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CONTENTS

1. REFERENCE NETWORKS

1.1. INTRODUCTION

This part of the Polish National Report on Geodesy is the quadrennial report on positioning works performed in Poland in a period 1999-2002. It summarises 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, etc. The activities concerning reference networks were conducted mainly at 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 Geodesy and Photogrammetry, Agricultural University in Wroclaw;
- Department of Mining Surveying and Environmental Engineering, University of Mining and Metallurgy 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 Stefan Cacon, Wladyslaw Goral, Jan Krynski, Adam Lyszkowicz, Stanislaw Oszczak, Wojciech Pachelski, Jerzy B. Rogowski, Andrzej Sas-Uhrynowski and Janusz B. Zielinski.

The bibliography of the related works is given in references.

Annual national reports to the IAG Sub-commission for EUREF (Baran et al., 2000; Pazus, 2002; Krynski et al., 2002) contain the extensive information on the activities concerning reference networks in Poland within the reported period.

1.2. MAINTENANCE OF EUREF-POL NETWORK

Following the recommendation of the EUREF Technical Working Group (Report of the EUREF Technical Working Group, 1999) the Head Office for Geodesy and Cartography in Poland confined to the Department of Planetary Geodesy of the Space Research Centre, Polish Academy of Sciences, in 2001, to re-survey the EUREF-POL network. The second EUREF-POL campaign was conducted in 26-30 September 2001. The same set of 11 stations as in the first EUREF-POL campaign was re-surveyed. One EUVN network station was also included in the campaign. The survey was conducted with Trimble 4000SSi receivers in five 24h sessions. The observations collected during the campaign were processed at the Department of Planetary Geodesy of the Space Research Centre, Polish Academy of Sciences, using Bernese v.4.2 software. The network was computed in the ITRF2000 reference frame for 2001.74 epoch and the results were transformed to the ETRS89. The comparison of results of the first and recent campaigns shows that the network is stable within the limits of accuracy of the epoch 1992. Estimated average differences in coordinates equal to ±3 mm (north), ±5 mm (east) and ±10 mm (up). Monumentation of the EUREF-POL stations proved to be robust and reliable.

Two permanent stations where antennas were modified show the difference of 20 mm in height. The coordinate differences obtained at the stations are listed in Table 1.1. A number of comparisons have been done between this solution and the solutions for POLREF network and the EUVN network (Jaworski et al., 2002). The EUREF-POL 2001 campaign demonstrated that the national geodetic system for Poland that is based on the EUREF-POL 92 solution is good enough for all practical purposes and needs no substantial modifications.

Table 1.1. Comparison of results of EUREF-POL 92 and EUREF-POL 2001 campaigns

Station	ΔLat [mm]	ΔLon [mm]	Δh [mm]
0216 BOROWIEC (BOR1 12205M002)	1.7	-4.0	4.5
0217 BOROWA GORA (BOGI 12207M003)	5.4	-3.6	20.0
0301 ROZEWIE	-1.3	4.7	-6.6
0302 LAMKOWKO (LAMA 12209M001)	-4.8	8.5	19.2
0303 MASZE	5.2	-6.7	14.0
0304 CZARNKOWIE	2.5	3.1	-4.3
0306 JOZEFOSLAW (JOZE 12204M001)	-4.6	-8.6	-10.0
0307 STUDNICA	1.0	3.0	13.6
0308 ROGACZEW	-0.2	3.7	-16.1
0309 ZUBOWICE	-1.8	4.9	1.2
0310 GRYBOW	-2.5	-0.1	3.9

1.3. OPERATIONAL WORK OF PERMANENT IGS/EUREF STATIONS

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 8 permanent GPS stations, i.e. Borowa Gora (BOGO, BOGI), Borowiec (BOR1), Jozefoslaw (JOZE, JOZ2), Lamkowko (LAMA), Krakow (KRAW) and Wroclaw (WROC) (Fig. 1.1) are in operation in Poland within the IGS/EUREF program (Table 1.2). A brief characteristic of those stations is given in Table 1.3. 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. Jozefoslaw and Krakow stations take part in the EUREF IP pilot project (Table 1.4) (http://www.epncb.oma.be/projects/euref_IP/euref_IP.html).

Table 1.2. Permanent GPS stations in Poland

Name (abbr.)	Latitude	Longitude	Status	Receiver
Borowa Gora (BOGI)	52°28’30’’	21°02’07’’	IGS, EUREF	Javad JPS Eurocard
Borowa Gora (BOGO)	52°28’33’’	21°02’07’’	EUREF	Ashtech Z-12
Borowiec (BOR1)	52°16’37’’	17°04’27’’	IGS, EUREF	Turbo Rogue SNR 8000
Jozefoslaw (JOZE)	52°05’50’’	21°01’54’’	IGS, EUREF	Trimble 4000 SSE
Jozefoslaw (JOZ2)	52°05’52’’	21°01’56’’	IGS	Ashtech Z-18
Krakow (KRAW)	50°03’58’’	19°55’13’’	EUREF	Ashtech μZ-12
Lamkowko (LAMA)	53°53’33’’	20°40’12’’	IGS, EUREF	Ashtech Z-12 Turbo Rogue SNR 8000
Wroclaw (WROC)	51°08’48’’	17°03’43’’	EUREF	Ashtech Z-18

Fig. 1.1. IGS/EUREF network of permanent stations in Poland

Table 1.3. 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 ZXII3** 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 Z18** ASH701941.B SNOW	02JAN2002	**Yes** LAB-EL Poland NAVI Ltd. Poland	24 h 1h	Ground water level Astrometry Gravity tidal GPS/GLONASS
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 ZXII3** ASH700936F_C SNOW	01DEC1994	Yes LAB-EL Poland	24 h	Gravity GPS
WROC	12217M001	**Wroclaw** Agriculture Academy	**Ashtech Z18** ASH700936D_M	28NOV1996	**Yes** LAB-EL Poland	24 h 1h	Ground water level GPS/GLONASS

Table 1.4. Characteristics of Polish stations participating in the EUREF IP pilot project

Location	Appr. Lat. [deg]	Appr. Long. [deg]	RTCM message types (update rate [s])	Bitrate [bits/s]	Site log file
Krakow	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

1.4. ACTIVE GPS/DGPS STATION NETWORK IN POLAND

The study group appointed in 1995 by the Polish Academy of Sciences recognised that the number of active multifunctional permanent GPS stations in Poland should be increased in the future. The distances between stations should amount about 50 km. The stations should form a new generation geodetic network, adequate for many social and economical needs. The local analysis centres in co-operation with national analysis centre should be engaged in processing of the permanent GPS observations. Conditions and limitations of using permanent GPS stations in common geodetic practice as well as in navigation were discussed (Dobrzycka et al., 1999; Oszczak et al., 1999a, 2000; Manzoni and Oszczak, 2000)

The technical project of ASG-PL network, ordered by the Head Office for Geodesy and Cartography in Poland, was reviewed by the study group (Baran et al., 2000b; 2000c). A sub-network 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 local (regional Silesian) authorities and it has reached a preliminary operational stage in February 2003. The map of this network is given in Fig. 1.2. The network consists of 6 permanent stations and is recently linked to EPN (BOGI, BOGO, JOZE, KRAW, LAMA, WROC) stations and two other permanent GPS stations (CBKA, INS1) (Fig. 1.4) that provide GPS data at 5 s sampling rate. Network stations are equipped with Ashtech μZ-12-CGRS receivers with ASH701945C_M SNOW antennas. Observations are made at 5 sec sampling rate and are transferred to the processing centre hourly.

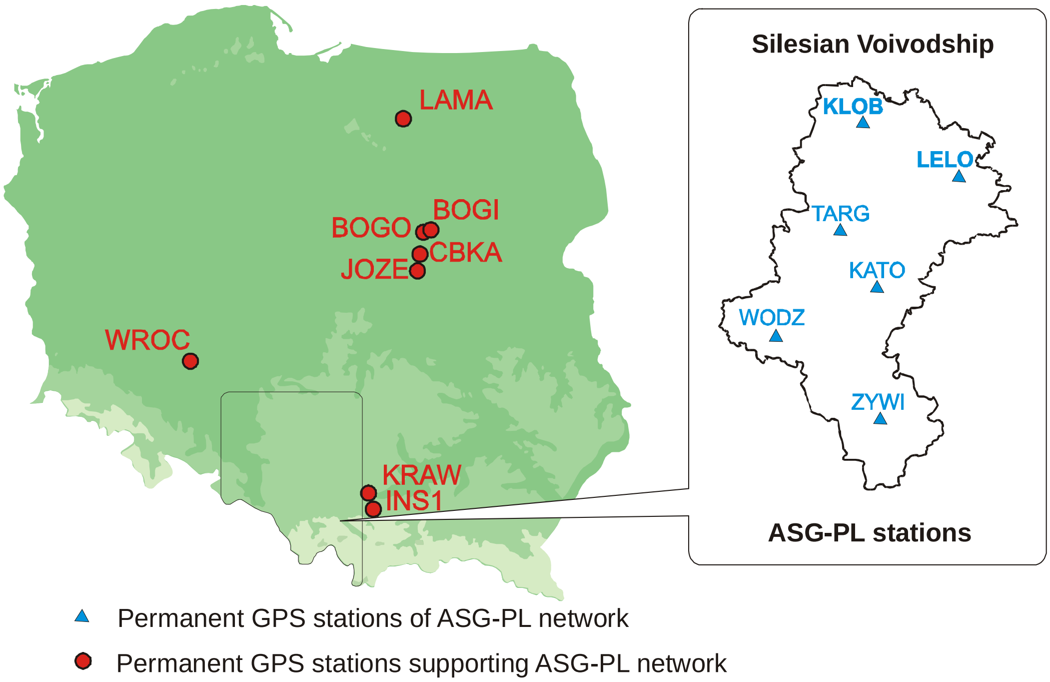

Fig. 1.2. Map of the operating in 2003 part of the Polish Active Control Network

The system of automatic processing of GPS data for ASG-PL network designated for the users is under testing.

1.4.1. DGPS/RTK Reference Stations

DGPS Maritime Navigational Service System

Two permanent reference DGPS stations: Dziwnow and Rozewie, equipped with 12-channel GPS receivers, complement the Baltic Sea maritime navigational network of stations along Polish seashore. Since 1995 they distribute the RTCM corrections on radio frequency. Redundancy of the equipment controlled by a computer system is provided in order to maintain high total hardware reliability and to ensure continuity of broadcasting. Local Integrity Monitor for faults and automatic change for hot stand-by blocks continuously monitor functioning of equipment. Data is accessible via telephone line modems for remote monitoring, controlling and alarm reporting purposes. The transmission is broadcast with MSK modulation in the band allocated for marine radio-navigation Region A1 (283.5-315 kHz). Both stations include second carrier emission spaced by 500 Hz to maintain RDF service when necessary. Assigned frequencies, nominal ranges for signal strength 34 dB (50μV/m) are shown in Table 1.5.

Table 1.5. DGPS broadcast stations in the Southern Baltic seashore

Station name	Function	Position	ERP [W]	Nominal Range [50μV/m]	Frequency [kHz]	Bit rate [Bit/s]	Emission	RTCM Message Type	ID code ID no	Antenna
Dziwnow	RDF DGPS	54°01' N 14°44' E	0.1	90 90	287.5 288.0	- 100	100HA1ABN 100HG1DCN	- 1,2,3,7,16	DZ 481	vertical mast
Rozewie	RDF DGPS	54°49' N 18°20' E	0.4	90 90	310.5 311.0	- 100	100HA1ABN 100HG1DCN	- 1,2,3,7,16	RO 482	horizontal 2T

Technical characteristics conform to standard adopted by ITU-R in Recommendation M.823 including data and message format based on RTCM SC 104 Version 2.0 standard. Data transmission is continuous with 100-baud rate; class of emission is G1D (digital with phase modulation). Maximum occupied bandwidth is less than 130 Hz. Transmitters coupled to omni-directional antennas share the nominal 100W output power for direction finding signal and DGPS data transmission.

Static accuracy of order of 1.5–3 m (95%) is provided by the DGPS service depending on the distance and propagation conditions. Radius of coverage of sea area for Rozewie and Dziwnow stations is practically about 120 km and 80 km, respectively.

DGPS/RTK Reference Station Local Network of Three-City Area Gdansk, Sopot, Gdynia

The project run by the Polish Committee of Scientific Research, the Gdansk Voivodship and the University of Warmia and Mazury in Olsztyn resulted in establishing the DGPS/RTK Reference Station Local Network for Gdansk, Sopot and Gdynia Metropolitan. The system is designated to support GPS surveying in the region (positioning for surveying, GIS data acquisition, cadaster modernization, etc.) as well as to land and sea navigation, in particular for augmentation of emergency and civil town services (police, fire brigades, first aid and ambulance services, transportation, etc.), real-time positioning and navigation, as well as bathymetric surveying. It consists of 3 reference stations, one in each city mentioned. Each reference station is equipped with Ashtech Z-FX dual frequency P-code GPS receiver with DGPS and RTK options. A computer, a system of radio-transmission of correction data, modems and transmission system to provide mutual connection between stations, make the complementary infrastructure of each reference station.

The Master Station monitors operation of reference stations, collects raw data from reference stations and monitors integrity. All reference stations process data and broadcast DGPS and RTK messages in RTCM 104 v.2.1 standard format as well as process users data. The link between reference stations and user receivers is held using radio link at frequency of about 450 MHz with 1 W transmission power. The system became fully operational in 2001.

DGPS Reference Station of the Institute of Geodesy and Cartography, Warsaw

Since April 1998, the Ashtech Dorne Margolin GPS antenna of BOGO station is used by a permanent DGPS station at Borowa Gora, run by the Ashtech G-12 receiver. The RTCM 104 messages with DGPS corrections are transmitted via a system consisting of a GSM cellular phone and a modem (Cisak et al., 2000a).

In October 1999 in the Institute of Geodesy and Cartography in the city centre of Warsaw there was installed another reference DGPS/RTK station equipped with the receiver Z-12 Sensor and a NAVI software; also the mobile phone system Plus GSM is used (Cisak et al., 2000b). The research on the use of RTK – GSM surveying in urban area is in progress.

DGPS Reference Station of the Space Research Centre, Warsaw

DGPS Reference Station operates at the Space Research Centre of the Polish Academy of Sciences in Warsaw. It has been established as a base station for the research project on DGPS surveying in urban areas with use of mobile GPS laboratory. The differential corrections are broadcast once a day during one-hour period. The operational range of the network depends on radio propagation conditions and reaches about 3 to 5 km away from the base station.

1.4.2. Some Applications of DGPS/RTK Techniques

Chair of Satellite Geodesy and Navigation, Olsztyn University of Warmia and Mazury

Since 1997 the University of Warmia and Mazury in Olsztyn has been engaged in experimental works on application of DGPS service for the needs of Gdansk agglomeration. Three multifunctional DGPS and RTK reference stations were established in Gdansk, Sopot and Gdynia (Oszczak et al., 1999).

Some experimental works on accuracy of real-time DGPS and RTK positioning were carried out (Bakula and Oszczak, 2000; Ciecko and Oszczak, 2000). In particular, the joint project of the University of Warmia and Mazury, Olsztyn, and the Military School of Airforce, Deblin, on testing RTK for navigating the flight of the jet aircraft equipped with GG24 receiver as well as its landing, was conducted. Aircraft trajectory determination using DGPS and RTK techniques as well as its accuracy was analysed (Ciecko et al., 2002a, 2002b; Grzegorzewski et al., 2000, 2001a, 2001b, 2001c, 2002).

Institute of Geodesy and Cartography, Warsaw

Three receivers of the Institute of Geodesy and Cartography, Warsaw, took part in the joint project of the University of Warmia and Mazury, Olsztyn and the Military School of Air force, Deblin. The project was designated to testing RTK for navigating the flight of the jet aircraft equipped with GG24 receiver as well as its landing. Two receivers located at the Geodetic-Geophysical Observatory at Borowa Gora and one on the roof of the Institute of Geodesy and Cartography at Warsaw were used as base stations for the RTK survey during five flights. The experiment lasted for 5 days. Data collected during the experiment were post-processed. The results of the experiment were published.

RTK with GSM data transfer was extensively tested at the Institute of Geodesy and Cartography, Warsaw. Test surveys with Ashtech GPS receivers were conducted in urban area as well as at the sites with no obstructions. Internal accuracy of RTK was tested as well as its dependence on the distance from the base station. The superiority of GSM data transfer in RTK over conventional radio link was indicated. The results of the experiments as well as practical recommendations were presented (Cisak et al., 2001)

Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology

Some Polish institutions have designed and established active DGPS stations that can operate upon request. The Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology installed at the Astro-Geodetic Observatory in Jozefoslaw the Trimble 4000 CORS Station with a mobile phone system for distribution of DGPS corrections in RTCM 104 format (Bogusz J., at all 2000, 2001a, 2001b). In 1999 another experimental station was established in the centre of Warsaw on the top of the main building of the University. The experience gained by Polish institutions will be used in creating Polish GNSS system operating in RTK/post processing modes for geodetic and land, air and marine navigation purposes. Such a system based on about 70 active multifunctional reference stations is now developed in Poland in the frame of international project EUPOS (European Position Determination System) (Sledzinski and Albin, 2002).

1.5. VERTICAL NETWORK

1.5.1. Re-levelling of the Vertical Control Network in Poland

In 1999-2002 the 1st order Vertical Control Network in Poland was re-surveyed (Pazus, 2002). It is the 4th precise levelling campaign in history of Poland (Table 1.6).

Table 1.6. Levelling campaigns of the 1st order precise levelling network in Poland

Epoch	Duration	Total length of lines	Comments
1st campaign 1927-1937	12 years	10 046 km	Vertical datum: „Normal Null" Amsterdam by the reference benchmark in the wall of the Town Hall in Torun
↕ 20 years			
2nd campaign 1947-1950 1952-1955	9 years	4 403 km 5 778 km	Levelling in western and north-eastern Poland as an extension of the 1st campaign within new borders of Poland
↕ 19 years			
3rd campaign 1974-1979 (UPLN) 1952-1955	9 years	10 438 km 17 015 km	rms of differences between fore and back (sections) 0.29mm/km rms of differences between fore and back (lines) 0.55mm/km rms of closing loops 0.92mm/km Lallemand formula random error 0.40mm/√km systematic error 0.10mm/km included 10 438 km of UPLN
↕ 17 years			
4th campaign 1999-2002	4 years	17 015 km	Re-levelled benchmarks of the 3rd campaign. No changes in the location of levelling lines.

The particularities of the 4th levelling campaign in Poland are given in Table 1.7 (Pazus, 2002).

Table 1.7. The 4th levelling campaign in Poland 1999-2002

	Number	**Average length**
Loops	135	221 km
Lines	371	46 km
Sections	~16 000	1.1 km
Total length of lines 17 015 km		
Levels used		
Automatic Ni002 – Zeiss (9 field teams)	Digital DiNi – Zeiss (4 field teams)	Digital NJ – Topcon (2 field teams)
Staves used on iron spikes		
3 m strip of invar (double-scaled in 0.5 cm)	Coded staves	Coded staves
Field procedure		
Double levelling (fore & back) with length of site up to 40 m Reading sequence: „back-fore-fore-back” and then „fore-back-back-fore” or „back-back-fore-fore”		

The map of the levelling lines, node points and computed misclosures including maximum acceptable misclosures in the loops is given in Fig. 1.3.

Fig. 1.3. Levelling lines and node points with computed misclosures

The results of preliminary analysis of closing errors in 135 loops of the network were presented to EUREF in 2002 (Krynski et al., 2002). Linking the network to the vertical control of neighbouring countries is in progress. First results of network adjustment are expected in July 2003.

1.5.2. Sea Level Changes

The PHASE software developed in the Space Research Centre of the Polish Academy of Sciences was used to determine geocentric positions of 9 points of the network in the south region of the Baltic Sea in two observation epochs, based on GPS measurements performed in 1993 and 1997 (the campaigns BSL'93 and BSL'97). The point positions were then used to determine ellipsoidal heights and height changes of the points, that together with other data can be a subject to geophysical analyses aiming at detailed description and interpretation of changes of the Baltic Sea level. The determined height changes should, however, be considered only as an initial information on possible tendencies of geotectonic movements in the region (known as Fennoscandian Land Uplift).

With the Baltic Sea Level Project terminated, the Department of Planetary Geodesy of the SRC PAS continues the research on sea level changes. It took part in the COST Action 40 "EOSS-European Sea-Level Observing System", where the scientific and technical foundation for the international service has been discussed and the final concept has been defined. Organisation of this service named ESEAS started in 2002 and the new GPS/Tide Gauge Station in Wladyslawowo was established (Zdunek et al., 2001).

1.5.3. Analysis of Levelling Campaigns in Poland

Poland has extensive records of precise levelling networks. Four primary levelling campaigns 1926-1937, 1947-1955, 1974-1982 and 1999-2002 were conducted. The adjustment of 4^{th} levelling campaign in Poland (1999-2002) is now in progress. Data from the first and second campaigns were available in the hard copy archive. The database for that data was established in 2002 (Lyszkowicz et al., 2002).

Three precise levelling networks of Poland were selected as the subject of study of detecting the existence of non-random effects in levelling networks (Lewandowicz et al., 2002). Line discrepancies and loop misclosures from the first, second and third levelling campaigns were tested for normal distribution, rejection of observations and the absence of systematic errors. The tests did not reveal any systematic effects. The 3^{rd} levelling campaign 1974-1982 was re-adjusted with use of new gravity data and with normal gravity referred to GRS80 ellipsoid (Gajderowicz, 1999). The results were compared with UELN and EUVN heights.

1.6. NEW GRAVITY NETWORK

New Polish gravity network was established in 1994-1998 (Sas-Uhrynowski et al., 2000). It consists of 354 gravity points with 12 absolute gravity stations (Fig. 1.4). All network points used for relative gravity measurements were monumented with the concrete pillars of size of 80×80×100 cm.

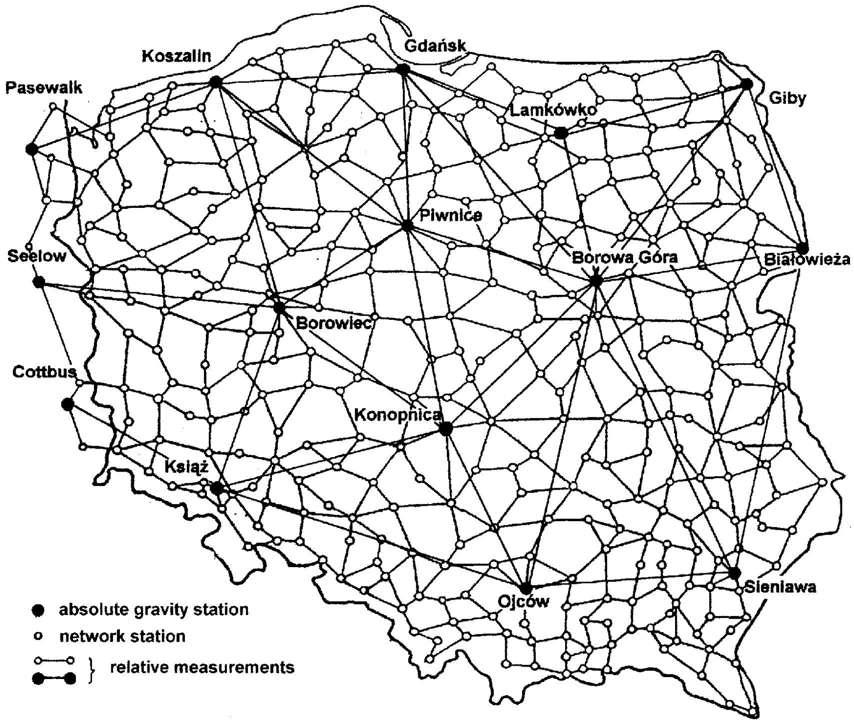

Fig. 1.4. The new Polish gravity network

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2. ADVANCED SPACE TECHNIQUES

2.1. 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 1999 to 2002. It summarises investigations such as operational activity of SLR and GPS permanent stations (Baran and Oszczak, 1999), achievements in GLONASS observations, time transfer and time comparison, data analysis and orbit determination, modelling of ionosphere and troposphere, satellite gradiometry, etc. Those activities were conducted mainly at 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 Geodesy and Photogrammetry, Agricultural University in Wroclaw;
- Department of Mining Surveying and Environmental Engineering, University of Mining and Metallurgy 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 Lubomir W. Baran, Stefan Cacon, Wladyslaw Goral, Jan Krynski, Jerzy B. Rogowski and Janusz B. Zielinski.

The bibliography of the related works is given in references.

2.2. SATELLITE LASER RANGING

The Satellite Laser Ranging station in Astro-Geodynamic Observatory of the Space Research Centre, Polish Academy of Sciences in Borowiec (ILRS 7811) tracked during 1999-2002 over 3000 successful passes of 30 satellites: LAGEOS-1 and LAGEOS-2, High Orbiting Satellites (GPS, GLONASS and ETALON), ESA satellites (ERS-1, 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.

Data acquired at Borowiec SLR station supported scientific missions with those satellites and were used for orbits calculations by ESA, NASA, Center for Space Research University of Texas (CSR), Communications Research Laboratory (CRL) in Tokyo, Mission Control Centre in Russia (MCC), Delft University of Technology (DUT), Natural Environment Research Council (NERC) in United Kingdom, Shanghai Astronomical Observatory (SAO), US Naval Observatory (USNO), GeoForschungsZenter (GFZ) and several other institutions. They were presented in daily, weekly or be-weekly reports of those organizations.

The important upgrading of the SLR system in Borowiec during the reported program was executed. It concerned, in particular, the introduction of the time interval counter STANFORD SR620 (started in May 2002) as well as introduction of the time and frequency from a new caesium frequency standard HP5071A. The significant improvement (30%) of the single shot precision from about 3 cm to 2 cm has been achieved in the end of 2002 as the result of that modernization.

2.3. GPS PERMANENT STATIONS

Eight GPS permanent stations operating in Poland are listed in Table 2.1:

Table 2.1. GPS permanent stations operating in Poland

Station	Program	Host Institution
Borowa Gora (BOGI)	EUREF, IGS	Institute of Geodesy and Cartography, Warsaw
Borowa Gora (BOGO)	EUREF	Institute of Geodesy and Cartography, Warsaw
Borowiec (BOR1)	EUREF, IGS	Space Research Centre, Pol. Acad. of Sciences
Jozefoslaw (JOZE)	EUREF, IGS	Warsaw University of Technology
Jozefoslaw (JOZ2)	EUREF	Warsaw University of Technology
Cracow (KRAW)	EUREF	University of Mining and Metallurgy in Cracow
Lamkowko (LAMA)	EUREF, IGS	University of Warmia and Mazury in Olsztyn
Wroclaw (WROC)	EUREF	Agricultural University in Wroclaw

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

The permanent station BOGI (Domes number 12207M003) at Borowa Gora Geodetic-Geophysical Observatory, 34 km north-east of Warsaw, became operational in June 2001. The station is equipped with JPS Eurocard GPS-GLONASS receiver with Ashtech Dorne Margolin choke ring antenna installed at EUREF 0217 site. The permanent station BOGI has been included into the worldwide network of stations operating in the framework of IGS/IGLOS program. It also operates as EUREF EPN station. GPS data as well as meteorological data collected is regularly transferred in daily and in hourly blocks to the Local Data Centre in Graz, Austria. BOGI is one of 11 stations of EUREF-POL network as well as a station of EUVN (European Unified Vertical Network)

2.3.2. Borowa Gora (BOGO) Permanent GPS Station

Permanent GPS Station BOGO at Borowa Gora as a site of EUREF Network of Permanent GPS Stations (Domes number 12207M002) operates since 1996. Data collection at the station is based on Ashtech Z-12 3 receiver equipped with Ashtech Dorne Margolin choke ring antenna with radome. The rubidium frequency standard is used as an external standard for GPS service. GPS data as well as meteorological data collected is regularly transferred in daily and in hourly blocks to the Local Data Centre in Graz, Austria. GPS data provided by the BOGO station together with data from other permanent GPS stations is used in international programmes such as computation of precise ephemeris in “almost real time” for GPS satellite orbits and investigations on ionosphere and troposphere. In April 2001 BOGO permanent GPS station together with the additional GPS/GLONASS Javad receiver with Ashtech Dorne Margolin choke ring antenna installed at EUREF 0217 site participated in the IGS international observational campaign „HIRAC/SolarMax Campaign” designated to the research of the ionospheric impact on satellite navigation data. During the campaign that lasted for 7 days of high rate solar activity, both GPS and GLONASS data were collected with 1 s rate. Data collected at Borowa Gora during that campaign was delivered to the JPL computing centre in California.

2.3.3. Borowiec (BOR1) GPS Permanent Station

The permanent GPS station BOR1 (Domes number 12205M002) located at the Astrogeodynamical Observatory of the SRC PAS at Borowiec, 20 km south-east of Poznan, operates continuously tracks GPS satellites in the framework of the International GPS Service (IGS) and European Reference Frame (EUREF) networks. Since 1999 the station provides data in hourly files. In May 1999 the station's antenna was upgraded that substantially improved the quality of observations. BOR1 participates in all major GPS campaigns including specific IGS campaigns like the Solar Eclipse 1999 Campaign and the High-Rate Solar Max IGS/GPS Campaign.

2.3.4. Jozefoslaw (JOZE) GPS Permanent Station

The IGS permanent GPS station Jozefoslaw (JOZE) (Domes number 12204M001) is located at the Astro-Geodetic Observatory of the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology, 14 km south of Warsaw city centre. The permanent GPS service in the framework of IGS is maintained in the observatory since August 1993. Since 1996 the Observatory has also been operating within EPN (EUREF Permanent Network). Trimble 4000SSE receiver with Trimble Geodetic L1/L2 antenna is used as the basic GPS equipment. Three rubidium frequency standards are available at the station; one of them is used as an external standard for IGS service (Bogusz et al., 1999, 2000a, 2000b, 2001a, 2001b). On January 1, 1995 the second GPS receiver, a Turbo Rogue SNR8000 with Dorne Margolin T antenna was set up at the station. Recently one more GPS receiver, i.e. TRIMBLE 4000 TRS operates permanently in Jozefoslaw. The permanent GPS IGS service is maintained by Trimble 4000SSE and Turbo Rogue SNR8000 receivers. Trimble 4000SSE serves as the main receiver and the observations collected by this receiver are transmitted to the international data centres: Local Data Centre for Central Europe at Graz, Austria, and the Regional Data Centre at Frankfurt/Main, Germany. The observations from Jozefoslaw are used for IGS service and for the maintenance of the EUREF system. The observations from the Turbo Rogue SNR receiver are available upon request. JOZE station takes part in the activities of the IGS Ionosphere Working Group.

The Jozefoslaw station is located at the distance of a few kilometres from the Warsaw airport (Warszawa-Okecie). Thus, meteorological service maintained at the station can be supported by nearby permanent meteorological service of the Warsaw airport.

The monumentation of the reference point for IGS GPS observations was made according to the IGS standards. Due to the geological conditions the pillar could not be monumented on the bedrock. Jozefoslaw station is the reference point of several international GPS networks, e.g. EUREF (European Reference Frame), EXTENDED SAGET (Satellite Geodetic Traverses), CEGRN (Central Europe GPS Reference Network realised in the frame of the project CEI CERGOP (Central European Initiative Central Europe Regional Geodynamics Project) and BSL (Baltic Sea Level Project). The eccentricity of the EUREF point with respect to that of other campaigns is X = 0.079 m, Y = 0.030 m, Z = 0.108m.

2.3.5. Jozefoslaw (JOZ2) GPS Permanent Station

The permanent station JOZ2 (Domes number 12204M002) at Jozefoslaw Astro-Geodetic Observatory became operational in January 2002. The station is equipped with Ashtech Z-18 GPS/GLONASS receiver with Ashtech Dorne Margolin choke ring antenna installed at EUREF 0306 site. The rubidium frequency standard is used as an external standard for GPS service. Permanent station JOZ2 operates as EUREF EPN station. GPS data as well

as meteorological data collected is regularly transferred in daily and in hourly blocks to the Local Data Centre in Graz, Austria. JOZ2 station participates in IGS/IGLOS programme and also takes part in the EUREF IP pilot project.
(http://www.epncb.oma.be/projects/euref_IP/euref_IP.html).

2.3.6. Cracow (KRAW) GPS Permanent Station

New Polish permanent GPS station KRAW (Domes number 12218M001) started operating in 2002. In 26 January 2003 the station was included into the EUREF Permanent Network (EPN). The permanent GPS station KRAW is located in the premises of the Faculty of Mining Surveying and Environmental Engineering, University of Mining and Metallurgy in Cracow. The station is equipped with the Ashtech μZ12 Continuous Geodetic Reference Station and Ashtech choke ring antenna with radome. Data collected at the station (formatted in hourly and daily files) is transmitted to Data Centre in BKG, Germany. The WUT, GOP, OLG and SUT Local Data Centres process GPS observations from the KRAW station, at present. KRAW station participates in the EUREF IP pilot project.
(http://www.epncb.oma.be/projects/euref_IP/euref_IP.html).

2.3.7. Lamkowko (LAMA) GPS Permanent Station

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 Z12-3 reciever with Ashtech Dorne Margolin choke ring antenna with radome installed at EUREF-0302 site. The LAMA station (Domes number 12209M001) 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. LAMA is one of 11 stations of EUREF-POL network as well as a station of EUVN (European Unified Vertical Network).

In 1998 a new GPS station LAM5 was established at Lamkowko observatory. Its antenna on the roof of Observatory building and is used as a reference station for RTK experiments. The station is equipped with rubidium frequency standard and system recording meteorological data LAB-EL Poland.

GPS data acquired in Lamkowko and in other Polish and European IGS/EUREF stations are used by the observatory team for research on geodynamics, analysis of the influence of GPS satellite orbits' quality on positioning, analysis of spatial and temporal variations of ionosphere. The research is conducted in co-operation with Polish research institutions and also with Western Department of the Institute of Geomagnetism, Ionosphere and Radio Waves Propagation, Russian Academy of Sciences, Kaliningrad, Russia.

2.3.8. Wroclaw (WROC) GPS/GLONASS Permanent Station

The permanent GPS station WROC (Domes number 12217M001) has been established in November 1996 and is operating within the EUREF network. The station was equipped with Ashtech Z12 receiver and the Dorne Margolin ASH (ASH700936D_M) antenna. In July 1999 lightning stroke damaged the GPS antenna. Since May 2000 the Ashtech Z12 receiver was replaced with Ashtech Z18 receiver with the Dorne Margolin ASH (ASH701941.1) antenna and since then the permanent GPS/GLONASS observations are conducted. GPS data as well as meteorological data collected is regularly transferred in daily and in hourly blocks to the Local Data Centre in Graz, Austria. WROC is the first station in Lower Silesia Region, located in the city of Wroclaw, on the epivaristic tectonic platform. The station is operated by the Department of Geodesy and Photogrammetry of the Agricultural University of Wroclaw. The WROC station will be one of the reference stations for the local geodynamic investigation GPS networks in south–western part of Poland (Bosy and Kontny, 2001).

The test for quantitative and qualitative analysis of data from GPS/GLONASS permanent station Wroclaw was introduced to routine data pre-processing. The test was developed on the basis of the reports of regional data centres of EUREF project. Realization of qualitative analysis depends on the influence of external conditions (meteorological and ground water level) on determined coordinates of antenna. The analyses proved high quality of observation data, and efficiency in data distribution process for WROC station (Bosy and Kujawa, 2002).

2.4. TIME TRANSFER AND COMPARISON

The development of Polish National Atomic Time Scale TA(PL) is undertaken in the Astrogeodynamical Observatory of the Space Research Centre in Borowiec. All institutions equipped with caesium frequency standards in Poland, altogether 10 laboratories, participate in the project. Links to the international time scale are maintained by GPS using TTS-2 time transfer receivers.

The Observatory started in 2000 the GLONASS P-code observations for the needs of the international precise time transfer and for geodetic purposes. The international calibration of the GLONASS P-code receivers was carried out at Borowiec in the cooperation with the BIPM. The analysis of results of the trans-Atlantic time transfer show better results then the ones obtained with GPS (Lewandowski et al., 2001; Bogdanov et al., 2002).

2.5. DATA ANALYSIS AND ORBIT DETERMINATION

2.5.1. SLR Data Analysis.

In 1999-2002 the general aim of research activities in the Space Research Centre based on SLR data was the investigation of stability of global network solutions estimated from satellite laser measurements. In particular, the study has been focused on the influence of station dependent range biases on station coordinates determined. SLR data of LAGEOS-1 and LAGEOS-2 from 60 stations of the global SLR network acquired during 3-year period of 1993-1995 was analysed. Estimated values of the range biases were compared with the solutions obtained using independent techniques (investigation of stability of mobile systems and collocation method). The results, analysed in terms of internal consistency and absolute quality, clearly indicate that the introduction of the bias estimation leads to noticeable improvement of station coordinates determination (Rutkowska, 1999; Rutkowska and Noomen, 1999; Rutkowska et al., 1999). The SLR station coordinates in ITRF2000 were determined and their stability over the period 1999-2001 was analysed. In particular the coordinates of Borowiec SLR station were determined for the period 1993.5 - 2001.5. Their stability was at the level of 17 mm over 8 years (Wnuk et al., 2002; Schillak et al., 2001).

The orbit of the new cannonball satellite WESTPAC (launched in 10 July 1998 into a circular orbit with the altitude of 835 km and inclination of 98º) was investigated. The investigation concerned the influence of the modelling of different physical effects on the motion of WESTPAC satellite, in particular in terms of orbit quality. Observations from the global network of laser stations acquired during the period from 1 August 1998 until 30 March 1999 were used. To obtain a high-quality orbit solution, all forces acting on the satellite need to be modelled as accurately as possible. The study resulted in fitting the laser range observations at the level of 3.7 cm and in orbit quality of about 5, 10 and 20 cm in radial, cross-track and along track directions, respectively (Rutkowska and Noomen, 2000, 2002).

2.5.2. Analysis of GRACE mission orbits

The orbits of GRACE Mission (Gravity Recovery And Climate Experiment) SVs were investigated at the Space Research Centre in 2002. The GRACE mission consists of two identical spacecraft flying about 220 km apart in circular polar orbits 500 km above the Earth at inclination of 89º. The evolution of orbits, the relative distances and the velocities have been studied. The short-term changes are of the period of one revolution while the long-term changes are close to the linear trend. Long-term changes of distances and velocities per week are equal to 14.420 km 17 m/s, respectively. The average changes of distance and velocity are equal to 2061 m/day and 2.43 m/s/day, respectively. The semi-major axes for GRACE-A and GRACE-B decrease at an average rate of about –29.6 m/day (Rutkowska and Zielinski, 2002). All computations were conducted using GEODYN II, SOLVE (NASA/GSFC) and 3DMOTION (DUT) software in cooperation with NASA and Delft University of Technology (DUT).

2.5.3. Activities of the EUREF WUT Local Analysis Centre

The EPN WUT Local Analysis Centre is the integral part of the Astro-Geodetic Observatory in Jozefoslaw. The main objectives of this Centre are (1) the research on the new strategy of the densification of ITRF (IERS Terrestrial Reference Frame) stations and (2) the permanent processing of a EUREF sub-network that actually consists of 36 GPS stations of EPN placed in Central and Eastern Europe (Fig. 2.1) (Bogusz et al., 2002). Work on data processing strategy in the networks of permanent GPS stations are conducted since 1995 at Warsaw University of Technology in close cooperation with the CODE Centre of the Institute of Astronomy, University of Bern. The strategy is used since 1996 to process the EPN data at Local Analysis Centres (LAC) of EUREF. Recently 15 LAC operates in Europe.

Besides this routine work the Centre performs the post-processing of the epoch periodic campaigns. One of them are the Central European Regional Network (CEGRN) realised under the umbrella of CEI (Central European Initiative) in the frame of Central European Regional Geodynamics Project (CERGOP) (Becker et al., 2002) and Project EXTENDED SAGET initiated and coordinated by the Institute of Geodesy and Geodetic Astronomy WUT. The Centre is one of 5 Centres participated in CERGOP project and associated in CEGRN Consortium (Bogusz et al., 1999b, 2000a, 2000b, 2001b; Figurski and Liwosz, 2000). WUT EUREF LAC processed the data collected at CERGOP network (Fig. 2.2) within consecutive observational campaigns in 1994, 1995, 1996, 1997, 1999 and 2001 and participated in analysis of the results. Data from CERGOP and CERGOP2 campaigns were reprocessed in 2002 according to recent EPN standards. The results obtained were combined with those of all CERGOP Data Processing Centres (Becker et al., 2002)

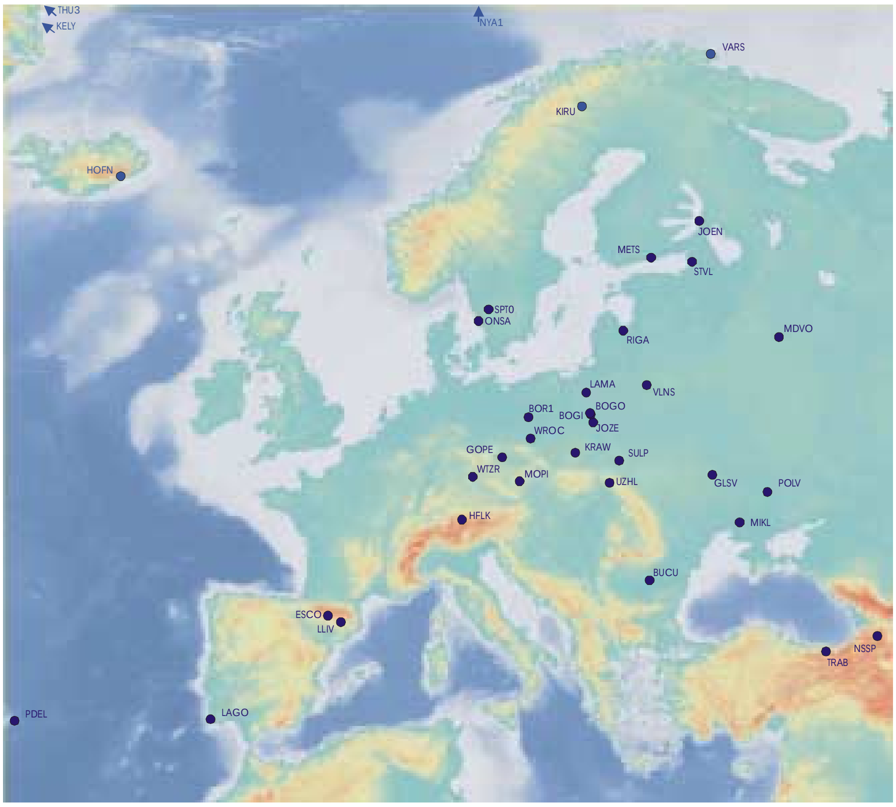

Fig. 2.1. Network of EPN stations providing data for processing at WUT EUREF LAC

Fig. 2.2. CERGOP-2 2001 network

2.5.4. 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 Geodetic Geophysical Observatory at Borowa Gora was conducted at the Institute of Geodesy and Cartography, Warsaw. 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 (Krynski et al., 2002b; Krynski and Zanimonskiy, 2002). 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. Variations in the obtained results showed a remarkable regularity. Spectral analysis indicated two significant periods: a stronger one of 12 h and a weaker one of 24 h (Cisak et al., 1999; Krynski and Cisak, 2000). Regularity of the obtained time variations was investigated (Krynski and Zanimonskiy, 2001a; 2001b). Variations in GPS solutions have a complex structure. They can be represented in terms of biases as well as components generated by both random and chaotic processes. Short-term variations, i.e. diurnal and sub-diurnal are of particular importance for quick and efficient precise positioning. Regular terms with distinguished periodicity dominate in those variations (Krynski and Zanimonskiy, 2001b). Variations in GPS solutions are caused by numerous factors (Zanimonskaya et al., 2000). Modelling the biases is required to get better accuracy of positioning with the use of shorter observing sessions. Separation of periodic biases onto three groups depending on ground segment (receiver, antenna and software), space segment (orbits and satellites configuration) and environmental segment (troposphere and ionosphere models) and eventual real displacements of the sites, is needed to work on modelling the biases. Some of the biases detected seem to be artefacts (Krynski et al., 2002b). In addition, due to a non-linearity of the system, data noise generates biases in computed results (Krynski and Zanimonskiy, 2002).

The use of GPS solutions obtained from overlapped sessions enables efficiently detect chaotic effects and separate them from biases. Variations in GPS solutions were analysed in terms of GPS observations modelling errors, variability of satellite configuration and weaknesses of algorithms used in GPS data processing. Feasibility study on modelling short-term variations in the time series of GPS solutions were the objectives of the research. Meteorological, troposphere (TZD) and ionosphere (TEC) data, together with gravity data, are substantial for separating effects that cause variations and developing empirical models (Krynski et al., 2002c). Correlation of diurnal and sub-diurnal periodic variations of GPS derived vector components with variations of residual gravity, variations of meteorological parameters as well as variations of ionosphere and troposphere state, was used to derive their empirical models (Krynski and Zanimonskiy, 2001c). Numerous recommendations on improvement of GPS data processing with use of commercial software as well as more efficient precise GPS positioning were given (Krynski and Zanimonskiy, 2002).

Requirements for temporal resolution of time series of GPS solutions used for detection and separation periodic biases have been elaborated and the optimal strategy has been developed. An increase of temporal resolution of GPS solution series by shortening sessions computed and/or by processing overlapped sessions is an effective tool for detecting biases and reducing chaotic effects in the solutions. The strategy developed could be applied for

- more realistic accuracy estimation of GPS solutions,
- reliability estimation of GPS solutions,
- improvement of mathematical model for GPS observations,
- creating empirical models for improving GPS solutions,
- GPS mission planning,

- setting up the strategy of GPS data processing.

2.6. TROPOSPHERE AND IONOSPHERE STUDIES

Correlation of diurnal and sub-diurnal periodic variations of GPS derived vector components with variations of meteorological parameters as well as variations of ionosphere and troposphere state, was used to derive their empirical models (Krynski and Zanimonskiy, 2001c). The atmospheric impact on GPS solutions was investigated for both middle and high latitudes (Krankowski et al., 2001; Cisak et al., 2002). In particular a response of polar ionosphere to a magnetic storm from GPS data was investigated (Baran et al., 2002b).

Investigation of ionosphere using GPS technique have been carried out in 1999-2002 by the Institute of Geodesy of the University Warmia and Mazury in Olsztyn jointly with the West Department of the Institute of Geomagnetism, Ionosphere and Radio Waves Propagation (IZMIRAN) of the Russian Academy of Sciences in Kaliningrad.

The GPS observations acquired at the IGS stations were used to study TEC (Total Electron Content) changes in global scale during November 1997 storm. Spatial and temporal TEC changes were analysed through time series at selected sites and maps for different sectors of northern hemisphere, in comparison with the quiet periods of TEC variations. The positive effect in the behaviour of TEC during the storm was prevailed in global scale at middle latitudes. The strong negative effect was observed at auroral and subauroral latitudes only over America (Baran at al., 2001a).

The GPS measurements carried out by European IGS and EPN stations were used for the analysis of spatial correlation of ionosphere during the same intensive magnetic November 1997 storm. Correlation was estimated by comparison of the absolute TEC to the ionospheric Doppler shift variations for individual satellite passes at different stations. The maximum distance between stations amounted up to 1500 km while the minimum distance was about 20 km. It was shown that the spatial correlation of the TEC variations is lower during the storm. It essentially depends on the presence of the travelling ionosphere disturbances. The coherent length was determined with the horizontal scale of the TIDs. The large-scale TIDs prevailed during the storm (Baran et al., 2001b).

TEC data, obtained from over 60 GPS stations, were used to study the ionospheric effects of September 1999 magnetic storm over Europe. The spatial and temporal changes of the ionosphere were analysed as a time series of TEC maps presenting 15-minute averages of TEC. The data set consisting of GPS observations, collected by a dense network of European stations with sampling rate of 30 seconds, enable to release TEC maps with high spatial and temporal resolution. It was found out that the large- and medium–scale irregularities have developed in high-latitude ionosphere during the storm. The multi-stations technique, employed to create TEC maps, was particularly successful when studying the mid-latitude ionospheric trough (Shagimuratov et al., 2002). During the most disturbed period the ionospheric trough moved down to latitude of about 50°N (Fig. 2.3). Under those conditions the horizontal gradients in the ionosphere essentially increased. The horizontal gradients may have an impact on ambiguity resolution when processing GPS data. Registered medium-scale structures decreased the spatial correlation of the ionosphere (Baran et al., 2002a, 2002b).

The ionospheric storms have considerable influence on the accuracy estimation of vectors coordinates. The results show the exact dependence between TEC changes and repeatability of the North, East and Up vector components (Baran et al., 2001c; Krankowski et al., 2002).

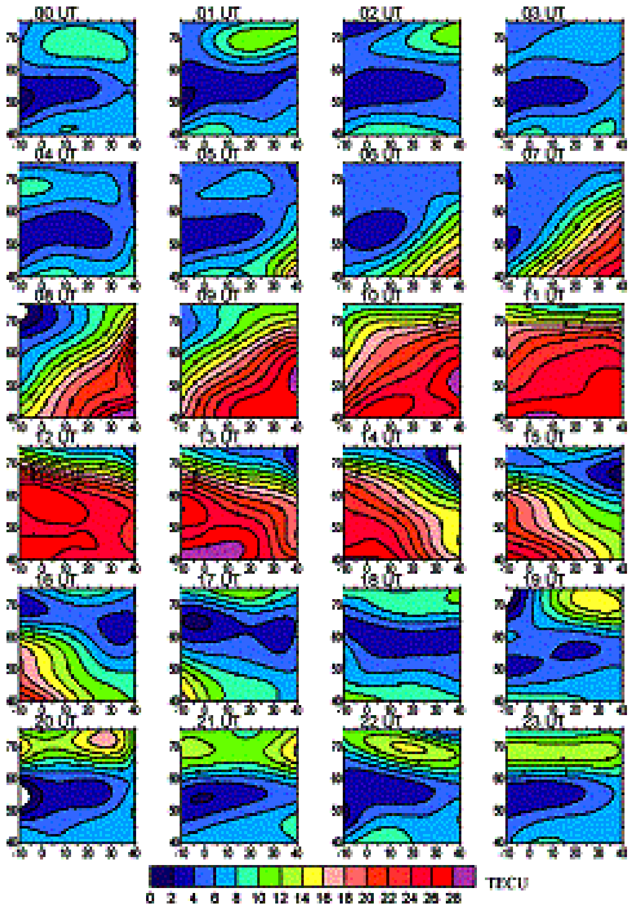

Fig. 2.3. TEC maps for December 1999 demonstrating the development of the trough over Europe

The GPS observations from EUREF permanent GPS network were used to detect the response of TEC to the total solar eclipse (11 August 1999) under quiet geomagnetic conditions of the daytime ionosphere. The effects of eclipses were detected in diurnal course. They were more distinct in the variations of TEC along individual satellite passes. The effect of the eclipse was also detected at distances over 1500 km to the north from the path of the eclipse (Baran et al. 2002c). The influence of the ionospheric refraction on positioning precision was also investigated (Figurski et al., 2000).

Data based on the IRI model was compared with TEC estimated using the continuous GPS observations of European Part of IGS network. The variability of a measured TEC was analysed for the period 1996-1997 that corresponds to low solar activity period. It was shown that the difference between the model and the measured TEC depends on latitude and season (Ephishov et al., 2000). Global TEC maps show that GPS derived ionosphere models, contrary to the IRI, make possible investigating ionospheric response to the solar activity in the global and regional scales. The IRI provides monthly-predicted averages, so it cannot respond to the real, daily solar activity. The results of comparison show a dynamic problem at high latitudes in the IRI model (Figurski and Wielgosz, 2002).

Procedure of local meteorological conditions modelling (interpolation) in a GPS network using meteorological observations acquired simultaneously with GPS measurements at selected network points was elaborated. Analyses for assessment of meteorological data influence on the process of tropospheric delay modelling were performed. SNIEZNIK network was chosen as the test network. GPS and meteorological observations from 2001 measurement campaign were analysed (Borkowski et al., 2002).

Study of reduction of errors due to ionospheric refraction using GPS data from local satellite networks was conducted. The problem is particularly essential during high solar activity. A local model of ionosphere developed from the regional model augmented with data from a local network has been tested at three levels. The criteria included comparison with a global model, the success rate of ambiguity determination using the quasi–ionosphere free and wide-lane/narrow-lane strategies, and analysis of residuals in the position domain. The results show that the local model increases the success rate for ambiguity determination for the wide-lane/narrow-lane strategy and, moreover it is sooner available than the global models.

Application of ionosphere models to processing GPS data on one carrier frequency only (Figurski et al., 2000) improves the results but in some cases leads to overestimated lengths of the vectors. 24 hours L1 data can be used in geodetic practice on baselines up to 40 km when using ionosphere information.

WUT EUREF LAC as one of 17 local analysis centres provides parameters for ionosphere model (Figurski et al., 2002). It also conducts works on determination of water vapour content in troposphere (Kruczyk and Rogowski, 2002). The results of the determination of water vapour were compared with radio-sounding results and Unified Model for Poland (UMPL) and gave significant correlation (Kruczyk, 2000; Kruczyk et al., 2001a, 2002).

2.7. SATELLITE GRADIOMETRY

Starting from 2001 the Space Research Centre is involved in the preparation of the GOCE mission devoted to the improvement of the geopotential model. The theoretical studies aim to the regional solution of the satellite gradiometry problem and to the calibration problem (Zielinski et al., 2001). A new calibration/validation experiment for GOCE mission is proposed. Simultaneously with the satellite mission another gradiometer will be flown on the board of the stratospheric balloon on the altitude of 20-40 km (Zielinski and Petrovskaya, 2002). The measurements from the balloon can be compared with satellite data. The advantage of the method is that the same functionals, i.e. gravity gradients are compared. The post-mission external calibration/validation is more direct than through the comparison with the ground truth gravity anomalies or geoid undulations. Analytical procedure of the downward continuation is applied. It allows for comparison of the observables what has been illustrated by numerical examples. Similar approach is applied to the comparison of data from GOCE and GRACE missions. The new method of the upward continuation of the point gravity values has been proposed. It is based on the use of the approximate reference model (Upward Continuation with the Reference Model - UCRM) (Petrovskaya et al., 2002). Numerical tests are performed using data simulated by the IAG Special Study Group "Gravity Field Missions".

2.8. GPS POSITIONING OF THE MOVING OBJECTS

In the Space Research Centre the methods and algorithms have been developed for the testing of the Integrated Satellite Navigation Systems (ISNS) comprising the high accuracy satellite sensor(s) (the DGPS code observable, and the phase observable) and the low quality non-satellite sensors such as Low-Cost IMU MotionPak-I, MotionPak-II, single axis very low quality accelerometer, single axis gyro of very low quality (quartz) and of medium quality, electronic compasses of various makes. The works were conducted in cooperation with the GPS Centre Nanyang Technological University, Singapore, and the Institute of Flight Guidance and Control, Technical University, Braunschweig, Germany.

2.9. OTHER GPS APPLICATIONS

At the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology the works on different applications of satellite DGPS and RTK positioning systems are carried out. They concern the monitoring of water reservoirs and determination of trajectory of the moving objects especially to the ship models. The results of tests conducted in Ilawa test area of the Foundation for Safety of Navigation and Environmental Protection showed the possibility of its successful implementation. Another works concerned determination of ship manoeuvre parameters and ship orientation by means of set of different GPS receivers. The study focuses on the possibilities of adoption of fix measurements taken by sets of DGPS or RTK receivers installed on the same ship to determine her heading and attitude. The main goal of the research is to make some reference system for investigation of different ships' sensors like compasses or for identification of the dynamic ship characteristics (Bogusz et al., 1999c, 1999d, 1999e). Some other works concerned application of GPS to navigation.

Different applications of GPS positioning were tested at the Chair of Satellite Geodesy and Navigation, the University of Warmia and Mazury in Olsztyn. They concerned the use of GPS positioning methods for the calibration of satellite images (Bakula and Oszczak, 2001), the use of RTK for modernization of geodetic control (Baryla and Oszczak, 2002), the use of GPS technique for modernization of land registration (Ciecko et al., 2000), the use of DGPS/DGLONASS positioning in maritime navigation (Oszczak et al., 2002a), the use of techniques of satellite positioning for land navigation (Oszczak et al., 2000b), the integration of satellite positioning with digital terrain model (Walawski et al., 2001). An extensive research was carried out on the use of GPS in bathymetric surveying (Oszczak and Popielarczyk, 2000; Popielarczyk and Oszczak, 2000, 2001, 2002a, 2002b).

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, 2001; Sekowski, 2000).

2.10. Research on EGNOS System

Research on the EGNOS system was conducted at the Chair of Satellite Geodesy and Navigation, the University of Warmia and Mazury in Olsztyn (Oszczak and Grzegorzewski, 2000). First results of satellite positioning with EGNOS system test BED (ESTB) signal in Poland were analysed (Cydejko and Oszczak, 2001). The EGNOS system Test Bed Performance in Poland was tested (Cydejko and Oszczak, 2002).

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3. GRAVITY FIELD MODELLING AND GRAVIMETRY

3.1. INTRODUCTION

This part of the Polish National Report on Geodesy is the quadrennial report of gravimetric works performed in Poland in a period from 1999 to 2002. It summarises investigations such as national gravity surveys, absolute and relative gravity measurements, non-tidal gravity changes monitoring, data handling and mapping, theoretical research on gravity field and modelling geoid and quasi-geoid for Poland, etc. Those activities were conducted mainly at 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, University of Mining and Metallurgy 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, Jozef Beluch, Jan Krynski, Adam Lyszkowicz and Andrzej Sas-Uhrynowski.

The bibliography of the related works is given in references.

3.2. ABSOLUTE GRAVITY DETERMINATION

Study on portable ballistic gravimeter TBG was further advanced at the Institute of Geodesy and Cartography, Warsaw. Methods of estimation of calibration accuracy of the TBG were discussed (Zanimonskiy et al., 1999). The series of experiments conducted with low-cost TBG-95 portable gravimeter was used to the determination of optimal strategy of measurements that leads to gravity determination at the accuracy level of 10 μGal. It concerns a maximum internal auto-control together with a necessary external control. In particular, it has been demonstrated that the auto-seismic effect in rise-and-fall gravimeters can be reduced to the level of that in free-fall gravimeters by improving instrument's rigidity and implementing randomisation of disturbances (Zanimonskiy et al., 2000). The pressure level of 10^{-6} Torr in the ballistic chamber is usually considered as a basic requirement in the precise absolute gravimeters. The problem with the higher-pressure level in the ballistic chamber was investigated. It was shown that gravity can be determined with rise-and-fall instrument with 10 μGal accuracy by taking the measurements at different levels of residual pressure, e.g. between 0.1 Torr and 0.01 Torr, and at different parts of trajectory of rising and falling test-body. Thus the increase of residual pressure by 4 orders of magnitude may result in degrading gravity determination by one order of magnitude only. Some components of the strategy developed when experimenting with portable ballistic gravimeter are usable in improving absolute gravity survey of higher level of accuracy (Zanimonskiy et al., 2002).

The absolute rise and fall ZZG gravimeter, constructed at the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology, was used in 1999-2002 for absolute gravity survey at some stations of the Polish national gravimetric network.

It was also used as one of the absolute gravimeters in the international campaigns (Poland, Slovakia, Czech Republic, Hungary, Germany) (Zabek et al., 2002) as well as in the project on the establishment of the Polish-Slovak latitudinal gravimetric baseline Warsaw-Niedzica-Poprad-Modra Piesky (Bratislava). Periodic gravity variations at the Jozefoslaw Astro-Geodetic Observatory were investigated with use of repeated gravity measurements with ZZG gravimeter (Pachuta et al., 2001; Robertson et al., 2001).

ZZG gravimeter took part in gravity measurements conducted in the framework of EU/CEI project UNIGRACE (Unification of Gravity Systems in Central and Eastern Europe) (Sledzinski et al., 1999; Reinhart et al., 1999). The project was launched in 1997 as multipurpose interdisciplinary project and concluded in 2002. It consisted in establishing the absolute gravity stations covering the area from the Baltic Sea to Adriatic and the Black Sea and forming the frame for connection of all national gravimetric networks and providing the unified precise gravity frame in Central and Eastern Europe joined with the network of the Western Europe. The main aim of the Project UNIGRACE is to provide a reference gravity frame indispensable for unification of gravity systems existing in Central and Eastern European countries and for the definition of a unique height system. It contributes considerably to the determination of the geoid in Europe and for sea level variation studies. Ten absolute gravity intra-plate and seven tide gauge stations were measured in 12 countries: Austria, Bulgaria, Croatia, Czech Republic, Finland, Germany, Hungary, Italy, Poland, Romania, Slovakia, Slovenia. The gravity surveys were made by five absolute gravimeters from Austria, Finland, France, Germany and Poland (Zabek and Pachuta, 2000a; Robertson et al., 2001). Two observation campaigns of the UNIGRACE project have been successfully conducted in 1998/1999 and 2000/2001.
The project was realised under the umbrella of the Central European Initiative CEI WG Science and Technology Section C "Geodesy" and was financially supported by the European Commission from the INCO COPERNICUS Programme. The analyses of the precise gravity data of UNIGRACE campaigns indicate that there are considerable changes of the gravity at some absolute gravity stations. Those changes cannot be interpreted in terms of station displacements ground water level variations or atmospheric effects. Further investigation of the gravity time changes will be carried out.

3.3. NATIONAL SURVEYS OF GRAVITY

The new gravity control network for Poland was established in 1993-1998 (Sas-Uhrynowski et al., 1999a; Sas, 1999; Siporski, 1999; Sas-Uhrynowski et al., 2000). It contains 12 absolute gravity stations, at which 21 absolute gravity measurements, using 5 various ballistic gravimeters: FG5 No.101, FG5 No.107, JILAg-5, ZZG and IMGC, have been performed (Sas-Uhrynowski and Cisak, 2001). The first four gravimeters were applied for absolute gravity measurements in 1994-1998 at the station Borowa Gora. Borowa Gora station was accepted as the fundamental station of the network. Several results obtained have varied from the others even up to 30 μGal. Therefore the verification of the absolute measurements results was necessary. The verification was carried out by comparison of gravity differences (Δg) between the pairs of stations, obtained from absolute and relative measurements. Relative measurements were conducted between the absolute gravity stations by means of long-link method (150-350 km), using 4 LaCoste&Romberg gravimeters. The results of relative gravity measurements on 25 long spans have been used for the verification. The location spans against the gravity network is shown in Fig. 3.1.

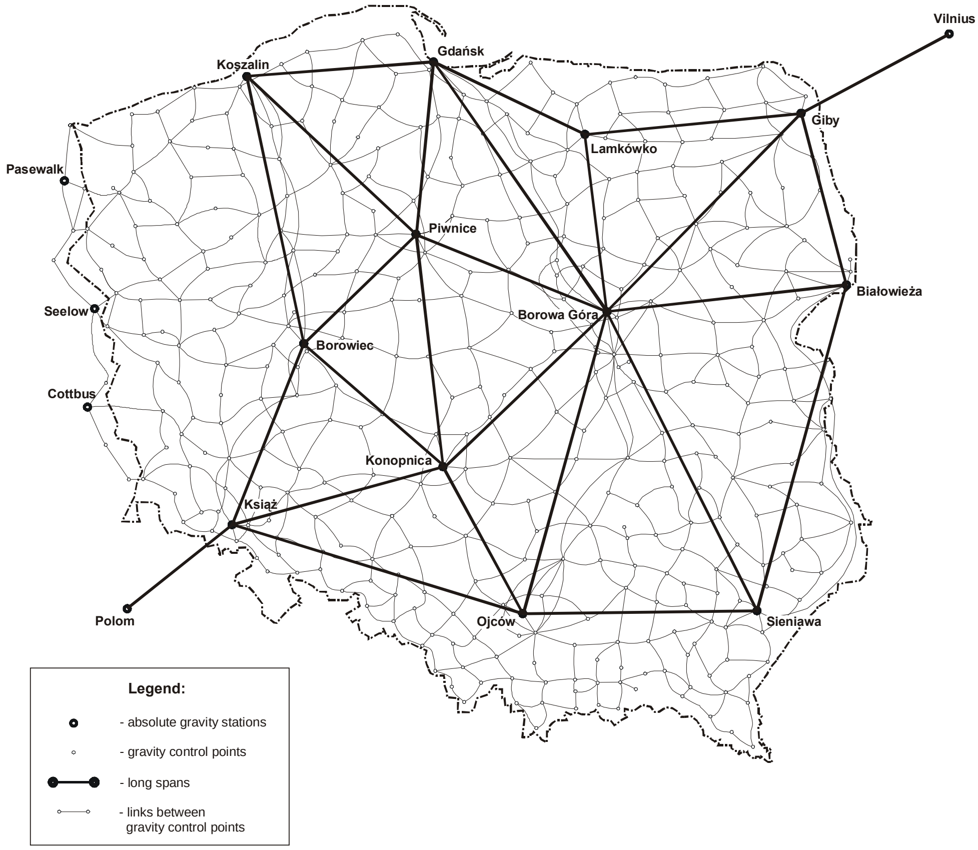

Fig. 3.1. Polish national gravity control network '99

The measurements at long spans have been conducted using simultaneously three LCR gravimeters. Each span was measured according to the A-B-A scheme, in three subsequent days. Twelve values of gravity, determined at 10 stations have been verified positively. They were obtained with JILAg-5 and both FG5 gravimeters. Both gravity and gravity differences were then adjusted. The rms errors of adjusted gravity did not exceed 4 μGal. The adjusted gravity values have been accepted as the national gravity standard of the zero order (Siporski et al., 2000; Sas-Uhrynowski, 2002). Then, the gravity differences at 685 links in a new gravity network have been adjusted, providing gravity values for 354 network stations. Gravity at those stations define a national gravity standard for practical use (Krynski et al., 2002). After adjustment, the rms of gravity at 97 % points does not exceed 10μGal. Mäkinen repeated the absolute gravity measurements at the station Borowa Gora in 2000, using the JILAg-5 gravimeter. The result obtained differs from the one of 1995 by 3μGal.

Each of 348 stations of POLREF network (a densification of EUREF-POL network that provides the ETRF reference for geodetic and surveying and mapping applications in Poland) as well as each of 554 stations of the military geodetic control WSSG was tied with two stations of the gravity control network using three LCR gravimeters. The measurements have been carried out twice, according to A-B B-A scheme. Gravity for each geodetic control point was individually adjusted. The similar gravity measurements and adjustments have been conducted to tie 33 stations of the Polish Geodynamic Network to the national gravity control.

The Institute of Geodesy and Cartography participated in 1998-2000 in establishing the Lithuanian Gravity Control Network. The Lithuanian gravity network has been tied with the

Polish one. The Polish team has measured gravity using four LCR gravimeters following the strategy applied in surveying Polish gravity control (Sas-Uhrynowski et al., 2002a).

The Institute of Geodesy and Cartography continued the co-operation with the Ukrainian Institute of Metrology in absolute gravity measurements, gravimetric metrology (Zanimonskiy et al., 1999a; Zanimonskiy et al., 1999b; Sas-Uhrynowski and Zanimonskiy, 1999a; 1999b), and terrain ballistic gravimeter (TBG) construction (Sas-Uhrynowski et al., 2001b).

The geodynamic profile about 230 km long, was established across the T-T zone in the South-East of Poland. The gravity and magnetic measurements have been carried out at six stations of the profile in three subsequent years. The results and the preliminary interpretation have been published (Krolikowski and Sas-Uhrynowski, 1999).

Within the framework of the geodynamic investigation projects, the regular gravity measurements on sub-monthly intervals at Borowa Gora Geophysical Observatory have been conducted (Zanimonskiy et al., 2000).

The original technology of calibration of static gravimeters by tilting method developed at the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology was applied for calibration of precise gravimeters for Polish enterprises that deal with geophysical prospecting (Pachuta et al., 2001; Sledzinski et al., 2001).

3.4. INVESTIGATIONS OF THE NON-TIDAL GRAVITY CHANGES

Periodic gravity surveys are carried out four times a year on the meridian baselines of the observatory of Jozefoslaw to investigate the time variations of the vertical (Barlik, 2000b). Data is interpreted with astronomical latitude and hydrological observations (Pachuta and Barlik, 2000). Gravimetric measurements on geodynamical traverses and networks are performed in the framework of different research projects, e.g. PIENINY, SUDETES (Barlik and Cacon, 2000; Barlik, 2000d), and GRYBOW (Barlik, 2000a) using LCR, SCINTREX CG-3M and Worden – Master gravimeters.

3.5. GEOID AND STUDY ON THE GRAVITY FIELD IN POLAND

Since 1993, Polish GPS users have available the models of quasigeoid for determination normal heights. The availability of additional gravity data to the Department of Planetary Geodesy made possible the to compute a new quasigeoid model for Poland named Quasi97b. The comparison of that model with GPS/levelling geoid heights has shown discrepancies in long to medium wavelengths. Therefore the empirical corrector surface was developed that relates the Quasi97 model to the reference system of GPS and levelling heights (Lyszkowicz, 2000). The advantage of such quasigeoid model is that it will support direct conversion between the ellipsoidal reference system and normal vertical datum, even if their reference are not consistent.

The gravimetric geoid recently computed in Department of Planetary Geodesy includes a number of short wavelength components. They are as expressed as high gradient bands or broad gradient zones on the map of geoid. The analysis showed that these bands and zones coincide more or less with seismically detected faults or fracture zones that dissect consolidated basement of Poland.

Gravity data in Poland was investigated using spectral analysis with the view of refining geoid estimation methods. The analysis was based on estimates of empirical covariance function and degree variances derived from local gravity observations. Models for the variance of geoid undulations are derived for test areas. Finally the resolution of gravity data required for a centimetre to decimetre accuracy level of geoid is estimated separately for marine, flat and mountainous areas (Lyszkowicz, 2002).

The project on the cm geoid in Poland, granted in 2002 to the Institute of Geodesy and Cartography, Warsaw, by Polish State Committee for Scientific Research, came into operational stage. Several research groups are involved in the project, namely Chair of Engineering Surveying, University of Warmia and Mazury in Olsztyn; Chair of Photogrammetry and Cartography, University of Warmia and Mazury in Olsztyn; Chair of Satellite Geodesy and Navigation, University of Warmia and Mazury in Olsztyn; Institute of Geodesy, University of Warmia and Mazury in Olsztyn; Institute of Geodesy and Cartography, Warsaw; Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology; State Institute of Geology, Warsaw.

In the first step of the project a qualitative and quantitative analysis of all available data, i.e. gravity data (terrestrial, sea-borne and air-borne), deflections of the vertical, GPS/levelling, altimetry, tide gauge, topographic data (DTM), crust density. Some supplementary control surveys will be conducted. The independent geoid models, i.e. gravimetric, astro-geodetic, GPS/levelling, using the uniformed data will be computed and their internal accuracy will be estimated. Finally a geoid model based on a combination of gravimetric, astro-geodetic, GPS/levelling data will be derived (Krynski, 2001). The project is in progress. Its completion is expected by the end of 2005.

Sensitivity and stability of recent gravimeters allow for detecting gravity variations with periods from a few hours to a few weeks. The method of spectral analysis with synchronous detecting using tidal model as a basic signal was developed for determining regular gravity variations of amplitudes up to the level of a few microgals that are correlated with tidal variations and station-dependent (Krynski and Zanimonskiy, 2000).

3.6. GRAVITY IN APPLIED SURVEYING

The concept of combining two surveying techniques for detecting mining extraction effects was elaborated in the Department of Mining Surveying and Environmental Engineering, University of Mining and Metallurgy in Cracow (Szczerbowski, 2001). It suggests the essential relationship between gravity anomalies and subsidence. The presented model is based on presumed correlation between the excavation geometry and the geometry of dilatancy of deformed space in rock massif. The geometric parameters describing size and location of excavation are in fact common factors for considered functions. The model of density changes was presumed. The purpose of the approach presented is to create a model of deformation based on gravimetric and positioning methods. Combination of a group of scientific methods is useful for

- getting more valuable parameters of excavation as a result of so called back analysis in the case abandoned extraction or uncontrolled solution mining,
- expansion of old anthropogenic or natural (resulted from suffosion or karst processes) excavations,
- monitoring of the stability of areas influenced by mining excavations,
- better prediction of surface damage.

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4. GENERAL THEORY AND METHODOLOGY

4.1. INTRODUCTION

This part of the Polish National Report on Geodesy is the quadrennial report of works on theory, evaluation and methodology performed in Poland in a period from 1999 to 2002. It summarises investigations such as deformation analysis, least squares theory and evaluation, research on GPS, research in metrology, etc. Those activities were conducted mainly at 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 Geodesy and Photogrammetry, Agricultural University in Wroclaw;
- Department of Mining Surveying and Environmental Engineering, University of Mining and Metallurgy 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, Jozef Beluch, Stefan Cacon, Jan Krynski, Wojciech Pachelski, Zbigniew Wisniewski.

The bibliography of the related works is given in references.

Feasibility study on future targets and goals of geodesy as a discipline was conducted. In particular, the future activities in geodesy in 21st century at the Institute of Geodesy and Cartography, Warsaw were determined (Krynski and Sas-Uhrynowski, 2000).

Review of the first results of the CHAMP mission in terms of gravity field modelling, magnetic field modelling as well as ionosphere and troposphere investigations was conducted (Krynski, 2002).

4.2. DEFORMATION ANALYSIS

The definition of a geodetic reference frame by modern techniques (GPS) requires a determination of the systematic temporal changes of the defining stations' positions. Local and regional geodynamic studies need evaluation of inner (intraplate) velocities, reference points' velocities first of all. Relative velocities between selected EPN stations can be evaluated using different approaches (time series analysis, ITRF2000 velocities, NUVEL1A–NNR velocities APKIM velocities). The method of the mean trend congruency analysis of EPN stations coordinates time series (from weekly EUREF solutions) was proposed. The results of time series analysis of EPN stations, located no more then 700 km from local geodynamic network (LGN) in Sudety Mts. and Sudety Foreland (Central Europe), performed for the selection of the best reference stations are presented (Borkowski et al., 2001). Presented analysis has been limited only to the horizontal coordinates and velocities. The work was performed in the framework of Special Project of EUREF Permanent Network (http://www.epncb.oma.be/projects/sp_timeseries.html; Kenyeres et al., 2001).

The deformation analysis of upper lithosphere layer is of cognitive and practical significance. It is especially important for large urban and industry agglomeration areas and engineering object locations. An example of such analysis is the estimation of ground changes in Wroclaw on the basis of levelling conducted in 1968 and in 1998 (Cacon and Grzempowski, 2002). Reliability of geodetic deformation measurements was discussed by Cacon (2001).

Deformation measurements in the areas subdued to mining exploitation are substantial for the protection of the surface objects in such areas. Finding fixed reference points and estimating a realistic uncertainty of surveying are the major problems in deformation determination. Owing to the global satellite technology and the use of precise EDMs it becomes possible to achieve a sub-centimetre level of accuracy in the determination of the horizontal position and height of surveyed points. The results of survey and experiments concerning the measurement of deformation in the mining area of the salt mine in Wieliczka nearby Cracow (Krakow) were presented (Maciaszek and Szewczyk, 1999). They prove a usefulness of the combination of satellite and total station data to determine the post-exploitation deformations of the area.

Deviation decompositions between survey results concerning certain boundary processes in relation to the analytical description resulting from differential equations for regular and distributional solutions were investigated (Piwowarski and Bobula, 1999). Descriptive parameters of the discussed processes were analysed as certain statistical parameters estimated on the basis of survey results. Obtained solutions were verified for the purpose of an asymptotic post-mining dislocation process.

The problem of determination of one- and multi-stage prediction of post-mining surface dislocations was investigated (Piwowarski, 2000). The finite and chronologically ordered vector of surveyed data describes a variable herein. Completed surveys show that the analysed process can be presented as a composition of both deterministic process and a singular one. Hence the quantitative description of the kinetics of the process of forming dislocation has been assigned to the class of the stochastic model. The optimisation of one-stage prediction with use of the Durbin-Levinson algorithm has been carried out for a defined model of certain mining-geological conditions and surveying results. The obtained analytical representation and optimal prediction of the kinetics of vertical dislocations corresponded well to the surveying results that can be testified by adequate measures of the quality of description of the process.

The generalized kinematical model estimation parameters that can be the basis of engineering structures displacements and deformations description were investigated (Preweda, 2002). The possibility of implementation of the conditions that can guarantee deformations continuity, ability to transformation into dynamic model or simplification into commonly know models is a particular feature of the model. Parameters of the general linear model have been estimated by the least squares method, including Gauss-Markov conditions for a quadratic form described with Lagrange’s function. Necessary conditions for minimum of Lagrange’s function lead to the system of equations that has been solved and presented by means of block matrix generalized vertex.

4.3.LEAST SQUARES – THEORY AND EVALUATION

Some aspects of accuracy estimation of control networks in a form of polygonal traverses have been presented (Beluch, 1999a, 1999b). It concerns the densification of the control network using so called “free station” method. The formulae for mean square errors of some functions of observations were developed. They can efficiently be used in planning observations considering the required accuracy in the projects.

Different correlation coefficients were analysed in terms of their application as well as their analytic and geometric interpretation (Czaja and Preweda, 2000).

Pearson correlation coefficient is always used for quantitative random variables since it is related with random variable distribution parameters and it has a straight geometric interpretation. The coefficient is determined by significance level for values predicted from linear regression model. Pearson correlation coefficients also define correlation matrix elements for a multidimensional random variable that is the basis of all statistic analyses of such variables.

A method for determination of the most effective, unbiased and invariant variance coefficient $\boldsymbol{\sigma}_0^2$ (in the model $\boldsymbol{\Sigma} = \boldsymbol{\sigma}_0^2\mathbf{Q}$ covariance matrix of observation results) in the class of quadratic estimators is given (Wisniewski, 1999a). The method follows from minimization of a function that determines the variance of the estimator as well as from application of vector transformations proposed in the paper (Wisniewski, 2002a). Basic relations between vectors derived from matrix elements are given in that paper. The transformations are carried out with matrices of transformation. The latter are defined taking advantage of developing operators. The task of those operators is to perform a unique transformation of a set of matrices into a block matrix. The vectors described, their transformations and the developing operators can provide a suitable tool for simplifying numerical operations as well as performing some theoretical analyses.

Robust method of estimation of variance coefficient $\boldsymbol{\sigma}_0^2$ has been developed (Wisniewski, 1999b). The concept of the method consists in searching for matrix $\boldsymbol{\Omega}_R$ that minimises variance of the quadratic form $\boldsymbol{\varepsilon}^T(\mathbf{R}^* \boldsymbol{\Omega}_R)\boldsymbol{\varepsilon}$ with $\mathbf{R} = \mathbf{R}(\boldsymbol{\varepsilon})$ being a function of observation errors $\boldsymbol{\varepsilon}$. Invariant, unbiased and most effective, with respect to the $\mathbf{R}$ matrix, estimator of variance coefficient is then $\boldsymbol{\sigma}_{0R}^2 = \boldsymbol{\varepsilon}^T\boldsymbol{\Omega}_R\boldsymbol{\varepsilon}$. The estimator obtained in such a way is the most effective for given matrices $\mathbf{R}_\gamma = \mathbf{R}_\gamma\ (\boldsymbol{\varepsilon})$ and $\boldsymbol{\gamma}$-matrix of observation error excess coefficients (Wisniewski, 2002b). Some forms of $\mathbf{R}_\gamma = \mathbf{R}_\gamma\ (\boldsymbol{\varepsilon})$ function and gain functions were derived (Wisniewski, 2002c).

The adjustment task that makes possible to estimate local coefficients of variance, asymmetry and kurtosis, assigned to respective observation group using the least-squares method is derived (Wisniewski and Kasietczuk, 1999). Next, using the maximum likelihood method the adjustment algorithm, making application of obtained estimators possible, was formulated.

4.4. RESEARCH ON GPS

In 1999 - 2002 the development of the original method and software for undifferenced processing GPS phase measurements was continued in the Space Research Centre of the Polish Academy of Sciences. It consisted of a programmed solution for GPS phase ambiguities and cycle slips in a single observation epoch. For that purpose a special package LAMBDA, kindly made available by the University of Delft, was implemented. The new version of the program PHASE was thoroughly tested. The obtained, tested and properly modified for a large number of observing stations and large inter-station distances, long observation sessions, and inhomogeneity of station receivers, features and properties of the PHASE software allow to be classified as a new technology available to relevant research projects. They can be particularly useful for a continuous service in real time of permanent observations for navigation and geodynamics, with a possible use of GPS, GNSS and Galileo systems.

The strategy for local precise GPS networks data processing allowing to connect the local networks with the global and the regional IGS/EPN networks was developed in (Bosy et al., 2003). In the research on precise local network data processing, the results of regional and global networks solutions (coordinates, systems of normal equations, tropospheric models and precise orbits) were used. High precision local network surveying requires taking into account the effects of ionospheric refraction when processing GPS data. This becomes particularly important during periods of high solar activity. It has been shown that the use of global and regional/local models of ionosphere improves the success rate of ambiguity resolution. Ionospheric activity modelling on a regional as well as local scale should provide a more accurate representation of the distribution of electrons. Those analyses have shown that local ionosphere models may be used for ambiguity resolution instead of global ones. A vital conclusion from this study is that the local model should be available with a significantly reduced delay time (just after the measurements) as opposed to 24 hours or more for global models. The presented strategy has been used for processing the latest observation campaigns (1997 – 2002) in the local GPS networks situated in test areas of the Sudety Mountains and the Fore-Sudetic Block.

Research on GPS positioning technique was continued at the Chair of Satellite Geodesy and Navigation, the University of Warmia and Mazury in Olsztyn (Baran and Oszczak, 2000). It concerned, in particular, the accuracy analysis of the rapid static technique (Bakula and Jarmolowski, 2001), accuracy of GPS kinematic positioning in real-time and in post-processing modes (Ciecko and Oszczak, 2001), accuracy of absolute GPS positioning with SA switched off (Oszczak et al., 2001).

4.5. RESEARCH ON GRAVITY

Results of research conducted at the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology on the application of the vertical gradient of gravity (Barlik, 2000d, 2000e; Zabek and Pachuta, 2000) and deflection of vertical (Barlik, 1999; 2000b) in the process of adjusting the geodetic control networks, gravimetric reductions (Pachuta et al., 1999; Pachuta, 2000), determination of local geoid etc. in (Barlik, 1999, 2000a, 2000c, 2000f; Walo, 2001), as well as concerning the application of the horizontal gravity gradient to determination of the geoid in (Barlik, 2001) were published.

4.6. RESEARCH IN METROLOGY

New methods in the field of surveying metrology were developed at the Metrological Laboratory of Department of Mining Surveying and Environmental Engineering of the University of Mining and Metallurgy in Cracow (Beluch et al., 2000). Conventional and electronic instruments as well as precise levelling staffs, both a traditional and bar-code ones were used in the research. A few models of bases for metrological tests of various surveying instruments, with particular emphasis on their precision, were analysed (Beluch, 2002). The usefulness of the model in determination of the EDM constants was evaluated. It was proved that the rms of the EDM constant could be reduced when two groups of sections: short and long ones were measured in test measurements. It was found that covariance of y co-ordinates of base points taken into account in the computation procedure makes the estimation of precision of constants determination more realistic.

The method of determination of linear expansion thermal coefficient for invar tape that is a part of precise levelling stuff was developed (Frukacz et al., 2000). The influence of rate temperature changes onto value of coefficient was determined. The way of the observations modification that eliminates imperfection of measurement series was shown.

Technology of comprehensive verification of precise levelling staffs based on the vertical calibrator with the use of HP 5529 laser interferometer was described (Pokrzywa et al., 2000).

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5. GEODYNAMICS

5.1. INTRODUCTION

This part of the Polish National Report on Geodesy is the quadrennial report of geodynamic works performed in Poland in a period from 1999 to 2002. It summarises 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 at the following research centres listed in an alphabetic order:

- Department of Geodesy and Geodynamics, Institute of Geodesy and Cartography in Warsaw;
- Department of Geodesy and Photogrammetry, Agricultural University in Wroclaw;
- Department of Mining Surveying and Environmental Engineering, University of Mining and Metallurgy in Cracow;
- Department of Planetary Geodesy, Space Research Centre, Polish Academy of Sciences in Warsaw;
- Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology.

The content of the chapter is based on the material prepared by Marcin Barlik, Jozef Beluch, Aleksander Brzezinski, Stefan Cacon, Wladyslaw Goral, Marek Kaczorowski, Barbara Kolaczek Jan Krynski, Jerzy B. Rogowski and Andrzej Sas-Uhrynowski.

The bibliography of the related works is given in references.

5.2. GEODYNAMIC NETWORKS IN POLAND

5.2.1. Polish Geodynamic Network

The Polish Geodynamic Network (PGN) that consists of nearly evenly distributed 36 chosen carefully points marked with a solid monuments has been established by the team of the Institute of Geodesy and Cartography, Warsaw, in 1997-1998. The data acquired during zero-epoch GPS campaign was processed and the network was adjusted in co-operation with WUT Local Analysis Centre of EUREF using Bernese v.4.0 software, according to presently valid standards. Solution of PGN has been compared at the common stations with solutions for EUREF-POL and POLREF networks obtained from the earlier respective campaigns. The evidence of biases was found (Dobrzycka and Cisak, 2001). Biases have been carefully analysed. The effect of phase centre modelling was tested and discussed in particular.

5.2.2. Geodynamics Research in the Sudety Mountains and Fore-Sudetic Block (SW Poland)

The local geodynamic research in the area of South-western Poland was continued in the period 2000–2002 in the framework of the research project “GEOSUD II” (Fig. 5.1).

Regional Czech–Polish GPS SUDETY network as well as existing local geodynamic networks: GEOSUD, SNIEZNIK MASSIF, PACZKOW GRABEN and STOLOWE MTS. were re-surveyed and reprocessed (Barlik and Cacon, 2001; Blachowski and Cacon, 2002; Cacon, 2001; Cacon and Dyjor, 2002; Kontny, 2001; Schenk et al., 2000, 2001, 2002).

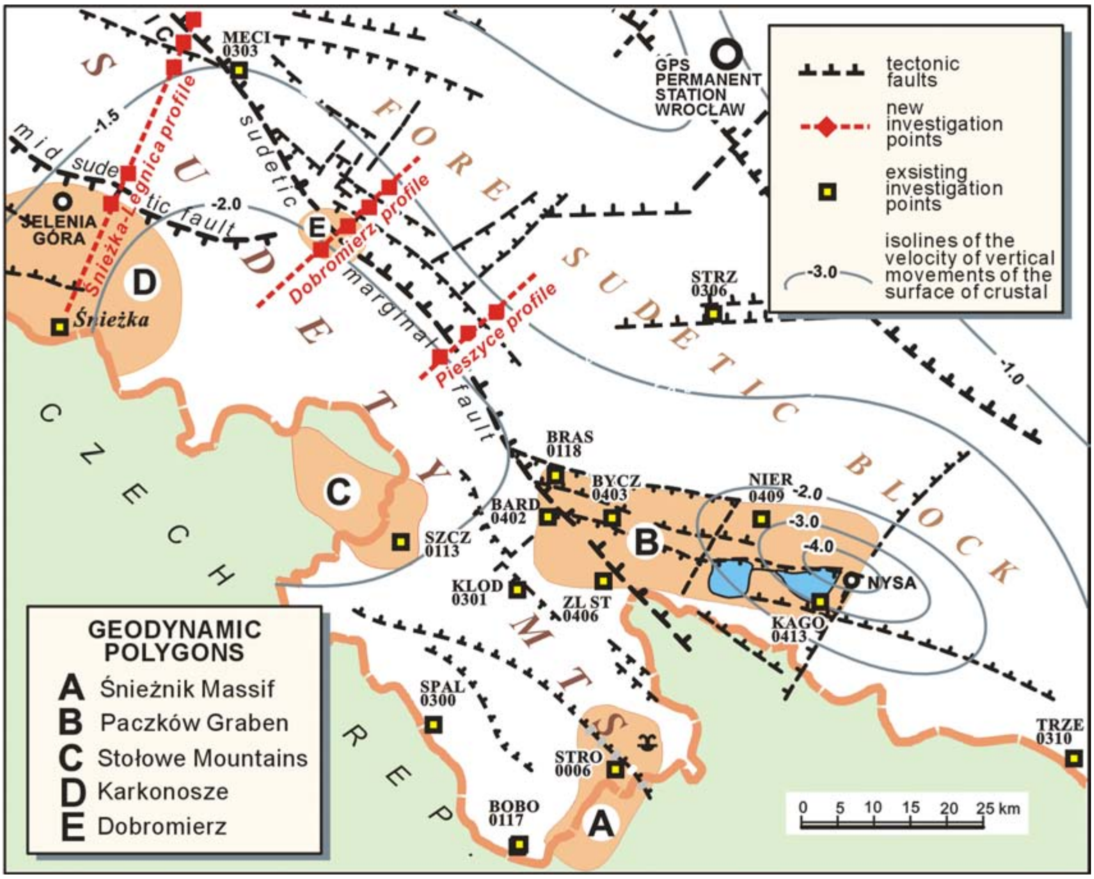

Fig. 5.1. Location of the investigated points in Sudety Mts. and Fore-Sudetic Block

GEOSUD network was modernized and expanded to the western part of Sudetes (Cacon and Dyjor, 2000). Also the new test micro–network DOBROMIERZ, suitable for repeatable terrestrial geodetic, GPS, gravimetric and relative (extensometric) measurements, was established for monitoring the tectonic dislocations node close to the water dam located in the area (Cacon et al., 2002). The new local geodynamic GPS and gravimetric KARKONOSZE network, covering highest part of Polish Sudetes, was established in 2000 and two first measurement campaigns were performed (Kontny et al., 2002; Makolski et al., 2001). The investigation of natural tectonic hazard for engineering objects in Lower Silesia on the basis of GPS data has been initiated (Kontny, 2002).

5.2.3. Tatra Mountains Geodynamics

Project on Geodynamics of Tatra Mountains “Tatra Mts. without border” was launched in 1997 (Czarnecki and Mojzes, 1999; Mojzes et al., 2001). The general objectives of the project are investigation of geodynamics of the Tatra Mts. and determination of the local quasigeoid in the region. As a by-product the heights of some Tatra's picks will be determined. GPS monitoring campaigns are organised every year by Slovak and Polish teams to survey the Tatra reference satellite network (Czarnecki et al., 2001b). The seminars on geodynamics of Tatra Mts. take place every year in fall.

5.2.4. Geodynamic Network in Cracow Area

The recent geodynamic network in Cracow area can be considered as consisting of two parts. The eastern part comprises the area of "Wieliczka" salt-mine and its vicinity (including Cracow area). The western part covers the eastern Silesian Coal Basin, one of the biggest in the world. The network is situated in the foothills of Carpathian massive, about 100 km north of its highest part – the Tatra Mountains. The area is densely populated and highly industrialised.

The Wieliczka salt mine area (1 km × 10 km) is located about 15 km south-east of the centre of Cracow. In 1994-1996, an integrated control network of high precision in Wieliczka and Cracow area was established for terrain deformation monitoring and geodynamics research.

Upper Silesia Industrial Area is situated about 40 km west of Cracow. It is a region that suffers the biggest changes in Poland due to extensive mining and industry. Measurements of deformations carried out for more than a century in the areas influenced by mining exploitation, in most cases refer to the mining area of a single mine or at most a few mines. At the same time there are many regions where mining activities are simultaneously run by many mines. In 1968, observations of vertical movements of benchmarks of GOP vertical control, called GIGANT (Giant), have started. The network recently consists of 1655 node benchmarks, including 23 reference points. Total length of the network in 1998 was 1370 km (Banasik et al., 1999). One of the future tasks is to integrate the GIGANT network with GPS network and to determine local geoid (Banasik, 2001). The GIGANT network is a natural development in the western direction of the geodynamic traverse established in 1994-96 in the region of Cracow and Wieliczka (Goral et al., 1999; Banasik et al., 2000a, 2000b). Research on results of repeated levelling (Banasik, 1999) and with support of high precision GPS positioning, especially for height determination, has been carried out (Goral et al., 1999; Goral, 1999).

Establishing of KRAW permanent GPS station in Cracow that was included in January 2003 into EUREF Permanent Network, as well as establishing of local Active Geodetic Network (ASG-PL), composed of six permanent GPS stations, west of Cracow (about 70 km) makes possible the intensification of geodynamic research in Cracow area (Goral 2002).

Rock mass changes observed in the "Kinga" and the "Danilowicz" shafts in Wieliczka salt mine were analysed (Jozwik and Szczerbowski, 2002). They are interpreted in terms of geodynamics. The main aim of that work is to proof that in the case of non-typical rock mass existing in Wieliczka there is a need for full description of its movement including horizontal observations. The results of analysis of such observations were presented. The results of the shaft guides vertical measurement indicate directions of geodynamic movements that occur in Wieliczka rock mass. The described method of observation can be defined as the underground monitoring of the geodynamics movements.

5.2.5. Cross-Border Czech-Polish-Slovak Geodynamics Research

Project "Czech-Polish-Slovak cross-border studies of regional geodynamics (Sudetes, Beskydy, Tatra, Pieniny Mts.)" is realised as bilateral/multilateral agreement (Mojzes et al., 2001). Long borderline between Poland, Czech Republic and Slovakia coincides generally with interesting geotectonic formations of different age. That gives an excellent opportunity to undertake comparative studies of a significant scientific and practical value. The main objectives of the Project have been defined as long-term investigation of variations of the recent crustal movements, periodic monitoring of the horizontal and vertical displacements in the structural tectonic zones of the Polish and Czech parts of the Sudetes Mts., Western Carpathians (Tatra Mts. and Pieniny) as well as in the regions neighbouring with the existing and planned investments and technical constructions (water reservoirs and dams, power stations, communication lines, etc.). Since 1999 the co-ordinated GPS surveying campaigns with use of about 35 GPS receivers from the Czech Republic, Poland and Slovakia were conducted to in Sudetes Mts., Pieniny and Tatra Mts.

The studies of geodynamics of the Pieniny Klippen Belt were initiated in the mid-wars period. The Pieniny Klippen Belt test-field was established in the sixties. Geodetic, geophysical and geomorphologic methods were applied to study recent geodynamics in the area (Czarnecki et al., 2000; 2001c; 2002). The water dam on the Dunajec river and artificial lake covering the river valley were established in mid-nineties. The water loading and probable water penetration in limestone structures might contribute to the stresses and movements distribution over the area. The Pieniny test-field is currently revisited as the present geodynamical status of the area has been changed. The project includes re-observing the control networks and executing auxiliary geophysical studies: shallow seismic and electric resistance profiling. The project is sponsored by the Polish State Committee for Scientific Research. Last geodetic measuring campaigns were performed in 2000-2002; also geophysical studies have already been executed.

5.2.6. Geodynamic Network in Copper Basin Area

Polish Copper Basin is located in South-western Poland, between two towns: Lubin and Glogow. In this area the following influences of mining exploitation on the surface and the rocks mass can be established:

- direct influences caused by displacement of the rocks filling free space created as a result of mining activity,
- indirect influences caused by water draining action in the mines.

Since 1992 the new concept of 3D control network measured with GPS was developed. The primary GPS control network in the Copper Basin area consisting of 53 new points was established (Wasilewski et al., 2000). The classical horizontal control network has been integrated with GPS determined one and tied to the POLREF network (Oszczak et al, 2000).

The method for deformation analysis and prediction of displacement has been developed (Wasilewski et al., 2001).

5.3. INTERNATIONAL GEODYNAMIC NETWORKS

5.3.1. CERGOP Project

The Institute of Geodesy and Geodetic Astronomy WUT is deeply involved in realisation of scientific geodetic and geodynamic programmes of the Central European Initiative (CEI) Working Group “Science and Technology” Section C “Geodesy” chaired by the Institute. The programme of activities of this Section includes regional European programmes (e.g. CERGOP - Central Europe Regional Geodynamics Project), local geodynamic projects and projects realised by the subgroups of the CERGOP Study Group CSG.5 “Geotectonic Analysis of the Region of Central Europe” (e.g. Geodynamics of Tatra Mts.), projects realised in bilateral/multilateral agreements of CEI countries, (e.g. Czech-Polish-Slovak Cross-Border Studies of Regional Geodynamics (Sudetes, Beskydy, Tatra, Pieniny Mts). Section’s Working Groups on University Education Standards and on Satellite

Navigation Systems are very active. Section C "Geodesy" undertakes close links with European Geophysical Society (every year EGS-CEI symposia "Geodetic and geodynamic programmes of the CEI") and the International Association of Geodesy (IAG Subcommission "Geodetic and geodynamic programmes of the CEI") within the IAG Section V "Geodynamics" Commission XIV "Crustal Deformation".

The first phase of the Project CERGOP was concluded in 1998 and now the second phase of the Project is being realised. Main objectives of the project are the establishment of the Central European GPS Reference Network CEGRN and studies on geodynamics in Central Europe. The proposal of the second phase of the Project CERGOP-2 "A Multipurpose and Interdisciplinary Sensor Array for Environmental Research in Central Europe (CERGOP-2/Environment)" was accepted by the European Commission and will be financially supported during the next three years. The Contract with European Union was signed early 2003. The following 14 countries participate in the second phase of the project: Albania, Austria, Bosnia and Herzegovina, Bulgaria, Croatia, the Czech Republic, Germany, Hungary, Italy, Romania, Poland, Slovakia, Slovenia and Ukraine. CERGOP-2 covers 63 stations. About thirty CERGOP-2 sites are permanent stations. Six monitoring GPS CEGRN campaigns were performed in 1994, 1995, 1996, 1997 (CERGOP-1) and in 1999 and 2001 (CERGOP-2). Graz Lustbühel Observatory hosts CERGOP Data Centre. Five research institutes have declared to maintain and operate CEGRN Processing Centres in the second phase of the project. They are FÖMI, Satellite Geodetic Observatory, Penc, Hungary; Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology, Warsaw, Poland; Agenzia Spaziale Italiana Centro di Geodesia Spaziale, Matera, Italy; Space Research Institute of the Austrian Academy of Sciences, Austria and Department of Theoretical Geodesy of the Faculty of Civil Engineering of the Slovak University of Technology, Bratislava, Slovakia. In the programme of CERGOP-2 there are at present thirteen study groups. They cover particular fields of activities supporting realisation of the project and form the respective "workpackages" of the EU Project CERGOP-2/Environment (Figurski et al., 2000; Figurski and Pfeil, 2000; Liwosz et al., 2001; Becker et al., 2002).

The CERGOP project was an impulse for establishment of the CEGRN Consortium of institutes. The CEGRN Consortium is a non-profit organisation of institutes that supports and promotes the establishment, maintenance and upgrade of CEGRN sites, monitoring the CEGRN by permanent and epoch type measurements and the establishment, maintenance and development of CEGRN Data Centre and Processing Centres. The member institutes contribute to the CEGRN with their own established and accepted sites, with site maintenance and with coordinated observations on these sites. They are committed for the highest quality standards of five-day observations every second year. They supply observational data to the common Data Centre. Additional contribution of designated institutes consists of operation the Data Centre and/or Processing Centres. The Consortium will also be a seedbed of new European projects and initiatives (Sledzinski 1999a, 1999b, 1999c, 1999d, 1999e, 2000a, 2000b, 2001a, 2001b; Fejes and Sledzinski, 2000).

5.3.2. Extended SAGET Programme

The main scientific objective of the EXTENDED SAGET (SAtellite GEodynamic Traverses) programme, initiated and coordinated by the IGGA WUT, was to organise GPS campaigns that give the precise geodetic frame for studies on the entire Teisseyre-Tornquist zone, investigations on the Carpathian Orogenic Belt and connection of geodynamic networks and local geodynamic test fields of Central European countries. Besides, the EXTENDED SAGET network joins geodynamic networks of the Mediterranean area and Scandinavia, i.e. two regions essential for European geodynamics. First EXTENDED SAGET campaign was organised in 1992. A follow up campaigns EXTENDED SAGET were performed in 1993, 1994, 1995, 1996, 1997, 1998 and in 1999. About 45-50 European stations participated every year in the campaigns EXTENDED SAGET (Hefty et al., 1999; Sledzinski et al., 1999; Figurski et al., 1999).

Progress and achievements in the projects CERGOP, EXTENDED SAGET and other programmes of the Section C are exhaustively reported at the Summit Meetings of the Heads of Governments of the CEI countries, at the meetings of the International Civil GPS Service Interface Committee, at the IAG EUREF symposia and at the General Assemblies of European Geophysical Society.

5.4. EARTH ROTATION

5.4.1. Theoretical Problem Related to Modelling and Monitoring Earth Rotation

Theoretical investigations concerning geophysical interpretation of modern Earth rotation observations and the related geophysical data, in particular, the study on the conceptual definition and practical realization of the conventional reference pole, taking into account current progress in monitoring changes in the orientation of the Earth and variations of the related geophysical processes, was continued. The results obtained could contribute to the scientific discussion organized and coordinated by the Sub-group T5 "Computational Consequences" of the IAU Working Group on the International Celestial Reference System. The discussion was finalized by the adoption of the new definition of the conventional reference pole (Resolution B1.7 of the IAU General Assembly 2000). Results of the work were presented in several publications (Brzezinski, 1999, 2000a; Capitaine and Brzezinski, 1999). Another theoretical study concerned the high precision numerical model of the rigid Earth rotation (Eroshkin et al., 2002).

5.4.2. Rotational Variations due to the Luni-Solar Torque on the Tri-axial Figure of the Earth

The luni-solar perturbations in Earth rotation associated with the multipole structure of the mass distribution within the Earth were studied in detail (Brzezinski, 2000c, 2001; Brzezinski and Capitaine, 2002). The analytical model of that fine effect (its total size is of the order of 0.1 mas) for a 2-layer model of the Earth comprising an elastic mantle and a liquid core was developed. Comparison of the model with the results of other research groups, executed during the discussion of the IAU Commission 19 Working Group on "Non-rigid Earth Nutation Theory", showed the sub-microarcsecond agreement. The discussion led to a consensus on the model of polar motion corresponding to high frequency nutation. It will be published in IERS Conventions 2000 as a part of realization of the new reference pole CIP (Celestial Intermediate Pole).

5.4.3. Regional Atmospheric Angular Momentum and its Impact on Polar Motion

The analyses of regional patterns of equatorial components of Effective Atmospheric Angular Momentum (EAAM) data computed both globally and in 108 geographic regions from the National Centres for Environmental Prediction and National Centre for Atmospheric Research (NCEP/NCAR) reanalysis data, for the period 1948-1999 were performed at different spectral ranges from seasonal to short period oscillations (Nastula and Salstein, 1999, 2000; Nastula, 2001). The coherence, correlation coefficients, fractional covariance between regional and global atmospheric or geodetic excitation functions were computed to identify the sectors of the globe over which changes contribute most significantly. Air pressure variations over Eurasia, North Pacific, Greenland and North Atlantic, and Southern Ocean near South America regions are important in exciting polar motion in spectral band from seasonal to short period oscillations. Applying the inverted barometer IB correction results in the dominance of Eurasia and North America, with disappearing contributions in almost all the ocean-dominated Southern Hemisphere regions, but the influence of the IB also depends on spectral band (Nastula, 2001). Results obtained from complex Empirical Orthogonal Functions (EOF) analysis of EAAM confirmed that regionally, the atmosphere over Eurasia and North America are particularly important (Nastula and Salstein, 2000).

5.4.4. Correlation of Seasonal and Sub-seasonal Variations of the Geodetic and Atmospheric Excitation Function of Polar Motion

The correlation of seasonal and sub-seasonal variations of the geodetic and atmospheric excitation functions of polar motion was investigated. The homogenous series of 50 years long atmospheric angular momentum, developed by the National Centre for Environmental Prediction/National Centre for Atmospheric Research and 40-years long time series of polar motion, EOP IERS 97C 04, developed by IERS were applied. High, stable correlation coefficient of the order of 0.8 was obtained for annual oscillations in the years 1970-2000. In the case of semi-annual and 120 days oscillations correlation coefficients became more stable starting from 1970 and 1980 and they reach 0.7-0.8 and 0.6—0.8, respectively (Kolaczek and Nastula, 2001; Nastula and Kolaczek, 2001, 2002).

5.4.5. Frequency-Dependent Time Lag Between Atmospheric and Geodetic Excitation Functions of Earth Rotation

The Fourier transform band-pass filter and the wavelet transform techniques were applied to compute time-frequency spectra of polar motion and its atmospheric excitation as well as spectra-temporal coherences and cross-covariance functions between these functions (Kosek and Popinski, 1999, 2000; Popinski and Kosek, 2000; Popinski et al., 2002). The maxima of the modules of cross-covariance functions allow the determination of frequency-dependent time lag functions between the polar motion and atmospheric excitation functions. A negative time delay for oscillations with periods of 180 and 120 days indicate that these oscillations in the equatorial components of the atmospheric excitation functions precede analogous oscillations in the geodetic excitation function by about 20 to 60 days (Popinski et al., 2002).

5.4.6. El Niño Impact On Polar Motion Variations

The influence of El Niño on the correlation between seasonal, namely annual, semi-annual and 120-day (ter-annual) oscillations of atmospheric and geodetic excitation functions of polar motion in forty years period, from 1962 to 2000 was investigated. It was found that disturbances of those correlation coefficients are highly correlated with epochs of El Niño /La Niña phenomena (Kolaczek et al., 1999, 2000; Salstein et al., 1999).

5.4.7. Atmospheric and Oceanic Excitation of Earth Rotation

An extensive analysis of a 40-year reanalysis time series of the atmospheric angular momentum (AAM) to estimate the high frequency effects, such as diurnal and semidiurnal variations, free core nutation, influence of the atmospheric normal modes was performed

(Brzezinski, 2000b; Brzezinski and Petrov, 1999, 2000); for review see the paper (Brzezinski et al., 2002a). In case of the oceanic effects (Brzezinski, 2003) the attention was focused on the excitation of the 14-month free Chandler wobble. By using a 11-year time series of the ocean angular momentum (OAM) it has been concluded (Brzezinski and Nastula, 2002) that within the limits of accuracy the coupled atmosphere/ocean system fully explains the observed Chandler wobble during the period 1985-1996. Similar study using a 50-year OAM series (Brzezinski et al., 2002b) yielded less promising results that could be attributed to the differences in the underlying ocean circulation models. The first attempt to estimate the non-tidal oceanic contribution to nutation (Petrov et al., 1999) showed that the OAM data is still not adequate for studying the diurnal and sub-diurnal effects.

5.4.8. Combined Oceanic and Atmospheric Excitation Function of Seasonal and Sub-seasonal Polar Motion

A constant-density ocean model driven by observed surface wind stresses and atmospheric pressure, for the period 1993-1995, was used to estimate the equatorial excitation functions for the ocean velocity and mass fields (Nastula and Ponte, 1999). The results of the analysis confirmed findings that oceanic excitation, when added to atmospheric excitation, leads to substantial improvements in the agreement with observed polar motion excitation at seasonal and intra-seasonal periods. In addition, the results point to the role of Effective Oceanic Angular Momentum (EOAM) signals in exciting polar motion at the period between 5 and 10 days. The combined oceanic-atmospheric excitation does not explain, however, all the observed polar motion excitation, especially for the equatorial component CHI2.

Comparisons of regional variations of EAAM and EOAM signals were performed for monthly and longer periods (Nastula et al., 2000) and for periods shorter than 10 days (Nastula et al., 2002). They have revealed the importance of specific areas for polar motion excitation. The results also confirm findings that oceans supplement the atmosphere as an important source of polar motion excitation. Regional characteristics of short period excitation are generally in agreement with those obtained from analyses performed for signals at monthly and longer periods. The EAAM and EOAM signals associated with pressure terms were found to be of the same order of magnitude while signals associated with winds were substantially larger then those associated with ocean currents. The strongest polar motion excitation due to variability of atmospheric pressure, oceanic pressure and wind terms is connected with areas over northern and southern mid-latitudes. The spatial pattern of pressure + inverted barometer (IB) term is dominated, however, by maxima over land areas. Oceanic excitation due to currents is strong in the North Pacific and the southern oceans.

5.4.9. Improvements of Polar Motion Prediction

The accuracy of the least-squares prediction of polar motion carried out in the IERS Sub-Bureau for Rapid Service and Prediction depends on starting prediction epochs due to irregular short period variations in Earth rotation (Kosek, 2000) but also on the irregular phase variation of the annual oscillation (Kosek et al., 2001a, 2001b). There were two significant increases of the annual oscillation phase of the order of 30°-40° associated with increase of polar motion prediction errors before and during the two largest 1992/93 and 1997/98 El Niño events, respectively. Auto-covariance prediction formulae of complex-valued time series were derived and applied to predict pole coordinate data transformed into the radius and angular distance (Kosek, 2002). The prediction errors of this method are of the same order of magnitude as the errors of the prediction method used in the IERS Sub-Bureau for Rapid Service and Prediction.

5.4.10. Rapid Oscillations of Polar Motion Determined by GPS

Spectral analysis of the GPS (CODE) polar motion series computed with a resolution of two hours in the years 1996 – 2001 show that data considered is sufficiently accurate to detect rapid oscillations of polar motion with periods shorter than 12 hours. Oscillations with periods of 6, 8, 12 hours and amplitudes of the order of 0.02 - 0.05 mas were detected. Oscillations with 8 and 12 hours were also detected in the dense set of equatorial components of EAAM based on surface pressure of the NASA GEOS Data Assimilation System with the resolution of three hours for the year 1995. It shows a possible association of high frequency polar motion oscillation and the atmospheric forcing (Weber et al., 2001).

Spectra of short period oscillations of Earth rotation parameters were computed for the period ranges from 150 days to daily and sub-daily periods (Kolaczek et al., 2000).

5.5. EARTH TIDE INVESTIGATIONS IN POLAND IN 1999–2003

Space Research Centre is carrying out tide gauge observations at the Ksiaz station (horizontal components) and at the Warsaw station (vertical component). At the Ksiaz station observations are made using Blum's pendulum and the observational series is already almost 30 years long.

Annual series of tidal observations is analysed and then the results are published. At the same time the observations are delivered to International Centre for Earth Tides in Brussels.

5.5.1. Monitoring of Tidal Signals:

Warsaw Gravity Station 0907

During the years 1999-2003 the gravimetric observations of Earth tides were continuously conducted at station 0907. Since May 1995 the station is equipped with LCR G-648 gravimeter with a digital force feedback system. The station 0907 is located in the premises of the Space Research Centre of the Polish Academy of Sciences in Warsaw. Data collected at the station is processed with a classic method of analysis based on the LS technique (Chojnicki, 1999, 2000, 2002). The results of analysis confirm a good quality of gravimetric data (m_0 = 0.52 μGal).

Ksiaz clinometric station 0906

Gravimetric as well as the clinometric data were continuously acquired at station 0906 during years 1999-2003. The station is situated at the Low Silesian Geophysical Observatory in Ksiaz. The clinometric station 0906 in Ksiaz is equipped with a pair of quartz horizontal pendulums. The instruments, numbered H-74 and H-75, are continuously operating since November 1973. The clinometric observations of Earth tides performed at the Ksiaz station are processed with a classic method of analysis based on the LS technique (Chojnicki and Weiss, 1999, 2000, 2002). The results obtained indicate high quality of clinometric data (m_{0NS} = 1.12 mas, m_{0EW} = 0.99 mas).

5.5.2. Improvement of Clinometric Measurement Technique

In 1997 the installation of the long water tube tiltmeter in the Low Silesian Geophysical Observatory in Ksiaz started. The works on a new tiltmeter were simultaneously conducted at Ksiaz Observatory as well as in the Space Research Centre of the Polish Academy of

Sciences, Warsaw. The instrument consists of two perpendicular to each other water tubes of 65 and 84 meters long. At the end of the tubes the interferometer gauges are installed. The classical Newtonian interferometers were applied to the measuring system of water level variations. Single mode red colour gas lasers were applied as a source of light for interferometers. The resultant pictures of the Newtonian rings are observed by a CCD camera and sent to a PC where they are stored on the hard disc. The long water tube tiltmeter possesses several valuable proprieties:

- the lack of instrumental drift,
- the extremely high sensitivity, at least three orders of magnitude larger then the accuracy of horizontal pendulum (0.002 msec),
- an extensive base of measurement (area with a radius of about a hundred meters, from which instrument collects signals).

The long water tube clinometer in Ksiaz station became fully operational in the middle of 2002. Preliminary results of observations fully confirmed a quality of the new instrument. The observing noise does not exceed 0.01 mas (Kaczorowski, 1999a, 1999b, 1999c).

The proprieties of the long water tube tiltmeter open a new range of investigations in geodesy and geodynamics, including

- the investigation of the second order tidal effects and non-linear theory of the Earth tidal response,
- the investigation of secular variations of gravity field produced by "global greenhouse effect”,
- the investigation of present movements of the tectonic plates,
- the research on tectonic formation and erosion processes (Sudeten).

The list of applications of a new tiltmeter also contains investigations of non-periodic effects of plumb line variations due to atmosphere. The horizontal pendulums applied till now have an instrumental drift that makes impossible to interpret the non-periodic parts of the long series of observation.

5.5.3. Investigation of Tidal Waves Modulation

Seasonal modulation of tidal waves is investigated during several years. The role of the Earth atmosphere as a main source of that phenomenon has not been, however, explained. Research on atmosphere tides was undertaken. The method of determination of non-seasonal modulation was elaborated. The preliminary investigations in the range of periods of 263 – 569 days show modulation in the range of Chandler periodicity, i.e. of 430-460 days (Chojnicki, 2000; Bogusz and Chojnicki, 2000).

5.6. GRAVITY AND GPS FOR GEODYNAMICS

The experiments conducted showed that LCR-G gravimeter equipped with electronic data recording and operating in thermostatic chamber provides high quality record of gravity data over the interval from a few hours to a few days. The usefulness of a few week long record of gravity data acquired with LCR-G gravimeter for analysis of short period variations of gravity has also been shown. The analysis of short time series of gravity could become a useful tool for improving Earth tide models. Such series together with time series of GPS solutions could be applied for modelling local geodynamics phenomena (Zanimonskiy and Krynski, 2000; Krynski and Zanimonskiy, 2001).

A particular attention has been paid to the analysis of variations of gravity residuals due to their relation to the variations in vertical component. Stands for continuous gravity surveying with automatic data recording with LCR-G gravimeter have been developed at Borowa Gora and Lamkowko observatories. Also automatic meteorological data recording was established in both observatories.

Time series of residual gravity acquired at those stations were analysed together with respective time series obtained from gravity recorded at a few European tidal stations participating in the GPP project. Correlation analysis shows common origin of part of the signal of variations of GPS solutions with variations of residual gravity. The observed signal is of local character (Zanimonskiy and Krynski, 2000).

5.7. SECULAR VARIATIONS OF THE EARTH MAGNETIC FIELD

The distribution of the geomagnetic field in space and time in the Baltic Sea has been investigated. On the grounds of the component magnetic survey on the profiles of about 55000 km long, the grid of 2 x 2 km has been generated. The grid consisting of about 220000 points has been used for working out the Magnetic Atlas of the Baltic Sea, which contains 5 maps of D, H, F, Z, and I magnetic components, the map of the secular variations of measured D, H and F components, 2 maps of the magnetic anomalies (for F, H) and also 2 maps of the normal field (for F and H), as well as the map of data coverage. The maps are made the scale of 1:5000000. The maps of D and F are also given in the scale of 1:1500000. (Sas-Uhrynowski et al., 1999b, 2000b, 2001b).

The magnetic anomaly field over Poland and adjacent regions by using MAGSAT Satellite Data has been also investigated (Rotanova et al., 2000).

Secular variations of the geomagnetic field have been investigated on the basis of the results of the magnetic measurements periodically repeated at the secular stations of magnetic network. The network of 19 stations in Poland exists already for almost 50 years. The 11 stations in Belarus and 6 stations in Lithuania have been established in the late 90-ties and then surveyed twice with use of Flux D/I absolute magnetometers and proton magnetometers (Sas-Uhrynowski et al., 2000a, 2001b, 2002).

Morphology and dynamics of the non-dipolar part of the vector geomagnetic field has been studied (Kasyanenko et al., 2000, 2001).

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