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Use of satellite data in mapping northern Caspian ice cover

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The rapid development of space technology in the 1970s in Russia resulted in fundamentally new and promising methods for the study of the hydrological regime of seas and oceans, including the assessment of sea ice status and dynamics. Launching specialized artificial satellites (AS) and creating the network of autonomous satellite information receiver stations (ASIRS) contributed to this. In 1975, such a receiver station was created on the basis of Astrakhan Zonal Hydrometeorological Observatory (AZHO). The first TV images of the Caspian Sea ice cover were received from NOAA satellite in winter 1976. They were used to verify the position of ice boundaries and edges acquired by visual aerial ice reconnaissance. A simple and rapid method was proposed for making ice maps based on ASIRS data, and that gave a start to the regular study of the Caspian ice using satellite information.

A characteristic feature of the hydrological conditions in the north of the Caspian Sea is the formation of quite a stable ice cover in cold season. Depending on winter severity ice remains from 1.5 to 5 months a year. Ice affects maritime industries significantly. Ice cover information scope and quality requirements increase each year. This became especially important in connection with the expansion of hydrocarbons exploration and production in the freezing waters of the sea. We began using satellite ice cover data in the field-work in 1975, upon commissioning Astrakhan autonomous satellite information receiver station. The advantages and disadvantages of conventional (aerial and ground) techniques of the Caspian Sea ice cover imaging were considered. The first attempt was made for the regular use of Meteor and NOAA satellite TV images in the ice maps preparation to better meet a marine industry need for providing a prompt service, and for scientific purposes.

This revealed new possibilities offered by satellite information in the study of sea ice when it is used together with the data obtained by traditional imaging techniques. A graphic-optical technique for transforming the Northern Caspian ice cover images made by Meteor and NOAA into ice maps (rationalization proposal No. 54 (1439) of 01.08.1980) was used in the field work for the first time in the Caspian Sea in 1978.

The proposed method will significantly speed up the process of receiving and processing satellite data (a very important factor in the field work), as well as improve the informativity of ice maps produced during satellite TV images decoding by performing imaging synchronous and quasi-synchronous with air reconnaissance [1].

Comparative accuracy analysis of ice maps produced using Meteor satellite TV images with synchronous ice aerial reconnaissance showed satisfactory matching of the fast ice boundaries, drifting pack-ice edges, and the size and position of flaw polynyas, equal to an average of 3-5 miles. Moreover, satellite data receiving and processing takes a minimum of 20-30 minutes, which greatly improves ice maps efficiency and quality. This allows satellite information to be used as primary information for flight training, for the approval of regular ice reconnaissance routes by aircraft crews, for updating and refining the ice situation in those areas of the sea where ice reconnaissance was not available for whatever reasons, as well as for operational support of marine industry and scientific purposes (Buharitsin, 1983, 1984, 1987).

Thanks to satellite data we were able to trace the origins and development of flaw polynyas— an important element of the winter and changing hydrological conditions. Ice aerial reconnaissance did not give such an opportunity due to lack of observation frequency and data completeness [2].

Polynya positions and their development processes are determined by speed, direction and duration of wind effect, as well as under-ice currents speed and direction. Using satellite data helped in finding that polynyas in the Northern Caspian develop from hundreds of meters wide and 10 miles long and more and sometimes up to 100 miles long or more due to stable and strong off shore winds between fast ice and drift ice. Surface drift currents resulting from wind influence on the ice-free sea surface contribute to such giant polynyas formation. Ice conditions can change very quickly when the wind alters. Drift ice covers existing polynyas, and creates new ones on the windward side at the same time.

Extensive flaw polynyas imaged by the satellite during 1980s-90s put on a generalised map made it possible to determine the areas of the North Caspian Sea where fast ice is stable, i.e. sea areas where fast ice remains throughout the entire ice period from its formation until ice fracturing in spring.

It was found that fast ice boundaries movement to the south does not occur gradually during the formation of ice, as was previously believed, but irregularly by tens of miles at once, as drift ice consolidates under the influence of wind and its subsequent freezing. The boundary between the older and newer fast ice are often clearly marked as kilometres of hummocky ice ridges similar to those which are formed in the Arctic seas drift divides. They are clearly visible on satellite images and easily deciphered.

During aerial ice reconnaissance in midwinter, observers often noted the presence of polynyas in those sea areas where fast ice was expected to be found. Attempts to explain this by the presence of only the dynamic factors (subglacial currents, ice drift) had not been confirmed.

Information about such polynyas has been accumulating with the appearance of satellites. Analysis of accumulated aerial and space data resulted in a conclusion that some polynyas are formed annually in the same places. S.A. Brusilovsky (1986) suggested that polynya locations are related to salt domes present in the Northern Caspian waters. Further studies confirmed this relationship: recurring polynya locations coincide with salt domes cropout on the North Caspian Sea bottom [2].

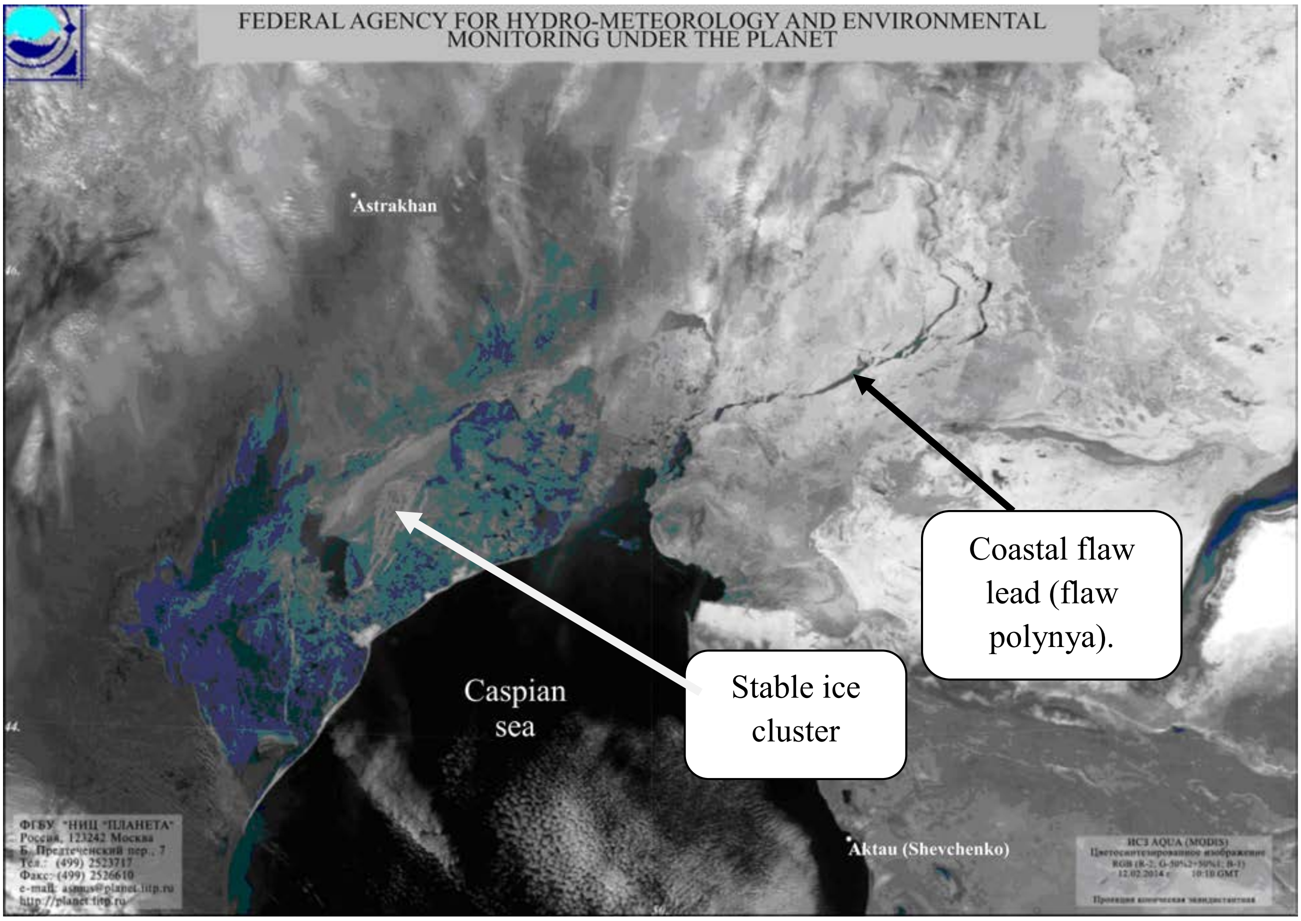

Figure. 1. AQUA (MODIS) image of the Northern Caspian waters with highlighted characteristic elements of the ice cover.

It has become possible to trace daily incremental ice distribution variations throughout the Northern Caspian thanks to the compatible aerial and satellite data, which could not be done using traditional methods of the past, including aviation. The findings are as follows:

- Drift ice in Guriyev Borozdina (“hollow”) does not enter the shallow Buzachi threshold in the western part of the sea even during intensive westward drift at the periods of lowstand at minus 29.0-28.5 m.abs. levels. Ice drift is limited by the physical dimensions of Guriyev Borozdina.
- Ice fractures and flaw polynyas appearance and positions depend on wind direction, speed and duration (Fig. 1).
- There is stable ice cluster that forms between the islands of Chistaya Banka and Little Pearl every year, and preserved there during the winter season (Fig. 1).
- The sequence of fast ice break processes in spring was traced.
- The possibility of detecting and identifying polluted ice boundaries was confirmed.
- The possibility to detect and determine the extent of spring ice blockages in the marine part of the Volga-Caspian canal.

Weather (mainly cloudy) affects satellite data quality and quantity significantly. Clouds reduce ice maps informativity drastically, and heavy clouds (7-10 score points) make using satellite TV imagery data completely impossible. The informativity of ice maps created using satellite imaging makes up 20-70% (average of 50%) of aerial ice reconnaissance informativity, which is taken as 100%.

Satellite ice information has been received, interpreted and used for operational and scientific purposes according to the guidelines (Buharitsin, 1981) since the winter of 1978-79. In subsequent years, ice cover data for the Northern Caspian has been received and processed by AARI, the Unified National Ocean Status Information System (UNOSIS) and other organizations, including foreign ones, on a regular basis. Aerial ice reconnaissance in the Northern Caspian has ceased almost completely in recent years, and satellite data have been the only source of information on Caspian ice distribution and dynamics. An electronic archive of the Northern Caspian ice maps was created as a result of long-term ice research. [3]

Analysis of strategic ice maps compiled by UNOSIS and AARI in winter season 2013 using satellite data showed high reliability and accuracy of ice cover characteristics such as the position of fast ice and floating ice boundaries, flaw polynyas and leads, compacted and open-pack ice zones, drift ice closeness and ice floe dimensions, and snow-covered ice (Fig. 2). However, one of the most important features, i.e. thermally accumulated ice thickness indicated on ice maps with respective symbols, does not correspond to the actual measured in-situ ice thickness. Thus, the results of numerous actual instrumental measurements of fast and floating ice thickness in the eastern part of the North Caspian made by the authors during the period from 6 to 15 February 2013 showed that minimum flat ice thickness was 45 cm, and the maximum made up 90 cm (corresponding to thin and medium size white ice classes) (Table 1).

According to the same satellite ice maps, ice thickness maximum does not exceed 25-30 cm of gray-white ice (Fig. 4) both in the western and eastern part of the sea for the entire cold season. This suggests that ice thickness estimates made on the basis of satellite images are currently very approximate and do not provide reliable and accurate results, so satellite information must be adjusted and corrected using ground-truth data (terrestrial) observations.

Table 1. Thermally Accumulated Ice Measured Thickness.

Observation date	**Measurement point No.**	**Coordinates**	**Sea depth, m**	**Measured ice thickness, cm**	**Remarks**
06.02.2013	1.	N 46^o 12' 00"; E 50^o 34' 02"	4,0	48	Measured dimensions of ice floes in hummocks (cm): 30×60; 80×120; 150×200. Individual floes reach the size of 2×4 m. Ice floe thicknesses ranging from 45 to 53 cm
	2.	N 46^o 12' 00"; E 51^o 00' 00".	6,5	40	Floating ice
08.02.2013	3.	N 45^o 52' 30"; E 51^o 00' 00"	9,0	41	Floating ice
	4.	N 45^o 52' 20"; E 50^o 45' 10"	3,5	45	Floating ice
	5.	N 45^o 59' 59";	7,9	45	Point No. 5 is in close

		E 51° 41' 74"			proximity to the giant ring stamukha formed presumably in late December-early January. Its extends for about 300 m. Height of the most prominent peaks of the stamukha had been measured by a helicopter altimeter: 10m, 13m, and 15m. The highest instrumentally measured peak reaches 17 meters. The stamukha incorporates ice floes of different sizes, from 30×30 cm to 100×150 cm and bigger. Some ice blocks are the size of a small room. Ice thickness varies within a wide range from 45cm to 90 cm. The most common thickness is 53-60 cm
15.02.2013	6.			54	Shore-fast ice
	7.	N 46° 53' 79; E 50° 28' 95		53	Fast ice, 5 km from the coast
	8.	N 46° 49' 35"; E 51° 26' 836		54	Fast ice, 10 km from the coast
	9.	N 46° 45' 006; E 51° 22' 980		45	Fast ice
	10.	N 46° 41' 133; E 51° 18' 465		49	Fast ice, 15 km from the coast
16.02.2013	11.	N 46.07.30; E 50.53.30	7,9	47	Floating ice
	12	N 45.57.60; E 50.47.00	3,6	48	Floating ice
	13.	N 45.57.60; E 50.53.30.	4,0	47	Floating ice
	14.	N 46.02.60; E 50.40.30	5,1	49	Floating ice
	15.	N 46.02.60; E 50.47.00.	5,5	50	Floating ice

	16.	N 46.02.60; E50.53.30	7,05	50	Floating ice
17.02.2014	17.	N 46.10.10; E 50.50.00	5,2	47	A small stamukha nearby the measurement point
	18.	N 46.10.10; E 50.53.30	5,9	49	Floating ice
	19.	N 46.10.10; E 50.57.00	6,0	47	Floating ice
	20.	N 46.07.30; E 50.40.30	4,0	47	Floating ice
	21.	N 46.07.30; E 50.47.00	4,9	53	Floating ice
	22.	N 46.07.30; E 50.57.00	7,0	49	Floating ice
18.02.2014	23.	N 46.00.00; E 50.37.30	5,2	48	Floating ice
	24.	N 45.54.00; E 50.41.10	7,0	49	Floating ice
	25.	N 45.52.30; E 50.37.30	4,0	47	A stamukha nearby the measurement point
	26.	N 45.48.30; E 50.53.30	4,5	45	Hummocks ridge extending from north to south, it stretches for 1.5-2.0 km. The ridge height is 2.0-3.0 metres.
	27.	N 45.45.00; E 50.37.30	4,0	49	Floating ice

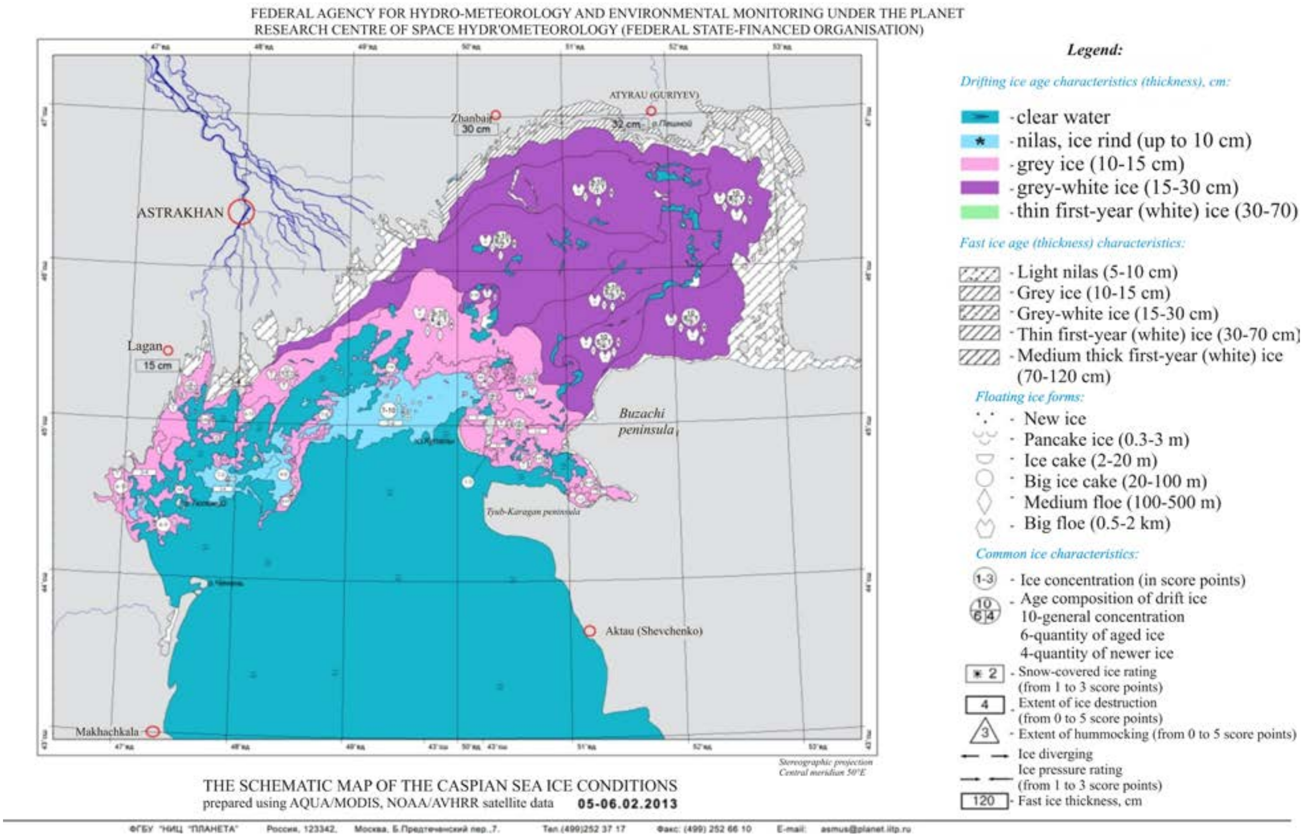

Figure. 2. The schematic map of the Caspian Sea ice conditions prepared in AARI using satellite data.

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