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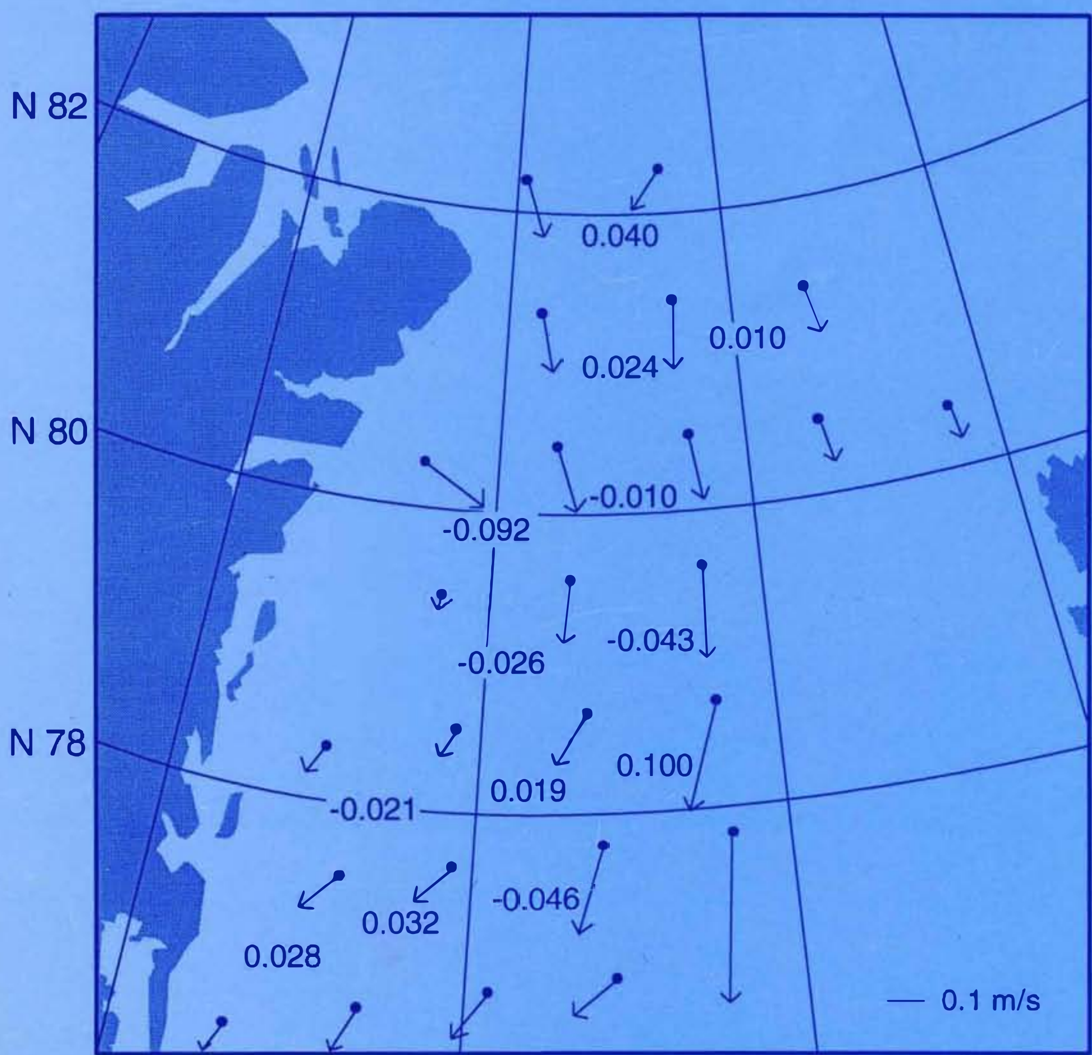

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Printed August 1993
ISBN 82-7666-054-1

Preface

The present report focuses on ice drift in the Fram Strait estimated from ERS-1 SAR and NOAA AVHRR in cloud free periods within the ERS-1 first ice phase (January - March, 1992). The authors jointly performed the work when Vitaly Aleksandrov (first author) visited Norsk Polarinstitutt 14 December, 1992 - 11 January, 1993.

This work thus represents a joint effort to collaborate experience and methods for the remote sensing of sea ice, to improve scientific communication between our respective institutes, and to make analysis more available to both institutes. Loshchilov *et al.* [3] and Korsnes [2] represent previous related work at our institutes.

Norsk Polarinstitutt, January 10. 1993
Vitaly Aleksandrov
Reinert Korsnes

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1 Aim of work

Time series of remote sensing imagery provide the determination of sea ice drift ice velocity and divergence. The ERS-1 ice phases give the opportunity to determine ice drift vectors from ERS-1 SAR images once every 3 days, with high precision within scenes of size 100 times 100 square km. NOAA images can dayly give similar information for much larger areas in periods of good weather conditions. The resolution and therefore the accuracy of ice drift estimates is therefore in principle less. However, since the ERS-1 precision position system (PRARE) is not operative, the absolute positioning of the ERS-1 SAR images has an accuracy of about 2 kilometre. Hence ERS-1 SAR may not give more precise ice drift vectors in cases where no land features can give absolute position reference.

This joint analysis of ERS-1 SAR and NOAA AVHRR images allows us to solve the following tasks:

- To estimate the accuracy of determination of ice drift characteristics from NOAA images, i.e. to use ERS-1 SAR data for validation purposes.
- To estimate the accuracy of determination of sea ice divergence from NOAA images.
- To estimate spatial and temporal variations of ice drift in the Greenland Sea.
- To estimate variations of ice drift within 3 days interval.

2 Data coverage

This report demonstrates the opportunity of joint use of ERS-1 SAR and NOAA AVHRR satellite images for ice drift estimates in the Greenland Sea.

A time series of ERS-1 SAR images covering the same area of 100 x 100 square km with a spatial resolution of about 30 m was used for ice drift estimates in the Fram Strait for the period January-March, 1992 (first ice phase of ERS-1 mission). Figure 1 shows the spatial outline for this time series of ERS-1 SAR images. Two time series from the periods February 2-17 and March 15-30, 1992 of NOAA AVHRR images covering approximately the same area of 2000 x 3000 km with spatial resolution of 1.1 km is used to estimate ice drift in the Greenland Sea for the period January-March, 1992. We received the NOAA AVHRR data from Tromsø Satellite Station (TSS) om the SHARP-1 format. These data provide geolocation information which we used directly in our analyses.

3 Analysis method

3.1 Estimating drift from NOAA images

AVHRR NOAA images cover all our area of interest. It is possible to determine different characteristics of sea ice and to distinguish separate ice floes from them due to their rather high resolution. Therefore ice drift vectors can be determined from a pair of successive cloud free images. Our task consists of recognising the same points on ice floes on successive NOAA images covering the same region and of determining their geographical coordinates. We have used the visual method to determine these positions. The image processing is carried out with the help of the programme RIMAP, designed by R. Korsnes. Two successive images are displayed in the upper half of the computer screen. Then frames to be processed are marked and plotted in the lower part of the screen. The corresponding points of ice floes are then visually identified and marked (for the ERS-1 images automatic point identification are used). The file, including geographical coordinates of the same ice floes in format (latitude1, longitude1, latitude2, longitude2) is the output of the programme. Figure 2 shows the view of the computer screen after completing the procedure of point identification.

3.2 Estimating drift from ERS-1 images

The estimation of ice drift from ERS-1 SAR images is based on identification of a reference configuration of ice points in a 10 $\times$ 10 square km regular grid with the centre at the position 79.75^o N 5^o W.

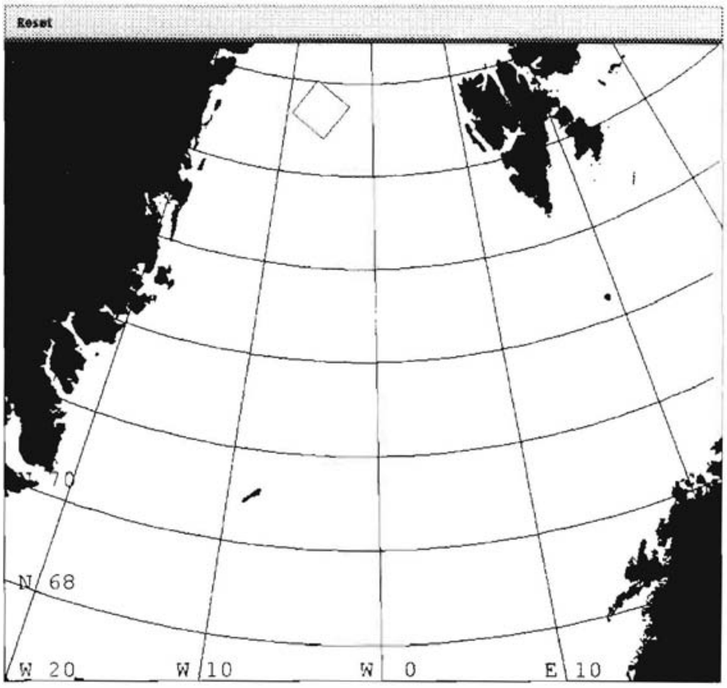

Figure 1: Spatial coverage of ERS-1 SAR image time series used to estimate ice drift in the Fram Strait January-March, 1992 (satellite mission first ice phase).

The drift is represented by a shift, stretch and rotation as in the 'Taylor-like' expansion (cf Korsnes [2]).

$$\boldsymbol{T}_{t_1,t_2}(\mathbf{x}) = \bar{\mathbf{y}} + \mathbf{A}(\mathbf{x} - \bar{\mathbf{x}}) + \epsilon \tag{1}$$

where $\bar{\mathbf{x}}$ and $\bar{\mathbf{y}}$ are the mean points of a reference configuration of corresponding ice points at the image times t_1 and t_2 respectively. The estimates for $\mathbf{A}$ minimise the mean square prediction error :

$$\bar{E}^2 \stackrel{\text{def}}{=} \sum_i \mid \mathbf{y}_i - \mathbf{A}(\mathbf{x}_i - \bar{\mathbf{x}}) - \bar{\mathbf{y}} \mid^2 m_i / \sum_i m_i \tag{2}$$

where $\mathbf{y}_i$ is the position at image time t_2 of the the point number i which at time t_1 was at position $\mathbf{x}_i$. The points $\mathbf{y}_i$ were identified by a semi-automatic procedure based on cross correlation. The author manually checked the results. If there are any doubt about the value of $\mathbf{y}_i$ the weight m_i was set to 0 (otherwise 1).

3.3 A comparison of NOAA and ERS-1 SAR data

The main aim of this work was to compare ice drift retrieved from NOAA and ERS-1 SAR images. It is somewhat complicated to compare these data due to different scales of images and random spatial distribution of ice drift vectors. We have compared ice drift vectors retrieved for the same positions of ERS-1 SAR and NOAA images for approximately equal time intervals. It is not always possible to obtain images from both satellites for the same time intervals. We therefore estimated how much ice drift depends on the time interval for ice drift vectors which are input to the estimation of ice drift. Because of their high resolution and precise geographical location, ERS-1 SAR images should be defined as 'calibration images' for NOAA and can be used for validation of NOAA images. To compare ice drift vectors retrieved from ERS-1 with NOAA data, we used the procedure of interpolation for randomly scattered ice drift vectors to points of a regular grid. We used the regular grid for the Arctic, described in Bushuev, A.V. and Bytchenkov, Yu.D. [1]. The RIMAP programme provided the coordinates of ice

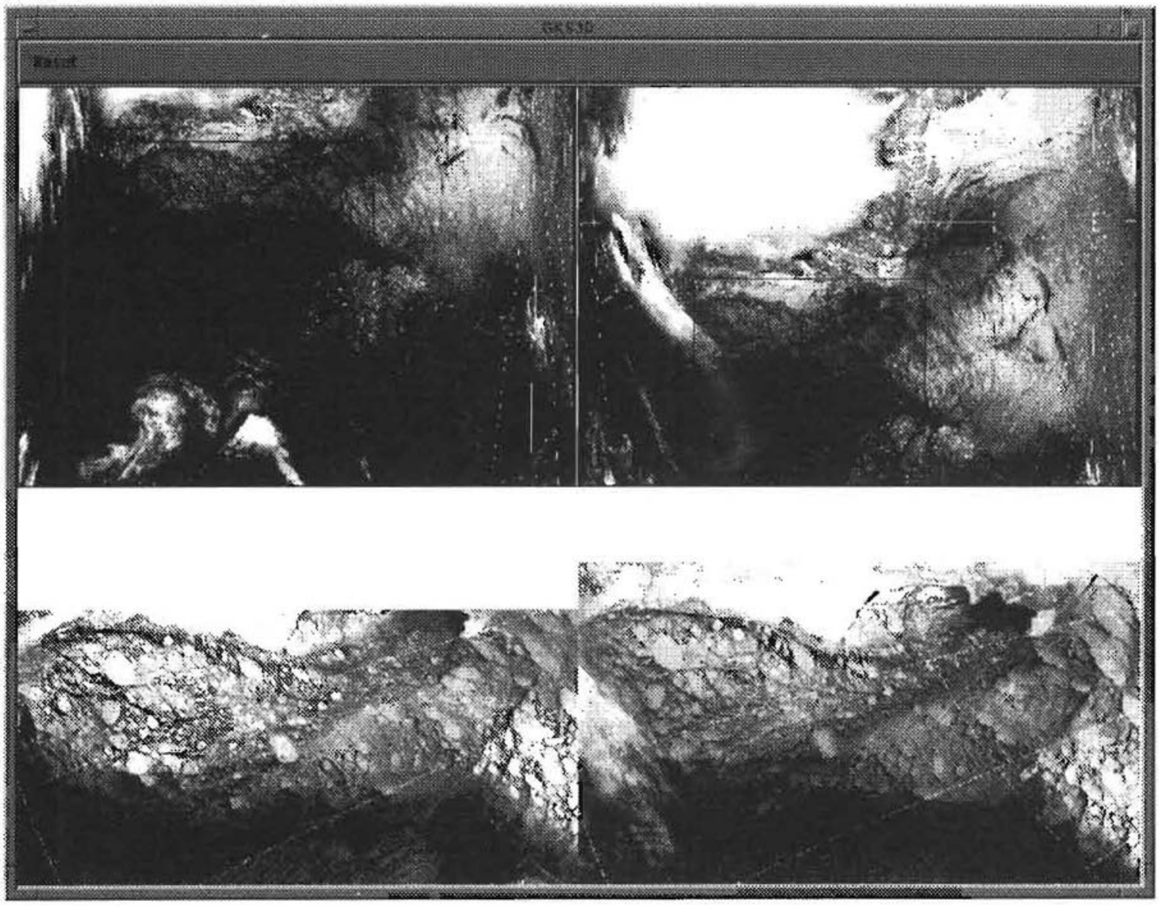

Figure 2: Example of output from the RIMAP programme.

drift vectors. The values of ice drift vectors are interpolated to the points of the grid. The interpolation is carried out according to the following procedure:

Define

$$R_1(x,y) = (\sum_i S_{0,i} \cdot w_i)/\sum_i w_i \tag{3}$$

and

$$R_2(x,y) = (\sum_i S_{90,i} \cdot w_i)/\sum_i w(i) \tag{4}$$

where

$$w_i = \left\{ \begin{array}{ll} e^{-r_i/s} & \text{if } r_i < r_0 \\ 0 & \text{otherwise} \end{array} \right\} \tag{5}$$

$S_{0,i}$ and $S_{90,i}$ are projections of ice drift vectors on the 0 and 90 meridians and r_i is the distance between the beginning of the ice drift vector and the knot of the grid point with coordinate (x, y). s is 50 km and r_0 is 70 km.

Velocity and direction of ice drift vector are determined according to the formulae:

$$S(x,y) = \sqrt{R_1(x,y)^2 + R_2(x,y)^2} \tag{6}$$

$$D(x,y) = \arctan \frac{R_2(x,y)}{R_1(x,y)} \tag{7}$$

The estimates of divergence in the ice field are based on ice drift vectors. Each estimate represents diverging or compacting for each cell in a fixed grid. The divergence is positive for diverging and negative for compacting. The ice drift vectors were interpolated for the points of of the same fixed grid.

4 Wind data

From the Norwegian Meteorological Institute we received wind estimates for January - March, 1992 at the position 78.7° N 5.4° W (10 minutes averages 10 m above surface). These estimates are based on a wind hindcast model. Figures 3 - 5 show these estimates.

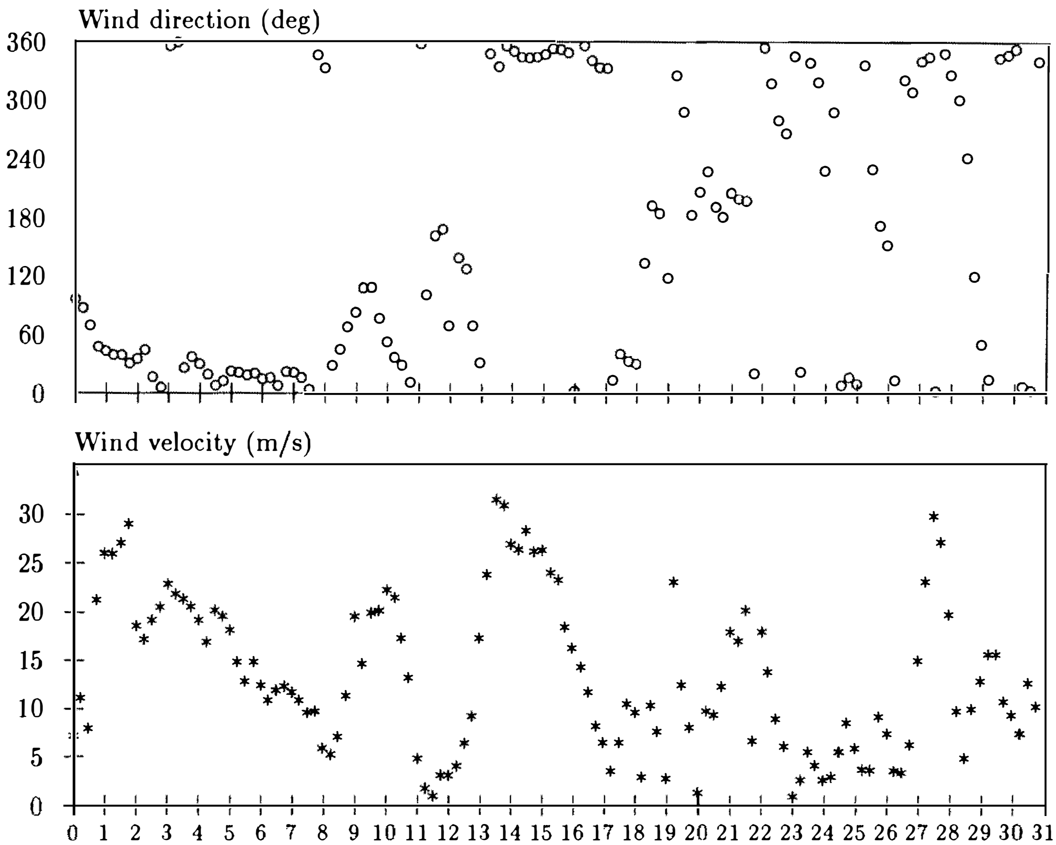

Figure 3: Hindcast wind data from January, 1992 at 78.7° N 5.4° W

5 Results

We obtained ice drift estimates for the periods February 8 - 11 and March 24 - 27, 1992. We produced ice drift velocities within these intervals for one-, two- and three -day periods. Tables 1, 2, 3 and 4 give the results from this procedure. These tables show that ice drift strongly depends on time. Ice drift velocity obtained for a one-day period can significantly differ from velocity obtained for a three-day period. Ice drift velocities retrieved for two or three day intervals are more similar, but even in these cases rather large difference may occur.

Ice divergence strongly depends on time. Values for two- or three- day intervals vary significantly and it is impossible to compare ice divergencies, retrieved from data for different time periods.

Determinations of ice drift vectors may be sensitive to the visual procedure of recognising the same ice floes on successive images. To estimate this factor, we repeated the processing of images obtained on February 24 and 27. We obtained some difference between results. However, these were small compared with results of ice drift vector determination for different time intervals. We also found that divergence of sea ice is less robust to these variations than ice drift vectors.

We compared ERS-1 SAR and NOAA data, obtained for same time intervals. Due to some reasons (such as meteorological, technical) we could only find four such three day intervals (05-08.02, 08-11.02,

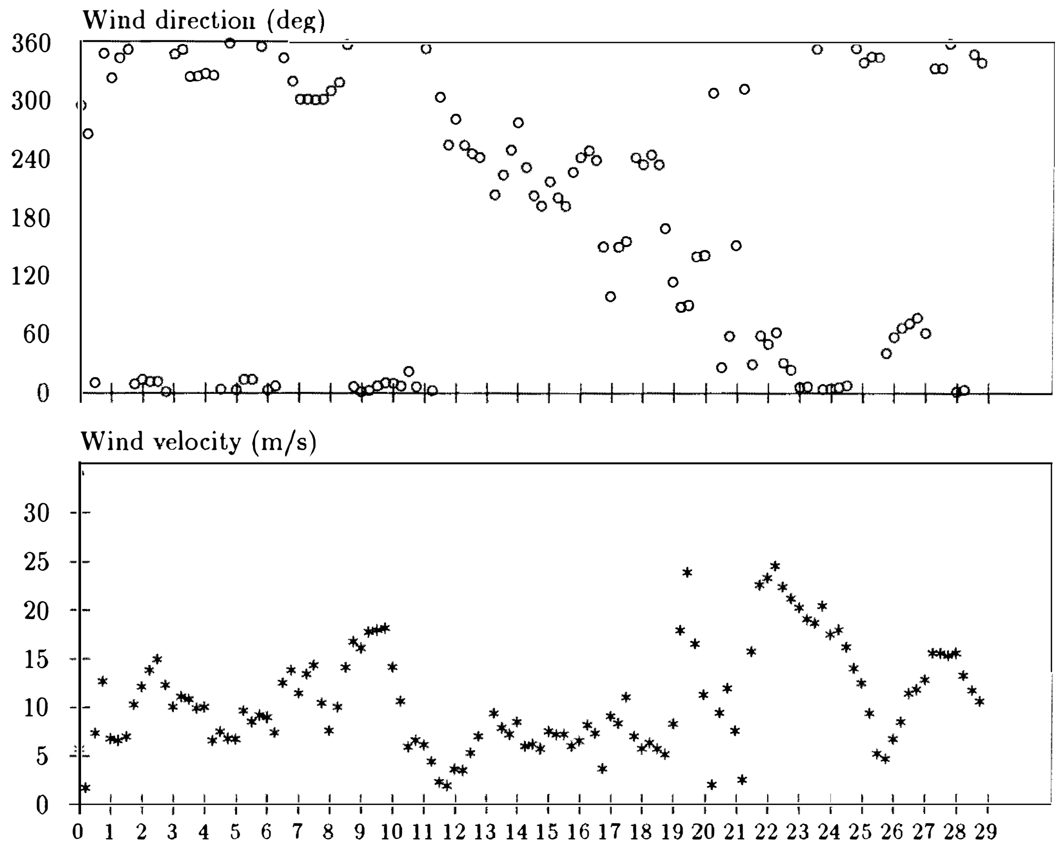

Figure 4: Hindcast wind data from February, 1992 at 78.7° N 5.4° W

Table 1: Velocities and directions of ice drift vectors for periods 8 - 9, 8 - 10 and 8 - 11 February, 1992.

Position (deg)		Velocity (m/s) and Direction (deg)					
Lat	Long	8-9		8-10		8-11	
77.79	-6.29	0.20	215	0.23	206		
77.66	-10.42	0.21	230	0.24	207		
77.47	-14.44	0.23	244				
78.76	-2.28	0.21	207	0.31	211	0.30	208
78.69	-6.80	0.21	211	0.29	212	0.28	214
78.55	-11.24	0.20	224				
79.66	-2.48	0.21	203	0.31	202	0.29	202
79.66	2.48	0.19	202	0.29	199		
79.59	-7.39	0.21	206	0.31	208	0.28	207
80.56	2.71	0.17	199	0.27	194	0.27	197
80.56	-2.71	0.20	198	0.32	198	0.27	195
80.48	-8.09	0.23	195			0.27	193
81.46	3.00	0.17	200			0.26	195
81.46	-3.00	0.21	196			0.26	191
81.37	-8.94					0.27	189

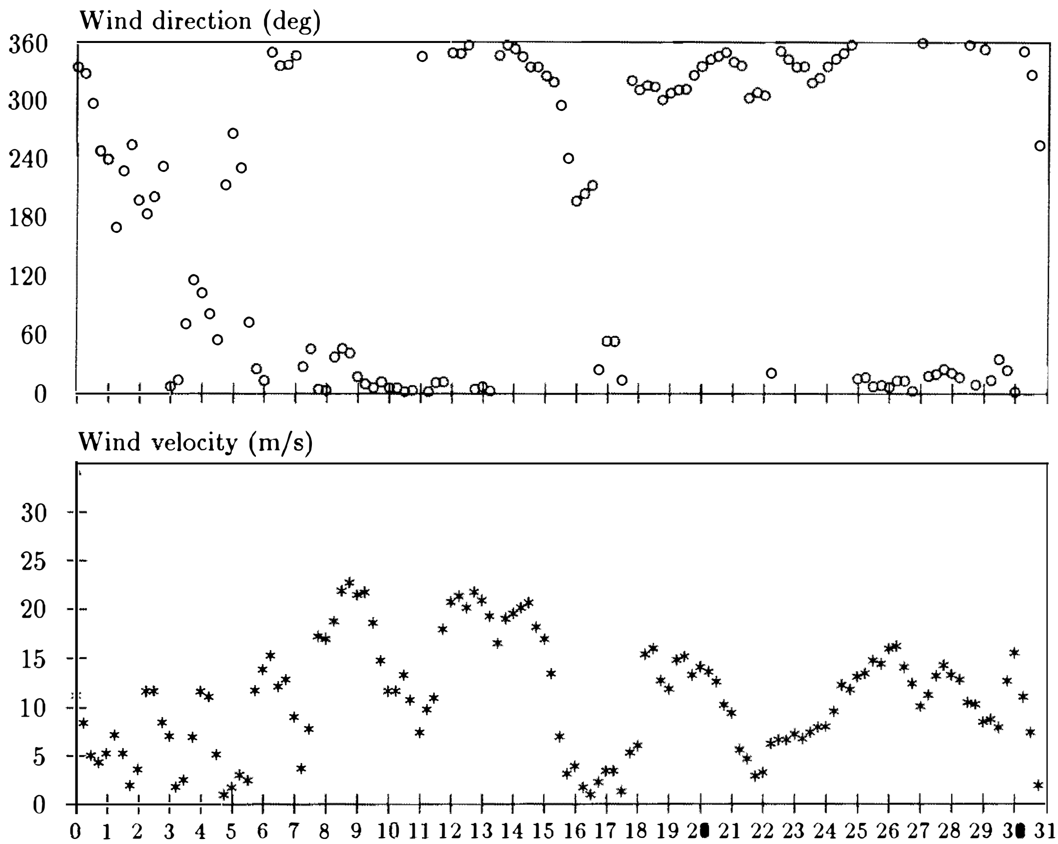

Figure 5: Hindcast wind data from March, 1992 at 78.7° N 5.4° W

Table 2: Divergence of ice drift for periods 8 - 9, 8 - 10 and 8 - 11 February, 1992.

Position (deg)		Divergence (1/day)		
Lat	Long	8-9	8-10	8-11
80.98	-5.69			-0.0136
80.12	0.00	-0.0069	-0.0225	
81.03	0.00	-0.0054		-0.0085
80.08	-5.17	-0.0330		-0.0484
79.18	-4.74	-0.0234	-0.0419	-0.0418
78.18	-8.69	-0.0220		

Table 3: Velocities and directions of ice drift vectors for periods 24-25, 24-26 and 24-27 March, 1992.

Position (deg)		Velocity (m/s) and Direction (deg)					
Lat	Long	24-25		24-26		24-27	
75.70	-12.61			0.17	189	0.15	215
75.49	-16.05			0.20	197	0.13	208
76.89	-5.86	0.12	230			0.22	214
76.77	-9.70	0.10	210	0.16	209	0.18	219
76.59	-13.46	0.10	204	0.15	206	0.16	219
76.36	-17.12	0.08	203	0.13	199		
77.86	-2.11	0.34	186	0.40	195	0.29	208
77.79	-6.29	0.18	197	0.28	197	0.24	211
77.66	-10.42	0.10	223	0.10	209	0.17	217
77.47	-14.44	0.10	223	0.13	210	0.15	220
77.22	-18.32	0.09	215	0.13	210		
78.76	-2.28	0.23	199	0.27	195	0.24	208
78.69	-6.80	0.12	209	0.17	198	0.19	212
78.55	-11.24	0.07	206	0.12	212	0.14	220
78.34	-15.55	0.07	208	0.08	213	0.11	232
79.66	-2.48	0.18	180	0.24	189	0.21	200
79.59	-7.39	0.13	185	0.17	188	0.16	205
79.43	-12.20	0.03	181	0.08	197	0.10	214
80.48	8.09	0.07	175	0.08	145		
80.56	2.71	0.09	165	0.11	183		
80.56	-2.71	0.13	170	0.19	183		
80.48	-8.09	0.13	161	0.21	180		
80.31	-13.34	0.14	119				
81.46	3.00	0.10	169				
81.46	-3.00	0.13	185	0.18	188		
81.37	-8.94	0.12	166	0.19	178		
82.36	-3.36	0.12	216				
82.26	-9.98	0.11	160	0.17	142		

Table 4: Divergence of ice drift for periods 24 - 25, 24-26 and 24-27 March, 1992.

Position (deg)		Divergence (1/day)		
Lat	Long	8-9	8-10	8-11
81.88	-6.32	0.0396		
80.98	-5.69	0.0236	0.0180	
81.03	0.00	0.0096		
79.96	-10.26	-0.0917		
80.08	-5.17	-0.0097	-0.0219	
79.07	-9.41	-0.0263	-0.0225	-0.0117
79.18	-4.74	-0.0430	-0.0180	-0.0203
78.02	-12.91	-0.0214	0.0107	0.0242
78.18	-8.69	0.0194	0.0336	0.0161
78.28	-4.37	0.0999	0.0732	0.0186
76.92	-15.83	0.0276	0.0236	
77.13	-12.01	0.0324	0.0182	-0.0003
77.29	-8.07	-0.0456		-0.011645
76.04	-14.81		0.056834	

11-14.02 and 24-27.03) in NOAA data for period February - March, 1992. We estimated ice drift vectors from these data and made the interpolation to a regular grid with cell size 100 km. Previously determined ERS -1 ice drift vectors were also interpolated to this grid. Due to the small swath width of the ERS-1 SAR images, they provided estimates only for one grid cell. Comparisons were therefore carried out only for the grid cell with coordinates of the center (79.59 N, 7.39 W). Table 5 gives the result. Determination of ice drift velocity from ERS-1 SAR and NOAA AVHRR images coincide in this case with accuracy 1 - 2 cm/sec for velocity and 5 degrees for direction for three cases from four. Because ice drift derived

Table 5: Comparison of ice drift vectors, retrieved from NOAA and ERS-1 SAR images at position 79.59° N −7.39° W.

Time interval	Velocity (m/s) and Direction (deg)			
	ERS-1 SAR		NOAA AVHRR	
02.05 - 08	0.19	190	0.20	184
02.08 - 11	0.27	203	0.28	207
02.11 - 14	0.09	183	0.08	185
03.24 - 27	0.22	198	0.16	205

from ERS-1 SAR were carried out with high accuracy, we can conclude that it is possible to determine ice drift vectors from NOAA images in condition of clear weather, rather low air temperatures, and ice features on both NOAA images can be distinguished. The accuracy of such determination is rather high.

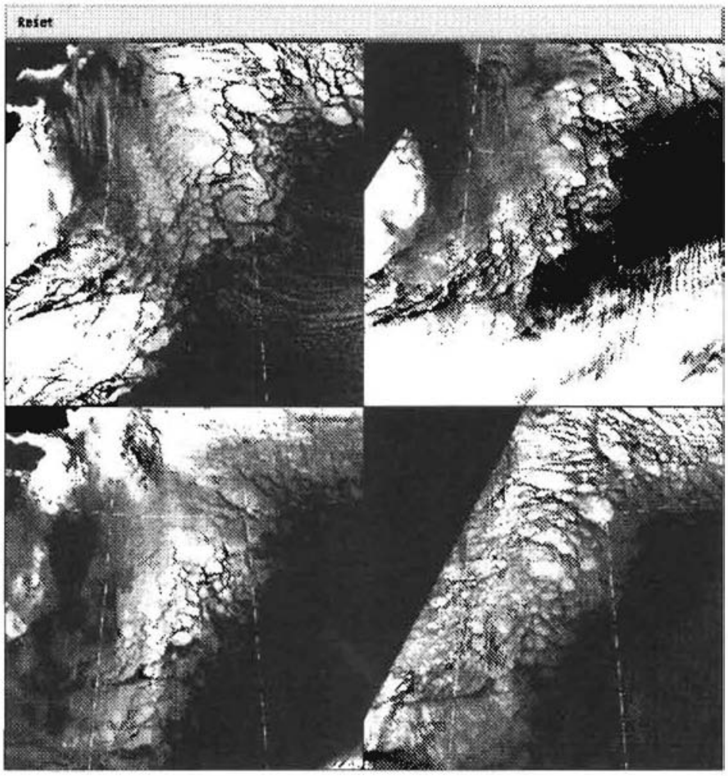

Figure 6: Resampled NOAA subscenes February 8 - 11, 1992.

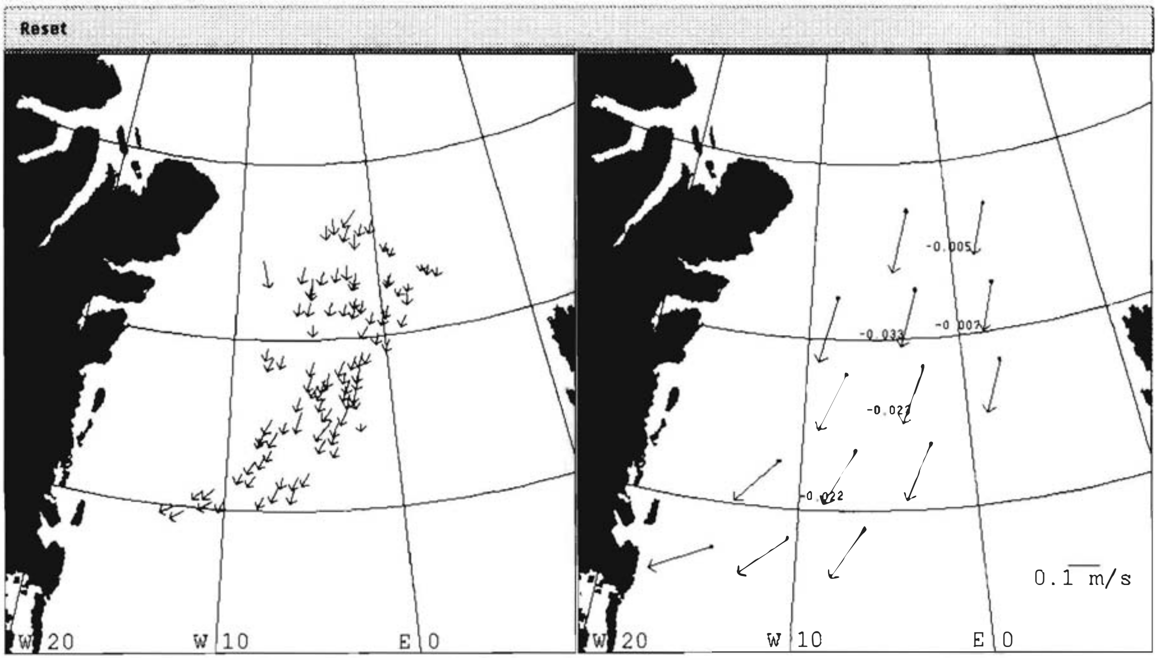

Figure 7: Ice movement in the period February 8 - 9, 1992, and estimates of ice velocity and divergence.

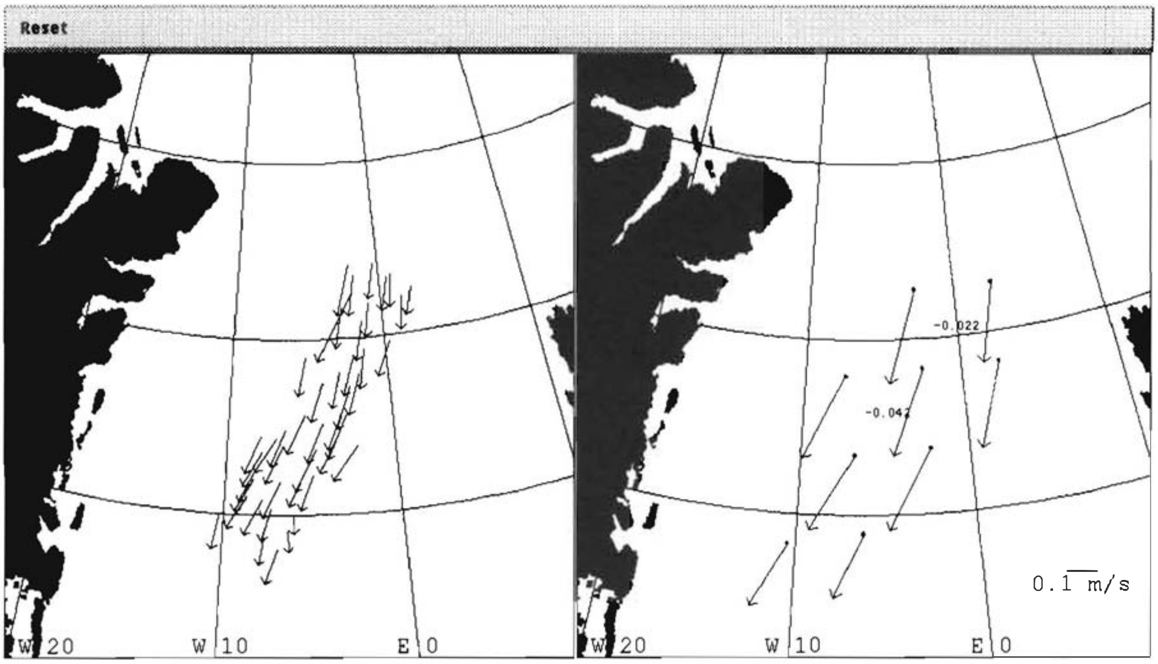

Figure 8: Ice movement in the period February 8 - 10, 1992, and estimates of ice velocity and divergence.

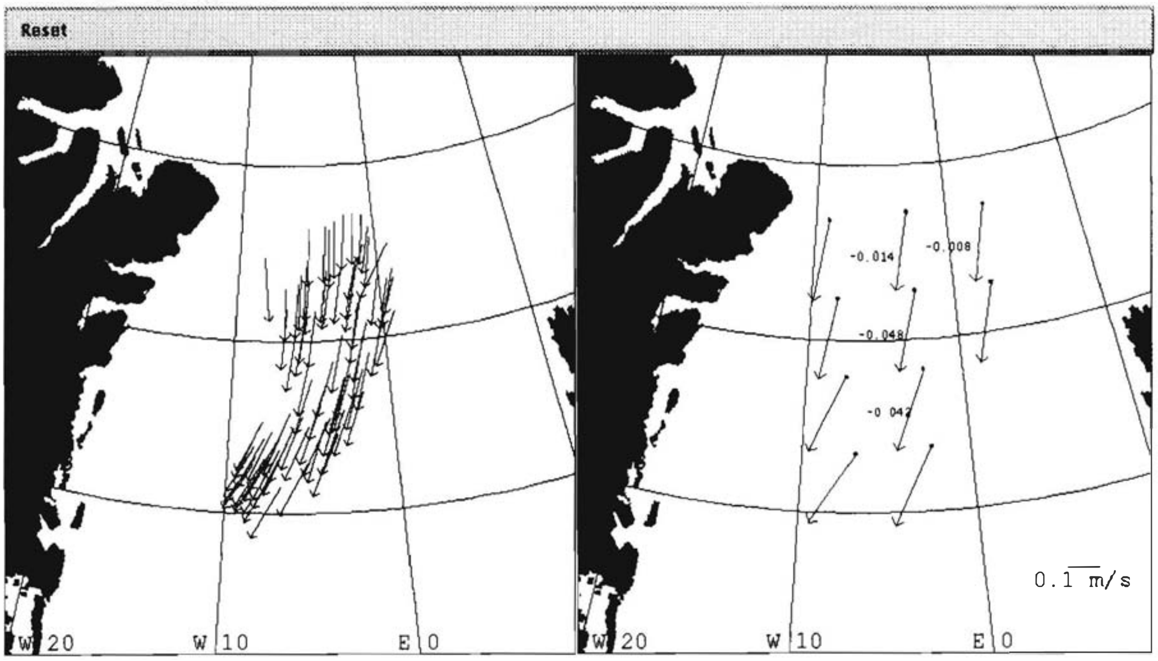

Figure 9: Ice movement in the period February 8 - 11, 1992, and estimates of ice velocity and divergence.

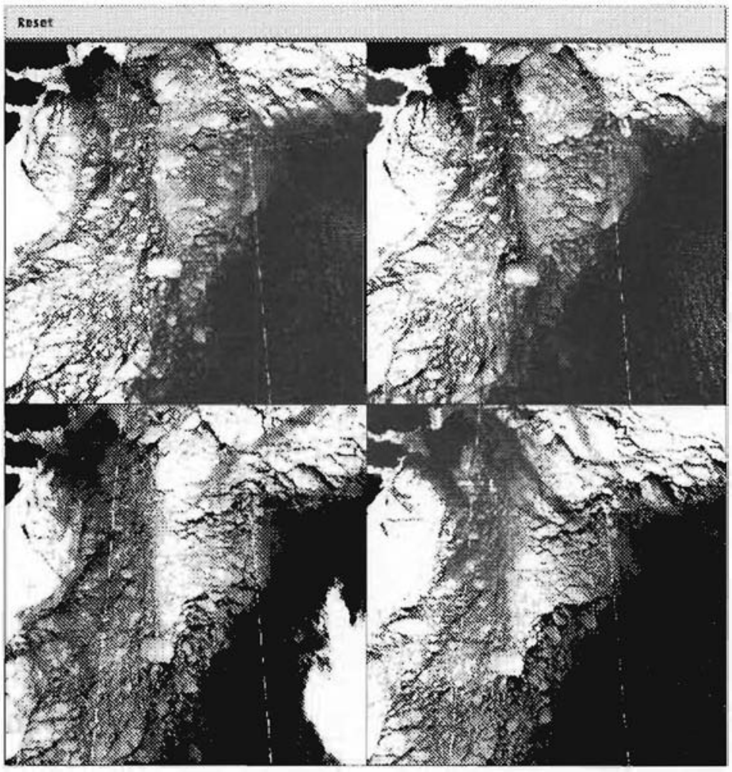

Figure 10: Resampled NOAA subscenes March 24-27, 1992.

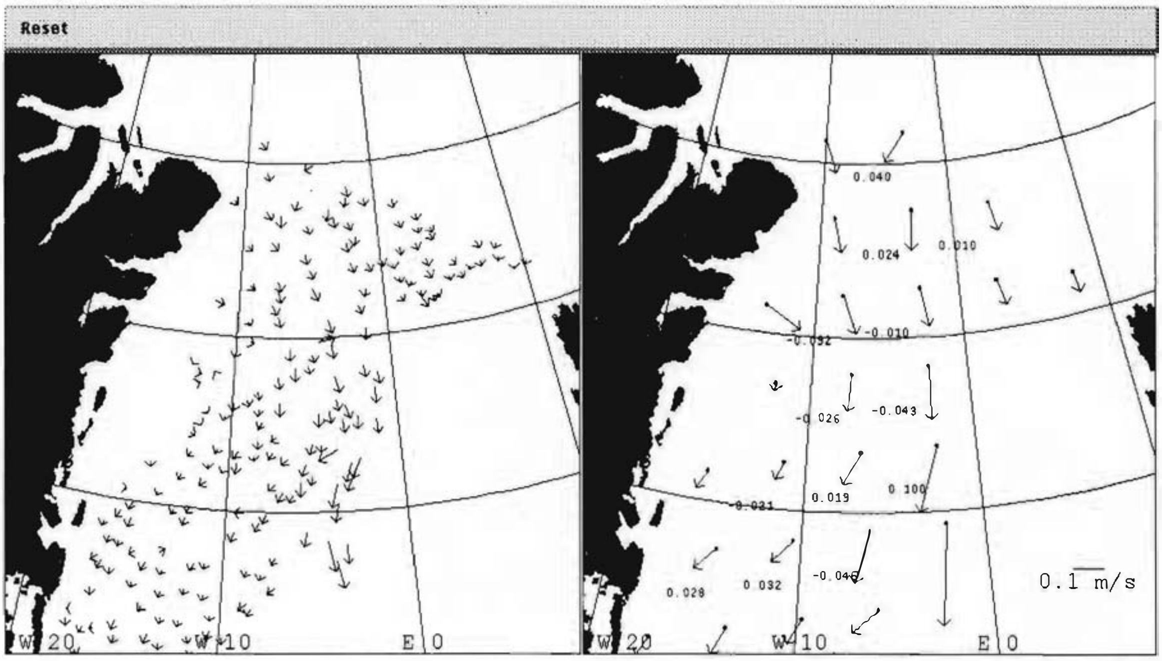

Figure 11: Ice movement in the period March 24-25, 1992, and estimates of ice velocity and divergence.

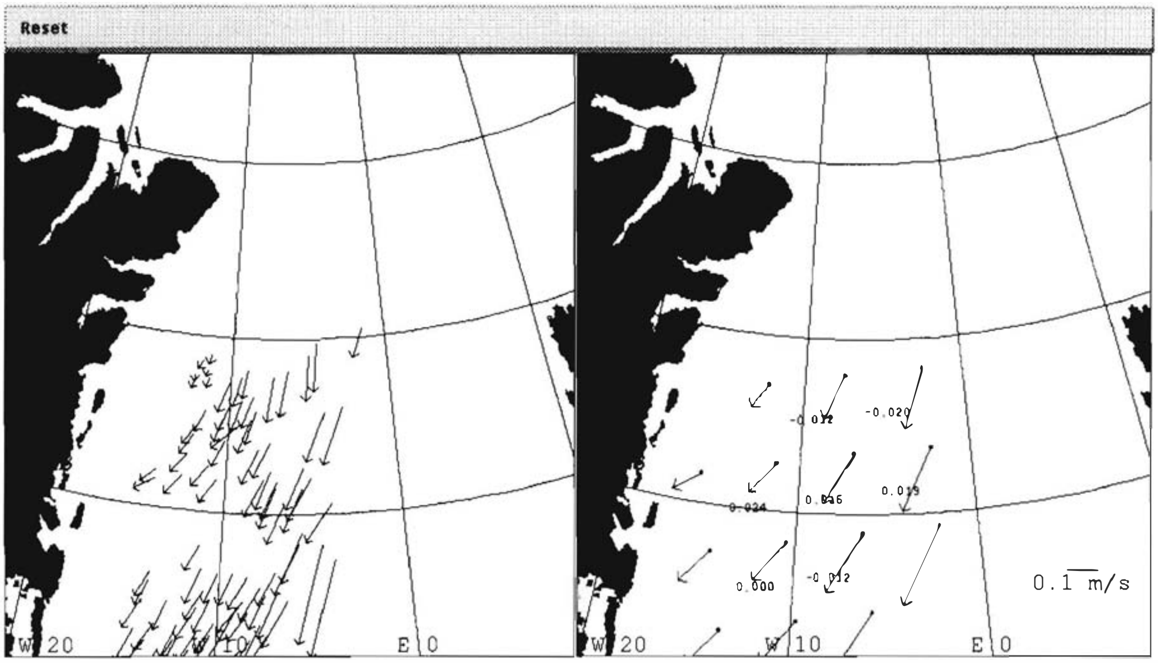

Figure 12: Ice movement in the period March 24 - 26, 1992, and estimates of ice velocity and divergence.

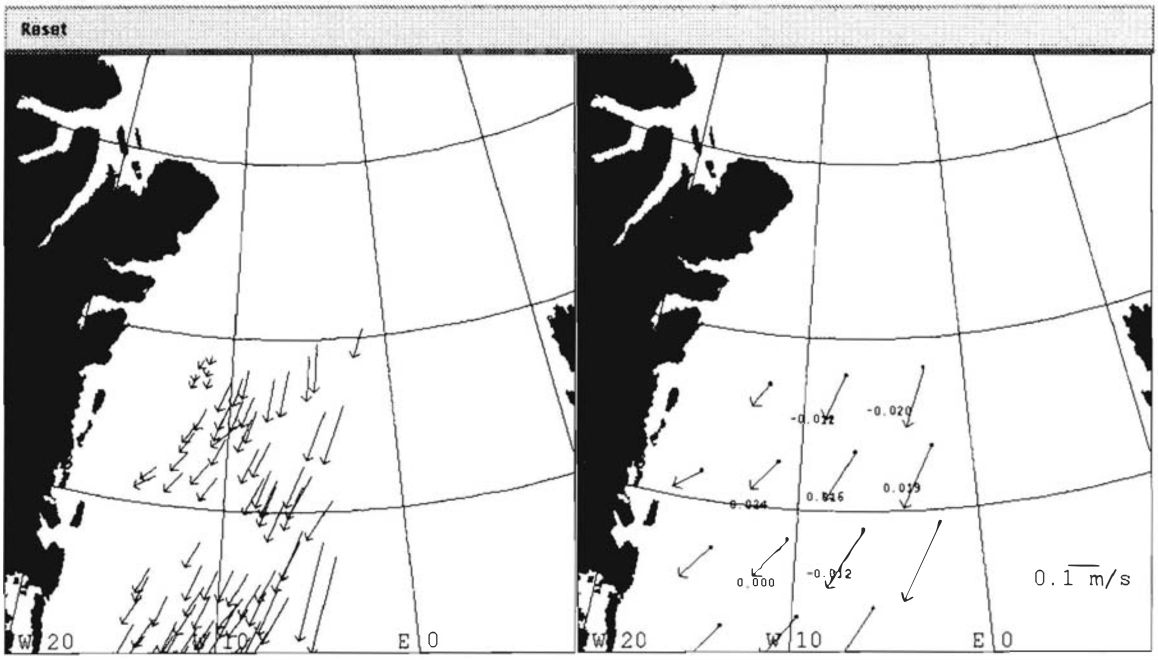

Figure 13: Ice movement in the period February 8 - 11, 1992, and estimates of ice velocity and divergence.

6 Conclusions

1. Ice drift vectors determined from ERS-1 SAR data can be concerned as 'calibration data' for NOAA images.

2. The preliminary analysis shows that the velocity and direction of ice drift vector strongly depend on the duration of the time interval, used for drift calculation. In the comparison of different images, approximately equal time intervals should be used.

3. The divergence of sea ice is a rather unstable characteristic for comparison.

4. Ice drift vectors retrieved from NOAA images coincided rather well with drift vectors retrieved from ERS-1 SAR images.

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