Observations of changes in surface water over the western Siberia lowland

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[1] We analyse the evolution of the fraction of water surface (FWS), derived by SSM/I between 1988 and 2002 over the Western Siberia Lowland. This whole region exhibits an increase in the amount of FWS that is in agreement with the observed trends of the Ob river discharge and precipitation. However, a similar increasing trend is not found over the most important wetland area of Sibirskie Uvaly Hills located in a region of sporadic permafrost. These observations support the hypothesis that climate warming in discontinuous permafrost environments may lead to a reduction of small lakes and wetland areas.

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1. Introduction

[2] Global warming is deeply affecting the Arctic regions that are witnessing significant perturbations to the water and carbon cycle [*Serreze et al.*, 2003; *Wu et al.*, 2005]. The increase in air temperature and in atmosphere greenhouse gases concentration is expected to intensify the Arctic hydrological cycle and accelerate permafrost thawing [*Houghton et al.*, 2001; *Stocker and Raible*, 2005]. In particular, important modifications to the terrestrial water cycle have been observed in Siberia. An increased trend in the discharge of the major Siberian rivers over the last decades has been reported by *Peterson et al.* [2002]. This has been related to an increase in precipitation but not all the precipitation data sets seem to agree with the magnitude of the observed trend [*Pavelsky and Smith*, 2006] and it remains difficult to identify the mechanisms responsible for it [*McClelland et al.*, 2004; *Berezovskaya et al.*, 2004]. For the period 1988–2001 [*Mialon et al.*, 2005], using passive microwave remote sensing, observed an augmentation in the wetland area over the Ob river basin. However, an analysis of optical remote sensing images by *Smith et al.* [2005] showed a reduction in the number of Arctic lakes in West Siberia that could be related to permafrost thawing. According to *Smith et al.* [2005] climate warming in discontinuous permafrost environment may well lead to a decrease in the number of lakes and wetlands.

[3] The behaviour of wetland and inundated surface and the role of permafrost on the water cycle under the impact of climate change remain unclear, especially for Siberia where in-situ observations are scarce. Reaching a better understanding of these phenomena is extremely important since changes in peatland and wetland areas will alter the water and carbon cycle and change the amount of carbon released to the atmosphere [*Oechel et al.*, 1993]. Feedback mechanisms between the biosphere, the cryosphere and the atmosphere may further accelerate these processes [*Freeman et al.*, 2001].

[4] The aim of this paper is to provide further insights on the evolution of wetland, small lakes and inundated surfaces and its relation to permafrost in the western Siberia lowland by analysing trends in the fraction of water surface (FWS) derived by SSM/I between 1988 and 2002.

2. Study Area

[5] The Western Siberian Lowland contains a large percentage of the northern wetland and shallow lakes that are both net sinks for atmospheric carbon dioxide and source for methane [*Sheng et al.*, 2004]. The study area (Figure 1), that includes most of the lower Ob river basin, is in a region of permafrost transition (Figure 2). Within this area we further selected three test regions (Figures 2 and 3): the first one (a) along the Ob river, the second one (b) in the wetland bogs area of Sibirskie Uvaly Hills on the Siberian Ridge in a region of sporadic permafrost (located North of the Ob at 63°N) and the third one (c) in the Khanty-Mansiysk region in a permafrost free zone (South of the Ob and West of the Irtysh rivers at about 60°N) in swamped taiga containing more than 25,000 lakes [*Sheng et al.*, 2004; *Frey and Smith*, 2003].

3. Water Fraction Estimation by Passive Microwave Satellite Measurements

[6] Passive microwave sensors are very sensitive to the amount of surface water on their footprint and they have been successfully employed to derive the fraction of water surface (FWS) corresponding to small lakes and reservoir, inundated surfaces and natural wetland areas [*Fily et al.*, 2003; *Mialon et al.*, 2005]. FWS derived from SSM/I has been also used to improve flood forecasting over the Mackenzie river basin [*Temimi et al.*, 2005].

[7] The SSM/I brightness temperatures at 37 Ghz provided by National Snow and Ice Data Center (NSIDC) with 625 km^2 resolution have been used to compute the FWS area present in the satellite pixel. To minimise the spatial

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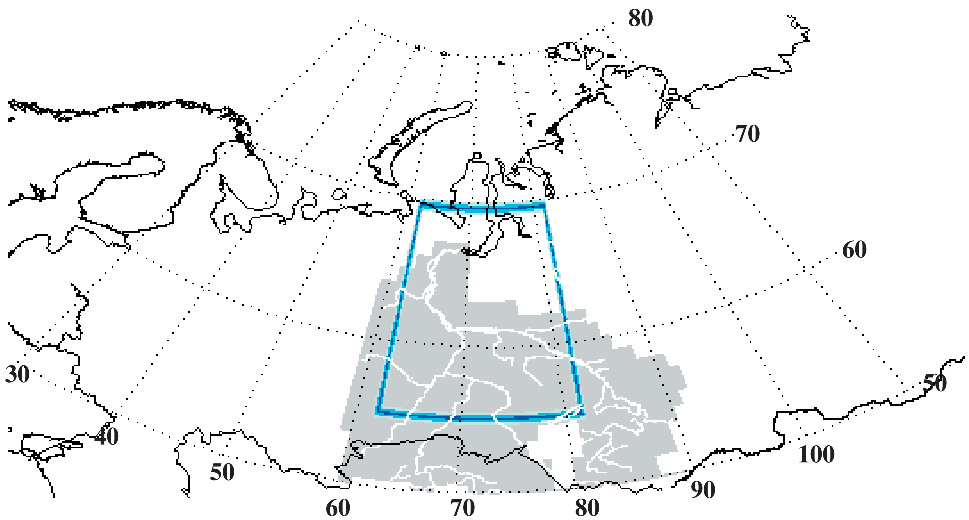

Figure 1. Location of the study area and the Ob river basin (shadow area in gray).

gaps resulting from the swath width the daily data have been averaged over pentads (5-day averages). The methodology, fully described by *Fily et al.* [2003], is based on the estimation of the emissivity ϵ_p from the measured brightness temperature using linear relationships (that are site dependent) between surface emissivity at vertical and horizontal polarisation. We used the global emissivities data set by *Prigent et al.* [1998] to derive the coefficients of this linear relationship for the study area. The FWS is then derived from the retrieved emissivity ϵ_p at polarisation p by the following equation:

$$\epsilon_p = \epsilon_{water} \times FWS + \epsilon_{dry} \times (1 - FWS) \quad (1)$$

where ϵ_{water} is the water emissivity and ϵ_{dry} is the emissivity of a dry surface at 37 GHz. Following *Mialon et al.*, [2005] ϵ_{water} and ϵ_{dry} have been set respectively equal to 0.664 and 0.965. The derived FWS values correspond to a combination of different surface contributions including lakes and reservoirs smaller than the SSM/I EASE-Grid pixel, shallow open water, saturated wet surfaces, flooded surfaces, swamps, ponds, marshes, fens, bogs or pits.To a lesser extent they are also sensitive to the soil moisture in the first few centimeters. For this analysis we only consider the summer values of FWS (July and August) when snow and ice are absent.

4. Analysis Results

4.1. Comparison With Discharge Over the Ob River Basin

[8] We found significantly high correlations between the interannual variation of the FWS (spatially averaged over the part of the study area within the Ob river basin shown in Figure 1) and the Ob river discharge measured at the station of Salekhard at the Ob river estuary in summer (the discharge values were obtained by A Regional, Integrated Hydrological Monitoring System for the Pan-Arctic Land Mass (ArcticRIMS), http://rims.unh.edu/, 2003). An example of the interannual evolution of the FWS and the discharge in July and August is shown in Figure 4 (the correlation R- value is in this case equal to 0.87). The consistency between the FWS and discharge independent data sets provides a further validation of the capability of SSM/I for monitoring the interannual variations of FWS. No correlation was instead found between precipitation (also shown in Figure 4, CRU data set by *Mitchell et al.* [2003]) and discharge or water fraction. Regarding trends, FWS, precipitation and discharge data are all consistent and they show a significant increase over the period 1988–2002 (Table 1).

4.2. FWS Trends

[9] Figure 5 shows the spatial distribution of FWS (August) and precipitation (July and August) temporally averaged over the 1988–2002 time period and their trends

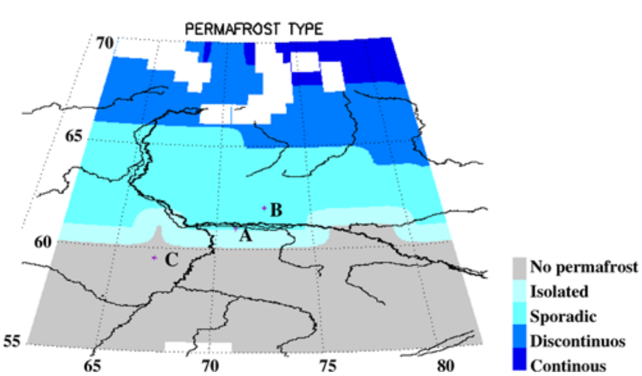

Figure 2. Map of permafrost types for the study area [*Brown et al.*, 1998]).

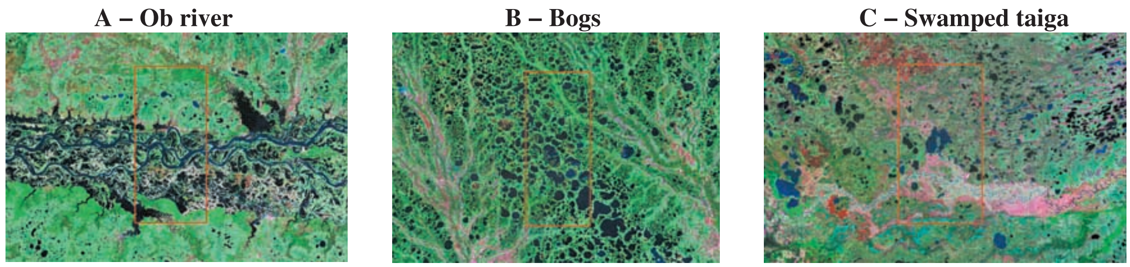

Figure 3. Landsat images showing part of the three selected test regions (red boxes show the SSM/I footprint) within the study area: (a) along the Ob river, (b) in the Sibirskie Uvaly Hills bogs area and (c) in the Khanty-Mansiysk swamped taiga. The geographical location of these test sites is shown in Figure 2.

over the same period (we average precipitation over a two month period to also take into account the rain events that occurred in the month preceding the FWS observations). Averaged high values of FWS are found along the lower part of the Ob river and over the two main wetland regions of Sibirskie Uvaly Hills and Khanty-Mansiysk. A significant positive FWS trend is evident along the Ob river and over its major affluents. This trend is consistent with the discharge increase measured at the Ob estuary and the significant augmentation in the summertime inundations' extent on its floodplain. A positive FWS trend is also observed over the Khanty-Mansiysk area (C) but this is not the case for the Sibirskie Uvaly Hills (B), the zone where the averaged values of FWS are highest, despite the precipitation positive trends over the whole region. This is quite surprising since the Sibirskie Uvaly Hills area is characterized by bogs, a wetland system entirely fed by precipitation. A similar behaviour is observed for the FWS in July (not shown).

[10] More details on the behaviour of these three regions are provided in Figure 6, that shows the interannual variations of FWS (August) and precipitation (July and August) at three selected $0.5^\circ \times 0.5^\circ$ test points (shown in Figure 3) and in Table 2 that reports the corresponding trends in FWS and precipitation during summer.

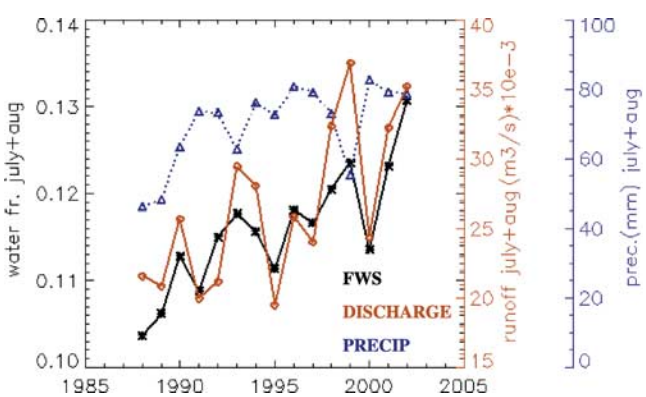

Figure 4. Comparison between the interannual variability of summer (July and August) FWS and precipitation spatially averaged over the Ob river basin (above 55°N) and of the Ob river discharge measured at Salehard.

5. Conclusions and Perspectives

[11] The western Siberia lowland region analysed here extends across the transition zone between sporadic permafrost in the Sibirskie Uvaly Hills, and the permafrost free region of Khanty-Mansiysk. This whole region exhibits an increasing trend in the amount of summer precipitation, in the average amount of water surface and in the discharge measured at the Ob's estuary. When the location of the FWS trend is mapped, it becomes evident that the main region affected by the FWS increase is along the Ob river. The wetland located in the permafrost free region yields also a significant but lower increase in water surface whereas the wetland in the Sibirskie Uvaly Hills does not exhibit any significative trend despite the increase in precipitation that is the largest over this area.

[12] These observations could confirm the hypothesis by *Smith et al.* [2005] that disappearing Arctic lakes could represent a diffuse lake drainage front where warming permafrost first experiences widespread degradation. However, further work needs to be done to understand the reasons for the observed trends that could be also due to changes in surface evaporation or to differences in the hydrological conditions of the three sites analysed, such as differences in soil permeability, groundwater outflows and soil characteristics.

[13] Reaching a deeper understanding of the Western Siberia hydrology is extremely important because this region contains a large percentage of the worlds peatlands and contributes for a significant portion to the total terrestrial freshwater flux to the Arctic Ocean. These recent

Table 1. Trends in FWS and Precipitation Averaged Over the Ob River Basin (Above 55°N) and Trends in the Ob River Runoff Measured at Salehard[a]

Months	Trends FWS	Trends Precip.	Trends Discharge
July	+18%	+15%	+14%
August	+12%	+48%	+97%
July+August	+15%	+32%	+44%

[a]Percentage trends are calculated as the change over the period 1988–2002 divided by the mean over the same period.

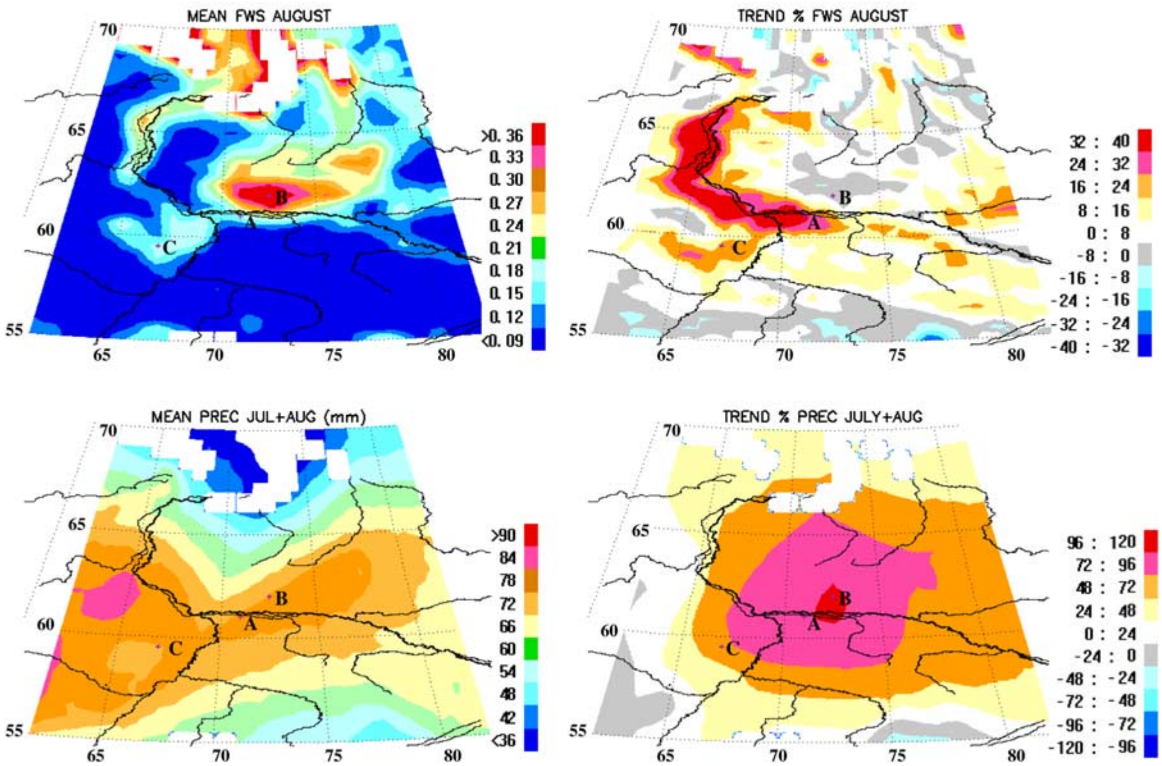

Figure 5. (top) Water fraction surface in August and (bottom) precipitation in July and August: (left) mean values over the period 1988–2002 and (right) trends over the same period.

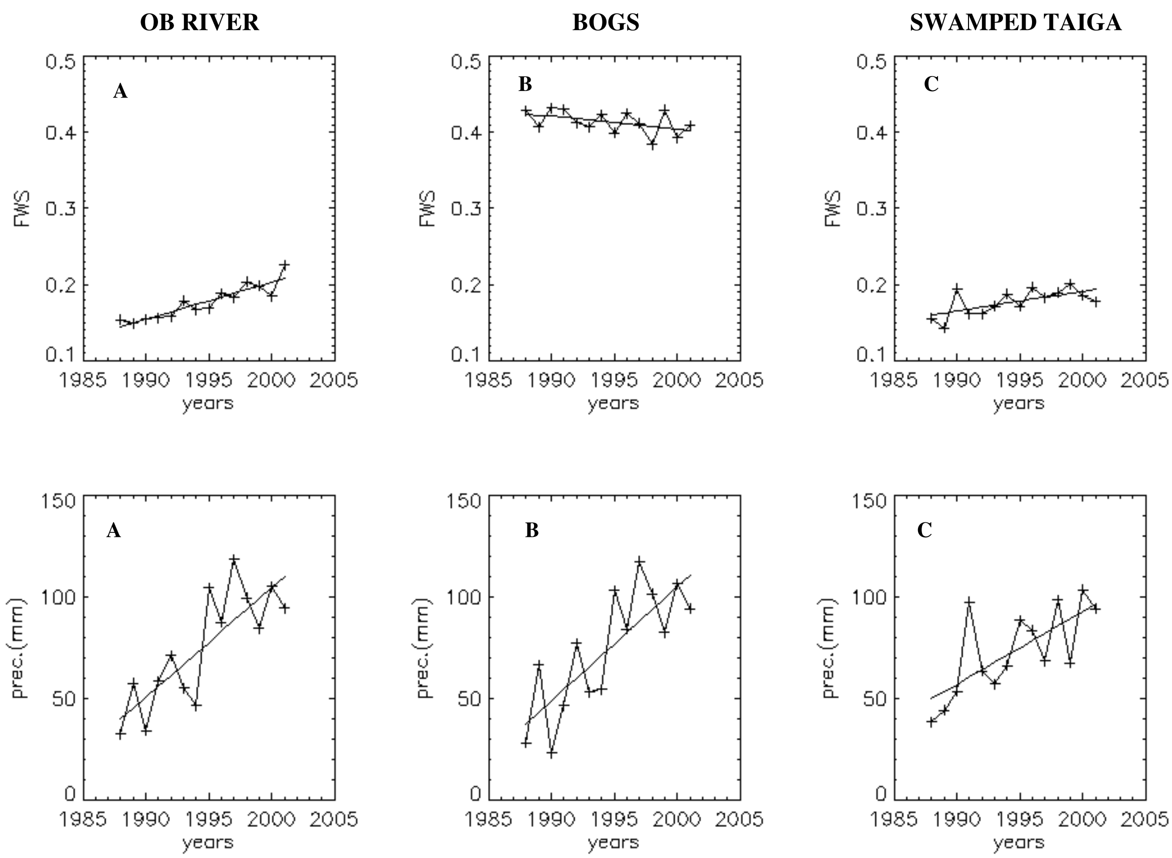

Figure 6. (top) Temporal evolution of the FWS in August and (bottom) precipitation in July and August for three selected sites.

Table 2. Trends in FWS and Precipitation for the Three Selected Test Sites in Figure 6[a]

Test Point	FWS Jul	FWS Aug	Precip Jun+Jul	Precip Jul+Aug
A	35.6%	50.0%	50.4%	93.6%
B	1.2%	−5.2%	54.0%	109.6%
C	27.6%	18.8%	79.2%	63.6%

[a]See caption of Table 1.

climatic trends may, therefore, have globally significant repercussions.

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