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

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1. Royal Observatory of Belgium (ROB)

The Section "Time, Earth Rotation and Space Geodesy" of the Royal Observatory of Belgium (ROB) contributes to the elaboration of reference systems (terrestrial and celestial) and time scales through both theoretical developments and observations.
These scientific objectives result in three main research activities in geodesy: geodetic and geophysical studies based on the observation of the artificial satellites of the Global Positioning System (GPS) (Carine Bruyninx, René Warnant, Fabian Roosbeek, Eric Pottiaux, Georges Carpentier), time and time transfer (Pascale Defraigne, Fabian Roosbeek, and Carine Bruyninx) and studies of Earth Rotation, and in particular of the theoretical nutations (Véronique Dehant, Olivier de Viron, Tim Van Hoolst, Pascale Defraigne, Fabian Roosbeek, Stéphanie Ponsar, and Frédéric Renaud). More recently, this field has been extended to the rotation of the planet Mars (Véronique Dehant, Tim Van Hoolst, Pascale Defraigne, René Warnant, Marie Yseboodt, Pascal Rosenblatt, Julien Duron, Laurent Morel, Olivier Witasse, Olivier Verhoeven, Attilio Rivoldini, Mikael Beuthe).

In 1988, the ROB started to study the use of GPS for geodetic and geophysical applications. During the period 1999-2002, this research program focused on the following topics: reference frame maintenance, measurement of long-term ground deformations, time and frequency transfer, and the assesment of different error sources affecting GPS positioning, in particular the 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 i.e., mainly, mantle convection, core-mantle interactions, ocean, and atmosphere.

The Section "Seismology, Earth Tides and Gravimetry" does also contribute to the activities performed at the Royal Observatory of Belgium related to IAG. Relative gravimetry, as explained here below, is a long tradition at the ROB. In particular, the ROB hosts the International Center for Earth Tides since 1958 (Bernard Ducarme). Contribution of gravimetry to the determination of the Belgian geoid is another mission of the ROB (Michel Everaerts, Tim Van Hoolst, Bernard Ducarme, Michel Van Ruymbeke), and research in absolute gravimetry, as well as in related applications, is presently performed (Michel Van Camp).

1.1. SATELLITE GEODESY

Experiments and observations with the ROB GPS observation network

Since January 1994, 4 permanent GPS 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 GPS 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 GPS user community and allow users to connect their local GPS 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 on the data (tropospheric and ionospheric effects) and investigations of the stability of GPS-derived coordinates (related to the solid Earth tides, the ocean loading, the regional tectonics…);
- ✓ By including the Belgian permanent network into international networks, the ROB participates to large scale geodynamics studies.

In 1997, the ROB installed three additional permanent GPS 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.

Participation to international observation networks

IGS

The IGS (International GPS Service) operates in close collaboration with the International Earth Rotation Service (IERS). By using data from more than 200 permanent GPS stations, operated by various institutions world-wide, the IGS provides the services such as high accuracy GPS satellite ephemeris, GPS-derived Earth rotation parameters, coordinates and velocities of the IGS tracking stations, GPS 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

The EUREF (EUropean REference Frame) permanent network (EPN) is built up since 1996 and includes almost 140 permanent GPS stations distributed all over Europe (32 countries). It serves as the realization of the International Terrestrial Reference System (ITRS) for Europe and the European Terrestrial Reference System (ETRS89). The ETRS89 is used by EuroControl, the EC and several mapping agencies all over Europe. EUREF closely collaborates with the global IGS network: it is the European densification of the IGS network (see the EUREF report). Part of the ROB GPS stations participates to the EPN network: Brussels, Dentergem, Dourbes and Waremme. The data from the ROB's EPN stations are made available hourly to international data centers. The ROB is one of these data centers. Analysis centers from all over Europe retrieve these data and use them to compute a highly precise European reference network integrated in the global reference network. The ROB is one of these analysis centers. The coordination of the EPN is done at the ROB (C. Bruyninx).

Experiments to measure small-scale deformations using GPS, gravity measurement, and seismology

The idea of this project is to use GPS and absolute gravimetric measurements to determine the present day rates of local deformation in several regions of Belgium. The error sources to which GPS and absolute gravity are susceptible, are different. Determining the deformation rates with two independent systems will provide additional confidence in our results. The results obtained should resolve the current discrepancy in rates determined from comparisons of first order leveling and geology. To achieve these goals, 3 additional permanent GPS stations (Bree, Meeuwen, Membach) have been installed in 1997. Regular absolute gravimetric measurements and continuous superconducting gravimetric measurements are regularly performed at the Membach location.
The stations of Bree and Meeuwen (North of Belgian Limburg) have been installed in order to monitor the tectonic rate of deformation across the active fault discovered in the vicinity of the town Bree. Indeed, paleoseismic investigations realized in 1996 along a 10-km long fault scarp near Bree indicate the occurrence of three earthquakes having produced coseismic surface faulting during the last 14000 years. To evaluate the present-day seismic hazard, it is important to know the present-day rate of tectonic deformations.
At Membach (region of Verviers), in addition to the absolute gravity measurements, the GPS receiver is collocated with a superconducting gravimeter that measures the gravity changes with time. Actually, in addition to being able to monitor crustal motions, gravimeters are also sensitive to the change of mass distribution inside the Earth or close to the gravimeter. This would seem to limit the ability of gravity to identify a tectonic signal associated with vertical crustal motions, as the signal might be contaminated by a mass movement signal. However, by extending the observation period of gravity over a few years, we have dissociated the seasonal gravity changes of atmospheric and hydrologic origin from a gravity trend resulting from tectonic processes. In addition, the collocation with GPS helps to solve this problem because mass movements do not affect the positions measured by GPS at the same level.

Time transfer observations

The ROB operates one of the few time laboratories collocated with an IGS station and uses this station to contribute with its clocks (3 Cesium clocks and 1 Hydrogen-maser) to the realization of the International Atomic Time (TAI). Within this frame, a computer program for performing time transfer for TAI with the data from geodetic (IGS) receivers has been developed and is presently used worldwide.
On the other hand, ROB's IGS station located at Brussels, has been selected as one of the "fiducial clock" stations within the IGS/BIPM experiment project. This IGS/BIPM project aims at taking advantage of IGS receivers driven by stable atomic clocks in order to generate an IGS timescale which has a good short term stability. The IGS timescale is complementary to the TAI timescale which is characterized by its long term stability. The ROB thus contributes with the same clock and the same GPS receiver to both the TAI and IGS timescales and offers, with its infrastructure, the indispensable link between both timescales. Thanks to the program mentioned above, the same GPS receiver can be used to contribute to both the IGS and TAI timescales, offering the possibility to link both timescales.

Reference frame maintenance

Processing of the Belgian network, enlarged with neighbouring IGS sites, is performed at the ROB since September 1994.

In the beginning of 1996, the ROB started with the daily processing of all EPN and IGS stations in Belgium, Great Britain, France and the Netherlands. The processed network included at the start about 15 stations, but has presently grown up to 30 stations including now also stations in Germany, Denmark and Sweden. This work is done within ROB's engagements as EPN Local Analysis Center. These solutions are submitted to EUREF and

flow to the IGS and the IERS. In addition, daily statistics about the data analysis are available on http://www.gps.oma.be/ as reference to other analysts using the same station data.
By combining the daily solutions, at the normal equation level, into a multi-year solution the internal consistency of the ROB solution has been checked. The rms error of the coordinates is then obtained from the comparison of the daily solutions with the combined solution: 1 to 2 mm for the horizontal components and 4 to 5 mm for the vertical.

In addition to this, the ROB is responsible for the coordination of the activities related to the EUREF Permanent Network, comprising its permanent GPS stations, several data centers, and 16 analysis centers. The Central Bureau of the permanent EUREF network is hosted at the ROB. It consists of Web pages (http://epncb.oma.be/), an ftp-site and a lot of computation and quality control.

Time and frequency transfer using GLONASS P-code data

We have used GLONASS P-codes from different geodetic GPS/GLONASS receivers, involved in the IGEX campaign (an initiative of the IGS), to perform frequency/time transfer between remote clocks. GLONASS time transfer is commonly based on the clock differences between GLONASS system time and the local clock computed by the time receiver. We choose another approach and analyse the raw P-code data, available in the RINEX files. This allows working also with the data from geodetic receivers involved in the IGEX campaign. As a first point, we have shown that the handling of the external frequency in some of the IGEX receivers is not suited for time transfer applications. We also point out that the GLONASS broadcast ephemerides give rise to a considerable number of outliers in the time transfer, compared to the precise IGEX ephemerides. Due to receiver clock resets at day boundaries, characteristic of the R100 receivers from 3S-Navigation that we used, continuous data sets exceeding one day are not available. In this context, it is therefore impossible to perform RINEX-based precise frequency transfer with GLONASS P-codes on a time scale longer than one day. Because the frequency emitted by each GLONASS satellite is different, the time transfer results must be corrected for the different receiver hardware delays. After this correction, the final precision of our time transfer results corresponds to a rms of 1.8 nanoseconds (ns) (maximum difference of 11.8 ns) compared to a rms of about 4.4 ns (maximum difference of 31.9 ns) for time transfer based on GPS C/A-code observations.

The effect of the atmospheric refraction on GPS positioning

At present, many applications of GPS in geophysics require a (long-term) precision of the order of the millimeter in the determination of positions and a (long-term) precision of the order of the millimeter per year in the measurement of deformations. As a consequence, the effects of different error sources on the computed positions have to be removed from the data. Nowadays, the atmospheric refraction remains the main error source in GPS positioning. This error mainly affects the altitude component of the positions. The atmospheric refraction has two components: the ionospheric refraction and the tropospheric refraction. Both are studied at ROB.

In the frame of the ionosphere effects on GPS, we have developed a software in order to compute the TEC using the so-called "geometric-free" combination of GPS dual frequency measurements. This software has been applied to the data collected in the permanent GPS stations operated by the Royal Observatory. This method has allowed studying the TEC behaviour at Brussels over a long period of time (1993-today). In addition, the data collected in the permanent stations have been used to study irregular ionospheric phenomena such as Traveling Ionospheric Disturbances and scintillations. These phenomena can give rise to large errors in GPS positioning. In particular, statistics concerning the occurrence of Traveling Ionospheric Disturbances at Brussels have been computed. The number of observed TIDS has a peak between 10:00 and 16:00 (local time) during a day, has a seasonal maximum in December-January and is larger when solar activity increases. Then, all the information concerning the TEC behaviour has been used to refine the correction of the ionospheric error. This work has taken all its meaning in the last years: indeed, we have observed a very large increase of the ionospheric activity at the maximum of the 11-year solar activity cycle reached in 2000. When Solar activity is high, it is particularly important to handle the ionospheric error with much care. The experience gained with this research program has been applied to the study of the ionosphere of the planet Mars. We are indeed preparing a space geodesy experiment that should be launched in 2009, the NEIGE experiment (NEIGE is for Netlander Ionosphere and Geodesy Experiment).

The tropospheric error is the effect of the neutral atmosphere on GPS signals. This error contains a dry and a wet component. The wet component depends on the water vapor distribution over the observing station. In 1999, the Royal Observatory of Belgium started a research project on the tropospheric refraction effect on GPS signals. The goal of the project is to use the measurements collected by water vapour radiometers, radiosondes and GPS receivers collocated with meteorological sensors in order to improve the correction of the wet component of the tropospheric error.

In a first step, procedures are developed in order to compute the integrated water vapour content from 3 independent measurement techniques:

- ✓ GPS observations and meteorological ground measurements (pressure, temperature and humidity): when the position of the observing station is precisely known (as it is the case for our permanent stations), GPS measurements combined with ground meteorological data can be processed in order to compute the water vapour content.
- ✓ Measurements made by a water vapour radiometer installed at Brussels during the year 2000. After a rather complex calibration process, the radiometer supplies the integrated water vapour content.
- ✓ Radiosonde observations performed twice a day by the Royal Meteorological Institute: the integration of the humidity profile in altitude measured by the radiosonde is integrated to compute the water vapour content over Brussels.

Then, the information obtained over water vapor from these 3 independent techniques has been used to refine the correction of the tropospheric error.

1.2. NUTATIONS AND EARTH ROTATION

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 small triaxiality of the Earth 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 ocean and atmosphere perturbations on the nutations. These effects can be computed either from considering the angular momentum exchange between the solid Earth and those geophysical fluids, or from considering the torques of the atmosphere and the ocean on the solid Earth (pressure torque, gravitational torque and friction torque). We have shown that the computed effects are far above the observation precision and must thus be taken into account, and that both approaches provide complementary information.

Recently, our team has worked on geodesy of the planet Mars and Mercury. We have studied the tides and librations of Mercury. The tidal displacements on Mercury are of the order of one meter, and tidal measurements are very sensitive to properties of the core. Concerning Mars, the precession and nutation motions, the length-of-day variations, and polar motion were modeled in order to prepare a space mission (NetLander) that is planned for launch in 2009 to the planet Mars. We also developed an accurate tidal potential for Mars, and calculated tidal surface displacements, external potential variations and gravity variations. We have shown that gravity variations induced by Phobos can be measured with sufficient accuracy by the Netlander mission to obtain information on the core. The Martian gravity field is studied as well in preparation for this mission. The geodesy data of the Netlander mission will be Doppler shift measurements of radiosignal between four landers on the Martian surface and an orbiter around Mars, as well as between the orbiter and the Earth. The Doppler shifts will be used to determine relative positions in space, and consequently will allow us to get the variations of Mars' orientation and its gravity field. These geodesy data will be used to develop models of the interior of Mars and to study its atmosphere.

1.3. GRAVIMETRY

At ROB, there are also scientists working in the field of absolute (Michel Van Camp) and relative gravimetry (Bernard Ducarme, Michel Everaerts, Michel Van Camp, Tim Van Hoolst, Michel van Ruymbeke).

First Order Gravity Network of Belgium

Between 1998 and 2001 the Royal Observatory of Belgium and the National Geographic Institute of Belgium performed several gravity campaigns to establish a new Belgian Gravity Base Network (BLGBN98, B. Ducarme, M. Everaerts, Ph. Lambot, T. Van Hoolst, M. van Ruymbeke). It benefited from the cooperation of several Belgian and foreign Institutes who provided gravimeters and even field operators. There are 41 base points. The scale is well constrained by 8 absolute gravity stations. Nine gravimeters (LaCoste & Romberg and Scintrex) have been used on the field. The data have been reduced in a common adjustment. A scale factors has been determined for each instrument. The rms error on the unit weight reaches 19 µgal. The rms error on the gravity points is ranging between 4µgal and 10µgal. The results show the distortions of a previous reference network realised in 1978. The station descriptions and gravity values can be found in: http://www.astro.oma.be/D1/GRAVIMETRY/. Details can be found in Everaerts M., Lambot Ph., Van Hoolst T., van Ruymbeke M., Ducarme B., 2002,*"First Order Gravity Network of Belgium."*, Bulletin du Bureau Gravimétrique, 90, pp 27-42.

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

Scientists at ROB observe a very low trend in gravity of -0.45±0.1 µGal/year at the Membach station. Assuming the change in the observed gravity is only due to a vertical motion of the station, we can interpret it as uplift with a rate of about 2.5±0.5 mm/year. This agrees with the continuous GPS measurements recorded 3 km away from the station since 1997. Besides, we also performed an accurate phase calibration of the SG, which is important to constrain oceanic tidal models and global Earth models. Finally, we also demonstrated the possibility of reducing the noise of SG recordings in the lower frequency band of seismic-free oscillations.

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

Absolute gravity measurements using the FG5-202 gravimeter have been conducted twice a year since September 1999 along a 140 km long profile (8 stations) across the Belgian Ardennes and the Roer Graben. Our goal is to better constrain the estimation of the current deformation and to improve measurements of the possible uplift observed at the Membach station (cf. paragraph above) as well as to constrain its wavelength. The possible deformations could be linked to active faults in the Ardennes and/or bordering the Roer Graben, or be linked to the possible Eifel plume. This profile will also contribute to constrain Fennoscandia post-glacial rebound models. Since 1997, we have also performed absolute gravity measurements in Oostende (Belgian coastline) once a year and participate in the European Sea Level Service ESEAS.

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 +3.8±3.1 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.

Measurement of hydrological effects on long-term gravity variation

Since 2001, in the AG and SG gravity measurements performed at the underground Membach station (cf. two paragraphs above), there is a 5 µGal seasonal-like term assumed to be mostly due to hydrological variations. We have studied the geological neighbouring to correct the gravity variations induced by the highly variable mass of water stored in the soil. This work can be 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). On the other hand, studying the local seasonal variations also contributes to investigate the influence of the water storage variations in small river basins on the time dependent gravity field.

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 participate in the International Comparison of Absolute Gravimeters (2001, Bureau International des Poids et Mesures) and in several bilateral comparisons in Belgium, France, Germany and Switzerland.

Development of Tsoft

Since 1999, a free interactive software called Tsoft dedicated to time series analysis, has been widely used by gravimetrists, and also now by seismologists.

1.4. SERVICES AT ROB

Time, GPS, and IERS-related services

- The GPS data from our permanent GPS are freely available to the GPS community and can be retrieved using Internet (ftp://epncb.oma.be/gps_rob or http://www.gps.oma.be/gps_rob)
- We are hosting the Central Bureau of the EUREF permanent network http://epncb.oma.be/euref/
- GPS-based positions for a network of European stations is submitted weekly to EUREF where it flows to the IGS and gets included in the global GPS network and in the successive realizations of the International Terrestrial Reference System.
- 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.
- 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).

The International Center for Earth Tides (ICET)

The ROB is hosting ICET since 1958. Besides supporting completely ICET staff, the ROB provides numerous administrative and scientific facilities especially for the publication of the " Bulletin d'Information des Marées Terrestres" (BIM), for the tidal data processing and s ince 1997 for the maintenance of the ICET/GGP data base. Details can be found in the ICET report to IAG.

The Global Geodynamics Project (GGP)

The "Global Geodynamic Project" (GGP) is a network of more than 20 stations equipped with cryogenic gravimeters. Most of them are in operation since July 1997, using a similar hardware and similar procedures for data acquisition. A first 6 years term finishes in July 2003 and a second term 2003-2009 will start immediately after.

Besides tidal research, an important objective of the GGP is to carry out a coordinated study of the SGs measurements to detect elusive inertial accelerations such as seismic free oscillations of the Earth (periods shorter than 54 min), as well as core modes (periods up to several hours) or polar motion (one year or more). In fact the cryogenic gravimeters are extra-large band instruments covering phenomena with periods ranging from one hundred seconds to more than one year.

The "Global Geodynamics Project-Information System and Data Center" (GGP-ISDC, http://etggp.oma.be/) is operated by the ROB. The data owners upload themselves the original minute sampled data. The data are carefully preprocessed at ICET using a standard procedure, to correct for perturbations. Then, after analysis, the results are communicated to the data owners. This follow up is required to quickly detect anomalies that could affect the data. Raw and corrected minute data, the log files, and auxiliary data, when available, are edited on CD-ROMS yearly. The members of the GGP consortium may download data older than one year and the public, after two years. The GeoForschungZentrum Potsdam has provided the software for the management of GGP-ISDC.

2. Université Libre de Bruxelles (ULB)

Metaheuristics for optimising Geomatic Applications

Metaheuristic techniques, which are based on ideas of the Artificial Intelligence (AI), have developed dramatically in the early 1980s and have widespread successes in solving a variety of practical and difficult real-life applications, such as, statistic, engineering, mathematical programming and operational research. This field has interested ULB, and in particular Dr Hussain Aziz Saleh. Within the Satellite Navigation technology, these ideas have been researched, implemented, and investigated. Good results were achieved in the satellite surveying. In this most recent research, these ideas are dynamically expanded to efficiently provide flexible and computerized procedures for determining high-accuracy models with a higher resolution for other geomatic applications (e.g., GPS ambiguity resolution, precise orbit determination of low earth orbiters, modeling atmospheric effects, a global high-accuracy gravity field model, etc). The volume of geomatic data for these geomatic applications is growing rapidly, and sophisticated means to analyze this volume in a consistent, robust, and economical procedure are essential. This current research deals firstly with the computational burden associated with collecting and processing geomatic data in the context of data volume and number of parameters estimated. Then, it implements a more advanced area of research using metaheuristic techniques for effectively optimizing the computational burden search problem. As these techniques have both theoretical and practical interest, not only the best results have been reported, but some variants of these techniques have been proposed. This provides a strong motivation and fertile opportunity for innovation in adapting metaheuristics for solving other practical geomatic optimization problems where feasibility and good solutions are difficult to obtain.

3. Ghent University

In 1990, the Ghent University started with the education of future surveyors, as an option in Geography. The Ghent University was, and still is, the only Flemish university offering these courses. The main topics in the education of surveyors are law (specialized on property law), topography and geodesy, cartography and remote sensing. As this option in Geography is still very young, till now, only one student (Marijke Brondeel) finished a PhD in that direction.

Besides education, one of the important tasks of any university is research. The main fields of interest in Geodesy of the Geography Department are twofold. On one hand, research in the effects of surface displacements due to loading phenomena (like atmospheric loading) is done. For this research, the results of more than 80 IGS stations are compared to the theoretical calculated effects of atmospheric pressure loading. Influences of the loading on point positioning, as well as on the estimation of e.g. tropospheric delay parameters, are investigated. On the other hand, the definition of a geodetic "datum" and the transformation methods between geodetic data and cartographic projections are investigated. Members of the group were involved in the definition of the FLEPOS RTK-GPS system. This permanent network, of more than 30 GPS RTK-stations over the northern part of Belgium, was installed to help surveyors to work in a uniform reference system. The transformation of ETRS89 coordinates resulting from GPS measurements to Belgian Lambert-72 coordinates is now done on a regional basis. The northern part of Belgium is divided in several regions were local transformation parameters between both coordinate systems are calculated. The accuracy of the transformation, especially on the borders of the different regions, is investigated.

4. 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 then 2 mm for the first order, and between 2 and 3 mm for the second and third orders.

The existing horizontal network 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. All GPS baselines, most of them shorter then 10 km, were locally fitted into the national reference system (Lambert projection on the Hayford 1924 ellipsoid). For all the concrete markers, 4500 in total, next to the horizontal position, we obtained ellipsoidal heights through GPS and orthometric height levelling (not precise). The mean standard deviation of these markers is 3 cm, for x, y and H.

Much longer GPS baselines were observed during the establishment of the BEREF network (Belgian Reference Frame), a densification of the EUREF network. This was done in cooperation with the Royal Observatory of Belgium. BEREF, a sort of new first order three-dimensional network, consists of 36 stations with very precise ETRS89 coordinates (standard deviation about 15mm).

Since last year, the regional administrations started to establish GPS RTK networks. The network in Flanders (Flepos) is already fully operational; the network in Wallonia (Walcors) is being deployed at this moment and expected to be active this year. Finally, we should also mention a small network in the third region, Brussels, which can also deliver RTK and DGPS signals.
The NGI has linked the reference stations of these three networks to the BEREF network. We also determined the parameters needed for the transformation between ETRS89 and the national grid.

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