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
Reference systems and frames in Germany

1. Spatial reference
   - Reference system: ETRS89 (GRS80, non tide)
   - First realization: ETRF91 official name ETRS89/DREF91 (1994)

2. Physical Heights
   - Datum: Normaal Amsterdams Peil (NAP)
   - Kind: normal heights, GRS80
   - Permanent solid earth tide correction: no corrections applied (mean tide)

3. Gravity
   - Absolute gravity measurements
   - Permanent solid earth tide correction: zero tide
   - Current realization: DSGN94, DHSN96
Modernization of the German height reference frame - motivation

- 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

- 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

Design of the new network
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
New German height reference frame – Standards and conventions for the German Height System and its realization

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

- 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)

Final network design in comparison to the original draft
## Parameters of the adjustment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DHHN92 (without observations of neighboring countries)</th>
<th>DHHN2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lines</td>
<td>672</td>
<td>991</td>
</tr>
<tr>
<td>Number of nodal points</td>
<td>422</td>
<td>680</td>
</tr>
<tr>
<td>Number of unknowns</td>
<td>423</td>
<td>680</td>
</tr>
<tr>
<td>Number of datum points</td>
<td>1</td>
<td>72</td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td>250</td>
<td>311</td>
</tr>
<tr>
<td>$S_0$ of 1 km leveling</td>
<td>0.86 mm</td>
<td>0.64 mm</td>
</tr>
<tr>
<td>$S_{\Delta h}$ of height differences (mean of all lines)</td>
<td>4.15 mm</td>
<td>2.65 mm</td>
</tr>
<tr>
<td>$S_H$ of adjusted heights (minimum)</td>
<td>0.79 mm</td>
<td>3.43 mm</td>
</tr>
<tr>
<td>$S_H$ of adjusted heights (Maximum)</td>
<td>11.13 mm</td>
<td>8.14 mm</td>
</tr>
<tr>
<td>$S_H$ of adjusted heights (mean)</td>
<td>7.27 mm</td>
<td>4.84 mm</td>
</tr>
<tr>
<td>Length of overall loop</td>
<td>4743 km</td>
<td>5350 km</td>
</tr>
<tr>
<td>Closing error of overall loop/ permissible value</td>
<td>138.3 mm / 137.7 mm</td>
<td>-13.7 mm/ 146.3 mm</td>
</tr>
</tbody>
</table>
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 SAPOS®
  - 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
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
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 SAPOS© 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

Thank you for your kind attention!

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