Time-variable gravity models

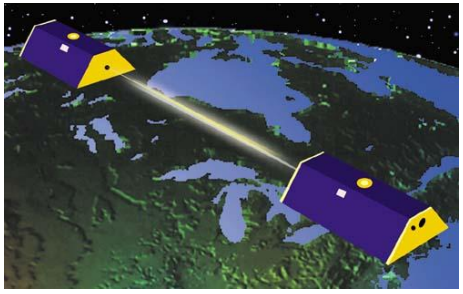
J.M. Lemoine [(1)], S. Bruinsma [(1)], P. Gégout [(2)], R. Biancale [(1)], S. Bourgogne [(3)]

(1) CNES/GRGS, Toulouse, France
(2) GET/UMR5563/OMP/GRGS, Toulouse, France
(3) Géode&Cie, Toulouse, France

Data used

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

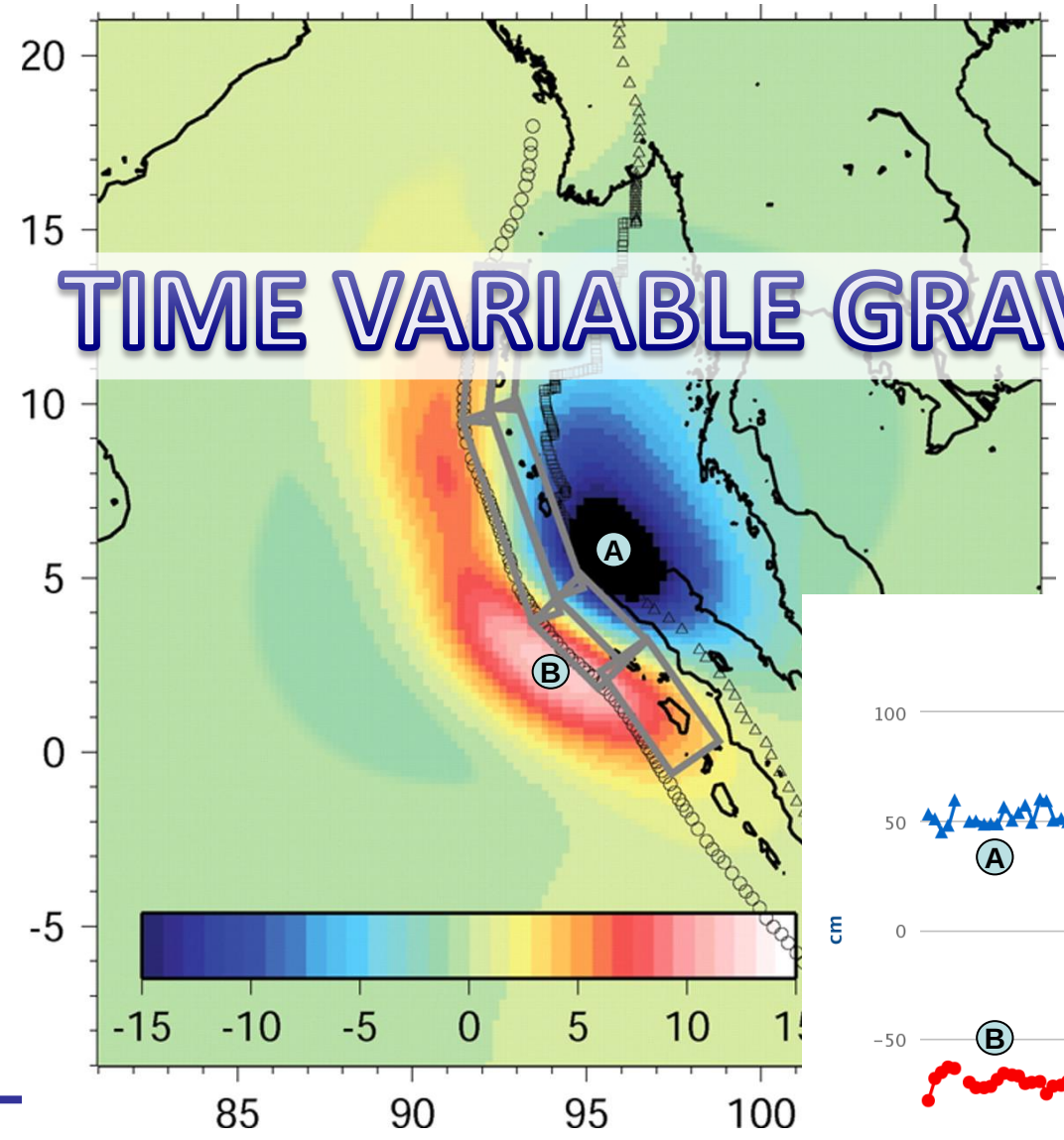
- Launched March 17, 2009 – Passed on November 11, 2013
- Altitude: ~ 260 km, Inclination: 96.7°
- GPS + SLR + gradiometer (0.5 m arm length)
- Gradiometer accuracy: 4 mE at 1 Hz (→ 4 10^{-12} m/s^2 /m)

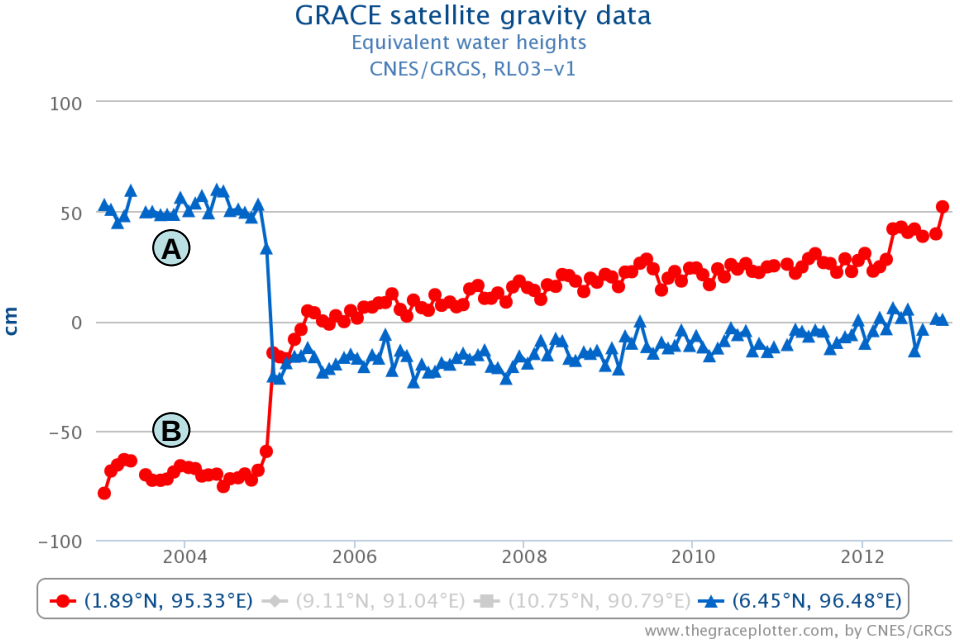
LAGEOS-1 & 2, Starlette and Stella

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

TIME VARIABLE GRAVITY FIELD

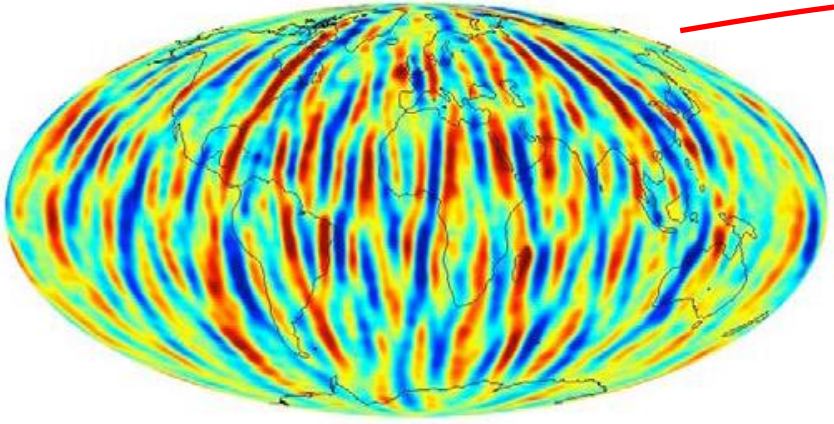
1

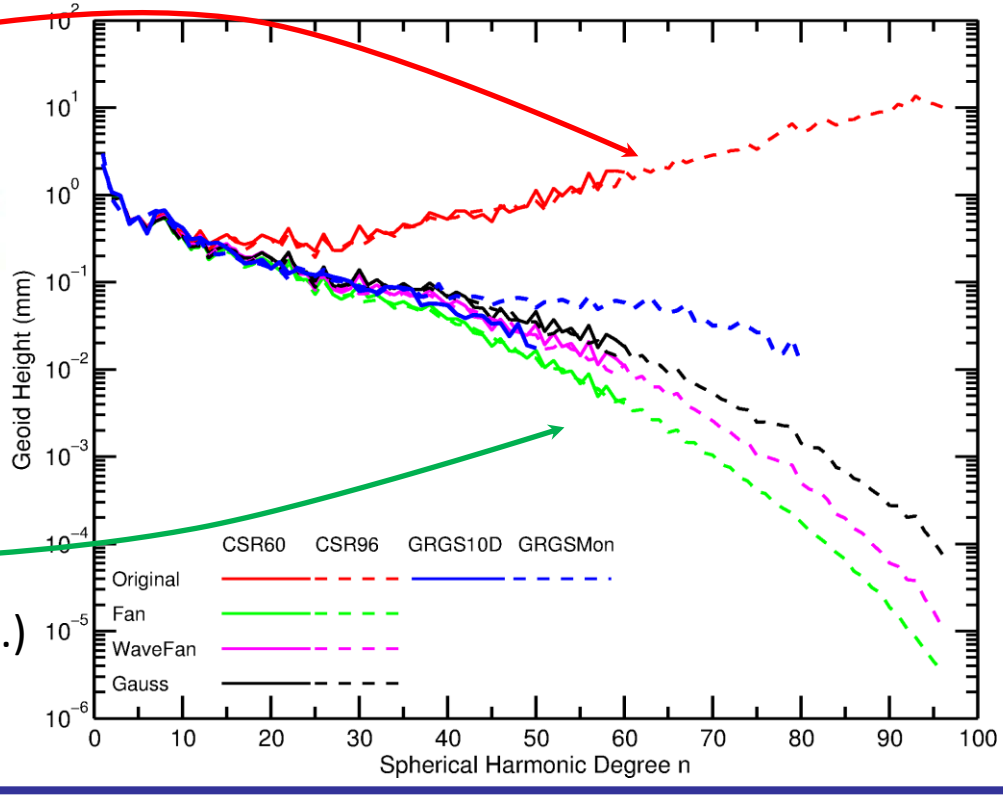




METHODOLOGICAL APPROACH

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





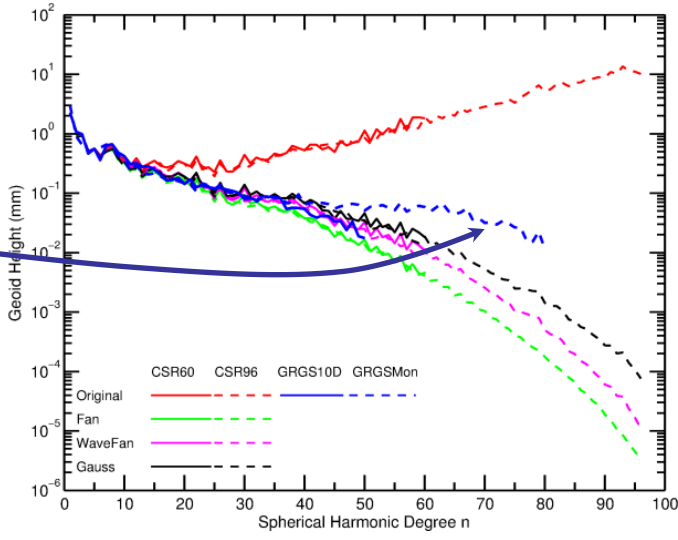
A posteriori filtering

… is necessary (DDK / Swenson & Wahr /…)

METHODOLOGICAL APPROACH

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

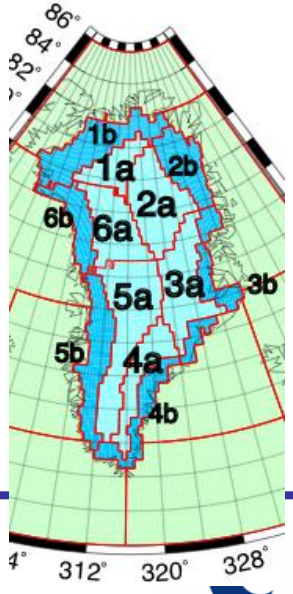
- Truncated SVD solution: **GRGS-RL03**
  (degree max: **80**)



A posteriori filtering… is **NOT** necessary

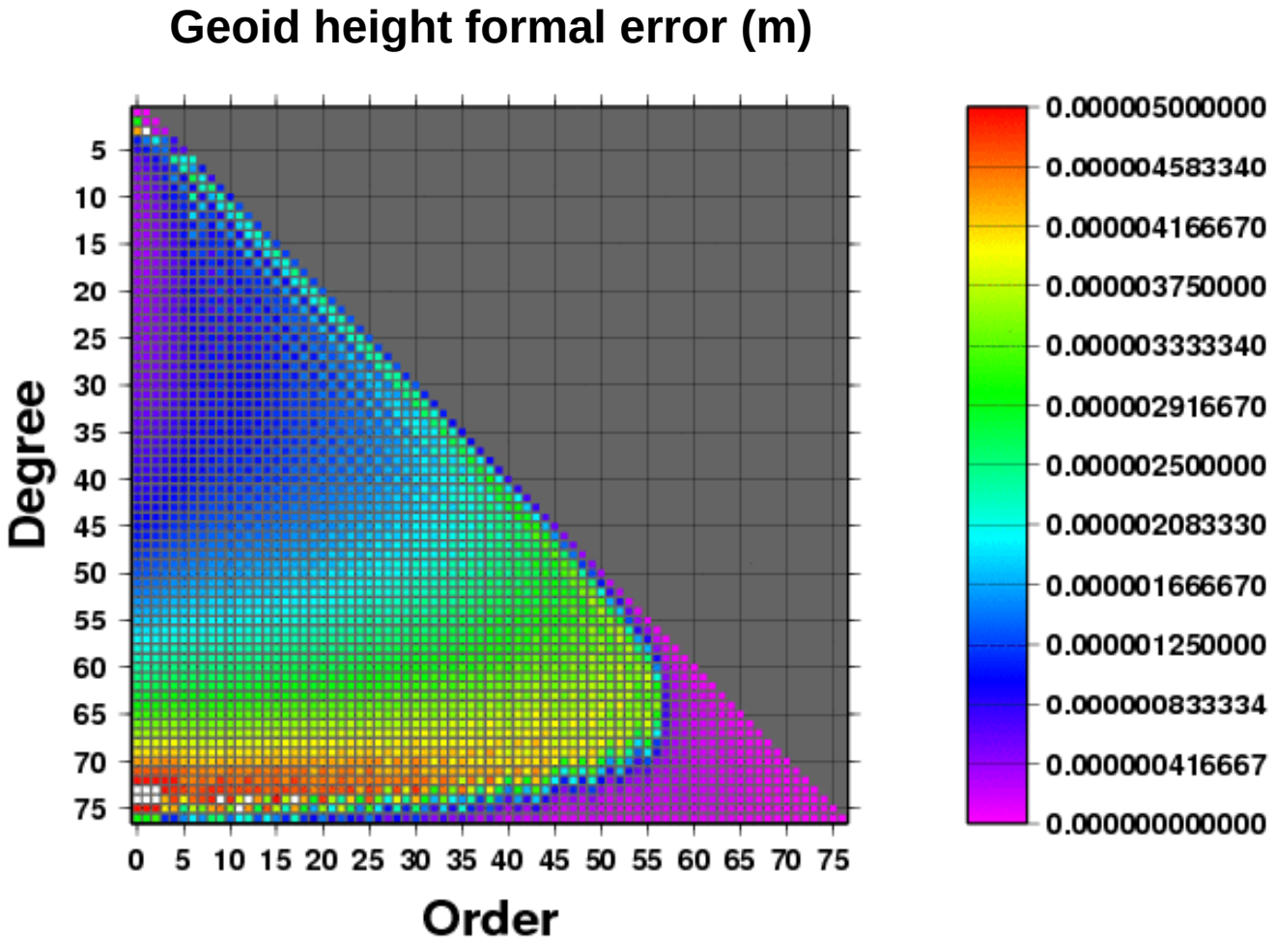
- Mascons: **GSFC** Computation of the direct effect of point masses on the KBRR measurements

- "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.



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

- Example where the first 4600 (upon 6400) Eigen values are kept (i.e. the first 4600 linear combinations of parameters are solved)

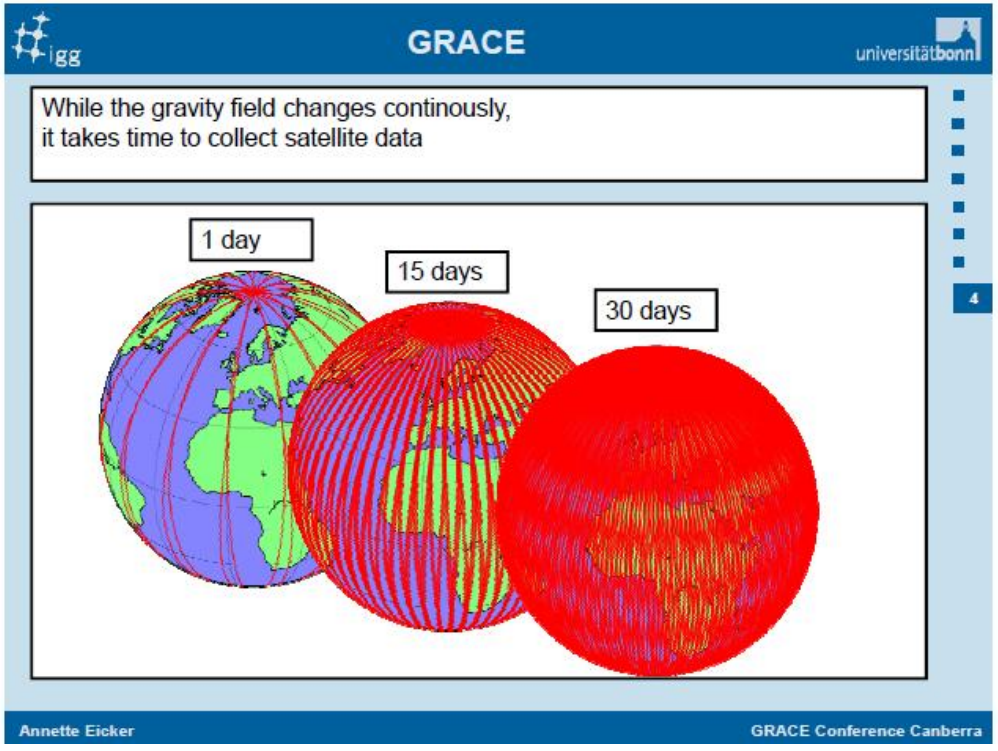


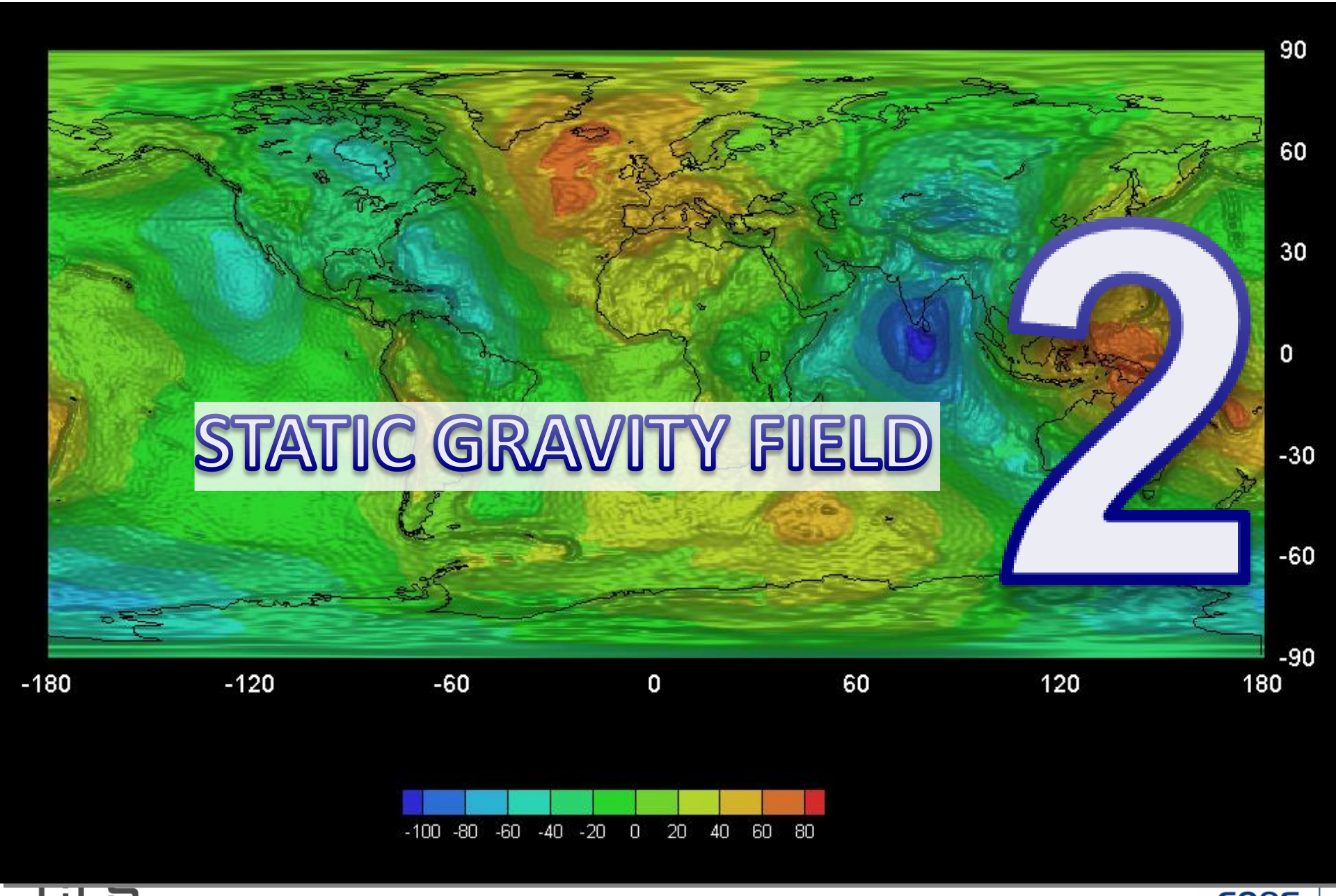
TIME SAMPLING

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

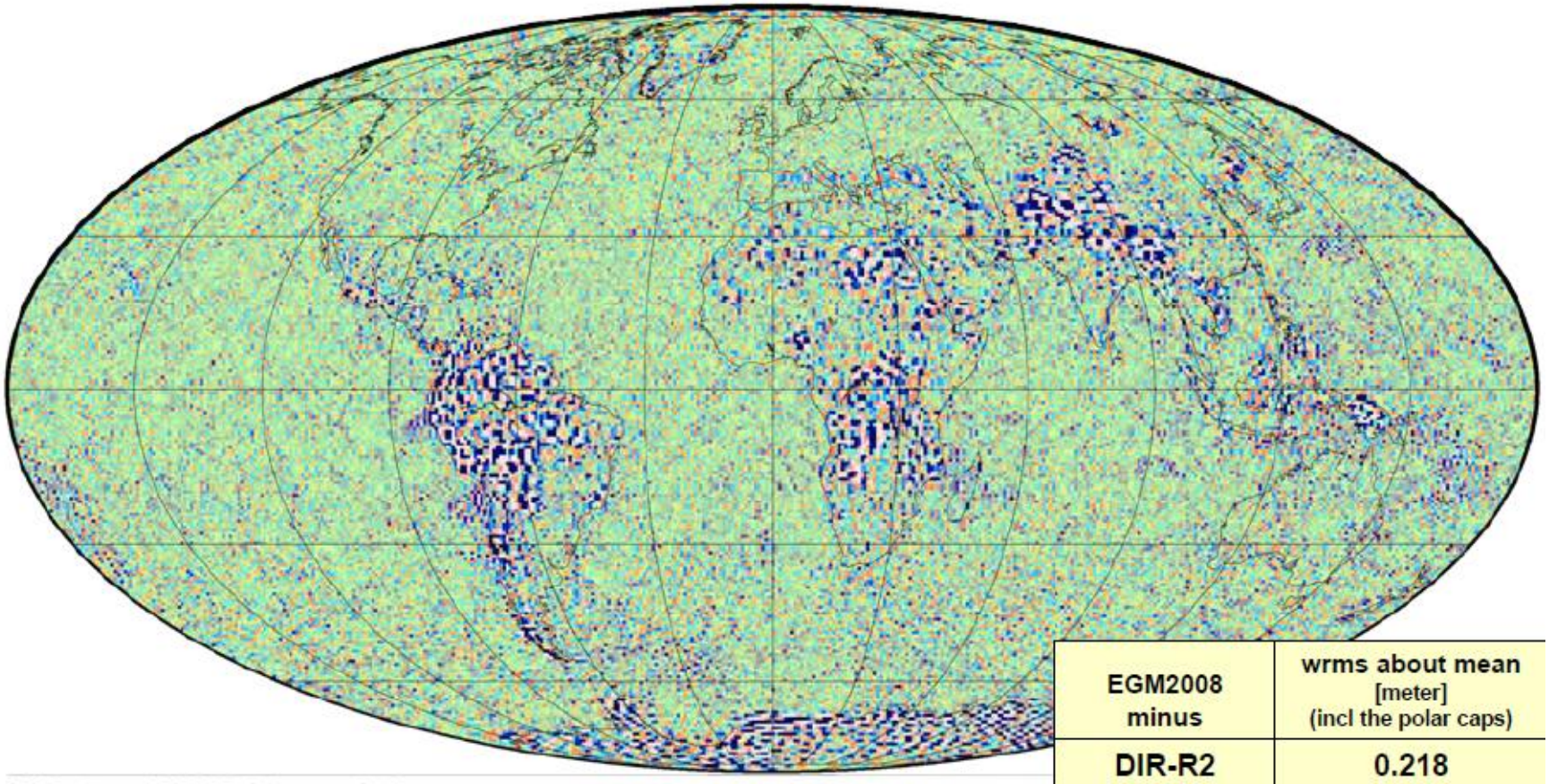
- Monthly: **CSR**, **JPL**, **GFZ**, **GRGS-RL03**
- 10-days: **GRGS-RL02**
- 1-day: **BONN**

Using a Kalman Filter scheme




STATIC GRAVITY FIELD
2
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
-100 -80 -60 -40 -20 0 20 40 60 80

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



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)

Normal equation combination scheme for EIGEN-6C3stat

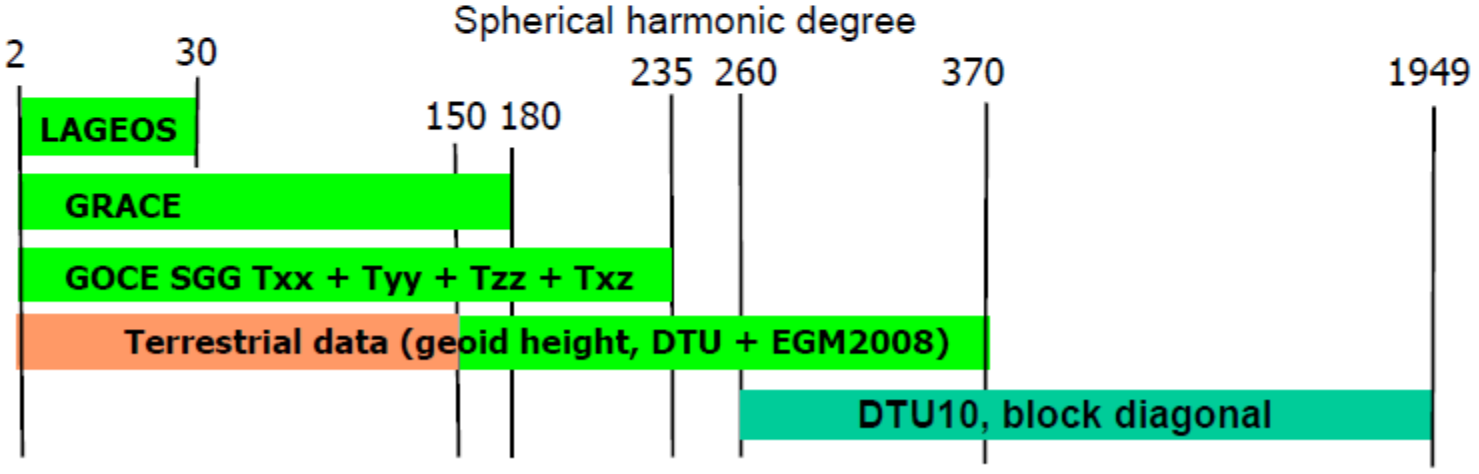
Accumulation of a full normal matrix up to d/o 370:

~200.000 parameters, ~ 250 GByte

contribution to the solution:

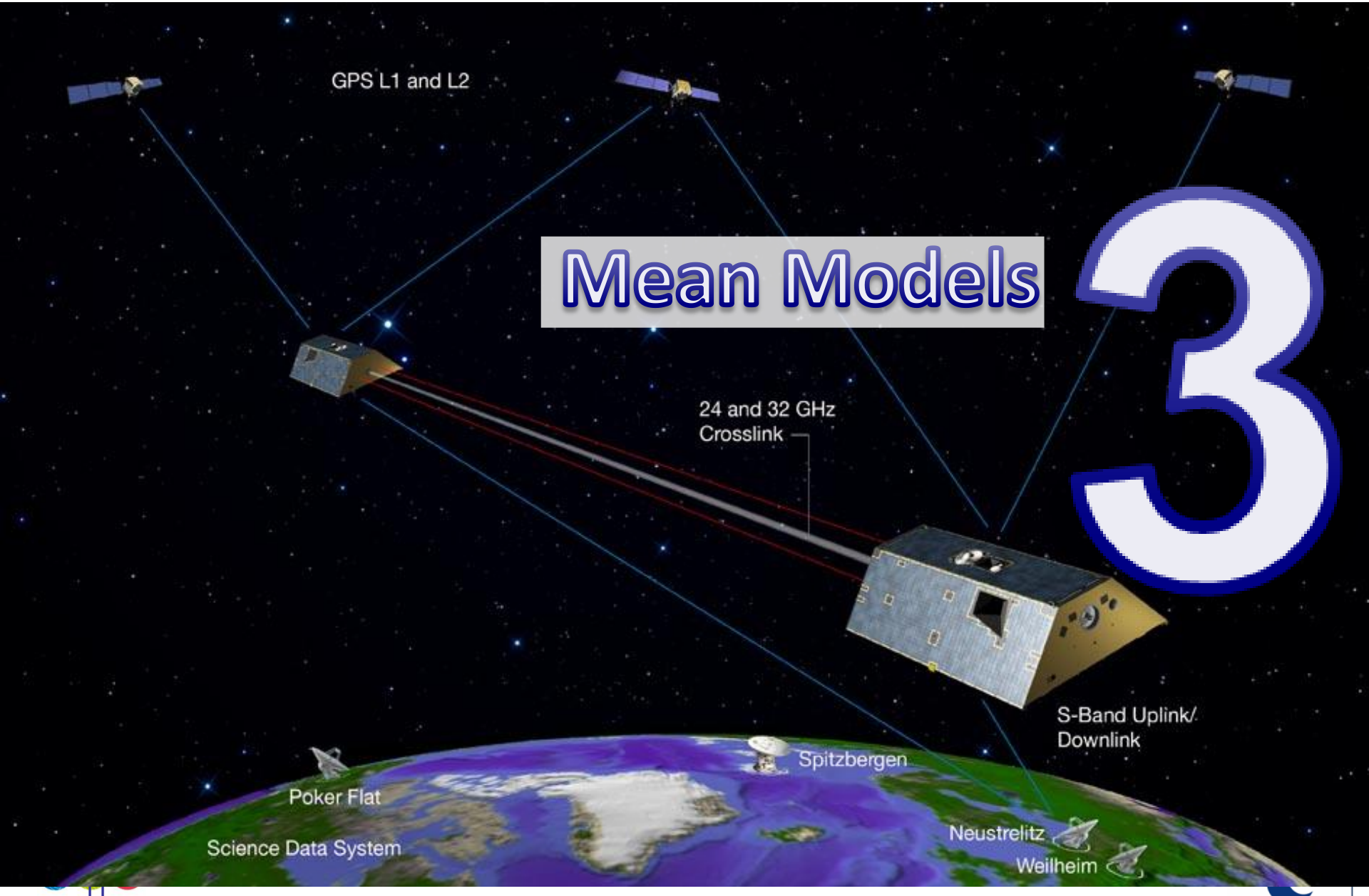
kept separately:

Separate block diagonal solution:



From Christoph Förste (2013)

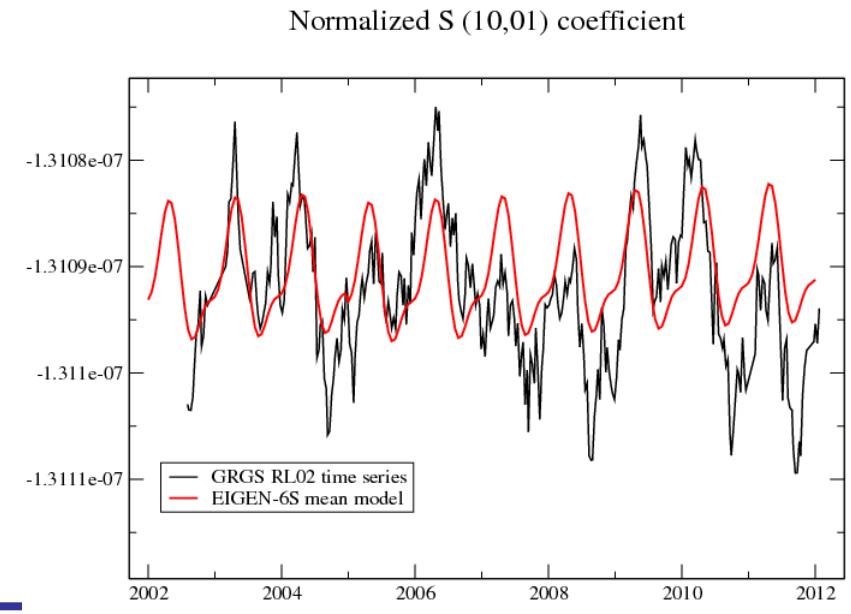
- **Next combined model will be EIGEN-6C4**


GPS L1 and L2
Mean Models
3
24 and 32 GHz
Crosslink
S-Band Uplink/
Downlink
Spitzbergen
Poker Flat
Science Data System
Neustrelitz
Weilheim

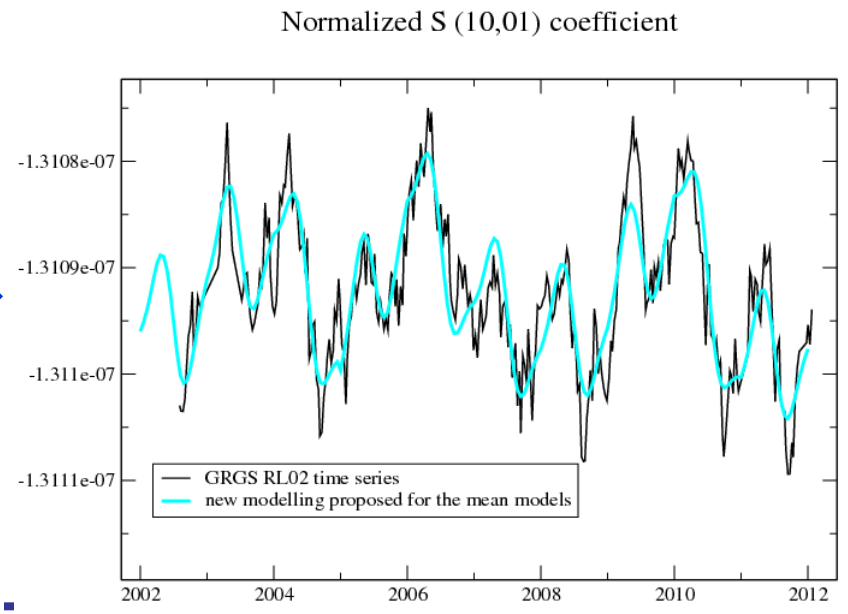
➢ **Some high resolution gravity field models include a time-variable part, which tends to be more and more complex…**

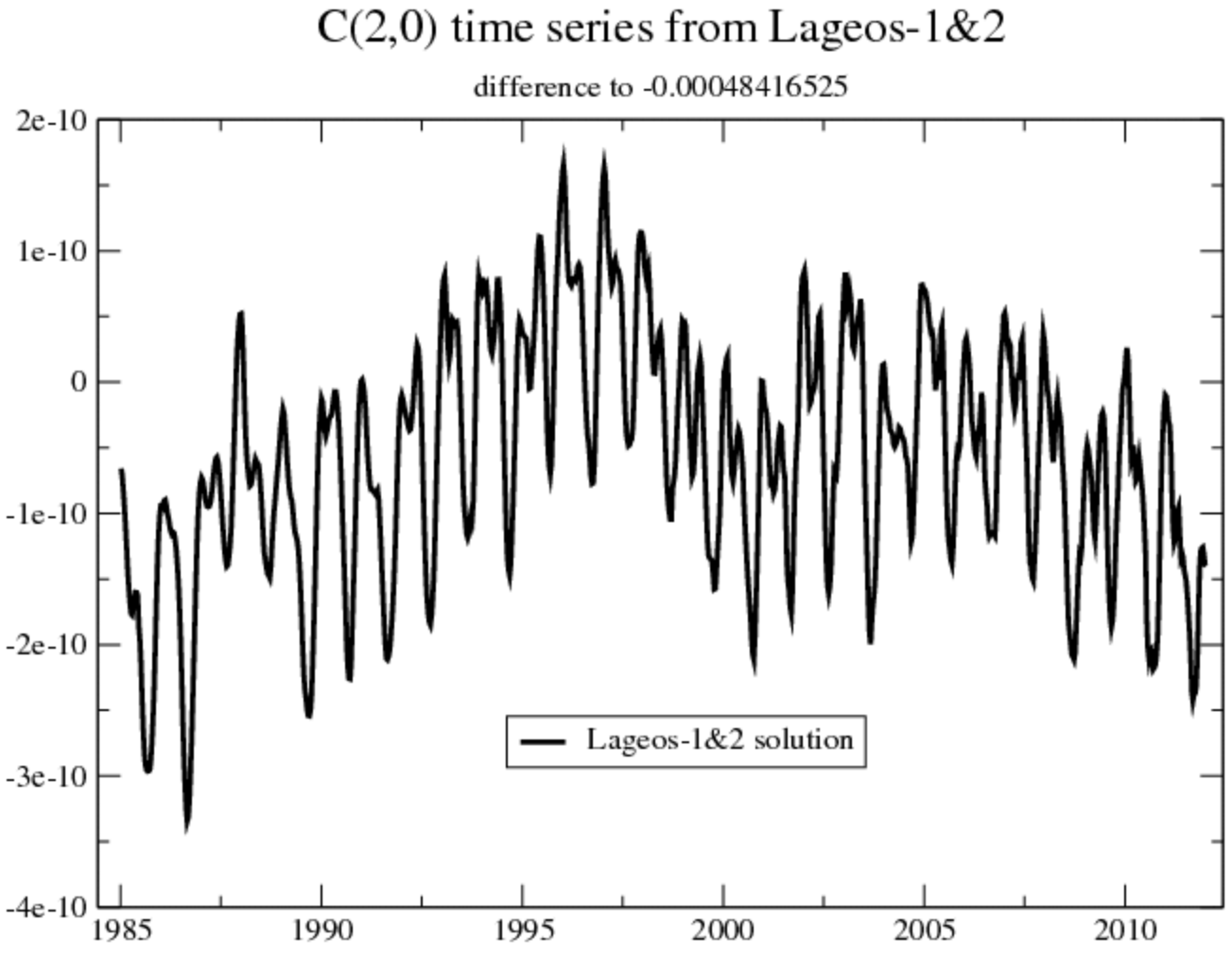
Mean models: "bias and slope" vs. "piece-wise-linear" modelling

• "bias and slope"

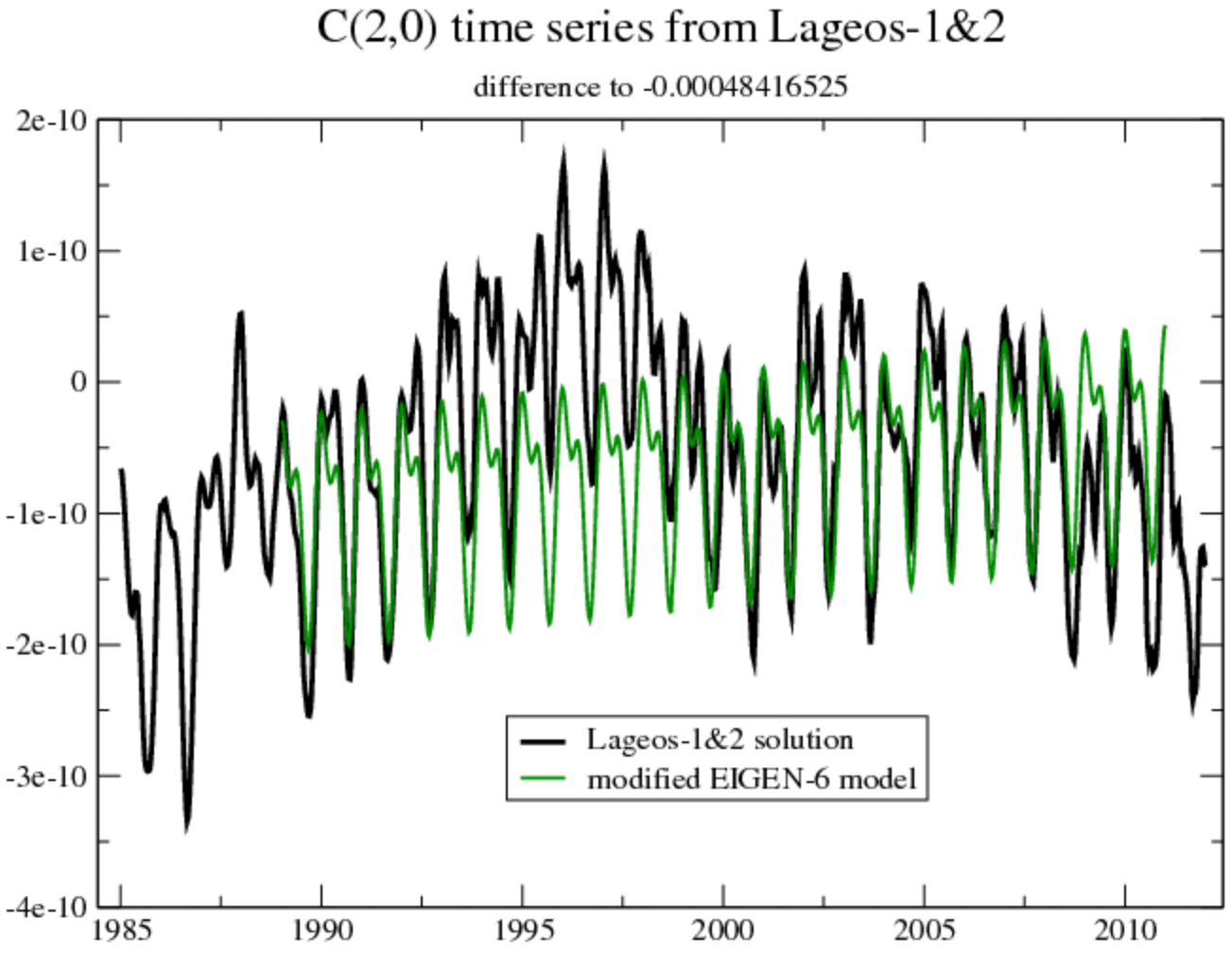


• "piece-wise-linear"



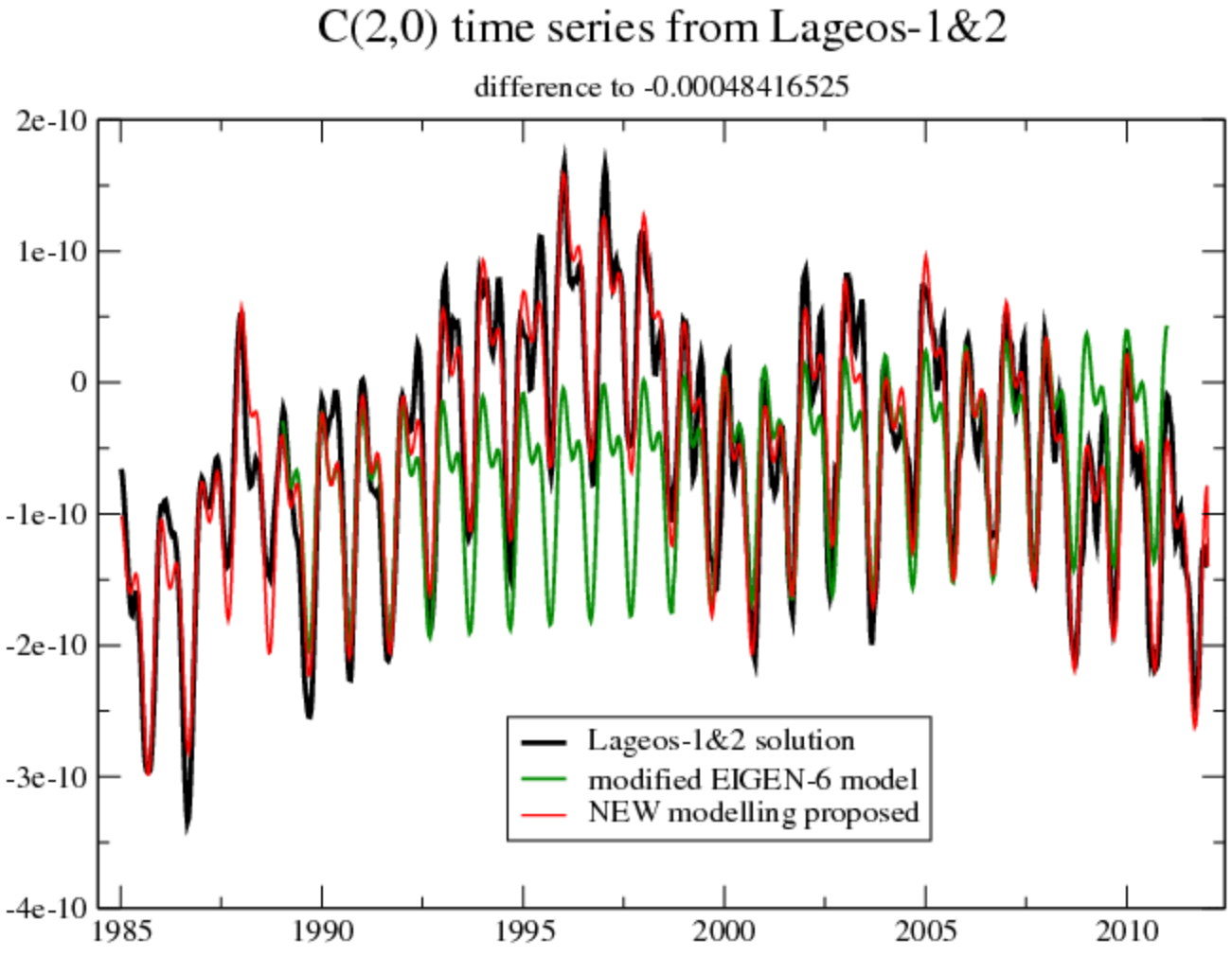


10-day models



trend in modified EIGEN-6

10-day models



trend in modified EIGEN-6 10-day models

new modelling

➢ Problem of the extrapolation outside of the GRACE era

1. **Periodic components: can probably be safely extrapolated**
2. **Drifts:**
   a) **Extrapolation of the drifts of the first and last years → very dangerous !**
   b) **Using for extrapolation the mean drift over the GRACE era → why not ?**
   c) **Setting the drifts to 0 outside of the GRACE era → most conservative option**

- **EIGEN-6S2 (extended.v2) (ITRF2014 processing) includes:**
  - One bias and one slope / year (continuous PWL except for “breaks”)
  - 3 breaks corresponding to the last 3 major earthquakes
  - Two mean annual and semi-annual components (sine and cosine) over the full time span
  - Zero-slope extrapolation

  → ~ 108000 parameters for 12 years and degree max = 80

- **EIGEN-GRGS.RL03-v2.MEAN-FIELD (GDR-E standards) includes:**
  - One bias and one slope / year (continuous PWL except for “breaks”)
  - 3 breaks corresponding to the last 3 major earthquakes
  - Two annual and semi-annual components (sine and cosine) / year
  - Zero-slope extrapolation

  → ~ 416000 parameters for 12 years and degree max = 80

Thank you for your attention