



Federal Agency for  
Cartography and Geodesy

# Heighting across borders – the European context

Martina Sacher

---

# Contents

- Historical development
- EVRF2007
- Development after 2008
- Application of EVRS
- Next realization
- Forecast to the future

# Development toward a European height system

## **Central European Triangulation (1864 – 1890)**

48 levelling loops, 42 tide gauges

Difference NAP– TG Genoa: -32cm

## **UELN-55 (1954 – 1963) United European Leveling Network**

(UELN, REUN) Western Europe; NAP, geopotential numbers

Final report 1963

## **UELN-73 (1971-1986)**

Western Europe, wide meshed networks; Realization UELN 73/86

## **EPNN: Unified Precise Leveling Network of Eastern Europe**

Common levelings and adjustments 1954 and 1978

## **UELN-95 (1995-1999)**

Extension to the East, full 1. Order networks; Realization UELN-95/98

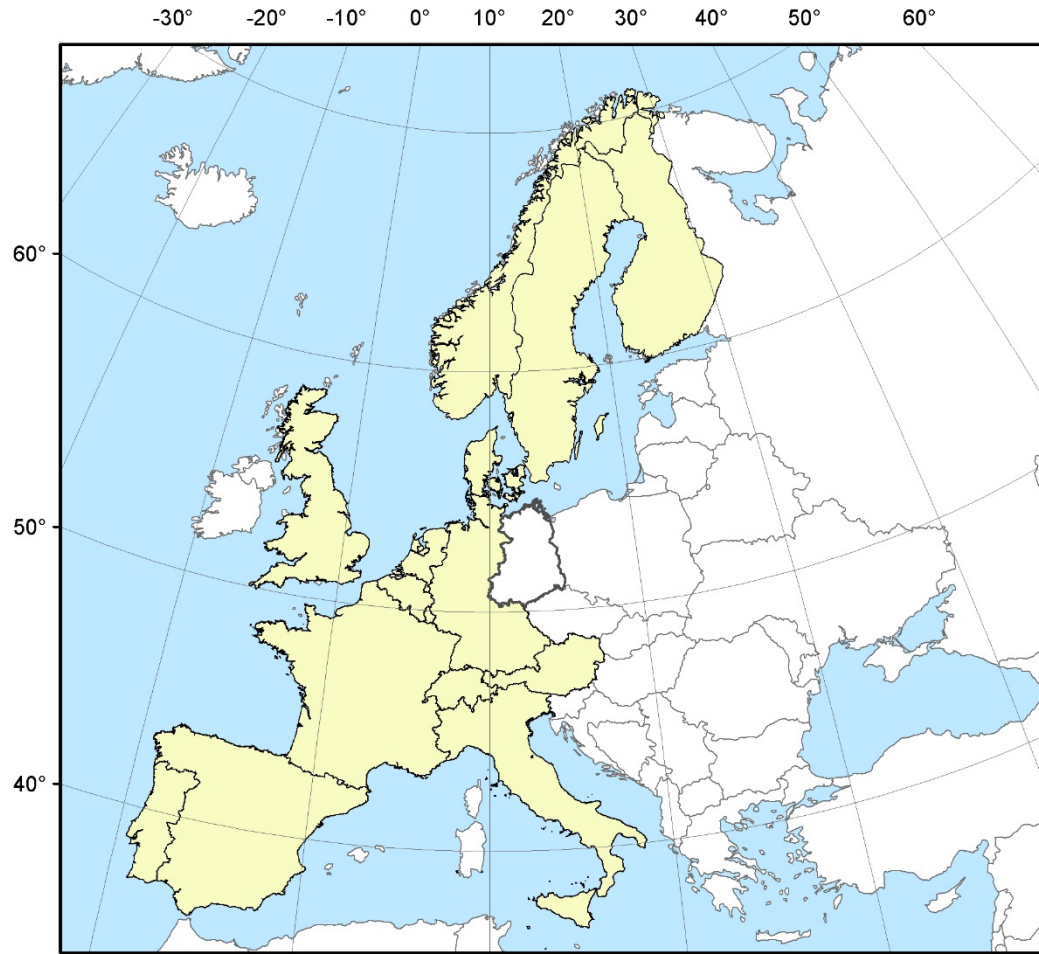
## **EVRF2000**

Extension of UELN-95/98 by EE, LT, LV, RO; Results not distributed

## **EVRF2007 (2000-2008)**

Adopted 2008 in Brussels; results distributed end of 2008

# Extent of UELN-73/86

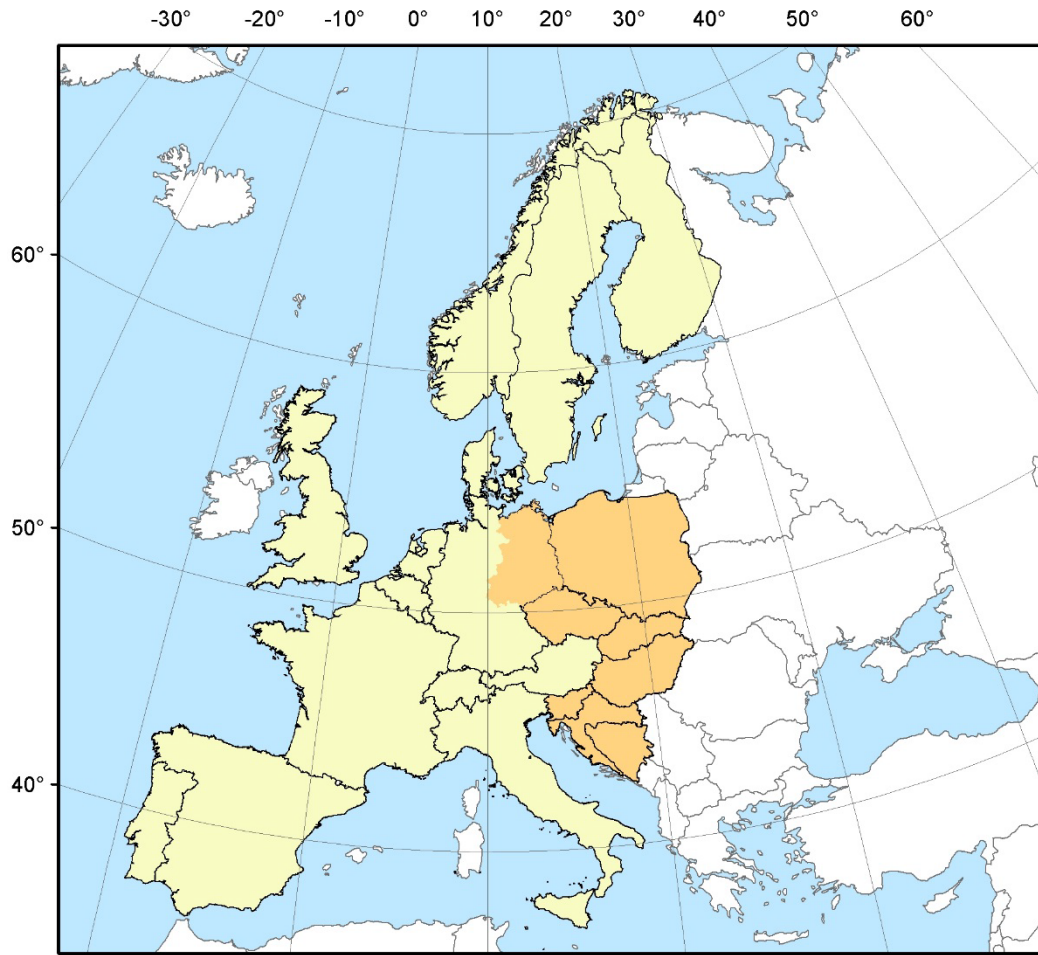


14 countries  
774 nodal points  
1083 lines

**Extent of UELN**

1986

# Extent of UELN-95/98

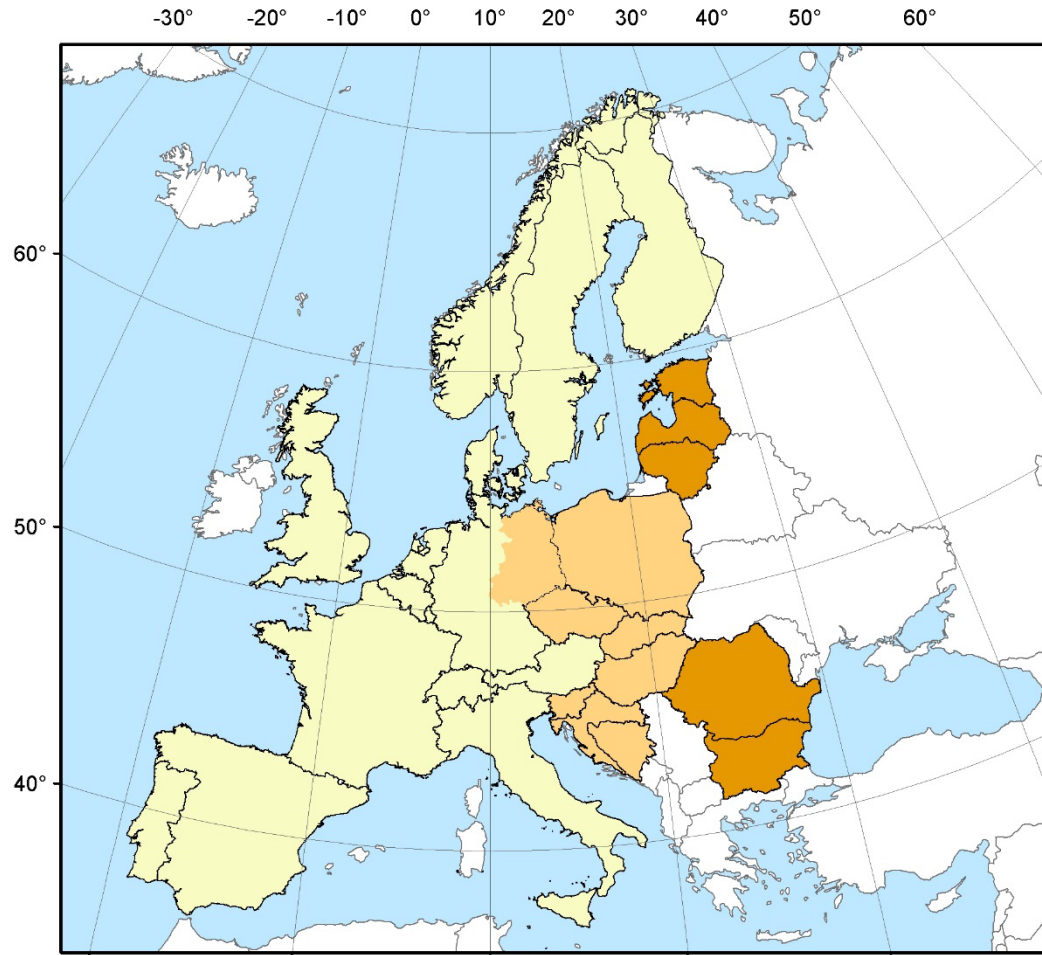


21 countries  
3064 nodal points  
4263 lines

## Extent of UELN

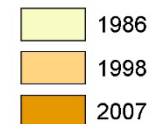
1986  
1998

# Extent of UELN in 2007

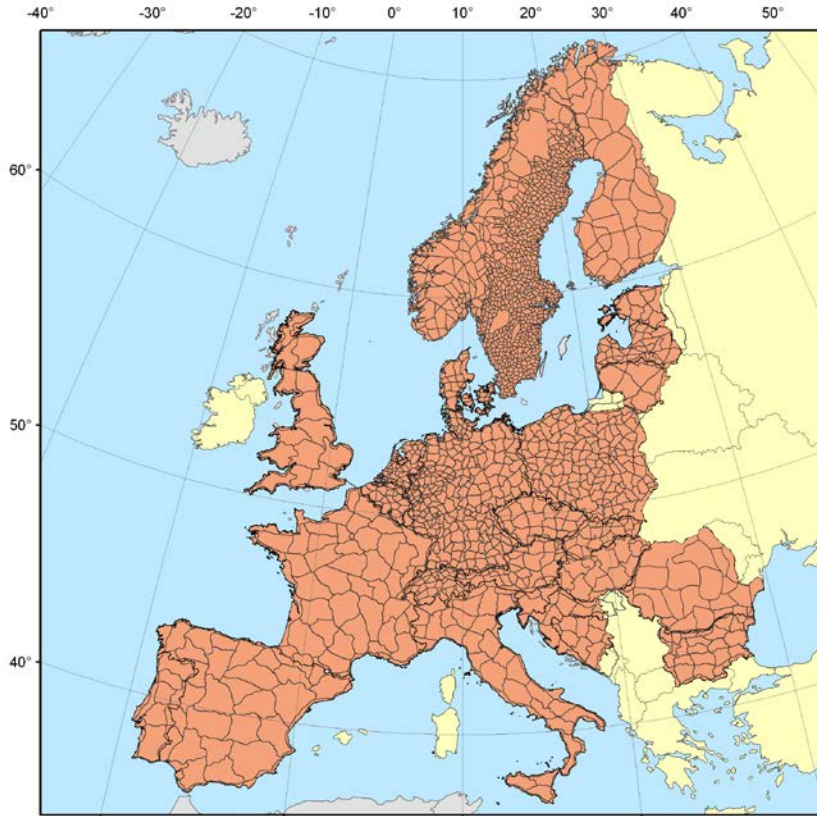


27 countries  
7939 nodal points  
10347 lines

## Extent of UELN



# EVRF2007



- 27 countries
- 13 datum points
- 7939 nodal points
- 10347 lines
- $s_0 = 1.11$  kgal·mm (error for 1km leveling)
- Adopted 2008 in Brussels

# 2007: Definition of the European Vertical Reference System (EVRS)

<b>System</b>	<b>EVRS</b>
description	gravity related height reference system, kinematical (NL: static)
datum	$W_0 = W_{0E} = \text{const.}$ , level NAP
scale	SI – meter, second, TCG time
kind of heights	Geopotential numbers: $-\Delta W_p = c_p = W_{0E} - W_p$ (NL: heights without gravity correct.) normal heights are equivalent (specification of reference gravity field)
tidal system	zero tide (NL: mean tide)
<b>Realization</b>	<b>EVRF2007</b>
datum	<a href="#">13 datum points</a> with their geopotential numbers of UELN-95/98
scale	rod scale and temperature correction, in the authority of the particular countries
reference gravity field	normal gravity field of GRS80
adjustment	free
network	UELN status 2007
tidal system	zero tide
reduction to a common epoch	FI, NO, SE, DK, PL, EE, LT, LV, parts of DE, PL reduced to 2000 by <a href="#">NKG2005LU</a>



# Development of the network since 2008

- Latvia (2011) update
- Russia(2012) extension
- Spain (2012) update
- Latvia (2012) update
- Germany (2015) update
- Switzerland (2015) update
- France (2015) addition of NIREF
- Netherlands (2016) corrections
- Estonia (2016) update
- Belarus (2017) extension

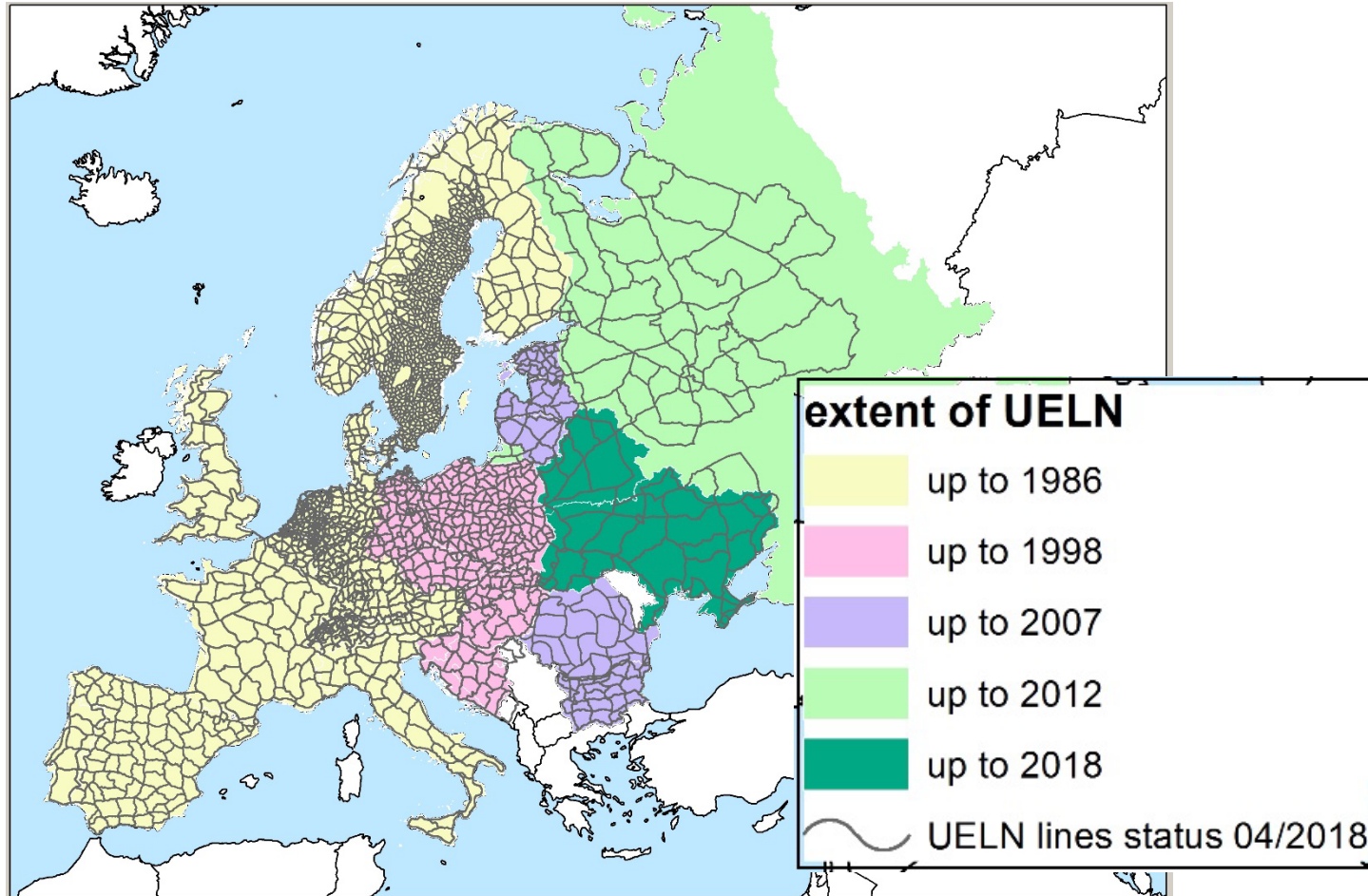
## 2018

- Belgium update
- Ukraine extension
- Czech Rep. update
- Slovenia update

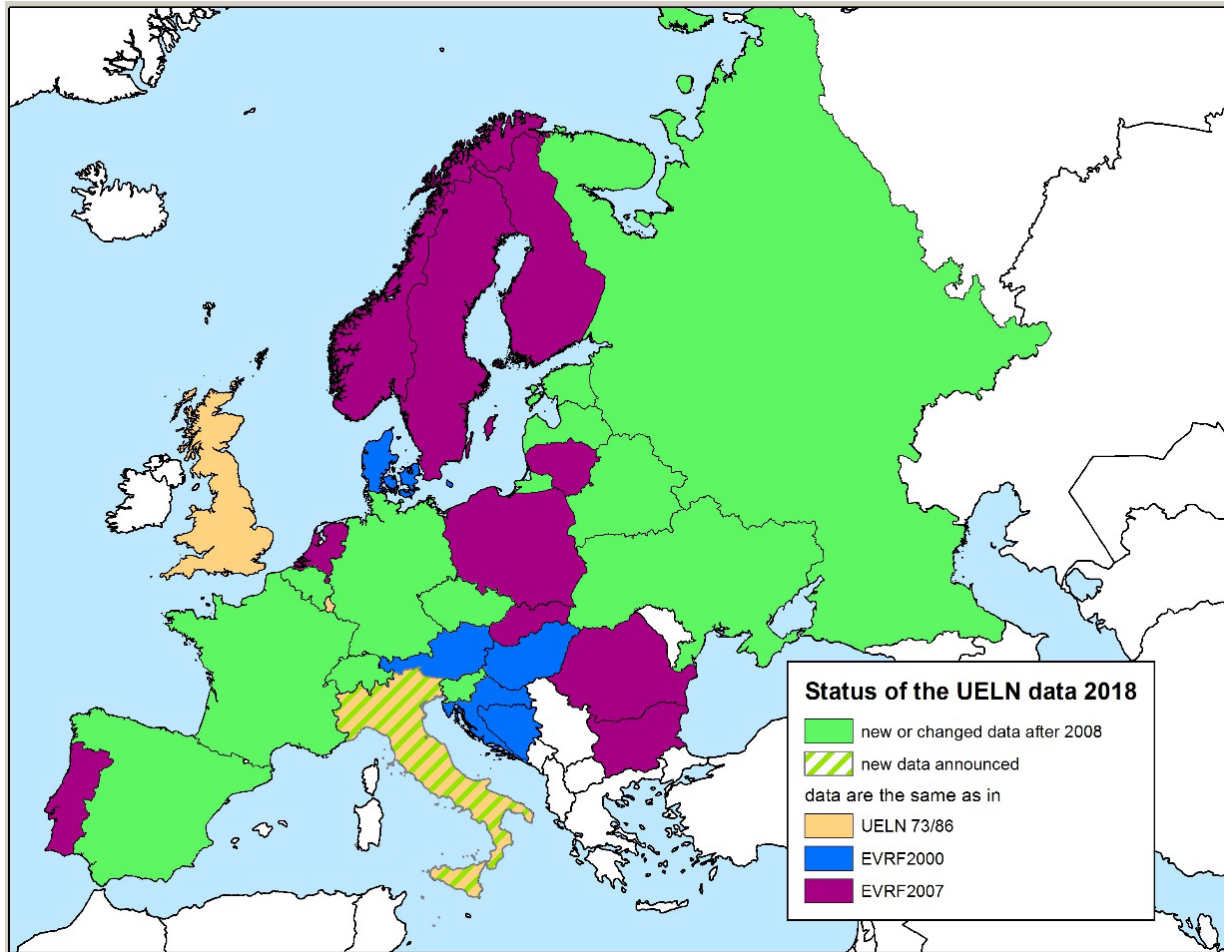
## Expected for 2018:

- Italy update
- Norway minor update
- Slovakia minor update

# Extent of the network



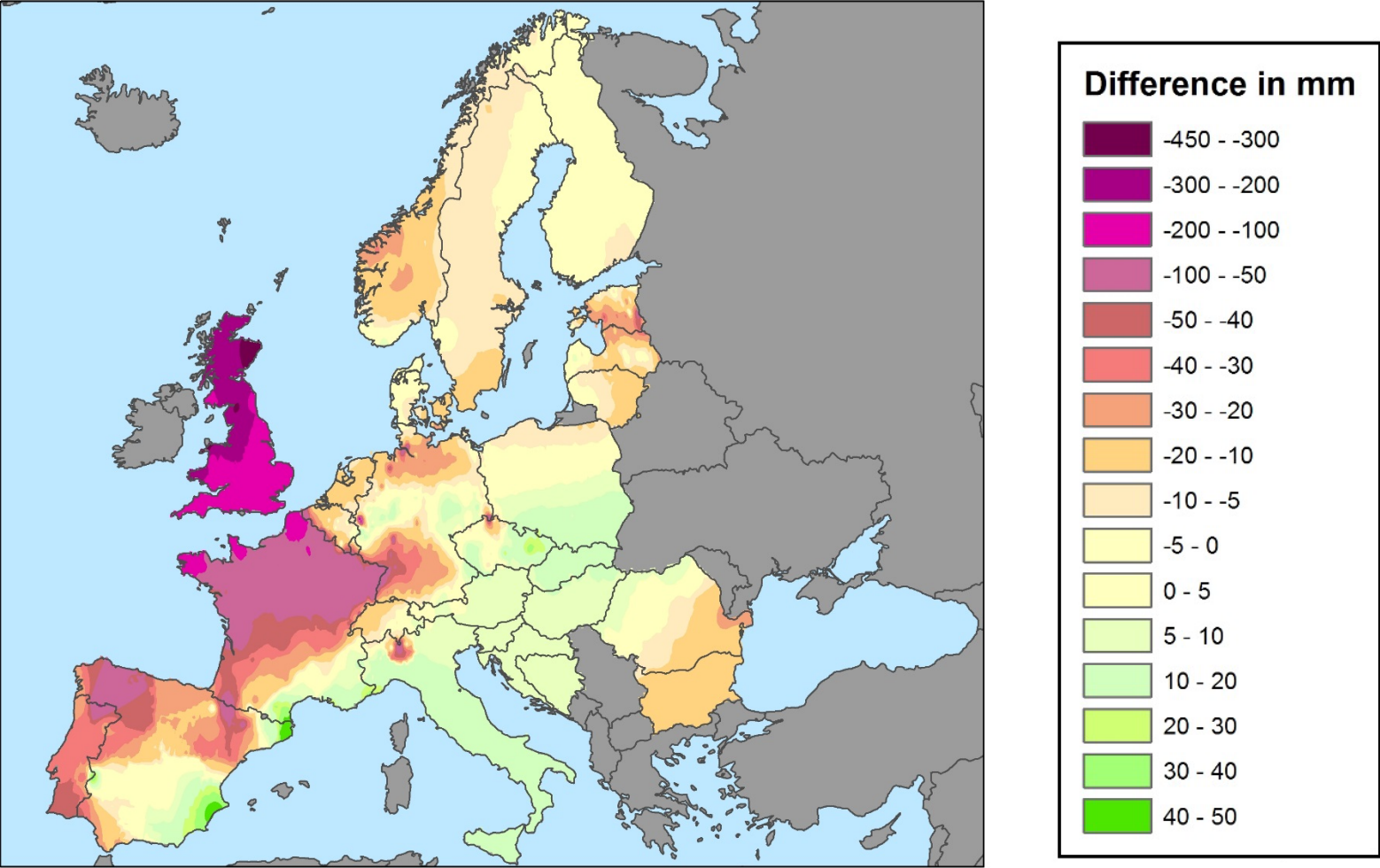
# Age of the data in UELN



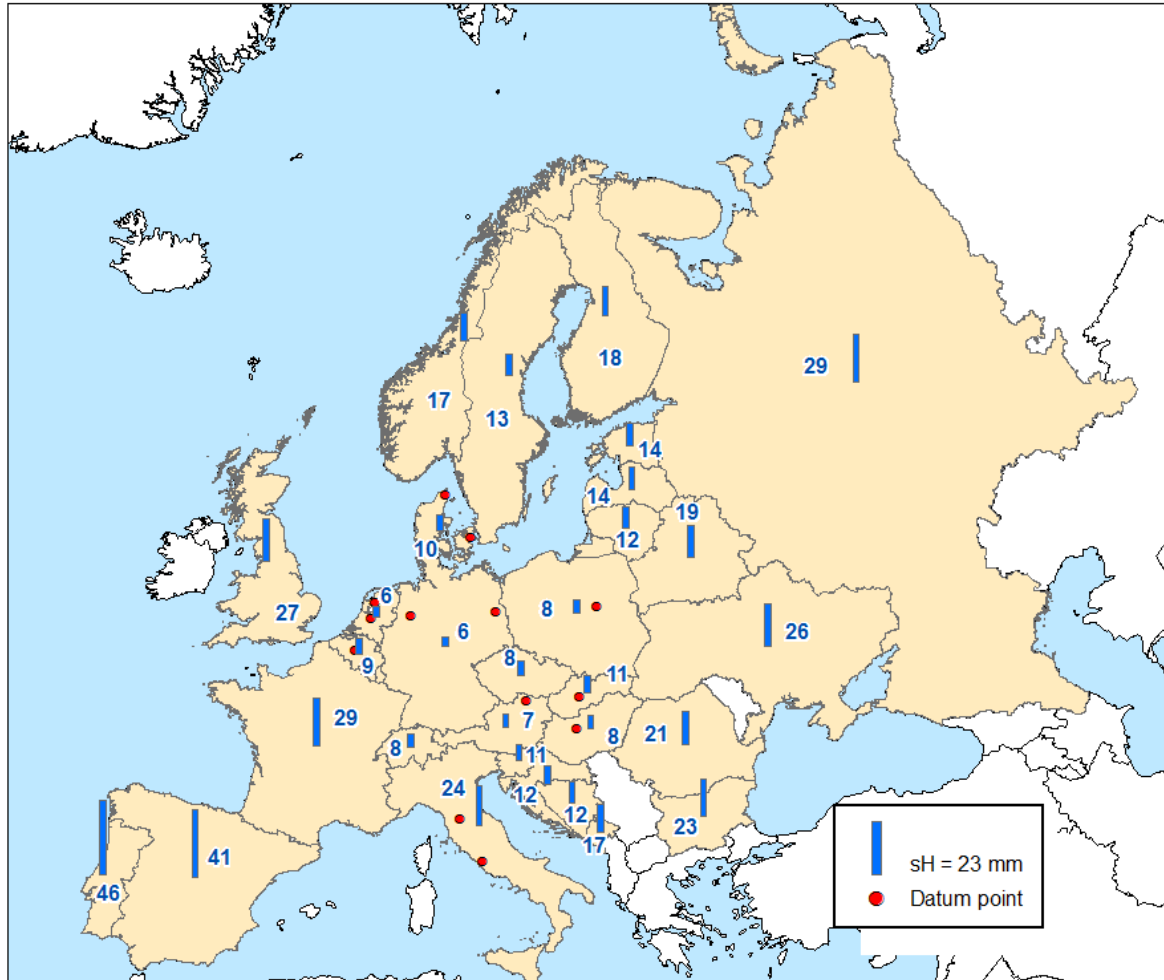
# Development of the network - Selected examples

- Extension of UELN to [Russia](#) (2012)
- Addition of a zero order network [NIREF](#) in France (2015)
  - Measured between 1983 and 2014
  - Tilt in IGN69 had been suspected in France since 1971
  - New observations show tilt between IGN69 and NIREF of 23 cm in N-S direction
- Addition of the measurement through the EURO tunnel: better [connection to Great Britain](#) (2015)
  - Up to 2015 connection GB-FR only by hydro-dynamical leveling
  - Measurements through Channel Tunnel 1994, 51km, 789 benchmarks
  - At the French end the tunnel line is connected only with NIREF network
  - Including of NIREF made it possible to include tunnel line

# Differences between EVRF2007 and preliminary solution 2018



# Standard deviation of the adjusted heights



- $S_H$  refers to the datum of the network
- Test adjustment with datum points in Spain and Portugal gives similar magnitude of  $S_H$  in that countries
- Reason: error propagation
- Network parts with large  $S_{\Delta h}$  are at the margins of the UELN

# Next realization of EVRS (1)

- New data of 15 countries
- Computation of the heights for Great Britain
  - $U_{ELN}(GB) = H(ODN) + \text{offset}$
  - Offset computed from adjustment+ tunnel measurement
  - Offset from adjustment 04/2018: -0,166m
- [New uplift model](#) for the Nordic countries  
NKG2016LU\_lev
  - Application to the data of  
BY, DK, EE, FI, LT, LV, NO, RU, SE
- Reduce of the Swiss measurements to a common epoch by velocities of [Swiss uplift model](#)

# Next realization of EVRS (2)

- Providing heights at a reference epoch (2000) + point velocities
- Tidal system
  - EVRF2007 in zero tide system according to **IAG resolution No. 16** adopted in **Hamburg 1983** and according to the EVRS definition
  - **IAG resolution No. 1** adopted in **Prague 2015** resolves mean tide for an International Height System
  - Users expect conformance of heights with mean sea level → mean tide
  - Providing mean tide additionally
- Release of the next realization of EVRS planned for 2019



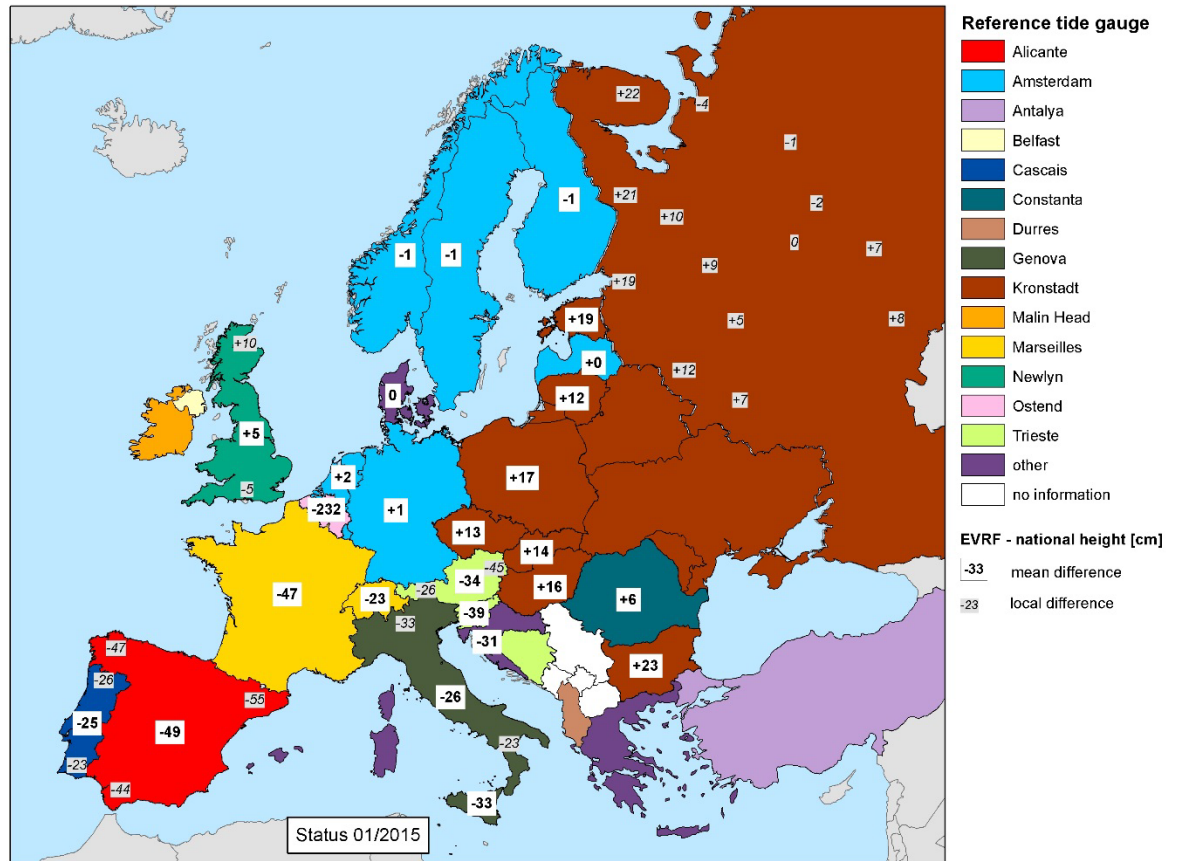
# Application of EVRS

- INSPIRE:
  - For the vertical component on land, the EVRS shall be used to express gravity related heights within its geographical scope
  - Other vertical reference systems related to the Earth gravity field shall be used ... in areas that are outside the geographical scope of EVRS
- National vertical reference systems can still be used
- Direct use of points (1. order) with heights in EVRF2007
  - Adjusted heights of the whole network of EVRF2007 were handed over to all participating countries (excepted Bosnia/ Hercegovina)
- Use of transformation parameters
  - <http://www.crs-geo.eu>
  - Future: transformation grid

# Information system about Coordinate Reference Systems in Europe <http://www.crs-geo.eu>

## Part for height:

- Description of height reference systems in Europe
- transformation parameters from national height reference frame to EVRF2007
  - Translation
  - Slope in N-S
  - Slope in E-W



# CRS-EU Online-transformation - Heights

DE\_AMST / NH to EVRF2007

## Source

national height

DE\_AMST / NH [m]   
(DHHN92 EPSG code: 5783)

## ETRS89 position of point

Latitude [DMS]     
Longitude [DMS]     
Longitude wrt Greenwich and positive to East

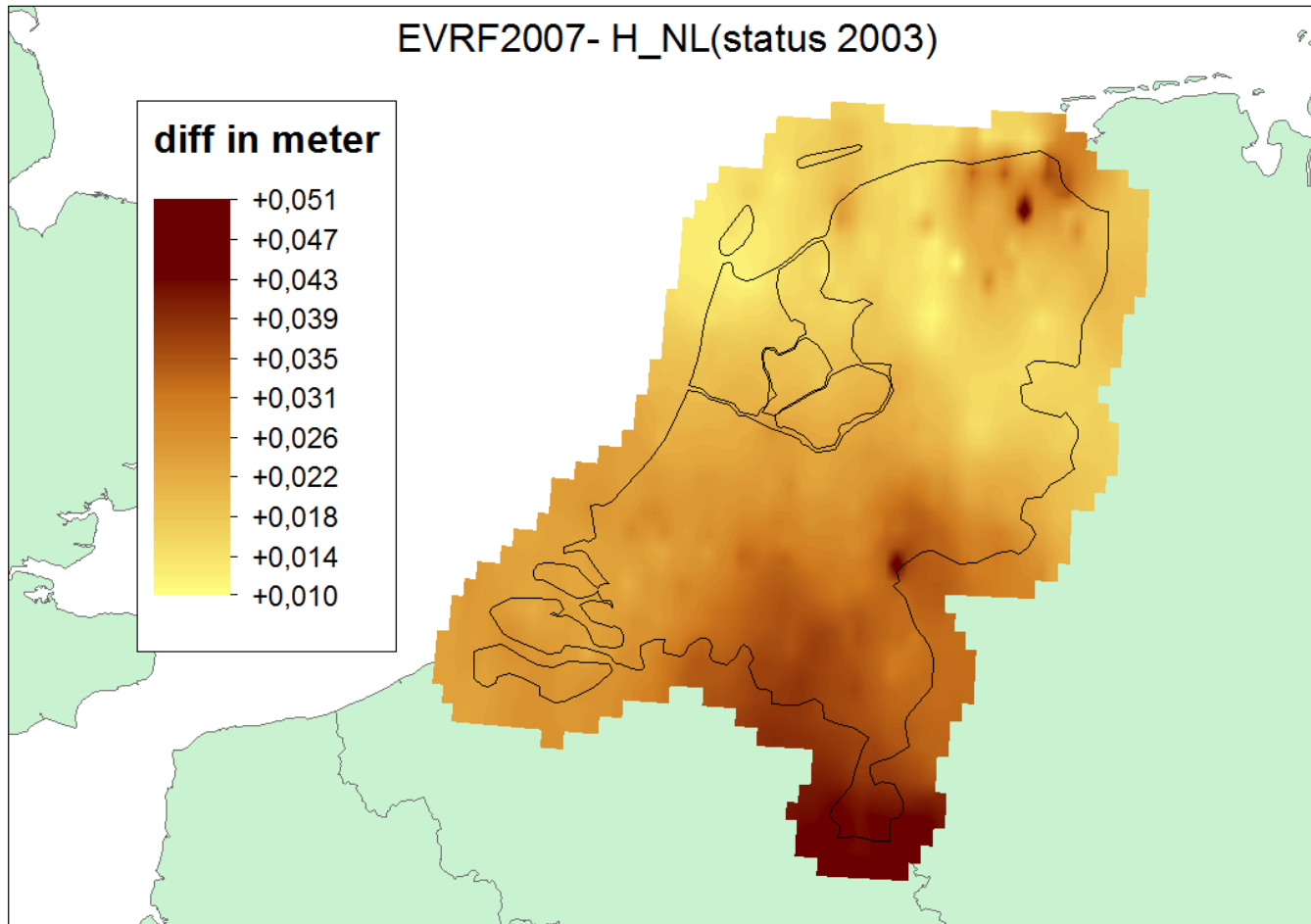
## Target

pan-European height

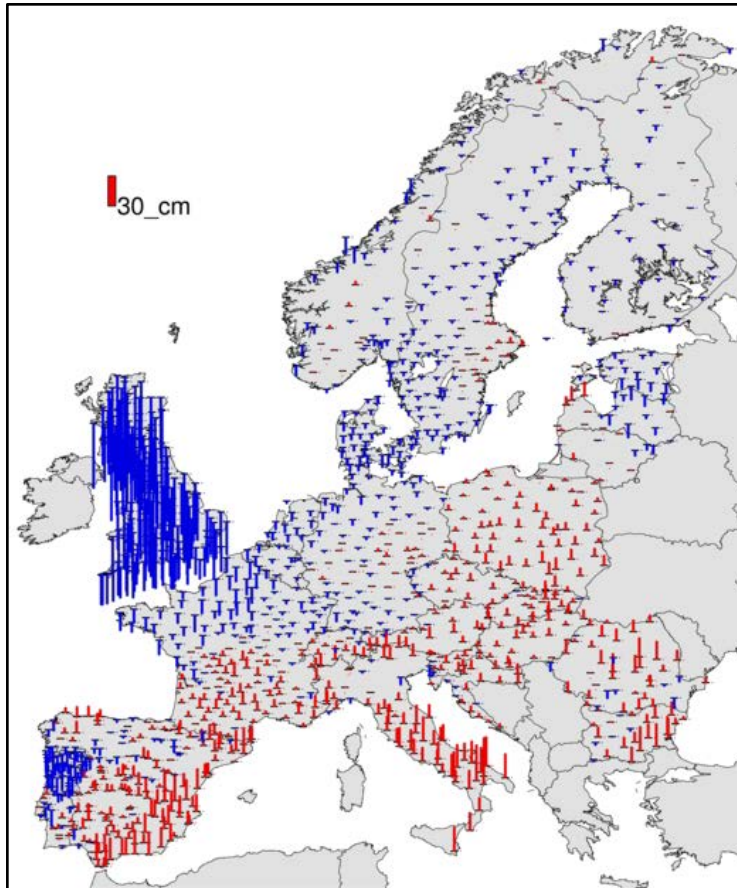
EVRF2007 [m]  RMS of transf. [m]

Compute

# Planned for next EVRF: providing a transformation grid



# Forecast to the future



Height anomaly differences of EUVN\_DA and EGG08.

- Update and improvement of EUVN\_DA (**EUVN** Densification Action): 1400 European GNSS/leveling points
- Computation of a correction surface to a European quasi-geoid model
- Computation of physical heights from GNSS measurements + European quasi-geoid model
- Possibility to provide heights in EVRS for islands and European areas outside UELN

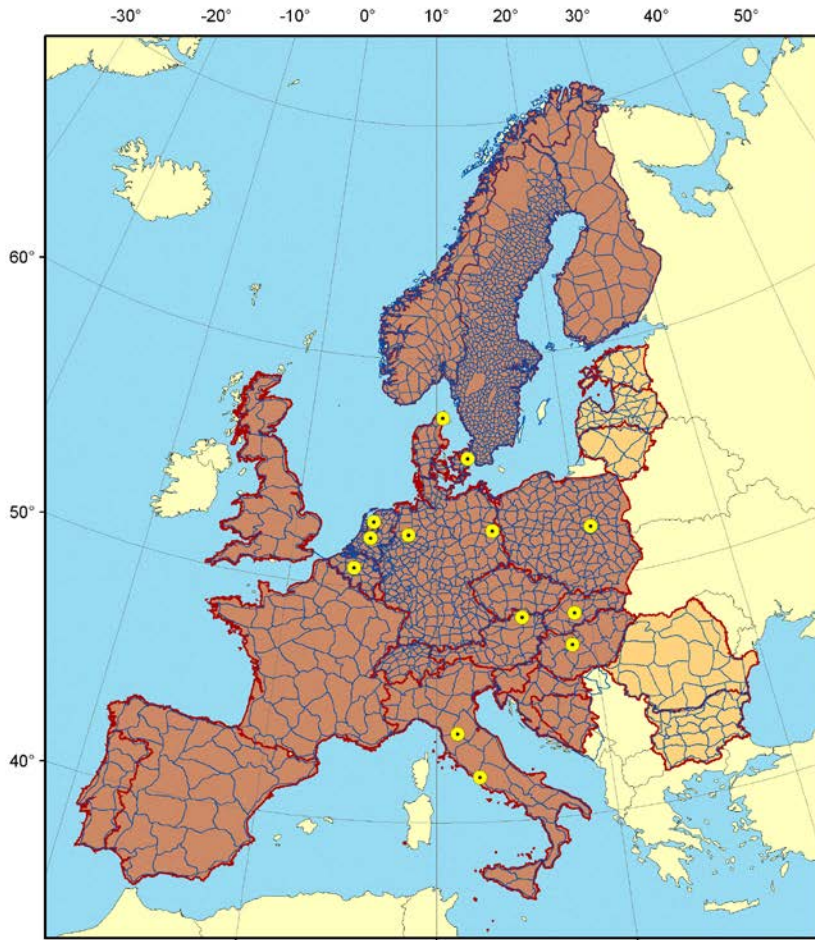
# Thank you for your kind attention!

## Contact:

Federal Agency for Cartography and Geodesy  
Section Integrated Spatial Reference  
Karl-Rothe-Str. 10-14  
04105 Leipzig, Germany

contact person  
Martina Sacher  
martina.sacher@bkg.bund.de  
www.bkg.bund.de  
Tel. +49 (0) 341 5634 423

# Datum points of EVRF2007



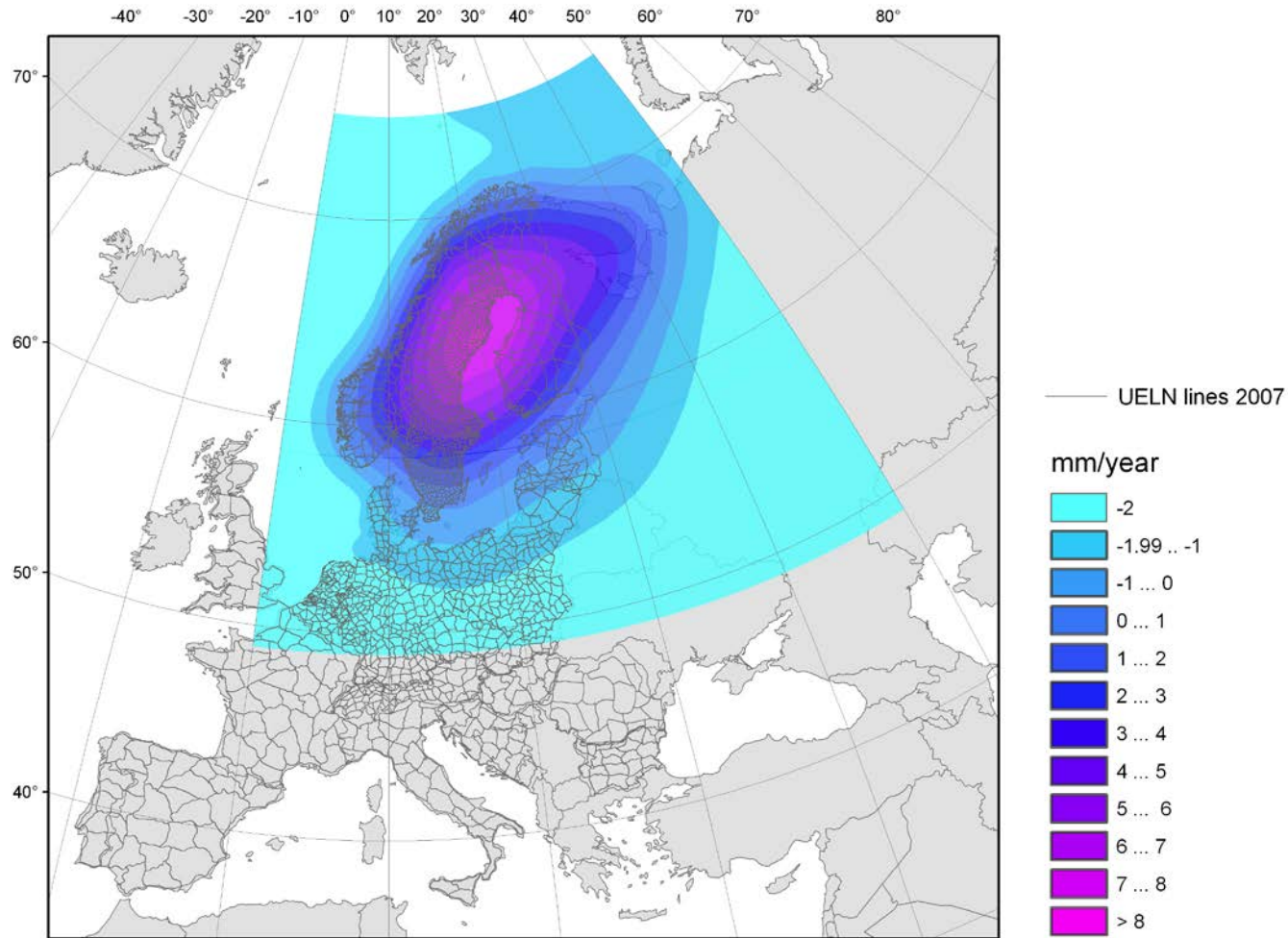
$$\sum_{i=1}^{13} (c_{UELN\ 95/98} - c_{EVRS\ 2007}) = 0$$

• Datum points of EVRF2007

**Extension of UELN**

- up to 1998
- as from 2003
- UELN lines

# NKG2005LU



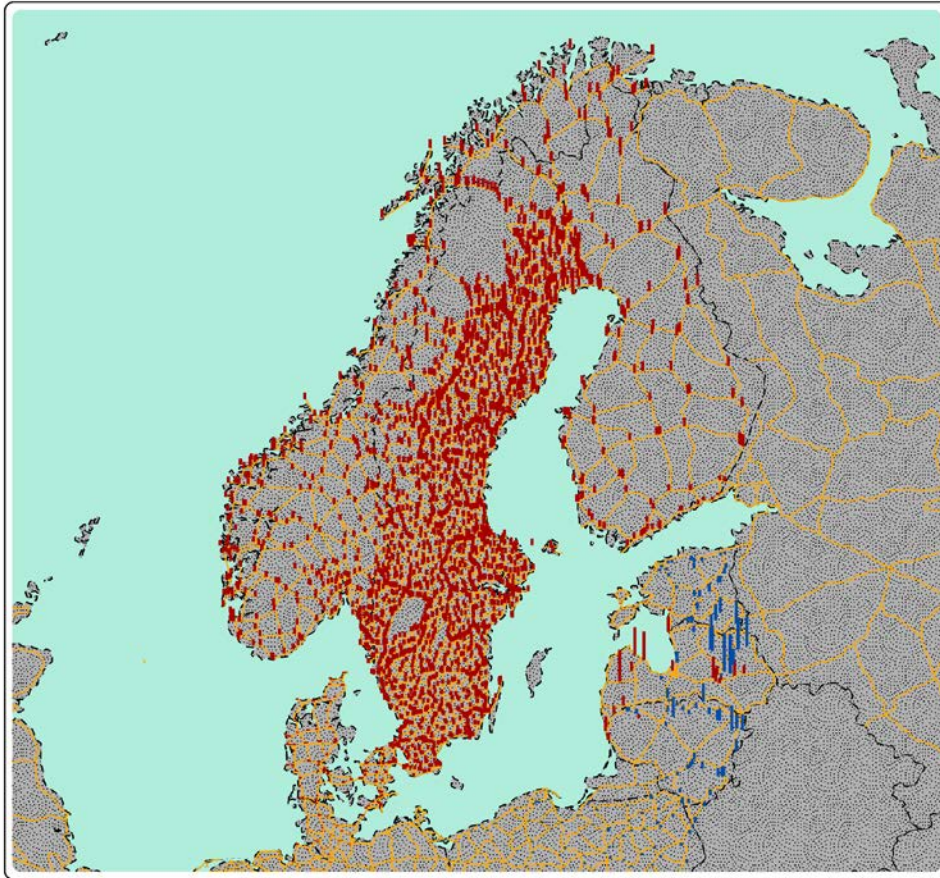


# Loop around the Baltic Sea



- 358 lines from DK, SE, FI, RU, EE, LV, LT, PL, DE reduced to epoch 2000 (by NKG2005LU)
  - Perimeter **7052 km**, loop misclosure **45.5 kgal·mm**
  - permissible value: 168 mm (164.6 kgal·mm)
- Computed by  $Z_U = \pm 2 \cdot \sqrt{U}$   
( $Z_U$  in mm,  $U$  perimeter in km):

# Height variations to EVRF2007 in the neighboring countries of Russia

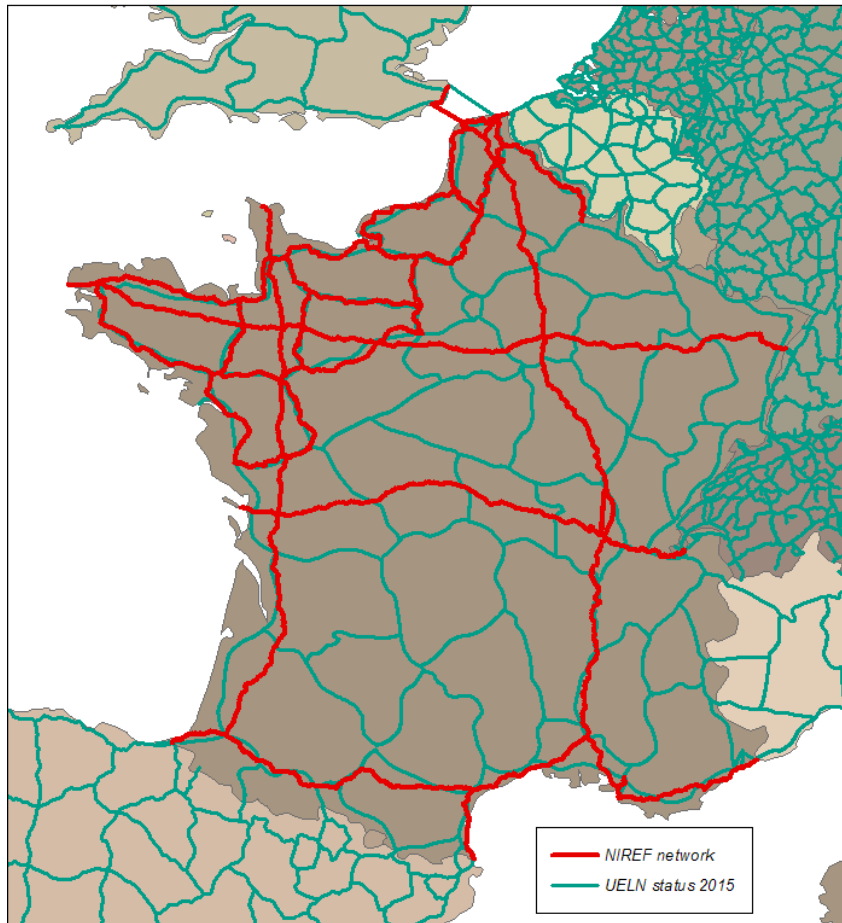


- Misclosures of cross-border loops influence mainly the network with the larger variance!
- Variance component estimation - standard dev. /variance factor:
  - SE: 1,00/ 1,00
  - FI: 0,74/ 0,54
  - RU: 2,26/ **5,11**
  - EE: 1,22/ 1,49
  - LV: 0,77/ 0,59
  - LT: 0,83/ 0,69

# Comparison NAP - Kronstadt

- point “Kronstadt” is Datum point in the Russian system with  $H=0.000$  m
- Adjustment of EVRF2007 + Russian data:  
 $H_{\text{zero}}$  (Kronstadt) = 0.182 m,  $s_H = 0.022$  m
- Conversion to mean tidal system  
 $H_{\text{mean}}$  (Kronstadt) = **0.146 m**
- 2 Vertical Coordinate Reference Systems in Eastern Germany – possibility of comparison:
  - SNN76 (related to Kronstadt by measurements from the 50s)
  - DHHN92 (related to NAP by UELN73/86)
  - **Mean Difference: 0.142 m**

# Connection of IGN69 and NIREF in UELN

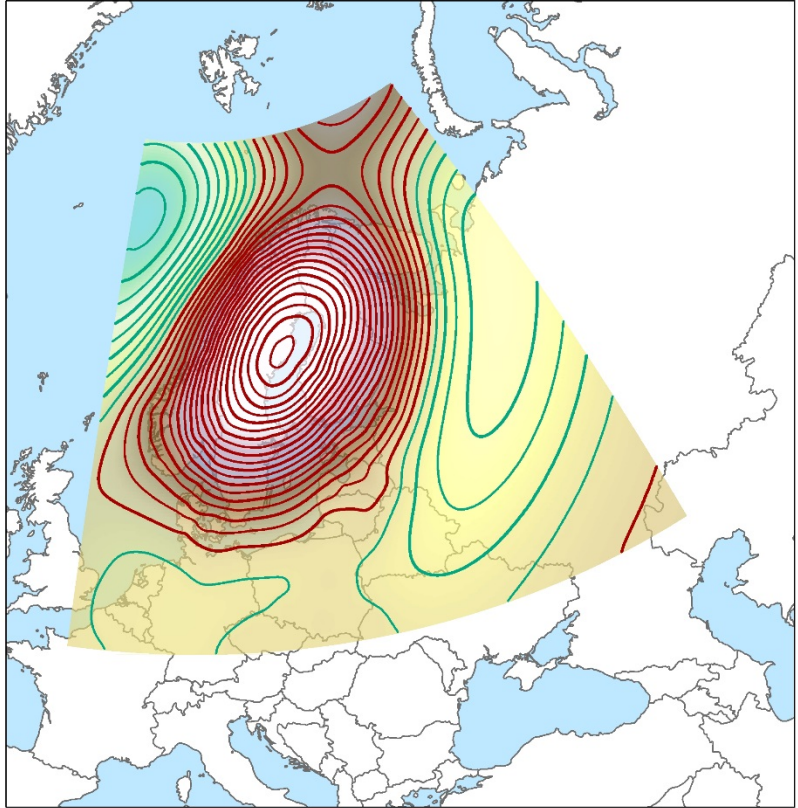


- 37 identical points were used for combination of the networks
- Common adjustment with variance component estimation:
  - IGN69: 3.83mm/km
  - NIREF: 1.26mm/km
- IGN69 is affected by systematic errors –they are not fully be considered in results of variance component estimation
- Answer: Including of IGN69 with very low weights (original variances were multiplied by factor 100)

# Results for Great Britain

- Height changes of the point G4868 (Dover) after including NIREF and the measurement through the Channel Tunnel:
  - $H_{GB}$  (ODN) 6.821m
  - $H_{EVRF2007}$  6.819m
  - $H_{UELN2018}$  6.655m
- UELN2018-EVRF2007 in Dover: -0.164m
  - caused by including NIREF (tilt of IGN69)  $\approx$  -0.09m
  - caused by connection through the tunnel  $\approx$  -0.05m
  - caused by including new data of Belgium (2018)  $\approx$  -0.025m
- **Offset  $H_{GB}$  (ODN) to UELN2018: -0.166m**
- System difference between FR-GB (at the Channel coast)
  - NIREF-ODN: 0.28 m
  - **IGN69-ODN: 0.47 m**

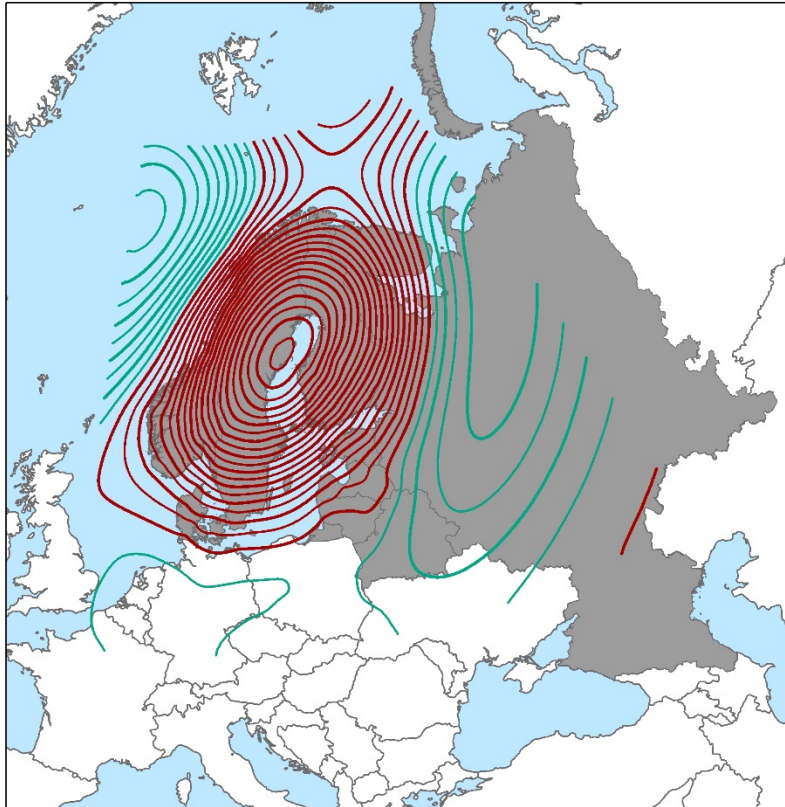
# New uplift model for the Nordic countries: NKG2016LU\_lev



contour lines  
at intervals of 0,5 mm/y

- NKG2016LU\_lev (pos.)
- NKG2016LU\_lev (neg.)

# National networks that are reduced to a common epoch

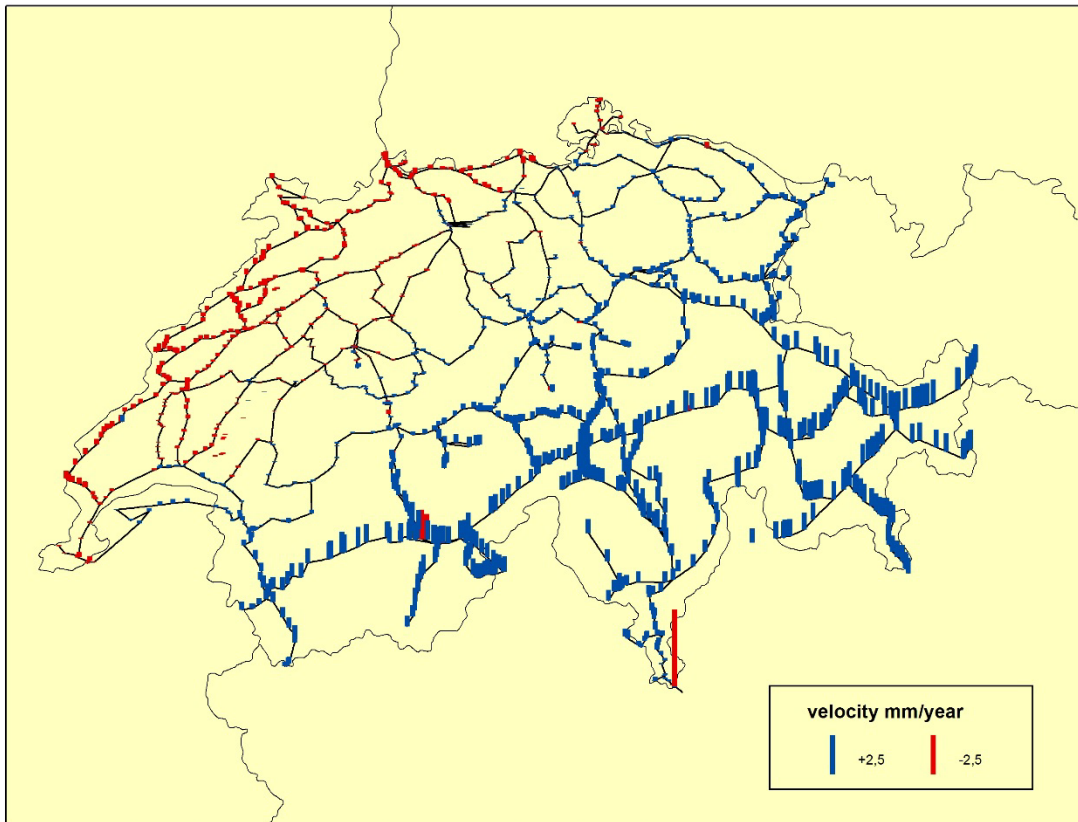


Reduce of observations in other countries at the margin of the model (NL, DE, PL) results in an increase of the standard deviation after adjustment.

contour lines  
at intervals of 0,5 mm/y

- NKG2016LU\_lev (pos.)
- NKG2016LU\_lev (neg.)
- reduced to epoch 2000

# Consideration of the vertical velocities of the Swiss points



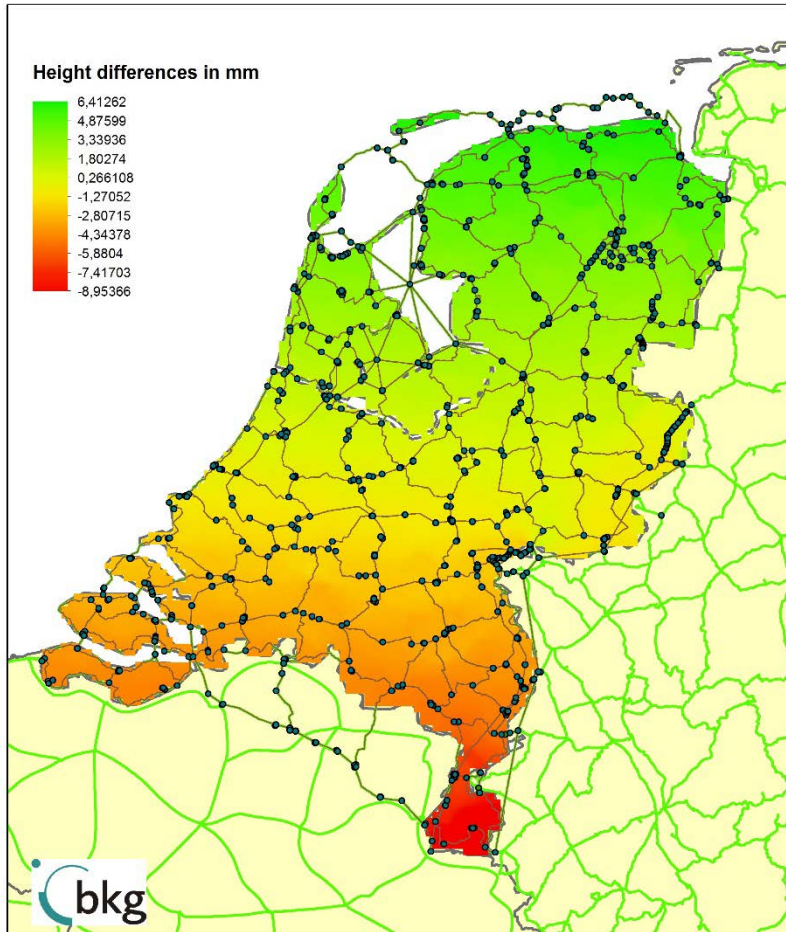
- Velocities from dataset UELN2015
- Graphic shows all points in UELN adjustment – including any instable points
- A posteriori - Standard deviation from adjustment CH in kgal-mm:
  - Static: 1,09
  - Kinematic : 0,86

**Velocities from:**  
**CHVRF15/UELN15**

Bundesamt für Landestopografie swisstopo  
Bereich Vermessung  
Dr. Andreas Schlatter / Dr. Urs Marti

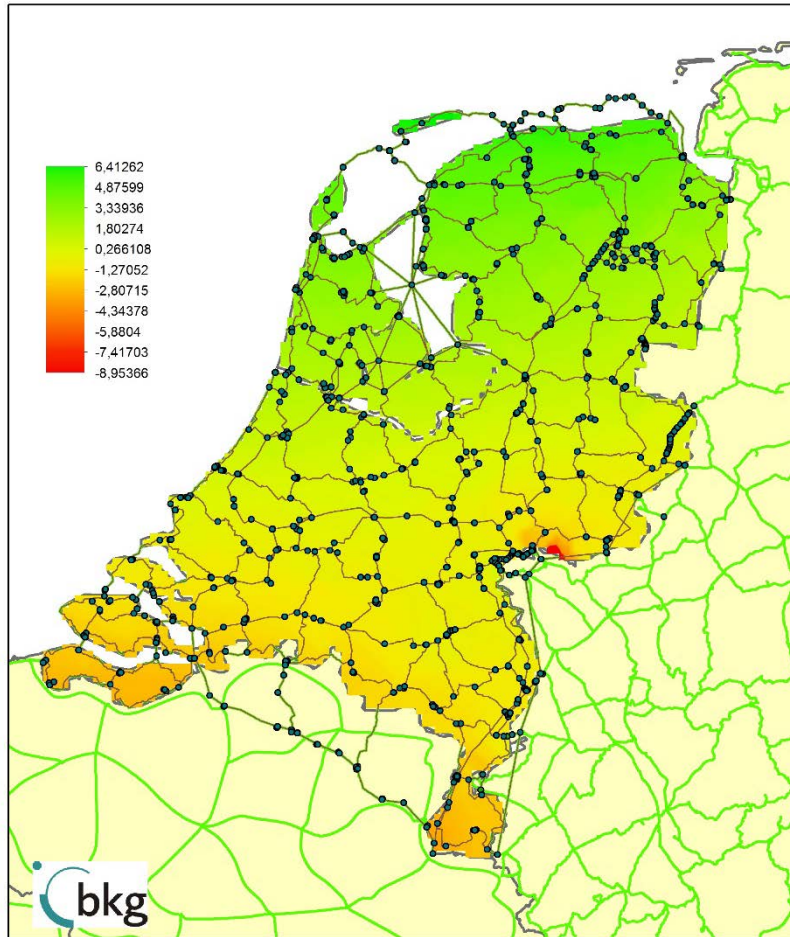


# Adjustment UELN data as in EVRF2007: Data of NL(new)- NL(old)



- 1.order leveling data of NL (1996-1999) had been delivered to BKG in 2003
- 2016 update of these data
- Measured height differences identical
- changes of geopotential differences between  $-2\text{kgal}\cdot\text{mm}$  and  $+2\text{kgal}\cdot\text{mm}$
- Reason: different gravity values
- New adjustment with the same data as in EVRF2007 for the neighboring countries
- Height Differences  $-9.1\text{mm}$  to  $+6.9\text{mm}$

# Adjustment UELN data status 2016 – Data NL(new)-NL(old)



- Results after including of new leveling data of Germany (2006-2012)
- Some long lines of the Dutch network running across Germany were deleted, because there are more recent German data available
- Height Differences -6.7mm to +5.8mm