Proc. NIPR Symp. Antarct. Geosci., 3, 37–45, 1989

GEOIDAL UNDULATION AND GRAVITY ANOMALY AROUND ANTARCTICA FROM GEOSAT SATELLITE ALTIMETRY

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Abstract: GEOSAT altimeter data were processed to obtain an altimetric geoid and gravity anomalies around Antarctica. As GEOSAT is the first satellite which can reveal the sea surface heights of the Antarctic summer seasons, it is strongly expected to provide new knowledge concerning the gravity fields in the Antarctic Ocean.

The data employed in this study were obtained during one repeat cycle of the GEOSAT Exact Repeat Mission (ERM). Geophysical corrections and crossover adjustments were made to obtain an altimetric geoid, and altimetric gravity anomalies were calculated by means of the FFT method. The results were compared with those of the former studies and the improvement of the accuracy near the Antarctic Continent was confirmed.

1. Introduction

There remain many areas in the Antarctic Ocean which have not been explored by ship because of their remote location, formidable climate and other reasons. Using the SEASAT radar altimeter, studies of the gravity fields in the Antarctic Ocean were undertaken by various authors (*e.g.*, SEGAWA and ASAOKA, 1982; SANDWELL 1984; SEGAWA *et al.*, 1984). These studies have greatly contributed to the improvement of the knowledge of the Antarctic Ocean and quite a few subsurface structures have been detected.

Unfortunately, SEASAT disappeared after only three months of operation, and to make matters worse for the studies in the Antarctic Ocean, its life time was during the austral winter. The data obtained were badly affected by Antarctic sea ice which caused not only short wavelength noise but also long wavelength bias in the altimetric measurements. SEGAWA *et al.* (1984) employed a digital filter to remove the noise of the sea ice, but they could not eliminate the long wavelength bias.

On the other hand, GEOSAT, which was launched in March 1985 by the U.S. Navy, has been providing a new data set of satellite altimeter, and the data have been accumulating for more than two years. GEOSAT measured the sea surface heights of the Antarctic Ocean during the austral summer for the first time. The obtained data are free from the noise or the bias of sea ice.

In this study we aim at investigating the effectiveness of the GEOSAT data. For this purpose, we take the following steps:

1) Processing the GEOSAT data during the austral summer and mapping geoidal undulations and gravity anomalies around Antarctica.

2) Examining their accuracy by comparing with the former studies.

2. GEOSAT Mission

As the details of the GEOSAT mission are found in CHENEY *et al.* (1986), we will briefly discuss the outline of the GEOSAT mission.

The GEOSAT mission was divided into two stages. The first stage called geodetic mission was primarily aimed at the improvement of marine gravity field. In the geodetic mission, the most suitable orbit for gravimetric studies was selected. It continued during the first 18 months after launch and an enormous amount of data seem to have accumulated. Though this must be a great success for the geodetic study, these data are classified because of their value to the U.S. Military.

In November 1986, the second stage of the GEOSAT mission called Exact Repeat Mission (ERM) started. In the ERM, GEOSAT was set into a repeat orbit. The satellite is now at an altitude of 800 km, with an inclination of 108° and a periodicity of 244 revolutions (period of 17.05 days). Mainly because the ground track of the

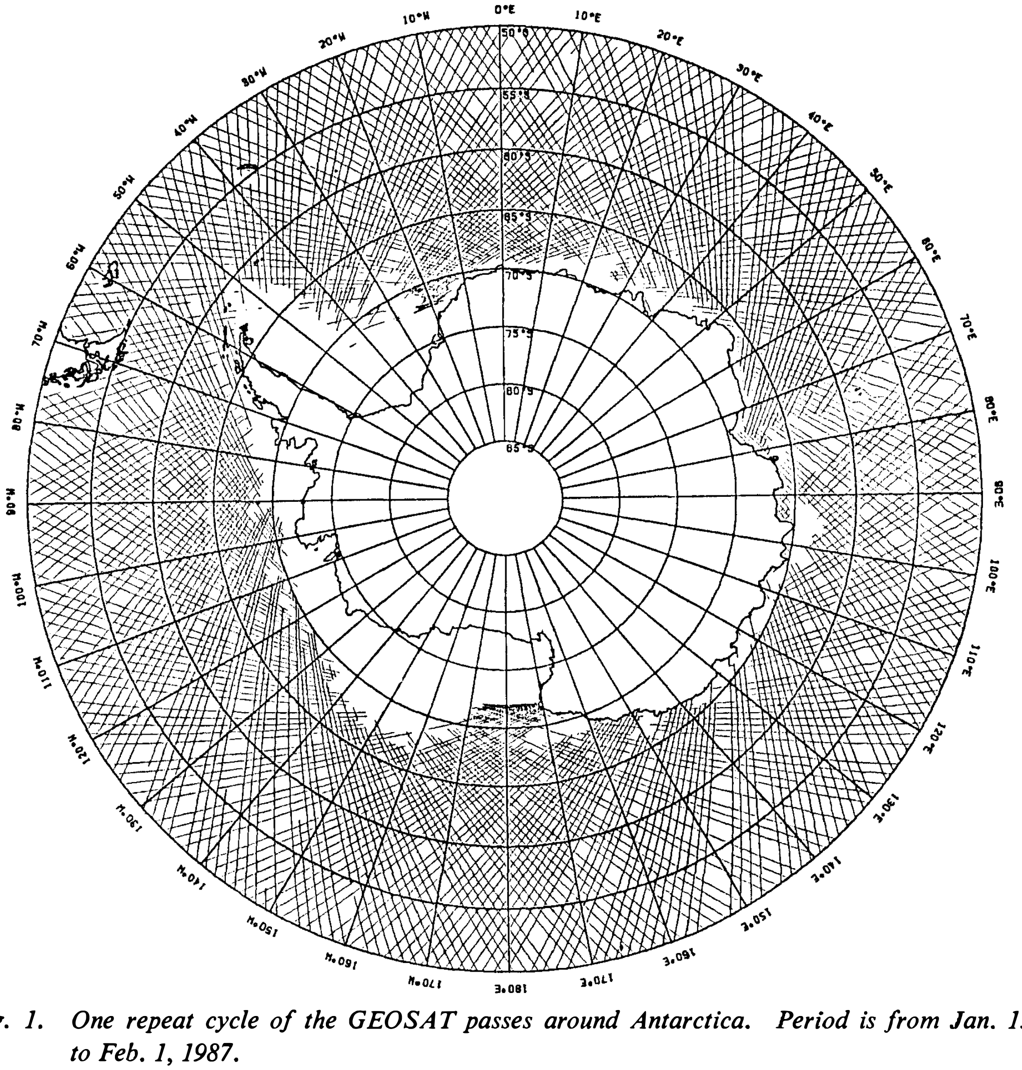

Fig. 1. One repeat cycle of the GEOSAT passes around Antarctica. Period is from Jan. 15 to Feb. 1, 1987.

ERM is very close to that of the SEASAT, the data are not classified and available from the National Oceanographic Data Center (NODC) of the National Oceanic and Atmospheric Administration (NOAA).

The data used in this study are from one repeat cycle of the ERM (Jan. 15–Feb. 1, 1987). Their passes around Antarctica are shown in Fig. 1.

3. Data Processing

The GEOSAT data provided from NODC have a standard format called Geophysical Data Record (GDR). The GDR has 34 items of information, namely, time, position, sea surface height, geophysical corrections which should be subtracted from the sea surface height, flag records and so on. The detailed descriptions are found in GEOSAT GDR user handbook (CHENEY *et al.*, 1987).

The general principle of the data processing mainly follows FUKUDA *et al.* (1988), and is summarized below.

(1) Transform the GDR into a convenient form for later processing and pick up the data in the area concerned.

(2) Make all geophysical corrections recommended in the user handbook (CHENEY *et al.*, 1987) to the raw data.

(3) Conduct crossover adjustments under the condition of minimum rms crossover error with reference field.

(4) Interpolate sea surface heights to get a grid data set by means of the BRIGGS' method (BRIGGS, 1974).

(5) Calculate gravity anomalies from altimetric geoid by means of the FFT method (MATSUMOTO *et al.*, 1985).

We make, however, some modifications in this study. One of the modifications is in crossover adjustments, which are done for the data of the whole southern hemisphere. However, the number of data is too large to execute our computer program at one time. Therefore, we divide the area into four subareas with 50 percent overlaps. Each subarea has the width of 180 degrees in longitude. We further adopt a linear function of time for the orbit error model while a quadratic function was adopted in FUKUDA *et al.* (1988). These modifications will reduce, at the small sacrifice of the accuracy, the computer storage required in the processing. After such adjustments, the rms crossover errors can be reduced to about 20 cm, which is slightly worse than that of FUKUDA *et al.* (1988) but is accurate enough to be accepted in this study. As we are working to revise the computer programs, these limitations will be overcome in the near future.

Another important modification is the change of the reference gravity model which was used in the conversion from altimetric geoid to gravity anomalies. To increase the accuracy of the conversion, it would be advantageous to employ a higher degree spherical harmonic model, and so we adopt the OSU86-D model which is complete up to degree and order 250 (RAPP and CRUZ, 1986), instead of GEM-T1 model (degree and order up to 36) (MARSH *et al.*, 1988).

4. Discussion

4.1. Accuracy of the altimetric geoid

Figure 2 shows the altimetric geoid obtained in this study. The accuracy of the GEOSAT altimetric geoid is considered to be around 20 cm to 30 cm (Fukuda *et al.*, 1988). In this study, we used only one cycle of the ERM data and no corrections for the time variations of the sea surface heights have been applied to. Although it is difficult to estimate these influences on the accuracy of altimetric geoid correctly, they are considered to be around 50 cm. So, the total accuracy of the altimetric geoid is prescribed by the time variations of the sea surface heights. It is 2 or 3 times as large as the rms crossover error.

Figure 2 was compared with the former SEASAT altimetric geoid (Figure 4 of Segawa and Asaoka, 1982). The comparison reveals that the average height of the SEASAT geoidal undulations is about 5 meters lower than that of the GEOSAT ones, while both resemble in short wavelengths. The discrepancy is too large, even if the different definition of the geodetic systems be taken into consideration. The

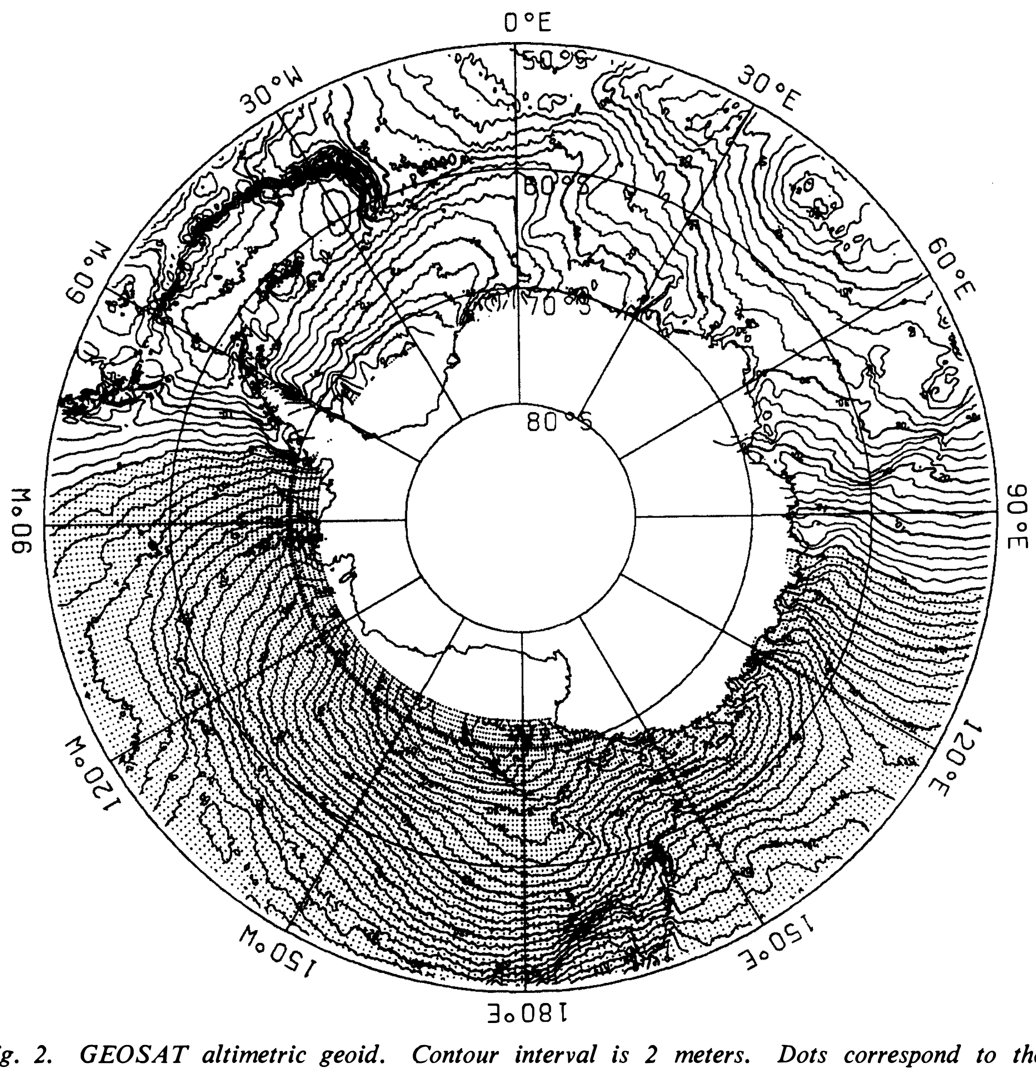

Fig. 2. GEOSAT altimetric geoid. Contour interval is 2 meters. Dots correspond to the negative area.

reason for this bias may lie in the method of crossover adjustment used in the former study. SEGAWA and ASAOKA (1982) adopted the method, presented by BRACE (1977), which has no constraint on the level of the sea surface heights, thus the zero level might have changed in the processing of crossover adjustment. The long wavelength components of the geoidal undulations obtained in this study are based on the reference geoid given in the GEOSAT GDR. This means that the geoid is fixed to the global framework, suggesting that the absolute level of the geoid is more reliable.

4.2. Comparison of altimetric gravity anomalies

The gravity anomalies are calculated from the altimetric geoid obtained in Sec. 4.1 on $10' \times 10'$ grid points. The map of the gravity anomalies is shown in Fig. 3. SEGAWA and MATSUMOTO (1987) gave the gravity values on the same grid points using the SEASAT altimeter data. The principle of their data processing is almost the same as the one of this study except the adoption of a digital lowpass filter to eliminate the noise of sea ice. We attempt the comparison of both gravity anomalies.

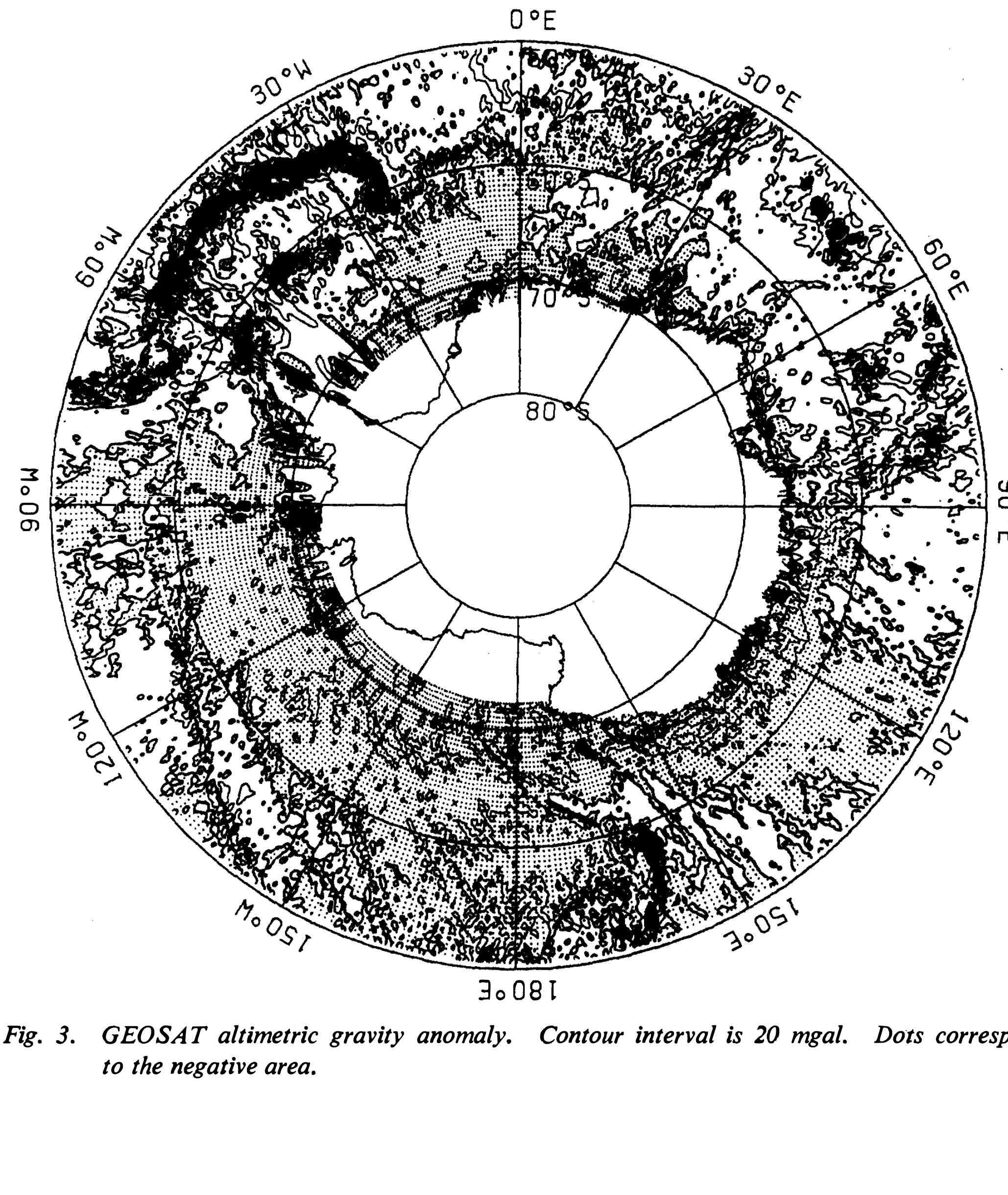

Fig. 3. GEOSAT altimetric gravity anomaly. Contour interval is 20 mgal. Dots correspond to the negative area.

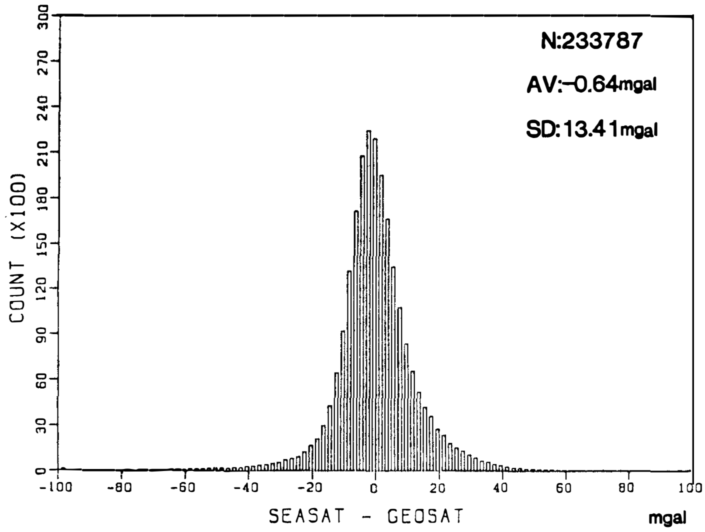

Fig. 4. Histogram of the differences between SEASAT and GEOSAT altimetric gravity anomalies.

The mean difference of SEASAT gravity anomalies minus GEOSAT gravity anomalies is -0.6 mgal and the rms difference is 13.4 mgal. Figure 4 shows the histogram of their differences.

To estimate the accuracy of the altimetric gravity, we made a test study by means of the least squares collocation (MORITZ, 1980). The least squares collocation is a method which describes the relationship among any geopotential quantities using the covariance function of the gravity disturbing potential T. This means that if the covariance function were known, any geopotential quantities could be estimated from others. So, we first determine an empirical covariance function, to fit the GEOSAT altimetric data to the model proposed by TSCHERNING and RAPP (1974). As we consider the residual parts of the covariance function, which is obtained by subtracting a gravity potential model from T, the form of the covariance function $K(\psi)$ is described by

$$K(\psi)=\alpha \sum_{i=0}^{N} \varepsilon_i(T, T)\left(\frac{R_E{}^2}{rr'}\right)^{i+1} P_i(\cos\psi)$$
$$+\sum_{i=N+1}^{\infty} \frac{A}{(i-1)(i-2)(i+24)}\left(\frac{R_B{}^2}{rr'}\right)^{i+1} P_i(\cos\psi)$$

where

$\varepsilon_i(T, T)$: the error degree variance associated with the employed gravity potential model,
N: degree of the potential model,
P_i: Legendre polynomial of order i,
ψ: angular distance between observation and estimation points,
r, r': radial distance of the points,
R_E: the mean earth radius,
R_B: the radius of so-called Bjerhammar sphere,
α, A: scaling constants which are estimated from the altimeter data.

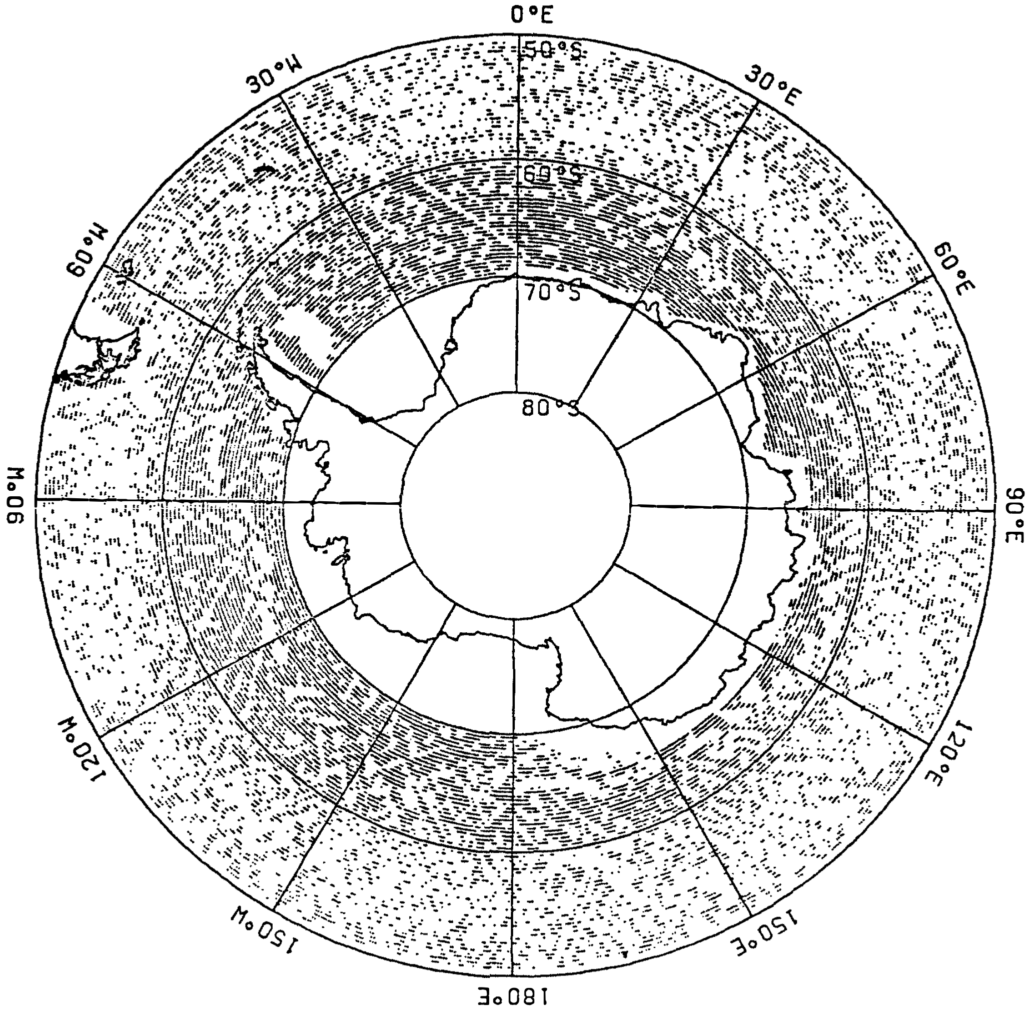

Fig. 5. Spatial distribution of the difference between SEASAT and GEOSAT altimetric gravity anomalies. The grid points where the gravity by SEASAT are greater than those by GEOSAT are shown by dots.

Once the empirical covariance function is determined, we can calculate the estimation errors of gravity anomalies assuming the distribution and accuracy of geoid data. Our test results suggest that the accuracy of the altimetric gravity is 10 to 20 mgal on typical data distribution around Antarctica. The results of the comparison between SEASAT and GEOSAT altimetric gravities agree with the error estimation.

To investigate the spatial distribution of the differences, on the other hand, we plot the grid points where the gravity anomaly by SEASAT is greater than that by GEOSAT in Fig. 5. The density of the points seems to increase towards higher latitude. As the gravity anomaly is a kind of differential quantity of the geoidal undulation, noise by the sea ice will not affect the long wavelength components of the gravity anomaly so much. However, it may be possible that the digital low pass filter applied to the SEASAT data results in the long wavelength bias. Although the amount of the differences in higher latitude is only 10 to 20 mgal, they may have been caused by the sea ice which affected the SEASAT data.

5. Conclusion

The usefulness of the GEOSAT altimeter data is verified in this study. Although we used only one cycle of the ERM data, the altimetric geoid and converted gravity anomalies thus obtained are effective enough to see the general structures in the Antarctic Ocean. Our comparison study also shows that the GEOSAT altimeter data or converted gravity anomalies are better than the SEASAT altimeter data. This is mainly because of the fact that the GEOSAT data are free from sea ice and partly because of the improved radar altimetry. Recently SANDWELL and MCADOO (1988) published the along-track deflection of the vertical calculated from the GEOSAT data. As the deflection of the vertical generally represents very short wavelength structures of gravity field (*i.e.* mass anomaly), the noise of sea ice which dominates in short wavelength is fatal to the study. The result of SANDWELL and MCADOO (1988) was another evidence of the usefulness of the GEOSAT data which were not affected by sea ice.

The GEOSAT data may have disadvantage from the limited spatial resolution because of its repeat orbit. However, the wide separation of ground tracks caused by the repeat mission is reduced in higher latitude. Our error estimation by means of the least squares collocation shows that the accuracy of the altimetric gravity is around 10 mgal. This fact encourages us in future studies of gravity field. There are still many areas around Antarctica which have not been surveyed. In the future, we intend to reprocess the GEOSAT data with newly available data combined. It is also planned to use surface gravity data together by means of the least squares collocation.

Acknowledgments

The authors thank Prof. R. H. RAPP of the Ohio State University who kindly provided the OSU86-D spherical harmonic coefficients. This work was partly supported by a Grant-in-Aid for Scientific Research, from the Ministry of Education, Science and Culture, Japan (No. 63740209 in 1988).

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(Received February 28, 1989; Revised manuscript received May 9, 1989)