CNES/GRGS gravity field solutions from GRACE: RL03-v2

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Summary

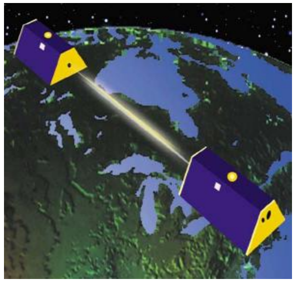
❖ **CNES/GRGS gravity fields from GRACE: RL03-v2**

- Data processing
- Inversion strategy for monthly models
- Mean gravity field model generation
- Extrapolation for orbit processing
- Model quality
- Model upgrading strategy

Data processing

GRACE (L-1B "Version2" data)

- K-Band Range-Rate data ($\sigma_{apriori}$ = .1 µm)
- Accelerometer / attitude / thrusters data
- **GPS data** (1-day arcs, σ_{code} = .8 m, **σ_{phase} = 20 mm / 30s resolution**)
  (actually: $\sigma_{2002\text{-}2003}$= 8 mm/30 s , $\sigma_{2003\text{-}2013}$= 20 mm/300 s, $\sigma_{2013\text{-}2015}$= 8 mm/30 s)

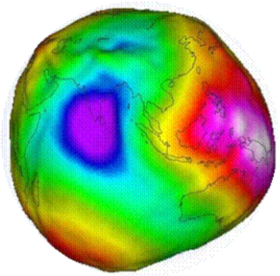


SLR

- Lageos1/2 data (10-day arcs, $\sigma_{apriori}$ = 6 mm)
- **Starlette/Stella data** (5-day arcs, $\sigma_{apriori}$ = 10 mm)

Physical parameters present in the normal equations

- Gravity spherical harmonic coefficients complete to degree and order 175 (truncated to 30 for LAGEOS and **40 for GPS** data)
- Ocean tides s. h. coefficients for 14 tidal waves with maximum degree/order ≤ 30



Models used (v0 → v2)

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*
3^{rd} 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*

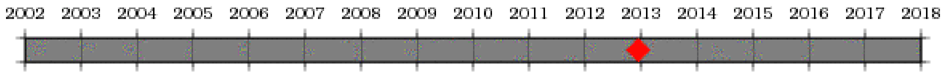
Other models

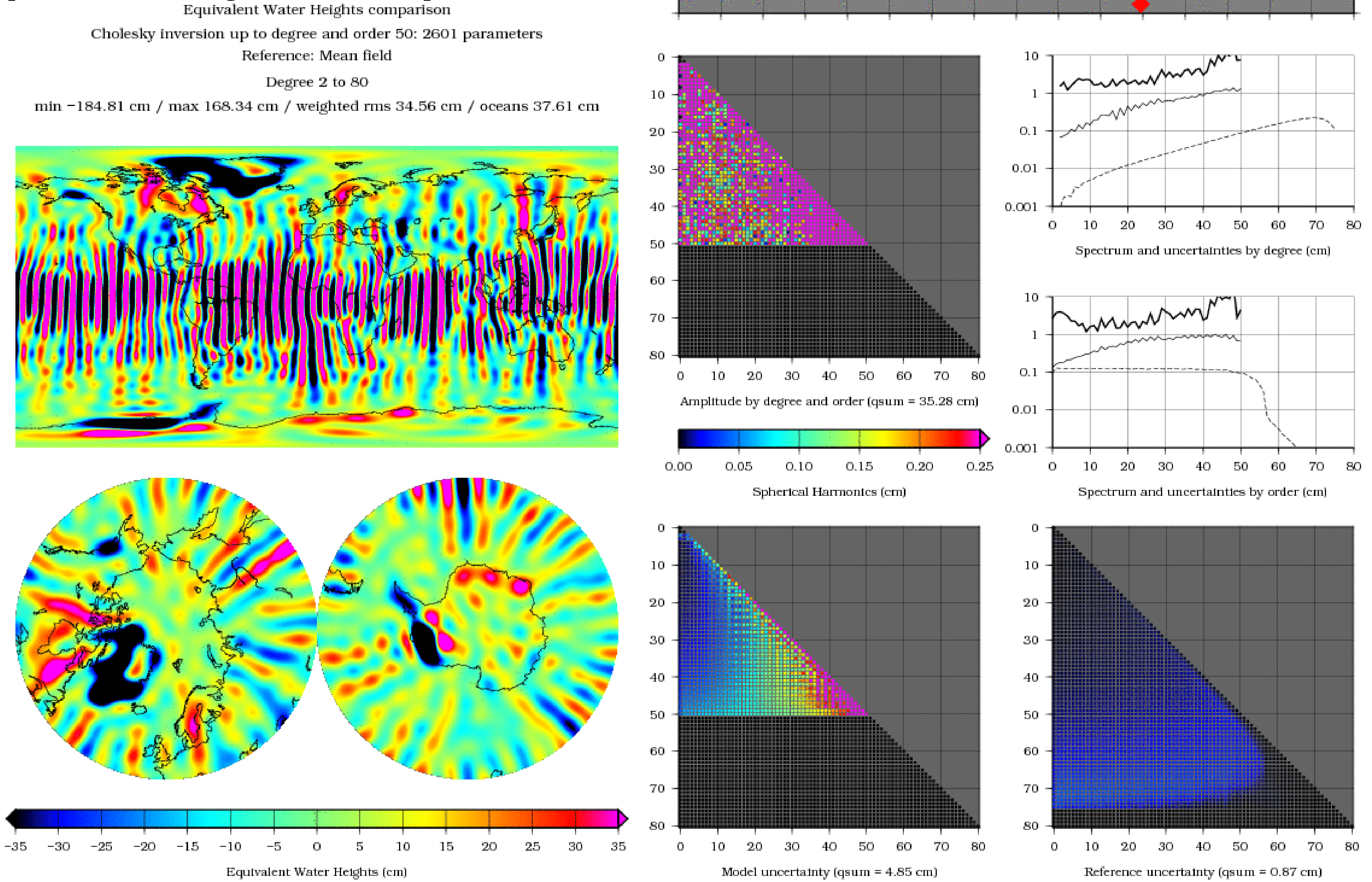
Hydrology	Taken into account by the a priori gravity field
Glacial Isostatic Adjustment	

Interest of truncated SVD

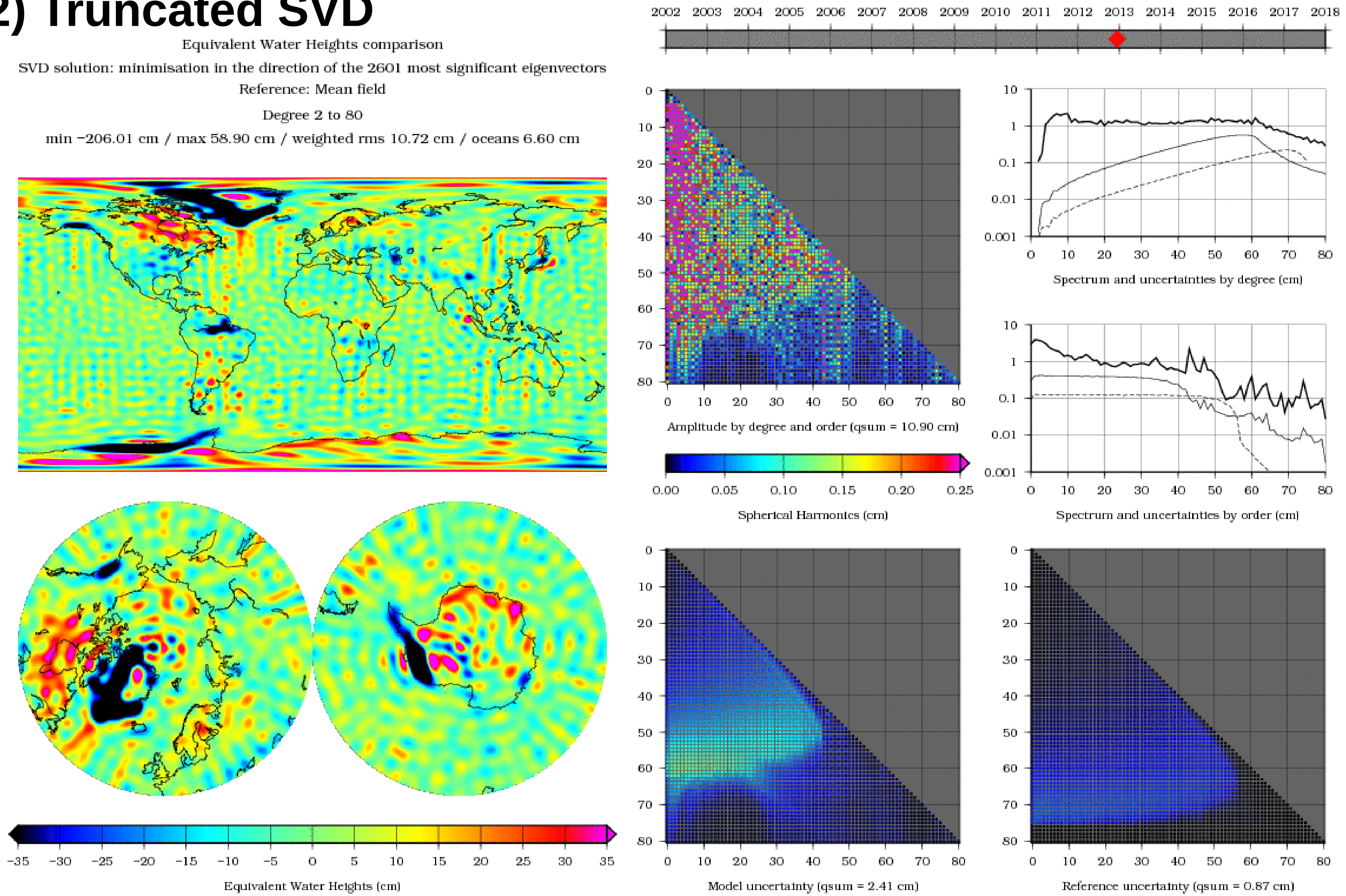
- **Inversion technique used for RL03 : truncated Singular Value Decomposition (SVD)**
  - It is more efficient to solve well chosen linear combinations of coefficients (by truncated SVD) than to solve indistinctly the coefficients (by Cholesky decomposition).
  - Demonstration with a normal matrix up to d/o 80:
    1) Solving for the first 2601 components of the canonical basis (i.e. spherical harmonic coefficients up to degree/order 50)
    2) Solving for the first 2601 components of the basis made by the eigenvectors of the normal matrix

1) Cholesky decomposition





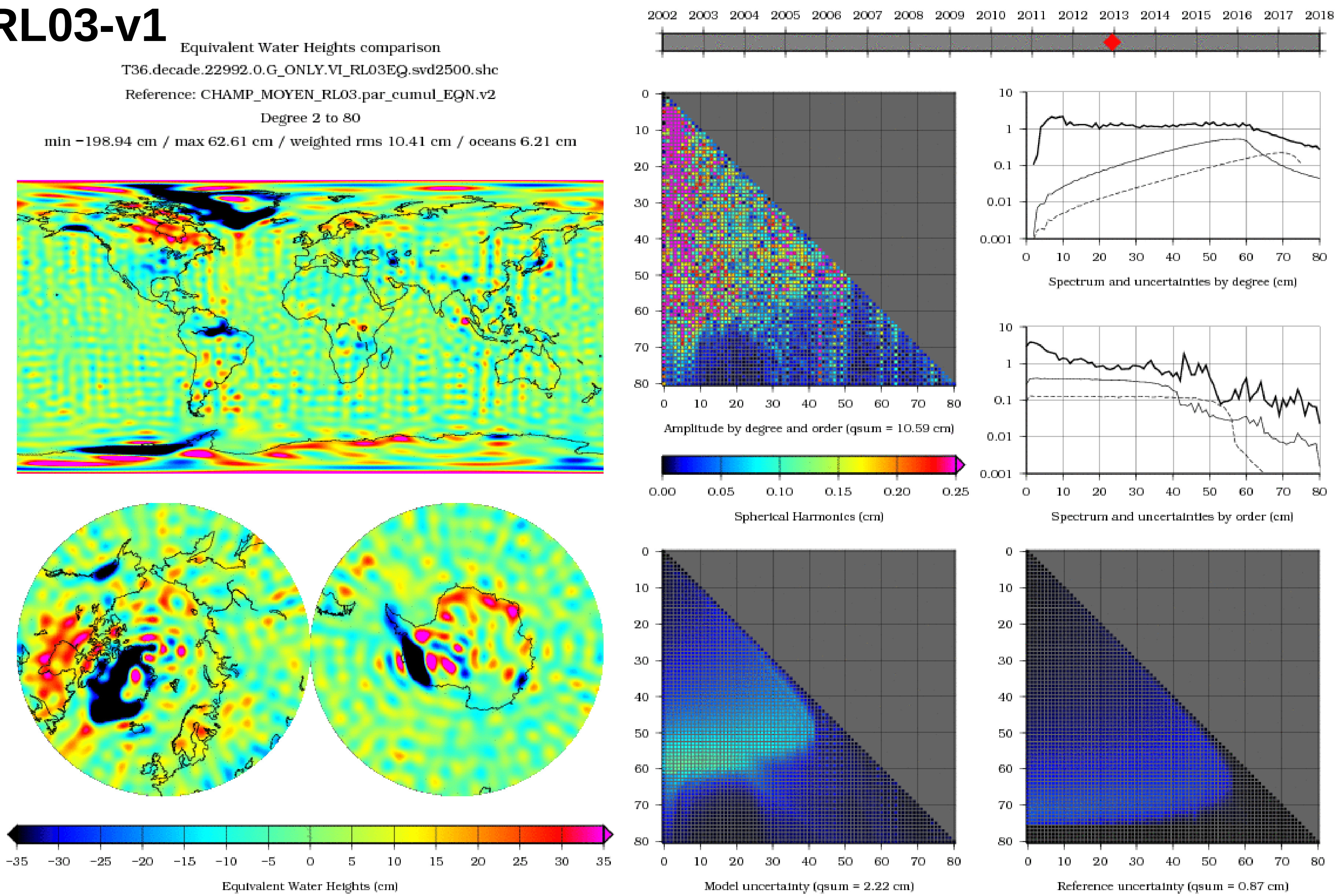
2) Truncated SVD



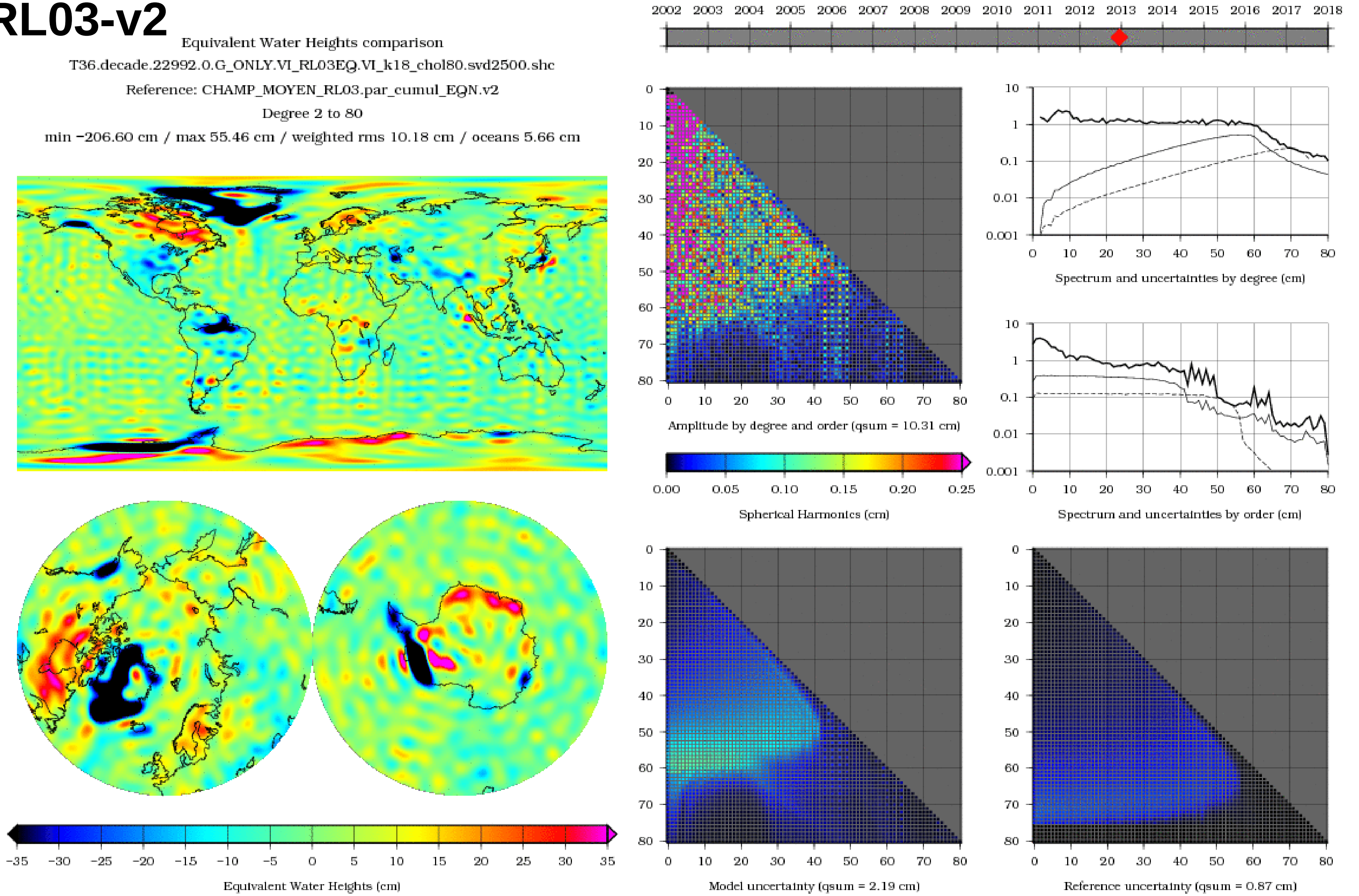
Inversion strategy

- **Trying to solve the problems at the poles**
  - Since SVD does not solve sectorial coefficients due to a lack of information, we need to introduce decent a-priori sectorial coefficients before using SVD
  - So we tried to establish a 2-step inversion in RL03-v2
    - First step: Cholesky inversion with constraints to obtain good sectorial coefficients
    - Second step: Truncated SVD inversion starting with the first step solution
- **Results**
  - The 2-step inversion improves the solutions mainly at the poles

RL03-v1


Equivalent Water Heights comparison
T36.decade.22992.0.G_ONLY.VI_RL03EQ.svd2500.shc
Reference: CHAMP_MOYEN_RL03.par_cumul_EQN.v2
Degree 2 to 80
min −198.94 cm / max 62.61 cm / weighted rms 10.41 cm / oceans 6.21 cm
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
−35 −30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30 35
Equivalent Water Heights (cm)
Amplitude by degree and order (qsum = 10.59 cm)
0.00 0.05 0.10 0.15 0.20 0.25
Spherical Harmonics (cm)
Spectrum and uncertainties by degree (cm)
Spectrum and uncertainties by order (cm)
Model uncertainty (qsum = 2.22 cm)
Reference uncertainty (qsum = 0.87 cm)

RL03-v2



Equivalent Water Heights comparison
T36.decade.22992.0.G_ONLY.VI_RL03EQ.VI_k18_chol80.svd2500.shc
Reference: CHAMP_MOYEN_RL03.par_cumul_EQN.v2
Degree 2 to 80
min −206.60 cm / max 55.46 cm / weighted rms 10.18 cm / oceans 5.66 cm
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Amplitude by degree and order (qsum = 10.31 cm)
Spherical Harmonics (cm)
Spectrum and uncertainties by degree (cm)
Spectrum and uncertainties by order (cm)
Equivalent Water Heights (cm)
Model uncertainty (qsum = 2.19 cm)
Reference uncertainty (qsum = 0.87 cm)

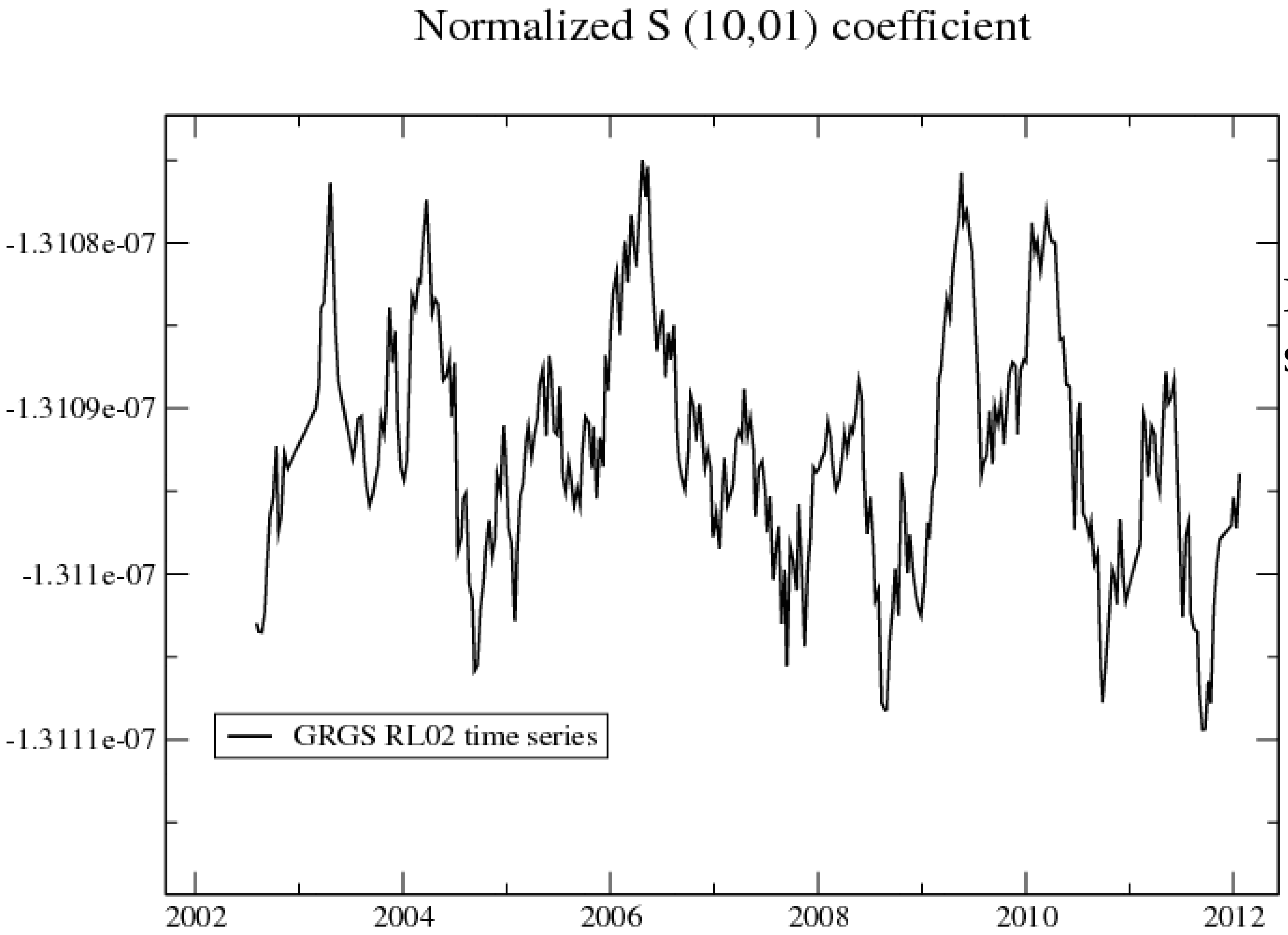
Mean model generation

❖ Mean Models generated from time series

- Fitting each series of monthly coefficients by a set of 6 parameters
- Used for operational computation (i.e. altimetric orbit processing) or TRF processing (i.e. ITRF2014)
- In order to better match with GRACE observations, gravity field models have become more complex. They contain now :
  - Yearly bias and slope : piecewise linear function except in case of …
  - Jumps caused by big earthquakes (3 so far : Sumatra, Concepcion and Tohoku)
  - Annual and semi-annual sine/cosine functions (with continuity constraints at hinge epochs)

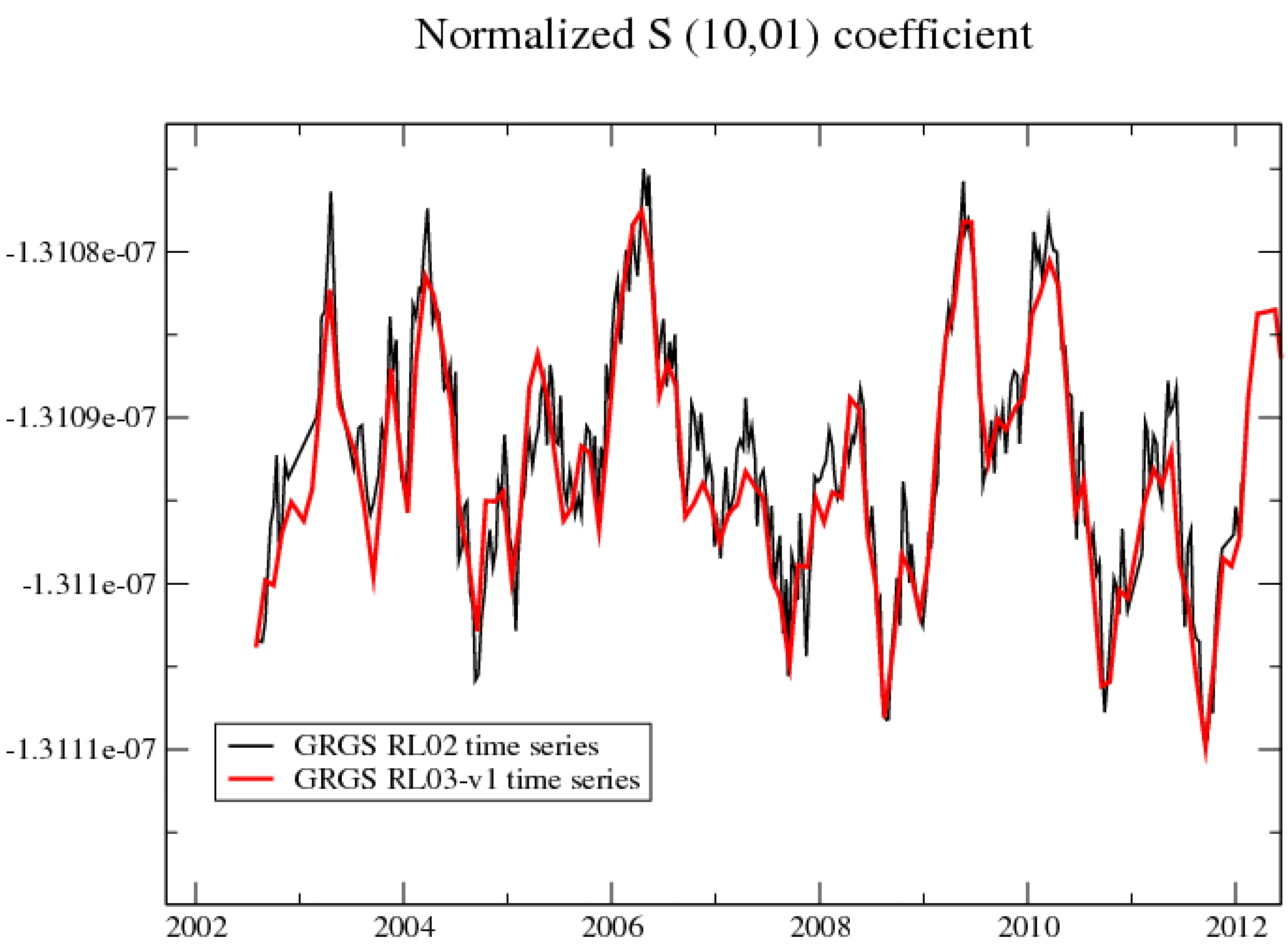
… it means 600 000 coefficients for a 80x80 s. h. model

RL02 10-day model



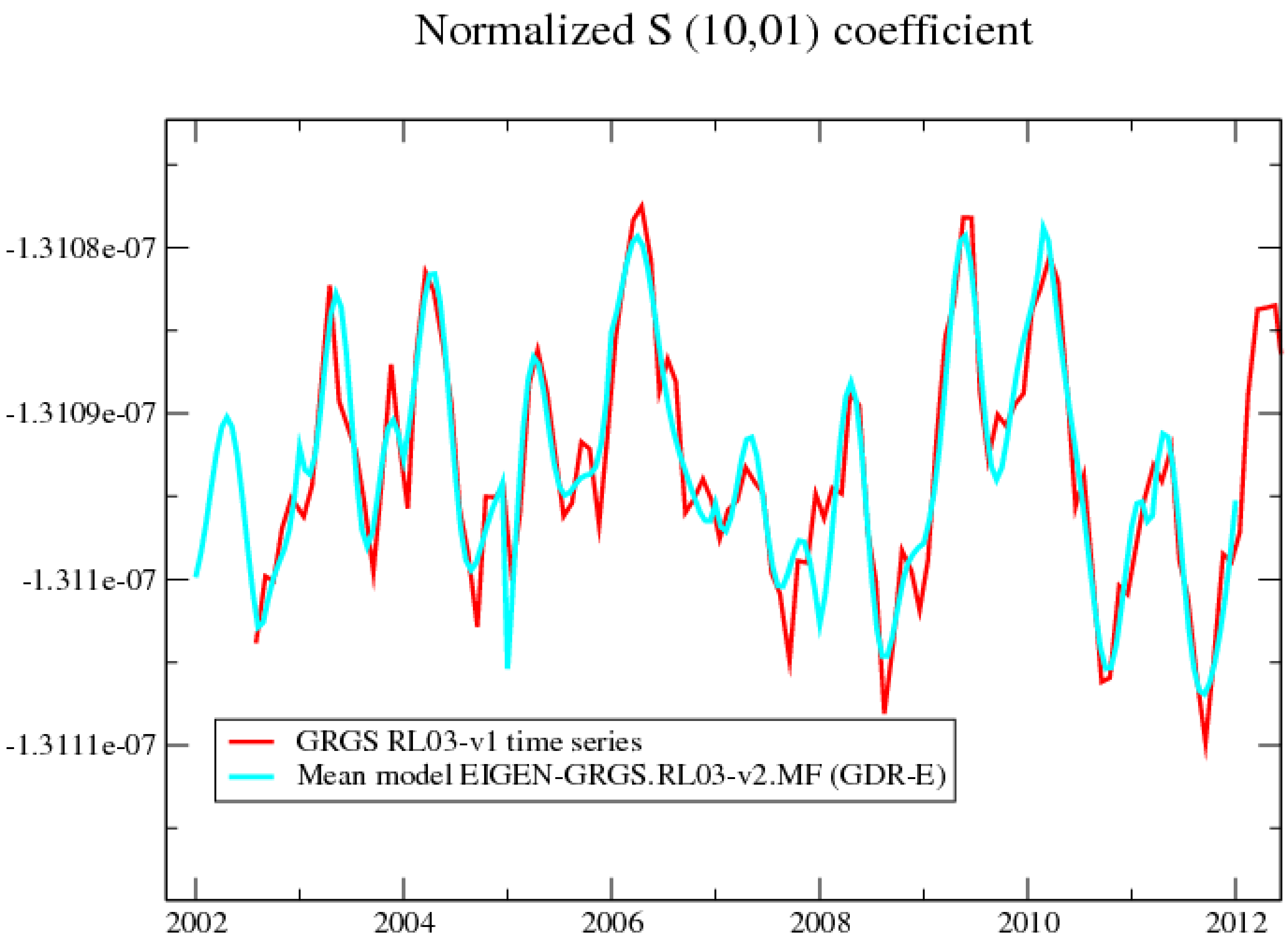
From RL02 10-day series

RL03 monthly model



From RL03 monthly series

RL02-v2 mean model



From RL03-v2 mean model with bias, drift per year, annual and semi-annual periodic terms per year

http://grgs.obs-mip.fr/grace/variable-models-grace-lageos/mean_fields

GRACE / LAGEOS

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GRGS TIME VARIABLE MODELS FROM GRACE / LAGEOS

- Presentation
- Introduction to GRACE solutions
- GRACE solutions release 01
- GRACE solutions release 02
- GRACE solutions release 03
- Formats
- **Mean fields**
- Interactive Tools

GFZ / GRGS EIGEN MEAN MODELS +

Introduction | Release 01 | Release 02 | Release 03

Mean gravity field models

The links below give access to the models. For a description of how the models are built, go to the tabs "Release 01", "Release 02" or "Release 03".

Associated with Release 03:

- EIGEN-GRGS.RL03.MEAN-FIELD (based on 28 years of LAGEOS data, 10 years of GRACE data and 3 years of GOCE data)
- Reference field_for_RL03-v1_grids: The geoid and EWH grids and images are computed by difference of the RL03-v1 solutions to a static reference mean field, which is an arbitrary reference. In the case of the RL03-v1 grids and images, we have used Reference field_for_RL03-v1_grids. This static mean field is close to the actual value of the Earth's gravity field at the date 2008.0
- EIGEN-GRGS.RL03-v2.MEAN-FIELD (based on 28 years of LAGEOS data, 12 years of GRACE data and 3 years of GOCE data)
- EIGEN-GRGS.RL03-v2.MEAN-FIELD.mean_slope_extrapolation (identical to EIGEN-GRGS.RL03-v2.MEAN-FIELD, except that the null slope on extrapolation is replaced by the average slope of the signal over the period 2003.0 - 2014.0)

Associated with Release 02:

- EIGEN-GRGS.RL02.MEAN-FIELD (based on 4.5 years of data)
- EIGEN-GRGS.RL02bis.MEAN-FIELD (update based on 8 years of data)
- EIGEN-6S2 (proposal for ITRF2013 standards)
- **EIGEN-6S2.extended** (this field is no longer available, there was an error in the TVG part for the years 2012-2013. It is replaced by EIGEN-6S2.extended.v2)
- EIGEN-6S2.extended.v2 (same as EIGEN-6S2, except that the TVG part has been extended to end of 2013 for the needs of the ITRF2013 computation)

Associated with Release 01:

- EIGEN_GL04S
- EIGEN_GL04S_ANNUAL
- EIGEN_GL04C

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FIRST EIGEN_03series.v2.PWL_PER_ANN.mean_slope.dg_300
CMMNT from GRACE-LAGEOS monthly gravity fields RL03-v2 (August 2002 to July 2014) + LAGEOS-1/2 (1985 - 2003) + GOCE-DIR5 (l > 80)
CMMNT Extrapolation = mean slopes over 2003.0 - 2014.0
EARTH 0.3986004415E+15 0.6378136460E+07
SHM     300  300 2.00 fully normalized exclusive permanent tide
G_BIAS    2    0 -.484165442874E-03 0.000000000000E+00 1.3920E-11 0.0000E+00 19500101.0000 19850109.1751 ynyn
GDRIFT    2    0 0.000000000000E+00 0.000000000000E+00 0.0000E+00 0.0000E+00 19500101.0000 19850109.1751 nnnn

G_BIAS    2    0 -.484165442874E-03 0.000000000000E+00 1.3920E-11 0.0000E+00 19850109.1751 19860101.0000 ynyn
GDRIFT    2    0 0.124657017393E-10 0.000000000000E+00 2.2600E-11 0.0000E+00 19850109.1751 19860101.0000 ynyn

GCOS1A    2    0 0.387007395388E-10 0.000000000000E+00 0.1117E-11 0.0000E+00 19500101.0000 20030101.0000 ynyn
GSIN1A    2    0 0.591814852349E-10 0.000000000000E+00 0.1101E-11 0.0000E+00 19500101.0000 20030101.0000 ynyn
GCOS2A    2    0 0.393538776211E-10 0.000000000000E+00 0.1107E-11 0.0000E+00 19500101.0000 20030101.0000 ynyn
GSIN2A    2    0 -.219462790927E-10 0.000000000000E+00 0.1104E-11 0.0000E+00 19500101.0000 20030101.0000 ynyn

G_BIAS    2    0 -.484165227624E-03 0.000000000000E+00 0.2330E-10 0.0000E+00 20030101.0000 20040101.0000 ynyn
GDRIFT    2    0 -.492366971847E-10 0.000000000000E+00 0.3806E-10 0.0000E+00 20030101.0000 20040101.0000 ynyn
GCOS1A    2    0 0.384911295545E-10 0.000000000000E+00 0.1096E-10 0.0000E+00 20030101.0000 20040101.0000 ynyn
GSIN1A    2    0 0.722385315628E-10 0.000000000000E+00 0.1354E-10 0.0000E+00 20030101.0000 20040101.0000 ynyn
GCOS2A    2    0 0.766906872209E-11 0.000000000000E+00 0.8906E-11 0.0000E+00 20030101.0000 20040101.0000 ynyn
GSIN2A    2    0 -.313633906172E-10 0.000000000000E+00 0.1522E-10 0.0000E+00 20030101.0000 20040101.0000 ynyn

G_BIAS    2    0 -.484165276861E-03 0.000000000000E+00 0.1476E-10 0.0000E+00 20040101.0000 20041226.0060 ynyn
GDRIFT    2    0 0.772123828542E-10 0.000000000000E+00 0.2719E-10 0.0000E+00 20040101.0000 20041226.0060 ynyn
GCOS1A    2    0 0.446978163033E-10 0.000000000000E+00 0.4782E-11 0.0000E+00 20040101.0000 20041226.0060 ynyn
GSIN1A    2    0 0.331550095538E-10 0.000000000000E+00 0.9492E-11 0.0000E+00 20040101.0000 20041226.0060 ynyn
GCOS2A    2    0 0.103868129375E-11 0.000000000000E+00 0.4411E-11 0.0000E+00 20040101.0000 20041226.0060 ynyn
GSIN2A    2    0 -.159947020906E-10 0.000000000000E+00 0.6033E-11 0.0000E+00 20040101.0000 20041226.0060 ynyn

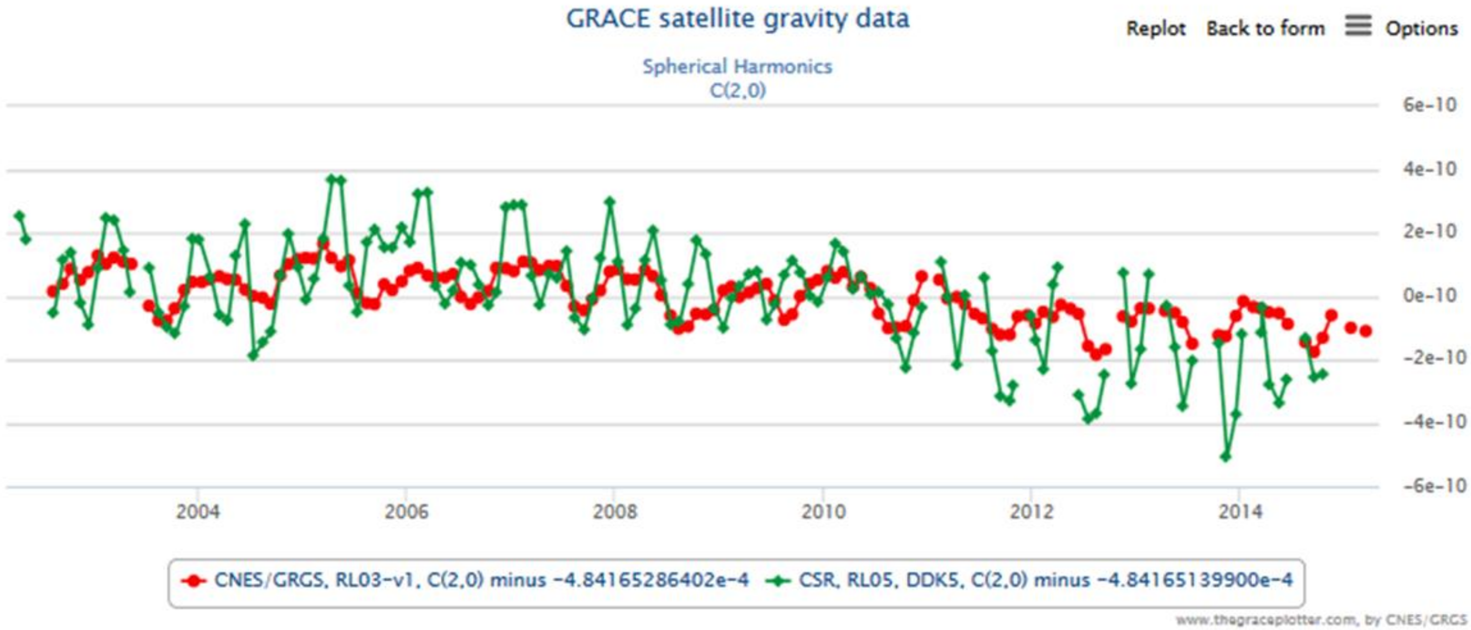
G_BIAS    2    0 -.484165332544E-03 0.000000000000E+00 0.1854E-09 0.0000E+00 20140615.0917 20500101.0000 ynyn
GDRIFT    2    0 -.147311624901E-10 0.000000000000E+00 0.4825E-11 0.0000E+00 20140615.0917 20500101.0000 ynyn
GCOS1A    2    0 0.332262028125E-10 0.000000000000E+00 0.2667E-11 0.0000E+00 20140615.0917 20500101.0000 ynyn
GSIN1A    2    0 0.480638590637E-10 0.000000000000E+00 0.2981E-11 0.0000E+00 20140615.0917 20500101.0000 ynyn
GCOS2A    2    0 0.466711549833E-11 0.000000000000E+00 0.2692E-11 0.0000E+00 20140615.0917 20500101.0000 ynyn
GSIN2A    2    0 -.174442524168E-10 0.000000000000E+00 0.2777E-11 0.0000E+00 20140615.0917 20500101.0000 ynyn
```

J2 behaviour

- **J2 monthly variations are extended from 1986 till now**
  - From LAGEOS, Starlette and Stella data
  - Need to be consistent with the 18.6 yrs ocean tide model

055.565 (Om1) : $\bar{C}_{20}^{+} = 0.5406$ cm, $\varepsilon_{20}^{+} = 270$ deg.

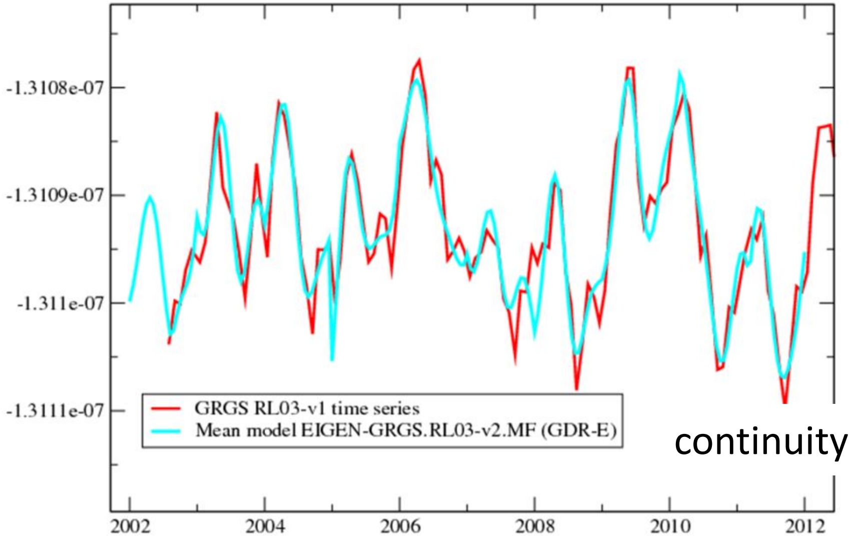
- **www.thegraceplotter.com**



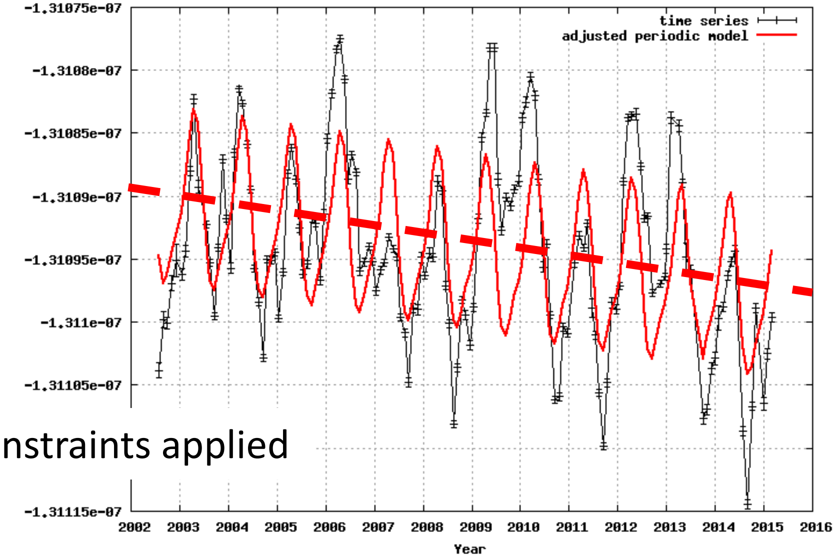
❖ Extrapolated coefficients

- Mean drift, mean annual and semi-annual periodic terms from the first (backward) and last (forward) determined biases
- Before 1986 for 2-degree terms determined from Lageos data
- Before August 2002 for all other terms up to degree/order 80
- After April 2015 until presently for all terms

S(10,1) within the GRACE period



S(10,1) outside the GRACE period

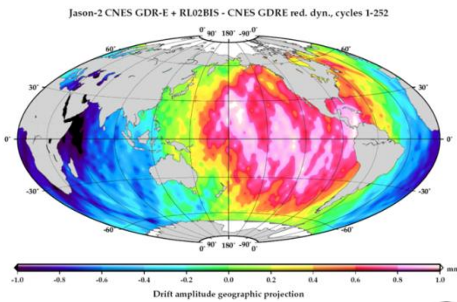


continuity constraints applied

❖ **The new RL03-v2 model** reduces the geographically correlated radial orbit drift rate, from more than 1 mm/yr (for the RL02bis mean model) to less than 0.6 mm/y over ~7 years, with respect to Jason-2 GDR-E reduced-dynamic orbits (from GPS+DORIS).

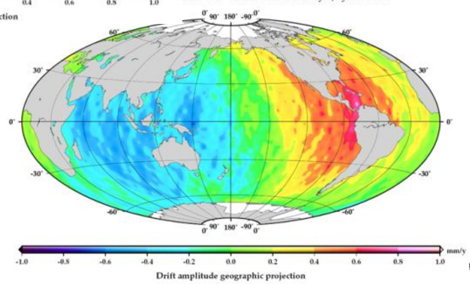
❖ **Jason-2 SLR residuals :**

➢ RL02: 1.36 cm rms

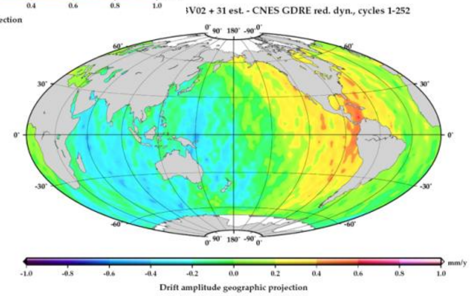


Radial orbit drift rate
Scale: -1 / +1 mm/yr
[A. Couhert & al., 2015]

➢ RL03-v2: 1.29 cm rms

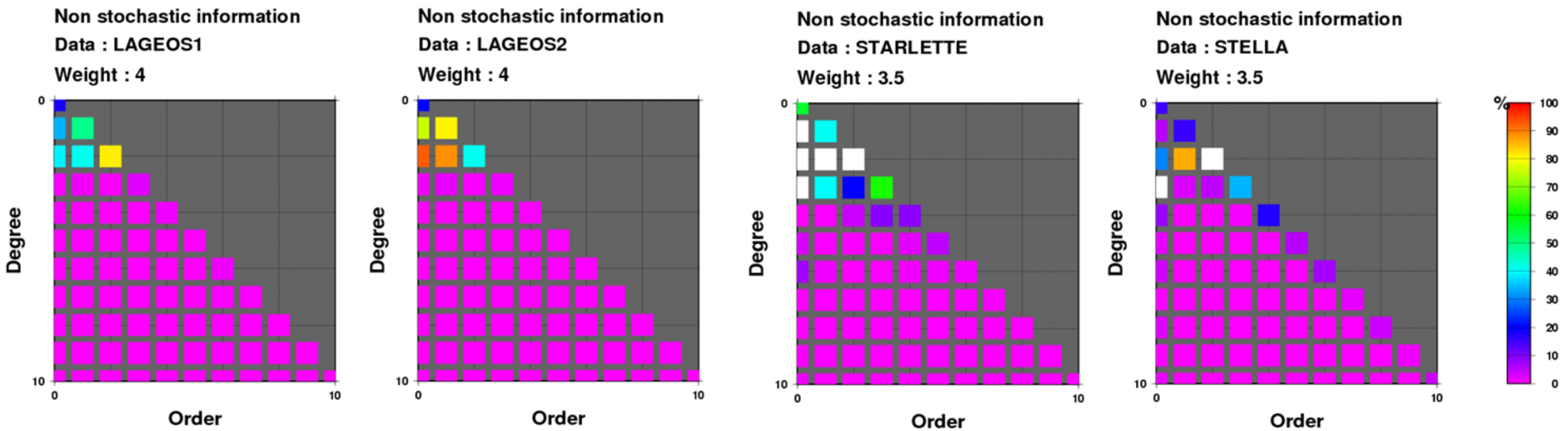


➢ RL03-v2 + C31 adjusted: 1.27 cm rms



❖ Next RL03-v3 model

- Improving the inversion process (Cholesky + SVD in a 2-step procedure)
- Adapting the relative weights (between GPS and KBR)
- Using more satellite data (Starlette, Stella, Jason)
- Increasing the temporal resolution (back to 10-days?)
- Using improved dealiasing models such as ocean tides (FES2014)



Delivery strategy

❖ Mean models could be updated each year :

- RL03-v3 should be ready for the end of the year
- The mean RL02-v3 model will contain extrapolated terms from mid-2015
- The completion (with adjusted terms) from 2015 till mid-2016 can be expected for end 2016
- Updated mean models could be delivered annually at the end of year