Federal Agency for Cartography and Geodesy

BKG
Wir geben Orientierung.

Status and future of the European Vertical Reference Frame

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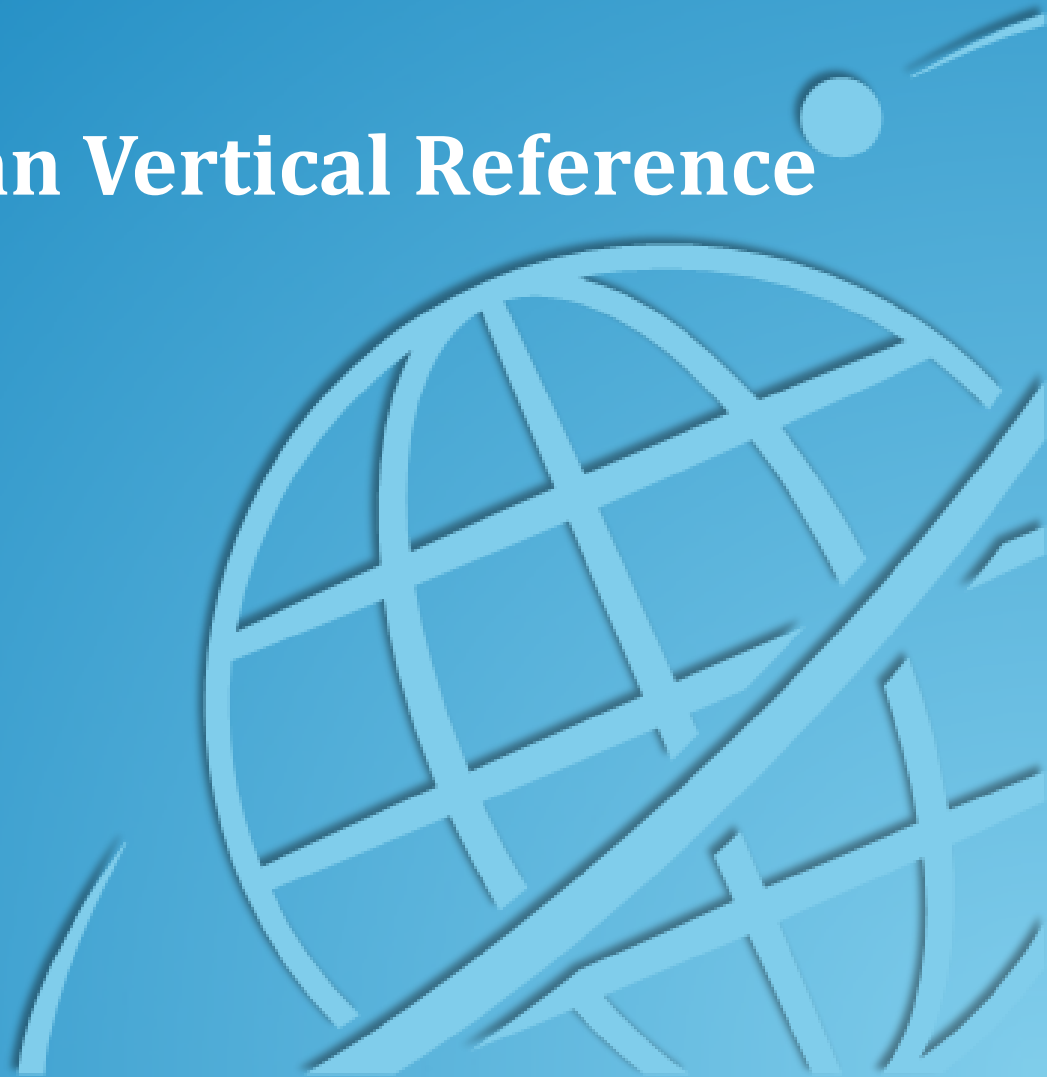
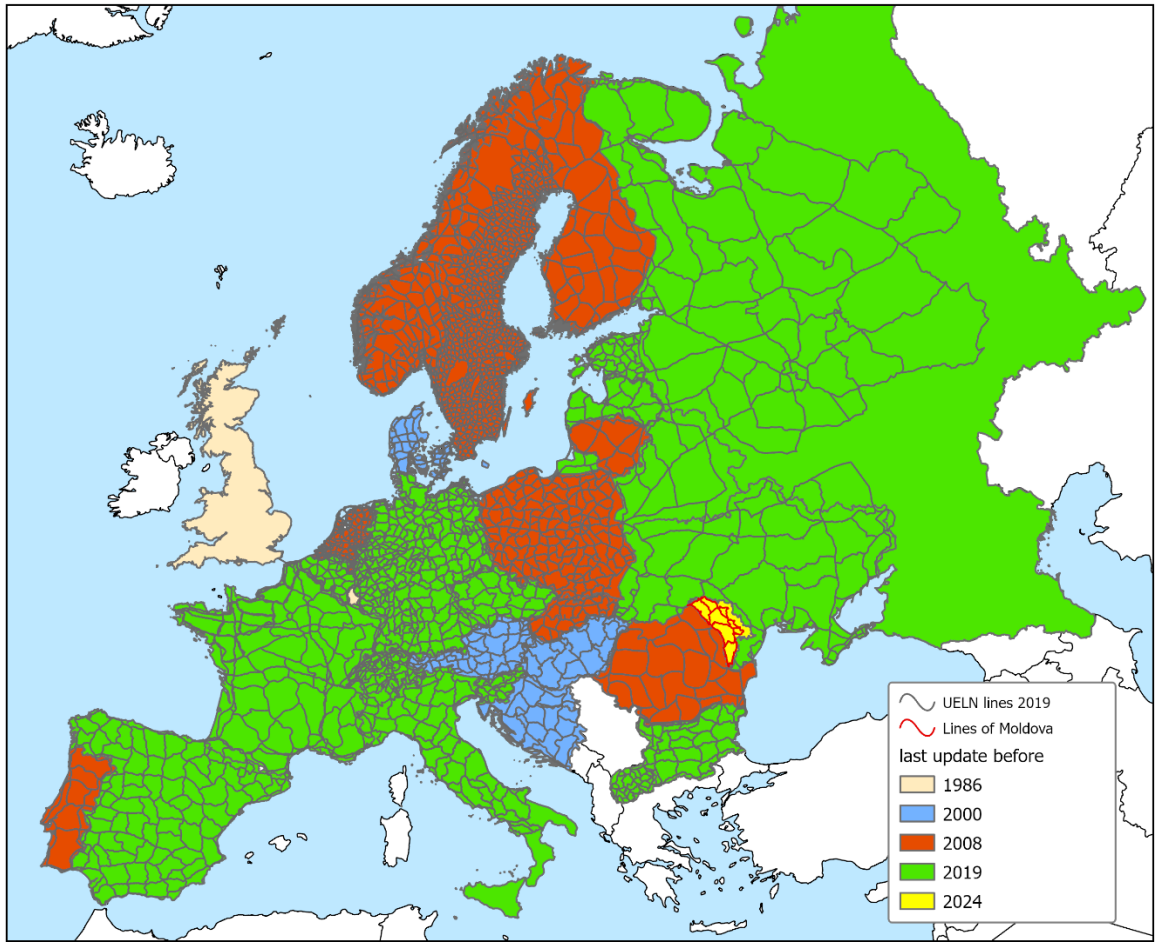


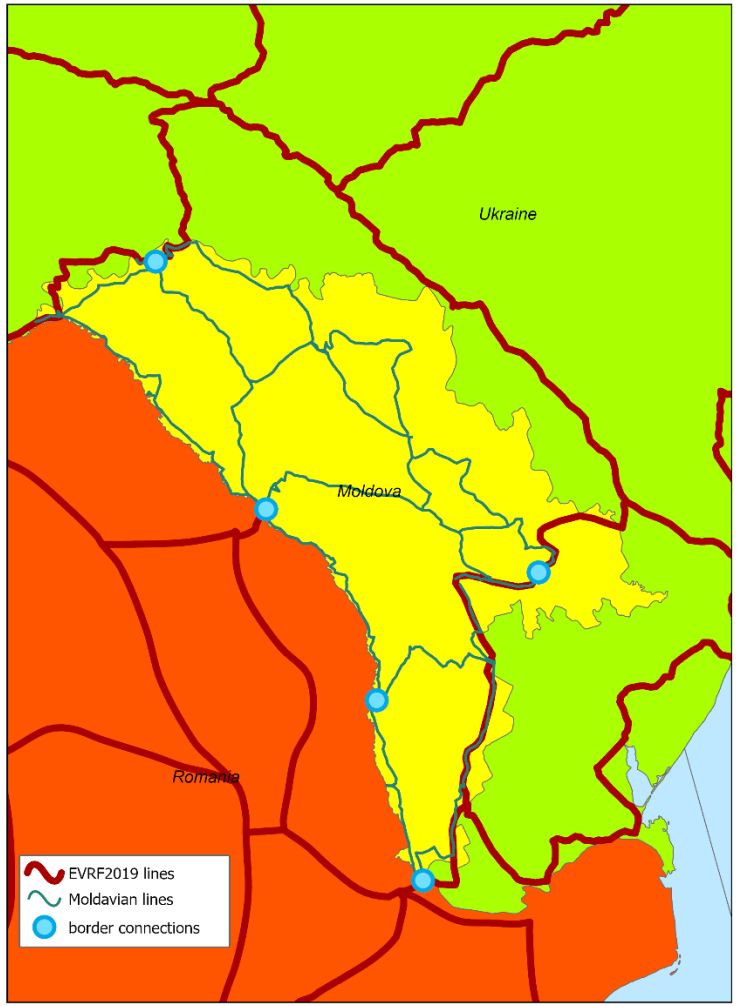
Content

1. **New leveling data in UELN since 2019**
2. Inclusion of hydrodynamic leveling

UELN status 2024



Including leveling data of Moldova



- Leveling network of Moldova was measured 2008-2021
- Handing over of measured height differences with (old) normal height corrections in December 2022
- Test adjustment of the measured height differences resulted in standard deviation of 1.3mm/km
- Integration into UELN possible by 5 border connections (3 RO, 2 UA)
- Because of Transnistria conflict, no measurements and connections to Ukraine at the Eastern border possible
- Provision of coordinates and gravity values initially scheduled for mid 2023
- Actual delivery of coordinates in January 2024
- Up to now, no gravity values are available
- Computation of geopotential differences ?

Computation of geopotential differences for Moldova

Geopotential differences are normally computed from measured height differences and gravity values:

Gravity values are missing.

$$\Delta C_P = \sum_1^n \frac{g_i + g_k}{2} \Delta h_{ik}$$

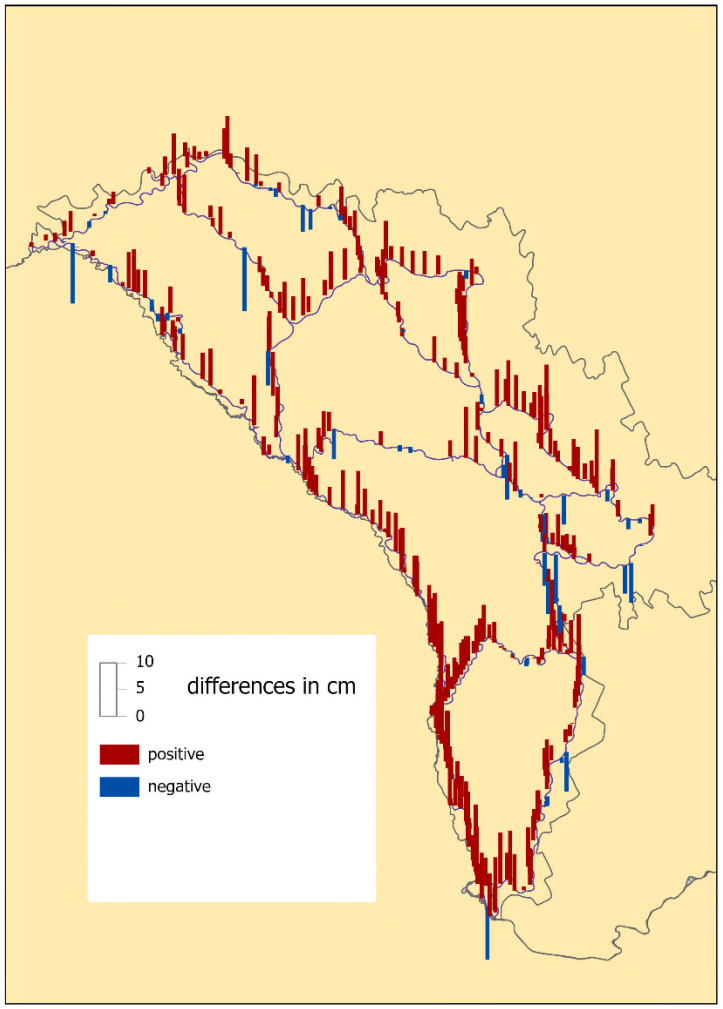
Alternative approach:

- Use of normal height differences (measured height differences including normal height correction) and normal gravity.
- Computation of normal gravity with the same formula and the same coordinates, which has been used for the computation of normal height correction. Normal height corrections in the Moldavian data are from the 1970s.

→ Use of Helmert formula and Pulkovo/83 reference system.

- Comparison of the adjustment results of normal height differences (provided by MD) and geopotential values/normal heights : -6mm < diff. < +4mm
- Reasons for differences: Low accuracy of old coordinates (from maps) and of normal height corrections (specified only within 1mm)

Differences h(ell)-H(EVRF2024)-EGG2015

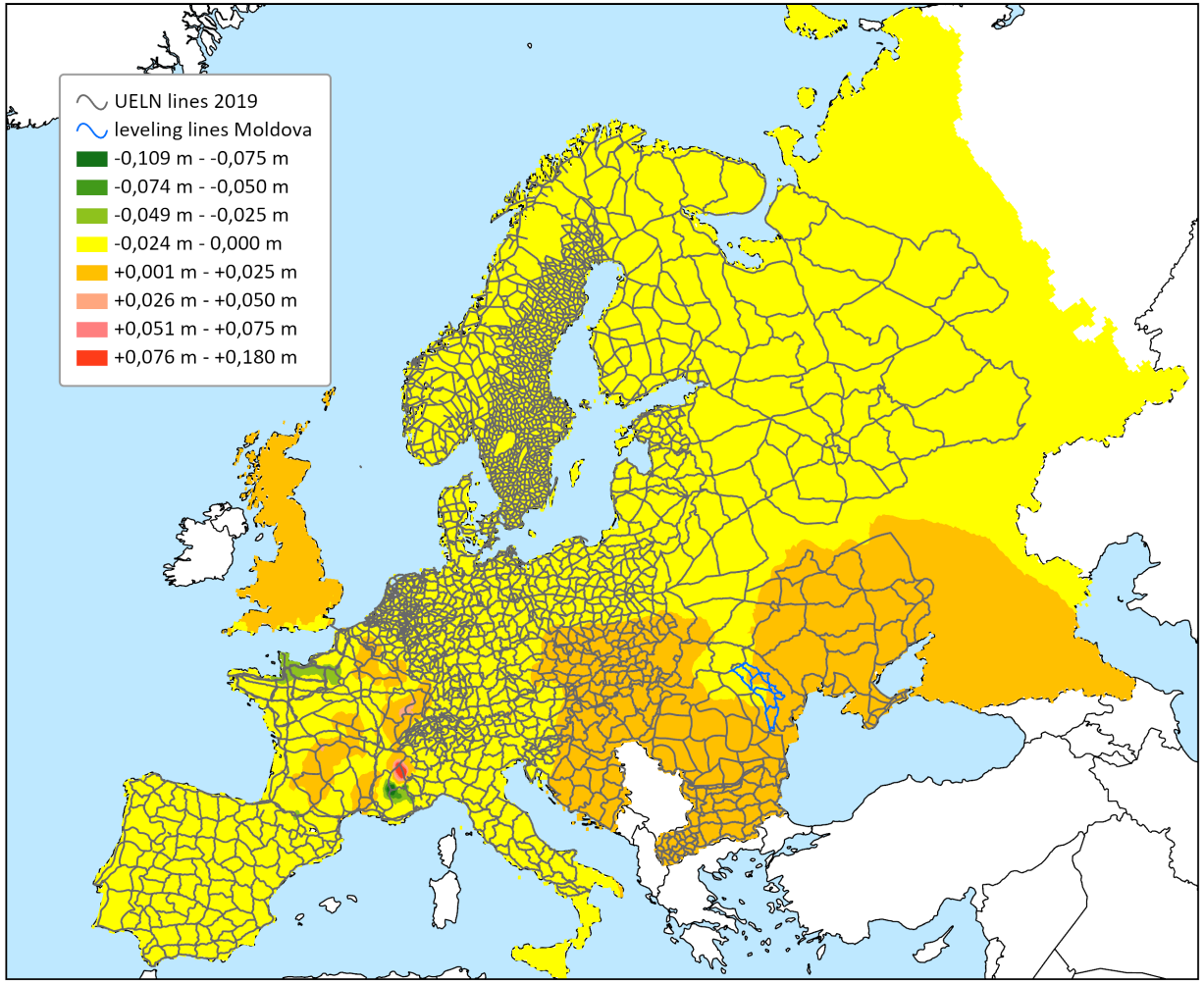


- Coordinates of Moldova have been provided including ellipsoidal heights
- 443 of 753 leveling points in Moldova have been indicated as suitable for GNSS/leveling by the colleagues of Moldova
- 37 outliers
- After computation of a new preliminary EVRS realization EVRF2024 with leveling data of Moldova, 406 EHRS_CP for Moldova are available:

Statistic for the differences h(ell)-H(EVRF2024)-EGG2015 in Moldova

Number of Points:	*406*
Standard deviation:	*± 4.3 cm*
Average:	*+ 3.6 cm*
Minimum:	*-14.2 cm*
Maximum:	*+14.9 cm*

Differences between EVRF2019 and preliminary EVRF2024



Differences caused by

- Change of French data
  - Reprocessed data of IGN
  - NIREF data between 1983-2018
  - Combination by 2500 identical points (only 37 in EVRF2019)
  - Change of border connections
- Inclusion of data of Moldova
- Additional border connections between Austria and
  - Hungary
  - Czech Republic
  - Germany
  - Switzerland

Content

1. New leveling data in UELN since 2019
2. **Inclusion of hydrodynamic leveling**

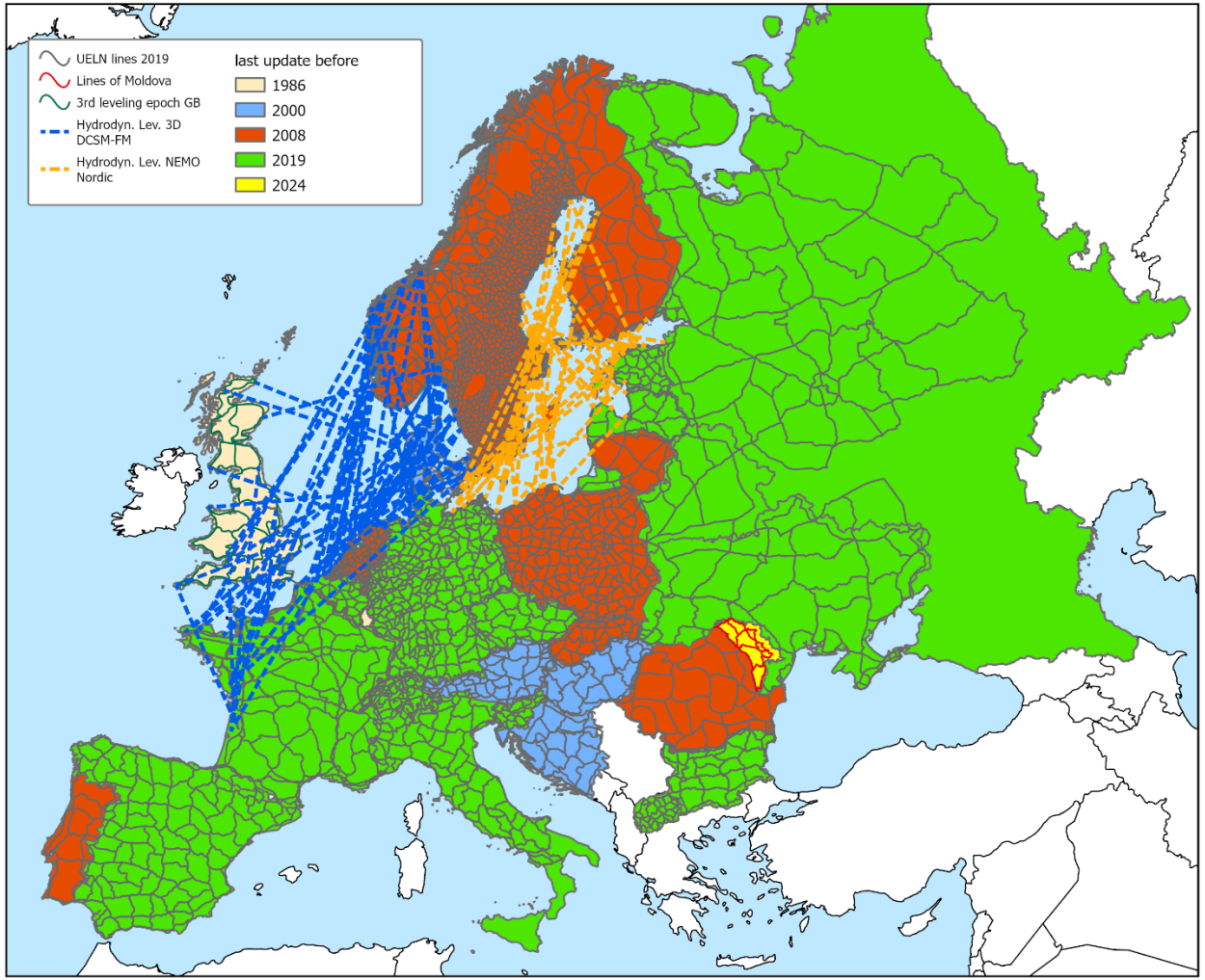
Versatile Hydrodynamics Project

- Versatile Hydrodynamics – Project of Delft University of Technology (2018-2023)
  - Deltares (independent institute for applied research in the field of water, subsurface and infrastructure) and Federal Agency for Cartography and Geodesy (BKG) were involved as external advisors
- One part of the project: Dissertation Yosra Afrasteh: "**Model based Hydrodynamic leveling – an impact study on the European Vertical Reference Frame"** (Afrasteh 2023)
- Combining spirit leveling data with model based hydrodynamic leveling data
  - Regional, high-resolution hydrodynamic model
  - Tide gauge observations
  - Connections between tide gauges and UELN benchmarks
- Possibilities and potentials of including model-based hydrodynamic leveling in UELN
  - Connection of islands
  - Reduction of systematic errors
  - Reduction of standard deviation

Test of hydrodynamic leveling

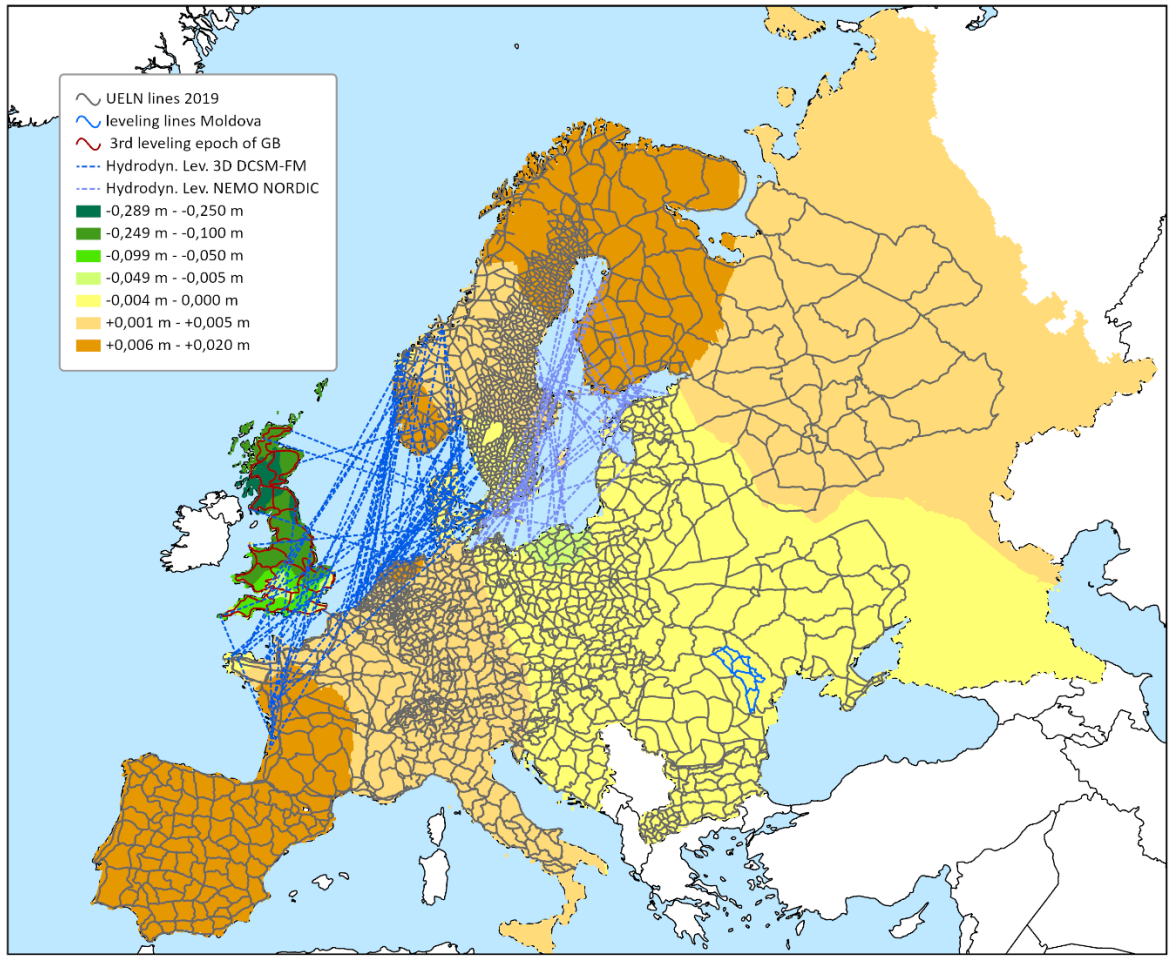
- Approach on UELN data of EVRF2019 using hydrodynamic connections in the Nordic area of UELN by Y. Afrasteh
- 3D DSCM-FM (“Dutch Continental Shelf Model – Flexible Mesh”) hydrodynamic model
  - Developed by Deltares (on request of Rijkswaterstaat (RWS))
  - Covers North-East Atlantic Ocean including the North Sea
  - Mean water level for summer periods 1997 to 2019 were used
- Nemo-Nordic model NS01
  - Developed by Swedish Meteorological and Hydrological Institutes
  - Covers Baltic Sea and North Sea, only Baltic Sea is used here
  - Mean water level for summer periods 2017 to 2021 were used
- This presentation describes the influence on current UELN data 2024
  - of 74 hydrodynamic connections using the 3D DSCM-FM model
  - of 49 hydrodynamic connections using the Nemo-Nordic model

Adjustment of UELN including network of Great Britain and hydrodynamic leveling



- Reinserting of 3rd leveling epoch of GB (as in EVRF2000 and EVRF2007)
- In (Afrasteh 2023) full variance-covariance matrix for hydrodynamic leveling (empirical noise model)
- Here only variances are used
  - 3D DCSM-FM: 33.8 - 41.5 kgal·mm
  - Nemo-Nordic: 38.4 - 59.9 kgal·mm
- Variance factors after variance component estimation:
  - 3D DCSM-FM: 1.29
  - Nemo-Nordic: 3.19

Differences between preliminary realizations EVRF2024 and EVRF2024HY



Largest differences of the adjusted heights:

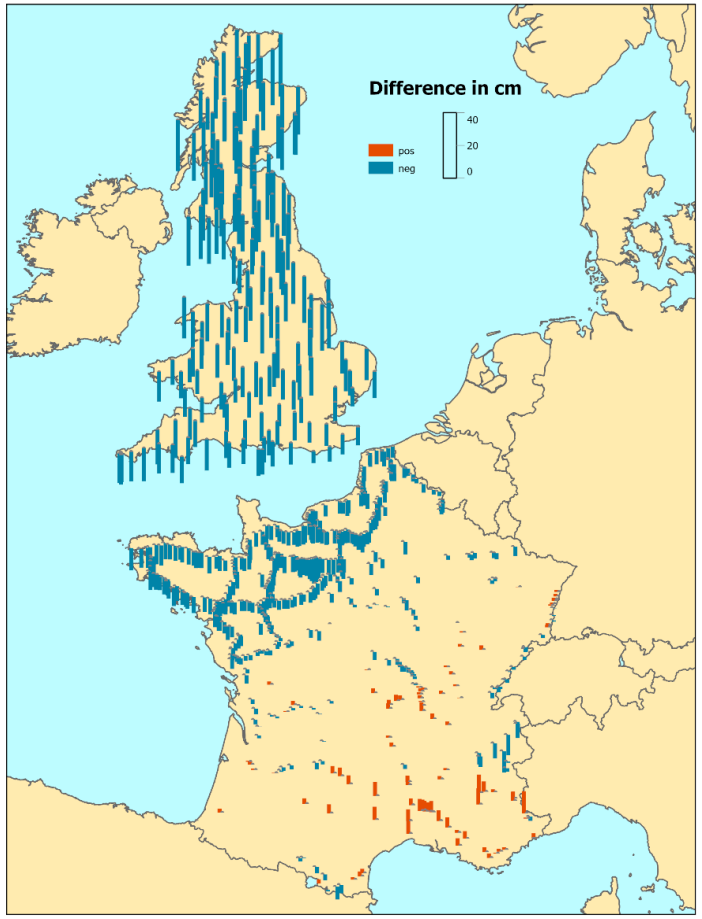
- **Great Britain: up to -300 mm**
- Poland up to -12mm
- NO, FR,FI : up to +14/13/12 mm
- NL, PT, RU, SE: < +10 mm
- Less than 5mm in all other countries

Decrease of standard deviation of adjusted heights:

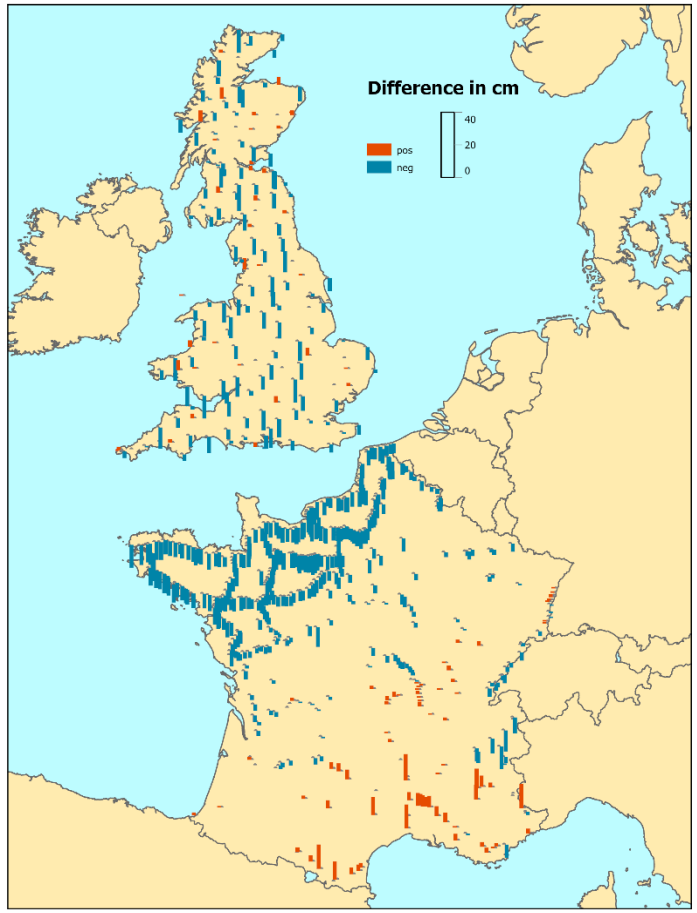
- Mean value of the whole network: Reduction from 14.7 mm to 13.4 mm
- Reduction to 72% in Sweden, 76% in Norway and Finland, 86% in Denmark, 88% in Estonia, 90% in Latvia, 93% in Lithuania, 94% in France, 96% in Russia, 98% in the Netherlands
- Increase from 26.8 to 44.8 mm in Great Britain

Influence of hydrodynamic leveling on EHRS_CP

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

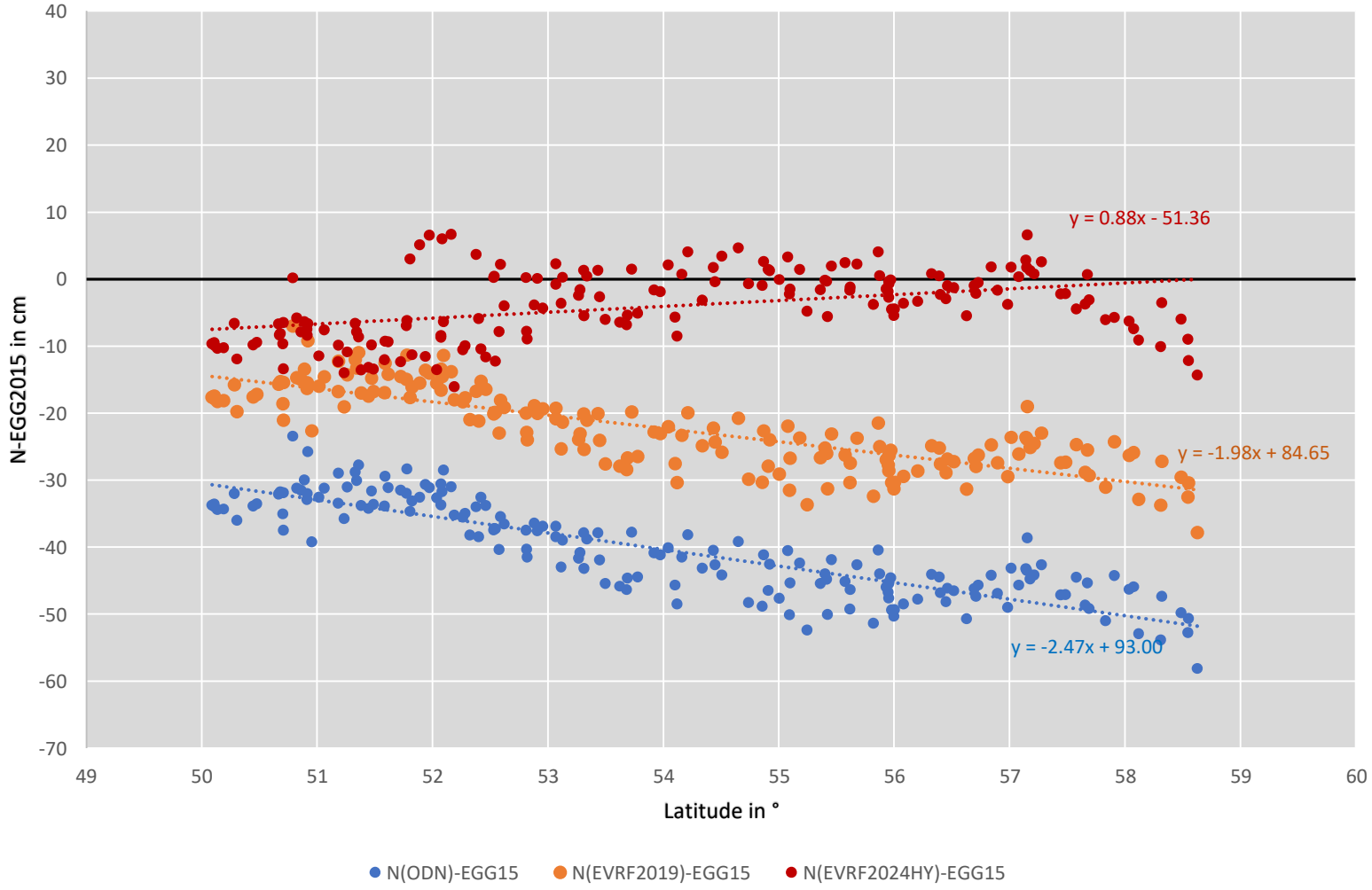


Differences h(ell)-H(EVRF2024HY)-EGG2015 in cm



- Left side: EVRF2024 - as in EVRF2019, but with new data of France
- Right side: EVRF2024HY - with hydrodynamic leveling data
- GB: decrease of mean difference from 22cm to 4cm
- France: almost no effect
- Too few hydrodynamic connections with the new data set of France

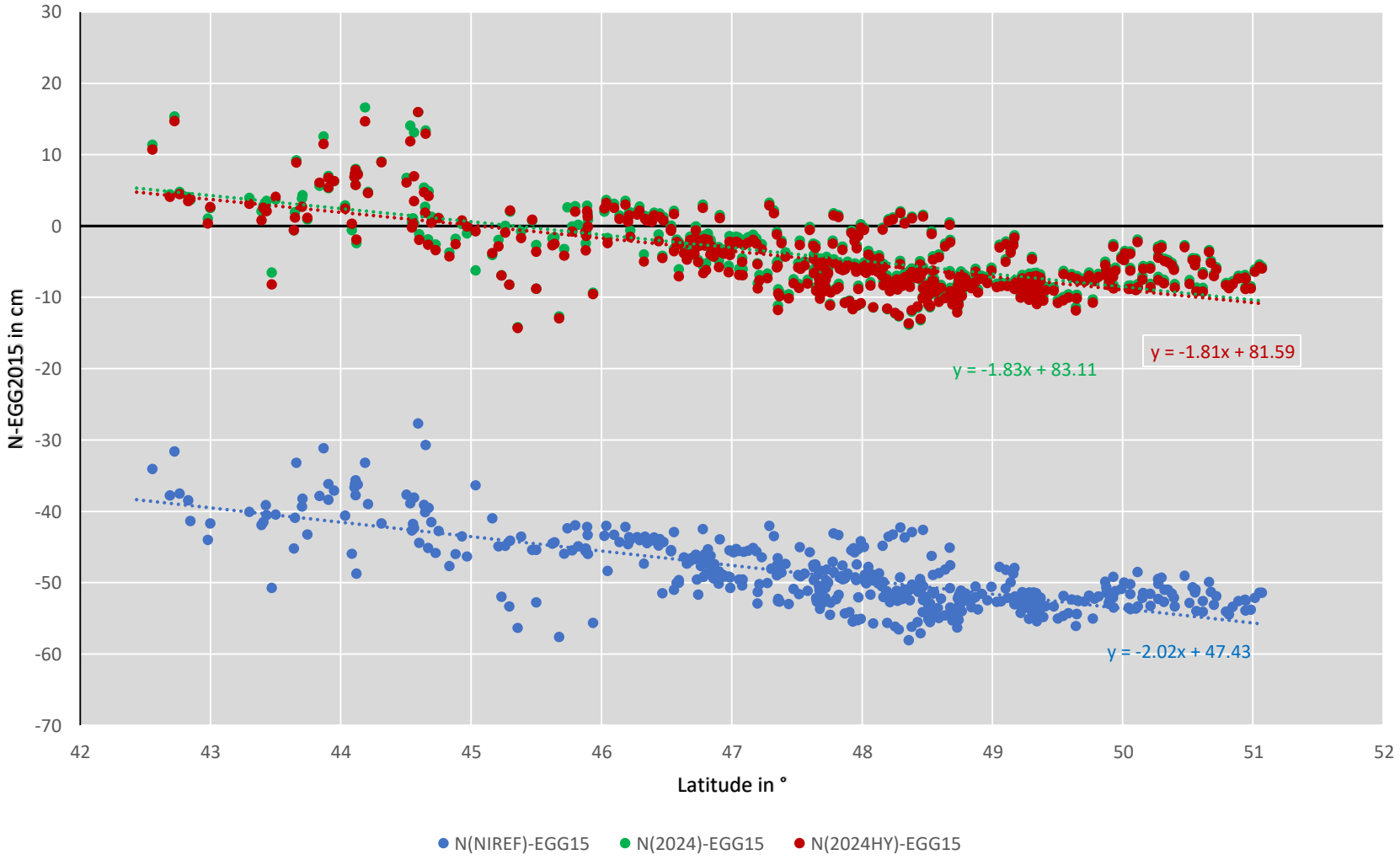
N-EGG2015 as a function of latitude in Great Britain



After inclusion of hydrodynamic connections →

- Small tilt in the opposite direction
- Offset of the British part of EVRF2024 decreases from about -15cm to about -8cm
- *Remember: there was a difference of 37cm between the leveled tunnel connections performed by France and by GB*

N-EGG2015 as a function of latitude in France



Inclusion of hydrodynamic connections →

- Very small effect on the tilt of the French part of EVRF2024
- Heights of French EHRS_CP were computed by interpolation, only 3 hours GNSS observations

Future steps

- Further tests of various approaches regarding weights (especially the 2 groups of French data)
- New choice of hydrodynamic connections to France
- Including variance-covariance matrix of hydrodynamic leveling (upgrade of adjustment program) ?

Delft University of Technology: Further studies on the topic hydrodynamic leveling could allow

- Improvement of accuracy of hydrodynamic connections
- Providing of additional connections in the area of North-East Atlantic Ocean to islands as
  - Ireland
  - Iceland
- Inclusion of hydrodynamic connections in other regions such as Mediterranean Sea, Black Sea
  - Decrease of standard deviation in parts of Southern UELN ?
  - Including islands such as Balearic Islands, Corsica, Sardinia
  - Greece?

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Thank you for your kind attention!

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