ENVISAT ASAR GM SOIL MOISTURE FOR APPLICATIONS IN AFRICA AND AUSTRALIA

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ABSTRACT

ScanSAR systems such as ENVISATs ASAR Global Mode allow monitoring of dynamic processes at medium resolution (1km). Hence they are especially useful for monitoring hydrologic processes such as soil moisture and inundation dynamics. Within the ESA DUE Tiger Innovator project SHARE (Soil Moisture for Hydrometeorological Applications) an operational monitoring scheme has been developed. As part of the Tiger initiative, it has been implemented first over the Southern African Development Community region (SADC). Within one year after the release of the final version numerous users from within Africa and all over the world have requested the datasets for applications such as water management (including catchment modeling), biodiversity, habitat modeling, soil erosion, carbon fluxes etc. A similar service has been setup for entire Australia and satisfactorily evaluated for water resources management purposes. In this paper we provide an overview of the use and validation of the soil moisture products within SHARE. Interannual variability (2005–2008) has been assessed for all months. The range of mean monthly soil moisture among the SADC countries was highest for Zimbabwe, Malawi and Mozambique and most pronounced during the second half of the rainy season in February and March.

Key words: soil moisture; SAR, Africa, Australia.

1. INTRODUCTION

This document provides an overview of validation activities carried out within the framework of the ESA Tiger Innovator project SHARE. SHARE aims at enabling an operational soil moisture monitoring service for the region of the Southern African Development Community (SADC). The long-term vision of SHARE is to supply soil moisture information for the entire African continent, at a resolution of 1 km, posted on the web, freely accessible to all [1]. Validation is a major prerequisite for such a service. The service has been recently extended to Australia.

The soil moisture information system is based on the newest radar satellite technology. The service uses data delivered by ENVISAT's ASAR sensor operated in global mode (GM) and the ERS-1/ERS-2 and MetOp scatterometer sensors. The synergistic use of both systems allows frequent, medium resolution monitoring of regional soil moisture dynamics. SHARE provides access to three products: coarse resolution soil moisture, a scaling layer which allows interpretation of the coarse resolution soil moisture product (25 km grid) and a medium resolution soil moisture product at 1km.

1. Medium Resolution Soil Moisture: The medium resolution soil moisture product is based on ENVISAT ASAR Global Mode data. ENVISAT ASAR Global Mode data allows monitoring of soil moisture for the entire Southern African Development Community (SADC) region on a weekly basis at 1 km resolution, however with a higher noise level compared to the coarse resolution soil moisture product. The ASAR global mode data represent soil moisture in the upper most soil layer (<5cm) and is developed for applications such as drought, yield, and flood forecasting or modelling. [2, 3, 4]

2. Coarse Resolution Soil Moisture: Global, coarse-resolution soil moisture data (25-50 km) are derived from backscatter measurements acquired with scatterometers on-board of the satellites ERS-1 and ERS-2 (1991 to present) and the three METOP satellites (2006 - 2020, in near real time via EUMETCast). (e.g. [5, 6])

3. Scaling layer: The scaling layer has been derived from ENVISAT ASAR Global Mode data. The scaling layer allows the interpretation of coarse resolution soil moisture information as provided by the scatterometer data at 1 km resolution by identifying targets which have similar backscatter characteristics as observed with the scatterometer. The soil moisture variations of these local targets will follow the variations observed in the scatterometer derived soil moisture. [7]

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In order to update our users about our soil moisture products and to demonstrate their potential applications, a bi-monthly bulletin was initiated at the Institute of Photogremmetry and Remote Sensing (IPF), Vienna University of Technology in March 2008. The bulletin updates data users and researchers that expressed their interest in the soil moisture products about current soil moisture conditions in the SADC region as represented by the ASCAT and ASAR GM data. Several researches requested the subscription to this bulletin and positively commented on this initiative shortly after the first issuance of the SHARE bulletin. In addition, already registered data users requested update of their data and several new data requests. The Australia product has been included in the bulletins since March 2009. All bulletins can be downloaded from IPF website: http://www.ipf.tuwien.ac.at/radar/share/index.php?go=bulletin.

2. DATA USAGE

Every single year, the African continent is hit by flooding and drought. Vast areas are affected at the same time. E.g. the year 2007 brought both extremes [8] above-average and below-average rainfall. Southern Africa suffered from El Niño-induced drought in the beginning of 2007, resulting in irreversible crop damage all over the subcontinent. Crop yields are especially susceptible to changes in water supply in these semi-arid regions. Most of the continent received above-average precipitation later in the same year. It caused the worst flooding in three decades in Sudan. Measures for continent-wide monitoring have been taken already for many years by various organizations, first and foremost United Nations programs. Satellite data play an important role in the regular investigation of such large regions. Satellite data which provide information on especially water related issues are critical datasets within the context of poverty also with respect to climate change [9].

Australia is the flattest and driest continent and receives high rainfall amounts only in coastal areas. Over two third of the continent receive less than 500 mm of precipitation per year. Australia also has a high year-to-year and decade-to-decade variation due, in part, to the El Niño Southern Oscillation (ENSO) phenomenon. The impacts of drought on agricultural production have been significant in the past [10] and also fresh water scarcity has repeatedly been a problem. There is significant public interest in Australia on issues dealing with water management. For example, the Murray-Darling basin, which accounts for about 40 percent of Australia's agriculture, has been experiencing severe drought conditions since 2002, as have other parts of densely populated southeast Australia. At the same time, northern parts of Australia have witnessed increased flood incidence. [11]

More than 50 users requested the 1 km Soil moisture product since the start of the project. The users originated from universities, research and governmental organizations in Africa (40%), Europe (43%), the USA (7%), Australia (4%), international organisations (8%), and one user from India (Figure 1). While majority of the users intended to use the dataset for research purposes, there were several requests aiming on incorporation of the data into decision making and planning strategies within SADC and Australia.

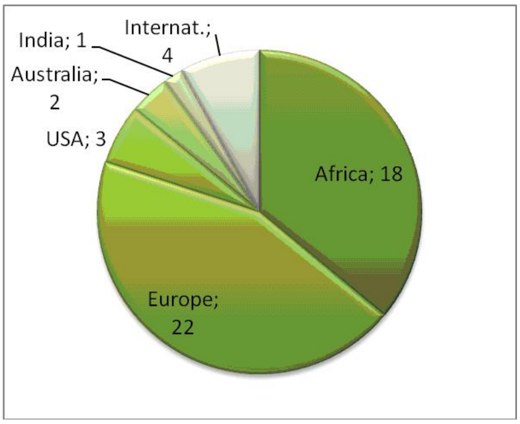

Figure 1. Origin of SHARE data users.

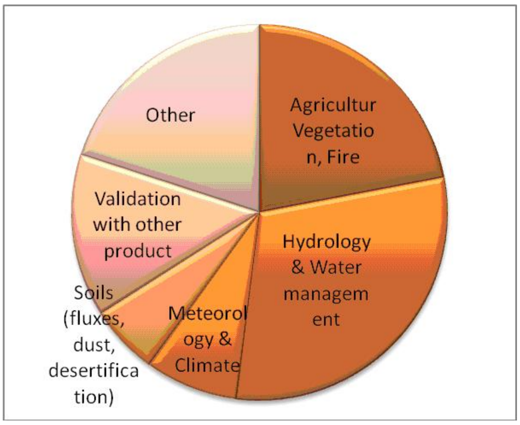

Figure 2. Fields of application of the 1km ASAR GM soil moisture product.

The most common applications of the ASAR GM SM included agricultural (i.e. crop yield modelling, phenological studies, effects of climate change on the vegetation distribution) and hydrological investigations (drought and flood assessment, water quality studies, water use efficiency). A large amount of users aimed on comparison and validation of the ASAR GM soil moisture product with their own or other available soil moisture products or in-situ measurements (Figure 2). A request for comparison of the ASAR GM soil moisture with in-situ data within the SMOSMANIA SMOS validation campaign was especially relevant for the scope of SHARE extension. Further requests were related to applications such as cattle movement monitoring, pasture management, soil erosion prediction, and climate change.

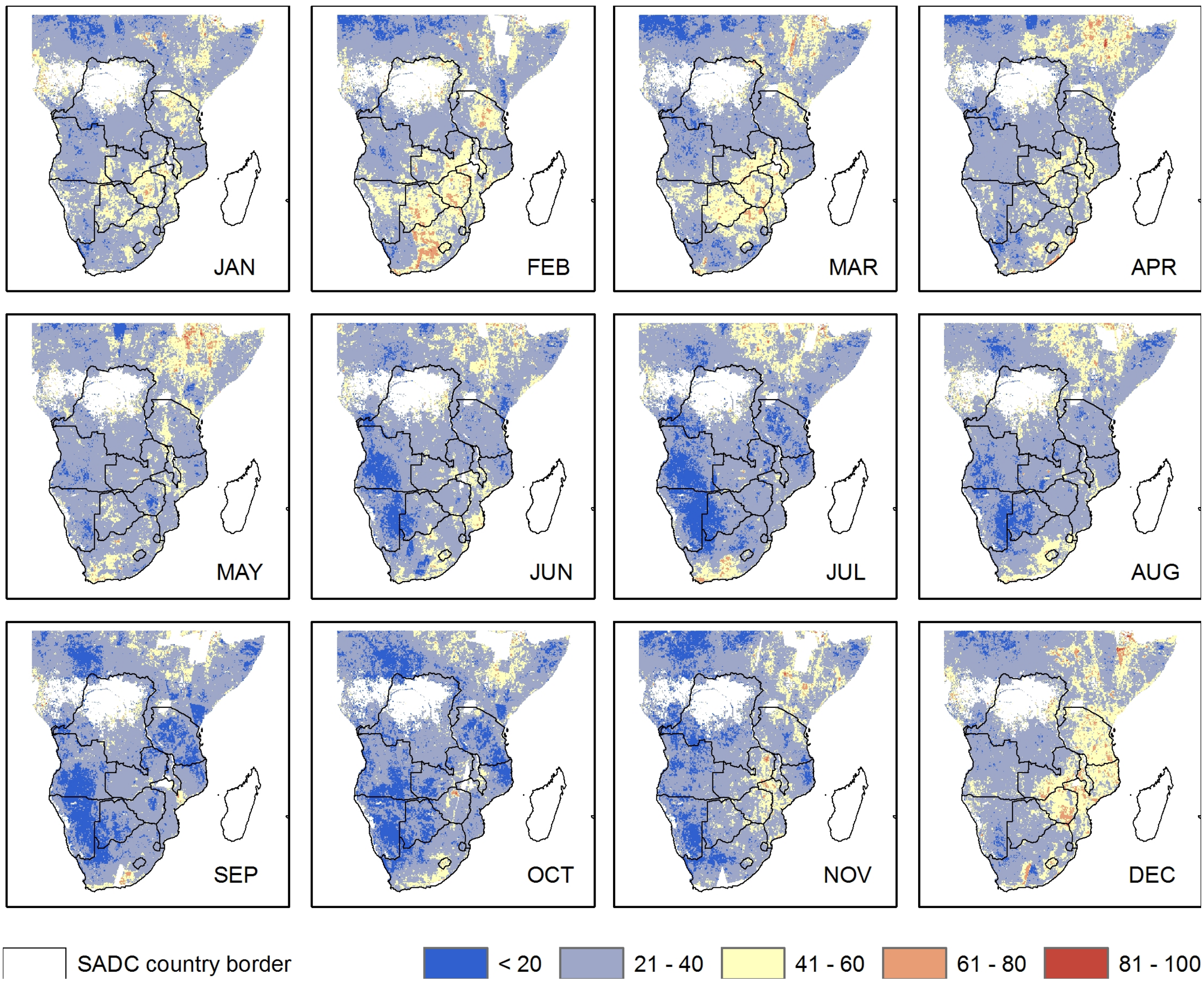

Figure 3. Range of mean monthly soil moisture (in %) from ENVISAT ASAR GM for the years 2005 to 2008 over SADC.

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Angola	22,9	24,0	21,9	22,3	20,7	17,6	16,3	18,7	17,8	18,2	19,4	24,6
Botswana	33,0	38,7	38,2	27,0	26,1	21,7	16,9	17,4	17,0	16,8	23,9	25,5
Congo, DRC	21,9	24,8	21,7	22,8	24,0	23,4	20,7	23,3	21,8	20,4	19,4	22,7
Lesotho	28,3	42,6	30,9	32,4	25,7	35,1	27,2	36,3	21,8	37,1	26,1	39,6
Malawi	30,1	33,2	38,0	34,3	29,2	27,0	23,9	25,6	22,3	26,3	29,7	39,3
Mozambique	28,7	31,1	31,3	29,1	25,6	27,3	22,9	24,5	21,5	20,0	27,3	39,4
Namibia	26,5	31,6	29,2	23,8	21,6	16,6	15,0	16,6	14,3	15,0	17,3	24,3
South Africa	26,8	36,1	28,4	28,0	28,7	26,6	24,4	28,5	21,4	24,1	21,2	26,7
Swaziland	26,3	31,0	26,3	27,3	27,7	26,8	22,5	35,5	21,8	19,2	25,6	23,6
Tanzania	31,4	31,7	25,3	25,4	26,4	21,2	18,7	21,8	17,5	18,8	25,4	39,4
Zambia	27,8	30,3	30,6	29,2	25,2	23,8	20,5	20,7	20,5	19,9	27,4	31,3
Zimbabwe	36,4	40,8	38,7	31,0	23,0	23,9	21,4	22,6	22,0	25,0	30,0	41,4

Figure 4. Country average range of mean monthly soil moisture (in %) from ENVISAT ASAR GM for the years 2005 to 2008 for single SADC counties.

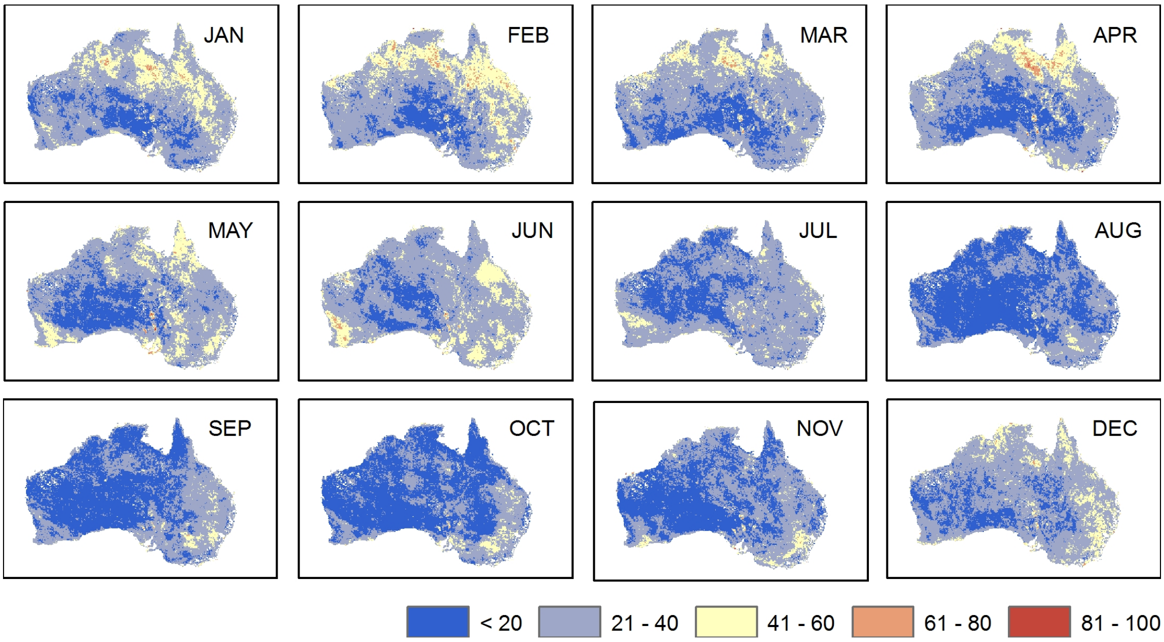

Figure 5. Range of mean monthly soil moisture (in %) from ENVISAT ASAR GM for the years 2005 to 2008 over Australia.

3. VALIDATION RESULTS

The datasets provided within SHARE have been assessed by comparison with modelled data, ground measurements of soil moisture, river runoff data and precipitation patterns apart from results from other microwave sensors. This validation and evaluation process is continuing.

The scatterometer soil moisture dataset which goes back to 1992 has been assessed for hydrological modelling in South Africa [12]. The existance of this historical dataset is very important as currently sufficient measurements/stations are not available. The used model was TOPKAPI. TOPKAPI is an acronym which stands for TOPographic Kinematic APproximation and Integration and is a physically-based distributed rainfall-runoff model. TOPKAPI requires ground measurements which have been available in the past in the South African catchment Liebenbergsvlei. A mean modeled SWI (Soil Water Index) was computed at catchment scale by averaging over the catchment the SWI computed at each TOPKAPI cell for 1996 and 1997. There was a very good correspondence between the two SWI estimates that is illustrated by the regression coefficients (R^2) of 0.78 for the first year and 0.92 for the second year.

The medium resolution ENVISAT ASAR GM soil moisture (available since December 2004) has been validated outside of the SADC region due to limited ground data availability. It was carried out over Oklahoma, USA instead [13, 14]. Comparisons of the remotely sensed surface soil moisture to in-situ soil moisture showed a good agreement between the two data sets. The ASAR GM surface soil moisture follows temporal trends in the in-situ FWI (Fractional Water Index) soil moisture data. Correlation coefficients R>0.6 were observed for 54% of the 115 stations.

River runoff is a point measurement integrating information on the hydrologic status of an entire catchment. To get a representative indicator, soil moisture data can therefore be integrated over all grid points of the sub basins to derive a "Basin Water Index" (BWI) from scatterometer or SAR derived Soil Water Index (SWI; [15, 16, 3]. Both, ERS scatterometer and ENVISAT ScanSAR derived BWI have been derived for the upper Okavango catchment in Angola and compared to discharge at Mohembo, the entrance to the Okavango inland delta in Botswana. The contribution of Okavango River discharge is essential for the maintenance of the complex wetland area which constitutes the delta. Depending on basin size a delay between BWI and measured river runoff (source: Global Runoff data Centre - GRDC) can be observed. Taking this offset into account a correlation between river runoff and BWI can be found. The relationship can be described by a logarithmic function. Correlations for ERS are 0.88 (R^2=0.77) for the entire upper active Okavango River basin. The correlation between monthly means from ENVISAT ASAR GM and river runoff at Mohembo is above 0.9 (R^2) [4].

A similar sensor as ERS-1 and ERS-2 has been launched with METOP ASCAT (Advanced Scatterometer) in

October 2006. The ground coverage is considerably improved compared to ERS due to a second swath and spatial resolution is 25 km [17]. Measurements are consistent with the preceding sensors and allow continuation of products developed for ERS [6, 18]. MetOP ASCAT derived surface wetness has been compared with ENVISAT ASAR GM soil moisture and also rainfall patterns for Australia [19]. The spatial patterns in the ASCAT SM and ASAR SM products corresponded well with rainfall. The 1 km ASAR SM product showed spatial details not visible in the 50 km ASCAT SM. The temporal correlation between the ASAR SM and ASCAT SM was strong, considering the difference in scale and high noise of the ASAR GM data, with best results for the Cropland category with R=0.73. When comparing ASCAT SM to Hamming resampled ASAR SM, RMSE values decreased and correlations increased significantly with R=0.91 for Cropland.

4. INTERANNUAL VARIABILITY PATTERNS

To date, four complete years (2005–2008) of ENVISAT ASAR GM soil moisture data are available for both SADC and Australia. This allows a first estimate of interannual variability and identification of regions with potential water stress related to plant available moisture apart from general availability. The range of mean monthly soil moisture has been computed for those years. Results highlight large differences between countries within SADC (Figure 3).

Eastern SADC showed generally higher interannual variability than other regions. The average range by country is highest in this area (Figure 4). Most affected are Zimbabwe, Malawi, Mozambique and Lesotho. Large parts of South Africa are also affected. The data coverage over SADC varies considerably between regions and also months. This results in data gaps and artifacts which may impact the results. It can be, however, observed that the largest variations occur at the beginning of the rainy season and during its decline. Soil moisture can especially vary in February affecting also Southern Africa.

The months January to April have been also characterized by high interannual variability over Australia (Figure 5). The most affected regions are the northern and northeastern part of the continent. The magnitude of the most extreme cases ranges between 60-80% similarly to what can be observed for SADC.

5. CONCLUSIONS

Satellite derived near surface soil moisture data provide measures on available moisture in the ground and its variability. Such information is required in especially subtropical environment where water resources are limited. Both ScanSAR and scatterometer can provide relevant data. In combination they can capture the spatial and temporal patterns of upper soil water content. The upcoming Sentinel-1 SAR mission will provide the possibility to continue and enhance the current services [20].

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