The Potential of PALSAR ScanSAR Mode for Soil Moisture Retrieval

FINAL REPORT

PI No 090

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ABSTRACT

This document is the final report for all activities related to the JAXA ALOS PI agreement 090. The initial research focus was on soil moisture monitoring in semi-arid regions. Attention was shifted to the assessment of landscape heterogeneity in the high latitudes during the extension period of the PI agreement.

Soil moisture monitoring requires frequent acquisitions in order to capture this highly variable parameter. The retrieval approach followed by the PI requires a large sample for each location, representing wet and dry conditions. Currently C-Band ENVISAT ASAR WS (Wide Swath, 150m) and GM (Global Mode, 1km) data are used for the establishment of a near real time processing chain. Similar data with regular intervals will become also available from Sentinal-1. L-Band advantageous compared to C-Band regarding vegetation penetration and sensitivity to changes of near surface soil water content. Regular acquisitions are however not available. The C-band capabilities have been assessed with the ALOS PALSAR data over Africa, but the sample of ALOS data was too small. The potential of the L-band data could be nevertheless demonstrated.

Soil moisture retrieval in tundra regions is impacted by landscape heterogeneity. Especially the abundance of small ponds needs to be taken into consideration. ALOS PALSAR fine beam data are used for the assessment of the small lakes detection capabilities of ENVISAT ASAR WS, which is available for regional to sub-continental analyses. The majority of lakes which are identifiable with fine beam can be also captured with ASAR WS. The difference in total water surface extent can be mostly attributed to rims around larger lakes.

Research in semi-arid as well as permafrost environment is still ongoing and is performed in cooperation with international project partners.

1. INTRODUCTION

The original research focus was on the investigation of the potential of PALSAR ScanSAR Mode for Soil Moisture retrieval on mostly the African continent and Spain. The requested data for this purpose have not been acquired. An analysis has been therefore done with Fine Beam data from the archive instead [1,2]. Financial support from national funding bodies (Austrian Science fund, project title: ScanSAR Mali) has been requested along with the ALOS PI application. The project was approved but completed by the time of ALOS data availability. Some of the planned ALOS investigations could nevertheless be carried out due to funding by the European Space Agency (Tiger Innovator DUE SHARE) and Austrian Science Fund (MISAR project) during the first phase.

Research interests have meanwhile shifted to the high latitudes. A JAXA PI proposal change has been therefore requested in 2009. It was granted the same year. The permafrost related studies are funded by national (Austrian Science Fund) and European sources (European Space Agency). Topics of interest are soil moisture as well as wetlands and landscape heterogeneity. This recent work also makes use of ALOS PRISM data. The relevant projects are still ongoing and will terminate end of 2011/ beginning 2012. Therefore only preliminary results can be presented in this report.

The main focus of the microwave remote sensing research group at Vienna University of Technology is the exploitation of active microwave data for operational monitoring of land surface hydrology. This includes near surface soil moisture, frozen ground conditions and permanent as well as temporary inundation. The ALOS data have been analyzed in this context.

This report is sorted in chronological order of the investigations and subdivided by region and topic of interest.

2. SURFACE SOIL MOISTURE MONITORING IN SEMI-ARID REGIONS

Soil moisture is a crucial component in the cycle of water and energy and has been recognized as an emerging Essential Climate Variable by the Global Climate Observing System [3]. Research into soil moisture retrieval from active and passive microwave sensors has been ongoing since the 1970’s. Since 1991, the ERS1 and

ERS2 satellites have supplied C-band scatterometer acquisitions. The development of a method for retrieving soil moisture estimates using change detection techniques has been carried out for almost a decade at Vienna University of Technology [4]. A global, multiyear database of soil moisture measurements has been build up. The change detection method has recently been transferred to the SAR domain within the SHARE project [5], which is part of the European Space Agency's TIGER Initiative [6]. By using data acquired by the ENVISAT satellite's Advanced Synthetic Aperture Radar (ASAR), a 1 km Surface Soil Moisture (1 km SSM) product has been derived.

Many field studies have shown that in the temporal domain soil moisture measured at specific locations is correlated to the mean soil moisture content over an area. This has been tested with ENVISAT WS data over a site in the Duero Basin, Spain [7] and later transferred to Global Mode.

Fig. 1: Location of Duero Basin

The precision of relative soil moisture estimates which are derived using radar time series depends strongly on the sensitivity of the signal to changes of dielectric properties (changing water content) in the soil, land cover and wavelength. The aim of the ALOS investigations was to assess the differences in sensitivity between L-band and C-band SAR.

Two sites have been selected, the Duero Basin in Spain [1] and the Volta basin in Ghana [2].

2.1 DUERO BASIN SPAIN

Two HH polarization ALOS fine beam scenes which were acquired during wet and dry conditions in 2007 (16.6. and 15.07. respectively) over the Duereo Basin (Spain) were selected for the comparison with ENVISAT ASAR WS. The backscatter difference between dry and wet conditions for L-HH was much smaller than the observed C-VV sensitivity (Fig. 2 and Fig. 3). The two available acquisitions of PALSAR FBD for the Duero Basin (Spain) are just one month apart. The dry reference image represents only the beginning of the summer drought. This may cause the low backscatter differences between the dry and wet conditions. This issue has been further investigated over the Volta Basin, Ghana with ENVISAT ASAR Global Monitoring mode data.

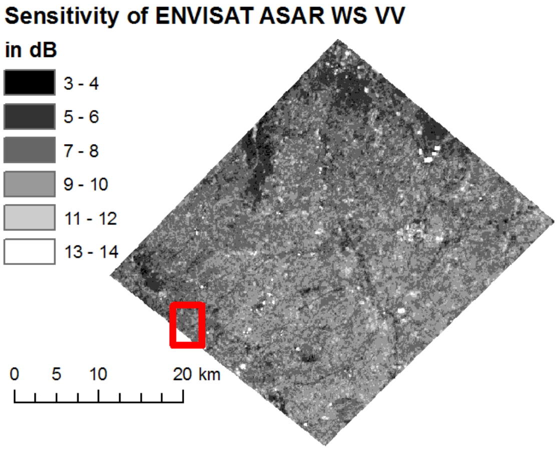

Fig. 2: ENVISAT ASAR Wide Swath (VV) sensitivity for the Duero Basin, Spain; rectangle shows extent of Fig. 3

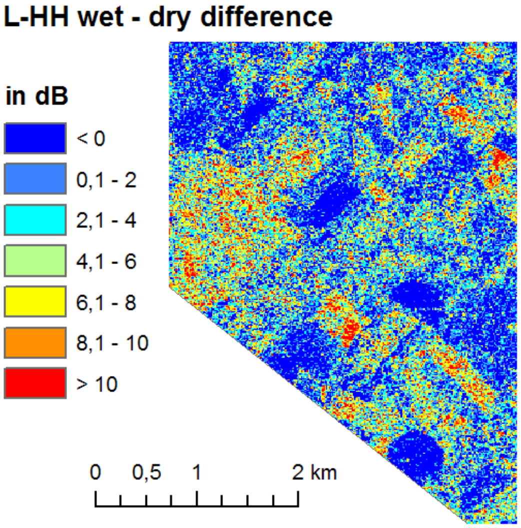

Fig. 3: ALOS PALSAR L-HH backscatter difference between wet condition (16.06.2007) and dry conditions (15.07.2007); for location see Fig. 2

2.2 VOLTA BASIN GHANA

40-60 scenes have been available from ENVISAT ASAR GM for the Volta Basin between April 2006 and February 2008. Only 3-4 images of ALOS fine beam mode images were available for the sites. They have been taken during both the dry and wet season. The sensitivity differences have been discussed using MODIS VCF (Vegetation continuous fields) (Fig. 4). Initial direct comparisons showed a higher dB range between dry and wet conditions in C-Band than in L-band [2].

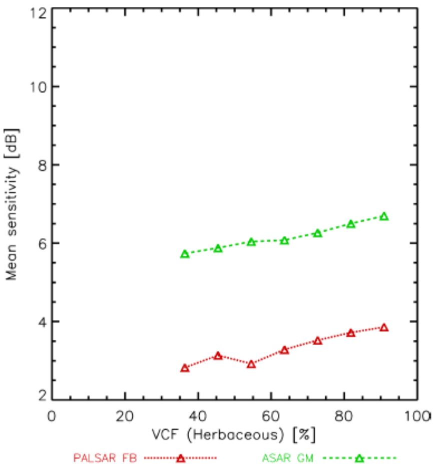

Fig. 4: Sensitivity dependence on fraction of herbaceous vegetation for the Ejura test site, Volta basin

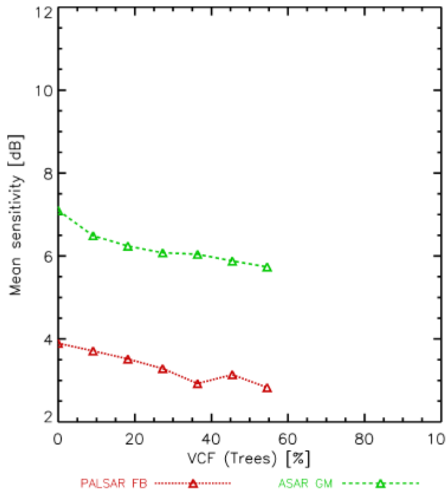

Fig. 5: Sensitivity dependence on fraction of tree cover for the Ejura test site, Volta basin

In order to interpret the results of the analysis, the representativeness of the data needs to be taken into account. The sensitivity estimates for ASAR are statistically more reliable since many measurements were taken into account in the calculation. Furthermore, in case of ASAR the estimates represent the sensitivity to the full range of soil moisture, basically from wilting level to field capacity. In the case of PALSAR, only 3 and 4 images were used for Tamale and Ejura respectively. Based on the site specific annual rainfall distribution, it was assumed that PALSAR images for reasonably wet and dry soil moisture conditions were included for each of the sites. However, it was neither an assumption, nor a requirement, to assume that the full range of soil moisture was captured in the PALSAR images. Instead, the initially derived sensitivities for PALSAR could be corrected by using information on the estimated range of soil moisture variation captured in the PALSAR images. This was done by using the 1 km Surface Soil Moisture product derived from the ASAR data. The corrected sensitivities for PALSAR could then be directly compared to the results for ASAR.

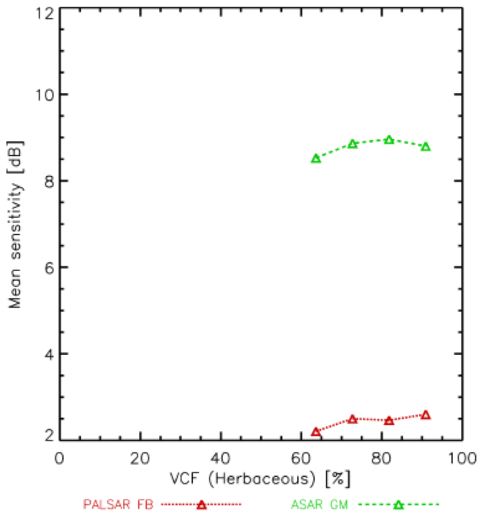

Fig. 6: Sensitivity dependence on fraction of herbaceous vegetation for the Tamale test site, Volta basin

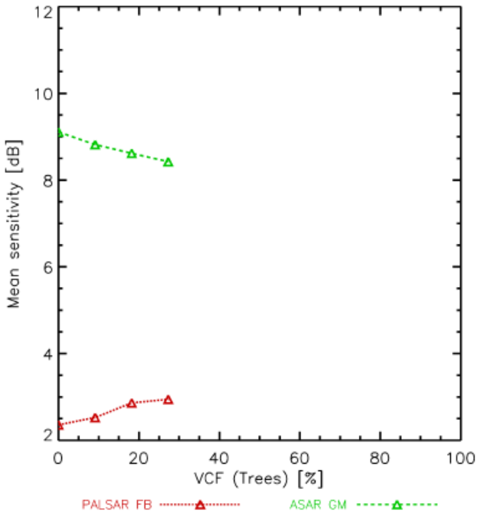

Fig. 7: Sensitivity dependence on fraction of tree coverage for the Tamale test site, Volta basin

The higher value of the corrected sensitivity for PALSAR when compared to the ASAR sensitivity in the Ejura site (see Tab. 1) was expected, since the L-band backscatter was expected to be less disturbed by vegetation than the C-band backscatter. Furthermore, the ASAR sensitivity was lower for the Ejura site than for the Tamale site, as a result of the higher vegetation density in the Ejura region. The sensitivity estimates for PALSAR for the Tamale site, however, are not consistent with what would be expected. Instead, the corrected sensitivity for PALSAR is less than half of the ASAR sensitivity.

	Ejura		**Tamale**	
	ASAR	**PALSAR**	**ASAR**	**PALSAR**
Mean	6.31	3.55	8.92	2.48
STD	0.56	0.95	0.63	1.20
Cor. Mean	-	8.50	-	4.41

Tab. 1: Mean and standard deviation of sensitivities for both test sites, in units of decibel. The corrected ALOS sensitivity means have been adjusted to the estimated range of soil moisture variations captured in the corresponding ASAR data

In general, the influence of vegetation on the dynamics of backscatter is not straightforward. An increase in vegetation density may decrease or increase the backscatter intensity, depending on the reflectivity of the underlying soil surface. A dense vegetation layer, such as a tree canopy, attenuates the response from the underlying surface signal while at the same time adding a volume scattering component which tend to increase the backscatter intensity [8]. This means that over a wet soil, a tree canopy will attenuate the total backscatter intensity, while over a dry soil, the result will be to increase total backscatter intensity. Either way, a dense vegetation canopy will always attenuate the sensitivity to soil moisture. Since L-band microwaves interacts less with vegetation than does C-band microwaves, it was expected that an increase in canopy density would have a greater effect on the ASAR data. However, both the C-band ASAR and the L-band PALSAR sensitivity showed the same trend, with about 0.2 dB per 10% increase in sub-pixel tree coverage over the Ejura test site (Fig. 5). The finding also conforms to the corresponding trend for herbaceous vegetation with about +0.2 dB and +0.1 dB per 10% increase in fractional coverage for the Ejura and Tamale sites respectively. A peculiar trend is observed in the PALSAR data over the Tamale site with a +0.23 dB increase in sensitivity per 10% increase in sub-pixel tree coverage [2]. Further work is required to explain this result. The ASAR data shows, as expected, a decreasing trend of 0.25 dB per 10% of fractional tree coverage over Tamale. The magnitude of the sensitivities must be interpreted taking the noise of the data into account. Due to the high noise in the ASAR GM data (1.2 dB), only a few classes of soil moisture are expected to be distinguishable. For the Ejura test site, the 6.3 dB mean sensitivity would result in about 5 classes of soil moisture. The PALSAR FB data on the other hand, with a noise of approximately 0.025 dB when averaged to the ASAR resolution, would theoretically allow more than 100 classes. In the case of PALSAR, other factors, such as model uncertainties, would instead be limiting for the number of soil moisture classes.

Limiting for the potential of soil moisture extraction using change detection methods in the case of PALSAR is the relatively sparse temporal coverage, which results from the PALSAR Observation Strategy focusing on high spatial resolution and a typical coverage of 3-5 observations per year.

A study in the proximity of wetlands in semi-arid environment is still ongoing. More than 20 scenes are available for the Okavango Delta. It will extent the analyses to the ScanSAR Mode (Wide beam), getting back to the original proposal.

3. THERMOKARST FEATURES IN HIGH LATITUDE PERMAFROST REGIONS

Permafrost is an essential climate variable (ECV). It is a subsurface phenomenon which cannot be directly measured with remotely sensed data. Yet, monitoring can be done based on indicators and via permafrost models. Indicators are especially thermokarst lake dynamics and surface elevation changes. Those phenomena need to be observed on a local scale. Regional to circumpolar monitoring requires the use of permafrost models. The European Space Agency project DUE Permafrost addresses both, the monitoring of indicators and parameters relevant for permafrost modeling [9].

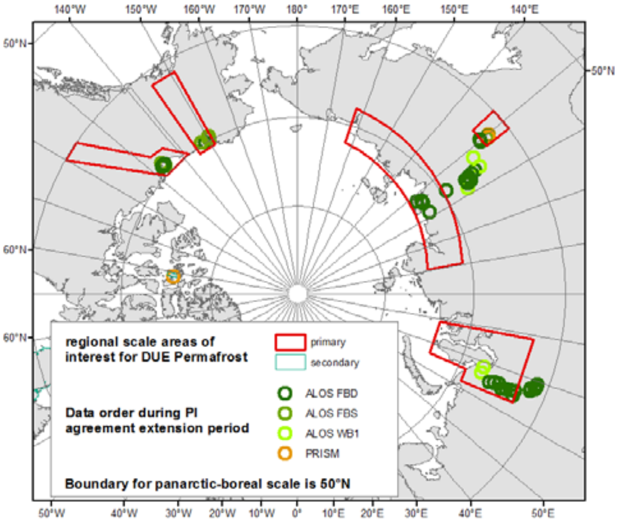

Fig. 8: Overview of ALOS data order during the extension period related to high latitude projects

The ESA DUE Permafrost project establishes a monitoring system on local to pan-boreal/arctic scale based on satellite data. Within this project permafrost relevant remotely sensed products are assessed and eventually provided to users. The circumpolar datasets will be provided weekly to monthly with a spatial resolution of 25 km x 25 km. Selected areas will also be monitored at 1 km x 1 km for snow extent (SE), LST, soil moisture, vegetation and at 75x75m for water surfaces. High resolution satellite data are used at selected local sites for evaluation of the regional and circumpolar datasets. ALOS data have been used in this context.

3.1 SURFACE WATER

A prominent thermokarst feature is the abundance of ponds. Water is a class in all available global and regional land cover maps. The spatial resolution of those existing products ranges between 300m to 1km. The majority of lakes within tundra environment is however much smaller than the spatial resolution of those maps. ENVISAT ASAR Wide Swath (WS) data with 150 m resolution can identify more than 50% more open water surface areas than land over maps based on MODIS (500m) ([10], example from Taymir Peninsula). Additional advantages of ENVISAT ASAR WS data are the frequent data availability, the possibility of straight forward identification of open water surfaces with SAR data and capability of operational pre-processing setup.

Many features and variation are however too small to be captured with ENVISAT ASAR WS. As it is a C-Band system, only open water can be detected. The limitations of WS are assessed using higher spatial resolution optical and SAR data. Analyses have been made using ALOS Palsar in Fine Beam (FB) mode (12.5m). L-band allows penetration through emerging vegetation. A preliminary assessment was made over the Mackenzie Delta, Central Yakutia and the Yamal Peninsula [11,12,13]. 33 % of a test site in the Mackenzie Delta has been classified as water from WS and 44% from Palsar FB. The additional water surfaces constitute mostly of rims around larger lakes (Fig. 6c).

This cross-comparison with ENVISAT ASAR WS is ongoing as part of the DUE Permafrost project as well as the ESA STSE ALANIS Methane project. The latter aims on the retrieval of seasonal inundation patterns in Northern Eurasia for validation and improvement of land-surface models and thus reduce current uncertainties in wetland-related CH4 emissions.

ALOS PALSAR wide beam images have been ordered as level 1.0 in several cases since 1.1 was not available and an own orthorectification was planned. Available software packages (SarScape, Gamma) however do not provide processing tools for this product level. The processing of these datasets remains therefore open.

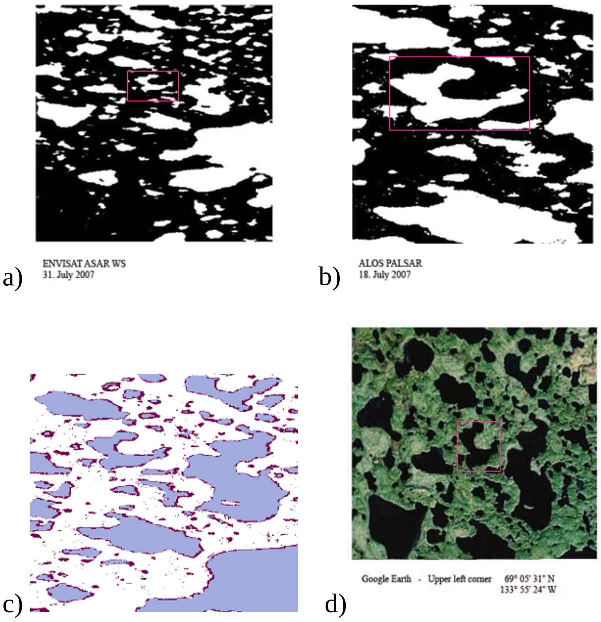

Fig. 9: ENVISAT ASAR WS Analyses over the Mackenzie Delta (Canada); a) ENVISAT ASAR WS lake classification, b) ALOS PALSAR lake classification, c) Overlay of (a-blue) and (b-red), d) Google earth map

3.1 TOPOGRAPHY

Topography is also an important issue in permafrost research. Information on terrain features as well as changes over time due to especially subsidence are required. ALOS PALSAR data can deliver this information via InSAR, what is investigated by DUE Permafrost project partner Gamma RS, Switzerland [14].

Terrain models at higher horizontal resolution can be derived using ALOS PRISM acquisitions. A digital elevation model at selected sites for five areas of interest will be derived. So far two areas have been processed, Polar Bear Pass, Canada and Central Yakutia, Russia. These and the remaining sites will be processed, validated and compared to InSAR results. An additional triplet has been ordered for Austria where high resolution Laser scanner data exist. This will allow the determination of the precision of method chosen to process the PRISM data. ERDAS LPS 2010 is used for orientation of the images and surface point extraction (correlation threshold 50) and opalsGrid (http://www.ipf.tuwien.ac.at/opals /opals_docu/ModuleGrid.html) which is developed at IPF, TU Wien for surface interpolation.

An independent assessment of the PRISM DEMs in arctic locations will be carried out by the Alfred Wegener Institute for Polar Research based on tachymeter surveys.

4. CONCULSIONS

Operational applications in the area of land surface hydrology demand regular acquisitions and continuous near real time availability of datasets. Both is not available with ALOS. Since ALOS PALSAR operates in L-band it does however have the advantage of higher sensitivity to soil moisture changes and can penetrate from water emerging vegetation. It can be therefore used to assess the accuracy of C-band products which are used on regional to continental scale but with different wavelength and spatial resolution such as ENVISAT ASAR.

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European Space Agency

- SHARE – Soil moisture monitoring for hydrometeorological applications in the Southern African Development Community Region (DUE Tiger Innovator project, No 605042) www.ipf.tuwien.ac.at/radar/share
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- STSE ALANIS Methane (ESRIN Contract No. 4200023054/10/I-LG) www.alanis-methane.info

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