# Comparison between modeled and Observed Gravity Tidal Parameters at Ny-Alesund, Svalbard

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**Abstract.** Among the geophysical corrections generally applied to the absolute gravity measurements, tidal corrections including the ocean tide effect are one of the largest corrections in magnitude. We have examined the accuracy of a tidal correction by comparing the predicted tide at Ny-Alesund, Svalbard in the Arctic with the tidal analysis results for the actual gravity data obtained from a superconducting gravimeter (SG). To assess the variance in the prediction, we also compared our estimations with those by Bos et al. (2002). Except for minor waves, the two independent computation results agree within a difference of ±0.05 μGal in amplitude, which is less than 4 % of the observed amplitude. Even though the accuracy of the global ocean models is reduced in the Arctic Ocean because of the lack of satellite altimeter data there which is used to constrain the models, the present results indicate that the tidal effect could be estimated to an accuracy as good as that at the mid-latitude sites.

**Keyword.** Absolute gravimetry, Ny-Alesund, superconduction gravimeter, tidal correction, ocean tide effects

## 1 Introduction

Recent absolute gravimeters have the capability to measure gravity at an accuracy of better than 3 μGal (1 μGal = $1.x10^{-8}$ $ms^{-2}$), if they are carefully operated under stable environmental conditions. This circumstance has been shown, for example, by the results from the Fifth International Comparison of Absolute Gravimeters (Robertson, et al., 2001), in which 16 different absolute gravimeters were compared at the BIPM in Sevres, France. To convert an observed raw gravity value to a value that could be compared with those obtained at other places or during different observational epochs, several geophysical corrections are applied. In general, they are: the vertical or/and horizontal gravity gradient/s, the effect of polar motion, the attraction and loading effects due to the atmospheric pressure as well as the earth tides including the ocean tide effects. Of these corrections, the tidal correction is the largest.

The tidal effects consist of two components: the body tide and the attraction and the loading effects of the ocean tides. The body tide can be predicted accurately, because the Love and Shida numbers are accurately determined from theoretical studies. In addition, these parameters are not so sensitive to the horizontal variations in the Earth's elastic and inelastic properties (except for the waves at around the period of the free core resonance). On the other hand, the ocean tide effect is not always well known at the location where the absolute gravity measurement is carried out. Fortunately, recent global ocean tidal models derived from satellite altimeter data such as TOPEX/Poseidon (T/P) provide an accurate estimate for the ocean tides at mid-latitude oceans (see, for example, Matsumoto et al., 2000). However, the accuracy of these models is substantially reduced in the oceans at the high latitude because of the lack of satellite altimeter data there (i.e. the T/P data are only available for the sea areas within ±66 degrees in latitude).

We compare here the predicted tides at Ny-Alesund (79°N in latitude) with a 3-year registration of SG data. Besides the high latitude of this observation site, the site is very close to the coast (about 100 m from the nearest sea). Therefore, Ny-Alesund provides us a good example for assessing the accuracy of the tidal correction. In this paper, we show the tidal analysis results for the short- and long-period tides using the SG data, and we compare them with the predicted tides. To assess the computation accuracy, we compared our estimation with an independent computational result by Bos et al. (2002).

## 2 Gravity observations at Ny-Alesund and the scale factor of the SG

A SG (GWR CT#039) was installed at the gravimeter room of the Ny-Alesund Geodetic Observatory in September 1999. The geographical coordinates of the observation site are 78.93061°N in latitude and 11.86717°E in longitude. The site is located near the edge of a steep slope of about 44 m above the sea surface. The distance between the gravity site and the nearest coast is about 100 m as described above. The SG signal passing through a low-pass filter (cut-off period: about 20 s) is sampled at the interval of every 1 s together with auxiliary data (air pressure, tilt error, temperature of the gravity room and so on). The resolution of gravity data is 0.1 nGal ($1.x10^{-12}$ $ms^{-2}$) and the timing of sampling is locked to UT with a GPS clock.

Since 1998, absolute gravity (AG) observations have been carried out 4 times at the same observation pier on which the SG is installed. All absolute gravity observations were performed by the FG5 absolute gravimeters manufactured by Micro-g Solutions. Until now, the scale factor (i.e. μGal/Volt) of the SG has been determined three times by comparing with FG5s, and the results are shown in Table 1 with their instrument numbers and the institutes responsible for the observations.

If we fit a line to the data shown in Table 1, we obtain a rate of $-0.261 \pm 0.034$ (μGal/Volt/yr) as a rate of changes in the scale factors. Although the range of the secular change in gravity is comparable in order to the 1–σ formal observation errors, Table 1 suggests that the scale factor is decreasing at a rate of 0.37 %/yr during this three year period. On the other hand, Figure 1 shows the temporal changes in the amplitude coefficient of the O1 wave, which were obtained from successive monthly tidal analysis of the original SG data in Volt unit. Here, the decrease in the coefficients corresponds to the decease in sensitivity of the SG system including the recording system. The mean of the coefficients over the three years and their rate of change are 0.0192 Volt/μGal and $-1.05x10^{-4}$ Volt/μGal/yr. Thus, the rate also suggests a decrease in the relative sensitivity (i.e. at about 0.2 %/yr). The rate (0.37 %/yr or 0.2 %/yr) shown above is about one order of magnitude larger than that usually obtained from other SGs, for example, 0.01 %/yr for the SG at Esashi, Japan. At the present time, the cause for this sensitivity change is not clear. We might to examine the relation between the sensitivity change and the tilt motion of observation pier, which is considered to be related to an instability of the permafrost at Ny-Alesund (Kumpel and Fabian, 2002).

Table 1. Scale factor of the SG CT#039 determined by the absolute gravimeters.

| Date | Instrument | Insti. | Scale factor (μGal/Volt) |
|---|---|---|---|
| July, 2000 | FG5#206 | EOS | -70.83 (0.37)* |
| August, 2001 | FG5#101 | BKG | -70.49 (0.57) |
| August, 2002 | FG5#216 | ECGS | -70.29 (0.32) |
| Mean | | | -70.54 (0.43) |

Note: EOS: Ecole et Observatoire des Sciences de la Terre, Strasbourg, France, BKG: Bundesamt fuer Kartographie and Geodaesie, Frankfurt, Germany, ECGS: European Center for Geodynamics and Seismology, Luxemburg. *: by Sato et al. (2001).

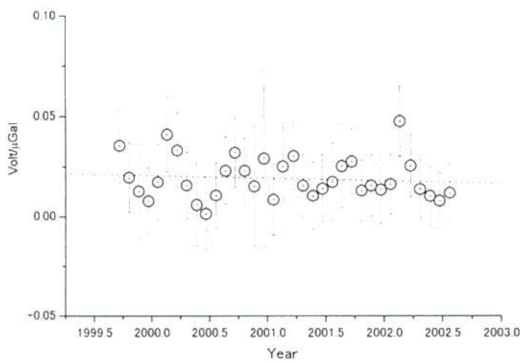


**Fig. 1.** Temporal variations in the amplitude coefficient of the O1 wave obtained from the successive monthly analysis of the SG data. Dotted line shows the best fitted linear curve.

## 3 Tidal analysis results for the short- and long-period tides

Tidal analysis was performed using the 3-year SG data from the beginning of the observation (i.e. September, 1999 - August, 2002), which were sampled at every 1-hour by using digital filters. For the analysis, we used here the mean scale factor shown in Table 1 (i.e. -70.54 μGal/Volt). The data include such irregular changes as spikes or steps due to earthquakes, adjustment of the SG, and human activity inside the observation room. They were corrected before the analysis. 7 steps were identified during the analysis period. The largest step is 42 μGal in magnitude, which occurred in September 6th in 2001 and other 6 steps are less than 4 μGal in magnitude.

A computer code called 'BAYTAP-G' (Tamura et al., 1991) and a modified version of it for the long-period tide were used for the analysis. Magnitude of the pressure admittances, obtained from successive yearly analysis, changes within a range between -0.32 and -0.45 in unit of μGal/hPa. We obtained a value of $-0.417 \pm 0.004$ μGal/hPa from the tidal analysis using the entire data of the 3-year span. The long-period tide (i.e. from the 4 - 5 days wave to the Mm wave) was analyzed using the trend component decomposed from the 1-h SG data by BAYTAP-G and sampled at every 1-day by taking the 24-hour mean. Results for the main 6 waves are given in Table 2. For the phase, a lag of the observed tide to the rigid tide is represented with the plus sign in this study.

**Table 2.** Observed tidal parameters for the 6 main waves. Numerical values enclosed by parentheses show the root mean square errors.

| | δ-factor | Amplitude (μGal) | Phase lag (degree) |
|---|---|---|---|
| Mm | 1.11 (0.06) | 7.13 (0.5) | -0.5 (4.0) |
| Mf | 1.13 (0.11) | 13.69 (0.2) | -1.4 (0.7) |
| O1 | 1.149 (0.006) | 13.475 (0.01) | -1.20 (0.06) |
| K1 | 1.153 (0.004) | 19.010 (0.01) | 1.84 (0.04) |
| M2 | 0.786 (0.005) | 2.180 (0.003) | -108.2 (0.1) |
| S2 | 1.40 (0.01) | 1.806 (0.003) | -58.4 (0.1) |

## 4 Predicted tides

Both the solid tide and the ocean tide effect were estimated using a computer code called 'GOTIC2' (Matsumoto et al., 2001). GOTIC2 takes into account the station height and the effect of the finite area of the ocean meshes in the computation of the Newtonian attraction. This is done by using an analytical formula that is integrated the Green's function over a rectangular ocean mesh (Sato and Hanada, 1984).

GOTIC2 usually carries out the convolution integral using the ETOPO5 map (resolution: 5' by 5'). However, since the observation site at Ny-Alesund is very close to the coast (about 100 m), in addition to this land-sea mask, we prepared other two digital maps to precisely represent the topography around the observation site. The resolutions of these additional maps are 1.0' by 2.5' and 3" by 7.5". The finest grid was applied to the area enclosed by 78°55'N - 79°00'N in latitude and 11°50'E - 12°00'E in longitude.

Table 3 shows the sensitivity of the computation results to the resolution of the maps. As shown in Table 3, the results are very sensitive to the precision of the topographic maps used in the computation. The sensitivity increases in the order of the long-period, diurnal and semidiurnal tides. This mainly reflects a scale of spatial variations in the ocean tide model of respective tidal species.

**Table 3.** Sensitivity of the estimated ocean tide effect to the resolution of grids used in the computation. AMP: Amplitude in μGal, PHS: Phase in degree.

| | | Mf | O1 | M2 |
|---|---|---|---|---|
| With fine grids | AMP | 0.546 | 0.432 | 4.451 |
| | PHS | -143.2 | -128.9 | -151.4 |
| Without them | AMP | 0.475 | 0.333 | 2.729 |
| | PHS | 33.0 | -136.3 | -133.3 |

Figure 2 shows the comparison of the observed amplitude factor (δ-factor) and phase with the predicted ones for the 16 waves. The computation was performed using the Love numbers given by Wahr (1981) for the 1066A earth model (Gilbert and Dziewonski, 1975). The loading Green's function was computed also using the 1066A model. As the ocean models, NAO.99b by Masumoto et al. (2000) and the model by Takanezawa et al. (2001) were used for the short- and long-period ocean tides, respectively. Fig. 2 clearly demonstrates that the predicted values do a good reproducing job at most of the characteristics in the observed amplitude factors (δ-factors) and phases, even though the site is located in the Arctic region at where the NAO.99b global ocean tide model built in GOTIC2 is not constrained with the T/P altimeter data.

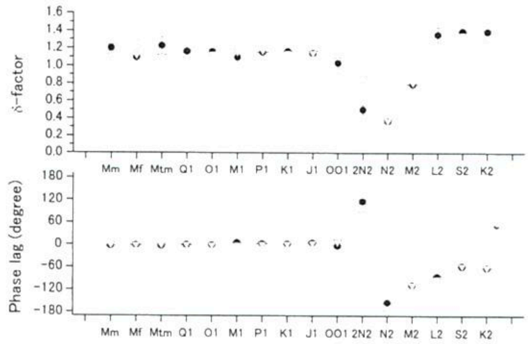


**Fig. 2.** Comparison of the estimated tidal factor and phase with the observed ones. Filled circles and open triangles show the observed values with their formal 1–σ error bar and the predicted values, respectively.

Bos et al. (2002) studied in detail the ocean tide in the Nordic seas and also discussed the oceanic effect at Ny-Alesund. We compared our results with their computations. They used two kinds of ocean tide models; FES98 (Lefevre et al., 2000) for the global model and a local model for Kings Bay spreading before the gravity observation site. For the local model, the tidal harmonics were analyzed using the tide gauge data at Kings Bay, and the harmonics were assumed to be constant over the bay. The Green's function for the PREM earth model (Dziewonski and Anderson, 1981) was used in their computation. According to the map given by Bos (personal communication), the finest grid used in their computation is at a size smaller than 1".

Different from NAO.99b, FES98 was derived without using the T/P data; therefore their results are useful to assess the errors in the estimation of ocean tide effect. The comparison is shown in Table 4. Both computation results are those at the SG site. As observed in Table 4, the two independent computations demonstrate a good agreement with each other for the main waves, even though the ocean models used in the respective computations are different. Table 3 and 4 clearly indicate that the largest error source in the estimation of the ocean tide effect at Ny-Alesund is the precision of topographic maps used for the computation. This is mainly due to the difference in the Newtonian attraction part of the gravity change estimated from the finer resolution different topographic maps.

**Table 4.** Comparison between two computations of the ocean tide effects by Bos et al. (2002) and by this study. AMP: Amplitude in μGal, PHS: Phase in degree.

| | | Mf | O1 | M2 |
|---|---|---|---|---|
| AMP | This study | 0.546 | 0.432 | 4.451 |
| | Bos et al. | 0.558 | 0.378 | 4.413 |
| PHS | This study | -143.2 | -128.9 | -151.4 |
| | Bos et al. | -163.6 | -163.6 | -152.4 |

## 5 Efficiency of using the observed tides for the correction to the AG measurement

Finally, we have investigated the effect of using different tidal models in the data processing of the absolute gravity measurements at Ny-Alesund.

If instead of the observed tidal parameters determined from the actual data of SG-CT#039, we use a nominal Earth tide and ocean loading model, we find that the mean value of gravity can differ by up to 1 μGal. Moreover, we have also confirmed that, compared with the results obtained using the default tide and the default pressure admittance value (i.e. -0.3 μGal/hPa) used in the data processing package of Micro-g, the standard error of the estimated absolute gravity value has been improved by about 50 % (from 2.1 μGal to 1.4 μGal) by using the observed parameters for the tide and air pressure changes.

## 6 Conclusions

We have investigated the accuracy of a tidal prediction to be corrected for the absolute gravity measurement based on the measurements at Ny-Alesund. From the comparison between the observation and prediction, we have determined that the tidal correction could be done with a reasonable accuracy at a level of 1 μGal, even the difficulties of a site such as Ny-Alesund from the point of view of the environmental conditions on the ocean tide effects. he other hand, our investigations clearly suggest the efficiency in using the observed tidal parameters obtained at the absolute gravity site. Therefore, if it is possible, it is desirable to carry out a tidal gravity observation at an absolute gravity site in order to guarantee an accuracy at a level of 1 μGal.

We have not discussed here the gravity changes in Sa (annual) and Ssa (semiannual) waves, but an assessment of the effect of sea level changes in this tidal frequency band is required. According to our analysis for the tide gauge data at Ny-Alesund, they have an amplitude exceeding in 100 mm as a total in Kings Bay, which is before the Ny-Alesund gravity site, and the gravity effect of these waves is estimated at a magnitude of about 2 μGal. Detail examination of the effect of these long-period ocean tides is left for further study as well as the gravity effect on the observation at Ny-Alesund due to the secular changes in mean sea level.

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