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Abstract
Ice reconaissance using almost daily satellite data from NOAA-AVHRR covering Storfjorden, Svalbard was performed by the SMHI during May to July 1987. This operational project aimed at forecasting the first possible date when a vessel was able to land at Haketangen on the eastern coast of Sörkappland, Spitsbergen. The sea ice forecasts were based on available satellite data and medium time (10 days) weather forecasts delivered from ECMRF in Reading, England. In addition climatological data were also used. The forecasts were delivered to the Norwegian-Swedish company POLARGAS which was going to explore the resources of natural gas at Haketangen. The forecasts were expressed by the probability of a given ice concentration to occur 5, 10, 15, 20 and 25 days ahead. It was difficult to guarantee the accuracy of the forecasts but they gave reasonably well the trend in the ice concentration decrease. The 20 day forecast had probabilities of 70 % that the ice concentration should be 30 % or less around June 22. From satellite data it was found that the ice concentration was 30 % on this date and almost 0 % on June 28.

Key words
Svalbard, Storfjorden, Sea ice, mapping, forecasts, remote sensing

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1. BACKGROUND

The company POLARGAS, which is owned by Norwegian and Swedish interests, started drilling for natural gas at Haketangen on Spitsbergen, Svalbard during the summer 1987. This operation was planned to start as early as possible in the summer season, in order to have time enough for the drilling project before the beginning of the winter season. The drillsite at Haketangen is located at the southeastern part of Spitsbergen close to the glacier Vasilievbreen. This area is exposed to both weather and sea ice

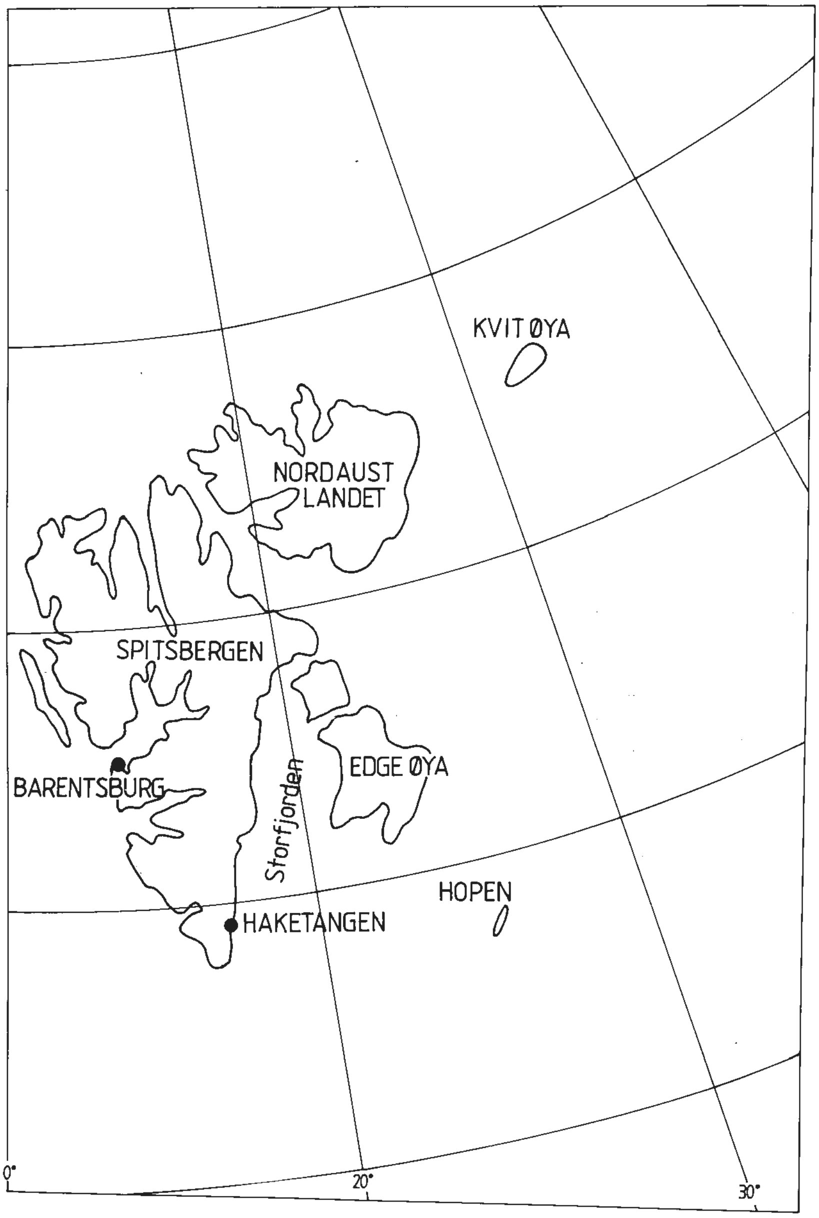

Figure 1: Map of the Svalbard region.

occurring in the Storfjorden (see figure 1). Weather and sea ice are obstacles, which an operation like the one described here, have to take into account, especially since it decides the date of landing with the ship carrying the equipment to the drill site.

The time for loading and transportation of the equipment was estimated by POLARGAS to take 25 days. To minimize the engagement of the ship the company needed forecasts of this extended range. To help to advance the date of landing on the proposed time scale the Swedish Meteorological and Hydrological Institute (SMHI) performed continous sea ice surviel-liance of the Storfjorden area along with medium and long time forecasts ofthe weather and ice situation. The ten-day weather forecasts were based on numerical prediction models from the European Center of Medium Weather Forecasts (ECMWF) in Reading, England, while the longer forecasts of 15, 20 and 25 days ahead were based on extrapolations of the 10-day forecast and climatic data. The sea ice survielliance was based upon satellite data from the US weather satellites in the NOAA-series, which was received by Tromsoe Telemetry station in Norway. The data were delivered to SMHI around 24 hours later for processing and ice mapping. By the end of June 1987 the recently installed equipment for receiving satellite data from the NOAA-series directly at SMHI was in function and a number of scenes per day were now at the projects disposal in real time. The sea ice forecasts were made by using available satellite data and the weather forecasts along with climatic data.

The climatic situation of sea ice and ocean currents in the Barent Sea is here shortly summarized. The maximum and minimum monthly extension of sea ice is shown in figure 2. These data are based on long term Russian observations published in Atlas of the Oceans (1980). According to the minimum extension in May it may be possible to have ice free conditions at the southern part of Storfjorden but still sea ice in the northen and middle part of the fjord can drift southward. In June and definitely in July it is possible to have ice free conditions during a mild or normal winter.

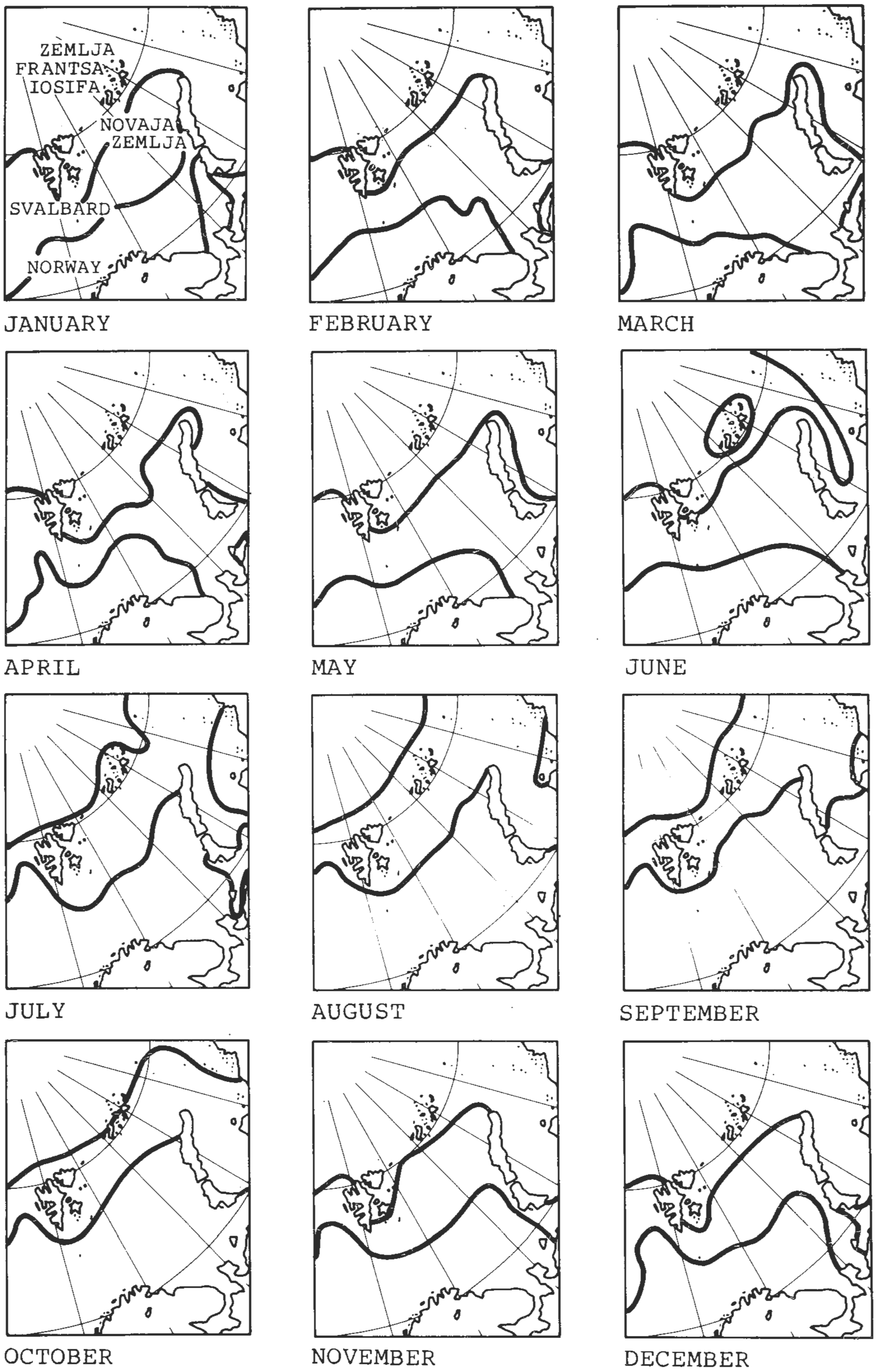

Figure 2: Maximum and minimum sea ice extension in the Barents Sea (from USSR Atlas of the Oceans 1980).

Table 1 shows the appearance and disappearance of sea ice at the island Hopen and Björnöya (from Vinje 1985). Note, that the disappearance of sea ice concentration larger than 4/10 occurs in the mean on July 18, while the extreme first day is June 15. According to these climatic data it should be possible to have ice free conditions in the southern and middle Storfjorden in late June or July.

Table 1: Mean and extreme dates of appearance and disappearance of sea ice at Hopen and Björnyöa during 1970 to 1981 (from Vinje 1985).

Concentration, octas	C > 0	C > 4	C > 7
		HOPEN	
Appearance of ice:			
Mean first day	1/11	6/11	12/11
Extreme first day	13/10-1977	19/10-1971	19/10-1971
Extreme latest day	12/12-1972	12/12-1972	12/12-1972
Disappearance of ice:			
Mean first day	27/7	18/7	8/7
Extreme first day	17/6-1973	15/6-1973	26/5-1976
Extreme latest day	6/9-1979	26/8-1979	12/8-1977
		BJØRNØYA	
Appearance of ice:			
Mean first day	13/12	17/12	22/12
Extreme first day	10/11-1971	14/11-1971	15/11-1971
Extreme latest day	9/2 -1973	13/2 -1973	13/2 -1973
Disappearance of ice:			
Mean first day	21/5	25/4	19/4
Extreme first day	10/4-1980	1/1 -1974	22/12-1973
Extreme latest day	29/7 -1977	27/6 -1977	27/6 -1977

Detailed data on the circulation patterns in the Barents Sea are sparse. The mean surface currents shown in figure 3 is based on Russian sources from 1959 and 1960 and is the one used in the modern litterature (cf. Midttun and Loeng 1987). In general, Atlantic surface water flows into the southern Barents Sea where it meets the colder and less saline and therefore less dense Polar water. The maximum ice extension mainly follow the position of this convergens zone, the oceanic Polar Front. Of particular interest for the present project is the East Spetsbergen current, running in a southwesterly direction from the northen Barents Sea into the Storfjorden area. If persistent, this current may transport sea ice into Storfjorden, making the existing ice situation worse.

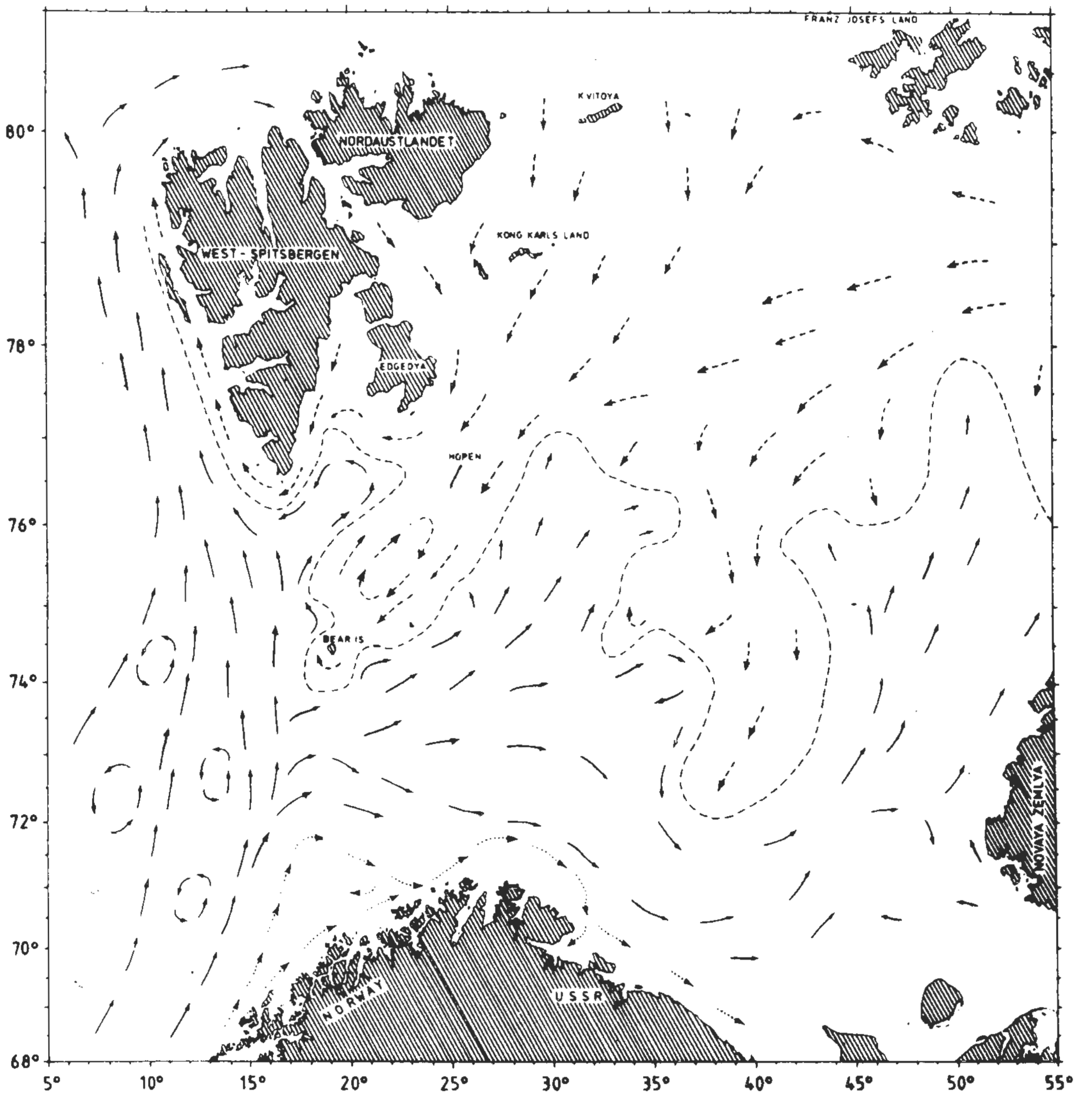

Figure 3: Surface currents in the Barents Sea. Arctic currents (- - ►) Atlantic currents (——►) and Coastal currents (······►).

2. SATELLITE DATA AND PROCESSING

Images from the Advanced Very High Resolution Radiometer (AVHRR) onboard the NOAA satellites have been demonstrated useful for ice mapping by several investigators (cf. Dey (1980)). These satellites are at the present time two in orbit. They have a period of revolution around the earth of102 minutes, which makes it possible to obtain data over the same area many times a day. Hence, the main limitation for surface applications like ice mapping are the cloud cover.

The radiometer measures the radiation from the atmosphere and the earth surface in five spectral bands: 0.58 - 0.68, 0.725 - 1.10, 3.55 - 3.93, 10.3 - 11.30 and 11.30 - 12.50 m. These spectral bands corresponds to one visual, one near infrared and three thermal infrared. The first two bands are well suited for ice mapping but requires sun light, also the last two bands are useful if the air temperature is cold enough (< 0 degrees) so that surface temperature gradients are created between and within the ice, land and water. The geometrical resolution is 1.1 km in nadir and the swath width is 2800 km.

During the project 14 images were used between May 5 and June 24 giving in the mean one image every fourth day. Of these were 6 cloude free, while 3 were covered with more than 50 % cloudes.

The processing of image data was done on a TERAGON workstation which is connected to a VAX 8600. The data were radiometrically reduced from 10 to 8 bits words so that they could be visually studied on the video screen. The so called RGB pictures were produced in which the visual, the near infrared and one thermal band were projected in red, green and blue, respectively. In this case blue represent open water, yellow ice and white clouds. Ice maps over the Storfjorden area were drawn using these images when the cloud cover permitted.

3. RESULTS

In spring the disappearance of sea ice begins with the increase in solar radiation and air temperature. In the marginal ice zone the horizontal variation of wind stress over sea ice and open water drives ocean surface currents which lifts warm water to the surface, causing the ice to melt from below. The break up of the ice cover is also closely related to the advection of sea ice caused by winds and ocean currents.

Hence, forecasts of sea ice disappearance needs both observations and models of atmospheric, ocean and sea ice variables. At the present time both ice observation by satellites and the weather forecasting are in operational use, while ocean forecasting is still at the research stage. This situation makes production of extended range sea ice forecasts (15-25 days) difficult and involves both experience, art and luck.

An example of how the sea ice situation may look like on a synoptic scale is shown in a satellite image from May 19 in figure 4. In this image there

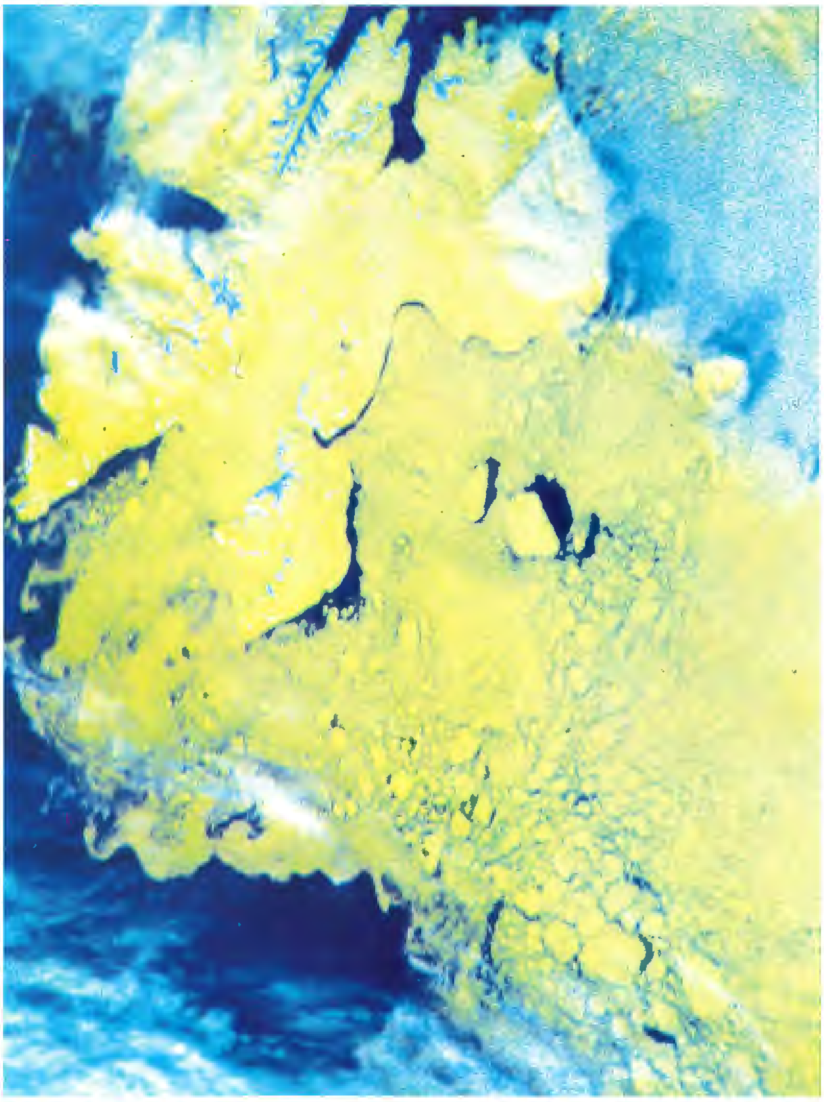

Figure 4: Satellite image from May 19 in multispectral mode (RGB).

are evidence of strong surface currents since the ice edge meander and eddies are formed southest of Hopen. There is also structures in the ice field showing eddying currents in the Storfjorden. All these patterns that can be seen in the sea ice field have lenghtscales typical for ocean currents and it therefore appears realistic to assume that ocean currents constitute the forcing of these ice drifts. In this particular image it may also be noted that the sea ice extension is closer to the minimum extension than to the maximum during this part of the year, according to figure 2.

Before discussing the outcome of the forecasts, the observations made during the project will be presented. In figure 5 windspeed and direction and air temperature are shown. These variables were obtained from the island Hopen in the Barents Sea and from Barentsburg on the western coast of Spitsbergen (see figure (1)). Between May 11 and June 24 there were three events with strong westerly winds (above 10 m/s); May 17 to 19, May 26 to 29 and June 15 to 17 according to the observations at Hopen.

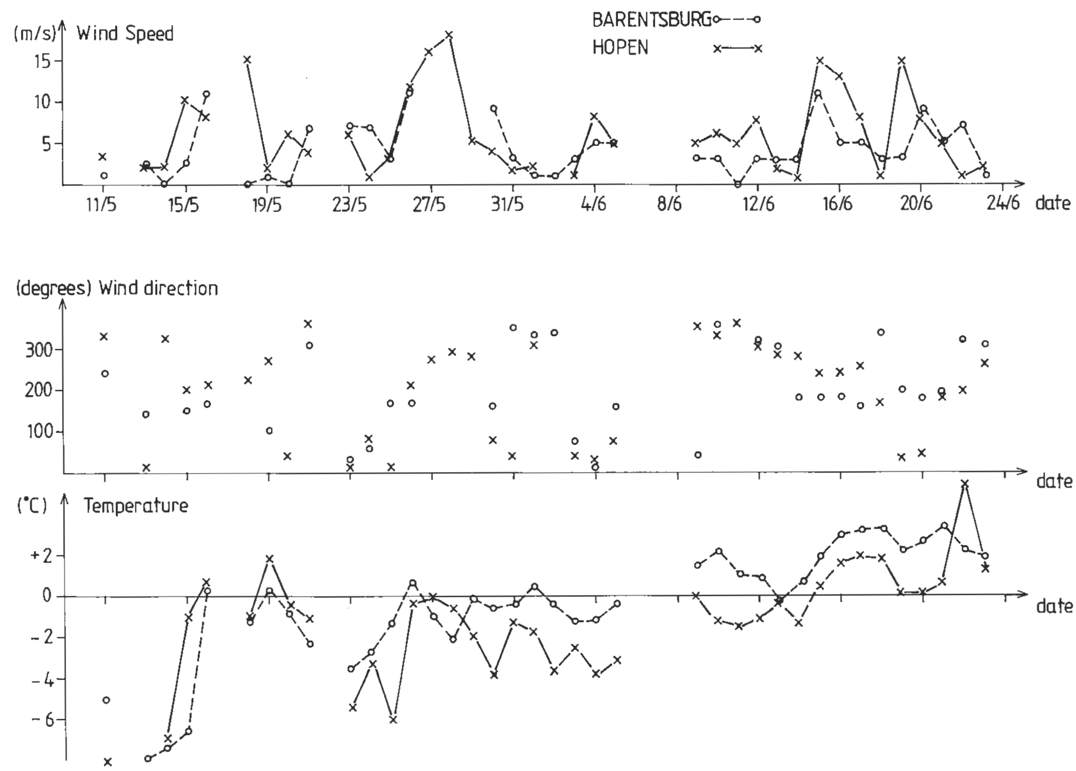

Figure 5: Daily observations of windspeed, -direction and air temperature at Hopen (x) and Barentsburg (o).

Noticable is also the rise in air temperature during these events both at Hopen and Barentsburg. However, at Barentsburg is the wind direction more southerly than at Hopen. This is most pronounced during the mid June event, but the trend is similar during the earlier events also, albeit some data are lost from the Barentsburg time series on these occasions. This difference in winddirection is also seen in the satellite images of which an example from May 27 is shown in figure 6. Using the low clouds as a tracer it can be seen how the westerly winds over the Greenland Sea passes south of Svalbard over Hopen while the Svalbard islands forces the westerly wind to turn north along the western coast of Spitsbergen leaving Storfjorden in a lee.

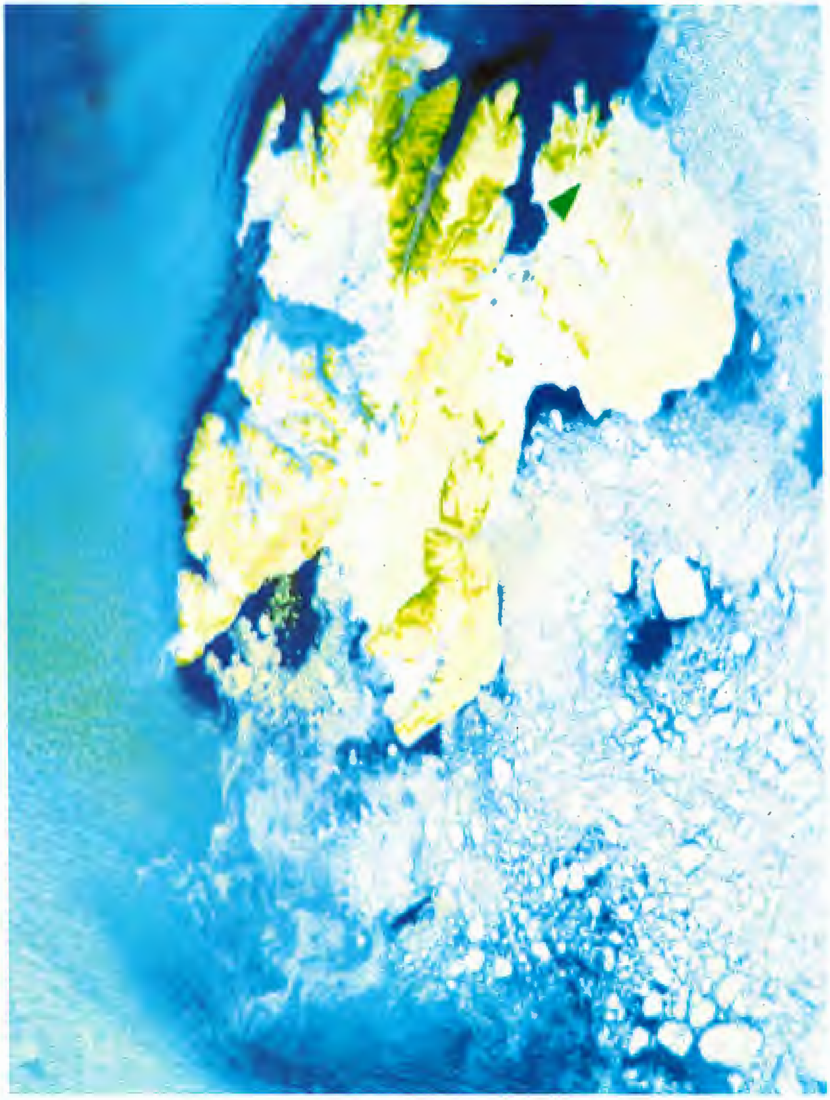

Figure 6: RGB image from AVHRR from 870527. The image demonstrates. the veering of the westerly wind to the north when reaching Spitsbergen.

The estimated icedrift using windspeed data from Hopen during May 27 and 28 seems to be 3 to 5 times higher than the measured ice drift in Storfjorden using satellite data from these two days, also demonstrating the lee effect. This supports the assumption made by the meteorologists (personal communication) at SMHI that westerly and southwesterly warm winds could be forced northward by the mountains and the cold air above Svalbard, creating a lee in Storfjorden.

A time series of the sea ice situation in Storfjorden is shown in figure 7. A disappearance of sea ice can be seen to take place between May to the end of June. Also noticable, is the withdrawal of the fast ice border outside the southeastern coast of Spitsbergen. These data were taken with almost the same sun elevation angle. In this case it can be expected that the decline in surface reflectance from the sea ice occuring between the May and June images mirrors the increased wetness of snow and bare ice produced during the melting process.

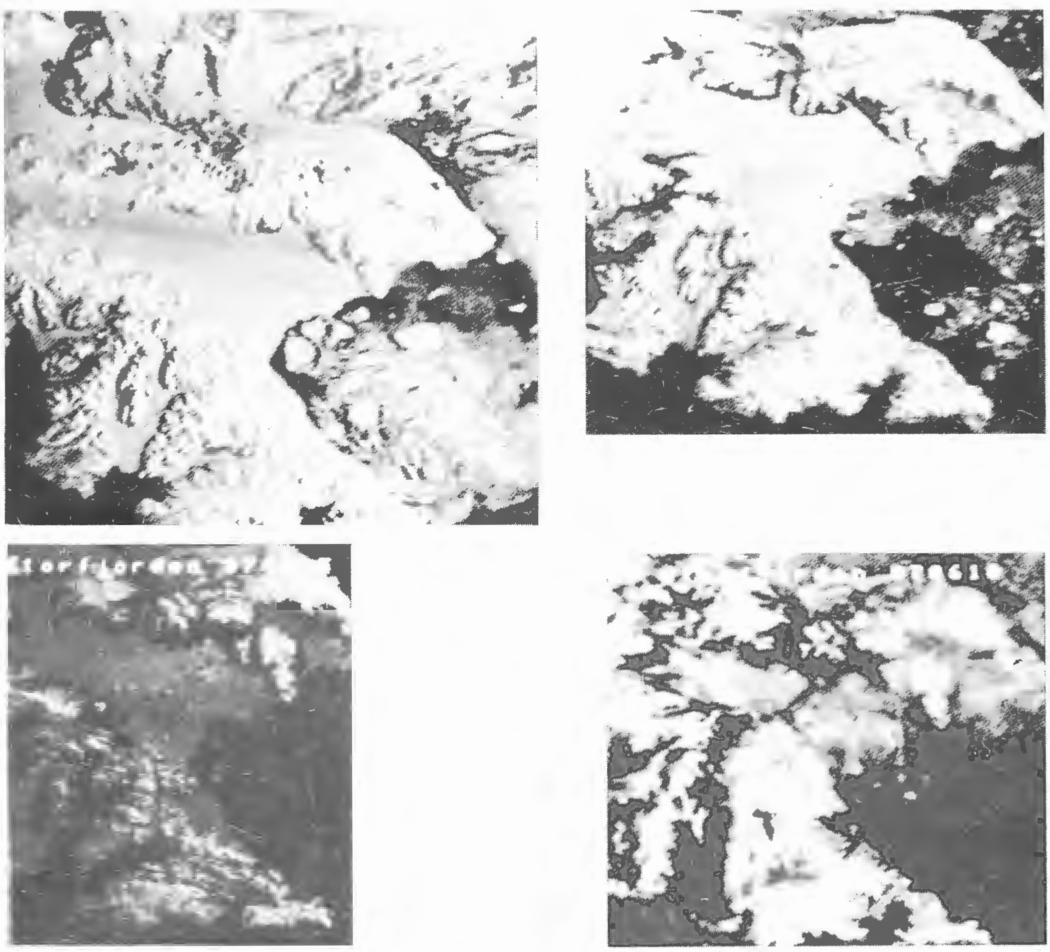

Figure 7: AVHRR data in the visual spectral band. These four images are geometrically corrected to the image from May 14.

The mean ice concentration in the Storfjorden area outside the fast ice border have been determined from satellite images. This was done by counting the relative amount of watercovered pixels in the image produced from the visual band. The result is shown in figure 8. The decrease in ice concentration between May 14 to June 18 is almost linear with a rate of - 1.5%/day, while the largest decrease appears to occur between June 18 to 24 with a rate of - 3.2%/day. It is interesting to note that this latter change most likely is related to a notherly wind during June 19 and 20 and with a period of warm weather with air temperatures above zero degrees Celcius beginning on June 16. Both factors should contribute to the disappearance of ice in the fjord.

The sea ice concentration estimates made from satellite data may be compared with observations made at the Hopen weather station. These data are also shown in figure 8. There is indeed a general agreement between sea ice concentration in Storfjorden and at Hopen during this particular period. Although, ice concentration at Hopen after June 24 occasionally increased to almost 90 % and ice free conditions was not obtained until beginning of August.

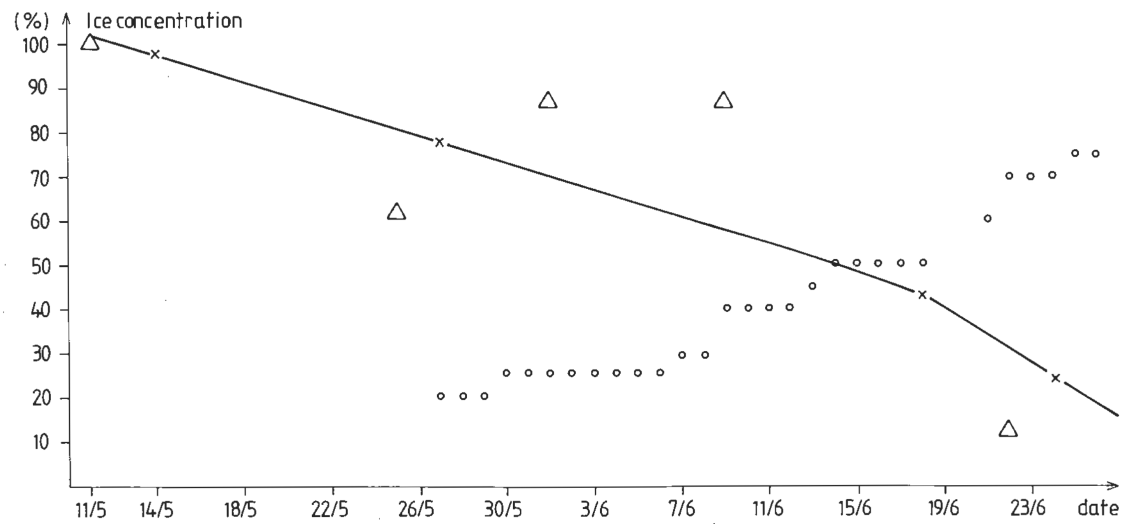

Figure 8: Ice concentration in the Storfjorden not covered by fast ice obtained from satellite data and observed concentration at Hopen (Δ). Also shown is the 20 day probability forecast of ice concentration of 30 % or less (o).

For forecasting purposes it may be stated that according to the above mentioned figures the Storfjorden area had a mean ice concentration lower than 30 % on June 22. This magnitude of ice concentration will be used in the following section as the upper limit when a vessel can navigate in the fjord to the drilling site at Haketangen.

4. DISCUSSION

The long time forecasts were given as probabilities for a certain maximum amount of ice concentration in the Storfjorden area. An example is shown in the table 1. The probability of ice concentration lower than

Table 2: Sea ice concentration forecast delivered daily to the company POLARGAS during the project.

Date 87-06-02

Forecast	valid date	probability of ice concentration of 3/10 or less	of 1/10 or less
+25 days	27/6	85 %	50 %
+20 "	22/6	70 %	40 %
+10 "	17/6	50 %	25 %
+ 5 "	12/6	30 %	0 %

Comments ice situation: Yesterdays satellite image shows that the fast ice has started to break up close the western coast in Storfjorden. Otherwise unchanged.
Comments weather situation: Weak to moderate winds about east during the first days. From 6/6 increasing to fresh and from 9/6 veering to about north still rather cold with temperatures 0 to 4 degrees.

30 % 20 days ahead rises from 25 % in the beginning of June to 90 % at the end (see figure 8). On June 2 the forecast gave 70 % probability of iceconcentration of 30 % or lower for June 22, which indeed is in agreement with the observations made later on. This forecast was good if the 70 % probability can be accepted as the lower limit when vessels can navigate in the area.

It may also be noted that the disappearance of sea ice concentration larger than 40 % observed at the island Hopen occurs in the mean on July 18 and the extreme first day is June 15 1973. These statistics are based on data between the years 1970-1981, see table 1. According to the observations of sea ice concentration at Hopen during 1987 the sea ice disappeared close to the above mentioned mean date. Taking into account the sea ice extension data shown in figure 2, the satellite data from Storfjorden 1987 indicates that this year correspond with the years with minimum sea ice extension. Thus, the disappearance of the ice in Storfjorden during 1987 can be characterized as fast and that the sea ice conditions may be significantly different from the conditions at Hopen during the late melting season.

To conclude, it should also be mentioned that for forecast purposes there are other factors which must be taken into account even when Storfjorden appears almost ice free. The East Spitsbergen current and easterly winds may easily bring sea ice into the fjord, since the ice concentration east of Svalbard always is high during this period of the year. Furthermore, there is fast ice in the northen part of Storfjorden which slowly disintegrate and this ice can move southward along the western part of the fjord. So, although it was reported that the landingsite at Haketangen was ice free already on June19 according to aerial ice reconaissance, belts of drift ice occured offshore and if drifted onshore could be dangerous for a vessel.

Acknowledgement

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