Release 3 of the GRACE gravity solutions from CNES/GRGS

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

(1) CNES/GRGS, Toulouse
(2) GET/UMR5563/OMP/GRGS, Toulouse

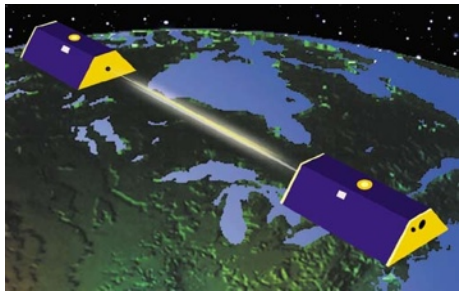
Summary

1. RL03 arcs
2. Inversion questions
3. Mean field
4. Preliminary results: time-series comparisons

Geodetic data in EIGEN-GRGS models

GRACE (L-1B "V2" data)

- K-Band Range-Rate data
- Accelerometer / attitude / thrusters data
- GPS data

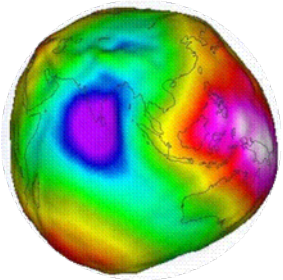


LAGEOS-1/2

- SLR data adjusting empirical biases in the orbital plane and along-track per 10-day arc as well as range biases

Physical parameters present in the normal equations

- Gravity spherical harmonic coefficients complete to degree and order 175 (truncated to 30 for LAGEOS processing)
- Ocean tides s. h. coefficients for 14 tidal waves with maximum degree/order ≤ 30



RL03 processing standards

Dynamical models

Gravity	*EIGEN-GRGS.RL02* → *EIGEN-6S2*
Ocean tide	*FES2004 (degree 80)* → *FES2012 (Legos)*
Atmosphere	*3-D ECMWF pressure grids / 6hrs* → *ERA-interim / 3hrs*
Ocean mass model	*MOG2D (non-IB) / 6hrs* → *TUGO (Legos) / 3hrs*
Atmospheric tides	→ *Not necessary any more*
3rd body	*Sun, Moon, 6 planets (DE405)*
Solid Earth tides	*IERS Conventions 2010*
Pole tides	*IERS Conventions 2010*
Non gravitational	*Accelerometer data (+biases and scale factors)*

Geometrical models

SLR stations	*ITRF2008 coordinates* → *updated*
GPS	*IGS orbits and CODE clock* → *IGS Repro-1 orbits and clocks*

Other models

Hydrology	Taken into account by the a priori gravity field
Glacial Isostatic Adjustment	

RL03 parameterization

- Maximal degree for static gravity field parameters : 175
- Maximal degree for variable gravity field parameters : 80
- KBRR and empirical forces:

  Compared to RL02, we have transferred a lot parameters from the KBRR measurements to the empirical accelerations:

  - KBRR parameterization : 31/day bias+drift terms = 1 bias+drift / half rev. Continuity constraint applied at each of the 30 connections between segments.
  - Accelerometer parameterization :
    2/day accelerometer biases along X, Y and Z satellite axes,
    1/day accelerometer scale along X, Y and Z satellite axes (later fixed to mean value)
  - Empirical accelerations : 15/day/satellite once/rev and twice/rev periodic parameters along X and Y satellite axes (= 2 sets of sine/cosine every orbit for each satellite)
- KBR phase centre coordinates : although we are processing the new JPL level-1B "V2" data, we still apply a "Horwath & Lemoine correction" on the KBR phase centre coordinates

RL03 data weighting and solutions

- Data weighting :

  KBRR : 0.1 μ/s with a down-weighting proportional to the cosine of the latitude

  GPS data have been much down-weighted and spaced to 300”

  GPS Range (1 epoch every 300”): 8 m

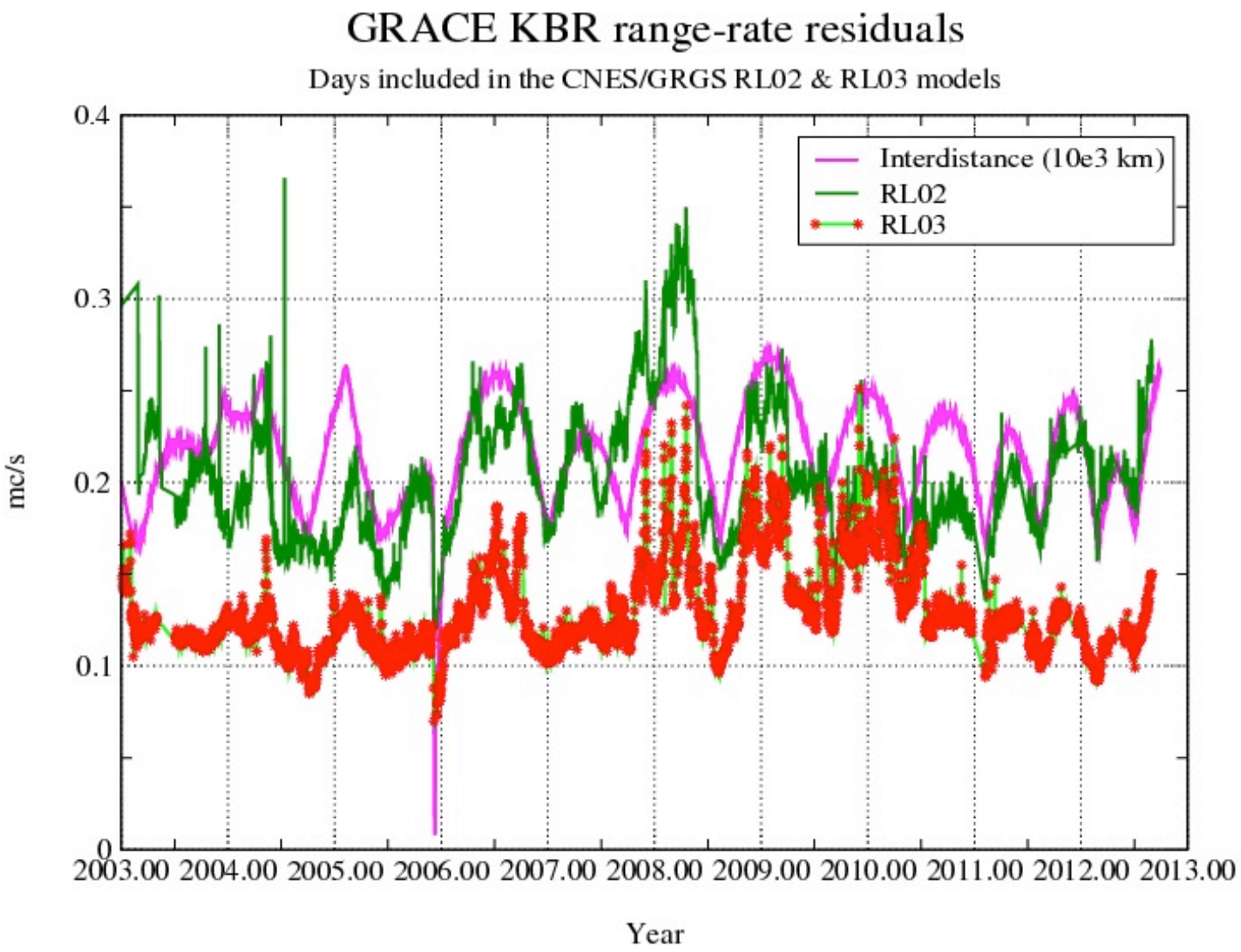
  GPS Phase (1 epoch every 300”): 2 cm

- Integer ambiguity fixing for GRACE GPS measurements ?

  For the time being we use real ambiguity (maybe later “IPPP” method)

- Solutions :
  - 10-day and monthly
  - inversion method changed between RL02 and RL03

RL03 KBRR residuals



RL03

- Current status
  - Arcs completed
  - Preliminary monthly solutions
  - New mean-field being processed, necessary for final solutions.
  - Inversion techniques at study

Inversion and stabilization process

- Different possible techniques

  Cholesky unconstrained + filters

  Cholesky + constraints

  Singular Value Decomposition

Inversion and stabilization process

- Least squares

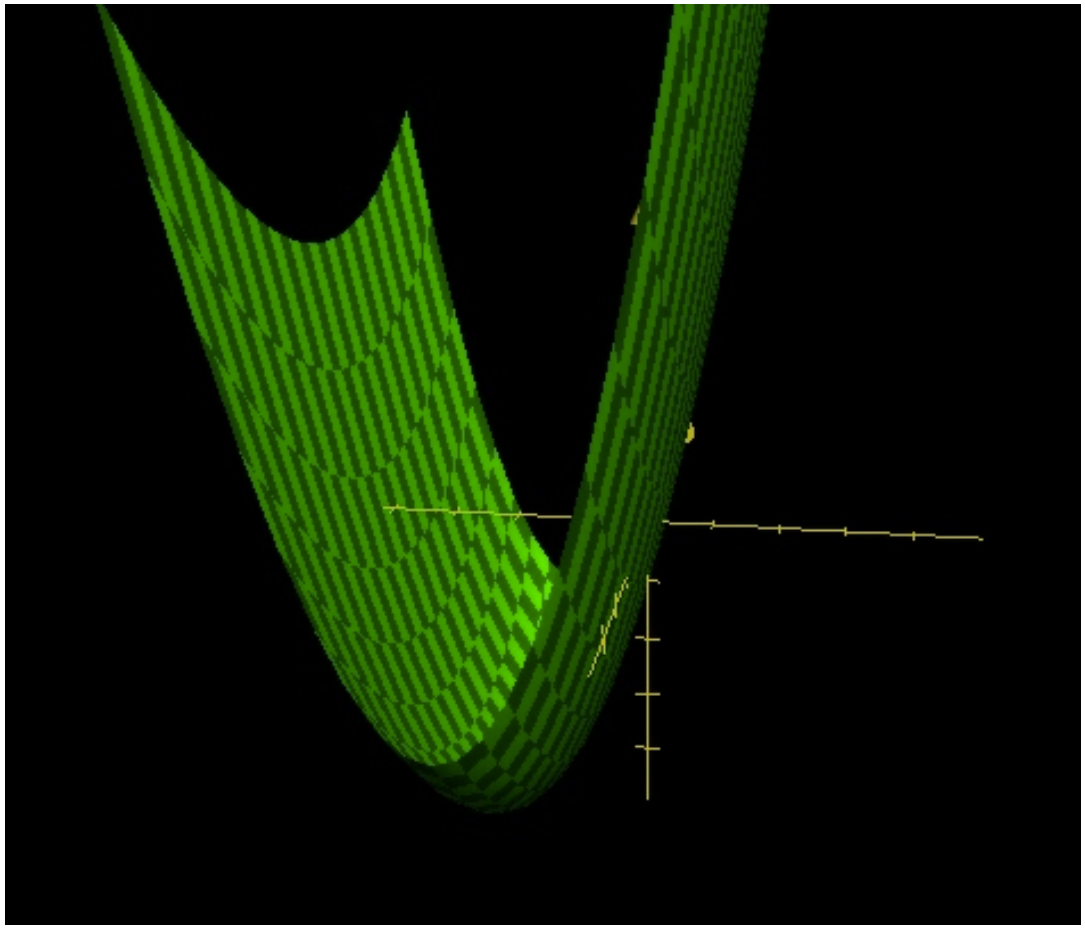
  p: parameter vector
  q: measurements vector
  $f(p)$: theoretical measurement vector (model)
  S: function to minimize (sum of squares of residuals)

$$S(p) = \sum_{i=1}^{m} (f_i(p) - q_i)^2$$

S is a function from the space of parameters to **R**.

$p0$: a priori parameter
Linear approximation: replace f by its partial derivatives
S becomes polynomial function of degree 2 of the parameter's components.
The quadratic term is defined by the normal matrix. The shape of the S function is replaced by a n-dimension paraboloid.

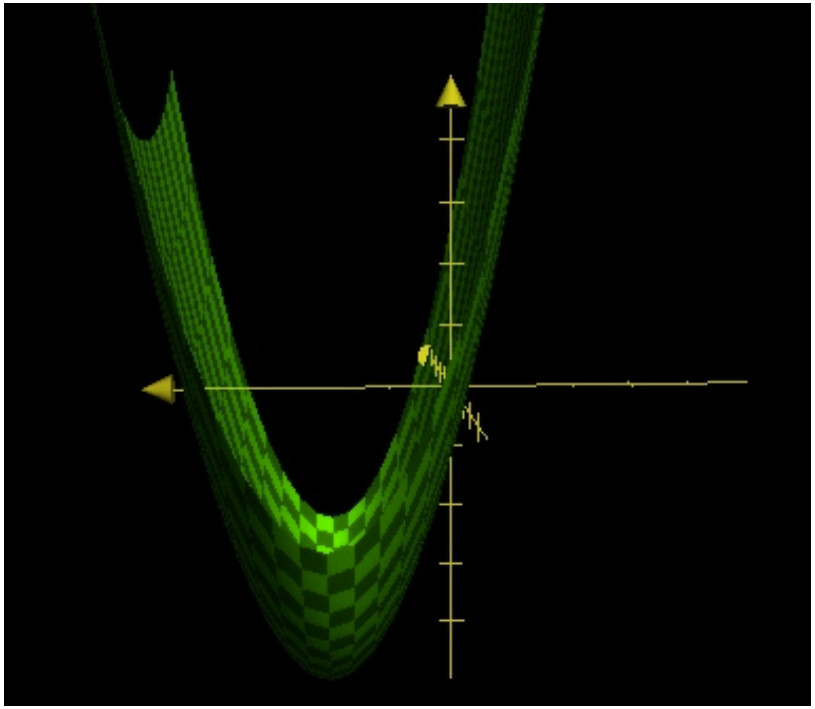
Inversion and stabilization process

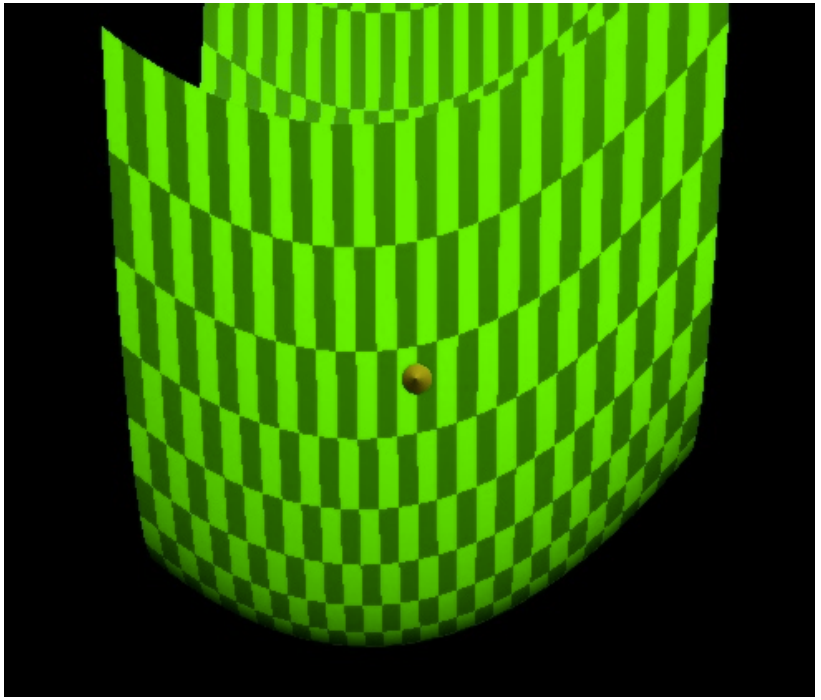


- Example: p in 2 dimensions:

  p0 is at the origin
  Solution is at the minimum of the paraboloid

Inversion and stabilization process

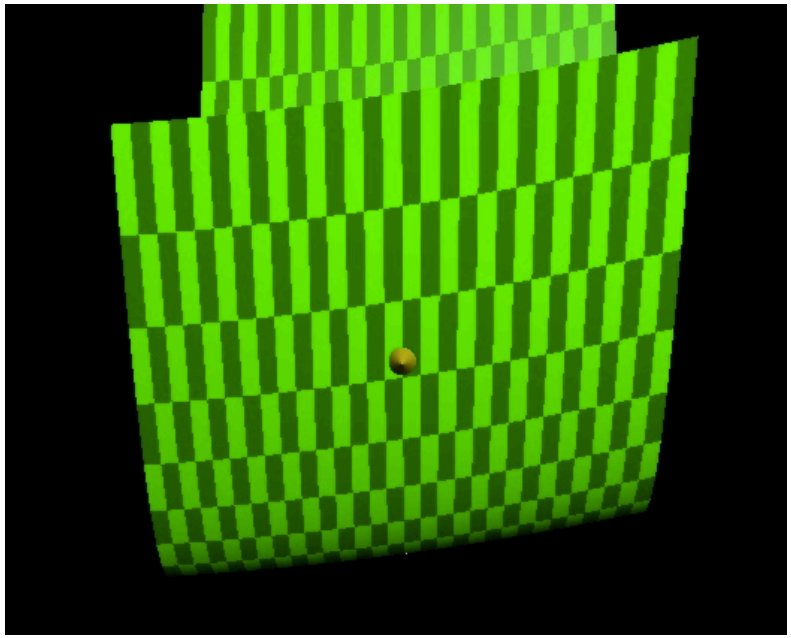




- Eigenvalues of the normal matrix are the coefficients of the parabolas in each one of the main directions

Inversion and stabilization process

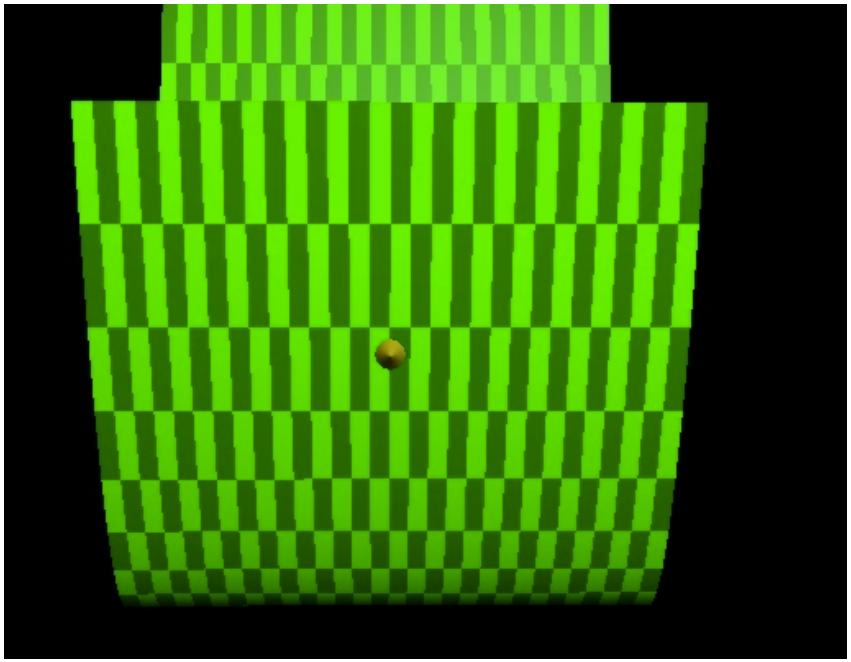
- Solving the whole system with Cholesky leads to the minimum of the paraboloid
- What happens with very small eigenvalues?

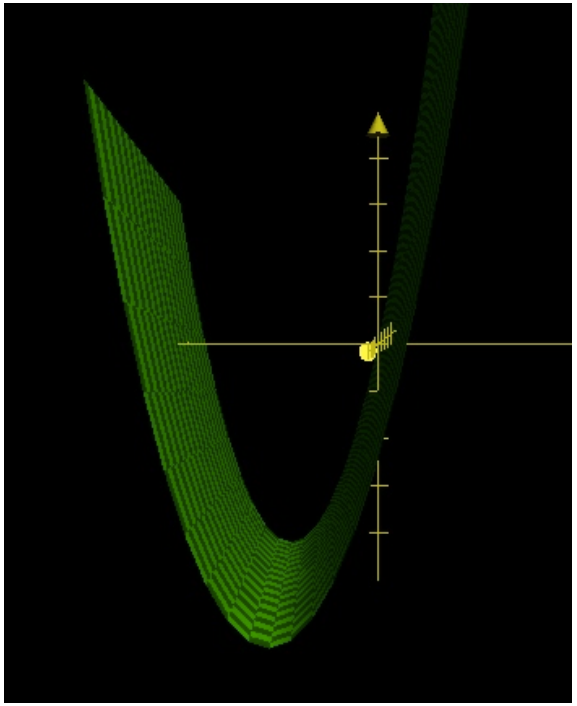


- Risk of getting out of the validity of approximation domain

Inversion and stabilization process

- Small eigenvalues are not meaningful: they will bring a very low improvement in *S* minimization but produce a big distance change in parameter.



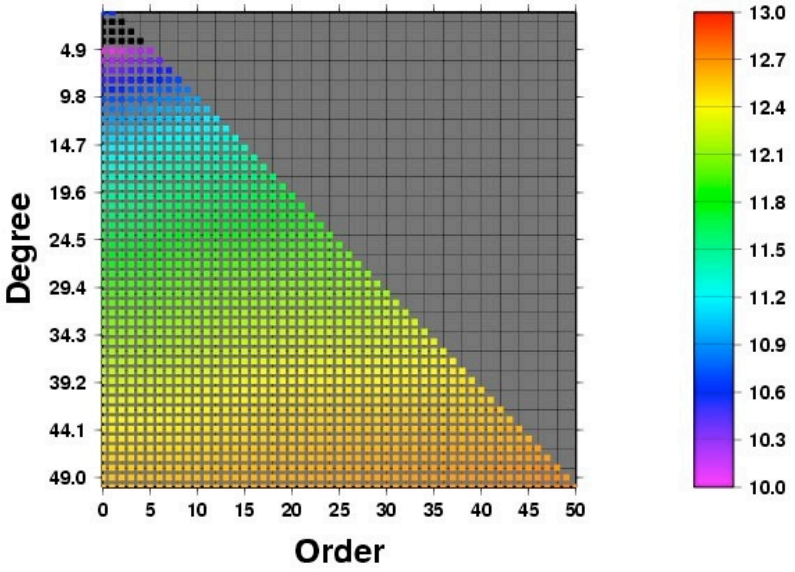


- In RL02, we used Cholesky full system inversion (with constraints), but in RL03 we use truncated SVD.
- No a posteriori filtering is needed.

Inversion and stabilization process

The stabilization process has been modified:

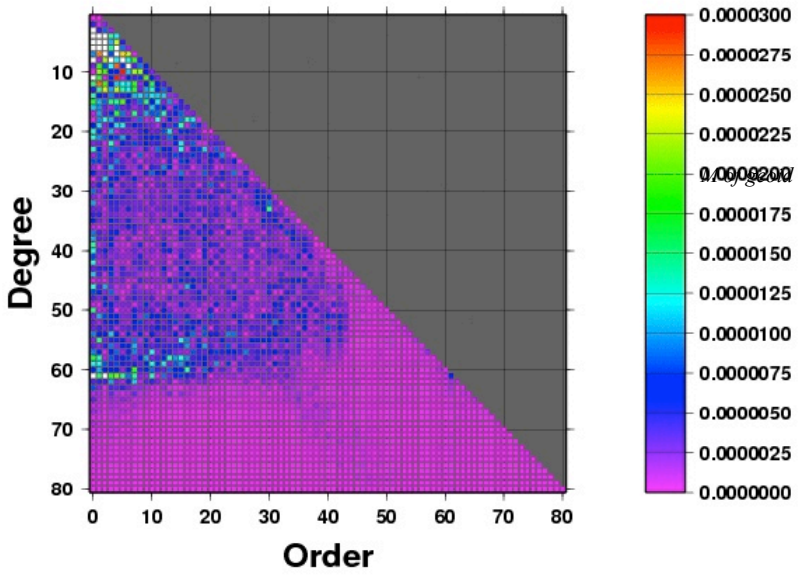
RL02: was constrained towards an a priori periodic gravity field model: EIGEN-GRGS.RL02 (with mean, dot, annual and semi-annual coefficients to d/o 50) following an adapted scheme.



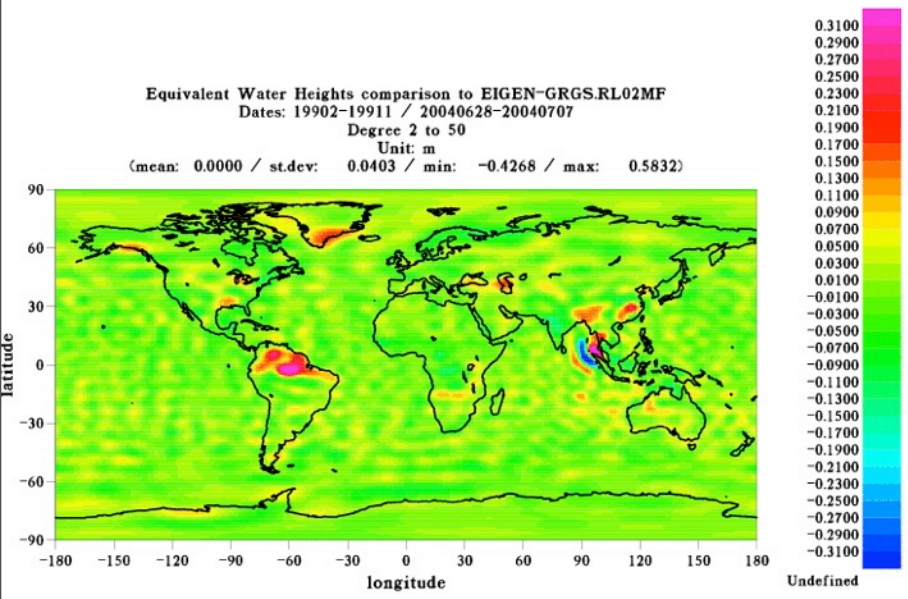
Sigmas applied for the constraint towards EIGEN-GRGS.RL02

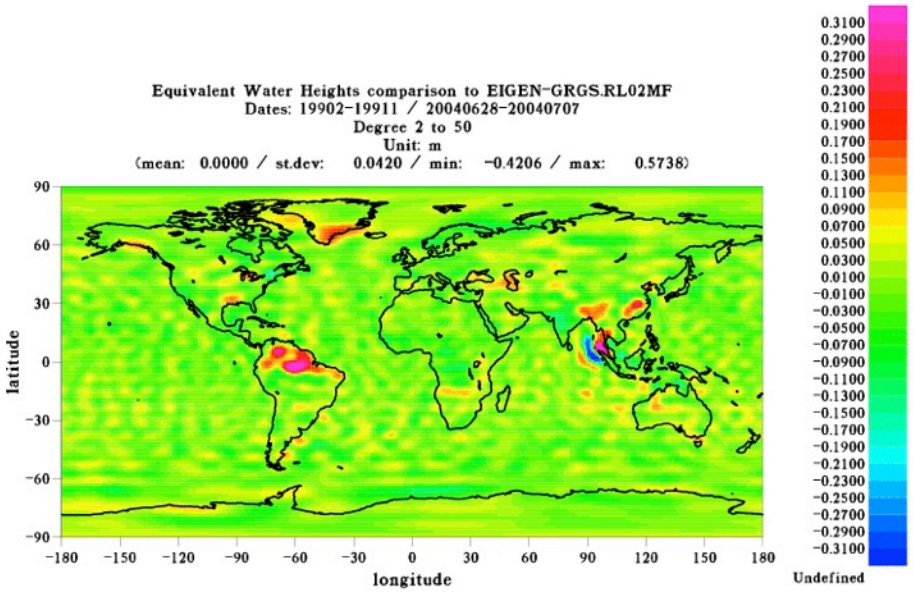
RL03: we use a truncated SVD scheme. Optimal criteria is still in study.

Monthly solution (April 2004) vs. static field

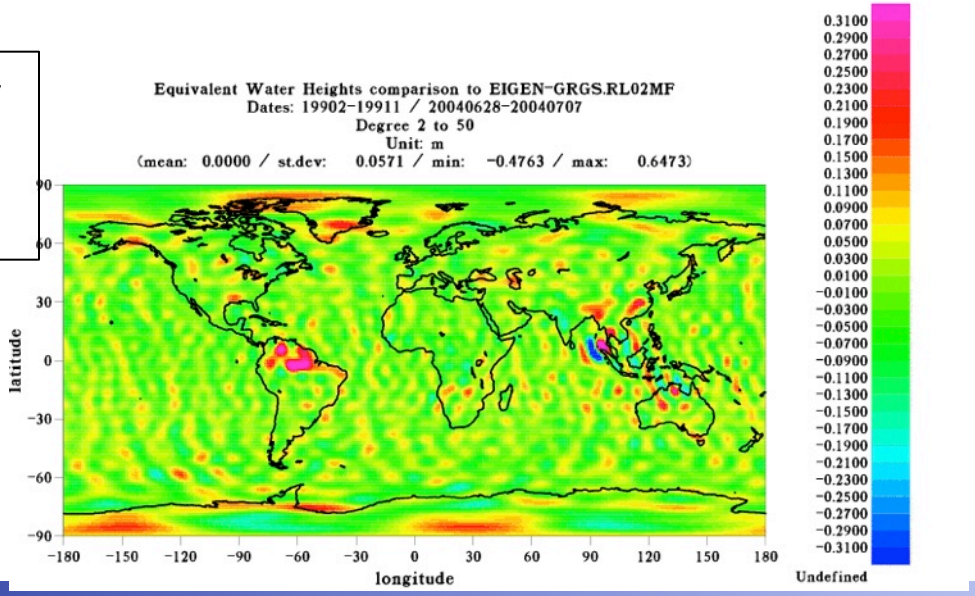


Inversions using truncated SVD





10-day solution (July 2004) using 3 different truncations



Inversions using truncated SVD

Cos(Lat) weighting…

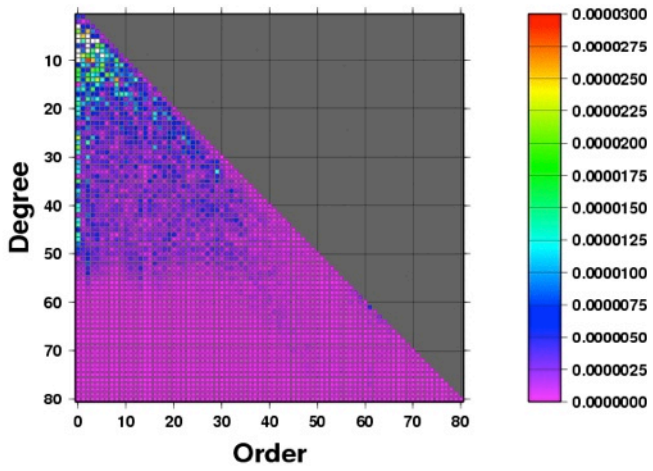
APPLIED

NOT APPLIED

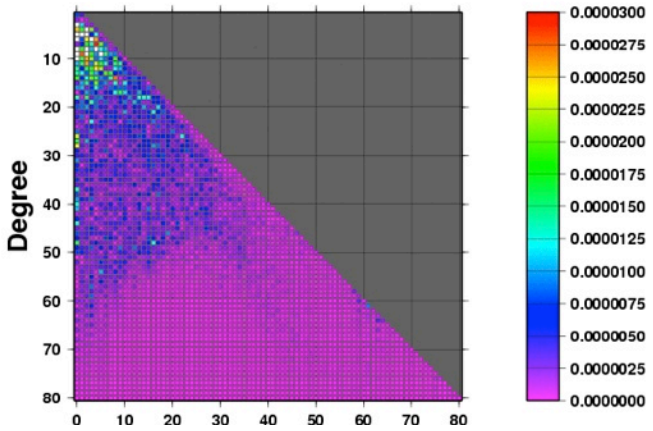
TRUNCATION:

99.5%

R0304.decade.19902.0.SVD.R03_995
/ EIGEN_from_RL02.date_19907

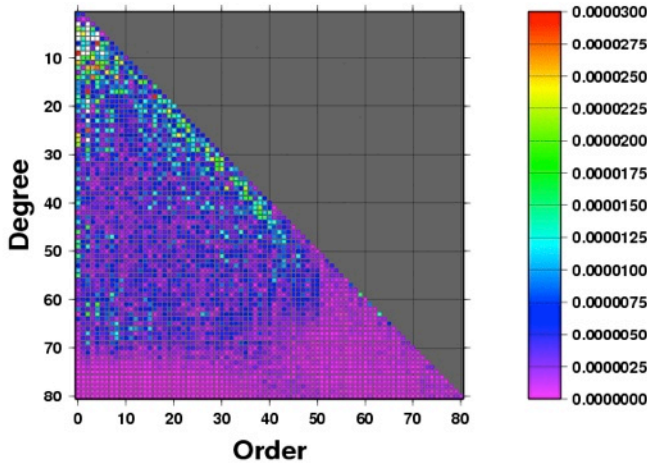


R0302.decade.19902.0.SVD.R03_995
/ EIGEN_from_RL02.date_19907

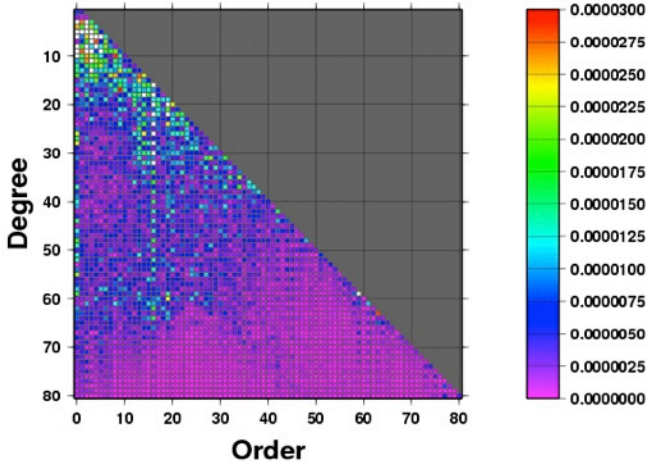


99.9%

R0304.decade.19902.0.SVD.R03_999
/ EIGEN_from_RL02.date_19907



R0302.decade.19902.0.SVD.R03_999
/ EIGEN_from_RL02.date_19907



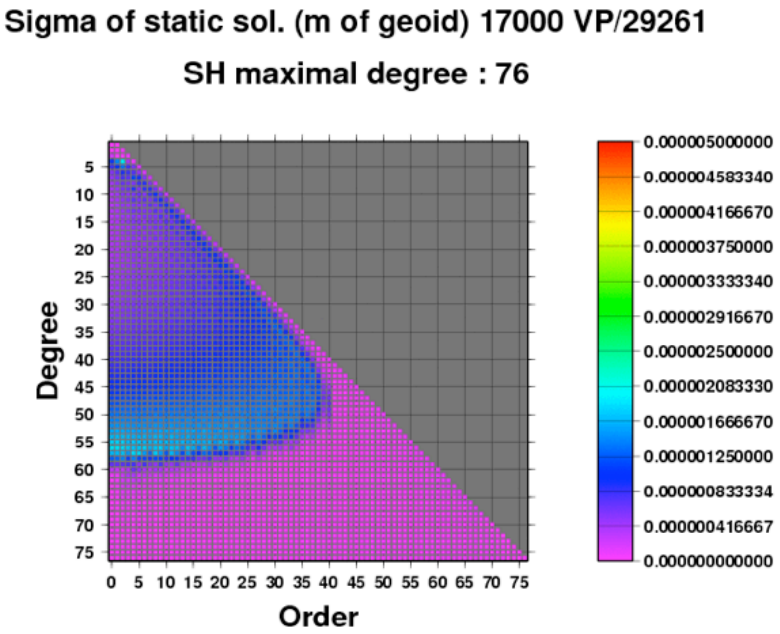
Mean Field

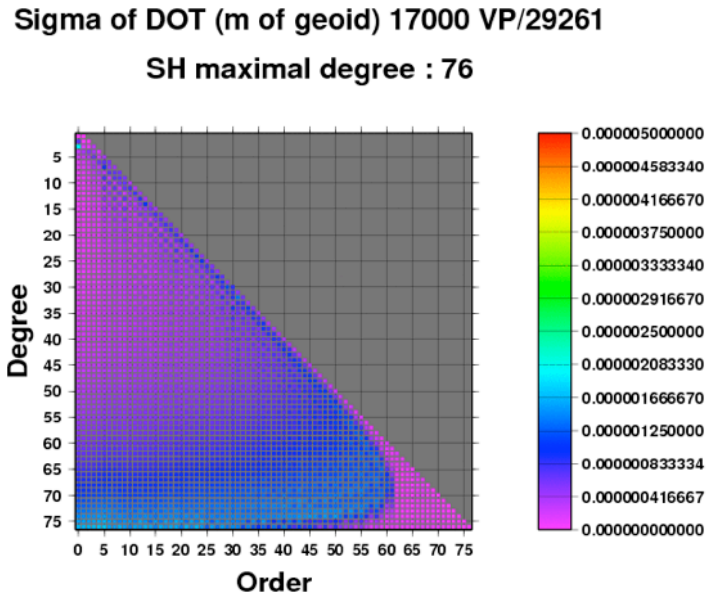
- New a-priori mean field
  The a-priori field acts as a constraint, since the truncation of eigenvalues will cancel parameter correction in those directions. It is important to start with a non-striped a-priori field.

- Time-variable terms until d/o 76.
  From monthly normal equations: Bias, drift, quadratic term, cos/sin annual and semi-annual terms (7 terms per coefficient)

- SVD solution
  Unhomogeneous terms (drift: per time unit, quadratic: per « square time» unit)
  Rescaling of units in order to solve parameters until the same d/o coefficients for bias, dot, and quadratic terms. (trend: 2.89, quadratic: 10.4, periodic terms: 0.707). Moreover, some perturbations appear on coefficients just before truncation line, so a light constraint was added.

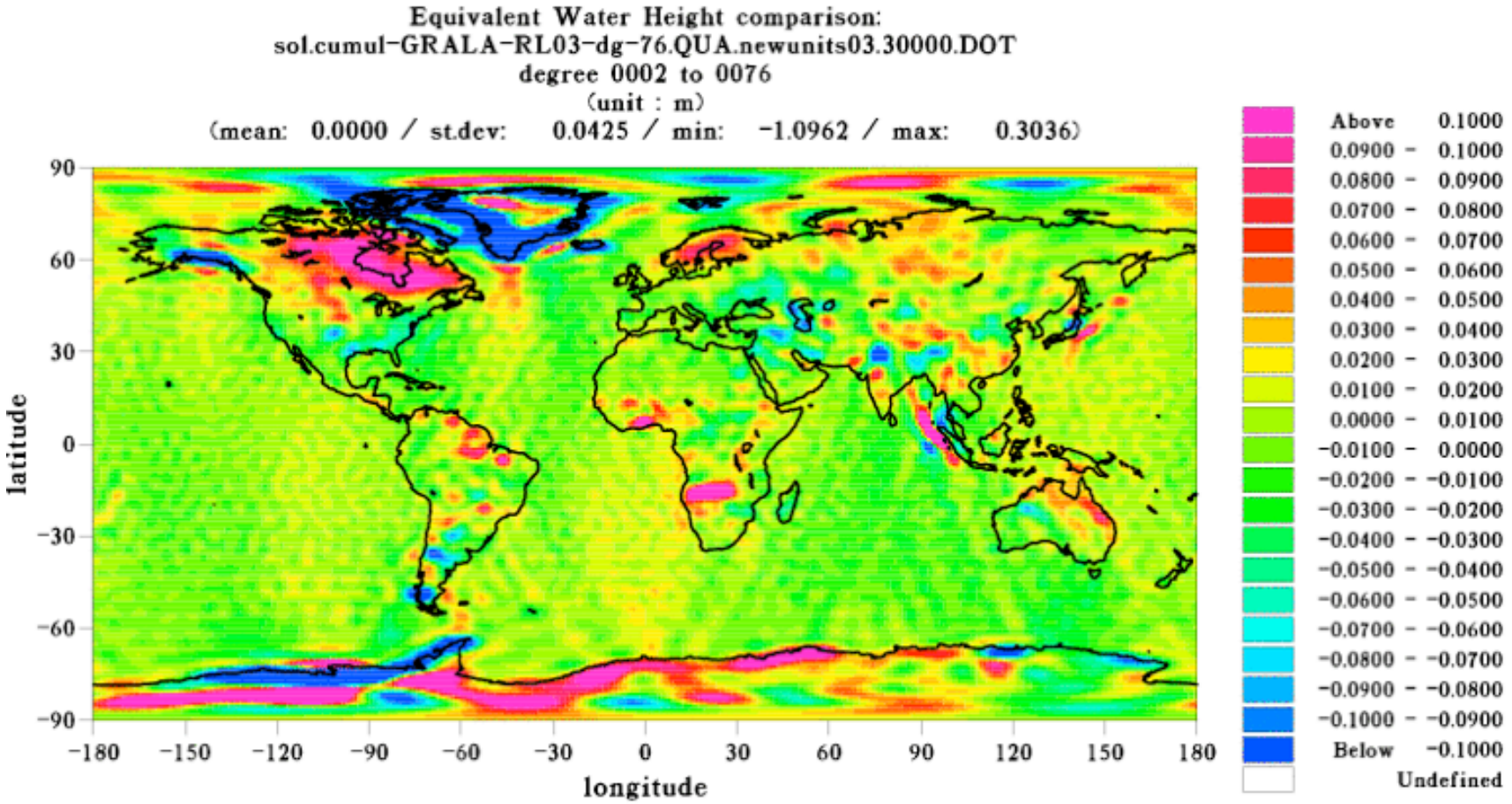
Mean Field



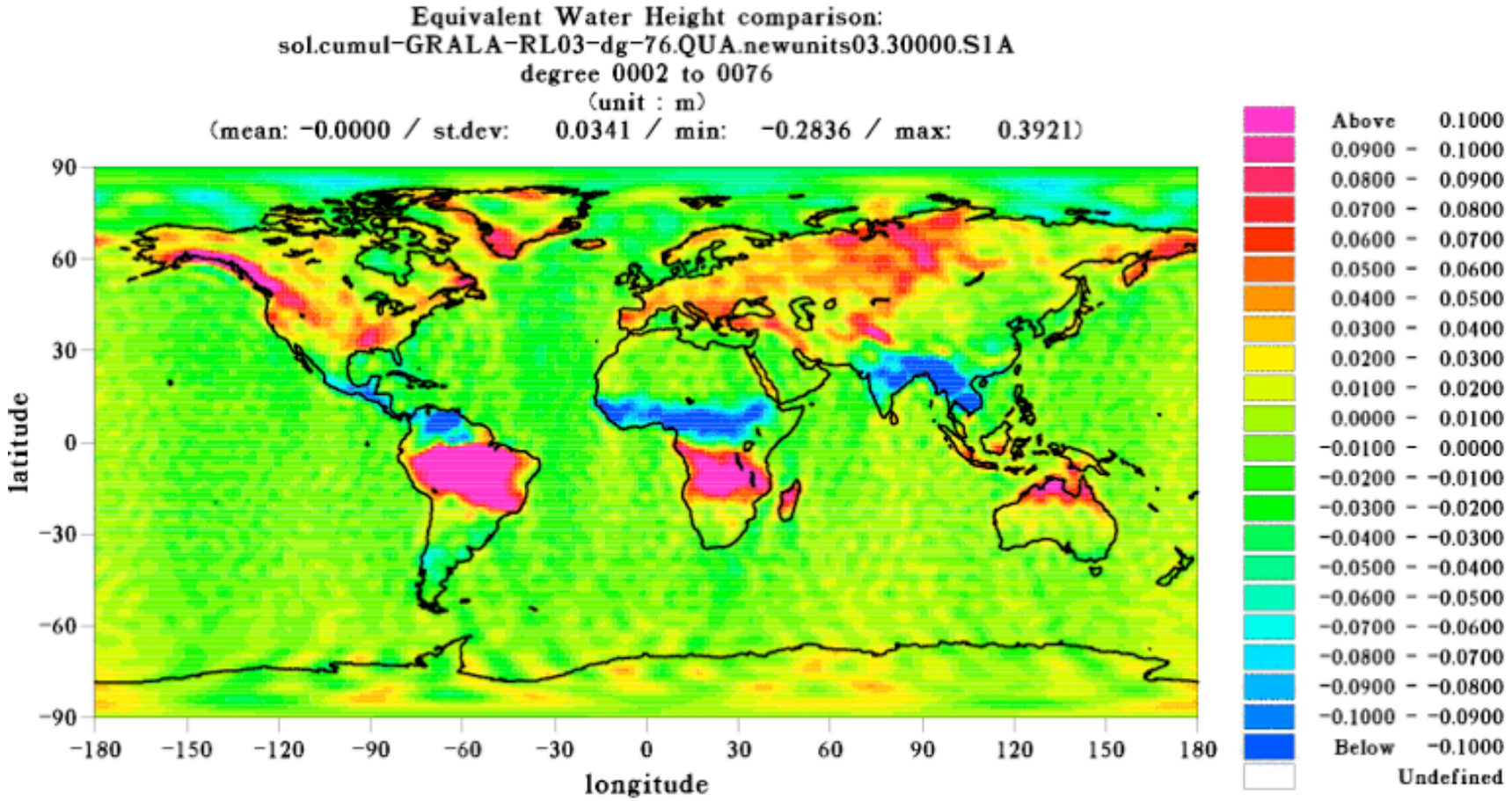


Unhomogeneous eigenvalues: impact on parameter resolution for bias and dot

Mean Field: drift



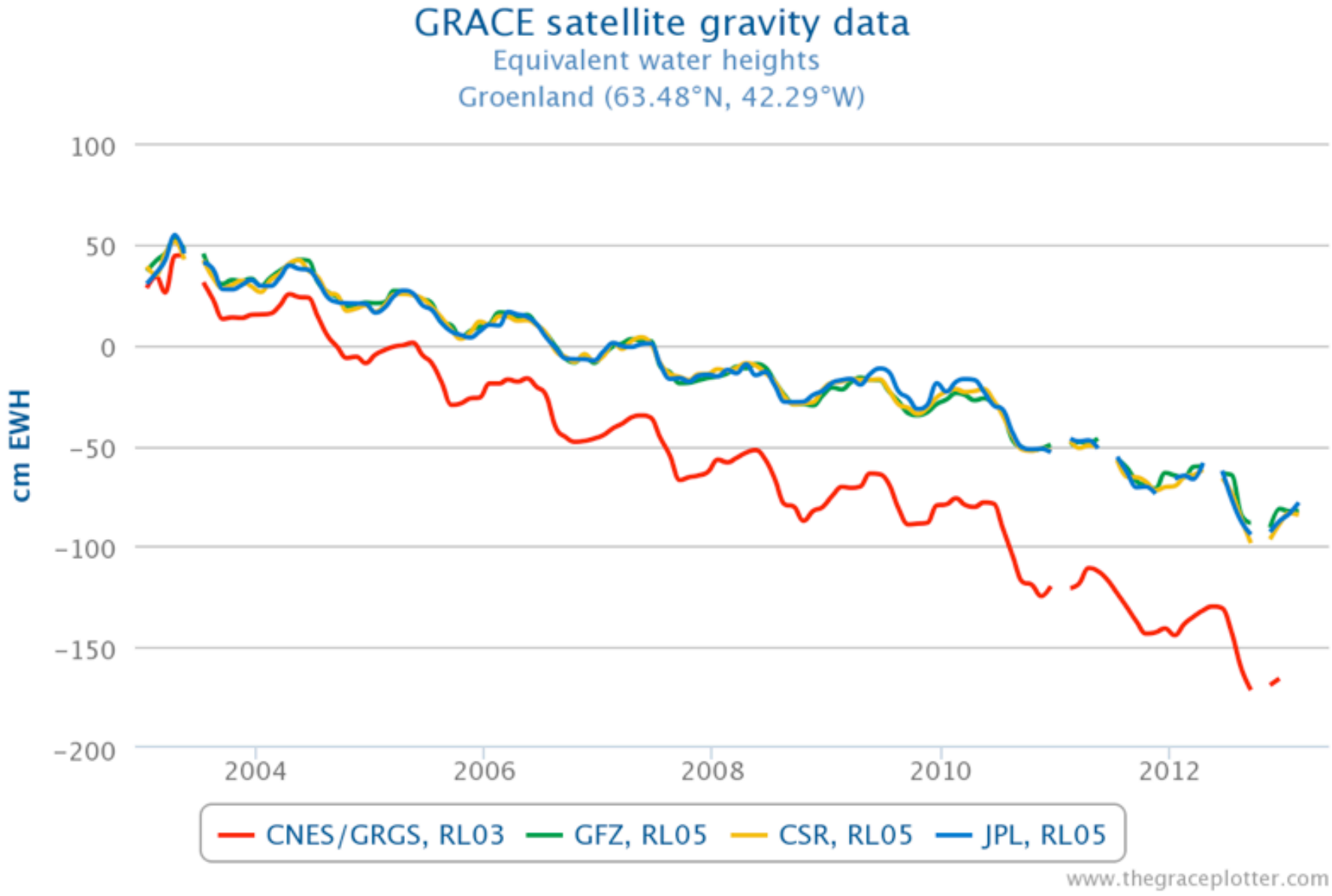
Mean Field: annual amplitude



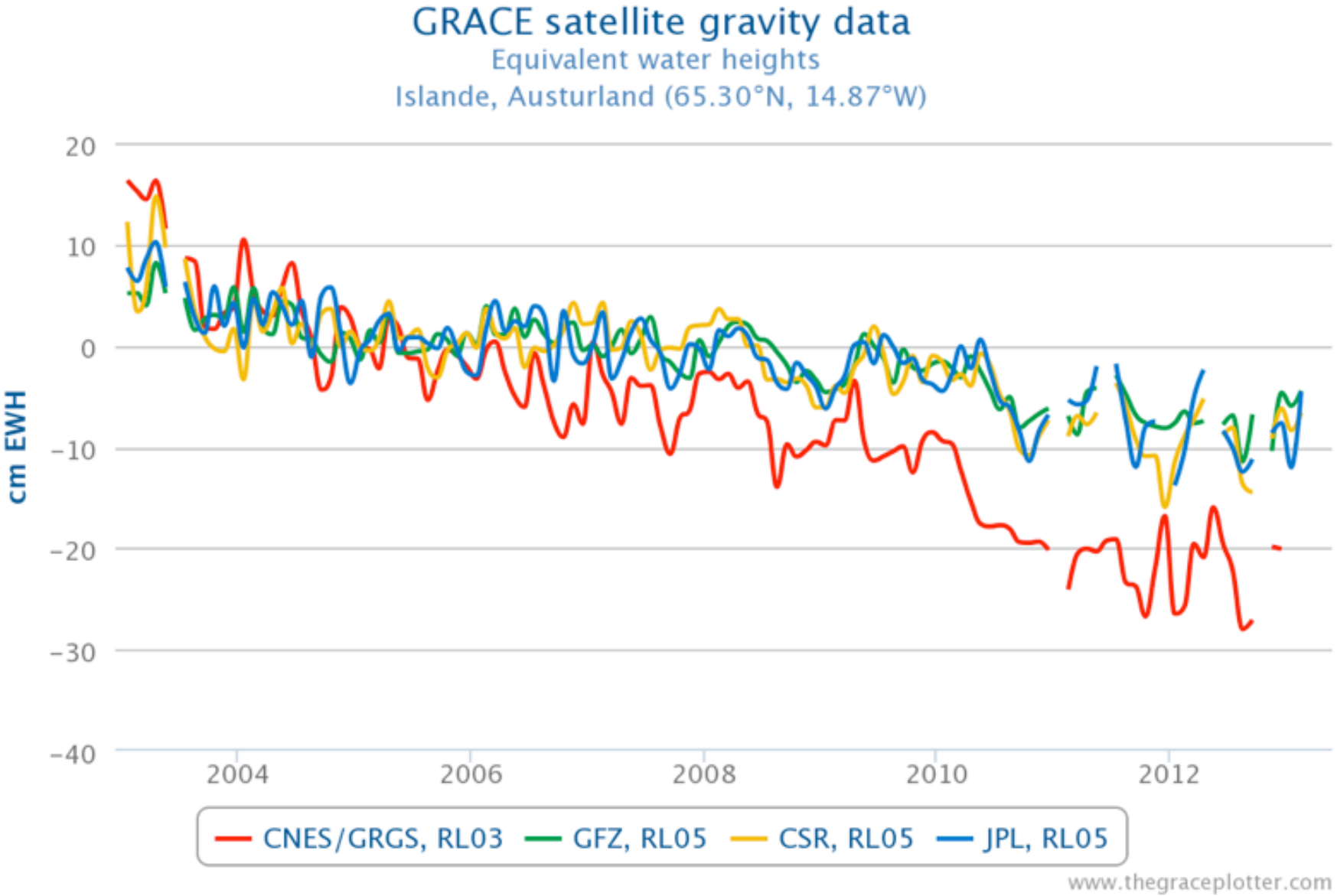
Preliminary results

- Preliminary results
  Monthly solutions, up to degree and order 80, using SVD, with an older a-priori gravity field.
- Time-series comparisons with GFZ, CSR, JPL RL05, using GRACE Tellus grids.

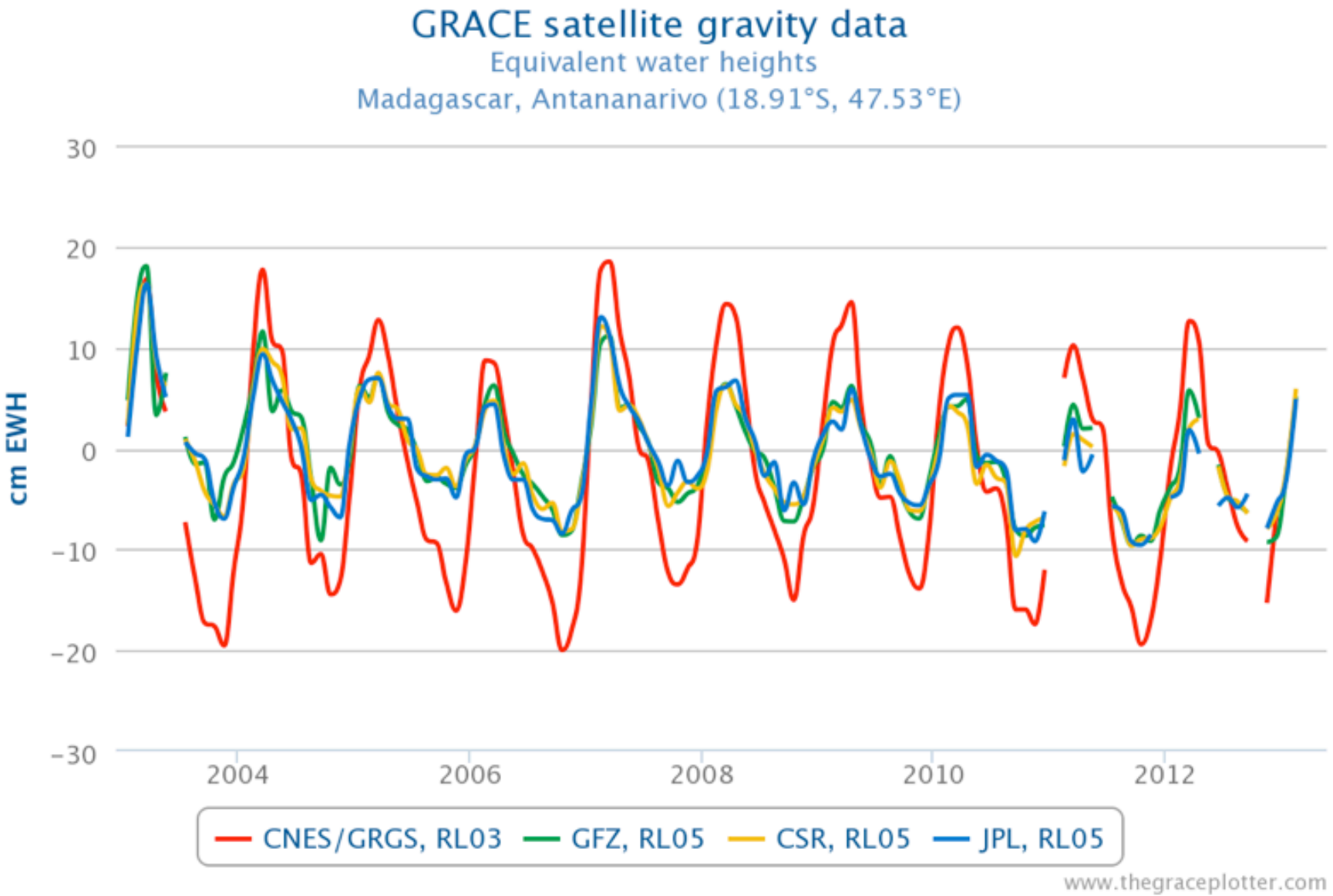
Preliminary results: trends



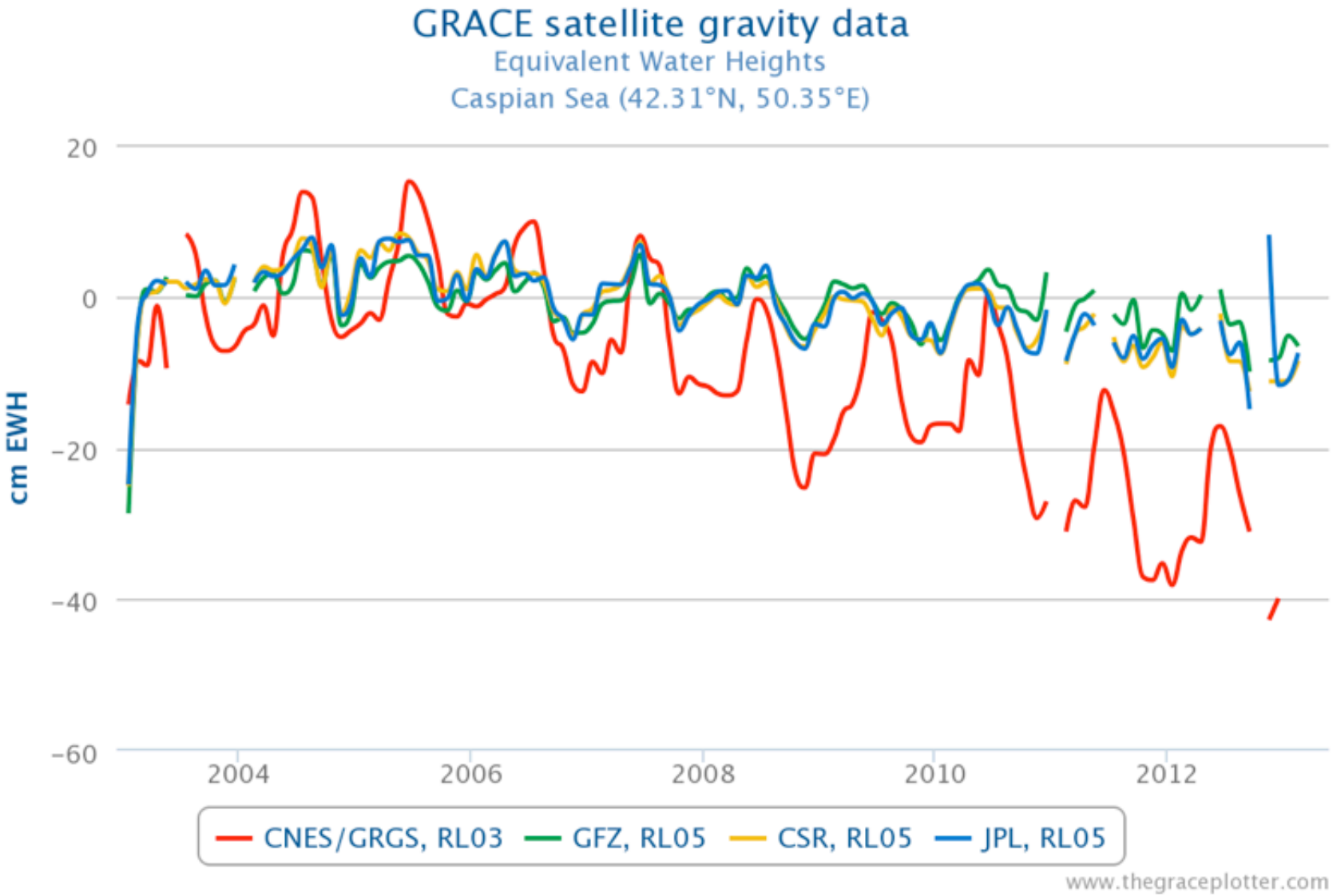
Preliminary results: trends



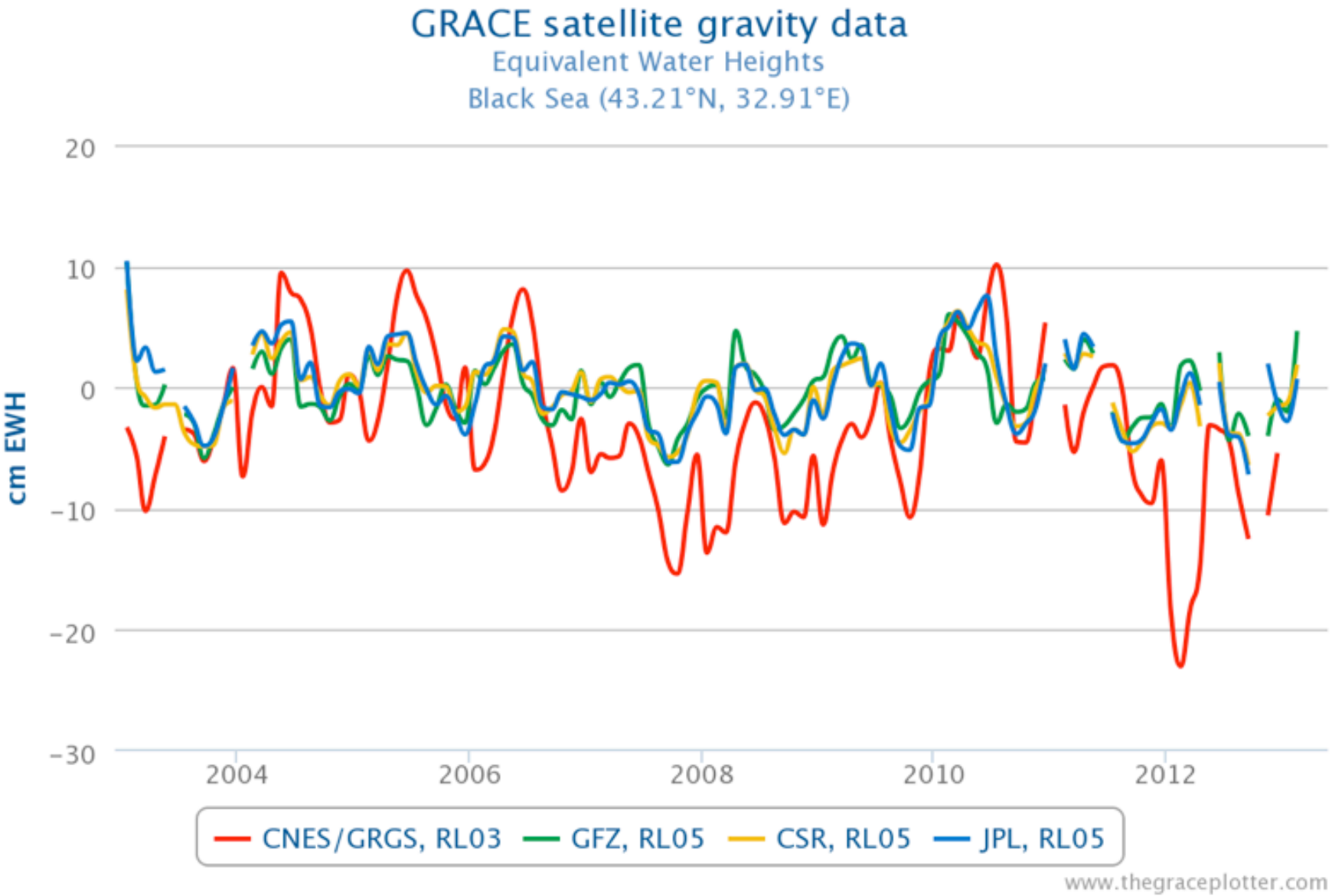
Preliminary results: amplitudes



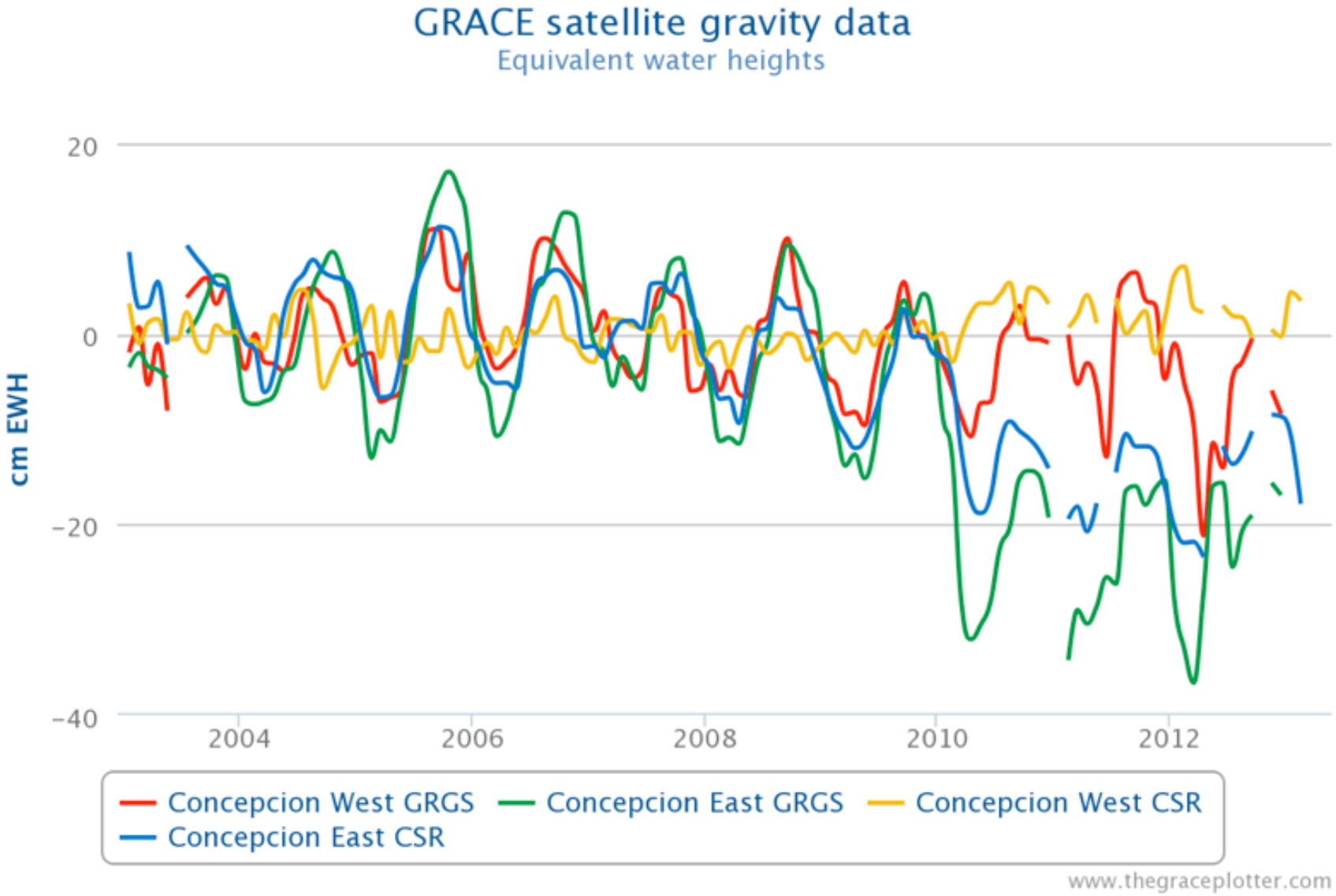
Preliminary results: amplitudes



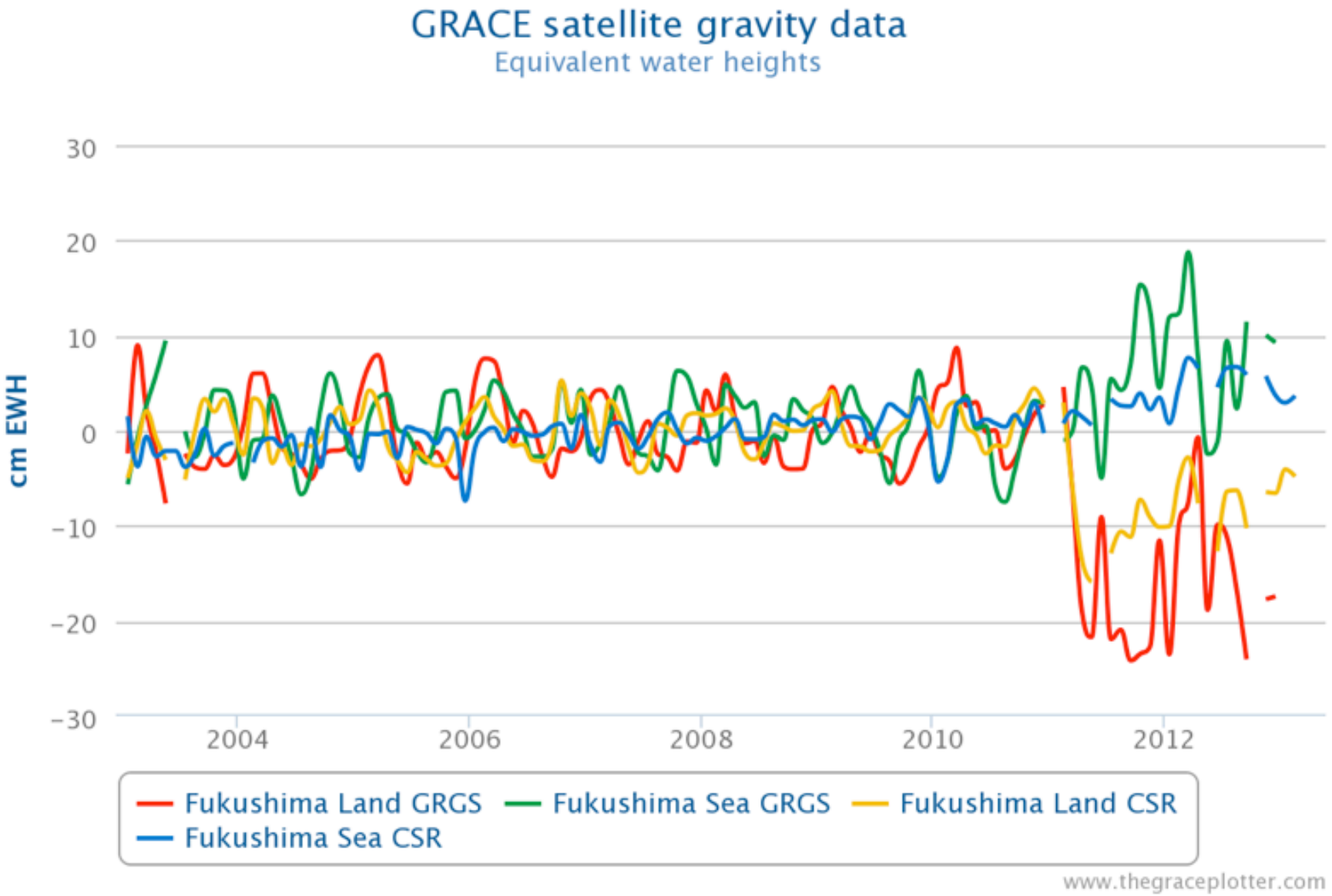
Preliminary results: amplitudes



Preliminary results: Concepcion earthquake



Preliminary results: Japan tsunami



Conclusion

- The processing of the arcs is completed, based on the version 2 of the GRACE level 1-B data and improved standards
- Preliminary monthly solutions have been computed. A new mean field is being computed before producing final solutions.
- The chosen strategy for inversion is SVD. The optimal criterium for truncation level is being studied.
- Comparison with GRACE Tellus grids show some quite important differences with the other groups. More extensive comparisons must be performed to fully evaluate the results.
- CNES/GRGS RL03 will then be available on our website (10-day and monthly solutions), by the end of the year.