NON TIDAL SIGNALS OF PLUMB LINE VARIATIONS OBSERVED WITH HELP OF THE LONG WATER-TUBE TILTMETER, IN GEODYNAMIC LABORATORY OF PAS IN KSIAZ

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Introduction

The observations of plumb lines variations are continued in Geodynamic Laboratory in Ksiaz since 1974. Up to 2002 we used a pair of quartz horizontal pendulums with photographic system of registration. In 2002 in the Geodynamic Laboratory in Ksiaz we started registration with long water-tubes tiltmeters. New tiltmeter system consists of two perpendicular tubes 65 and 83 meters long partially filled with water. The idea of measurements of the new tiltmeter is based on the principle of hydrostatic equilibrium. Luni-Solar forces as well as other large scale geodynamic phenomena generate asymmetric water level variations (increasing and decreasing) at the ends of the tubes. Water level variations are measured with the help of four interferometers installed at the ends of the tubes. Internal resolution of interference gauge is close to single nanometers of water level variation. It allows us to determine plumb line variations with internal resolution better than 10^{-2} millisecond of arc [mas] for several dozen meters long tube. High resolution of tiltmeter, lack of instrumental drift after application difference method for data reduction as well as other advantages open for us possibilities of investigations of non-tidal signals. Signals of plumb line variations consist of a periodical part of tidal origin as well as a non-periodical part or long period signals produced mainly by hydrological, meteorological, and geodynamical phenomena. Separation of tidal and non-tidal signals is relatively simple because we know exactly frequencies of tidal waves. In the case of water-tube observations we are able also to separate non-tidal signal from instrumental drift caused by effects of water evaporation and displacements of the tubes. To do that we subtract signals obtained from opposite ends of the tubes. Differentiation of signals causes double magnification of geodynamic signals as well as elimination of instrumental drift (Kaczorowski, 2006A). This circumstance helps us to investigate long-standing, non-tidal signals. With help of water-tube tiltmeter we observed five epochs of strong non-tidal signals. These phenomena took place in the autumn-winter and winter-spring transition periods as well as in the middle of summer (July 2006). Strong non-tidal signals of plumb line variations exceeded hundred of [mas]. We try to explain origin of such large effects. Specially suspected are local effects such as pressure or temperature variations in underground of laboratory.

Keywords: geodynamic, Earth tides, plumb line variations, non-tidal effects, tiltmeters.

1. **Observations of non-tidal signals with help of water tube tiltmeter**

Long standing non-tidal signals of irregular character was observed several times by quartz horizontal pendulums (Chojnicki T., Weiss J., 1981 and 1987). During thirty years of observations we irregularly observed epochs of unstable work of horizontal pendulums. Strong signals of non-tidal character occurred irregularly not only in transition periods between autumn-winter and winter-spring but also in the middle of summer or winter. Maximal values of non-tidal signal reach to hundred miliarcsecond of arc (a few tidal amplitudes of plumb line variations).

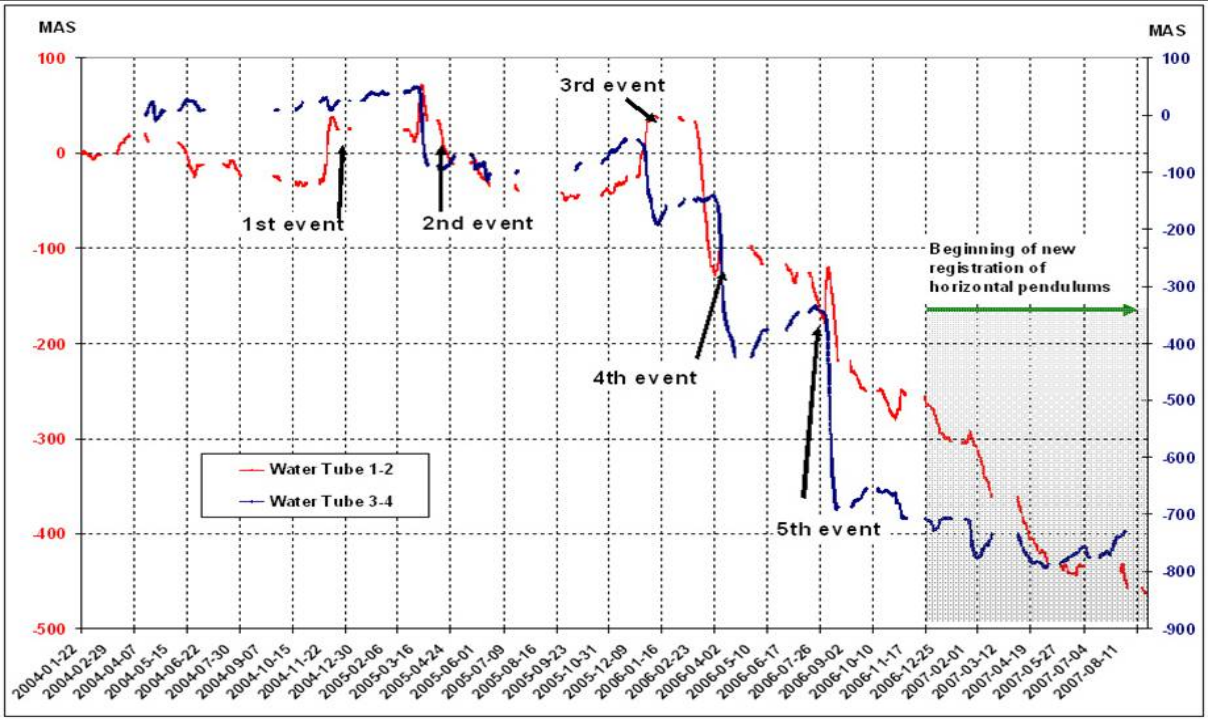

Fig.1. Non-tidal signal observed by long water-tube tiltmeter in period 2004-2007 in azimuth 58.6 [deg] (difference of signals 1-2) and in azimuth 148.6 [deg] (difference of signals 3-4)

Installation of the long water-tube tiltmeter in Ksiaz Geodynamic Laboratory opened in 2002 additional possibilities of investigating non-tidal irregular signals. Special features of new tiltmeter such as high sensitivity, possibility of elimination of instrumental drift by differential method of data reduction (Kaczorowski, 2006A) allowed us to initiate research on phenomena of strong, irregular signals of non-tidal origin. Application of differential method allowed us to eliminate from raw observations signals produced by effects of water condensation and evaporation from hydrodynamic system of tiltmeter (dotted lines on figures 2-5) as well as by displacements of the tubes (Kaczorowski, 2006A). Time series of plumb line variations were analyzed with help of program ETERNA 3.4 to eliminate tidal signals. After low pass filtration we obtained time series of non-periodical character. During years 2004-2007 we could observe five epochs of strong signals of plumb line variations (Fig.1.). These phenomena took place in the autumn-winter and winter-spring transition periods as well as in the middle of summer (July 2006). Therefore, we are able to exclude seasonal phenomena producing plumb line variations as reasons of large non-tidal signals. Very strong non-tidal signals were registered two times in 2006. Maximal signal exceeded 300 [mas]. Final azimuths of resultant plumb line variations differ less than -10 [deg] for all large events (Table 1). Directions of resultant azimuths are close to direction tectonic motions of plates observed by GPS permanent stations in Central Europe. Courses of strongest events are similar. The strongest effects occurred in azimuth close to the azimuth -31.4 of the tube named 3-4. For tube 3-4 moments of initiation of strong effects were preceded by few weeks long quiet intervals with tidal and evaporation effects only (Fig.2 and 3).

PERIODS OF STRONG SIGNALS AND DAYS OF DURATION			**AZIMUTHS AND AMPLITUDES OF PHENOMENA IN [MAS]**		**MEAN VELOCITY OF PLUMB LINE VARIATIONS [MAS]/DAY**		**RESULTANT AZIMUTH OF PLUMB LINE VARIATIONS**
From:	To:	Number of days	Tube 1-2 -121.4 ($58^0.6$)	Tube 3-4 -31.4 ($148^0.6$)	Tube 1-2	Tube 3-4	
17 November 2004	13 Decemb. 2004	26	60	No data	2.31	No data	No data
11 March 2005	28 March 2005	17	45	-140	2.64	-8.24	-13^0
16 December 2005	09 January 2006	23	56	-131	2.43	- 5.70	-8^0
24 March 2006	14 April 2006	20	-156	-290	-7.80	-14.50	-3^0
28 July 2006	18 August 2006	20	-109	-350	-5.45	-17.50	-13^0
Since September 2007 strong signals were not been registered							

Table 1. The strongest non-tidal signals determined with difference method from channels 1-2 and 3-4 (1,2,3,4 numbers of channels) in period 2004-2007.

Next, main effects with systematic trends of tilts lasting dozen or so days begin. In azimuth -121.4 of the tube 1-2 plots of tilts during strong effects show us extremes (Fig.4 and 5), effects of tilts decrease and then again increase in this azimuth. This phenomenon is well visible on plot of non-tidal signal presented in space and registered during event from July 2006 (Fig.6). For azimuth -121.4 strong effects are not preceded by long intervals with tidal and evaporation effects only. In 2006 we resumed measurements with help of horizontal pendulums equipped with new system of electronic registration. We expect that this circumstance will allow us on verification of strong non-tidal signals detected by long water-tube tiltmeter. Detection of correlation between both tiltmeters should confirm additionally the thesis that observed large signals are geodynamic, not instrumental origin. In the case of positive verification we will study thirty year long series of pendulums observations to investigate strong non-tidal signals.

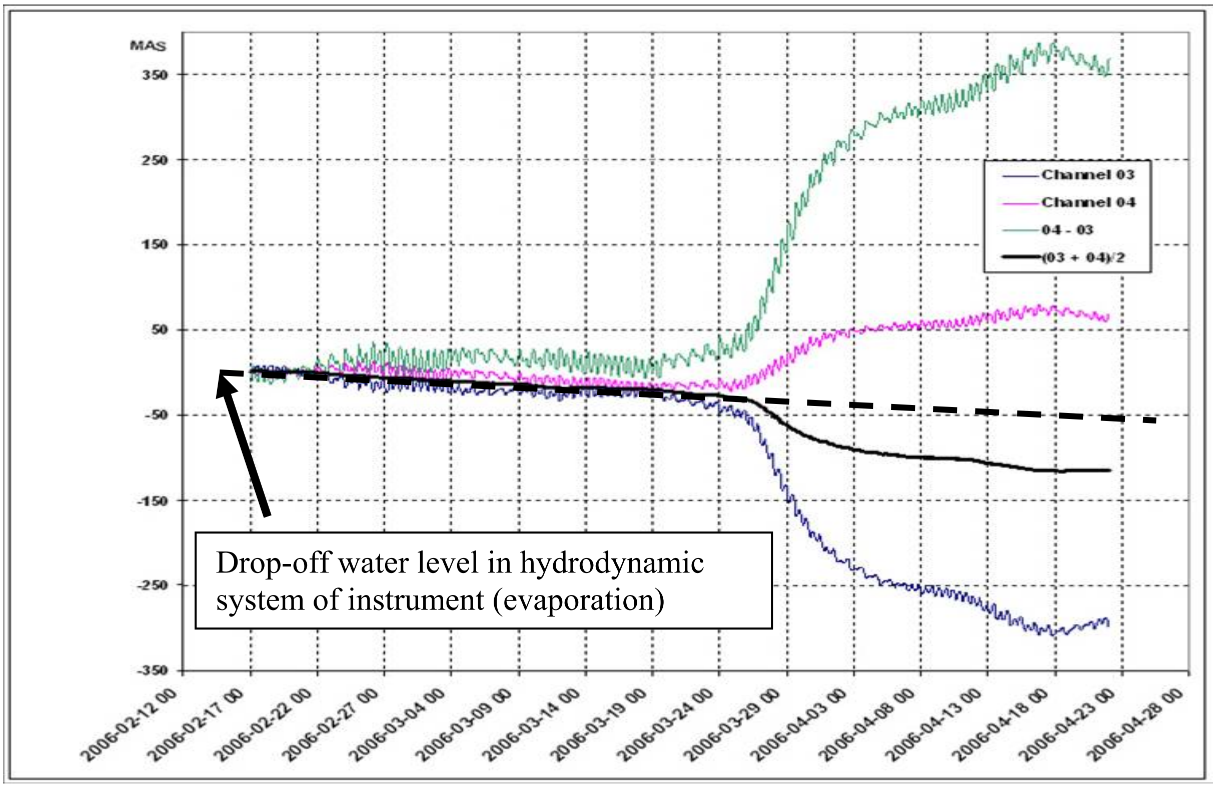

Fig.2. Raw signals (tidal and non-tidal) observed by tube 03-04 in March 2006 (event 4th)

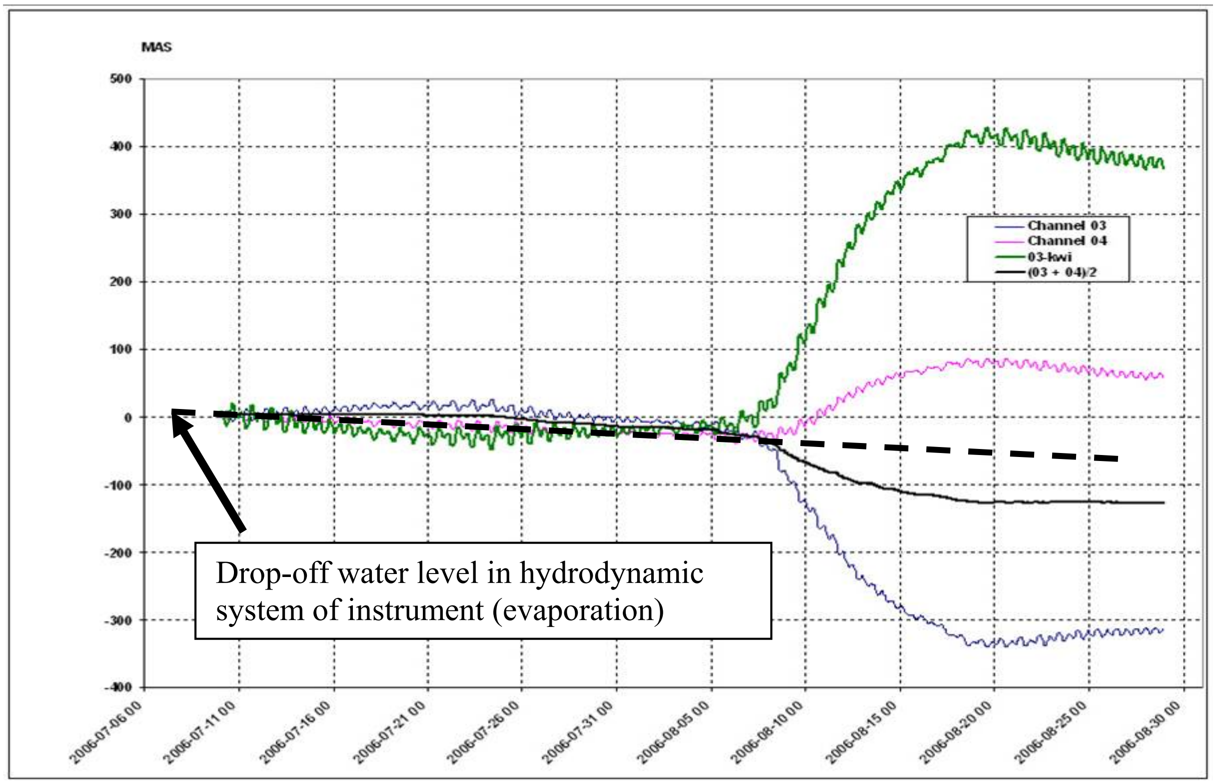

Fig.3. Raw signals (tidal and non-tidal) observed by tube 03-04 in July 2006 (event 5th)

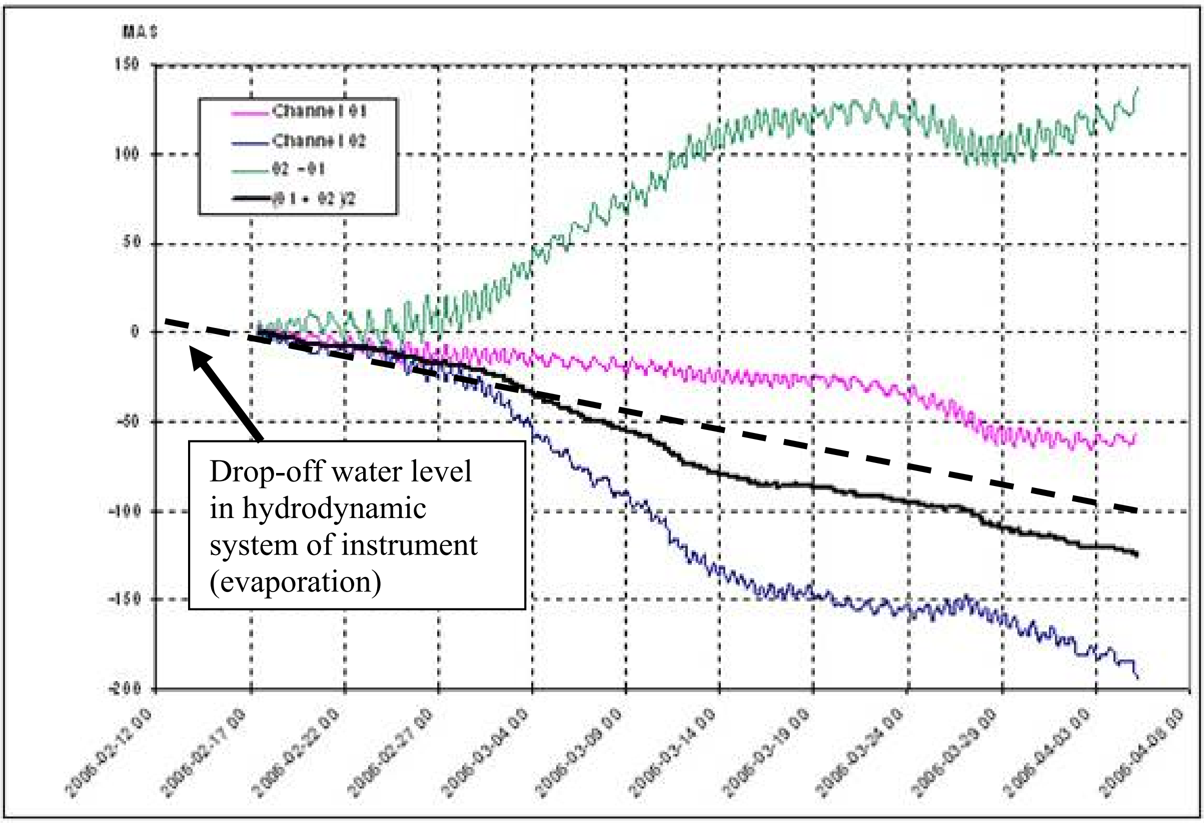

Fig.4. Raw signals (tidal and non-tidal) observed by tube 01-02 in March 2006 (event 4th)

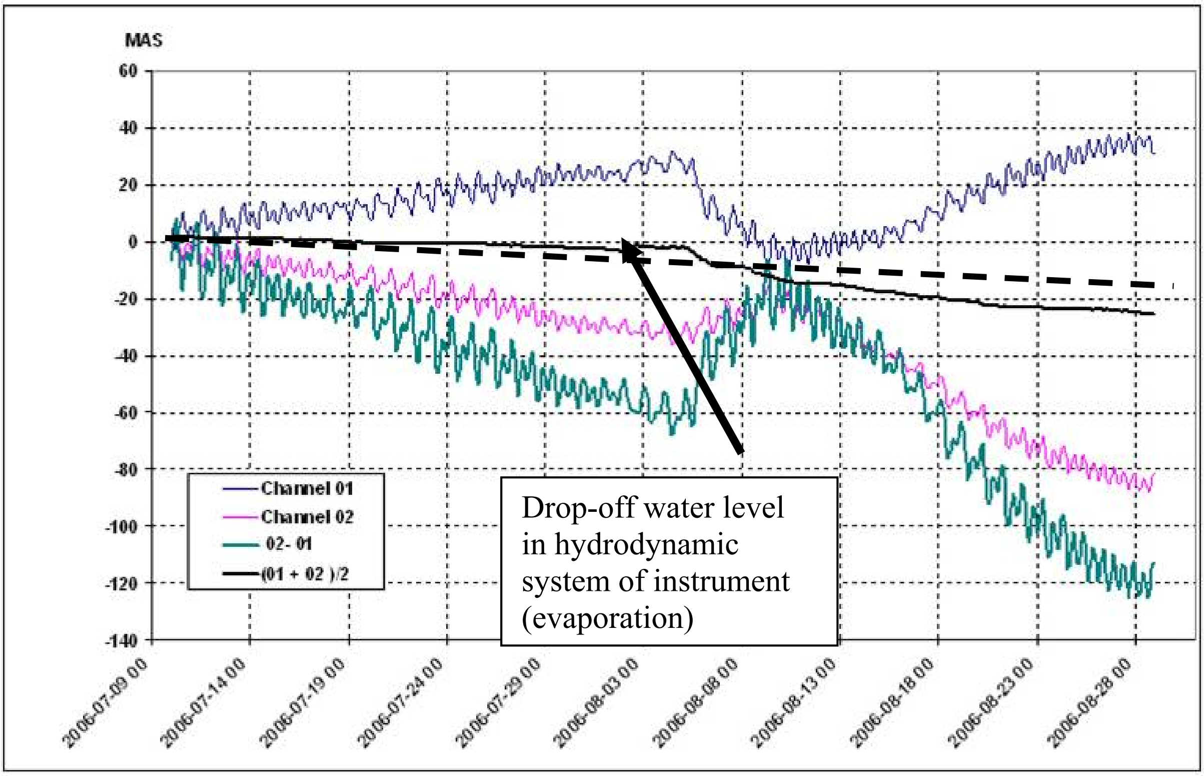

Fig.5. Raw signals (tidal and non-tidal) observed by tube 01-02 in July 2006 (event 5th)

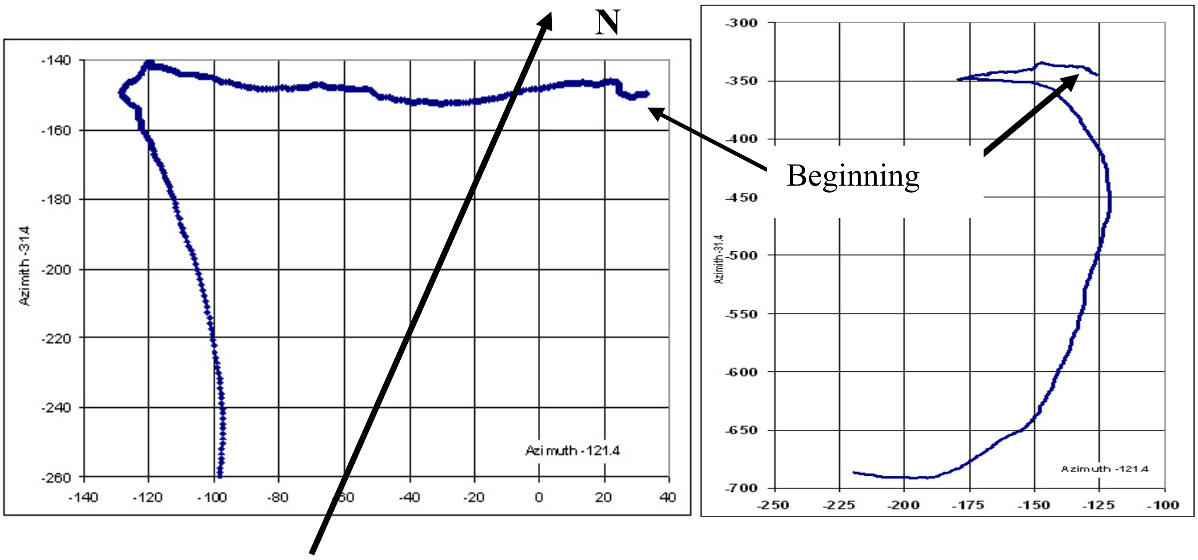

Fig.6. Non-tidal signals in space registered during event from March (left plot) and July (right plot) 2006

3. Possibility of generation of non-tidal signals by local effects such as pressure or temperature variations in gallery occupied by water-tube tiltmeter

Changes of pressure in underground can produce water level variations in tubes of tiltmeter by inverse barometric effect. Existence of horizontal component of pressure gradient along water-tubes is necessary condition to change water level. In the case when pressure changes produce asymmetric water level variations at the ends of the tubes, we can erroneously interpret these effects as non-tidal signals of plumb line variations. For 85 meters long tube and difference of pressure between ends of the tube equal to 4 10^{-3} [hPa] (pressure gradient is 5 10^{-5} [hPa/m]) inverse barometric effect produces signal of magnitude 100 [mas]. The gallery where tubes of tiltmeter were installed is open at one end and closed at the other. Surface of section of gallery is eighteen square meters. Horizontal component of pressure gradient appearing in gallery generates permanent motion of air along gallery from one side to opposite until pressure compensation. Because of large surface of section of gallery (18 m^2) horizontal component of pressure gradient vanishes in ten or less minutes. Experiment with artificial smog made in underground of laboratory show us horizontal velocity of air close to ¼ [m/sec]. Probably, we are able to expect great gradient of pressure 10^{-5} [hPa/m] but lasted maximally a few hours. Strong meteorological phenomena associated with rapid pressure variations initiate process of compensation of difference of pressure inside and outside of underground. During these events difference of pressure inside and outside underground can exceed 1 [hPa]. When process of compensation occurs variations of air pressure at both ends of the gallery (at both ends of the tubes) have the same trends - increasing or decreasing. Pressure variations of identical trends neither affect pressure gradient in gallery nor produce asymmetric signals of water level variations. Meteorological phenomena associated with effect of pressure compensation in underground lasted few days after which compensation trends became opposite. Therefore, explanation of a few weeks lasting systematic effects of water level variations by meteorological phenomena of pressure variations is improbable. Similarly to pressure variations the temperature variations in underground could also generate asymmetric signals of water level variations in water-tube tiltmeter. At the end of 2007 we installed system of continuous monitoring of temperature, pressure and humidity variations in underground of laboratory.

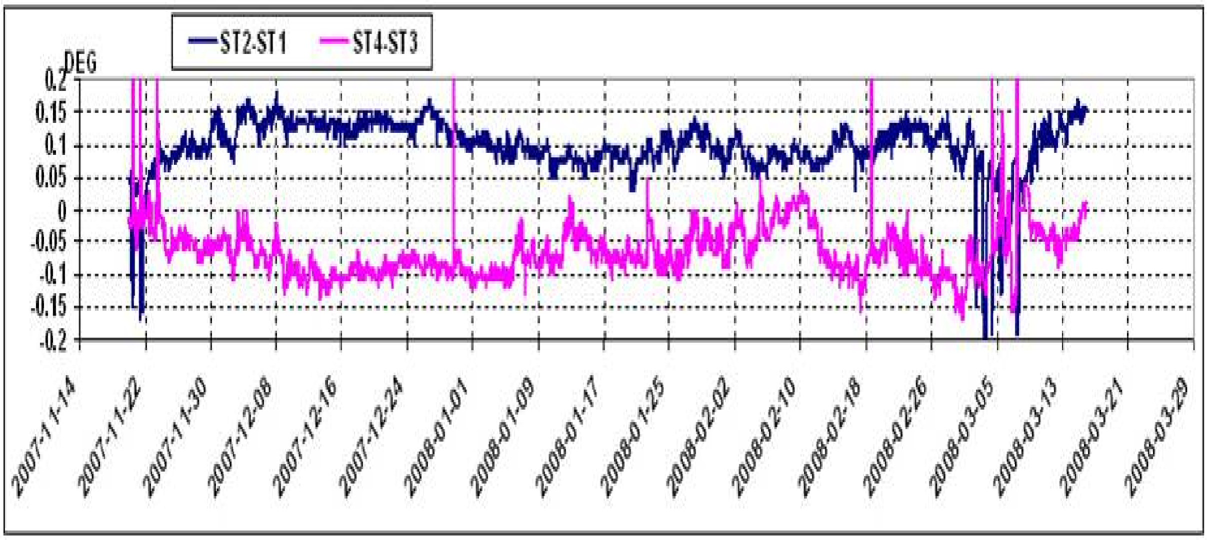

Fig.6. Plots of changes of differences of temperature occurring during winter period between ends of tubes

System consists of 26 sensors and their resolutions amount 0.01 [deg] for temperature, 0.01% for relative humidity and 0.1 [hPa]. Sensors were distributed among other at the ends of the tubes and in the room of horizontal pendulums. The results of measurements from October 2007 to March 2008 showed us that differences of temperature at the ends of the tube were close to 10^{-1} [deg]. Variations of temperature affected measurements of water-tube tiltmeter on several manners:

- Variations of volume of water in whole hydrodynamic system of tiltmeter produced by effect of thermal expansion of water.
- Variations of volume of the tubes due to thermal expansion.
- Variations of water density and height of equilibrium column of water.
- Variations of length of fasting screws in measuring platform of interferometer.

Effects of thermal variations of volume of water in hydrodynamic system of tiltmeter as well as variations of volume of tubes produce symmetric signal of water level variations and are reduced by the differential method of data reduction (Kaczorowski, 2006A). Temperature variations of density of water and height of water column above reflected lens as well as thermal variations of the length of fasting screws produce asymmetric signals in specific circumstance. To produce asymmetric signals of water level variations temperature changes ought to have opposite trends – increasing and simultaneously decreasing at the ends of the tubes. Situation when opposite ends of the gallery are simultaneously cooled and heated is improbable. Additional problem with explanation of strong non-tidal signals by temperature variations arrives if we take into attention small value of water thermal expansion (1.00004) and height of water column in interferometer (0.005 m). We evaluate thermal effect of variations of differences of temperature at the ends of the tubes between October 2007 and March 2008 on 10^{-7} [m]. This asymmetric signal of water level variations corresponds to 0.2 [mas] of plumb line variations.

4. Conclusions

The measurements from period 2004-2007 carried out by the long water-tube tiltmeter contained five epochs of strong (>100 [mas]) non-tidal signals. Strong non-tidal signals appeared in different months: November, March, December, and in the middle of summer.

Therefore, we are able to exclude any seasonal phenomena producing plumb line variations. Large, non-tidal signals registered by long water-tube cannot be simply explained by local effects such as pressure or temperature variations. Installed at the end of 2006 system of permanent monitoring of temperature, humidity, and pressure variations in underground of laboratory provides us information about possibility of generation of large, non-tidal signals by these changes. Magnitude of temperature variations (<0.1 deg) as well as horizontal gradient of temperature along the tubes (<<0.01 deg/m) observed between October 07 and March 08 exclude temperature variations as origin of large, non-tidal signals. It is also impossible to explain strong non-tidal signal by any pressure variations in underground of laboratory. There is difficult to show any mechanism of generation of lasting few weeks air pressure gradient in laboratory as well as to explain mechanism of simultaneous decreasing and increasing pressure at opposite ends of the gallery. In addition to observations of water-tube observations carried out with help of horizontal pendulums also contain strong non-tidal signals. Small size of pendulums, their construction and location in underground, exclude temperature and pressure effects as reason of strong non-tidal signals. On the basis of previous experiences we find that large non-tidal signals exceeding 100 [mas] are neither instrumental nor local origin. On account of magnitude of non-tidal signals we are able to exclude phenomena such as all known non-tidal loading and Newtonian effects of ocean (ocean tide effect in Ksiaz laboratory amount 1 mas for M2 wave) or meteorological origin.

In the case of meteorological effects explanation of large tilt signals by loading effects associated with horizontal gradient of pressure is difficult. There is too big difference between time of duration of large tilts effects (several weeks) and meteorological effects (several days). Moreover, the weather in March and July 2006 (4^{th} and 5^{th} events) was typically without anomaly. Because of technical problems about 35% of observations from period 2004-2007 are unavailable to be reduced by the differential method. Unavailable data were shown on (Fig.1) as empty spaces on plots of tilts. Therefore, evaluation of resultant tilts (-450 mas in azimuth 58.6 [deg] and -800 mas in azimuth 148.6 [deg]) (Fig.1) looks problematical. However, it is improbable that lost signals could compensate whole registered signals. During all large events in azimuths 58.6 [deg] plumb line variations were negative while in azimuth 148.6 [deg] they happened positive and negative. Taking into consideration variability of apparition of large tilt signals, four years long interval seems to be too short to answer the question of compensation of large tilt events. If we assume that for both components errors caused by lack of data are proportional to values of tilts, we are able to estimate azimuth of global resultant tilt equal to -2 [deg] for epoch 2004-2007. Azimuth of cumulated tilt associated with large tilt effects as well as azimuth of global resultant tilt are close to direction of tectonic motions in Central Europe. In this moment we incline to thesis that large non-tidal signals of plumb line variations are produced by recent crust movements.

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Bibliography

1. **Chojnicki T., Weiss J., 1981**, Results of clinometric observation of Earth tides in 1978-1979 at the Ksiaz station no 0906, Publs. Inst. Geophys. Pol. Acad. Sc. no, F-7 (146).
2. **Chojnicki T., Weiss J., 1987**, Results of clinometric observation of Earth tides in 1984-1985 at the Ksiaz station no 0906, Publs. Inst. Geophys. Pol. Acad. Sc. no, F-14 (200).

3. **Kaczorowski, M., 2004**, Water Tube Tiltmeter in Low Silesian Geophysical Observatory. Results of adjustment of half yearly series of plumb line variations Acta Geodynamica et Materialia vol.1, No.3 (135) pp.155-159.
4. **Kaczorowski, M., 2006A**, High-Resolution Wide-Range Tiltmeter: Observations of Earth Free Oscillations Excited by the 26 December 2004 Sumatra –Andaman Earthquake. **Monograph:** - Earthquake Source Asymmetry, Structural Media and Rotation Effects. pp. 493-520, Springer-Verlag Berlin Heidelberg 2006.
5. **Kaczorowski, M., 2006B,** Earth free oscillations observed in plumb line variations from the 26 December 2004 Earthquake. Acta Geodyn. Geomater., Vol.3, No.3 (143), 79-84.
6. **Melchior P., 1978,** The tides of the Planetary Earth, Pergamon Press.
7. **Wenzel H.-G., 1996,** The nanogal software: Earth tide data processing package: Eterna 3.4, Bull. Inform. Marées Terr. no 124, Obs. Royal de Belgique, Brussels, Belgium, pp. 9425-9439.