The Role of Gravity and Height for the GGRF

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1) GGRF, Physical heights, and Gravity

The UN Committee of Experts on Global Geospatial Information Management (UN-GGIM) (http://www.unggrf.org/)

- In February 2015 the UN GA adopted the resolution ***A global geodetic reference frame for sustainable development.***
- A broad interpretation of the GGRF will be adopted.
- The GGRF includes the terrestrial and celestial reference frames and their component observing systems, data centers, analysis centers, and combination and product centers. The GGRF terrestrial reference frame includes geometric, gravimetric, and physical height systems.
- At present a GGRF roadmap is in preparation.
- IAG has developed a position paper „Description of the Global Geodetic Reference Frame".
- The establishment of a regional GGRF Working Group is under development.

1) GGRF, Physical heights, and Gravity

The GGRF Roadmap is a political paper. The audience of the Roadmap is intended to be the Member States of UN GGIM Committee of Experts. The Roadmap will also serve as a briefing document into national political administrations, and more broadly for the public.

The Roadmap

- addresses global geodetic capability development through education, research and innovation, and capacity building.
- will additionally consider governance, collaboration, coordination, outreach and communication as fundamental facilitators to sustainability of the GGRF.
- consider especially the global geodetic infrastructure.
- will discussed at the Sixth Session of the Committee of Experts on Global Geospatial Information Management in New York, 3 - 5 August 2016

1) GGRF, Physical heights, and Gravity

The two IAG Resolutions 2015

No. 1 for the definition and realization of an International Height Reference System (IHRS)

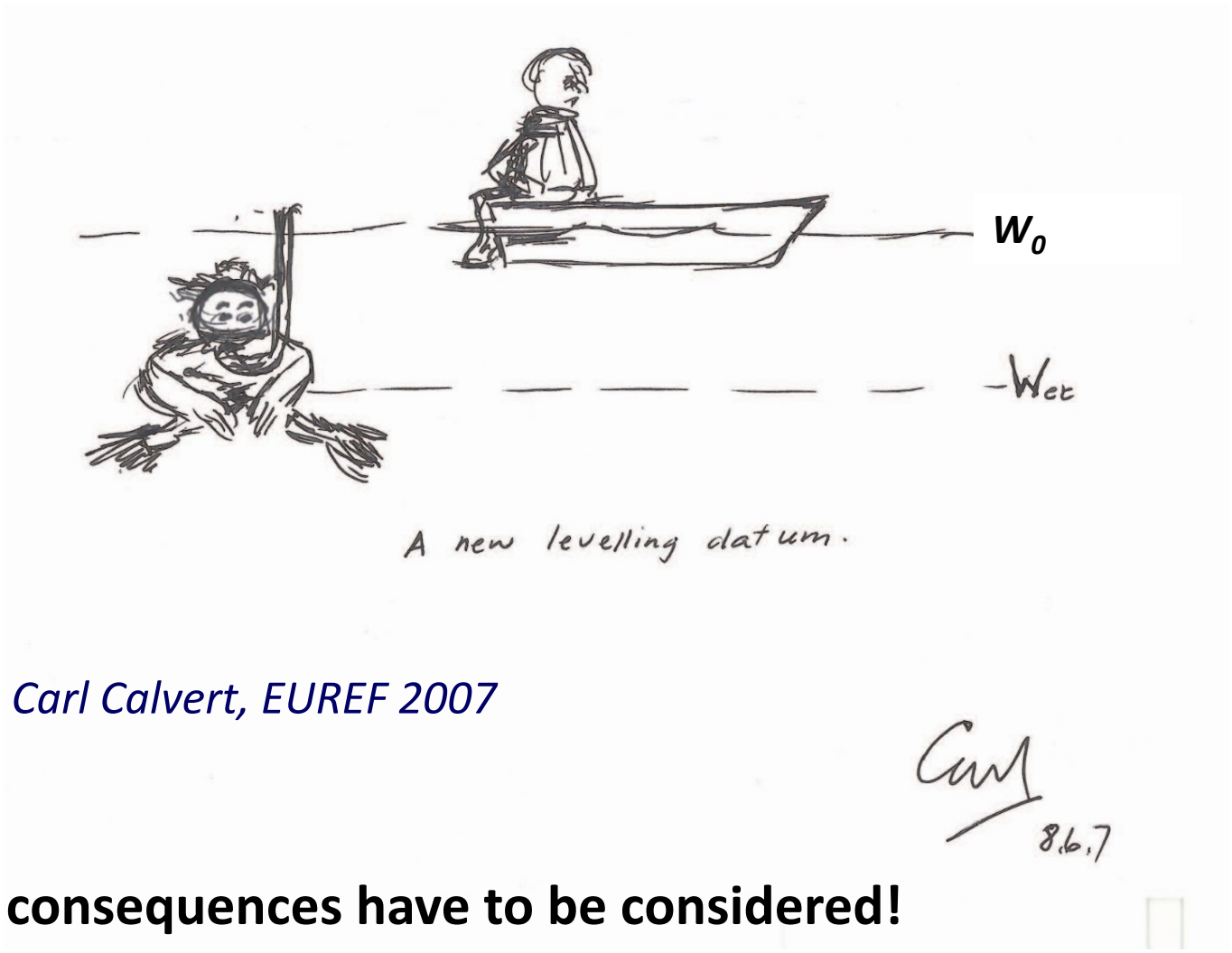
- Five conventions for the IHRS definition plus W_0 (as reference for IHRF)
- Requirements for the realization:
  - long-term stability and worldwide homogeneity
  - an integrated global geodetic reference frame with millimeter accuracy
  - removal of inconsistencies between analysis strategies, models, and products related to the Earth's geometry and gravity field
  - outlining of standards that allow a consistent definition and realization.

1) GGRF, Physical heights, and Gravity

The International Association of Geodesy,
resolves

- the following conventions for the definition of an International Height Reference System (see note 1):
  1. the vertical reference level is an equipotential surface of the Earth gravity field with the geopotential value W_0 (at the geoid);
  2. parameters, observations, and data shall be related to the mean tidal system/mean crust;
  3. the unit of length is the meter and the unit of time is the second (SI);
  4. the vertical coordinates are the differences $-\Delta W_P$ between the potential W_P of the Earth gravity field at the considered points *P*, and the geoidal potential value W_0; the potential difference $-\Delta W_P$ is also designated as geopotential number C_P: $-\Delta W_P = C_P = W_0 - W_P$;
  5. the spatial reference of the position *P* for the potential $W_P = W(\mathbf{X})$ is related as coordinates $\mathbf{X}$ of the International Terrestrial Reference System;
- $W_0 = 62\,636\,853.4\ m^2s^{-2}$ as realization of the potential value of the vertical reference level for the IHRS (see note 2).

Should the W_0 value be changed?



Carl Calvert, EUREF 2007

The consequences have to be considered!

1) GGRF, Physical heights, and Gravity

The two IAG Resolutions 2015

- No. 2 for the establishment of a global absolute gravity reference system resolves:
  - to adopt the Strategy Paper as the metrological basis for absolute gravimetry,
  - initiate a working group to compile standards for the definition of a geodetic gravity reference system based upon the international comparisons of absolute gravimeters,
  - to establish a gravity reference frame by globally distributed reference stations linked to the international comparisons of absolute gravimeters where precise gravity reference,
  - link the reference stations to the International Terrestrial Reference System by co-location with space-geodetic techniques,
  - initiate the replacement of the International Gravity Standardization Net 1971 (IGSN71) by the new Global Absolute Gravity Reference System (until IUGG 2019).

2) Physical Heights and Earth Gravity Field

The representation of the Earth gravity field is independent possible with to different kind of fields.

Both fields

- geo-potential scalar field $W(X)$
- the outer Earth gravity vector field $\vec{g}(X)$

connected by the relationship

$$\vec{g}_P = grad\, W_P = -g_P \begin{pmatrix} \cos\Phi & \cos\Lambda \\ \cos\Phi & \sin\Lambda \\ & \sin\Phi \end{pmatrix},$$

$$\boldsymbol{g_P = g(X) = |grad\ W_P|}$$

X position in natural coordinates: Φ astronomical latitude,

Λ astronomical longitude, W potential of Earth gravity field.

3) Elements for the International Height Reference System and Frame (IHRS/IHRF)

- The network of terrestrial IHRS points is global, with national and regional densification of the geodetic infrastructure.
- The reference geopotential value W_0 is achieved through best estimates. In the resolution No. 1 2015, the International Association of Geodesy resolves $W_0 = 62\ 636\ 853.4\ m^2s^{-2}$ as implementation of the potential value of the vertical reference level for the IHRS.
- A central element of the IHRF is a Global Gravity Model (GGM).

3) Elements for the International Height Reference System and Frame (IHRS/IHRF)

A GGM must be conventional.

The network of IHRF stations typically comprises (also part of the GGRF):

- The Earth gravity potential difference $-\Delta W_P$ in relation to a conventional W_0 shall be known through an existing highest-accuracy network of geodetic observation stations,
- The reference network conforming the IHRF shall follow the same hierarchy of the ITRF reference network; i.e. a global network with regional/national densifications.
- This network shall be collocated with: reference tide gauges (local vertical datum points); main nodal points of the levelling networks; border points connecting neighbouring vertical datum zones; geometrical reference stations (ITRF and densifications); fundamental geodetic observatories (connection between W_0, the International Atomic Time (TAI), and absolute gravity).

4) Global Absolute Gravity Reference System (IGSN)

Urs Marti, President of the International Association of Geodesy (IAG) Commission 2 «Gravity Field»
Philippe Richard, President of the Consultative Committee for Mass and related quantities (CCM)
Alessandro Germak, Chairman of the CCM working group on gravimetry (WGG)
Leonid Vitushkin, President of IAG SC 2.1
Vojtech Pálinkáš, Chairman of IAG JWG 2.1
Herbert Wilmes, Chairman of IAG JWG 2.2

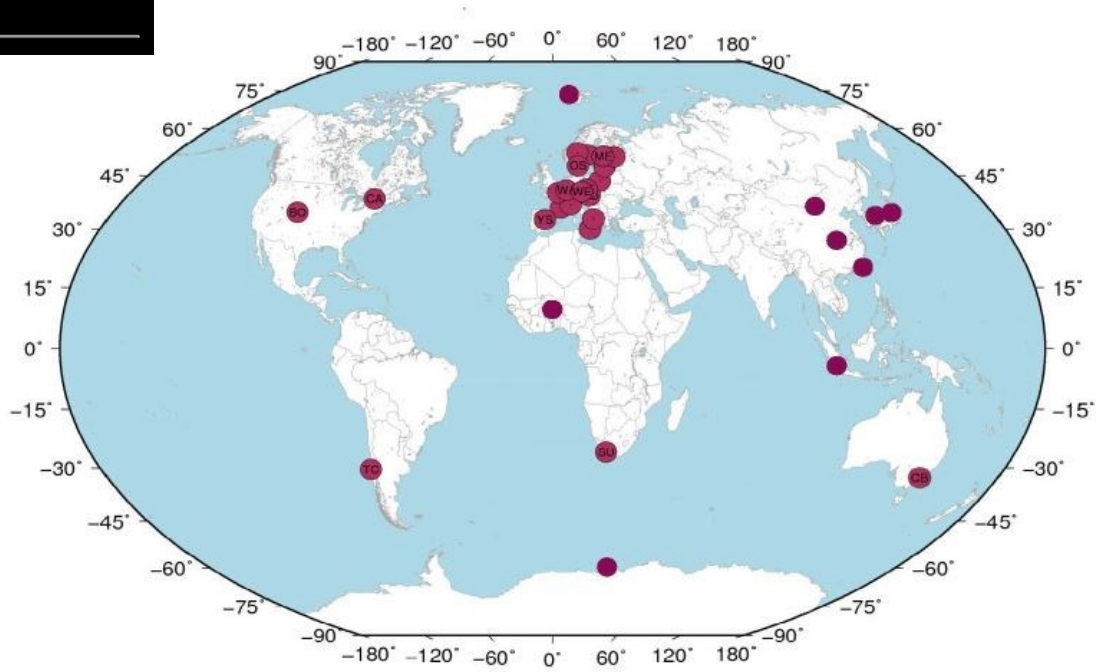
11 March 2014

CCM – IAG Strategy for Metrology in Absolute Gravimetry
Role of CCM and IAG

This network of GGRF stations typically comprises:

- The Earth gravity potential difference - ΔW_P in relation to a conventional

Proposed Gravity Reference Sites
for a distributed monitoring of the gravity component



5) What is the Global Geodetic Reference Frame - GGRF?

The Global Geodetic Reference System is the concept for a common reference for geometry and gravity field of the Earth: $W(\mathbf{X})$, or $P(\mathbf{X}, W)$ or $P(\mathbf{X}, W, g) = P(\mathbf{X}, W, -\partial W/\partial H)$ (Position/coordinate $\mathbf{X}$ of a physical point P, Potential of the Earth gravity field W, representing the physical height H, gravity value g).

The Global Geodetic Reference Frame is the Realization of the Global Geodetic Reference System.

The network of terrestrial points is global, with national and regional densification of the geodetic infrastructure. This network of GGRF stations typically comprises:

- fundamental geodetic observatories employing all space geodetic techniques co-located with gravimetric instruments, enabling the connection between *X, W*, and *g*;
- other geodetic stations also including reference tide gauges, height datum points, and gravity measurement points co-located where possible with space geodetic instruments.

5) What is the Global Geodetic Reference Frame - GGRF?

Fundamental geodetic observatories also include precise and stable time-keeping instruments and should be connected to time reference stations (in future using optical clocks for ΔW determination — relativistic geodesy) and gravity reference stations (equipped with absolute and superconducting gravimeters).

All GGRF stations must be:

- continuously operated, over the long-term, to ensure the stability of the GGRF;
- equipped with state-of-the-art observation technology so as to produce high quality measurements of geodetic quantities;
- continuously monitored to detect surface deformations of the Earth; and
- connected to height datums to precisely relate their geopotential differences for vertical datum unification.

5) What is the GGRF?

All the elements mentioned above form the physical infrastructure of the GGRF. For the realization we need an organizational/operational infrastructure in form of services and organizations.

GGRF as integrated network combine the ICRF, ITRF, IHRF and IGSN in geodetic observatories. Densifications networks shall represent *X, W(X), g(X)*.

(6) What is going on? Possible EUREF contributions.

GGRF as integrated network combine the ICRF, ITRF, IHRF and IGSN in geodetic observatories and special densification stations.

In the development the GGRF/Gravity Field activities several IAG entities are involved with overlapping tasks:

- GGOS Bureau for Products and Standards (BPS)
- GGOS/IAG Working Group on establishment of the GGRF (in connection with BPS).
- GGOS Focus Area 1 (Unified Height System).
- JWG on Strategy for the Realization of the International Height Reference System (IHRS); JWG of GGOS, Commission 2, IAG Commission 1, IAG ICCT, and IGFS, coordinated by the GGOS Focus Area 1 (Unified Height System).
- Sub-commission 2.2 Methodology for Geoid and Height Determination
- JWG 2.2 Establishment of a global absolute gravity reference system
- GGOS Bureau Network and Observation

(6) What is going on?

Numerical Standard Sets of conventional parameters

ellipsoid	Semi-major axis a in m	flattening f^{-1}	Geocentric gravitational constant GM in $10^8 m^3 s^{-2}$	U_0/W_0 in $m^2 \cdot s^{-2}$	γ_e in $m \cdot s^{-2}$
Int. Ell. 1930 (Hayford)	6 378 388	297	3 986 329		
GRS 67	6 378 160	298.247	3 986 030		
GRS 80	**6 378 137**	**298.257222101**	**3 986 005**	**6 263 6860.850**	**9.78032 677**
WGS 84	6 378 137	298.25722356			
IUGG 91	6 378 136.3 0.5		3 986 004.41 0.01		
IERS 2003/2010 Conventions (zero tide)	**6 378 136.6 ± 0.1**	**298.25642 ± 0.00001**	**3 986 004.418 ± 0.008**	**6 263 6856.0 ± 0.5**	**(9.78032 666)**
IAG 2016 Res. No. 1				**62 636 853.4**	
GRS XX				**62 636 853.4**	
Angular velocity of the Earth rotation ω	**7 292 115**	10^{-11} rad s^{-1}			

IAG has two complete sets of parameters in use and a new W_0 for the IHRF

(6) What is going on? Possible EUREF contributions.

The International Gravity Field Service (IGFS) plays a central role. The International Earth Rotation and Reference System Service (IERS) shall play a central role (note the connection to the IAU).

Within the next four years, an IAG inter-commission working group should be established to investigate the necessity and usefulness of replacing the GRS80 with a new GRS. If the computation of a new GRS is decided, this working group shall prepare and propose a full set of parameters to be presented and adopted at the IUGG 2019 General Assembly.

It is a very demanding and complex task. The IAG Inter-Commission Committee on Theory (ICCT) has to be involved.

Ten IAG entities are involved. All the work has to be coordinated.

At the GGHS2016 in Thessaloniki in WG meetings the work will be coordinated. EUREF can contribute with it experiences to the progress

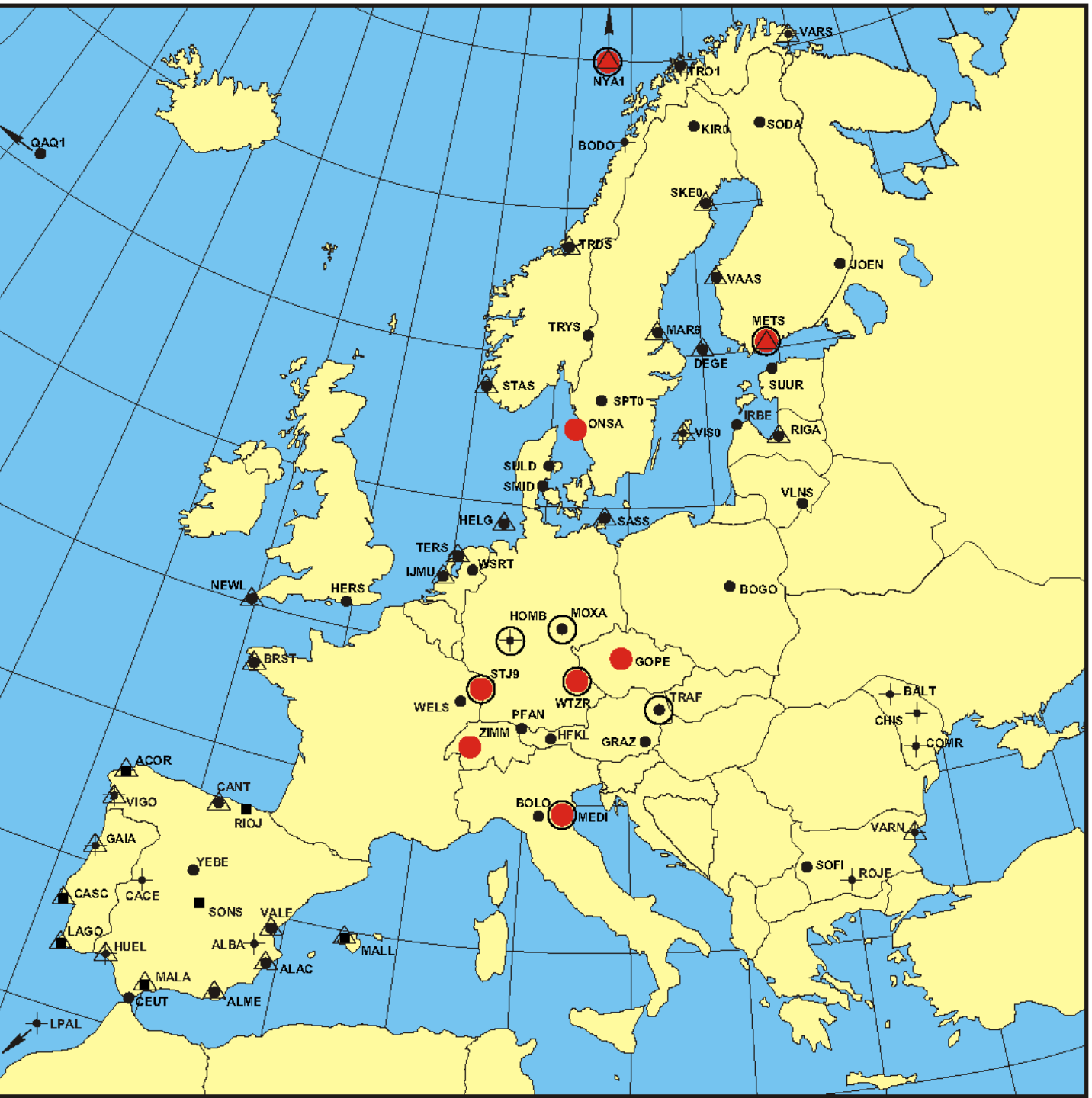
Concept and Status of the ECGN Project

J. Ihde[1], T. Baker[2], C. Bruyninx[3], O. Francis[4], M. Amalvict[5], A. Kenyeres[6], J. Makinen[7], S. Shipman[8], J. Simek[9], H. Wilmes[1]

[1] Federal Agency for Cartography and Geodesy
[2] Proudman Oceanographic Laboratory
[3] Royal Observatory of Belgium
[4] European Center for Geodynamics and Seismology
[5] Ecole et Observatoire des Science de la Terre
[6] FÖMI Satellite Geodetic Observatory
[7] Finnish Geodetic Institute,
[8] International Hydrographic Bureau
[9] Research Institute of Geodesy,Topography and Cartography

Objectives

- Maintenance the long-time stability of the terrestrial reference system with an accuracy of 10^{-9} in the global scale and for Europe
- Combination of geometrical positioning with the physical height and gravity field components in the cm-accuracy range.
- Modeling of influencing time dependent phenomena of the solid Earth, the Earth gravity field, the ocean, the atmosphere and the hydrosphere for different applications in positionig.
- A combined network contributes to gravity field modeling for the area of Europe and the generation of the best possible global model.



core station
station
candidate station
proposed station
super conducting gravimeter
tide gauge

Status 2004: ECGN status 1st call proposals

- 20 countries
- 72 stations with

- GPS (EPN)
- absolut gravity
- levelling to EVRS
- 6 super conducting g.
- 15 tide gauges