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Altimeter Data from ERS-1.

by

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Abstract. New ERS-1 altimeter data have been preliminaryly evaluated in the north North-atlantic ocean region with respect to selection criteria in order to avoid data influenced by errors caused by ice. The noise and resolution capacity have been determined. Furthermore, the gravimetric signal content has been analysed in the Norwegian Sea.

INTRODUCTION

Mid January ERS-1 Altimeter data from November 15 to 29, 1991, became available from ESA. Mid February the data with improved orbits were obtained from Delft University of Technology, Faculty of Aerospace Engineering, Netherlands, in a preliminary form for testing-purposes by the principal investigators only. Data were delivered as 1 second mean values on IGDR format including improved orbits and tide corrections. The IGDR's were produced at NOAA and contain UTC time, latitude, longitude, orbit height, sea surface height, geophysical corrections (atmospherical effects and tides), and other quantities derived from the altimetric observation (e.g. significant wave height and wind speed).

The purpose of this preliminary study is to evaluate the data in a broad sense. Only ocean data from the northern parts of the North Atlantic have been used ($50° < \phi < 82°$, $-80° < \lambda < 40°$). Of special interest is the area above 72° latitude, since altimeter data has never been available in this region before. Since the northernmost parts of this region are covered by ice, the effects of sea ice on the quality of the altimeter data are of special importance. Hence, the evaluation are carried out through the following steps:

1) Evaluating of data with respect to reflections from open ocean or ice covered sea.
2) Construction of a set of criteria for selection of observations.
3) Validation of selected altimetry with respect to resolution capacity and analysis of collinear tracks and crossover differences.
4) Investigation of the gravity field from difference between the OSU91A geoid and the crossover adjusted stacked altimeter data.

EFFECTS OF SEA ICE

The presence of ice affects the shape of the return pulse and, hereby, products such as the sea surface height and the significant wave height. The effect may increase the noise. Consequently, the standard deviations of the 11 to 20 values that form the 1 second

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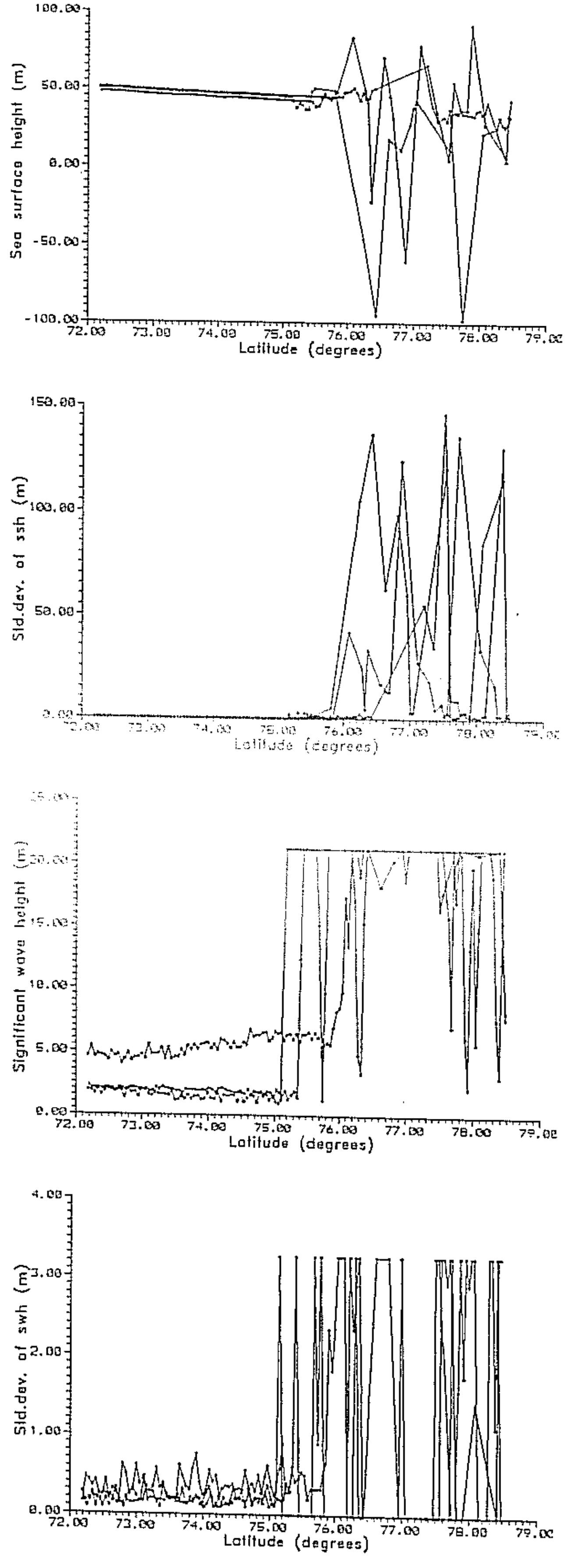

Figure 1. Data from three collinear ascending tracks entering ice covered sea east of Greenland from open waters of the Norwegian Sea.

mean values are increased. This is illustrated in Figure 1 showing data of ascending tracks entering ice covered water.

Data from 3 collinear tracks going north-east from the center of the ice free Norwegian Sea to the ice covered sea outside East Greenland are displayed in Figure 1. Here tracks of sea surface heights, standard deviations of sea surface heights, significant wave heights, and standard deviations of significant wave heights are shown. The effects of the ice are clearly seen from around 75°-76° latitude, where all four kinds of data become highly instable. Criteria for detecting these phenomena are constructed in the next section.

SELECTION CRITERIA

For a determination of a set of selection criteria observations were investigated in two separate areas. An open water area containing 8653 observations were defined in the Norwegian sea, and another area containing 4496 observations close to the Eastern coast of Greenland in the northernmost ice covered sea. Distributions of standard deviation of the sea surface height (σ_{ssh}), significant wave height (*swh*) and standard deviation of the significant wave height (σ_{swh}) were evaluated by computing histograms in the two regions separately. The sea surface height itself (*ssh*) is known to range between -100 and 100 meters globally.

Figure 2 illustrates histograms showing the distribution of standard deviation of sea surface height, significant wave height and standard deviation of significant wave height. The "normal" distribution of the quantities are represented by the behavior of the open sea observations (solid lines), while the "disturbed" observations from the ice covered area are represented by dashed lines. The tendency toward a smoother distribution with observations covering a broader spectra of values is the result of measurements in the ice covered region. There is clearly seen to exist limiting values for "normal" behavior for all three type of quantities.

Using these limits four criteria for selecting data unaffected by the presence of ice in the northern part of the Atlantic ocean were constructed. They are:

1) $-150.0 < ssh < 150.0$ m
2) $0.0 < \sigma_{ssh} < 0.2$ m
3) $1.0 < swh < 8.0$ m
4) $0.05 < \sigma_{swh} < 1.0$ m

The peak in the deviation of significant wave height around 3 meters of the observations from the ice covered area is a result of the maximum representative value in the IGDR. The similar effect is seen in Figure 1 for the significant wave height and the standard deviation of the significant wave height.

A prior selection of altimeter data was carried out in order to eliminate observations without ocean tidal corrections. In the North Atlantic region ($50° < \phi < 82°, -80° < \lambda < 40°$) a number of 1913 record were found (Figure 3) - mostly confined to the Baltic Sea, the Fox Basin and the Hudson bay.

Then observation were deleted using the criteria constructed above. This resulted in a removal of 6723 records (see Figure 4). The four criteria detected a number of 2039, 6220, 5553, and 6551 respectively. Hence, more than 97 % of the erroneous data were detected using the standard deviations of the significant wave heights alone, but it is obvious that most of the other quantities are affected simultaneously.

From a total number of 25984 ocean data about one third were removed as described above. This resulted in 17348 altimeter data (see Figure 5).

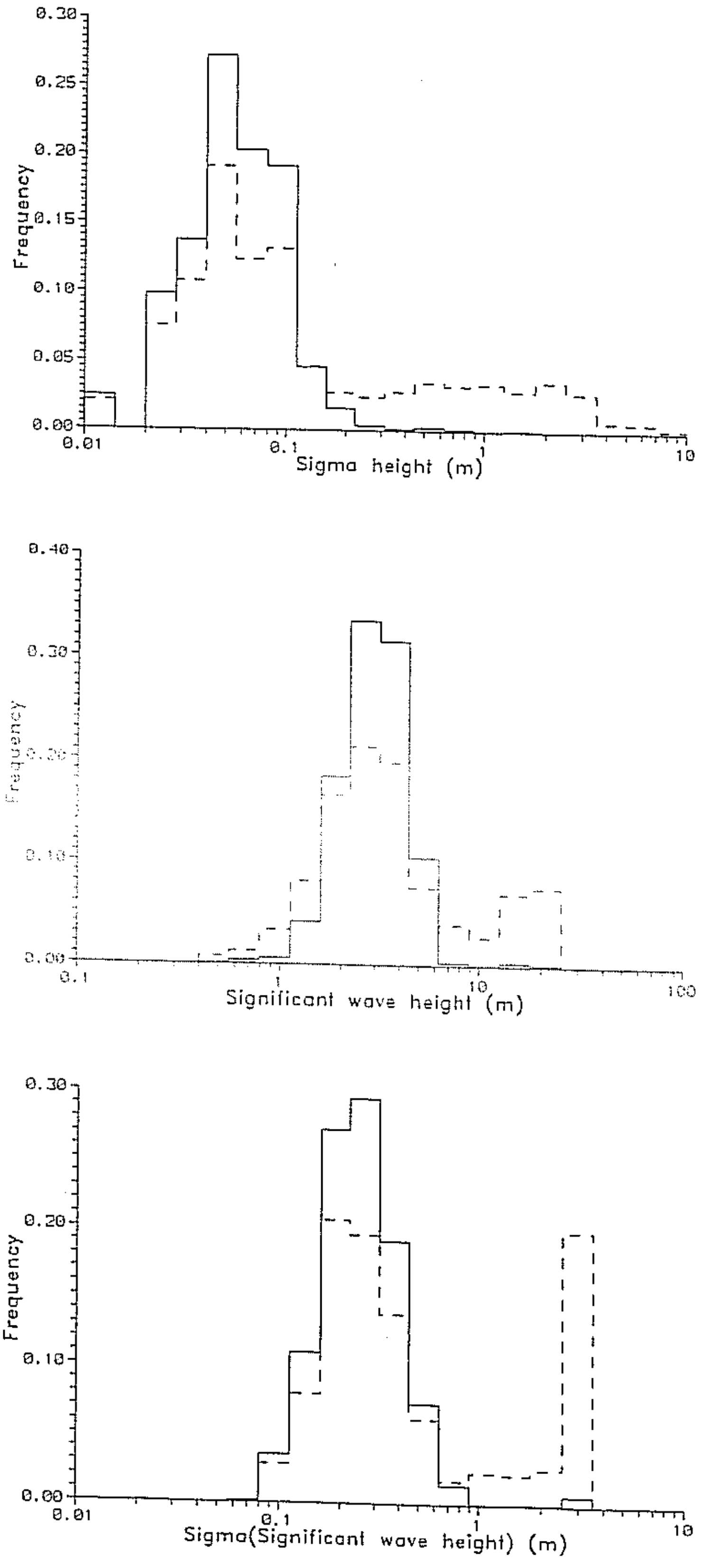

Figure 2. Histograms of data selected in areas of open water (solid) and ice covered sea (dashed). Numbers of data are 8653 and 4496 respectively.

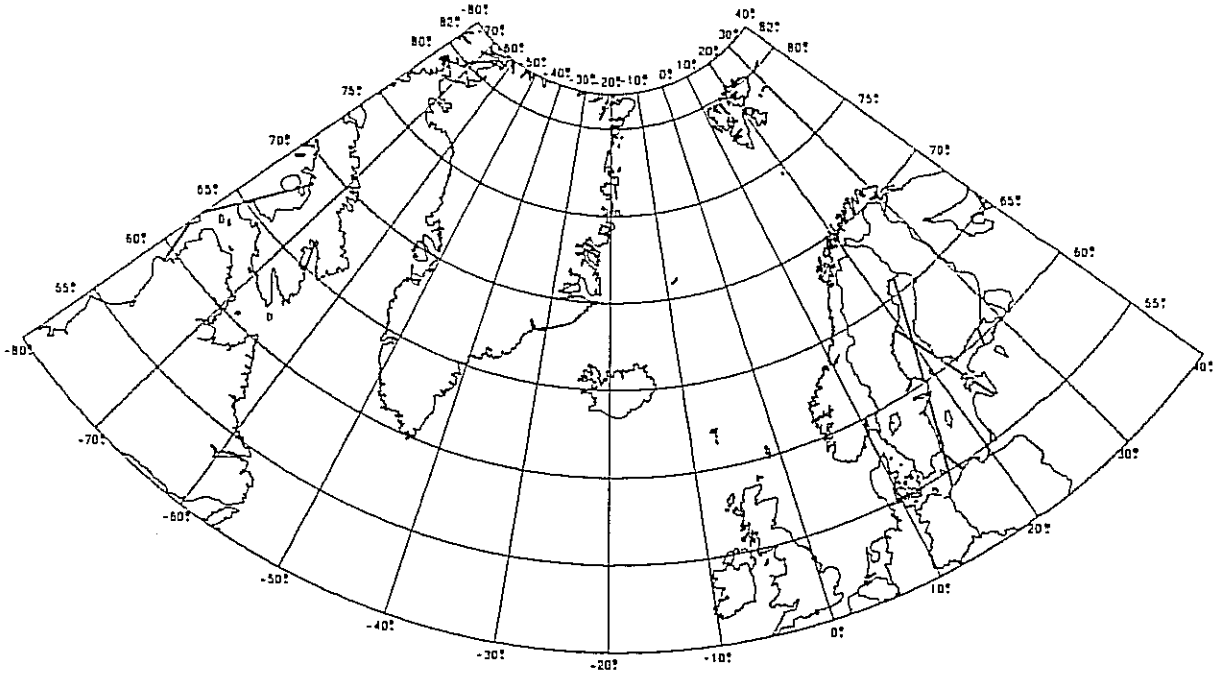

Figure 3. Location of off-shore data points without ocean tidal correction.

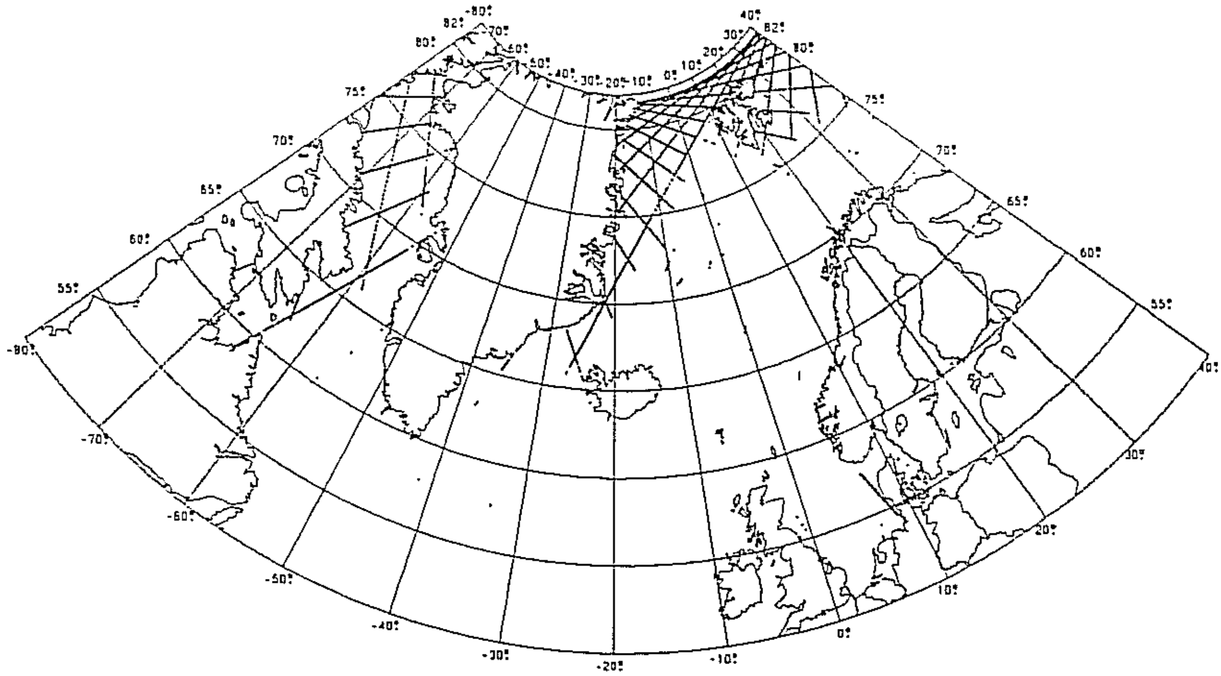

Figure 4. Erroneous data detected using criteria of SWH and standard deviations of SSH and SWH.

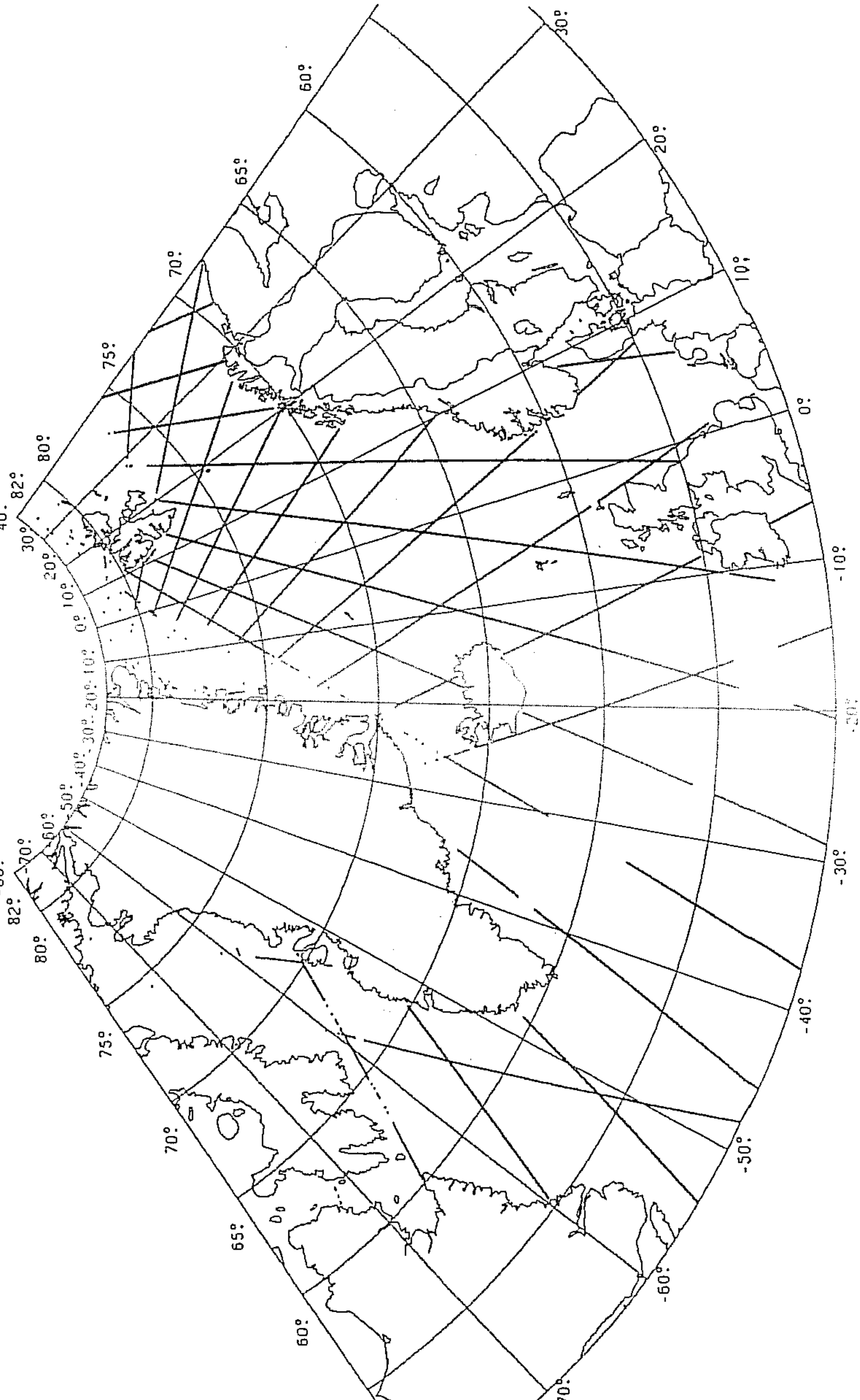

Figure 5. Altimeter data selected using criteria of SWH and standard deviations of SSH and SWH.

VALIDATION OF ALTIMETRY

The altimeter data were validated with respect to their accuracy in the Norwegian Sea ($65° < \phi < 82°$, $-20° < \lambda < 40°$). This was done using FFT along profiles and analysis of height differences between collinear and crossing tracks respectively.

In the analysis the tracks were identified using a revolution number starting from 1 at UTC 216,937,426.1 seconds. 43 revolutions are completed in a repeat period of 3 days, so the revolution time is 6027.9 seconds ($\approx$ 100 min).

A first accuracy estimate is obtained from IGDR. The standard deviation of sea surface heights has been calculated as the deviation from a linear fit to the 11-20 height values that were used to form the 1 second mean values. These values (σ_{ssh}) may be treated as altimeter noise and represent the errors of the measured distances between the sea surface and the satellite. In average these values are about 7-8 cm.

A more detailed analysis of the signal content has been carried out using FFT techniques and altimeter data of pairs of collinear tracks. The tracks have a length of 64 seconds, or 448 km, and linear trends were removed in order to avoid spectral leakage due to non-periodicity. For 10 pairs of collinear tracks power spectra were calculated of the sea surface heights and the differences between the tracks. Furthermore, the correlation coefficients per frequency were calculated. Then average power spectra were calculated from the 10 results. Note that the tracks were selected in the middle of the Norwegian Sea, where the gravimetric signal as well as the oceanographic signal are quite small.

Figure 6a shows the two averaged power spectra of the sea surface heights. Close to a frequency of 2 cycles per degree ($\lambda \sim 55$ km) the power has decreased to the noise level of 7.5 cm (dashed line). Above 4 cy/deg the power spectra appears to be completely dominated by noise. An evaluation of the noise may be carried out using the power spectrum of the differences (divided by 2).

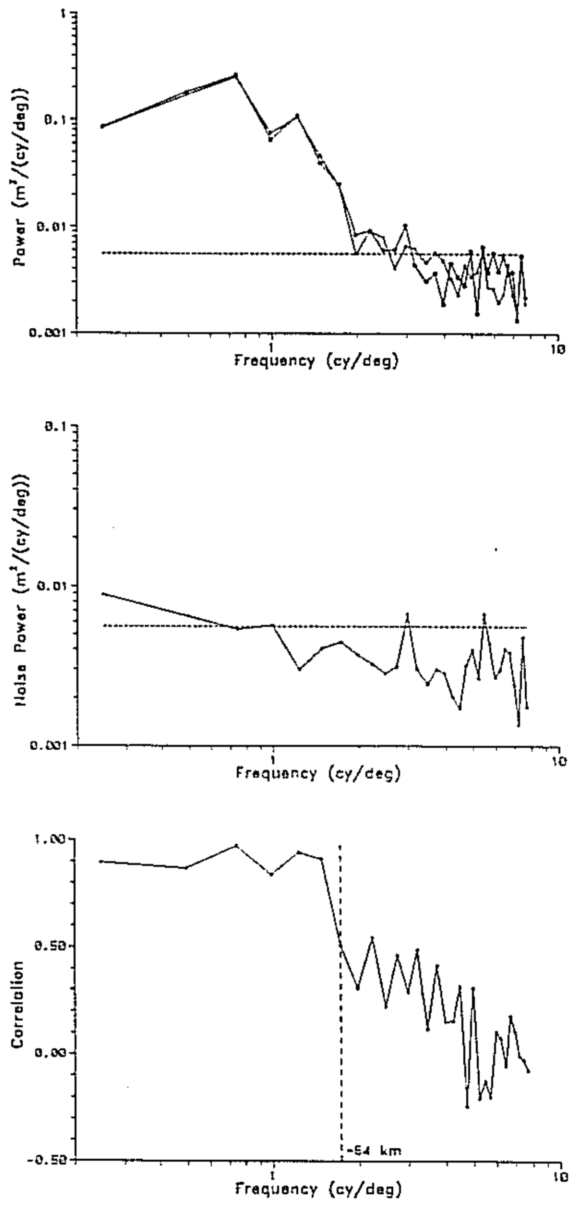

Figure 6. Power spectra. Fig. 6a. power spectra of two repeat tracks. Fig. 6b. Averaged Noise power spectra of 10 repeat tracks. Fig. 6c. Averaged correlation coefficients of 10 repeat tracks.

This spectrum (Figure 6b) contain measurement noise <u>and</u> an oceanographic signal due to e.g. mesoscale variability, which may cause the colored noise content that appears at the low frequencies. At higher frequencies (>2 cy/deg) the spectrum is more constant (white noise). The level can be estimated to be 0.0035 m^2, which corresponds to a noise level of 6 cm.

The averaged correlation spectrum shown in figure 6c indicates that the short resolution limit is around 64 km. (Defining this limit as the first position at which the correlation coefficient reach 50%).

As measurements of the sea surface height the altimeter data are influenced by errors in the computed height of the satellite. This error has a long wavelength character and show up as a bias and tilt in the data along the tracks. An indication of the magnitude of this error may be found by analysing collinear and crossover height differences. The magnitude (RMS value) of the differences in height between different tracks was found to be 2-3 m.

An estimation and removal of bias and tilt parameters from the altimeter data resulted in an *a-posteriori* RMS value of the crossover differences of 10 cm, which after a division by $\sqrt{2}$ agree with the magnitude of the σ_{ssh} values as observational noise.

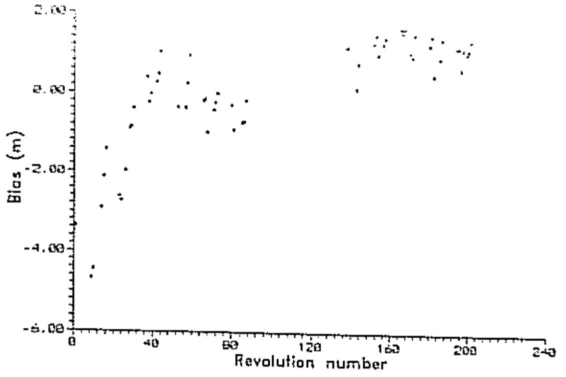

Figure 7. Relative biases of altimeter data tracks estimated in a bias/tilt crossover adjustment.

The estimated bias parameters are shown in Figure 7. The mean value of the biases is not resolved, but extreme biases of -5 to -2 m are found for revolution numbers 1-40. For revolution 40-80 the relative biases are around 0 m. For revolutions 150-200 the biases vary around 1.1 m by 0.4 m, so the accuracy appears to much better in this period. The long term variations may be caused by calibration problems, but also an inverse barometer effect may be seen, since no corrections for atmospheric pressure variations have been made.

GRAVITY FIELD RECOVERY

A recovery of the gravity field from ERS-1 altimetry was tested in the northernmost part of the Norwegian Sea ($70° < \phi < 80°$, $-10° < \lambda < 30°$).

For this purpose the stacked crossover adjusted altimetry was used, since the stationary geoid signal is evaluated. The geoid model OSU91A was used as a reference surface, so the residual sea surface heights contain wavelengths shorter than about 100 km. The magnitude of the remaining signal is 40 cm.

In a study of the gravity field for e.g. geophysical exploration purposes wavelengths shorter than 100 km contain valuable informations. Therefore, the gravity field is far from fully recovered when ERS-1 data from the 3 day repeat mission are used, since parallel tracks are separated by 100-200 km in this region and by 930 km at equator. However, interesting informations may be extracted along the satellites ground tracks, where the spacing is 7 km.

A map of the residual sea surface heights is shown in Figure 8. A conversion of the sea surface heights into gravity anomalies was carried out using FFT techniques. These quantities are shown in Figure 9.

Both maps (Figure 8 and 9) show lots of details. Especially west of Svalbard, where fracture zones associated with the continuation of the Mid-atlantic Ridge into the Norwegian Sea exist. However, a correlation of the anomalies of different tracks is difficult.

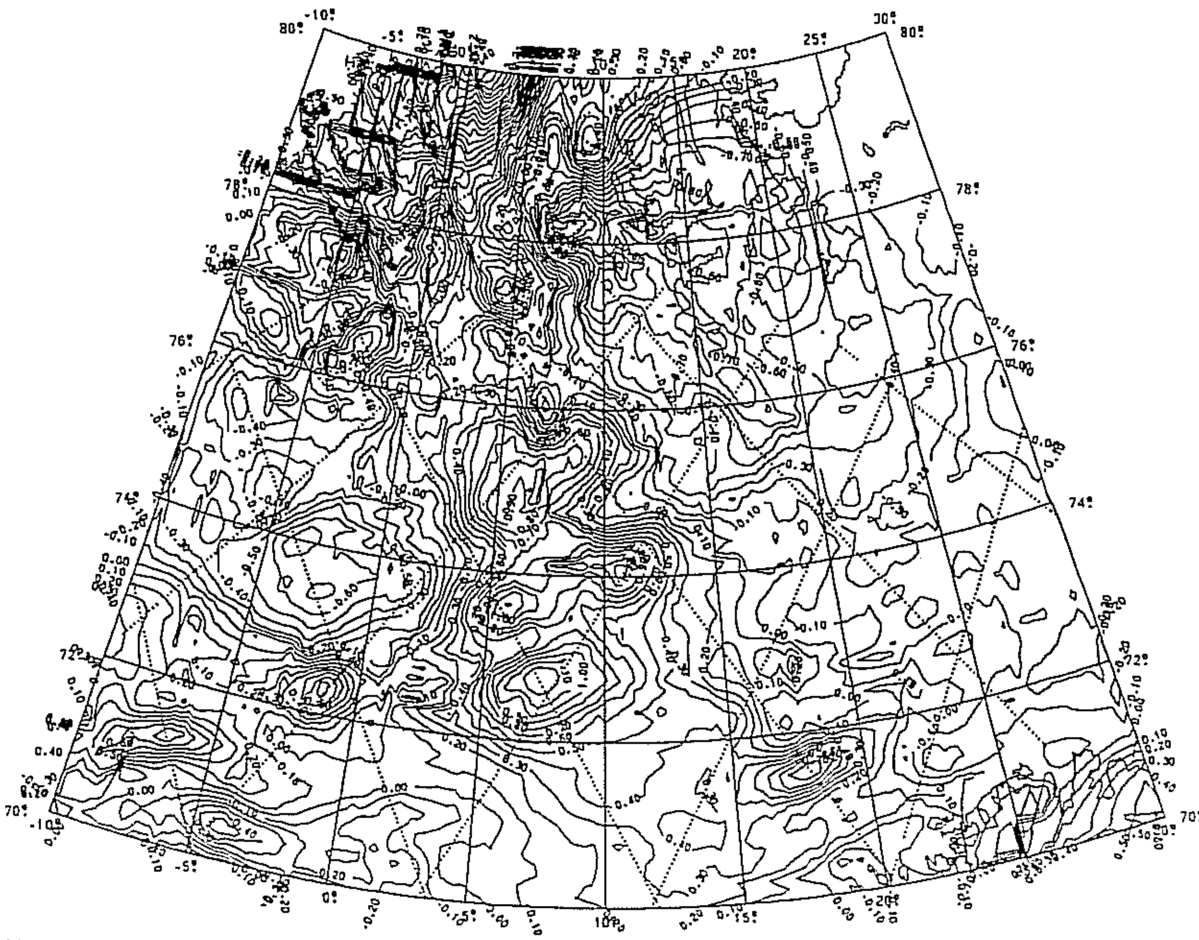

Figure 8. Sea surface heights from stacked ERS-1 altimetry relative to the OSU91A geoid mode. C.I. 0.25 m. Also location of altimetry (x).

CONCLUSION

This first evaluation of ERS-1 altimetry indicated the possibility of constructing a set of criteria for confining the altimetric observations to open ocean or ice covered sea. Using this criteria one can remove the erroneous observations from the ice covered areas of the oceans. Furthermore the observations must be evaluated with respect to the presence and accuracy of the tidal corrections.

A detailed validation of the selected altimetry has shown that the ERS-1 altimetry fulfil its requirement with respect to accuracy. A level of measurement noise of 6-7 cm was found. The accuracy of the orbit is quite poor, but that will be fixed in the near future.

A evaluation of the gravimetric signal content was carried out in the northernmost part of the Norwegian Sea showed that several interesting details exist in the data - but

The most significant problem arises form the 3 days repeat mission coverage. The parallel track distance is in the region between 100 and 200 km which makes it impossible to recover wavelength less than 200 km. Therefore we await the improved coverage from the satellite observations when it enters the 35 days repeat mission in the beginning of april '92.

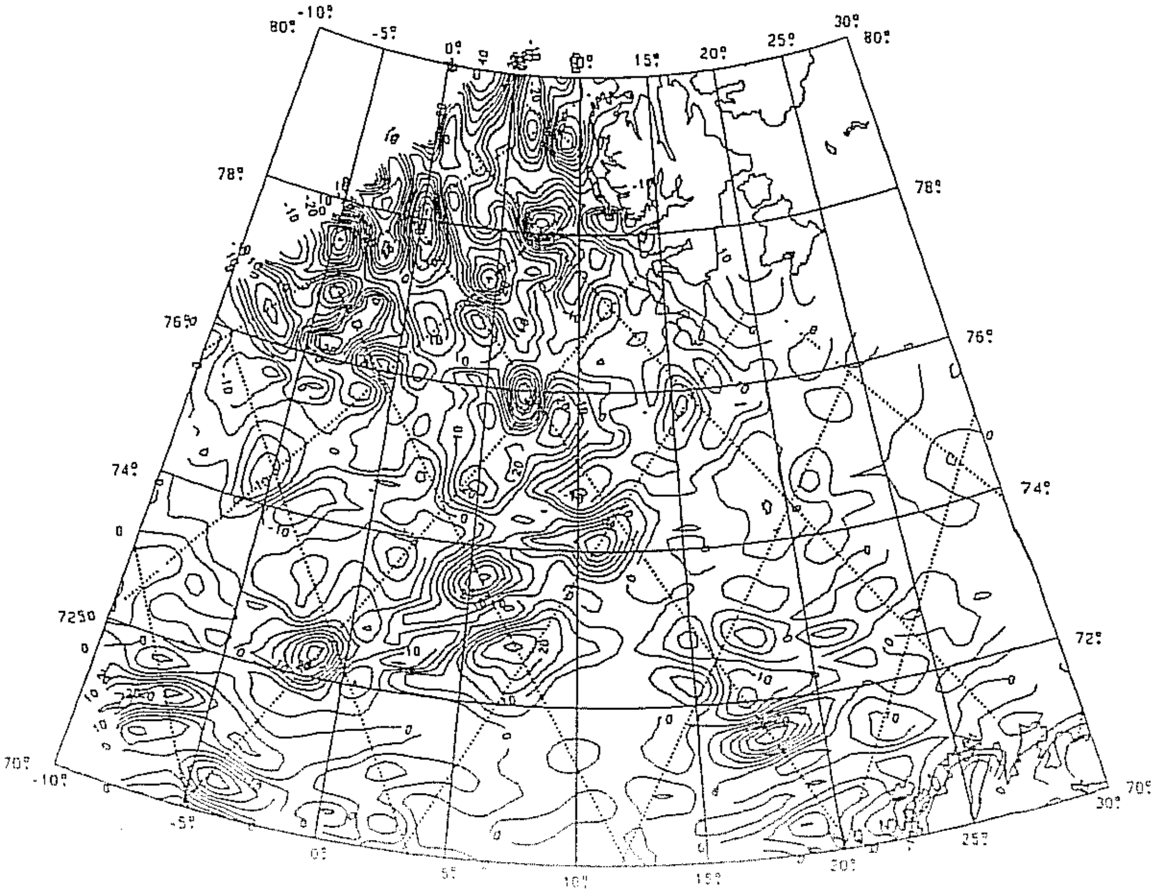

Figure 9. Free air gravity anomalies from stacked ERS-1 altimetry relative to the OSU91A gravity model. C.I. 5 mgal. Also location of altimetry (x).