# *ASCAT Verification, Calibration & Validation Plan*

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| Doc.No. | : | EUM/MET/TEN/11/0187 |
| Issue | : | v1C |
| Date | : | 9 June 2011 |
| WBS | : | |

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# 1 INTRODUCTION

## 1.1 Purpose and Scope

This document defines the calibration, validation and in orbit verification (CVV) plan for the ASCAT on Metop B. This plan complements the more general information contained in the overall calibration and validation plan [AD1].

The aim of ASCAT CVV is to ensure that the ASCAT products meet the performance requirements and to establish, where necessary, the actual performance.

This document identifies the tasks that have to be performed in order to produce calibrated products and specifies the methods that will be used to test these in order to ensure that the requirements have been satisfied.

These tasks will take place in the Metop B SIOV and commissioning phases which follow the launch and early orbit phase (LEOP) of satellite operations.

## 1.2 Terminology

The general terminology used in [AD1] and in this document is:

- Instrument characterisation: measurement of instrument parameters needed for ground processing and monitoring

- Instrument calibration: use of well characterised internal or external stimuli to establish the transfer function of the instrument in the form of key data. Key data are a set of instrument-specific parameters required for processing of instrument raw data to calibrated level 1 products.

- Generation of calibrated level 1 products: Application of the key data to the raw measurement data in order to give products containing calibrated values.

- Retrieval: application of retrieval algorithms to the level 1 data (possibly with use of auxiliary data sets) in order to give products containing data of direct interest to users.

- Product validation: use of independent data to establish the quality of the products.

## 1.3 Applicable Documents

[AD1] EPS Cal/Val Overall Plan (EUM.EPS.SYS.PLN.02.004)
[AD2] EPS Programme End User Requirements Document (EUM.EPS.MIS.REQ.93.001
[AD3] EPS Programme System Requirements Document (EUM.EPS.SYS.REQ.93001)
[AD4] EPS System Integration Verification and Validation File: An introduction (EUM.EPS.SYS.PLN.990005)

## 1.4 Reference Documents

[RD1] ASCAT Level 1 Product Generation Function Specification (EPS.SYS.SPE.990009)
[RD2] Satellite In-Orbit Verification (SIOV) Plan (not available at the moment)
[RD3] EPS Verification and Validation Plan (EUM.EPS.SYS.PLN.01.003)
[RD4] EPS Reference Operations Plan (EUM.EPS.SYS.PLN.00.002)
[RD5] EPS Program LEOP and Commissioning Management Plan (EUM.EPS.SYS.PLN.03.002)
[RD6] ASCAT Instrument Technical Description (MO-RP-DOR-SC-0001)
[RD7] ASCAT Calibration and Characterisation Plan (MO-PL-DOR-SC-0010)
[RD8] ASCAT In-flight Performance Verification Plan (MO.PL.DOR.SC.0072)
[RD9] ASCAT FM1 Performance Budget AS-14 (MO.TN.DOR.SC.0231)
[RD10] EPS/MetOp Programme, Single Space Segment, Satellite System Requirements (MO_RS-ESA-SY-0023)
[RD11] ASCAT Calibration and Validation Plan (EUM.EPS.SYS.PLN.01.011)

## 1.5 Acronyms

AGPO – antenna gain pattern and orientation
CVF – cal/val facility
CVV – calibration, validation and verification
CQR – commissioning quality report
DPS – data processing software
ECMWF – European Centre for Medium Range Weather Forecasting
GAPE – transponder gain at angular position
GCM – gain compression monitoring
H-SAF – hydrology satellite applications facility
LEOP – launch and early orbit phase
NTG – normalisation table generation
OSI SAF – ocean and sea ice satellite applications facility
PGP – power gain product
PPF – product processing facility
RMS – root mean square
SAF – satellite application facility
SIOV – satellite in-orbit verification
TCE – technical computing environment

# 2 ASCAT INSTRUMENT AND PRODUCTS

This section gives an overview of the ASCAT instrument, its products and requirements.

## 2.1 Instrument description

The ASCAT is a real aperture, vertically polarised C-band radar designed to measure the ocean surface backscatter with high radiometric accuracy and stability. Measurements are made in two swaths which are located on the left and right hand side of the satellite nadir track. Three antennas view the left hand swath and three antennas view the right hand swath.

ASCAT transmits long pulses with linear frequency modulation at a carrier frequency of 5.225 GHz. The received echoes are Fourier-transformed on board to give a power spectrum where the frequency components correspond to slant range. These are then averaged in range and azimuth, and transmitted to ground. Background noise is also measured by the antenna and similarly averaged.

Internal calibration is performed on board and a measure of the transmitted power combined with the receiver gain is calculated. This is transmitted to the ground so that it can be used in subsequent processing to compensate for any variation.

A detailed technical description of the instrument can be found in [RD6].

## 2.2 Level 1b Products

On ground, the power echoes are corrected for variations in transmit power and receiver gain. Corrections are also applied to remove the across swath ASCAT filter shape variations. An estimate of the noise is subtracted from the measurement. Normalisation factors are applied to convert the raw measurements into calibrated power and spatial averaging (smoothing) in the along and across track directions is applied at a set of grid points with the objective of obtaining a set of three backscatter values (from the fore, aft and mid beams) at each grid point.

The smoothing is performed at two different scales resulting in two products. Smoothing at 50 km resolution on a 25 km spacing grid gives the nominal ASCAT level 1b product, Smoothing at 25 to 34 km resolution on a 12.5 km spacing grid gives the high resolution product.

An additional full resolution product is also generated which consists of the individual backscatter values without any smoothing. This product is not distributed in near real time but is archived and accessible to users on request.

The level 1b products are produced at Eumetsat and distributed to users via the Eumetcast system.

## 2.3 Level 2 Products

Ocean backscatter models in which the ocean backscatter is a function of incidence angle, wind direction (with respect to the radar look direction) and wind speed have been developed over many years using data from the ERS 1 and 2 scatterometers.

The retrieval of wind speed from the three backscatter measurements is an inversion problem: given three backscatter values from the fore mid and aft beams, the wind vector is found that, according to the geophysical model function, has the highest probability of representing the true wind. An inversion problem presented in these probabilistic terms is usually equivalent to the minimisation of a cost function. As backscatter in the upwind and downwind directions is similar, two possible (ambiguous) solutions are typically found.

Level 2 products containing the retrieved wind speed products will be produced by the Ocean and Sea Ice Satellite Applications Facility (OSI-SAF). Two products, derived from the nominal and high resolution level 1b data, will be produced. Product quality and ambiguity removal information will be also be calculated and stored in these products.

Over land, the backscatter response is generally influenced by surface soil moisture, surface roughness (including soil type and land use) and vegetation. The last two of these are either static or have a known inter-annual signal. Their behaviour can be thus incorporated into a parameter database containing a statistical characterisation of the backscatter variability over any geographical location over land. Furthermore, vegetation has an incidence-angle signature that can be characterised.

Any remaining variability in the measured backscatter is assumed to be due to soil moisture variations with maximum backscatter values for a given location assumed to correspond to the surface soil wettest conditions, while minimum values are assumed to correspond to the surface soil driest conditions. For every instantaneous backscatter measurement over that location, it is thus possible to derive a surface soil moisture index, which can be interpreted as a degree of saturation in the upper soil.

Level 2 soil moisture products are currently produced in the EPS ground segment. At the time of the Metop B launch the Hydrology SAF (H-SAF) has the responsibility for maintaining the parameter database.

## 2.4 Requirements

Based on the information provided in [RD9] and [RD10], a summary of the requirement and performance budget levels of the parameters is provided in the following tables for the nominal (50km) and high (25km) resolution products.

For the 25 km resolution product, the figures are considered as a goal or target and do not apply strictly as requirements.

| Performance parameter | Unit | Requirement | Budget value |
|---|---|---|---|
| Spatial resolution | km | < 50 | < 50 |
| Spectral resolution | 1/km | > 0.0182 | > 0.0183 |
| Sampling interval | km | ≤ 25 | 25 |
| Radiometric resolution (Kp) (*) | | | |
| Mid Beams | | | |
| Near Low Cross Wind | % | < 3.00 | 2.75 |
| Near High Up Wind | % | < 3.00 | 2.67 |
| Far Low Cross Wind | % | < 7.92 | 3.03 |
| Far High Up Wind | % | < 3.00 | 1.97 |
| Side Beams | | | |
| Near Low Cross Wind | % | < 4.52 | 2.42 |
| Near High Up Wind | % | < 3.00 | 2.08 |
| Far Low Cross Wind | % | < 9.86 | 5.29 |
| Far High Up Wind | % | < 3.00 | 2.22 |
| Dynamic Range | dB | - | ok |
| Inter-beam radiometric stability | dBpp | < 0.46 | ≤ 0.465 |
| Radiometric accuracy | dBpp | < 0.57 | ≤ 0.465 |
| Aliasing | % | < 1.0 | ≤ 0.014 |
| Centre frequency | GHz | 5.255 | 5.255 |
| Swath length | - | Continuous | ok |
| Full performance swath width | km | 500 | 500 |
| Reduced performance swath width | km | 550 | 550 |
| Elevation angle at mid swath | - | Constant | ok |
| Localisation accuracy | km | < 10 | ≤ 4.11 |
| Polarisation | | VV | ok |
| Cross-polarisation | dB | ≥ 15 | 37.9 |
| Antenna azimuth angle values | | | |
| Right swath | deg | 45, 90, 135 | 45, 90, 135 |
| Left swath | deg | 225, 270, 315 | 225, 270, 315 |
| (*) Low wind speed corresponds to 4 m/s and High wind corresponds to 24 m/s | | | |

*Table 1. Level 1b performance requirements for 50 km resolution product.*

| Performance parameter | Unit | Goal | Budget value |
|---|---|---|---|
| Spatial Resolution | km | < 25 | < 34 |
| Spectral Resolution | 1/km | > 0.0364 | ≥ 0.026 |
| Sampling interval | km | 12.5 | 12.5 |
| Radiometric resolution (Kp) (*) | | | |
| Mid Beams | | | |
| Near Low Cross Wind | % | < 4.75 | 5.67 |
| Near High Up Wind | % | < 6.00 | 5.46 |
| Far Low Cross Wind | % | < 13.80 | 6.30 |
| Far High Up Wind | % | < 6.00 | 3.65 |
| Side Beams | | | |
| Near Low Cross Wind | % | < 7.36 | 4.82 |
| Near High Up Wind | % | < 6.00 | 3.62 |
| Far Low Cross Wind | % | < 16.50 | 11.41 |
| Far High Up Wind | % | < 6.00 | 4.26 |
| Dynamic range | dB | - | ok |
| Inter-beam radiometric stability | dBpp | 0.46 | 0.49 |
| Radiometric accuracy | dBpp | 0.57 | 0.48 |
| Aliasing | % | < 1.0 | ≤ 0.022 |
| Centre frequency | GHz | 5.255 | 5.255 |
| Swath length | - | Continuous | ok |
| Full performance swath width | km | ≥ 500 | 500 |
| Reduced performance swath width | km | ≥ 550 | 550 |
| Elevation angle at mid swath | - | Constant | ok |
| Localisation accuracy | km | < 10 | ≤ 4.11 |
| Polarisation | | VV | ok |
| Cross-polarisation | dB | > 15 | 37.9 |
| Antenna azimuth angle values | | | |
| Right swath | deg | 45, 90, 135 | 45, 90, 135 |
| Left swath | deg | 225, 270, 315 | 225, 270, 315 |
| (*) Low wind speed corresponds to 4 m/s and High wind corresponds to 24 m/s | | | |

*Table 2. Level 1b performance targets for 25 km resolution product.*

# 3 CVV PHASES

Calibration, validation and verification activities can be split into several phases which are described in detail in [AD1]

Phases A and B are the pre-launch and the launch and early orbit phase (LEOP). These involve the development and configuration of cal/val tools, and the definition of cal/val procedures.

Phase C, the commissioning phase, is split into two parts. It starts with the satellite in-orbit verification (SIOV) during which instruments are switched on, characterised and verified against the applicable instrument specifications. Following this is the in-orbit system calibration and validation (cal/val) phase. The activities described in this document will be performed during the SIOV and cal/val phases.

In phase D, regular operations, the quality of the ASCAT products is monitored, maintained and if possible improved, according to state of the art requirements and research in the scatterometry applications field.

# 4 CAL/VAL ACTIVITIES

The activities that have to be performed during the commissioning phase in order to give calibrated products and to ensure that these satisfy requirements are:

1. Internal calibration – locking of calibration constants
2. Level 1a product – monitoring of instrument telemetry
3. Level 1a product – reference function monitoring
4. Initial calibration – verification and refinement
5. Gain compression monitoring
6. External calibration – generation of normalisation tables
7. External calibration – geolocation accuracy assessment
8. External calibration – monitor ASCAT pulse shape
9. Level 1b product – monitoring of swath geometry
10. Level 1b product – validation using rainforests
11. Level 1b product – validation using ocean
12. Level 1b product – validation using sea ice
13. Level 1b product – quality flags assessment
14. Tuning and modification of product generation
15. Overall assessment and reporting

Note that additional activities involving the calibration and validation of the level 2 wind and soil moisture products will be performed by the OSI-SAF and H-SAF. These give valuable information regarding the quality of the level 1b data and will be considered in the final two activities on the above list.

The tuning and modification step allows the results of the various tests to feed back into product generation so that products can be improved. The final activity results in a document that details the outcome of the commissioning phase and will be made available to users

Many of the above activities are also required during the regular operations phase. In particular:

- Gain compression monitoring will be repeated at approximately monthly intervals to ensure that the SSPA drive level is appropriately set.
- External calibration will repeated approximately every 2 years to verify the accuracy of the calibration.
- Level 1a and level 1b products will be routinely monitored to detect any problems as soon as they occur.
- Level 1b and level 2 validation will be performed in order to ensure the quality of the products and detect any calibration problems.
- Tuning and modification will be carried out as required in order to maintain or improve product quality.
- Assessment and reporting will be performed at yearly intervals in order to detail the state of the instrument and the expected quality for users of the data.

## 4.1 Internal calibration – locking of calibration constants

The aim of this activity is to determine the values for the internal calibration constants. These are used by the processor to produce level 1a and 1b products.

The constants are determined by choosing them so that the power gain product produced by the processor has a value of 1 at a reference point and time. The reference point is taken to be over the transponders test site and the reference time will be shortly after the satellite enters the commissioning phase. Note that the reference time should also be approximately 5-10 orbits after instrument start up in order to ensure that it has reached thermal equilibrium.

The main input to this activity is a selected level 0 file which covers the reference point and time. This will then be processed off line with various values of the internal calibration constants until the output power gain product in all beams has a value of 1. The main output is the set of 6 calibration constants which will then be inserted into the auxiliary data used by the processor in the ground segment.

Summary:
- Inputs – level 0 data containing reference time and position.
- Outputs – a set of 6 calibration constants (one for each beam).
- Required resources – TCE, ASCAT PPF, product reader software.
- Method – process level 0 data with various values for the constants until the power gain product contained in the output level 1a data is 1 in all beams.
- Schedule – one off activity to be performed as soon as possible after instrument switch on.

## 4.2 Initial calibration – verification and refinement

The initial calibration for ASCAT-B is set by using the receiver gain setting and normalisation tables from the ASCAT-A. As the two instruments are similar this should give an initial calibration of acceptable quality.

The aim of this activity is to check the quality of the initial calibration by examining the backscatter from ASCAT-B over rainforest areas and comparing it against the values given by ASCAT-A.

Experience has shown that over rainforest areas the parameter $\gamma_0 = \sigma_0/\cos\theta$ is approximately stable (with respect to time, incidence angle, azimuth angle and location) and has a value of around -6.5 dB. Hence, if we calculate this parameter using data over the rainforest we can
- estimate the absolute radiometric accuracy,
- compare the values from each beam to determine their relative radiometric accuracy,
- compare against the values from the ASCAT-A to determine the relative calibration between the two instruments.

If the initial calibration is found to less accurate than expected (i.e. it produces $\gamma_0$ values that differ significantly from those produced by ASCAT-A) then a decision will be made whether or not to refine the initial calibration by using the cross calibration method described in

Appendix A. Factors in the decision will be the magnitude of the difference in $\gamma_0$ values, the time required to perform a full calibration using the transponders and the views of the data users.

Summary:

- Inputs – several weeks of level 1b data over rainforest from the two ASCATs
- Outputs – estimates of absolute and relative radiometric accuracy, assessment of the relative calibration between the two ASCAT instruments.
- Required resources – reader and analysis software running on CVF or TCE.
- Method – extract rainforest data, calculate mean $\gamma_0$ values as a function of incidence angle, compare against the values from ASCAT-A, generate reports.
- Schedule – to take place as soon as enough calibrated data is available (approximately 2 weeks).

## 4.3 Level 1a product – instrument telemetry monitoring

The objective of this activity is to monitor the instrument telemetry contained in level 1a products so that reasonable performance and product quality limits can be established. A secondary objective is to allow the time behaviour of the measurements to be examined and correlated with other time series of interest.

This is achieved by using data processing software (DPS) on the CVF to read telemetry data from level 1a products and write it into a database. The DPS then uses the database to generate reports showing the behaviour over time of the telemetry data. If time series of other measures are available (e.g. from other applications storing information into the database) then the DPS can be modified as required to report correlations.

Summary:

- Inputs – regular flow of level 1A products containing telemetry data.
- Outputs – updated database, regular reports.
- Required resources – CVF, DPS
- Method – use CVF to regularly run a DPS which extracts telemetry from level 1a products, stores it in data base and generate reports.
- Schedule – daily during commissioning and routine operations.

Note:
The level 1a products currently do not contain telemetry data as this part of the processor has not yet been activated. Telemetry data is routinely monitored by the satellite operators although this is only to monitor safe limits rather than to determine performance and product quality limits.

## 4.4 Level 1a product validation – reference function monitoring

The PPF calculates a number of reference functions and parameters which are stored in level 1a products and used in the calculation of calibrated level 1b backscatter. These include the receive filter shape ($h_{rx}$), power gain product (PGP) and noise. The aim of this activity is to monitor these so that a warning can be raised if they go outside accepted limits. A secondary objective is to allow their time behaviour to be examined and correlated with other measurements of interest.

This is achieved by using data processing software on the CVF to read the reference functions from 1a products and write them to a database. The DPS then uses the database to generate reports showing the recent behaviour of the reference functions. If other time series of interest are available (e.g. from other applications storing information into the database) then the DPS can be modified as required to report correlations.

Summary:

- Inputs – flow of level 1a products containing reference functions.
- Outputs – updated database, regular reports.
- Required resources – CVF, DPS.
- Method – use the CVF to regularly run DPS which extracts reference function data level 1a products, stores it in a database and generate reports.
- Schedule – daily during commissioning and routine operations.

## 4.5 Gain compression monitoring

The aim of this activity is to check that the SSPA drive level setting is within the allowed range and at a suitable level.

In order to do this, the ASCAT instrument is operated in measurement mode with a sequence of different drive level settings. The effective transmitted power at each setting can then be calculated from data in the instrument source packet. The drive level and the effective transmitted power are then used to produce two summary parameters, namely

- $p_{test}$ – which measures the linear behaviour of the transmitted power with regard to drive level setting, and
- $z_{gain}$ – which measures the deviation of the transmitted power from the nominal value.

If ASCAT is operating safely then the values of these parameters should not go beyond prescribed thresholds. If the ASCAT operates for too long in overdrive then the SSPA may be destroyed.

Values for $p_{test}$ and $z_{gain}$ are automatically produced by the ASCAT PPF whenever it detects a compression gain sequence and written to GCM products. Hence, a set of GCM files can be used to generate plots showing the behaviour of the $p_{test}$ and $z_{gain}$ as a function of time.

Summary:

- Inputs – set of GCM files.
- Outputs – reports containing time series plots.
- Resources required – product reader and analysis software running on CVF or TCE.
- Method – extract $p_{test}$ and $z_{gain}$ values from GCM data, plot in the form of a time series.
- Schedule – after the production of each new GCM file (approximately monthly).

## 4.6 External calibration – normalisation table generation

The aim of this activity is to calculate the normalisation factors that are used during the level 1b processing to convert the raw ASCAT measurements into calibrated backscatter. The normalisation factors are obtained by analysing the data from three transponders which are located in Turkey.

Whenever the transponder detects a signal from ASCAT it transmits back a time delayed copy with known signal strength. As ASCAT passes overhead, the transponder cuts through the beam produced by the antenna and hence the transponder signal received by ASCAT varies depending on where the transponder is located in the antenna gain pattern.

Given a sufficient number of passes (from at least two months of transponder operation) the gain pattern is adequately sampled and a model can be fitted to the data.

If we take a value of 1 for the surface backscatter coefficient, then the gain model allows the theoretical signal detected by ASCAT to be calculated. Dividing the actual ASCAT measurement by the theoretical value gives an estimate for the actual backscatter coefficient. Hence the theoretical value calculated from the gain model is the required normalisation factor that converts measurements into calibrated backscatter. Tables of normalisation values are calculated at multiple locations around the orbit in order to take into account height and geometry variations and these are interpolated to find the normalisation values at any required position.

The three steps in this procedure are referred to by GAPE (transponder gain at angular position), AGPO (antenna gain pattern and orientation) and NTG (normalisation table generation). The ASCAT PPF produces GAPE data whenever it detects that the satellite has switched into calibration mode. The AGPO step is performed offline using a set of GAPE data. The NTG step was initially an offline procedure but, in order to cope with non-frozen orbits, is now performed by the ASCAT PPF in real time whenever the orbit state vector is updated.

Summary:

- Inputs – one or two months of GAPE data.
- Ouputs – antenna gain model for use with ground segment PPF.
- Required resources – offline quality control software running on TCE, offline AGPO software running on TCE.
- Method – apply quality control measures to GAPE data (to reject passes where there were transponder problems), perform AGPO to determine antenna gain model and orientation.
- Schedule – following every calibration campaign (approximately every 1-2 years).

## 4.7 External calibration – geolocation accuracy assessment

The aim of this activity is to determine the accuracy of the latitudes and longitudes produced by the geolocation algorithm used by the ASCAT PPF.

This is achieved by examining calibration mode data to find the peak in the transponder signal. The time and frequency location of the peak are then used by the geolocation algorithm to estimate the latitude and longitude of the transponder. These can then be compared to the exact, known, transponder position. This is automatically performed as part of the GAPE processing. Given a set of GAPE data, a statistical difference between the measured and known transponder position can be determined. This is expected to be better than the node spacing in the full resolution data, i.e. less than 4 km.

Summary:

- Inputs – set of GAPE data.
- Outputs – estimate of the geolocation accuracy.
- Resources – reader and analysis software running on CVF or TCE.
- Method – extract estimated transponder location from GAPE data, calculate RMS difference between actual and estimated position.
- Schedule – after the production of every CAL file (approximately daily during a calibration campaign, approximately monthly during routine operations).

## 4.8 External calibration – monitor ASCAT pulse

The aim of this activity is to examine the ASCAT transmit pulse shape in order to ensure it is behaving as expected and does not differ significantly from the pulse shape used in the GAPE and NTG calibration steps.

When the transponders receive a signal from ASCAT they save a copy to a data file and send back a time delayed copy of known strength. The behaviour of the ASCAT transmit pulse shape is therefore determined by examining the data produced by the transponders.

Of particular interest are the central frequency, power spectrum and shape of the pulse. The shape of the pulse is expected to change over the lifetime of the instrument and if it deviates too much from the values used by the GAPE and NTG then the auxiliary data will need to be updated.

Summary:

- Inputs – transponder data files.
- Outputs – time series of transmit pulse characteristics, difference between actual and nominal characteristics.
- Resources – offline analysis software on TCE.
- method – process the data files and determine pulse characteristics, plot behaviour over time, compare to nominal values.
- Schedule – approximately yearly, or following a calibration campaign.

Note:
The analysis software to perform the activity has not yet been created. The pulse shape characteristics are expected to vary only slowly with time and hence this activity has been regarded as low priority.

## 4.9 Level 1b product – swath geometry monitoring

The aim of this activity is to monitor the geometrical characteristics of the level 1b data (in particular the incidence angles, azimuth angles and node spacing) to ensure that these meet requirements and to detect any problems.

This is achieved by using data processing software on the CVF to read the necessary information from 1b products and write it to a database. The DPS then uses the database to generate reports showing the recent behaviour. If predefined thresholds are exceeded then a warning can be raised.

Summary:
- Inputs – Level 1b products.
- Outputs – updated database, reports.
- Required resources – CVF, DPS.
- Method – use the CVF to regularly run DPS which extracts geometry information from level 1b products, saves it to a database and generates regular reports.
- Schedule – daily during commissioning and routine operations.

## 4.10 Level 1b product – validation using rainforest

The aim of this activity is to assess the radiometric accuracy and stability using rainforest backscatter.

Experience using previous scatterometers has shown that over Amazon rainforest areas the parameter $\gamma_0 = \sigma_0/\cos\theta$ is approximately stable with respect to time, incidence angle, azimuth angle and location and has a value of around -6.5 dB. Hence, if we calculate this parameter using ASCAT data over the rainforest we can then

- examine its behaviour with respect to incidence angle,
- compare the $\gamma_0$ values from each of the six beams to determine their relative radiometric accuracy,
- examine $K_p$ statistics as a function of backscatter and incidence angle,
- repeat this procedure at regular intervals in order to monitor the behaviour of the instrument and assess its radiometric stability.

Additionally, comparison of the $\gamma_0$ values against those from the ASCAT on Metop A will show the relative calibration between the two instruments.

Summary:
- Inputs – level 1b data over rainforest.

- Outputs – estimates of absolute and relative radiometric accuracy, assessment of the radiometric stability, assessment of the relative calibration between the two ASCAT instruments.
- Required resources – reader and analysis software running on CVF or TCE.
- Method – extract rainforest data, calculate mean $\gamma_0$ values as a function of incidence angle and as a function of time, compare mean $\gamma_0$ against those from Metop A, generate reports.
- Schedule – to take place as soon as a large enough set of calibrated data is available (approximately one month) and to be performed at regular intervals (approximately monthly).

Note:
Results from the ASCAT on Metop A suggest that rainforest $\gamma_0$ is not constant but decreases slightly as incidence angle increases. The inconsistency between these results and those from the scatterometers on ERS-1 and 2 is currently a topic of investigation.

## 4.11 Level 1b product – validation using ocean

The aim of this activity is to assess the radiometric accuracy and stability of ASCAT using the ocean calibration technique.

A number of empirical ocean backscatter models have been developed using data from previous scatterometers. These give the ocean backscatter as a function of incidence angle, wind speed and azimuth angle (between radar look direction and wind direction). Given an estimate of the wind vector (e.g. from ECMWF wind fields) these can be used to simulate $\sigma_0$ values that can then be compared to the actual $\sigma_0$ values given by ASCAT. The bias between model and data then gives an estimate of calibration accuracy.

In a similar manner to the rainforest validation we can
- examine the bias with respect to incidence and azimuth angles to determine if it is constant,
- estimate the absolute radiometric accuracy of each beam,
- estimate the relative radiometric accuracy between beams,
- examine $K_p$ statistics as a function of backscatter and incidence angle,
- investigate standalone calibration/validation methods without the use of external wind fields,
- investigate the impact of ocean currents,
- repeat this procedure regularly to assess the instrument radiometric stability,
- assess the relative radiometric accuracy between the instruments on Metop A and B.

Summary:
- Inputs – level 1b data over ocean, ECMWF wind fields, ocean backscatter model.
- Outputs – estimates of absolute radiometric accuracy, estimates of relative radiometric accuracy (between beams and between instruments), assessment of the radiometric stability.
- Required resources – reader software, analysis software running on CVF or TCE.

- Method – extract ocean data, use ECMWF wind fields to simulate $\sigma_0$, calculate bias between model and actual $\sigma_0$, generate reports showing bias in each beam and over time.
- Schedule – approximately monthly.

Note:
Ocean backscatter models have generally been developed from ERS scatterometer data which covers an incidence angle range of 19 to 55°. This is different from the 25-65° incidence angle range of ASCAT and hence the models may be inaccurate when extrapolated to large incidence angles.

## 4.12 Level 1b products – validation using sea ice

The aim of this activity is to assess the radiometric accuracy and stability of ASCAT using backscatter from regions of stable sea ice.

Analysis using ERS data has shown that some regions of sea ice are stable and can be accurately modelled. In particular de Haan & Stoffelen (2001) show that the backscatter from stable sea ice at any given incidence angle lies along a line in the three dimensional measurement space given be the fore, mid and aft backscatter values. The position along the line is found to be related to the age of the sea ice and they derive a model that gives the backscatter as a function of incidence angle and ice age.

Areas of stable sea ice can be located in ASCAT data by looking for regions where the mean difference between fore and aft beam backscatter values is small and has low temporal variability. As we have no knowledge of the age of the stable sea ice it is not possible to simulate the backscatter and investigate the bias between model and data. However, comparing a set of $\sigma_0$ values at a particular incidence angle against the ice line can give information about the relative bias between beams and between instruments. Also, by looking at the RMS difference between the data and the best fitting line we can convert this into a Kp value which can be compared to the ASCAT requirements.

Summary:
- Inputs – level 1b data over the Arctic and Antarctic.
- Outputs – estimates of relative radiometric accuracy (between beams and between instruments), assessment of the radiometric stability, estimate of Kp.
- Required resources: reader and analysis software running on CVF or TCE.
- Method – find regions of stable sea ice, examine difference between data and model, examine RMS difference between data and best fitting line, generate reports showing results.
- Schedule – approximately monthly.

## 4.13 Level 1b product – monitoring of quality flags

The aim of this activity is to assess the flags in the level 1b product to ensure that they are correct and behaving as expected.

The quality flags are provided for every $\sigma_0$ value and are:

- fs – indicates if any synthetic data has been used in the calculation of the backscatter or the reference functions. Also indicates if the data comes from the beginning or end of an ASCAT instrument operation where extrapolated reference functions are used.
- fv – indicates the quantity of synthetic data used,
- fsa – indicates if the data may be corrupted by solar array reflections,
- ftel – indicates if all telemetry is present and within expected ranges,
- fext – indicates if an extrapolated Rx filter shape has been used to correct the data,
- fland – indicates the fraction of land within a node area,
- fkp – indicates the quality of the Kp estimation,
- fs0 – summary flag indicating good, usable or bad .

During commissioning the behaviour of these flags will be inspected with respect to swath, time and geolocation and checked to ensure that they behave as expected (e.g. fsa will be checked to ensure that it only occurs over the equator, fs will be checked to ensure that it is only raised around the times when ASCAT turns on or off, fkp will be checked to ensure that it is only large over coast or land). During regular operations summary statistics will be regularly produced and inspected in order to detect any problems.

Summary:
- Inputs – level 1b data.
- Outputs – reports containing an analysis of flag behaviour and flag statistics.
- Resources – reader and analysis software running on CVF or TCE
- Method – extract flag information from level 1b data, analyse with respect to time, swath and geolocation to produce summary statistics and reports.
- Schedule – detailed investigation during commissioning, daily monitoring during routine operations.

## 4.14 Tuning and modification of product generation

The aim of this task is to review the results from all cal/val activities in order to determine if the products meet the requirements and the calibration is acceptable. The most important inputs for this are the results of the level 1b cal/val activities described in the preceding sections and results of the level 2 validations performed by the OSI-SAF and H-SAF.

If problems are found and can be quickly fixed then this will take place during the commissioning phase. The relevant cal/val activities will then be repeated in order to ensure that the quality has improved. If the problem is regarded as minor then the data may be released “as is” and the problem corrected at a later date.

The level 2 validations performed by the OSI-SAF and H-SAF include:

- Tuning wind retrieval to ASCAT-B data – creation of bias correction tables which allow wind vectors to be retrieved from ASCAT-B data using the ocean backscatter model that is currently in use with ASCAT-A data.
- Validation using triple collocation – inter-comparison of winds retrieved from ASCAT data, buoy measurements and ECMWF model wind fields.

- Monitoring of quality flags – inspection of flags in the wind product ensure that they are correct and behaving as expected.
- Tuning of soil moisture retrieval to ASCAT-B data – determination of bias corrections which allow the soil moisture parameter database developed for ASCAT-A to be used for data from ASCAT-B.
- Validation of soil moisture products – analysis of surface soil moisture values retrieved from ASCAT-B data along with in situ and model values.

## 4.15 Overall assessment and reporting

This activity takes place at the end of the commissioning phase and brings together the results from all the individual activities so that they can be presented in a single document, the commissioning quality report (CQR).

The CQR will contain

- introduction,
- overall assessment and recommendations for the operational phase,
- internal calibration report – locking of calibration constants,
- external calibration report – transponder calibration and generation of normalisation tables,
- level 1a product assessment – behaviour of telemetry and reference functions,
- level 1b product assessment – swath geometry assessment, rainforest validation, ocean validation, sea ice validation, flag assessment,
- level 2 wind product assessment – bias corrections, triple collocation, quality flag assessment.
- level 2 soil moisture product assessment – bias correction, validation.

# 5 REQUIRED RESOURCES

The calibration and level 1b validation activities described in this document will be performed by members of the ASCAT virtual team. This currently consists of

- Jens Lerch (ASCAT & transponder operations),
- Julia Figa (ASCAT product expert, PPF operations),
- Hans Bonekamp (ASCAT mission scientist),
- Craig Anderson (ASCAT calibration and validation),
- Colin Duff (ASCAT PPF maintenance and development),
- Leonid Butenko (ASCAT Level 2 soil moisture PPF maintenance and development),
- Julian Wilson (ASCAT instrument scientist).

The EUMETSAT facilities required to perform the calibration and level 1b validation activities are:

- EPS ground segment – operational production of ASCAT products,
- cal/val facility (CVF) – daily monitoring of products produced by the ground segment,
- technical computing environment (TCE) – general purpose facility for testing and development of the ASCAT PPF, investigating ASCAT products, performing the external calibration, validating the calibration, storage space for data sets.
- ground based transponders – three transponders which track the satellite, record the ASCAT signal and transmit a signal of known gain back to the satellite.

A number of file readers are required to support the cal/activities. These have all been developed, are capable of working on both the TCE and CVF and are:

- level 0 reader (required for locking of cal constants),
- level 1a reader (locking of cal constants, telemetry monitoring, reference function monitoring, monitoring of quality flags),
- level 1b reader (locking of receive gain value, swath geometry monitoring, rainforest validation, ocean validation sea ice validation, monitoring of quality flags),
- CAL file reader (external calibration, geolocation accuracy),
- GCM file reader (gain compression monitoring),
- transponder file readers (cal file quality control, ASCAT pulse shape),
- ECMWF wind vector reader (ocean validation).

The software tools required in order to support the EUMETSAT cal/val activities, and their present status, are:

- ASCAT PPF (needed for the locking of cal constants, locking of receive gain value, production of cal files and normalisation tables, testing of normalisation tables) – exists but needs to be developed to
  - perform AGPO (however this is a low priority due to availability of independent AGPO software)

  - include telemetry in level 1a files (low priority as telemetry is monitored in ground segment),
  - include additional check of gain compression monitoring (low priority due to availability of independent software to do this task).
- telemetry monitoring – needs to be developed but this is low priority as telemetry data is not currently included in level 1a files.
- reference function monitoring – exists as DPS running in CVF.
- gain compression monitoring – exists as part of the PPF and also as independent DPS running in CVF.
- CAL file quality control – exists and runs in TCE.
- GAPE software – exists as part of PPF and also as independent standalone software.
- AGPO software – exists as independent standalone software.
- NTG software – exists as part of PPF and also as independent standalone software.
- geolocation accuracy assessment – exists and runs as DPS in CVF.
- ASCAT pulse shape monitoring – needs to be developed but seen as low priority.
- swath geometry monitoring – exists and runs as DPS in CVF.
- rainforest validation – exists and runs as DPS in CVF and also as standalone on TCE.
- ocean validation – exists and runs on TCE.
- sea ice validation – exists and runs on TCE.
- quality flag monitoring – exists in basic form and runs as DPS in CVF. Needs to be modified to perform a more detailed analysis.

Note that production, calibration and validation of the level 2 wind products will be performed by the OSI-SAF. The production, calibration and validation of the level 2 soil moisture products will be done in cooperation with the H-SAF.

# 6 OPEN ISSUES

A number of problems have affected the transponders over the last few years which have prevented them from operating as expected. Hence there is the possibility that not all three transponders may be available during the commissioning of the ASCAT on Metop B.

If only one or two transponders are operating then the external calibration will still take place. However, in this situation the sampling of the antenna beams will be reduced which will lower the overall accuracy of the calibration and may miss localised features in the gain patterns. This will give a preliminary calibration with a full calibration taking place as soon as all three transponders are available.

If no transponders are available during commissioning then the ASCAT on Metop B will be cross calibrated against the ASCAT on Metop A using the procedure described in Appendix A.

# 7 SUMMARY

This document has defined the calibration and validation plan for the ASCAT on Metop B.

The overall aim of ASCAT verification, calibration and validation has been discussed and the activities necessary to produce calibrated products and to ensure that they meet requirements have been specified. Potential problems and workarounds have also been identified.

Each activity is described in detail and the inputs, outputs, the required resources and a time schedule are specified.

# 8 APPENDIX A. CROSS CALIBRATION AGAINST ASCAT-A

If the initial calibration is found to be poor or the transponders are not available during the commissioning period then it will be necessary to produce the normalisation factors for ASCAT-B by cross calibration against ASCAT-A.

This is achieved by comparing the full resolution data from the ASCATs on Metop A and B over a stable target of interest and calculating the ratio. The normalisation factors for Metop B are then given by scaling the Metop A normalisation factors by the same amount.

Data from the Amazon rainforest can be used as this is known to be relatively stable. In particular, the parameter $\gamma_0 = \sigma_0/\cos\theta$ is approximately stable with respect to time, incidence angle, azimuth angle and location. Hence the cross calibration procedure is

- collect full resolution Metop A and B data over the rainforest covering a time span of at least one orbital cycle,
- calculate the mean $\gamma_0$ value as a function of node position for both sets of data,
- find the ratio of the two data sets,
- scale the Metop A normalisation values by the same amount and use with Metop B.

It should be noted that this procedure is untested and will only produce an approximate calibration for Metop B. The procedure may also need refinements to take into account differences in the Metop A and B orbits which may give rise to differences in the viewing geometry and/or introduce spatial rainforest variations into the data.

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