1223

GEOPHYSICAL RESEARCH LETTERS, VOL. 19, NO. 17, PAGES 1795-1798, SEPTEMBER 4, 1992

ALTIMETRIC GRAVITY ANOMALIES IN THE NORWEGIAN-GREENLAND SEA - PRELIMINARY RESULTS FROM THE ERS-1 35 DAYS REPEAT MISSION.

Per Knudsen and Ole Baltazar Andersen
Kort- og Matrikelstyrelsen

C. Christian Tscherning
Geofysisk Institut, Københavns Universitet

Abstract. New fast delivery 35 days repeat ERS-1 altimeter data have been used to recover the gravity field in the Norwegian-Greenland Sea. Furthermore the spectral characteristics of the gravity field have been investigated from 18 arcs of 3 days repeat period data. The recovered gravity field correlates exclusively with the major geological structures, which clearly demonstrates the potential of these new ERS-1 altimeter data.

Introduction

Recently (May-June 1992) new fast delivery ERS-1 altimeter data from the 35 days repeat period became available from ESA. The data were obtained as 1 second mean values on IGDR (Interim Geophysical Data Record) format for testing-purposes by the principal investigators only. The IGDR's are produced at NOAA/NOS 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. The satellite orbits were provided by Delft University of Technology, Faculty of Aerospace Engineering, Netherlands. The ERS-1 satellite has been launched during 1991 in order to investigate the environment. It has a sun-synchronous, near polar orbit, and operates in a 3 days, a 35 days and a 176 days cycle. (ESRIN, 1992)

The purpose of this study is to analyse and map the gravity field in the Norwegian-Greenland Sea ($64° < \phi < 80°$, $-20° < \lambda < 20°$) from the 35-days altimeter data. Of special interest is the area above 72 degree latitude, since this is the northern limit of Seasat and Geosat altimetry and associated gravity field recovery (Haxby, 1987, Balmino et al. 1987).

Selection and Correction of Data

Prior to releasing, the data have been edited with the following selection criteria in order to exclude erroneous data due to the presence of land or sea ice: Data have been deleted if the 1 second mean values are calculated from less than 10 of the 20 per second data, if data are over land, if the standard deviation of the significant wave height range outside 5 cm and 100 cm, or if the peakiness parameter included in the IGDR range outside 1.0 and 1.7. The latter parameter describes the shape of the return pulse, and has been designed to detect sea ice.

The altimeter data were selected in the Norwegian-Greenland Sea ($64° < \phi < 80°$, $-20° < \lambda < 20°$). Observations without ocean tide corrections were eliminated, as well as observation of the sea surface heights that differ by more than 10 m from the OSU91A geoid model complete to degree and order 360 (Rapp et al., 1991).

Hereafter observations were corrected for atmospheric and tidal correction with the values provided in the IGDR. The selected observations from the 35 days cycle cover the time period from April 27 to June 2, and are shown in Figure 1.

Paper number 92GL01698
0094-8534/92/92GL-01698$03.00

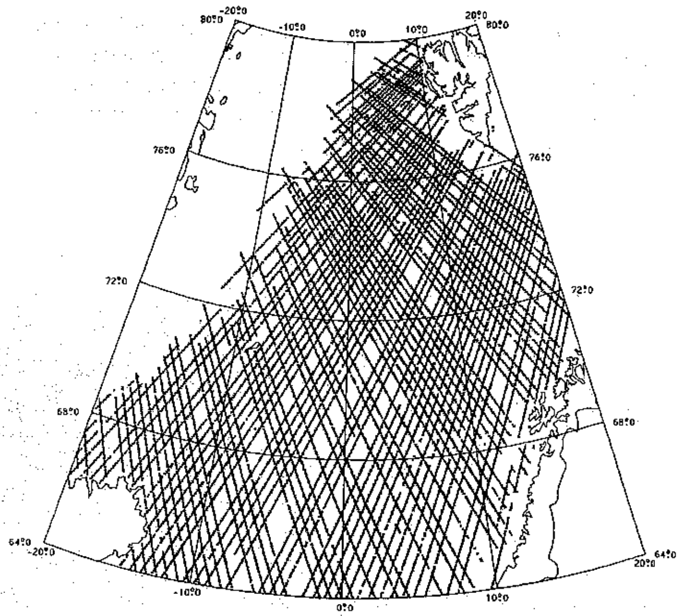

Fig. 1. Location of ERS-1 altimeter data.

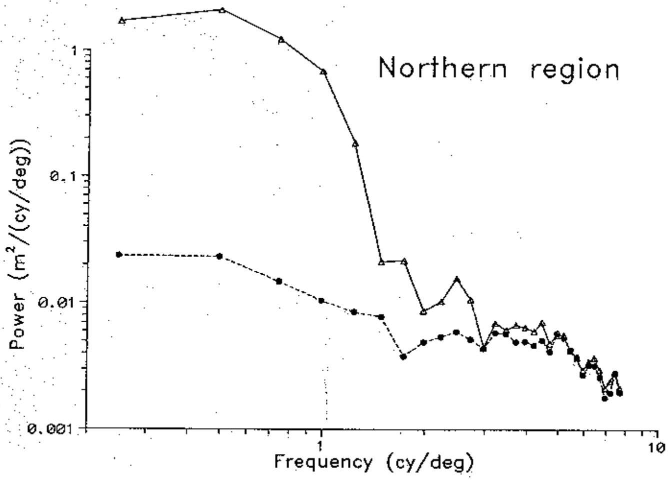

Fig. 2a. Average power spectra of sea surface heights (solid line) and sea surface height differences (dashed line).

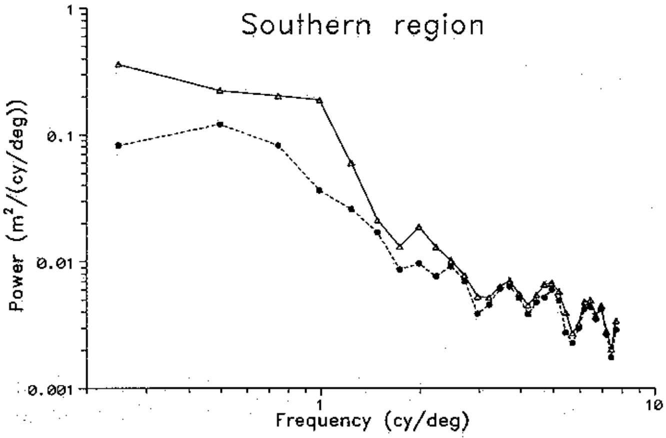

Fig. 2b. Average power spectra of sea surface heights (solid line) and sea surface height differences (dashed line).

Note that sea ice covers most of the north-western part of the region.

Spectral Characteristics of the Gravity Field

This detailed analysis of the spectral characteristics of the gravity field was performed using FFT techniques and altimeter data of pairs of collinear tracks (Marks and Sailor, 1986). The analysis was carried out using 3 days repeat data from 18 repeat periods covering January and March 1992 in a northern region and a southern region, in order to evaluate the gravimetric and time dependent content of the newly recovered gravity signal above 72 degrees latitude.

For all tracks in each region power spectra of the sea surface heights were calculated and subsequently averaged. In order to evaluate the time varying parts of the sea surface heights, power spectra of sea surface height differences along pairs of collinear tracks were calculated and averaged (all possible combinations were used). The tracks have a length of 64 seconds or 448 km. Linear trends were removed and the tracks were cosine tapered in order to avoid spectral leakage due to non-periodicity. The averaged power spectra are shown in Figure 2a (Northern region) and Figure 2b (Southern region).

In the northern as well as the southern region the power spectra of both the heights and height differences exhibit patterns of decay. From a frequency of 3 cycles per degree (3 cy/deg$\sim$35 km), which have a magnitude of about 7 cm, the spectra of the sea surface heights coincide with the spectra of the time varying parts of the sea surface heights. All spectra decrease to about $(0.05\ \mathrm{m})^2$/cy/deg around 10 cy/deg.

In the northern region the spectrum at the lower frequencies of the stationary parts of the signal (defined as the differences between the two spectra) is nearly 100 times larger than the spectrum of the time varying parts of the sea

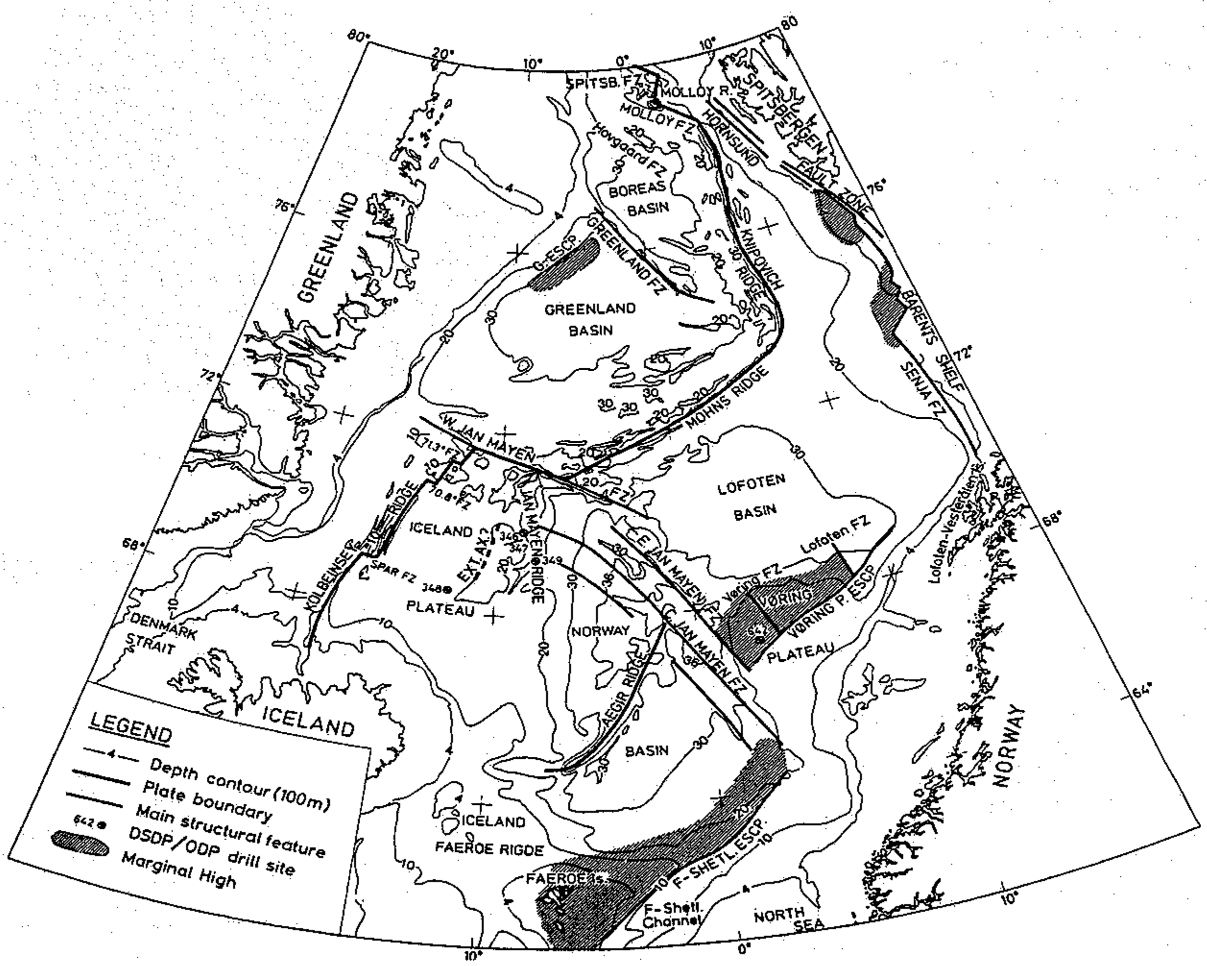

Fig. 3. Main structural features in the Norwegian-Greenland Sea (from Eldholm et al., 1990).

surface heights (Figure 2a). In the southern region this ratio is only around 3 (Figure 2b). The difference is caused by two factors: The gravimetric signal is much more prominent in the northern region, and the time varying signal is more prominent in the southern region. The increasing magnitude of the gravimetric signal in the northern region is partly caused by inaccuracies in the OSU91A model that occur north of 72 degrees latitude, where a detailed recovery of the gravity field previously has been hampered by lack of altimetry.

Altimetric Gravity Field Mapping

The gravity field in the Norwegian-Greenland Sea displays many geological features related to continental spreading along the extension of the Mid-atlantic Ridge. North of Iceland the Mid-Atlantic Ridge is divided into three main segments: The Kolbeinsey, the Mohns, and the Knipovich ridges (Figure 3, Eldholm et al., 1990). Furthermore, the breaking up of the North-American and the Eurasian plates has created a very complex system of fault and fracture zones separating basins and plateaus (see Figure 3). All these features have been seen in earlier gravity field maps compiled from marine gravimetry (e.g. Talwani & Grønlie, 1976).

The 35 days repeat period ERS-1 altimeter data provides a dense coverage of data, since the satellites groundtracks are separated by no more than 30 km (Figure 1). Hence, a valuable source of new information about the gravity field has become available.

The mapping of the gravity field from the altimetry was carried out relative to the OSU91A model complete to

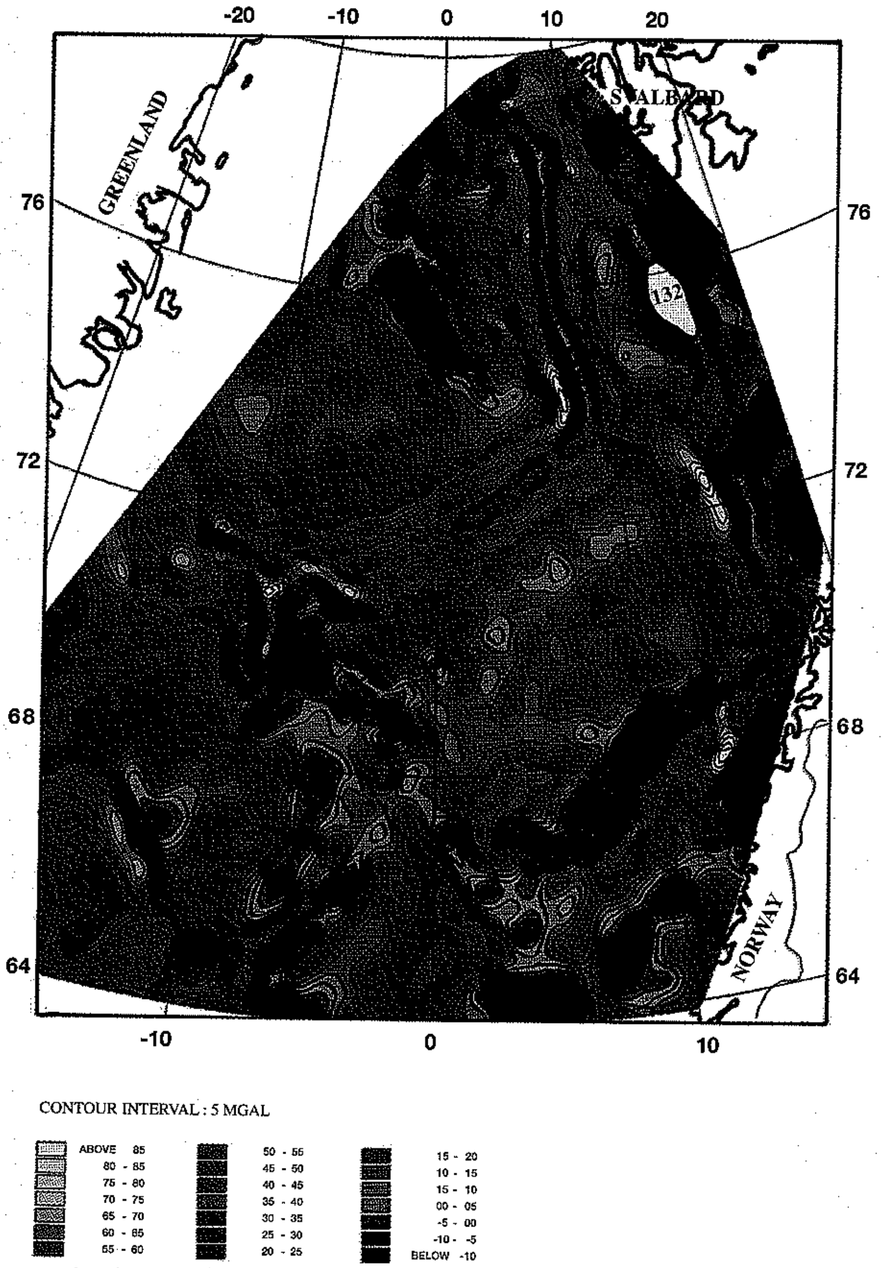

Fig. 4. Free air gravity anomalies from ERS-1 35 days altimeter data.

degree and order 360. To reduce effects of orbit errors and sea surface topography a crossover adjustment was carried out that simultaneously fitted the tracks to the OSU91A geoid model. This procedure (described in Knudsen & Brovelli, 1991) resulted in a reduction of the 1481 crossover discrepancies from 2.16 m to 8 cm. Relative to the geoid model the 16106 adjusted sea surface heights have a RMS value of 0.41 m. This RMS value increases from 0.26 m in the southern region to a value of 0.56 m in the northern region.

The conversion of geoid heights into gravity anomalies was done using FFT techniques (e.g. Schwarz et al., 1990). Subsequently, the OSU91A gravity anomaly model was added in order to obtain the free air gravity anomalies (Figure 4).

The altimetric gravity anomalies clearly reveal the geological structures and changes in bathymetry shown in Figure 3. Especially the Mohns and the Knipovich ridges are clearly seen, while the Kolbeinsey Ridge is partly outside the mapped region. Virtually all the geological structures shown in Figure 3 are clearly seen, and a closer look reveals even substructures in e.g. the ridges.

Conclusion

In this paper new preliminary ERS-1 altimeter data have been analysed, and a free air gravity anomaly map has been produced. The spectral analysis displays that the time varying parts of the sea surface heights dominate the signal at a level of about 7 cm at frequencies higher than 3 cy/deg. At lower frequencies a prominent stationary signal in the northern region shows up. The recovered gravity field correlates exclusively with major geological structures.

The results clearly demonstrate the potential of these new ERS-1 altimeter data. First of all, the 35 days repeat period provides altimetry with a significantly improved coverage compared with Geosat 17 days ERM data, more-over, data above 72 degrees latitude have become available even with a superior coverage. Hereby, valuable areas can be investigated: e.g. the Southern ocean around the Antarctic, the Barents Sea, and the Greenland Sea. Furthermore, determinations of the sea surface topography (e.g. Knudsen, 1992) can now be carried out in these regions.

In the future, when the satellite enters its 176 days repeat orbit (approx. April 1994), the coverage will be 5 times denser, superior mean sea surface heights can be computed and more fine structure gravity anomalies can be exposed.

Acknowledgement. The authors wishes to thank ESA for releasing the data, NOAA/NOS for preparing the Fast Delivery Data and finally TU Delft for providing the orbits.

References

Balmino, G., B. Moynot, M. Sarrailh and N. Vales: Free air gravity anomalies over the oceans from Seasat and Geos3 altimeter data, EOS, 68, no. 2, 17-18, 1987

Eldholm, O., J. Skogseid, E. Sundvor, and A.M. Myhre: The Norwegian-Greenland Sea. In: The Geology of North America. Vol. I. The Arctic Ocean Region. Geol. Soc. Amer., 351-364, 1990.

ESRIN: ERS-1 User Handbook, ESA Earthnet Program Office, ESRIN, C.P. 64, Frascati, Italy

Haxby, W.F.: Gravity field of the worlds oceans (Seasat altimetry). National Geophysical Data Center, NOAA, Boulder, Co. USA, 1987 (map).

Knudsen, P.: Estimation of Sea Surface Topography in the Norwegian Sea Using Gravimetry and Geasat Altimetry. Bull. Géod., 66, 27-40, 1992.

Knudsen, P., and M. Brovelli: Co-linear and Cross-over Adjustment of Geosat ERM and Seasat Altimeter Data in the Mediterranean Sea. Proc. Euro. Geophys. Soc. XVI Gen. Assembly, Wiesbaden, 22-26 April, in press 1991.

Marks, K.M. and R.V. Sailor: Comparison of Geos 3 and Seasat Resolution Capabilities. Geophys. Res. Lett., 7, 697-700, 1986.

Rapp, R.H., Y.M. Wang and N.K. Pavlis: The Ohio State 1991 geopotential and sea surface topography harmonic coefficient models. Report 410, Dept. Geod. Sci. Surveying, Ohio State University, Columbus, 1991

Schwarz, K.-P., M. G. Sideris, and R. Forsberg: Use of FFT methods in Physical Geodesy. Geophys. Jour. Int., 100, 485-514, 1990.

Talwani, M. and G. Grønlie: Free-air gravity field of the Norwegian-Greenland Seas. Geol. Soc. Amer., MC-15, 1976.

Ole Baltazar Andersen and Per Knudsen, Kort- og Matrikelstyrelsen, Geodæsidivisionen, Rentemestervej 8, DK-2400 København NV, Danmark.

C.C. Tscherning, Geofysisk Institut, Københavns Universitet, Haraldsgade 6, DK-2200 København N, Danmark.

(Received July 2, 1992
Revised July 15, 1992
Accepted July 15, 1992)