NWP SAF

*Satellite Application Facility for Numerical Weather Prediction*

*Associate Scientist Mission Report*

Document NWPSAF-MO-VS-033

Version 2.0

11 January 2006

# Implementation Plan for a NRT global ASCAT soil moisture product for NWP

## Part 9: ERS – METOP Scatterometer Cross-Calibration

K Scipal

Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, Austria.

ASCAT Soil Moisture Report Series No. 9

# ERS – METOP Scatterometer Cross-Calibration

VIENNA UNIVERSITY OF TECHNOLOGY
INSTITUTE OF PHOTOGRAMMETRY AND REMOTE SENSING

2006 January 11

How to reference this report:

Scipal, K., (2006). *ERS – METOP Scatterometer Cross-Calibration.* ASCAT Soil Moisture Report Series, No. 9, Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, Austria.

Contact Information:

Institute of Photogrammetry and Remote Sensing (I.P.F.)
Remote Sensing Group (Prof. Wagner)
Vienna University of Technology
Gusshausstrasse 27-29/E122
1040 Vienna, Austria

mbox@ipf.tuwien.ac.at
www.ipf.tuwien.ac.at

| **Status:** | Issue 1.3 | | |
|---|---|---|---|
| **Authors:** | IPF TU Wien (KS) | | |
| **Circulation:** | IPF, NWP SAF, EUMETSAT | | |
| **Amendments:** | | | |
| ***Issue*** | ***Date*** | ***Details*** | ***Editor*** |
| Issue 1.0 | 2005 Dec 20 | Initial Document. | KS |
| Issue 1.1 | 2006 Jan 11 | Several changes after internal revision of the document | KS |
| Issue 1.2 | 2006 Feb 2 | Added chapter 4 based on comments from D. Offiler | KS |

If further corrections are required please contact Klaus Scipal. (ks@ipf.tuwien.ac.at).

# Abstract

In 2006 EUMETSAT will launch the first METOP satellite, carrying the Advanced Scatterometer (ASCAT) instrument on board. As has been shown in previous studies the instrument is well suited for retrieval of soil moisture information. Currently efforts are underway to implement a time series based retrieval technique (TU Wien model) for near real time soil moisture retrieval at EUMETSAT by a team of the Vienna University of Technology.

Since the TU Wien model requires time series based retrieval of backscatter characteristics, applying the model *exclusively* to the new ASCAT data would start yielding reliable results only after approximately three years of operation. However, given the availability of nine years of global ERS scatterometers data, and the similarities of the ERS and ASCAT scatterometers, integration of the ERS scatterometer data in the ASCAT retrieval could allow starting near real time processing already at the beginning of the METOP mission series. Integration of the ERS scatterometer data in the ASCAT retrieval is however only possible if the differences in the design and operation of the two sensors are considered carefully.

This document will briefly review the differences in the ERS and METOP scatterometer design and operation, and will outline possible cross-calibration strategies.

# Contents

# 1 Statement of the Problem

The TU Wien model for the retrieval of soil moisture from scatterometer data is a change detection approach tailored to the design of the scatterometers onboard the ERS satellites. To quantify the various effects influencing the backscatter measurement, time series analysis techniques are applied to a multi-annual backscatter dataset. The model requires several years of backscatter data to be applicable. In case of the ERS scatterometers, a sufficient level of robustness was reached after a four year period.

Since the TU Wien model requires time series based retrieval of backscatter characteristics, applying the model *exclusively* to the new ASCAT data would start yielding reliable results only after approximately three years. However, given the fact that the scattering parameters in question have already been determined using ERS data and considering the similarities between the ASCAT and the ERS scatterometers, integration of the ERS scatterometer data in the ASCAT retrieval could allow starting near real time processing already at the beginning of the METOP mission series (Figa-Saldana et al. 2002), integration of the ERS scatterometer data in the ASCAT retrieval is however only possible if the differences in the design and operation of the two sensors are considered carefully (Table 1).

Table 1–1.

*Main instrument characteristics of the ERS and METOP scatterometers.*

| | ERS | METOP |
|---|---|---|
| Radar Frequency | 5.3 GHz | 5.225 GHz |
| Number of Swath | 1 | 2 |
| Swath Width | 500 km | 550 km |
| Incidence Angle Range | 18°-57° | 25°-65° |
| Spatial resolution | 45 | 50/25 |
| Interbeam stability | 0.46 dB | 0.46 dB |
| Radiometric Accuracy | - | 0.57 dB |
| Common Mode stability | 0.57 dB | - |
| Radiometric resolution at minimum crosswind | 8.5–9.7 % | 3.0–9.9 % |
| Radiometric resolution at minimum crosswind | 6.5–7.0 % | 3.0% |

These changes oblige a careful analysis, involving accurate characterization of the calibration properties of both sensors. Given the similarities of both sensors it is expected that backscatter measured by both sensors will be nearly identical within +/- 0.2dB ({Crapolicchio, 2006 #942}, personal communication). However, already these slight changes can have strong effects on the soil moisture retrieval. Figure 1-1 shows that an absolute mean calibration offset between backscatter measured by the ERS and METOP scatterometers of 0.1dB corresponds to an increase of 2-4% in the soil moisture estimates over large fractions of the land surface with peak values of to 8%.

If the results of the cross calibration analysis indicate that the differences in backscatter are outside the tolerance for soil moisture retrieval, we propose to add a correction factor to the ERS backscatter measurements in order to facilitate a retroactive processing.

Accurate cross-calibration is however not only important for integration of ERS scatterometer in the METOP scatterometer processing chain, it will also be important to generate a consistent long term soil moisture data sets required for climate studies and trend analysis.

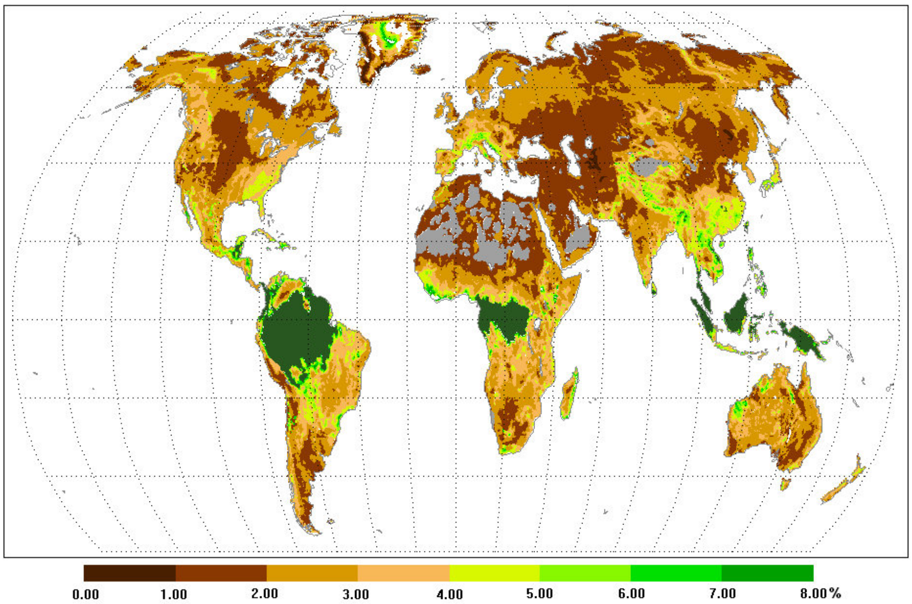


Figure 1–1.

*Percentual increase of wetness as effect of a 0.1 dB absolute calibration offset between backscatter measured by the ERS and METOP scatterometers. Desert (grey) and tropical forest (dark green) areas are masked in this figure.*

# 2 METOP Sensor Modifications with Respect to ERS

The ERS scatterometers were conceived about twenty years ago. During the intervening period, there has been a considerable evolution in the capabilities of space borne hardware. Additionally, experience acquired with nearly one decade of operations and the use of the derived products led to an optimization of the sensor system. It is expected that the changes and improvements in the sensor design and operation will not only lead to a higher radiometric accuracy and more reliable backscatter measurements, but that it will also lead to differences in absolute and relative backscatter.

Especially modifications with regard to the antenna operating principle, the centre frequency, the incidence angle range and the increase spatial resolution may impact the soil moisture retrieval. Their characteristics are briefly summarized in the following sections. Some of these modifications are very subtle. Without the availability of backscatter data measured by both sensors their impact is difficult to assess.

## 2.1 Antenna Operating Principle

In contrast to the scatterometer used on the ERS platform, which relied on the transmission of continuous wave pulses with durations of around 100 µs and peak powers of several kilowatts, ASCAT transmits linear frequency-modulated pulses with a markedly longer duration of around 10 ms, at a relatively low peak power of 120 W (ESA 1993; Gelsthorpe et al. 2000).

## 2.2 Antenna Calibration

In principle both scatterometer systems use the same calibration concept, i.e. they will be calibrated using transponders and natural targets. However, for ASCAT new transponders have been developed and the actual implementation of the calibration algorithms differ (Rostan 2000; Wilson et al. 2005).

## 2.3 Radar Frequency

The ASCAT centre frequencies will be shift by 45 MHz compared to the ERS scatterometers (Figa-Saldana et al. 2002). When compared to the central frequency itself, in the order of 5.3 GHz, this shift will however not have a major influence on the consistency of the backscatter data.

## 2.4 Incidence Angle Range

The incidence angle range for the METOP scatterometer will be shifted to higher values compared to the ERS scatterometer. Within the soil moisture retrieval algorithm, the available range of incidence angles has an influence on the sensitivity of the backscatter measurements to soil moisture content. In natural units, the sensitivity decreases approximately exponentially with increasing incidence angle, due to the more pronounced attenuation of microwaves in the vegetation canopy at higher incidence angles. The approximately 7° incidence angle shift could thus induce uncertainties in the model. The exact quantitative effect is currently difficult to foresee. A straightforward solution to this problem could be the removal of measurements taken above 57° incidence angle (which is the maximum incidence angle of the ERS scatterometer). In any case data will only be removed if there is sufficient evidence of a negative impact of high incidence angle measurements on the retrieval.

## 2.5 Spatial Resolution

One of the improvements of ASCAT is an increased spatial resolution of 25 km. Recent tests of reprocessing ERS Scatterometer data to a resolution of 25 km show very promising results concerning the separation of physically meaningful details in comparison to the 50 km resolution product. Figure 2-1 compares ERS backscatter images of 25 and 50 km resolution over the central-northern part of European Russia. The coniferous forest patterns of the land cover map are clearly more recognizable in the 25 km product, similarly to the humid grassland and water areas as well as the contour and location of the strongly 'reflecting' city of Moscow. A change of scale from 50 to 25 km resolution will result in a different dynamic range of backscatter and might also lead to an absolute shift of backscatter.

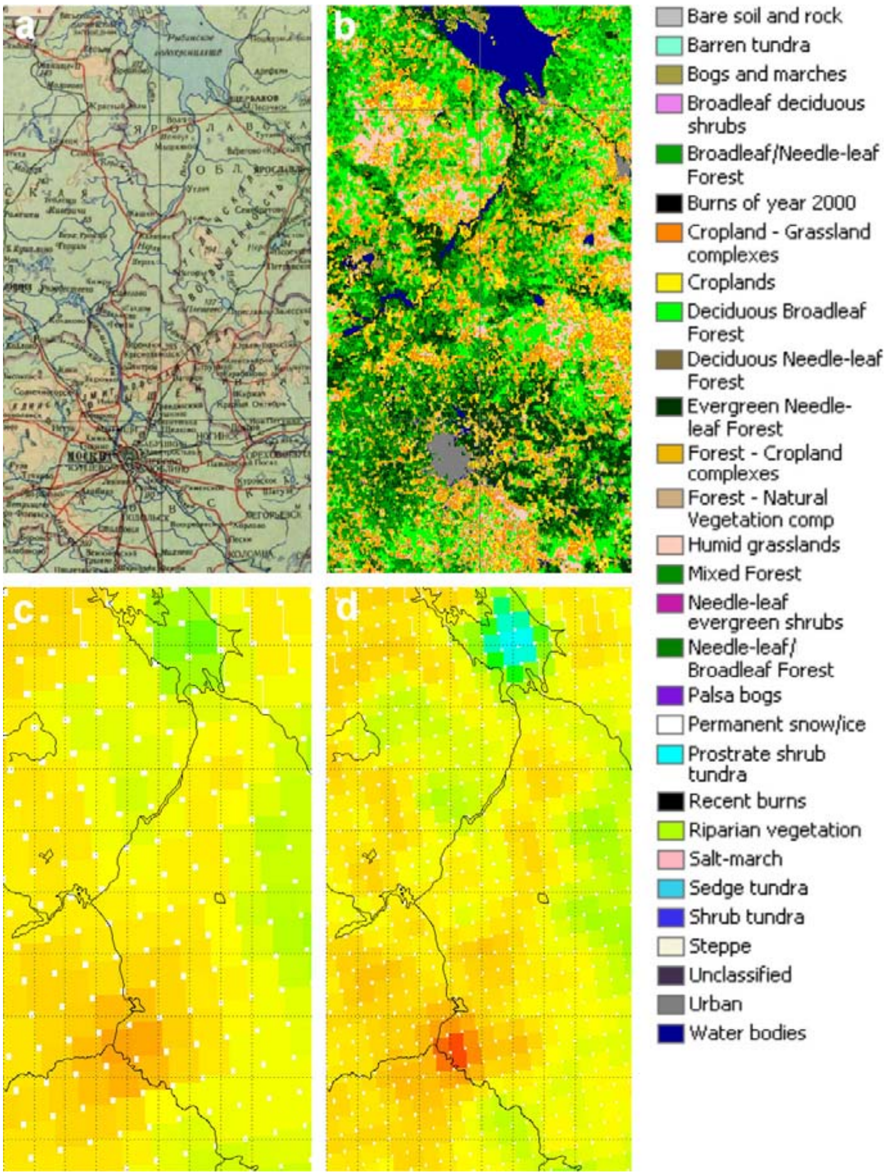


Figure 2–1.

*Comparison between the ERS scatterometer 50 and 25 km resolution products, (c) and (d) respectively. The features of the GLC2000 land cover map in (b) are recognisable to a higher degree of details in the 25 km resolution back-scatter plot. The legend belongs to the land cover map in (b). Backscatter values are not corrected for incidence angle and originate from ERS-2 orbit number 21711 (cycle 43), acquisition time June 15, 1999, 19:16.55 (ascending node). Source for (a): http://www.veslo.ru/maps.html.*

# 3 Scatterometer Cross-Calibration

In order to operate the near real time soil moisture processor, immediate after the start of the METOP platform a careful analysis, involving accurate characterization of the differences in backscatter measured by both sensors, is of utmost importance. Currently the exact magnitude of differences in the sensor and calibration design and operation on the backscatter measurements cannot be quantified easily. Some of the effects might be negligible, such as the shift in frequency, others might have a measurable impact. It is however expected that the superposition of all effects will change both the absolute backscatter as well as the dynamic range, which are both critical for the soil moisture retrieval. Figure 3-1 shows the scenarios which have to be considered when implementing a retrospective soil moisture retrieval based on ERS scatterometer data. Most likely the relation between backscatter measured by the ERS and the METOP scatterometers can be described by a linear relation.

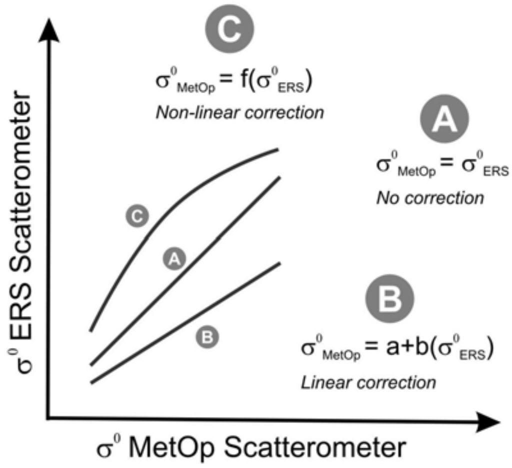


**Figure 3–1.**

*Relation between ERS and METOP backscatter.*

For a robust, exact determination of the shape of the cross calibration model, measurements covering the entire incidence angle range under different land-cover conditions (bare soil to fully vegetated land) are required. The coefficient of the cross-calibration model can be determined by exploiting: 1) The results of the absolute and relative calibration and 2) The intended overlap in the operation of the ERS and METOP sensors.

The most exact results will be delivered by the absolute and relative calibration using transponders. Using the transponders the impulse response function, the exact spatial resolution, the antenna pointing errors, the gain constants, the azimuth antenna patterns and the calibration pulse I/Q characterization can be determined. As the transponder gives an absolute (and stable) reference radar cross section results from two different transponder can be compared with an accuracy defined by the single stability of the transponder. Transponders are however not adequate for fine tuning as there will not be enough measurements across the entire incidence angle range. This deficiency is currently solved using distributed stable natural targets (Lecomte and Attema 1993; Lecomte and Wagner 1998).

With the traditional calibration procedures only the absolute power is determined. As the transmission is done at fixed power parameters like the sensitivity can not be determined. To cover also these aspects we propose to use additionally a wider range of natural targets characterised by stable scattering conditions like deserts and permanently frozen areas.

## 3.1 Scatterometer Absolute and Relative Calibration

The objectives of engineering calibration are to ensure that the backscatter expected from a known target is actually measured by the instrument (absolute calibration), and that the variation over the range of incidence angles of the instrument is unaffected by the local attenuation from the antennae (relative calibration). Calibration is hence translated into three elements:

- The radiometric stability
- The absolute calibration
- The relative calibration across the swath for a given antenna (antenna patterns) and between the different antennae.

External instrument calibration is achieved by using a combination of internal (for the radiometric stability) and external references (Lecomte and Attema 1993; Rostan 2000; Wilson et al. 2005). Two different types of external references are used, point targets (transponders) and distributed targets (areas of known, constant backscatter), addressing respectively the absolute and the relative calibration. Each pass over a transponder allows the measurement error in backscatter at a particular incidence angle, to be computed from the power of the returned signal, and that measured at the transponder. The observation time of the transponders (in range and in azimuth) is used to verify proper antennae pointing.

Although the transponders give accurate measurements of antenna attenuation at particular points within the antenna pattern, they are not adequate for fine tuning across all incidence angles, as there are simply not enough samples. This could be solved by deploying and operating a large number of transponders, so that many measurements can be made across the entire swath. To obviate the enormous costs, related to such a system, calibration makes use of large scale natural targets with a known response. The tropical rain forest in South America has typically been used as a reference distributed target. The target is assumed to be isotropic and time invariant.

## 3.2 Simultaneous METOP – ERS Operations

For cross comparison of the ERS and METOP backscatter time series an optimum condition would be a scatterometer "tandem" mission, where both sensors are operated in parallel, i.e. they observe the earth surface at exactly the same time to avoid any discrepancies due to changing environmental conditions. Currently such a parallel operation is not foreseen, and it remains open if the ERS orbit can be synchronized with the METOP orbit. However given that the METOP scatterometer will observe 80% of the earth surface within one day, quasi simultaneous observations (with a few hours difference) will be achieved for large areas of the globe.

Currently ERS has its time of the descending node (the sub-satellite track crossing the Equator from north to south) at approx. 10:30 AM whereas the equivalent time for METOP is envisaged to be one hour earlier. The side-looking characteristics of the instruments combined with the double swath of ASCAT and its different incidence angle range results in slightly different local solar times for the backscatter measurements than the ones corresponding to the sub-satellite track. As Fig. 3-2 shows, the 1 hour difference at the Equator passage can actually mean that the time difference between ERS and METOP measurements can range between 30 minutes and over 2 hours during descending orbits at the Equator. At higher latitudes, the range of timing differences between the two instruments gets larger and from around latitudes of 50 and more it is actually possible that ERS measurements occur before some of the ASCAT measurements. ASCAT backscatter measurements will on average take place earlier than ERS measurements, an aspect that is important to remember when comparing for instance soil moisture time series derived from the two sensors: topsoil moisture conditions especially early in the morning or late in the afternoon can vary substantially when measured one or two hours apart.

To minimise errors due to environmental effects in the cross comparison of backscatter acquired at different times it is proposed to analyse measurements only over areas of stable backscatter conditions. In contrast to the approach used for the absolute and relative calibration of the sensor, which is limited to measurements taken over the tropical forests (Lecomte and Wagner 1998), we propose to extend the range of potential target areas. The tropical forest has been selected as reference target as it acts as pure volume scatterer. To be able to compare backscatter also for surface scatterers, permanently frozen areas and desert areas should be envisaged as target areas. Figure 3-3 shows potential target areas. In principal areas with a dynamic backscatter range of less than 1.5 dB should be suitable for cross comparison of backscatter data. Under this assumption large desert areas and permanently frozen areas can be included in the cross calibration.

Using these target areas and considering that backscatter over these areas has been stable for a period of more than nine years, a cross calibration seems feasible even in case the sensors are not operated simultaneously, i.e. if the ERS sensor fails before the launch of the METOP satellite.

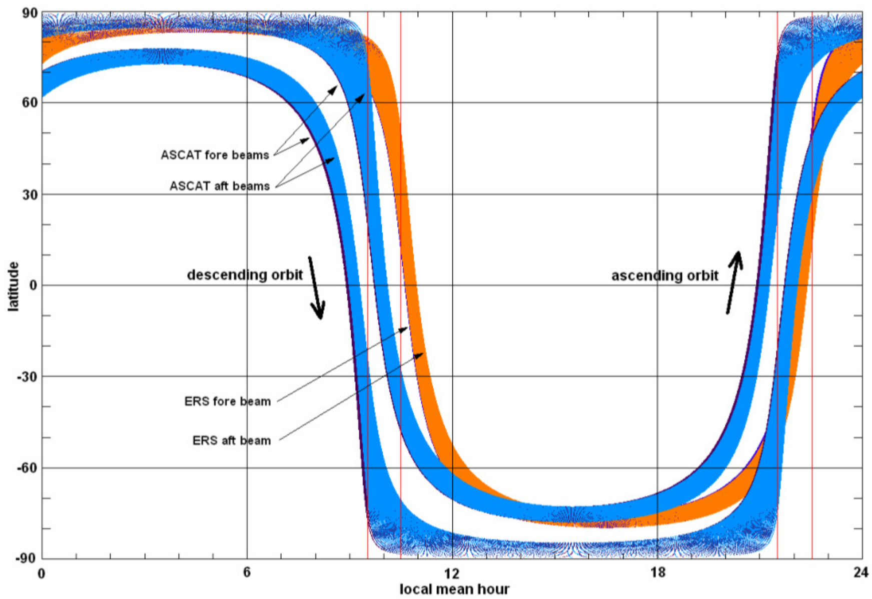


**Figure 3–2.**

*The relationship between the times of the day (local solar time) when ERS (red) and ASCAT (blue) measurements are expected to occur and the geographic latitude*

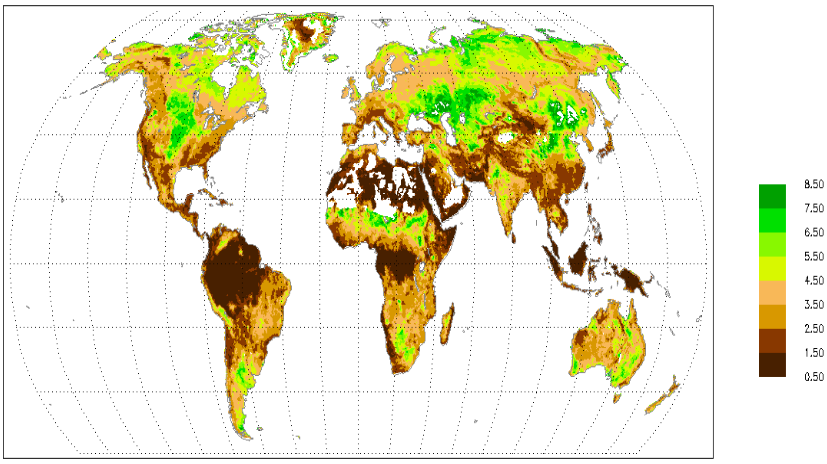


Figure 3–3.

*Dynamic range of backscatter extrapolated to a reference incidence angle of 40° over a nine year period. Dark brown areas indicate stable backscatter conditions*

# 4 Accuracy Requirements

In this section the accuracy of the ASCAT soil moisture product will be discussed based upon the expected performance of the instrument. Also, the question how the cross calibration will affect the performance of the system will be addressed.

## 4.1 System Accuracy

To estimate the accuracy of the soil moisture retrieval we use the radiometric accuracy requirements specified for the wind retrieval and put them in relation to the sensitivity. According to Table 1-1 the radiometric accuracy of the ASCAT sensor shall meet 0.57 dB. Since in the soil moisture retrieval the measurements of the three antennas are averaged, the accuracy of the backscatter measurement is further improved. Assuming independent measurements with a Gaussian error distribution in the logarithmic range, the actual radiometric accuracy increases by a factor of $1/\sqrt{3}$ to a value of 0.32 dB. This value can be compared to the sensitivity of the backscatter to soil moisture variations (Figure 4-1) which shows that the estimated soil moisture accuracy ranges between 3 and 12 % with peak values around 20 %. These numbers agree reasonably well with error budgets estimated for the ERS sensor. Figure 4-2 shows the accuracy of surface soil moisture due to sensor noise and azimuthal effects based upon ERS scatterometer data. Brown colour tones represent values below 10%. Peak values are around 15%.

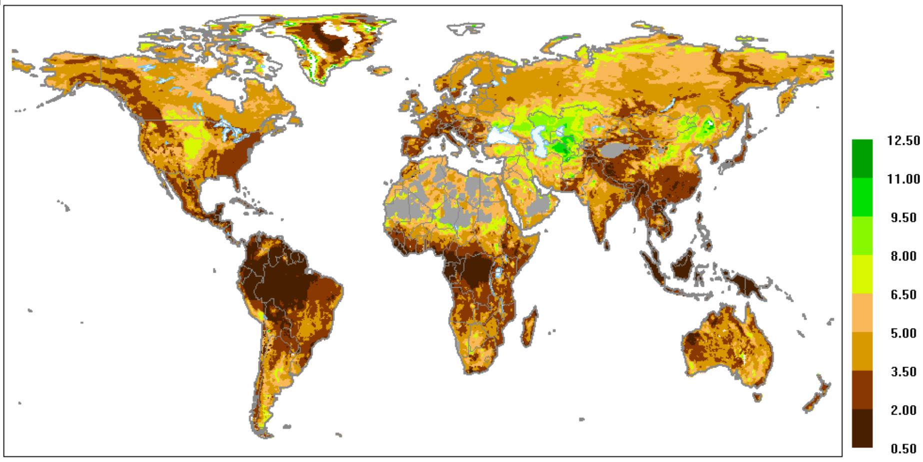


**Figure 4–1.**

*Sensitivity of backscatter to soil moisture variations. Desert (grey) areas are masked in this figure.*

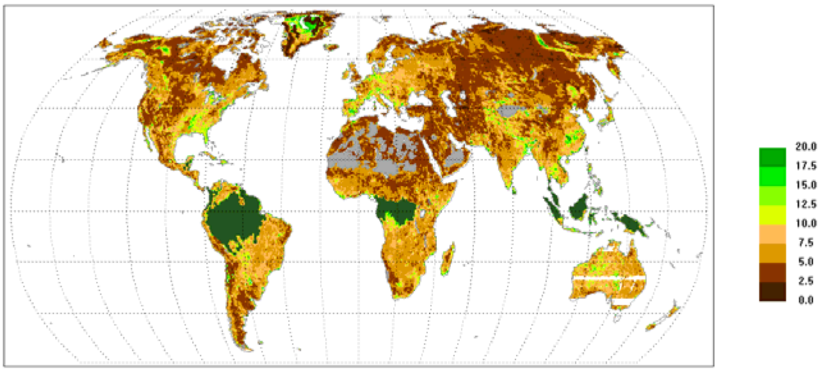


**Figure 4–2.**

*Accuracy of surface soil moisture due to sensor and azimuthal noise based on ERS scatterometer data. Brown colour tones represent values below 10%. Peak values are around 15%. Desert (grey) and tropical forest (dark green) areas are masked in this figure. The white stripes in Australia are due to incomplete data series.*

## 4.2 Cross Calibration Accuracy Requirement

For the discussion of effects of cross calibration offsets we separate two cases, the nominal soil moisture retrieval and long term studies.

1. In long term climate studies based on data from both the ERS and METOP scatterometers (1991 up to now) an accurate calibration between the ERS and METOP backscatter measurements is critical. As can be seen in Figure 1-1 already a shift of as little as 0.1 dB can result in an absolute bias of 2-4% with peak values of 8% if the retrieval of soil moisture from METOP ASCAT will be based on parameters retrieved from the ERS sensor. If not considered carefully this offset can be interpreted as a wrong climate signal.

2. The requirements for the nominal retrieval of soil moisture are less critical. A slight offset between backscatter measured with the ERS and METOP scatterometers will result in biased estimates of the parameters required for soil moisture retrieval. For example, the dry and wet reference values estimated from ERS will be slightly biased compared to the METOP measurements, which will result in an offset of the soil moisture estimates. However, since the bias is expected to be smaller than the instrument noise, the effects will not be apparent for one or few ASCAT images.

Using the transponders and distributed targets and exploiting the planed parallel operation of the ERS and the METOP sensor it should be possible to achieve a cross calibration accuracy below 0.1dB. The transponder gives an absolute (and stable) reference radar cross section. Considering the nearly identical frequency and resolution, calibration measurements of the ERS and METOP scatterometers can be compared with an accuracy defined by the single stability of the transponder ({Crapolicchio, 2006 #942}). Experience with the ERS scatterometer has shown that the transponder is "stable" within 0.5 dB. For the rain forest calibration target similar values have been achieved ({ESA, 2001 #941}). The required cross calibration accuracy of 0.1dB can only be achieved if a statistically significant number of measurement pairs, i.e. >100, is available.

## 4.3 Expected Accuracy vs. Soil Moisture Requirements

There is no common consensus among users concerning the accuracy ({Kidd, 2005 #943}). Different users and different applications have different requirements for global soil moisture data, ranging from 0.5 to 4 vol%. For the following consideration we will assume a minimum accuracy requirement of 4 vol%, which corresponds the specification for the SMOS mission.

As the TUWien model does not allow an absolute retrieval we have to convert this value to a percentage index. Assuming that the scatterometer measures soil moisture between completely dry conditions (0 vol%)and saturated conditions (as a proxy we will assume saturation at 50 vol%) the specified accuracy translates to a value of 8%. As can be seen in Figure 4-2 for most parts of the world this requirement will be met.

# 5 Conclusions & Recommendations

Assessing the differences in backscatter measured by the ERS and the METOP scatterometers is of high importance for the soil moisture retrieval. To determine differences in the backscatter characteristics the absolute and relative calibration using transponders and natural targets will be analysed by the cal/val teams of ESA, EUMETSAT and other organisations involved in the cal/val activities. For establishing the cross calibration of ERS and METOP, it is highly desirable to operate both sensors simultaneously to enable comparison of backscatter data over stable scattering areas such as tropical forests, desert areas and permanently frozen areas at same incidence angles. Backscatter measurements over these areas should cover the entire incidence angle range and different backscatter intensities to enable a robust estimation of the parameters of the cross-calibration model. Considering that backscatter over some of these areas has been relatively stable since the launch of ERS-1, a cross calibration can be attempted even in case a parallel operation of the sensors is not possible, i.e. if the ERS scatterometer fails before the launch of the METOP scatterometer. In this case backscatter characteristics of historic time series will be compared to actual measurements to quantify any difference in the absolute and relative measurements

If the results of the cross calibration analysis indicate that the differences in backscatter are outside the tolerance for soil moisture retrieval, we propose to add a correction factor to the ERS backscatter measurements in order to facilitate a retroactive processing.

# Bibliography


Crapolicchio, R. (2006). Personal communication, 2006-19-01.

ESA (1993). *ERS-2 Satellite to Ground Segment Interface Specification*, E. S. Agency.

ESA (2001). ERS-2 Wind Scatterometer Cyclic Report from 4th December 2000 to 8th January 2001 Cycle 59, In: ESRIN (Ed.) *Wind Scatterometer Cyclic Reports*: 46.

Figa-Saldana, J., J. J. W. Wilson, E. Attema, R. Gelsthorpe, M. R. Drinkwater and A. Stoffelen (2002). *The advanced scatterometer (ASCAT) on the meteorological operational (MetOp) platform: A follow on for European wind scatterometers.* Canadian Journal of Remote Sensing **28**(3): 404-412.

Gelsthorpe, R. V., E. Schied and J. J. W. Wilson (2000). *ASCAT - Metop's advanced scatterometer.* ESA Bulletin-European Space Agency(102): 19-27.

Lecomte, P. and E. Attema (1993). Calibration & Validation of the ERS-1 Wind Scatterometer. First ERS-1 Symposium - Space at the Service of our Environment, Cannes, France, European Space Agency.

Lecomte, P. and W. Wagner (1998). *ERS wind scatterometer commissioning and in-flight calibration*. ESA SP(SP-424): 261, European Space Agency (Special Publication).

Rostan, F. (2000). Calibration of the MetOp/Advanced Scatterometer (ASCAT). International Geoscience and Remote Sensing Symposium (IGARSS).

Wilson, J. J. W., P. L. Phillips, J. Figa-Saldaña, K. Dumper and T. Fiksel (2005). Radiometric Calibration of the Advanced Wind Scatterometers Carried On-Board the METOP Satellites. IGARSS 2005, Seoul, Korea.