The Earth's time-variable gravity field observed by GOCE

GOCE+ Time-Variations, part of STSE
(Theme 4, Innovative Feasibility Studies)

J. Bouman, M. Fuchs, C. Haberkorn, V. Lieb, M. Schmidt
T. Broerse, E. Schrama, B. Vermeersen, P. Visser

http://gocedt.dgfi.badw.de/

Possible GOCE contribution

- GRACE K-Band ranging in principle better suited to detect time-variable gravity field than GOCE
- But:

GRACE	GOCE
Orbit height 450 km	Orbit height 260 km
Track coverage not fixed	Fixed repeat (61 days)
KBR = 1D	Gradients = tensor
Very accurate at long wavelengths	High resolution information
2002 – 2015 (?)	2009 – 2013 (?)

Innovative feasibility study

1. Focus on large mass variations
2. Aim for higher spatial resolutions

- Greenland ice mass variations
- Chile Mw 8.8 February 2010 & Japan Mw 9.0 March 2011 earthquake

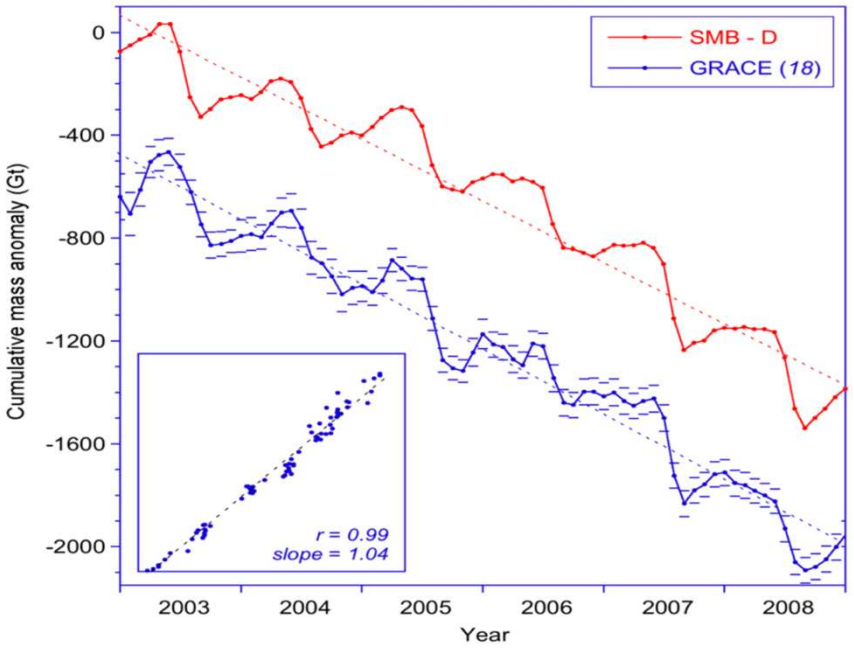
Study Team

- Deutsches Geodätisches Forschungsinstitut (DGFI), Munich, Germany
  - Gravity gradient analysis
  - Regional gravity field recovery
- TU Delft (DEOS), Delft, the Netherlands
  - Forward modelling
  - Interpretation of gravity analysis
- Study runs April 2011 – October 2012

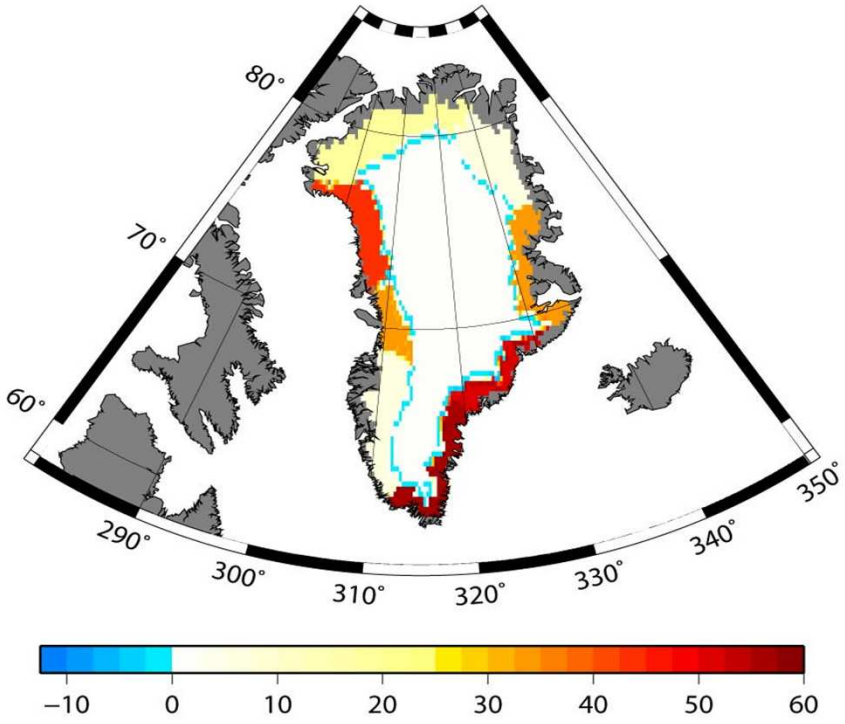
Greenland ice mass variations: State-of-the-art

- Monthly GRACE solutions as input
- Spatial resolution ~ 300 km (Gaussian smoothed)
- Same overall mass loss from different studies, but significant regional differences exist
- Refined observation of regional ice mass losses will serve to improve model-based predictions of future mass loss from the Greenland Ice Sheet

Greenland ice mass variations: State-of-the-art



(Van den Broeke et al., Science, 2009)

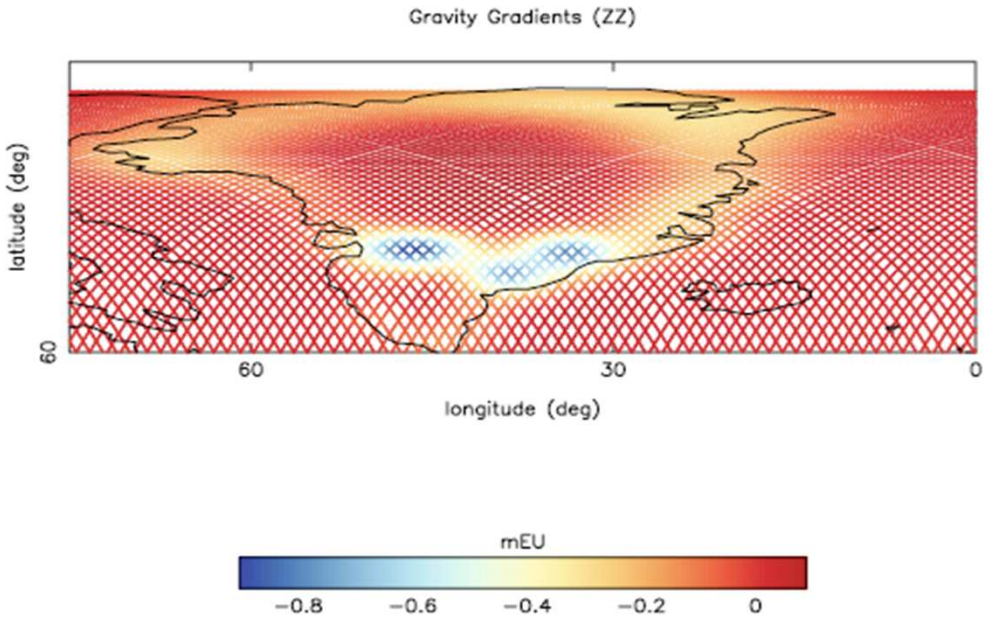


(Schrama & Wouters, JGR, 2011)

Greenland: forward modelling

- Ice mass loss from simulations
- Agrees well with analysis from GRACE
- Linear trend in 7 yr period amounts to 1 mE in V_{ZZ}

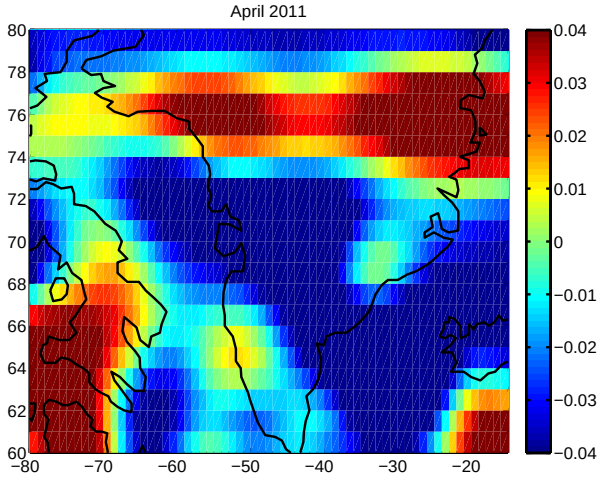
ZZ signal at GOCE altitude due to ice mass loss for a 7 year period

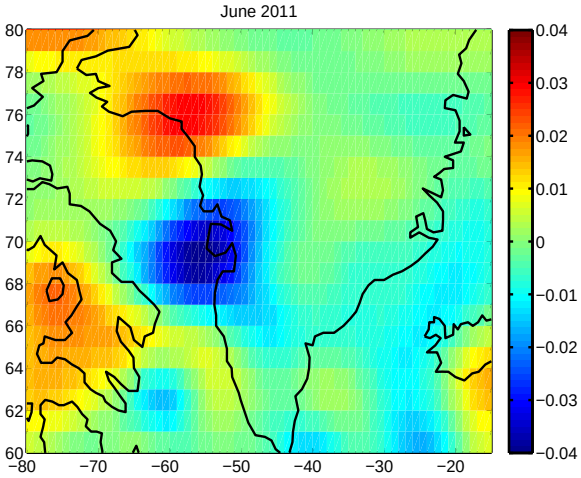


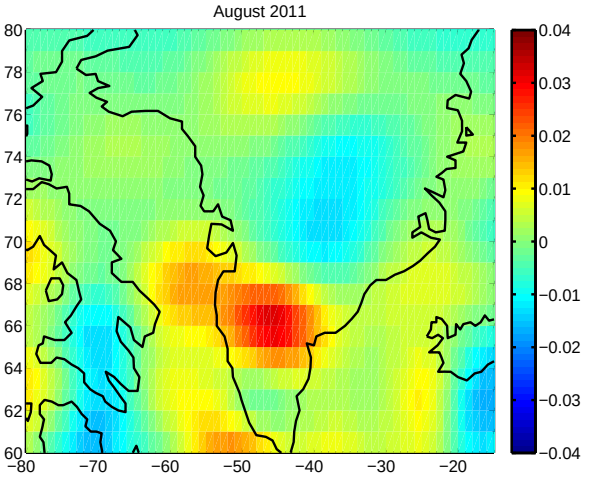
Greenland: Time series of gravity gradient residuals

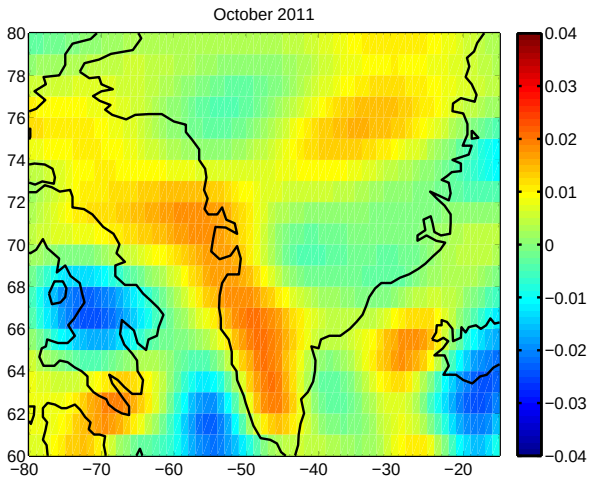
- Compute difference GOCE V_{ZZ} – GOCO03S
- Orbital repeat is 61 days
  - April 2011 ± 15 days
  - June 2011 ± 15 days
  - August 2011 ± 15 days
  - October 2011 ± 15 days
  - December 2011 ± 15 days
  - Februar 2012 ± 15 days
- Filter in tailored MBW + Gaussian smoothing
- Variation with respect to mean

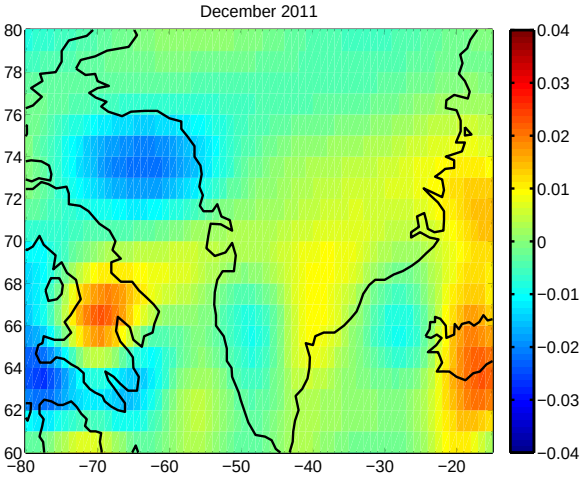
V_{ZZ} variation with respect to mean
(units are mE)

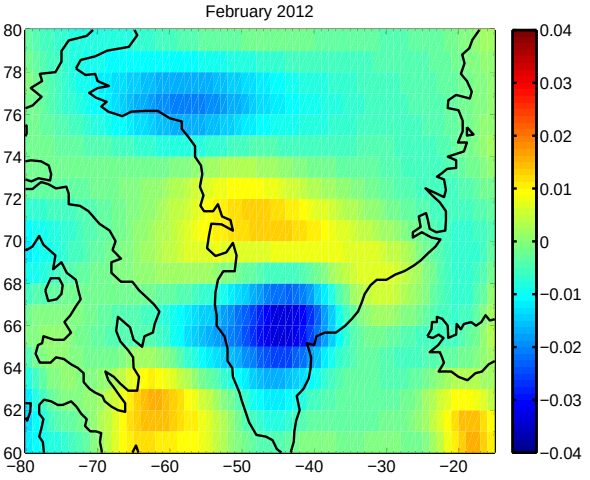




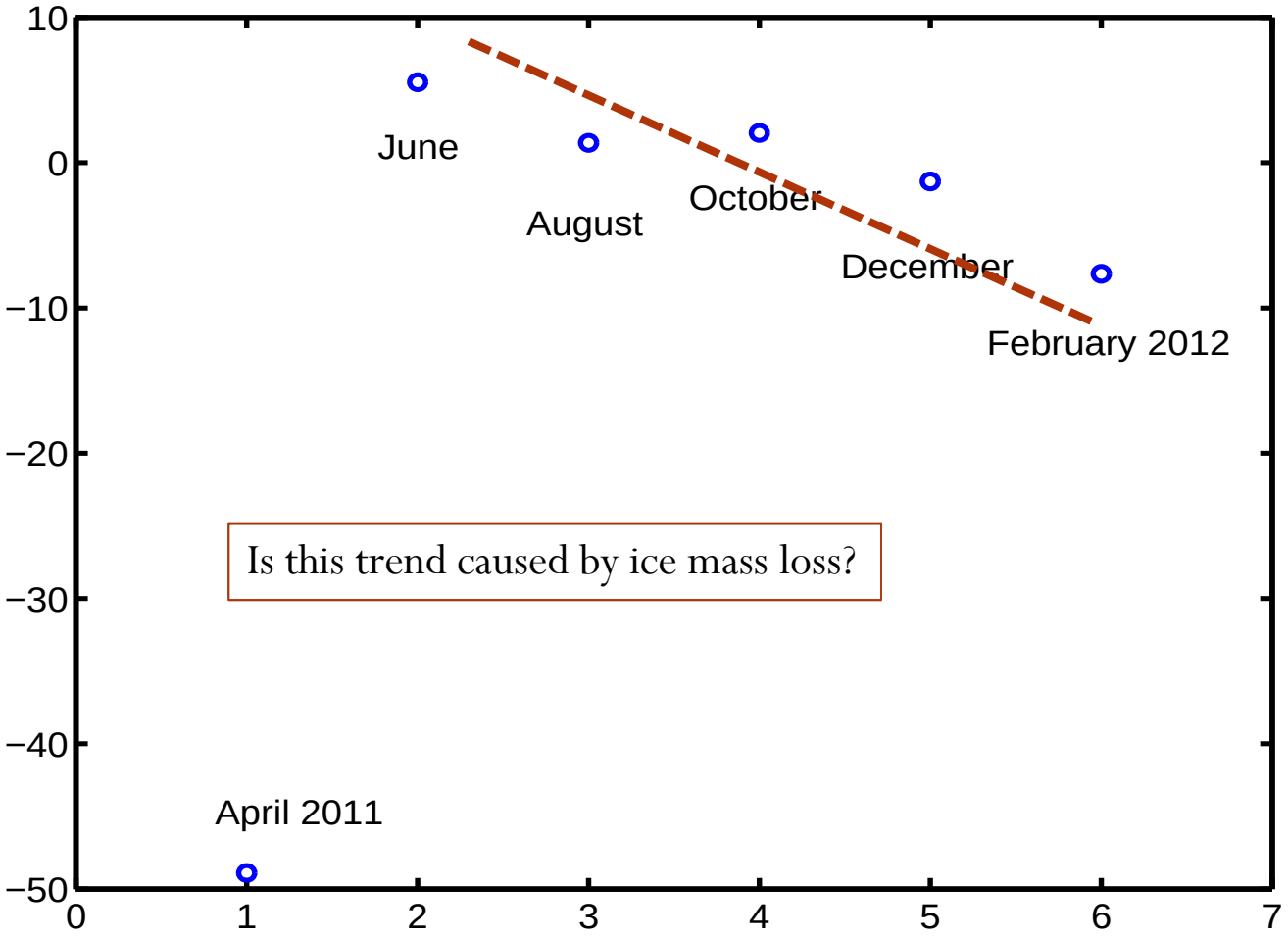








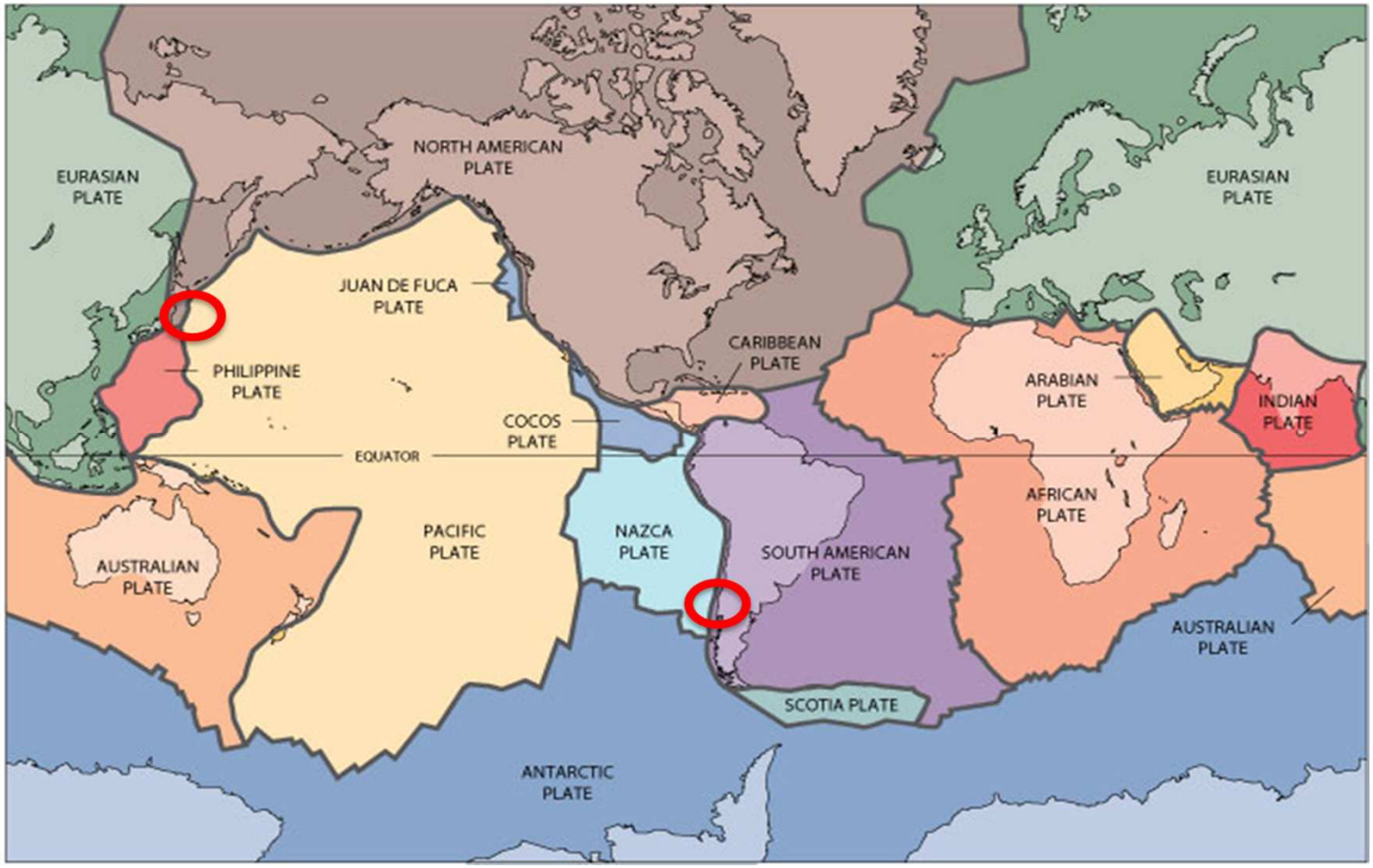
Average V_{ZZ} for Greenland



Greenland's regional gravity field

- GOCE gradients have been used to compute time series of regional gravity fields for Greenland
- See presentation Lieb et al. later today

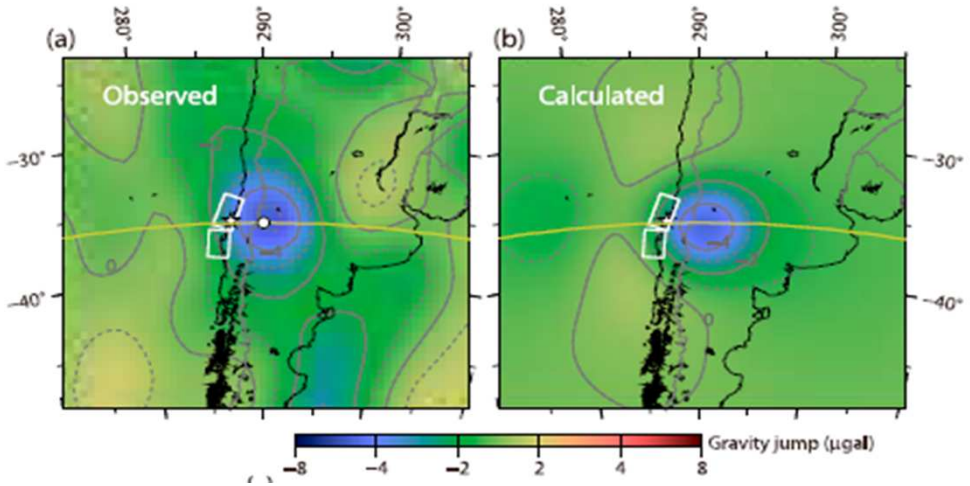
Earthquakes:
Chile Mw 8.8, Japan Mw 9.0



Source: USGS

Megathrust earthquakes: State-of-the-art

- Gravity field changes due to Sumatra 2004 (Mw 9.3) , Chile 2010 (Mw 8.8) and Japan 2011 (Mw 9.0) earthquakes detected by the GRACE mission
- Monthly GRACE fields, SH = 60
- Reduction of longitudinal stripes
- Noise reduction by spatial filter with averaging radius of 300 – 350 km

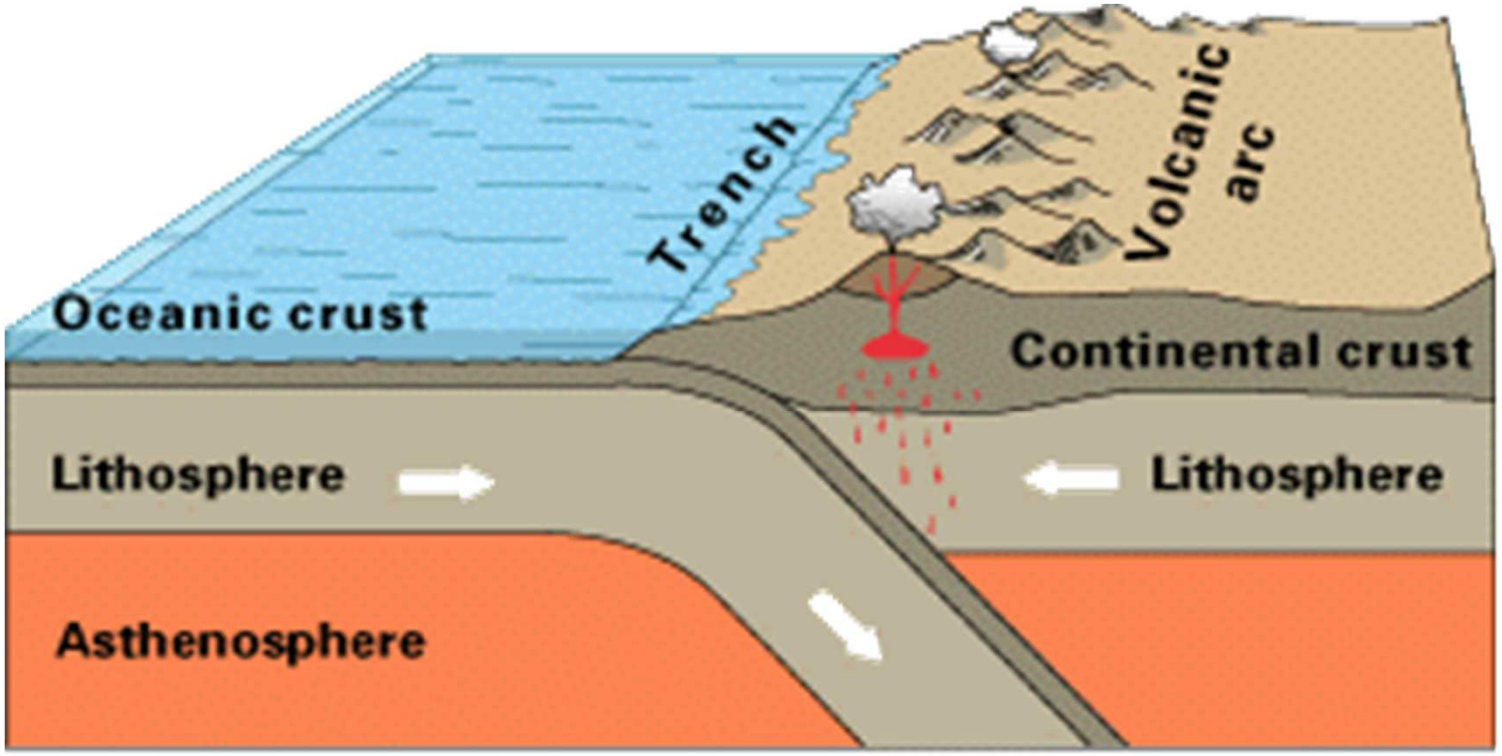


(Heki & Matsuo, GRL, 2010)

Megathrust earthquakes: Possible GOCE contribution

- GOCE gravity gradients provide (incomplete) tensor information, K-Band ranging is 1D
- Improved spatial resolution
- Allow improvement of interpretation of larger earthquakes (> Mw 8)
  - Earth structure: e.g. lateral variations in crustal and lithospheric thickness
  - Earth rheology: discrimination between linear and non-linear rheologies
- Contributes to improving our knowledge of the mechanisms of stress accumulation and stress release

Co-seismic vertical deformation & gravity

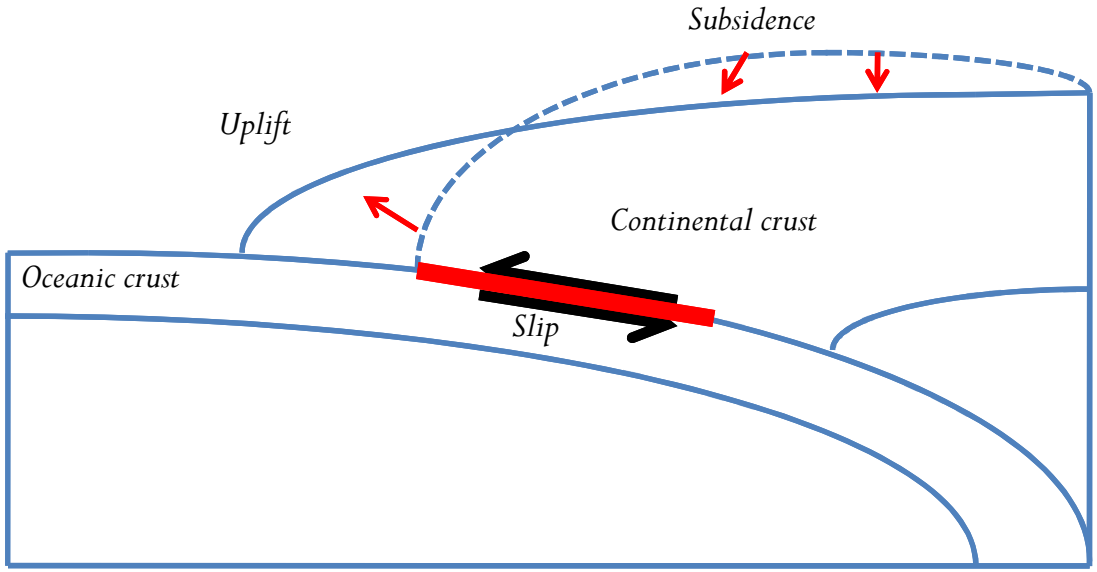


Oceanic-continental convergence

Source: USGS

Co-seismic vertical deformation & gravity

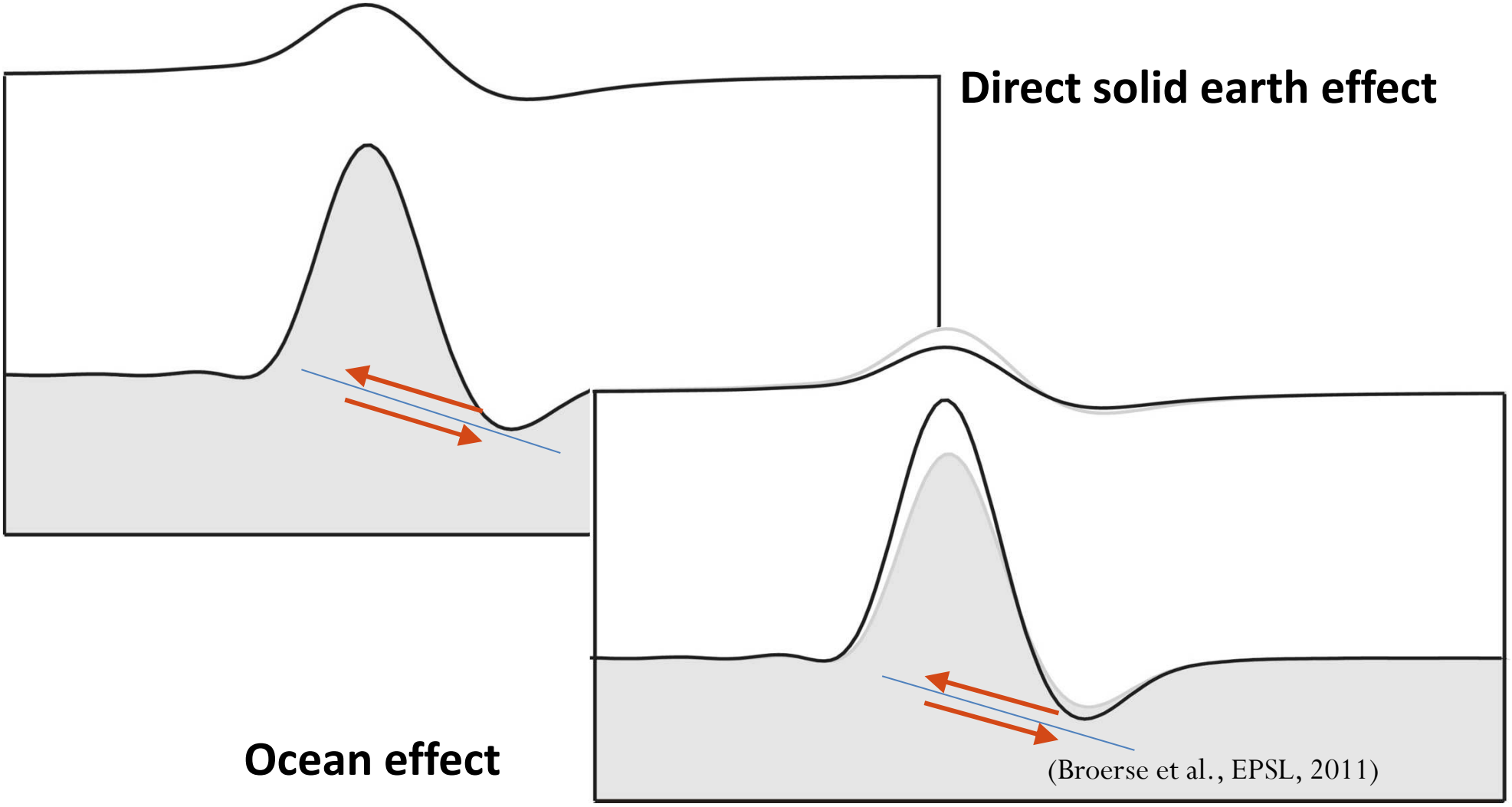
Simplified elastic model



Forward modelling

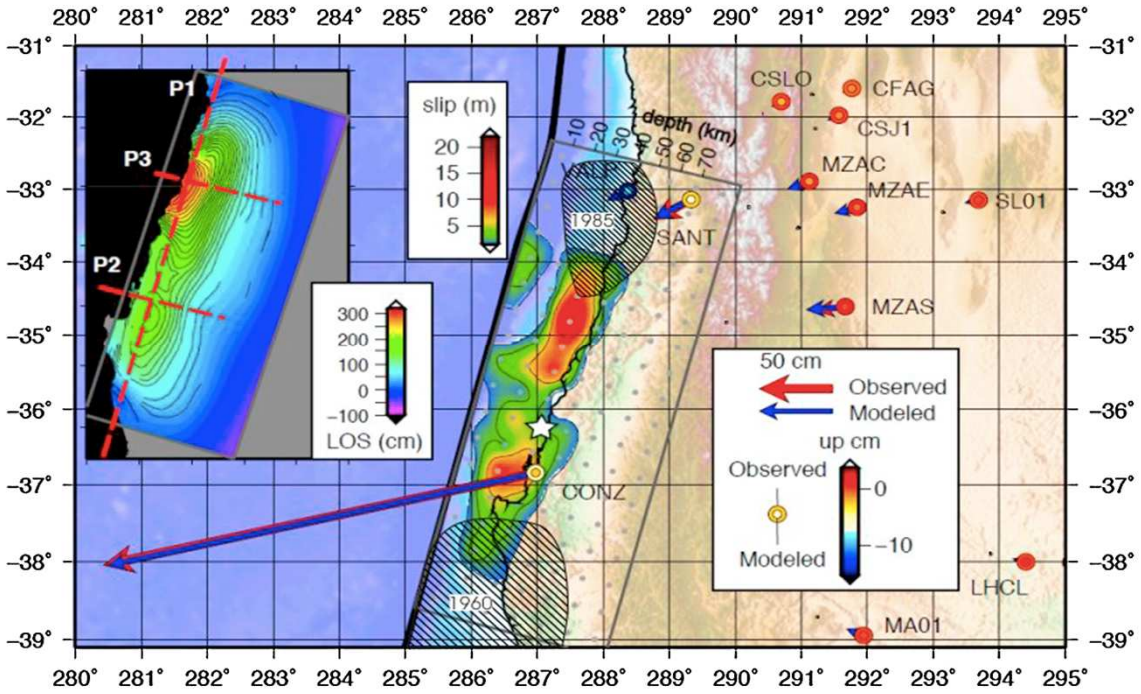
- Reference slip model =>
  - Location and nature of slip
- Solid earth model =>
  - semi-analytical normal mode model
  - spherically layered earth, compressible rheology
- Sea level model =>
  - sea level equation

Forward modelling



Slip models

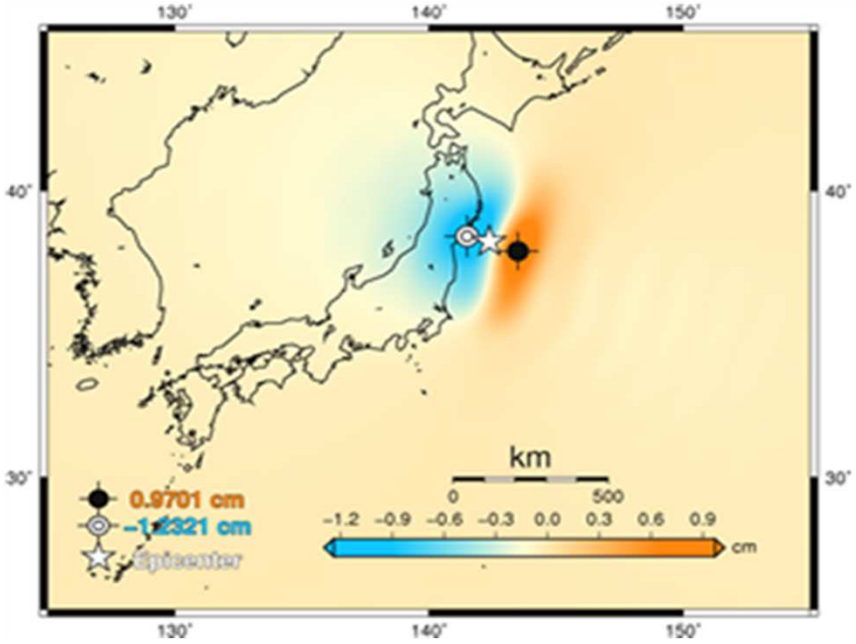
- **Chile**:Delouis et al. (2010)
  GPS, broadband teleseismic data, InSAR
- **Japan**:Hayes (2011), Wei et al. (2011) GPS, broadband teleseismic data



Geoid height change from forward modelling

Japan: -1.2 – 1.6 cm

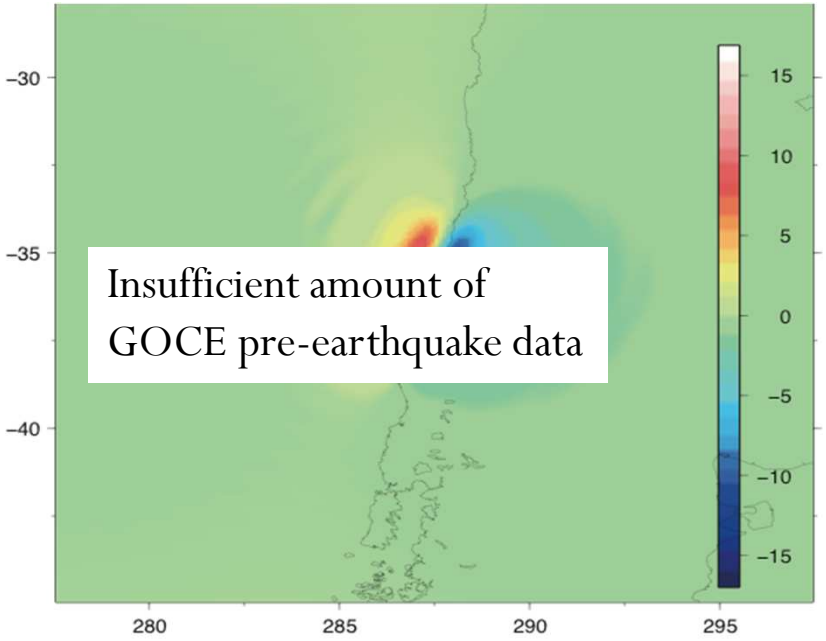
(Wei model)



GOCE GG: Nov 2009 – March 2011 & March 2011 - March 2012

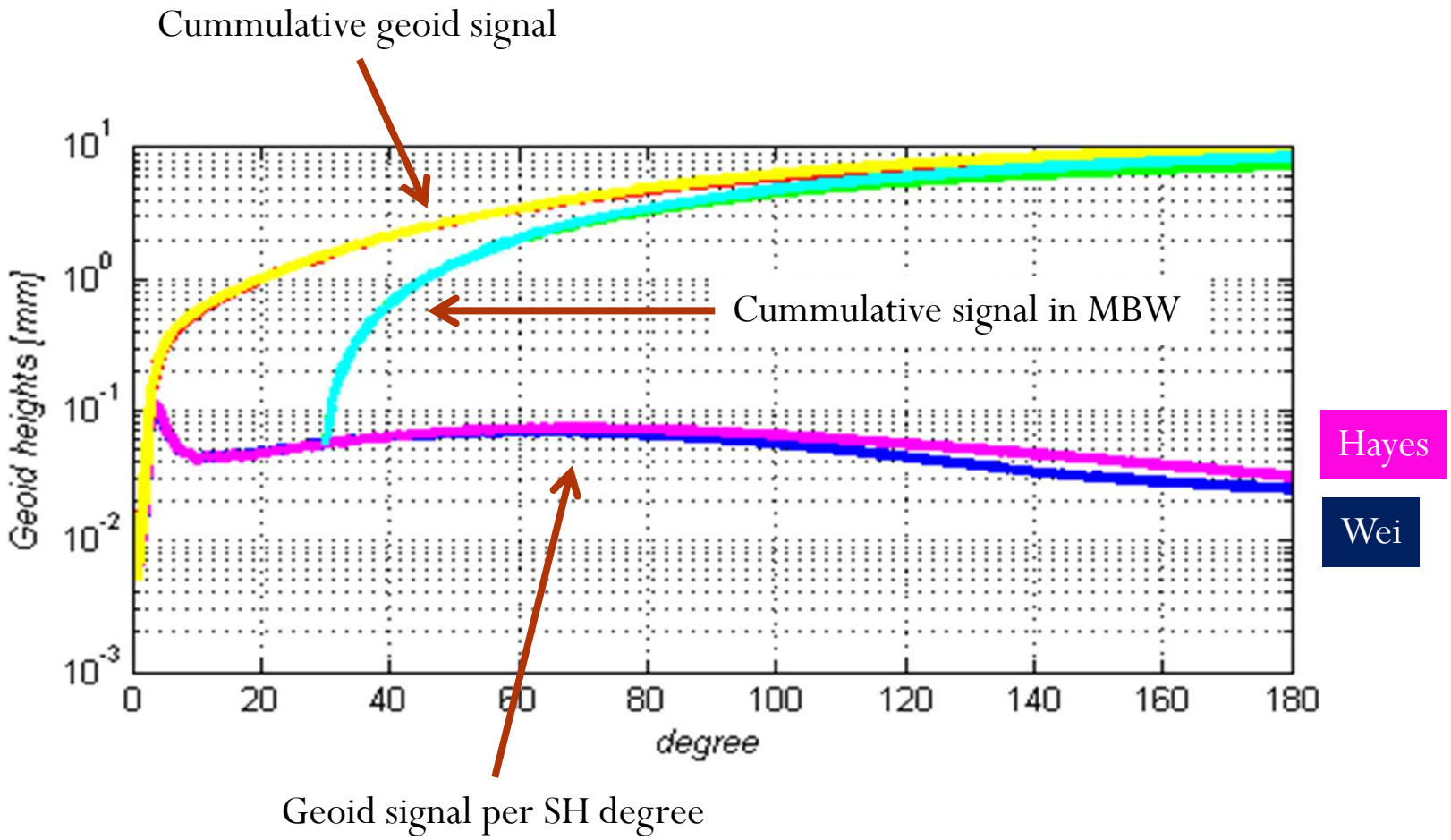
Chile: -1.1 – 0.9 cm

(Delouis model)



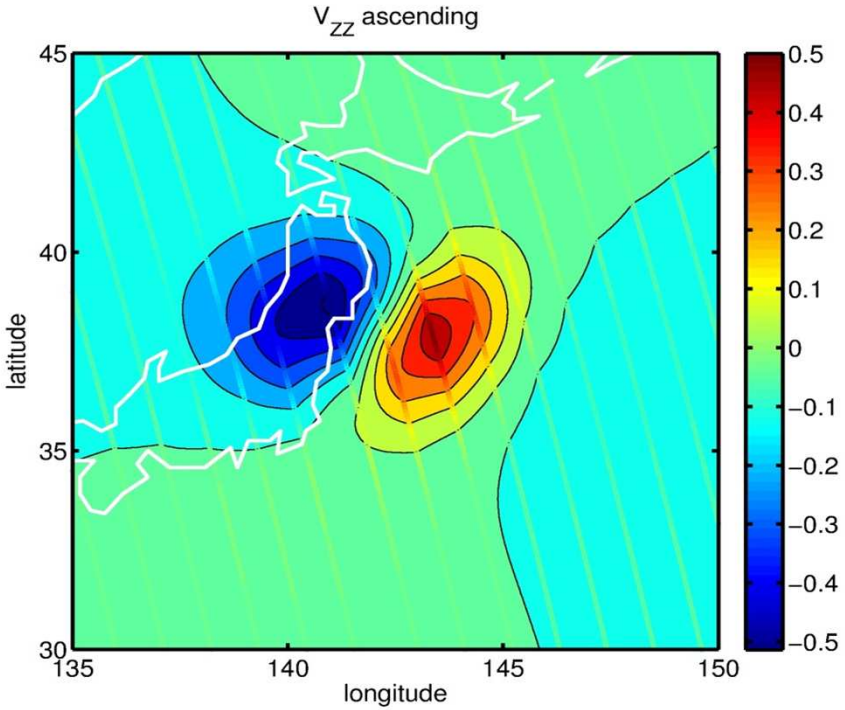
GOCE GG: Nov 2009 – February 2010 & February 2010 - March 2012

Japan Tohoku-Oki earthquake: SH geoid spectrum

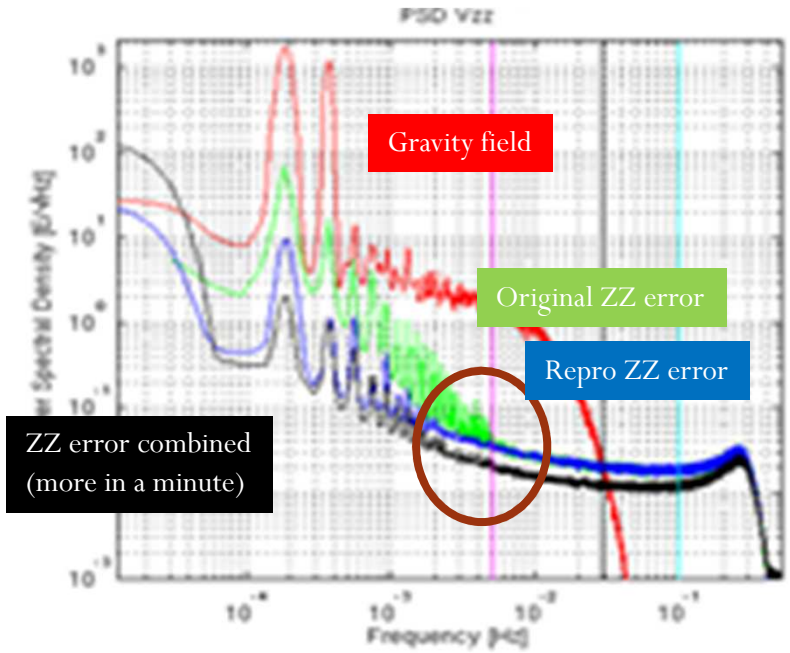


Gradients at satellite altitude

V_{ZZ} from modelling



Gradient error PSD: 20 mE/Hz$^{1/2}$ for V_{ZZ}

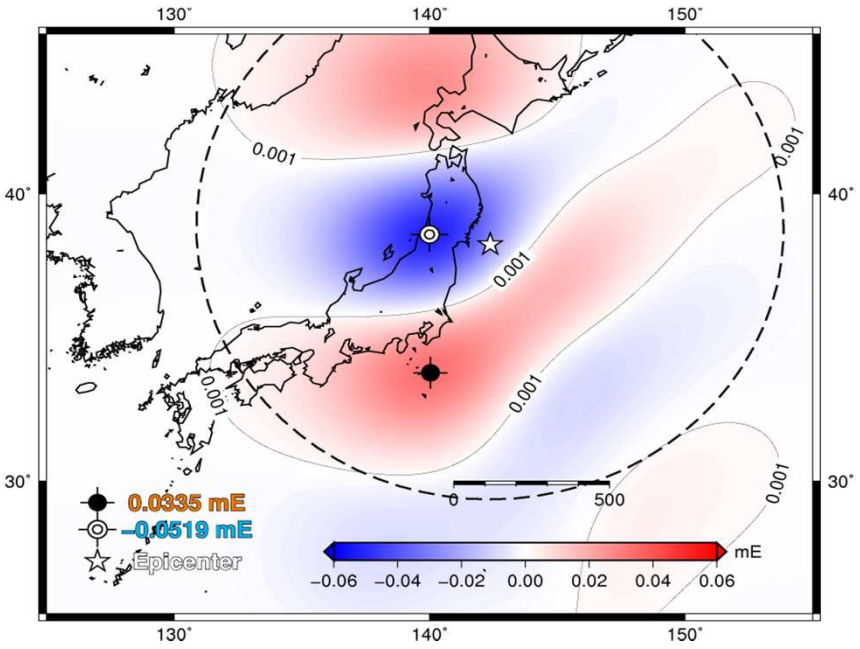


Band-pass and Gaussian filtering

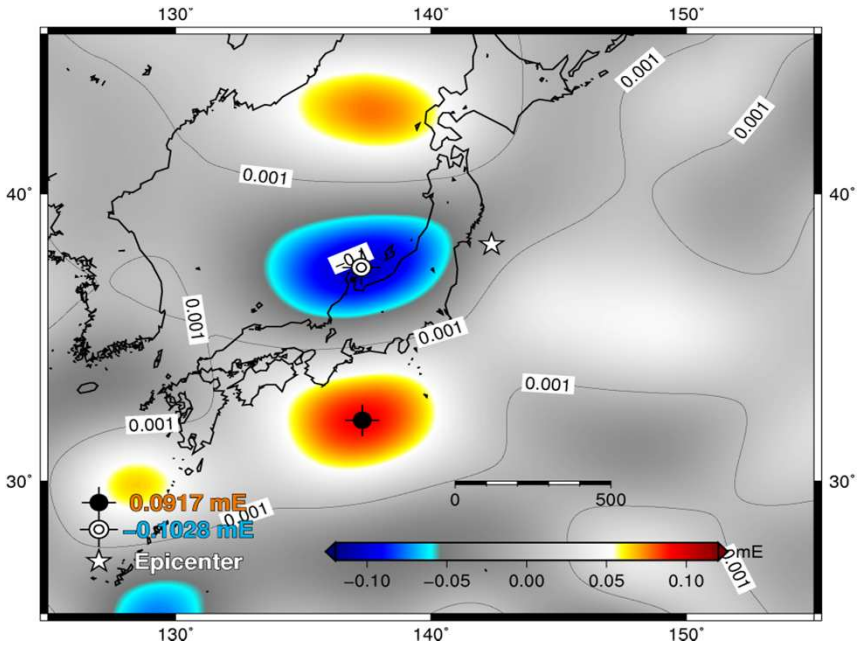
- Noise V_{ZZ} two times that of V_{XX} and V_{YY}
- Use Laplace equation: $V_{ZZ}^{C} = (V_{ZZ} - V_{XX} - V_{YY})/2$
- Reduces error in vertical gradient with 40 %
- Analyse residuals with respect to GOCO03s
- Band-pass filter in MBW:
  - Low cut-on frequency includes 1/f errors
  - High cut-off frequency includes white noise
- Additional Gaussian smoothing with 220 km half- width

Japan Tohoku-Oki Earthquake

Forward model V_{ZZ}
(Wei slip model)



GOCE data analysis



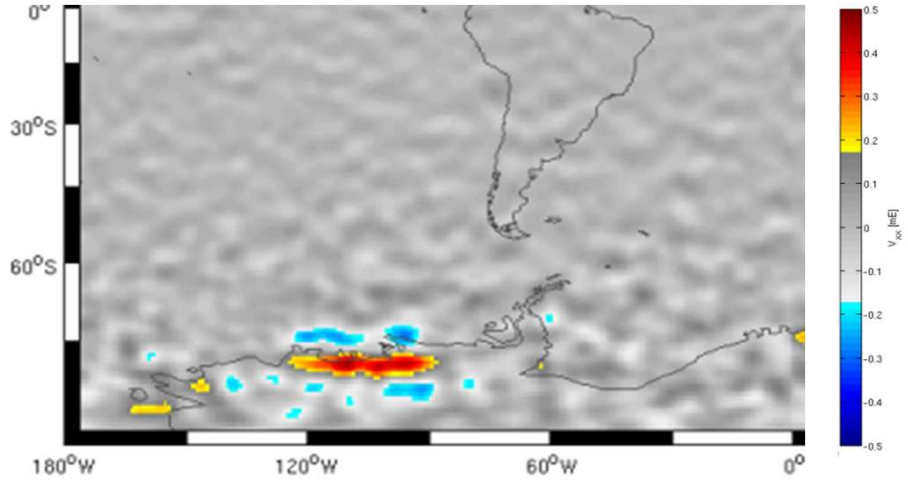
Summary

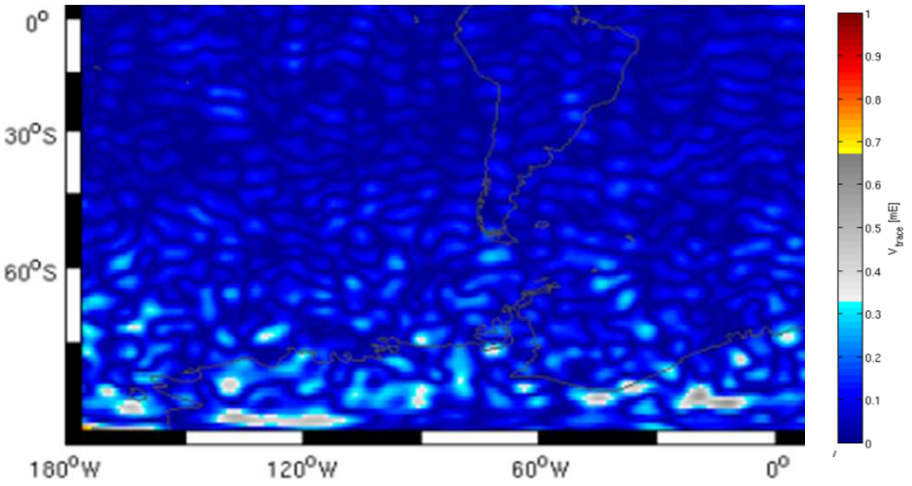
- Forward modelled Greenland ice mass loss and Chile 2010, Japan 2011 earthquakes
- Signals at GOCE altitude are 1 mE or less
- To detect these is very challenging
  - Measurement noise
  - Systematic errors for low frequencies
- Greenland: trend visible? (To be confirmed)
- Chile: probably insufficient amount of GOCE data before earthquake
- Japan: earthquake seems visible in GOCE data, difference in amplitude between model and GG to be explained yet

And what about Antarctica?

V_{XX} GOCE – GOCO03s averaged over 2.5 years, filtered 5 – 30 mHz

Trace treated similary as V_{XX}





Results are very fresh (last week), but
first comparisons with forward modelling are encouraging

A word of advice

- Don't try this at home
- Unless you fancy to search the needle in the haystack
- Dedicated data editing and data massage are needed
- Time-variable gravity field signatures are likely to be visible in the GGs