Science Applications Enabled by the IGS

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Overview

- **Motivation: Two Challenges**
  - **slow processes** (years to decades)
  - **fast processes** (seconds to hours)
- **Products of the IGS for these challenges**
- **Science:**
  - **Solid Earth: plate tectonics ↔ earthquakes**
  - **Atmosphere: “climate” ↔ weather prediction**
  - **Precise LEO orbit determination for EO satellite missions**
- **Challenges for the IGS**
- **Conclusions**

Motivation: Two Challenges

Two Major Challenges Global Earth Monitoring

Reliable detection of small, long-term trends:

- Sea level rise
- Glacial Isostatic Adjustment (GIA)
- Plate tectonics
- Global change: water vapor, troposphere height)

Fast event detection and quantification:

- Earthquakes, tsunami
- Volcanic eruptions
- Landslides
- Hurricanes
- Space weather

Contrast in IGS Service: Postprocessing - Real-Time

Reliable detection of small, long-term trends:

- Post- or re-processing
- Long time series
- IGS: reprocessing effort
- IGS: final products, reference frame solutions
- Global network solutions
- Highest accuracy and consistency (1-5 mm)

Fast event detection and quantification:

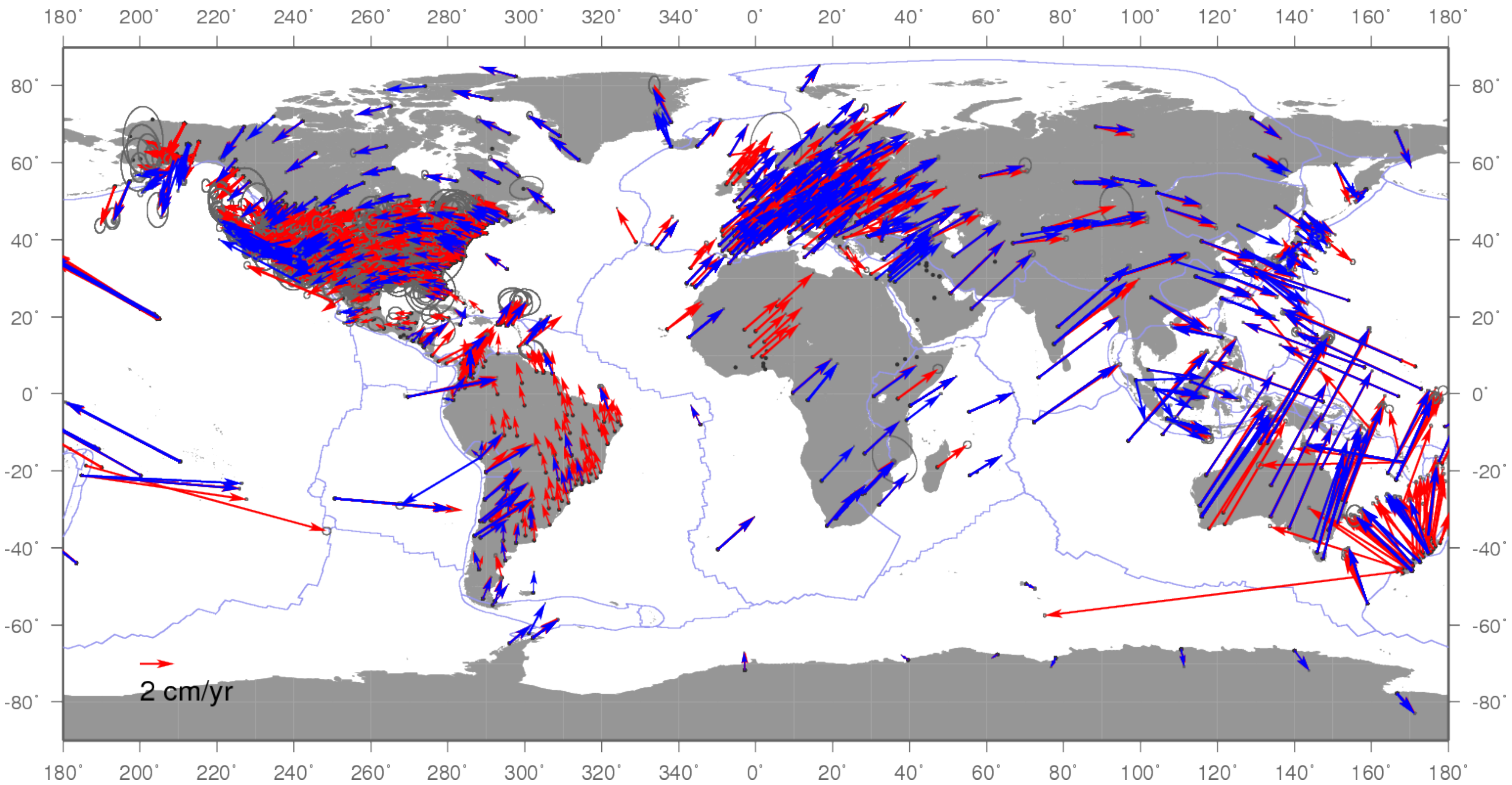
- (Near) real-time processing
- Real-time data streams
- IGS: real-time project
- IGS: predicted orbits, real-time clocks
- PPP
- Lower accuracy (2-10 cm)

→ IGS is providing products for both challenges

Solid Earth:

Plate Tectonics ↔ Earthquakes

Long-Term Trends: Plate Tectonics, Global Velocity Field

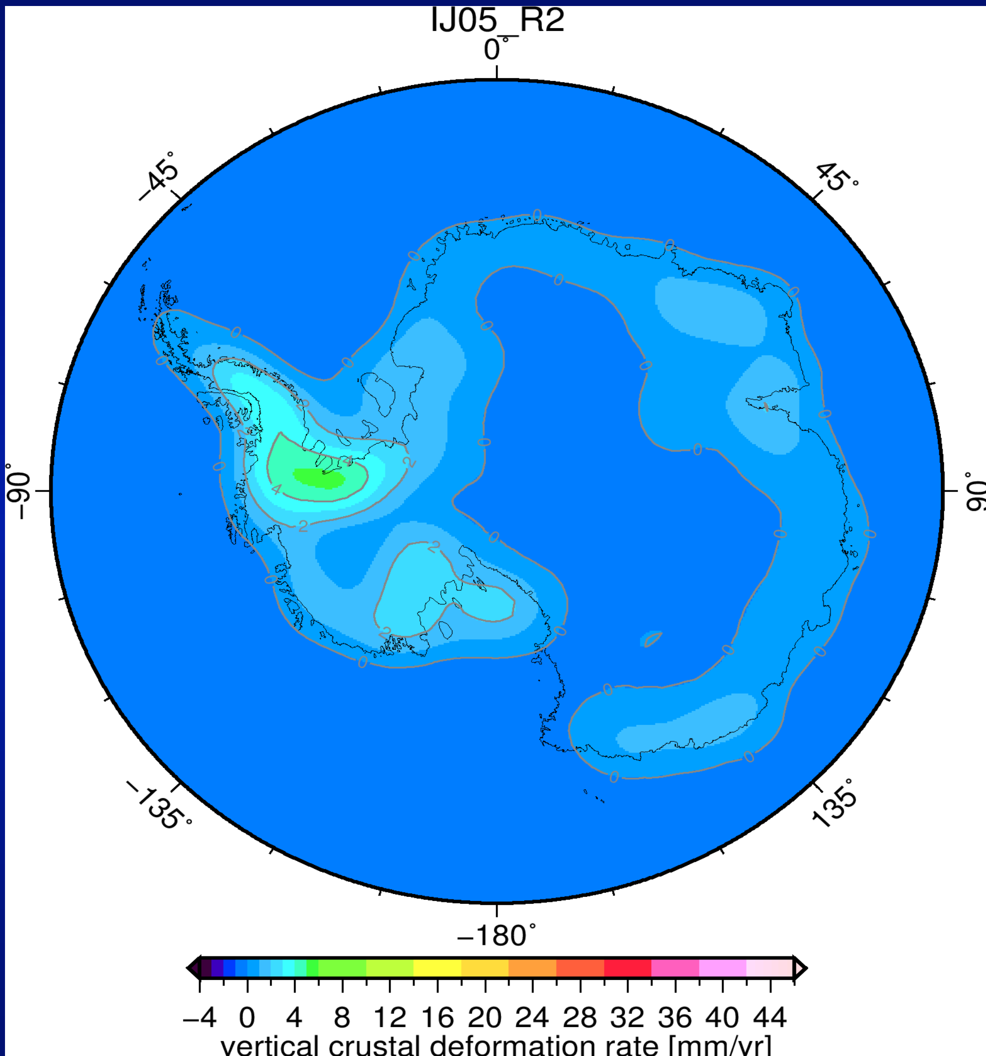


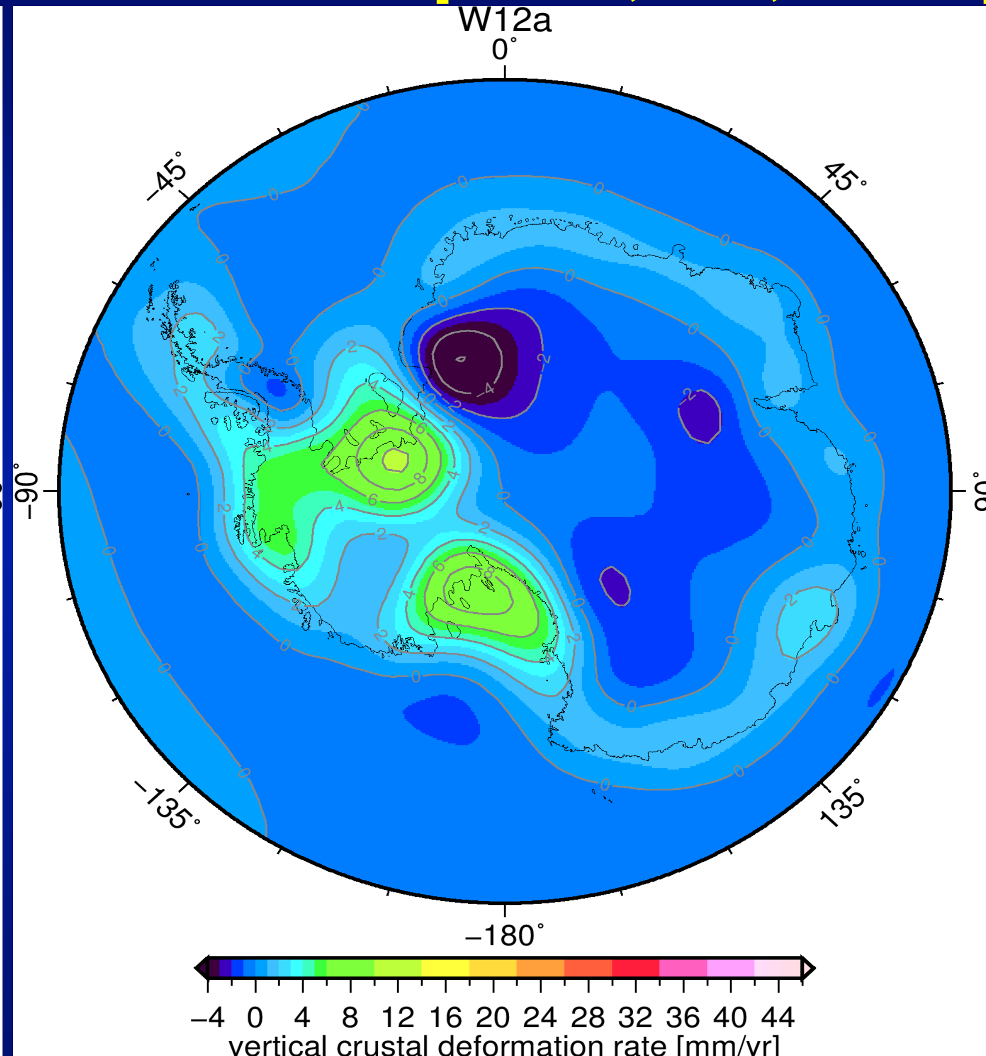
ITRF2008 **GPS Core networks**

[Bruyninx et al., 2011] IAG WG on Regional Dense Velocity Fields

Long-Term Trends: Vertical Crustal Deformation: GIA

[Dietrich, Groh, Fritsche]

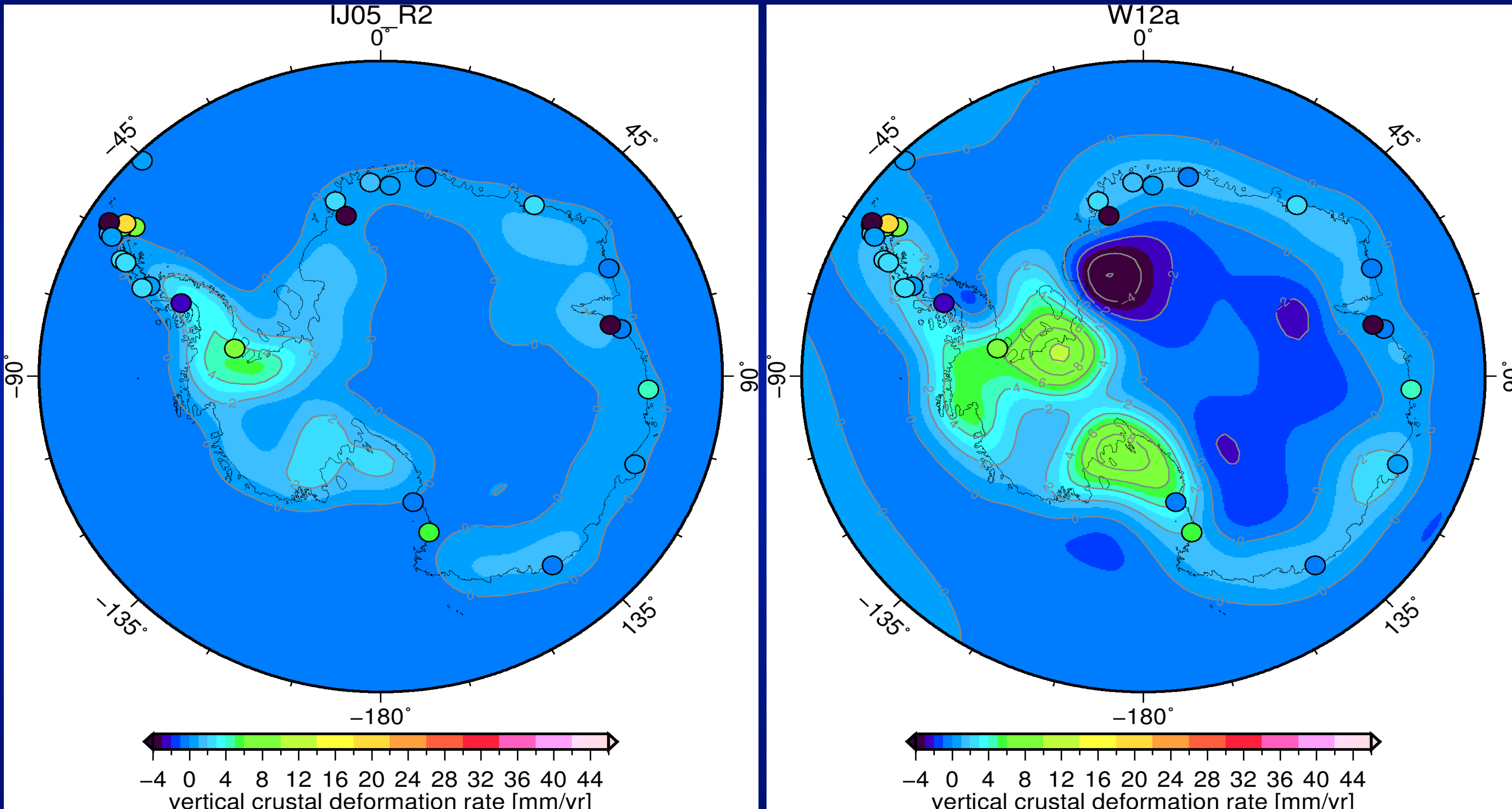




Ivins et al. (2013)

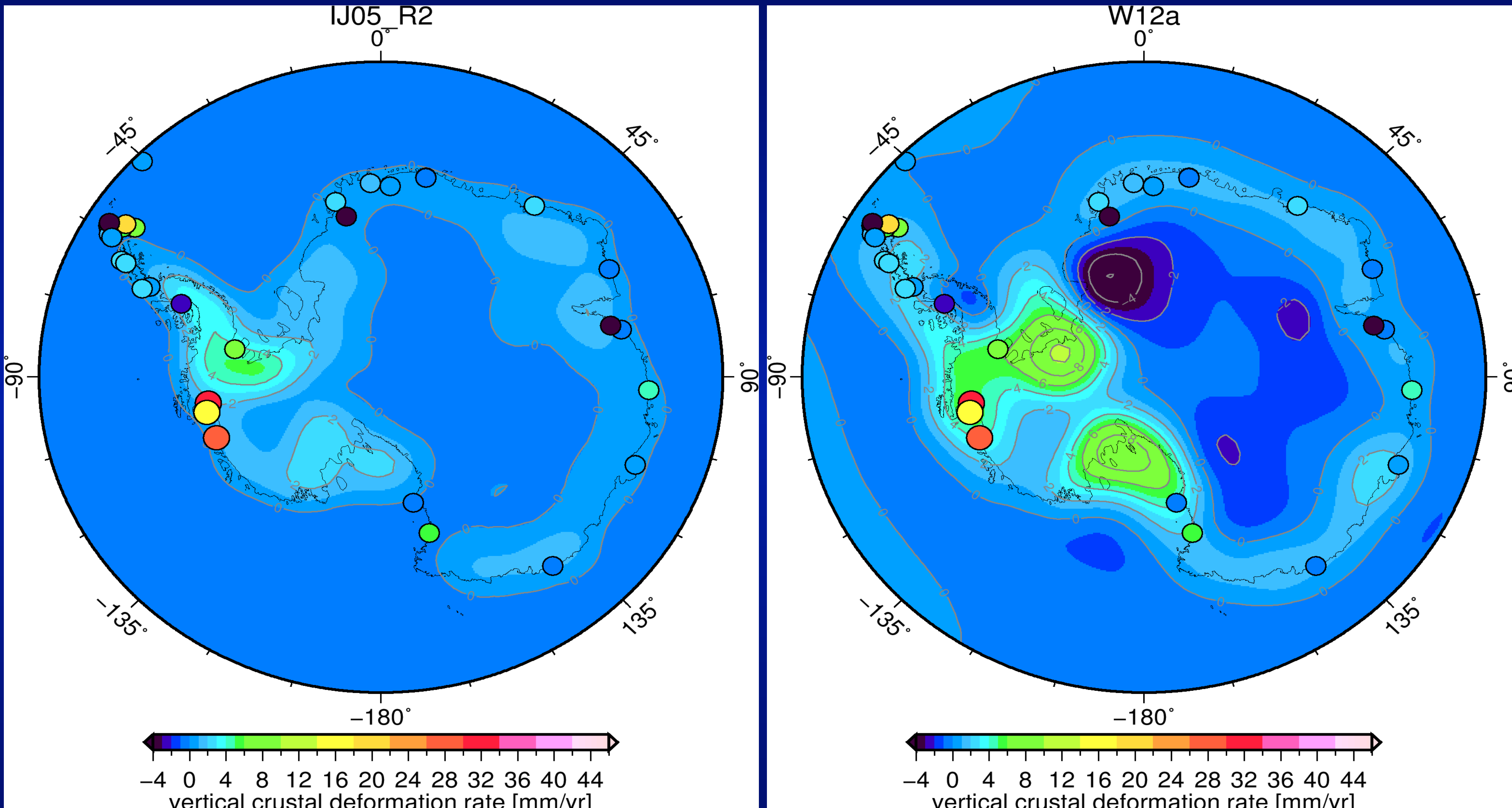
Whitehouse et al. (2012)

Vertical Crustal Deformation: GIA vs. GPS



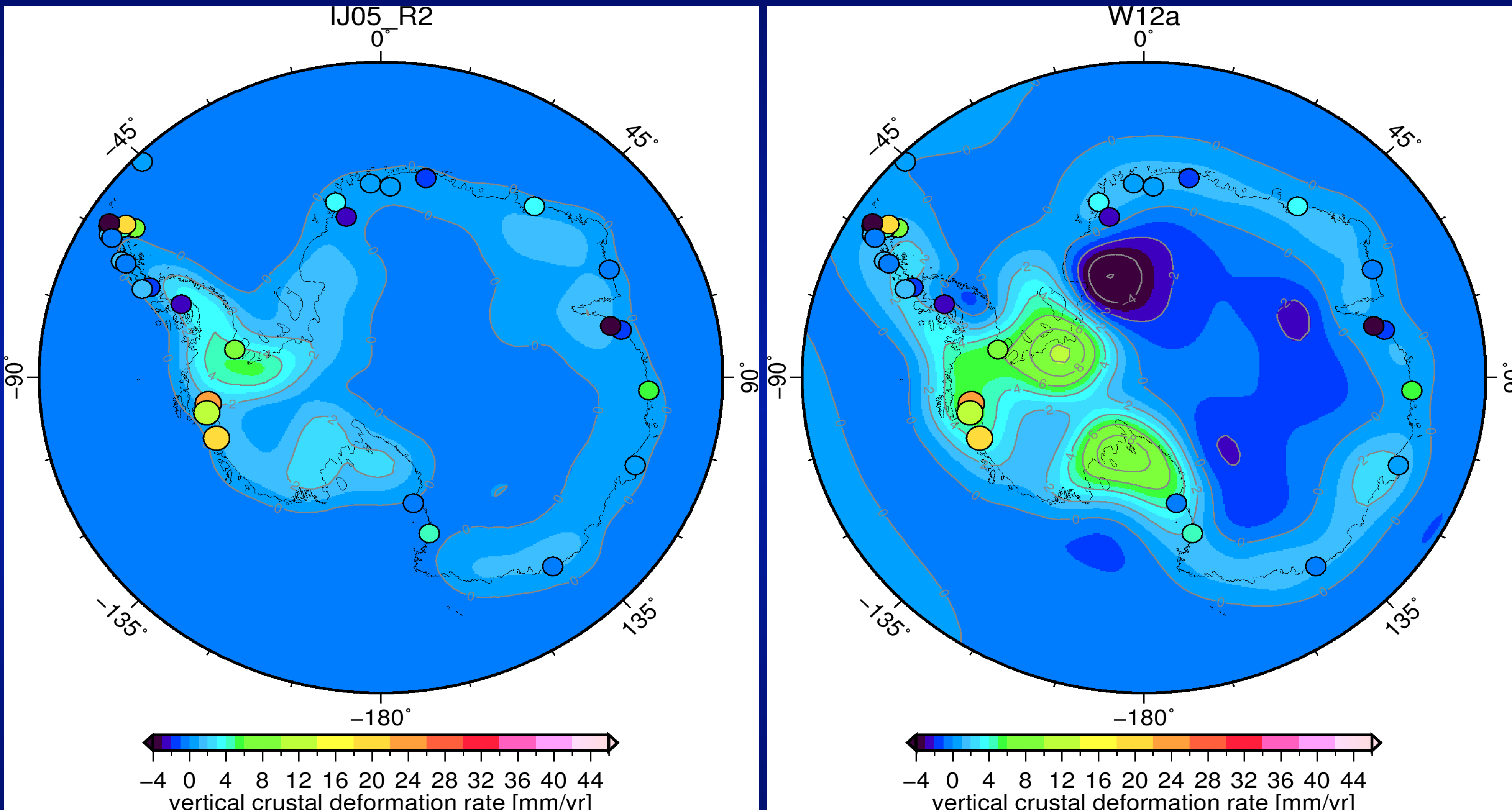
[Dietrich, Groh, Fritsche]

Vertical Crustal Deformation: GIA vs. GPS



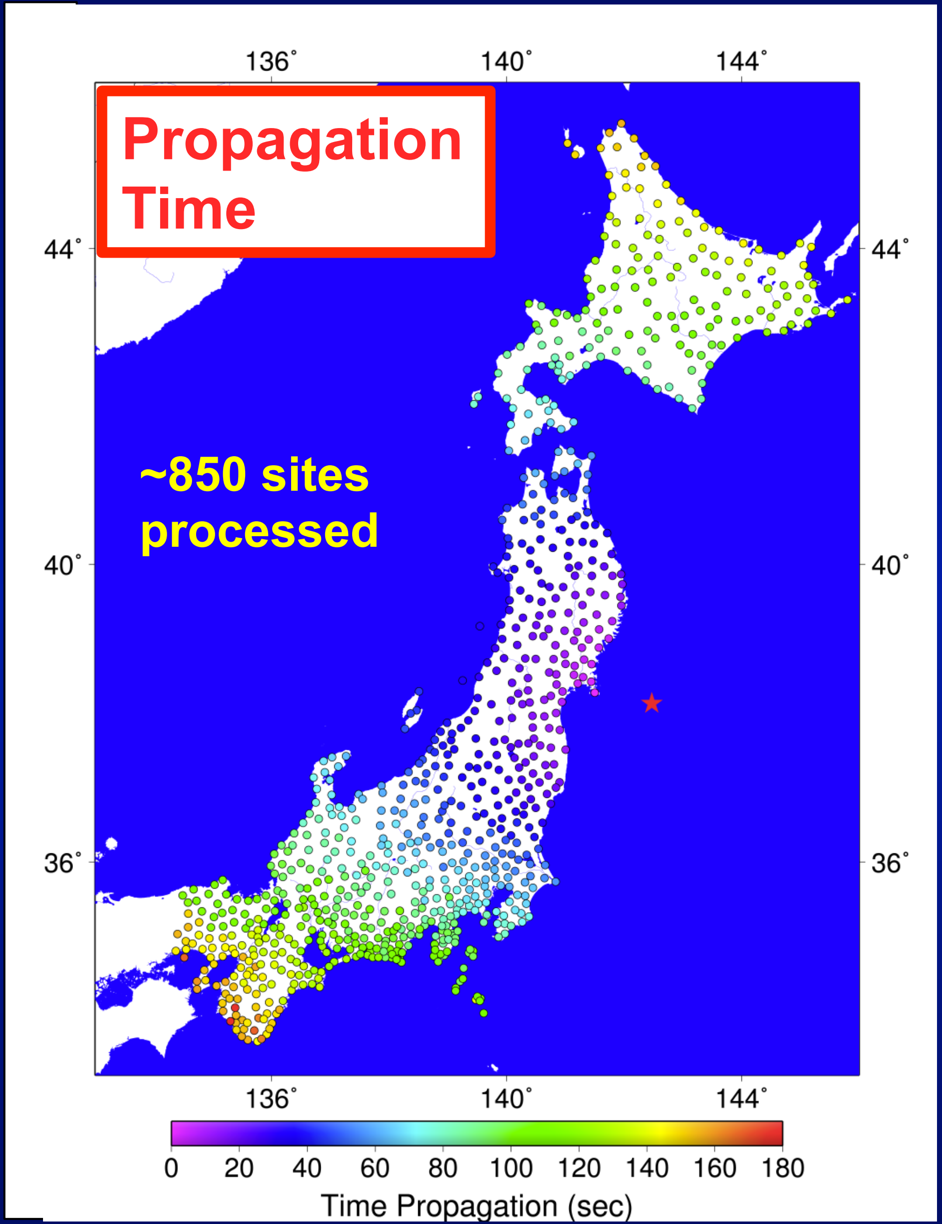
[Dietrich, Groh, Fritsche]

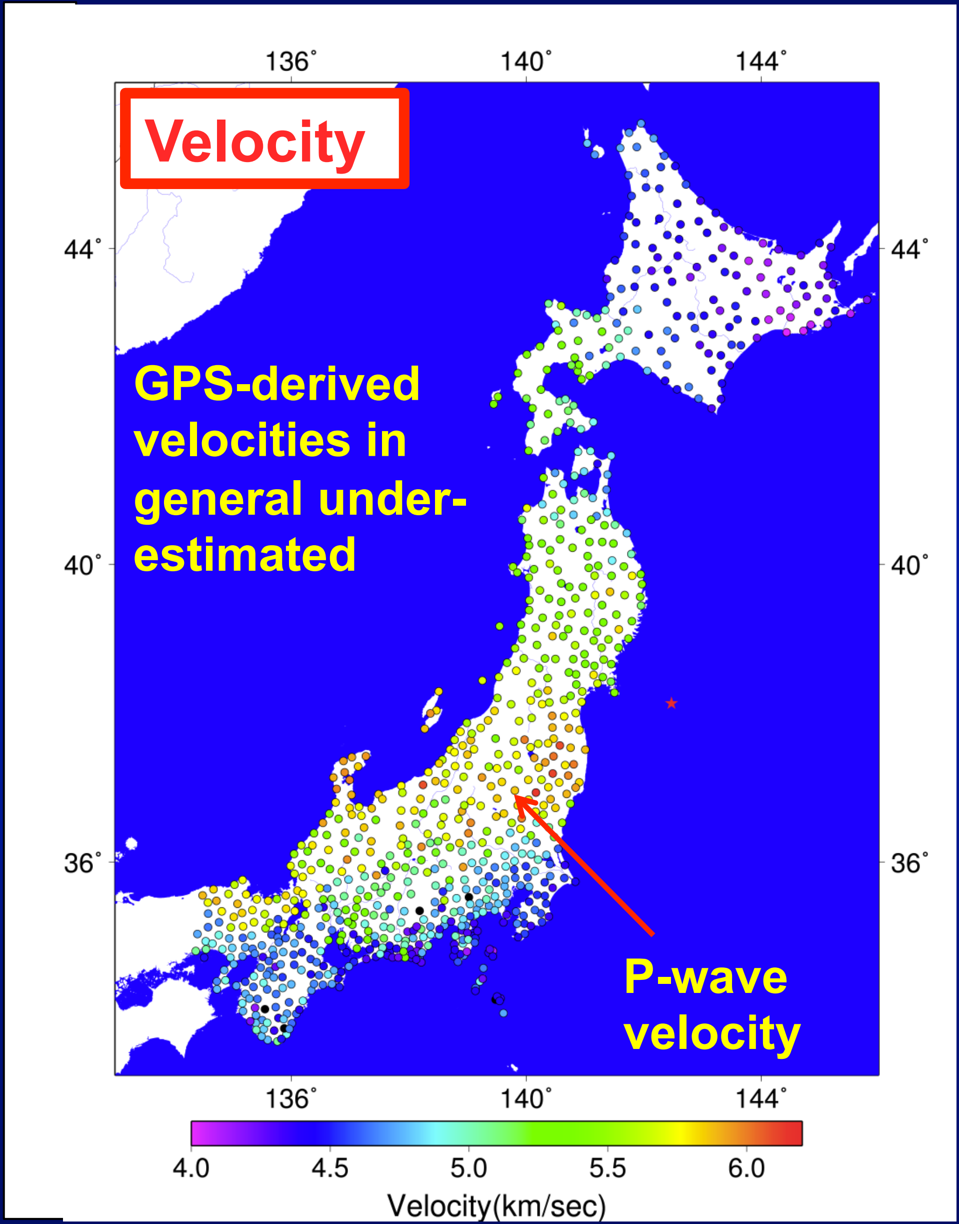
Vertical Crustal Deformation: GIA vs. GPS



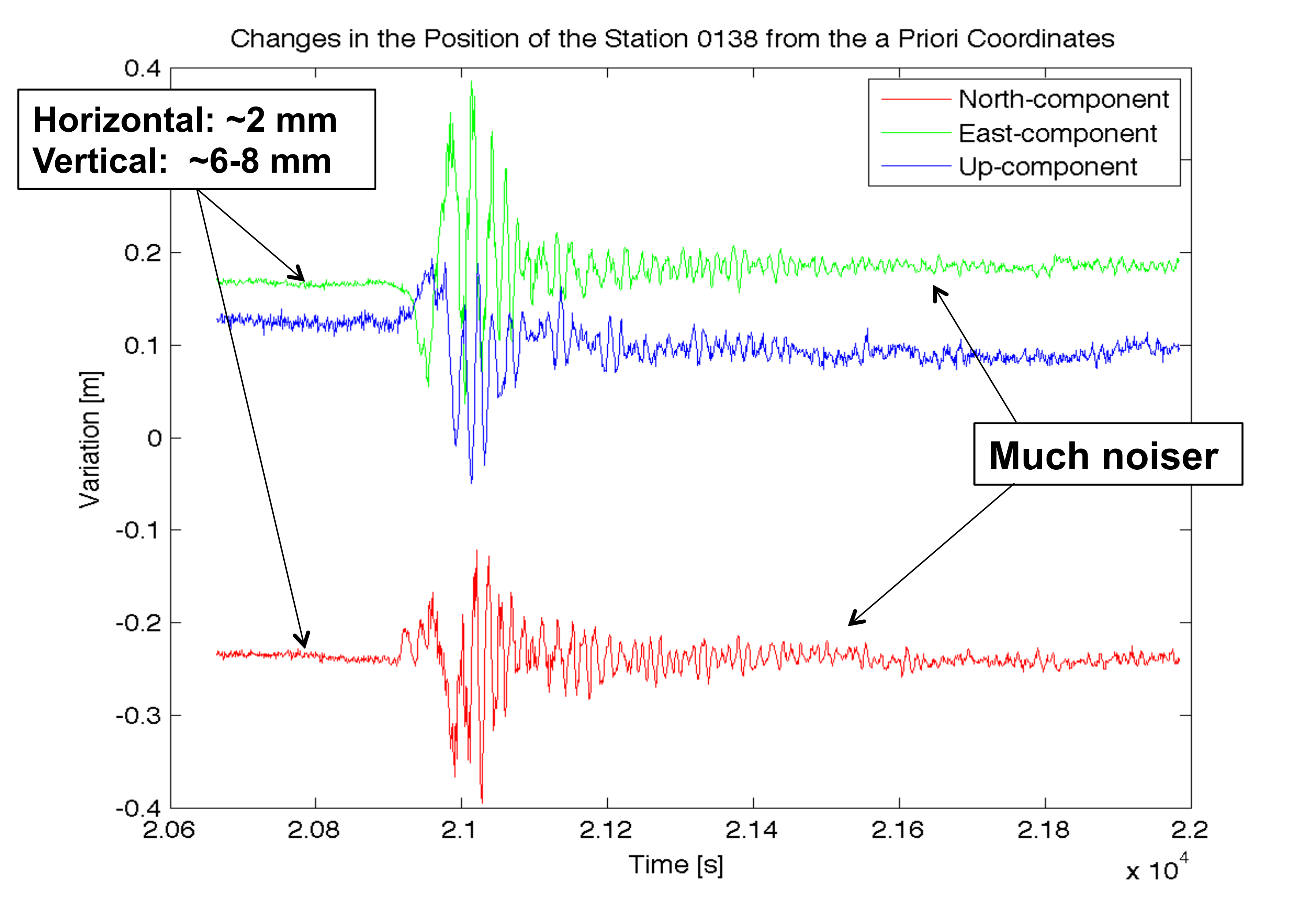
elastic correction applied for current mass loss **[Dietrich, Groh, Fritsche]**

Fast Detection: Tohoku-Oki with 1Hz PPP

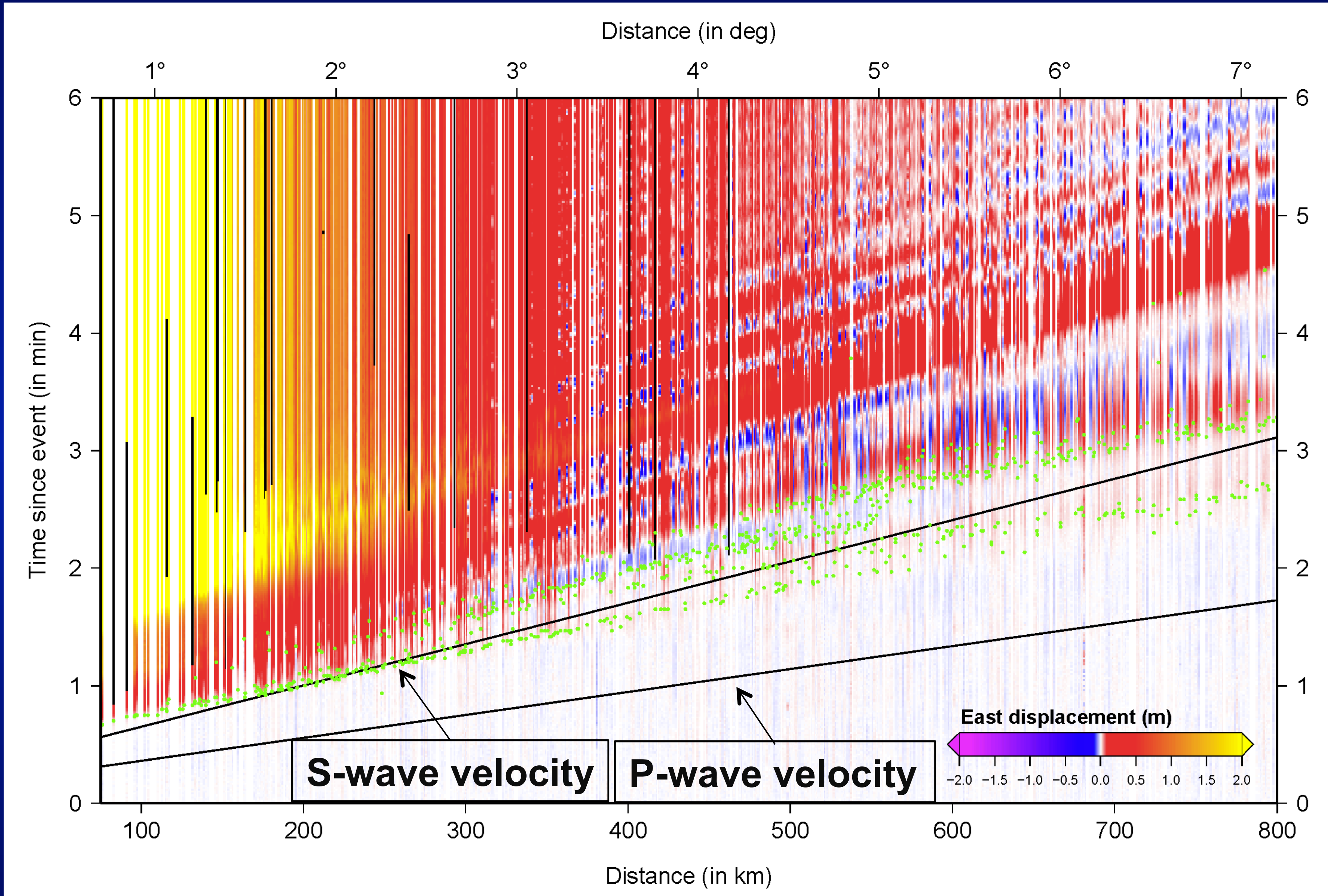




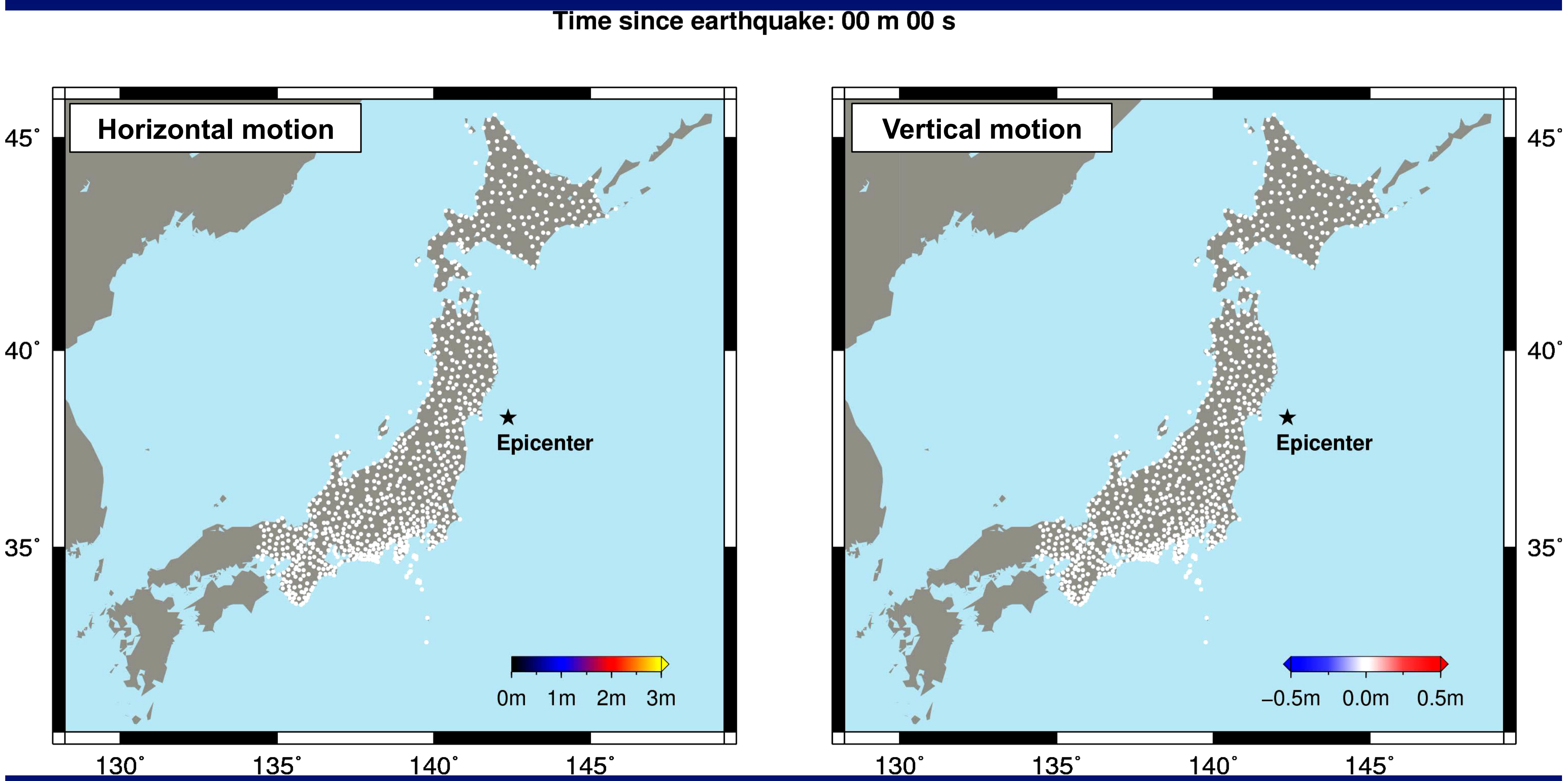
Example of the kinematic GPS Results with PPP



Tohoku-Oki Earthquake: East Displacements and Waves



Fast Event Detection: Closer and Closer to Real-Time
Earthquake ground displacements with GNSS, early warning



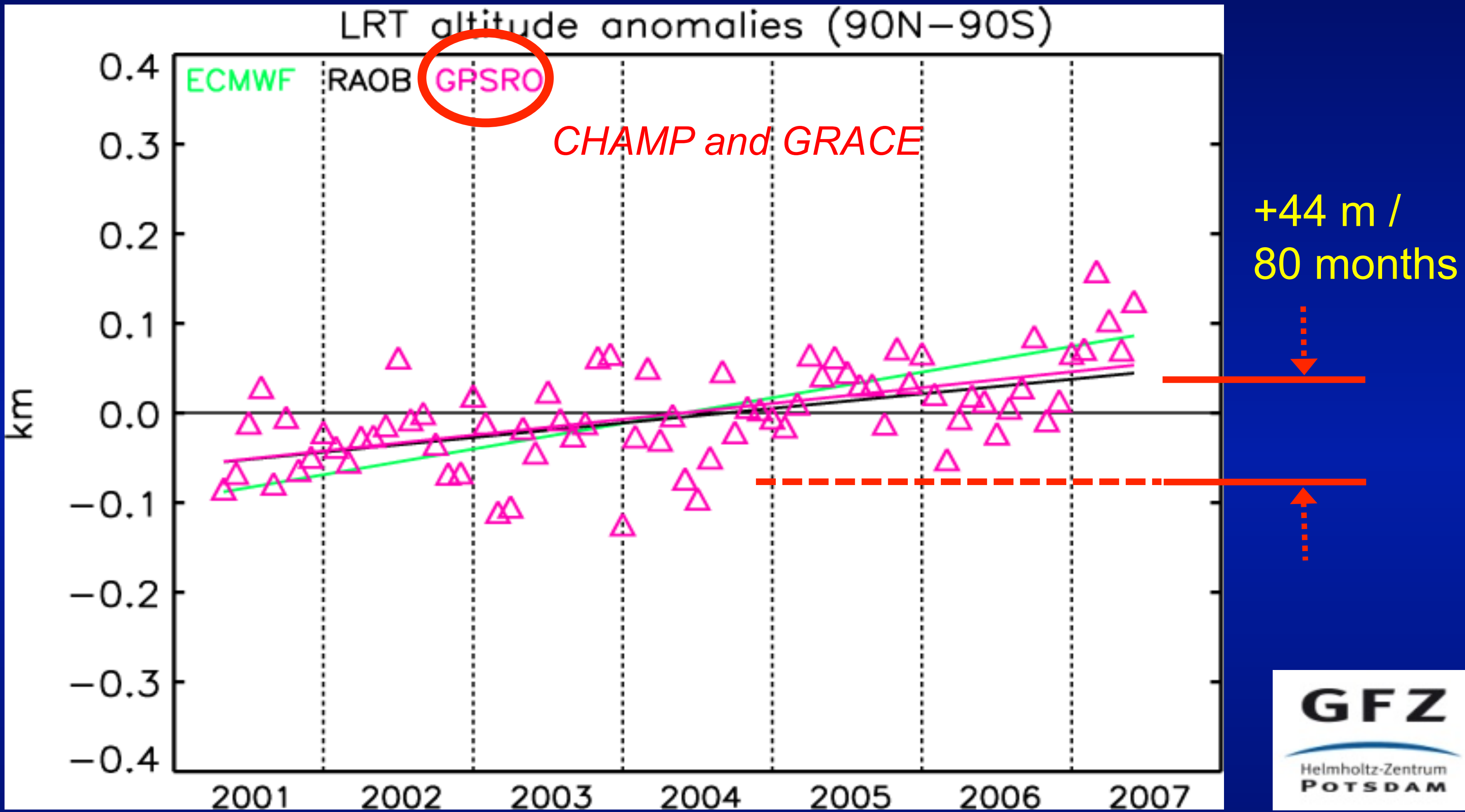
GPS 1-Hz, Tohoku-Oki earthquake

G. Blewitt et al., GRL, 2006 → rapid magnitude determination etc.

Atmosphere:

„Climate“ ↔ Weather Forecast

Reliable Detection of Long-Term Trends: Climatology: Height of the Tropopause



GFZ Helmholtz-Zentrum Potsdam

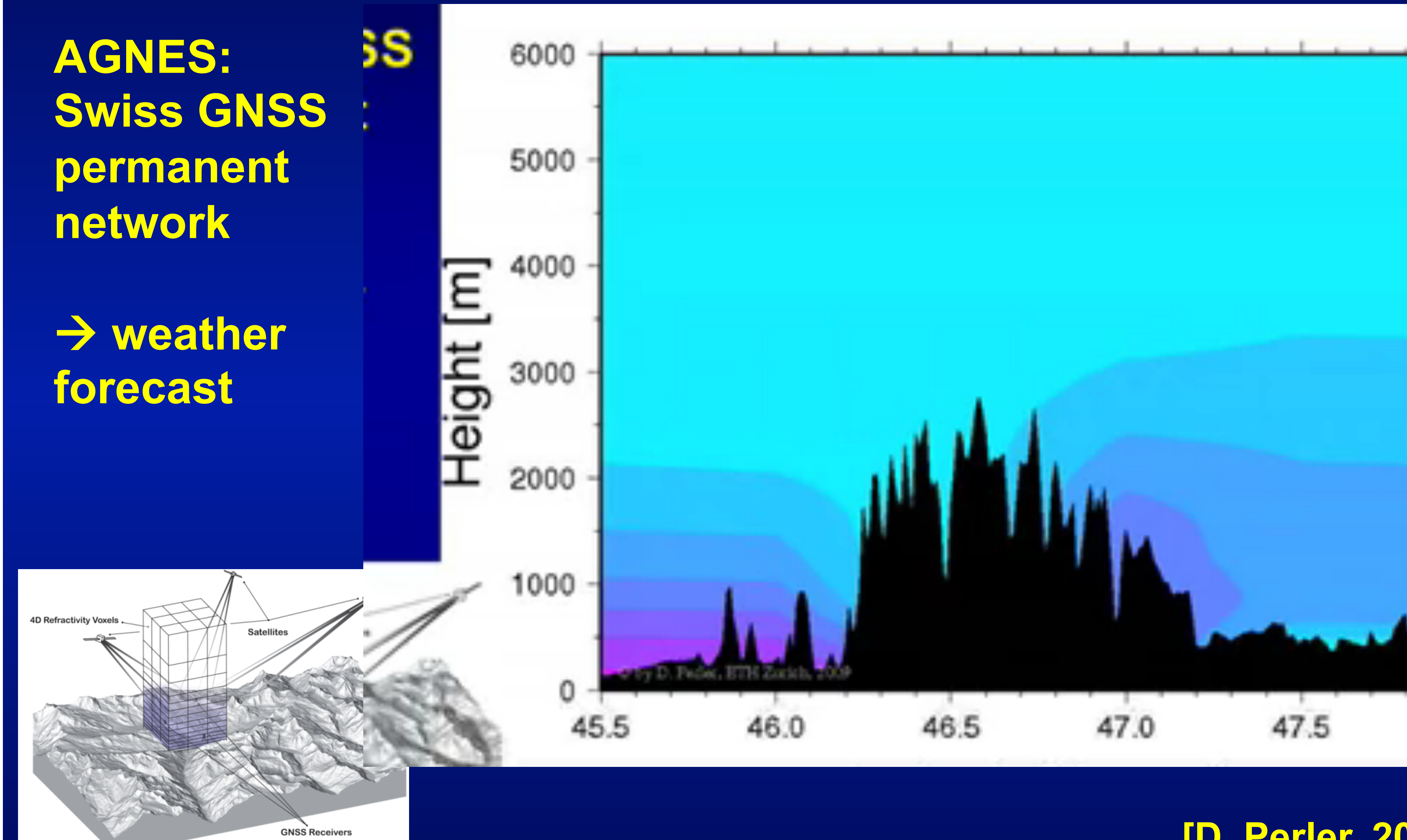
Increase ~66 m/decade, in agreement with global RS data (e.g. Seidel/ Randel 2006, ~64 m/decade 1980-2004)

[Schmidt et al, 2008]

Fast: Water Vapour Tomography with Ground-Based GPS

AGNES: Swiss GNSS permanent network

→ weather forecast



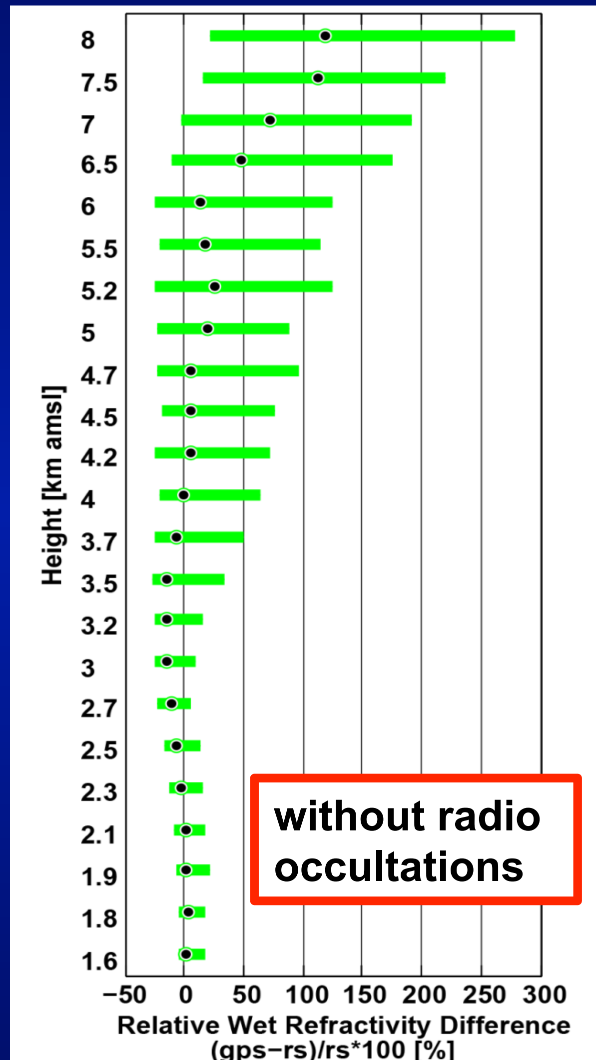
[D. Perler, 2011]

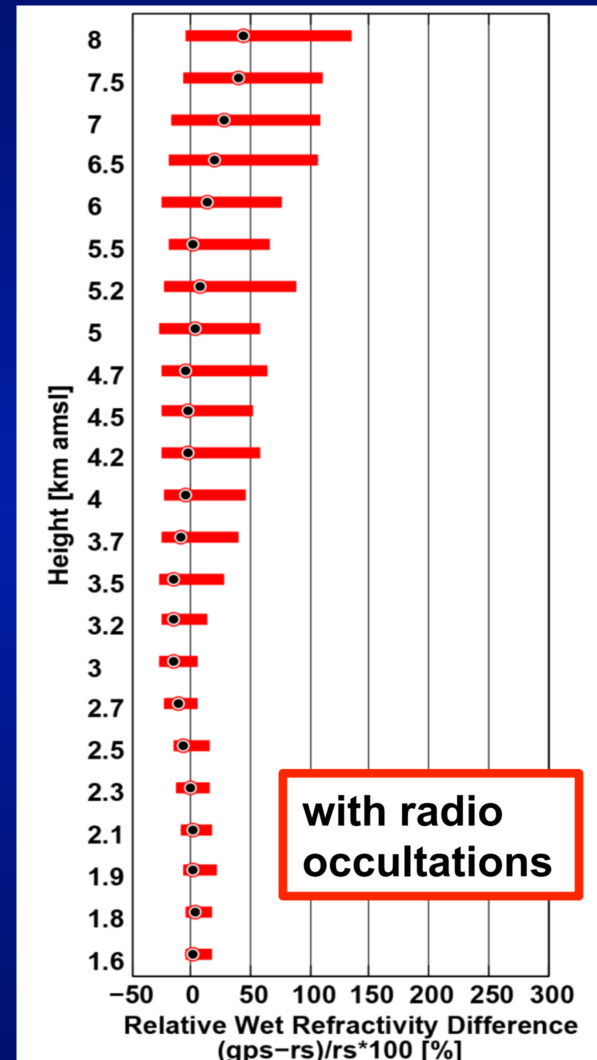
Combination of Water Vapor Profiles from Ground-Based GPS with Radio Occ.

Comparison with radiosonde data at Payerne in Switzerland: 2132 profiles over 3 years

IGS Final Orbits used for both, ground-based GNSS tomography and GNSS radio occultations

GPS + Ground meteo

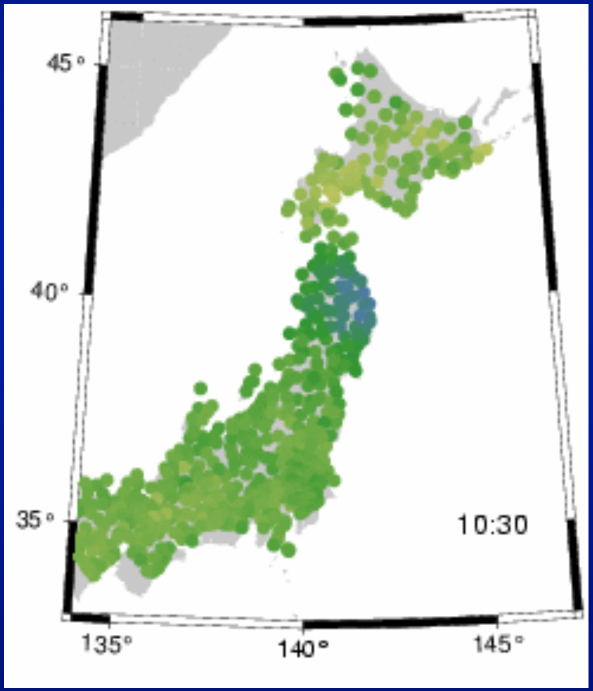




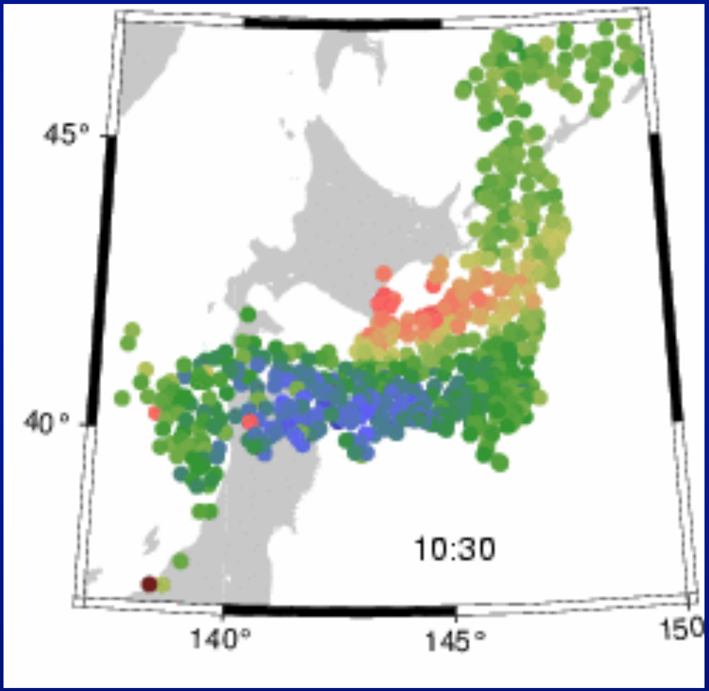
[F. Hurter & O. Maier, 2013]

Fast Detection: Earthquake Visible in the Ionosphere

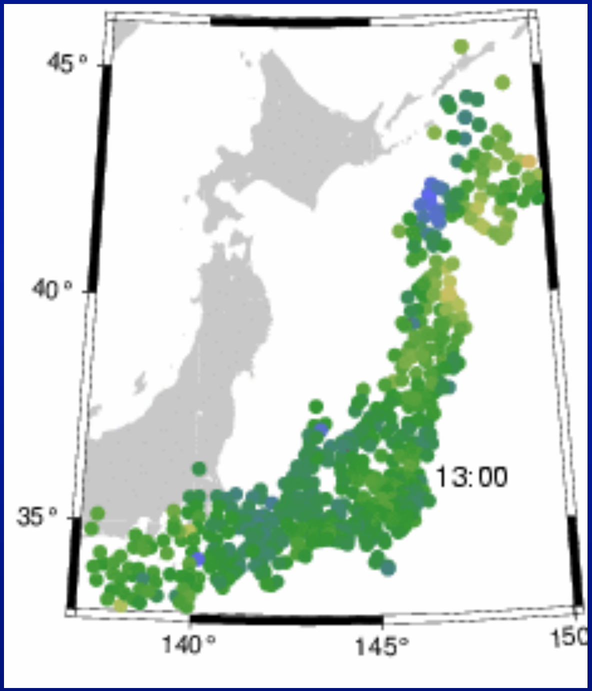
- Co-seismic accustic waves propagating through the ionosphere
- 2003 Tokachi-Oki earthquake, Hokkaido (Mw=8.0)
- Ionospheric delays for different satellites, stations of the Japanese GEONET



SVN 24



SVN 13



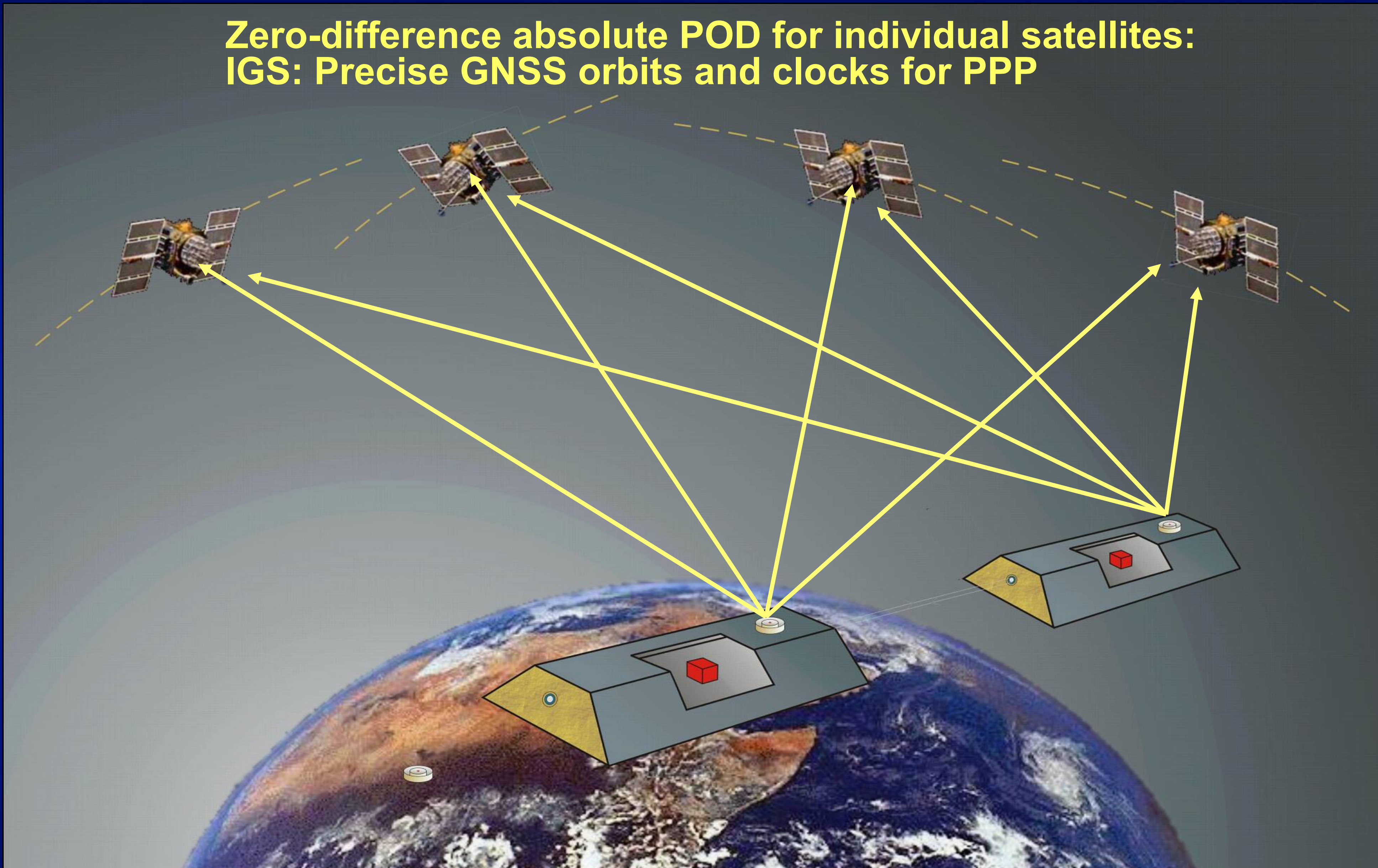
SVN 27

Precursors of large earthquakes [K. Heki, 2011] ?

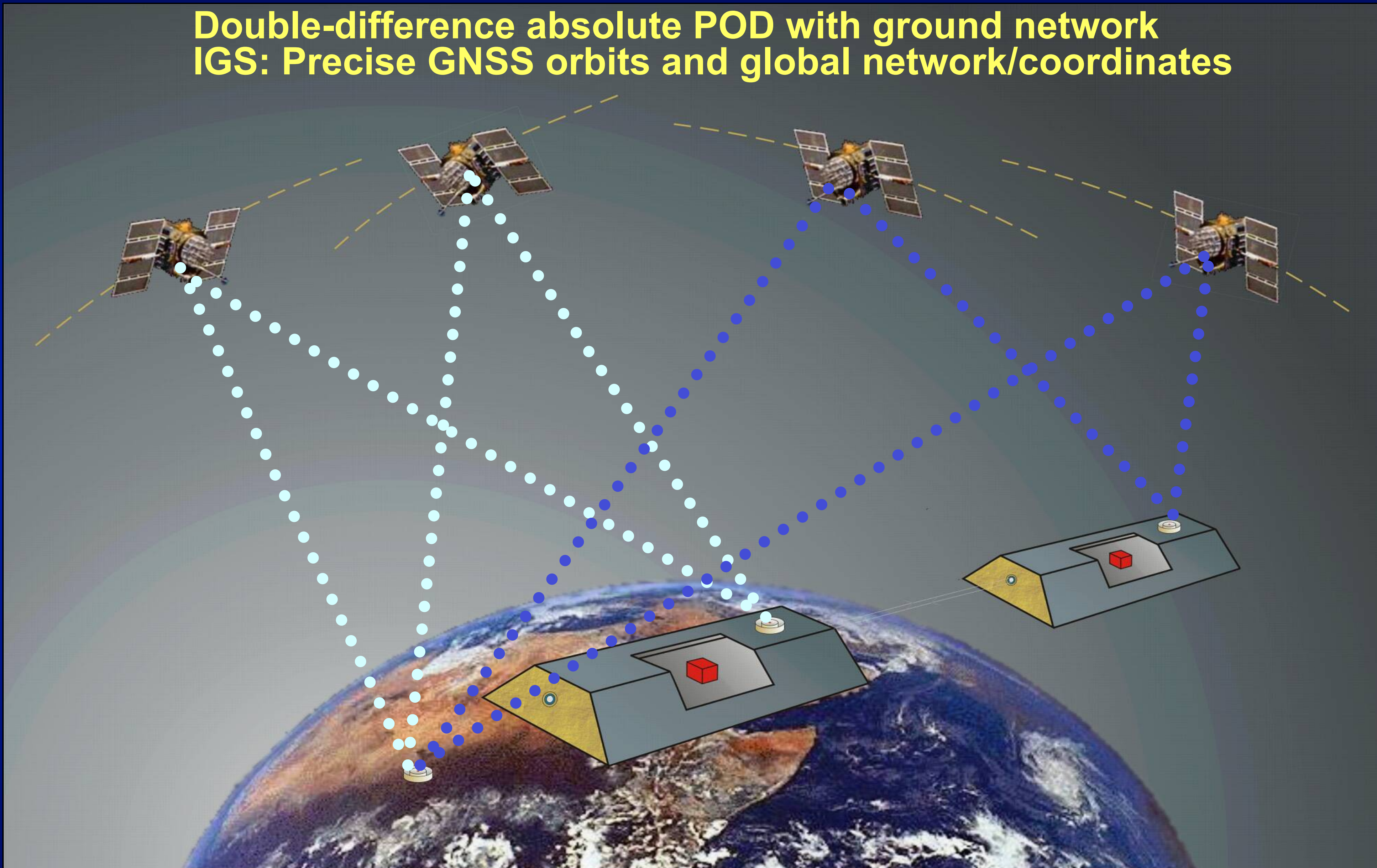
[K. Heki, 2009]

Precise Orbit Determination

Precise Orbit Determination Strategies (GRACE)

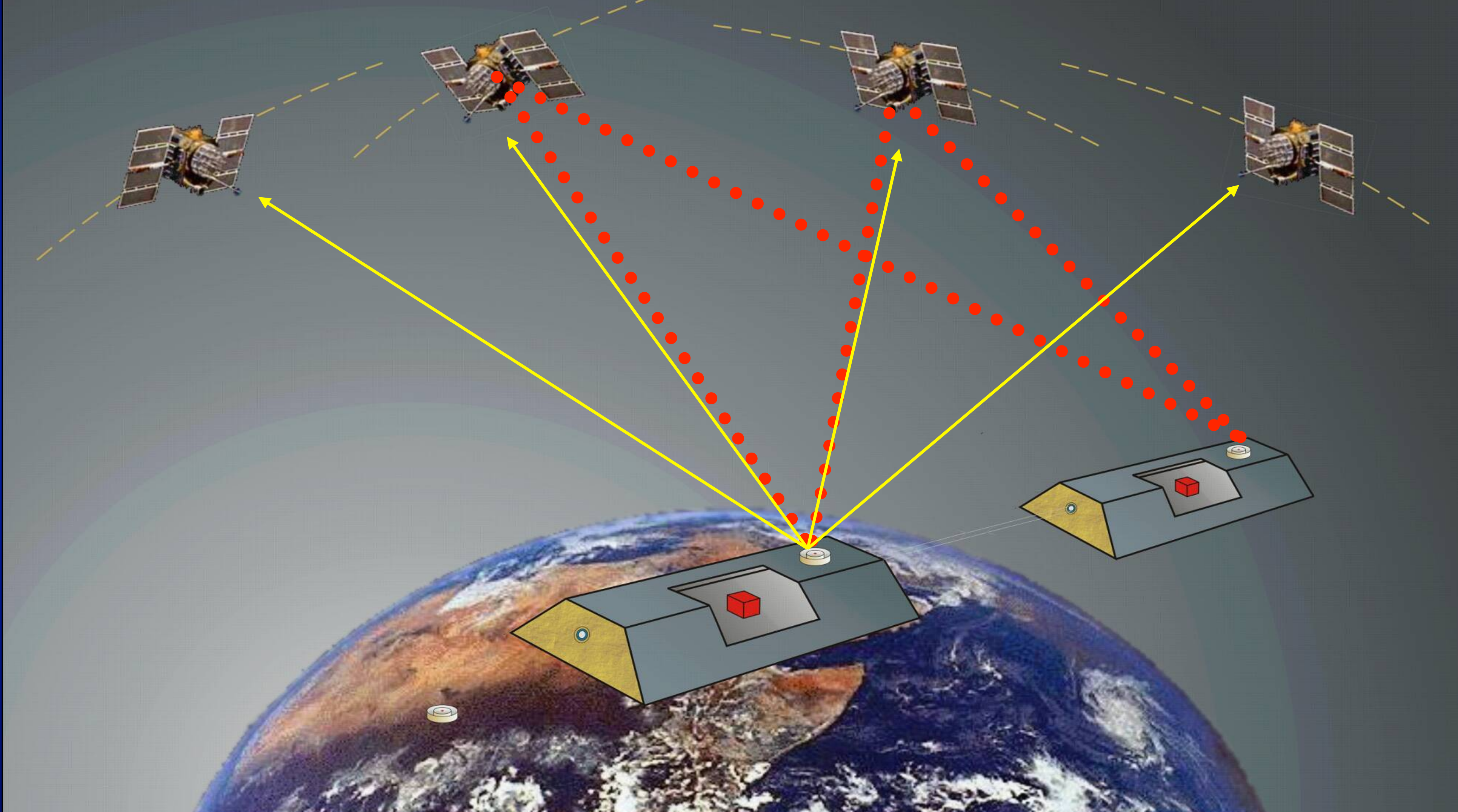


Precise Orbit Determination Strategies (GRACE)

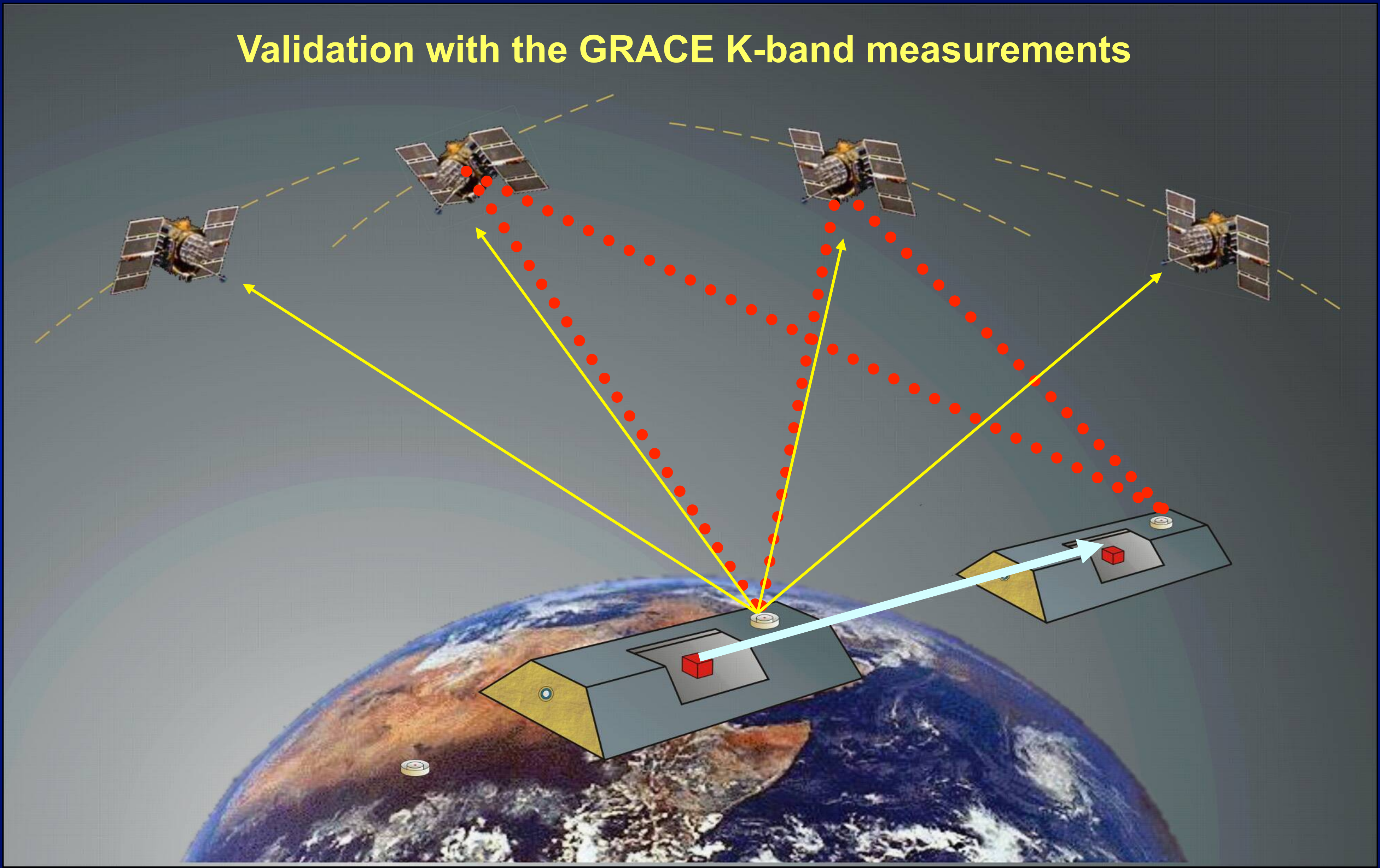


Precise Orbit Determination Strategies (GRACE)

Combined zero (absolute) & double-difference (relative) POD:
IGS: Precise GNSS orbits and clocks



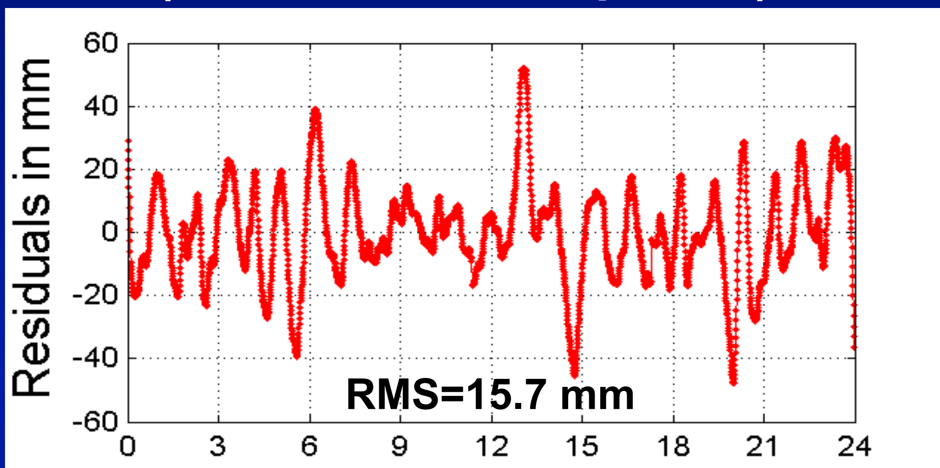
Precise Orbit Determination Strategies (GRACE)



GRACE Orbits from GPS

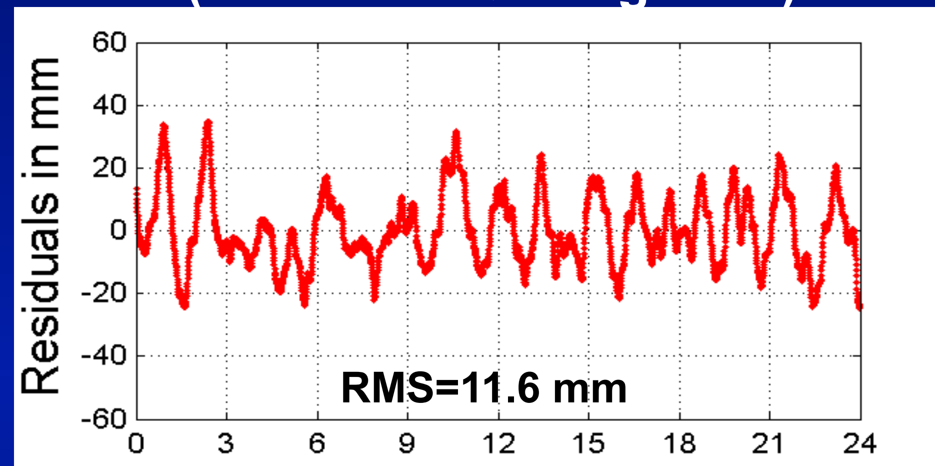
Validation with K-band measurements

Zero-difference orbits
(GRACE A & B separate)



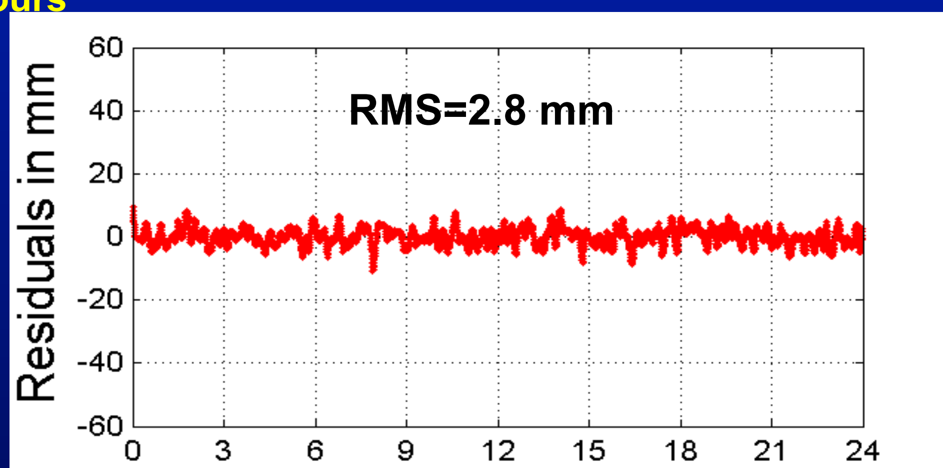
Time in hours

Baseline with Float ambiguities
(GRACE A & B together)



Time in hours

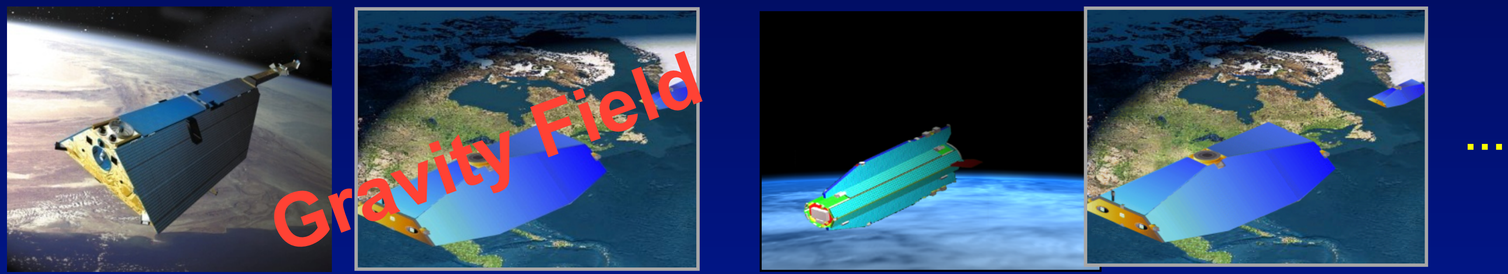
Baseline with Fixed ambiguities (GRACE A & B together)



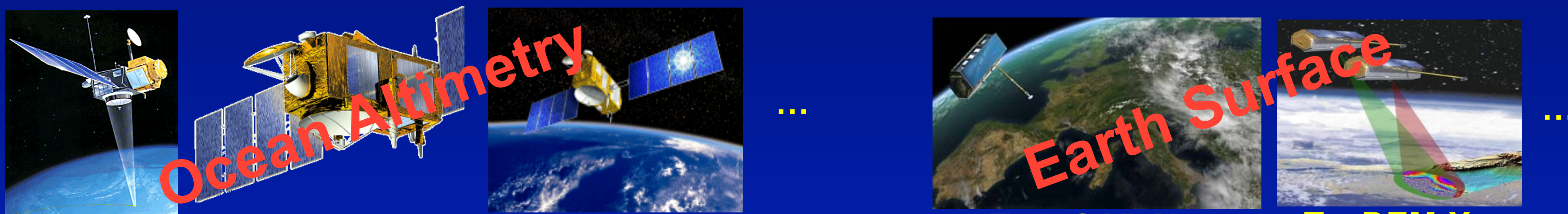
[D. Svehla, 2004]

Even more refined methods lead to 1mm accuracies (Montenbruck, Jäggi, …)

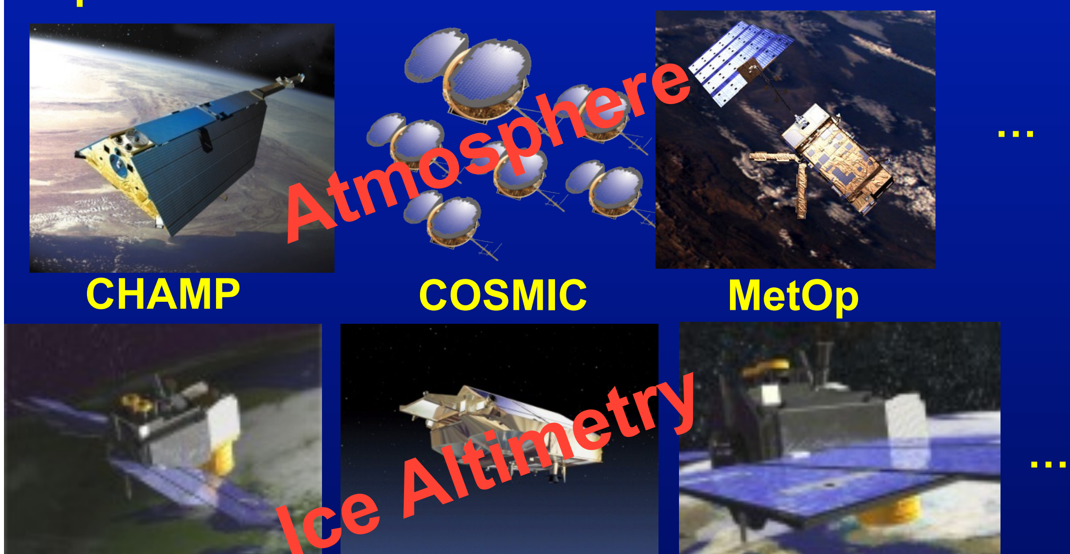
Precise Orbit Determination enabled by the IGS



CHAMP GRACE GOCE GRACE Follow-on ?



Topex/Pos. JASON-1 JASON-2 TerraSAR-X TanDEM-X



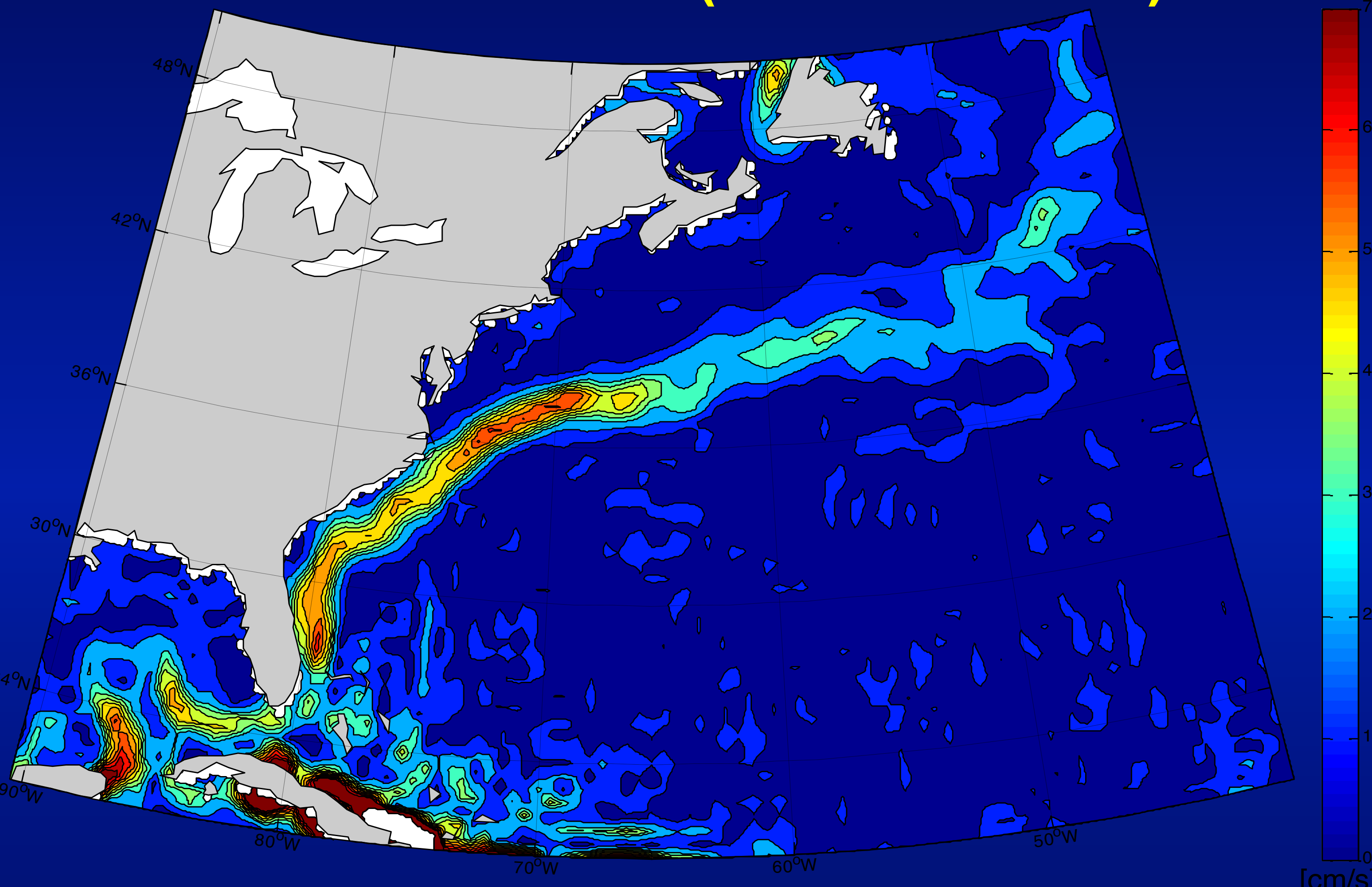
CHAMP COSMIC MetOp

IceSat-1 Cryosat-2 IceSat-2

Precise orbit determination based on IGS products is a pre-requisite for many satellite mission

Former IGS WG on LEO POD

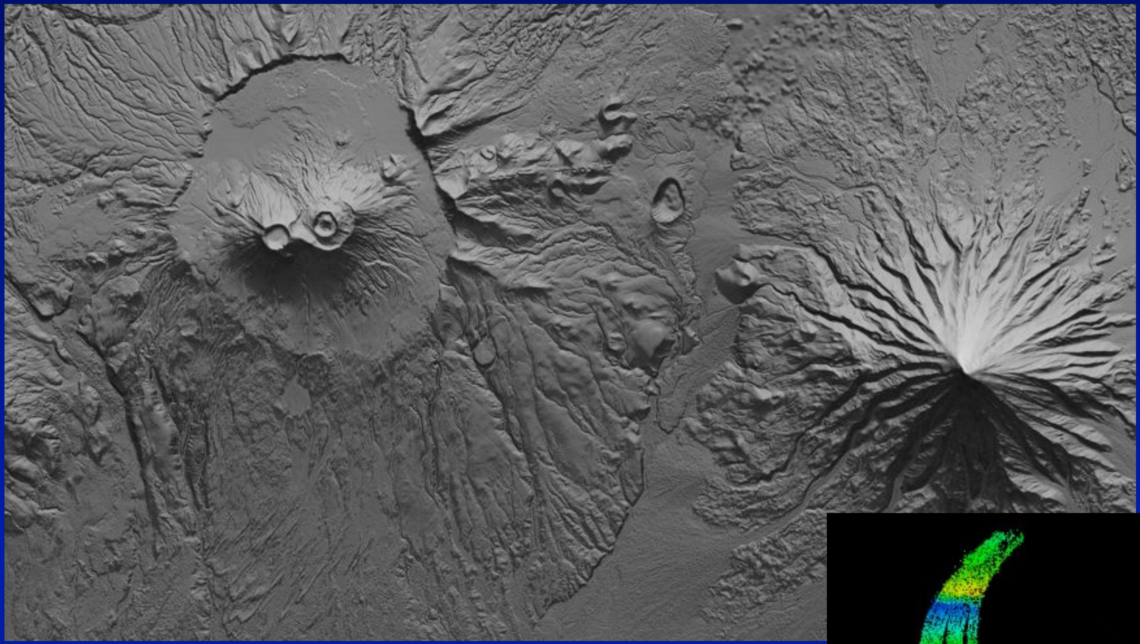
Example GOCE and Satellite Altimetry: Golf Stream (North Atlantic)



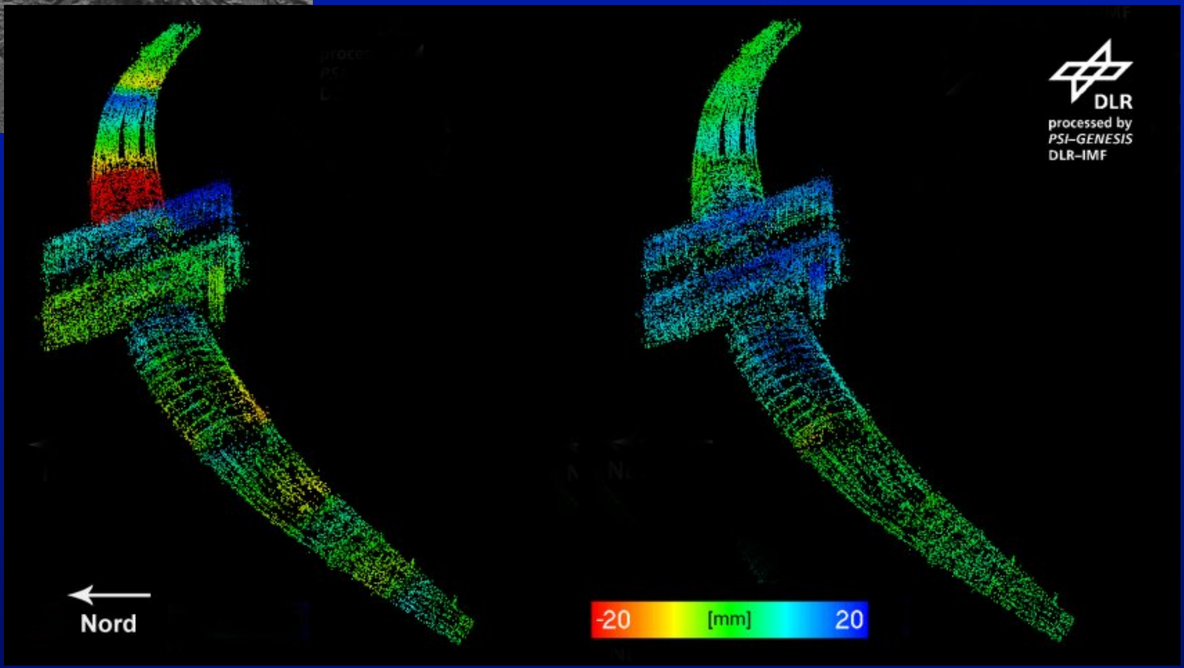
Geostrophic current velocities: difference between GOCE geoid and mean sea surface topography from satellite altimetry

[IAPG, TU Munich]

Example TanDEM-X – TerraSAR-X: DEMs / Deformation



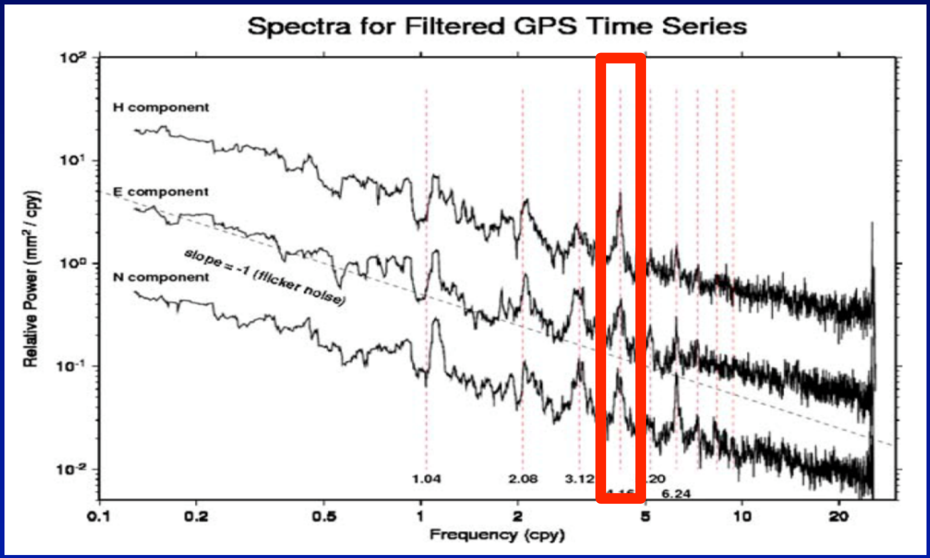
Elevation model of the volcanoes on the Russian Kamchatka Peninsula (image credit: DLR)



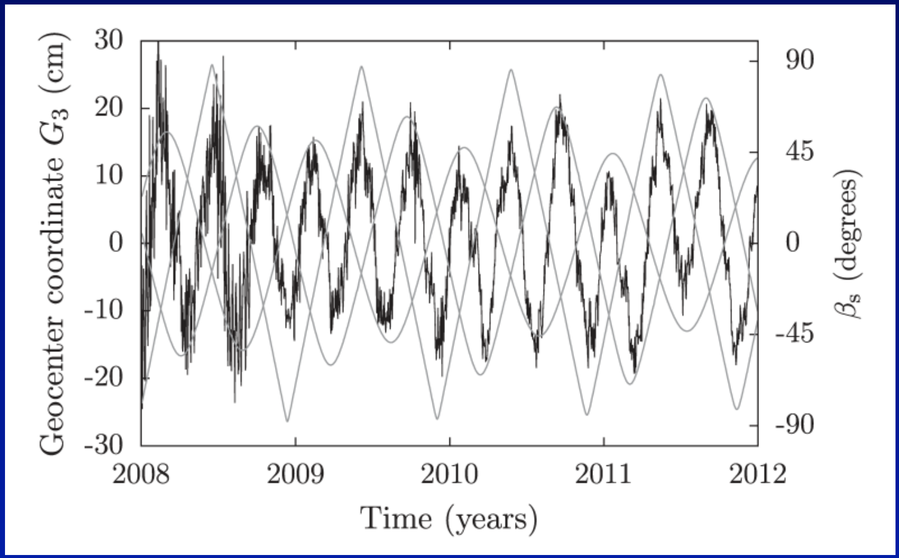
New Main Station in Berlin: seasonal deformation due to temperature changes (image credit: DLR)

Challenges for small trends and fast detection

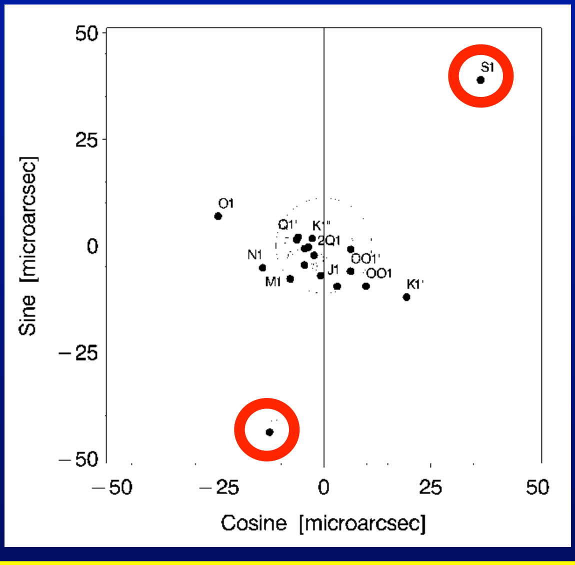
Small Trends: GNSS Orbit Model Deficiencies



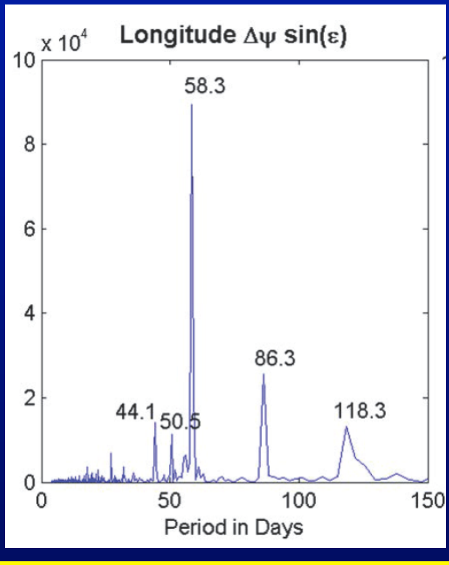
Draconitic periods in site coordinates [Ray et al., 2007]



Draconitic periods in geocenter coordinates from GLONASS [Meindl et al., 2013]



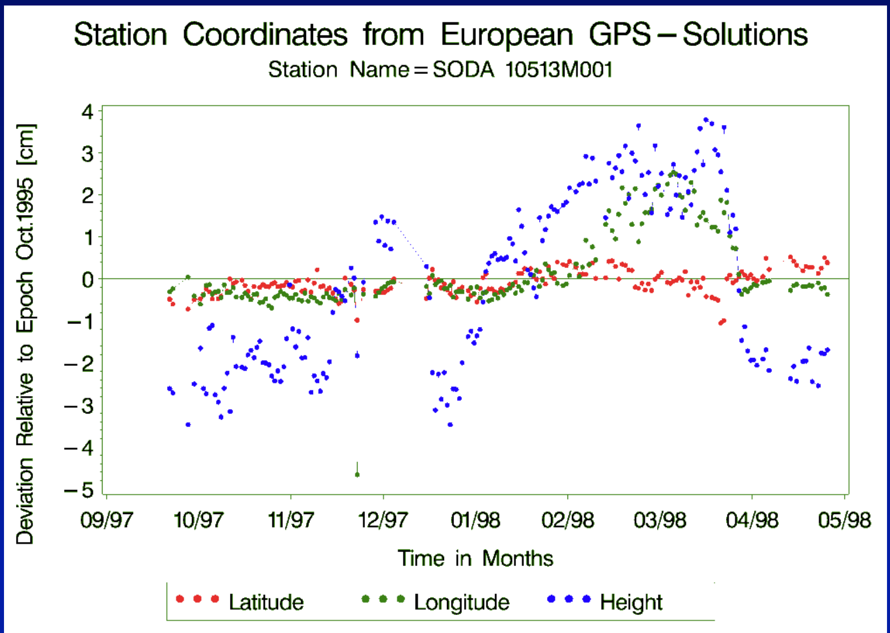
Deviations in ERP tidal terms from GPS around 24 hours [Rothacher et al., 2001]



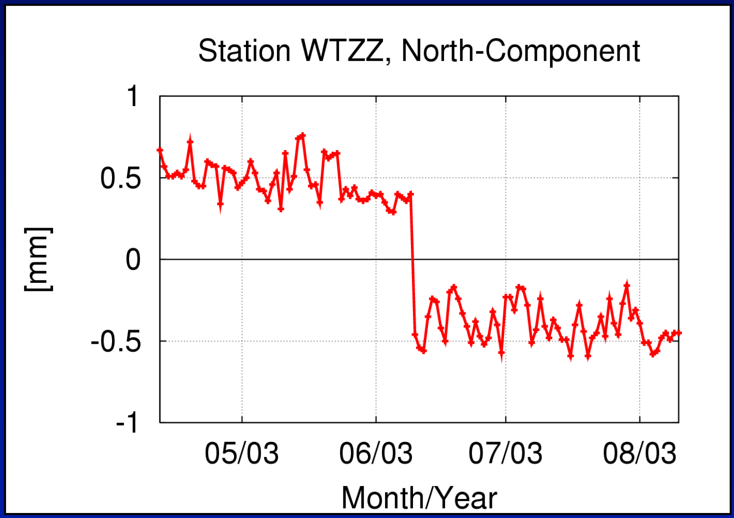
Draconitic periods in nutation rates from GPS
6·58.3 ≈ 351 days

→ Detailed modelling, use of high-precision clocks, accelero-meters onboard Galileo

Smalll Trends: Equipment Changes, Environmental Effects



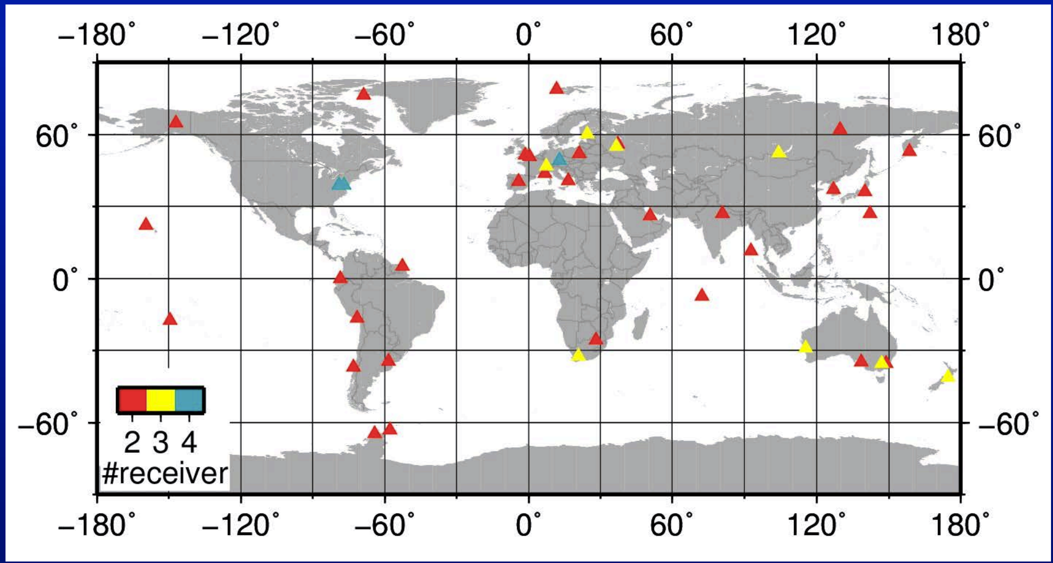
Finland: snow on the antenna



Monitoring with sub-millimeter level (between 0.1-0.2 mm for all comp.)

50% of GNSS sites in ITRF have discontinuities

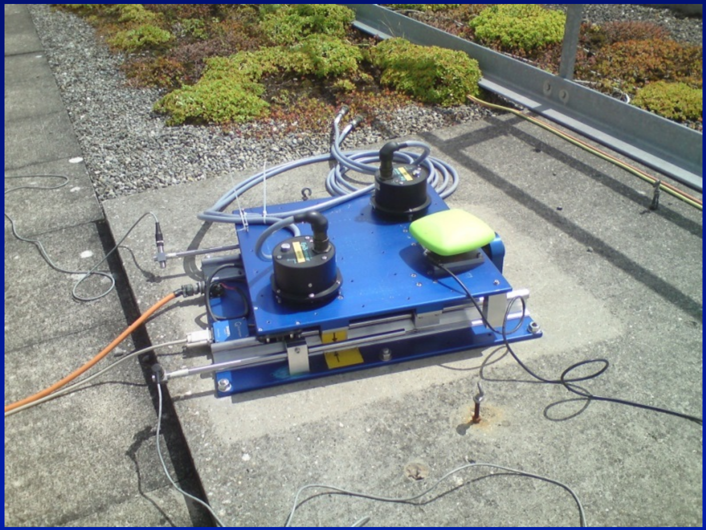
- → 3 antennas/receivers to monitor the relative positions
- → P. Steigenberger, T. Herring



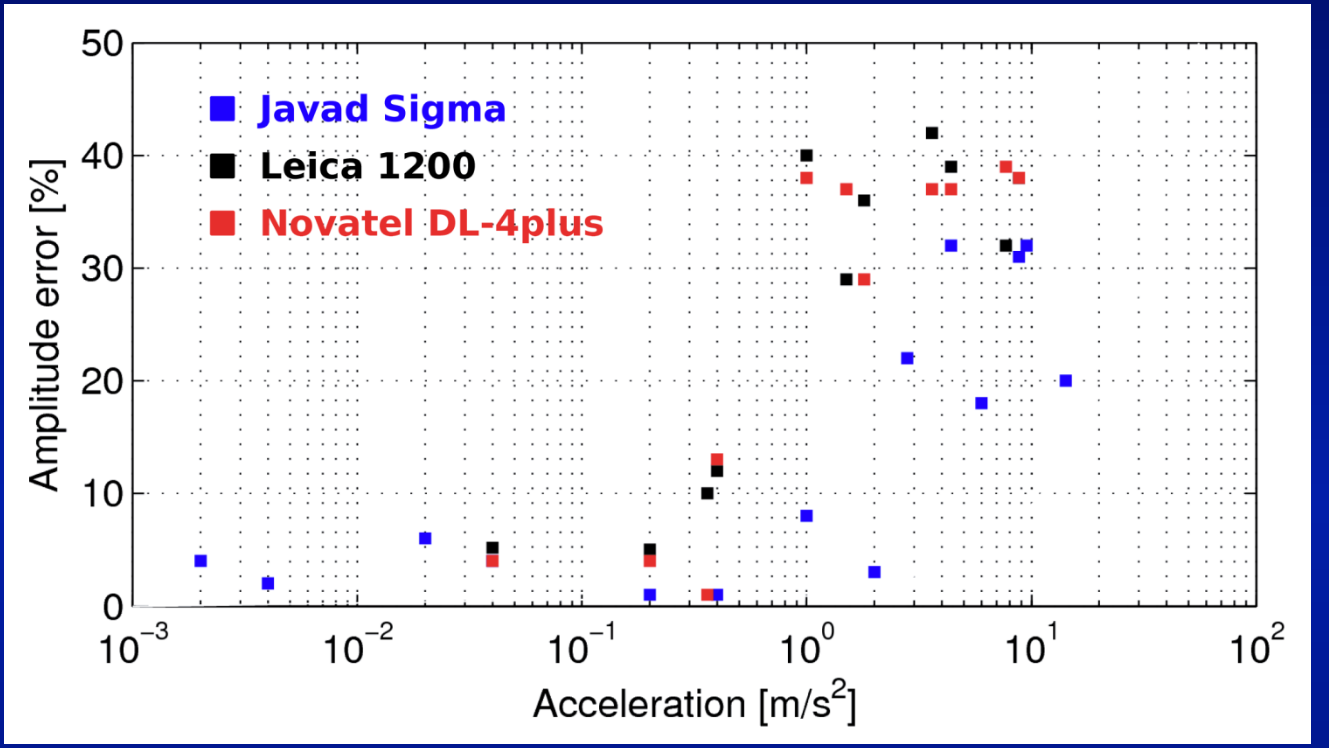
About 40 sites now in the IGS with 2 or more antennas/receivers

Geodetic GNSS Receivers are not All-Purpose Sensors

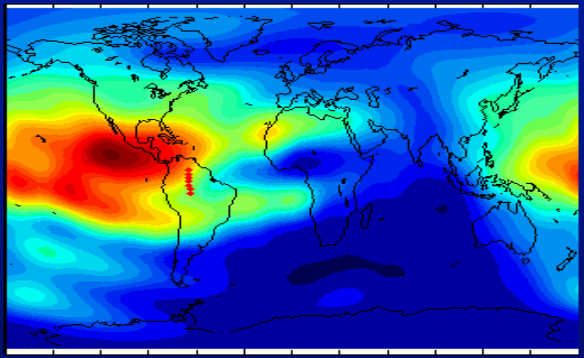
Shake table results: retrieval of sine signals



Shake table for 1-D earthquake simulation



Significant amplitude errors for all receiver types



Ionosphere scintillations

→ To be considered when equipping IGS sites as part of a **multi-purpose network**

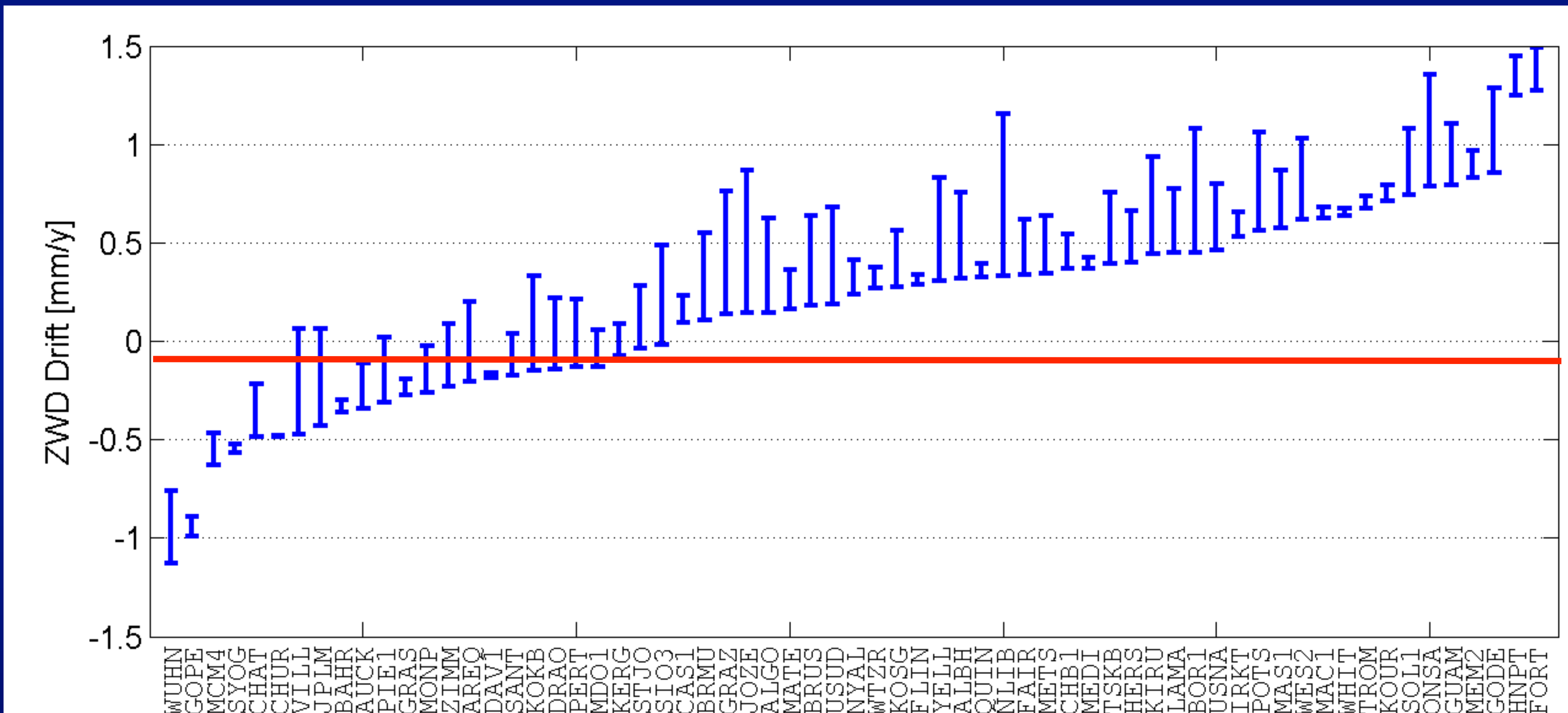
Conclusions

- **Challenges in Earth Observation:**
  - very small, inconspicuous trends (sea level, GIA, …)
  - very fast events (earthquakes, tsunami, land slides, …)
- **IGS enables a large variety of science and Earth monitoring with its diversity of products:**
  - Reprocessing and final products
  - Real-time and ultra-rapid products
- **Challenges in both areas:**
  - GNSS orbit modeling and site discontinuities / environ. Effects
  - Behavior of the GNSS receivers for multi-purpose networks

Thank you for your attention !

Reliable Detection of Small Long-Term Trends

Global change: determination of drifts in the zenith wet delay from GNSS for a global network (N_{ZD} > 40,000)



→ **Reprocessing effort extremely important**

[P. Steigenberger, 2007]