INVESTIGATIONS ON THE FIELD OF GRAVITY IN POLISH TIDAL LABORATORIES

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1. INTRODUCTION

Presently there are two laboratories in Poland investigating field of gravity. The Geodynamic Laboratory of Space Research Centre in Ksiaz is placed in the south-western part of Poland in horizontal galleries built in slope of the valley. In 1974 in the laboratory the measurements carried out with help of two quartz-horizontal pendulums equipped with photographic system of registration were begun. In 2002 in the laboratory the long water-tube tiltmeter was built. It is consisted of two perpendicular tubes 65- and 83-meter long, partially filled with water. In 2007 in the laboratory the relative gravimeter LaCoste&Romberg G-648 was installed. The Gravimetric Laboratory of Astro-Geodetic Observatory in Józefosław is placed in central part of Poland. It has been investigated tidal gravity changes since 1993 using first LC&R model G gravimeter, then D-model. Since 2001 laboratory is equipped with LC&R ET-26 meter. In 2005 the laboratory was equipped with FG5-230 gravimeter for monitoring of the absolute gravity variations. The paper presents current state-of-art of the researches aimed at investigation on field of gravity carried out by Polish scientific institutions.

2. ASTRO-GEODETIC OBSERVATORY IN JOZEFOSLAW

2.1. Absolute gravity determinations

Since June 2005 Warsaw University of Technology has possessed the FG5-230 absolute gravimeter, which gave an occasion for performing researches related to:

- scientific studies of long-term gravity changes (Astro-Geodetic Observatory in Jozefoslaw);
- investigations of non-tidal variations at main tectonic units on the territory of Poland;
- unification of gravimetric reference system for Polish GNSS stations and geodynamical test fields;
- modernisation of Polish national „zero order" gravity network;
- modernisation of the gravimetric calibration baselines in Poland.

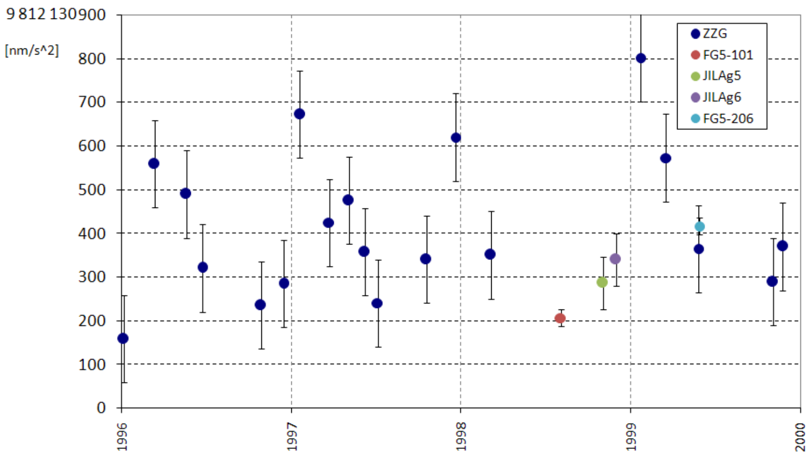

Fig. 1. Gravity absolute determinations made till 2000.

Till 2000 monitoring of gravity changes in Jozefoslaw was performed using ZZG apparatus, occasionally controlled by the foreign researches mainly from Germany and Finland with help of FG5 or JILAg instruments (Fig. 1).

Since June 2005 the measurements using FG5 have been carried out. The observations, made once a month, could answer several questions concerning the long-term stability of the gravity in Jozefoslaw (Fig. 2).

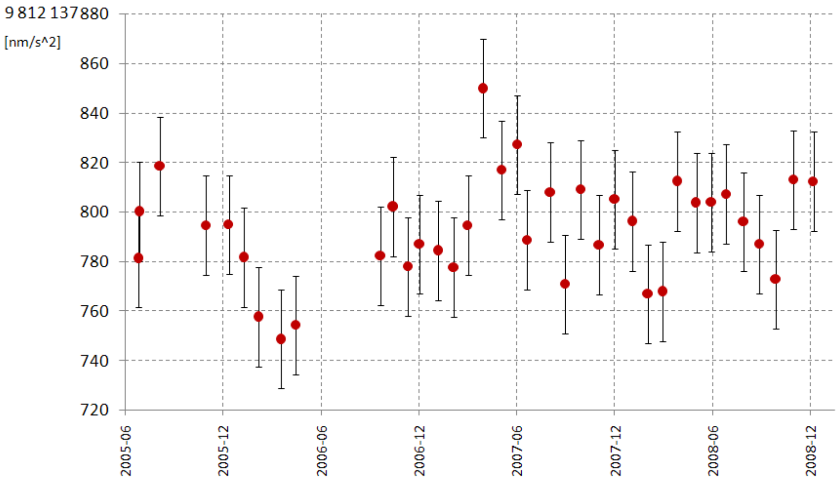

Fig. 2. Absolute gravity determinations made from 2005.

Next project which utilises AG measurements is the monitoring of the non-tidal variations at main tectonic units. Five sites on different cratons were chosen:

Giby, Lamkowko and Jozefoslaw (East European Craton);
Borowiec (Fore Sudetic Monocline);
Ojcow (Malopolska Massif);

The gravity on theses stations were measured in 2006, 2007 and 2008 and compared to the determinations made in 90’s. From Table 1 we can notice the slight decreasing of gravity which is rather strange, because from satellite gravimetric missions such as CHAMP or GRACE we know that the gravity increases with time, mainly due to the global water storage.

Table. 1. Differences of gravity on main Polish tectonic units

Site	Reference epochs	Difference [nm/s^2]
Lamkowko	1996	-150
Giby	1997	-50
Borowiec	1995	-110
Ojcow	1996	-200
Józefosław	1997 - 2001	-15

The map in Fig. 3 presents the GNSS sites which operate in Polish Active Geodetic network (ASG-EUPOS) together with sites working in IGS and EPN. In order to unify the gravimetric reference frame for these stations in 2007 and 2008 special campaign was performed: 5 sites were measured (Jozefoslaw, Borowa Gora, Krakow, Lamkowko and Borowiec) together with 2 geodynamical test fields Pieniny and Sudety.

Fig. 3. Unification of gravimetric reference system for Polish GNSS stations.

Next research is related to the Polish national gravity network (Fig. 4). The project assumes establishment or modernisation of 366 stations including 16 absolute sites. Most of the absolute determinations were performed until now.

Fig. 4. Polish National Gravity Network.

Also the modernisation of the gravity calibration baselines (Fig. 5) was performed in 2007 and 2008 using FG5-230 absolute gravimeter.

Fig. 5. Modernisation of the gravimetric calibration baselines in Poland.

2.2. Tidal gravity measurements

First tidal observations in Poland using modified Ascania gravimeters were carried out in 80's (station Bartycka, numbered as 0906 in Federation of Astronomical and Geophysical Data Analysis Services – FAGS). In 1995 the tidal observations in Astro-Geodetic Observatory in Jozefoslaw using LaCoste&Romberg G-model started, presently in the Observatory ET-26 gravimeter works.

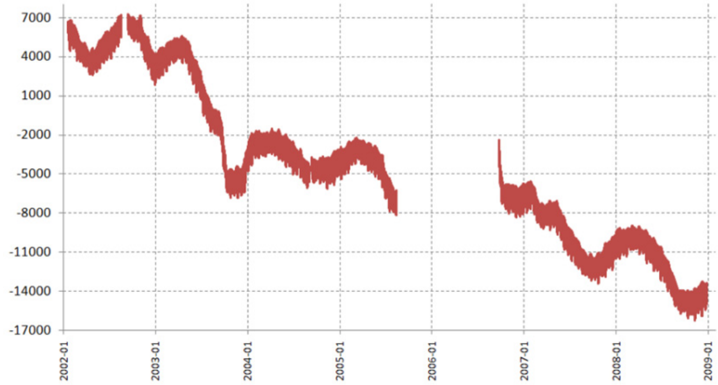

Fig. 6. ET-26 observations from 2002 to 2009 [nm/s^2].

Fig. 6 presents observations collected from 2002 till the end of 2008. From these observations tidal potential model has to be subtracted. Each tidal potential catalogue consists of two parts: astronomical tides which are precisely known from celestial mechanics and the transfer function by means of the set of parameters describing reaction of the viscous-elastic Earth on the tidal forces. By subtracting the HW95 model (Hartman and Wenzel, 1995) we obtain the curve (Fig. 7) containing this transfer function, but also instrumental drift, pillar's instability, ocean and atmosphere indirect effects, local hydrological influences and calibration uncertainties as well.

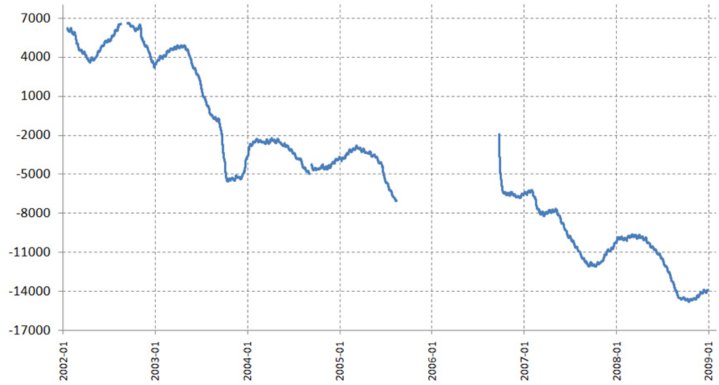

Fig. 7. Drift curve [nm/s^2].

Ocean tidal loading is quite simple for modelling, atmospheric indirect effect has to be based on observations, so the special equipment was set up by means of pressure, temperature and humidity sensors (Fig. 8). The tidal variations in rainfalls, water table and soil moisture changes are not expected to be found, but it makes sense to implement them to the data adjustment thus it improves the signal-to-noise ration and makes the determinations more reliable.

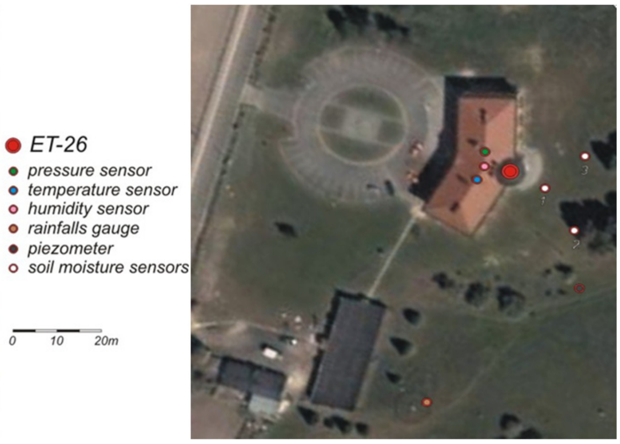

Fig. 8. Distribution of the sensors for environmental monitoring.

The results of the tidal data adjustment are the amplitude factor – the amplification of the gravity changes due to elastic response of the Earth and the phase shift – the time lag of the Earth's reaction due to its viscosity. From the described data set 31 constituents were able to be determined (Fig. 9) using Eterna 3.4 software (Wenzel, 1996).

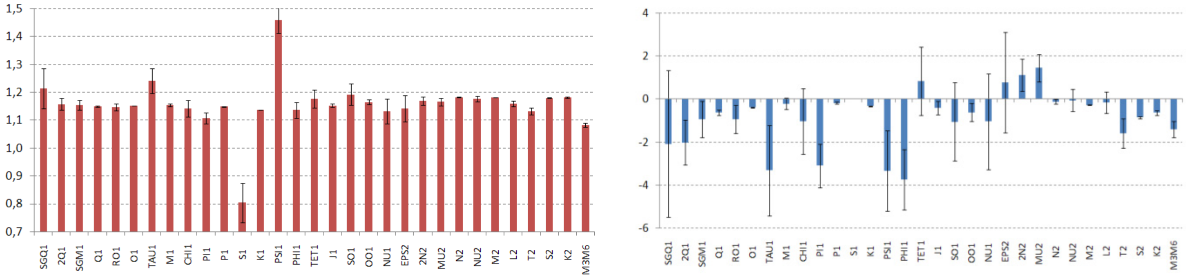

Fig. 9. Amplitude factor (left) and phase shift [°] (right).

Having AG and tidal instrument gave us the opportunity to make the calibration of the relative gravimeter. Eight independent gravity determinations from 2006 and 2007 were used. Fig. 10. presents measurements made by both instruments during two days in 24 series.

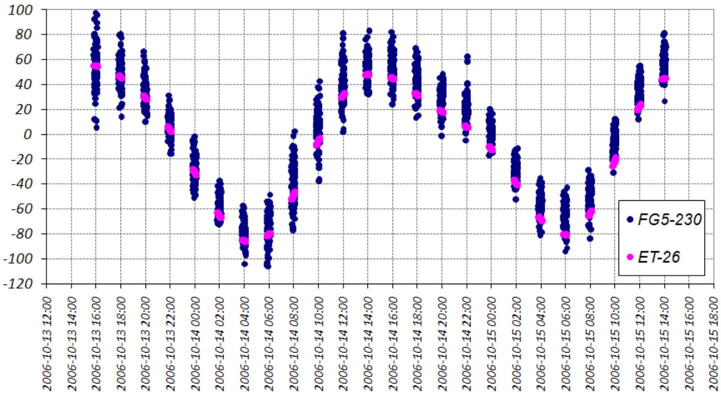

Fig. 10. Relative and absolute gravity measurements [nm/s^2].

The relation between them contains calibration factor and the shift which in this case is out of importance. Least squares method was implemented for obtaining final calibration factor which carries out 1.00059 ±0.007911.

3. GEODYNAMIC LABORATORY IN KSIAZ (GLK)

Geodynamic Laboratory in Ksiaz (GLK) is situated 51 meters below the Earth surface, in galleries built in Devonian orogen. Rocks surrounding laboratory are conglomerates consisting of metamorphic materials (gneiss). Devonian rocks are very hard, durable and do not saturate with water.

The research programme of GLK contains following topics:

- investigations of tidal phenomena:
    - determination of clinometric and gravimetric geodetic coefficients and their seasonal variability;
    - investigations of tidal indirect effects;
    - determination of Love's numbers *h* and *k* and their variability in the time;
- investigations of systematic or long period plumb line variations;
- investigations of short period (non-tidal) PLV associated with phenomena of free oscillations of the Earth body;
- comparative works between WT and HP tiltmeters;
- investigations of the influence of pressure, temperature, and humidity variations on geodynamic measurements.

Instruments presently working in GLK and their location in galleries were shown in Fig. 11.

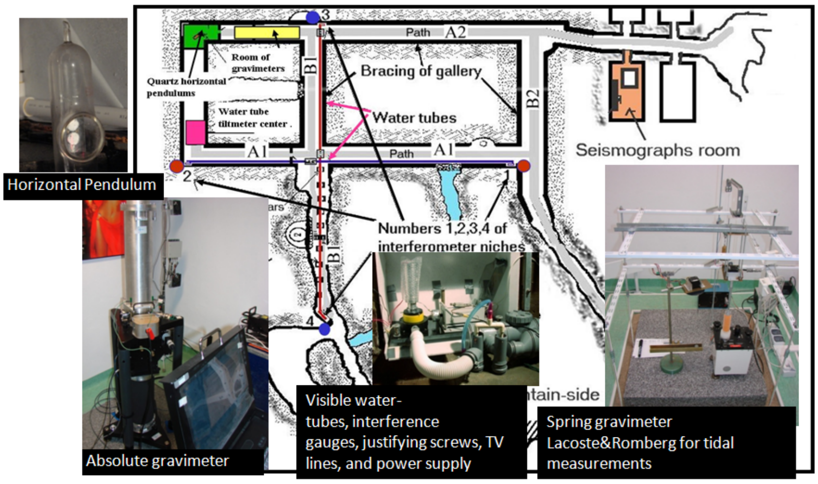

Fig. 11. Instrumentation of GLK and distribution in underground galleries.

The PLV are measured in GLK with help of horizontal pendulums (HP) and water-tube (WT) tiltmeters. The idea of measurements of WT tiltmeters bases on the principle that free surface of any fluid being in state of hydrostatic equilibrium is an equipotential surface (Kaczorowski, 2004). Precise measurements of water level variations at the ends of the tubes bring us information of variations of equipotential surface in azimuth of the tube – plumb line variations (PLV) (Kaczorowski, 2006a).

The main features of WT tiltmeters are following:

- 1 degree variation of the phase of interference image corresponds to 0.6608×10^{-9} m of water level variation;
- sensitivity of the tiltmeter in azimuth 238.6° (tube 65.2 m long) - 1 degree variation of the phase of interference image corresponds to 2.089×10^{-3} mas;
- sensitivity of the tiltmeter in azimuth 328.6° (tube 83.5 m long) - 1 degree variation of the phase of interference image corresponds to 1.632×10^{-3} mas;
- lack of instrumental drift (after differentiation signals from opposite ends of the tubes).

For each tiltmeter we have got two signals of water level variations from opposite ends of the tubes. Differentiation of signals causes double magnification of all geodynamical signal, while summation bring us signal with reduced all geodynamic signals and double magnification effects of water evaporation or vertical displacement of the tube (Fig. 12).

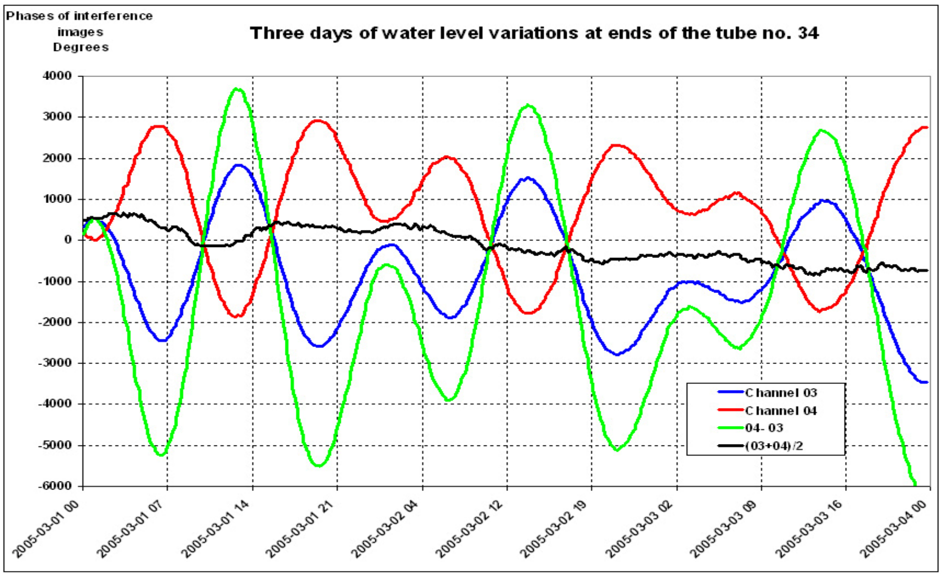

Fig. 12. Results of differentiation of signals and summation. Green plot represents geodynamic signal of tidal PLV without local or instrumental effects and black plot shows effect of water evaporation without any geodynamic signals.

Because of lack of instrumental drift WT tiltmeters are useful for investigation of the non-tidal signals (Kaczorowski, 2007, 2008). Fig. 13a shows the event from March 2005. Plots obtained from tube situated in azimuth 238.6° (left plot) show the effect of PLV registered independently by gauges on opposite ends of the tube (plots green and blue). These signals are 180^0 difference of phases. Red plot shows the result of differentiation of red and blue signals. Differentiation of signals causes double magnification of geodynamic signals (visible enlargement of tidal ondulations on red plot) and similarly reduces instrumental and local effects (yellow plot) such as water evaporation.

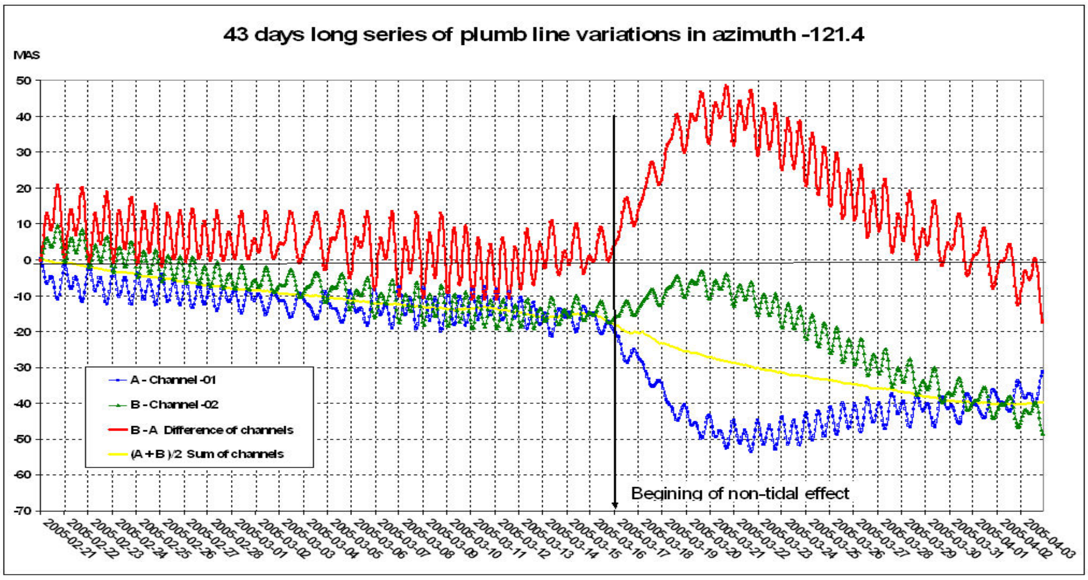

Fig.13a. 43-days long series of raw observations with distinct non-tidal trend obtained with help of long water-tube tiltmeter in azimuth 238.6°.

Similar situation was shown on Fig. 13b for tube in azimuth 328.6°.

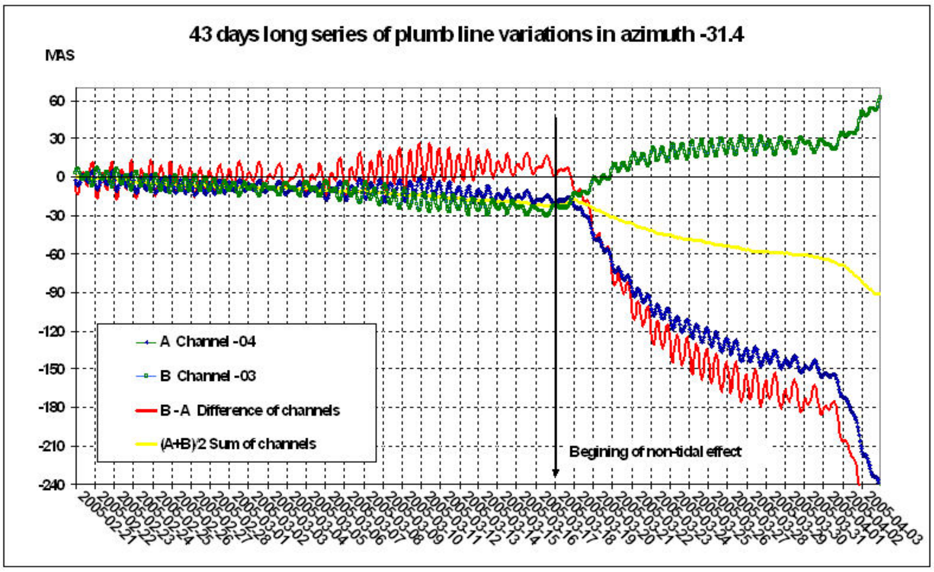

Fig. 13b. 43-days long series of raw observations with distinct non-tidal trend obtained with help of WT tiltmeter in azimuth 328.6°.

The WT is also capable of monitoring effects of PLV associated with free oscillations of the Earth body produced by strong earthquakes (Kaczorowski, 2006b). This peculiarity of WT results from proper application of dumping system, high sensitivity of WT measurements as well as from unlimited range of measurements. In Fig. 14. the PLV observed in GLK after extremely strong earthquake in 26 December 2004 is shown (Sumatra–Andaman). Red colour circle marks beginning of the day. The effect of aftershock is shown in small window.

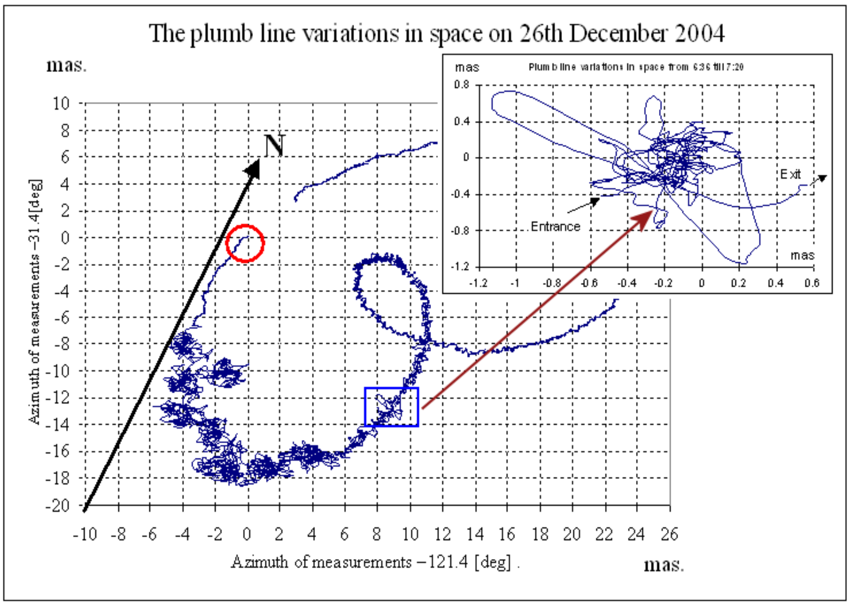

Fig. 14. Plot of PLV in space after Sumatra-Andaman earthquake in 26 December 2004 registered by WT in Ksiaz.

Spectral analysis of the time series of PLV obtained with help of the WT in 26 December 2004 showed existence of fundamental modes (n=0) in the Earth free oscillations. Amplitudes of these modes varied in time and did not exceed 0.4 mas (Fig.15). In the figure spheroidal ${}_0\mathbf{S}_2$ and ${}_0\mathbf{S}_3$ and toroidal ${}_0\mathbf{T}_2$ vibrations of free oscillations are shown.

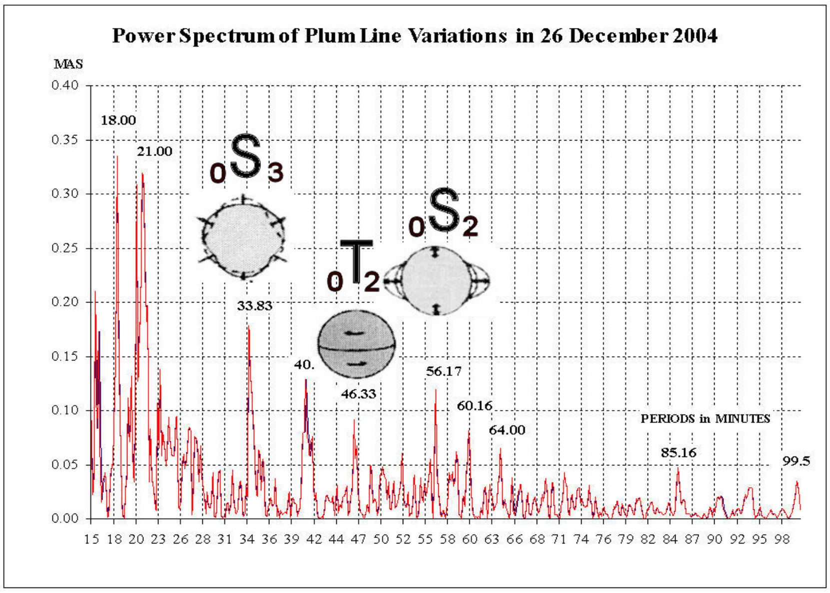

Fig. 15. Power spectrum of plumb line variations in 26 December 2004 in azimuth 238.6°. There have been shown Spheroidal ${}_0\mathbf{S}_2$ and ${}_0\mathbf{S}_3$ and Toroidal ${}_0\mathbf{T}_2$ fundamental modes (n=0) of free oscillations. Small icons describe shape of deformations of the Earth body associated with spherical harmonics.

4. SUMMARY AND PLANS FOR THE FUTURE

- in 2010 GLK will be equipped with the interferential extensometer and GPS receiver for investigation surface determinations of the crust and self motions of the laboratory;
- international connection spans between Polish and Ukrainian, Lithuanian and Belarusian gravimetric networks will be made using FG-5 absolute gravimeter;
- successive applications for GWR superconducting gravimeter will be used in scientific program of Global Geodynamical Project.

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