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The effects of sea-surface height variations on the long-period gravity changes

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Abstract. The effects of sea-level variations may be one of the noise sources of some of the solid-earth observations. Since the effects are so small as to be usually neglected for conventional observations, they have not been studied in detail so far. However, the recent observation using superconducting gravimeters (SG) has the potential to detect such a very weak gravity signal. Our preliminary estimation using TOPEX/Poseidon altimeter data showed that the induced gravity signal reached a few micro Gals in peak to peak amplitude. The estimation, however, may contain some errors due to inclusion of steric components of sea surface height (SSH) variation, which actually produce no gravity effect. In this study, we thus recalculate the gravity effects by removing the steric components from SSH. The data sets employed are POCM (Parallel Ocean Climate Model) SSH and the steric components are evaluated from SST (sea surface temperature) which used to calculate the POCM SSH. To investigate the characteristic of the gravity changes obtained, we applied the EOF analysis to both SSH data and induced gravity changes. The results show that one of the EOF components is strongly correlated to ENSO like SSH variations. The amplitude of expected gravity changes in the pacific equatorial regions may reache 2 to 3 μGal. This amount of amplitude could be detectable enough through a careful gravity observation of ground base and/or through satellite gravity missions now being planed.

1. Introduction

It is well-known that observed gravity signals are usually contaminated by numerous of

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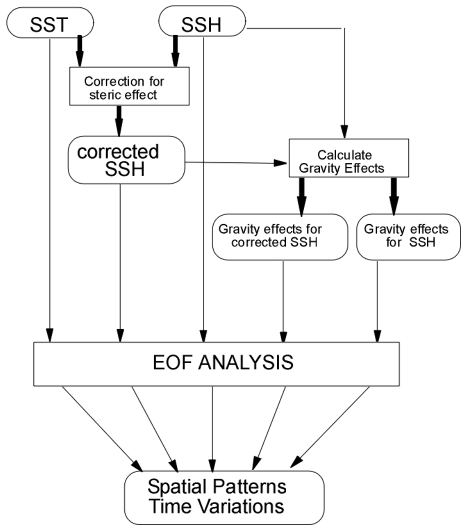

Fig. 1 - Outline of data processing.

oceanic variations. Among them, ocean-tide loading is the most typical signal, and many efforts have been devoted to removing its effects. Recently, thanks to the TOPEX/Poseidon altimeter data, very precise ocean-tide models, especially in the short-period ranges, have been developed (e.g. Matsumoto et al., 1995). Using those models, we can now calculate the tidal effects on gravity observations very accurately, e.g. at the level of 0.1 μGal in magnitude.

Regarding more long-period sea level variations, however, we do not have so much information about their gravity effects. Fukuda and Sato (1997) roughly estimated the effects of sea level variation using satellite altimeter data. Their result shows that a few micro gals gravity changes may be expected, especially near the coastal stations. Their estimation, however, may contain some errors due to inclusion of steric components of sea surface height (SSH) changes, which produce no gravity effect actually. In general, it is a rather difficult problem to estimate the steric part of SSH changes, because we need not only temperature profiles but also salinity data in the whole ocean for the calculation. We thus adapted a rather simple method for the calculation of the steric parts using SST data only. This method may not be rigorous from an oceanographic point of view, but we think it is sufficient to see the general characteristics of gravity effects.

In this paper, we first outline the data processing, and then discuss the characteristics of the gravity effects using mainly the results of EOF analysis.

2. Data sets and data processing

In our previous works, we employed TOPEX/Poseidon altimeter data as the SSH data.

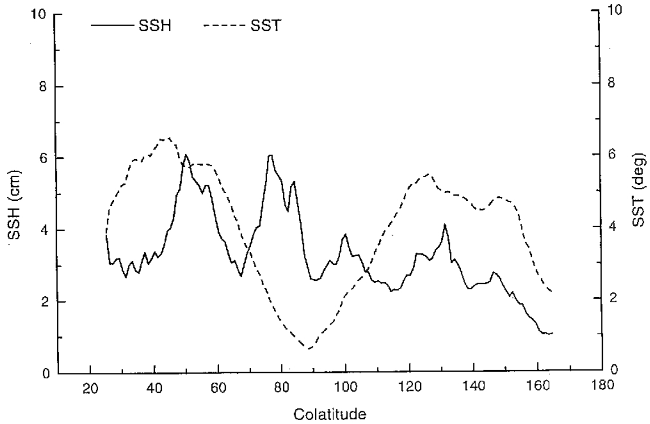

Fig. 2 - Zonal average of annual amplitudes of SST and SSH.

However, the orbit of the TOPEX/Poseidon satellite does not cover the polar regions causing a serious problem for the interpretation of SG data at the Japanese Antarctic gravity station, Showa (Sato et al., 1997) . Hence, we decided to use the data from a global circulation model (GCM) which gives a homogeneous data set after some comparative checks between TOPEX/Poseidon data. The SSH data set we actually adopted is from a POCM model (Stammer et al., 1996). We also adopted the SST data for the consistency of the data set, then used to drive the POCM model.

Fig. 1 shows the outline of the data processing.

In this study, one of the most important problems is to remove the thermal effects from the SSH data, i.e. calculating the steric component of SSH changes. As far as global circulation models are concerned, the steric parts were automatically obtained in the model calculation. Thus, we might use the data for steric components obtained in the POCM model. However, we decided to recalculate the steric part using the SST data set, because SST is an observable quantity, and it will be more practical, for instance, to use SSH data from satellite altimetry and SST from AVHRR data sets in future works.

To calculate the steric parts of SSH changes from SST data, we first investigated the correlation between the zonal average of the annual amplitudes of SSH and SST. Fig. 2 shows the results. It can be seen that the correlation varies according to the latitude, and, generally speaking, it is high in mid-latitude and low near the Equator. This figure clearly shows that it is impossible to convert SST to SSH by a unique coefficient in a global sense. Although the coefficient varies from 0.04 to 0.90 cm/dg locally, we finally adopted a unique value of 0.60 cm/dg for the steric correction. This value is obtained at an open-sea area in the North Pacific where the relation between SST and SSH is considered to be rather simple and straight forward.

Using the corrected and original SSH data, we calculated the gravity effects (Newtonian and loading effects) of SSH changes on land areas at 5 dg by 5 dg grid points. Then we conducted EOF analysis for all five data sets (i.e. one SST, two SSH and two gravity data sets) to examine those spatial patterns and characteristics of the time variations.

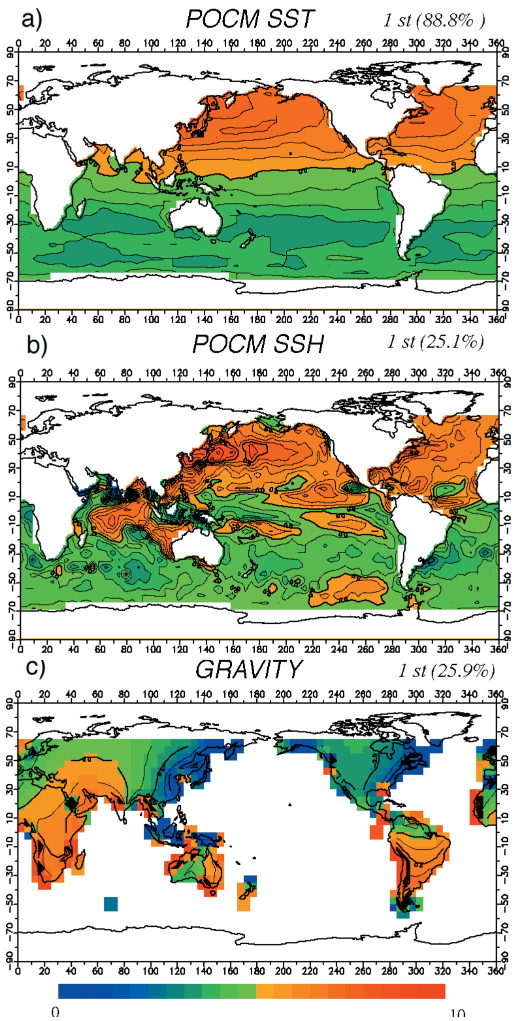

Fig. 3 - The first EOFS of SST, SSH and the gravity effect of SSH.

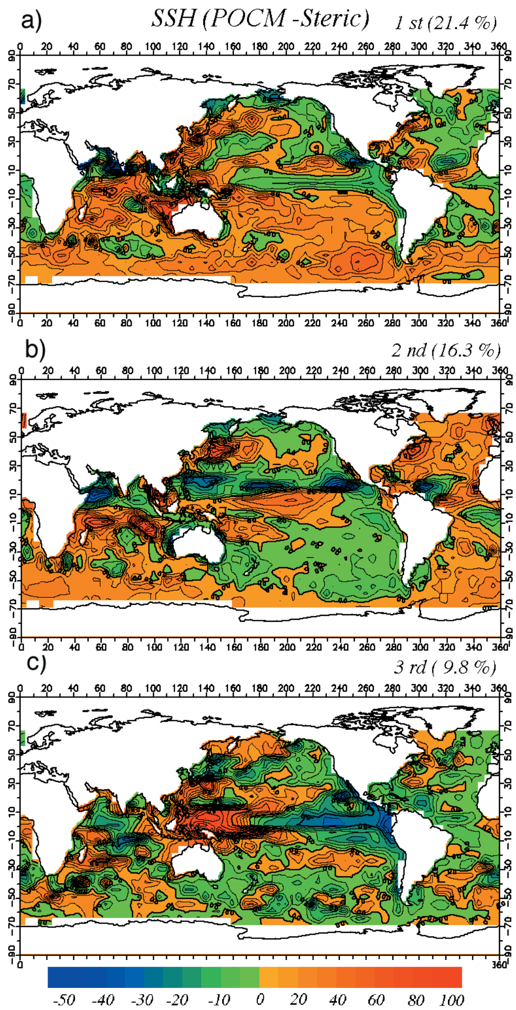

Fig. 4 - The first three modes of EOF analysis for SSH after steric correction.

3. Results

It is almost obvious that the most dominant signal of the original SSH variation is due to the annual variation of SST. Fig. 3 shows the first mode of SST, the original SSH and the gravity effects calculated using the SSH data, respectively. All the plots are symmetrical with respect to the equator and this mode clearly shows the thermal effects. Hence, the gravity changes of this mode may be apparent, and higher modes may have significant meanings as far as gravity changes are concerned.

Fig. 4 shows the first three modes of the EOF analysis for the corrected SSH. Compared with Fig. 3b, it is obvious that the annual thermal signal disappeared in Fig. 4a. Although, there are some interesting features in these maps from an oceanographic viewpoint, one of the most important points is the ENSO-like oscillation, appear clearly in the third mode. Fig. 5 shows the

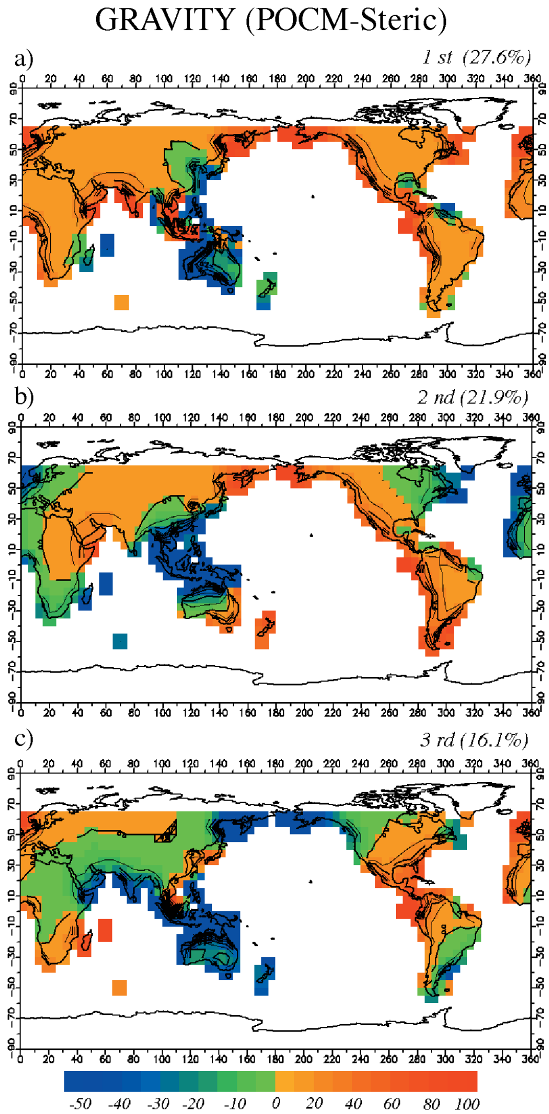

Fig. 5 - The first three modes of EOF analysis for gravity effect due to corrected SSH.

corresponding gravity changes, and here again the ENSO-like oscillation appears in the third mode.

The time variations of both the SSH and the gravity changes in the third mode are quite similar and this mode definitely represents the ENSO-like sea-surface oscillation. Hence, our interest is to see the amplitude of gravity changes corresponding to the oscillation. Fig. 6 shows the gravity effects calculated at appropriate points along the Equator. Note that these points are selected from islands or land areas. Each plot from the lower one to the upper one corresponds to the point from west to east, and it can be seen that the amplitude and the phase changes accordingly. The expected gravity signal reaches about 3 μGal in peak to peak amplitude.

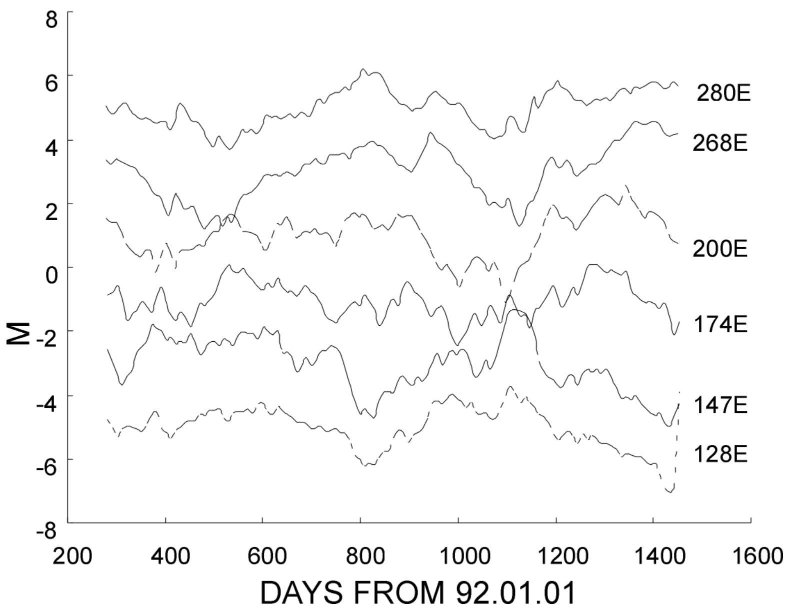

Fig. 6 - Gravity changes due to ENSO like sea level oscillation.

4. Conclusion

We estimated the amount of gravity changes due to sea-level variations by considering the thermal expansion of the seawater. The estimated gravity changes have an amplitude of more than 1 micro gal in the coastal areas. In the tropical Pacific region especially, it is expected that the ENSO-like oscillation causes 2 to 3 μGal gravity changes. Although some part of SSH variations are due to baroclinic currents, which may cause no gravity changes, careful observation by superconducting gravimeters, absolute gravimeters and/or dedicated satellite gravity missions in the near future should detect these signals. Moreover, the most important point is that gravity observations can detect actual mass changes and provide an independent data set for the modeling of sea-level variations. It is obvious that gravity observations play an important role in oceanographic studies as well.

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