EIGEN-GRGS.RL03.MEAN-FIELD: new mean gravity field model for altimetric satellite orbit computation

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GRACE RL01, 02 and 03 at CNES/GRGS, general picture

- **RL01 (08/2002 – 05/2008):**
  - one solution every 10 days, incorporating 3x10-d of data (sliding window)
  - Stabilization by a degree-wise constraint

- **RL02 (08/2002 – 08/2012):**
  - one solution every 10 days, incorporating only the data of those 10 days
  - Stabilization by a degree-and-order-wise constraint

- **RL03 (01/2003 – 12/2012…):**
  - Monthly solutions, incorporating the data of the month
  - Inversion by truncated SVD (not Choleski anymore)

Mean gravity field models for orbit computation

- Associated with RL01:
  - **EIGEN-GL04S** (**GDR-C**): Contains time-variable components: drift, annual and semi-annual periodic terms.

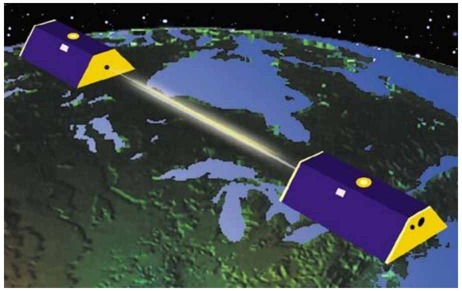
  Drift terms however were not considered in the GDR-C orbit computation since they were determined over only two years.

- Associated with RL02:
  - **EIGEN-GRGS.RL02bis.MEAN-FIELD** (**GDR-D**): Based on 8 years of GRACE+LAGEOS data.
  - **EIGEN-6S2.extended.v2**: used for **ITRF2013** computation.

- Associated with RL03:
  - **EIGEN-GRGS.RL03.MEAN-FIELD**: Based on 10 years of GRACE+LAGEOS data. Contains bias+drift every year. Proposed for **GDR-E**.

Geodetic data in EIGEN-GRGS models

GRACE (L-1B "Version2" data)

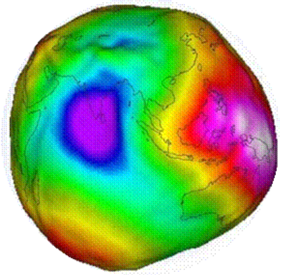


- K-Band Range-Rate data
- Accelerometer / attitude / thrusters data
- GPS data

LAGEOS-1/2 (wf = 3.)

- 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



- Time variable gravity spherical harmonic coefficients complete to degree and order 80 (truncated to 30 for LAGEOS processing), static coefficients complete to degree and order175
- 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	

New modelling for the mean field

Due to the non-linear evolution of the EWH in many areas of the world (for instance the Murray-Darling basin or the Victoria lake), the mean models consisting of bias, drift, annual and semi-annual terms are not adequate to represent the behaviour of the gravity field over long periods (10 years for GRACE, 30 years for Lageos considering C20).

Modelling annual bias and drift offers new advantages such as:

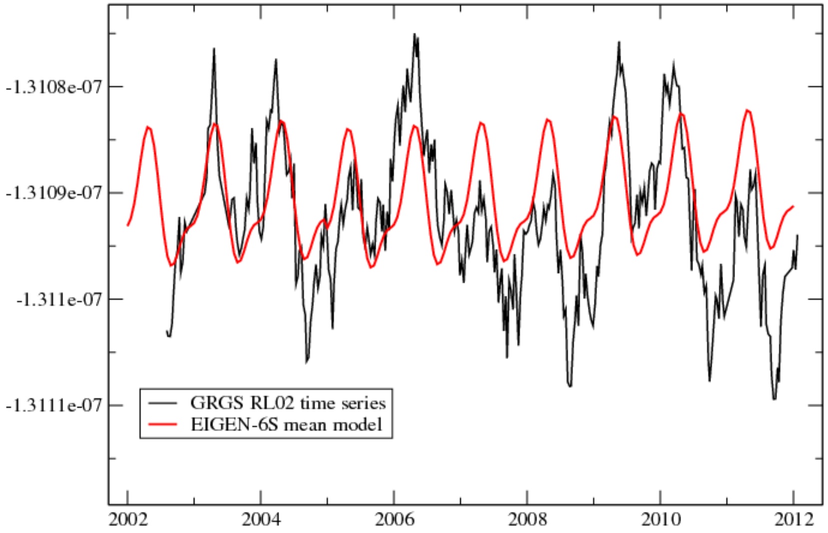
- Better agreement with 10-day or monthly series;
- Easy introduction of jumps to account for the major earthquake deformations.

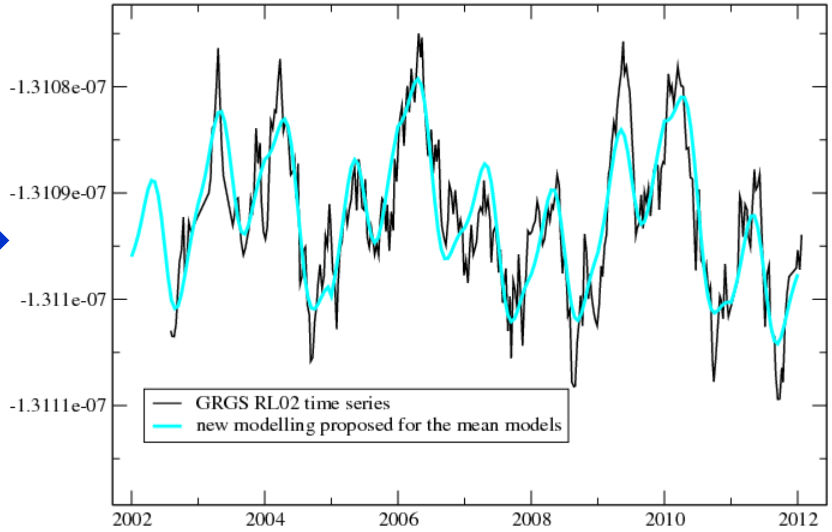
Examples on coefficients : S(10,1) and C(2,0)

Time variations modeled in EIGEN-GRGS.RL03MF

Mean models: "bias and slope" vs. "piece-wise-linear" modelling

"bias and slope"	"piece-wise-linear"
EIGEN-GRGS.RL02bis.MEAN-FIELD	**EIGEN-GRGS.RL03.MEAN-FIELD**



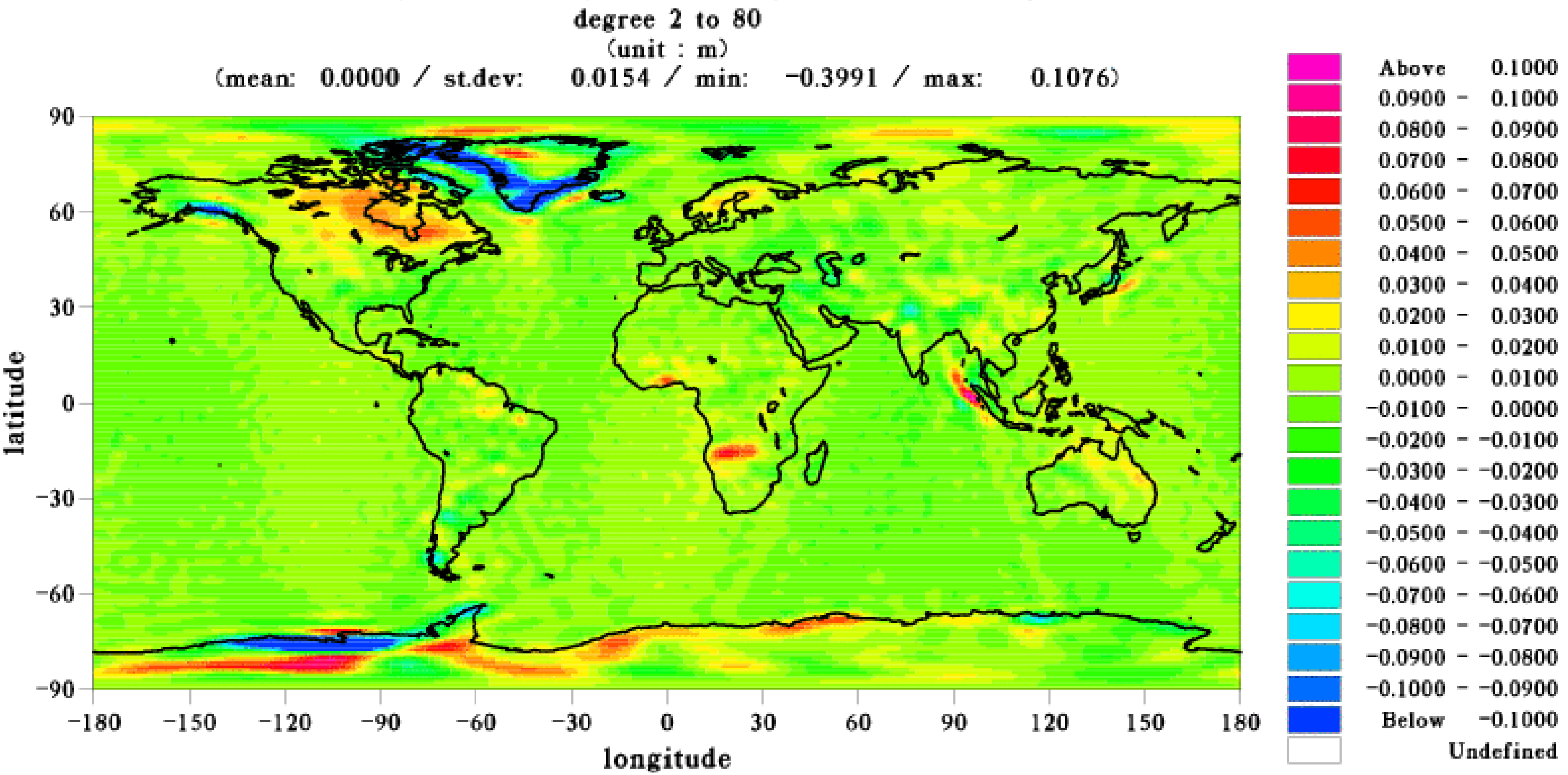


Example of format

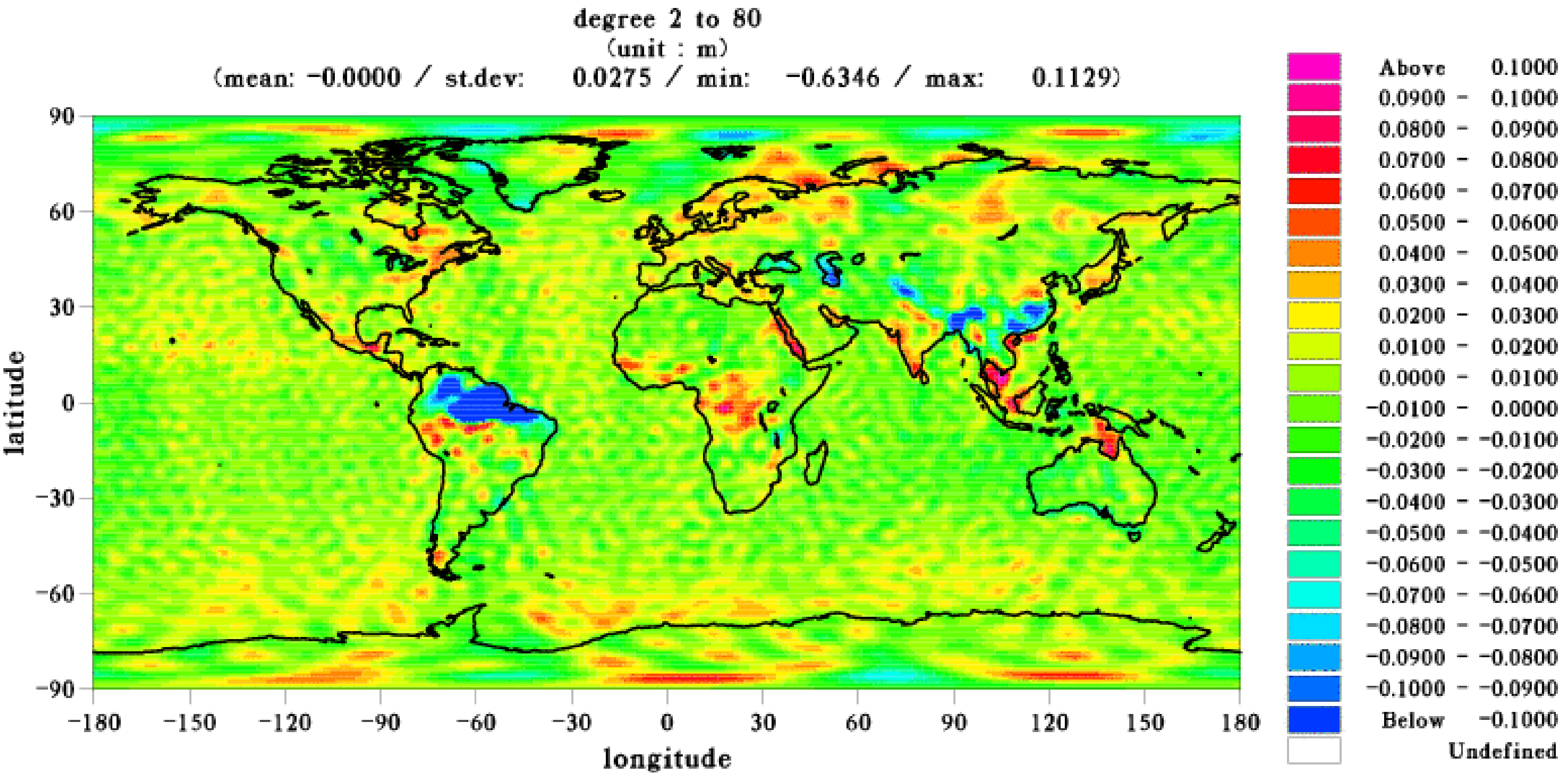
```
G_BIAS    2    0 -.484165479521E-03 0.000000000000E+00 0.1392E-10 0.0000E+00 19500101.0000 19850109.1751
GDRIFT    2    0 0.104634158251E-11 0.000000000000E+00 0.5603E-12 0.0000E+00 19500101.0000 19850109.1751
G_BIAS    2    0 -.484165356094E-03 0.000000000000E+00 0.7295E-11 0.0000E+00 19900101.0000 19910101.0000
GDRIFT    2    0 0.162048658823E-10 0.000000000000E+00 0.1449E-10 0.0000E+00 19900101.0000 19910101.0000
GCOS1A    2    0 0.386222759789E-10 0.000000000000E+00 0.3748E-11 0.0000E+00 19500101.0000 20500101.0000
GSIN1A    2    0 0.542428904167E-10 0.000000000000E+00 0.3404E-11 0.0000E+00 19500101.0000 20500101.0000
GCOS2A    2    0 0.379017840266E-10 0.000000000000E+00 0.3617E-11 0.0000E+00 19500101.0000 20500101.0000
GSIN2A    2    0 -.163073508081E-10 0.000000000000E+00 0.3494E-11 0.0000E+00 19500101.0000 20500101.0000
```

- “Bias and Slope” approach

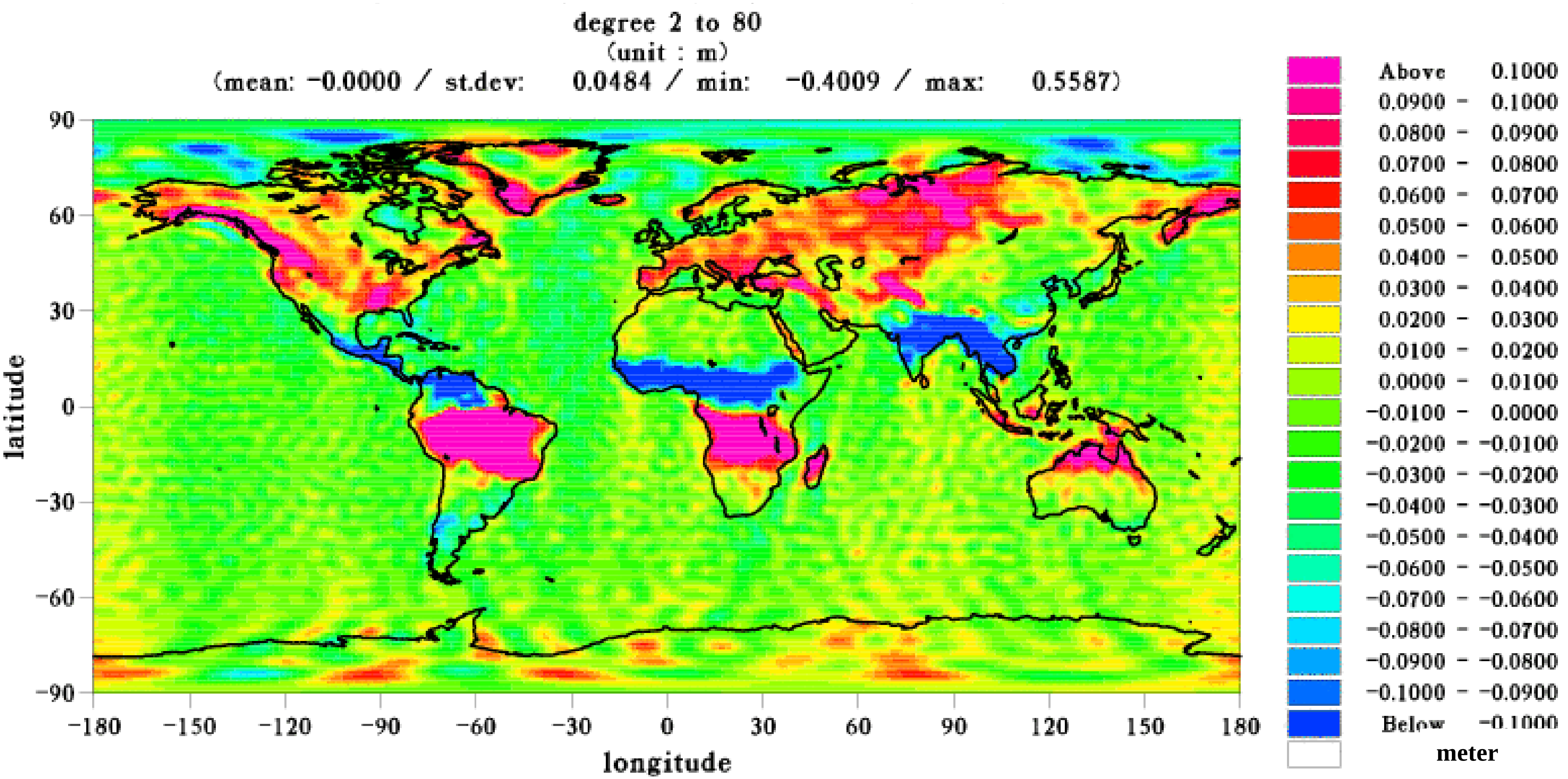
Slope (= ***average*** DRIFT parameter)



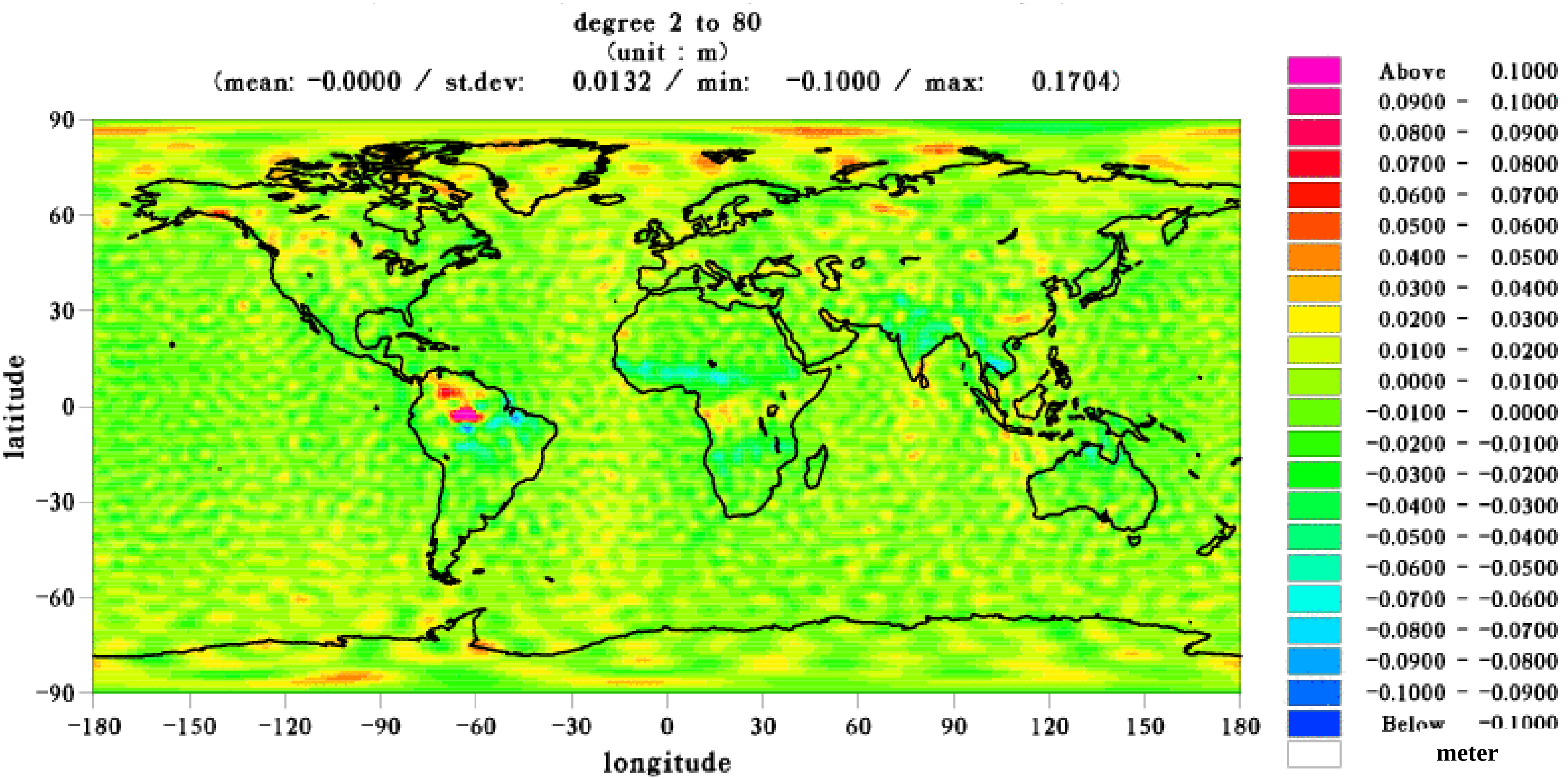
Cosine of ANNUAL signal (max on January 1st)



Sine of ANNUAL signal (max on April 1st)

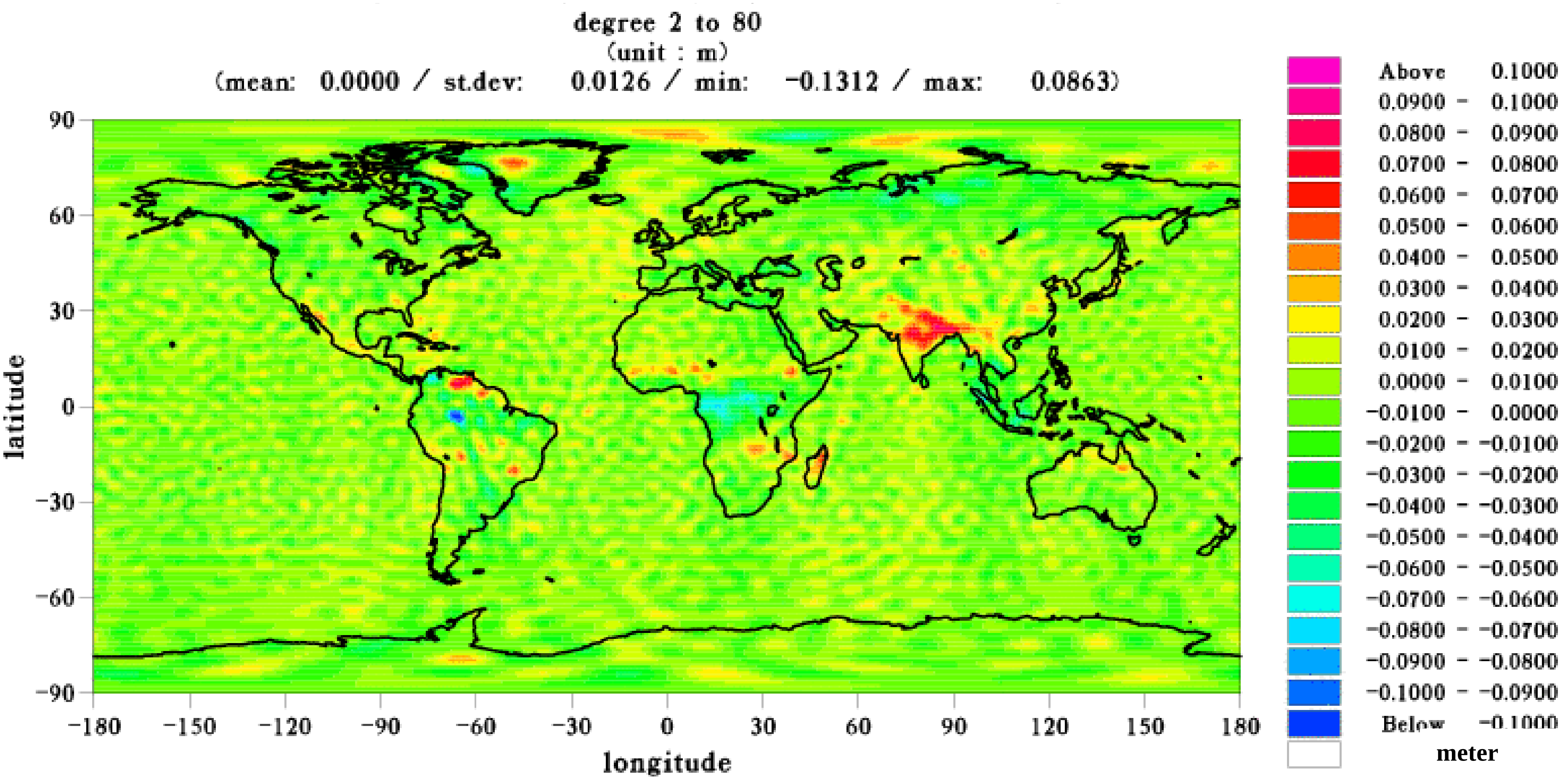


Cosine of SEMI-ANNUAL signal (max on January 1st and July 1st)

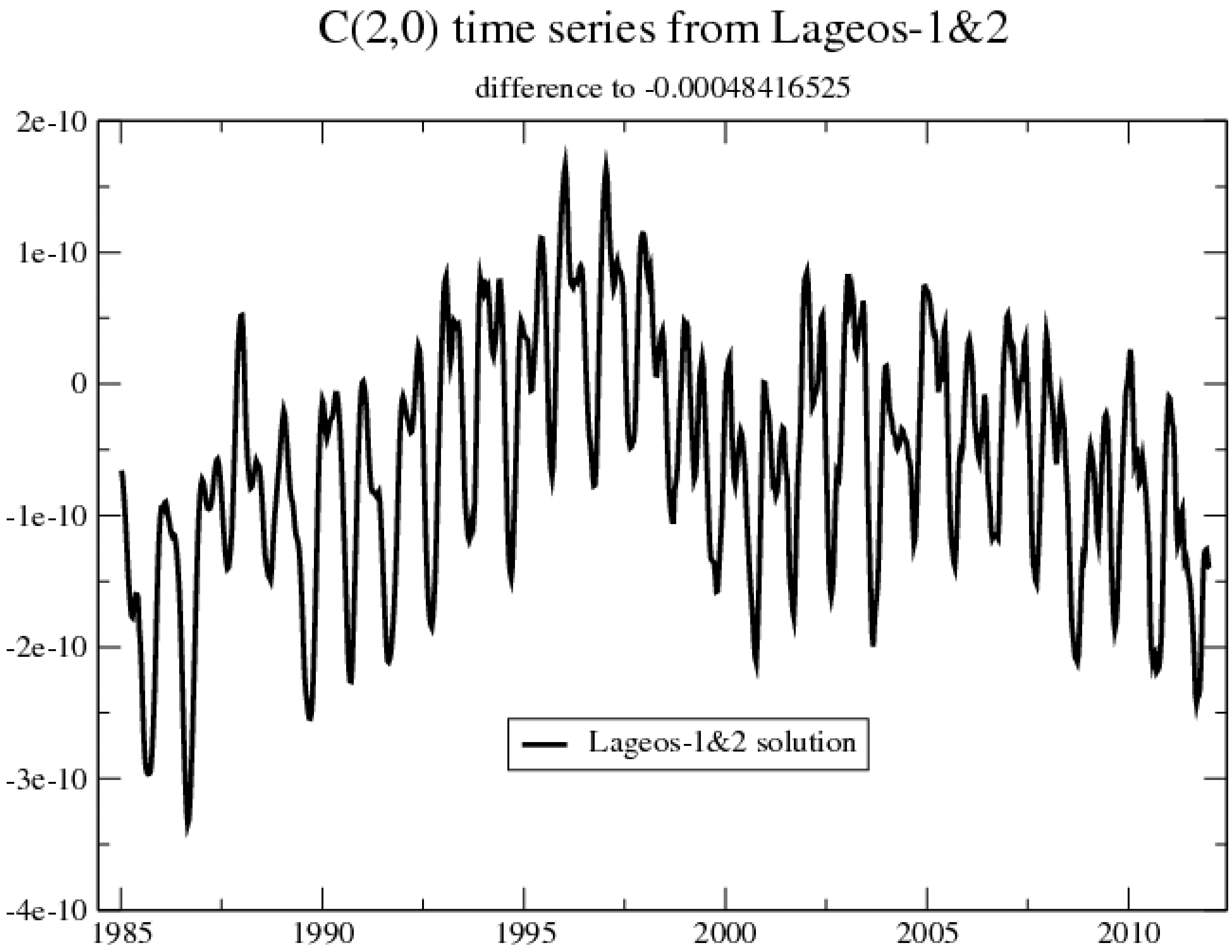


Time variations modeled in EIGEN-GRGS.RL03MF

Sine of SEMI-ANNUAL signal (max on February 15st and August 15st)

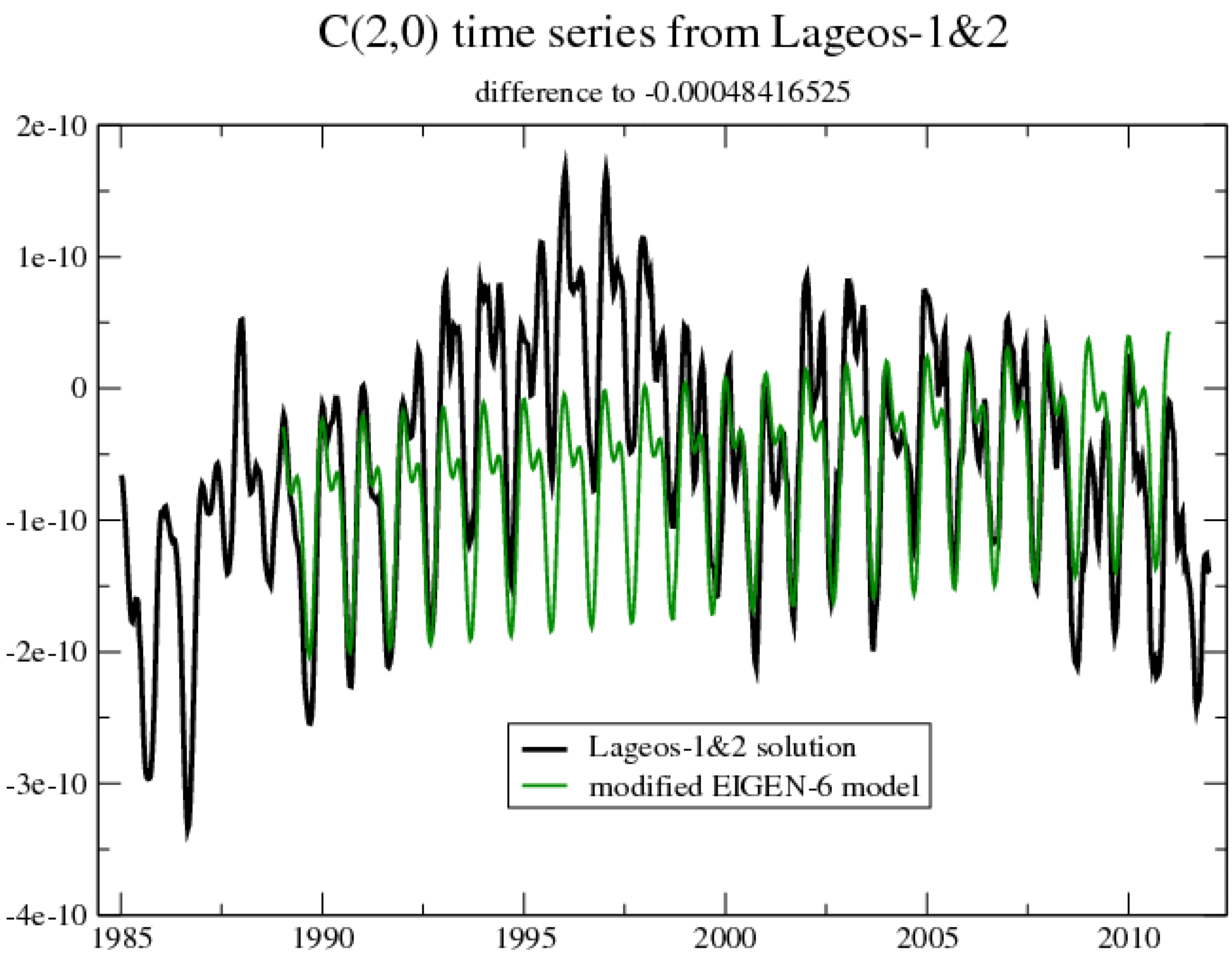


Non linear behaviour of C20



10-day models

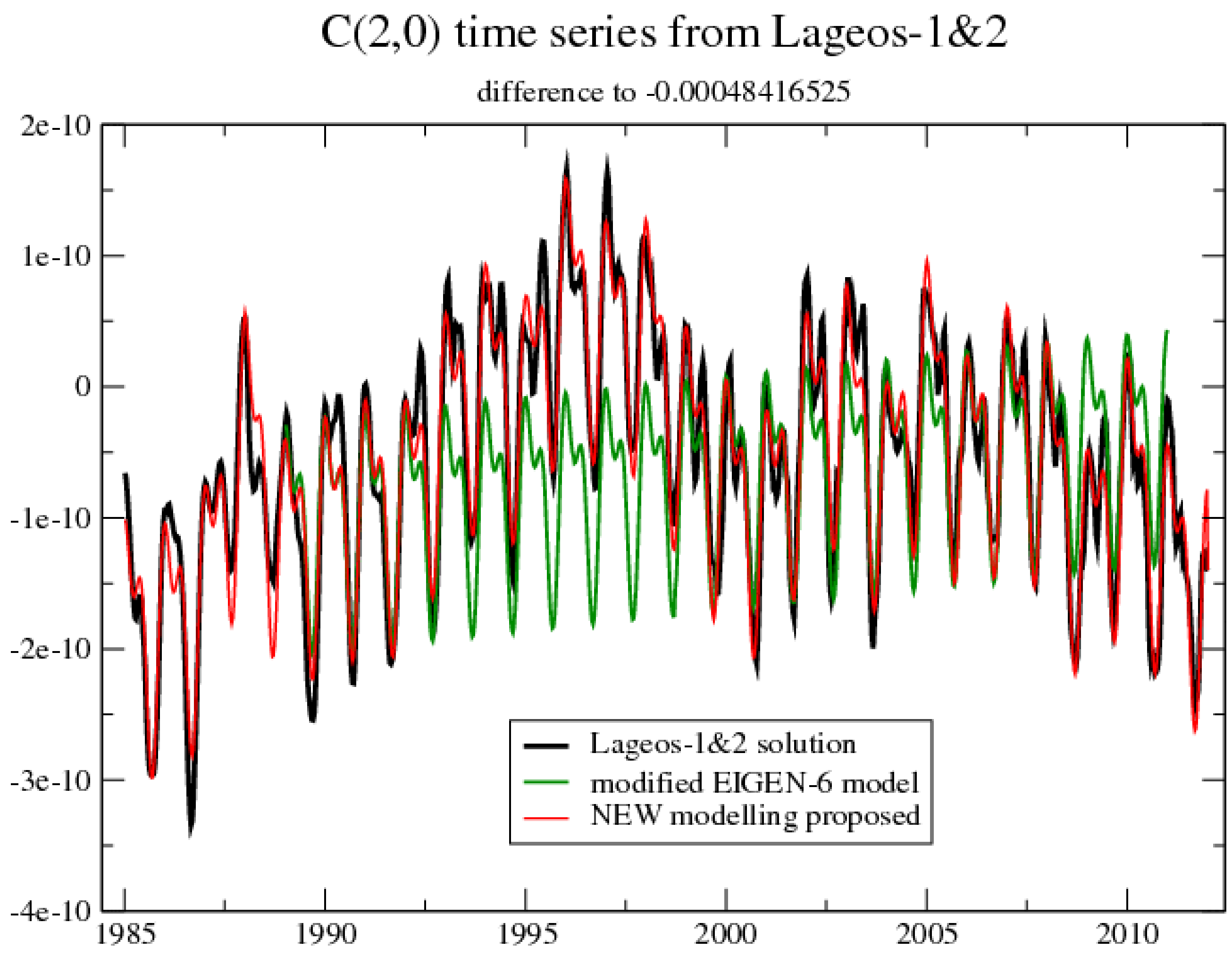
Non linear behaviour of C20



trend in modified EIGEN-6

10-day models

Non linear behaviour of C20



trend in modified EIGEN-6

10-day models

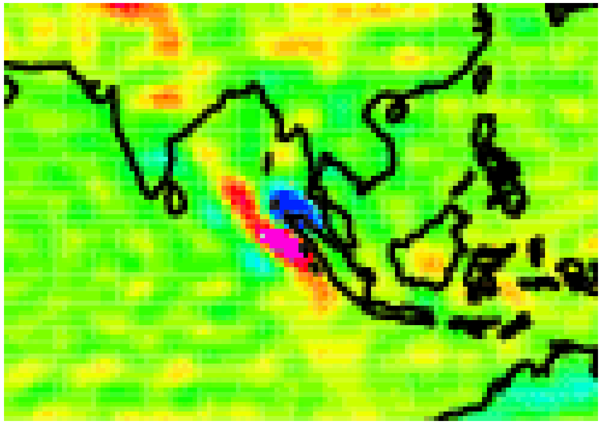
new modelling

Time series and mean fields available at: grgs.obs-mip.fr

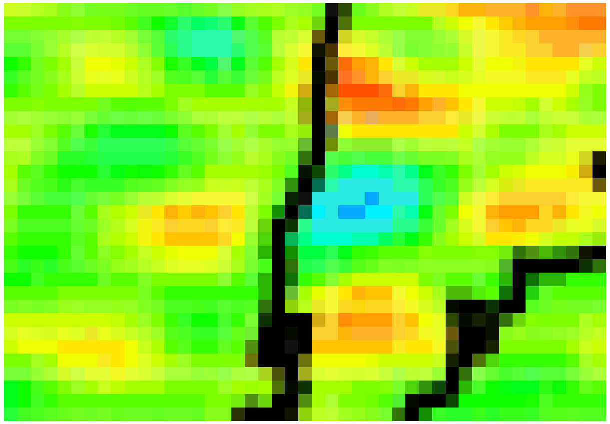
http://grgs.obs-mip.fr/grace/variable-models-grace-lageos/grace-solutions-release-03

Major earthquakes can cause some discontinuities in the Stokes' coefficients which are taken into account in the new modeling. Annual biases are then interrupted and new defined at the time of the event (instead of at the beginning of the year).

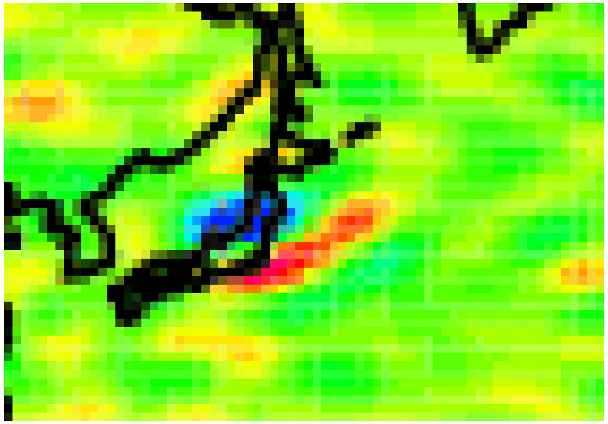
SUMATRA (Dec. 2004)



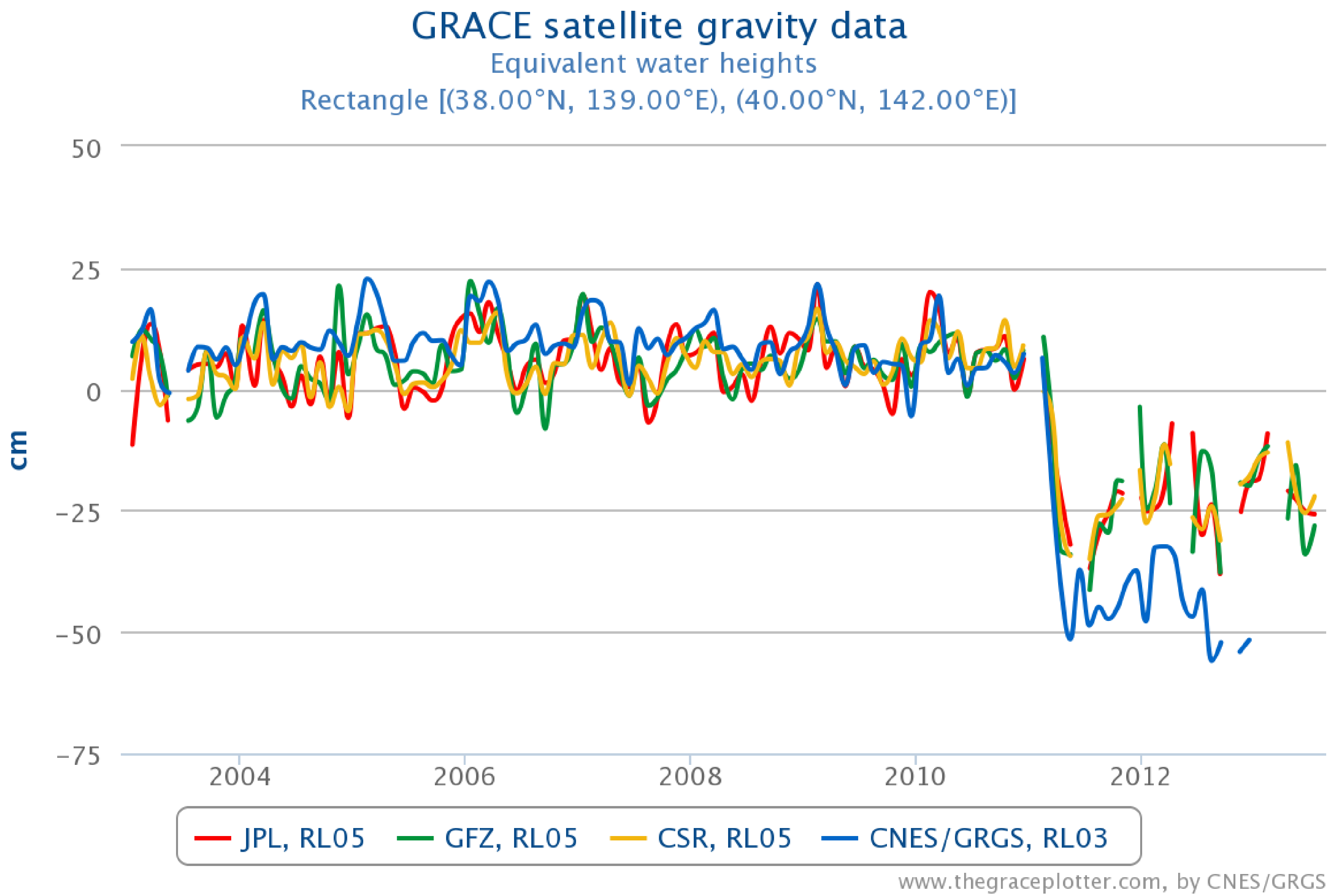
CONCEPCION (feb. 2010)



TOHUKU (March 2011)

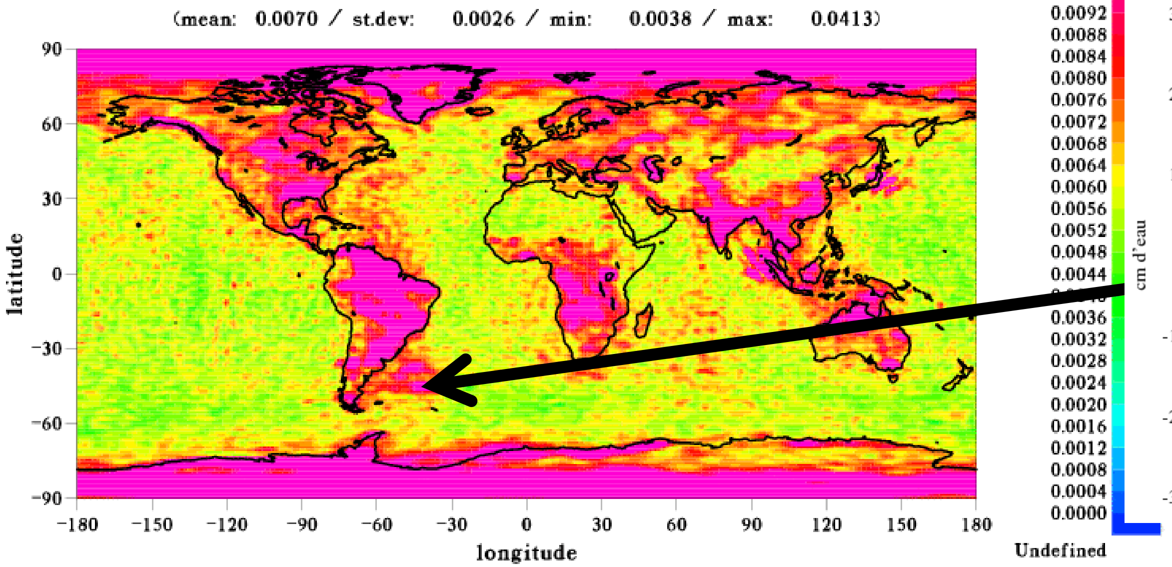


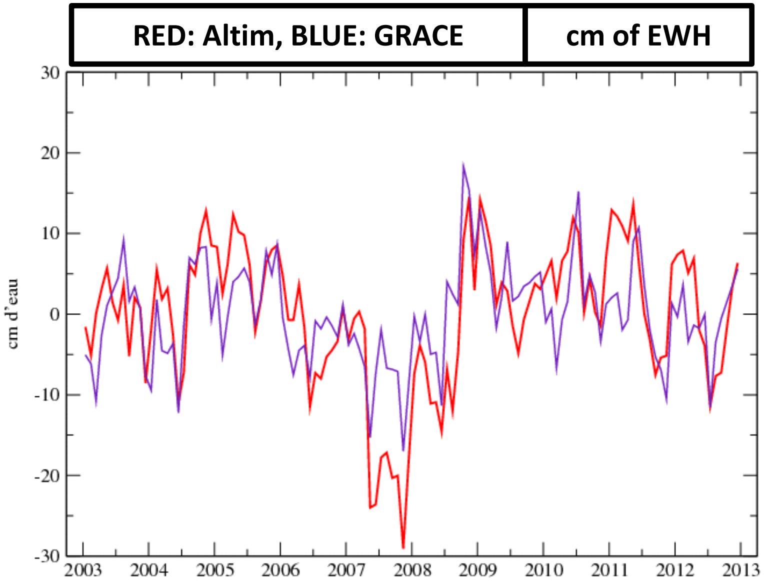
Tohuku earthquake gravity signal



Validation in the Zapiola-Gyre test zone

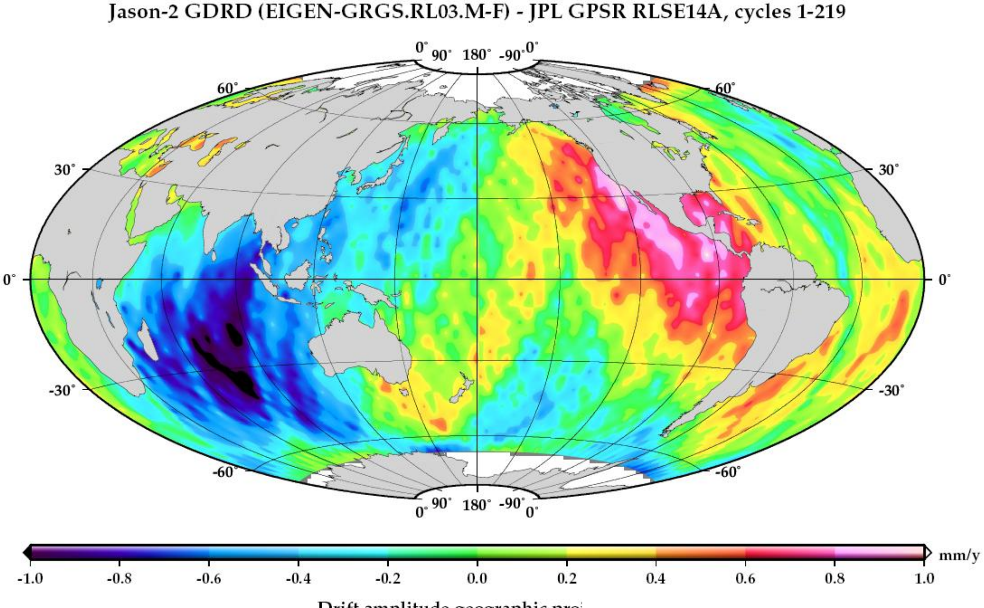
Residual variance of the RL03 solutions, once the drift and the annual and semi-annual periodic terms have been removed





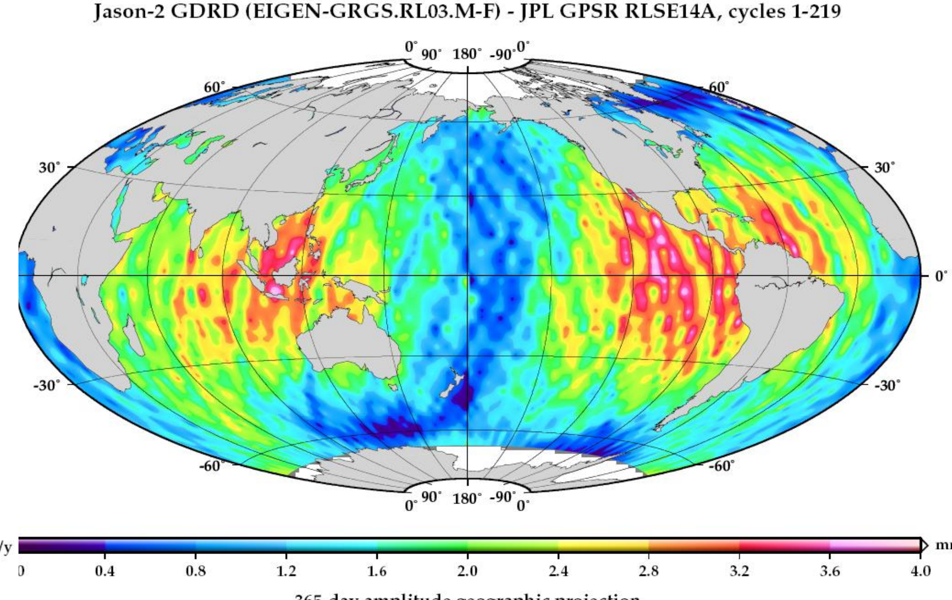
Comparison to altimetry	Percentage of correlation
JPL RL05	**58.6 %**
GFZ RL05	**66.4 %**
CSR RL05	**69.5 %**
CNES RL03	**71.0 %**

Jason2 GDR-D (model **EIGEN-GRGS.RL03.MEAN-FIELD**)
vs. JPL reduced dynamic orbit
(cycles 1-219)



Scale: -1/+1 mm/y

DRIFT term

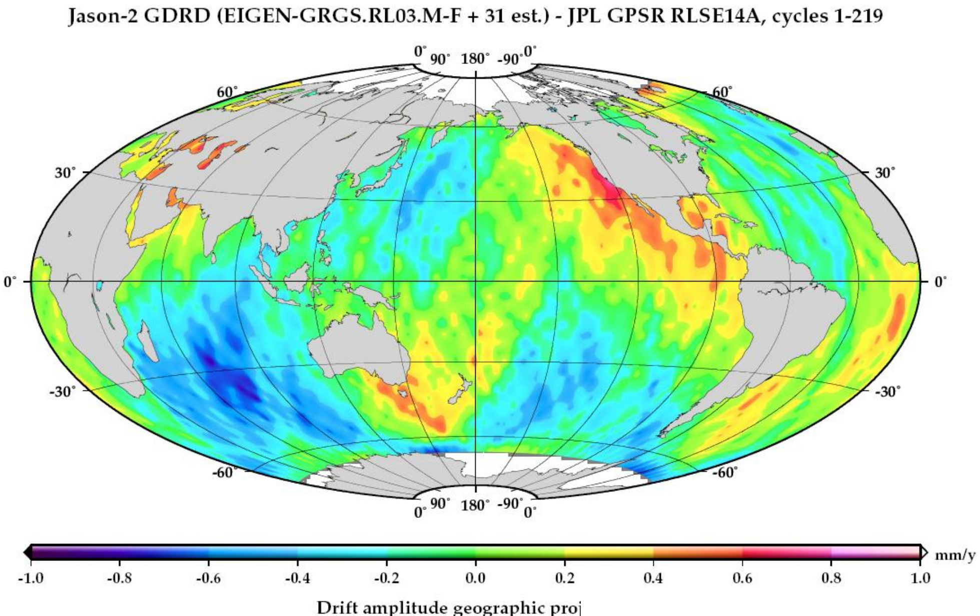


Scale: 0-4 mm

ANNUAL term

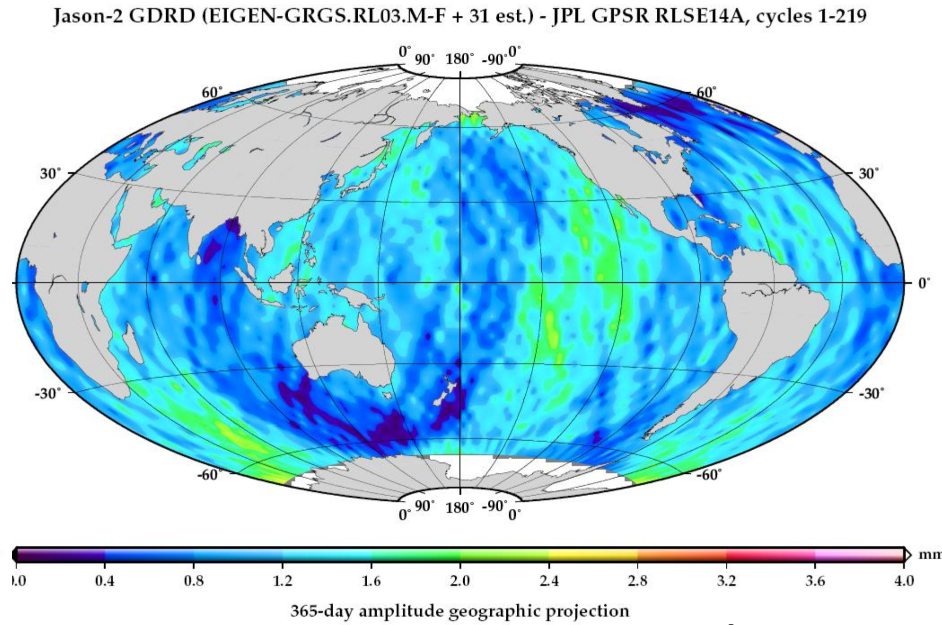
Images courtesy of Alexandre Couhert, CNES

Jason2 GDR-D (model **EIGEN-GRGS.RL03.MEAN-FIELD**)
+ **C/S(3,1) coefficients adjusted** vs. JPL reduced dynamic orbit
(cycles 1-219)



Scale: -1/+1 mm/y

DRIFT term



Scale: 0-4 mm

ANNUAL term

Images courtesy of Alexandre Couhert, CNES

Summary

- **EIGEN-GRGS.RL03.MEAN-FIELD** is now available for altimetric satellite orbit computation (**Jason GDR-E**).

- It is based on 10 years of GRACE data and 30 years of Lageos data.

- It includes average annual and semi-annual periodic variations, yearly biases and drifts, as well as steps representing the earthquakes of Sumatra, Concepcion and Tohoku.

- In terms of geographically correlated orbit error and East-West centering, it represents an improvement over **EIGEN-GRGS.RL02bis.MEAN-FIELD** (**Jason GDR-D**), but only the additional adjustment of coefficients C/S(3,1) can allow to reach a quality similar to JPL's reduced dynamic orbit.

Prospective

EIGEN-GRGS.RL03.v1 series will be upgraded in order to mitigate some artifacts from which a RL03.v2 mean field could be derived

- Adding more low degree information from SLR satellites such as Starlette and Stella

- Iterating the adjustment process to improve low degree coefficients (Cholesky + SVD)

- Taking advantage in the future of new de-aliasing products (tides…)

- Providing again series of 10-day gravity field models