SOIL MOISTURE TIME SERIES FROM ACTIVE RADAR IN SUPPORT OF RUNOFF MONITORING ON LOCAL, CATCHMENT AND REGIONAL SCALE

A. Bartsch, C. Pathe, D. Sabel, W. Wagner, and M. Doubkova

Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, Gusshausstraße 27-29, 1040 Vienna, Austria, email: ab@ipf.tuwien.ac.at

Abstract

Soil moisture is a crucial parameter for hydrological modelling. It reflects soil properties as well as hydrometeorological conditions. A processing chain for ENVISAT derived soil moisture (1km) was setup within the ESA Tiger DUE Innovator project SHARE for hydrometeorological applications in the SADC region. It complements the ERS scatterometer dataset which is available for 1992-2000 for the southern African subcontinent. Within the presented study, location specific relative soil moisture has been analysed from ENVISAT ASAR Global Mode data and ERS scatterometer data for the Okavango upper catchment and compared to river discharge. Correlations above 0.8 can be observed in subtropical climates independent on the spatial resolution of the active microwave data. Such operational monitoring schemes as established within SHARE provide valuable complementary information to altimeter measurements.

Key words: ScanSAR; scatterometer; flood prediction; drought monitoring.

INTRODUCTION

The ERS C-band scatterometer system derived soil moisture has been proven suitable for the derivation of location specific near surface soil moisture variations, e.g. [1, 2]. ERS scatterometer time series are available since 1992 and are complemented by Metop ASCAT globally since 2007. The latter also provides an improvement of spatial resolution from 50km to 25km and increased daily coverage. Metop ASCAT will thus provide improved and operational global soil moisture retrieval [3]. ENVISAT ScanSAR data in ASAR Global Mode are less frequently acquired then scatterometer data but provide up to weekly samples on 1km resolution since December 2004. The soil moisture derivation approach developed by [4] has been transfered to ENVISAT ASAR GM within the SHARE project. SHARE is 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 was the aim of SHARE to develop an experimental medium resolution (1 km) soil moisture indicator solely based on ENVISAT GM data using the change detection algorithm. Additionally SHARE provides access to a coarse resolution (25 km) soil moisture product from ERS scatterometers together with a scaling layer (derived from ScanSAR data) which allows interpretation of the coarse resolution soil moisture product at 1 km resolution. This paper provides details on river runoff comparison of both the ENVISAT ScanSAR (1km) and ERS scatterometer (50km) derived soil moisture.

DATA AND STUDY SITE

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 [5]. GM data are available since December 2004.

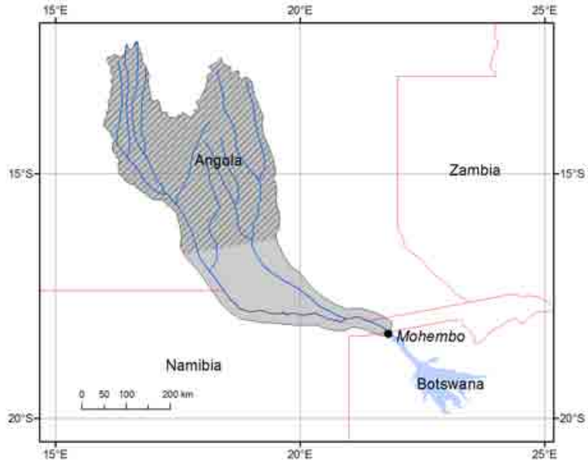

Fig. 1. Okavango upper catchment (grey) and delta (blue); area which contributes most runoff is hatched

The size of the currently active upper catchment of the Okavango river is almost 200.000 km^2. It is mostly located in Angola. Recharge of the Okavango tributaries takes place in the Angola highlands during the rainy season (hatched area in Fig. 1). There are water management plans for water abstraction in Namibia shortly before the Okavango River arrives at the floodplain in Botswana. The region south of the Angola Highlands including the Okavango delta is semi-arid with evaporation four times higher than rainfall [6]. Measurements of monthly mean river runoff are available from the station at Mohembo which is located approximately where the Okavango River enters the delta.

METHODS

Soil moisture plays an important role for runoff generation. Saturated soil moisture conditions cause increased runoff compared to dry soil moisture conditions. This hydrological parameter can be derived from ERS scatterometer (C-band) as a relative measure on global scale with data records available since 1992 [7, 8]. The near surface soil moisture can be determined by time series analysis. A dry and wet reference is identified for each grid point and each single measurement scale between these limits. By application of a simple infiltration model profile soil moisture is derived [4]. The latter is referred to as Soil Water Index (SWI) and available globally as 25km grid cells in 10 day intervals [8]. For this study SWI and daily runoff (10-day average) data have been analysed until the year 2000.

The coverage of ENVISAT ASAR Global Mode data is highly variable over space and time. For regular maps of an area with a size such as the Okavango upper catchment, only monthly intervals are suitable. Therefore, monthly mean soil moisture maps have been created and then compared to monthly mean discharge measurements. A SWI could not be derived from the ENVISAT dataset so far due to the infrequent sampling (since December 2004). The used relative soil moisture values are therefore only representative for surface wetness. A further implication of the short period of data availability is the limited determination of a suitable dry and wet reference from the ENVISAT data. Some regions in the semi-arid to arid environment may not have received precipitation since data became available. Therefore probabilities are introduced based on the eight year ERS scatterometer record. The experimental soil moisture maps have been validated with ground data over Oklahoma [9].

Discharge measured at a specific point represents the information of the entire upstream area. The SWI can be integrated over all grid points of basin in order to get a representation of this information [10]. The result is a Basin Water Index (BWI_{SWI} or $BWI_{surfwet}$). Correlation functions have been applied directly as well as for offsets of multiples of 10 days and 1 month respectively. This is based on the assumption that runoff following a precipitation triggered soil moisture increase is delayed depending on contribution area [10].

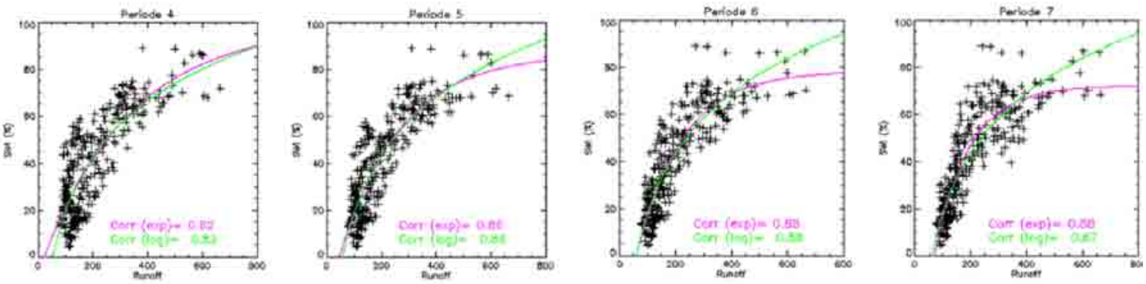

Fig. 2. Basin water index (BWI_{SWI}, 10 day intervals) from scatterometer integrated for catchment upstream from Mohembo (the entrance of the Okavango river to the delta) in comparison with discharge measurements (40 - 70 day offset = Period 4 -7).

RESULTS

Depending on basin size a delay between BWI and measured river runoff can be observed. Taking this offset into account a correlation between river runoff and BWI can be found. Correlations are close to 0.9 for the nine year ERS dataset over Okavango (Fig. 2). Similar values have been observed for the Zambesi River [10] with a clear offset dependence on basin size. Although high runoff - soil moisture correlations can be found in permafrost regions as well (after snowmelt has ceased), no specific offsets can be determined [11].

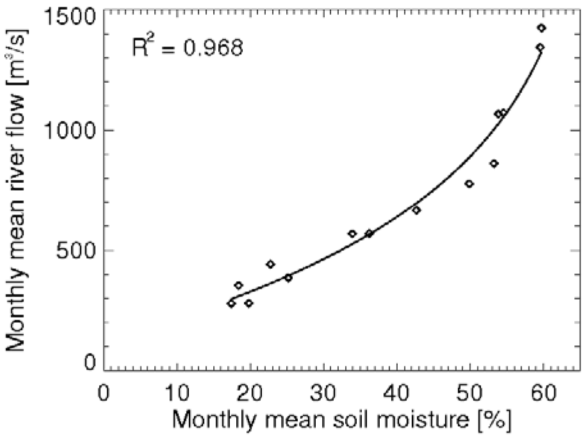

Fig. 3. Monthly mean soil moisture and river runoff scatterplot for the period January 2005 - May 2006 after shifting the datasets three months relative of each other

The correlation between monthly means from ENVISAT ASAR GM and river runoff at Mohembo is above 0.9 for 2005/2006 (Fig. 3). The offset in case of the two monitored years is three months. This value is higher than for the scatterometer example (60-70 days, Fig. 2) which is based on data from 9 consecutive years. This difference may result from one or several of the following factors:

1. The scatterometer derived BWI is based on SWI values which result from a temporal filtering approach. The global mode derived BWI represents near surface soil moisture before infiltration.
2. The year 2006 was an anomalous year. Precipitation during the rainy season was above average.
3. The time steps differ. The 10 day intervals allow to capture variation within single months. This is not possible for GM.
4. Data coverage with GM varies over the catchment and thus the monthly average may represent differing time periods from point to point.

DISCUSSION

The river runoff measured at Mohembo equals the inflow into the large wetland area of the Okavango Delta which is entirely located within Botswana (Fig. 1). Flooding within the delta peaks during September each year. The wet area is highly variable and depends also on internal parameters such as aggradation (water flow redistribution) and local rainfall (groundwater table, antecedent conditions) [11, 12]. Models have been developed which aim at the prediction of inundation based on these discharge measurements [13, 14]. The observed soil moisture within the upper catchment with ENVISAT depicts runoff patterns already three months ahead what may enhance prediction capabilities considerably.

Regions with saturated soil conditions which generate runoff at a certain time are easily identified with the relative soil moisture maps. This gives insight not only into local but also catchment scale hydrology.

Frequent and regular satellite data coverage supports the monitoring on regional scale. This has been exploited within the SHARE project. Monthly mean soil moisture maps could be extracted for entire SADC (Southern African Development Community). Large scale anomalies as occurred within 2006 and 2007 over southern Africa can be observed. Fig. 4 shows maps of monthly mean relative soil moisture for February 2006 and February 2007. The drought patterns in 2007 can be clearly seen.

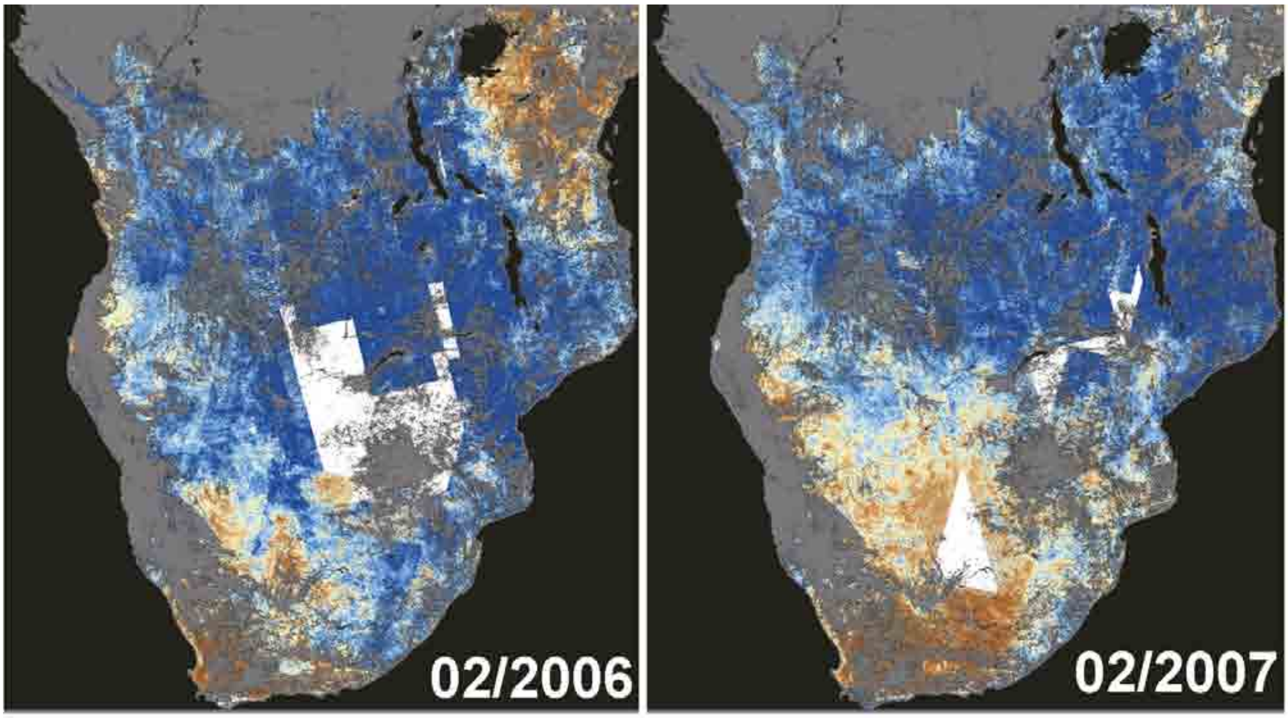

Fig. 4. Monthly soil moisture composites from ENVISAT ASAR Global Mode, February 2006 and 2007

CONCLUSIONS

Saturated surfaces which contribute to a large extent to surface runoff and thus increased river flow can be identified with the 1km ENVISAT ScanSAR as well as the 50 km ERS scatterometer dataset. Such observations are of high value for modelling on local and catchment scale (flood prediction) as well as regional scale (drought monitoring). Operational monitoring schemes as established within SHARE provide valuable complementary information to altimeter measurements.

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