WARP^{NRT} 2.0 Reference Manual

How to reference this report:

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Summary

This document represents the software documentation of WARP^{NRT} 2.0, a software for near real-time surface soil moisture retrieval from ASCAT data. Written in C programming language, the software applies algorithms developed by the Institute of Photogrammetry and Remote Sensing (I.P.F.) to derive surface soil moisture products in orbit geometry, including several quality parameters for 50 and 25 km resolution ASCAT products.

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List of Acronyms

ASCAT	Advanced Scatterometer
DGG	Discrete Global Grid
DSR	Data Set Record
ECMWF	European Centre for Medium-Range Weather Forecasts
EPS	EUMETSAT Polar System
ERS	European Remote Sensing Satellite
ESD	Estimated Standard Deviation
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GLWD	Global lakes and wetlands database
GTOPO30	Global Topography - 30 arc-seconds
IDL	Interactive Data Language
MPH	Main Product Header
NRT	Near-Real Time
NWP	Numerical Weather Prediction
PPF	Product Processing Facility
SPH	Secondary Product Header
TU WIEN	Vienna University of Technology
WARP	WAter Retrieval Package
WARP^{NRT}	WAter Retrieval Package for Near-Real Time

Contents

1 Introduction

This Reference Manual summarises the scientific background, the implementation and product definitions of WARP^{NRT} 2.0. WARP^{NRT} 2.0 is a software package for producing surface soil moisture products having either 50 or 25 km resolution ASCAT data as input, in the native EPS format. Apart from the ASCAT data, to enable the soil moisture retrieval, WARP^{NRT} 2.0 requires a global parameter database, describing scattering characteristics for each point of the land surface of the Earth. To assemble this parameter database, the software WARP 5.0 (soil WAter Retrieval Package) is used. This software allows the retrieval of backscatter characteristics of the land surfaces based on the analysis of multi-annual ERS-1/2 backscatter time series. WARP 5.0 is written entirely in the software language IDL (Interactive Data Language).

The scientific basis and algorithms have been fully published in a series of conference and journal papers, most important of which are Wagner et al. (1999a, 1999b, 1999c), Wagner and Scipal (2000), Wagner et al. (2003) and Ceballos et al. (2005).

Further information

See the website of the Microwave Remote Sensing Group of the Institute of Photogrammetry and Remote Sensing, Vienna University of Technology: http://www.ipf.tuwien.ac.at/radar).

1.1 What is WARP^{NRT} 2.0?

WARP^{NRT} 2.0 is a software for near real-time (NRT) processing of surface soil moisture products from 50 km or 25 km ASCAT data in the EPS format. The software is written in C programming language for a UNIX environment and foreseen for implementation at EUMETSAT's central product processing facility (PPF). One input of the software is a global parameter database extracted from multi-annual time-series of ERS-1/2 scatterometer data (08/1991-01/2001; for most DGG grid points the period is 08/1991-01/2001, due to restricted coverage of the ERS-2 scatterometer after this date).

The following processing steps are implemented:

- Reading the ASCAT backscatter data.
- Resampling of the global parameter data base to the scatterometer swath grid.
- Application of the algorithms to retrieve the surface soil moisture. Additional products such as the normalised backscattering coefficient at 40° incidence angle ($\sigma^0(40)$) and its estimated noise, the estimated noise of the surface soil moisture, etc. are calculated.
- Setting of complementary correction, processing, and advisory flags (internal quality checks and specific processing details).
- Storing the products.

Fulfilling the NRT-precondition, once all scatterometer parameter database files are restored, the processing of one complete scatterometer orbit is done in a matter of several seconds.

1.2   System Requirements

WARP^{NRT} 2.0 is developed in C for UNIX environments. The software has been tested on an IBM machine with standard system libraries (IBM RS6000/43P, AIX version 4.3.3, Compiler version 5), as well as a small subset of general C libraries developed at the I.P.F. For the processing of data, WARP^{NRT} 2.0 requires a parameter database, which is provided in form of binary files, along with sample ASCAT data.

1.3   Software Installation

Unzip the file WARP_NRT_2.0.zip. For Windows32 platforms, the executable file for the processing is called `WARP_NRT_2.0.exe`, whereas for UNIX environments, it is called `WARP_NRT_2.0`.

The directory `Sample_EPS_Input_Data` contains sample ASCAT data, one file as an example for 50 km resolution data and one file for 25 km resolution. Both files cover the same orbit, dated 13 March 2007.

The directories `param_input` contain the scatterometer database binaries.

Software Usage

Calling sequence of the executable:

```
WARP -s <IN_PATH_1> -a <IN_PATH_2> -o <OUT_PATH> [-h]
```

The following attributes can be set:

- `-s <IN_PATH_1>`

  The full path and file name of the input EPS file. This can be either a 50 km resolution file (SZO) or 25 km (SZR). Example on Win32:
  ```
  -s "D:\temp\WARP_NRT_2.0\Sample_EPS_Input_Data\ASC
  A_SZO_1B_M02_20070213231202Z_20070214005359Z_N_O_2
  0070214005934Z.nat"
  ```

- `-a <IN_PATH_2>`

  The full path to parameter binaries. These are:
  - directories: `curv`, `curv_noise`, `dry`, `dry_noise`, `frozen`, `ms_mean`, `slop`, `slop_noise`, `snow`, `wet` and `wet_noise`. All these directories contain daily files of the form `MMDD.bin`.
  - files: `azim_coeff.bin`, `caloff_o.bin` or `caloff_r.bin` (depending on the resolution of the ASCAT input file), `esd.bin`, `indexarr.bin`, `lat.bin`, `lon.bin`, `lonstep.bin`, `topo.bin`, `uniqlat.bin`, `wetcorr.bin` and `wetland.bin`.

  Example for Win32:
  ```
  -a "D:\temp\WARP_NRT_2.0\param_input"
  ```

- `-o <OUT_PATH>`

  The path to where the output binary EPS_MS file will be placed. The output file will have the same name as the input file with an additional `_ms` suffix and the extension `.bin`.

- `-h`

  Displays usage information (help).

The software used to produce this software was Microsoft Visual C++ .NET, Microsoft Development Environment 2003. For code editing/recompiling purposes, the distribution also contains the full source code. This is found in the directory `Code\Win32\`. The project file is `WARP_NRT.vcproj` and the main procedure is found in `warp.cpp`.

For usage in UNIX environments, the software was also compiled and tested on an IBM machine with standard system libraries (IBM RS6000/43P, AIX version 4.3.3, Compiler version 5). The source C++ code was the same as for the Windows version, and the AIX makefile is provided in the directory `Code/AIX/`.

1.4   Related Documents

Table 1–1 lists already existing documents of the ASCAT Soil Moisture Report Series that acted as input to this document.

Table 1–1

ASCAT Soil Moisture Report Series.

Report Series No.	Report Title
1	Kidd, R. (2005). *NWP User Community Requirements Summary.*
2	Kidd, R. (2005). *METOP ASCAT Data Streams and Data Formats.*
3	Bartalis, Z. (2005). *Azimuthal Anisotropy of Scatterometer Measurements over Land.*
4	Kidd, R. (2005). *Discrete Global Grid Systems.*
5	Wagner, W. (2005). *Implementation Plan for a Soil Moisture Product for NWP*
6	Bartalis, Z. (2005). *Selection of Resampling Procedure.*
7	Scipal, K. et al. (2005). *Definition of Quality Flags.*

2 The Soil Moisture Retrieval Method

To allow a better understanding of the implementation of WARP^{NRT} 2.0 and its attached databases we will present a brief summary of the TU Wien model and its implementation in WARP 5.0 in the following section.

The TU Wien method for retrieving soil moisture from ERS/ASCAT scatterometer data is, from its conception, a change detection method (Wagner, et al. 1999b). Instantaneous ASCAT backscatter measurements are extrapolated to a reference incidence angle (taken at 40°) and are compared to dry and wet ERS backscatter references (σ^0_{dry} and σ^0_{wet} respectively). The influence of vegetation is determined by exploiting the multi-incidence angle viewing capabilities of the ERS/ASCAT scatterometer sensors. The theoretical background of the TU Wien model is described in detail in Wagner et al. (1999a, 1999b, 1999c) and Wagner and Scipal (2000). As a result, time series of the topsoil moisture content m_s (< 5 cm) are obtained in relative units ranging between 0 (dry) and 1 (saturated). All parameters required for the processing of raw backscatter measurements are derived from analysis of multi-annual backscatter time series of the period 08/1991 to 01/2001 (for most DGG grid points this period is 08/1991-01/2001, due to restricted coverage of the ERS-2 scatterometer after this date).

2.1 Methodology

Retrieval of soil moisture parameters as established under WARP 5.0 is implemented as a program package that allows a stepwise processing of raw ERS scatterometer data. In a pre-processing step, the scatterometer data are rearranged from the orbit geometry to a time series format. In this way, multi-year time series of scatterometer measurements are built up over a predefined global grid. The further processing steps use as input all available scatterometer data. The processing steps are:

Step 1: Resampling of data

ASCAT measurements in orbit geometry are resampled to a fixed Discrete Global Grid (DGG), using a Hamming window of 36 km width.

Step 2: Azimuthal normalisation

Backscatter values are normalised in terms of their acquisition azimuth angle, based on look-up tables with long-term mean values. The binary file with the azimuthal normalisation coefficients is `param_input\azim_coeff.bin`.

Step 3: Estimated standard deviation of σ^0

Estimate the standard deviation (ESD) of σ^0 due to instrument noise, speckle and azimuthal effects based on the measurements of the fore- and aft antennas. The binary file with the ESD values is `esd.bin`.

Step 4: Incidence angle dependency

Determine the mean annual cycle of the incidence angle behaviour of σ^0 by making use of the fact that the scatterometer provides instantaneous measurements at two different incidence angles. The incidence angle dependency is described by a second order polynomial determined by the slope σ' and the curvature σ''. The slope and the curvature show a distinct annual cycle, determined by vegetation growth and decay. Slope and curvature parameters are determined by fitting a first degree polynomial to each group of local slope values. The results are the first and second derivatives of backscatter at 40° for each day of year. The final slope and curvature values are the result of averaging these derivative values over several periods with different duration (14-84 days). Corresponding noise values are also calculated. The incidence angle parameters are found in daily files in the directories `slop`, `slop_noise`, `curv`, and `curv_noise`.

Step 3: Normalisation $\sigma^0(40)$

Extrapolate all σ^0 taken over the entire incidence angle range from 18 to 59° to a reference angle of 40° and calculate the average $\sigma^0(40)$ based on the backscatter triplet.

Step 4: Estimated noise of $\sigma^0(40)$

Based on the rules of error propagation the estimated standard deviation of $\sigma^0(40)$ is calculated.

Step 5: $\sigma^0(40)$ under dry and wet conditions

After σ^0 has been normalised with respect to the incidence angle, vegetation phenology effects and $\sigma^0(40)$ outliers have been removed, dry and wet soil backscatter reference curves, $\sigma^0_{dry}(t)$ and $\sigma^0_{wet}(t)$ are determined. These maximum and minimum $\sigma^0(40)$ are determined by statistical methods of noise analysis. The dry and wet parameters are

found in daily files in the directories `dry`, `dry_noise`, `wet`, and `wet_noise`.

Step 6: Wet reference correction

In dry climates the wet reference estimation can be biased given that there may never be enough rainfall to thoroughly wet the soil surface layer (Wagner and Scipal 2000). To correct biased $\sigma^0_{wet}(t)$ in such dry climates, Koeppen climate classification data is used in conjunction with the sensitivity to soil moisture (defined in turn as the difference between the dry and wet parameters derived in the previous step). The binary file with the wet reference values is `esd.bin`.

Step 7: Surface soil moisture

Calculate the surface soil moisture m_s by comparing $\sigma^0(40)$ to the dry and wet reference values.

Step 8: Estimated noise of the surface soil moisture

Calculate the estimated standard deviation of the surface soil moisture by rules of error propagation.

2.2 Underlying Assumptions

The TU Wien model is based on certain assumptions:

- At the resolution of the scatterometer, roughness and land cover are temporal invariant. The measurement process, due to the low resolution of the sensor, suppresses local fluctuations.
- Vegetation phenology influences σ^0 on a monthly scale. The measurement process, due to the low resolution of the sensor, suppresses local short-term fluctuations.
- There exist distinct incidence angles θ_{dry} and θ_{wet}, where the back-scattering coefficient σ^0 is relatively stable despite seasonal changes in above ground vegetation biomass for dry and wet conditions.
- The relationship between soil moisture and σ^0, expressed in dB, is linear.

2.3 The Product Quality

The quality control of the product has been investigated following several strategies, ranging from comparison with precipitation data to comparison with modelled data or in-situ soil moisture data.

The correlation between soil moisture of the 0-50 cm layer and rainfall anomalies as well as with a global vegetation and water balance model shows that soil moisture data agree reasonably well over tropical and temperate climates (Lehner and Döll 2004). The performance of derived soil moisture data in a semi-arid Mediterranean environment shows significant correlation with soil moisture measured by a network of soil moisture stations (Ceballos, et al. 2005).

3 The NRT Software Implementation

3.1 Processing Steps Overview

Near real time processing as implemented in WARP$^{\text{NRT}}$ 2.0 is in principle identical to the processing architecture of WARP 5.0, briefly described in the previous chapter. The processing is however limited to the generation of products and does not require the intermediate parameter retrieval steps. Following processing steps are therefore implemented in WARP$^{\text{NRT}}$ 2.0:

- **Step 1**: Restoring the time-independent WARP 5.0 parameter database binary files: `esd.bin`, `topo.bin`, `wetcorr.bin` and `wetland.bin`.

- **Step 2**: Reading in the ASCAT EPS input product.

- **Step 3**: Checking for data quality, setting of respective processing flags.

- **Step 4**: Correcting ASCAT σ^0 values using an external calibration look-up table, stored in `caloff_o.bin` or `caloff_r.bin` (depending on the resolution of the ASCAT input file).

- **Step 5**: Normalising the corrected ASCAT σ^0 values with respect to their acquisition azimuth angles. The file `azim_coeff.bin` is used for this purpose.

- **Step 4**: Generating a neighbourhood of each ASCAT measurement location, for subsequent resampling of the parameter database fixed grid to the orbit node in question. For this, look-up tables specific to the WARP 5.0 ellipsoid-based fixed Discrete Global Grid (DGG) are used: the array of latitudes and longitudes of the grid points in the DGG (`lat.bin`, `lon.bin`), the indexing array determining the intrinsic position of each grid point in the DGG (`indexarr.bin`), the array of unique latitudes of the DGG (`uniqlat.bin`), the array of longitudinal steps between consecutive grid points on the same latitude circle (`lonstep.bin`),

- **Step 5**: Restoring the time-dependent scattering parameters, found in binary files of the form `MMDD.bin`, in each of the following directories: `curv`, `curv_noise`, `dry`, `dry_noise`, `frozen`, `ms_mean`, `slop`, `slop_noise`, `snow`, `wet` and `wet_noise`.

- **Step 6**: Resampling (Hamming window) of parameters.

- **Step 7**: Calculation of extrapolated backscatter at 40° incidence angle, its estimated noise, and setting respective processing flags.

- **Step 8**: Calculation of final surface soil moisture value, its estimated noise, and setting respective processing and correction flags.

- **Step 9**: Setting of climatological advisory flags related to the probability of snow cover and frozen soil. Setting of advisory flags related to terrain topography, occurrence of wetlands and the long-term surface soil moisture mean.

The abovementioned processing steps are shown schematically in Figure 3–1.
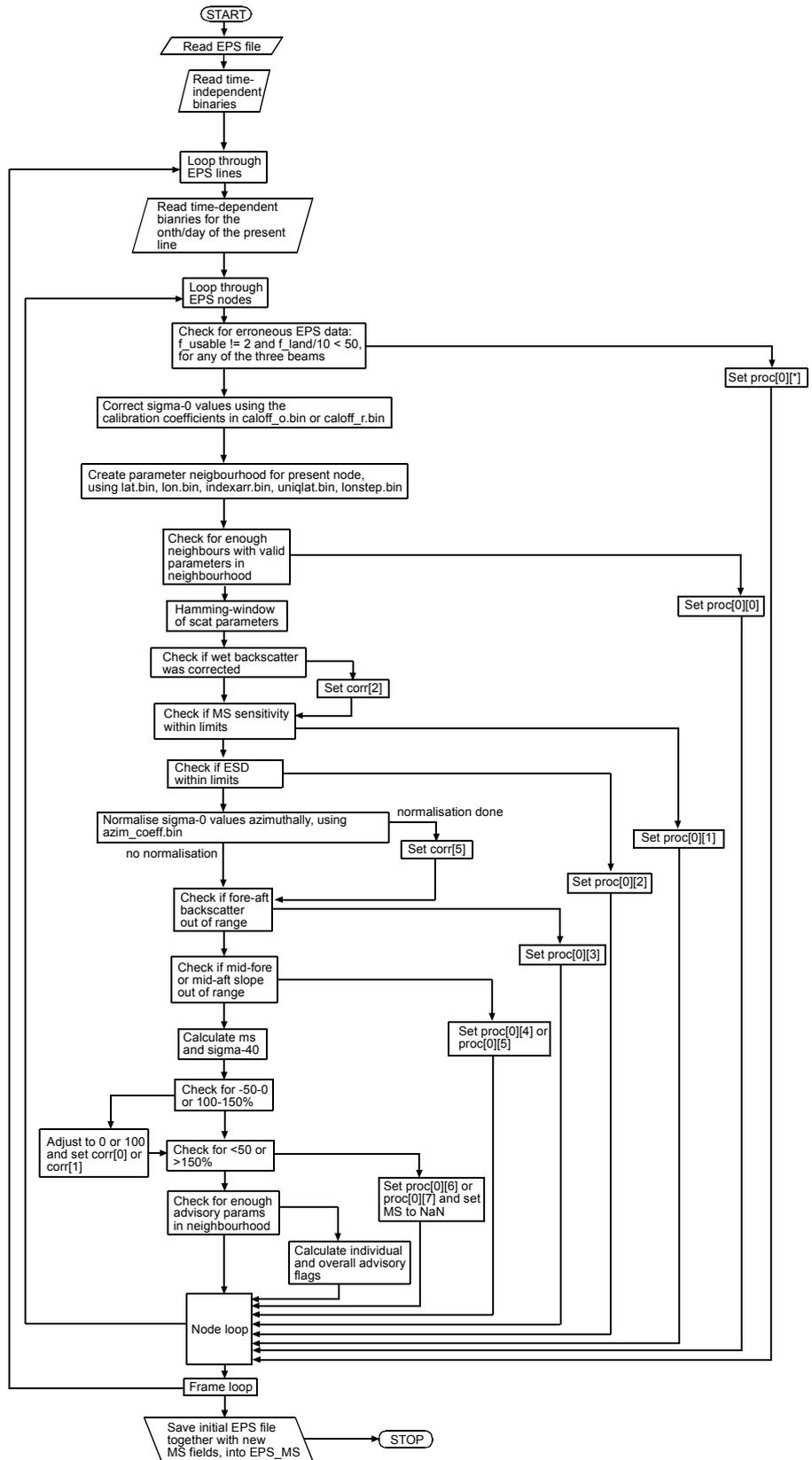
Figure 3–1

Flowchart of the NRT processing steps.

3.2 Input Data

3.2.1 Scatterometer Data

As input data the TU Wien model uses the ASCAT Scatterometer data. ASCAT is a multi-incidence angle radar operating at 5.255 GHz (C-band), VV polarization and is flown on the MetOp series of satellites. The current implementation of the TU Wien NRT soil moisture product is based on ASCAT data in EPS format.

As ASCAT orbits the Earth, it generates two swaths, each yielded by three antenna radar beams looking 45 degrees forward, sideways, and 45 degrees backwards with respect to the satellites' flight direction. These beams illuminate a 500 km-wide swath as the satellite moves along its orbit, and each provides measurements of radar backscatter on a 25 km grid (for nominal, 50 km resolution data) or a 12.5 km grid (for experimental, 25 km resolution data). The result in each swath is three independent backscatter measurements for each grid point, obtained using the three different viewing directions and separated by a short time delay.

Further information about the ASCAT EPS format

EUMETSAT documentation:
- *EPS Programme Generic Product Format Specification*
  (Ref.: EPS.GGS.SPE.96167).
- *ASCAT Products Guide*
  (Ref.: EUM/OPS-EPS/MAN/04/0028).
- *ASCAT Product Generation Function Specification*
  (Ref.: EUM.EPS.SYS.SPE.990009)

3.2.2 The Parameter Database

To enable retrieval of soil moisture information knowledge about the specific scattering characteristics of the land surface is required. These parameters are derived from the analysis of multi-annual time series and are stored for each point of a predefined DGG in a parameter database. The database contains 1035365 grid points. An example of the contents of one of the binary files (esd.bin) is shown in Figure 3–2.

The following is a list of the parameter database files and directories delivered with WARP[NRT] 2.0:

- **directories with 366 files each**: curv, curv_noise, dry, dry_noise, frozen, ms_mean, slop, slop_noise, snow, wet and wet_noise. All these directories contain daily files of the form MMDD.bin. Exactly 1035365 values are stored in each of

these files, with `frozen` and `snow` files holding byte values while the remaining files store 32-bit floating point values.

- **files:**
  - `azim_coeff.bin`, holding an array of 1035365 structures defined in `C_azimCoeffStruc`, within the source code.
  - `caloff_o.bin` or `caloff_r.bin` (depending on the resolution of the ASCAT input file), holding a matrix of 32-bit floating point values. Dimensions: $3 \times 42 \times 2$ or $3 \times 82 \times 2$.
  - `esd.bin`, `lat.bin`, `lon.bin` and `wetcorr.bin`, each holding an array of 1035365 32-bit floating point values.
  - `topo.bin`, `wetland.bin`, each holding an array of 1035365 bytes.
  - `indexarr.bin`, holding a matrix of 32-bit unsigned integer values. Dimensions: 1601×3231.
  - `lonstep.bin` and `uniqlat.bin`, each holding an array of 1601 32-bit floating point values.

The values in the above binary files use the Little Endian byte order (Intel). Matrix dimensions are given in the column-major notation ([row, column])

Figure 3–2

Example of one layer of the parameter database. Shown is the spatial distribution of the ESD, given in dB.
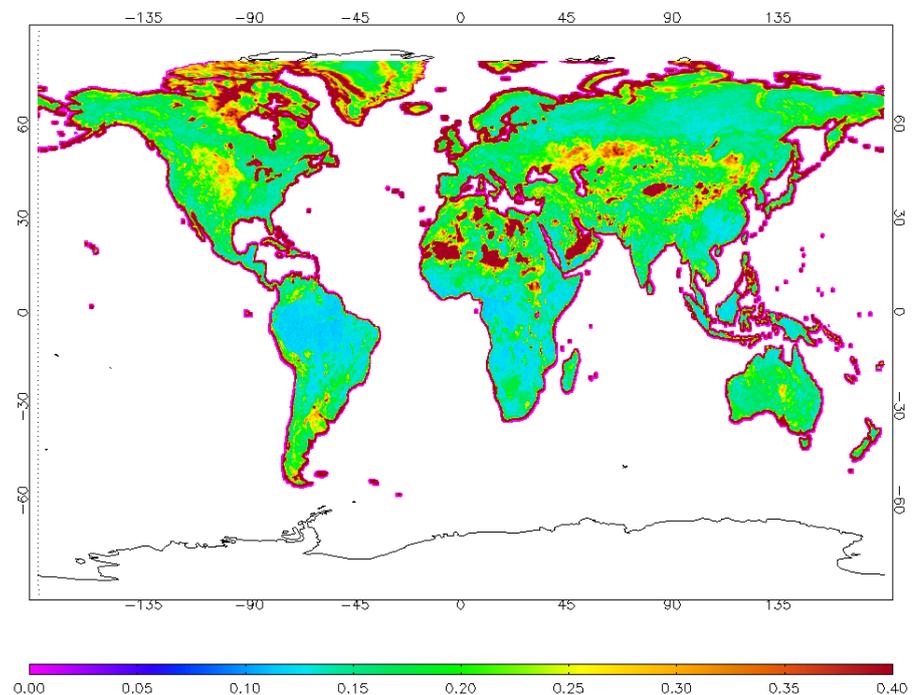
3.3   The Output Product

WARP^{NRT} 2.0 generates a number of products and associated parameters, which will briefly be discussed here. Format details are presented in the ASCAT Soil Moisture Working Note 4: *WARP^{NRT} 2.0 Binary Data Format.* An example of visualisation of a 50 km and 25 km WARP^{NRT} 2.0 product is shown in Figure 3–3.
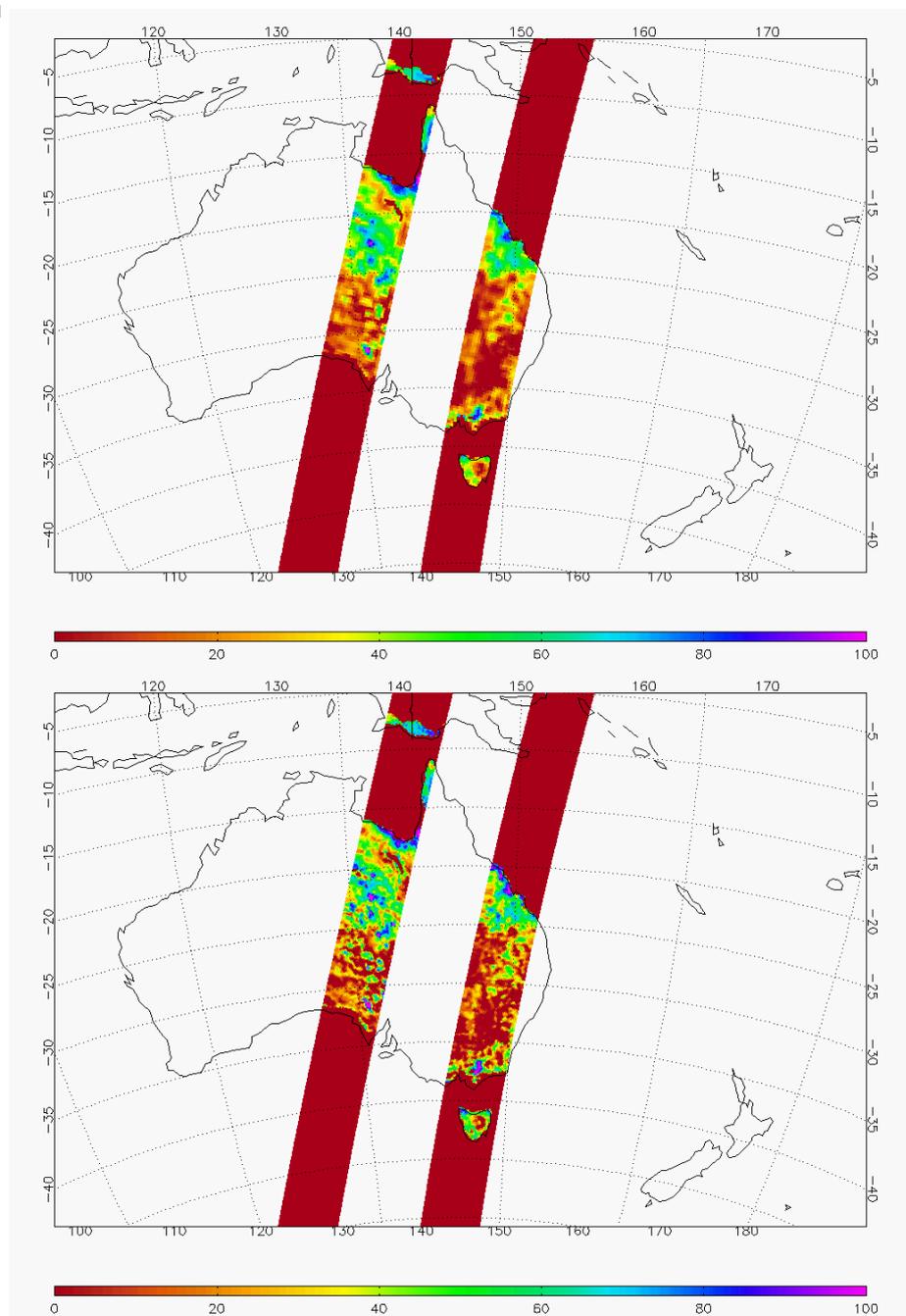

Figure 3–3

Product example of surface soil moisture (in %) over Australia. Top: 50 km resolution data. Bottom: 25 km resolution data.

3.3.1   Surface Soil Moisture and Its Noise

The surface soil moisture measure represents the degree of saturation of the topmost soil layer (< 5 cm) and is given in percent, ranging from 0 (dry) to 1 (wet). The surface soil moisture is complemented by its noise, derived by error propagation of the backscatter noise (covering instrument noise, speckle and azimuthal effects).

3.3.2   Normalised Backscatter Coefficient and Its Noise

The ERS scatterometers measure backscatter under various incidence angles. The normalised backscatter coefficient is equivalent to backscatter at a reference incidence angle of 40°. The normalised backscatter is complemented by its noise, derived by error propagation of the backscatter noise (covering instrument noise, speckle and azimuthal effects).

3.3.3   Seasonal Variation of Slope and Its Noise

The incidence angle dependency of the backscatter is largely determined by the amount of above ground biomass and by surface roughness. Mathematically it can be described by a second order polynomial determined by a slope and a curvature term. The slope term is especially sensitive to vegetation growth and senescence. The slope is complemented by the its noise, derived by error propagation of the backscatter noise (covering instrument noise, speckle and azimuthal effects).

3.3.4   Sensitivity, Dry Backscatter Reference, Wet Backscatter Reference

The sensitivity of the TU Wien model to measure soil moisture is defined by the difference of the dry and wet backscatter reference values $\sigma^0_{dry}(40)$ and $\sigma^0_{wet}(40)$. For a given point in time generally, the sensitivity depends on the amount of above ground biomass. High amounts of biomass result in a low sensitivities to soil moisture. The dry and wet backscatter reference values are complemented by their noise, derived by error propagation of the backscatter noise (covering instrument noise, speckle and azimuthal effects).

3.3.5   Mean Surface Soil Moisture

The TU Wien model is very sensitive in tracking soil moisture changes, but less sensitive in determining the absolute soil moisture level. The soil moisture mean is therefore a subsidiary measure to assist in the interpretation of the surface soil moisture product. The mean is

derived from surface soil moisture data of the period 08/1991-05/2007 (for most DGG grid points 08/1991-01/2001, due to restricted coverage of the ERS-2 scatterometer after this date). Considering the short observation period and the relative low temporal sampling (once/twice per week), the mean soil moisture has been derived for monthly intervals to obtain a reliable measure (i.e. all measurements of each calendar month have been averaged). Daily data has been derived by interpolation of the monthly means.

3.3.6 Rainfall Detection

Surface soil moisture is very sensitive to rainfall events. In principal simple change detection should allow to track rainfall events in the surface soil moisture product. Currently a suitable method has not been implemented but given the importance of rainfall information in various applications, this flag has been reserved for future use.

3.4 Advisory Flags

Soil moisture cannot be estimated if the fraction of dense vegetation, open water surfaces or snow/frozen soils dominates the scatterometer footprint. To support data users in judging the quality of the soil moisture products, advisory flags are stored as complementary information.

3.4.1 Soil Moisture Quality

This is an aggregated quality control indicator that serves as an overall quality flag depending on the advisory flags of snow cover fraction, frozen land surface fraction, inundation and wetland fraction, and topographic complexity.

3.4.2 Snow Cover Fraction

Backscatter measurements are very sensitive to snow properties. The exact scattering behaviour of snow depends on the dielectric properties of the ice particles and on their distribution and density. Therefore soil moisture cannot be retrieved under snow conditions. The implementation of the snow flag uses a historic analysis of SSM/I snow cover data and gives the probability for the occurrence of snow for any day of the year. Examples of snow cover probabilities are given in Figures 3–4 and 3–5.
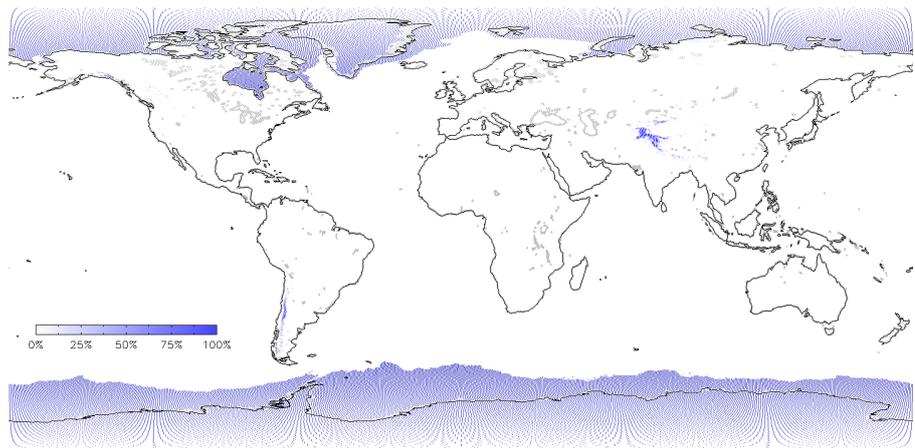

Figure 3–4

Snow Cover (SSM/I) for the 1ˢᵗ of January.
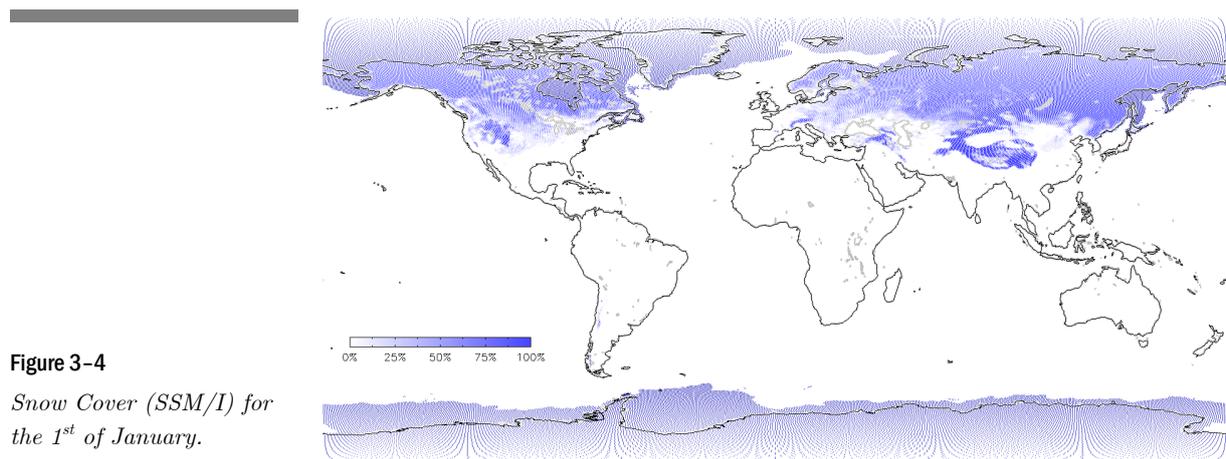
Figure 3–5

Snow Cover (SSM/I) for the 1st of July.

3.4.3 Frozen Land Surface Fraction

Taking into consideration the processes mentioned for snow, freezing can result in low backscatter, but also in high backscatter e.g. over frozen lakes. To avoid any negative implication in the use of backscatter representing frozen conditions these measurements have to be masked. The flag is based on a historic analysis of modelled climate data (ERA-40) and gives the probability for the frozen soil/canopy conditions for each day of the year (Figures 3–6 and 3–7).
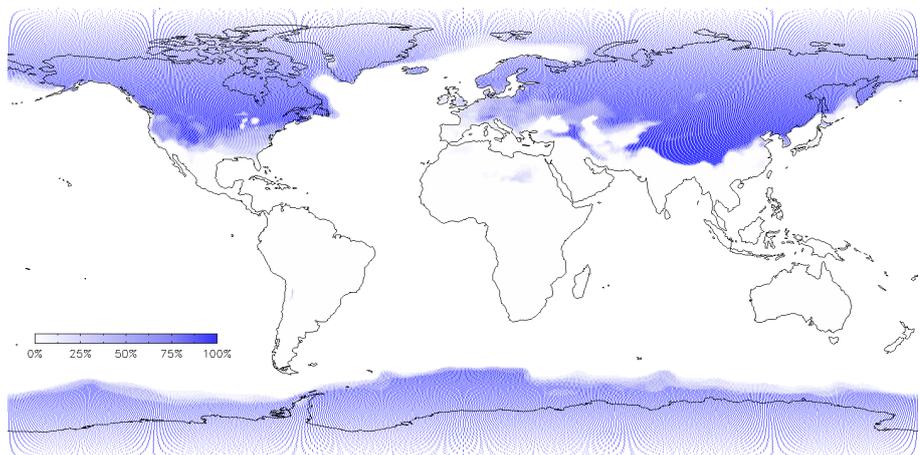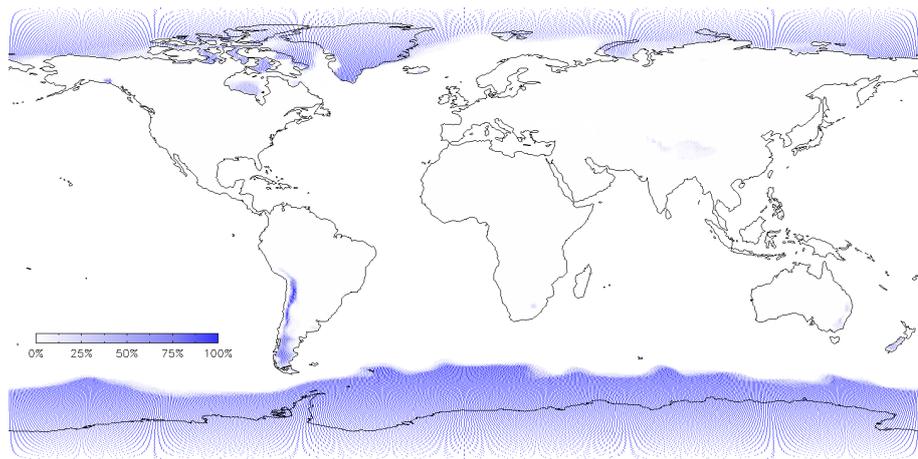

Figure 3–6

Frozen soil probability (ERA-40 modelled product) for the 1st of January.

Figure 3–7

*Frozen soil probability (ERA-40 modelled product) for the 1ˢᵗ of July.*

3.4.4   Inundation and Wetland Fraction

The penetration depth of C-band microwaves into water is less than about 2 mm and therefore, as is the case for bare soil and wet snow, σ^0 of water is dependent on the roughness of the surface. When the water surface is calm, then specular reflection occurs and σ^0 at off-nadir angles is very low. Wind generates water waves that increase scattering into the backward direction. The radar return is highest when the radar looks into the upwind or downwind direction and is smallest when it looks normal to the wind vector. The main contributions do not come from large waves, even if they are many meters in height. Rather, scattering is dominated by short waves that ride on the top of the larger waves . Generally, open water should not effect the retrieval, if the percent area covered by the open water surface is small. Nevertheless, there exist regions were the area percentage of open water surfaces can reach a significant magnitude which result in dominating backscatter effects.

To account for this, the open water flag is defined as fraction coverage of inundated and wetland areas. These areas are derived from the *Global Lakes and Wetlands Database (GLWD)* level 3 product which includes several wetland and inundation types . An example of the inundation and wetland fraction is given in Figure 3–8.

Figure 3–8

*Inundation and wetland fraction derived from GLWD.*
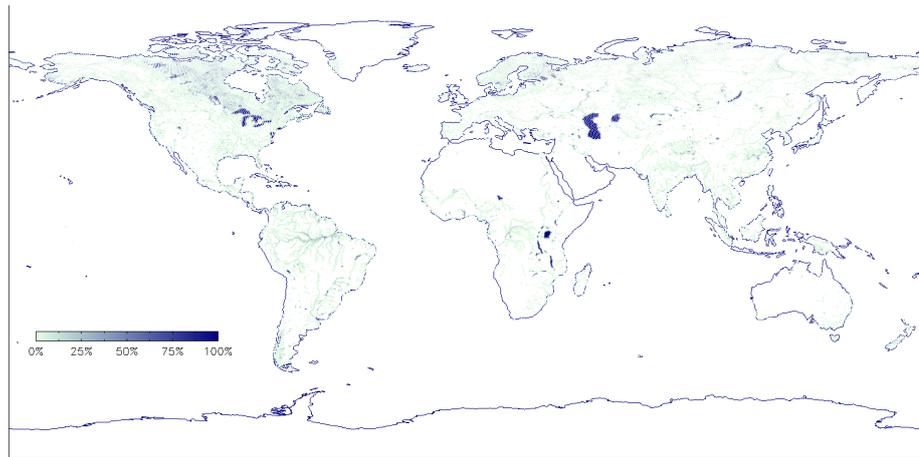
3.4.5   Topographic Complexity

Backscatter of mountainous regions can be subject of several distortions. Main error sources are calibration errors due to the deviation of the surface from the assumed ellipsoid and the rough terrain, the influence of permanent snow and ice cover, a reduced sensitivity due to forest and rock cover and highly variable surface conditions.

The topographic complexity flag is derived from GTOPO30 data. For each cell of the Discrete Global Grid, standard deviation of elevation is calculated and the result is normalized to values between 0 and 100 %, as can be seen in Figure 3–9.

Figure 3–9

Topographic Complexity (Normalized standard deviation of topography), derived from GTOPO30.
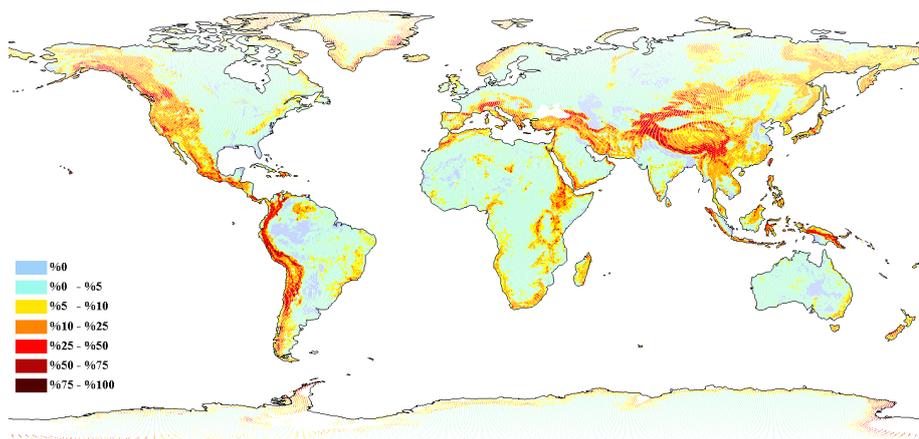
Further information   Report Series No. 7 *Definition of Quality Flags*

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