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The Altimeter Geoid of the Region of Korean peninsula

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ABSTRACT

This paper is to provide a reference surface geoid for geodetic applications of satellite altimeter data. The paticular satellite alone or the combination with other altimeter data could be used for the recovery of geoid undulations and gravity anomalies in the ocean areas. This paper also describes the geoidal undulation in the ocean area of Korean Peninusla using Geosat, ERS-1 and Topex/Poseidon data. The results show that the quasi-stationary sea surface topography (SST) is estimated to be less than 10 cm RMS value in the ocean area of Korean Peninsula. This can be considered as an altimeter geoid.

要 旨

한반도 주변의 해상고도데이타를 이용한 지오이드면을 결정하였다. 사용된 해상위성 데이타는 Geosat, ERS-1 및 Topex/Poseidon으로부터 계산된 고도데이타이며, 각각의 위성으로 부터 계산된 데이타를 Cross-Over 조정방법에 의하여 조정하였다. 조정계산결과 해면고도는 RMS 10 cm 이하로 해상지오이드면으로 채택할 수 있음을 알 수 있었다. 그러나 한반도 주변 해상에서의 지구물리학적인 특성을 연구하기 위하여는 보다 광범위한 연구와 계속적인 데이타의 수집이 필요하다.

1. Introduction

The altimeter geoid is based on altimeter measurements of the geodetic earth orbiting satellite. The satellite is used as a moving platform for a sensor which transmits microwave pulses in the radar frequency domain to the ground, and receives the return signals after reflection at the earth's surface. The altitude of the satellite above a global ellipsoid can be derived from an orbit computation with respect to a geocentric reference frame[7].

Fig. 1. shows that a radar altimeter can be used to scan directly the sea surface and hence approximately the ocean geoid.

Using altimetry from seasat, Geosat (Geodynamics Experimental Ocean satellite), ERS-1 (European Remote Sensing Satellite) and TOPEX/POSEIDON (Ocean TOPography Experiment), procedures were developed to estimate sea level variability, marine geoid, accurate orbits, and various altimeter corrections, etc. The main objective of Seasat-1 was

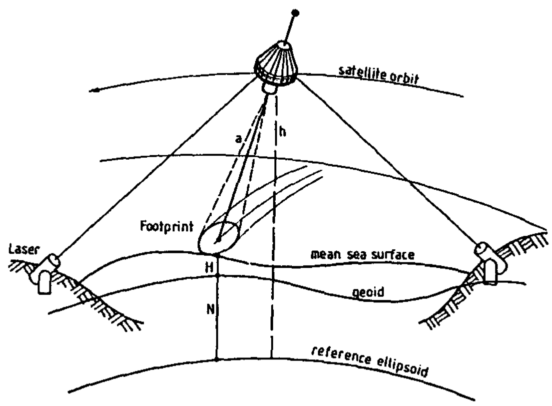

Fig. 1. Basic concept of satellite altimetry[5]

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the mapping of ocean surface data through remote sensing techniques. The improved version of the one flown on Seasat is the Geosat. The main objective of Geosat was to map the marine geoid at high resolution. The precision for height measurements is about 3.5 cm[6].

ERS-1 allows all-weather high-resolution imaging over land, coastal zones and polar ice caps, measures ocean wave heights and wavelengths, wind speeds and directions, various ice parameters, sea surface temperatures, cloud cover, atmospheric water vapour content, and precise altimetry over oceans and ice. It carries an altitude and orbit control system (AOCS) to maintain the platform orientation in flight. This system contains infrared earth-sesors, sun-sensors, an inertial core of six gyros, and three orthogonal reaction wheels[7].

The design accuracy of ERS-1 altimeter is 10 cm. TOPEX/POSEIDON is a satellite mission that carries a radar altimeter system, and jointly conducted by the NASA and the French Space Agency (CNES). The mission includes two altimeters. The orbit determination is supported by a laser retroreflector array and the French DORIS (Doppler Orbitography and Radio positioning Intergrated by Satellite) tracking system. In addition, an experimental GPS receiver is flown onboard. Fig. 2. show the recent altimeter satellits.

The raw altimeter data are radar measurements of the distance between the satellite and the ocean surface. The radar altimeter data from satellites yielded a variety of information on geophysical phenomena; one very important result is mapping of mean sea surface and the geoid in the ocean

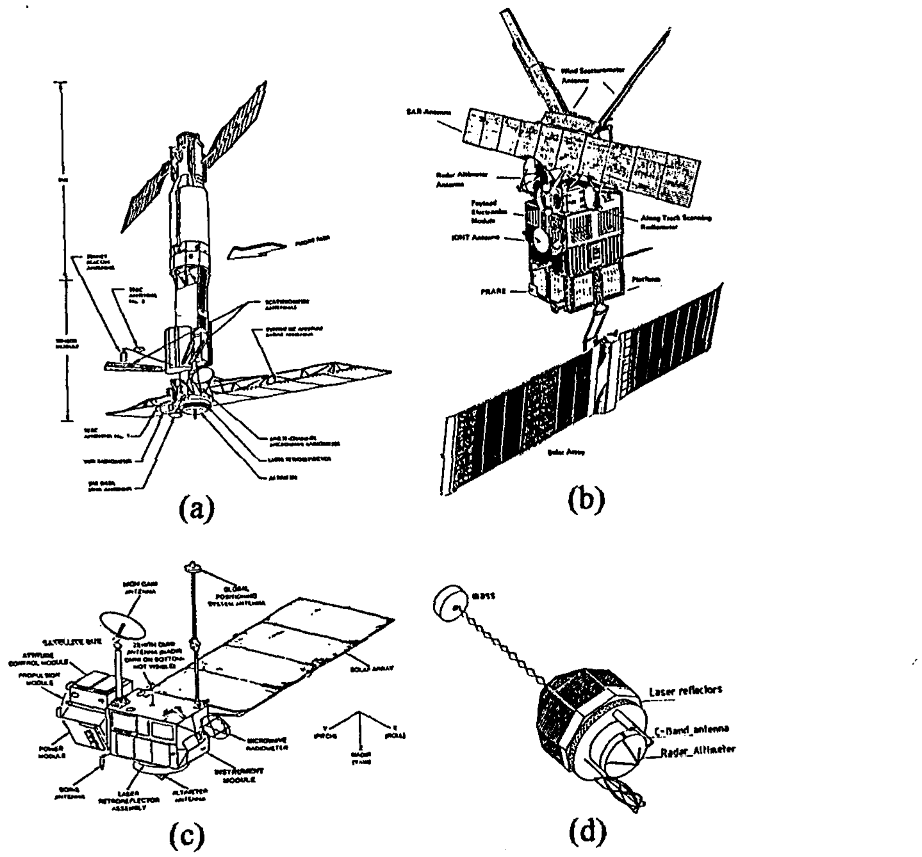

Fig. 2. (a) Seasat-1, (b) ERS-1, (c) Topex/Poseidon and (d) Geo-3[5]

Table 1. Altimeter satellites, year of lunch, inclination, repeat period, noise and altimeter accuracy[6]

Satellite	Year of lunch	Inclination	Repeat Time	Noise	Alt. Accuracy
GEOS-3	1975	115°	N/A	0.20	±60 cm
SeaSat	1978	108°	17, 3	0.08	±10 cm
GeoSat	1985	108°	-3, 17	0.04	± 3 cm
ERS-1	1991	98.5°	3, 35, 165	0.03	±10 cm
Topex/ Poseidon	1992	63°	10	0.01	±2 cm

Table 2. The orbit parameters used for Geosat, ERS-1 and Topex/Poseidon

Parameter	Geosat	ERS-1	Topex/Poseidon
A (km)	7162.600	7153.135	7711.634
e	0.0008	0.0012	0.00150
I (deg)	108.033	98.5227	6.0435
(deg/day)	-1.723	-2.9700	-0.4500
(deg/day)	2.048	0.9890	-2.0830
Mo (deg/day)	-2.362	-3.1130	1.0240
Kepleriann (rew/day)	14.3218	14.3529	12.8198

The constants: GM = 398,600.64 km^3/sec^2, R = 6,378.137 km, C2, 0 = -484.1649×10^{-6} S = 366.2422/365.2422

area with a very high precision and resolution. The radar altimeter of the satellite transmits radar pulses to the sea surface. a number of corrections have to be applied before these radar measurements can be used as sea surface height observations. they are correction terms such as corrections for in atmospheric refraction effects and sea state related biases[9].

This paper is the datermination of the altimeter geoid for the region of Korean Peninsula using some altimeter data of the following Table 1.

2. The Altimeter Data

2.1 The Satellite Orbit

Design of a satellite mission includes a decision on how the satellite should be flown, i.e. the orbital parameters which are the inclination and the period etc. have to be determined because we have to consider how the altimeter data will be distributed on the earth. In Table 1 the orbit inclination, the repeat period and the noise are considered as a sort of standard configuration. The orbit parameters used for GEOSAT, ERS-1 and TOPEX/POSEIDON are given in Table 2. the altitude of the satellite is about 800 km circular orbit above the surface of earth (Topex: 1350 km). At this altitude perturbations in the satellites orbit due to the geopotential are important to consider, when the precise position of the satellite is calculated.[8] for this purpose a geopotential model such as GEM-T2 from NASA/GSFC is used. In fact tracking data are used to compute these geopotential models.

2.2 The Radar Measurement

The radar altimeter works by transmitting a short pulse of radar energy and measuring the return time from the sea surface. By measuring the travel time of the pulse it is possible to obtain data on the shape of the sea surface. This data is usually given as a set of geophysical data records (GDR) that include altimeter measurement information, as well as corrections that should be applied to the data. The corrections include : (1) corrections due to instrumental errors, (2) time tag corrections, (3) geophysical corrections for the atmosphere's effect on a radar range measurment, and (4) corrections for the effect of earth tides, ocean tides, and barometric pressure.

Knowing the orbital altitude of the satellite above a reference ellipsoid (e.g. GRS 80), the geoidal height can be obtained as follows:

$$N = h - \xi = (r - a) - \xi \quad (1)$$

where

N : geoidal height

r : geodetic height of the satellite

a : measured radar altitude on board the satellite above the ocean surface, corrected for a number of instrumental and geophysical effects

h : height of sea-surface above the reference elliposid

ξ : sea surface topography

The altimeter operates at 13.5 GHz. A resolution of 1 cm would requires too broad a frequency band (30 GHz). Instead the measurement is carried out using a 300 MHz (3 ns) pulse centred at 13.5 GHz. Then this relatively long pulse is analyzed by curve fitting.

The necessary signal-to-noise ratio is achieved by averaging e.g. 50 pulses (Seasat). At this rate the automatic gain control (AGC) is updated. Such a pulse average is used in the determination of a height each 0.05 second (or two average to a height each 0.1 second). The shape of the return pulse highly depends on the shape of the reflecting surface e.g. from an ocean surface the shape of return pulse depends on significant wave height (SWH).[6,7]

The effects of the wave height on the shape of the return pulse are actually used to provide an estimate of the SWH. From the SIGMA NAUGHT value (backscatter coefficient) provided from the AGC we can get an estimate of the wind speed applied corrections for e.g. satellite height, receive temperature, and altitude/SWH effects[6].

The distance from the altimeter to the centre of mass can be measured. In vacuum the altimeter height is obtained from the time using the velõcity of light. However, propagation of electromagnetic waves is affected by ionospheric (between 60 and 1,000 km) of which the effect are 6 mm at night and 12 cm at day time and troposheric delay (0-40 km) of which the magnitude is 2.3 m. The wet component depends on water vapour and range from about 6 to 30 cm. The surface temperature, pressure, and water vapour are supplied by the Fleet Numerical Oceanography Centre (FNOC)[7]. The height of the sea surface can be derived using equation (2). In order to eliminate a major source to sea surface variations, both ocean and earth tide models are used. Normally altimeter date are distributed as geophysical data records (GDR).

2.3 The Sea Surface Height Observation

In the field of geodesy the geoid is the important signal and in oceanography the sea surface topography is of main interest. The altimeteric observation of the sea surface height can be described according to the following expression[6,3]

$$h=N+H+\varepsilon \qquad (2)$$

where,

N : the geoid height

ξ : the permanent sea surface topography

ε : the error

In fact, all signal and error terms of satellite altimetry find areas of interest. In there, however, the remaining signals/errors are contained in the error term of equation (2), which can be described as follows:

$$\varepsilon=\varepsilon^{o}+\varepsilon^{ot}+\varepsilon^{A}+n \qquad (3)$$

where,

ε^{o} : the radial orbit error

ε^{ot} : the ocean tide residuals

ε^{A} : the additional errors (the wet tropopsheric correction)

n : the measurement error

A typical error budget of altimeter data is shown in table 3[6]

In Table 3 the biggest error component is the radial orbit error splited into an errors caused by geopotential errors and errors caused by initial state vector errors, drag, and solar radiation pressure, which for precise orbits is about a few decimeters. The

Table 3. Typical error budget of altimeter data corrected for tidal effects

Phenomena	Magnitude (cm)	Wavelength (km)
Altimeter		
Bias	2	
Noise	5	
Orbit Error:		
Geopotenital	20	40,000
others	20	-
Wet troposhere	3	50- 500
Dry -	0.7	1,000
Ionosphere	3	50-10,000
Clouds, Rain	10-100	30- 50
Wave height	2% SWH	500- 1,000
Atm. pressure	3	200- 1,000
Ocean tide	10	500- 1,000
Earth tide	2	20,000

second biggest error term which is not related to the altimeter measurements itself is the tidal models applied in order to convert an instantaneous sea surface hight into mean sea surface height.

2.4 Cross-Over Adjustment

The cross-over technique is widely used in the evaluation of altimeter measurements. in a cross-over adjustment track related errors are estimated in order to minimize height differences at cross-over of the tracks. Cross-over discrepancies are computed as differences in heights between north and south going tracks, that is $d_k=h_i-h_j$. If the track related errors are modelled by bias terms, then

$$h_i-h_j=a_i-a_j+v_{ij} \tag{4}$$

where (a_i, a_j) are the unknown bias parameters.

If we takes matrix form for estimating the unknown bias parameters in a least squares adjustment, that is

$$\underline{x}=(A^TC_d^{-1}A+cc^T)^{-1}C_d^{-1}\underline{d} \tag{5}$$

If the track related errors are modelled by bias and tilt terms, then the residuals, v_{ij} are minimized in a least squares adjustment of

$$h_i-h_j=(a_i+b_i\mu_j)-(a_j+b_j\mu_i)+v_{ij} \tag{6}$$

where,

(h_i-h_j) is a cross-over difference.

(a_i, b_i, a_j, b_j) are the unknown bias and tilt parmeters.

$\mu_i\mu_j$ are the coordinates along the i'th and the j'th track respectively.

Such a cross-over adjustment has a rank deficiency of four and the free surface is described by a bilinear function as follows[14).

$$D=s_1+s_2\mu_j+s_3\mu_i+s_4\mu_j\mu_i \tag{7}$$

After then the altimeter data were corrected using the bias and tilit parameters, which were estimated in the free cross-over adjustment, equation (6) may be described in terms of ΔN, ξ^s, the free surface, equation (7), and v by

$$h^c=\Delta N+\xi^s+D+v \tag{8}$$

Often the effect of the stationary SST and the free surface are that the altimetric surface does not fit the geoid model after the cross-over adjustment, even if the extension of the area are longer than the wavelengths included in the geoid model. If the altimeter data, equation (8), are used as geoid height observations a removal of such deviations usually will improve the quality of the data. It may be carried out by estimation the parameters s_1, s_2, s_3, and s_4, of the free surface, equation (7), and removes it from the data. This procedure also removes the long wavelength parts of the stationary SST and long wavelength discrepancies between the geoid and the geoid model.

Hence, the altimeter data are observations of the relatively short wavelength parts of both the geoid, N, and the stationary SST, $\delta\xi^s$ as follows:

$$h^d = h^c - D = \delta N + \delta\xi^s + \nu \quad (9)$$

The deviation between the altimeter data and the geoid model may alternatively be removed before the cross-over adjustment by fitting each of the individual tracks to the geoid model. Again using a bias and a least squares adjustment minimizing the residuals, V_{ik}, along the i'th track as follows:

$$h_k = a_i^o + b_i^o \mu_k V_{ik} \quad (10)$$

The residuals, $V_i k$, contain geoid and stationary SST of wavelength shorter than the length of the i'th track. For sufficiently long tracks the residuals may be used as geoid height observations, $h^b = V_{ik}$, like the h^d values in equation (9)

2.5 Altimeter Mode

The coordinates of the satellite and the satellite height above any reference ellipsoid can be computed at any moment from orbit determination. The NASA has adopted GRS80 as the reference ellipsoid with a=6,378,145.0 m, f=1/298.255 for the evaluation of altimeter data. The computed satellite heights are erroneous due the tracking errors:

$$h = h_c + d \quad (11)$$

where,

h_c : computed satellite alltitude above NASA reference ellipsoid

d : unknown orbital error

By correcting the transmitted altimeter measurement for model refraction influence and constant instrumental bias we get the observed altimeter distance:

$$\rho = \rho_s - r + c_m \quad (12)$$

where,

ρ_s : altimeter measurement

r : refraction correction

c_m : constant instrumental bias

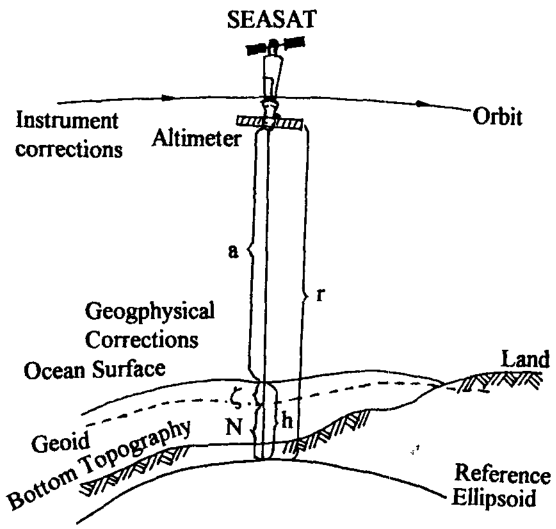

Fig. 3. Geometry of Geoidal and Sea-surface height determination by Satellite Altimetry

As known by MARTIN and BUTLER 1977[14], the instrumental bias depends on the altimeter mode. The altimeter measures short 3.55 m in long and 5.30 m in short pulse mode. The instantaneous sea surface height can be easily computed by

$$\xi = h - \rho \quad (13)$$

Approximating the geoid by the mean sea level, the instantaneous sea surface heights have to be corrected for time dependent sea level variations H to get geoid heights N from altimeter measrements:

$$N = \xi - H \quad (14)$$

3. Paractical Computation and Discussion

3.1 The altimeter geoid in the ocean area of Korean Peninsula

The altimeter data included Geosat, ERS-1, and Topex/Posedion data are used. The area of geoid computation is as follow: [$30^o \le \phi \le 50^o$; $120^o \le \lambda \le 140^o$].

The geoid undulations were computed using satellite altimeter data as follows: Geosat, ERS-1, and Topex/Poseidon. The Topex/Poseidon data has

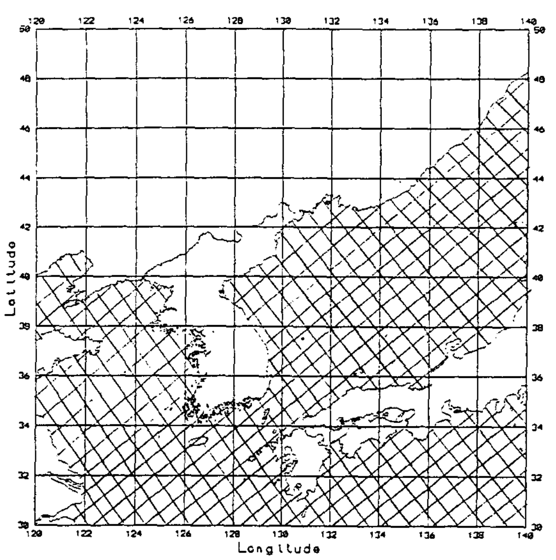

Fig. 4. Location of the Computation Area

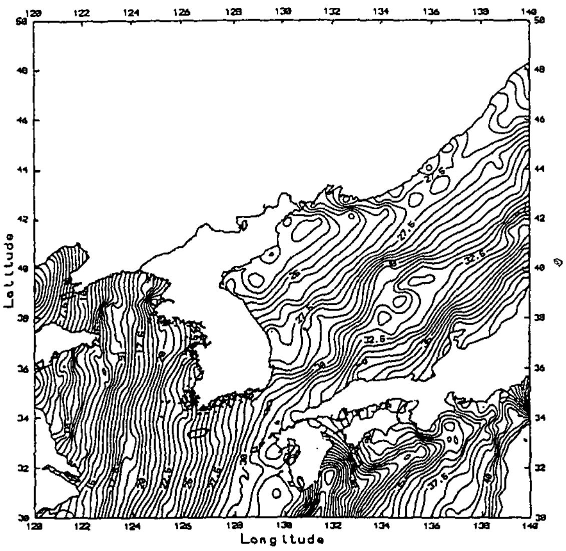

Fig. 5. The altimeter Geoid in the region of Koren Peninsula, contour interval: 0.5 [m]

been stacked over one year (cycle 3 to 39, 1992-1993) and adjusted over the whole world by a cross-over adjustment using sinusoidal functions (five parameters per half-resolution). The cross-over height difference is 1.9 cm RMS after adjustment compared 3.4 cm before adjustment. The Geosat

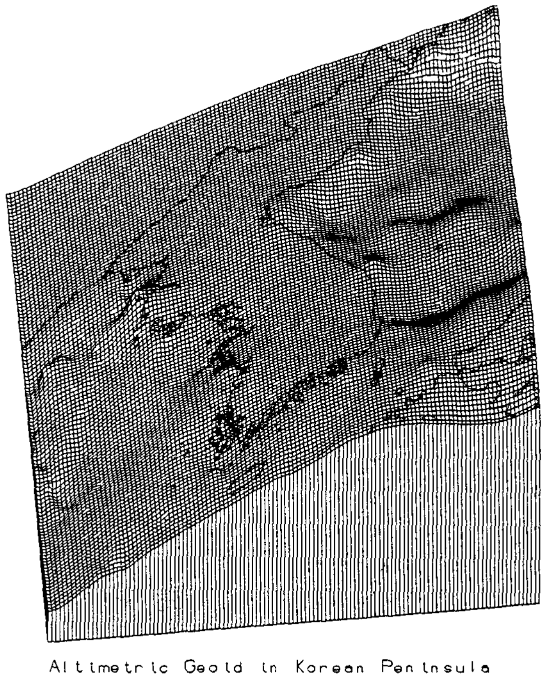

Fig. 6. Three dimensional geoid surface with viewing angle, 65 degree

data has been stacked also over one year, using the first 22 ERMs starting in Nov. 1986. The Geosat arcs have been locally adjusted on Topex/Poseidon arcs over an area going from 120° to 150° in longitude and 20° to 50° in latitude. The Geosat- cross-over RMS is 26.3 cm before adjustment and 9.6 cm after. But ERS-1 data wasn't stacked and used cycle 9 which is supposed to be good. There ERS-1 contain much oceanographic signal since tides and oceanic circulation are quite important in this area. These arcs where adjusted in the same way as Geosat arcs and the cross-over RMS goes from 22.6 cm down to 13.5 cm after adjustment.

A surface is computed with these data, and subtracted the Levitus permanent oceanic circulation from this surface, so as to keep only the geoid surface. According to the above results the quasi-stationary sea surface topography is estimated to be less than 10 cm in the Korean Peininsula area which can be considered as an altimeter geoid. A map of the altimeter geoid (mean sea surface) is given in

Figure 3. The latitude and longitude is the geodetic coordinates referred to GRS-80 ellipsoid, the geoid height N is also refers to GRS-80 ellipsoid.

4. Conclusion

This paper describes the determination of a geoidal undulation using Geosat, ERS1 and Topex/Poseidon altimeter tracking data which were tracked over one year of exact repeat mission (ERM). In a case of Topex/Poseidon data, the cross-over height difference is 1.9 cm RMS is 26.3 cm before adjustment and 9.6 cm after. But ERS-1 data contain much oceanographic signal since tides and oceanic circulation are quite important is this area. These arcs where adjusted in the same way as Geosat arcs and the cross-over RMS goes from 22.6 cm down to 13.5 cm after adjustment.

According to the above results the quasi-stationary sea surface topography is estimated to be less than 10 cm in the Korean Peninsula area can be considered as an altimeter geoid.

If in the ocean areas a dense grid of geoidal undulations in available from altimetry it is worthwhile for geophysical investigations to transform the data into gravity anomalies.

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