Cover

ERS-1/2 SAR monitoring of dangerous ice phenomena along the western part of Northern Sea Route

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The Northern Sea Route (NSR) as a part of the Arctic Ocean is very important for sea transportation to the Siberean coastal and river settlements, as well as for future transportation between Europe and the Pacific Ocean countries. Recent opening of the gigantic oil and gas deposits on the Siberean shelf will require the build-up of a special fleet for efficient marine oil and gas operations in this area.

However, round-the-year navigation as well other marine operations (fishery, mining, oil and gas reconnaissance, etc.) at the different parts of the Arctic Ocean is a very complicated problem and an optimal choice of the concrete sea route directions depends on numerous environmental factors.

Environmental conditions which determine the high-latitude navigation in the North Pole area depend on seasonal and mean-annual distribution of water masses in the Arctic Ocean.

An important factor which influences marine operations in the Arctic Ocean is the presence of round-the-year ice. This is a complicated regional and global-scale process which depends on the location and properties of basic oceanic massif ice regime, on patterns of seasonal and mean-annual distribution of the basic massif's spurs, on the behaviour of the local ice massifs which in each area of the Arctic Ocean have their own characteristic features of the seasonal and mean-annual variability.

The location and drift of the basic oceanic ice massif's spurs are variable parameters. These spurs consist of the residual first-year ice, and the second-year and multi-year pack ice floes. The thickness of this ice can be more than 3 m and its invasion in the NSR area creates an especially dangerous situation for marine operations. Control of this phenomenon by all-weather remote sensing instruments is therefore extremely desirable.

Another significant factor which creates the favourable influence for the ice navigation in the Arctic Ocean is the round-the-year presence of the vast recurring

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polynyas in the compact pack ice area. Ice conditions in these polynyas are lighter and therefore the determination of their presence and the precise evaluation of their location should be made by means of all-weather satellite data.

A short summary of the parameters describing the massifs and polynyas is as follows (Krutskikh 1978):

(*a*) The location and state of the pack ice edge, ice concentration and boundaries.
(*b*) The total and partial (according to development) concentration of the pack ice.
(*c*) The general features of pack ice dynamics.
(*d*) The location of the open water and friendly ice areas in the ice.
(*e*) The ice age (development) parameters.
(*f*) The extent, thickness, hummocking and other parameters of fast-ice.

The present study of this problem is based on the availability of ERS-1/2 Synthetic Aperture Radar (SAR) images from the western part of the Arctic Russian coastal waters collected since 1992 (*Johannessen et al.* 1996). From 1993 ice information derived from ERS-1/2 radar images has been transmitted to the Russian nuclear icebrakers (I/B) operating along the Siberean coast and to the Marine Operational Headquarters in Dikson. Studies have the overall objective of validation, decoding and thematic interpretation of ERS-1/2 SAR data to provide near real time satellite monitoring of the ice cover in the Kara, Barents and Pechora Seas, and aim to plan and assess risks of round-the-year ice navigation along the western part of the North Sea Route. Studies were accomplished within the Agreement on Technical Cooperation with Icebreaker Fleet Service of the Murmansk Shipping Company (MSC). From the fall of 1995 this study was continued as the cooperative Project between the European Space Agency and the Russian Space Agency.

Figure 1 (cover) demonstrates the example of revealing one of the dangerous ice phenomena: invasion of multi-year and residual ice floes to the main ship line in the NSR area. The mapping of the compact and very close pack ice breccia location, which sometimes filled the whole Vilkitskogo Strait area, was of considerable help in choosing the optimal route for the nuclear icebreaker (I/B) *Sovetskiy Soyuz*. It should be noticed that on 4 November 1993 at 13:40GMT the ERS-1 SAR image fixed an especially dangerous situation when invasion of the residual and old ice floes in this region was accompanied by the closing of the alternative route through the Taymyrskaya recurring polynya.

Vilkitskogo Strait is one of the narrow parts of the NSR area which creates many problems for convoy steering from Murmansk to the sea ports in the east. Invasions of multi-year ice similar to the one shown create a situation which may be compared to a cork in a bottle.

Our analysis of more than three years ERS-1/2 SAR archive data confirms that the ice conditions in the Vilkitskogo Strait are defined by the dynamics of ice regime of the following three ice massifs:

1. The Severokarski massif of pack ice, which has the maximum area 217 000 km^2.
2. The Severozemelski massif of fast ice, maximum area is 278 000km^2.
3. The Taymyrski massif of pack ice (situated in the northwestern part of the Laptev Sea and joins the east shores of the Severnaya Zemlya Archipelago and the Taymyr Peninsula).

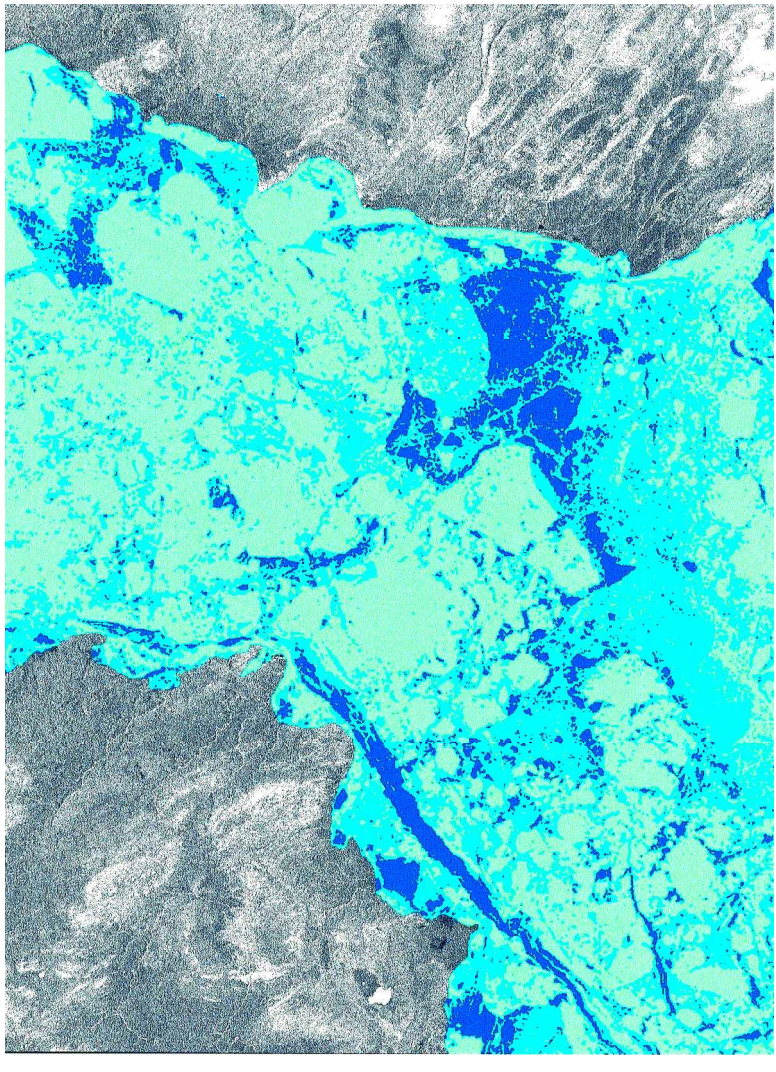

Figure 1. ERS-1 SAR image, 4 November 1993. ©ESA 1993. The image covers 100 by 150 km of the Vilkitskogo strait centered at 78°N and 104°E, between Bolshevik island (upper part of the image) and Cape Chelyuskin (lower part of the image) which is the northernmost point of the Eurasian continent. Colour code: light green: multiyear ice; blue: first-year ice; dark blue: thin ice; various grey shades: land areas.

Invasion of the hostile multi-year ice floes into the NSR area is of course a very dangerous phenomenon which happens frequently. Another type of dangerous natural process that takes place in the Arctic Ocean is the occurrence of almost unknown ice phenomenon which happens under relatively light ice conditions. This is the so called 'ice river' or organized ice flux. This phenomenon has been mapped by the ERS-1 SAR on seven occasions from December 1994 till April 1995. It was mapped on 9 January 1995; 07:44GMT in the image shown in figure 2.

The winter of the 1994–95 season was abnormally warm in the Kara Sea, and ice navigation along this part of the NSR was relatively easy. The ice edge was

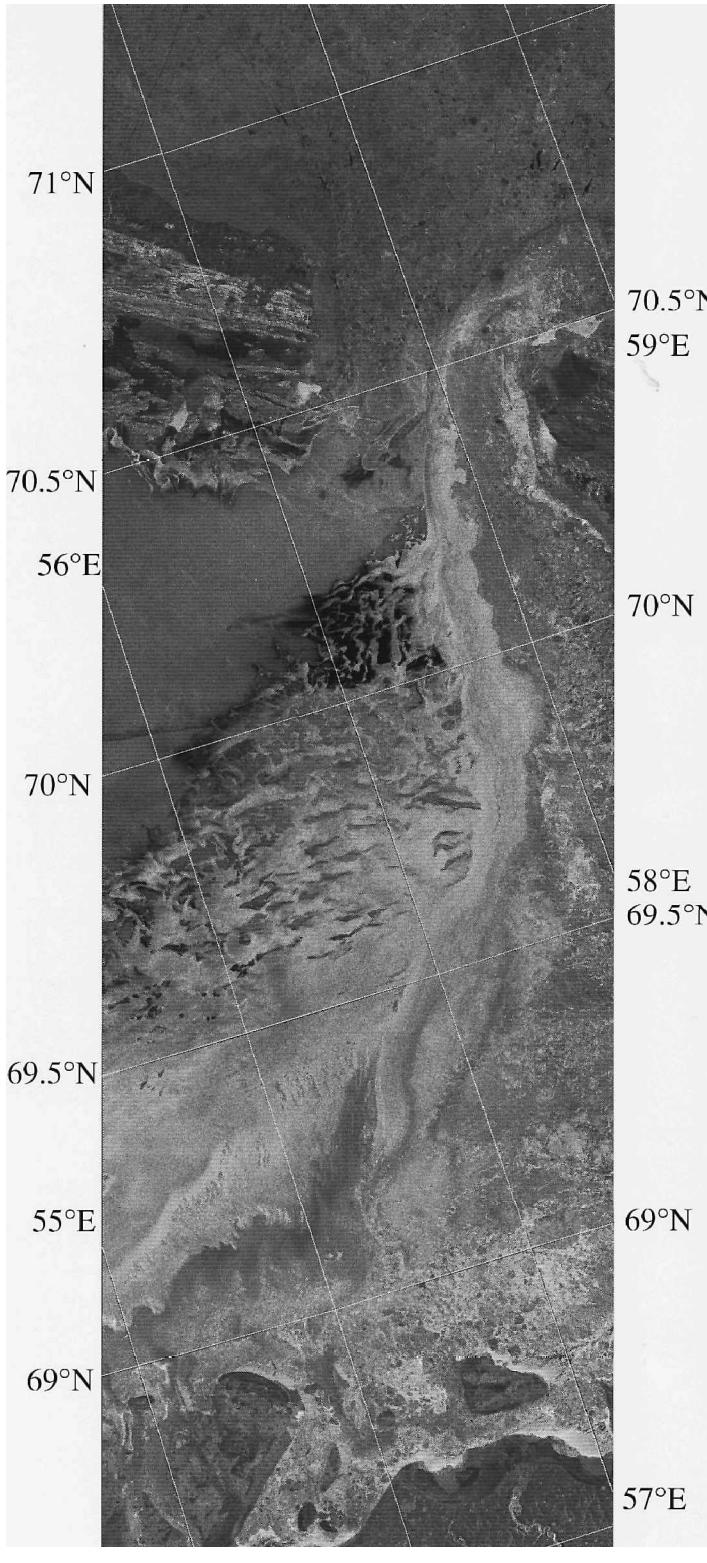

Figure 2. ERS-1 SAR image, 9 January 1995. ©ESA 1995. The image covers 100 by 300 km of the area between the Kara Gate between Novaya Zemlya and Vaigach island (70.5°N) and the Russian mainland (south of 69°N).

generally located in the southern part of the Kara Sea, and all commercial ships sailed through the Kara Gate without the need for icebreaker assistance. The dangerous 'ice-river' is caused by a specific combination of the atmospheric and ice processes in this part of the Kara region. It consists of a very small ice cakes and brash ice. This randomly orientated flux of small particles can move with a rather high velocity and is very dangerous because it can force even large vessels under the waterline, damage the rudder and the propellers. A ship without the possibility to steer can easily be grounded on the shallow banks. As we see from the ERS-1 SAR data the scale of this phenomenon is very large, i.e., almost 200 km. The nuclear icebreaker *Lenin* met this situation in the seventies and lost near 2 days in the Kara Gate ice river. Such ice phenomena are usually unexpected ones for crews. It takes place under heavy cloud and cannot be controlled by traditional *in situ* and satellite observations. Only the use of ERS-1/2 all-weather mapping can in this case strongly improve the safety of the Arctic Ocean navigation.

It is also important that the use of ERS-1/2 images by mapping of the ice motion make the study of heat transfer to and from the Kara Sea possible, and also the evaluation of the volume, the time and spatial scale of the water and ice exchange between Kara, Laptev and Pechora Seas. In conclusion, our examples demonstrate the possibility of using the all-weather radar satellite system for the ice and ocean monitoring, especially in support of Arctic marine operations and ship routing through the Northern Sea Route.

References

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