Federal Agency for Cartography and Geodesy

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Status report for the EUREF Working Group "European Unified Height Reference"

Joachim Schwabe, Martina Sacher on behalf of the WG members

Gunter Liebsch, Martin Lidberg, Heiner Denker, Jonas Ågren, Anders Alfredsson, Riccardo Barzaghi, Mirjam Bilker-Koivula, Artu Ellmann, Bruno Garayt (with IGN colleagues), Andreas Hellerschmied, Ambrus Kenyeres, Urs Marti, Sander Varbla, Cornelis Slobbe, Pasi Häkli, Bas Alberts

Federal Agency for Cartography and Geodesy (BKG), Leipzig, Germany

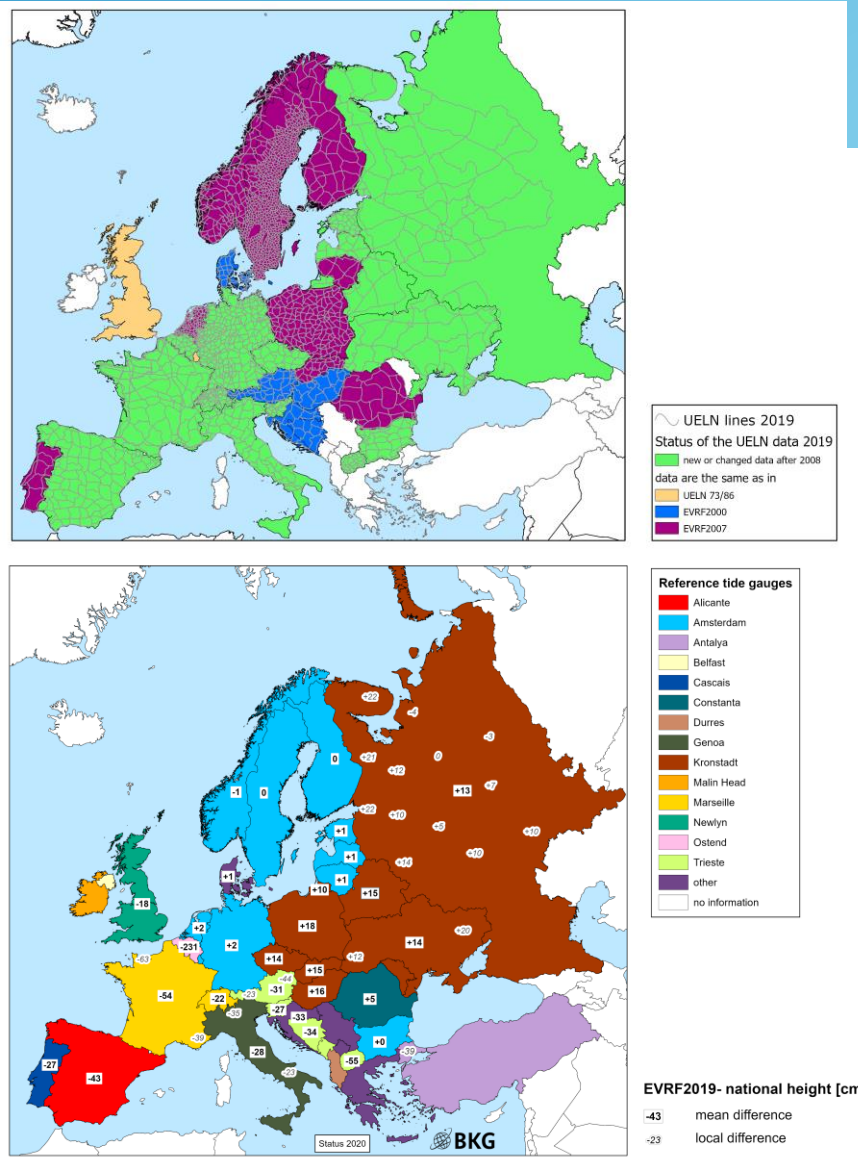
EUREF Symposium 2024, Barcelona, 6 June 2024

Introduction

Heights in Europe are not as unified as 3-D coordinates…*

- National height systems remain in use (with good reason)
- Official realization of the EVRS is based on the UELN
- Latest realization EVRF2019
- GNSS-based height determination in EVRF2019 requires fitted height reference surface (quasigeoid model) to transform ETRF20xx <> EVRF20xx seamlessly and
- No such official product so far from EUREF

** cm … sub-dm for ETRS89 datum ensemble!*



Introduction

Working Group

- Established 2021 through EUREF Resolution No. 1/2021

Goals

- Provide comprehensive and easily accessible information about the national integrated spatial reference
- Improve interoperability of the national products of the height reference across borders
- Enable seamless GNSS-based height determination, thereby strengthen the importance of the EVRS
- Implement European height reference surface as an official realization of EVRS which is compatible to the latest realizations of ETRS89 and EVRS (= fulfill EUREF resolutions, e.g. No. 5/2009)

Actions

- **CRS-EU** Revised database with enhanced information on the vertical reference (geoid models)
- **EHRS_CP** New homogenized **GNSS/leveling dataset** in current ETRS89/EVRS realization
- **EHRS** Develop and provide **quasigeoid model fitted to ETRS89/EVRS realizations** *(cooperation with IAG SC2.4a European Geoid / European Geoid Project)*

Inventory of national realizations

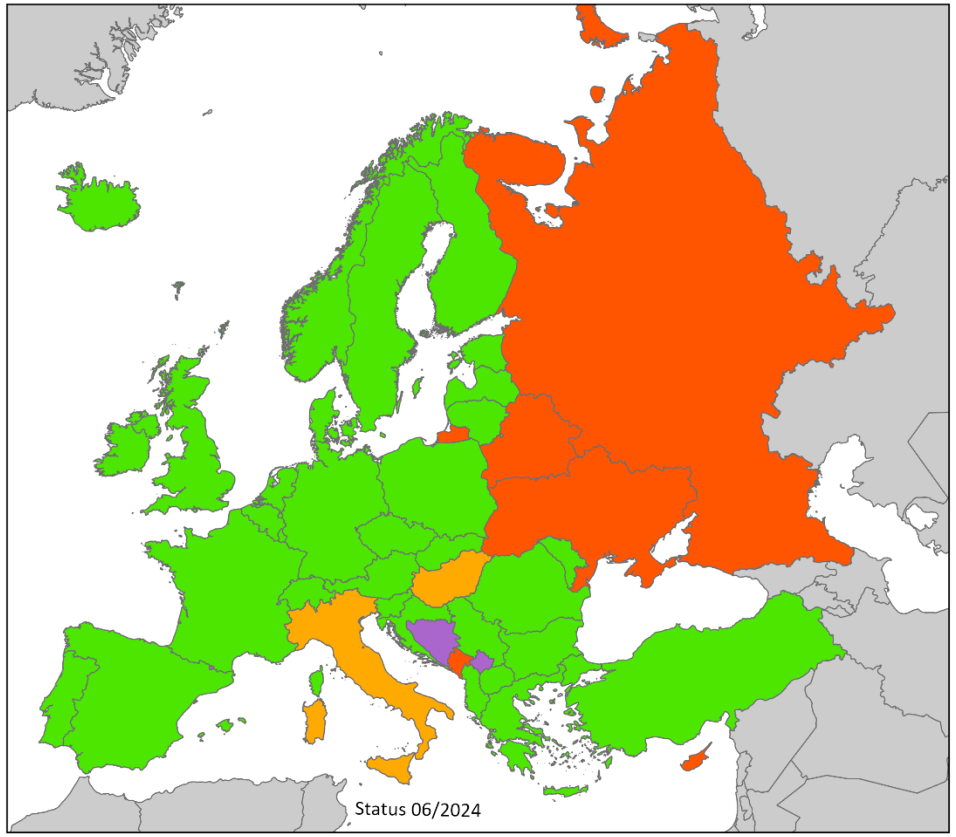
Questionnaire about integrated spatial reference (ETRS89 realization, heights, geoid etc.)

Status

- Still waiting for information from a few countries where revisions are ongoing
- Data inserted into draft CRS-EUv2 database (internal at BKG)
- Static overview document of national reference frames and geoid models to be published soon on EVRS website (*evrs.bkg.bund.de*) → *see next slide*

Next steps

- Adapt CRS-EU website for new database structure
  → currently pausing due to lack of resources



The border of Kosovo is used without prejudice to positions on status and is in line with UNSC 1244 and the ICJ Opinion on the Kosovo declaration of independence.

Inventory of national realizations

- Modified structure of EVRS website (ongoing)
  - *Activities* → New subpage for the Working group
  - *Results and products* → Height datum relations, National realizations (ETRS89, heights, geoids)
- Overview document of national realizations (will be published after confirmation by the countries)

Table 1 Overview of GNSS reference frames (national ETRS89 realizations) in Europe

Background colors: **Grey** No longer in use

CC	Country	Date of info	Valid from	Valid until	Name of realization	Target frame	Epoch [yr]	Tx [mm]	Ty [mm]	Tz [mm]	D [ppb]	Rx [mas]	Ry [mas]	Rz [mas]	Re-marks	EPSG
AT	Austria	2022-04-29	unknown	unknown	ETRS89 Austria 2002	ETRF2000	2002.56									
BE	Belgium	2022-05-23	unknown	unknown	BEREF (Belgian Reference Frame)	ETRF2000	2002.73									
BG	Bulgaria	2022-04-12	unknown	unknown	BGS2005 (Bulgarian Geodetic System 2005)	ETRF2000	2005.0									7797
CH	Switzerland	2021-08-24	unknown	unknown	CHTRF95	ETRF93	1993.0								[1]	4933
CZ	Czech Republic	2022-06-15	unknown	unknown		ETRF2000	2007.0									
DE	Germany	2022-04-29	ca. 2003	2016-11-30	ETRS89/DREF91 Realization 2002	ETRF2000	2002.79	63.9	−93.9	53.2	−10.9	−2.400	−0.800	2.300		
		2022-04-29	2016-01-12	unknown	ETRS89/DREF91 Realization 2016	ETRF2000	2008.46	0.0	0.0	0.0	0.0	0.658	−0.208	0.755		10283

Inventory of national realizations

- Modified structure of EVRS website (ongoing)
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Table 2 Overview of national height reference surfaces (geoid models). For more details on the GNSS realizations, please refer to Table 1.

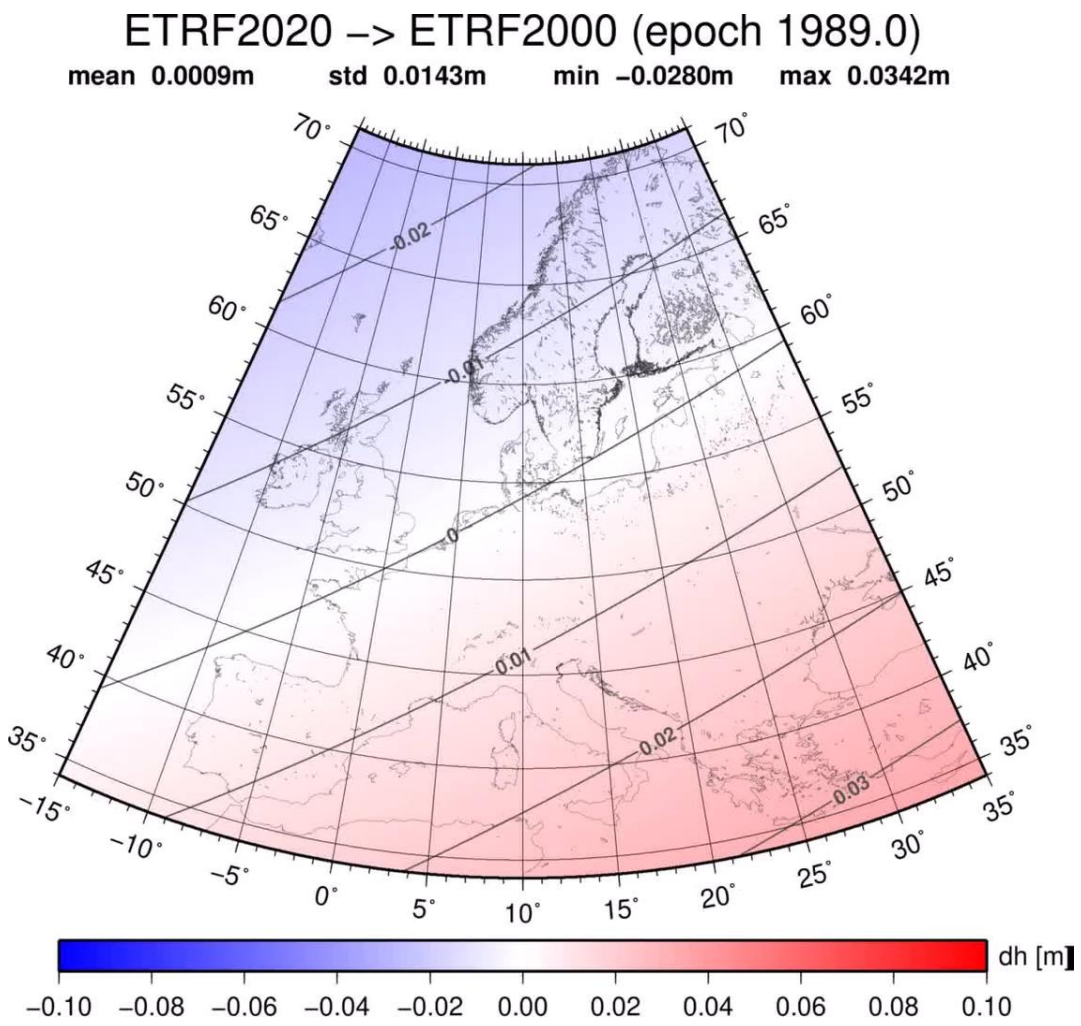
Height types: **NH** Normal heights, **NOH** Normal-orthometric heights, **OH** Orthometric heights (Helmert heights not precluded), **OH(H)** Helmert orthometric heights (confirmed), **U** Uncorrected for gravity

Background colors: **Yellow** CRS of grid is not ETRS89 geographic (longitude, latitude) → projected coordinates nmd/or other datum, **Grey** No longer in use

Standard CRS of interpolation grids: "ETRS89 geographic" (i.e., any ETRFxxxx) assumed as EPSG:4258, "WGS84 geographic" (i.e., any ITRFxxxx) assumed as EPSG:4326

CC	Country	Subregion	HRS grid	Valid from	Valid until	CRS of grid	GNSS realization of ellipsoidal height	ETRS89 datum?	Ell. height linked to	Height realization	Height datum	Height type	Re-marks	Link
AT	Austria		**Austrian Geoid 2008 (GRS80)** (EPSG:9276)	2008-01-01		ETRS89 geographic	**ETRS89 with GRS80 ellipsoid** (EPSG:4937)	yes	ETRF2000 (2002.56)	**EVRF2000 Austria** (EPSG:9274)	Amsterdam (NAP)	OH	[1] [2]	Info ZIP
AT	Austria		**Austrian Geoid 2008 (Bessel)** (EPSG:9277)	2008-01-01		MGI geogr. with Bessel (EPSG:4312)	**MGI with Bessel ellipsoid** (EPSG:9267)	no	ETRF2000 (2002.56) by transf.	**EVRF2000 Austria** (EPSG:9274)	Amsterdam (NAP)	OH	[1] [2]	Info ZIP
AT	Austria		**Höhen-Grid plus Geoid** (EPSG:9499)	2013-11-08		MGI geogr. with Bessel (EPSG:4312)	**ETRS89 with GRS80 ellipsoid** (EPSG:4937)	(yes)	ETRF2000 (2002.56)	**GHA height** (EPSG:5778)	Triest (MGI/Adria)	NOH	[2]	Info ZIP
BE	Belgium		**hbG18**	2018-08-01		ETRS89 geographic	**BEREF** (EPSG:4937)	yes	ETRF2000 (2002.73)	**TAW/DNG height** (EPSG:5710)	Ostende	U		ISG

Apparent height drift of ETRF2000 with respect to ETRF2020



EHRS_CP GNSS/leveling data

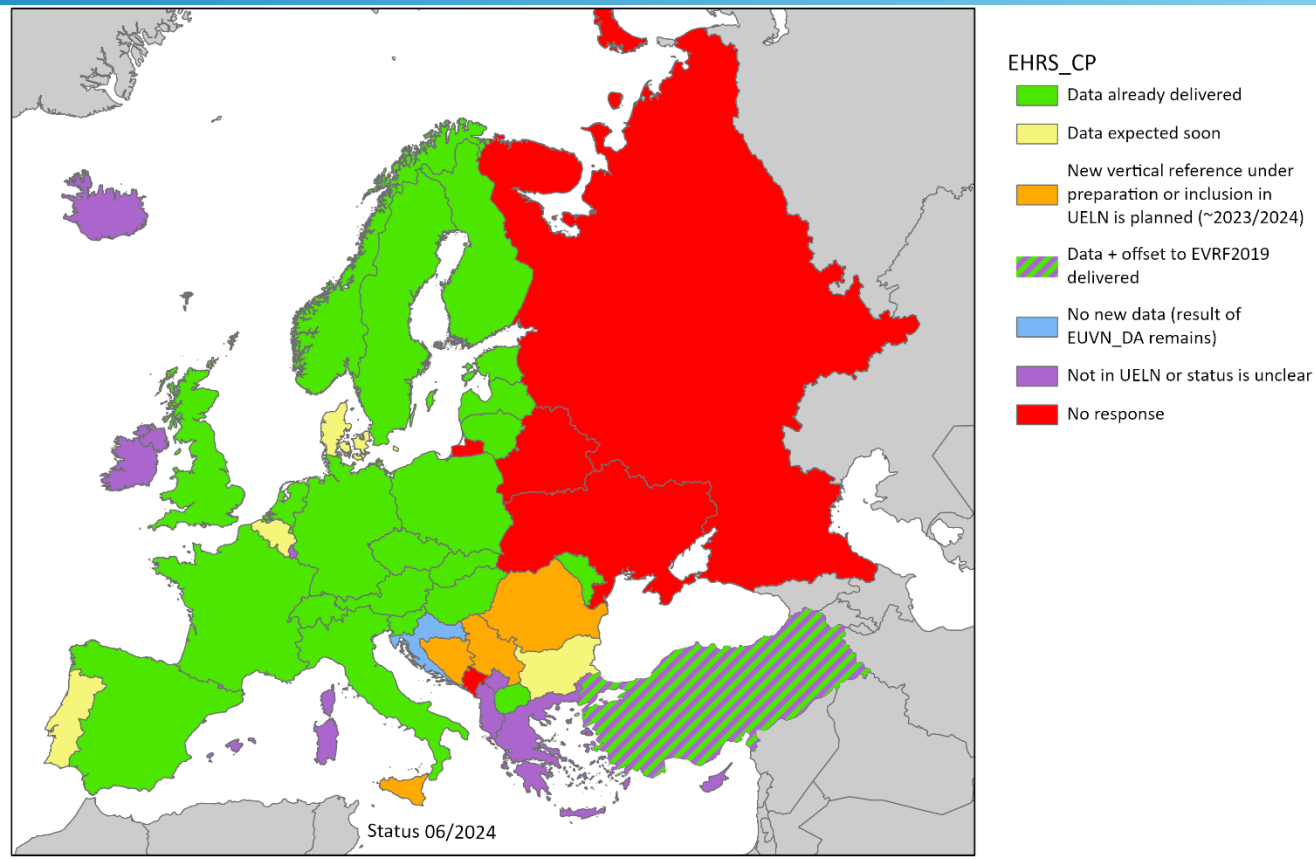
New set of GNSS/leveling control points (CP) for the European Height Reference Surface (EHRS)

→ Homogenization of GNSS heights (ETRF2020)

→ EVRF heights

Status

- Data provided by most UELN countries
- New or updated countries in UELN
  → *see next talk by M. Sacher*
- New data (e.g. NL, FI, LV, SI),
  updates to be processed (AT, LV, HU)
- Some countries are still under progress
- Significant gap only in Balkan region
- Updated internal dataset *(see next slides)*



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EHRS_CP GNSS/leveling data

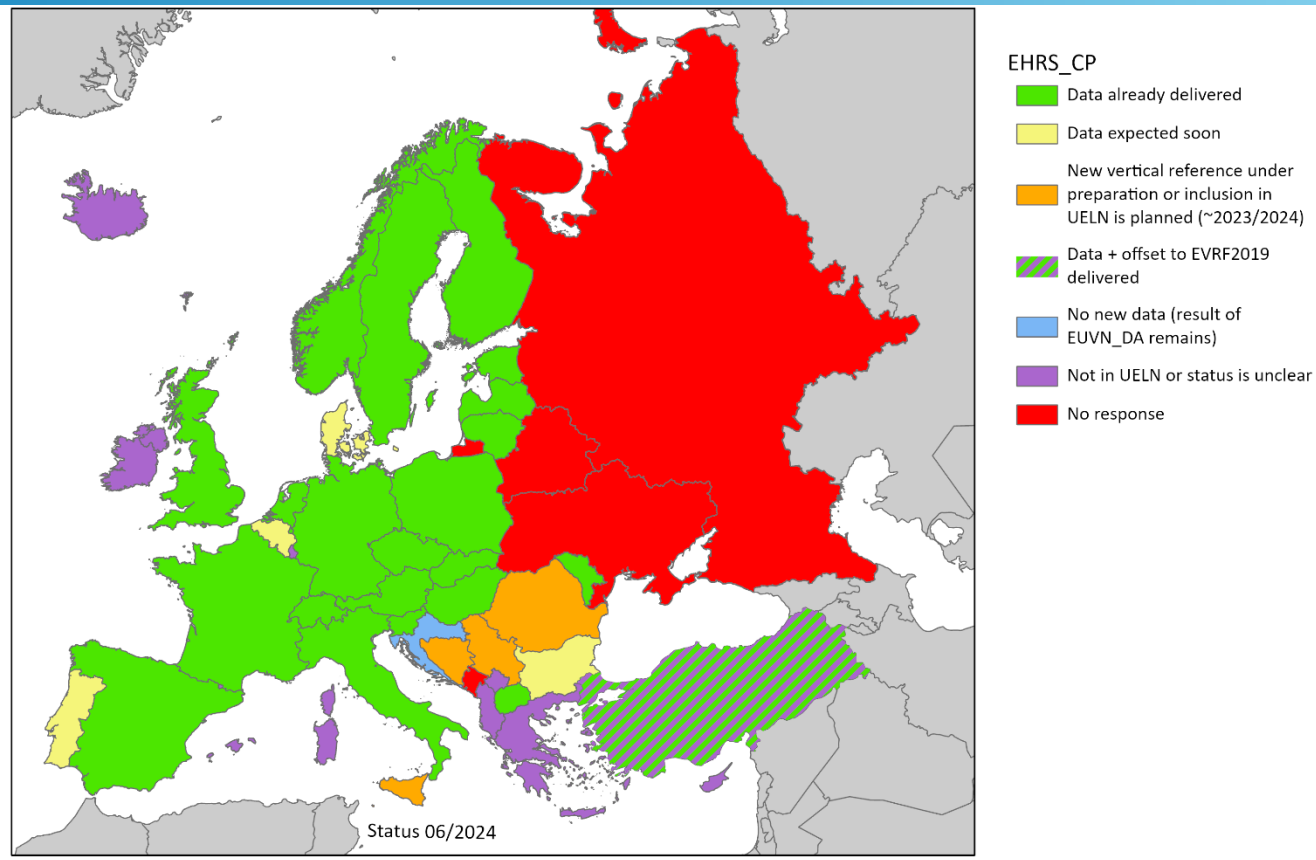
New set of GNSS/leveling control points (CP) for the European Height Reference Surface (EHRS)

→ Homogenization of GNSS heights (ETRF2020)

→ EVRF heights

Next steps

- Continue data collection (reminders)
- Refined analysis of potential improvements
  → *see next slides*
- Updated UELN solutions → New EVRF version?
  → *see next talk by M. Sacher*



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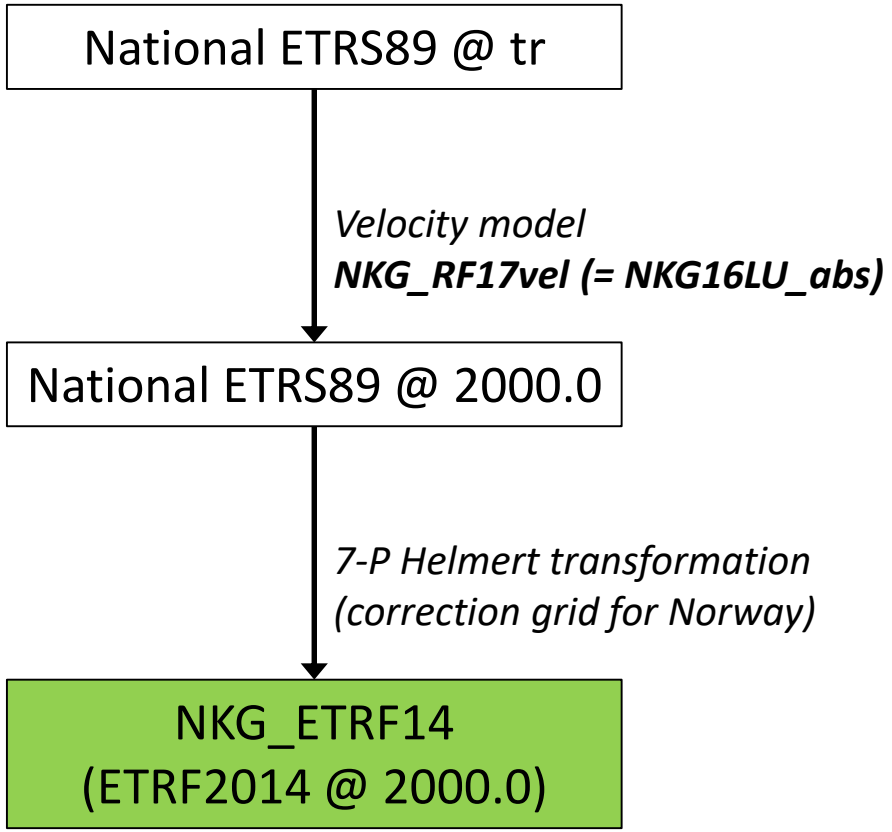
Activities to improve consistency between GNSS/leveling and quasigeoid

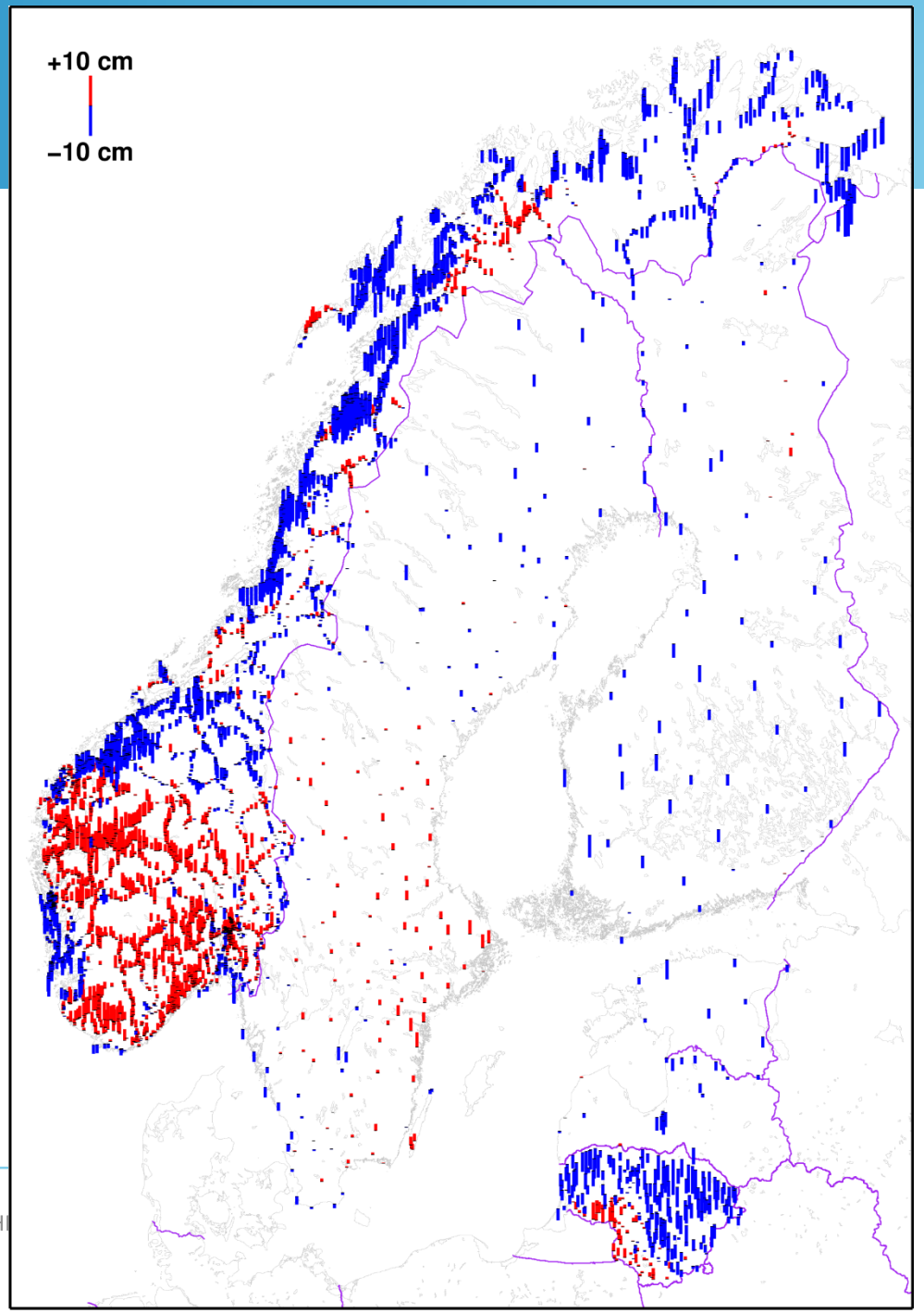
- WG online meeting 2024-04-12
- Updated internal version of homogenized dataset
  - Workflow to transform coordinates of each country to ETRF2014 (or ETRF2020)
  - EUREF transformation parameters (optional application of vertical velocity models)
  - NKG Transformations 2008 or 2020 (for nordic countries)
- Basis for forthcoming detailed investigations
  - … on the corrector surface
  - … to improve the consistency of all three components (GNSS, leveling, quasigeoid), in particular along the borders

NKG Transformations 2020 *(Häkli et al. 2023)*



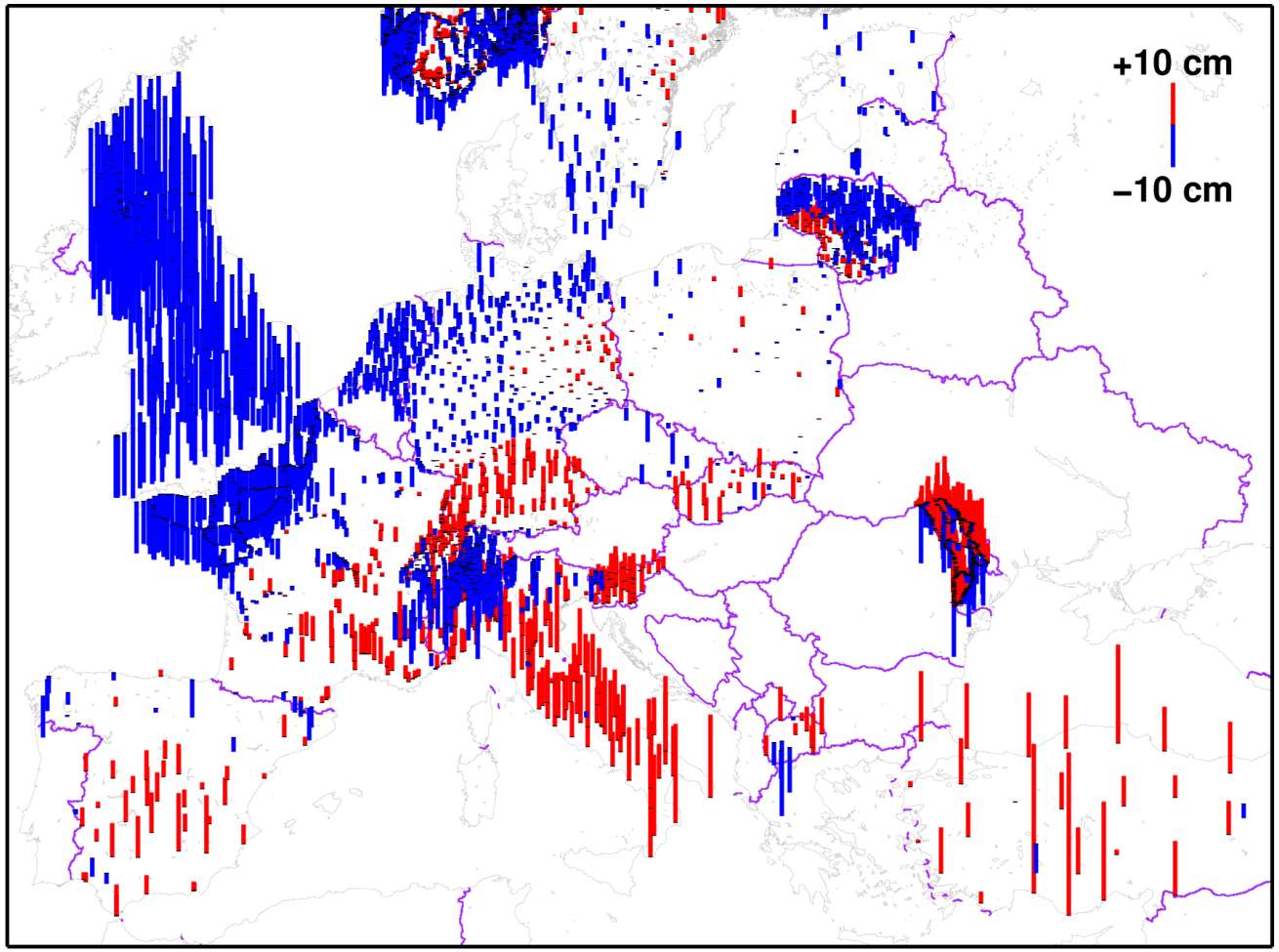
Comparison with NKG2015 (updated)

CC	#	#out	Mean	Med.	STD (mean)	Max. (mean)	*STD (plane)*	*Max. (plane)*
EE	11		**–7.0**	–6.7	**1.5**	3.8	***1.3***	*2.9*
FI	74		**–6.9**	–7.0	**1.9**	5.2	***1.8***	*4.4*
LT	241	4	**–7.0**	–7.4	**3.2**	9.1	***2.3***	*6.4*
LV	18		**–7.3**	–7.3	**1.9**	3.3	***1.4***	*3.0*
NO	3224		**–5.0**	–4.6	**3.5**	16.9	***3.0***	*13.6*
SE	185		**–4.4**	–4.3	**1.9**	4.9	***1.8***	*5.2*



Comparison with EGG2015 (updated)

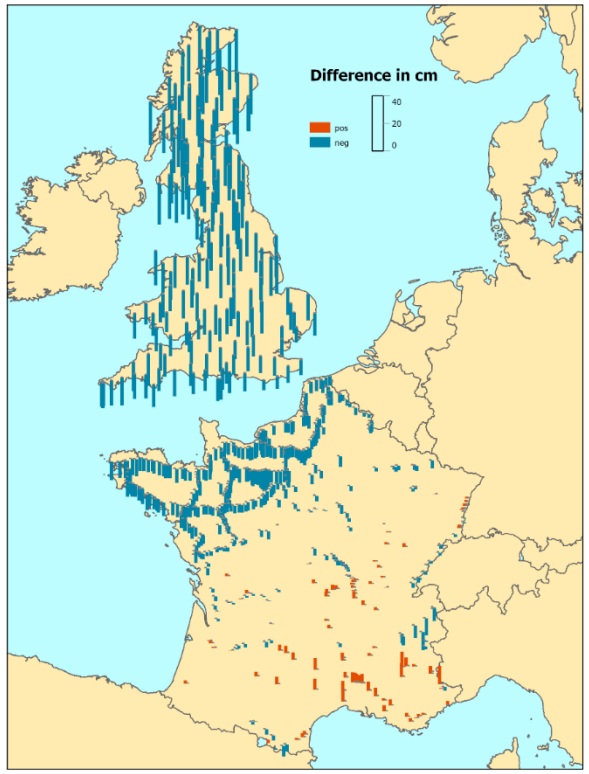
CC	#	#out	Mean	Med.	STD (mean)	Max. (mean)	STD (plane)	Max. (plane)
CH	208	1	**–2.4**	–1.4	**4.8**	17.3	***4.3***	*14.4*
CZ	6		**–4.3**	–3.7	**2.4**	3.0	***2.1***	*2.4*
DE	359		**–0.3**	–0.8	**2.2**	6.4	***1.5***	*4.7*
ES	53		**+2.7**	+2.8	**4.9**	12.5	***3.9***	*8.5*
FR	463		**–3.6**	–4.4	**4.5**	17.1	***2.8***	*15.4*
GB	241	3	**–19.5**	–20.4	**6.0**	17.7	***3.7***	*12.7*
IT	148	2	**+6.9**	+7.1	**6.7**	20.8	***5.0***	*18.7*
MD	405		**+3.3**	+3.6	**4.3**	17.7	***4.2***	*17.2*
MK	13		**+0.4**	+2.8	**8.3**	18.2	***7.2***	*15.2*
NL	82		**–3.6**	–3.6	**0.9**	2.9	***0.8***	*2.5*
PL	38		**–0.3**	–0.4	**1.5**	3.4	***1.5***	*2.9*
SI	46	1	**+3.8**	+3.2	**4.1**	9.9	***2.4***	*5.6*
SK	29		**+2.4**	+2.0	**2.7**	6.5	***2.2***	*5.9*
TR	26		**+10.8**	+10.6	**10.6**	27.9	***10.5***	*24.5*



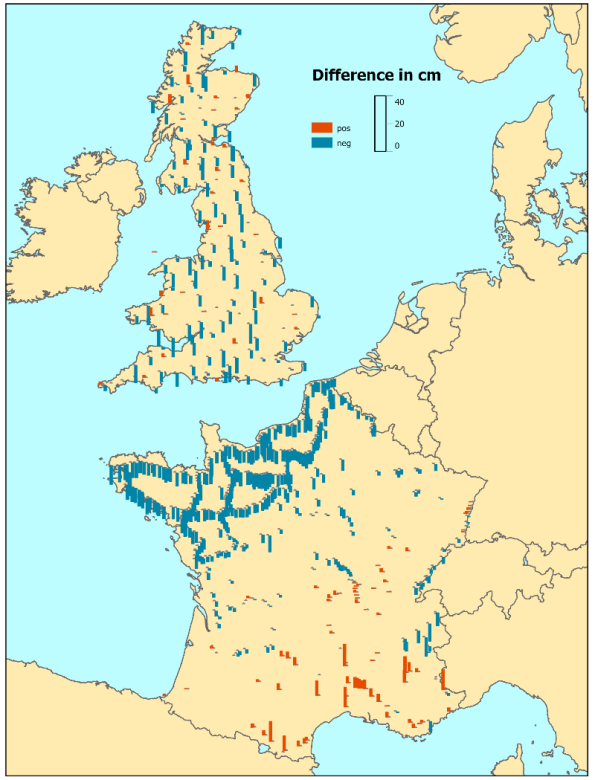
Leveling:
Experimental UELN solution with hydrodynamic leveling connections

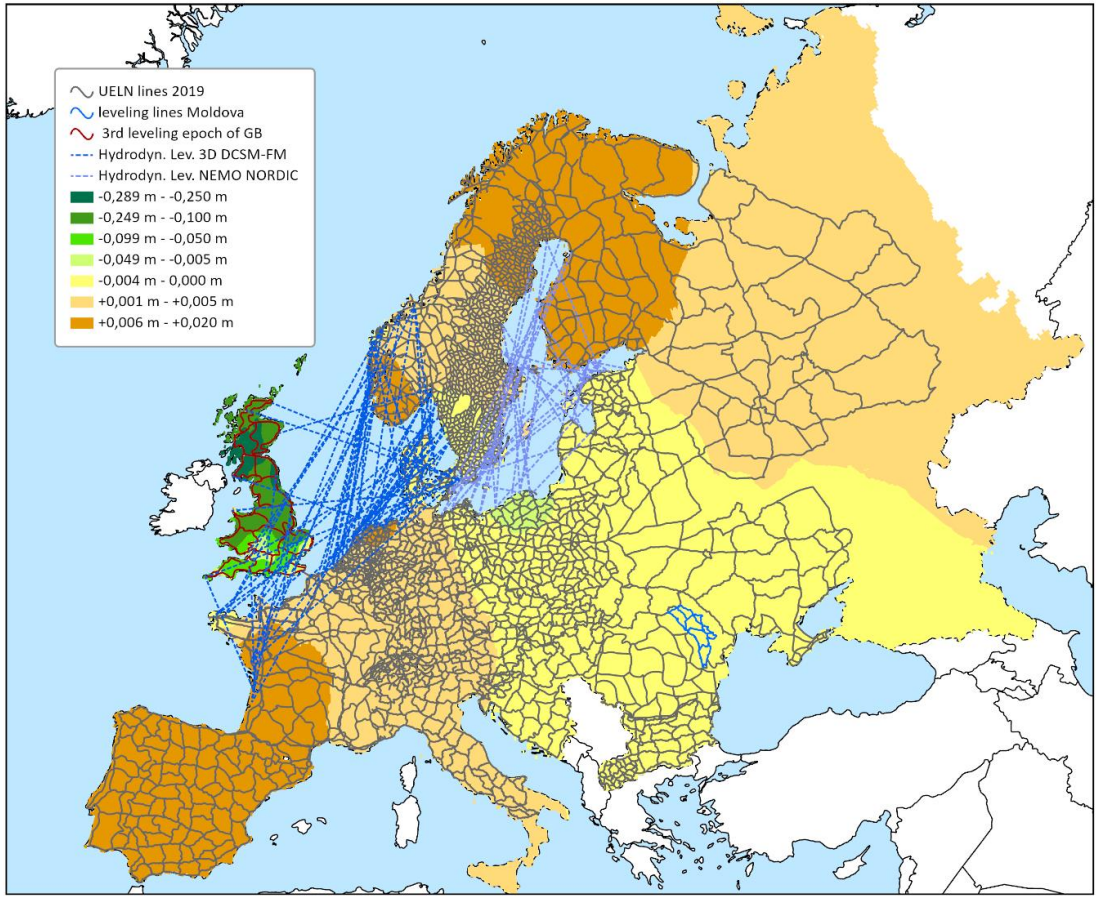
➢ *see next talk by M. Sacher*

Differences h(ell)-H(EVRF2022)-EGG2015 in cm



Differences h(ell)-H(EVRF2024HY)-EGG2015 in cm

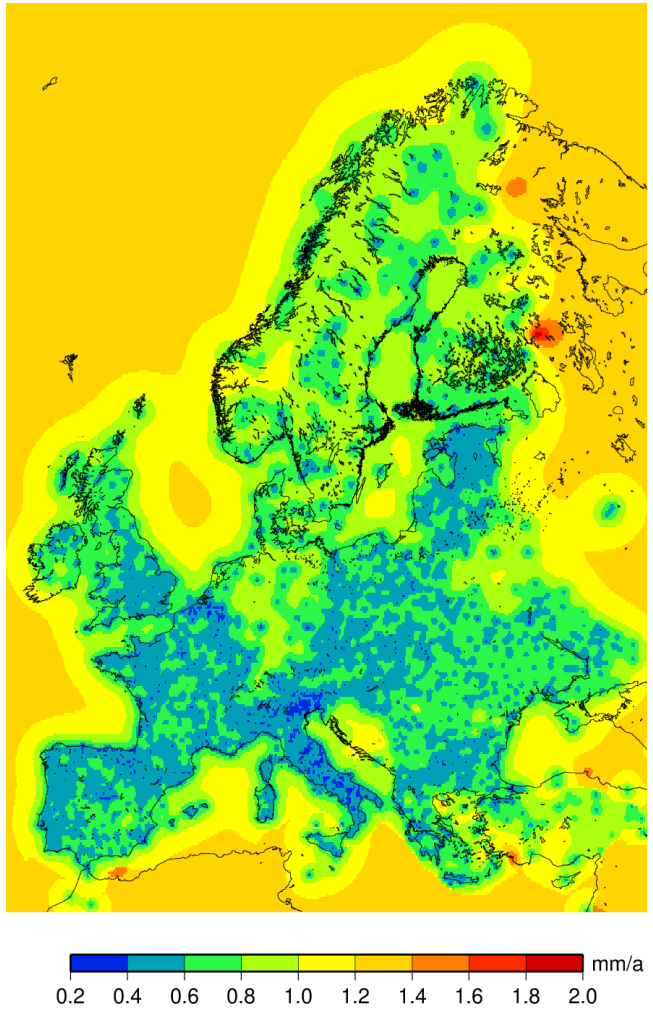


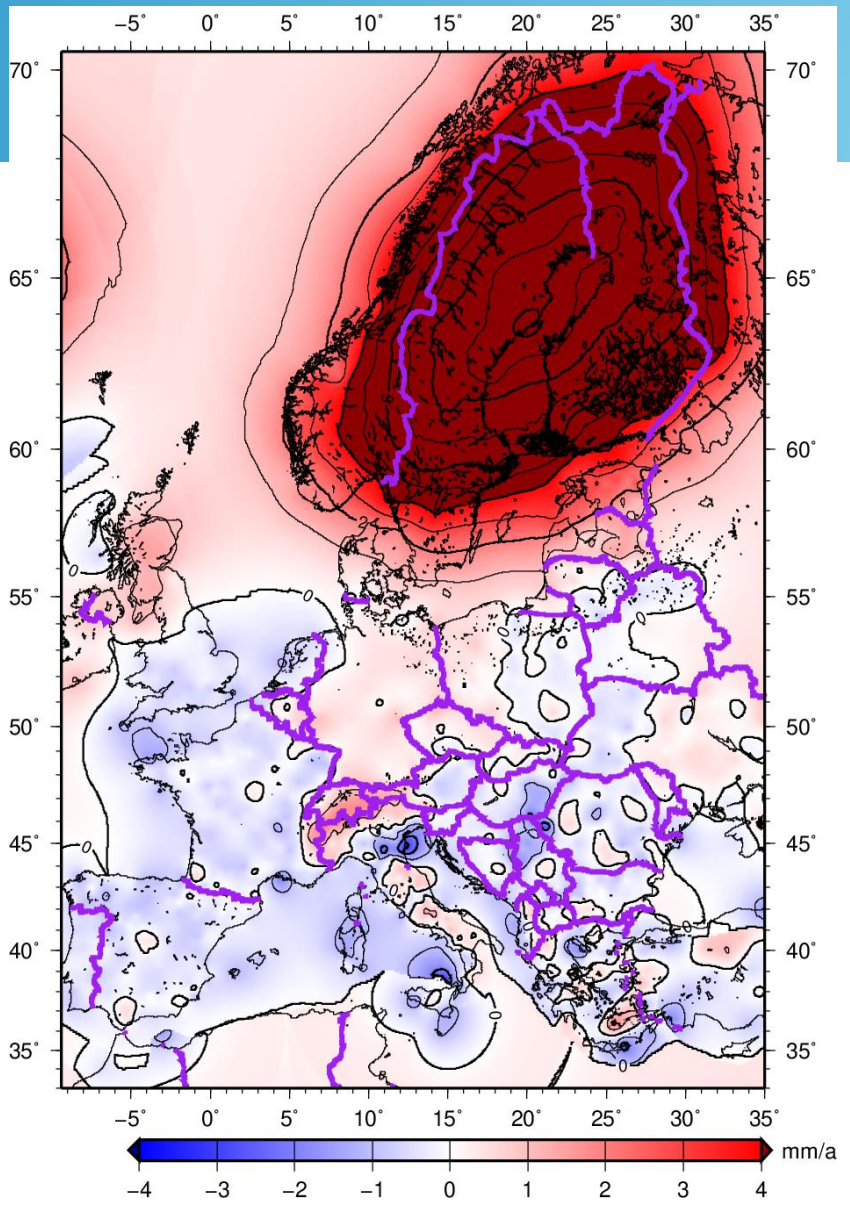


GNSS and leveling: Investigation of vertical velocity models

- **EuVeM2022** (Lantmäteriet 2023, Steffen et al. 2022)
- Low data density in DE and CH

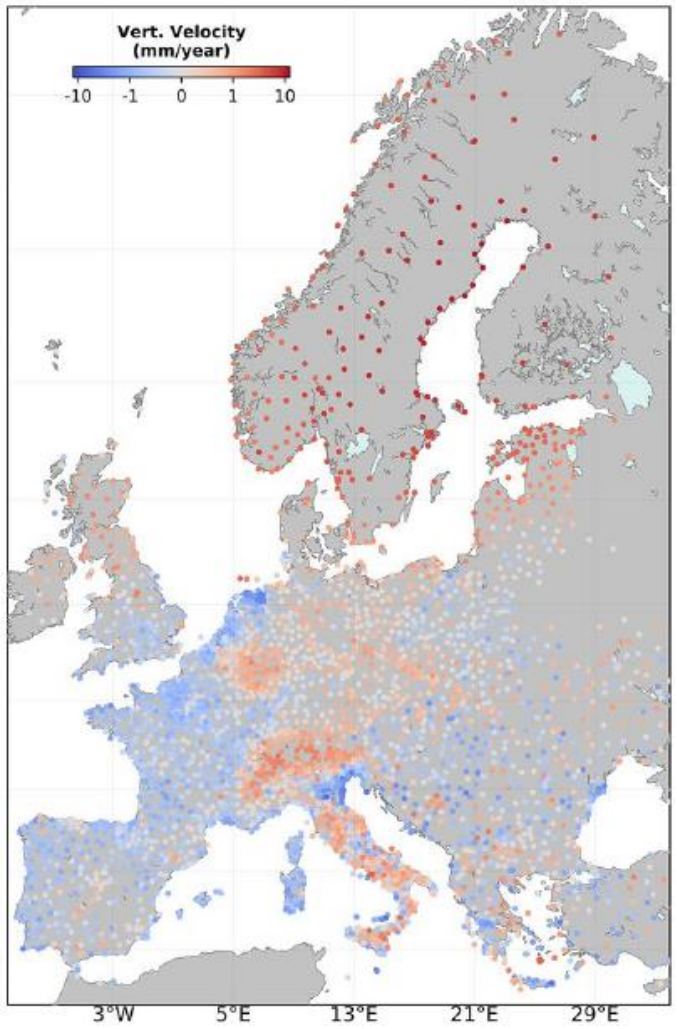
Standard deviation

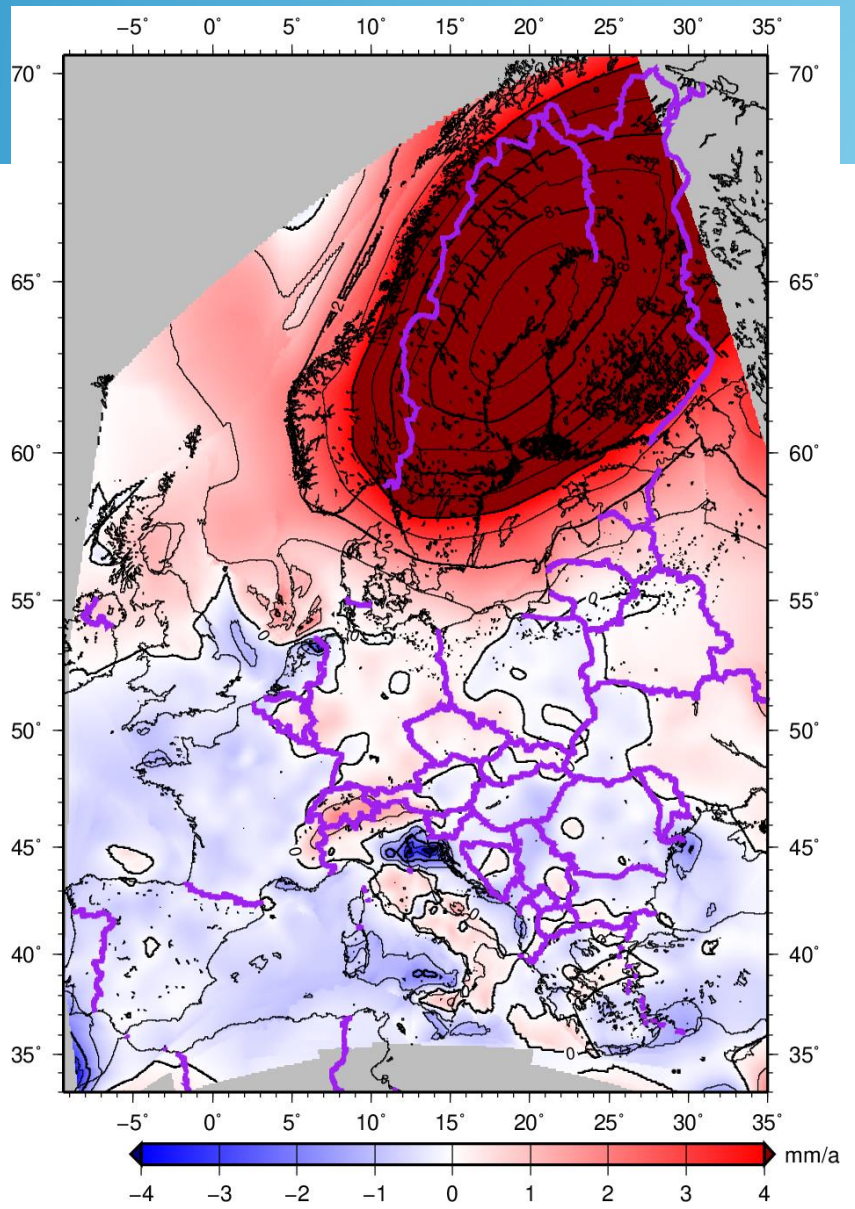




GNSS and leveling: Investigation of vertical velocity models

- **Piña-Valdés** et al. (2022)



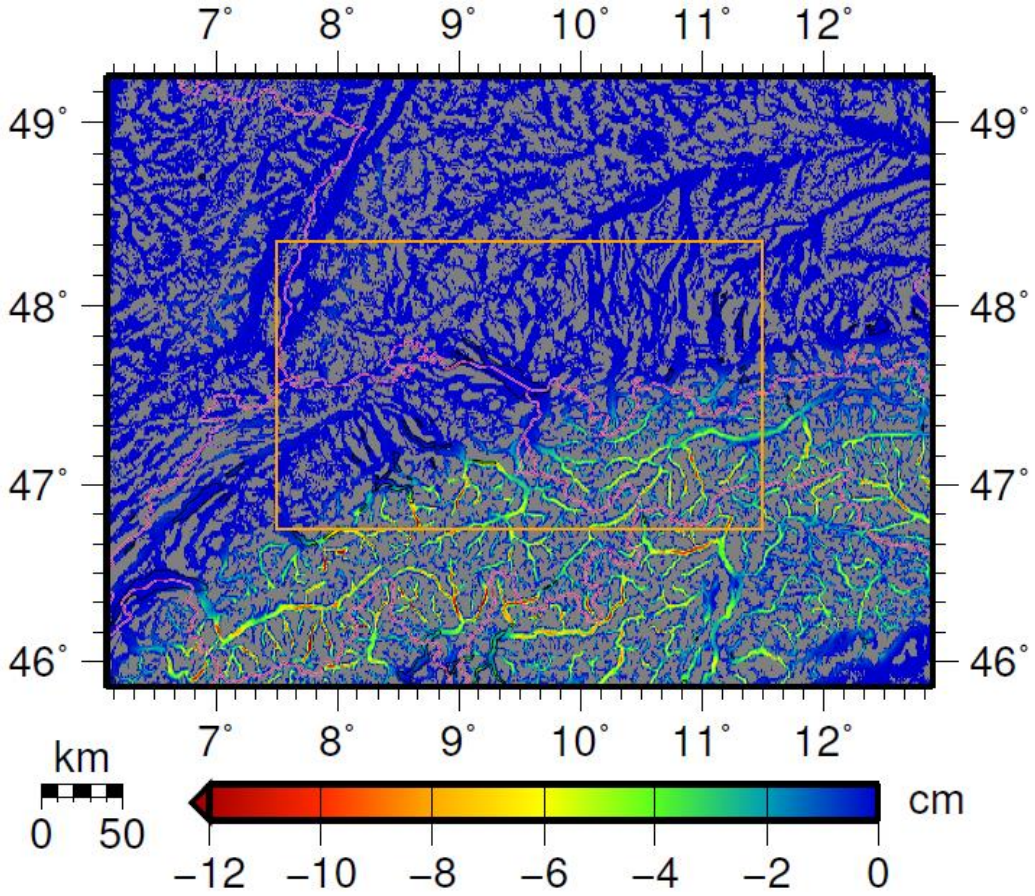


Quasigeoid:
Refined harmonic correction in residual terrain modeling

$$\zeta_{\mathrm{HC}} = -\frac{2\pi G\rho}{\gamma}(H - H_{\mathrm{ref}})^2, \text{ where } H < H_{\mathrm{ref}}$$

(e.g. Klees et al. 2023, Schwabe et al. 2024)

Effect for a high-resolution RTM surface (according to SH degree 2160 ~ 18 km) ▶
Maximum values up to ca. 20 cm



Schwabe et al. (2024, Journal of Geodesy, accepted)

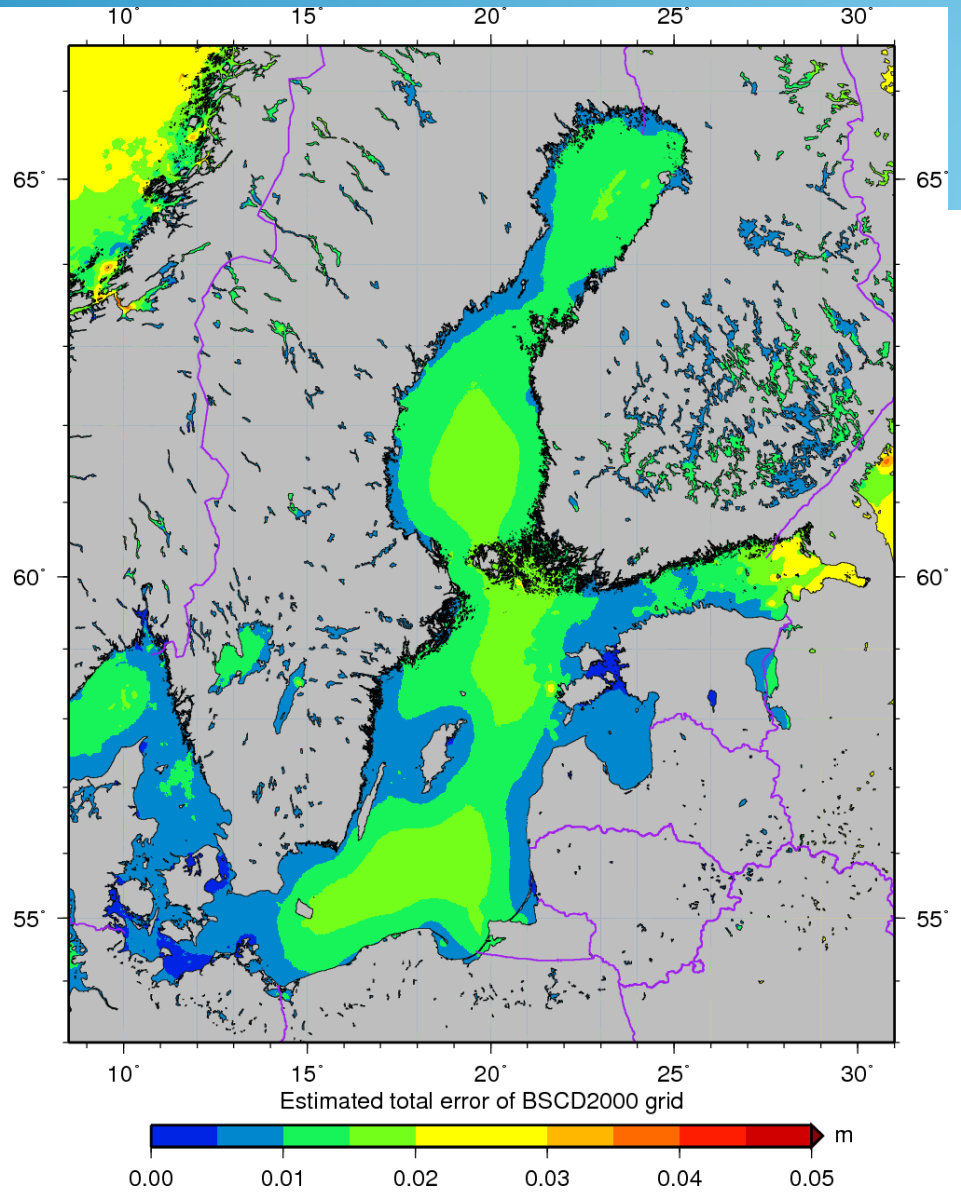
- So far usually not applied in „remove-compute-restore“ scheme
- Neglecting HC leads to systematic positive bias in quasigeoid in deep valleys
- Confirmed in Alpine quasigeoid study with independent method and GNSS/leveling data
- ➢ **Improved quasigeoid for the Alps (~2026/27) (European Alps Geoid project)**

Baltic Sea Chart Datum 2000

FAMOS
FINALISING SURVEYS FOR THE BALTIC MOTORWAYS OF THE SEA
Co-financed by the European Union
Connecting Europe Facility

- **BSCD2000 is implemented as unified chart datum for nautical maps and water levels in the Baltic Sea**
- Grids published November 2023
- https://www.bshc.pro/iho-bscd2000/
- BSCD2000 transformation grid is seamlessly fitted to national ETRS89 coordinates and national EVRS-based leveling heights
  → *Navigation and hydrographic surveys*
- Also available: Gravimetric quasigeoid solutions from the forerunning FAMOS project
  → *Scientific use*

- Ongoing activity: **„BalMarGrav“ project** for marine gravity in the Southern Baltic Sea **(EU-Interreg Baltic Sea Region)**



BSCD2000 Release Note (Schwabe et al. 2023)

Summary and outlook

- First static overview of the national integrated geodetic reference coming soon (~ July 2024)
  → Check EVRS or CRS-EU website, EUREF newsletter
- Focus on work related to EHRS_CP towards new EVRF202x and first dataset release
- BSCD2000 transformation surface published for unified chart datum in the Baltic Sea
- New regional gravimetric quasigeoid solutions envisaged for 2026/2027
  (NKG geoid, Alps, Germany, Italy, …) as further cornerstones for a first version of the EHRS

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Thank you for your kind attention!

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Comparison with NKG2015 / EGG2015 (updated)

CC	#	#out	Mean	Med.	STD (mean)	Max. (mean)	*STD (plane)*	*Max. (plane)*
EE	11		**–2.4**	–2.3	**1.3**	2.7	***1.3***	*3.0*
FI	74		**–1.0**	–1.0	**2.1**	6.3	***1.8***	*5.3*
LT	241	4	**–3.5**	–3.8	**3.1**	8.4	***2.2***	*6.5*
LV	18		**–4.1**	–3.6	**1.7**	3.2	***1.3***	*2.6*
NO	3224		**–2.6**	–1.9	**4.0**	24.4	***3.7***	*21.7*
SE	185		**0.0**	+0.2	**2.2**	7.2	***2.2***	*7.1*

EGG2015 (RTM without HC for quasigeoid)

CC	#	#out	Mean	Med.	STD (mean)	Max. (mean)	*STD (plane)*	*Max. (plane)*
EE	11		**–7.0**	–6.7	**1.5**	3.8	***1.3***	*2.9*
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SE	185		**–4.4**	+4.3	**1.9**	4.9	***1.8***	*5.2*

NKG2015 (KTH method with different approach)

Comparison with EGG2015 (updated)

CC	#	#out	Mean	Med.	STD (mean)	Max. (mean)	*STD (plane)*	*Max. (plane)*
EE	11		**–2.4**	–2.3	**1.3**	2.7	***1.3***	*3.0*
FI	74		**–1.0**	–1.0	**2.1**	6.3	***1.8***	*5.3*
LT	241	4	**–3.5**	–3.8	**3.1**	8.4	***2.2***	*6.5*
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