Time Variable Gravity (TVG) in GRGS REPRO2 solution (GR2)

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TV Gravity fields and IGS

Impact on IGS-like products ? That was already a question 2 years ago in Olstyn.
Tests made on two weeks of data presented by J. Ray: few mm on orbits / few usec for LOD and mm impact on global translations and stations coordinates.

Today's models used, according to *IGS_AC_ops_status.xls* (compiled by J. Griffiths) :

EGM2008 : *CODE/EMR/JPL/MIT/NGS/SIO/ULR* : **bias and drift (DOT) for low degrees**

EIGEN-GL04S1 : *GFZ*

EIGEN-GL05C : *ESA*

EIGEN-6S2 : *GR2/GRG*

Seasonal terms for low degrees

....an inhomogeneous situation.

Summary of this talk

- Eigen-6S2 : description & properties
- Validation (outside of GNSS world)
- Tests done during REPRO2 (EGM2008 vs Eigen-6S2)
- Conclusions

EIGEN-6S2 - Model description

- Complete to degree and order 260:
  - degree 2 to 50 (limited to degree 12 for GNSS)
    - 2003-2013: variable field from a regression on the GRGS-RL02 10-day time series
    - 1985-2003: degree 2 solution from a GRGS SLR-only (Lageos+Lageos-2) solution
  - degree 51 to 260: static field from the most recent GRACE+GOCE solution (GFZ)
- Computed with specific 'dealliasing products'...

  - Atmospheric + Ocean variable potential computed from 3h ECMWF ERA-interim model and 3h TUGO barotropic model (F. Lyard, LEGOS/CNRS) for the oceanic response to the ERA-interim pressure and wind forcing (provided by P. Gegout)

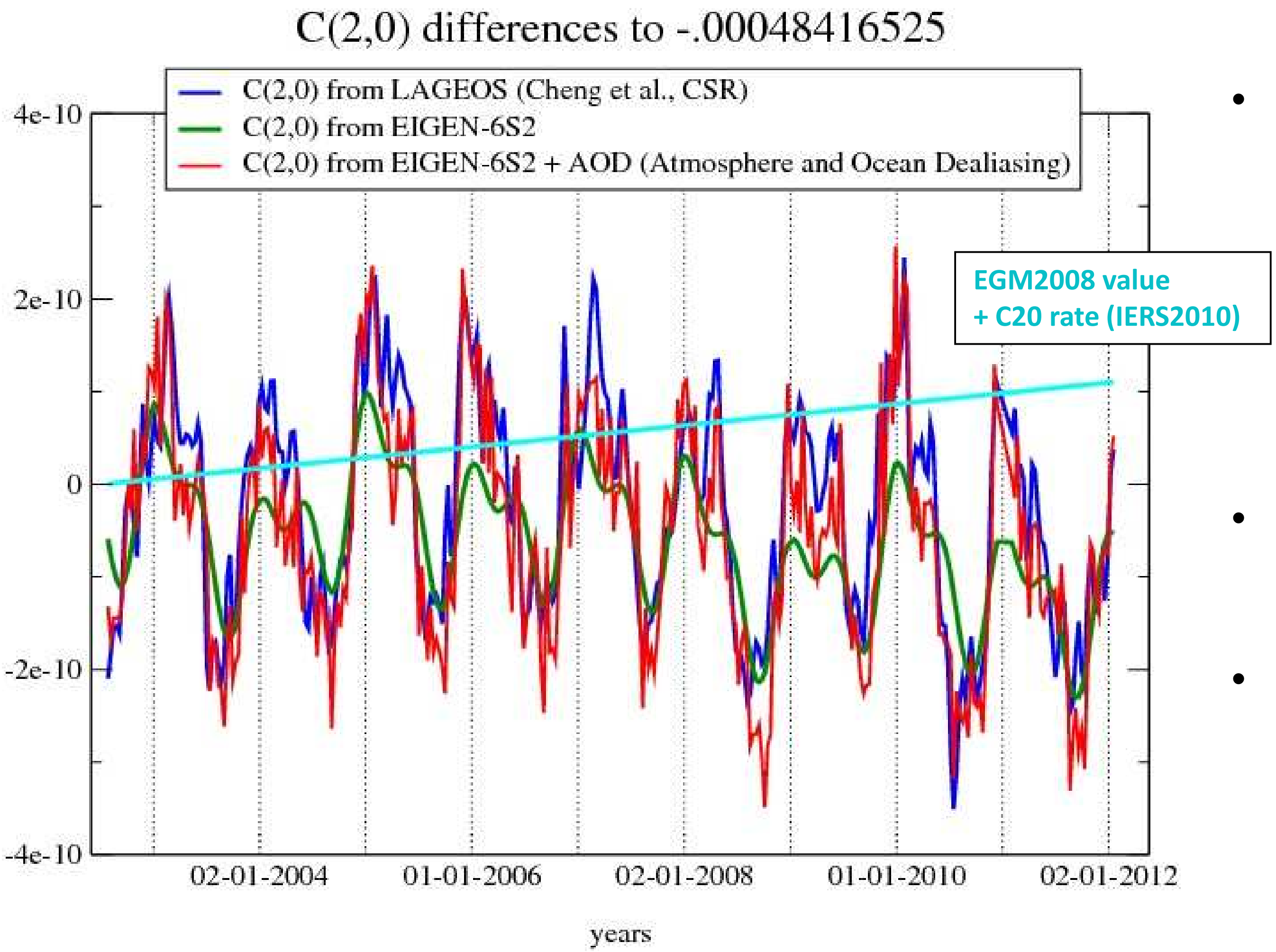
  - Consistent with FES2012 ocean tide model (F. Lyard)

More details :

For each Stokes coefficient $C_{l,m}/S_{l,m}$:
-Two annual and two semi-annual coefficients + One bias and one drift for each year (piece wise linear function, except in the case of earthquakes)
Outside of the measurements period (1985-2013 for degree 2, 2003-2013 for degrees 3 to 50), the gravity field is extrapolated with a zero-slope assumption.
Full description : http://grgs.obs-mip.fr/grace/variable-models-grace-lageos/mean_fields
On this model, cf. : *Rudenko S., Dettmering D., Esselborn S., Schoene T., Foerste C., Lemoine J-M., Ablain M., Alexandre D., Neumayer K.-H.; **Influence of time variable geopotential models on precise orbits of altimetry satellites, global and regional mean sea level trends;** Advances in Space Research, doi: 10.1016/j.asr.2014.03.010, 2014*

Main impact of TVG for GNSS-type orbits

- For a GNSS-type orbit the main impact of TVG comes from degrees 1 & 2
- Degree 2, order 0: comparison between (EGM2008 + constant rate) and EIGEN-6S2



- *Main difference EGM2008/EIGEN-6S2 : seasonal signal + biais & drift per year*

  The TVG signal of EIGEN-6S2 represents the variations of the hydrosphere and cryosphere
- *The amplitude of the annual term of EIGEN-6S2 is ~ 7 e-11, the semi-annual term ~ 4 e-11*
- *The AOD products have to be added to EIGEN's TVG to reach the full amplitude of the signal*

Impact of TVG for LEO satellites

(from Rudenko et al. 2014)

- Radial orbit error:

VER2 = static gravity field

VER6 = EIGEN-6S2

Table 10
Mean scatter of radial errors (cm). The best results are marked with bold numbers.

Satellite	VER2	VER3	VER4	VER5	VER6	VER7
ERS-1	1.68	1.75	1.69	1.63	**1.57**	1.64
ERS-2	2.11	2.12	2.11	2.03	**2.02**	2.03
Envisat	1.55	1.52	1.65	**1.40**	1.41	1.41

- Impact on sea level trends:

Not neglected today

for altimetric products!

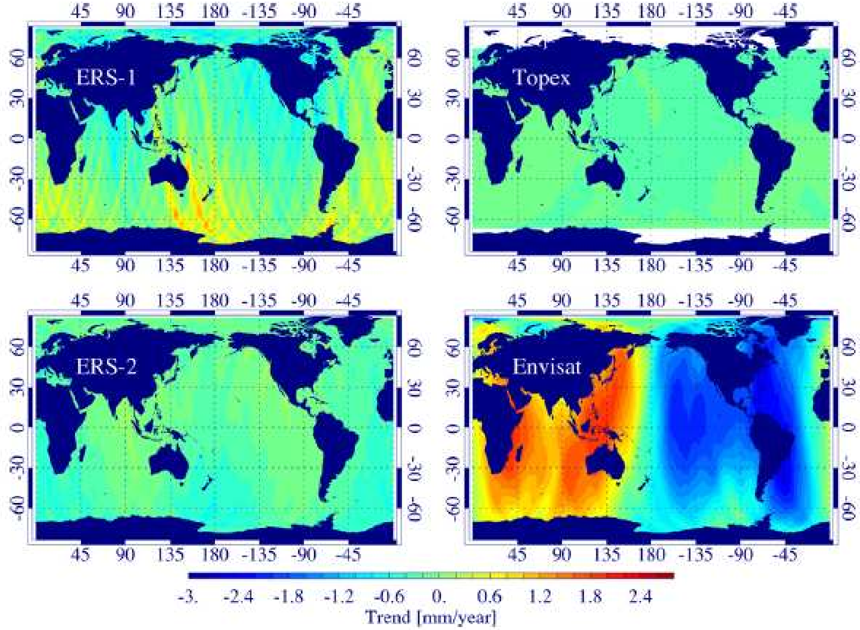


Fig. 22. Map of the drift [mm/year] between the radial components of the VER6 and VER2 orbits for ERS-1 (October 1992–June 1996), ERS-2 (May 1995–June 2003), TOPEX (March 1993–May 2004), and Envisat (October 2002–December 2010).

Expected impact of change in C20 term on ascending node rotation and LOD

C20 directly related to the rate of the ascending node of the orbits , then, a difference on C20 will impact Earth Rotation Rate determined from GNSS ($d\Omega/dt$ directly proportional to LOD)

$$\mathbf{d\,\Omega\,/dt = -1.5\;n\;J2\;(a_{earth}/a)^{2}\;cos(i)}$$

(with i= 55 deg. a= 26560 km for GPS)

above formula neglect lumped coefficients contribution (higher degrees C40 C60 …etc)

	C20 (constant)	C20 (SA) *	C20 (SSA)*
amp. of C20	-0.48 e-3	+/- 7 10^{-11}	+/-4 10^{-11}
$d\,\Omega\,/dt$ (deg/day)	-0.04	+/- 6 10^{-09}	3.3 10^{-09}
Corresponding LOD amp.	9.6 sec	1.3 usec	0.8 usec

**amplitudes computed without dealiasing contribution*

Then, we can expect LOD differences of the order of **1.3 usec** (at annual period) between a static C20 and a modern TVG.

Non negligeable given the accuracy of todays results.

Test on 4 years of data processing :EIGEN vs EGM2008

---> 4.5 years of data processed with the same standarts and the same data except the gravity field used.

TVG: Reference set use EIGEN-6S2 + dealiasing products + FES2012 (the solution processed for REPRO2 and delivered under the name 'gr2')

Static : Alternative set use EGM2008 instead (+drifts) + FES2004

---> The continuous series obtained allow comparisons and spectral analysis of the differences.

I. Residuals

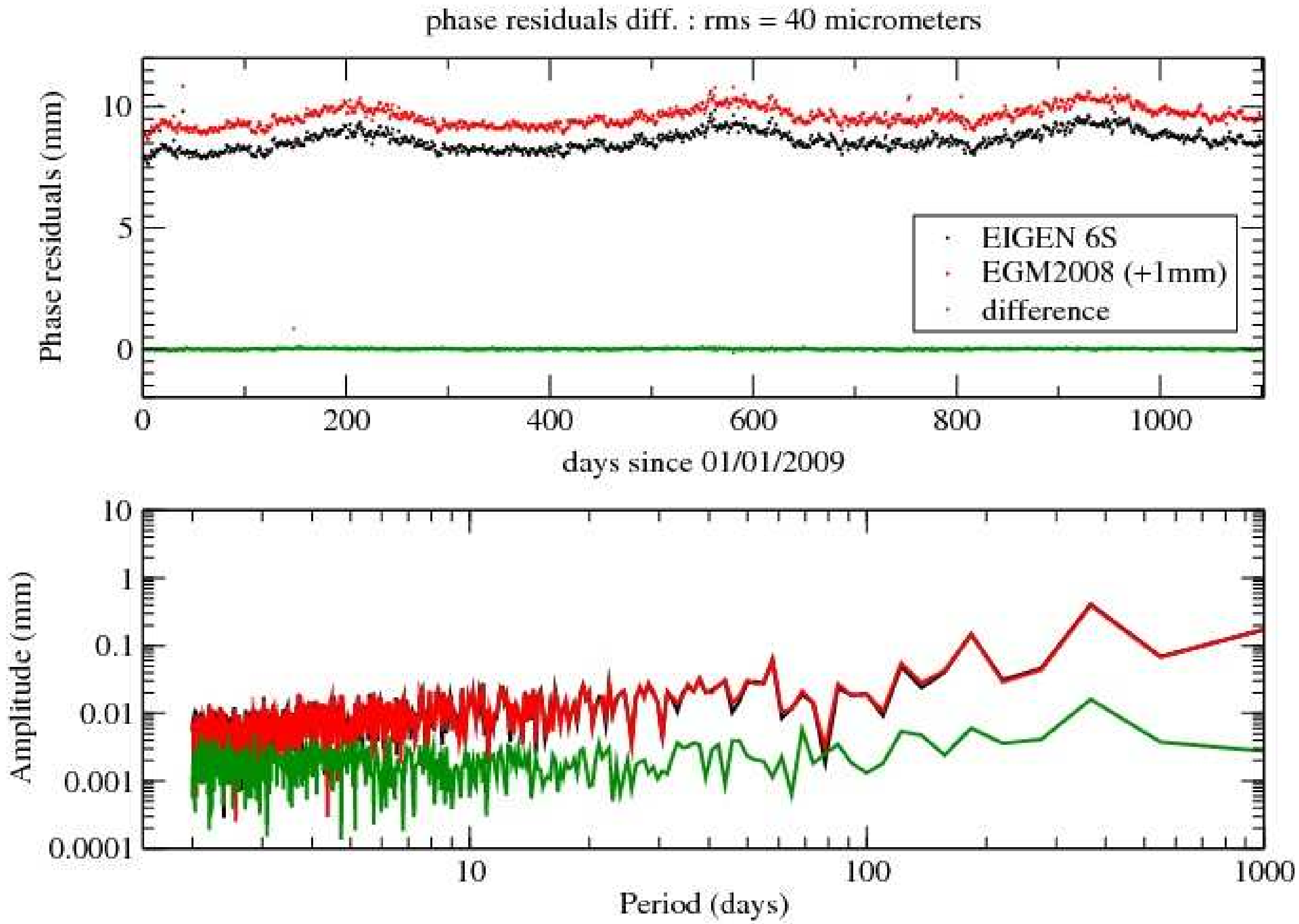
II. Orbits differences

III. Global network translations

IV. EOP differences

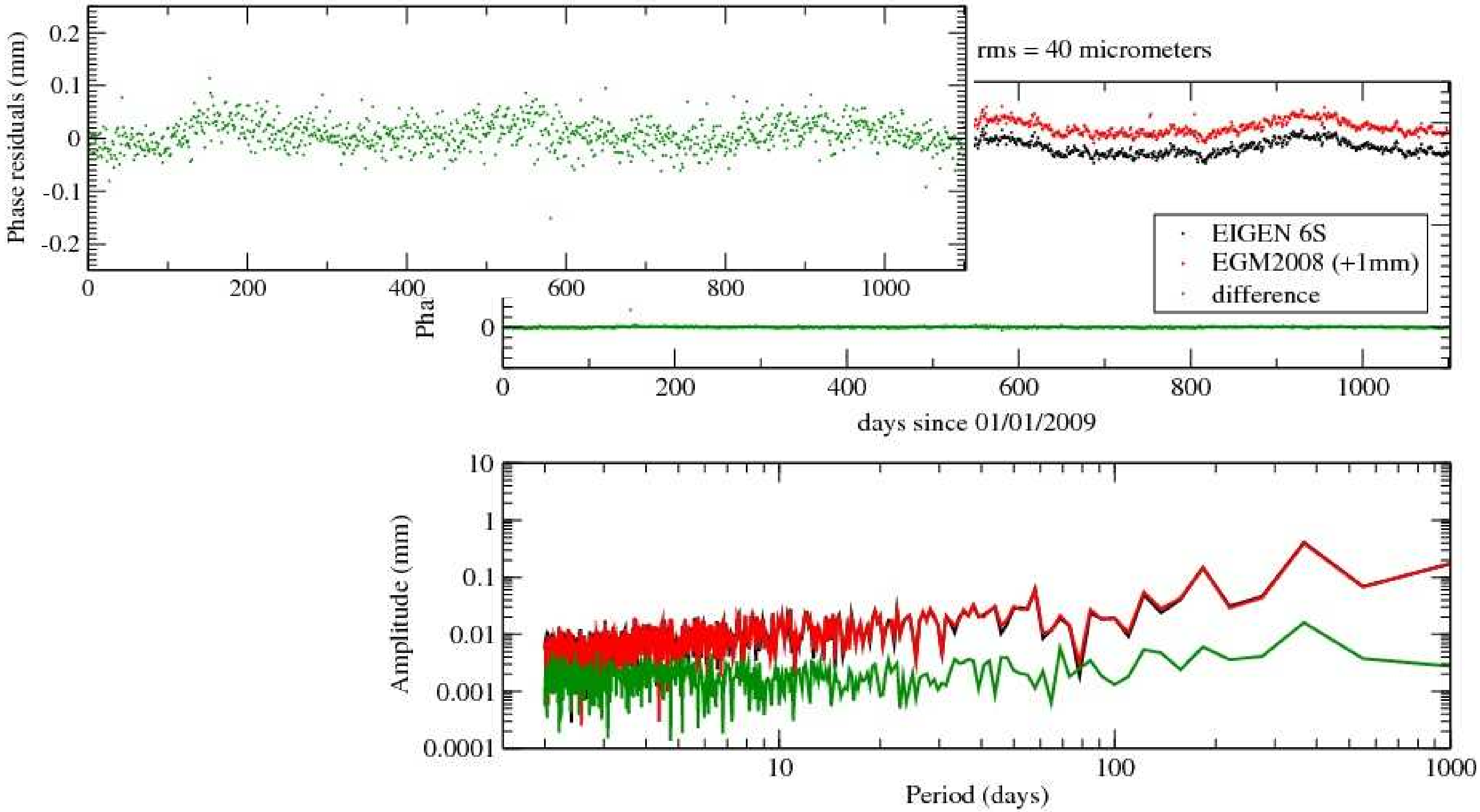
EGM2008/EIGEN-6S2 : Undifferenced Phase Residuals (1/2)

Main signal in the residuals : trend + annual signal

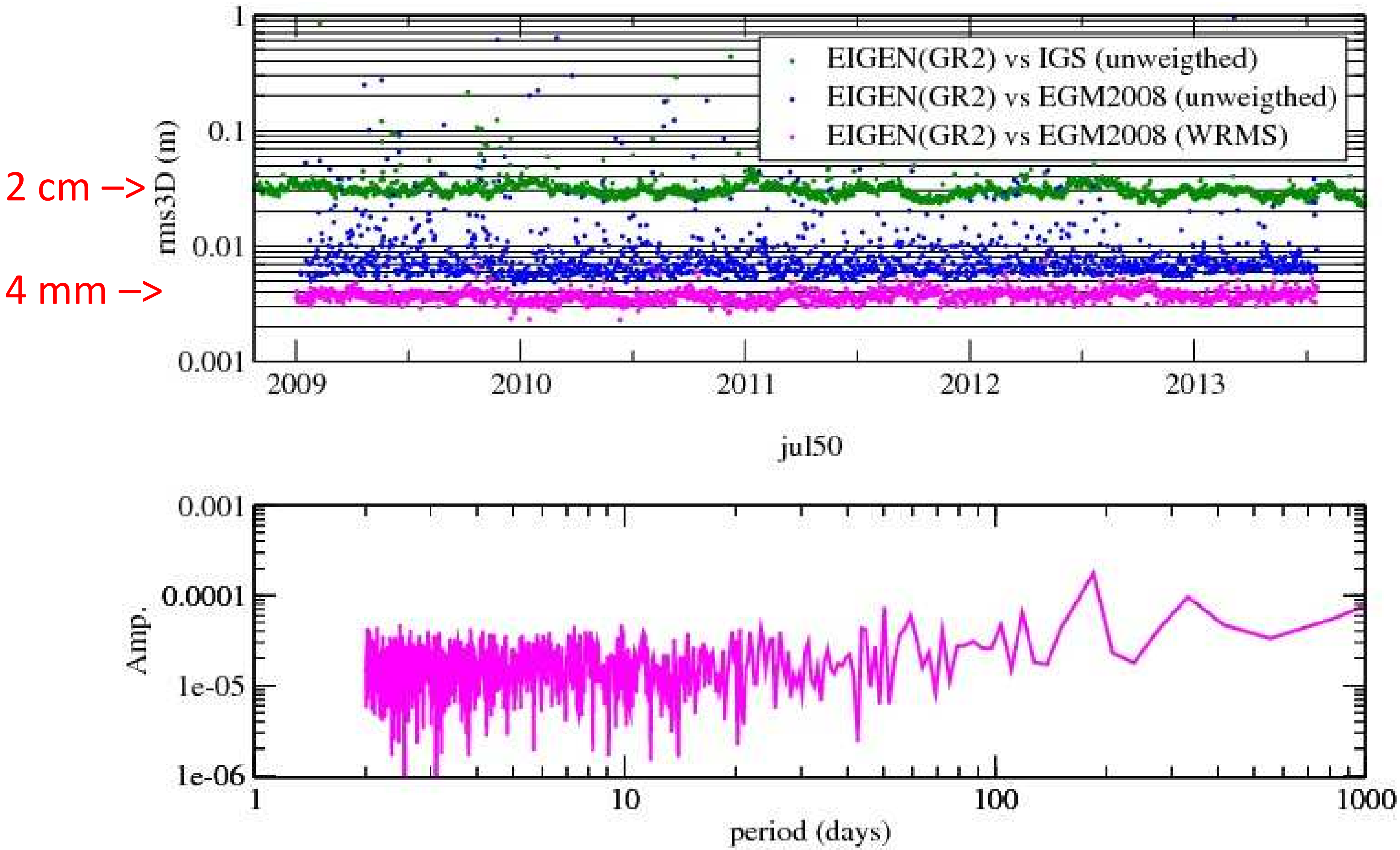


EGM2008/EIGEN-6S2 : Undifferenced Phase Residuals (2/2)

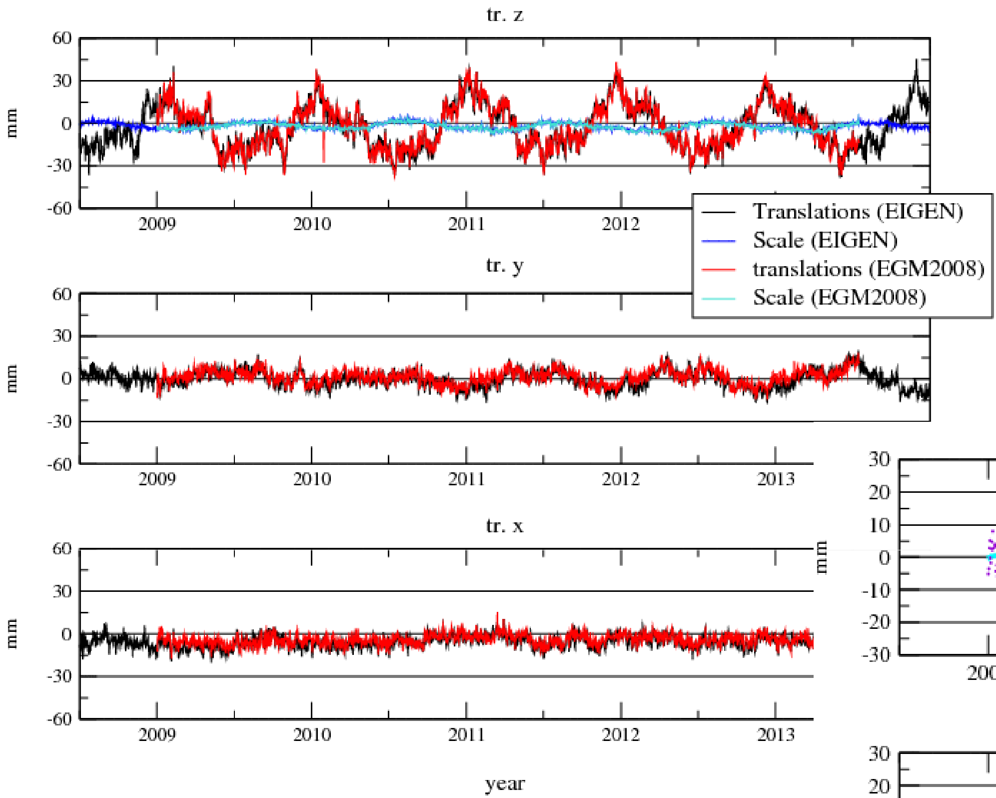
Residuals are **nearly equals** between the two experiments



EGM2008/EIGEN-6S2 : 3D Orbits differences

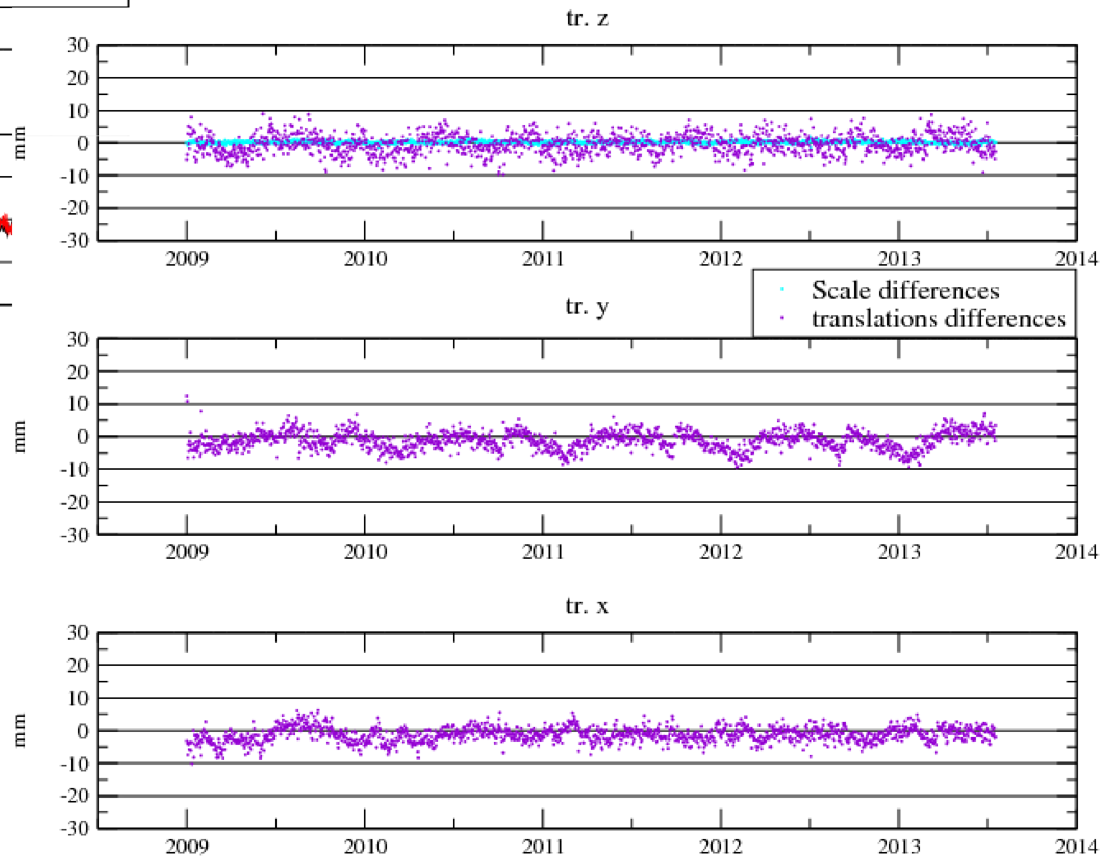


TGV / EGM2008 : Impact on global network translations…



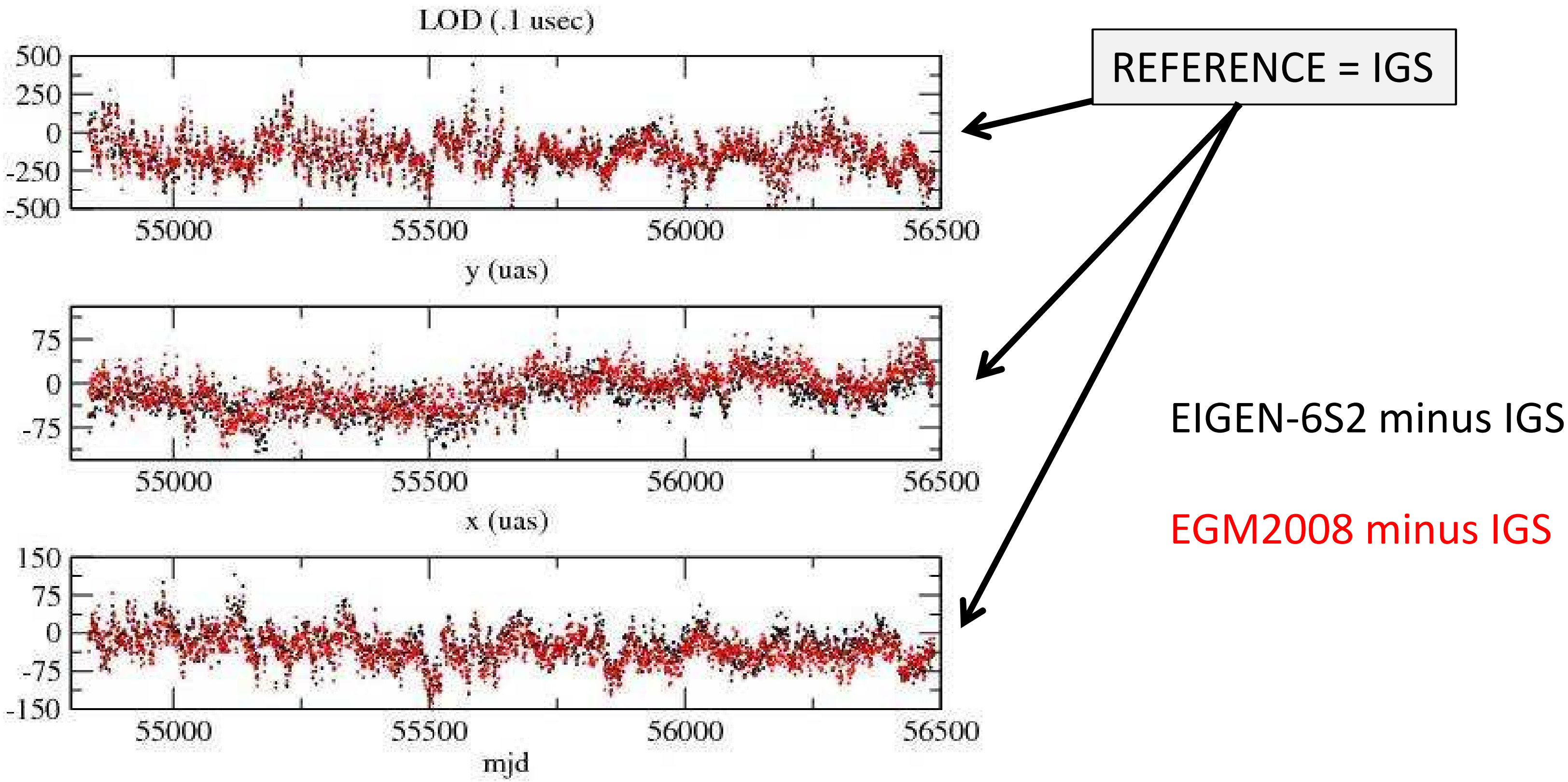
Observed translations

Differences

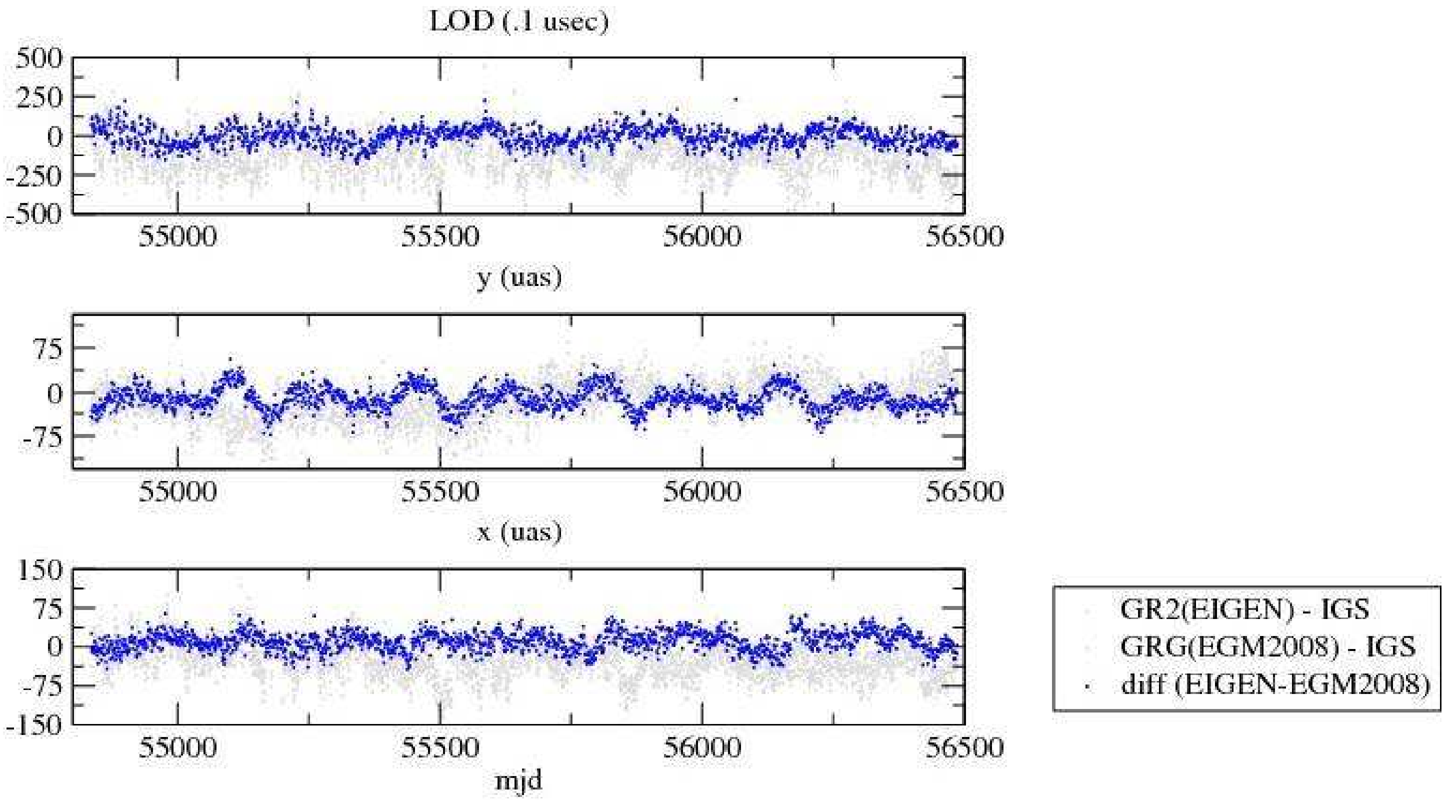


Différences: +/- 4 mm,
dominated by seasonal signal.

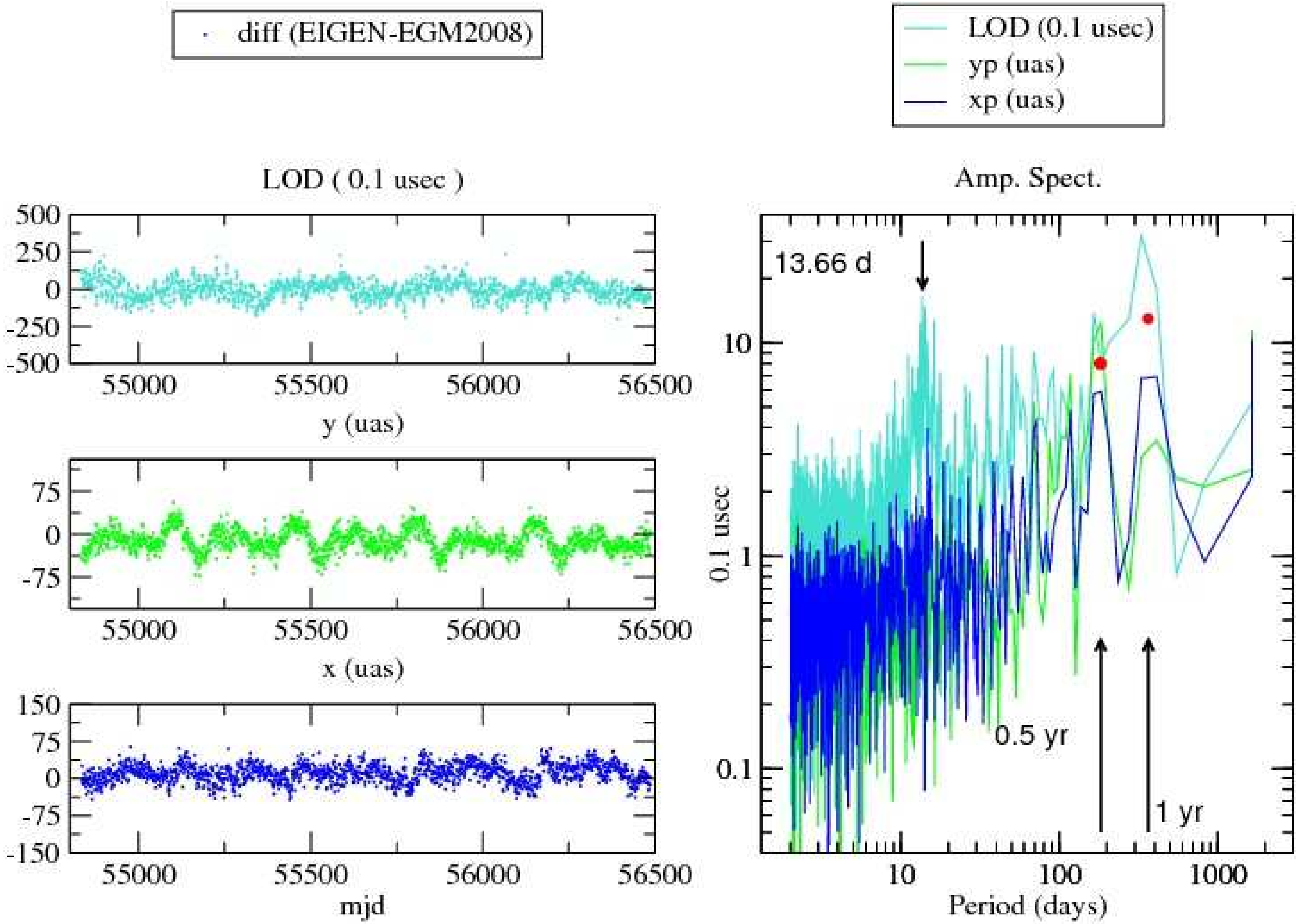
EGM2008/EIGEN-6S2 : EOP differences (1/3)



EGM2008/EIGEN-6S2 : EOP differences (2/3)



EGM2008/EIGEN-6S2 : EOP differences (3/3)



13.66 d (M2) may be due to differences between Fes2004/Fes2012 tidal models (not verified).
Red points correspond to the values computed on slide 8 for LOD (no AOD).

Summary/comments (1/2)

Impact of gravity field variations on GNSS products :

Residuals	< 0.1 mm on phase undifferenced observations	Not significant
Orbit	RMS3D ~ 4mm SSA ~ 0.3 mm	Below todays ACs differences
Frame translations	+/- 4 mm	Dominated by seasonal variations
EOP	Few tens of uas in xp/yp Up to 2 usec in LOD for SA	In the order of magnitude of IGS ACs discrepancies LOD differences directly linked to C20 differences.

- Impact on the products is sufficiently high to consider today these effects, especially on the EOP !
- Good agreement between modern TVG issued from Grace & Lageos data processing 'providers' : GOCO, EIGEN-6S2, TVG 4x4 (GSFC)...etc
- Laser data (Lageos) provide a good insigth of C20 variations before Grace data (and after…)

Summary/comments (2/2)

- Availability of the dealiasing products: at the present time ~ 3-month latency. In 1-2 years this could be reduced to a few (or even one) days.

➔ No problem for REPRO2 computations…

➔For real-time applications, a mean model of the atmosphere and ocean variations, at the annual and semi-annual periods, could be built.

Note : IDS & altimetry POD teams made the choice to use TVG without dealiasing products (latency 1 month for POD, 1 day for MOE).

- Extrapolation of the gravity field: EIGEN-6S2 is a mean model, based on 10 years of data (28 years for degree 2). After 2013, only the annual and semi-annual components are kept; the model is extrapolated with a zero-slope assumption (the most conservative option).


GR 2

BACKUP SLIDES ……………………………………………

From 'old' to reprocessing standards
Status of GRG/GR2 processing standards implying gravity.

	Gravity	Oceanic tides	Polar tides	Dealiasing products
GRG before week 1717 (12/2012)	Eigen_gl04s_annuel	fes2004	-	-
GRG before week 1758 (09/2013)	Eigen_gl04s_annuel	fes2004	desai2002	Ray/Ponte (subdiurnal atm. tides)
GRG (today)	eigen-6s2	Fes2004 *(but should be fes2012)*	desai2002	Ray/Ponte
GR2	eigen-6s2	fes2012	desai2002	Atm pressure from tugo 3h*
Tests done with EGM2008	EGM2008 + IERS2010 low-degree variations (dot)	fes2004	desai2002	Ray/ponte

* Subdiurnal atm pressure included in tugo 3h replace S1/S2 model of Ray/Ponte
Tugo 3 hours not available for GRG final computations.

EIGEN-6S2 : Model description

- Full description :

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

- A paper on this model, by Sergei Rudenko et al.:

  Rudenko S., Dettmering D., Esselborn S., Schoene T., Foerste C., Lemoine J-M., Ablain M., Alexandre D., Neumayer K.-H.;
  Influence of time variable geopotential models on precise orbits of altimetry satellites, global and regional mean sea level trends;
  Advances in Space Research, doi: 10.1016/j.asr.2014.03.010, 2014

How to obtain EIGEN-6S2?

- EIGEN-6S2 can be downloaded:
  - From http://gravitegrace.get.obs-mip.fr/data/RL02/static/EIGEN-6S2.txt (Extension of official Grace format)
  - From http://gravitegrace.get.obs-mip.fr/data/RL02/static/EIGEN-6S2.gfc2 (ICGEM-V2 format)
- GRGS provides an **interactive tool** to compute a static gravity field at any given date from this model:

http://grgs.obs-mip.fr/grace/variable-models-grace-lageos/interactive-tools/Computation-of-the-mean-variable-field-at-a-given-date

- Additionally two **software packages** in Fortran90 are available for download:
  - GRACE to ICGEM-V2 (and vice versa) format converter:

http://gravitegrace.get.obs-mip.fr/data/routines/kit_conversion_ICGEMV2_GRACENF_formats.tar

  - a tool kit to compute the gravity field at any given date from the new extended GRACE format:

http://gravitegrace.get.obs-mip.fr/data/routines/kit_interpolation_of_mean_variable_field.tar

Model evaluation

Until now, based on LEO satellites POD :

- “The EIGEN-6S2 gravity field reduces the errors previously identified on the inter-annual signal of Sea Level at regional scale compared to the one available in the GDR-D standards”, A. Ollivier et al. 2013 http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2013/oral/Ollivier_Orbit.pdf
- “We recommend this model also as a background geopotential model for precise orbit determination to compute individual solutions to be used for the generation of a new realization of the International Terrestrial Reference Frame ITRF2013”, S. Rudenko et al. 2013 https://www.joss.ucar.edu/sites/default/files/meetings/2013/ostst/abstracts/rudenko.pdf

Consistency with other models

- Associated de-aliasing models :
  - provided by : Pascal Gegout
  - Computed from:
    - The ERA-interim reanalysis of ECMWF (60 model levels, every 3 hours) for the atmospheric part;
    - The TUGO barotropic model (Florent Lyard, LEGOS/CNRS) for the oceanic response to the ERA-interim pressure and wind forcing (every 3 hours).
  - The gravitational potential has been integrated at each model level in order to obtain the total gravitational effect outside the atmospheric masses; this is why it is called a "3D" gravitational potential.
  - The solid Earth response to this time-variable atmosphere & ocean potential has been taken into account through the use of the k' Love numbers (Gégout P., article in preparation).
  - Available from: http://grgs.obs-mip.fr/grace/atm_ocean
  - Warnings:
    - The stationary mean part of the oceanic tides forced by the **atmospheric tides S1 and S2 are included in the FES2012 tidal model**. This stationary mean part of the oceanic tides have been removed from the ocean de-aliasing time series available online. Hence only the departure of the oceanic tides S1, S2 from their mean stationary tidal-like structure is included in the oceanic time series.
    - ONLY for gravity analysis (not loading purposes)
- Consistent with FES2012 ocean tide model
  - Provided by : Florent Lyard
  - Available from: the LEGOS web site

EGM2008/Recommended REPRO2

EGM2008 constants:

a=6378136.30 m (semi-major axis of WGS 84 ellipsoid)
GM=3.986004415 x 10^{14} $m^3 s^{-2}$ (Product of the Earth's mass and the Gravitational Constant)

Associated models recommended by IERS2010 :
ocean tides: FES2004 (Lyard et al., 2006),
ocean pole tide: Desai (2003, see Section 6.5),
atmosphere and ocean de-aliasing: AOD1B RL04 (Flechtner, 2007).

Updated values for time-variations of low-degree coefficients given in IERS Conventions (2010) Chapter 6:

Table 6.2: Low-degree coefficients of the conventional geopotential model

Coefficient	Value at 2000.0	Reference	Rate / yr^{-1}	Reference
$\bar{C}_{20}$ (zero-tide)	-0.48416948×10^{-3}	Cheng *et al.*, 2010	11.6×10^{-12}	Nerem *et al.*, 1993
$\bar{C}_{30}$	0.9571612×10^{-6}	EGM2008	4.9×10^{-12}	Cheng *et al.*, 1997
$\bar{C}_{40}$	0.5399659×10^{-6}	EGM2008	4.7×10^{-12}	Cheng *et al.*, 1997