CURRENT STATUS AND PLANS OF THE EUREF WUT LOCAL ANALYSIS CENTRE

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ABSTRACT

The GPS Processing Centre at the Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology (IGGA WUT) was established in the early 1990s. In 1992 it started data processing of large geodetic networks, including EXTENDED SAGET frame which was observed on yearly basis over the years 1992-1998. CERGOP Processing Centre was set up in 1994. The Centre performed data processing of the successive campaigns conducted annually in the years 1992- 1998 on the CEGRN frame established within this project. In 1996 the WUT GPS Processing Centre became one of the European Local Analysis Centres operating within the framework of EUREF (WUT EUREF LAC). The Centre performs systematic data processing for a selected number of permanent stations, which participate in the EUREF permanent network.

For several years now research and works have been conducted on continuous monitoring of the ionosphere and troposphere and on modelling geophysical phenomena for the GPS needs. This paper presents current state of the art of the Centre's activities.

1. INTRODUCTION

The basic responsibilities of the Processing Centre include:

- **Participation in the processing of the permanent EUREF frame, which includes 22 stations from Central and North Europe;**
- **Processing of CEGRN and EXTENDED SAGET, which include about 50 stations,**
- **Processing of the local networks for geophysical and geodetic needs in the area of Poland,**
- **Testing the hourly data computation strategies.**

The analysis of observations from 1998 performed by the Processing Centre of WUT is based on Bernese v 4.0 and authorial software. In 1996 the Observatory joined the group of the ten centres which are to process the permanent EUREF network. Each of the centres is responsible for processing a certain specified section and the results are presented as a system of standard equations written down in SINEX format (the format for the exchange of computation results between various programmes).

The essential thing in this kind of computations is the invariability of the a priori parameters. For this reason, the Processing Centre for the EUREF network, seated in Brussels, has to be informed of each and every change being introduced. All computations are fully automated. In the beginning, due to frequent changes and testing of the computation methods, the computation process used to be a part of a larger system whose aim was to carry out a detailed analysis of both the data, the results of computations and the strategy of solutions for GPS permanent networks.

Finally the following strategy of the computations has been developed:

1. Checking and preparation of observation data.
2. Introduction of precise efemeris, the Earth rotation parameters, etc.,
3. Clock corrections and information on errors in satellite motion are collected from CODE.
4. Transformation of the data from RINEX2 to BERNESE formats.
5. Comparison of the single differences and networks with n-1 number of vectors.
6. Automatic removal of the phase ambiguities in a two-step iterative process.
7. Determination of the phase ambiguities for each baseline.
8. Determination of the ionosphere parameters.
9. Final estimation of the coordinates of the stations.

All the processes are performed using BPE module (Bernese Processing Engine), which together with Bernese software constitutes the nucleus of the computations. At present, being regarded as an integral unity, the computation system has been ceded onto the account of EUREF so as to eliminate any out-of-control changes in the tests. Daily solutions, based on normal equation, are used to develop weekly equations, which are then sent to IFAG and its European Data Centre. In addition to its basic duty, which is weekly solutions within the framework of IGS/EUREF, the centre is responsible for testing strategies and new models of geophysical phenomena as well as those, which affect the determination of coordinates in the GPS system.

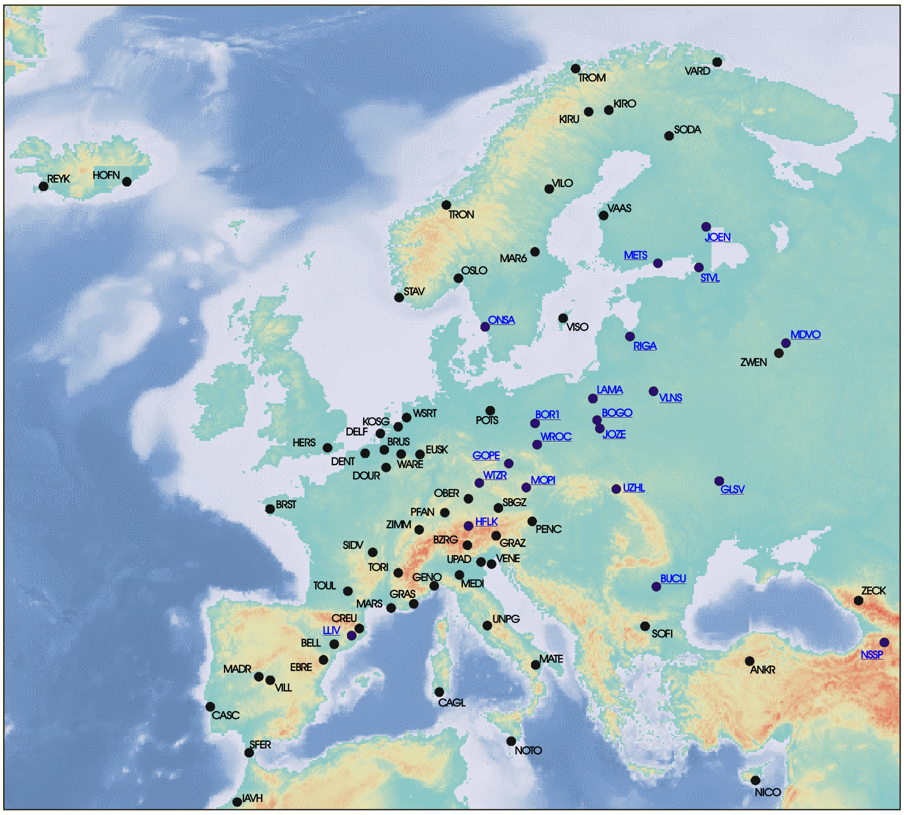

Fig. 1. IGS sites in Europe (underlined – sites adjusted by WUT EUREF LAC)

2. ACTIVITIES WITHIN THE EUREF FRAME.

The WUT EUREF LAC (Warsaw University of Technology EUREF Local Analysis Centre), which is an integral part of the Astro-Geodetic Observatory at Józefosław, deals with day-to-day data processing for the regional subframe EUREF consisting of 19 stations located in Central Europe and the several epoch campaigns. The works are performed within the framework of IGS (International GPS Service for Geodynamics) and they are aimed at developing a new strategy for the distribution of sites within the ITRF (IERS Terrestrial Reference Frame) by combining local and regional solutions with the IGS global one. Today the WUT EUREF Local Analysis Centre is a one the 11 centre of this kind operating in Europe. The distribution of the global IGS stations in Europe and those of the local EUREF frame, which is processed and analysed by the WUT Local Analysis Centre, is shown in Fig. 1. One of the products of the Centre's activity are daily coordinates of adjusted stations. Fig. 2 presents latitude, longitude and height of Polish EUREF stations registered from 1996 to end of 1998.

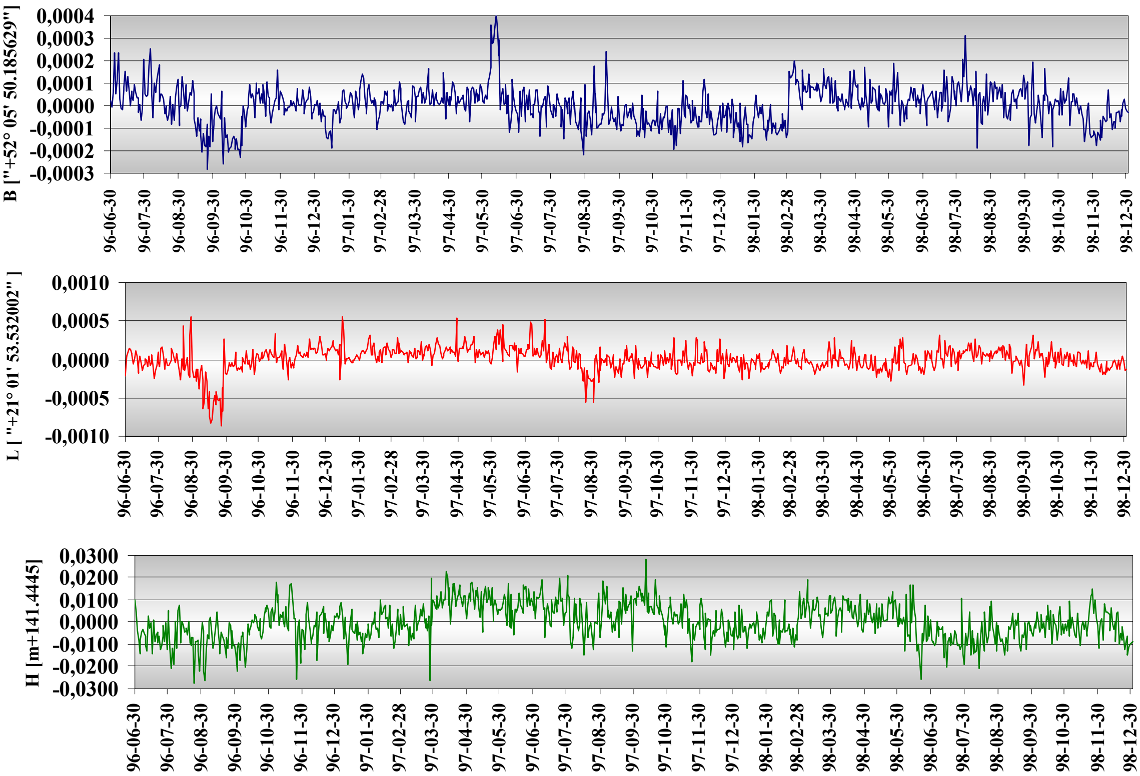

Fig. 2A. BLH coordinates of Józefosław site.

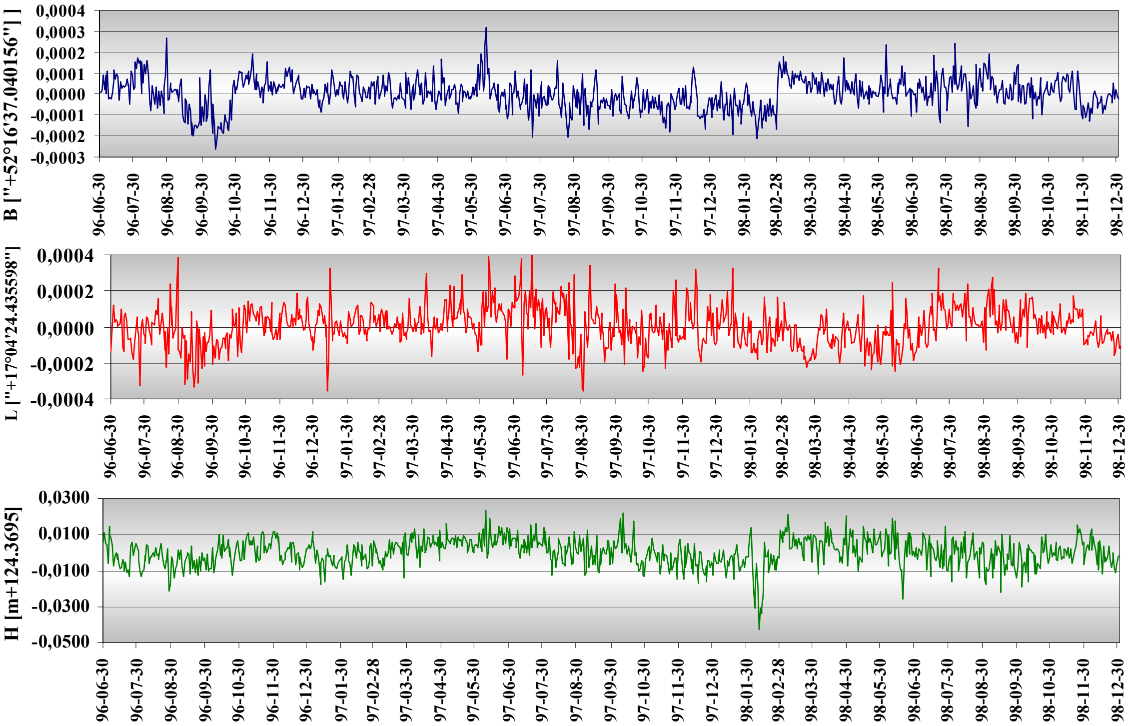

Fig. 2B. BLH coordinates of Borowiec site.

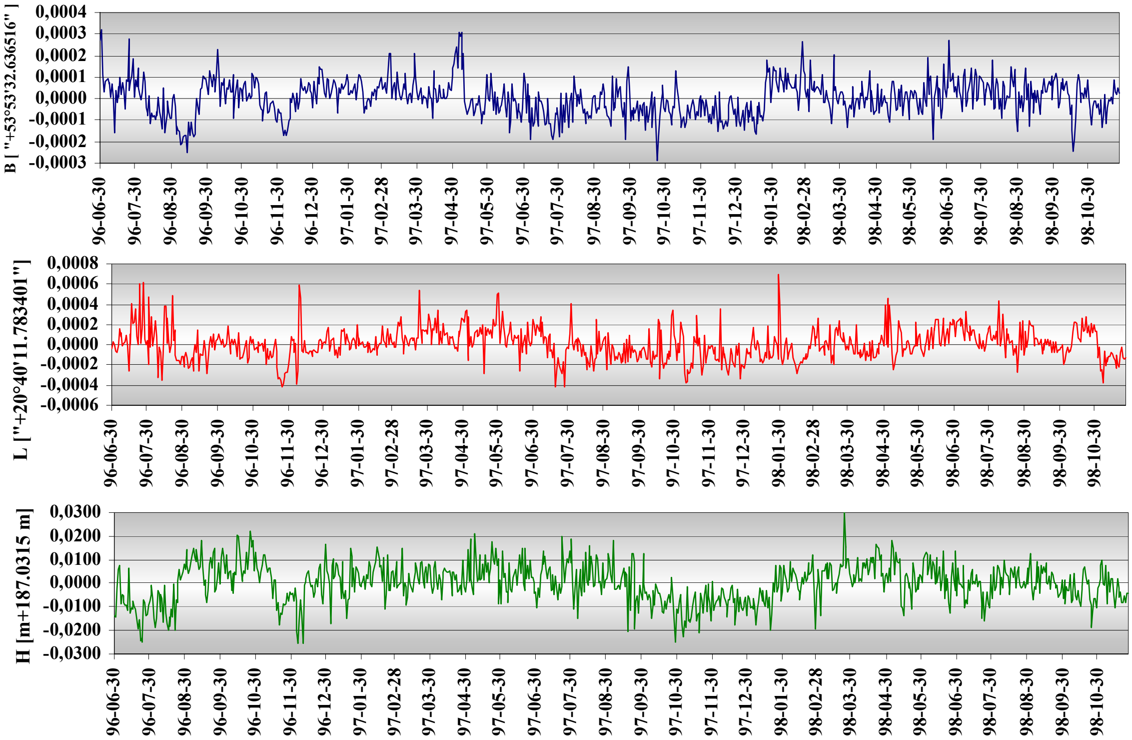

Fig. 2C. BLH coordinates of Lamkówko site.

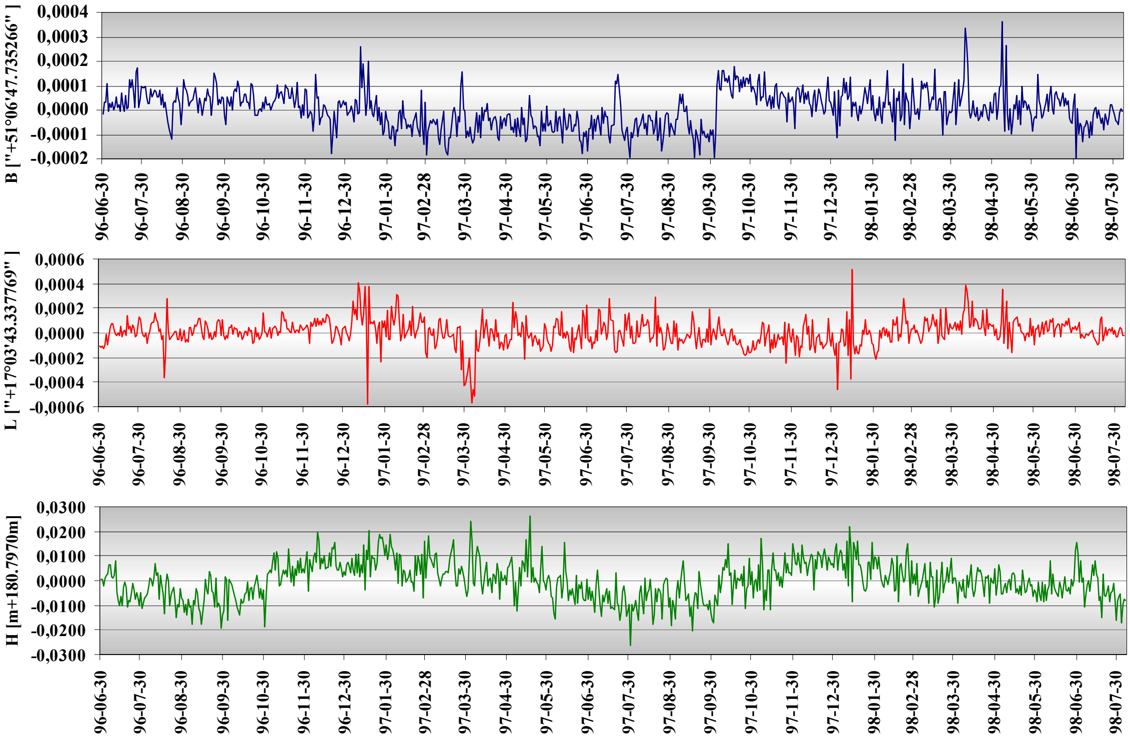

Fig. 2D. BLH coordinates of Borowa Góra site.

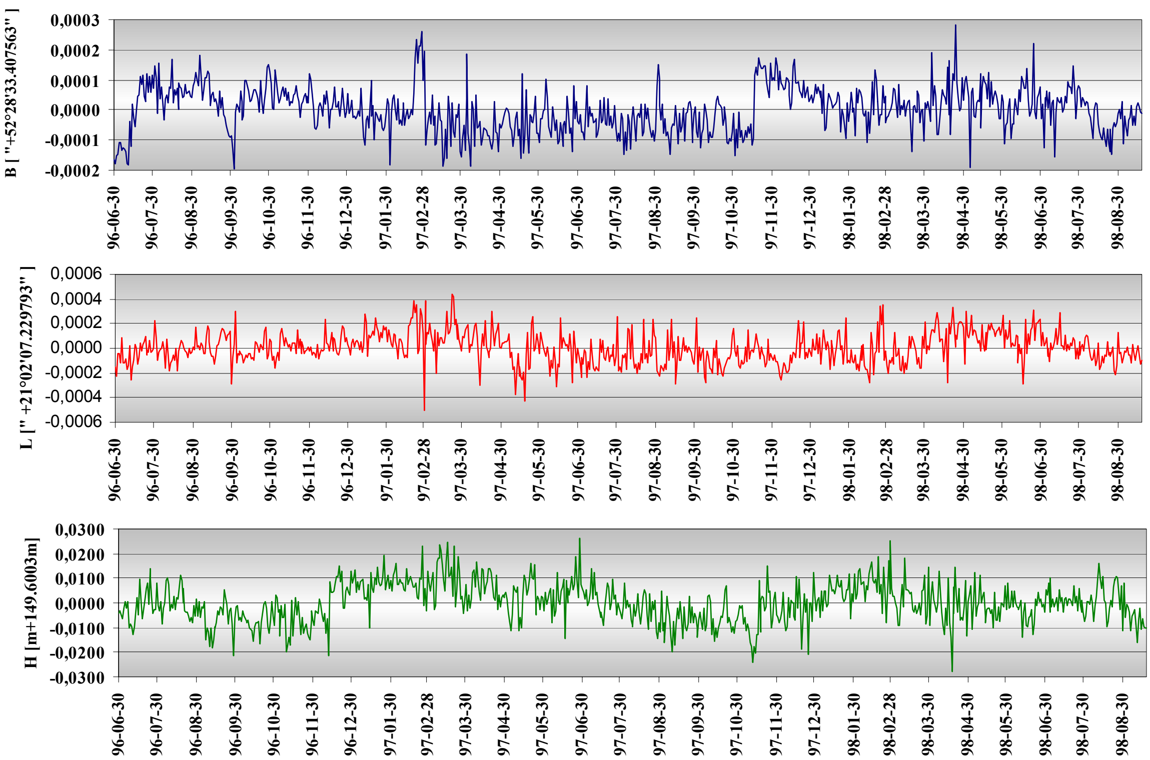

Fig. 2E. BLH coordinates of Wrocław site.

All coordinates presented above are linear trend eliminated. The magnitudes of these trends of the coordinates are confronted in Table 1. Table 2 presents results of spectral analysis of the height changes after height approximation by the model presented on Fig. 3.

Table 1

Station	North [cm/year]	East [cm/year]
Borowiec	1.59	1.99
Józefosław	1.54	2.23
Lamkówko	1.49	2.02
Wrocław	1.57	2.03

Table 2

Station	Period	Amplitude [mm]	Ampl. error [mm]	Phase [°]	Phase error [°]
JOZE	1 rok	2,25	0,37	110,06	9,53
	½ roku	3,97	0,37	31,54	5,39
BOGO	1 rok	5,49	0,36	73,72	3,75
	½ roku	3,58	0,36	357,94	5,73
BOR1	1 rok	4,43	0,37	110,63	4,82
	½ roku	2,42	0,37	9,55	8,88
LAMA	1 rok	6,36	0,41	102,40	3,65
	½ roku	1,87	0,40	60,74	12,36
WROC	1 rok	6,28	0,31	86,84	2,84
	½ roku	2,66	0,31	359,44	6,72

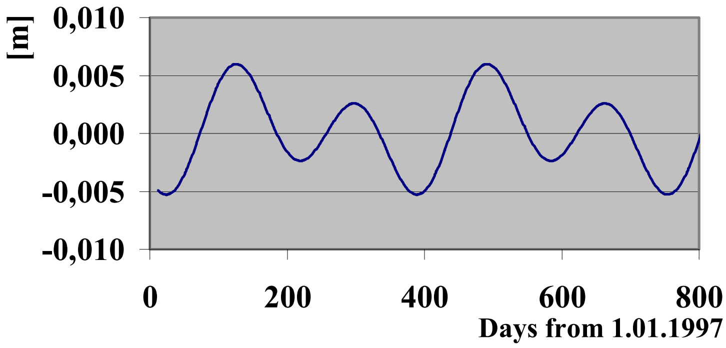

Fig. 3. Model of the height changes.

3. TESTING THE ADJUSTMENT OF 1-HOUR GPS OBSERVATIONS.

Adjustment of 1-hour GPS observations is now in the pilot phase. It is based on the Bernese v 4.0 software with self-written BPE module (Bernese Processing Engine). Only a couple of stations are storing and sending observations with 1-hour intervals. They are:

BOGO (Borowa Góra, Poland)
BOR1 (Borowiec, Poland)
GOPE (Pecny, Czech Republic)
GRAA (Graz, Austria)
PENC (Penc, Hungary)
PFAN (Pfander, Austria)
UPAD (Padova, Italy)
ZIMM (Zimmerwald, Switzerland)

The difficulties with data sending from particular stations disabled us to improve final version of data adjustment. Taking this into account we had to elaborate new method of 1-hour data acquisition from daily RINEX files. Observations prepared in this way are almost identical with 1-hour ones, but created with a big delay.

A several tests were performed before final data processing system preparation. They were aimed at determination of the magnitudes of changes of results compared to daily observation adjustment.

In 1-hour GPS observations we are able to register only 120 30-seconds epochs. In such a short time we have to use all of the observations performed (in daily data adjustment – one from every three). Within one hour we observe, as a rule, the same satellites and we can define a priori errors of phase ambiguity determination in easier way, without they weighting. Although computer simulations showed us, that in spite of this convenience phase ambiguity determination for hourly GPS data is almost impossible because of a great changes of the station coordinates in the consecutive solutions.

In daily solutions there are assumed the mean month coordinates, which errors amounted 1-2 cm in all three components. Phase ambiguities for each baseline independently are determined by fixing coordinates of one of the vector's point. If we apply such a solution to hourly observations we will be able to determine only 10% of ambiguities. This problem may be solved by determination of the temporary coordinates without specifying of the ambiguity, which could be then used a priori for each baseline ambiguity determination.

Point's coordinates of particular vectors are then assumed as erroneous. This modification enabled us to determine above 60% ambiguities. This value may be different for each baseline because of distinctions in baseline lengths, which is also important factor in QIF strategy of solution. Taking the above remarks into account we determined minimum value of observation epochs to be needed for baseline creation.

We also analysed possibility of elevation mask changes. Assumption of 15 degrees caused loss of a part of observations (10-15%). But this value is a minimum for Saastamoinen model application, so we were made to apply another model for lower elevations (e. g. Neill model). As an optimum value we have assumed 10 degrees of elevation mask, but we think that this value have to be assumed individual for particular stations.

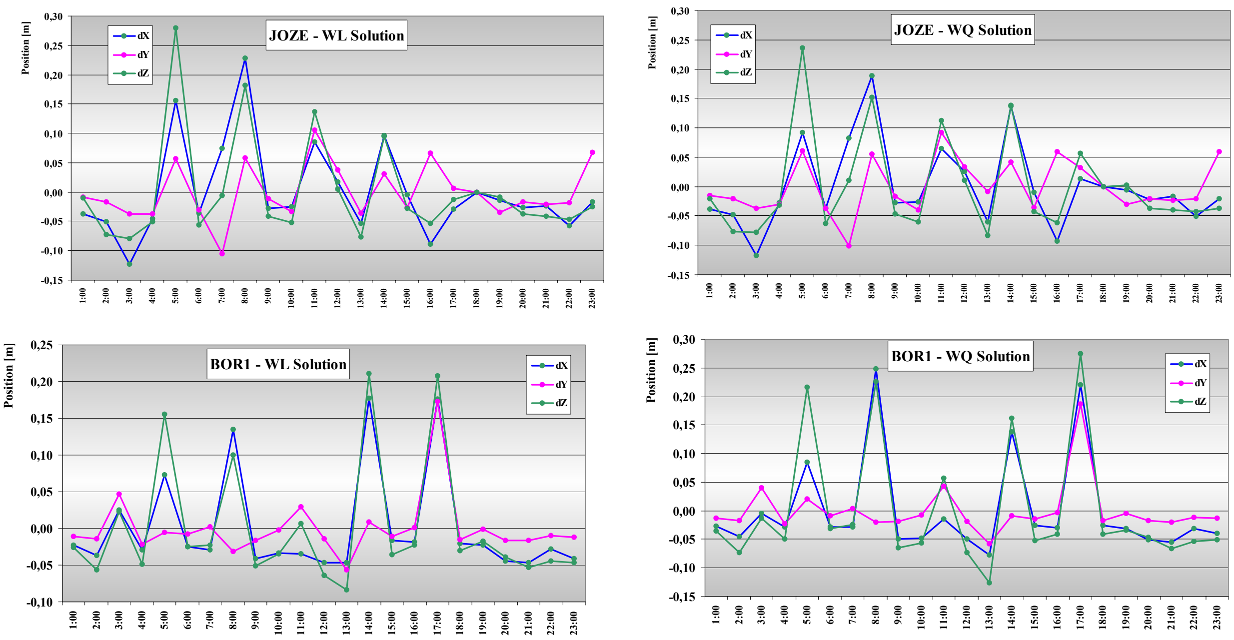

Fig. 4. Hourly solution for two Polish IGS stations.

In pilot tests we have also introduced ocean loading model according to IERS standards and diurnal and sub-diurnal tide terms in polar motion. Fig. 4 presents results of such processing. On this figure WQ means base solution without ocean loading and diurnal and sub-diurnal tide terms in polar motion introducing, elevation mask – 10 degrees, a priori assumption of estimated phase ambiguities, full tropospheric delay determined once every 15 minutes. WL means solution with ocean loading and diurnal and sub-diurnal tide terms in polar motion.

We also estimate ionosphere parameters for particular processing session, by development into spherical harmonics of 12th degree and 8th order. Results are stored in IONEX format and compared to the daily ones. For each session we also generate normal equations, which serve as a basis for combining of hourly to the daily solutions.

4. EPOCH CAMPAIGNS.

The Astro-Geodetic Observatory at Józefosław is one of the major sites in the CERGOP project (Central Europe Regional Geodynamics Project) and its Processing Centre is one of the basic Analysis Centres in this project. All works related to the project are coordinated by section C "Geodesy" of the Central Europe Initiative (CEI). The Processing Centre is responsible for the analysis of the Central European GPS Regional Network (CEGRN) and EXTENDED SAGET network (Fig. 5). The detailed results of these campaigns are presented in scientific works numbered [4] and [5] in Bibliography. In this paper we would like only exhibit the velocity vectors of Eurasian Plate evaluated by our Centre according to CEGRN and EXTENDED SAGET campaigns (Fig. 6).

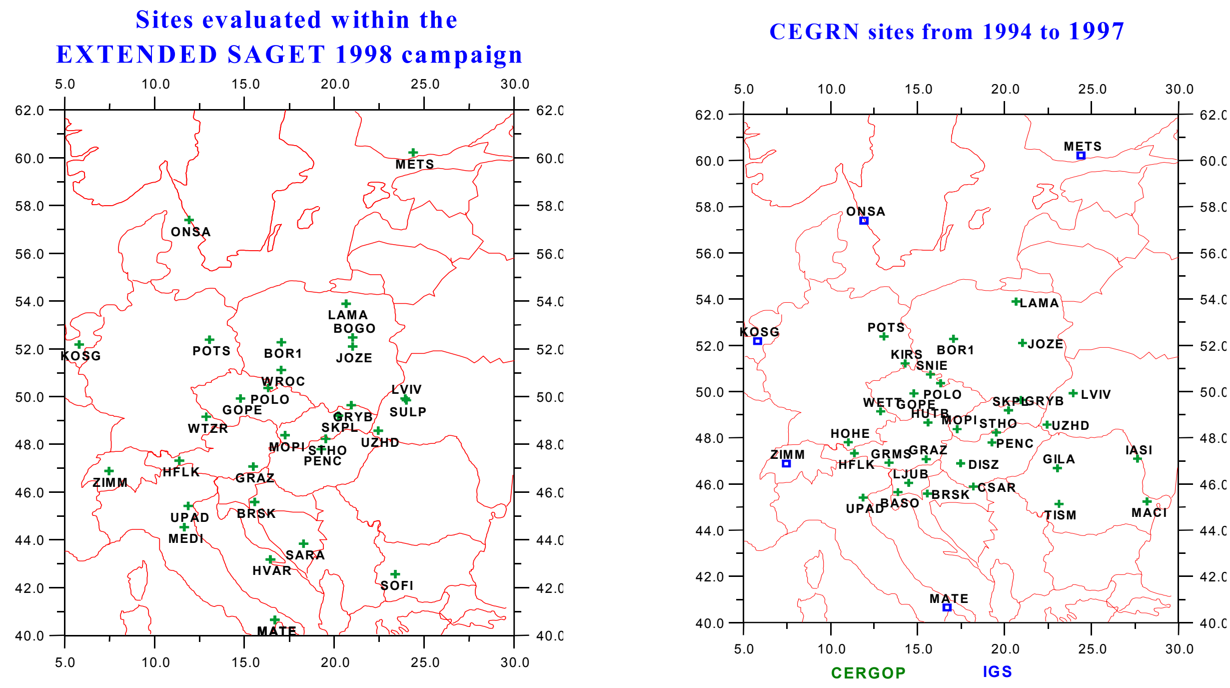

Fig. 5. CEGRN and EXTENDED SAGET projects.

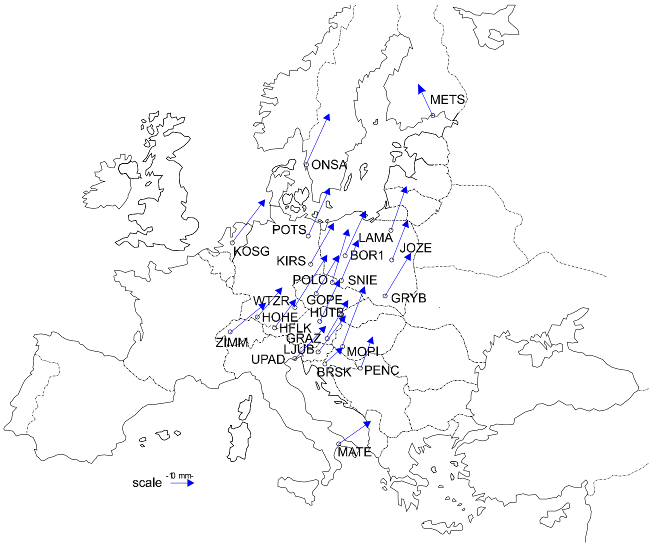

Fig. 6. Eurasian Plate motion determined from CEGRN and EXTENDED SAGET campaigns.

5. ATMOSPHERE PROBING BY GPS.

The computation methods developed in 1996-1998 allowed achieving the accuracy of up to 1 cm for the two-dimensional components and 1,5 cm for the height estimated based on the analysis of the repeatability of coordinates for the past three years. By completing such results, we were led to verify the computation method and modify our approach to the phenomena of atmospheric interference that occur in the troposphere and ionosphere and had always been treated as a source of the radio signal interference. Armed with highly accurate GPS ephemerides and coordinated determined with an accuracy of 1 cm, we can regard space as a source of information and try to model its parameters.

According to these assumptions we are able to estimate two parameters responsible for iono- and tropospheric delay in GPS bands. Examples of the maps of TEC (total electron content) are presented in Fig. 7.

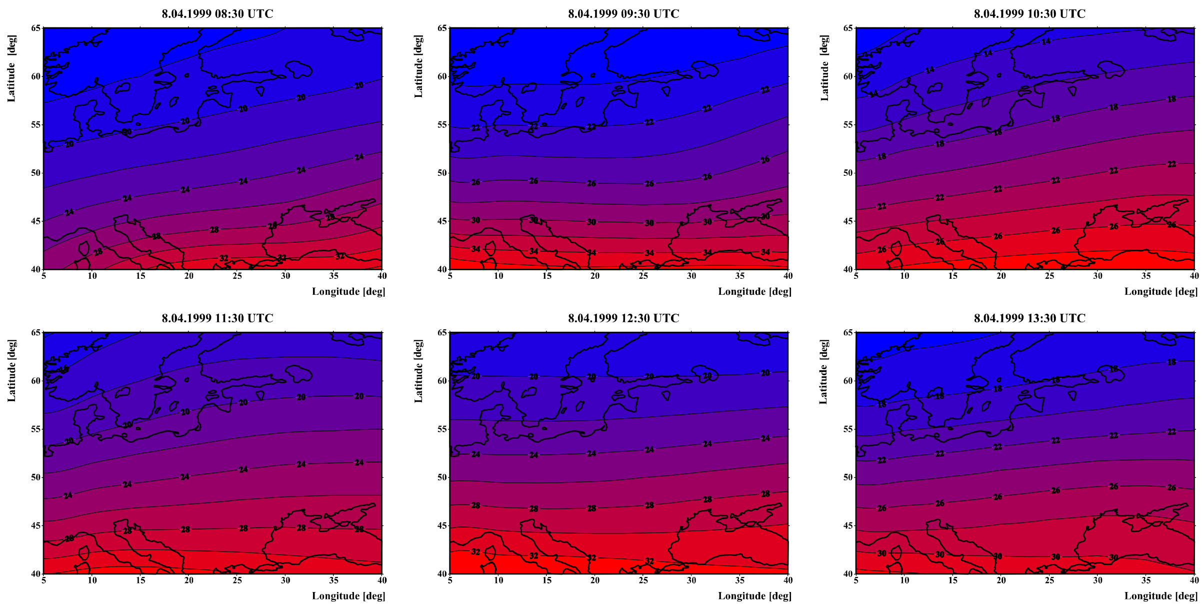

Fig. 7. Magnitude of TEC for Central Europe (in TECU).

Water and water vapour have a great influence to processes taken place in the troposphere also in local weather as well as global climate changes. The great dynamics of the water vapour changes in the atmosphere is major obstacle in creating a model of the troposphere, which will be able to describe with a big probability, every changes in the time ahead. The methods of the adjustment of the GPS data developed in last few years make us possible to determine the delay in the GPS signal carrier band and extricate the part caused by water vapour. From the geodetic point of view atmosphere is a main source of the errors, which are eliminated in the GPS data adjustment. When we know high-accurate coordinates of the station and we've got the precise satellite orbits then we are able to estimate the total zenith tropospheric delay, which depends also upon mapping function applied to satellites in greater zenith distances.

Exact relation between the wet delay and total amount of the water vapour in the vertical direction (IWV) as written in equation (1), where the inquired value κ is given by next relation. *R* is gas constant for the water vapour and T_m is the term so-called „mean temperature" weighted by pressure, which is described by equation (10).

$$IWV = \int \rho * r * dh \approx \kappa * \Delta^{o}_{trop,wet} \qquad \textbf{(1)}$$

$$\frac{1}{\kappa} = 10^{-6}\left(\frac{C_3}{T_m} + C_2^{'}\right)R_V \qquad \textbf{(2)}$$

$$T_m = \frac{\int \frac{P_V}{T} dh}{\int \frac{P_V}{T^2} dh} \qquad \textbf{(3)}$$

Pressure and temperature vertical profiles in this relation should be determined from the atmospheric sounding. In case of absence of such a data we can use the experience-determined function, which is describing the correlation between mean temperature and the temperature measured at the surface (Davis, 1985; Bevis *et al.*, 1992). After stochastic estimation of zenith total tropospheric delay coming from a priori model of tropospheric refraction if we have meteorological data collected at GPS sites determination of wet delay (i.e. total delay – hydrostatic delay from Elgered formula (1991)) is possible. Calculating Integrated Water Vapour/Precipitable Water goes like above.

Fortunately in closer vicinity of Warsaw routine radiosonde observations are performed by polish Institute of Meteorology and Water Administration in Legionowo station. This is roughly between two permanent GPS sites JOZE and BOGO (8 km distance).
We will use this possibility not only to compare 'in situ' calculated tropospheric delays but to check and improve model parameters hitherto applied.

Using radiosonde data in one year span we've got local formula for mean temperature:

$$T_m = 99.6 + 0.617 * T_s$$

This coefficient values (in K) vary between day and night and from month to month. Quality of adjustment can be seen in Fig. 8.

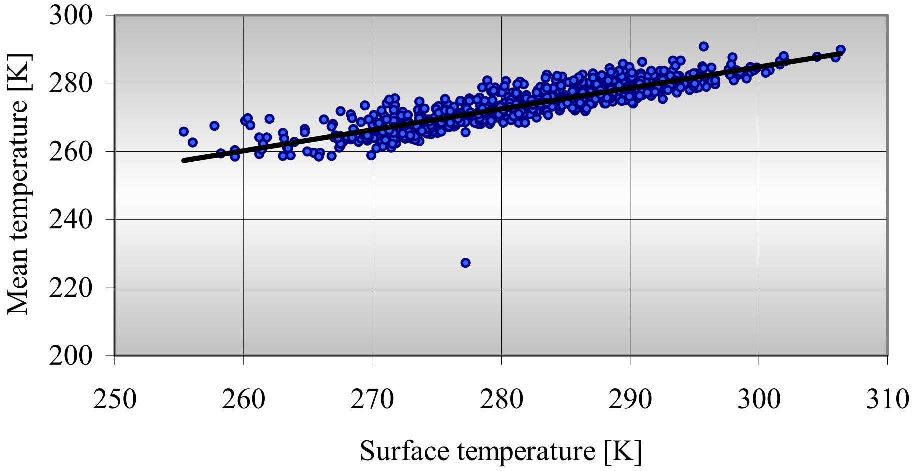

Fig. 8 Mean temperaure relative to surface temperature.

Zenith wet delay calculated by numerical integration of radiosonde profile shows considerable correlation with these derived from GPS processing but is biased by some systematic and scale errors (probably caused by inputs in Elgered formula (Fig. 9,10)

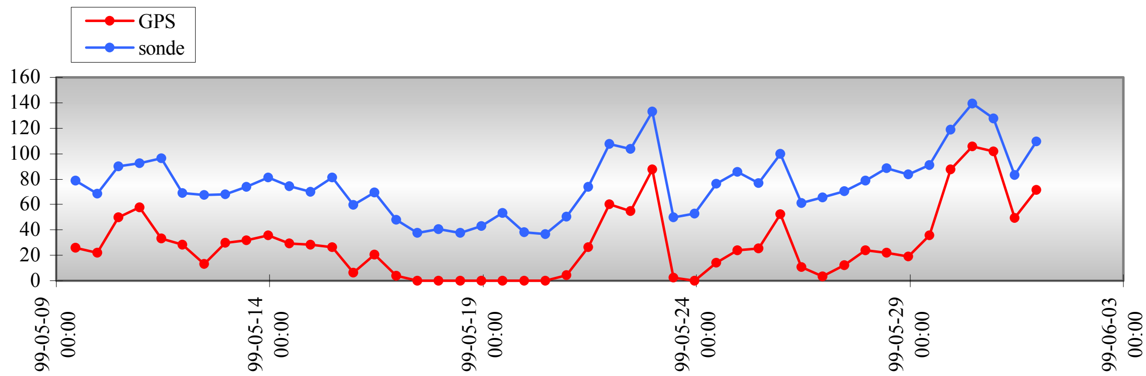

Fig.9 Zenith Wet Delay from radiosonde and WUT solution for JOZE

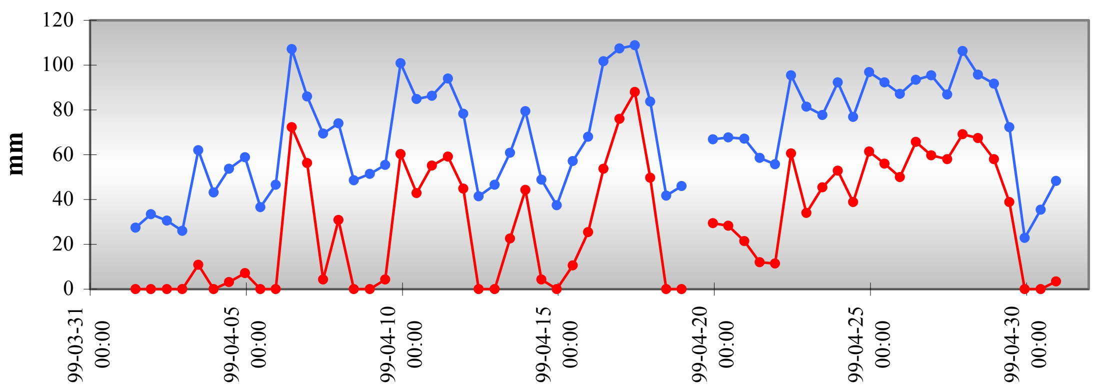

Fig. 10 Zenith Wet Delay from radiosonde (high) and GPS (BOGO - CODE sloution) (low).

The goal of further studies will be to assess model coefficients for every EUREF site separately and maybe creating some regional model. We will test the possibilities of constant monitoring of the changes in the troposphere to support meteorological activities in a small as well as in the large area. As proposed in numerous publications GPS networks will act as an auxiliary meteorological tool (especially in weather prediction). For connection between GPS and meteo quantities see Fig. 11,12

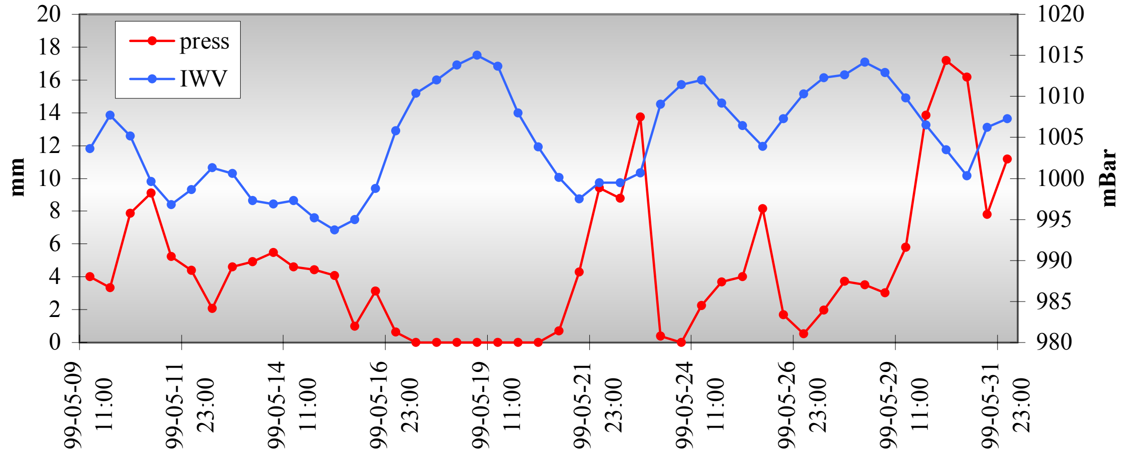

Fig. 11 Integrated Water Vapour (GPS) vs. surface atmospheric pressure

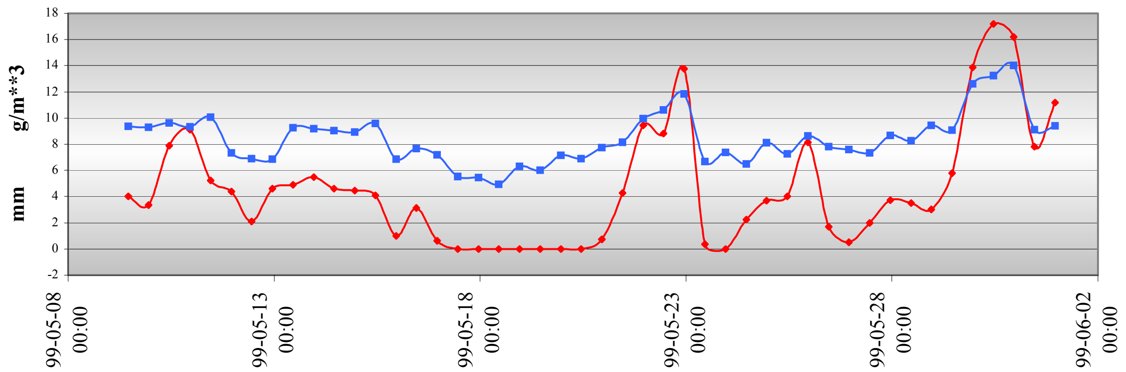

Fig. 12 IWV (from GPS) vs. absolute humidity

Next step will be collaboration with the team of Interdisciplinary Centre for Mathematical and Computational Modelling in Warsaw maintaining UMPL weather model which could both act as a source of vertical profiles and use GPS IWV assessments as additional constrain.

6. PLANS FOR THE FUTURE

Apart from a standard processing performed for the EUREF subnetwork, the Centre is engaged in research on new methods of processing GPS observations with a special emphasis laid on hourly observations. For this purpose, models of geophysical effects, such as the Earth tides, ocean and atmosphere loading are tested. The research is aimed, above all, at increasing the stability of the solutions at both daily and hourly intervals.

7. CONCLUSIONS.

Research performed by the Warsaw University of Technology Local Analysis centre aims at improving the method of processing GPS observations. Research on the troposphere and ionosphere will be of prime importance among the research to be conducted in 1999. The research will focus on improving the accuracy of the tropospheric refractory correction and ionospheric delay in GPS observations. It will be possible to conduct this research on condition that hourly data can be transmitted in real time and processed in quasi-real time within the framework of the local EUREF network. Works connected with the introduction of the hourly service are soon to be finalised.

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