New RL04 CNES/GRGS gravity field solutions

J.-M. Lemoine[1], R. Biancale[1], S. Bourgogne[2]

[1] CNES/GRGS, Toulouse, France (jean-michel.lemoine@cnes.fr)
[2] Géode & Cie, Toulouse, France

RL03-v3 status

- **CNES/GRGS-RL03-v3 models**
- Time variable models RL03-v3 up to degree/order 80
- Computed from 2002/08 to 2016/05 (152 monthly solutions, 436 10-day solutions)
- Based on EIGEN-GRGS-RL03-v2 mean field up to degree order 300 + annual/ semi-annual and drift terms per year up to degree/order 80 computed over the period 2003.0 - 2014.0 with averaged slope of the signal outside

- **Available on grgs.obs-mip.fr and www.thegraceplotter.com**

Toward RL04

- **Improving a priori models**
  - starting from the mean field + annual/semi-annual + drift terms
  - using ITRF-2014 for SLR processing (Lageos1/2, Starlette, Stella)
- **Revisiting the parameterization**
  - ACC parameter behavior
  - KBRR parameter behavior
- **Stabilization**
  - Constraints on parameters (relative vs. absolute)
  - SVD "soft" truncation
- **Modelling**
  - Spherical harmonics up to degree/order 90
  - Alternative surface mass modelling per 2° square
  - Hybridizing spherical harmonic representation (degree/order <= 25) and surface masses over continents
- **Validation**
  - Map comparison in EWH
  - Power spectrum evaluation
  - Test areas (comparing with altimetry or on gravitationally stable areas)

GINS data processing summary

GRACE / 1 d-arc	samp-ling (s)	nb of meas./d	bias per	scale per	nb of bias/d	absolute constraint	relative constraint	a priori σ	mean residuals
ACC (m/s^2)	5	~34500	½ rev.	day	192	- 10^{-2}X,10^{-3}YZ	10^{-9}XZ,5.10^{-9}Y	-	-
KBRR (m/s)	5	~17000	½ rev.		64	Bias: 10^{-7} Drift:10^{-11}	10^{-9}	10^{-7}	.16 10^{-6}
GPS (m) range phase	 30 30	 ~43000 ~43000	 pass & meas.		 ambig. ~700 clock ~6000	 10 1000		 1 .002	 ~.5 ~.005
SLR (m) / 5 d-arc	passes / 5 d	meas. / 5 d			nb of range bias / 5 d				
Lageos Lageos2 Starlette Stella	112 93 121 68	~1025 ~935 ~1175 ~550	station “ “ “		~20 (10-30) ~19 (10-30) ~18 (10-25) ~17 (10-25)	~.02	-	~.02	8.4 10^{-3} 8.0 10^{-3} 10.5 10^{-3} 10.4 10^{-3}
GRACE (for validation)	15	~300			~10				2.5 10^{-2}

RL04 inversion procedure

The inversion procedure is done in 2 steps:

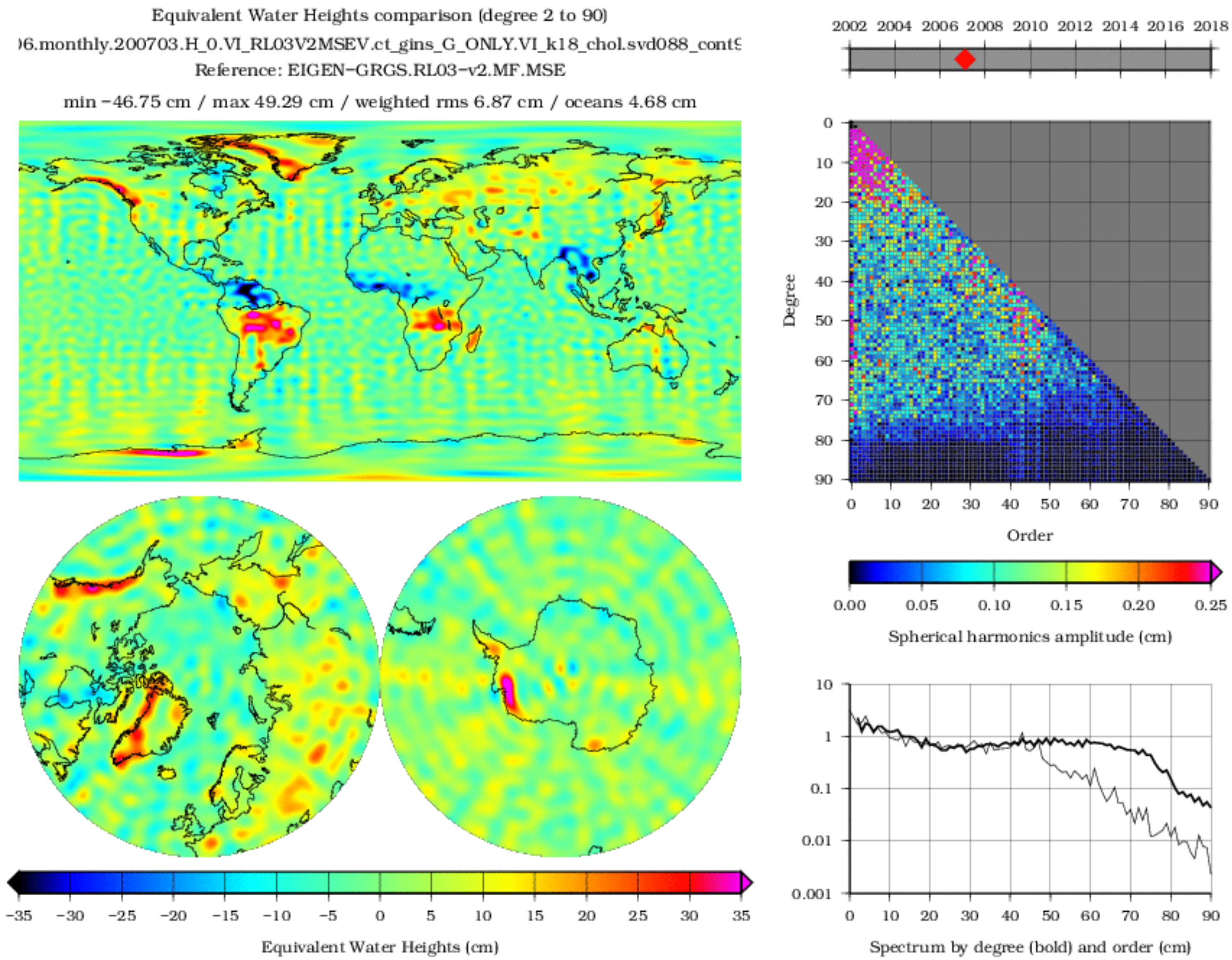
- **First step** (to get solution not depending on the a priori model)

  - Cholesky's inversion method from degree 2 to degree 80, constrained (according to the Kaula's rule) toward the a priori model from degree 11 + some additional constraints for sectorial (and 2 side-bands) coefficients as well as for resonance order 46.

- **Second step** (to avoid post-filtering)

  - Inversion by SVD
  - "Soft" truncation from the 961st eigenvalue (equivalent to degree/order 30) by smoothing to 0 the eigenvalue inverses up to ~90% of the total power.

RL04 monthly solution



Modelling by surface masses

Truncating spherical harmonic expansion tends to mitigate the gravity signal where strong discrepancies appear (for instance along coasts).

Considering that oceanic masses vary mainly at long wavelengths and that hydrology variations over continents appear at shorter wavelengths and can present abrupt steps, we propose to represent surface mass variations differently between oceans and continents:

- ocean mass variations are represented in s.h. expansion up to degree/order 25 (800 km resolution), hence extending over continents;

- mass variations from degree 26 are represented by a 2 deg.*2 deg. grid of surface masses distributed over the continents (and on a few small oceanic areas experiencing short scale mass variations).

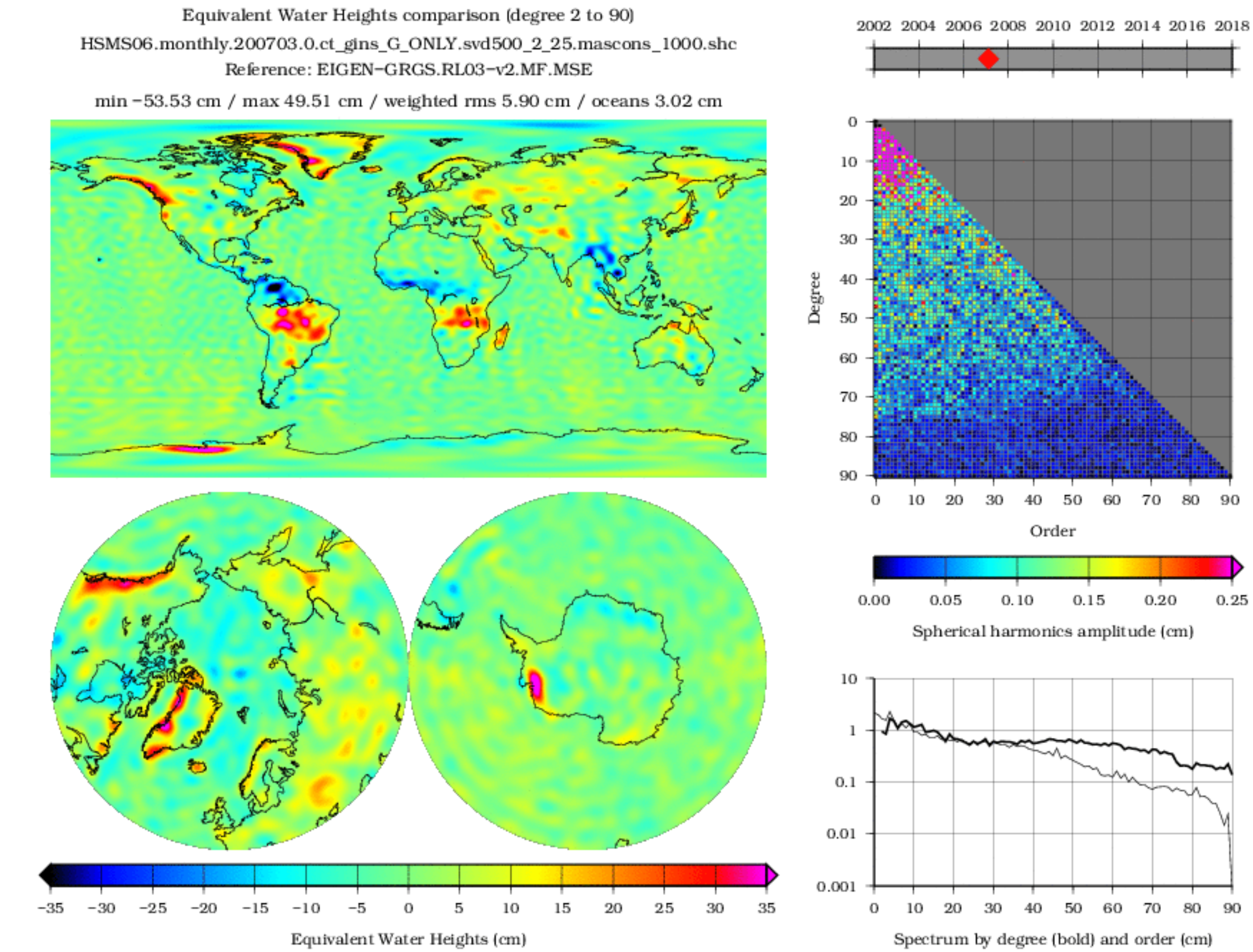
Hybrid procedure (s.h. + surface masses)

The hybrid procedure merges the spherical harmonic expansion with surface masses (in terms of water height mainly located on continents).

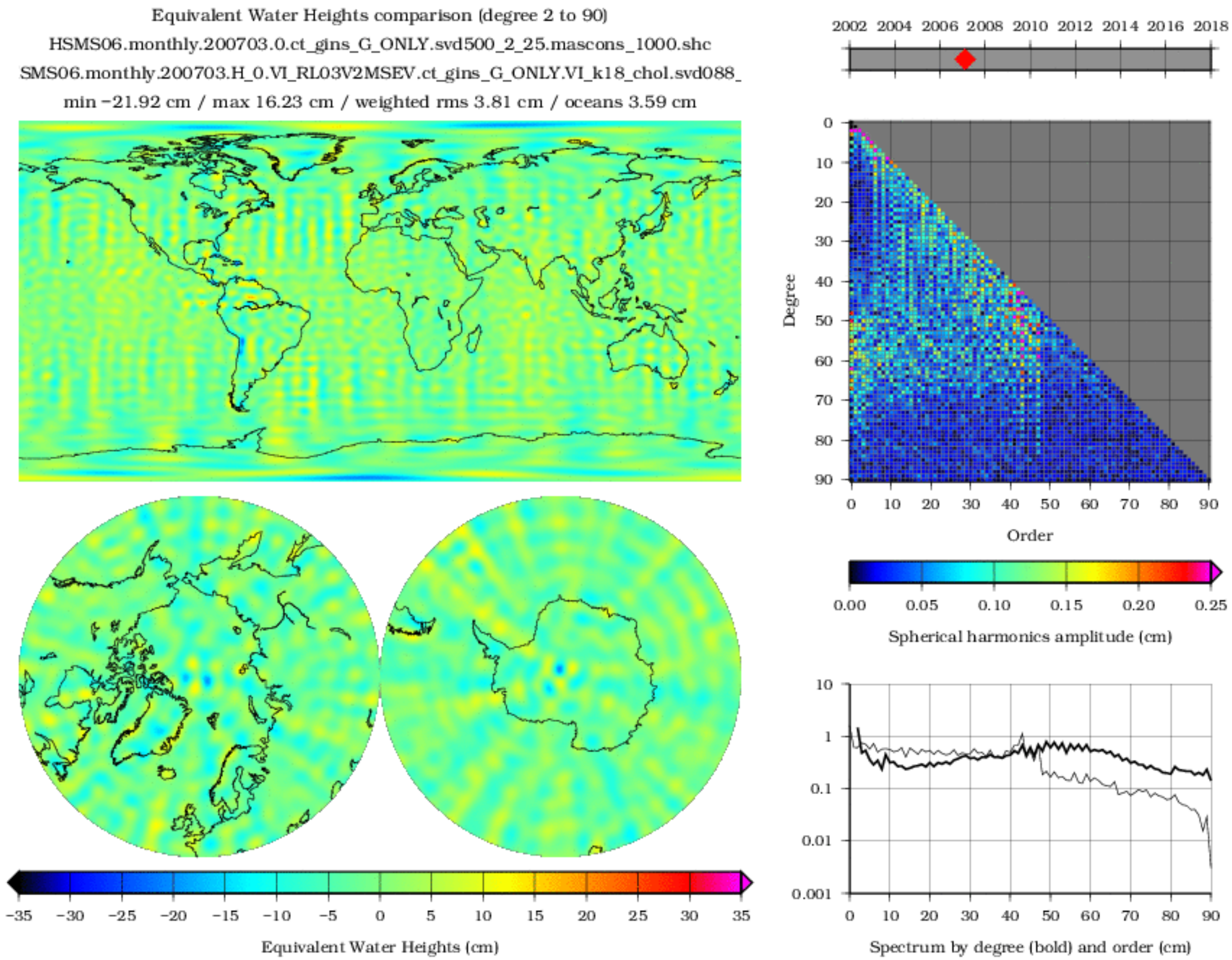
The procedure is following:

1. **Setting up the normal equation for s.h. coefficients up to degree/order 90 (8190 coefficients) and around 6000 2 deg.*2 deg. surface masses**
2. Reducing all non gravitational parameters
3. **Solving for low degree s.h. coefficients up to degree/order 25 by SVD decomposition** (keeping 500 eigenvalues from 625)
4. Re-inserting the s.h. solution into the normal equation
5. Reducing all parameters other than the surface masses
6. **Solving for surface masses by SVD** restricted to the 1000 larger eigenvalues (among 6000)
7. Converting the low degree s.h. expansion into 2 deg.*2 deg. grid
8. Adding this grids to the one of surface masses
9. Converting the complete grid into s.h. expansion up to degree/order 90

The surface mass approach

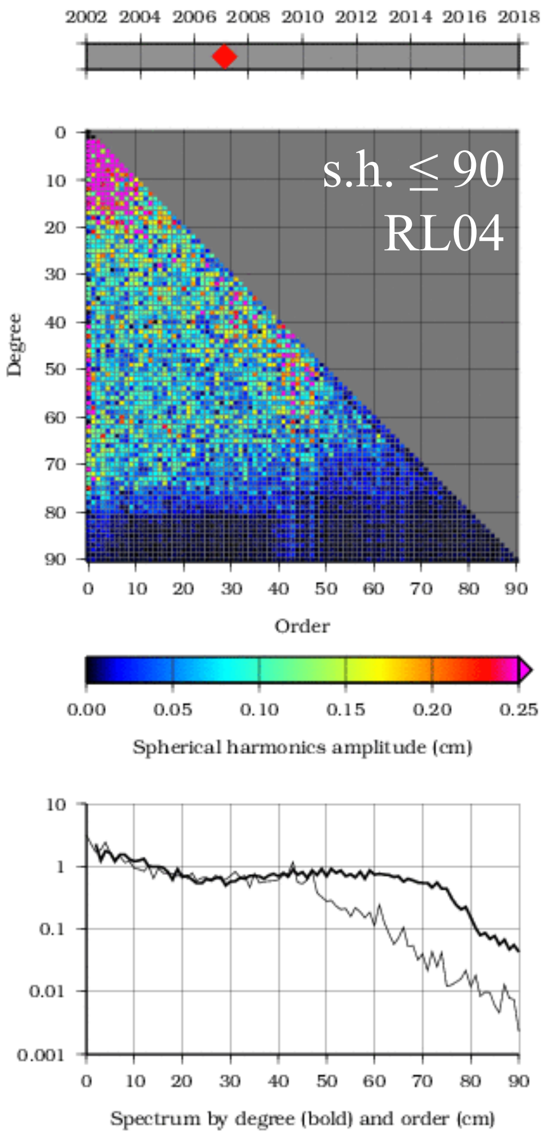


Difference



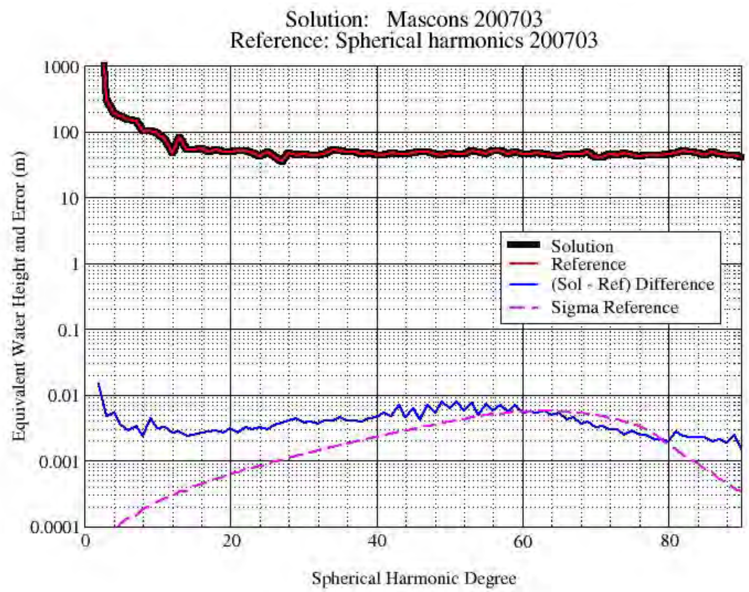
Equivalent Water Heights comparison (degree 2 to 90)
HSMS06.monthly.200703.0.ct_gins_G_ONLY.svd500_2_25.mascons_1000.shc
SMS06.monthly.200703.H_0.VI_RL03V2MSEV.ct_gins_G_ONLY.VI_k18_chol.svd088_
min −21.92 cm / max 16.23 cm / weighted rms 3.81 cm / oceans 3.59 cm
2002 2004 2006 2008 2010 2012 2014 2016 2018
Degree
Order
0.00 0.05 0.10 0.15 0.20 0.25
Spherical harmonics amplitude (cm)
10
1
0.1
0.01
0.001
Spectrum by degree (bold) and order (cm)
−35 −30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30 35
Equivalent Water Heights (cm)

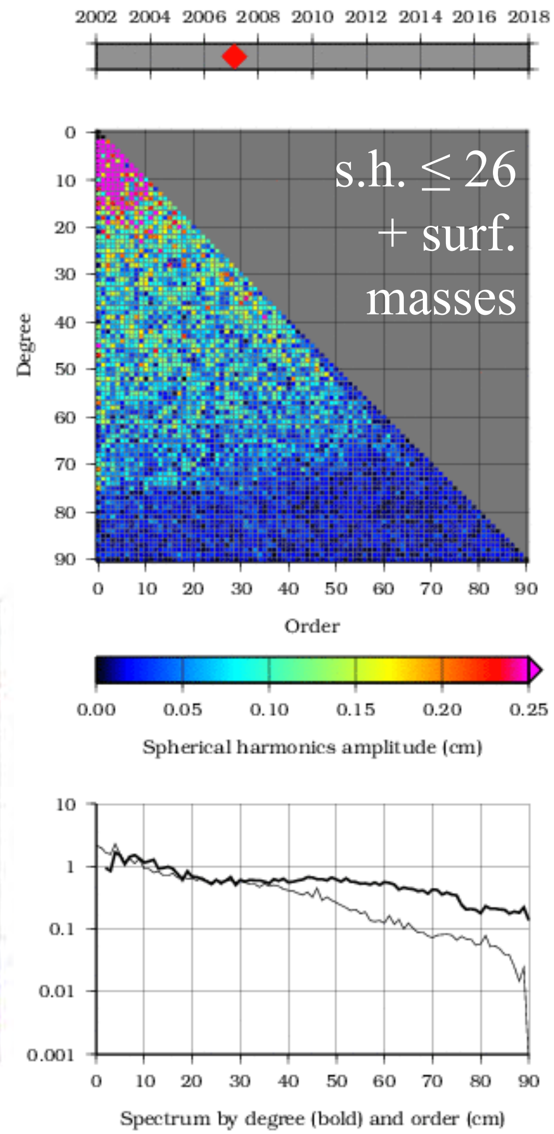
Comparison



The power spectrae of both solution are comparable at a few mm level.

The surface mass representation at higher resolution avoids amplifying resonance effects and allows smoother spectrum behaviors by degree and order.

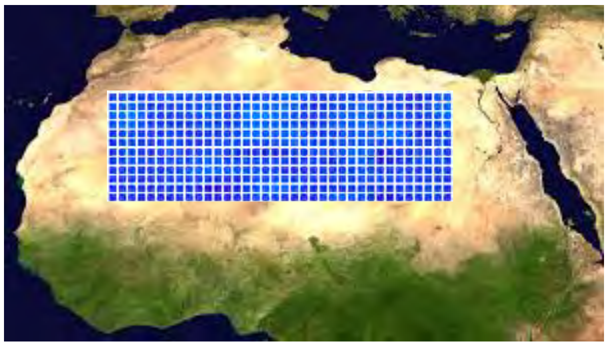




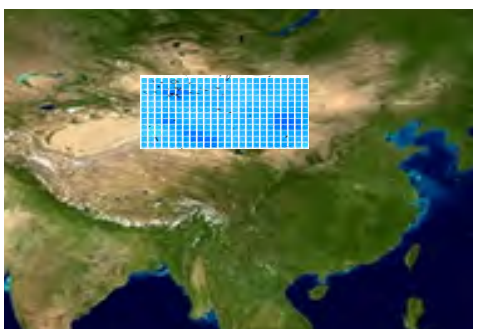
RL03/RL04 evaluation

Quality assessment can be made:

1. In areas with no or very little mass variations: Sahara and Gobi deserts, East Antarctica, South Pacific
2. In comparison with altimetry over large water stretches: the Caspian sea

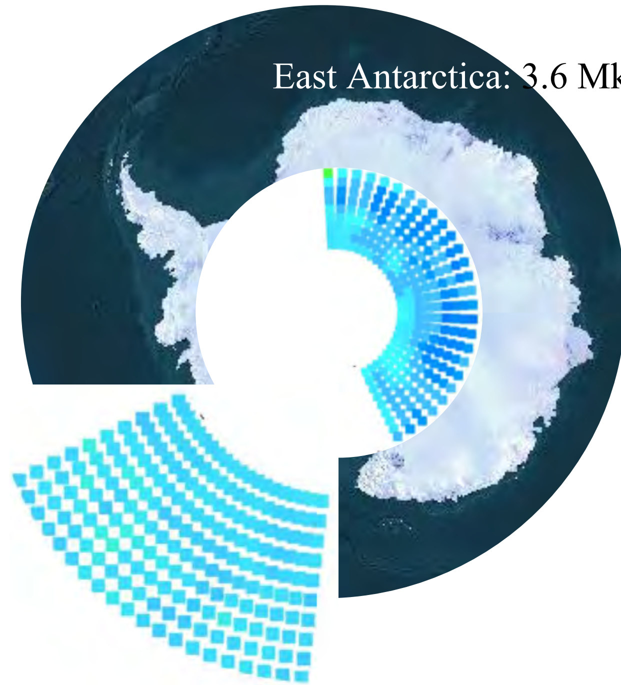


Sahara desert: 2.2 Mkm^2

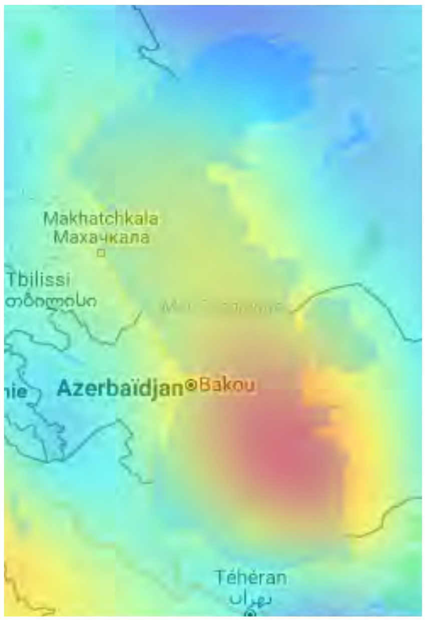


Gobi desert: 1.6 Mkm^2

East Antarctica: 3.6 Mkm^2



South Pacific 6.7 Mkm^2



Caspian sea: 371 000 km^2

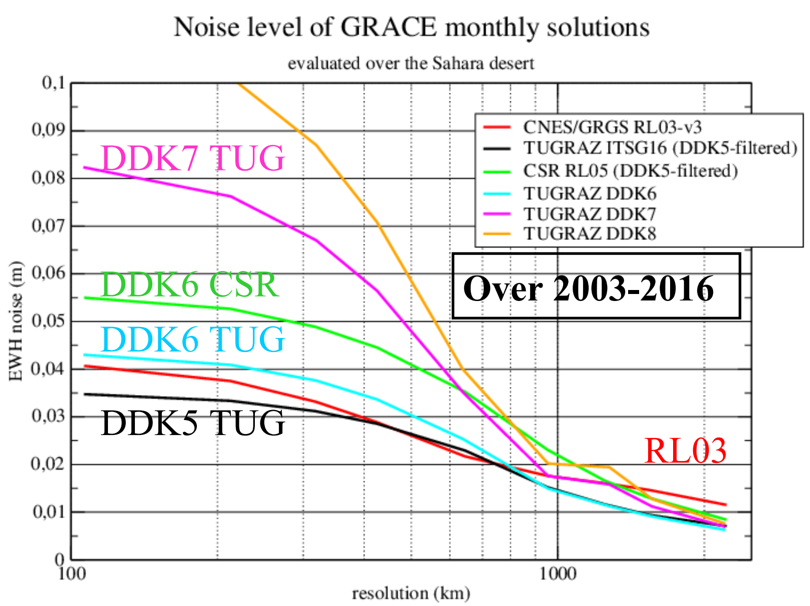
Model assessment over the Sahara

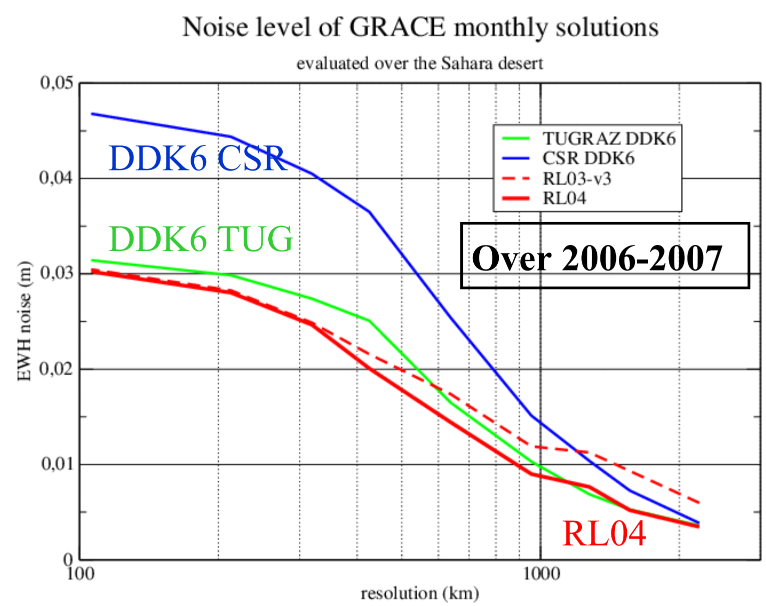
The Sahara desert shows very little hydrological variations. We have delimited a rectangular zone of 2.2 Mkm^2 where almost no gravity variation is suspected (except a small depletion of 1.3 mm/yr in South Libya due to oil pumping).

It is hence well dedicated to control the quality of gravity field variation models.

The surface is first divided in 2 deg.*2 deg. blocs (⇔ degree/order 90), then averaged in blocs of larger size up to 20 deg.*20 deg. Drift and annual/semi-annual variations are fitted a priori.

Different time-varying gravity models are compared spectrally in this way from 100 km to 2200 km.





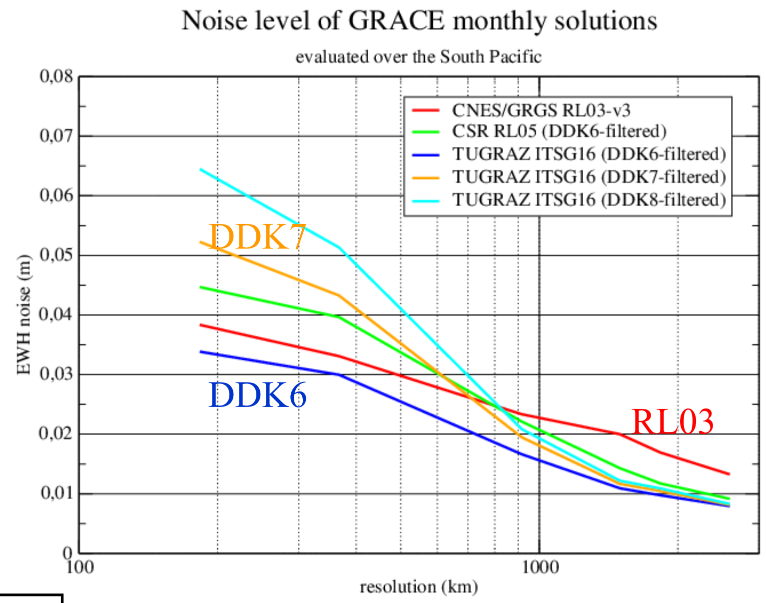
Model assessment

Other areas exhibit as well very small temporal gravity signal such as:

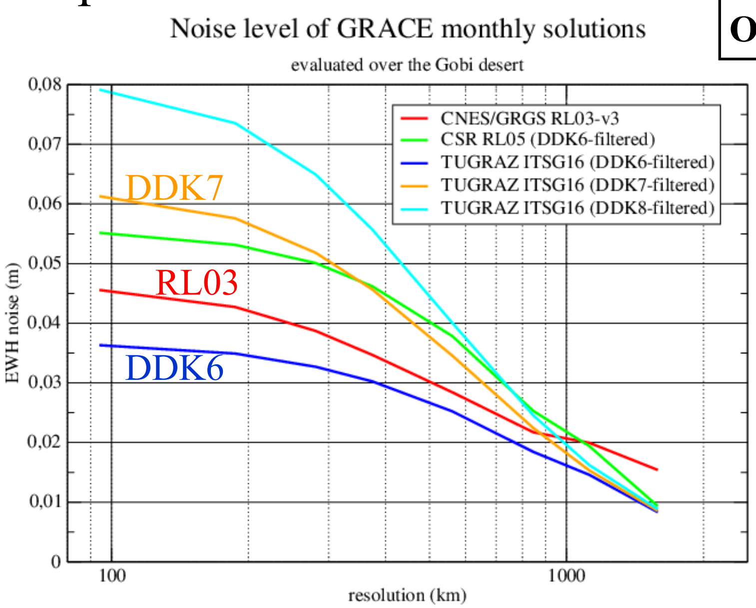
- The Gobi desert
- East Antarctica
- South Pacific

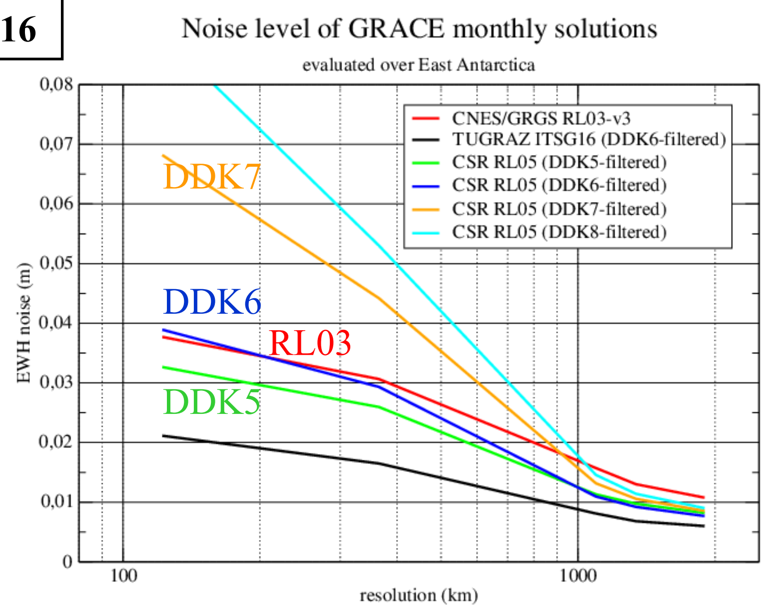
Results depend a lot on the type of smoothing applied.

As seen previously RL03 long wavelengths are improved in the RL04 series.



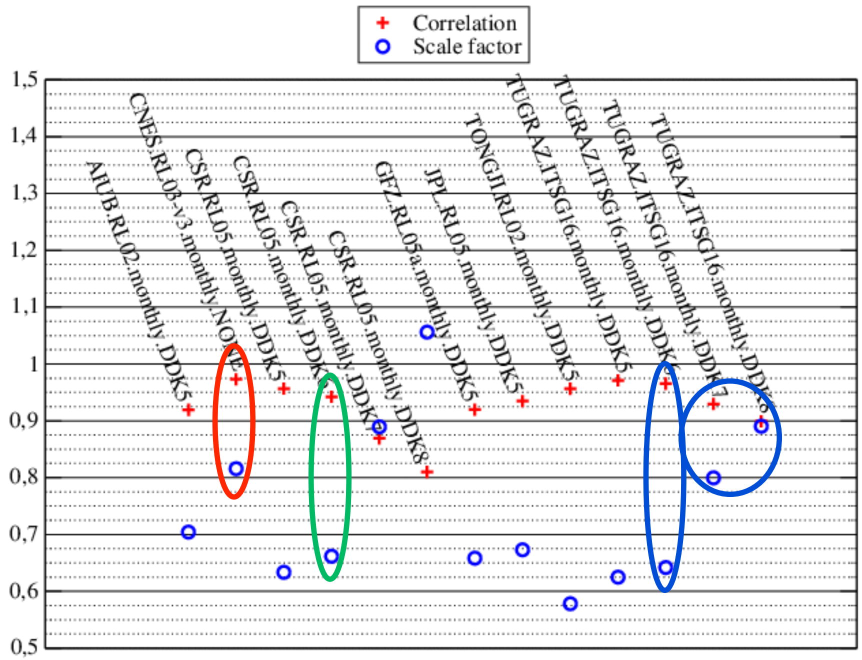
Over 2003-2016

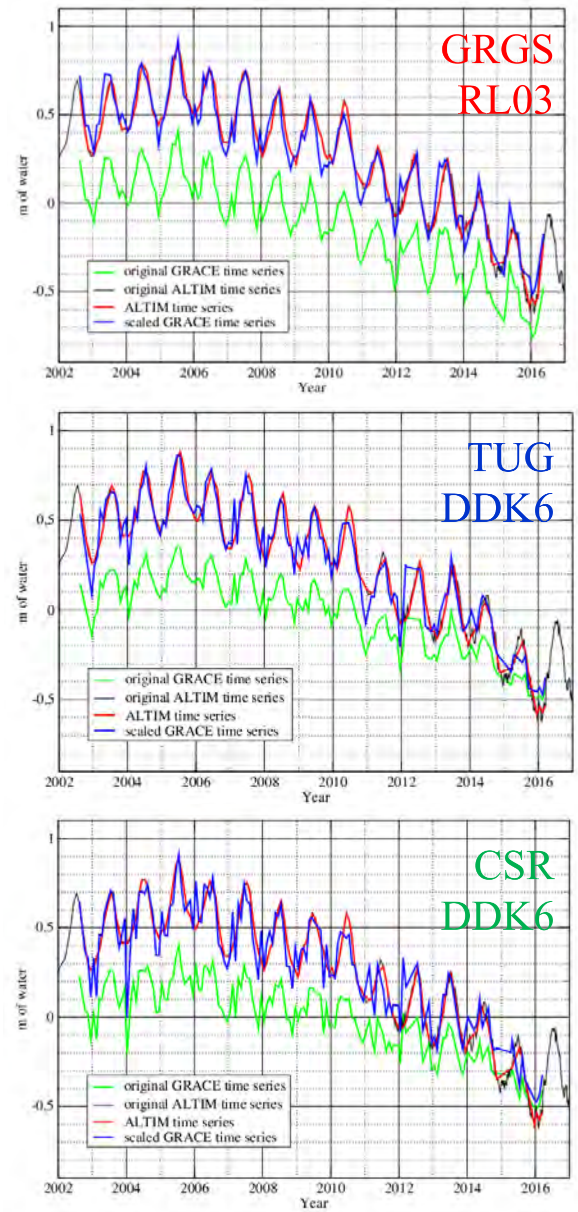




Model assessment over the Caspian sea

Comparison with altimetry can be considered as well as a quality test although sea surface height variations are not only caused by mass variations.





The scale factor fits at best the gravity signal amplitude (taken in the middle of the sea) to the integrated one from altimetry, the correlation term indicates the agreement between both techniques.

Summary

- GRGS-RL04 series

  improves compared to the previous RL03-v3 series, mainly at the poles and at very long wavelengths

- Hybrid solution (s.h. + surface masses)

  provides an alternative solution with refined mass locations and less meridian artifacts

- Validation sets of 2 types: over areas with very few gravity signal or in comparison with altimetry

  show a good quality of GRGS solutions

- The new series up to degree/order 90 will be available from end of December on grgs.obs-mip.fr and www.thegraceplotter.com as usual