Global monitoring of wetlands – the value of ENVISAT ASAR global mode

A. Bartsch[a],*, W. Wagner[a], K. Scipal[a,b], C. Pathe[a], D. Sabel[a], P. Wolski[c]

[a] Institute of Photogrammetry and Remote Sensing, Vienna University of Technology
Gusshausstraße 27-29, 1040 Vienna, Austria

[b] European Centre for Medium Range Weather Forecast, Shinfield Park, RG2 9AX
Reading, UK

[c] Harry Oppenheimer Okavango Research Centre, private bag 285, Maun, Botswana

* Corresponding author. Tel.: +43 1 58801 12221, Fax: +43 1 58801 12299, email:
ab@ipf.tuwien.ac.at (A. Bartsch)

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Abstract

This paper elaborates on recent advances in exploitation of ScanSAR technologies for wetland related research. Applications of such active satellite radar systems comprise monitoring of inundation dynamics as well as time series analyses of surface soil wetness. Wetlands need to be monitored for short and long-term management in especially dry regions. Another aspect is the impact of climate change in permafrost transition zones where peatland forms one of the major land cover types. Therefore examples from boreal and subtropical environments are presented. The analyzed ENVISAT ASAR Global Mode (GM, 1 km resolution) data were acquired in 2005 and 2006. In case of the ENVISAT ASAR instrument, data availability of the rather coarse Global Mode depends on request priorities of other competing modes but acquisition frequency may still be on average fortnightly to monthly depending on latitude. Peatland types covering varying permafrost regimes of the West Siberian Lowlands can be distinguished from each other and other land cover by multi-temporal analyses. Up to 75 % of oligotrophic bogs can be identified in the seasonal permafrost zone in both years. The high seasonal and inter-annual dynamics of the subtropic Okavango Delta can also be captured by GM time series. Response to increased precipitation in 2006 differs from flood propagation patterns. In addition, relative soil moisture maps may provide a valuable data source in order to account for external hydrological factors of such complex wetland ecosystem.

Keywords: wetland, peatland, satellite radar, time series, inundation, soil moisture

1. Introduction

Specific mechanisms of water supply and storage are essential for wetland maintenance. Any change, directly by e.g. water abstraction or indirectly through climate variation, does considerably impact wetland ecosystems. Disturbances impede their role as natural habitats, anthroposphere and alter greenhouse gas cycling. In addition, marginal wetlands – shallow lakes and streams that undergo seasonal drying – are major sources of atmospheric mineral dust. The extent and properties of wetlands are quite variable in space and time. Wetland areas - in particular temporal dynamics of wetlands – are a lacking key information on global scale. In recent years, active radar (microwave) remote sensing has been proven a useful technique in monitoring components of the hydrosphere and yields a high application potential (e.g. Oldak et al., 2003; Alvarez-Mozos et al., 2005; Frappart et al., 2005; Wagner et al., 2007). Employed satellite sensors can be grouped into SAR, ScanSAR and scatterometer systems. SARs have good spatial sampling characteristics (e.g. ERS with 25m) but the lowest temporal sampling (≈ monthly). Regarding wetlands, they are mainly applied for inundation mapping. Scatterometer on the other hand can provide even several measurements per day depending on latitude. The footprint, however, is in the range of several tens of kilometers. These data are used for global derivation of relative soil moisture (Wagner et al., 2003). ScanSAR systems are characterized by a sampling in between SARs and scatterometers. It is proposed that they are suitable for both inundation and soil moisture mapping. The ENVISAT ASAR is such a ScanSAR system. In Global Mode (GM) several images per week can be acquired with varying incidence angle and 1 km resolution (500 m pixel spacing).

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 (Wagner et al., 2007) and freeze-thaw changes (Bartsch et al., 2007).

The objective of this paper is to discuss the capabilities of medium resolution satellite microwave data for global monitoring. The major advantage of these data are the comparably short revisit intervals. The global availability is analyzed under the viewpoint of wetland types and distribution. The parameters which can be derived are inundation extent and duration and potentially also relative soil moisture. This study concentrates on the former two parameters. Two examples are shown which represent different wetland types and environments. Both subtropic and subarctic regions are environments which are highly sensitive to climate change. The subtropical Okavango Delta is a wetland with pronounced seasonal dynamics. The boreal peatlands of the West Siberian Lowlands are characterized by permafrost features and seasonal snowmelt patterns. Advantages and disadvantages of ENVISAT ASAR GM data are discussed for the two selected sites.

2. Data and processing

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. It provides radar data in different modes with varying spatial and temporal resolution and alternating polarization at C-Band (~5.6 cm wavelength). The following case studies utilize 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 (Desnos et al., 2000). For further processing these data require georeferencing with respect to earth curvature and terrain (Meier et al., 1993). Digital elevation data of sufficient resolution are only available below 60°N from the Shuttle Radar Topography Mission (SRTM, 100 m x 100 m, USGS). 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 angle and distance from sensor (near and far range) are removed (Roth et al., 1993; van Zyl et al., 1993). The resulting backscatter images show the backscatter coefficient at the reference angle of 30 degree expressed in decibels. A processing chain has been developed for ENVISAT

ASAR which allows the analyses of GM (1km) as well as Wide Swath (WS, 150m) mode data over large regions (Bartsch et al., 2004).

Whereas ASAR WS data are suitable for wetland analyses on regional scale (Bartsch et al., in press), GM offers a much wider perspective. Coverage varies due to acquisition mode priorities and latitude. Frequency is highest at northern latitudes and over Antarctica. Europe and northern Africa have low GM coverage due to high demand for other modes (Figure 1). Average numbers for different wetland types have been derived using the Global Lakes and Wetland Database (GLWD; Lehner and Döll, 2004, Tab. 1).

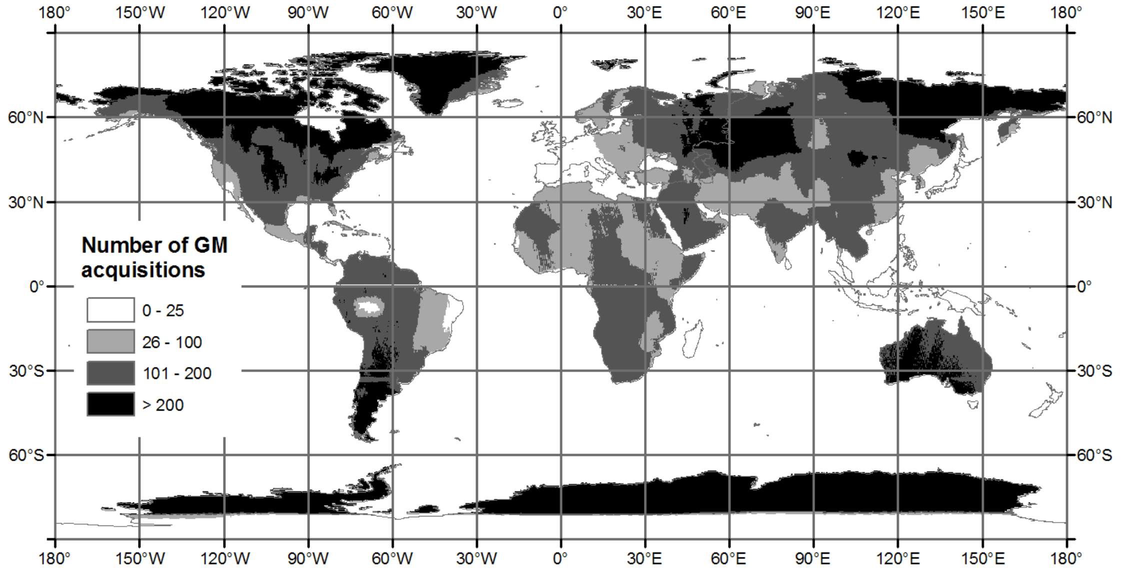

Figure 1. ENVISAT ASAR GM coverage December 2004 – October 2006

Table 1. Number of acquisitions by wetland type for December 2004 to October 2006 (source: Global lakes and wetland database, Lehner and Döll, 2004)

ID	Wetland type	Mean	STD
1	peatland	231	75
2	50-100%	224	58
3	25-50%	200	62
4	freshwater marsh, floodplain	163	67
5	intermittent	146	66
6	pan, brackish/saline	138	58
7	swamp	122	52
8	coastal	129	91
9	complex (0-25%)	99	27

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 22 months (starting December 2004). Fortnightly 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.

3. Example 1: Boreal peatlands

Both wide swath and global mode have been used for the derivation of boreal peatlands in central Siberia (Bartsch et al., in press). ASAR WS data for central Siberia are available for this study for summer 2003 and GM for summer 2005 and 2006. The Wide swath data have been analyzed within the framework of the Siberia II project (Schmullius et al., 2003). The mapping approach is transferred to the West Siberian Lowlands for ASAR GM. A validation of the GM classification results is carried out by use of the West Siberian Lowland (WSL) database (Sheng et al., 2004) which has been complied using topographic maps.

3.1. Study site

The initially investigated peatlands are located at approximately 60° N at the eastern rim of the West Siberian peat basin (Bartsch et al., in press). Although it is located at relatively low latitudes it still features sporadic permafrost (Stolbovoi and McCallum, 2002). The study site is located west of the Yenisey River. Open bogs are an important land cover type in this region albeit not dominating. These peat bogs are characteristic of the eastern portion of Western Siberia (Botch and Masing, 1983). They are important for discharge, geochemistry and sedimentology of the Yenisey River (Kremenetsky et al., 2003). 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 (Sheng et al., 2004). This also includes the region north of the chosen study area. The Ob River flows through this region from SE to NW.

3.2. Open peatlands

The previous study (Bartsch et al., in press) showed that ASAR WS data are suitable for mapping of open peatland 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 images, 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 WS data. Such data were only 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. Figure 2 shows a comparison between the ASAR WS results from 2003 and the classification result for GM data in 2005.

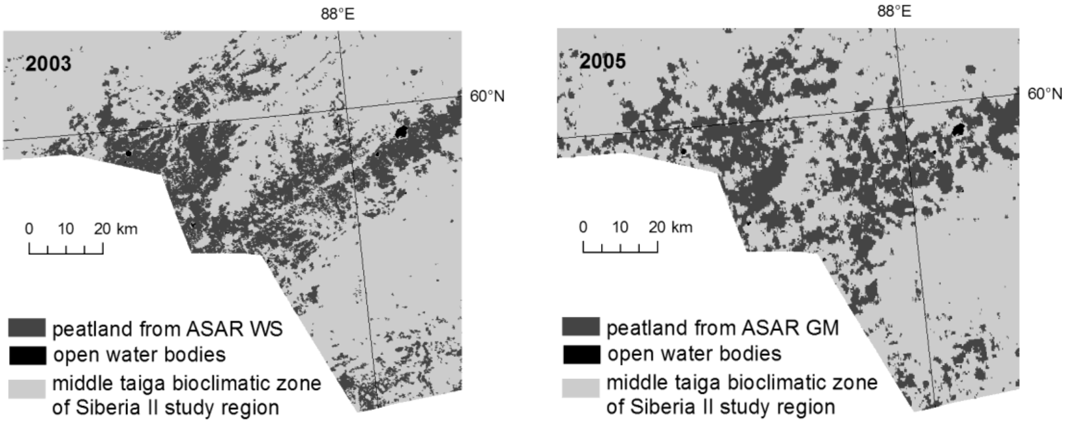

Figure 2. Peatland classification results: a) ASAR WS data from 2003, 150 m resolution, b) ASAR GM data from 2005, 1 km resolution. Area of interest is limited by administrative boundary of Krasnoyarsk Kray (part of Siberia II study region, Bartsch et al., in press).

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 threshold based classification developed for WS data 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 (Figure 3). This variation over the area of interest needs to be considered for the classification. Specific thresholds have been determined with the use of the West Siberian Lowland database (Sheng et al., 2004). All regions with high summer and autumn backscatter (> -3.5 dB) in more than 20% of available acquisitions are classified as peatland.

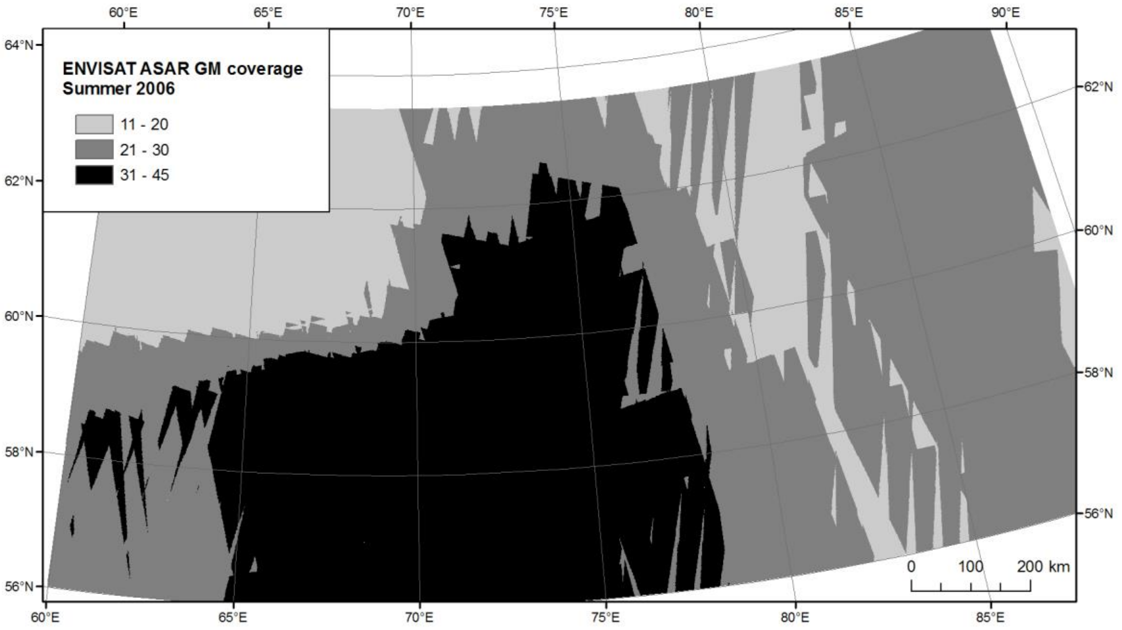

Figure 3. ASAR Global Mode coverage 2006 for southern part of West Siberian Lowlands

A comparison with the WSL database (Sheng et al., 2004) shows that oligotrophic to mixed peatlands with an approximate minimum carbon density of 150 kgC/m² can be identified with the method. Such high density values can be found south of the Ob River. Peatlands cannot be distinguished from other land cover to the north, between 70-77E (Figure 4, northern area), where carbon density is lower than 100 kgC/m². This is a permafrost transition area (Stolbovoi and McCallum, 2002) 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 (Figure 4, northern area). In comparison with the peatland map by Sheng et al. (2004) only 8 % can be identified in 2005 and 18% in 2006. In the southern area with seasonal permafrost about 76 % of the extent (mainly oligotropic peatland) can be determined correctly (Table 2).

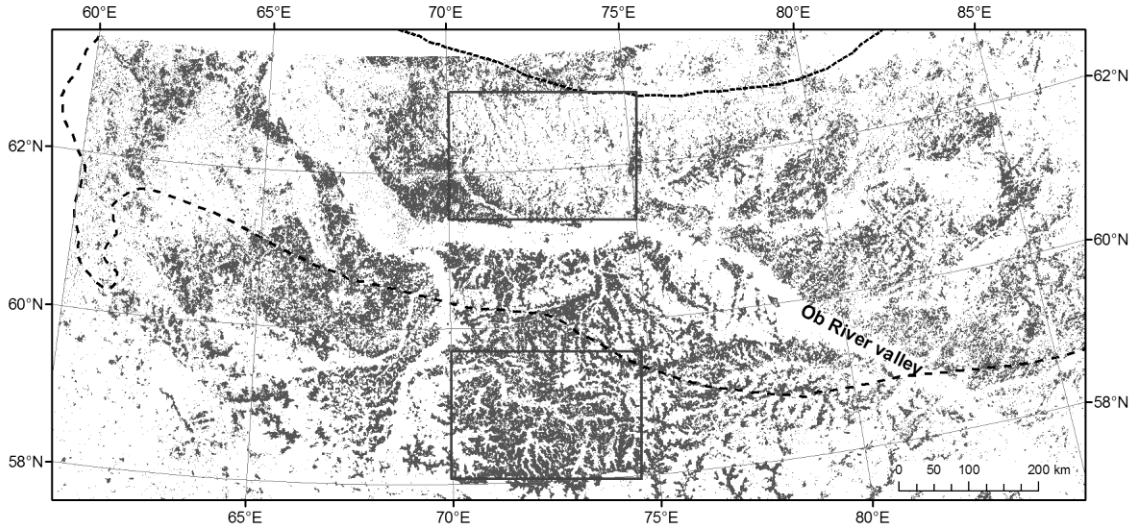

Figure 4. ASAR Global Mode 2006 classification result: open peatlands. Rectangles indicate northern and southern area of interest. Area south of long dashes – seasonal permafrost, area between long and short dashed lines – 25-50% frozen ground and area to the north has up to 75 % permafrost (source: Stolbovoi and McCallum, 2002).

Table 2: Comparison of GM classification results (2005 and 2006) with peatland map by Sheng et al. (2004) for the northern and southern areas of interest (for location see Figure 4). Partition of peatland types of all land cover and percentage of peatland types correctly identified. Overall classification results and percentage of false peatland.

	Northern site			Southern site		
Peatland type	Proportion of land cover	Identified as peat		Proportion of land cover	Identified as peat	
		2005	2006		2005	2006
Oligotrophic	41	6	14	32	76	77
Transitional	7	10	25	2	74	70
Eutrophic	1	17	30	1	68	75
Mixed	6	13	33	13	71	74
All types	55	8	18	48	74	76
Non-peatland	45	5	16	52	13	17

In this case a further step is necessary during which inter-seasonal backscatter behavior is analyzed. Data representing the late winter and spring period (April to June) have been added to the database. The entire time series of normalized backscatter for different land cover types is shown in Figure 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.

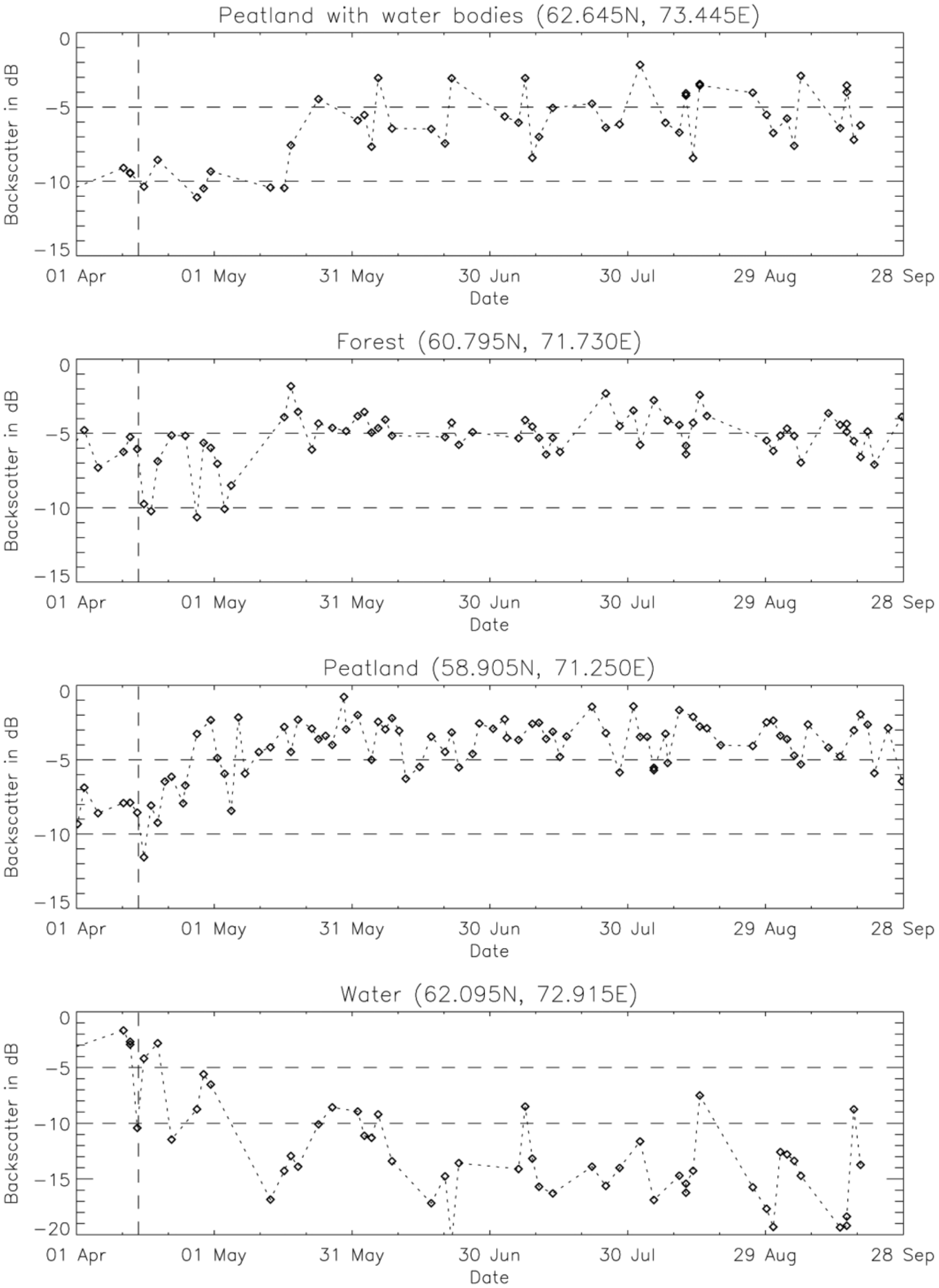

Figure 5. Normalized backscatter time series for peatland with small ponds, forest, peatland without ponds and open water from spring and summer 2006. Begin of snowmelt is indicated by vertical dashed line for comparability.

4. Example 2: Subtropical floodplain

A time series including all GM data available since December 2004 has been established for the semiarid, subtropical Okavango Delta. Due to the large size of the wetland (12 000 km^2), its entire area is covered by GM images only at approximately monthly interval (Bartsch et al., 2006). This limits the application of the radar images for detailed system-wide studies, however, extents and complements previous flood dynamics analyses which have so far been carried out using optical satellite data (Gumbricht et al., 2004; Wolski and Murray-Hudson, 2006). On the other hand, parts of the system are covered at least once a week, which forms a good base for monitoring relative soil moisture patterns.

4.1. Study site

The region of the Okavango Delta is semi-arid with rainfall of 460 mm/year and evaporation four times higher (Ringrose et al., 2005). The wetland is strongly flood-pulsed, with a single annual flood event caused by inflow of the Okavango River originating in the high rainfall zone of central Angola, and to a lesser extent by local rainfall. Due to slow propagation of the flood wave, inundation in the Delta achieves it maximum in September, 5-6 months after the end of rainy season. The dynamics of flooding within the Okavango Delta depend on internal as well as external factors (Gumbricht et al., 2004; Wolski and Savenije, 2006). The wetland area varies at decadal, multi-decadal and millennial time scales, in response to variation in regional climate (McCarthy et al., 2000). Additionally, aggradation and tectonic processes cause episodic and gradual changes in distribution of inundation within the Delta occurring at various time scales (Wolski and Murray-Hudson, 2006a). Monitoring of flood size and distribution is therefore a necessary prerequisite for short and long term management of the wetland.

4.2. Wet area extent

Total of local precipitation of the 2006 rainy season (720 mm) exceeded that of the previous year (380 mm). The extent of inundated and saturated soil at the end of rainy season was therefore larger in 2006 than in 2005. In June 2006 it was 7060 km^2, which is comparable with the maximum wetland extent observed in 2005 (7090 km^2, Fig.6). Since the 2006 inflow to the system was relatively low, the maximum inundation and wet area extent of 2006 reached approximately 8200 km^2. This corresponds to a 10% increase within three months for the 2006 dry season compared to a 27% increase in 2005 for the same time period. In the end of September 2006 70% was determined as wet area. The overlap of inundated and high surface soil moisture area in September of the two consecutive years was 40%.

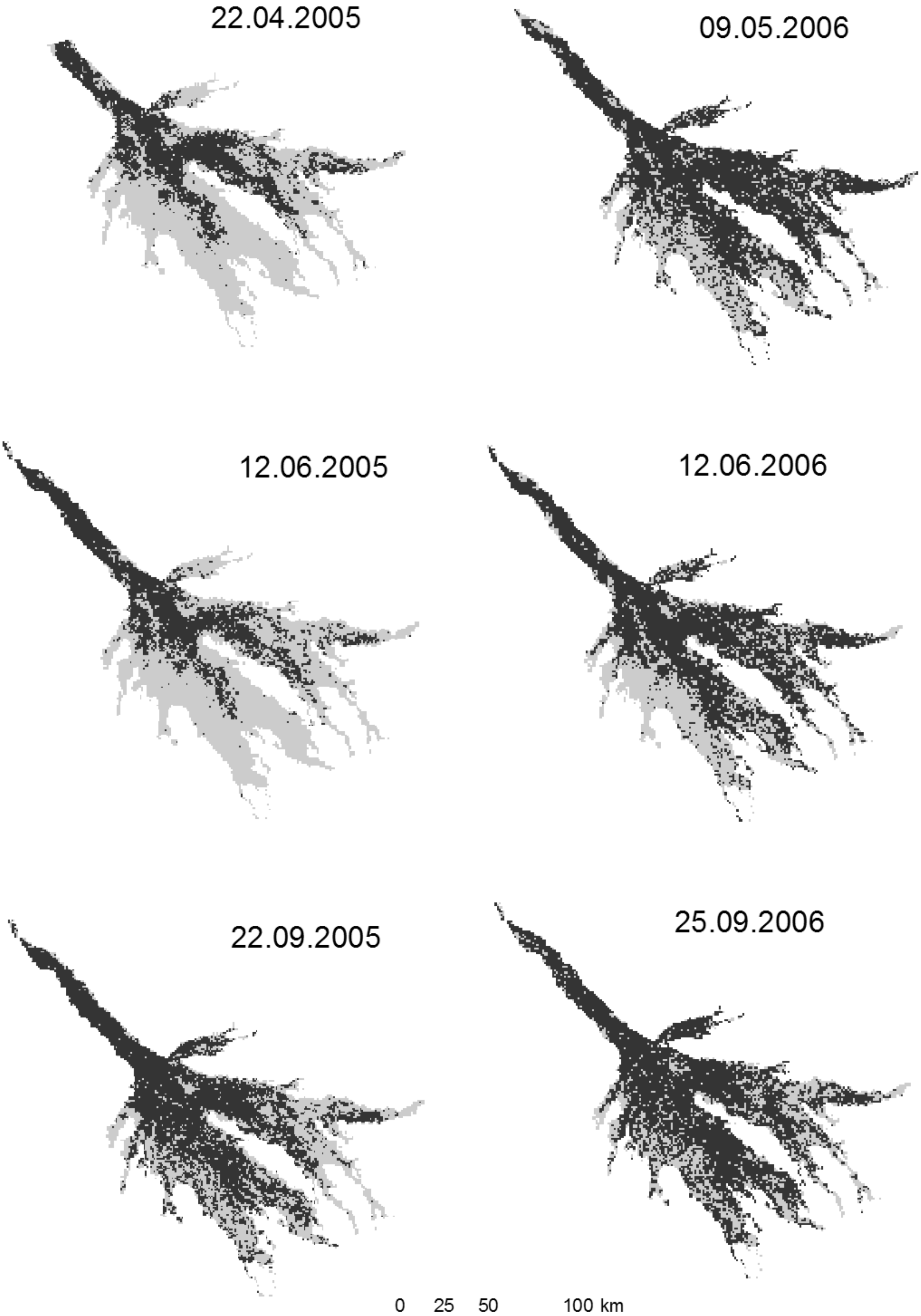

Figure 6. Comparison of ASAR GM derived wet area 2005 and 2006 : a) April – end of rain season, b) June – dry season and c) September – maximum inundation extent

Complex interactions of internal and external parameters cause that the distribution of inundation is different between the two analyzed years. The flood in the eastern branch is known to be triggered by the local rainfall (Wolski and Murray-Hudson, 2006b). Thus, the inundation is more extensive there at the end of the wet season in 2006 than in 2005. The effects of the Okavango River flood pulse are not strongly accentuated, thus the inundation there does not expand towards September, but remains stable, or even reduces slightly. The western part, in turn, responds strongly to the flood pulse of Okavango River, and much less to local rainfall. Thus, there is a strong increase in inundated area between April and September in both years.

5. Discussion

ENVISAT ASAR GM coverage is highly variable but could allow at minimum weekly observations at single points. The lack of data over large areas such as Western Europe impedes global monitoring capabilities. Additionally, the size of the area of interest is important for the sampling interval at which the entire area can be covered. Despite of these limitations, GM data can be used to map some peatland types and to monitor dynamics at a monthly basis for areas of up to 200 x 200 km size.

Apart from data coverage, the size of investigated objects influences monitoring capabilities. High numbers of small lakes below GM resolution do not allow a straight forward identification (threshold method) of boreal peatland. By use of the high temporal sampling rate of less than a week a time series analyses can be carried out and thus specific characteristics during the snow melt period determined.

Inundated area with emergent vegetation can be confused with high soil moisture land area. This restricts the comparability to other fine resolution maps from e.g. optical satellite sensors. In comparison to such data, radar images allow to identify the real extent of the wet due to its sensibility to near surface soil moisture.
The irregular timing of acquisitions prohibits the provision of a regular time series. Some differences in the intra-annual comparison for the Okavango Delta for example may occur due to the fact that the exact date of maximum flood extent cannot be determined and/or covered with the available dataset.

Apart from 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 (Scipal et al., 2005), that even coarse resolution scatterometer derived soil moisture time series relate well with river discharge measurements in subtropic environments. Regular measurements of global soil moisture are available from scatterometer data (Wagner et al., 2003) at 25-50 km resolution. The retrieval approach relies on high temporal sampling. Since ENVISAT ASAR GM features a comparably high sampling rate it could similarly be used for derivation of relative soil moisture maps with 1 km resolution. Estimates from fewer ScanSAR measurements may be possible by combination with optical satellite data as demonstrated by Yang et al. (2006) for Radarsat. An incorporation of a spatially improved soil moisture product from the upper catchment of the Okavango may for example improve prediction models for the wetland region. Additionally, the size of GM data is lower than any high resolution product and thus makes operational processing feasible on global scale.

6. Conclusions

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. Data availability is restricted for especially Europe but is sufficient for most boreal and also subtropic environments which are susceptible to climate change and thus demand regular monitoring. Relative soil moisture maps at 1 km resolution from C-band ScanSAR systems may enhance and complement existing coarse scale products.

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