MICROWAVE REMOTE SENSING OF HYDROLOGY IN SOUTHERN AFRICA

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ABSTRACT

ScanSAR systems such as ENVISATs ASAR Global Mode allow monitoring of dynamic processes at medium resolution. Hence they are especially useful for monitoring hydrologic processes such as soil moisture and inundation dynamics. In this paper we present two studies which investigate the capabilities of ScanSAR ASAR Global Mode (1 km resolution) on the southern African subcontinent. One study focuses on the monitoring of the Okavango delta, Botswana. Temporal and spatial dynamics for the year 2005 have been investigated on approximately monthly time steps. The second study, SHARE, aims at enabling an operational soil moisture monitoring service for the region of the Southern African Development Community (SADC) by using ASAR Global Mode data in combination with ERS/METOP scatterometer data to build a synergistic 1 km soil moisture product. In this study ASAR Global Mode data is used in two ways: First it is used directly to retrieve soil moisture information using a simple change detection algorithm; Secondly, a scaling layer is defined which allows enhanced interpretation of coarse resolution (25 km) scatterometer data.

Keywords: Southern Africa, satellite radar, soil moisture, wetlands, monitoring.

1 INTRODUCTION

Radar signals are strongly dependent on hydrological conditions in addition to surface roughness and vegetation structure. Thus the analysis of radar time series allow the detection of environmental processes that are important for the functioning of terrestrial biota, in particular inundation dynamics, soil moisture and freeze-thaw changes. Results from a range of microwave sensors have shown a large potential for hydrological applications. For example, coarse resolution scatterometer data have been used successfully for global soil moisture monitoring [1]. Currently, our group at TU Wien develops algorithms foreseen to be implemented at EUMETSAT for operational Near Real Time (NRT) processing data from the METOP satellite series [2]. Beside scatterometers ScanSAR systems hold a large potential for the monitoring of hydrologic processes [3]. Systems such as ENVISATs ASAR Global Mode allow analyses on better spatial scale compared to scatterometers at the cost of reduced temporal resolution. In this paper we present two recent studies which investigate the capabilities of ScanSAR ASAR Global Mode (1 km) on the southern African subcontinent. One study focuses on the frequent monitoring of the Okavango Delta. The other project, SHARE, has a broader view, covering the entire SADC region (Figure 1a). The Okavango delta is located in northern Botswana (Figure 1b) and is part of SADC.

2 ENVISAT ASAR GLOBAL MODE

ENVISAT was launched by ESA (European Space Agency) in February 2002 into a sun synchronous orbit at about 800 km altitude and an inclination of 98.55°. The ASAR (Advanced Synthetic Aperture Radar) instrument is one of the instruments installed aboard. ASAR provides radar data in different modes with varying spatial and temporal resolution and alternating polarizations in C-Band (~5.6 cm wavelength). The presented studies utilize ASAR data acquired in Global Mode (GM). The polarization is C-HH and pixel spacing is 500 m which corresponds to an approximate spatial resolution of 1 km. Each swath covers an area of 405 km width [4]. GM data are available since December 2004. ENVISAT ASAR GM data are acquired as backup if no other mode is requested. This setting alleviates data procurement considerable. Data can be downloaded directly from a rolling ESA FTP archive without planning and issuing specific data orders. The comparably low data volume (40MB for a swath covering entire Africa) of the global mode makes access of the data easy.

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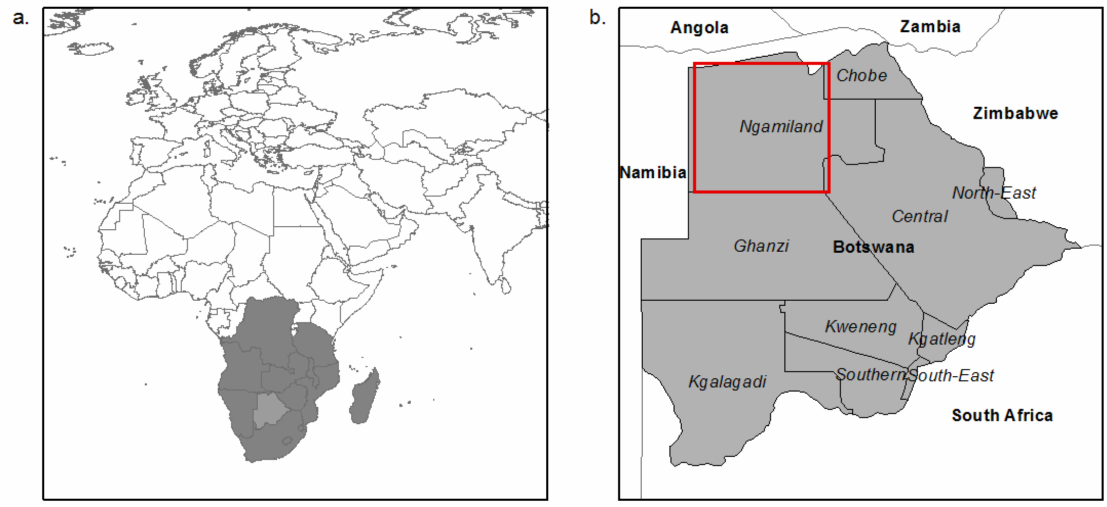

Figure 1. Location of study sites: a) the SADC countries, Botswana highlighted, b) Okavango region in northern Botswana.

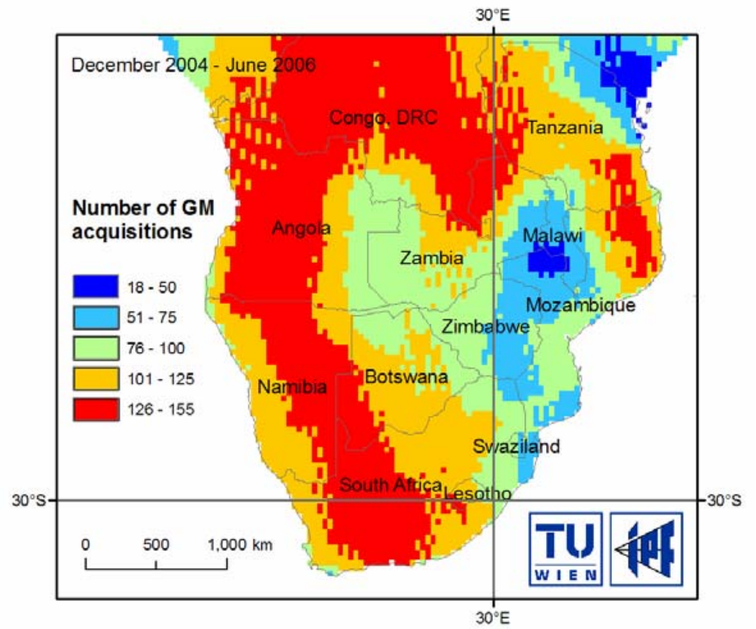

Figure 2. Number of ENVISAT ASAR Global Mode acquisitions in the SADC region since start of data availability (December 2004 until June 2006).

Coverage for southern Africa is shown in Figure 2. It varies from 18 to more than 150 images, which corresponds on average to 1 to 8 acquisitions per month. The Okavango site in Botswana is covered approximately once per week, but in practice intervals are irregular and often the delta is covered only partly. On average one image per month is available for complete wetland monitoring at this site.

For analysis these data require georeferencing with respect to earth curvature and terrain [5]. For geocoding of Global Mode data the GTOPO30 digital elevation model (improved with SRTM data) provided by USGS is sufficient. Within a normalization step the effects on the backscatter due to varying incidence angel and distance from sensor (near and far range) are removed [6], [7]. To achieve sub pixel accuracy DORIS orbit information is used for precise geocoding. For all pre-processing steps an in-house software (ESCAPE) was developed [8], which uses modules of the commercial software Sarscape (Sarmap). ESCAPE allows efficient operational ENVISAT ASAR data processing, what is essential for monitoring large regions such as the southern African subcontinent.

3 WETLAND MONITORING – OKAVANGO DELTA

3.1. STUDY AREA

The region of the Okavango delta is semi-arid with evaporation four times higher than rainfall [9]. The wetland area varies at decadal, multi-decadal and millennial time scales, in response to variation in regional climate. Periods of drier and wetter than contemporary conditions were present in the last 7000 years. The dynamics within the delta – especially the flooding extent – depends on internal as well as external factors ([10], [11], Figure 3). Recharge of the Okavango tributaries takes place in Angola during the rainy season. There are water management plans for water abstraction in Namibia shortly before the Okavango River arrives at the floodplain in Botswana. Aggradation processes cause changes in distribution of inundation within the Delta. The western part of the system progressively dried in the last 150 years (e.g. Gumare flats).

3.2. RESULTS

The 2005 flood in its maximum extent covered areas corresponding roughly to the regularly inundated zone. The largest expansion of the flood (the difference between annual maximum and annual minimum inundation extent) was observed in the SW part of the system, while in the NE part the flood expansion was smaller. Such behavior corresponds to the known differences in dynamics of inundation between these parts of the Delta.

The year 2005 was characterized by below average rainfall and inflow. The maximum wet area was, however, 6670 km² (Figure 4 and 5; excl. 300 km² of upper pan handle) larger than the 1985-2004 mean maximum inundation area (6280 km²). This reflects the influence of antecedent conditions on flooding in the Okavango Delta (Figure 3): flood of the preceding year 2004 was very large, reaching 10.000 km².

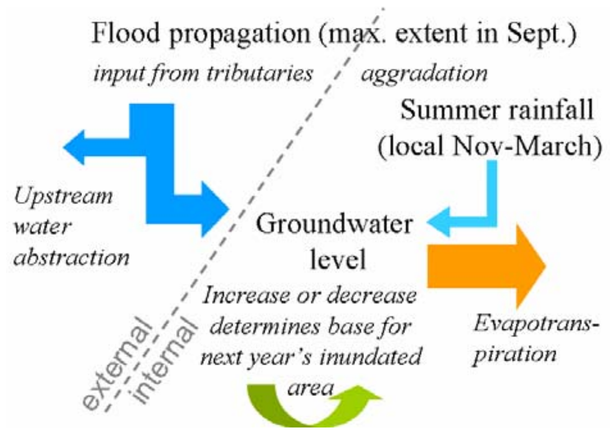

Figure 3. Internal and external factors influencing inundation patterns/wetland maintenance in the Okavango delta.

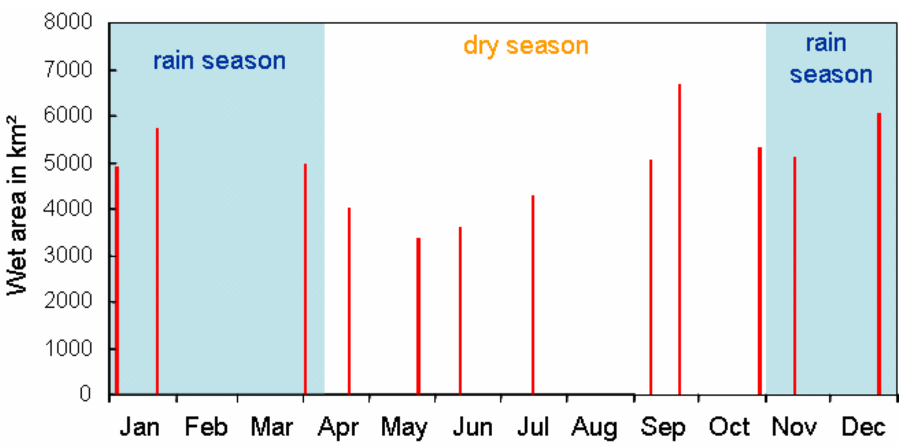

Figure 4. Wet area in km² (note: not equal to inundated area especially during rain season) for each acquisition date 2005 within the delta (excluding upper pan handle, approximately. 300 km², see Figure 4).

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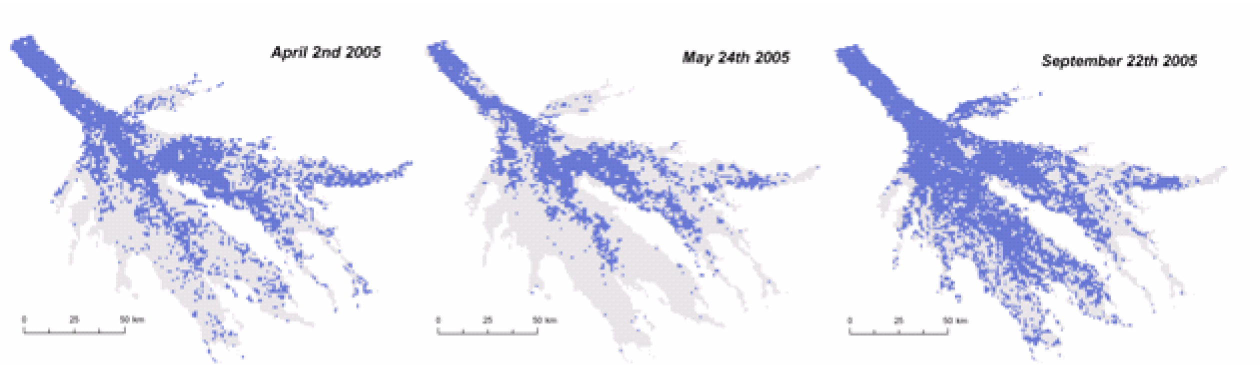

Figure 5. Wet areas (blue) at end of rain season (April), first half dry season (May) and maximum inundation (September). Grey – delta extent

4 'SHARE' – ENHANCED SOIL MOISTURE MONITORING

4.1. THE PROJECT

SHARE is a project funded within the framework of the ESA TIGER initiative. SHARE aims at enabling an operational soil moisture monitoring service for the region of the Southern African Development Community (SADC) by using ASAR Global Mode data and ERS/METOP scatterometer data. With its service it addresses today's most severe obstacle in water resource management which is the lack of availability of reliable soil moisture information on a dynamic basis (weakly coverage or better). It is the aim of SHARE to develop an experimental medium resolution (1 km) soil moisture indicator solely based on ENVISAT GM data using a simple change detection algorithm. Additionally SHARE provides access to a coarse resolution (25 km) soil moisture product from ERS/METOP scatterometers together with a scaling layer (derived from ScanSAR data) which allows interpretation of the coarse resolution soil moisture product at 1 km resolution.

4.2. THE EXPERIMENTAL SOIL MOISTURE INDICATOR

The experimental soil moisture indicator is a 1 km resolution soil moisture product based on a data driven change detection approach showing soil moisture changes of the topmost soil layer scaled between a low and a high backscatter limit. Change detection has been found to be a powerful tool for the retrieval of geophysical parameters from radar data [12]. Especially in practical applications it was found to be more useful than physical based retrievals. In several studies the potential of change detection has been outlined. For example, based on 32 ERS SAR images (C-band) acquired over the Orgeval watershed in France [13] developed a methodology for retrieving soil moisture. The algorithm was based on a selection of "sensitive targets", for which vegetation and surface roughness effects can easily be estimated and removed if needed. The results of this study suggested that at the watershed scale the mean effect induced by different mixed roughness states is about constant during the year. Similar studies further demonstrated that change detection approaches for retrieving soil moisture at regional scales from C-band SAR time series can successfully account for surface roughness effects and to some extent for low vegetation cover [14], [15].

The foreseen method relates each radar backscatter measurement to a reference backscatter value. This reference value is derived from a pixel specific backscatter time series. In a first step, no roughness and vegetation correction is applied, as a static influence of soil surface roughness and vegetation cover is assumed. We are well aware that this is a critical simplification as especially vegetation may exhibit a seasonal cycle. However, regarding from a time series perspective the sensitivity of C-band backscatter to soil moisture is much stronger than the sensitivity to changes in vegetation. The effect of vegetation growth on backscatter is even less strong in case of HH polarization, as used for ENVISAT ASAR GM mode, as for the VV polarized scatterometer data. Therefore, in a first step we neglect vegetation effects, which is the main reason for calling the ENVISAT ASAR GM products "experimental" soil moisture products. For a correct description of seasonal effects external data sets would be required in order to account for the multi incidence angle observations and for the noise and speckle effects inherent in the Global Mode backscatter observations. In contrast to vegetation, for surface roughness there is evidence that at the scale of Global Mode data temporal effects can be neglected. [16] found that at the scale of the watershed, field-specific roughness effects are averaged out for C-band ERS data. A similar observation was made by [17] who observed a high correlation between backscatter and soil moisture at catchment scale and a decrease in correlation at more detailed scales.

4.3. THE SCALING LAYER

In 2002 TU Wien produced the first, global remotely sensed soil moisture dataset based on data acquired with the scatterometer on board of the European Satellites ERS-1 and ERS-2 [1]. Since the year 2002 the data have been distributed to about 100 users worldwide, which lead to the increasing acceptance of this technology and a growing number of research papers that investigate the quality and application potential of scatterometer soil moisture data. Amongst the first research users of the soil moisture products are meteorological services and research centres such as Met Office UK, Météo-France/CNRM and the European Centre for Medium Range Weather Forecasting (ECMWF). Currently, TU Wien is developing on behalf of EUMETSAT software for near-real-time processing of global ASCAT Level 2 surface soil moisture data in orbit geometry. It is planned to implement the operational system at EUMETSAT's central processing facility in Darmstadt, Germany, by 2008 in order to distribute the ASCAT Level 2 data over EUMETCast within 135 minutes after sensing.

To facilitate the use of this data in hydrologic applications such as flash flood forecasting, SHARE will develop a scaling layer. The scaling layer allows the interpretation of coarse resolution soil moisture information at 1 km resolution by identifying targets which have similar backscatter characteristics at local (observed with the ENVISAT ASAR Global Mode sensor) and regional (observed with the ERS/METOP scatterometers) scale. For these targets soil moisture trends observed in the coarse resolution product can be used instantaneously at 1 km scale.

The retrieval of the scaling layer is based on a well established concept in hydrologic sciences to describe the relation between local and regional soil moisture. This concept is known as "temporal stability" method and was introduced by [18] in 1985. Since then the method has for example been used by [19] and by [20] to describe the relation between local *in-situ* soil moisture data and regional soil moisture trends. In the SHARE project we envisage to apply this concept to remotely sensed data acquired by ENVISAT’s ASAR Global Mode sensor. To retrieve the scaling layer ENVISAT ASAR Global Mode data is geocoded and resampled to a regular 1 km grid. In a second processing step the correlation between a time series of local and regional backscatter spanning from December 2004 to June 2006 is derived for each grid point. In this calculation the local scale data are the instantaneous ASAR Global Mode backscatter measurements. The regional scale data are generated by aggregating Global Mode backscatter measurements up to 25 km using simple linear averaging with equal weight given to each measurement.

Figure 6 shows an example of the scaling layer for the Okavango catchment. It is a measure of the spatial homogeneity of surface soil moisture. The backscatter in the delta itself differs considerably from its surroundings and therefore has correlation coefficients (R^2) close to zero. Values are above 0.5 for most of the catchment. This would allow the use of a by ASAR GM improved scatterometer derived soil moisture which plays an important role for river discharge and thus accounts for external factors (Figure 3) determining flooding within the Okavango delta. It has been shown in previous analyses for the Zambesi River [21], that even coarse resolution scatterometer derived soil moisture time series relate well with river discharge measurements. An incorporation of a spatially improved soil moisture product from the upper catchment of the Okavango may improve prediction models for the wetland region.

5 SUMMARY AND CONCLUSIONS

The ENVISAT ASAR Global Mode data allow monitoring of soil moisture and wetland dynamics. A case study in the Okavango delta showed that a monthly full coverage is possible for an area of this size (150 km x 150 km area of interest) and location. As the priority for certain ASAR modes vary, time steps are irregular. The entire available Global Mode data set (since December 2004) can be used to derive a scaling layer which is a measure of spatial heterogeneity of backscatter and thus soil moisture. It allows to improve coarse spatial but good temporal resolution relative soil moisture data which are derived from scatterometer measurements. Such a scaling layer has been created for the entire southern African subcontinent. It is anticipated to enable an operational soil moisture monitoring service for the SADC region. In case of the Okavango wetland area it may contribute to an enhanced modeling of external factors of flooding dynamics.

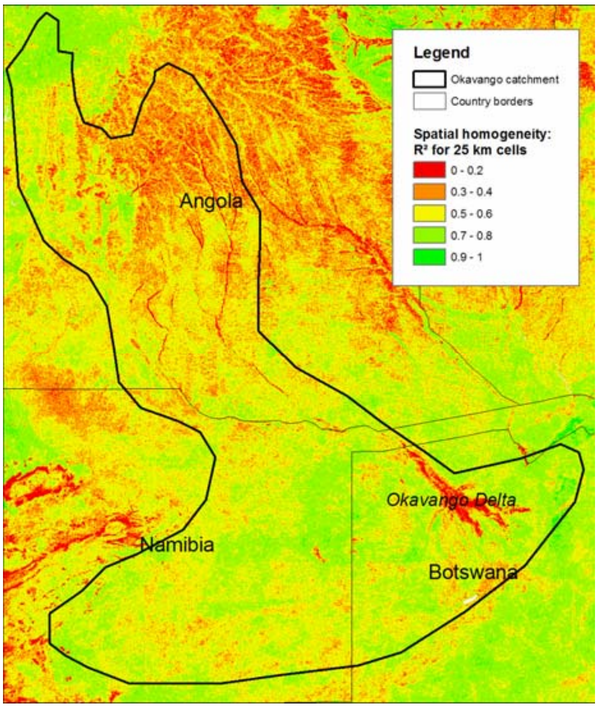

Figure 6. Okavango catchment - spatial homogeneity of backscatter with respect to 25 km grid cells based on all available ASAR GM data from December 2004 to June 2006.

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