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Ice charting based on multispectral satellite data in the Baltic Sea

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ABSTRACT. Results are presented from an experiment concerning operational space-borne ice charting based on the Russian Ocean and Resource satellite systems. The surface truth consisted of routine operational data, helicopter-borne reconnaissance, and some ground measurements. Examples of the satellite imagery are given and identification of ice types is described. Cluster-analysis has been used for automatic image segmentation. The potential of these satellites in operational ice charting is discussed. A 160 m resolution optical scanner and a 2 km resolution radar are found to be very useful complements to the present routine system.

INTRODUCTION

Ice occurs annually in the Baltic Sea for up to six months. Due to the needs of winter shipping, operative ice charting is performed daily by the Ice Service of the Finnish Institute of Marine Research (FIMR). The principal sources of ice information are remote sensing satellites, primarily the NOAA series. These provide an excellent basis but have some limitations. Their reliability is weather-dependent and the spatial resolution (1.1 km) is limiting for local ice observations.

Research is in progress to develop remote-sensing methods further, e.g. utilisation of the ERS-1 satellite (Leppäranta and others, 1993). This new research also includes examination of the potential for using the Russian Ocean and Resource series satellites (Golovko and others, 1991).

Ocean and Resource satellites provide new additional input to local ice mapping systems through two windows: high to moderate resolution (30–300 m) optical scanners and a low resolution (2 km) radar. The goal of the project is to examine the use and usefulness of a real-time data transmission system whereby (1) the satellite data are received in Moscow by NPO Planeta, (2) the data are pre-processed at NPO Planeta, (3) products are transmitted to Helsinki via telephone, and (4) the products are integrated into the Ice Service ice charting system.

This paper considers an experiment in March 1990 in the Bay of Bothnia, northern Baltic Sea, consisting of validation and real-time data transmission of sensed ice conditions.

THE EXPERIMENT

Routine ice charts and reports provide information for the validation of the satellite-sensed data. These are produced daily by the FIMR Ice Service and are based on NOAA/AVHRR data, aerial reconnaissance, observations at coastal stations and observations from icebreakers. The data describe ice type, ice concentration, ice and snow thickness, ridging intensity, and the occurrence of leads. For this experiment in March 1990, additional ice information was obtained from a specific measurement campaign (Leppäranta and others, unpublished).

Ice and weather conditions

The ice season 1989/90 was very mild, of a kind that occurs on average less than once a decade. In March the Bay of Bothnia was 50 to 70% ice-covered (Fig. 1). The best satellite data were produced on 3 and 24 March. On these days the ice extent was similar, but other ice conditions and meteorological conditions were markedly different.

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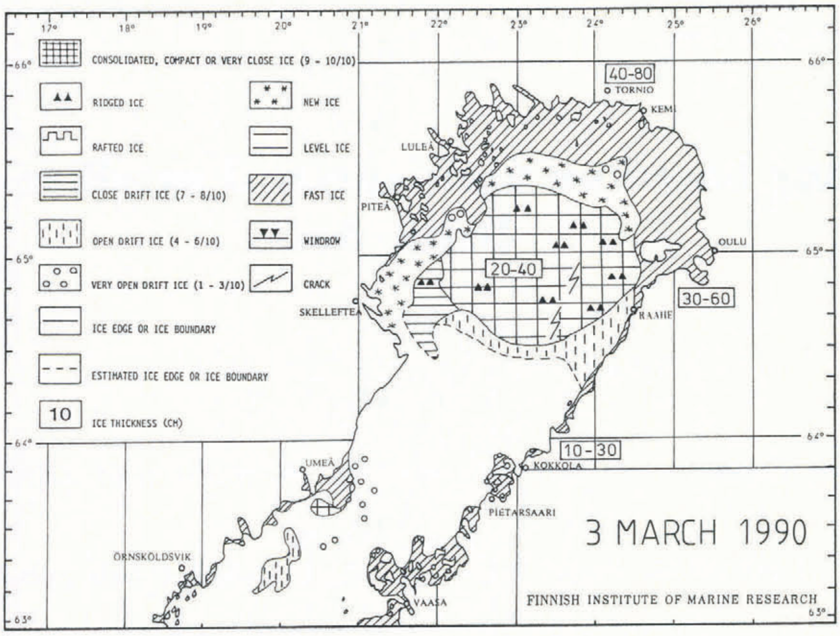

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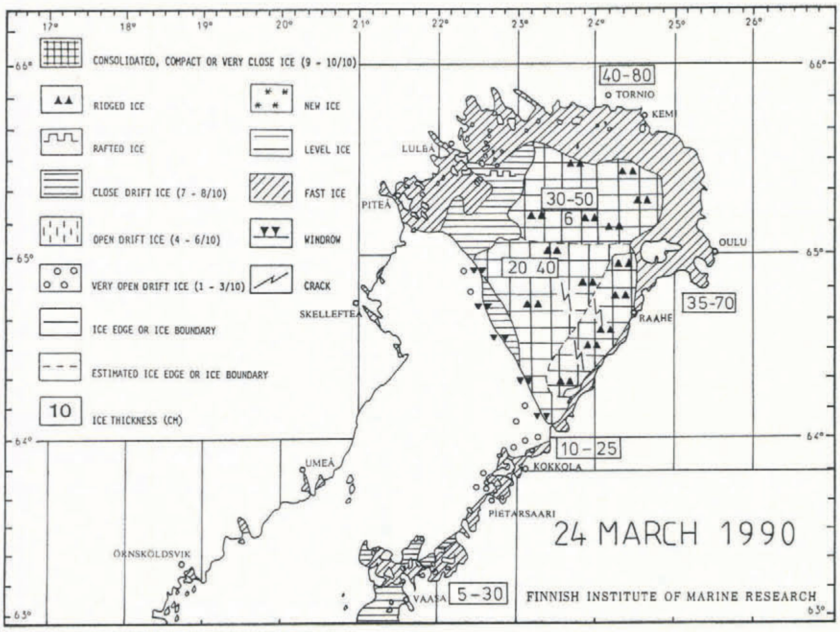

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Fig. 1. Ice conditions in the Bay of Bothnia on a, 3 March 1990, and b, 24 March 1990.

Meteorological conditions on 3 March were near average for the mid-winter period. Air temperature was –4.2 to –6.6°C and the wind was 8 to 12 m s^{-1} from the northwest. There was fast ice on the coast and archipelago areas in the Bay of Bothnia (Fig. 1a), 40 to 80 cm thick in the north decreasing to 10 to 30 cm in the south. Snow thickness was 5 to 15 cm. In the north and west there was a 10 to 20 km wide lead at the fast-ice edge. The heaviest pack ice was concentrated in a patch about 100 km wide, consisting of ice floes 20 to 40 cm thick and up to 2 km wide; between the floes there was new ice. Ridges were most frequent in the northern side, with sail heights typically 0.3 to 0.5 m. In the south the surface was in places bare. Further south, beyond the heavy pack ice, there was a narrow zone of open drift ice, concentration 4 to 6/10; the thickness of ice was 10 to 30 cm and the surface was mostly bare. The ice edge was located at 64°30′ N.

Cold weather prevailed until mid-March. The spring melting season began with strong winds from the southwest compressing the ice northeast and causing the ice edge to shift slowly. New ridges formed in the drift ice field. On 24 March the air temperature was –1.8 to +0.3°C. The ice edge lay in the centre area of the basin (Fig. 1b). Off the fast ice boundary there was a heavily ridged ice field, thickness 30 to 50 cm. There were also leads and cracks in the boundary region. Southwest from the heavily ridged ice field there was 20 to 40 cm thick very close drift ice consisting of floes 1 to 100 m wide, partly frozen together. At the ice edge there was a 200 to 400 m wide brash ice belt. The ice surface was bare in places. Snow, when it occurred, was very wet and melt ponds existed in both drift-ice and fast-ice regions.

Satellite data

NPO Planeta Scientific-Industrial Corporation exploits the Russian space systems Meteor-2 and-3, Ocean-01 and Resource-01 (Vasuyukhina and Volkov, 1988). Ocean-01 and Resource-01 are studied for Ice Service ice mapping systems. Ocean-01 has an X-band Side-Looking Radar (SLR) with about 2 km resolution and 450 km swath width. Simultaneous pictures from the SLR and from an optical scanner with the same scale and space resolution are provided for Arctic shipping in the Northern Sea Route. Resource-01 is equipped with optical and infrared sensors for more accurate mapping of the earth's surface. For ice mapping in the Baltic Sea the Multizonal Conical Scanner with Moderate Resolution (MS-MC) is expected to be very helpful. For a swath width of 600 km, the system has four channels in the optical and near-infrared regime with 160 m resolution and one thermal infrared channel with 600 m resolution. Table 1 shows the data collected for further analysis in the March 1990 experiment. They consist of two Resource-01 MS-MC images and two Ocean-01 SLR images.

Table 1. The satellite data for the experiment in March 1990

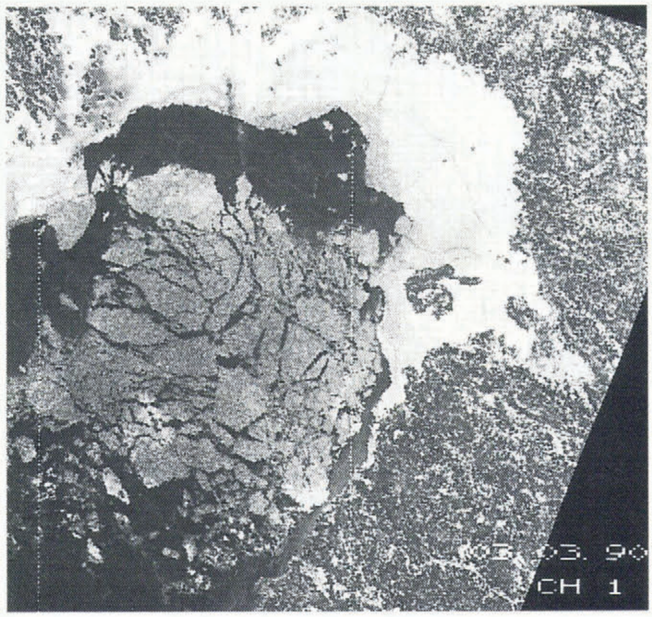
Satellite	*Channels*	*Time*
Resource-01	0.5–0.6, 0.6–0.7, 0.8–1.1, 8.0–11.6 μm (Nos 1, 2, 4, 5)	3 and 24 March; 1500 UTC
Ocean-01	X-band (3.2 cm)	18 and 28 March; 0600 UTC

The main requirement of digital imagery comparison is pixel-by-pixel compatability. For the MS-MC data set being used this has been made possible through transformation of the data into a single cartographic projection, with the same centre and scale for each image. Brightness signatures were smoothed, error lines removed, and the images transformed to Mercator projection. The final resolution was 320 m. The thermal channel pixels were doubled to get the 320 m apparent pixel size. The thermal image was then matched with the other channels.

RESULTS

Resource-01

One optical channel and the thermal channel data from Resource-01 for 3 March are shown in Figure 2. They illustrate the main features in the ice pack. The optical data show, in the north, the snow-covered fast-ice zone as white and the large lead as black. Grey tones in the pack-ice field indicate variable snow conditions in the region. Also seen in the ice field are a number of small leads and fractures. The thermal image shows the surface temperature differences. The more ice and snow, the colder the surface. The leads are best seen in the thermal image which shows high contrast between open water and older ice. At the lead edges there appear colder zones which are due to new ice production. These new ice zones do not show up well in the other channels. For the 24 March case the interpretation of the imagery is more difficult since much of the contrast has disappeared due to the melting of snow during the month. The near-infrared channel data are shown, for example, in Figure 3. The ice edge in this image is remarkably clear.



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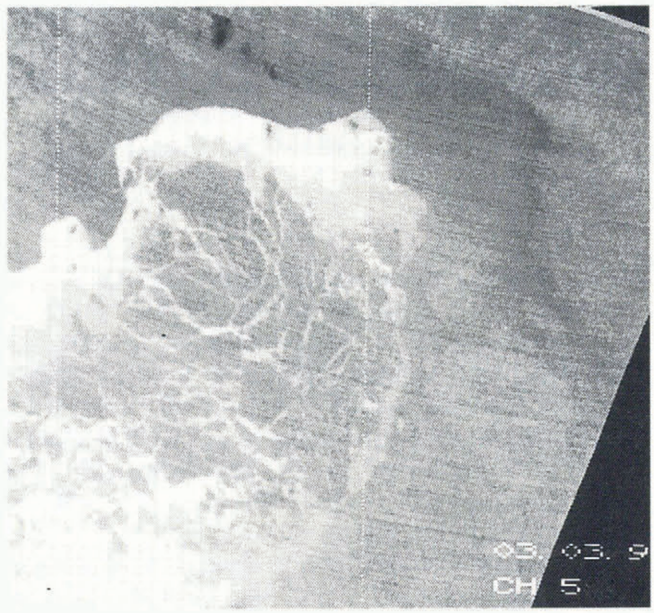

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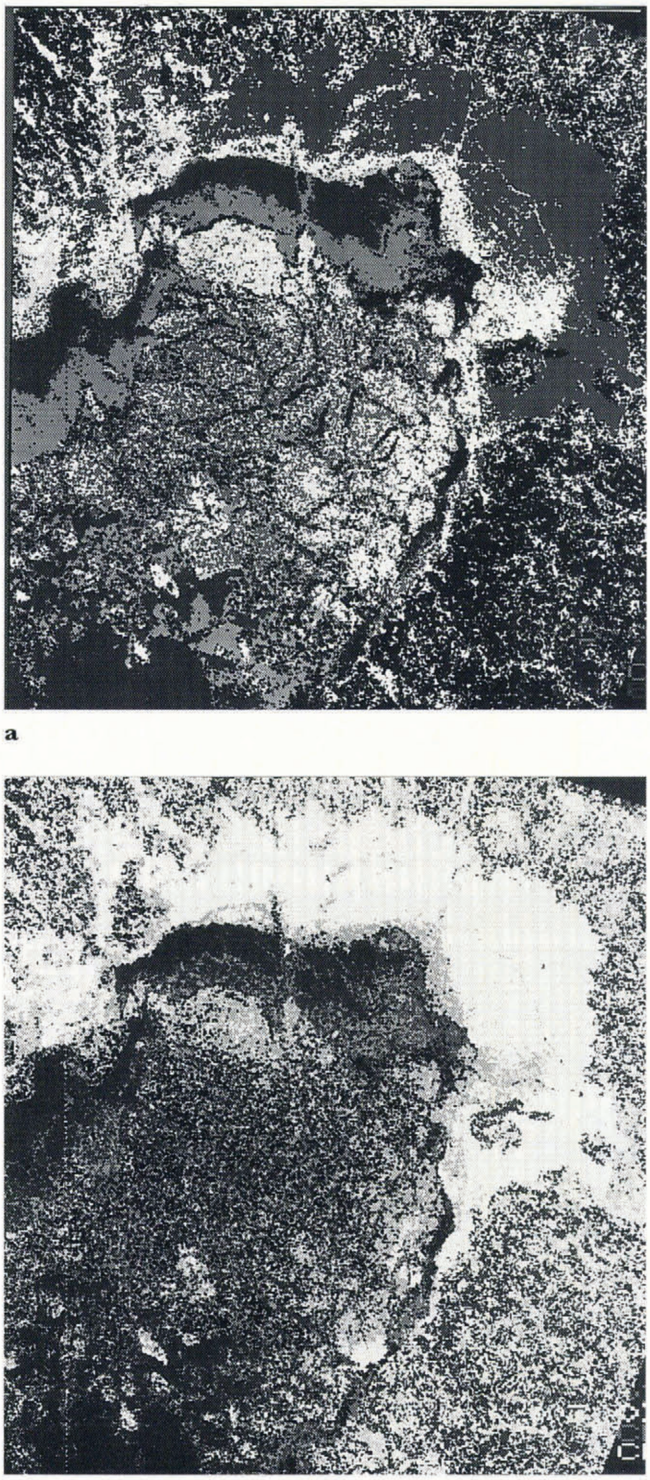
Fig. 2. Image over the Bay of Bothnia taken with Resource-01 MS-MC, 3 March 1990. a, channel 1 (0.5-0.6 μm) and b, channel 5 (8.0–11.6 μm).

To produce objective satellite information on ice fields, cluster analysis was performed on the data. The algorithm used is a so-called self-teaching system which uses a 16 × 16 or 32 × 32 base grid and a Euclidean

Fig. 3. Image over the Bay of Bothnia taken with Resource-01 MS-MC, 24March 1990. Channel 4 (0.8–1.1 µm).



a

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Fig. 4. Cluster analysis results for 3 March 1990. a, 10 clusters, channels 1, 4 and b, 14 clusters, channels 1, 4, 5.

distance measure for the multi-channel pixel values. This algorithm, tested earlier on NOAA/AVHRR data, has been found useful for ice-field classification (Golovko and Pakhomov, 1988; Golovko, 1990). For the 16 × 16 grid the mean brightness varied within 1 to 20%, while the standard deviation did not exceed 5%. A set of 10 clusters was found characteristic for the present imagery. The most informative channels for 3 March were sets {4,1,5} and {4,1} and for 24 March, set {2,4}.

Comparisons between cluster analysis products and one-channel images show that this method is able to reveal new features in the ice field (Fig. 4). For the 3 March case, the snow-covered consolidated ice is much more clearly discriminated in the cluster analysis product. This is also true of new ice and open water. The ridged ice zone at the fast-ice edge becomes observable in the cluster analysis product. For the 24 March case supporting results were obtained. New ice was well discriminated from open water and from older and thicker consolidated floes.

Ocean-01 radar

In March 1990 two radar images were obtained (Table 1). The quality was not high because the relatively wet surface conditions smoothed much of the contrast in the backscatter intensity. Figure 5 shows the radar image for 28 March. It can be compared with the ice chart for 24 March shown in Figure 1b. It is easy to recognise the coast, the coastal fast-ice zone (low backscatter), drift ice (variable return strength), and then the open water (low backscatter). Although no details can be seen, it is clear that this kind of all-weather ice information might be particularly valuable in bad weather conditions. Lost structure detail in low-resolution radar images was also pointed out by Askne and others (1992) for the Baltic Sea.

DISCUSSION AND CONCLUSIONS

Preliminary results have been presented here, from a joint Russian–Finnish project aimed at utilising Ocean and Resource-series satellites in operational ice charting in the Baltic Sea. The work is based on a campaign in March 1990 in the Bay of Bothnia. The original satellite data

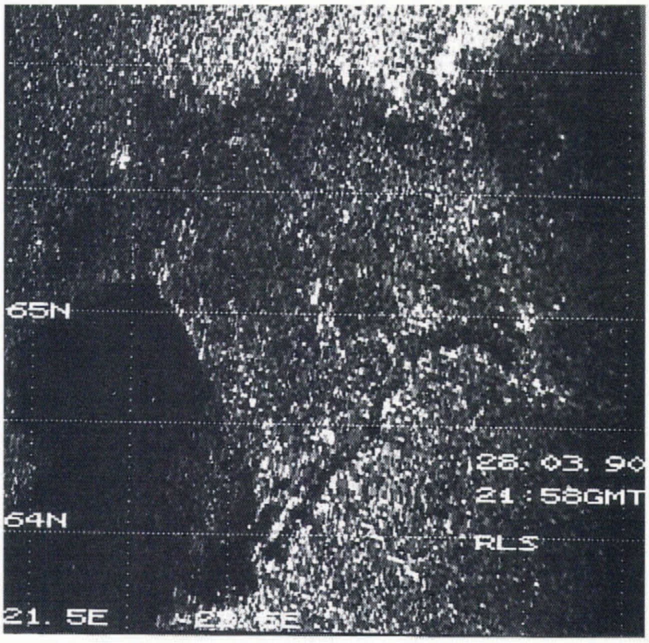

Fig. 5. Ocean-01 Side-Looking Radar image over the Bay of Bothnia, 28 March 1990.

showed very good correspondence with independently produced ice charts. The use of cluster analysis for analysing the multichannel satellite images revealed features which were not well seen in the original one-channel data. Clusters coincided with ice types and open water and described in more detail the structure of the ice pack.

The results lead to the following conclusions: (1) moderate resolution (160 to 320 m) optical and near-infrared imagery is very useful for Baltic Sea ice mapping, (2) the use of low resolution (2 km) side-looking radar seems promising although problems of interpretation need further research and (3) cluster analysis is a powerful aid for ice-type classification. Research into techniques for further utilising the Ocean and Resource satellite data is presently in progress. In particular, a real-time ice monitoring campaign was incorporated in the International Space Year (1992) activities in the Baltic Sea (Strübing and others, 1991). However, the 1992 ice season was particularly mild and a new campaign is still required to evaluate the Ocean and Resource systems fully.

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