ENVISAT ASAR GLOBAL MODE CAPABILITIES FOR GLOBAL MONITORING OF WETLANDS

A. Bartsch[(1)], W. Wagner[(1)], K. Scipal[(1)], C. Pathe[(1)], D. Sabel[(1)], P. Wolski[(2)]

[(1)] *Institute of Photogrammetry and Remote Sensing, Vienna University of Technology Gusshausstraße 27-29, 1040 Vienna, Austria, Email: ab@ipf.tuwien.ac.at*
[(2)] *Harry Oppenheimer Okavango Research Centre, private bag 285, Maun, Botswana*

ABSTRACT

This paper elaborates on recent advances in exploitation of ScanSAR technologies for wetland related research. This comprises monitoring of inundation dynamics as well as time series analyses of surface soil wetness. In case of the ENVISAT ASAR instrument, data availability of the rather coarse Global Mode (GM, 1km) depends on request priorities of other competing modes but acquisition frequency is on average biweekly to monthly depending on latitude. Examples from boreal and subtropical environments show that there is a high application potential of ScanSAR data. Peatland types of the West Siberian Lowlands can be distinguished from each other and other land cover by multi-temporal analyses. The high seasonal and inter-annual dynamics of the Okavango Delta can also be captured by GM time series. In addition, relative soil moisture maps provide a valuable data source in order to account for external hydrological factors of this complex wetland ecosystem.

1. INTRODUCTION

Radar signals are strongly dependent on hydrological conditions in addition to surface roughness and vegetation structure. Thus multi-temporal approaches allow the detection of environmental processes that are important for the functioning of terrestrial biota, in particular inundation dynamics, soil moisture [1] and freeze-thaw changes [2]. Results from a range of microwave sensors have already shown a large potential for hydrological applications. We tested the ScanSAR system ENVISAT ASAR for wetland monitoring in boreal and subtropic environments. A processing chain has been developed for ENVISAT ASAR which allows the analyses of global mode (1km) as well as wide swath (150m) mode data over large regions. The suitability of global mode with 1km spatial resolution has been of specific interest due to its frequent and global coverage.

2. ENVISAT ASAR DATA AND PROCESSING

ENVISAT has been 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. It provides radar data in different modes with varying spatial and temporal resolution and alternating polarisation at C-Band (~5.6 cm wavelength). The following case studies utilise ASAR data acquired in Global Monitoring (GM) mode. GM data for our studies are available in C-HH polarization with 1km resolution.

ENVISAT ASAR Image and Wide Swath modes are acquired on request. GM mode serves as backup mode if no other is ordered. The image data provided represent swaths with 405 km width [3]. For further processing these data require georeferencing with respect to earth curvature and terrain [4]. Digital elevation data of sufficient resolution are only available below 60°N from the Shuttle Radar Topography Mission (SRTM, 100 m x 100 m). Since wetlands occupy mostly flat regions and the terrain in the study area is moderate in higher latitudes the GTOPO30 (USGS) based correction, however, is sufficient. Within the normalization step the effects on the backscatter due to varying incidence angel and distance from sensor (near and far range) are removed [5,6].

3. GLOBAL MODE COVERAGE

Whereas ASAR WS data are suitable for wetland analyses on regional scale [7], GM offers a much wider perspective. Coverage varies due to acquisition mode priorities and latitude. Frequency is highest at northern latitudes and over Antarctica. Especially Europe and northern Africa have low GM coverage due to high demand for other modes (Fig. 1). Average numbers for different wetland types have been derived using the Global Lakes and Wetland Database (GLWD, [8], Tab. 1).

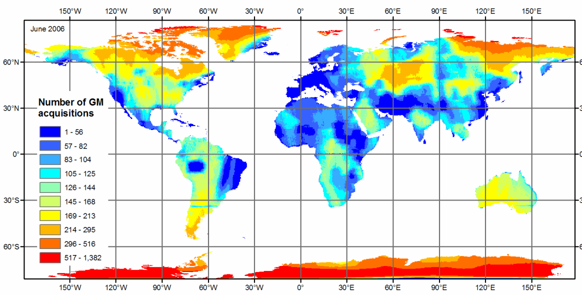

Figure 1. ENVISAT ASAR GM coverage December 2004 – June 2006

Proc. 'GlobWetland: Looking at Wetlands from Space', Frascati, Italy, 19–20 October 2006 (ESA SP-634, November 2006)

ID	Wetland type	Mean	STD
1	peatland	191	58
2	50-100%	172	52
3	25-50%	161	47
4	freshwater marsh, floodplain	135	58
5	intermittent	116	52
6	pan, brackish/saline	112	51
7	swamp	98	43
8	coastal	94	72
9	complex (0-25%)	80	25

Table 1. Number of acquisitions by wetland type for December 2004 to June 2006 (source: Global lakes and wetland database [8])

Data from northern peatlands (ID 1 for Asia and 2 for North America in Table 1), however, have been acquired weekly on average during the first 18 months (starting December 2004). Biweekly to monthly intervals are available for subtropical floodplains. Both estimates depend on size and acquisition mode priorities. Coverage on pixel level even exceeds these estimates, adding up to two per week in high latitudes and weekly intervals in the subtropics.

4. EXAMPLE 1: BOREAL PEATLANDS

Both wide swath and global mode have been used for the derivation of boreal peatlands in central Siberia [7]. ASAR WS data for central Siberia are available for this study for summer 2003 and GM for summer 2005 and 2006. Wide swath data have been analysed within the framework of the Siberia II project [9]. A validation of the GM classification results is carried out by use of the West Siberian Lowland (WSL) database [10] which has been complied using topographic maps.

4.1. Study site

The initially investigated peatlands are located at approximately 60° N west of the Yenisei river and at the eastern rim of the West Siberian peat basin [7]. Although it is located fairly south it still features sporadic permafrost [11]. The study site is located west of the Yenisey river. Open bogs are an important landcover type in this region albeit not dominating. These peatbogs are characteristic of the eastern portion of Western Siberia [12]. They are important for discharge, geochemistry and sedimentology of the Yenisey river [13]. The mapping approach was then applied to the southern part of the West Siberian peat basin which stretches from approximately 60° to 90° E and 56° to 64° N. The area of interest within this boundary covers ca. 1 Mio km². All peatland within the West Siberian Lowlands are estimated to cover 600.000 km² and thus contribute a considerable share to the global terrestrial carbon pool [10]. This also includes the region north from the chosen study area. The Ob River flows through that region from SE to NW.

4.2. Open peatlands

Within the previous study [7] it could be shown that ASAR WS data are suitable for mapping of open peatlands in the boreal environment. Although that GM data have a much coarser resolution it is expected that they perform well over large peatland areas. A direct comparison between GM and WS, however, is not possible since they cannot be acquired at the same time. At the initial test site, autumn data have been found most suitable for detection of all peatland types when using ASAR wide swath data. Such data have only been available for the year 2003. Since GM data distribution started after December 2004, the earliest possible summer and autumn season that can be investigated is 2005. Fig. 2 shows a comparison between the ASAR WS results from 2003 and the classification result for GM autumn data in 2005.

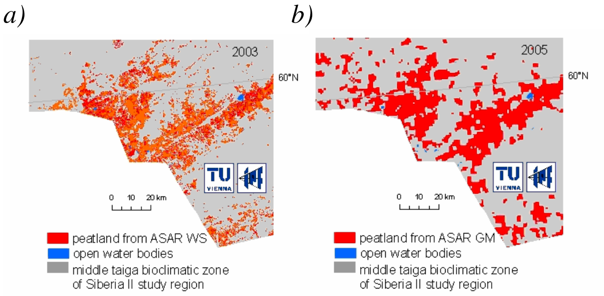

Figure 2. Peatland classification results: a) ASAR WS data from 2003, 150 m resolution, b) ASAR GM data from 2005, 1 km resolution.

There are discrepancies introduced by scale differences and possible intra-annual variations in surface soil wetness. With a suitable temporal resolution these changes in relative surface soil wetness could be monitored with ASAR GM data. A data base was established which comprises all available GM data for June – September 2005 and 2006. The for wide swath data developed threshold based classification method was applied to this data set for the mapping of peatland extent. GM coverage varied from 0 to 46 in 2005 and 11 to 45 in 2006 (Fig. 3). This variation over the area of interest needs to be considered for the classification. Thresholds have been determined with the use of the West Siberien Lowland database [10]. All regions with high summer and autumn backscatter (> -3.5 dB) in more than 20% of available acquisitions are classified as peatland.

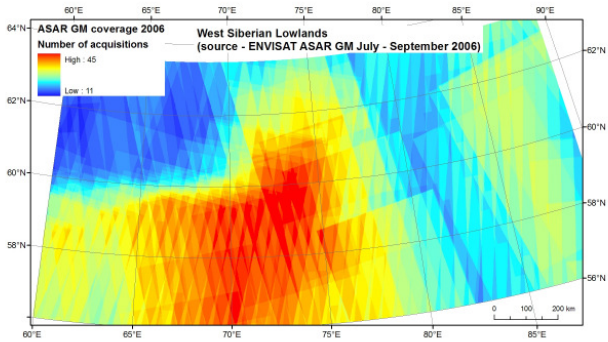

Figure 3. ASAR Global Mode coverage 2006 for southern part of West Siberian Lowlands

A comparison with the WSL database [10] shows that oligotrophic to mixed peatlands with an approximate minimum carbon density of 150 kgC/m² can be identified with the used method. Such high densitiy values can be found south of the Ob River. Peatlands cannot be distinguished from other land cover to the north, between 70-77E (Fig. 4), where carbon density is lower than 100 kgC/m². This is a permafrost transition area [11] with a large number of lakes, which can only be monitored using the ASAR GM data starting from a size of 2km² depending on their shape. Smaller lakes, which are abundant in this region, contribute to the backscatter signal in such way, that these peatlands cannot be distinguished from surrounding forests and other land cover with the used method (Fig. 4).

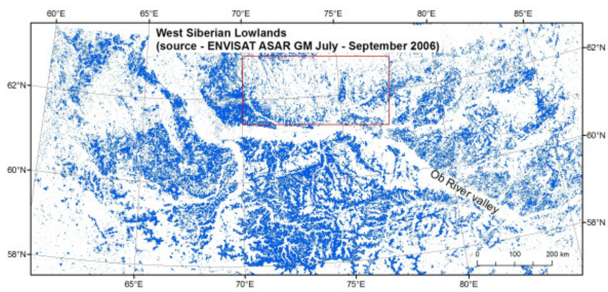

Figure 4. ASAR Global Mode 2006 classification result: open peatlands. Red rectangle indicates region where peatlands could not be identified due to abundance of small lakes below GM resolution.

In this case a further step is necessary during which inter-seasonal backscatter behavior is analysed. Data representing the late winter and spring period (April to June) have been added to the database. The entire timeseries of normalized backscatter for different landcover types is shown in Fig. 5. Open peatlands as found south of the Ob River are characterized by on average -8 dB during winter. Values increase to more than -4 dB within approximately three weeks after snowmelt. Surrounding forest has higher backscatter in winter ranging between -6 and -7 dB. During snowmelt values drop to -10 dB and rise afterwards to on average -5 dB. Peatlands with a high amount of open water surfaces below GM resolution have comparably low backscatter values during winter (-10 dB) and show similar mean values like forest during the summer although variation is higher and it does not result from volume scattering but from a mixture of high surface soil moisture and specular reflection from the water surface. After start of snowmelt backscatter stays low for about a month until the snow cover disappears and melt water has drained. With global mode data, this delay in backscatter increase can be determined and may also be used for discrimination of this wetland type from other peatland.

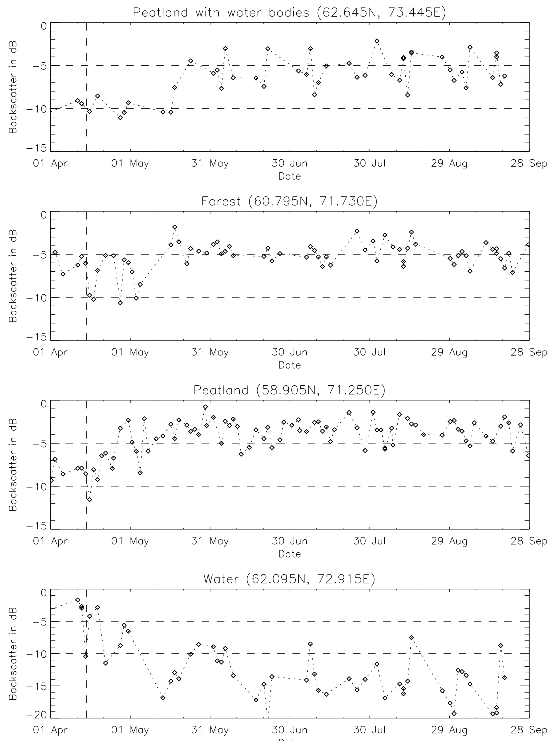

Figure 5. Normalized backscatter time series for peatland with small ponds, forest, peatland without ponds and open water from spring and summer 2006. Begin of snowmelt is indicated by vertical dashed line for comparability.

5. EXAMPLE 2: SUBTROPICAL FLOODPLAIN

A time series including all GM data available since December 2004 has been established for the semiarid, subtropic Okavango delta. When looking at the entire floodplain each time (200 km x 200 km) it can be investigated in approximately monthly intervals [14]. This restricts the wetland mapping but extents and complements previous analyses which have so far been carried out using optical satellite data [15]. Single points on the other hand are covered at least once a week, what forms a good base for monitoring of relative soil moisture patterns.

5.1. Study site

The region of the Okavango delta is semi-arid with evaporation four times higher than rainfall [16]. The dynamics within the delta especially the flooding extent depend on internal as well as external factors [15, 17]. The wetland area varies at decadal, multi-decadal and millennial time scales, in response to variation in regional climate. 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 as wetland identified area covers almost 10.000 km² at present.

5.2. Wet area extent

As precipitation amounts of the 2006 rain season exceeded the previous year, the extent of inundation and saturated soil conditions already reached the maximum inundation extent of September 2005 in June 2006 which corresponds in both cases to 60% of the entire Okavango delta (Fig.6).

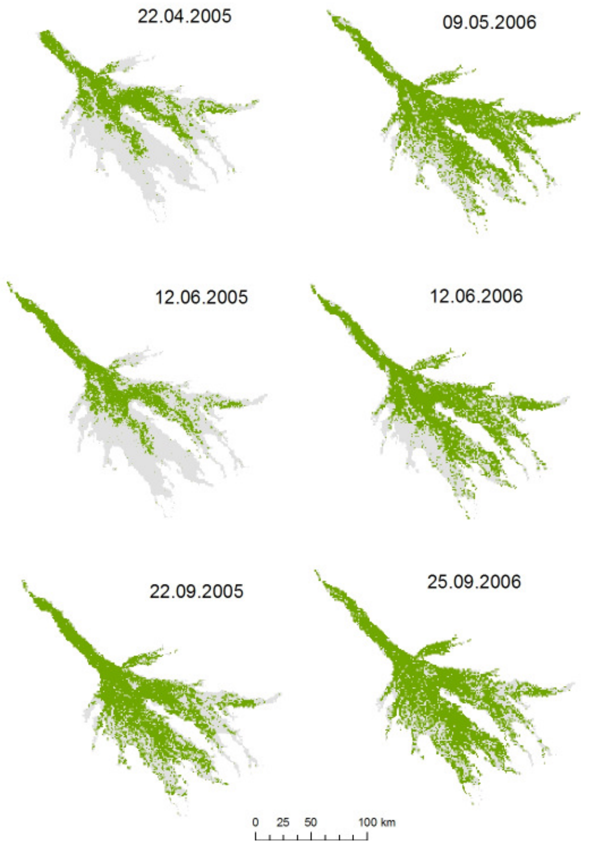

Figure 6. Comparsion of ASAR GM derived wet area 2005 and 2006 : a) April – end of rain season, b) June – dry season and c) September – maximum inundation extent

Only two third, however, cover the same area due to complex interactions of internal and external parameters. The rain induced wet area of 2006 covers much of the eastern branch. The inundation due to flood propagation in September 2005 as well as 2006 was more concentrated in the western part of the delta. 40% of the entire designated wetland area was inundated or characterized by high surface soil moisture during maximum flood extension in both years. In the end of September 2006 70% was determined as wet area. This corresponds to a 10% increase within 3 months for the 2006 dry season compared to a 27% increase in 2005 for the same time period. Beside the increase, the characteristic shift of wet area does occur from June to September in 2006. Some locations in the eastern branch fall dry, whereas the western branch benefits from flood propagation. This pattern was similar in 2005 but additional wet area can be detected at the most southern tips in 2006. Some differences may also occur due to the fact that the exact date of maximum flood extent cannot be determined and/or covered with the available dataset.

5.3. Soil moisture - an outlook

Beside monitoring the Okavango delta itself it would be of large value to monitor the upper catchment concerning soil moisture. It has been shown in previous analyses for the Zambesi River [18], that even coarse resolution scatterometer derived soil moisture time series relate well with river discharge measurements in subtropic environments. An incorporation of a spatially improved soil moisture product from the upper catchment of the Okavango may improve prediction models for the wetland region.

ASAR GM data are investigated within SHARE (www.ipf.tuwien.ac.at/radar/share/), which 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).

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. A study based on 32 ERS SAR images (C-band) acquired over the Orgeval watershed in France [13] developed a methodology for retrieving soil moisture. The results 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 chosen 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 rseasonal 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 seasonal 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.

6. SUMMARY

ENVISAT ASAR global mode coverage is highly variable but could allow at minimum weekly observations for single points. The lack of data over large areas such as entire western Europe impedes global mapping capabilities. A processing chain has been established which has been tested on subcontinental scale (Southern Africa) but would also aloow the processing of ASAR GM at global scale for wetland and soil moisture monitoring. The two case studies show that although ASAR Global Mode data feature only 1km resolution it is capable of capturing not only extent but also monitoring dynamics of wetland areas. Relative soil moisture maps at 1km resolution may enhance and complement existing coarse scale products.

7. ACKNOWLEDGMENTS

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