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

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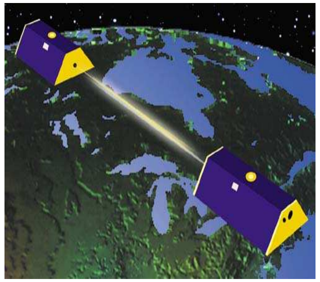
GRACE (L-1B "Version2" data)

- **K-Band Range-Rate** data ($\sigma_{apriori}$ = .1 µm)
- Accelerometer / attitude
- **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)

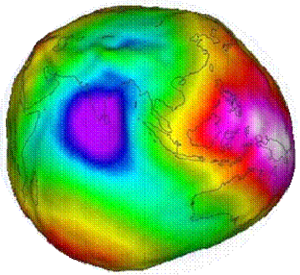


SLR

- **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 (not used yet)



Models used : v0 → v2

Dynamical models

Gravity	*EIGEN-GRGS.RL02* → *EIGEN-6S2 (LAGEOS/GRACE/GOCE)*
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 clocks* → *IGS Repro-1 orbits and clocks*

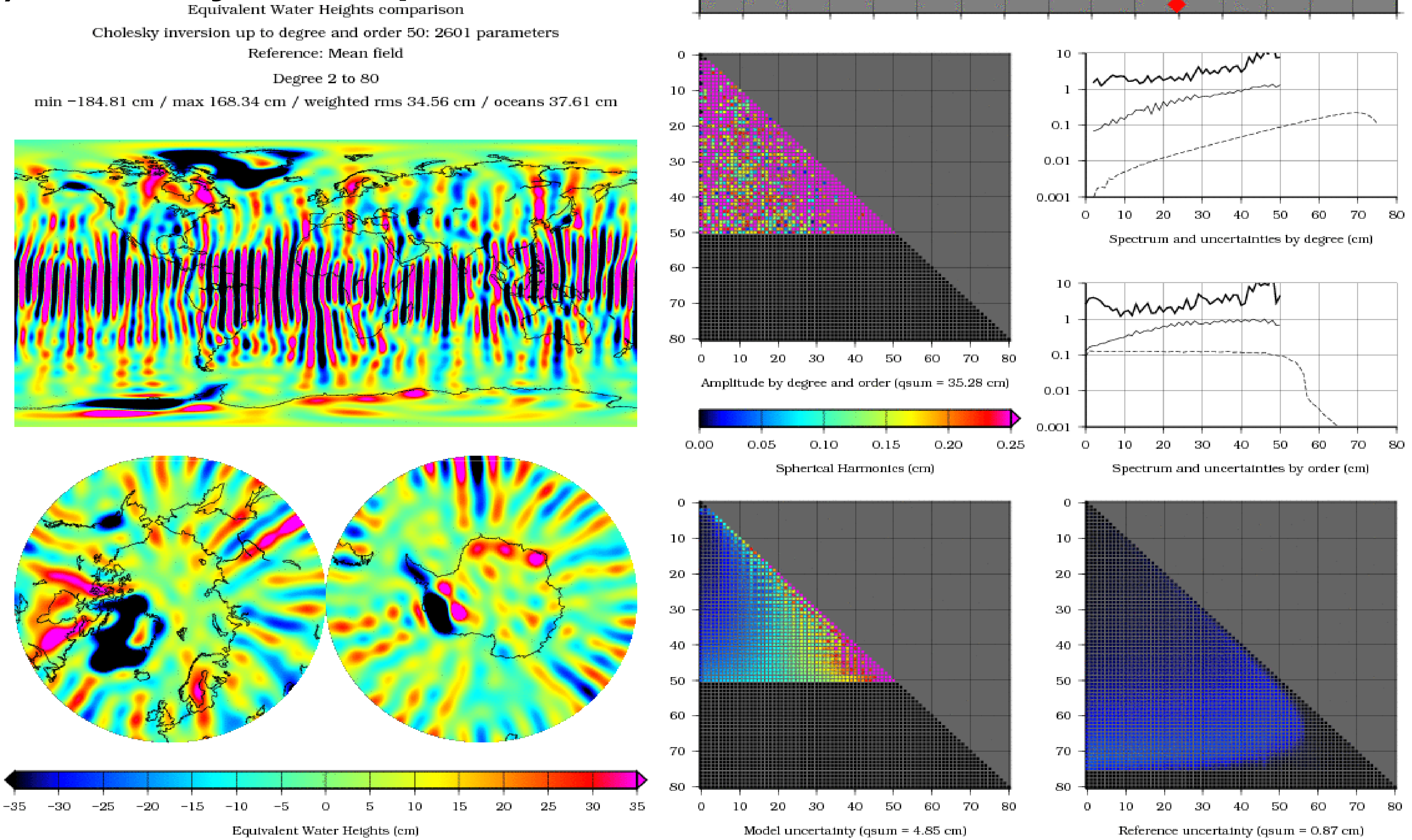
Other models

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

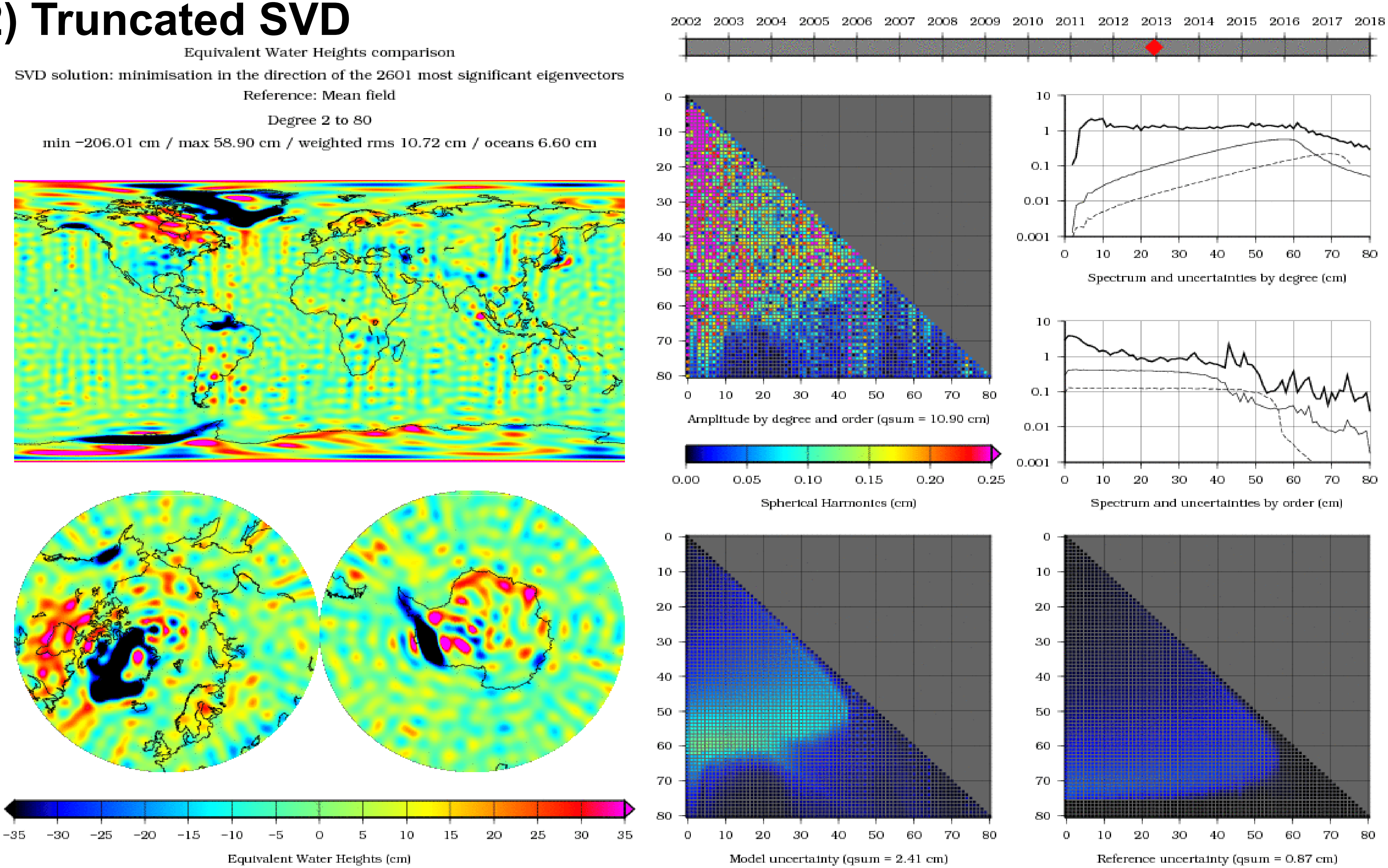
Interest of truncated SVD

- **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 degree/order 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

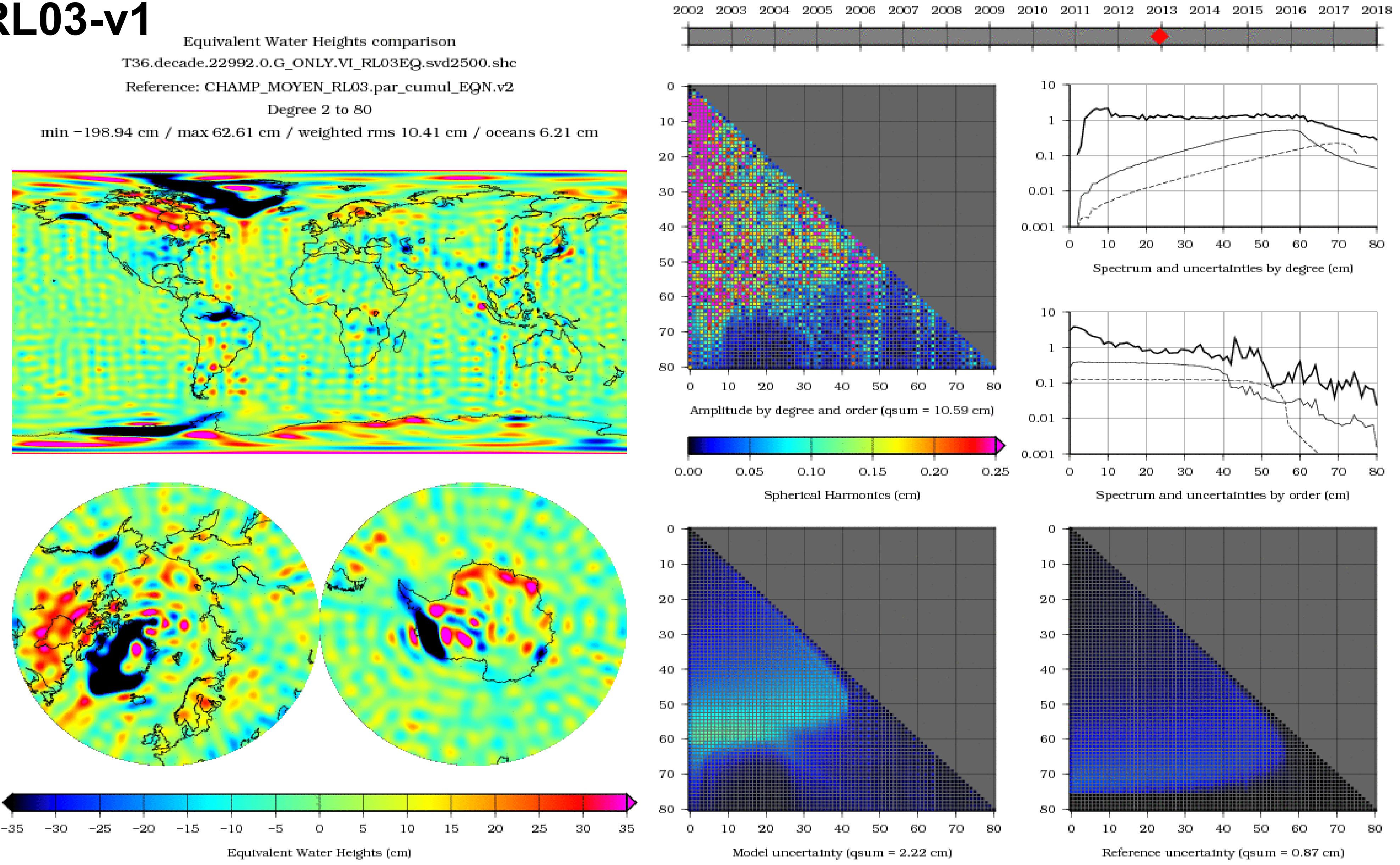
❖ Trying to solve the problems at the poles

- 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

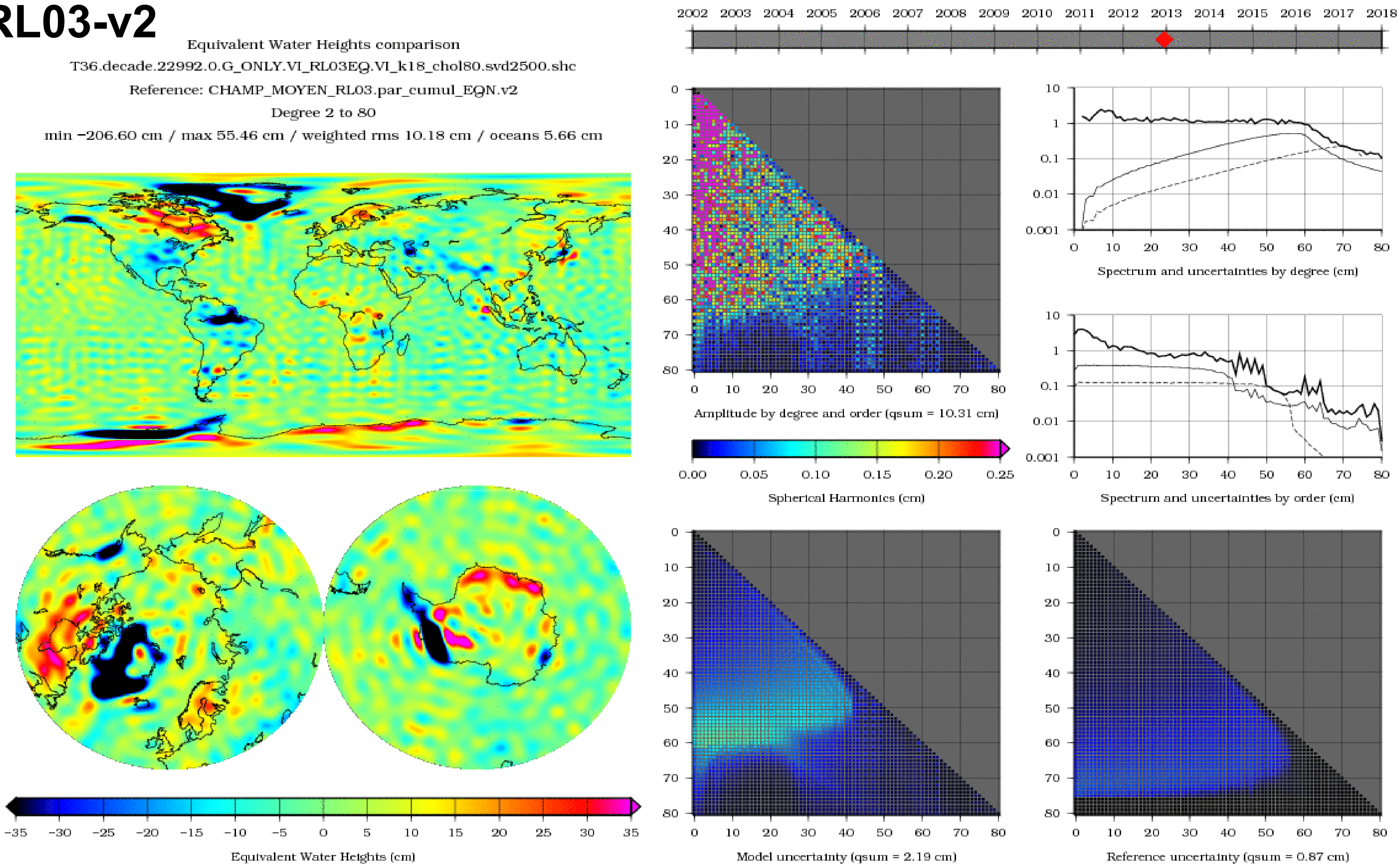
❖ Results

- 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
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)
−35 −30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30 35
Equivalent Water Heights (cm)
Model uncertainty (qsum = 2.22 cm)
Reference uncertainty (qsum = 0.87 cm)

RL03-v2

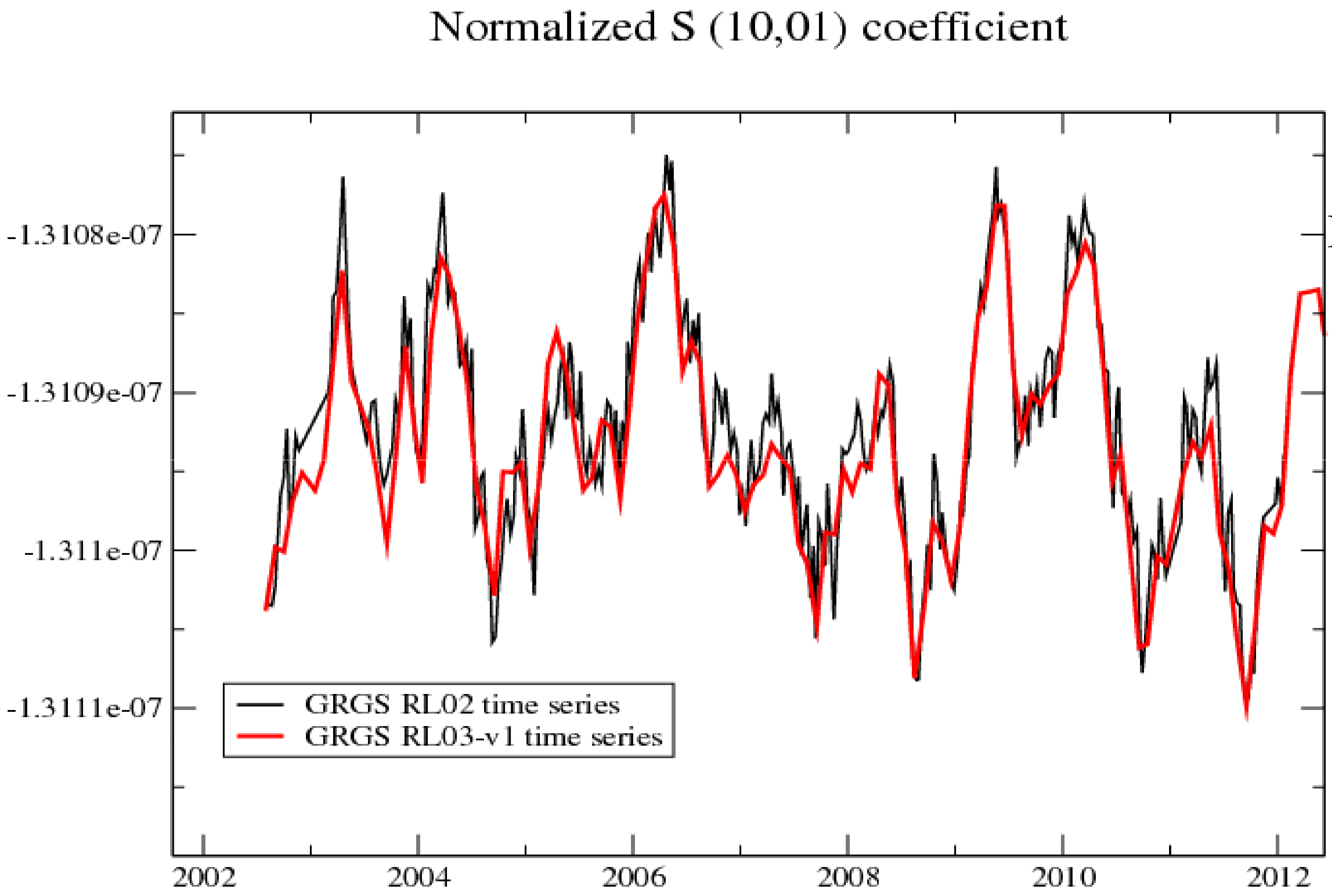

Equivalent Water Heights comparison
T36.decade.22992.0.G_ONLY.VI_RL03EQ.VI_k18_chol80.svd2500.shc
Reference: CHAMP_MOYEN_RL03.par_cumul_EQN.v2
Degree 2 to 80
min −206.60 cm / max 55.46 cm / weighted rms 10.18 cm / oceans 5.66 cm
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016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

Mean model generation

❖ Mean models are now generated from time series

- Fitting each series of monthly spherical harmonic coefficients by a set of 6 parameters :
  - 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 spherical harmonic model which better match with GRACE monthly models
- Used for operational computation (i.e. altimetric orbit processing) or TRF processing (i.e. ITRF2014)

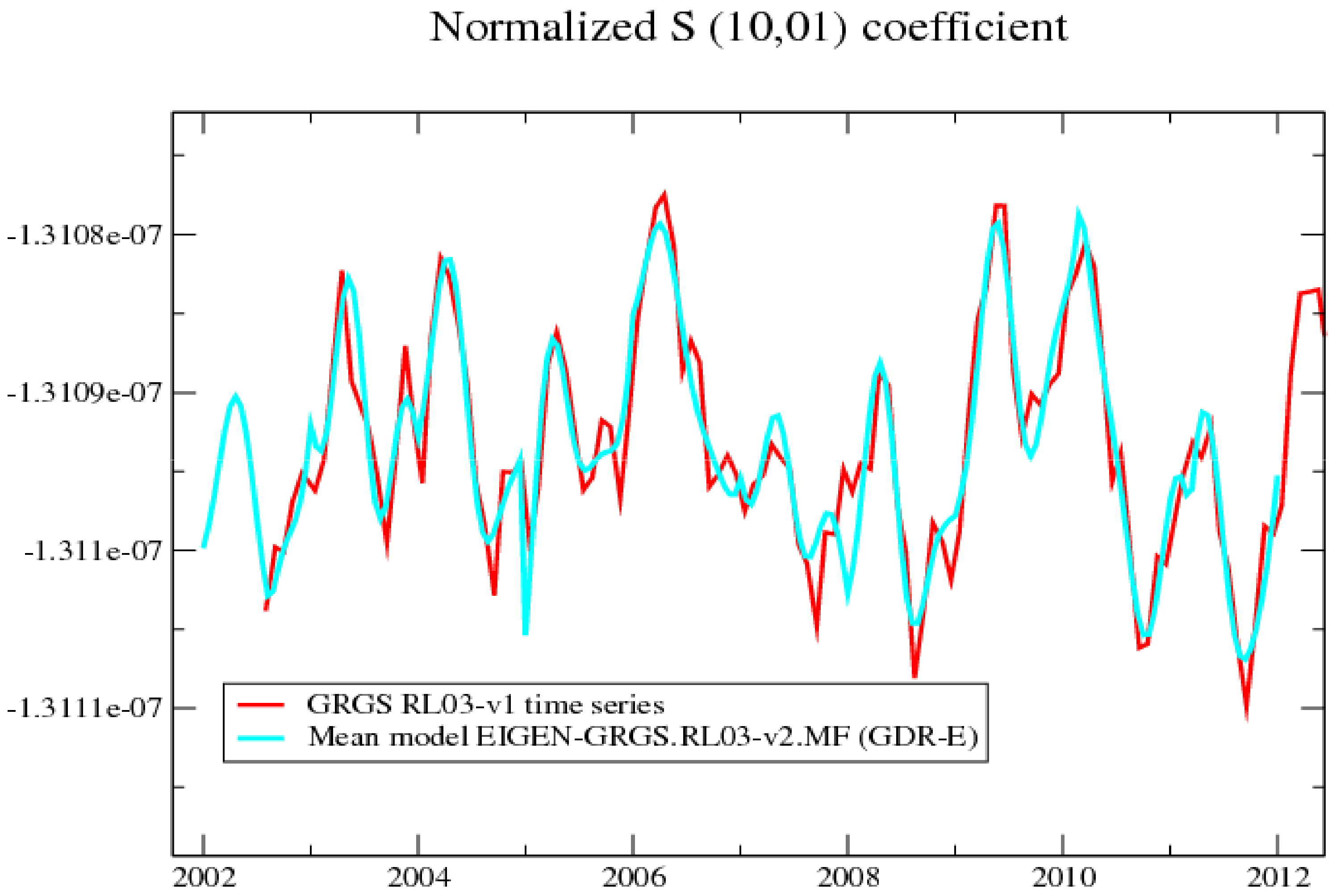
RL03 monthly model



In black: from RL02 10-day series

In red : from RL03 monthly series

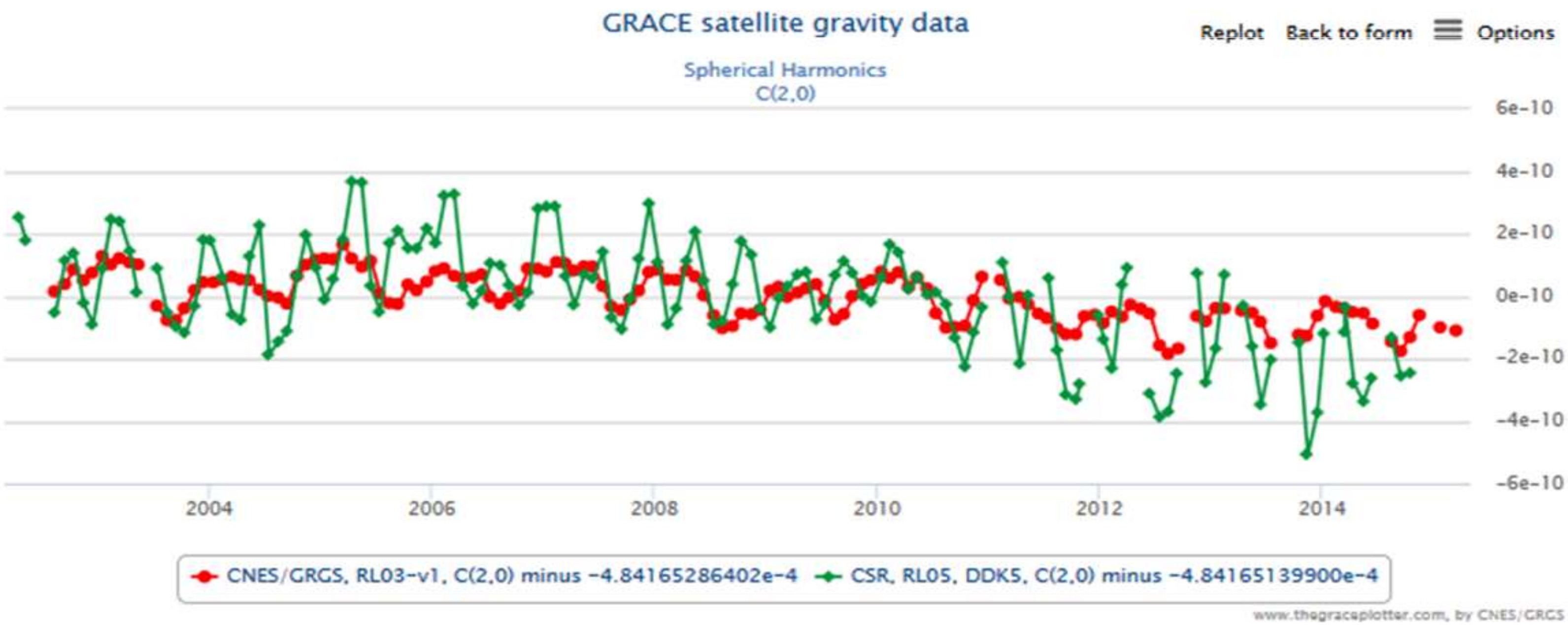
RL02-v2 mean model



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

J2 behaviour

- J2 monthly variations are extended from 1986 till now
  - From Lageos, Starlette and Stella data
  - Need to be consistent with other time variable models, e.g. ocean tides (Ssa, Sa, Ω_1)
- www.thegraceplotter.com (CNES/GRGS)

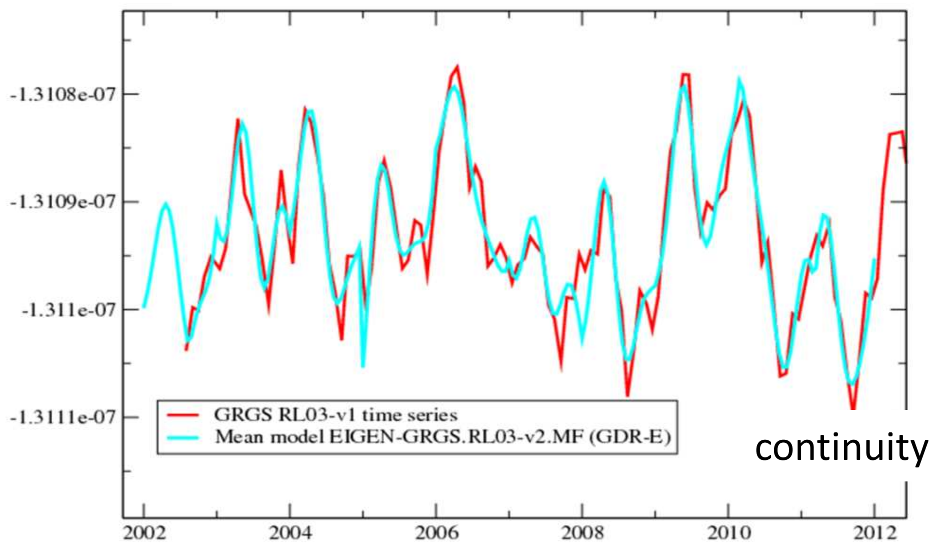


Coefficient extrapolation

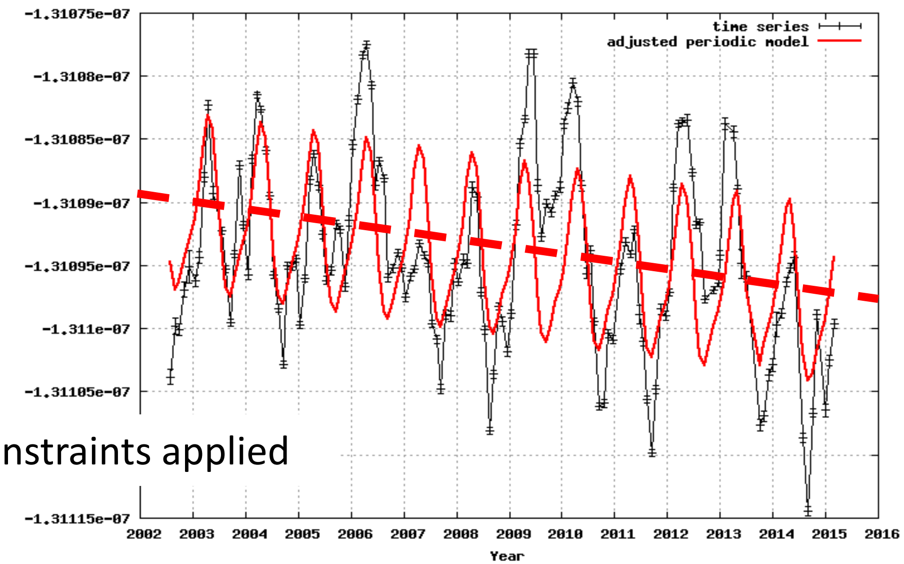
❖ Extrapolated coefficients

- 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
  - From 2014 forward for all terms (RL03-v2 model)

S(10,1) within the GRACE period



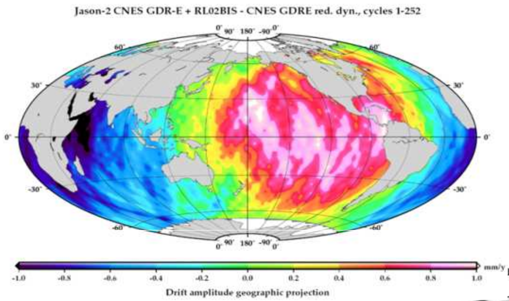
S(10,1) outside the GRACE period



continuity constraints applied

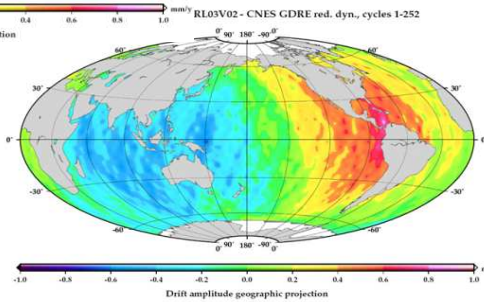
- **The new RL03-v2 model** reduces the geographically correlated radial orbit drift rate, from more than 1 mm/yr (for the RL02bis mean model) to less than 0.6 mm/y over ~7 years, with respect to Jason-2 GDR-E reduced-dynamic orbits (from GPS+DORIS).

- **Jason-2 SLR residuals :**

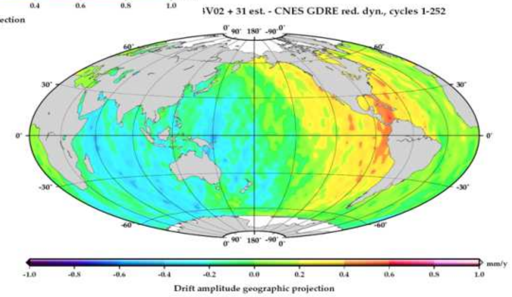


Radial orbit drift rate
Scale: -1 / +1 mm/yr
[A. Couhert & al., 2015]

➢ RL02: 1.36 cm rms



➢ RL03-v2: 1.29 cm rms



➢ RL03-v2 + C31 adjusted: 1.27 cm rms

Summary

- RL02-v2 is used for GDR-E orbit production
- It is expanded in sets of 6 yearly coefficients (bias, slope, annual and semi-annual terms) per degree/order up to 80, and contains constant terms (from EIGEN6-S2) up to degree/order 175
- Extrapolated time-variable terms (before August 2002 and after July 2014) are based on global fits of monthly coefficients over 12 years of GRACE data
- Degree 2 time-variable terms are adjusted back to 1986 from Lageos data
- RL02-v2 is available on: http://grgs.obs-mip.fr/grace/variable-models-grace-lageos/mean_fields

❖ Next RL03-v3 model

- ➢ Improving the inversion process (Cholesky + SVD in a 2-step procedure)
- ➢ Completing the years 2014-2015 (no longer extrapolated)
- ➢ Homogenizing the relative weights (between GPS and KBR)
- ➢ Using more satellite data (Starlette, Stella, Lares, Jason…)