Future and development of the European Combined Geodetic Network ECGN

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Abstract.
In this paper we discuss future, need and structure of the European Combined Geodetic Network ECGN. It combines the integration of time series of spatial/geometric observations with GNSS technique, and physical quantities with gravity field related observations and parameters including precise levelling, tide gauge records, gravity observations, and earth and ocean tides. The objective of ECGN as an integrated European Reference System for Spatial Reference and Gravity is the maintenance of the terrestrial reference system with long-term stability for Europe.

1. Background

The European Combined Geodetic Network (ECGN) was initiated by the IAG Commission 1 (Reference Frames) Sub-Commission 1.3.a for Europe EUREF, and IAG Sub-Commission for Europe of the International Gravity and Geoid Commission (IGGC) in the business meeting of the IGGC at the Gravity and Geoid 2002 Symposium in Thessaloniki. The primary idea was in connecting the height component with the gravity field related observations and parameters including precise levelling, tide gauge records, gravity observations, and earth and ocean tides (Ihde et al., 2004, 2005). Objectives include maintenance of a long time stability of the terrestrial reference system with an accuracy of 10^{-9} for Europe, especially in the height component, and modelling of influences of time-dependent gravity-related parameters. Moreover, a large variety of supplementary information (meteorological parameters, surrounding information of the stations, e.g. eccentricities and ground water level) also exist.

In order to ensure the long-time stability of the terrestrial reference systems 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 systems and the related observations have to be considered. This implies the combination of geometric positioning with physical height and gravity parameters in better than 1 cm accuracy level and the modelling of influences of time depended parameters of the gravity field, atmosphere, oceans and hydrosphere.

During last decades geodetic observations and permanent observing networks have provided a more detailed picture of the Earth's surface and gravity, their temporal variations in all scales, and global changes in the Earth's shape, mass distribution, sea level and orientation in the inertial frame. The increased accuracy reveals inconsistencies between observing techniques, requires more precise reference frames, and especially requests combination of techniques and observing networks, both space-borne and traditional ones, under an integrated geodetic observing system. Such an integrated infrastructure for geodetic observations is asked for a wide range of scientific and practical applications both regionally and on the global level.

In 2007 at the XXIV General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Perugia, Italy, the Global Geodetic Observing System, GGOS, became a full component of the International Association of Geodesy (IAG) as its permanent observing system. Current status and goals are described in (Pearlman and Plag, 2009). GGOS is based on existing IAG Services, see (http://www.iag-aig.org/) for details and access points to the services and their products.

The development of the GGOS started already in the beginning of 2000's (Beutler et al., 2000, Rummel et al., 2000). Parallel to the development of the GGOS regional systems were also initiated. These included also the ECGN. Originally, such regional observing systems as ECGN were thought to be regional densifications of GGOS. Development of the GGOS, however, lead to a structure where regional "GOS"s do not play a significant role but GGOS is based on the existing IAG services. This put the regional observing systems in a situation where their tasks and future status is to be reconsidered. Definitions of ECGN originally included also their status as a regional implementation and densification of GGOS. A similar development happened with the Nordic Geodetic Observing System, NGOS (Poutanen et al., 2005, 2007). In the General Assembly of the Nordic Geodetic Commission (NKG) in Sundvollen, Norway in September 2010, NGOS was integrated as a part of the NKG working group of Geodetic Infrastructures (NKG, 2011).

2. ECGN first call and current status

The first call for participation in the ECGN in 2003 was directed to the implementation of the ECGN stations. The call for Participation was sent out to about 150 potential institutions and organisations in Europe. As a response more than 20 European countries sent proposals. About 70 stations were proposed to participate in the ECGN, and after the evaluation of their suitability, the final number was reduced to 62 (status of 2007-07-02).

The accepted stations included the standard GNSS observation techniques, gravity (super-conducting gravimeter and/or absolute gravimeter), levelling connections to nodal points of the European levelling network (UELN) and meteorological parameters. The stations were divided into four categories:

- *core* (criteria for ECGN are fulfilled and there are additionally some special conditions like fundamental station/observatory and/or measurements of SG)
- *OK* (criteria are fulfilled at present or will fulfilled in the future)
- *candidate* (few of the criteria are not fulfilled (e.g. perm GPS not yet realised))
- *proposed* (some more criteria are at present and perhaps will not be fulfilled in the future).

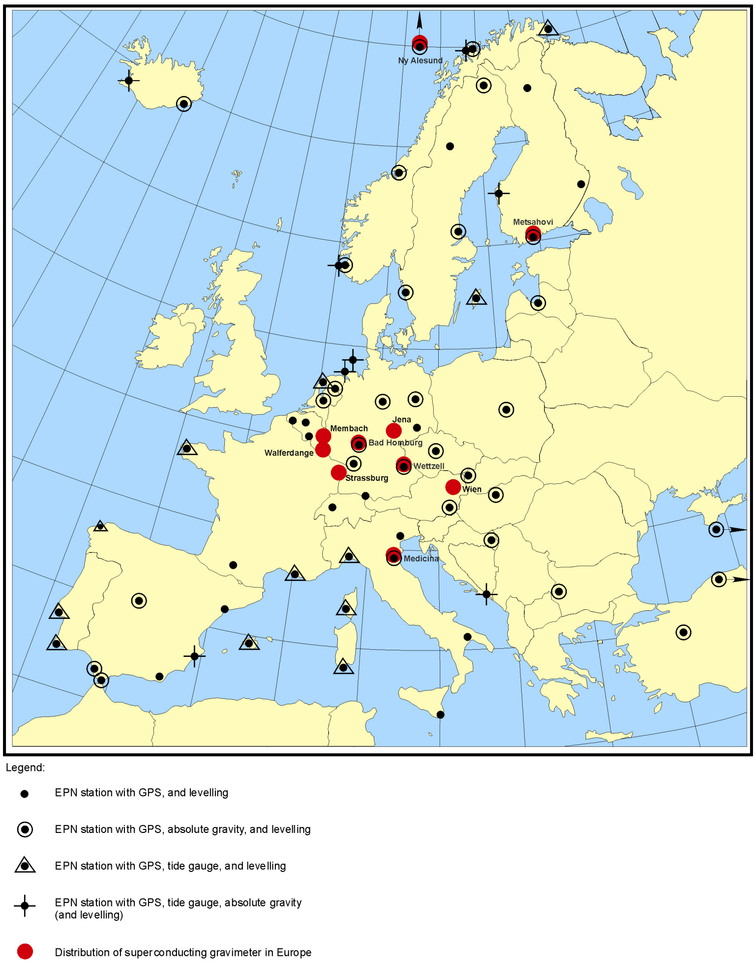

Figure 1. ECGN candidate stations after 1st call.

After the first call, stations and their information were listed on the ECGN web page (ECGN, 2011). Guidelines for different components were also prepared. Components which were considered as a part of ECGN developed independently but ECGN itself was not much advanced. Most of the components are in place, and no further efforts are needed to establish any new structure. In the following there is a short summary of them.

Status of GNSS: The European Permanent GNSS network (EPN, 2011) is up and running and it is fully organized. There exist operational and analyzing centers, as well as data base which is easy to access. Standards for becoming a GNSS EPN Station are given on the EPN web page.

Status of levelling network: The United European Levelling Network (UELN) exists, data are archived in a data bank, and European-wide adjustments have been made. Guidelines for connecting the ECGN stations to UELN exist and there is a recommendation that all ECGN stations should be connected to UELN. Objective of UELN is to establish European-wide unified vertical datum. Based on the definition of the European Vertical Reference System (EVRS) and the UELN adjustment, a realization EVRF (European Vertical Reference Frame) has been created, the latest one being EVRF2007. More details of the EVRS/EVRF are given in http://www.bkg.bund.de/geodIS/EVRS/EN/Home/homepage__node.html__nnn=true.

Status of gravity measurements: There exist a data base and archive for absolute gravity (AG) measurements (http://agrav.bkg.bund.de/agrav-meta/index.html), but still a lot of data are missing there. There exists also ECGN guidelines for Absolute Gravity measurements and for superconducting gravimeter (SG) observations (under the Global Geodynamic Project, GGP). For superconducting gravimetry a common data base exists via the GGP. Relative gravimetry data are in many cases not freely available and there exist no common data base. Gridded data or Bouguer anomaly maps are in most cases available from various sources.

Status of Tide gauge measurements: For Tide Gauge measurement the data of Permanent Seal Level Observing System - PSMSL and the project European Sea Level Service - ESEAS should be used. There exists the ECGN Standards for Tide Gauge measurements. Contrary to the other techniques, many tide gauges are maintained and owned by non-geodetic organizations. This implies either lack of full control over physical existence of the stations or some restrictions to the data access.

Status of VLBI, SLR and DORIS: These techniques are not considered as an active part of the ECGN. All these stations are included in the respective IAG services. If needed, data access and results are obtained via the services.

Co-located sites, local ties and metadata: A crucial aspect is the co-location of different techniques. The observations of different techniques should be in a close range according to the conditions of the ECGN station. Each type of observation has its own reference, and local ties between the instrument and a local reference network should be obtained in a mm-accuracy. The accuracy should be consistent and reliably controlled over long time periods. Currently, local ties are not fulfilling all requirements, and further development must be done in the future to reach the goal. The goal is common with e.g. GGOS. ECGN guidelines for local ties should be rewritten.

Metadata: The metadata base should be an essential part of ECGN. There exists the ECGN metadata form but the database is not complete and more effort is needed to obtain all necessary information; some of data (e.g. some local ties, meteo data, …) may not yet exist. Database is out-of-date.

3. Defining the (new) objectives and tasks of ECGN

The original motivation for the ECGN was to integrate the monitoring of gravity (repeated absolute gravity, superconducting gravimeters) and gravity-related heights to the monitoring of the 3-D reference for Europe. According to the definition of GGOS, it will not have a regional substructure, and it is not to be concerned with continental networks of precise levelling like the UELN. In this respect there would be an obvious task for ECGN to develop as a regional program in Europe, using its existing tools (EPN, UELN) as a basis in this task.

Currently, there is no realization of a unified global height reference which will be needed e.g. in studying the global change and seal level rise. There are hundreds of local or regional height systems which are realized by spirit levelling and fixed to different tide gauges with inconsistencies more than a metre due to sea surface topography and different epochs. There are also discrepancies between geometrical (GNSS based) and gravity field related values.

Considerable amount of new data have been obtained during recent years from the satellite altimetry and gravity field missions allowing consistent modelling of both geometric and gravimetric related heights. The Unified World Height System (WHS) under development integrates geodetic space techniques, gravity measurements, levelling, and tide gauge records. ECGN should be developed in parallel to the WHS as a regional realization consistent of the WHS.

Combining and analyzing multiple space techniques (like SLR, VLBI, GNSS) at a limited number of fundamental stations is more properly done within a global framework under the GGOS. Therefore these techniques are not included in the ECGN plan. Another issue is regional processing of GNSS data. For a proper handling of satellite orbits and temporal evolution of station coordinates, especially the vertical component, a global processing strategy is needed. This may limit the use of EPN current products in ECGN related purposes. However, in the future, a reprocessing of the EPN data history may change this picture but a careful analysis and discussion will be needed to solve for the question.

Proposed techniques and their role are shown in Table 1.

Table 1. Techniques and components considered to the ECGN

Technique	*Objectives*	*Accuracy*	*Components where contribution*
GNSS	Point positioning relative to a satellite system/geocentre	E: 1-2 cm *) C: 1-2 mm	Surface displacement, 3-D reference frame, geometrical height
Levelling	Height differences of points relative to the geoid, UELN	< 1 mm/km$^{1/2}$	Surface displacement, vertical reference frame, physical height
Tide gauges	Height of points relative to sea level, sea level changes	E: 10 cm C: 1 cm	Surface displacement, vertical reference frame, physical height
Absolute gravimeters	Absolute gravimetric accelerations	2-3 μGal	Surface displacement, gravity systems, mass changes, physical height
Superconducting gravimeters	Relative gravimetric accelerations	0.1 μGal – <1 nGal	Surface displacement, Earth rotation, gravity/mass changes, local effects
Spring gravimeters	Relative gravimetric accelerations	2-3 μGal	Surface displacement, gravity systems, mass changes, physical height
Gravity satellites	Regional geopotential differences and temporal variations		Geopotential differences, temporal variation, reference frames
Local ties	Connecting different techniques	1-5 mm	Reference frame
Metadatabase	Access to the data repositories		

*) *E means episodic and C continuous measurements*

4. Tasks and structure of ECGN

The objectives of ECGN can be summarized as follows:

- Monitoring the long time stability of the terrestrial "3D+1" reference system for Europe with an accuracy of 10^{-9}, including 3D geometric parameters together with the gravity related height component
- In-situ combination of geometric positioning (C-GNSS time series) with physical height (UELN) and repeated gravity measurements in 1 cm accuracy level or better
- To contribute in the maintenance and improvement of precise geoid models
- To provide connection to the sea level and sea level changes via tide gauges in the area
- To maintain databases (via existing components, such as EPN) and a metadata base for access to the data and product of the ECGN

The following ECGN Network structure will be needed for objectives

- A dense C-GNSS network (EPN stations or equally established and maintained national or regional network stations) with repeated absolute gravity and connection to the UELN network = Class-C ECGN station
- IGS stations with existing repeated absolute gravity and connection to the UELN network = Class-B ECGN station
- GGOS Fundamental Stations with all major space geodetic techniques, repeated absolute gravity and connection to the UELN network = Class-A ECGN station
- Any category may have a connection to a tide gauge (both 3-D geometric and leveling) and a superconducting gravimeter
- Local ties between techniques exist on sub-cm level

Revised call for participation and implied tasks

- Revised call for participation to be sent to National Authorities and other organizations participating EPN
- To revise the list of stations based on replies; Class A, B or C ECGN stations
- Maintenance of the meta database giving list of ECGN stations, and links to databases
- Integration of GOCE results with the ECGN gravity data
- Re-analysis of EPN time series in a global frame; strategy, schedule and possibilities to be discussed

Products of the ECGN

- Combination of data based on participating components; including e.g.
    - gravity change relative to the 3-D motions (C-GNSS time series + absolute gravimetry time series)
    - Tracking the 3-D vectors of ECGN stations based on (revised?) EPN time series, or computed in the frame fixed by Class A and B stations in the area
    - Tide gauge changes connected to the ECGN points (geometry, gravity and leveling)

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Specialities of ECGN Working Group Members

	TWG member	GNSS	Gravity	Levelling Height	Tide gauges	Local ties	Meta data
Markku Poutanen	yes	yes	-	-		yes	-
Martine Amalvict	-	-	yes	-	-	-	-
Carine Bruyninx	yes	yes	-	-	-	-	-
Olivier Francis	-	-	yes	-	-	-	-
Johannes Ihde	yes	-	-	yes	-	-	-
Ulla Kallio	-	yes	-	-	-	yes	-
Ambrus Kenyeres	yes	yes	-	-	-	-	-
Gunter Liebsch	-	yes	-		-	-	yes
Jaakko Mäkinen	yes	-	yes	yes	-	-	-
Steve Shipman	-	-	-	-	yes	-	-
Jaroslav Simek	-	yes	-	-	-	-	-
Simon Williams	-	yes	yes	-	yes	-	-
Herbert Wilmes	-	-	yes	-	-	-	-