Belgian Report of activity in the frame of the International Association of Geodesy

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Contents

This report has gathered together input from different institutes in Belgium. It must be noted that some institutions where geodesy teaching, research, developments, or applications are performed have not yet contributed at this stage. They may be included in a later stage.

1. Royal Observatory of Belgium (ROB)

The mission of the Operational Direction 1 "Reference Systems and Planetology" is to contribute to the elaboration of reference systems (terrestrial and celestial) and timescales, theoretically as well as observationally, to integrate Belgium in the international reference frames (concerning space geodesy and time), and to obtain information on the Earth's interior, rotation, dynamics, and crustal deformation, at local, regional, and global levels. The ultimate goals are the understanding of the dynamics of the Earth's interior and surface deformation.

These scientific objectives result in three main research activities in geodesy: geodetic and geophysical studies based on the observation of the artificial GNSS (Global Navigation Satellite Systems) satellites (Carine Bruyninx, Juliette Legrand, and collaborators), time-varying gravity (Michel Van Camp, Michel van Ruymbeke) time and time transfer (Pascale Defraigne and collaborators) and studies of Earth Rotation, and in particular of the theoretical nutations (Véronique Dehant, Tim Van Hoolst, and collaborators). Additionally to the planet Earth, these objectives have been extended to the other terrestrial planets, Mars, Venus, and Mercury, and to the moons of the solar system planets. The Operational Direction 1 is also involved in planetary missions presently flying or included in a long-term vision.

In 1988, the ROB started to study the use of GPS (Global Positioning System) for geodetic and geophysical applications. During the period 2005-2011, this research program focused on the following topics: reference frame maintenance, measurement of long-term ground deformations, time and frequency transfer, and the assessment of different error sources affecting GPS positioning, in particular the ionospheric and atmospheric refraction.

The rotation of the Earth is of interest for two reasons. Whenever one is processing data observed at terrestrial tracking stations, but coming from extra-terrestrial natural or artificial bodies, one has to link two reference systems: a terrestrial one and a celestial one. Precise knowledge of the Earth Rotation is thus needed for the connection of the reference systems. On the other side, Earth Rotation variations reflect a variety of geodynamical and geophysical processes. They are closely correlated with Earth tides, global and regional atmospheric processes, as well as with climate changes and processes in the Earth's interior. The research developed in this frame at the ROB focuses on the modeling of the Earth rotation (precession, nutations, polar motion and variations of the length of day) accounting for all geophysical contributions and in particular on the core-mantle boundary coupling mechanisms.

The Operational Direction 2 “Seismology and Gravimetry” does also contribute to the activities performed at the Royal Observatory of Belgium related to IAG. Gravimetry, as explained here below, is a long tradition at the ROB. In particular, the ROB hosted the International Center for Earth Tides from 1958 to 2008 (Bernard Ducarme). Contribution of gravimetry to the determination of the Belgian geoid is another mission of the ROB (Michel Van Camp, Michel Van Ruymbeke), and research in absolute gravimetry, as well as in related applications, is presently performed (Michel Van Camp).

1.1 SATELLITE GEODESY

The objective of the GNSS research group (http://www.gnss.be) is to integrate Belgium in international terrestrial coordinate reference systems through the integration of several continuous observing GNSS reference stations and associated services in international GNSS observation networks. The ‘GNSS’ group contributes actively to the European and global developments of GNSS observation networks, their products and applications since more than ten years. This has resulted in a number of responsibilities within the EUREF Permanent GNSS Network (EPN) and the International GNSS Service (IGS). The continuation of these responsibilities, and the services associated with them, is one of the main objectives of this project.

The group is also involved in the Solar Terrestrial Center of Excellence (STCE) where GNSS observations are used to monitor the Earth’s ionosphere and troposphere targeting the high-end GNSS user community and scientific applications by taking advantage of the GNSS data available in the international services to which the project is contributing. In addition, as it was the case in several European Agencies simultaneously involved in the EPN data analysis and performing tropospheric research, these activities found a natural synergy and led to the involvement in the EUMETNET E-GVAP project.

The service activities described above are based on a solid dose of research that guarantees that the services are of the highest level. The research concerns the modeling, mitigation and understanding of the GNSS error sources affecting the services mentioned above. Examples are the investigation of the influence of the reference frame, the GNSS antenna calibration, the troposphere and the ionosphere.

At the moment, a part of the services is already based on multiple GNSS, more specifically on GPS and GLONASS (Russian equivalent of GPS) observations. With the upcoming GALILEO positioning system, the scientists involved in this project will also work on the incorporation, processing, and enhancement of GALILEO observation in the research and the services they maintain.

1.1.1 Experiments and observations with the ROB GPS observation network

Since January 1994, 4 permanent GNSS tracking stations, installed by the ROB, are continuously operating. These stations cover the Belgian territory. The main goals of this network are:

- ✓ to integrate Belgium into international reference systems;
- ✓ to offer to the GNSS user community a set of reference stations, of which the coordinates are precisely known in the global and European reference systems (ITRS and ETRS89); the data from the ROB stations are freely made available to the GNSS user community and allow users to connect their local GNSS network to a homogeneous international reference;
- ✓ The data from the ROB reference stations are the basis for scientific research done at the ROB: atmospheric perturbations (tropospheric and ionospheric effects) and investigations of the stability of GNSS-derived coordinates.

In 1997, the ROB installed three additional permanent GNSS stations dedicated to geophysical applications. Two of them (Bree and Meeuwen) are on both sides of a seismic fault and the other one (Membach) is collocated with an absolute gravimeter and a superconducting gravimeter in order to compare possible changes in the station ground deformation (and gravity changes) observed by two independent instruments. Recently, all ROB stations have been configured to deliver real-time data in addition to hourly and daily data.

In 2010, the first 3-constellation (GPS, GLONASS and GALILEO) GNSS receiver was installed at ROB. ROB is now completely upgrading the rest of its GNSS observation network from a GPS-only network to a GPS+GLONASS+GALILEO observation network. ROB also installed a high precision dual frequency permanent GPS stations at the Princess Elisabeth (PE) base, Utsteinen, Antarctica. The aim is to assess the mass balance of the Antarctic ice sheet in the vicinity of the new Belgian station by a combination of GPS and absolute and relative gravity measurements. While GPS data provide a measure of ground movements due to the elastic and viscoelastic rebound of the continental lithosphere as a result of present-day and historic ice load change, gravity measurements, which estimate the mass changes, are necessary to separate the lithospheric movements induced by the post-glacial adjustment and by the present-day ice mass changes.

1.1.2 Participation to international observation networks and reference frame maintenance

IGS

The IGS (International GNSS Service) operates in close collaboration with the International Earth Rotation Service (IERS). By using data from more than 200 permanent GNSS stations, operated by various institutions world-wide, the IGS provides the services such as high accuracy GNSS satellite ephemeris, GNSS-derived Earth rotation parameters, coordinates and velocities of the IGS tracking stations, GNSS satellite and tracking station clock information, ionospheric information, and troposphere information. The ROB permanent GPS station in Brussels has been contributing to the IGS without major interruptions since November 1993.

EUREF

EUREF, the "Reference Frame Sub-Commission for Europe" is part of the Sub-Commission 1.3, Regional Reference Frames, under Commission 1 of the IAG. EUREF is responsible for defining, maintaining and providing access to the European Terrestrial Reference System (ETRS89) and European Vertical Reference System (EVRS). A key instrument in that respect is the EUREF Permanent Network (EPN). Created in 1996, the EPN is based on a partnership with site operators of continuously operating GNSS sites who are willing to share their data with the public. Completely based on voluntary contributions, today, the EPN runs almost 250 GNSS stations in a well-organized environment. The EPN constitutes the European contribution to, and densification of, the International GNSS Service (IGS), and as such it strives complete consistency with the IGS standards and models: IGS orbits and Earth Rotation Parameters are used for all EPN processing and the same models are used for the antenna phase centers of the both satellites and receivers.

The GNSS research group of ROB is heavily involved in the EUREF activities. C. Bruyninx chairs the EUREF Technical Working group and she manages the EPN Central Bureau. The EPN Central Bureau (http://www.epncb.oma.be/), responsible for the day-to-day management of the EPN, acts as liaison between station operators and analysis centers, providing the necessary station configuration metadata and ensuring that the datasets meet the requirements of the analysis. Its monitoring procedures permanently verify the EPN tracking data and meta-data. In addition, the submissions provided by the EPN Analysis Centers are checked and compared to provide feedback to the participating analysis centers. During the last years, ROB included new tools in the EPN Central Bureau, e.g. an on-line transformation tool between any realization of the ITRS and ETRS89 (and vice versa) and multi-GNSS data quality monitoring. Part of the ROB GNSS stations participate to the EPN network: Brussels, Dentergem, Dourbes and Waremme. The data from the ROB's EPN stations are made available in real-time, and in hourly and daily batches to the EPN data centers. The ROB is one of these data centers providing real-time, hourly and daily data from the EPN to the user community. In addition the ROB also maintains the historical EPN data center hosting the data used for EPN reprocessing activities. Analysis centers from all over Europe use the EPN data to compute a highly precise European reference network integrated in the global reference network. The ROB is one of these analysis centers providing daily and weekly network solutions to EUREF.

1.1.3 Influence of the Reference Frame

At the establishment of the EPN in 1996, it was decided that the GNSS data analysis would be performed on a regional (European) level. However, today with the improving computing facilities and GNSS data analysis software, it has become feasible to perform a global analysis. Therefore, as a preparation for the EPN reprocessing, we analyzed and compared the classical regional approach to a global one.

We showed that positions and velocities obtained from a regional GNSS network tied to the ITRF2005 using minimal constraints, can differ (up to 2 mm in the horizontal and 8 mm in the vertical for the positions and up to 0.5 mm/yr in the horizontal and 2 mm/yr in the vertical for the velocities) w.r.t. a global solution. When considering the residual velocity fields after removing the rigid block rotation, the velocity differences are considerably reduced but can still reach up to 0.8 mm/year in horizontal component. The disagreement between regional and global positions and velocities is caused by the so-called "network effect" and it is amplified when the reference stations used in the regional solution cover a smaller geographical area or the different solutions to be combined exhibit large discrepancies at common sites. This means that sites showing different discontinuities, time spans or large non-linear signals should be treated with extreme care. The network effect, of course, challenges the provision of a consistent dense velocity field partly based on regional position/velocity solutions.

Upon the release of the ITRF2008, new tests with the ITRF2008 frame showed that the disagreement between the global and regional position/velocity solutions has been considerably reduced. It can nevertheless still reach 1 mm/yr in the vertical and 0.5 mm/yr in the horizontal.

1.1.4 Working Group on "Regional Dense Velocity Fields"

From 2007 until 2011, a member of ROB's GNSS research group (C. Bruyninx) chaired the IAG Working Group (WG) on 'Regional Dense Velocity Fields'. The long-term goal of this WG is to provide a globally referenced dense velocity field based on GNSS observations which could also be used as a densification of the global ITRF (International Terrestrial Reference Frame). More details on the WG can be found at its web site http://epncb.oma.be/IAG/.

The WG is embedded within IAG sub-commission 1.3 on "Regional Reference Frames" where it co-exists with the regional reference frame sub-commissions for Europe (EUREF), Latin America and the Caribbean North America, Africa, South-East Asia and Pacific, and Antarctica. . Representatives from these regional sub-commissions are also WG members. Their expertise, coordination role for their region, and their capability to generate a unique and unified cumulative solution for their region, including velocity solutions from third parties (even campaigns), is a key element for the WG.

After a first combination of the submitted position and velocity solutions, it was shown that the network effect affecting the different regional contributions was the main problem challenging the provision of a good quality combined velocity field . Therefore in order to reduce the network effect, it was concluded that an optimal combination requires:

- ✓ to have the best possible agreement between the solutions we want to combine (by e.g. using similar data span, outlier rejection and discontinuity epochs for the common stations as well as a similar analysis strategy),
- ✓ to increase as much as possible the geographical coverage of each of the solutions we want to combine (best is global),
- ✓ to increase to a maximum extend the redundancy between regional and global solutions in order to mitigate individual problems at the common stations.

For that purpose, the new solutions were submitted to the WG. These submissions were restricted to contain only the (regional) core networks over which the analyst has full control so that the same analysis approaches could be applied. J. Legrand and C. Bruyninx demonstrated that the 3D-RMS of the agreement of the new solutions with the ITRF2008 (after outlier rejection) varies between 0.6 and 1.1 mm/yr; it is extremely good for some solutions, while others still require more iteration to reach the required level of agreement. In order to investigate the disagreements, all contributors provided residual position time series allowing for the first time an in depth comparison of the solutions from regional reference frame sub-commission with each other, with global solutions and with the ITRF. Thanks to these residual position time series, we were able to identify that a part of these disagreements often originate in the use of different data time spans within the ITRF2008 and submitted solution. It is clear that a careful inspection and comparison of both ITRF2008 and regional time series is mandatory before using any site as a frame-attachment site.

1.1.5 Monitoring of the ionosphere and the troposphere

1.1.5.1 Ionosphere

The GNSS team investigated the presence of small variations in the ionosphere during the 2010 August storm period (in response to a Solar Coronal Mass Ejection). For that purpose the TEC (Total Electrion Content) variation along the GPS signal paths between the EPN ground stations and the GPS satellites were examined. Disturbances for this geomagnetic storm present amplitudes from 3 to more than 7 TECU and have an apparent periodicity of 30 minutes.

A method to generate in near-real time 0.5°x0.5° grid TEC (Total Electron Content) maps and TEC variance over Europe each 15 min. from the EPN data has been developed. The maps are now routinely produced and available from http://www.gnss.be/Atmospheric_Maps/ionospheric_maps.php. The comparison of the resulting TEC maps with Global Ionospheric Maps (GIMs) showed good agreement with mean differences lower than 1 TECU, except during stormy days when GIMs seem to underperform.

The beginning of the 23rd Solar cycle (May 1996 to December 2008) coincided with the start of the catalogue of global ionospheric monitoring based on GNSS data from ground networks. In addition, many parameters of the Solar activity are historically measured. Study of the 23rd Solar cycle revealed a clear correlation between the F10.7 observed flux solar parameter and the global daily mean TEC obtained from GNSS. Based on this study, the ionospheric climatological model developed at ROB will allow to predict mean daily ionospheric total electron content at a global scale from the F10.7 Solar parameter only.

The group also showed that using GNSS data from national GNSS densification networks in addition to the EPN provides an added-value for tropospheric tomography. In the case of ionospheric tomography, the additional stations induce inhomogeneities in the GNSS signal distribution and therefore mainly densification stations located in the UK and Scandinavia (homogenizing the overall inter-station distances) will provide a real added value.

1.1.5.2 Troposphere

As part of its research program on the troposphere, the ROB progressively developed the necessary expertise to contribute to GNSS-meteorology in Europe. Since 2004, the ROB actively maintains and improves its service as a GNSS data analysis centre participating in the different European programs (from COST-716 up to E-GVAP II). Today, the ROB processes each hour a European network of about 220 permanent GNSS stations, most of them being EPN stations. The ROB provides its 15-min sampled GNSS tropospheric delays within 30 to 45 minutes after observations and with a precision and accuracy below 5 mm of tropospheric path delay. These tropospheric delays are then used by meteorological agencies belonging to EUMETNET for assimilation in the Numerical Weather Prediction (NWP) models and for nowcasting applications.

In addition, the team used GNSS data from the Belgian dense network (ROB GNSS stations complemented by regional densification networks such as FLEPOS, WALCORS and GPSBru) to compute the integrated water vapour (IWV) to monitor the location, movement and variability of small-scale atmospheric water vapour structures. The results showed that the GNSS network densification is mandatory to sense the small-scale structures and to provide valuable information for weather forecasting and nowcasting applications.

1.1.6 Galileo

C. Bruyninx is one of the members of the ESA GGRI (Galileo Geodetic Reference Interface) Working Group responsible for addressing the needs of all potential geodesy users of Galileo, both as sole system or in combination with other GNSS. The goal of this Working Group is to write the service requirements for the upgrade from the Galileo OVF (Orbit Validation Facility) to the FOC (Full Operative Capability) Galileo Reference Service Provider (GRSP). The GRSP will provide geodetic products to external users in addition to the ones provided to the Galileo Control Centre.

In addition, the GNSS team participates to the FP7 project SX5 (Scientific Service Support based on GALILEO E5 Receivers) which aims at developing a software application for precise positioning based on an E5 GALILEO receiver primarily targeting scientific users and at exploiting the benefits derived by the use of the GALILEO E5 signals with respect to services to the scientific community. The role of ROB in the consortium is to use its expertise in GNSS positioning and deformation monitoring to evaluate the scientific potential of the GALILEO E5 receivers.

1.1.7 Time transfer observations

The scientists involved in this project have the responsibilities to establish the Belgian time scale (UTC(ORB)) and to participate in international timescales by incorporating Belgium in these timescales. We maintain presently five high-quality clocks for participation in two international timescales: the International Atomic Time (TAI) and the International GNSS Service Timescale (IGST). The present requirement for the clock precision and stability is at the level of the nanosecond over one day, which can only be achieved with high-quality clocks, when located in temperature-controlled environment. Our five clocks are located in such an environment and their performances are continuously monitored by inter-comparison between themselves and also with atomic clocks of other laboratories participating to TAI or IGST.

In order to perform these comparisons, as well as to transfer time at the centers where the computations for the international timescales are performed, we need methods which insure a time-transfer precision matching the required precision of the timescales. The scientists of this project developed a GPS+GLONASS data analysis tool dedicated to time and frequency transfer using the Precise Point Positioning approach. This tool is used in an operational routine allowing the comparison of the frequency standards of time laboratories with a frequency stability of 1e-15 at the 1 day averaging time.

The ROB team is also involved in the preparation of the timing aspects of the Galileo navigation system, which should be operational in the near future.

The scientists of this project also take care of the legal issues related to the legal time. An additional important part of the work is related to the quality control and maintenance of the clocks, as our involvement in the definition of international timescale impose us a quasi-perfect reliability.

1.2 NUTATIONS AND EARTH ROTATION

The objectives of the project ‘Earth rotation’ are to better understand and model the Earth rotation and orientation variations, and to study physical properties of the Earth’s interior and the interaction between the solid Earth and the geophysical fluids. The work is based on theoretical developments as well as on the analysis of data from Earth rotation monitoring and general circulation models of the atmosphere, ocean, and hydrosphere. The scientists involved in this project work on the improvement of Very Long Baseline Interferometry (VLBI) and GNSS observations and of the determination of geophysical parameters from these data, as well as of analytical and numerical Earth rotation models. They study the angular momentum budget of the complex system composed of the solid Earth, the core, the atmosphere, the ocean, the cryosphere, and the hydrosphere at all timescales. This allows them to better understand the dynamics of all the components of the Earth rotation, as Length-of-day variation (LOD), polar motion (PM), and precession/nutation, as well as to improve their knowledge and understanding of the system, from the external fluid layers to the Earth deep interior.

When studying Earth rotation, we investigate the causes of the variations in rotation rate (and thus of variations of the length-of-day) and in the orientation of the Earth's rotation axis in space and in the Earth (precession, nutations, polar motion). The Earth responds to external forcing (lunisolar attraction, planetary attraction) as a complex system. To derive the motions of the rotation axis (or of the figure axis) in inertial space, the Earth is, in a first step, considered as a rigid body. By doing so, the celestial mechanics problem of determining the tidal potential is separated from the physics of the planetary interior. Next, the non-rigid effects on nutations are calculated for each frequency of the rigid nutation series by using a transfer function, which is defined as the ratio between the nutation amplitudes for the non-rigid and rigid models considered at the same frequencies. Wahr's (1981) transfer function, corresponding to the adopted model by the IAU in 1980, accounts for the existence of a deformable ellipsoidal inner core, a liquid outer core and a deformable ellipsoidal mantle. Since that time, scientists of ROB have incorporated the effect of mantle heterogeneities inside the mantle. This consists in considering that there are heterogeneities in the mantle at the equilibrium state of the Earth (equilibrium at nutation time scale), and in computing the buoyancy forces associated with these heterogeneities. The derived flow and pressure also deform the boundaries, and in particular the CMB. By accounting for the deformation of the CMB in the nutation transfer function computation, a large part of the difference between the adopted model and the VLBI nutation observations can be explained. Additionally to that, there is an electromagnetic torque at the core-mantle boundary and at the inner core boundary, and we are presently working on that topic. The electromagnetic interactions are dissipative and could be used to explain the discrepancies between calculated and observed out-of-phase nutations. In the above models, the Earth is considered to be biaxial, in the sense that there is polar flattening but not equatorial flattening. We have studied the effect of the topography at the core-mantle boundary on the main free rotational modes of the Earth. The transfer function for nutation is dominated by the resonances with the rotational normal modes, and we are investigating the influence of triaxiality on the nutations.

The ROB team has also worked on the combination of GNSS and VLBI observation in order to obtain the nutations.

Our team is also heavily involved in studies in the field of geodesy of the other terrestrial planets (Mars, Venus, and Mercury) and of many natural satellites of the solar system (including large icy satellites but also smaller objects like the Martian moon Phobos).

1.3 GRAVIMETRY

At ROB, there are two scientists working in the field of absolute (Michel Van Camp) and relative gravimetry (Michel van Ruymbeke).

1.3.1 Measurement of a superconducting (SG) and an absolute (AG) gravimeter at the Membach station (eastern Belgium)

At the time the ROB initiated absolute and superconducting gravity measurements at the Membach station, there was no comprehensive investigation estimating the actual ability of terrestrial gravity measurements to monitor slow gravity changes caused by tectonic or climatic processes.

To ensure the reliability of the terrestrial gravity measurements, we became proficient in the control of all the steps of the measurement processes. (1) we published the first comprehensive study on the uncertainties of repeated absolute gravity measurements (Van Camp et al., 2005); (2) We showed that SGs are superior to the best seismometers in order to monitor the longest Earth's free oscillations (<1 mHz) (Van Camp, 1999); (3) We were the first to calculate the transfer function of an SG, which allowed us to provide the first on-line SG time series to the IRIS data centre (www.iris.edu). This was done in close collaboration with seismologists (Van Camp et al., 2008).

1.3.2 Measurement of intraplate deformations with an absolute gravimeter across the Ardennes and the Roer Graben

In contrast to GPS measurements, absolute gravity measurements provide an absolute reference for vertical land motion, which is paramount e.g. for relative sea level studies. Repeated absolute gravity measurements have been performed in Oostende (Belgian coastline) and at eight stations along a southwest-northeast profile across the Belgian Ardennes and the Roer Valley Graben (Germany), in order to estimate the tectonic deformation in the area. The AG measurements, repeated once or twice a year, can resolve elusive gravity changes with a precision better than 3.7 nm/s²/yr (95% confidence interval) after 11 years, even in difficult conditions. After 8–15 years (depending on the station), we found that the gravity rates of change lie in the [−3.1, 8.1] nm/s²/yr interval and result from a combination of anthropogenic, climatic, tectonic, and glacial isostatic adjustment (GIA) effects. After correcting for the GIA, the inferred gravity rates and consequently, the vertical land movements, reduce to zero within the uncertainty level at all stations except Jülich (because of man-induced subsidence) and Sohier (possibly, an artifact because of the shortness of the time series at that station) (Van Camp et al., 2011).

1.3.3 Measurement of man-induced subsidence

Since October 2000, absolute gravity measurements have been performed twice a year at the Jülich Research Center. This station is located 4 km away from two brown coal mines. To prevent the mines from being flooded, continuous water pumping is being performed for 50 years, inducing a subsidence of more than 1 cm/yr. Up to now a trend of $+3.9\pm1.0$ µGal/year is observed. Our absolute gravity measurements contribute to the relative gravity campaigns, repeated leveling, InSAR and GPS measurements already performed in the Jülich area, to investigate compaction processes causing the subsidence.

1.3.4 Measurement of hydrological effects on long-term gravity variation

As with other geodetic quantities, gravity integrates many phenomena, and it remains a challenge to isolate the contribution from any of them, especially tectonic and hydrological effects. Therefore, the ROB pioneered three studies on hydrological effects on gravity: (1) Seeking the effects of the environmental noise on long term gravity measurement, he characterized long-time scale hydrological effects on gravity to improve the detection of tectonic signals (Van Camp et al., 2010); (2) To confirm our strong indications that local environmental effects did dominate the hydrological gravity signal, we set up a project with hydrologists and geologists, which demonstrated the important role of the unsaturated zone around the SG (Van Camp et al., 2006). This work is essential to correct local effects that can mask regional effects such as changes in continental water storage. Local effects, indeed, perturb ground-based gravity measurements and prevent an optimal combination with satellite data (e.g. GRACE).; (3) Additionally, the group demonstrated for the first time the utility of an absolute gravimeter (AG) to investigate the hydrological cycle in a karst water system (Van Camp et al., 2006).

1.3.5 Participation in international comparison campaigns

The gravity is a space- and time-dependent geophysical quantity. Its value is required in the determination of mass-related quantities such as pressure or electrical current. Gravity is also a key-factor in the Watt balance experiment, which aims at expressing the kilogram in terms of the meter, the second and the Planck's constant, by equating electrical and mechanical powers. From a geodetic point of view, gravity plays an important role in geodesy and geophysics studies such as crustal deformations or mass changes. In order to be able to interpret the data, perfect calibration of the instruments is fundamental.
Therefore we participated in the Regional Comparison of Absolute Gravimeters (2007, 2011, Walferdange) and in several bilateral comparisons in Belgium and Luxembourg (2005, 2006, 2008, 2010, 2011).

1.3.6 Belgian Gravity Base Network

In collaboration with the National Geographic Institute it has been possible to include the sites of the WALCORS GPS network in the Belgian Gravimetric Base Network BLGBN98. The WALCORS network includes 23 GPS stations, most equipped with special concrete pillars providing good conditions for gravity measurements. This new network insures the collocation of two complementary techniques for Geodetic purposes. Moreover the integrity of these sites is guaranteed. We performed 2 spring campaigns and 2 autumn ones between September 2006 and April 2008. The scale of the network is constrained by 6 reference stations: 3 absolute gravity stations and 3 stations taken from BLGBN98. The difference between the nominal and adjusted values at the reference points is lower than 3µgal, so that the network is very well constrained. In the global adjustment of the 4 campaigns the RMS error on the points is ranging between 5 and 7 µgal. The gravity values deduced from a common adjustment are 3.7±1.4 µgal higher for the spring campaigns than for the autumn ones.

1.4 SERVICES AT ROB

1.4.1 Time, GNSS, and IERS-related services

- ✓ The GNSS data from our permanent GNSS stations are freely available to the GNSS community and can be retrieved using Internet (ftp://gnss.oma.be/gnss/data or http://www.gnss.be/gps_rob)
- ✓ We are hosting the Central Bureau of the EUREF permanent network http://epncb.oma.be/
- ✓ GNSS-based positions for a network of European stations are submitted daily and weekly to EUREF as a basis for the maintenance of the ETRS89.

- ✓ We are hosting the historical EPN data center containing all observation data of the EPN stations since the start of the network in 1996.
- ✓ The ROB participates to the realization of the International Atomic Time by sending the data from its maser and its 4 Cesium clocks to the Bureau International des Poids et Mesures, in Paris.
- ✓ ROB operates an E-GVAP analysis center providing in near-real time tropospheric zenith paths delays to meteorological agencies for numerical weather prediction applications.
- ✓ We provide information (and in the future, data) about the Earth's core on the Web in order to serve the Earth rotation community. We are hosting the Special Bureau for the Core (http://www.oma.be/KSB-ORB/SBC/main.html) in the frame of the IERS (International Earth Rotation Service).

2. National Geographic Institute (IGN)

Contribution from Pierre Voet.

One of the main tasks of the National Geographic Institute is to establish and maintain the national geodetic networks.

A complete revision of the second general levelling has been performed during the period 1981-2000. As a result 19.000 markers (first, second and third order all together) with precise heights are available. The mean standard deviation for a unit of weight is smaller than 2 mm for the first order, and between 2 and 3 mm for the second and third orders.

The old horizontal network, consisting of about 4500 concrete pillars, has been upgraded and densified using static GPS observations. The final goal, a density of 1 marker/ 8 km^2, has been reached in 2002. The mean standard deviation of these markers is 3 cm, for x, y and H. But, during the last decade, as a practical basis for daily geodetic work this old network has been gradually replaced by the GPS RTK networks, which are managed by regional governmental agencies.

That is why the department of geodesy at the NGI since a couple of years, focuses on:

- The determination of the precise coordinates of the reference stations of the RTK networks, as well in the European as the national reference system
- The monitoring of the long term stability of these reference stations
- The transformation procedures between the European and national reference systems
- The creation of a modern national reference system and mapping projection

The initial coordinates of the RTK reference stations have been calculated at the start-up of the networks (2002 – 2003). Recently (in 2011) all the hardware of these stations was upgraded from GPS-only to full GNSS. As all antennas have been replaced, all coordinates changed slightly. The most recent processing was done according to the EUREF recommendations.

To check their long term stability all RTK reference stations are reprocessed on a weekly basis. The resulting time series are available for all users through a dedicated website (http://www.ngi.be/agn/NL/NL2-1.shtm).

One of the official Belgian mapping projections is Lambert72, based on a reference system using the international ellipsoid. Many efforts have been done to establish an accurate transformation procedure between this reference system and ETRS89. The best solution is to use one 7-parameter set combined with two correction grids, one for and x and y and one for

the height component. The errors introduced by this transformation are rather small (standard deviation = 1.2 cm for the horizontal components and 2 cm for the vertical).
However, to avoid any kind of distortion, we introduced the Lambert2008 projection, which is based on the GRS80 ellipsoid. Detailed information about this map projection can be found here: http://www.ngi.be/NL/NL2-1-7.shtm.

3. University of Liege (ULg)

At the University of Liege, Section Geodesy and GNSS was created in 2005 inside the Geomatics Unit of the Department of Geography. The Section is responsible of education in the field of Geodesy and GNSS. In particular, specialized lectures on Space Geodesy and GNSS are given in the frame of the Master in Space Sciences and of the Master in Geography-Geomatics.

As far as research is concerned, our Section is active in the field of GNSS. Main research topic is the monitoring and the modelling of the ionospheric activity and the mitigation of its effects on GNSS positioning. At the present time, we are involved in the following studies:

- Total Electron Content (TEC) monitoring: we exploit the added value of new GNSS signals (modernized GPS and Galileo) to develop new TEC reconstruction techniques. First results based on triple frequency measurements indicate an improvement of a factor 3 with respect to the “usual” dual frequency techniques.
- Ionospheric correction for Galileo single frequency users: the official Galileo ionosphere correction algorithm is based on the NeQuick model. The performances of this algorithm have been assessed based on a global network at Solar maximum. The main model weaknesses have been identified and explained; in addition, different improvement procedures have been proposed.
- Effect of ionospheric variability on relative positioning: local irregularities in the ionosphere TEC can strongly degrade the accuracy of real time positioning applications like Real Time Kinematics (RTK). On the one hand, we have implemented operational software in order to detect ionospheric irregularities and to assess their effects on RTK. On the other hand, we are developing a statistical model allowing to forecast the probability of occurrence of ionospheric irregularities. Physical origin of these disturbances is also investigated.
- Precise point positioning (PPP): We exploit the added value of new GNSS signals in order to improve the mitigation of ionospheric effects in PPP data processing algorithms.

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