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Contents

1. REFERENCE FRAMES AND REFERENCE NETWORKS

1.1. INTRODUCTION

This part of the Polish National Report on Geodesy is the quadrennial report on research activity concerning reference frames and reference networks performed in Poland in a period 2003-2006. It contains a summary of the works on implementation of IAU2000 and IUGG2003 resolutions on reference frames, the state of art of Polish national zero-order geodetic control network, permanent GPS stations operating in Poland, active GPS/DGPS station network in Poland, vertical network, Polish national gravity control network, Polish national magnetic control as well as theoretical works on network solutions. The activities concerning reference networks were conducted mainly in the following research centres, listed in an alphabetic order:

- Chair of Satellite Geodesy and Navigation, University of Warmia and Mazury in Olsztyn;
- Department of Geodesy and Geodynamics, Institute of Geodesy and Cartography in Warsaw;
- Department of Planetary Geodesy, Space Research Centre, Polish Academy of Sciences in Warsaw;
- Institute of Applied Geodesy, Warsaw University of Technology;
- Institute of Geodesy, University of Warmia and Mazury in Olsztyn;
- Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology.

The content of the chapter is based on the material prepared by Jan Krynski, Adam Lyszkowicz, Stanislaw Oszczak, Witold Proszynski, Jerzy B. Rogowski, Andrzej Sas-Uhrynowski, Zbigniew Wisniewski and Ryszard Zdunek.

The bibliography of the related works is given in references.

Annual national reports to the IAG Sub-commission for EUREF (Krynski et al., 2004a, 2005a, 2006a, 2007a) contain the extensive information on the activities concerning reference networks in Poland within the reported period.

1.2. IMPLEMENTATION OF IAU2000 AND IUGG2003 RESOLUTIONS ON REFERENCE SYSTEMS

The resolutions of the IAU XXIV General Assembly (Manchester, 2000) on reference systems, adopted by the IUGG XXIII General Assembly (Sapporo, 2003) were recommended for implementation starting from 1 January 2003. An extended research on the implementation of the new paradigm of celestial reference systems, time systems and transformations was performed at the Department of Geodesy and Geodynamics of the Institute of Geodesy and Cartography, Warsaw (Krynski, 2004c). New algorithms and computing programs were developed for calculating ephemeris for the Astronomical Almanac (Rocznik Astronomiczny) of the Institute of Geodesy and Cartography (Fig. 1.2.1). The Astronomical Almanac for the year 2004 (Krynski and Sekowski, 2003a) of the Institute of Geodesy and Cartography was the first Astronomical Almanac in the world that fully implemented the IAU2000 resolutions with complete description of new systems and transformations. Following editions of the Astronomical Almanac (Krynski and Sekowski, 2004b, 2005b, 2006b) have subsequently been updated. The 2007 edition of the Astronomical Almanac (Krynski and Sekowski, 2006b) additionally implemented the resolutions of the IAU XXVI General Assembly in Prague in 2006.

Fig. 1.2.1. The Astronomical Almanac of the Institute of Geodesy and Cartography

Numerous aspects concerning celestial and terrestrial reference systems, time systems and relevant transformations were the subject of research of a few research groups. An extensive discussion of those matters including nomenclature and educational aspects took place during the workshop on "New celestial and terrestrial reference systems and their mutual relationship" in Warsaw in 2004 (Brzezinski, 2004; Kolaczek, 2004a, 2004b; Kosek et al., 2004; Krynski, 2004a, 2004b; Krynski and Rogowski, 2004; Rogowski and Figurski, 2004; Sekowski, 2004, 2006b). Also the influence of choice of fundamental catalogue on calculated apparent places of stars was investigated (Sekowski, 2006a).

1.3. MAINTENANCE OF THE EUREF-POL, POLREF AND EUVN NETWORKS

Raw data from the EUREF-POL, POLREF and EUVN campaigns that made the basis of the Polish national geodetic reference were substantially verified in the Institute of Geodesy and Cartography, Warsaw in cooperation with the Military University of Technology, Warsaw (Krynski and Figurski, 2006). Data from those campaigns were reprocessed using unified EPN standards. The results obtained have been carefully analysed. The superiority of the solutions obtained in the ITRF2000 over those obtained in previous realizations of the ITRF was indicated. The use of new antenna models, processing all data in one block, precise determination of velocities of reference stations as well as careful analysis and verification of source data also contributed to the reduction of standard deviations of coordinates determined. Referencing all campaigns to the same permanent stations allows for eliminating biases.

Measured with standard deviations uncertainty of station coordinates obtained from the 2005 solution for the POLREF network are substantially larger than those from the original solution of 1996. The fit of the POLREF sites coordinates calculated using data from control survey to those from reprocessing the POLREF campaign in 2005 is twice better than to those from the 1996 solution. Mean square errors of adjusted coordinates of the EUREF-POL, POLREF and EUVN sites in the ITRF are given in Table 1.3.1 (Krynski and Figurski, 2006; Krynski et al., 2007a).

Table 1.3.1. Mean square errors of adjusted coordinates of the EUREF-POL, POLREF and EUVN sites in the ITRF

	ITRF	N [mm]	E [mm	U [mm]
POLREF 1994	ITRF2000	3.09	5.70	9.13
	ITRF92	3.94	6.49	9.67
POLREF 1995	ITRF2000	2.25	2.29	8.28
	ITRF93	2.55	2.46	8.38
EUREF-POL 2001	ITRF2000	1.13	0.81	2.28
EUREF-POL 1992	ITRF2000	2.71	3.92	5.89
	ITRF91	3.31	4.78	6.58
EUREF-POL 1994	ITRF2000	1.76	2.39	4.35
	ITRF92	2.76	3.99	6.07
EUREF-POL 1995	ITRF2000	1.86	2.23	6.49
	ITRF93	1.98	2.28	8.90
EUVN 1997	ITRF2000	0.92	0.86	2.63
	ITRF97	1.44	1.10	3.70
EUVN 1999	ITRF2000	2.09	2.55	3.35
	ITRF97	2.08	2.56	3.37

1.4. OPERATIONAL WORK OF PERMANENT IGS/EUREF STATIONS IN POLAND

Permanent GPS stations of IGS and EUREF networks operate in Poland since 1993. The number of GPS stations in Poland was growing within last years. Recently 10 permanent GPS stations, i.e. Borowa Gora (BOGO, BOGI), Borowiec (BOR1), Jozefoslaw (JOZE, JOZ2), Katowice (KATO), Lamkowko (LAMA), Krakow (KRAW), Wroclaw (WROC) and Zywiec (ZYWI) (Fig. 1.4.1) are in operation in Poland within the IGS/EUREF program (Table 1.4.1).

Fig. 1.4.1. IGS/EUREF network of permanent stations in Poland

Table 1.4.1. Permanent GPS stations in Poland

Name (abbreviation)	Latitude	Longitude	Status	Receiver
Borowa Gora (BOGI)	52º28'30"	21º02'07"	IGS, EUREF	Javad JPS Eurocard
Borowa Gora (BOGO)	52º28'33"	21º02'07"	EUREF	Ashtech Z-12
Borowiec (BOR1)	52º16'37"	17º04'27"	IGS, EUREF	Turbo Rogue SNR 8000
Cracow (KRAW)	50º03'58"	19º55'13"	EUREF	Ashtech μZ-12
Jozefoslaw (JOZE)	52º05'50"	21º01'54"	IGS, EUREF	Trimble 4000 SSE
Jozefoslaw (JOZ2)	52º05'52"	21º01'56"	IGS	Ashtech Z-18
Katowice (KATO)	50º54'20"	18º56'13"	EUREF	Ashtech μZ-12
Lamkowko (LAMA)	53º53'33"	20º40'12"	IGS, EUREF	Ashtech Z-12 Turbo Rogue SNR 8000
Wroclaw (WROC)	51º08'48"	17º03'43"	IGS, EUREF	Ashtech Z-18
Zywiec (ZYWI)	49º41'12"	19º12'21"	EUREF	Ashtech μZ-12

A brief characteristics of those stations is given in Table 1.4.2 (http://www.epncb.oma.be/_trackingnetwork/stations.php). Products of the permanent GPS stations in Poland, together with such stations in Europe, were the basis of the networks that are applied for both research and practical use in geodesy, surveying, precise navigation, environmental projects, etc. Data from those stations is transferred via internet to the Local Data Bank for Central Europe at Graz, Austria and to the Regional Data Bank at Frankfurt/Main, Germany. The EPN stations at Borowa Gora, Borowiec, Jozefoslaw, and Wroclaw participate in IGS/IGLOS program. Borowa Gora, Cracow, Jozefoslaw, and Wroclaw take part in the EUREF IP pilot project (http://www.epncb.oma.be/_organisation/projects/euref_IP/index.php) (Table 1.4.3).

Table 1.4.2. Characteristics of Polish EPN stations

4 char Station ID	Domes Number	**Location**/ Institution	**Receiver**/ Antenna	Started operating	**Meteo**/ Rec. device	Data transfer blocks	Additional observations
BOGO	12207M002	**Borowa Gora** Inst. of Geodesy and Cartography	**Ashtech Z-12 3** ASH700936C_M SNOW	08JUN1996	**Yes** LAB-EL Poland	24 h 1h	Ground water level Astrometry Gravity GPS
BOGI	12207M003	**Borowa Gora** Inst. of Geodesy and Cartography	**Javad JPS Euro-card** ASH700936C_M SNOW	06MAY2003	**Yes** LAB-EL Poland	24 h 1h	Ground water level Astrometry Gravity GPS/GLONASS
BOR1	12205M002	**Borowiec** Space Research Centre, PAS	**Rogue SNR-8000** AOAD/M_T	01JAN1994	**Yes** NAVI Ltd. Poland	24 h 1h	SLR GPS/GLONASS
JOZE	12204M001	**Jozefoslaw** Inst. of Geodesy and Geod. Astr., WUT	**Trimble 4000SSE** TRM14532.00	03AUG1993	**Yes** LAB-EL Poland NAVI Ltd. Poland	24 h 1h	Ground water level Astrometry Gravity tidal GPS
JOZ2	12204M002	**Jozefoslaw** Inst. of Geodesy and Geod. Astr., WUT	**Ashtech Z-18** ASH701941.B SNOW	02JAN2002	**Yes** LAB-EL Poland NAVI Ltd. Poland	24 h 1h	Ground water level Gravity absolute Gravity tidal GPS/GLONASS
KATO	12219S001	**Katowice** Marsh. Off. of the Siles. Prov.	**Ashtech μZ-12** ASH701945C_M SNOW	30JAN2003	**No**	24 h 1h	
KRAW	12218M001	**Krakow** AGH UST	**Ashtech μZ-12** ASH701945C_M SNOW	01JAN2003	**Yes** LAB-EL Poland	24 h 1h	GPS
LAMA	12209M001	**Lamkowko** Inst. of Geodesy, UWM	**Ashtech Z-12 3** ASH700936F_C SNOW	01DEC1994	Yes LAB-EL Poland	24 h	Gravity GPS
WROC	12217M001	**Wroclaw** Univ. of Env. & Life Sciences	**Ashtech Z-18** ASH700936D_M	28NOV1996	**Yes** LAB-EL Poland	24 h 1h	Ground water level GPS/GLONASS
ZYWI	12220S001	**Zywiec** Marsh. Off. of the Siles. Prov.	**Ashtech μZ-12** ASH701945C_M SNOW	30JAN2003	**No**	24 h 1h	

Table 1.4.3. Characteristics of Polish stations participating in the EUREF IP pilot project

Location	Latitude [degrees]	Longitude [degrees]	RTCM message types (update rate [s])	Bitrate [bits/s]	Site log file
Borowa Gora	52.48	21.04	3(10), 18(1), 19(1), 22(10)	4000	BOGI
Cracow	50.01	19.92	1(1), 3(30), 16(60), 18(1), 19(1), 22(60)	1900	KRAW
Jozefoslaw	52.10	21.03	1(1), 3(60), 18(1), 19(1), 22(60), 31(1)	1200	JOZ2
Wroclaw	51.11	17.06	3(30), 9(1), 18(1), 19(1)	6000	WROC

1.5. ACTIVE GNSS STATION NETWORKS IN POLAND

1.5.1. ASG-EUPOS Network

The technical project of the ASG-PL network of active multifunctional permanently operating GPS stations in Poland, ordered by the Head Office of Geodesy and Cartography in Poland, was reviewed in 2000 by the Special Study Group of the Committee on Geodesy and the Committee on Space and Satellite Research of the Polish Academy of Sciences. A subnetwork of the ASG-PL with data processing centre was established in Upper Silesia by the end of 2002, as a pilot project of governmental and regional Silesian authorities. It has reached a preliminary operational stage in February 2003 (Krynski et al., 2004a, 2005a). In 2006, new 4 stations in Malopolska region joined the ASG-PL network. The map of the extended network is given in Figure 1.5.2. The network consists of 9 permanent stations and is recently linked to 10 EPN and IGS stations (BOGI, BOGO, BOR1, JOZE, JOZ2, KRAW, LAMA, WROC, KATO, ZYWI) and eight other permanent GPS stations (CBKA, ELBL, GDAN, JOZ3, KWBB, LAM6, POZN, TORU) (Fig. 1.5.1) that provide GPS data at 5 s sampling rate. The ASG-PL network stations in Upper Silesia and Malopolska region are equipped with Ashtech μZ-12-CGRS receivers with ASH701945C_M SNOW antennas. Observations are acquired at 5 s sampling rate and are transferred to the processing centre hourly. The ASG-PL network operating in the Upper Silesia and Malopolska region is the first stage of the ASG-EUPOS project for the entire territory of Poland.

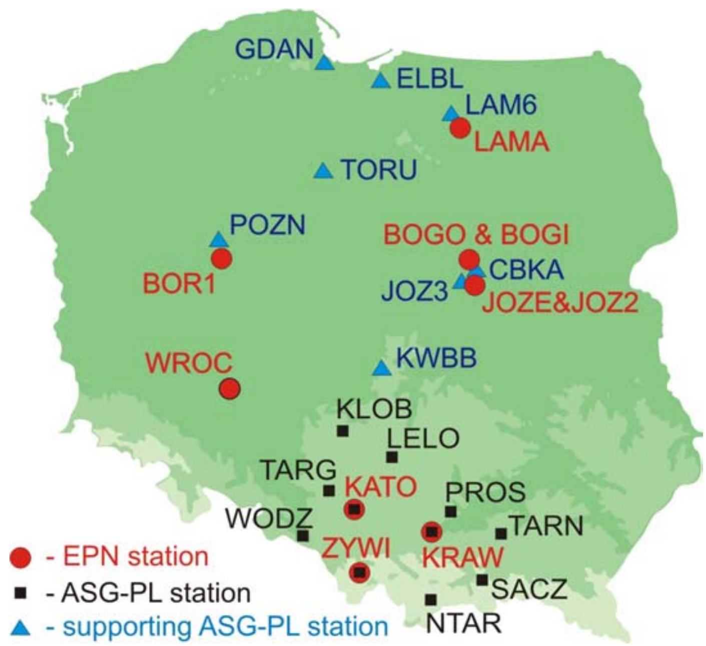

Fig. 1.5.1. Map of ASG-PL stations together with collaborating stations (stage at the end of 2006)

The team of the Chair of Satellite Geodesy and Navigation of the University of Warmia and Mazury in Olsztyn was involved in validation of the performance of the ASG-PL Network (Bakula, 2006).

Fig. 1.5.2. Map of the operating in 2007 part of the Polish Active Control Network for Upper Silesia and Malopolska region

The European Project EUPOS (European Position Determination System) consists in establishment of about 440 multifunctional satellite reference stations in fourteen Central and Eastern Europe countries (Fig. 1.5.3, Table 1.5.1).

Table 1.5.1. Number of planned EUPOS reference stations

Country	Area [km^2]	Number of EUPOS reference stations	Average distance between stations [km]
EU member countries			
Bulgaria	110 950	23	70
Czech Republic	78 870	26	70
Estonia	45 220	13	60
Hungary	93 030	36	70
Latvia	64 600	24	70
Lithuania	65 300	13	70
Poland	312 680	87	70
Romania	237 500	48	70
Slovak Republic	49 035	21	65
Slovenia (observer status)	20 270	15	50
West Balkan States			
Bosnia and Herzegovina	51 000	30	65
Macedonia (Fyrom)	25 330	15	60
Serbia and Montenegro	88 360	32	70
Russian Federation			
Russian Federation	17 075 000	500 stations (in 7 federal districts, will cover not whole area)	30 – 100
Ukraine			
Ukraine	603 700	13	
T o t a l		**900**	

The system will use a standard signal of the European system Galileo as the basis as soon as it is available and is optional for GPS and GLONASS (Sledzinski and Graszka, 2006). The EPN stations included in the EUPOS network give a proper realisation of the reference frame in that network.

The agreement between the Head Office of Geodesy and Cartography in Poland and the Polish Ministry of Economy on financial support for the establishment of 87 EUPOS reference stations in Poland (Krynski et al., 2006a) has been signed in August 2005. The respective fund as given in the Project EUPOS was accepted and support will be given from the structural ERDF EU (European Regional Development Found) programme.

The network of reference stations (Fig. 1.5.4) should become operational by September 2007. The network will provide a signal for both positioning of geodetic control points and for land, air and marine navigation. Several levels of positioning accuracy will be offered. Standard services, as required by the general EUPOS assumptions including the following sub-services: NAVGIS (network RTK for real time kinematic DGNSS applications), NAVGEO (network RTK for precise real time kinematic DGNSS applications), POSGEO DGNSS for precise DGNSS post processing applications will be offered (Sledzinski and Graszka, 2006; Krynski et al., 2007a). Connection to the European reference system ETRS89 will be realised by means the 10 EPN stations in Poland (BOGI, BOGO, BOR1, JOZE, JOZ2, KRAW, LAMA, WROC, KATO, ZYWI).

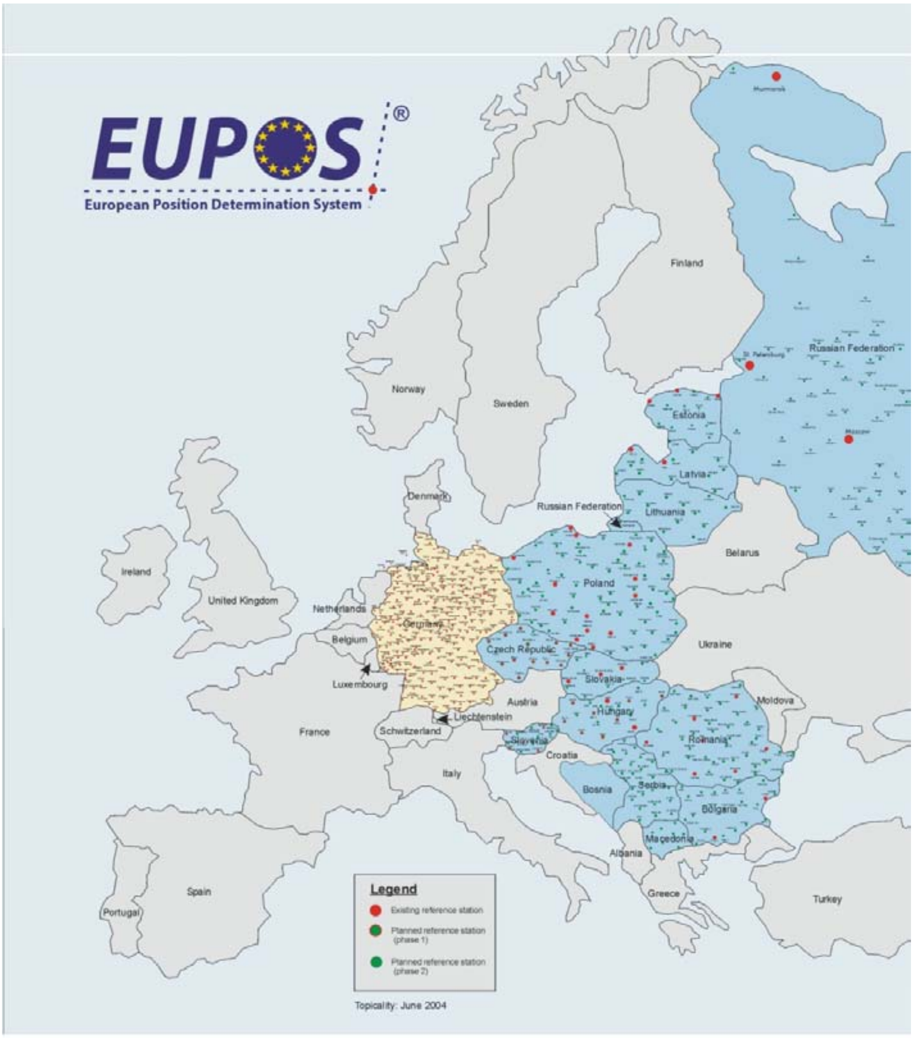

Fig. 1.5.3. Planned and existing EUPOS stations

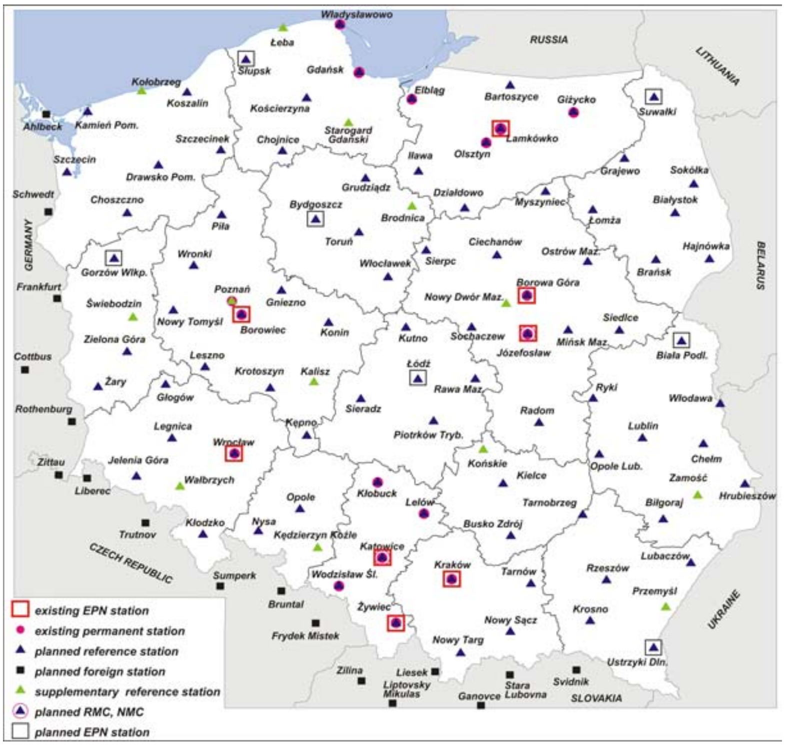

Fig. 1.5.4. Reference stations of the Polish part of the EUPOS network

1.5.2. Local GNSS Networks

The network of 3 reference stations: Elblag, Gizycko and Olsztyn in the northern part of Poland (Fig. 1.5.5) was build up and the teletransmission of data via GSM/GPRS for RTK and DGPS survey using the IP technology and mobile phone data transfer was developed and implemented at the Chair of Satellite Geodesy and Navigation of the University of Warmia and Mazury in Olsztyn (Ciecko et al., 2006a, 2006b). The system which is still in the testing phase (Initial Operational Capability status) consists of a network of GPS reference stations (3 stations recently) connected to the system's main server using IPSEC tunnels. The system's server collects data from all existing GPS reference stations, manages data and distributes data to mobile users in real time.

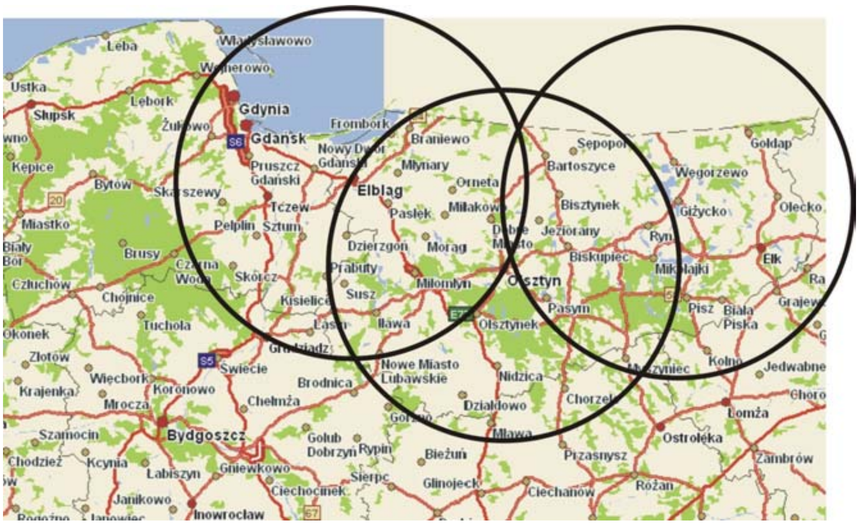

Fig. 1.5.5. Network of 3 reference stations and theoretical range of the DGPS/RTK services in North-East Poland

A special GPRS modem was designed and built in cooperation with Biatel Company. A GPRS modem is compact in size, light and is operated by one switch (Fig. 1.5.6). The possibility of upgrading the modem's software is essential for the project.

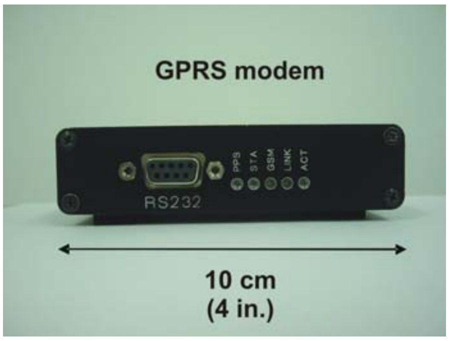

Fig. 1.5.6. GPRS modem designed by Biatel

Each reference station of the network is equipped with Thales Navigation/Ashtech MicroZ (iCGRS) receiver, choke ring antenna, computer, router links, UPS EVER 350W. The receivers are remotely monitored via VNC server and through encrypted https ssl-128 bit with VPN connection. Data is uploaded in the RTCM sc-104 v.2.3, U-files and RINEX format.

Several static experiments were performed in order to confirm the continuity, reliability and integrity of data transmission system. The tests were performed with the use of the reference station of the Chair of Satellite Geodesy and Navigation. At the station with well known coordinates the receiver set up for continuous observation first in DGPS mode and later in RTK mode. The results of the RTK test are shown in Figure 1.5.7.

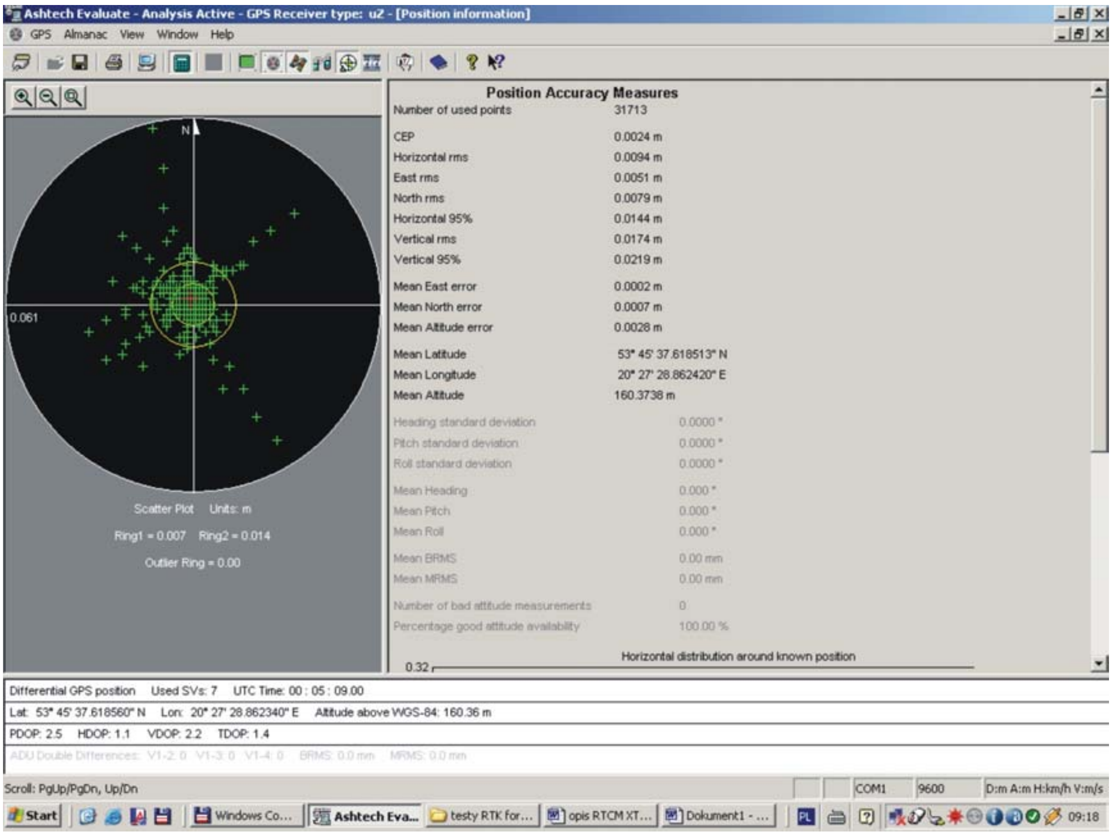

Fig. 1.5.7. The results of the RTK test lasting for nine hours with very optimistic continuity of data transmission and very good positioning accuracy

The maximum deviation from the true position reaches 6 cm in the whole time span of 9 hours of observation. Only 5-6 very short gaps in the delivery of corrections were recorded. Majority of the positions were determined with the use of corrections. Their accuracy is at the level of 2 cm.

1.6. MAINTENACE OF VERTICAL CONTROL IN POLAND

1.6.1. Adjustment of Re-levelled Vertical Control Network in Poland

The re-levelling of the 1st order vertical control in Poland with total length of 382 lines of 17 516 km has started in May 1999 and was completed in June 2002. The levelling network adjustment was conducted at the University of Warmia and Mazury. Levelling rod comparation corrections as well as thermal and tidal corrections have been implemented to raw levelling (Krynski et al., 2005a). Based on differences between back and fore levelling of a section (about 16 000 sections surveyed) mean square error of levelling equals to ±0.278 $mm/km^{1/2}$. Random and systematic errors of levelling estimated using Lallemand formula are ±0.264 $mm/km^{1/2}$ and ±0.080 mm/km, respectively. Normal heights determined in preliminary adjustment of the network in the mode of free network adjustment fit very well to those from the previous levelling campaign in 1974-1982. Estimated standard error of observation of unit weight equals to ±0.088 mm/km and coincides with the one obtained in previous campaign. The network was tied with the vertical control of Belarus, Czech Republic, Germany, Lithuania, Russia, Slovakia and Ukraine.

The vertical control network has been adjusted as a free-network with one fixed point Warszawa-Wola in Kronstadt2006 system. Normal height of that point was obtained using the constraint of zeroing mean difference between heights in Kronstadt2006 system and the respective ones in Kronstadt86 at secular stations of the network. Those differences at secular stations vary from –19 mm in Northern Poland to 22 mm in Southern Poland (Krynski et al., 2007a).

Independent efforts towards the adjustment of the fourth levelling campaign (1998-2002) in Poland were conducted using the *Geolab* software, which is the world-leading software for adjustment of GPS and conventional geodetic data (Łyszkowicz and Jackiewicz, 2005) First experiences verified that the *Geolab* is a powerful and versatile tool for adjustment of geodetic networks.

1.6.2. Sea Level Change Monitoring

Time series from all Baltic tide gauges examined exhibit a distinguished similarity. Common features of the records from tide gauges in Baltic Sea basin were used to generate the empirical model of Baltic Sea level (BSLM) variations by averaging tidal records from different sites at the Institute of Geodesy and Cartography, Warsaw (Krynski and Zanimonskiy, 2004; Krynski et al., 2005b, 2006b). The model was considered as representation of temporal variation of Baltic Sea level with time-independent spatial distribution of its scale factor. The results of regression and correlation analysis of BSLM show that the model derived represents very well both global and regional features of Baltic Sea level variations (Fig. 1.6.1).

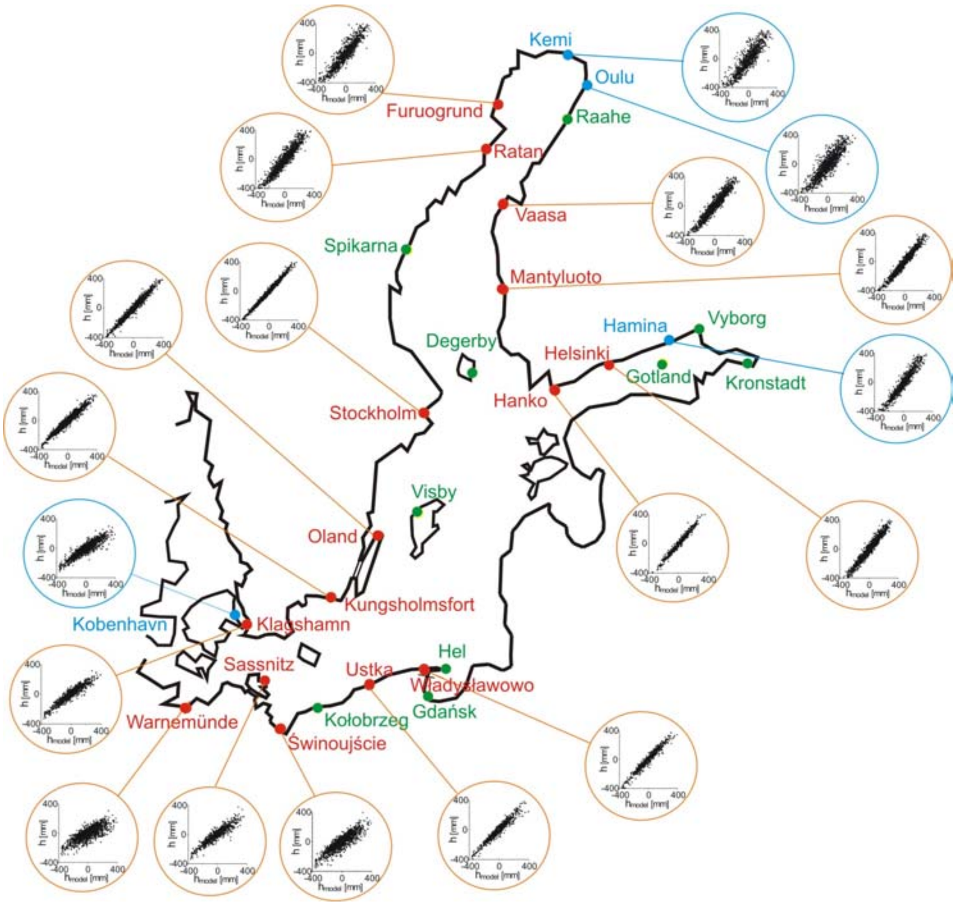

Fig. 1.6.1. Location of tide gauges along the coast of the Baltic Sea with the examples of correlation between regional component and individual site data; (red dots) - sites used for the model determination, (blue dots) - sites used for testing the model, (green dots) - sites not used

The existence of three distinguished, geographically associated groups of sites that exhibit similar characteristics of tidal records-derived sea level variation was observed (Fig. 1.6.2, 1.6.3).

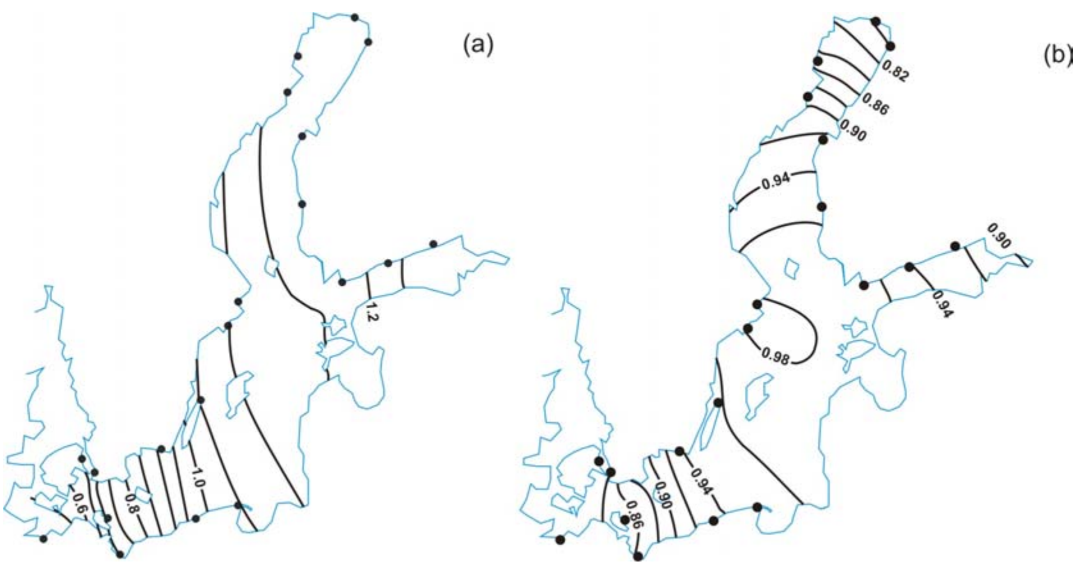

Fig. 1.6.2. 2D distribution of the BSLM scale factor (a) (coefficient of regression of tidal records with the model time series), and its confidence level (b) (coefficient of correlation of tidal records with the model time series)

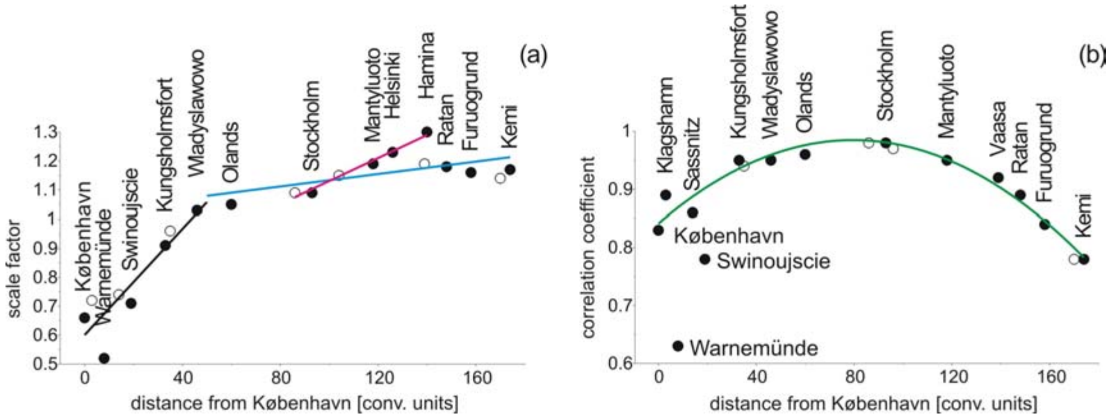

Fig. 1.6.3. Regression and correlation coefficients of tidal records with respect to the model time series vs. distance from København along Baltic Sea central waterline profile

One group consists of northern and middle Baltic sites from northern coast of the Bothnia Bay down to Oland. In that region sea level varies in the uniform way. To the second group belong the majority of Southern Baltic sites. Tidal records in the southern region indicate smaller sea level variations that grow easterly. The third group contains tide gauges along Stockholm-Helsinki axis (Krynski and Zanimonskiy, 2004; Krynski et al., 2005b, 2006b).

Removing the regional model from the time series of individual tide gauge makes it possible to estimate the rate of trend with substantially smaller errors. For the majority of tide gauge records, estimated rate of change of sea level coincides within a single standard deviation. The coincidence is affected by the fact of different intervals of records available from tide gauges as well as different lengths of data records.

A simple and evident technique of estimation of rate of trend and average sea level was applied. The average value over a variable window length with the fixed starting or ending epoch, called a progressive total window (PTW) was determined. Fixing the ending epoch is more commonly applied due to practical needs for mean sea level determination. Both average and median practically coincide and the estimated error of average becomes smaller then 5 mm if the length of PTW exceeds 25 years. Figure 1.6.4 shows the example of dependence of the dispersion of estimated rate of change of sea level on the length of data record examined (Krynski and Zanimonskiy, 2004; Krynski et al., 2005b, 2006b).

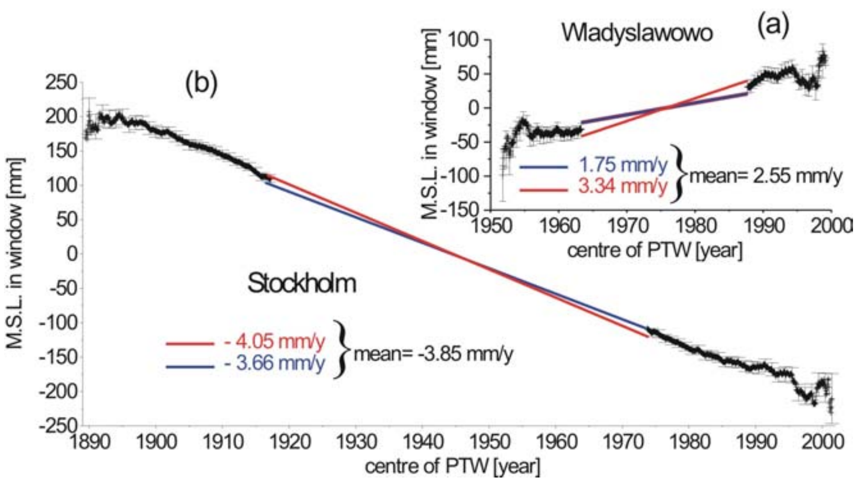

Fig. 1.6.4. Estimation of rate of change of a relative sea level with the use of a progressive total window (max 25 years), in Wladyslawowo (a) and Stockholm (b)

With the use of BSLM the sea level at a site can efficiently be determined from data records of 10 years or even shorter. Thus the relatively short tide gauge data records can possibly be used in research on Baltic Sea level variability. Removing the BSLM from the time series of individual tide gauge makes possible to estimate the rate of trend with substantially smaller errors. Rates of trend estimated with dispersion of ±0.05 mm/year at Stockholm and of ±0.23 mm/year at Wladyslawowo (Fig. 1.6.5) coincide with those obtained by Wöppelmann except the dispersions at the sites are reduced by a factor 3 (Krynski and Zanimonskiy, 2004; Krynski et al., 2005b, 2006b).

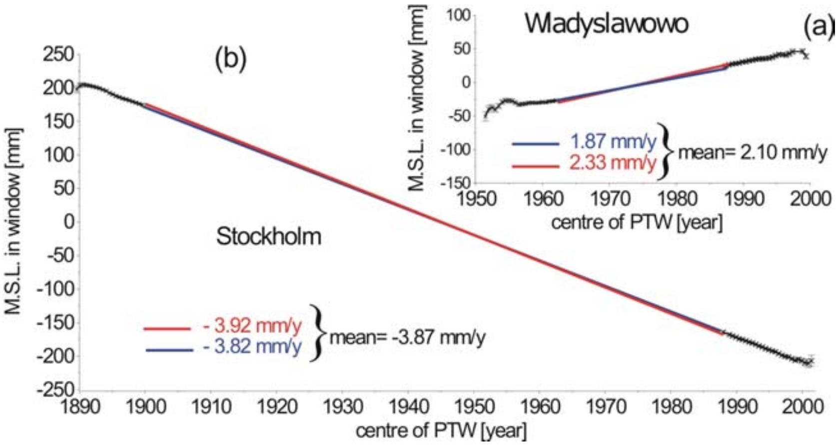

Fig. 1.6.5. Estimation of rate of trend of sea level with the use of progressive total window (max 25 years) to residuals after removing regional model at Wladyslawowo (a) and Stockholm (b)

A method of reduction of uncertainty at the digital spectral analysis based on the increase of samples has been developed and verified with the use of tide gauge data from Baltic Sea (Zanimonskiy et al., 2006).

Methodology for using GPS data, absolute gravity data (AG) and precise levelling for studies of sea level and climate changes or ocean-atmosphere interaction in long time intervals has been developed in the frame of COST Action 40. The physical network consisting of more than 150 of the European tide gauges has been implemented in the frame of ESEAS (European Sea Level Service). The ESEAS-RI project (EVR1-CT-2002-40025) accepted and signed in 18 October 2002 as a 3-years Pilot Project of ESEAS Service, supported the augmentation of ESEAS Observing Sites (EOS) - tide gauges collocated with continuous GPS (CGPS) and absolute gravity (Fig. 1.6.6). The EOS covers several areas of Europe with types of coasts being affected by different physical processes (e.g. tectonic activity, post-glacial rebound, sedimentary compaction, anthropogenic effects), which should be better modelled in the future (Zhang et al., 2005).

In cooperation of the Space Research Centre, PAS, Warsaw (SRC) with the Institute of Meteorology and Water Management, Maritime Branch in Gdynia, (IMGW) two tide gauge stations of the ESEAS network at the Polish coast of the Baltic Sea: Wladyslawowo and Darlowko have been modernized and equipped with the new automatic tide gauge (pressure and floating type) and sea surface temperature sensors. New sensors operate with higher accuracy and higher time resolution, simultaneously with the old ones. A new GPS station WLAD, equipped with Ashtech μZ-12 and Ashtech Dorne-Magolin choke-ring antenna, supported with sensors for monitoring atmospheric parameters, operates in a permanent mode in Wladyslawowo since April 2003. In order to detect and eliminate hardware problems or surrounding disturbances the quality control is performed on a daily basis. In addition, a new gravimetric station was established with two different, separated monumentations: one for absolute and an one for relative (permanent) gravity measurements. Tide gauges are calibrated and stability of the vertical connections of all those instruments are checked by means of periodic precise levelling, connected to the first order national vertical control network (Fig. 1.6.7).

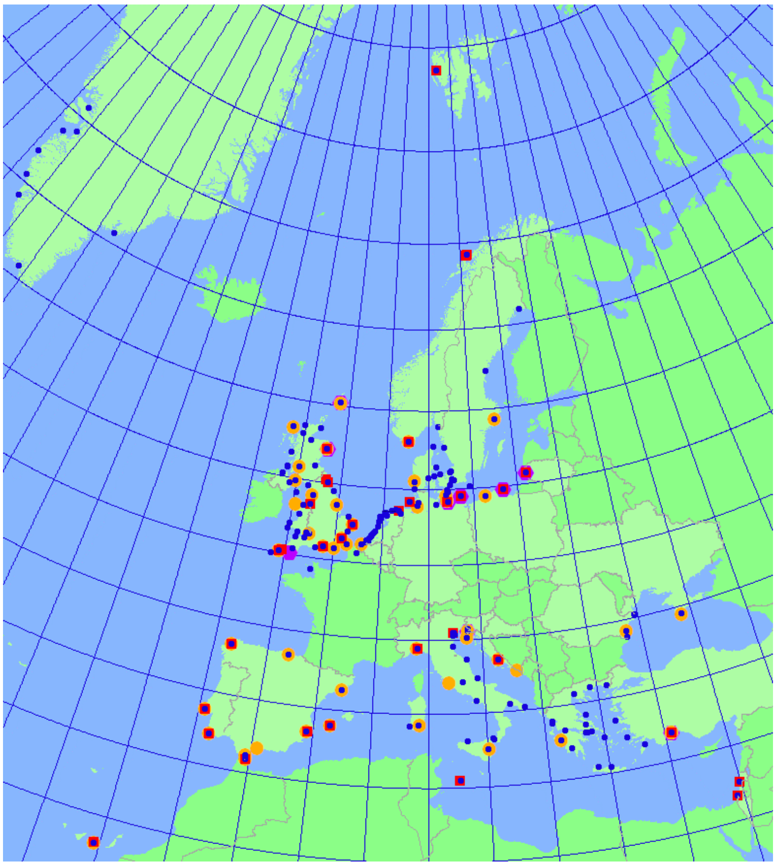

Fig. 1.6.6. ESEAS Observing Sites; small blue circles – tide gauges, red squares - CGPS, orange circles - episodic GPS stations, pink hexagons – absolute gravity points

Fig. 1.6.7. Collocation of different observing techniques at CGPS WLAD station

The upgrade of WLAD station made possible to improve the accuracy of sea level records and to relate them to the common, global, geocentric reference frame for further studies and analysis on a continental scale. Two absolute gravity and three precise levelling campaigns were performed. The results obtained compared with those from the previous projects (e.g. EUVN'97) were used for selecting the primary tide gauge benchmark and checking vertical stability of the inner pier benchmarks and tide gauge benchmarks in longer time scale. In order to determine reliable characteristics of station vertical movement and the adjacent land, CGPS data must be acquired for minimum 3-4 years continuously. Some of a new CGPS stations established in the framework of ESEAS-RI project 17 have still too short observing span (Ayhan et al., 2004). CGPS WLAD station operates continuously since 2003, 115 DOY using the same equipment, so until now it has almost four years observing interval. Data from EOS Wladyslawowo is collected on SRC, IMGW and ESEAS servers and is available on their websites.

To define, implement and validate a CGPS processing strategy, with special emphasis on the vertical component, which enables to determine vertical station velocities in a consistent reference frame on a long time scale with an accuracy of 1mm/year, required for most scientific applications mentioned above, several analysis centres (AC) were established. Each AC uses different combination of software (*GIPSY*/*OASIS-II*, *Bernese*, *GAMIT*), global parameters (IGS Final, IGS Rapid, JPL), data processing methods (Precise Point Positioning or Double Differenced and global or regional realization of the reference frame). One of such AC operates in SRC.

The results obtained from several tests of the data analysis performed within ESEAS-RI project by each AC and its comparison indicates that in spite of a progress reached the processing and analysis methods for GPS at tide gauge data, providing such high accuracy, are still in a research state (Kierulf et al., 2005).

1.6.3. Analysis of Levelling Campaigns in Poland

At the University of Warmia and Mazury the accuracy of three levelling campaigns in Poland (1925-1937; 1947-1955; 1974-1892) were analysed in terms of Lallemand's formula (Łyszkowicz and Leończyk, 2005). Basing on that formula the mean random error of ±0.265 $\mathrm{mm}/\sqrt{\mathrm{km}}$ and the mean systematic error of ±0.077 mm/km were estimated for the data from the fourth levelling campaign in Poland (1999-2002). The systematic error of ±0.097 mm/km was also computed for that campaign from the loop misclosures. It was shown that in the successive campaigns in Poland the random errors were substantially decreasing while the systematic errors remained almost the same. As an alternative the fourth levelling campaign was estimated by the methods of variance-covariance analysis, which shows that the levelling lines are contaminated by a systematic error.

Data from third (1974-1982) and fourth (1999-2002) levelling campaigns were analysed at the University of Warmia and Mazury in terms of the vertical crustal movement (Kowalczyk, 2006). The relative land uplift and the land uplift referred to the mean sea level were computed and modelled by the least square collocation method. The results obtained were compared with those published in 1986 by the Institute of Geodesy and Cartography, Warsaw.

1.7. MAINTENANCE OF GRAVITY CONTROL IN POLAND

The Polish gravity control network POGK99, established in 1993-1998, consisting of 354 field gravity stations and 12 absolute stations has further been extended by the team of the Institute of Geodesy and Cartography, Warsaw. By 2006, 24 new field gravity stations were monumented with the concrete pillars of size of 80×80×100 cm, and tied to the existing gravity control with relative gravity measurements. Gravity gradients were also surveyed at those stations. In October 2004, the network was extended by one more absolute gravity station in Zakopane, at the foothills of the Tatra Mountains. The absolute gravity survey at Zakopane has been performed together with the Finnish Geodetic Institute using the ballistic gravimeter FG5 No 221. Standard deviation of measured gravity has not exceeded 3 μGal (Sas et al., 2005). The absolute gravity station in Zakopane has been tied with three neighbouring field station of the gravity control network. The gravity network (Fig. 1.7.1) was re-adjusted first in 2004 and then, adding new field gravity stations in 2005, providing the POGK04 and POGK05 solutions, respectively. The last adjustment caused minor changes of gravity at some stations, but it certainly improved the consistency and accuracy of the network. It could be observed, in particular at Zakopane station where the difference of 0.020 mGal between the absolute survey and the adjustment 2004 of relative gravity data has been reduced to 0.002 mGal when considering the result of 2005 adjustment.

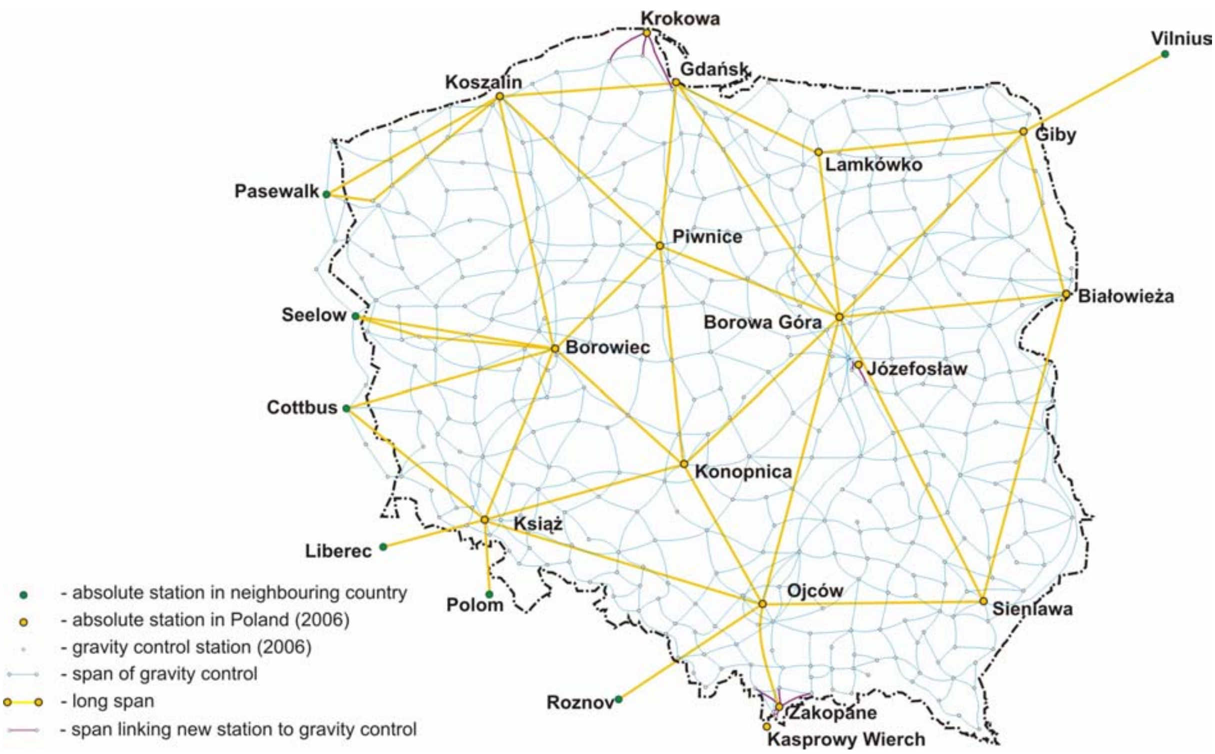

Fig. 1.7.1. The Polish national gravity control (2006)

In November 2005, the absolute gravity stations of the Polish gravity control network were linked with long spans with the absolute gravity stations in Czech Republic (Ojców - Roznov, Książ - Polom, and Książ - Liberec) by the team of the Institute of Geodesy and Cartography, Warsaw, and in Germany (Koszalin - Szczecin - Passewalk, Borowiec – Łagów - Seelow, Borowiec - Cottbus, Książ - Cottbus) by the team of the Warsaw University of Technology.

Historically, gravity systems in Poland were developed in two streams, one by the Polish Institute of Geology for a semi-detail and detail geological gravity survey, and the second – by the Institute of Geodesy and Cartography for precise gravity control consistent with international standards. The Polish Institute of Geology has developed two gravity systems: PGI-62 and PGI-IGSN71. In the latter system point gravity data were stored in the geological gravity database. Moreover, the coordinates of gravity points were referred to the "Borowa Gora" geodetic system that had no known analytical relationship with any well defined regional geodetic datum. The Institute of Geodesy and Cartography has developed the following gravity systems: IGiK-66, IGiK-68, IGiK-IGSN71, IGiK-POGK-99, IGiK-POGK-04, IGiK-POGK-05. The algorithms for transformations between the consecutive gravity systems were developed in the Institute of Geodesy and Cartography with the use of common gravity stations (Krynski et al., 2005c). The corrections when calculating gravity from the PGI-IGSN71 gravity system to the IGiK-POGK-99 and IGiK-POGK-04 gravity systems are given in Figure 1.7.2. Transformation uncertainty $\sigma_{\delta g}$ equals to 0.018 mGal; it might be considered negligible due to 0.075 mGal precision of point gravity data.

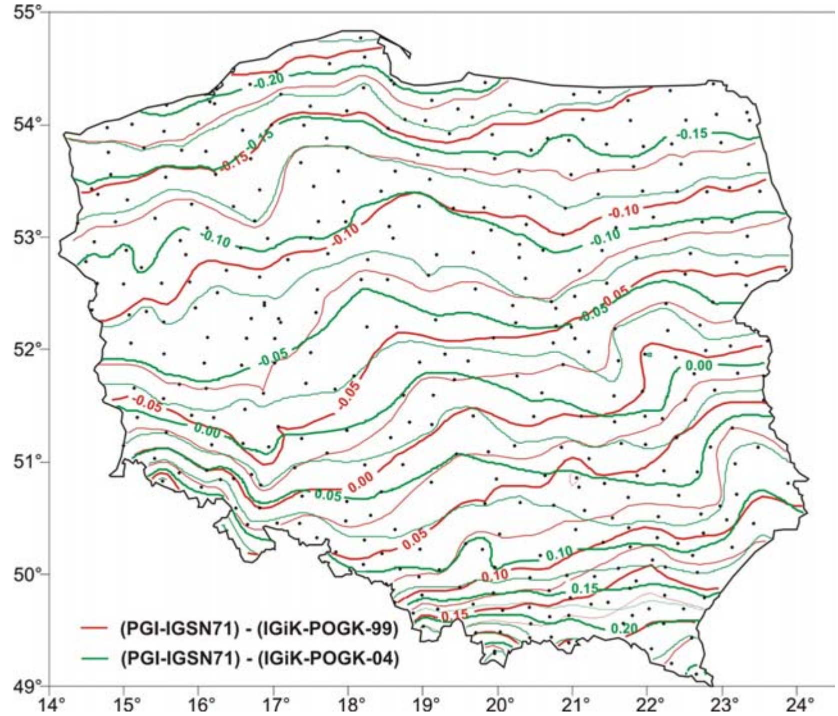

Fig. 1.7.2. Corrections due to transformation from PGI-IGSN71 to IGiK-POGK-99 and IGiK-POGK-04 [mGal]

Also the algorithms for transforming coordinates of points of the gravity database from the "Borowa Gora" datum to the reference system ETRS89 were developed and verified at the Institute of Geodesy and Cartography. X, Y coordinates of geodetic control points in Gauss projection referred to "Borowa Gora" and 'Pulkovo42' datum were compared at maps at the scale of 1:100 000. Average ΔX and ΔY were calculated for each map sheet. Regular grid of ΔX and ΔY was used to interpolate corrections to X and Y coordinates. Transformation uncertainty $\sigma_{\Delta X} = \sigma_{\Delta Y}$ equals to 4.5 m. Transformation from 'Pulkovo42" datum to "1992" or "2000" national reference systems referred to GRS80 ellipsoid is routinely done with the use of available algorithms that ensure a decimetre accuracy. Applying correction due to geodetic datum to positions of gravity points removes bias of 0.532 ±0.005 mGal in gravity anomalies (Krynski et al., 2005c). Corrections to planar coordinates from "Borowa Gora" to 'Pulkovo42' datum are shown in Figure 1.7.3.

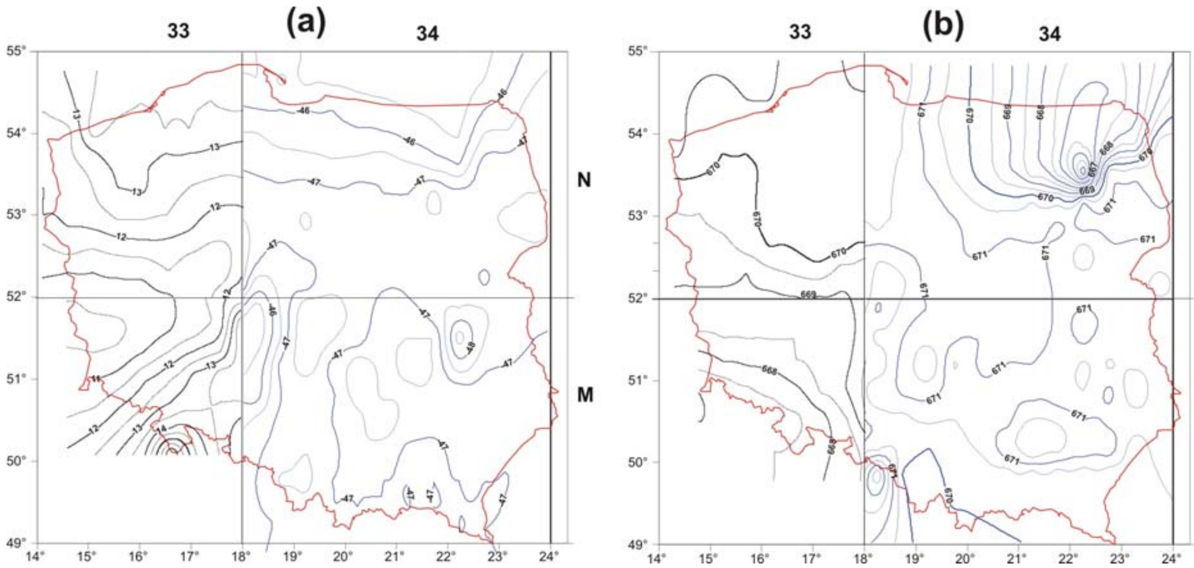

Fig. 1.7.3. Corrections to *Y*-coordinate (a) and to *X*-coordinate (b)
from „Borowa Gora" to „Pulkovo42" datum [m]

1.8. MAINTENANCE OF MAGNETIC CONTROL IN POLAND

In the 1950. the magnetic declination survey in Poland was performed. After more than 50 years the new types of magnetometers and the new techniques of data processing allow to obtain more accurate results. To verify recent quality of magnetic declination prediction, the survey at 456 magnetic field stations (15% stations of the previous survey) was conducted. At those stations, exactly at the same site, the measurements of magnetic declination have been repeated in 2003 and 2004 by the team of the Institute of Geodesy and Cartography, Warsaw, and reduced to the epoch 2003.5. Results of the survey obtained 50 years ago have also been reduced to the epoch 2003.5 and then compared with those obtained from repeated measurements. Analysis of the existing material indicated the need of successive maintenance of magnetic control in Poland and has shown that in the anomalous regions, mainly in the South-Eastern Poland, the new survey should be performed (Sas-Uhrynowski et al., 2004).

The magnetic repeat station network in Poland, established in 1955, consists of 19 field stations. Three components of magnetic field vector were surveyed at first every 2 – 4 years at each network station. Beginning from 1970, the survey is performed every 2 years. Data from two magnetic observatories – Belsk and Hel, are also used in determining secular variations of the Earth Magnetic Field in Poland.

The magnetic repeat station networks were also established in Belarus in the framework of the Polish-Belarusian cooperation and in Lithuania in the framework of the Polish-Lithuanian cooperation in 1997 and 1999, respectively. In both countries the magnetic surveys have been performed with participation of specialists from the Institute of Geodesy and Cartography, Warsaw, using magnetometers of that Institute. The survey has been repeated every 2-3 years and the data acquired is analysed in cooperation of the teams involved (Kowalik and Obuchowski, 2005). The integrated magnetic repeat station network is shown in Figure 1.8.1.

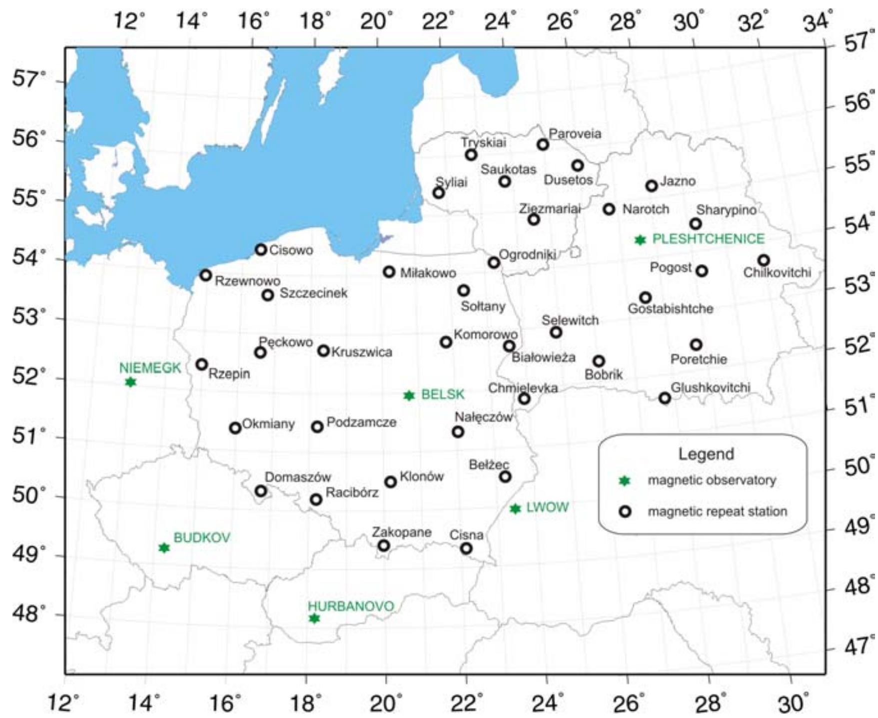

Fig. 1.8.1. Integrated Polish, Belarussian and Lithuanian magnetic repeat station network

Polish magnetic repeat station network is getting improved continuously. During each survey the station marks are controlled and in case of necessity the marks are corrected. In the case of damage of the station or in the case when the station demands are not longer fulfilled, it is displaced to the other site; at the new location a special procedure is applied to secure the continuity of observations.

1.9. ADVANCED THEORY OF NETWORK SOLUTIONS

An advanced research on theory of network adjustment was conducted at the Institute of Geodesy of the University of Warmia and Mazury in Olsztyn. A new method of adjustment based on the theory of *M*-estimation with asymmetric weight function was developed. Such a function is obtained by multiplying original weights by asymmetric attenuation function. The attenuation function consists of some, dependent on excess, terms of the Edgeworth series (Dumalski and Wiśniewski, 2006). Attenuation matrix in robust, free adjustment was investigated (Duchnowski and Wiśniewski, 2006). Also further developments in PAC method of adjustment of geodetic networks were presented (Dumalski, 2006). An extensive research concerned advanced adjustment problems in precise marine navigation was performed in co-operation with Marine Military Academy in Gdynia. The possibility of using one of the robust methods for fixing a single sea object position. was investigated. Experimental damping function, known as the Danish function is presented in the suggested method (Czaplewski and Wiśniewski, 2003a). A trial of supplementing the set of observations with the DGPS observations (consolidation of the navigational structure) was undertaken (Czaplewski and Wiśniewski, 2003b, 2003c). The position coordinates of a vessel, determined in this way, have been treated in the sequential process of the navigational structure adjustment as pseudo-observations characterized with the established covariance matrix (Czaplewski and Wiśniewski, 2003b) or only as the initial data in the structure development. Theoretical basis for compensation of elementary and advanced observation system in maritime navigation was presented. The results of numerical test were presented with the use of ramark system (Szubrycht and Wiśniewski, 2003). The adjustment task concerning the interactive navigational structure and its solutions referred to the basic principles of robust *M*-estimation was analysed. The equivalent weights matrix, applied in this estimation, was substituted with the decisive-equivalent matrix (Czaplewski and Wiśniewski, 2006a). The description and the solution of the problem of optimisation, conforming to the interactive navigational structure, represented by the functional model and the model of deterministic errors was developed. The objective functions of the optimisation problem have been formulated basing on the *M*-estimation theory, extended with adjustment points (free *M*-estimation) (Czaplewski and Wiśniewski, 2006b).

At the Warsaw University of Technology it has been shown that the minimum-trace datum definition as used for computing 2D and 3D positions and displacement vectors as well as their accuracy characteristics does not yield a physically interpretable datum with respect to orientation (Prószyński, 2003). This is explained on the basis of the analysis of mutual relationships between datum constraints in the initial non-linear Gauss-Markov model (GMM) for a local network and the corresponding constraints in the linearised model. A property of the minimum-trace datum for 2D networks is proved which, in spite of the above mentioned drawback, convinces one of the safe use of this datum in practice. The property is illustrated on a simple practical example, being a 2D linear-angular monitoring network.

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2. GRAVITY FIELD MODELLING AND GRAVIMETRY

2.1. INTRODUCTION

This part of the Polish National Report on Geodesy is the quadrennial report on gravity field modelling and gravimetric works performed in Poland in the period from 2003 to 2006. It contains a summary of the investigations such as geoid modelling and study on the gravity field in Poland, absolute and relative gravity surveys, maintenance of gravimetric calibration baselines in Poland, monitoring of non-tidal gravity changes, satellite gradiometry, and gravity in applied surveying, etc. Those activities were conducted mainly in the following research centres listed in an alphabetic order:

- Department of Geodesy and Geodynamics, Institute of Geodesy and Cartography in Warsaw;
- Department of Mining Surveying and Environmental Engineering, AGH University of Science and Technology in Cracow;
- Department of Planetary Geodesy, Space Research Centre, Polish Academy of Sciences in Warsaw;
- Institute of Geodesy, University of Warmia and Mazury in Olsztyn;
- Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology.

The content of the chapter is based on the material prepared by Marcin Barlik, Andrzej Drozyner, Wladyslaw Goral, Jan Krynski, Adam Lyszkowicz, Andrzej Sas-Uhrynowski and Janusz B. Zielinski.

The bibliography of the related works is given in references.

2.2. GEOID MODELLING AND STUDY OF THE GRAVITY FIELD IN POLAND

The first gravimetric quasigeoid model for Poland of accuracy of about 10 cm was calculated at the Department of Planetary Geodesy of the Space Research Centre PAS in Warsaw in 1993, using the least squares collocation combined with the integral method. It was followed by the quasi97b gravimetric quasigeoid model of 5 cm accuracy, developed with the FFT technique using substantially extended gravity data coverage (Krynski and Lyszkowicz, 2006a).

Access to raw gravity data form geological gravity database, development of high-resolution digital terrain models, densification of precise GPS/levelling heights, re-levelling of Polish vertical control network (1999-2002) stimulated the efforts towards undertaking an extensive research on modelling a precise quasigeoid in Poland (Krynski and Lyszkowicz, 2005d). The team of researchers, representing different disciplines of Earth sciences, under the leadership of the Institute of Geodesy and Cartography, Warsaw, was conducting in 2002-2005 an advanced research on modelling a centimetre quasigeoid in Poland with the use of geodetic, gravimetric, astronomic, geological and satellite data, in the framework of the project ordered and supported by the Polish Committee for Scientific Research (Krynski and Lyszkowicz, 2006b).

Geodetic (Lyszkowicz and Gajderowicz, 2005), gravimetric (Krynski et al., 2005d, 2005e; Jarmolowski, 2005a), astronomical (Rogowski et al., 2005a), geological (Polechonska and Krolikowski, 2005a) and satellite (Jarmolowski, 2005a; Krynski et al., 2005f, 2005g; data acquired within cooperation of national research centres (Institute of Geodesy and Cartography, Warsaw; Polish Geological Institute, Warsaw; University of Warmia and Mazury, Olsztyn; Warsaw University of Technology; Wroclaw University of Technology and Military

University of Technology, Warsaw) and foreign research centres (Danish National Space Center, Copenhagen and Slovak University of Technology, Bratislava) have been extensively qualitatively analysed in the framework of the research project (Krynski, 2005a). They have been transformed to unified reference systems (ETRS89, POGK99 etc.) in accordance with recent standards (Krynski et al., 2005d, 2005e; Cisak and Sas, 2005a), and archived in the respective databases (Sekowski, 2005a). It concerned, in particular, consisting of over a million gravity data set from Poland, acquired within last 50 years, and provided for the project by Polish Geological Institute. The effect of systematic and random errors in gravity data on the quality of geoid model was investigated (Duchnowski and Baran, 2005; Duchnowski, 2006).

An extensive research was conducted on the use of the existing data for precise quasigeoid modelling, its methodology and estimation of accuracy of the determined quasigeoid models. Analysis of digital terrain models (Krynski et al., 2005a; 2005b, 2005c, 2006c; Krynski and Lyszkowicz, 2006a, 2006b), technology of terrain correction computation (Grzyb et al., 2005a, 2006a 2006b; Krynski and Lyszkowicz, 2006a, 2006b), methodology of mean gravity anomaly determination (Krynski and Lyszkowicz, 2006a), methodology of mean sea level of the Baltic Sea determination (Krynski et al., 2004a, 2005h, 2006b) and the choice of global geopotential model (GGM) best suited for quasigeoid modelling in Poland (Fig. 2.2.1 and Fig. 2.2.2) (Krynski and Lyszkowicz, 2005b, 2005c, 2006d), should be listed amongst the achievements that are most worth of notice.

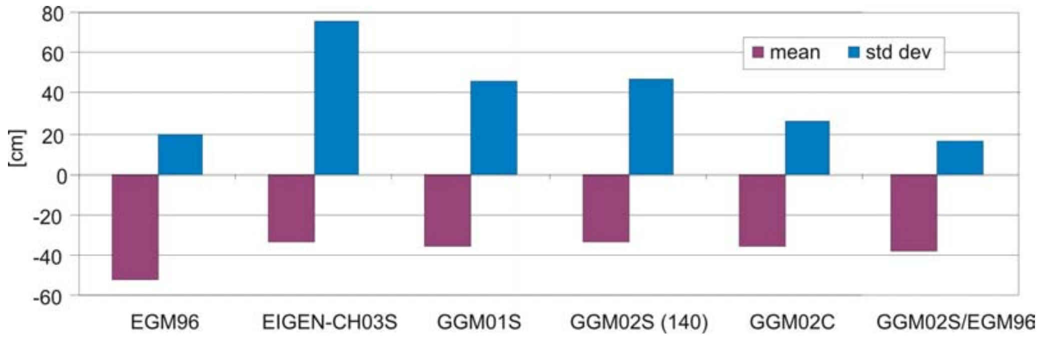

Fig. 2.2.1. Means and standard deviations of the differences between height anomalies computed form GGMs and the respective ones derived from GPS/levelling at the POLREF sites

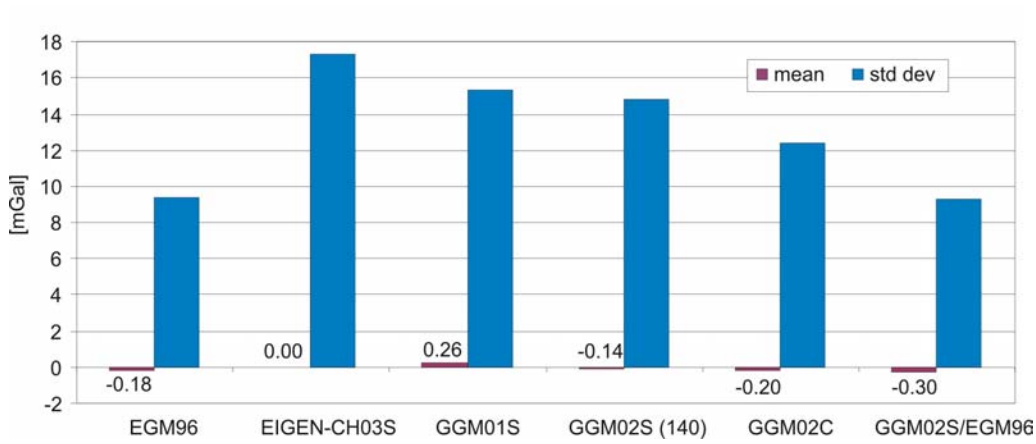

Fig. 2.2.2. Means and standard deviations of the differences between gravity anomalies computed form GGMs and the respective ones derived from terrestrial and marine gravity survey

The analyses of the existing data have been supported with astronomic, geodetic and GPS control surveys; some observations acquired within control surveys were further included into data used for quasigeoid modelling. Establishing of 869 km long control GPS/levelling traverse running from SW part of Poland to NE borders, and consisting of 205 stations on levelling benchmarks, precisely surveyed with GPS (Fig. 2.2.3), is the unique achievement of the project (Cisak and Figurski, 2005a; Krynski and Lyszkowicz, 2006a, 2006b).

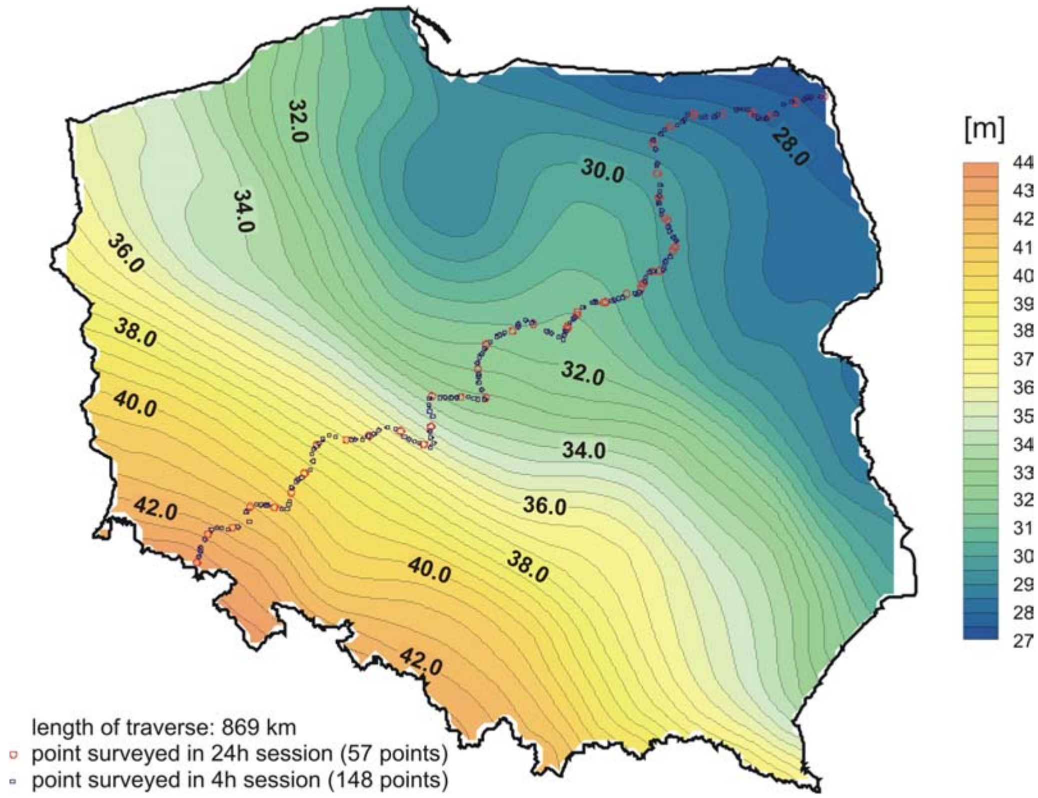

Fig. 2.2.3. GPS/levelling control traverse

Precisely determined quasigeoid heights of dense control traverse stations were compared with the corresponding ones from the official GUGiK 2001 quasigeoid model (Cisak and Figurski, 2005a; Krynski and Lyszkowicz, 2006a) (Fig. 2.2.4).

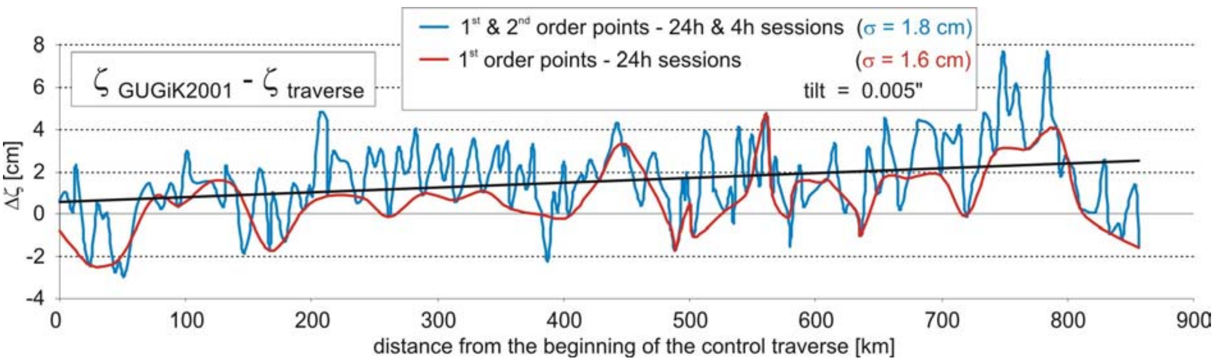

Fig. 2.2.4. Quasigeoid heights of control traverse stations vs. the corresponding ones of GUGiK 2001 quasigeoid model

Quasigeoid heights of control traverse stations were used for quality control of astro-geodetic, gravimetric, GPS/levelling, and integrated quasigeoid models developed (Krynski, 2005a, 2005b; Krynski and Lyszkowicz, 2006a, 2006b, 2006f) as well as best fitted to the height of the POLREF sites (Krynski and Lyszkowicz, 2006c, 2006e) quasigeoid models developed (Fig. 2.2.5).

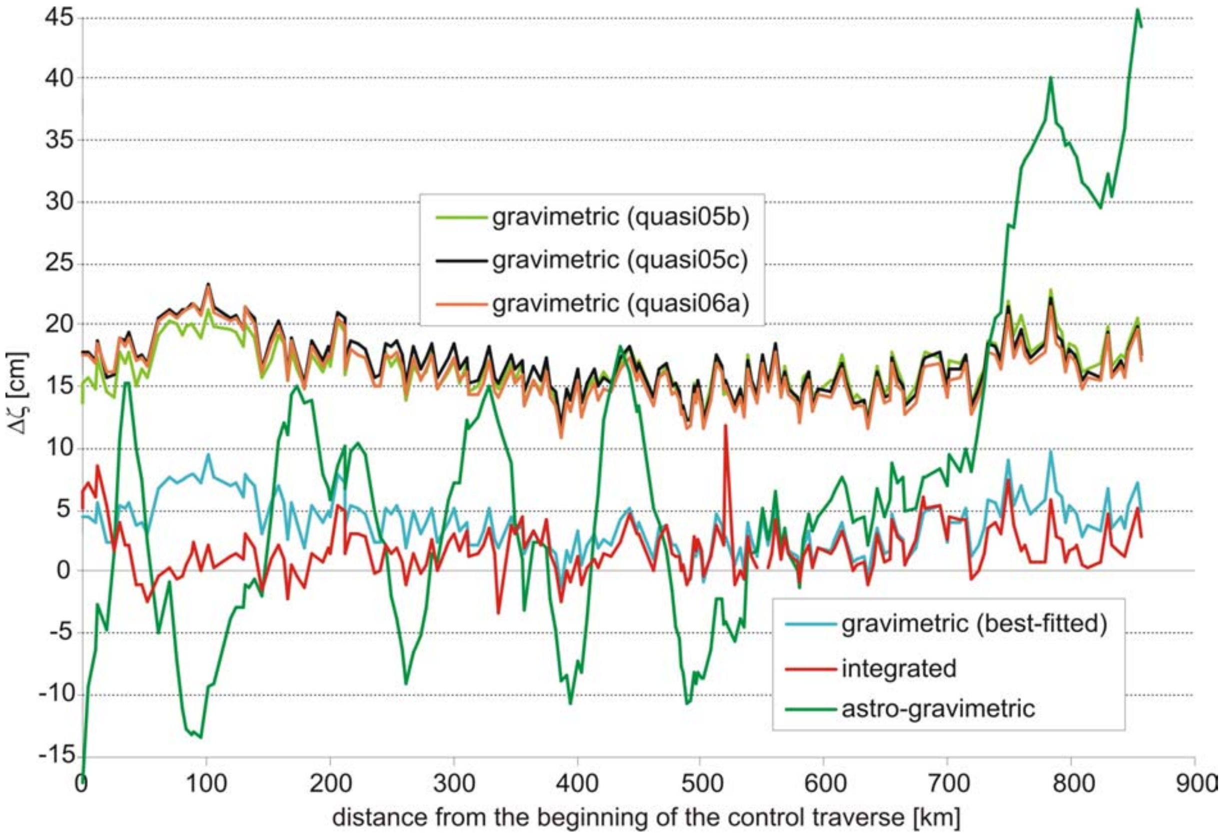

Fig. 2.2.5. The fit of quasigeoid models to the GUGiK 2001 quasigeoid model at the sites of GPS/levelling control traverse [cm]

Recently developed quasigeoid models in Poland: astro-gravimetric quasigeoid (Rogowski et al., 2005b), gravimetric quasigeoid (Jarmolowski, 2005b; Lyszkowicz, 2005a), GPS/levelling quasigeoid (Krynski et al., 2005f; Krynski and Lyszkowicz, 2006a), integrated quasigeoid (Osada et al., 2005a; Krynski and Lyszkowicz, 2006a), exhibit very high quality. Accuracy of best fitted gravimetric quasigeoid and integrated quasigeoid referred to GPS/levelling control traverse has been estimated as below 2 cm (Cisak and Figurski, 2005a; Krynski and Lyszkowicz, 2006a, 2006b, 2006c, 2006e) (Fig. 2.2.6).

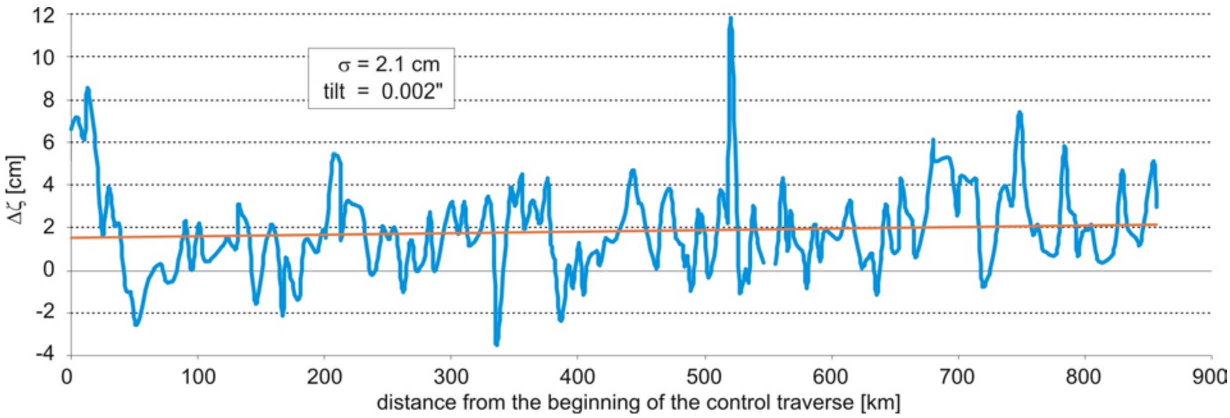

Fig. 2.2.6. Integrated quasigeoid model vs. GPS/levelling traverse

Quality of heights of the sites of the POLREF network, that results from surveying strategy and technology used was found not sufficient for the use as the basis for best fitted gravimetric quasigeoid model, that could provide height accuracy required for levelling with GPS in Poland.

The results obtained in the project can efficiently be applied to further improvement of quasigeoid models for Poland. They indicate the methods and tools that ought to be used to improve quasigeoid models. They also make possible more reliable quality assessment and accuracy estimate of quasigeoid models developed (Krynski, 2005c).

The system of databases developed (Sekowski, 2005a) is a unique source of complex information for geodynamics research in Poland. It is also a valuable starting point for further research on precise quasigeoid modelling in Poland. The system of databases can widely be used for research on the figure of the Earth, study the structure of the upper crust, geological cartography, as well as for solving hydrological and environmental problems.

The results obtained unambiguously indicate that one of the models of quasigeoid best fitted to the POLREF stations, of accuracy at the level of 2 cm, should replace the GUGiK 2001 quasigeoid model that is recently used in surveying practice in Poland.

First computations of gravimetric deflections of the vertical in Poland were done for the Head Office of Geodesy and Cartography in 1996. In the Space Research Centre PAS a new set of the gravimetric deflections of the vertical was calculated by the effective FFT method using the Vening Meinesz integral and the EGM96 model (Łyszkowicz, 2003). Those deflections were compared with the exiting measured astro-geodetic and astro-gravimetric deflections of the vertical. The standard deviations of the obtained differences with astro-geodetic data were 0.55" and 0.47" for ξ and η components, respectively, while with astro-gravimetric data: 0.50" and 0.57", respectively.

The gravimetric quasigeoid model of Slovakia GMSQ03B calculated using point gravity data from Slovakia, some point data in the Polish part of Tatra Mountains as well as 5' × 7.5' mean Bouguer anomalies (10 km × 10 km) from outside Slovakia up to three degree from the borders, was developed using the FFT approach and the EGM96 global geopotential model. The GMSQ03B model was verified in the high Tatra area with astro-geodetic deflections of the vertical, in the framework of cooperation of the teams of the Warsaw University of Technology Slovak University of Technology in Bratislava (Mojzes et al., 2006). Astronomical observations at 13 points that approximately uniformly cover the test area, have been performed using the circumzenithal CZ 50/500 with the precision of 0.14"-0.34". Figure 2.2.7 represents both gravimetric and astronomical deflections of the vertical according to GMSQ03B quasigeoid isoclines.

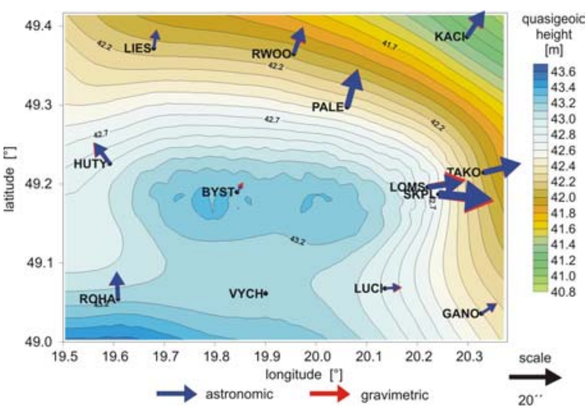

Fig. 2.2.7. Astronomical and gravimetric deflections of the vertical

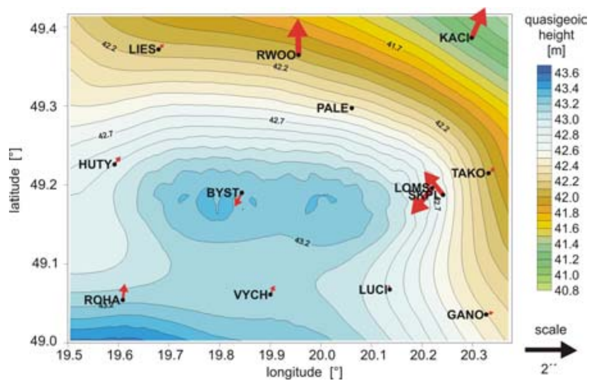

Fig. 2.2.8. Differences between astronomical and gravimetric deflections of the vertical

Differences between astronomical and gravimetric deflections of the vertical caused by large gaps between gravimetric points in eastern part of the Tatra Mountains, especially in Poland, were modelled by second degree polynomial for each component and computed with least squares method. The residuals obtained (Fig. 2.2.8) vary from –1.15" to 1.40" in latitude and from -0.49" to 0.63" in longitude; they indicate high quality of GMSQ03 quasigeoid model in the Tatra Mountains.

2.3. ABSOLUTE GRAVITY SURVEYS IN POLAND

12 absolute gravity stations (Fig. 2.3.1), at which 21 measurements performed in the framework of international cooperation using 5 various ballistic gravimeters: FG5 No. 101 (Germany), FG5 No.107 (USA), JILAg-5 (Finland), IMGC (Italy) and ZZG (Poland) has been established in 1994-1998 as the basis for the new gravity control network in Poland. At some of those stations the additional absolute gravity measurements were performed in 1999-2002 with the use of the absolute rise and fall ZZG gravimeter, constructed at the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology. Two other absolute gravity stations Krokowa and Jozefoslaw were established in two international campaigns 1998/1999 and 2000/2001of the UNIGRACE (Unification of Gravity Systems in Central and Eastern Europe) project. In Borowa Gora - the fundamental point of the Polish Gravity Control Network a number of absolute gravity surveys were conducted within last 10 years with different ballistic gravimeters. Absolute gravity was also few times surveyed at Jozefoslaw within past decade.

The network of absolute gravity stations was extended in 2004 by Zakopane station with the use of FG5 No 221 of the Finnish Geodetic Institute (Sas et al., 2005). With the same ballistic gravimeter absolute gravity was surveyed in 2004 at two other stations: Kasprowy Wierch – the upper station of the Vertical Gravity Calibration Baseline in the Tatra Mountains, and in Wladyslawowo – the tidal station at the coast of Baltic Sea, participating in the Pilot Project of ESEAS Service. The map of the existing absolute gravity stations in Poland is given in Figure 2.3.1.

Since June 2005 the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology uses its absolute ballistic (non – symmetrical, Micro-g Solutions) FG5 No 230 gravimeter (Barlik et al., 2006a). At the Jozefoslaw Astro-Geodetic Observatory the special stand was built in gravimetric laboratory, in the Observatory cellar, at 6 m depth, mostly to avoid microseseimses, for permanent gravity observations and also for comparison absolute gravimeters. The station offers 7-8 μGal precision of a single drop that proofs its good stability for gravity measurements (Fig. 2.3.2). Repeatable gravity absolute measurements at Jozefoslaw are used for tracking the non-tidal gravity changes (Barlik et al., 2006c). Gravity obtained with FG5 No 230 in Jozefoslaw in 2005 differs from those determined during the UNIGRACE campaigns by only -1.1 μGal.

Two comparison campaigns with the FG5 No 230 gravimeter have been performed (Barlik et al., 2006b). The first one in the Astro-Geodetic Observatory in Pecný, Czech Republic, and the second in the BKG Gravimetric Observatory in Bad Homburg, Germany. The comparison corrections of FG5 No 230 gravimeter of -0.3 μGal and +1.2 μGal in reference to the FG5 No 215 (Czech) and FG5 No 201 (German) gravimeters, respectively, have been determined. The differences in the gravimeters performance appear smaller than a total uncertainty of the gravity obtained in a single measurement session (say 24 hours), namely 2.1 μGal.

Two observatories: Borowa Gora and Jozefoslaw equipped in the basic facilities have been submitted in 2006 to the BIPM as a joint regional laboratory for comparisons of absolute gravimeters.

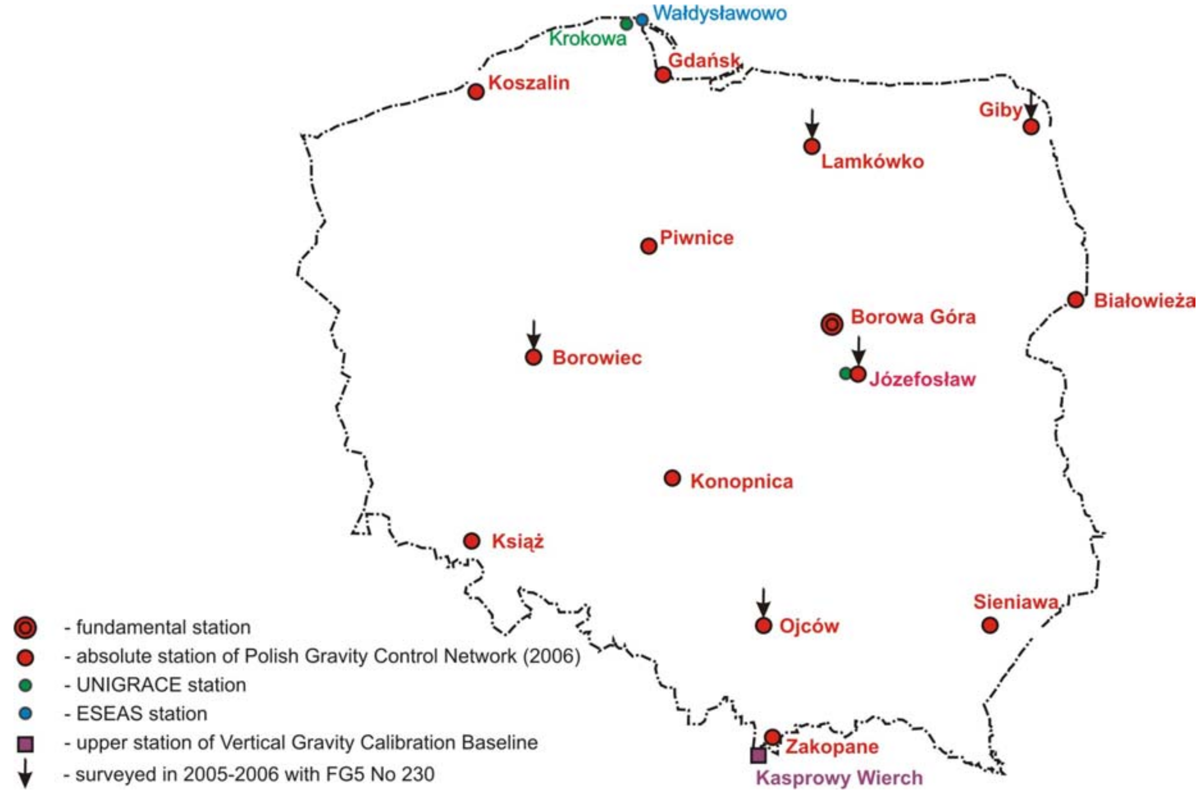

Fig. 2.3.1. Absolute gravity stations in Poland (2006)

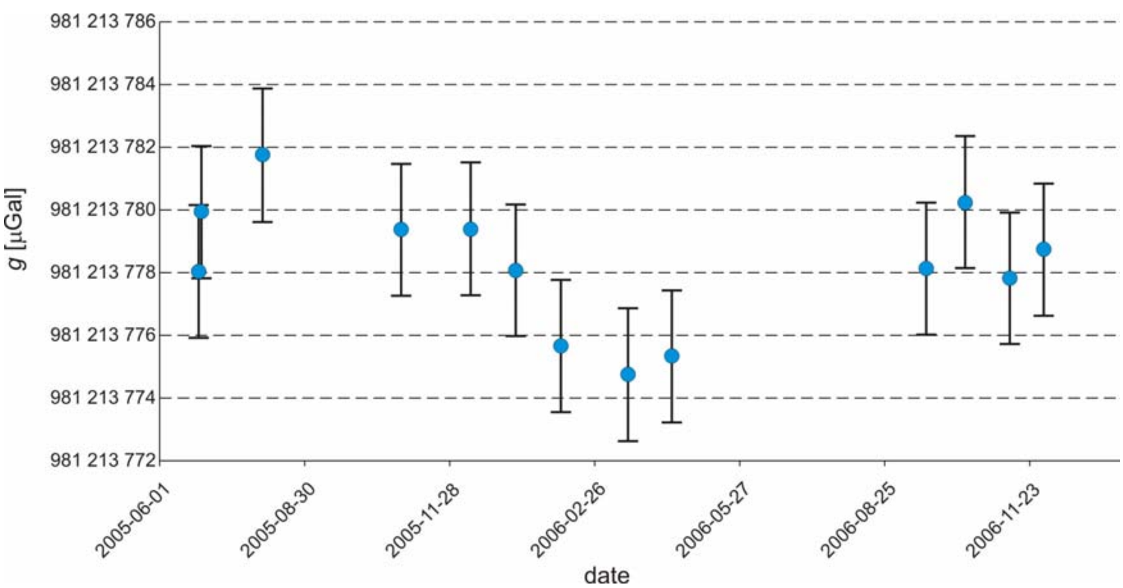

Fig. 2.3.2. Absolute gravity measurements at Jozefoslaw with FG5 No 230

The modernization of the Polish fundamental gravity control network is foreseen for next few years. All existing absolute gravity points are planned to be re-surveyed and seven new absolute gravity stations will be established (Barlik et al., 2006b).

2.4. MAINTENANCE OF GRAVIMETRIC CALIBRATION BASELINES IN POLAND

In October 2004, two new absolute gravity stations: one in Zakopane, at the foothills of the Tatra Mountains, and the second one in high mountains at the Tatra Meteorological Observatory on Kasprowy Wierch were established. They were designed at the Institute of Geodesy and Cartography, Warsaw, as the extension of the Central Gravity Calibration Baseline [Gdansk-Borowa Gora-Ojcow] to the southern border of the country to cover the whole area of Poland with its range (Fig. 2.4.1). Both new stations constitute the vertical gravity calibration baseline of the range of ~250 mGal, which is indispensable for research of mountain dynamics. The absolute measurements have been performed together with Finnish Geodetic Institute using the ballistic gravimeter FG5 No 221. At both stations the standard deviations of measured gravity have not exceeded 3 μGal (Sas et al., 2005). Three intermediate stations of the vertical gravity calibration baseline were monumented and surveyed with relative gravimeters. Vertical gradients were also determined at all stations of the vertical gravity calibration baseline (Krynski et al., 2006a).

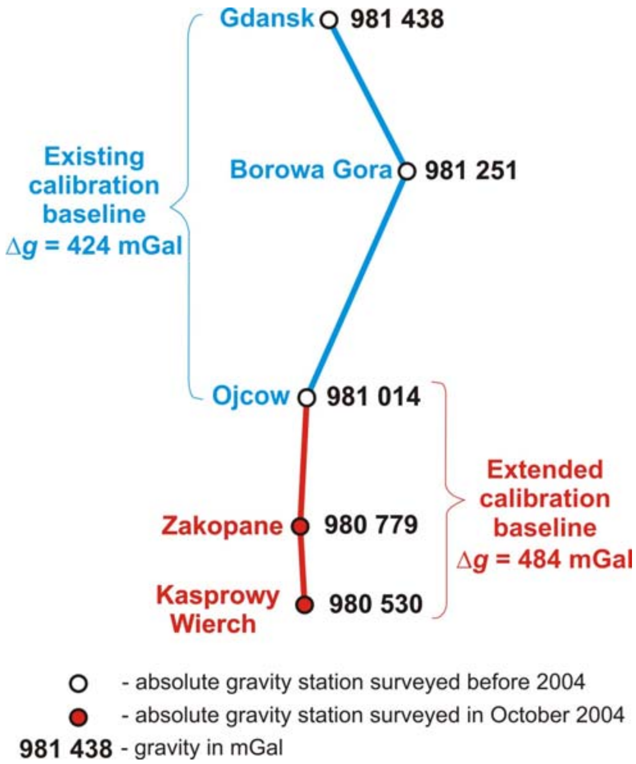

Fig. 2.4.1. Central Gravity Calibration Baseline in Poland (2004)

The joint team of the Institute of Geodesy and Cartography, Warsaw and the Warsaw University of Technology conducted an extensive research on the modernization of gravimetric calibration baselines in Poland. Two modernised gravimetric calibration baselines: the Central and the Western one, will be based on absolute gravity stations that are up to 100 km apart from each other; gravity difference between the stations will range from 40 to 120 mGal (Fig. 2.4.2). The project designed for 2 years has started in October 2006.

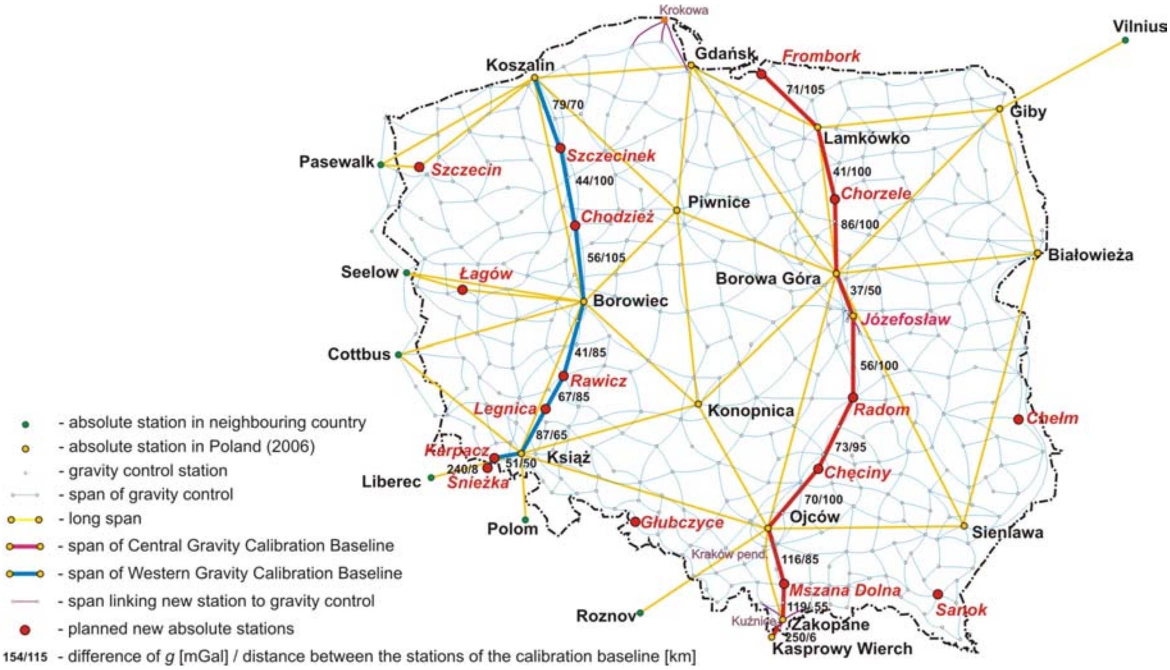

Fig. 2.4.2. Modernised Gravity Calibration Baseline in Poland (2006 – project)

2.5. INVESTIGATIONS OF THE NON-TIDAL GRAVITY CHANGES

Installation of the FG5 No 230 absolute gravimeter in the Astro-Geodetic Observatory at Jozefoslaw of the Warsaw University of Technology gave a possibility for the continuation of the gravity variations monitoring (Barlik et al., 2006a, 2006b, 2006c). The previous investigations were performed using ZZG ballistic (symmetric) gravimeter, constructed in Poland. Starting from June 2005, the repeated absolute gravity measurements with FG5 regularly once a month are performed. Simultaneously with the gravity the following supporting observations are conducted in Jozefoslaw: ambient pressure, temperature and humidity, soil moisture, rainfalls volume, depth of the ground water table and snow coverage thickness.

Measurements of non-tidal gravity effects were performed on the hydro-technical object "Zarnowiec" by the team of the Warsaw University of Technology, in the framework of research project "Satellite and gravimetric methods for monitoring changes in hydrotechnical earth built structures" (Barlik et al., 2003; Olszak et al, 2003; Pachuta et al., 2003a, 2003b). Special automation of the static gravity meters calibration by tilt method and on the gravimetric baseline was developed for that purpose (Pachuta, 2003). Theoretical studies on gravitation influence of density lateral changes were performed for an interpretation of the gravity changes observed at "Zarnowiec" object near the pumped-storage power station (Barlik, 2003).

Gravity changes as a component of geodynamic studies in the Pieniny Klippen Belt in the Czorsztyn region near Poland – Slovakia border were investigated (Czarnecki et al., 2005). The results of processing of three year by year repeated gravity measurements on the sites of geodynamic test field network, together with GPS data and spirit levelling indicated very clearly a closed relation between gravity oscillations and variations of vertical coordinates, ellipsoidal and orthometric heights as well as those caused by a construction of a big dam on Dunajec river and water reservoir near Sromowce village.

The team from the AGH University of Science and Technology, Cracow, investigated geodynamic processes in the Carpathians. Movements of the crust masses were observed grom gravity data surveyed along two profiles (Łój et al., 2005; Porzucek et al., 2006).

Since 1992 ten gravimetric survey campaigns have been performed in the eastern part of Sudety Mountains (Barlik et al., 2004). All observations were executed using static gravimeters LaCoste&Romberg G and Scintrex Autograv CG-3M. As suggested during international bilateral (Poland – Czech Republic) conference, gravity value at a point in the Wroclaw University of Environmental and Life Sciences established in 1992 and completed by last works was used as the reference value (gravity level) for those relative determinations (Barlik et al., 2005). The largest changes in gravity, approaching 300 μGal, were observed in Karkonosze Mountains and Paczkow Graben in a period of four years The disastrous flood in 1997 might be the reason of the observed gravity changes.

2.6. SATELLITE GRADIOMETRY

Theoretical and simulation works related to the ESA gradiometry mission GOCE have been continued in the Space Research Centre of the Polish Academy of Sciences and in the University of Warmia and Mazury. In particular the validation method of the satellite gradiometry data has been developed permitting to compare the satellite data with the low altitude data (e.g. balloon on the altitude of 30-40 km). The method is based on the Upward Continuation with the Reference Model approach (Zieliński et al., 2005). The method uses existing quite precise global geopotential models and upward continuation of residuals. The same method enables to compare other data on different altitudes, e.g. the GRACE data with GOCE data when available.

Development of theory followed by simulation of the GOCE satellite orbit determination using the gravity tensor observations were conducted at the University of Warmia and Mazury, Olsztyn (Bobojć and Drożyner, 2003). In the process of the satellite orbit determination the initial dynamic state vector corrections are obtained. Those corrections are estimated by means of gravity gradiometry measurements. The usefulness of gradiometry data (with the GPS-based observations) to the GOCE satellite orbit determination has been proven.

2.7. GRAVITY IN APPLIED SURVEYING

The Department of Geodesy and Geodynamics of the Institute of Geodesy and Cartography, Warsaw, carried out gravity measurements with LaCoste&Romberg G gravimeters at various sites, where the knowledge of gravity was needed, e.g. at the gas transmitting tube stations, at the sites where standard of manometers is determined, and others for various enterprises like Polish Oil and Gas Company, Central Measuring and Research Laboratory, etc.

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3. GEODYNAMICS AND EARTH ROTATION

3.1. INTRODUCTION

This part of the Polish National Report on Geodesy is the quadrennial report of geodynamic works performed in Poland in a period from 2003 to 2006. It contains a summary of investigations such as establishment, maintenance and analysis of geodynamic networks of continental, regional and sub-regional scale, theoretical research and analysis of Earth rotation data, Earth tides monitoring, etc. Those activities were conducted mainly in the following research centres listed in an alphabetic order:

- Department of Geodesy and Geodynamics, Institute of Geodesy and Cartography in Warsaw;
- Department of Mining Surveying and Environmental Engineering, AGH University of Science and Technology in Cracow;
- Institute of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences;
- Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology.
- Space Research Centre, Polish Academy of Sciences in Warsaw;

The content of the chapter is based on the material prepared by Marcin Barlik, Aleksander Brzezinski, Janusz Bogusz, Stefan Cacon, Wladyslaw Goral, Marek Kaczorowski, Barbara Kolaczek, Wieslaw Kosek, Jan Krynski, Jerzy B. Rogowski, Miloslawa Rutkowska, Andrzej Sas-Uhrynowski and Janusz Walo.

The bibliography of the related works is given in references.

3.2. MAINTENANCE OF REGIONAL GEODYNAMIC NETWORKS

3.2.1. The Polish Geodynamic Network an Related Investigations

For the purposes of geodynamic research on a national scale using geodetic methods, the Polish Geodynamic Network (Polish acronym: PSG) was set up in the last decade of 20 century. The work on the establishing of the network was undertaken by the Institute of Geodesy and Cartography, Warsaw, in 1991-1992, in cooperation with the Head Office of Geodesy and Cartography, which was at that time carrying out a full-scale modernization of the Polish geodetic control. The PSG network project was additionally consulted with all of Poland’s geodetic groups involved in research in the field of geodynamics. The basis for the selection of the location of the PSG stations was a map showing the boundaries of principal and subsidiary geological structures. Location of the PSG stations as well as a boundaries of geological structure are presented in Figure 3.2.1.

The PSG network is made up of 36 stations, consisting of:

- 11 EUREF-POL “0”-order network points (including 4 permanent GPS stations);
- 22 points, selected from the POLREF network, being a densification of the EUREF-POL network;
- 3 additional stations : WROC (the permanent GPS station of Wroclaw University of Environmental and Life Sciences) and two SAGET (Satellite Geodetic Traverse) network points (Belchatow and Swiety Krzyz).

Those stations were monumented in a manner enabling their fixedness to be maintained for several decades (Fig. 3.2.2). The GPS observation campaign at the PSG network corresponding to a zero-epoch of geodynamics research was conducted in 1997-1998. The data acquired was used to derive a set of coordinates of the PSG stations.

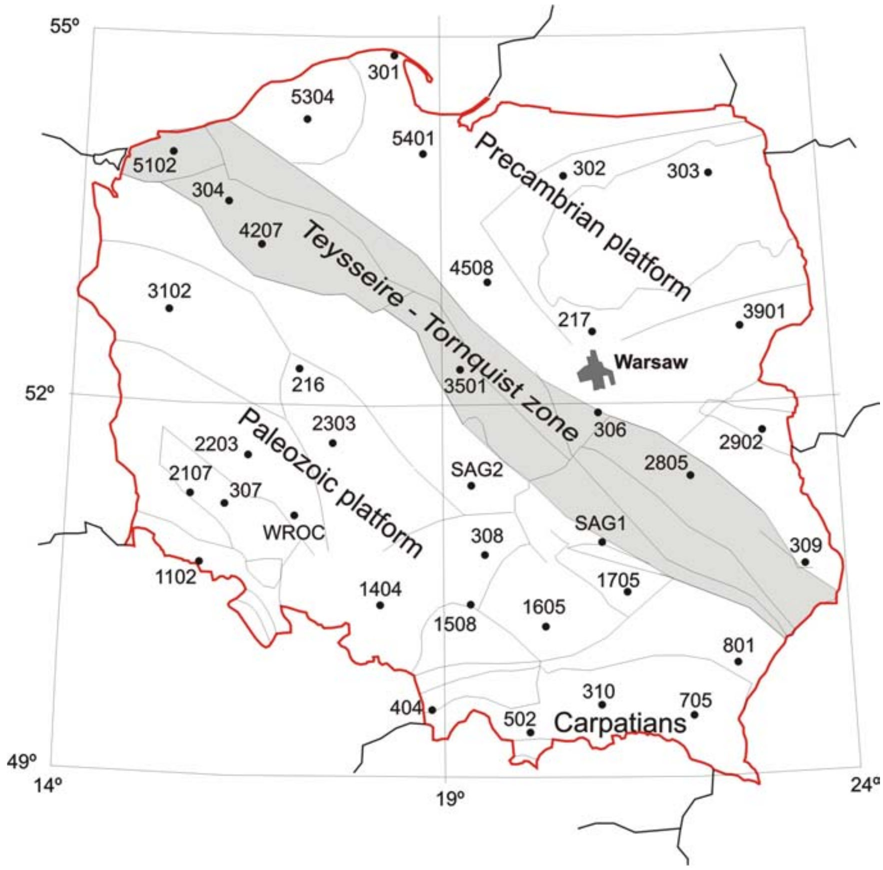

Fig. 3.2.1. The PSG network stations on the background of geological-structure boundaries in Poland

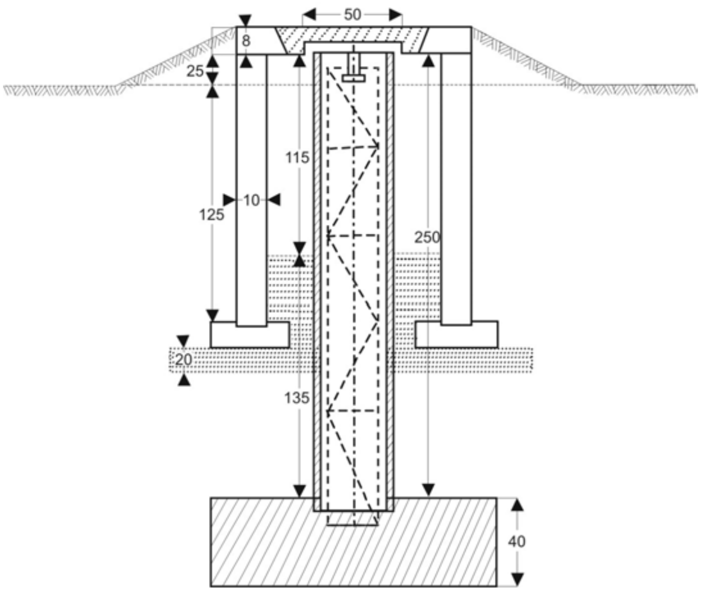

Fig. 3.2.2. Monumentation of the PSG stations

The value and significance of the PSG network for geodynamic research in Poland, the need for carrying out further observing campaigns at the stations of that network, and also the main principles concerning observation strategy and the processing of GPS data for geodynamics were all formulated in resolutions workshop entitled "Geodynamic research using PSG", organised by Earth Dynamics Section of the Committee for Geodesy of the Polish Academy of Sciences in 2002. The representatives of the geodetic, geological and geophysical research communities took part in the workshop. The following were declared as necessary:

1. analysing the correctness of the position of the existing PSG network stations,
2. carrying out new GPS campaign at the PSG network stations using new, higher-quality measuring equipment, in a manner coordinated with geological measurements, in the integration of PSG with the CERGOP network – in a similar manner to the 1997-1998 operation,
3. carrying out new gravity survey at PSG network stations, by means of relative measurements referred to absolute gravity stations, and also linking to gravimetric points situated outside the geological unit; survey of gravimetric profiles and supplementary detail gravity survey,
4. carrying out a detailed analysis of the monumentation of PSG stations (annual changes – thermal influence, ground water, changes in atmospheric pressure, indirect impact on deformation of movements inside the Earth's crust),
5. investigating whether in the new CERGOP II project it would not be necessary to take into account of new stations (the TT zone is highly differentiated) and to increase the density of stations of the geodynamic network. Such stations could be taken from two geodynamic profiles: South-East and North-West, established as part of the EUROPROBE project,
6. analysing the standards of permanent GPS stations with regard to their usefulness for geodynamic purposes, especially from the point of view of the precision of the data determined,
7. increasing the number of permanent GPS stations in Poland (for monitoring horizontal movements, checking on deformations, e.g. on both sides of the Pieniny strip, determining the main directions of deformations within Poland, functions other than geodynamic),
8. a uniform processing of data from the GPS campaigns and gravimetric survey at PSG network stations (1997-1998 observations, and also new measurements) and also carrying out of a detailed analysis of the results,
9. carrying out a joint geological and geodetic interpretation of the results of geodetic measurements.

In 2006 a new geodynamical project was prepared and recommended for realisation by the Committee for Geodesy of the Polish Academy of Sciences. The main goal of the project is the complex analysis of recent geokinematics and geomechanics of the Earth crust in the territory of Poland. The archive data as well as the new data acquired during the realisation of the project will be analysed. Combined analysis of GNNS data obtained from the epoch observations at the stations of the PSG network and the stress measured in the drilling holes will be conducted. The new thermomechanic 2D geodynamic model will be determined using the finite element method.

The start point of this project are a preliminary model of the stresses in the Earth's crust over the area of Poland, showing regularities in the distribution of tectonic-compression directions (Jarosiński, 2006) (Fig. 3.3.3) as well as deformation parameters obtained using a CERGOP data processing. The direction of stresses agree with the directions of deformation, calculated using observations made as part of the CERGOP campaigns (Fig. 3.2.3), as well as with the directions of the principal axes of deformation ellipses (Klek, 2005) (Fig. 3.2.4).

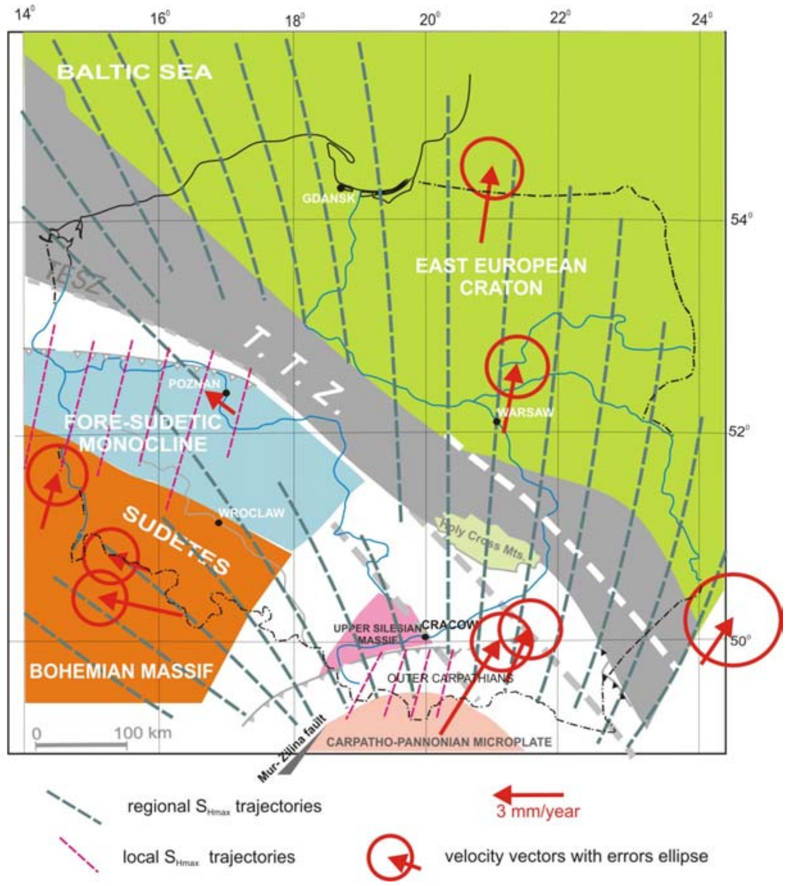

Fig. 3.2.3. Accordance of present-day tectonic-stress trajectory directions and interplate movement vectors

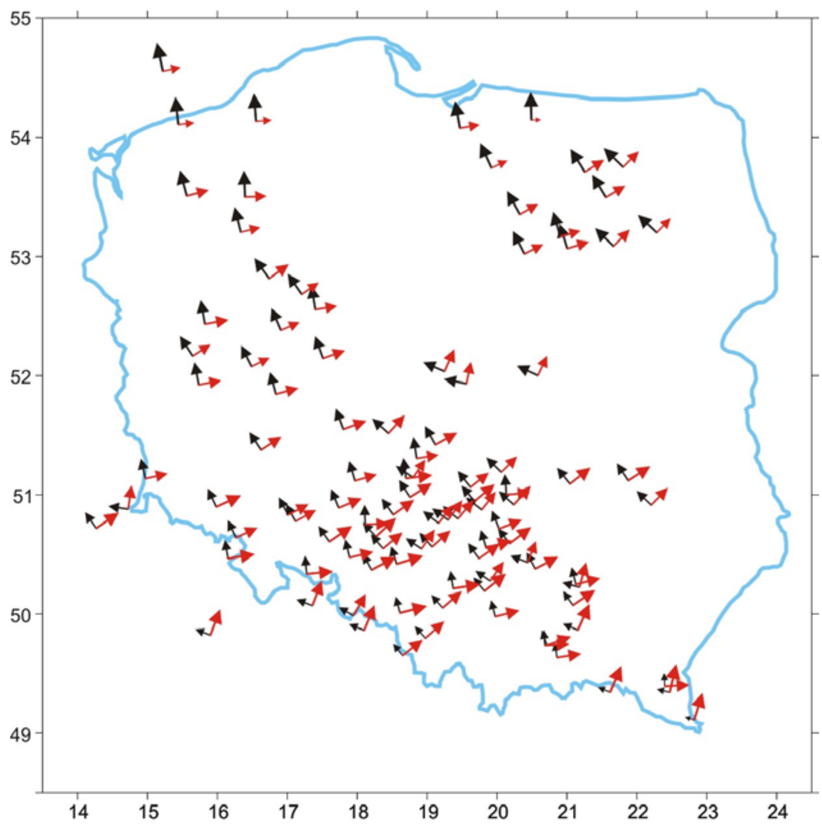

Fig. 3.2.4. Main deformation-direction axes from the CERGOP campaign

Because the distribution of CERGOP stations in Poland is not sufficient for studying kinematics and dynamics of the Earth crust, two consecutive GPS campaigns on 6 selected points of the PSG network were designed as supplementary data for the geodynamic operation carried out as part of the CERGOP project and the Polish section of the EPN network (Fig. 3.2.5). At those stations, a 5-day observation campaign was carried out in spring of 2006 by the team of the Warsaw University of Technology, and is to be repeated in 2007. The results of observations in the network composed of the stations shown in Figure 3.2.5 will serve to specify interplate velocities and their interpretation.

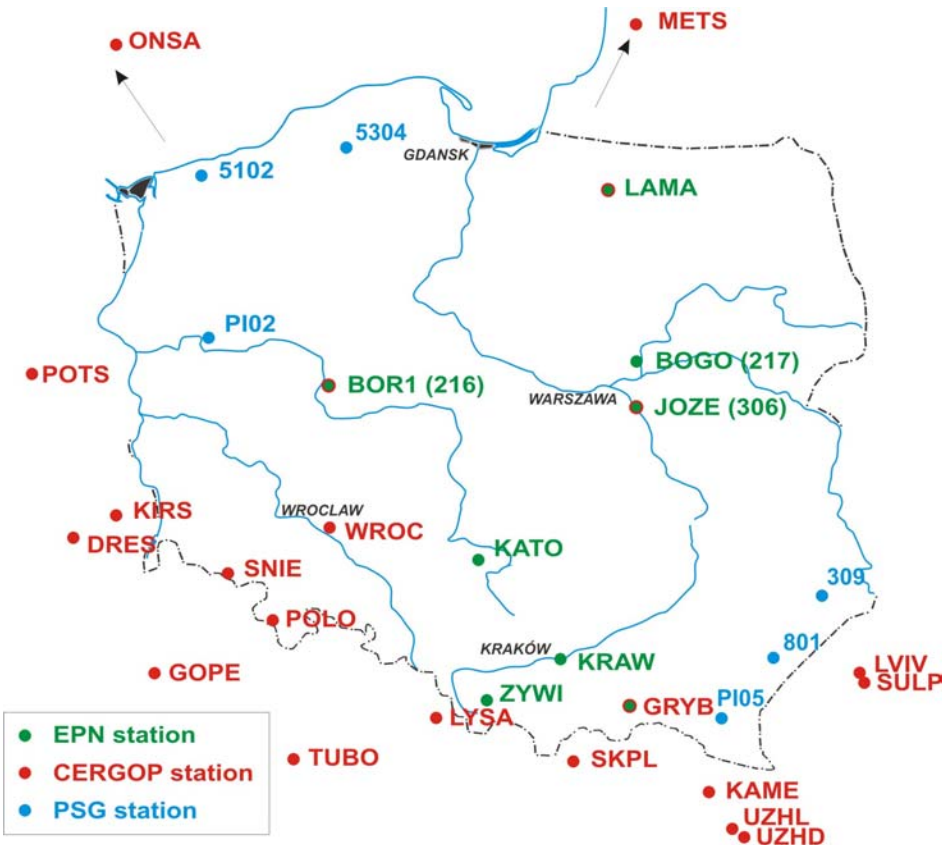

Fig. 3.2.5. The CERGOP, EPN and selected PSG stations

The results of the research presented have enabled to develop the foundations of the project, the implementation of which is expected during 2008.

3.2.2. Geodynamic Research in the Sudety Mountains and Fore-Sudetic Block (SW Poland)

Monitoring of active tectonic structures of Sudety Mountains and Fore –Sudetic Block (SW Poland) were continued in 2003-2006 by the team of the Institute of Geodesy and Geoinformatics (former Department of Geodesy and Photogrammetry) of Wroclaw University of Environmental and Life Sciences (former Agricultural University of Wroclaw), mainly in the framework of the European project COST 625 "3D-Monitoring of Active Tectonic Structures" (Fig. 3.2.6).

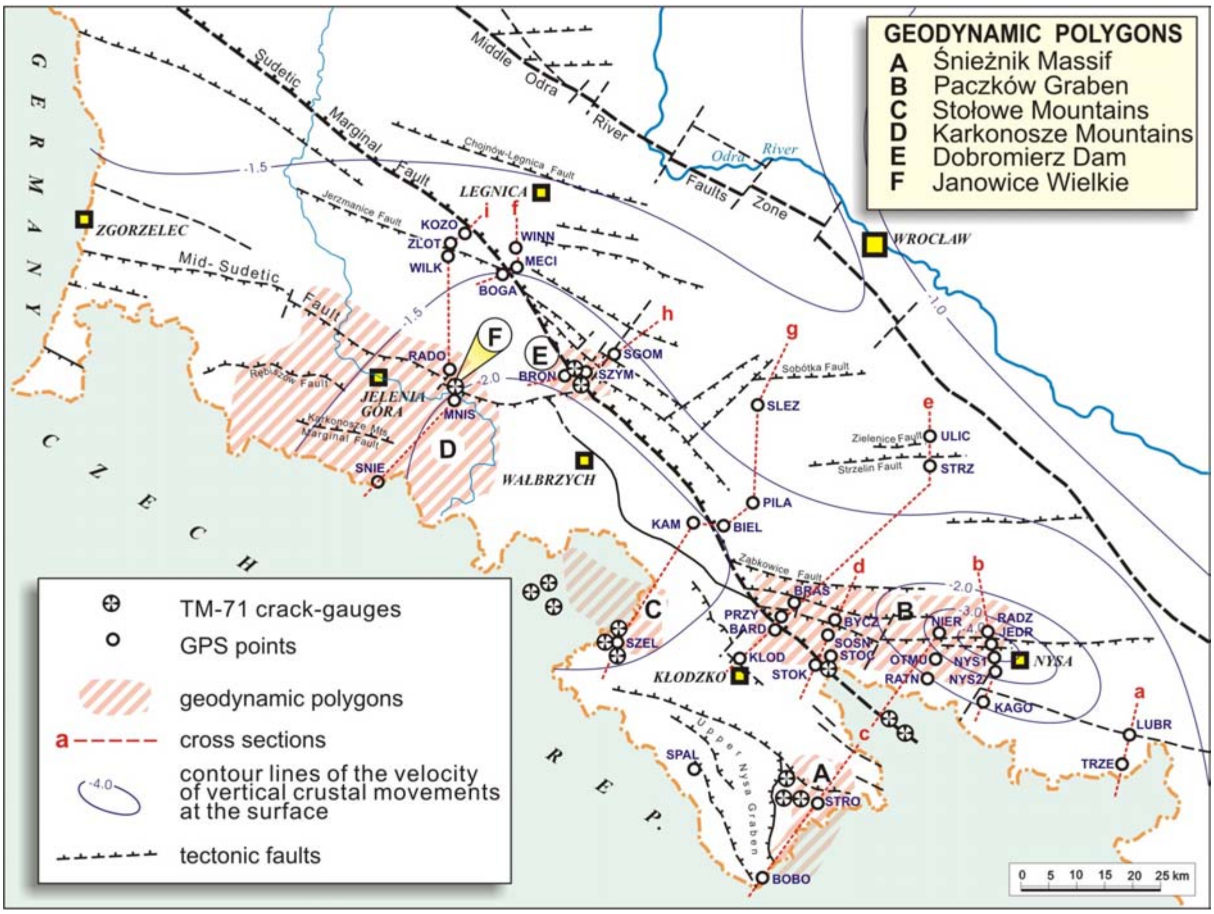

Fig. 3.2.6. Sudety Mountains and Fore Sudetic Block geodynamic areas; GEOSUD network and geodynamic polygons

Two new geodynamic research polygons in the Polish Sudety Mountains were established: Dobromierz area in the Sudetic Marginal Fault zone (Cacon et al., 2005b) and Janowice area in the Mid-Sudetic Fault. Geodynamic polygons set up earlier in SW Poland, like Snieznik Massif area (set up in 1992), Szczeliniec Wlk. (1993) area in Stolowe Mountains and GEOSUD research network (1996), were also included into the studies conducted within the COST 625 project (Cacon et al. 2004a, 2004b, 2004c; Kontny and Bosy, 2004; Kontny et al., 2005). Besides of local research areas also the recent deformations of whole area of Polish Sudetes, particularly Sudetic Marginal Fault zone and Karkonosze Mountains were investigated (Bosy et al., 2006; Cacon et al., 2004b, 2005a; Kontny, 2004; Kontny and Bosy, 2004, Kontny et al., 2004b, 2006). Some results of the research are presented in Figures 3.2.7, 3.2.8 and 3.2.9. Correlation between EPN station velocities and the tectonics of Europe were investigated, as well (Kontny et al., 2004a).

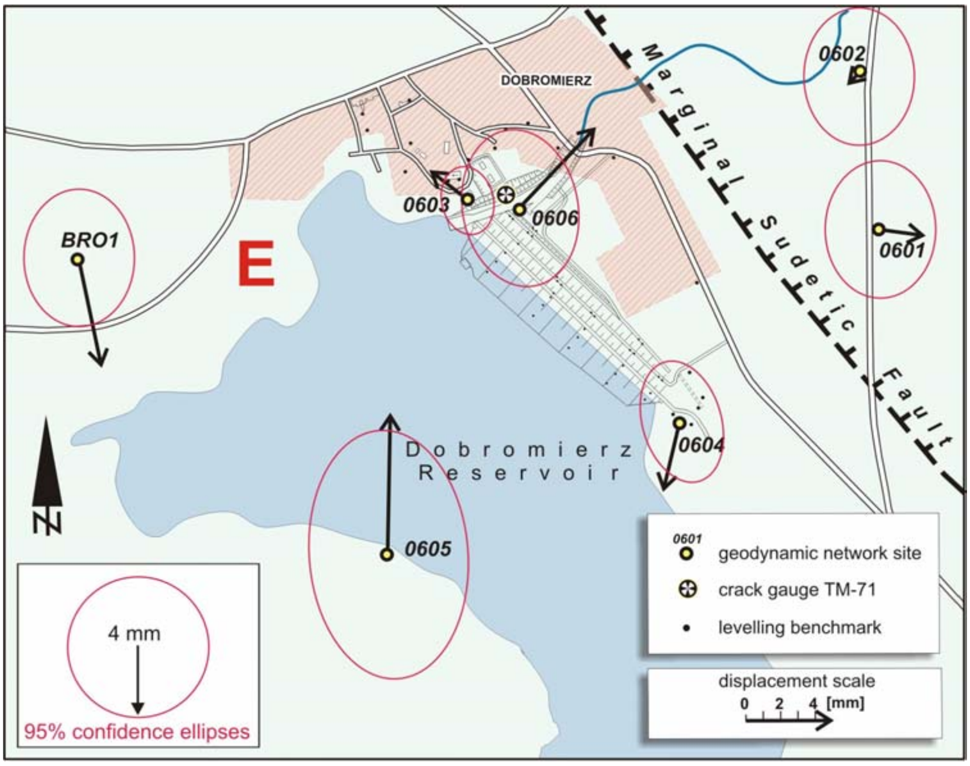

Fig. 3.2.7. Results of geodynamic research in 2001-2005 in Dobromierz Dam polygon

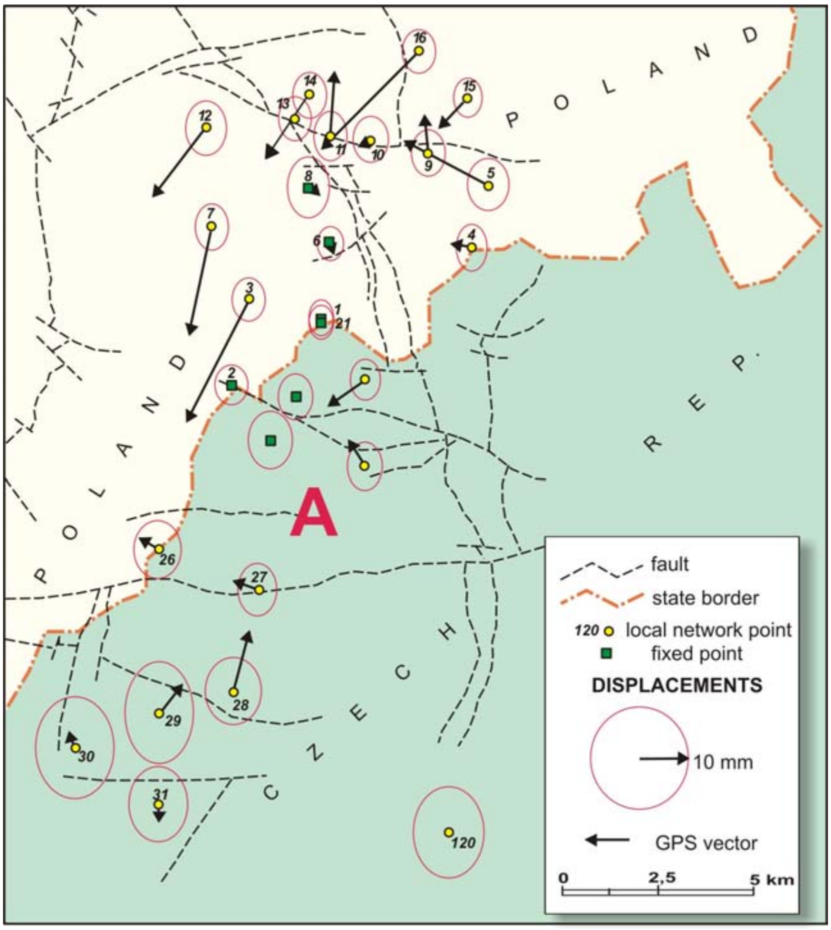

Fig. 3.2.8. Horizontal displacements in Snieznik Massif - results from 1993-2004 (Cacon et al., 2004c)

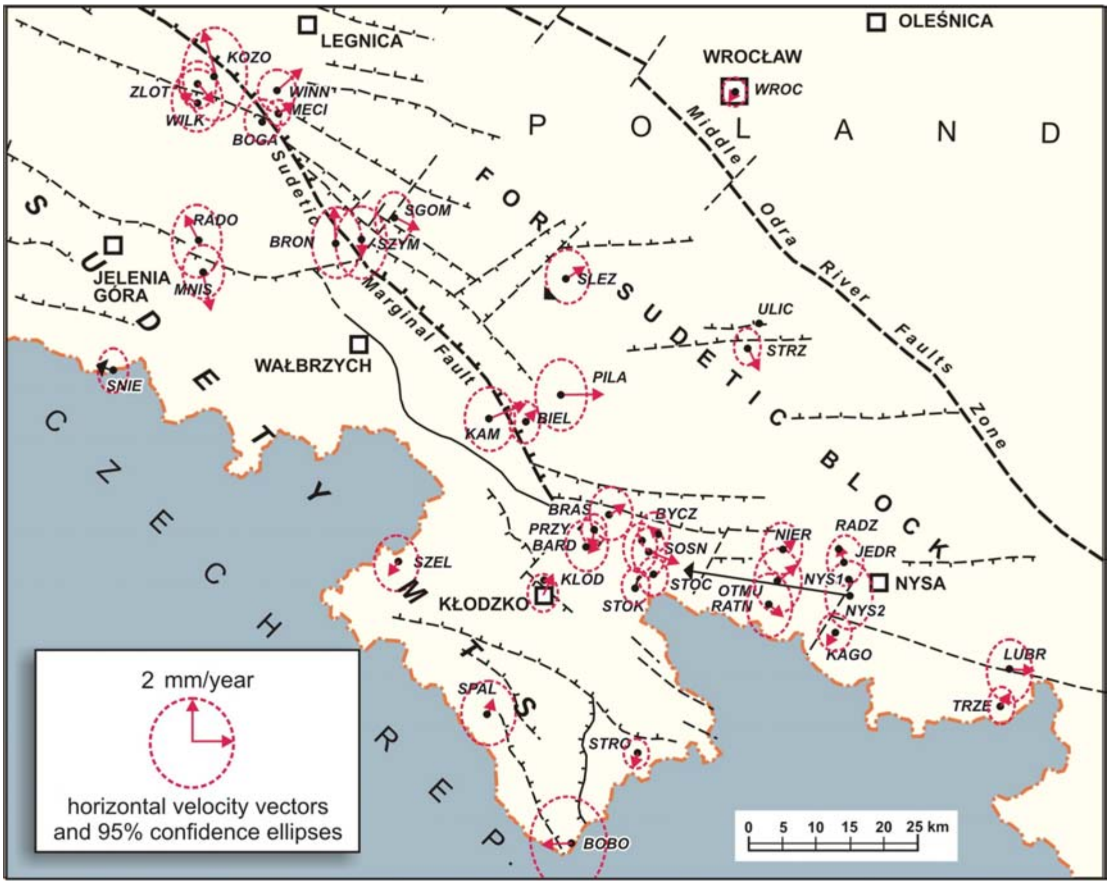

Fig. 3.2.9. Horizontal velocity vectors with 95% confidence ellipses in GEOSUD - results from 1996-2005 (Bosy et al., 2006)

3.2.3. Tatra Mountains Geodynamics

Geodynamic research in Tatra Mountains was conducted in the framework of cooperation of the teams of the Warsaw University of Technology and the Slovak University of Technology in Bratislava. It was concentrated on the determination of the preliminary relative velocity vectors (Czarnecki and Mojzes, 2004a). The GPS network established in 1998 in the area 40 km × 60 km of the Tatra Mountains with maximum relative height difference 1800 m between sites, consists of 11 sites, 7 in Slovak Republic and 4 in Poland. The network consists of two parts: the outer one that is situated outside the zone of interest and the inner one that is used for self-monitoring. Data from six epoch campaigns performed annually from 1998 to 2003 was processed with the *Bernese* v.4.2 software using the same nearest five IGS GPS permanent stations as the fiducial ones. The velocity vectors were determined with the use of two different models (Mojzes et al., 2006). The differences obtained in horizontal variations of position are not significant. The mean local horizontal velocity of the High Tatra Mountains subregion equals 2.3 mm/year in NE direction while of the flysh subregion equals 1.5 mm/year in N direction. It has been shown that for reliable determination of horizontal and vertical positions of the points in the extreme troposphere conditions the periodic GPS observation campaigns must last for at least 6 days.

3.2.4. Eastern Silesian Geodynamic Network

The Upper Silesian Coal Basin (USCB) area is the most man-transformed area in Poland due to extended mining and other industry. A comprehensive look at the range of the changes shows an urgent need for modernization of classical geodetic network in the area of USCB in Poland. The Eastern Silesian Geodynamic Research Network (ESGRN) is located in the area enclosed by four permanent GPS stations: KRAW, ZYWI, KATO, LELO (Fig. 3.2.10).

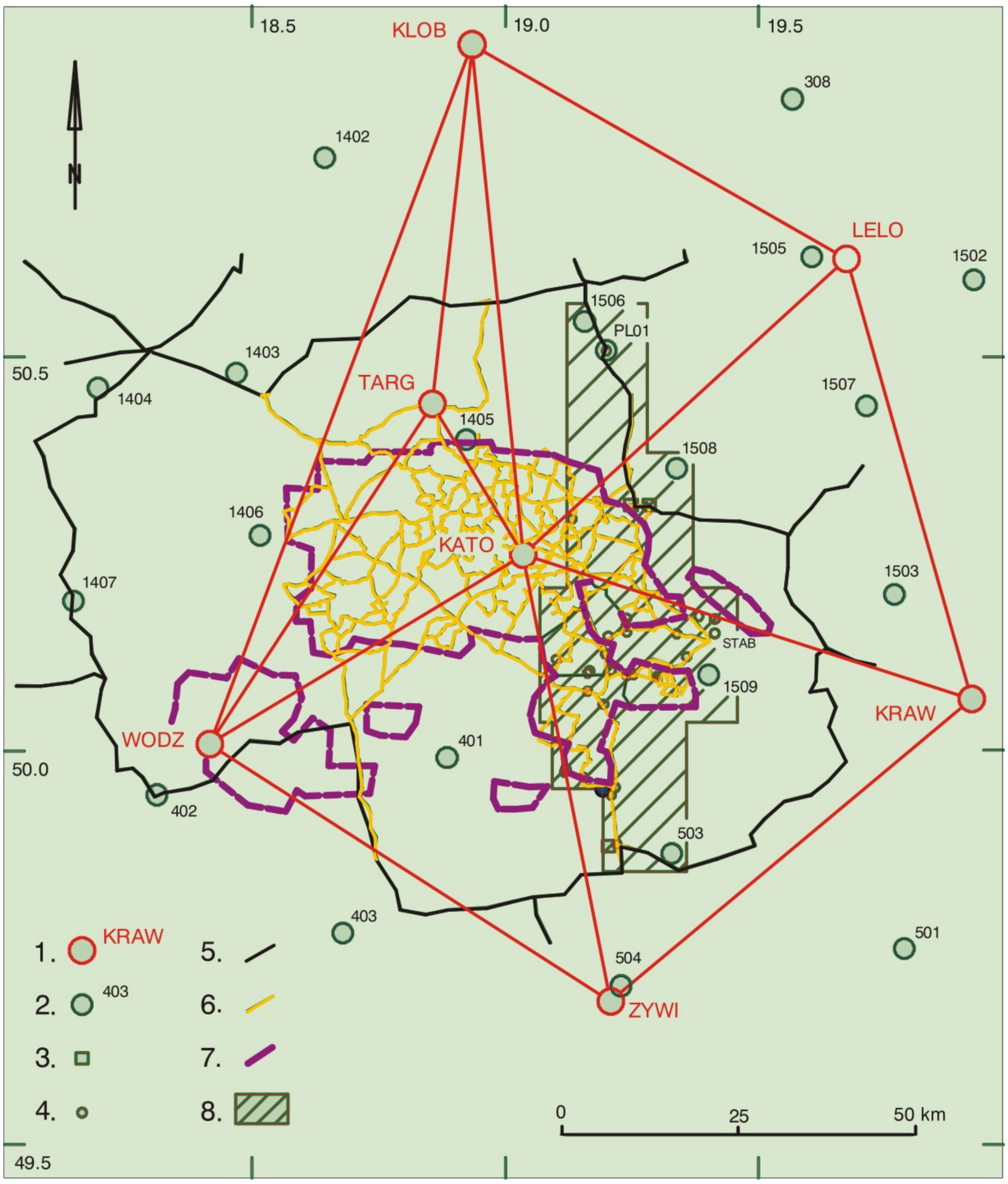

Fig. 3.2.10. The Eastern Silesian Geodynamic Research Network.
1 - permanent GPS station; 2 – point of the POLREF network; 3 – initial fundamental levelling benchmark of GIGANT network; 4 – GPS points; 5 – 1st order levelling network; 6 – GIGANT (2nd order levelling network); 7 - mines area; 8 - area of the research geodynamic network

The research network covers the area over 1000 km^2 of the length is ca. 50 km in N-S direction and about 15 – 20 km in E–W direction. Six mines are located in the research area: “Brzeszcze”, “Ziemowit”, “Piast”, “Janina”, “Jaworzno” (Fig. 3.2.11), and “Trzebionka”.

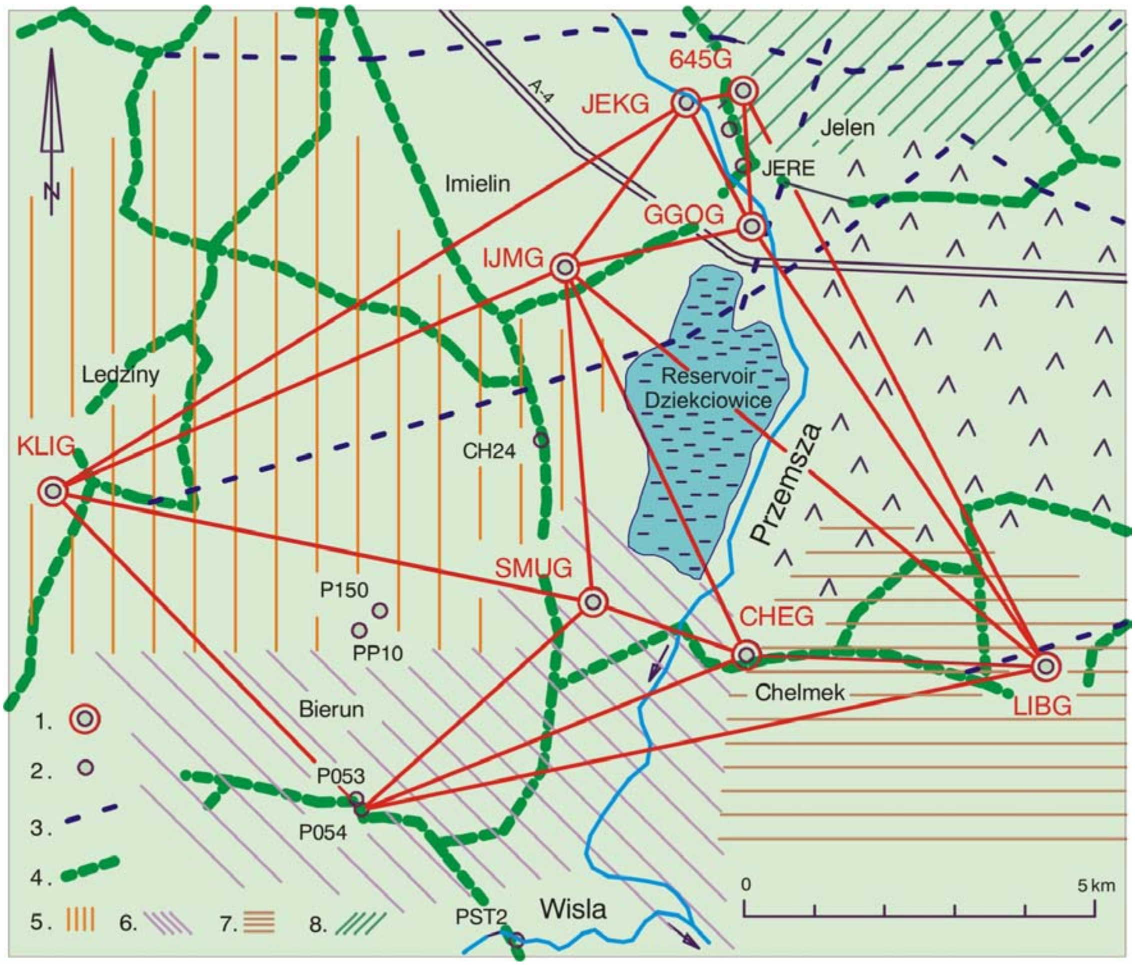

Fig. 3.2.11. The research geodynamic network along the "Przemsza" river.
1 - geodynamic network points (GPS, gravimetry, levelling); 2 – GPS monitoring points;
3 – tectonic faults; 4 – fragment of the GIGANT levelling network;
5, 6, 7, 8 – areas of the mines: "Ziemowit", "Piast", "Janina", "Jaworzno", respectively

Currently the network consists of 40 points surveyed with GPS in 2003–2004 by the team of the Department of Mining Surveying and Environmental Engineering, AGH University of Science and Technology in Cracow. The GPS sites were selected after detailed geological and geodetic analysis. The points of the research network were set up in locations suitable for GPS observations, often close to the points of the geodetic control. They have mostly been monumented directly on triassic outcrops. Only SMUG point has been monumented with blocks of concrete with heads for forced centering. Network points have been concentrated on the triassic outcrops along the valley of Przemsza river, between the Jelen and Chelmek points: 645G, JEKG, IJMG, GGOG, CHEG, LIBG, SMUG (Fig. 3.2.11). Gravity and vertical gravity gradients measurements have been accomplished in cooperation with the Department of Geophysics AGH-UST on twenty points, using SCINTREX CG-3M gravimeter. Twenty points of the GPS network were also tied by precise levelling to the neighbouring benchmarks of 2nd order levelling network GIGANT and 1st order vertical control (Banasik and Góral, 2005).

GPS technology proved its convenience for long term monitoring of spatial displacements of points caused by different factors. Properly used GPS technology can provide the positions of points in a fixed coordinate frame with accuracy of a few millimetres. Recently, the establishment of the permanent GPS stations in Southern Poland, has become an important means in the mine surveying work. GPS surveying technology can also be used to collect, update and modify data for mine geographic information system. With the GPS technology one can survey and modify ground control network for mine area, and survey the observation station of surface movement. The permanent ASG-PL + KRAW network will provide valuable data for understanding and modelling the GPS error spectrum over a wide range of spatial and temporal scales, and enables characterization and understanding of distribution and time dependence of deformations within (USCB) in Poland (Banasik et al., 2004, 2005; Banasik and Goral, 2005).

The work on the software package enabling research on local differential tropospheric and ionospheric refraction is continued at the Faculty of Mining Surveying and Environmental Engineering of AGH-UST, Cracow. Presented approach enables the estimation of differential tropospheric delay for any pair of permanent GPS stations with no information on meteorological conditions. It also allows to remove any un-modelled effects of the troposphere that cannot be predicted with the use of empirical models. Presented method is especially useful in processing GPS measurements in mountainous areas where the significant height differences occur. The discussed approach gives an insight into refraction correction, especially for satellites near the horizon (Góral, 2003a, 2003b).

3.2.5. Geodynamic Network in Pieniny Klippen Belt

Horizontal network of the test field in Pieniny Klippen Belt has periodically been surveyed since 1978 by the team of the Warsaw University of Technology. The results from 1978-1985 showed some tendency of distances shortening in latitudinal component. In 1993 the network was rearranged to become compatible with GPS measurements and was surveyed three times in 1993, 1994, and 1995. In 2001 the network was rearranged again (Walo et al., 2005) and since then the GPS survey was repeated at 10 reference stations (5 in Magura Nappe and 5 in Podhale Flysh) and at 8 control stations in the Pieniny Klippen Belt (Fig. 3.2.12).

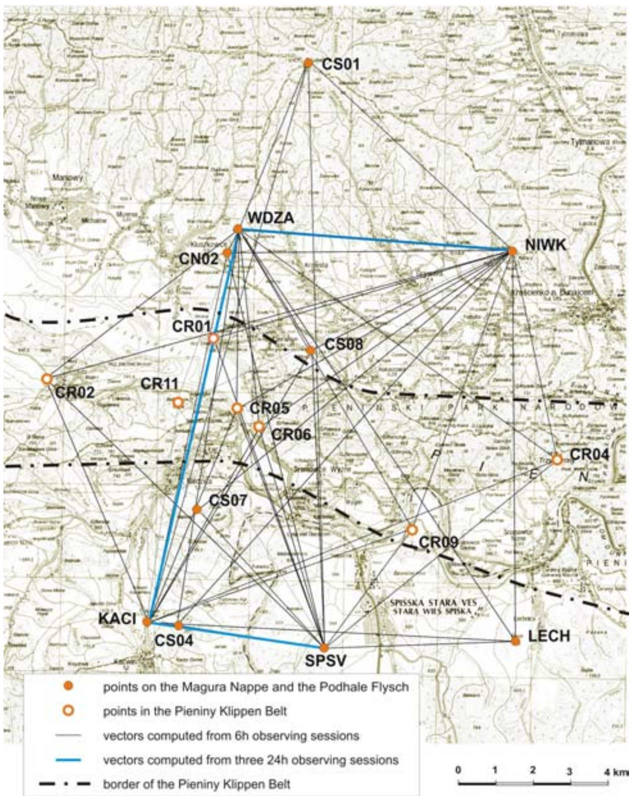

Fig. 3.2.12. GPS network in Pieniniy Klippen Belt

In 2001-2005 GPS measurements were regularly performed in three 6h observing sessions in each annual campaign, using dual frequency receivers. Four reference stations were observed in three 24h sessions. Constrained centering ensuring precision better then ±0.5 mm was applied (Walo et al., 2006). Table 3.2.1 shows statistical summary of adjustments for seven successive measuring epochs.

Table 3.2.1. Summary of the network adjustment

Epoch	No of points	No of baselines	A posteriori standard deviation	Test χ^2
1994	15	61	0.63	passed
1995	15	61	0.79	passed
2001	19	112	0.84	passed
2002	19	88	1.23	passed
2003	20	92	0.75	passed
2004	17	88	0.74	passed
2005	18	91	0.70	passed

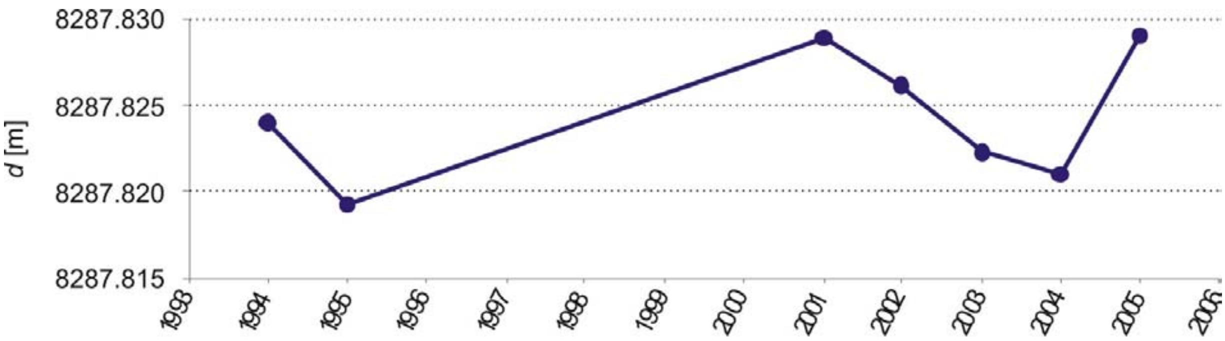

Fig. 3.2.13. Distance changes between 'mean points' (mean value of coordinates of control points situated at the separate tectonic structure) situated at the Magura Nappe and Podhale Flysh

Mutual approaching trend of the Magura Nappe and the Podhale Flysh was disturbed during the period of 1995-2001 when the dam on the Dunajec-river was constructed and the water reservoir was filled. A hypothesis that the filling of the reservoir resulted in temporarily driving apart the Magura Nappe and Podhale Flysh has been presumed. After 2001 the tectonic structures started again to approach each other.

The results of the 2005 campaign indicate a new disturbance in above mentioned trend. It could be caused by the earthquake in November 2004 that had happened near the test field. This hypothesis should be verified in next years by the following observational campaigns. The control points within the limits of the Pieniny Klippen Belt have demonstrated oscillatory changes of coordinates in the range of ±15 mm.

3.2.6. Geodynamic Research in Test Areas in Greece and Italy

Local GPS networks were established in the framework of international cooperation of the team of the Institute of Geodesy and Geoinformatics (former Department of Geodesy and Photogrammetry) of Wrocław University of Environmental and Life Sciences (former Agricultural University of Wroclaw) with the research groups from Italy and Greece in three research areas in those countries: Gargano GPS Network in the Mattinata Fault (Gargano Peninsula, Italy), Norcia Network in Norcia Tectonic Basin (Central Apennines, Italy) and Kaparelli Network in the Kaparelli Fault Zone (Gulf of Corinth, Greece) and GPS surveying campaigns were conducted.

In the Gargano promontory, which is one of the sectors of the Apulian foreland in southern Italy, the Mattinata Fault System represent the most important tectonic and seismogenic features (Tondi et al., 2005). The Norcia seismic area, located in the axial zones of the central Apennines, represent the intramontane basin and is affected by several faults of Late-Quaternary age which cut through, or reactivate, previous thrust-related features. Local geodynamic research GPS networks were established in Gargano area in July 2002 and in Norcia area in November 2004. Both networks consist of 6 GPS sites located on the both sides of the monitored faults and were surveyed once or twice a year. Preliminary results (Fig. 3.2.14 and Fig. 3.2.15) indicate local relative movements with the velocity up to 1.5 mm/year.

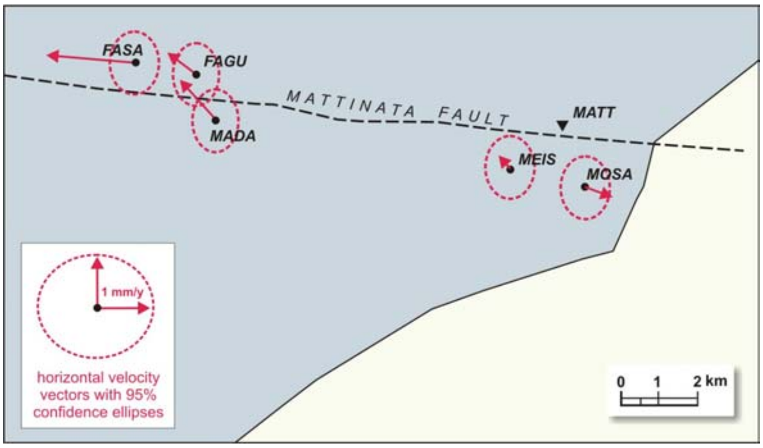

Fig. 3.2.14. Horizontal velocity vectors of Gargano network sites

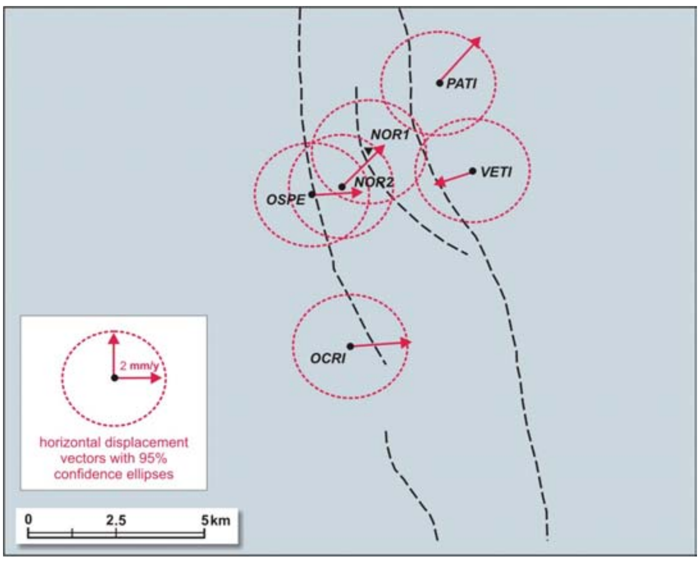

Fig. 3.2.15. Horizontal displacement vectors 2005-2006 of Norcia network sites

Local geodynamic research network was established in November 2003 in Kaparelli fault in the eastern part of the Gulf of Corinth, in cooperation with the Greek colleagues (Drakatos et al., 2005). Recent geological and GPS data showed that the Kaparelli area forms the boundary between fast-slipping normal faults in Corinth-Perachora regions and slow-slipping faults in Viotia, Attica (Drakatos et al., 2005; Cacon et al., 2005b). Geodynamical research results from the Kaparelli research area are presented in Figure 3.2.16.

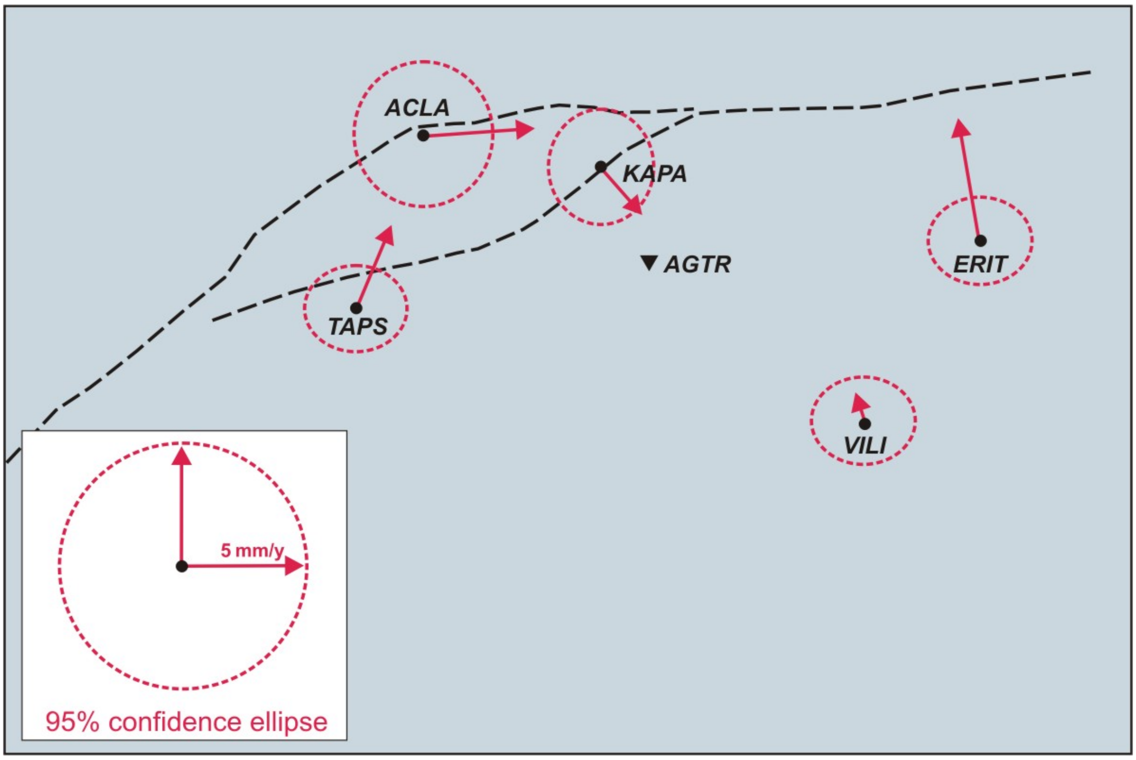

Fig. 3.2.16. Total horizontal displacement vectors of Kaparelli network sites from 2004-2006 data

3.3. INTERNATIONAL GEODYNAMIC NETWORKS

3.3.1. CERGOP Project

The Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology is deeply involved in the realisation of CERGOP (Central Europe Regional Geodynamics Project) Project that gathers teams form Austria, Croatia, the Czech Republic, Germany, Hungary, Italy, Romania, Poland, Slovakia, Slovenia and Ukraine. The project was initiated in 1993. Its main objectives are to integrate the geodynamic research in the Central European region, based on high accuracy space geodetic measurements on a geodynamic network, to investigate the most profound geotectonic features in the Central European region, the Teisseyre-Tornquist zone, the Carpathians, the Bohemian Massif, the Pannonian Basin and their relation to the Alpine-Adria region, as well as to provide a stable reference frame for sub-regional, local or across the borders investigations and deformation studies. The results of the project are regularly published in the series Reports on Geodesy edited by the Institute of Geodesy and Geodetic Astronomy WUT. In 2003-2006 the following issues of the Reports on Geodesy concerning CERGOP activities were published: No 1(64), 2003; No 3(66), 2003; No 2(69), 2004; No 4(71), 2004; No 2(73), 2005; No 4(75), 2005; No 1(76), 2006; No 3(78), 2006; No 4(79), 2006; No 5(80), 2006; and No 6(81), 2006.

It was clear from the beginning of CERGOP, that a project duration of 3 years, although is sufficient for getting interesting initial results, should be extended for at least another 3-5 years. In order to obtain a reliable 3D intraplate tectonic velocity field in the Central European region a new phase of CERGOP project named CERGOP-2 was started 1 April 2003.

Seven Polish sites were accepted in the second phase of the CERGOP-2 Project. Four stations are IGS (International GPS Service) permanent stations and four belong to the EUREF permanent network (EPN) (Table 3.3.1). The station Nowy Sacz was established in 2005 in the framework of activity of the CERGOP WP.3.

Table 3.3.1. GPS CERGOP-2 stations in Poland

Station (P) – permanent (E) – epoch	Permanent services	Programmes	Institution
Borowiec (P)	GPS SLR Time service	IGS EUREF-EPN EUREF-POL CERGOP	Space Research Centre, Polish Academy of Sciences
Jozefoslaw (P)	GPS Gravimetric tidal Astrometric serv. Ionospheric TEC	IGS EUREF-EPN EUREF-POL CERGOP	Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology
Lamkowko (P)	GPS Ionospheric TEC	IGS EUREF-EPN EUREF-POL CERGOP	Institute of Geodesy, University of Warmia and Mazury, Olsztyn
Wroclaw (P)	GPS	IGS EUREF-EPN CERGOP	Department of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences
Grybow (E)		EUREF-POL CERGOP	Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology
Sniezka (E)		CERGOP	Department of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences
Nowy Sacz (P)		CERGOP	Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology

All Polish CERGOP-2 stations participated in the CEGRN'2003 and CEGRN’2005 GPS campaigns. Data as well as the results of processing of the CERGOP campaigns were transmitted to the CERGOP Data Centre in Graz, Austria.

Data Processing Centre at the Institute of Geodesy and Geodetic Astronomy WUT operates as EUREF Local Analysis Centre, and as CERGOP Processing Centre. Two GPS CERGOP-2 campaigns 2003 and 2005 were processed at the WUT Local Analysis Centre. In 2003 campaign data from 71 stations (32 permanent, 39 epoch) were processed (Fig. 3.3.1a), while in 2005 campaign processing included data from 96 stations (35 permanent, 61 epoch), (Fig. 3.3.1b). It has been performed using the *Bernese* v.4.2 GPS software, according to rules specified by Work Package 5 of the CERGOP project.

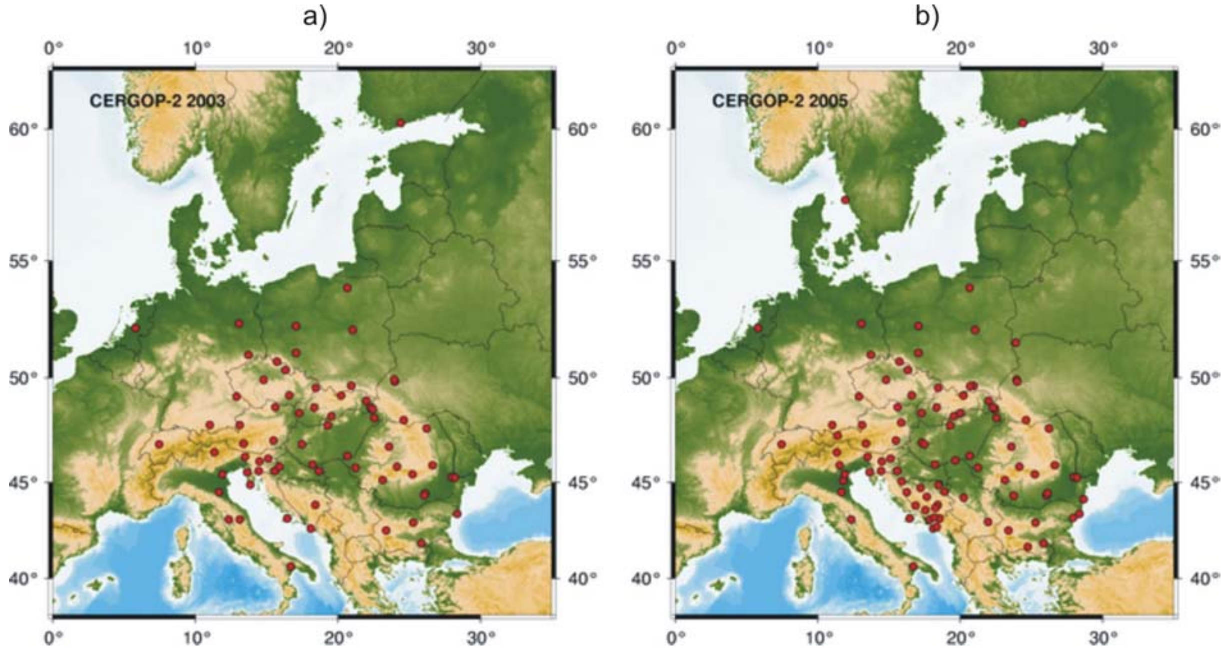

Fig. 3.3.1. Stations participating in 2003 (a) and 2005 (b) CERGOP-2 campaigns

3.3.2. Determination of Deformations from CERGOP GPS Observation Campaigns

7 observation campaigns were conducted in the framework of CERGOP and CERGOP II in 1994-2005. Stations in the CEI (Central European Initiative) countries form the CEGRN network. Different number of stations participated in the successive GPS observation campaigns. The stations that participated in two or more observations campaigns were used for determination of deformations parameters (Klek and Rogowski, 2006). The list of stations with GPS CERGOP campaigns processed is given in Table 3.3.2.

Coordinates obtained from data processing performed in different observation campaigns were transformed to the common epoch and common reference frame.

Velocity vectors were determined using linear regression method. Deformation parameters were computed using the algorithm developed by Altiner. For determination of deformation parameters the independent triangular network was created. Processing was performed using horizontal velocities only due to insufficient precision of height data. In the framework of the project the values of dilatation and extension as well as main direction of the strain were determined. Figure 3.3.2 shows principal directions of the strain: dilatation (negative value of deformation) is shown on the left, extension (positive value of deformation) on the right.

Table 3.3.2. List of stations participating in GPS CERGOP campaigns

	1994	1995	1996	1997	1999	2001	2003
BASO	×	×	×	×			
BOR1	×	×	×	×	×	×	×
BOZI					×	×	×
BRSK	×	×	×	×	×	×	×
BUCA		×	×	×	×		×
BUCU					×	×	×
BZRG					×	×	×
CAOP						×	×
CSAN					×	×	×
CSAR	×	×	×	×	×	×	×
DISZ	×	×	×	×	×	×	×
DRES					×	×	×
DUBR						×	×
FUN3					×	×	×
GIL2				×	×		
GOPE	×	×	×	×	×	×	×
GRAZ	×	×	×	×	×	×	×
GRYB	×	×	×	×	×	×	×
HARM			×	×			×
IAS3			×	×	×		
JOZE	×	×	×	×	×	×	×
KAME					×	×	×
KIRS	×	×	×	×	×		
KOSG	×	×	×	×	×	×	×
LAMA	×	×	×	×	×	×	×
LEND					×	×	
LJUB	×	×	×	×	×	×	×
LVIV		×	×	×	×	×	×
LYSA					×	×	×
MACI		×	×	×			
MALJ					×	×	×
MATE	×	×	×	×	×	×	×
MEDI					×	×	×
METS	×	×	×	×	×	×	×
MOPI	×	×	×	×	×	×	×
ONSA	×	×	×	×	×	×	×
OSJE						×	×
PART					×	×	×
PENC	×	×	×	×	×	×	×
POL1					×	×	×
POTS		×	×	×	×	×	×
SBGZ					×	×	×
SKPL	×	×	×	×	×	×	×
SNIE	×	×	×	×	×	×	×
SOFI			×	×	×	×	×
SRJV					×	×	×
STHO	×	×	×	×	×	×	×
SULP				×	×	×	×
TARP					×	×	×
TIS3			×	×	×		×
TUBO		×			×	×	×
UNPG						×	×
UPAD	×	×	×	×	×	×	
UZHD	×	×	×	×	×	×	×
UZHL						×	×
VAT1				×	×		
VRN1				×	×	×	×
WROC					×	×	×
WTZR			×	×	×	×	×
ZIMM	×	×	×	×		×	×

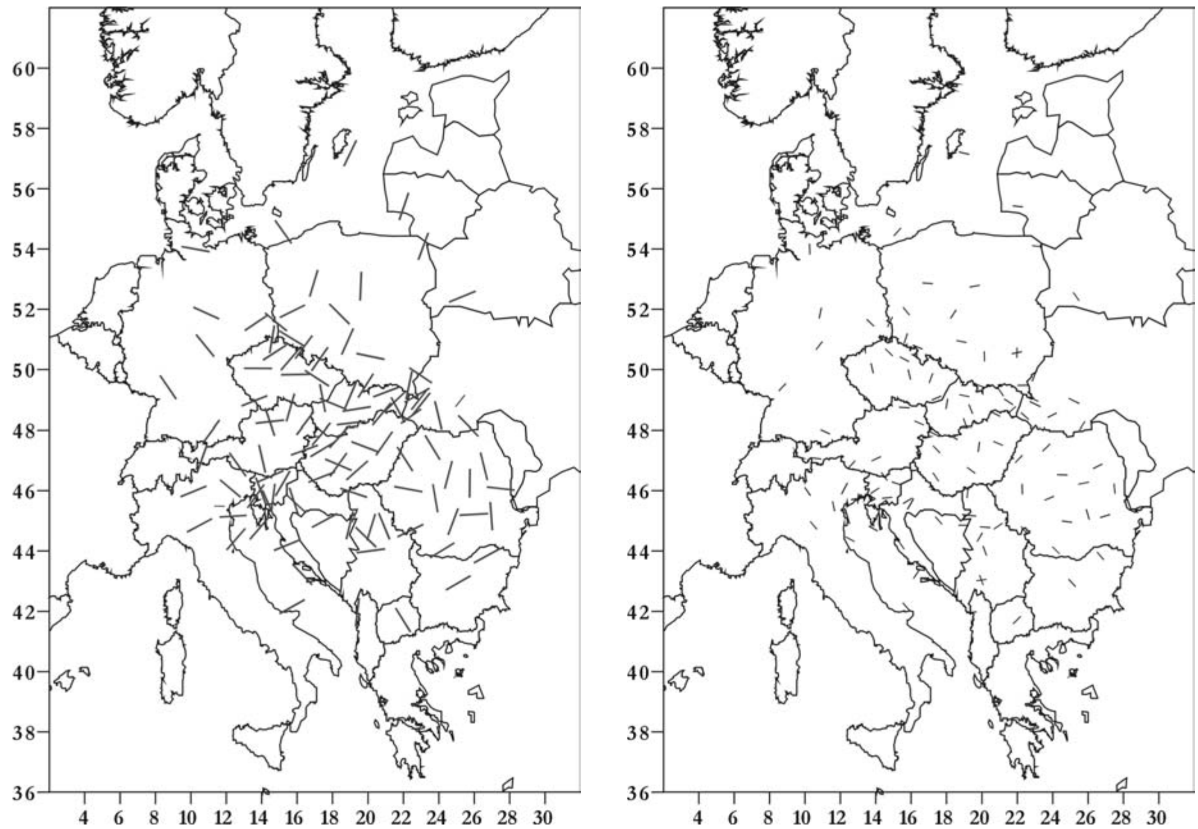

Fig. 3.3.2. Principal directions of the strain

Principal axis of deformations ellipse obtained from analysis of CERGOP campaigns are similar to the model of stress on the bases of geological data (Fig. 3.3.3) (Jarosiński, 2006).

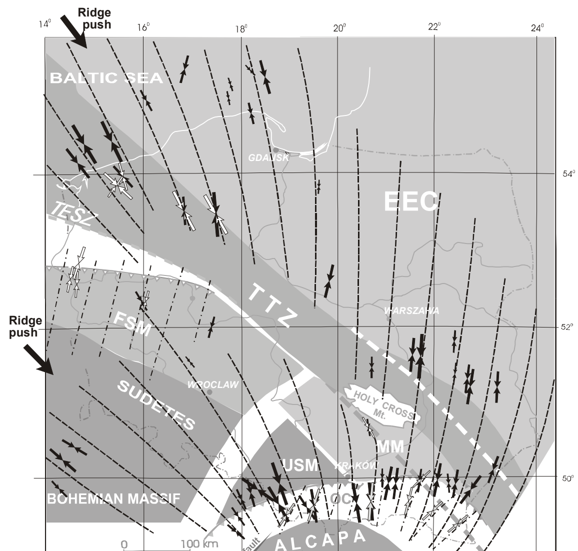

Fig. 3.3.3. A sketch map of the S_{Hmax} orientation from breakouts and hypothetical trajectories of S_{Hmax} for Poland

3.4. EARTH ROTATION

Earth rotation has been recently recognised in the IAG flagship project Global Geodetic Observing System (GGOS) as one of three pillars of modern geodesy. The Earth orientation parameters (EOP) which are determined on the regular basis from the observations of space geodesy, are sensitive to the global mass and angular momentum exchanges between the solid Earth and its fluid envelopes, the atmosphere, the oceans, the land hydrosphere and the core. Hence, the analysis of the observed EOP and of the related geophysical parameters is important for understanding the global processes in the system Earth. In the last few years quick developments of investigations of geophysical excitation functions of Earth Rotation have been observed. The new models of Oceanic Angular Momentum (OAM) and Hydrological Angular Momentum (HAM) have been worked out. Modelling and predicting of Earth rotation are also essential for the realization of the global reference systems, the International Terrestrial Reference System ITRS and the International Celestial Reference System ICRS.

In Poland, investigations concerning Earth rotation has been done mostly by the researchers of the Space Research Centre of the Polish Academy of Sciences in Warsaw. They participated in the activity of the international scientific organisations (IAG, IAU, etc.) and of their commissions and working groups. Results of their research have been reported at the international conferences, workshops, and published in the scientific journals. Short summaries of the most important results of these investigations are presented below.

3.4.1. Investigations of Geophysical Excitations of Earth Orientation Parameters

3.4.1.1. Theoretical problems

Luni-solar perturbations in Earth rotation associated with the departures of the Earth's dynamical figure from the rotational symmetry were investigated. Those small variations (about 0.1 milliarcseconds corresponding to ca. 3 mm at the Earth surface) appear in both the equatorial component of rotation (polar motion and nutation) and the axial component (variation of the UT1 and the length of day). The research concentrated on the equatorial component that should be treated as polar motion, in accordance with the recently adopted definition of the celestial intermediate pole published in IERS Conventions 2003 (IERS Technical Note No 32). That component of the luni-solar perturbation, usually referred to as "subdiurnal nutation", has been neglected in earlier investigations due to its small size. The discussion of the IAU Commission 19 WG on Nutation, coordinated by A. Brzezinski, led to an agreement on the model whose accuracy is expected to be at the level of 1 microarcsecond (Brzezinski and Mathews, 2003; Brzezinski, 2003b). The model was included in the IERS Conventions 2003 as an element of the transformation between the terrestrial and celestial reference systems (IERS Technical Note No 32). The corresponding Fortran program *PMsdnut.for* is available from the IERS Conventions website (ftp://tai.bipm.org/iers/convupdt /chapter5/). A successful attempt to retrieve the diurnal and semidiurnal components of polar motion and UT1 from analysis of the routine observations by the very long baseline interferometry (VLBI) was made (Bolotin and Brzezinski, 2006; Brzezinski, 2006b). Those components are expressed by time series beginning in 1984, which can be interpreted by comparison with geophysically determined excitation functions. In a frame of modelling efforts, the algorithm of computation of the so-called geodetic excitation of nutation based on time variability of the celestial pole offsets determined from the VLBI observations, was developed and implemented (Brzezinski, 2006c). A separate study, done in cooperation with the researchers from the Pulkovo Observatory in Russia, concerned numerical modelling of the rigid Earth rotation on the basis of precise ephemerides of the celestial bodies (Eroshkin et al., 2004).

3.4.1.2. Modelling geophysical excitation

The high-precision modelling of the Earth rotation parameters requires understanding of the global angular momentum exchanges between the solid Earth and the dynamically coupled system atmosphere/oceans. The investigations of that problem were focused on the role played by the non-tidal variability of the ocean, where by "non-tidal" - the global processes driven by the atmospheric forcing and by the heat and freshwater fluxes were understood. A scope of the research was defined in the review paper (Brzezinski, 2003a).

Tab. 3.4.1. Atmospheric and non-tidal oceanic contributions to nutation (a) and prograde diurnal polar motion (b) due to the Sun-synchronous component S_1 of excitation (from Brzezinski et al., 2004). Analysis is done over the period 1993.0 to 2000.5. Phase of excitation is referred to the epoch J2000, phase of nutation and polar motion to the standard astronomical argument

(a)

Term	Excitation		Nutation			
	Amplitude	Phase	Amplitude	Phase	In-Phase	Out-of-Phase
Excitation: S_1^- Component; Nutation: Prograde Annual (T = 365.26 days)						
Air pressure	1.771 ± 0.056	171.0 ± 1.8	72.7 ± 2.3	84.3 ± 1.8	-7.3 ± 2.3	-72.3 ± 2.3
Air pressure IB	1.459 ± 0.037	134.1 ± 1.4	59.9 ± 1.5	47.4 ± 1.8	-40.6 ± 1.5	-44.0 ± 1.5
Wind	13.507 ± 0.274	-17.5 ± 1.2	27.7 ± 0.6	75.1 ± 1.2	-7.1 ± 0.6	-26.8 ± 0.6
Ocean mass	1.754 ± 0.074	105.0 ± 2.4	72.0 ± 3.0	18.3 ± 2.4	-68.3 ± 3.0	-22.6 ± 3.0
Ocean currents	2.167 ± 0.106	46.8 ± 2.8	4.4 ± 3.0	139.4 ± 2.8	3.4 ± 0.2	-2.9 ± 0.2
AAM					-14.4 ± 2.4	-99.1 ± 2.4
AAMIB					-47.7 ± 1.6	-70.8 ± 1.6
OAM + AAMIB					-112.6 ± 3.4	-96.3 ± 3.4
VLBI data					**10.4**	**-108.2**

(b)

Term	Excitation		Polar Motion			
	Amplitude	Phase	Amplitude	Phase	x_p ampl. sin	x_p ampl. cos
S^+_1 Component, Period 0.9999999 day						
Air pressure	2.024 ± 0.042	12.7 ± 1.2	4.9 ± 0.1	-169.6 ± 1.2	0.9 ± 0.1	-4.8 ± 0.1
Air pressure IB	1.577 ± 0.023	-8.8 ± 0.8	3.8 ± 0.1	168.9 ± 0.8	-0.7 ± 0.1	-3.8 ± 0.1
Wind	2.238 ± 0.038	90.8 ± 1.0	5.2 ± 0.1	-91,5 ± 1.0	5.2 ± 0.1	-0.1 ± 0.1
Ocean mass	3.270 ± 0.054	66.5 ± 0.9	7.9 ± 0.1	-115.8 ± 0.9	7.1 ± 0.1	-3.4 ± 0.1
Ocean currents	2.249 ± 0.050	-137.7 ± 1.3	5.2 ± 0.1	40.0 ± 1.3	-3.3 ± 0.1	4.0 ± 0.1
AAM					6.1 ± 0.1	-5.0 ± 0.1
AAMIB					4.4 ± 0.1	-3.9 ± 0.1
OAM + AAMIB					8.2 ± 0.2	-3.3 ± 0.2
VLBI data					**27.4**	**-13.0**

Oceanic contribution to polar motion from intraseasonal to decadal periods using different estimates of the oceanic angular momentum (OAM) was discussed (Brzezinski et al., 2005). They concluded that adding the oceanic contribution to the atmospheric excitation, expressed by the atmospheric angular momentum (AAM), brings the modelled geophysical excitation closer to that inferred from space-geodetic observations over a broad range of periods. The only exception is the decadal component, the so-called Markowitz wobble, which cannot be explained by the combination of the atmospheric and oceanic processes. The non-tidal oceanic excitation of nutation and diurnal/semidiurnal polar motion by using a new 7.5-year time series of the OAM derived from the barotropic ocean model was estimated (Brzezinski et al., 2004). Comparison with the VLBI observations, after accounting for the atmospheric effects, was far from being conclusive; see Table 3.4.1 for details. Clearly, that research should be continued in the next future using alternative subdiurnal estimates of the atmospheric and oceanic angular momenta.

3.4.1.3. Free oscillations in Earth rotation

There have been continued investigations concerning the most important free oscillations in Earth rotation, the Chandler wobble and the free core nutation (FCN). The research concerned in particular theoretical modelling of the free signals (Brzezinski, 2005a, 2005b, 2006a), and their prediction (Brzezinski and Kosek, 2004); see also Sec. 3.4.3 for report regarding prediction of Earth rotation parameters. Geophysical excitation of the FCN signal using the available subdiurnal estimates of the AAM and OAM was also studied (Brzezinski and Bolotin, 2006). The work will be continued using new data sets.

3.4.1.4. Comparison of polar motion excitation series derived from GRACE and from analysis of geophysical fluids

Three sets of degree-2, and order-1 harmonics of the gravity field, derived from the Gravity Recovery and Climate Experiment (GRACE) data processed at the Center for Space Research (CSR), Jet Propulsion Laboratory (JPL) and the Geoforschungs Zentrum (GFZ), were used for computing polar motion excitation functions χ_1 and χ_2 (Fig. 3.4.1).

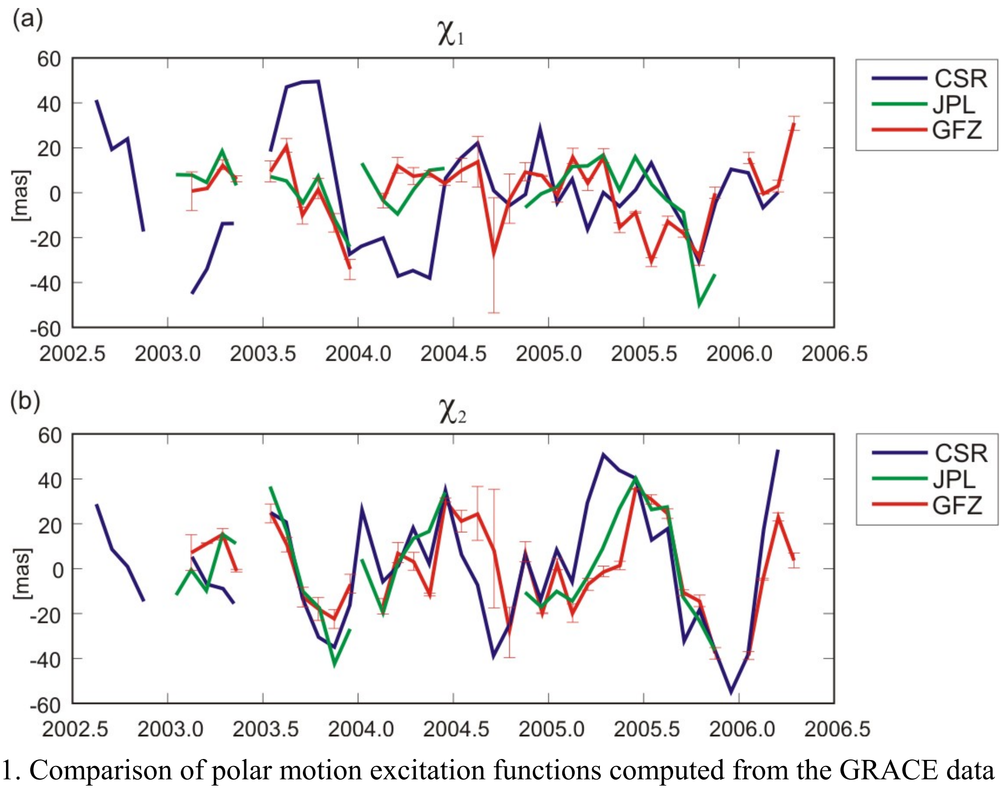

Fig. 3.4.1. Comparison of polar motion excitation functions computed from the GRACE data provided by CSR (blue lines), JPL (green), and GFZ (red)

The excitations obtained by GFZ and JPL as well as χ_2 excitation obtained by CSR compare generally well with geodetically observed excitation after removal of effects of oceanic currents and atmospheric winds. The agreement considerably exceeds that from previous GRACE data releases. For the JPL series, the best levels of correlation with the geodetic observations and the variance are comparable to, but still lower than, those obtained independently from available models and analyses of the atmosphere, ocean, and land hydrology. Improvements in data quality of gravity missions are still needed to deliver even tighter constraints on the effects of mass on the excitation of polar motion.

3.4.1.5. Investigations of Hydrological Angular Momentum (HAM) of different models

Hydrological Angular Momentums were computed from various hydrological data series (NCEP, ECMWF, CPC water storage and LaD World Simulations of global continental water). HAM series obtained from those four models and the geodetic excitation function GEOD computed from the polar motion COMB03 data were compared in the seasonal spectral band. The results show large differences between those hydrological excitation functions as well as between their spectra in the seasonal spectra band (Fig. 3.4.2). Seasonal oscillations of the global geophysical excitation functions (AAM + OAM + HAM) in all cases besides the NCEP/NCAR model are smaller than the geodetic excitation function (Fig. 3.4.3).

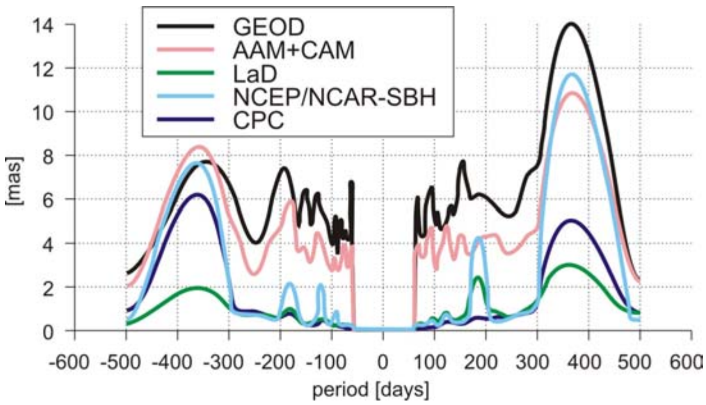

Fig. 3.4.2. The FTBPF (Fourier Transform Band Pass Filter) amplitude spectrum of the geodetic and geophysical excitation functions in 1985-2002 filtered by the Butterworth FTBPF with the 600 day cut-off period and computed for the parameter $\lambda = 0.02$

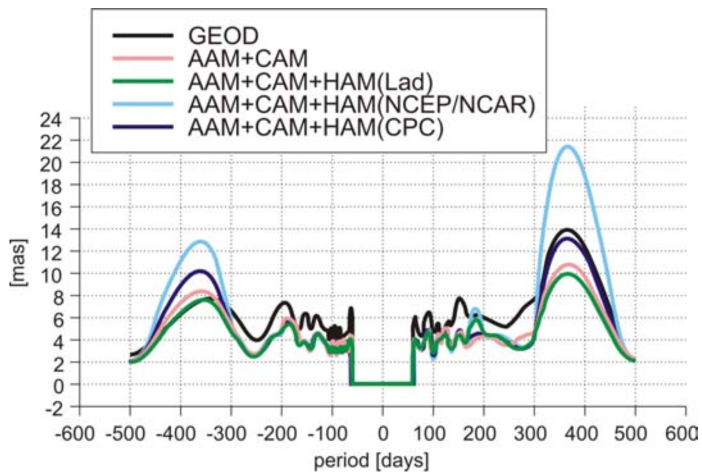

Fig. 3.4.3. The FTBPF (Fourier Transform Band Pass Filter) amplitude spectrum of the geodetic and global geophysical excitation functions in 1985-2002 filtered by the Butterworth FTBPF with the 600 day cut-off period and computed for the parameter $\lambda = 0.02$

HAM excitation functions do not improve the agreement between the observed geodetic excitation function and the global geophysical excitation function of polar motion. HAM excitation functions computed from different water storage models are not homogeneous and also substantially differ in temporal characteristics and in their spectra in the seasonal band. The HAM models need further improvements (Nastula and Kolaczek, 2005a; Nastula et al., 2006a).

3.4.1.6. Studies of regional atmospheric pressure excitation function of polar motion

The new set of atmospheric excitation functions of polar motion, namely the regional equatorial components of atmospheric angular momentum, was computed at high spatial resolution for a network of 3312 equal-area sectors over both land and ocean for the years 1948-2005. There were computed from the surface pressure fields of the NCEP-NCAR reanalyses (Kalnay et al., 1996) using the Barnes et al. (1983) formulation. They were computed on the basis of the atmospheric surface pressure derived from the NOAA Operational Model Archive Distribution System (http://noma2.ncep.noaa.gov). The Inverted Barometer (IB) model is applied here to the pressure fields.

Regional sources of polar motion excitation at several seasonal bands as well as in the band centred on the Chandler wobble period were recomputed. Additionally, the polar motion excitation function, named GEOD, was computed from the COMB02 series of polar motion. As it was shown in earlier studies, the correlations and covariability with the global atmospheric angular momentum and the polar motion excitation itself over land regions in the northern middle latitudes, especially over Asia, are exceptionally strong. The pressure term of the atmospheric excitation of polar motion over the ocean, though containing a clear annual signal, is weak if subject to the Inverted Barometer correction. The area over the entire ocean responds as its mean value, which has a strong annual signal and is highly correlated with the annual oscillation of the global geodetic excitation function of polar motion. (Nastula and Kolaczek, 2005b).

3.4.1.7. Empirical patterns of variability in atmospheric and oceanic excitation of polar motion

The atmosphere and ocean exhibit spatial patterns, which contribute to polar motion excitation. Modes of patterns of variability regional atmospheric and oceanic excitation functions were examined using complex Empirical Orthogonal Function (EOF) analysis. The EOF method is a ‘map-series’ method of analysis that takes variability in the time evolving fields and transfers it onto a number of independent modes, which can be represented as patterns, with an associated times series corresponding to each mode. Here, the first mode is clearly significant in both atmospheric excitation functions and oceanic excitation functions and their associated time series have strong annual oscillations with temporally varying amplitudes. The first mode of atmospheric excitation functions has a strong signal over central Asia, Greenland, Australia and the southern tips of South America and Africa and those of oceanic excitation functions are over the mid-latitude North Pacific and North Atlantic as well as areas of the Southern Ocean. Others modes, though only marginally significant have elements of noted climate signals such as the North Atlantic Oscillation or Pacific-North American patterns (Nastula et al., 2003).

3.4.1.8. Short periodic excitations of polar motion by atmospheric and oceanic variabilities

It is so far widely accepted that atmospheric and oceanic variabilities play a major role in the excitation of polar motion at period longer than 10 days. However for shorter periods the effect is not clear. The role of the AAM and OAM variabilities on the excitation of high frequency polar motion variations was analysed taking advantage of a recent OAM data with the resolution of one hour derived by R.M. Ponte and A.H. Ali. The results proved that the influence of AAM + OAM excitation function of polar motion is meaningful for oscillations with periods longer than 4 days. The highest correlation between AAM + OAM and geodetic excitation functions of polar motion was achieved for the GPS combined series 9083 determined by the EGS. The origin of polar motion variations in spectral band below 4 days needs more investigation. (Nastula and Gambis, 2005). An extensive study on the atmospheric and oceanic contributions to nutation and diurnal/semidiurnal polar motion was done by Brzezinski et al. (2004); see Sec. 3.4.1.2 for details.

3.4.1.9. Excitations of polar motion from an ensemble of global atmospheric models

The optimum use of atmospheric models for understanding excitations of polar motion was investigated. The set of models consists of those contributed world-wide meteorological centres participating in the Atmospheric Model Intercomparison Project, which are forced solely by a prescribed set of sea surface temperature fields. Monthly mean values of excitations were calculated from the resulting surface pressure fields over the 17-year study period. With such historical variability, and with the spread inherent in the suite of models, one can gain a measure of the excitations of polar motion, including variability at intraseasonal and seasonal scales, and view the impact of interannual variability, including El Nino events. The results were compared with the excitations determined by atmospheric analyses, as well as the geodetic excitation functions themselves, determined from the analysis of observations. Based on the suite of atmospheric models the spread in the variance of the polar motion excitation from the ensemble of 19 different models was estimated. The difference between the highest and lowest standard deviations of the excitation is about a factor of two.

AMIP-2 model polar motion excitation results were intercompared and then compared with those of a meteorological analysis system and geodetically-determined results. It has been found that on seasonal scales, each AMIP model is good enough to be used for polar motion analyses, but on subseasonal scales, they are typically not well correlated with polar motion. There are certain epochs for which residuals of model results and both observations and geodetic results are large, related in part to El Nino events (Nastula et al., 2005).

3.4.1.10. Monthly maps of regional variability of atmospheric excitation functions for polar motion pressure and pressure with IB for years 2003 and 2004

Monthly maps of standard deviation of the amplitude of complex-valued atmospheric excitation functions (pressure and pressure with the IB) were displayed in 3312 equal-area sectors to show sub-monthly variability in regions (Nastula and Grygorczuk, 2006).

3.4.1.11. Spectra of rapid oscillations of Earth rotation parameters determined during the CONT02 campaign

Over the two weeks of two campaigns, the CONT02 Campaign in October 2002 and the CONT05 Campaign in September 2005 the Earth Rotation parameters were determined with the resolution of one hour by VLBI and also by GPS. Analysis of the two very precise polar motion and UT1-UTC series reveals oscillations with periods of 8 and 6 hours. Additionally polar motion excitation functions were computed from the VLBI and GPS data series and analysed in order to estimate the power necessary to excite rapid polar motion. The atmospheric angular momentum and oceanic angular momentum data series with high time resolution were used in the analysis too. Common retrograde oscillations with the period of 8 hours could be detected in the spectra of both, the VLBI and GPS series of polar motion. The 8 hours oscillation is also apparent in the VLBI UT1-UTC (respectively integrated GPS LOD) series. The spectra have similar character but the variations in the VLBI spectra are more distinct. Retrograde oscillation with periods of 8 hours and week oscillation of 6 hours are present in the spectra of the atmospheric excitation functions. The oceanic excitation function of polar motion shows very week oscillation in the 8 hours band (Schuh et al., 2004; Nastula et al., 2006b).

3.4.1.12. Invited review papers

Several invited review papers describing developments of investigations of polar motion geophysical excitations of polar motion and improvements of terrestrial and celestial fundamental systems and frames were presented at the international symposia and conferences and published (Nastula, 2003, 2005; Nastula and Kolaczek, 2004, 2005b; Kolaczek, 2004a, 2004b, 2004c; Salstein and Nastula, 2006).

3.4.2. Prediction of Earth Rotation Parameters

3.4.2.1. Modelling and prediction of the free core nutation

The least-squares extrapolation based on the sinusoidal model of FCN and the autoregressive models were also applied for prediction of the observed irregular component of nutation (Brzezinski and Kosek, 2004). The analysis of the FCN filtered from the celestial pole offsets showed that its retrograde period appears to be a function of time, apparently changing between 410 and 490 days. Those changes are correlated with Niño 4 data and with C_{20} coefficients of the global geopotential model. The FCN amplitude is correlated with negative change of the pressure term of the AAM excitation function (Kalarus et al., 2006).

3.4.2.2. Chandler wobble excitation

The pole coordinates data were analysed and predicted in polar coordinate system in which polar motion radius and angular velocity show the beat oscillations created by oscillations in pole coordinates data (Kosek, 2003; Kosek and Kalarus, 2003). It was noted that the 6-7–year beat period of the Chandler and annual oscillation is variable and its change is correlated with the change of the Chandler amplitude. The increase of the Chandler oscillation amplitude is associated with decrease of the phase of the annual oscillation in pole coordinates data and in the joint atmospheric-oceanic angular momentum excitation function (Kosek, 2004). The exchange of the AAM and OAM with each other and with the solid Earth at the frequency of one cycle per year, represented by the annual oscillation in the joint atmospheric-oceanic excitation, is not only the cause of the excitation of the annual polar motion but also of the Chandler wobble. Decrease of the phase of the annual oscillation in the sum of the joint atmospheric-oceanic excitation causes the increase in the leakage of the power from the annual to the Chandler oscillation, which then is the cause of the increase of the Chandler amplitude (Kosek, 2005).

3.4.2.3. Prediction techniques

The artificial neuron network has been applied for forecasting pole coordinates data (Kalarus and Kosek, 2004). The prediction method developed can be applied alone, however better accuracy forecasts were obtained by combination of the least-squares extrapolation and neural networks prediction of the residuals. The combined prediction algorithm, consisting of the least-squares extrapolation and autoregressive prediction (Kosek et al., 2004), is applied to compute weekly predictions of pole coordinates data in the IERS Rapid Service/Prediction Centre (IERS RS/PC), starting from January 2007. The mean prediction errors computed by that method are about 20% smaller than the errors of the current algorithm of pole coordinates data predictions provided by the IERS RS/PC (Johnson et al., 2005). Different stochastic prediction techniques were applied to predict pole coordinates and UT1-UTC data. It was found that the prediction accuracy of the UT1-UTC data obtained by the combination of the least-squares extrapolation and the autoregressive prediction depends on the starting prediction epochs. The mean prediction errors for up to 70 days in the future of this combination method are of the same order as those computed by the IERS RS/PC (Kosek et al., 2005a, 2005b). To predict UT1-UTC data the combination of the discrete wavelet transform (DWT) decomposition based on the Meyer and Shannon wavelet function concept and the autocovariance prediction method was applied. In that combined prediction method the signal is decomposed into different frequency band components and each frequency band component is predicted separately by the autocovariance prediction (Kosek et al., 2005a). The combination of the DWT decomposition and autocovariance prediction has been also used to predict pole coordinates data in polar coordinate system (Fig. 3.4.4) (Kosek and Popinski, 2006).

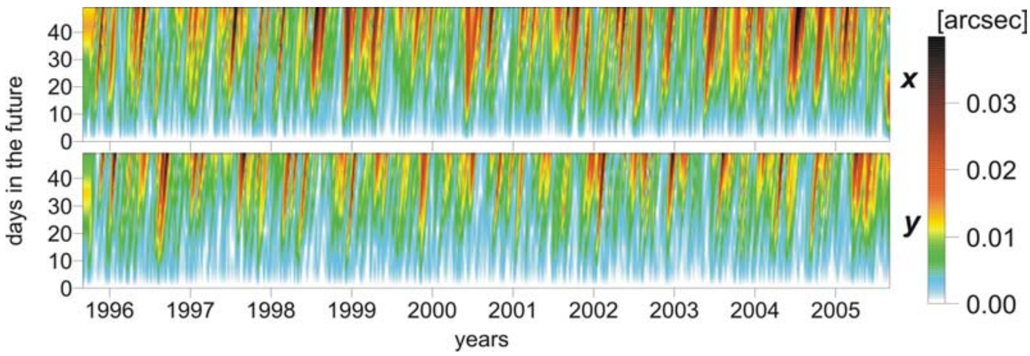

Fig. 3.4.4. The absolute values of the difference between *x*, *y* pole coordinates data and their predictions for 50 days in the future, at different starting prediction epochs, obtained by the DWT+AC technique with Shannon wavelet function

3.4.2.4. Influence of irregular amplitudes and phases of oscillations on EOP predictions

Since the forced annual oscillation in polar motion and UT1-UTC data is related to the seasonal thermal cycle, its phase fluctuates around its well-defined expected value. The phase of the free Chandler oscillation in polar motion has not an expected value, so its phase may show a drift. The wavelet transform techniques as well as other methods comprising: complex demodulation, Hilbert transform, Fourier transform filter and the least-squares method were applied to compute the phase variations of the most energetic oscillations in the EOP data. It was shown that there is a good agreement between the phase variations computed by different techniques in the most energetic oscillations in the pole coordinates, length of day and celestial pole offsets data (Kosek et al., 2006). The irregular variations of amplitudes and phases of the most energetic oscillations in EOP data cause the increase of the EOP prediction errors.

3.4.2.5. EOP prediction activity within the IERS

The Space Research Centre of the Polish Academy of Sciences, Warsaw together with the Technical University of Vienna organized the Earth Orientation Parameters Prediction Comparison Campaign (EOP PCC) as an effort to determine the current state of the art in EOP predictions, in the framework of IERS. Since October 2005 nine participating groups have been submitting prediction results of x, y pole coordinates, UT1-UTC and LOD data as well as of the celestial pole offsets dX, dY (or $d\psi$, $d\varepsilon$). First results of the EOP PCC were presented at the EGU General Assembly in Vienna 2-7 April 2006 (Schuh et al., 2006). Current results of the PCC are available on the Space Research Centre PAS website (http://www.cbk.waw.pl/EOP_PCC/), that is permanently updated. At the EGU 2007 General Assembly in Vienna the IERS Working Group on Prediction (IERS WGP) was established to investigate which of the IERS prediction products are useful to the user community in addition to making a detailed examination of the fundamental properties of the different input data sets and algorithms. The IERS WGP subgroup on algorithms is chaired by Kosek from the Space Research Centre PAS. The activity plans of the IERS WGP were presented at the AGU 2006 Fall Meeting in San Francisco, 11-15 December (Wooden et al., 2006).

3.4.2.6. Sea level change and its prediction

In order to test the forecast methods applied to the EOP predictions, they have been also applied to global mean monthly sea level anomalies (SLA) from TOPEX/Poseidon satellite altimetry and sea surface temperature (SST) data. Those data play an important role in computation of the OAM models which are useful in geophysical interpretation of the EOP variations. Forecasting SLA and SST data has been performed by means of multivariate autoregressive models. It was shown that the monthly SLA predictions computed in 2003 were the most accurate when the SST data were taken into account (Niedzielski and Kosek, 2005).

3.5. EARTH TIDE INVESTIGATIONS IN POLAND IN 2003–2006

Tidal signals were monitored in Poland on a permanent basis in 2003-2006 in two observatories. At the Jozefoslaw Astro-Geodetic Observatory of the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology the vertical component was monitored, while the horizontal components were monitored at the Ksiaz station of the Space Research Centre of the Polish Academy of Sciences at the Low Silesian Geophysical Observatory.

3.5.1. Monitoring of Vertical Component of Tidal Signals

Vertical component of tidal signals is monitored at the Jozefoslaw gravity station 0909 of the Warsaw University of Technology with LaCoste&Romberg ET-26 gravimeter since January 2002. First results of analysis of tidal records were obtained in 2003 using a classical least squares method (Bogusz, 2003). Those results became the basis for the new model of gravimetric Earth tides of the accuracy of 4.0 nm/s^2 for Jozefoslaw Observatory, that is the most precise model for tidal stations in Poland (Bogusz, 2004). Data from LaCoste&Romberg ET-26 gravimeter is being analysed with one year spacing and the results are being sent to the

International Centre for Earth Tides. Some investigations concerning theory of tidal adjustment were also carried out (Bogusz and Lemanska, 2005). In 2005 the gravimetric laboratory at Jozefoslaw Astro-Geodetic Observatory was equipped with FG5 ballistic gravimeter. That gave the opportunity to start the investigations of the long period gravity changes where precise tidal model is indispensable (Barlik et al., 2006b).

To obtain more reliable Earth tides model many environmental parameters must be considered. These are: ocean, atmosphere and ground water level tides, influence of soil moisture changes, as well as rainfalls and snowfalls. Appropriate observations aimed at monitoring of these effects started in 2004 (Bogusz, 2005) together with the research project (Barlik et al., 2006a). The aim of the project is to study environmental influences to the gravity changes at Jozefoslaw Astro-Geodetic Observatory.

3.5.2. Monitoring of Horizontal Components of Tidal Signals

3.5.2.1. Analysis of the observed horizontal components of tidal signals - selected results

Results of the tidal adjustment of the plumb line variation series over 2002 to 2006, obtained with the use of the long water-tube tiltmeter, were reported (Kaczorowski, 2004b, 2005). The analysis was performed in the Space Research Centre PAS using two distinct algorithms: one based on the classic method of adjustment developed by Chojnicki and the other one based on the method proposed by Wenzel. General evaluation of accuracy indicates smaller rms errors in the series of differences of the water level at the opposite ends of the tubes, than in the two times longer series expressing measurement by one sensor only. That result confirms that computing the difference leads to the increase geodynamic signals to noise ratio by factor two. The rms errors of determination of individual coefficients of tidal waves amplitude do not exceed 0.006 for measurements in the azimuth of -121.4º and 0.004 in the azimuth of -31.4º, except the wave P1. The rms errors of shifts of phases for main tidal waves do not exceed 0.6º. The long water-tube measurements have been performed for the second time by using the program “Analyze” which is a part of the package ETERNA 3.4, with sampling intervals equal to 5 and 60 minutes. The Hartmann-Wenzel tidal potential catalogue containing 12935 waves was used. According to the recommendation of the authors of ETERNA 3.4, low-pass filtering of the series was performed prior to analysis. The results of adjustments confirm stable and well determined azimuth of measurements of the long water-tube and show the uniform influence of the ocean indirect effect on the semidiurnal tidal components in Ksiaz.

3.5.2.2. Improvements of the clinometric measurement technique in Ksiaz Laboratory

The measurements of the plumb line variations have been considerably improved after construction of the long water-tube tiltmeter in Ksiaz Laboratory. The instrument has several advantageous properties, such as high sensitivity of measurements, lack of instrumental drift and absolute units of measurement (length of wave of the He-Ne laser light) (Kaczorowski, 2004a). The accuracy of measurements of water level variations is close to one nanometer, which corresponds to the accuracy of the plumb line variations better than 10^{-2} milliarcseconds (mas). Measurements of water level variations at all ends of the tubes, which allowed us to apply the differential method started in 2003. The use of that method results in reduction of instrumental drift and decrease the level of errors (Kaczorowski, 2006a). Elimination of the instrumental drift makes possible an extension of investigations to the long periodic and systematic plumb line variations. The measurements with the Blum's horizontal pendulums carried out for almost 35 years were stopped in 2003 due to the obsolete technique of registration using the photographic paper. They were re-started in 2006 after introducing a new system of registration shown in Figure 3.5.1.

Fig. 3.5.1. New system of registration of quartz horizontal pendulums H-74 and H-75

3.5.2.3. Investigations of the observed non-tidal plumb line variations

Recordings of the large earthquake (8.6 magnitude) which took place in 25 September 2003, and of the Sumatra-Andaman earthquake (9.1 magnitude) in 26 December 2004 (Fig. 3.5.2), provided important verifications of the long water-tube measurements. Both earthquakes produced effects of the Earth body free oscillations, with the corresponding plumb line variations of the size of few mas. The low-pass filters which were introduced in the tubes in order to diminish the rate of water level waving and to reduce the number of cycle-slip effects during main phase of free oscillations, enabled recording the free oscillations. Both the spheroidal and toroidal fundamental modes of Earth free vibrations were determined from observations. The power spectrum in Figure 3.5.3 shows the maxima at periods of 56, 46, 40, and 33.8 minutes (Kaczorowski, 2006a, 2006b). The special peculiarities of the long water-tube, such as possibility of elimination of the instrumental drift, allowed to investigate the non-tidal plumb line variations of seasonal, long periodic or systematic character.

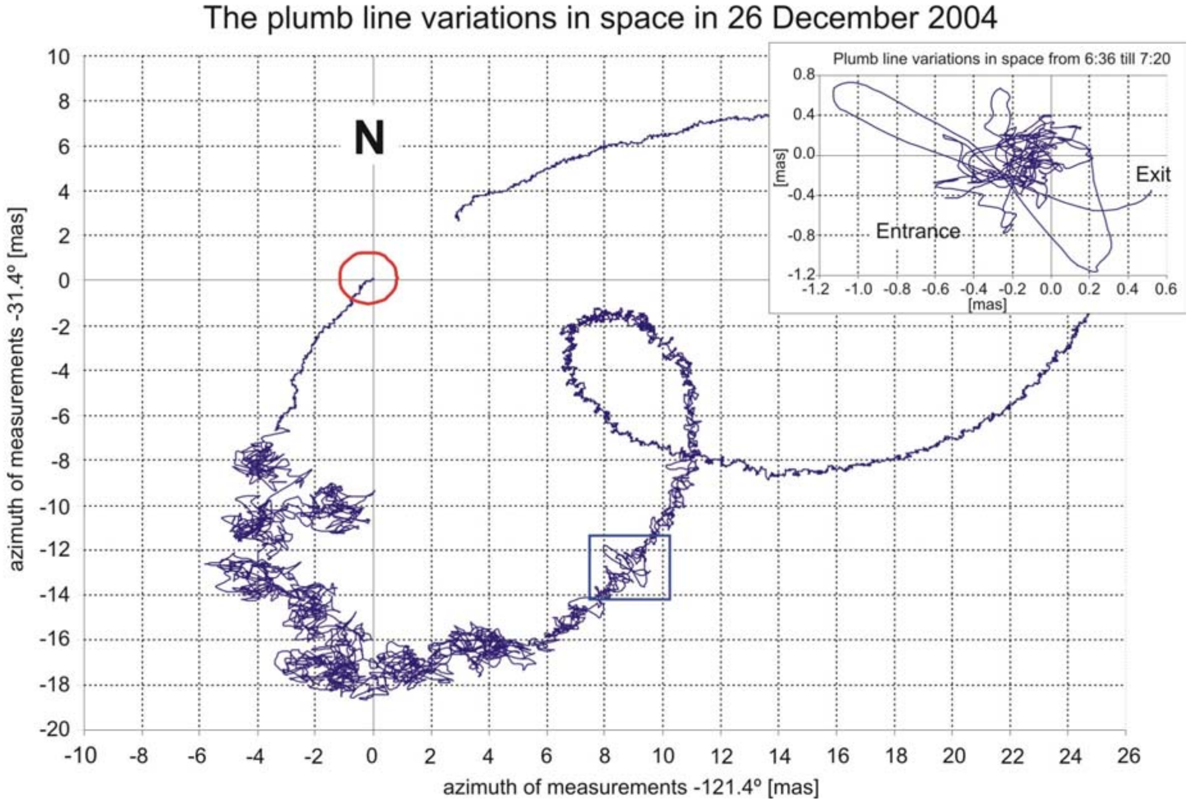

Fig. 3.5.2. Plot of plumb line variations in 26 December 2004 in space on the basis of measurements of long water-tubes in azimuths: -31.4º and -121.4º

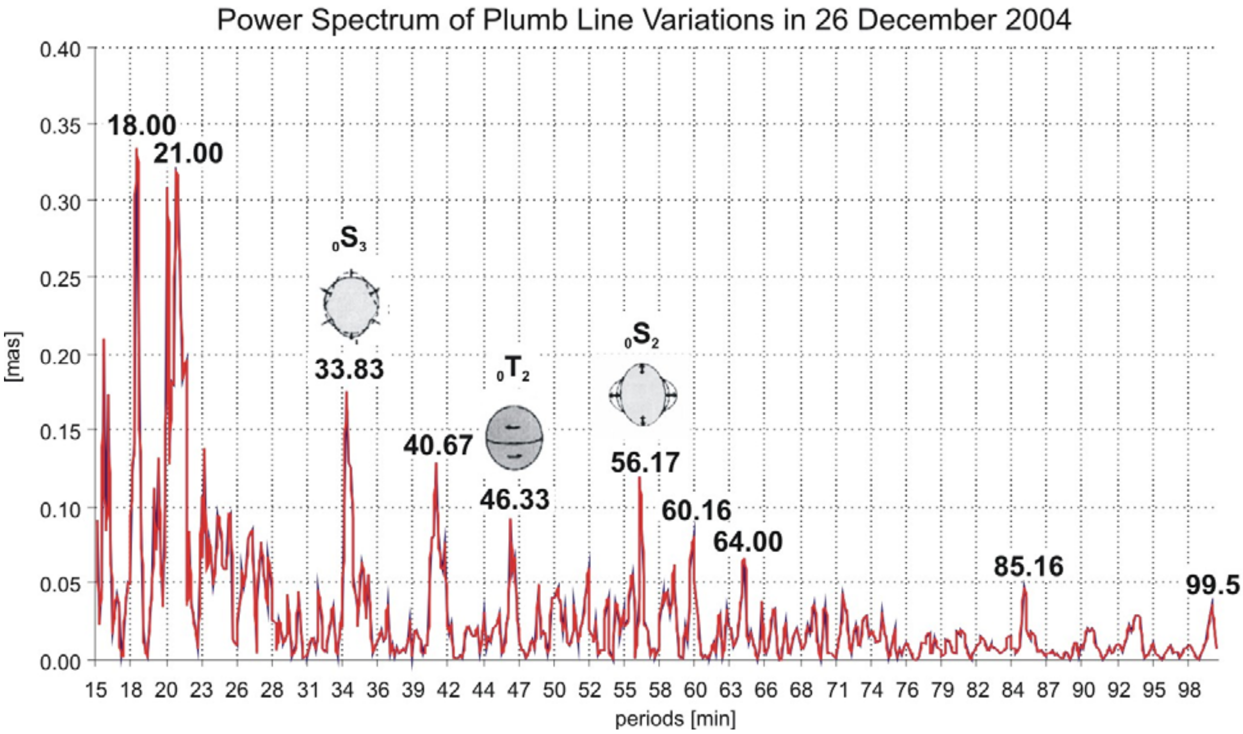

Fig. 3.5.3. Power spectrum of plumb line variations in 26 December 2004 in azimuth –121.4º. There have been shown spheroidal ${}_0S_2$ and ${}_0S_3$ and toroidal ${}_0T_2$ fundamental modes (n = 0) of free oscillations. Small icons describe shape of deformations of the Earth body associated with spherical harmonics

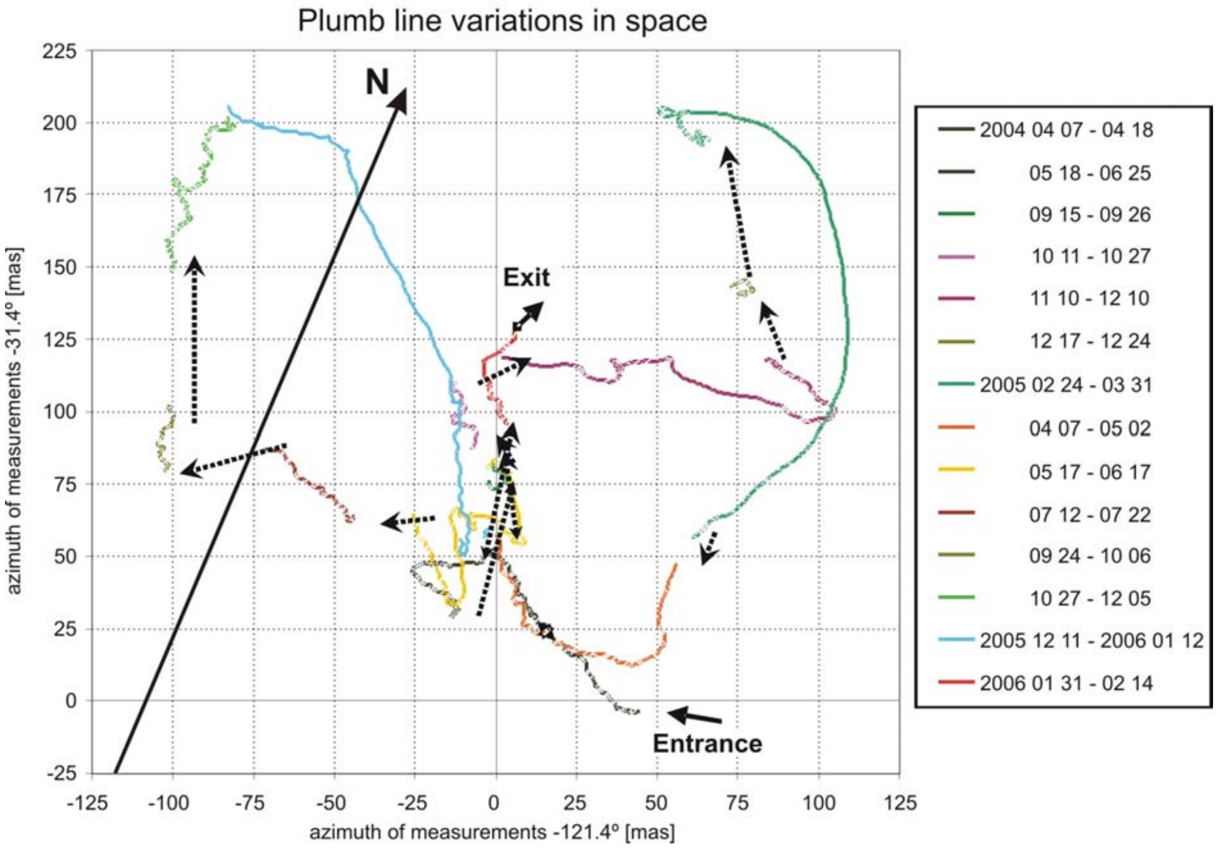

Fig. 3.5.4. Graph of plumb line variations in space during 2004-2005

Due to the discontinuities in the observation time series, the conclusions have to be limited to the following four:

- Largest variations of the plumb line of non-tidal origin, exceeding hundred of milliarcseconds, take place in the transition seasons autumn-winter and winter-spring.
- Especially large effects of non-tidal plumb line variations are terminated rapidly through the reversal of their trends.
- There is no visible relation between the shape of plot of non-tidal plumb line variations and the local tectonic structure.
- During 2004 to 2005, the plumb line performed two loops in the retrograde (clockwise) direction (Fig. 3.5.4) that suggests the existence of the annual effect.

3.5.2.4. Comparison of two kinds of tiltmeters - quartz horizontal pendulums versus long water-tubes

Measurements of the plumb line variations began in the Ksiaz geodynamic laboratory about 35 years ago with quartz horizontal pendulums. A long time series of continuous measurements has been provided by the pair of pendulums, designated H-74 and H-75. However, there appeared problems which were impossible to solve on the basis of measurements of the horizontal pendulums only. Installation of the long water-tube tiltmeter opened a good opportunity for comparative investigations (Kaczorowski, 2005). Both tiltmeters differ fundamentally in the principle of their performance. After having gathered of enough long series of simultaneous measurements of both instruments, one will be able to address the following questions:

- How the thermal waves and pressure variations in underground and outside affect both tiltmeters?

- Are the large discrepancies between shifts of phases of the observed tidal waves and theoretical predictions produced by topographical and cavity effects?
- What part of phase shifts is generated by instrumental effects?
- What part of non-tidal signals is of instrumental or environmental origin and what part is due to the geodynamics phenomena?
- What are the reasons of the relatively large rms errors of the long water-tube measurements?

The ratio of the rms errors of measurements of pendulums and water-tube tiltmeters is in the range of 2.5 to 3 while the ratio of sensitivity of both instruments is close to 1/100. This situation results neither from any faults of water-tube measurements system nor algorithms of data analysis. Relatively large values of the rms error of the time series of measurements by the long water-tube might be associated with the local disturbances of the water free surface, mainly related to the air pressure variations in the underground. Large divergence between shifts of phases of main tidal waves determined was found on the basis of measurements of both pendulums and the long water-tube. The phase shifts of main diurnal waves are positive for H-74 pendulum. The results of horizontal pendulums measurements indicate the existence of systematic error. Before installation of the long water-tube, discrepancies between the observed phases and theoretical predictions were explained by cavity and topographical local effects. That hypothesis appeared to be false. The cavity and topographical effects ought to produce similar disturbances of shifts of phase in both tiltmeters but for long water-tube the negative shifts of phases for all principal waves were obtained. It seems that the reason of phase discrepancies is an errors of determination of the pendulums azimuths of measurements.

3.6. MONITORING OF GEODYNAMICS PHENOMENA

The results of long-standing astronomical observations conducted since 1963 with the passage instrument at Borowa Gora Geodetic-Geophysical Observatory of the Institute of Geodesy and Cartography were summarized (Krynski et al., 2005a). Retained observational data were transformed from FK5 catalogue system to the Hipparcos catalogue system. Data series from last 19.5 years is particularly valuable for the analysis; it contains the unique information on time variation of astronomical latitude of Borowa Gora Observatory.

Systematic error of +0.0327 s in astronomical longitude of Borowa Gora was estimated and conventional value of astronomical longitude of the passage instrument at Borowa Gora was discussed; new conventional value of astronomical longitude of the passage instrument at Borowa Gora has been suggested (Krynski et al., 2005a). Complex spectral analysis of a long-standing rotational time data series from 1986.0-2005.5 was performed. A number of periodic terms were separated from the series investigated (Table 3.6.1) and the numerical model of the series has been formed. That model was used for modelling variations of longitudinal component of the deflection of the vertical in Borowa Gora (Fig. 3.6.1).

Common features of the records from tide gauges in Baltic Sea basin were used to generate the empirical model of Baltic Sea Level (BSLM) variations by averaging tidal records from different sites. The model was considered as representation of temporal variation of Baltic Sea level with time-independent spatial distribution of its scale factor (Krynski and Zanimonskiy, 2004; Krynski et al., 2005b, 2006).

Table 3.6.1. Periods and amplitudes of main components of the spectrum of time series $(UT1-UTC)^{BG}-(UT1-UTC)^{BIH}$

Period [days]	Amplitude [s]
7	0.00228
182.625	0.00358
365.25	0.00842
378	0.00392
416	0.00171
2485 (6.80 years)	0.00274
3250 (8.90 years)	0.00311
4180 (11.44 years)	0.00893

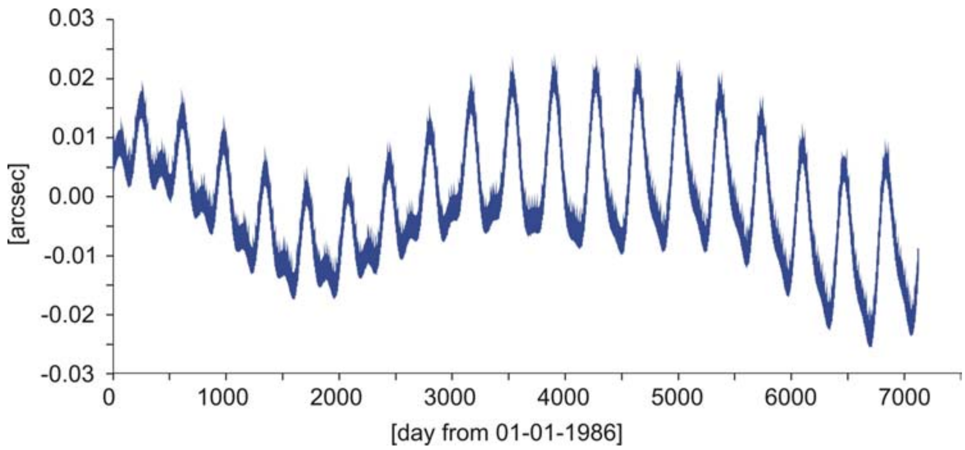

Fig. 3.6.1. Variations of longitudinal component of the deflection of the vertical in Borowa Gora derived from astronomical observations in 1986.0-2005.5

The BSML was found suitable for estimating a rate of trend of sea level variations that contain land uplift component. Removing the BSLM from the time series of individual tide gauge makes possible to estimate the rate of trend with substantially smaller errors. The use of BSML seem also suitable to study non-linear components of land uplift as well as to increase reliability of sea level and land uplift determination from short tide gauge data records (Fig. 3.6.2). With the use of the BSLM the sea level at a site can efficiently be determined from data records of 10 years or even shorter. Thus, the relatively short tide gauge data records can possibly be used in research on kinematics of land uplift in the region using BSLM (Krynski and Zanimonskiy, 2004; Krynski et al., 2005b, 2006).

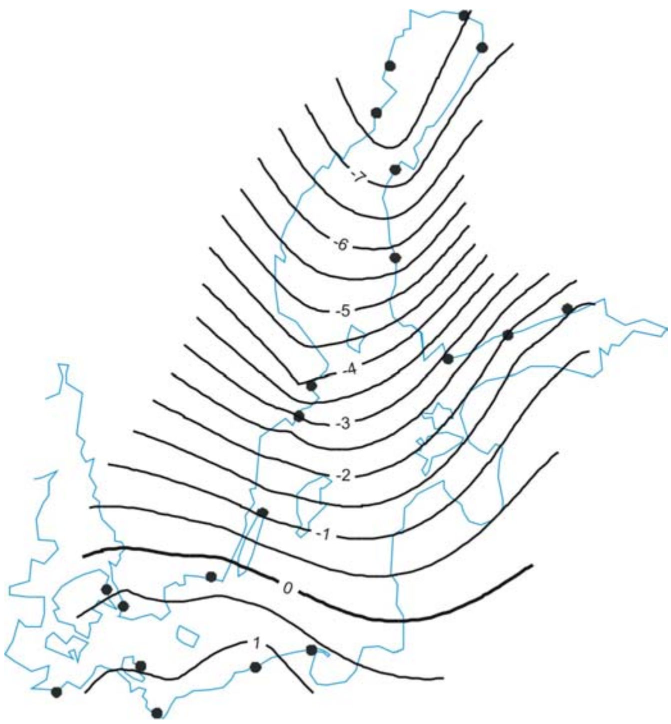

Fig. 3.6.2. Land uplift rates [mm/year] derived from tide gauge records with use of BSLM

Spectral analysis of the model of Baltic Sea level variations indicates the existence of distinguished term of Chandler period besides two major terms of annual and semi-annual period (Fig. 3.6.3). The existence of polar motion component in Baltic Sea level variations indicates a common source of those two different geophysical phenomena. Large irregular-like disturbances observed in sea level variations strongly affect the estimations of rate of trend as well as the mean sea level and cause substantial difficulties in using polar motion data for modelling those variations. There exist, however periods when tide gauge data provided is particularly favorable for geodynamics research. Such irregular effects can substantially be reduced when using an empirical model of sea level variations.

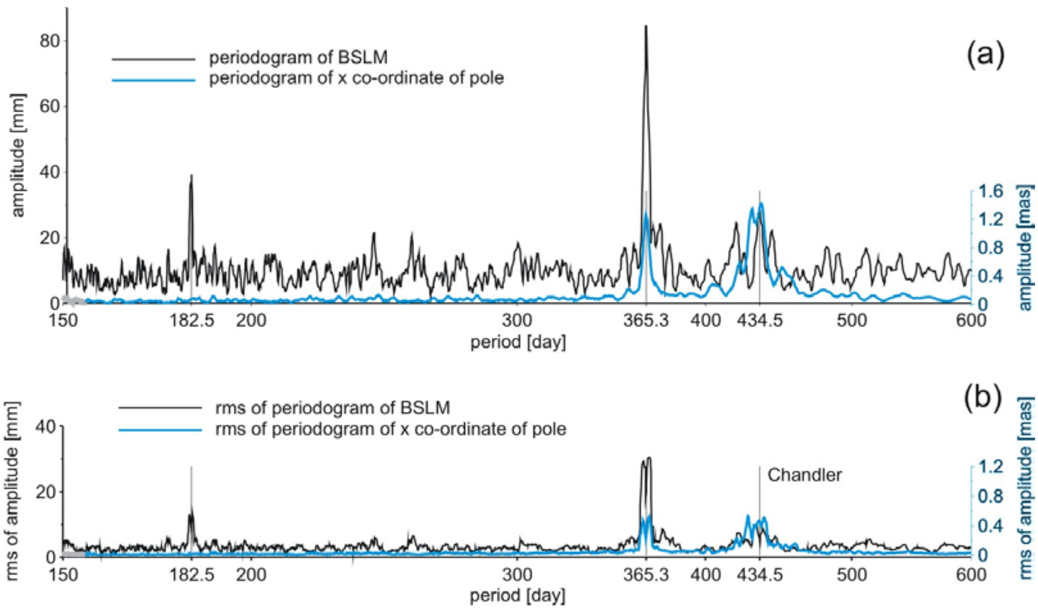

Fig. 3.6.3. Periodograms of variations of the Baltic Sea level and variations of x-coordinate of pole (a), and rms of their estimated amplitudes (b)

The coordinate shifts caused by the tectonic plates motions were analysed in the Space Research Centre, PAS (Kraszewska and Rutkowska, 2004). The study was based on SLR data of LAGEOS-1 and LAGEOS-2 at the global network of SLR stations (59 in total) during the 3-year period. Coordinate shifts of 23 selected stations were analysed. The results were compared with the NNR-NUVEL1A and Drewes' models. For most stations a very good agreement between the three solutions was found. At the majority of stations the errors of estimated coordinate shifts were smaller than 1mm/y. The influence of the number and localization of stations on accuracy estimation of the tectonic plate motion parameters Ω(Φ, Λ, ω) using SLR and GPS data and the maintenance of particular stations located on the boundary of plate were analysed. For eight stations randomly distributed on each plate, estimated parameters of the tectonic plates motions and their errors are already getting stable. It is illustrated in Figure 3.6.4 for the European plate. The orbit, station positions and coordinate shifts were determined using the *GEODYN II* software (NASA/GSFC).

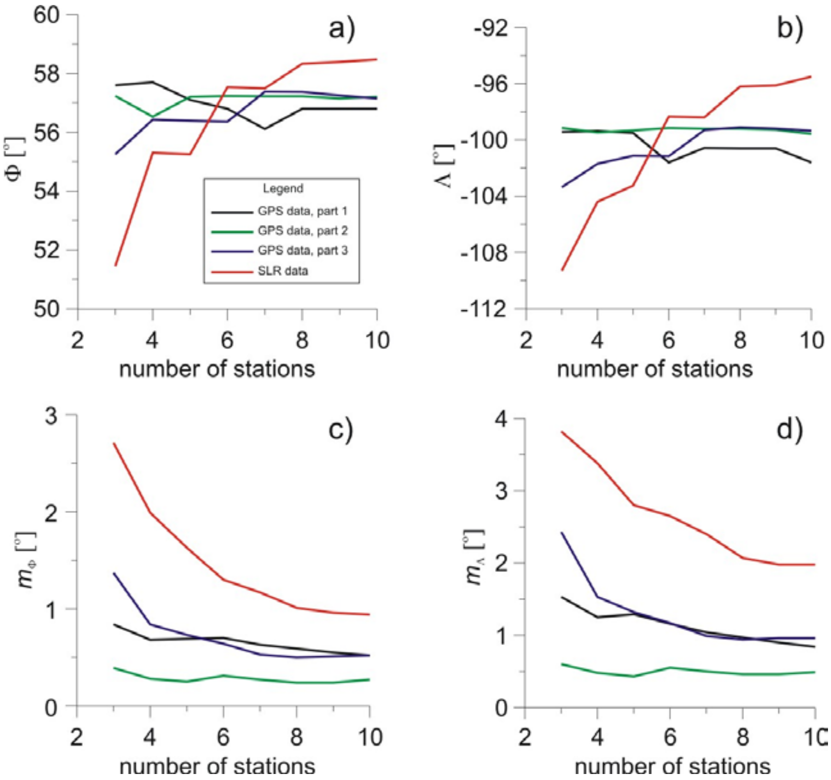

Fig. 3.6.4. Φ (a) and Λ (b) parameter of the tectonic plate motion from SLR and GPS data (ω = 0.25 degrees/million years); m_Φ (c) and m_Λ (d)errors of determination of parameters of the tectonic plate motion using SLR and GPS data

3.7. SECULAR VARIATIONS OF THE EARTH MAGNETIC FIELD

According to the IAGA resolution No 4 from the XXIII IUGG General Assembly in Sapporo in 2003, the common European repeat station survey initiative MagNetE (Magnetic Network of Europe) of 22 countries started in 2003 (Fig. 3.7.1). It was decided that all participated European countries will conduct measuring campaign in the period 2004–2006. The same period of the survey and the same measuring procedure should facilitate detailed studies on geomagnetic field distribution, secular variation and information on lithosphere contained in magnetic data. First results were presented at the 2nd IAGA Workshop on the project, Warsaw, April 2005 organised by the Institute of Geodesy and Cartography. The team of the Institute of Geodesy and Cartography, Warsaw presented the results of the investigations on geomagnetic field distribution in the Baltic Sea (Sas-Uhrynowski and Kasyanenko, 2005; Welker et al., 2005), the method of modelling the magnetic secular variations using a set of dipoles (Sas-Uhrynowski et al., 2005), and the magnetic declination on the former eastern Polish territories, worked out on the basis of the magnetic survey, which has been conducted in the 1930. (Sas-Uhrynowski and Welker, 2005).

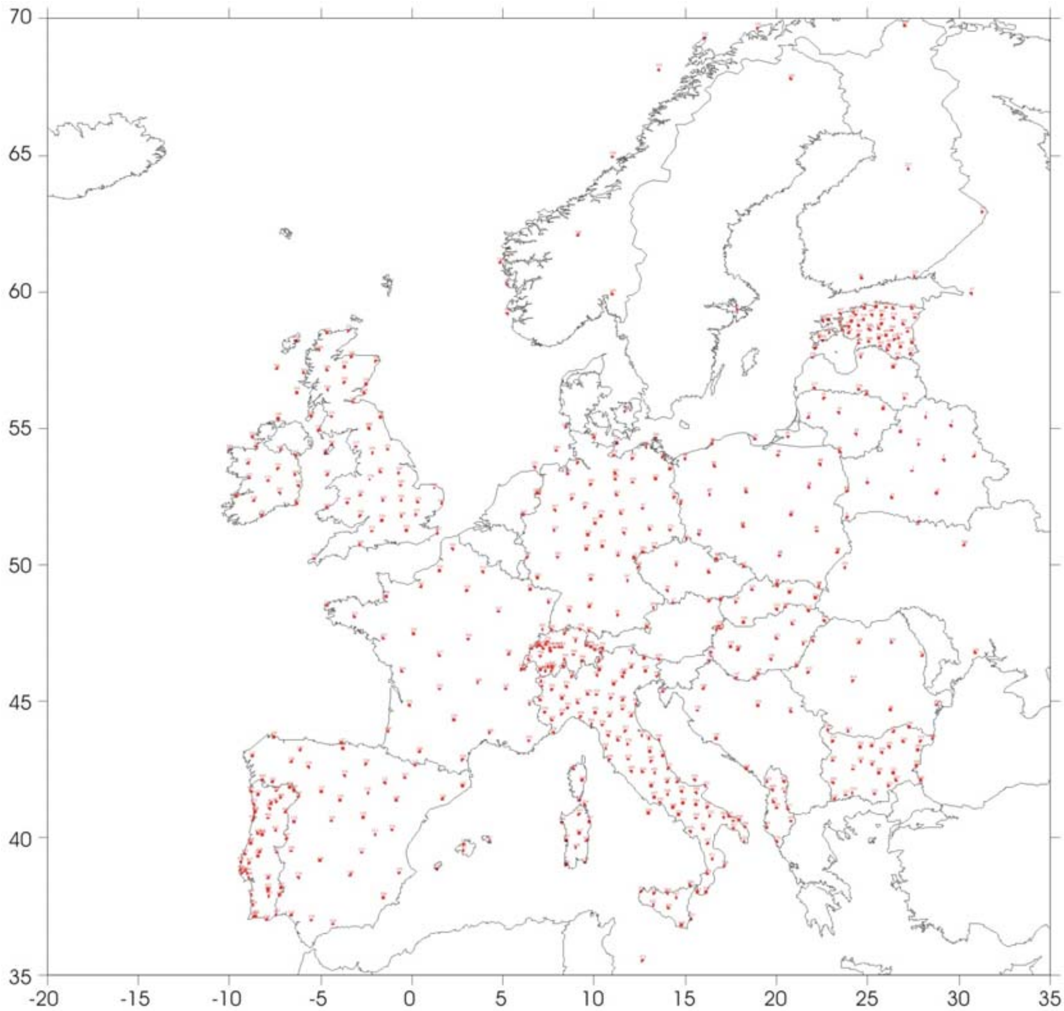

Fig. 3.7.1. European geomagnetic repeat station network (data available in 2005)

In 2002-2004 the project on "Dipole Model of Earth's Magnetic Field Secular Variations" was carried out at the Institute of Geodesy and Cartography, Warsaw. A new approach to the geomagnetic field modelling using the system of dipoles has been worked out. Unlike the previous solutions, no initial assumptions concerning the number of dipoles, their localization, magnitudes and orientations are necessary. Orientation of dipoles became possible due to the of all three geomagnetic components instead of one, as it was in practice before. Each dipole has been described by means of six parameters. They have been determined iteratively. About 40 dipoles have been selected using data form one hundred years (1900-2000). Their parameters have been determined for the epochs every 5 years. Besides determining the location of the dipoles the model makes possible to investigate their variability in time.

It has been shown that among revealed dipoles (Fig. 3.7.2), besides the central one, only 12 existed during the whole period of 100 years. They are responsible for large global magnetic anomalies. Remaining dipoles, living shorter than 100 years, may be divided into two groups. One group consists of 5-7 dipoles, which live 50-80 years, responsible for large regional anomalies. The second one, containing about 20 dipoles, are characterized by 20-50 years of life, much less magnitudes, and larger distances from the Earth centre. They are then responsible for the differentiation of the local space-and-time distribution of the geomagnetic field. The variation of dipole parameters have a period of 20-30 years. It has been observed that the smaller dipole magnitude the less is the stability of their parameters in the course of iteration process. The parameter time series have been smoothed out and extrapolated to the epoch 2015.5, also in 5 year intervals. Comparison of the dipole model of geomagnetic field, computed using central and 12 mentioned above dipoles with the IGRF field has shown their close similarity. In order to describe the local properties of the geomagnetic field, it is necessary to include to the computation the successive dipoles, living shorter than 100 years (Demina et al., 2004a, 2004b; Sas-Uhrynowski et al., 2004). The studies on modelling the geomagnetic field using the main dipole an a set of long-living dipoles are continued (Demina et al., 2006).

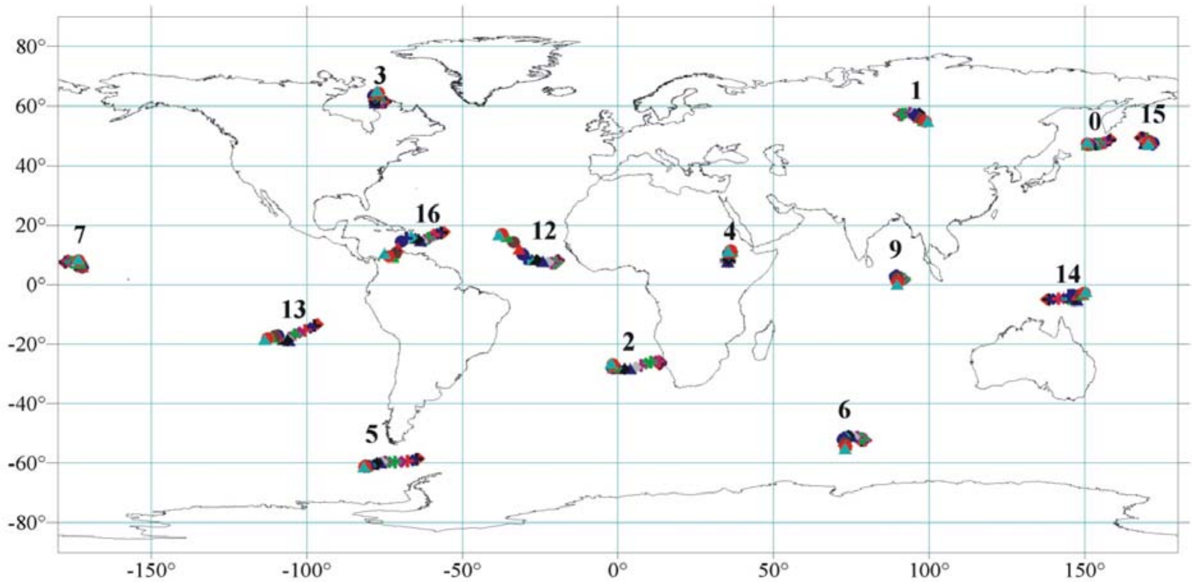

Fig. 3.7.2. Radial projection of dipoles on the Earth surface and their motion during 100 years investigated

The old magnetic data, covering the former Polish territories, which presently belong to Russia (Kaliningrad Region), Lithuania, Belarus and Western Ukraine, together with the data on secular variations in the period 1940–2000 obtained from annual magnetic reports published by European magnetic observatories were re-processed. The data have been verified using three Polish as well as seven Belarussian and six Lithuanian magnetic repeat stations, established and surveyed within the framework of Polish-Belarussian and Polish-Lithuanian cooperation. The archive data reduced to the epoch 2000.5 have been used to work out the new map of magnetic declination for mentioned above territories (Fig. 3.7.3) that is available at the Institute of Geodesy and Cartography, Warsaw (Welker et al., 2003; Welker and Sas-Uhrynowski, 2004a, 2004b).

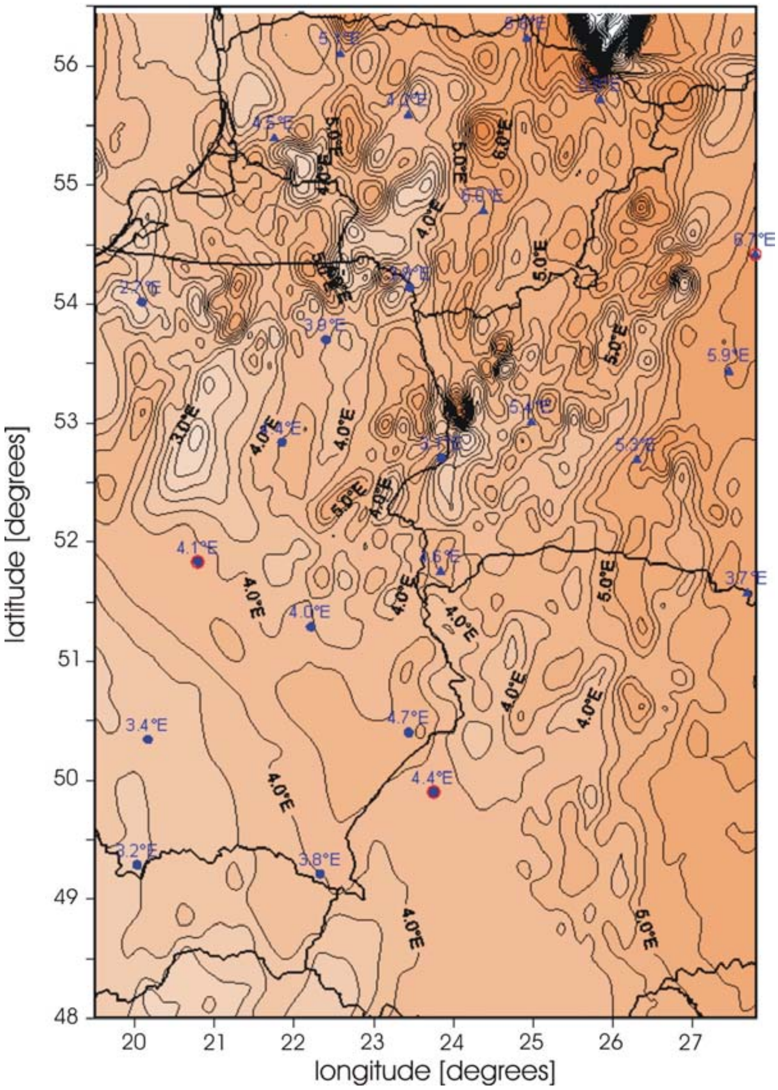

Fig. 3.7.3. Magnetic declination for the epoch 2000 on the former Eastern Polish territories

In the 1970. and the 1980., the Earth's magnetic field components F, H, Z and D were measured in Southern Baltic Sea at about 57000 points. The survey was conducted by the Institute of Geodesy and Cartography, Warsaw, in cooperation with the Institute of Earth Magnetism, Ionosphere and Radio Wave Propagation (LOIZMIRAN), Leningrad, USSR, using the nonmagnetic research schooner "Zaria", owed by the Russian Academy of Sciences. Acquired data together with the information on geomagnetic secular variations were used to work up in 1999 the Atlas of Magnetic Maps of the Baltic Sea. In 2005 the updated maps of the magnetic declination and the total vector of geomagnetic field, were worked up for the epoch 2005.5 (Welker et al., 2005). The map of magnetic declination is shown in Figure 3.7.4.

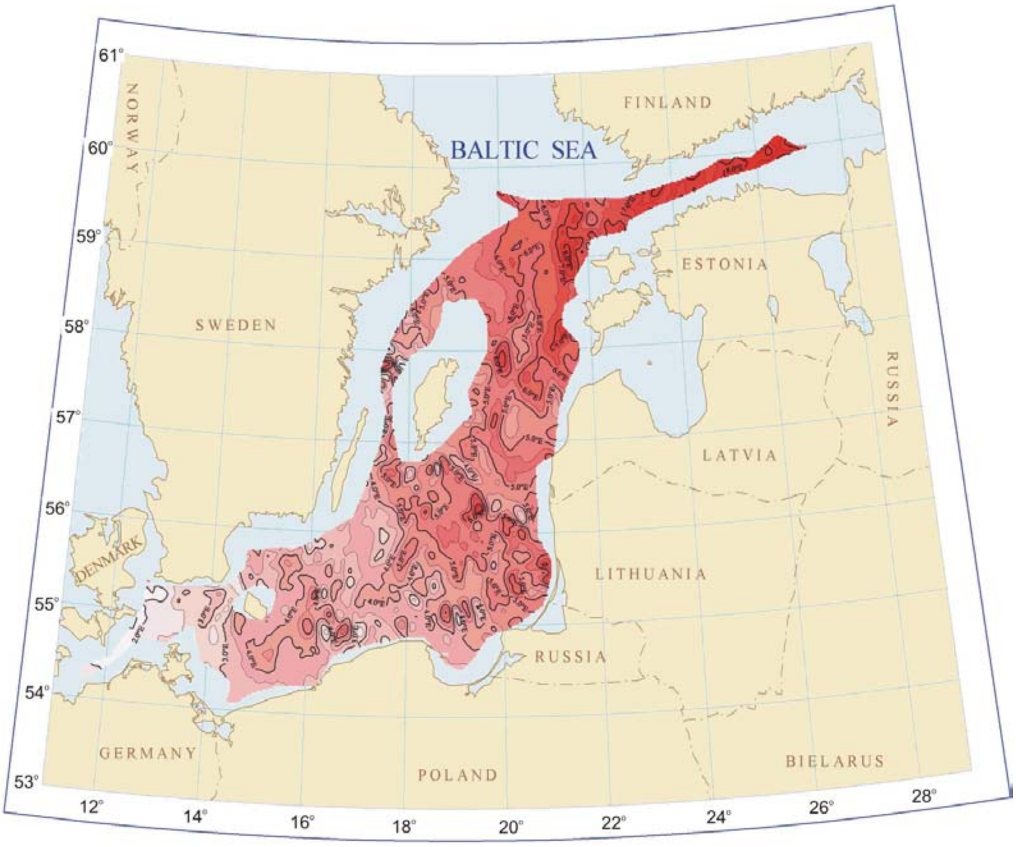

Fig. 3.7.4. Map of the magnetic declination for the epoch 2005.5 in the Baltic Sea

On a dozen of aerodromes in Poland, every five years the special measurements have been performed by the team of the Institute of Geodesy and Cartography, Warsaw, to determine or to control the magnetic declination that is indispensable for navigational purposes. In 2006, the similar measurements have additionally been performed at four aerodromes in Lithuania.

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4. POSITIONING AND APPLICATIONS - ADVANCED SPACE TECHNIQUES

4.1. INTRODUCTION

This part of the Polish National Report on Geodesy is the quadrennial report of works on advanced space techniques performed in Poland in a period from 2003 to 2006. It contains a summary of investigations such as operational activity of SLR and GPS permanent stations, time transfer and time comparison, data analysis and orbit determination, modelling of ionosphere and troposphere, GNSS applications, etc. Those activities were conducted mainly in the following research centres, listed in an alphabetic order:

- Chair of Satellite Geodesy and Navigation, University of Warmia and Mazury in Olsztyn;
- Department of Geodesy and Geodynamics, Institute of Geodesy and Cartography in Warsaw;
- Department of Mining Surveying and Environmental Engineering, AGH University of Science and Technology in Cracow;
- Department of Planetary Geodesy, Space Research Centre, Polish Academy of Sciences in Warsaw;
- Institute of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences;
- Institute of Geodesy, University of Warmia and Mazury in Olsztyn;
- Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology.

The content of the chapter is based on the material prepared by Lubomir W. Baran, Stefan Cacon, Wladyslaw Goral, Jan Krynski, Stanislaw Oszczak, Jerzy B. Rogowski, Milena Rutkowska, Stanislaw Schillak and Janusz B. Zielinski.

The bibliography of the related works is given in references.

4.2. SATELLITE LASER RANGING

The Satellite Laser Ranging station in the Astrogeodynamic Observatory of the Space Research Centre, Polish Academy of Sciences in Borowiec (ILRS 7811) produced and delivered during 2003-2006 over 60 000 normal points to the scientific user community, successfully tracking almost 4000 passes of 22 satellites: LAGEOS 1 and LAGEOS 2, High Orbiting Satellites (GLONASS and Etalon), ESA satellites (ERS-2 and Envisat), GRACE, CHAMP, Jason-1 and other Low Orbiting Satellites in the framework of the International Laser Ranging Service (ILRS) and EUROLAS Consortium. Quality of SLR data provided by the Borowiec station, expressed in the form of an average single shot RMS, normal points RMS and orbital estimation provided by Analysis Centres equals to 20 mm, 4 mm and 14 mm, respectively.

Data acquired at Borowiec SLR station supported scientific missions with those satellites and were used for orbits calculations by ESA/ESOC, Joint Center for Earth System Technology/Goddard Space Flight Center (JCET/GSFC), Center for Space Research University of Texas (CSR), National Institute of Information and Communication Technology (NICT) in Japan, Mission Control Centre (MCC) in Russia, Delft Institute for Earth Oriented Space Research (DEOS), Natural Environment Research Council (NERC) in United Kingdom, Shanghai Astronomical Observatory (SAO), GeoForschungsZentrum (GFZ), Geoscience Australia and several other Analysis Centres. They were presented in daily, weekly or bi-weekly reports of those organizations.

The important upgrading of the SLR system in Borowiec during the reported program was executed. It concerned in particular, introduction of the constant fraction discriminator TENNELEC in start and stop channels (Bartoszak and Schillak, 2005), implementation of a new Consolidated Laser Ranging Prediction Format (CPF), modernization of the post-observation software (Kucharski, 2006), installation of a new transmitting telescope and the system for change of the laser beam divergence. Ranging to high orbiting satellites (GLONASS, Etalon) was a result of that system upgrading. The detailed analysis of the SLR error sources were presented in the several papers and presentations (Schillak, 2004a, 2005b). The spin parameters of LAGEOS 1 and Gravity Probe-B satellites were determined on the basis of the data of kilohertz laser ranging in Graz.

4.3. GNSS PERMANENT STATIONS

Ten GNSS permanent EPN stations operating in Poland are listed in Table 4.3.1.

Table 4.3.1. GNSSS permanent stations operating in Poland

Station	Program	Host Institution
Borowa Gora (BOGO)	EUREF	Institute of Geodesy and Cartography in Warsaw
Borowa Gora (BOGI)	EUREF, IGS	Institute of Geodesy and Cartography in Warsaw
Borowiec (BOR1)	EUREF, IGS	Space Research Centre, Polish Academy of Sciences
Cracow (KRAW)	EUREF	AGH University of Science and Technology in Cracow
Jozefoslaw (JOZE)	EUREF, IGS	Warsaw University of Technology
Jozefoslaw (JOZ2)	EUREF	Warsaw University of Technology
Katowice (KATO)	EUREF	Reg. Centre of Doc. of Geod. and Cart. in Katowice
Lamkowko (LAMA)	EUREF, IGS	University of Warmia and Mazury in Olsztyn
Wroclaw (WROC)	EUREF, IGS	Agricultural University in Wroclaw
Zywiec (ZYWI)	EUREF	City Office in Zywiec

4.3.1. Borowa Gora (BOGO) Permanent GPS/GLONASS Station

BOGO permanent GPS/GLONASS station (IERS domes number 12207M002) is a part of Geodetic Geophysical Observatory Borowa Gora and belongs to the Institute of Geodesy and Cartography, Warsaw, Poland. The Observatory is located 35 km north of Warsaw. The antenna of the station is installed on the unused chimney above the roof of the Observatory main building, directly connected to the ground (Fig. 4.3.1 and Fig. 4.3.2). In 8 June 1996 the station equipped with Ashtech Z-12 receiver and ASH700936C_M SNOW antenna started to operate as a permanent one in the EPN network. In 11 January 2007 the new GPS/GLONASS receiver TPS EUROCARD S/N MT312310851 replaced the Ashtech receiver. No antenna was changed. The rubidium external frequency standard FTS-74 is a source of input frequency of 5 Mhz for the receiver. Three types of data streams from BOGO as well as BOGI station are produced. Data in 30 s rates and transferred in 24 hours and 1 hour blocks to BKG, OLG GNSS and GOPE Data Centres. Data in 5 s rate in 1 h blocks is provided to the Polish ASG-EUPOS Network Managing Centre in Katowice. Meteorological data collected using meteorological sensors LAB-EL LB-716 in 10 min interval and transformed to the RINEX METEO format are transferred with GNSS data. The ARP point has been directly levelled to the first order levelling benchmark. Tidal and absolute gravimetric observations are periodically made in the Observatory. The magnetic field components are permanently registered and elaborated in the Observatory. The Station is a part of the ECGN network.

Fig. 4.3.1. BOGO antenna location

Fig. 4.3.2. BOGO antenna monumentation

4.3.2. Borowa Gora (BOGI) Permanent GPS/GLONASS Station

BOGI permanent GPS/GLONASS station (IERS domes number 12207M003) is a part of Geodetic Geophysical Observatory Borowa Gora and belongs to the Institute of Geodesy and Cartography, Warsaw. The Observatory is located 35 km north of Warsaw. The antenna of the station is installed at the concrete pillar of EUREF 0217 site, about 100 m from the main building of the Observatory. The JPS E_GGD S/N AEVWYXOEY2O GPS+GLONASS receiver with ASH701945C_M SNOW S/N CR520005005 antenna is working in the frame of IGS/IGLOS and EPN network (Fig. 4.3.3). The station started to transfer the data to international service in 3 January 2001.

Fig. 4.3.3. BOGI antenna monumentation

The external rubidium standard FTS-74 is a source of input frequency of 5 Mhz for the receiver. Besides 30 s data in 24 hours and 1 hour blocks, 5 s data in 1 hour blocs, and real time data in RTCM format is provided by BOGI station. The real time data stream is available as Ntrip in the EUREF IP project.

Meteorological data collected using meteorological sensors LAB-EL LB-716 in 10 min interval and transformed to the RINEX METEO format are transferred with GNSS data to BKG, OLG GNSS and GOPE Data Centres as well as to the Polish ASG-EUPOS Network Managing Centre in Katowice. The ARP point has been directly levelled to the first order levelling benchmark.

4.3.3. Borowiec (BOR1) Permanent GPS Station

The permanent GPS station BOR1 (Domes number 12205M002) located at the Borowiec Astrogeodynamical Observatory of the Space Research Centre of the Polish Academy of Sciences (Fig. 4.3.4), 20 km south-east of Poznan, operates continuously and tracks GPS satellites in the framework of the International GPS Service (IGS) and European Reference Frame (EUREF) networks since January 1994. Turbo Rogue SNR8000 receiver with AOAD/M_T antenna (Fig. 4.3.5) and caesium 5MHz frequency standard is used. BOR1 is included in the network of the IGS Reference Frame realization IGS2000 and retained in

IGS2005. Data in 30 s rates and transferred in 24 hours and 1 hour blocks to BKG, OLG GNSS and GOPE Data Centres. Data in 5 s rate in 1 h blocks is provided to the Polish ASG-EUPOS Network Managing Centre in Katowice. Meteorological data are collected using meteorological sensor LAB EL and Navi with data sampling interval 30 min and in the RINEX METEO format are transferred with GNSS data.

Fig. 4.3.4. BOR1 antenna location (right)

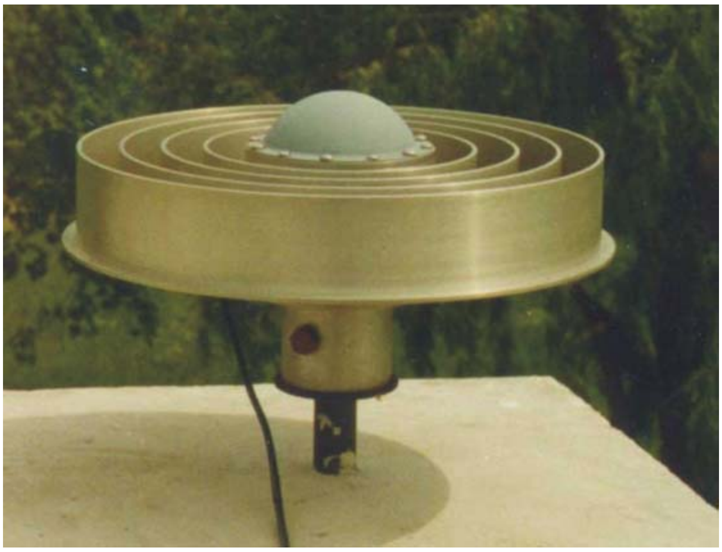

Fig. 4.3.5. BOR1 antenna a monumentation

4.3.4. Cracow (KRAW) Permanent GPS Station

The permanent GPS station KRAW (Domes number 12218M001) is located on the roof of the building of the Faculty of Mining Surveying and Environmental Engineering of the AGH University of Science and Technology(AGH-UST) (Fig. 4.3.6). The station is equipped with the Astech μZ-12- CGRS (Continuous Geodetic Reference Station) and Ashtech choke ring ASH701945C_M SNOW antenna with radome (Fig. 4.3.7). The permanent GPS service in the framework of EPN (EUREF Permanent Network) is maintained since January 2003. Data in 30 s rates and transferred in 24 hours and 1 hour blocks to BKG, OLG GNSS and GOPE Data Centres. Data in 5 s rate in 1 h blocks is provided to the Polish ASG-EUPOS Network Managing Centre in Katowice. Meteorological data collected using meteorological sensors LAB-EL in 15 min interval and transformed to the RINEX METEO format are transferred with GNSS data. KRAW station also participates in the EUREF-IP Pilot Project. Since May 2003 GPS data stream from station KRAW are broadcasted via BKG's Ntrip Caster. In early 2005 the Ntrip Caster software was installed at the Faculty of Mining Surveying and Environmental Engineering, and since February 2005 data stream from KRAW is also broadcasted via AGH's NtripCaster (http://gps1.geod.agh.edu.pl:2101).

Fig. 4.3.6. KRAW antenna location

Fig. 4.3.7. KRAW antenna monumentation

4.3.5. Jozefoslaw (JOZE) Permanent GPS Station

The permanent GPS station JOZE (Fig. 4.3.8) (IERS domes number 12204M001) is a part of Jozefoslaw Astrogeodetic Observatory and belongs to the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology. The Observatory is located 15 km south of Warsaw. In 1991 the Observatory joined the International GPS Service for Geodynamics (IGS) and started operating as a permanent GPS station in 3 August 1993 of both IGS and EPN networks. The station is equipped with Trimble 4000SSE receiver and TRM14532.00 antenna (Fig. 4.3.9). The rubidium external frequency standard TEMEX NEUCHATEL TIME SA is a source of input frequency of 10 Mhz for the receiver. Two types of data streams of 30 s rate are produced in the station, one consisting of 24 hour blocks and the other of 1 hour blocks and transferred to BKG and OLG GNSS Data Centres. Data is also available in CDDIS, IGNI and GOP Data Centre. Meteorological data in 30 min sampling rate is acquired using two meteorological sensors LAB EL and Navi, and in the RINEX METEO format is transferred with GNSS data. Gravimetric observations both absolute and relative tidal are made in the Observatory (see Sections 2.3 and 3.5.1). The ground water and soil humidity are measured in the Observatory for studying their effect on gravity and vertical displacement.

Fig. 4.3.8. JOZE antenna location

Fig. 4.3.9. JOZE antenna monumentation

4.3.6. Jozefoslaw (JOZ2) Permanent GPS/GLONASS Station

The permanent GNSS station JOZ2 (IERS domes number 12204M002) is a part of Jozefoslaw Astrogeodetic Observatory and belongs to the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology. The Observatory is located 15 km south of Warsaw. JOZ2 is located on the roof of the new building of the Observatory (Fig. 4.3.10). The Ashtech Z18 GPS+GLONASS receiver with ASH701941.B SNOW antenna is operating in the frame IGS/IGLOS and EPN network. The external rubidium standard TEMEX NEUCHATEL TIME SA is an external source of reference frequency for the station receiver. Three kinds of data streams are available from JOZ2: data in 30 s rate in 24 hours and 1 hour blocks as well as real time data in RTCM format. JOZ2 real time data steams message type 1(1), 3(60), 18(1), 19(1), 22(60), 31(1) in RTCM 2.2 format are available (in the bracket update rate in seconds is shown). The real data streams are available by the NtripCaster address: www.euref-ip.net:2101 - mountpoint (JOZ20).

Fig. 4.3.10. JOZ2 antenna location and monumentation

4.3.7. Katowice (KATO) Permanent GPS Station

The permanent GPS station KATO (IERS domes number 12219S001) is placed in Regional Centre of Documentation of Geodesy and Cartography in Katowice. The responsible agency is the Head Office of Geodesy and Cartography, Warsaw. The station is equipped with Ashtech μZ-12 receiver and ASH701945C_M SNOW antenna on the roof of the building (Fig. 4.3.11). Its monumentation is shown in Figure 4.3.12. The station started operating as a permanent station in the EPN network in 12 October 2005. Data in 30 s rate are transferred to OLG and BKG Data Centres in 24 hours and 1 hour blocks. Data in 5 s and 1 s rates are transferred to the Polish ASG-EUPOS Network Managing Centre in Katowice.

Fig. 4.3.11. KATO antenna location

Fig. 4.3.12. KATO antenna monumentation

4.3.8. Lamkowko (LAMA) Permanent GPS Station

The permanent GPS station LAMA (IERS domes number 12209M001) belongs to the Lamkowko Satellite Observatory (LSO) (Fig. 4.3.13) of the University of Warmia and Mazury in Olsztyn. The Observatory is located 30 km north-east of Olsztyn. The first permanent GPS observations at Lamkowko Satellite Observatory were carried out in early 1994 first with use of TurboRogue SNR 8000 receiver and later with Ashtech Z-12-3 receiver with Ashtech Dorne Margolin choke ring ASH700936F_C SNOW antenna, installed at EUREF 0302 site (Fig. 4.3.14). The LAMA station takes part in IGS program since 1 December 1994. GPS data as well as meteorological data collected is regularly transferred in daily blocks to the Local Data Centre in Graz, Austria, and then to global data analysis centres. In 1996 LAMA Station was also included to the EUREF Permanent Network (EPN). Currently observations from LAMA are continuously sent to the Local Data Centre in Graz and to the Regional Data Centre in Frankfurt am Main, in both hourly and 24h modes. In 2005, a measuring well, equipped with a measuring float for monitoring variations in the level of ground water, was constructed in Observatory. Meteorological data collected using meteorological sensors LAB-EL in 10 min sampling interval are in RINEX METEO format transferred with GNSS data.

Fig. 4.3.13. Lamkowko Satellite Observatory building

Fig. 4.3.14. LAMA antenna monumentation

4.3.9. Wroclaw (WROC) Permanent GPS/GLONASS Station

The permanent GPS station WROC (IERS domes number 12217M001) has been established in November 1996. The station is run by Institute of Geodesy and Geoinformatics (former Department of Geodesy and Photogrammetry) of the Wroclaw University of Environmental and Life Sciences (former Agricultural University of Wroclaw). Originally the station was equipped with Ashtech Z–12 receiver and the Dorne Margolin ASH (ASH700936D_M) antenna installed on the roof of the building (Fig. 4.3.15). Its monumentation is shown in Figure 4.3.16. In July 1999 lightning stroke damaged GPS antenna. In May 2000 the station was equipped with Ashtech Z–18 receiver with the Dorne Margolin ASH (ASH701941.1 SNOW) antenna. Since 13 April 2007 at WROC operates Leica GRX1200PRO receiver with LEIAT504GG antenna and acquiring GPS/GLONASS observations is continued. The external rubidium standard FTS-74 is a source of input frequency of 5 Mhz for the receiver. Meteorological data is acquired using two meteorological sensors LAB EL and Navi with 15 min data sampling interval. The WROC station has been included to EUREF Permanent Network (EPN) in 1996 and to the International GNSS Service (IGS) in 2002. Four types of data streams from WROC station are produced. Data in 30 s rates and transferred in 24 hours and 1 hour blocks to BKG, OLG GNSS and GOPE Data Centres. Data in 5 s rate in 1 h blocks is provided to the Polish ASG-EUPOS Network Managing Centre in Katowice. WROC station also participates in the EUREF-IP Pilot Project.

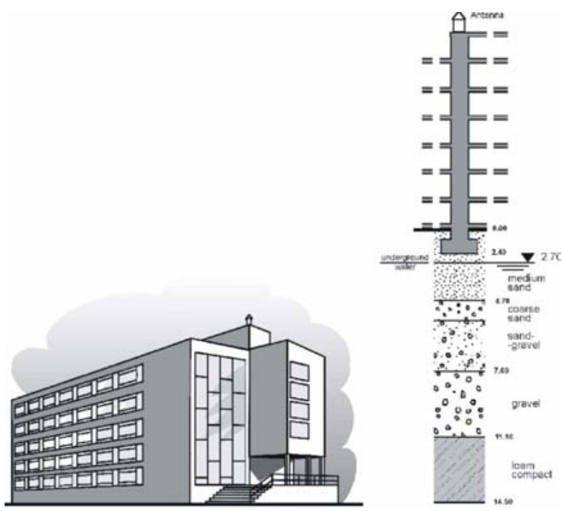

Fig. 4.3.15. WROC antenna location


Fig. 4.3.16. WROC antenna monumentation

4.3.10. Zywiec (ZYWI) Permanent GPS Station

The permanent GPS station ZYWI (IERS domes number 12220S001) is placed in City Office in Zywiec. The responsible agency is the Head Office of Geodesy and Cartography, Warsaw. The station is equipped with Ashtech μZ-12 receiver and ASH701945C_M SNOW antenna on the roof of the building (Fig. 4.3.17). Its monumentation is shown in Figure 4.3.18. The station started operating as a permanent station in the EPN network in 22 August 2002. Data in 30 s rate are transferred to OLG and BKG Data Centres in 24 hours and 1 hour blocks. Data in 5 s and 1 s rates are transferred to the Polish ASG-EUPOS Network Managing Centre in Katowice.

Fig. 4.3.17. ZYWI antenna location

Fig. 4.3.18. ZYWI antenna monumentation

4.4. TIME TRANSFER AND COMPARISON

4.4.1. Development of Polish National Time Scales TA(PL) and UTC(PL)

Following time laboratories in Poland: Central Office of Measures (GUM), Borowiec Astrogeodynamic Observatory (AOS), Institute of Telecommunications (IL), Polish Telecom (TPSA), Tele-Radio Research Institute (ITR), Military Metrology Centre (CM), and one laboratory in Lithuania - Lithuanian Bureau of Standards (LT) (Fig. 4.4.1) participate in the definition of the time scales TA(PL) and UTC(PL). TA(PL) enters as a contribution to the international time scale TAI and further UTC.

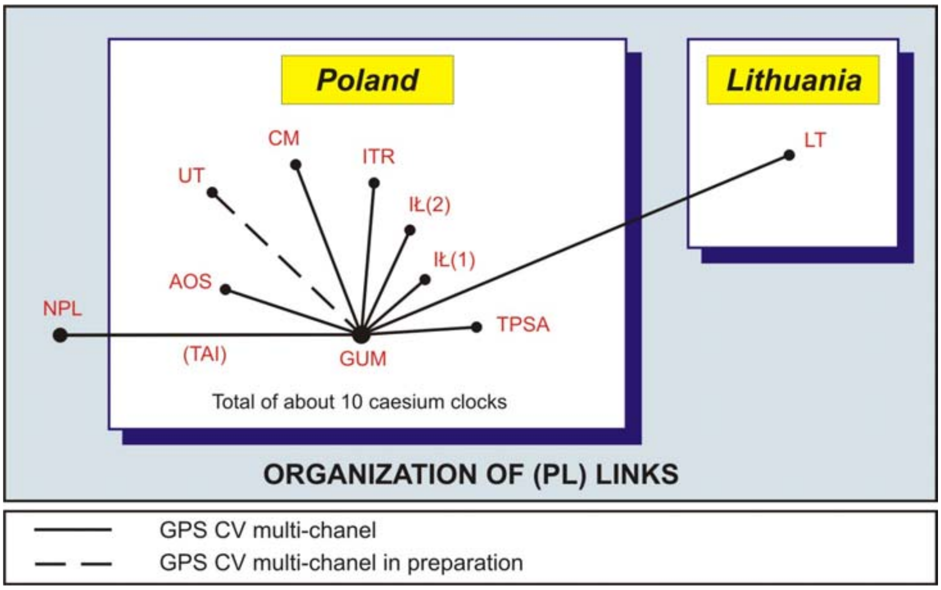

Fig. 4.4.1. Configuration of laboratories contributing to TA(PL)

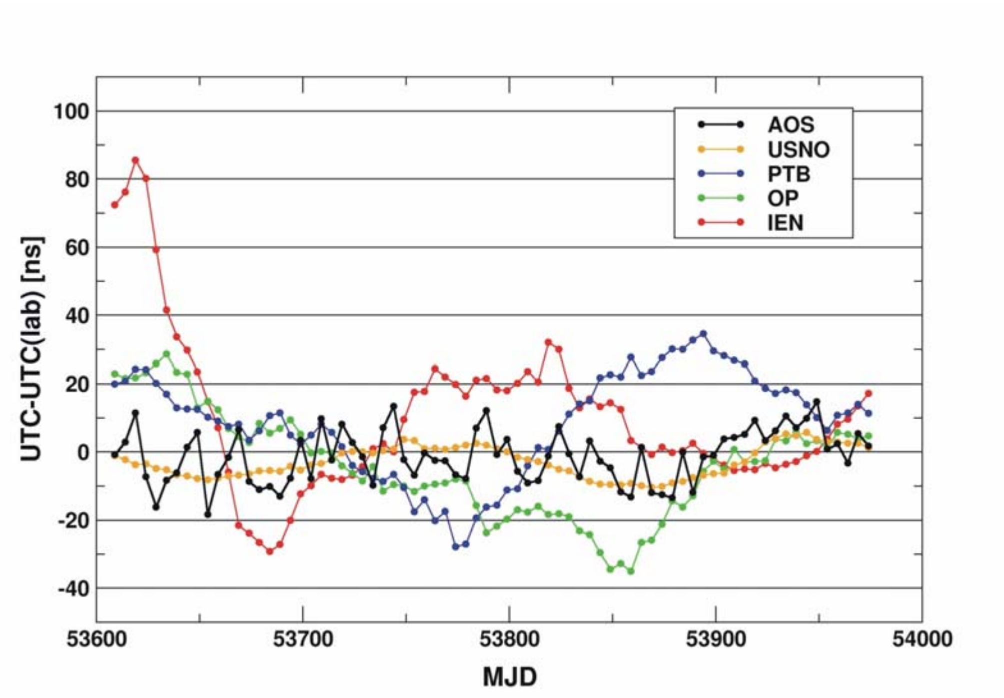

Fig. 4.4.2. Realization of UTC(AOS)

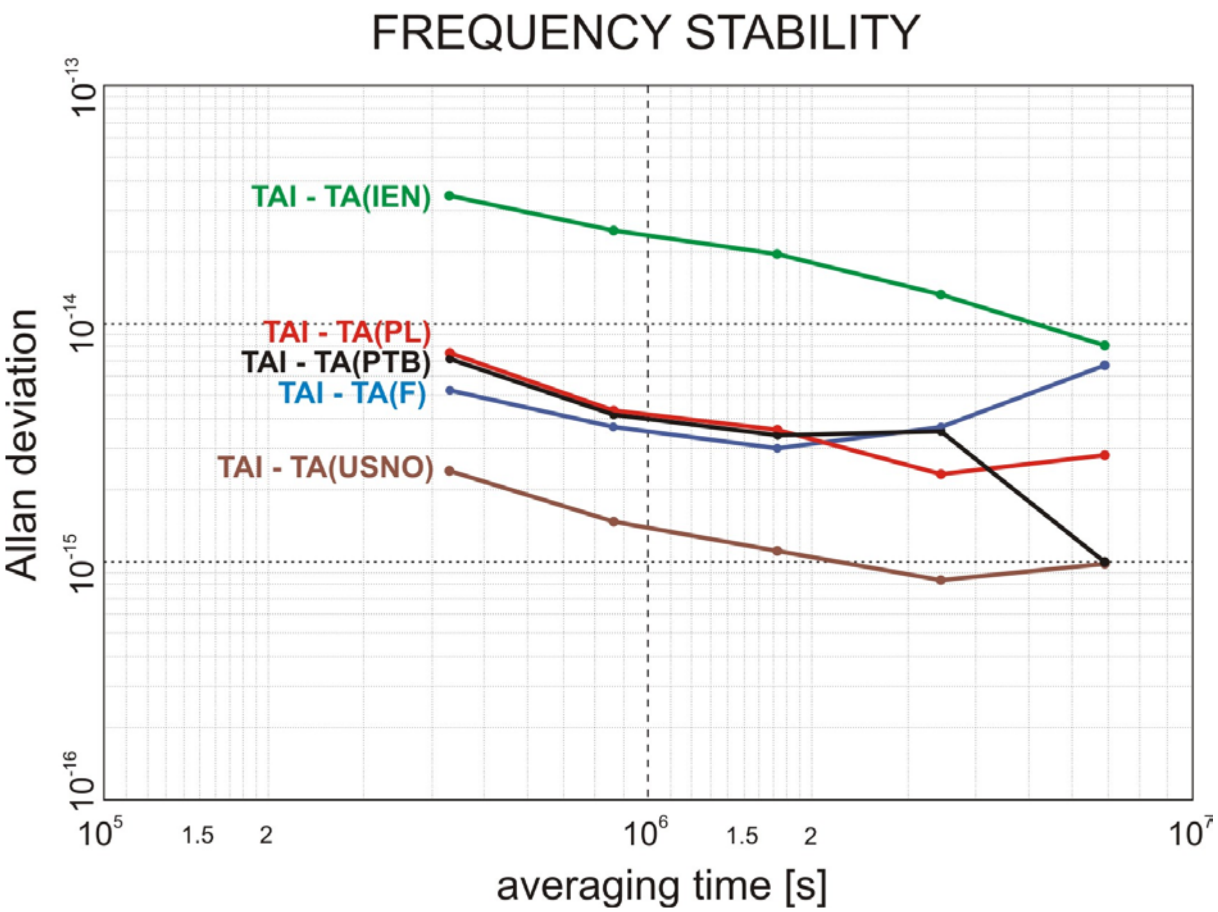

Fig. 4.4.3. Allan deviation analysis of the stability of TA(PL)

4.4.2. Development of Techniques and Equipment for Time and Frequency Needs (GNSS Receivers for Timing, Timing Software)

Borowiec Astrogeodynamic Observatory of the Space Research Centre (SRC) specializes in the development of timing GNSS receivers for time and frequency applications. In 2003-2005 a new receiver for time transfer (Time Transfer System - 3, TTS-3) (Fig. 4.4.4) was developed (Nawrocki et al., 2005b, 2006a). Its characteristics is as follows:

- GPS and GLONASS C/A-code, GPS and GLONASS P-code modes, integrates observations of all available navigation satellites: GPS, GLONASS, WAAS and EGNOS (Foks et al., 2005; Lewandowski et al., 2005; Lewandowski and Nawrocki, 2006; Nawrocki et al., 2005a), and in the future Galileo;
- precision in multi-channel reconstructed GPS P-code mode, when using measurements of ionospshere and precise ephemerides may reach 1 ns for intercontinental time links and below 1 ns for continental time links;
- the system is working under LINUX, providing multitasking and integration with networks.

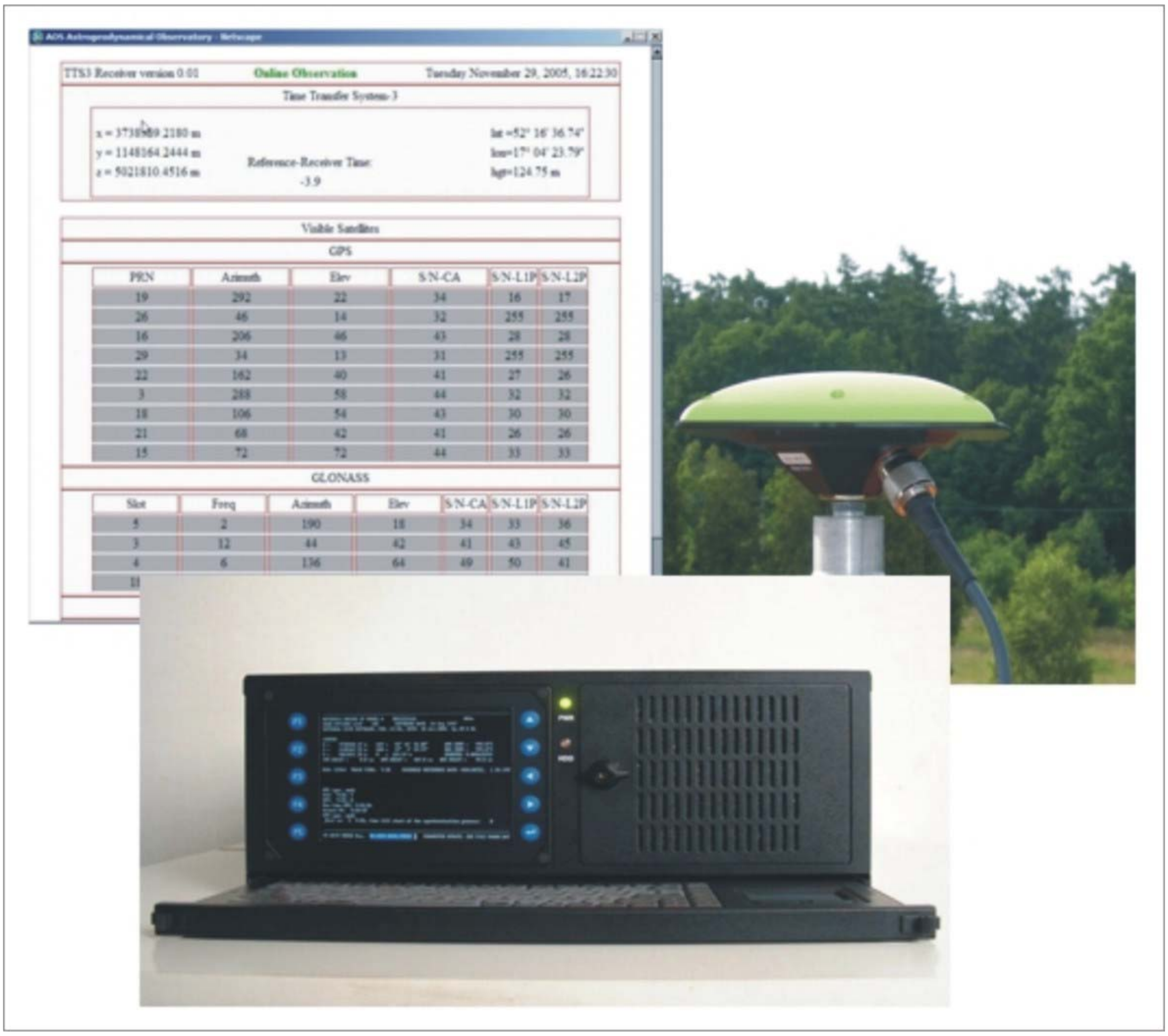

Fig. 4.4.4. TTS-3, Time transfer system developed by the Borowiec Astrogeodynamic Observatory of the Space Research Centre (AOS)

Currently the TTS-3 and TTS-2 (older version) receivers are working at number of time observatories, i.e. Bureau International des Poids et Measures (BIPM) (4 receivers), United States Naval Observatory (USNO) (2 receivers), Physikalisch-Technische Bundesanstalt (PTB), Germany, Paris Observatory (LPTF), France.

4.4.3. Participation in the Realization of the Galileo Time Service Provider Prototype (GTSP)

Realization of the reference time for European Satellite Navigation System Galileo called Galileo System Time, is carried by the international consortium Fidelity. Borowiec Astrogeodynamic Observatory of the Space Research Centre PAS is a member of that consortium. Galileo System Time will be based on an ensemble of clocks from the best European time laboratories and clocks from Galileo ground segment.

The Galileo Time Service Provider (GTSP) shall compute and provide to the PTF the time and frequency offsets and necessary steering parameters for GST in order to ensure that the relationship between GST and TAI/UTC falls within the following bounds: a maximum offset of 50 ns (95% over any yearly interval); a maximum uncertainty of the offset of 28 ns (95% over any 10 day period).

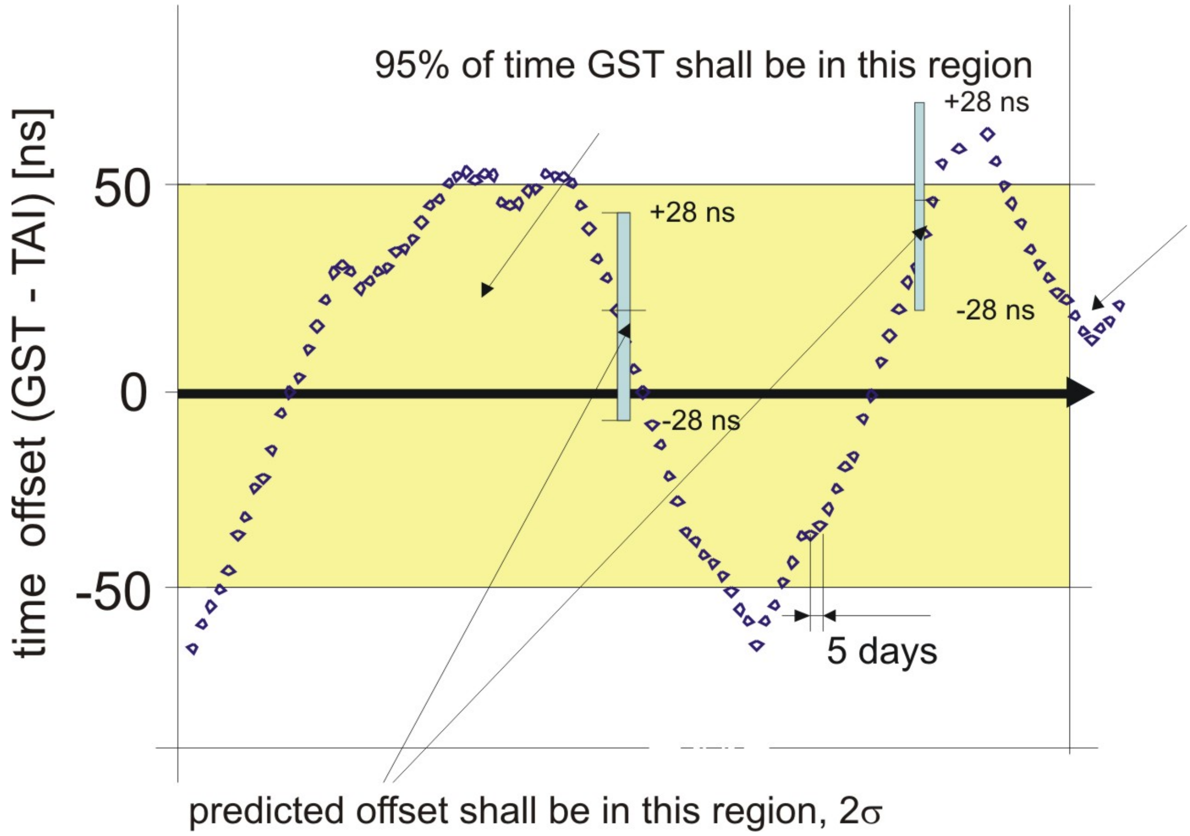

Fig. 4.4.5. Realization of the Galileo System Time by Galileo Time Service Provider

4.4.4. Participation in the Realisation of the Precise Time Facility (PTF)

Galileo System Time will physically be realized by the Precise Time Facility (PTF) part of the control segment of Galileo Satellite Navigation System: Ground Mission Segment. Two PTF stations: Fucino (Alenia-Spazio), Pfafenhofen,(DLR) will operate, running in parallel as master and slave. Borowiec Astrogeodynamic Observatory of the Space Research Centre PAS is one of the partners developing Fucino station. It is responsible for: Time Transfer Algorithms; TWSTFT Management SW unit, interface with SARTRE MODEM, VSAT, SATSIM; GPS CV SW unit (output measurement in CCTF-CGGTTS format, interface with the receiver based on a SSH-TCP-IP layer); Galileo CV SW unit (output measurement in CCTF-CGGTTS format, input from GSS Real Time Lan, protocol TBD); GGTO and PTF1-PTF2 evaluation; determination of the time offset and hand-over from PTF1 to PTF2 in case of failure of PTF1(Requires GST1 – GST2 with ns uncertainty); PTF to USNO - determination of time offset GPS time – GST. Based on agreements between USA, EU, and ESA. Will be realised during IOV phase; PTF to GPS (Galileo) satellites - determination of time offset (GPS time – GST). Continuous observations of GPS (and Galileo) satellites.

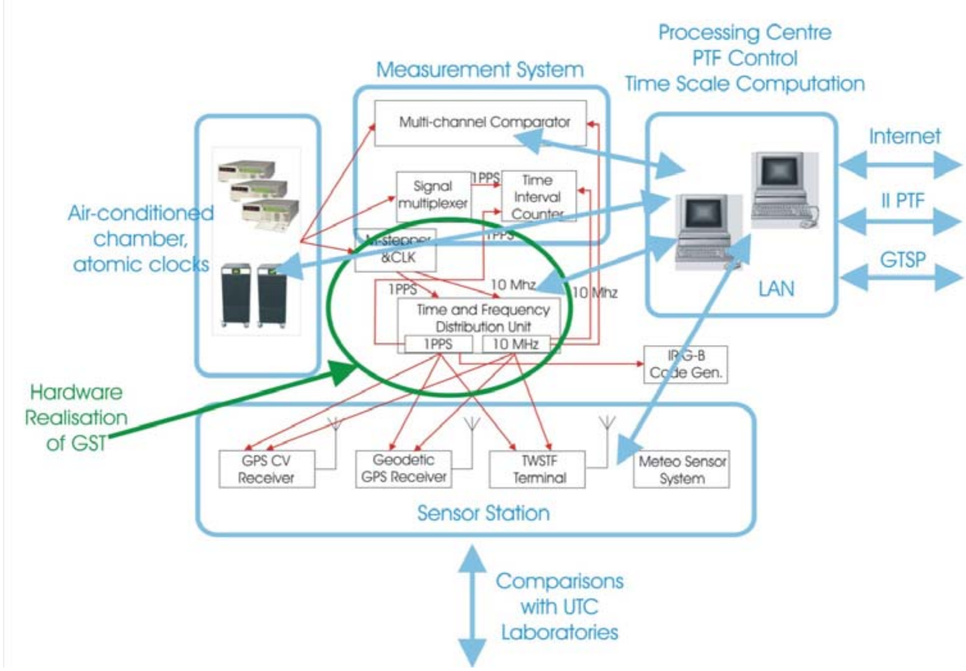

Fig. 4.4.6. Simplified diagram of Galileo Precise Time Facility

4.4.5. Participation in the Realization of the BALTICTIME Project – "Reinforcing eGovernment Services in Baltic States through Legal and Accountable Digital Time Stamp"

The objective of the BALTICTIME project realized within the 6th European Framework Programme by the BALTICTIME consortium is to develop the legal and accountable digital time stamping (DTS) system in Baltic States. The central part of the project is the Time Stamping Authority station ensuring auditable, accountable and transparent time stamping service. One of the main issues of the Time Stamping Authority (TSA) is that the time used for the stamping of the e-documents must be based on National Time Standard Authority (NTSA) generating legal and official time. Borowiec Astrogeodynamic Observatory of the Space Research Centre PAS works on timing interfaces between TSA and NTSA, and the organization of the clock ensemble at TSA. As the main method of time transfer between TSA and NTSA GPS/Galileo timing receivers are proposed.

4.5. DATA ANALYSIS AND ORBIT DETERMINATION

4.5.1. SLR Data Analysis

The determination and analysis of the SLR stations coordinates by means of NASA *GEODYN-II* orbital program were continued in the Borowiec Observatory. The positions and velocities of the Borowiec SLR station on the basis of data from 1993.5 to 2003.5 (Schillak, 2004b), and coordinates of all SLR stations in 1999.0-2004.0 in the ITRF2000 were determined and analysed (Schillak and Wnuk, 2004, Schillak and Michałek, 2006). The velocities show good agreement with tectonic plate motion model NUVEL1A. In that period two real stations position displacement in horizontal plane as result of the earthquakes were detected. It concerned Tateyama station (7339): 4.5 cm in June-August (Schillak *et al.,* 2006), and Arequipa station (7403): 62.3 cm in 23 June 2001 (Schillak and Wnuk, 2003). The results of the station positions stabilities were used for quality control of the SLR stations (Schillak, 2005a). The second task in the field of orbital analysis was the determination of low satellites orbits and calculation of station coordinates from the tracking data of low satellites. The orbital RMS determined from Starlette and Stella low satellites for 10 days arcs was lower than 2 cm, the station coordinates calculated from those orbits were comparable with those from the LAGEOS data (Lejba et al., 2006).

4.5.2. SLR Orbit Determination

Orbits of the low satellites WESTPAC, LARETS as well as GRACE-A and GRACE-B were calculated and analysed in the Space Research Centre, PAS. The orbits of WESTPAC and LARETS satellites are strongly affected by perturbing forces such as irregularities of the gravity field, atmospheric drag, solid Earth and ocean tides. The effect of those forces on accuracy of orbit estimation was investigated. The use of GRIM-5S1 geopotential model, MSIS86 atmospheric density model, the Ray tides model, drag coefficients solved-for at 12-hour intervals gives a fit of laser range data of 2.5-3.5cm for 7-day arcs (Rutkowska, 2003, 2004, 2005a, 2005b). For GRACE-A and GRACE-B satellites the preliminary orbits and changes of the distance between satellites were calculated and analysed (Rutkowska and Zieliński, 2003).

4.5.3. Activities of the EUREF WUT Local Analysis Centre

4.5.3.1. Data processing at Local Analysis Centre at WUT

The team of the Warsaw University of Technology elaborated in 1995 in close cooperation with the CODE Centre of the Institute of Astronomy, University of Bern, the strategy of data processing in the networks of permanent GPS stations. The strategy developed adjusted to EPN standards is used since 1996 to process the EPN data at the WUT Local Analysis Center (LAC) of EUREF. Currently 16 LACs operates in Europe (Fig. 4.5.1). Data from 58 permanent GNSS stations of EPN (Fig. 4.5.2) are processed at the Warsaw University of Technology EUREF Local Analysis Centre (WUT EUREF LAC) on the daily basis using the *Bernese* v.5.0 software (Rogowski et al., 2006) according to EPN standards.

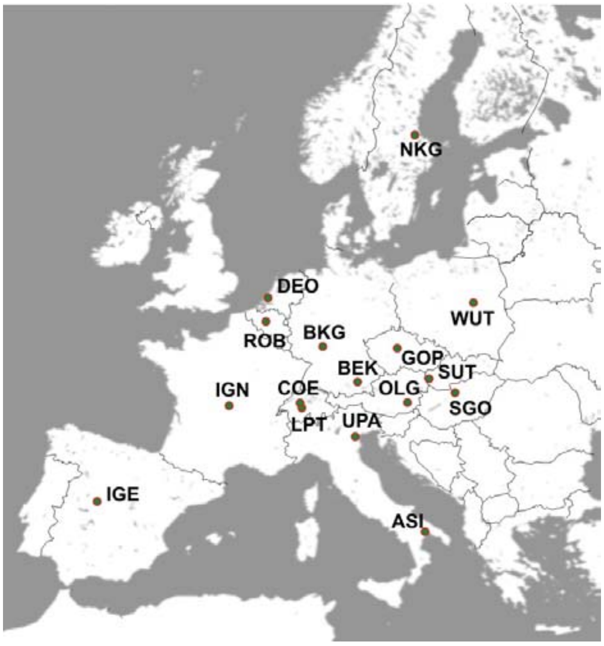

Fig. 4.5.1. EPN Local Analysis Centres http://www.epncb.oma.be/gif/analcent.jpg

Fig. 4.5.2. Network of EPN stations providing data for processing at WUT EUREF LAC
http://www.epncb.oma.be/_dataproducts/analysiscentres/subnetwork.php?lac=WUT

WUT EUREF LAC as one of 16 local analysis centres provides parameters for ionosphere model http://leo.wic.wat.edu.pl/~abwe . Fully automatic system for Zenith Total Delay (ZTD) estimation in Near Real Time (NRT) has been successfully set up and it operates since fall 2006. The system processes data from a subnetwork of over 20 EPN/IGS GNSS stations located in Central Europe. Test campaign of automated NRT processing comprised 22 stations (Fig. 4.5.3) and time span of 2005DOY 164-217 (Kruczyk et al., 2006). The example of comparison with IGS rapid troposphere product is presented in Table 1.
Solution minutes:

- *Bernese* v.4.2 GPS Software,
- coordinates of all stations fixed to EUREF weekly solutions,
- IGS Ultra Rapid orbits used,
- no *a priori* tropospheric model, Dry Niell as mapping function, ZTDs estimated every hour,
- 30 sec observation sampling, 1/cos (z) weighting functuion, 10°cut off angle,
- 4 hours sliding window, no ADDNEQ, RINEX files concatenated (teqc),
- ambiguities resolved using QIF.

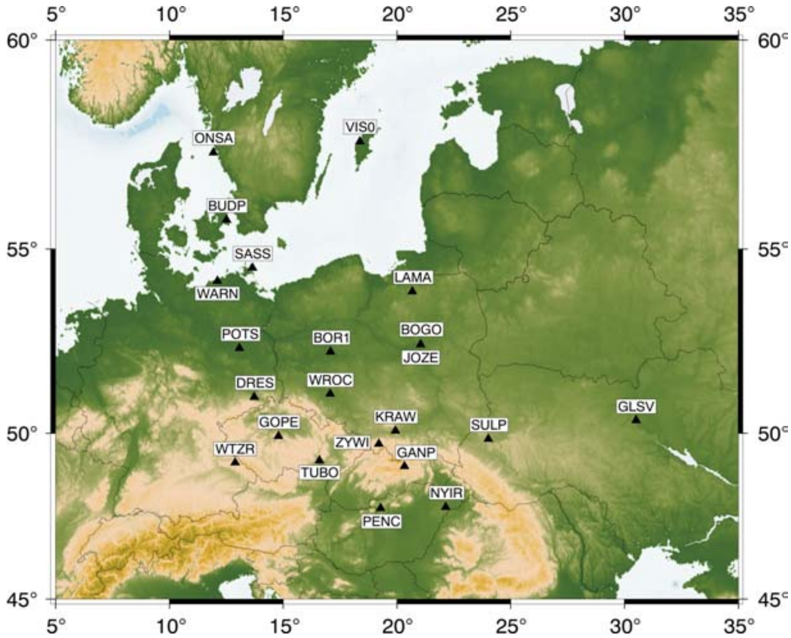

Fig. 4.5.3. NRT processing test campaign

Table 4.5.1. Differences between ZTD obtained from NTR solutions and ZTD from Rapid IGS solutions

Station	Averaged difference NRT-PW	Averaged absolute difference	No. of solutions considered
BOR1	1.82	7.42	626
GOPE	5.15	8.52	529
POTS	1.70	7.43	899
WTZR	1.88	7.06	1027
HOFN	-2.05	7.24	55
ONSA	1.62	6.08	541

4.5.3.2. User automatic on-line service OGPSP

The on-line service for individual users enables to determine automatically the position of the GPS user. The service was developed and established at the Warsaw University of Technology in 2005. OGPSP (Online GPS Processing) system processes the data of the user using GPS data from the subset of EPN/IGS stations in Central Europe. The system is based on the *Bernese* v.4.2 GPS Software (Linux platform) but its original panels and BPE are not used (Kruczyk et al., 2006). All necessary scripts for preparation input files, processing control, data download, error/exception handling etc. have been written in *Perl*. The system uses EUREF weekly coordinate solutions and IGS cumulative solutions for reference frame realisation. The system utilises the most precise IGS orbits available at the time of the user data submission (final, rapid, ultra-rapid).

The choice of the IGS/EPN stations can be performed in 3 ways:

- system automatically will choose 3 nearest stations,
- user will specify 1 to 4 stations,
- system automatically will choose 3 optimal stations evenly distributed around the user station (in testing)

Communication with the user is arranged via web page (Fig. 4.5.4) for observation file upload and via e-mail to send back the results.

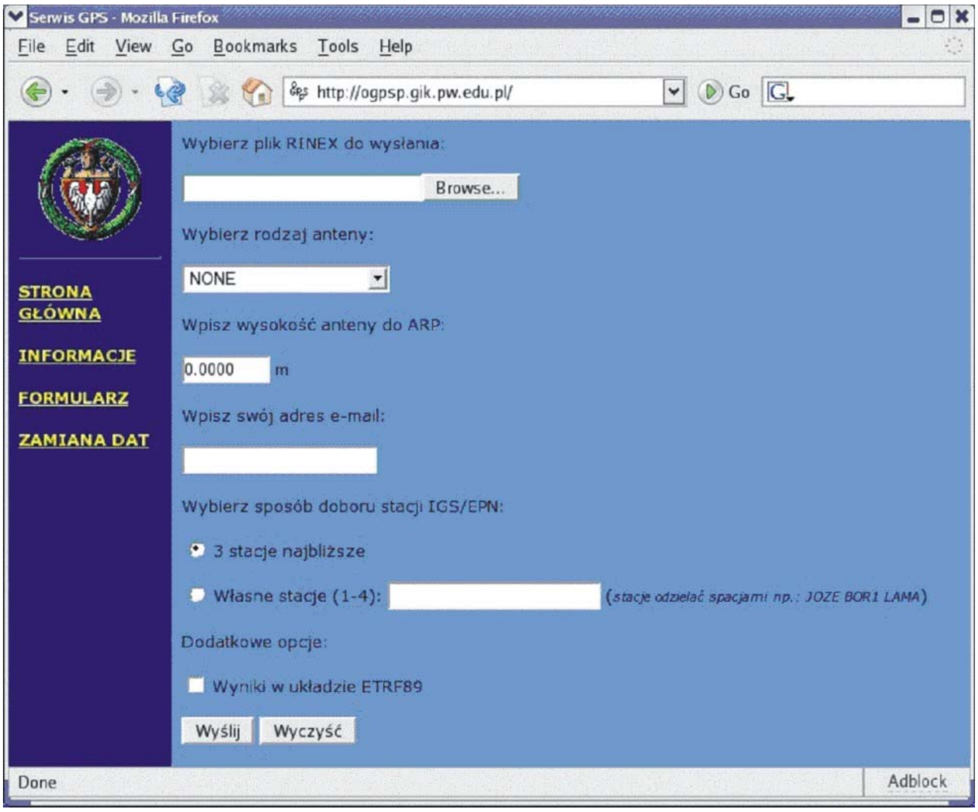

Fig. 4.5.4. OGPSP service - main webpage http://ogpsp.gik.pw.edu.pl

In the nearest future the PPP method will become implemented into the user automatic on-line service OGPSP. First results are shown in Figure 4.5.5.

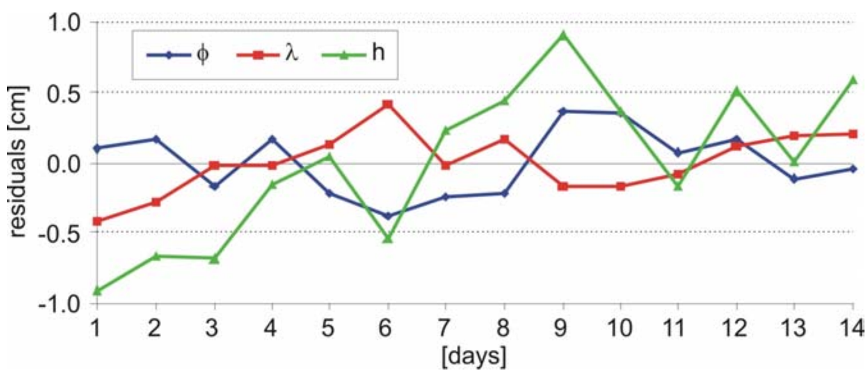

Fig. 4.5.5. Test results of PPP data processing to be implemented in OGPSP service

4.5.4. Study on Accuracy and Reliability of Precise GPS Positioning

The extensive qualitative and quantitative analysis of short-periodic variations of vector components derived from GPS data provided by numerous EPN stations as well as from observing campaigns at mini-network in the Borowa Gora Geodetic Geophysical Observatory was conducted at the Institute of Geodesy and Cartography, Warsaw (Krynski and Zanimonskiy, 2003). Time series of GPS solutions were generated with use of both scientific (*Bernese* v.4.2) and commercial (*Pinnacle*) software. The optimum computing strategy in terms of temporal resolution as well as accuracy was developed (Fig. 4.5.6) (Krynski and Zanimonskiy, 2003, 2005b).

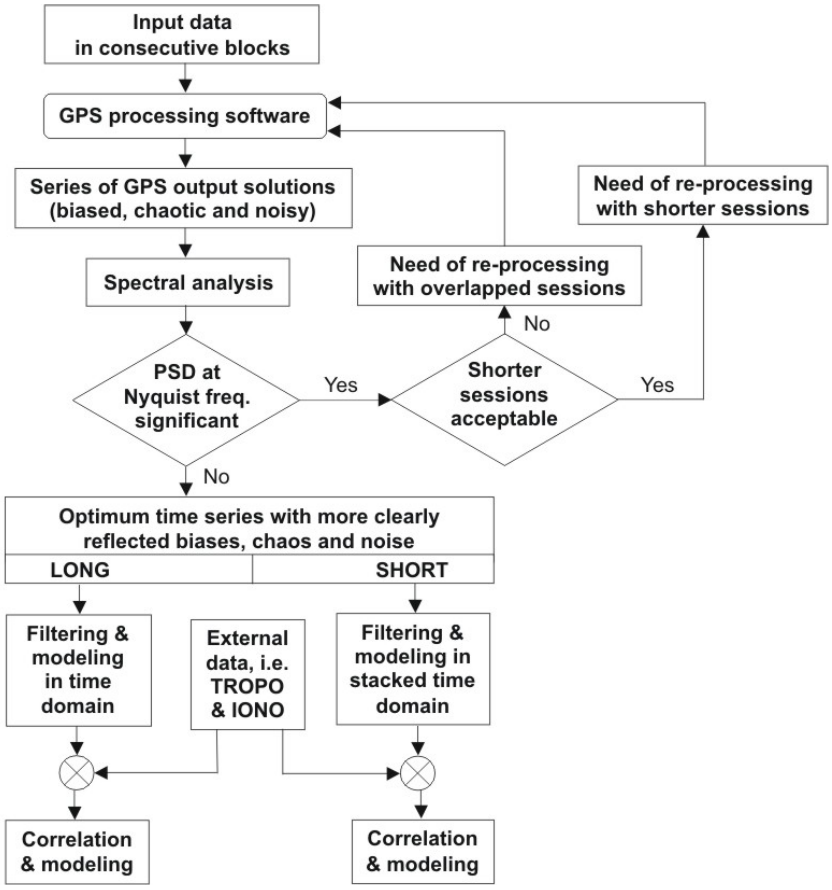

Fig. 4.5.6. Flowchart of the strategy of GPS solutions quality analysis

The choice of optimum length of eventually overlapped data sessions that assures the required accuracy and appropriate temporal resolution of GPS solution series is the major component of the strategy.

A dispersion of GPS-derived vector components considered as an external accuracy estimate does not coincide with processing software-provided estimated accuracy that is the internal accuracy estimate (Krynski and Zanimonskiy, 2005a). The discrepancy between externally and internally estimated accuracy was investigated using statistical analysis of time series of vector components obtained with the *Bernese* and *Pinnacle* software (Fig. 4.5.7).

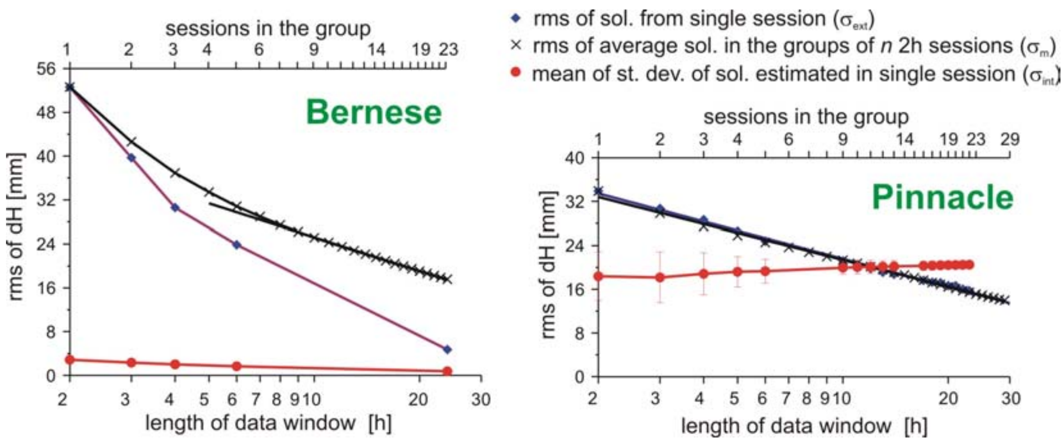

Fig. 4.5.7. Standard deviations of the GPS-derived vertical component provided by processing softwares, and estimated by statistical analysis of time series of GPS solutions

Internal accuracy provided by the *Bernese* software differs from the external one, in cases investigated, by a scale factor of about 7 and 10 for a vertical component and vector length, respectively (Fig. 4.5.8) (Krynski and Zanimonskiy, 2005a, 2005b). Internal accuracy estimation provided by the *Pinnacle* software can be considered as the acceptable rough estimate of accuracy.

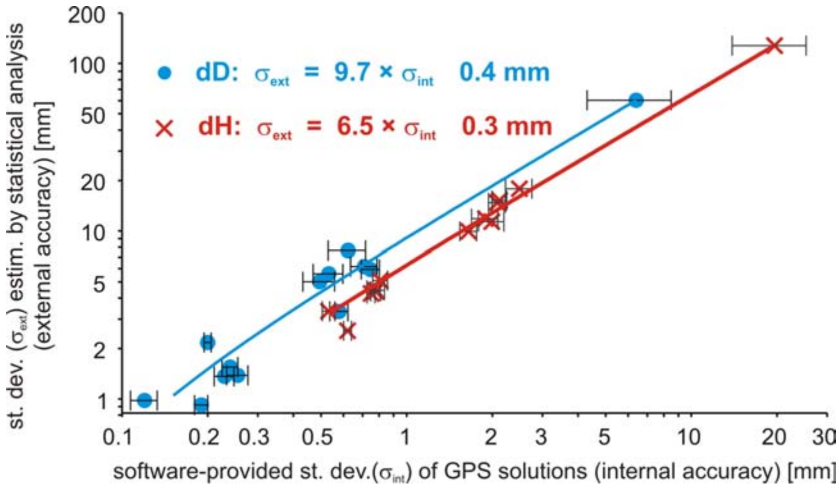

Fig. 4.5.8. Correlation between the external accuracy σ_{ext} and the internal accuracy σ_{int} of GPS solution for distance (D) and vertical component (H) provided by the *Bernese* software

Accuracy of GPS solutions based on data from permanent stations or from long-term geodynamics campaigns can efficiently be estimated by investigating time series of overlapping solutions using the tools of statistical analysis. The developed strategy of quality analysis of GPS solutions, besides filtering, allows for estimation of biases and chaotic effects. That procedure is not suitable for estimation of accuracy of GPS solutions obtained from single, short time occupation of sites. The majority of noise can be filtered using simplified statistical analysis of overlapped solutions based on sub-intervals of the observed session. Biases and jerks, however, can only be roughly estimated externally using the results of extended statistical analysis.

GPS positioning based on shorter than 12h single observing session could not provide the solution for vector components with accuracy below 1 cm, even for short vectors (Krynski and Zanimonskiy, 2005a).

4.5.5. GNNS Antenna Calibration

An extensive research on the variations of GPS antenna phase centre initiated at the Institute of Geodesy and Cartography, Warsaw in 1999 has been continued first in the framework of a new SCAR project “In situ GNSS Antenna Tests and Validation of Phase Centre Calibration Data” established in 2004 and then since 2005 in the framework of the research project on the development of the method of GNSS antennae calibration taking into account the parameters of local conditions. A simple, portable prototype of the device for antenna calibration was constructed in co-operation with the “Metrologia” Institute, Kharkiv, Ukraine (Fig. 4.5.9).

Fig. 4.5.9. The first prototype of portable dynamic tilting device for field calibration of GNSS antenna, checked in the Borowa Gora Observatory

First test measurements were performed in Borowa Gora and Lamkowko Observatories in Poland as well as in the Ukrainian Antarctic "Akademik Vernadsky" station. The use of the antenna tilting device developed enables to determine the mean phase centre offset (Fig. 4.5.10) as well as the phase centre variations (PCV) in the field conditions, taking into account local site multipath and scattering effects. Modelled and observed variations of satellite-antenna distance for PCV determination are shown in Figure 4.5.11.

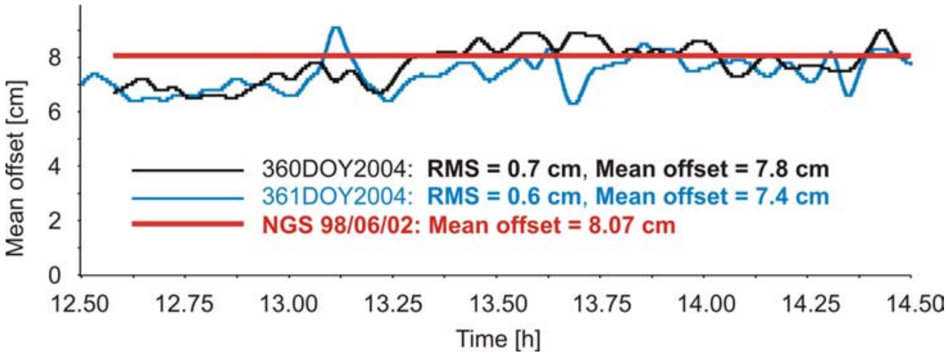

Fig. 4.5.10. The example of mean offset determination

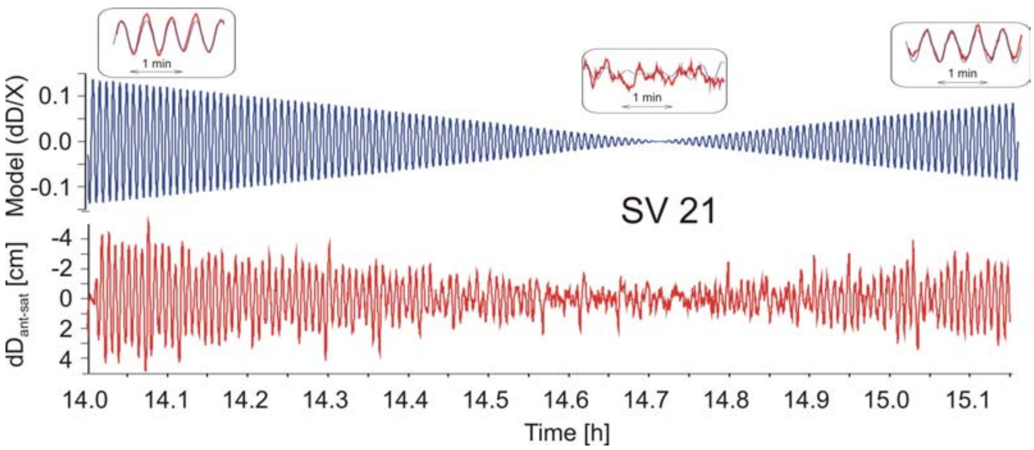

Fig. 4.5.11. Time series of modelled and observed variations of satellite-antenna distance for PCV determination

In the beginning of February 2006 (GPS week 1360) some local effects on IGS LAMA station co-ordinate changes were observed. A snow cover of the GPS antenna during a very snowy winter of 2005/2006 caused the disturbances of co-ordinates determined. Using an Ashtech Choke Ring antenna of the Institute of Geodesy and Cartography, Warsaw, the investigation of the effect of snow was performed at the end of winter 2006 at Lamkowko. The antenna was placed about 70 m from LAMA site, on a similar concrete pillar. Different layers of the snow up to complete covering the antenna were put on the pillar. The height changes reached the level of 10 cm. (Fig. 4.5.12).

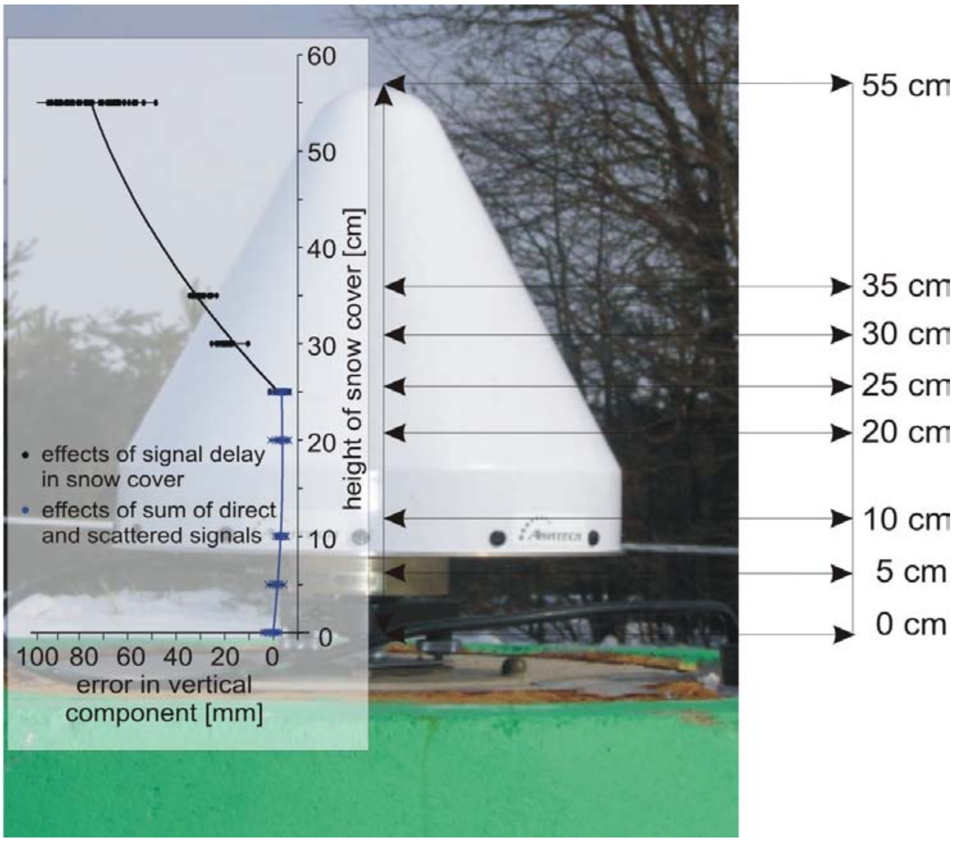

Fig. 4.5.12. Dependence of vertical component determined on the coverage of the antenna with the snow

4.6. TROPOSPHERE STUDIES

Research on the impact of the atmosphere on GPS solutions was conducted in the Institute of Geodesy and Cartography, Warsaw. The use of time series of overlapping GPS solutions makes possible to detect sudden changes in the GPS-derived vector components (Krynski and Zanimonskiy, 2003). An increase of temporal resolution of GPS solution series by processing overlapped sessions is an effective tool for detecting biases and reducing errors in the solutions. Particular attention was paid to the influence of atmosphere on GPS solutions. Time series of Total Electron Content (TEC) in ionosphere, Total Zenith Delay (TZD) in troposphere and meteorological parameters such as temperature, air pressure and humidity as well as of solar activity parameter were generated for time intervals corresponding to time series of GPS-derived solutions investigated (Krynski and Zanimonskiy, 2003) (Fig. 4.6.1).

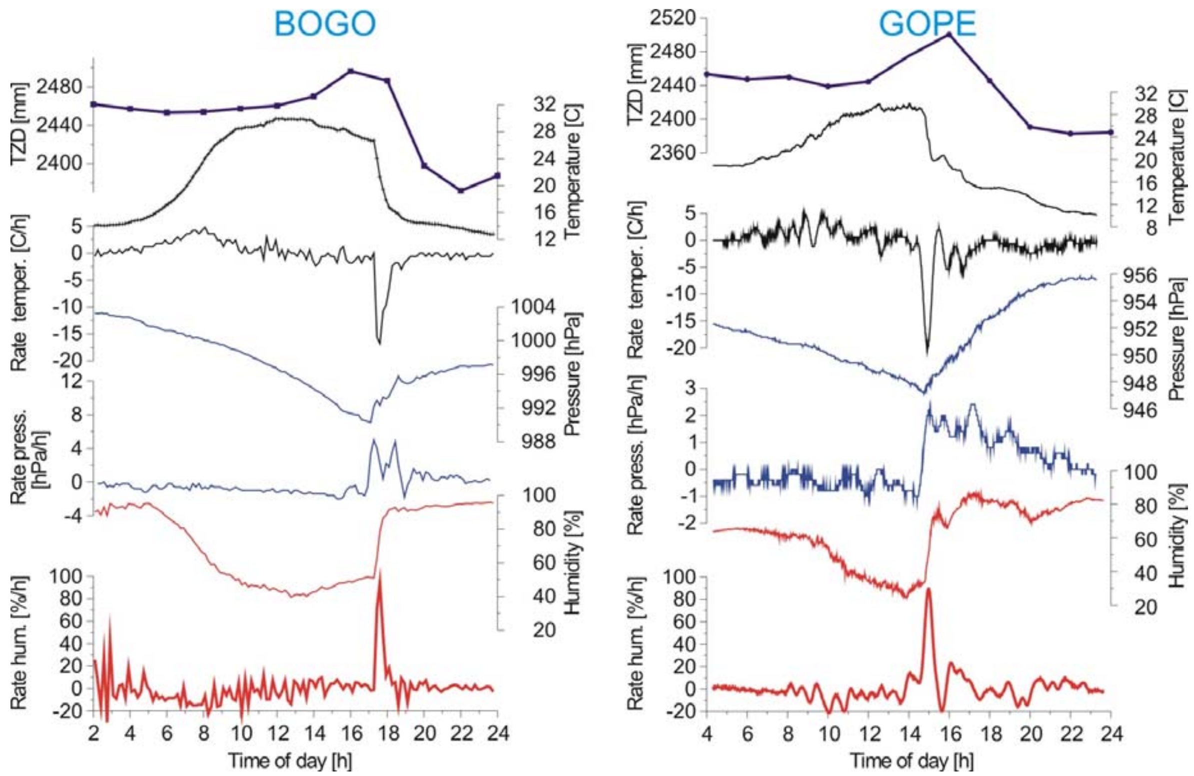

Fig. 4.6.1. Dynamics of variations of meteorological parameters and TZD
when the atmospheric front was passing over BOGO and GOPE stations in 27 August 2001

Quality of improvement of GPS solutions increases with the increase of periods of actual atmospheric disturbances. In the case of passing tropospheric front those periods are close to 1h or even shorter. Regional troposphere processes were investigated with the use of the EPN data (Krynski and Zanimonskiy, 2004). Correlation between short-period variations of vector components and variations of TZD (with special attention to atmospheric fronts) as well as variations of TEC (with special attention to magnetic storms) were investigated. Empirical models based on correlation between short-period variations of vector components and variations of TZD developed (Fig. 4.6.2).

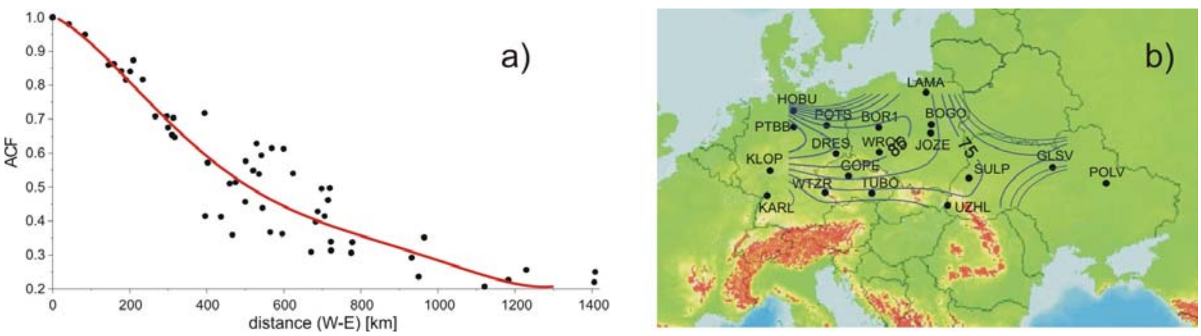

Fig. 4.6.2. Correlation function of TZD in space domain for a section of Central Europe (a)
with interpolated contour lines of correlation coefficient (b)

The models developed can be used for detection of the large-scale troposphere process such as cold front. The atmospheric fronts that pass from west to east keep frequently the same structure when moving along 1-2 thousand kilometres during one or two days. Relatively simple structure of motion of such atmospheric fronts as compared with West European fronts allows their effective investigation using GPS-derived and meteorological data. Processes of forming and moving of solitary tropospheric waves were qualitatively modelled similarly to soliton modelling in water (Fig. 4.6.3) (Krynski and Zanimonskiy, 2003, 2004).

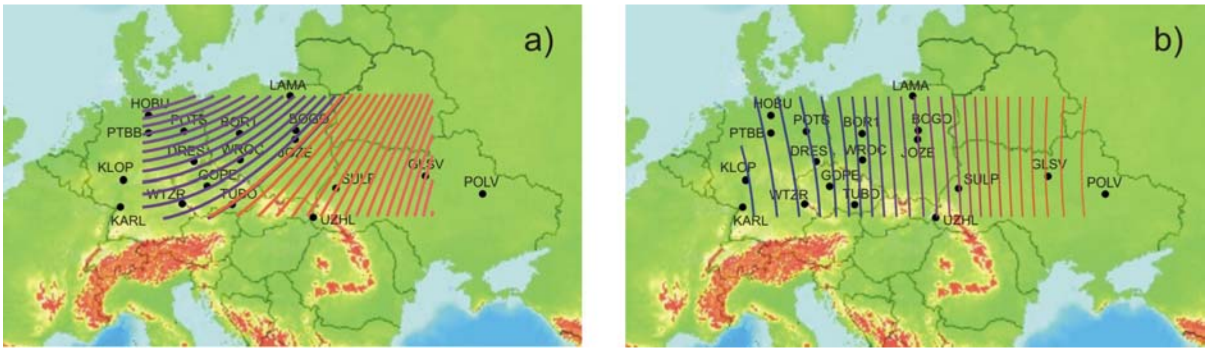

Fig. 4.6.3. Contour lines (2h) of the atmospheric fronts of 27-29 August 2001 (a), and of 21-22 January 2002 (b) on the background of the map of EPN stations used

Research on troposphere sounding by the use of GPS signal propagation, conducted by the team of the Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology, comprised several interconnected areas:

- standard tropospheric solution in the EPN framework,
- NRT experimental solution,
- ZTD solutions quality monitoring,
- ZTD values verification by means of radiosounding profiles,
- IPW/IWV series analysis in search for geophysical interpretations,
- works on identification of synergies between numerical weather prediction and geodetic solutions.

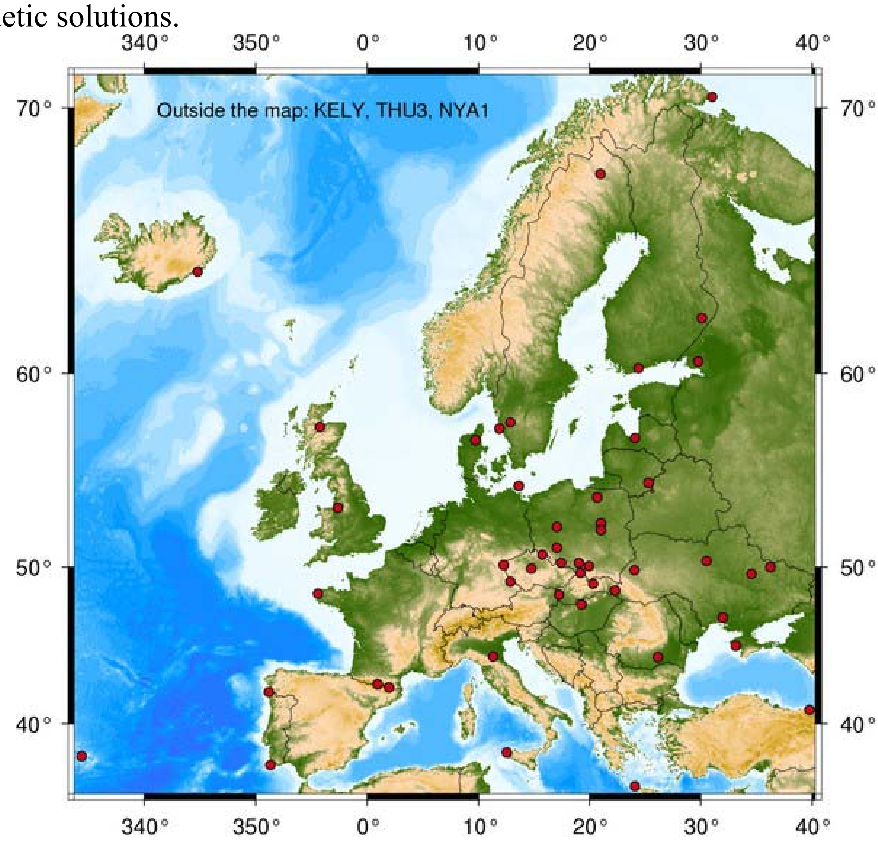

Fig. 4.6.4. The Warsaw University of Technology EPN LAC network

Warsaw University of Technology EPN LAC provides daily tropospheric solution since a week 1113 as a part of standard LAC activity. In the week 1318 the solution has been switched from the *Bernese* v.4.2 to the one of the *Bernese* v.5.0. For verification means the solutions for GPS weeks 1318-1323 have been calculated both 4.2 and 5.0 versions of the *Bernese* (Figurski et al., 2006).

NTR troposphere processing in the automatic mode has been successfully set up and worked for over half a year. The system processes data from 22 EPN/IGS GPS stations from Central Europe. The solution is provided by the *Bernese* v.4.2 GPS Software (BPE). ZTDs are estimated every hour inside a sliding window of 4 hours (no ADDNEQ) using RINEX files concatenated (teqc); coordinates of all stations are fixed to EUREF weekly solutions. IGS Ultra Rapid orbits, no *a priori* tropospheric model, and dry Niell as mapping function are used. Observations with sampling of 30 sec and cut off angle of 10° are weighed using the function 1/cos(z). Ambiguities are resolved using QIF strategy (Kruczyk et al., 2006).

Quality monitoring of WUT tropospheric solutions has been performed with the use of official EPN tropospheric combination (codename: EUR), and till 2005 also by independent combination made by GFZ. Additional verification was accomplished by comparisons with various tropospheric solutions: IGS combination, SIO and CODE global daily final solutions. Interesting conclusion is that in the years 2003-2004 there was a systematic difference between the 'European' and global solutions (the *Bernese* v.4.2 used in EPN) that significantly decreased after introducing the new version of the *Bernese* software. WUT NRT tropospheric solution was tested by comparison with final solutions, GFZ NRT solution (made in the frame of GASP) and radiosoundings (Liwosz et al., 2005). The results obtained were very satisfying: low bias (discernible mainly in comparisons with radio-soundings) and very high correlation with GFZ NRT solution series.

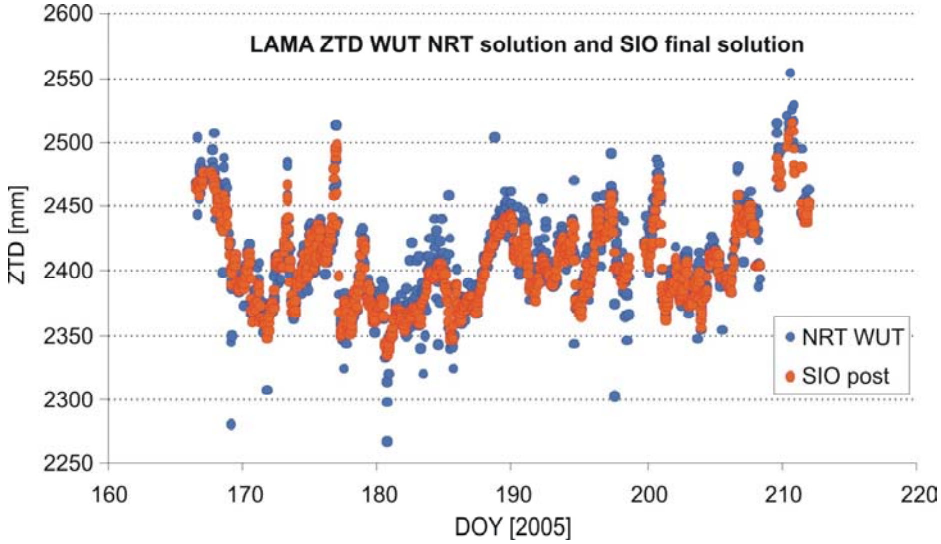

Fig. 4.6.5. Final ZTD solution (global IGS by SIO) and WUT NRT solution

Prominent field of research at the Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology, is a IPW (Integrated Precipitable Water) retrieval and analysis (sometimes also ZTD series analysis). Major developments worth mentioning are as follows (Kruczyk, 2005; Kruczyk et al., 2003, 2004a, 2004b, 2006)

- Obtaining long 'climatological' series of IPW for various station locations to analyse long term PW behaviour: some climate features visible in IPW series derived from final solutions (continental or oceanic character), year to year variability similar for the most of the continent, height dependence (mountain stations like ZIMM) etc.Analysing ZTD series correlation coefficient as a function of the distance; for the stations on the same longitude in western circulation zone one can even spot (and calculate) the time lag of the same weather pattern for subsequent longitudes.

- Illustrating ZTD height dependence - change of ZTD for two close stations with height difference (BOGO & BOGI case - also very close but one point on the building roof).
- Finding the lack of linear regression for IPW/IWV vs. surface meteorological values.

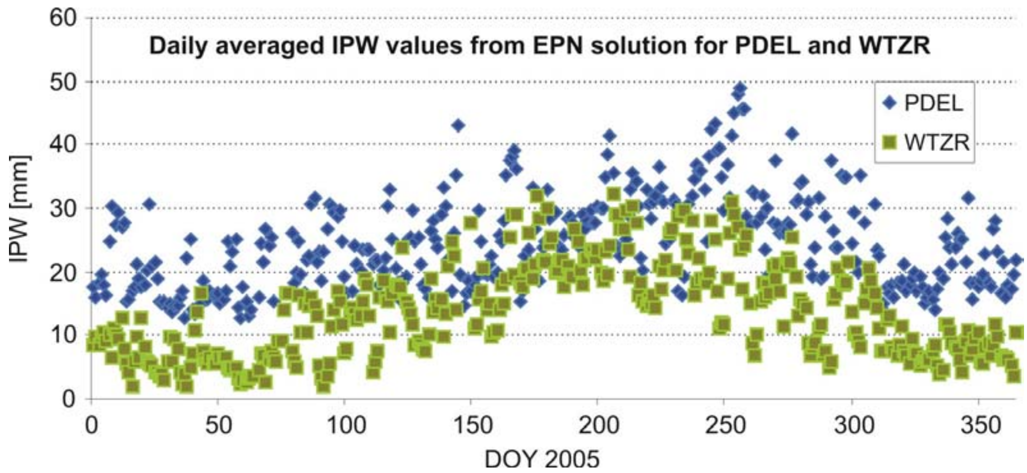

Fig. 4.6.6. Daily average values of Integrated Precipitable Water for continental (WTZR -Bayern) and ocean (PDEL –Azores) station during one year

Works are conducted to strengthen the links with numerical weather prediction and meteorological community in the field to cross-use of data relating to atmospheric refraction and column water vapour content.

The team of the Institute of Geodesy and Geoinformatics (former Department of Geodesy and Photogrammetry) of Wroclaw University of Environmental and Life Sciences (former Agricultural University of Wroclaw) developed the procedure of local meteorological parameters modelling (interpolation) in a GPS network area on the basis of meteorological observations, carried out independently of GPS measurements (Bosy and Borkowski, 2005).

4.7. IONOSPHERE STUDIES

The team of the Institute of Geodesy of the University of Warmia and Mazury in Olsztyn (UWM) takes advantage of long time series of GNSS observations, carried out by IGS/EPN stations since 1994, to study the Earth's ionosphere. The studies were performed in collaboration with the West Department of the Institute of Geomagnetism, Ionosphere and Radio-Wave Propagation of the Russian Academy of Sciences in Kaliningrad (WD IZMIRAN) (Baran et al., 2003). In the last quadrennium (2003-2006), the research was focused on the following problems:

- studies of the ionosphere over Europe with high spatial and temporal resolution
  - to evaluate geomagnetic storms,
  - to detect the solar eclipse effects,
  - to detect earthquake effects;
- behaviour of the Total Electron Content (TEC) fluctuations at high latitude ionosphere during severe geomagnetic disturbances;
- impact of strong TEC fluctuations on the accuracy of GNSS positioning;
- short-term forecasting of TEC;

- local and regional ionosphere modelling for precise GNSS positioning;
- impact of the external ionospheric models on the accuracy of RTK position estimation.

GPS data from 65 European permanent stations was used for the analysis of latitudinal TEC distribution. TEC measurements for an individual satellite pass include both, temporal and spatial variations of the ionosphere. Simultaneous multi-station observations were used to resolve both, temporal and spatial variations of TEC. The distribution of TEC over Europe was analysed as a time series of TEC maps. More than 4300 TEC profiles were created from those maps with 1h interval during the solar maximum activity (1999-2001) for both, quiet and disturbed conditions. Diurnal and seasonal variations were obtained from the TEC maps. Day-to-day variations were found to be maximum in winter and minimum in summer. During the day-time, TEC decreases monotonously towards the high latitudes. The latitudinal gradients are larger in winter than in summer (Wielgosz et al., 2004a). During the disturbances, the latitudinal dependence is more variable (Fig. 4.7.1). In Figure 4.7.1, the effects of the strong storm of 4-5 October 2000 are demonstrated.

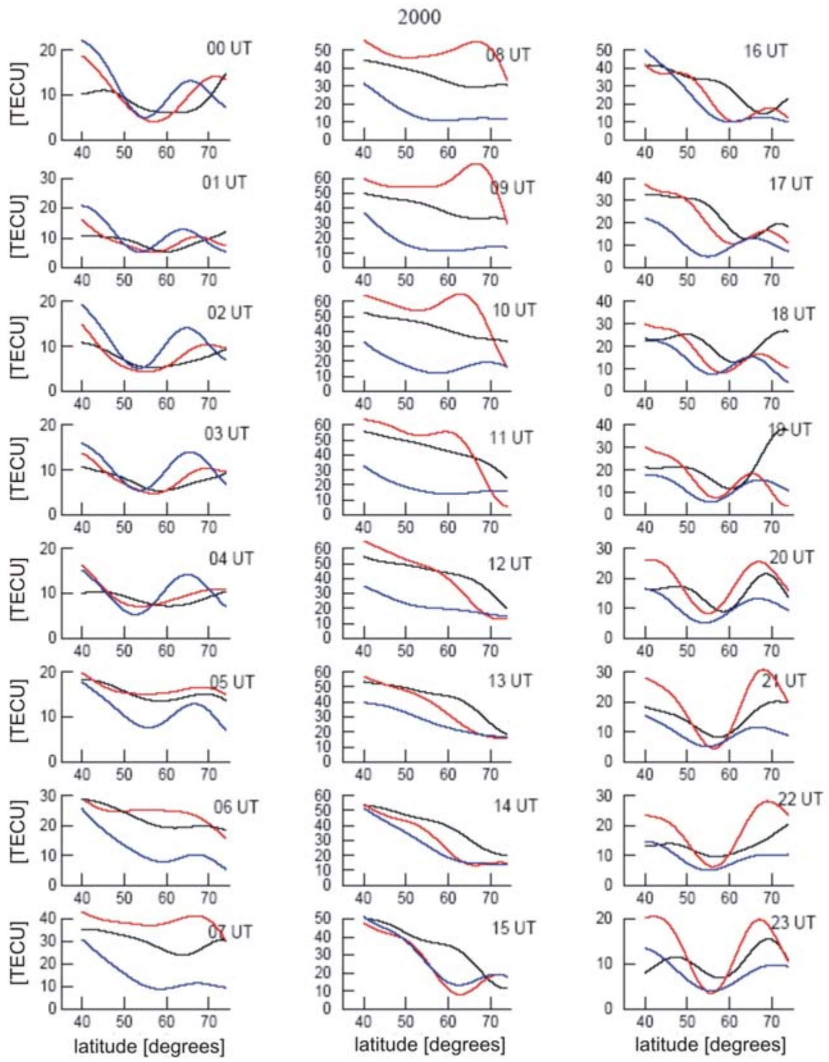

Fig. 4.7.1. Latitudinal TEC profiles over Europe at longitude 20°E. Black line – 2 October (ΣKp = 16), red line – 4 October (ΣKp = 40), blue line – 5 October (ΣKp = 53) (Wielgosz et al., 2004a)

The comparison of GPS-derived TEC profiles with the IRI model shows, that the IRI model might not reproduce the latitudinal TEC variations correctly (Fig. 4.7.2).

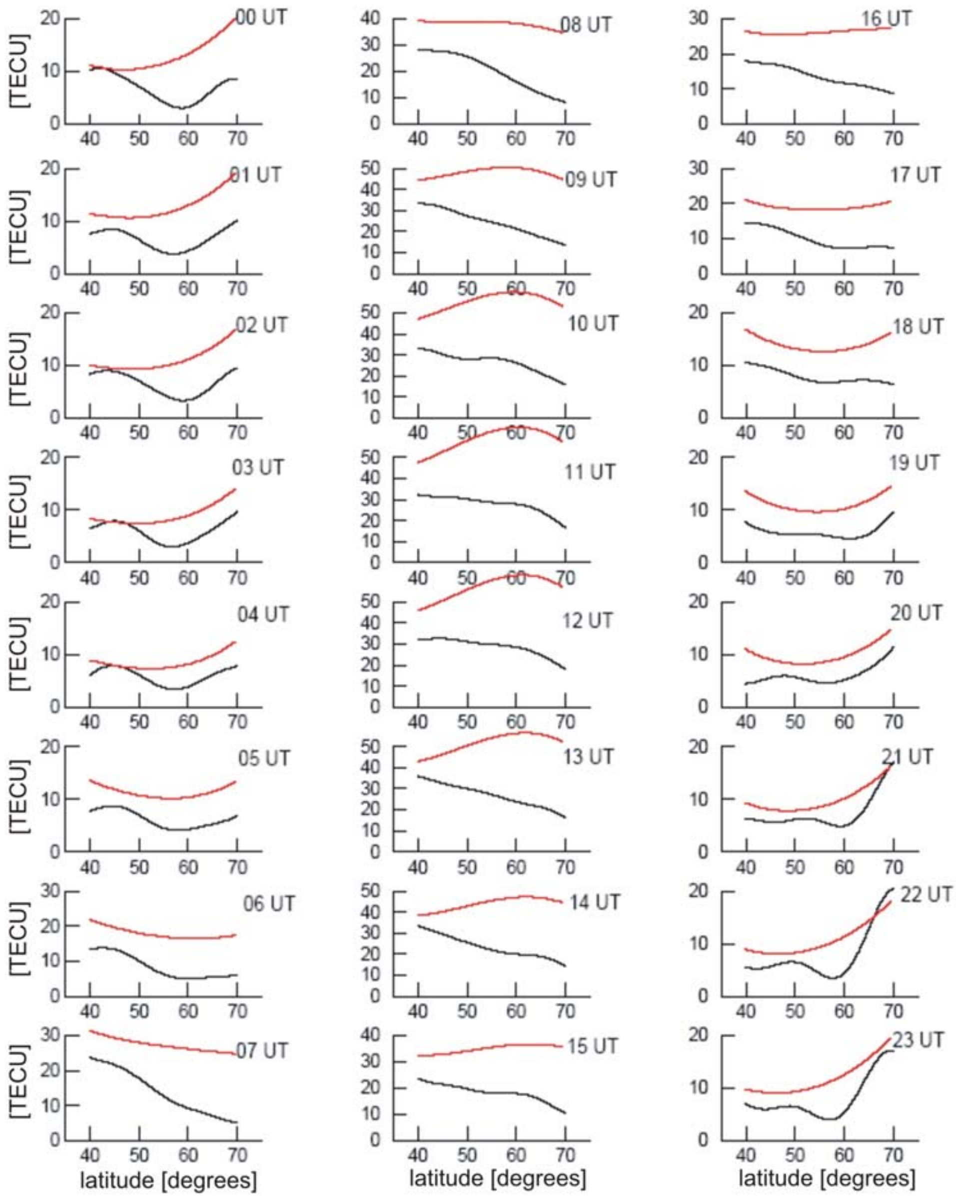

Fig. 4.7.2. Comparison of latitudinal profiles of GPS-derived TEC (black) with IRI model (red) for 15 December 1999 (Wielgosz et al., 2004a)

The effects of another severe geomagnetic storm of 5-8 November 2001 are discussed in (Krankowski et al., 2004b). More than 80 GNSS permanent stations were included in the analysis of the response of TEC to this storm. Latitudinal variations of TEC during the storm are presented in Figure 4.7.3.

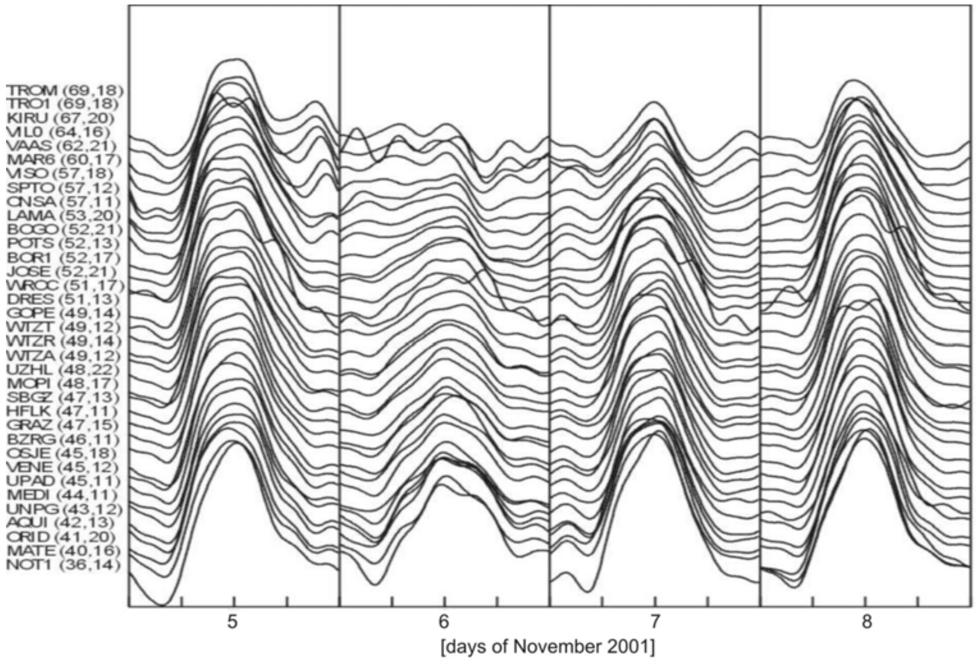

Fig. 4.7.3. Diurnal variations of TEC at different latitudes during storm of 5-8 November 2001 (Krankowski et al., 2004b)

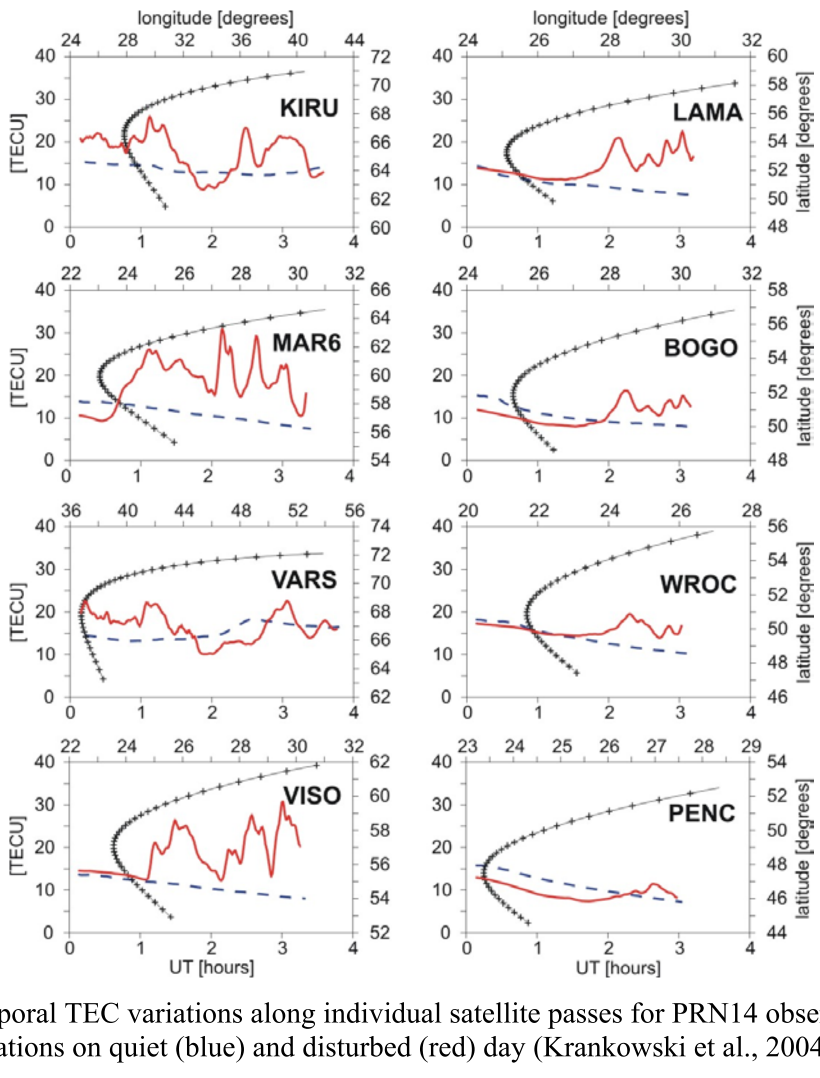

Fig. 4.7.4. Temporal TEC variations along individual satellite passes for PRN14 observed at different stations on quiet (blue) and disturbed (red) day (Krankowski et al., 2004b)

In order to obtain the spatial and temporal variation of TEC and to create TEC maps, the results of measurements were fitted to a spherical harmonic expansion in terms of geographic latitude and longitude. The spherical harmonic expansion was truncated to the order and degree of 16. Large number of GNSS stations in Europe provide a good coverage for satellite data and enable to get high-accuracy TEC maps with an error at the level of 0.5-2 TECU, with spatial resolution of ~200 km and with time resolution of 15 min (Krankowski et al., 2004b).

The analyses of TEC variations for individual satellite passes show that during the driven phase of the storm, different scale irregularities developed in the ionosphere. Figure 4.7.4 shows that during the storm large- and medium-scale irregularities caused deep fluctuation of TEC at mid-latitude stations: Lamkowko (53N) and Wroclaw (51N). The behaviour of TEC at those stations spaced by 300-500 km was also different. Those conclusions are useful for GNSS users, because the horizontal ionospheric gradients can lower ambiguity resolution and affect the accuracy of GNSS positioning.

Data from more than 80 European and 100 American permanent GNSS stations was used to study the response of the ionosphere to the storm of 31 March 2001 (the largest one in recent years) over European, North American and Antarctic sectors. It was stated that the response of the ionosphere to the storm was more pronounced and longer over North American sector than over Europe (Krankowski et al., 2004a).

Results of GPS observations collected by 70 EUREF permanent stations were used for presentation of the eclipse effects and spatial behaviour of TEC over Europe during 11 August 1999 total solar eclipse. The single-site and multi-site techniques were used for analysis of the TEC behaviour during the eclipse (Baran et al., 2003). The two-dimensional TEC maps constructed with 15 mimutes interval show that the eclipse produced the clear changes in the structure of the ionosphere (Fig. 4.7.5).

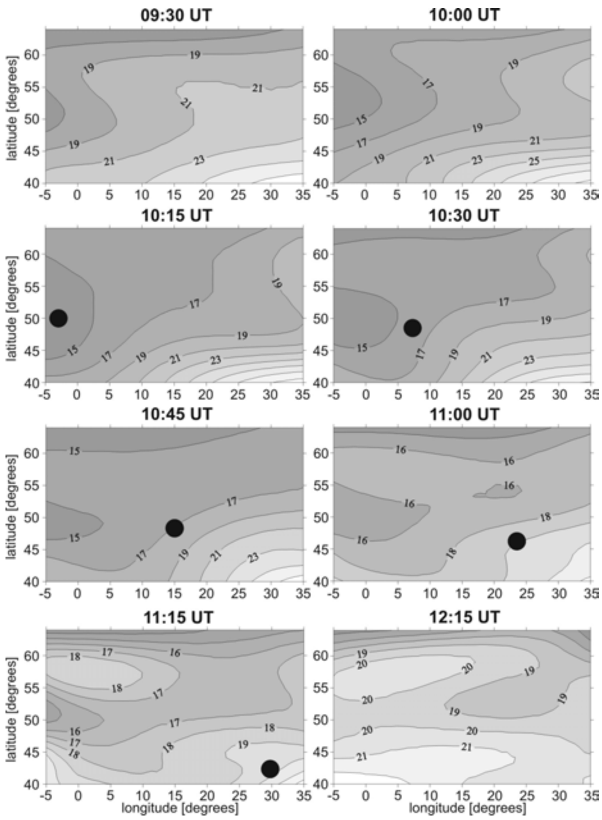

Fig. 4.7.5. The maps of TEC for the eclipse day of 11 August 1999. The dark circle is Moon's shadow (Baran et al., 2003)

The 3D Global Self Consistent Model of the Termosphere, Ionosphere and Protonosphere (GSMTIP), developed in WD of IZMIRAN, was used for TEC calculation during 11 August 1999 solar eclipse (Korenkov et al., 2003). The numerical model results have been compared with the experimental data of TEC, obtained with GPS measurements at the European stations located close to the path of totality. Model results have shown substantial decreasing of TEC (25-30%) with delay of about 30 min. Comparison with experimental TEC data shows a reasonable agreement for a number of station, such as Graz, Lamkowko, Sofia and Ankara.

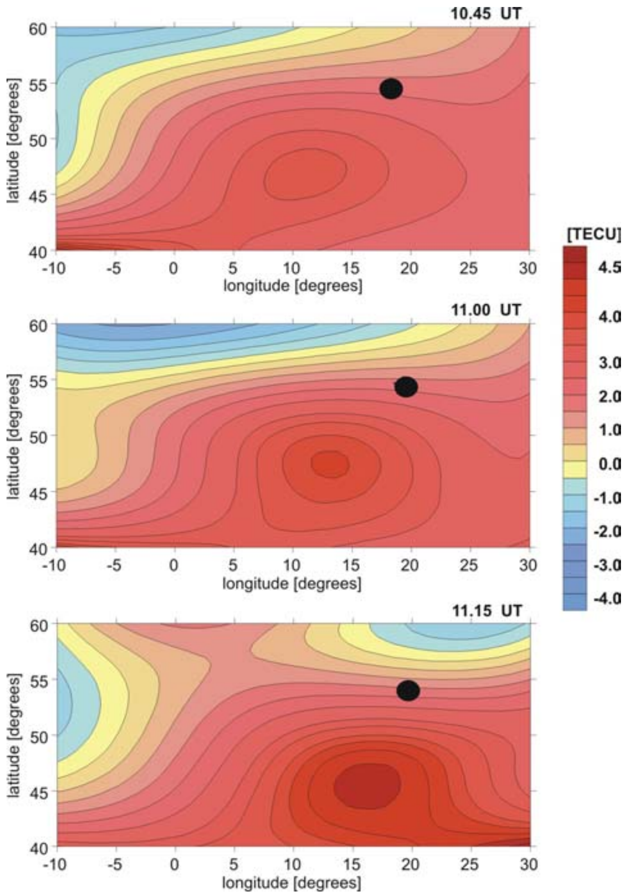

Fig. 4.7.6. Differential TEC maps over Europe for 20 September compared to 19 September 2004 with 15-minutes resolution. The black points indicate location (in geographic coordinates) of epicentre of earthquake (Krankowski et al., 2006a)

GPS observations of the European permanent stations were used to identify seismo-ionospheric precursors of Baltic Sea earthquake of 21 September 2004. It was a very rare event in that region of Europe. The mean magnitude of the earthquake, obtained from five Polish seismic centres was about 5.0. That value is the threshold for the occurrence of seismic effects in the ionosphere. In TEC data over the region of the earthquake, a specific ionospheric anomaly appeared one day before the earthquake was detected. The ionospheric variability had a positive sign with an enhancement of about 4-5 TECU relative to the non-disturbed state of the ionosphere. The anomaly had duration of 4-5 hours during the day time (Krankowski et al., 2006a). The spatial size of this anomaly was about 1000 km (Fig. 4.7.6). The characteristic parameters of the anomaly show that it can be associated with ionospheric precursors of the earthquake.

A modification of the ionosphere before the 26 December 2004 Indonesian earthquake was presented (Zakharenkova et al., 2006).

GPS observations carried out at Antarctic stations, belonging to the IGS network, were used to study TEC fluctuations at the high-latitude ionosphere during storms (Krankowski et al., 2004c, 2005a, 2006b; Krankowski and Shagimuratov, 2006). Dual-frequency GPS phase measurements along individual satellite passes served as raw data.

As it is known, ionospheric irregularities of a different scale develop in the auroral and polar ionosphere. It is a common phenomenon which causes phase fluctuations of GPS signals. As a measure of TEC fluctuations, the rate of TEC index (ROTI), expressed in TECU/min was used. Large scale ionospheric structures cause an increase in horizontal gradients and difficulties with the carrier phase ambiguity resolution (Fig. 4.7.7). In turn, the phase fluctuations can cause cycle slips. The occurrence of TEC fluctuations depends on the geomagnetic latitude of a site. Maximum TEC fluctuations were recorded at polar stations. During storms the variations of TEC reached 10-40 TECU. The enhancement of TEC exceeded 2-8 times relative to quite ionosphere.

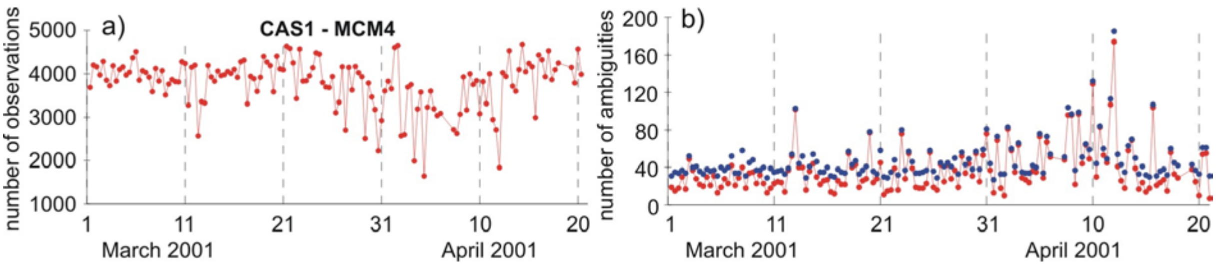

Fig. 4.7.7. Total number of observations of double-differences (a), the total number of all ambiguities (blue circles) and unresolved ambiguities (red circles) for CAS1-MCM4 vector in March-April 2001 (b) (Krankowski and Shagimuratov, 2006)

The intensity of phase fluctuations depends on geomagnetic activity. During the maximal phase of the severe storm on 31 March 2001, fluctuations of moderate intensity were observed at middle-latitude station O'Higgins (63.3° southern latitude). The ionospheric gradients increased essentially during the storm. This can be a cause of major errors while determining phase ambiguities of GNSS observations in the Antarctic region (Krankowski et al., 2005a).

Deep TEC fluctuations at Antarctic stations were associated with polar patches. As it is known, polar cap patches are regions of enhanced ionization, which drift across the polar cap in an anti-sunward direction from the source region, near the dayside auroral oval. The intensity of patch structures increased during geomagnetic disturbances. In GPS data, the patch structures were recognized as TEC eruption in variations of TEC along satellite passes. The value of ROTI was used as a measure of the patch intensity. Maximum ROTI (6 TECU/min) were observed at McMurdo4 station (Krankowski et al., 2006b).

The TEC time series of ionospheric quiet and disturbed conditions over different European stations for a half of the solar cycle period, from 1995 to 2001, were analysed in (Krankowski et al., 2005b, 2005c, 2006c). The wavelet analysis (Krankowski et al., 2005b) enabled to detect disturbances in TEC during the period considered, as well as to compute coherences and time delays between wavelet transform coefficients of TEC, corresponding to different stations located near the same meridian (Fig. 4.7.8). The information about the time delay between different GNSS stations can be useful for prediction purposes.

The prediction of ionospheric TEC is essential to provide high-accuracy GPS positioning, VLBI observations and to calibrate ionospheric delay space measurement techniques and satellite communication systems. An empirical model has been developed to provide the prediction of ionospheric electron content during magnetospheric disturbances (Krankowski et al., 2005c). The new algorithm provides an improvement of TEC prediction of more than 75-80%, compared to the IRI model. Such improvement in short-term predictions can be achieved using the correction on the current geomagnetic measurements.

A statistical approach for a single-station TEC forecasting was presented (Krankowski et al., 2005b, 2006c). In statistical methods (autocovariance, ARMA, similar pattern) the prediction is computed as a function of the TEC observed from one particular station only. The prediction accuracy depends on the time span of the data only. It was stated that the ARMA (Autoregressive Moving Average) method provides an acceptable accuracy even during intensive geomagnetic storms (Krankowski et al., 2005b).

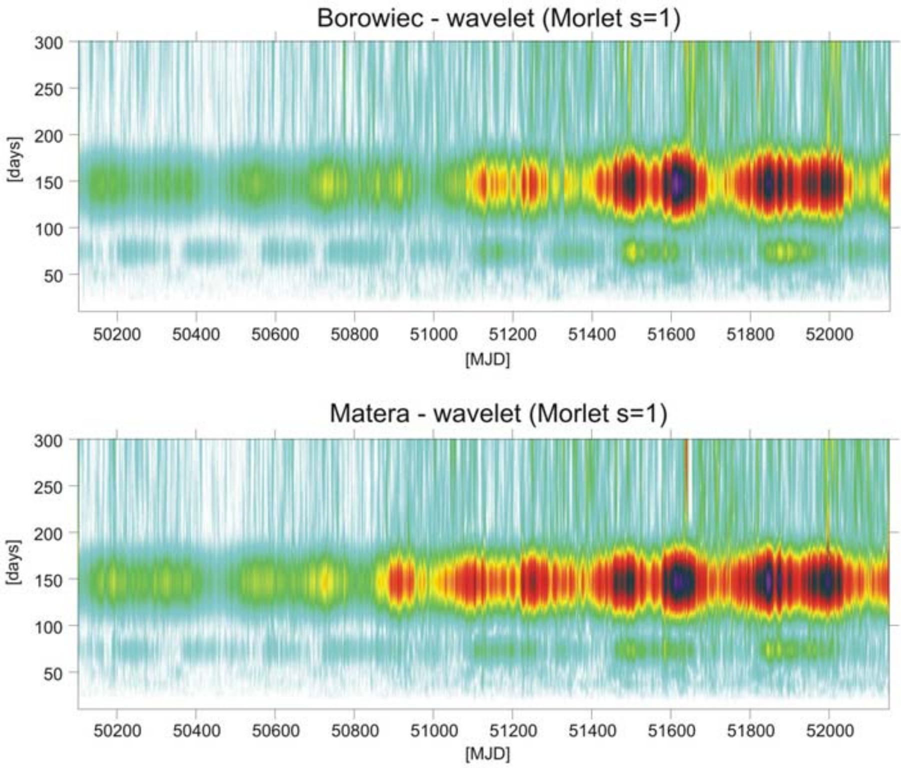

Fig. 4.7.8. Wavelet time-frequency spectrum of the TEC data from Borowiec (a) and Matera (b) during the period of 1996 to 2001 (Krankowski et al., 2005b)

Problems of the local and regional modelling of ionosphere were extensively discussed (Bosy et al., 2003; Grejner-Brzezinska et al., 2005c; Kashani et al., 2004b, 2005a; Wielgosz et al., 2003a, 2003c, 2005b, 2005c). A concept and practical examples of instantaneous mapping of regional ionosphere based on GPS observations from the State of Ohio continuously operate reference stations (CORS) network were presented (Wielgosz et al., 2003a, 2003c). Instantaneous ionosphere mapping is defined as a technique applying simultaneously measured TEC values at a limited number of locations to generate TEC maps referred to a specific time epoch. Interpolation technique, such as kriging (KR) and the Multiquadric Model (MQ), which are suitable for handling multi-scale phenomena and unevenly distributed data, were used to create the TEC maps. The quality of the ionosphere representation was tested by comparison to the reference IGS Global Ionosphere Maps (GIMs). GPS Observations collected by a relatively dense Ohio CORS network (~100 km station separation, one second sample rate) were used in this study. The primary advantages of the instantaneous regional ionosphere mapping are the high temporal and spatial resolution.

KR and MQ methods applied to regional GPS data allowed detecting local features in the ionosphere, as compared to GIMs.

The network-derived ionospheric correction accuracy during extremely varying – quiet and stormy – geomagnetic and ionospheric conditions was analysed (Wielgosz et al., 2005b). In addition, the influence of the correction accuracy on the instantaneous (single-epoch) and on-the-fly (OTF) ambiguity resolution in long-range RTK GPS positioning was investigated, and the results, based on post-processed GPS data, were provided. The network used to generate the ionospheric corrections consists of three permanent stations selected from the Ohio CORS network. The average separation between the reference stations was ~200 km and the test baseline was 121 km long. The results show that during the severe ionospheric storm, the correction accuracy deteriorates to the point when the instantaneous ambiguity resolution is no longer possible and the OTF ambiguity resolution requires much more time to fix the integers (Fig. 4.7.9).

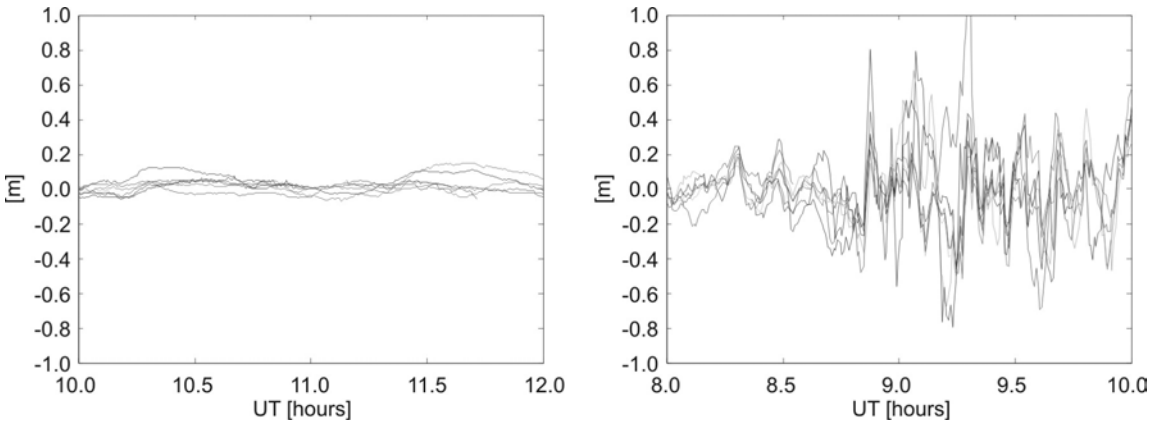

Fig. 4.7.9. DD ionospheric correction residuals with respect to the reference "truth" during the analysed quiet and stormy periods (COLB-LEBA, 121 km) (Wielgosz et al., 2005b)

The network RTK technique using weighted ionospheric corrections to assist fast ambiguity resolution over long baselines (>100 km) in a single-baseline mode and under severe ionospheric conditions was analysed (Wielgosz et al., 2005c).

Three methods of the ionospheric correction modelling and estimation, with varying spatial and temporal resolution, based on reference GPS permanently tracking network (the Ohio CORS), were presented, and the impact of those models on the positioning accuracy at the user location was discussed (Grejner-Brzezinska et al., 2005b). The following ionospheric models were tested: 1) absolute (biased) carrier phase-based model, decomposed from double-differenced (DD) ionospheric delays; 2) absolute model based solely upon undifferenced dual frequency ambiguous carrier phase data; 3) tomographic model using pseudorange-levelled phase data (a 3D model). Those models were used to derive the ionospheric delay corrections for the rover. One CORS station was selected as a rover, and the data reduction was performed in the post-processing mode, using the Multi Purpose GPS Processing Software (MPGPS™), developed at the Ohio State University. Subsequently, the rover position estimation was performed in each case, and the analysis of the applicability of each model to high-accuracy RTK GPS was performed. In particular, the time required to fix the ambiguities applying various ionospheric models and the quality of the resulting kinematic positioning were analysed.

The analysis of the accuracy of an absolute precise point positioning (PPP) in the instantaneous, kinematic and static modes was performed (Wielgosz et al., 2004c, 2005a). In addition, an applicability of local and global ionosphere models in PPP was evaluated. The preliminary tests show that centimetre-level static PPP is feasible when using precise IGS products and local ionosphere information based on one hour of GPS data. A horizontal positioning at the level of few decimetres can be assured when using ionosphere-free linear combination, or a single-frequency data with the global ionosphere information. The instantaneous solution presents a sub-metre accuracy. The above results demonstrated that PPP, with use of the currently available mature GPS products, is an attractive alternative to the relative positioning.

The team of the Institute of Geodesy and Cartography has investigated correlation between variability of GPS solutions, solar activity and parameters of atmosphere (Krynski and Zanimonskiy, 2003). The example of variability of vertical component and the length of BOGO-BOR1 vector as well as χ^2 against of solar activity Kp, filtered TEC and mean square errors of TZD is shown in Figure 4.7.10. It shows that the state of ionosphere particularly strongly depends on the solar activity in polar regions. The effect of ionosphere on GPS solutions was further investigated in the framework of the international project "The Atmospheric impact on GPS observations in Antarctica" (Cisak et al., 2003, 2004)

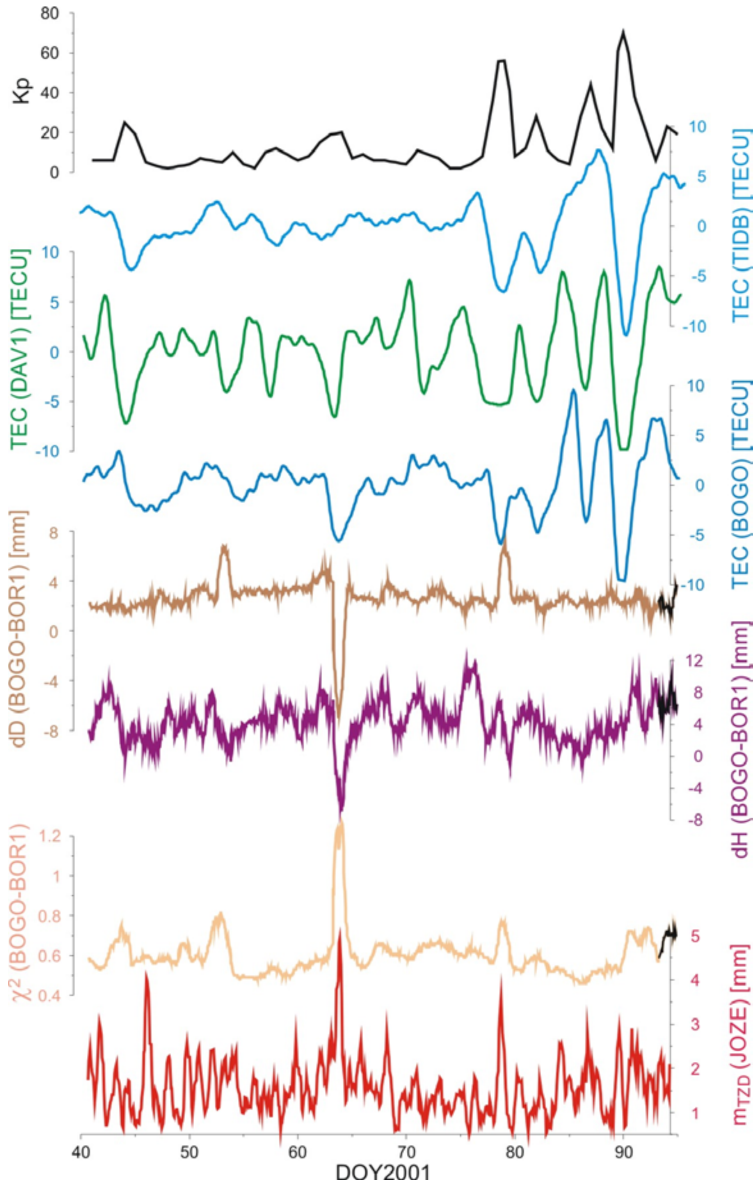

Fig. 4.7.10. Variability of vertical component and the length of BOGO-BOR1 vector as well as χ^2 against of solar activity Kp, filtered TEC and mean square errors of TZD

The investigations on atmospheric impact on the results of the precise geodetic measurements with GPS technique in polar conditions was conducted at the Institute of Geodesy and Cartography, Warsaw, in the framework of the GIANT (Geodetic Infrastructure of Antarctica) program project of SCAR. Both theoretical as well as experimental aspects of the influence of ionosphere on GPS solutions were examined. During the occurrence of large electron concentration gradients the ionospheric refraction can strongly affect the determination of ambiguity and result in growing errors in GPS solutions. The correlation between the growth of unsolved ambiguities and variations in TEC values due to ionospheric storms is clearly visible when calculating vectors from GPS data in polar regions; it leads to erroneous determination of vector components (Cisak et al., 2003).

Annual variations of TEC values for 2001 obtained from IONEX data by calculating daily averages over Antarctic Davis (DAV1) and European Borowa Gora (BOGO) stations as well as the Ap index representing in linear scale a measure of geomagnetic activity are presented in Figure 4.7.11.

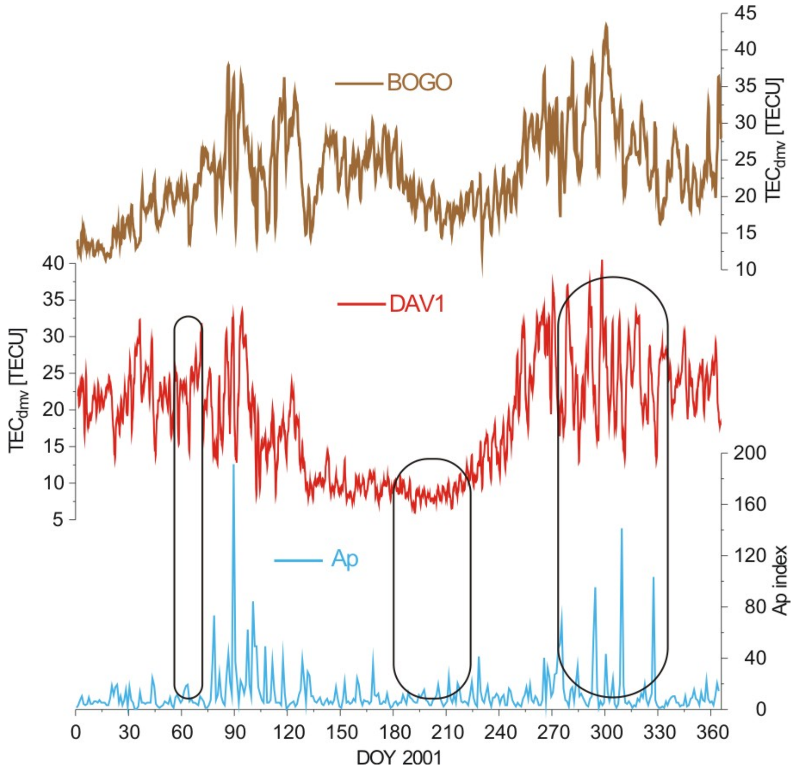

Fig. 4.7.11. The Ap index and annual variations of diurnal mean TEC over DAV1 and BOGO stations obtained from IONEX data

Two periods of ionospheric storms in March and October-November are marked on the graph. The third period marked on the graph shows the lowest electron concentration and the lowest geomagnetic activity in 2001. The GPS data acquired at the Antarctic GPS permanent station during those three periods were processed and the results were analysed. A correlation between vector length and Total Electron Contents was found for all vectors investigated. The example of Davis–Casey vector is shown in Figure 4.7.12.

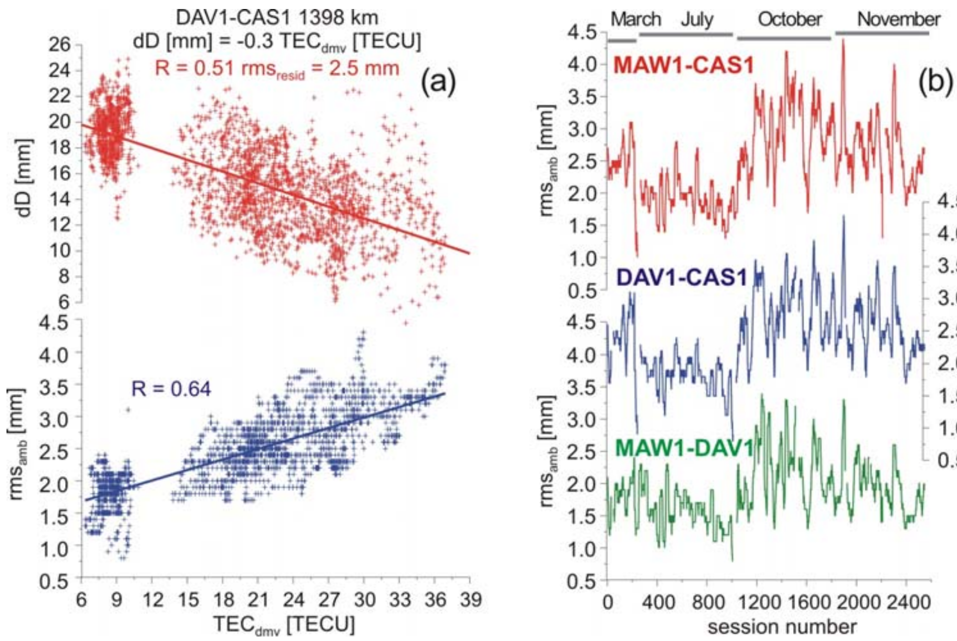

Fig. 4.7.12. Variations of vector length and uncertainty of ambiguity estimation versus TEC (a), and time series of uncertainties of ambiguity estimation for the periods of different stability of ionosphere (b)

4.8. GPS POSITIONING OF THE MOVING OBJECTS

Numerous tests with GPS positioning of the moving objects were performed in the Chair of Satellite Geodesy and Navigation, the University of Warmia and Mazury in Olsztyn. They concerned the accuracy estimation of aircraft, airplane, boat, car and pedestrian trajectory determination with GPS techniques such as OTF post-processing mode, RTK, DGPS in real time/post processing and stand alone mode (Ciecko and Oszczak, 2003; Popielarczyk, 2005b). Other experiments performed in cooperation with the University of Trieste, Italy, and the Air Force Academy in Kosice, Slovakia concern navigation and positioning of a moving vehicle with the use of GPS satellite system and the corrections from EGNOS satellites (Oszczak et al., 2003a, 2003b; Ciecko et al., 2003b). Substantial experience with real-time GPS positioning of the moving objects was gained during the European Rally Championships. In cooperation with rally teams special GPS/GPRS safety boxes were designed and made. Monitoring of all 7 rally stages with GPS receivers and a method of calibrations of the maps were presented.

The accuracy of aircraft positioning during the en-route and approach phase of flight with the use of two techniques: radar and GPS/EGNOS satellite systems, was investigated. The results obtained indicated that GPS receivers can be regarded as primary navigation instruments (Grzegorzewski et al., 2004).

4.9. OTHER GNSS APPLICATIONS

The team of the Chair of Satellite Geodesy and Navigation, the University of Warmia and Mazury in Olsztyn was involved in the application of DGPS/GPRS satellite navigation and hydrographic systems for monitoring and safety sailing on Great Mazurian Lakes (Popielarczyk and Oszczak, 2003; Popielarczyk, 2005a, 2005b). The integrated technology of bathymetry surveying, that makes possible navigation of the small hydrographic boat along the pre-defined profiles, examination of bottom shape, computation of water volume, elaboration of bathymetric charts and monitoring of dangerous shallow places was developed. A number of professional equipment units like: DGPS/RTK/GPRS receivers, EA 501P Simrad single frequency digital echo sounder, SportScan side scan sonar and special GPS/CAD software is used in the developed Integrated Bathymetric System (Popielarczyk and Oszczak, 2006). The same team was involved in the development of GPS positioning methods for the calibration of satellite images (Bakula and Oszczak, 2003), in the accuracy and efficiency aspects of DGPS and RTK technique in severe observational conditions (Bakula, 2003a, 2003b, 2004, 2005; Bakula and Oszczak, 2006; Ciecko et al., 2003a) and the analysis of performance of VRS (Bakula, 2006). The system of quick and effective creation of Digital Terrain Model based on GPS and GSM/GPRS technology was developed. Precise RTK technique is used for real time determination of horizontal and vertical coordinates of the points used in the model (Ciecko et al., 2006a, 2006b). GPS/RTK OTF method with different types of receivers and teletransmission lines as well as EGNOS (ESTB) performance and positioning accuracy (Manzoni et al., 2004) were examined in Pompeia archaeological site in the experiments conducted in cooperation of the team of the Chair of Satellite Geodesy and Navigation, the University of Warmia and Mazury in Olsztyn with the teams of Italian Universities in: Trieste, Napoli Seconda, Salerno, Catania, Cagliari, Pisa and Padova.

The team of the Institute of Geodesy and Cartography, Warsaw, takes part in the international geodynamics projects for Antarctica as well as in the projects of mapping some regions of Antarctica of special interest (Cisak et al., 2003, 2004, 2005; Wielgosz et al., 2005d).

4.10. ACTIVITIES WITHIN GALILEO PROGRAM

Upon her entry into the European Union in May 2004, Poland became one of the co-owners of European global satellite navigation system Galileo. However, Polish involvement in the development of EGNOS - precursor to Galileo and Galileo system itself dates back several years before.

In the Space Research Centre of the Polish Academy of Sciences the EGNOS Range an Integrity Monitoring Station (RIMS) has been integrated and started its operation in September 2004 (Fig. 4.10.1).

Fig. 4.10.1. Antenna A of the EGNOS RIMS station in Warsaw

The station is an element of the European EGNOS network of 34 stations established for the determination of corrections and integrity flag to the signals of GPS satellites. The station consists of the receiver equipped with two antennas located on the roof of the building of the SRC, separated by the distance 60 m. The receiver, 2 rubidium clocks and data transmission system are housed in the air-conditioned room. The separate receiver – Septentrio - monitors the behaviour and quality of the EGNOS signal. The Ashtech receiver operates as the permanent reference station; it also transmits the DGPS/RTK correction signal (Krynski et al., 2006). Another station established in SRC PAS monitoring the quality of the entire EGNOS sub-system operates in the framework of the PERFECT project. Data from that station are routinely analysed for the control of the EGNOS performance and the results are displayed every day in the ESA web site *http://www.esa.int/navigation*.

In 2004, the Galileo Information Point Poland was established within the Space Research Centre PAS. It concentrates on the promotion of the development and utilisation of Galileo applications in Poland and in other accession countries, offering information and advisory services. A number of Polish research institutes and commercial companies developing GNSS-based applications in different areas such as transport, air and maritime navigation, time service, geodesy, agriculture, personal navigation, civil protection and others. The University of Warmia and Mazury, Olsztyn, participates in Proddage project of 6th EU Framework Programme.

Important contribution of the Borowiec Astrogeodynamical Observatory SRC PAS to that program in the realization of Galileo Time Service Provider should be highlighted (see Section 4.4.3). It is realized in the framework of the Galileo EU FP6 Project "FIDELITY - Implementation of Galileo Time Service Provider Prototype" and the contract „Precise Time Facility". The second task concerns time comparison of Baltic countries „BALTICTIME - Reinforcing Government Services in the Baltic States through legal and accountable Digital Time Stamp".

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