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Seasonal variability of the Western Siberia wetlands from satellite radar altimetry

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SUMMARY

Boreal wetlands play an important role in the global water and carbon cycle but their water regime is far from being well understood. The aim of this paper is to study wetland hydrological regime over the 21 mid-size watersheds of the Western Siberia – one of the most bogged regions of the world. By using ENVISAT RA-2 radar altimetry data we analyze seasonal variability of wet zones extent, water level and storage in wetlands. We have identified three main types of wetland water regime characterized by: (1) spring inundation and following deep drainage with/without secondary peak in autumn; (2) spring inundation and low summer variation; (3) spring inundation with medium summer drainage and second autumnal peak. Our estimates show that the floodplain inundation contributes less than 8% to the total wet zones extent. Analysis of the timing of melt and freeze onset and other specific phases of hydrological regime has been done. It was found that the spring inundation lasts for almost 2 months with a latitudinal gradient of melt onset of 8 days/2°. No considerable latitudinal gradient has been found for dates of full freeze onset. Our results show that seasonal amplitude of water level variation for northern part of Western Siberia from altimetry is 0.7–1.5 m for lakes and 0.2–0.5 m for bogs. This represents seasonal variation of wetland water storage of 480 mm for non-permafrost and 130 mm for permafrost-affected zones.

0. Introduction

Boreal wetlands play an important role in the global water and carbon cycle. The Western Siberian plain is one of the most bogged regions of the world – in some parts up to 70–80% of its territory is covered by bogs, in overall 1 million km^2. In this region modern climate conditions (excess of precipitation over evaporation, short and cold summers) and specific geomorphology (flat relief, low slopes, presence of permafrost in the northern part) favor the formation of a multitude of interconnected natural objects – large and small rivers and streams, extensive floodplains, lakes and, especially peat-producing wetlands. The presence of large flooded areas, lakes and wetlands results in a rate of evaporation higher than for any other large boreal regions (Sokolov, 1952). These natural objects temporarily store water after the spring snowmelt, and then gradually release this water in summer. So, due to higher evaporation and water storage wetlands significantly influence river discharge regime through attenuation of flood peaks and prolongation of flood time.

With about 40% of the world pristine peatlands located there, Western Siberia plays an important role in the global cycle of carbon. In the southern part, peatlands act as a terrestrial sink of atmospheric carbon through photosynthesis and carbon accumulation in peat deposits, while in the northern permafrost-affected regions peatlands represent a source of methane emission to the atmosphere. As the role of emission depends on wetness conditions of peatlands, knowledge of wetland hydrological regime is important to understand the water and carbon cycle in this vast region.

Existing historical Soviet (Vodogretskiy, 1973; Ivanov and Novikov, 1976) and global (Lehner and Doll, 2004) data provide estimations of wetland and lake extent over the different watersheds of the Western Siberia. These data are based on the cartographic analysis of maps and represent static minimal values, without account of seasonal or interannual variability of wetland extent. *In situ* observations on wetland extent are difficult to realize and thus they are not part of regular observations done at

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the meteorological or hydrological stations. In this context an evident choice is the use of satellite observations, especially in the microwave range (not affected by the presence of cloud cover).

Satellite observations in the microwave range provide reliable, regular and weather-independent data on surface properties. One way to estimate the presence of water on land is to analyze the backscatter coefficient from active microwave instruments (such as SAR, scatterometer, and radar altimeter). The backscatter coefficient is the ratio between the power reflected from the surface and the incident power emitted by the onboard radar, expressed in decibels (dB), and this parameter is very useful to discriminate wet or flooded areas from the land.

Side-looking radars and scatterometers have been successfully used for studies of soil wetness (Pathe et al., 2009) and open water identification. Papa et al. (2007) have used a multisatellite method, based on a combination of passive microwave data (SSM/I), ERS-1 scatterometer and AVHRR NDVI to estimate pixel fractional coverage of open water at the 0.25° resolution at the Equator (773 km^2 pixel size). They have estimated spatial and temporal variations over the Ob' River with monthly resolution for 1993–2000. Bartsch et al. (2007a) have used ENVISAT ASAR in global mode to identify and create the static mask of boreal peatlands in the Western Siberia. They have also used QuickScat scatterometer data to analyze spatial and temporal variability of spring freeze/thaw cycles for the Central Siberia (Bartsch et al., 2007b).

Another promising source of active microwave data are observations from the radar altimeters. Due to nadir-looking capabilities they are much more sensitive to variations in the surface type than the side-looking instruments, because surface echo strongly decreases with looking angle. Compared to many instruments, the altimetric data are also able to enhance the information content due to their high spatial resolution (400–600 m depending on satellite mission) along the track. While the theoretical footprint of the altimeter data is about 12 km (for the oceanic-type surface), over the land the main part of the backscatter signal comes from a small area with a diameter of 1–2 km, which occurs in the case of the quasi-specular signal over ice (Legresy and Remy, 1997) or calm water (rivers and small lakes). High radiometric sensitivity and spatial resolution along the satellite track can be successfully used for estimating the extent of wet and flooded zones, as well as formation and disappearance of lake and river ice.

A combination of simultaneous active and passive data from radar altimeters and passive microwave observations from SMMR-SSM/I has also been successfully used for studies of freezing and melting processes of the five largest Eurasian continental water bodies – the Caspian and Aral seas, and the Baikal, Ladoga and Onega lakes (Kouraev et al., 2003, 2004b, 2008, 2009), as well as for the Ob' River (Troitskaja et al., submitted for publication).

Papa et al. (2006) have used TOPEX/Poseidon dual-frequency radar altimeter to study inundated wetland dynamics over boreal regions up to 66°N (TOPEX/Poseidon orbit limitation). Frappart et al. (2010) also used TOPEX/Poseidon altimeter for studies of the inundation dynamic of the Ob' River floodplain. But it is still unclear whether the water regime of wetlands on interfluvial areas is different from that of floodplain. ENVISAT RA-2 radar altimetry data have been also used to estimate seasonal wetland extent variability for the Poluy, Nadym, Pur and Taz rivers (Kirpotin et al., 2009; Zakharova et al., 2009) located on the far North of the Western Siberia plain in the permafrost-affected zone. In this area the flat and big mound bogs are largely developed. They significantly redistribute river runoff, retaining in spring on average 37% of meltwater (Zakharova et al., 2011) by increasing the wet area extent on 25–35% (Zakharova et al., 2009). Does the water regime of other Siberian wetlands express the same seasonal pattern?

In this work we focus on seasonal variability of wetland extent over the whole Western Siberia. To do this, we use ENVISAT radar altimeter data over the 21 mid-size watersheds that belong to the Ob' River basin or are located in the neighboring regions (the Taz, Pur and Nadym rivers). Among them is also an area within the Ob' watershed that does not contribute to the Ob' River system (Inner watershed). The selected watersheds cover the regions located in different natural conditions and thus present a good base to analyze the seasonal dynamics of wetlands as a result of combination of different factors (climate, soil, relief, vegetation, etc.).

First we present natural conditions of these watersheds (Section 1), describing the climate, relief, permafrost conditions and different morphological types of peatlands occuring in the Western Siberia. Then, using the altimetric data from ENVISAT (Section 2) we analyze seasonal variability of wet zones extent for 21 watersheds and assess their relation with evapotranspiration and liquid precipitation (Section 3). We then analyze how different parts of the watershed react to snowmelt and precipitation by quantitatively estimating for the Taz River watershed the role of the floodplain in the seasonal wetland extent dynamics (Section 4). Wetland extent is an important parameter, but in order to estimate water budget of wetlands we need to complement it by simultaneous estimates of water level. In Section 5 we present the results of water level variability of different elements of bog landscapes (lakes, fens, string bogs, etc.) from radar altimetry and evaluate the seasonal water storage in wetlands for 6 watersheds of the northern part of Western Siberia.

1. Natural conditions of the Western Siberian plain and selected watersheds

Western Siberian plain extends on more than 2000 km from south to north and on more than 1300 km from west to east. It is a vast flat region located between the Urals Mountains and the Middle Siberian Highland (Fig. 1). Most of its territory comprises the Ob' River watershed (almost 3 million km^2), while in its northern part are located rivers Nadym, Pur and Taz, as well as left (western) tributaries of the Yenisey River. According to the hydrographic conditions and river regime, the Ob' is usually divided into the three main parts – the Upper Ob' (from the confluence of Biya and Katun' rivers in Altai Mountains up to the confluence of Ob' and Tom' rivers near Tomsk), the Middle Ob' (from the Tom' mouth to the Irtysh mouth near Khanty-Mansiysk), and the Lower Ob' (from the Irtysh mouth to the Ob' Bay).

The absolute elevation is in general between 105 and 130 m above sea level. Sibirskiye Uvaly hills (altitude ranging from 170 to 200 m in the west to 230–280 m in the east) are an uplift terminal moraine that divides the plain on two parts: northern and southern.

In our study we use river basin approach. We have selected 21 middle-size watersheds located in different climatic and natural zones of the Western Siberia. Watersheds north of the Sibirskiye Uvaly include the Taz, Pur and Nadym rivers (not flowing directly to the Ob' River, but to the Ob' and Taz estuaries), the Shuchya and Poluy rivers (joining the Ob' in its lower reaches), and the Kazym River (flowing west from the Sibirskiye Uvaly). South from Sibirskiye Uvaly are the right (the Ket', Tym, Vakh, Tromyugan, Lyamin, Nazym and Kazym) and left (the Bol'shoy Yugan and Vasyugan rivers) tributaries of the Middle Ob'. Four watersheds (the Tura, Tavda, Konda and Severnaya Sos'va rivers) are located between the Urals Mountains and the Irtysh and the Lower Ob'. Two watersheds (the Om' River and the Inner watershed) are located in the southernmost part of the Western Siberia between the Irtysh and Ob' rivers. The area of the selected watersheds varies from more than 100,000 km^2 for (the Taz and Pur rivers and Inner watershed) down to 10,000 km^2 (Pim, Nazym and Shuchya rivers).