ENVISAT ASAR

CALIBRATION/ VALIDATION PLAN

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1 INTRODUCTION

ENVISAT is an advanced Earth observing satellite designed to provide measurements of the atmosphere, ocean, land and ice over a five-year period. As the successor to the highly successful ERS-1 and ERS-2 satellites it will provide continuity of measurement with most ERS instruments, thereby extending to more than 10 years the long term data sets critical for global environmental monitoring, and furthering many operational and commercial applications.

As a total package the capabilities of ENVISAT exceed those of any previous or planned Earth observation satellite. The payload includes three new atmospheric sounding instruments designed primarily for atmospheric chemistry, including measurement of ozone in the stratosphere. There is an Advanced Synthetic Aperture Radar (ASAR) which can collect high resolution images with a variable viewing geometry, together with new wide swath and selectable dual polarisation capabilities. A new imaging spectrometer is included for ocean colour and vegetation monitoring, and there are improved versions of the ERS radar altimeter, microwave radiometer and visible/near infra-red radiometers, together with a new very precise orbit measurement system.

ENVISAT is scheduled for launch in September 2001 and an Overall Calibration and Validation Plan has been established to provide early results during the 6 months of Commissioning Phase, as well as geophysical product validation 9 months after the launch (Validation Workshop). ASAR products are scheduled to be calibrated within the Commissioning Phase period for Image, Wave and Wide Swath modes for VV polarisation and all subswaths, whereas it is previewed that HH polarisation, Alternating Polarisation and Global Monitoring mode products will be calibrated by the Validation Workshop.

This document describes the detailed plan to calibrate the ASAR instrument, to verify the PF-ASAR processor and to validate all the ASAR products. In section 3 the ASAR calibration/validation team is presented together with the individual responsibilities and mutual interfaces. More detailed sections on the instrument calibration, the processing facility (PF) - ASAR verification and the wave product validation follow the overview of the plan. Detailed schedules are provided covering the pre-launch phase, the 6-month commissioning phase and the further 3-month until the Validation Workshop. Finally in section 8 the activities required to maintain the instrument and product performance during the operational phase of the ENVISAT mission are described.
2 DOCUMENTATION

2.1 Applicable Documents


2.2 Reference Documents


[R2] CALIB Design Document

2.3 Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>ADC</td>
<td>Analog-Digital Converter</td>
</tr>
<tr>
<td>ADF</td>
<td>Auxiliary Data File</td>
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<tr>
<td>AGC</td>
<td>Automatic Gain Control</td>
</tr>
<tr>
<td>AIT</td>
<td>Assembly, Integration and Test</td>
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<tr>
<td>AIV</td>
<td>Assembly, Integration and Verification</td>
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<tr>
<td>ANT</td>
<td>Antenna</td>
</tr>
<tr>
<td>ASA</td>
<td>Antenna Subassembly</td>
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<tr>
<td>ASAR</td>
<td>Advanced Synthetic Aperture Radar</td>
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<tr>
<td>ASS</td>
<td>Antenna Services Subsystem</td>
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<tr>
<td>BAQ</td>
<td>Block Adaptive Quantisation</td>
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<tr>
<td>BW</td>
<td>Bandwidth</td>
</tr>
<tr>
<td>CDR</td>
<td>Critical Design Review</td>
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<tr>
<td>CESA</td>
<td>Central Electronics Subassembly</td>
</tr>
<tr>
<td>CSS</td>
<td>Control Subsystem</td>
</tr>
<tr>
<td>CW</td>
<td>Continuous Wave (Sine Wave)</td>
</tr>
<tr>
<td>dB</td>
<td>Decibel</td>
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<tr>
<td>DSS</td>
<td>Data Subsystem</td>
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<tr>
<td>EM</td>
<td>Engineering Model</td>
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<tr>
<td>EMC</td>
<td>Electromagnetic Compatibility</td>
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<tr>
<td>ERS-1/ERS-2</td>
<td>Earth Remote Sensing Satellite 1/2</td>
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<td>ESA</td>
<td>European Space Agency</td>
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<td>FAR</td>
<td>Flight Acceptance Review</td>
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<tr>
<td>Acronym</td>
<td>Definition</td>
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<td>TBC</td>
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<tr>
<td>TBS</td>
<td>To be Supplied</td>
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<tr>
<td>TC</td>
<td>Telecommand</td>
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<tr>
<td>TCIU</td>
<td>Tile Control Interface Unit</td>
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<tr>
<td>TCP/IP</td>
<td>Transmission Control Protocol/Internet Protocol</td>
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<tr>
<td>TLM</td>
<td>Telemetry</td>
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<td>Telemetry</td>
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<td>Tile PSU</td>
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<tr>
<td>TSS</td>
<td>Tile Subsystem</td>
</tr>
<tr>
<td>TV</td>
<td>Thermal Vacuum</td>
</tr>
<tr>
<td>Tx</td>
<td>Transmit</td>
</tr>
<tr>
<td>USO</td>
<td>Ultra Stable Oscillator</td>
</tr>
<tr>
<td>V</td>
<td>Vertical Polarisation</td>
</tr>
<tr>
<td>Vpp</td>
<td>Volt peak-to-peak</td>
</tr>
<tr>
<td>Vrms</td>
<td>Volt root mean square</td>
</tr>
<tr>
<td>VSWR</td>
<td>Voltage Standing Wave Ratio</td>
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<tr>
<td>W</td>
<td>Watt</td>
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<tr>
<td>W/G</td>
<td>Waveguide</td>
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3 ORGANISATIONAL ASPECTS

3.1 ASAR CAL/VAL Team organisation

In order to perform the numerous tasks involved in the ASAR calibration and validation, the ASAR Cal/Val team has been established. The team is organised in four different sub-groups:

- the instrument calibration team,
- the ASAR ground processor verification team,
- the Wave product validation team, and
- the interferometry team.

Team composition is made up of ESA staff, Expert Support Laboratories (ESL), Instrument Contractor representatives, selected CAL/VAL proposals from ENVISAT “Announcement of Opportunity” (AO) from the submitted CAL / VAL proposals and operational processor representatives. The INSAR activity is a prototype development for future WS-IM and AP-IM interferometric products. It can be regarded as an experimental activity and it is therefore not further discussed within this document.
Because of the large number of beams, modes and polarisations ASAR calibration and validation requires numerous activities, which have to be performed in the proper time sequence and in a co-ordinated manner. Responsibilities have to be distributed over the teams and clear interfaces have to be defined. The following section lists these responsibilities for the three sub-groups and the interfaces between them.

### 3.2 Responsibilities

The instrument calibration team is responsible for:

- the analyses of the instrument and identification of critical parts in the electronics with respect to the calibration performance
- the extraction and distribution of parameters from the instrument characterisation data base
- the development, calibration, deployment and operation of the ESTEC transponders
- the co-ordination of other calibration targets (e.g. RADARSAT transponders)
- the development of the antenna beam calibration model including pre-flight characterisation data, measurements in special modes and rain forest acquisitions
- the verification of the gain droop compensation
- the antenna beam calibration for all 32 beams
- the absolute gain calibration for all beams and modes

The processor verification team is responsible for:

- the pre-launch processor check-out using simulated data and ERS data
- the preparation of a processor test plan for the commissioning phase
- the verification of the product annotation for all products
- the verification of the FBAQ Decoding
- the verification of processor normalisation for all image products and especially for the ScanSAR modes
the verification of the Doppler Centroid estimation and ambiguity resolving accuracy for all image products and the Doppler Centroid continuity in range and azimuth for ScanSAR and stripline image products

the verification of the antenna pattern and range spreading loss correction

the verification of geometric and radiometric resolution, ISLR and PSLR, range and azimuth ambiguity ratios and NES0 for all image products

the verification of the ScanSAR beam merging and scalloping correction

the verification of the image geometry for all image products

the verification of the radiometric an geometric continuity for stripline products

the verification of the interferometric performance including phase preservation and orbit accuracy

The Wave product validation team is responsible for:

the development of the Wave Level 2 validation strategy

the pre-launch geophysical validation of ASAR WV products simulated from ERS Image and Wave Mode data

establishing and testing the infrastructure for world-wide collocation and acquisition of in-situ data

performing a real simulation of the activities to be fully verified during the CP

the generation of the required calibration parameters for the Level 2 algorithm using the procedure established in the pre-launch phase

the validation by comparing parameters retrieved from Level 1 and Level 2 products with in-situ measured wind/wave parameters

the comparison of ASAR Level 1 products with ERS-2 products

supporting the assimilation experiment of Level 2 products into NWP at ECMWF
4 ASAR CALIBRATION OVERVIEW

The generation of calibrated (Level 1) ASAR products requires two major efforts: instrument calibration and processor (PF-ASAR) verification. Those activities will be described in detail in the following chapters 5 and 6. Chapter 7 deals with the validation of the Wave mode Level 2 products, which will be derived operationally from calibrated WV Level 1 products.

The Instrument Calibration Team will perform instrument calibration. Critical hardware components have been identified in a detailed analysis of the sensor. The T/R modules are the most critical elements and most of the instrument calibration activities are devoted to monitor the module behaviour and derive information to adjust the phase and gain settings.

With an active antenna, internal calibration and in-flight antenna pattern verification are closely connected. Internal monitoring of any gain and phase variations is performed during operations and is based on a series of calibration pulses, which allow to measurements on the whole antenna array (row by row) in 5-35 second cycles. A special mode, the so-called Module Stepping (MS) mode, uses the same pulses to check the individual T/R modules. Any drifts of individual modules can then be adjusted via offsets and patches to the coefficients in the automatic temperature compensation.

Internal calibration and MS require a calibration network (which has been implemented as a complete replica of the signal distribution network) and do not cover the passive part of the antenna, namely the radiating elements. This part is supposed to be very stable and will be check every six months by operating the special External Characterisation (EC) mode. This mode allows characterising the radiating elements and the calibration network (mainly the calibration coupler at the module output) by comparison of on-board phase and gain measurements with ground receiver measurements. This mode is also performed on a row by row basis.

The above internal calibration measurements together with the results from the special modes and pre-flight characterisation data will be used to obtain estimates of the elevation patterns and gains for all beams and polarisation. Rain forest acquisitions and data from transponders will provide an independent set of measurements. All these data and the pre-flight patterns will be combined to finally obtain the elevation gain patterns and absolute calibration factors, which will be used by PF-ASAR to generate calibrated products.

4.1 Calibration Requirements

Calibration requirements including:

- Spatial Resolution
- Peak Sidelobe Ratio
- Spurious Sidelobe Ratio
- Integrated Sidelobe Ratio
- Point Target Ambiguity Ratio
- Distributed Target Ambiguity Ratio
- Noise Equivalent Sigma Nought
- Radiometric Resolution
- Dynamic Range
- Radiometric Accuracy
- Cross Polarization Ratio
- Swath Width and Mid Swath Look Angle
- Radiometric Stability
- Localisation Accuracy

have been defined in \[A2\].

A mode/beam/product is regarded as being calibrated, if the following has been achieved:

- 5 consistent external characterisation measurements per polarisation
- 5 consistent rain forest measurements per beam and per polarisation
- consistency between antenna pattern estimates from rain forest and from special modes and preflight characterisation
- 20 consistent transponder measurements per mode and beam and polarisation
- all mage quality requirements

Consistency in the above means, that the measurements are within the requirements specified in \[A2\].

4.2 Automatic Monitoring of the ASAR Calibration Effort

The ASAR Cal/Val effort includes numerous activities, which have to be performed by the Cal/Val Team members in a proper time sequence and in a coordinated manner. To achieve this it is required:
• to provide actual information on the Cal/Val progress (which is necessary to perform subsequent tests and which could influence the results of those tests) to all team members

• to minimise confusion within the team

• to monitor the conduction of the numerous tests

• to provide overview information on status of ASAR calibration

• to track changes in the instrument, in the ADFs and in PF-ASAR

To satisfy these requirements it is planned to implement a database including all the activities and allowing for specific queries to obtain the actual status and to monitor the progress of the Cal/Val effort. The database will be accessible by all team members via Internet.

A detailed description can be found in [R2].

4.3 Verification & Calibration tools

Different tools are being developed in order to verify and calibrate the ASAR products and to monitor and assess the sensor performance during the mission lifetime.

These tools will be used to perform all the activities foreseen during the Commissioning and the Routine phase and they will be used, whenever the development status permits it, during the pre-launch phase.

It is necessary to ensure the compatibility between these different tools, particularly when the same functionality is available in more than one system. A set of ASAR test products has been used to run similar functions on different systems and comparison of results is on going.

A summary of these tools and their status is provided hereafter:

QUAC (Quality Analysis Computer)

The aim of the this system is to perform a systematic and automatic quality control of ASAR products in order to detect and classify eventual anomalies, synthesise the quality of the production and raise alerts and reports in a short time. Furthermore, QUAC will allow the long-term monitoring of the overall instrument behaviour and the mission planning performance through the statistics based on daily sampled data.

It is worth mentioning that QUAC will be completely embedded in the PDS, which will make possible the systematic access to all products.
SARCON (SAR product CONtrol software)

SARCON is a system dedicated to the off-line detailed analysis of ERS SAR and ENVISAT ASAR products, including the following main features:

- Product validation, i.e. possibility to perform a complete analysis of the product quality, including Level 0 data, and assess the correct operation of the end-to-end data chain.
- Product calibration, i.e. capability to derive the parameters needed to perform and absolute radiometric calibration, including antenna pattern and calibration constant derivation.
- Product quality anomalies investigation, i.e. capability to investigate the source of quality anomalies detected on the products.
- Product quality and sensor performance monitoring, i.e. capability to analyse the product quality parameters stored in SARCON database (as a function of time, geographical location or any available parameter), compare them with established thresholds and detect trends in performance evolution.

A first version of SARCON is available at ESRIN since December 2000. However, the system is being upgraded in order to ensure the availability of all the features required - along the lines listed above- during both the CP and the follow-on routine phase. A new version of the system will be available by the ENVISAT launch and the final system will become operational by the end of the CP [TBC].

IECF (Instrument Engineering Calibration Facility)

As its name suggests, this is a facility focussed on sensor and product calibration activities. It is designed as a global system for all the instruments on board of ENVISAT, but the available functionality's are independent for each different sensor.

IECF capabilities include the detailed ASAR product quality analysis and calibration (although less extensive than SARCON), the monitoring of product and sensor performance and basically the processing and analysis of special instrument calibration modes, such the module stepping and external characterisation. IECF is in particular responsible for the generation of the auxiliary files needed by PF-ASAR for precise product generation.

The final IECF version will be available by [TBC].

MDA product quality analysis tools

This is a set of simple and very basic tools designed to perform a basic check of the ASAR product quality, including IRF measurements and complete decoding of the product annotations. Although almost all these tools are also available in SARCON and IECF, their utilisation in some particular cases is not discarded.
These tools are available.

Other tools

Other tools, both at ESA and at the team members’ premises, are available or are being developed to perform additional analysis of ASAR products. In particular, a PDS tool for product comparison is being developed and it will allow to perform automatic comparison of products generated from different processor versions (or using different processing parameters).
5 INSTRUMENT CALIBRATION PLAN

This part of the ASAR Calibration/Validation Plan describes all activities required to calibrate the ASAR sensor. It starts with an analysis of critical parts in the electronics. After an overview of the various tasks involved, the detailed plans for in-orbit checkout, internal calibration, antenna pattern characterisation and absolute gain calibration are presented. A section on external calibration targets concludes this chapter.

5.1 Critical parts of the ASAR electronics

Unlike the passive ERS AMI-SAR, ASAR has an active antenna made up of 320 T/R modules. Each T/R module has two transmit chains, one for horizontal and one for vertical polarization, and one receive chain. The three chains are independently programmable in amplitude and phase to provide the required elevation beam patterns. Any instabilities in the gain and phase characteristics of the T/R modules will distort the beam patterns and can potentially contribute to radiometric errors in the SAR image.

To reduce the temperature variations in the T/R modules, the tiles are thermally insulated the radiating surface of the antenna. To further reduce any phase and gain variations with temperature each tile is equipped with an automatic temperature compensation, which monitors the temperature of the T/R modules and adjusts the settings for every module in 16 s intervals.

The signal and calibration networks are well designed and partly installed in the controlled environment of the tile. The wave-guide section is under thermal cover and has shown to be very stable with temperature.

The ASAR performance specification allows for up to 6% of the modules to fail over the five years lifetime.

During the development of ASAR, a number of effects came to light, which could not be solved in hardware and will have an impact on the radiometric performance if they are subsequently ignored. They all concern the gain of the T/R modules only. A change on gain can be achieved by changing the drive current of the transistors. Therefore it does not affect the electrical path length and hence no phase effects have been observed. During the commissioning phase all of these effects must be monitored so that the impact on performance may be reduced as far as possible. They are described in detail in the following.
5.1.1 VGA GATE LAG EFFECT

An anomaly in the behaviour of the variable gain amplifiers (VGA) of the transmit/receive modules (TRM) of ASAR occurs when a change in the VGA gain setting is requested.

The ASAR VGA gain has a range of between –20 and 0dB and is set by a 6-bit code word. When a new gain is requested which is higher than the current gain (a positive change) then the new gain achieved falls short of its target by 3% in dB of the gain difference between old and new setting. Thus if the current setting is –20dB and 0dB is the requested new gain then initially the actual new gain will be $0 - 3\% \times 20\text{dB} = -0.6\text{dB}$. For the case of a negative change (reducing the gain) the initial new setting is 6% in dB of the gain difference between old and new setting, higher than requested.

**Temperature dependency**

The VGA gate lag effect is heavily temperature dependent with respect to the time it takes for the VGAs to settle following a beam change. The following table gives the measured settling time as a function of temperature for a decrease in gain. The settling times for an increase in gain are approximately half as long as those shown here:

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Settling time</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>25ms</td>
</tr>
<tr>
<td>25</td>
<td>600ms</td>
</tr>
<tr>
<td>0</td>
<td>30s</td>
</tr>
<tr>
<td>-15</td>
<td>90s</td>
</tr>
</tbody>
</table>

**Sidelobe Structure**

The sidelobe structure is affected very slightly until the VGAs have settled. The impact, however on the ambiguity suppression is negligible falling easily within the margin allowed for the end-of-life performance of the T/R modules.

**Mainbeam**

The maximum deviation in the mainbeam is 0.16 dB which is the difference between the nominal pattern and the VGA gate lag modified pattern as a result of the switch from SS4 to SS1.

**Mode Dependency**

In general the transmit beam is unaffected since there is no amplitude taper. For IS5 and IS7, which are tapered however, there will be an effect.

**Image Mode** Will be unaffected since by the time the transition has been made into the mode the VGAs will have settled to the appropriate requested gain.

**Alternating Polarization Mode** Will not be measurably affected. The gain settings for the two different receive beams (H and V) are sufficiently similar that the initial gain setting error will be of the order of only 0.1dB.
Wave Mode  Also not measurably affected. As with image mode, the VGAs will have settled by the time the transition into the mode has been made. In the case where the vignettes come from different swaths the VGAs will not have time to settle to the new value particularly since this is a cold mode. The impact on the radiometry will therefore also be negligible.

Wide Swath Mode  This is likely to be the most severely affected mode. As a hot mode, the length of each burst (around 20ms) is similar to the settling time of the VGAs at this temperature (~40°C). In addition, five sub-swaths are used including SS4 (IS5) which has tapered transmit. The sub-swath transition order is 1-3-5-2-4 so there is a transition from SS2 (IS3) into SS4 and a transition from SS4 to SS1. These are the worst affected sub-swaths with SS1 showing a maximum 0.16dB error in the mainbeam and SS2 0.06dB, See figures 5.1.

Global Monitoring Mode  This mode should be largely unaffected since it is a cold mode and the VGA settling time will therefore be significantly longer than the length of the burst (~5ms).

Figure 5.1: Comparison (left) of SS1 mainbeam without gate lag (black) and with gate lag after transition SS4 – SS1 (red), difference between the two beams (right)
5.1.2 RECEIVER GAIN DROOP EFFECT

During the receive or echo window, the gain has been observed to “droop” by up to 0.9dB above the nominal gain and return back to the nominal value within around 390μs. The initial gain increase is temperature dependent from 0.4dB when the antenna is hot (45°C) compared to 0.9dB when it is cold (-10°C), see figure 5.2.

The governing equation has been determined at T/R module level to be:

\[ \Delta G(T,t) = (-0.004739T+0.403) e^{-t/25} + (-0.004232T+0.4697) e^{-t/175} + (0.0006683T-0.06206) \]

In this relation, the gain change, \( \Delta G \) is in dB for \( T \) in degrees Celsius and \( t \) in microseconds, where \( t \) is in the range \( 0 \leq t \leq 360 \mu s \).

In addition, instrument level tests indicate that the gain measured by the P2 (receive calibration pulse) is also influenced by the droop effect. This however, is not consistent. In the case calibration order 1, where the P2 calibration pulse comes after the echo window and before the transmit pulse (see figure 5.3), the gain of the pulse is seen to “recover” to the higher gain level depending on the time since the end of the receive window. For calibration order 0 where P2 comes after the transmit pulse this recovery is not seen.

This suggests that the gain droop is somehow “reset” by the transmit pulse although exactly how this happens is not fully understood. The difference in the behaviour of the P2 pulse as measured on the FM instrument is shown in figure 5.4.
Figure 5.3: Calibration pulse timing diagram

Figure 5.3: Recovery of the receive calibration pulse P2, time axis in µs, vertical axis in dB
The intention is to compensate for the droop in the processor, taking account of the calibration pulse order.

5.1.3 VGA GAIN DRIFT EFFECT

The nominal gain of the VGAs has been seen to change over time whether or not the device has been used. The exact cause has variously been attributed to Hydrogen contamination or manufacturing defects but ultimately it is not completely understood. The largest changes in gain to have been seen are around 6dB but 2-3dB is more common. The changes can be expected in all 960 VGAs over time. So far, in more than one year, only around 100 VGAs have drifted. By means of the module stepping mode, these changes can be tracked and compensated for either by using the gain offsets or the K0 correction. Assuming the drifts are compensated there is no effect on performance and allowing for the fact that few drift at any one time then, prior to correction, the impact is easily absorbed by the end-of-life margin built in to the antenna beam patterns.
5.2 **ASAR Instrument Calibration Tasks**

The calibration activities after the launch start with the in-orbit checkout, during which the general instrument functionality will be verified. System temperature variations are the major factor causing gain changes. Therefore one important part of the in-orbit checkout is the verification of in-flight temperature profiles. For the most sensitive part, the T/R-modules, we expect one stable temperature per operating mode. This stability has to be verified and the actual temperature has to be determined. Furthermore the influence of different operation scenarios (e.g. IM following WV and vice versa) on the temperature conditions will be determined.

For monitoring of any instrument gain drifts a separate calibration network, to couple out part of the transmit signal or to inject chirp signals into the receiver chain, has been implemented. Calibration pulses will be included into the high-rate data stream and will be analysed by the ground processor in order to estimate the necessary gain drift corrections. Internal calibration includes also the in-orbit verification of the VGA drift, gate lag and gain droop, and the compensation of these effects if possible.

With an active antenna in-flight antenna pattern verification is a major task and it includes measurements in special modes, like module stepping and external characterisation, as well as acquisitions over rain forest and pre-flight characterisation. A sophisticated antenna model combines the various data and provides the elevation and azimuth patterns for the processor.

**Figure 5.4:** ASAR Instrument Calibration Tasks
The absolute overall system gain can be most accurately determined from the image response of point targets with high and well-known RCS. ASAR high precision transponders will be deployed in the Netherlands and will serve as the main external calibration targets. A special transponder mode (a transmit frequency offset of approximately 5 MHz will be compensated by the transponder) will be used for the low resolution Global Monitoring mode and essential allow to decouple the transponder response and the background contribution. Well-characterised distributed targets will be used as well.

All the above corrections have to be applied in the processor to generate calibrated products. Details on how the processor ingests this information are provided in Chapter 6.

5.3 Initial checks during and following in-orbit checkout

- Compare temperature profiles with pre-flight predictions for the various operating modes starting from “cold” Wave Mode ... to “hot” IM
- Calibration pulses from one full orbit in Wave Mode plus temperature from telemetry, comparison with pre-flight measurements, correlation of phase/gain variations with temperature?
- Initial MS for comparison with pre-flight measurements

We need:
- pre-flight data easily accessible for comparison

5.4 Internal Monitoring/Calibration

The ASAR instrument incorporates a very comprehensive system for internal calibration, which is necessary in order 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 module. For an active phased array antenna beam pattern/gain calibration and internal calibration are closely connected. The internal calibration network is the key hardware element for both activities. Within this chapter we describe the calibration network and the various pulses to monitor instrument gain variations. Special operation modes for beam calibration also include the cal-network, but will be discussed in the section 5.5
5.4.1 DESIGN

There is an individual calibration path to each of the 320 T/R modules. In one of the special modes of operation, the so-called Module Stepping Mode, each individual module is checked for any gain or phase drifts (details will be discussed in 5.5). The internal monitoring is carried out on a row by row basis for each of the 32 rows.

Calibration pulses are included in the instrument timeline as initial calibration sequences as well as during imaging and consist of:

- a transmit calibration pulse – P1/P1a (actually split into two due to the fact that four T/R modules share a single power supply unit, see below),
- a receive calibration pulse – P2 and
- a central electronics calibration pulse – P3 (see Fig. 5.5)

![Calibration Pulse Diagram](image)

**Figure 5.5:** Calibration Pulse Diagram

- Transmit Calibration Pulses 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 whilst 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. Thereby minimizing their interference to the measurement of the ‘wanted’ row.
- Transmit Calibration Pulse 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 now 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.

- **Receive Calibration Pulse P2**
  The receive path of the instrument is also characterised but since no variation is expected from power supply load variations it is possible to characterise on a row by row basis.

- **Central Electronics Calibration Pulse P3**
  The auxiliary receive and transmit path of the central electronics are included in the P1/P1a and P2 characterisations, respectively. This part of the central electronics is therefore characterised independently by means of P3

### 5.4.2 NON CORRECTED EFFECTS

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 through external characterisation using the transponders. It is also not possible to correct for short-term variations in the instrument, nor variations in the calibration loop itself.

### 5.4.3 GROUND PROCESSING OF CALIBRATION PULSES

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 and together with embedded row patterns and the external characterisation factor, it is possible to calculate the elevation beam pattern and the relative gain variation. To re-scale it to absolute gain values the calibration pulse measurements have to be combined once with an absolute gain measurement over ASAR transponders. This is then used to detect any deviation to the reference instrument gain pattern as characterised on ground. The typical update rate for this calculation is 5 to 35 seconds (mode dependent).
5.5 **Antenna Pattern Characterisation**

![Diagram of Antenna Beam Characterisation Measurements](image)

**Figure 5.6: Antenna Beam Characterisation Measurements**

5.5.1 **PREFLIGHT CHARACTERISATION MEASUREMENTS**

The following pre-flight characterisation measurements are relevant for antenna beam and gain calibration:

- **Reference Module Stepping mode (MS22) measurements from RFC test**

  During the RFC test in February 2001 the final set of Module Stepping mode data has been acquired. These parameters are the reference for the first in-orbit check on the T/R modules.

- **Preflight antenna patterns**

  All antenna beams have been measured on a near field test range.
- **Embedded row elevation beam patterns**

  The embedded row patterns have been measured for each row individually on the near field test range. The results account for the mutual coupling between adjacent rows and include the array phase factor \( k n dy \sin \theta \), where
  
  - \( k \) is the wave number,
  - \( n \) is the row number,
  - \( dy \) is the row distance and
  - \( \theta \) is the elevation angle.

  Normalisation of the patterns has to be performed to one common reference (for absolute antenna gain to the input power of the ASA, for gain in dBi to the output power of the antenna). The T/R modules were set to uniform gain (0 dB) and uniform phase (0 deg), i.e. the beam set used was IS0. For two-dimensional antenna pattern optimization the embedded row patterns have to be divided by the array factor. Both sets with and without array factor have to be prepared.

- **Nominal values of the calibration pulses**

  The nominal values of the calibration pulses have been measured during the RFC test campaign using beam set IS0.

### 5.5.2 MODULE STEPPING MODE MEASUREMENTS

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 re-synthesize the antenna beam patterns should that be required.

### 5.5.3 EXTERNAL CHARACTERISATION MEASUREMENTS

ASAR can be put into External Characterisation Mode while flying over a calibration transponder. This involves sending a series of pulses from each of the 32 rows in turn. These pulses are detected both by the internal calibration loop and the receiver embedded in the transponder (see figure 5.7). Comparison of these data allows characterising the passive part of the antenna and the calibration network. The baseline is to repeat measurement every six months.
5.5.4 ANTENNA PATTERN SYNTHESIS FROM SPECIAL MODES AND PRE-FLIGHT CHARACTERISATION DATA

\[ E(\varphi, \theta) = \sum_{m=0}^{N_{row}^{-1}} EX_m \cdot f_m(\varphi, \theta) \cdot e^{jk \sin \varphi_r \sin \delta_r (m - N_{row}^{-1}) \sin \Delta_r} \cdot \sum_{n=0}^{N_{col}^{-1}} ERR_{m,n} \cdot e^{jk \cos \varphi_r \sin \delta_r (n - N_{col}^{-1}) \sin \Delta_r} dx \]

- \( \varphi, \theta \) = spherical co-ordinates of observation direction
- \( dx, dy \) = distance of sub-arrays (ASAR sub-array consists of 24 radiating elements in a row)
- \( N_{row} \) = number of rows of the antenna array (32)
- \( N_{col} \) = number of sub-arrays per row (10)
- \( EX_m \) = excitation law (taper) for all sub-arrays
- \( f_m(\varphi_r, \delta_r) \) = radiation pattern of single sub-array (individual embedded row pattern in elevation and sinc-function in azimuth), embedded row patterns from characterisation have to be corrected for the array phase factor and the gain

**Figure 5.7: External Characterisation**
5.5.5 ANTEenna PATTern ESTIMATION FROM DISTRIBUTED TARGETS (RAiN FOREST)

The reasons images of the Amazonian rain forest are used for the characterisation of the antenna beam pattern are that it is a stable, large-scale, isotropic distributed target with a relatively high backscatter and 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.

Alternative distributed targets at different latitudes are being investigated. Promising results have been found from ERS data over Lake Vostok in Antarctica. Antenna pattern estimates at different latitudes could be used to verify the round-orbit performance of the ASAR.

5.5.6 COMBINATION OF THE VARIOUS ANTEenna PATTern MEASUREMENTS

All the above measurements will be combined in the ASAR Beam Calibration Model (see figure 5.8). The pre-flight characterisation data are the reference for all pattern and gain measurements. Rain forest estimates include the gain droop effects, whereas measurements in special modes are unaffected. Comparison could allow verifying the gain droop effects if temperature is taken into account. Calibration pulse P2 also suffers from gain droop effects. Corrections as a function of the cal-order will be applied during ground processing of the internal calibration pulses.

\[
\begin{align*}
\text{ERR}_{m,n} &= \text{T/R module drift/failure matrix (from Module Stepping tests)} \\
k &= \text{wave number (}2\pi/\lambda)\end{align*}
\]
5.5.7 ANTENNA PATTERN MAINTENANCE

The strategy for beam maintenance throughout the instrument lifetime is schematically shown in figure 5.9. Initially, the on-ground characterisation data will be used. TRM drifts occurring during the first years of operation will be detected during module stepping and compensated for, individually, by applying corresponding offsets, in order to bring the TRMs back to the initial conditions. Should compensation not be sufficient after TRM eventual failures, the antenna beam characterisation data will be updated in the ground processor with a new calculated antenna pattern. At the end of the instrument lifetime, beam optimisation by re-calculation of new sets of beam coefficients will also be possible.

The use of rain forest images, antenna synthesis software based on pre-flight embedded row tests, and eventually the actual near-field raw data acquired during the pre-flight beam characterisation will be used, in parallel, to verify any change.
5.6 Absolute Gain Calibration

The purpose of the ASAR gain calibration is to provide the users of ASAR data with the possibility to determine the absolute level of backscatter from any target, point ($\sigma$) or distributed ($\sigma_0$). For ASAR this is achieved in fundamentally the same way as for ERS, namely by providing an Absolute gain Calibration Factor (ACF) in the header of the (processed) product. Since ASAR, however, has a total of eight beams and five different modes and up to four polarisations more ACFs will need to be determined for ASAR than for the ERS single beam, single polarisation with two modes.

The method to be used to determine the ACFs is to image a target of known radar cross-section, integrate the power in its Impulse Response Function (IRF) corrected for the associated background (clutter) power and hence calculate the correction (the ACF) which must be applied to the image values in order to arrive at the same cross-section for that target. For this purpose, precision calibration transponders are deployed in the Netherlands. The radar cross-section of these transponders is 65dBm$^2$ and is known to within ±0.13dB and they are stable to 0.08dB [2]. It is necessary to use active radar calibrators (transponders) 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 calculated it will be possible to make a direct comparison with the on-ground measurements of the end-to-end system gain carried out during FM testing.
5.6.1 GLOBAL MONITORING MODE

This is a special case since the spatial resolution of 1000×1000m makes the normal use of the transponders unfeasible. For a reasonable calibration to be made (3σ value of ± 0.5dB), a signal to clutter ratio of better than 30dB is required. If the clutter at the calibration sites typically has a sigma nought of –6dB then this would require a transponder RCS greater than 84dBm². This would inevitably saturate the receiver invalidating the calibration. As a result, it is necessary to come up with an alternative scenario for calibrating this mode.

The first option (baseline) is using the other modes (namely Wide Swath and Image) to calibrate GM mode by means of the Amazonian rain forest. Since the σ₀ of the rain forest is stable to within 0.3dB it will be possible to use the σ₀ value obtained from a previous (or subsequent) pass in WS or IM to calibrate GM mode. In addition, other relatively stable distributed targets may be used such as the ice caps and specific desert regions (Gibson, Gobi etc).

The second option will allow direct calibration using a special global monitoring mode setting and a modified calibration transponder. The intention is to use the ASAR’s digital chirp generator to offset the centre frequency by 5MHz. This is possible since the chirp bandwidth in GM mode is only around 1MHz. In the calibration transponder, the received signal is shifted back by 5MHz allowing it to be received by the ASAR. As the clutter return will all be outside the range of the reduced bandwidth filter in GM mode, only the transponder response will be seen in the processed image against a background of noise. The result of this operation is to provide a transponder signal to clutter ratio of between 25 and 30dB allowing for reliable calibration of Global Monitoring Mode.

5.6.2 CALIBRATION TRANSPONDER

Since the commissioning phase is planned to last only six months following switch-on of the instrument it is necessary to make use of every possibility of imaging the transponders during that period. Furthermore the placement of the transponders must be optimised to ensure that each of the seven image mode swaths can be acquired over the transponders sufficiently to allow for reliable calibration of each beam. Based on a detailed coverage analysis four locations in the Netherlands have been selected. Three transponders will be fixed. One mobile unit will be used for calibrating the Wave Mode and to support interferometric investigations during later phases of the ENVISAT mission.

Three precision calibration transponders have been developed by MPB (Canada) based on an ESA prototype and were...
delivered to ESTEC in April 2000 (figure 6). Validation of the calibration performance will be supported by the four RADARSAT transponders deployed over a latitude range from 45°-74° in Canada [3]. As RADARSAT operates at 5.3GHz, the actual RCS of these transponders at 5.331GHz will decrease by about 0.4dB.

Other targets of opportunity (e.g. corner reflectors) will be included for different purposes depending on their performance.
6 PF-ASAR VERIFICATION

6.1 Objectives

This chapter describes the activities required to verify that the established product quality requirements are met for all the ASAR products generated by the ASAR processing facility (PF-ASAR) and to derive the parameters needed to perform a geophysical product calibration.

An overview of the PF-ASAR is presented highlighting the critical steps to be considered for product calibration. The detailed activity plan including the pre-launch and the Commissioning Phase activities is described. The requirements versus which the products will be considered calibrated and details on the overall organization are also provided.

6.2 PF-ASAR main characteristics and configurations

6.2.1 PROCESSOR CONFIGURATIONS

In order to start the verification of the ASAR processor before the launch and with the aim of having larger flexibility for product analysis after the launch, different processor configurations will be installed. All these configurations will correspond to the same PF-ASAR version, the one installed in the Envisat Ground Segment, which will be the one to verify. Basically they consist in stand-alone environments allowing to process products in resources different than the whole Envisat PDS, which provides more flexibility to modify some processing parameters / algorithms and gives easier interfaces to manually process the products.

Four different configurations will be used during the pre-launch activities and the Commissioning Phase:

- The operational PF-ASAR integrated in the PDS
- A stand-alone configuration able to process ENVISAT ASAR Level 0.
- A stand-alone configuration where multiple breakpoints have been included to obtain intermediate results after each major processing step and where modifications to the operational processor will be first tested.
- A stand-alone configuration able to process ERS SAR products

All these different configurations are installed on different computer resources in order to obtain the maximum processing capability to perform the required tests.
6.2.2 OPERATIONAL PF-ASAR

PF-ASAR is the processing facility of the PDS in charge of generating Level 1b and Level 2 ASAR products from Level 0 data (HR and LR imaging modes). The only data interface to the IPF is the PF-Host, which supplies it with all the needed information to perform the task whereas some resource status is provided to the CMC for monitoring purposes.

The PF-ASAR processor is a generic PDS element, which means that the same version is installed in all the stations and centers. This ensures product quality independence from the location where products are generated. The operational version of PF-ASAR will be used to provide the reference ASAR products to the ASAR CAL/VAL members on which quality performance analysis will be made.

The PF-ASAR instances used during Commissioning Phase will be installed in:

- the PDHS-E (Esrin) and PDHS-K (Kiruna) for HR/LR processing
- the PACs (UK-PAC, D-PAC, I-PAC) for HR processing (and LR in the D-PAC)
- the LRAC (for LR data)
- the PDCC (Esrin) via ESF

It is assumed that other versions of the PF-ASAR installed in other national stations providing ESA services will not be considered during Commissioning Phase activities. It is also assumed that during the early stage of CP the major processing load for near real time processing will be at PDHS-K, as the station will receive direct high rate downlink from the satellite. ENVISAT data, operationally provided to the PDHS-E via the ARTEMIS data relay satellite, might be acquired at the beginning of CP at the Svalbard station in Norway and supplied to Esrin through physical media (DLT). This will be the chosen option in case of delays in the launch or commissioning of ATEMIS. Raw data will also be supplied to the PACS for off-line processing [TBC]. The LRAC version will be used for low rate (Wave and GM mode) products consolidation.

PF-ASAR has the capability to process acquired data to generate medium resolution and their corresponding browse images in stripline mode. The input acquisition segment is divided into different slices and provided to multiple instances of PF-ASAR installed on different processing nodes. This is done systematically in near real time processing for Image, Alternating Polarization, Wide Swath and Global Monitoring modes. Geometric and radiometric continuity between these
slices will have to be verified during CP. All Wave mode data will be also systematically processed in near real time.

Furthermore PF-ASAR will allow to process High Resolution Products from Image or Alternating Polarisation acquisitions (Precision Images, Single Look Complex or Ellipsoid Geocoded products) in near real time or off line.

The product processing can be seen as a single step where the following information needs to be supplied to the processor:

where:

- the level 0 file contains all the raw data and internal calibration information
- the work order specifies the product to be processed, start time and duration and the auxiliary information to be used
- the product model provides information needed to fill the MPH
- the PF-ASAR auxiliary files are made up of:

  - ASA_INS_AX is an auxiliary file containing instrument characterization
  - ASA_XCA_AX is an auxiliary file containing external calibration information
  - ASA_XCH_AX is an auxiliary file containing information from the External Characterization instrument mode
  - ASA_CON_AX is and auxiliary file containing processor configuration

- The Orbit Information contains the necessary state vectors. In NRT the supplied state vectors might be among¹:

  - Doris Navigator Level 0 product (DOR_NAV_0P)
  - FOS predicted Orbit File (AUX_FPO_AX)

¹ The order on the list indicates selection priority and best precision.
whereas in off-line processing the information might be between:

- Doris precise orbit (DOR_VOR_2P)
- Doris preliminary orbit (DOR_POR_2P)
- FOS restituted orbit (AUX_FRO_AX)

- the time conversion file contains the SBT to UTC correspondence
- the status and reports are files transfer all appropriate status information to the PF-HS
- the internal logs and intermediate results file, not accessible by the user.

The major processing steps followed in PF-ASAR are:

- Pre-processing analysis which includes:
  - FBAQ echo data decoding
  - S&M noise data decoding
  - Full- 8 bits data decoding
  - Calibration pulse analysis
  - Chirp replica reconstruction
  - Elevation gain calculation
  - Noise estimation
  - Raw data analysis
  - Auxiliary data contained in the Instrument source packets validation
- Doppler estimation
  - Use of MLCC algorithm on single swath products (single / multiple Doppler estimates)
  - Use of Madsen’s algorithm on multiple swath products and PRF diversity (WS / GM).
- Range Doppler algorithm for IMS, IMP, IMG, WVI and APS products including:
  - Raw data unpack
  - Raw data correction
  - Range FFT
  - Range matched filter multiply
  - Range inverse FFT
  - Range-dependent gain correction
  - Range-line alignment including filling the alternate (missing) polarization with zeroes
  - Azimuth FFT
  - Range Cell Migration Correction
  - Slant to Ground Conversion (product dependent)
  - Look extraction
  - Look matched filter multiplication
  - Azimuth inverse FFT
  - Azimuth interpolation (product dependent)
  - Detection (product dependent)
  - Look summation (product dependent)
Specan algorithm for IMM, APP, APG, APM, WSM, GMM products
- Raw data unpack
- Raw data correction
- Range FFT
- Range reference Function multiplication
- Inverse FFT of the matched filtered range line
- Range Cell Migration Correction by range interpolation
- Azimuth De-ramp
- Azimuth FFT
- Add bursts incoherently
- Range interpolation (barber pole compensation)
- Azimuth interpolation
- Geocoding for IMG and APG products
- Cross-Spectra and ocean wave inversion for WVS and WVW products

Although PF-ASAR integrated in the PDS is the processing reference from where all nominal products will be processed, the main limitation of this configuration is the lack of flexibility to change parameters and perform some special processing required for specific tests. This is why the “stand-alone” configurations of the processor will be used during CP.

6.2.2.1 PF-ASAR in the ESF environment

The Engineering Support Facility (ESF) is the support system in the PDS dedicated to

- Maintenance and reprocessing of all PDS software and solving of anomalies using validation means assembled in a Reference System
- Management and control of the overall PDS configuration
- Management of the logistics, including operator training

This Reference System is a continuation of the Reference Platform used of integration and test activities during PDS development designed as a standalone system with user-friendly MMI structure available to the operators. It can be configured to any PDS center or PAC for maintenance and trouble shooting activity and has the capability to reproduce the functionality of any Facility in the operational system. As such PF-ASAR is also integrated in the ESF.

The purpose of the PF-ASAR installed in the ESF during Commissioning Phase will be to solve integration problems, test and validate new IPF versions before integrate them in the PDS Reference Platform and investigate any software anomaly transmitted by the Ground Segment Planning Facility (GSP). It is not intended to use the ESF as a processing chain to generate products with special requirements or different processing parameters. The use of PF-ASAR in the ESF environment for cal/val purposes during CP will be therefore limited.
### 6.2.3 STAND-ALONE PF-ASAR AND “DEBUGGING VERSION”

The PF-ASAR integrated in the PDS does not give enough flexibility to change the processing parameters specified in the internal configuration files, re-process the data with special options (i.e. no antenna pattern correction for detected products, no gain droop correction, etc) or avoid the limitation of standard product sizes. On the other hand, fast access to the products on disk and the internal logging files is needed for fast product quality analysis. The stand-alone configuration allows the CAL / VAL team to process products independently from the PDS environment. It is installed at ESRIN on a single workstation provided with external devices for data ingestion / output.

In this configuration, the same PF-ASAR version as the PDS one, is driven by a PF-HS simulator developed for processor validation. Processor interfaces need to be extracted as auxiliary products from the PDS (i.e. instrument characterization files) or produced separately (i.e. work order) with the help of special generation tools. The PF-HS driver is able to send all the specific commands to the processor, send the raw data and auxiliary files and retrieve the processed products and status to the local disk.

The debug PF-ASAR version consists of a preparation of a test environment to debug the processor during commissioning phase: a certain number of breakpoints within the code will be added, so that data and internal files can be accessed at intermediate processing steps. The processor will output these special intermediate results after code recompilation with special compilation flags. The main stages are described hereafter although they will be modified in case of contingencies during early phase of the commissioning phase:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppler estimation</td>
<td>Fractional Doppler and ambiguity intermediate results needed to calculate the sensor dependent parameters</td>
</tr>
<tr>
<td>Range-Doppler</td>
<td>Before and after range / azimuth normalization steps</td>
</tr>
<tr>
<td></td>
<td>After range compression</td>
</tr>
<tr>
<td></td>
<td>After azimuth compression</td>
</tr>
<tr>
<td></td>
<td>After look detection</td>
</tr>
<tr>
<td>Specan algorithm</td>
<td>After look detection</td>
</tr>
<tr>
<td></td>
<td>Before and after descaling correction</td>
</tr>
<tr>
<td>ScanSAR and AP</td>
<td>After range compression for each beam</td>
</tr>
<tr>
<td></td>
<td>Before look summation within beam</td>
</tr>
<tr>
<td></td>
<td>Before beam merging</td>
</tr>
<tr>
<td>Wave mode</td>
<td>After look detection images (for cross spectra generation)</td>
</tr>
</tbody>
</table>

The stand-alone configuration is currently being used as a processing resource during pre-launch activities. It allows distributing products within the CAL / VAL team containing simulated scenes (point targets and modulated pseudo-random noise) for all ASAR modes. It is also a major tool to
ensure the absolute compatibility between the space and the ground segments and to verify the processor using satellite data.

### 6.2.4 ERS INTERFACE: THE PF-ERS

The PF-ERS is a stand-alone ERS interface to the PF-ASAR system that allows to generate ASAR-like products from ERS raw data using the ASAR generic processor. Because its flexibility (e.g. direct interface with ERS raw data), the PF-ERS sub-system is an excellent tool to provide simulated ASAR products in Image Mode, Wave Mode and in Alternating Polarisation Mode (one polarisation only) where continuous ERS data is treated as a burst mode acquisition. All output products are generated using the PF-ASAR algorithms and follow the same product quality specifications and product formats than the ASAR products.

The direct interface with PF-ASAR allows to verify the processor and detect image quality problems using large ERS data sets. It provides via a user-friendly interface an easy way to process raw data acquisitions in different input formats with the advantage that the ASAR processor is still the same than the operational one (i.e. only changes in the interfaces). PF-ERS is also an excellent tool to verify the new ASAR cross spectra algorithm for Level 1b and the wave spectra and wind determination for the Level 2 products during the pre-launch phase. The following figure shows the interface differences between the PF-ASAR integrated in the PDS and the PF-ERS. All products containing ERS scenes are generated with this version for pre-launch activities purposes.
An update will be done to the PF-ERS interface in order to handle ENVISAT ASAR level 0 products, so that ASAR data can be processed more efficiently than using the PF-HS test driver embedded in the stand-alone configuration. In that way it will become the major test bench during commissioning phase, as all products that will need special processing, following the requirements of all team members, will be processed with this interface.

The accepted input formats on the facility are:

- ENVISAT ASAR Level 0
- ERS CEOS
- ERS EIC
- ERS ACS DLT TRANSCRIPTION

and the available media:

- Exabyte
- CD-ROM
- DISK
- DLT

This processor configuration has already become the major source of products for processor verification during the pre-launch phase, as it is able to provide products processed with the PF-ASAR algorithms which contain scientific meaningful data from ERS SAR. During commissioning it will be used to generate products which require special processing parameters specified by team members. All parameter changes will be done uniquely when using this interface. Configuration control of the changes in the parameters will be tracked via the overall ASAR CAL / VAL database.

### 6.2.5 PROCESSING ALGORITHMS

The following table describes the algorithms used to process each product in the PF-ASAR. It also includes whether the products are processed off-line, under user request, or systematically in Near Real Time (NRT). In this last case all acquired data is processed to medium resolution products using a stripline technique to improve throughput: segments are divided into consecutive slices that are passed to different processor instances installed on different processing nodes. Processor design is such that it ensures radiometric and geometric continuity between the different processed slices. NRT products will be available to the users 3 hours after acquisition.

The table also includes the Doppler algorithm used to perform Doppler estimation on a product basis and the number of estimations calculated and reported (interpolation between estimations) on each product.
<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>ALGORITHM</th>
<th>STRIPLINE / OFF-LINE</th>
<th>DOPPLER ALGORITHM</th>
<th>DOPPLER ESTIMATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASA_IMS_1P</td>
<td>RANGE-DOPPLER</td>
<td>OFF-LINE</td>
<td>MLCC</td>
<td>1</td>
</tr>
<tr>
<td>ASA_IMP_1P</td>
<td>RANGE-DOPPLER</td>
<td>OFF-LINE</td>
<td>MLCC</td>
<td>1</td>
</tr>
<tr>
<td>ASA_IMG_1P</td>
<td>RANGE-DOPPLER</td>
<td>OFF-LINE</td>
<td>MLCC</td>
<td>1</td>
</tr>
<tr>
<td>ASA_IMM_1P</td>
<td>SPECAN</td>
<td>STRIPLINE</td>
<td>MLCC</td>
<td>Every 30 sec.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reported every 1.5 sec.</td>
</tr>
<tr>
<td>ASA_APS_1P</td>
<td>MODIFIED RANGE- DOPPLER</td>
<td>OFF-LINE</td>
<td>MLCC</td>
<td>1</td>
</tr>
<tr>
<td>ASA_APP_1P</td>
<td>SPECAN</td>
<td>OFF-LINE</td>
<td>MLCC</td>
<td>2 (1 reported)</td>
</tr>
<tr>
<td>ASA_APG_1P</td>
<td>SPECAN</td>
<td>OFF-LINE</td>
<td>MLCC</td>
<td>2 (1 reported)</td>
</tr>
<tr>
<td>ASA_APM_1P</td>
<td>SPECAN</td>
<td>STRIPLINE</td>
<td>MLCC</td>
<td>Every 30 sec.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Each pol</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reported every 1.5 sec.</td>
</tr>
<tr>
<td>ASA_WSM_1P</td>
<td>SPECAN</td>
<td>STRIPLINE</td>
<td>MADSEN+POWER</td>
<td>Every 30 sec.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BALANCING+PRF</td>
<td>each beam</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DIVERSITY</td>
<td>Reported every 6 sec.</td>
</tr>
<tr>
<td>ASA_GM1_1P</td>
<td>SPECAN</td>
<td>STRIPLINE</td>
<td>MADSEN + PRF</td>
<td>Every 90 sec.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DIVERSITY</td>
<td>each beam</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reported every 6 sec.</td>
</tr>
<tr>
<td>ASA_WVI_1P</td>
<td>RANGE-DOPPLER</td>
<td>STRIPLINE</td>
<td>MLCC</td>
<td>1 per imagette</td>
</tr>
<tr>
<td>ASA_WVS_1P</td>
<td>N / A</td>
<td>STRIPLINE</td>
<td>N / A</td>
<td>N / A</td>
</tr>
<tr>
<td>ASA_WVW_2P</td>
<td>N / A</td>
<td>STRIPLINE</td>
<td>N / A</td>
<td>N / A</td>
</tr>
</tbody>
</table>

Special mention needs the modified Range-Doppler algorithm for APS generation. Its main steps are:

- Range lines of the alternate polarization are zeroed out.
- The inverse of the azimuth beam pattern is applied to the SLC in the frequency domain.
- The processed bandwidth is modified for each azimuth line to be four times the burst bandwidth.
- A rectangular window is used to extract the single look.
- The azimuth matched filter is generated in the time domain and FFT’d.
- A single IFFT is used after azimuth compression.

The fact of using one single IFFT for the whole azimuth spectrum will modulate the azimuth IRF shape due to the bursty nature of the data. This modulation can be removed during Insar processing by common bandwidth filtering techniques. A complete description of the processing algorithms can be found in [R13] and [R14].
6.2.6 PRODUCTS GENERAL CHARACTERISTICS

PF-ASAR generates either complex or detected (amplitude) products which values proportional to the radar brightness. The processor does not apply any incidence angle correction nor any absolute calibration constant gain variation. Noise power is neither subtracted during processing although the average noise power is estimated using all the noise source packets included on each level 0 and annotated on the final product.

Elevation antenna pattern and range spreading loss corrections are also applied only to detected products. Further corrections applied to all the products are the elevation gain at the reference angle correction (following the internal calibration scheme), the gain droop correction on the raw data and the raw data correction. This latest correction is polarization dependant in the case of AP products. Azimuth antenna pattern modulation is corrected on the products processed with the Specan algorithm and in the APS product to avoid scalloping effects (i.e IMM, AP products, WSM, GMM).

Further characteristics of the ASAR products are the slant to ground projection chosen for stripline products which keeps the incidence angle at the center of the swath at a fixed position within the image. The co-ordinates reference system chosen to geolocate the products is the WGS 84 ellipsoid. The complete list of products and their description can be found on [A2].

6.2.7 AUXILIARY FILES

Additional information required to execute the processing is passed to the PF-ASAR through the auxiliary files. These files are archived and selected by the PF-HS based on the validity period contained in the filename. The user has the capability of selecting a specific auxiliary file when ordering a product on the USF. The complete description of the file contents can be found on [2]. The four specific ASAR auxiliary files are:

- External Calibration: Contains the absolute calibration constants to be derived during commissioning phase for all products and swaths and the elevation antenna patterns with their reference angles.
- External Characterization: Contains the characterization factors derived from the External Characterization ASAR mode of functioning when overflying the transponders and the antenna pointing error derived from the same measurements.
- Processor Configuration: Contains the threshold values for setting the PCD flags.
- Instrument Characterization file: Contains the instrument parameters used by the processor:
  - Radar frequency and sampling rate
  - Offset frequency for wave mode calibration pulses
  - Nominal amplitude and phases for calibration pulses
  - Nominal chirp amplitudes and phases
  - Azimuth antenna patterns
  - Range gate bias
  - FBAQ / S&M/Full 8 bits decoding LUTs
  - Instrument mode timelines and data compression characterization
- Calibration row sequence
- Embedded antenna row patterns
- VGA gain droop compensation characterization

The above auxiliary files are maintained and passed to the PDS by the IECF. During CP it will be the role of the instrument team to verify all the values to be provided to the processor. The thresholds for automatic flagging within the products will be based on a statistic analysis of a large set of products. This analysis will be done by the QARC tool as it has access to the product annotations stored in the PDS.

During CP the ENVISAT attitude file AUX_ATT_AX will also be used to verify the ASAR mispointing. The file includes the yaw, pitch and roll ASAR mispointing angles which are calculated by the IECF based on a statistical number of Doppler measurements extracted from the products. This auxiliary information is not used within the processor.

6.3 Processor parameters to be set up during commissioning phase

Some processor parameters will have to be set up during early phase of the commissioning phase to achieve the correct processor behaviour. Although some preliminary values are already defined, based on the ERS SAR and geometry previsions, they will have to be reviewed for ASAR as some of them are sensor dependant.

These processor parameters are:

- Processor Gain: This parameter scales the final image. It is product and mode dependant.
- System offset frequency: This parameter is used for Doppler ambiguity estimation. It depends on the ASAR antenna pointing and might be different for each beam.
- Min-Max elevation angles: This parameter fixes the amount of black pixels on near an far range to accommodate for SWST changes on long stripline products.

There are other parameters, which will always be used during nominal processing. However under cal / val team members request they can be switched off / on to verify related functionalities within the processor. This will always be done within the stand-alone configuration of the PF-ASAR and products will be processed manually. The complete list and the test verification are included in the following table:

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna elevation pattern correction</td>
<td>Antenna elevation pattern verification</td>
</tr>
<tr>
<td>Antenna elevation gain correction</td>
<td>Internal Calibration verification</td>
</tr>
<tr>
<td>Raw data correction</td>
<td>FBAQ / RDA correction</td>
</tr>
<tr>
<td>RMS equalization</td>
<td>FBAQ decoding verification</td>
</tr>
<tr>
<td>Constant SNR filter / Inverse azimuth antenna pattern correction (AP Products only)</td>
<td>Descalloping verification</td>
</tr>
<tr>
<td>Beam merging algorithm parameter</td>
<td>Beam merging algorithm verification</td>
</tr>
</tbody>
</table>
Parameters included in the auxiliary files related to the instrument in the section [2.7] will be under the responsibility of the instrument subgroup. Thresholds for automatic product quality flagging will be done after each product is considered as calibrated.

### 6.4 Processor verification

#### 6.4.1 PRE-LAUNCH ACTIVITIES

Different activities are foreseen during this phase in order to ensure that the processor is fully able to generate ASAR products meeting the expected quality requirements, that all the tools needed for the product quality analysis during the CP are available and properly verified and that there is a common understanding between the team members on the strategy to be followed during CP to verify and calibrate the products.

The main foreseen pre-launch activities are described hereafter.

#### 6.4.1.1 Product simulation

Availability of simulated products is of major importance during the pre-launch phase. Many simulated products have been generated and used for activities such as the PF-ASAR testing. However, the foreseen pre-launch activities require the use of products simulated with the latest instrument settings, as realistic as possible in terms of signal and internal calibration data content and also over strategic sites such as Flevoland or the rain forest. For this reason, simulation of new ASAR products is considered as a basic pre-launch task and it is already on-going.

ASAR simulated products can be classified as follows:

**a) Products simulated with ERS data**

These products are generated at ESRIN with PF-ERS from ERS RAW data and they are therefore limited to IM, AP and WV products for IS2 and VV polarisation. Level 0 products cannot be realistically used for verification since the source packet format and all the internal calibration information correspond to ERS. These products are mainly used to simulate ASAR images over the Flevoland transponders and over the Amazon rain forest.
- Products availability: Simulated products over both sites are available (using the latest processor version).

b) Products containing simulated point targets (PT) and pseudo-random noise (PRN)

These products are generated by PF-ASAR at ESRIN from Level 0 products containing PT and PRN simulated by MDA. They are therefore available for any mode and product type and where used for the PF-ASAR processor validation. The Level 0 products follow the ASAR source packet format, including the noise and the calibration pulses information and they can be used to test the tools developed for the ASAR quality analysis. Level 1 products generated from these raw data can be used to characterise the PF-ASAR product quality and verify that it meets the established quality requirements

- Products availability:
  - Level 0 and Level 1 products are available for all modes and product types using preliminary instruments settings.
  - Level 0 products using the latest instrument settings and ASAR timeline are being re-simulated by MDA. Products will be available by mid May 2001.
  - Level 1 products from the updated Level 0 products will be generated at ESRIN using the latest PF-ASAR version. Products will be available by end May 2001.

c) WSM and GMM products simulated with ERS

WSM and GMM products can be simulated from ERS data as the ERS swath covers part of the ASAR SS1 and SS2 ScanSAR subswaths. ERS raw data is modified to the current ASAR instrument settings (e.g. bandwidth, resampling…). This permits the partial verification of WSM products since they are generated using meaningful data for SS1 and SS2 beams. It allows also the verification of the ScanSAR radiometric normalization across range and the beam merging algorithm settings. These raw data raster products will be converted to the ASAR Level 0 format by MDA in order to process them with PF-ASAR.

- Availability: Two simulated raw datasets over Flevoland (transponders) and Matera (homogeneous area) are available.

d) Products simulated from reformatted ERS Level 0 data

A few ERS raw data product have been used by MDA to simulate ASAR-like Level 0 products, i.e. following the ASAR source packet format and including FBAQ data coding. These products are used to verify the ASAR product quality on meaningful data.

- Availability: IM, AP products over Flevoland (IS2, VV) and WV IS2 VV using preliminary instrument settings are available.

e) ASAR Level 0 data

e.1) Instrument measurements
This data has been recorded using all antenna panels and the final instrument timeline and settings. It contains the complete internal calibration information and noise signal data. It is used to verify the correct handling of real instrument data (including internal calibration scheme) and to check the interface between the satellite and the ground segment.

- Availability: This data is available for all ASAR modes, including the experimental IM SS1 mode.

**e.2) ARTS data**

These Level 0 files have been obtained directly facing the ASAR instrument to a ground beacon (ARTS) which introduces a delay in the transmitted ASAR pulses and transmits them back again to the ASAR antenna. In this way data from ARTS represent the most realistic information available before launch. The data sets can be processed by PF-ASAR using only the compression in range to obtain the instrument IRF in this direction. Moreover calibration pulses, chirp replica reconstruction and internal calibration in the PF-ASAR can be verified. The data set also provides the possibility of ensuring total compatibility between the instrument source packets format and the processor ingestion and decoding procedure.

- Availability: ARTS data have been recorded during the RFC test on the complete FM including the full antenna.

**6.4.1.2 Full PF-ASAR validation**

The aim of this activity is to verify and calibrate the processor with all available data before launch, i.e. using all the different ASAR simulated products mentioned in previous section.

These tasks shall be performed using the tools that will be available during the CP (see section 4.3) and according to the cal/val plan strategy.

This activity will be mainly carried out by ESRIN with the contribution of all team members and will include the following tasks:

**Verification and calibration of Level 1 ASAR products simulated with ERS data (IM and AP, WV, IS2, VV)**

A detailed product quality analysis of IM, AP and WV Level 1 products over Flevoland and the rain forest will be carried out in order to derive:

- the product quality measures for ERS products when processed with the ASAR product generation parameters (e.g. 4 azimuth looks for and IMP) and when generated using the ERS products characteristics (e.g. 3 azimuth looks for a PRI). In the latter case, results can be directly compared to those obtained with the VMP, which becomes a reference platform in this context;
- the identification of processing anomalies related to the IM, AP and WV product generation;
- the evaluation of quality parameters specifically related to stripline products;
- the appropriate settings of the processor configuration parameters to obtain calibrated products from ERS data.

After this activity PF-ASAR will be calibrated for all those products containing ERS data, including also wave mode imagettes.

**Verification of Level 0 ASAR products from instrument measurements and simulated with PT and PRN**

These products will be mainly used to verify the processor capability to handle ASAR Level 0 products, including data decoding, chirp reconstruction, noise analysis and calibration pulses processing.

The expected result will be an assessment of the PF-ASAR ability to handle Level 0 products, particularly regarding the internal calibration information.

**Verification of Level 1 ASAR products simulated with PT and PRN**

A full verification of these products will be carried out following, whenever possible, the product analysis activities foreseen during CP. See Section 6.3.2 for a complete list of activities.

This activity will be mainly carried out at ESRIN with contribution from all team members.

Expected results are:
- the product quality measurements for all ASAR products;
- the comparison with the ASAR product requirements;
- the identification of any product quality anomaly;
- a table of expected quality measures to be verified during the CP;
- a list of processing parameters to be tuned during the CP and their default values.

It should be noticed that this activity was partially carried out during the PF-ASAR acceptance tests but the update of the instrument settings and the modifications introduced since then in the processor demand a quality characterization verification.

**Verification of Level 1 ASAR WSM mode products simulated from ERS (SS1 & SS2)**

The analysis to be performed on these products are those specific to ScanSAR, mainly the verification of the radiometric normalisation in range and the analysis of scalloping effects. The activity will be mainly carried out by Polimi and ESRIN.
Summary of simulated product types to be used for the pre-launch PF-ASAR verification

<table>
<thead>
<tr>
<th>Processing Level</th>
<th>Image Mode</th>
<th>Alternating Polarisation Mode</th>
<th>Wide Swath Mode</th>
<th>Global Monitoring Mode</th>
<th>Wave Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0 Instrument Source Packets</td>
<td>ASA.IM_0P</td>
<td>ASAAPH_0P</td>
<td>ASA_WS_0P</td>
<td>ASA_WV_0P</td>
<td>ASA_WS_0P</td>
</tr>
<tr>
<td>L1b Medium Resolution (150m)</td>
<td>ASA_IMM_1P</td>
<td>ASA_APM_1P</td>
<td>ASA_WSM_1P</td>
<td>ASA_WV_0P</td>
<td>ASA_GM_1P</td>
</tr>
<tr>
<td>L1b Low Resolution (1km)</td>
<td>ASA.IM_B0P</td>
<td>ASA_GM_1P</td>
<td>ASA_GFM_1P</td>
<td>ASA_WV_1P</td>
<td>ASA_WM_2P</td>
</tr>
<tr>
<td>Browse</td>
<td>ASA.IM_B0P</td>
<td>ASA_APM_B0P</td>
<td>ASA_WSM_B0P</td>
<td>ASA_WV_0P</td>
<td>ASA_GM_B0P</td>
</tr>
<tr>
<td>L1b Single Look Complex (SLC)</td>
<td>ASA.IMS_1P</td>
<td>ASA_APS_1P</td>
<td>ASA_WS_1P</td>
<td>ASA_WV_0P</td>
<td>ASA_WS_1P</td>
</tr>
<tr>
<td>L1b Precision Image (PRI)</td>
<td>ASA_IMP_1P</td>
<td>ASA_APP_1P</td>
<td>ASA_WV_1P</td>
<td>ASA_WV_1P</td>
<td>ASA_WM_2P</td>
</tr>
<tr>
<td>L1b Geocoded Image (GEC)</td>
<td>ASA.IMG_1P</td>
<td>ASA_APG_1P</td>
<td>ASA_WV_1P</td>
<td>ASA_WV_1P</td>
<td>ASA_WM_2P</td>
</tr>
<tr>
<td>L1b Imagette and Cross Spectra</td>
<td>ASA.IMS_1P</td>
<td>ASA_APS_1P</td>
<td>ASA_WS_1P</td>
<td>ASA_WM_2P</td>
<td>ASA_WM_2P</td>
</tr>
<tr>
<td>L1b Cross Spectra</td>
<td>ASA.IMS_1P</td>
<td>ASA_APS_1P</td>
<td>ASA_WS_1P</td>
<td>ASA_WM_2P</td>
<td>ASA_WM_2P</td>
</tr>
<tr>
<td>L2 Wave Spectra</td>
<td>ASA.WV_1P</td>
<td>ASA_WV_2P</td>
<td>ASA_WV_2P</td>
<td>ASA_WM_2P</td>
<td>ASA_WM_2P</td>
</tr>
</tbody>
</table>

Table: ASAR simulated product types for the pre-launch activities

6.4.1.3 **Investigation of alternative techniques to calibrate the ASAR new low & medium resolution products**

ASAR will provide new low and medium resolution products, which demand product calibration and verification strategies different from those used with the full resolution products and from those used typically with ERS.

For GMM, a new frequency offset mode is being implemented in the ASAR transponders (see Chapter 5 “Instrument Cal-Val plan” for more details on this mode).

As an alternative the accuracy of medium resolution product calibration using transponders can be assessed by the analysis of IMM and APM products simulated with ERS data and can be compared with the accuracy obtained using homogeneous distributed targets such as the Amazon rain forest.

The activities planned to define the calibration procedure for medium resolution products are the following ones (a correct implementation of the elevation antenna pattern is here assumed):

ASAR products simulated (partially or completely) with ERS data  
ASAR products simulated with PT and PRN
- Generate at least 3 IMM and APM products from ERS data over the Flevoland transponders and over the rain forest
- Use traditional IRF analysis and integration method over the transponders response to derive the calibration constant.
- Use the obtained calibration parameters to calibrate the images over the rain forest and assess the radiometric accuracy assuming that rain forest gamma nought for C-band and VV polarisation is expected to be $-6.5 \pm 0.25$ dB over the range of image incidence angles.
- On the other hand, derive the calibration constant over the rain forest images and compare with the value obtained over the transponders.
- Calibrate the images over Flevoland with the parameters obtained over the rain forest and assess the radiometric error over the transponders.
- Assess the goodness of each method and define the strategy to be followed during the CP.

During CP, verification of the cross-calibration possibility (using transponders or rain forest scenes) for medium and low resolution products shall be extended to all sub-swaths.

### 6.4.1.4 Processing optimisation and investigation of product quality anomalies

**Processing optimisation**
Investigation of optimal processing parameters was carried out in an earlier phase using preliminary instrument settings. This analysis shall be partially repeated with the final instrument settings. The main parameters to be tuned are related to ScanSAR products:
- look bandwidth
- look overlap
- number of looks
- total processed bandwidth
- Hamming window parameter
- Range reference function for GMM

**Investigation and fixing product quality anomalies**
Quality analysis of ASAR products simulated with ERS data and with PTs (using preliminary instrument settings) has allowed the detection of some processing anomalies. Further product simulation and analysis during the pre-launch campaign may point out other anomalies requiring slight changes on the processor.

Known processor anomalies include scalloping effects and Doppler ambiguity estimation errors. Analysis is on-going at MDA and for the mentioned anomalies and a solution should be implemented by beginning of June 2001.

### 6.4.1.5 PF-ASAR Auxiliary files update

The PF-ASAR requires several auxiliary files which contain instrument related information and configuration processing parameters (see section 6.2.7 for a detailed description of these files). A
preliminary version of these files was created to allow the processing of simulated datasets. However, evolution of the required instrument parameters and availability of updated instrument related information require a new version of the instrument file containing the latest pre-flight information.

Update of the auxiliary files is being carried out by MDA. Introduced changes include:
- latest on-ground elevation antenna pattern measurements, which will be used as initial antenna pattern after launch;
- new FBAQ LUTs;
- updated instrument characterisation data set (including central frequency, timeline, etc);
- availability of different azimuth antenna patterns for each beam.

During CP, update of auxiliary files content will be one of the EICF main tasks.

6.4.1.6 Validation of available tools and methodologies for product verification and calibration

It is foreseen that each team member participates to the verification and calibration of ASAR simulated products using his/her own tools for product quality analysis.

The objectives of this exercise are to cross-check the results on processor verification analysis obtained by the PF-ASAR CAL/VAL team members and to get the team feedback on upgrades/improvements of the ASAR product verification methods and tools. In addition, the aim of this activity is that all team members:
- get trained in the calibration of the ASAR products using meaningful data;
- start the modification and validation of existing tools or the development of new ones for the analysis of these products;
- verify the established methodologies with well-known data sets simulated and processed with the best possible quality.

This requires the production of large Envisat ASAR datasets containing ERS SAR data in order to validate mainly: (1) the PF-ASAR product quality (2) the interferometric capabilities of the AP mode algorithm chosen to process single look complex products and (3) the new wave cross spectra and ocean wave inversion methodologies.

6.4.2 CP ACTIVITIES

During the commissioning phase and until the validation workshop, all ASAR products will be verified and calibrated.

The following sections describe the established priorities in terms of modes and product types and the main activities to be performed per each type of product during the commissioning period.
6.4.2.1 Product verification priorities

Priorities have been established in order to concentrate first on the ASAR products that are more similar to the well-known ERS SAR products (i.e. products over swath IS2 in VV polarisation). The product verification priorities are given in the table below. IM, WV and WSM VV will be calibrated for the Commissioning Phase workshop (i.e. 6 months after the launch) and AP, WSM HH and GMM will be calibrated by the Validation Workshop (i.e. 9 months after the launch).

<table>
<thead>
<tr>
<th>ASAR PRODUCT CALIBRATION SCHEDULE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IM, VV, IS2, IMP, IMS, Pre-validated</td>
</tr>
<tr>
<td>IM, VV, IS2, IMM, IMG Pre-val &amp; IM VV, IS2, IMP, IMS Calibrated</td>
</tr>
<tr>
<td>IM, VV, Level 1, IS2, pre-validated</td>
</tr>
<tr>
<td>WV, VV, Level 1, IS1, pre-validated &amp; WV, VV, Level 1, IS2 Calibrated</td>
</tr>
<tr>
<td>IM, VV, IS1, IS3-IS7, IMP, IMS, IMM, IMG Pre-val</td>
</tr>
<tr>
<td>IM, VV, IS1, IS3-IS6, IMP, IMS, IMM, IMG Calibrated</td>
</tr>
<tr>
<td>WSM, VV, Pre-val</td>
</tr>
<tr>
<td>WSM, VV, Calibrated</td>
</tr>
<tr>
<td>AP, HH/VV/VH, HH/VV APS, APP, IS1-IS7 Pre-validated</td>
</tr>
<tr>
<td>AP, HHHV/VV/VH, HH/VV APS, APP, APM, APG, IS1-IS7 Calibrated</td>
</tr>
<tr>
<td>IM, WSM, HH, Calibrated</td>
</tr>
<tr>
<td>GMM HH &amp; VV Calibrated</td>
</tr>
</tbody>
</table>

6.4.2.2 Product verification and calibration

The complete product validation activity is divided in a first phase of basic product quality parameters verification and a second phase of calibration, where calibration indicated the conversion of instrument measurement output data into physical units. Products will be delivered to users after the first phase.

The activities required to verify and calibrate the ASAR products are described hereafter. The order of the activities reflects the sequence of analysis to be carried out on the products.

6.4.2.2.1 Product verification

6.4.2.2.1.1 Main processing parameters settings
Product verification and calibration shall be performed after setting two main processing parameters: the processing gain and the system offset frequency.

The first one is the overall processor gain and it shall be set in order to obtain a pre-established mean intensity output over a well known area such as Flevoland and verifying that no saturation over the transponders is obtained.

The system offset frequency is a sensor dependent parameter used in the Doppler ambiguity estimation algorithm. It must be established by processing an image of known Doppler ambiguity. It is planned to do that using the pre-flight Doppler frequency characterisation along the orbit and selecting an area where the expected Doppler frequency is close to zero (to ensure the absolute Doppler remains in the baseband) or using one of the transponders site.

6.4.2.2.1.2 Visual product inspection (level 1b products)

This is the first check to be performed on any Level 1b product and it provides a quick overview of the expected product quality and possible main anomalies.

Product visualisation can be performed with a large set of tools including ASAR specific ones (such as EnviView, SARCON, IECF) and standard image processing software (in the latest case, it is necessary to skip or remove the product MPH, SPH and ADSRs to obtain a standard raster binary file).

6.4.2.2.1.3 Product format and annotations verification (Level 0 & Level 1b products)

Verification of the correct product format is important to ensure complete product compatibility with all the tools available for product analysis. No major problem is expected in this area since this will have been extensively tested before launch.

Product verification can be carried out by reading the products with the available ASAR product reading tools, such as EnviView, STBX, SARCON or others, and checking that no anomalies are encountered when comparing the ingested product with the expected format.

Validation of the parameters annotated in the product requires a detailed analysis and is critical to ensure a correct further utilisation of the products.

Annotations verification requires reading the product using the above mentioned tools and comparing the value of key parameters with their expected values or with the values derived by an independent tool such as SARCON.

6.4.2.2.1.4 Raw data verification (Level 0 products)
The aim of the raw data verification is to identify any sensor anomaly that would impact on the quality of the products and which could require corrections at instrument level. This activity will be carried out in co-operation with the instrument calibration team.

The following analysis shall be performed:

**Echo, noise and calibration pulses decoding verification**

In ASAR Level 0 products, echo data is FBAQ coded, noise is S&M coded and calibration pulses are in full 8-bits format.

Before processing, these data must be decoded using specific LUT for each data type. Correct decoding by the processor needs to be verified using independent tools such as SARCON and comparing the decoded data statistics.

**FBAQ LUT verification**

Optimal matching of FBAQ LUTs to the ASAR data dynamic range will be analysed by monitoring the distribution of the block identifiers used to decode the data. The aim is to identify potential saturation at intermediate quantisation levels.

**Raw data statistics**

Statistics on I and Q channel shall be derived after FBAQ echo decoding. They include the mean value and standard deviation for I & Q channels, the IQ gain imbalance and the IQ non-orthogonality. Results are used to perform raw data correction. Values derived by PF-ASAR (annotated in the corresponding Level 1 products) will be compared with those derived by tools such as IECF and SARCON.

**Saturation analysis**

In general, no saturation is expected due to the use of the FBAQ encoding for the signal data. However, saturation level will be verified on scenes with high contrast or high backscattering peaks. In order to do that, the raw data distribution shall be analysed and the percentage of samples lying on the higher and lower quantisation bins after raw data correction shall be derived. This provides an indication of the raw data saturation level which can be solved at instrument level if necessary. A threshold shall be defined to flag the raw data as saturated when the percentage of these samples is higher than the threshold.

This activity can be performed using both SARCON and IECF.

**Noise analysis**

Noise pulses are included in the ASAR source packets and its periodicity is mode dependent. Noise information is available at least, at the beginning and at the end of each acquisition for any mode and it is periodically available during the acquisition sequence for WSM, GMM and WV.

The processor estimates the noise level from all noise pulses available on the raw data segment and annotates it in the product. No noise subtraction is performed by the processor, which does not introduce any unrecoverable radiometric error if the noise level is kept rather constant. However,
this assumption must be verified by monitoring the level of system noise per each acquisition mode and the short-term (i.e. during an acquisition segment) variation of noise.

A noise power value at the beginning of the acquisition can be estimated from the initial noise pulses available for each mode. Variation of noise power can be obtained by estimating the noise power from each periodic noise cycle during the acquisition (WSM, GMM and WV) or by monitoring the reference gain variation in reception calculated from the calibration pulses in reception (P2).

This monitoring can be performed using both SARCON and IECF.

**Calibration pulses analysis**

ASAR internal calibration strategy includes four different types of calibration pulses which are used by the processor for reconstructing the chirp replica and derive the elevation gain at the reference angle.

Calibration pulse power, phase and shape shall be monitored to detect variations in the instrument gain and sensor performance (see Chapter 5 for more details on the internal calibration pulses). This monitoring can be carried out using both IECF and SARCON. Results can be compared with those derived by the processor and annotated in the Level 1 products.

**Chirp replica reconstruction verification**

The chirp replica is reconstructed by PF-ASAR from the calibration pulses and used to perform optimal range compression. Correct chirp replica reconstruction and anomalies related to the calibration pulses can be analysed both using SARCON and IECF.

**Elevation gain at the reference angle verification**

The elevation gain is derived from the calibration pulses in transmission and reception, using the measurements from the External Characterization and the embedded row patterns to compensate for instrument gain drifts. This gain will be monitored along the orbit and throughout long acquisitions to verify instrument temperature compensation and gain stability.

**Gain droop compensation verification**

Gain Droop verification will be basically done on two issues:

- Verification of echo data compensation
- Verification of pulse P2 correction

The verification of the echo data will be done on rainforest scenes where the antenna pattern has been corrected. The remaining image additional gain will be considered due to the gain droop effect. This will be checked for all different modes where different antenna temperatures have been assumed.

For the calibration pulse P2 correction different pulses along the orbit will be considered where the different SWL and SWST timings will allow obtaining pulses before or after the echo window.
(calibration order 0 and calibration order 1). On the calibration order 0 case, the stability of the pulse extra gain will be checked. For calibration order 1 the pulse location precision and the amplitude dependance with it will also be analyzed.

6.4.2.1.5  Basic image quality parameters verification (Level 1b products)

A basic product quality assessment is obtained through the IRF analysis over transponders, corner reflectors and targets of opportunity. The obtained results for each parameter and product type shall be compared with those obtained before launch on the simulated products (see pre-launch activities) and with the product quality requirements.

The result of this analysis shall be the validation of the basic product quality parameters or the identification of quality anomalies to be investigated.

For ASAR, it is foreseen to perform this analysis using the ASAR transponders deployed in The Netherlands, the RADARSAT transponders deployed in Canada and a set of corner reflectors in different areas around the world (e.g. Germany for WSM). See Chapter 5 (“Instrument Cal-Val plan”) for more details on the locations of these targets and their revisiting frequency.

**Measurement methodology**

IRF measurements are obtained by extracting a 128 x 128 pixel sub-image centred on the point targets, deriving the mean background intensity, converting the sub-image to intensity, interpolating by a factor of 8 and subtracting the mean background intensity from the interpolated image.

In the case of complex products, it is necessary to detect the data before performing the IRF measurements. This is carried out by re-sampling the complex data by a factor of 2 and ensuring the power spectrum is completely within the sampling window. A spectrum shift is required if the spectrum is folded over from one end of the sampling window to the other.

**Spatial resolution in range and azimuth**

Spatial resolution is defined as the width of the IRF where the intensity reaches 50% of the peak value (i.e. 3dB width). It is computed as the distance between the points to either side of the peak in a one-dimensional cross-section through the impulse response function which are 3dB below the peak power. [R2]

**Peak Side Lobe ratio (PSLR)**

It is defined as the ratio of the intensity of the most intense peak of the IRF outside a rectangle of 2x2 resolution lengths and within a rectangle of 10x10 resolution lengths to the peak intensity in the mainlobe (i.e. within a rectangle of 2x2 resolution lengths). The value is expressed in dB. [R2]

Five main values can be derived, namely the near range and far range PSLR, the early and late azimuth side lobe ratio as well as the maximum PSLR.

**Spurious sidelobe ratio (SSLR)**
It is defined here as the ratio of the intensity of the most intense value of the IRF outside a rectangle of 10x10 resolution lengths and within a rectangle of 20x20 resolution lengths, to the peak intensity in the mainlobe (2x2 resolution lengths). The value is expressed in dB. [R2]

**Integrated Side Lobe Ratio (ISLR)**

The ISLR measure expresses the energy spread from the main lobe of the impulse response function into the side lobe region as a result of processor operations.

It is defined here as the ratio of the energy in the sidelobes (outside a rectangle 2x2 resolution lengths and within a rectangle of 20x 20 resolution lengths) to the energy in the mainlobe (2x2 resolution lengths. The value is provided in dB. [R2]

**Ratio of total power to peak height**

This parameter indicates the shape of the IRF and it is specified defined as the ratio of energy within the IRF mainlobe (2x2 resolution lengths) to the IRF peak value. The value is reported in dB.

Integration of results from the team members

Some of these analysis will be performed in parallel by more than one team member, using independent tools whenever possible. A cross-check between independent results will be carried out in order to derive a final value and detect any possible anomaly.

6.4.2.2.1.6 Basic radiometric quality verification

Radiometric Level 1b product characterisation and comparison with expected performance are necessary to assess the basic product quality. The activities listed below shall be performed.

**Equivalent Number of Looks (ENL)**

The ENL performance requirement is specified as a minimum permitted ENL calculated over a homogeneous region of a processed image.

The ENL of a region of imagery is defined as:

\[ ENL = \frac{\mu^2}{\sigma^2} \]

Where:

\[ \mu = \text{mean of signal power in the region} \]
\[ \sigma = \text{standard deviation of signal power in the region}. \]

This analysis can be performed both by SARCON and IECF.

**Radiometric accuracy**
It is planned to assess the radiometric accuracy using rain forest images of single calibrated beams and using transponder measurements.

In the first case, i.e. for a distributed target, the radiometric accuracy is specified as the worst case uncertainty resulting from individual cross section measurements of a uniform invariant target situated anywhere within the operating dynamic range of the system, anywhere in the swath and anywhere in the orbit, assuming that the standard deviation of the multiple sigma nought estimates in zero. [R3]

In the second case, i.e. for a point target, the radiometric accuracy is defined as the worst case 3σ uncertainty resulting from measurements of the cross section of a known point target and assuming that the standard deviation of the RCS measurements is zero. [R3]

Data acquired over rain forest and transponders on the same orbit shall be used whenever possible.

This analysis can be performed both by SARCON and IECF.

**Radiometric resolution**
Radiometric resolution is defined in dB as:

\[
\text{Rad} \ Re s = 10 \times \log_{10}(1 + q_r)
\]

where the parameter \( q_r \) is the normalised standard deviation of the intensity of a distributed target including instrument noise. [R3]

**Radiometric stability**
The radiometric stability is specified as the standard deviation of the results obtained measuring on a number of independent occasions, the radar cross section of identical invariant targets of such magnitude that the receiver noise is insignificant. A time sequence of RCS measurements over the transponders will be used to derive this parameter. [R3]

**Noise equivalent sigma nought derived from the images**
The noise equivalent sigma nought is specified as the backscattering coefficient of a uniform scene that produces an output intensity in the image equal to the thermal plus quantisation noise.

For the computation, mid-swath homogenous areas with very low backscattering response shall be used. [R3]

Noise level will also be measured using the noise samples provided at the beginning and at the end of each image sequence (for IM and AP modes) and at periodic intervals during the acquisition sequence for WSM, GMM and WV mode. See Noise Analysis description in the Raw Data Analysis section. These values will be compared with the ones obtained from the low backscattering regions.
6.4.2.2.1.7 Ambiguity performance verification

Ambiguity analysis shall be performed in azimuth and in range, using images acquired over the transponders and ground stations.

Three main parameters will be computed: the ambiguity location offset, the ambiguity radar cross section and the point target ambiguity ratio.

**Azimuth ambiguity location offset**

It is specified as [R12]:

\[
\Delta \text{AziAmb} = \frac{c R_p}{2 f_0 V_s} \frac{PRF}{PRF}
\]

where:

- \( c \) = speed of light
- \( R_p \) = slant range to point target
- \( f_0 \) = SAR frequency
- \( V_s \) = satellite velocity
- \( PRF \) = SAR Pulse Repetition Frequency

**Range ambiguity location offset**

For detected products (i.e. IMP, APP, IMM, APM, WSM and GMM) it is defined as:

\[
\Delta \text{RanAmb} = \text{GR}(R_p + Mc/2PRF) - \text{GR}(R_p)
\]

and for complex products (i.e. IMS, APS), it is defined as:

\[
\Delta \text{RanAmb} = (R_p + Mc/2PRF) - R_p
\]

with:

- \( \text{GR}(R_p + Mc/2PRF) \) = ambiguity ground range distance
- \( R_p \) = point target slant range distance
- \( M \) = positive integer (1, 2...) for the far range ambiguities and negative integer (-1, 2, ...) for the near range ambiguities.
- \( c \) = speed of light
- \( PRF \) = SAR pulse repetition frequency
- \( \text{GR}(R_p) \) = point target ground range distance

and \( \text{GR}(R) \) computed as:

\[
\text{GR}(R) = R_T (\pi / 180). \cos^{-1} \left( \frac{R_s^2 + R_p^2 - R^2}{2R_s R_p} \right)
\]

with:
R_s = satellite radius  
R_T = earth radius  
R = slant range distance

Note: The ambiguity slant range (R_p + Mc/2PRF) must be less than \(\sqrt{(R_s^2 - R_T^2)}\) for the far range ambiguities and it must be greater than (R_s – R_T) for the near range ambiguities.

**Ambiguity background radar cross section**

For detected products (i.e. IMP, APP, IMM, APM, WSM and GMM) it is defined as:

\[
\sigma_\text{amb}^0 = \frac{<I^2> \sin(\alpha_\text{amb})}{K \sin(\alpha_\text{ref})}
\]

where:

- \(\sigma_\text{amb}^0\) = ambiguity background target radar cross-section
- I = pixel digital number
- \(<I^2>\) = average pixel intensity of the ambiguity background
- K = ASAR calibration constant (product type dependent)
- \(\alpha_\text{amb}\) = ambiguity background incidence angle
- \(\alpha_\text{ref}\) = reference incidence angle

and for complex products (i.e. IMS, APS):

\[
\sigma_\text{amb}^0 = \frac{<I^2> \sin(\alpha_\text{amb})}{K \sin(\alpha_\text{ref})} \frac{1}{S_f^2} \frac{1}{G(\theta_\text{amb})^2} \frac{R_\text{amb}^3}{R_\text{ref}^3}
\]

where in addition to the above:

- \(S_f\) = sampling factor for detection of complex data
- \(G(\theta_\text{amb})^2\) = 2-way elevation antenna pattern gain for the ambiguity background
- \(\theta_\text{amb}\) = ambiguity background target look angle
- \(R_\text{amb}\) = ambiguity background target slant range
- \(R_\text{ref}\) = ASAR reference slant range distance

**Point target ambiguity ratio**

It is defined as the ratio between the ambiguity total power and the point target total power [R12].

Ambiguity analysis can be performed using SARCON.

### 6.4.2.2.1.8 Geometric accuracy verification

**Absolute location error (ALE)**)
The ALE is specified as the error in the estimate of the position of a point target. It requires accurate knowledge of the 3-D location (latitude/longitude/height) of the transponder or corner reflector used for the measurement as well as precise knowledge of the internal electronic delay in the case of a transponder. [R3]

ALE with different types of orbits is foreseen to assess the impact of the different orbits accuracy on the final ALE.

**SWST bias**
The additional delay due to the instrument electronics will be verified with measurements over corner reflectors with known exact location as baseline. Values will be cross-checked with measurements over the ASAR transponders, where the internal delay is also available.

**Swath width and position**
The swath shall be verified by measuring distances on the image between known ground features. The swath position will be characterized by the look angle at near range mid swath and far range, the swath width and the position from nadir [R2]. The minimum and maximum incidence angles will be used within the processor to set up the image margins on all stripline products (see 6.3).

**AP channel co-registration**
This is defined here as the miss-registration between the two channels of an AP product. It can be computed by deriving the precise location of a point target IRF peak in both image channels and comparing the results.

This analysis can be done using SARCON and IECF.

**AP phase characterisation**
Phase characterisation of the two channels in AP mode may be assessed from the review of point target responses. [Details TBC]

6.4.2.2.1.9 Doppler Centroid frequency verification

Errors and inaccuracies in the estimation of the fractional and absolute Doppler frequency may lead to important product quality anomalies (e.g. defocusing, location errors, scalloping, etc). It is therefore important to verify the correct estimation of the Doppler Centroid frequency by the PF-ASAR, for which different activities have been foreseen:

**Accuracy of Doppler Centroid Frequency estimation**
Defocussing encountered during the measurement of the basic image quality parameters (IRF response analysis) and scalloping effects may be an indication of errors in the estimation of the Doppler Centroid frequency and large azimuth location errors are an evidence of errors in the ambiguity number estimation.
Comparison of the Doppler frequency estimated by PF-ASAR with the one estimated by independent means such as SARCON (only fractional Doppler estimation) will be one of the possibilities for verifying the PF-ASAR Doppler estimations.

Verification of the correct absolute Doppler frequency estimation (and basically the right ambiguity number) can be carried out using the satellite attitude information (mainly yaw and pitch) which is available through a standard auxiliary file (Envisat attitude data file). Attitude data can be used to derive a geometric Doppler frequency component, which is very close to the total Doppler frequency (which includes contribution from target movement) in most of the cases. It is expected that satellite attitude information will be precise enough to roughly estimate the absolute Doppler frequency and certainly accurate enough to derive the expected ambiguity number. The advantage of such a method is that it will allow the estimation of an orbit based Doppler frequency behaviour, allowing the verification of the processor Doppler frequency at any position around the orbit. Comparison with along-orbit Doppler frequency estimated for low resolution products (WV and GM) available for most of the orbit interval and comparison with punctual Doppler frequency measures from high rate products will be performed in order to assess the accuracy and validity of the attitude-based method. [TBC]

**Doppler frequency continuity between slices (stripline products)**

The aim of this analysis is to verify that consecutive slices of stripline products, processed independently by different processor nodes, present a continuous Doppler frequency.

The analysis can be done by simple check of the stripline product annotations (Doppler frequency estimates are provided periodically) using EnviView plotting capabilities and also by using SARCON.

**Doppler frequency continuity across range (ScanSAR products)**

The aim of this analysis is to verify the continuity and accuracy of Doppler Centroid across range for ScanSAR products. This requires derivation of Doppler Centroid frequency independently for each sub-swath and comparison with the range Doppler polynomial annotated in the product by PF-ASAR.

6.4.2.2.2 **Product calibration**

6.4.2.2.2.1 In-flight elevation antenna pattern verification

ASAR products will be initially processed using the latest pre-launch estimation of the elevation antenna patterns and it will be a primary CP task to verify the accuracy of those patterns as well as their correct implementation in the processor.

Verification of the elevation antenna pattern shall be performed over homogenous areas of stable backscattering such as the Amazon rain forest and over the image range of incidence angles.

It is assumed that the radar gamma nought for C-band radar data over the Amazon rain forest is constant around $-6.5\pm 0.25$ dB both for HH and VV polarisations. Verification will therefore
consist in deriving the gamma nought profile on images acquired over the rain forest and checking it is rather constant across range [allowed variation is TBC].

Comparison of obtained gamma nought value with the expected one will provide a first indication of the calibration constant value. A more precise value is to be derived using the available transponders.

This strategy applies easily to IM and AP products, for all swaths and co-polarised products. For ScanSAR products, the accuracy of the elevation antenna pattern for SS2 to SS5 will be already verified from the image mode analysis. For SS1, in order to isolate the antenna pattern accuracy from beam merging effects, it is foreseen to use IM data acquired over SS1 (experimental mode) as well as range compressed data generated independently for each sub-swath both by the stand-alone PF-ASAR (intermediate result) and by SARCON.

6.4.2.2.2.2 In-flight elevation antenna pattern derivation

The overall approach to derive the in-flight elevation antenna pattern for ASAR is presented in Chapter 5. In this section it is discussed the verification approach based on the analysis of ASAR products over homogeneous stable areas such as the Amazon rain forest.

Image mode images will be primary used to derive the 2-way elevation antenna pattern for all the sub-swath and co-polarisation possibilities. These antenna patterns will be applicable to IM, AP co-polarised images and sub-swath SS2 to SS5 of ScanSAR products.

At least 2 ascending and 2 descending images [TBC] over a stable homogeneous area of known sigma nought will be needed for each beam. The area to be used is the Amazon rain forest although some investigations are on-going to identify additional suitable areas.

A single image elevation antenna pattern as a function of the incidence angle will be derived from each one of the images, masking the non-homogeneous areas, and the four results will be optimally combined to derive a mean elevation antenna pattern.

It is important to remark that only 2-way elevation antenna patterns can be obtained from the image analysis since there is a difference between transmit and receive antenna patterns.

For cross-polarised patterns, the stable and flat gamma nought response over the Amazon rain forest remains to be verified. Cross-polarised pattern cannot be obtained from the co-polarised patterns as they cannot be easily separated in transmit and receive patterns. Therefore, alternative methods will be initially used to derive the cross-polarised pattern (see Chapter 5 “Instrument cal/val plan” for a complete description of other possible ways to derive the elevation antenna pattern for ASAR) and it will be used to characterise the cross-polarised response over the rain forest and establish whether the area is suitable for monitoring this particular antenna pattern.

The baseline for deriving the elevation antenna pattern for SS1 will be the use of IM SS1 images acquired in experimental mode over the Amazon rain forest. The antenna pattern can be derived
from these images in the same way as for any other single beam product. In addition, in order to
identify possible radiometric or pointing inconsistencies, the different ScanSAR beams should also
be verified simultaneously. In order to do that, an independent range compressed image for each
sub-swath will be generated as PF-ASAR intermediate result or using SARCON.

Derivation of the elevation antenna pattern from image analysis can be carried out using both
SARCON and IECF.

6.4.2.2.2.3 In-flight azimuth antenna pattern derivation
In-flight azimuth antenna pattern will be verified from the azimuth spectra of data acquired over
the Amazon rain forest averaged in range.

6.4.2.2.2.4 Calibration constant determination
The calibration constant will be derived over the ASAR and RADARSAT transponders after a first
verification of the accuracy of the pre-launch elevation antenna pattern.

Verification of K for any sub-swath will be carried out both on the transponder and on the rain
forest images.

For detected on-ground projected products, the calibration constant is obtained using the response
of a transponder as follows:

\[
K = \frac{I_p}{C_F} \frac{P_A}{\sigma_{\text{nom}} \sin(\alpha_p)} \sin(\alpha_{ref})
\]

where:
- \( K \) = product calibration constant
- \( I_p \) = total power in the point target mainlobe
- \( C_F \) = relative power in the point target sidelobes = \( 1/(1+\text{ISLR}) \)
- \( \text{ISLR} \) = integrated sidelobe ratio
- \( P_A \) = on-ground product pixel area
- \( \sigma_{\text{nom}} \) = target nominal radar cross section
- \( \alpha_p \) = point target incidence angle
- \( \alpha_{ref} \) = reference incidence angle

For complex slant-range products, the calibration constant is obtained as:

\[
K = \frac{I_p}{C_F} \frac{P_A}{\sigma_{\text{nom}} \sin(\alpha_{ref})} \frac{1}{S_p^2} \frac{1}{G(\theta_p)} \frac{R_p^3}{R_{\text{ref}}^3}
\]

where:
- \( K \) = calibration constant
- \( I_p \) = total power in the point target mainlobe
C_F = relative power in the point target sidelobes = 1/(1+ISLR)  
ISLR = integrated sidelobe ratio  
P_A = slant-range product pixel area  
$\sigma_{nom}$ = target nominal radar cross section  
$\alpha_{ref}$ = reference incidence angle  
$S_F$ = sampling factor for detection of complex data  
$G(\theta_p)^2 = 2$-way elevation antenna pattern gain at point target  
$\theta_p$ = point target look angle  
$R_p$ = point target slant range distance  
$R_{ref}$ = ASAR reference slant range distance

Derivation of K over the transponders can be performed using IECF and SARCON. A set of measurements over the same subswath is required to derive the final K value. A minimum of 5 results is required to verify the stability of the results.

For low and medium resolution products (GM, IPM, IMM, WSM), K will be derived using the transponders and also images of the rain forest (with the assumption of a constant gamma nought around $-6.5 +/- 0.25$ dB). See pre-launch activities for more details. This method cannot be directly applied to APM cross-polarised products, since in this case the assumption of a constant gamma nought around $-6.5$ dB needs still to be confirmed.

For GMM, a frequency offset mode on one of the transponders will be used. Processing of those images requires a manual ingestion of the expected Doppler value (i.e. from the attitude files or from experimental along-orbit Doppler frequency behaviour for GMM) and will provide a transponder response containing minimum background contribution. Methodology to derive K on the final image remains unchanged.

6.4.2.2.2.5 ScanSAR specific calibration

Two main quality issues are specific to ScanSAR data (WSM and GMM): scalloping and beam boundary effects. ScanSAR products will be carefully analysed to characterise the level of these effects and introduce corrective measures in the processor with the aim to obtain ScanSAR products where those effects are kept below the permitted limits (see section 6.2 for the quality requirements).

These effects are being extensively investigated and characterised before launch to ensure the correct handling of the involved parameters by the processor.

Scalloping

The peak-to-peak error over homogeneous images will be measured, both on the whole swath and on the central 80%. As already mentioned, scalloping is linked to errors in the Doppler Centroid estimation or eventually to errors in the azimuth antenna pattern used as descalloping function.
The expected error in the Doppler Centroid will be derived from the measured scalloping error and feedback to the processor to verify the quality improvement with the refined Doppler frequency. In case considerable Doppler Centroid estimation errors are found, alternative or complementary measurements of the Doppler frequency will be carried out (using the expected Doppler value around the orbit or the attitude files). The azimuth antenna pattern will be verified in-flight and used by the processor to generate the descalloping function. Monitoring of the azimuth antenna pattern accuracy and use of the most recent one in the processor should avoid contribution to scalloping due to inaccuracies in the applied antenna pattern.

See section 6.2 for details on the descalloping functions applied in the processor.

**Beam boundary effects**

This radiometric error is mainly related to elevation beam pointing error. The elevation beam pointing error will be measured in the external characterisation mode and provided to the processor via the external characterisation file.

This error will be characterised by the relative radiometric error between beams and the absolute radiometric error with respect to a reference sigma nought value for the imaged area (typically the Amazon rain forest).

Improvement of beam merging effects will be possible by tuning the parameter controlling the weighting of the antenna patterns in the overlap region. The value of this parameter will be however adjusted in the pre-launch phase based on the on-ground measured antenna patterns.

### 6.4.2.3 Summary of the product verification activities

The activities to be performed to verify and calibrate ASAR products, depending on the mode and product type are summarised in the table below.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Format Verification</td>
<td>All products</td>
</tr>
<tr>
<td><strong>Raw Data Analysis</strong></td>
<td></td>
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<tr>
<td>I-Q statistics</td>
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<td>Saturation analysis</td>
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<td>Noise analysis</td>
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<tr>
<td>Calibration pulses analysis</td>
<td>All IM, AP, WSM, GMM, WV level 0 products</td>
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<td>Chirp Replica analysis</td>
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<td>Timing Monitoring</td>
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<td>Gain Droop Compensation Verification</td>
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<tr>
<td><strong>IRF analysis (based on ASAR transponders)</strong></td>
<td>IMP, IMS, IMM, IMG, APS, APP, APG,</td>
</tr>
<tr>
<td>Section</td>
<td>Method(s)</td>
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<tr>
<td>----------------------------------------------</td>
<td>-----------------------------------------------</td>
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<tr>
<td>Image quality parameters check</td>
<td>APM, WSM, GMM, WVI imagette</td>
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<tr>
<td>(resolution, peak intensity, PSLR, ISLR,</td>
<td></td>
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<tr>
<td>point target radar cross section, etc.)</td>
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<tr>
<td><strong>Ambiguity analysis (based on ASAR transponders)</strong></td>
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</tr>
<tr>
<td>Ambiguity location offset</td>
<td>IMP, IMS, IMM, APS, APP, APM, WSM, GMM</td>
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<tr>
<td>Ambiguity radar cross section</td>
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</tr>
<tr>
<td>Point target ambiguity ratio</td>
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</tr>
<tr>
<td><strong>Geometric analysis (based on ASAR transponders)</strong></td>
<td></td>
</tr>
<tr>
<td>Localisation accuracy</td>
<td>IMP, IMS, IMM, IMG, APS, APP, APM, WSM, GMM, WVI imagette</td>
</tr>
<tr>
<td>SWST bias determination</td>
<td></td>
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<tr>
<td>Swath width and position</td>
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</tr>
<tr>
<td><strong>Radiometric analysis (based on ASAR transponders)</strong></td>
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</tr>
<tr>
<td>Radiometric resolution</td>
<td>IMP, IMS, IMM, IMG, APS, APP, APG, WSM, GMM, WVI imagette</td>
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<tr>
<td>Radiometric accuracy</td>
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<tr>
<td>Radiometric stability</td>
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</tr>
<tr>
<td>ENL estimation</td>
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</tr>
<tr>
<td>NE$\sigma^0$ calculation (still water bodies)</td>
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</tr>
<tr>
<td><strong>External calibration (based on ASAR transponders)</strong></td>
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<tr>
<td>Calibration constant derivation</td>
<td>IMP, IMS, IMM, APS, APP, APG, APM, WSM, GMM, WVI imagette</td>
</tr>
<tr>
<td>Activity</td>
<td>Products</td>
</tr>
<tr>
<td>---------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>In-Flight antenna pattern monitoring</td>
<td>IMP, IMM, APP (2 patterns per product), APM (2 patterns per product), WSM (SS1). Products with no antenna correction</td>
</tr>
<tr>
<td>Rainforest acquisitions</td>
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<tr>
<td>Antenna pattern derivation</td>
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<tr>
<td>Calibration constant verification</td>
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<tr>
<td>Overall instrument gain determination</td>
<td>All IM, AP, WSM, GMM, WV level 0 products</td>
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<tr>
<td>Calibration pulses analysis</td>
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<tr>
<td>External characterisation pulses analysis</td>
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</tr>
<tr>
<td>Stripline analysis</td>
<td>IMM, APM, WSM, GMM, WVI</td>
</tr>
<tr>
<td>Doppler variation within slices</td>
<td></td>
</tr>
<tr>
<td>Doppler continuity along strips</td>
<td></td>
</tr>
<tr>
<td>Doppler evolution along the orbit</td>
<td></td>
</tr>
<tr>
<td>Radiometric continuity between slices</td>
<td></td>
</tr>
<tr>
<td>ScanSAR specific analysis</td>
<td>WSM, GMM</td>
</tr>
<tr>
<td>Radiometric normalisation inter-subswath</td>
<td></td>
</tr>
<tr>
<td>Doppler monitoring across subswaths</td>
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</tr>
<tr>
<td>Beam merging</td>
<td></td>
</tr>
<tr>
<td>Scalloping analysis</td>
<td>APP, APS, APM, WSM, GMM</td>
</tr>
<tr>
<td>InSAR performance analysis</td>
<td>IMS, APS</td>
</tr>
<tr>
<td>35-days repeat pass interferogram generation</td>
<td></td>
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<tr>
<td>Wave specific analysis</td>
<td>WVI, WVS</td>
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<tr>
<td>Spectrum peak</td>
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<td>Centre of gravity</td>
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<td>Direction and wavelength of spectrum maximum</td>
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</tr>
<tr>
<td>Doppler ambiguity monitoring</td>
<td></td>
</tr>
<tr>
<td>AP mode specific analysis</td>
<td>APP, APS, APM</td>
</tr>
<tr>
<td>Cross polarised noise level</td>
<td></td>
</tr>
<tr>
<td>Intensity imbalance</td>
<td></td>
</tr>
</tbody>
</table>

Table (continued): Activities required for ASAR verification

6.5 Work organisation
The activities to be performed during the CP will be shared between the PF-ASAR team members under ESRIN co-ordination. A detailed description of these activities is provided in the team member’s SoWs [R5-R11].

A summary of these activities with the team members involved in each one of them is provided in [R4].
7 VALIDATION OF WAVE MODE PRODUCTS

ENVISAT Wave mode Level-1 and Level-2 are the products, which will be considered during the validation activity. The Level-1 product is derived from Single Look Complex imagette using the cross spectra methodology. The cross spectra product represents an improvement on the corresponding spectra obtained from ERS. Enhancements are related to the removal of the direction ambiguity and the improvement to the signal-to-disturbance ratio, which is in the order of >20dB higher.

The Level-2 product is generated from the Level-1b complex imagette using a new inversion algorithm developed by the ESL (Expert Support Laboratory: NORUT-IFREMER) and implemented in the operational ASAR processor. The validation activities for the ASAR Wave Mode products will consist of a pre- and a post-launch activity.

7.1 Involved PIs

The work will be performed by PIs and related institutions/companies as summarised in Table 7.1. Section 7.2 lists pre-launch activities while work performed during the commissioning phase is detailed in section 7.3. The ESL carries out major activities on fine tuning the ESA algorithm and products, while the contribution of ARGOSS, ECMWF and CEPT to the validation plan is detailed in Sections 7.1.1, 7.1.2 and 7.1.3.

<table>
<thead>
<tr>
<th>AO ID</th>
<th>PI</th>
<th>PI Company/Institution</th>
<th>Co-PI Company/Institution</th>
<th>Theme</th>
</tr>
</thead>
<tbody>
<tr>
<td>162</td>
<td>D. Hauser</td>
<td>CEPT</td>
<td>IFREMER, Meteo-France</td>
<td>Airborne flights campaign (C band polarimetric RADAR),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Post-launch validation</td>
</tr>
<tr>
<td>270</td>
<td>A. Hollingsworth</td>
<td>ECMWF</td>
<td>-</td>
<td>Data assimilation, Post-launch validation</td>
</tr>
<tr>
<td>534</td>
<td>C. De Valk</td>
<td>ARGOSS</td>
<td>ECMWF, Meteo-France, NORUT IT, DLR, GKSS, Met. Office, IFREMER</td>
<td>Testing retrieval algorithms, Post-launch validation</td>
</tr>
<tr>
<td>799</td>
<td>H. Johnsen</td>
<td>NORUT IT</td>
<td>IFREMER</td>
<td>Pre-launch validation and processor presetting, Post-launch validation</td>
</tr>
</tbody>
</table>

Table 7.1: ASAR core validation programme
7.1.1 AO 534 ACTIVITIES

The team involved can be divided into two groups: developers and users. Members of the first group work at institutes involved in the development of algorithms to retrieve geophysical parameters from the SAR data. This group includes ARGOSS, NORUT IT, DLR, GKSS and IFREMER. The second group consists of institutes and companies who will apply the ocean wave spectra derived from the ASAR in their products and services. This group includes weather centres, which run a sea-state forecasting model (Meteo-France, Met. Office, ECWMF) and ARGOSS, which provides a commercial wave climate service for the offshore industry.

The main objective of this study is to inter-compare SAR derived wave spectra from different algorithms and to validate several wave spectra derived from the ASAR wave mode against buoy measurements. In the pre-launch phase, development and testing of retrieval algorithms will be done based on ASAR Level 1b and Level 2 derived from ERS-2 raw wave mode data. Results from different algorithms will be cross-compared to identify improvements for the ESA algorithm. Figures 7.2 and 7.3 show an example of products commercially distributed by ARGOSS.

Testing retrieval algorithms will be done during the commissioning phase in two stages:

- ENVISAT retrieved wave spectra will be compared with output of the global numerical wave model running at the ECMWF and with buoys. This will allow for a first assessment of the quality of both the ASAR Level 1b product, as well as of the retrieval algorithms.
- The quality of the wave spectra of ENVISAT ASAR are compared with those from ERS-2 SAR in wave mode, by using global ECMWF-WAM model spectra as a go-between.

![Figure 7.3: Annual mean significant height of swell only, in metres (© ARGOSS)](image)
Figure 7.4: Annual mean significant height of wind-sea only, in metres (© ARGOSS)

7.1.2 AO 162 ACTIVITIES

The Centre d'étude des Environnements Terrestre et Planétaires (CEPT) will carry out a field experiment using a new airborne polarimetric radar, which will take place during the ENVISAT commissioning phase. Among the objectives of the experiment:

- To validate ASAR Level 1b and Level 2 data against products generated by the experiment.
- To investigate the optimal measuring configuration in the ENVISAT ASAR wave mode (incidence, polarization).
- To cross-compare existing methods for wind estimates to refine the ESA algorithm
- To study the benefit brought by the dual-polarization (or full-polarimetric mode) to the estimate of wind and wave fields by radar.

The system will be installed on the MERLIN-IV airplane of Météo-France. STORM is a C-band radar derived from two airborne radar systems previously developed at CETP, it combines the characteristics of the mono-polarized C-Band radar RESSAC with the characteristics of the polarimetric radar RENE. STORM has been designed and built with the support of CNES and the French "Institut des Sciences de l'Univers". Figure 7.5 sketches the observation geometry of STORM.
Figure 7.5: Geometry of observations with STORM. The flight level will be approx. 2500 m. The corresponding footprint is about 900 m x 320 m.

About twenty-five aircraft flights will be performed under the ENVISAT ASAR swath (and ERS-2 if operated in tandem with ENVISAT). SLC data will be acquired for one month approximately (October-November 2001 TBC) and radar measurements carried out along a total track of about 400 km for each flight. Coincident in-situ acquisitions (see Figure 7.6 plus four buoys operated by the UK met-office and operational models such as VAGATLA operated by Météo-France) will be gathered during the campaign.
Measurements include:
- Directional spectra of the long waves in HH and VV polarization states within the ASAR swath.
- Radar cross-section measurements from low to moderate incidence angles [5-40°] in HH, VV, HV polarization states and as a function of azimuth looking angles (Within the ASAR swath).
- Wind direction from the radar cross-section measured at moderate incidence angle.
- Wind speed by using empirical functions (C-MOD for the VV polarization, modified C-MOD for the HH polarization).

7.1.3 AO 270 ACTIVITIES

The programme of work replicates adapts and extends the work carried out by ECMWF for the validation of ERS-1 and ERS-2 data products. In particular the following will be performed:
- Quality assessment of the ASAR SLC Imagette cross spectra (ASA_WVS_1P) and its derived wave level 2 product ASA_WVW_2P. Both products will be routinely produced by the ESA PDS and systematically routed to ECMWF.
• Scatter plots for the comparison of Wave Mode significant wave height and propagation direction with the WAM Analysis data, and with data from moored buoys
• Statistical comparison of collocated WAM wave spectra and ASAR wave spectra

During the commissioning phase ENVISAT data, NWP model data, and WAM data will be analysed to generate the results required for the reports. Scientific analysis will be done to formulate recommendations for algorithm development. An assimilation methodology will be developed and optimised for processing of ENVISAT data products and observation system experiments will be performed to demonstrate the impact of the ENVISAT data on analysis and forecast.

7.2 Pre-Launch

The objectives of the pre-launch validation are to:
• Establish the necessary calibration strategy for the Level 2 product.
• Perform a limited geophysical validation of the ASAR Wave Mode products simulated using ERS data in Wave and Image mode.
• Establish a preliminary setting of the ASAR wave level 1b and Level2 processing algorithm using ERS data.
• Establish and test the infrastructure for worldwide collocation and acquisition of the needed 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.

7.2.1 LEVEL 1B CROSS SPECTRA VALIDATION METHODOLOGY

The ERS acquisitions processed to ASAR Level 1 products are co-located with in situ wave information, which allows simulating Cross Spectra. The in situ data consist of directional wave spectra and wind vector and are provided by wave models or directional buoys. The comparison is then performed between simulated Cross Spectra from in situ observations and ERS SAR derived Cross Spectra. The Level1b performance statistics will be performed by comparing the wave spectral parameters from the product with in situ observation. Preliminary results indicate that the swell system, is detected and the propagation ambiguity is resolved in 80% of the cases.

7.2.2 LEVEL 2 WAVE SPECTRA VALIDATION METHODOLOGY

The ERS acquisitions will be co-located with in situ observations and wave models. The necessary calibration of algorithm will be established using part of the collocated data set (reference data set). The ERS data will be processed to Level 2 products wave spectra using the newly developed ASAR inversion algorithm. The wave spectra will be validated against wave model spectra. Wave parameters will be compared and 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.

7.2.3 ASAR LEVEL 1B FROM ERS-2 RAW WAVE MODE DATA

Four CD-ROMs containing simulated ASAR wave mode Level 1b products have been produced. Products have been processed from ERS-2 wave mode raw data and were distributed on 18/04/2001 to cal/val PIs for the pre-launch validation activities. The products will be analyzed and the processor setting will be verified and optimized. The Level 1b simulated wave mode data can be summarized as follows:

*Distributed on 18/04/2001 (Level 1b WVI-WVS products):*
- 10 products from 02/03/98 to 17/03/98 containing ERS-2 data collocated covering the Vendee Globe race (60 imagettes)
- 5 products from 01/06/1997 (95 imagettes) distributed worldwide
- 5 products 18/06/1997 (74 imagettes) covering NOAA buoys off W-coast of Canada
- 16 products of 26/06/1997 (279 imagettes) covering Hawaiian 2 products of 09/10/1997 & 25/02/1998 (29 imagettes) covering Norwegian buoys

After the PIs co-ordination meeting (27th June 2001), additional Level 1b WVI-WVS products will be available processed from ERS-2 wave mode raw data. The number of additional products is still to be defined and it is driven by the identification of the complete in-situ data set.

The possibility of adding a limited Level 2 WVW set of products is under consideration. Requirements for this data will be gathered at the ASAR Wave Cal/Val team meeting on 27/06/2001.

7.2.4 IN-SITU DATASET CONSOLIDATION

In the pre-launch phase, collocated historical data and new acquisitions of ERS Wave and Image Mode data will be gathered over a network of in-situ stations. In-situ information includes data from buoys, meteorological stations and numerical models data.
Figure 7.7: Location of preliminary selection of in-situ buoys

Figure 7.7 shows the location of a preliminary selection of in-situ stations to be used for the validation activities. This list will be refined during the pre-launch phase based on input from all participants. A final list is expected by mid February 2001. Table 7.2 and Table 7.3 provide the identification of the preliminary selection and type of measurement.

<table>
<thead>
<tr>
<th>In-Situ ID</th>
<th>Latitude and Longitude</th>
<th>In-Situ Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>F01_Brest</td>
<td>48.37, -4.55</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>RAYO_EstacafBares</td>
<td>44.06, -7.62</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>RAYO_Sisargas</td>
<td>43.49, -9.21</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>Gullfaks</td>
<td>61.2, 2.3</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>Frigg</td>
<td>59.9, 2.0</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>Ekofisk</td>
<td>56.5, 3.2</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>Sleipner</td>
<td>58.4, 1.9</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>Draugen</td>
<td>64.3, 2.8</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>Heidrun</td>
<td>65.3, 7.3</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>Norne</td>
<td>66.0, 8.1</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>Halten</td>
<td>65.05, 7.34</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>K3_UK</td>
<td>53.50, -19.48</td>
<td>Wd, Ws, H, D</td>
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<td>K4_UK</td>
<td>55.61, -12.68</td>
<td>Wd, Ws, H, D</td>
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<td>K5_UK</td>
<td>59.07, -11.40</td>
<td>Wd, Ws, H, D</td>
</tr>
<tr>
<td>WAM Model</td>
<td>Norwegian Sea</td>
<td>Wd, Ws, H, D</td>
</tr>
</tbody>
</table>

Table 7.2 Identification and location of in-situ stations in Europe. Wd = wind direction, Ws = wind speed, H = Heave spectra including spectral parameters, D = directional spectra including directional parameters.
Table 7.3 Identification and location of in-situ stations in America. Wd = wind direction, Ws=wind speed, H= Heave spectra including spectral parameters.

7.2.5 ON-GOING ACTIVITIES

Test data were generated from simulated ASAR Level 1 product (2-D swell wave spectrum and the wind speed). The SAR Image Mode wind field retrieval algorithm (version 1) is implemented and validated using data from ESA and Tromsø Satellite Station (TSS). Archived ERS Image Mode data acquired over selected buoys was processed into SLC products (CEOS format, 36 scenes, 21 scheduled for processing over US buoys). Figure 7.8 indicates the location of in-situ data collocated with the processed scenes. European buoys. Some additional data collocated with a Weather Ship (66.0N, 2.0E) are provided by TSS. Small sub-images simulating an imagette are going to be extracted and processed the Level 2 products. Achievements are incorporated into the new version of the ASAR Wave Mode Level 2 algorithm to improve the wave retrieval and to add information on the local wind field as well.

A new Level-2 algorithm SRD (v.2.2) was made available in May 2001, it reflects major latest changes that will be implemented in the operational processor. The wind estimator has been further
refined and will use the wind direction provided by ECMWF as input. If now model wind direction is available 45deg will be assumed.

Figure 7.8: In-situ data collocated with ERS-2 Image mode data

7.3 Post-Launch

The post-launch activities will consist in:

- Setting the ASAR instrument configuration in wave mode to ERS-2 like mode Swath IS2 and VV polarisation.
- Verifying the processing quality of SLC imagette (quality parameters, geo-location, phase preserving test).
- Calibrating the ASAR wave mode product using the ASAR mobile transponder transported to a dedicated wave-mode calibration site.
- Acquiring systematically over the wave mode validation test sites during the Commissioning phase, Envisat ASAR Wave Mode data.
- Establish the required calibration parameters for the Level 2 algorithm using the procedure established as part of the pre-launch cal/val activity.
- Validating by comparison parameters retrieved from Level 1 and Level 2 products (SAR cross spectra, SAR ocean wave spectra, wind speed, wind direction) with the in-situ measured wind/wave parameters and wave models as described in the pre-launch validation section.
- Comparing ASAR Wave mode Level 1 Products with equivalent products generated from ERS-2 wave mode data acquisition (half an hour time difference).
- Support an assimilation experiment of Level 2 product into NWP at ECMWF and DNMI (depend on national funding), similar to what was performed for the ERS Wave Mode product.

<table>
<thead>
<tr>
<th>Name</th>
<th>Parameter</th>
<th>Accuracy</th>
<th>Coverage</th>
<th>Resolution</th>
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<tr>
<td>ASA_WVW_2P</td>
<td>wave-mode</td>
<td></td>
<td>One product per 20 imagettes with</td>
<td>Single spectrum is made from one 5km x 5km imagette wavelength: range</td>
</tr>
<tr>
<td></td>
<td>wave spectra</td>
<td></td>
<td>imagette of 5km x 5km every 100km</td>
<td>from 20 to 1000m in 24 logarithmic steps direction: 0-360 degrees in 10</td>
</tr>
<tr>
<td></td>
<td>-wave height</td>
<td>- 1m</td>
<td></td>
<td>degree steps</td>
</tr>
<tr>
<td></td>
<td>-wind</td>
<td>- 40 degrees</td>
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</tr>
<tr>
<td></td>
<td>-wind direction</td>
<td>- 2.4 m/s</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>-wind speed</td>
<td></td>
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<tr>
<td>ASA_WVI_1P</td>
<td>Wave Mode</td>
<td>n/a</td>
<td>One product per 20 imagettes with</td>
<td>1 look in azimuth, 1 look in range for the SLC imagette. Pixel size of</td>
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<tr>
<td></td>
<td>SLC imagette</td>
<td></td>
<td>imagette of 5km x 5km every 100km</td>
<td>about 4 m (azimuth) and 7.8 m (range)</td>
</tr>
<tr>
<td></td>
<td>and imagette</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cross Spectra</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASA_WVS_1P</td>
<td>Wave Mode</td>
<td>n/a</td>
<td>Up to 20 spectra acquired every</td>
<td>wavelength range from 20 to 1000 m in 24 logarithmic steps direction 0-360</td>
</tr>
<tr>
<td></td>
<td>Imagette</td>
<td></td>
<td>100 km, product coverage 5km x 5km</td>
<td>degrees in 10 degree steps (only half real part and imaginary part of</td>
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<tr>
<td></td>
<td>Cross Spectra</td>
<td></td>
<td>minimum</td>
<td>spectra in product</td>
</tr>
</tbody>
</table>

Table 7.4 ASAR Data Products

The Level-1b and Level-2 ESA algorithms verification and consistency will be performed by the ESL (against ERS-2 acquisitions, in-situ measurements and pre-launch results), Table 7.4 describes the products to be validated. The ESL and the principal investigators will also perform the essential geophysical validation activities that include comparison to a network of buoys, stations and model data previously defined.
### 7.4 Project Milestones

<table>
<thead>
<tr>
<th>Event Description</th>
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<tbody>
<tr>
<td>Presentation of cal/val organisation and activities</td>
</tr>
<tr>
<td>Activity plan received by ESL</td>
</tr>
<tr>
<td>Presentation of results at OCEANWIND 2000 (IFREMER)</td>
</tr>
<tr>
<td>Progress mtg at IFREMER</td>
</tr>
<tr>
<td>SoW and CCN signed</td>
</tr>
<tr>
<td>Presentation of results at IGARSS 2000</td>
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<tr>
<td>DOSTAG presentation</td>
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<tr>
<td>New SRD Level 1 released</td>
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<td>TN on calibration issued</td>
</tr>
<tr>
<td>New SRD for Level 2</td>
</tr>
<tr>
<td>Dataset for Level 2 testing ready</td>
</tr>
<tr>
<td>Presentation of results at Gothenburg Symposium</td>
</tr>
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<td>Progress mtg at ESRIN</td>
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<td>ERS-2 raw wave dataset set-up, 1st slice</td>
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<tr>
<td>ASAR Level 2 processed from ERS-2 Image mode</td>
</tr>
<tr>
<td>CEPT proposal received</td>
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<tr>
<td>ARGOSS KO</td>
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<tr>
<td>New SRD v2.2 for Level 2</td>
</tr>
<tr>
<td>1st Meeting with all PIs</td>
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<tr>
<td>ERS-2 raw wave dataset set-up, 2nd slice</td>
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<tr>
<td>Refined wind estimator module</td>
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<td>2nd PI Meeting</td>
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<td>CEPT airborne experiment</td>
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