Federal Agency for
Cartography and Geodesy

Validation and Unification of national height reference frames in Europe

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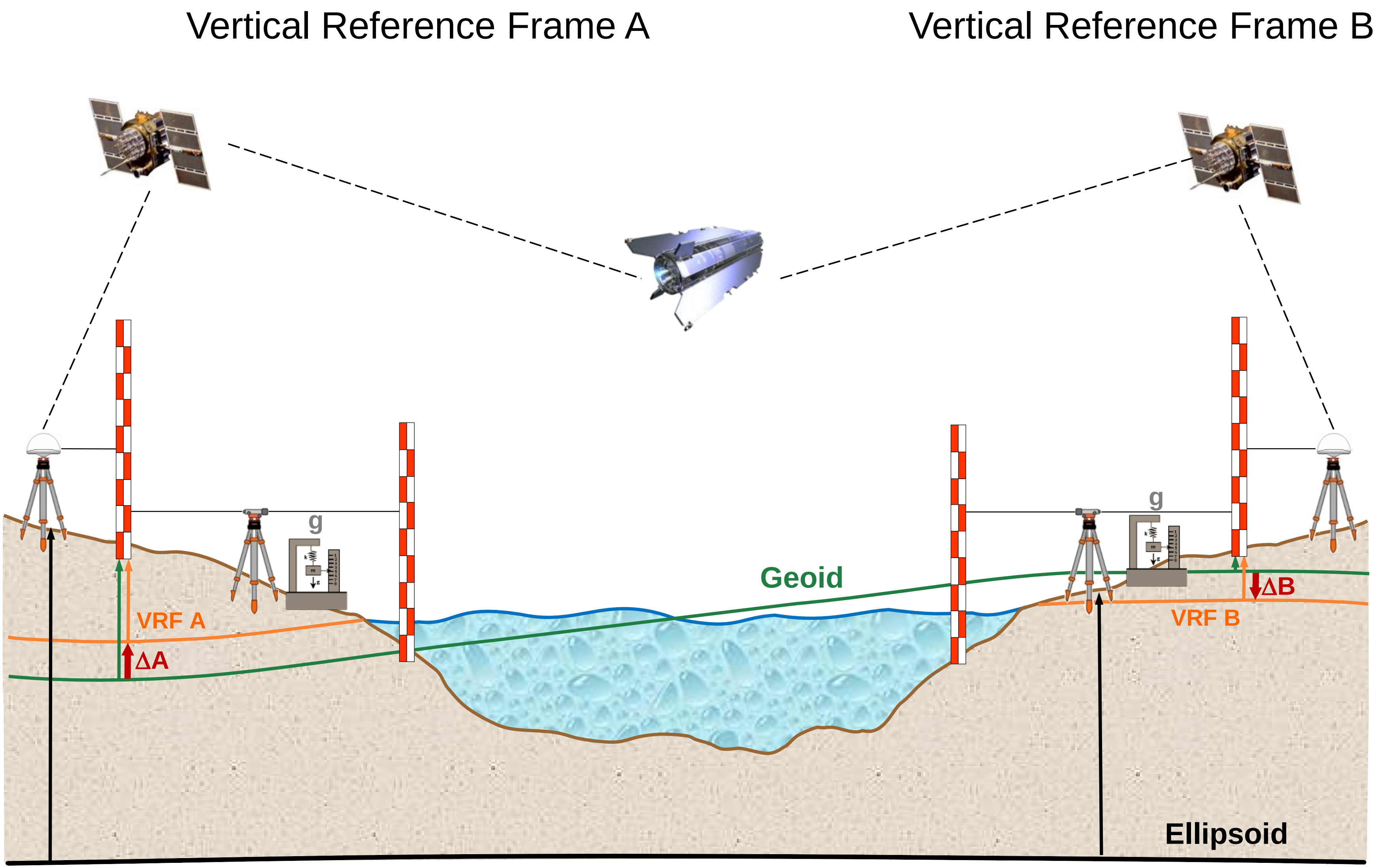
Principle


Vertical Reference Frame A
Vertical Reference Frame B
g
g
Geoid
VRF A
ΔA
ΔB
VRF B
Ellipsoid

Unification of vertical reference frames - Principle observation techniques

Marker of the vertical reference frame	Physical height difference	Ellipsoidal height difference and geoid model
Benchmark	Precise levelings and gravimetric observations (leveling approach)	GNSS (gravity field approach)
Tide gauge	Oceanographic model	Satellite altimetry

Each observation technique has assets and drawbacks with respect to

- Temporal resolution
- Spatial Resolution
- Accuracy
- Availability

Approaches for height reference frame unification - *Spirit leveling approach*

Common adjustment of *potential differences* obtained from first order leveling networks and c*ross-border connections,* Example: EVRF2007 (Sacher et al. 2009)

Weaknesses

- different epochs of leveling observations; ➔ very long observation periode
- information about height changes ➔ common epoch of adjustment
- different national standards for leveling ➔ different accuracy of the national leveling networks
- number and quality of the leveling lines between neighbouring countries
- geographical restrictions, e.g. observation across waters (UK, Fennoscandia, islands)
- low redundancy of leveling networks ➔ susceptible to systematic errors

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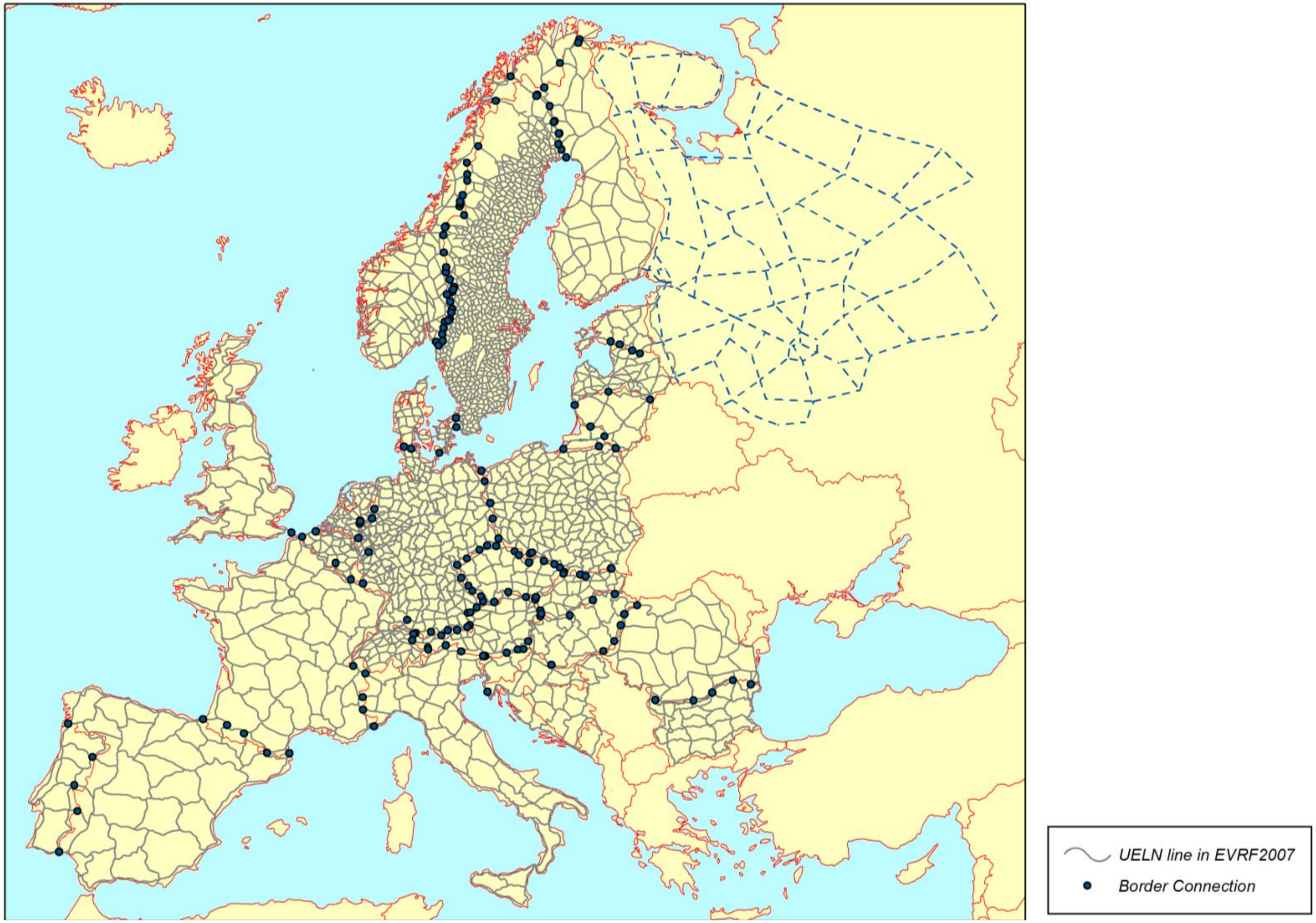
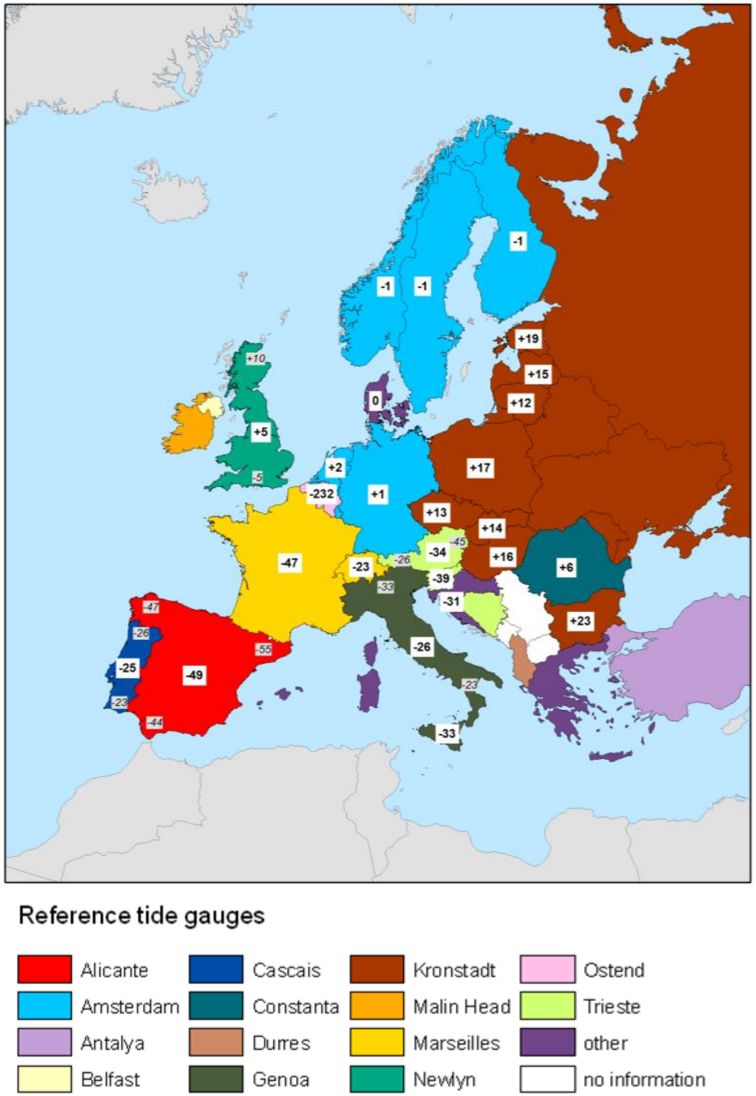
Spirit leveling Approach EVRF2007



Spirit leveling approach
Transformation parameter



Estimation of 3 parameters (plane) as transformation parameters between the national vertical reference frames and EVRF2007

$$H_{EVRF\,2007} - H_{NVRF} = m_1 - e + \left[m_2 M_0 (\varphi_i - \varphi_0) + m_3 N_0 (\lambda_i - \lambda_0) \right]$$

m_1	height offset
m_2, m_3	tilt (North-South, West-East)
φ_0, λ_0	Coordinates of reference point P_0
M_0, N_0	radius of curvature in meridian and perpendicular to the meridian in P_0

http://www.crs-geo.eu

Approaches for height reference frame unification – *Gravity field approach*

Combination of ellipsoidal heights (GNSS), physical heights (national height reference frame) and gravity field model

Advantage

- no direct observations between national height reference frames needed
- determination of height offsets is independent from the levelings used for the determination of the vertical reference frame
- Independent validation of the vertical reference frame possible

ESA Project GOCE+ Height System Unification

Goal: investigation of the impact of GOCE on the unification of height systems

Project partner:

- Technical University Munich
- University of Calgary
- National Oceanographic Center Liverpool
- BKG

Gravity field approach
Method

Comparison of observed anomalies and anomalies from a gravity field model

$$\Delta\zeta_i^z = \zeta_{iObs}^z - \zeta_{iMod}^z$$

Transformation of all quantities to the zero-tide system

$$\zeta_{iObs}^z = h_i^a + \delta_{a\to z}^h - (H_i^b + \delta_{b\to z}^H)$$

tidal corrections

Estimation of 3 parameter (plane)

$$\Delta\zeta_i^z = m_1 - e + \left[m_2 M_0(\varphi_i - \varphi_0) + m_3 N_0(\lambda_i - \lambda_0)\right]$$

with

m_1	Offset
m_2, m_3	tilt (North-South, West-East)]
φ_0, λ_0	Coordinates of reference point P_0
M_0, N_0	radius of curvature in meridian and perpendicular to the meridian in P_0

Gravity field approach
Data sets

Satellite-only gravity field models

- GOCE TIM R3 d/o 250 (Pail et al. 2011)
- GOCO03S d/o 250 (Mayer-Gürr et al. 2012)

High resolution gravity field models

- EGM2008 d/o 2190 (Pavlis et al., JGR, 2012)
- EGG2008 grid 1‘x1‘ (H. Denker, IfE Hannover)

National physical and ellipsoidal heights

- 954 points in Germany
- 272 points in Germany (preliminary results from the modernization of the German height reference frame)
- 1316 points of the EUVN_DA dataset
  - ellipsoidal ETRS89, zero-tide system
  - Physical height in the national height reference frame, tidal system of 23 European countries (Kenyeres et al., IAG Symposia 135, 2010)

Combination of gravity field models

Catenation of spherical harmonic series (shc-combined models)

GOCE TIM R3 d/o 190 + EGM2008 d/o 191-2190

GOCO03S d/o 190 + EGM2008 d/o 191-2190

Combination by Gaussian filtering (filter-combined models)

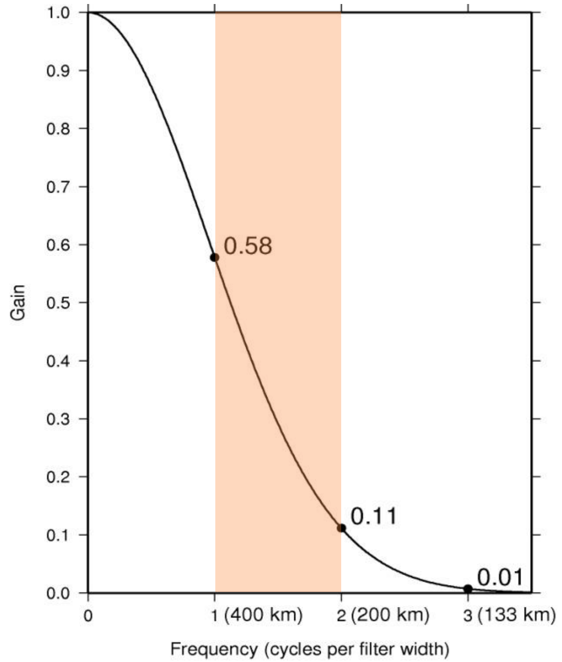
Synthesis of satellite-only GGM and regional GM on grid

low pass filter of satellite-only GGM

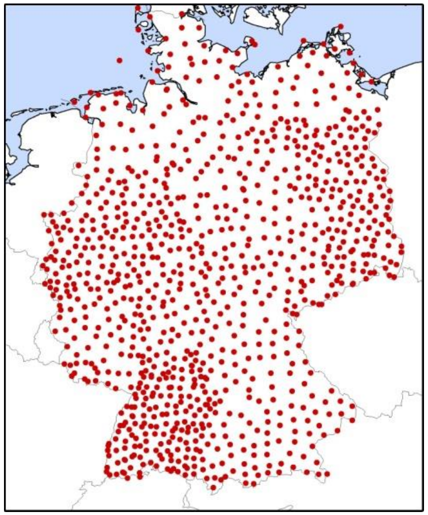
high pass filter of regional GM

summation of both parts

$$G = e^{-2\pi\sigma f} \quad \text{with} \quad \sigma = \frac{1}{6} b$$

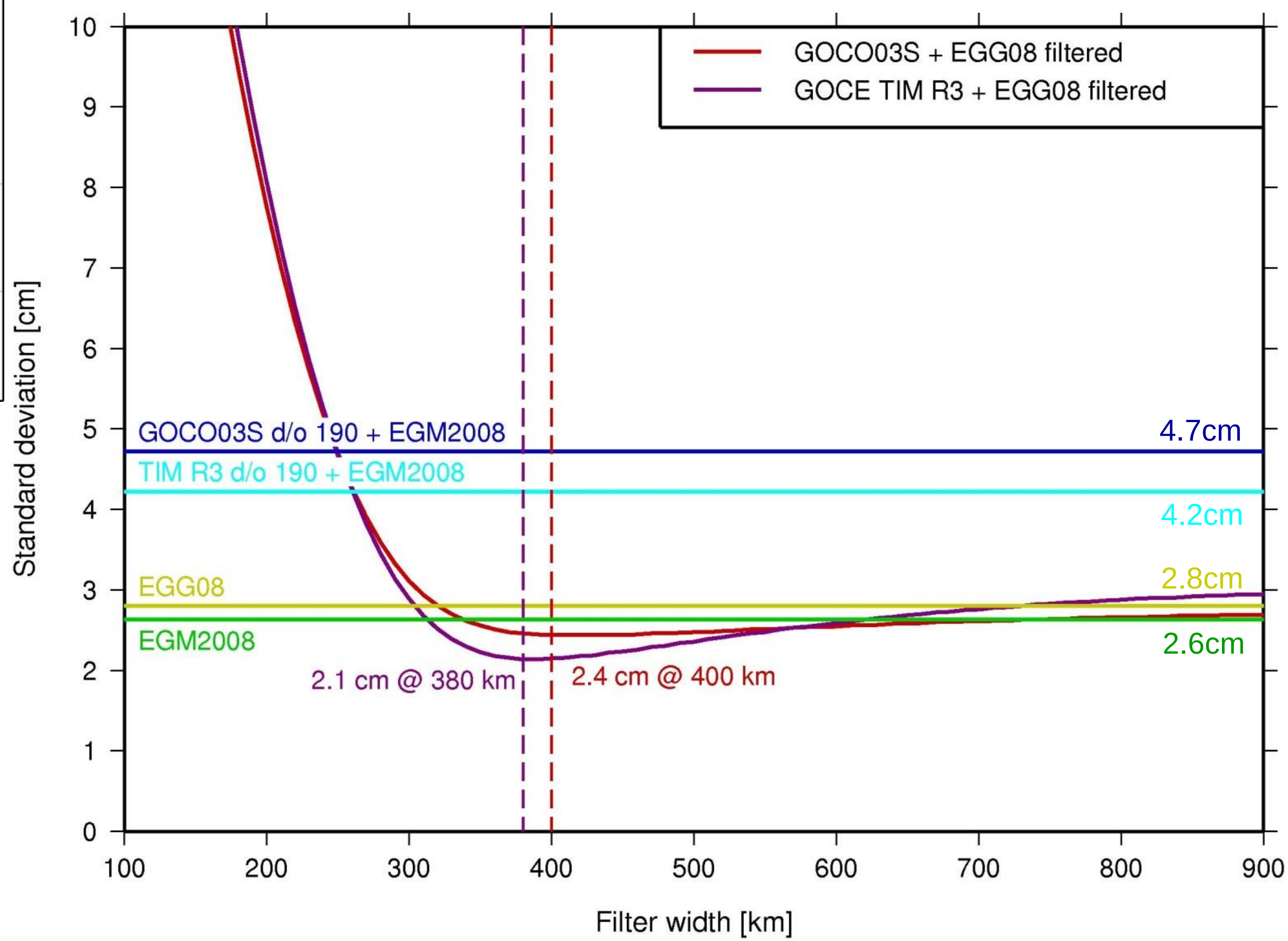


Gravity field models vs. GNSS/leveling data in Germany



954 GNSS/leveling points

ellipsoidal heights:
ETRS89
physical heights:
DHHN92



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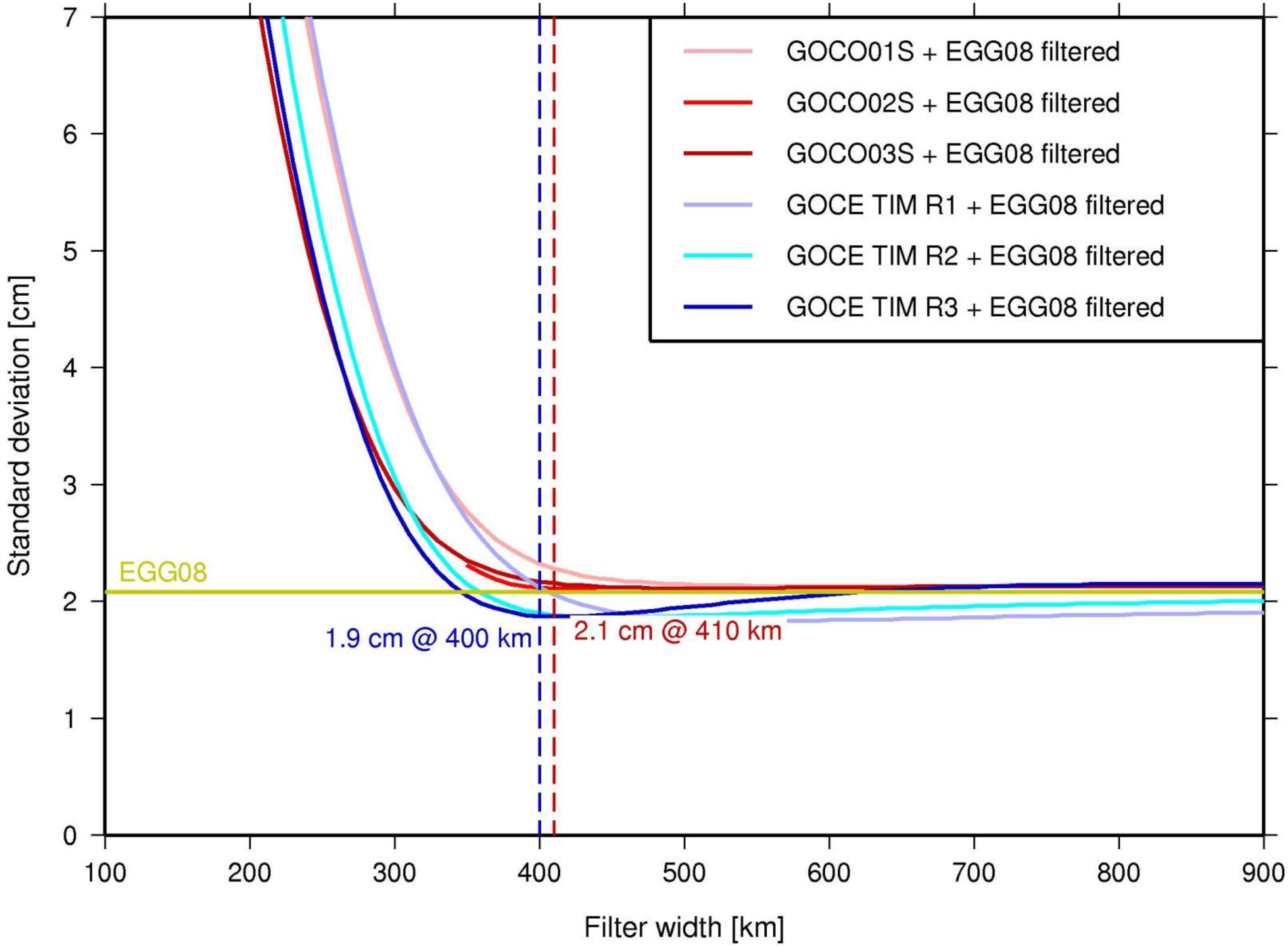
DHHN20xx vs. GOCE + EGG08



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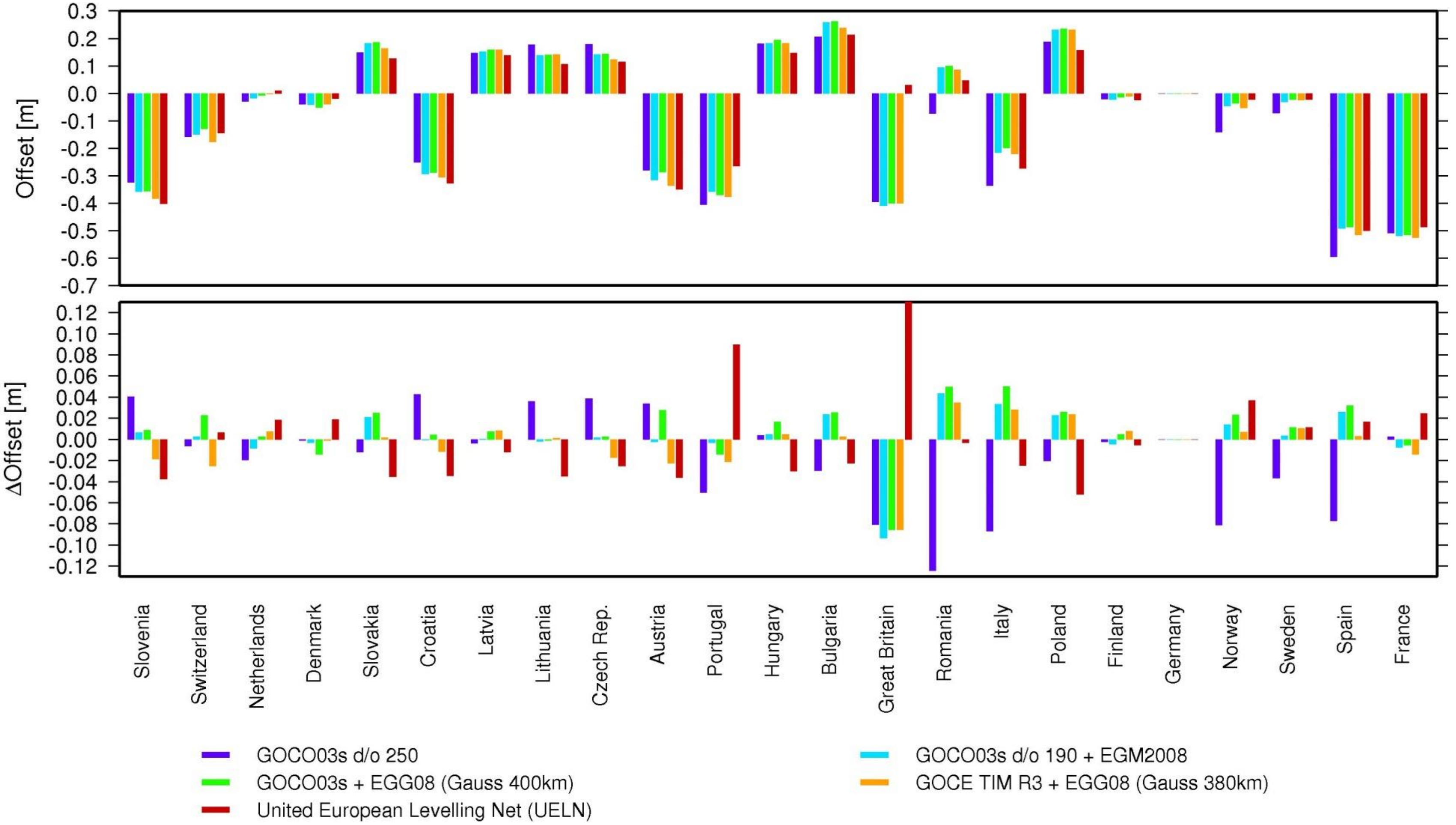
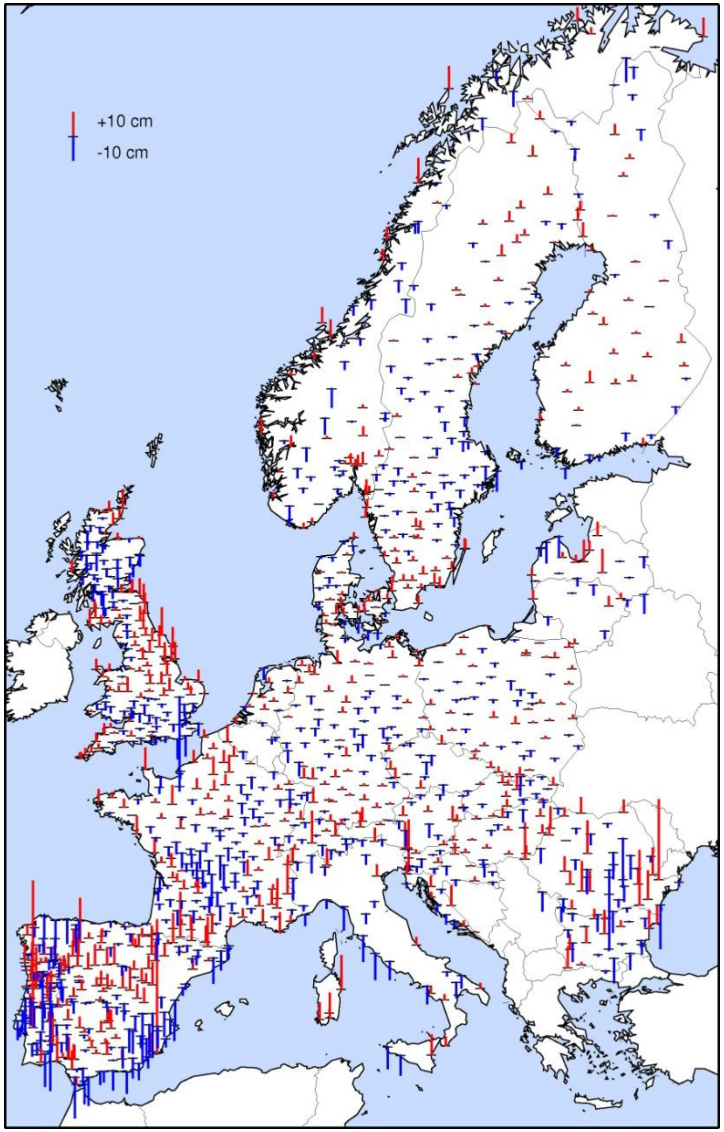
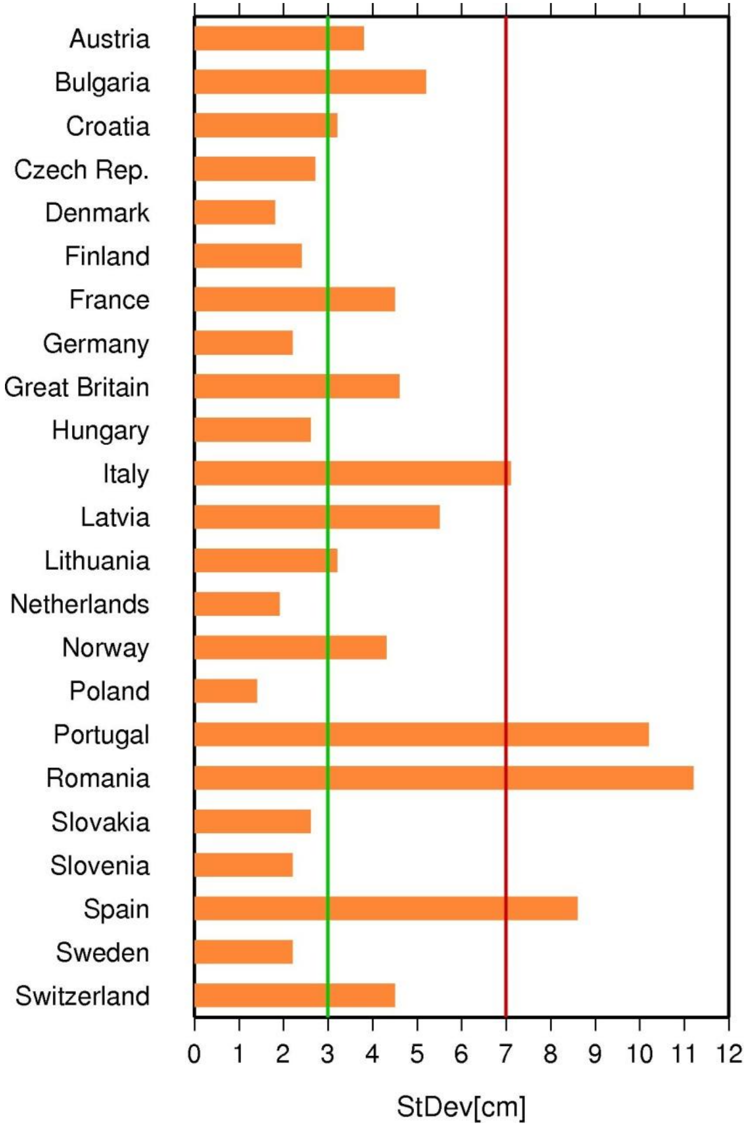
Height offsets - Gravity Field vs. Spirit leveling approach

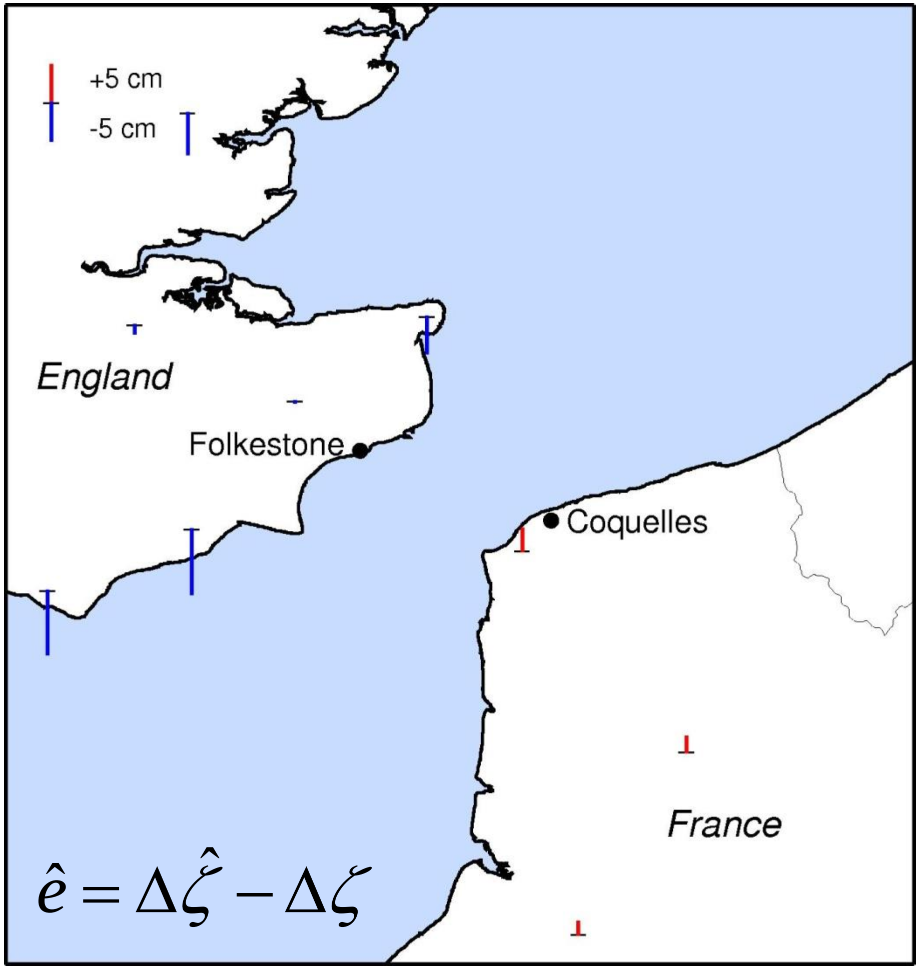


Standard deviation - (GOCO03S+EGG2008, filter-combined)





Example: English Channel



$$\hat{e} = \Delta\hat{\zeta} - \Delta\zeta$$

$H_{Folkestone} - H_{Coquelles}$

Observed (leveling through Tunnel)
40 cm +- 2 cm (Greaves et al. 2007)

Spirit leveling approach (3 parameter)
47.2 cm

GF approach (3 parameter)
33.8 cm

Gravity field approach (with additional regional residual pattern)
33.8 cm
\+ ~4 cm (residual England)
\+ ~2 cm (residual France)
= ~40 cm

Conclusions and Summary

- Gravity field approach is a very good alternative for the unification of height reference frames compared to the leveling approach.
- It has a number of advantages, like the independence from geographical restrictions and national leveling networks.
- It has a high accuracy potential provided that
  - the gravimetric geoid model uses information from GOCE for the long wavelength part
  - the gravimetric geoid model has a high spatial resolution (this presuppose an gravimetric data set with a homogeneous data distribution and corresponding density)
  - there are precise and up to date ellipsoidal and physical heights of the national reference frames (GNSS/leveling data set of sufficient density, e.g. EUVN-DA)
- The overall error budget for gravimetric geoid, physical and ellipsoidal heights of 3 cm and even less show the reasonable accuracy of many national vertical reference frames in Europe.
- The current and upcoming high resolution geoid models in Europe enables an independent evaluation of the national vertical reference frames.

Summery and Outlook

- Furthermore, the comparison of the official national height reference surfaces (along the borders and/or with respect to a European geoid model) may give valuable information for the unification of the national height reference frames in Europe as well as for our customers.
- We should collect these kind of information and could extend the data base about the coordinate reference systems in Europe (CRS-EU). In this way we may open the possibility to include information also for these countries, which are currently not part of the United European Leveling Network. This is also a step towards a Global Vertical Reference Frame.
- The gravity field approach can also be used as an realization of the European Vertical Reference Frame (EVRF), like in Northamerica (USA, Canada).
- Upcoming realization of the EVRF should include an official quasigeoid model in order to support an easy access to the EVRF by the costumer (e.g. Chart Datum Working Group (CDWG) for the Baltic Sea discuss about the adoption of EVRS as a common chart datum in the Baltic Sea area). Later it even could replace the United European Leveling Network (UELN).

Summary and Outlook

- The EVRF is more and more of practical relevance (e.g. INSPIRE, CDWG).
- Is the “zero tide” convention of the EVRS the right decision for a height reference frame of practical use?
  - related to an artificial earth not the real world
  - not used for all geodetic observations even in the scientific community
  - difficult to explain to a real user