HUNGARIAN NATIONAL REPORT ON IAG 2011-2014

József Ádám

This report outlines the activities of Hungary in the field of geodesy for the period from January 2011 to December 2014. It has been prepared for submission to the International Association of Geodesy (IAG) at its General Assembly in Prague, Czech Republic during the XXVIth General Assembly of the International Union of Geodesy and Geophysics (IUGG) on 22 June – 2 July, 2015. It is issued on behalf of the IAG Section of the Hungarian National Committee for IUGG.

Since the last XXVth General Assembly in Melbourne, Australia, July 27-July 8, 2011 there have been some minor changes in the list of members of the IAG Section of the Hungarian National Committee for IUGG. Currently the National Correspondent to the IAG is also the Chairman of the IAG Section. The members of the IAG Section for the period of 2012-2015 are as follows: J. Ádám (Chairman), L. Bányai (Secretary), Á. Barsi, P Biró, G. Csapó (passed away in 2014), S. Frey, Gy. Grenerczy, A. Kenyeres, Gy. Mentes, G. Papp, Sz. Rózsa, Gy. Tóth, P. Varga, L. Völgyesi, and J. Závoti.

Cooperating institutions in the field of IAG in Hungary are as follows:

- Department of Geodesy and Surveying, Budapest University of Technology and Economics (BME) (http://www.geod.bme.hu),
- Satellite Geodetic Observatory of the Institute of Geodesy, Cartography and Remote Sensing, Budapest-Penc (http://www.sgo.fomi.hu),
- Geodetic and Geophysical Institute of the Research Centre for Astronomy and Earth Sciences of the Hungarian Academy of Sciences, Sopron (http://www.ggki.hu),
- Institute of Geoinformatics of the Alba Regia Technical Faculty of the Óbuda University at Székesfehérvár (http://www.geo.amk.uni-obuda.hu),
- Hungarian Geological and Geophysical Institute (MFGI), Budapest (http://www.mfgi.hu),
- Geoinformation Service of the Hungarian Defence Forces, Budapest (http://www.honvedelem.hu/szervezet/mh_geosz).

The national report has been divided into commissions in accordance with the new structure of IAG. The commission reports are compiled by the authors indicated in brackets, who are responsible for the content of their corresponding reports, namely I. Commission "Reference Frames" (A. Kenyeres, Gy. Grenerczy, S. Frey and T. Horváth), II. Commission "Gravity Field" (L. Völgyesi, G. Papp and Gy. Tóth), III. Commission "Earth Rotation and Geodynamics" (P. Varga and Gy. Mentes), IV. Commission „Positioning and Applications" (Gy. Mentes and Sz. Rózsa), V. Inter-Commission Committee "Theory" (L. Bányai and J. Závoti) and VI. Communication and Outreach Branch (J. Ádám, Sz. Rózsa and Gy. Tóth). This report would not be possible without their efforts.

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HUNGARIAN CONTRIBUTION TO THE RESEARCH OF REFERENCE FRAMES - IAG COMMISSION 1

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1 Geodetic infrastructure

1.1 Active GNSS network and related services

The Hungarian GNSS reference station infrastructure and services have been established by the GNSS Service Centre (GSC) of the Institute of Geodesy, Cartography and Remote Sensing (FÖMI). The network consists of 35 Hungarian GNSS stations (Figure 1). In addition to these, observation data of 19 stations from the neighbouring countries are collected and processed in real time to provide nationwide homogeneous coverage with cm-accuracy services. The average inter-station distance is less than 60 km, enabling accurate modelling of distance-dependent errors like ionosphere, troposphere and orbits. All of the Hungarian stations and most of the integrated external sites are equipped with state-of-the-art GPS+GLONASS hybrid sensors and individually calibrated choke-ring antennas. Seven units are also Galileo-ready.

During this 4-year period the following station re-positionings had been performed:

- NYLE had been moved in 2011 few meters away to provide more stable monumentation;
- PENC had been doubled in May 2013, a new monument (PEN2) had been established on an elevated part of the main building of the SGO. At PEN2 a Galileo-capable receiver had been installed, which also became part of IGS and EPN. PEN2 as part of the IGS MGEX project provides RINEX 3.02 data;
- due to site-maintenance difficulties SUME station had been moved to TPOL (Tapolca) in November 2013.

The GNSS Service Centre uses the GNSMART network RTK software package (Geo++ GmbH) to provide reference data for both real-time and post-processing applications.
Real-time data is provided via the Ntrip protocol in various formats:

- single station DGNSS data in RTCM 2.1 and RTCM 3.0 formats,
- single station RTK data in RTCM 2.3, RTCM 3.0 and CMR formats,
- network RTK data in RTCM 2.3, RTCM 3.1 and CMR formats.

All major network RTK concepts (PRS, FKP and MAC) are supported.

RINEX and virtual RINEX data is provided for post-processing via the GSC website in RINEX version 2.11 format.

Since January 2013 we are running a new service (autopostGNSS) supporting users who want to run the post-processing of their own field measurements in our dedicated server using the SSRPOST module of GNSMART.

As of December 2014 more than 1200 organisations registered for FÖMI's GNSS services and the number of registered user account exceeded 2100. The majority of land surveying tasks in Hungary are carried out using real-time GNSS technique, but the most dramatically growing user segment is the precision agriculture (Figure 2).

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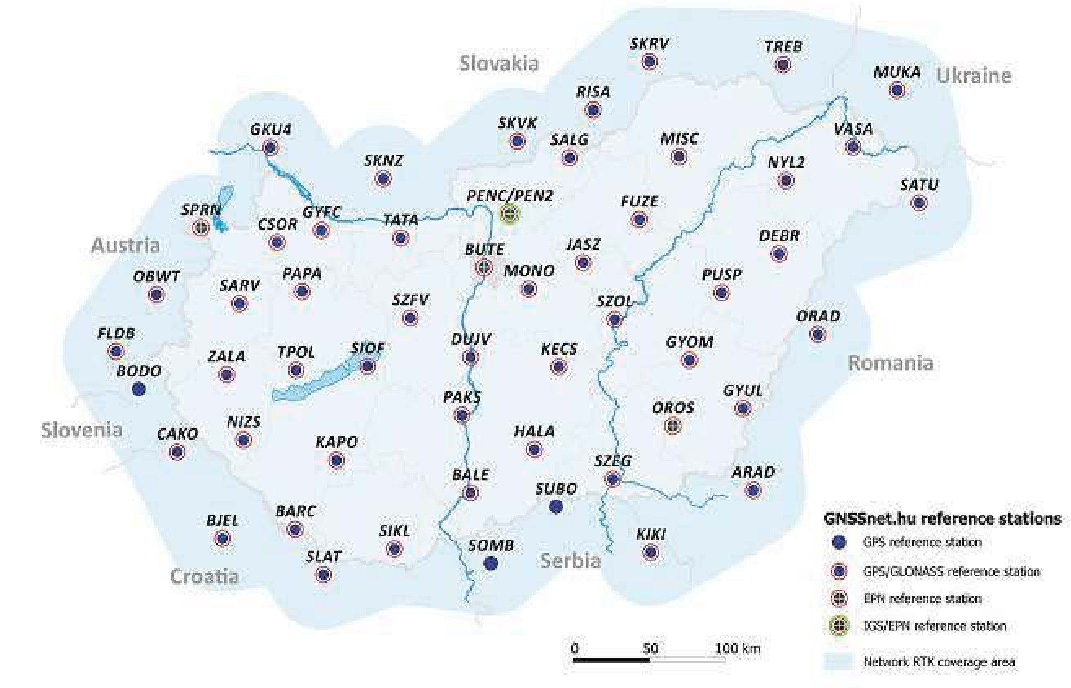

Figure 1. Sites of Hungarian Active GNSS Network

GNSSnet.hu reference station coordinates are determined in ETRF2000 reference frame. Transformation to the Hungarian local grid (EOV) is supported in both real-time and post-processing mode. A new online transformation service (EHT) is provided at the GSC website and a significantly improved real-time version (VITEL) is available for most receiver brands as an extension of the RTK rover receivers' controller software. The transmission of transformation information via RTCM messages is also supported.

The GSC concentrates its efforts on service quality improvements. Besides the automatic quality control of the GNSMART software the GSC developed a number of real-time and post-processing quality monitoring tools for both internal use and information dissemination to the clients. The current status of the service can be monitored online via the GSC website: http://www.gnssnet.hu. A special monitoring tool has been developed for mobile phones. This enables users working on field to judge whether the system performs according to the expectations.

1.2 Integrated Geodetic Network (INGA)

In 2008 FÖMI, in agreement with the academic institutions, initiated the realization of the Integrated Geodetic Network, called INGA. At the INGA benchmarks GPS, levelling and gravimetric measurements are performed and their coordinates are expressed in all geodetic reference frames available in Hungary (EOV, ETRS89, EOMA). The points are primarily selected from levelling benchmarks, where undisturbed GNSS measurement is possible. The MGGA (National GPS Geodynamic Network) sites are part of INGA by default and also the suitable markers of the Hungarian Gravity Base Network are incorporated. New markers are only installed where the network geometry could be guaranteed from existing sites. The INGA site separation is about 15-20 km, the country will be covered by some 1000 benchmarks. The INGA sites will have enhanced physical and legal protection to ensure the long term existence of the network and the represented reference frames. This work was started in 2007 at the NE part of Hungary and by 2014 the network establishment had been completed east from the river Danube. Further continuation of the network realization is pending.

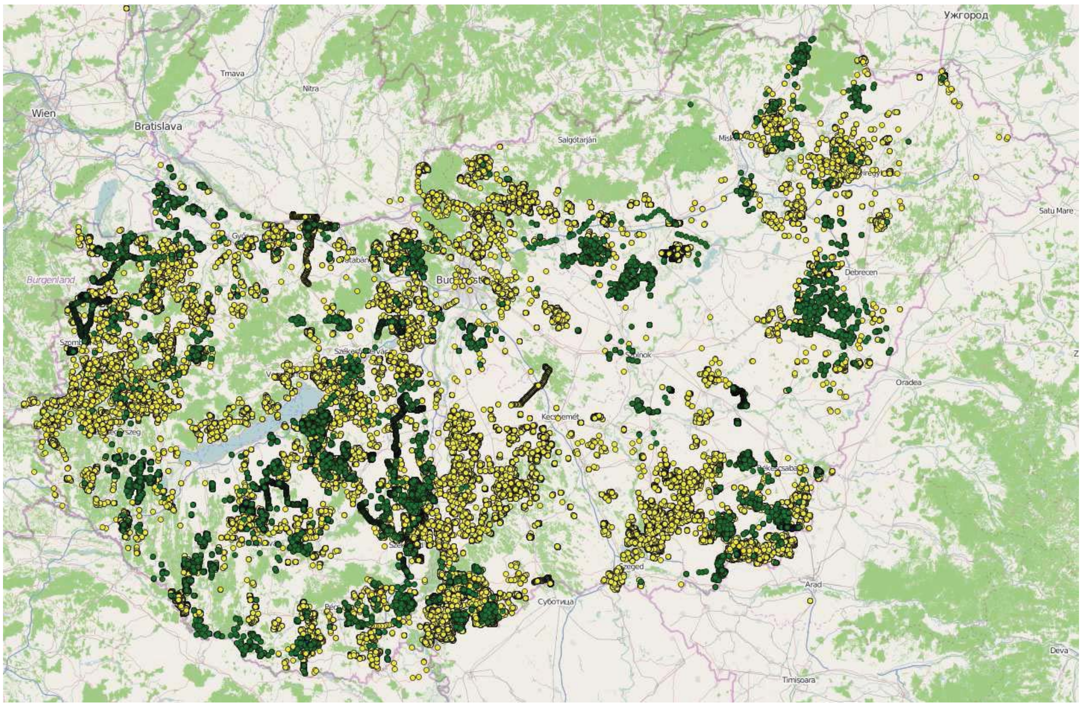

Figure 2. Coverage of the agriculture users in 2014

2 SGO GNSS Analysis Centre

Since December 2001 the FÖMI Satellite Geodetic Observatory (SGO) is running a EUREF Local Analysis Centre (LAC). The SGO LAC is routinely processing the GNSS data of 22 EPN (EUREF Permanent Network), 35 GNSSnet.hu sites and 41 additional permanent stations from the neighbouring countries. The processed sub-network concentrates on the Central and East European region. The daily and weekly EPN sub-network solutions are submitted to the EPN Combination Centre.

FÖMI SGO is also contributing to the maintenance of the ETRS89 using the periodically updated EPN cumulative solution. The EPN Reference Frame Coordinator is acting at the SGO and provides the official EPN coordinate and velocity estimates, which are updated in every 15 weeks. In addition, SGO as initiator of the EPN Densification has started the integration of all European active GNSS network products to provide a high quality, homogeneous and dense position and velocity product in close cooperation with all national data providers and relevant initiatives as EUPOS and EPOS.

3 GPS geodynamics and PS InSAR

We continued our investigation in the framework of the GPS crustal deformation monitoring program -commenced in 1991. Horizontal crustal motions have been better constrained and the vertical tectonic signals have been detected, the main crustal blocks and faults and their present-day kinematics were also investigated. To archive this it was necessary to continue high-precision GPS measurements within the MGGA (Hungarian GPS Geodynamics Network) and the CEGRN (Central European GPS Geodynamic Reference Network) networks (Grenerczy 2012, Caporali et al. 2011). In addition, we performed geodynamic applicability tests of the OGPSH (National GPS Network) to significantly increase spatial resolution. After tests had been successful, we organised and performed nationwide high-precision GPS measurement campaigns of the OGPSH increasing the geodynamic site density by a factor of five. More than two-decade-long observation history of the MGGA enabled us to construct the 3D crustal deformation map of the Pannonian Basin providing significant new knowledge for geosciences.

We developed and refined the reference frame motion monitoring, and took part in relevant international co-operations. Significantly increased spatial and temporal resolution of geokinematic information in the Pannonian Basin (Grenerczy 2012). We achieved major scientific results with the creation of the first ever three-dimensional crustal deformation map of the Pannonian Basin and with the first high-rate GPS deformation studies and the most distant dynamic deformation detection in the world using space geodesy. Tectonic results has indirect social impact and serves valuable input for seismology e.g. in assessing hazards, for geomechanics, geomorphology, river dynamics e.g. in Quaternary river evolution, geodesy e.g. in celestial and terrestrial reference frames, basin analysis, rock physics e.g. in assessing pore pressure, and tectonics related topics in geology and geophysics as well.

We continued introduction of Synthetic Aperture Radar Interferometry (InSAR) technique to Hungary and performed the first applications and major demonstrations about its capability (Grenerczy 2012, Grenerczy and Wegmüller 2011). We have been carrying out InSAR related research for more than a decade supported also by the European Space Agency since 2005. Our current research topic is InSAR Integration: common referencing and combined three-dimensional hazard mapping with Sentinel-1. Major tasks involve multi-technique hazard monitoring in various environments. It also includes study of active and passive SAR point targets, design and establishment of collocation of techniques including SAR reflectors, common referencing with other geodetic networks, techniques, and also Sentinel-1 wide area mapping, tests and demonstrations of geodetic integration.

Beside our major tasks we are performing anthropogenic motion monitoring and study of the anatomy and dynamics of surface instabilities related to various human activities. We compare land and space-based techniques, methodologies, and their effectiveness and work out best-practice approach. Technological development possibilities are also studied especially in relation to state surveying. Information dissemination, university lectures, student consultations, employment of young scientist and InSAR related supervisions and reviews of related works are also among our activities.

4 VLBI activities

The International Celestial Reference Frame (ICRF) is defined by the positions of selected radio-loud active galactic nuclei (quasars) measured by Very Long Baseline Interferometry (VLBI). Some of these positions appear variable based on long-term geodetic/astrometric VLBI monitoring observations. The apparent proper motions can reach several hundred microarcseconds per year in some cases. We continued to study the possible relation between the quasars' apparent proper motion and their radio structure imaged with VLBI. The analysis of a sample of 62 objects with significant and reliable proper motion values, and their 8-GHz VLBI imaging observations and brightness distribution models revealed a general correlation between the characteristic directions of the proper motions and the extended radio jet structure on ~1 to 10 milliarcsecond scales. However, there are notable cases where quasar jets are significantly misaligned with respect to the apparent proper motion direction (Moór et al. 2011).

With the successful launch of the Gaia optical astrometry mission (2013) by the European Space Agency (ESA), it will soon become possible to directly link the most accurate radio reference frame with the Gaia optical reference frame using a large number of common extragalactic objects. We performed a case study to test the level of coincidence between the radio and optical positions of compact active galactic nuclei, using the best catalogues available at present. We found that ~4% of the sample of nearly 1300 objects common in the ICRF2 catalogue and the Sloan Digital Sky Survey Data Release 9 are significantly offset (by more than 3 sigma positional uncertainty), as explained mostly by astrophysical reasons. Since the optical and radio centroids of quasars do not necessarily coincide at the level of accuracy to be achieved, a reliable Gaia-VLBI reference frame link will require a careful selection of a common set of objects by eliminating the outliers (Orosz and Frey 2012, 2013).

References

Caporali A, Barlik M, Becker M, Grenerczy Gy, Hausleitner W, Hefty J, Medak D, Milev G, Mojzes M, Mulic M, Odalovic O, Rus T, Simek J, Sledzinski J, Stangl G, Stopar B, Vassileva K, Vespe F, Zablotskyj F (2011): New challenges for the CEGRN. Reports on Geodesy, 9-18.

Grenerczy Gy (2012): A concept for the optimal mapping of present-day surface motions of Hungary (in Hungarian with English abstract), Geomatika Közlemények, 15, 109-119.

Grenerczy Gy, Wegmüller U (2011): Persistent scatterer interferometry analysis of the embankment failure of a red mud reservoir using ENVISAT ASAR data. Natural Hazards, 59(2), 1047-1053, DOI: 10.1007/s11069-011-9816-6

Grenerczy Gy, Wegmüller U (2013): Deformation analysis of a burst red mud reservoir using combined descending and ascending pass ENVISAT ASAR data. Natural Hazards, 65(3), 2205-2214, DOI: 10.1007/s11069-012-0470-4

Ihde J, Habrich H, Sacher M, Söhne W, Altamimi Z, Brockmann E, Bruyninx C, Caporali A, Dousa J, Fernandes R, Hornik H, Kenyeres A, Lidberg M, Mäkinen J, Poutanen M, Stangl G, Torres JA, Völksen C (2011): EUREF's Contribution to National, European and Global Geodetic Infrastructures. IUGG XV General Assembly, June 28–July 7 2011 – Melbourne, Australia. In Rizos C – Willis P (Eds.), "Earth on the Edge: Science for a Sustanaible Planet", IAG Symposia, 139, DOI: 10.1007/978-3-642-37222-3_15

Kenyeres A (2011): Categorizaton of permanent GNSS reference stations. Bolletino di Geodesia e Scienze Affini, 69(2–3), 375–390.

Moór A, Frey S, Lambert SB, Titov OA, Bakos J (2011): On the Connection of the Apparent Proper Motion and the VLBI Structure of Compact Radio Sources. Astronomical Journal, 141-178.

Orosz G, Frey S (2012): Radio-optical outlier quasars – a case study with ICRF2 and SDSS. Memorie della Società Astronomica Italiana, 83, 990-993.

Orosz G, Frey S (2013): Optical-radio positional offsets for active galactic nuclei. Astronomy and Astrophysics, 553, A13.

Poutanen M, Ihde J, Bruyninx C, Francis O, Kallio U, Kenyeres A, Liebsch G, Mäkinen J, Shipman S, Simek J, Williams S, Wilmes H (2011): Future and development of the European Combined Geodetic Network ECGN. IUGG XV General Assembly, June 28–July 7 2011 – Melbourne, Australia. In: Rizos C – Willis P (Eds.), "Earth on the Edge: Science for a Sustanaible Planet", IAG Symposia, 139, 121–127, DOI:. 10.1007/978-3-642-37222-3_15

Rózsa Sz, Weidinger T, Gyöngyösi AZ, Kenyeres A (2012): The role of GNSS infrastructure in the monitoring of atmospheric water vapor. Időjárás, 116(1–2), 1–21.

HUNGARIAN CONTRIBUTION TO THE RESEARCH IN GRAVIMETRY, GRAVITY FIELD MODELLING AND GEOID DETERMINATION - IAG COMMISSION 2

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The gravity field related research has relevant tradition and history in Hungary. Nowadays the most important instruments of the modern gravimetry are the absolute gravimeters, which measure the gravity based on the law of free fall. Our study gives a short summary about the related main research fields and applications, where an absolute gravimeter will provide essential contribution. Beyond some theoretical introduction the possible causes of the time-variable gravity are summarized, the importance of the equipment ingravimetric and geodetic networks is emphasized (Csapó et al, 2011a), and its applications in the geodynamical studies are described. The parameters and capabilities of the A10 absolute gravimeter are also shown (Csapó et al. 2011b).

The Hungarian Gravimetric Network (MGH) is maintained by the Geological and Geophysical Institute of Hungary (the former Eötvös Loránd Geophysical Institute). According to its condition in 2014, the MGH contains 20 absolute stations and 446 1st or 2nd order base points. The maintenance work includes checking the status of base points as well as substitution or installation of destroyed or new base points (Csapó and Koppán 2013). Between 2011 and 2014, 8 base points and one absolute station were reinstalled, and one base point was newly installed. These stations were linked to the 3 nearest MGH base points through relative measurements.

In order to improve the reliability and accuracy of the network, the gravity acceleration was redetermined on 11 absolute stations between 2011 and 2014. The measurements were carried out by using the AXIS FG-5 No. 215 absolute gravimeter operated by the staff of Výzkumný ústav geodetický, topografický a kartografický, v.v.i. (VÚGTK, Czech Republic). Before the absolute measurements, vertical gravity gradient (VG) was determined on every station by LCR-G gravimeters, using a 3-level arrangement and at least 6 series of measurements.

Whereas the VG can deviate significantly from the normal value (-0.3086 mGal/m) in Hungary, vertical gradients were determined on further 24 base points between 2011 and 2014.

To utilize the results of the latest absolute and relative measurements, a new adjustment of the MGH was carried out in 2013. The RMS error (μ_0) of the network was ±0.0137 mGal (Csapó 2013).

A gravimeter calibration facility exists in the Mátyáshegy Gravity and Geodynamical Observatory of Geological and Geophysical Institute in Hungary. During the calibration a cylindrical ring of 3200 kg mass is vertically moving around the equipment, generating gravity variations. The effect of the moving mass can be precisely calculated from the known mass and geometrical parameters. The main target of the calibration device was to reach a relative accuracy of 0.1-0.2% for the calibration of Earth tide recording gravimeters. The maximum theoretical gravity variation produced by the vertical movement of the mass is ab. 110 μGal, so it provides excellent possibility for the fine calibration of LCR gravimeters in the tidal range.

The instrument was out of order for many years and in 2012 and 2013 it was renovated and automatized. The calibration process is aided by intelligent controller electronics. A new PLC-based system has been developed to allow easy control of the movement of the calibrating mass and to measure the mass position. It enables also programmed steps of movements (waiting positions and waiting times) for refined gravity changes. All parameters (position of the mass, CPI data, X/Y leveling positions) are recorded with 1 Hz sampling rate. The system can be controlled remotely through the internet.

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As it is well known, variations of the magnetic field can influence the measurements of metal-spring gravimeters, therefore magnetic experiments were carried out on the pillar of the calibration device as well, in order to analyze the magnetic effect of the moving stainless steel mass. During the movements of the mass, the observed magnetic field changes significantly. According to the magnetic measurements and modelling, a correction for the magnetic effect can be applied on the measured gravimetric data series (Kis et al. 2014, Koppán et al. 2014).

An experimental development of a computer controlled photoelectric ocular system applied for the LaCoste and Romberg G949 gravimeter made the continuous observation of time variation of gravity possible. The system was operated for half a year in the Sopronbánfalva Geodynamical Observatory to test its capabilities. The primary aim of this development was to provide an alternative and self-manageable solution instead of the standard electronic (Capacitive Position Indicator) reading of this type of gravimeter and to use it for the monitoring of Earth tides. It, however, turned out (Papp et al, 2012) that this system is sensitive enough to observe the effect of variable seismic noise (microseisms) due to the changes of ocean weather in the North Atlantic and North Sea regions at microGal level (1 μGal = 10^{-8} m/s^2). Up to now little attention was paid to its influence on the quality and accuracy of gravity observations due to the large distance (>1000 km) between the observation site (generally the Carpathian–Pannonian Basin) and the locations (centres of storm zones of the northern hydrosphere) of triggering events. Based on an elementary harmonic surface deformation model the noise level of gravity observations was compared to the spectral characteristics of seismic time series recorded at the same time in the observatory. Although the sampling rate of gravity records was 120 s, the daily variation of gravity noise level showed significant correlation with the variation of spectral amplitude distribution of the analysed high pass filtered (cut-off frequency = 0.005 Hz) seismograms up to 10 Hz. Available daily maps of ocean weather parameters were also used to support both the correlation analysis and the parameterization of the triggering events of microseisms for further statistical investigations. These maps, which were processed by standard image processing algorithms, provide numerical data about geometrical (distance and azimuth of the storm centres relative to the observation point) and physical (mass of swelling water) quantities. The information can be applied for characterizing the state of ocean weather at a given day which may help the prediction of its influence on gravity measurements in the future. Probably it is the first attempt to analyse quantitatively the effect of ocean weather on gravity observations in this specific area of the Carpathian–Pannonian region.

Based on the results described above an Austrian-Hungarian cooperation started to coordinate the Earth tide monitoring in the Alps-Carpathians-Pannonian Basin region to provide the best fitting tidal models for high precision absolute gravimetry on this specific area (Benedek et al. 2014).

In the 20th century, a large amount of torsion balance measurements have been made in Hungary mainly for geophysical purposes. Only the horizontal gradients were used for geophysical prospecting, the curvature gradients measured by torsion balance remained unused. The knowledge of the figure of the Earth, i.e. the geoid is an important problem from many scientific and practical aspects. The gravity data provide the essential basis for the study of the geoid. In the framework of a collaboration between the Geological and Geophysical Institute of Hungary and the Budapest University of Technology and Economics, the collection of past project reports on Eötvös torsion balance measurements has been started for more than a decade. The torsion balance data reported either in report sheets or on maps have been digitized and collected in uniform databases. Recently, the torsion balance database includes about 45000 records containing the curvature and/or gradient data of Eötvös measurements carried out on the historical territory of Hungary.

Gravity gradients are very important and useful data in geodesy. With the help of the gradients precise vertical deflections can be calculated by interpolation and the fine structure of the geoid can be derived. Based on the horizontal and the curvature gradients of gravity the full Eötvös tensor (including the vertical gradients) can be derived (Völgyesi 2012a, 2012b). A summary of the possible applications of torsion balance measurements can be seen on Figure 1.

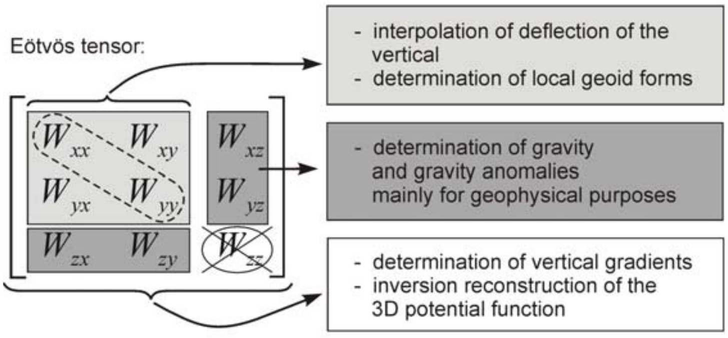

Figure 1. Possible applications of the torsion balance measurements

A laboratory has been developed to make various tests and measurements by the Eötvös torsion balance in the Budapest University of Technology and Economics. These tests were made with our AUTERBAL (Automatic Eötvös-Rybar Balance) equipment. Cameras with CCD sensors were mounted on the reading arms for automatic readout (Völgyesi and Ultmann 2012). Control of the cameras and taking shots was computer-driven with the necessary software developed under the Linux operating system. Since with these cameras several shots and readings per second for a long period of time can be taken, a new perspective is ahead of us to observe hitherto unknown phenomena.

Four shots per second were taken within several, 40-50 min long records in all azimuths to study damping of the balance. Time resolution was increased up to 12 shots per second (i.e. 0.08 s sampling period) to examine the finest details of the damping curve, whereas two 24-hour long records were taken to study possible long-period kinetics of the balance. It became feasible, for example, to study damping characteristics of the device in far more detail and accuracy than it was previously possible.

The main problem of torsion balance measurements is the long damping time, however it is possible to significantly reduce it by our solution. The damping curve can be precisely determined by CCD sensors as well as computerized data collection and evaluation. The first part of this curve makes it possible, at least theoretically, to estimate the final position of the arm at rest. A finite element solution of a fluid dynamics model based on Navier-Stokes equations was investigated to solve this problem.

Our study showed that these achievements may lead to making it possible in the near future to cut down measurement time in each azimuth from 40 to 10 minutes to obtain estimate of the home position of the balance with enough accuracy (Tóth et al. 2014).

Before starting the measurements by torsion balance it is necessary to set the starting azimuth to the astronomical North direction, using a special compass enclosed with the pendulum. Using this special compass the magnetic declination (angle between the astronomical and the magnetic North direction) should be taken into consideration.

The most common geodetic and navigational problem is to determine the precise geomagnetic declination on a given place and time. For lack of the known declination the compass cannot be used with reasonable accuracy neither for geodetic nor for navigational purposes. Determination of the true value of the magnetic declination by field measurements is a complicated and time consuming task. If such a field measurement is carried out, the great advantages, the speed and simplicity, of the application of the compass would be lost. The other remaining possibility is to determine the normal value of declination by computation. In practice, of course, the real value of the declination would be needed, but instead of this, the normal value is used only as an approximation. However, the normal value of the declination, except under very rare circumstances does not correspond to the real value and difference between these two values is the declination anomaly. Using the compass for geodetic or navigation purposes, declination anomaly is the error which biases the determined northern direction. In our study determination of the normal value of geomagnetic declination

$D(\varphi, \lambda, t)$ is discussed and the possible error sources of the determination is attempted to estimate (Völgyesi and Csontos 2014a, 2014b).

Linear variation of the gravity gradients between the adjoining network points is an important demand for different interpolation methods in geodesy (e.g. interpolation of the vertical deflection, geoid computations, and interpolation of the gravity values or the vertical gradients of gravity). To study the linearity of gravity gradients, torsion balance measurements were made both at the field and in a laboratory: one is at the southern part of the Csepel Island, and the other in the Geodynamical Laboratory of Loránd Eötvös Geophysical Institute in the Mátyás Cave.

On Figure 2 the results of the computations are summarized for the 7 points of the earlier torsion balance measurements E220, E218, E238, E208, E206, E204, E207 with and without topographic reduction respectively, and the results for the new torsion balance measurements 3.a-3.b-3.c-3.d-3.e between the points E238 and E208 can be seen.

Based on our results, decreasing the length of the measuring line improves the linearity of gravity gradients (since it increases the values of R^2). Data comparison shows that decreasing distances between the torsion balance points from 1000-1500 m to 150-300 m does not increase significantly the improvement of linearity (Völgyesi and Ultmann 2014).

Finally, it is concluded that the mean point density of the earlier torsion balance measurements does not meet the requirement of linear variation of gravity gradients between neighbouring network points.

Moreover the problem could not be solved even applying topographic reduction. The results of our investigations show that the linearity of the gravity gradients mainly depends on the given point density and the geological fine structure of rocks and shallow subsurface density. It seems the given point density of the earlier torsion balance stations may not be enough for some geodetic purposes, moreover the problem could not be solved applying topographic reduction of gravity gradients (Völgyesi and Ultmann 2014).

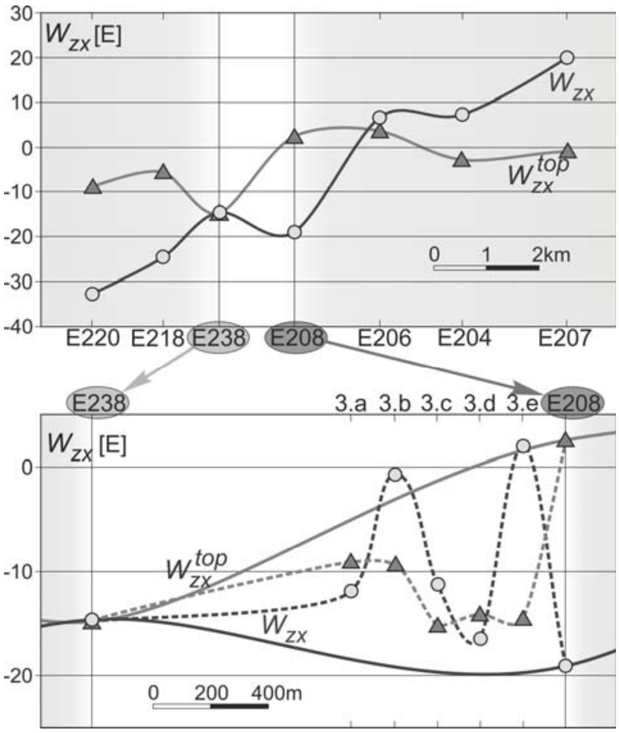

Figure 2. Linearity test of the torsion balance measurements: changing of the horizontal gradient W_{zx} on the original points (upper part of the figure) and on the denser net (lower part of the figure)

Further investigations are planned to study the effects of the nonlinearity on geodetic quantities, regarding e.g. the deflection of the vertical and precise geoid computation. Investigations would be important to study the connection between the spatial structure of the gradients of gravity field and the geological fine structure of rocks near-surface inhomogeneities and shallow subsurface density.

All the elements of the Eötvös tensor can be measured by torsion balance, except the vertical gradient. The knowledge of the real value of the vertical gradient is more and more important in gravimetry and geodesy (Völgyesi et al. 2012).

Determination of the 3D gravity potential $W(x,y,z)$ can be produced by inversion reconstruction based on each of the gravity data W_z (= g) measured by gravimeters and gravity gradients W_{zx}, W_{zy}, W_{Δ}, W_{xy} measured by torsion balance. Moreover, vertical gradients W_{zz} measured directly by gravimeters have to be used as reference values at some points. First derivatives of the potential W_x, W_y (it can be derived from the components of deflection of the vertical) may be useful for the joint inversion, too. Determination of the potential function has a great importance because all components of the gravity vector and the elements of the full Eötvös tensor can be derived from it as the first and the second derivatives of this function. The second derivatives of the potential function give the elements of the full Eötvös tensor including the vertical gradients, and all these elements can be determined not only at the torsion balance stations, but anywhere in the surroundings of these points.

For checking the 3D inversion algorithm, test computations were performed at the south part of the Csepel Island where torsion balance and vertical gradient measurements are available. There were about 30 torsion balance, 21 gravity and 27 vertical gradient measurements on our test area. Only a part of the 27 vertical gradient values was used as initial data for the inversion and the remaining part of these points were used for controlling the computation (Völgyesi et al. 2012).

The 27 vertical gradient measurement points can be seen on Figure 3, the structure and the spatial distribution of the values of vertical gradients is illustrated by isolines. The values of the isolines on the Figure 2 is in mGal/m (1 mGal/m = 10^{-5} 1/s^2 = 10 000 E =10 000 Eötvös Unit), coordinates are in meters in the Hungarian Unified National Projections (EOV) system.

Comparing the measured vertical gradient data to the computed value at the 6 controlling points the root mean square of the differences is ±11.6 μGal/m which is the order of magnitude of the measurements of the vertical gradient.

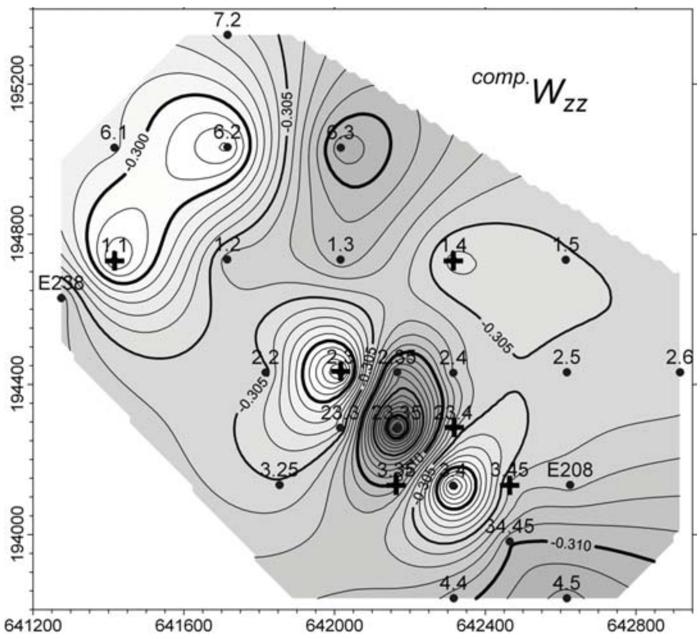

Figure 3. Computed vertical gradients W_{zz} from the joint inversion, values are in mGal/m

So this is a strong demonstration of the applicability of the inversion reconstruction of the gravity potential for the determination of the vertical gradients based on torsion balance data.

Creating the optimal geometry of the interpolation net is an important part of the computation of deflection of the vertical based on torsion balance measurements. The triangle network fitted to the torsion balance stations should be designed to be adequate for the interpolation, namely the distances between the adjacent points should be minimal and the curvature gradients between that selected torsion balance points should be as linear as possible. So far this task has been performed manually with huge efforts furthermore it has not always succeeded in finding the optimal geometry. Delaunay triangulation offers a new opportunity to solve the problem by computer. Selecting the most suitable pairs of points, the automatic creation of the interpolation network is successful by an appropriate modification of the Delaunay triangulation (Ultmann and Völgyesi 2013).

Global gravity field models are most recently refined by GOCE data. As GOCE presents band limited observations, an efficient spectral filtering method for eliminating the unreliable content of the observations is of high relevance. Polgár et al. (2013) has derived an appropriate filter for the purpose. Földváry et al. (2014a) has derived the errors of the filtered gravity gradients using the classical error propagation laws. Földváry et al. (2014b) then implemented the semi-analytical approach for the band-limited GOCE gravity gradient observations.

The unprecedently low altitude of the GOCE satellite (demonstrated by Figure 1 of Somodi and Földváry 2011) is also challenging from the orbit determination point of view. Considering purely dynamic orbits, error estimate of GOCE orbit determination has been performed by Somodi and Földváry (2011, 2012). The studies analyzed the "ever" effect of the near surface mass variations by inclusion of high degree gravity field information, an ocean tide model, a reliable estimate of solid earth tides and of polar motion. The investigation has been extended to GPS satellites (at altitude of 20200 km or so) as well, as they serve as the basis of the orbit determination of the GOCE satellite.

The GRACE satellites delivers monthly resolution gravity models enabling the determination of annual or longer periodic mass variations. In a warming climate, it is critical to accurately estimate ice-sheet mass balance to quantify its contribution to present-day sea level rise. In Földváry (2012) temporal mass variations in Antarctica are investigated based on monthly GRACE gravity solutions. In order to diminish the effect of large uncertainties in glacial isostatic adjustment models, an approach is developed to estimate the acceleration of the ice-sheet mass, assuming the presence of accelerated melt signal in the GRACE data. Though the estimate of accelerated melt does not provide an absolute value for the volume of the melting ice, it was found to be a viable tool for characterizing the present-day ice sheet mass balance. The method has been refined by separation of different regions of melt rates by Földváry et al. (2014).

A new quasigeoid model for Hungary was determined by combining gravity data, GPS/levelling and vertical deflections (Tóth and Szűcs 2011). Reduction of the measurements was performed by using Earth Gravitational Model 2008 (EGM2008) and Shuttle Radar Topographic Mission (SRTM) elevation data sets. Calculation method was Least Squares Collocation (LSC) with Forsberg's self-consistent planar logarithmic covariance model. In the computations the weights of GPS/levelling data were large, in this way normal heights obtained from levelling are consistent with GPS heights and with the quasigeoid model. Astrogeodetic-gravimetric, pure astrogeodetic and pure gravimetric solutions have been calculated besides the combined solution to investigate the discrepancies among the different models. The combined quasigeoid model fits to the GPS/levelling data with standard deviation of ±4.9 cm, nevertheless at some GPS/levelling sites large differences were indicated. Comparison of the astrogeodetic-gravimetric and combined quasigeoid solutions shows a mean bias of -2.74 cm and a standard deviation of ±3.04 cm. These two solutions are very close to each other in most parts of the country (Figure 4.), except for the region in southeast, where the GPS/levelling observations do not fit well to the other observation types. This region is located in the Great Hungarian Plains, which is covered by young, unconsolidated sediments. In this context the main problem is that levelling and GPS measurements do not refer to the same epoch. First-order polygons of the Unified National Vertical Network (EOMA) were measured in the 1970s, the OGPSH network was established in the 1990s.

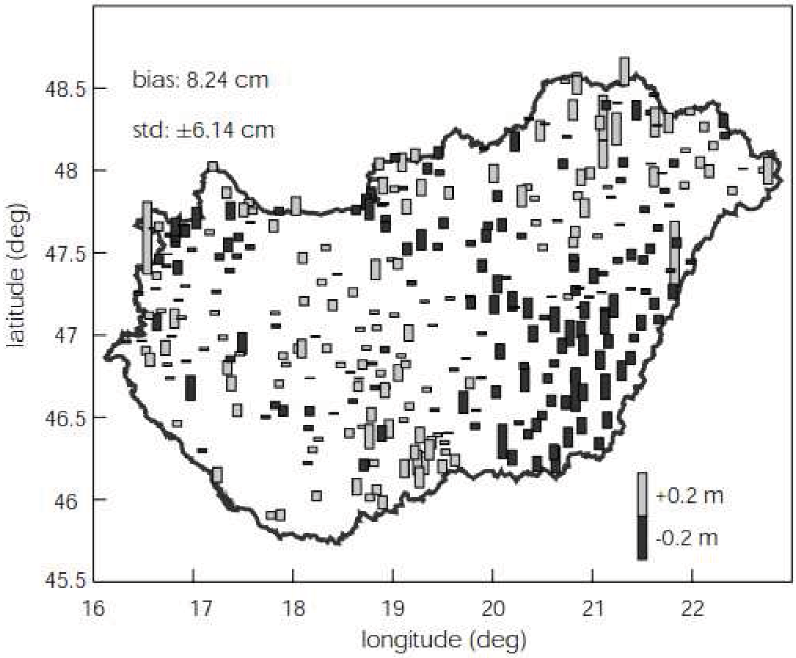

Figure 4. Differences of astrogeodetic-gravimetric quasi-geoid heights at OGPSH sites (bias removed)

Furthermore, levelling of the GPS/levelling sites was achieved using the third order levelling network of the country, not the first order one and besides of this GPS observations were carried out using rapid measurement technology. Processing of re-measurement data of part of the EOMA levelling network confirms a suspected recent subsidence.

Recent high degree geopotential models and certain computational procedures in physical geodesy require the evaluation of integrals (truncation coefficients) that are products of very high degree Legendre polinomials (or functions) with various kernels over a given domain. The oscillating character of integrands (more than 10,000 zeros) makes it difficult to evaluate such integrals. A highly accurate quadrature has been developed for fast computation of these integrals based on the Glaser-Liu-Rokhlin root finding algorithm and Gauss-Lobatto quadrature between the roots (Tóth and Fáncsikné 2013). Our procedure successfully eliminates the instability of the recursive algorithm developed by MK Paul for the solution of Stokes' integral at very high degrees. It can be applied in several fields of physical geodesy, e.g. for gravity field modelling based on surface or satellite gravity gradients.

Szűcs (2012) presents the validation of the first and second generation GOCE-only models using terrestrial data sets in Hungary. Besides GOCE-based GGMs satellite only GRACE models were evaluated to assess the improvements by GOCE observations with respect to GRACE in gravity field determination. EGM2008 as the state-of-the-art model and SRTM3 elevation model were applied to provide that measurements involving Hungarian data sets and model derived gravity field functionals have almost the same spectral content. Results with GPS-levelling and gravity data support that there is an improvement in the determination of medium-wavelength parts ($200 < \lambda < 250$ km) of the gravitational field with GOCE models. Although vertical deflections characterize the short-wave part of the gravity field, they are also capable of sensing the advancement of SGG observations.

Szűcs et al. (2014) investigated the spectral characteristics of terrestrial data sets mentioned above. They estimated the spectral contribution of gravity anomalies, vertical deflections and gravity gradients using both Fourier PSD and covariance analysis depending on the spatial distribution of data points. From the spectral characteristics of terrestrial measurements weights for spectral combination of a global gravity field model, gravity and gravity gradient data were derived. Besides the frequency domain investigations the information content regarding the different wavelength structure comprised in terrestrial and EGM2008 model was investigated also in the space domain based on covariance analysis. As a combined validation process the gravity degree variances were transformed to the necessary auto- and cross covariance functions to predict geoid height from gravity anomaly, which ensures an independent validation process of the computed spectrum.

Special attention was paid to the evaluation of SRTM3 surface model which has been extensively used for residual terrain modelling recently. On a well surveyed local, partly forest-clad area Papp and Szűcs (2011) determined its deviation from a digital terrain model digitized from 1:10 000 topographic maps and found close correlation between the deviations and canopy heights reaching sometimes 10 m – 15 m. They transformed the height differences to a 3D mass density model discretized by rectangular prisms to derive gravity anomalies, geoid heights and second derivatives by forward gravitational modelling. The direct gravitational effect of the differences between surface and terrain models is insignificant (< 1 mm) on geoid heights but it is considerable if terrain corrections for gravity anomalies and torsion balance measurements are required for geophysical interpretation.

Szűcs and Benedek (2014) extensively investigated in which frequency band gravity gradients measured by Eötvös torsion balance could contribute to the refinement of gravity field features. They used different kernel modifications of the gradiometric boundary value problems in the numerical evaluation of integral transforms, especially the integrals transforming horizontal gravity gradients to vertical gravity gradient, to gravity anomaly and to potential. Closed-loop differences between gravity field quantities derived from integral transforms and their “true” value obtained from EGM2008 GGM were synthetically analysed for various wavelength bands both in space and in frequency domain.

In order to support the evaluation of different geoid solutions based on physical approaches (e.g. gravimetric geoid) the development of a digital zenith camera system (DZCS) has been started in the Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences. DZCS-s are astronomical-geodetic measurement systems for the observation of the direction of the plumb line. The DZCS key component is a pair of tiltmeters for the determination of the instrumental tilt with respect to the plumb line. Highest accuracy (i.e., 0.1 arc-seconds or better) is achieved in practice through observation with precision tiltmeters in opposite faces (180° instrumental rotation), and through application of rigorous tilt reduction models. A novel concept proposes the development of a hexapod- (Stewart platform)-based DZCS. However, hexapod-based total rotations are limited to about 30°-60° in azimuth (equivalent to ±15° and to ±30° yaw rotation), which raises the question of the impact of the rotation angle between the two faces on the accuracy of the tilt measurement. Hirt et al. (2014) investigated the expected accuracy of tilt measurements to be carried out on future hexapod-based DZCS, with special focus placed on the role of the limited rotation angle. A Monte-Carlo simulation study is carried out in order to derive accuracy estimates for the tilt determination as a function of several input parameters, and the results are validated against analytical error propagation. As main result of the study, limitation of the instrumental rotation to 60° (30°) deteriorates the tilt accuracy by a factor of about 2 (4) compared to a 180° rotation between the faces. None the less, a tilt accuracy at the 0.1 arc-second level is expected when the rotation is at least 45°, and 0.05 arc-second (about 0.25 microradian) accurate tilt meters are deployed. Consequently a hexapod-based DZCS can be expected to allow sufficiently accurate determination of the instrumental tilt. This provides supporting evidence for the feasibility of such a novel instrumentation.

In view of the recent re-measurement campaign of the Hungarian Levelling Base Network the role of gravimetric observations was studied (Kratochvilla et al. 2011). Adjustment of the network was performed using geopotential numbers, which can be converted into an equivalent metric quantity, the normal heights. The normal heights can also be derived directly from raw observed height differences by adding two normal correction terms, K_1 and K_2. Both of them have been determined based on an earlier network adjustment. The second term, K_2 is a function of Δg along the levelling line, which is implicitly an estimate of the effect of long-wavelength gravity field. The accuracy demand of gravimetric data for normal correction under different terrain conditions was discussed.

In the recent years several investigations have been performed on the newly constructed subway line of Budapest, line no. 4 (Metro 4). From the physical geodetic aspect the effect of the excavation on the gravity field (potential surfaces, plumb lines) is of interest. In fact, the change of the gravity field may affect the monitoring of the vertical deformation during the construction, as the method of repeated leveling assumes the local horizontal and vertical to be constant in time (Égető and Földváry 2011). In the study of Égető et al. (2014) the direct effect of the mass loss on leveling measurements due to the excavation of the two tunnels and of the stations of Metro 4 has been considered. The corresponding numerical accuracy issues are presented by Égető and Földváry (2013). The method has been refined by inclusion of the indirect effect of the actual vertical deformations (subsidence) of the physical surface on the leveling in Égető et al. (2013). According to the results, under certain arrangements of the leveling line, the direct effect can reach the 5 μm order of magnitude, which is equivalent to the precision of the precise leveling, while the indirect effect due to subsidence is below 0.1 μm, thus negligible.

References

Benedek J, Kis M, Koppán A, Meurers B, Papp G, Szűcs E, Blaumoser N (2014): Comparative measurement of 3 relative spring gravimeters and the GWR SG025 for calibration purposes. COBS Journal, 2014(3), 19.

Csapó G, Kenyeres A, Papp G, Völgyesi L (2011a): Analysis of the influential effects of the absolute gravity measurements (In Hungarian). Geodézia és Kartográfia, 63(1), 8-13.

Csapó G, Kenyeres A, Papp G, Völgyesi L (2011b): Plans and works of the applications of the absolute gravimetry in Hungary (In Hungarian). Geodézia és Kartográfia, 63(2), 4-9.

Csapó G (2013): Az országos gravimetriai hálózat (MGH) 2013. évi kiegyenlítése és a hálózat megbízhatósági vizsgálata. Geodézia és Kartográfia, 65(11-12), 4-6.

Csapó G, Koppán A (2013): The results and works of the latest adjustment of Hungarian Gravimetric Network (MGH-2010). Acta Geod. Geoph. Hung., 48(1), 9-16, DOI: 10.1007/s40328-012-0001-5

Égető Cs, Földváry L (2011): The effect of the Metro 4 tunnel system on the gravity field (in Hungarian with English abstract), Geomatikai Közlemények, 14(1), 17-26.

Égető Cs, Földváry L (2013): Numerical accuracy analysis of modelling excavation induced gravity field variations, In: Proceedings in Global Virtual Conference, GV-CONF 2013, 8-12 April 2013, Žilina, Slovak Republic, Editors: Z. V. Sovreski, M. Mokryš, Š. Badura, A. Lieskovský, EDIS - Publishing Institution of the University of Zilina.

Égető Cs, Földváry L, Huszák T (2013): The effect of tunnelling on repeated precise levelling measurements for vertical deformation control of the Metro 4 project (In Hungarian). Journal of Geodetic Science, 3(2), 95-102.

Égető Cs, Rehány N, Földváry L (2014): Variations of the gravity field due to excavations of the Budapest Metro 4 subway line. Periodica Polytechnica Civil Engineering, 58(2), 131-136.

Földváry L (2012): Antarctica accelerated melting from GRACE monthly gravity field solutions. In: Geodesy for Planet Earth, Proceedings of IAG Symposium in Buenos Aires, IAG Symposia, 131, 591-597.

Földváry L, Kiss A, Su ZX, Wang GC, Wang L (2014): Accuracy investigations of GRACE-borne ice mass variations in Antarctica, Earth Science Frontiers, (in print).

Földváry L, Sujbert L, Polgár Zs (2014a): On the filtering of GOCE gravitational gradients and related accuracy aspects (in Hungarian with English abstract). Geomatikai Közlemények, 17, 33-45.

Földváry L, Kemény M, Asbóth P (2014b): Semi-analytical approach for adjusting GOCE SGG observations. 9th International Symposium on Applied Informatics and Related Areas – AIS2014, Székesfehérvár, 12 November 2014, 31-36.

Hirt C, Papp G, Pál A, Benedek J, Szűcs E (2014): Expected accuracy of tilt measurements on a novel hexapod-based digital zenith camera system: a Monte-Carlo simulation study. Meas. Sci. Technol., 25(8), DOI: 10.1088/0957-0233/25/8/085004

Kis M, Koppán A, Kovács P, Merényi L (2014): Moving-mass gravimeter calibration in the Mátyáshegy Gravity and Geodynamical Observatory (Budapest). Geophysical Research Abstracts, 16, EGU2014-14816.

Koppán A, Kis M, Kovács P, Merényi L. Vadász G (2014): Observatory gravimeter calibration results with magnetic correction. Conference papers of 6th Croatian-Hungarian and 17th Hungarian Geomathematical Congress, 145-150.

Kratochvilla K, Földváry L, Tóth Gy (2011): Effect of long-wavelength gravity field on the normal correction of first order Uniform National Height System (in Hungarian with English abstract). Geomatikai Közlemények, 14(1), 7-16.

Papp G, Szűcs E. (2011): Effect of the difference between surface and terrain models on gravity field related quantities. Acta Geod. Geoph. Hung., 46 (4), 441-456, DOI: 10.1556/AGeod.46.2011.4.6

Papp G, Szűcs E, Battha L (2012): Preliminary analysis of the connection between ocean dynamics and the noise of gravity tide observed at the Sopronbánfalva Geodynamical Observatory, Hungary. Journal of Geodynamics, 61, 47-56, DOI: 10.1016/j.jog.2012.07.004

Polgár Z, Sujbert L, Földváry L, Asbóth P, Ádám J (2013): Filter design for GOCE gravity gradients. Geocarto International, 28(1), 28-36, DOI:10.1080/10106049.2012.687401

Somodi B, Földváry L (2011): Application of numerical integration techniques for orbit determination of state-of-the-art LEO satellites. Periodica Polytechnika Civil Engineering, 55(2), 99-106.

Somodi B, Földváry L (2012): Accuracy of numerical integration techniques for GOCE orbit determination. In: Mokryš M, Lieskovský A (Eds.), Proceedings in Advanced Research in Scientific Fields: The 1st Virtual International Conference, Zilina, Slovakia, 03-07 December 2012, EDIS Zilina University Publishers, Zilina, 1578-1583.

Szűcs E (2012): Validation of GOCE time-wise gravity field models using GPS-levelling, gravity, vertical deflections and gravity gradient measurements in Hungary. Periodica Polytechnika Civil Engineering, 56(1), 3-11.

Szűcs E, Benedek J (2014): Possible applications of Eötvös torsion balance measurements in the practical evaluation of gradiometric boundary value problems (in Hungarian with English abstract). Geomatikai Közlemények, 17, 45-58.

Szűcs E, Papp G, Benedek J (2014): A study of different wavelength spectral components of the gravity field derived from various terrestrial data sets. Acta Geodaetica et Geophysica, 49(3), 327-342.

Tóth Gy, Szűcs E (2011): On the determination of a new combined EGM2008 based quasi-geoid model for Hungary. Acta Geodaetica et Geophysica Hungarica, 46(4), 417-430.

Tóth Gy, Fáncsikné HÉ (2013): Fast computation of truncation coefficients for the extended Stokes function (in Hungarian with English abstract). Geomatikai Közlemények, 16, 51-62.

Ultmann Z, Völgyesi L (2013): Creating optimal geometry by Delaunay triangulation for interpolation of deflection of the vertical (in Hungarian with English abstract). Geomatikai Közlemények, 16, 63-72.

Völgyesi L (2012a): A gravimetria mai jelentősége és helyzete Magyarországon. Magyar Tudomány, 173(6), 706-723.

Völgyesi L (2012b): Application and importance of the torsion balance measurements in geodesy (in Hungarian with English abstract). Geomatikai Közlemények, 15, 9-26.

Völgyesi L, Dobróka M, Ultmann Z (2012): Determination of vertical gradients of gravity by series expansion based inversion. Acta Geodaetica et Geophysica Hungarica, 47(2), 233-234, DOI: 10.1556/AGeod.47.2012.2.11

Völgyesi L, Laky S (2014): Reducing the Measurement Time of the Torsion Balance. Earth on the Edge: Science for a Sustainable Planet (Eds: Rizos C, Willis P) International Association of Geodesy Symposia, Vol. 139, Springer Verlag, Berlin, Heidelberg, 341-347.

Völgyesi L, Ultmann Z (2012): Reconstruction of a torsion balance, and the results of the test measurements. In: Kenyon S, Pacino MC, Marti U (Eds.): Geodesy for Planet Earth, Buenos Aires, Argentina. 2009. International Association of Geodesy Symposia, Vol. 136, Springer Verlag, Berlin, Heidelberg, 289.

Völgyesi L, Ultmann Z (2014): High-Resolution Measurements of Non-Linear Spatial Distribution of Gravity Gradients in Hungary. Earth on the Edge: Science for a Sustainable Planet (Eds: Rizos C, Willis P) International Association of Geodesy Symposia, Vol. 139, Springer Verlag, Berlin, Heidelberg, 435-444.

Völgyesi L, Csontos A (2014a): Importance of the geomagnetic field in geodesy and navigation (in Hungarian). Geodézia és Kartográfia, 66(5-6), 4-9.

Völgyesi L, Csontos A (2014b): Determination of the geomagnetic North for geodesy and navigation (in Hungarian). Geodézia és Kartográfia, 66(7-8), 4-7.

HUNGARIAN CONTRIBUTION TO THE RESEARCH OF EARTH ORIENTATION, EARTH ROTATION, POLAR MOTION, NUTATION AND PRECESSION – IAG COMMISSION 3

Péter Varga, Bálint Süle

The absence of long series of complete earthquake data is a serious difficulty in seismic hazard research as well as in preparation of the worst-case models for the location, size, and peak ground acceleration (PGA) of potential future earthquakes. That is why predictions based on probabilistic and to a lesser extent on deterministic principia do not fit in aptly with observed reality and do not help to determine reliable design parameters even in the comparatively well-known past occurrences, despite their evidently serious mathematical foundations (Varga 2011a). By means of combined use of geodetic strain rate data and the seismic moment data set, the probable recurrence time was determined for past seismic events. This combination represents a new and independent approach to estimate the order of magnitude of future seismic activity. Using a modified version of Kostrov's equation and the catalogue of seismic moments, the recurrence of the strongest earthquakes of a source area was estimated. It was found in Varga (2011b) that the recurrences in a given source zone in case of earthquakes $M_W \geq 9.0$ are of the order of some hundred years. For the large and medium earthquakes the expected Δt is well above some 10^3 years.

The geographical locations of great ($M \geq 7$) earthquakes, first of all the shallow ones, delineate the lithospheric plates, among them primarily the lithospheric slabs penetrating into the mantle. Only a part of subduction zones are marked beside shallow by deep earthquake zones too. The estimated global length of subduction zones is $6.7 \cdot 10^4$ km, while length of those which are related to deep events – according to our calculations carried out with a methodology based on inverse mapping equations and applied to a given map projection – is only $1.9 \cdot 10^4$ km (28%). For the aims of the present study maps completed with Mollweide projection were in use. Examination of the seven source zones circumscribed in Varga and Süle (2014), aside from one (Honsu-Kamchatka), in which both shallow and deep $M \geq 7.0$ earthquakes occur, shows that linear distribution of deep earthquakes is considerably shorter than that found for the shallow earthquakes, which determine the length of the zone (Figure 1). The distribution of earthquake energy release along latitudes has no correlation with the number of earthquakes and with the distribution of topographic structures usually interpreted as subduction zones. At the same time a clear axial co-ordination of radiated seismic energy is demonstrated with maxima at latitudes close to critical values (±45°).The radiated energy has the highest peak close to 0°±5°, with respect to the tectonic equator, which is inclined about 30° with respect to the geographic equator.

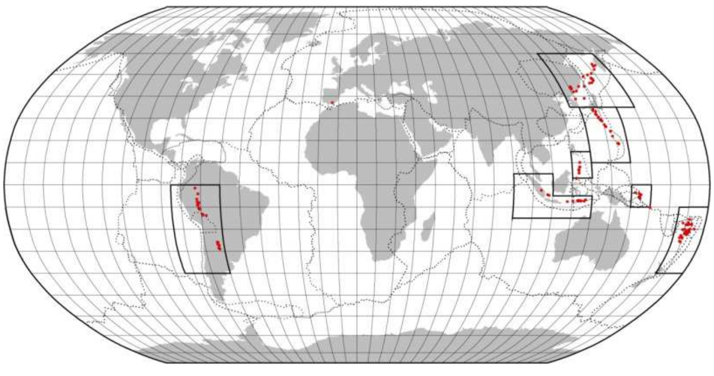

Figure 1. The geographical locations of deep $M \geq 7$ earthquakes. The epicentres are marked with dotes, the boundaries of investigated source zones are shown with thick straight lines

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This fact indicates the presence of external forces that influence seismicity and it is consistent with the fact that Gutenberg-Richter law is linear, for events with $M > 5$, only when the whole Earth's seismicity is considered, and it points at an astronomical control on plate tectonics. This external factor is most probably the despinning (reduction of the Earth's angular rotation) of the Earth axial rotation caused primarily by tidal friction due to the Moon (Varga et al. 2012b, Varga and Süle 2014).

Examining variations in the Earth's rotation during the geological history the relationship between the axial despinning and changes in the structure of the planetary interior was investigated. It was found that for the present epoch a growth rate of the core comprised between 1 and 10 mm/cy seems to be plausible guess, leading to a relative decrease of LOD comprised roughly between 10 and 100 μs/cy. Such values do not affect significantly the observed secular increase of LOD caused by tidal braking, which amounts to about 1.79 ms/cy. However, in the remote geological past, before Phanerozoic, the effect of the core growth may have been much more important, because the total change of LOD associated with core formation has been estimated to be 2.4 hours for an initially undifferentiated old Earth, and 3.1 hours for an initially undifferentiated hot Earth. Paleo-LOD measurements see to far slow core formation during the Proterozoic contrarily to the now largely prevailing hypothesis that the iron core formed very early in the Earth's history and during a geologically short time interval. From recent estimates of the age of the inner core based on the theory of thermal evolution of the core, it was estimated that nowadays the growth of the inner core generates a relative decrease of 2 to 7 μs/cy, what may contribute to the observed overall secular increase of LOD caused mainly by tidal friction (i.e., 1.72 ms/cy) by a relative decrease of 2 to 7 μs/cy, what does not produce any detectable change of length of day (Denis et al. 2011).

From the study of palaeogeographical maps for the last 600 Ma it was concluded that during this time-interval of Earth's history the tectonic activity had a significant change: increase occurred in the lengths of mid-ocean ridges (spreading centres) and subduction zones. In the same time there has been a large change of the length of the shelf zones. This change can explain contemporary change of the despinning rate from about 0.35 ms/cy to about 1.79 ms/cy (Varga et al. 2012c). The mechanisms that move plates are not entirely understood. In order to clarify the issue the compilation of palaeogeographical maps in the time span 0.6 Ga BP to Present in terms of (a) the ratio between continental to oceanic crust areas in order to estimate the speed of continental growth, and (b) the surface motion of continental plates under the influence of global forces of tidal friction and Eötvös force ("pole-fleeing") was investigated. It was concluded that the area of the continents during the Phanerozoic was continuously growing and it exhibited a rate ~0.5 km^3/yr. On the other hand, it was found that beside the westward oriented tidal frictional forces the Eötvös force can possibly play also a role in the plate tectonic processes. In Figure 2 it is shown that the continental plates on average tend to find a position close to the equator during the whole investigated 600 Ma time-interval (Varga et al. 2014a).

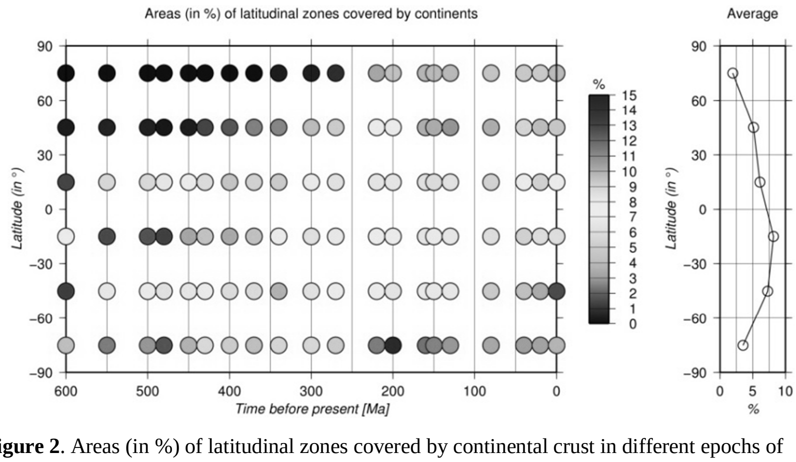

Figure 2. Areas (in %) of latitudinal zones covered by continental crust in different epochs of Late Proterozoic and Phanerozoic and the average distribution

Based on mathematical considerations an extension of the MacCullagh formulae was derived. In particular, for excitation functions with a vanishing harmonic coefficient of degree zero, the diagonal incremental moments of inertia can be expressed by excitation coefficients. Four types of excitation functions are considered: (i) tidal excitation, (ii) loading potential, (iii) centrifugal potential, and (iv) transverse surface stress. One application of the results could be a model computation of the length-of-day variations and polar motion, which depend on the moments of inertia (Varga et al. 2012a).

In order to study theoretically the geodynamic behaviour of the Earth on a short (elastic Earth) and on a long scale of geological periodic variations (for an almost perfectly liquid Earth), the changes of the moment of inertia are decomposed into two parts: the first, described by a volume integral, explains the effect of the density variations, while the second gives the impact of the surface variations using a surface integral. Based on mathematical considerations it was concluded that only minor changes occurred during time interval from 2.5 to 0.5 Ga BP in the main features of the inner structure of our planet which was practically finished at the very beginning of the history of the Earth. This conclusion coincides with recent results of geochemists who concluded that the formation of the core and of the main features of the mantle was completed 3.5-4.0 billion years ago (Varga et al. 2014b).

References

Denis C, Rybicki KR, Schreider AA, Tomecka-Suchon S, Varga P (2011): Length of the day and evolution of the Earth's core in the geological past. Astronomisches Nachrichten, 332(1), 24-35.

Varga P (2011a): Earthquake prediction (in Hungarian). Hungarian Science, 7, 826-843.

Varga P (2011b): Geodetic strain observations and return period of strongest earthquakes of a given seismic source zone. Pure and Applied Geophysics, 168(1-2), 289-296, DOI: 10.1007/s00024-010-0112-2

Varga P, Grafarend E, Engels J (2012a): From Gravitostatics to Gravitodynamics:The space-time dependent gravity field by Eulerian versus Lagrangean force fields: Examples. Geophysical Research Abstracts, Vol.14, EGU2012-14247, EGUGeneral Assembly 2012.

Varga P, Krumm F, Riguzzi F, Doglioni C, Süle B, Wang K, Panza GF (2012b): Global pattern of earthquakes and seismic energy distributions: insights for the mechanisms of plate tectonics. Tectonophysics, 530-531, 80-86, DOI:10.1016/j.tecto.2011.10.014

Varga P, Krumm FW, Doglioni C, Grafarend EW, Panza G, Riguzzi F, Schreider A, Sneeuw N (2012c): Did a change in tectonic regime occur between the Phanerozoic and earlier Epochs? Rendiconti Lincei, 23(2), 139-148, DOI 10.1007/s12210-012-0172-6

Varga P, Süle B (2014): Great deep earthquakes (in Hungarian). World of Science, 145(5), 202-206.

Varga P, Krumm FW, Grafarend EW, Sneeuw N, Schreider AA, Horváth F (2014a): Evolution of the oceanic and continental crust during Neo Proterozoic and Phanerozoic. Rendiconti Lincei, 25(2), 255-263, DOI: 10.1007/s12210-014-0298-9

Varga P, Grafarend E, Engels J (2014b): Temporal variations of the polar moment of inertia and the second-degree geopotential. Geophysical Research Abstracts Vol.16, EGU2014-1745, 2014 EGU General Assembly 2014.

HUNGARIAN CONTRIBUTION TO THE RESEARCH ON EARTH TIDES AND TECTONIC MOVEMENTS OBSERVED BY EXTENSOMETERS – IAG COMMISSION 3

Gyula Mentes[1], Ildikó Eperné Pápai[1], Katalin Gribovszki[1], Márta Kis[2], András Koppán[2]

Recent tectonic movements have been recorded by extensometers in three stations (Budapest, Sopronbánfalva, Vyhne) in the Pannonian Basin (Figure 1) for more than two decades. All extensometers are assembled from quartz tubes of the same parameters. The capacitive sensors of the extensometers and the calibration device and calibration method of the instruments were developed and made in the MTA CSFK Geodetic and Geophysical Institute. This fact renders the consistent measurement of small tectonic movements possible. In addition to the instrumentation, properties of the observatories and the environmental effects, the quality of extensometric measurements strongly depends also on the anelasticity and lateral heterogeneities of the Earth's mantle. Intensive research work was done to investigate the above mentioned effects to increase the reliability of the interpretation of tectonic measurements. In the first step of the research work the results of extensometric measurements obtained in the Sopronbánfalva Geodinamic Observatory (SGO) and in the Mátyáshegy (Budapest) Gravity and Geodynamic Observatory (MGGO) were analysed and compared (Eperné Pápai et al. 2014, Mentes et al. 2014). It was pointed out that the tidal transfer of the MGGO is better than that of the SGO since the tidal transfer in the diurnal tidal range is about 80% of the semidiurnal in the SGO (Figure 2).

Figure 3 shows the long-term strain variations measured in the SGO and in the MGGO by extensometers. The strain rates in both observatories are in good agreement with the strain rates inferred from GPS measurements of the Hungarian GPS Geodynamic Reference Network and the Central European GPS Reference Network (Mentes 2012a, b). The strain rate (-4.88 μstr/y) measured in Sopronbánfalva is much higher than those measured in the MGGO in Budapest which can be attributed to the geographical location of the SGO. The area belongs to the marginal mountainous region of the Pannonian Basin and this East Alpine region is characterized by different vertical deformation velocities compared to the central parts of the basin. The folding and compression of the weak lithosphere absorbs the strain in the Pannonian Basin which explains the small strain rates measured in Budapest (Mentes 2012a, b).

The rock deformation data series collected by extensometers provide an opportunity for studying various changes in the geological properties and rock-physics of the environment, caused by earthquakes (e.g., displacement, deformation of rock mass). Hereby further information can be achieved about the nature of these effects, complementing the analysis of seismograms (as e.g. in the frequency range embraced by extensometers it is possible to record changes with much higher time of periods). The appearance of effects of earthquakes in extensometric data were investigated on data

Figure 1. Location of the Budapest (MGGO), Sopronbánfalva (SGO) and Vyhne extensometric stations

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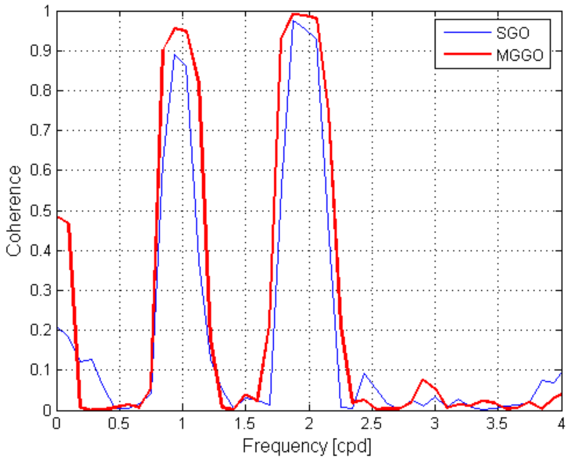

Figure 2. Tidal frequency transfer function of the Budapest (MGGO), and Sopronbánfalva (SGO) extensometric stations

series collected in the Matyashegy Gravity and Geodynamical Observatory in Budapest in the time of significant ($M > 7$) earthquakes, and spectral analysis was carried out (Kis et al. 2014). Results of the examinations were compared to the spectrum of records of a typical, undisturbed lapse of time, as well as to the spectrum calculated from seismograms of Kövesligethy Radó Seismological Observatory in Budapest, nearby the gravity observatory.

In the Sopronbánfalva Geodynamic Observatory the natural radon concentration is very high and it depend on meteorological parameters (indoor and outdoor temperature, barometric pressure), ventilation of the observatory, etc. Simultaneous strain measurement by extensometer and radon concentration measurement by an ALPHAGuard™ instrument is a unique possibility to study the relationship between rock strain and radon concentration variations in this observatory. The long-periodic part and seasonal variations of the signals were examined by cross-correlation and regression analysis. It was found that the strain induced radon concentration variations are in the order of $10^{-1} – 10^{-2}$ kBq nstr^{-1}, while the concentration variations bear more considerable similarity and relation to the temperature and air pressure variations (Mentes 2012a). The theoretical tidal potential at the location of the measurement site and tidal components computed from strain, meteorological and radon concentration data were compared with each other. The tidal evaluation proved the lack of the principal lunar semidiurnal M2 and diurnal O1 tidal waves, which have the strongest effect on the deformation of the solid Earth, but they are explicit components in the theoretical tidal and rock strain variations. These results does not reveal any connection between radon concentration variations and Earth's tide induced rock strain at the measurement site and the tidal components appearing around the noise level in the radon concentration are presumably due to the random variation of the weather (Figure 4).

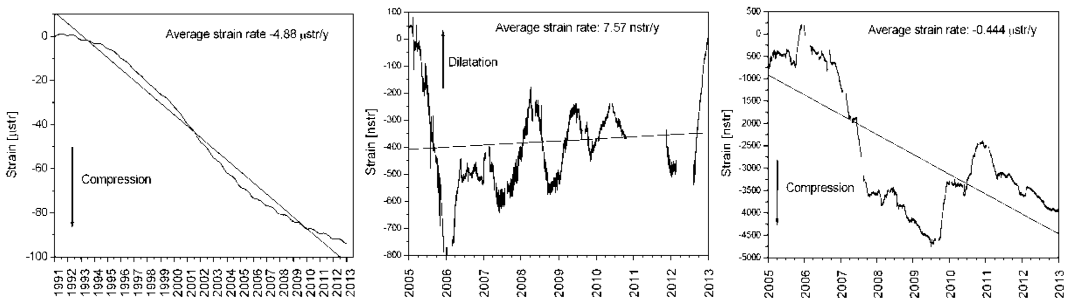

Figure 3. Long-term strain variations measured a) in the SGO (azimuth of the instrument: 116°) and in the MGGO by the extensometers b) E1 (azimuth of the instrument: 114°) and c) E2 (azimuth of the instrument: 38°)

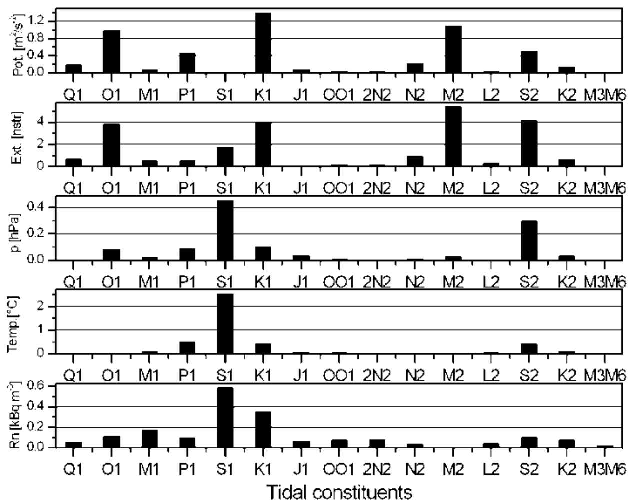

Figure 4. Theoretical tidal potential (Pot.), tidal components calculated from the extensometric (Ext.) barometric pressure (p), temperature (Temp.) and radon concentration (Rn) data

References

Eperné Pápai I, Mentes Gy, Kis M, Koppán A (2014): Comparison of two extensometric stations in Hungary. Journal of Geodynamics, 80, 3-11. SI: Understand the Earth, DOI: 10.1016/j.jog.2014.02.007

Kis M, Gribovszki K, Kiszely M, Koppán A (2014): Analysis of an earthquake based on extensometric and seismological measurements. In: Cvetkovic M, Zelenika KN, Geiger J (eds.): Proceedings of 6th Croatian-Hungarian and 17th Hungarian Geomathematical Congress. Croatian Geological Society, 129-134.

Mentes Gy (2012a): Observation of local tectonic movements by a quartz-tube extensometer in the Sopronbánfalva Geodynamic Observatory, in Hungary-Validation of extensometric data by tidal analysis and simultaneous radon concentration measurements. Journal of Geodynamics, 58, 38– 43, DOI: 10.1016/j.jog.2012.01.004

Mentes Gy (2012b): Observation of strain rate variations by a quartz-tube extensometer in the Sopronbánfalva Geodynamic Observatory, Hungary. 16th General Assembly of Wegener, Earthquake geodesy and geodynamics: from giant to small scale events. Volume of Abstracts. University of Strasbourg Collège Doctoral Européen, 17-20 September 2012, Université de Strasbourg, France, 74. http://wegener2012.sciencesconf.org

Mentes Gy, Eperné Pápai I, Kis M, Koppán A (2014): Analysis of long-term extensometric data of Sopron and Budapest geodynamical observatories. In: Cvetkovic M, Zelenika KN, Geiger J (Eds): Proceedings of 6th Croatian-Hungarian and 17th Hungarian Geomathematical Congress, 135-136.

HUNGARIAN CONTRIBUTION TO THE RESEARCH ON POSITIONING AND APPLICATIONS - IAG COMMISSION 4

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According to the research objectives of the international IAG WG 4.2.4: Monitoring of Landslides & System Analysis (chair of the working group: Gyula Mentes) the Geodetic and Geophysical Institute was working:

- on development of dynamic monitoring and data evaluation systems for landslide prone areas,
- on study of the interactions between landslides and geophysical, geological, geomorphological, hydrological, geomechanical, meteorological, etc. processes,
- on study of the relationships between landslide movements and vital processes of vegetation.

For the investigations three test sites were used in Hungary (high banks of river Danube at Dunaföldvár and Dunaszekcső and a wooded slope in the Hidegvízvölgy-valley in the vicinity of the town Sopron). On the high bank in Dunaszekcső a geodetic network was established for GPS, electronic distance measurements and precise levelling. The intermittent geodetic measurements were repeated in time intervals according to the rate of the movements (Bányai et al. 2013a, b, Mentes et al. 2012). On both high banks continuous tilt measurements were also carried out by highly sensitive borehole tiltmeters (Mentes and Bányai 2014). In Dunaföldvár, in addition to the continuous tilt measurements the vertical movements of the high bank were measured by a borehole extensometer developed in the Geodetic and Geophysical Institute (Mentes 2011a, 2012). At both test sites the precipitation, the ground water level and the water stage of the River Danube were also recorded. This complete measurement system is very suitable for the investigation of the kinematic behaviour of landslides and together with other (e.g. hydrological, meteorological, etc.) parameters for the study of dynamics of landslides. On these test sites the influence of geological, geomorphological, hydrological, meteorological, etc. factors and their role in triggering landslides were investigated.

New method was developed for the integrated evaluation of different geodetic measurements (Bányai 2011) and a new dynamic model was developed for a better understanding of the recurring landslides in Dunaszekcső (Újvári et al. 2011, Mentes et al. 2012, Bányai et al. 2013b, Bányai et al. 2014a).

In this period new measurement methods applying accelerometers (Mentes, 2011b) and their mathematical background for detecting very small displacements were developed for early detection of landslides. An instrument for calibration of accelerometers was also developed (Mentes, 2011b). According to the results of the research, the acceleration measurements can be used for stability assessment of landslide prone areas. The InSAR technology was intensively studied and scattering surfaces (passive reflectors) were developed for increasing the accuracy of this technology for landslide and tectonic observation (Bányai et al. 2014b).

The results of the investigation of the relationships between high bank tilts and vital processes of the vegetation demonstrate that the daily tilt amplitudes show a clear seasonal characteristic which coincide with the active (from April till October) and passive (from November till March) periods of the vegetation. Figure 7 shows the relationships between PET, and the monthly averages of the precipitation and tilt amplitudes at the two test sites. Figure 1 demonstrates very clearly that during higher potential evapotranspiration (PET) the tilt amplitudes are also high. It can also be observed that in dry periods, when the amount of the precipitation is small, the tilt amplitudes are higher than in the rainy seasons. The effect of precipitation on the seasonal variations of the tilt amplitudes is of minor importance which means that the vegetation has much more important role in the water balance of the upper layer of the soil than the precipitation (Mentes and Bódis 2011, 2012, Bódis and Mentes 2012).

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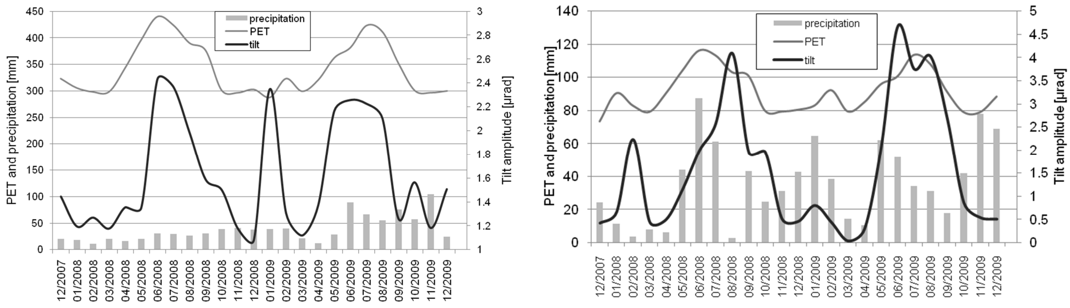
On the test site in the Hidegvíz-valley (Figure 2) beside the ground tilt (EW and NS directions) the following meteorological and hydrological parameters were measured:

- direction and velocity of the wind: at heights of 30, 23, 19, 14 and 2 m;
- air temperature and humidity: at heights of 30, 23, 19, 14 and 2 m;
- total solar radiation: at heights of 30, 23 and 2 m;
- precipitation: at a height of 20 m;
- soil temperature: at heights of 0.05, 0 m and at depths of: 0.05, 0.1, 0.2, 0.5, 1 m;
- soil moisture content: at depths of 0.1, 0.2, 0.3, 0.4, 0.6, 1 m.

Quantitative relationships were determined between the measured tilt values and the above mentioned parameters (Mentes et al. 2014). It was pointed out that under unfavourable conditions, the common effect of the investigated parameters can trigger slope slides. The complex study of these effects can contribute to the identification of different ground processes and can provide useful information for development of early warning systems and mitigation of landslide hazards.



a) b)

Figure 1. Relationships between PET (potential evapotranspiration), monthly averages of the precipitation and tilt amplitudes on the Dunaföldvár (a) and Dunaszekcső (b) test site

a) b)

Figure 2. The Hidegvíz-valley test site. a) Instruments for hydrologic measurements, b) tower for the measurement meteorological parameters

References

Bányai L (2011): 3D integrated adjustment of geodetic measurements (in Hungarian with English abstract). Geomatikai Közlemények, 14, 45-54.

Bányai L, Mentes Gy, Újvári G (2013a): Geodetic Observation of High Bank Failures at Dunaszekcső (in Hungarian). Geodézia és Kartográfia, 65(11-12), 7-11.

Bányai L, Mentes Gy, Újvári G, Gribovszki K, Papp G (2013b): The motion tendency and model of the landslide in Dunaszekcső deduced from coordinate time series (in Hungarian with English abstract). Geomatikai Közlemények, 16, 73-82.

Bányai L, Mentes Gy, Újvári G, Kovács M, Czap Z, Gribovszki K, Papp G (2014a): Recurrent landsliding of a high bank at Dunaszekcső, Hungary: Geodetic deformation monitoring and finite element modelling. Geomorphology, 210, 1-13.

Bányai L, Szűcs E, Kalmár J, Eperné Pápai I, Bán D (2014b): The basics of InSAR technology and the characteristics of scattering surfaces (in Hungarian with English abstract). Geomatikai Közlemények, 17, 59-67.

Bányai L, Újvári G, Mentes Gy (2012): Kinematics and dynamics of a river bank failure determined by integrated geodetic observations. Case study of Dunaszekcső landslide, Hungary. In: Pandian MS (Ed.): Proceedings of the Annual International Conference on Geological and Earth Sciences (GEOS 2012), Singapore, 3-4 December 2012. Organized and Published by Global Science and Technology Forum (GSTF).

Bódis VB, Mentes Gy (2012): The role of vegetation in the daily and yearly small tilt variations of the Danube's high bank, Hungary. Zeitschrift für Geomorphologie, 56(2), 133-141, DOI: 10.1127/0372-8854/2012/S-00095

Mentes Gy (2011a): Borehole Wire Extensometer for Measurement of Small Displacements. In: Kopáčik A, Kyrinovič P, Roič M (Eds): INGEO 2011 Proceedings of the 5th International Conference on Engineering Surveying 2011, 307-314.

Mentes Gy (2011b): Apparatus for producing small displacements with different time functions and for calibration of accelerometers (in Hungarian with English abstract). Geomatikai Közlemények, 14(1), 97-104.

Mentes Gy (2012): A new borehole wire extensometer with high accuracy and stability for observation of local geodynamic processes. Rev. Sci. Instrum. 83, 015109, DOI: 10.1063/1.3676652

Mentes Gy, Bányai L (2014): Observation of Landslide Movements by Geodetic and Borehole Tilt Measurements. In: Kopáčik A, Kyrinovič P, Štroner M (Eds.): Proceedings of the 6th International Conference on Engineering Surveying INGEO 2014, Czech Technical University Prague, Faculty of Civil Engineering, 2014. Prague, Czech Republic, 3-4 April 2014. TS2-4 Networks and GNSS application. 53-58.

Mentes Gy, Bányai L, Újvári G, Papp G, Gribovszki K, Bódis VB (2012): Recurring mass movements on the Danube's bank at Dunaszekcső (Hungary) observed by geodetic methods. Journal of Applied Geodesy, 6(3-4), 203-208, DOI 10.1515/jag-2012-0011

Mentes Gy, Bódis VB (2011): Relationships between short periodic slope tilt variations and vital processes of the vegetation. Proceedings on the Joint International Symposium on Deformation Monitoring. Hong Kong, China, 2-4 November 2011. Session 3I: Natural Effects (Groundwater, Erosion, etc). 3I-02. 158.

Mentes Gy, Bódis VB (2012): Relationships between short periodic slope tilt variations and vital processes of the vegetation. Journal of Applied Geodesy, 6(2), 83-88, DOI: 10.1515/jag-2012-0009

Mentes Gy, Bódis VB, Vig P (2014): Small slope tilts caused by meteorological effects and vital processes of trees on a wooded slope in Hidegvíz Valley, Hungary. Geomorphology, 206, 239–249. http://dx.doi.org/10.1016/j.geomorph.2013.09.027

Újvári G, Bányai L, Mentes Gy, Papp G, Gribovszki K, Bódis VB, Bokor Zs (2011): Post-event movements on the high bank at Dunaszekcső (in Hungarian with English abstract). Geomatikai Közlemények, 14(1), 105-110.

HUNGARIAN CONTRIBUTION TO THE RESEARCH ON REMOTE SENSING THE ATMOSPHERE USING GNSS - IAG COMMISSION 4

Szabolcs Rózsa[1], András Zénó Gyöngyösi[2], Ambrus Kenyeres[3], Tamás Weidinger[2]

In the reporting period, a group of Hungarian scientists was active in the field of remote sensing the atmosphere using GNSS techniques, too.

Since the active GNSS network had reached the spatial resolution of ca. 60 km, therefore the application of this network for monitoring the atmospheric water vapour became feasible. A research project funded by the National Research Fund (OTKA) was initiated to realize a near real-time processing facility to estimate the zenith tropospheric delays (ZTD) and the integrated water vapour (IWV) in the atmosphere using ground based GNSS observations (Rózsa et al. 2012, Rózsa 2012, Rózsa et al. 2013). The observations are routinely processed and the results are disseminated to the EUMETNET E-GVAP programme. The Hungarian Meteorological Service is currently investigating the effect of the assimilation of ZTDs to the numerical weather prediction models.

GNSS based ZTD estimates are usually evaluated with radiosonde comparisons. Since the estimation of the uncertainties of ZTDs and IWV values stemming from radiosonde profiles is necessary for a rigorous comparison and evaluation of the results, Rózsa (2013) developed a rigorous method to estimate these uncertainties from the atmospheric profiles. The results showed that the interlayer correlations of the water vapour content cannot be neglected to achieve correct results. The estimated uncertainties agreed remarkable well with the results obtained during the WMO radiosonde intercomparison campaigns.

1 Establishment of an Observatory for GNSS Meteorology

The cooperation of the Department of Geodesy and Surveying of the Budapest University of Technology (BME) and the Hungarian Meteorological Service (HMS) helped to establish a collocated permanent GNSS station in the Meteorological Observatory of the HMS in Szeged, where radiosonde facilities as well as microwave radiometer observations are available.

This facility provides important observations to study the accuracy of GNSS based ZTD estimations and to develop the optimal data filtering techniques for the assimilation of ZTDs in numerical weather prediction models.

2 Evaluation and development of troposphere models for ground based augmentation systems

The Department of Geodesy and Surveying of the BME participated in an international project aiming the development of a new troposphere model for ground based augmentation systems. BME's task was to evaluate the state-of-the-art troposphere models using radiosonde observations and to introduce a modelling approach for a troposphere model derived from local radiosonde observations (Rózsa, 2014). The results showed that the locally derived troposphere model improved the modelling bias by 95% with respect to the RTCA-MOPS model.

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References

Rózsa Sz, Weidinger T, Gyönygösi AZ, Kenyeres A (2012): The role of GNSS infrastructure in the monitoring of atmospheric water vapour. Időjárás (Quartely journal of the Hungarian Meteorological Service), 116(1), 1-20.

Rózsa Sz (2012): Estimation of integrated water vapour from GPS observations using local models in Hungary. International Association of Geodesy Symposia, 136, 817-823.

Rózsa Sz, Kenyeres A, Weidinger T, Gyöngyösi AZ (2013): Near real-time estimation of integrated water vapour from GNSS observations in Hungary. International Association of Geodesy Symposia, 139, 31-41.

Rózsa Sz (2014) Modelling Tropospheric Delays Using the Global Surface Meteorological Parameter Model: GPT2. Periodica Polytechnica Civil Engineering 58(4), 301-308.

HUNGARIAN CONTRIBUTION TO THE RESEARCH ON NUMERICAL THEORIES AND SOLUTIONS IN MATHEMATICAL GEODESY – IAG INTER-COMMISSION COMMITTEE

László Bányai[1], József Závoti[1], László Bácsatyai[2], Kornél Czimber[3], Lóránt Földváry[4], János Kalmár[1], Davaadorzsin Monhor[2], Béla Paláncz[5], Lajos Völgyesi[4], Erik Papp[6], Balázs Somodi[4]

The theoretical and practical background of the similarity transformation together with the simultaneous estimation of local geoid undulations is presented in Bányai (2011). The mean features of the traditional network adjustment on the local ellipsoids are summarized and the different Hungarian networks and known geoid solutions are shortly described as the basic data of the test computations. The eigenvalue and eigenvector decomposition revealed that the seven parameter similarity transformation cannot be applied together with the simultaneous local geoid estimation because the rotations about the X and Y axes significantly destroy the condition of the normal equations. However, the replacement of the rotations about the X, Y and Z axes by the rotation about the ellipsoidal normal of the datum point can provide a very well-conditioned solution, which takes into account the special role of the datum point of the astro-geodetic network adjustment. Based on the unit weights of the input data an optimal adjustment strategy is demonstrated from a computational point of view, where the five transformation parameters can be estimated together with a very large number of local geoid undulations. The geoid has to be known in the global reference system. The geoid unknowns describe only the relative position of this known geoid with respect to the local reference system. The application of the available and the simultaneously estimated local geoid solutions proved that neglecting local geoid heights has a most significant impact on the scale parameter, while it has no significant effects on the horizontal residuals from the statistical point of view. The small scale difference (1 ppm) and the small rotation (−0.5 arc sec) about the datum point and its ellipsoidal normal of the Hungarian local system with respect to the global GPS system demonstrate the high quality of the traditional measurements as well.

Classical numerical integration methods were tested for determining the orbits of most recent Low Earth Orbiter (LEO) satellites. In general, numerical integration techniques for orbit determination are commonly used to fill the gap between two discrete, observed epochs. In Somodi and Földváry (2011, 2012) orbits were determined using the EGM96 gravity model by the Euler, Runge-Kutta, Bulirsch-Stoer and Adams-Moulton numerical integration techniques among others. These analyses were performed for LEO satellite GOCE and for one medium altitude GPS satellites. The orbits were integrated under different assumptions on the roughness of the force model, considering effects of elasticity, high order gravity and non-static Earth generated accelerations on the orbits.

Subdivision surfaces are widely used in computer aided design and animation, but rarely in geoinformatics. In the paper of Czimber (2011) the most important subdivision methods are discussed and a new procedure is presented, which is able to control the interpolation or approximation by points and the adaptive subdivision of the triangles in geoinformation systems.

The exterior orientation of sensors (e.g. camera-systems) is one of the basic tasks of the photogrammetry. The parameters for exterior orientation can be determined from the mathematical equations between the image coordinates and the corresponding object or ground coordinates. The mathematical models for this problem have been available since decades; huge program packages utilize the methods which have proved to be successful in practice. In Závoti and Fritsch (2011) a new

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alternative solution is given. This paper proposes an alternative solution, which does not use iteration and approximate data. The equations in this work are in coherence with the photogrammetric theory of exterior orientation; the only difference is in the mathematical solution. This kind of mathematical treatment of the problem can be considered as novelty.

In Bányai (2012) the exact least-square line fit with errors in both coordinates is investigated together with the approximate solution based on the formalism of the linear Gauss-Helmert model or the unified adjustment approach of the classical textbooks. The similarities and the differences are described in details. In spite of the small differences the exact solution is preferable and the calculations are simpler. This paper does not deal with the errors-in-variables (EIV) models solved by the total least-squares (TLS) principle, since the exact line fit solution is used to validate this general approach, which is basically designed to solve more sophisticated nonlinear tasks. In the most general case the fit of Person's data with York's weights is iteratively solved starting with the arbitrary zero initial value of the slope. The test computation with different but systematically chosen weights proved that in special cases – e.g. the weighted least-square sum of the distances between the data points and the estimated line is minimised – there is no need for iterations at all. It is shown that the methods described by Závoti (2012b) are special cases of the general exact solutions. The simple linear estimation of variance-covariance matrix of the exact solution is also demonstrated. The importance of the stochastic models coupled with exact solution is also demonstrated.

In Paláncz (2012) the algebraic solution of the geometric model of photogrammetric exterior orientation is presented by a system of multivariate polynomial equations. Employing Dixon resultant, the determination of the roots of this system can be reduced to the computation of the roots of a single variable polynomial of fourth order. In this case the Dixon matrix does not have full rank; therefore the standard Nakos-Williams algorithm cannot compute the resultant of the polynomial system.

The laws of nature in general and the relations and laws, particularly in geodesy, can be expressed in most cases by nonlinear equations, which are generally solved by transforming them to linear form and applying iteration. The process of bringing the equations to linear form implies negligence and approximations. In certain cases it is possible to obtain exact, correct solutions for nonlinear problems. In Závoti (2012a) rotation matrix parameters are introduced and used for the solutions of 2D and 3D similarity transformations. This method involves no iteration, and it does not require the transformation of equations into linear form. The scale parameter is determined in both cases by solving a polynomial equation of second degree. This solution is already known, but this derivation is worth to be considered because of its simple nature.

In the last ten years the application of computer algebra systems to special basic tasks has become one of the most rapidly developing branches of geodetic research. The conventional methods for solving problems involve approximation and iteration; and because of the lack of proper innovation, this is the general approach even today. Computer algebra systems have led to the construction of models, which give exact, analytical solutions. In many cases these models can't be applied, because increasing the number of the data leads to a combinatorial explosion, that is, a general solution can't be computed even with today's modern computers. The paper of Závoti (2012b) describes some basic geodetic tasks, for which new, stable solutions already exist.

The demand for integrated adjustment of different geodetic observables arose from practical reasons. The popular basic concept of the seventies and sixties was reconsidered in Bányai (2013). A new procedure was developed for the adjustment of precise geodetic observables, by which the astro-gravimetric data – geoid undulations and deflections of the vertical – can be taken into account in different ways. New "quasi-linear" observation equations were introduced for geodetic total station measurement, which have a more convenient numerical advantage with respect to traditional approach. The method is tested and demonstrated by field measurements. Rotational residuals and additional parameters – scale differences and antenna phase centre offsets – can be used to handle the outliers of GNSS baseline components aided by proper statistical tests. The common application of GNSS baselines and levelled height differences proved to be an efficient tool to improve the height component of local 3D networks. If the deflections of the vertical are comparable to the accuracy of geodetic total station measurements the integrated adjustment is preferable.

Datum transformation has been widely used in geodesy and a number of different algorithms have been known and applied. However, many of them are based on the assumption of small rotations, and linearization is needed in order to derive the datum transformation parameters. In Papp (2013) the concept of quaternions is described to represent the rotation and scale parameters in Bursa-Wolf geodetic transformation model. The main advantage of this algorithm is that it can be applied in case of arbitrary size rotation; it does not need linearization and iteration for computation of the datum transformation parameters for a non-linear transformation model.

The Dirichlet distribution is one of the most important multivariate probability distributions with wide range of applications in various areas of statistics, probabilistic modelling, engineering and geosciences. The paper of Monhor (2013) is an application-driven short and simplified introduction to the fundamental issues of the Dirichlet distribution and gives some useful representations of bounds on the Dirichlet distribution function. A new polynomial representation for the bivariate Dirichlet distribution is established. The potential possibility of geodetic and geophysical applications of the Dirichlet distribution is briefly described within the framework of recent developments and trends of statistical science and applied probability.

In the paper of Paláncz et al. (2013) the Pareto optimality method is applied to the parameter estimation of the Gauss-Helmert weighted 2D similarity transformation assuming that there are measurement errors and/or modeling inconsistencies. In some cases of parametric modeling, the residuals to be minimized can be expressed in different forms resulting in different values for the estimated parameters. Sometimes these objectives may compete in the Pareto sense, namely a small change in the parameters can result in an increase in one of the objectives on the one hand, and a decrease of another objective on the other hand. In this study, the Pareto optimality approach was employed to find the optimal trade-off solution between the conflicting objectives and the results compared to those from ordinary least squares (OLS), total least squares (TLS) techniques and the least geometric mean deviation (LGMD) approach. The results indicate that the Pareto optimality can be considered as their generalization since the Pareto optimal solution produces a set of optimal parameters represented by the Pareto-set containing the solutions of these techniques (error models). From the Pareto-set, a single optimal solution can be selected on the basis of the decision maker's criteria. The application of Pareto optimality needs nonlinear multi-objective optimization, which can be easily achieved concurrently via hybrid genetic algorithms built-in engineering software systems such as Matlab. A real-word problem is investigated to illustrate the effectiveness of this approach.

In Földváry and Csapó (2014) the role and the suitability of point data for describing analytical surfaces in surveying and geodesy is discussed. Within the frame of this study no overall analysis is presented, but rather the relevance of the problem is emphasized through an actual case study; i.e. the reliability of describing the gravity field by gravimetric networks. All in all, the conclusion is that as long as the points are not capturing precisely the extremes with suitable point distribution, the surface may fail. In the case of several quantities, such as gravity, the extremes cannot be located uniquely based purely on observed data. In such cases contour lines of the quantity of interest derived on the point-wise data may drastically differ from the real shape of the surface, as it is experienced by the unrealistically high alteration of two different epochs of the Hungarian gravity network (based on notably different point distribution), MGH-50 and MGH-2000.

There are continuous observations, which are carried out with varying sampling rates, however, their processing needs high resolution. To solve the problem different approximation and interpolation methods were investigated in Kalmár (2014). It was experienced that the trigonometric polynomials can be applied very efficiently to interpolate geomagnetic baseline measurements and to derive the measurement errors. This procedure can be easily implemented even in Excel spreadsheet.

In Mohamed et al (2014) integrated baseline adjustment and similarity transformation method is proposed as an alternative strategy for the regional size Cairo Network to estimate intra-plate deformations using GPS observations. The proposed method is demonstrated to estimate coordinate changes, global rotations and scale parameters in one computational step. The proposed method is used to investigate the significance of the impact of global plate motions on regional crustal movement network. Simulated data of the regional Cairo network is used for this evaluation. The estimated plate motions, simulated scale bias (due to miss-modelling of troposphere effect on GPS data) and baseline noise proved that the impact of plate motions have to be taken into account in the case of Cairo network if the investigation period is near or larger than ten years.

In Bácsatyai (2014) the description of the HUGAPRO program system is given, which was created for transformation between all the projections and reference systems used in Hungary for practical, educational and research purposes. It can be applied to compute the transformation parameters, projection reductions, standard deviations and maximum discrepancies in any combination between two chosen projection, reference or auxiliary systems. Between arbitrary projections the parameters of 7 parameter similarity or polynomial transformations can be determined and can be used to carry out the necessary transformations.

The paper of Závoti (2014) presents an important theoretical problem of geodesy: we are looking for a mathematical dependency between two spatial coordinate systems utilizing common pairs of points whose coordinates are given in both systems. In geodesy and photogrammetry the most often used procedure to move from one coordinate system to the other is the 3D, 7 parameter (Helmert) transformation. Up to recent times this task was solved either by iteration, or by applying the Bursa-Wolf model. Producers of GPS/GNSS receivers install these algorithms in their systems to achieve a quick processing of data. But nowadays algebraic methods of mathematics give closed form solutions of this problem, which require high level computer technology background. In everyday usage, the closed form solutions are much simpler and have a higher precision than earlier procedures and thus it can be predicted that these new solutions will find their place in the practice.

References

Bácsatyai L (2014): Projection transformations by means of software HUNGAPRO V5.13. (in Hungarian with English abstract). Geomatikai Közlemények, 17, 19-31.

Bányai L (2011): The relationship between the Hungarian local and global geodetic reference frames estimated together with local geoid undulations. Acta Geod. Geoph. Hung., 46(1), 50-70.

Bányai L (2012): Some remarks on linear least-squares fits with errors in both coordinates. Acta Geod. Geoph. Hung., 47(4), 441-451.

Bányai L (2013): Three-dimensional adjustment of integrated geodetic observables in Earth-centred and Earth-fixed coordinate system. Acta Geod. Geoph., 48(2), 163-177.

Czimber K (2011): Subdivision surfaces in geoinformatics (in Hungarian with English abstract). Geomatikai Közlemények, 14, 71-79.

Földváry L, Csapó G (2014): On characterization of continuous surfaces with point data (in Hungarian). 20 Éves a Térinformatika Tanszék, Székesfehérvár, 2014 december 15, 327-336.

Kalmar J (2014): Estimation of trigonometric polynomials in practice (in Hungarian). Dimenziók, Matematikai Közlemények, 2, 27-34.

Mohamed AS, Mousa A, Bányai L, Nadia AA, Ali R, Khalil H (2014): Impact of the plate motion on the deformation analyses of Cairo Network: Case study with simulated data. A Scientific International Journal, Published by The Egyptian Geophysical Society, 12(1), 41-48.

Monhor D (2013): Dirichlet distribution with views on geodesy and geophysics. Acta Geod. Geoph., 48(2), 235-245.

Paláncz B (2012): Solution of the exterior orientation in photogrammetry applying Dixon resultant. (in Hungarian with English abstract). Geomatikai Közlemények, 15, 85-94.

Paláncz B, Awange JL, Völgyesi L (2013): Pareto optimality solution of the Gauss-Helmert model. Acta Geodaetica et Geophysica, (48)3, 293-304.

Papp E (2013): Geodetic datum transformation by quaternion (in Hungarian with English abstract). Geomatika Közlemények, 16, 17-28.

Somodi B, Földváry L (2011): Application of numerical integration techniques for orbit determination of state-of-the-art LEO satellites. Periodica Polytechnika Civil Engineering 55(2), 99-106.

Somodi B, Földváry L (2012): Accuracy of numerical integration techniques for GOCE orbit determination. In: Mokryš M, Lieskovský A (Eds.), Proceedingsin Advanced Research in Scientific Fields: The 1st Virtual International Conference. Zilina, Slovakia, 2012.12.03-2012.12.07, EDIS Zilina University Publishers, 1578-1583.

Závoti J, Fritsch D (2011): A first attempt at a new algebraic solution of the exterior orientation of photogrammetry. Acta Geod. Geoph. Hung., 46, 317-325.

Závoti J (2012a): A simple proof of the solutions of the Helmert- and the overdetermined nonlinear 7-parameter datum transformation. Acta Geod. Geoph. Hung., 47(4), 453-464.

Závoti J (2012b): Application possibilities of computer algebraic systems in geodesy (in Hungarian with English abstract). Geomatikai Közlemények, 15, 27-42.

Závoti J, Kalmár J (2014): Some alternative possibilities for the solution of 3D non-linear similarity datum transformation compared to the Bursa-Wolf model (in Hungarian with English abstract). Geomatika Közlemények, 17, 7-18.

REPORT OF THE COMMUNICATION AND OUTREACH BRANCH OF IAG

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1 Introduction

The period of 2011-2015 is the third term in the operation of the Communication and Outreach Branch (COB) hosted at the Department of Geodesy and Surveying of the Budapest University of Technology and Economics (BME).

The Communication and Outreach Branch is one of the components of the Association. According to the new Statues (§5) of the IAG, the COB is the office responsible for the promotional activities of the IAG and the communication with its members.

The Terms of Reference and program of activities of the COB, and a short report on the IAG website ("IAG on the Internet"), were published in The Geodesist's Handbook 2012 (Ádám and Rózsa, 2012; Rózsa, 2012), respectively.

In the past period of the third term (since the 2011 IUGG General Assembly in Melbourne till June, 2015 in Prague IUGG GA) the COB's President attended the Executive Committee (EC) meeting in four cases (Singapore, 15 August 2012; Vienna, 7 April 2013; Potsdam, 1 September 2013 and Vienna, 26 April 2014), while COB's Secretary represented COB on the EC meeting in San Francisco, 5 December 2011. A joint meeting of the IAG Office (H. Drewes and H. Hornik) and the COB (J. Ádám, Sz. Rózsa and Gy. Tóth) was organized in Budapest in 22-23 November 2012, where the following topics were discussed:

- the structure and operation of the website;
- IAG gifts/merchandising during the 150th anniversary year at the SA in Potsdam.

Another joint meeting of the IAG Office (H. Drewes and H. Hornik) and the COB (J. Ádám and Sz. Rózsa) was organized in Melk, Austria in 21 August 2013 just before of the IAG Scientific Assembly (SA) in Potsdam, Germany, 2-6 September 2013. At this steering committee meeting the above two topics were again discussed and improved.

Note that the COB (J. Ádám, Sz. Rózsa and Gy. Tóth) organized a special meeting with Professor Ivan I. Mueller, Past President of the IAG in 12 June 2012 at the Budapest University of Technology and Economics, Hungary. During this discussion we outlined the possibilities how to improve the COB activities and the celebration of the 150th anniversary of IAG in Potsdam IAG SA meeting in 2013.

2 The IAG Website

The Communication and Outreach Branch maintained the IAG Website. The website has been operational, no significant downtime has been experienced in the service. A regular update of the content has been carried out using the material provided by Association and Commission leaders, conference organizers and other members of the Association. The website has been redesigned in 2012/2013 introducing some new features like the section of the „hot topics", a slide-show introducing the most important information on the IAG website, according to the decision of the joint meetings of the IAG Office and COB. In the new section of „Hot topics" the actual topics in Geodesy can be highlighted. Moreover a separate section is devoted to the history of the association celebrating the 150 years anniversary of IAG. The updated website was available for the SA in Potsdam.

Since the submission of the last quadrennial report the following features have been also added to the website:

- Facebook integration: all the pages of the website can be 'liked' on FB.
- Regenerating forgotten passwords automatically for the IAG Forum and the Members' Area.

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Note that the number of visitors of the IAG Homepage is about 1500 visitors/month (in daily average approx. 50 visitors) during the past four years (Figure 1).

3 The IAG Newsletters

Altogether 48 IAG Newsletters have been published from June 2011 till June 2015 and can be accessed on the IAG website in HTML, HTML print version and in PDF formats. Each issue of the IAG Newsletter in 2012, 2013 and 2014 contains a special IAG logo designed for the 150th anniversary of the IAG. We strive to publish only relevant information by keeping the Newsletter updated on a per-monthly basis. The IAG Officers, Individual Members, IUGG and JB GIS Presidents and Secretaries as well as interested persons mainly in developing countries received it each month in PDF and/or text attachments, with a link in the e-mail message to access the actual HTML Newsletter on the IAG website. Selected contents of the electronic Newsletters were compiled and have been sent regularly to Springer for publication for 46 issues of the Journal of Geodesy (Vol 85(9) – 89(8)). Starting from the double issue 82(11-12) the volume of the Springer IAG Newsletters is limited to 3-4 pages due to a change in the editorial policy to improve the impact factor of the journal. We try to publish only new and/or relevant material here as well.

4 Outreach Activities

The COB has been active in the publishing of information material in the reporting period. A new version of the IAG brochure has been published (16 coloured pages), which targets the wider public and decision makers by introducing Geodesy in general as well as the role of the Association to the readers (Ádám and Rózsa 2013). It has a chapter on the Global Geodetic Observing System, and provides information on the IAG components (Commissions, Inter-Commission Committee, Services, etc.). The brochure can be downloaded from the opening page of the IAG website, together with the updated IAG leaflet (Ádám and Rózsa 2013). Ádám and Drewes (2012) prepared a summary on “The International Association of Geodesy (IAG) – Historical Overview”.

Naturally, the task of the COB is the IAG public relation in particular by maintaining the IAG Homepage and publishing the monthly Newsletter online and in the Journal of Geodesy. It also keeps track of all IAG related events by the meetings calendar.

Furthermore, various examples for IAG gifts were prepared (badges in 1000 pieces, key rings in 600 pieces, wooden pencils in 1000 pieces, caps with 5 segments in 200 pieces, muslin scarfs in 200 pieces and bag hook in 200 pieces, etc.) and merchandised during the 150th anniversary year at the SA in Potsdam in 2013.

5 Summary

To sum it up, the following activities were done:

1) the IAG website was updated, improved and continuously maintained,
2) the IAG Newsletter was regularly issued monthly and distributed electronically, and
3) selected parts of them were prepared to publish in the Journal of Geodesy as IAG News,
4) new version of the IAG Leaflet was prepared, printed in 1000 copies and distributed at different IAG meetings,

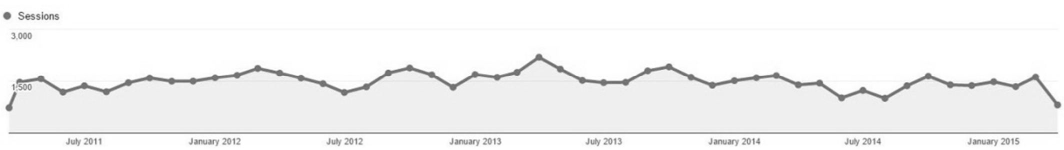

Figure 1. Monthly visitors from May 2011 to April 2015

5) the large IAG Brochure was reprinted in 1000 copies and distributed at different IAG meetings,
6) some works were made in preparation and for finalizing The Geodesist's Handbook 2012 (Drewes et al., 2012),
7) various examples for IAG presents (badges, key rings, caps, wooden pencils, scarfs, bag hook, etc.) were prepared to be distributed before, during and after IAG Scientific Assembly/150 Years Celebration, and
8) many e-mail correspondences to the community as part of the outreach activities.

References

Ádám J, Drewes H (2012): The International Association of Geodesy – A Historical Overview. The Geodesist's Handbook 2012. J. Geod., 86 (10), 793-799.

Ádám J, Rózsa Sz (2013): Advancing Geodesy – a Leaflet of the International Association of Geodesy (IAG). IAG Communication and Outreach Branch (COB), 4th Edition, Budapest (1st Edition in 2004, 2nd Edition in 2006 and 3rd Edition in 2007).

Ádám J, Rózsa Sz (2012): Communication and Outreach Branch (COB). The Geodesist's Handbook 2012. J. Geod., 86(10), 958-959.

Ádám J, Rózsa Sz (2013): International Association of Geodesy (IAG). Brochure, 2nd Edition, p.20, IAGCommunication and Outreach Branch, Budapest, August. (1st edition in 2009).

Ádám J, Rózsa Sz, Tóth Gy (2013): Communication and Outreach Branch (COB). IAG Travaux, Report of the International Association of Geodesy 2011-2013, 38, 3.

Drewes H, Hornik H, Ádám J, Rózsa Sz (Editors) (2012): The Geodesist's Handbook 2012. J. Geod., 86(10), 787-974.

Rózsa Sz (2012): IAG on the Internet. The Geodesist's Handbook 2012. J. Geod., 86 (10), 965-967.