Acta Geodyn. Geomater., Vol. 3, No. 3 (143), 69-77, 2006

# IMPACT OF SUMATRA 2004 EARTHQUAKE ON GEODYNAMIC STATION GOPE (CZECH REPUBLIC)

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(*Received* January 2006*, accepted* April 2006)

**ABSTRACT**

The aim of this contribution is a detection of geodynamic effects at a very distant geodynamic station GOPE in the middle of Europe (Czech Republic). Strong earthquake, followed by strong indirect effect (tsunami), with the parameters (26.12.2004, 00:58:53.4 UTC, mag. 9.0, latitude 3.295N, longitude 95.982E, depth 30 km) was analysed from the records of tidal gravimeter (ASK No.228) with respect to free oscillations of the Earth (spheroidal component), by spectral analysis. This analysis detected significant vertical component of GOPE position in relatively long time interval (several hours) after the beginning of the earthquake. To verify the geodynamic tendencies of the GOPE station movements the GPS observations were analysed at the same time interval. We had data with 1s sampling interval at our disposal. For analysis we used PPP (Precise Point Positioning) method which produces absolute values of the coordinates in the ITRF 2000 system. Possible correlations between the results of both ways have been searched. We concentrated consequently to the determination of mean displacements and on the attempt of detection of some amplitudes of following free oscillations of the Earth. Mean change of position of the station GOPE during and after the earthquake, detected from the results of GPS observations is about 1.5 cm in horizontal and height components. Amplitude magnitudes for frequencies of the free oscillations of the Earth, which were analysed either from gravimetric data or from the GPS data, are equal in order. The study of free oscillations of the Earth by application of GPS is completely new. Studying of free oscillations is usualy accomplished by data from seismometers, tiltmeters or superconducting gravimeters.

**KEYWORDS:** free oscillations, tidal gravimeter, GPS, PPP - Precise Point Positioning, spectral analysis

## 1. GRAVIMETRIC DATA

Strong earthquake can cause oscillations of the elastic Earth of global extent. These oscillations are called free oscillations of the Earth. Frequencies of the free oscillations depend on density distribution and elastic parameters of the Earth's body. Free oscillations cause the changes of the Earth's figure and consequently the changes of gravity acceleration and they can be monitored either by seismographs or by tidal gravimeters. We used for monitoring of this phenomenon the records of the tidal gravimeter ASK 228 - see Fig. 2a, which was installed on the Geodetic Observatory Pecný GOPE (Czech Republic, 49.90N, 14.78E) - see Fig. 1b - for permanent tidal observations since 1975 (archived are 5s and 1min averages, RMS of 1 hour records is 1 $nm^{-2}$). Records of gravimetric observations were reduced by synthetic (theoretical) Earth tides and by anomal influence of atmospheric masses. Method of FFT (Fast Fourier Transform) was used for analysing the free oscillations of the Earth. The beginning of the analysed data was chosen at 0.21 days after coming the earthquake signal to the station GOPE; it means after 01:10:00 UTC (26.12.2004), with aim to eliminate random noise of earthquake signal after the time of arrival of the event. For the method FFT no windowing was used. Different range of data was analysed, first of all the time intervals 0.21–3.05 and 0.21–5.90 days after the coming of the event. Spectrum of frequencies was perfectly distinguishable

(0.004 mHz resp. 0.002 mHz). Positions of frequency peaks perfectly correspond to the free oscillation peaks from model PREM, but this is not the main topic of this contribution. As an evidence of the vertical changes in the position of station GOPE and for the determination of their amplitudes and damping shorter time intervals were used (mainly time interval 0.21-0.92 days after the coming of the event) - see Fig. 5.

## 2. GPS DATA

The GPS station GOPE (Czech Republic, 49.91N, 14.78E) was incorporated to the international service of permanent stations (IGS) since 1992 (http://igscb.jpl.nasa.gov/network/site/gope.html). Station gives different kinds of data for IGS, EUREF-EPN, project LEO and some others. LEO project = Determination of the precise orbits of "low Earth orbiting" satellites. In this project orbits of LEO satellites are determined by means of "kinematic GPS technology". Satellites have on board GPS "black jack" receiver. Precise position of satellite is determined by postprocessing method using GPS simultaneously observed data from satellite and surface stations. For our purposes the data of project LEO were important, where 1s data from observations on GPS-NAVSTAR satellites are distributed at 15 min intervals to data center. For checking of interpretation of results was also analysed the data from station POTS (Potsdam, Germany), which is also the station of the LEO project with 1s data. To determine absolute variations of the station space position during and after seismic event the method PPP (Precise Point Positioning) was used, which was developed at Geodetic Survey Division, NRCan in Ottawa, Canada (http://www.geod.nrcan.gc.ca/index_e/products_e/services_e/ppp_e.html). Problems of the analyses were, however,with unknown parameters of satellite clocks at 1s intervals, because there are no precise satellite clocks given in 1s in the world. We had only 30s intervals given to IGS by analysing center JPL, in which some other unconsistencies were, which led to systematic influences at resulting positions. These circumstances had us to use 5 min intervals for processing, like in ITRF2000 system, variant ITRF00b, using final GPS satellites orbits and satellite clocks at 5 min interval for IGS solutions. NRcan technology was used. Precise orbits and corrections of satellite clocks were obtained from final solution of the IGS at 5 minute intervals. It would be optimum to use 1s solution - but it would be necessary to monitor corrections of satellite clocks at shorter intervals and to use interpolation. Corrections of clocks at 30s intervals are published by JPL (Jet Propulsion Laboratory) but there is conflict with IGS orbits due to different approach to introduction of corrections from excentricity of phase centers of antennas on satellites between JPL and IGS. This conflict is so decisive that only IGS solution at 5 minute intervals could be used. Inner accuracy of the results is characterized by formal standard deviation in the directions NLAT/NLON/NHGT : 1/1/2 cm. Resulting positions and corresponding records of gravimeter are at Fig. 4 and Fig. 7. Results of the position determination for 1s intervals (with interpolated clock data from JPL) for stations GOPE and POTS (seismic signal coming 5s later than to GOPE) are shown in Figs. 6a,b,c. Computations were carried out for the time interval of seismic event course only, but for that interval 1s GPS data and also the records of gravimeter are insufficient. Computed correlation coefficient is in Fig. 8. Differences between 5 min data of GOPE and POTS stations, which should be almost zero especially at the time interval, where only free oscillations of the Earth are effective, show that real accuracy of the GPS results is about 2 times worse than their declared standard deviation. Better time interval for mutual analyses of the gravimeter records and the results of the GPS positions changes is time interval after earthquake when the free oscillations start. Spectrograph of the gravimetric records shows periodicities very similar to geophysical prediction but the results of the GPS position changes are contaminated by other systematic effects. If we admit ourselves on the 5min data only, the correlation between the amplitudes from gravimeter and the changes of vertical component from GPS is -0.14, see Fig. 9.

## 3. CONCLUSIONS

From the concept and also from the possibilities of the experiment carried out (using 5min GPS data for the analysis), it is clear that no detection of amplitude magnitudes of horizontal and vertical displacements was possible during the earthquake event. We concentrated consequently to determination of mean displacements and on the attempt of detection of some amplitudes of following free oscillations of the Earth. Mean change of position of the station GOPE during and after the earthquake, detected from the results of GPS observations is about 1.5 cm in horizontal and height components.

Amplitude magnitudes for frequencies of the free oscillations of the Earth, which were analysed either from gravimetric data or from the GPS data, are equal in order. Greater equality between both groups of results is limited, unfortunately, by the accuracy of the GPS observations. So the maximum equality is at free oscillation frequency ${}_0S_9$ - see Tab. 1, which is, as it is clear from frequency spectrum for periods of free oscillations longer than 10 minutes, the most significant. The equality for other free oscillation frequencies (${}_0S_2$, ${}_0S_3$, ${}_0S_5$, ${}_0S_7$) is not good. Greater amplitudes appear for shorter periods but they are from 5min GPS data unidentifiable. Amplitude magnitudes of the free oscillations of the Earth analysed from the records of the tidal gravimeter were transformed to the metric values by simple method, using standard (normal) gravity gradient. The values of amplitudes are generated by Fast Fourier Transform

**Table 1** Summary of the results from GPS and their comparison with some results from gravimetry. Amplitude magnitudes for frequencies of the free oscillations of the Earth, which were analysed either from gravimetric data or from the GPS data, are equal in order. The maximum equality is at free oscillation frequency $_0S_9$, which is, as it is clear from frequency spectrum for periods of free oscillations longer than 10 minutes, the most significant. The equality for other free oscillation frequencies ($_0S_2$, $_0S_3$, $_0S_5$, $_0S_7$) is not good. "Mean relative shift" is shift of station during time interval when earthquake exists. After earthquake the station "goes back" to initial position. This shift was computed as subproduct of spectral analysis software.

| | GPS | | | Gravimeter |
|---|---|---|---|---|
| | DHGT | | | |
| mode | Period of free oscillations (days) | Amplitude (m) | sd (m) | Amplitude (m) |
| $_0S_2$ | 0.03742 | 0.003 | 0.007 | 0.0004 |
| $_0S_3$ | 0.02470 | 0.008 | 0.007 | 0.0005 |
| $_0S_5$ | 0.01378 | 0.007 | 0.007 | 0.0012 |
| $_0S_7$ | 0.00940 | 0.016 | 0.007 | 0.0012 |
| $_0S_9$ | 0.00733 | 0.005 | 0.007 | 0.0033 |
| | Further (parazite) periods | | | |
| | 0.22993 | 0.011 | 0.007 | |
| | 0.09072 | 0.006 | 0.007 | |

| | DLAT | | |
|---|---|---|---|
| mode | Period of free oscillations (days) | Amplitude (m) | sd (m) |
| $_0S_2$ | 0.03742 | 0.015 | 0.004 |
| $_0S_3$ | 0.02470 | 0.014 | 0.004 |
| $_0S_5$ | 0.01378 | 0.009 | 0.004 |
| $_0S_7$ | 0.00940 | 0.016 | 0.004 |
| $_0S_9$ | 0.00733 | 0.005 | 0.004 |

| | DLON | | |
|---|---|---|---|
| mode | Period of free oscillations (days) | Amplitude (m) | sd (m) |
| $_0S_2$ | 0.03742 | 0.015 | 0.004 |
| $_0S_3$ | 0.02470 | 0.014 | 0.004 |
| $_0S_5$ | 0.01378 | 0.009 | 0.004 |
| $_0S_7$ | 0.00940 | 0.017 | 0.004 |
| $_0S_9$ | 0.00733 | 0.004 | 0.004 |

| Mean relative shift during and after earthquake for GOPE detected from GPS | | |
|---|---|---|
| DLAT | DLON | DHGT |
| 0.013 (± 0.002) | 0.008 (± 0.002) | -0.018 (± 0.002) |

from whole analysed time interval, so the amplitudes don't represent its maximum values at the start of time interval.

Discusion and comparison with other corresponding studies is not possible from reason of novelty of this topic.

**ACKNOWLEDGMENT**

Authors are gratefully appreciated to Ministry of Education, Youth and Sport of the Czech Republic for support of this work in the frame of projects LC506 "Recent Dynamics of the Earth".

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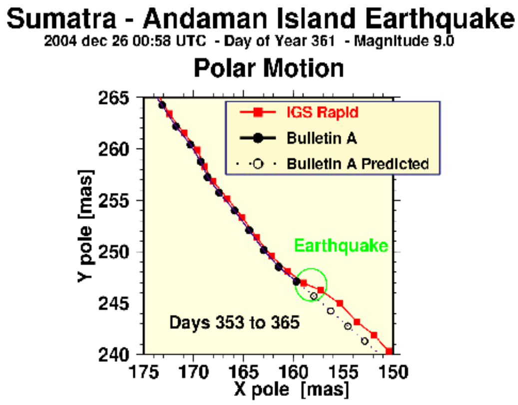
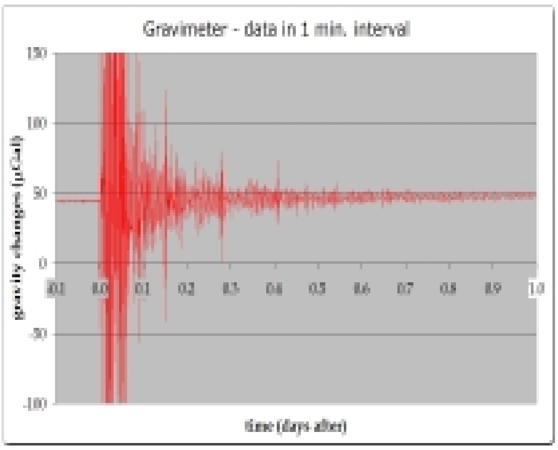



Fig. 1a Influence of the earthquake on the polar motion (G. Gendt, GFZ, 2005)


Fig. 1b Localization of the geodynamic station GOPE in the territory of the Czech Republic

Fig. 2a GOPE - tidal gravimeter ASK 228 (right side)

Fig. 2b GOPE - GPS station (ASHTECH Z-18)



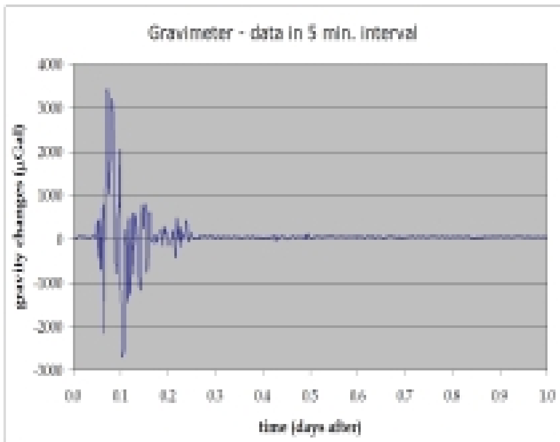




**Fig. 3** 1 minute averages from the record of gravimeter ASK 228. There is very well visible periodical growing of signal dispersion, which indicate periodical passing of surface waves

**Fig. 4** 5 minute samples from the record of gravimeter ASK 228 used for computation of correlations between gravity and GPS measurements

**a**

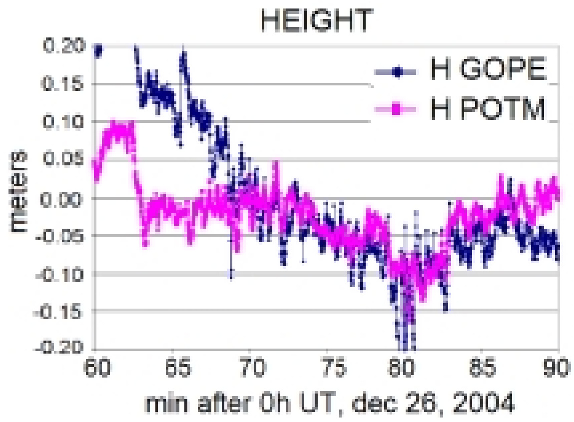
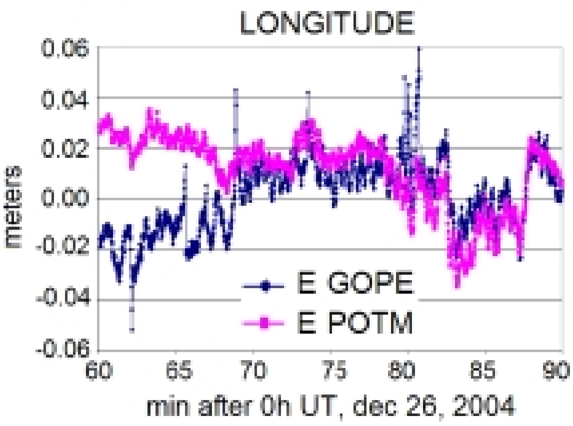



**Fig. 6a** Results of height component computation from GPS in 1s interval for station GOPE and station POTS (GER) in time interval of the earthquake

**b**




**c**

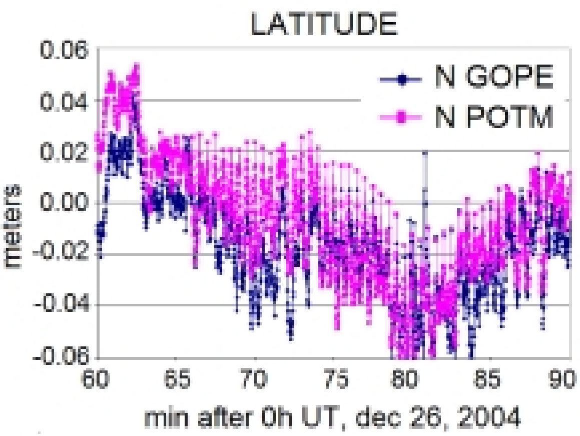



**Fig. 6b,c** Results of horizontal position computation from GPS in 1s interval for station GOPE and station POTS (GER) in time interval of the earthquake.

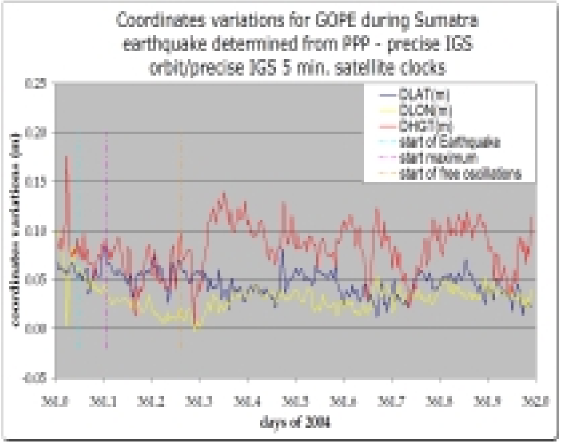



**Fig. 7** Coordinates variations for GOPE station from GPS Precise Point Positioning (5 min. interval).

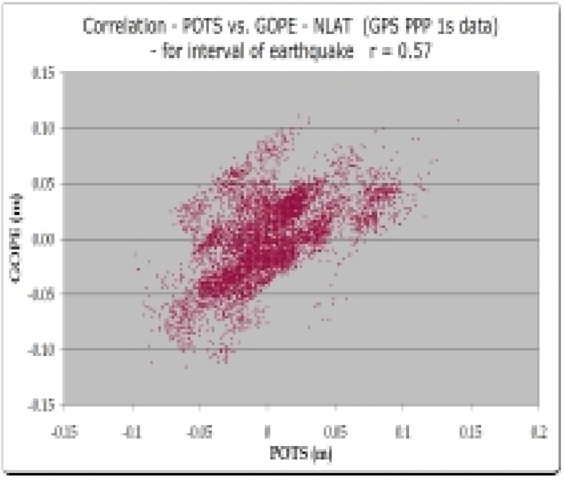



**Fig. 8** Correlation between coordinate changes (latitude) POTS vs. GOPE for time interval of earthquake from GPS Precise Point Positioning 1s data.

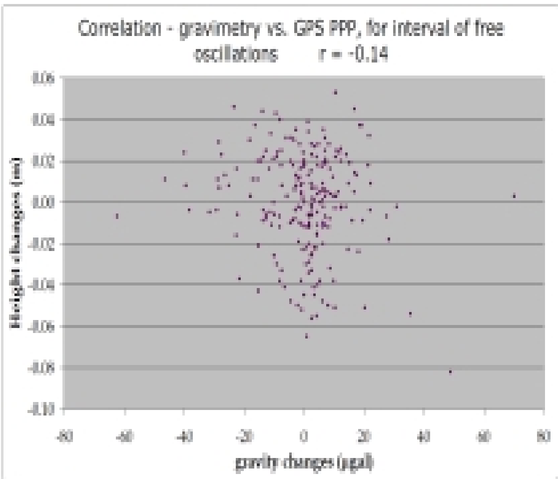



**Fig. 9** Correlation between gravimetry and GPS PPP in time interval of free oscillations (both from 5 min data).

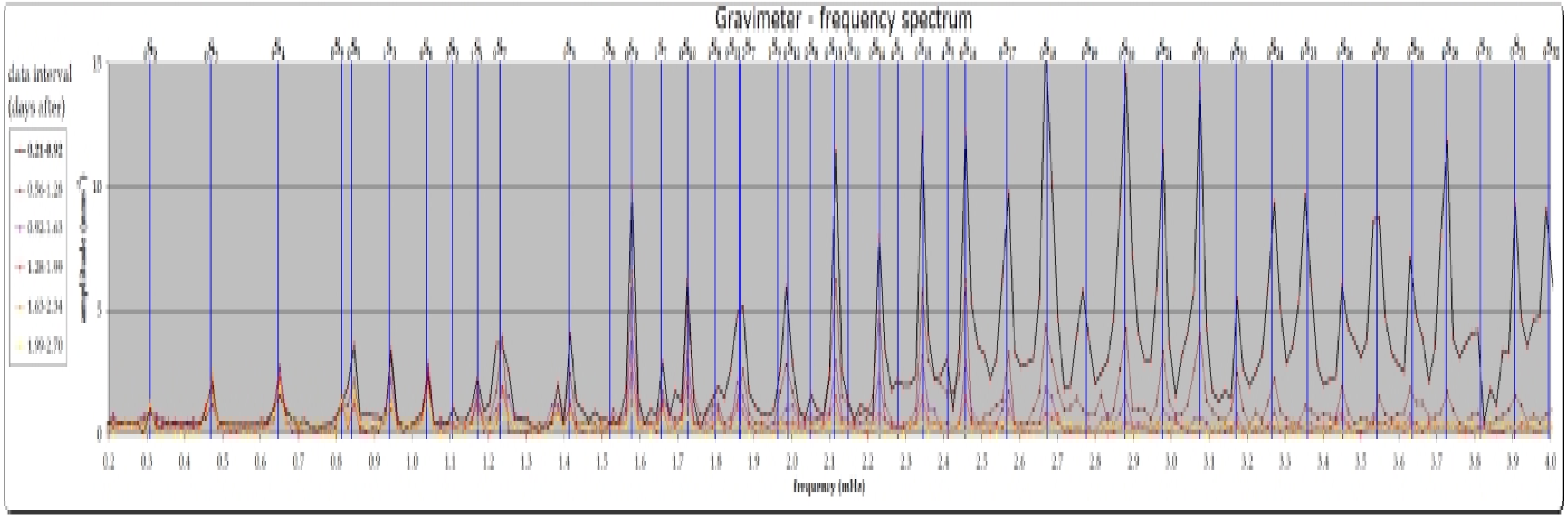



**Fig. 5** Frequency spectrum from the record of gravimeter ASK 228 for several time intervals. Vertical blue lines represent frequency positions of the Earth's free oscillations derived from the model PREM. There is very well visible different speed of damping for high and low frequencies of free oscillations.