.

2. Receive Calibration Pulse P2

The receive path of the instrument is characterised. Since no variation is expected from power supply load variations it is possible to characterise on a row-by-row basis.

3. Central Electronics Calibration Pulse P3

The central electronics T/R paths are included in the P1/P1a and P2 characterisations. The central electronics are therefore characterised independently by means of P3.

Despite the comprehensive nature of the internal calibration system, it is not possible to use it to calibrate the passive part of the antenna, which falls outside of the calibration loop. This is achieved instead through end-to-end calibration using the transponders. It is also not possible to correct for short-term variations in the instrument, nor variations in the calibration loop itself.

Using the amplitude and phase of the calibration pulses (P1/P1a, P2 and P3) for each row it is first necessary to calculate the amplitude and phase of P2 relative to P3 and to subtract P1a vectorially from P1. From these values for each of the 32 rows, together with the external characterisation factor, it is possible to calculate the elevation beam pattern. This is then used to detect any deviation from the reference instrument gain pattern as characterised on-ground. The typical update rate for this calculation is 5 to 35 seconds (mode dependent).

A replica of the chirped pulse is calculated from a complete calibration row cycle using the P1/P1a, P2 and P3 measurements, the ground-characterised row patterns and the external characterisation data. This is also typically updated every 5 to 35 seconds.

2.1.2 Antenna Pattern Characterisation

In order to provide the required image quality, the two-way antenna beam pattern should be known to a high degree of accuracy (0.1 dB). The T/R antenna patterns have been accurately measured on-ground for all eight beams (IS1-IS7 and SS1) and for both H and V polarisations. In-flight, the patterns will be re-determined using several techniques:

1. Images taken over the Amazonian rainforest (two-way, only mainlobe pattern measured),
2. Module Stepping mode (T/R module characteristics only),
3. External Characterisation mode over an ASAR transponder (only transmit pattern measured).

Initially, the on-ground characterisation data will be used, although as variations are detected they can be compensated for either by updating the antenna pattern characterisation data in the ground processor or by modifying the on-board antenna coefficients in the case of changes to the T/R modules nominal gains (drifts).

1. Rainforest

Images of the Amazonian rainforest (e.g. fig. 2.2) are used for the characterisation of the antenna beam pattern because this is a stable, large-scale, isotropically distributed target with a relatively high backscatter and there is a well-understood relationship between backscatter and incidence angle. In order to determine the two-way beam pattern, an uncorrected rain forest image is averaged in the azimuth direction. In the final processed image, the inverted beam pattern is applied and hence the effect of the pattern on the backscatter is removed.

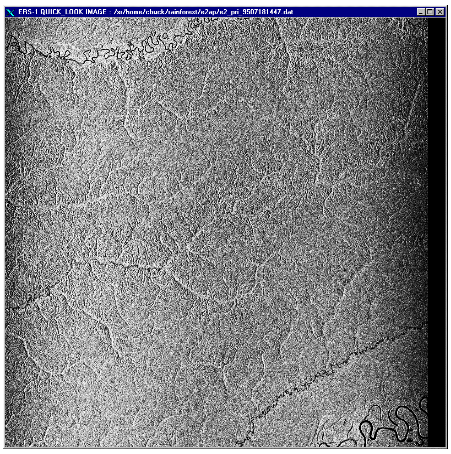

Figure 2.2: ERS-1 quick-look image over the Amazonian rain forest

2. Use of Module Stepping

ASAR has a dedicated Module Stepping Mode, which is used to gather data from all 320 T/R modules automatically. The entire procedure takes less than one second following which the data are downloaded to the ground for processing. After processing, the results are compared with the reference data from on-ground tests in order to determine any T/R module gain or phase drifts, temperature behaviour and any eventual module failures. Using this information it is possible to implement any corrections necessary to the T/R module coefficients and to re-synthesize the antenna beam patterns should that be required.

3. External Characterisation

ASAR can be put into External Characterisation Mode whilst flying over a calibration transponder. This involves sending a series of pulses from each of the 32 rows in turn followed by each of the 10 columns. These pulses are detected both by the internal calibration loop and by the receiver embedded in the transponder. Comparison of these data, together with instrument telemetry, allows the characterisation function to be computed (row and polarisation dependent). The PDS Generic Processor then uses this. The baseline is to repeat measurements every six months.

2.1.3 Gain Calibration

The purpose of the gain calibration is to enable the users of ASAR data to determine the absolute level of backscatter from any target, point target (sigma) or distributed target (sigma zero). For ASAR this is achieved in fundamentally the same way as for ERS by providing an absolute gain calibration factor (ACF) in the header of the (processed) product. However, since ASAR has a total of eight beams, five different modes and up to four polarisations, many more ACFs will need to be determined for ASAR than was the case for ERS with its single beam, single polarisation and two modes. This detail is summarised in table 2.1.

	Polarisation					
Mode	**HH**	**VV**	**HHVV**	**HHHV**	**VVVH**	**Total**
Image	7	7				14
Wave		7				7
Wide Swath	1	1				2
Global Monitoring	1	1				2
Alternating Polarisation			7	7	7	21

Table 2.1: Number of ACFs to be calculated for each mode and polarisation of ASAR

As in the case of ERS, the ACFs will be determined by imaging a target of known radar cross-section and integrating the power in its Impulse Response Function (IRF) which will need to be adjusted for the associated background (clutter) power. Thus, the correction (the ACF) can be calculated and this must be applied to the image values in order to arrive at the same cross-section for that target (e.g. fig. 2.3). For this purpose, precision calibration transponders will be deployed in the Netherlands. The radar cross-section of these transponders is known to within ±0.13 dB and they are stable to 0.08 dB. It is necessary to use active radar calibrators (transponders, e.g. fig. 2.4) as opposed to passive ones (e.g. corner reflectors) since the ratio of signal to clutter determines the accuracy to which the calibration can be made. Once the ACF for a particular configuration has been determined it will be possible to make a direct comparison with the on-ground measurements of the end-to-end system gain carried out during Flight Model testing. For the narrow swath modes the method described will be used exclusively. However, for the ScanSAR modes there will be a combined use of the narrow swath calibration together with dedicated calibration processing.

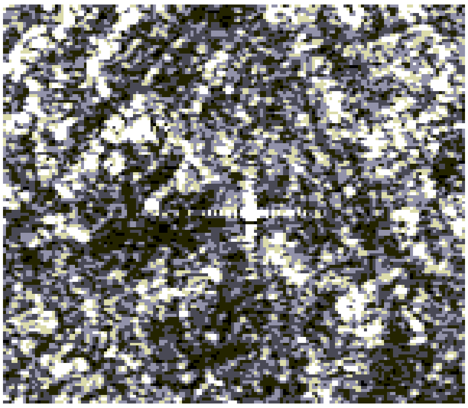

Figure 2.3: Transponder response image

Three precision calibration transponders have been developed by MPB (Canada) based on an ESA prototype; they were delivered to ESTEC in April 2000. The selection of suitable sites for the deployment of the transponders will be optimised for Envisat. One mobile unit will be deployed at a dedicated wave mode calibration site.

Figure 2.4: Prototype ASAR Transponder

2.1.4 In-Flight Evaluation of Performance Parameters

The calibration transponders are not only used for calibration, they also provide useful point targets from which many performance parameters can be derived. These include spatial resolution, side-lobe levels, point target ambiguity levels, radiometric accuracy and stability, and localisation accuracy (fig. 2.5). The minimum backscatter level recordable by the ASAR instrument (noise-equivalent sigma zero) is determined from the apparent backscatter obtained over a body of still water such as a lake in an image.

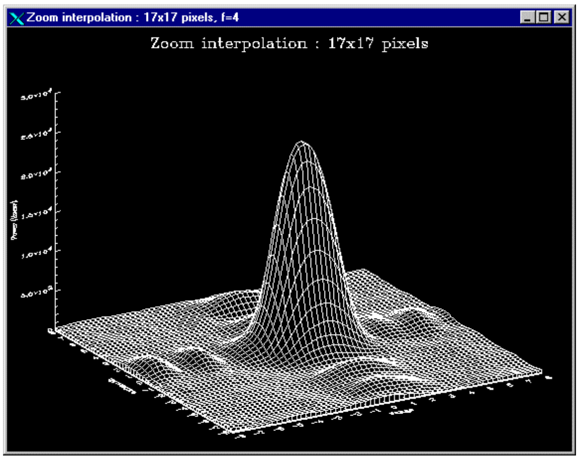

Figure 2.5: Interpolated point target response

Instrument internal parameters are routinely monitored and checked to be within pre-set limits. The critical parameters with respect to performance and calibration are the antenna equipment temperatures such as those of the T/R modules and the power supply units, and the DC power consumption of the tiles. Limit checks are performed on the module temperatures in absolute and tile-to-tile variation terms. Should any of these parameters appear out of limit, this is an indication of potential equipment malfunction in the antenna. Parameters within the Control Electronics Sub-Assembly (CESA) are also monitored, but these are less critical to instrument performance.

2.2 Verification

The ASAR processor verification is divided into two main phases:

- A pre-launch phase, which is already underway, and
- A commissioning phase, which is due to commence after the launch of Envisat.

2.2.1 Pre-Launch Activities

It is proposed to perform two main activities during the pre-launch period, a calibration of ASAR products and a full validation of the ASAR processing facility (PF-ASAR).

The exercise will consist of the verification and calibration of ASAR products (table 2.2) simulated from ERS SAR data, using the ERS interface to the PF-ASAR. The calibration will be carried out according to the ASAR cal/val plan and using the quality analysis tools that will also be available during commissioning. Special ERS acquisitions over ERS transponders located at Flevoland, and over the new Envisat ASAR transponders, will be undertaken in Image and Wave modes of operation. Rainforest scenes will be also be acquired to analyse the antenna pattern and the radiometric stability.

Other techniques to calibrate the new medium resolution products will be studied and compared to the currently used integral method. The activity is to be performed only on the products that can be simulated from ERS raw data. As a result of the exercise the PF-ASAR will be calibrated for all those products containing ERS data. In the case of wave mode calibrated imagettes, the L1 WVI will be used to further validate the L2 WVW product. Moreover a table of quality measurements of ERS data processed with PF-ASAR parameters will be produced.

A full verification of the ASAR processing facility (PF-ASAR) will be performed during the commissioning phase. The current instrument settings will be maintained and also included will be a complete quality analysis of the simulated products that have been processed during the acceptance test campaigns and which use the same quality analysis tools that will be employed during the commissioning phase. The objective of this activity is to establish, before launch, the processor settings to be used as default values in the operational environment after launch, and to verify the quality requirements for all L1 ASAR products.

As an activity that is already underway, the simulated datasets used to test the ASAR processor are currently being regenerated by MDA. This includes the use of the latest instrument settings provided by the instrument subgroup. They will be further reprocessed using the updated processing parameters to verify that they do not introduce quality degradation in any of the products. The auxiliary files reflect the nominal instrument configuration. As a rehearsal activity, further checks will be undertaken using the available quality control tools

Processing Level	Image Mode H or V	Alternating Polarisation Mode HH/VV, HH/HV VV/VH	Wide Swath Mode HH or HV	Global Monitoring Mode HH or VV	Wave Mode HH or VV
L0 Instrument Source Packets	ASA_IM_0P	ASA_APH_0P ASA_APV_0P ASA_APC_0P	ASA_WS_0P	ASA_GM_0P	ASA_WV_0P
L1b Medium Resolution (150m)	ASA_IMM_1P	ASA_APM_1P	ASA_WSM_1P		
L1b Low Resolution (1km)				ASA_GMM_1P	
Browse	ASA_IM_BP	ASA_AP_BP	ASA_WS_BP	ASA_GM_BP	
L1b Single Look Complex (SLC)	ASA_IMS_1P	ASA_APS_1P			
L1b Precision Image (PRI)	ASA_IMP_1P	ASA_APP_1P			
L1b Geocoded Image (GEC)	ASA_IMG_1P	ASA_APG_1P			
L1b Imagette and Cross Spectra					ASA_WM_1P
L1b Cross Spectra					ASA_WVS_1P
L2 Wave Spectra					ASA_WVW_2P

ASAR products verified with ERS   ASAR products verified with simulated datasets

Table 2.2: ASAR products from ERS data

2.2.2 Commissioning Phase activities

During the commissioning phase, and until the validation workshop, all ASAR products will be verified and calibrated. Priorities have been established in order to concentrate first on the ASAR products that are more similar to the well-known ERS SAR products (e.g. products over swath IS2 in VV polarization). The product verification priorities are given in the table 2.3.

Verification of the ASAR products requires a series of activities to be performed on different product levels for dedicated transponder and rainforest scenes, as well as for arbitrary data sets. This also includes analyses of the Wave, ScanSAR and AP mode products and of interferometric products. Table 2.4 summarises the various activities.

Mode	Polarisation	Swath
Commissioning workshop (6 months after the launch)		
IM	VV	IS2
WV	VV	IS2
IM	VV	IS1, IS3-IS7
WS	VV	SS1, SS2-SS5
Validation workshop (9 months after the launch)		
AP	HH/HV, VV/VH	IS2. IS4
AP	HH/HV, VV/VH	IS7, IS1
AP	HH/HV, VV/VH	IS3, IS6, IS5
IM	HH	IS1-IS7
AP	HH/VV	IS1-IS7
WS	HH	
GM	VV	
GM	HH	

Table 2.3: Product priorities during commissioning phase

Activity	Products
Product Format Verification	All products
Raw Data Analysis I-Q statistics Saturation analysis Noise analysis Calibration pulses analysis Chirp Replica analysis Timing Monitoring Gain Droop Compensation Verification	All IM, AP, WSM, GMM, WV level 0 products
IRF analysis (*based on ASAR transponders*) Image quality parameters check (resolution, peak intensity, PSLR, ISLR, point target radar cross section, etc.)	IMP, IMS, IMM, IMG, APS, APP, APG, APM, WSM, GMM, WVI imagette
Ambiguity analysis (*based on ASAR transponders*) Ambiguity location offset Ambiguity radar cross section Point target ambiguity ratio	IMP, IMS, IMM, APS, APP, APM, WSM, GMM
Geometric analysis (*based on ASAR transponders*) Localisation accuracy SWST bias determination Swath width and position	IMP, IMS, IMM, IMG, APS, APP, APM, WSM, GMM, WVI imagette
Radiometric analysis (*based on ASAR transponders*) Radiometric resolution Radiometric accuracy Radiometric stability $NE\sigma^0$ calculation (still water bodies)	IMP, IMS, IMM, IMG, APS, APP, APG, APM, WSM, GMM, WVI imagette
External calibration (*based on ASAR transponders*) Calibration constant derivation	IMP, IMS, IMG, IMM, APS, APP, APG, APM, WSM, GMM, WVI imagette

Table 2.4: Activities required for the verification of the ASAR products

Activity	Products
In-Flight antenna pattern monitoring Rainforest acquisitions Antenna pattern derivation Calibration constant verification	IMP, IMM, APP (2 patterns per product), APM (2 patterns per product), WSM (SS1). Products with no antenna correction
Overall instrument gain determination Calibration pulses analysis External characterisation pulses analysis	All IM, AP, WSM, GMM, WV level 0 products
Stripline analysis Doppler variation within slices Doppler continuity along strips Doppler evolution along the orbit Radiometric continuity between slices	IMM, APM, WSM, GMM, WVI
ScanSAR specific analysis Radiometric normalisation inter-subswath Doppler monitoring across subswaths Beam merging	WSM, GMM
Scalloping analysis	APP, APS, APM, WSM, GMM
InSAR performance analysis 35-days repeat pass interferogram generation	IMS, APS
Wave specific analysis Spectrum peak Centre of gravity Direction and wavelength of spectrum maximum Doppler ambiguity monitoring	WVI, WVS
AP mode specific analysis Cross polarised noise level Intensity imbalance	APP, APS, APM

Table 2.4 (continued): Activities required for the verification of the ASAR products

2.3 Wave Product Validation

Envisat ASAR wave mode L1 and L2 products will be considered during the validation activities. The L1 product is derived from Single Look Complex (SLC) imagettes using the cross spectra methodology. The cross spectra product represents an improvement in the equivalent spectra obtained from ERS. Enhancements are related to the removal of the direction ambiguity and the improvement of the signal-to-disturbance ratio which is in the order of > 20 dB higher. The L2 product is generated from the L1b complex imagette using a new inversion algorithm developed by the ESL and implemented in the operational ASAR processor. The validation activities for the ASAR wave mode products will consist of pre- and post-launch efforts.

2.3.1 Pre-Launch Validation

The objectives of the pre-launch validation are to:

- Establish the necessary calibration strategy for the L2 product,
- Perform a limited geophysical validation of the ASAR wave mode products simulated using ERS data in Wave or Image mode,
- Establish a preliminary setting of the ASAR wave L1b and L2 processing algorithm using ERS data,

- Establish and test the infrastructure for worldwide collocation and acquisition of *in situ* wind and wave data,
- Evaluate availability, format and quality of *in situ* observations,
- Perform a real simulation of the activities to be fully verified during the commissioning phase.

In the pre-launch phase, collocated historical data and new acquisitions of ERS wave and image mode data will be gathered over the *in situ* stations. *In situ* information includes data from buoys, meteorological stations and numerical models. The network of *in situ* stations included buoys in the North Sea, the North Atlantic and along the east and west coasts of North America.

ERS data will be processed to equivalent ASAR products using the ASAR processing algorithm. The products will be analysed and the processor settings will be verified and optimised. The products generated in image mode will be calibrated using ERS transponders. Products generated from the ERS wave mode calibration may also be calibrated using the ASAR transponders.

The ERS acquisitions processed to ASAR L1 products will be collocated with *in situ* wave information which will allow the simulation of the cross spectra. The *in situ* data will consist of directional wave spectra and wind vectors and will be acquired from wave models or directional buoys. Comparisons will be performed between simulated cross spectra from *in situ* observations and ERS SAR-derived cross spectra. Comparing the wave spectral parameters from the product with in situ observations will derive the L1b performance statistics. Preliminary results indicate that the swell system can be detected and the propagation ambiguity is resolved in 80% of the cases.

The ERS acquisitions will be collocated with *in situ* observations and wave models (WAM, HIRLAM). The necessary calibration of the algorithm will be established using part of the collocated dataset (reference dataset). The ERS data will be processed as L2 wave spectra products using the newly developed ASAR inversion algorithm. The wave spectra will be validated against wave model spectra and wave parameters will be compared. Of particular importance are the significant wave height, wave direction and period within the SAR imaging domain. The wind speed and direction will be validated directly against wind information from *in situ* measurements.

2.3.2 Post-Launch Validation

The post-launch activities will consist of:

- Establishing the required calibration parameters for the L2 algorithm using the procedure established as part of the pre-launch cal / val activities.
- Locally, the wind and wave *in situ* data will be used to simulate cross spectra that can be directly compared to the ASAR data product. The wave model will be used to validate the wave spectra obtained from SAR data. The wind speed and direction will be validated directly against wind information from *in situ* measurements.
- Regionally, validation will be performed by comparing wind and wave statistics from ASAR products with model data and independent observations (ECMWF, AO PIs).
- Comparing ASAR wave mode L1 products with equivalent products generated from ERS-2 wave mode (half an hour time difference).

Table 2.5 indicates the products to be validated.

Name	Parameter	Accuracy
ASA_WVW_2P (L2 wave mode product derived using the cross spectra methodology)	Wave mode wave spectra. - Wave height - Wind direction - Wind speed	 - 1 m - 40 degrees - 2.4 m/s
ASA_WVI_1P	Wave mode SLC imagette and cross spectra imagette	N/a
ASA_WVS_1P	Wave mode imagette cross spectra	N/a

Table 2.5: ASAR Wave Mode Data Products

2.4 Development of New Products

A study is ongoing by Politecnico di Milano, Politecnico di Bari, Remote Sensing Laboratories at the University of Zurich and the Swiss company SARMAP. The objective is the development of a prototype processor for the generation of interferometric products from a combination of either:

- ScanSAR raw data (WSM or GMM) and image mode or AP mode SLC images, or
- Image mode raw data and AP mode SLC data.

3 MERIS & AATSR

There is a significant overlap in the requirements for MERIS and AATSR validation. This applies to both the correlative measurements proposed and some of the personnel involved. For these reasons, validation activities relating to MERIS and to AATSR have been combined under the MERIS and AATSR Validation Team (MAVT) although the sensors are described separately in the following sections.

3.1 MERIS

The cal/val of MERIS products consists of the following main components:

- Instrument calibration and L1b processor verification
- Vicarious calibration
- Level 2 algorithm verification
- Water products validation
- Clouds and water vapour products
- Vegetation product and atmospheric corrections over land

The locations of the validation measurements are detailed in table 3.1 and in figure 3.1.

Activity	Location
Radiance Land Measurements	Alpine grasslands, snow and ice fields in Scandinavia, desert sites in Australia, Africa, Mexico and China, and Greenland ice cap
Radiance sea measurements	Baltic, Australian waters, North Sea and voyage measurements
Observations over stable sites	Twenty desert sites in Africa, Northwest Mediterranean, Baltic, Desert sites in Australia, Africa, Mexico, China and Greenland ice cap
Geophysical validation: land	Twenty desert sites in Africa, France and other locations in Northern Europe
Geophysical validation: Case I Waters	Mediterranean, Southwest African coast, Philippines, voyage measurements
Geophysical validation: Case II Waters	Northeast Spanish coast, Baltic Sea, European coasts, Australian coasts, Skagerrak, North Sea, German Bight, West Canada coast, Lake Constance, Arabian Sea

Table 3.1: Location of validation measurements

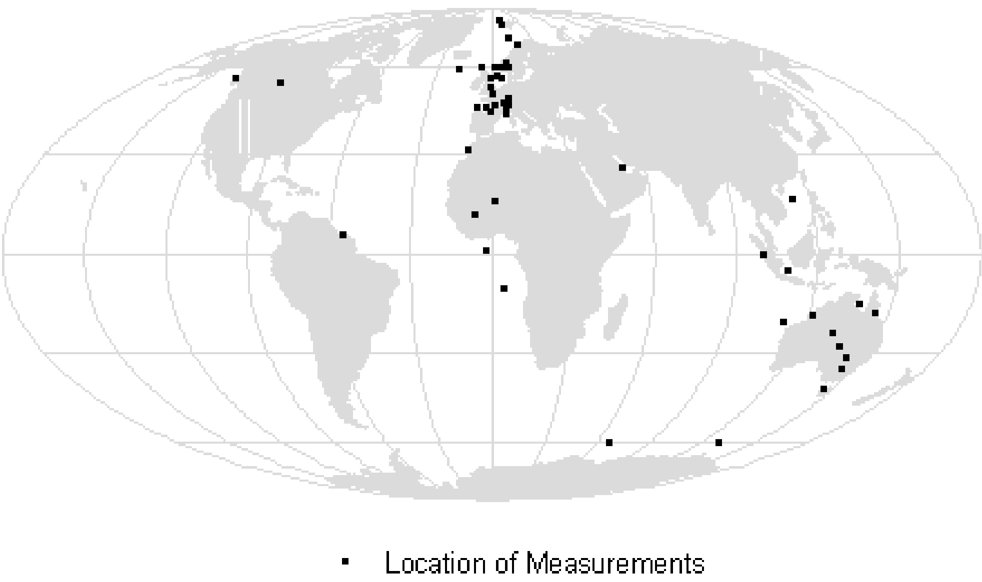

Figure 3.1: Surface locations of MERIS cal/val measurements

3.1.1 Instrument Calibration and Level 1b Processor Verification

The in-flight calibration of MERIS will use the on-board sun-lit calibration diffuser plates. These plates are made of SPECRALON, which offers high reflectance and near-Lambertian diffusion characteristics. The calibration plates have been extensively characterised, using a dedicated bench, to an absolute accuracy of better than 1%. A round-robin exercise (involving NASA) is currently in progress to compare BRDF measurements made at various laboratories.

The diffuser plates have been exposed to post-production processing in order to reduce the degradation (browning) of their scattering characteristics in a space environment. According to on-ground simulations of the space environment, degradation over the mission lifetime will be minimal. However, as a means of verification, degradation of the more frequently used (every 15 days) diffuser-1 will be monitored through comparison with the results from diffuser-2, which will be deployed every 90 days.

Spectral calibration will be performed using an Erbium doped diffuser plate which offers two spectral absorption features, one in the visible part of the spectrum and one in the near infra-red (NIR). Feedback from the vicarious calibration activities (described in section 3.1.2) will be injected into the diffusers' BRDF models in such a way as to guarantee the highest level of accuracy of the MERIS radiance product over the mission lifetime.

The Expert Scientific Laboratory (ESL) team will perform algorithm verification activities. These activities range from consistency verification of the instrument processing parameters (L1b product) to sensitivity analysis of the scientific processing algorithms (L2 product).

The verification of the instrument processing parameters will include the following activities:

- Verification of the instrument pointing characteristics and the removal of overlapping pixels,
- Determination of the harmonic (orbital) variation of the CCD s dark current (offset),
- Determination of the harmonic (orbital) variation of the instrument gain,
- Generation of the preliminary radiometric calibration coefficients,
- Verification of the stray light processing parameters,
- Verification of the instrument s non-linearity response,
- Verification of the instrument s spectrometric characteristics,
- Determination of the fine spectrometric characteristics needed for the processing of the O_2 band (pressure products).

3.1.2 Vicarious Calibration

Validation of Top of the Atmosphere (TOA) radiance measured by MERIS will be achieved by comparison with TOA radiance values determined through the following vicarious calibration methods:

- Simultaneous *in situ* measurements of natural targets (absolute),
- Rayleigh scattering over clear water (absolute),
- Sun glint (relative: inter-bands),
- Stable deserts sites (relative: multi-sensor, multi-temporal, multi-angular),
- Simultaneous acquisition from other sensors, (relative: multi-sensor).

3.1.2.1 Simultaneous in situ measurements of natural targets

The validation activities involve measurements of Bottom of the Atmosphere (BOA) reflectance and of parameters that are needed to convert them to TOA radiances. These vicarious calibrations use either reflectance- or radiance- based methods for the acquisition of surface parameters. In the case of reflectance calibration, spectroradiometers use a sun-lit target of known reflectance as a calibration source, whereas for radiance calibration, an airborne measurement is made using a laboratory-calibrated radiance source. Sun photometers are used for all atmospheric correction activities and are usually complemented by other sensors.

During intensive campaigns, radiance or reflectance will be observed *in situ* at the time of the satellite overpass, and also atmospheric correction parameters will be measured with the closest possible collocation in time and space. The surface measurements will often be complemented by near-TOA observations from airborne instruments. These measurements will alleviate the problem of resolution differences by acquiring data on a scale intermediate to ground-based point measurements and the extended ground coverage of MERIS pixels. In addition, the accuracy of the derived TOA reflectance will be less sensitive to inaccuracies in the atmospheric correction parameters. Campaigns over the sea will include upwelling radiance and downwelling irradiance (by in- and/or above- water radiometers) and aerosol optical thickness measurements.

A set of airborne spectrometers will be used to validate the reflectance and radiance products. Sensors include a radiance spectroradiometer, OVID (Optical Visible and near Infra-red Detector), and CASI (Compact Airborne Spectrographic Imager), which can be programmed with band settings to match those of MERIS.

3.1.2.2 Rayleigh scattering over clear water

Calibration using the Rayleigh scattering method is based on radiative transfer simulations of molecular scattering in the atmosphere over oligotrophic (clear) waters. This signal is bright in the visible part of the spectrum (up to 665 nm) and fairly uniform across the swath of MERIS. The radiative transfer models that will be used to compute the TOA signal will be validated with those used to generate the MERIS L2 look-up tables (LUTs). The following pixel selection criteria will be applied:

- Oligotrophic (clear) waters (area > 500 x 500 km),
- Cloud free (> 30 km from clouds),
- Low aerosol load (TOA reflectance (865 nm) — Rayleigh reflectance (865 nm) < 0.003),
- No white caps (Wind speed < 5 m/s).

The accuracy of this method is approximately 2% and may be subject to the following error sources:

- Aerosol type and load: clear sky scenes have to be identified and the residual aerosol load included in the radiative transfer simulations.
- Marine reflectance: oligotrophic waters have to be identified and the marine signal included in the radiative transfer simulations.
- Sun glint and white caps: areas including sun glint and experiencing high winds (> 5 m/s) have to be discarded for the validation exercise. Geometric considerations will be addressed for the sun glint, and wind analysis fields from ECMWF used for white cap identification.
- Atmospheric absorption: the radiative transfer simulations will include corrections for atmospheric absorption. These will be computed using atmospheric analysis fields from ECMWF, such as total column ozone.
- Atmospheric pressure: the local mean sea level pressure field from ECMWF will be used to compute the TOA Rayleigh signal.

The biggest error source is the marine signal. Sites have been selected which include *in situ* measurements of the marine signal (the DYFAMED site). This will improve the quality of the results generated over this site.

3.1.2.3 Inter-band calibration using sun glint targets

In order to extend the absolute calibration obtained by the Rayleigh method to the NIR (665 nm – 1040 nm), sun glint targets will be used. Although the sun glint signal varies significantly due to the height of ocean waves, the spectral signature of the signal is very stable. The inter-band calibration method using sun glint is based on radiative transfer simulations of the specular reflection of the sun over oligotrophic (clear) waters. As in the case of the Rayleigh method, the radiative transfer models that will be used to compute the TOA signal will be validated with those used to generate the MERIS L2 LUTs.

The sun glint signal is bright over the MERIS spectral range (390 nm – 1040 nm) but is limited to a view angle that lies within 8° of the sun's specular direction. The pixel selection criteria will be identical to that used in the Rayleigh method complemented by the geometric consideration mentioned above and a glitter reflectance of over 15%. The accuracy of the inter-band method (560 nm – 865 nm) is approximately 1% when iterations with the results from the Rayleigh method are included in the determination of the sun glint signal.

3.1.2.4 Stable desert sites

A number of desert sites with stable and known surface characteristics have been selected for long-term routine comparisons. The BRDF of these sites have been initially characterised using field equipment and complemented by the use of bidirectional TOA measurements from other sensors. Due to the stability of these sites, the temporal collocation requirement for inter-comparison is relaxed. This means that after initial surface characterisation (ongoing since 1987), only atmospheric characterisation is needed to compare successive TOA radiance measurements of these sites.

Measurements from a number of sensors over the stable sites are being assimilated into a host database structure co-ordinated by CNES-QTS. This will allow for the comparison of TOA radiances from all these sensors. CNES-QTS has been using this method for a long time (for SPOT since 1987) and has used it extensively for the calibration of POLDER and VEGETATION. It has now been extended for AVHRR and for SeaWiFS and will also include MERIS, AATSR, ATSR-2, MODIS, MISR, METEOSAT and MSG.

3.1.2.5 Simultaneous acquisition from other sensors

Observations from other satellite sensors will be used for campaigns and routine measurements. In general, collocation and simultaneity are required. However, over stable sites this requirement can be relaxed as intercalibration between sensors becomes possible. Such activities will be carried out for both land (desert sites) and sea (open ocean) targets.

A special case is calibration using specific cloud targets that have predictable spectral properties. This activity involves the intercalibration of AATSR and MERIS using tropical convection clouds, and absolute calibration using Arctic stratus clouds, which are flat and have homogeneous and predictable properties. Direct inter-comparison of TOA radiances derived from MERIS and from other sensors over stable sites (reducing the simultaneity requirement) will also be performed.

3.1.3 L2 Algorithm Verification

Sensitivity analyses of the scientific processing algorithms will include tests for all L2 products and will include the following activities:

- Verification (and threshold tuning if needed) of surface classification flags,
- Verification (and threshold tuning if needed) of Product Confidence Data (PCD) flags,
- Testing of all the MERIS geophysical products.

Testing of the scientific processing algorithms does not constitute a validation of the actual geophysical product. The acceptance criteria will be limited to the following:

- The algorithm s surface classification step works accurately,
- The processing generates product values within the expected range (e.g. pigment index between 0.01 and 30 mg/m^3 or water vapour between 0 and 70 kg/m^2),
- The processing generates product values which are qualitatively in accordance with expected geophysical values,
- The processing generates images which have no visual artefacts (e.g. tiling or stripes) neither in the L1b nor the L2 product,
- The processing generates few or no PCD flags.

3.1.4 Water Products Validation

Proposals to validate MERIS ocean colour products for Case I waters involve the installation of optical buoys, *in situ* data collection during research cruises, and instrumentation on board third party vessels. Data acquisition will include:

- Water-leaving radiances and downwelling irradiances in visible and infra-red channels,
- Concentrations and inherent optical properties (absorption and volume scattering function) of chlorophyll,
- Suspended particulate matter and yellow substance concentrations,
- Aerosol optical thickness and type.

The techniques for the validation of MERIS ocean colour products for Case II waters have much in common with those used to validate equivalent products for Case I waters. They include the use of optical buoys, *in situ* sampling and participation on research cruises.

Measurement protocols largely based on SeaWiFS protocols but tailored to MERIS specifications, have been defined and distributed to the different validation teams to ensure consistency in the quality of measurements acquired throughout the validation exercise. These protocols also describe how the basic radiometric *in situ* measurements of water-leaving radiance and downwelling irradiance, generally taken in the vertical direction, can be converted to a comparative MERIS radiometric product, i.e. directional water-leaving reflectance.

Just before the start of the cal/val campaigns an inter-calibration exercise for practically all radiometric instruments to be used will be organised by the UK Plymouth Marine Laboratory to enforce consistency of radiometric measurements. This opportunity will also be used for the comparison of measurement techniques for ocean pigments.

Aerosol optical thickness and type will be measured at sea on-board merchant and research ships through the use of the SIMBAD radiometer, which has been used extensively for the cal/val of POLDER and SeaWiFS. The SIMBAD radiometer will also provide measurements of water-leaving radiance, which will be converted to water-leaving reflectance using knowledge of the aerosols. For a few coastal areas, the aerosol properties will be determined from the CIMEL stations which make up the AERONET network and which are used in the validation of POLDER and MODIS.

Case I water pigment concentrations and water-leaving reflectances will be monitored from two deep-sea moorings in the Mediterranean Sea. One buoy will be located at the DYFAMED site (43.25° N, 7.52° E), which is positioned at the centre of a permanent cyclonic circulation and thus horizontal advection is negligible there. Stable oligotrophic conditions appropriate for cal/val prevail there during winter and summer, yet there is a distinct bloom in the spring and, to a lesser extent, in the autumn. The other buoy will be located above the Blanes canyon, close to the coast of Catalonia. This site is in a region where cloud-free conditions prevail and where sea-surface colour, temperature and the sea level exhibit significant variability at seasonal and shorter frequencies. Thus, a large range of measurement conditions will be available.

Also relevant to the validation of open ocean products is the Atlantic Meridianal Transect (AMT) project, which is focused on EO research over the Atlantic Ocean, spanning 52° N to 52° S. The AMT project, which is managed by the UK Plymouth Marine Laboratory, has been extended and will run from 1999 to 2004. An AMT cruise will take place from the UK to the Falkland Islands from September to October 2001 and/or during the spring of 2002. The cruise will provide correlative measurements of the spectral water-leaving radiance and downwelling irradiance for the eight MERIS visible wavebands and the derived products for Case I open oceanic waters. The specific objectives will be to measure the water-leaving radiance and reflectance to better than 1 % absolute accuracy, and phytoplankton pigments to better than 30 % accuracy. The schedule of activities will follow the procedures established on recent AMT cruises, with two data gathering events daily, one before noon, which will be timed to coincide with the overpass of MERIS, and a second in mid-afternoon. At each station optical measurements will be made and samples of seawater will be collected from the surface down to 2 optical depths (a depth lying approximately between 10 and 30 m). The water samples will then be filtered and analysed for phytoplankton pigments. In accordance with MERIS requirements, atmospheric measurements (to determine aerosol optical thickness) and surface radiometric measurements will also be acquired.
The retrieval of the in-water composition of coastal case II waters (in terms of concentrations of suspended particulate matter, yellow substance and chlorophyll) will be carried out through:

- Dedicated campaigns in various European coastal waters (good spatial sampling, poor temporal sampling),
- Permanent monitoring at few dedicated fixed sites (poor spatial sampling, good temporal sampling),
- Satellite intercomparison.

3.1.4.1 Dedicated campaigns within case II waters

Case II water properties will be monitored from ships and buoys in the Baltic Sea, the North Sea, and also in Lake Constance (inland water). Using a package of *in situ* optical profilers deployed from a helicopter (a technique perfected during the COASTLOOC EC project), optical field measurements will be carried out during or close to MERIS overpasses. The concentrations of phytoplankton pigment, total suspended particulate matter, and gelbstoff will additionally be determined from water samples collected over an extensive sampling grid that covers most of Europe (1500 sites).

Complementary campaigns will cover the waters of the Skagerrak where the optical constituents vary considerably in space and time and are significantly different from typical values measured in the German Bight and the Baltic Sea. An important question is how the optical properties change along the coast from the English Channel into the North Sea, including the German Bight, and finally into the Skagerrak where North Sea water and the Jutland Current mix with Baltic water before they become part of the Norwegian coastal current. Particular emphasis will be placed upon the analysis of the relationship between the inherent optical properties and the water constituents (chlorophyll-a, phaeopigment, organic and inorganic suspended particulate matter) at regular intervals for a number of locations. The objective is to determine the geographical and temporal variability of this relationship, e.g. in response to the seasonal variability of phytoplankton composition or the spatial variability of inorganic suspended particle size.

Using measurements of the inherent optical properties and concentrations it will be ascertained whether the optical parameters used in the water reference model for the development of the MERIS processing algorithms match with the environmental conditions derived from the *in situ* observations. Measurements of water-leaving radiance, downwelling irradiance, and sky and sun radiances will also be used to test the atmospheric correction over turbid Case II waters and to identify alternative processing schemes if deemed necessary.

3.1.4.2 Permanent monitoring within case II waters

This will involve extensive measurements of ocean colour from three selected areas of the coastal shelf: the Adriatic Sea, the English Channel and the North Sea. All sites are equipped with identical instrument packages, special attention being paid to calibration and inter-calibration to ensure compatibility of measurements from the different sites. The acquired data will be processed to derive biophysical and geophysical marine and atmospheric parameters, which will be available for comparison with equivalent MERIS products.

3.1.4.3 Satellite intercomparison

Quantitative comparison of MERIS data with other satellite sensors, e.g. SeaWiFS, MODIS and POLDER-2, will be carried out taking into account differences in sensor characteristics and processing algorithms, as well as spatial and temporal coverage. Airborne multi-spectral sensors such as CASI, configured to match MERIS wavebands, will also be deployed.

3.1.5 Clouds & Water Vapour Products

Water vapour and cloud features are key parameters for weather prediction and climate studies. The radiation balance of the earth / atmosphere system is significantly altered by both water vapour and clouds. MERIS will provide information on:

- Cloud optical thickness and cloud albedo,
- Cloud top pressure,
- Water vapour content over land and ocean.

3.1.5.1 Cloud optical thickness and cloud albedo

The accuracy of the operational retrieval algorithm is in the order of 0.01 for cloud albedo and of 3 - 5 for cloud optical thickness. The validation of cloud albedo and cloud optical thickness will mainly rely on aircraft campaigns.

Aircraft observations will help to validate the retrieval procedures and to estimate the accuracy. Backscattered radiation is measured from an aircraft flying above the cloud whilst cloud microphysical properties are measured *in situ* from an in-cloud operation aircraft. An in-cloud flying aircraft is additionally required for the observation of the vertical structure of the clouds (cloud base and cloud top height, number of decoupled layers). For cal/val purposes it is necessary to conduct the campaign for cloudy conditions over both water surfaces (well defined surface albedo) and land surfaces, where ground-truth measurements of the surface albedo are required. The Institut für Weltraumwissenschaften operates a high spectral resolution spectrometer OVID (Optical Visible and near Infra-red Detector) and a CASI (Compact Airborne Spectrographic Imager) which can be configured to the same spectral band characteristics as MERIS.

In situ measurements of cloud droplet sizes and concentrations are an important component in the calibration strategy. They provide detailed information about the microphysical and geometrical structure of clouds. The cloud optical thickness can be calculated directly from microphysical quantities for different types of clouds such as stratocumulus and stratus. These kinds of measurements are the only independent comparison possible for MERIS-derived cloud optical properties.

3.1.5.2 Cloud Top Pressure

The cloud top pressure retrieval accuracy is dependent upon the penetration depth of solar radiation into the cloud, the transparency of thin clouds within the oxygen and reference channels, and the spectral slope of the underlying surface. Two dedicated coincident flight missions will take place to compare MERIS data with CASI and OVID measurements in northern Germany. The comparison of cloud top temperatures of thin clouds, retrieved from AATSR measurements, with cloud top pressures retrieved from MERIS, together with pressure and temperature profiles from radiosoundings, will be applied to estimate the accuracy of the retrieval of optically thin clouds as well as to estimate the impact of the surface albedo slope. SCHIAMACHY measurements will be used to estimate the spectral location of MERIS channels.

3.1.5.3 Water Vapour

Water vapour content will be derived from MERIS data over ocean and over land. The accuracy of the retrieval algorithms with respect to transfer simulations is in the order of 1.6 kg/m^2 over land and about 2.5 kg/m^2 over water surfaces. The accuracy of the retrieval will be ascertained through comparison with collocated radiosoundings, GPS, MWR and Lidar estimates. Over water surfaces, the use of the nadir-looking MWR will allow for completely collocated accurate retrievals of the columnar water vapour path. Global comparison with assimilation models (generated by ECMWF) will be performed.

3.1.6 Vegetation Product & Atmospheric Corrections over Land

The land product validation activities for MERIS will focus only on a vegetation index (the MERIS Global Vegetation Index, MGVI), the only L2 land product to be generated from MERIS data.

The use of satellite data from, amongst others, POLDER and MODIS, will be used to validate the MGVI products from MERIS. This activity will be closely related to the validation of MERIS radiances. More specific validation work will involve the development of retrieval models for vegetation biophysical variables using MERIS and AATSR data. These results will be tested against available algorithms. Reference sites where biophysical variables can be acquired at ground level, such as the AERONET sites, will also be used for the validation. Data from the EU CORINE land use database will also be utilised for the validation of the MGVI.

A variety of ground-based methods will be used to provide correlative measurements related to atmospheric parameters. Instruments comprising the AERONET network will provide aerosol measurements. This programme is supported by CNES, NASA and NASDA and relies on automatic sun and sky scanning spectral radiometers, which enable frequent measurements of atmospheric aerosol optical properties and precipitable water from remote sites. CIMEL instruments will also provide information for the validation of the cloud optical thickness product by measuring the downwelling radiance. Where conditions are cloud-free, CIMEL will provide aerosol measurements of size, distribution, phase function and optical thickness. The intercomparison of MERIS water vapour retrievals over land and water will be achieved through the use of collocated radiosoundings, analysis of GPS measurements, microwave radiometers and Lidar estimates.

3.2 AATSR

The overall aim of the AATSR commissioning phase is to demonstrate that the instrument meets key, verifiable performance requirements, and to optimise the subsystems to ensure that the scientific data is of the highest quality. Additional aims will be to optimise the AATSR data processing system and to refine the flight operations support interfaces and procedures. Full details of the activities that will be undertaken can be found in the "AATSR Commissioning Plan" (PO-PL-RAL-AT-0501).

3.2.1 Calibration

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 vicarious calibration of the visible channels, where visible channel data from AATSR are compared with data from other instruments, can be classified as either calibration or validation. Within the AATSR validation programme, vicarious cal/val is treated under the title of validation.

An algorithm verification exercise will be undertaken to 'commission' the AATSR processor and to ensure that the processing chain is performing as intended according to the specifications it was developed against prior to the detailed scientific product validation. To exercise the processor using real AATSR data, a subset of the unit, system and acceptance tests defined for the prototype processor will be repeated. The tests will focus on key stages of the processing such as telemetry unpacking, derivation of calibration parameters, geolocation and re-gridding, land flagging, cloud clearing, spatial averaging of brightness temperatures / reflectance, calculation of sea surface temperatures and normalized difference vegetation index values, and the formatting of output products.

Algorithm verification also includes the task of analysing, tuning and regenerating all the auxiliary files used with the processor. This will be done as a separate, but parallel, task as part of the AATSR prototype processor post-launch operation and maintenance activities.
Also as part of this activity, consideration will be given to the use of existing data from other instruments and satellites to test the processor before launch. Any requirements for specific instrument commanding during the commissioning phase (e.g. over specific geophysical targets, over a particular land / sea boundary, or operating the instrument in low gain mode) will also be examined.

3.2.2 Validation

The AATSR validation programme has two strands to it:

- A core validation programme, and
- An external validation programme conducted by the scientific user-community.

The core validation programme consists of validation activities that are considered essential for the validation of AATSR data products, and includes a combination of AO and non-AO proposals. The external validation programme represents activities that will be conducted by the wider scientific community throughout the lifetime of the mission. Table 3.2 details the AATSR data products; data will be produced at three levels (0, 1b and 2). Validation covers the L1b and L2 products.

Level	Product
0	Instrument Source Packet
1b	Gridded Brightness Temperature/Reflectance, GBTR Browse
2	Spatially Averaged Surface Temperature, AST Gridded Surface Temperature, GST

Table 3.2: Levels of AATSR data products

In addition to the products listed in Table 3.2, other products are also being developed. These include a land surface temperature product. Validation for additional products will take place after the commissioning phase and do not form part of the core programme. Documents providing a more detailed description of validation activities can be found on the AATSR website http://www.le.ac.uk/physics/research/eos/aatsr/.

3.2.2.1 The Core Validation Programme

The core programme will be composed of an initial and an ongoing validation of the instrument. The AATSR products to be validated are shown in Table 3.3.

Name	Parameter	Accuracy	Coverage	Resolution
ATS_NR_2P Distributed product for land and ocean	Gridded sea surface temperature	<0.3 K	512km x 40000km	1km x 1km
ATS_AR_2P Averaged TOA brightness temperature for different land and sea cells at four geometric resolutions, cloud top temperature	Spatially averaged sea surface temperature	<0.1 K	512km x 40000km	4 resolutions in parallel: 50km x 50km, 17km x 17km, 30 x 30 minute of arc cells, 10 x 10 minute of arc cells

Table 3.3: AATSR L2 Data Products

The initial core validation will be completed within the commissioning period of the AATSR instrument i.e. in the first six months after launch. The aims of the initial core validation are:

- 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 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).

A routine core validation programme should be ongoing for the duration of the AATSR mission. Its aims are:

- To make detailed assessments of the quality of the AATSR SST data products in an increasing number of sites and seasons.
- To monitor the quality of the AATSR data products over the duration of the mission (e.g. to investigate the success of the SST retrievals in periods of high aerosol contamination following a volcanic eruption). This is essential for ensuring continuity of the climate record.
- To monitor changes in the calibration of the short-wave channels and, in particular, the 1.6 µm channel.

For both initial and ongoing validation, the core programme has two main strands to it:

1. Validation of sea surface temperature,
2. Validation of land surface reflectance / temperature.

1. Sea Surface Temperature

Validation of sea surface temperature (SST) involves measurements of high accuracy, moderate accuracy and more general measurements. The core validation activities for SST are thus 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.
-

Broad Scale

SSTs from AATSR will be compared with SST analysis fields and with *in situ* buoy data. This will be done on a routine basis by the U.K. Meteorological Office / Hadley Centre, and should enable gross errors in spatially averaged SST to be recognised very quickly. Validation by this method means data is compared on a global scale. This will be invaluable, particularly in areas where manual measurements are difficult to make or are unavailable.

Moderate Scale

Moderate accuracy autonomous measurements will be acquired from ships of opportunity. By using autonomous instrumentation, a good coverage can be made at relatively low cost. Spot values will be collected for comparison with the gridded data. As the instruments are not manned, values will be of a moderate accuracy, but there will be good coverage. Two examples of autonomous instruments are the Infra-red Sea surface skin temperature Autonomous Radiometer (ISAR; designed and developed by C. Donlon), and the scanning TASCO radiometer (developed by F. Prata at CSIRO Atmospheric Research in Australia). The TASCO is housed on-board the Rottnest Island Ferry operating off the coast of Perth, Western Australia.

High Accuracy

Measurements of high accuracy using precision instruments provide fewer validation points. However, the measurements collected are of very high accuracy and will have been acquired by a highly trained scientific operator who can observe atmospheric conditions and make sure the instrument is functioning correctly. Precision instrumentation to be employed includes the SISTeR (designed by T. Nightingale at RAL), a M-AERI (Marine Atmosphere Emitted Radiance Interferometer), and the DAR011 radiometer (developed at CSIRO), which is deployed on research ships of opportunity from Hobart.

2. Land Surface Reflectance / Temperature

The core validation activities for land surface temperature / reflectance are summarised into two types of validation:

- Vicarious - comparison of reflectance values with data from other sensors,
- Field campaigns and the collection of ground-based measurements - specific or 'piggyback' campaigns.

Vicarious Validation

Vicarious validation for AATSR will be carried out in a similar way to the MERIS programme. Top of the atmosphere (TOA) radiances from AATSR and MERIS will be compared to TOA measurements from similar sensors, for a range of stable sites. Continuing work in monitoring stable sites using ATSR and ATSR-2, radiances from AATSR will be compared to those derived from the previous ATSR sensors. Comparisons with radiances from other sensors such as MERIS, SCIAMACHY and AVHRR and from VEGETATION will also be made. Stable sites include the Libyan Desert, Algerian Desert, Dunhuang Desert in China, Sonora Desert in Mexico and three sites in Australia (Thangoo, Amburla and Hay).

Field campaigns and the collection of ground-based measurements

In addition to comparison with data from similar sensors, some ground-based measurements are needed. Extensive field campaigns, collecting data for validation will be carried out in Australia. These use the DAR011 radiometer and sites in Uardy (Hay plains, New South Wales), Amburla (Tanami Desert, Northern Territory) and Thangoo.

3.2.2.2 Additional validation activities

Additional validation activities involving AATSR data will provide useful additional information into the validation process, but will not contribute directly to the core validation programme. Such activities include the further investigation of:

- SSTs using *in situ* ship and buoy data,
- Atmospheric parameters including atmospheric aerosols and aerosol opacity,
- Land surface temperature and bidirectional reflectance,
- Cloud optical thickness, cloud albedo and reflectance using cloud targets.

4 Atmospheric Chemistry Instrumentation

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 will also be included. It will be important to ensure that correlative measurements are collocated with the Envisat products being validated. Given the dynamic nature of the atmosphere, 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 data products from GOMOS, MIPAS and SCIAMACHY to be validated are shown in Table 4.1. In addition, each sensor provides a L2 Meteorological Product which is a subset of these products and does not require specific validation activities. For details of the specification and validation of off-line SCIAMACHY products, the reader is referred to the SCIAMACHY Validation Document (SVDS-01 January 1998).

	GOMOS		**MIPAS**		**SCIAMACHY**	
Data product	GOM_NL_2P		MIP_NL_2P		SCI_NL_2P	
Description	Atmospheric constituent profiles		Profiles of pressure, temperature and primary trace gases		Integrated column amounts of various trace gasses	
Parameter	**Precision**	**Accuracy**	**Precision**	**Accuracy**	**Precision**	**Accuracy**
P			2 %	2 %		
T	1 K	2 K	1 K	2 K		
O_3	0.2 – 1%	1 – 2 %	1 %	5 %	1 %	4 %
H_2O	TBD	TBD	5 %	5 – 10 %	1 %	5 %
NO_2	5 – 20 %	5 – 20 %			2 %	23 %
N_2O			10 %	20 %	5 %	10 %
NO_3	5 – 20 %	5 – 20 %	TBD	TBD		
HNO_3			4 %	5 – 20 %		
OClO					5 %	15 %
BrO					5 %	10 %
H_2CO					20 %	37 %
CO					5 %	5 %
CH_4			5 %	8 %	1 %	3 %
SO_2					10 %	30 %
Cloud					Cover fraction, Top height	
Aerosol	10 – 40 %	10- 40 %			Absorption Index	

Table 4.1: NRT L2 Data Products from GOMOS, MIPAS and SCIAMACHY

Precisions and accuracies obtainable by GOMOS depend strongly on the star that is observed in occultation, in particular on its intensity and temperature. Two values are therefore presented in table 4.1, the first representing values related to Sirius, the second to a star with magnitude 2.0. SCIAMACHY accuracy and precision values shown in table 4.1 for OClO are valid for observations in the polar vortex region; H_2CO values are relevant to the tropical background concentrations. When observing higher concentrations (biomass burning) accuracies of 22 % are expected to be achievable. Similarly, the SO_2 accuracy values shown in table 4.1 are representative of tropospheric pollution concentrations. When observing higher concentrations (from volcanoes) an accuracy of 20% should be achievable. The routine production of profiles of gas species will be a feature of Envisat operations. As an example, figure 4.1 shows an ozone product derived from the GOME instrument.

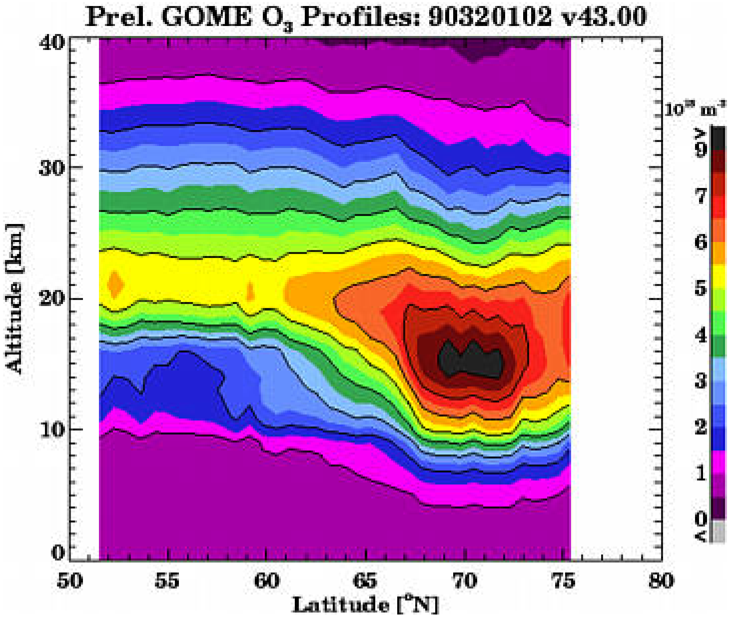

Figure 4.1: Ozone profile derived from GOME data (Acknowledgment IFE Bremen)

Fundamental components of the atmospheric chemistry algorithm verification activities are the in-flight instrument and retrieval characterisation carried out during initial commissioning. Related to this work is the tuning of variables in the Envisat processing algorithms following early analyses of data from individual sensors. Other work will include the specific validation of aspects of data processing, such as the polarisation-checking algorithm, which will use the Sun as a source of unpolarised light.

The cal/val activities relating to the atmospheric chemistry instruments are organised into:

- Three instrument-specific subgroups for the verification of each of the processors (L1b and L2):
- MIPAS,
- GOMOS,
- SCIAMACHY.
- Four subgroups (which are non-instrument specific) that will perform associated validation activities. These groups will use a combination of different techniques to validate the instruments on both global and single point scales. The subgroups are divided into:
- Balloon and aircraft campaigns,
- Model assimilation,
- Satellite intercomparison,
- Campaign database and ground-based measurements.

4.1 MIPAS

MIPAS will routinely sense upper tropospheric and stratospheric limb emissions and provide global data on a number of essential geophysical parameters, primarily vertical temperature, pressure profiles and the volume-mixing ratio (VMR) of the target species O_3, H_2O, CH_4, N_2O, NO_2 and HNO_3. To meet the envisaged performance of the instrument and its on-ground processing chain, a number of specific characterisation and calibration measurements and related analyses are planned. These will support the update of critical on-board control parameters and allow the optimisation of auxiliary input data required by the L1b and L2 algorithm components.

During the early in-orbit operation of MIPAS, the sensor will undergo a number of checks and calibration measurements. Analyses of these will allow the verification of the basic functionalities of the instrument and on-ground software components, and will assess essential performance parameters. The latter include, in particular, noise equivalent spectral radiance (NESR), radiometric accuracy, systematic line-of-sight (LOS) mispointing, and the instrument lineshape (ILS). The initial work will result in optimised instrument configuration parameters, especially the tables controlling signal processing and LOS pointing, and in the definition of enhanced settings for periodic calibration measurements.

Further analyses will include the identification and correction of potential inconsistencies in the L0 to L1b algorithm components as well as the generation of a fully revised set of auxiliary data. Finally, the overall performance of the L1b processing stage will be assessed and total error budgets of primary L1b results, including both instrument and algorithm induced error sources, will be compiled.

The L2-related analyses in principle rely on the availability of fully, i.e. radiometrically and spectrally, calibrated limb radiances and related characterisation data. However, a number of specific L2 tasks can be performed at an early stage before finalising the L1b-related validation work. Such work will include, for example, the tuning of critical settings of the inversion algorithm, the updating of auxiliary databases, and the compilation of preliminary performance / error budgets, to support preparation and analysis of correlative measurements.

The envisaged MIPAS activities can be grouped according to:

- Initial performance verification and update of instrument configuration & calibration,
- L1b algorithm characterisation & verification,
- L2-related characterisation & verification,
- Geophysical validation by comparison with non-Envisat correlative data.
-
- Figure 4.2 illustrates the essential steps of the initial MIPAS cal/val and lists the basic tasks according to the above classification.
-

Specific calibration activities will include:

- Characterisation & optimisation of the primary instrument parameters (analog & digital signal processing),
- (Re-) characterisation of detector non-linearity and verification of the on-ground correction scheme,
- Analysis of the radiometric gain / offset calibration algorithm,
- Verification of spectral axis calibration & ILS retrieval algorithm,
- Routine generation and maintenance of L1b-related auxiliary data bases,
- NESR and radiometric accuracy verification,
- Characterisation of systematic LOS mispointing (bias & orbit harmonics),
- Generation of template data for L1b-related validation functions,
- Initialisation of long-term performance monitoring functions.

Specific validation activities will include:

- Generation of intermediate L2 processing results for use in analyses,
- Characterisation of the overall L2 algorithm performance through analysis of specific quality parameters from L2 products,
- Enhancement of L2 processing parameters through iterative tuning of algorithm sub-components,
- Acquisition and re-formatting of L2-related auxiliary data bases,
- Verification of overall consistency of auxiliary data bases, taking into account interdependencies,
- Initialisation of long-term performance monitoring and validation functions.
-

Whereas specific analysis tasks will be carried out by the individual cal/val team members, a number of essential activities will be performed by the ESA operated Instrument Engineering Calibration Facility (IECF) and will make use of the various facilities and software tools available at the involved institutes. These so-called ‘core’ tasks comprise of:

- Acquisition and processing of instrument data for dedicated, non-standard characterisation measurements,
- In-flight (re-) characterisation of essential performance parameters and update of instrument settings,
- Generation of specific intermediate results for use in off-site analyses by the ESL or AO project teams,
- Processing of calibration data for use by the Instrument Processing Facility (IPF) / Level 1b component,

- Routine monitoring & analysis of key quality parameters generated by the MIPAS IPF,
- Acquisition and verification of auxiliary databases generated by the ESL or AO teams.
-

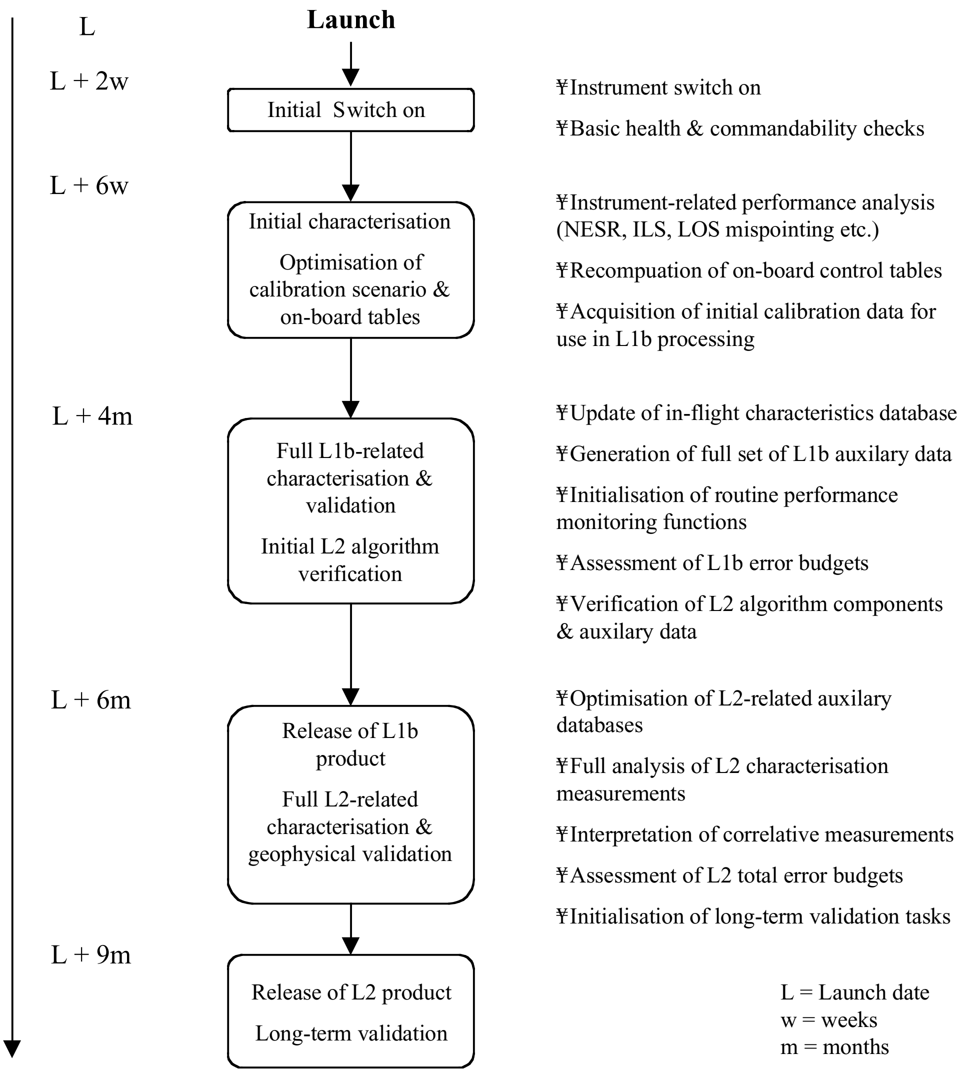

Figure 4.2: MIPAS cal/val activities and timeline

4.2 GOMOS

The GOMOS operating principle relies on the occultation method. A star outside the atmosphere is identified (thus providing a reference stellar spectrum) and tracked as it sets through the atmosphere (thus providing spectra with absorption features). When these occulted spectra are divided by the reference spectrum, nearly calibration-free horizontal transmission spectra are obtained, assuming the instrument response function does not change during one occultation, and this typically lasts 30 to 40 seconds. These transmissions provide the basis for retrieval of atmospheric constituent density profiles and benefit from the fact that observing the star light confines the measurement to a "thin" well defined volume.

An overview of the GOMOS cal/val activities, including its interfaces with external entities, top-level data flow, and global timeline, is provided in figure 4.3.

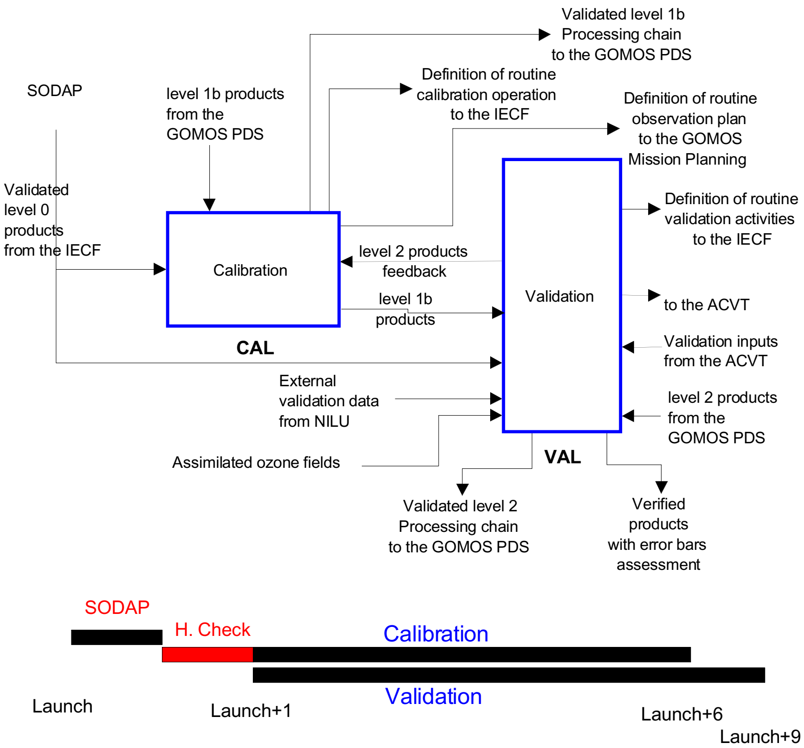

Figure 4.3: GOMOS cal/val top-level organisation and timeline

4.2.1 Calibration

The objective of the GOMOS calibration activities is to achieve, at the end of the commissioning phase, a complete GOMOS calibration, including:

- Full in-flight calibration and re-characterisation of GOMOS,
- Complete verification of the L1b processor (tuning of all parameters, regeneration of all L1b auxiliary products),
- Upgrade of the L1b processor,
- Definition of the routine calibration operations (to start at the end of the commissioning phase for the whole duration of the mission),
- Definition of a routine observation plan.

In order to achieve its objectives, the calibration activities have been split into four main tasks:

- Verification of the instrument health,
- Derivation of GOMOS instrument characteristics,
- Derivation of validated and tuned L1b chain,
- L1b products verification.

The instrument signal level (thermistor temperature, dark charge level, SFA angles, SATU data, star spectra shape, limb level) will be analysed and the band setting reassessed. This will verify the location of the star spectra on the CCD and enable the validation or redefinition of the spatial bands for the observations in occultation and linearity modes. A first evaluation of the stability of the dark charge versus time and spacecraft latitude will also be provided.

The study of the internal stray light level, the dark charge variation along the orbit, the effect of band setting, the effect of SFA angles and the polarisation on the recorded signal will be evaluated.

The primary objective of this task is to reassess the instrument parameters and to validate (including possible updates) the two auxiliary products, Instrument physical characteristics (GOM_INS__P) and Instrument calibration (GOM_CAL__P). Calibration and monitoring of GOMOS parameters such as electronic gain chain, read-out noise and offset, non-linearity, dark charge, pixel response non-uniformity, radiometric sensitivity, spectral line spread function, wavelength assignment, vignetting, and stray light will be performed.

The main L1b product of GOMOS is geolocated and spectrally calibrated transmission absorption spectra. Prior to calculating the transmission, the individual spectra will be corrected for saturation, cosmic rays, dark charge, detector response variation, offsets and non-linearity. The spectra will furthermore be spectrally shifted using the tracking unit pointing shift data. The precise geolocation of the transmission spectra will be computed using the satellite and star positions and a ray-tracing model through the atmosphere characterised using ECMWF data combined with a climatological model above the ECMWF upper pressure level.

The first task of the L1b processing check activity will be to ensure the internal correctness of the above processing steps, and to verify that the processor operates as expected according to the configuration options. As soon as the L1b chain is verified at module level, the parameters of the L1b processing chain will be tuned in order to confirm or identify the new operational configuration. The auxiliary L1b processing configuration product (GOM_PR1__P) will be updated.

A specific activity dedicated to the validation of the two L1b products will start as soon as the L1b chain is verified at module level. The geolocated calibrated transmission spectra and photometer fluxes (GOM_TRA_1P) and the geolocated calibrated background spectra (GOM_LIM_1P) products will be validated. The analyses of the products will also provide recommendations for the routine observation plan.

4.2.2 Validation

A preliminary GOMOS validation will have been carried out on the basis of GOMOS data and preliminary results of some validation campaigns by the time the validation workshop takes place (9 months after launch). This will include:

- Verification of the L2 processor (tuning of all processing parameters, first regeneration of all L2 auxiliary products),
- Consistent geophysical products (at the end of commissioning phase),
- Upgrade of the L2 processor,
- Error bars will be attached to the products (by the Validation Workshop),
- Definition of routine validation activities.

In order to achieve these objectives, the validation activities have been split into three main tasks:

- Verification of the L2 processor,
- L2 products verification,
- L2 products validation.

The L2 processor is verified through a series of processing steps. The transmission spectra, which come from the GOMOS L1b product, are first corrected for dilution and scintillation effects. The remaining transmission can then be connected to the atmospheric constituent densities (O_3, NO_2, NO_3, aerosols, Rayleigh, O_2, H_2O) whose retrieval is the main mission objective of the GOMOS instrument. The inversion is then performed in a sequential way. First, a spectral inversion is performed and this produces horizontal column densities of different constituents. Then, a vertical inversion is performed, assuming a local purely radial dependence of the atmosphere, and produces local density profiles of the constituents. Iterative loops over the spectral and vertical inversion may be performed. A high resolution temperature profile will also be retrieved from the exploitation of the time delay difference between the data from the two photometers.

The parameters of the L2 processing chain will be tuned using GOMOS data. As a result, the L2 processing configuration auxiliary product (GOM_PR2__P) will be updated.

The products that will be validated during this task are the GOMOS temperature and atmospheric constituents profiles (GOMO_NL_2P), the Residual extinction (GOM_EXT_2P), and the meteo user products, which are extracted profiles at reduced spatial resolution for NRT dissemination to meteo users (GOM_RR_2P). This activity may obviously have an impact on the final recommendations of processing parameters setting.

It is planned to define the routine validation activities from the synthesis of all the validation activities. From the analysis of the L2 products produced during the commissioning, it is also planned to specify the observation plan requirements for a routine observation plan.

4.3 SCIAMACHY

4.3.1 Calibration

Spectrally and radiometrically calibrated solar irradiance, as well as limb and nadir radiances, are the main input for any higher level SCIAMACHY product. These quantities also form the basis for intercomparison with other satellite- and ground- based spectrometers. Therefore, it is essential to achieve and maintain the highest achievable accuracy within a calibration scheme.

The accuracy of the calibration mainly depends on knowledge about the instrument itself and also about an appropriate data processor, whose task will be to transform the measured binary units back into physical radiance or irradiance units as appropriate. These two information sources cannot be clearly separated from each other.

The first step in the calibration process is to verify that the SCIAMACHY instrument behaves in-flight as predicted from on-ground calibration measurements. This will be achieved by analysing SCIAMACHY data that has been obtained measured by various on-board calibration sources. The sun, moon and partly the atmosphere itself will also be used as “calibration targets”.

Calibration activities will focus on the characterisation of:
- Dark current
- Dead and bad pixels
- Etalon/pixel to pixel gain
- Spectral Calibration
- Straylight
- Polarisation sensitivities
- Throughput

On the basis of the nature of any detected deviation between on-ground and in-flight behaviour, the calibration database will be updated. In addition, comparison to other, satellite- and ground- based spectrometers and their calibration will be performed. The latter will particularly helpful in the estimation of the calibration accuracy.

The calibration process will be maintained throughout the mission lifetime. Most of the previously mentioned activities will be repeated over time. This will ensure that changes in, for example, the radiometric response and the polarisation sensitivity will be compensated for whenever possible.

4.3.2 Level 2 Algorithm Verification

The objectives of the L2 algorithm verification activities are to:
- Detect errors in the L2 software,
- Study the correctness/applicability of the algorithms,
- Report on software and algorithm errors and propose changes.

There is an important link between this group and the correlative and modelling groups. The SCIAMACHY L2 algorithm verification group will systematically search for 'suspect' behaviour, and bring their findings to the attention of the other groups, who can check this, for example, with the correct subsample of correlative data. The other groups may find deviations with other instruments, and depending on the behaviour of these deviations with respect to some parameter, this group can study the behaviour of the algorithms to this parameter.

Subsets of the L2 products will be looked at in detail in order to detect non-physical values or patterns. The detailed examination of one small subset (a few ground pixels) would be valuable, as would large statistically relevant datasets (up to months) of data. Detailed examination of the products will lead to the detection of errors in the software. Necessary tasks to achieve this include:

- Examination of trace gas column values as a function of orbital position, the detection of jumps, and the identification of the origin of the jumps (surface albedo, sza, latitude, auxiliary data).
- Examination of trace gas column values as a function of scan mirror angle, and the detection of jumps.
- The study of the behaviour of the data with respect to cloud / no cloud transitions, and albedo (land, sea, snow and ice) transitions.
- Comparison of backscan pixel trace gas column values to forward pixel values.
- Comparison of trace gas columns from different fitting windows.
- Study of the behaviour of the data with respect to integration time transitions.
- Study of the behaviour of the data with respect to instrumental parameter transitions.
- Viewing of intermediate products (e.g. AMFs, slant columns) as a function of the orbital position and other parameters.
- Interrogation of trace gas and T/P profiles and specifically looking at values at one height as a function of orbital position.
- Checking of trace gas, and T/P profiles.
- Looking at error bars and quality flag behaviour along the orbit.
- Comparison of NRT and OL data for trace gas column values.

Independent calculations (using the same scientific algorithms and / or methods) will be performed to try and reproduce subsets of the L2 data. This will allow the detection of any misinterpretation of the scientific algorithms particularly during implementation.

4.4 Balloon and Aircraft Campaigns

The objective of the Envisat Stratospheric Aircraft and Balloon Campaign (ESABC) is to contribute to the validation of the MIPAS, GOMOS and SCHIAMCHY L1b and L2 data products. This will be achieved by using several sensors installed on aircraft and stratospheric balloons. The leading scientists in the field of stratospheric flights will participate in the campaigns.

The components of the ESABC campaign have been selected to perform as complete a validation as possible for the three Envisat Atmospheric Chemistry instruments whilst optimising the use of existing facilities and launch sites. Consequently, several sites have been selected and these are located at mid-latitudes, at northern latitudes and near the Equator. The flights have been organised to ensure the measurement of atmospheric constituents during several seasons. The acquisition of data at northern latitudes in the Arctic vortex during the winter is of great importance and has been given special attention. This strategy also implies that the ESABC activities span beyond the validation activities performed during the commissioning phase.

The flight programme comprises large and small balloons as well as high altitude aircraft, the German Falcon and the Russian M-55, also called Geophysika. The flight programme is shown figure 4.4. The first campaign will take place in Aire sur l'Adour, France, and will comprise the launch of two SAOZ payloads. Such payloads can be launched by relatively small balloons of 15 000 m^3. A similar campaign will take place in Nov-Dec 2001 in Bauru, Brazil.

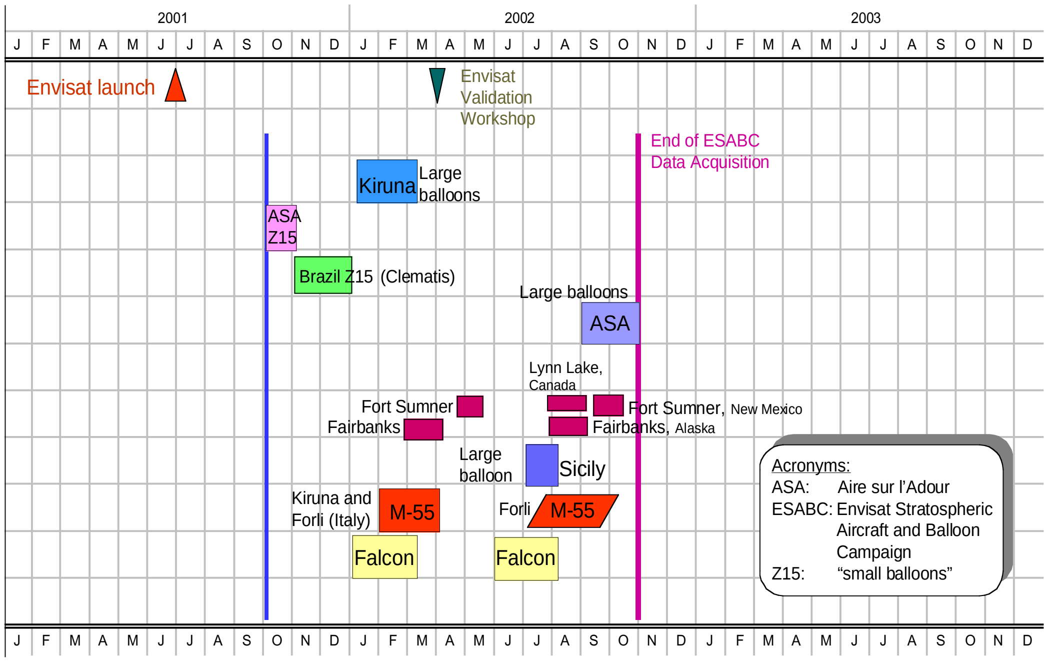

Figure 4.4: ESABC flight programme

A large balloon campaign will take place in Kiruna (fig. 4.5), Sweden, from January to March 2002. The key objective of this campaign is to acquire data from the Arctic vortex and to compare the campaign data to Envisat data, thus validating the algorithms in the high-latitude regions. Balloons of 150 000 to 400 000 m^3 will be used during the two large campaigns.

Figure 4.5: Launch of a balloon from Kiruna

Another large flight campaign will take place in Aire sur l'Adour during September and October 2002. The data will be used to validate the Envisat products at mid-latitudes. The payload of the large balloons will be composed of a number of instruments. These will include AMON, CESAR, DOAS, ELHYSA, MACSIMS, MIPAS-B2, SALOMON, SAOZ, SDLA, SPIRALE and TRIPLE.

In addition to these two major balloon campaigns additional balloon flights will be performed from the site of Trapani, in Sicily and from a range of North American sites.

Compared to stratospheric balloons, which can reach higher altitudes, aircraft have the ability to fly for many hours at an altitude of approximately 20 km, and are able to perform flights spanning several thousand kilometres. In addition, aircraft possess high flexibility to achieve close temporal and spatial coincidence with satellite overpasses almost anywhere on the globe and under most weather conditions. As in the case of the large balloon campaigns, two aircraft campaigns are planned, one during the winter and the other in late summer 2002.

Two carriers will participate in the ESABC. The first aircraft is the meteorological research aircraft Falcon 20 operated by the German Aerospace Centre (DLR). It is a well-established research platform that can carry a payload of 1100 kg at a maximum altitude of 13 000 metres. The payload is composed of a radiometer (ASUR), an Ozone Lidar (OLEX) and a spectrometer (AMAXDOAS). For each campaign, the aircraft will perform flights from its home base in Munich, Germany, to Kiruna and Greenland or to the Seychelles.

The second contributing aircraft will be the high-altitude plane M-55 depicted (fig. 4.6). The M-55 can carry a payload of 1500 kg to an altitude of 22 km. Its endurance of over 6 hours makes it possible to perform long flights over large areas. The payload of the M-55 is composed of a dozen sensors well adapted to the validation of GOMOS, MIPAS and SCIAMACHY. Some of the key sensors are MIPAS-STR, SAFIRE-A, ECOC, FOZAN and FISH. Additional details on the aircraft, the payload and the campaign record can be retrieved from the Airborne Polar Experiment home page http://ape.iroe.fi.cnr.it/. Two campaigns are planned during February and March 2002 from Forli, Italy, to Kiruna, and a mid-latitude campaign in the Summer 2002 at Forli.

Figure 4.6: The Russian high-altitude M-55 aircraft

4.5 Model Assimilation

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. In particular, numerical weather forecast assimilation techniques are used to combine measurements from satellites, balloons, ground stations etc., with weather models in order to predict and analyse the state of the atmosphere at a given position and time. Today, in atmospheric chemistry research, data assimilation techniques are also being developed which will enable the exploitation of information that would not be available from models or observations alone.

The assimilation efforts will be organised into two main activities:

- Assimilation into Numerical Weather Prediction (NWP) models. These will be performed by operation meteo entities such as the European Centre for Medium-range Weather Forecasting (ECMWF). These types of models assume a neutral atmosphere (i.e. no chemistry details are involved) and are a tried and tested operational assimilation technique.

- Assimilation into Chemical Transport Models (CTM). These are applied at a research level and details of the atmospheric chemistry are represented.

In addition, provision of a service to other ACVT participants by delivering extracts of the model assimilation analysis results for a requested location and time. This service could be used, e.g. by operators of ground-based instruments to compare their results with Envisat measurements interpolated to the specific location and time of the ground-based measurements.

4.5.1 Assimilation into Numerical Weather Prediction Models (ECMWF)

Envisat products relevant to meteorological applications will be analysed using the ECMWF data assimilation system. Detailed statistical analyses will be made of the differences between the Envisat 'meteo' products and ECMWF's assimilation field for the corresponding geophysical quantities. This will assist the Envisat instrument teams in the characterisation of errors and biases of the data products and will also help ECMWF to characterise errors and biases in the model. In addition, ECMWF will provide, for ESA, a long-loop monitoring capability to help maintain the quality and integrity of the Envisat 'meteo' products.

It must also be noted that ECMWF forecast data is to be ingested into the Envisat processing chain to improve the quality of the generated data products.

4.5.2 Assimilation into Chemical Transport Models

4.5.2.1 Sequential Assimilation Scheme

A sequential assimilation system is proposed based on one originally developed for GOMOS ozone and which has recently been extended to assimilate MIPAS and SCIAMACHY ozone products. The data will be assimilated in a global chemistry-transport model (CTM). The chemistry considers a comprehensive set of species and reaction. The necessary dynamic inputs will come from ECMWF. The following activities are planned:

- Assimilation of GOMOS, MIPAS and SCIAMACHY ozone products independently in order to perform an inter-comparison between the resulting analysis fields. This will allow the comparison of ozone measurements acquired by the three instruments regardless of their different observation geometries and viewing directions.
- Geophysical validation with independent sources. GOMOS, MIPAS and SCIAMACHY ozone products will be assimilated and compared to independent measurements from the ground (e.g. ozone measurements from NDSC stations) and from satellites (e.g. GOME). The assimilation will be used to interpolate the respective Envisat measurements in space and time to the location of the validation measurements.

4.5.2.2 4D-VAR Assimilation Scheme

A different system proposed uses a 4D-VAR assimilation approach. The 4D-VAR strategy is fundamentally different from a three-dimensional sequential assimilation, since it takes into account the temporal evolution of the state of the atmosphere within a given analysis time window. Figure 4.7 depicts the principal differences between a sequential and a 4D-VAR assimilation. In a sequential scheme, a newly analysed field value is computed by an optimal interpolation between the model and the measurement, weighted by their respective errors. The analysis field is then propagated forward in time until the next measurement, when the procedure is repeated. In the 4D-VAR approach, a time interval is chosen. A first-guess model trajectory (dashed line) is computed by running the model from time 0 to time T. During this run, the differences between model calculation and measurements are recorded. A second model run is performed with the 'adjoint model', which transports the mismatches backwards in time in order to estimate an improved start value for a new model run within the time window. This iterative procedure is repeated until convergence is reached. The final results will therefore not show jumps within the time window and optimal compliance with both the model and data will be assured.

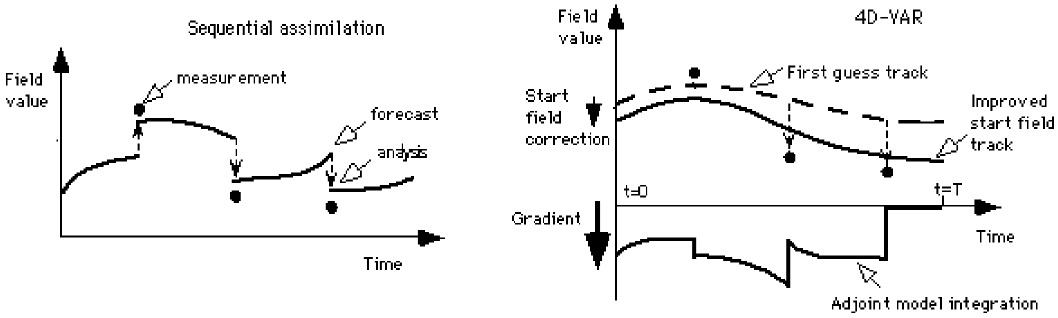

Figure 4.7: The differences between sequential and 4D-VAR (Courtesy KNMI, De Bilt, The Netherlands)

The 4D-VAR approach will particularly help to constrain species in the analysis according to their chemistry model relation and interaction with other species. This system can therefore be helpful in the examination of the consistency between measurements of different species, e.g. GOMOS measurements of ozone and NO_2. Time series and / or total columns from the assimilation analyses of the measured species will be provided.

The main goal of the technique is operational Envisat atmospheric composition measurements assimilation. This consists of the assimilation of species profiles independently for GOMOS, MIPAS and SCIAMACHY. Global maps of the measurements will be created and biases analysed. Rather than near-real time data, quality-checked data will be used in order to ensure the highest quality.

SCIAMACHY ozone measurements will also be validated through assimilation into a system presently being used for GOME ozone assimilation. The GOME assimilation model uses the 4D-VAR technique and a global tracer advection model. In the lower stratosphere, most ozone change on time scales of one or a few days is due to transport. Therefore, ozone can be used as a tracer of air masses. The model simplifies the ozone transport problem assuming that a single two-dimensional latitude-longitude wind field can describe the evolution of ozone columns. The assimilation therefore uses the wind field at the altitude where most of the ozone variability occurs, typically around 10 - 20 km. High quality wind fields are taken from the ECMWF model. The tracer transport model is run at a high resolution of 100 x 100 m^2, a resolution comparable to the size of the GOME ground pixel.

This assimilation application focuses on the atmospheric dynamics rather than on the atmospheric chemistry. The system is being operationally used for GOME ozone column assimilation. Figure 4.8 shows an example of the assimilation of GOME ozone columns in the Southern Hemisphere under ozone hole conditions.

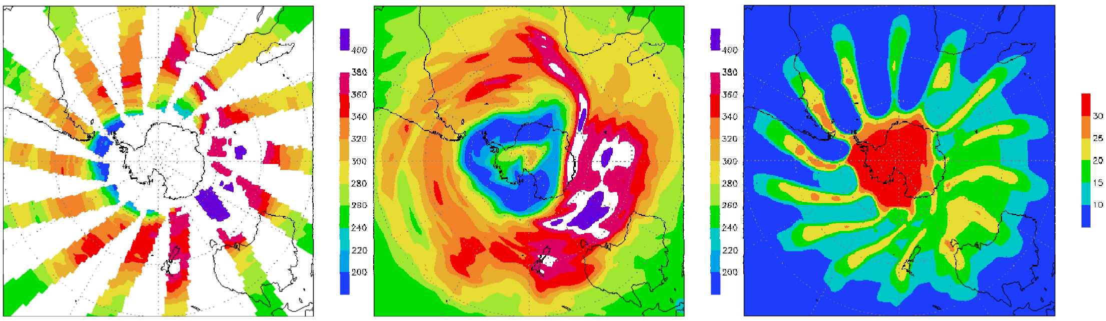

Figure 4.8: The ozone hole of September 11, 1996. The southern hemisphere GOME total ozone data used as input for the assimilation are shown in the left plot. The middle plot shows the assimilated field at 12 GMT. The corresponding uncertainty distribution is shown in the right-hand plot. All scales are in Dobson units. (Courtesy KNMI, De Bilt, The Netherlands)

The model will be adapted and further developed to assimilate SCIAMACHY ozone profiles. Near real time assimilations are planned using ECMWF forecast wind fields. For SCIAMACHY validation, two- and three- dimensional ozone fields including their errors will be provided.

4.6 Satellite Intercomparison

The comparison of equivalent products from other satellite systems is an effective method of validating products on a global scale. A variety of products will be validated including, at L1, irradiances, radiances, reflectances, and polarisation measurements, and at L2, trace-gas columns and profiles, aerosols and cloud detection. Data from AMSR/ADEOS-II, AMSU/NOAA, AVHRR/NOAA, ATSR2/ERS2, GOME/ERS2, HALOE/UARS, HIRLDS/EOS, IUE, METEOSAT, MLS/UARS, MOPITT/EOS, OMI/EOS, OSIRIS/ODIN, POAMIII, POLDER, SABER, SAGEIII/EOS, SBUV, SMR/ODIN, SOLSPEC/Alpha, and TOMS will be used.

The intercomparison of large samples of coincident satellite measurements will enable a global validation under various different observational and atmospheric conditions. This will result in the estimation of product and retrieval algorithm accuracy. Analyses of time series will be used to detect potential time varying biases between different instruments. This activity will furthermore contribute to the establishment of consistent long-term global data sets (e.g. ozone), which combine observations from different satellite instruments.

The data assimilation system of the Data Assimilation Office at NASA Goddard Space Flight Centre has been developed for observations of ozone and other atmospheric constituents. The system consists of a solver for a prognostic equation that describes the ozone-mixing ratio and of an advanced analysis package that solves a set of equations analogous to those used in meteorological analysis systems. The system calculates the three-dimensional ozone field based on total ozone observations from the Total Ozone Mapping Spectrometer (TOMS) on-board NASA’s Earth Probe satellite and on stratospheric ozone profiles from the Solar Backscatter UV (SBUV/2) instruments flying on the NOAA satellite series. The assimilated data sets are validated against independent balloon- and space- borne instruments.

Assimilations of TOMS and SBUV/2 ozone data will be used for comparison with GOMOS, MIPAS and SCIAMACHY ozone L2 products, rather than for assimilating Envisat measurements. This approach is highly complementary to the assimilation approaches described previously, because the original GOMOS, MIPAS and SCIAMACHY L2 data products themselves are the basis for comparison. The relative time and location of ozone fields from the assimilation of TOMS and SBUV/2 will be used with the respective GOMOS, MIPAS and SCIAMACHY ozone measurements for direct comparison. The errors of the assimilation field and of the GOMOS, MIPAS and SCIAMACHY L2 data will necessarily be considered.

The systematic differences of GOMOS, MIPAS and SCIAMACHY, respectively, to the TOMS and SBUV/2 assimilation fields will be analysed with particular focus on systematic biases.

4.7 Campaign Database & Ground-based Measurements

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 intercomparison with GOMOS, MIPAS and SCIAMACHY L2 products. Most ground-based spectrometers are operated routinely, and soundings are performed between once and three times per week. Lidar instruments will be operated during “visibility” by the atmospheric sensors.

Instruments at many sites covering the globe will perform these frequent observations. Since the ground-based group will generate the largest number of coincident data sets, statistical analyses will be possible already early in the commissioning phase. The data acquired will also be used for detailed analysis of the differences found during intercomparison, and some of the parameters will be relevant for validation of L1 products.

Dedicated Lidar measurements will be performed as close as possible in time and space to Envisat instrument observations. For routine measurements, collocations will be identified *a posteriori* from the Envisat and correlative datasets. Trace gas columns from ground-based instruments will be compared to columns and integrated profiles from Envisat. For ground-based profiles and soundings, further pre-processing is needed to take into account the differences in altitude resolution. Both a qualitative assessment of GOMOS, MIPAS and SCIAMACHY accuracy and precision, and an investigation of deviations will be performed. Figure 4.9 details the global locations of measurements acquired for the validation of Envisat's atmospheric chemistry sensors. Figure 4.10 shows the number and the type of instruments to be deployed and the geophysical parameters that they will measure.

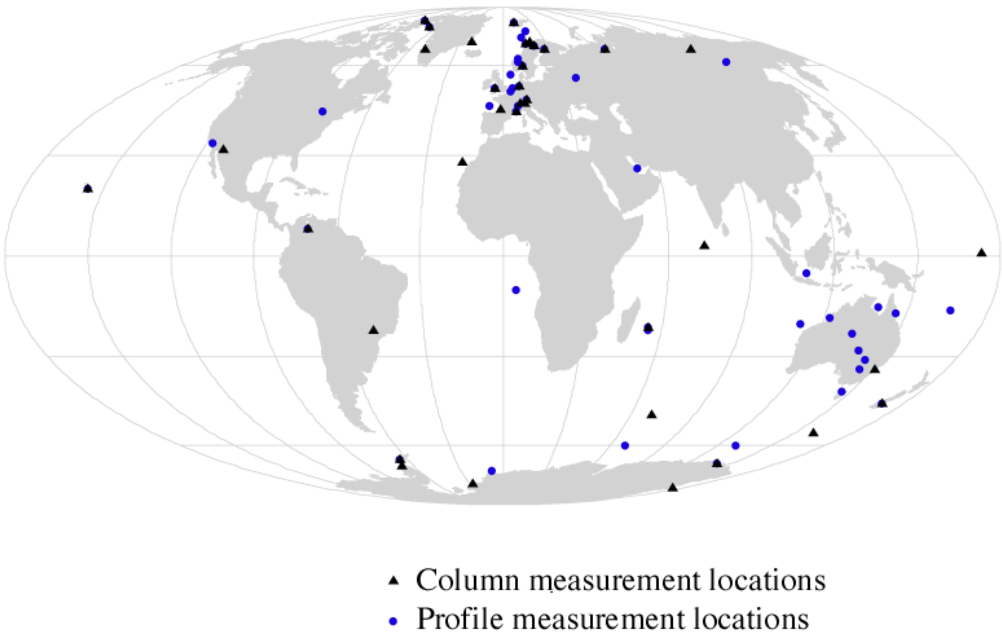

Figure 4.9: Global locations of measurements acquired by the atmospheric chemistry validation team

4.7.1 Sonde Measurements

Ozone and PTU sondes will provide routine sets of data for use in Envisat validation activities. Most of the validation opportunities relate to L2 products. Whilst ozone sondes are subject to routine launch by meteorological offices, there are opportunities for additional launches to meet the validation requirements during the commissioning phase. Ozone sondes are insensitive to the presence of clouds.

4.7.2 Spectrometers

The Network for the Detection of Stratospheric Change (NDSC) and other participants will provide more than seventy-seven UV-VIS spectrometers. These spectrometers will generate measurements of total O_3, NO_2 and, in unpolluted areas, the integrated stratospheric column of NO_2. Amongst these, nineteen instruments of the SAOZ-type will provide preliminary data in near real time. Dedicated UV-VIS spectrometers will measure the column abundance of BrO and OClO. Total O_3 will also be measured through the use of twenty-two Dobson and Brewer spectrophotometers (e.g. fig. 4.11). Nine DOAS instruments will provide BrO and OClO columns in addition to O_3 and NO_2.

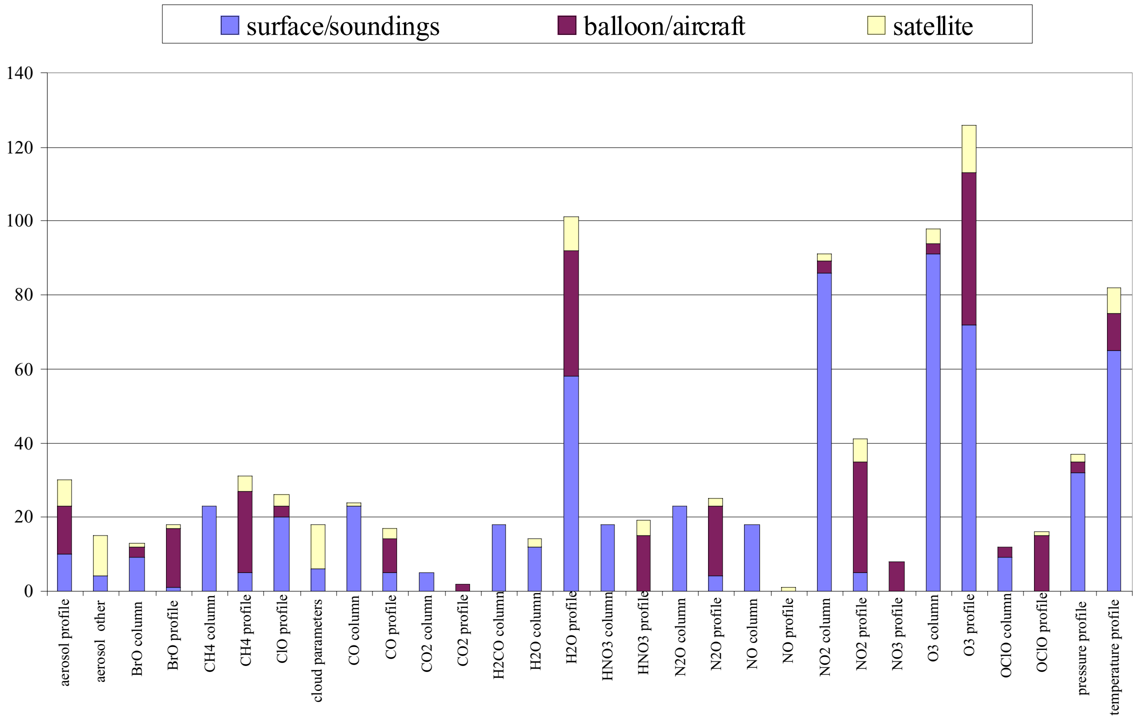

Figure 4.10: Number and type of atmospheric chemistry validation instruments and the geophysical parameters they measure

Figure 4.11: Brewer spectrophotometer, Punta Arenas, Chile (Acknowledgment Laborat rio de Oz nio, Quiat Projecto)

4.7.3 Radiometers

Twenty-one ground-based microwave radiometer instruments (MWR) will contribute to the Envisat validation activities. These are capable of retrieving O_3, H_2O, ClO, and most of them also retrieve temperature. They are highly stable and O_3 retrieval is largely unaffected by clouds. The disadvantages are that measurements can only be made for altitudes above 12 km and that data integration times for some species can take several hours. Ozone and temperature can be retrieved from about 12 km up to 55 km and for some instruments even up to 80 km.

4.7.4 Lidars

The NDSC and other participants will provide routine measurements of ozone, temperature, aerosol backscatter and extinction, and cloud parameters, as a function of altitude. Twenty-two ozone lidars will provide profiles of O_3 and temperature, among them Raman systems that also retrieve aerosol profiles. Four additional Lidars will be dedicated to the retrieval of aerosol parameters and two systems have been constructed to retrieve water vapour. Lidars can be tuned to match specific validation requirements and they cover a wide range of altitudes; O_3 can be retrieved up to 50 km altitude, dedicated systems are capable of retrieving temperature up to 90 km, and aerosol and cloud backscatter can be acquired up to 95 km at resolutions varying from 150 to 300 m. Stratospheric ozone lidars are only usually operated at night, but some lidars have been adapted for day-time use. In day-time mode these systems have a lower sensitivity due to the higher straylight intensity.

4.7.5 Fourier Transform (FTIR/FTS) Spectrometers

Three UV-VIS-IR Fourier-Transform absorption Spectrometers (FTS) and nineteen Fourier-Transform Infrared Spectrometers (FTIR) will be deployed. The FTS instruments will provide not only columns of O_3, H_2O, NO_2, N_2O, CH_4, and CO, but also profiles of these trace gasses. The FTIR instruments are capable of retrieving columns of H_2O, H_2CO, CH_4, N_2O, O_3, HNO_3, ClO, NO_2, and additional species that will indirectly support the validation activities. In addition, vertical profiles of O_3, CH_4, HNO_3 and N_2O will be experimentally retrieved.

4.7.6 Other Instrumentation

Sun photometers and GPS receivers will be used to validate products such as water vapour and aerosol column data.

5 RA-2 & MWR

In-flight calibration consists of absolute calibration, where all terms contributing to the observable are estimated with independent measurements, and relative calibration, where end products are compared to those of other instruments. Validation activities for the Radar Altimeter 2 (RA-2) and the Microwave Radiometer (MWR) have been combined into the RA2/MWR Validation Team.

5.1 RA-2 Calibration

5.1.1 Absolute Range Calibration

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 determination is extremely challenging and set at 1 cm in bias error and 1 mm/year in bias drift.

Such accuracies can only be achieved by employing an experiment design that includes the following characteristics:

- A large number of measurements to reduce random errors,
- A diverse suite of measurement techniques to reduce systematic errors,
- Independent data analyses to reduce susceptibility to systematic errors.

The experiment design also has to take account of practical limitations such as limited temporal sampling due to the 35-day repeat orbit of Envisat, and logistic constraints that limit the geographical scope and limited resources.

The overall absolute range calibration concept is to achieve a regional calibration that effectively makes use of the northwestern Mediterranean basin as a reference surface (fig. 5.1).

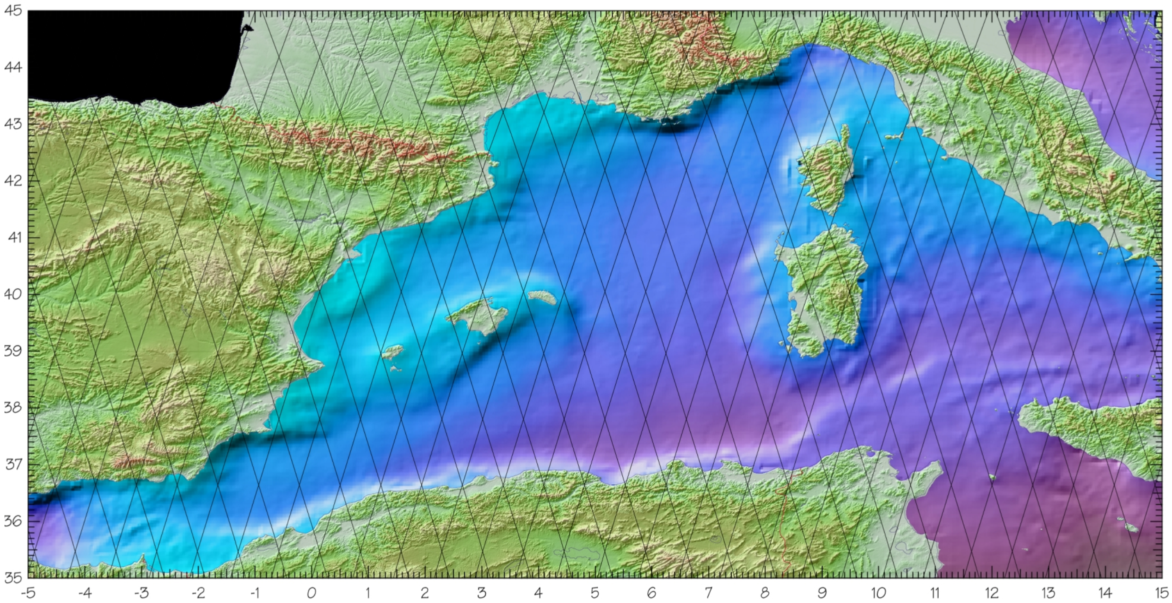

Figure 5.1: The northwestern Mediterranean basin and the proposed ground tracks for Envisat

5.1.2 Absolute Sigma Zero Calibration

Absolute sigma-0 calibration has never been attempted before. 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 newly developed transponder. The altimeter will operate in a preset mode to acquire transponder echoes due to the long delay-line in the transponder, needed for clutter suppression. Acquisition of individual echoes (no pre-averaging) by RA-2 will be commanded over the transponder.

5.1.3 Instrument Calibration & Level 1b Algorithm Verification

The objective of the RA-2 In-flight Instrument Calibration and Level 1b Verification is to ensure the correct and optimised functionality of the instrument in-flight, and the quality of the data to be used for calibration and validation purposes.

During the six-month commissioning phase, an in-flight instrument verification activity will also be performed which will have the following main objectives:

- Instrument verification of the main capabilities and operations in all modes.
- Instrument parameter tuning and optimisation. The optimum setting of the instrument parameters will be verified in-flight once the instrument is acquiring scientifically meaningful data.
- Algorithm parameter optimisation, and verification of the auxiliary data retrieval and use in these algorithms,
- Routine instrument verification.

5.2 RA-2 / MWR Cross Calibration and Validation

The core 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.

5.2.1 Range Cross Calibration

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. Due to the huge number of globally distributed measurements processed, the relative calibration is significantly more precise than local absolute calibration. This is where the major strength of this technique lies in that it ensures consistency between two different but momentarily overlapping missions.

Cross-calibration performed with data taken during a limited overlap between two altimetric missions does not estimate long-term drifts, but bias estimates performed on successive segments during the overlap can assess short-term drifts. Even though both an absolute and a relative calibration exercise will be carried out during the commissioning phase, there is also a need to have a long term drift estimation strategy. 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. The permanent tide gauge network is also necessary to cross-calibrate non overlapping missions.

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 RA-2 relative calibration approach is based on the global comparison of Envisat and ERS data products, as well as TOPEX/POSEIDON, GEOSAT Follow-On, and/or JASON, and local differential observations on equipped (tied tide gauge, laser ranging) natural targets (e.g., the Channel), again using the products. The following methods are envisaged:

Cross-calibration of the RA-2 main geophysical parameters against ERS-2 (and/or Topex/Poseidon, GFO, Jason), range, significant wave height and wind speed (sigma-0):

- Global comparison at cross-overs and along the collinear tracks of millions of globally distributed data (significant error reduction), including cross-calibration of medium and low resolution tracking modes with the ERS-2 ice mode,
- Global statistical comparison against ERS-2, models and *in situ* data.

Long-term drift detection:

- Comparison of sea level heights monitored by RA-2 and by a global tide gauge network.

The output of these methods is the estimate of a bias plus its formal error. Drifts will be estimated on the long-term. Both the crossover method and the repeat track method have their own advantages. The advantage of the repeat track method, applicable only to satellites on the same orbit but providing many more data points for comparison, is its higher accuracy. Tide gauge networks are efficient at monitoring slow temporal drifts.

For optimum results during the Envisat commissioning phase, ERS-2 will follow Envisat after 30 minutes and will fly along the same ground track. The time lag between satellites is required to be smaller than the decorrelation time of the fastest meteoceans signals; a time lag of 30 minutes is highly satisfactory.

5.2.2 L2 Algorithm Verification

The objective of the L2 product validation is to authorise the distribution of validated products to all users within six months after launch. The geophysical processing algorithms will undergo post-launch verification on real data with the objective to assess algorithm performance, tune processing parameters, and apply relevant calibration coefficients at the end of the commissioning phase. There is a special emphasis on verifying the impact of novel aspects of RA-2, i.e. S band channel data and automatic tracking mode switching.

The accuracy to which each parameter needs to be cross-calibrated (for both RA-2 and MWR) is given in table 5.1. Drift is included for the long-term drift monitoring.

Extensive validation of all RA-2 and MWR algorithms used in the Ground Segment will have been carried out before launch using both simulated and reconditioned data from other missions and by means of advice from independent experts. Some aspects of the second generation Radar Altimeter are novel, thus effort will be dedicated to special evaluation and validation tasks, particularly involving the S-band channel data and the automatic tracking mode switching:

- Dual frequency ionospheric correction validation, using the novel S-band data,
- Dual frequency rain flag validation, using the S-band data,
- Evaluation of the impact on geophysical applications of the novel automatic tracking mode switching,
- Sea state bias preliminary estimation in both Ku and S band during the commissioning phase, refined on a longer-term dataset.

Parameter	Relative Bias	Drift	Dynamic Range
Range/sea surface height	1 mm	1 mm/yr	
Sigma-0 (Ku)	0.01 dB		- 5 to 20 dB
Wind speed	2 cm/s	2 cm/s/yr	3 to 20 m/s
Wind speed slope	1%		
Significant waveheight	1 cm	1 cm/yr	1 to10 m
Significant waveheight slope	1%		
Brightness temperature	0.1 K	0.5 K/yr	100 to 350 K
Wet tropospheric correction	1 mm	1 mm/yr	0 to 50 cm

Table 5.1: Cross-calibration objectives for RA-2 & MWR data. The slope in wind speed and wave height refers to the slope of a regression line between RA-2 data and other sources (e.g. *in situ* data or models).

The post-launch product validation tasks will consist of:

- Verifying, with real data, the consistency of the product package (document, format and actual dataset: valid global data coverage, outliers, flag consistency),
- Quantifying the inherent validity and accuracy of range, wave height, wind speed, and geophysical corrections,
- Determining orbit error in the data products (via crossover analysis),
- Estimating time tag errors by minimization of crossover height differences.

The data will be used for the cross-calibration activities and this will enhance the quality and thoroughness of the validation.

5.2.3 MWR Validation

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 (to mitigate slow accumulation of collocated data, preliminary comparison with spaceborne water vapour measurements will be done),
- Comparison with coincident simulated brightness temperature from ECMWF meteorological fields,
- Comparison with other radiometers and especially with the ERS-2 MWR.

6 Precise Orbit Determination

The Precise Orbit Determination (POD) activities will rely on the work of a POD Working Team in which the POD Project team and Science Investigators working in this area collaborate. ESA has the responsibility for producing various types of orbits, namely the FOS predicted orbit, the FOS restituted orbit, the DORIS Navigator orbit, the DORIS Medium accuracy orbit (MOE), and the Precise orbit (POE). One central objective is to nominally have the 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. The POD Working Team will compute and check the orbits operationally and external experts will validate the orbit system and products.

6.1 Orbit Verification

The verification activities will be conducted both during the orbit production process (operational verification) and afterwards (expert verification).

The goal of the operational verification is to ensure, as far as possible, that the orbits included on the IGDRs and the GDRs meet mission accuracy requirements. Operational verification is performed whilst producing the orbits, and the results are summarised in a systematic verification report which will assess whether the orbits that have been generated may be reliably used in the processing of measurements acquired by other Envisat instruments (mainly the altimeter) at the geophysical level.

The expert verification focuses on a more detailed understanding of the nature of the orbit error, and of its impact on the end users. It includes long-term monitoring of the orbit quality, especially to enable the early detection of potential drifts. This verification is performed both by the POD project team and the experts of the POD Working Team and is conducted year round without formal time constraints. Expert members of the POD working team may have access to the orbit data before delivery, for verification purposes. Others will conduct their verification efforts once the orbits are officially available.

6.1.1 Main tools for verification

The tools for orbit verification are traditionally divided among internal and external tests.

Internal tests require no other data than those used for orbit production. Their key feature is the fact that they can be performed during the orbit production process itself. On the other hand, they usually lack the ability to identify systematic errors.

External tests are based on the use of data not included in the orbit determination, or on orbits produced by different groups using different software and/or configurations. These tests are therefore dependent on the availability of these data. However, they are very powerful in detecting systematic errors and long-term trends. In addition, external tests performed using altimeter data can evaluate the orbit quality in terms that are relevant to oceanographic users.

In the case of Envisat, because only two tracking systems are available, namely the DORIS system and the laser technique, and because the MOE will be produced using DORIS data only, laser data (SLR data) will be used for external tests. For the POE, the same tests will be internal tests. A list of existing tests is given in table 6.1.

Many ancillary parameters are estimated in the orbit determination process. Some of these parameters represent meaningful physical quantities for which ranges are known. Others can be correlated with external information. When collected together, the verifications give a different vision of the inner workings of the orbit determination process. These may be characterised into dynamic parameters, some “DORIS” parameters, and some “SLR” parameters. Among the dynamic parameters, the major ones to be monitored are the drag coefficient (whose value should correlate with solar activity variations), the solar radiation pressure coefficient, amplitudes of terms absorbing errors in surface force models (for instance at the 1 cycle/rev period), and the amplitude of stochastic empirical forces absorbing residual dynamic model errors.

DORIS parameters include the frequency bias per pass, the on-board USO frequency, and the station coordinates. In terms of SLR parameters, a range and a time bias per pass will be monitored to control how station coordinates errors are absorbed.

Test	Description	Use	Notes
Data residuals interpretation	Analysis of the statistical and temporal distributions of the residuals (spectral analysis).	After MOE and POE orbit determination	
Data residuals interpretation	Decomposition of the residuals into time and range biases and analysis of the fluctuations and trends in these biases.	Part of the MOE and POE final verification	
High elevation SLR residuals	Selected high elevation laser tracking passes provide an accurate measurement of the spacecraft range when it is close to the zenith and thus is a good estimate of the spacecraft altitude.	Part of the POE final quality verification	
Overlaps	Orbits computed for the same time period using different data sets are compared. This can be used to test overlaps between: • Successive orbits (comparison over the few hours in common), • The arc of a nominal length (e.g. 7 days) and shorter arcs, • Orbits computed over the same period by splitting the data into two independent subsets.	Part of the POE verification	Provide a good evaluation of orbit quality. Overlaps with reduced dynamic orbits (possible using DORIS), which contain data in common, provide limited information because the orbit closely follows the data.
Altimeter data Crossover residuals	Residuals of altimeter measurements at crossover points are computed.	Part of the POE final quality verification. Also validates the MOE after delivery.	
Comparison between orbits	Orbits computed by groups using different configuration and/or different software are compared.	Expert verification only	Orbits generated by other groups may be compared with the "official" Envisat orbits.

Table 6.1: Tests for orbit verification

6.2 Plan and Methodology for Envisat

Activities to obtain efficient 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.

The pre-launch verification of the POD project orbit software and procedures is mainly inherent within the work already done for TOPEX/POSEIDON. However, some specific tasks and tests may still be identified and worked on to complete the task.

The assessment of POD models and standards is an important task. Some studies have demonstrated that tailored gravity models are still the best way to lower the orbit error budget in a drastic manner. However, this is still controversial and new elements relating to this topic may appear once CHAMP, GRACE and GOCE will have flown and provided their expected gravity model enhancements. This is not only a matter of substituting a “static” gravity model with a new one. Indeed, the static gravity field is not truly static, but contains time variations that may now appear significant enough with respect to the other terms of the orbit error budget. Evaluation and analysis of each term of the orbit error budget, plus analysis of the accuracy requirements from the altimetric mission objectives, will highlight how important it is for Envisat to be innovative or not in specific areas of the orbit computation for altimeter missions.

Many other questions will be discussed that will require verification efforts. Examples of such questions deal with the geodetic reference frame that is defined by the geodetic stations used in satellite tracking, or with some parameter estimation strategies. This type of questions also concern other altimetric missions, e.g. Jason-1. Consequently, links and exchanges with the Jason-1 POD team will have to be strengthened.

Post-launch orbit accuracy validation and verification mostly contains now very classical issues with respect to the altimeter / orbitography community and is partly described in table 6.1 in terms of the activities to be performed.

Results from the POD verification will be passed on to the RA-2 calibration and validation teams. It is crucial that the altimeter and POD groups interface as much as possible to ensure consistent cal/val of the altimetric system on-board Envisat. It is now well accepted that the orbit is the core of any altimetric system. The production of an orbit error budget is intrinsic to the POD activities. However, a comprehensive overall altimetric system error budget includes the estimation of altimeter instrument errors, of environmental and propagation errors, and of orbit errors.

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. The ingredients of the technique and its performances have been well assessed to assure confidence that local control of the orbit may be reached. This will be very useful over the Mediterranean area where extensive calibration and validation activities will be performed.

The Envisat POD verification will have to address many other issues than those already summarised previously. The POD verification team will generate a detailed plan providing all the objectives, techniques, data requirements, and schedule of the work to be done. The other topics to be addressed are for example:

- The verification of other types of orbits: FOS predicted and restituted orbits, as well as the DORIS navigator orbits to be used for the generation of near-real products˚when needed,
- All topics dealing with the interactions between Envisat and other altimetric missions e.g. the evaluation of the need for reprocessing ERS orbits taking advantage of Envisat findings, and how to take advantage of the fact that Envisat and Jason-1 use the same DORIS system.