ACTIVITIES OF JÓZEFOSŁAW ASTRO-GEODETIC OBSERVATORY IN THE LAST FIVE DECADES

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ABSTRACT

Astro-Geodetic Observatory in Józefosław, which belongs to the Department of Geodesy and Geodetic Astronomy of the Warsaw University of Technology, started to permanent observations in 1958. First of them was time service started in February 1958, coordinated by BIH. From 1959 astrometrical latitude measurements have been done with aim to determine the parameters of the Earth rotation. In 1991 the Observatory was joined to the International GPS Service for Geodynamics (IGS) and started to operate as a permanent one in 1993. There have been performed many observations and scientific researches, such as: GPS in the frame of IGS/IGLOS/EUREF; tidal observations; absolute gravity measurements; changes of the vertical, based on the gravimetric measurements; astrometric observations and meteorology. Moreover, studies on RTK and DGPS measurements using mobile phone for data transmission are performed since 1998. WUT EUREF Local Analysis Centre, one of the 17 Local Analysis Centres acting in Europe, is a very important part of the Observatory. The Centre makes continuous service of one-week and daily solution in the frame of EPN network, processes national and international GPS campaigns (CEGRN, EXTENDED SAGET etc.), models ionosphere and troposphere parameters, compute tidal components and changes of the vertical according to astrometric and gravimetric measurements. This paper presents history and current state of the art of the Observatory's activities.

1. A SHORT HISTORICAL OUTLINE

The year 1949 is generally regarded as the date from which we may date the history of the Observatory at Jozefosław. It was in that year that, following the initiative put forward by Prof. E. Warchałowski, the Chair of Geodesy of the Faculty of Geodesy and Cartography, Warsaw University of Technology, took possession of the plot together with the apartment and farm buildings situated on it. The plot once used to be a part of an abandoned farm. The grounds were at first used mainly for field trainings in geodesy. In 1954, Prof. F. Kępinski, the then Head of the Chair of Geodetic Astronomy, began setting up an astronomical observatory on the plot. First, an "azimuth" pavilion was built and then its coordinates were determined. At the same time a transit Zeiss instrument was purchased, but lack of an adequate observation stand prevented the scientists from undertaking research in which the instrument could have been used.

On July 1st, 1955, Prof. W. Opalski was appointed Head of the Chair of Geodetic Astronomy. In 1956 a one-storied apartment building was adapted for the needs of the Observatory. After its repair, a Riefler pendulum clock rented from the Polish Academy of Sciences was set up on a special post. Despite its poor condition, which kept deteriorating with the passage of time, the building served the Observatory for over 20 years (Fig.1).

Fig. 1. The first Observatory building.

In December 1956 the construction of a new pavilion for a transit instrument started. In 1958 the Chair of Geodetic Astronomy applied for inclusion of the Observatory in the national programme conducted within the frame of the International Geophysical Year IGV), namely in the Longitudinal Operation of the IGY. The IGY Commission of the Polish Academy of Sciences approved of the application and included the Observatory in Józefosław as an observation station No. B-091 in the Polish plan of research to be conducted within the frame of the International Geophysical Year.

The station was supposed to carry out one and a half years' cycle of longitude determinations. One of the natural consequences resulting from this research were observations conducted for the Time Service. These were performed from November 1960 to October 1964. Results of the observations were published in the Observatory's own monthly Circulars.

In 1957 a Zeiss visual zenith telescope was purchased and the construction of an observation pavilion was completed. Apart from a short interruption lasting from August 1959 till October 1960 and resulting from the necessity to clear away some faults in Zeiss factory, the observations initiated in March 1959 have been continued up 2004. The leading role in this service play professor Barbara Kolaczek. At first, observation results were sent to BIH (Bureau International de l'Heure) and IPMS (International Polar Motion Service) and then, after the reorganization of these services, they were transmitted to GOSSTANDART in Moscow as well as to the Observatory in Shanghai, which plays the role of a co-ordinator of this research.

Since 1964 results of the observations of the latitude variations have been published in the quarterly "Latitude Circular". The observations are used to determine the secular variations in the Earth rotation and to investigate the plumb line stability. The astrometric data together with the observations conducted at a special gravimetric station since 1976 constitute one of the elements of the day-to-day monitoring of geodynamic processes that occur on the border of the T-T (Teisseyre-Tornquist) zone.

As regards satellite observations, they were initiated in 1957 when, soon after the first artificial Earth's satellites had been launched into orbit, 10 stations were established on the territory of Poland to conduct visual observations by means of AT-1 telescopes for ephemeridal purposes. The Observatory at Jozefosław was included in the list of these stations under No. 1160. In the years 1966-1970 photographic observations were conducted with the help of a NAFA -25C camera rented from the Polish Academy of Sciences. They were simultaneous observations of the satellites Echo I, Echo II and PAGEOS. Since no approval was obtained for the exchange of observation data with foreign stations and due to the poor accuracy of the camera, decision was taken to interrupt satellite observations from Józefosław. Those initially modest activities as regards the use of artificial satellites in geodesy gathered momentum with the era of satellite navigation systems.

The year 1976 was crucial in the Observatory's history. It was in 1976 that , thanks to the efforts made by professor Z. Ząbek, the then Director of the Institute of Geodesy and Geodetical Astronomy, they began the construction of the Observatory building. The Institute of Geodesy and Cartography in Warsaw offered much support in the construction, which was conducted with the active participation of the Institute's employees. The construction was completed in 1978. It was a wooden building, of a STOLBUD type, as presented in Fig. 2.

Fig. 2. The building of the Observatory since 2001.

Another important date is the year 1991 when the Observatory was invited to join the International GPS Service for Geodynamics (IGS), actually named International GNSS Service. Consequently, in 1993 it acquired the status of a permanent station. In recognition of its contribution to practical and theoretical work, the station became an IGS Core Station and the Analysis Centre operating within the IGS at the Institute of Geodesy and Geodetic Astronomy, WUT, acquired the status of an IGS Associated Analysis Centre. Owing to the participation in the research into new strategies for data processing within IGS, which consisted in the establishment of Regional Analysis Centres for IGS nets, in January 1996 the Institute was accepted as a Regional Analysis Centre for Central Europe within the IGS pilot scheme aimed at densifying ITRF through analysis of regional nets. The project started on April 1st, 1996. Allowing for a great number of stations in Europe, a special subcommittee of the International Association of Geodesy-EUREF (European Reference Frame) was appointed to coordinate the entire project. It suggested a new division of tasks and created a new basic level in the form of Local Analysis Centres (EUREF LAC) in the structure of the Analysis Centres operating within the IGS pilot project. One of the first local centres of this kind in Europe was the Centre operating in the Institute of Geodesy and Geodetical Astronomy, WUT, which also operates within the frame of CERGOP-CEI (Central

Europe Regional Geodynamic Project - Central European Initiative) project. Being an integral part of the Observatory, the GPS Analysis Centre carries out day-to-day processing of satellite observations conducted within the frame of CERGOP project which is co-ordinated by Section C of the Central European Initiative. Additionally, it carries out analyses of GPS observations conducted within other regional and local projects.

Along with the development of research into the Earth's crust deformations, more laboratories were opened in the Observatory in 1993, including a laboratory for absolute gravimetric measurements equipped with a ballistic gravimeter designed and constructed at the Institute of Geodesy and Geodetical Astronomy recently equipped also with FG-5 absolute gravity-meter; a tidal laboratory conducting day-to-day observations with the help of LC&R gravimeter, model D, and recently also with LC&R gravimeters, model ET. Results of tidal observations analysis are transmitted to the International Centre for Earth Tides (ICET) in Brussels, where station Józefosław is registered under No. 0909.

In the early 1994 the Observatory started its meteorological service providing information on the local weather processes. The bank is supplemented with observation data from other stations run by the Institute of Meteorology and Water Management. The use of supplementary data is very extensive, ranging from satellite observations to gravimetric measurements.

There has been a general increase in the demand for precise land navigation in the past few years. For this reason, since 1997 the Observatory has been offering services which make it possible to transmit corrections for positions of mobile satellite receivers operating in RTK and DGPS systems via radio or cellular telephony networks. Another purpose of these day-to-day observations conducted in the Observatory is to monitor the continental plate movements and the current Earth's crust deformation processes. Józefosław along with the German station Wettzell serve as the reference stations for the absolute gravity measurements within the frame of the European project UNIGRACE (Unification of Gravity Systems in Central and East Europe) which aims at unifying the gravity systems in Central and East Europe.

Another crucial date in the Observatory's history is the year 1997 when, following the initiative put forward by professor Śledziński, Director of the Institute and professor Rogowski Deputy Dean of the Faculty of Geodesy and Cartography work on developing a concept for a new Observatory building was undertaken. The construction was financed by means obtained from the Committee State for Scientific Research and from WUT's own funds. The new building was put to use in the first half of 2001. At present it is being equipped with computers and all the necessary apparatus. The new building housing the Observatory is presented in Fig. 3.

Fig. 3. The new building of the Astro-Geodetical Observatory in Józefosław.

In 2009 the frame of scientific network join Institute of Geophysics Polish Academy of Science and Department of Geodesy and Geodetical Astronomy of the Warsaw Unversity of Technology the GNSS Station in Belsk Observatory are established in collocation with Solar Radiometer CIMEL. The project realised in the frame of this network concerned the evaluation of the results of water vapour determination in troposphere.

2. OBSERVATION AND RESEARCH CONDUCTED IN THE OBSERVATORY

Research as well as observations carried out for its needs, are aimed at the following problems:

- **Methodology of processing day-to-day GPS observations for the needs of maintaining systems of coordinates and for the research into the Earth's crust kinematics conducted within the framework of IGS, EUREF and CERGOP,**
- **Developing models of the Earth's crust deformations with the help of a collocation of various measuring techniques,**
- **Determination of atmosphere parameters based on day-to-day GPS observations,**
- **Improving methods of GPS observations conducted for practical needs.**

2.1. Observations conducted in the Observatory

The data collection system used at the Astro-Geodetical Observatory in Józefosław and its connection with the GPS Analysis Centre in the Observatory are presented in Fig. 4.

Four receivers are used in the GPS/GLONASS/GALILEO data collection system:

TRIMBLE 4000 CORSTATION in the frame of IGS/EUREF networks (station JOZE continually operating since 1993);

Leica 1200 GRX (GPS/GLONASS) in the frame IGS/EUREF/IGLOS, IGS IP and ASG EUPOS (station JOZ2 operating since 2008;

Leica 1200 GRX (GPS/GLONASS) operating in the frame IGS/IGLOS network (station named JOZ3);

JAVAD Delta G3T (GPS/GLONASS/GALILEO)

The observation system consists also of the following elements:

I. **Gravity measurements:**
    Tidal observations conducted with the help of two LaCoste&Romberg gravimeters, model D and model ET (see Fig. 5.),
    Absolute observations conducted with a ballistic gravimeter (see Fig. 6.),
    Meteorological observations,
II. **Observations of the ground water level variations.**

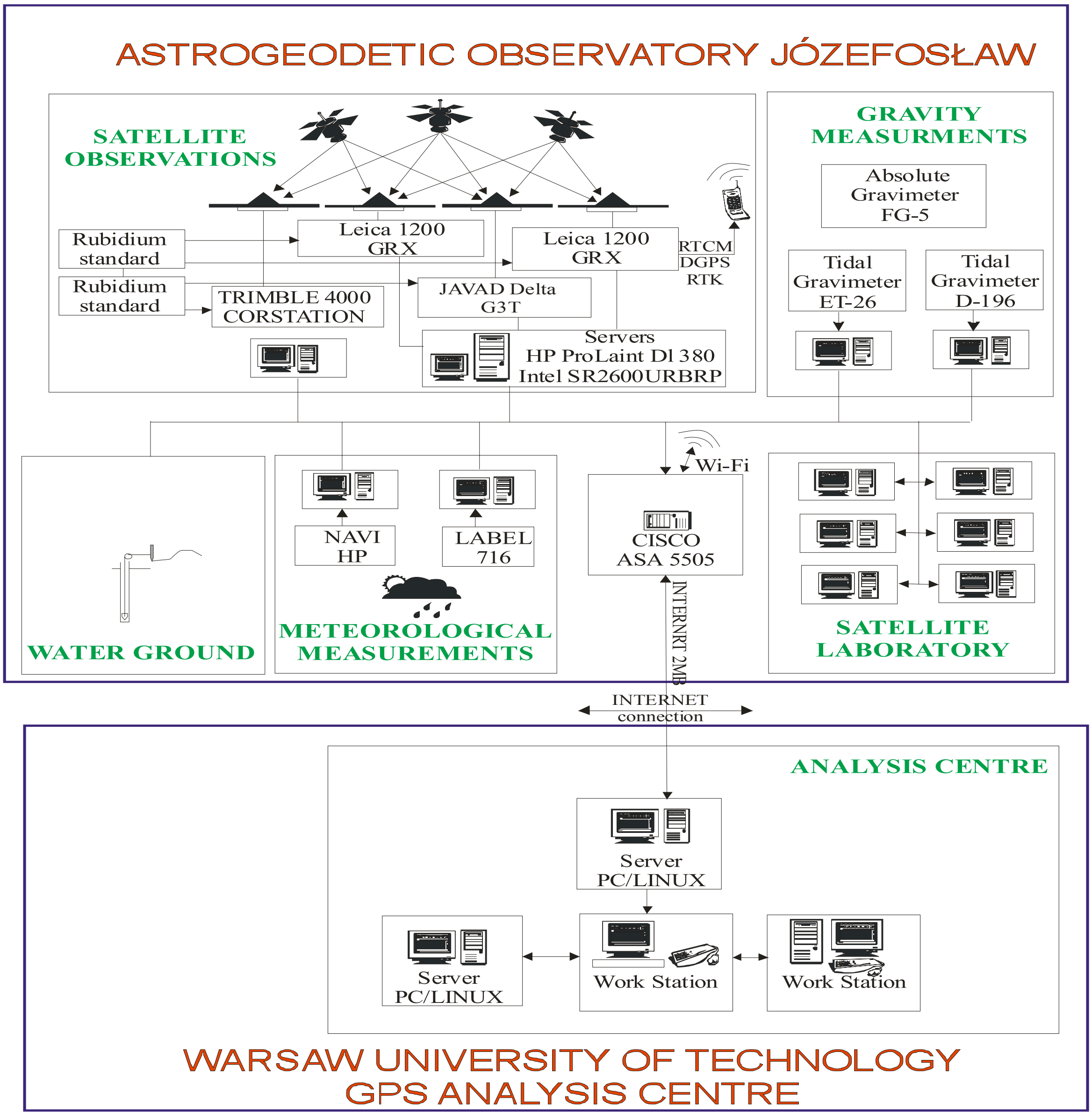


Fig. 4. Data collection system at the Astro-Geodetical Observatory in Józefosław.

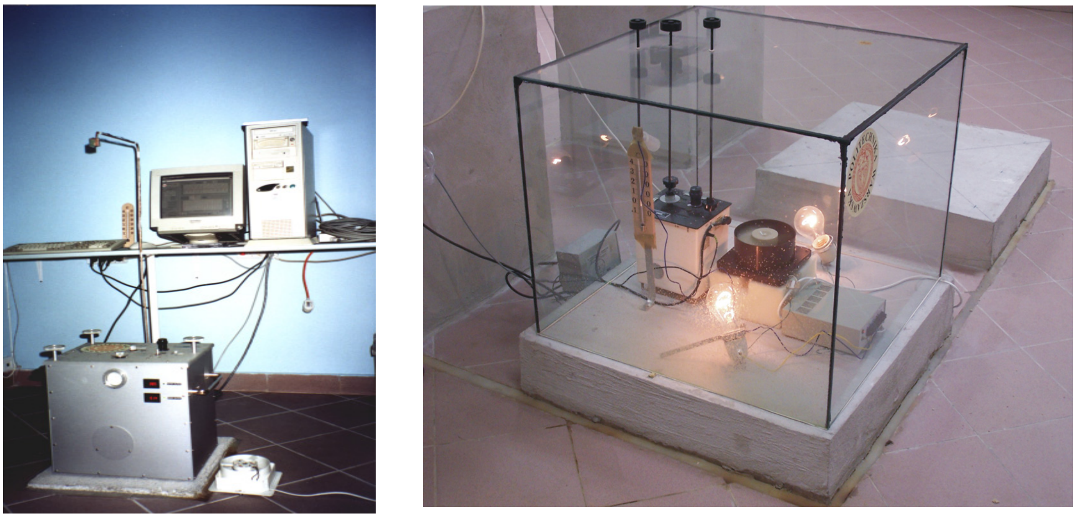


Fig. 5. LaCoste&Romberg ET and D gravimeter.

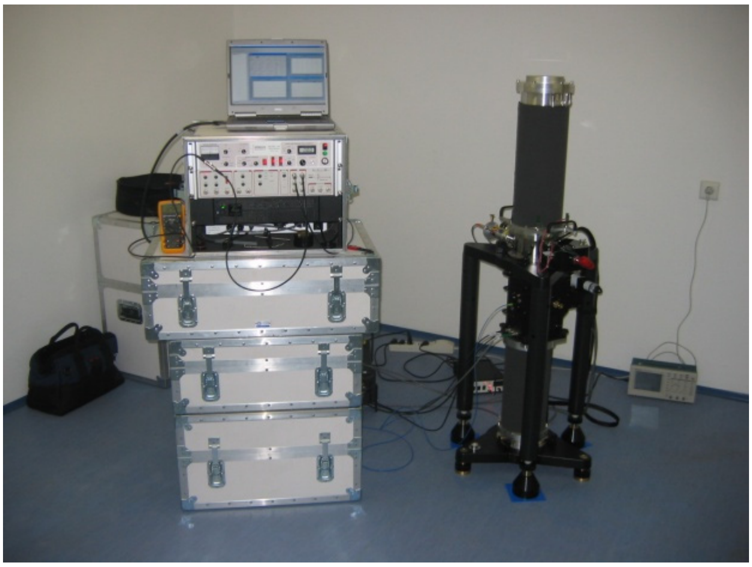


Fig. 6. Absolute Gravity-meter FG-5.

2.2. Activities of the WUT EPN local analysis centre

Warsaw University of Technology has been operating WUT EPN LAC since January 1996. WUT LAC analyses the EPN sub-network which consists of 80 stations located mainly in Central Europe. Six new stations were added to the network in 2010. The sub-network assigned to WUT is presented in Fig. 7.

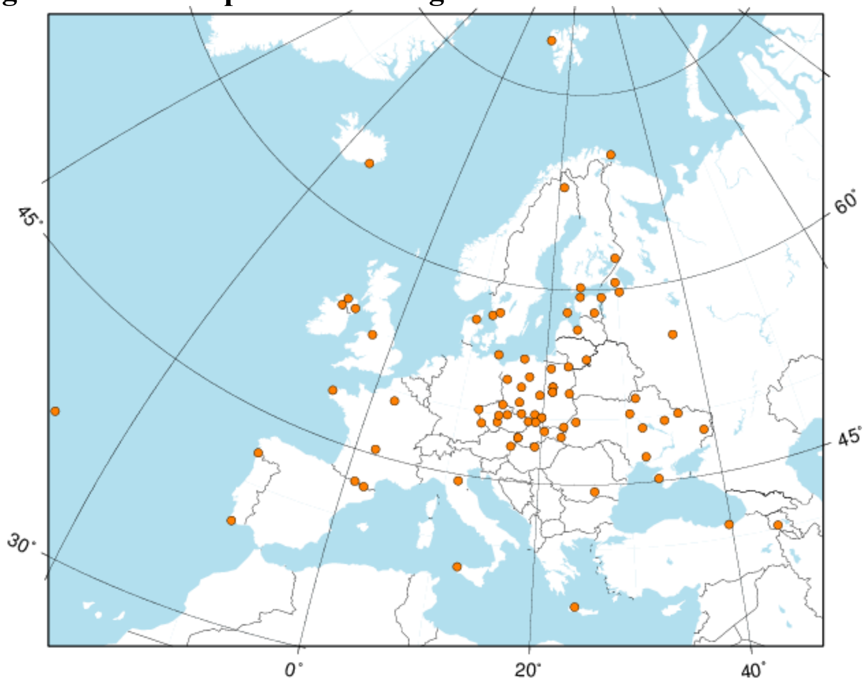


Fig. 7. Network of stations processed by WUT EPN LAC.

WUT LAC contributes to EUREF with weekly and daily results based on IGS final products, and with rapid daily coordinate solution based on IGS rapid products. Rapid daily solutions were completed at WUT in December 2009, but official submission to EPN started in early January 2010.

WUT LAC uses Bernese GPS Software ver. 5.0 to analyse GPS observations. Data are processed according to EPN AC guidelines. All WUT products are available at the EPN regional data centre located at BKG (ftp://igs.bkg.bund.de/EUREF/products).

In 2010 WUT has joined EPN Re-processing Project which aims at reprocessing of all observations since 1996, using recent models and developments in processing strategy. Up to now, we have reprocessed data of 55 stations of year 2006.

2.3. Determination of ZTD and IPW from GPS data analysis and its verification using meteorological data sources

One of main areas of research by the WUT EPN LAC is a standard ZTD estimation, monitoring of the results and research on IPW time series derived from our solutions and EPN combination.

We investigate both IPW (Integrated Precipitable Water, also IWV) derived from GPS tropospheric solutions and ZTD's itself.

Most important conclusion from EPN ZTD series monitoring is a dramatic decrease of differences between individual LAC solutions in 2007 (solutions after GPS week 1400 showing best conformity since the year 2003). Results from 2005 – period of new Bernese software version 5.0 introduction in some LACs only show greatest discrepancies. The cause of excellent conformity from the GPS week 1400 is in all probability cumulative effect of Bernese 5.0 almost exclusive 'reign', absolute antenna PCVs and new reference frame ITRF2005/IGS05.

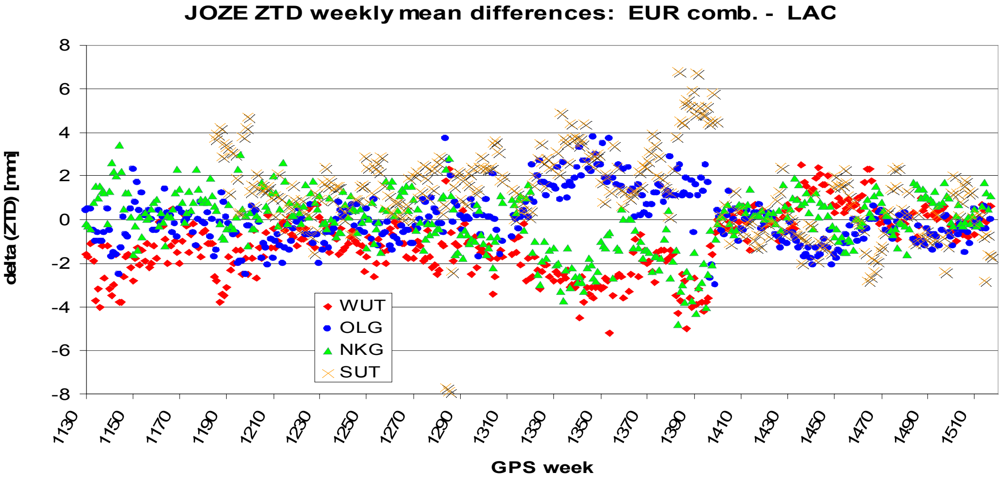


Fig. 8. ZTD weekly mean differences: EUR combined product - individual LAC for JOZE.

WUT LAC ZTD series monitoring is a proof of good tropospheric solution quality: example visualisation of differences between between selected LAC solutions (only those including Józefosław) and EPN combination after 2007 is shown on the Fig. 9.

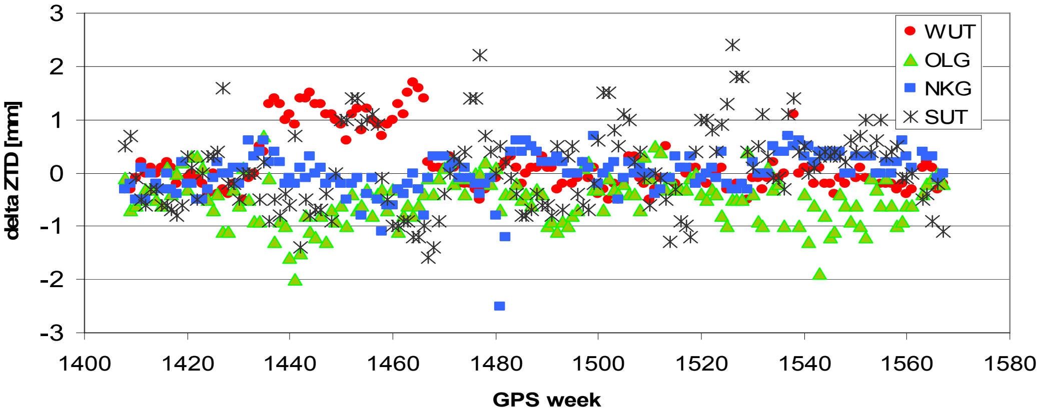


Fig. 9. ZTD weekly mean biases: EUR combined product - individual LAC for all EPN stations in the Center's solution.

IPW values coming from GPS (different EPN solutions and combination) is of reliable quality compared with three meteorological water vapour data sources from three meteorological water vapour data sources (routinely derived): radiosoundings, sun photometer (CIMEL, Central Geophysical Observatory PAS, Belsk) and input fields of operational numerical prediction model (NWP) COSMO-LM (maintained by Polish Institute of Meteorology and Water Management).

Only CIMEL sunphotometer data seems more genuine source. Results from earlier years were so promising that we decided for direct collocation of GPS measurements and sunphotometer.

In May 2009 JOZE station GPS receiver Trimble SSE (one of the oldest in the whole network) was replaced by more recent model. The old receiver was placed on the roof of Central Geophysical Observatory in Belsk and works permanently thereafter.

Data was analysed in the manner very similar to EPN standard tropospheric solution but in somewhat smaller network (27 stations). Results from September 2007 are presented on the figure 10. You can see clearly decreasing data conformity with increase of GPS receiver distance.

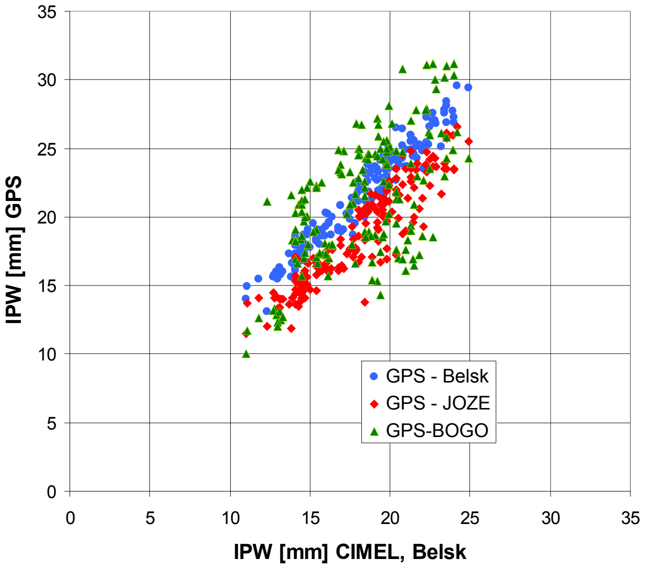


Fig. 10. IPW from sunphotometer in Belsk and GPS data 'in situ', JOZE (33 km distance) and BOGO (73 km) in September 2009.

NWP model (COSMO-LM) treated as meteorological database can produce (as our calculations demonstrate) ZTD and IWV for all stations independently from sparse RAOB network. Unfortunately procedure is not so straightforward (e.g. interpolations concerns in not so dense a grid). We found that Numerical Weather Model topography is greatest concern for the proper ZTD derivation (Kruczyk, 2008).

We further investigate the value of GPS IPW as a geophysical tool: clear physical effects evoked by station location and weather pattern. Especially intriguing are long series of IPW (daily averaged) which can serve as 'climatological' information. On the next figure sinusoidal model has been adjusted to the series (LS method) for JOZE, every year separately – different are not only amplitudes but also phases. Figure 11. illustrates the results for 5 year period when it got +0.6 mm/year IPW trend. For the following years not visible (Kruczyk, 2009).

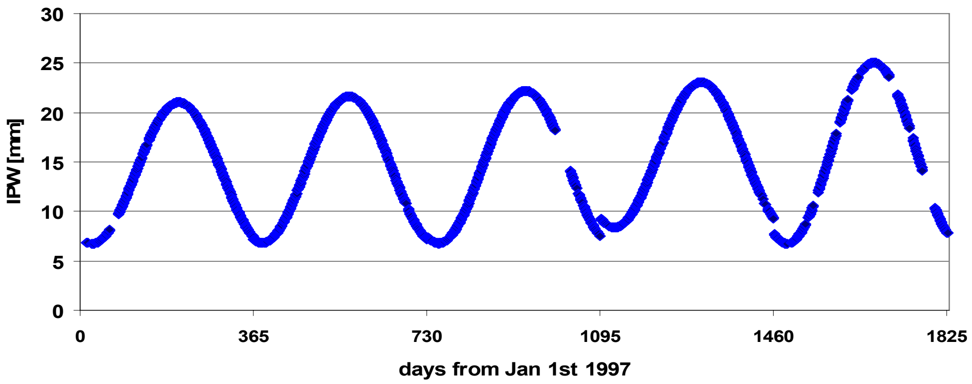


Fig. 11. Simple model of daily IPW values series (sinusoid + constant) derived from IGS CODE ZTD solution for JOZE 1997-2001.

2.4. Studies on the earth crust deformation model

The actual relationships between the International Celestial Reference Frame (ICRF), which is a quasi-inertial system in which the orbits of the artificial Earth's satellites are computed, and the International Terrestrial Reference Frame (ITRF) in which points on the Earth's surface is determined, and the observations that are used for position determination in both the systems are one of the fundamental problems faced by modern geodesy and geodynamics. The theoretical bases that help us to define these systems and signal the relationships occurring between the systems and the observations conducted on the Earth's surface were tentatively presented in 1980, and the definitions and principles for the practical application of the systems appeared in 1991, and they did not differ much from the currently binding ones. What is important in the transformation process between the ICRF system and the ITRF one is that we should know the parameters of the precession and nutation models and the quantities determined based on the observations and the Earth rotation parameters such as coordinates of the instantaneous Earth pole and the Earth rotation time processed by the International Earth Rotation and Reference System Service (IERS). Observations performed in order to obtain the aforementioned Earth rotation parameters determined by the IERS and to obtain the coordinates of points on the Earth's surface should be corrected by changes in the position caused by Earth's crust deformations resulting from such phenomena as: the Moon's and the Sun's gravity (tides), non-tidal deformations (i.e. variations in the air pressure and ground water level) and movements

of the Earth's crust. A diagrammatic division of the deformations that are subject of research conducted at the observatory is presented in Fig. 12.

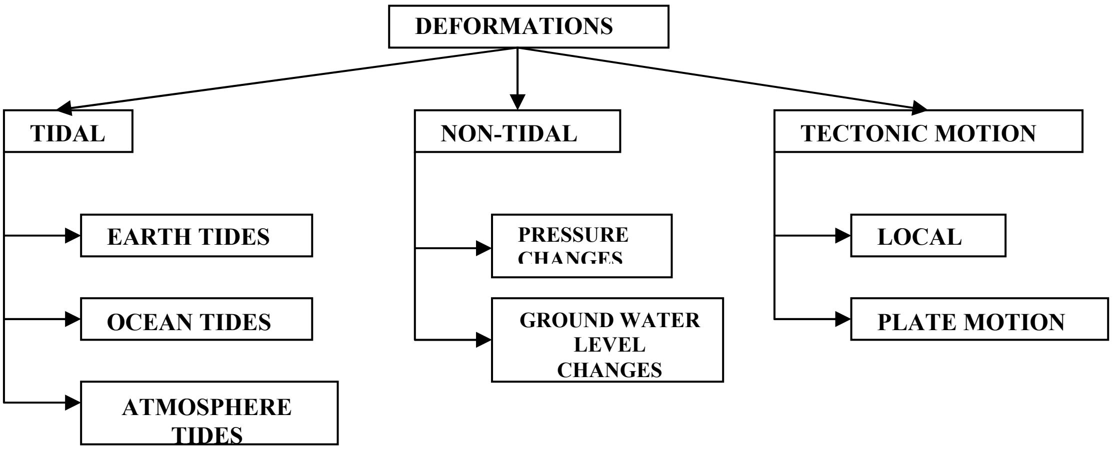


Fig. 12. Types of deformations.

2.4.1 Solid Earth tides

Firs attempts to investigate in tidal gravity were held in 90'. Since 2002 Tidal Laboratory is equipped with LaCoste&Romberg Earth Tide No. 26 (Bogusz, 2002) which is dedicated for continonos stationary measurements. After serious repair in 2006 it operates without significant gaps. Parallel observations with FG-5 ballistic gravimeter allows us for precise determination of gravimeter scale factor and investigation in its variation at 1% level. High quality of records collected in previous years allows us to study different tidal phenomena.

Tidal gravity parameters in diurnal and semi-diurnal bands are computed using international standard data processing technique (results are shown in table 1). What should be underline is fact that recently fitting tidal waves with least square method gives r.m.s.e. below 1nm/s^2 Moreover, it is possible to investigate in small environmental signals such as gravity changes due to ocean loading, influence of atmosphere caused by attraction and loading, background noise.

Importance of pressure reductions was studied and admittance factor were computed (-3.5nm/s^2). The numerical results showed seasonal variation of this factor.

Subtracting body tides from results yields a differences up to 10nm/s^2 which are in good common with computed indirect effect of ocean using most recent models. It clearly explains main source of disagreement between results from measurements and tidal models, despite of long distance to nearest ocean.

Table 1. Least square adjustment results of amplitude factors (δ) and phases (φ) compared to amplitude factors for tidal Wahr-Dehant model ($\delta_{W\text{-}D}$)

Name	A^{th} [nm s^{2}]	$\delta_{W\text{-}D}$	δ	m_δ	φ [^{0}]	m_φ [^{0}]
Q_1	57.7	1.1480	1.1480	0.0005	-0.069	0.024
O_1	301.3	1.1505	1.1505	0.0001	0.087	0.005
M_1	23.7	1.1518	1.1518	0.0014	0.062	0.071
P_1	140.2	1.1486	1.1486	0.0002	0.129	0.012
S_1	3.3	1.1949	1.1949	0.0152	-6.199	0.734
K_1	423.6	1.1361	1.1361	0.0001	0.103	0.004
PSI_1	3.3	1.2892	1.2892	0.0100	1.805	0.447
PHI_1	6.0	1.1663	1.1663	0.0061	-0.015	0.298
J_1	23.7	1.1572	1.1572	0.0011	0.038	0.056
OO_1	13.0	1.1530	1.1530	0.0018	-0.005	0.087
$2N_2$	8.7	1.1683	1.1683	0.0024	1.216	0.119
N_2	54.3	1.1774	1.1774	0.0005	0.957	0.025
M_2	283.8	1.1827	1.1827	0.0001	0.642	0.005
L_2	8.0	1.1964	1.1964	0.0055	0.063	0.265
S_2	132.0	1.1749	1.1749	0.0002	-0.197	0.011
K_2	35.9	1.1788	1.1788	0.0007	0.077	0.033
M_3M_6	3.4	1.0826	1.0826	0.0042	0.104	0.220

2.4.2 Studies on secular changes of gravity

Measurements of absolute gravity were performed previously with different types of gravity-meters – ZZG, JILAg, FG5 since 90'. Since 2005 our laboratory is equipped with FG-5 ballistic gravimeter which serves for obtaining non-tidal gravity series. The details of measurements and results are given in other article in this issue so we delimited this section giving short summary that evaluate long term non-tidal gravity changes is difficult as comparing older results with new series is improper due to different systematic instrumental errors. On the other hand present five year long series is consistent at 100 nm/s^2 level but subtracting secular changes is still problematic as there is a few environmental effect which can affect results – mainly global and local hydrology and pressure effects (loading, attraction). Those effects are reduced by models using auxiliary measurements (atmosphere pressure, water table level) but further analysis are needed with special treatment on these disturbances.

2.4.3 Atmospheric loading effect

One of the sources of the GPS-determined coordinates is the atmospheric loading. This effect was calculated according using the formalism of surface loading Green's functions (Farrell, 1972) as follows:

$$u(\psi)=\frac{a}{m_e}\sum_{n=0}^{\infty}h_nP_n(\cos\psi)$$

where:

$m_{ij}(\psi)$ – mass of the considered atmosphere element,

$u_{ij}(\psi)$ – Green's function of radial displacement:

n - number of zones,

m - number of sectors,

and using meteorological data obtained from the Polish Institute of Meteorology and Water Management. For an example changes of the Up component computed from this data for the Astro-geodetic Observatory in Jozefoslaw in the period covered 1999 year are presented in Fig. 13. the magnitude of this effect is 10mm.

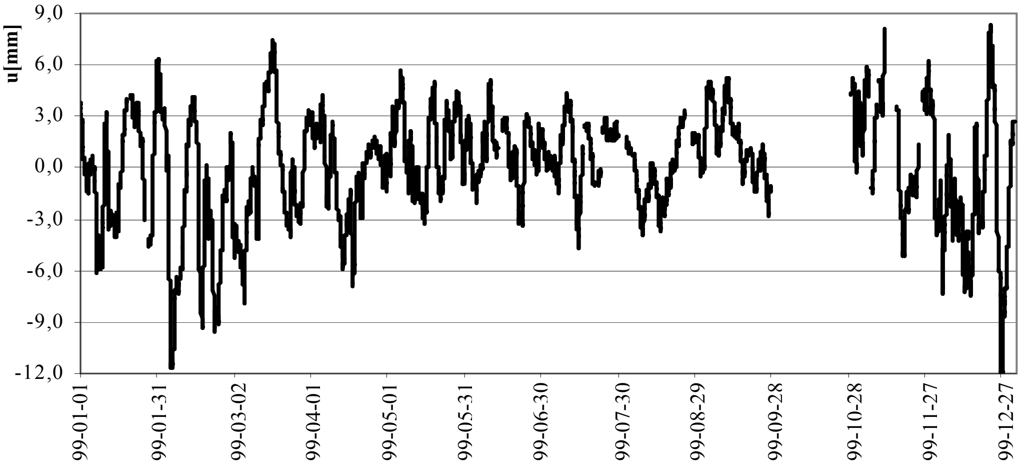


Fig. 13. Vertical displacement computed from meteorological data.

2.4.4 Ground water level changes

Geological structure near the gravimetric and GPS station Józefosław are presented as follows:

in the depth from 1.0 to 2.0 meters occur sands;

in the depth from 2.0 to 12.0 meters occur clay;

under the clay there occurs the sandy layer of thickness from 5.0 to 16 m.

The ground water level is actually in the depth of approximately 12 meters. The examples of the one of geological profile are presented in Fig. 14. The ground water changes are observed using the piezometer (*Pz*).

The influence water level changes to gravity measurements can be computed using the following formula:

$$\Delta g = 102.6 \cdot \Delta H$$

where:

g – gravity changes [μGal],

H – changes of ground water level [m]

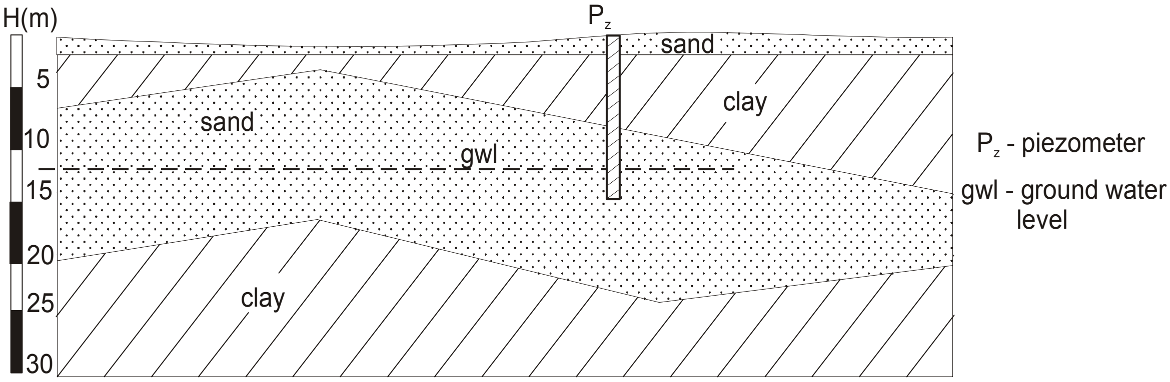


Fig. 14. Scheme of hydro-geological situation in Józefosław.

The ground water level changes in 2005-2009 are presented in Fig. 15. Gravity and high changes in this year are presented in Fig. 16 and 17.

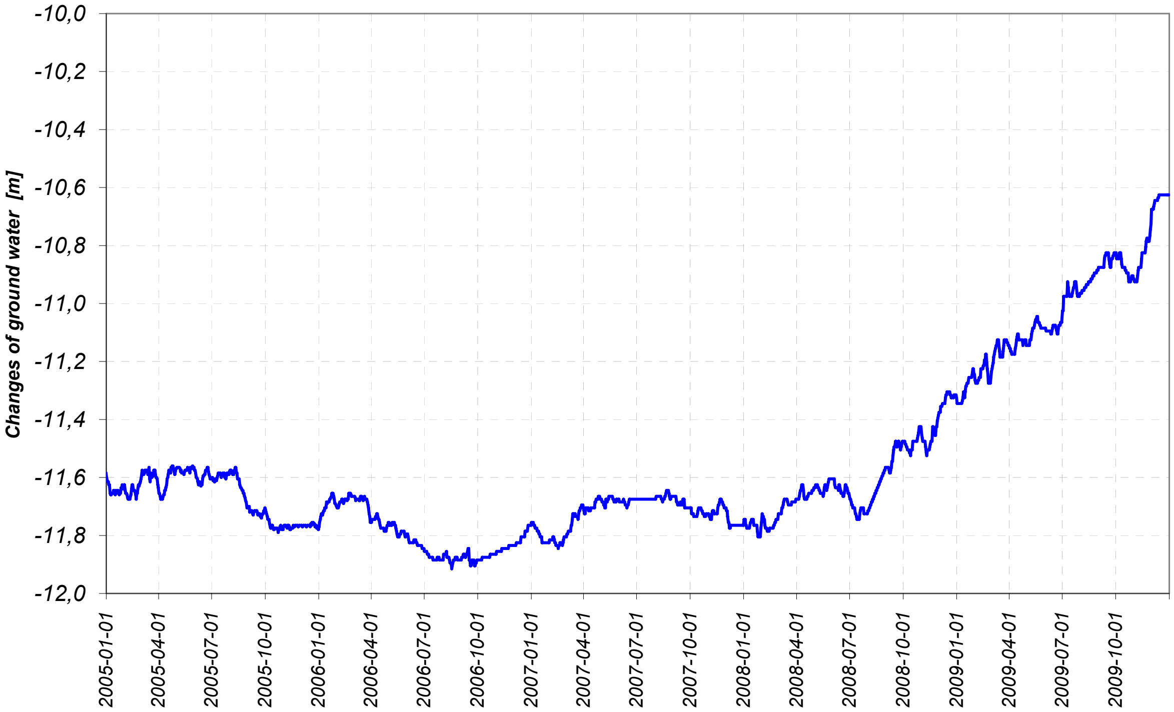


Fig. 15. Ground water level changes.

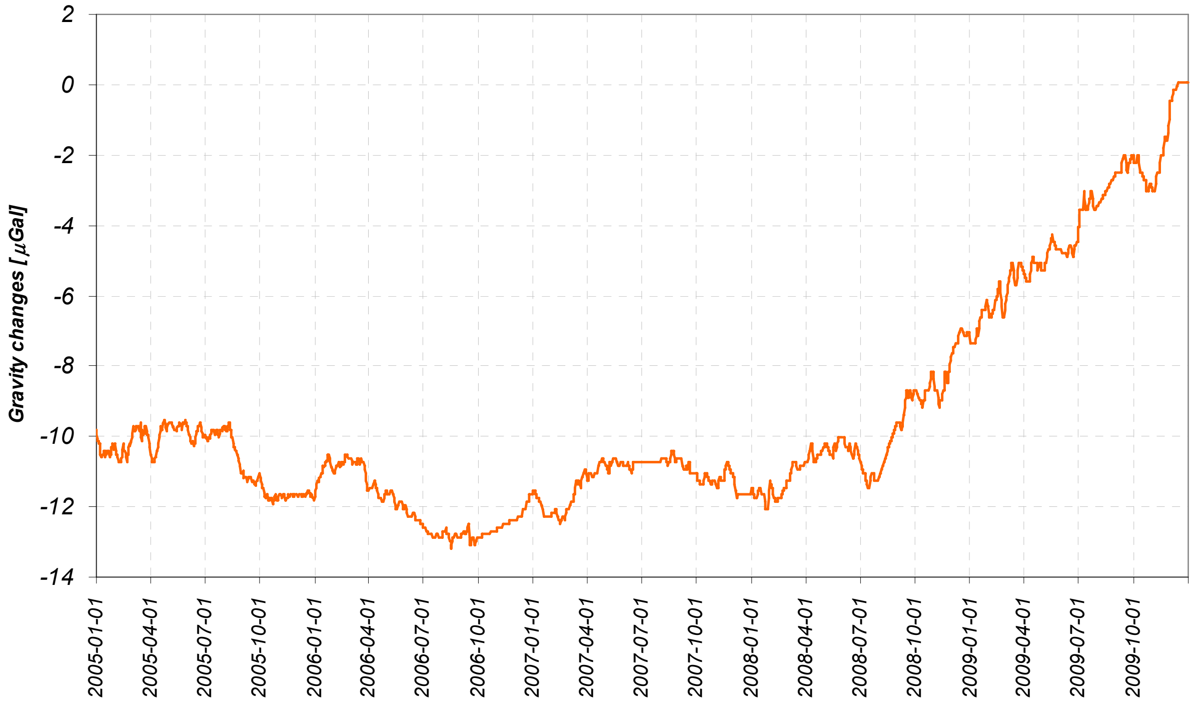


Fig. 16. Gravity changes as consequence of water level variations.

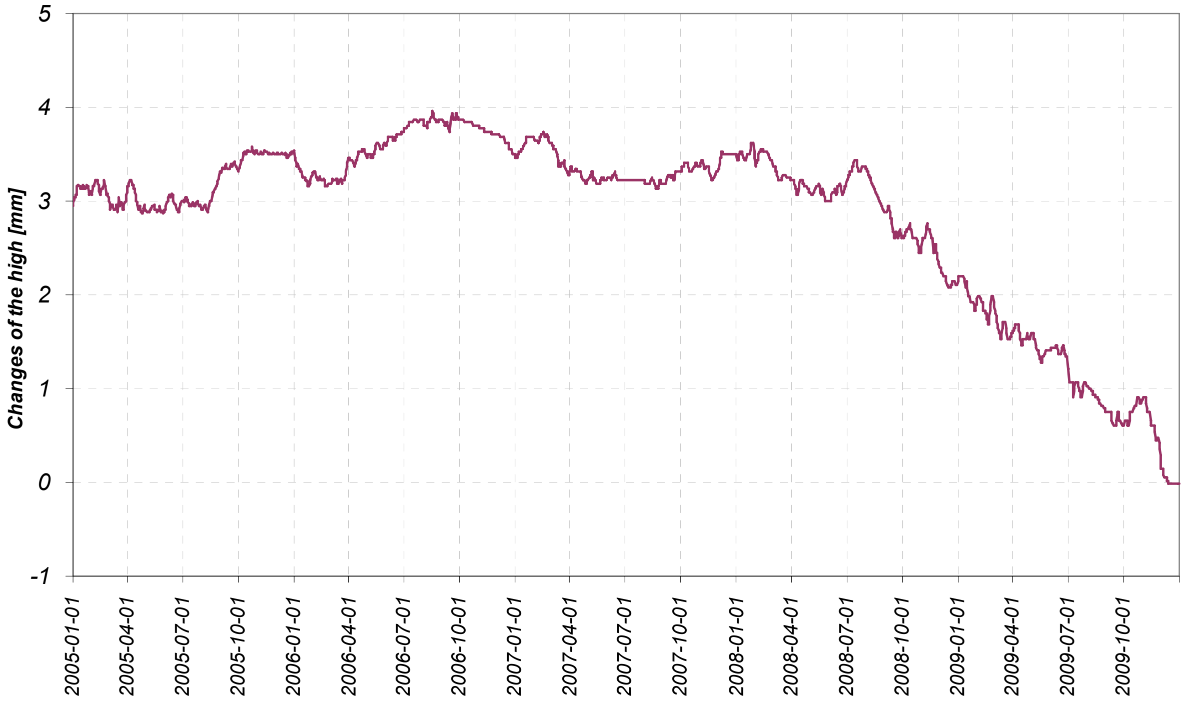


Fig. 17. High changes as consequence of water level variations.

2.4.5 Changes of the vertical from Astrometric Observations

Permanent latitude observations have been taken by means of Zeiss zenith telescope since 1959 at Astro-Geodetic Observatory in Jozefoslaw. Thanks to reduction using HIPPARCOS catalogue we have tried to determine astrometric coefficient $\lambda=1+k-l$ for tidal deformations in the plumb line variations for M2 wave separately and for complete

luni-solar tidal effect. Best results of 7-parameter model LS-method fitting occurs for years 1977-82 respectively:

$$\lambda(M_2) = 0.81 \pm 0.98$$

$$\lambda(\text{entire effect}) = 0.6 \pm 0.46$$

This results are still insufficiently precise to evaluate exact value of λ (correct value should be close to 1.15) (see Fig. 18) to asses good quality of the adjustment.

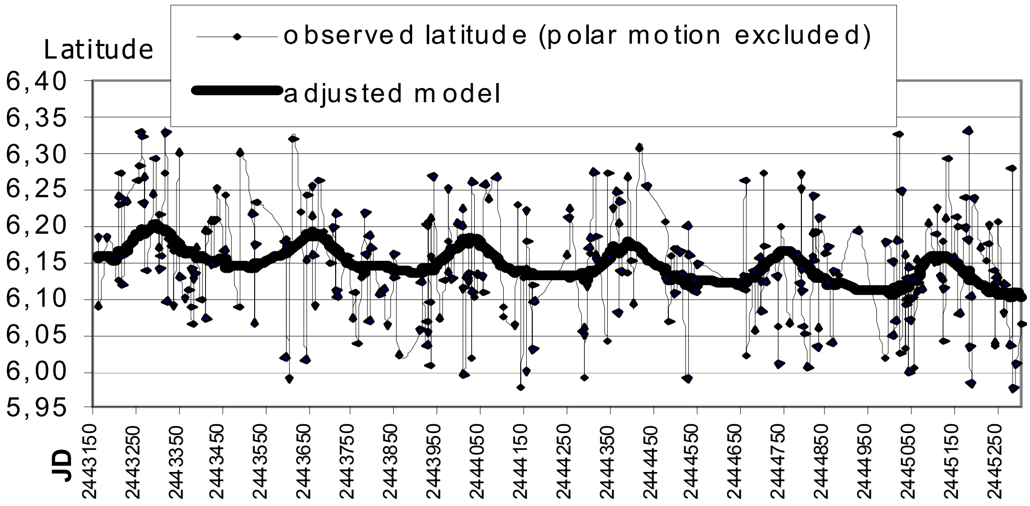


Fig. 18. Changes of the latitude.

2.4.6 Tectonic plate motion

Based on GPS observations made during periodic campaigns CERGOP and EXTENDED SAGET there were determined velocity vectors of the part of Eurasian plate. To estimate these vectors of Least Squares Adjustment method was used.

Calculation were made using ADDNEQ program, part of Bernese v. 4.0 software.

Comparatively velocity vectors determined from global model NUVEL-1A were also presented. Velocity vectors were determined for 33 stations, which took part in CERGOP campaigns '94, '95, '96, '97 and EXTENDET SAGET campaign '98 (fig. 19.)

To determine velocity vectors the most accurate model is NUVEL-1A, based on geological data. To compute velocities one can use following formulae

$$V_X=(\omega_{(Y)} \cdot Z_0-\omega_{(Z)} \cdot Y_0);$$
$$V_Y=(\omega_{(Z)} \cdot X_0-\omega_{(X)} \cdot Z_0);$$
$$V_Z=(\omega_{(X)} \cdot Y_0-\omega_{(Y)} \cdot X_0);$$

where:

X_0, Y_0, Z_0 are coordinates of analyzed stations.

Table 2. Plate motion for JOZE station [mm/year]

Method	$V_{(X)}$	$V_{(Y)}$	$V_{(Z)}$
CERGOP solution	**-19.1**	**16.1**	**9.3**
Linear regression WUT EUREF LAC solution	**-18.2**	**17.2**	**11.0**
NUVEL – 1A	**-17.2**	**17.2**	**7.7**
ITRF'94	**-19.2**	**15.3**	**9.0**

Fig. 19. Tectonic Plate Motion in Central Europe.

2.4.7 Analyses of GPS time series of Józefosław coordinates

Day to day GPS data processing performed in Jozefoslaw Observatory is the part of routine data processing of the EPN (EUREF permanent Network) analysed by WUT EUREF LAC. Adjustment of 1-hour GPS observations is now in the pilot phase. Variations of Józefosław coordinate obtined from 1 day and 1hour intervals are presented in Fig. 20.

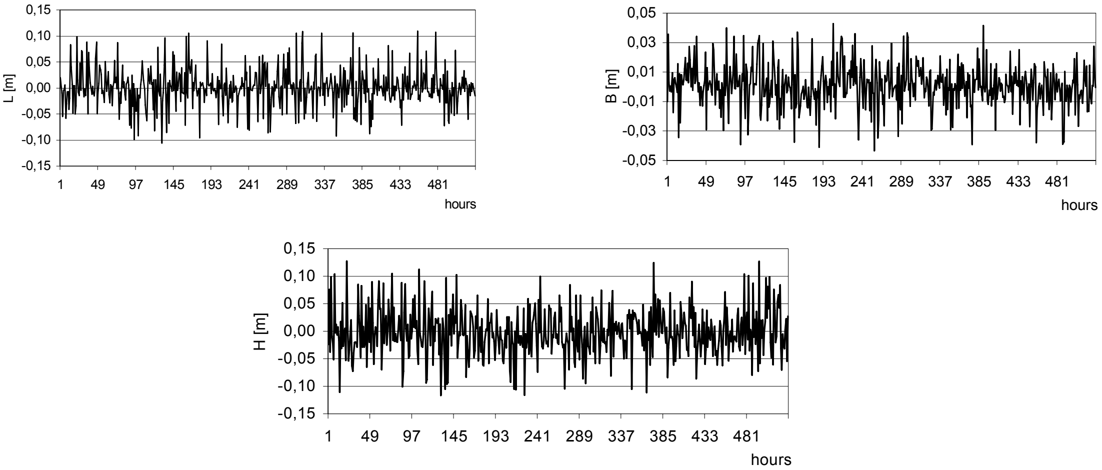


Fig. 20. Results of 1-hour data processing.

For the two types of data processing presented above the influences of tidal corrections using IERS'96 conventions (Schwidersky model) was also processed and analyzed for Jozefoslaw. The results of spectral analysis of this theoretical values of tidal influences and practical time series are presented in following section.

Model of tidal spatial displacement compatible to IERS'96 conventions (Schwidersky model) was analysed for Jozefoslaw - June 1997. Results are shown on the below figures. Model derived components in the local system and 22 days hourly solutions were a subject of the spectral analysis.

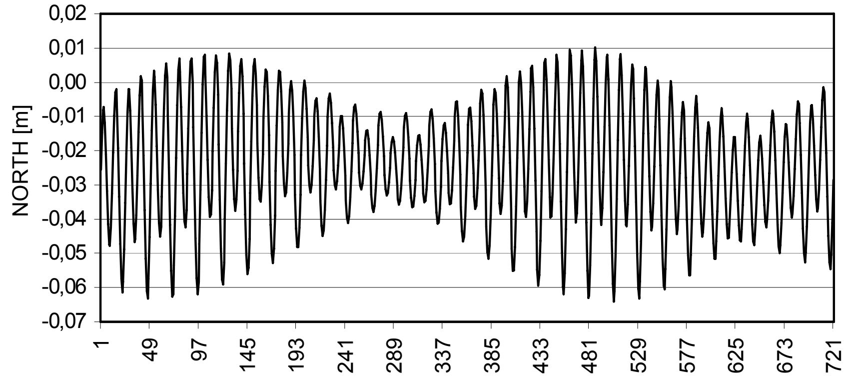
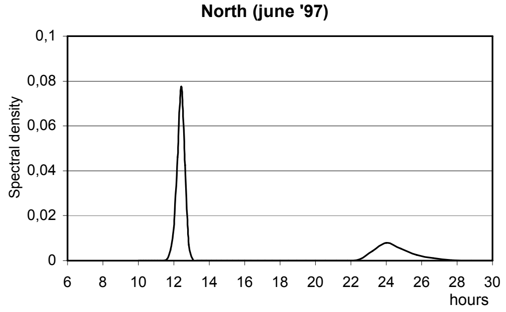


Fig. 21. North component of the tidal model.

Below figure shows Fourier transformation of component North of the model.



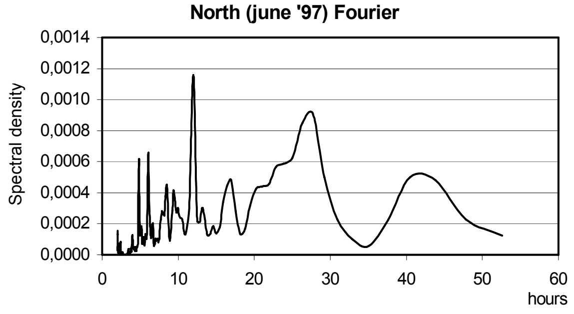


Fig. 22. Power spectra of North component of the model (22 days in June 1997).

Fig. 23. Spectra of 1-hours observations, North component (June 1997).

Also MESA method was applied for real displacement analysis.

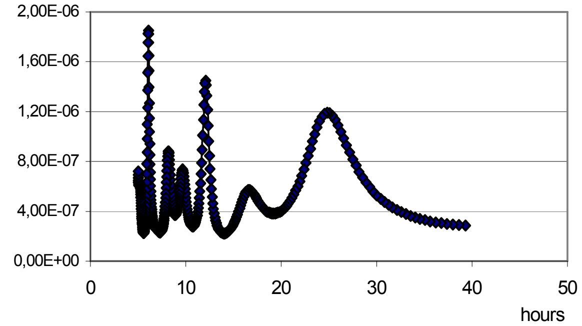


Fig. 24. NORTH component power spectra hourly solutions (June'97) Jozefoslaw - maximum entropy method Blackman weight window.

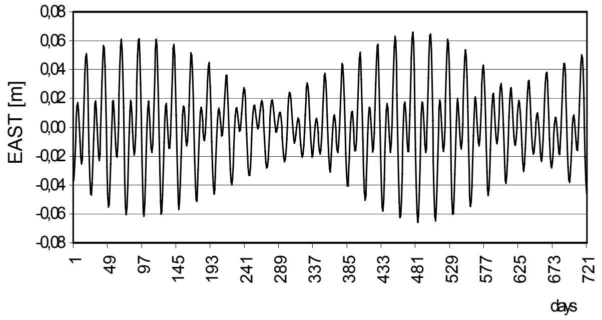


Fig. 25. Component East of the tidal model.

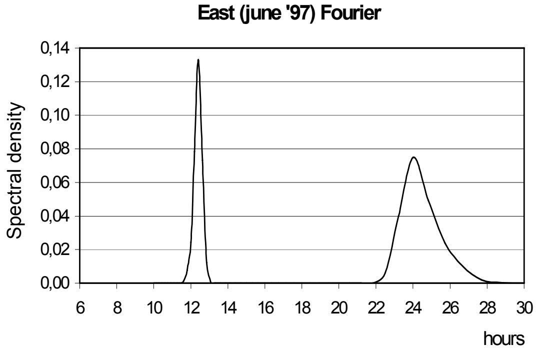


Fig. 26. Power spectra of the model East component, Fourier (June 1997).

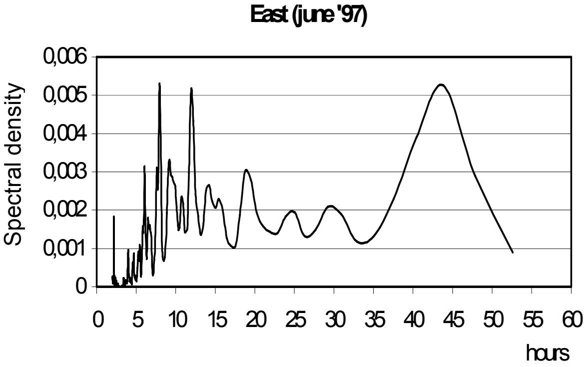


Fig. 27. Spectra of 1-hour observations, East component (June 1997).

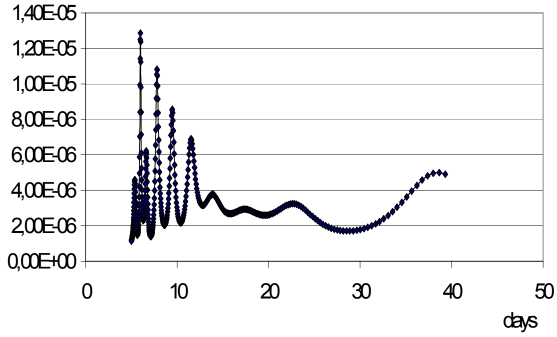


Fig. 28. EAST component power spectra hourly solutions (June'97) Jozefoslaw - maximum entropy method Blackman weight window.

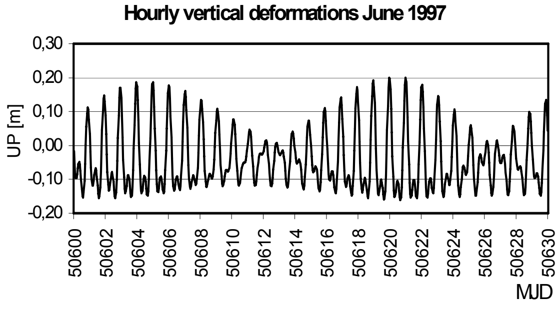


Fig. 29. Component Up of tidal model.

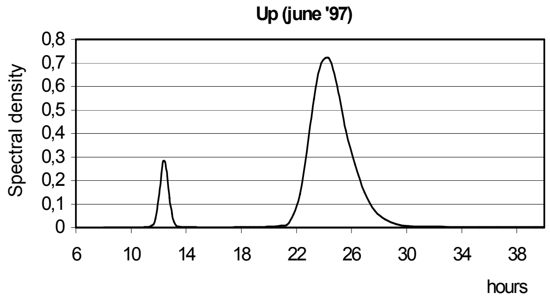


Fig. 30. Spectra for vertical model component.

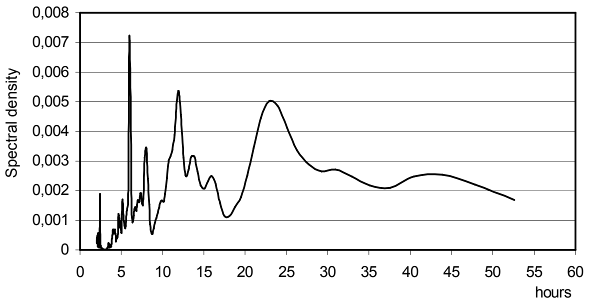


Fig. 31. Fourier spectra of hourly solutions, UP component (June '97).

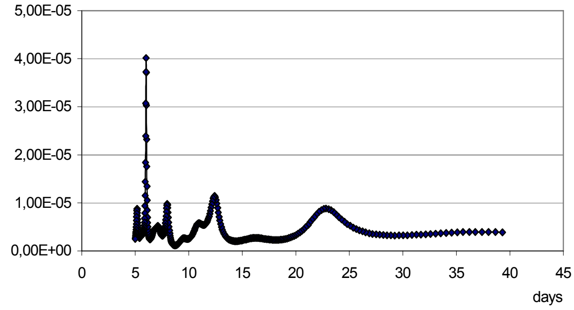


Fig. 32. UP component power spectra hourly solutions (June'97) Jozefoslaw - maximum entropy method Blackman weight window.

Next hourly displacements were averaged over 24 hours and spectrally analysed in the one year span (1997), to compare with daily coordinate solutions power spectra.

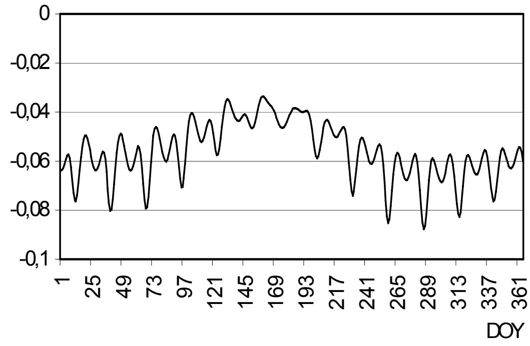


Fig. 33. Daily averaged displacements (UP components –1997).

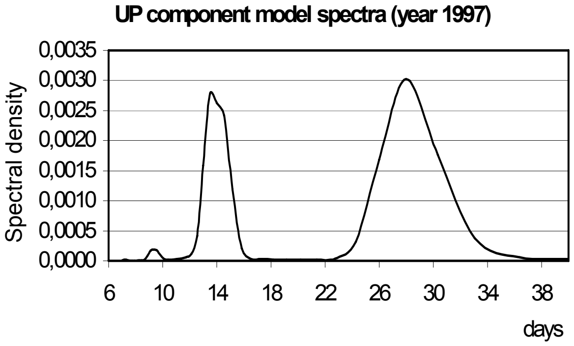


Fig. 34 Spectral analysis of daily averaged hourly deformations (Fourier method).

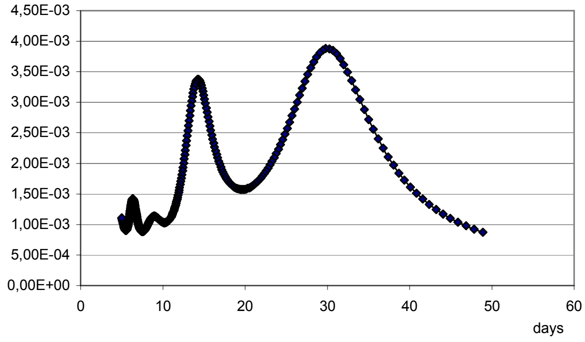


Fig. 35. UP displacement component power spectra (MESA, Parzen window) – daily solutions (1997).

It is worth noting that both Fourier and MESA spectra of UP component shows especially good conformity with the tidal model.
Hourly observations was subject of the band-pass filtering (FFT filter) of 12 and 24 hours period.
Extracted oscillations were summed and can be compared to the model (Up component below).

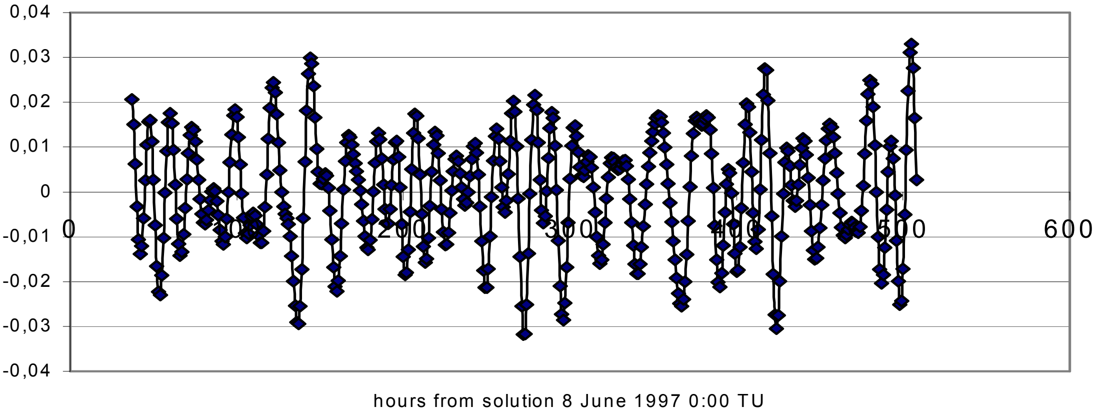


Fig. 36. Two periods (12, 24) filtered from hourly solution.

2.4.8 Studies on inflences of regional hydrology to the high obtined from PPP GPS analysis

The main goal of this studies was to compare hydrological loading with changes of height obtained from GPS measurements.
We used WaterGAP hydrology model which is very well suited for our investigations as it contains equivalent of all kinds of water i.e. canopy, snow, soil-water, groundwater, surface water (rivers, lakes, wetlands, inundation areas). Moreover, this model has appropriate temporal (month) and spatial (0.5 degree) resolution. Total continental water storage was used to compute temporal crustal deformation using convolution with Green function for PREM Earth Model according to equation:

$$L(r) = \rho \iint\limits_{Earth} G(|r - r'|) \cdot H(r') \cdot dA$$

where ρ is density of water, *G* is integrated Green function given by (Farell 1972), *H* is height of equivalent of water in cell and *dA* is elementary surface.

Numerical experiments showed that it is necessary to consider wide area in those computations – at least a few thousands of kilometres far from station.

For comparison with observed signal we computed variations of height from GPS measurements in Józefosław. For this purpose we used Precise Point Positioning technique (using consistent products - "repro1") as it is free from any network constraints and correspond to position changes relative to geocenter.

Deformations caused by continental water storage has strong yearly signal with range of 1cm (Fig. 37). In processing results we see clearly yearly signal with amplitude of the same level. In those result we can see also half-year period which is probably due

aliasing problems. However the agreement of seasonal height variations is very well, some discrepancies could be due other loading effects (i.e. atmospheric pressure).

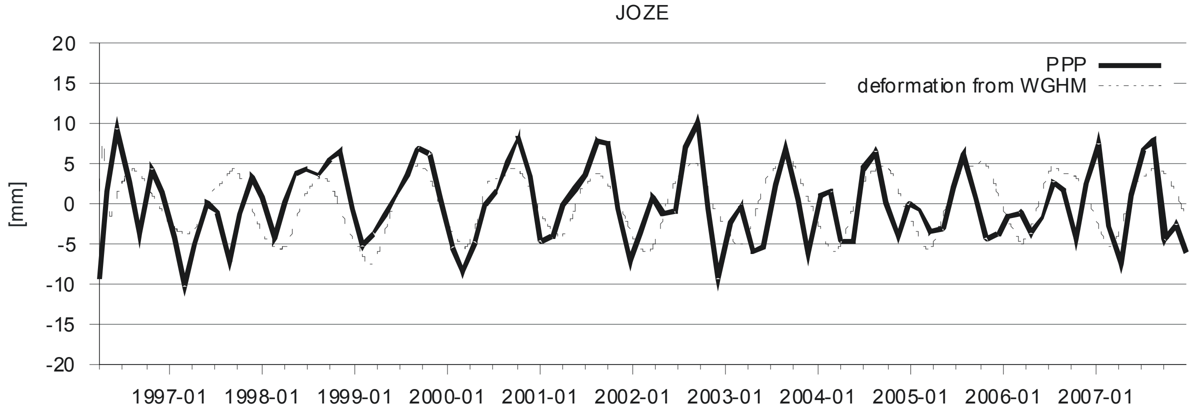


Fig. 37. Height changes from smoothed GPS daily PPP results (with Bezier curve, solid line) compared with modelled deformation(intermittent line).

2.4.9 Conclusion about studies on deformations models

Joint analysis of the astrometric, gravimetric and GPS observation did not allowed us to improve the tidal model that actually is used by Warsaw University of Technology EUREF Analysis Centre (compatible with IERS standards). It was mainly caused by the low accuracy of the astrometric measurements in spite of the systematic error removal and recalculation to the HIPPARCOS catalogue. Further research under the tidal model improvement will be held as a part of GPS data processing using Bernese software probably using PPP technology.

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