Scatterometer and ScanSAR Soil Moisture observations of the contiguous United States

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Abstract— **Soil moisture has been identified as a land surface parameter of great importance in various fields of application. Based on long-term time series data of various radar sensors, change detection methods for scatterometer and ScanSAR data are presented. After data processing and model parameter estimation, individual radar backscatter measurements are compared to references describing location specific backscatter conditions representing dry and wet surface soil moisture. Using exponential filtering, also profile soil moisture can be calculated. The method have been implemented in a fully automatic data processing chain for soil moisture retrieval for ERS-1/2 and MetOp ASCAT data and Envisat ASAR ScanSAR data. Various validation studies showed good agreement between the remotely sensed soil moisture products and reference data.**

I. INTRODUCTION

Soil moisture as key element in global cycles of water, energy and carbon cycle can be measured accurately in the field using in-situ measurement techniques [1]. Different from other climate relevant parameter, soil moisture is not measured on a large scale [2]. Long-term soil moisture monitoring at continental to global scales is not feasible. Radar remote sensing methods can give repeated estimates of soil moisture at different temporal and spatial scales [3]. Scatterometers offer data at high temporal but low spatial resolution, whereas conventional SAR sensors operated in strip-map mode provide data at high spatial but low temporal resolutions. Due to the temporal variability of soil moisture, SAR sensors with their temporal resolution are not suited for soil moisture monitoring. Advanced current and future SAR sensors such as Radarsat-1/2, Envisat ASAR or Sentinel-1 can be operated in ScanSAR mode to obtain data at spatial and temporal resolutions in between the other sensor configurations [4].

Active radar sensors are sending out short pulses of radar waves towards the Earth's surface and receive the signals scattered back towards the sensor. Backscattering is controlled by the sensor parameters frequency, polarization, look angle and by the terrain attributes (soil moisture, surface roughness and vegetation cover) [5, 6]. Using backscatter models, all non-soil moisture related signal components can be identified. They range from simple empirical regression models to sophisticated theoretical models describing the interaction of radar waves with bare soil surfaces and vegetation layers. The applicability of theoretical models for describing scattering by natural soil surfaces and vegetation has increasingly been questioned and many experimental studies did only find weak relations between modeled and measured bare soil backscatter [7-9]. This is mainly due to unrealistic assumptions on the geometry of soil surfaces and vegetation canopies. Vegetation scattering models often underestimated the penetration of the microwaves into the vegetation canopy [10, 11]. In recent years significant progress has been made in the use of coarse-resolution (25-50 km) scatterometer systems for soil moisture retrieval and several soil moisture products derived from C-band (5.3 GHz) scatterometer measurements [12-14] have become available. With the availability of medium resolution ScanSAR data as offered by the Envisat ASAR sensor, a transfer of methods has become an option to improve the spatial resolution of remotely sensed soil moisture products.

The Microwave Remote Sensing Group at the Institute of Photogrammetry and Remote Sensing (I.P.F.) at the Vienna University of Technology developed and implemented change detection algorithms for scatterometer data and based on this for Envisat ASAR ScanSAR data. The technical specifications of the radar sensors are listed in Tab. 1.

TABLE I. TECHNICAL SPECIFICATIONS OF USED SENSORS

	ERS-1/2 Scatterometer	**Envisat ASAR Global Mode (GM)**	**MetOp ASCAT**
Frequency	C-band (~5.3 GHz)		
Spatial Res.	25/50 km	1 km	25/50 km
Temporal Res.	2-8 days (irregular)	2-5 days (irregular)	Daily
Radiometric Res.	0.3 dB	1.2 dB	0.3 dB

All I.P.F. soil moisture products derived from scatterometer and ASAR ScanSAR sensors are provided free of charge to interested users via the dedicated website: http://www.ipf.tuwien.ac.at/radar/

II. SOIL MOISTURE FROM SCATTEROMETER AND SCANSAR DATA

Retrieving soil moisture information from single date spatial high resolution data using bare soil or vegetation backscatter models is still limited to experimental settings due to the required input data demand, which are not available in operational environments. As an alternative, change detection methods have been developed for use with multi-temporal data sets. These models are based on the assumption that the parameters controlling radar backscatter are acting on different time scales, where short term changes in radar backscatter are related to changes in the soil moisture content. Changes in radar backscatter levels are observed over time and related to soil moisture. A change detection model has been developed for C-band scatterometer data by [15-17]. Radar backscatter in dB is modeled as a function of empirical backscatter parameters and the relative surface soil moisture content. The location specific empirical backscatter parameters are extracted from multi year backscatter data and characterize backscatter conditions at dry surface soil moisture conditions at wilting level (0%) and at saturated surface soil moisture conditions at field capacity (100%). To account for seasonal vegetation effects, the capability of the ERS scatterometer to measure backscatter at three incidence angles per acquisition is exploited. The radar typical incidence angle behavior due to changes in backscatter levels at different incidence angles with growing vegetation is modeled and used for vegetation correction [16].

The ASAR operated in Global Mode only delivers one backscatter measurement at some incidence angle per acquisition. Therefore the change detection approach originally developed for ERS scatterometer data needs to be adopted. Vegetation correction using the instantaneous incidence angle behavior can not be applied. Analysis of the multi-temporal ERS scatterometer and ASAR GM data sets showed that the influence of vegetation on radar backscatter is distinctively weaker for the ASAR GM data. This can to some be explained by the different incidence angle ranges and polarizations of the backscatter data. While the ERS data are acquired over an incidence angle range of 18° to 59°, the ASAR GM data only cover the incidence angle range from 20° to 40°. Furthermore, the scatterometer acquires data in VV polarization whereas the ASAR GM data are delivered in HH polarization, which better penetrates vegetation [18].

Processing of scatterometer data has been implemented in an automatic processing chain. Scatterometer data are rearranged from an image format to a time series format without altering the data. In this way, multiyear time series of scatterometer measurements are built up for a defined regular global grid [19]. The processing includes characterization of noise level, correction of incidence angle dependency, model parameter estimation, and calculation of relative surface soil moisture m_s and soil water index (*SWI*). The *SWI* is a relative measure for the profile soil moisture content estimated from surface soil moisture m_s time series by filtering with an exponential function [17]. Measurements affected by snow and/or frozen soil conditions are masked. If soil hydrologic properties are known (wilting level, field capacity, and porosity) the plant available water content can be calculated from m_s. Soil moisture retrieval from ASAR GM data requires a number of preprocessing steps: geocoding, radiometric calibration and resampling. The geocoding and radiometric calibration is done using a commercial software package, which performs a backward geocoding based on the range-Doppler approach. By incorporating precise orbit information and digital elevation data, this procedure does not require ground control points and works without user interaction. To enable efficient further data handling, the ASAR GM data are transferred from image to time-series format by resampling them to a fixed global grid with boxes covering a 0.5° by 0.5° tile. As grid interval 15 arc seconds have been chosen, which corresponds to a distance of about 500 m at the equator. Acquisition time and local incidence angle are stored together with the backscatter coefficient σ^0 in each time series file. Soil moisture retrieval comprises local incidence angle correction using a linear model [20], model parameter estimation, and extraction of relative surface soil moisture m_s.

III. RESULTS

Soil moisture related information from scatterometer and ScanSAR data are derived on a regular basis. Two examples of scatterometer derived surface soil moisture products over North America are presented in Fig. 2 and 3. In Fig. 2 the monthly averaged *SWI* profile soil moisture and its deviation from the long-term mean for July 2008 are shown. The anomaly map reveals that for most areas no pronounced deviation from the long term mean is observed. Areas in the central part of the USA and at the Atlantic coast show drier conditions, whereas over Kansas and Nebraska, slightly wetter conditions are detected.

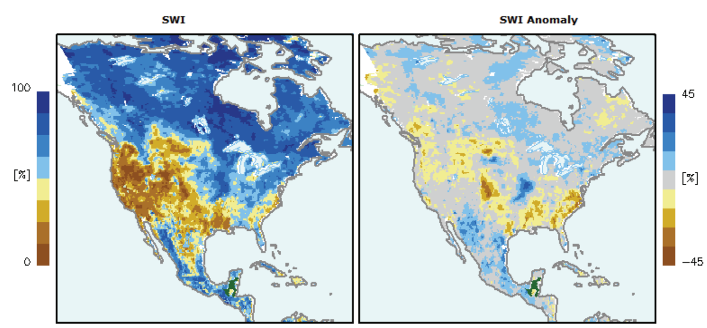

Figure 1. Monthly mean profile soil moisture SWI and anomaly for July 2008 over North America retrieved from ERS scatterometer data.

The maps in Fig. 4 illustrate the evolution of surface soil moisture conditions derived from ASCAT scatterometer data during the passage of hurricane Hanna in 2008. Shown are 3-day anomalies, which describe the deviation of actual surface soil moisture conditions from a long-term mean. In this case, the long-term statistics are derived from the scatterometer data time series archive, which dates back to 1991. Heavy precipitation occurred when the hurricane made landfall on September 6 at the Atlantic coast near the North Carolina-South Carolina border. The resulting high soil moisture conditions are reflected in the surface soil moisture map from September 7.

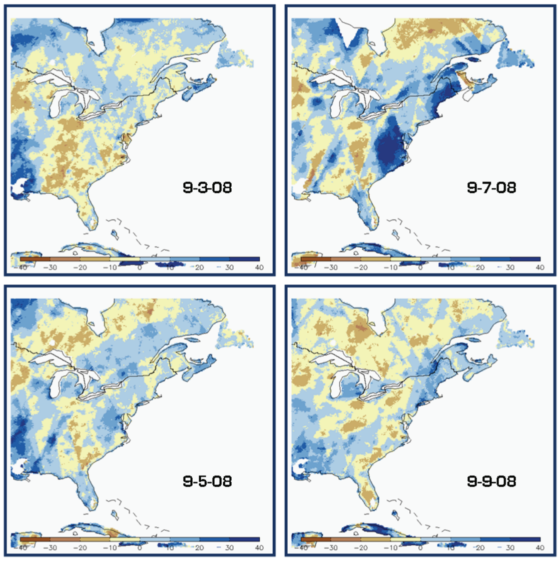

Figure 2. 3day anomaly of ASCAT derived surface soil moisture during hurricane Hanna

The scatterometer derived soil moisture products were subject of various studies, comparing them to other land surface parameters and model results. They showed, that the quality of soil moisture information is good over regions with low to moderate vegetation cover in temperate and tropical climates [12, 21-26], while retrieval is of lower quality or not possible in densely forested areas, desert areas, high-latitude areas and mountainous regions. Data from the ASCAT scatterometer will ensure data continuity and extend scatterometer time series archive. A recent study proved the transferability of the scatterometer soil moisture retrieval approach from ERS to ASCAT. Shifts in observation incidence angles did not show a significant influence [27].

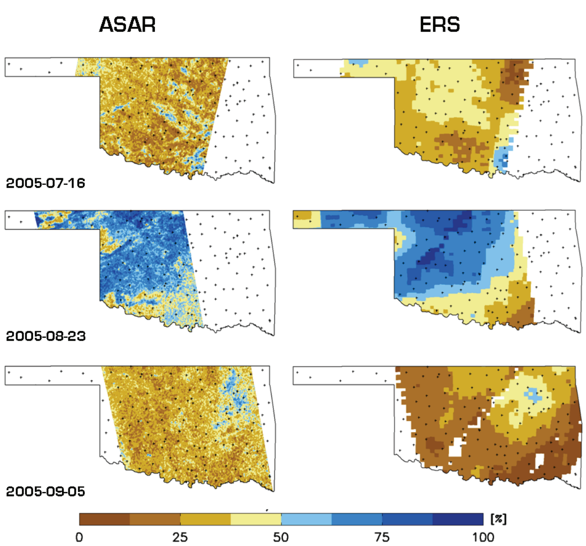

Figure 3. Surface soil moisture maps of Oklahoma retrieved from ERS scatterometer (left) and ASAR GM (right) measurements for three different dates in summer 2005

Examples of maps showing the spatial distribution of soil moisture extracted from the ERS scatterometer data and the ASAR GM data over Oklahoma are presented in Fig. 4. The overall patterns of low and high soil moisture are similar in the soil moisture maps from both sensors. The most apparent difference is the spatial resolution between the ERS soil moisture and the ASAR GM soil moisture. Due to this difference, the ERS soil moisture maps appear much smoother than the ASAR GM soil moisture maps. This effect is enhanced by the high ASAR GM noise level.

In a recent study, surface soil moisture extracted from ASAR GM was validated using in-situ soil moisture data from the Oklahoma Mesonet as well as ERS-1/2 scatterometer derived surface soil moisture [18]. The results showed that ERS-1/2 scatterometer derived soil moisture shows a slightly better agreement with the in-situ measurements than the ASAR GM surface soil moisture, but ASAR GM data still offer surface soil moisture information with much more spatial details than the ERS-1/2 scatterometer data while keeping the capability of the scatterometer data to map temporal surface soil moisture trends.

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