ERS-1 SAR over open water in the Baltic Sea

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ABSTRACT

ERS-1 SAR imagery from the wintertime Baltic Sea are examined for oceanographic studies and for finding help for the ice/open water discrimination. A qualitative analysis has been made of the open sea SAR imagery using the low resolution (100 m) data from January-March 1992. The following features were found: (1) Surface wave and swell fronts and wave breaking; (2) Traces of wind fronts; (3) Internal waves; (4) Smooth slicks on the lee side of islands and at the ice edge; (5) Small eddies; and (6) Fresh water plume from a river. These results are described here.

1. INTRODUCTION

Sea ice remote sensing has been a major research field in the Baltic Sea since mid-1980s. This has been motivated by the needs of basic sea ice science as well as operational ice charting and reporting (e.g., Askne et al., 1992; Leppäranta et al., 1992). Active microwave methods have been of particular interest because of their weather independency and high resolution; consequently, a local effort BEERS (Baltic Experiment for ERS-1) was designed as a part of PIPOR (A Programme for International Polar Oceans Research) to examine the use of ERS-1 SAR in ice mapping in the Baltic winter.

For sea ice remote sensing in the Baltic Sea, the discrimination between ice and open water is generally recognized as the primary problem. For this problem radars provide essential information as the radar return is normally different for ice and open water surfaces. However, the difference may have either sign due to the very high sensitivity of the open water backscatter to winds which modify the near-surface layer of the sea (see, e.g., Fedorov and Ginsburg, 1992). Therefore information additional to radar data is needed. Knowledge of the wind would be a way to discriminate ice and open water (e.g., Askne and Ulander, 1989), possibly used in a surface layer model for the sea. Apart from the geophysical conditions, the open water and ice signatures are sensitive to the radar imaging geometry.

The BEERS experiment has created a lot of interesting SAR imagery over open water surfaces. A careful qualitative analysis has in the following been made of these data. The purpose is to identify structures created by the Baltic Sea upper layer physics. Such analysis is interesting as the first one of its kind in the Baltic Sea and also as providing guidance to the ice/open water discrimination problem. The present paper gives the results of this qualitative analysis.

2. THE DATA

The winter 1992 was very mild, and the BEERS campaign was performed in the Bay of Bothnia, northern basin of the Baltic Sea during January-March 1992 (Leppäranta et al., 1993). Validation data for the ERS-1 SAR were collected through the whole period, consisting of routine operational data (FIMR, 1992) and results of two field experiments based on R/V Aranda (Leppäranta and Lensu, 1992).

The ice charts provided the basic information about the boundaries of the ice and open water areas. An example of typical ice conditions is shown in Fig. 1. The ice edge lay most of the time in the northern part of the Bay of Bothnia and much of the research areas mapped were open water. Leads occurred occasionally at the fast ice boundary. As the BEERS field effort was ice-oriented, information of oceanographic conditions is limited. However, good wind data are available from the coastal weather stations, most helpful background data for understanding the sea surface roughness.

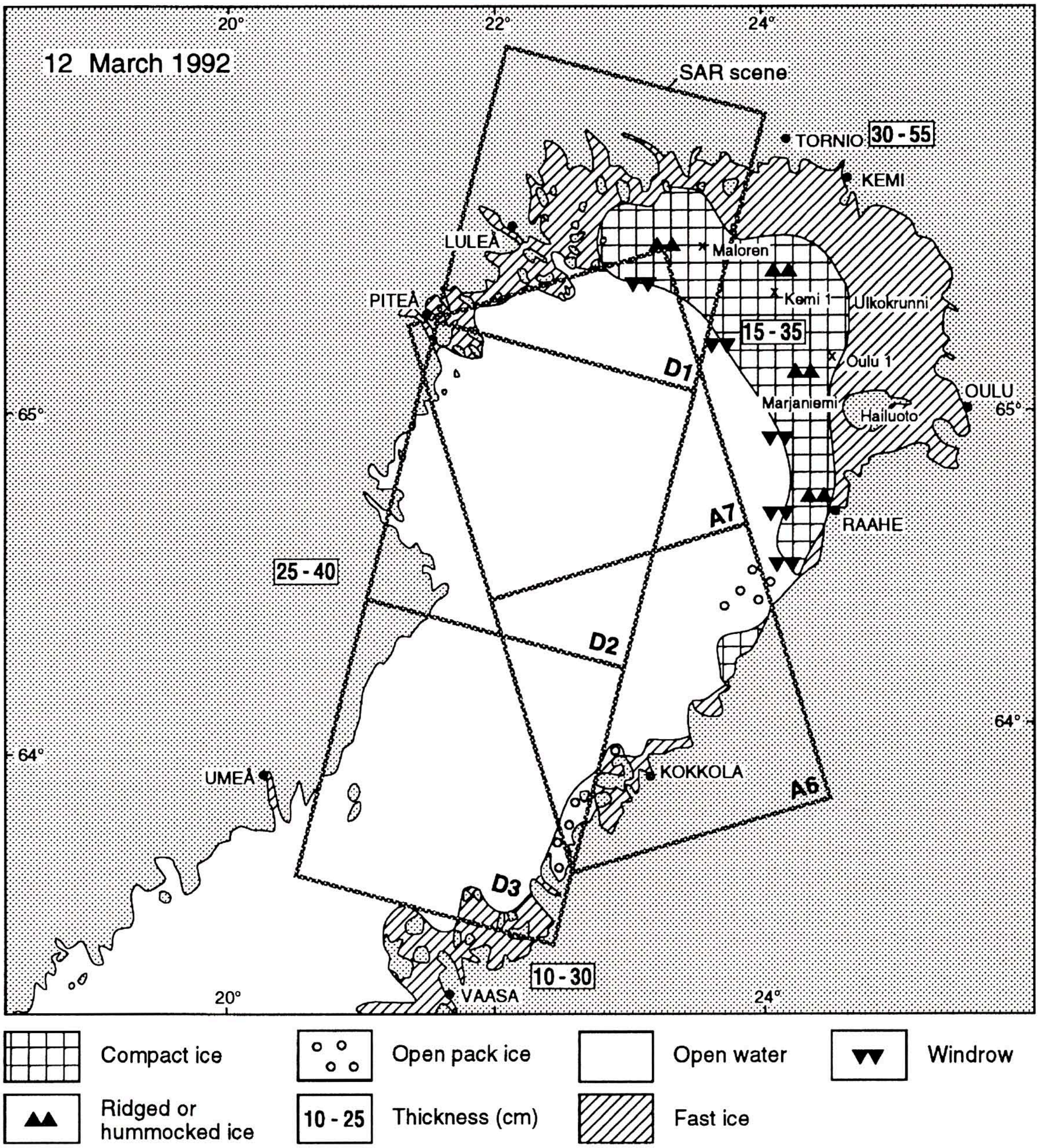

Fig. 1 - An ice chart of the northern Baltic Sea on 12 March 1993 (FIMR, 1992). Also shown are the scenes A6-A7 from the ascending orbit A and scenes D1-D3 from the descending orbit D. The overflight times were 2010 UTC for A and 0948 UTC for D

ERS-1 SAR data were obtained as 100 x 100 km full resolution fast delivery (FD) scenes at the Finnish BDDN terminal. Low resolution (100 m) scenes for the present work were produced by sampling from the FD data. A case study showed that no essential new information could be obtained when using the full resolution data. The FD images are not absolutely calibrated and therefore no intercomparisons between the backscatter levels can be made for different images. In January-March 1992 ERS-1 was performing the 3-day repeat cycle orbits. The SAR swaths over the Bay of Bothnia are shown in Fig. 1. Their width is 100 km. The ascending orbit (A) crossed the Bay of Bothnia at 2010 UTC on day #2 and the descending (D) at 0948 UTC on day #3.

3. THE RESULTS

3.1 General

The first results from the BEERS campaign showed that ERS-1 SAR is a powerful ice mapping tool (Leppäranta et al., 1993). But for this particular ice season, as the ice was thin and the ice situation quite changeable, the ice and open water areas were often very hard to discriminate from the SAR information. A rich variety existed in the open water signatures and a number of physical phenomena could be identified. Also ship tracks were clearly seen in the open sea surface.

3.2 Surface Waves and Winds

The wind field gives direct rise to several kind of roughness features on the sea surface that show up in SAR data in many ways. Fig. 2 shows a frontal structure in the form of long stripes in a SAR image. The wind was blowing from the direction of 30-50° (counted as clockwise from north) which is perpendicular to this frontal structure. The wind speed was 5-6 m/s at the time of the satellite overflight; several hours earlier the wind was considerably stronger and from the same direction. The stripes or fronts are parallel to the satellite's track, i.e. the waves are moving perpendicular to the track; in such situation they can be detected more clearly. If waves are moving azimuthally (along the track) the doppler shift due to the movement of the individual water particles makes the detection of distinct wave fronts more difficult (Allan, 1983). But the spacing between the stripes (1-2 km in this figure) and the absence of any apparent wave diffraction, damping or other shoaling effects by the bottom near the coast indicate that the wavelike pattern in this figure is caused by atmospheric gravity waves or pressure and wind perturbations in the atmosphere as is described by Thomson and Vachon (1992).

Another case of wind or surface wave caused stripes in a SAR image is shown in Fig. 3. Here the wind was strong at the time of the overflight. According to the observations of three weather stations the wind speed was 10 - 15 m/s and the wind direction was 220° which is roughly parallel to the satellite's track. The unclear stripelike signature across the whole image is likely due to foam building and wave breaking caused by the strong wind and surface waves travelling azimuthally. The long NE-SW sharper lines perpendicular to the unclear stripes are most likely due to ice floes driven by the wind.

A very intersting image is shown in Fig. 4 illustrating a variability of wave features in a single image. A wind front reveals itself as a clear border between a darker area of very weak wind (speed < 2 m/s) and a lighter area with

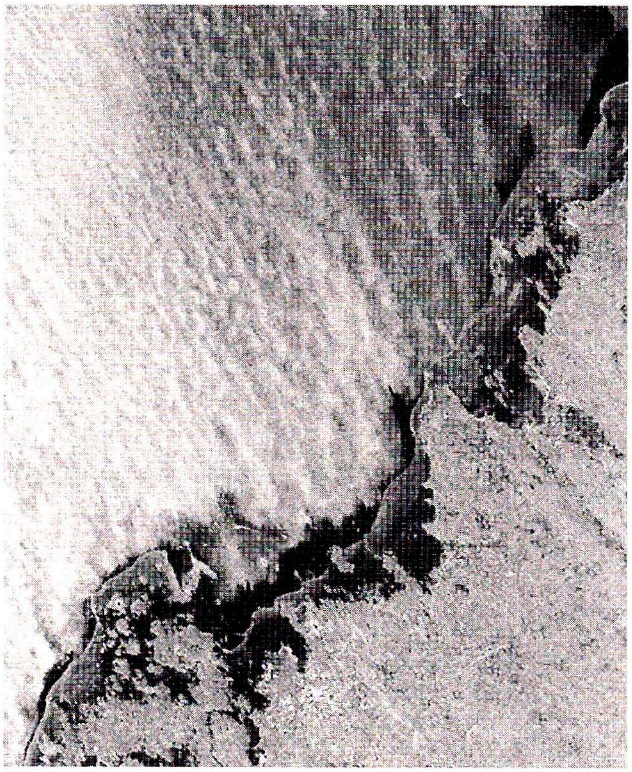

Fig. 2 - A subimage from the middle of ERS-1 SAR scene A6, 4 February 1992 at 2010 UTC. North is up and natural size is 60 x 70 km. Copyright ESA

Fig. 3 - A subimage from the upper left part of the ERS-1 SAR scene D3, 8 February 1992 at 0948 UTC. North is up and natural size is 68 x 86 km. Copyright ESA

Fig. 4 - Full ERS-1 SAR scene D2, 23 February 1992 at 0948 UTC. Copyright ESA. Natural size is 100 X 100 km

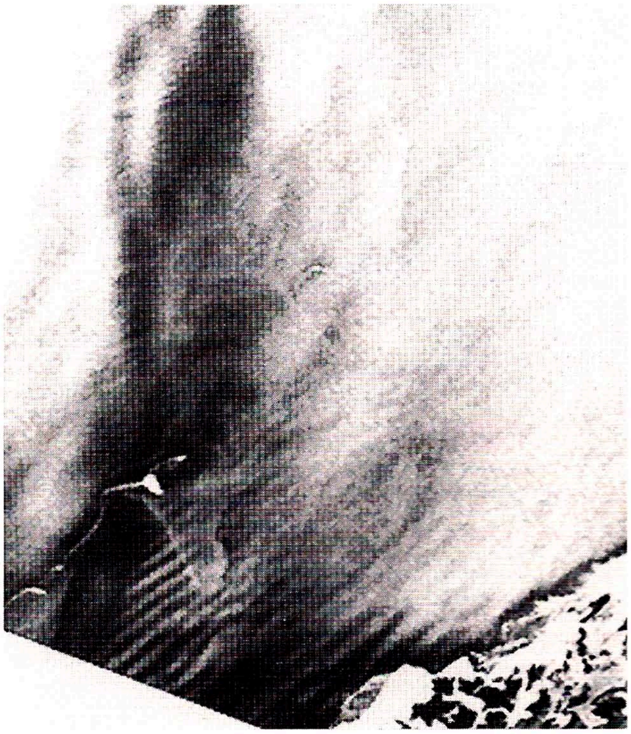

Fig. 5 - An enlargement from the lower right hand corner of ERS-1 SAR scene D2 (Fig. 4), 23 February 1992 at 0948 UTC. The image width is 25 km. Copyright ESA

somewhat stronger wind (3-4 m/s) and hence a stronger backscatter. The white regular stripes in the center of the figure are possibly caused by wind convection, atmospheric boundary layer rolls, or atmospheric gravity waves (e.g. Alpers and Brümmer, 1993); these phenomena all modify the sea surface roughness due to the rapid response of capillary waves to pressure and wind changes. With the presently available wind and atmospheric data it is not possible to distinguish between the different mechanisms causing the white stripes. The spacing between these stripes is 1-2 km.

3.3 Internal Waves

Internal waves are detected often in SAR images if the wind is not too strong (less than 10 m/s), because they affect the surface roughness by modulating small ripples. In the Bay of Bothnia there is a winter pycnocline at a depth of 30-40 m where internal waves may be generated by wind-driven currents. Fig. 5 shows an enlargement of the lower right-hand corner of Fig. 4. Down in the very corner there is Finnish archipelago covered with fast ice; then there appear internal wavelike features off the fast ice edge. They are aligned perpendicular to the ice edge with a wavelength of 700-800 m.

Fig. 6 - An enlargement of ERS-1 SAR scene A6, 26 March 1992 at 2010 UTC. North is up and image width is 43 km. Copyright ESA

Fig. 6 shows features that may be internal waves generated by a coastal current outside Kokkola on the eastern side of the basin. At the time of the satellite overflight the wind was blowing from northeast (along the coast) with a speed of 4-7 m/s. A few days earlier the wind was considerably stronger and from the same direction; this may have generated the coastal current. The wavelength of these features, possibly internal waves, is about 1000 m. Another explanation to the wave pattern would be sea surface roughness effects due to atmospheric pressure and wind perturbations.

3.4 Bottom Topography Effects due to Currents

When there is a significant current flow and the water depth is small the bottom topography influences the surface roughness via current field modifications. The water flow over shallow areas thus 'feels' the bottom and this interaction modifies the ripples or small waves on the surface. The backscattering that is detectable by the SAR is then changed. This is a possible explanation to the features seen in Fig. 7. The bottom is steeply sloping from 20 to 120 m in this area and the structure of the image may be a combination of internal waves, generated at the shelf break and propagating towards the coast, and a direct influence of the bottom to the surface. Another feature that may have been caused by the topography and (or) internal waves can be seen in the lower part of Fig. 8 showing the narrow undulating lines in the southern Bay of Bothnia. The area is shallow and strong currents occur in this region.

Fig. 7 - Full ERS-1 SAR scene D2, 27 January 1992 at 0948 UTC. Copyright ESA. Natural size is 100 X 100 km

Fig. 8 - An enlargement of the lower part of ERS-1 SAR scene D3, 3 March 1992 at 0948 UTC. North is up and natural size of the image is 48 x 50 km. Copyright ESA

3.5 Fresh Water Plume and Eddies

Eddies are fascinating dynamical features which may come up visible in SAR imagery. However in the BEERS data set they were quite rare. A fine example is shown in Fig. 9. This is an image in the northern part of the Bay of Bothnia where the Luleå river discharges into the sea. The river water plume appears as a dark fingerlike low backscatter area. This may be due to a very thin ice film or ice crystals just starting to build up on the surface as the fresher river water freezes more easily. It is not certain whether there was any ice or not; if there was not the reason for the backscatter difference is unknown. The enlargement in Fig. 9b shows clear eddylike features that are counter-clockwise with a diameter of 3-4 km. The length of the whole finger seen in Fig. 9a is about 60 km.

4. CONCLUDING REMARKS

ERS-1 SAR has been examined in wintertime Baltic Sea for description of oceanographic phenomena and for discrimination of ice and open water areas. The data are from January-March 1992 as the satellite was performing the 3-day cycle orbits. Using the low resolution (100 m) data, a careful qualitative analysis has been made of the

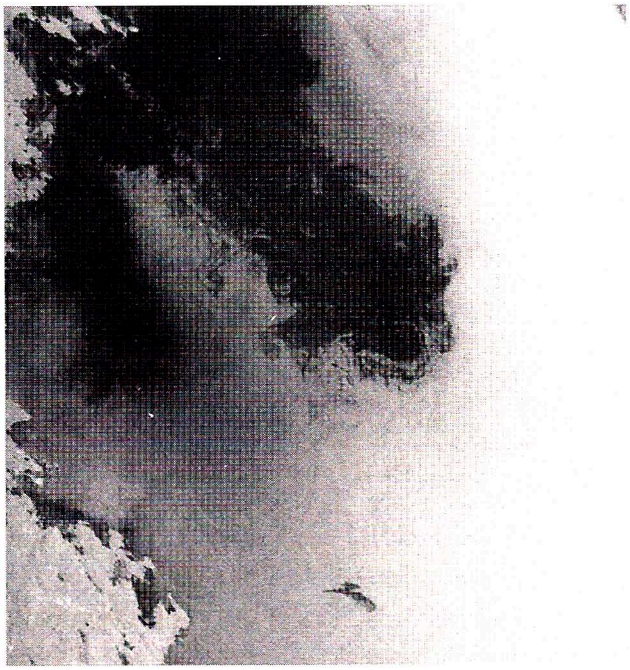

Fig. 9a - Full ERS-1 SAR scene D2, 27 March 1992 at 0948 UTC. Copyright ESA. Natural size is 100 X 100 km

Fig. 9b - Enlargement ERS-1 SAR scene D2, 27 March 1992 at 0948 UTC shown in Fig. 9a. North is up and natural size is 40 X 49 km. Copyright ESA.

open sea SAR imagery. The following features were found: (1) Surface wave and swell fronts and wave breaking; (2) Traces of wind fronts; (3) Internal waves; (4) Smooth slicks in the lee side of islands and at ice edge; (5) Small eddies (3-4 km); and (6) Fresh water plume from a river.

Analysis of oceanographic conditions and the knowledge of their SAR signatures may greatly aid the discrimination between ice and open water surfaces. From pure image information, the scale of SAR signatures is not very helpful for the ice/open water problem but the texture shows clear differences: open water features tend to show up in regular wave patterns and also in eddy structures while ice texture shows up convex ice floes and fracture lines. The ice edge zone, if compact, is normally bright and clear because of the geometry of the ice floes in the ice edge zone. Also sequential imagery helps since the differential movement within ice and open water patches is highly dissimilar. On the basis of the BEERS data scattered low concentration ice fields may be very difficult to treat. Much more can be learned for the ice/open water discrimination from deeper oceanographic case analyses; a major problem is here the sensitivity of SAR to ripples. Such analyses necessiate the availability of surface layer models, bottom topography and wind information.

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