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Cartography and Geodesy

The geodetic infrastructure for height determination in Germany

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Organization and responsibilities for surveying and mapping in Germany

- Shared responsibilities for Surveying and mapping because of the federal structure of Germany
- 16 Federal states responsible for official surveying and mapping, each with its own legal foundations and different resources
- Tasks of BKG have been determined in federal law, e.g.
  - geodetic reference systems and frames in Germany
  - connection between German, European and international reference frames and systems
- Cooperation of the federal states and BKG is coordinated by AdV (Working Committee of the Surveying Authorities of the Laender of the Federal Republic of Germany)
- Guidelines for the uniform integrated geodetic spatial reference for Germany (2006, 2014) are one result of this cooperation

Description of the Guidelines

- Official reference systems in Germany
- Their realizations (first order networks)
- The 4 different kinds of benchmarks and networks
  - Fundamental survey marker (GNSS, leveling and gravity measurements)
  - Height benchmarks (leveling)
  - Gravity benchmarks (absolute or relative gravity observations)
  - Permanent GNSS reference stations (basis for positioning service)
  - For each of these types of benchmarks and networks
    - Definition and purpose
    - Density of the benchmarks in the networks
    - Design of the survey marker and number of control points
    - Precision of the coordinates
    - Intervals for inspection and regional re-measurements
    - cycles for the resurvey of the entire network
- The height reference surface (quasi-geoid)

Integrated geodetic spatial reference

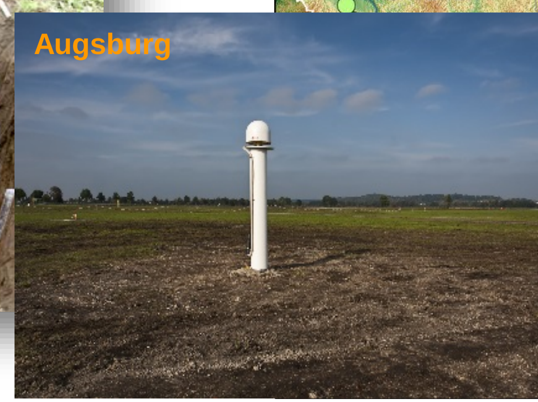
- consistent approach of geometric (positioning) and physical (height and gravity) components of geodetic spatial reference
- Essential for the determination of the height reference surface (quasi-geoid) and GNSS heighting
- **Fundamental survey marker**: long-term stability of the monuments; optimal conditions for GNSS and gravity observations; connection to the first order levelling network (no permanent reference stations on roofs !)





GREF - Integrated Geodetic Reference network of Germany

- BKG´s permanent reference station network
- Construction of the network since the mid-90s
- Long-term stable pillars made of concrete or steel
- depth of the foundation up to 15m depending on the geological conditions at the station
- Protection against environmental influences



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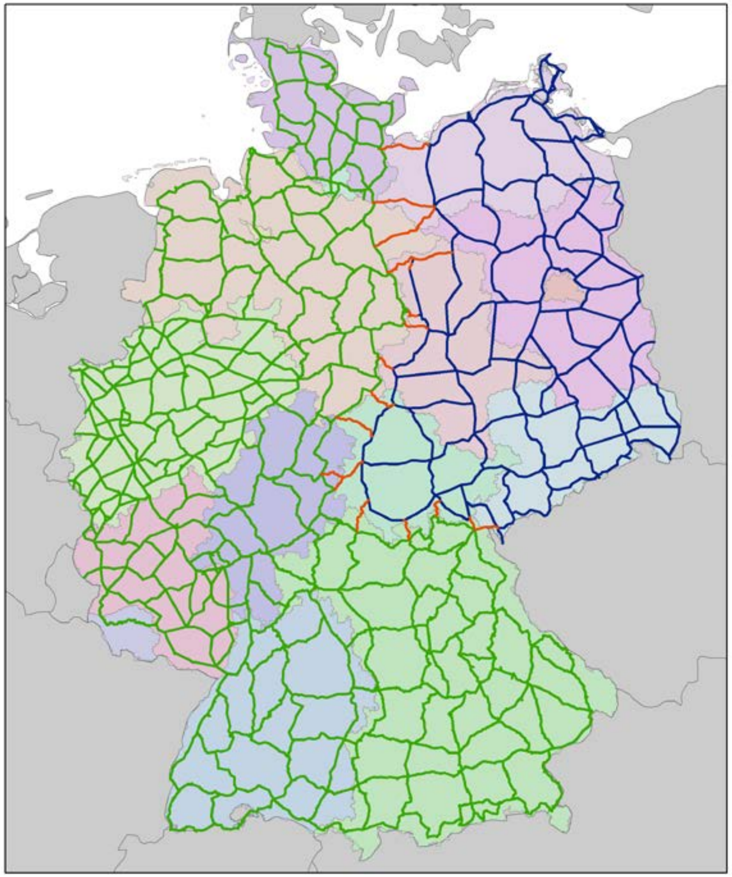
Reference systems and frames in Germany

1. Spatial reference
   - Reference system: ETRS89 (GRS80, non tide)
   - First realization: ETRF91 official name ETRS89/DREF91 (1994)
   - Current realization: ETRS89/DREF91(2002)
2. Physical Heights
   - Datum: Normaal Amsterdams Peil (NAP)
   - Kind: normal heights, GRS80
   - Permanent solid earth tide correction: no corrections applied (mean tide)
   - Current realization: DHHN92 (measurements 1974 – 1992)
3. Gravity
   - Absolute gravity measurements
   - Permanent solid earth tide correction: zero tide
   - Current realization: DSGN94, DHSN96

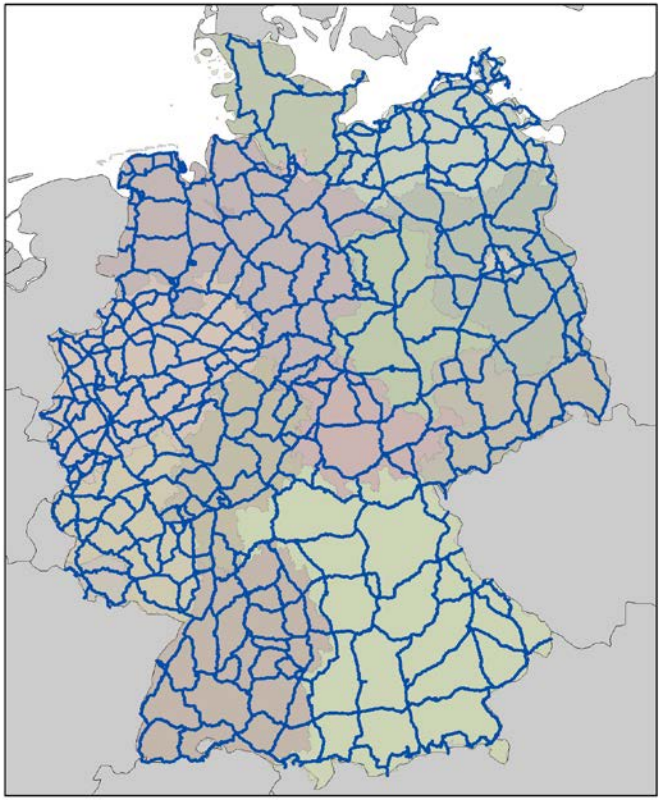
Modernization of the German height reference frame - motivation



Parts of DHHN92

- Current network DHHN92 is compounded by 3 networks from different epochs (East:1974-1982, West: 1977-1988, connection measurements 1990-1992)
- In 2000 levelings about 30 years old
- Point damage 3-5% per year
- height variations because of mining (coal, gas, salt)
- 2002: first considerations about the modernization of the German height reference frame
- 2002-2005: planning stage (overall concept; guidelines describing the technology of the different observation techniques; error margins; total cost estimate; …)

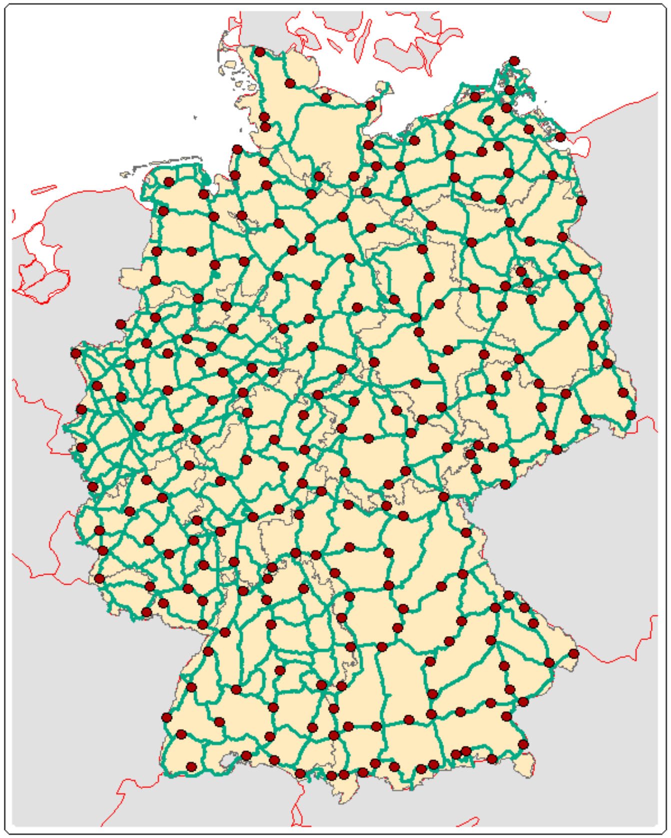
Modernization of the German height reference frame - objectives



Design of the new network

- Investigation and modernization of the height reference frame
- Detection of height variations and network strains
- improvement of German quasigeoid, improved possibility of height determination with GNSS methods and SAPOS®
- Integration of geometric and physical components of the spatial reference

Modernization of the German height reference frame – network configuration



- leveling, GNSS and gravity (mostly absolute) measurements on 250 identical points
- GNSS observation campaign in May/June 2008 (middle of levelling epoch, period of low solar activity)
- 2 X 24 h observation
- 250 stations are the backbone of the Geodetic Fundamental Network

Leveling lines epoch 2006-2012

Stations of the GNSS campaign 2008

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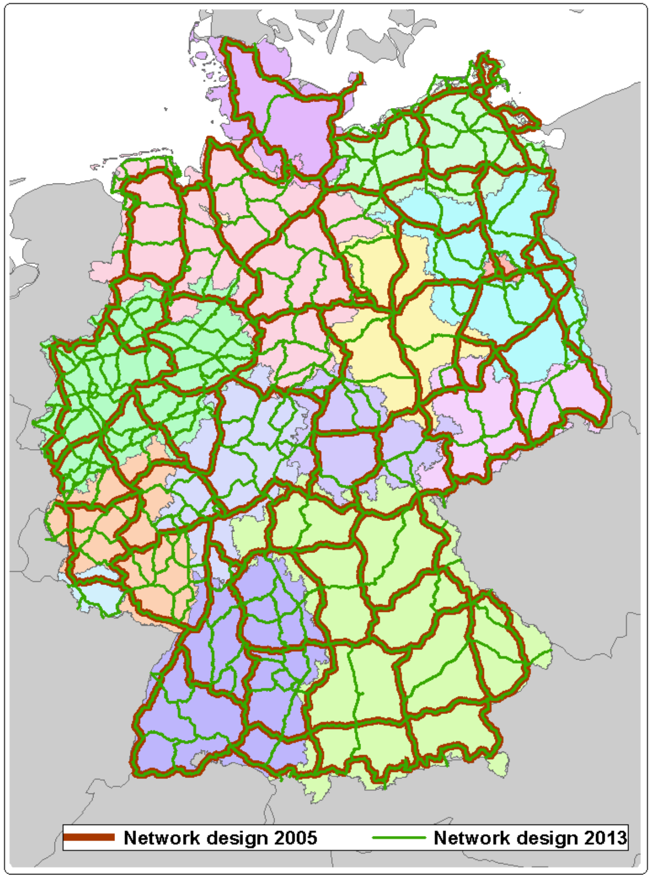
New German height reference frame – Standards and conventions for the German Height System and its realization

Specification	New realization (DHHN2016)	Current realization (DHHN92)
datum	**NAP**	
scale	**SI - Meter**	
realization of the scale	rod scale and temperature correction, determined by vertical comparator	rod scale and temperature correction
adjustment	free	
realization of the datum	72 points (7 underground benchmarks + 62 GNSS+ 3 ref. stations)	1 point
heights of the datum points	heights from DHHN92, no velocity supposed	geopotential number from UELN 73/86, no velocity supposed
physical parameter	**normal gravity field of GRS80**	
kind of heights	**normal heights**	
tidal effects	**mean tide**, variable part eliminated	**mean tide**, variable part not eliminated
ocean load effects	eliminated (in Northern Germany)	not eliminated

New German height reference frame DHHN2016 – statistical data



Final network design in comparison to the original draft

- Total length of leveling lines: 29 809 km (113% of DHHN92)
- only 14 000 km originally planned
- Measurements between 2006 and 2012
- 2 computing centers with different software and approaches (adjustment of geopotential numbers or normal heights)

Parameters of the adjustment

Parameter	*DHHN92 (without observations of neighboring countries)*	DHHN2016
Number of lines	*672*	991
Number of nodal points	*422*	680
Number of unknowns	*423*	680
Number of datum points	*1*	72
Degrees of freedom	*250*	311
s_0 **of 1 km leveling**	*0.86 mm*	0.64 mm
$s_{\Delta h}$ **of height differences (mean of all lines)**	*4.15 mm*	2.65 mm
s_H **of adjusted heights (minimum)**	*0.79 mm*	3.43 mm
s_H **of adjusted heights (Maximum)**	*11.13 mm*	8.14 mm
s_H **of adjusted heights (mean)**	*7.27 mm*	4.84 mm
Length of overall loop	*4743 km*	5350 km
Closing error of overall loop/ permissible value	*138.3 mm / 137.7mm*	-13.7 mm/ 146.3mm

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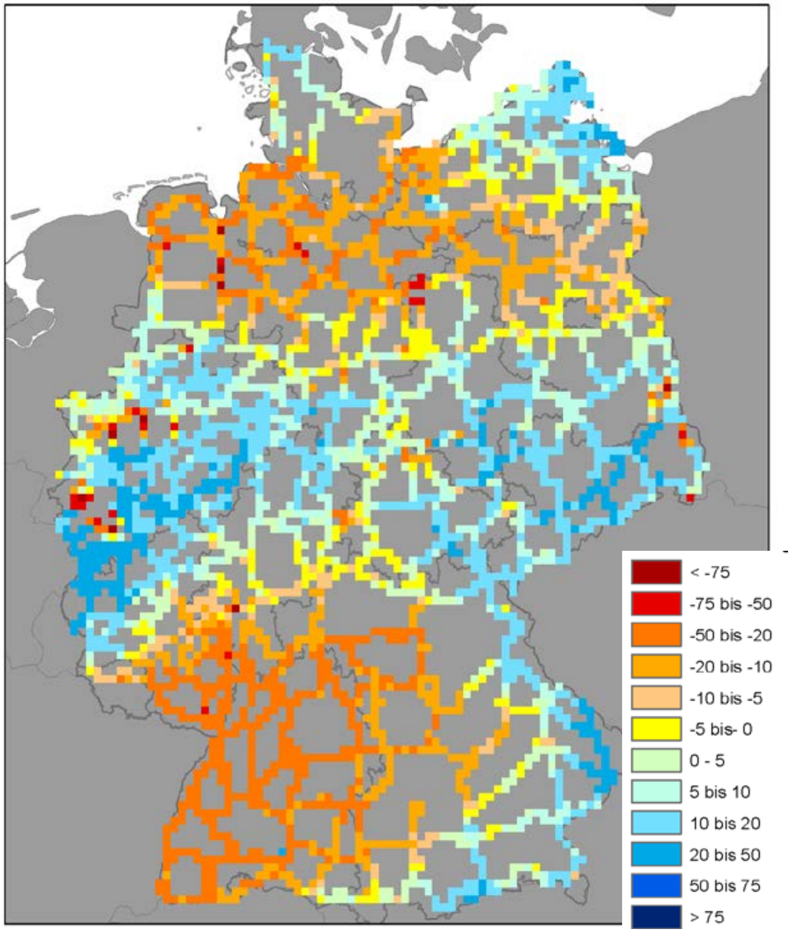
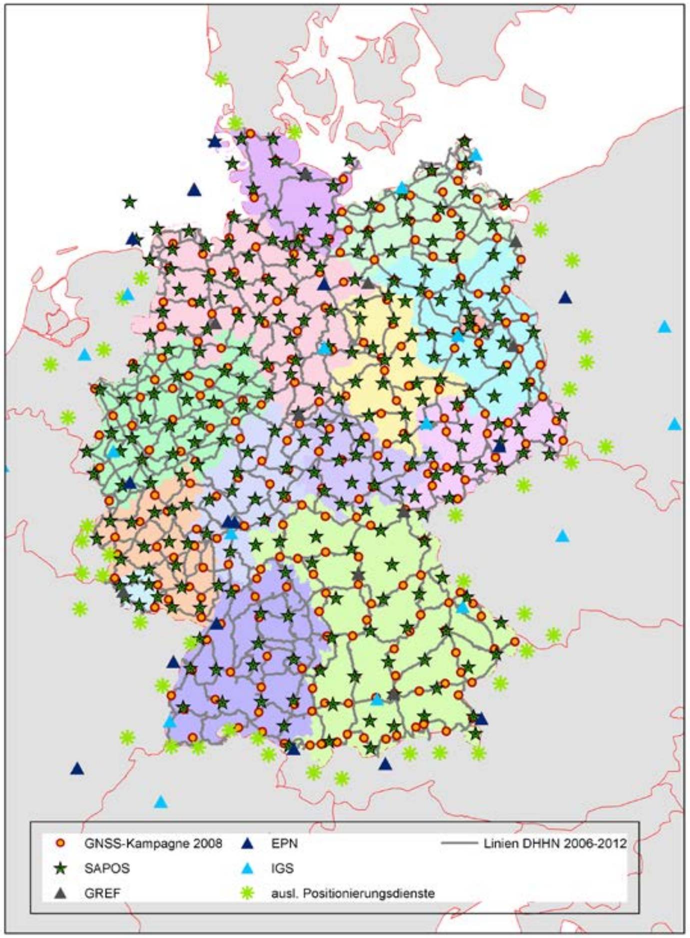
Height differences in mm between DHHN2016 and DHHN92



- Blue: uplift, Red: subsidence
- Maximum of height differences between -35mm and +33mm (besides of single height changes in mining areas)
- Interpretation is pending
- In the north-east (island of Rügen): assumed uplift because of postglacial rebound
- Uplift in the Eifel and Taunus region (Rhenish Slate Mountains) is well-known by geologists
- In some areas (south-East) differences go into reverse by comparison of older epochs (1985-1960)

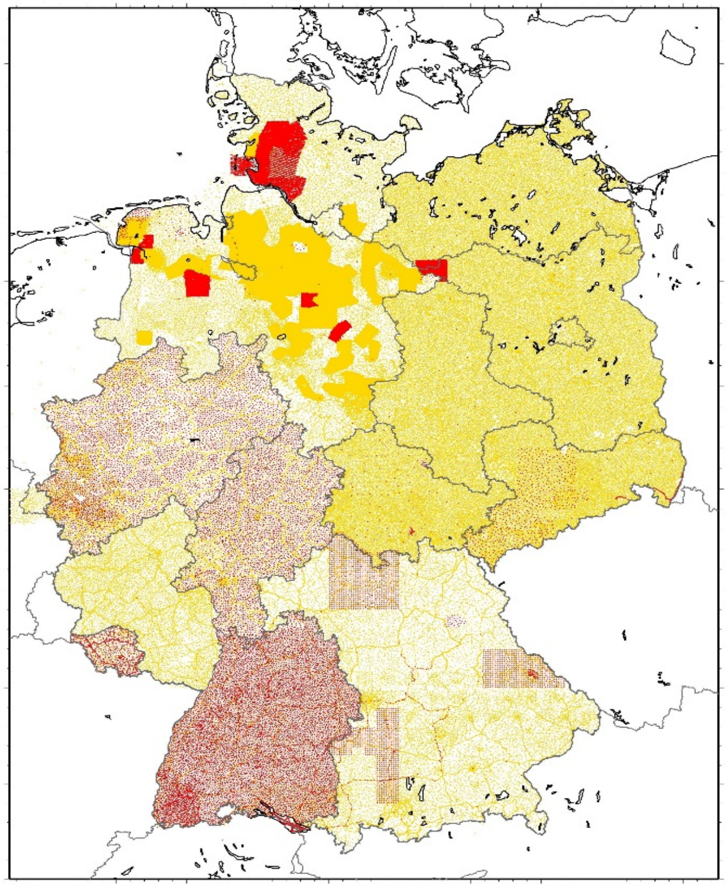
GNSS-Campaign 2008



- 600 stations involved
  - 250 fundamental survey markers
  - 272 stations of the positioning service SA*POS*®
  - 34 reference stations of IGS/EPN/GREF
  - 44 stations of positioning services of neighboring countries
- 2 computing centers
  - BKG (Bernese 5.0)
  - LGLN Lower Saxony (GNSMART 1.4)
- Precision: Position <1mm, height 2-3mm
- Adjustment without constrains (orbits IGS2005)
- Transformation into ITRF2005
- Transformation into ETRF2000 (memo 8)
- 3 Parameter (Rotation) Transformation into ETRS89/DREF91 (2016)

New quasigeoid model

- New gravity data
  - In Germany (red points in figure) from the German states
  - Data exchange with neighboring countries, e.g. Czech Republic, Netherlands, Belgium
  - Data from International Gravimetric Bureau (BGI), e.g. France, North Sea
  - Oil industry
  - measurements of BKG in cooperation with several partner
- New digital elevation model
  - Germany (DGM25)
  - Bathymetric data of Lake Constance
- Improvement of the software for terrain corrections and geoid modelling



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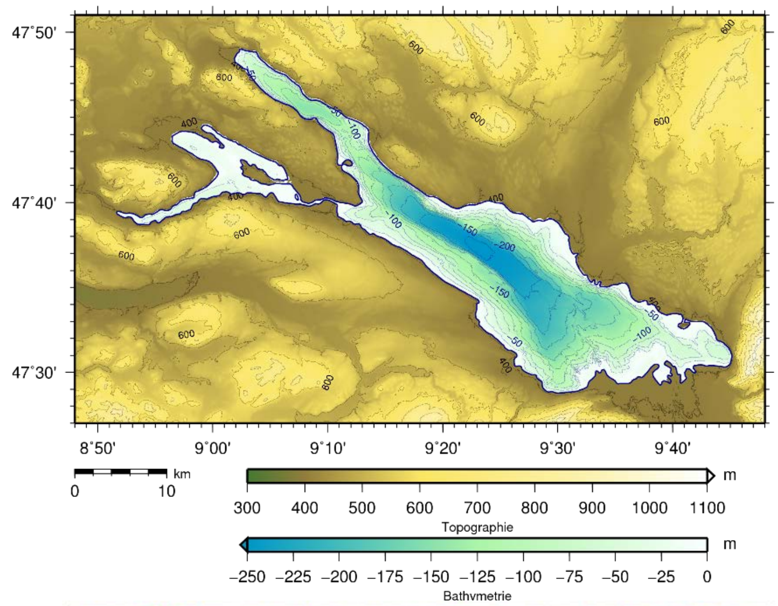
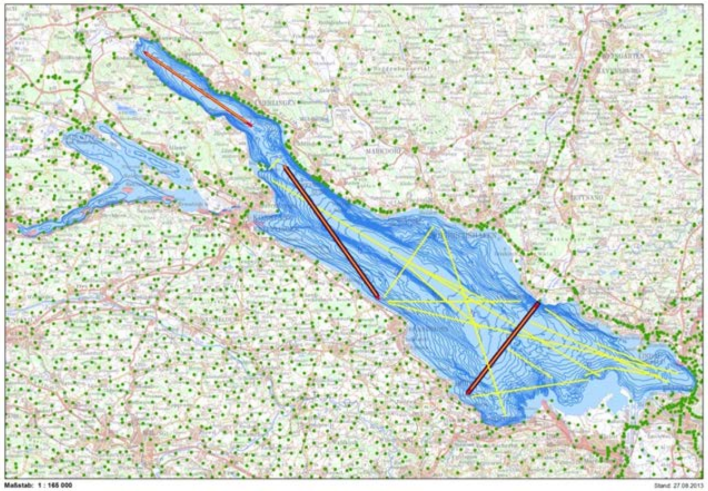
Example I: Lake Constance

- Depth of the lake of up to 250m was neglected in geoid modelling so far
- Larger differences between gravimetric geoid and GNSS/Levelling data over the lake and in the vicinity of the lake (up to 10cm)
- 2012: Gravimetric measurements on the lake in Cooperation with Geoforschungszentrum Potsdam (GFZ) and the Institut für Seenforschung Langenargen (ISF)
- Total profile length: 320 km within 3 days





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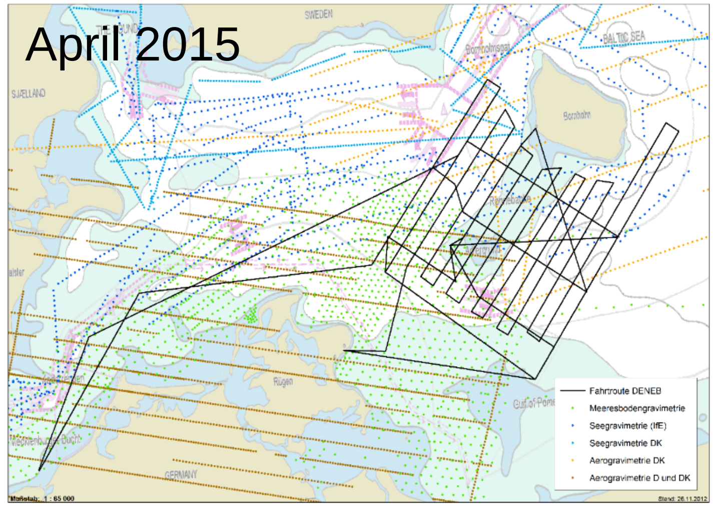
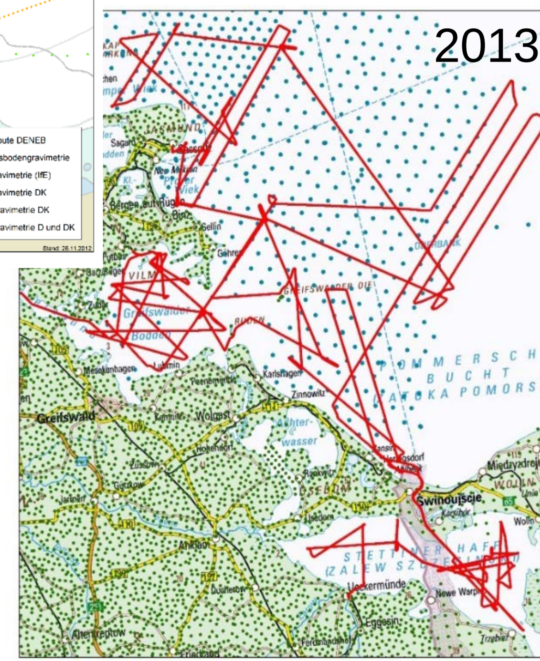
Example II: Seaborne gravity measurements in the Baltic Sea and the North Sea

2013: Baltic Sea,
10 days, 1500 km
2015 (April): Baltic Sea
10 days, 1600 km
2015 (June): North Sea

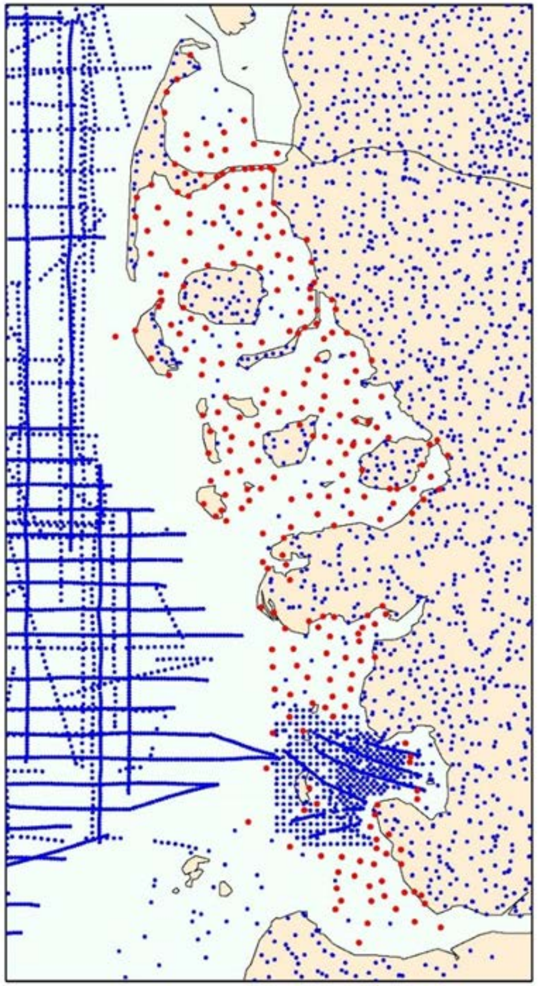




- Cooperation with
  - Geoforschungszentrum Potsdam (GFZ)
  - Bundesamt für Seeschifffahrt und Hydrographie (BSH)
  - Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein
  - FAMOS project

Example III: Gravimetric Survey of intertidal mudflats

- Almost no gravity data in the intertidal mudflats so far
- Measurements 2014 (red points in the map) and 2015: about 450 points in cooperation with
  - Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz Schleswig-Holstein
  - Landesamt für Vermessung und Geoinformation Schleswig-Holstein
  - Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz
  - Wasser- und Schifffahrtsverwaltung
  - Landesamt für Geoinformation und Landesvermessung Niedersachsen



Introduction of DHHN2016

- Accurate determination of physical heights by GNSS methods needs coordinates of SA*POS*® stations, height reference frame and quasigeoid to be high accurate, up to date and consistent
- After providing of the adjustment results 04/2014 German countries need time for
  - further measurements in subordinated leveling networks
  - including the data of subordinated leveling networks (new or digital available old data) in the new reference frame
- At the same time computation of a new German quasigeoid by BKG
- Computation of a model for height transformation from old to new height reference frame and providing in the internet
- 2017: synchronized introduction of heights: DHHN2016, quasigeoid: GCG2016, gravity: DHSN2016 and coordinates: ETRS89/DREF91/2016

Thank you for your kind attention!

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