Earth Planets Space, **50**, 883–885, 1998

Comment on "Incessant excitation of the Earth's free oscillations" by Nawa *et al.*

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(Received April 22, 1998; Revised July 9, 1998; Accepted July 23, 1998)

The report of Nawa *et al.* (1998) that incessant excitation of the Earth's free oscillations was discovered in the low frequency spectra of the superconducting gravimeter at the Syowa station in Antarctica is reexamined. The mean spectra for Syowa are compared with those for Matsushiro, another superconducting gravimeter station in an extremely calm circumstance, hence showing a much lower noise level than Syowa. Although the spectra for Syowa have many peaks below 3 mHz corresponding to those present in the time-frequency diagram of Nawa *et al.*, no similar peaks are found in the spectra for Matsushiro. This result suggests that the peaks below 3 mHz in the Syowa spectra are not real signals of the Earth's free oscillations.

1. Introduction

Nawa *et al.* (1998; hereafter referred to as N98) reported that spectral analysis of the data from the superconducting gravimeter at the Syowa station in Antarctica yielded the evidence for incessantly excited normal modes of the Earth's free oscillations. It was shown that the known set of earthquakes solely was not sufficient for explaining the observed spectra. The atmosphere was suggested as a plausible source of excitation so that some features of the spectra were well explained.

The same group reported in a companion paper (Suda *et al.*, 1998) that analysis of ten year gravity data from the IDA network yielded spectral peaks from 2 to 7 mHz corresponding to the fundamental spheroidal modes, which are not of earthquake origin. Similar results have also been reported by several other works (e.g. Kobayashi and Nishida, 1998; Tanimoto *et al.*, 1998). However, it has been noticed that the superconducting gravimeter spectra of Syowa indicate some different features from the spectra obtained with other instruments (Suda *et al.*, 1998). A notable fact is that the peaks in the lowest frequency range down to 0.3 mHz are visible only in the Syowa spectra. This fact has sometimes been ascribed to the extraordinary "resolution" of the superconducting gravimeter data of Syowa.

If the free oscillations of the Earth are really excited continuously (whatever the source of excitation is), signals with the same frequencies and comparable magnitude should be observed also at other places, as long as an instrument capable of resolving them is installed in a quiet condition. The reported amplitude of the oscillations is on the order of 1 nGal ($= 10^{-11}$ m s^{-2}). A signal with this amplitude is not too small for normal registration of a superconducting gravimeter to resolve. The nominal resolution of recording for a superconducting gravimeter is typically less than 1 nGal. It could be even higher with the MODE filter due to the extra gain by a factor of $\sim$25 (GWR Instruments, 1989). N98 mentions that the quiet condition of the Syowa station enables identification of gravity signals of 1 nGal amplitude with a resolution of 1 pGal ($= 10^{-14}$ m s^{-2}) for the MODE data. This description is somewhat misleading; such an extremely small unit of digitization is not of practical significance, because observational noises from the sources other than digitization limit will be dominant. In fact, according to the recent comparison of the quiet day spectra from superconducting gravimeters (Sato and Imanishi, 1997), the noise level of Syowa in the normal mode band is significantly higher than the typical level at the best stations. N98 argues that most of the observed low-frequency noise may be actually the signals of the Earth's free oscillations, but this can not be the case at least for the Syowa gravimeter.

In this paper, the result of N98 is reexamined by using the data from the superconducting gravimeter at Matsushiro (Imanishi *et al.*, 1997). This station was established in December 1995 in an underground seismological observatory of Japan Meteorological Agency, and the environmental condition is extremely stable. Although the nominal resolution of gravity recording was only about 10^{-12} m s^{-2} (prior to June 1998), Matsushiro shows a much lower noise level than Syowa. Therefore, the same oscillations as N98 observed from the Syowa data should be observed with a higher signal-to-noise ratio at Matsushiro, if they are real signals of the Earth's free oscillations.

2. Analysis and Result

Thanks to an experimental exchange of gravity data as a local activity of the GGP-Japan network (Sato and Imanishi, 1997), the one-month data from Syowa in August 1993 are available to the author. So this data will be used here to compare the spectra at the two stations, Syowa and Matsushiro. For the Matsushiro station, the data in the same period as for Syowa are not available. Considering that according to N98 the oscillations have larger power in austral winter, and also that the noise level at Matsushiro is lower (though only slightly) in summer than in winter, the one-month period in August 1997 is chosen for Matsushiro so that the signal-to-

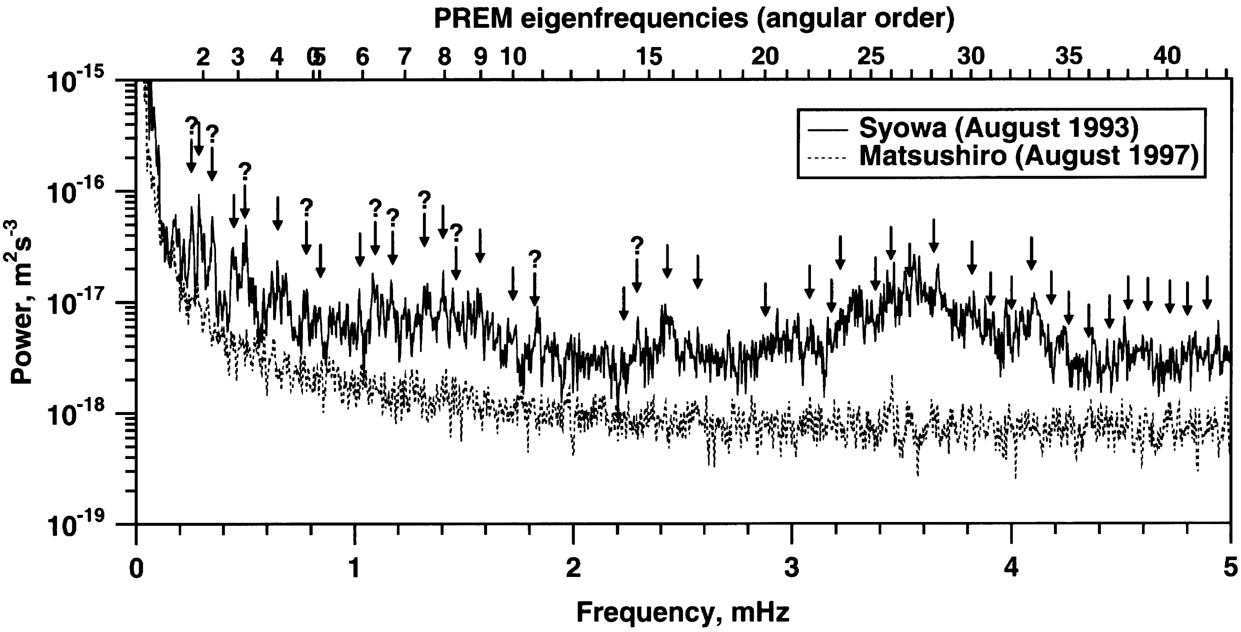

Fig. 1. Averaged spectra for the superconducting gravimeters at two stations, Syowa (solid line) and Matsushiro (broken line). Arrows indicate the locations of the frequencies measured by Nawa *et al.* (1998). The ? marks indicate the frequencies which were not identified as fundamental spheroidal modes.

noise ratio would be higher.

Because the MODE data are not available for Matsushiro, the data as output of the TIDE filter (with no extra gain) are used for both stations (use of the MODE data does not improve the spectra of Syowa significantly). First, the data are corrected for the theoretical Earth tides, using the admittance determined from the tidal analysis of the gravity data for respective stations. Next, the effect of atmospheric pressure on gravity (Newtonian attraction and loading) is subtracted from the gravity data using the data of local atmospheric pressure. A single coefficient of -3×10^{-9} m s^{-2}hPa^{-1} is adopted for this correction and therefore no frequency dependence is assumed (e.g. Crossley *et al.*, 1995). Even with this simple correction, the noise level of the low frequency gravity spectrum is significantly improved in the frequency range up to 1–2 mHz. The residual series is then visually inspected for disturbances due to the earthquakes, which are simply removed and linearly interpolated. The length of the interpolated intervals is dependent on the earthquake waveform, ranging from several minutes to one day. Although this may not be sufficient for completely eliminating the free oscillation signals of earthquake origin, it will not affect significantly the overall profile of the spectra and the existence of major spectral peaks described later. Finally, the stepwise changes (of instrumental origin) in the gravity data are corrected.

The one month gravity data after these corrections are used to calculate the power spectral densities. For the choice of the time domain window, the author follows N98; in other words, a three-day long window is applied to the data and is successively shifted by one day. The resultant spectra are then averaged to give the monthly-averaged spectra shown in Fig. 1.

It can be seen from the figure that averaging the Syowa data over one-month period has reproduced most of the peaks below 3 mHz observed by N98. This indicates that existence of the spectral peaks below 3 mHz can be regarded as a robust feature of the gravity records from Syowa. In other words, the oscillations below 3 mHz are so coherent that they can be retrieved from the data of only one-month period. Also, the enhanced power around 300 s period has been reproduced. The peaks above 3 mHz are not visible in the spectra, corresponding to the fact that the vertical lines above 3 mHz are less prominent than those below 3 mHz in Fig. 3(a) of N98. Although it is not quite obvious how N98 observed the peaks above 3 mHz, such peaks as found by the other works (e.g. Suda *et al.*, 1998) should emerge if one averages the Syowa spectra (and also the Matsushiro spectra) over a much longer period than used here.

On the other hand, the averaged spectra of Matsushiro shown in Fig. 1 have a smooth profile with respect to frequency. This is much closer to the typical profile of the low frequency spectra in quiet days which we are familiar with. The spectral intensities of Matsushiro are lower than those of Syowa by a factor of 3–10 over the whole frequency range in terms of power spectral density. No clear peaks corresponding to those present in the Syowa spectra below 3 mHz are found. Even the most prominent peaks of Syowa in the lowest frequency range do not have their counterparts in the Matsushiro spectra.

This result clearly indicates that the spectral peaks below 3 mHz present in the Syowa spectra can not be the signals of such global phenomena as the Earth's free oscillations. They must be either the signals of some local geophysical phenomena or observational noise instead. If they are signals at all, an independent observation in the Antarctic area with comparable or better quality would be very useful to investigate the nature of the observed signals. If they are observational noise, they are most likely to be instrumentally generated, because they have steady frequencies. Generally speaking, possible sources of such periodic noise in the superconducting gravimeter systems include electric problems related with the grounding of the electronics package, and interference between the gravity signal and the tilt compensation system.

3. Discussion

The above statement contradicts the signal identification made by N98. In the N98 paper, it was concluded that the peaks of the Syowa spectra were the signals of the normal modes, based on the fact that the observed frequencies were exact to 0.02 mHz. This conclusion, however, appears to be too optimistic. Although the eigenfrequencies of the fundamental spheroidal modes are known to the accuracy better than 0.1% (Dziewonski and Anderson, 1981), the relative errors in the observed frequencies are on the order of 1%. In particular, for some peaks in the lowest frequency range, the discrepancies in frequency are too large (see Fig. 1), even if we take the accuracy of frequency measurement (0.01 mHz) into account.

Moreover, there exist such peaks below 3 mHz in the Syowa spectra that do not agree with the locations of any fundamental modes. Although some of them were identified tentatively as overtones, the others lie where no modes (including overtones) exist. Even worse, these peaks (indicated by ? in Fig. 1) have relatively large power (this is one of the points that were not so obvious in the 2D diagram of N98). This fact strongly suggests the existence of some periodic signal or noise other than the Earth's free oscillations in the Syowa data. In the presence of these unidentified peaks, the remaining peaks can not be reliably identified as normal modes.

It appears that the "vertical lines" in the spectrogram of N98, especially the most persistent ones in the lowest frequency range, have given rise to the idea of the incessant excitation of the Earth's free oscillations. Also, the large seasonal variation of the spectral intensities and the enhanced power around 300 s period were interpreted as evidence in favor of the atmospheric (or oceanic) excitation. None of these features are, however, generally known for low frequency gravity spectra. It is not correct to conclude that they were discovered only because of the exceptionally high detection power of the superconducting gravimeter of Syowa. Rather, such features of the Syowa spectra should be regarded as evidence of local problems of the gravimeter system. For example, the period of 300 s coincides with the characteristic period of the temperature change in the gravimeter room of Syowa (T. Sato, personal communication). Further interpretation of the Syowa spectra may require a thorough check of the possible effects of the environment on the observation, as well as other instrumental problems.

In conclusion, the analysis of Matsushiro data does not support the detection of the incessantly excited free oscillations below 3 mHz reported by N98. This conclusion may provide at least a partial solution to the question raised by Suda *et al.* (1998) on the difference in the signal appearances between the Syowa spectra and the IDA spectra. It is expected that the global network of superconducting gravimeters called GGP (Crossley and Hinderer, 1995), whose observation period has just started, would provide an ideal dataset for further investigation of this issue.

Acknowledgments. I thank Prof. Ichiro Nakanishi and Prof. Jiro Segawa for discussions. Comments by Dr. Hitoshi Kawakatsu and an anonymous referee were helpful for improving the manuscript.

References

Crossley, D. and J. Hinderer, Global Geodynamics Project—GGP: Status report 1994, in *Proc. Second IAG Workshop on "Non-Tidal Gravity Changes: Intercomparison between Absolute and Superconducting Gravimeters"*, Cahiers du Centre Européen de Géodynamique et de Séismologie, Luxemburg, **11**, 244–274, 1995.

Crossley, D., O. Jensen, and J. Hinderer, Effective barometric admittance and gravity residuals, *Phys. Earth Planet. Inter.*, **90**, 221–241, 1995.

Dziewonski, A. M. and D. L. Anderson, Preliminary reference Earth model, *Phys. Earth Planet. Inter.*, **25**, 297–356, 1981.

GWR Instruments, Superconducting gravity meter operating manual, 1989.

Imanishi, Y., J. Segawa, I. Furuya, S. Kashiwabara, H. Takayama, and Y. Nishimae, Gravity observation by means of a superconducting gravimeter at Matsushiro, Japan, in *IAG Proceedings "Gravity, Geoid and Marine Geodesy"*, 115–122, 1997.

Kobayashi, N. and K. Nishida. Continuous excitation of planetary free oscillations by atmospheric disturbances, *Nature*, 1998 (in press).

Nawa, K., N. Suda, Y. Fukao, T. Sato, Y. Aoyama, and K. Shibuya, Incessant excitation of the Earth's free oscillations, *Earth Planets Space*, **50**, 3–8, 1998.

Sato, T. and Y. Imanishi, A superconducting gravimeter network—GGP-Japan network, poster presented at the International Symposium on "New images of the Earth's interior through long-term ocean-floor observations", 1997.

Suda, N., K. Nawa, and Y. Fukao, Earth's background free oscillations, *Science*, **279**, 2089–2091, 1998.

Tanimoto, T., J. Um, K. Nishida, and N. Kobayashi, Earth's continuous oscillations observed on seismically quiet days, *Geophys. Res. Lett.*, **25**, 1553–1556, 1998.

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