CNES
CENTRE NATIONAL D'ÉTUDES SPATIALES

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→ 25 YEARS OF PROGRESS
IN RADAR ALTIMETRY SYMPOSIUM

IDS WORKSHOP

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Azores Archipelago, Portugal

The new time-variable gravity field model for POD of altimetric satellites based on GRACE+SLR RL04 from CNES/GRGS

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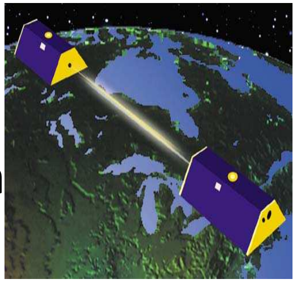
Introduction

- Precise orbit determination is a key element in the overall accuracy of the altimetric measurements.
- Since 2002, thanks to the GRACE (and GOCE) missions, we have now a very good knowledge of the Earth gravity field and its time evolution.
- Based on 14 years of GRACE data (2002.5-2016.5), 3 years of GOCE data and 33 years of SLR data (1985-2018), the **EIGEN-GRGS.RL04.MEAN-FIELD** is the gravity model that is proposed for the GDR-F standards.
- It contains a time-variable gravity (TVG) part until degree and order 90, and a static part coming from the model GOCE-DIR5 up to degree and order 300.
- The TVG part is modeled for each year between August 2002 and June 2016 as an annual bias + slope + annual and semi-annual periodic components.
- For the low degrees of the gravity field, the TVG part prior to August 2002 will either :
  - Be modeled, for degree 2 only, by SLR data from January 1985 to July 2002
  - Or be modeled in a more ambitious way thanks to a “mascon” approach (see John Moyard’s presentation, following talk).

GRACE (L-1B "Version2" data)

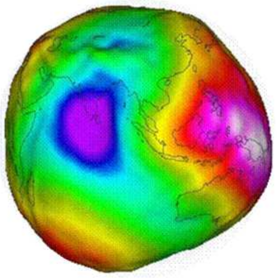


- **K-Band Range-Rate** data (**$\sigma_{apriori}$ = .1 µm/s**)
- **GPS** data (1-day arcs, σ_{code} = 80 cm, **σ_{phase} = 20 mm / 30s resolution**)
- **ACC** and **SCA** data (KBR CoP coordinates solved once / day)

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 90** (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:

Dynamical models

Gravity	*EIGEN-GRGS.RL03-v2.MEAN-FIELD*
Ocean tide	*FES2014 (Legos)*
Atmosphere	*3-D ECMWF ERA-interim pressure grids / 3 hrs*
Ocean mass model	*TUGO (Legos) / 3 hrs*
Atmospheric tides	*→ Not necessary because of the 3 hrs dealiasing time sampling*
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	*ITRF2014 coordinates*
GPS	*IGS Repro-2 orbits & clocks*

Other models

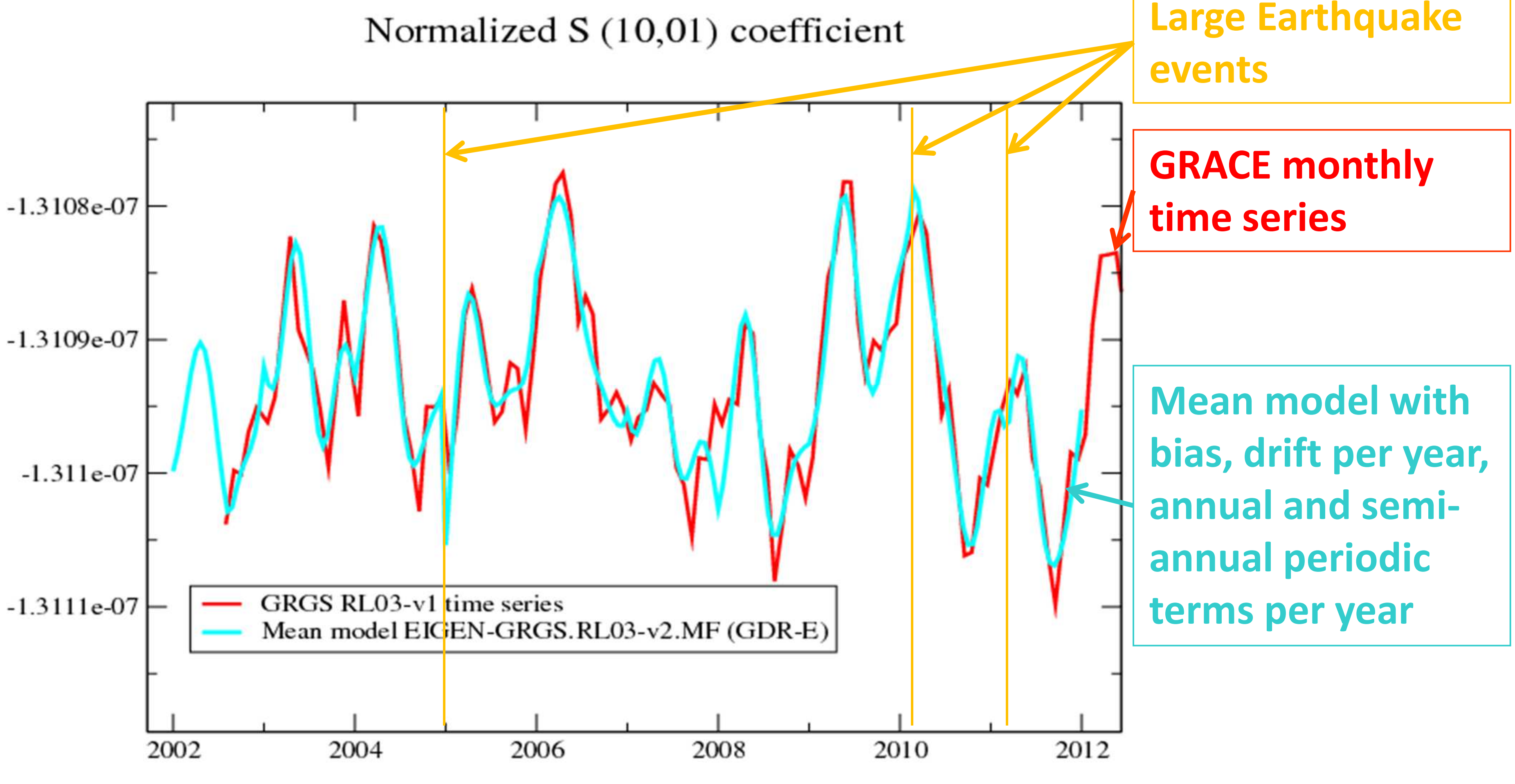
Hydrology	Taken into account by the a priori gravity field
Glacial Isostatic Adjustment	

From GRACE monthly solutions to mean gravity models

- **Using directly GRACE/GRACE-FO monthly solutions is not appropriate for POD because of:**
  - Data gaps in the GRACE time series (e.g. after 2011 and between GRACE and GRACE-FO)
  - The problem of extrapolation before 2002 and after 2016
- **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 (so far : Sumatra/2005.0, Concepcion/2010.2 and Tohoku/2011.2)
    - Annual and semi-annual sine/cosine functions (with continuity constraints at hinge epochs)
  - It means 750 000 coefficients for a 90x90 spherical harmonic model

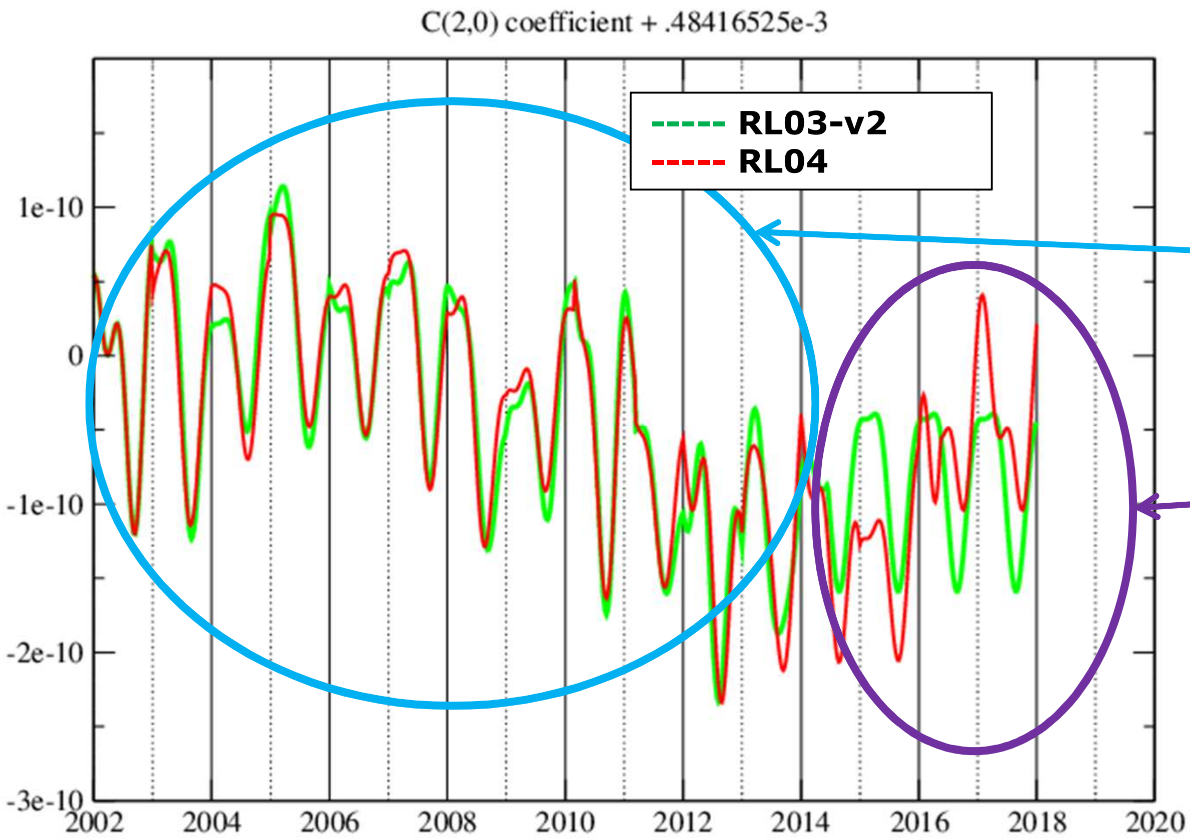
RL04 mean model

- Example for one spherical harmonic coefficient:



Mean model: from RL03-v2 to RL04

- The new mean field updates the previous one over 2 years: mid-2014 to mid-2016.
- Example for the C(2,0) spherical harmonic coefficient:

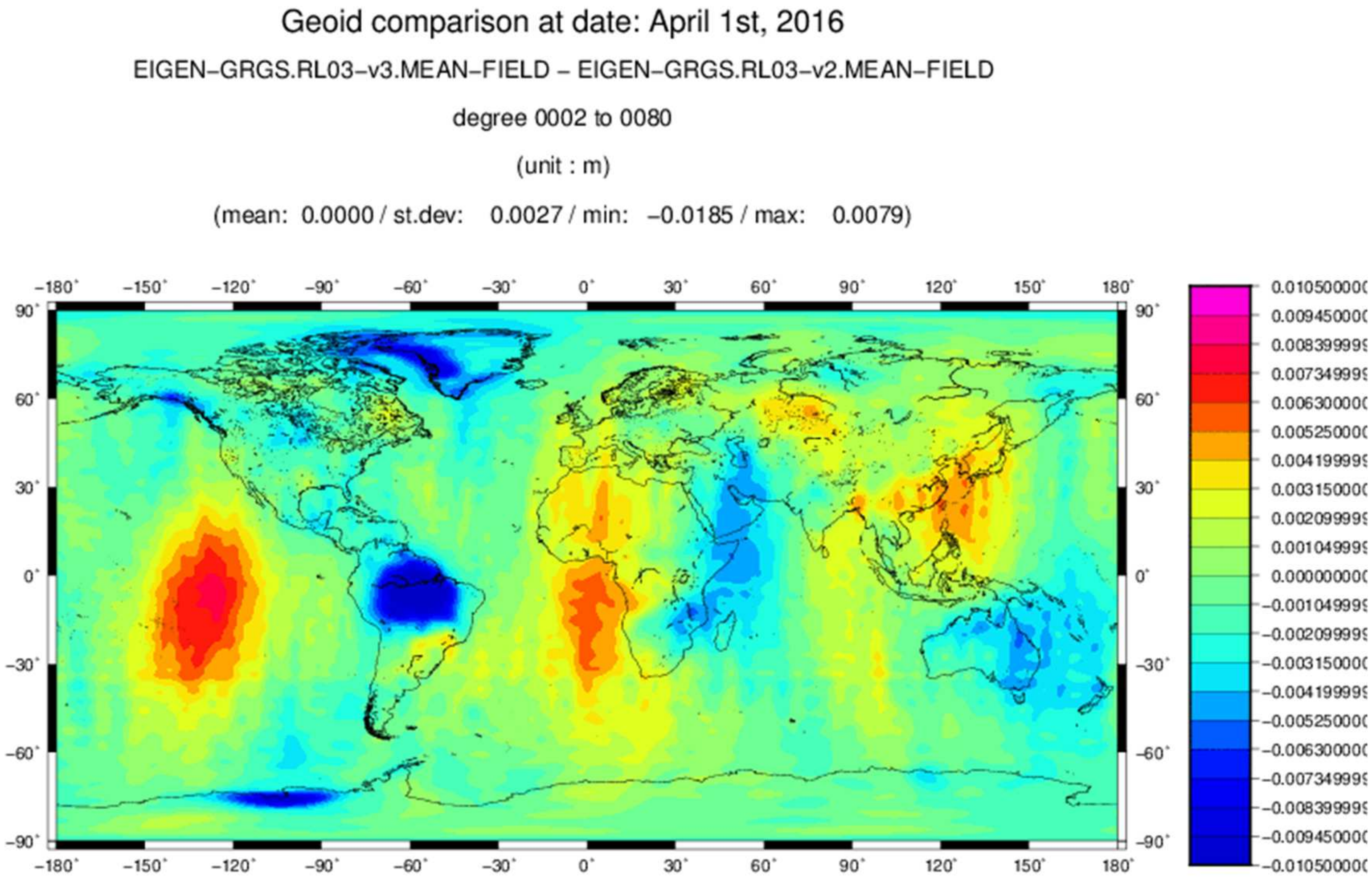


Small changes due to the transition from RL03-v2 to RL04

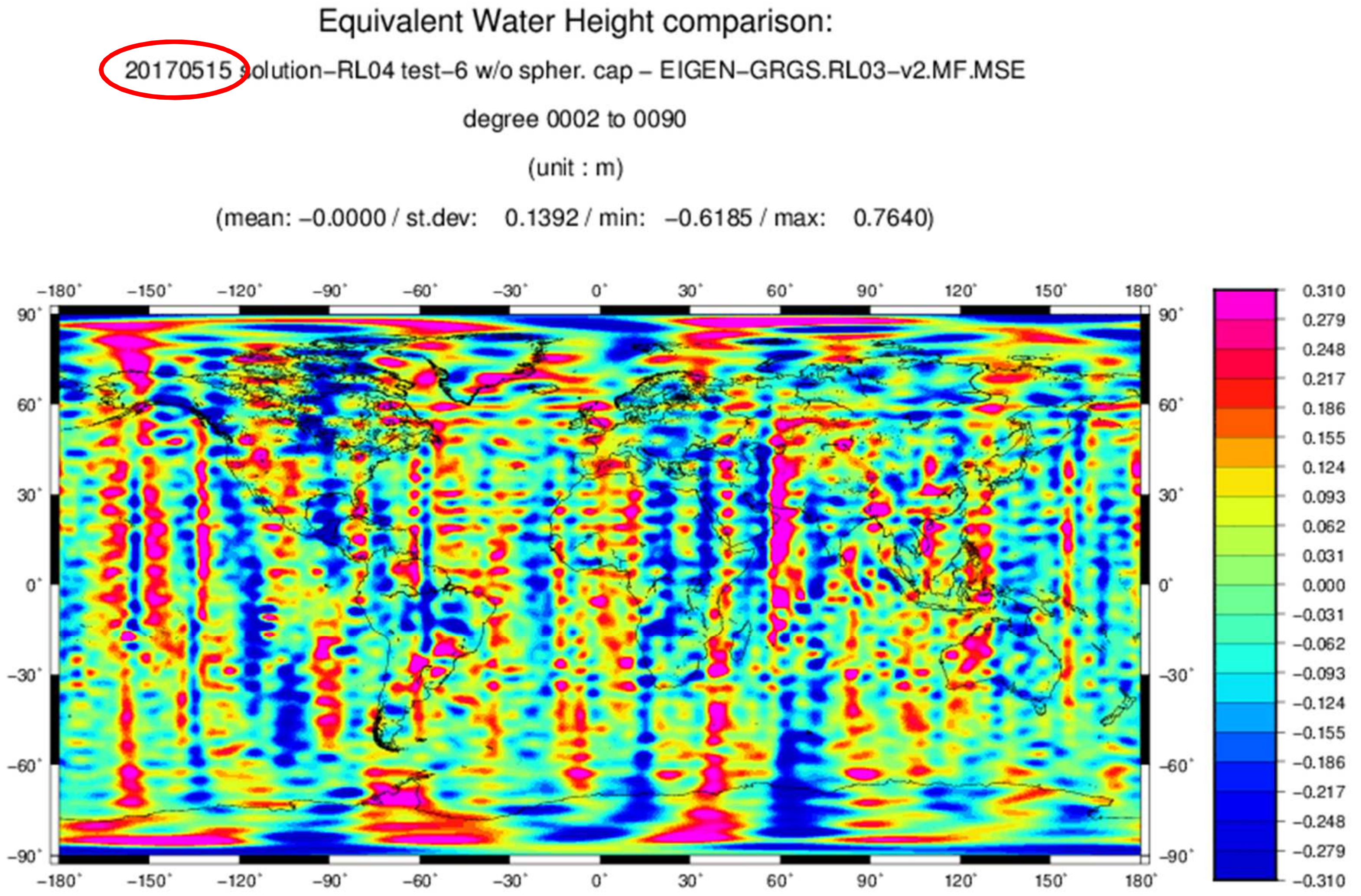
Important changes due to the addition of 2 more years

Update of the mean model from -v2 to v3

- Extrapolation vs. real data after 2 years: difference between mean-field –v2 and mean field –v3 at mid-2016



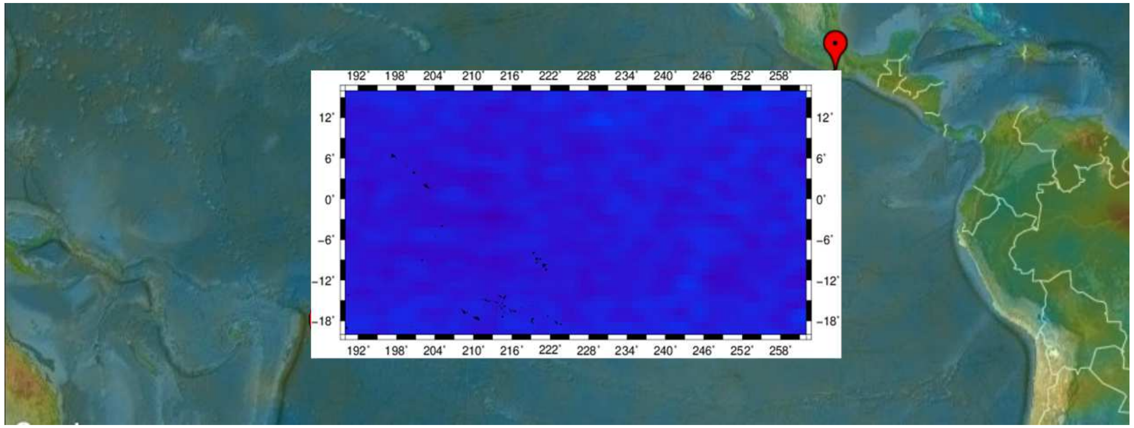
Improvement of RL04 wrt RL03-v2



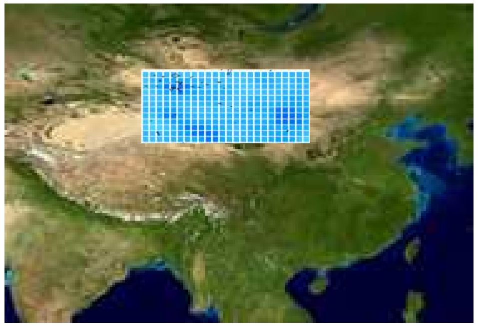
RL03/RL04 evaluation

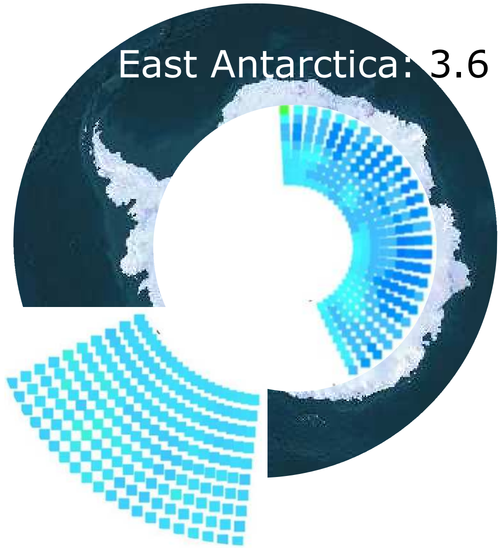
Noise assessment can be made in areas with no or very little mass variations: Sahara and Gobi deserts, East Antarctica, South and Equatorial Pacific


Sahara desert: 2.2 Mkm^2



Equatorial Pacific: 31.6 Mkm^2


Gobi desert: 1.6 Mkm^2


East Antarctica: 3.6 Mkm^2

South Pacific 6.7 Mkm^2

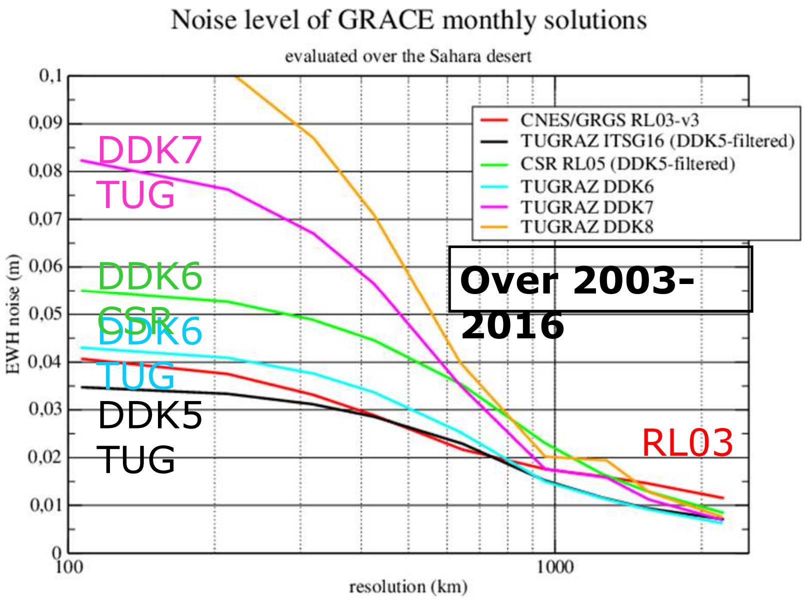
Noise assessment over the Sahara

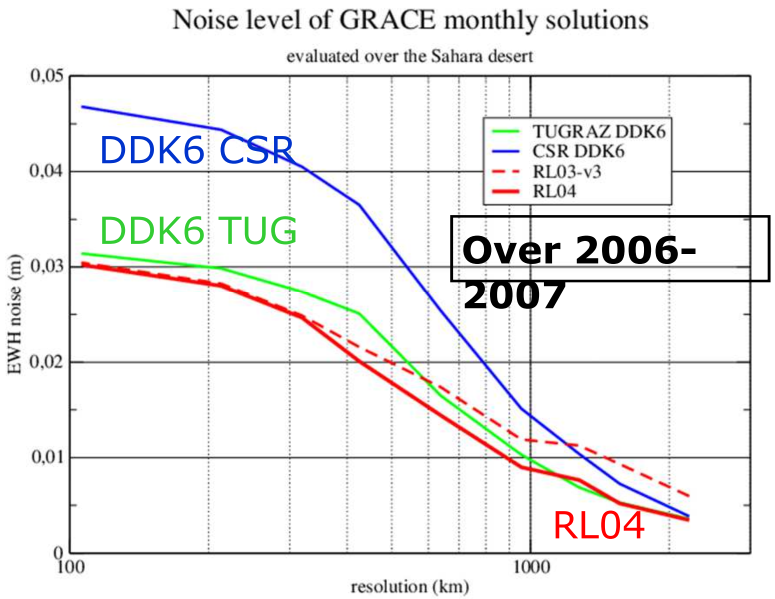
The Sahara desert shows very little hydrological variations. We have delimited a rectangular zone of 2.2 Mkm^2 where almost no gravity variation is suspected (except a small depletion of 1.3 mm/yr in South Libya).

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

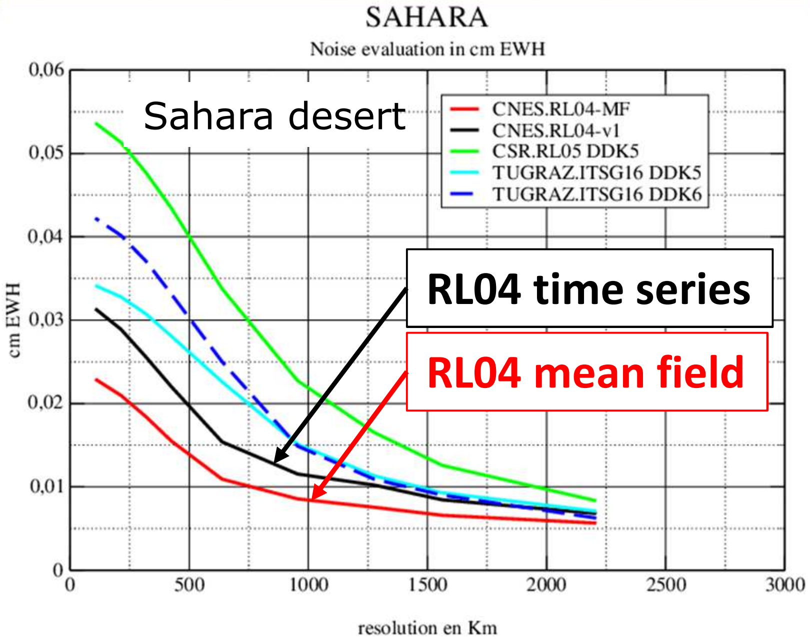
The surface is first divided in 2 deg.*2 deg. blocs (⇔ degree/order 90), then averaged in blocs of larger size up to 20 deg.*20 deg. Drift and annual/semi-annual variations are fitted a priori.

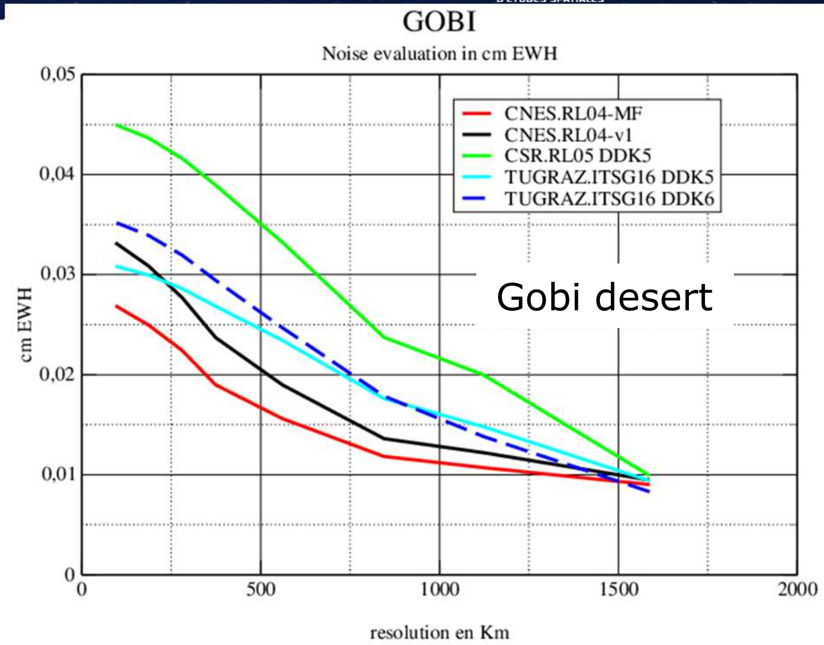
Different time-varying gravity models with various DDK filters (Kusche et al.) are compared spectrally in this way from 100 km to 2200 km.

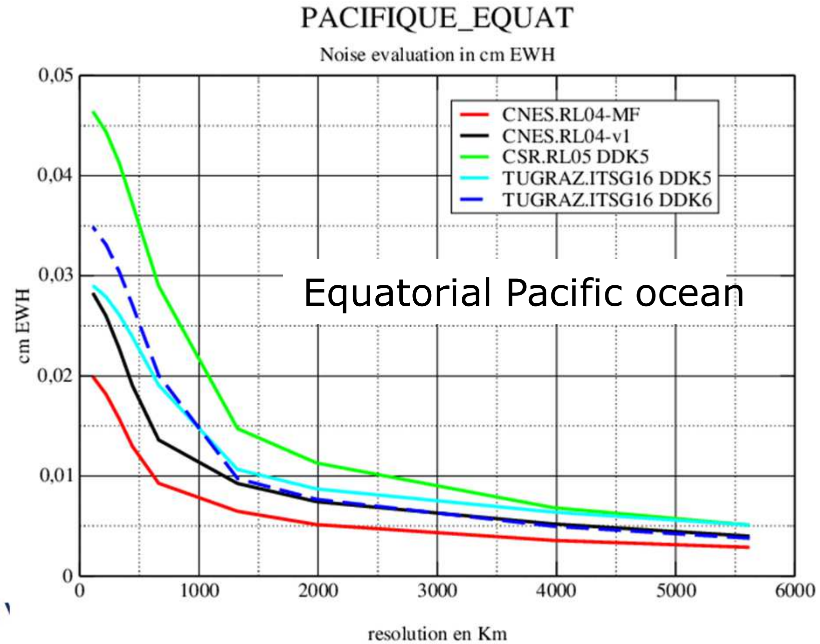


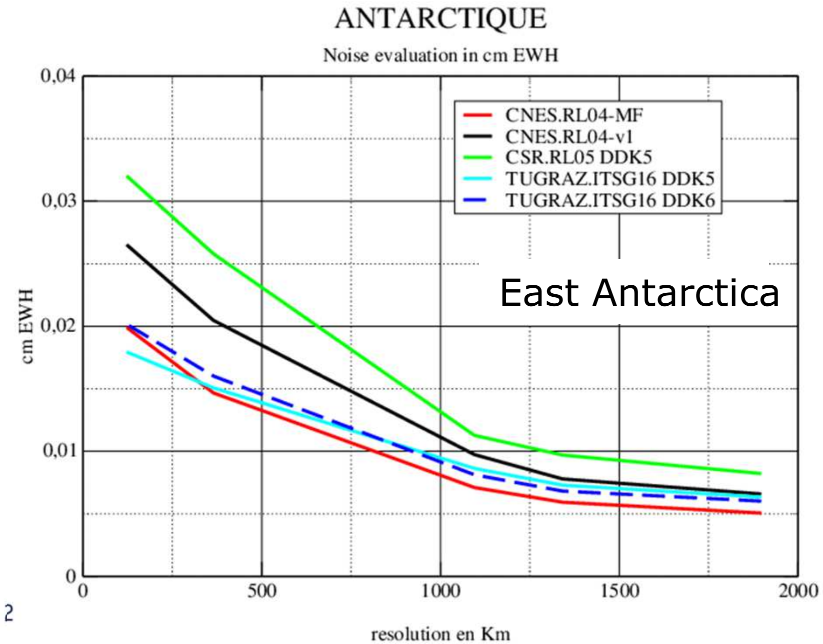


Noise assessment over “deserts”

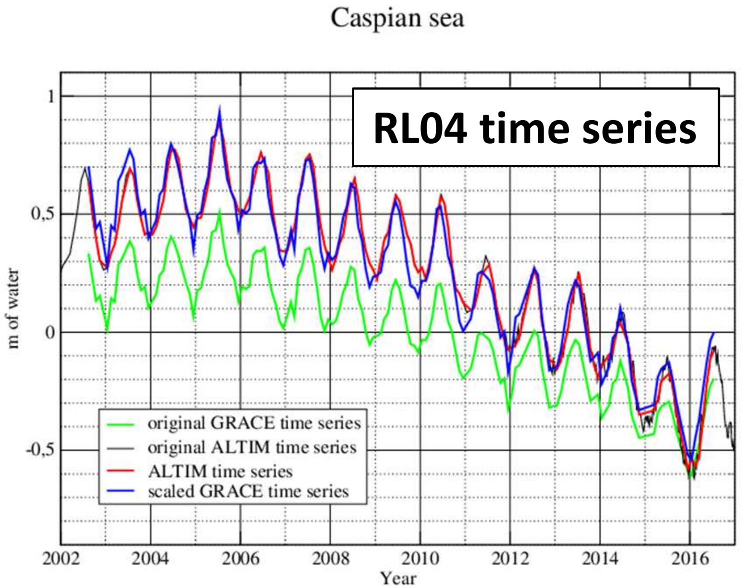


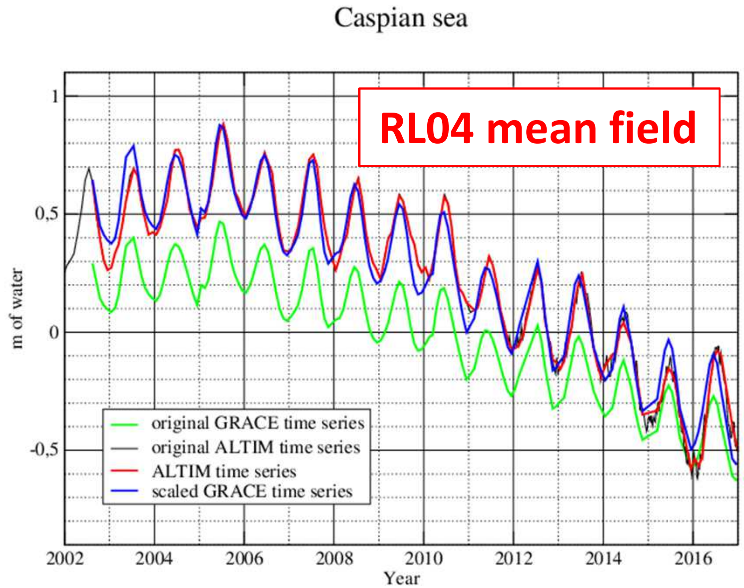


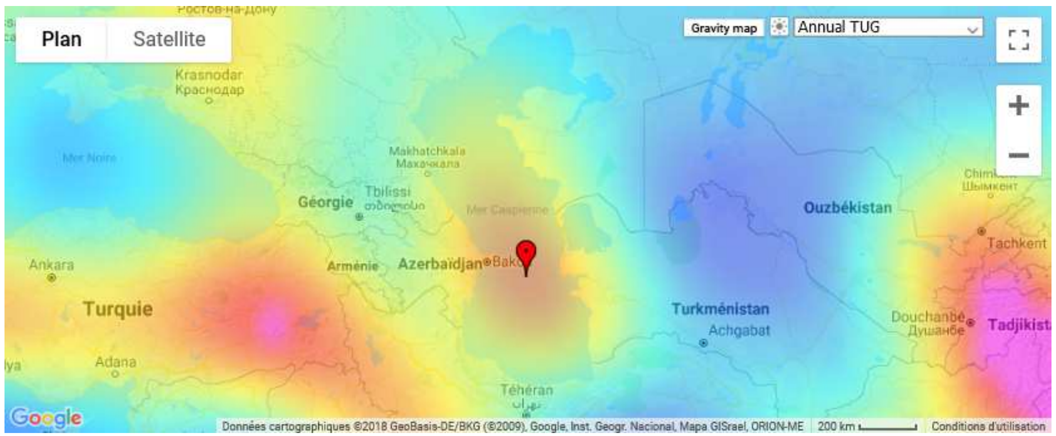


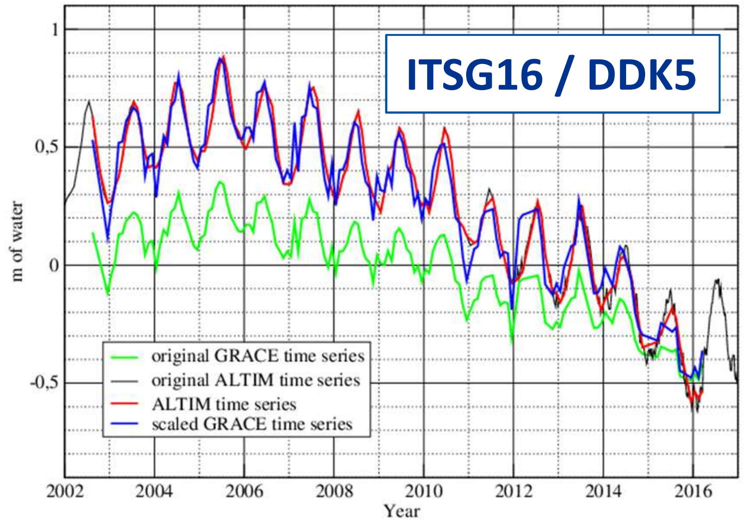


Signal assessment by comparison to altimetry
(Caspian Sea)





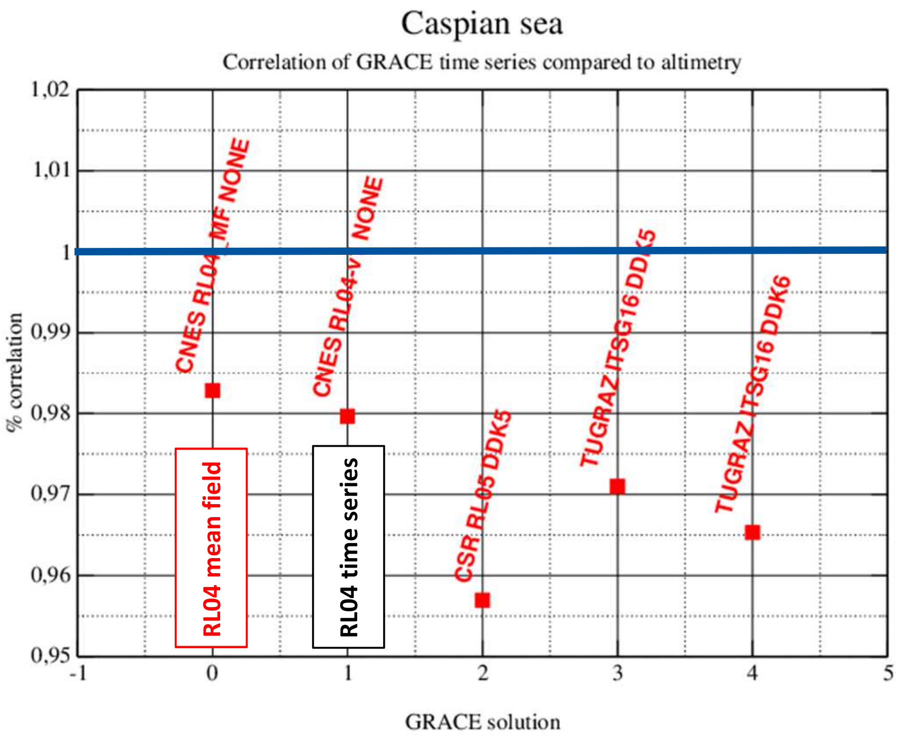




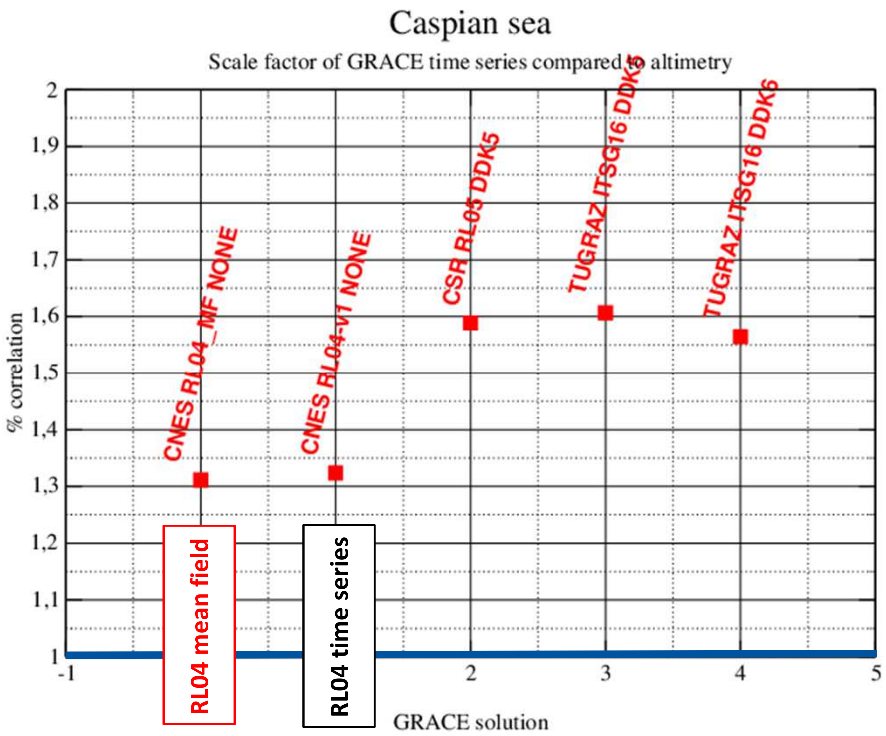
Altimeter time series from Hydroweb (https://sso.theia-land.fr)

Signal assessment by comparison to altimetry
(Caspian Sea)

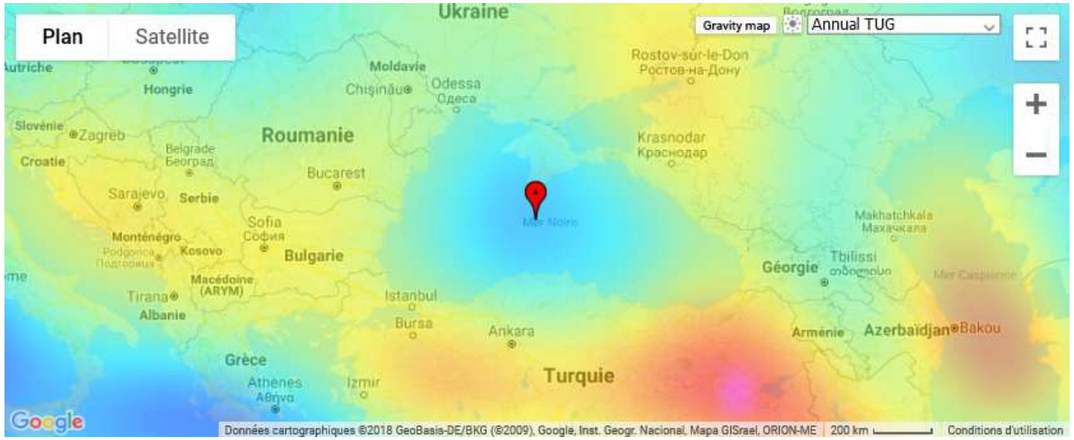
CORRELATION



SCALE FACTOR

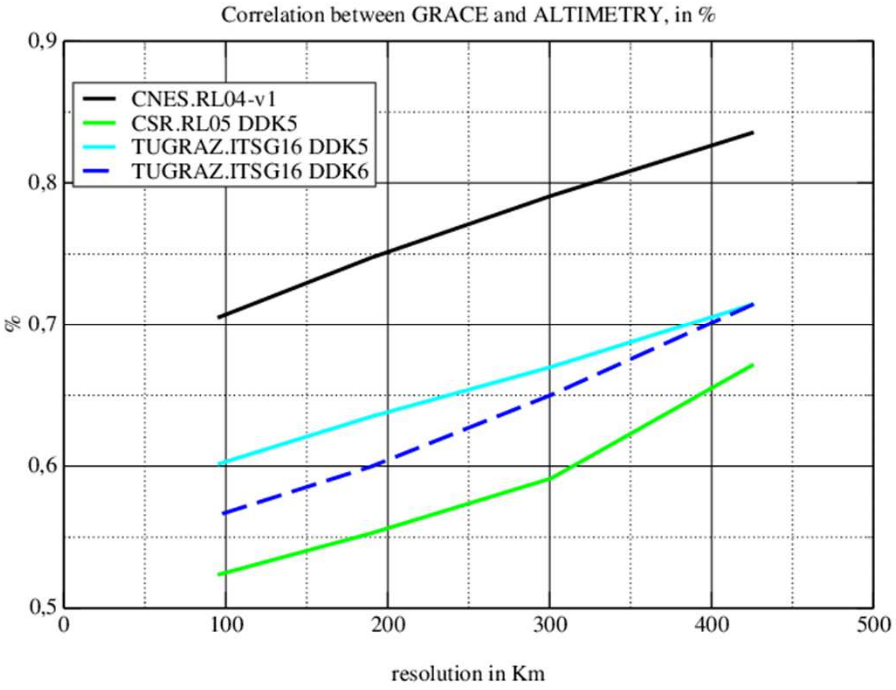


Signal assessment by comparison to altimetry
(Black Sea)

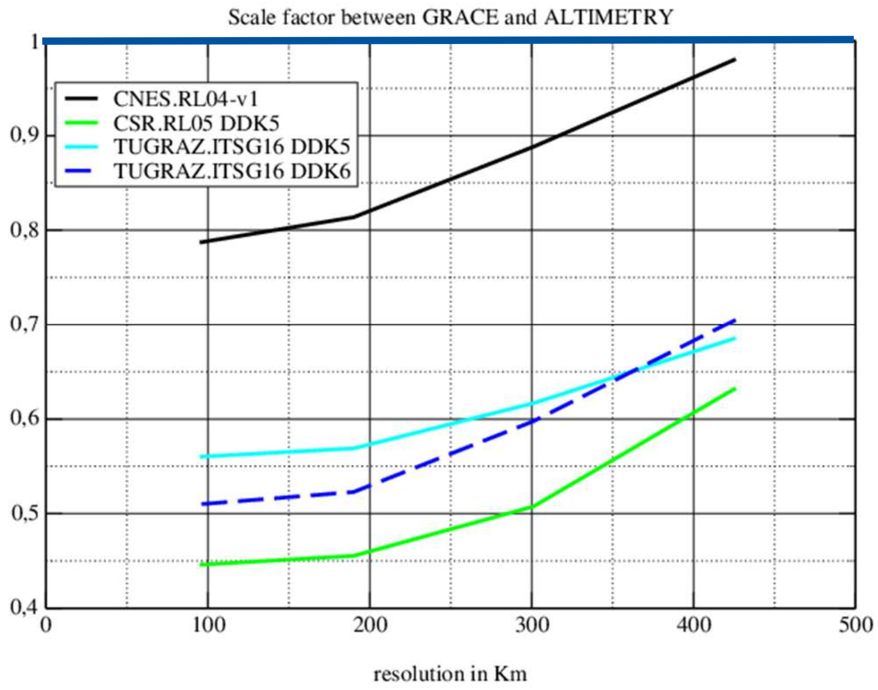


Altimeter time series from Copernicus (http://marine.copernicus.eu).

CORRELATION



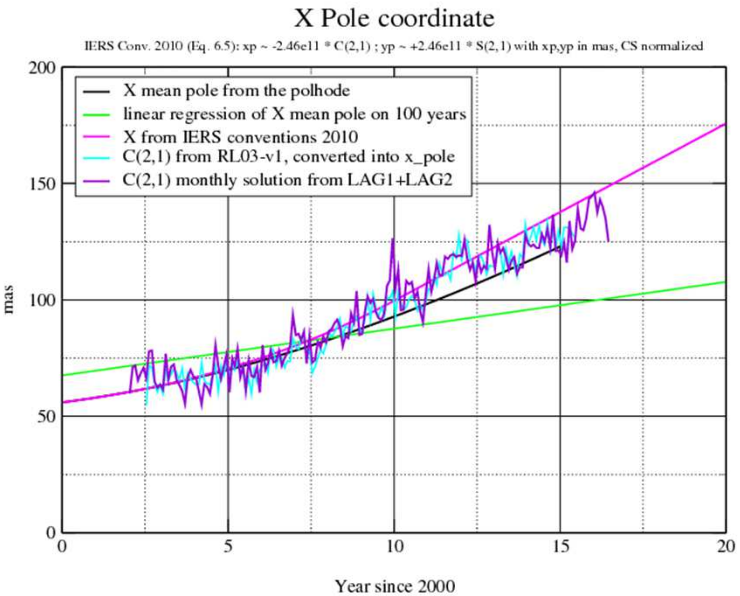
SCALE FACTOR

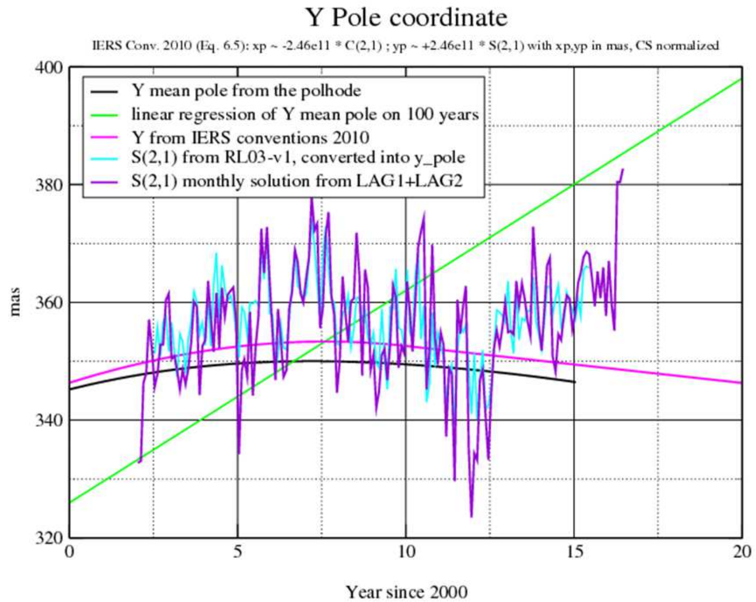


Need for consistency

<u>MEAN POLE MODEL and GRAVITY FIELD</u>

- When using the C(2,1)/S(2,1) values of a gravity field model, one must adopt the **same mean pole convention** as the one used for the computation of the model.
- CNES/GRGS is using the mean pole of the **IERS2010 conventions**. If the conventions change for a **linear mean pole**, then the C(2,1)/S(2,1) coefficients of the mean gravity model will have to be adapted to this new convention.





<u>DEALIASING MODELS and GRAVITY FIELD</u>

- The same goes for the **dealiasing models** : CNES uses 3-hour ERA-Interim & TUGO models → <u>the same models should be used for POD</u>

Conclusions and perspectives

- The new mean gravity field model based on CNES/GRGS RL04 is available for the GRACE period (2002 – 2016)
- Validation tests (noise and signal w.r.t. altimetry) show a good performance of this RL04 mean field
- Extrapolated periodic terms (before August 2002 and after May 2016) are based on global fits of monthly coefficients over 14 years of GRACE data
- It still needs to be completed before and after the GRACE period by additional data coming from SLR data (and DORIS data ?) in order to follow the long-term evolution of the lower degrees
- Possibly an accurate modeling of only the degree 2 through SLR and DORIS data is sufficient to achieve good POD performances
- When doing POD one must ensure that the models used are not only “good” but also <u>consistent</u> !!!