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

Part 7: Definition of Quality Flags

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Definition of Quality Flags

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Executive Summary

The present document constitutes the report of Work Package 3 of the project *Processor for ERS-SCAT-based Soil Moisture*. The proposal was submitted by the Institute of Photogrammetry and Remote Sensing (I.P.F.) at Vienna University of Technology (TU WIEN) as a response to EUMETSAT's Request for Quotation 05/934. The objective of the project is to develop a demonstration software application for near real time (NRT) surface soil moisture retrieval from ERS-1/2 scatterometer (ESCAT) data, using version 4.0 of I.P.F.'s WARP (soil WAter Retrieval Package) processing software.

Work Package 3 deals with the definition of quality flags. The task of defining quality flags was not specifically mentioned in EUM.MET.SOW.04.010. However, first discussions with the NWP SAF consortium about their requirements showed that it is crucial for them that each product is accompanied with suitable quality flags. This is because it is more important to the NWP users that data of good quality are assimilated rather than data of maximum coverage. Further, the definition of quality flags complementing the soil moisture products builds a basis for the definition of the BUFR Format. Although the responsibility for the BUFR specification of the Soil Moisture product, is with EUMETSAT (the soil moisture part of the BUFR template) TU WIEN will provide the input to precisely define the required attribute list.

Based on a critical review of the algorithm functionality and the processing flow this report defines the flags required to support data users in judging the quality of the soil moisture products. Based on this assessment existing global data sets suitable for populating the quality flags will be reviewed and collected.

Acronyms

AMSR	Advanced Microwave Scanning Radiometer
ASCAT	Advanced Scatterometer
AVHRR	Advanced Very High Resolution Radiometer
BUFR	Binary Universal Form for the Representation of meteorological data
DEM	Digital Elevation Model
DGG	Discrete Global Grid
EASE Grid	Equal-Area Scalable Earth Grid
ECMWF	European Centre for Medium-Range Weather Forecasts
ESA	European Space Agency
ESCAT	ERS-1 and ERS-2 scatterometers
ESD	Estimated Standard Deviation
ERS	European Remote sensing Satellite
GLI	Global Imager
GLWD	Global lakes and wetlands database
GRIB	GRIdded Binary format
GSHHS	Global Self-consistent, Hierarchical, High-resolution Shoreline Database
GTOPO30	Global Topography - 30 arc-seconds
HDF	Hierarchical Data Format
IMS	Interactive Multisensor Snow and Ice Mapping System
IPF	Institute of Photogrammetry and Remote Sensing
MODIS	Moderate Resolution Imaging Spectroradiometer
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
NRT	Near Real Time
NSIDC	National snow and ice data centre
NWP	Numerical Weather Prediction
POES	Polar-orbiting Operational Environmental Satellites
SAF	Satellite Application Facility
SRTM	Shuttle Radar Topography Mission
SSM/I	Special Sensor Microwave/Imager
SWE	Snow Water Equivalent
TU Wien	Vienna University of Technology
UR	User Requirement
USGS	U.S. Geological Survey
WARP	Water Retrieval Package
WDB	World Data Bank
WMO	World Meteorological Organization
WVS	World Vector Shoreline
WWF	World Wildlife Fund

Contents

1 Introduction

Since 1994 the Institute of Photogrammetry and Remote Sensing (I.P.F.) at the Vienna University of Technology (TU WIEN) is actively involved in deriving soil moisture data using scatterometer measurements from the ESCAT instruments onboard the ERS-1 and ERS-2 satellites. A result of this undertaking is the development of the WARP (soil WAter Retrieval Package) processing software which is based on the TU WIEN model. The scientific basis and algorithms for the TU WIEN model have been fully published in a series of conference and journal papers, most important of which are (Wagner et al. 1999a; Wagner et al. 1999b; Wagner et al. 1999c), (Ceballos et al. 2005; Wagner and Scipal 2000; Wagner et al. 2003). The most complete descriptions of the algorithms can be found in the Ph.D. thesis of (Wagner 1998) and (Scipal 2002).

With the project *Processor for ERS-SCAT-based Soil Moisture*, the I.P.F. will develop a demonstration application software (called WARP^{NRT} 1.0) in which the TU WIEN-method is applied in near real-time (NRT) mode to incoming ESCAT backscatter measurements, demonstrating the NRT generation of surface soil moisture data.

Work Package 3 of the EUMETSAT MET project is dedicated to the definition of quality flags. The task of defining quality flags is not specifically mentioned in EUM.MET.SOW.04.010. However, first discussions with the NWP SAF consortium about their requirements showed that it is crucial for them that each product is accompanied with suitable quality flags. This is because it is more important to the NWP users that data of good quality are assimilated rather than data of maximum coverage. Further, the definition of quality flags complementing the soil moisture products, builds a basis for the definition of the BUFR Format. Although the responsibility for the BUFR specification of the Soil Moisture product, is with EUMETSAT (the soil moisture part of the BUFR template), TU WIEN will provide the input to precisely define the required attribute list.

Based on a critical review of the algorithm functionality and the processing flow this report will define the flags required to support data users in judging the quality of the soil moisture products. The quality indicators will be grouped into quality flags and advisory flags, regarding their functionality. Quality flags are directly derived from the incoming scatterometer data. They describe the intrinsic quality of the soil moisture product and will allow to transparently tracing the involved processing steps.

As the TU WIEN model is subjected to certain limitations (for example soil moisture retrieval is not possible under the presence of snow) the quality flags will be complemented by Advisory Flags. These flags are required to allow proper use of the data. As these flags can not be populated based on the incoming scatterometer data they have to rely on external data. This report will therefore not only define the required quality flags but also review existing global data sets, suitable for populating the advisory flags.

2 Data Product Definition

The TU WIEN model for retrieving soil moisture from ERS scatterometer data is from its conception a change detection method (Wagner et al. 1999b). In a first step backscatter data measured by the ESCAT is normalised with respect to the viewing geometry. As a result backscatter at 40° incidence angle, $\sigma^0(40)$, is available. In a second step instantaneous $\sigma^0(40)$ values are corrected for the influence of vegetation and are compared to dry and wet backscatter reference values denoted $\sigma^0(40)_{dry}$ and $\sigma^0(40)_{wet}$. The reference values are derived from the lowest and highest $\sigma^0(40)$ values recorded during the period August 1991 to January 2001. Assuming a linear relationship between $\sigma^0(40)$ and the soil moisture content, a relative measure of soil wetness in the surface layer, m_s, is obtained, ranging between 0 and 1 (0 % to 100 %). If $\sigma^0{}_{dry}$ represents a completely dry soil surface and $\sigma^0{}_{wet}$ a saturated soil surface then m_s is equal to the degree of saturation which is the soil moisture content expressed in percent of porosity (also called total water holding capacity). The derived surface soil moisture product represents an average over all bare ground surfaces and areas covered by translucent vegetation types such as grassland or agricultural land within the footprint of the sensor.

To guarantee largest possible transparency of the processing chain and support data users in judging the quality of the soil moisture product, several quality and processing flags will be delivered with the data. The quality flags comprise information about the intrinsic product quality, internal quality checks and specific processing details (Table 2–1). The flags are derived directly from the incoming scatterometer data.

Additionally to these quality flags, advisory flags are defined (Table 2–2). These flags are required because in its current conception the TU WIEN model is subject of certain limitations, i.e. soil moisture can not be estimated if the fraction of dense vegetation, open water or snow/frozen soils dominate the scatterometer footprint. The advisory flags will support the user in judging the reliability of the soil moisture product and to reject unreliable measurements. As these indicators can not be derived from scatterometer data, they have to rely on external data sets.

The definition of the quality and advisory flags is based on the processing architecture of WARP 4 and on the experience gained in several pilot projects funded by ESA (Beck et al. 2003; Beck et al. 2002; Beck et al. 1999; Beck et al. 2000).

Additionally, the following points have been raised in the discussion with the NWP community and reflect their user requirements. Regarding the error estimation it was requested, that errors should be provided in relevant units, relating to dynamic ranges, and numerical precision of product. As additional accuracy indicators following parameters have been requested:

UR G6.1: Provision of anomaly of soil moisture from its climatologic mean

UR G6.2: Indication of snow and frozen surfaces

UR G6.3: Inclusion of wet/dry reference range.

Table 2–1

Overview of soil moisture products and complement quality flags.

Symbol / Variable Name	**Details**	**Type**	**Unit**	**Range**
Software Identification *SOFT*	Version of software WARP^{NRT}	F	–	–
Database Identification *PARAM_ DB*	Parameter database needed for retrieval	F	–	–
m_s *MS*	Surface soil moisture	F	%	[0,100]
$ESD(m_s)$ *NOISE_ MS*	Estimated error in surface soil moisture	F	%	[0,100]
$\sigma^0(40)$ *SIGMA40*	Extrapolated backscatter at 40 degree incidence angle	F	dB	[-35,0]
$ESD(\sigma^0(40))$ *NOISE_ SIG40*	Estimated error in extrapolated backscatter at 40 degree incidence angle	F	dB	[0,5]
$\sigma'(40,t)$ *SLO40*	Slope at 40 degree incidence angle	F	dB/deg	[-0.8,0.1]
$\varepsilon_{\sigma'}$ *NOISE_ SLOPE*	Estimated error in slope at 40 degree incidence angle	F	dB/deg	[0,0.5]
S *SENS*	Soil moisture sensitivity **	F	dB	[0,25]
$\sigma^0{}_{dry}$ *DRY*	Dry backscatter	F	dB	[-30,-5]
$\sigma^0{}_{wet}$ *WET*	Wet backscatter	F	dB	[-25,0]
$\overline{m}_s$ *MS_ MEAN*	Mean surface soil moisture	F	%	[0,100]
Rainfall Detection *RAIN*	Rainfall detection * (currently not implemented)	B	%	[0,200]

* Stored values have to be multiplied by a factor of 0.5 to obtain actual values.

** Requested by NWP community.

Table 2–1 (continued)

Overview of soil moisture products and complement quality flags.

Symbol / Variable Name	Details	Type	Unit	Range
Correction Flag *CORR*	*Bit1:* m_s between -20% and 0% *Bit2:* m_s between 100% and 120% *Bit3:* Correction of wet backscatter reference *Bit4:* Correction of dry backscatter reference *Bit5*: Correction of volume scattering in sand *Bit6-Bit8*: Reserved All 8 bits set to 1 means flag is missing.	B	–	–
Processing Flag *PROC*	*Bit1:* Not soil *Bit2:* Sensitivity to soil moisture below limit *Bit3:* Azimuthal noise above limit *Bit4:* Backscatter Fore-Aft beam out of range *Bit5:* Slope Mid-Fore beam out of range *Bit6:* Slope Mid-Aft beam out of range *Bit7:* m_s below -20% *Bit8:* m_s above 120% *Bit9-Bit16:* Reserved All 16 bits set to 1 means flag is missing.	B2	–	–

* Stored values have to be multiplied by a factor of 0.5 to obtain actual values.
** Requested by NWP community.

Table 2–2

Overview of advisory flags.

Symbol / Variable Name	Details	Type	Unit	Range
Soil moisture quality *MS_ QUAL*	Aggregated quality flag *	B	%	[0,200]
Snow cover fraction *SNOW*	Probability and fraction of snow cover * **	B	%	[0,200]
Frozen land surface fraction *FROZEN*	Probability of soil temperature below 0°C *	B	%	[0,200]
Inundation and wetland fraction *WETLAND*	Area of open water surfaces (lakes, rivers, wetlands) *	B	%	[0,200]
Topographic complexity *TOPO*	Normalised standard deviation of elevation *	B	%	[0,200]

* Stored values have to be multiplied by a factor of 0.5 to obtain actual values.
** Requested by NWP community.

Table 2–3

Data types of the product.

Data type	Meaning
F	4-byte float
A	7-character ASCII
B	1 byte or 8 bits (flags)
B2	2 bytes or 16 bits (flags)

No Data Value:
Float: -999999999.
Long Int: -999999999
Byte: 255

3 Quality Flags

In the following sections a brief description of the quality flags is given. For ranges, units and precision of the flags see Table 2–1. All quality flags will be derived directly from the incoming scatterometer data or from the WARP^{NRT} parameter database. The only exception builds the water flag which will be derived from an external water mask but which will also be included in the WARP^{NRT} parameter database. The definition of the flags reflects the current processing architecture and quality standards of the TU WIEN model and its implementation in WARP 4. To account for potential future developments several bits have been reserved in the processing and correction flag (see Table 2–1).

3.1 Product Noise

Based on the difference of the simultaneously measured fore and aft beam backscatter, an estimate of the standard deviation of σ^0, denoted ESD, is derived for each point of the land surface. The Estimated Standard Deviation integrates measurement noise, speckle and azimuthal noise and is used to calculated the standard deviation of $\sigma^0(40)$ and the surface soil moisture m_s by means of rigorous error propagation. The estimated standard deviation of $\sigma^0(40)$ is a static parameter. The estimated standard deviation of the surface soil moisture m_s is dynamic and depends on the sensitivity of backscatter to soil moisture variations which in turn depends on the vegetation cover and its dynamics.

3.2 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 08/1991-01/2001.

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 the month January have been averaged). Daily data has been derived by interpolation of the monthly means.

3.3 Sensitivity

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 of the amount of above ground biomass. High amounts of biomass result in a low sensitivities to soil moisture. Consequently the sensitivity is a dynamic quantity changing over the course of the year.

3.4 Correction Flag

The correction Flag indicates if any action has been taken to correct measurements due to known anomalies. Currently, correction algorithms are applied if 1) m_s exceeds the nominal range but is still within certain limits and 2) if the retrieval of the dry reference backscatter value is biased. Other correction terms included in this flag are currently under investigation and will likely be implemented in WARP 5.

The correction flags are defined in Boolean format. This implies that the users does not get any information about the magnitude of the applied correction but only that a certain action has been taken. We decided to limit the flags to Boolean type as the applied corrections are very specific and require a comprehensive knowledge of the TU WIEN model which most users do not need. Nevertheless for reasons of transparency and to be able to reconstruct the processing cycle we believe it is important to include this information.

Bit1: m_s *between -20% and 0%*

This flag indicates m_s values out of the nominal range of 0-100% but in the range -20 – 0 %. These measurements are set to the extremes of 0 during the processing.

Bit2: m_s *between 100% and 120%*

This flag indicates m_s values out of the nominal range of 0-100% but in the range 100 – 120 %. These measurements are set to the extremes of 100 during the processing.

Bit3: Correction of wet reference backscatter

The TU WIEN model assumes that at least once the land surface is observed under saturated conditions. In very dry climates, this assumption is violated, as soils might never reach saturation. Based on an empirical relationship a simple correction method has been implemented. This flag indicates measurements where the wet reference correction has been applied.

Bit4: Correction of dry reference backscatter

The TU WIEN model assumes that at least once the land surface is observed under completely dry conditions in long time series. In very wet climates, this assumption is violated, as soils might never dry out completely. Potential correction methods are currently studied. This flag indicates measurements where the dry reference correction has been applied.

Bit5: Correction of volume scattering in sand

In the current implementation of the TU WIEN model volume scattering effects of very dry sand deserts are not represented. Potential correction methods are currently studied. This flag indicates measurements where the volume scattering correction has been applied

3.5 Processing Flag

The TU WIEN model encompasses rigorous quality control during all processing steps. If a backscatter measurement does not meet the defined quality standards it is disregarded from further processing. The processing flag contains information about these quality controls. If one of these flags is set, soil moisture retrieval is not possible.

Bit 1: Not soil

During the processing various parameters are required to derive soil moisture information. These parameters are available for each point of a predefined discrete global grid (DGG) and are resampled to the orbit grid of the satellite swath geometry. A detailed description of the grid definitions and the resampling procedure can be found in the Eumetsat MET WP 2 report. If not at least 3 points of the DGG are available in the vicinity of an incoming backscatter measurement this flag is set. Reasons for an insufficient number of DGG points can for example be inland lakes or coastal zones where parameter information is not available.

Bit 2: Sensitivity to soil moisture below limit

If the sensitivity of the backscatter to soil moisture is below 1.67 dB, then soil moisture is not retrieved. Reason for a low sensitivity is a high level of above ground biomass. In principal this rule takes effect in the tropical rain forests along the equatorial belt.

Bit 3: Azimuthal noise above limit

In the current implementation of the TU WIEN model the azimuthal viewing geometry is not correctly represented. Especially in regions characterised by surface patterns with distinct azimuthal orientation (e.g. sand deserts) high noise is introduced. A correction method has been developed under the NWP Visiting Scientist Programme. Up to the implementation of this method this flag will be set when the azimuthal noise is above the limit of 1 dB. In principal this flag takes effect in sand desert areas.

Bit 4: Backscatter Fore-Aft beam out of range

This flag is set if the absolute difference between backscatter measured with the fore and aft beam antenna is above 6 times the estimated standard deviation of σ^0.

Bit 5: Slope Mid-Fore out of range

This flag is set if the difference of the local slope derived from the mid and fore beam backscatter measurement and the modelled slope is above three times the estimated standard deviation of the slope.

Bit 6: Slope Mid-Aft out of range

This flag is set if the difference of the local slope derived from the mid and aft beam backscatter measurement and the modelled slope is above three times the estimated standard deviation of the slope.

Bit 7: m_s below -20%

This flag indicates unnatural low m_s values (m_s below -20).

Bit 8: m_s above 120%

This flag indicates unnatural high m_s values (m_s above 120).

4 Advisory Flags

Soil moisture retrieval from ESCAT is subject of certain limitations, i.e. soil moisture can not be estimated if the fraction of dense vegetation, open water or snow/frozen soils dominate the scatterometer footprint. Unfortunately those effects cannot be modelled from sent data alone. The advisory flags are crucial to support the user in judging the reliability of the soil moisture product and to reject unreliable measurements. The necessity has been stressed in several pilot application studies (Beck et al. 2003; Beck et al. 2002; Beck et al. 1999; Beck et al. 2000) and during the formulation of User requirements which was carried out with the support of the NWP community.

One limitation of these flags is that they can not be populated based on the incoming scatterometer data but they have to rely on external data sets. To our knowledge there exist currently no other flags in the ASCAT product or any other near real time satellite data product which are populated with external data set. We only found one semi operational product that uses external data to populate a flag. This product is a QSCAT product provided by Remote Sensing Systems, (http://www.ssmi.com), which uses SSM/I data to detect and flag Sea Ice: *"Scatterometer data processing uses contemporaneous microwave radiometer measurements for rain flagging and sea ice detection. Remote Sensing Systems processes both microwave scatterometer and radiometer data in a semi-operational, near-real-time (NRT) environment. Thus, the various data sets can be combined to obtain improvements in the individual products. For the case of QuikScat, we use 4 satellite microwave radiometers (F13 SSM/I, F14 SSM/I, F15 SSM/I, and TMI) to determine if rain is present at the location of the QuikScat observation. In addition, the three SSM/Is are used to detect sea ice. Using the SSM/I daily observations of sea ice, the scatterometer observations can be properly flagged so that reliable wind vectors can be obtained immediately next to the marginal ice zone."*

It currently remains open how the flags will be populated. Important issues are not only the availability of reliable reference data in near real time but also property rights which have to be solved beforehand. We therefore propose a flexible definition of these flags. In the simplest form the flags are defined as probability flags. The probabilities are based on the analysis of historic data. These probability maps will be saved in the Discrete Global Grid parameter data base format which is part of WARP^{NRT}. For near real time processing the resampling procedures developed under the EUMETSAT MET project Work Package 2 can be used.

If respective information becomes available in near real time and if an implementation in the soil moisture products is possible these flags can be upgraded to near real time flags.

4.1 Snow

4.1.1 Backscatter of Snow

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. Unfortunately it is not possible from scatterometer data alone to detect the presence of snow (Ulaby and Stiles 1980). Dry snow consists of ice particles distributed in an air medium. As freezing results in a strong decrease of the dielectric constant of water, dry snow is more or less transparent at C-Band (Mätzler and Schanda 1984), (Rott 1984), (Rott and Mätzler 1987). Backscatter of dry snow is thus strongly affected by reflections from the soil below the snow cover. A study of ERS-Scatterometer data over the Canadian Prairies has shown that a dry shallow snow pack overlying a soil is almost identical to σ^0 of the snow free situation (Wagner 1995). In the presence of liquid water dielectric losses strongly increase, resulting in a distinctly different backscatter behaviour. The penetration depth for wet snow with a liquid water content of 2-4 vol. % is typically of the order of one wavelength (Mätzler and Schanda 1984). The dominating scattering mechanism is therefore surface scattering and the backscatter intensity depends on surface roughness. If the snow surface is smooth σ^0 of a wet snow layer might be lower than σ^0 of a dry bare soil. If, however the snow surface is rough then σ^0 of a wet snow layer is comparable to σ^0 of wet bare soils. Figure 4-1 shows in this particular example how a layer of snow adulterates the soil moisture estimate depending on the temperature. In this particular example, dry snow has low backscatter characteristics leading to low soil moisture estimates. During melting events backscatter increases leading to high soil moisture estimates. Backscatter measurements of snow cover should therefore rigorously be masked.

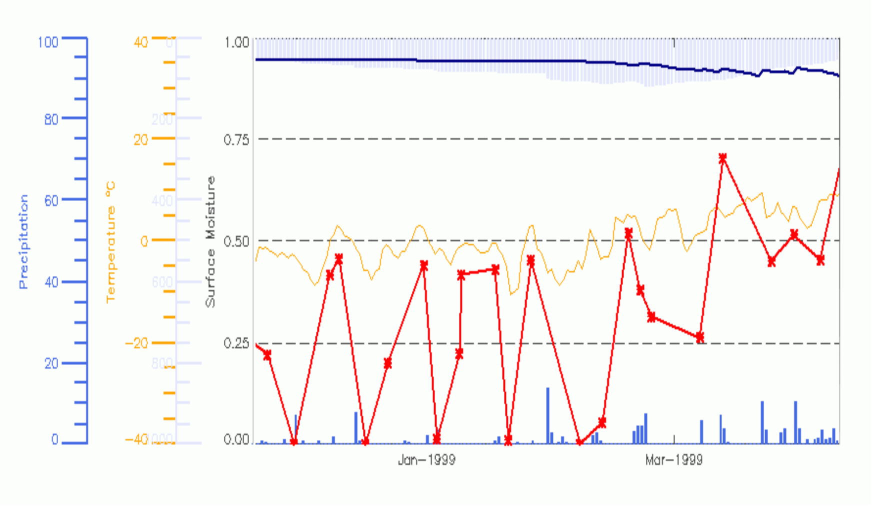

Figure 4-1.

Surface soil moisture (red) and meteorological data (temperature – orange; precipitation – blue bottom bar chart; snow depth – blue top line) for a station in southern Austria during winter 1999..

4.1.2 Snow Cover Data

Both optical and microwave systems are used to retrieve information on snow cover and there exist several hemispheric-scale satellite-derived snow-cover maps (Hall et al. 2002). Among these, snow cover maps based on SSM/I, AMSR-E and MODIS are operationally available with daily updates from the United States National Snow and Ice Data Center NSIDC (Table 4-1).

The quality of these products has been studied by comparing the different satellite-derived snow maps. The main conclusions of these studies are:

Passive-microwave sensors offer the possibility to map snow depth and snow-water equivalent (SWE) as well as snow extent. Additionally they allow monitoring under cloud cover and during night.

The maps derived from visible and near-infrared data are more accurate for mapping snow cover than are the passive-microwave-derived maps (Hall et al. 2002).

High-resolution optical data are particularly important near the snowline when thin, dry, or wet snow may not be mapped using passive-microwave techniques, or when snow and frozen ground have similar microwave signatures (Salomonson et al. 1995).

Early in the season, the SSM/I snow mapping algorithms are unable to identify shallow and wet snow as snow cover, while the MODIS snow maps perform well under those circumstances. (Foster et al. 2002).

Dataset name	MODIS/Terra MODIS/Aqua Snow Cover Daily L3 Global 0.05Deg CMG	Near Real-Time SSM/I EASE-Grid Daily Global Ice Concentration and Snow Extent	AMSR-E/Aqua L3 Global Snow Water Equivalent EASE-Grids	IMS Daily Northern Hemisphere Snow and Ice Analysis at 4 km and 24 km Res.
Distributor	NSIDC	NSIDC	NSIDC	NSIDC
Description	The dataset consists of 7200-column by 3600-row global arrays of snow cover in a 0.05 deg climate modelling grid (CMG).	Snow extent is mapped separately using an algorithm developed for SMMR / SSM/I data. The NISE product is updated daily using the best available data from the past five days.	Snow water equivalent is mapped to Northern and Southern Hemisphere 25 km EASE-Grids.	Snow coverage map, stemming from analysis of several datasets in a 1024 by 1024 grid
Sensor Source	MODIS/Terra MODIS/Aqua	SSM/I	AMSR-E/Aqua	NOAA
Data format	HDF-EOS	HDF-EOS	HDF-EOS	Flat binary
Spatial coverage	Global	Global	Northern and southern hemispheres	Northern hemisphere
Spatial resolution	0.05°	25 km	25 km	24 km
Temporal coverage	24/02/2000 – cont. (Terra) 04/07/2002 – cont. (Aqua)	04/05/1995 – cont.	19/06/2002 – cont.	Jan/2003 – cont.
Temporal resolution	Daily	Daily	Daily	Daily
File size	~102 MB (each data granule)	~2.5 MB (each data granule)	~2.1 MB (each data granule)	20 to 60 KB
Dissemination	Ftp / Free	Ftp / Free	Ftp / Free	Ftp / Free
Reference URL	http://nsidc.org/data/myd10c1.html	http://nsidc.org/data/nise1.html	http://nsidc.org/data/ae_5dsno.html	http://nsidc.org/data/g02156.html

Table 4–1.

Overview of operational snow cover data sets.

4.1.3 Snow Cover Flag

Given the high temporal variability of snow cover extend and its properties, the optimum snow cover flag should be based on near real time data providing the fraction of snow cover for each scatterometer footprint. Based on a simple threshold, which can be defined by the user, it should then be possible to mask the measurements disturbed by snow effects. Near real time data is in principal available through the NSIDC (Table 4-1), but it has to be tested if this data can be accessed and processed within the required time limits.

For the current implementation we therefore propose the implementation of a probability snow flag. This snow flag will build on a historic analysis of SSM/I snow cover data and gives the probability for the occurrence of snow for any day of the year.

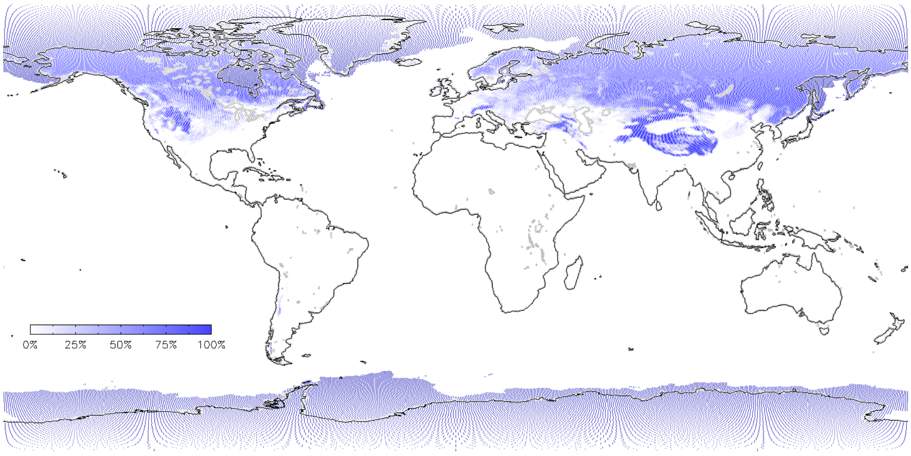

Figure 4–2.

Snow Cover (SSM/I)

1st of January

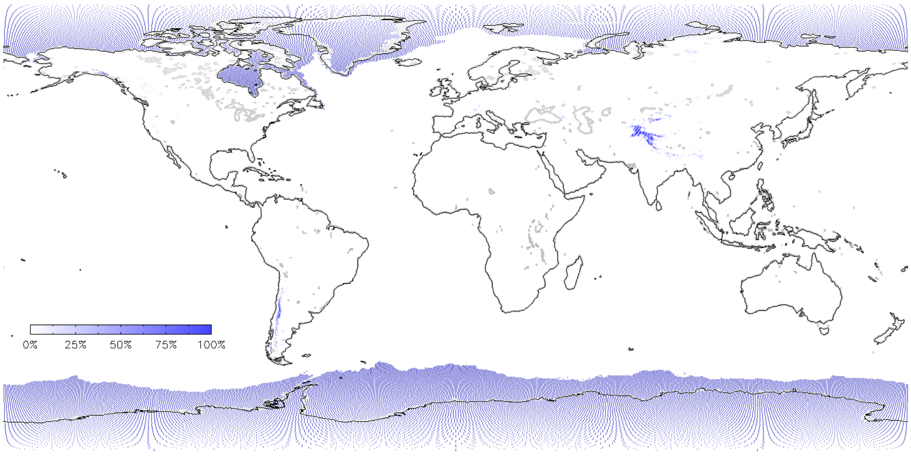

Figure 4–3.

Snow Cover (SSM/I)

1st of July

4.2 Frozen Land Surface

4.2.1 Backscatter of Frozen Surfaces

At microwave frequencies, freezing results in a strong decrease of the dielectric constant and thus the backscatter of soil. Hallikainen (Hallikainen et al. 1984) made dielectric measurements of soils in the 3 GHz to 37 GHz band between -50°C and 23°C. For several soil types, two samples with a volumetric water content of 5 % and 25 % were prepared in the laboratory and quickly frozen. For silt loam at -2°C Hallikainen (Hallikainen et al. 1984) found ε' to be about 3.3 and 5.5 for the dry and wet samples respectively. Despite these values are slightly larger than for a completely dry soil sample it can be concluded that backscatter of dry and frozen soils are similar. In case of the presence of vegetation canopy the effect of freezing is more complex. Principally a cell structure dies when it freezes. Plants therefore dispose of several strategies to avoid freezing, for example by discarding the leaves, increasing the concentration of sugar in the cytoplasm or by minimizing the water content in the outer parts of the plant. Such, plants can survive temperature down to -70°C (Schröder 1998). Normally a drop of the temperature below 0°C will therefore result in low backscatter comparable to those of a dry soil/canopy. However this may not generally be the case. For example in some arctic environments an increase in backscatter during the “cold season” can be observed by scatterometers (Scipal and Wagner 1998) found it most likely that this increase is caused by special stratigraphic feature of shallow lake ice.

Considering the above mentioned processes freezing can therefore result in low backscatter, but also in high backscatter over frozen lakes. To avoid any negative implication in the use of backscatter representing frozen conditions these measurements must be masked.

4.2.2 Freeze/Thaw Data

Currently there exists no global freeze/thaw data set. Several initiatives are underway to build up a NRT soil surface temperature data set (e.g. the GEOLAND initiative) but it can not be foreseen when such data will become operational available. The only data type currently available on soil surface temperature is climate modelled data like NCEP/NCAR or ERA-40 re-analysis datasets.

The NCEP/NCAR Reanalysis Project is a joint project between the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). The goal of this joint effort is to produce new atmospheric analyses using historical data (1948 onwards) by using state-of-the-art models and as well to produce analyses of the current atmospheric state (Kistler et al. 2001). The analyses are available on the surface level, 16 mandatory levels from 1000mb to 10mb, at the tropopause level, and a few others. Amongst other parameters like surface pressure, sea level pressure, geopotential height, and temperature, also soil temperature and soil water content are measured.

The ERA-40 Re-Analysis Project is produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). It consists of a number of climate datasets spanning the period September 1957 to August 2002 using a consistent model. The data set includes ~40 layers of information (e.g. wind, pressure, temperature, precipitation, radiation etc). For the parameter soil temperature, there exist data for four soil layers (0-7, 7-28, 27-100 and 100-289 cm depth), at an 6-hourly daily basis.

Dataset name	NCEP Global Tropospheric Analyses, 2.5x2.5, daily 1997Apr- continuing (ds083.0)	ECMWF ERA-40 soil temperature data at level 1
Distributor	NCEP	ECMWF
Description	DSS presents the Global Final (FNL) Analyses on a pair of 2.5x2.5 degree hemispheric grids every twelve hours.	40 year re-analysis of climate data from mid-1957 to August 2002 using a consistent model, ~ 40 different parameters
Sensor/Source	Gridded analyses, observations	Gridded analyses, modelled data
Data format	GRIB	GRIB
Spatial coverage	Global	Global
Spatial resolution	2.5°	0.5°/2.5°
Temporal coverage	Apr/1997 - continuing	Sep/1957 – Aug/2002
Temporal resolution	Daily	Daily (6 hourly)
File size	~3 MB/day	~2 MB/day
Dissemination	NCEP FTP on request	ECMWF, British Atmospheric Data Centre
Costs	Free	On request
Reference URL	http://dss.ucar.edu/datasets/ds083.0/	http://www.ecmwf.int/research/era/

Table 4–2.

Overview of operational freeze/thaw data sets.

4.2.3 Frozen Land Surface Flag

Considering the unavailability of a global operational observed soil freezing data set a near real time implementation of this flag is unrealistic. We therefore propose to implement a probability flag. This flag will build 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.

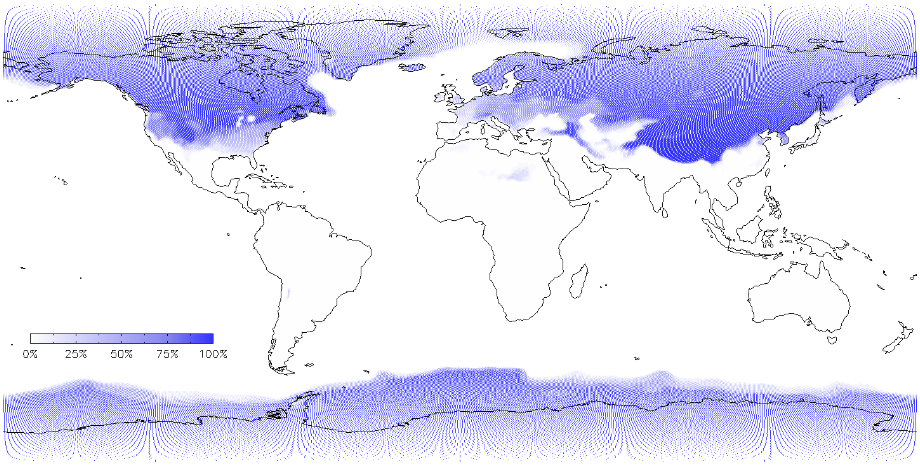

Figure 4–4.

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

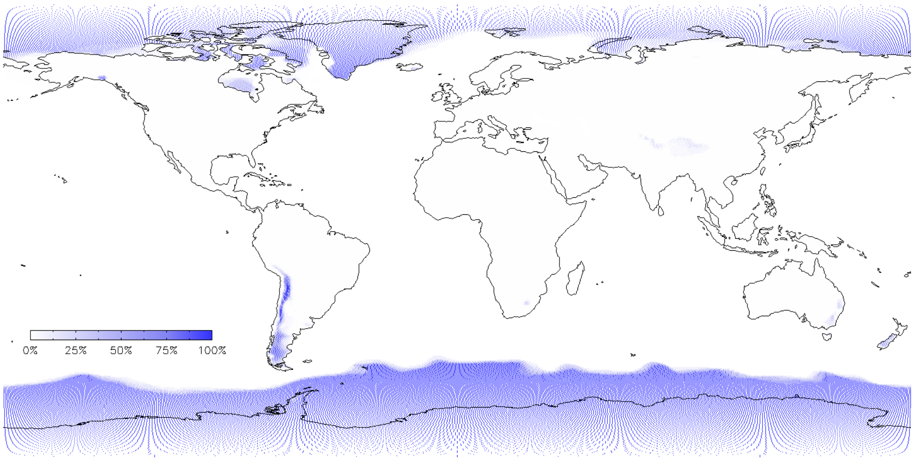

Figure 4–5.

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

4.3 Inundation and Wetlands

4.3.1 Backscatter of Open Water

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 (Ulaby et al. 1982). 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.

In principal a water flag is already contained in the quality flag definition. However this flag only considers permanent water bodies such as inland lakes, rivers and reservoirs. Dynamic inundation events such as observed in wetlands or paddy rice cultivation are not considered. These can lead to considerable errors in the retrieval of soil moisture. For example backscatter anomalies have been observed for paddy rice cultivation areas along the lower course of the Yangtze river in China (Beck et al. 2002).

4.3.2 Water Cover Data

Based on several geographic sources a *Global Lakes and Wetlands Database (GLWD)* has been created on existing maps, data and information (Lehner and Döll 2004). The database focuses in three levels on large lakes and reservoirs, smaller water bodies, and wetlands. The data may serve as an estimate of wetland extents for global hydrology and climatology models, or to identify large-scale wetland distributions and important wetland complexes.

Another dataset-derivative of already established data is the *GSHHS - A Global Self-consistent, Hierarchical, High-resolution Shoreline Database* (Wessel and Smith 1996). The global data is developed from two datasets: the World Data Bank II (WDB; also known as CIA Data Bank) which contains coastlines, lakes, political boundaries, and rivers, as well as the World Vector Shoreline (WVS), which only contains shorelines along the ocean/land interface. The data can be used to simplify data searches and data selections or to study the statistical characteristics of shorelines and landmasses.

Table 4-3.

Overview of operational water cover data sets.

Dataset name	Global lakes and wetlands database (GLWD)	GSHHS - A Global Self-consistent, Hierarchical, High-resolution Shoreline Database
Author	WWF (World Wildlife Fund)	NGDC (National Geophysical Data Center)
Description	3 data levels	The data is constructed from two datasets: the World Data Bank II (WDB; also known as CIA Data Bank) which contains coastlines, lakes, political boundaries, and rivers, as well as the World Vector Shoreline (WVS), which only contains shorelines along the ocean/land interface.
Sensor/Source	Several sources	World Data Bank II , World Vector Shoreline
Data format	ARC-INFO coverage, GRID	ASCII, SHP
Spatial coverage	Global (except Antarctica)	Global
Spatial resolution	30"	-
File size	27 MB	~90 MB
Dissemination	WWF FTP / free	NGDC FTP / free
Reference URL	http://www.worldwildlife.org/science/data/globallakes.cfm	http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html

4.3.3 Inundation and Wetland Flag

As inundation shows a high temporal variability the optimum water flag should be based on near real time data. Currently near real time data or similar products on open water extend do not exist. The open water flag will therefore be defined as fraction coverage of areas with inundation potential. The inundation potential will be derived from the *Global Lakes and Wetlands Database (GLWD)* level 3 product, which includes several wetland and inundation types (Lehner and Döll 2004). Figure 4–6 gives the fraction of water covered surface derived from the GLWD dataset.

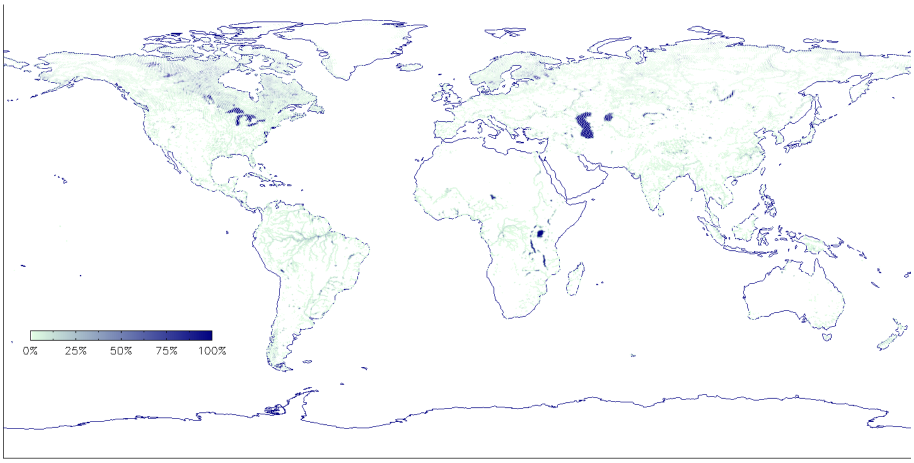

Figure 4–6

Inundation and wetland fraction derived from GLWD.

4.4 Topography

4.4.1 Backscatter of Mountainous Regions

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.

4.4.2 Topographic Data

Elevation data stemming from the *Shuttle Radar Topography Mission (SRTM)* are currently the most comprehensive, consistently processed, highest resolution topographic dataset ever produced for the Earth's land surface (Gesch et al. 2001)). Serving as precursors to SRTM datasets, the U.S. Geological Survey (USGS) has produced and is distributing seamless elevation datasets named *GTOPO30* that facilitate scientific use of elevation data over large areas. GTOPO30 is a global elevation model with a 30 arc-second resolution (approximately 1-kilometer).

Dataset name	USGS 30-second Global Elevation Data, (GTOPO30)	Global Land One-km Base Elevation (GLOBE) Project	Shuttle Radar Topography Mission (SRTM)
Author	USGS (U.S. Geological Survey)	NGDC (National Geophysical Data Center)	USGS (U.S. Geological Survey)
Description	GTOPO30 was derived from several raster and vector sources of topographic information.	GLOBE is an internationally designed, developed, and independently peer-reviewed global digital elevation model (DEM), at a latitude-longitude grid spacing of 30 arc-seconds (30")	Collection of Interferometric Synthetic Aperture Radar (IFSAR) data over 80 percent of the landmass of the Earth
Sensor/Source	Several sources (DEM, maps)	NASA GTED, GTOPO30 and additional contributions	IFSAR
Data format	16-bit signed integer data in a simple binary raster	16-bit signed integer data in a simple binary raster	HGT
Spatial coverage	Global	Global	Nearly global (60N-56S)
Spatial resolution	30"	30"	3"
Accuracy	+/- 650 m (vertical)	15" (in most cases)	+/- 20m (horizontal), +/- 16m (vertical)
File size	2.7 GB	~2 GB	?
Dissemination	USGS FTP / free	NGDC FTP / free	USGS FTP / free

Table 4-4.

Overview of operational topographic data sets.

4.4.3 Topographic Complexity Flag

The topographic complexity flag will be derived from GTOPO30 data. For each cell of the Discrete Global Grid, standard deviation of elevation will be calculated and the result will be normalized to values between 0 and 100.

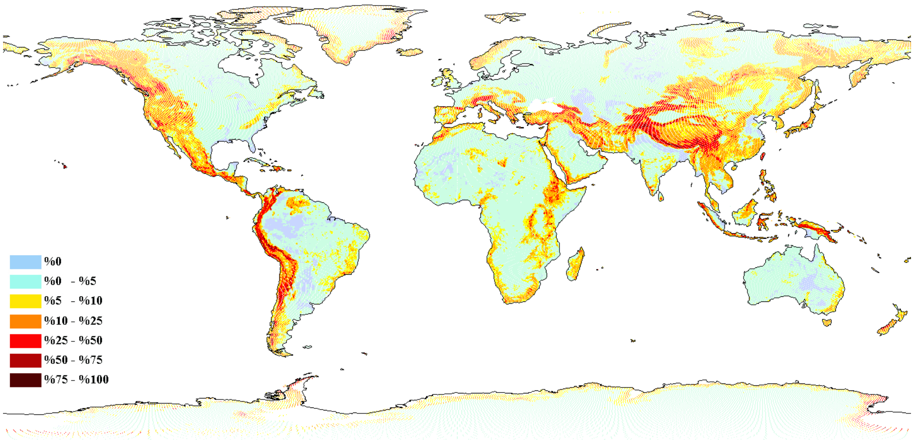

Figure 4–7

Topographic Complexity (Normalized standard deviation of topography) derived of GTOPO30.

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