Estimation of Equivalent Deformed Ice Thickness from Baltic Sea Ice SAR Imagery

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I. Introduction

FIMR has been utilizing the Radarsat-1 ScanSAR data in operational sea ice monitoring for several years. The surface scattering dominates the backscattering at C-band [1], but it is still possible to estimate ice thickness based on this surface roughness visible in SAR data in some areas of the Baltic Sea, because typical Baltic Sea drift ice becomes more and more deformed as it gets older and thicker, i.e. there is correlation between Baltic Sea ice surface roughness and thickness.

For ship navigation in the Baltic Sea ice ridging is another important ice parameter, in addition to ice thickness. However, it is impossible to detect single ridges from our operational SAR data, Radarsat-1 ScanSAR Wide images in 100 m resolution. One ice parameter closely related to ridging is the equivalent deformed ice thickness (T_{def}). The total (mean over an area) ice thickness (T) is the sum of the level ice thickness (T_{lev}) and equivalent deformed ice thickness:

$$T = T_{lev} + T_{def}. \quad (1)$$

In this paper we study estimating of T_{def} from our operational Radarsat-1 data, and also make some comparisons to Electromagnetic induction (EM) based ice thickness measurements.

II. Data

We divided our SAR data from the EM measurement days and the adjacent days into two sets of about equal size. One set was used as a training set (12 SAR scenes) and the other set (13 SAR scenes) as a test set.

EM measurements were made in the Gulf of Bothnia during the winter 2003-2004, using a helicopter-borne EM instrument, by Alfred Wegener Institute. The EM measurements were mainly made over compact deformed ice fields. Hence, also the obtained dependencies are valid only for such ice fields. The existence of dependencies is due to the strong correlation between large scale ice surface roughness and ice thickness. Same kind of correlation does not prevail for land fast-ice and for brash ice. These areas are identified, based on sea ice classification algorithms and ice history, before applying the ice thickness estimation. Also open water classification [4] and masking are performed before the ice thickness estimation.

The data are in different resolutions, the sampling rate of the EM measurement is 3-4 m and the EM measurement resolution is around 20-30 m, and the Radarsat-1 images are in 100 m resolution.

III. Algorithm

First, an incidence angle correction was performed for the SAR backscattering coefficients [2] by an appropriate scaling. The performed scaling has specifically been developed and verified for the Baltic Sea ice. After this correction the radar backscattering values are on average independent of the incident angle and the incidence angle can be neglected in the later computations.

Then dependence between scaled SAR backscattering coefficients and measured ice thickness was modeled with a linear model based on our training data set. The coefficient of determination (R^2) between the linear model and the training data set was 0.784. The linear dependence of the estimated ice thickness ($\hat{T}$) on the incidence angle corrected SAR backscattering coefficient σ^0 (in dB), according to our training data set, was

$$\hat{T} = 15.21\sigma^0 + 328.27. \quad (2)$$

The fit line vs. the dependence computed based on the training set is shown in Fig. 1. From Fig. 1 one can observe that without linearizing the regression function consists of four major parts: a relatively low growth part up to -18 dB, a steep increase part on the range from -18 dB to -16 dB (transition from level ice area to partly ridged ice area), after which the increase diminishes little prior a steep increase on the highest σ^0 values (the most ridged areas). This method of

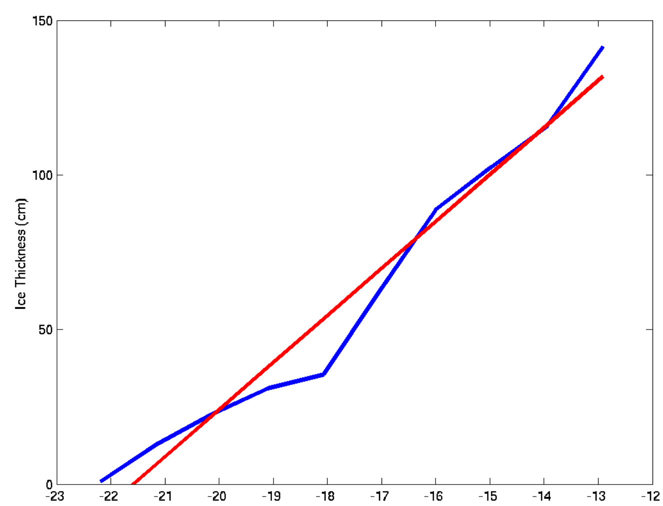

Fig. 1. Dependence of the measured ice thickness on the SAR backscattering coefficient for our training data (blue) and the linear fit (red).

estimating ice thickness directly relates the ice thickness and SAR backscattering, unlike our earlier attempt [3], in which the ice thickness estimates only vary within the limits given by the previous available ice chart, and these limits describe the variation of level ice thickness. At the time of developing our earlier algorithm we did not have calibrated Radarsat-1 data at our disposal. However, the winter 2003-2004 data, which we have been using in this study, have been calibrated.

The observed dependencies between the SAR backscatter values and thickness measurements are statistical averages. Hence, large sample sets are required to be able to give meaningful thickness estimates. In the proposed approach the SAR image is first segmented with an edge preserving segmentation [3]. Then segment-wise ice thickness estimates are computed using the obtained linear relation (3). The estimates for the equivalent deformed ice thickness are then computed using the most recent available digitized ice chart as an additional information source. The digitized ice chart is generated at Finnish Ice Service (FIS) daily and contains mean level ice thickness values T_{lev} over the Gulf of Bothnia and Gulf of Finland. These values are based on field observations and remote sensing data. The ice charts are made by the FIS sea ice experts. The most recent digitized ice charts are typically from the previous day and their resolution is also coarser (resolution in practice 5-10 km) than our SAR resolution. That's why a matching of the digitized ice chart and SAR segments [3] is made and the digitized ice chart is updated to better correspond to the SAR segmentation. The estimates for T_{def} are then computed as $\hat{T}_{def} = \hat{T} - \hat{T}_{lev}$, where $\hat{T}$ is the estimate based on the linear model and $\hat{T}_{lev}$ is obtained from the digitized SAR-matched ice thickness chart.

IV. Experimental Results

We compared the segment-wise ice thickness estimates along EM measurement lines to EM measurement means within each segment along a flight line. Only segments with more than five SAR pixels and more than 20 EM measurements were used in the comparison. The comparison was made this way, because it is difficult to get reliable estimates for the level ice thickness from the EM measurements. The values of the measured ice thickness (EM measurement means over segments along the flight lines) and the estimated ice thickness are shown in Fig. 2. To compare the estimates and EM measurements we used root mean-square error (RMSE), which is computed as

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(T_i^{EM} - \hat{T}_i)^2}{N}}, \tag{3}$$

where T_i^{EM} is the segment-wise EM mean value for segment i and $\hat{T}_i$ is the estimated ice thickness value. N is the total number of segments. RMSE for the test data set was as high as 38.2 cm.

In Figs. 3 and 4 we show an example of the estimation of T_{def} for SAR image. First the classification of the ice types is performed and a masking based on this classification is then applied. Then the estimated ice thickness for the unmasked areas is computed using the linear relation of Eq. (3) and the values derived from the SAR-matched digitized ice charts are subtracted to yield equivalent deformed ice thickness charts like the example shown in Fig. 4.

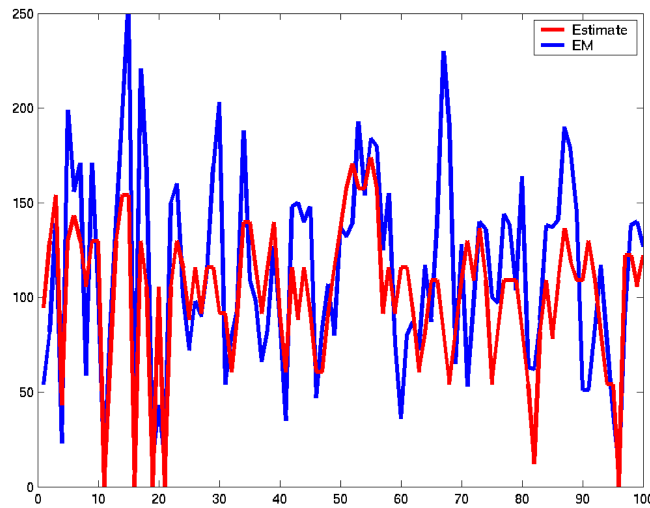

Fig. 2. Segment-wise ice thickness estimates (red) along EM measurement lines and measured EM ice thickness means (blue).

V. Conclusions and Remarks

We have studied the dependence, of the Baltic Sea ice thickness on the SAR backscattering coefficient σ^0 based on EM measurements . Based on our data there seems to be a clear statistical dependence, and we have modeled this dependence with a linear model to estimate ice thickness and equivalent deformed ice thickness from SAR backscattering coefficients.

According to comparisons between estimates for our test data and EM measurements, it seems that in many areas the model-based estimates follow the EM data, but the estimate dynamics is attenuated, and it typically underestimates high thickness values. This is also the reason for the high RMSE.

Because the EM measurements were made mostly over deformed ice fields, the model is applicable only over such areas. To locate these areas ice type recognition before applying the algorithm is required. For this purpose we have developed an algorithm to recognize and mask off open water (open water detection based on [4]), smooth ice, fast ice and brash ice regions.

In the future the level ice thickness input to our algorithm will probably be obtained from the local thermodynamical ice growth estimates given by the operative ice model at FIMR rather than ice charts, which are based on human interpretation. This will make the algorithm completely automated. We are also working on development of more efficient algorithms for estimating the ice thickness with improved accuracy.

References

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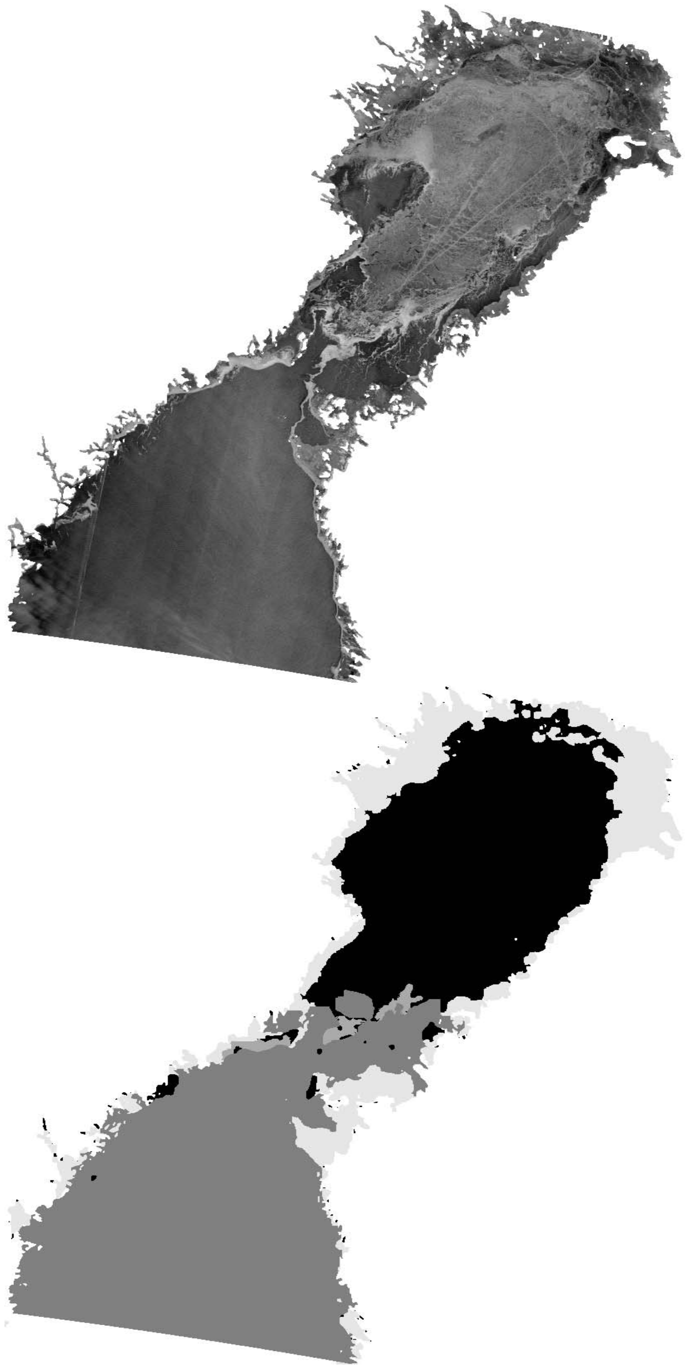

Fig. 3. A SAR image (with incidence angle correction), February 4th 2004 at 05:42 UTC, Gulf of Bothnia (top), and SAR-based ice type classification (bottom). The ice classes from dark to light tones are: (1) deformed and rafted ice, (2) open water and new level ice, (3) brash ice, (4) fast ice. All classes except (2) are masked off.

Fig. 4. Masked version of the SAR image in Fig. 3 (top), and the masked equivalent deformed ice chart for the SAR image (bottom). $\hat{T}_{def}$ value increases from darker to lighter gray tones.

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