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Development of a European Combined Geodetic Network (ECGN)

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Abstract

To ensure the long-time stability of the terrestrial reference system with an accuracy of 10^{-9} in the global and continental scale, the interactions between different time-dependent influences of the system Earth to the terrestrial reference system and the related observation has to be considered in the evaluation models. It is proposed to establish a kinematic European Combined Geodetic Network (ECGN) and to integrate the spatial and height reference system into the Earth gravity field parameter estimation. This plan is in agreement with the foreseen IAG project of an Integrated Global Geodetic Observation System (IGGOS). In selected European stations ECGN will establish the combination of time series of spatial/geometric GNSS observations, precise levelling and tide gauge records with gravity field related observations (gravity, Earth tides). Observations are complemented with meteorological parameters, surrounding information of the stations, e.g. eccentricities and ground water level. A first call for participation in the project was directed to the implementation of the ECGN stations. These stations include the standard observation techniques GNSS (GPS/GLONASS—permanent), gravity (super conducting gravimeter and/or absolute gravimeter—permanent or repeated), levelling connections to nodal points of the European levelling network (UELN) (repeated) and meteorological parameters (permanent). A basic constituent of the ECGN stations is a local network for controlling the eccentricities at the 1 mm accuracy level in all three spatial components. For the contributing observation techniques, guidelines have been agreed upon to ensure equal observation principles.

Keywords: GPS; Geodetic reference system; Height reference; Gravity; Tide gauges

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1. Introduction

Since the mid-1990s the IAG Subcommission for Europe (EUREF) of the Commission X, Global and Regional Networks has worked on the establishment and development of a unified European height system. European height projects made good progress thanks to the close cooperation between the National Mapping Agencies (NMA) and universities. The European Vertical Reference Network (EUVN) is a successful example for the combination of GPS, levelling, tide gauge, and gravity observations.

Within EUREF, the European Permanent GPS Network (EPN) is in operation since 1996. Experiences with tide gauge observations are available, and EUREF started with the adjustment of repeated levellings. In 2001 EUREF announced the participation of the EPN stations in the IGS GPS Tide Gauge Benchmark Monitoring Pilot Project (TIGA-PP).

Several absolute gravity projects within Europe in the last 15 years have been carried out: National gravity networks, geodynamic networks (e.g. to monitor the Fennoscandic uplift, or to monitor the rifting of Iceland, and Ardenne and Roer Graben studies), monitoring of sea level changes (e.g. tide gauge stations around U.K., or the SELF project), international gravity networks (campaigns of US-NIMA within Eastern Europe in the 1990s, the UNIGRACE-project from 1997 to 2001) and studies of temporal variations of the gravity field with superconducting gravimeter and absolute gravimeter time series.

A proposal for the development of the European Combined Geodetic Network (ECGN) has been prepared and discussed at the EUREF Symposium in Ponta Delgada 2002 (Ihde et al., 2003). The competences of EUREF (now in the new IAG structure European Sub-Commission (SC) 1.3a of SC1.3 Regional Reference Frames of Commission 1 Reference Frames) and IGGC/Europe in such fields as set-up and use of spatially referenced systems, acquisition of terrestrial gravity data, and gravity field modelling will be of great benefit to the overall realisation of the project.

The ECGN is considered as a European contribution to the Integrated Global Geodetic Observation System (IGGOS)—the central IAG project (Rummel et al., 2000, 2002). It is designed to integrate in a European network time series of spatial/geometric observations, gravity field related observations and parameters (gravity, tides, ocean tides), as well as supplementary information (meteorological parameters, eccentricities and ground water level). The combination serves to compare techniques, to investigate influences to the stations in particular and the models of the reference systems.

2. Background and motivation

One of the fundamental development potentials in geodesy at present and for the near future lies in the improvement of the accuracy level availability of the gravity field related height component and the gravity field itself. Whereas geometrical positioning made dramatic progress in accuracy and operability during the last 15 years, there was no substantial development in the Earth's gravity field modelling until the start of the satellite gravity missions.

GPS has superseded traditional terrestrial methods of positioning in both, science and practical applications. The positioning accuracy in the global scale is better than 10^{-9} with near real time availability. On the other hand, precise height determination, which is an integral component of geodetic positioning, continues to be based on classical terrestrial methods. With its accuracies of 10^{-6} to 10^{-7}, it falls short of three-dimensional GPS positioning by the order of two. Since the classical terrestrial methods are restricted to their respective continents, there is no standardized reference system of heights on the global level.

The renewal cycle of the height reference systems takes about 30 years in Europe. Consequently the height component from levelling for GPS positioning is not adequate in accuracy and operability. This fact does not only considerably impair the referencing of geo-information systems through GPS as to their overall efficiency, but also the performance of scientific kinematic and dynamic studies and investigations of the geosphere.

Absolute gravity time series provide key information for long-time stabilisation of height reference systems. On the other hand gravity time series need precise position information to separate position variations from observed gravity variations.

Recent works show that the satellite gravity field missions CHAMP, GRACE and GOCE bring considerable improvements to the long and medium wavelength of the gravity field. The short-wavelength components of the Earth's gravity field, ensuring continuity at the 1 cm accuracy level in the local scale on the long run, needs to be acquired by terrestrial

Table 1
Components for height parameter combination and their dependence from tidal systems (Ihde and Augath, 2002)

	Gravity ($g/\Delta g$)	Geoid (W/N)	Levelling height (ΔH)	Altimetry (h)	Mean sea level (msl)	Position (X/h)
Mean tidal system, mean/zero crust (stokes is not valid if masses outside the Earth surface)	Δg_{m}	N_{m}	ΔH_{m}	Relation to N_{m} for oceanographicstudies	h_{msl}	
Zero tidal system, zero/mean crust (recommended by IAG Res. No. 16, 1983)	$\Delta g_{\mathrm{z}} \xrightarrow{\text{Stokes}} \underset{\text{(EGG97)}}{N_{\mathrm{z}}}$	(EVRF2000) ΔH_{z}				
Non-tidal system, non-tidal crust (far away from the real earth shape—there is no reason for the non tidal concept)	$\Delta g_{\mathrm{z}} \xrightarrow{\text{Stokes}} \underset{\text{(EGM96)}}{N_{\mathrm{z}}}$					Xn ITRFxx ETRS89

gravity data. Therefore, it is necessary to combine the data from satellite gravity field missions with terrestrial gravity data reduced to a standard height level.

To ensure the long-time stability of the terrestrial reference system with an accuracy of 10^{-9} in the global scale and for Europe, a common space/gravity reference system realized by collocation stations for different observations is required. Today's results show clearly that, only in conjunction, absolute and superconducting gravimeters time-dependent gravity variations at the μGal-level. Therefore, they offer a basis for research on secular gravity and height variations.

In processing combined networks like ECGN the collocations between techniques are very important. Generally, the ECGN sites should deploy multiple techniques sufficiently close to one another that the vectors of their separations can be very accurately measured. This is absolutely essential for inter-technique combinations. Collocation also ensures that external systematic errors are common to the various independent systems. Systematic errors are often poorly characterized or quantified, which can lead to precision estimates being mistakenly used for highly optimistic accuracy expectations. In this way, collocation sites are of worth for studying sources of systematic errors and assessing their magnitudes.

The availability of the reference frames for real-time and near-real-time positioning needs a highly sensitive modelling of the time dependent phenomena of the solid Earth, the Earth gravity field, the ocean, the atmosphere and the hydrosphere. The recording of relevant data to describe and model these phenomena is an integrated part of the maintenance of the terrestrial reference system.

The experiences within the European Vertical Reference Network (EUVN) project have shown the practical and methodological problems with the combination of different geodetic observation techniques, especially geometrical spatial and gravity field related data (Ineichen et al., 1999; Ihde et al., 1999, 2000; Wöppelmann et al., 2000).

Furthermore there is no closed reference system for spatial and gravity systems defined at present. For example the UNIGRACE project (Unification of Gravity Systems in Central and Eastern Europe) which evolved from the CERGOP initiative (Central European Regional Geodynamics Project) followed the purpose to set up a unified gravity reference frame but was realized without a directly measured connection to a space network (Reinhart et al., 1998).

Table 1 shows the components of an integrated geodetic reference system and their dependency on the tidal systems. It points out that a unique concept for the reduction of observations and related parameters is necessary (Ihde and Augath, 2000).

Gravity-related components are given in a zero tidal system, conforming to the IAG Resolution No. 16 adopted in Hamburg 1983 and to the handling of the gravity data. Contrary to this, the ITRFyy coordinates are given in the non-tidal system, the same holds for the global geopotential model EGM96. The European geoid was reduced to the zero tidal system. The non-tidal system/crust is far off the real Earth shape—there is no justification for the non-tidal concept. The Stokes formula is not valid for the mean tidal system, but the mean sea level is reduced to the mean/zero geoid for oceanic studies.

3. Objectives

In order to ensure the long-time stability of the terrestrial reference system with an accuracy of 10^{-9} at both the European and global scale, the interaction between the different time-dependent influences of the system Earth to the terrestrial reference system and the related observations has to be considered in the evaluation models. The strategic objective of this project is to realise an integrated geodetic reference frame for the entire territory of Europe.

In the context of the ECGN project the height is the most important component of the three-dimensional positions of the participating stations. However, in the regional or global terrestrial reference system, heights are less accurately determined than the horizontal components. This is due to the geometry and the properties of the (mostly spatial) observations, which are sensitive to various systematic errors. Therefore, improvements can be expected from the careful combination of different spatial observation techniques (preferably at the observation level), such as GPS and Satellite Laser Ranging (SLR), collocated at the same site, taking into account the strengths (and weaknesses) of each individual technique.

The complement of the geometrical positioning with the physical height component of matching accuracy, operability and efficiency needs the gravity and a high-precise geoid in the cm-accuracy range. The project contributes to gravity field modelling for the area of Europe and to the generation of the best possible global model.

The planned activities aim at linking the spatial reference system with gravity field related parameters in order to contribute to a consistent description of the general processes of the system Earth. These processes shall be kinematically integrated into a combined monitoring system of position and gravity. Products of the satellite gravity field missions will be combined with the data of the integrated geodetic terrestrial reference frame.

It is a matter of course that the European spatial reference system realised by the European GPS Permanent Network (EPN) is based on, resp. contributes to, global systems. Consequently, the entire project must be seen in the global context. The work on the integrated kinematic network must be understood as a European contribution to a global integrated geodetic network. This project will support the activities towards an improvement of the European Vertical Reference System (EVRS, 2000) for scientific work and for the supply of relevant data to European authorities and institutions.

The analysis of GPS time series shows that the height component is not sufficiently verified. The combination with other data with vertical information gives the possibility to stabilize the vertical velocities. The main technological aspect is the combination of time series of different techniques.

The proposed ECGN may substantially contribute to meet the geodetic basic needs of the geo-information sector within Europe. Moreover, in the course of the further development of the ECGN, the needs and requirements as well as the demands made on a DGPS Real-Time positioning service will be allowed for. Additionally ECGN could be a component of a future European disaster monitoring network. The tasks of relating geodata and geodynamic investigations require a precise spatial reference system in real-time or near real time, which takes the complex interrelationships between the solid Earth and the ocean, the atmosphere, and the gravity field into account. Establishment of this network is carried out in accordance with the technological state of the art of positioning by means of satellite navigation systems and considers the foreseeable developments in the user strategies.

4. The techniques

The ECGN stations have the standard observation techniques GNSS (GPS/GLONASS and in future GALILEO—permanent), gravity (super conducting gravimeter and/or absolute gravimeter—permanent or repeated), levelling connections to nodal points of the United European Levelling Network (UELN—repeated) and meteorological parameters (permanent). Standard for the ECGN stations is a local network for the derivation of eccentricities at a 1 mm accuracy level. All ECGN stations are part of the European GPS Permanent Network (EPN). For the observation techniques guidelines have to be fulfilled. This chapter describes the single techniques in relation to the future combination in this project as well as the relations to running international projects.

4.1. European Permanent GPS Network (EPN)

The EUREF Permanent Network (EPN) is a network of permanent GPS tracking stations whose weekly computed coordinates are used by EUREF to realise the European Terrestrial Reference System. Supported by EuroGeographics, this reference network forms the backbone for all geographic and geodetic projects on the European territory both on national as on international level (Habrich, 2003).

Presently, the network consists of more than 150 stations distributed in 32 European countries. The stations provide high quality GPS data in daily batches. In support of near-real time applications, such as the determination of the tropospheric zenith path delay for numerical weather prediction, 58% of the stations also contribute with hourly data. Real-time applications are supported by the EUREF-IP subnetwork in which the contributing EPN stations distribute RTCM corrections through the Internet.

Sixteen analysis centres guarantee the data analysis of the EPN data. The weekly coordinate solutions they provide are the basis for the unique weekly EPN network solution that delivers precise coordinates for all stations in the EPN to the GPS community. The precision of the computed coordinates is about 2–3 mm for the horizontal components and 5–6 mm for the vertical component. The GPS data quality and data flow of all EPN stations is checked on a daily basis. In addition, weekly updated coordinate time series allow monitoring the influence of equipment changes on the computed coordinates.

In summary, next to geodetic applications, the EPN is also valuable for scientific applications such as geodynamics, sea level monitoring and weather prediction (http://www.epncb.oma.be/).

The long-term maintenance implicitly involves the monitoring of the station coordinate time series. This is a key issue in ECGN, where we are primarily interested in the analysis of the height component variation due to real (geo)physical phenomena and we have to separate them from technique-related effects. It is well known that all changes in the observing environment, equipment, and processing mostly affect the height component. These effects appear as sudden variation (jump) in the height component (up to several cm!). In addition outliers in the time series can be observed, caused by temporal inconsistencies at the specific station. The basic task of the monitoring is the clean-up of the time series with identification, estimation and elimination of outliers and offsets. This step provides a cleaned, bias-free coordinate time series, which may serve as an excellent basis for:

- improved site velocity estimation and
- estimation of periodic signals in the time series.

The GPS time series monitoring, cleaning and velocity estimation is being performed at the EPN Special Project for "Time Series Analysis". The estimation of periodic signals in the time series could be the most relevant contribution of EPN to ECGN, where the different time series (continuous and/or epoch-wise) are handled together and will serve as a basis for the identification and interpretation of geophysical processes of the European continent. The time series monitoring would refer also to the treatment of the continuous superconducting gravity, tide gauge, repeated absolute gravity and levelling observations (Bruyninx et al., 2002, 2003; Kenyeres et al., 2003).

4.2. Absolute gravity

Comparing vertical movements and gravity changes, a relation in the order of 3 mm/1 μGal (free air gradient) to 5 mm/1 μGal (tectonic uplift) can be found. It can be concluded that to confirm a station uplift in the order of a few mm (which is realistic with modern geometric geodetic instrumentation) it will be necessary to determine the gravity values with an accuracy of 1–2 μGal which corresponds to $1–2 \times 10^{-9}$. Modern absolute gravimeters have the potential to meet this requirement.

The present instrumentation for the absolute gravity measurements which represents the state of the art is the FG5 gravimeter produced by the commercial company Micro-g, USA. The instrument development goes back to a technology transfer in 1990 when the instrument realization at a scientific institute was transferred to a modern industrial production and significant improvements were made in the realisation of physical standards, the measurement precision, data evaluation and correction models.

To verify and ensure the stability of the instrument sensor it is necessary to check the physical standards (rubidium clock and stabilized laser) repeatedly with great care for each individual instrument. Instrument stability and possible offsets need to be assessed by repeated observations at stable reference stations, by mutual instrument comparisons and by the participation in the international comparison of absolute gravimeters organized by the IAG and IGGC

The FG5 absolute gravimeter is an instrument which provides the claimed accuracy under indoor conditions only. Therefore, the absolute gravity stations have to be specially selected under environment aspects and need to be prepared for the gravity measurements. Either a stable building foundation or a dedicated pier is required for the instrument installation. Stronger changes in the surrounding, e.g. of groundwater or other mass changes should be avoided or need to be observed and accounted for in the data analysis.

The objectives of the precise absolute gravity measurements can be the establishment of precise national or supranational gravity networks or profiles providing an optimal reference for various geodetic and geophysical applications. Repeated absolute gravity observations will reveal possible gravity changes at the occupied stations. As described before, the gravity measurement is sensitive to height changes as well as to mass changes in the vicinity. These influences can be caused by geophysical processes and/or environmental influences related to natural or human-induced effects. Whereas the vertical component of geometric GPS observation will reflect height variations induced by station displacements and Earth crust deformation and variations of the reference frame for the satellite-based observation, the physical gravity observation reflects the vertical movement of the reference station as well as changes of masses (in quantity and position) acting upon the gravity sensor.

The absolute gravity measurement is carried out typically in single-station occupations. The repetition rate has to be chosen in agreement with the expected (and observed) gravity variations and is selected between 6 months and 1 or 2 years.

The work of this project will start from the realization of the gravity stations in connection with the other sensors with repeated observations at certain epochs. The reoccupation of the site necessarily includes the observation of the geometric ties and all environmental parameters. Only the consideration of all influences like ocean and atmospheric loading, mass attraction by groundwater, ocean and atmosphere, etc. will make it possible to correlate the movements of the different sensors. The final aim will be a description of the dependencies between the different kind of observations and the determination of time-dependent station coordinates with an improved accuracy (Wilmes et al., 2002).

4.3. Super-conducting gravimeter measurements

The Global Geodynamics Project (GGP) is to study geodynamical problems through the observation of the variations of the Earth's gravity field recorded by the super-conducting gravimeters (SGs) existing in the world. SGs are at the moment the most sensitive gravimeters (nanoGal or 10^{-9} m s^{-2}). The first period of this program started in July 1997 and has been extended in July 2003 at the IUGG meeting held at Sapporo.

There are 20 stations worldwide, 9 of which are located in Europe, 2 stations in North America, 5 in Asia and 1 in Spitsbergen and only 3 in the Southern hemisphere. The phenomena studied by the GGP range from the seismic ones up to the wobble modes of the Earth and any long-period phenomena. One of the great advantages of the GGP is the homogeneity of the recordings of its network (sampling rate, filters, etc.) which enables to compile the data of different stations.

Special importance for the execution of absolute gravity measurements is shown for stations with a superconducting gravimeter (Fig. 1). The absolute gravity measurement is needed to determine the linear drift of the superconducting gravimeter and by the combination of both measurement types detailed investigations about the gravity signal variations and correlation studies with other environmental parameters on the vertical position, as well as upon the gravity signal, are possible.

The SG's raw data are regularly sent by the different stations to a common database (hosted by ICET in Brussels and Geoforschungszentrum Potsdam). The data are immediately available to the participants of the GGP and after 1 year they can be distributed to anyone. In addition to SGs the absolute gravimeters (AG) are useful first for a precise calibration of the SG and second for a confirmation of any trend and/or seasonal variation observed in the long-term gravity changes.

The main fields addressed by GGP are listed as follows on GGP website: Earth tides and the nearly diurnal free wobble, core modes, atmospheric interactions, Earth rotation and polar motion, gravity changes due to tectonic motions, enhancing absolute gravity measurements, seasonal effects, and geodesy (http://www.eas.slu.edu/GGP/ggphome.html).

4.4. Tide gauges

Tide gauges around the European coasts provide an important component of ECGN. The mean sea level at some tide gauges provides the national levelling height datum, e.g. Newlyn and Marseille. Tide gauges which have very long series of annual mean sea levels (i.e. >50 years) are of particular importance for the ECGN. The mean sea level data are

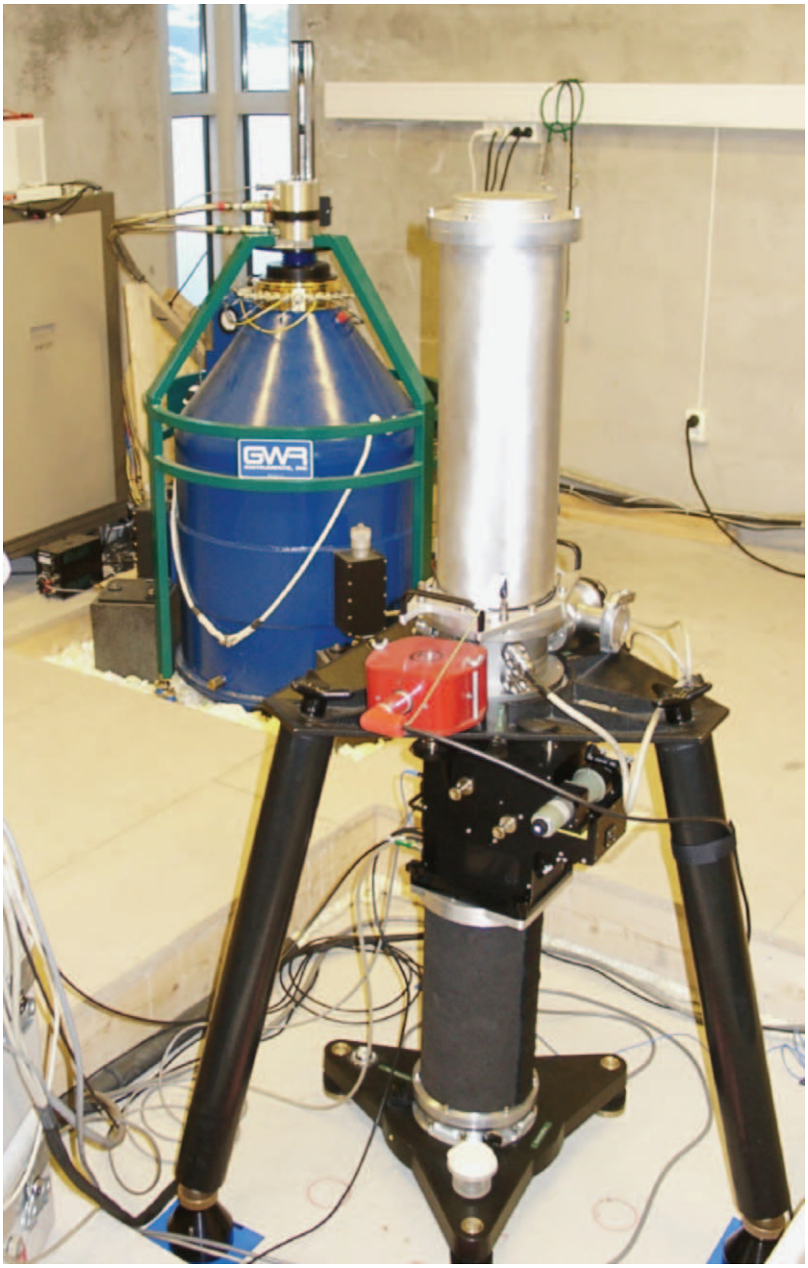

Fig. 1. Micro-g gravimeter FG5 and superconducting gravimeter, Ny Alesund 2001.

available from the Permanent Service for Mean Sea Level (PSMSL) (http://www.pol.ac.uk/psmsl). The Revised Local Reference ("RLR") data set of PSMSL is the most relevant, since for these tide gauges the Tide Gauge Benchmark (TGBM) histories are available, and so the data can be used to construct time series of the mean sea level variations in a common local datum. Continuous GPS (CGPS) and absolute gravity measurements are required at these tide gauges in order to separate the climate-related component of changes in mean sea levels from the vertical land movements at the tide gauges (Baker, 1993, Baker et al., 1997).

Following various international workshops, the IGS set up a global pilot project called TIGA on using CGPS to monitor tide gauge benchmarks (http://op.gfz-potsdam.de/tiga/index_TIGA.html). This includes CGPS measurements at several European tide gauges. CGPS and absolute gravity measurements of vertical land movements at tide gauges are also very important components of the recently formed European Sea Level Service (http://www.eseas.org).

Published results are already available from GPS measurements at European tide gauges (e.g. Teferle et al., 2002 and Becker et al., 2002). Results from absolute gravity measurements at tide gauges have also been used to determine the vertical land movement at the gauges and to test geophysical models of post-glacial rebound (Williams et al., 2001). GPS measurements at tide gauges can also be used for determining mean sea level with respect to the ellipsoid, which then provides a valuable test at the centimetre level of available geoid and sea surface topography models (Bingley et al., 2002).

The main objective of the above CGPS and absolute gravity measurements at tide gauges is to determine the vertical land movements to better than 1 mm/year in order to correct the observed secular changes in mean sea levels for vertical land movements. However, as a first step, the CGPS measurements at tide gauges will be extremely valuable for testing the accuracy of vertical velocities determined from GPS. Due to reference frame uncertainties, the absolute accuracy of vertical velocities from GPS is presently of the order of ± 3 mm/year (http://igscb.jpl.nasa.gov/components/prods.html). For tide gauges with more than 50 years of continuous data, the secular change in mean sea level can be determined to a few tenths of a millimetre per year. The climate related rise in mean sea levels over the past century, determined by the Intergovernmental Panel on Climate Change (IPCC) is 1.5 mm/year $\pm$ 0.5 mm/year. The IPCC value can be used to correct the mean sea level trend determined from a tide gauge and hence provide an estimate of the vertical land movement, which can be used to check the accuracy of the vertical velocities determined from CGPS. Similarly, Holocene geological sea level indicators from nearby sites can be used to provide a further test of the vertical velocities. Thus, it can be seen that CGPS measurements at coastal sites will be extremely useful for checking the biases in the vertical velocities in the GPS solutions.

4.5. Levelling

The basis for the gravity field related vertical reference is the existing United European Levelling Network (UELN). After a break of 10 years, the work on the UELN was resumed in 1994 under the name UELN-95. The objectives of the UELN-95 project were to establish a unified height system for Europe at the sub-decimetre level with the simultaneous enlargement of UELN as far as possible to include Central and Eastern European countries and the development of a kinematical height network step by step. Starting point for the UELN-95 project has been a repetition of the adjustment of the UELN-73/86 (Adam et al., 2000).

The adjustment of the UELN-95 is performed in geopotential numbers as nodal point adjustment with variance component estimation for the participating countries and as a free adjustment linked to the reference point of UELN-73 (Tide Gauge Amsterdam). The a-posteriori standard deviation referred to the levelling distance of 1 km is 1.1 kgal mm.

At the UELN data and computing centre at the Bundesamt für Kartographie und Geodäsie (BKG) the data handling and adjustments are carried out (Sacher et al., 2002).

All ECGN points shall be connected by precise levellings to UELN lines to have a common height reference. In the UELN adjustments different observations over a time period of about 50 years are used. With that the UELN is very inhomogeneous. To overcome this problem a common adjustment of observations of different measurement epochs is necessary (Sacher et al., 2003).

5. Status of the project

5.1. Call for participation

The call for participation is structured in two stages. The first call is directed to the implementation of the ECGN stations following the concept of the project. In parallel the ECGN working group will prepare the second call for analysis and investigations. In the first step, the main action of the ECGN working group will be a pilot study of the combination of the different observations using available collocations at stations, e.g. Medicina, Wettzell, etc. and this to get experiences in the combination of spatial information with gravity field related data.

5.2. Implementation of the ECGN stations (first call)

This call concerns the establishment of the observation network for ECGN stations. The ECGN stations have the standard observation techniques

GNSS (GPS/GLONASS, GALILEO)—permanent
Gravity (super-conducting gravimeter and/or absolute gravimeter)—permanent or repeated
Levelling connections to the UELN/EVRS—repeated
Meteorological parameters—permanent.

For the realisation of the EVRS, the connection to tide gauge projects and the recording of vertical changes between sea level and the solid Earth surface, it is necessary to include selected tide gauges (permanent) along European coast lines.

Standard for the ECGN stations is a local network for the determination of eccentricities at a 1.0 mm accuracy level in all three spatial components (repeated). All types of observation techniques at an ECGN station should be situated within a distance of about 1 km.

Optional are the establishment of ground water gauges at gravity stations and absolute gravity observations at tide gauge stations.

It is proposed to qualify some stations as core stations. Core stations should give the possibility to study the combination of different observation techniques and kinematical effects in any case.

All ECGN stations are or should become part of the EPN. For GNSS observations and data flow, the guidelines for EPN stations & Operational Centres have to be fulfilled (http://www.epncb.oma.be/_organisation/guidelines/).

For super conducting gravimeter observations, the Agreements and Standards of the Global Geodynamic Project (GGP) are definite (http://www.eas.slu.edu/GGP/ggpas.html).

For absolute gravity measurements, agreements and standards are in preparation, including data formats for archiving.

The tide gauges have to be realised following the requirements of the Permanent Service of Mean Sea Level (PSMSL) (http://www.pol.ac.uk/psmsl/datainfo/contrib.html). The status of ECGN station distribution can be found in Fig. 2.

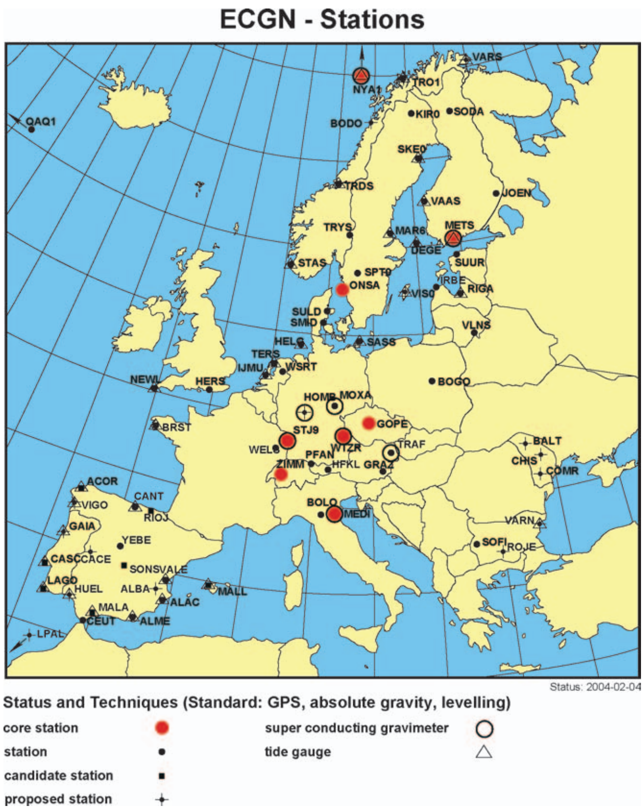

Fig. 2. The European Combined Geodetic Network (ECGN), under preparation.

5.3. Methodology and analysis (second call)

For super conducting gravimeter data, the GGP data centre could be used for data collection. Levelling data of ECGN will be collected at the UELN/EVRS data centre. Local data centres for absolute gravity data and super conducting gravimeter data should be installed in the first stage by the ECGN working group.

In a second call it could be asked for

- Analysis centres for the combination of time series observations of all ECGN stations.
- Combination of space techniques (GPS/GLONASS, GALILEO, VLBI, SLR).
- Methodical investigations for the combination of spatial observation data with gravity field-related data.

6. Investigations of combination

In the modelling of a geophysical process, say, of glacial isostatic adjustment (GIA), input data and predictions on gravity change combined with all types of data: 3D, geoid change, etc. A recent discussion of relevant global processes can be found for instance under http://www.iers.org/workshop_2002a/program/. However, as a first step, single-station multi-technique observation series need to be screened and interpreted for kinematics and dynamics, and then the primary companion of gravity usually is vertical motion.

For some geophysical phenomena approximate rules of thumb are often used to gauge the relationship between gravity changes and vertical movement rates. To take an example about GIA, the −0.2 μgal/mm observed in Fennoscandia (Ekman and Mäkinen, 1996) or the −0.16 μgal/mm modelled by Wahr et al. (1995) are frequently applied. For elastic surface loading, the free-air gradient −0.3 μgal/mm is assumed. In the interpretation of observed gravity and height at a single-station a key question often is that gravity is highly sensitive to all density variations in the near field, whether or not they are associated with the phenomenon being modelled.

The dashed line is the ratio of elastic gravity (i.e. deformation effect only, no Newtonian term) and vertical displacement. In the solid line gravity includes the attraction of the load, approximated by a layer at station elevation. This is all right for far zones in flat topography but inappropriate near the station. Gravity is positive down and displacement is positive up. Comments in text.

To illustrate some of the issues involved, consider models of regional surface loading by say, subsurface water. The ratio of the Green's functions for gravity change and vertical motion is about −0.23 μgal/mm when the attraction of the load is not included and around −0.3 μgal/mm when it is included. In the centre of a spherical water cap 100 mm thick and 4° radius the predicted vertical displacement would be −3 mm and gravity change +0.9 μgal. However, locally the same water storage can produce an additional +4.2 μgal (the Bouguer approximation) not included in the prediction.

Thus the joint interpretation of variation in height and gravity has best chances of success when a number of environmental parameters are monitored as well (Zerbini et al., 2001). A monitoring in terms of regional variations in mass will be provided by the GRACE satellite and will in the future be a key element in the modelling of surface gravity change too. Note that correlation of time series ultimately cannot replace observation and modelling. In the example quoted, the local hydrological attraction will usually be coherent with the regional loading, possibly with other seasonal signals, and regression models will produce opaque results.

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