Terrestrial gravity field modeling by spatial means: current state of the art…

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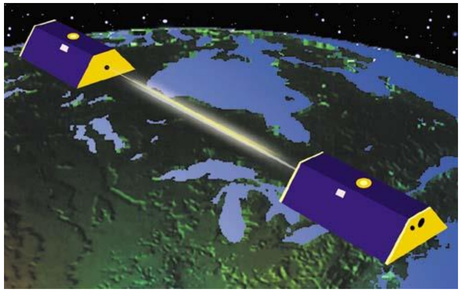
Summary

1. Time variable gravity field
2. Static gravity field
3. Perspectives

Satellite missions

GRACE

- Launched in 2002
- 2 satellites separated by ~220 km
- Altitude: ~ 440 km, Quasi-polar orbit (89°)
- GPS + accelerometers + SLR + K-Band Ranging
- KBR accuracy: ~ 1 µm, 0.1 µm/s



GOCE

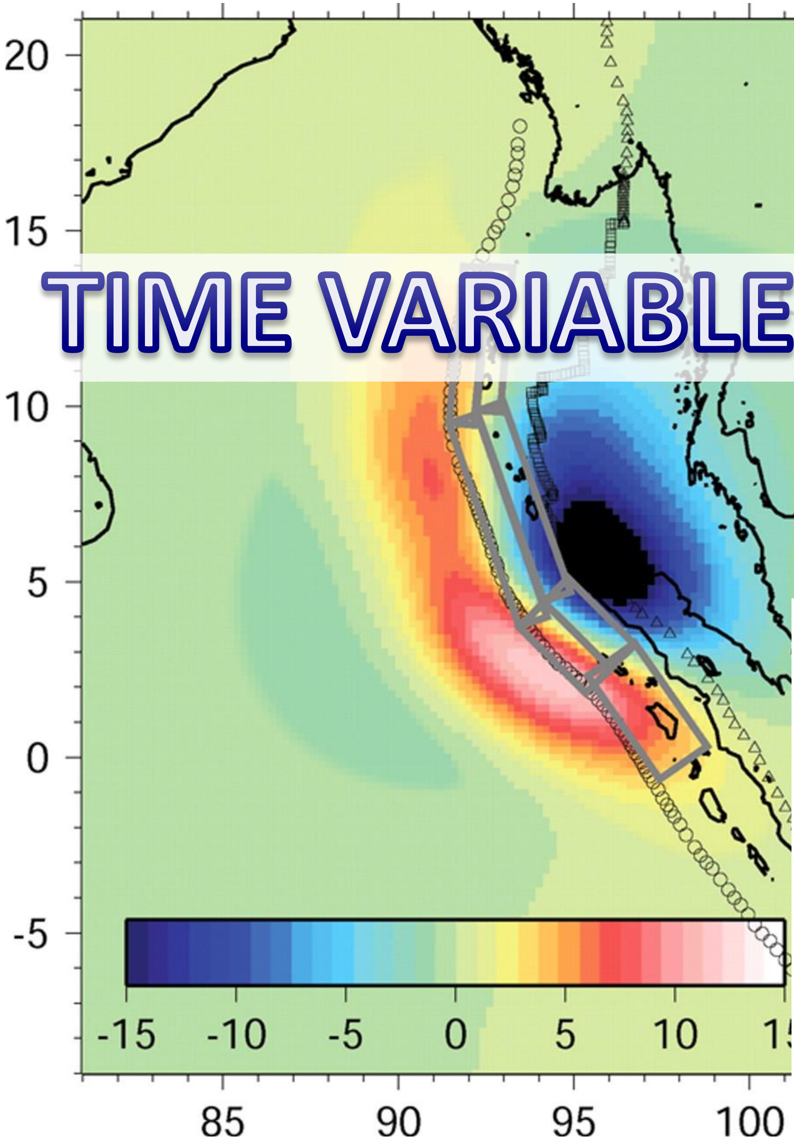
- Launched March 17, 2009 – Passed on November 11, 2013
- Altitude: ~ 260 km, Inclination: 96.7°
- GPS + SLR + gradiometer (0.5 m arm length)
- Gradiometer accuracy: 4 mE at 1 Hz (→ 4 10^{-12} m/s^2 /m)

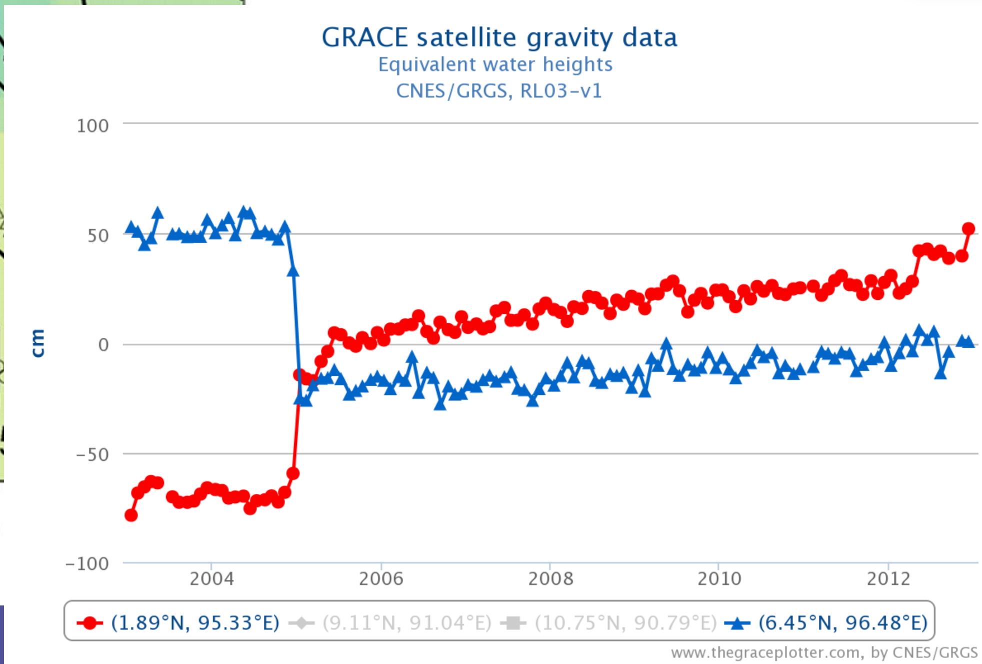
LAGEOS-1 & 2, Starlette and Stella

- Passive SLR satellites
- Altitudes: 5900 km and 800 km
- Inclinations: 110° / 53° / 50° / 99°

TIME VARIABLE GRAVITY FIELD

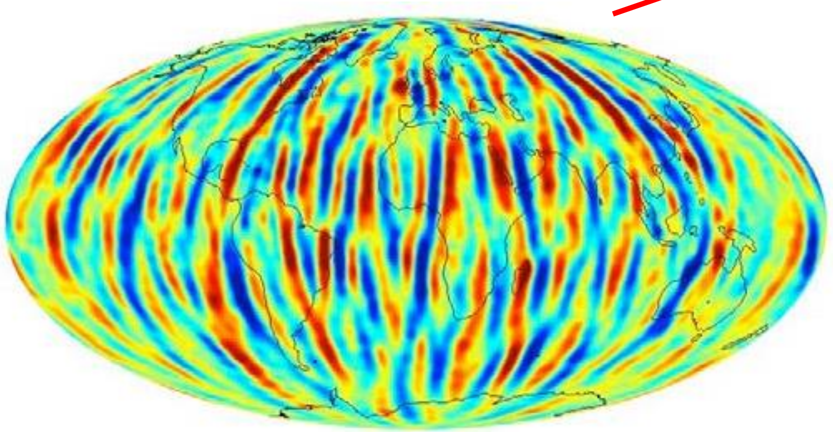
1

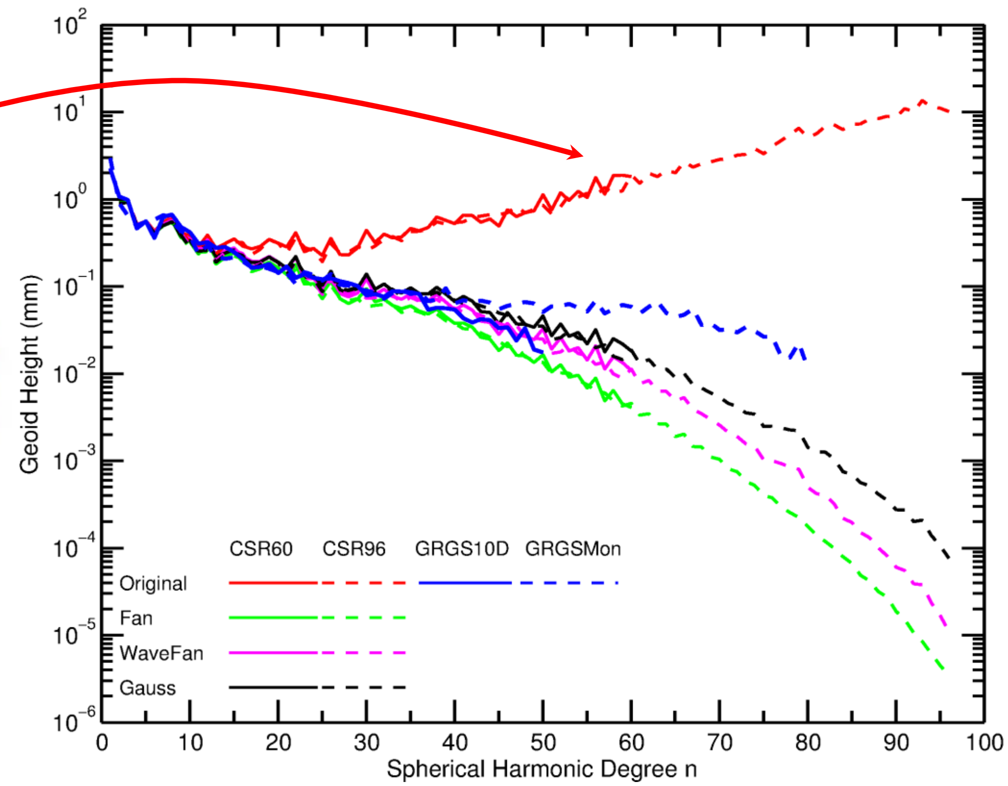




METHODOLOGICAL APPROACH

- Unconstrained Choleski inversion up to a certain degree cutoff:
  CSR: **60**, then **96**, **JPL** and **GFZ**: **90**

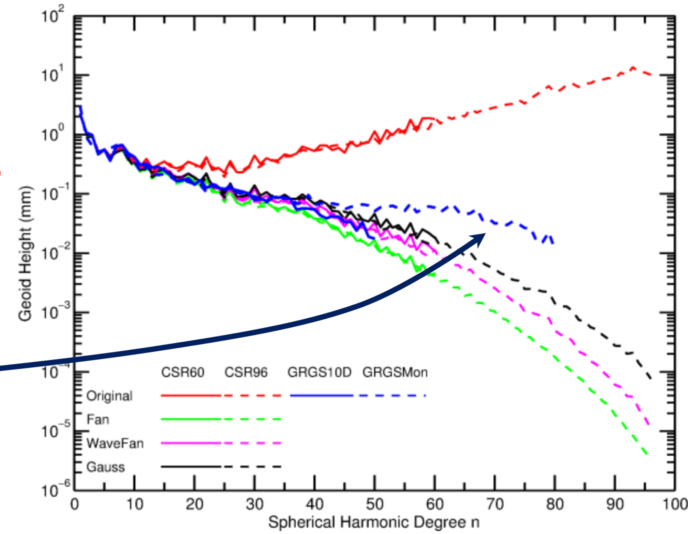




METHODOLOGICAL APPROACH

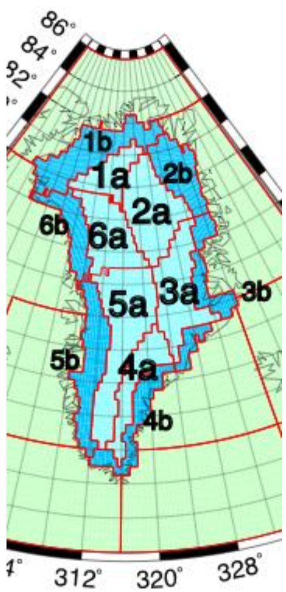
- Constrained Choleski inversion: **GRGS-RL02** (degree max: **50**)

- Truncated SVD solution: **GRGS-RL03** (degree max: **80**)



- Mascons: **GSFC** Computation of the direct effect of point masses on the KBRR measurements

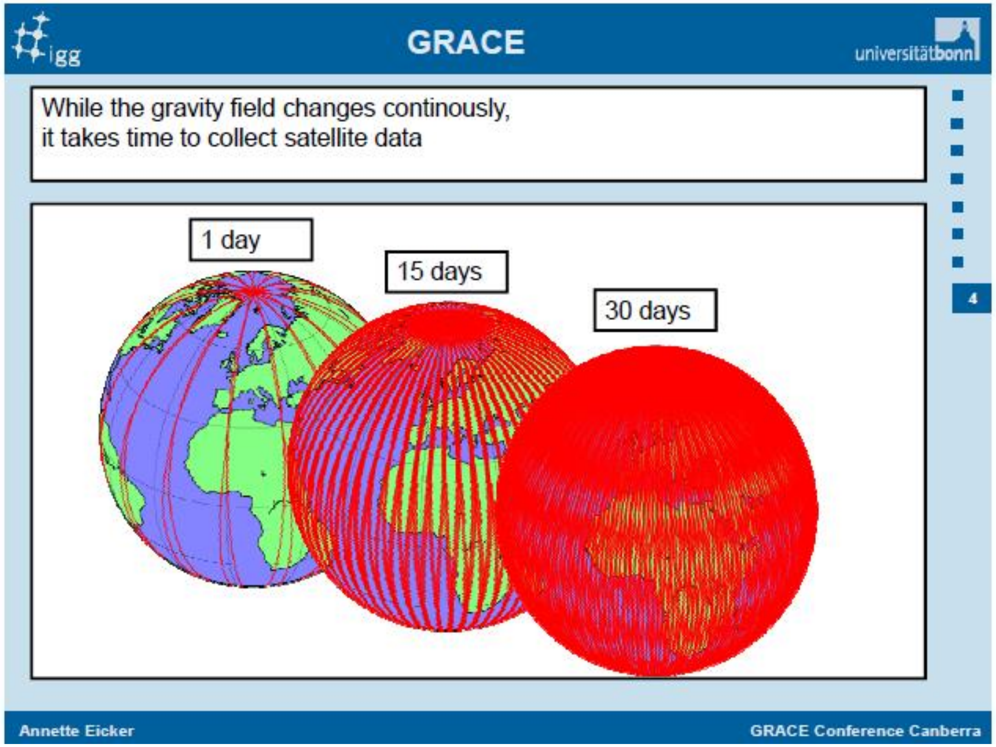
- “Integral of Energy” technique: **Ramillien & Seoane** Based on the equivalence between kinetic and potential energy. The velocity residuals (KBRR) are taken as the opposite of the potential perturbations.



TIME SAMPLING (all groups use dealiasing products for the atmospheric pressure and ocean response)

- Monthly: **CSR**, **JPL**, **GFZ**, **GRGS-RL03**
- 10-days: **GRGS-RL02**
- 1-day: **BONN**

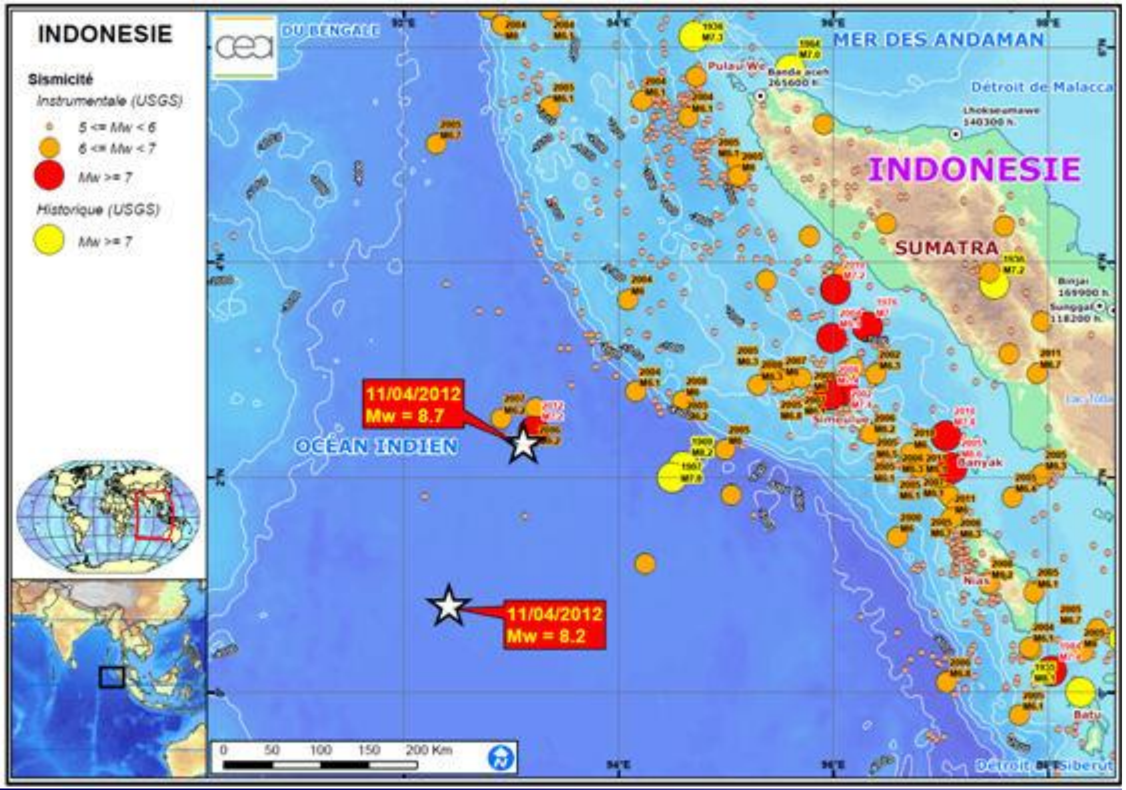
Using a Kalman Filter scheme

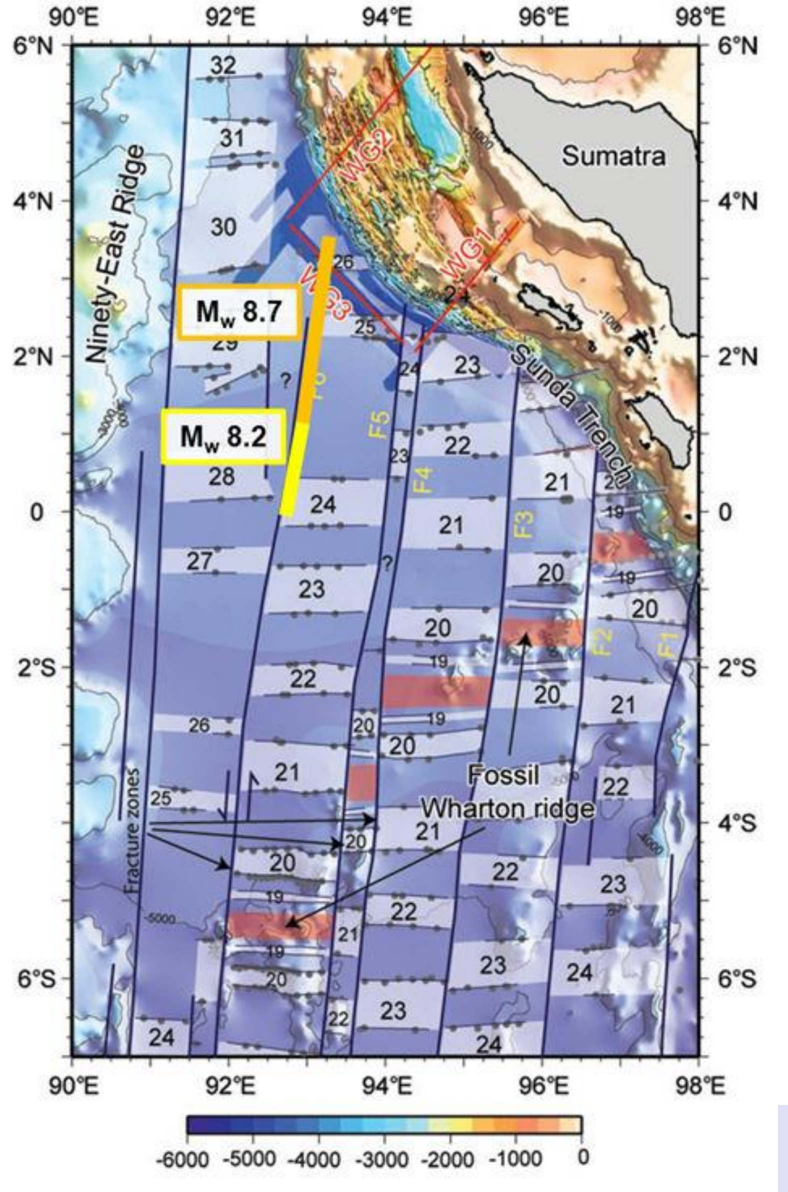


APPLICATIONS

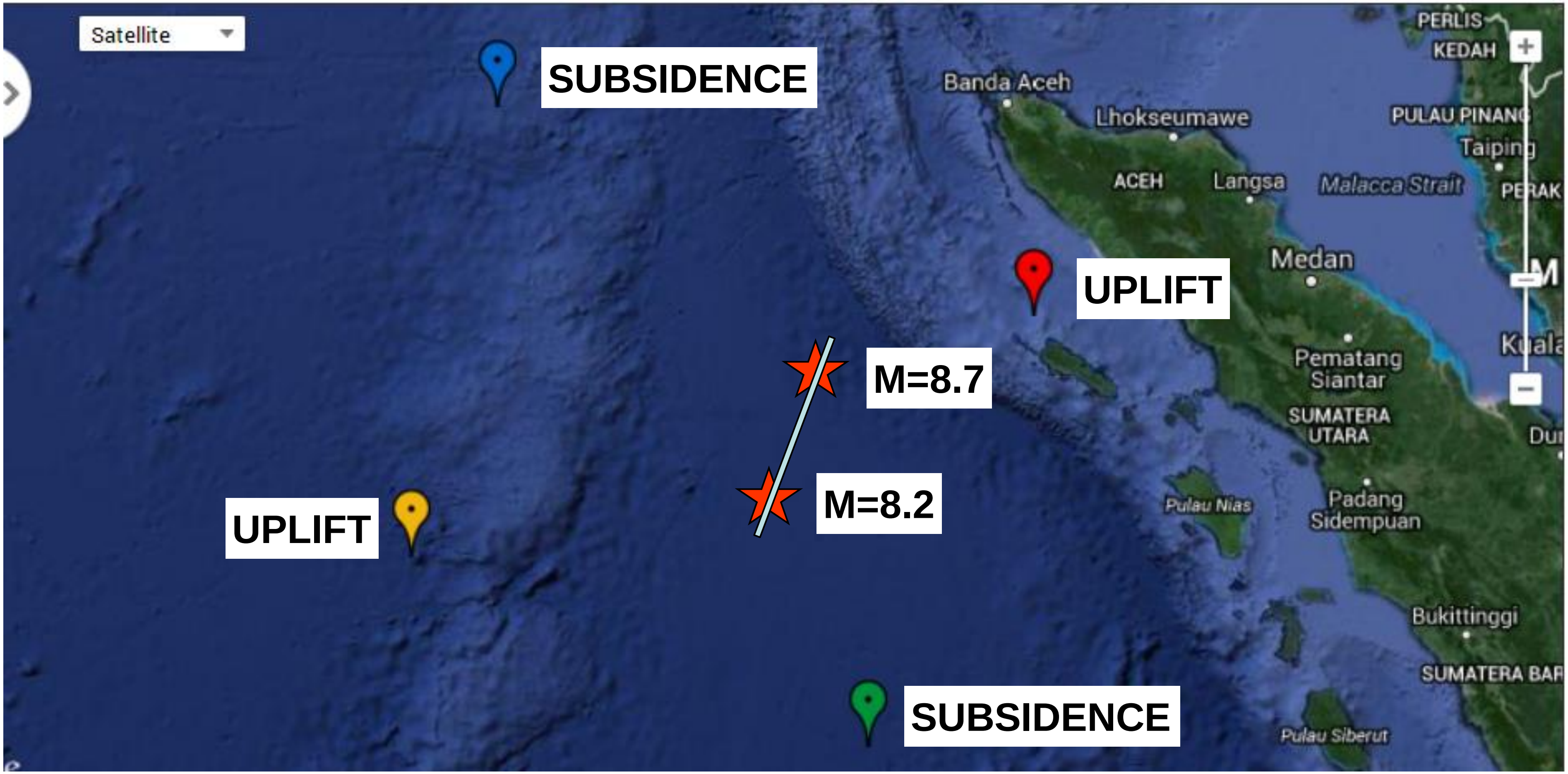
TVG applications: 1.1 Solid Earth

- On the 11th of April 2012 two major earthquakes took place at 2 hours interval.
- M=8.7, depth=22 km
- M=8.2, depth=25 km
- Strike slip fault
- Maximum horizontal slip ~ 25 m



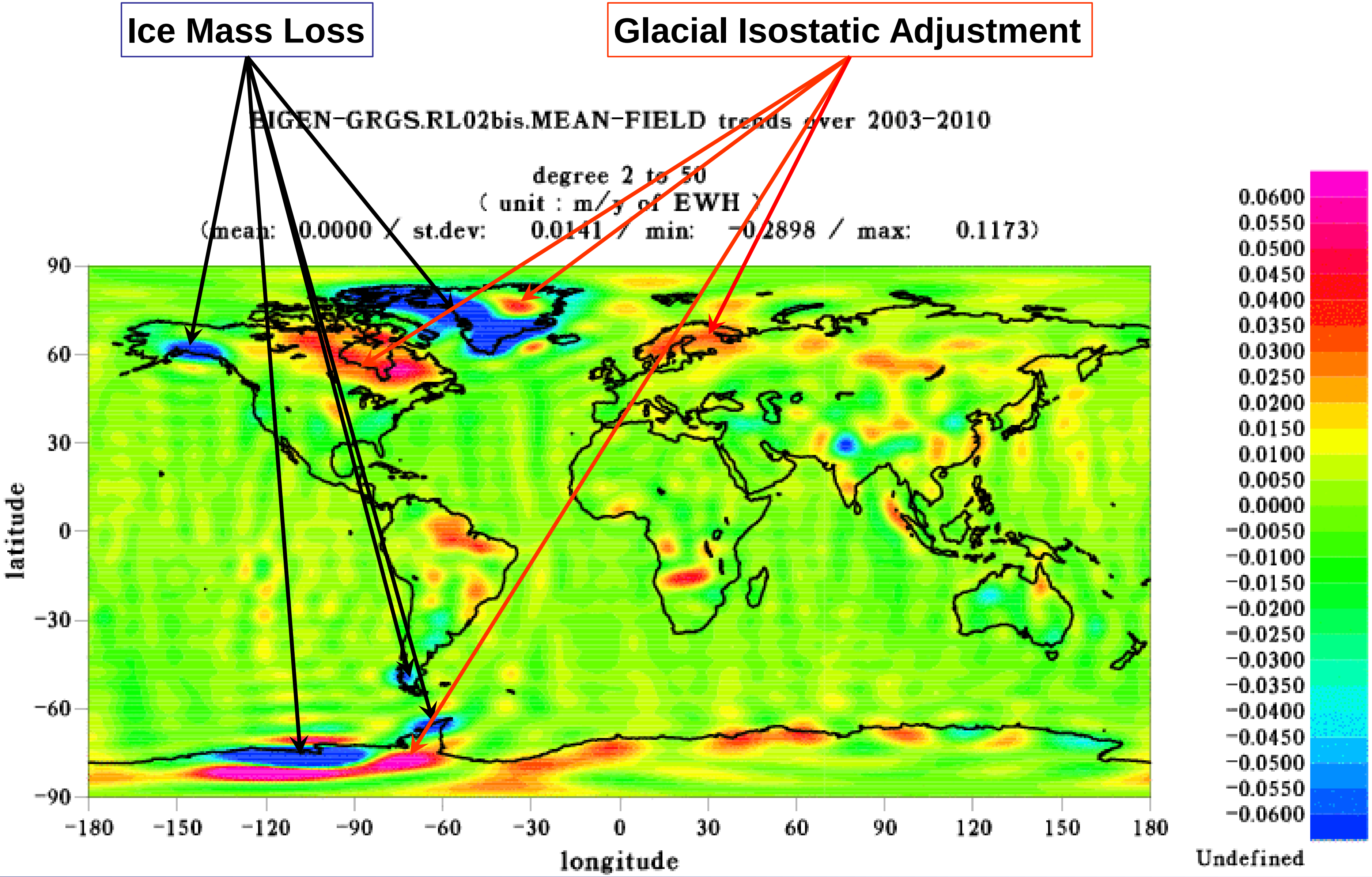


Sumatra: 2012 earthquake



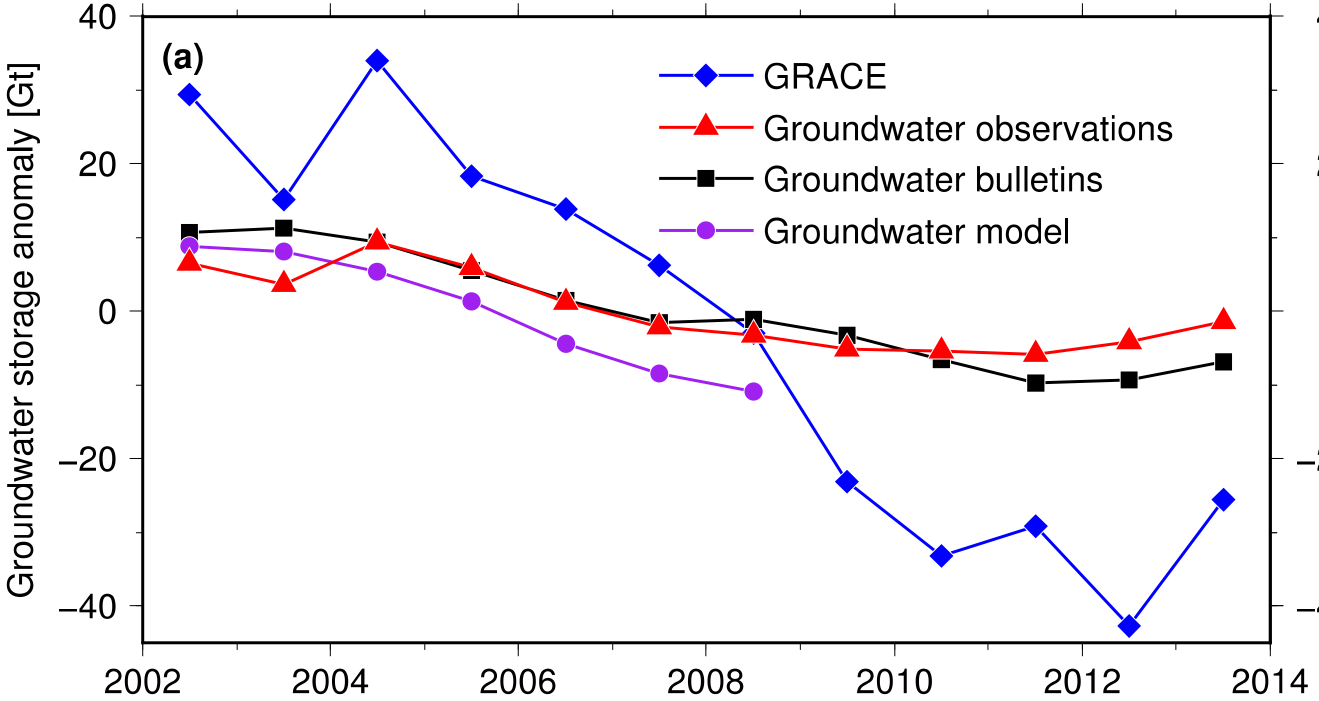
- The maximum positive and negative gravity anomaly variations are located on either sides of the intra-plate slip fault
- They form a quadrupole
- This signal appears to be rather post-seismic than co-seismic
- Only GRACE is able to bring information in such a place !!!

TVG applications: 1.2 GIA & Ice mass loss



TVG applications: 1.3 Continental hydrology

Long-term Ground Water Storage trend in the North China Plains



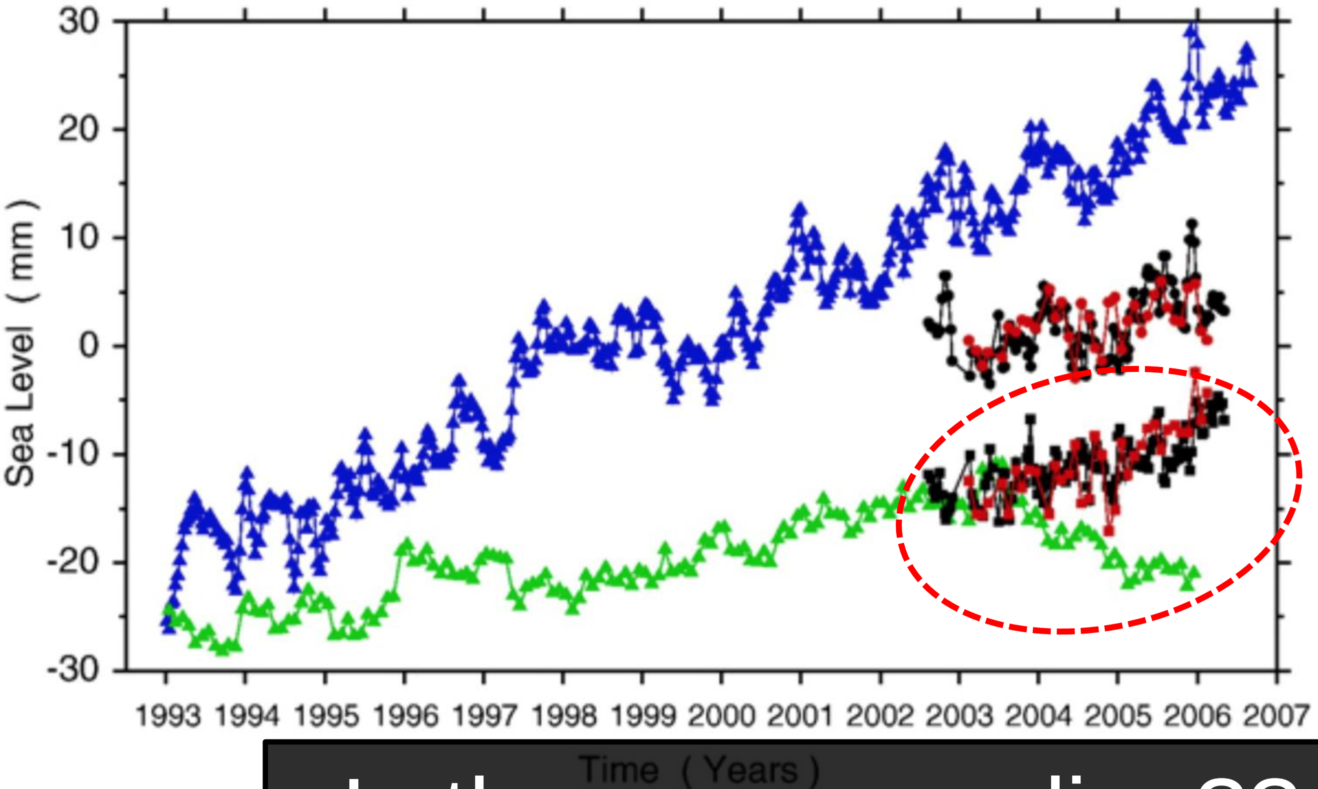
From Feng Wei PhD defence (November 14, 2014)

Gt/yr

	GW observations	GW bulletins	GW model	GRACE
2002-2013	-1.2 ± 0.1	-2.0	--	-7.1 ± 1.0
2002-2008	-1.8 ± 0.2	-2.5	-4.0	-5.0 ± 1.8

"In the North China plains, the ground water depletion rate is 2 to 4 times greater in the deep aquifers than in the shallow aquifers, due to irrigation."

Global mean sea level rise



Altimetry

GRACE (GRGS, GFZ)

Altimetry-GRACE

Steric SLV (Ishii)

Lombard et al. 2007

Is the ocean cooling??

Lyman et al. 2006

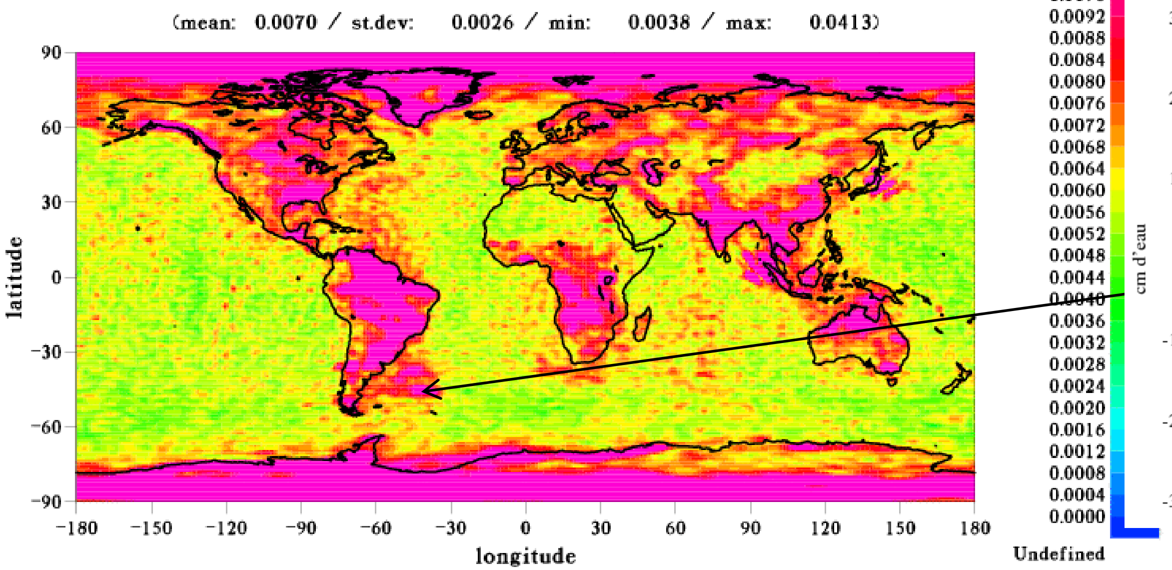
No! There are biases in expendable bathythermograph (XBT) data.

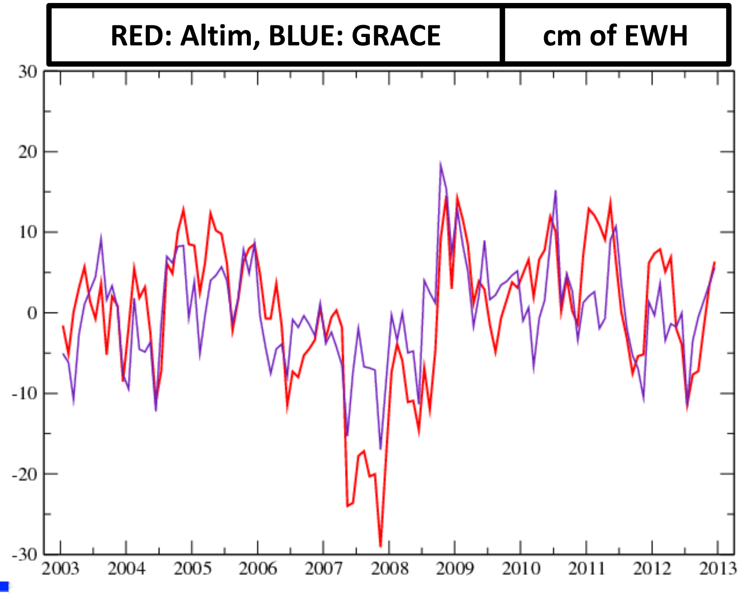
Willis et al. 2007

TVG applications: 1.4 Oceanography

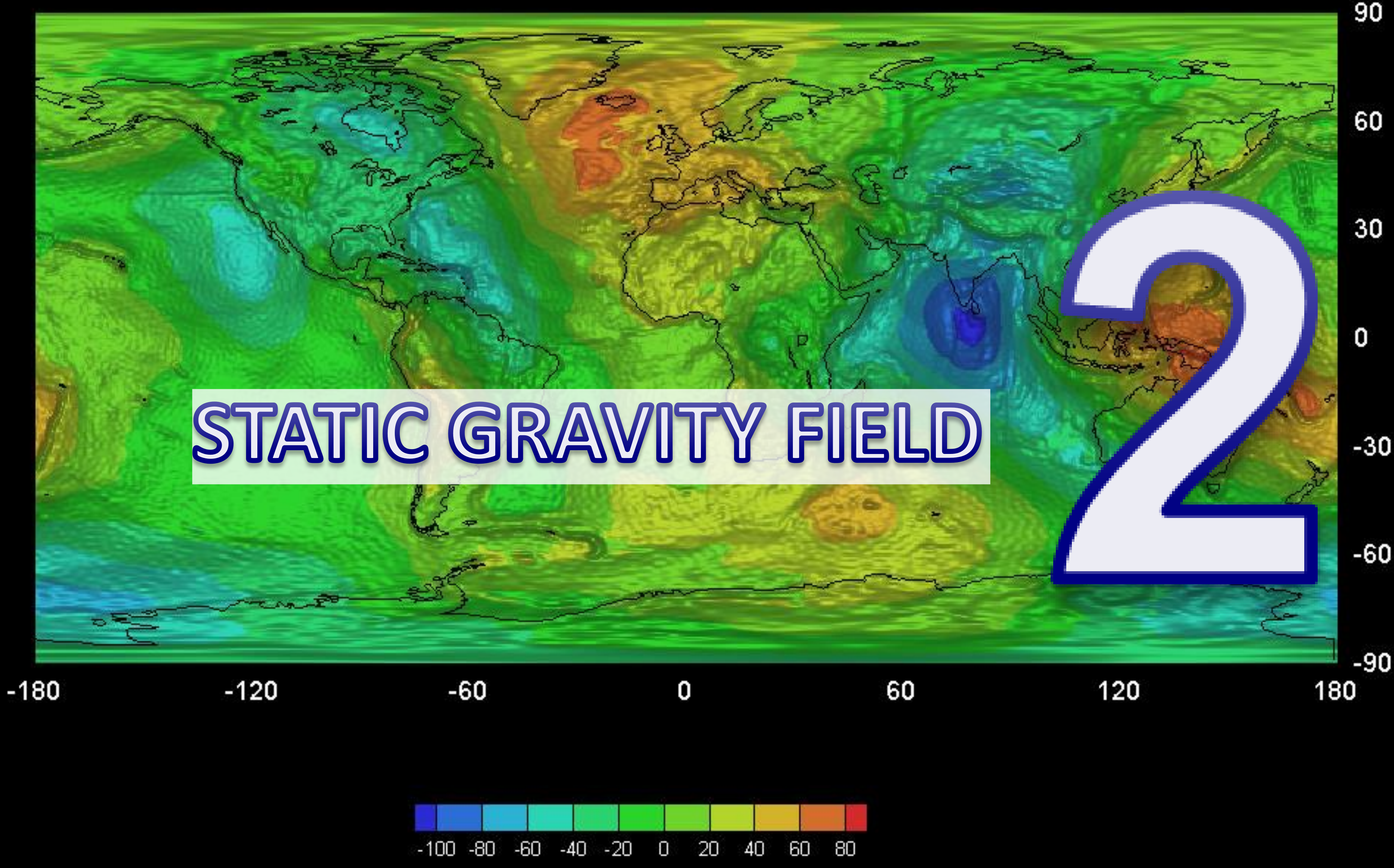
Zapiola-Gyre test zone

Residual variance of the RL03 solutions, once the drift and the annual and semi-annual periodic terms have been removed





Comparison to altimetry	Percentage of correlation
JPL RL05	58.6 %
GFZ RL05	66.4 %
CSR RL05	69.5 %
CNES RL03	71.0 %

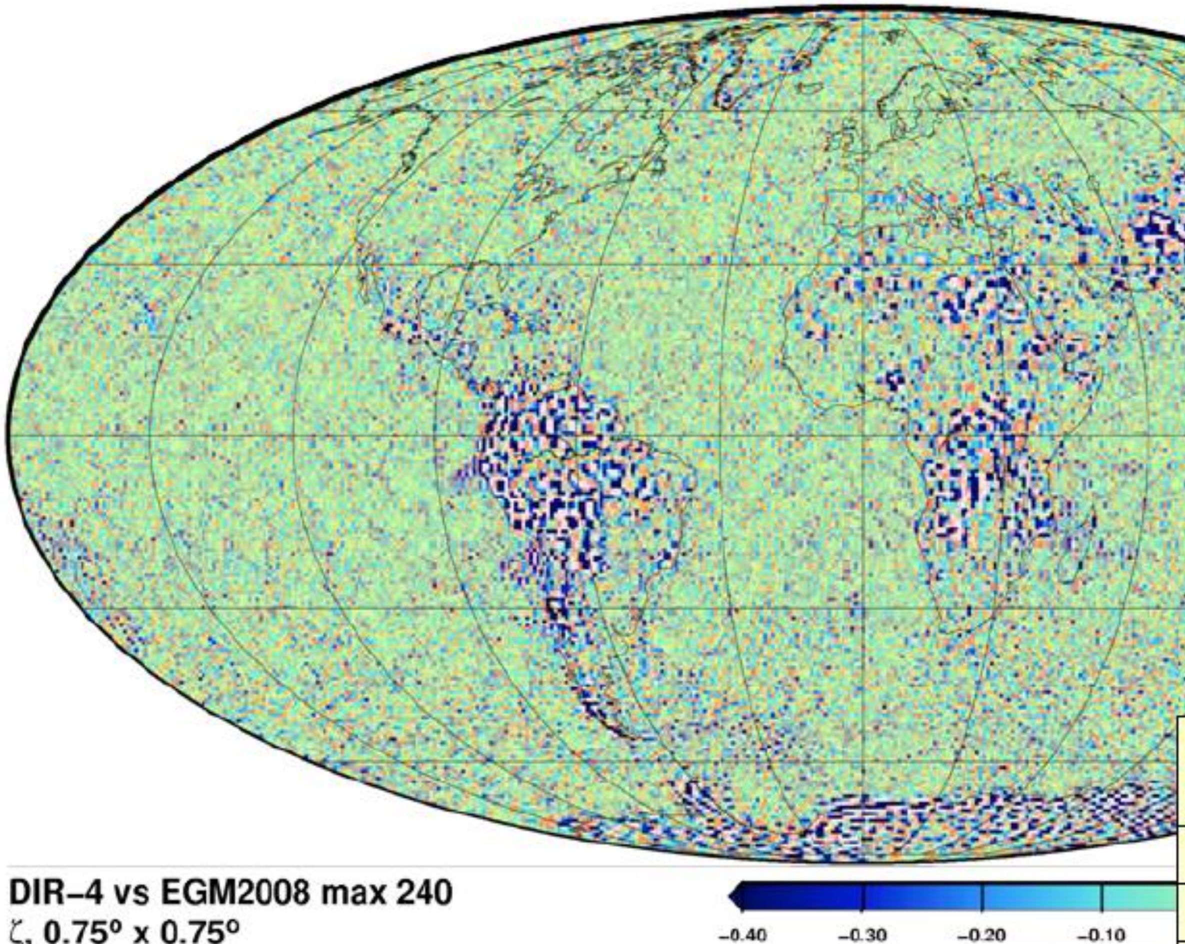


STATIC GRAVITY FIELD

2

Official GOCE solutions

GOCE geoid height differences: DIR-R4 vs. EGM2008 (max d/o 240)

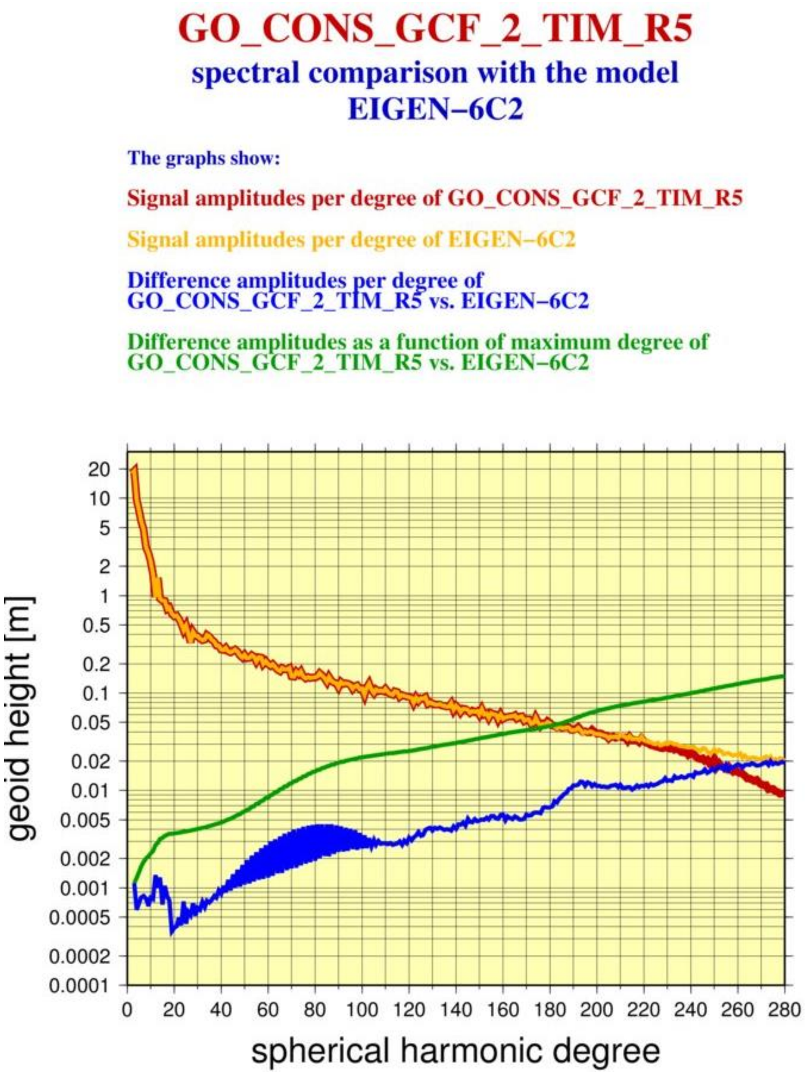


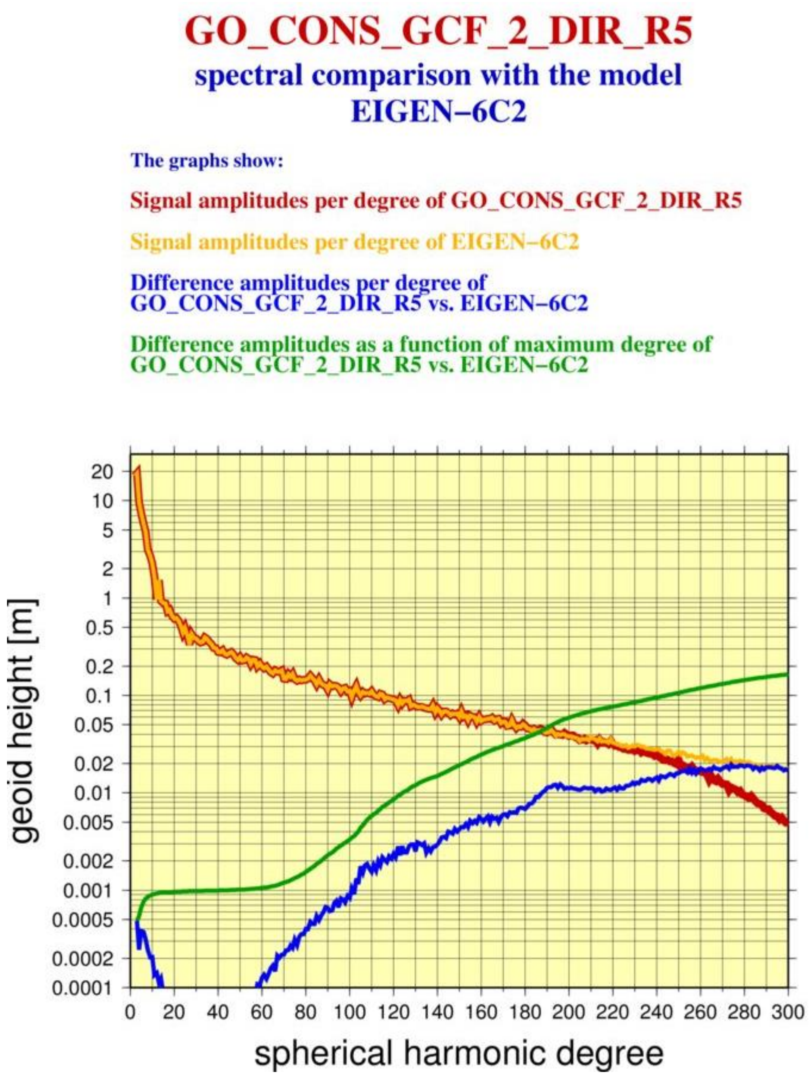
DIR–4 vs EGM2008 max 240
ζ, 0.75° x 0.75°
wrms about mean / min / max = 0.1804 / –3.27 / 3.161 meter

EGM2008 minus	wrms about mean [meter] (incl the polar caps)
DIR-R2	0.218
GOCO02S	0.228
DIR-R3	0.217
GOCO03S	0.207
DIR-R4	0.180

From Christoph Förste (2013)

- **Latest official GOCE models: EGM-TIM-R5 and EGM-DIR-R5**





From the ICGEM web site

Combined models GRACE+GOCE+surface data

Normal equation combination scheme for EIGEN-6C3stat

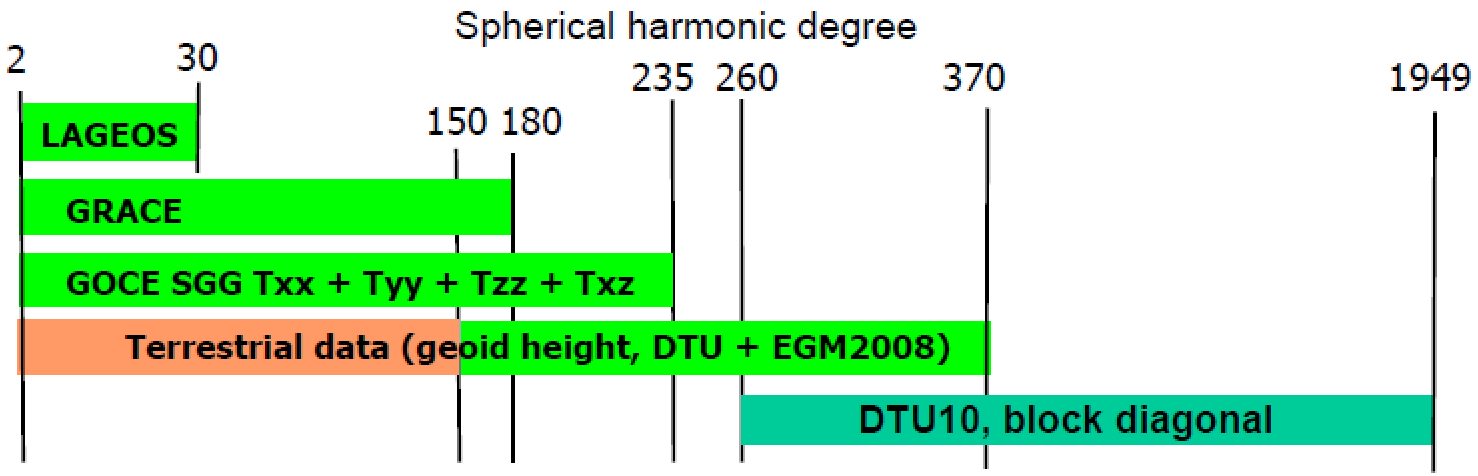
Accumulation of a full normal matrix up to d/o 370:

~200.000 parameters, ~ 250 GByte

contribution to the solution: (green)

kept separately: (orange)

Separate block diagonal solution: (teal)



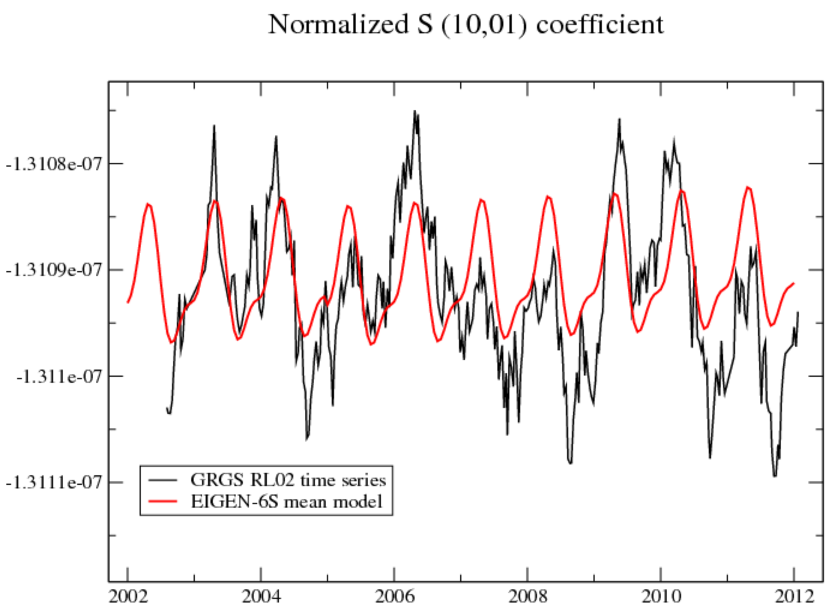
From Christoph Förste (2013)

➢ **Next combined model will be EIGEN-6C4**

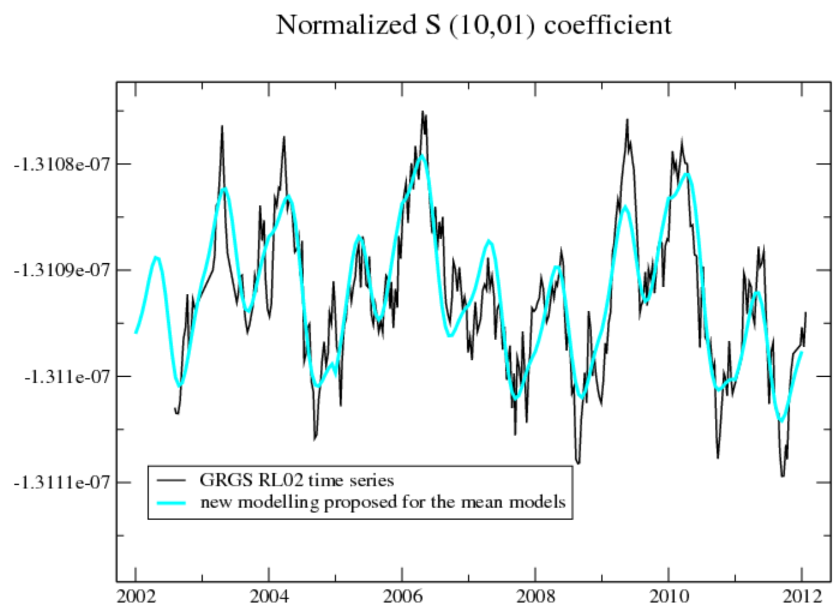
- Some high resolution gravity field models include a time-variable part, which tends to be more and more complex…

<u>Mean models:</u> "bias and slope" vs. "piece-wise-linear" modelling

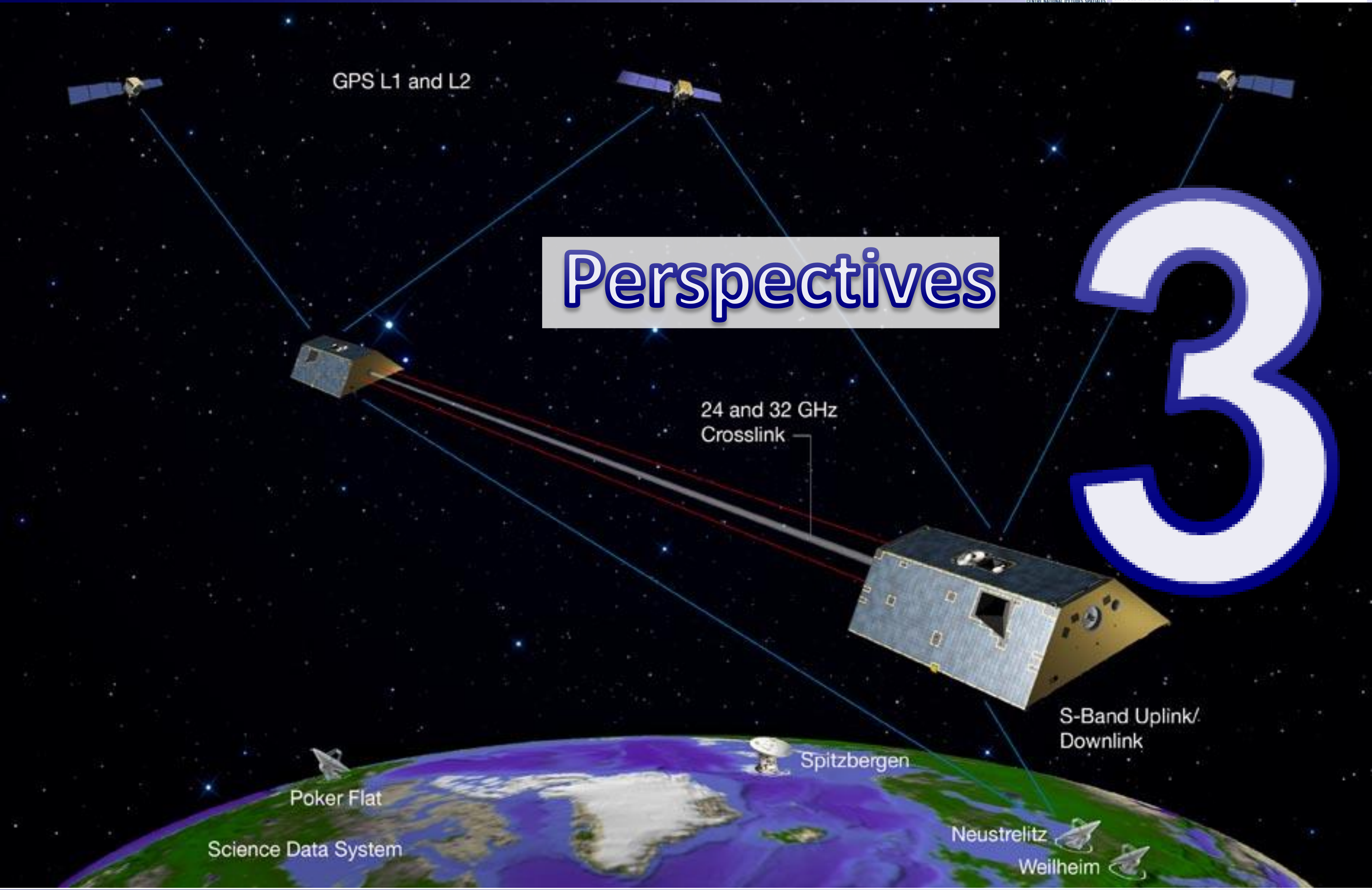
• "bias and slope"



• "piece-wise-linear"

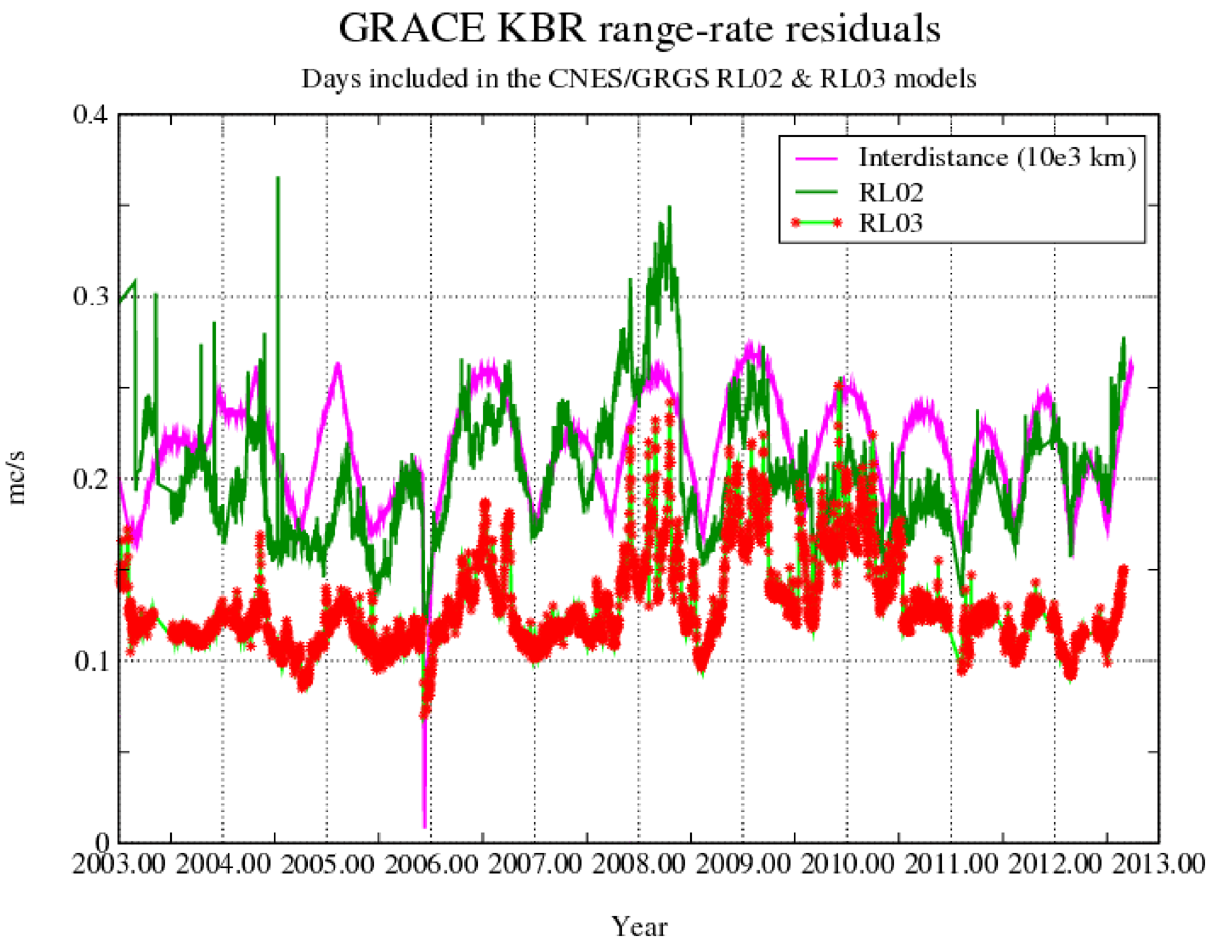


3 Perspectives



Perspectives

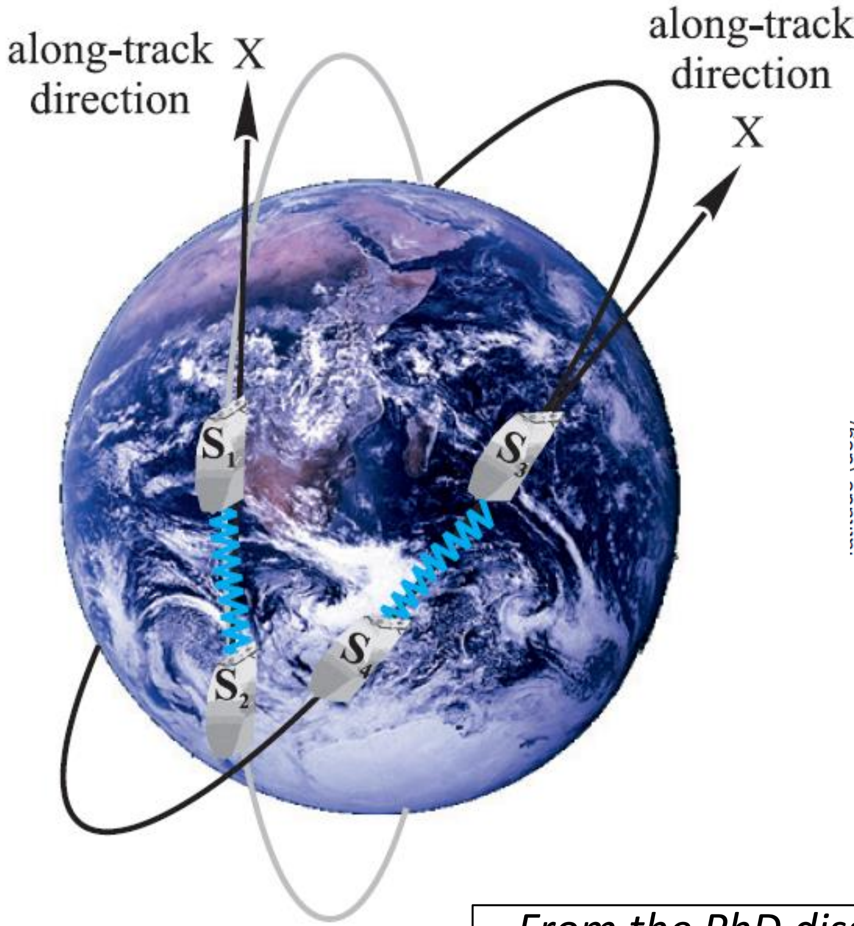
- **GRACE Follow-on is due for launch in August 2017. It will carry a laser interferometer. Expected accuracy: 50 nm/√Hz**

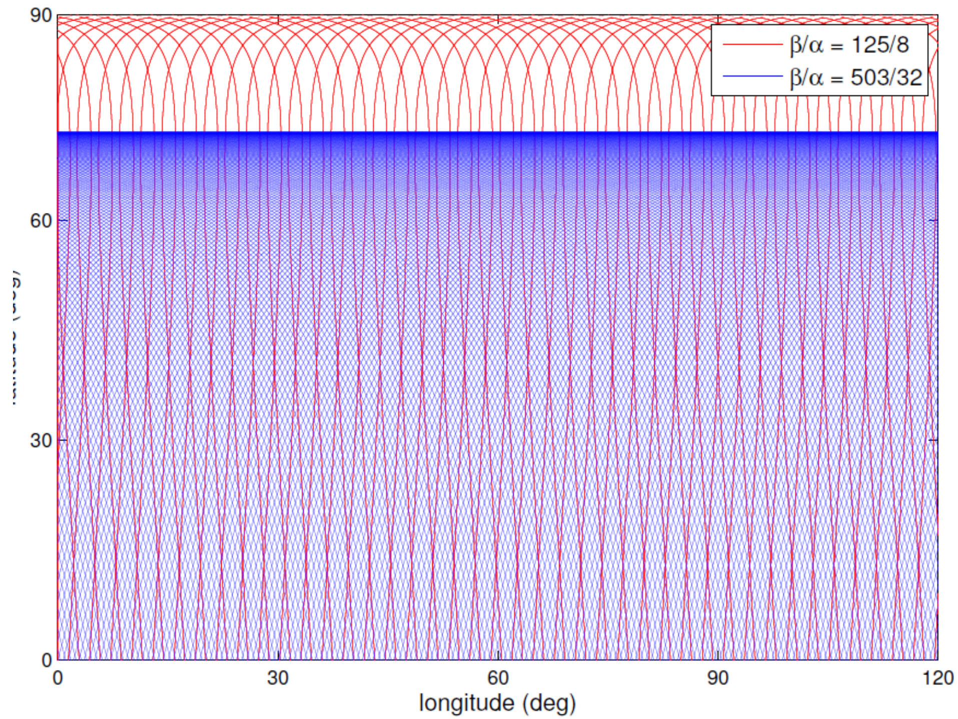


But the measurement accuracy might not be the limiting factor!... (dealiasing, etc.)

Perspectives

- **A Chinese GRACE mission is forecasted in 2017. It would be wonderful if it were on a different inclination than GRACE-FO…**





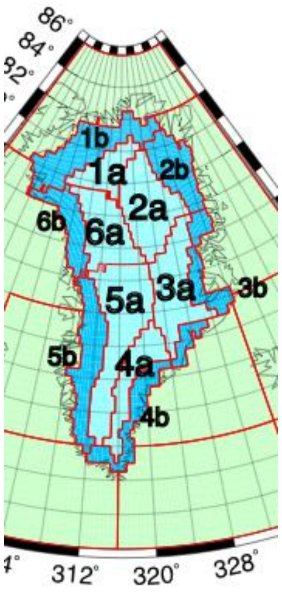
From the PhD dissertation of Siavash Iran Pour (August 20, 2013)

But politics!...

Thank you for your attention

Backup slides

GSFC "mascon" technique…



- **We directly estimate, from the inter-satellite K-band Range Rate data (KBRR), mass change in regions of interest as geographically specific mascons**
  - **… as opposed to global coefficients that are smoothed or averaged to reconstruct mass change locally without connection to the fundamental KBRR observations**
  - **Uses knowledge that the geophysical signal is not distributed uniformly, such as the errors, but is concentrated in regions.**
  - **This is an excellent way of filtering the solution to maximize signal to noise and to get the "filter gain" through the formal reduction of the KBRR data.**

- **We take advantage of the denser ground track sampling at higher latitudes by performing local cryosphere mascon solutions resulting in improved temporal and spatial resolution.**

- **We can further smooth our solutions by combining spatial and temporal constraint equations together with the GRACE tracking data in a simultaneous solution (as opposed to Gaussian smoothing gravity solution products *a posteriori*)**

New modelling for the mean field

Due to the non-linear evolution of the EWH in many areas of the world (many examples: Greenland, Alaska, Murray-Darling basin, Lake Victoria…), the mean models consisting of bias, drift, annual and semi-annual terms are not adequate to represent the behaviour of the gravity field over long periods (10 years for GRACE, 30 years for Lageos considering C20).

Modelling annual bias and drift offers such advantages as:

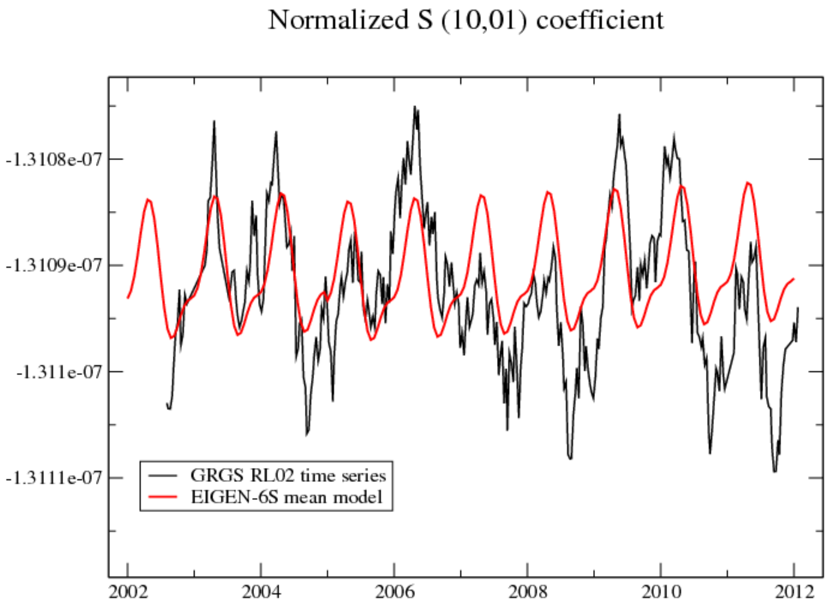
- Better agreement with 10-day or monthly series;
- Easy introduction of jumps to account for the major earthquake deformations.

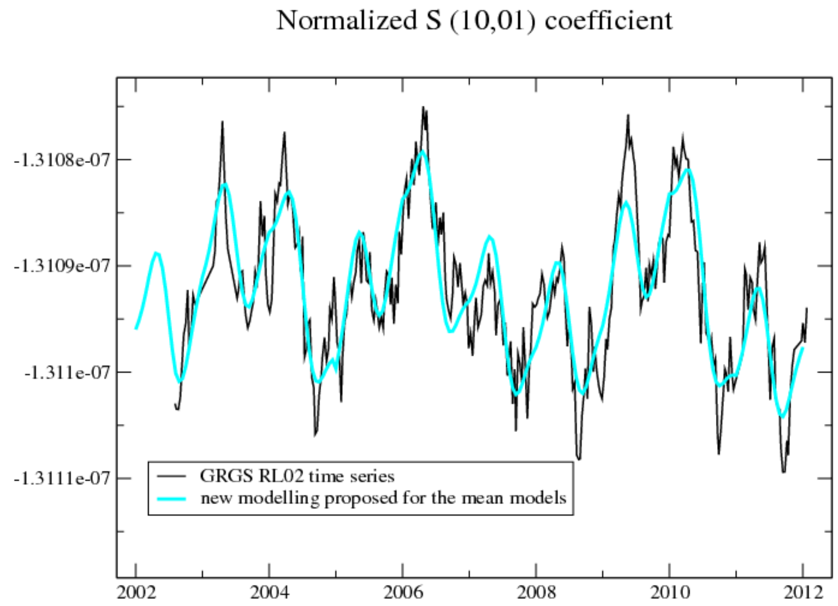
Examples on coefficients : S(10,1) and C(2,0)

Mean models: "bias and slope" vs. "piece-wise-linear" modelling

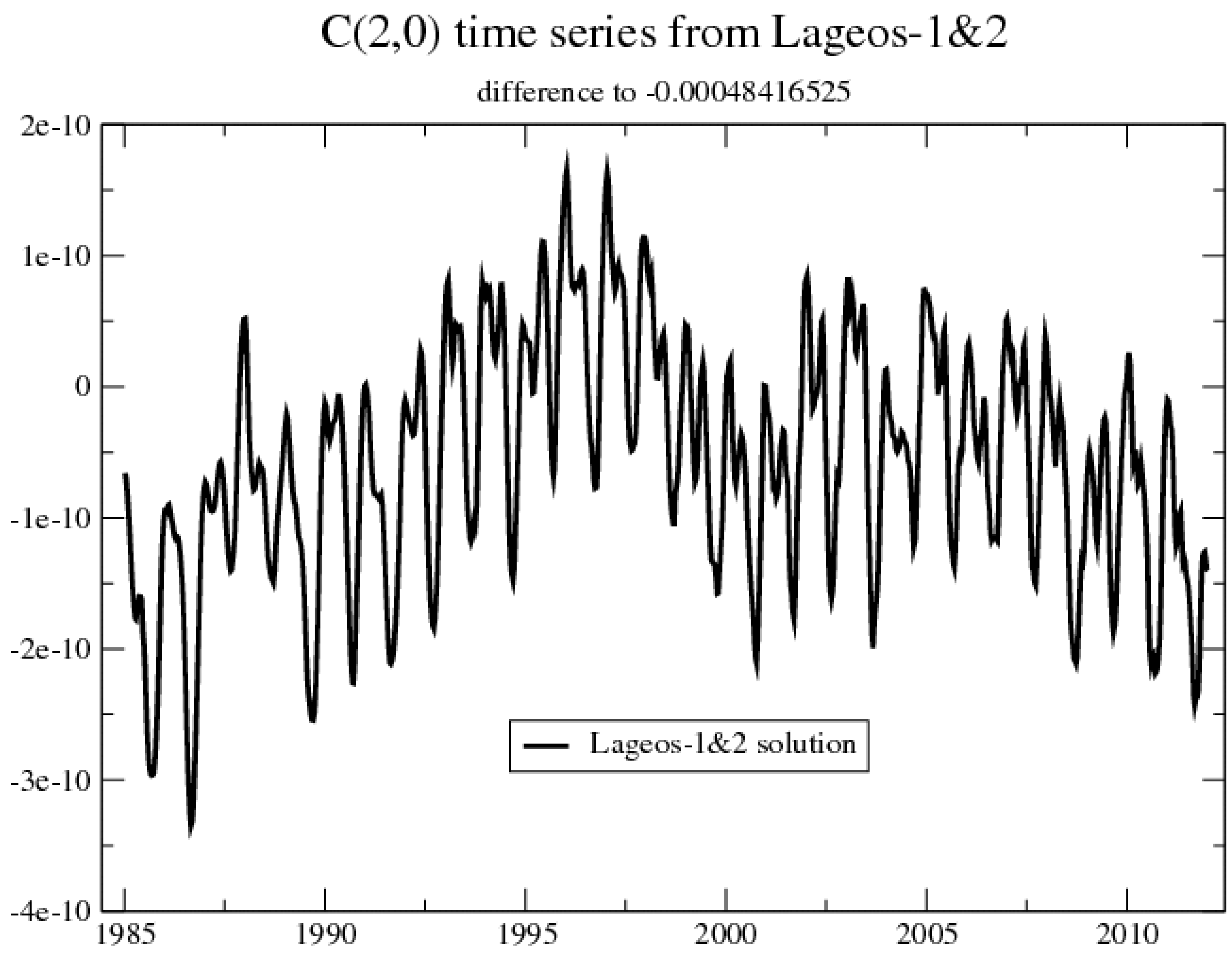
- "bias and slope"

- "piece-wise-linear"



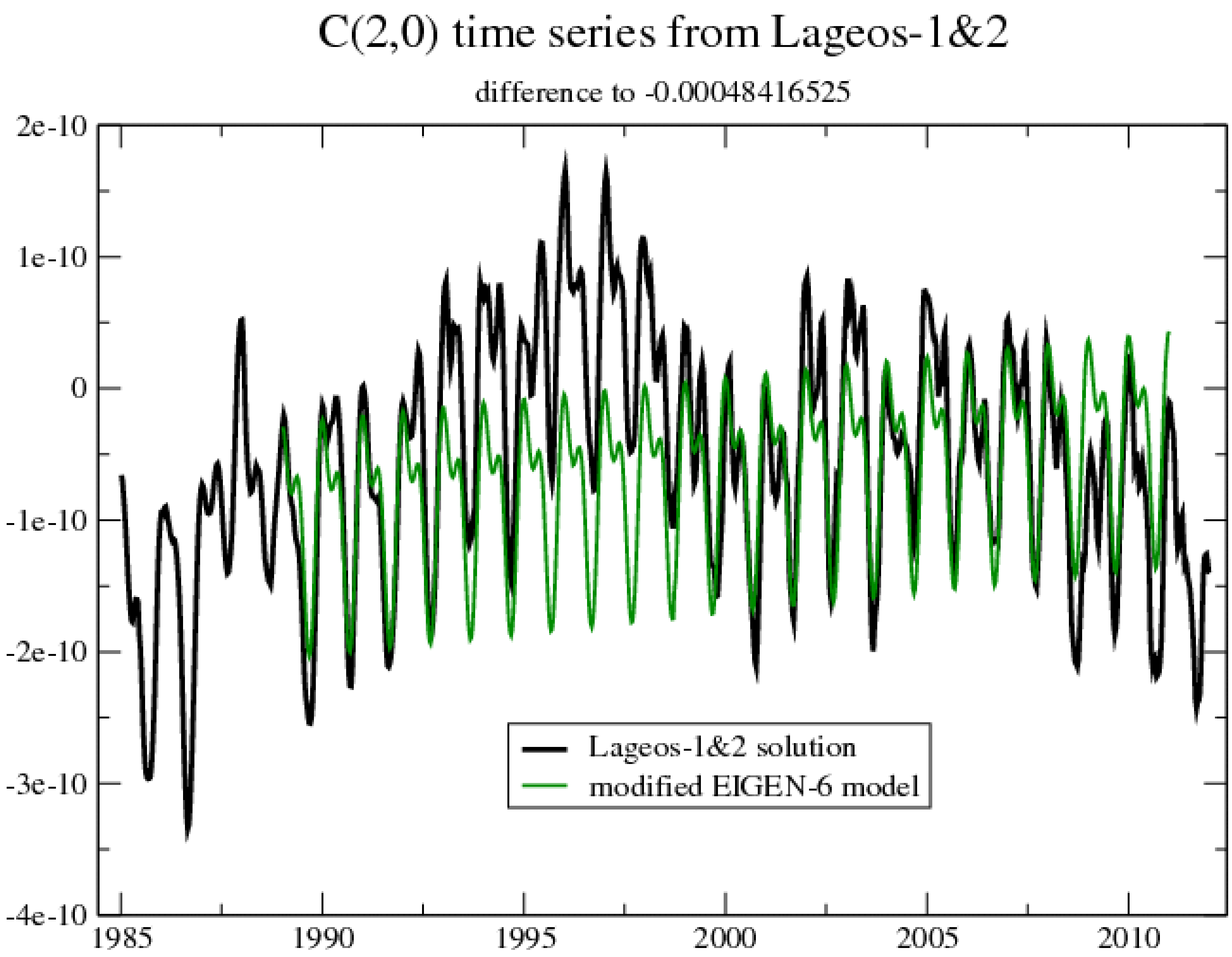


Non linear behaviour of C20



10-day models

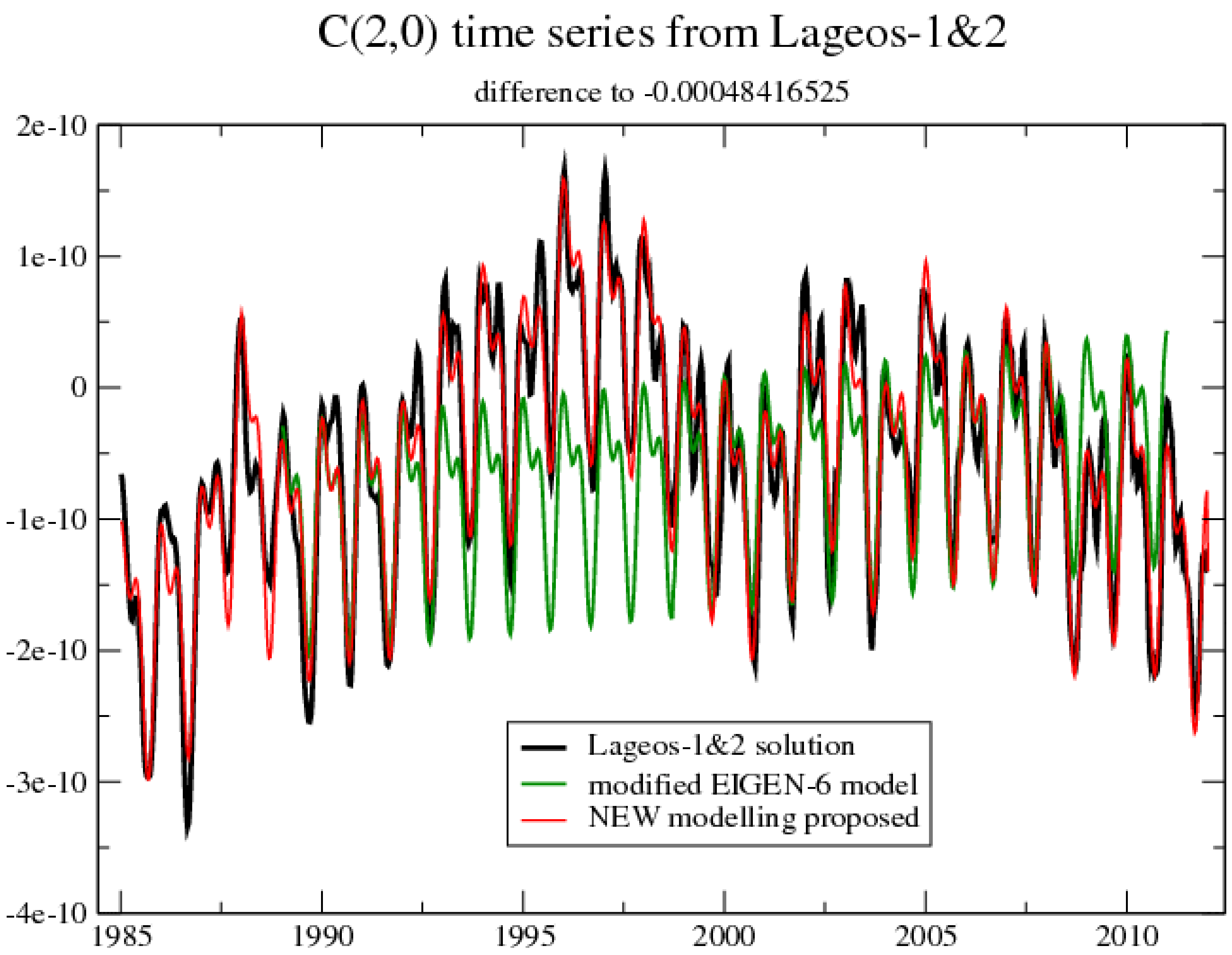
Non linear behaviour of C20



trend in modified EIGEN-6

10-day models

Non linear behaviour of C20



trend in modified EIGEN-6

10-day models

new modelling