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TECHNICAL REPORT

Evaluation of the operational Radarsat Ice Mapping in the Cape Farewell Waters During Summer 1999

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Preface

This report was prepared under the project: *Evaluation of Operational Radarsat Ice Mapping in the Cape Farewell Waters During summer 1999*. The project was proposed in internal memo of the 14th of December 1999 from Hans Valeur to Erik Bødtker, in order to evaluate the data collected during the summer 1999. Rashpal S. Gill has been the project leader and Rasmus Tonboe, Martin Rosengreen, Palle Eriksen and Keld Hansen have all participated in the work leading to the conclusions in this report. The large amount of data from the summer campaign has been processed to a higher level for the evaluation, which answers urgent questions at this stage in our operational use of Radarsat ScanSAR wide for ice mapping.

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1. Conventions

1.1 List of tables and figures

1.2 List of abbreviations

DMI	Danish Meteorological Institute
DERA	Defence Environmental Research Agency
SAR	Synthetic Aperture Radar
CDPF	Canadian Data Processing Facility
Radarsat ScanSAR	Special mode on Radarsat (Narrow/Wide)
NOAA-AVHRR	National Oceanographic and Atmospheric Administration- Advanced Very High Resolution Radiometer (channels in visual-infrared)
ERS SAR	SAR onboard European Remote Sensing satellite (swath width 100 km, res. ~50m)
EU	European Union
IMSI	Integrated use of microwave satellite data for improved sea ice observation
DMSP-SSM/I	Passive microwave sensor on Defence Ministry Satellite Programme
ICE LUT	Look Up Table applied during processing to enhance sea ice.
SEA LUT	Look Up Table applied during processing to enhance ocean features
ADC	Analogue to Digital Conversion
HF	High Frequency (radio)
GPS	Global Positioning System
ERS -SCAT	scatterometer onboard European Remote Sensing satellite (C-band)
UTC	Universal Time Convention

2. Summary

This report presents the evaluation of Radarsat imagery for operational season 1999. Radarsat ScanSAR wide from the Cape Farewell region has been investigated in detail during the melt season. The evaluation includes 13 underflights and 77 Radarsat scenes from Gatineau and West Freugh processing facilities. During the entire season 1999, 500 scenes has been received and analysed. This evaluation campaign differ from the former in 1996 and 1998 (Gill and Valeur, 1996; Gill and Rosengreen, 1998; Tonboe and Rosengreen, 1998) in the very detailed analysis of regions in the Cape Farewell area and in the defining of very important ice parameters used during ice analysis of Radarsat imagery. In addition this evaluation is addressing the significance of proper SAR processing for the image quality and indirectly the quality of the ice charts from aerial reconnaissance. The documented conclusions from this report concerning the difference between images processed by the DERA SAR processor and the CDPF SAR processor has been important facts for improved processing. West Freughs DERA SAR processor has been upgraded with and ICE LUT since January 2000 which has improved the usefulness of the data for ice mapping.

The conclusions of this investigation does not differ from the evaluation in 1997 by Gill and Rosengreen (1998). Based on the detailed evaluations carried out during the summer melt season 1999 it is not recommendable to rely solely on Radarsat ScanSAR wide for the ice mapping. Problems in interpreting the ice situation are in particular found in near range of the image and inside the Julianehåb Bay where ice surface melting and complex wind induced wave patterns are found over the open water. The most important ice parameters, the ice edge and the ice concentration, can occasionally not be determined with the required certainty.

As the aerial reconnaissance is reduced and Radarsat becomes the source for the ice analysis most of the work previously done in the service is transferred from the Ice Central in Narssarssuaq to DMI in Copenhagen. Parallel to the transfer of work, conventions concerning the ice mapping must be expressed in terms of SAR data and image interpretation techniques during the ice analysis. The final product is however the same, the navigational community receives information in WMO egg-code format on ice concentration, ice type and floe sizes etc. Conventions and definitions of the most important ice parameters in terms of navigational needs are described in this report and used throughout the evaluation.

Finally the evaluation and the operational service using Radarsat during 1999 has lead to one important recommendation for the future. Other modes of Radarsat ScanSAR should be tested for the mapping of the ice in the summer: The ScanSAR narrow has a spatial resolution comparable to the floe size in the Cape Farewell and this and other modes on Radarsat may also be applicable for the in-shore mapping presently done using helicopter.

3. Introduction

The ice service at DMI is responsible for providing information on sea ice for the safety of navigation in Greenland waters. Since the beginning of the 1990's the service has included an increased number of satellite data which was otherwise based on aerial reconnaissance. In the beginning the satellite data consisted of NOAA-AVHRR visual/infrared data, but in 1995 ERS SAR data were tested for ice mapping in Greenland and already in 1996 shortly after its launch Radarsat ScanSAR data were tested. It became clear through evaluation (partly sponsored by EU, IMSI project contract No. ENV4-CT96-0361) that Radarsat could replace most of the activities in ice mapping done with aerial reconnaissance.

Radarsat was for the first time used during the entire season 1999 for the operational ice mapping in the Greenland Ice Service. This report describes the Radarsat evaluation campaign during the summer season 1999 and its results. Conclusions during earlier investigations and operational tests of Radarsat for ice mapping in Greenland waters (Gill and Valeur, 1996; Gill and Rosengreen, 1998) still holds: *Radarsat can be unreliable during the summer/melt season*. There are situations where the ice is undetectable using Radarsat ScanSAR. However the detection of ice can be improved by tuning the SAR processor and for the ice analyst to gain both SAR interpretation experience and understanding of ice dynamics. The interpretation problems are particularly severe in the Julianehåb Bay, but examples where the ice is difficult to detect in the Radarsat imagery with the required precision, are found in all areas. This report will conclude on the following:

1. The ability of the Radarsat data, processed with different enhancement methods, to delineate the ice edge in each of the sectors defined in figure 3.
2. Extraction of Ice concentration and accuracy comparison with validation data and reports from users,
3. Timeliness of the ice charts (from the time the area first imaged by the satellite to the time we at DMI sends out the induced ice charts. This aspect has also been addressed in Gill and Rosengreen (1998)),
4. Determine the quality of the ice charts based on aerial reconnaissance (it is an indirect result of this evaluation).

The report is divided into 8 chapters where 3, 4, 5 and 6 are describing the report and its aims, the setting of the investigation and the type of ice conditions found here, and the method and conventions used during the study. Chapter 7 is presenting the results from the evaluation campaign discussing the data and presenting examples where there were discrepancies between the underflights validation data and the Radarsat interpretation. Finally chapter 8 the conclusions. The material produced during the re-analysis of the Radarsat scenes is included as appendices.

4. The sea ice characteristics near Cape Farewell

The Greenland waters south of 62°N are covered by multi year sea ice of Arctic Ocean origin from mid winter until late summer. During the spring and early summer the ice drifts around Cape Farewell and some years continues several hundred kilometres north along the West Coast. The belt of sea ice in South Greenland, drifting in the East Greenland Current, is 100-200 km wide. The ice floes are severely affected by winds, waves and melting so when they reach the Cape Farewell area they are mostly less than 100 m in diameter, typically 10-20 meters. The average drift speed is 10-20 km/day of the ice along the East Coast. However sea ice movements larger than 50 km/day have been observed.

Because the image quality is dependent on the physical conditions in the area, as well as the incidence angle of a radar measurement, images can both have regions where the ice is possible to map with the desired precision and regions which do not fulfil the demands for ice charting purposes. The same image can be excellent in one area and virtually useless in another area. To take this into account when evaluating the images, the waters of Cape Farewell are subdivided into 4 sub areas with different ice conditions.

East coast: *Coastal areas North and East of Cape Farewell***.** The ice is most of the time packed against the coast, resulting in ice areas having very high concentration and a well defined ice edge.

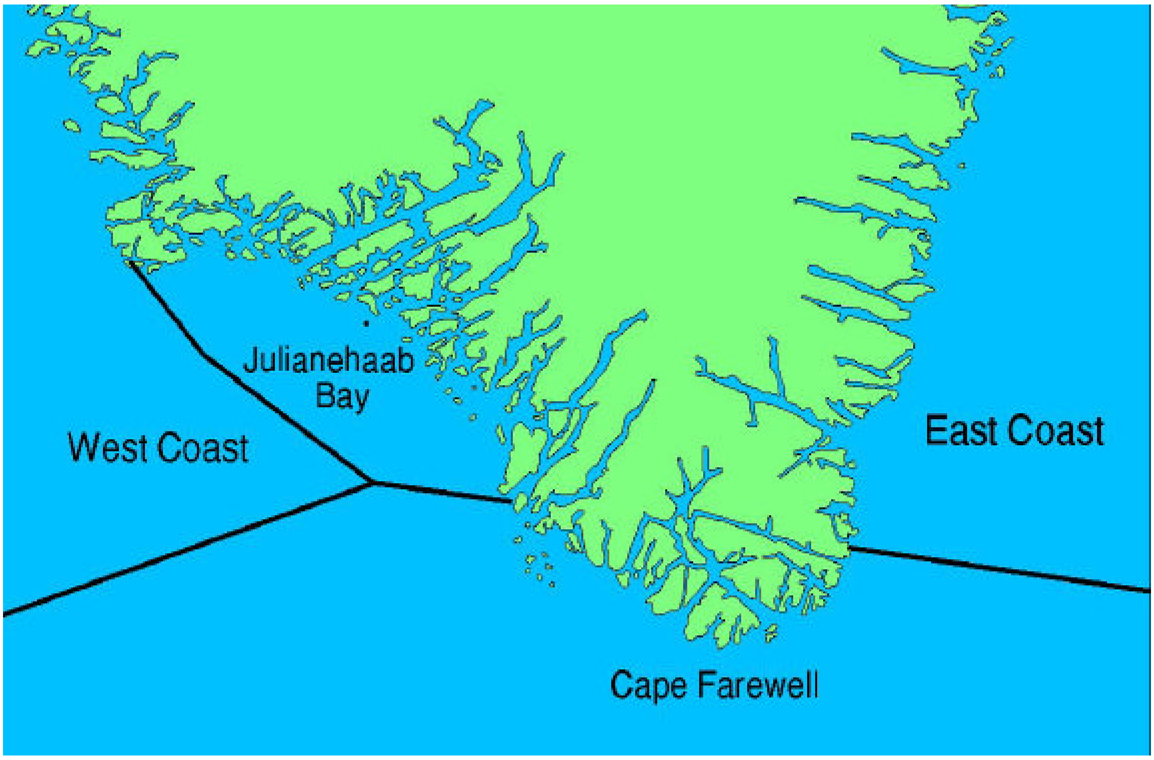

Figure 1. The different areas around Cape Farewell have been divided into 4 different reaions

Cape Farewell: *Offshore and coastal areas south of Cape Farewell*. The most hazardous area, and therefore our primary concern. Most often, ships only require information about the outer ice edge boundary.

Julianehåb Bay: *Coastal areas NW of Sermersoq and SE of Nunarssuit*. Currents and wind often tend to disperse the ice nearly uniformly across the area. During summer, there are frequent combination of calm winds, low ice concentration and surface melt water. Important ship harbours in the Bay and thus detailed ice mapping is required for navigation.

West coast: *Offshore waters NW of Cape Farewell and coastal areas N of Nunarssuit* . In these waters ice concentrations are seldom high and the ice edges are often diffuse. As in the Cape Farewell sector, highly detailed charting is rarely needed in this area.

5. Data

The data for this investigation includes: 1) Radarsat imagery and whenever available NOAA-AVHRR, DMSP-SSM/I and Meteorological data, 2) 13 ice charts produced during the aerial reconnaissance and photographs and positions and observations acquired during the aerial reconnaissance.

5.1 Radarsat image quality

During the SAR processing with the processors at Gatineau and West Freugh, a special ice look up table (ICE LUT and SEA LUT respectively) is used, developed for enhancing ice features. West Freugh did not before 1/1 2000 use the ICE LUT, but instead used a SEA LUT which was not optimal for ice enhancement.

500 Radarsat ScanSAR wide scenes have been received and analysed in near real time at DMI during the year 1999. In particular, the time from the reception of the data onboard the satellite to the last byte had entered the server at DMI it was found that, 30% of the scenes were below 3 hours, 63% below 4 hours and 80% below 5 hours. A few scenes were in the house within 2 hours from reception.

The calibration and development work at the processing facilities in Gatineau Canada, and West Freugh Scotland is resulting in continuously improving image quality. Latest when ScanSAR from CDPF was declared officially calibrated in February 1999 and West Freugh started to use ICE LUT 1st of January 2000. However a visual inspection of the data will reveal several unwanted artefacts like:

1) Scalloping are dark stripes in azimuth direction. The peak to peak distance for these bands in azimuth is about 1.2 km. Scalloping is caused by errors in Doppler parameter estimation, lately scalloping has been reduced considerably in the data received at DMI.
2) The Nadir ambiguity is a bright line in azimuth direction. It is found in all images where the satellite was situated over open water during the data acquisition. The Nadir ambiguity is due to a nadir reflection from the ocean surface, which is not compensated for during the processing. The satellite is over open water during data acquisition for all Cape Farewell images.
3) The ScanSAR principle combines raw data from different beam scans. For ScanSAR wide it is the beam combination w1,w2,w3 and s7. The data from the 4 different beam scans can be seen as 4 areas in range separated by small differences in DN between each area. This is caused by spacecraft attitude uncertainties (Beal, 2000).
4) Analogue to Digital Conversion (ADC) saturation is often a problem in the near range part of the image for open water. Even though Radarsat is operating with an automatic gain control, areas in near range sometimes reach saturation when the return power is distributed unevenly between the two half swaths, for example because of varying wind conditions. (Vachon et al. 2000).

5.2 Reprocessing of West Freugh data.

DMI requested a number of Radarsat ScanSAR images processed with SEA LUT to be reprocessed at West Freugh processing facility using ICE LUT. Data processed at Gatineau has since DMI first received Radarsat data (1996) been processed using ICE LUT a scheme which is developed especially for enhancing ice features in the processed image. West Freugh used until 1st of January 2000 SEA LUT for their processing. The same images processed with ICE and SEA LUT has been evaluated for ice mapping independently.

6. Method

In order to evaluate the ice charts in this investigation it was nessessary to develop a categorisation standard for the two most important ice parameters assessed during the production of ice charts based on satellite imagery: 1) ice edge and and ice area boundary 2) The concentration of ice within a certain ice infested area.

Delineation of ice edge and ice areas: Because of the thickness of multi year ice it is always a serious hazard to navigation and cannot be ignored, regardless of concentration. In some cases the ice edge between open water and ice infested waters is very distinct and no explicit definition is needed, while in other situations the concentration decrease gradually, making the location less obvious. Some ice services like the Canadian Ice Service and the National Ice Center (USA) define the 10% concentration isoline as the ice edge. This is a practical definition in relation to first year ice, but in the Cape Farewell it is necessary to detect and map even lower concentrations because of the multi year ice and the needs of the navigational users. The threshold defining the distinction between open water and ice infested waters is for the purpose of this investigation set to 5%. This ice edge definition is set for the Cape Farewell region. The delineation between different ice areas in Cape Farewell is mainly decided due to concentration differences.

Concentration: Although concentration as a concept is perhaps better defined, the actual measure is quite difficult to determine. An investigation carried out among our colleagues, comparing automatically generated concentrations with manual estimates done by the test person, revealed that;

1) There are differences of up to 20 % in the concentrations estimated by the ice analysist.
2) Most of the different ice analysists overestimate the concentration.

Since it is generally not possible to determine concentration completely objectively, all categorisations rely on estimates by the trained image interpreters.

The navigators onboard ships sailing in Greenland are accustomed to the ice concentrations given in the ice charts. These ice concentrations are estimated by navigators trained in ice observation. All the ice observers employed to produce the ice charts have before been users of ice charts while they were navigating ships in the ice infested waters. This type of recruitment among the ice observers has settled a standard which is closely related to the possibilities and difficulties for navigating ice enforced ships in waters infested with **multi year ice**.

1/10 (possibly belts)	Proceed with care
1-3/10 (possibly belts)	Proceed with care, slow advancement in dense areas
3-5/10 (possibly belts)	Very difficult
5-7/10	Areas > 5/10 to be avoided, difficult and dangerous
>7/10	Inaccessible

6.1 Ice chart types and navigational needs.

To reflect the user demands, two different sets of ice chart standards are used:

- **Offshore charts**: These charts are primarily intended to provide users enough information to avoid the ice cover, and resemble the ice charts that were traditionally produced by aerial reconnaissance, and broadcast via HF radio. Ships passing by Cape Farewell en route between Europe and Greenland's West coast are the typical users of these charts.
- **Inshore/Piloting charts**. Ships that are penetrating the ice areas bound for ports or coastal areas and fjords, require more detailed information. This type of ice chart can only be disseminated via modern communication means such as satellite fax or data transfer.

The above categories are defined to meet the specific needs of the ship navigational community. The visible range under normal conditions from a ship's bridge is approximately 7 km, during this analysis 7 km has then been chosen to be the allowable displacement of an ice class boundary on the chart compared to what it was in reality. The tolerance in concentration is +/-1/10. A misinterpretation of the concentration greater than 1/10 will seriously alter the possibilities and conditions for navigation and therefore cannot be accepted.

Tolerances are the same in offshore and piloting charts. However in piloting charts, all sub-areas greater than 8 km in any dimension, must be marked separately. Specifications are shown in table 1.

Image categorisation			
All areas			
Category	**1**	**2**	**3**
	Good/ Inshore	Acceptable/ Offshore	Unacceptable/
Outline uncertainty	≤5000m	<7000m	≥7000m
Concentration uncertainty	≤1/10	≤1/10	≥1/10
Regardless of the overall image quality, any ice chart that leaves uncharted even small areas of ice with concentration above 1/10 is considered unacceptable.			

Table 1. Image categories with specifications

6.2 Dedicated underflights

Radarsat images were acquired while the ice reconnaissance flights were conducted to produce the ice chart. During the ice reconnaissance the navigator was charting the ice situation using the 360 degree ice radar, GPS and visual inspection of the situation. At the same time the position was logged every 10 seconds and aerial photographs were taken on both sides of the aircraft every 3 minutes. Both the aerial reconnaissance ice chart and the aerial photographs were used during the evaluation of Radarsat.

6.3 Analysed Radarsat images

The interpretation of the ice situation and the composition of the ice chart is called an ice analysis. Sometimes several data sources are used in synergy to produce the correct interpretation, but in the Cape Farewell region Radarsat is often the only source for the ice analysis.

The ice analysis was done independently for Radarsat data processed at Gatineau with ICE LUT and West Freugh data with ICE and SEA LUT. All reprocessed Radarsat data were analysed according to the following rules and the following data sources were used in order to make the analysis comparable to the operational ice charts:

1. Meteorological data and forecasts may be consulted for image interpretation,
2. NOAA-AVHRR data may be used,
3. SSM/I and ERS-SCAT data may be used (as it is less effected by weather conditions)
4. The validation data (aerial photographs, ice charts from ice central) may NOT be used at this stage of the validation - that exercise is to be carried out at a later stage - for training purposes, quantitative parameters etc.,
5. If for one day there are 2 images (one from West Freugh and the other from Gatineau) then both of them may be used to draw the final ice chart for the day,
6. The ice charts computed during the operational phase for these months i. e. during the last summer may NOT be consulted - this is to be an independent evaluation exercise.

7. Results and Discussion

All the Radarsat images during the summer 1999 has been evaluated for ice mapping. The evaluation is following the method outlined in chapter 6 and each region is given a score (good: 1, acceptable: 2 and unacceptable:3). The score system is outlined in table 1. Table 2 is showing the average score for each data type (processing method) and for each region. A number between 1 and 2 is classifying the average score to be between good and acceptable, a number between 2 and 3 is indicating that there are images with the grade unacceptable.

The four areas seen in figure 1 delineate different physical environments but also represent different areas with different incidence angle in the Radarsat scene.
East coast: The area is in addition to the favourable ice conditions positioned in the far range of ascending passes (processed in Gatineau) which is an advantageous incidence angle for ice detection. There are generally few difficulties charting this area.
Cape Farewell: The prevailing high winds can reduce image quality considerably, but very seldom to the point that the ice edge cannot be determined.
Julianehåb Bay: During summer, the frequent combination of calm winds, low ice concentration and surface melt water, can make ice virtually undetectable in the SAR image. There are important harbours in the Bay and thus detailed ice mapping in the region is required.
West coast: There are some difficulties detecting the ice and the ice edge, but most often there is enough wind to create contrast between the open water and the ice areas. As in the Cape Farewell sector, highly detailed charting is rarely needed in this area, still detection of ice concentrations <1/10 is a problem as the floes have further deterioated and are mostly <20m.

The most important result is the great improvement of the data quality for ice detection of the data from West Freugh. This is facilitated by the implementation of the new ICE LUT processing. The SEA LUT used in West Freugh most often made the image quality unacceptable for ice detection in the two western sectors of Cape Farewell (Julianehåb Bay and West Coast), in spite of the fact that these are lying in the far range, which is a favourable incidence angle for detecting sea ice.

The scores in table 2 for the 'East coast' and 'West coast' is varying between good and unacceptable. These areas are often in near range (difficult incidence angle for ice detection) or far range (advantageous incidence angle for ice detection) which then gives a large variation in the score.

	East coast	Cape Farewell	Julianehåb Bay	West coast
CDPF	1.07	1.37	1.82	1.76
WF Sea	1.5	1.79	2.25	2.4
WF Ice	1.61	1.62	1.22	1

Table 2. Average image quality of the different processing methods, shown for each of the regions (shown in figure 1). Notice that before the new LUT, WF images were on average of unacceptable quality (average above 2) for analysing Julianehåb Bay and the West Coast.

The statistics is based on 32 CDPF (Gatineau) scenes, 26 West Freugh SEA LUT scenes and 19 West Freugh ICE LUT scenes.

The explanation for the improvement of the data from West Freugh for ice detection is that a different Look-Up-Table (LUT) was used during the reprocessing. The new ICE LUT used at West Freugh processing facility imitates the ICE LUT used in Gatineau processing facility. The ICE LUT enhances the part of the signal which is backscattered from the ice areas, and gives the image the necessary dynamic depth for ice detection. The detection of ice in a SAR image is done by looking at the texture, shape and general appearance of the different features in the image. It is therefore crucial that the sea areas which may be infested by ice show as much texture as possible, even faint difference are important. The images processed at West Freugh using SEA LUT often represents the ice infested waters by 2-6 different pixel values, which makes it very difficult or impossible to determine whether the feature is ice or not.

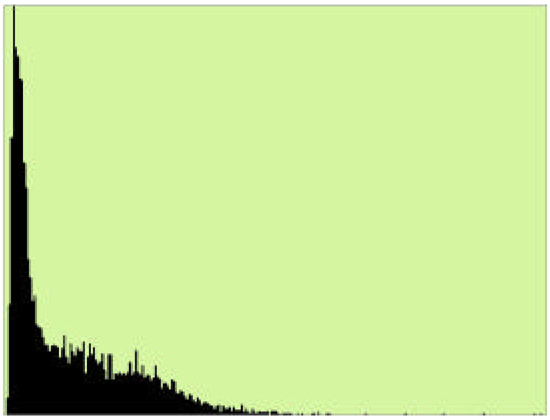

Figure 2. Histogram of the occurrence of data pixel values from West Freugh using SEA LUT the 22nd of July

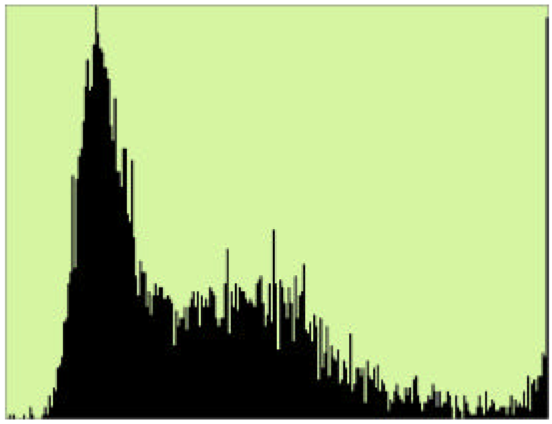

Figure 3. Histogram of the same scene as figure 2 processed at Gatineau with ICE LUT

Figure 2 and 3 show histograms of pixel values in a the entire scene the 22nd of July 1999. The two figures are representative for all images we have receive from West Freugh (before 1/1 2000) and Gatineau (and West Freugh after 1/1 2000) respectively. The pixel values on the x-axis range from 0-255 and the number of occurrences are indicated along the y-axis. The spectra in figure 2 is narrow and only about half of the possible 255 pixel values are used. The spectra in figure 3 is represented by all possible 255 pixel values.

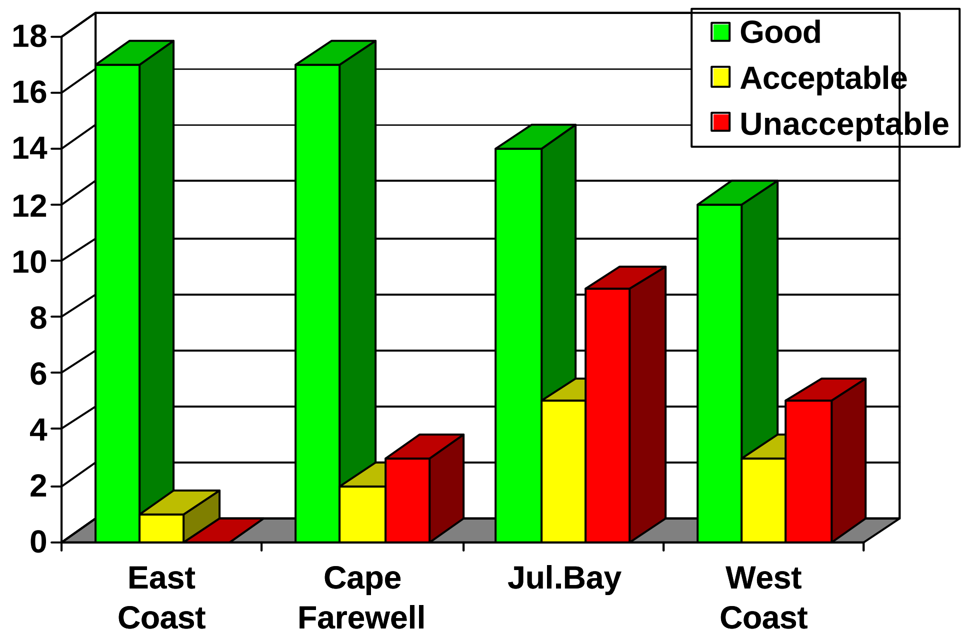

Figure 4. Quality of images processed with ICE LUT in Gatineau. Definitions are outlined in table 1.

Figures 4 , 5 and 6 show the image quality for the respective processing facilities/methods in absolute numbers. Most of the images are acceptable or even good but there are problems in certain areas. The Gatineau images may occasionally be difficult to interpretate in near range which concerns the regions West Coast and to some extent Julianehåb Bay. The quality of West Freugh images processed with SEA LUT are not satisfactory for ice mapping in the entire Cape Farewell area. This is especially the case in the far range (at high incidence angles). The far range of the West Freugh images are the regions West Coast and Julianehåb Bay. The image quality of the West Freugh data processed with SEA LUT is so poor that only part or no ice chart can be based on the data.

20 images acquired and processed at West Freugh using SEA LUT were reprocessed with the ICE LUT, a LUT similar to the one developed for ice at Gatineau. The reprocessing resulted in images of good quality only with occasional degradation in near range.

All 20 reprocessed West Freugh images were reanalysed (independently of the previous analysis) and new ice charts were based on the 20 images. Even with the new processing of the images there were situations where the ice was difficult or impossible to map with the required accuracy. The accuracy of the mapping did however improve with the new processing of the data.

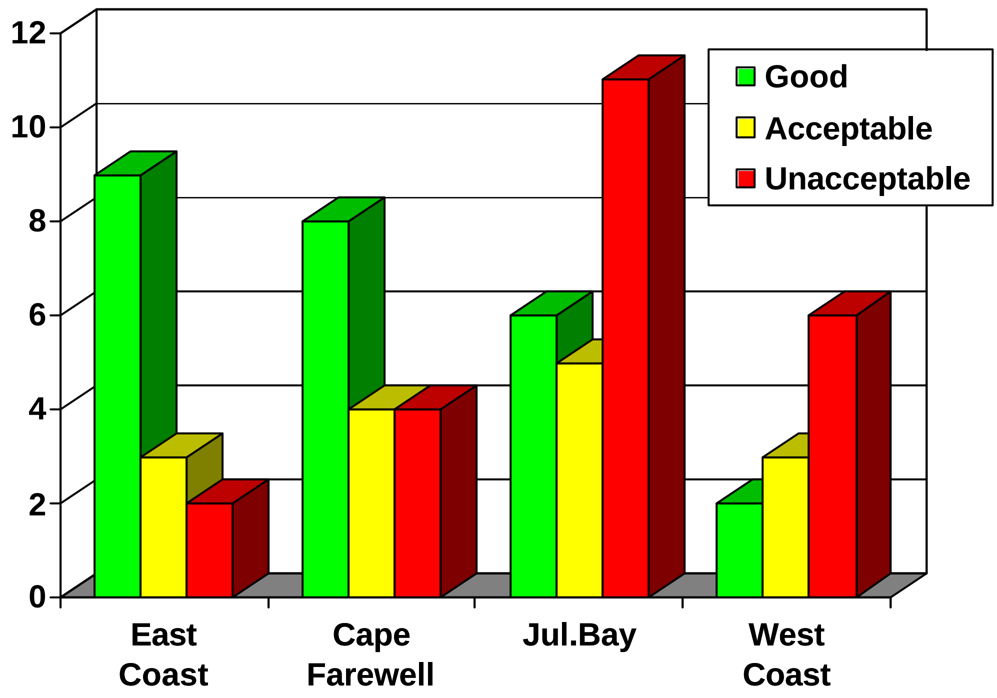

Figure 5. Image quality in images processed at West Freugh with SEA LUT. The categories

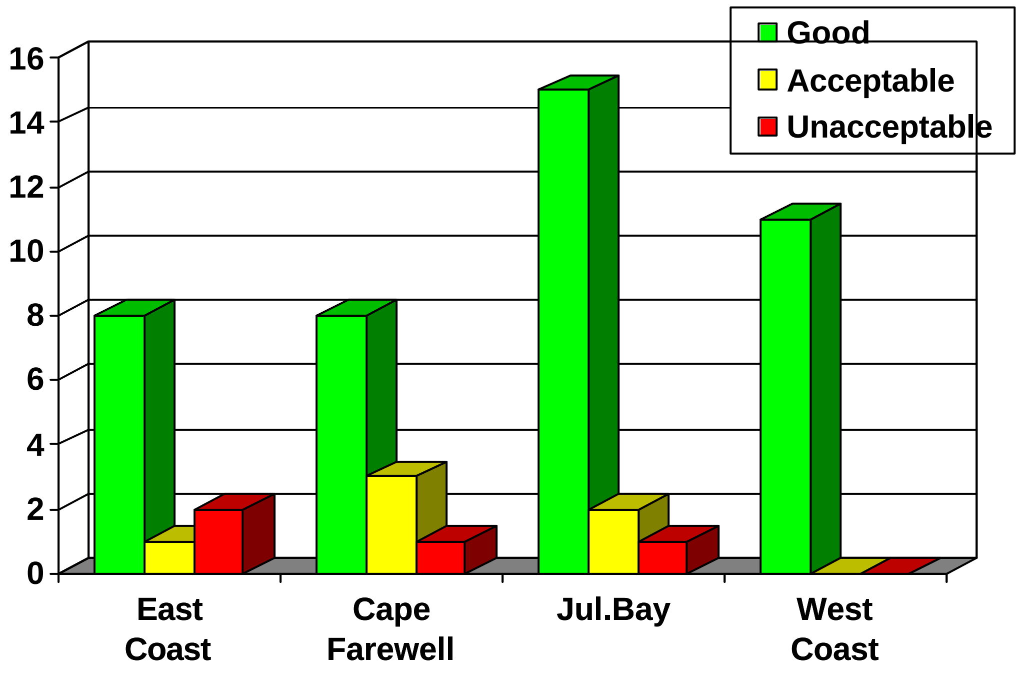

Figure 6. Image quality in West Freugh data, processed with ICE LUT

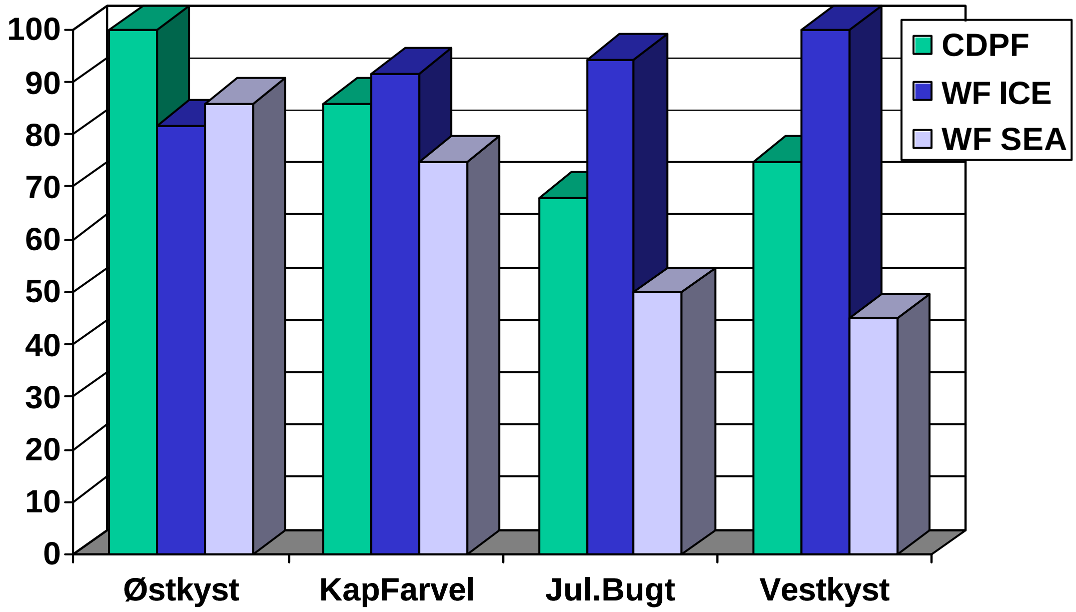

Figure 7. Percentage of images that are 'acceptable' or 'good'.

7.1 Evaluation of ice charts and Radarsat imagery using underflights photographic ground truth.

Out of the 13 underflights during the summer 1999 where the ice was mapped from aircraft near simultaneously with the Radarsat scene acquisition, 3 aerial reconnaissance ice charts were found to differ significantly from the ice chart based on the Radarsat scene. Radarsat covers the Cape Farewell area at about 9.30 UTC on the descending passes received in West Freugh and about 20.30 UTC on the ascending passes received in Gatineau. The aerial reconnaissance was usually conducted from 12-15 UTC to comply with airport opening hours and optimal daylight conditions. During those few hours between the reconnaissance and the satellite scene acquisition, the ice conditions may change. The ice drift speed in the area is usually about 2 km/hour and melting of ice may occur surprisingly fast especially outside the cold waters of the East Greenland current. The difference in the 3 aerial reconnaissance ice charts and the Radarsat ice charts were not due to the natural ice drift or melting but because either the Radarsat image was misinterpreted (most often) or because the situation was judged incorrectly in the aerial reconnaissance ice chart. These three cases were analysed in detail using the photographs acquired during the aerial reconnaissance.

7.2 Three special case studies

The following is describing 3 cases where there were serious differences between the Radarsat ice analysis and the aerial reconnaissance flight chart. All charts are found in the appendix.

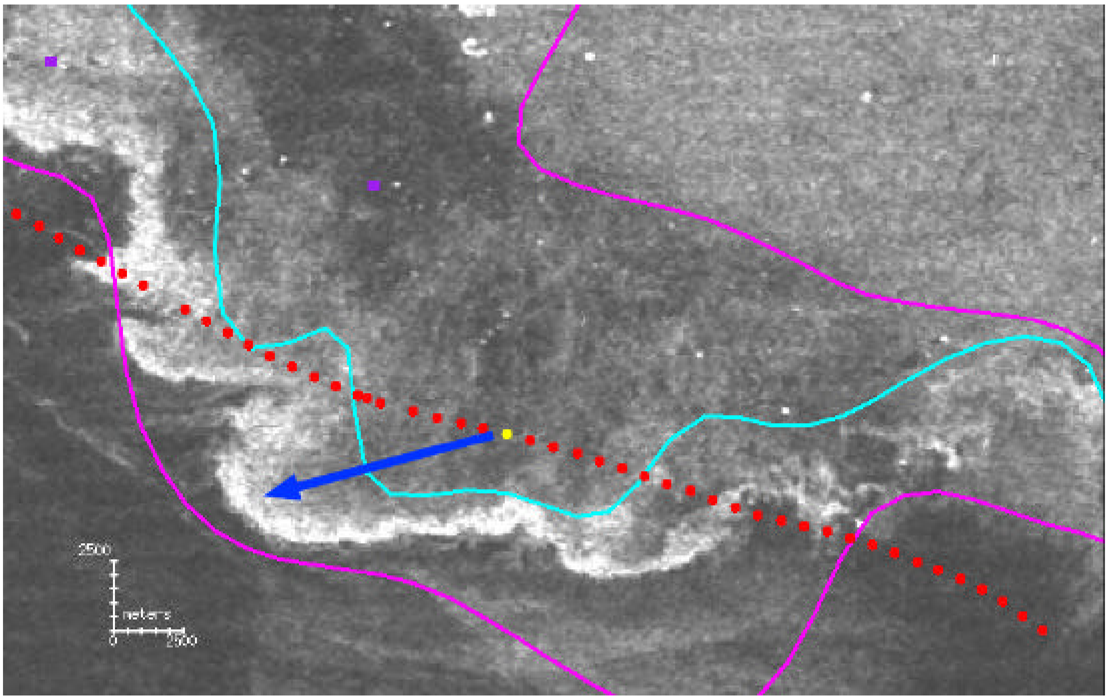

Figure 8. Part of Radarsat image from the 2nd. of July 1999. The drawn ice edge is shown in magenta and the logged position of the aircraft are marked with red dots, one every 10 seconds. The yellow dot and the arrow indicates position and heading of the camera taking the photograph in figure 9.

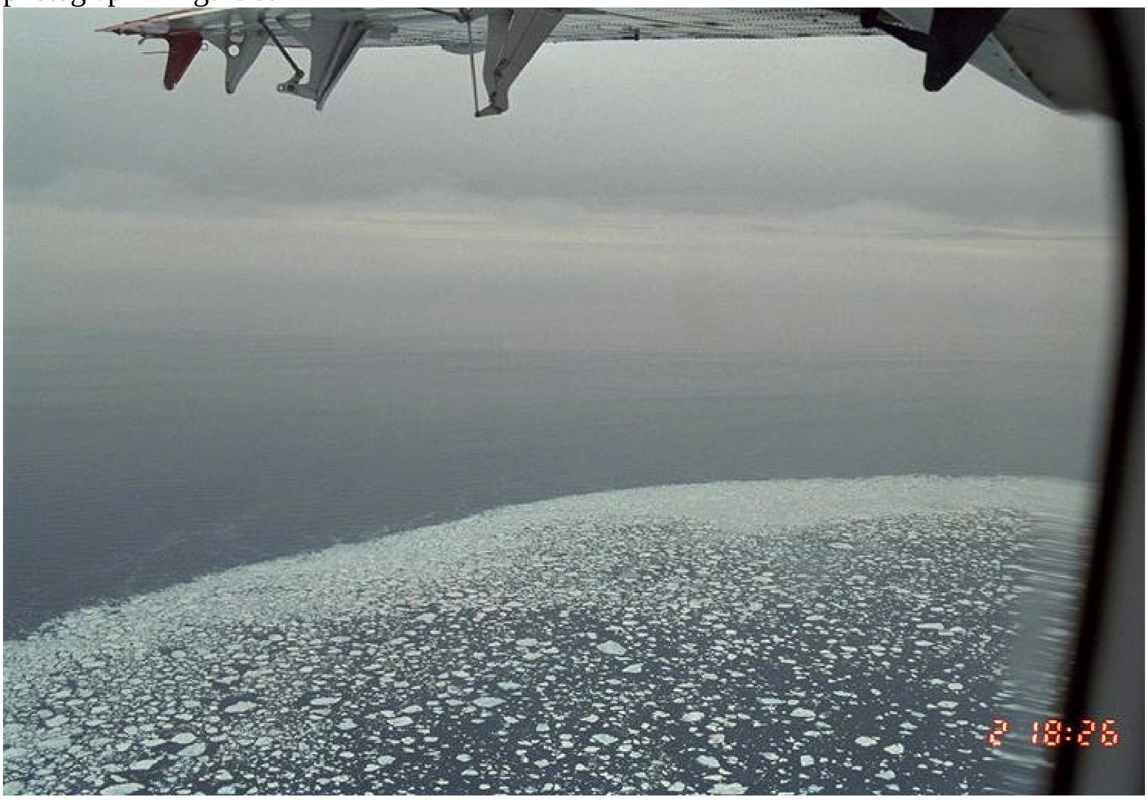

Figure 9. Photograph of the ice edge seen in figure 8, taken from the aircraft.

7.2.1 28th of June:

Data:
West Freugh Radarsat image (9.24UTC) processed with SEA-LUT.
West Freugh Radarsat image (9.24UTC) processed with ICE-LUT (reprocessed at Gatineau)
Gatineau Radarsat image (20.56UTC) processed with ICE-LUT
Underflight, photographs taken and ice chart made by ice-observer

Weather conditions:
The wind is eastern in the Cape Farewell region 10-12 m/s from west and the temperatures 1-2 degrees. The ice drifts eastwards at estimated speeds of 2.5 km/h at open sea to 1.5 km/h near the coast (ice drift is estimated from difference between ice features in the image at 9.24 UTC and 20.56 UTC).

The reprocessing of the West Freugh image with the ICE-LUT produced an image with higher dynamics and better enhancement of the ice areas. The two West Freugh images were mapped independently with different results. All areas except the Cape Farewell region were mapped with greater detail in the reprocessed image than in the original operational SEA-LUT image. The Cape Farewell area was in both West Freugh images difficult to interpret, because of the wind and ice conditions. The ice chart from the underflight and the photographs taken revealed that ice areas even with high concentrations in the Cape Farewell region (Area A) were difficult to detect in the West Freugh SEA-LUT images. The Gatineau Radarsat image at 20.56 UTC was fairly straight forward to interpret, also in the Cape Farewell region, and the ice chart produced with the Gatineau image produced a more detailed ice chart than the chart from the ice reconnaissance. The interpretation of the ice situation the 28th of June 1999 compiling all data revealed that concentrations in the ice charts are in general overestimated both in areas A and B. Concerning the ice chart produced during the ice reconnaissance the compiled data interpretation suggested that the details and the concentration estimate became more uncertain the broader the ice area. The ice chart during the ice reconnaissance was at certain points based on observations more than 50 km away (from 5000 ft. flight altitude). The aircraft radar can at this range pick up ice edges and ice features but a visual interpretation of the ice concentration is impossible.

Conclusion: The disagreement between the various charts was caused primarily by the LUT used during processing of the Radarsat image from West Freugh, and problems in estimating ice concentration from the aeroplane. The Radarsat image from Gatineau provided the best ice information, partly due to a high incidence angle in the ice covered area. Also the image from DERA West Freugh was of sufficient quality provided the ICE LUT was used, but there were some difficulties in determining the ice concentration near Cape Farewell because it was in the near range.

7.2.2 2nd of July:

Data:
Gatineau Radarsat image (20.35UTC) processed with ICE-LUT
Underflight, photographs taken and ice chart made by ice-observer
(West Freugh Radarsat image (9.07UTC) processed with SEA-LUT.)
(West Freugh Radarsat image (9.07UTC) reprocessed with ICE-LUT at Gatineau)

The discrepancies in this case are in the northern most area of Julianehåb Bay, Area A. The aerial reconnaissance shows 1-2/10, while the Radarsat based chart has open water.

Unfortunately the problem lies approximately 20 km from the flight path, so the concentration cannot be judged accurately from the photographs. The true concentration seems to be somewhere between 5 and 10 %, which is often charted as 1-3 tenths in ice reconnaissance charts, and perhaps should have been charted as '1/10' or 'less than 1/10' by the image analysts. On closer inspection, it seems that the Radarsat image was misinterpreted and that is the reason for the discrepancy.

The descending pass only covers a part of Julianehåb Bay, and the sectors to the east, and therefore does not show the controversial areas in this particular case.

Conclusion: Both the ice reconnaissance and the Radarsat chart were in error. The ice chart produced on the basis of the Radarsat image seems to be sufficiently precise, but the image is complicated to interpret and experience could in this case improve the ice chart quality.

7.2.3 22nd of July:

Data:
Gatineau Radarsat image (20.52UTC) processed with ICE LUT.
Underflight, photographs taken and ice chart made by ice observer.
West Freugh Radarsat image (9.23UTC) processed with SEA LUT.
West Freugh Radarsat image (9.23UTC) reprocessed with ICE LUT at Gatineau.

The ice reconnaissance, the Gatineau image and the West Freugh ICE LUT image describe the same ice situation. The problem here is that the processing with the West Freugh SEA LUT giving an image showing no ice in Julianehåb Bay, Area A, while the other sources do. It is a typical summer day towards the end of the ice season, with uniformly scattered ice in Julianehåb Bay at relatively low concentration, melting water on top, and not very much wind.
The photographs reveal that the three first mentioned data sources are correct, and that the West Freugh SEA LUT image is grossly in error.

Conclusion: The SEA LUT used for the processing of the original West Freugh image did not provide an image quality which could be used for ice mapping in this area.

8. Conclusions

Based on the evaluations carried out during the 1999 summer season and the earlier evaluations described in Gill and Valeur (1996) and Gill and Rosengreen (1998), the conclusions are, that there still are situations using Radarsat ScanSAR wide where the ice may be difficult or even impossible to detect in Cape Farewell (3 situations described in chapter 7). However, what has been experienced, when problematic images processed with West Freughs SEA LUT are re-processed with ICE LUT, is that the image quality is improved and the number of problematic images are reduced significantly. The processing method of the images is very important for the image quality and the possibilities for detecting ice.

As was stressed in Gill and Rosengreen (1998) 'the ice services DMI is entrusted to provide in the Greenland waters is foremost for the safety of navigation'. Therefore 1) not being able to identify the ice edge in some of the images and, 2) there was a general feeling of uncertainty when identifying the position of the ice edge and the concentration of ice in certain areas, means that it would be unwise to rely solely on Radarsat ScanSAR wide during the summer melt season. During all other seasons Radarsat ScanSAR wide is good, perhaps even better than aerial reconnaissance, for the ice mapping of Cape Farewell.

The ability of Radarsat to delineate ice in different sectors is determined by several factors 1) is the area of interest in near or far range 2) is the ice edge sharp, meaning if the ice area ends abruptly to continue into open water or the ice area continues into open water gradually: diffuse ice edge 3) the condition of the ice (surface melting, concentration, floe size) and the weather/oceanographic conditions (mainly wind speed and direction and current patterns). Radarsat ScanSAR wide provide most often a very exact and detailed delineation of the ice edge. However the examples from the 2nd and 22nd of July show that it may be that this very important parameter is not found correctly during the analysis.

The quality of the ice concentration estimate in different sectors using Radarsat is affected by the same factors as when the ice edge is delineated. In near range and with strong wind this parameter is virtually impossible to determine correctly only using the information from Radarsat ScanSAR wide.

The timeliness of the data was addressed in detail in Gill and Rosengreen (1998). During 1999 there were occasions where the transfer and processing of data has been unacceptable. The delays has both been made by the processing facilities and the internal data handling and processing at DMI. 80 % of the data are on the server at DMI within 5 hours from the data are received onboard the satellite, these data are all considered acceptable. Data arriving from the processing facility in Gatineau during the night (local Danish time) are not analysed before the morning. Including analysis this delays the information so that it is 12-14 hours old when ships receive it onboard.

During this analysis a categorisation standard for ice charts was defined based on navigational needs. According to this standard an ice edge misplacement of >7km is unacceptable. Normal ice drift velocities in Julianehåb Bay are in the order of 1.5 km/h often making the ice chart unacceptable for navigation within less than 5 hours. Normally the turn around time for Radarsat data from West Freugh to the ice information is received on the ship is around 5 hours and is therefore normally acceptable, but the ice information based on data from Gatineau can not be considered up to date for navigation.

The quality of charts from aerial reconnaissance are not directly evaluated during this report but the example of the 28th of June is indirectly raising some of the problems of using aerial reconnaissance. The concentration of an ice area is determined visually sometimes far from the flight path, at this very low angle of sight the concentration is difficult to estimate and it is often overestimated. Ice edges and ice belts on the other hand are usually positioned very accurately because it is possible to spot them both visually and on the radar.

The new processor in West Freugh has significantly improved the image quality and reduced the number of images which are difficult or impossible to use for ice mapping. The upcoming evaluation of Radarsat ScanSAR (Summer 2000) will evaluate the usefulness of ScanSAR narrow and standard modes of Radarsat. In 2001 data from the coming ENVISAT mission may further improve possibilities of using space borne SAR for ice mapping. For now the aircraft is not disposable during the summer.

8.1 Recommendations

The floe size of the ice in the Cape Farewell area is typically 20-30 m which is below the resolution of ScanSAR wide (resolution ~80-130m). Among the different modes on Radarsat, ScanSAR narrow provide images with a spatial resolution of ~50m. An evaluation of this mode should reveal if it is possible to detect the ice in the difficult areas on the expense of coverage.

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11. Appendices

11.1 Appendix

RADARSAT evaluation form
Offshore and Inshore charts

Date:_______________________ ☐ **Ascending** ☐ **De-scending**

Processing facility: ☐ **CDPF** ☐ **DERA WF**

Lookup table: ☐ **ICE** ☐ **SEA**

Area	**Category**		**Comments**				
	Outline	Concentration	Near range	Weather	Diffuse iceedge	RA	Misc.
East coast							
Cape Farewell							
Julianehåb Bay							
West coast							

RADARSAT evaluation form

Inshore/Piloting icecharts

Date:____________________ ☐ **Ascending** ☐ **Descending**

Processing facility: ☐ **DERA WF** ☐ **CDPF**

Lookup table: ☐ **ICE** ☐ **SEA**

Area	**Category**		**Comments**			
	Outline	Concentration	Near range	Weather	Diffuse iceedge	Misc.
Inshore						
Offshore						