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Research Report No 98

Robin Berglund and Lauri Seitsonen

IMPROVED SATELLITE IMAGES USING INNOVATIVE INTERACTION

FOREWORD

In this report no 98, the Winter Navigation Research Board presents the results of the research project ISII. Two methods for providing additional information from existing satellite images were investigated and prototype implementations were made of both methods.

The first method was compensating for the changes in intensity in the images due to incidence angle variations across the images. This will reduce the risk of misinterpretation of images and helps compare images taken at different times.

The second method was warping of existing satellite images according to forecast ice drift vectors to produce a forecast image of the ice field. This could help plan ice breaker operations.

Prototype implementations of both methods were successful and showed that the methods are promising for operational use.

The Winter Navigation Research Board warmly thanks Robin Berglund and Lauri Seitsonen for this report.

Turku

October 2017
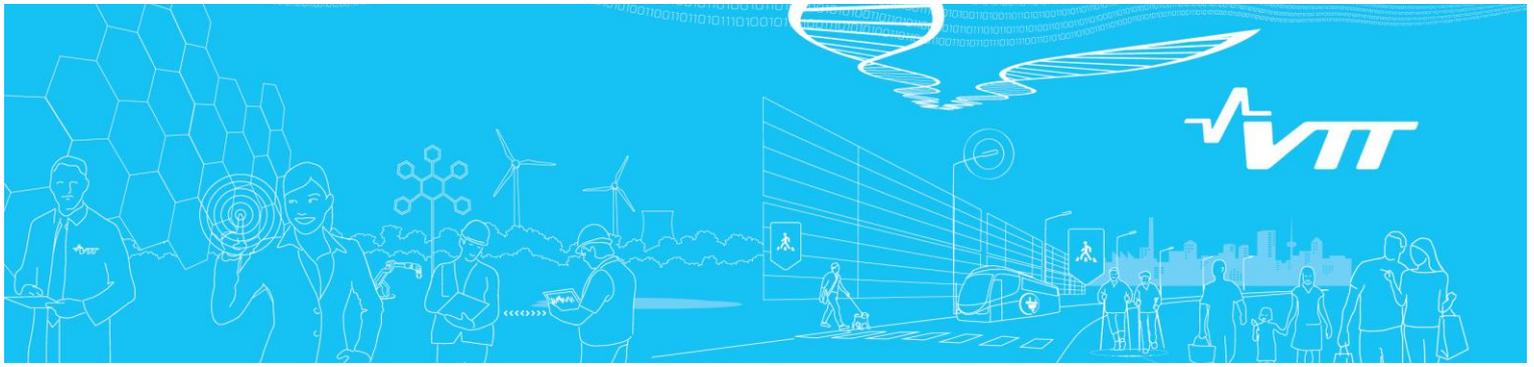

Jorma Kämäräinen

Finnish Transport Safety Agency

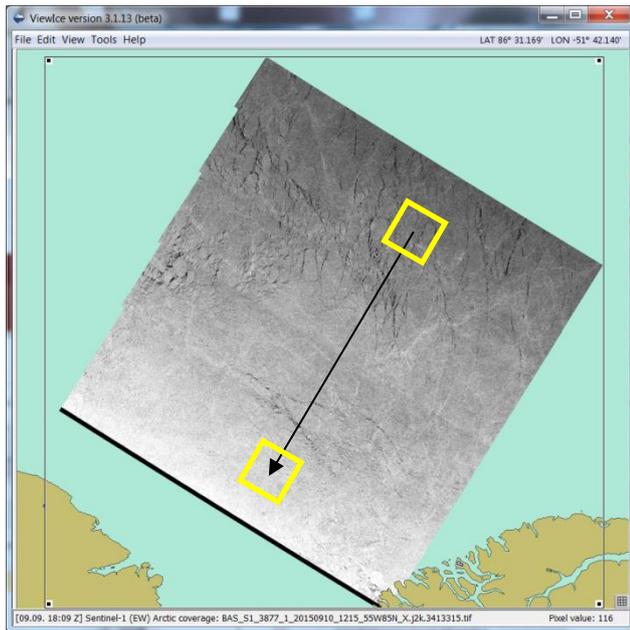Markus Karjalainen

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Improved satellite images using innovative interaction

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Summary

This study is about the technical feasibility and the usefulness of two methods to provide additional information from existing satellite images for ice monitoring purposes by means of a prototype implementation. The first method shows how to make radar satellite images more homogenous compensating for the changes in intensity that are due to incidence angle variations across the images. This method could reduce the risk for misinterpretation of the images and also helps compare images taken at different moments for detection of changes like ice drift.

The other method – warping of images based on predicted ice drift – could help the users assess the current ice situation especially regarding the location of the ice edge and updated position of possible cracks and openings in the ice.

The prototype implementation of the functionalities showed that technically the ideas are rather straightforward to implement. For users in the Baltic Sea, however, the interactive incidence angle correction does not give very much added value as long as the satellite images are radiometrically calibrated according to the instructions by the satellite data provider. For the advanced users, this functionality could be useful for getting the most out of the image data.

Regarding the image warping functionality, the value depends strongly on the accuracy of the drift forecasts. When included as part of an ice monitoring system for a fleet of icebreakers, the idea of applying observed ice drift vectors to the most recent satellite images, is definitely worth developing further. Using a separate component for the actual image warping, as in the pilot implementation, this nicely divides the implementation into well-defined modules that can be integrated into operational decision support systems. The prototype implementation demonstrates one possible way to do this integration.

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Winter Navigation Research Board

Preface

This report presents the results of a study funded by the Winter Navigation Research Board concerning two ideas of improving visualisation of satellite images to users on board the icebreakers, to the operators of these icebreakers and to the maritime administrators that monitor and coordinate the activities.

The project has been supervised by a Steering Group consisting of the following people: Ulf Gullne, Swedish Maritime Administration, Tuomas Taivi from the Finnish Transport Agency, Stefan Eriksson from the Swedish Transport Agency and Jorma Kämäräinen from the Finnish Transport Safety Agency.

We want to thank the Steering Group for their support, and specially Ulf Gullne, for coming to Finland for the meetings and for the active feedback regarding the contents.

Espoo 24 January 2017

Authors

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1. Introduction

Synthetic Aperture Radar (SAR) satellites provide the most useful capabilities for monitoring dynamic sea ice conditions. In the Baltic Sea the icebreakers do need fresh information daily and with the new EO satellites (SENTINEL-1) the goal is almost met. However, to fully utilise the potential of the satellite images the users should be provided with tools for easy interaction with the material. This report describes the results and experiences of two ideas that have been piloted in a study funded by the Winter Navigation Research Board. The ideas are as follows:

1. The inhomogeneity due to incidence angle dependency in the radar image causes problems when trying to interpret the image and also specially when combining information with different polarisation settings. Automated processing parameters for incidence angle compensation have been developed, but in many cases an experienced user is more suited to adjust the parameters to achieve optimal compensation
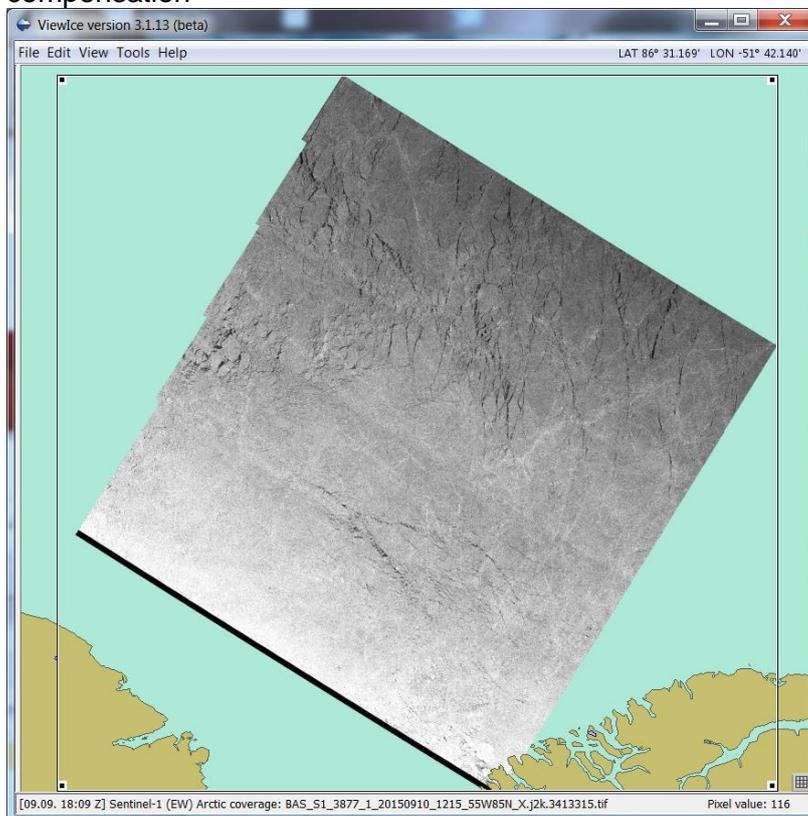

Figure 1. A Sentinel-1 image from the Barents Sea showing the incidence angle dependency as the lower part of the image is much brighter than the upper part of the same image.

In the image above the incidence angle dependency is clearly seen. The idea is to demonstrate an interactive tool for adjusting the image so that the incidence angle dependency is compensated and the image is homogenised. Interactive adjustment is easier to apply than automatic methods as the incidence angle compensation depends on the ice type (level ice, deformed ice or open water). This is a more advanced tool than the present contrast and brightness adjustment, as the adjustment is done differently in different parts of the image.

2. Visualisation of ice drift ("forecasted ice images"). In the IBPlott-system used by the icebreakers, there is the possibility to move a satellite image linearly. Now, in reality the ice field does not move in a homogenous way – fast ice does not move at all and the rest of the ice field is deformed in a non-linear manner. The idea is to enable the

user to specify drift vectors (displacement) on top of an image interactively and warp the image to simulate how ice drift probably has affected the ice field. This can then be used to "update" a satellite image while waiting for real updated information and in this way make the task easier for the icebreaking people to evaluate the present ice situation. A starting value for the drift vectors can be obtained from the numerical ice drift forecasts combined with user specified areas of fast ice.

2. Goal

The goal of the study was to implement a prototype functionality to determine the feasibility of the proposed concepts and to get user feedback of the usefulness of the proposed functionalities.

3. Description

To obtain a representative Proof-of Concept, the framework and user interface built by VTT, was used. This had the advantage of being able to display the data in a format familiar to the users and to use example satellite data as well as numerical forecast data from the operational system.

3.1   Background – backscatter of microwave signals

The Synthetic Aperture Radar is an active microwave instrument. Radars measure the ratio between the power of the pulse transmitted and of the echo received. There is a sender transmitting a microwave pulse and then the receiver, by means of an antenna array, receives the reflected (scattered) microwave radiation. As a result of complicated processing, the origin of the reflected signal can be deduced. The variation of the strength of the backscattered signal contains information about the target that has caused the reflection. The ratio between the scattered and incident powers is called the backscatter. When the target is sea ice and the wavelength is C-band (7.5 – 3.75 cm) or X-band (3.75 – 2.5 cm), the main part of the reflection is determined by the surface characteristics of the reflecting target. The purpose of radiometric calibration is to normalise the signal to compensate for the geometry of the imaging setup. Thus the information only represents the reflection characteristics of the target itself, which enables intercomparison of images taken at different angles and processed by different processors. When doing radiometric calibration of Synthetic Aperture Radar images there are some fundamental concepts that are usually referred to. When dealing with the calibration of diffuse area targets (not point scatterers) the backscatter coefficients β_0, γ_0 and σ_0 are defined as follows:

β_0 is the backscatter coefficient regardless of the scatterer's orientation (also called radar brightness).

γ_0, is the backscatter coefficient normalised to the radar wave plane (a plane perpendicular to the slant range).

 σ_0 is the backscatter coefficient normalised by the area of the object on the ground. This is the most appropriate measure for horizontal ice areas. σ_0 is obtained by Radiometric Calibration of the processed radar image pixel value [ESA 2016].

The satellite image data provider delivers the needed coefficients to do a proper calibration of the image data, in the metadata of the image. Also coefficients that can be used to compensate for the varying noise levels depending on incidence angle, are provided in the metadata. The result is an image where the intensity value variations in the azimuth direction (perpendicular to the satellite flight path) are compensated with respect to antenna and imaging geometries.

What still needs to be compensated for – if the aim is to have a homogenous image showing similar ice types with similar brightness values – is the incidence angle variation of the backscatter which is due to the roughness properties of the ice surface itself and thus causing variations of the backscatter coefficients depending on the incidence angle.
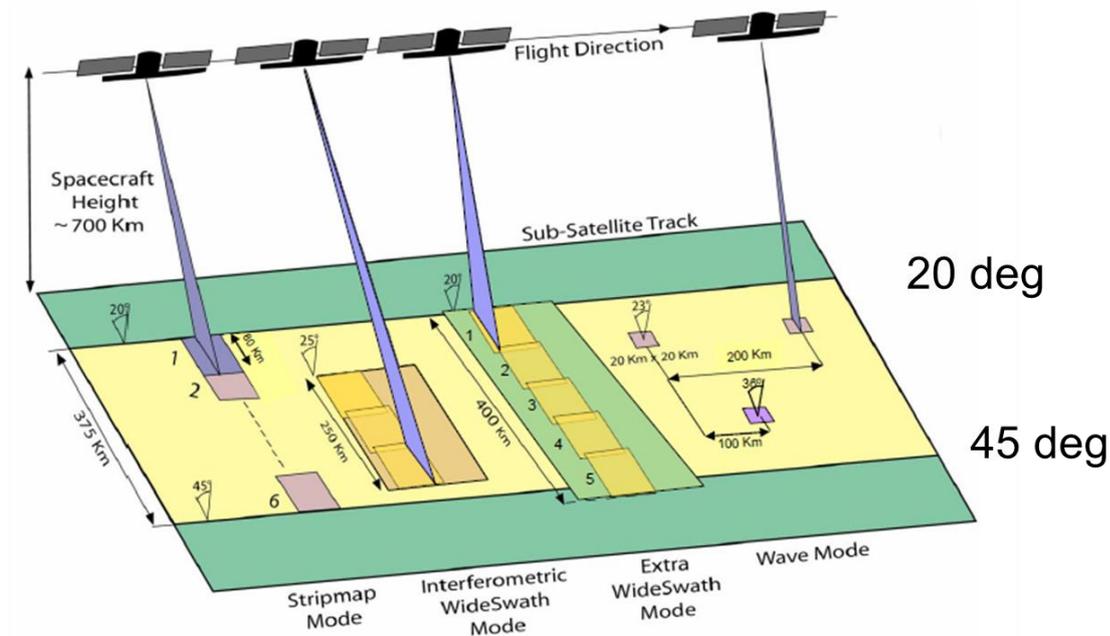

Figure 2. Imaging modes of the Sentinel -1 satellite also showing the incidence angle ranges.

3.2 Variation of backscatter coefficients as a function of incidence angle and ice types.

In a study reported by Mäkynen et. al [Mäkynen 2002], the incidence angle variation of the backscatter may depend on the ice type as shown in the figures below. (The incidence angle dependence is much dependent on the wetness of the snow on top of the ice and other factors as well, but the point here is to illustrate that compensating for the incidence angle variation generally requires knowledge of the ice conditions.) Although the study by Mäkynen et al was

made based on RADARSAT images the results are also applicable to SENTINEL-1 images that operate in the same C-band frequency range as RADARSAT.

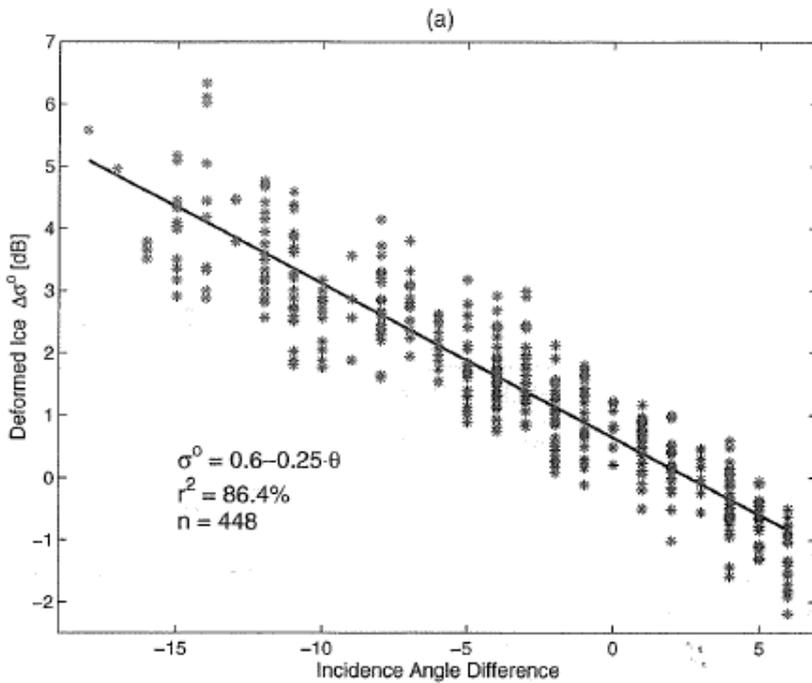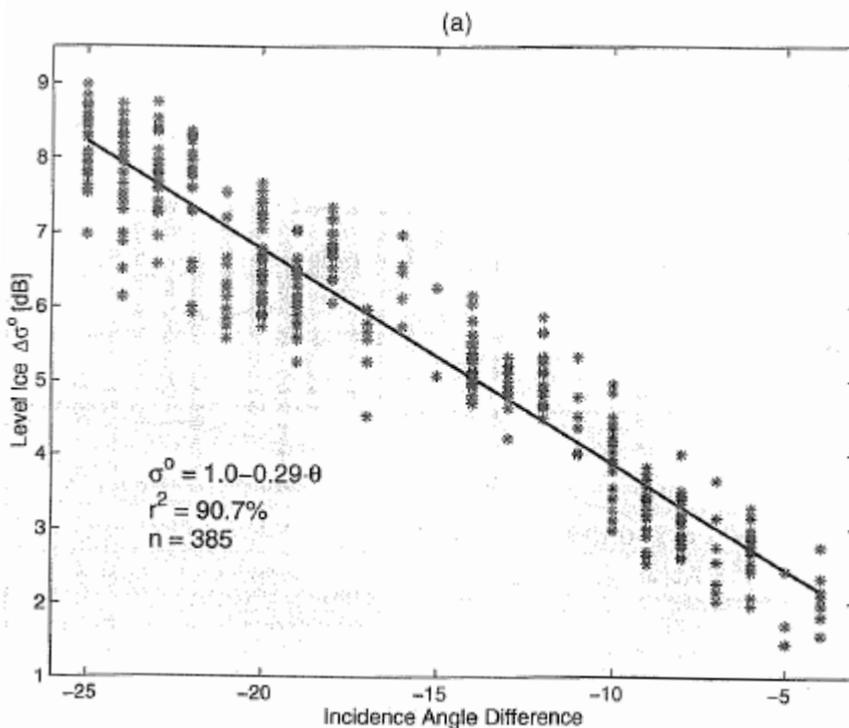*Figure 3 Backscatter variation for Deformed ice [Mäkynen 2002]*

Figure 4 Backscatter variation for Level ice [Mäkynen 2002]

As seen in the figures above, the backscatter variation in dB for level ice is about 0.29 * the incidence angle whereas for deformed ice the variation is 0.25 * incidence angle. For an incidence angle difference of 25 degrees, the total difference in dB would then be 0.04 * 25 =

1 dB, which causes a clearly visible change in image brightness. A general preprocessing step that would apply the linear compensation of incidence angle to the image data, is not a good idea as it could cause excessive effects on the backscatter signal level from open sea and new ice areas with increased risk of misinterpretation of these areas of the image.

3.3 Image warping and ice drift forecasts

Sea ice – when not being landfast – is drifting as a function of surface winds and sea currents. This may cause the ice situation to change within hours. Near-real time imagery may provide the users with new information about the ice cover within an hour of the satellite overpass, but then there is a gap in time until the same area is imaged again. Forecasting of ice drift has been done for a long time. For the Baltic Sea a thorough analysis was done in 1980's by M. Leppäranta [Leppäranta 1981]. Since then the numerical ice drift forecasts have improved all the time, with the advances in computing power enabling more detailed forecasts to be generated. The prototyped idea in this study is to use the ice drift forecasts and modify, i.e. "warp", the most recent satellite image using the best available drift forecast and thus create a "forecasted" satellite image. Although not completely accurate, it may be used to indicate where the existing leads and cracks in the ice are likely to be found as predicted by the ice drift. This could also be used in combination with other methods of monitoring ice drift and ice resistance to obtain as good as possible estimate of the ice situation for ice routing purposes [Kotovirta 2011]. Experiments in this direction have been tried before, but the advances in computing power and accuracies in ice forecasts, have made this approach more attractive than what was possible to achieve some years ago.

4. Limitations

Regarding the Incidence Angle compensation, the available data (satellite images) were enough to demonstrate the usefulness.

When validating the warped image methodology, the cases were restricted by suitable examples, i.e. availability of image pairs within a suitable timeframe. The limitations of the material have not enabled any more thorough statistical analysis of the accuracy of the drift forecasts. The focus of this study is not on the accuracy of the numerical forecasts, but on the visualisation methodology, thus a systematic accuracy assessment of the forecasts would have been out of scope for the study.

5. Methods

5.1 Implementation of the Image Incidence Angle compensation demonstrator

The demonstrator was implemented as part of the ViewIce visualisation software by VTT. Implementation programming language was Java. The user interface was kept simple. The starting point is a satellite image shown on a map. The user then activates the Incidence angle compensation tool and draws an arrow on the image. The arrow indicates the direction in which the incidence angle changes, i.e. the range direction of the radar beam.

The compensation is done by adding an offset to the pixel values where the offset is determined by the position of the projected vector from each pixel to the user drawn vector. The user drawn vector is assigned two values: one for the starting point and the other one at the end point of the vector. These values represent the offset to be added to the pixels of the image. The offset at each point of the vector is calculated by linear interpolation between the end points and extrapolation outside of the endpoints.

The first version of the tool required the user to input the offset parameters for the endpoints numerically (i.e. the offset at each end of the vector). An improved version was then developed which calculates image value statistics around the endpoints. A neighbourhood of 20 x 20 pixels in a square around each of the endpoints was used and the median of each of these squares were determined and used as estimates for the intensity level at the endpoints. These values were used as defaults with the user being able to correct the values if considered necessary.

The image compensation was done on the visible satellite images. It was possible to adjust several images – each individually, but not possible to save the adjusted images to be used outside ViewIce, as this was not considered essential for the demonstration purpose.

5.2 Implementation of the image warping demonstrator

The image warping demonstrator was implemented using the ViewIce visualisation framework. Input data was numerical forecasts from FMI - the same forecasts that have been delivered to the icebreakers in the Baltic Sea. SENTINEL-1 satellite images were used as the target, but also as the reference to compare with. Technically the geocoded and rectified satellite images were warped using a separate image warping tool, GDALWARP, which is part of the Open Source package GDAL (Geospatial Data Abstraction Layer).

The processing includes the following steps:

1. *Fixing areas that do not move.* Land areas do not move and these parts of the image should therefore not be warped. A way to achieve this is to include points from the coastline at a given interval. This was not a good solution as the distance between fixpoints on the coastline measured in image pixels varied very much depending on the coastline topography. An improved approach was to create the fixpoints from a regular grid and only include points along a buffer zone from the coast towards the inland.

2. *Calculating the ice drift from the drift speed vectors in the numerical forecast.* The numerical forecast contains the ice drift vectors as speed vectors. To obtain the ice drift (displacements), the speed vectors have to be integrated. The numerical forecast is generated by the forecast provider in time slices, i.e. the values in the forecast change depending on the forecast time. Therefore the integrator has to do the integration using time dependent values for the drift speed. Also a conversion of the displacement vectors to the map coordinate system has to be performed.

3. *Generating parameters and calling the warping utility with these parameters.*
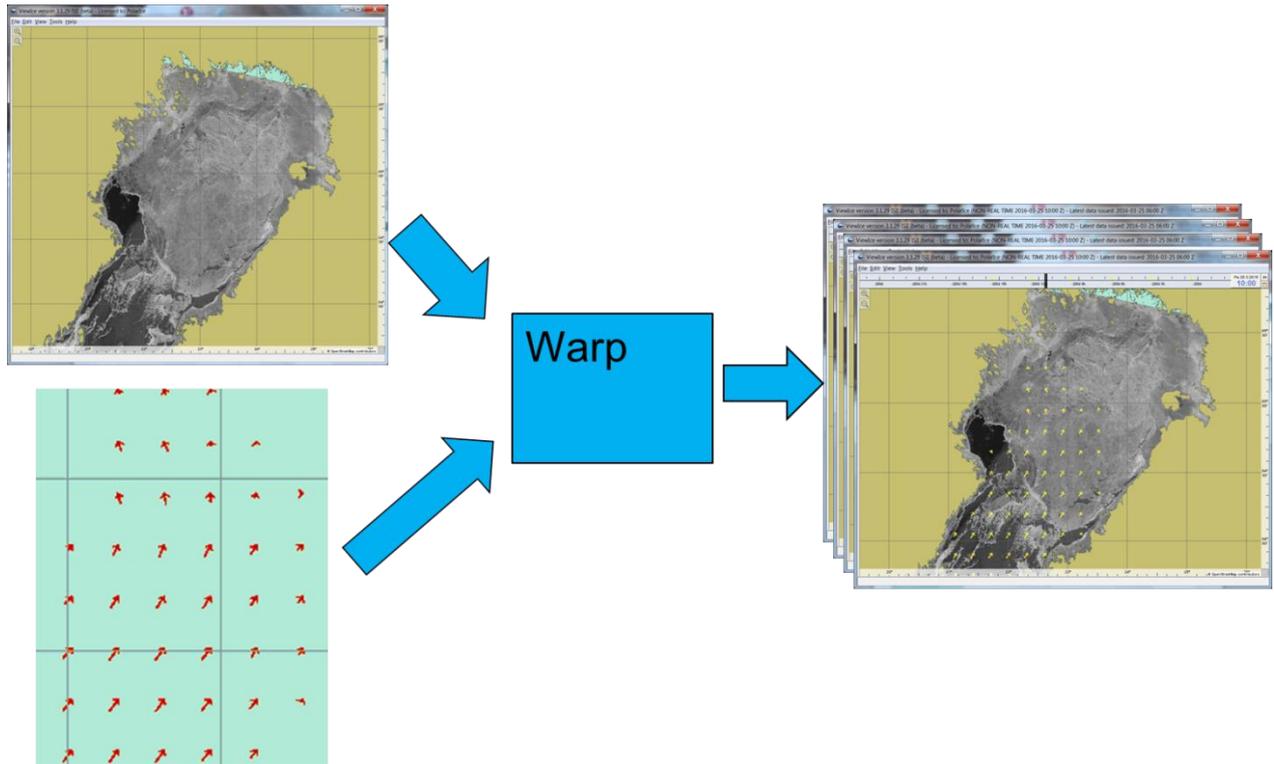
4. *Display the warped images.*

Figure 5 Principle for the image warping system. The forecasted ice drift vectors are used to generate warped images that visualise the ice situation. The generated images represent different time steps, i.e. forecasts at different points in time (three hour intervals in the prototype).
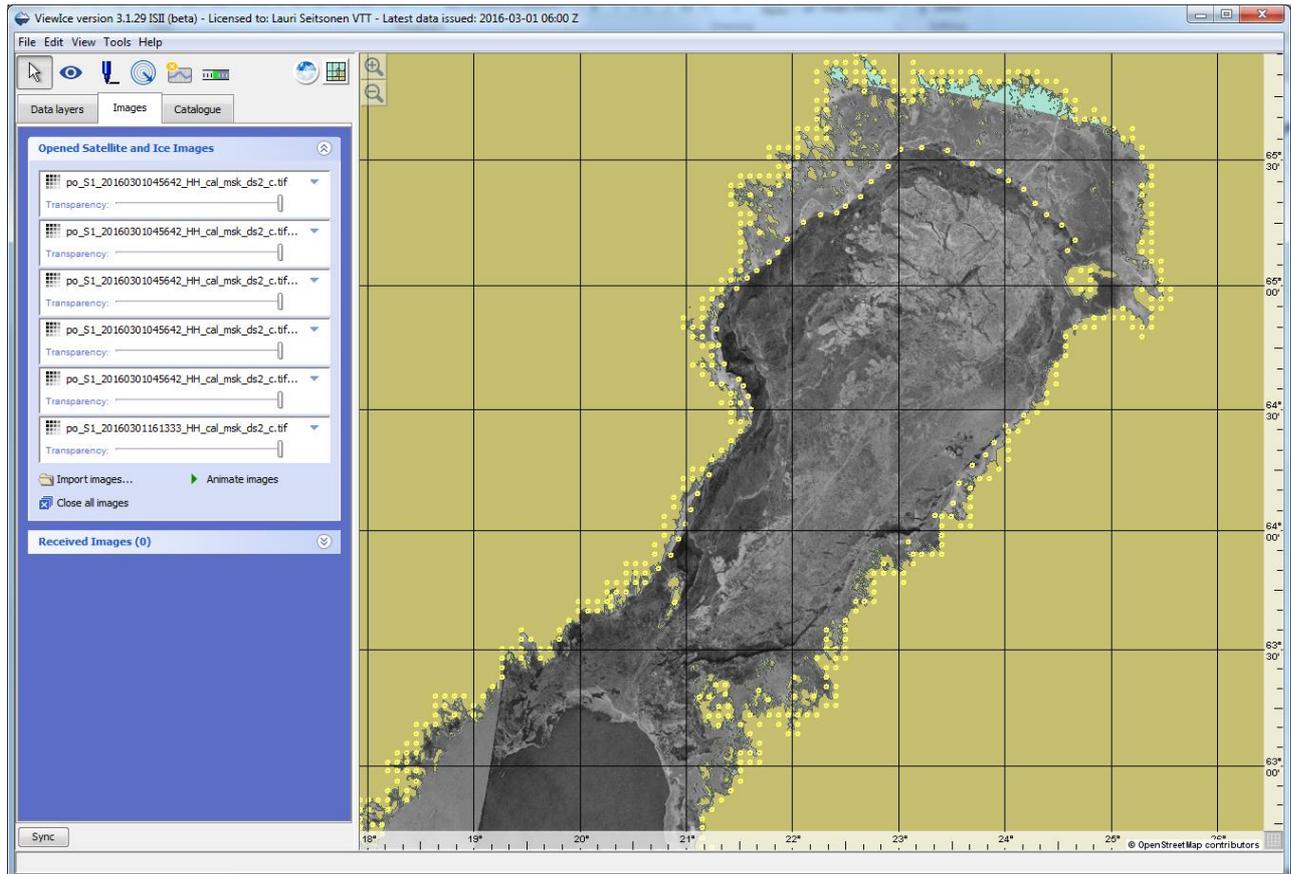
Figure 6 Screenshot of ViewIce showing the way of limiting image warping only to the drift ice part of the satellite image. Along the coastline there is a buffer area that has been used to filter the gridpoints along the coastline. In addition, the fast ice limit is fixed manually by adding fixpoints along the fast ice edge. These fixpoints can be saved in a file and easily applied to a subsequent image. It is also possible to edit these points.

When designing the process, there were possible alternatives how to do the warping over a time period of several hours. One approach would have been to integrate the displacement from the start time all the way to the end time and to do this for each gridpoint in the forecast. The total displacement vectors would then be applied to the image and the "forecasted" image produced in one warping. The problem in this approach would have been in the increased probability that the displacement vectors would start to cross each other which would have either caused error conditions in the warping utility OR just giving weird results.

The other approach was to generate intermediate images using only three hours ice drifts (i.e., the length of the ice forecast time slice). This would also enable a display of the ice drift as an animation of images only three hours apart. Furthermore this approach would be easier to monitor and debug.

6. Results

6.1   Incidence Angle compensation results

Technically the incidence angle compensation worked very well. The calculation is straightforward enabling instantaneous display of the compensated image. When looking at the histogram of the compensated image, it can be observed that the intensity variations over the image do decrease and thus may also be a step before automatic classification of the different regimes that are visible on the image.
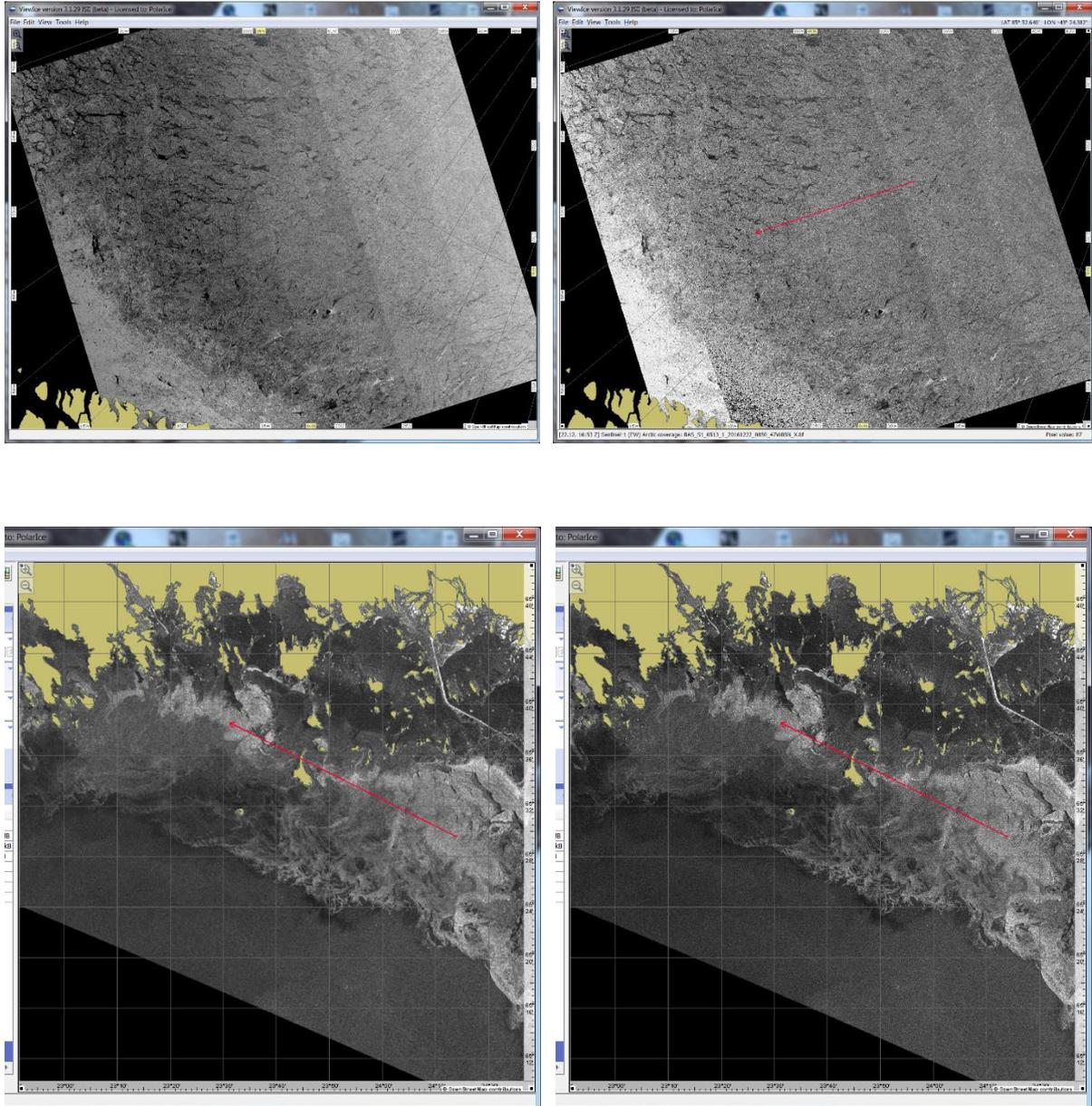
Figure 7 Examples of the incidence angle compensation. Top left: uncompensated image. Top right: Compensated image. The brightness does not vary with the incidence angle. Bottom left: Uncompensated image from the Bay of Bothnia. Bottom right: compensated image. The example shows that the compensation can be done between arbitrary parts of the image and can thus be applied to other areas than sea ice as well.

6.2   Image warping demonstrator results

Initial situation
1.3.2016 04:57 Z

Forecast
1.3.2016 07:30 Z

Forecast
1.3.2016 10:30 Z

Forecast
1.3.2016 13:30 Z

Forecast
1.3.2016 16:30 Z

Real situation
1.3.2016 16:14 Z

Fairly good estimate!
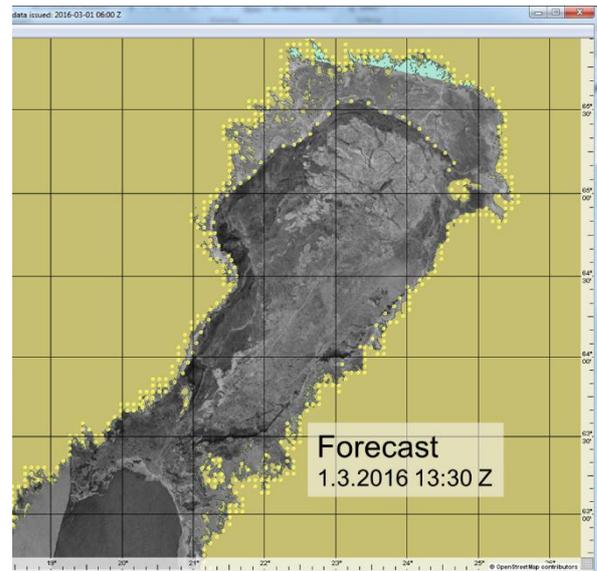The ice drift has been
underestimated
slightly with the
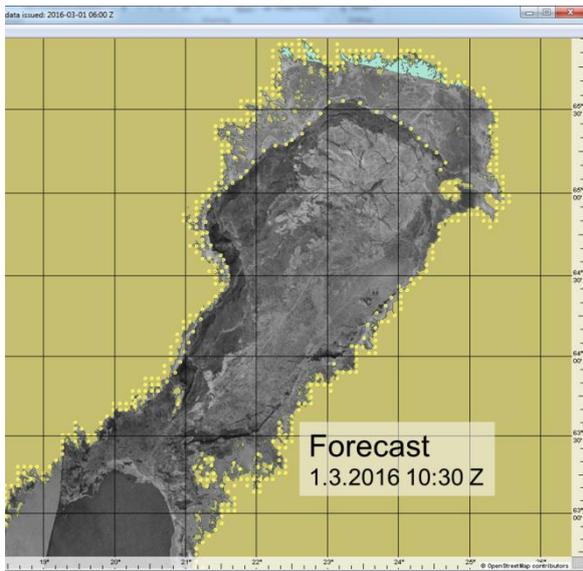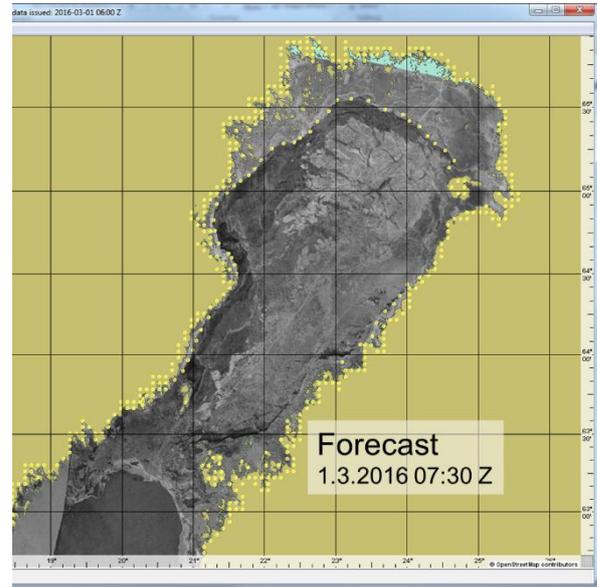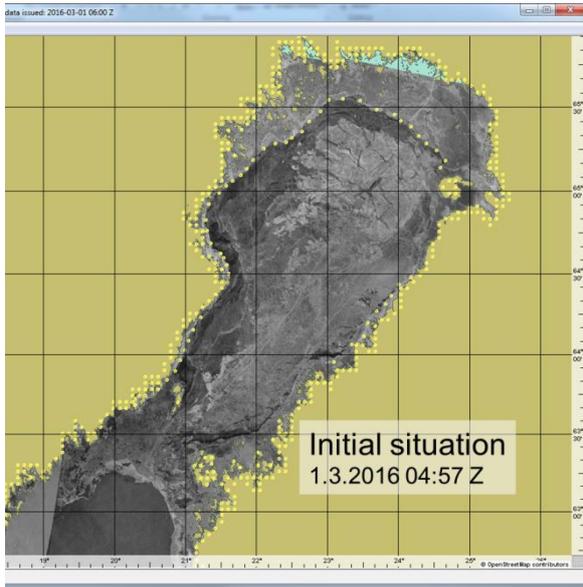largest discrepancies
at the ice edge
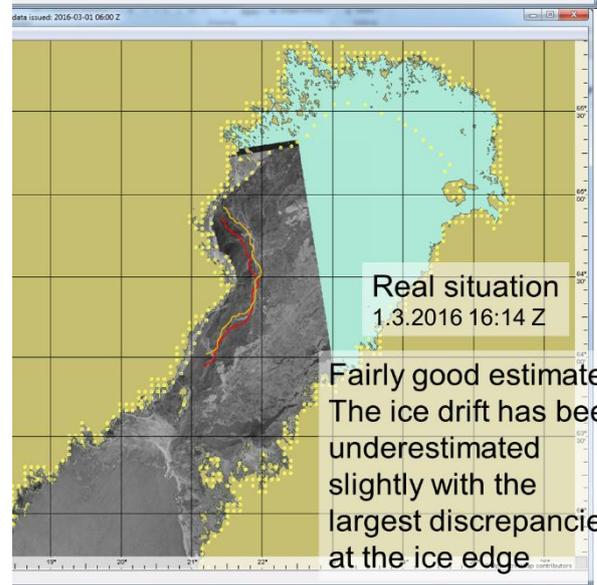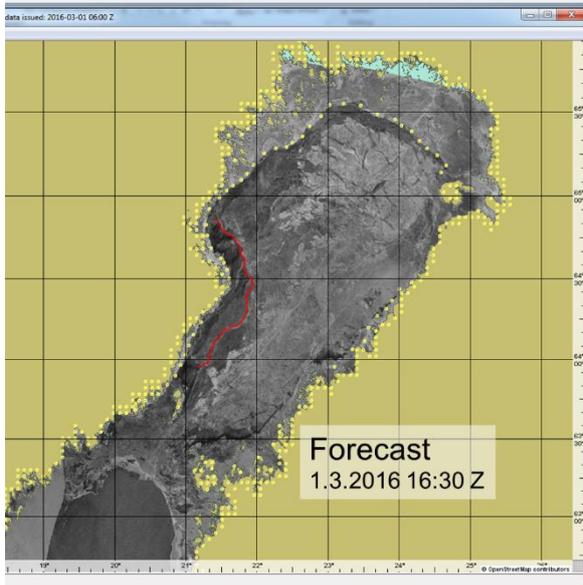
Figure 8 Screenshots of one of the cases demonstrated. The last picture shows the actual satellite image at the same time as the forecast. The ice edge of the forecasted image based on an overpass in the morning has been manually highlighted in red and the actual ice edge from the satellite image in the afternoon in yellow. This example illustrates that the warping method preserves the image textures quite well, but the forecast has missed the drift at the ice edge in the Quark.

The processing time for the image warping of a 10 Mpixel image, was around 1.5 minutes. As a new image was generated for every 3 hours, 18 hours of forecasted images can be processed in less than 10 minutes.

7. Validation of results

7.1   Incidence Angle compensation validation

The validation was done in the form of a feedback session with the icebreaker masters during their annual meeting on board a Swedish icebreaker. Generally, the compensation gave a visually valid result. When considering the situation on the icebreakers in the Baltic Sea, the satellite images most often do not cover the full incidence angle range of the Wide Swath SAR image, and thus the incidence angle variations are not that large.

7.2   Image warping demonstrator validation

The image warping technology has been validated using three different cases. The criteria for case selection were:

1. User experience: periods with strong ice drift were recalled by persons in the Swedish Icebreaker Management personnel

2. Availability of satellite images with a time difference of less than 24 hours. In practise this meant acquisitions either during the same day (morning and afternoon overflights) or evening and then morning overflight the next day.

3. Area: Bay of Bothnia

These criteria limited the possibilities to only a few validation cases. On the other hand, as the goal was not to validate the forecasts as such, but more to validate the visualisation technique, the three cases can be considered enough to evaluate the usability of this approach.

The three cases were as follows:

Case	From (UTC)	To (UTC)	Comment
1	1.3.2016 04:57	1.3.2016 16:14	Ice drift underestimated
2	22.3.2016 15:49	23.3.2016 05:13	Ice drift underestimated
3	4.3.2010 05:02	4.3.2010 19:59	Slight overestimation of the ice drift

Technically the approach worked very well. Using ViewIce as the platform for the image warping enabled a smooth integration with existing datasets.

8. Conclusions

8.1   Incidence Angle compensation conclusions

Regarding the Incidence Angle Compensation, the conclusion was that for Baltic Sea use, as long as the radiometric calibration is handled correctly by the producer (at the moment the Finnish Meteorological Institute is the main provider of processed satellite images), the need for this interactive Incidence angle compensation tool is not large. However, for other areas, where the satellite images cover larger areas and the incidence angle varies over the full range, the situation is different. Also, if the images come from different producers with not-so-perfect radiometric calibration, a correction tool as the one implemented here, would be useful.

The algorithm that was piloted here used a linear compensation equation (offset linearly dependent on incidence angle). This could be extended to a non-linear one, with a drawback of adding extra complexity to use the functionality. Unless there are validated non-linear incidence angle dependency models that could easily be taken into use, the simple linear incidence angle dependent compensation is definitely the preferred one.

For the advanced user a mechanism enabling the user to see the calibrated backscatter coefficient σ_0 in numerical form for every pixel in the image, in spite of the range dependent compensation, would be an advantage.

8.2   Image warping demonstrator conclusions

The user feedback of the image warping demonstrator was fairly positive. If implemented as part of the operational icebreaker system, it would be advantageous to automate the production of the predicted images in such a way that the predicted images would be generated as soon as a new satellite image would have arrived on board. In that way the processing time of the image warping would probably not be considered annoying.

One challenge in the operational system would be how to show the list of generated images in such a way that the user would not be overloaded with alternatives.

A drawback of the warping algorithm is that it is not able to create totally new ice areas, like cracks that have not existed before. Also creation of ridges with higher backscatter values (brighter areas), is not possible with the chosen approach. Showing the convergence/divergence as semitransparent colour overlays could be a way to compensate for this lack of capability.

The warped image would also be an intuitive way of validating the forecast. A comment by the users was about the possibility for the user to correct an obviously erroneous forecast based on the latest observation. This is not a trivial task to be solved in general, but for limited areas it would be fairly simple to apply a correction to the drift forecasts to make the predictions more in line with the observations. Errors regarding the drift speed are easier to correct than errors in the drift directions in which case simple rules for corrections are hard to determine. This could be, however, an interesting subject for further development ideas in collaboration with ice drift modellers.

A related idea was to study how well a simple ice drift model would work where only forecasted wind fields would be used as input data and then applied via simple rules, i.e. the ice moves with 2% of the surface wind speed and is deflected about 30 degrees clockwise compared to the wind. In combination with manual definition of the ice edge this might give a reasonable result in cases, where no sophisticated ice drift model forecast is available.

For further work, discussions with experts on ice drift modelling are recommended.

Another idea would be to collect ice drift observations from as many of the icebreakers in the area as possible. If these drift vectors would be applicable to the latest satellite images, a redistribution of the vectors to the icebreakers would enable them to have an updated ice situation visualised as a satellite image. The amount of data to be distributed between the icebreakers to achieve this would then be minimal (only the drift vectors with some metadata attached).

9. Summary

The objective of this study was to gain knowledge of the technical feasibility and the usefulness of two methods to provide additional information from existing satellite images for ice monitoring purposes by means of a prototype implementation. The first method focusses on how to make radar satellite images more homogenous compensating for the variations that are due to incidence angle changes across the images. When successful, this method could reduce the risk for misinterpretation of the images and also help compare images taken at different moments for detection of changes.

The other method – warping of images based on predicted ice drift – could help the users to assess the current ice situation especially regarding the location of the ice edge and updated position of possible cracks and openings in the ice.

The prototype implementation of the functionalities showed that technically the ideas are rather straightforward to implement. For users in the Baltic Sea, however, the interactive incidence angle correction does not give very much of added value as long as the satellite images are radiometrically calibrated according to the instructions of the satellite data provider. As part of an advanced toolkit for the users, this functionality should be considered to add to the requirements of an advanced ice routeing tool that uses SAR images as input data.

Regarding the image warping functionality, the value depends strongly on the accuracy of the drift forecasts. When included as part of an ice monitoring system for a fleet of icebreakers, the idea of applying observed ice drift vectors to the most recent satellite images, is definitely worth developing further. Using a separate component for the image warping, as in the pilot implementation, nicely divides the implementation into well-defined modules that can be integrated into operational decision support systems. The prototype implementation makes it easy to specify how this integration should be done.

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