A 3.7 mHz - gravity signal on June 10, 1991

by

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1 Introduction

The paroxysmal Mount Pinatubo eruption of June 15, 1991 excited Rayleigh waves which traveled around the globe (Kanamori and Mori, 1992; Widmer and Zürn, 1992; Kanamori et al., 1994; Zürn and Widmer, 1996). These waves were essentially bichromatic with frequencies of 3.68 and 4.44 mHz and were identified as vertical modes of the atmosphere (i. e. Lognonné et al., 1998) excited by the volcanic eruption. These oscillations in turn excited the observed Rayleigh waves.

Japanese scientists recently observed continuous vibrations of the earth ("hum" for short) in the frequency band between 2 and 7 mHz involving the fundamental spheroidal modes ${}_oS_l$ (e. g. Nawa et al. 1998, Suda et al. 1998, Kobayashi and Nishida 1998, Tanimoto et al. 1998). Atmospheric pressure fluctuations are the preferred source of excitation because seasonal variation of the amplitudes on one hand and higher amplitude of the modes near 3.68 mHz on the other were also observed and energy estimates corroborate this idea (e. g. Kobayashi and Nishida 1998; Tanimoto and Um 1999; Nishida and Kobayashi 1999; Ekström, 2001).

Among other observations Zürn and Widmer (1996) mention a harmonic signal with 3.68 mHz five days before the Pinatubo eruption. This will be described in more detail in the following.

2 Observations

On June 10, 1991 between 15:30 and 17:45 UTC a phase-coherent oscillation with a double amplitude of 40 nanogals was observed in the record of the LaCoste-Romberg Earth Tide gravimeter (ET-19, Richter et al. 1995) at BFO (Fig. 1).

The double amplitude of the Pinatubo Rayleigh waves at BFO was estimated to be about 500 nanogals, the incessantly excited modes have amplitudes of at most 1 nanogal. A magnitude 6.5 earthquake on the Northern Midatlantic ridge constrains the analysis at the end of the time window, but from the BFO record it appears as if the harmonic signal dies out shortly before the first arrivals from this event. Spectral analysis showed, that the frequency of this oscillation was 3.68 mHz (Fig. 2).

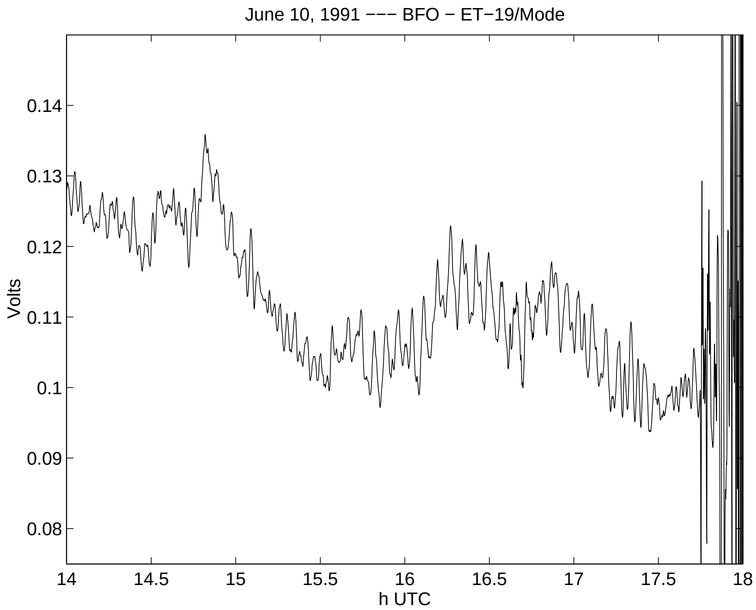

Figure 1: Record from mode-channel of the LaCoste-Romberg gravimeter ET-19 at BFO from 14:00 to 18:00 on June 10, 1991 (UTC). Note the oscillation between 15:30 and 17:30 which has a double amplitude of 40 nanogals. After 17:30 the waves from an earthquake on the Northern Midatlantic ridge arrive at BFO.

Subsequently records from seismic stations around the world were inspected for similar oscillations but signals could only be detected clearly in the records of vertical component STS-1 seismometers at ECH and SSB (GEOSCOPE) and at BNI (MedNet) in the same time period. Stations BFO, ECH and SSB are located on one side (northern and western) of the Alps, BNI lies centrally in the western Alps (Fig. 3).

While at SSB and ECH the oscillation was also phase-coherent, this was not the case at BNI, where a phase jump of $\pi/2$ occurred in the middle of the record. This is the reason for the deformed spectral peak for this record (Fig. 4).

All other instruments at BFO (STS-1 prototypes, strain- and tiltmeters) did not show this signal clearly above the noise. Since the 3.68 mHz pointed to an atmospheric connection, we also inspected barograms and magnetograms from several German and French stations but without success. Unfortunately a barometer record from SSB was not available for this time period.

3 Search for a possible source

Of course, our first suspects were the then active volcanoes Mount Pinatubo (Philippines) and Mount Unzen (Japan). However, no especially violent eruptions occurred on that day at either of these two and if one of them had been the source of these waves the rather quiet stations in Japan and China should have shown the oscillations very clearly, which is not the case. Although several volcanoes were active at the time, we were not able to identify an unusually violent phase at any of them. Note that a few

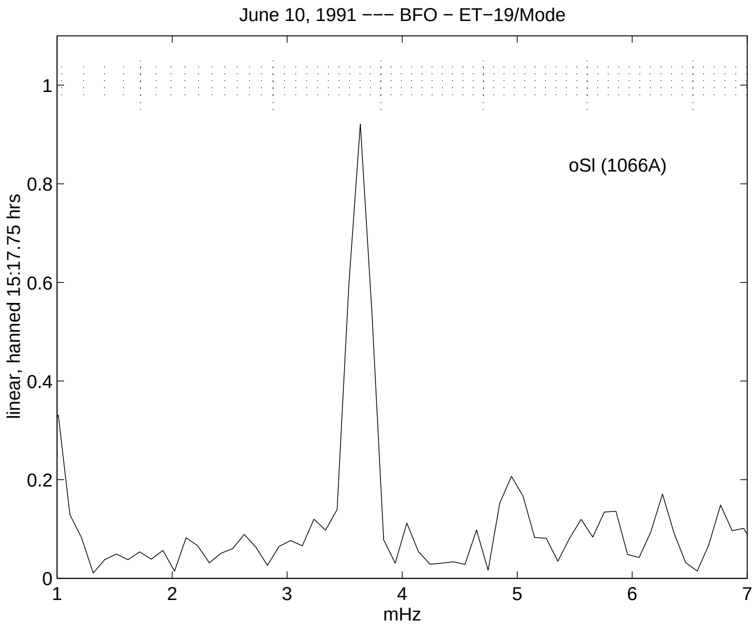

Figure 2: Spectrum of the part of record shown in Fig. 1 between 15:00 and 17:45 after application of a hanning window and padding with zeros. Theoretical frequencies of the fundamental spheroidal modes for 1066A are indicated at the top (longer lines belong to ${}_oS_{10}$, ${}_oS_{20}$ and so forth to ${}_oS_{60}$). The peak aligns well with ${}_oS_{28}$. Raw seismograms were used here.

violent eruptions at other times were checked for Pinatubo/El Chichón type signals as described in Zürn and Widmer (1996) but without success, while Kanamori et al. (1994) found a signal from Mount St. Helens in the nearfield of the volcano.

Since huge thunderstorms also produced oscillations with this frequency in the ionosphere (Georges, 1973) we had to look also for sources in the atmosphere. We tried to obtain information about unusual meteorological phenomena in Central Europe by phone calls and letters to meteorologists and atmospheric physicists at the universities of Karlsruhe, Frankfurt and Zrich, without finding anything unusual. According to meteorologists in Karlsruhe (Hoeschele, pers. comm.) there were a few thermal thunderstorms in the general area of the 4 stations, but none of them was especially powerful. Studies of weather maps also did not reveal anything special on this day.

We obtained satellite photos of Central Europe from EUMETEOSAT in the spectral bands 0.5 - 0.9 μm (visible spectra, VIS), 5.7 - 7.1 μm (water vapor, WV) and 10.5 - 12.5 μm (infrared, IR). The photos were taken every half hour. In the WV band (only) an interesting very weak plane-wave like feature with a wavelength of 94 km could be identified. The crests of these waves were oriented in EW direction and were about 300 km long, while the NS extent was about 1000 km. The center of the field lies between Paris and Strasbourg, i. e. west of station ECH. The possibility exists, that this is an acoustic-gravity wave with a horizontal wavelength of 94 km and a frequency of 3.7 mHz, but then why does it not show up on the high resolution

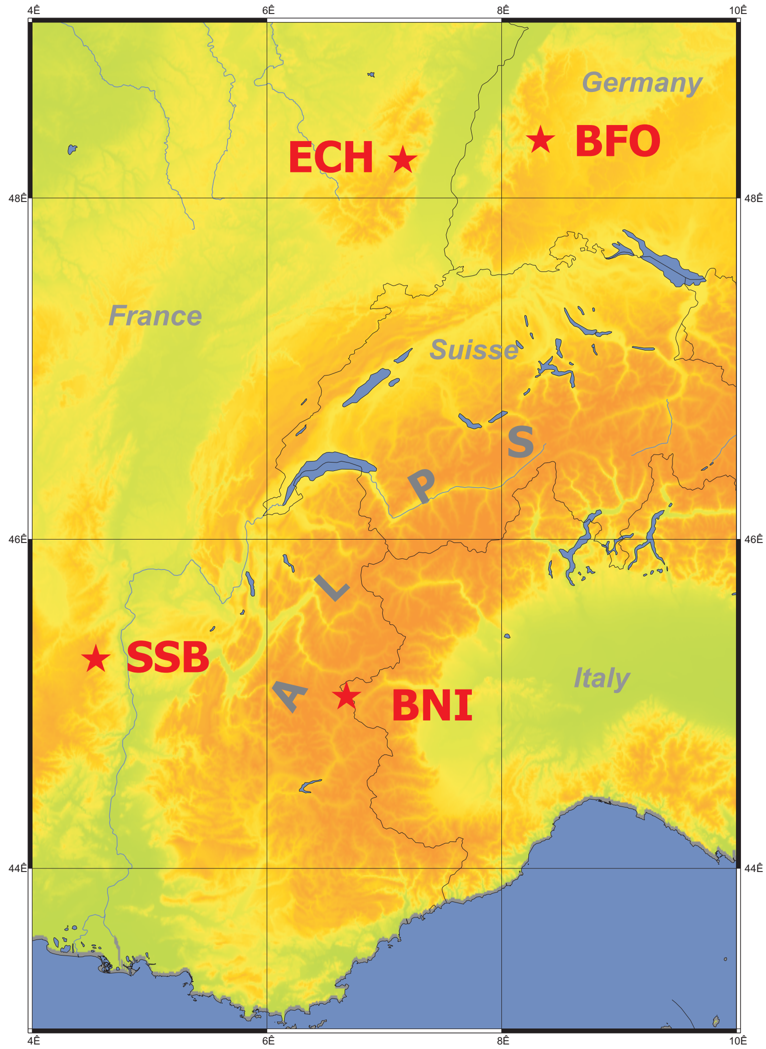

Figure 3: Map showing the locations of the 4 stations.

barograms of Strasbourg and BFO? For an isothermal atmosphere with a scale height of 9000 m the vertical wavenumber would be imaginary for these parameters, but an isothermal atmosphere is a poor approximation to the real one. Another question then would be why the frequency of this wave is a identical to the eigenfrequency of a vertical mode of the atmosphere while it is propagating horizontally. The feature in the satellite photos is so weak, that a propagation of the feature with time could not be determined. We have not yet ruled out the possibility that this feature is an artifact in the satellite pictures.

Lognonné (pers. comm. 1998) suggested a meteorite impact on the earth's atmosphere could have excited this mode of the atmosphere just like Shoemaker-Levy did on Jupiter in 1994, since the signal was observed during a summer afternoon in Central Europe nothing is known about such an event.

The atmospheric Lamb waves from Krakatoa, Mount St. Helens, the 1908 Tunguska event and atmospheric nuclear explosions were dispersed wave trains, not monochro-

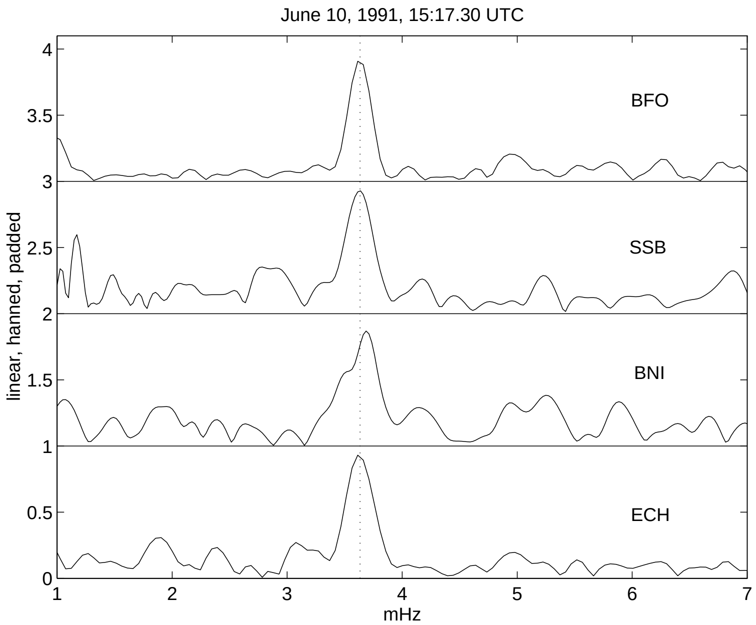

Figure 4: Spectra of the seismograms (15:00 - 17:30) of the 4 European stations. Note the deformation of the peak for BNI. Using a boxcar window results in a double peak for this station.

matic oscillations for nearly two hours. Just like in the cases of Mount Pinatubo and El Chichón the source was most likely an oscillatory one. We inspected the records from the BFO gravimeter for the years 1976 through 2001 for similar (or larger) harmonic signals without success outside of earthquakes and the volcanoes mentioned.

The only evidence pointing to a source in the atmosphere is the special frequency, nothing else. On the other hand, the frequency belongs to the fundamental spheroidal mode ${}_oS_{28}$ of the solid earth. Impulsive sources (e. g. earthquakes, including slow and silent ones) have a broad spectrum and cannot excite monochromatic oscillations. However, could this be a special (extremely strong) case of the "hum", once in 25 years? On the other hand, could signals like this (whatever the source) contaminate the hum studies and produce statistically the higher amplitude at this frequency?

4 Global signal after all ???

In desperation we looked at the seismograms of the Global Seismic Networks again after 10 years. IRIS and GEOSCOPE data of vertical component STS-1 seismometers were retrieved from the data center and hanned spectra were computed for overlapping 3 hour windows and inspected for energy at 3.7 mHz. We did not find conspicuous peaks in the majority of them. However, there were peaks in the spectra for stations RPN (Easter Island) and ESK (Scotland) but with smaller signal-to-noise ratios (SNR) than for the Central European stations. Then we inspected these time series again between 14:30 and 17:30 UTC and selected the 20 most quiet seismograms and separated those into two groups by quality. The 10 best were ANMO, CAN, COR, ESK, GSC, INU, PAS, SBC, SUR and TAM, the nine of slightly lesser quality were ERM, HRV, HYB, ISA, KIP, MAJO, RPN and WFM. The raw time series were divided by the magnitude of the transfer-function at 3.7 mHz to get true acceleration spectra in the vicinity of our signal. Then the spectra were multiplied and the product spectrum showed an extremely clear peak at 3.68 mHz. In several steps we then removed the stations which appeared to reduce the SNR when included in the product and retained only the 10 "best": ANMO, COR, ESK, KIP, MAJO, PAS, RPN, SBC, SUR and WFM. This product spectrum is shown in Fig. 5. The only individual spectrum of the 10 showing a clear peak is from RPN, shown in Fig. 6.

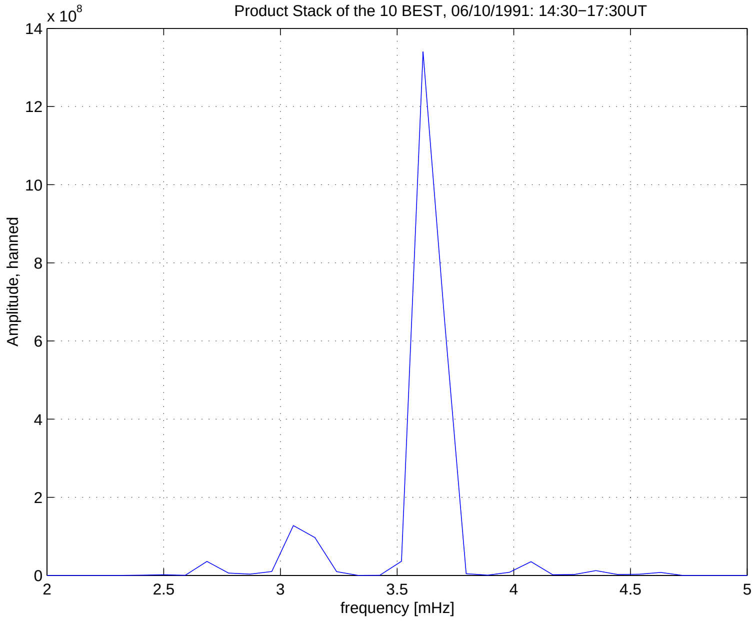

Figure 5: Product spectrum of the 10 quietest stations found for this time interval. These stations are: ANMO, COR, ESK, KIP, MAJO, PAS, RPN, SBC, SUR and WFM. Note that none of the spectra shown in Fig. 3 was used.

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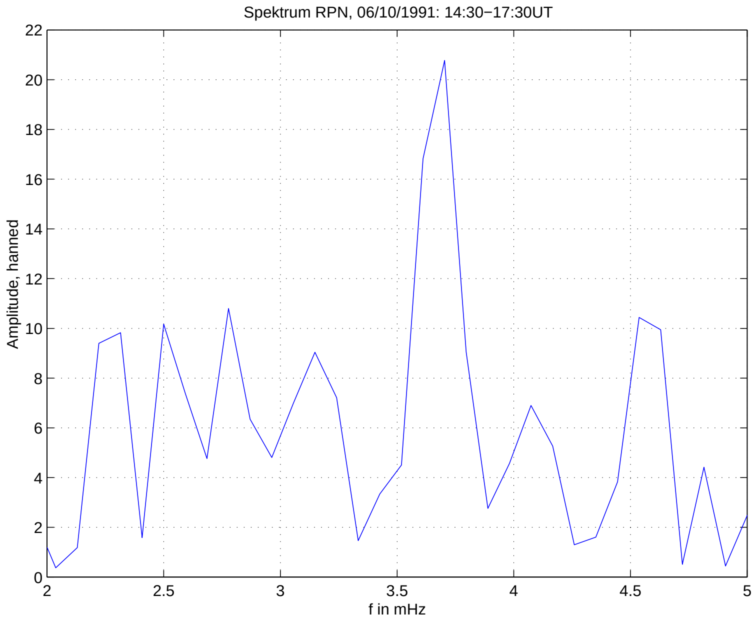

Figure 6: Spectrum of the seismogram (14:30 - 17:30) from RPN. Note that SNR is inferior to the ones in Fig. 4.

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