

WINTER HYDROLOGY AND ICE REGIME OF THE OB –YENISEY ESTUARIES: RESULTS OF SATELLITE SAR COMPREHENSIVE STUDIES

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Abstract - Winter hydrology and ice regime of the Ob and Yenisey estuaries, including the Ob-Yenisey recurring Polynya are studied with using satellite ERS /RADARSAT/Envisat SAR and multi-spectral data obtained by satellite "Resours". Results of satellite microwave sounding of sea, brackish- and fresh-water ice in this area are attracted. Sub-satellite field experiments of the coastal zones were provided onboard nuclear icebreaker "Sovetsky Soyuz", "Jamal" and "Arktika". Comprehensive studies of ice cover parameters of shallow water in the Ob Gulf were organized in frame of ARCDEV experimental voyage onboard icebreaker "Kapitan Dranytsyn" (April-May 1998). Yenisey Gulf and Ob-Yenisey estuaries were investigated onboard i/b "Vaygach" and "Taymir" in frame of several pilot studies that were provided in the Siberian Arctic since October 1993 till now.

Keywords: SAR signature, ice age and ice origin, dissolved organic matter, recurring polynya

1. INTRODUCTION.

The Ob Bay and Yenisey Gulf are represented the vast expanded zones of saline and fresh water mixture outstretched, correspondingly, a hundreds and a thousand kilometers in meridian direction. As a giant water intake for the most part of the Siberia these water areas are integrated a huge sub-continental input from the great Siberian Rivers – Ob, Taz, Pour, Yenisey as well from infinite number of small rivers and rivulets. On the other hand, the northern part of the Ob Bay and Yenisey Gulf are in the possession of the saline waters penetrating relatively far from the Kara Sea southward. Overall it's resulted that the spatial arrangement of water masses in studied bays and estuaries has been affected by the measure of land - sea interaction.

Our approach assumes that modification of snow coverage in the Western Siberia during the winter season, variability of the precipitation total in dry and humid summer and fall as well a drastic change-over of sub-continental humidification and soil moisture shrinkage due to global warming could be indicated and numerically assessed by using passive microwaves and radar observations of ice cover arrangement in the Ob-Yenisey estuary. Satellite multi-spectral observations allow also assessing different dangerous ice phenomena.

As it was presented in our field experimental studies (Kondratyev *et al.*, 1992), a distribution of saline and fresh water mixture in the Ob Bay and in the Khatanga Bay could be charted by using airborne

multi-spectral microwave measurements. But unfortunately, the microwave contrast of fresh and saline waters during the open water season is not large. It's not exceeded a 2-3 K at the long-wave range and could be masked on the state of water surface and wind conditions. In our recent comprehensive studies (Melentyev *et al.*, 1997, Kondratyev *et al.*, 1998, Melentyev *et al.*, 2004), a multi-spectral airborne and satellite data were applied for the assessment of influence of modifications of the water catchments on the ice features during the fall-winter season. In frame of these studies SAR signatures of different types of saline and fresh-water ice (and its seasonal and inter-annual variability) were classified and systematized. According to (Melentyev *et al.*, 2001), L-band radar investigation of the system "Earth-Atmosphere" allows providing a deep-laid sounding of ice and revealing the type of large-scale atmospheric processes.

2. OBJECTIVE AND TASKS

The objective is further development our knowledge about winter hydrology and ice regime of the Grand Siberian rivers and estuaries, including the Ob-Yenisey recurring Polynya. In frame of presented paper a multi-disciplinary investigations were provided with using satellite ERS/RADARSAT/Envisat SAR and multi-spectral data obtained by satellite "Resours". Results of passive microwave sounding of the sea as well a brackish- and fresh-water ice are used also. Sub-satellite field investigations of the coastal zones were provided onboard nuclear icebreakers "Sovetskiy Soyuz", "Jamal" and "Arktika" (linear class). Comprehensive studies of ice cover parameters of the shallow waters in the Ob Bay were organized in frame of ARCDEV experiment onboard icebreaker "Kapitan Dranytsyn" (April - May 1998). Yenisey Gulf and Ob-Yenisey estuaries were investigated onboard nuclear i/b "Vaygach" and "Taymir" (shallow water class) in frame of several pilot projects that were organized by NERSC/NIERSC in the Siberian Arctic since October 1993 till now.

Specific features of the ice in the Ob, Taz, Pour, Gyda Bays, Yenisey Gulf as well in the Ob-Yenisey recurring polynya has been accomplished and compared with *in situ* data. Wind parameters and air temperature were controlled. The following ice parameters are investigated: ice development (age), color of the ice and its connection with origin of ice (sea ice, fresh-water and brackish-water ice), hummocking and rafting of ice, fast ice and drift ice

features: its formation and destruction, ice arrangement and its connection with the type of winter severity. The reconstruction of the history of ice formation with comprehensive using optical and radio-physical observations is fulfilled. The modification of the processes of water and ice exchange between Ob-Yenisey estuary and Kara Sea for the different winter severity is investigated. Based on the multi-temporal optical and radar survey, the methodology for satellite support of ice navigation and offshore operations at the Siberian Arctic is developed. Also climatic study has been made: seasonal and annual modification of ice parameters and frozen grounds were studied.

RESULTS OF THE THEMATIC INTERPETATION

A) Satellite SAR studies of the river ice in the Ob Bay. Ice conditions in the Ob Bay during the winter season are determined by the wind regime (Figure 1). In spring time it's depended on the type of thermal forcing, impact of spring flood and alluvial fresh waters (Figure 2). In the utmost northern part of Ob Bay it's affected on the impact of tidal currents. Analysis of brightness and texture of signal allows revealing ice homogeneity and degree of roughness, stage of melting and destruction of ice, presence of ice jam structures, orientation of ice arcs and dams, formation of washaways, fractures and cracks, snow cover condition, rise of ice heaving on to the shores.

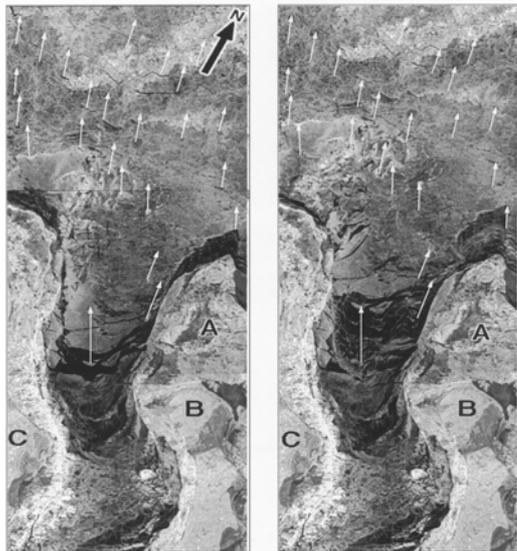


Figure 1. Regular opening and multiple freezing of the Ob-Yenisey recurring polynya in winter season and attendant dangerous ice phenomena: formation of stamukha - grounded hummock stationary area (A) situated northward Jaway Peninsula (B)

The following dangerous ice phenomena are assessed using ERS-1 SAR - 23 May 1996: fast ice foot is frozen to the shore; un - homogeneities of ice were resulted in freeze-up stage due to external dynamical, thermal, meteorological

forcing. A few flaw and mouth polynya, ice shearing zones are fixed. Location of zones of undercurrents and tension of ice as well a washaways is revealed from the position and orientation of cracks.

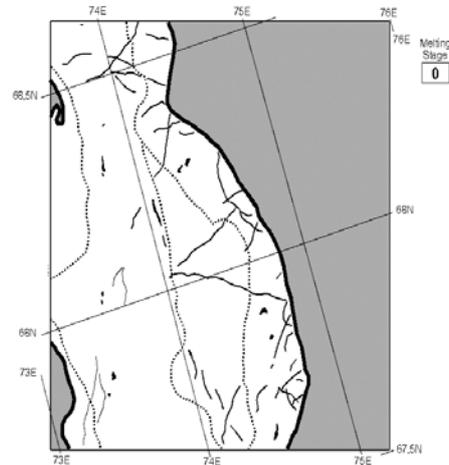


Figure 2. ERS-1 SAR image - 23 May 1996.

B) Satellite SAR studies of the river ice in the Taz Bay. Thematic interpretation of ERS-1 SAR data (26 May 1996 as example) was provided and allow to reveal a regularities of ice formation and fix some dangerous ice phenomena: vast area of ice jam (dark signature) - a zone of compressed and rafted ice causing problems for routing and transportation is. Great number of ice cracks and shearing was originated during freeze-up stage; no signs of melting of ice and snow. The system of ice arcs is contoured a zone of interaction of water masses originated from Ob and Taz.

C) Flooding and Flooded Areas in the Ob Bay. Regular multi-spectral satellite charting of the Ob river, the city Salekhard and surrounding area was provided using satellite "Resours 01" data (Melentyev *et al.*, 2001), In case of a synthesized image usage (20 June 1997) a combination of channels 4, 3, 2 "Resurs-01" data was applied for documentary fixing the extent of land flooding by river Polouy and river Ob. The flood zones were determined by comparing the satellite data with available data set of the vector maps of city Salekhard and suburbs. The industrial objects and the farming areas within the boundaries of the watering of urban construction were charted. Transforming and correction of satellite images by using topographic markers and digital electronic maps was used for selection and classification of dangerous ice phenomena, for revealing the type and degree of flooding.

D) Inter - annual variability of fresh water discharge: river Ob and river Pour as example. Inter-annual displacement and climatology of the northern limit of fresh water discharge (NLFWD) is studied using ERS/RADARSA/Envisat archive data.

ASAR 11.Mar.05 16:11z Kara Sea for MSC.

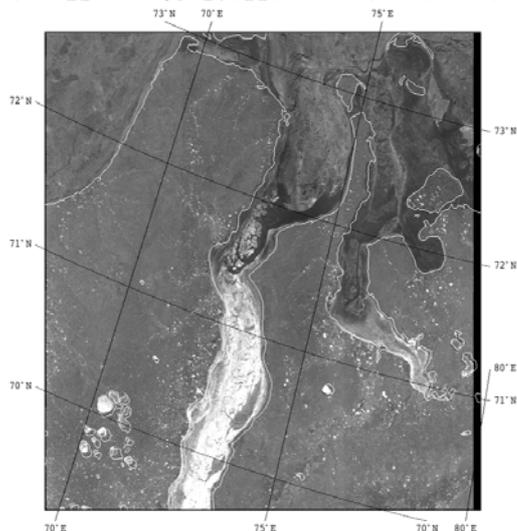


Figure 3. Satellite Envisat SAR image 11 March 2005.

In March 2005 NLFWD was situated: r. Ob – $71^{\circ}45'$; r. Pour – $71^{\circ}10'$ (bright white signature). Zone of mixing of fresh and sea waters should be located northward. Validation was provided in frame ARDEV experiment.

E) Dissolved Organic Matter, Saline and Fresh Water Discharge. The ice features of the lower Ob in fall are formed under the influence of warm and fresh waters out flowed by Ob and tundra rivers. These waters contain a lot of mineral and organic suspended particles. But a great importance is effected here also a salt waters input from the Kara sea. Processes of mixing of saline and fresh waters is determined the character of ice formation and properties of newly-formed ice: presence of salts and dissolved organic is resulted a weakening of convection and accelerate the ice formation.

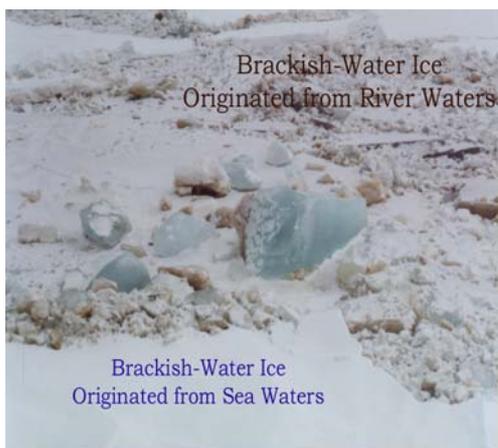


Figure 4. *In situ* observations of ice, icebreaker “Kapitan Dranytsyn”, April-May 1998.

Satellite data allows providing a zoning of the origin of ice (Figure 5). Synthesizing of multi-spectral satellite “Resours 01” data allows to divide brackish-water ice originated from river waters

(brown color) with brackish-water ice originated from sea waters (blue color).

F) Ice and water exchange between the Ob Bay and south-western part of the Kara Sea. Thematic analysis of satellite SAR data allows revealing the specific features of winter hydrology of the lower Ob and estuary. Malygin Strait due to presence of a strong clockwise current around the Island Belyy purveys the inflow of fresh waters with a greater amount of organic and mineral particle westward the Jamal Peninsula. This flux provokes the first forming of ice. Different origin of water masses and different concentration of suspended matter resulted in a reddish-yellow coloration of ice contrasting with light-blue ice formed in the Kara Sea. Differences of type of ice forming in the Ob – Yenisey, estuary and surrounding waters is fixed using satellite SAR and multi - spectral “Resours” data.

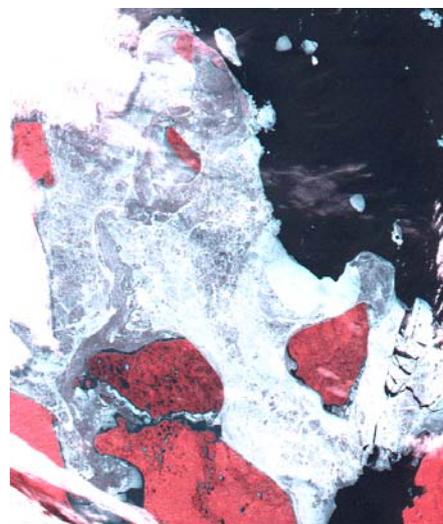


Figure 5. Satellite “Resours 01” image of the NW part of Ob Bay. 7 June 1998: 13.44 Local Time.

CONCLUSIONS

Nowadays evolution of ice regime and modification of fresh water discharge of the river Ob, Taz, Pour, Yenisey and estuaries due to global warming as well the different dangerous ice phenomena were studied by combined use of multi - spectral satellite “Resours 01” and SAR images data. The validation program supposes the providing sub - satellite investigations onboard research vessel and icebreaker in combination with airborne (helicopter) and *in situ* observations. Exemplified examples are demonstrated of the possibility of multi-purpose application of satellite data for the environmental control in the shallow waters and coastal zones in the Siberian Arctic.

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