

Concept and Status of the ECGN Project

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Abstract

In order to ensure the long-time stability of the terrestrial reference system with an accuracy of 10^{-9} in the global and continental scale, the interaction 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. The EUROPEAN COMBINED GEODETIC NETWORK (ECGN) integrates the spatial and height reference system into the Earth gravity field parameter estimation. This is in agreement with the planned IAG project of an Integrated Global Geodetic Observation System (IGGOS). In geodetic fundamental stations the ECGN will establish a European network for the continuation of time series of spatial/geometric

observations (GNSS - GPS/GLONASS and in the future GALILEO), precise levelling and tide gauge records with gravity field related observations and parameters (gravity, Earth tides), complemented with supplementary information (meteorological parameters, surrounding information of the stations e.g. eccentricities and ground water level). The 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 and in future GALILEO), gravity (super conducting gravimeter and/or absolute gravimeter), levelling connections to nodal points of the European levelling network (UELN) and meteorological parameters. 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. All ECGN stations are part of the European GPS Permanent Network (EPN). For the contributing observation techniques, guidelines have been agreed upon to ensure equal observation principles.

1. Introduction

Since 2001 the Technical Working Group EUREF and the IAG Subcommission for Europe of the International Geoid and Gravity Commission (IGGC) has discussed the continuation of the work serving the realisation of an integrated kinematic geodetic reference system for Europe, which allows to meet the increasing accuracy requirements for spatial and height reference systems.

Following the discussions, in 2002 EUREF and IGGC/Subcommission for Europe (IGGC/Europe) agreed to develop an integrated geodetic network ECGN for Europe. A proposal for the development of the European Combined Geodetic Network (ECGN) has been prepared, which was discussed at the EUREF Symposium in Ponta Delgada 2002 (Ihde et al., 2003).

The ECGN Project is linked with many current international geodetic projects and will contribute to them. Among these are the satellite gravity field missions CHAMP, GRACE and GOCE and the sea level tide gauge projects TIGA-PP and ESEAS. The ECGN is considered as a European contribution to the Integrated Global Geodetic Observation System (IGGOS) – the central IAG project (Rummel et al., 2000 and 2002). However, the ECGN also constitutes an independent component of its own. The

primary concern of the project consists in connecting the height component with the gravity determination while allowing for measuring data that are acquired in the European coastal regions and above adjacent seas.

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. (Ihde et al. 1999, 2000 Wöppelmann et al., 2000, Ihde & Sacher 2002)



Figure 1. Station distribution of the unified gravity reference network UNIGRACE

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 (Figure 1). (Reinhart et al., 1998)

The project is being initialized in two steps. A 1st Call for participation aimed at establishing the necessary observation stations thus ensuring appropriate forward planning. The stations shall combine the various geodetic techniques: GPS, leveling, gravity and tide gauge observations in coastal zones. In 2004 the 2nd Call for participation serving for the complex analysis of the data acquired as well as for their combination and matching with further observations will be launched. The 1st Call was addressed to scientific institutions, geodetic national mapping agencies, and also to station-operating institutions.

The activities are organized and accompanied by a Working Group. The ECGN Working Group was formed in January 2003. The members of the Working Group are the authors of this paper.

2. 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.

The European spatial reference system realised by the European GPS Permanent Network (EPN) is based on, resp. contributes to, global systems and therefore is also a component of the latter. 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 height reference system 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 geoinformation 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 grav-

ity 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.

3. Status of the Project

(<http://www.bkg.bund.de/ecgn/>).

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 ect. and this to get experiences in the combination of spatial information with gravity field related data.

Implementation of the ECGN stations (First Call)

The first call was sent out in March 2003. This call concerns the establishment of the observation network of ECGN stations. The ECGN stations have the standard observation techniques

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

For the realisation of the European Vertical Reference System 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. (Ihde & Augath 2000, 2002) 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.

The first ECGN call was supported by 19 countries until end of August 2003. Altogether 71 stations were proposed to participate at the ECGN (Figure 2). The distribution of the proposed stations shows that there is need of additional stations especially in regions and countries which are not well covered yet. Corresponding authorities will be contacted personally [e.g. General Assembly of Euro-Geographics]. Generally the first ECGN call is still open. Further proposals are welcome and can be accepted.

The proposals have to be evaluated by the ECGN Working Group.

Methodology and Analysis (Second Call)

The second ECGN call is still a matter of further discussions. It will consider the status of the project

(stations, data availability, meta database, data policy). In a second call it could be asked for Methodical investigations for the combination of spatial observation data with gravity field related data

- AG/SG combination
- AG/SG array for GOCE validation
- Combination of space techniques (GPS/GLONASS, GALILEO, VLBI, SLR)
- Single station analysis of different observation techniques
- Analysis centers for the combination of time series of all ECGN stations
- Establishment of co-operations to solve the above mentioned questions.

4. The Observation Techniques at the ECGN Stations

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). 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.

ECGN - Stations



Status: 2004-02-04

Status and Techniques (Standard: GPS, absolute gravity, levelling)

- | | | | |
|-------------------|---|-----------------------------|---|
| core station | ● | super conducting gravimeter | ○ |
| station | ● | tide gauge | △ |
| candidate station | ■ | | |
| proposed station | ✦ | | |

Figure 2: The distribution of stations of the European Combined Geodetic Network (ECGN), under preparation

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 to 3 mm for the horizontal components and 5 to 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 and 2003, Kenyeres et al. 2003)

4.2 Absolute gravity

Comparing vertical movements and gravity changes, a relation in the order of 3 mm / 1 μ Gal (free air gradient) to 5 mm / 1 μ Gal (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 μ Gal which corresponds to 1 - 2 * 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 stan-

dards (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 (Figure 3).

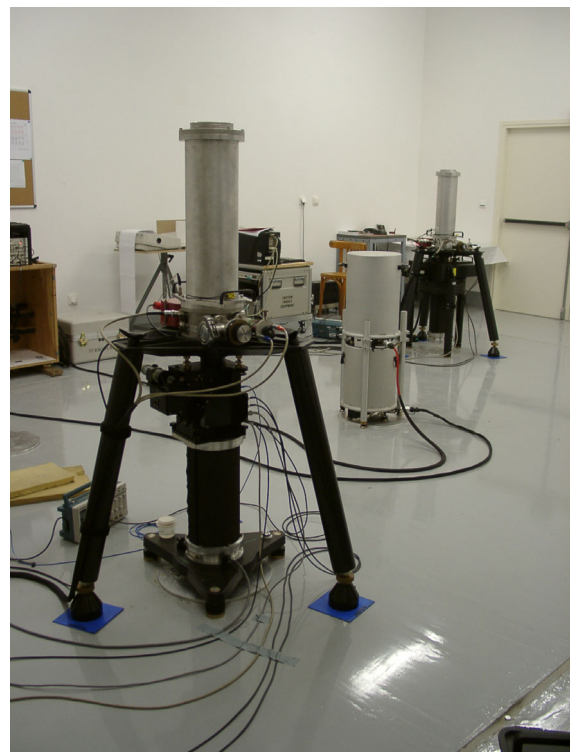


Figure 3: International comparison of absolute gravimeters, ICAG2001 at BIPM Paris, Micro-g gravimeter FG5 (front and background) and field gravimeter A10 (middle)

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 one or two 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, 2003)

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} ms⁻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 (sam-

pling 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 (Figure 4). 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.



Figure 4. Micro-g gravimeter FG5 and superconducting gravimeter (background) at the ECGN core station Moxa (Germany)

The SG's raw data are regularly sent by the different stations to a common database (hosted by ICET in Brussels and GFZ in Potsdam). The data are immediately available to the participants of the GGP and after one 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 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.eslas.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, Baker and Jeffries, 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 1mm/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 uncer-

tainties, the absolute accuracy of vertical velocities from GPS is presently of the order of $\pm 3\text{mm/year}$ (<http://igs.cb.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 $1.5\text{mm/year} \pm 0.5\text{mm/year}$. 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 ten 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 (Amsterdam).

The development of the UELN-95 is characterized by two different kinds of enlargements: The substitution of data material of such network blocks (which had been already part of UELN-73) by new measurements with improved network configuration, and on the other hand by adding new national network blocks of Central and Eastern Europe which were not part of UELN-73. 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)

The parameters of the last adjustment version of the UELN are the following: Number of fixed points: 1; number of unknown heights of the nodal points: 3654; number of measurements: 5127 lines; average redundancy: 0.287; a-posteriori standard deviation referred to the levelling distance of 1 km: 1.13 kgal · mm.

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.

5. Cooperation

Since the ECGN can be seen as a part of the IGGOS or, in broader sense, as a part of an Earth monitoring system underlying the Integrated Global Observing Strategy (IGOS), it may represent, on a continental scale, a summary contribution of geodesy to the IGOS. Generally, each monitoring system implicitly includes three mutually tied essential aspects - conceptual, realization and institutional aspect.

The concept of the monitoring system should identify all potential users and their needs for specific products. The user requirements should essentially specify the properties of the required products, such as availability, timeliness, integrity, reliability, consistency and accuracy. Also the specifications for the performance and quality of the system as well as for relevant components and tools should be included in the concept. A concept should be formulated in a way that avoids any voluntaristic approach to the realization and implementation resulting in fluctuation of contributors and, consequently, in inconsistencies of provided data and products.

While the concept of the monitoring system should well correspond to present and future scientific and society needs, the realization aspect, manifested by a manifold of observation facilities, communication tools, data processing and data analysis facilities

should meet the specifications and objectives given by the concept including the performance and quality control of the products provided by the system. The institutional aspect aims at the financial and political support of the realization part.

With regard to the conceptual and realization aspects an important part of both the data providers and the users of a geodetic monitoring system may be governmental institutions represented by administration authorities, national mapping agencies, research institutions and higher education facilities. Therefore, a synergetic feature is characteristic for the system and its operation and both science-driven and institution-driven aspects are inherent to a network like the ECGN. Thus, a support from the relevant political level provided through governmental organizations and institutions is important to ensure its long-term operability and performance.

A high degree of synergy can be traced, for example, in the evolution of EUREF during the last fifteen years. Here the science-driven aspect is represented by the IAG and its corresponding subcommission for Europe whereas the institution-driven aspect has been fostered by the CERCO, later EuroGeographics, the inter-governmental body representing the European national mapping agencies (NMAs) and realized by individual NMAs themselves, often in mutual collaboration among them. It is interesting, that the idea to develop a new continental reference frame based on space geodetic techniques emerged almost simultaneously and independently on the platform of both above mentioned bodies and that this idea has evolved up to

the present EPN as a rudiment of a modern multi-purpose monitoring system. It is supposed that this way will be continued also in building the ECGN.

Among the important tasks of the geodetic community are the development of tools to perform the global reference system combinations optimally and self-consistently and to distribute the results to users with services. Both of these are areas of very active efforts. The first is more a challenge for the universities and research institutions, the second mainly for NMAs and government institutions.

If the observation system should fit well to a broad range of applications, adequate interfaces to the user community are to be developed. The interfaces and services should be unified, standardized, user friendly, comprehensive and simple. Ideally, an internationally recognized central authority should be responsible for this important activity. This is a challenge for a body active within the IAG but governmental and inter-governmental bodies should be asked for a long-term support.

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