Reference frames

gravimetric (dynamic) reference frame

- today:
- global reference from satellites
  - global sph.-harm. gravity models (band limited), geocenter
  - direct link to point-wise potential on Earth surface (clock networks, tide gauges) difficult
- hi-res (full) regional / continental geoid models:
  - fitted to networks of leveling, GNSS (local reference)
  - errors often attributed to regional geoid model

gravimetric (dynamic) reference frame

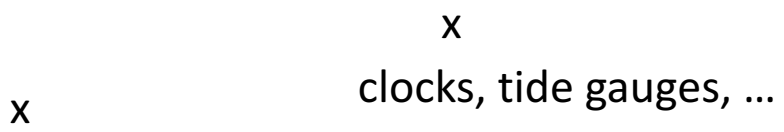
- future:
- hi-res (full) regional / continental geoid models tied to satellite gravity models (and geocenter)
- comparison with point-wise relativistic potential
- could confirm global potential reference
- or reveal deficiencies / issues in the global reference (due to geocenter issues, force models, systematic errors in space geodesy techniques, time-variable gravity and mass distribution, …)
- as soon as continental or intercontinental networks become available

geometric reference network (ITRF)

in between: continuous kinematics

future gravimetric reference network

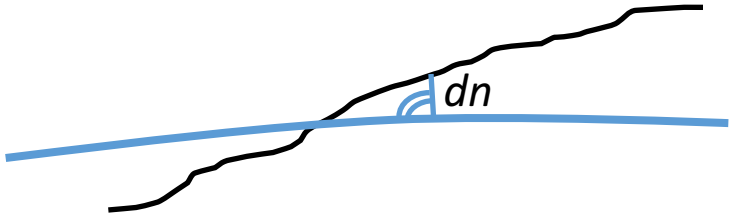
in between: continuous potential model



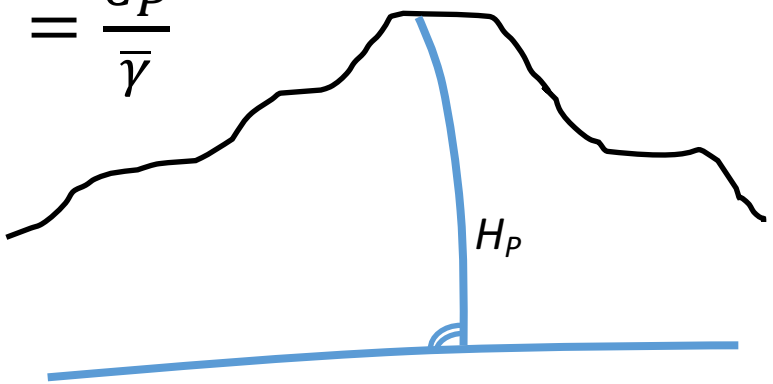
using point-wise data for a continuous reference

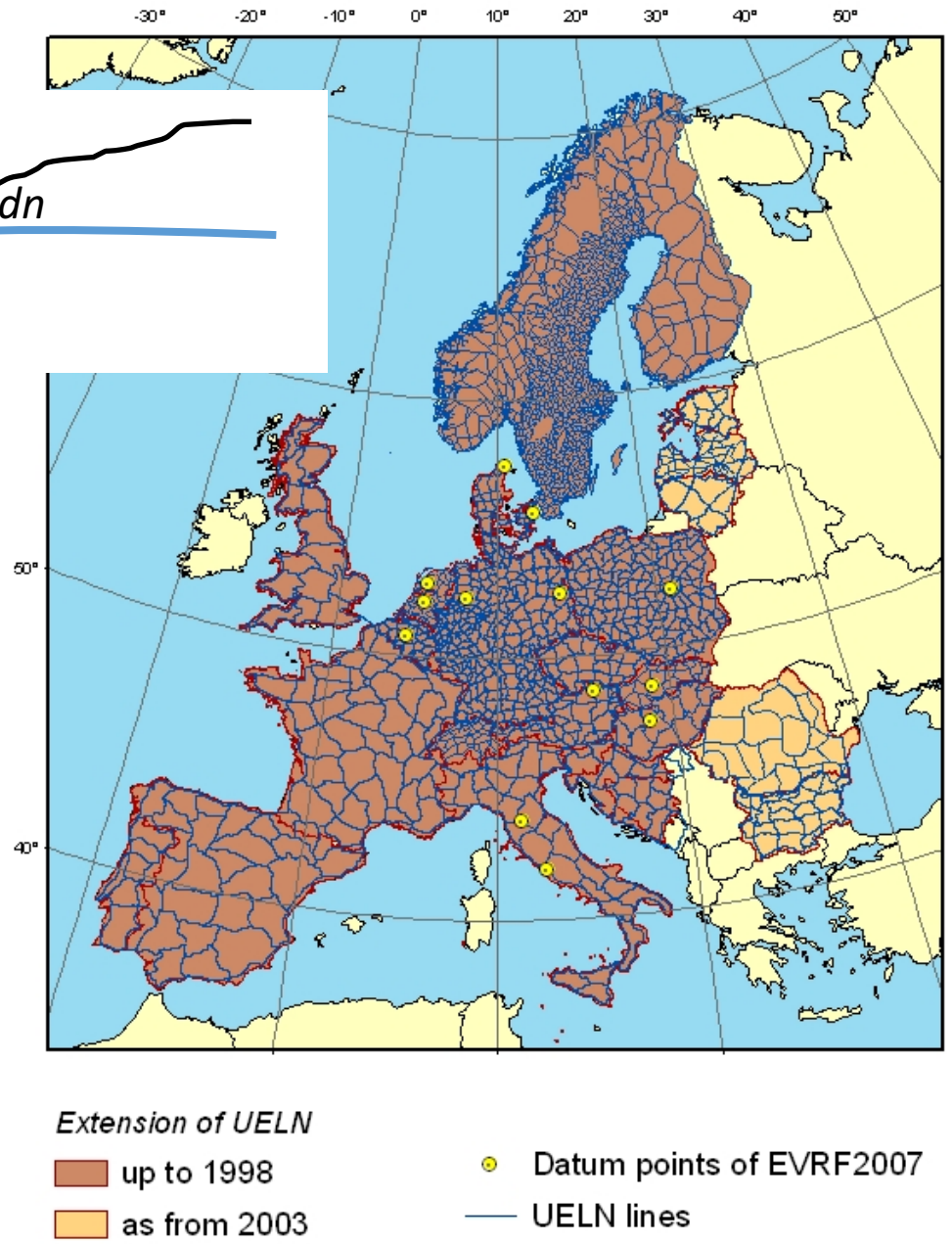
Classical potential and geoid modeling

spirit leveling



- first order networks:
- potential differences $\Delta W = -\int g \, dn$
- geopotential numbers $C_P = W_0 - W_P$
  - e.g., 10 000 m²/s² is approx. 1000 m height
- orthometric height $H_P = \frac{C_P}{\bar{g}}$
- normal height $H_P^N = \frac{C_P}{\bar{\gamma}}$

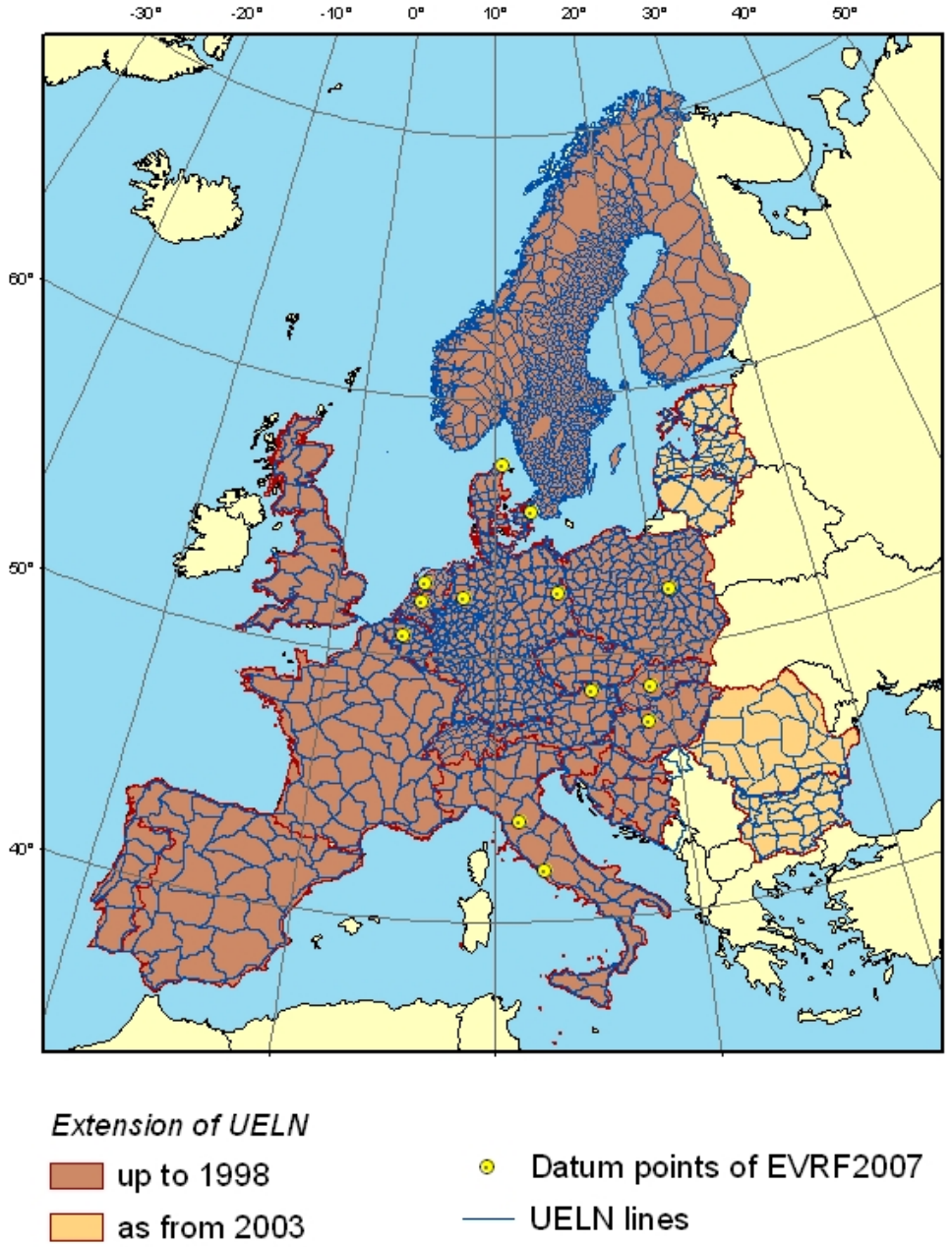




BKG

spirit leveling

- issues:
  - limited network stability
  - inhomogeneous network
  - w.r.t. epochs, sensors, procedures, standards,...
  - uncertain constraints in tide gauges
  - stability in time (geophysical and anthropogenic processes, ...)
  - limited accessibility of height reference
  - ...



BKG

high-resolution combined potential modeling

- $W = U + T$

  normal + disturbing potential

- global sph.-harm. model (satellites, global gravity grids)

  $T = \frac{GM}{r} \sum_l \left(\frac{a}{r}\right)^l \sum_m P_{lm}(\cos\theta)(\Delta C_{lm} \cos m\lambda + \Delta S_{lm} \sin m\lambda)$

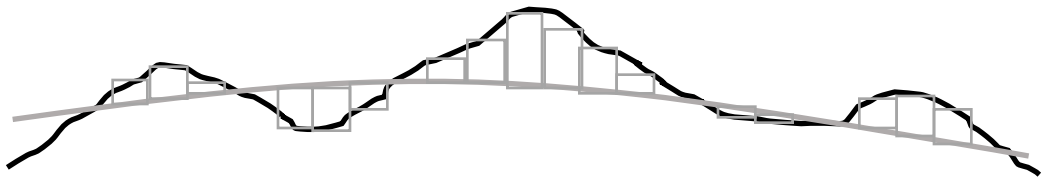
  e.g., EGM2008, band-limited (l_{max} 2160)

- regional terrestrial gravity anomaly data

  $T' = \frac{R}{4\pi\gamma} \int (\Delta g + \cdots) S(\psi)\, d\sigma$

  Stokes / Molodenskii integration

- mass models (topography, …) T_{DTM}



high-resolution combined potential modeling

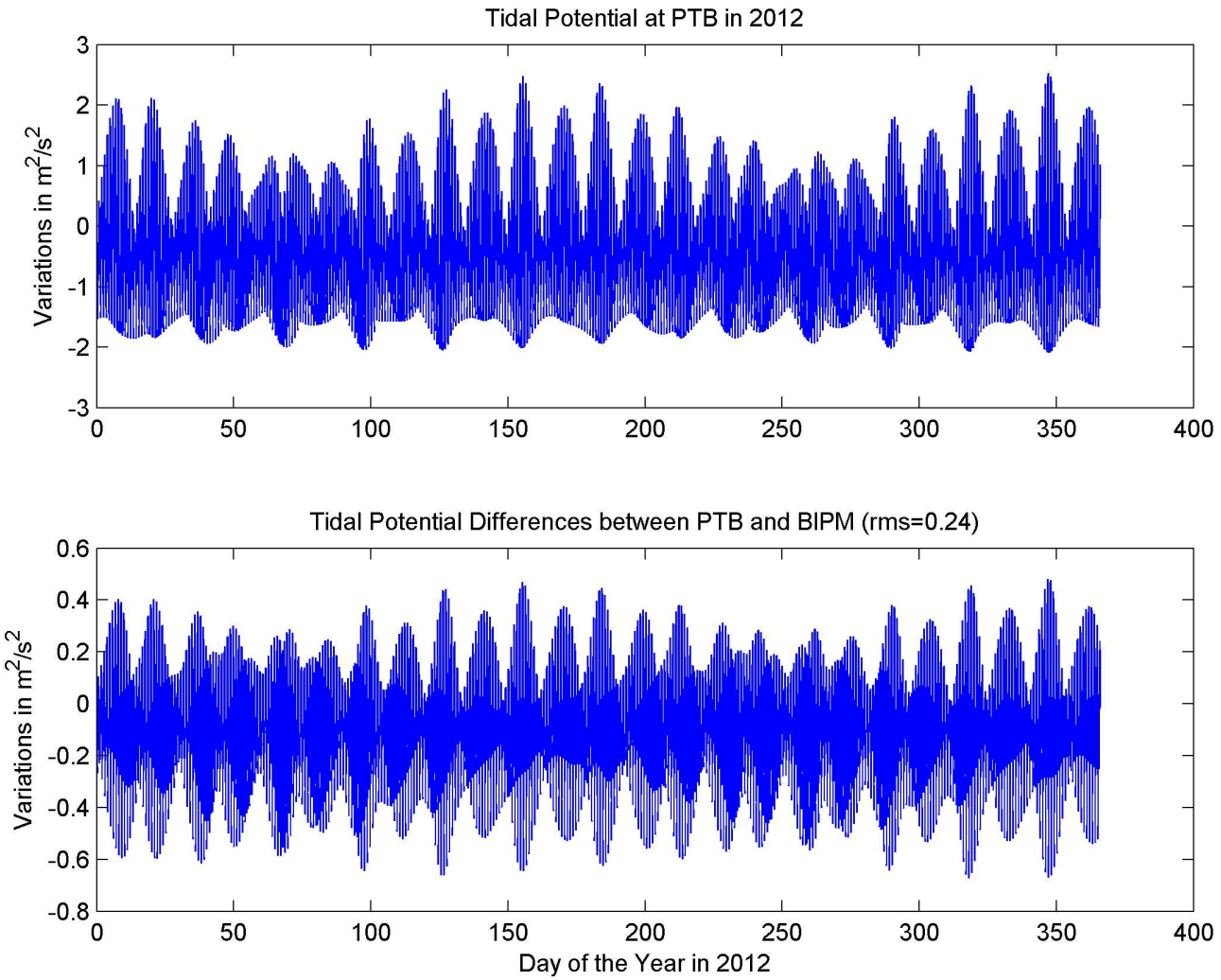
- height anomaly (geoid height) $\zeta = \frac{T}{\gamma}$
- normal height from ”gravity field approach”

$$H^N = h^{GPS} - \zeta$$

modeling issues

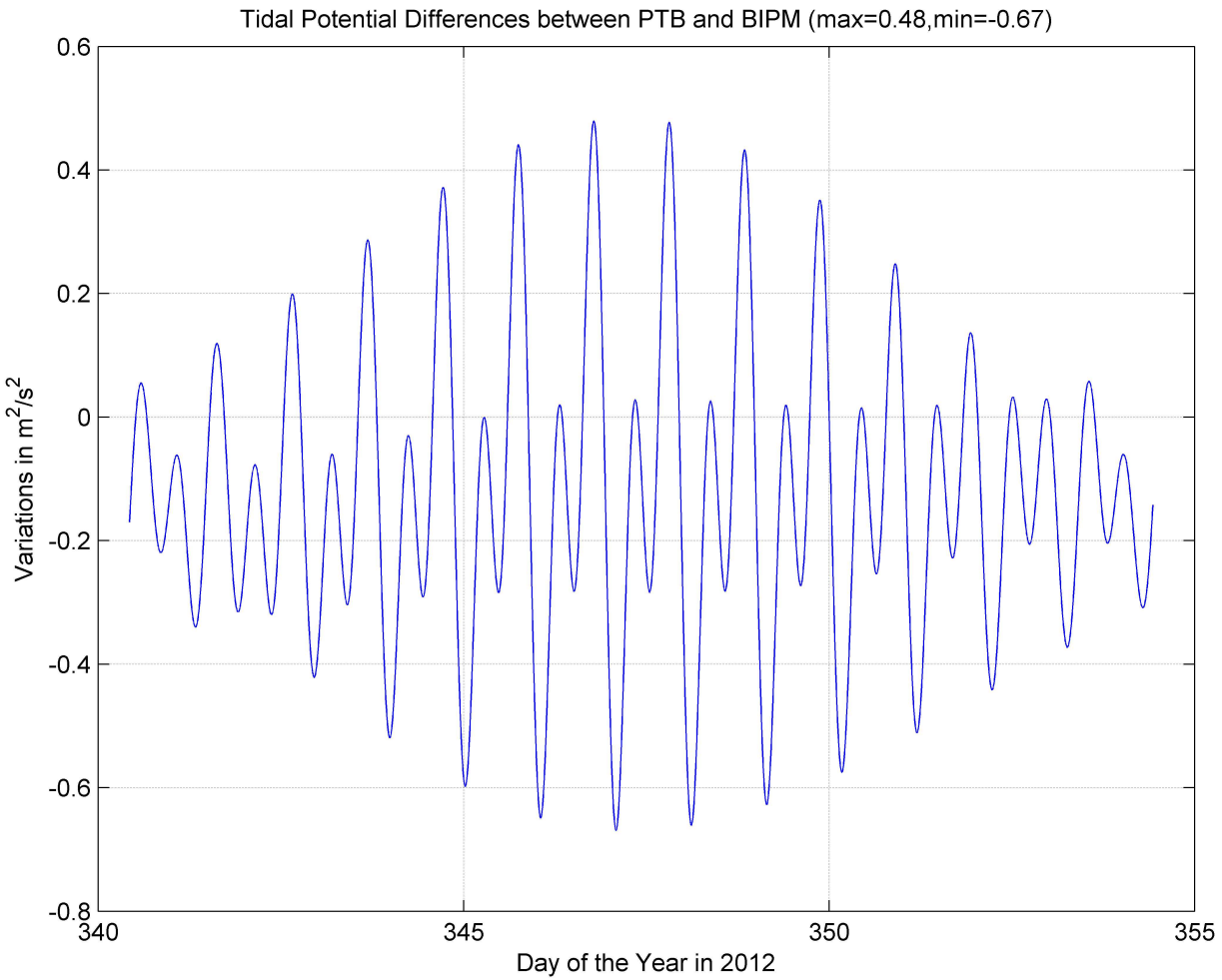
- atmospheric masses
- tidal conventions
- details of mass modeling (DTM curvature, …)
- datum offsets and distortions in data sets (gravity anomalies, DTM, ...)
- W_0
  - topic on its own
  - from satellite altimetry and global sph.-harm. model

tidal potential



L. Timmen (IfE)

tidal potential

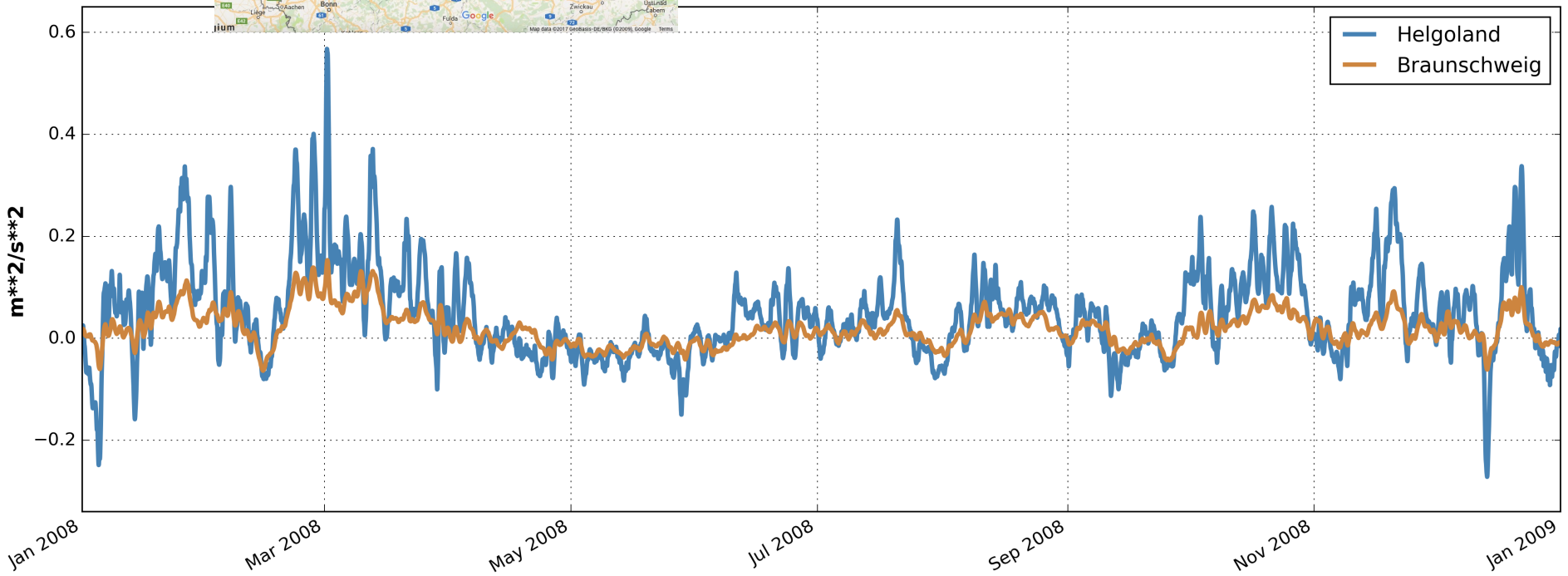


L. Timmen (IfE)

… needs to be considered

non-tidal time-variable potential

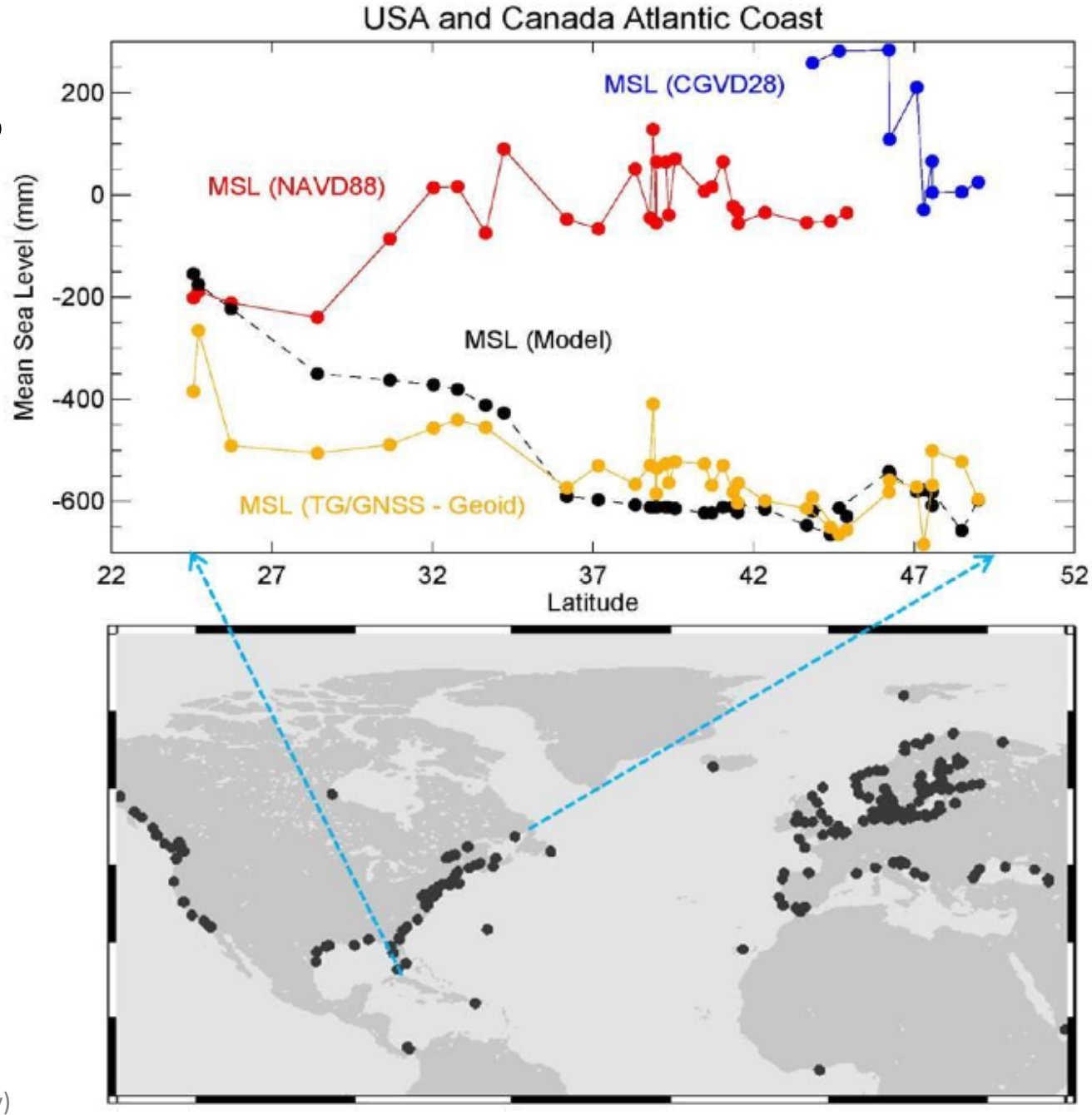
- sum of direct potential variation and surface deformation due to loading
- may become relevant
- complementary to gravimetry, GNSS loading



Lars Leßmann (IfE)

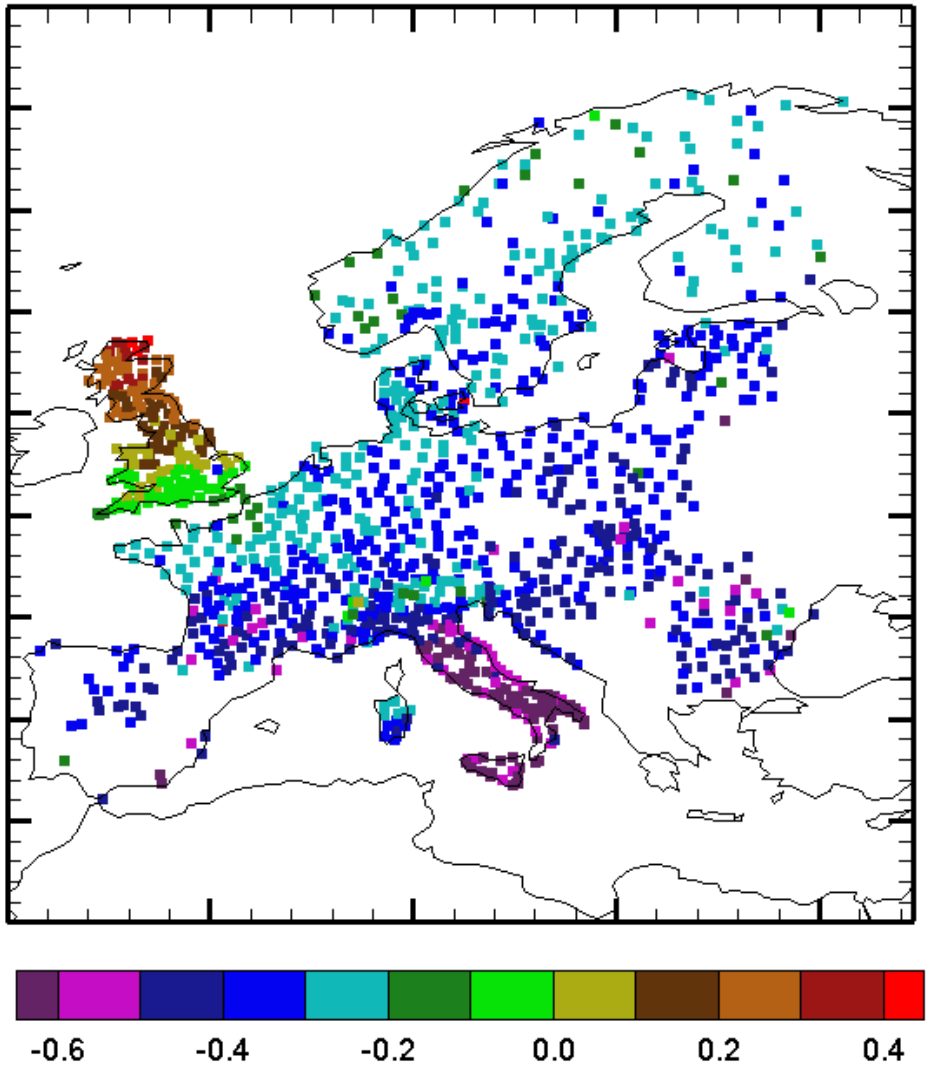
height inconsistencies

- decimeter inconsistencies
- hamper combination of tide gauges
- efforts for **height system modernization**
- **clocks** could provide **in-situ cm** accuracy referred to **well-defined W_0**



Sideris et al 2013 (GOCEplus study)

height inconsistencies

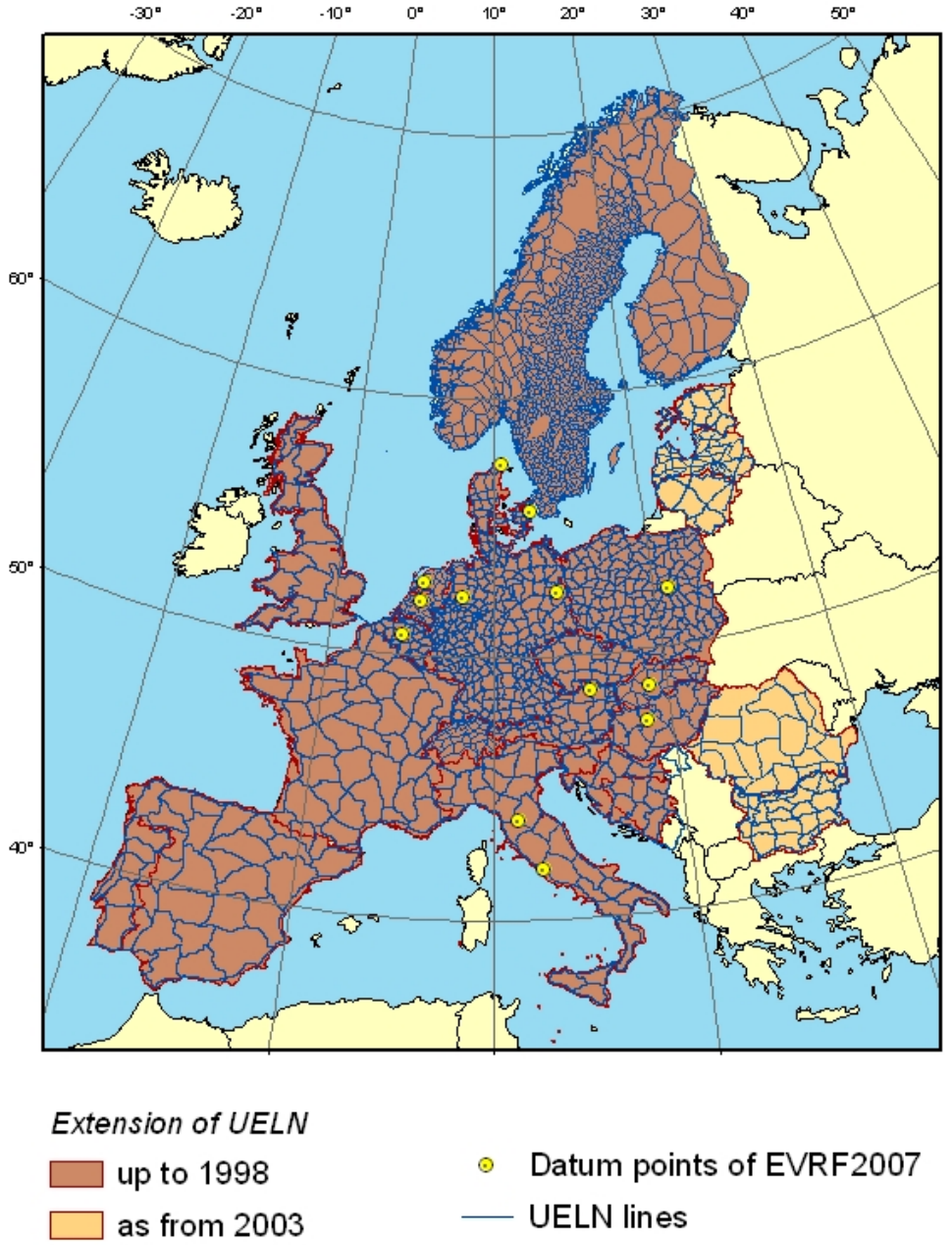


Gruber 2013

Use of accurate clocks for gravity potential determination

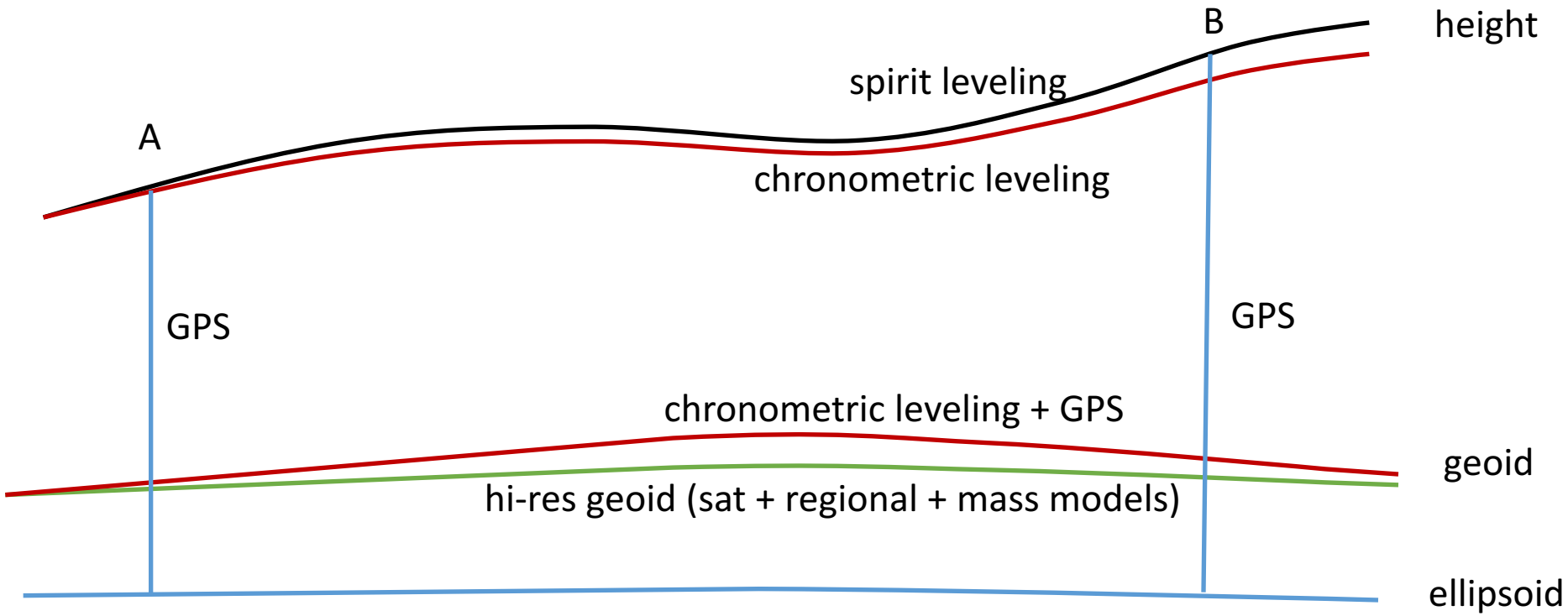
perspective 1

- check / investigate classical geoid models and height networks
- with, e.g., a European clock network
- several points per country
- where?
- combination with regional / continental geoid models
- identify and quantify error sources



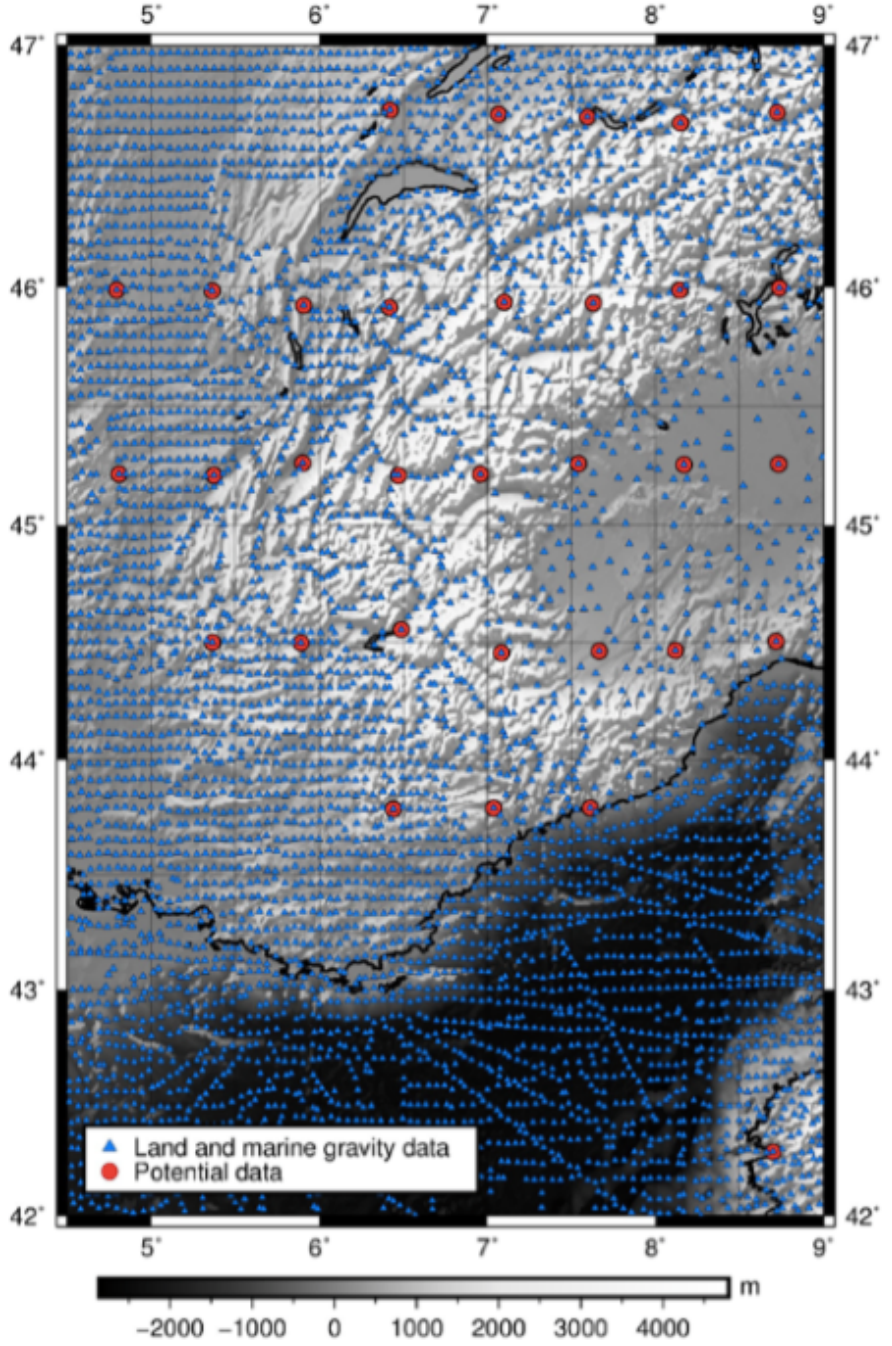
perspective 1

- assessing leveling and geoid errors (separately)
- understand and quantify error contributions



perspective 2

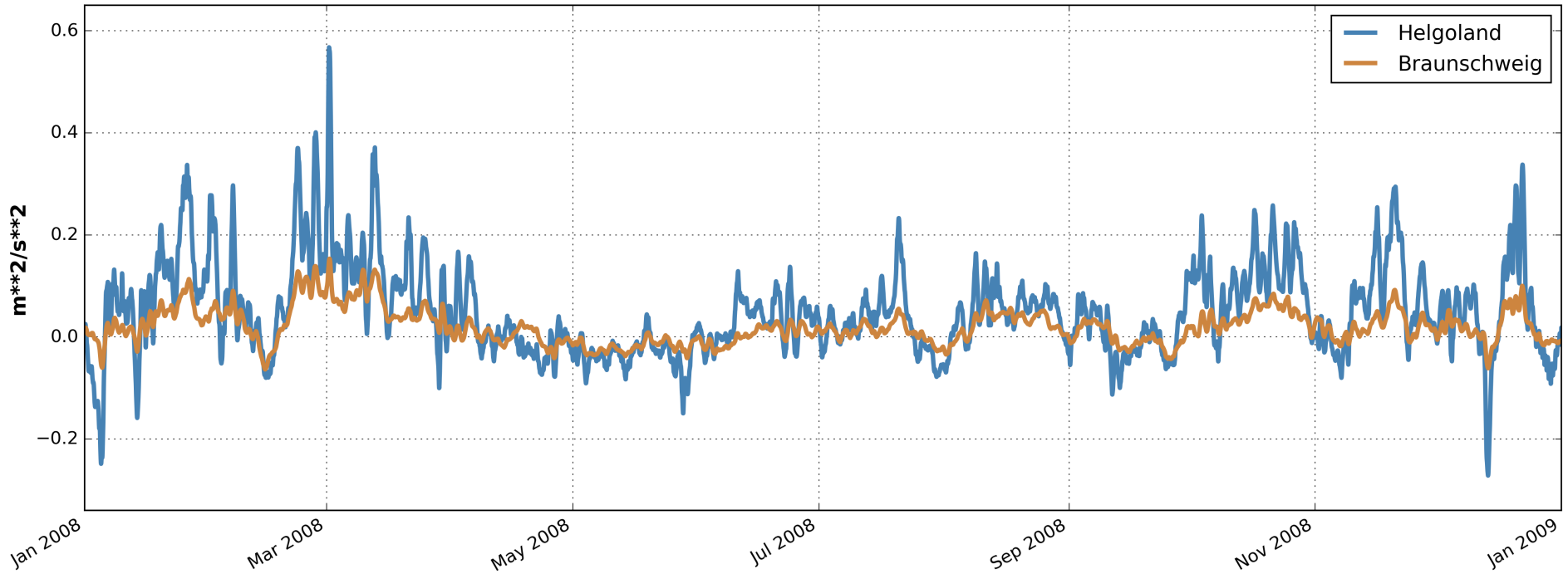
- combine / tie classical and relativistic potential data
- e.g., with least squares collocation



Lion et al 2017

perspective 3

- investigate the time variable gravity potential to study geophysical processes and regional gravity modeling
- very high clock accuracy and good network design needed



perspective 4

- strengthening / investigating the global gravimetric reference frame
- “Figure of the Earth”
- combining point-wise clock (and tide gauge) data with global potential models (and geocenter) through hi-res regional models
- link to “master clock in space”

benefits of relativistic height reference

atomic standards for geoid and heights
independent control in first order networks
assess height networks quality, quantify systematic errors
assess quality of “gravity field approach” to heights (GNSS + hi-res geoid modeling)
tie regional geoid models together, quantify geoid modeling problems
assess and monitor long-term stability
strengthen tide gauge reference (with clocks at or close to tide gauges)
combined geoid modeling including relativistic information
co-location with GNSS, other techniques
long-term: intercontinental connections via optical satellite links