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INFLUENCE OF THE EARTH EIGENVIBRATIONS ON THE GRAVITATIONAL WAVE ANTENNA

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Abstract

The records of the gravitational wave antenna of the GEOGRAV experiment in Rome are analyzed together with the records of a gravimeter. The aim of the study is to detect whether the records of the antenna are connected with the excitation of eigenvibrational modes of the Earth. Although a correlation between the two types of records is found, the explanation of the coupling mechanism remains an open question.

1. INTRODUCTION

The detection of gravitational waves is a challenging task, and various groups around the world have tackled the problem using different types of instruments. As the theoretically expected signal is very weak, i.e. a deformation in the order of 10^{-17} - 10^{-19}, all possible noise sources on the instrumentation have to be carefully studied and possibly eliminated. The GEOGRAV experiment in Rome (Bronzini et al., 1985) was set up to detect possible influences of geophysical origin on a Weber type Al-cylinder antenna (M=2300 kg, L=3 m, D=0.6 m). Among these are seismic excitations, free oscillations of the Earth, and Earth tides. In order to monitor these phenomena, the instrumentation of the experiment includes the room-temperature antenna, seismographs, a La Coste-Romberg gravimeter and a thermometer. The main goal of the present analysis is to detect possible influences of the Earth free oscillations on the gravitational wave antenna (GW--antenna).

The term "free oscillations" indicates the normal modes of the Earth, which are described by the displacement field $\mathbf{u}(\mathbf{r}, t)$ throughout the Earth. The modes can be split into two groups (Pekeris et al., 1961): the spheroidal modes, which are due to rotation-free divergence-waves and the torsional modes, which are due to divergence-free rotational waves. The torsional modes have a vanishing radial component, whereas the spheroidal modes give rise to a perturbation of the Earth gravity field; a perturbation which is absent or much smaller for torsional modes. Thus it follows that only spheroidal waves can be detected by a gravimeter. The periodicities of free oscillations range from about one hour

Table 1

Periods of the first oscillation modes of the Earth (Dziewonski and Gilbert, 1972)

Mode*	Period [min]
$0S2$	54
$0T2$	44
$0S3$	36
$0T3$	28
$0S4$	26
$1S2$	25

* Spherical and torsional modes are indicated by letters S and T, respectively

to a few minutes. In Table 1 we list the periods of the first modes. The free oscillations are exited by an earthquake, and the oscillation amplitude of each mode depends on the depth, magnitude and rupture-mechanism of the earthquake.

2. DATA SELECTION

The considerations presented above suggest the procedure to analyze simultaneous records of the antenna and gravimeter. The data from the antenna provide an estimate of the oscillation square amplitude of the first longitudinal mode of cylinder. The gravimetric data are a measure of the variation of the gravity acceleration g. The data at our disposal have been recorded from May 1984 to March 1985. We select corresponding

Table 2

List of selected earthquakes

Region	Date	Origin time [h : m]	Depth [km]	M_b
Dominican Republic	1984 June 24	11 : 17	25	6.0
Solomon Islands	1984 July 05	05 : 21	30	6.0
Kyushu	1984 August 06	19 : 06	45	6.3
California	1984 September 10	03 : 14	10	6.1
Tajik	1984 October 26	20 : 22	33	6.0
Central Midatlantic Ridge	1984 November 01	04 : 48	10	6.5
Chile	1985 March 03	22 : 59	33	6.7

time intervals in which major earthquakes have occurred. Thus we base our analysis on time intervals during which the excitation of the Earth eigenvibrations are the greatest. Furthermore, during the pre-earthquake intervals the Earth modes are presumably quiet

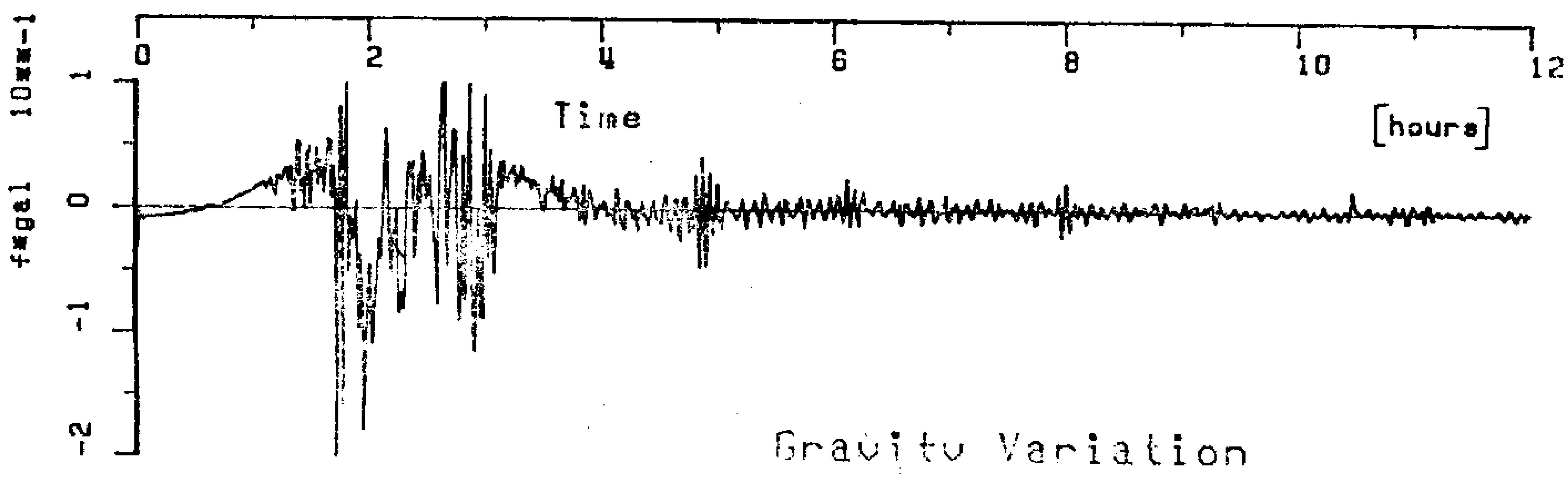

Fig. 1. Record of the gravimeter during 12 hours following the Chile earthquake of 1985. The conversion factor f is approximately $f = 0.2 \times 10^{-3}$

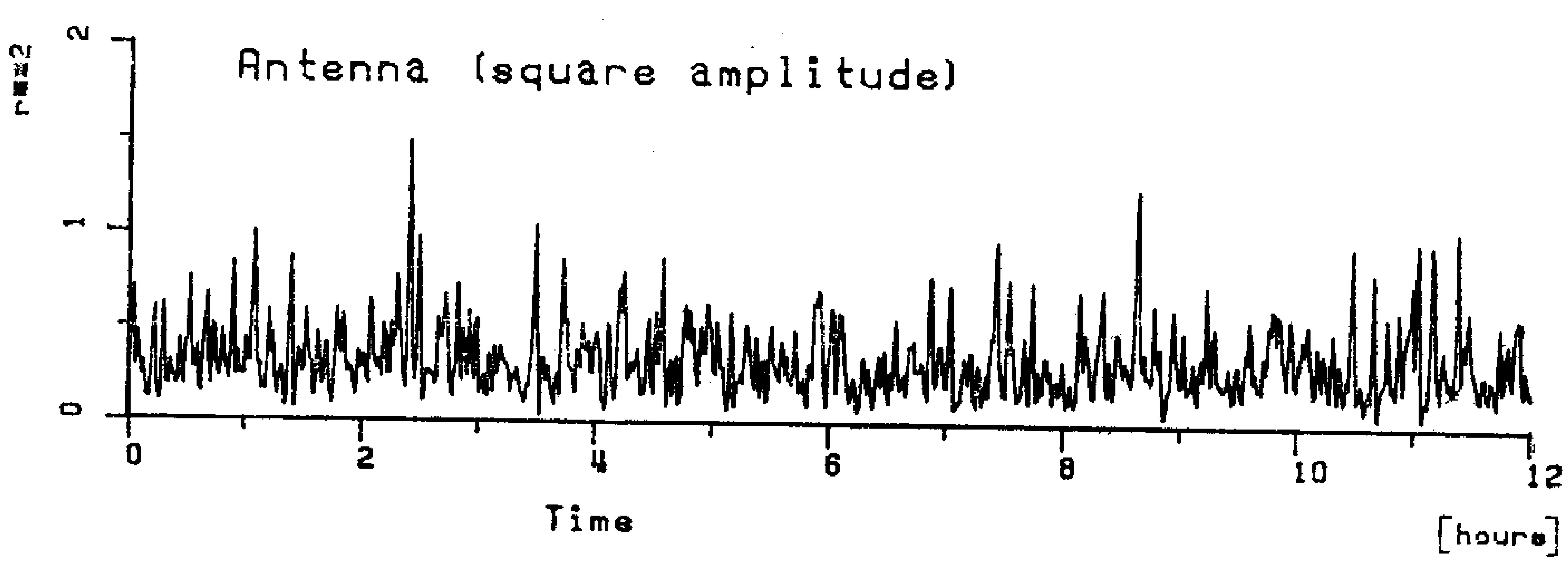

Fig. 2. Record of the antenna during 12 hours following the Chile earthquake of 1985. The record provides an estimate of the square amplitude of the first longitudinal mode of solid aluminium cylinder. The measurement unit is $r = 5 \times 10^{-16}$ m

and so the comparison of the two epochs is important. The selected earthquakes are listed in Table 2. By far the greatest excitation of free oscillations was due to the Chile earthquake in 1985. The gravimetric and antenna records during 12 hours following the Chile earthquake are shown in Fig. 1 and 2.

3. METHODS OF DATA ANALYSIS

The methods used in the analysis of data are as follows. For every earthquake we create pre- and post-earthquake time series of antenna and gravimetric data. Each file covers the time interval of about 3 days and the sampling is 1 minute. The gravimetric data have to be preliminarily treated to eliminate the diurnal tidal variation and the instrumental drift. The drift is eliminated by least squares fit to a regression cubic and the tidal variation by high-pass filtering. Furthermore, the data show spurious peaks. These are eliminated with a peak searching algorithm. Fig. 1 displays the gravimetric record after its preliminary treatment.

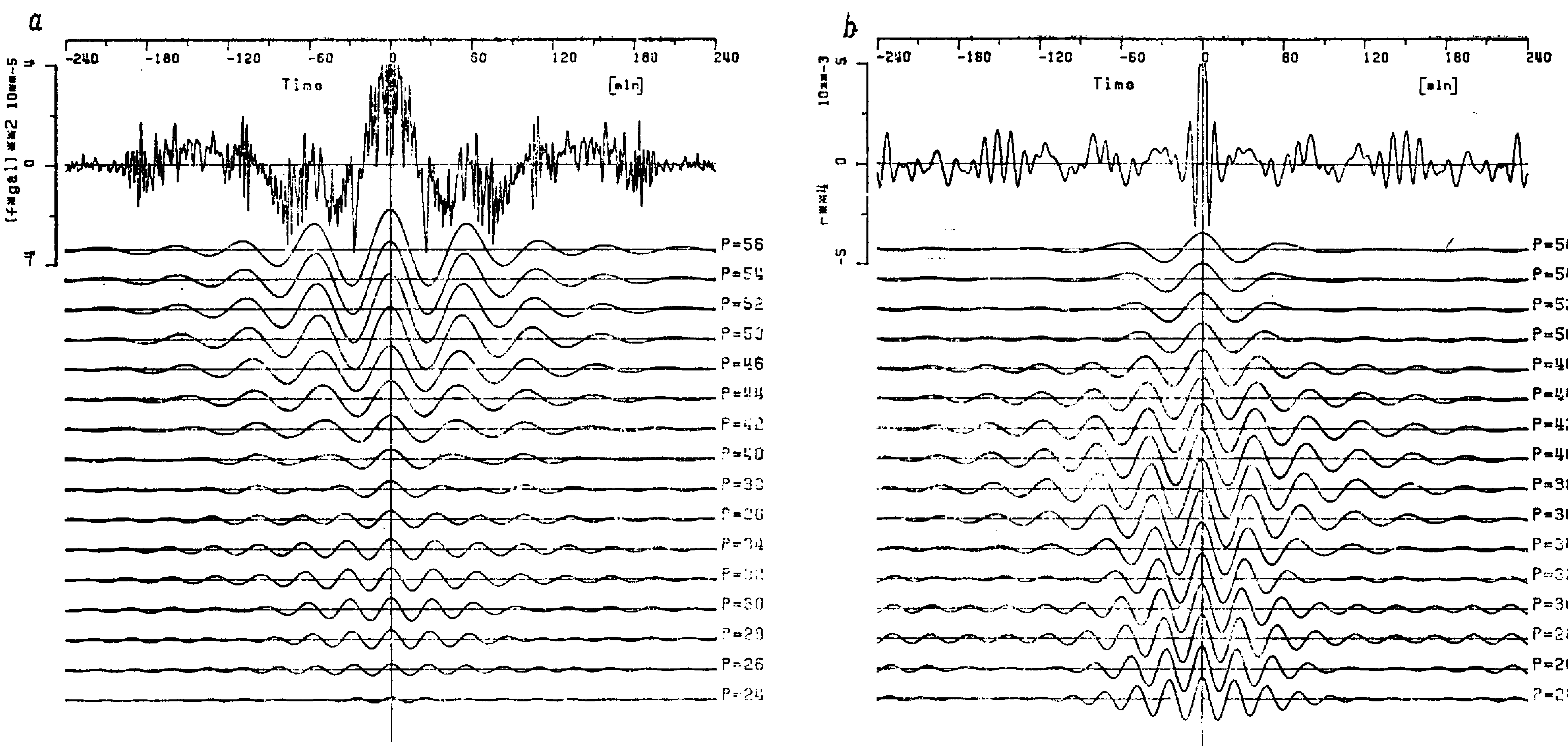

Fig. 3. Autocorrelation function of gravimeter (a) and antenna (b). The first trace shows the correlation function and the successive 16 traces show the band pass filtered correlation functions. *P* is the inverse of the frequency on which the filter is centred

3.1. Spectral density evaluation.

3.1.1. We evaluate the spectral density of all time series. This is achieved by calculating firstly the autocorrelation function of each time series for lags up to 20 percent of the duration of the record. The correlation function is tapered with the Parzen lag window (Bendat and Piersol, 1966) and then the Fast Fourier Transform algorithm is applied. We then limit ourselves in the examination of the spectra only to periods ranging from a few hours to 10 minutes. The study of the spectra is not extended to shorter periods for the following reason. With increasing mode number of the oscillation mode, the difference in frequency of two successive modes decreases. With the given frequency resolution dictated by the data length, the different modes cannot be separated for periods shorter than about 10 minutes.

3.1.2. Signal to noise ratio (SNR). In the study of the spectra we use a quantity akin to the SNR. We define the SNR for our purpose by the ratio of the mean value of the N greatest peaks in the spectrum to the mean value of the spectrum. The integer N and the considered period interval are common to all spectra. N is taken equal to 10 and the period interval covers the range from 500 to 10 minutes.

3.2. Auto- and cross-correlation functions. We evaluate the auto-correlation functions of all gravimetric and antenna data and also the cross-correlation function between simultaneous records of the two instruments. The Fourier transform of each correlation function is band-pass filtered with the band centred on 16 frequencies ranging from 1/56 to 1/24 cpm. The 16 frequencies sample the interval that contains the frequencies of the first few free oscillation modes. The filters are Gaussian filters. The pass-band, defined as the interval in which the transfer function of the filter assumes values greater than $1/\sqrt{2}$, is equal to $\Delta f=0.0066$ cpm (Zadro, 1963).

Fig. 3 illustrates the auto-correlation function of gravimeter and antenna (first trace) and after application of the filter (successive 16 traces).

4. RESULTS

The application of the described methods allowed to make the following observations. As expected, spheroidal free oscillation modes are clearly detectable by the spectrum analysis of gravimetric data. The lowest modes are detectable in pre- as well as in post-earthquake time intervals, which higher modes are observable only after an earthquake of considerable magnitude. For the Chile 1985 earthquake we were able to detect an increase of the spectral energy density by a factor of the order of 100. In some cases we detected also some lower torsional modes.

Referring to the antenna, the principal object of the present study, some interesting facts have emerged from the analysis. For the records after the occurrence of a violent earthquake (Chile, Solomon, Tajik), some emerging spectral lines could be detected. Evaluating the SNR as defined above, we find it increasing by a few percent in the spectra of post-earthquake periods with respect to pre-earthquake periods. Consistent with this is the observation that the ratio between the standard deviation and mean of the spectra appears to be greater in the post-earthquake intervals than in the pre-earthquake intervals. Especially two periodicities have emerged in the data and these are at the periods of $P_1 = 28$ min and $P_2 = 40$ min. These periods are close to the torsional modes $0T3$ and $0T2$, respectively. From the filtered auto-correlation functions of the antenna we find that in some cases the periodicity of 28 min is persistent over an interval of more than 4 hours. Another periodicity which seems to be always present in the data is of about 300 min to 240 min. It is interesting to note that in the past low frequencies in this range have been detected by geophysicists studying free oscillations.

After having studied the antenna and gravimetric data separately, we continued by confronting the simultaneous registrations of the two instruments. The comparison of the periodicities identified in the two records does not lead to any strict relationship between them. From the cross-correlations no convincing results could be extracted.

5. DISCUSSION AND CONCLUSIONS

The fact that the SNR, as defined above, of the antenna data is increased after an earthquake leads to a hypothesis that the antenna is indeed influenced by the oscillations of the Earth. This, because the only phenomenon known to geophysicists that is in the considered frequency range and is excited by earthquakes, consists of the spheroidal and torsional oscillations of the Earth. On the other hand, the identification of the modes with the gravimeter does not match with the observations from the antenna. This indicates that the observations made by the antenna depend on the excitation of torsional modes rather than spheroidal modes. In spite of the fact that occasionally torsional modes are detected by the gravimeter, the gravimeter cannot be used to infer reliably the excitation of these modes. Theoretically these modes should not appear at all in the gravimetric data. But this prediction is based on the assumption of homogeneous stratification of the Earth, which in reality is an approximation. In order to verify whether the observations made by the antenna are correlated with torsional modes, our analysis should be repeated. The gravimeter, however, must be replaced for example by long period horizontal seismometer. Up to now the interaction, responsible for the link between the oscillation modes and the records of the antenna, is not known.

The present analysis is a part of the Doctoral Theses at the University of Triest presented in 1987, where further details can be found.

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WPŁYW SWOBODNYCH WIBRACJI ZIEMI NA ANTENĘ FAL GRAWITACYJNYCH

Streszczenie

W pracy analizuje się zapisy anteny fal grawitacyjnych uzyskane w ramach eksperymentu GEOGRAV w Rzymie. Przeprowadzono również jednoczesną analizę rejestracji grawimetru. Celem badań jest sprawdzenie, czy zapisy anteny są związane ze swobodnymi wibracjami Ziemi. Pomimo, że zależność taka została stwierdzona, pozostał otwarty problem, czy antena reaguje bezpośrednio na oscylacje Ziemi, czy też na fale grawitacyjne generowane przez te oscylacje. Drugi przypadek jest mało prawdopodobny: taka emisja grawitacyjna byłaby za słaba, aby została zarejestrowana przez urządzenie antenowe.