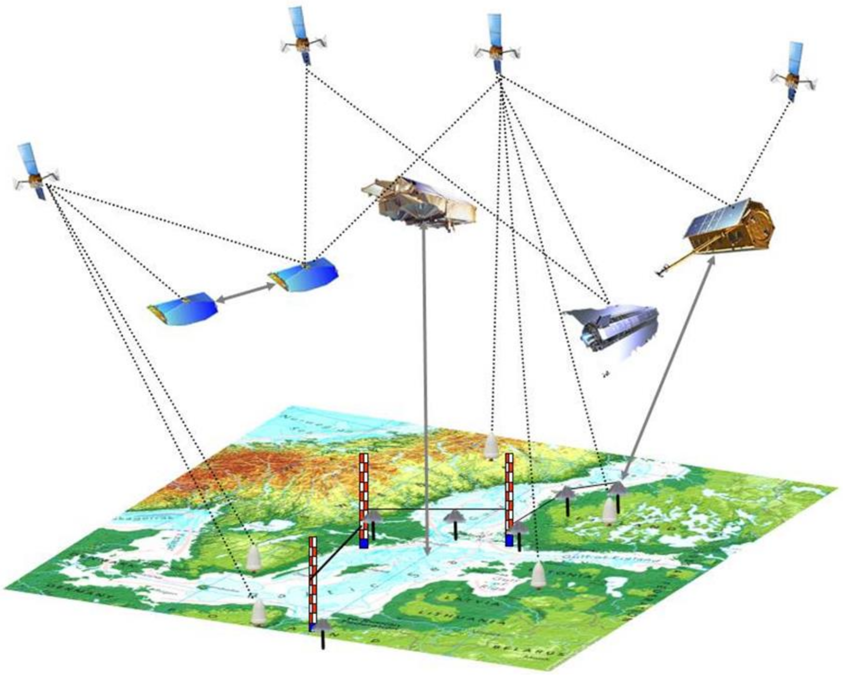
Geodetic Space Sensors for Height System Unification and Absolute Sea Level Determination

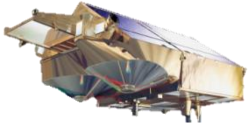


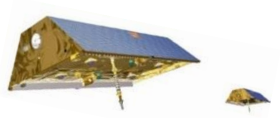
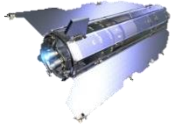
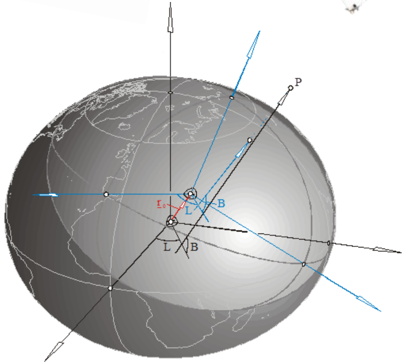
Th. Gruber, M. Willberg, N. Pfaffenzeller

Institute of Astronomical &
Physical Geodesy (IAPG)
Technische Universität
München

Outline

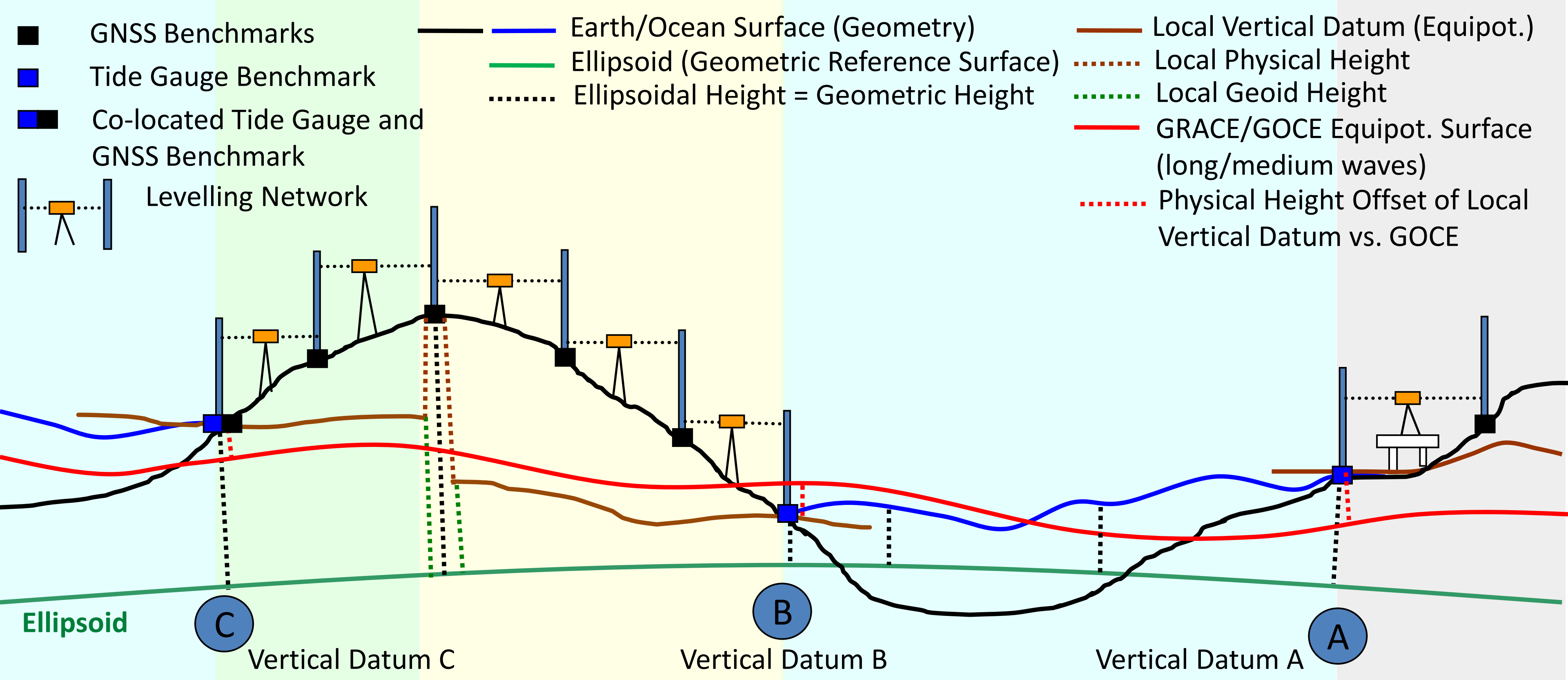
- Introduction & Problem Definition
- Tide Gauges as Sea Level Sensor and Height Systems Reference
- Geometric Space Sensors
- Gravimetric Space Sensors
- Geometric & Gravimetric Reference Frames Consistency
- Summary & Conclusions

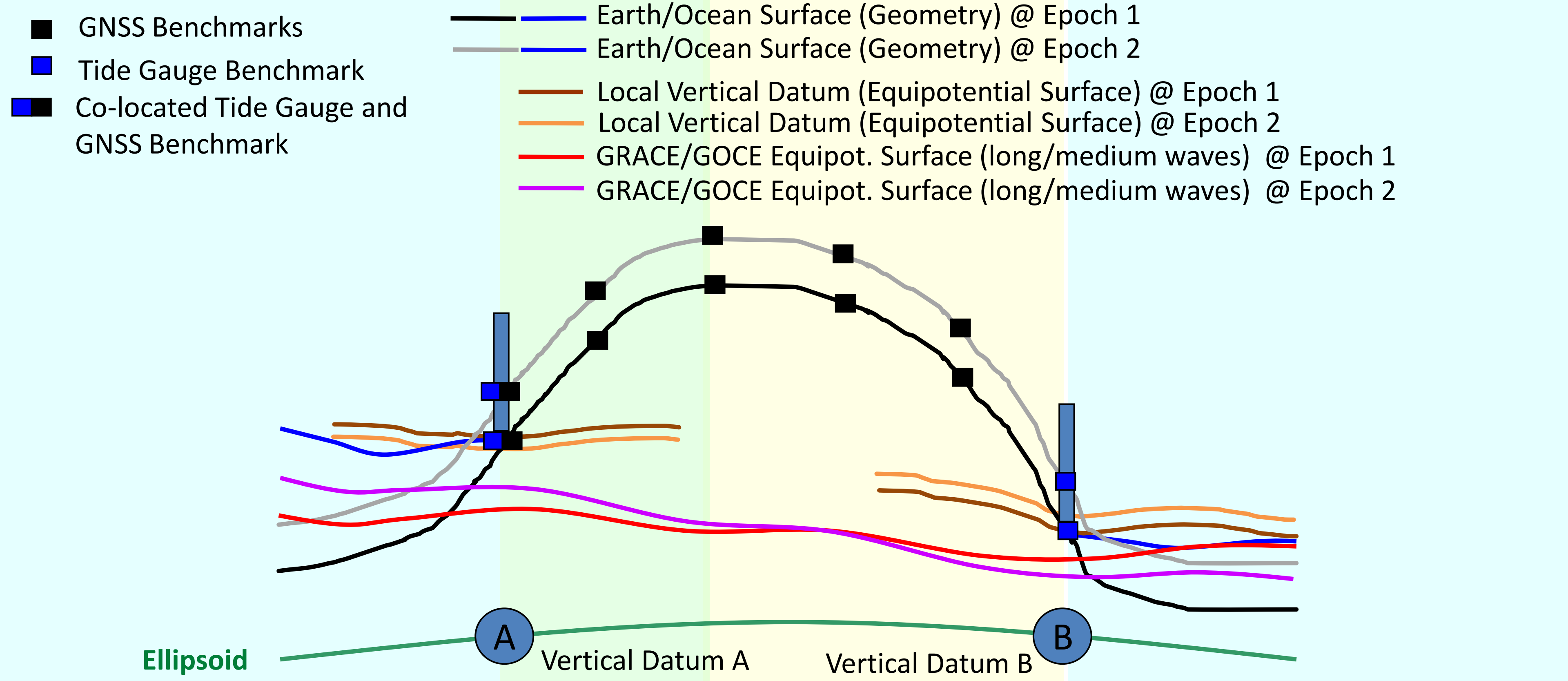
Introduction & Problem Definition

Geometrical and Physical Shape of the Earth – **Static Case**



Introduction & Problem Definition

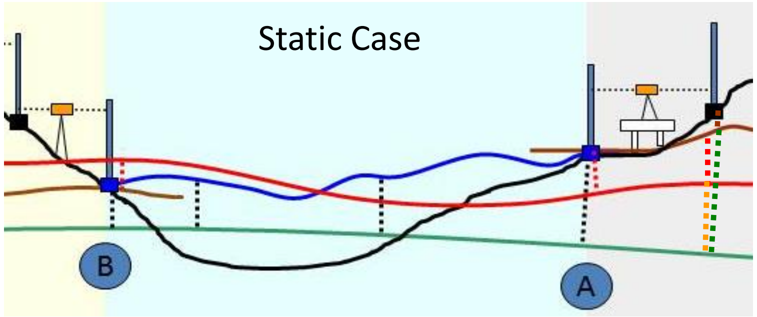
Geometrical and Physical Shape of the Earth – Dynamic Case



Height Systems, Sea Level & Space Sensors

Absolute sea level observations, height system unification and GNSS-Levelling require the knowledge of the global static geoid.

➢ What is the role of the GOCE static geoid?

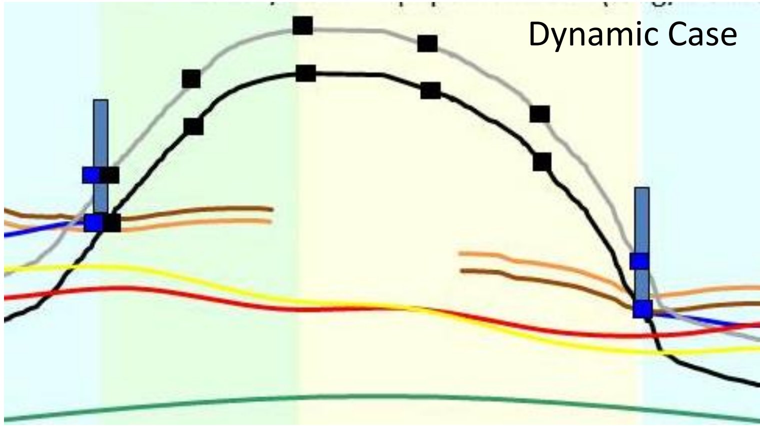


For GNSS-Levelling geometric and gravimetric reference frames need to be compatible.

➢ What is the impact of reference frame incompatibilities?

Sea level observations require knowledge about vertical changes of the geometric shape of the Earth.

➢ How can vertical changes of land be observed on a systematic base?

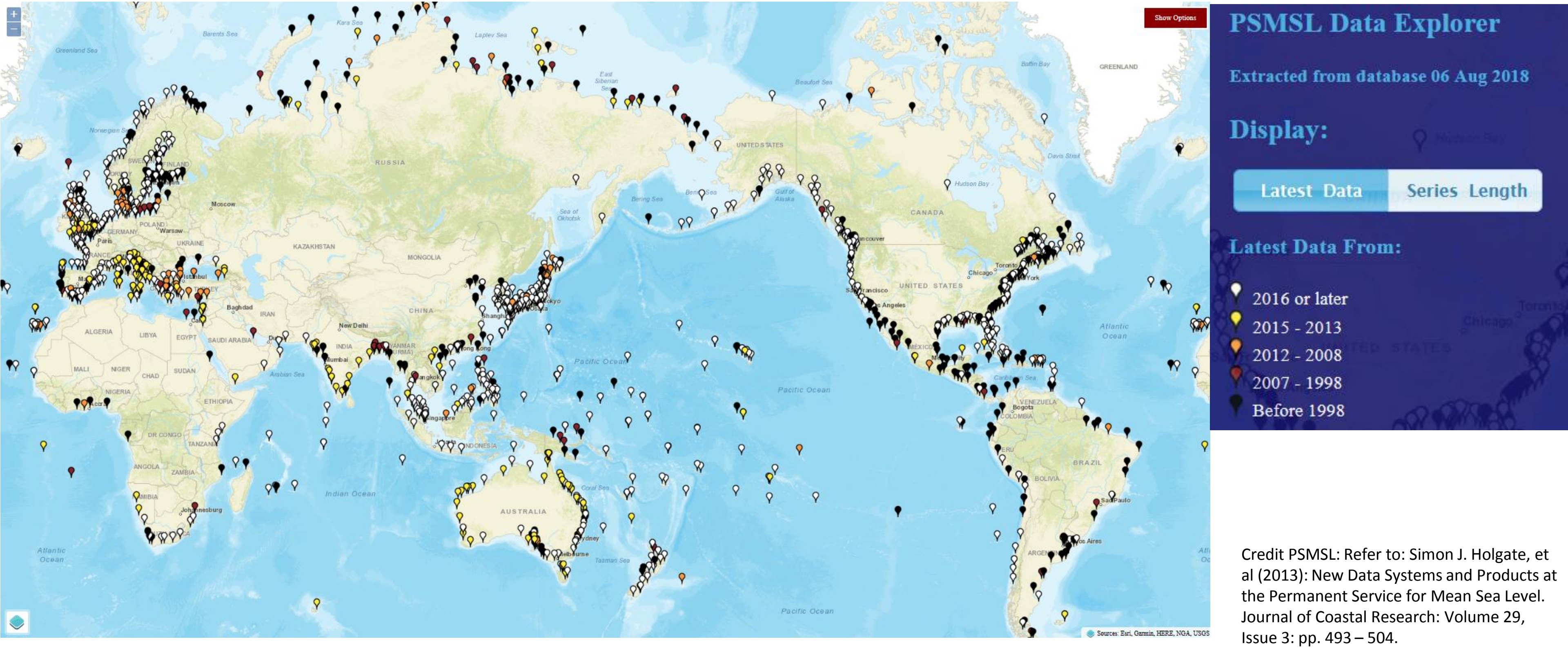


Mass variations cause variations of the reference equipotential surface. This has impact on absolute sea level observations, height systems and GNSS-Levelling.

➢ What is the impact of mass variations and how can it be observed?

Ground based Sensors - Tide Gauges

Permanent Service for Mean Sea Level (PSMSL) – Global Distribution Tide Gauge Stations (Status Aug. 2018)

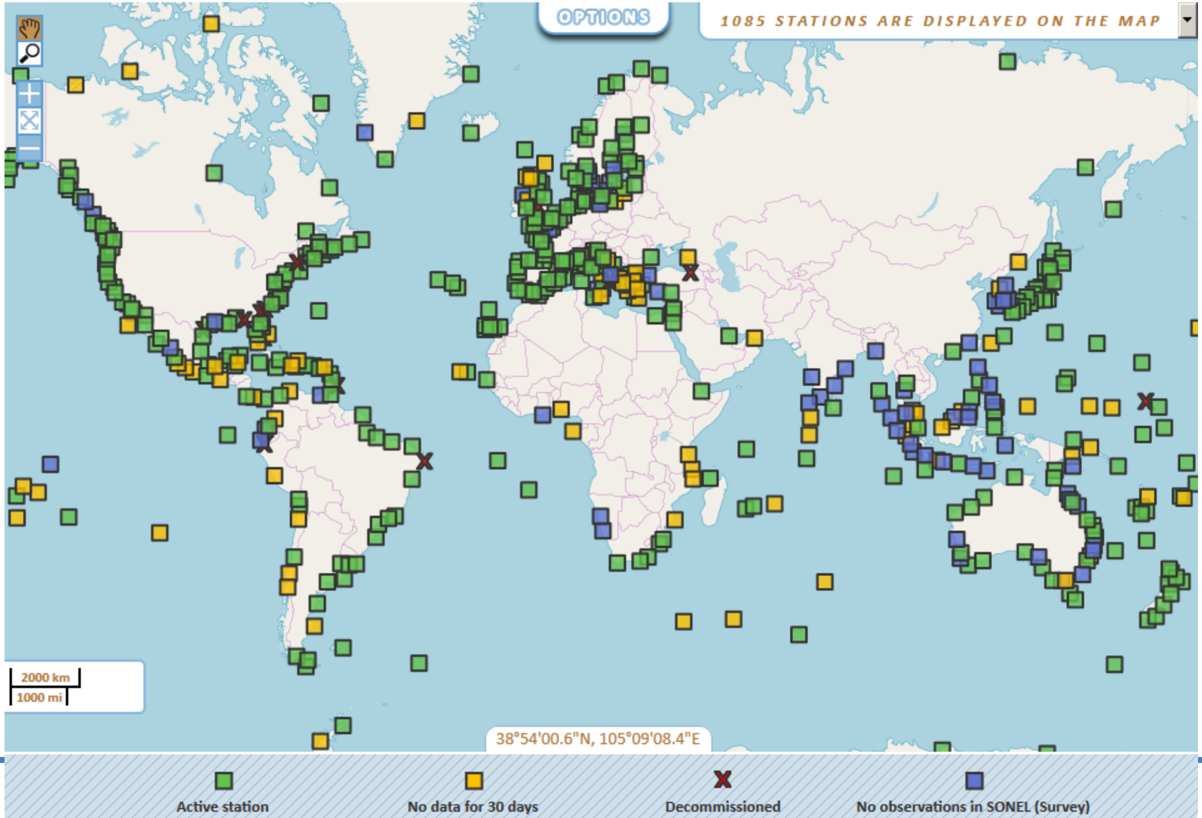


Credit PSMSL: Refer to: Simon J. Holgate, et al (2013): New Data Systems and Products at the Permanent Service for Mean Sea Level. Journal of Coastal Research: Volume 29, Issue 3: pp. 493 – 504.

Geometric Space Sensors - GNSS

How can vertical changes of land be observed on a systematic base?

Tide gauges co-located with permanent GNSS stations within 10-15 km distance

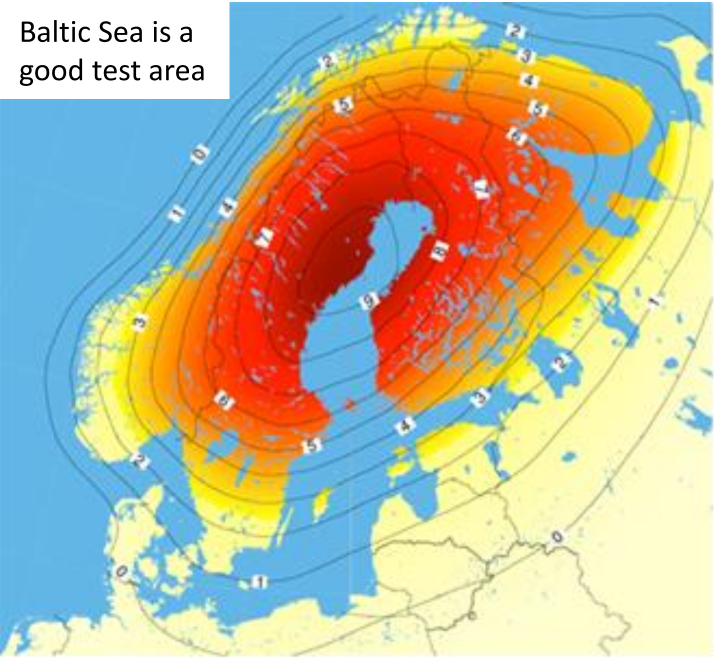


Status August 2018
from SONEL
http://www.sonel.org

Geometric Space Sensors - GNSS

How can vertical changes of land be observed on a systematic base?

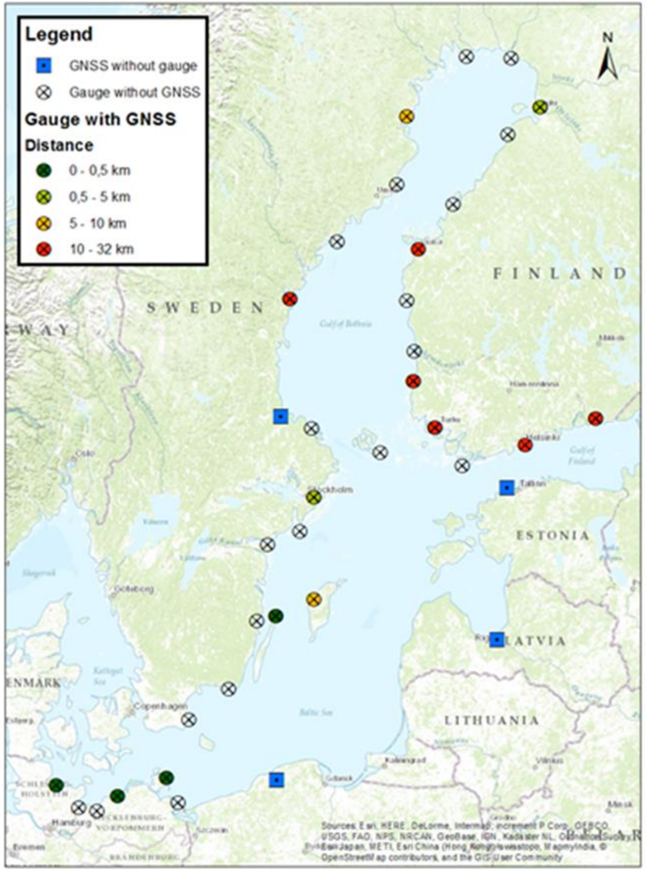
Baltic Sea is a good test area



Postglacial land uplift in Scandinavia [mm/yr]
http://www.fgi.fi/fgi/themes/land-uplift

<u>Primary Technique:</u>
Observation of vertical movement of tide gauge stations by GNSS.

<u>Alternative:</u>
Coastal altimetry can be a technique to link the geometric shape of the oceans with the shape of land at tide gauges and its temporal changes. Problem: Large uncertainties close to coastlines.

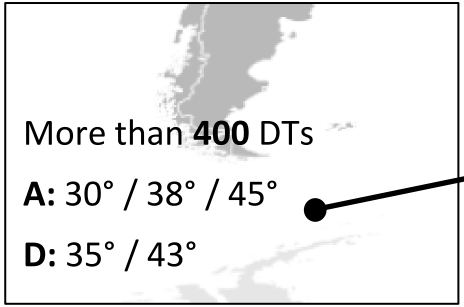


Data Sources: psmsl.org & sonel.org, August 2015

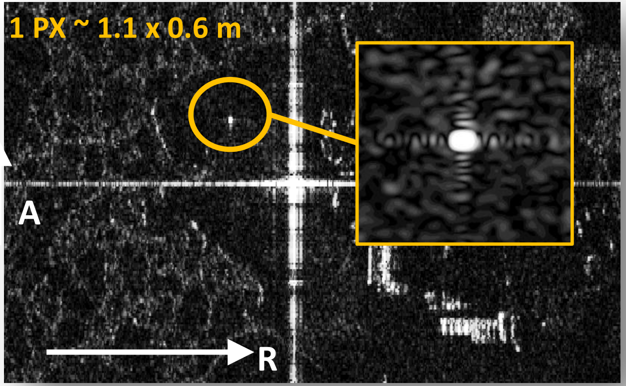
Geometric Space Sensors – Geodetic SAR Positioning

How can vertical changes of land be observed on a systematic base?

TerraSAR-X data since 03/13



2 corner reflectors with known reference coordinates (< 5 mm)

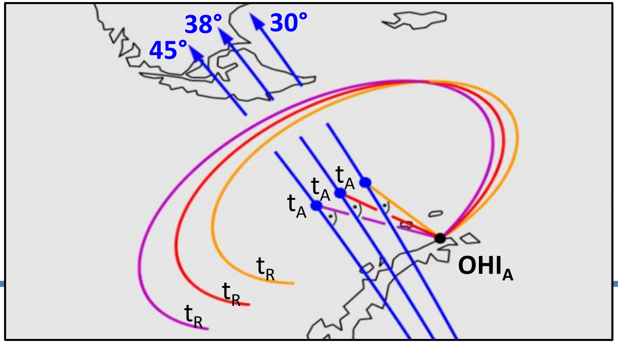


Radar Timings
Range t_R
Azimuth t_A

Corrections
Atmosphere
Geodynamics
Calibration

3D Solution
Corrected Observ.
Orbit

Results
- Coordinates
- Statistics



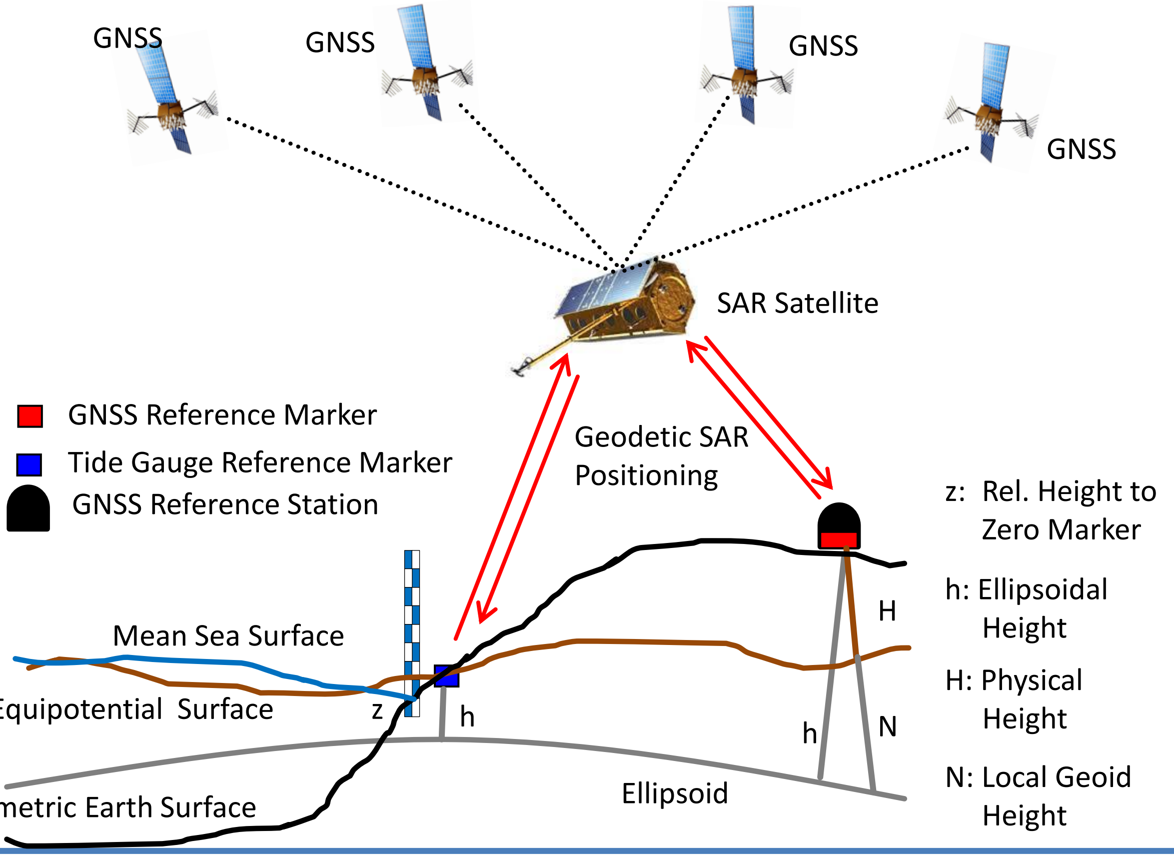
CR	Coordinates ΔN [cm]	Coordinates ΔE [cm]	Coordinates ΔU [cm]	Statistics (95%) s_N [±cm]	Statistics (95%) s_E [±cm]	Statistics (95%) s_U [±cm]
OHI_A	-1.5	-1.2	-0.5	1.1	1.9	1.6
OHI_D	-1.4	-1.5	0.3	2.1	4.2	3.7

Geometric Space Sensors – Geodetic SAR Positioning

How can vertical changes of land be observed on a systematic base?

Geodetic SAR positioning for height transfer
(SAR-Levelling)

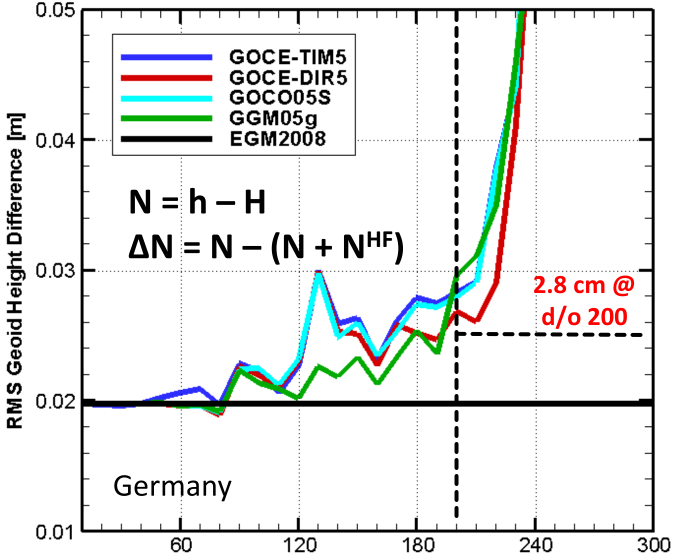
Active Transponder

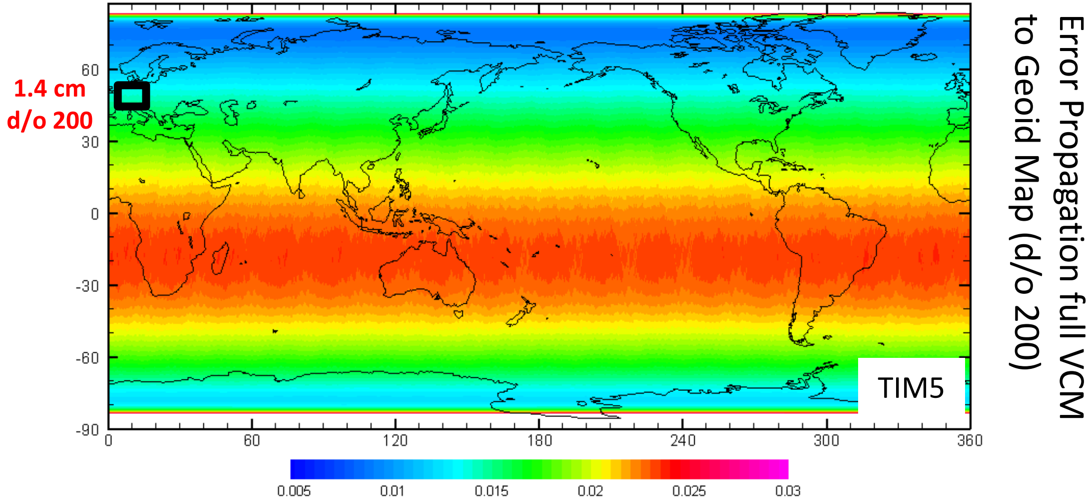


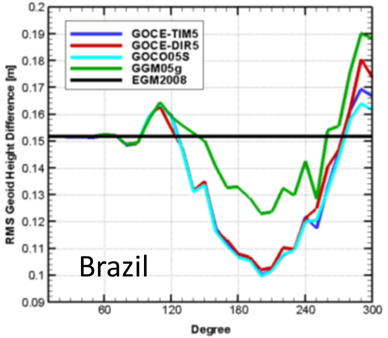
Gravimetric Space Sensors - GOCE

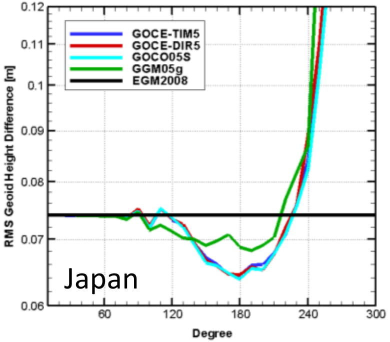
What is the role of the GOCE static geoid?

External Validation by GNSS-Levelling Comparisons









GNSS-Levelling error is composed by:

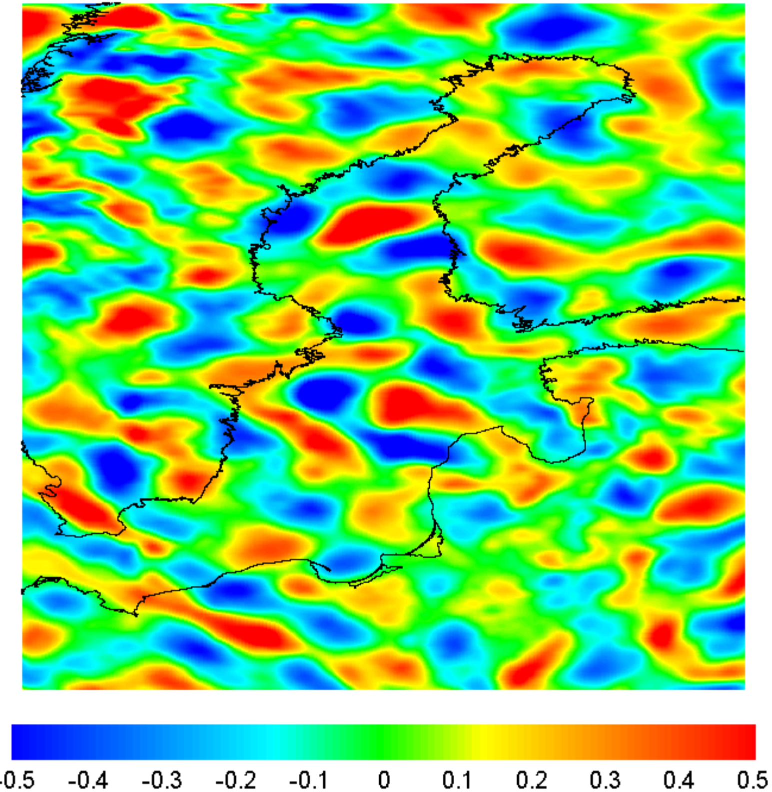
GPS height error **h**: ≈ 1.5 cm + Normal height error **H** ≈ 1.5 cm + Error of EGM2008 $\mathbf{N^{HF}}$ ≈ 1.0 cm = Total error: 2.4 cm

GOCE geoid **N** error (reverse propagation) 1.4 to 1.5 cm, consistent to geoid error map

Gravimetric Space Sensors - GOCE

What is the role of the GOCE static geoid?

Geoid signal beyond the GOCE resolution in the Baltic Sea (Omission error from EGM2008)

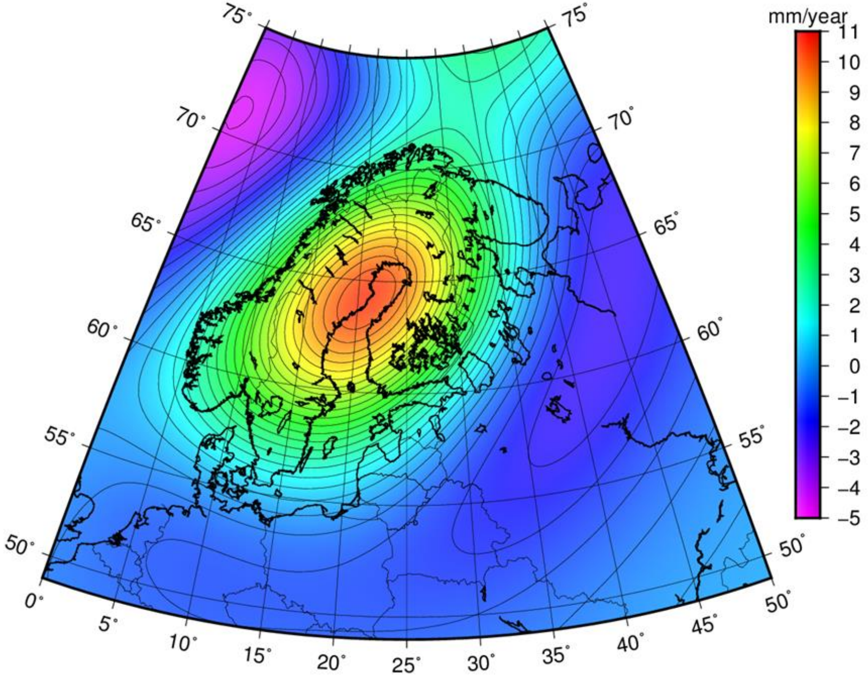


- The GOCE geoid represents a global reference for height systems and absolute sea level observations.
- The GOCE geoid accuracy at 100 km spatial resolution is between 1 and 2 cm quasi globally (within GOCE orbit coverage).
- The omission error needs to be estimated or computed from observations.
  - For height reference stations / tide gauges a local high quality geoid based on the GOCE geoid shall be computed based on gravity observations and terrain model (with data of at least 100 km around the point of interest).
  - In sparsely surveyed areas the GOCE geoid in many cases represents the best possible reference surface.

Gravimetric Space Sensors - GRACE

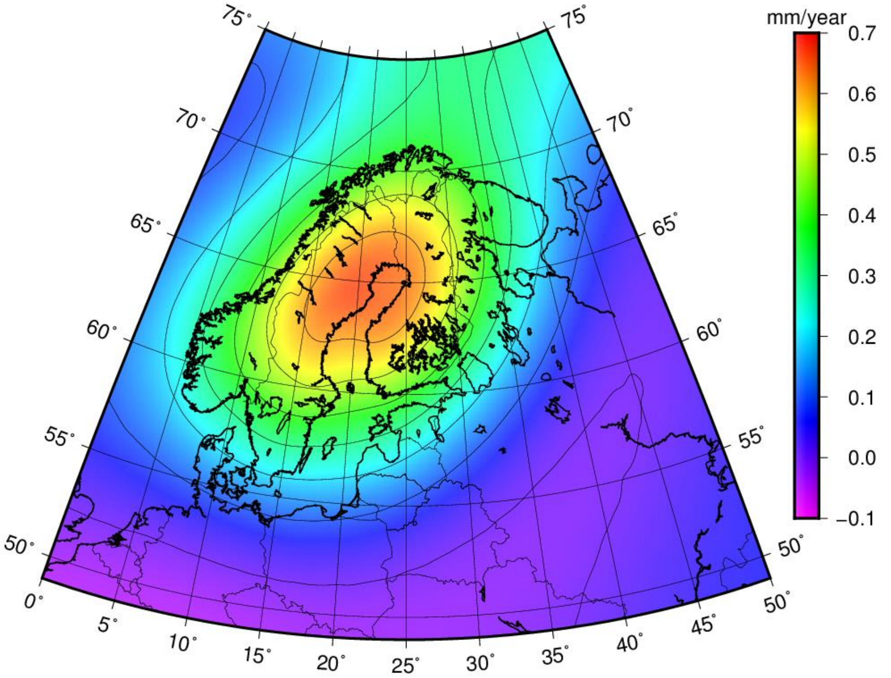
What is the impact of mass variations and how can it be observed?

NKG2016GIA_prel0306 – vertical land uplift



Gridded vertical geometric displacement rate
(Steffen & Ågren, pers. comm.)

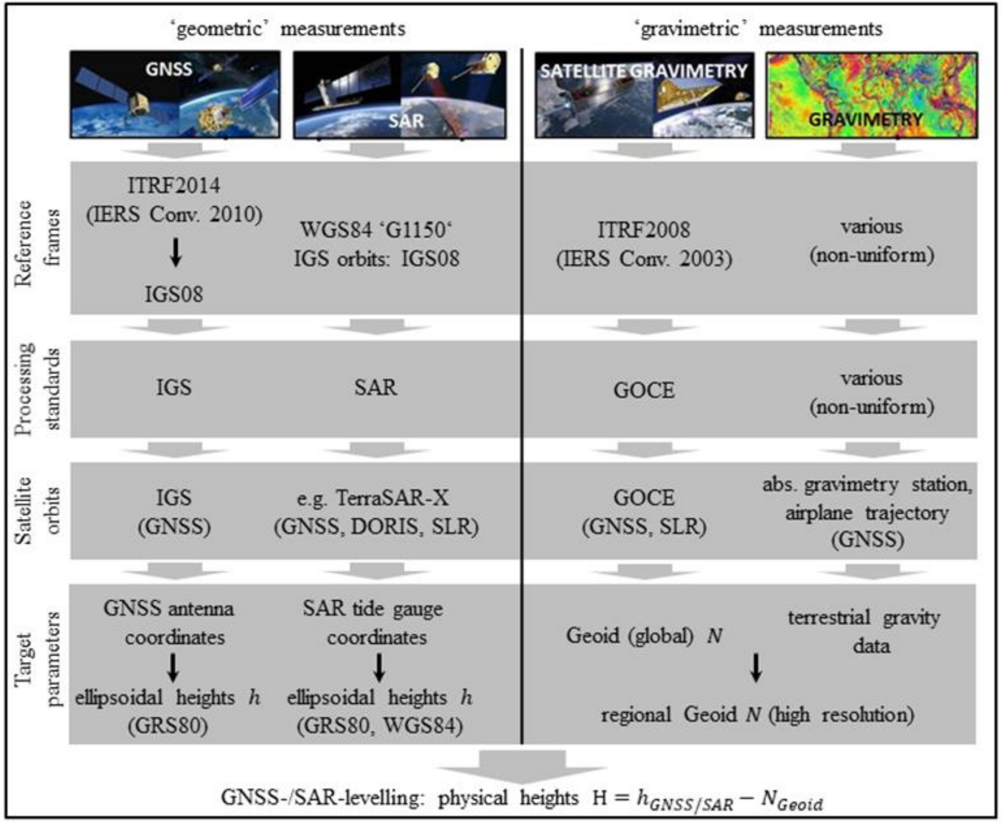
NKG2016GIA_prel0306 – Geoid rise



Gridded geoid change rate
(Steffen & Ågren, pers. comm.)

Space Sensors – Reference Frames

What is the impact of geometric and gravimetric reference frame incompatibilities?



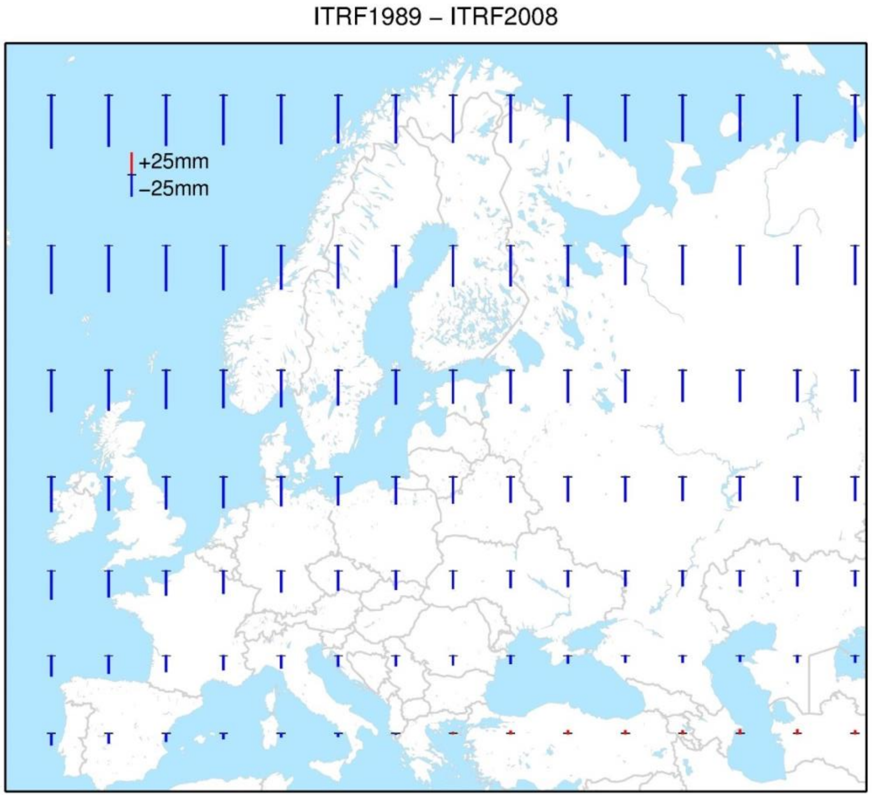
Simplified scheme for the determination of ellipsoidal heights from the geodetic SAR technique and GNSS (left) and the determination of physical heights referring to a common physical reference surface based on GOCE and terrestrial/airborne data (right).

Courtesy: D. Angermann, DGFI-TUM, 2018

Space Sensors – Reference Frames

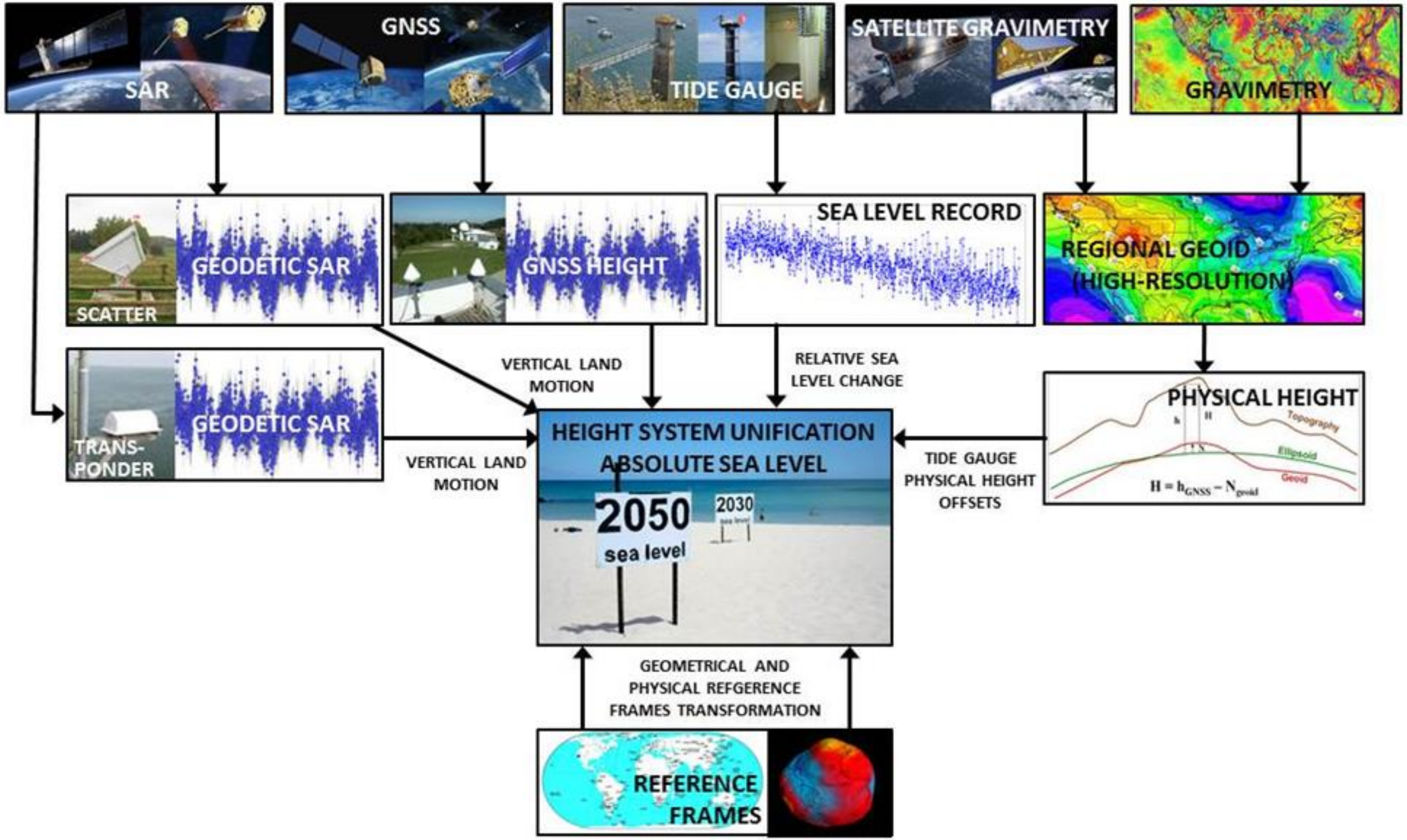
What is the impact of geometric and gravimetric reference frame incompatibilities?

Impact of Coordinate Frame Transformations on GNSS Heights (Study performed by G. Liebsch, BKG)



- GNSS and geoid heights need to be in a consistent frame (reference ellipsoid).
- GOCE geoid heights refer to CoM.
- GNSS ellipsoidal heights refer to an ITRFxxxx with a center of origin which is not CoM.
- ITRF2008 is known to be close to CoM.
- ITRF1989 (ETRF1989) to ITRF2008 offset is (x,y,z): 2.8 - 3.9 - 10.1 cm
- 7 parameter Helmert transformation result in height change of up to 7 cm in Europe (see figure).
- For any combined use of geometric and physical heights this needs to be taken into account.

Space Sensors for Heights & Sea Level – Summary



Space Sensors for Heights & Sea Level - Conclusions

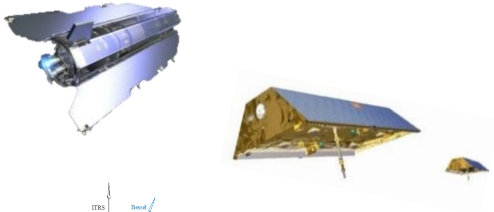
Tige Gauges

- Should be kept operational worldwide.

Geometric EO Sensors (GNSS, Altimetry, SAR)

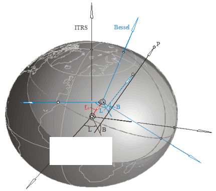
- Sustained observations available from Sentinel missions & others.
- Ground processing to be further developed (e.g. SAR positioning, coastal altimetry).

Gravimetric Space Sensors



- Spatial resolution of static global gravity field to be improved with new observation technologies (e.g. cold atom gradiometry on satellite).
- Sustained observation of temporal variations of gravity field with improved spatial & temporal resolution (e.g. double-pair concepts).

Reference Frames Consistency



- Joint systematic observation of geometric & physical reference frames (e.g. CoM versus Center of Figure)