ICE COVER OF EURASIAN WATER BODIES AND RIVERS FROM SATELLITE AND IN SITU OBSERVATIONS

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ABSTRACT

We present studies of ice cover of continental water bodies and rivers using the synergy of more than 15 years-long simultaneous active (radar altimeter) and passive (radiometer) observations from radar altimetric satellites (TOPEX/Poseidon, Jason-1, ENVISAT and Geosat Follow-On) complemented by SSM/I passive microwave data. Five largest Eurasian continental water bodies - Caspian and Aral seas, Baikal, Ladoga and Onega lakes, and the Ob' river in the Western Siberia are selected as examples. We use an ice discrimination approach based on a combined use of the data, that has been validated using in situ and independent satellite data in the visible range. We then analyse evolution of ice conditions for the lakes and inland seas using historical data, recent satellite observations and our field studies on the lakes Ladoga and Baikal.

1. INTRODUCTION

Because of its response to regional and global variations in the climate system, arctic and sub-arctic lakes, internal seas and rivers are not only an integrator of climate processes, but also strong indicator of existing or potential change. It is important to well understand what are temporal and spatial scales of variability of natural parameters, what are teleconnections, feedbacks and mechanisms responsible for the changes, what are natural and anthropogenic causes of recent and historical changes in the hydrophysical and meteorological parameters. Changes in natural parameters are important for human activity (navigation, transport, fisheries, tourism etc) and affect large population living around.

We present studies of ice cover of continental water bodies and rivers using the synergy of more than 15 years-long simultaneous active (radar altimeter) and passive (radiometer) observations from radar altimetric satellites (TOPEX/Poseidon, Jason-1, ENVISAT and Geosat Follow-On) complemented by SSM/I passive microwave data. Five largest Eurasian continental water bodies - Caspian and Aral seas, Baikal, Ladoga and Onega lakes, and the Ob' river in the Western Siberia are selected as examples (Fig. 1).

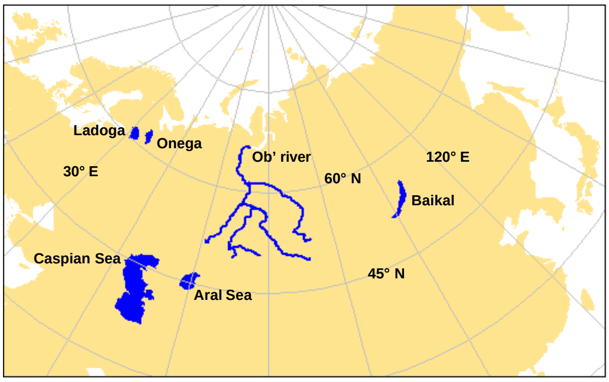

Figure 1. Study regions

2. ICE COVER OF LAKES AND INTERNAL SEAS

A dedicated methodology for ice discrimination has been developed and tested for the Caspian and Aral seas and for the Ladoga, Onega and Baikal lakes [Kouraev et al., 2003, 2004a, 2004b, 2007a, 2007b, 2008a, 2008b, 2010, 2011]. This methodology uses the active and passive data from several altimetric missions (T/P, Jason-1, Envisat and GFO) complemented by the passive SSM/I data.

All four altimeters have two main nadir-looking instruments – a dual-frequency (single-frequency for GFO) radar altimeter operating in Ku (13.6 GHz), C (5 GHz) or S (2 GHz) bands, and a passive microwave radiometer operating at two or three frequencies. The fact that these are simultaneous observations from the same platform significantly enhances the data analysis capability.

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This method is based on the analysis of the spatio-temporal evolution of two parameters: the altimeter backscatter coefficient (s 0) and the average value of the brightness temperature values at two frequencies. The backscatter coefficient is the ratio between the power reflected from the surface and the incident power emitted by the onboard radar altimeter, expressed in decibels (dB). We use the Ku band (13.6 GHz) backscatter. The second parameter, the average value of the brightness temperature values at two frequencies (18 and 37 GHz for T/P and Jason-1, 18.7 and 34 GHz for Envisat and 22 and 37 GHz for GFO) is measured in ºK. Open water has a low backscatter coefficient and low brightness temperature values, while ice cover is characterised by a high backscatter coefficient and elevated brightness temperatures.

We then complement these data by the passive microwave observations from the SSM/I radiometer. Using the combination of ice discrimination approaches for altimetric and SSM/I data we can define the timing of specific ice events (the first appearance of ice, the formation of stable ice cover, the first appearance of open water and the complete disappearance of ice) for each water body or its sub-region. In most cases it is possible to define ice event dates using these maps with a five-day temporal resolution and an uncertainty of 2.5 days.

3. ICE COVER OF THE OB' RIVER

One of the largest Siberian rivers - the Ob' - has 14 hydrological stations in its middle and lower reaches over a distance of about 3000 km. On these stations the water level and ice parameters are observed regularly but the data are not easily available. Using ENVISAT altimetric mission it is possible to retrieve the information on water level and ice regime at the so-called "virtual stations" - crossovers of satellite ground track and river channel. Between the Novosibirsk reservoir and the Ob' mouth (the Middle and Lower reaches of the river) 58 ENVISAT virtual stations have been established (fig.2).

A methodology for ice discrimination algorithm from altimetric satellite missions is based on the analysis of two parameters: a) backscatter value (Ice2 retracker) from 18 Hz ENVISAT active radar altimeter data and b) difference between brightness temperature (dTB = TB365-TB238) from passive microwave radiometer 1 Hz data [Kouraev et al., 2007a, 2008a, 2013]. For each virtual station data have been selected using a fine geographical window. As temporal resolution for each virtual station is coarse (35 days), they have been grouped onto 11 zones around selected in situ stations in order to increase temporal resolution. An average value of backscatter and dTB for each virtual station has been calculated, and then referred to as one of the observations for a specific zone with a specific time

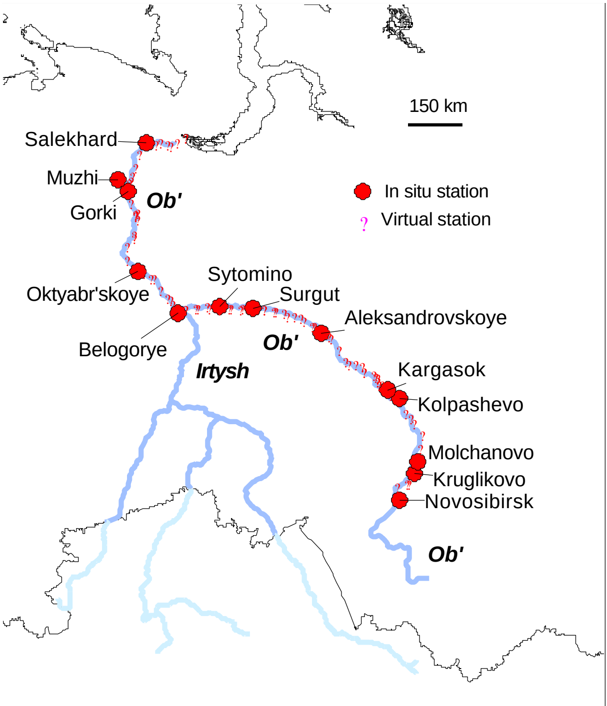

Figure 2. In situ stations and virtual stations along the main Ob' river channel.

Spatial variability of altimeter-derived dates for ice formation and break-up are in good agreement with in situ data for each zone. The algorithm and chosen threshold perform better on ice break-up detection, showing the dates of full disappearing of ice with an average bias that equals to 0 and maximal bias ranging from - 5 to 8 days. For 8 from 11 zones the altimeter-derived dates of ice formation correspond also well to in situ observations characterising a full ice coverage conditions with an average positive 3 days [Troitskaya et al., 2013].

4. BAIKAL ICE RINGS

We address another interesting natural phenomenon - formation of giant rings on Baikal Lake ice. These rings (diameter 5-7 km, thickness of dark layer - 1 - 1.8 km) have perfect circular shape. The rings have been observed since the early 1970ies by satellite imagery in various regions of the lake. We present several existing hypotheses of the origin of these rings and discuss strengths and weaknesses of each hypothesis. We present observation of the formation, development and disappearance of these rings using various satellite data. We discuss the conditions needed to create and maintain these rings, the timing of and duration of their existence, as well as horizontal and vertical structure of ice and snow cover and of temperature and conductivity before and during the appearance of rings.

5. FIELD STUDIES

Since 2010 we conduct field studies on the ice cover parameters of the lakes Ladoga and Baikal (Figure 3). In spring 2013 observations have been carried out simultaneously with the recently launched SARAL/AltiKa satellite and have been conducted along the two AltiKa tracks.

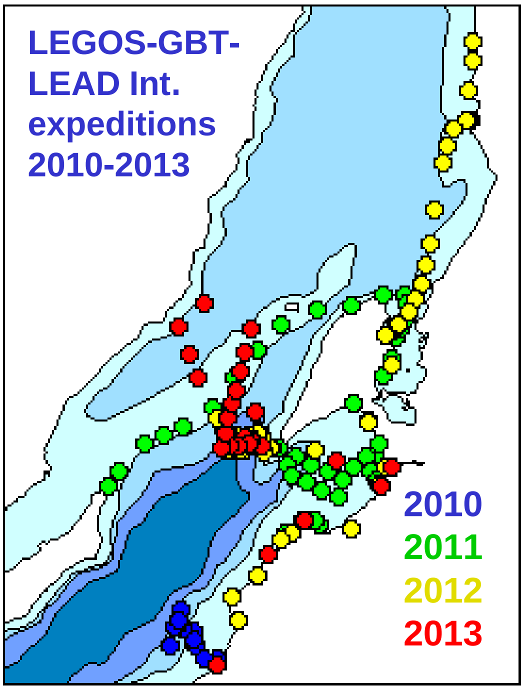

Figure 3. Sampling points of the field measurements on the Lake Baikal.

Looking at the temporal changes of the AltiKa signal, we observe a significant decrease (10-15 dB) of backscatter values between the first (end of March-beginning of April) and second (May) cycles for both tracks. No ice cover drift was observed during this time so these changes should be attributed to ice thinning and metamorphism. One of the typical examples of ice metamorphism is the formation of air channels ("shakh" in Russian) on the ice surface in spring (Fig. 4) and development of needle ice.

Thanks to the in situ oibservations we now have a detailed information of ice cover thickness and structure, as well as vertical profiles of temperature and conductivity in the upper 100 m of water column.

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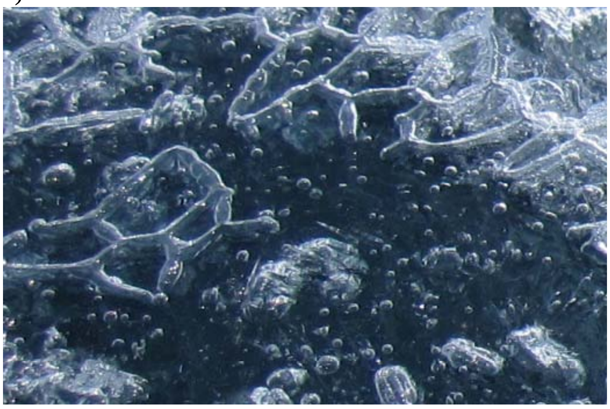
a)



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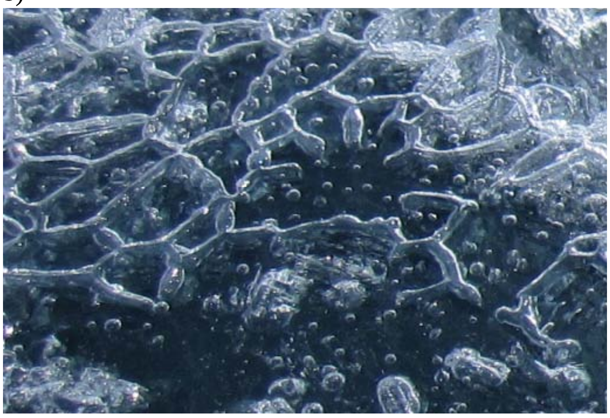

c)

Figure 4. Formation of channels in the surface layer of Lake Baikal ice in 2012. a - Location of study area (dark spot), b - initial state and c - final state after 9 min 30 sec of observations.

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