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)

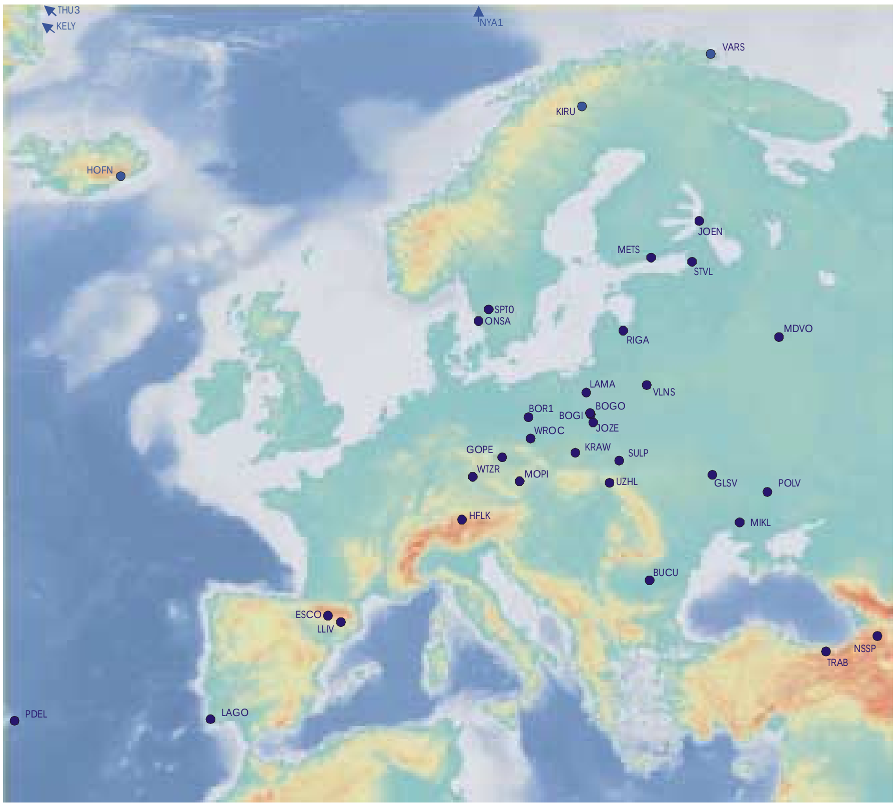

Fig. 2.1. Network of EPN stations providing data for processing at WUT EUREF LAC

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).

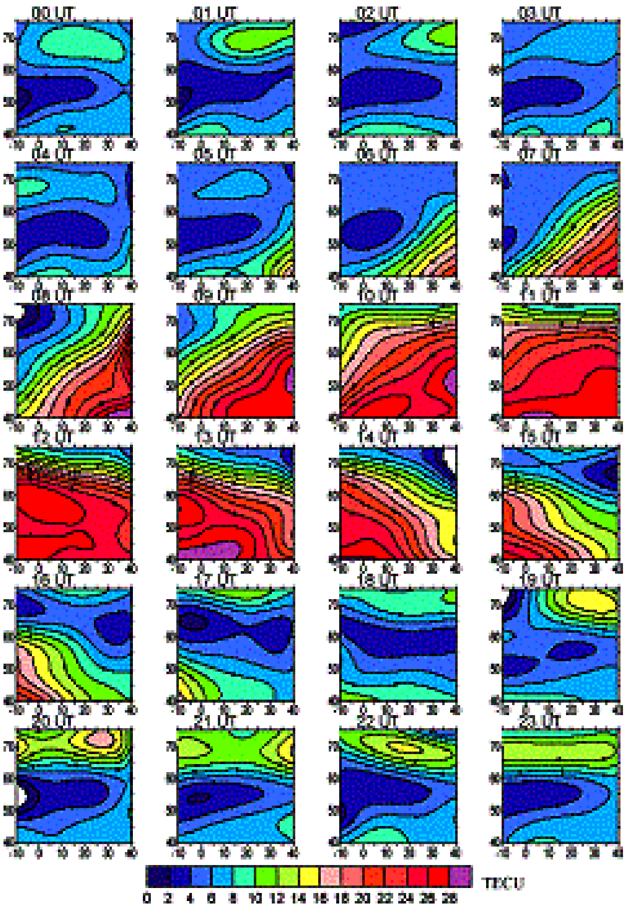

Fig. 2.3. TEC maps for December 1999 demonstrating the development of the trough over Europe

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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