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RIVER FLOW & WETLAND MONITORING WITH ENVISAT ASAR GLOBAL MODE IN THE OKAVANGO BASIN AND DELTA

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ABSTRACT
Wetlands in semiarid regions such as the Okavango Delta depend not only on local rainfall but also on external inflow. Flooding patterns can be estimated if the precipitation and other hydrological parameters of the contributing area are known. The water is intermediately stored in the soil and either evaporates, is taken up by plants or contributes to surface or subsurface runoff. While spatially continuous high resolution rainfall data are difficult to obtain, soil moisture can be derived from microwave satellite data. An approach for derivation of relative soil moisture on 1km resolution in semiarid regions has been realized within the ESA Tiger Innovator project SHARE (Soil moisture for Hydrometeorological Applications over SADC). Active microwave data which are acquired with ENVISAT ASAR operating in Global Mode have been used for the now operational processing chain. With this work we demonstrate that the relative soil moisture derived from the ENVISAT ASAR GM data can be clearly related to river discharge measurements. Additionally, we show the ability of ENVISAT ASAR Global Mode to monitor dynamics of wet or inundated areas as a response to precipitation and soil moisture variation respectively in the upper Okavango basin.

KEY WORDS
Remote Sensing, Soil Moisture, Active Microwaves, Wetland, Inundation

1. Introduction

The ability to monitor soil moisture conditions with active microwave data has been amply demonstrated [1, 2]. SHARE is an ESA funded project (Tiger DUE Innovator) which aims at enabling an operational soil moisture monitoring service for the region of the Southern African Development Community (SADC). With this service SHARE 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 at a frequency of a week and less.

The central product of the service is the experimental soil moisture indicator based on ENVISAT Global Mode data. The experimental soil moisture indicator is a 1 km resolution soil moisture product based on a change detection approach showing soil moisture changes of the topmost soil layer (< 2 cm) in 3-5 classes with an update frequency of two weeks. All products are available on request through the SHARE website (http://www.ukzn.ac.za/sahg/share/ or http://www.ipf.tuwien.ac.at/radar/share/) and are continuously updated. More than 2500 experimental soil moisture maps have so far been derived from ENVISAT Global Mode data which are available since December 2004. Additionally, an archive containing coarse resolution soil moisture has been compiled for the SADC region for the years 1992-2000.

The number of users rose to more than 20 within the first half year after the completion of the project (June 2007). African investigators originate from Botswana, Zimbabwe, Mozambique, Lesotho, Kenya and South Africa. The major application is crop yield monitoring, in addition to flood and drought monitoring, flux and hydrological modelling, and climate change assessment.

Within this paper we demonstrate the relationship of relative soil moisture derived from the ENVISAT ASAR GM data to river discharge measurements and dynamics of wetland areas. This has been investigated in detail for the Okavango upper basin and the delta. The Okavango Delta is located in a semi-arid region with rainfall of 460 mm/year and evaporation four times higher [3]. The wetland is strongly flood-pulsed, with a single annual flood event caused by inflow along the Okavango River that arises in the high rainfall zone of central Angola, and to a lesser extent by local rainfall. Inundation of the Delta is at its maximum in September, 5 to 6 months after the end of rainy season, due to the slow movement of the flood wave. The dynamics of flooding within the Okavango Delta depend on internal as well as external factors [4, 5].

2. Methods

The original approach for relative soil moisture derivation from active microwave data was first demonstrated for ERS scatterometer [1]. The retrieval of the soil moisture data is based on a simple change detection approach, which relates the instantaneous measurement to dry and wet backscatter references derived from multi-year time series. The approach has been transferred to SAR data. High revisit intervals are required in order to capture the dynamics. The length of the records are equally important. Driest and wettest possible conditions need to be retrieved for each single location. In semiarid regions two to three years of data are required depending on the actual revisit intervals. ENVISAT ASAR Global Mode data fulfl this requirement. Records start in December 2004. The temporal sampling can be weekly, depending on acquisition mode priorities. The variability of data availability for SADC is shown in Figure 1.

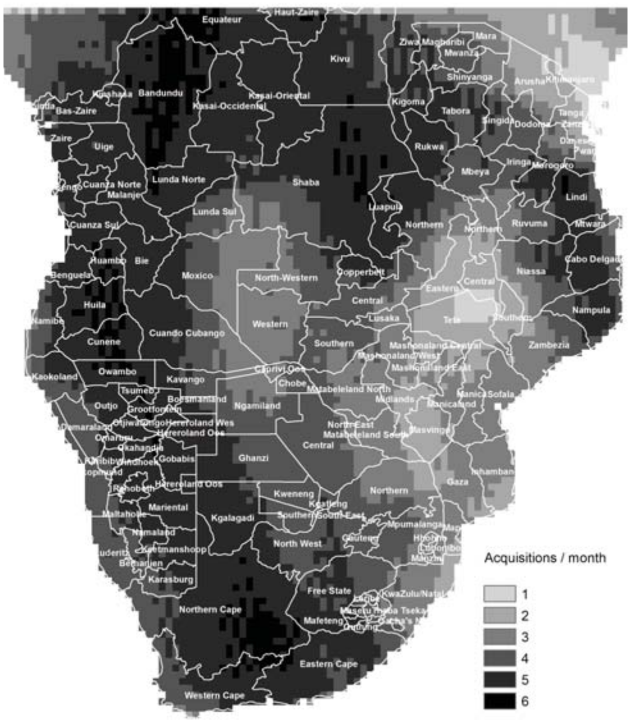

Figure 1. Mean monthly coverage by ENVISAT ASAR GM data for single provinces of the SADC region (2005/2006)

In order to derive soil moisture information the following processing steps are applied:

1. Orthorectification (Georeferencing with respect to terrain)
2. Radiometric calibration and normalization = effects on the backscatter due to varying incidence angle are removed
3. Resampling to tiles (120*120 km)
4. Derivation of dry and wet reference (minimum and maximum backscatter for each single location) for each single location
5. Scaling between wet and dry references, that represent the backscatter at completely wet and completely dry conditions, respectively (Method described in detail in [1, 6])

Images have been resampled to predefined tiles in order to allow efficient time series analyses. The scaled backscatter provides an estimate of the relative soil moisture at each location. The validation of the relative soil moisture itself was performed within the Oklahoma MESONET network (USA) that comprises of 97 measurement sites within 77 counties of Oklahoma [6]. A comparison between monthly means of FWI (Fractional Water Index) and GM surface soil moisture has been carried out. A linear correlation coefficients up to R=0.9 has been detected.

The actual absolute soil moisture depends especially on soil properties. The relative measure provides saturation levels. If a soil is saturated surface flow is generated. The relationship between river runoff and the relative soil moisture was investigated for the Okavango basin using monthly mean values from the Mohembo station which is located at the delta inflow. ENVISAT ASAR GM images cover swaths of 400 km width. As the basin is larger than that, several swaths from different acquisition dates need to be combined. Appropriate composites can be obtained for Okavango on monthly scale. Smaller basins could be investigated in shorter intervals. A temporal offset between soil moisture maxima (saturated soil conditions) and runoff response is expected and thus a correlation analyses for different intervals (one to four months) performed.

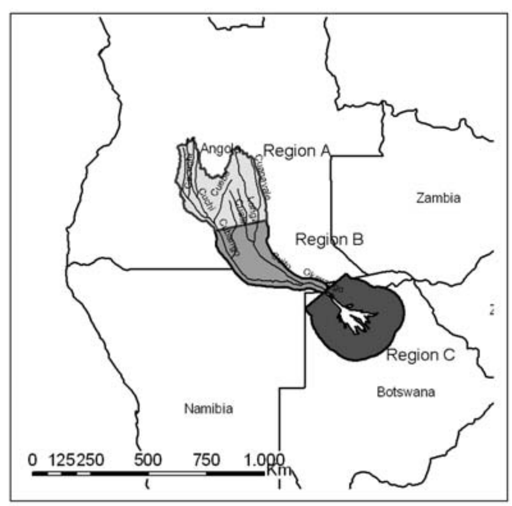

Figure 2. The Okavango basin and delta. Angola Highlands and buffer area around the delta which was analysed for soil moisture are shown.

Additionally, regions with high monthly backscatter and high soil moisture respectively have been extracted from ENVISAT ASAR Global Mode data for the Okavango Delta in order to derive the wetland dynamics. The inundated areas in the Okavango Delta quickly overgrow with emergent aquatic vegetation, and open water surfaces are rarely present. Thus, the inundated areas show high backscatter due to double bounce of the microwaves in C-band. A threshold of -7 dB has been determined in order to distinguish between inundated and non-inundated areas [7]. Landsat based classification results (30x30m) have been available for verification wether this corresponds to indunation or high soil moisture conditions during the maximum extent in September [8]. In a first step the fraction of inundation for each 1x1 km pixel of ENVISAT ASAR GM was derived from the Landsat based classification. A comparison with the actual microwave backscatter was carried out in a second step.

Additionally, monthly relative soil moisture of the surroundings is investigated in order to analyse the relationship between upper basin soil moisture, water inflow (river discharge) into the Delta, wetland extent and local soil moisture. Mean monthly values have been calculated for each single location (1km cells) and averaged over the relevant areas. For the Okavango Delta surroundings a 100 km buffer area was selected for analysis (Figure 2).

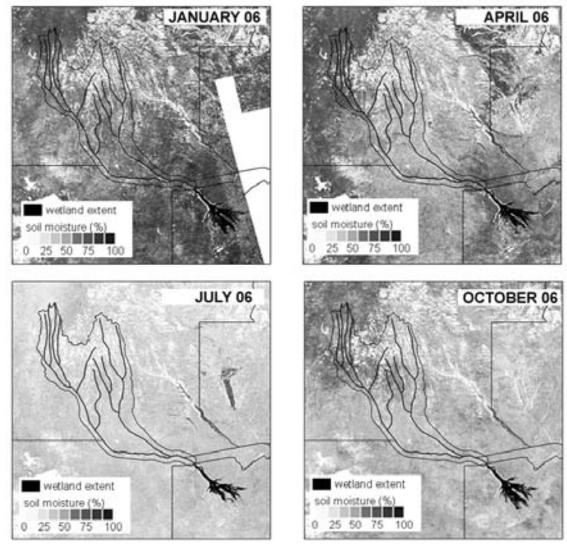

Figure 3. The soil moisture conditions in the upper Angolan highlands and corresponding extent of the wet area (black) in the Okavango delta. (white - no data)

3. Results & Discussion

Figure 3 shows example maps of relative soil moisture and actual wet area (including inundation) extent for four different months in 2006. Soil moisture is relatively high in the entire region during the rainy season (e.g. January). The wet area extent (area with high soil moisture conditions and/or indundation) for the delta was close to its maximum due to local rainfall in January 2006. Inundated areas in January are much smaller than those in August/September. Earlier work using optical remote sensing [9] revealed that the minimum annual inundation is usually achieved in January/February. The large extent of wet areas observed in January probably results from backscattering by rain-saturated surface soil layer being similar to that of inundated, vegetated areas. The proportion of inundation and high soil moisture areas respectively could not be determined as there are no Landsat images available from this time of the year (cloud cover). In April, most of the Okavango basin started to dry up. The minimum wetland extent occured during July. A second maxium is reached in the end of the dry season due to flood propagation. During this time the area surrounding Okavango delta was still very dry. Thus, it was evident that external inflow from upper Okavango basin must caused the rapid increase in the wetland extent.

3.1 Inundation

It is evident that the ASAR GM normalized backscatter increases with increasing fraction of inundated areas (Figure 4). While values of -8 dB represent areas with low fraction of inundated areas (0 to 0.1), values of -6 dB are typical for high (0.8 - 1.0) fraction.

The wetland maps based on the chosen threshold of -7 dB for the determination of wetland extent correspond to minimum 20% of water fraction as derived from Landsat data during the maximum inundation period in 2007 . This may differ during the rainy season when high soil moisture values may cause high backscatter outside the flooded areas. Since optical satellite data are constraint by cloud cover, no comparison can be made for that period.

3.2 Soil moisture

The saturated areas with high soil moisture values contribute to a large extent to surface runoff in the upper Okavango basin. A high correlation can be observed between the relative mean soil moisture in the upper Angola highlands (Figures 5 and 6, soil moisture from ”A”, see Figure 2) and the river discharge measurements at Mohembo station (R^2 = 0.96, [10]) with a shift of approximately three months. Peak discharge values aboth 1300 m^3/s (monthly mean) correspond to maximum observed mean upper basin soil moisture of 60%. The discharge maximum at Mohembo station in 2007 is not evident in mean soil moisture values. A temporal offset be also observed for all years between soil moisture and wetland extent measurements due to flood propagation within the delta. A second maximum in wetland extent which even exceeds the September/October maximum can occur during the rainy season.

Relative soil moisture in the surrounding of the delta

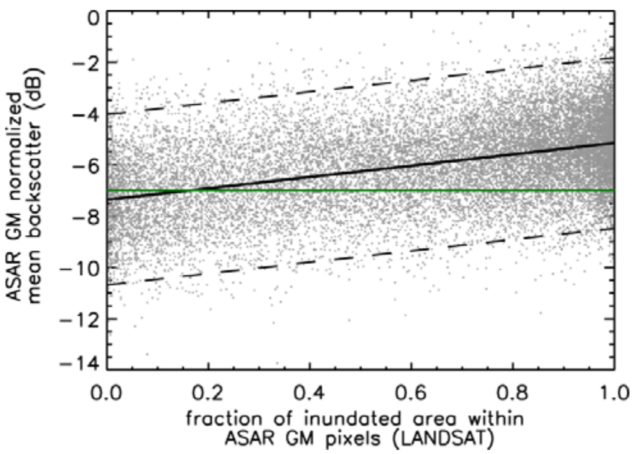

Figure 4. Monthly mean C-band backscatter at 1km resolution and water fraction from Landsat based inundation maps [8] September 2007; black solid line is linear fit, dashed black lines correspond to two standard deviations and green line is the -7 dB threshold for classification of inundated area from ENVISAT ASAR Global Mode

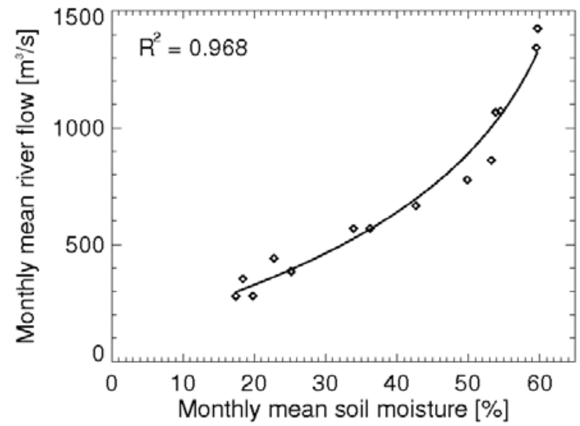

Figure 5. Relationship between mean monthly river discharge measured at Mohembo and mean monthly relative soil moisture observed in the Angola Highlands three months before; 2005 and 2006, source [10]

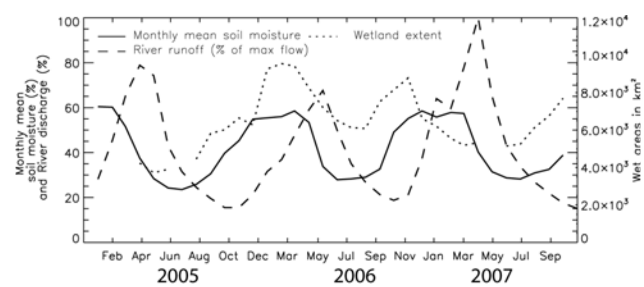

Figure 6. Time series of river discharge at Mohembo, monthly mean soil moisture in the Angola Highlands and inundation extent in the Okavango Delta for 2005, 2006 and 2007

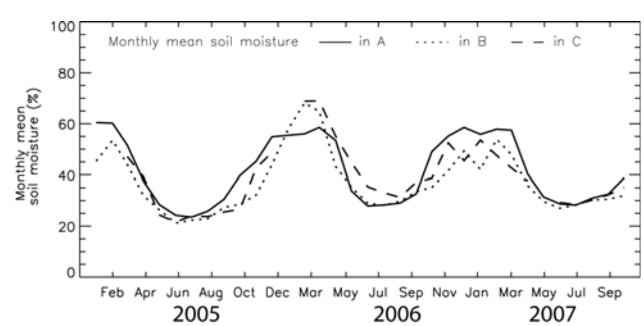

Figure 7. Time series of monthly mean soil moisture in the Angola Highlands and monthly mean soil moisture in the surrounding of the Okavango Delta for 2005, 2006 and 2007

exceeded values of those in the Angola Highlands in 2006 (Figure 6). This does not imply that the absolute water content was also higher. Observations reached the local maximum recorded during the period of satellite data availability in that area. The same was observed for the lower part of the basin (Region ”C”) which normally does not receive much precipitation. The annual minimum of mean soil moisture for the Angola Highlands was lowest during the dry season in 2005. It was 5 % higher in 2006 what may be related to the increased precipitaion before. As also the soil moisture in region ”A” in October was higher than in the year before, a small fist peak in river discharge was recorded three monthy later in January 2007. The maximum flow in 2007 cannot directly be related to the mean relative soil moisture values. A detailed analyses for single subbasins may provide more information.

4. Conclusion

The relative soil moisture derived from the ENVISAT ASAR GM data was clearly related to the river discharge measurements. The 1km dataset may also be used to investigate scaling properties and thus enhance the applicability of coarse resolution soil moisture products such as the 25km relative soil moisture dataset from Metop ASCAT [11]. This is especially important because these kind of data will become available in near real time in the near future. The ability of ENVISAT ASAR Global Mode to monitor dynamics of wetland areas as a response to the relative soil moisture in the upper Okavango catchment was demonstrated and verified with Landsat derived inundation maps. An incorporation of spatially improved soil moisture and wetland products may improve prediction models for the wetland region.

Acknowledgements

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