

## Observations of changes in surface water over the western Siberia lowland

Manuela Grippa, N.M. Mognard, Thuy Le Toan, S. Biancamaria

► **To cite this version:**

Manuela Grippa, N.M. Mognard, Thuy Le Toan, S. Biancamaria. Observations of changes in surface water over the western Siberia lowland. *Geophysical Research Letters*, American Geophysical Union, 2007, 34, pp.1-5. <10.1029/2007GL030165>. <ird-00392556>

**HAL Id: ird-00392556**

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Submitted on 8 Jun 2009

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## 2 Observations of changes in surface water over the western Siberia 3 lowland

4 M. Grippa,<sup>1</sup> N. M. Mognard,<sup>2</sup> T. Le Toan,<sup>1</sup> and S. Biancamaria<sup>2</sup>

5 Received 27 March 2007; revised 18 May 2007; accepted 15 June 2007; published XX Month 2007.

7 [1] We analyse the evolution of the fraction of water  
8 surface (FWS), derived by SSM/I between 1988 and 2002  
9 over the Western Siberia Lowland. This whole region  
10 exhibits an increase in the amount of FWS that is in  
11 agreement with the observed trends of the Ob river  
12 discharge and precipitation. However, a similar increasing  
13 trend is not found over the most important wetland area of  
14 Sibirskie Uvaly Hills located in a region of sporadic  
15 permafrost. These observations support the hypothesis that  
16 climate warming in discontinuous permafrost environments  
17 may lead to a reduction of small lakes and wetland areas.

18 **Citation:** Grippa, M., N. M. Mognard, T. Le Toan, and  
19 S. Biancamaria (2007), Observations of changes in surface water  
20 over the western Siberia lowland, *Geophys. Res. Lett.*, *34*,  
21 LXXXXX, doi:10.1029/2007GL030165.

### 23 1. Introduction

24 [2] Global warming is deeply affecting the Arctic regions  
25 that are witnessing significant perturbations to the water and  
26 carbon cycle [Serreze *et al.*, 2003; Wu *et al.*, 2005]. The  
27 increase in air temperature and in atmosphere greenhouse  
28 gases concentration is expected to intensify the Arctic  
29 hydrological cycle and accelerate permafrost thawing  
30 [Houghton *et al.*, 2001; Stocker and Raible, 2005]. In  
31 particular, important modifications to the terrestrial water  
32 cycle have been observed in Siberia. An increased trend in  
33 the discharge of the major Siberian rivers over the last  
34 decades has been reported by Peterson *et al.* [2002]. This  
35 has been related to an increase in precipitation but not all the  
36 precipitation data sets seem to agree with the magnitude of  
37 the observed trend [Pavelsky and Smith, 2006] and it  
38 remains difficult to identify the mechanisms responsible  
39 for it [McClelland *et al.*, 2004; Berezovskaya *et al.*, 2004].  
40 For the period 1988–2001 [Mialon *et al.*, 2005], using  
41 passive microwave remote sensing, observed an augmenta-  
42 tion in the wetland area over the Ob river basin. However,  
43 an analysis of optical remote sensing images by Smith *et al.*  
44 [2005] showed a reduction in the number of Arctic lakes in  
45 West Siberia that could be related to permafrost thawing.  
46 According to Smith *et al.* [2005] climate warming in  
47 discontinuous permafrost environment may well lead to a  
48 decrease in the number of lakes and wetlands.

49 [3] The behaviour of wetland and inundated surface and  
50 the role of permafrost on the water cycle under the impact of  
51 climate change remain unclear, especially for Siberia where

in-situ observations are scarce. Reaching a better under- 52  
standing of these phenomena is extremely important since 53  
changes in peatland and wetland areas will alter the water 54  
and carbon cycle and change the amount of carbon released 55  
to the atmosphere [Oechel *et al.*, 1993]. Feedback mecha- 56  
nisms between the biosphere, the cryosphere and the atmo- 57  
sphere may further accelerate these processes [Freeman *et al.* 58  
*et al.*, 2001]. 59

[4] The aim of this paper is to provide further insights on 60  
the evolution of wetland, small lakes and inundated surfaces 61  
and its relation to permafrost in the western Siberia lowland 62  
by analysing trends in the fraction of water surface (FWS) 63  
derived by SSM/I between 1988 and 2002. 64

### 2. Study Area 65

[5] The Western Siberian Lowland contains a large 66  
percentage of the northern wetland and shallow lakes that 67  
are both net sinks for atmospheric carbon dioxide and 68  
source for methane [Sheng *et al.*, 2004]. The study area 69  
(Figure 1), that includes most of the lower Ob river basin, is 70  
in a region of permafrost transition (Figure 2). Within this 71  
area we further selected three test regions (Figures 2 and 3): 72  
the first one (a) along the Ob river, the second one (b) in the 73  
wetland bogs area of Sibirskie Uvaly Hills on the Siberian 74  
Ridge in a region of sporadic permafrost (located North of 75  
the Ob at 63°N) and the third one (c) in the Khanty- 76  
Mansiysk region in a permafrost free zone (South of the 77  
Ob and West of the Irtysh rivers at about 60°N) in swamped 78  
taiga containing more than 25,000 lakes [Sheng *et al.*, 2004; 79  
Frey and Smith, 2003]. 80

### 3. Water Fraction Estimation by Passive 81 Microwave Satellite Measurements 82

[6] Passive microwave sensors are very sensitive to the 83  
amount of surface water on their footprint and they have 84  
been successfully employed to derive the fraction of water 85  
surface (FWS) corresponding to small lakes and reservoir, 86  
inundated surfaces and natural wetland areas [Fily *et al.*, 87  
2003; Mialon *et al.*, 2005]. FWS derived from SSM/I has 88  
been also used to improve flood forecasting over the 89  
Mackenzie river basin [Temimi *et al.*, 2005]. The SSM/I 90  
brightness temperatures at 37 Ghz provided by National 91  
Snow and Ice Data Center (NSIDC) with 625 km<sup>2</sup> resolu- 92  
tion have been used to compute the FWS area present in the 93  
satellite pixel. To minimise the spatial gaps resulting from 94  
the swath width the daily data have been averaged over 95  
pentads (5-day averages). The methodology, fully described 96  
by Fily *et al.* [2003], is based on the estimation of the 97  
emissivity  $\epsilon_p$  from the measured brightness temperature 98  
using linear relationships (that are site dependent) between 99

<sup>1</sup>Centre d'Etudes Spatiales de la BIOSphère, Toulouse, France.

<sup>2</sup>Laboratoire d'Etudes en Géophysique et Océanographie Spatiales, Toulouse, France.

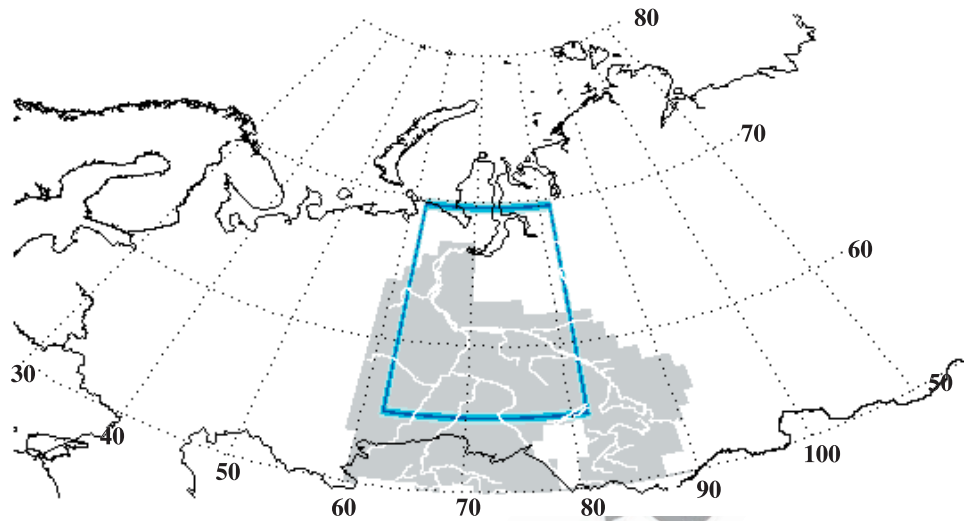


Figure 1. Location of the study area and the Ob river basin (shadow area in gray).

100 surface emissivity at vertical and horizontal polarisation. We  
 101 used the global emissivities data set by Prigent *et al.* [1998]  
 102 to derive the coefficients of this linear relationship for the  
 103 study area. The FWS is then derived from the retrieved  
 104 emissivity  $\epsilon_p$  at polarisation  $p$  by the following equation:

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

106 where  $\epsilon_{water}$  is the water emissivity and  $\epsilon_{dry}$  is the emissivity  
 107 of a dry surface at 37 GHz. Following [Mialon *et al.*, 2005]  
 108  $\epsilon_{water}$  and  $\epsilon_{dry}$  have been set respectively equal to 0.664 and  
 109 0.965. The derived FWS values correspond to a combina-  
 110 tion of different surface contributions including lakes and  
 111 reservoirs smaller than the SSM/I EASE-Grid pixel, shallow  
 112 open water, saturated wet surfaces, flooded surfaces,  
 113 swamps, ponds, marshes, fens, bogs or pits. To a lesser  
 114 extent they are also sensitive to the soil moisture in the first

few centimeters. For this analysis we only consider the  
 115 summer values of FWS (July and August) when snow and  
 116 ice are absent.  
 117

#### 4. Analysis Results

##### 4.1. Comparison With Discharge Over the Ob River Basin

[7] We found significantly high correlations between the  
 121 interannual variation of the FWS (spatially averaged over  
 122 the part of the study area within the Ob river basin shown in  
 123 Figure 1) and the Ob river discharge measured at the station  
 124 of Salekhard at the Ob river estuary in summer (the  
 125 discharge values were obtained by A Regional, Integrated  
 126 Hydrological Monitoring System for the Pan-Arctic Land  
 127 Mass (ArcticRIMS), <http://rims.unh.edu/>, 2003). An exam-  
 128 ple of the interannual evolution of the FWS and the  
 129

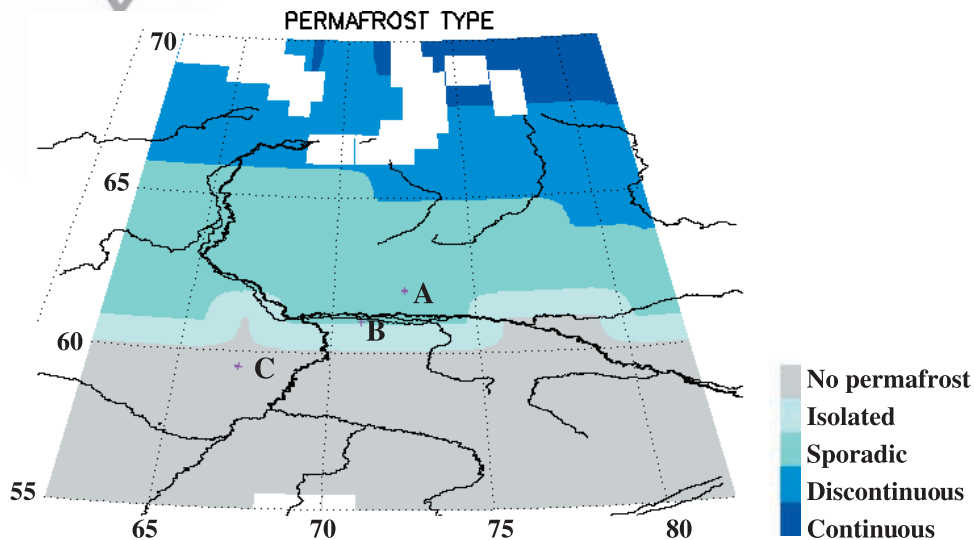
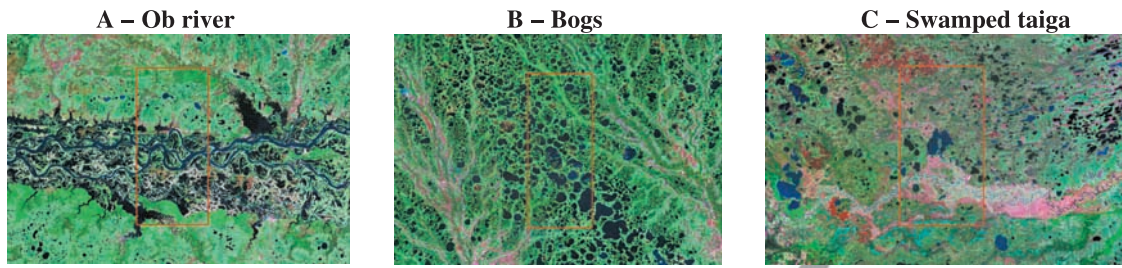


Figure 2. Map of permafrost types for the study area [Brown *et al.*, 1998]).



**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.

130 discharge in July and August is shown in Figure 4  
 131 (the correlation R- value is in this case equal to 0.87).  
 132 The consistency between the FWS and discharge independ-  
 133 ent data sets provides a further validation of the capability  
 134 of SSM/I for monitoring the interannual variations of FWS.  
 135 No correlation was instead found between precipitation  
 136 (also shown in Figure 4, CRU data set by *Mitchell et al.*  
 137 [2003]) and discharge or water fraction. Regarding trends,  
 138 FWS, precipitation and discharge data are all consistent and  
 139 they show a significant increase over the period 1988–2002  
 140 (Table 1).

141 **4.2. FWS Trends**

142 [8] Figure 5 shows the spatial distribution of FWS  
 143 (August) and precipitation (July and August) temporally  
 144 averaged over the 1988–2002 time period and their trends  
 145 over the same period (we average precipitation over a two  
 146 month period to also take into account the rain events that  
 147 occurred in the month preceding the FWS observations).  
 148 Averaged high values of FWS are found along the lower  
 149 part of the Ob river and over the two main wetland regions  
 150 of Sibirskie Uvaly Hills and Khanty-Mansiysk. A signifi-  
 151 cant positive FWS trend is evident along the Ob river and  
 152 over its major affluents. This trend is consistent with the  
 153 discharge increase measured at the Ob estuary and the  
 154 significant augmentation in the summertime inundations’  
 155 extent on its floodplain. A positive FWS trend is also

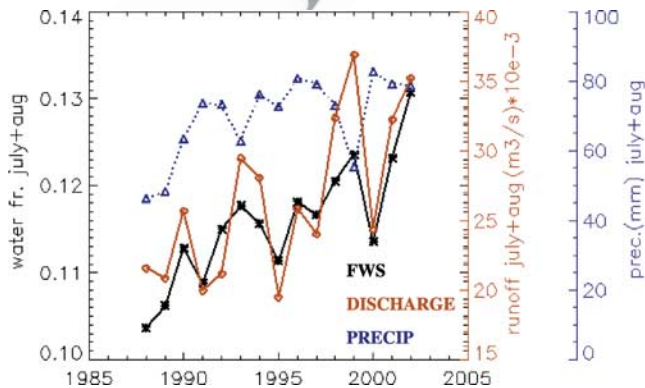
observed over the Khanty-Mansiysk area (C) but this is 156  
 not the case for the Sibirskie Uvaly Hills (B), the zone 157  
 where the averaged values of FWS are highest, despite the 158  
 precipitation positive trends over the whole region. This is 159  
 quite surprising since the Sibirskie Uvaly Hills area is 160  
 characterized by bogs, a wetland system entirely fed by 161  
 precipitation. A similar behaviour is observed for the FWS 162  
 in July (not shown). 163

[9] More details on the behaviour of these three regions 164  
 are provided in Figure 6, that shows the interannual varia- 165  
 tions of FWS (August) and precipitation (July and August) 166  
 at three selected  $0.5^\circ \times 0.5^\circ$  test points (shown in Figure 3) 167  
 and in Table 2 that reports the corresponding trends in FWS 168  
 and precipitation during summer. 169

171 **5. Conclusions and Perspectives**

[10] The western Siberia lowland region analysed here 172  
 extends across the transition zone between sporadic perma- 173  
 frost in the Sibirskie Uvaly Hills, and the permafrost free 174  
 region of Khanty-Mansiysk. This whole region exhibits an 175  
 increasing trend in the amount of summer precipitation, in 176  
 the average amount of water surface and in the discharge 177  
 measured at the Ob’s estuary. When the location of the FWS 178  
 trend is mapped, it becomes evident that the main region 179  
 affected by the FWS increase is along the Ob river. The 180  
 wetland located in the permafrost free region yields also a 181  
 significant but lower increase in water surface whereas the 182  
 wetland in the Sibirskie Uvaly Hills does not exhibit any 183  
 significant trend despite the increase in precipitation that 184  
 is the largest over this area. 185

[11] These observations could confirm the hypothesis by 186  
*Smith et al.* [2005] that disappearing Arctic lakes could 187  
 represent a diffuse lake drainage front where warming 188  
 permafrost first experiences widespread degradation. 189

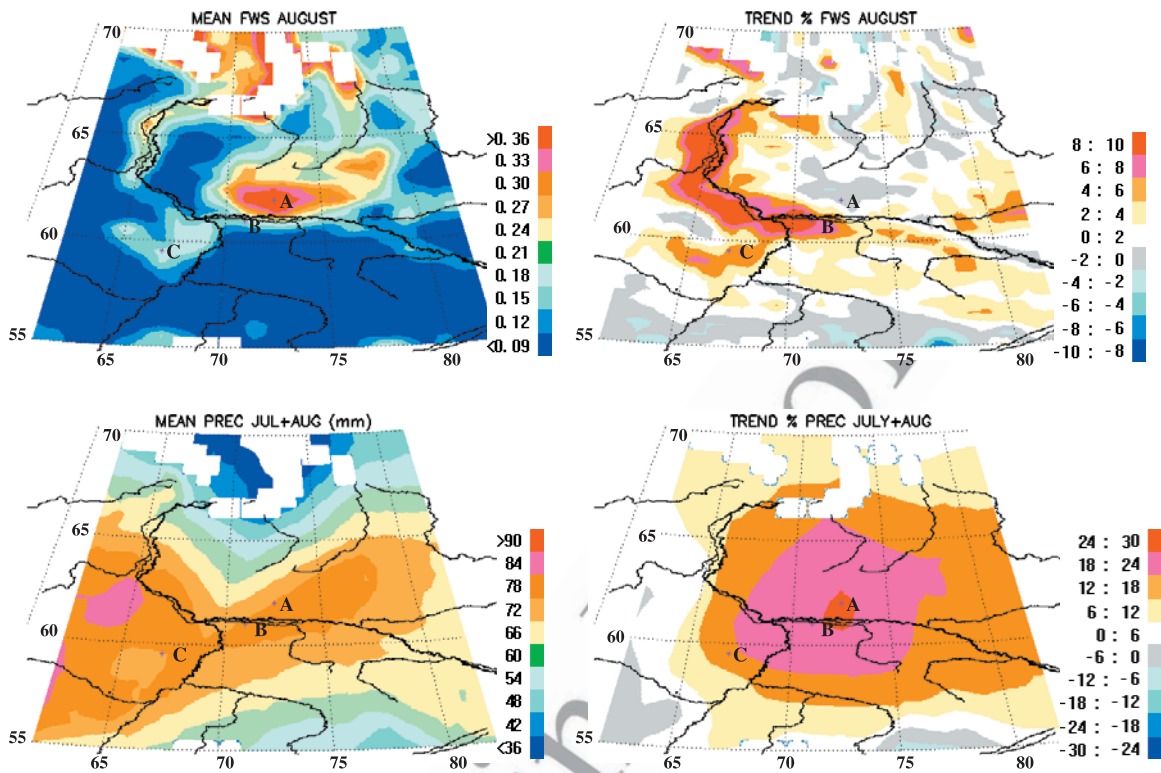


**Figure 4.** Comparison between the interannual variability of summer (July and August) FWS and precipitation spatially averaged over the Ob river basin (above  $55^\circ\text{N}$ ) and of the Ob river discharge measured at Salehard.

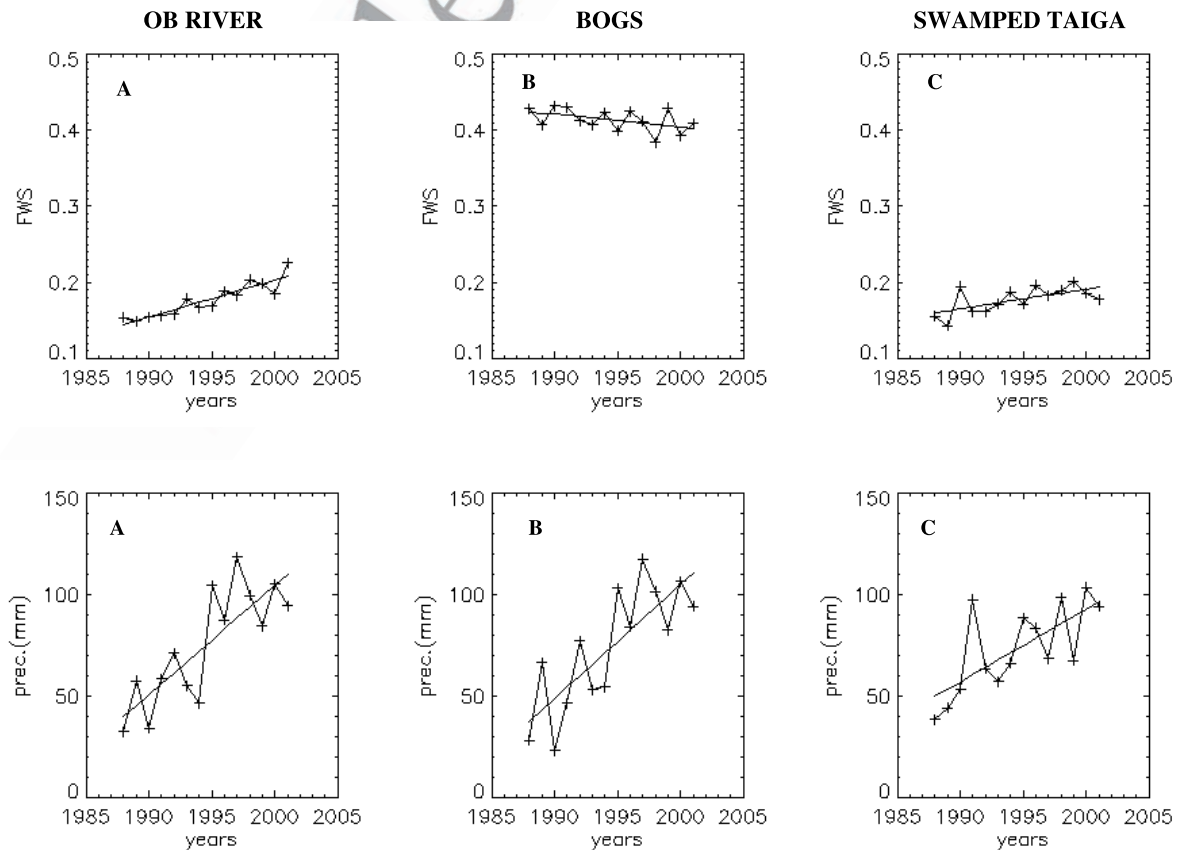
**Table 1.** Trends in FWS and Precipitation Averaged Over the Ob River Basin (Above  $55^\circ\text{N}$ ) and Trends in the Ob River Runoff Measured at Salehard<sup>a</sup>

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

<sup>a</sup>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.

t2.1 **Table 2.** Trends in FWS and Precipitation for the Three Selected Test Sites in Figure 6<sup>a</sup>

t2.2	Test point	FWS Jul	FWS Aug	Precip Jun+Jul	Precip Jul+Aug
t2.3	A	8.9%	12.5%	12.6%	23.4%
t2.4	B	0.3%	-1.3%	13.5%	24.7%
t2.5	C	6.9%	4.7%	19.8%	15.9%

t2.6 <sup>a</sup>See caption of Table 1.

190 However, further work needs to be done to understand the  
191 reasons for the observed trends that could be also due to  
192 changes in surface evaporation or to differences in the  
193 hydrological conditions of the three sites analysed, such  
194 as differences in soil permeability, groundwater outflows  
195 and soil characteristics.

196 [12] Reaching a deeper understanding of the Western  
197 Siberia hydrology is extremely important because this  
198 region contains a large percentage of the worlds peatlands  
199 and contributes for a significant portion to the total terres-  
200 trial freshwater flux to the Arctic Ocean. These recent  
201 climatic trends may, therefore, have globally significant  
202 repercussions.

203 [13] **Acknowledgments.** We thank A. Mialon, CESBIO, and two  
204 anonymous reviewers for their comments and suggestions that helped  
205 considerably improve this paper.

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S. Biancamaria and N. M. Mognard, Laboratoire d'Etudes en  
273 Géophysique et Océanographie Spatiales, 18 Av. E. Belin, F-31401  
274 Toulouse, France. 275  
M. Grippa and T. Le Toan, Centre d'Etudes Spatiales de la Biosphère,  
276 18 Av. E. Belin, F-31401 Toulouse, France. (manuela.grippa@cesbio.  
277 cnes.fr)