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 aims the integration of time series of spatial/geometric observations obtained from GNSS, physical quantities obtained from gravity field related observations and other parameters including precise levelling, tide gauge records, 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 focussing to the long-term stability for Europe.

1. Background

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 at all scales, and of global changes in the Earth's shape, mass distribution, sea level and orientation of the inertial frame. The increased accuracy reveals inconsistencies between different observation techniques, requiring more precise reference frames, and especially requesting co-location of techniques and observing networks, both space-borne and traditional ones, under an integrated geodetic observing system.

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.

Parallel to the development of the GGOS also regional systems were initiated, including the European Combined Geodetic Network (ECGN). Because GGOS is based on the existing IAG services and not on regional networks, the role and tasks of regional systems is to be reconsidered.

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 consisted in connecting the height with the gravity field related observations and parameters including precise levelling, tide gauge records, gravity observations, solid earth and ocean tides, and modelling their time-dependent variations (Ihde et al., 2004, 2005). The objectives also include maintenance of the long-term stability of the terrestrial reference frame with an accuracy of 10^{-9} for Europe, especially in the height component. This implies the combination of geometric positioning with physical height and gravity parameters in better than 1 cm accuracy level and modelling the influences of time depended parameters of the gravity field, atmosphere, oceans and hydrosphere. Moreover, a large variety of supplementary information (meteorological and environmental parameters and station related data) also exists and should be included in the database.

The concept of a World Height System (WHS) is being developed as a part of the GGOS strategy. The WHS shall be realized using a combined global network, which integrates precise absolute and relative gravity, levelling, tide gauges and geometric information from GNSS. The goal is to use the available infrastructure of the IAG/GGOS Services. In the practical implementation, ECGN could serve as a regional network which provides necessary data and infrastructure for the WHS.

2. ECGN first call and current status

The first ECGN call for participation in 2003 focussed on the implementation of the ECGN observing 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 the status of fundamental station with co-location of several instruments)
- *OK* (criteria are presently fulfilled or will fulfilled in the near future)
- *candidate* (some criteria are not yet fulfilled, e.g. permanent GPS not yet realised)
- *proposed* (some more criteria are at present not fulfilled without guarantee for the future).

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 the components.

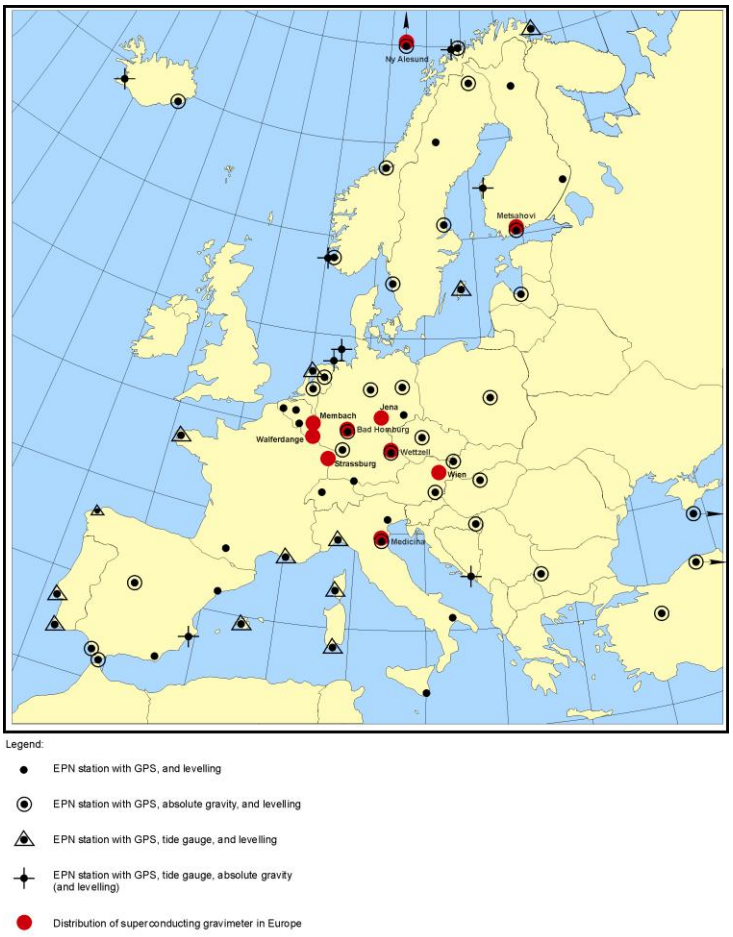

Figure 1. *ECGN stations and candidate sites after 1st call.*

Status of GNSS: The EUREF Permanent GNSS network (EPN, 2011) is up and running and it is fully organized (see http://www.epncb.oma.be/). There exist operational and analysis centres, as well as a database 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/), 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) have been developed. For superconducting gravimetry a common data base exists via the GGP. Relative gravimetry data are in many cases not freely available and there exists 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 Sea Level Observing System - PSMSL and the project European Sea Level Service - ESEAS should be used. ECGN Standards for Tide Gauge measurements are available. Contrary to the other techniques, many tide gauges are maintained and owned by non-geodetic organizations. There may be a lack of repeated geodetic ties of the stations to the national height network 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 global IAG services and no regional sub-networks exist. Data access and results are obtained via GGOS.

Co-located sites, local ties and metadata: A crucial aspect in the ECGN 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 with mm-accuracy. This 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. The ECGN metadata form has been created but the database is not complete and out-of-date. More effort is needed to obtain all necessary information; some of data (e.g. local ties, meteo data, …) may not yet exist.

3. Revised objectives and structure of ECGN

The original motivation for the ECGN was to integrate the monitoring of gravity (repeated absolute gravity, superconducting gravimeters) and gravity-related heights within the monitoring of the 3-D European reference. According to the definition of GGOS, 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.

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. Currently, there is no commonly agreed 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. The WHS aims in integrating geodetic space techniques, gravity measurements, levelling, and tide gauge records. ECGN should be developed keeping in mind the requirements of 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. In order to reduce the network error on station positions and their time evolution especially in the vertical component, a global processing strategy is needed. This may limit the use of current EPN products in ECGN related purposes. However, in the future, a reprocessing of the EPN all data will be performed and most probably this reprocessing will include global reference stations.

Table 1. *Techniques and components considered to the ECGN*

Technique	*Objectives*	*Accuracy*	*Precision*	*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^{½}		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	22μGal/sqrt(Hz)	Surface displacement, gravity systems, mass changes, physical height
Superconducting gravimeters	Relative gravimetric accelerations		10μGal/sqrt(Hz)	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*

As discussed above, objectives and tasks of ECGN can be summarized as follows:

1. To identify a network of stations with collocated techniques shown in Table 1.
2. To provide access to the related data. This implies maintenance of databases, most of them via existing components, such as EPN, and a metadata base as a part of the ECGN portal
3. To contribute to initiatives aiming at the maintenance and improvement of precise geoid models in Europe; Integration of GOCE results with the ECGN gravity data
4. Collocation of geometric positioning (C-GNSS time series) with physical height (UELN) and repeated gravity measurements in 1 cm accuracy level or better, and to provide connection to the sea level and sea level changes via tide gauges in the area.
5. To contribute to the realisation of the WHS
6. To contribute to the evaluation of the uncertainty of the Terrestrial Reference Frame origin
7. 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.

The implementation of the revised ECGN will be started with item (1) above by a call for participation. The main purpose of the call is to update the list of stations fulfilling the requirements for an ECGN station. As a minimum, an ECGN station should have a C-GNSS receiver with repeated absolute gravity and a connection to the UELN network. The stations should belong to IGS or EPN or be a part of national or regional networks which are established and maintained comprising the IGS or EPN guidelines. The core stations should additionally have other major space geodetic techniques fulfilling the GGOS Fundamental Station definition. A connection to a tide gauge (both 3-D geometric and levelling) and a superconducting gravimeter are options which should be included where available. Local ties between techniques should exist on a sub-cm level.

Parallel to the station information update, the web portal is to be developed to provide access to (for the ECGN) significant co-located data, products and metadata of these stations (item 2 above). The list above also implies the expected products and outcome of the ECGN.

ECGN will be using existing structures and databases where available. However, following subgroups are foreseen:

1. Stations and local ties; needed to organize the call for participation, to maintain the list of stations and local ties, and to maintain respective guidelines
2. GNSS; current organization for EPN already exists and is sufficient for this
3. Gravity and heights; a coordination is needed between existing groups and networks
4. Tide gauges; connections to the existing geodetic networks

4. Summary

We have discussed objectives and tasks of the ECGN. ECGN should be developed as a part of a European initiative to maintain an integrated system of reference frame and gravity. It will contribute to the WHS, but also as an ultimate goal, enable long-term monitoring the stability of the terrestrial "3D+1" reference system for Europe with an accuracy of 10^{-9}.

First tasks to achieve the goals are the revised call for participation to be sent to National Authorities and other organizations running suitable stations in order to revise the list of

stations and to maintain the ECGN metadata base. The observing network and other components mostly exist, but re-analysis of time series, strategy, schedule, products and possibilities are to be discussed.

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