EGSIEM
European Gravity Service for Improved Emergency Management

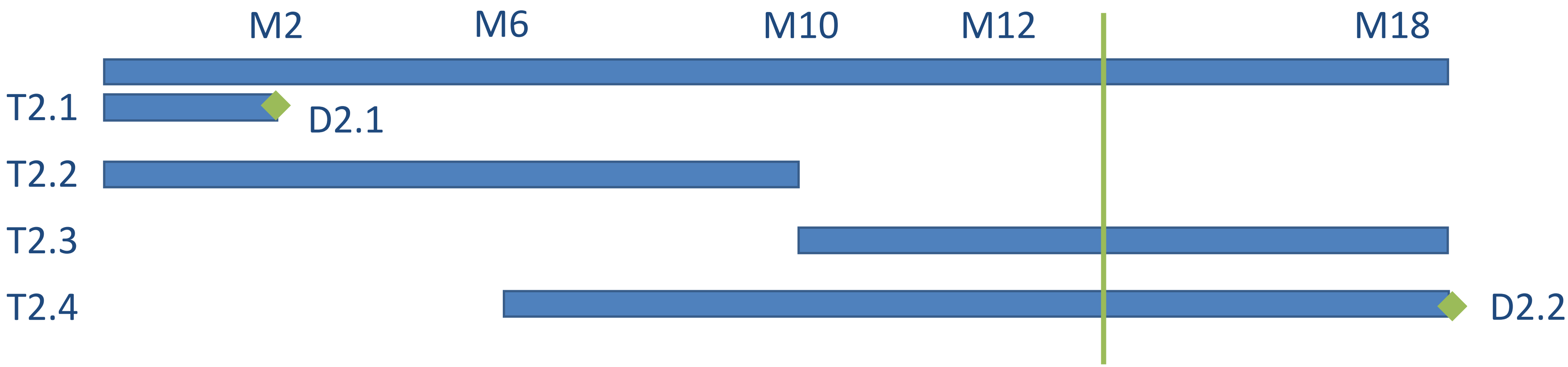
Title: **WP2 Gravity field analysis**

Presenter: Torsten Mayer-Gürr and all ACs

Affiliation: TUG

UNIVERSITÄT BERN | UNIVERSITÉ DU LUXEMBOURG | GFZ Helmholtz Centre Potsdam | TU Graz Graz University of Technology | Leibniz Universität Hannover | cnes | DLR | géode&cie | Horizon2020

WP2 Gravity field analysis – Time Table



T2.1 Processing Standards and Models

Document delivered

T2.2 Improved processing tools

Presentation of results today: AIUB, GZF, TUG,CNES/GRGS, ULux

T2.3 Data analysis

Discussion today

T2.4 Instrumental behavior and End-to-end Simulator

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European Gravity Service for Improved Emergency Management

Title: **AIUB processing**

Presenter: Ulrich Meyer

Affiliation: AIUB

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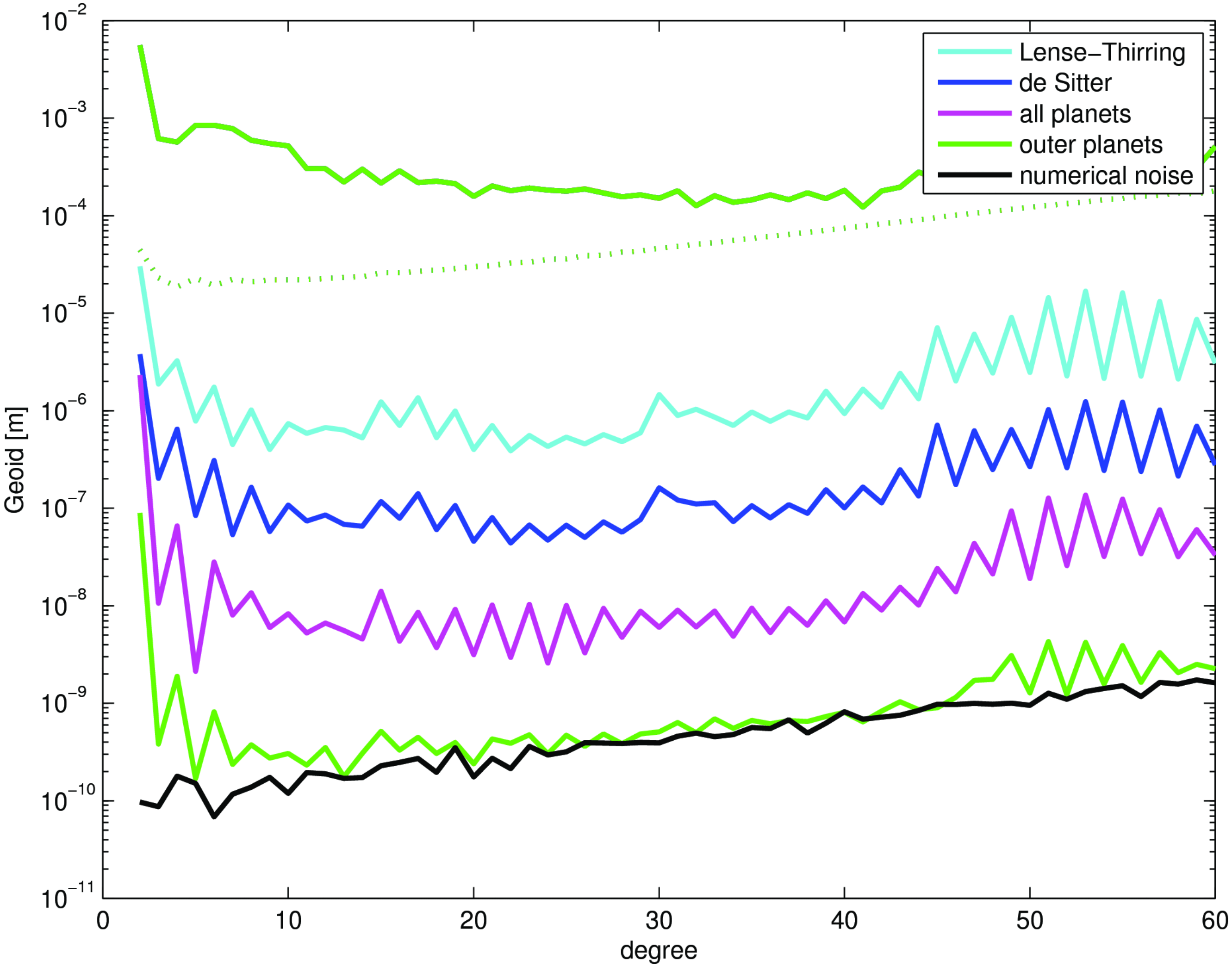
Adaption of Standards: Relativity and third bodies



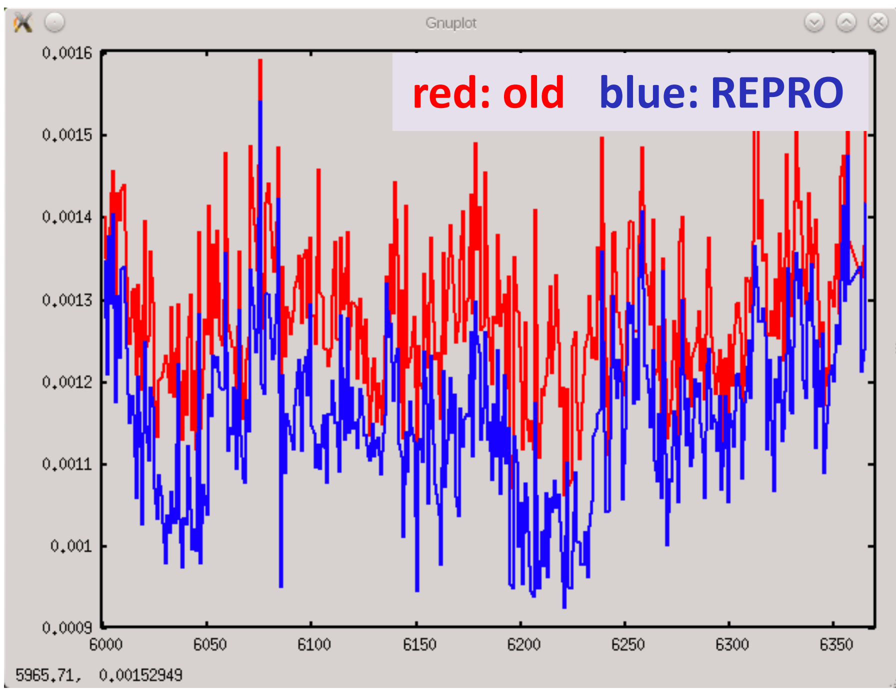
All effects well below formal errors.

Largest effect: Lense-Thirring (may be visible in degree 2).

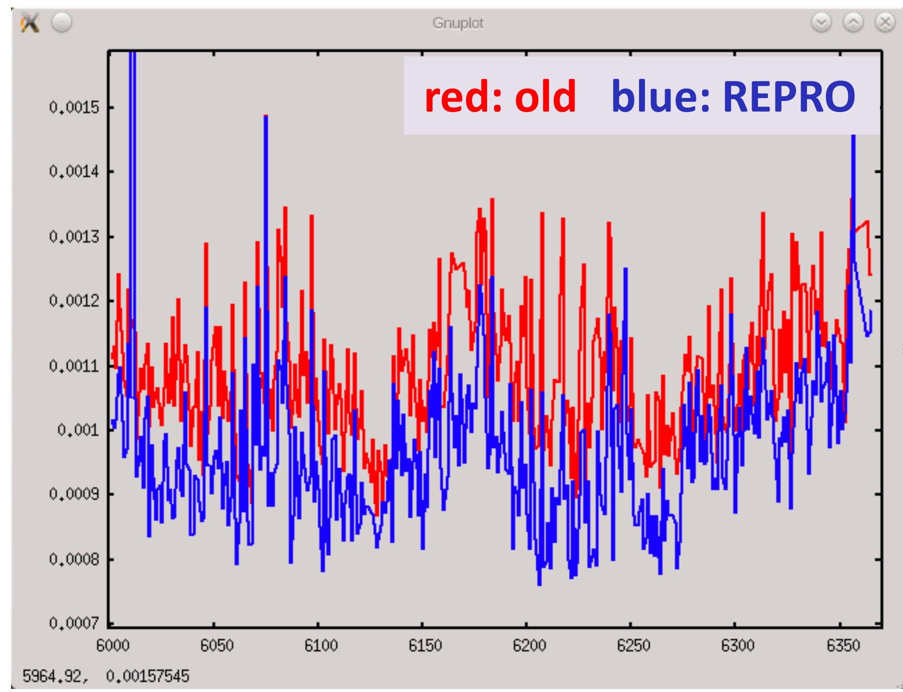
REPRO: GPS orbits and clock corrections (1/3)

Daily RMS of reduced-dynamic orbit fit to kinematic orbits (position fit transformed to phase fit): gain in consisteny of 10-20%

GRACE A: 2006

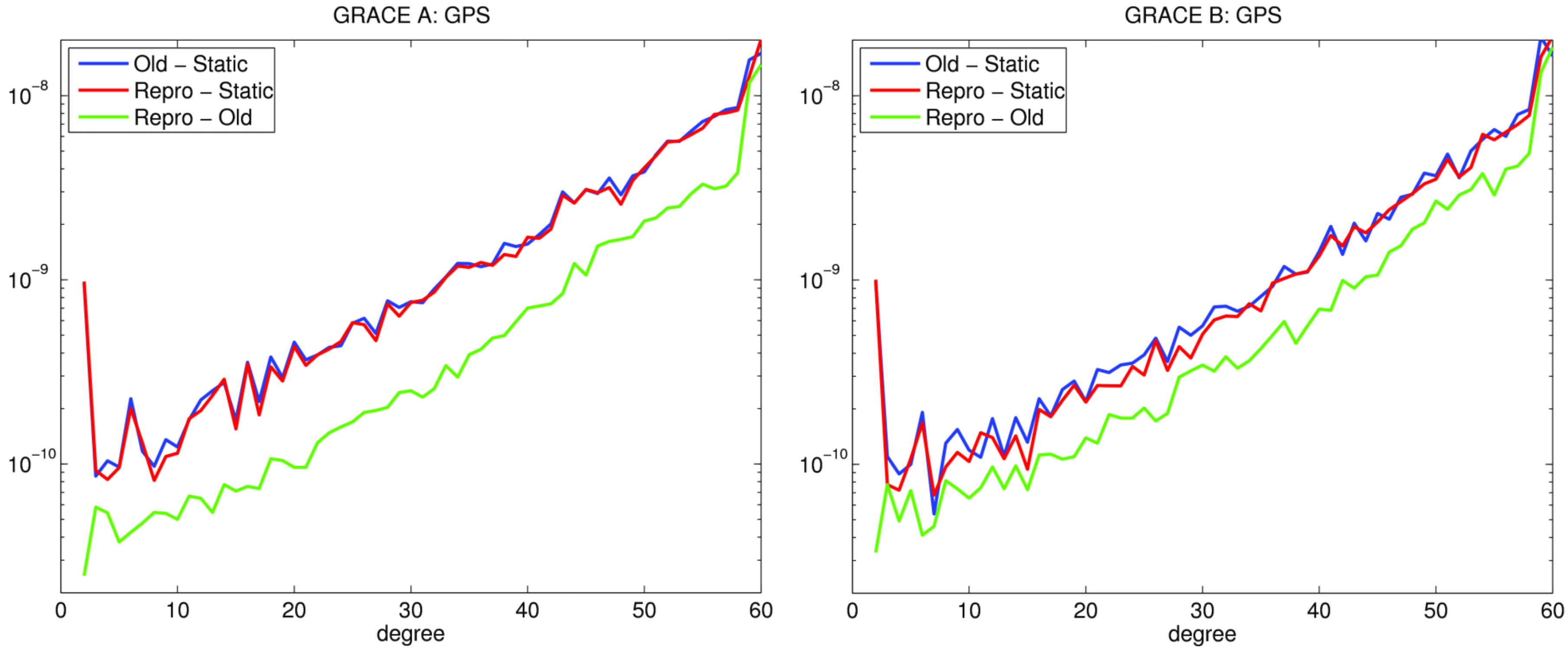


GRACE B: 2006

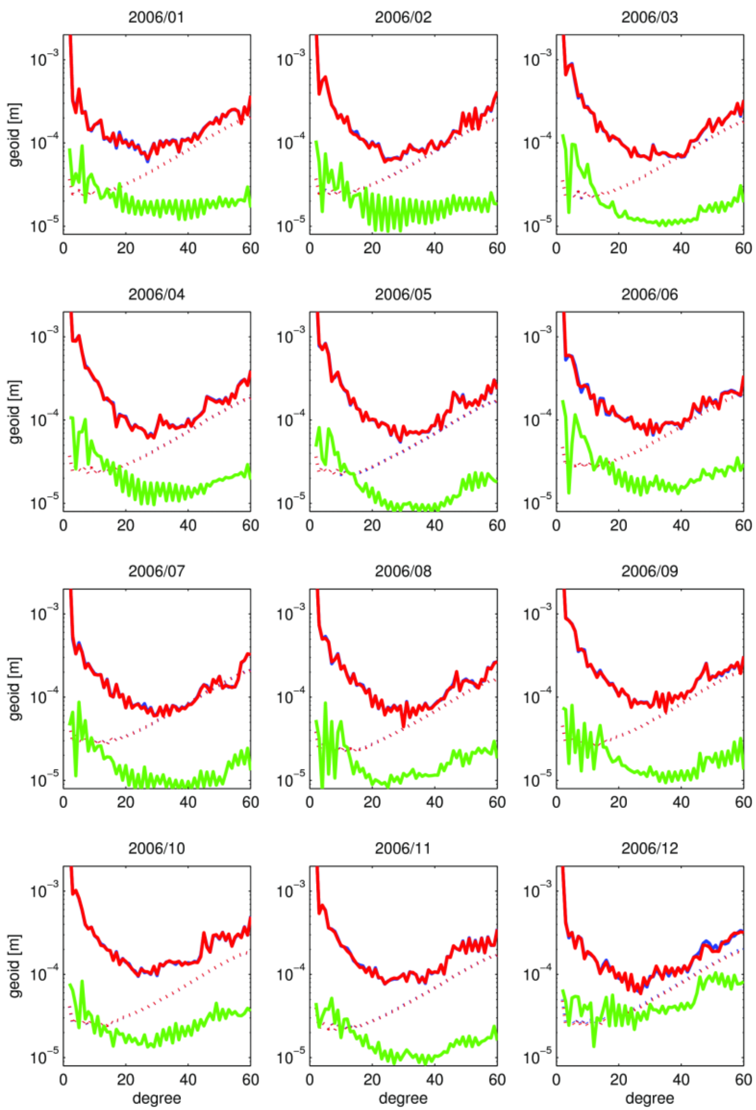


REPRO: GPS orbits and clock corrections (2/3)

Quality gain in 1-year GRACE GPS-only gravity fields (relative to static GPS + K-Band gravity field).



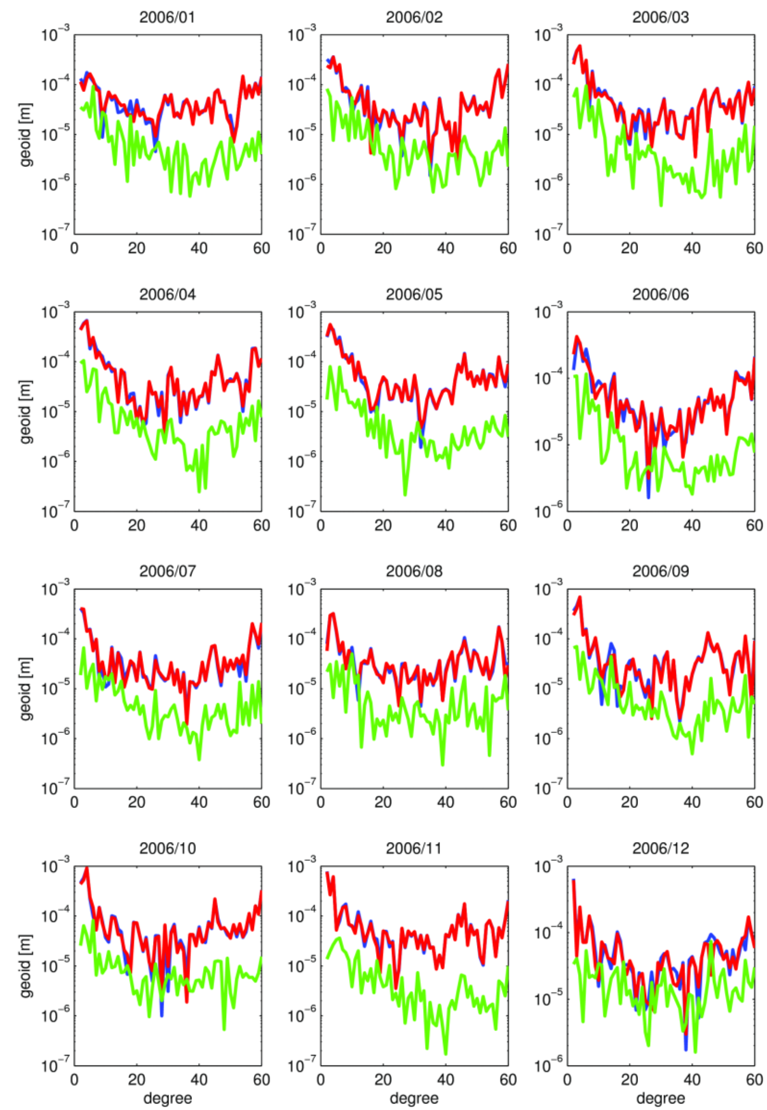
REPRO: GPS orbits and clock corrections (3/3)



Effect on monthly GRACE GPS + K-Band gravity fields.

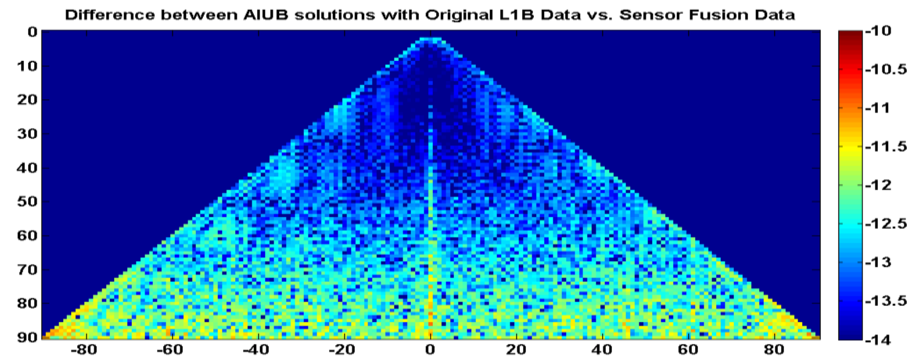
Left: difference degree amplitudes

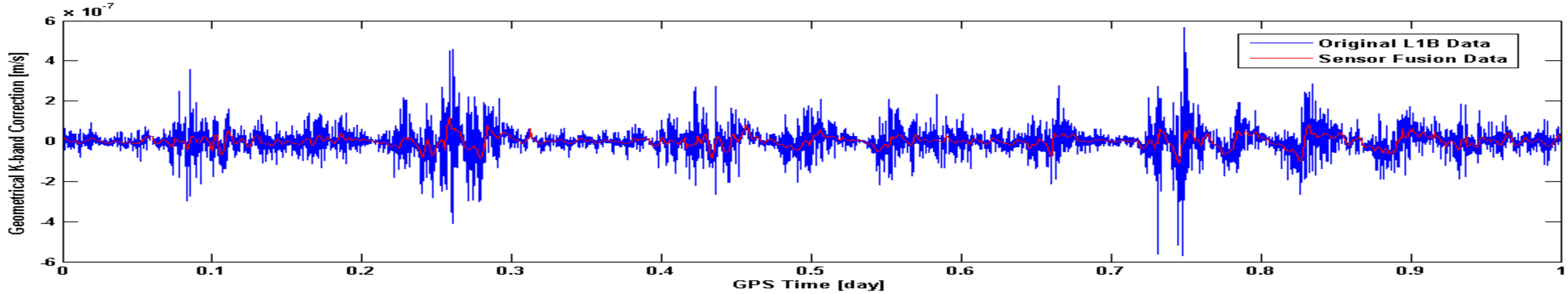
Right: sectorial terms only

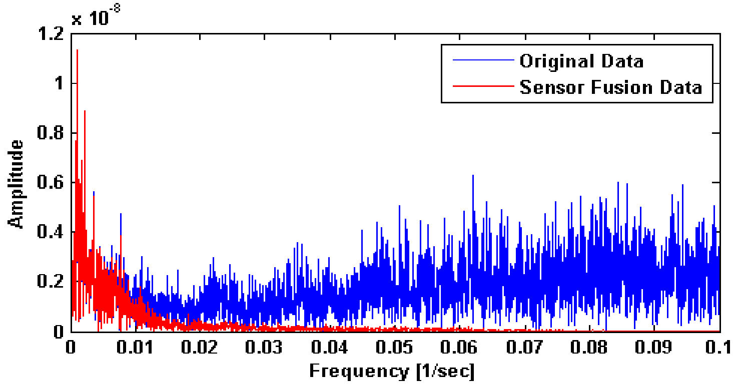


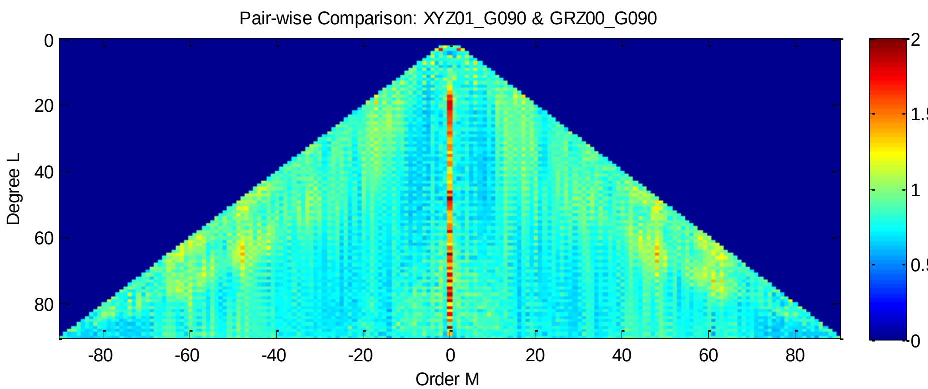
Sensor Fusion Data (1/2)

- Test period: January 2007
- processing method: CMA (AIUB)
  - Case 1: original L1B
  - Case 2: ITSG sensor fusion

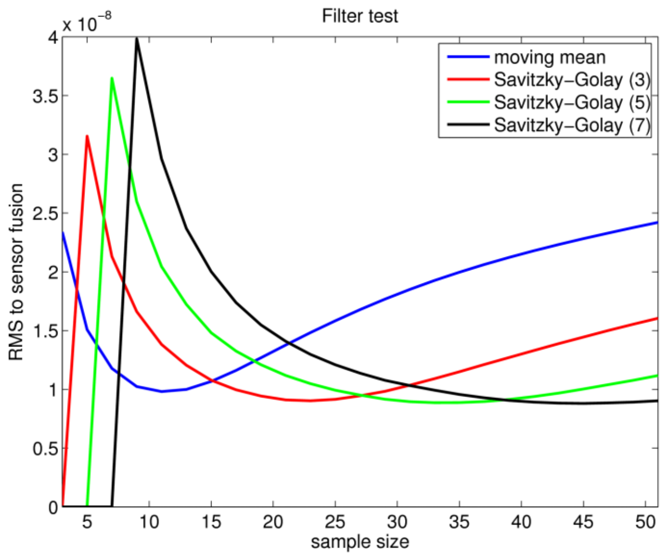


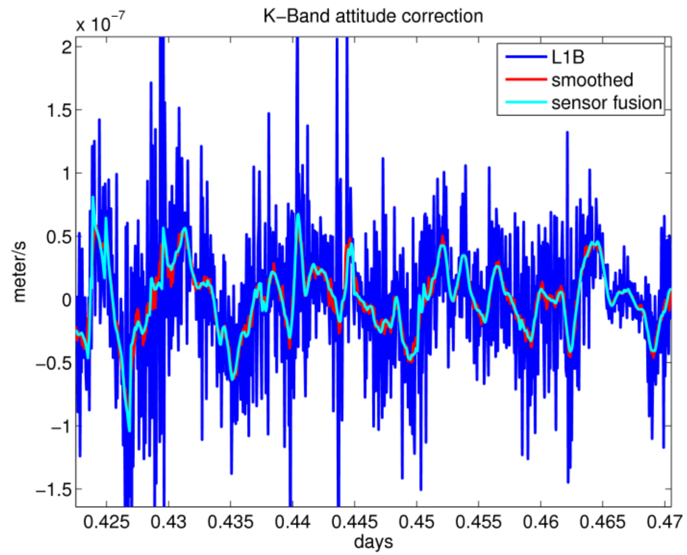






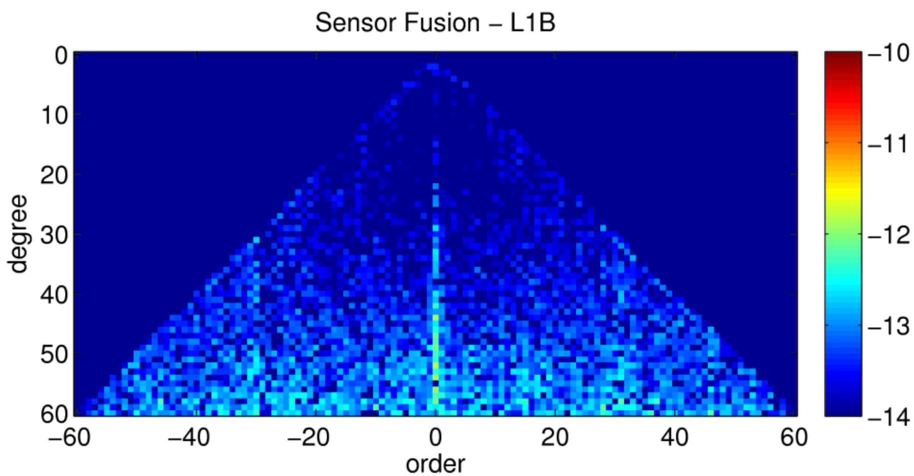
Sensor Fusion Data (2/2)

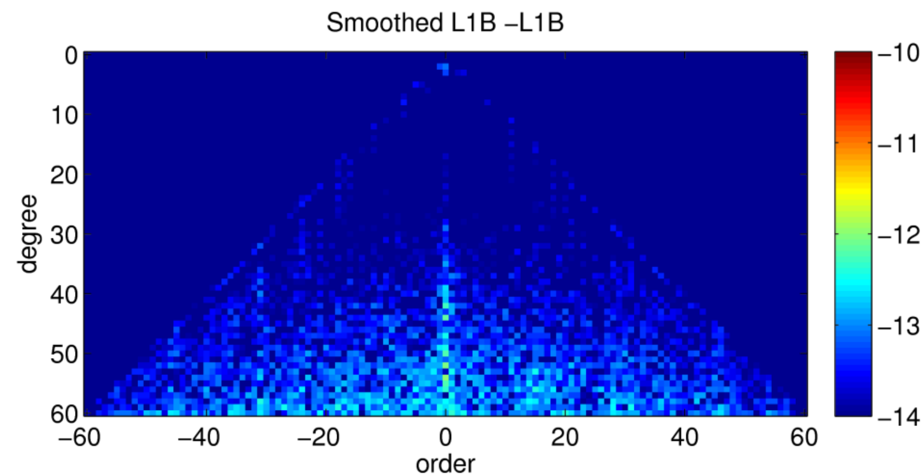




Main effect of sensor fusion data: K-Band attitude correction.

May be replaced by smoothed L1B attitude correction.





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Title: **GFZ processing**

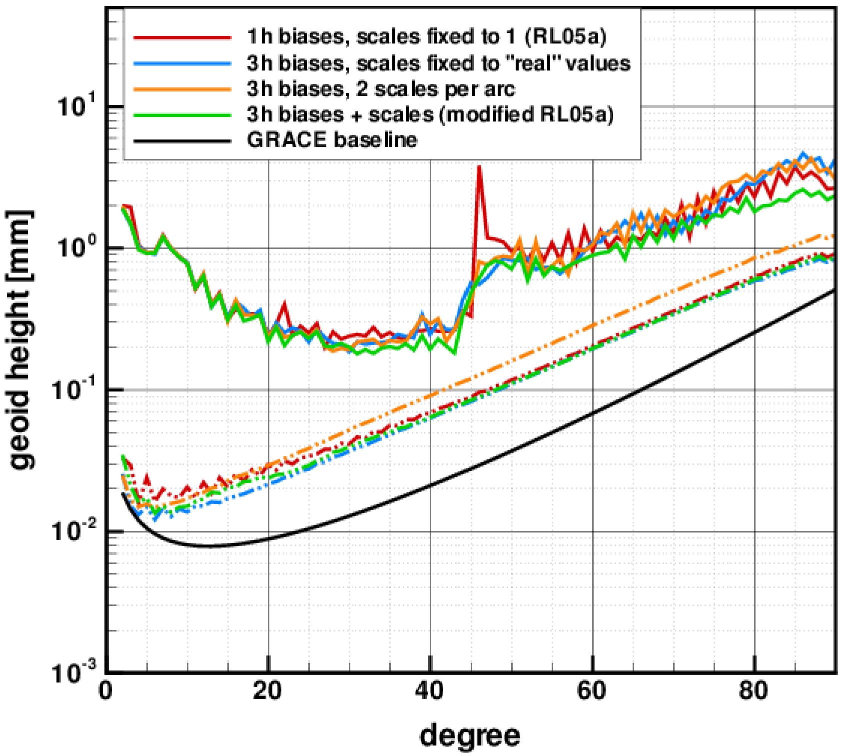
Presenter: Frank Flechtner

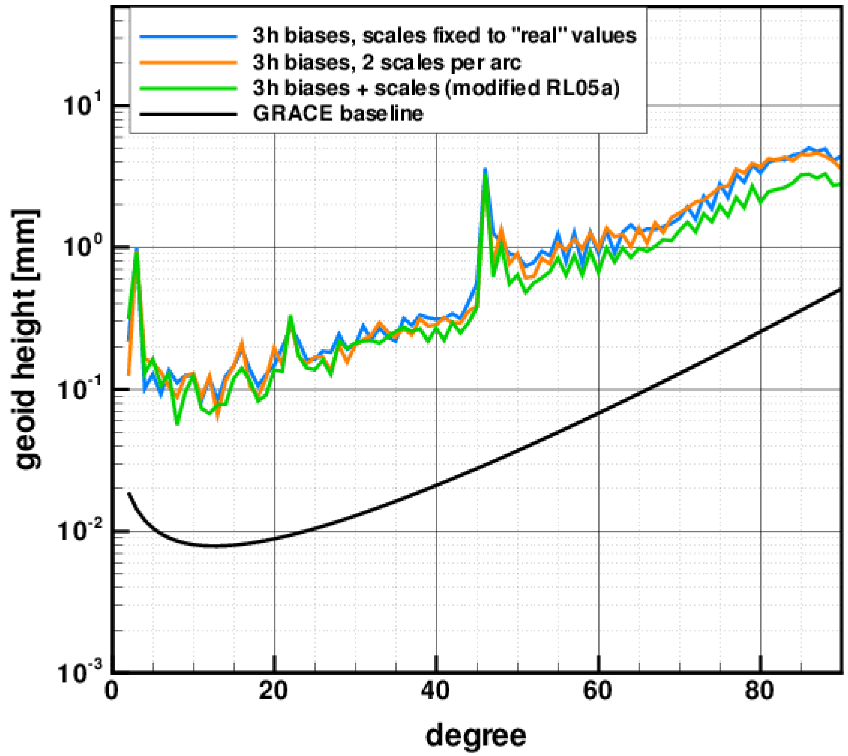
Affiliation: GFZ

ACC parameterization:

- Test month: 2012/07

Differences relative to RL05a solution:





Task 2.2 Improved Processing Tools GFZ

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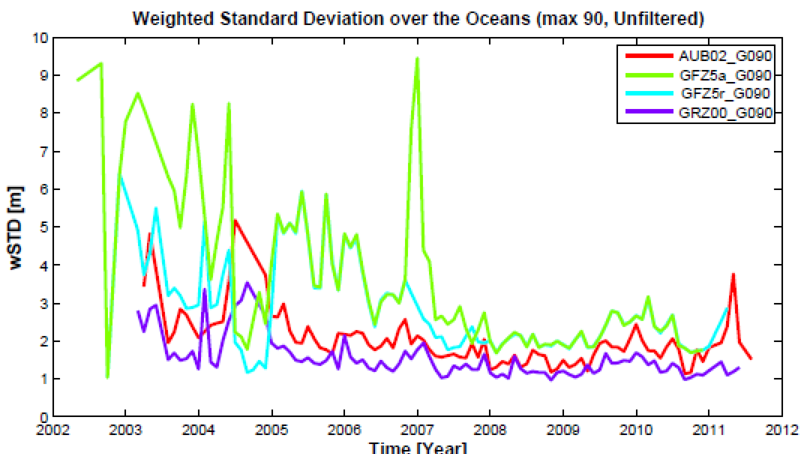
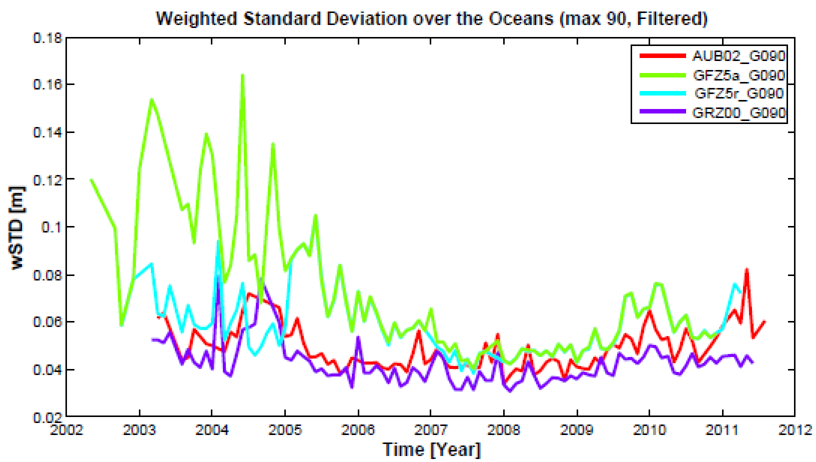
ACC parameterization (lessons learnt):

- Fixing ACC scales to 1 should be avoided
- Parameterization with 3h biases + scales shows least high-frequency noise and has been chosen for modified RL05a processing
- Impact of this parameterization on time-series is shown below:
  - Alternative RL05a solutions for the years 2003, 2004, 2007, 2012 & 2013 (Jan-May) have been reprocessed for comparison with official RL05a





Figures provided by Yoomin Jean (AIUB)

Task 2.2 Improved Processing Tools GFZ

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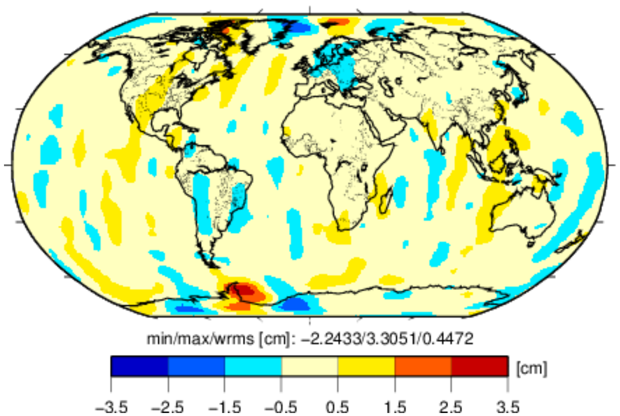
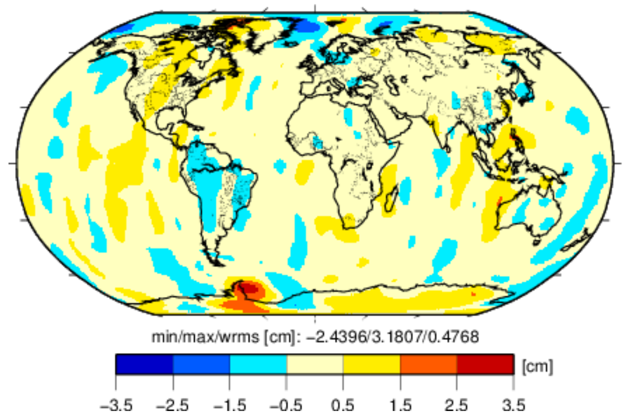
New ocean tide model FES 2014:

- Test month: 2007/12
- Case 1: FES2014 up to 80x80, Om1/Om2 from EOT11a up to 80x80 (source TMG)
- Case 2: FES2014 up to 80x80, only d/o (2,0) provided by GRGS for Om1/Om2
- Case 3: FES2014 up to 100x100, only d/o (2,0) provided by GRGS for Om1/Om2
- EWH differences (DDK2) relative to GFZ RL05a solution using EOT11a are largest where EOT11a is known to be less accurate (Stammer et al. 2014, Rev Geophys)

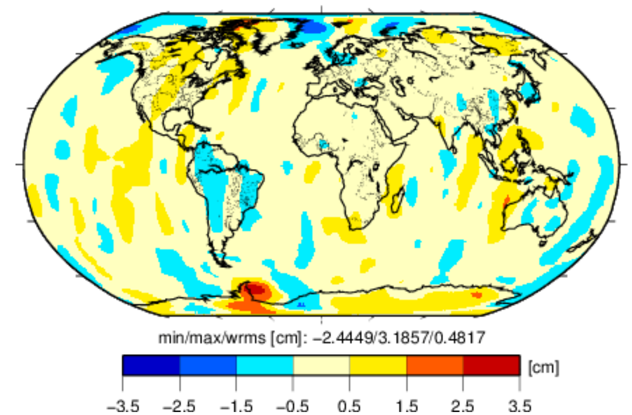
Case 1



Case 2



Case 3



Task 2.2 Improved Processing Tools GFZ

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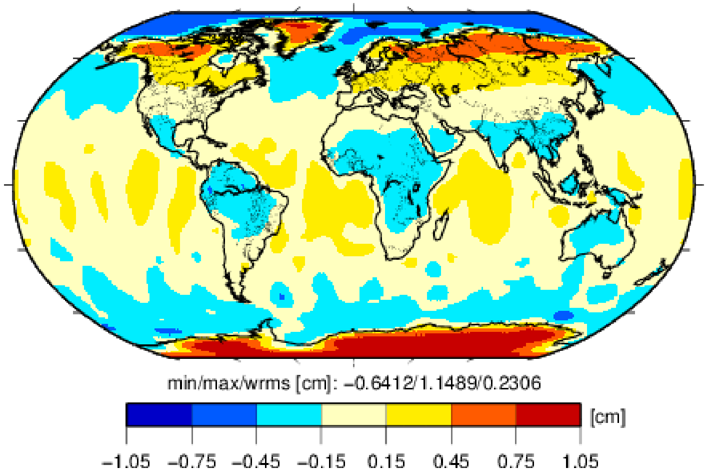
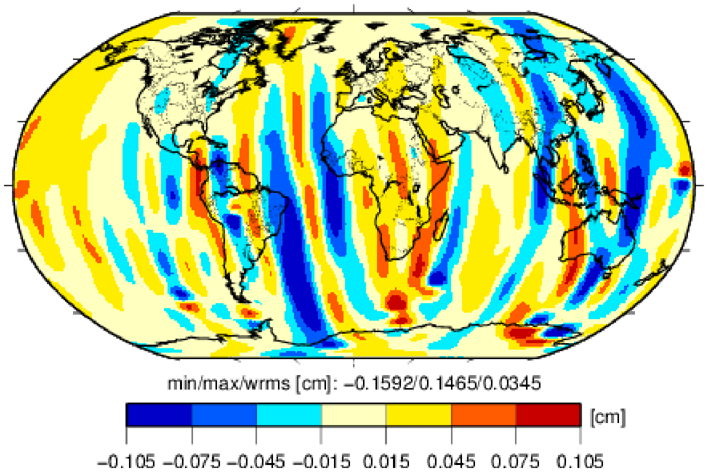
New ocean tide model FES 2014:

- Difference Case 1 – Case 2:
  - Might be on the edge of GRACE accuracy
  - Does it make sense to use d/o (2,0) only for Om1/Om2?



- Difference Case 2 – Case 3:
  - Well below GRACE accuracy level
  - Further test with FES2014 up to 180x180 planned



Task 2.2 Improved Processing Tools GFZ

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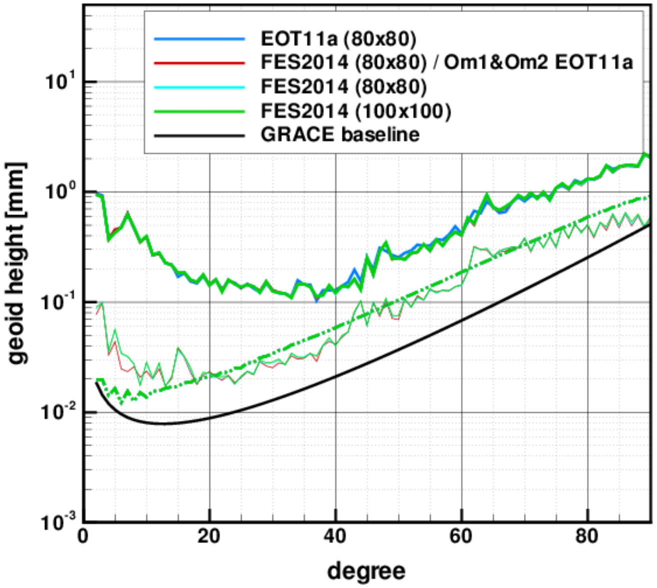
New ocean tide model FES 2014:

- Using FES2014 instead of EOT11a shows
  - No significant impact on KBR pre-fit residuals
  - Slightly decreased GPS phase pre-fit residuals (~1%)
  - No significant impact on wRMS over oceans



- Only minor differences visible in degree amplitudes, but differer lines in plot) are larger than (formal) errors (dashed lines) at le

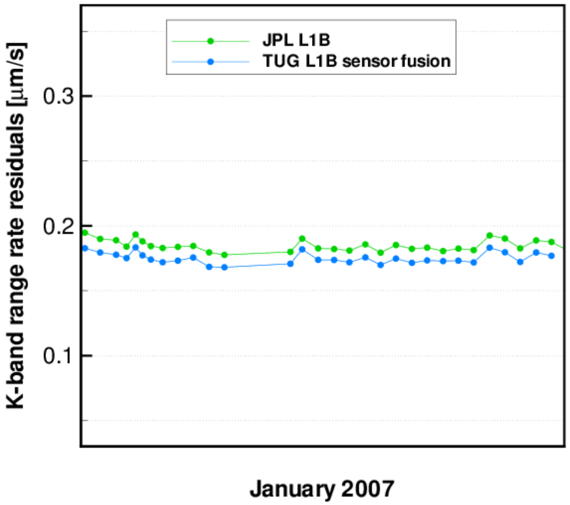
- As shown above, regional effects are clearly visible!

- Max. degree of OM1/OM2 to be discussed with GRGS

Alternative SCA1B/KBR1B data provided by TU Graz:

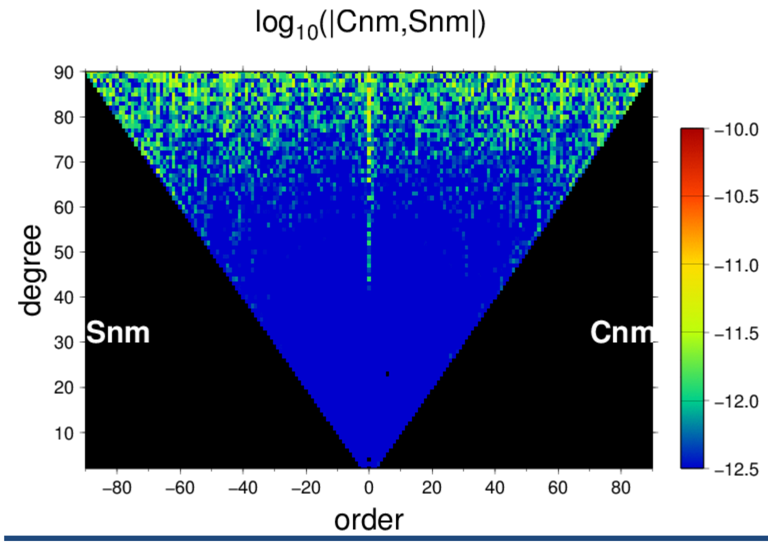
- Provided data: so-called “Sensor Fusion” data for 1 month (2007/01)
  - SCA1B: new attitude based on combination of L1B star camera data and angular accelerations
  - KBR1B: newly computed antenna center correction based on new attitude product

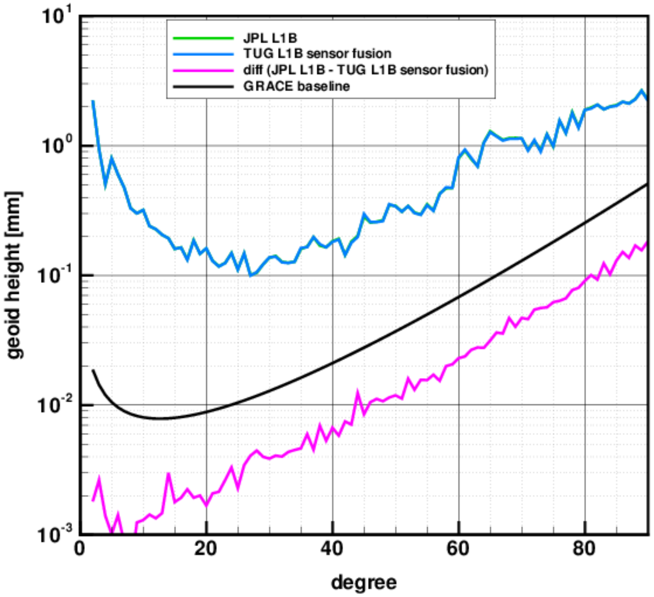
- KRR pre-fit residuals decrease by ~5%
  - mean JPL L1B: 0.185 microm/s
  - mean TUG L1B: 0.175 microm/s
  - slightly more (~0.8%) KRR observations remained after screening
- GPS pre-fit residuals are not affected



Alternative SCA1B/KBR1B data provided by TU Graz:

- No impact at all visible in degree amplitudes
  - Effect is well below GRACE baseline
- Differences (JPL L1B – TUG L1B sensor fusion) on coefficient level:
  - mainly zonal coefficients for n > 40 are affected





Alternative SCA1B/KBR1B data provided by TU Graz:

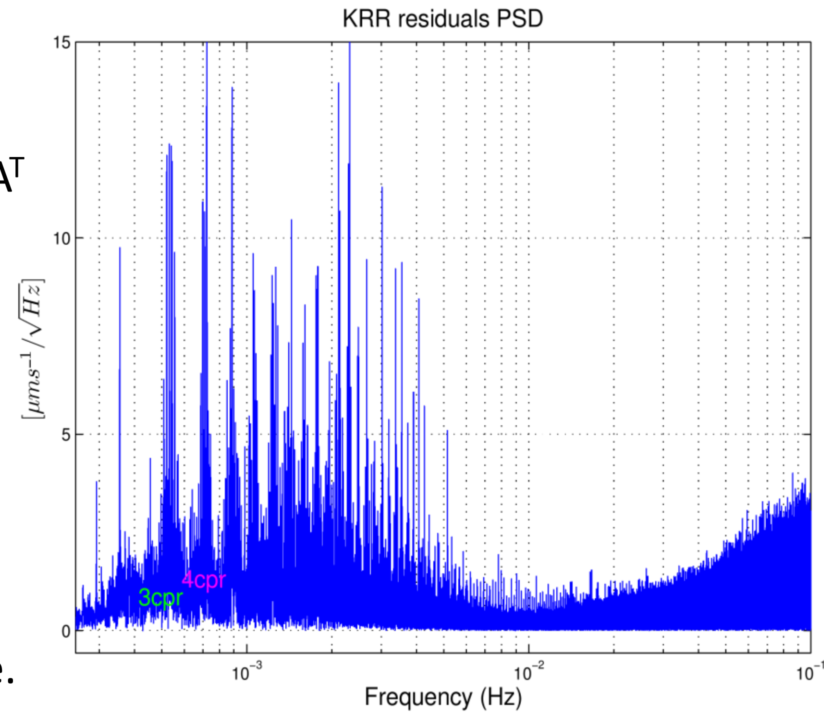
- Results are in line with results from similar tests at TU Graz
- But: For ITSG2014, in addition antenna center corrections have been estimated (using the recomputed values as a priori) → this affects even more zonal coefficients, in particular also for very low degrees (up to $n = 7$), but also quite many near-sectorial coefficients of higher degrees (approx. from $n > 20$)
- According to Torsten Mayer-Guerr, estimation of antenna center corrections alone (i.e. with official L1B data) does not improve the solutions, or even degrades them

⇒ "Sensor Fusion" data alone has no significant impact on gravity field solutions, but might be beneficial in combination with other processing details

⇒ Approach will not be followed, GFZ will wait for new JPL L1B data in the frame of RL06 reprocessing (end 2016)

"Whitening" of residual noise

- Observation Equation (residuals): $v = A x - b$
- Covariance Matrix: $Q_{vv} = M\{v, v^T\} = Q_{bb} - A Q_{xx} A^T$
- Factorized Matrix: $F = chol(Q_{vv})^{-1}$



Leads to a new equation system (with F acting as filter) for each monthly model:

- $A_2 = F\ A$
- $x = (A_2^T A_2)^{-1} A_2^T b$

with (hopefully) de-correlated observation noise.

Software already available, thorough testing has started and shall be finished till February 28 to be used in reprocessing

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European Gravity Service for Improved Emergency Management

Title: **TUG processing**

Presenter: Beate Klinger

Affiliation: TUG

Improvements since ITSG-Grace2014

Multiple improvements within the processing chain:

- Updated background models
- Instrument data screening & calibration
- Improved numerical orbit integration
- Improved covariance function estimation
- Co-estimation of constrained daily variations: constraints based on improved error estimates for the dealiasing models

Data screening

Instrument data screening step included:

- CoM and KBR calibration maneuvers are excluded:

  $\Rightarrow$ based on SoE file

- Time periods around yaw-turns are excluded:

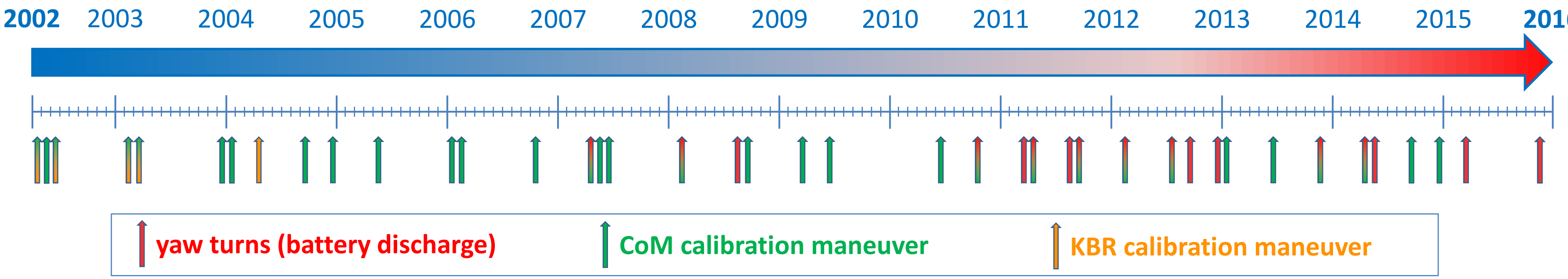
  $\Rightarrow$ based on inter-satellite-pointing angles (yaw)

- Simulation of non-conservative forces (atmospheric drag, solar radiation pressure and albedo):

  $\Rightarrow$ a-priori calibration of accelerometer bias

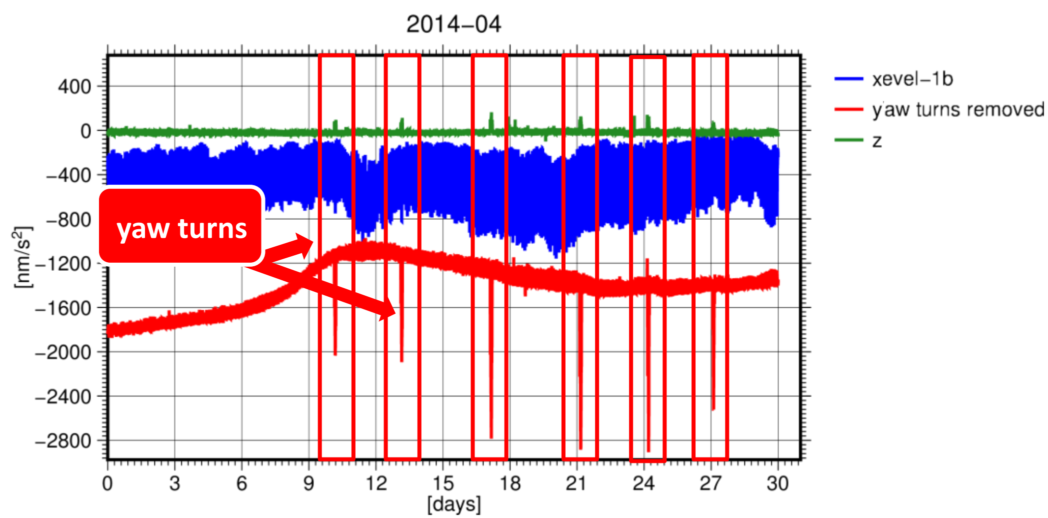
  $\Rightarrow$ detection of large outliers

Data screening



Yaw turns:

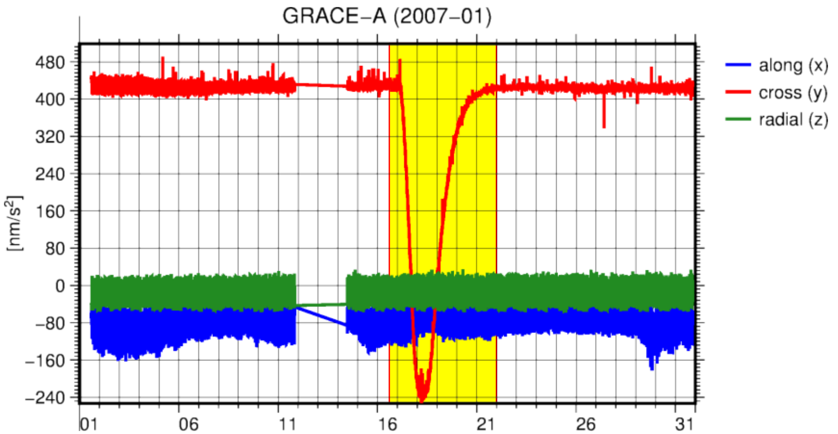
- Necessary for battery maintenance
- No KBR data available, **but edge effects still visible.**

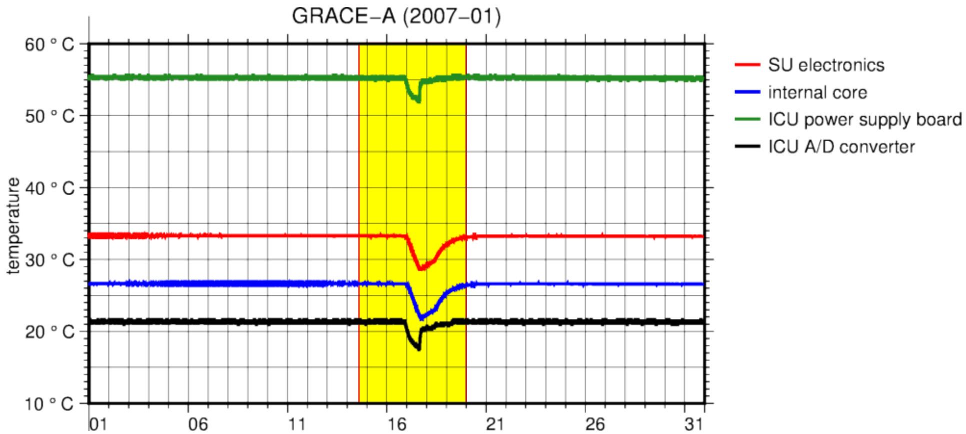


Data screening

Accelerometer calibration:

- Temperature-dependent effects (bias drift)
- Calibration based on simulated accelerometer data





Numerical orbit integration

- Elliptical reference orbit replaces linear motions:

  ⇒ improved force model integration for dynamic orbit computation

  ⇒ promising results for reducing processing artifacts in adjusted SST observations and residuals

Covariance estimation

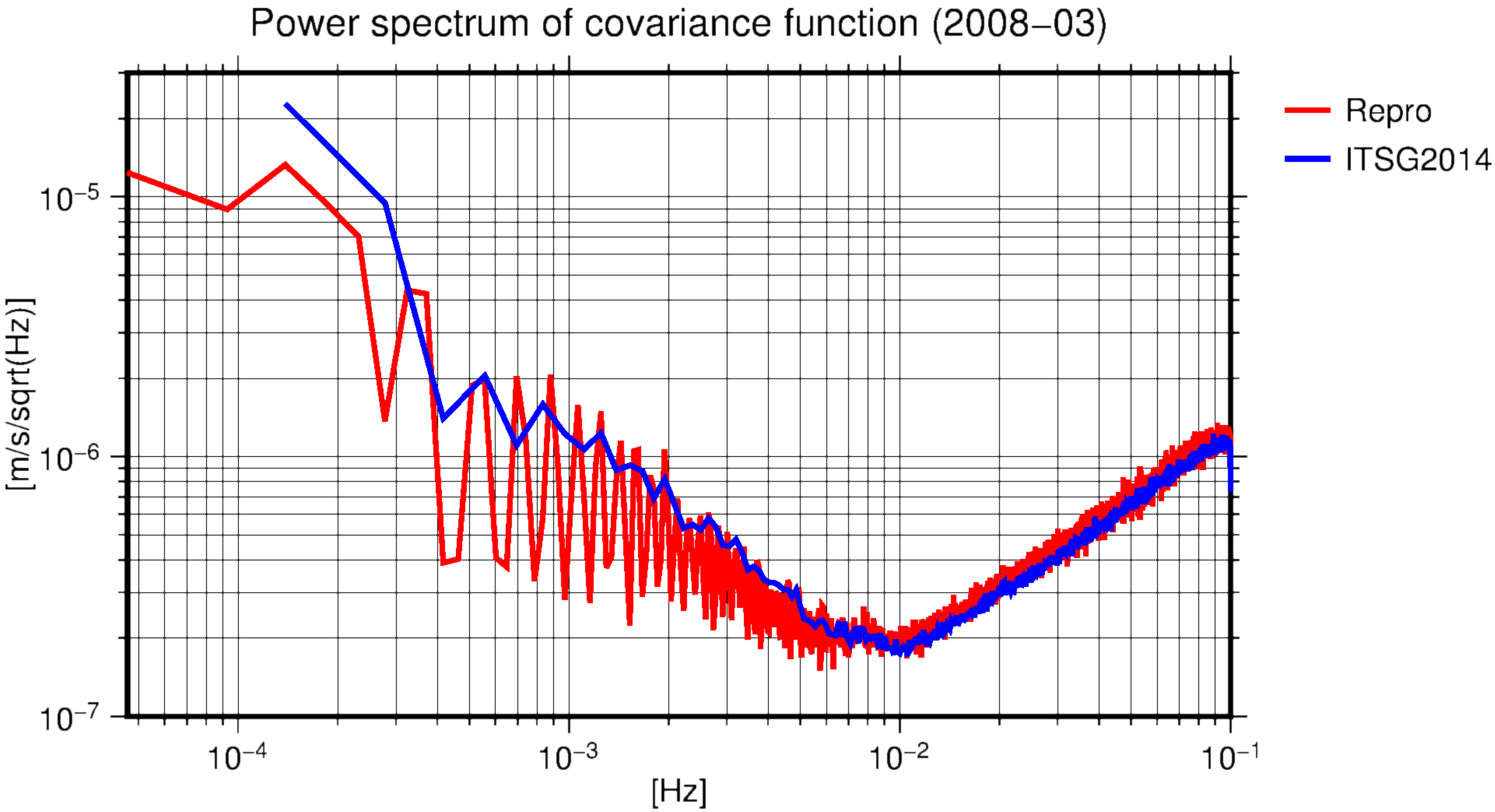
- Decorrelation of KBR range-rate data by an empirical covariance function

  ⇒ length increased from 1 to 3 hours

- Robust covariance estimator

  ⇒ guarantees that the covariance estimation is resistant to outliers

Covariance Estimation



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Reprocessing

- **Reprocessed time series: 2003-03 to 2015-04**
  (Test run: only up to degree 60)
- Comparison with

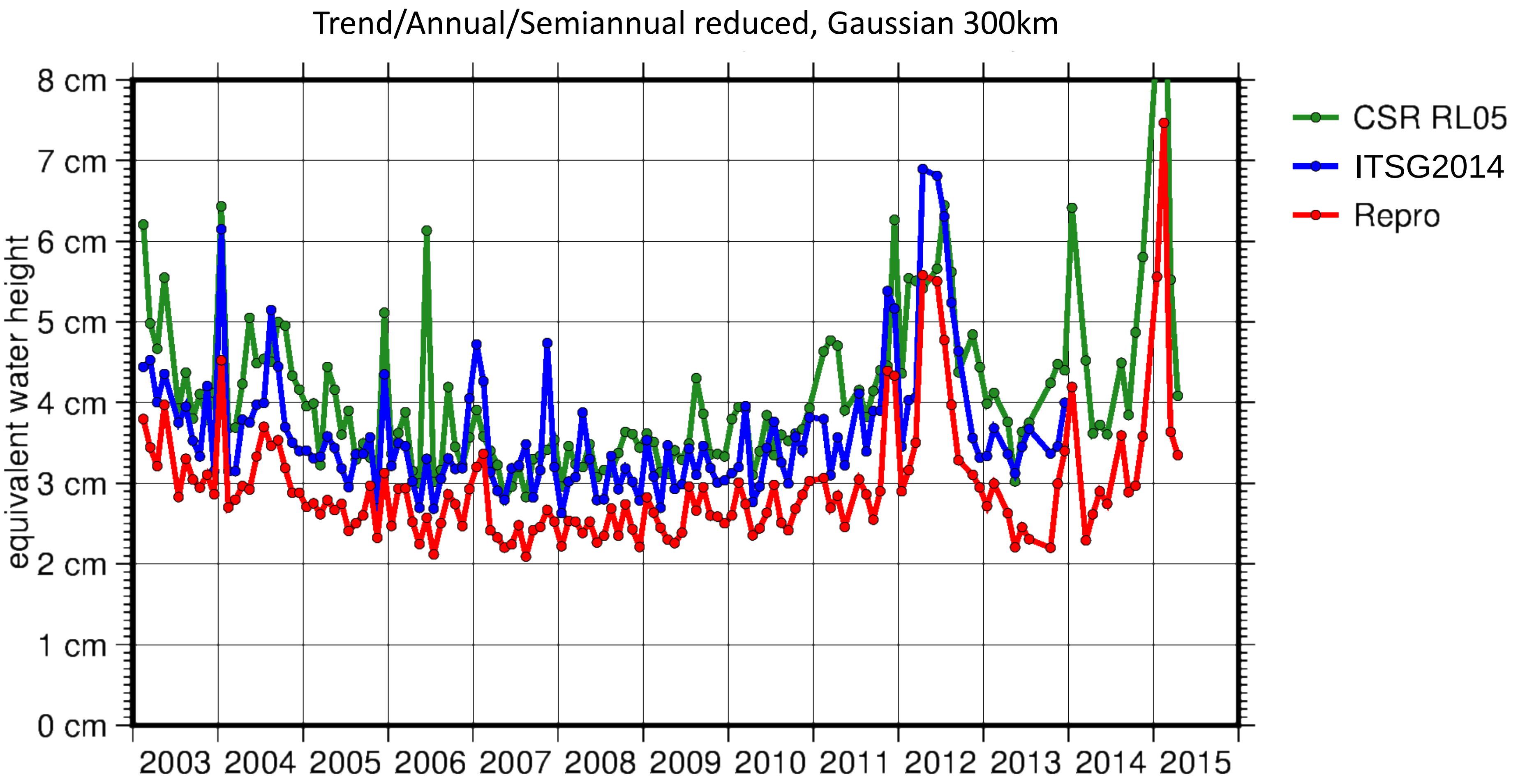
  ⇒ ITSG-Grace2014 (degree 60)

  ⇒ CSR RL05 (degree 60)

- For comparison: monthly time series from 2003-03 to 2013-07

  ⇒ Following month are not included (data missing, repeat orbtis):
  2003-06
  2004-01, 2004-07, 2004-08, 2004-09, 2004-10
  2010-12
  2011-01, 2011-02, 2011-06
  2012-03, 2012-04, 2012-05, 2012-06, 2012-07, 2012-08, 2012-10
  2013-03

Variability over the oceans



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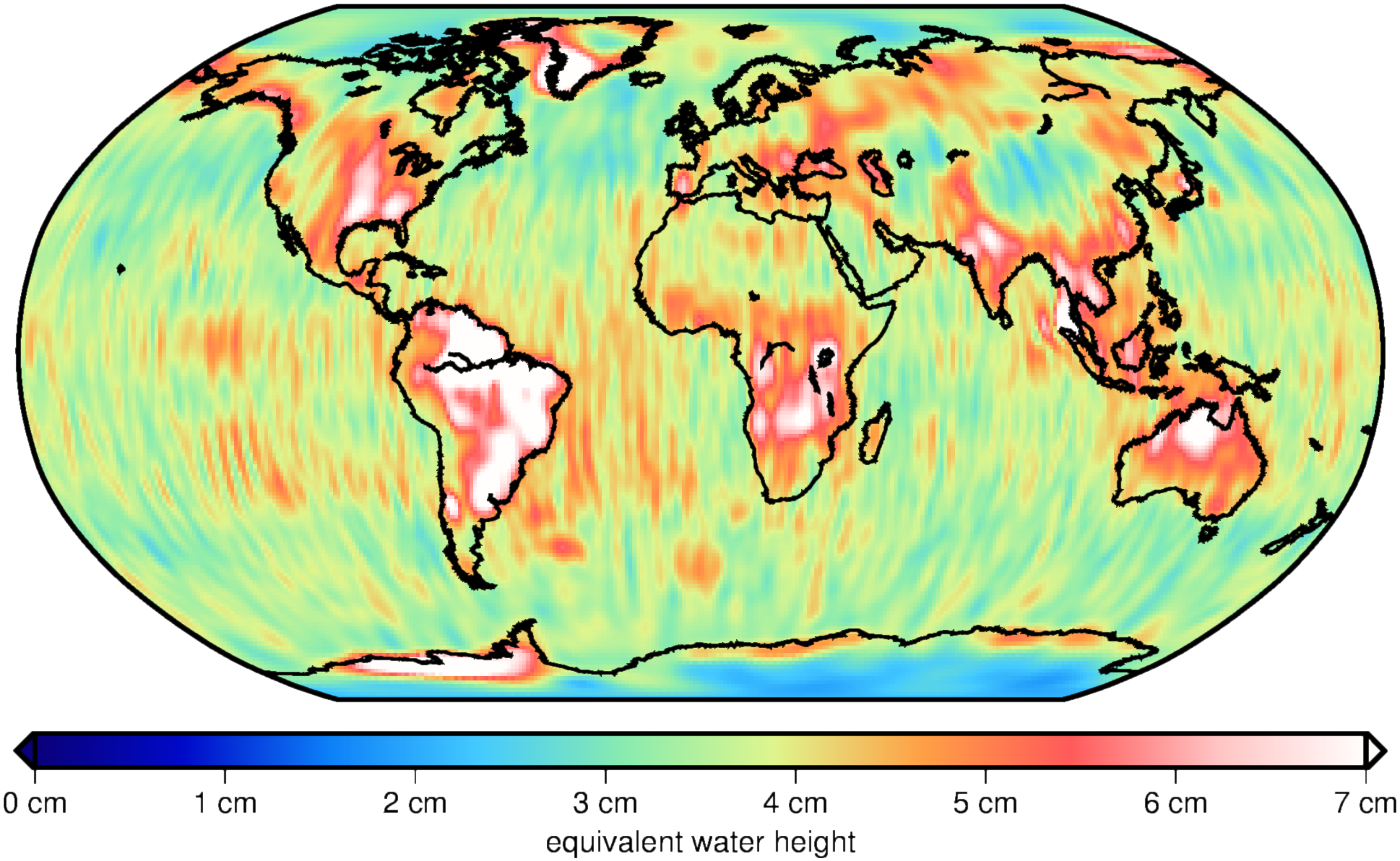
Temporal RMS

CSR RL05
Trend/Annual/Semiannual reduced, Gaussian 300km



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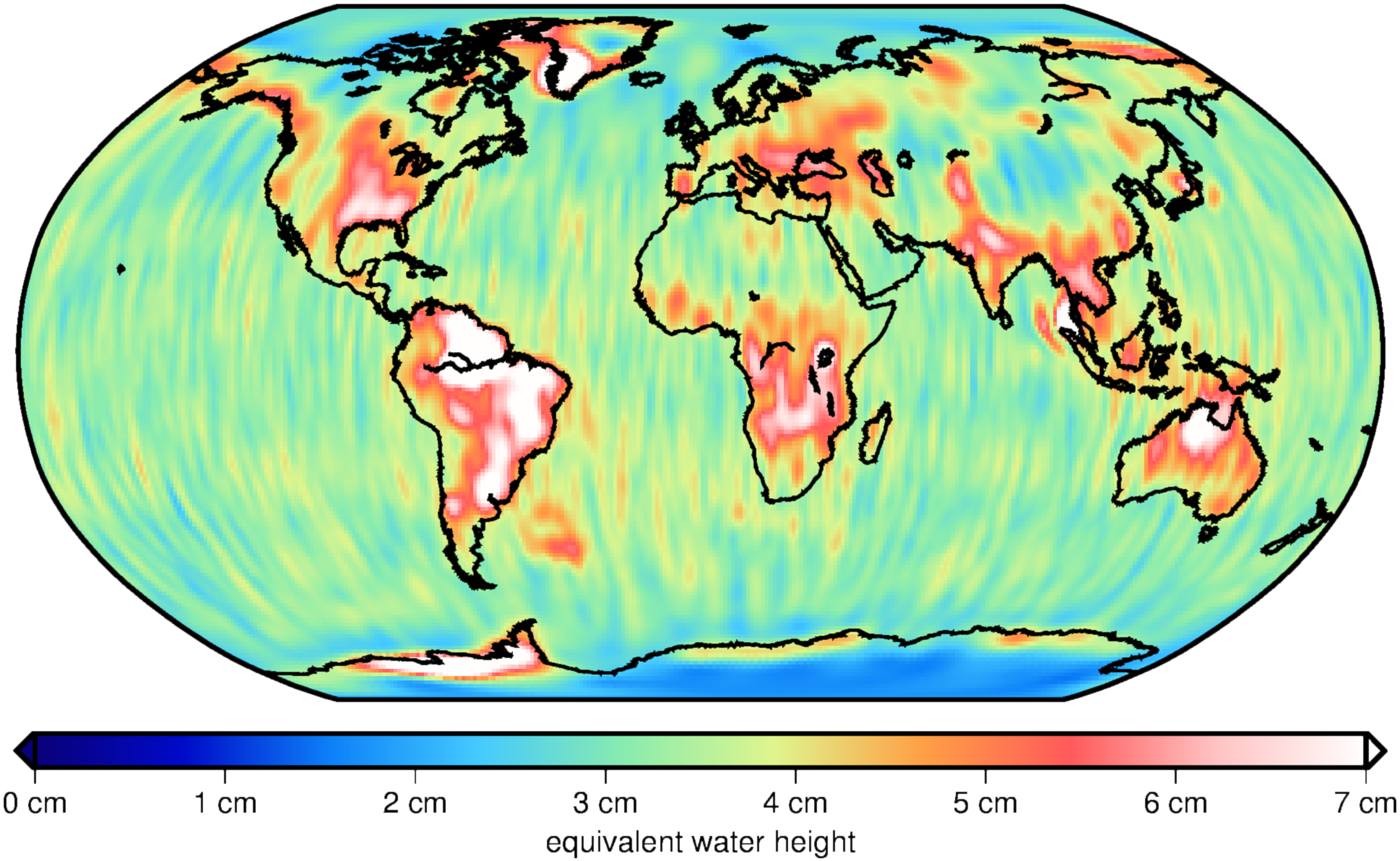
Temporal RMS

ITSG2014

Trend/Annual/Semiannual reduced, Gaussian 300km



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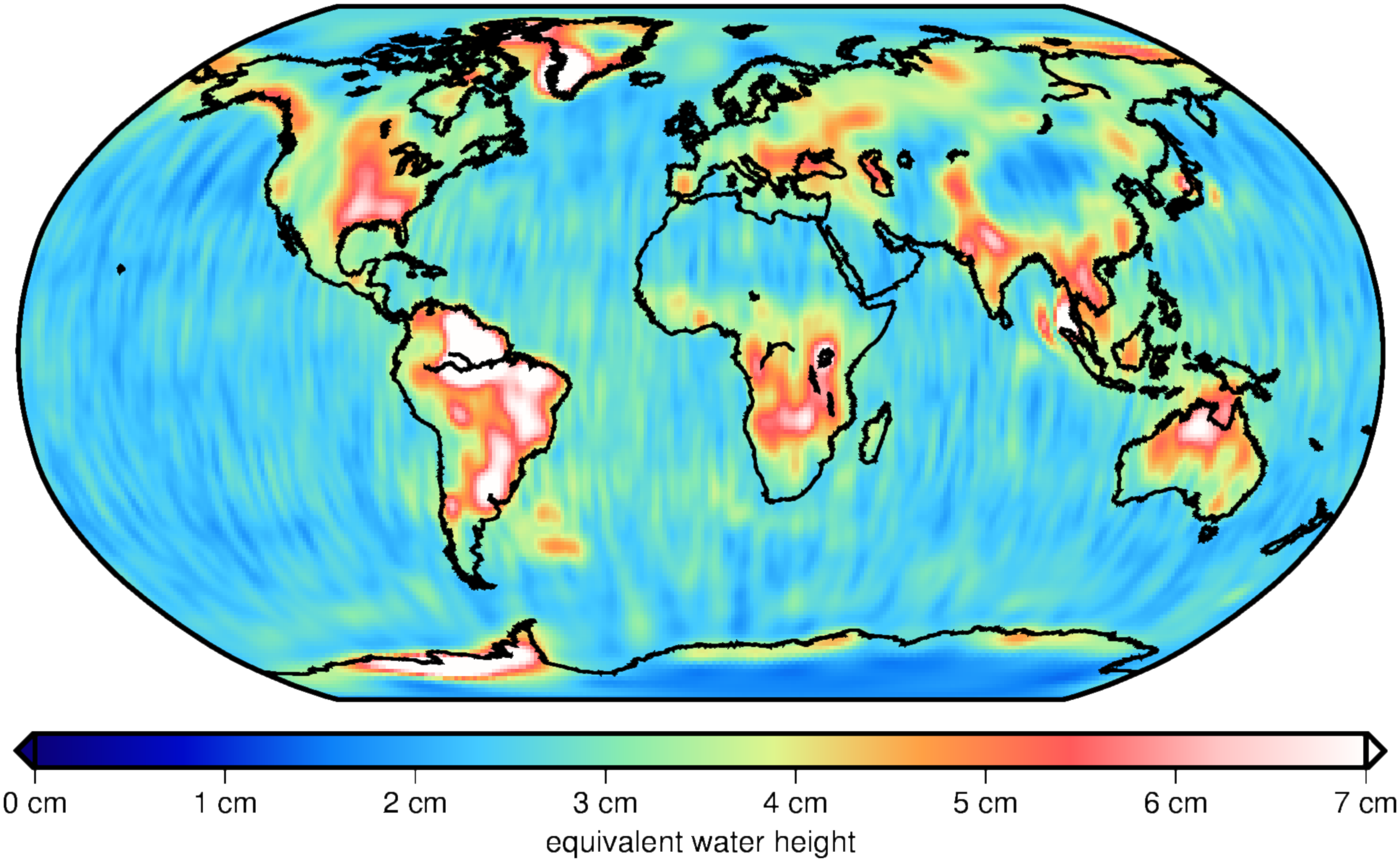
Temporal RMS

Repro

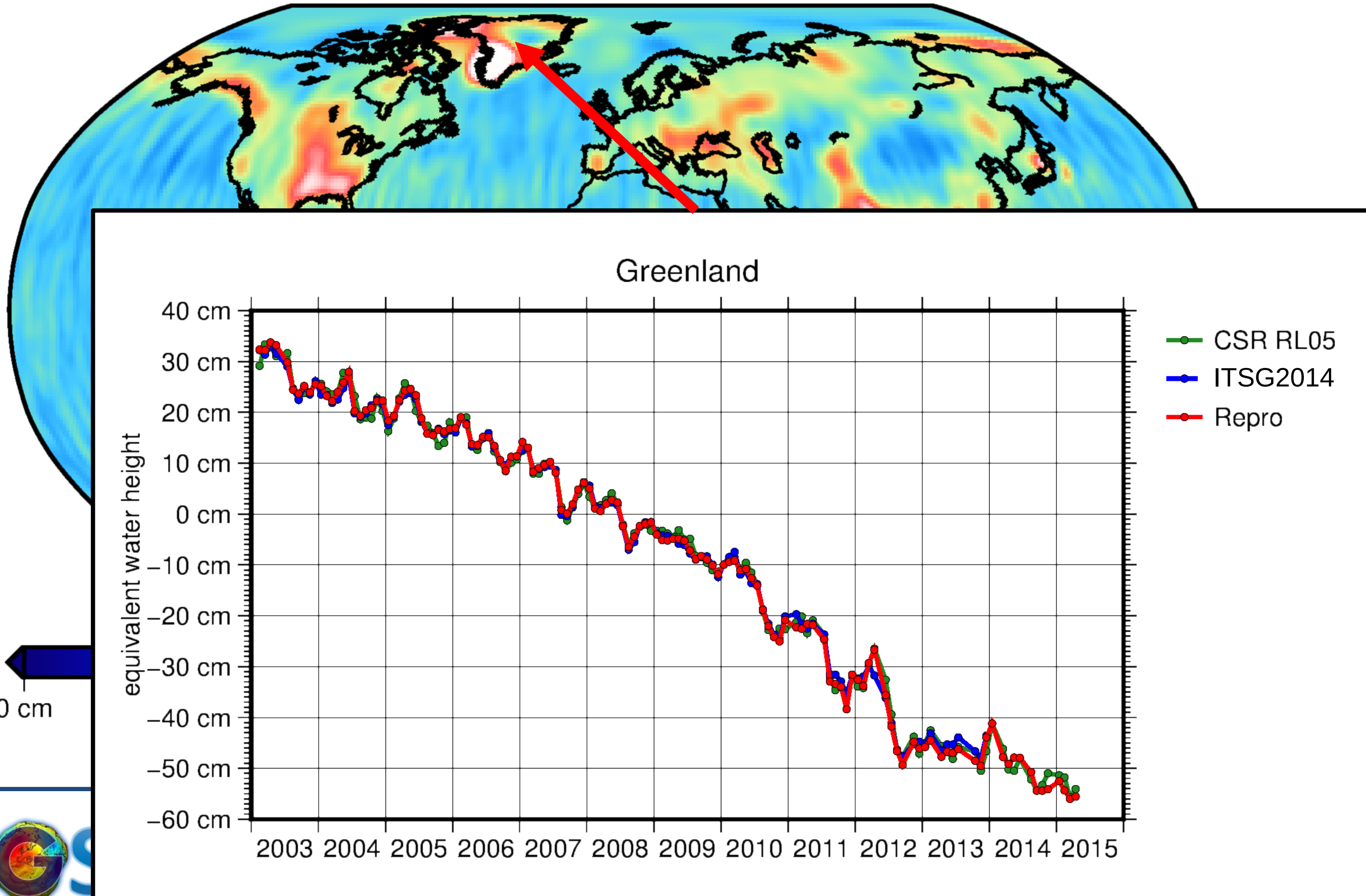
Trend/Annual/Semiannual reduced, Gaussian 300km



Comparison of signals

Repro

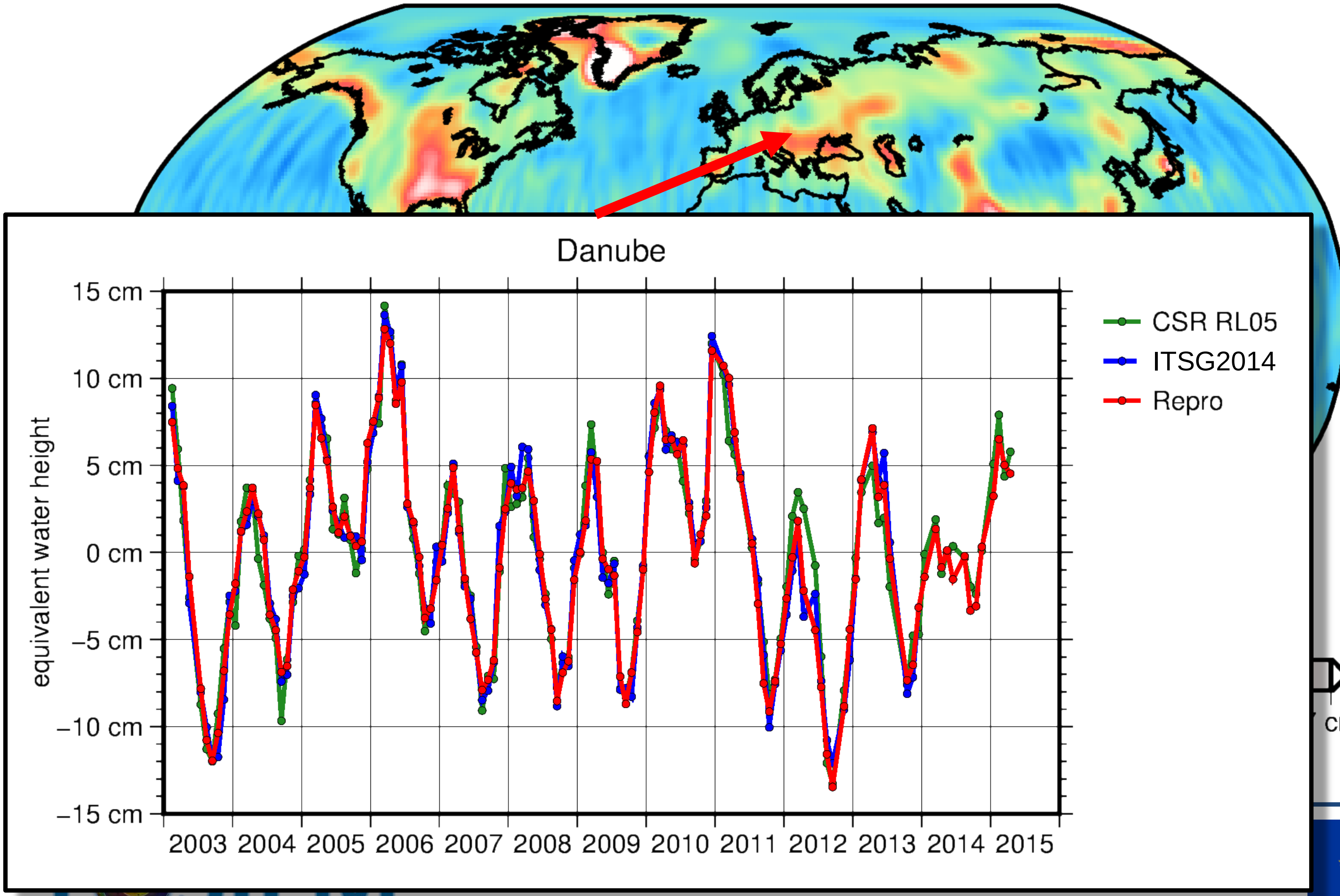
Trend/Annual/Semiannual reduced, Gaussian 300km



HORIZON 2020

Comparison of signals

Repro
Trend/Annual/Semiannual reduced, Gaussian 300km



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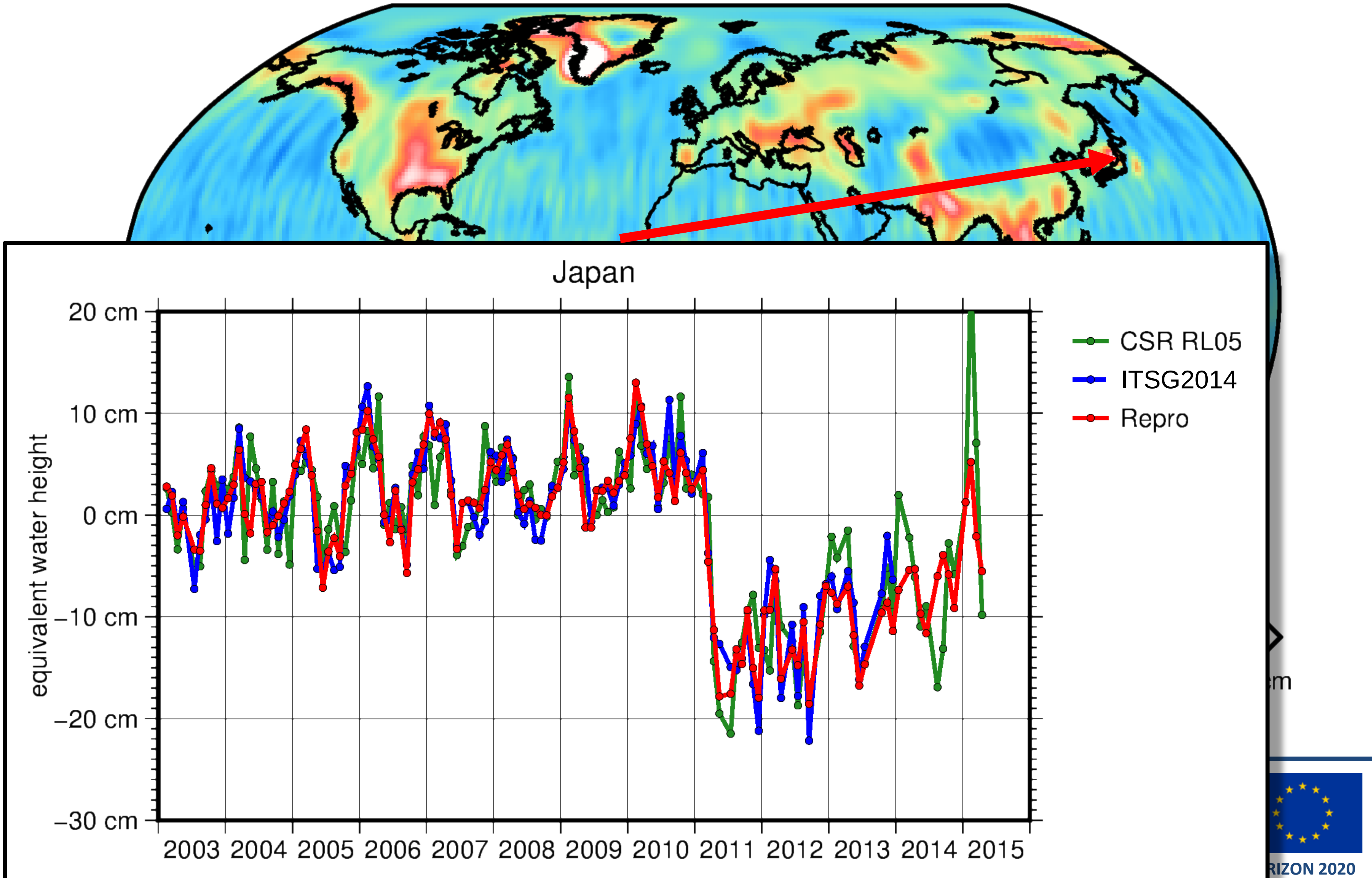
Comparison of signals

Repro

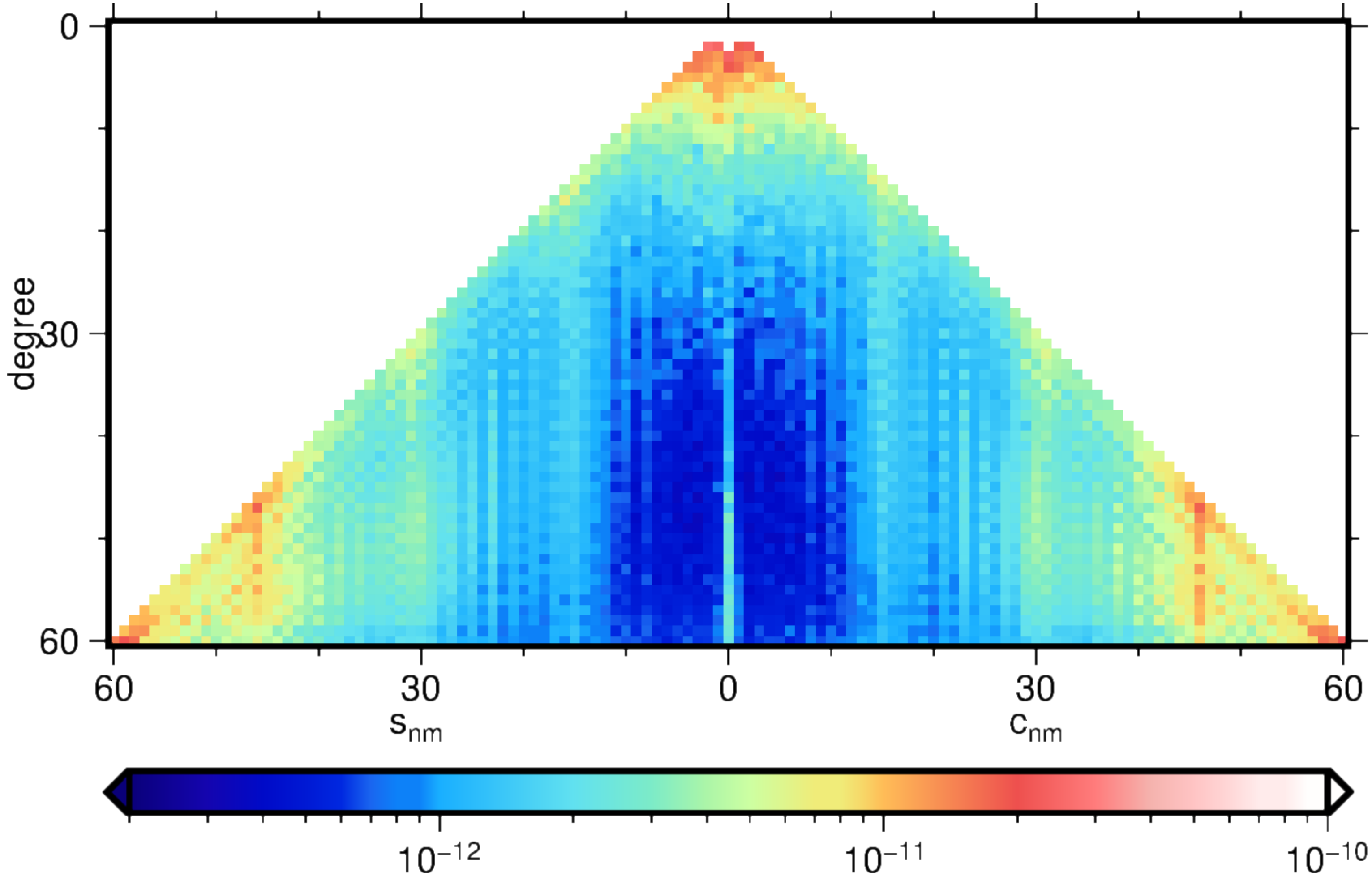
Trend/Annual/Semiannual reduced, Gaussian 300km



Temporal RMS

CSR RL05

Trend/Annual/Semiannual reduced, Gaussian 300km



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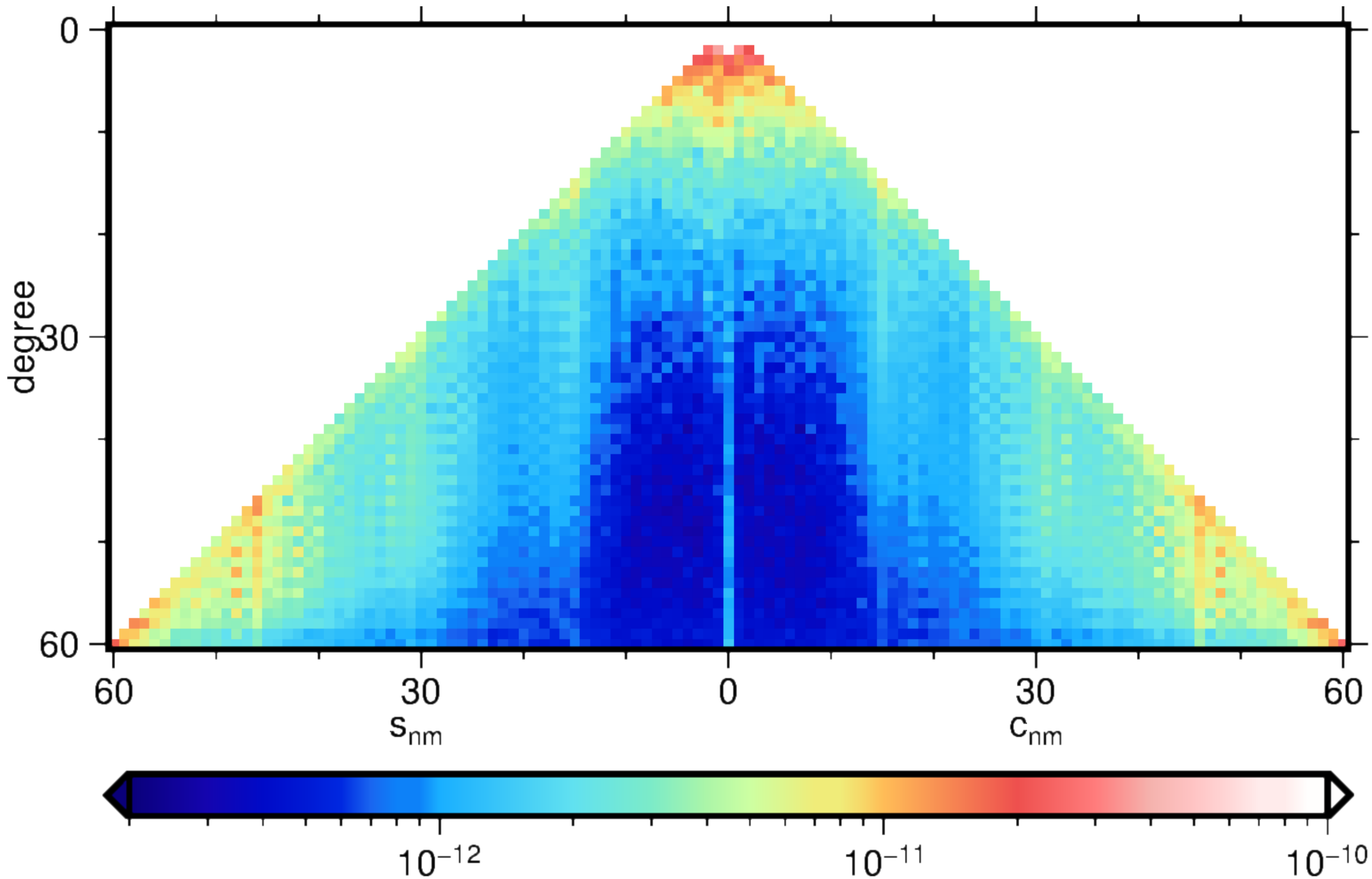
Temporal RMS

ITSG2014

Trend/Annual/Semiannual reduced, Gaussian 300km



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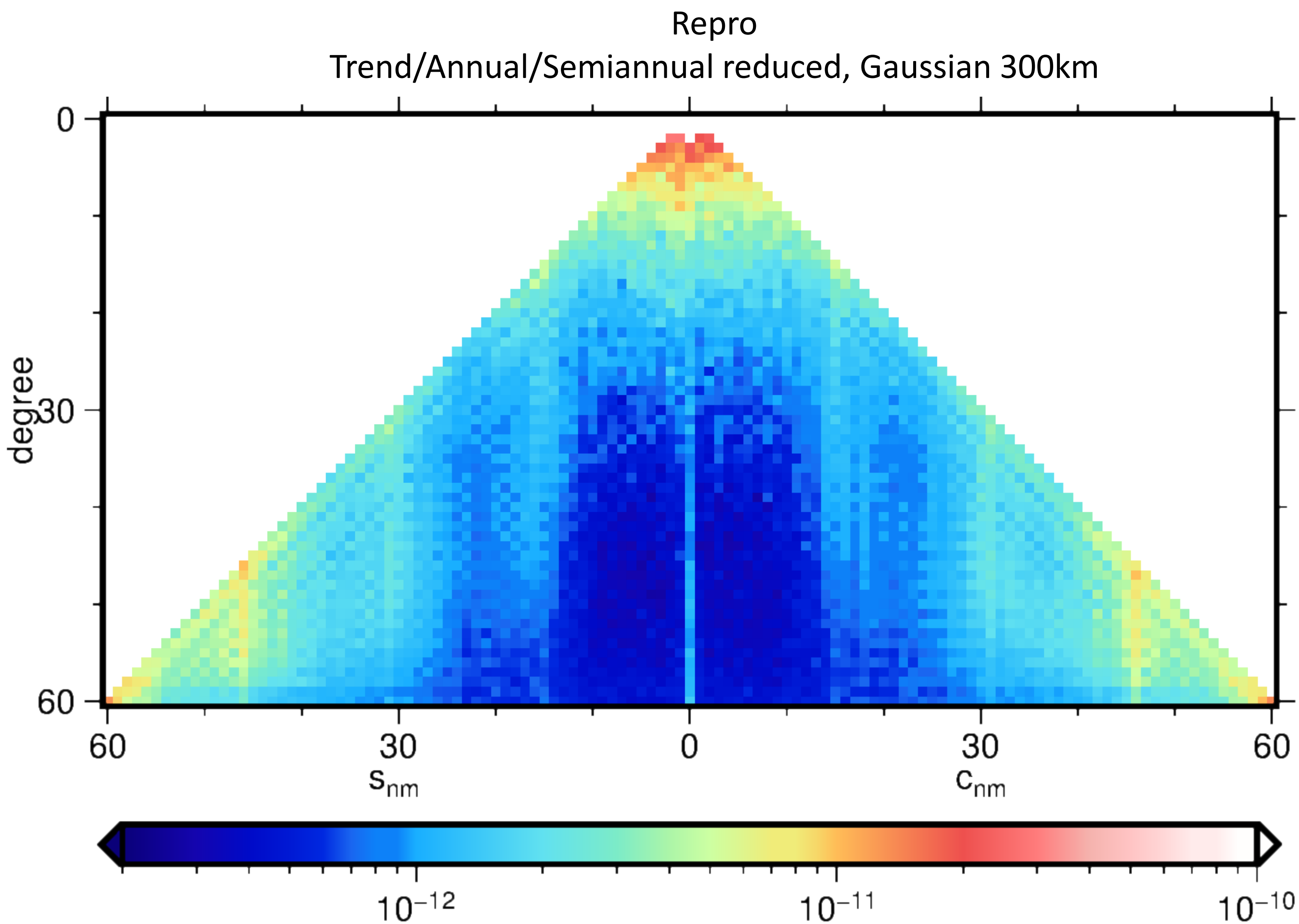
Temporal RMS



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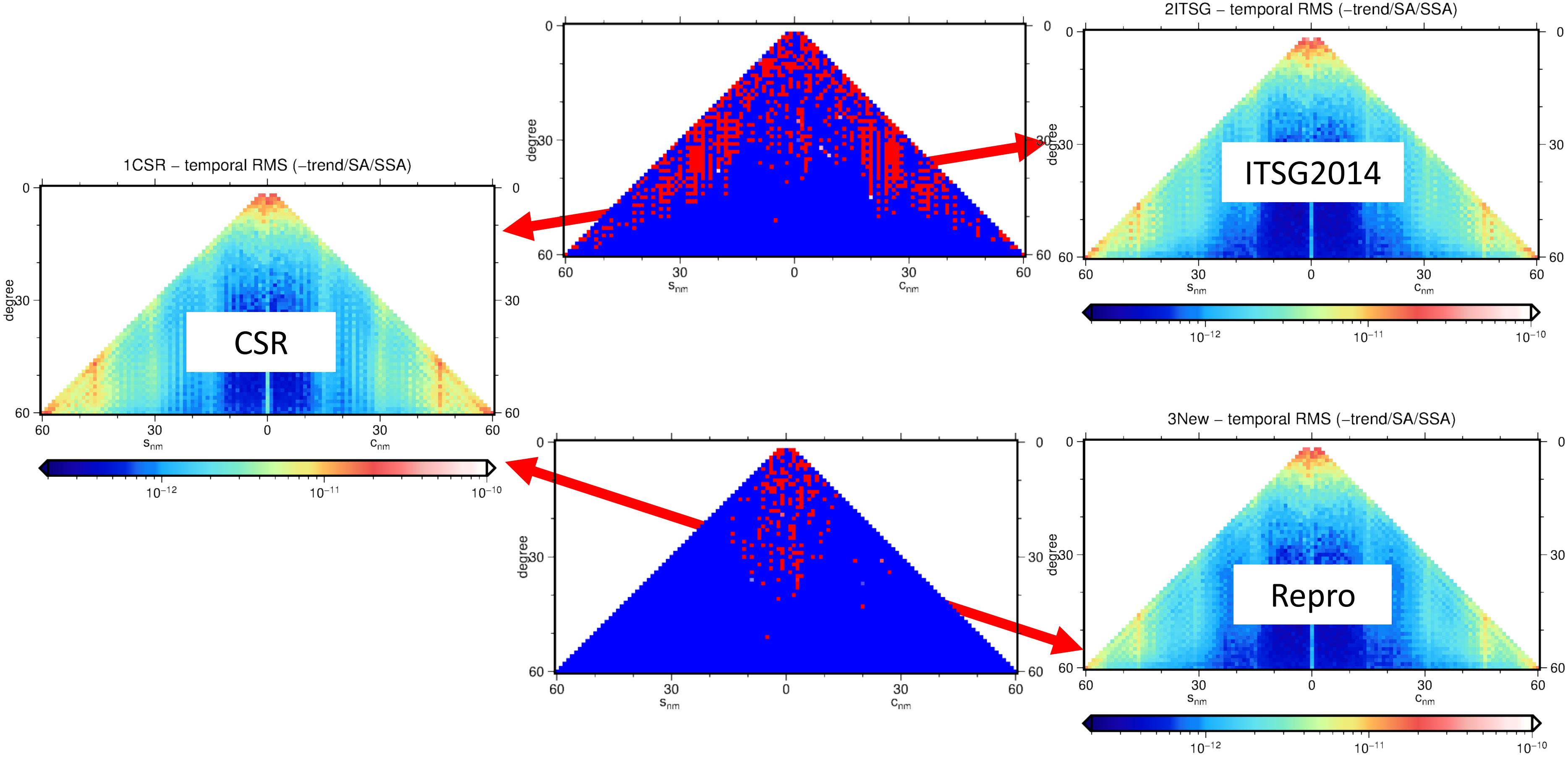
Temporal RMS

Red coeff.: CSR has less scatter



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European Gravity Service for Improved Emergency Management

Title: **CNES/GRGS processing**

Presenter: Richard Biancale / Jean-Michel Lemoine

Affiliation: CNES / GRGS / G &C

EGSIEM - WP2
CNES/GRGS GRACE processing

J.M. Lemoine [(1)], S. Bourgogne [(3)], R. Biancale [(1)], S. Bruinsma [(1)], P. Gégout [(2)]

(1) CNES/GRGS, Toulouse, France
(2) GET/UMR5563/OMP/GRGS, Toulouse, France
(3) Géode & Cie, Toulouse, France

Summary

1. Study of FES2014 ocean tide model
2. Study of GPS and KBR weighting
3. Explanation of problems at the poles

Validation of FES2014

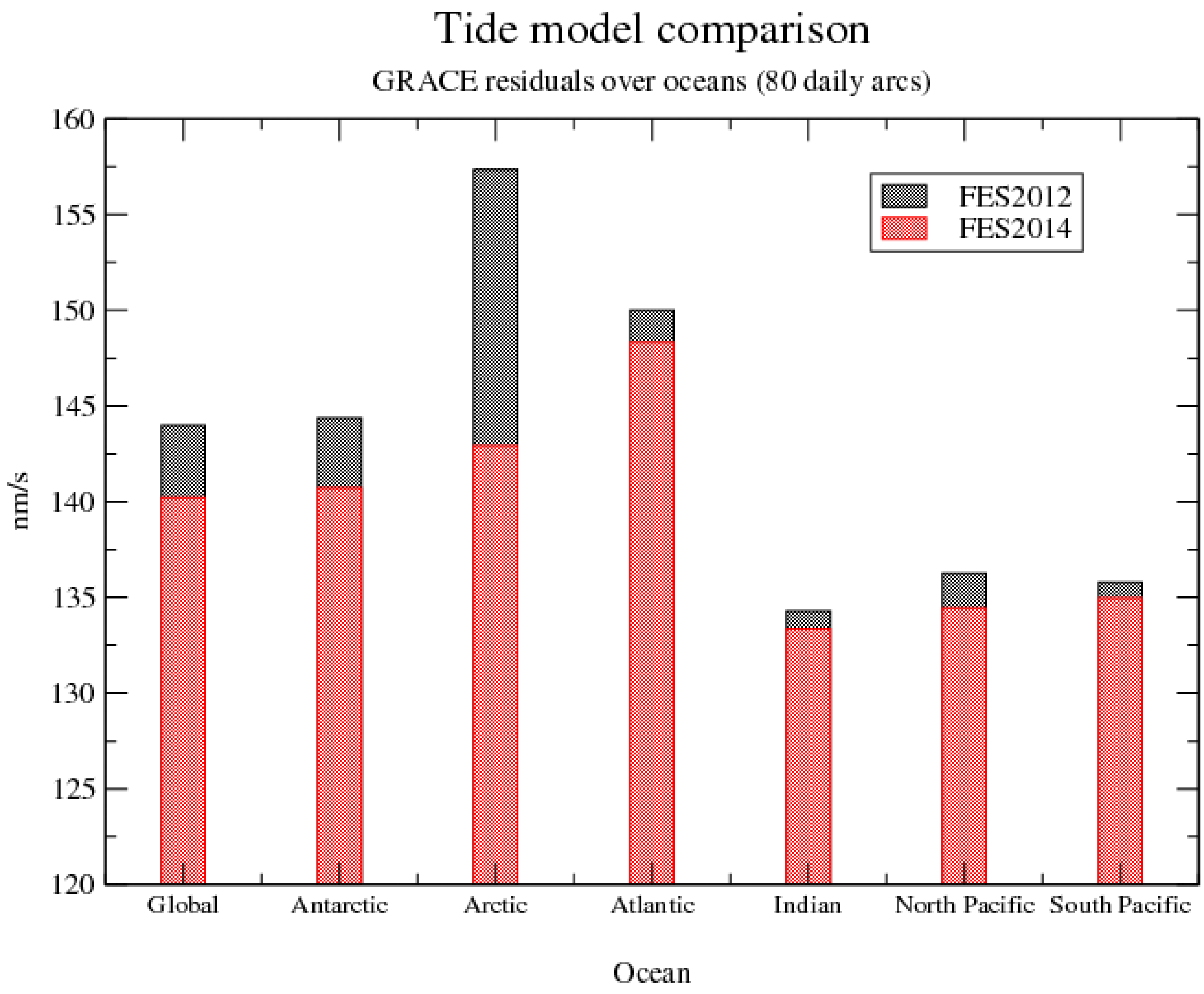
- **FES2014**: ocean tide model released by **LEGOS**, Toulouse, France
- Comparison of GRACE results using **FES2012** or **FES2014**:
  - Study of **GRACE residuals** over oceans
  - Study of differences in **gravity field** restitution

FES2014: GRACE residuals

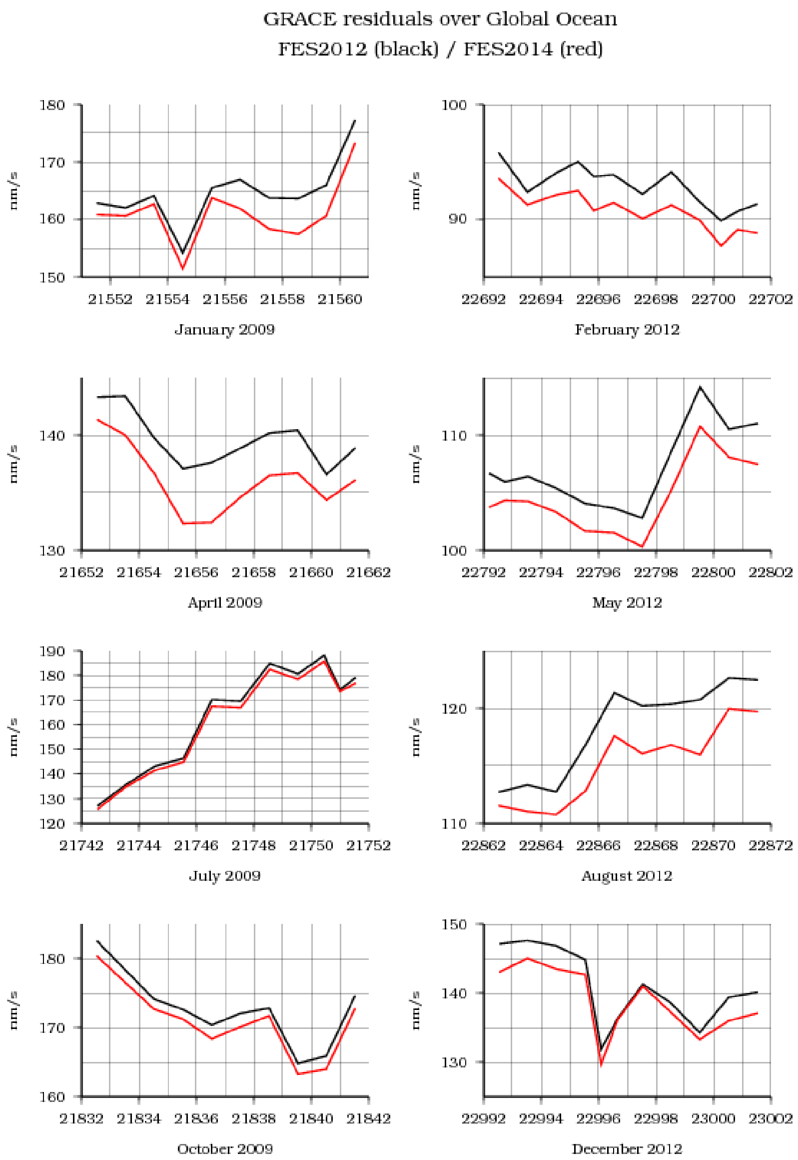
- Test on 8 10-day periods: January, April, July, October 2009 and February, May, August, December 2012.
- GRACE KBRR residuals (nm/s)

Ocean	FES2012	FES2014	Change
Global.dat	143.981	140.203	-2.62 %
Antarctic.dat	144.376	140.721	-2.53 %
Arctic.dat	157.366	142.939	-9.17 %
Atlantic.dat	150.002	148.318	-1.12 %
Indian.dat	134.272	133.367	-0.67 %
NPacific.dat	136.275	134.449	-1.34 %
SPacific.dat	135.807	134.965	-0.62 %

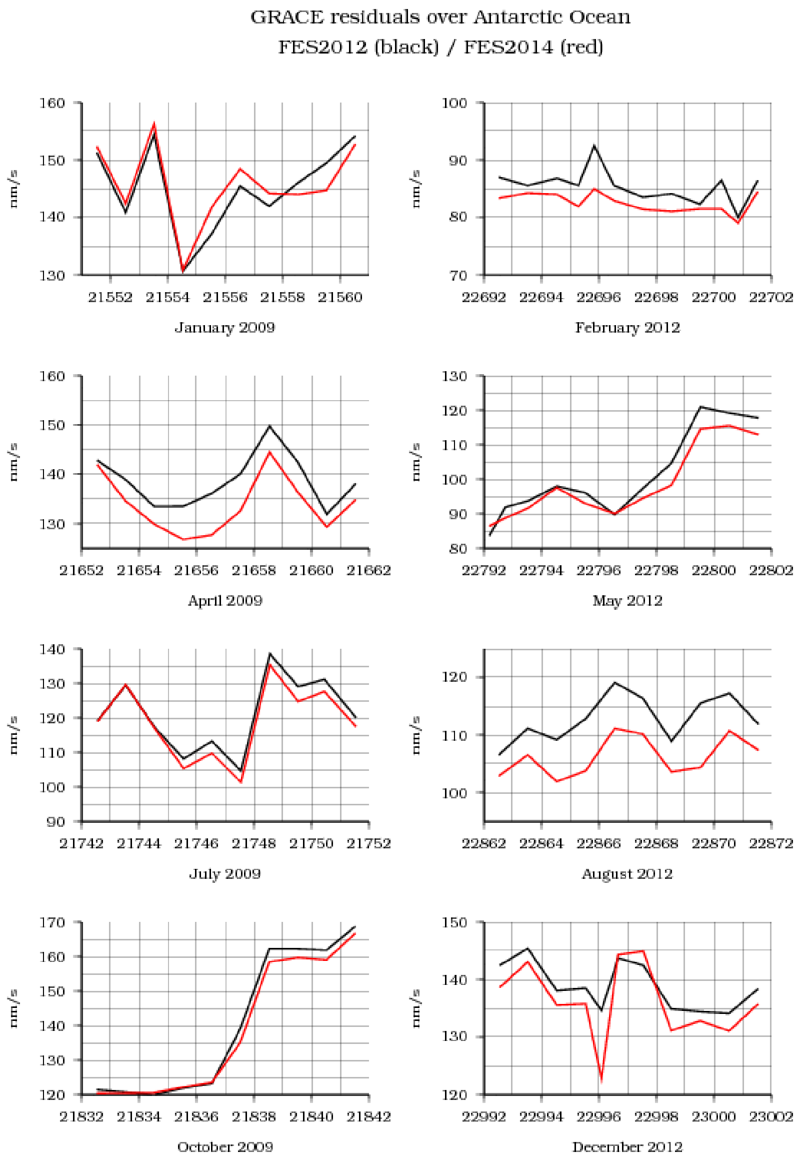
FES2014: GRACE residuals

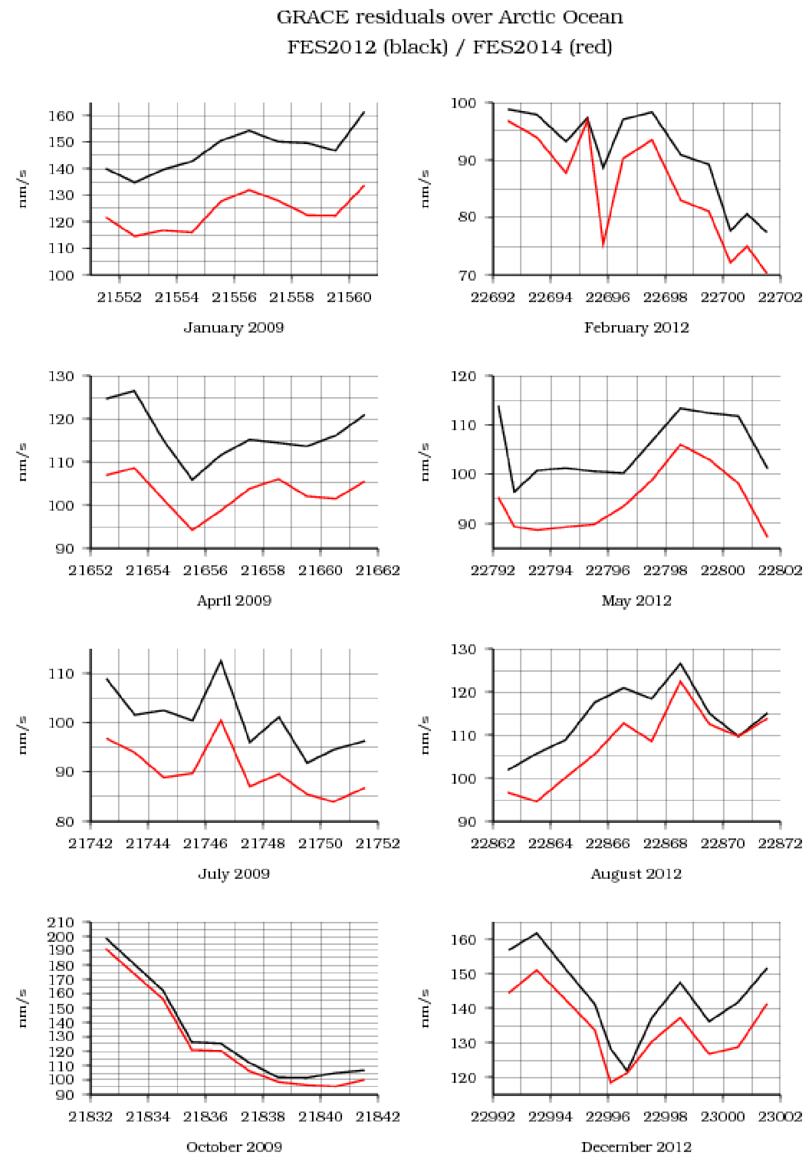


FES2014: GRACE residuals



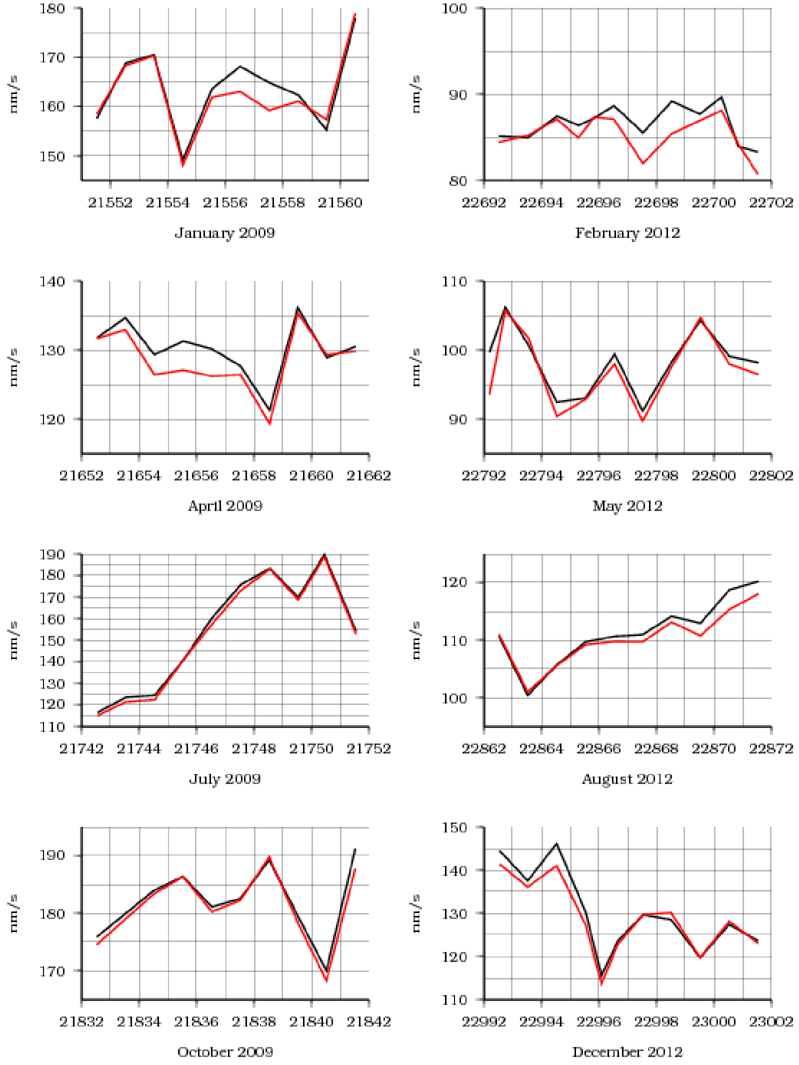
FES2014: GRACE residuals



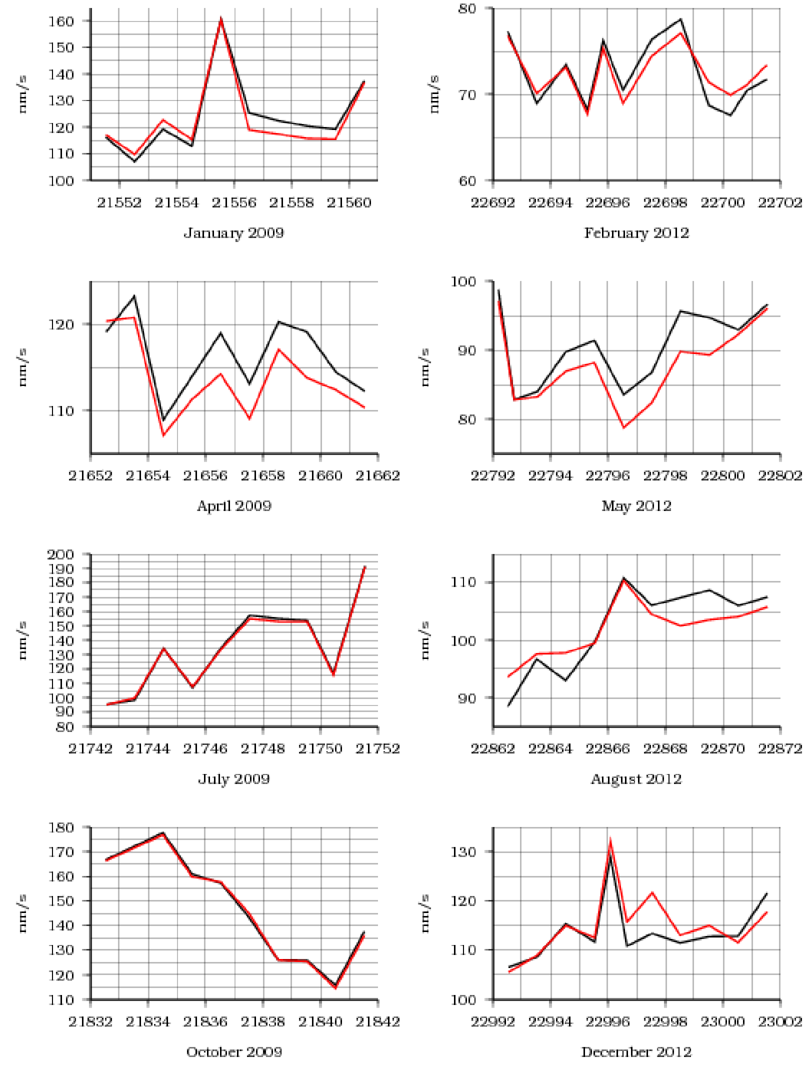


FES2014: GRACE residuals

GRACE residuals over Atlantic Ocean
FES2012 (black) / FES2014 (red)

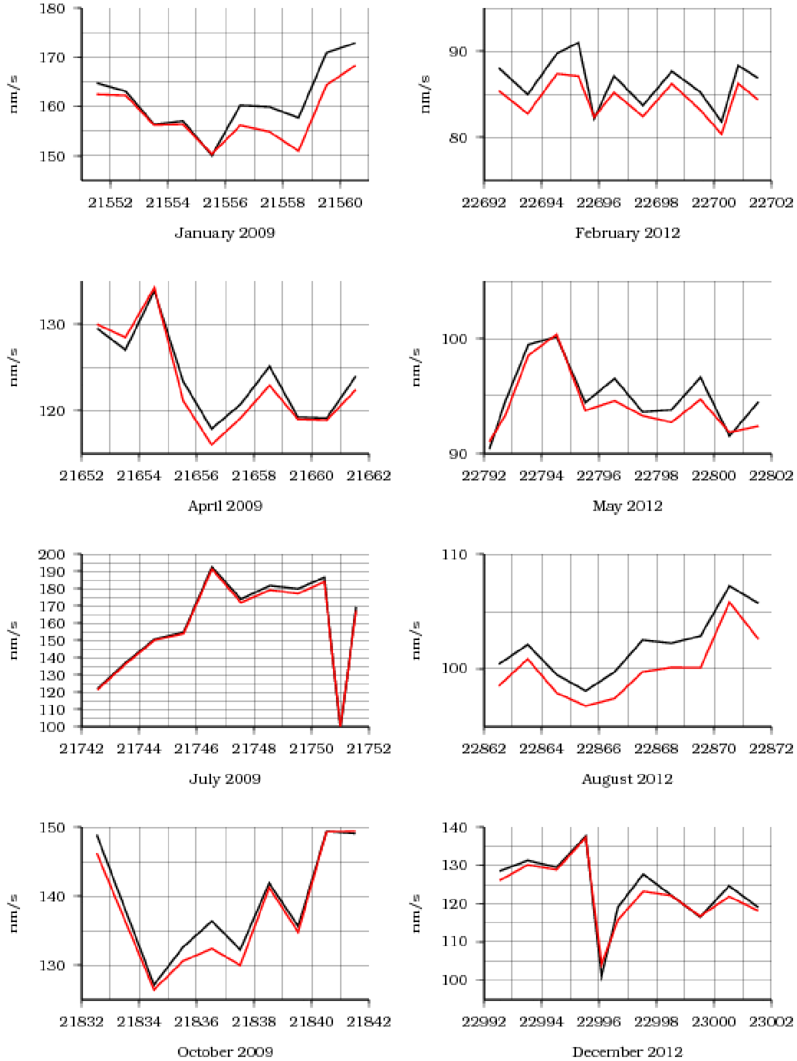


GRACE residuals over Indian Ocean
FES2012 (black) / FES2014 (red)

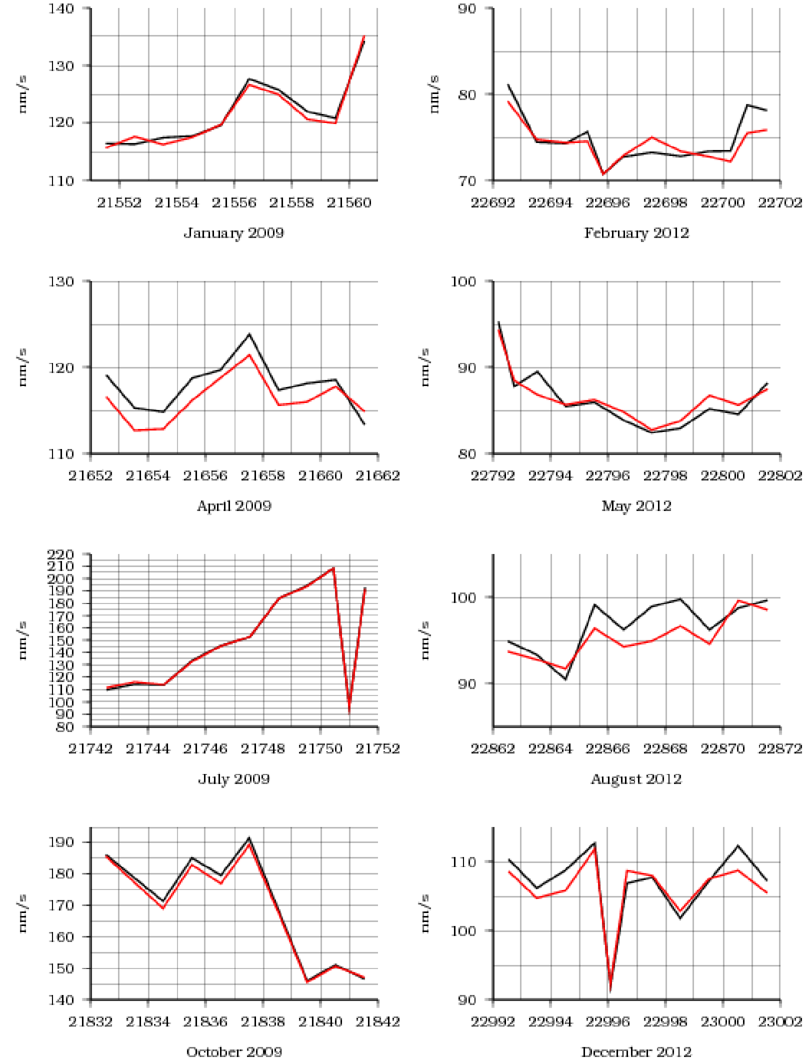


FES2014: GRACE residuals

GRACE residuals over NorthPacific Ocean
FES2012 (black) / FES2014 (red)

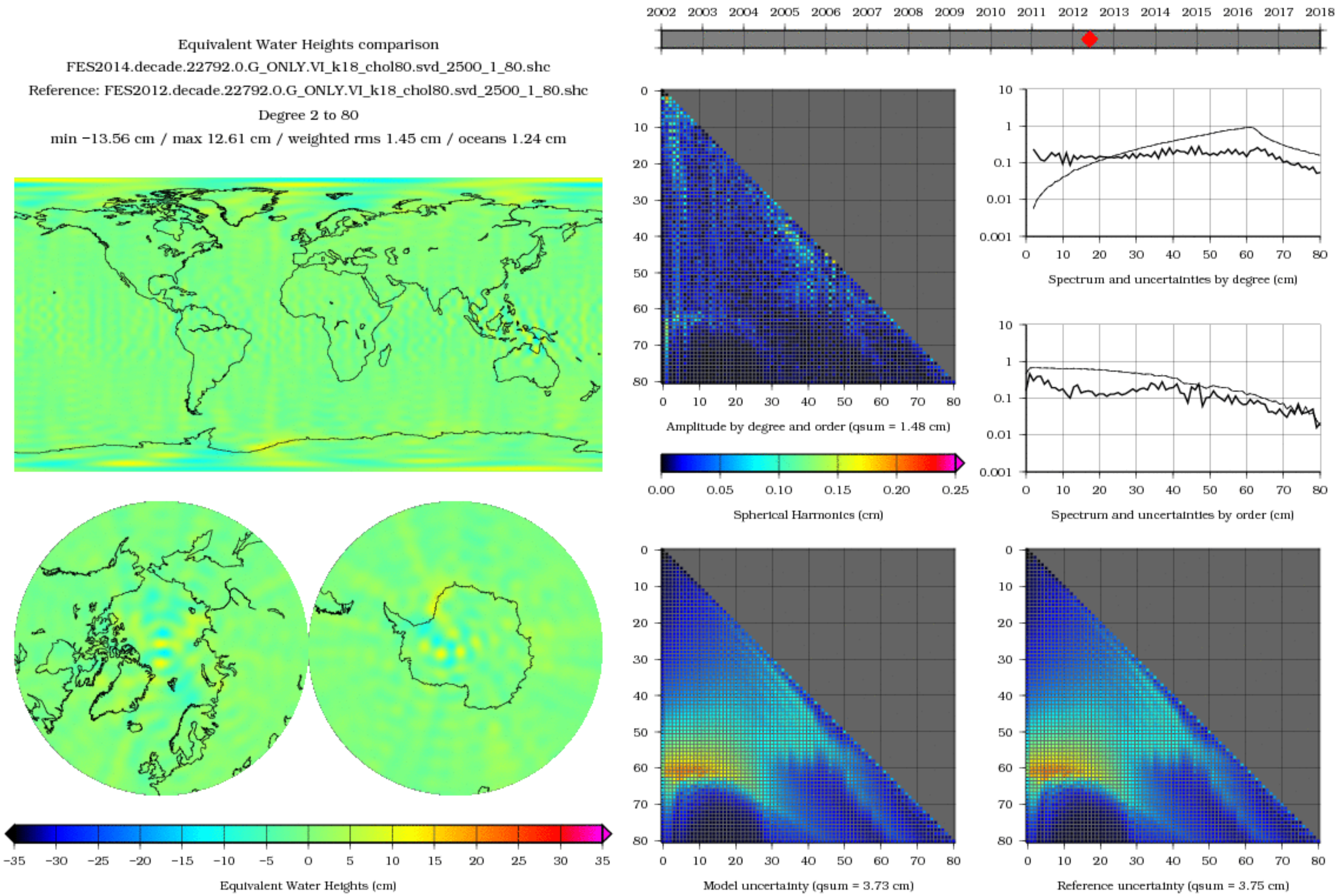


GRACE residuals over SouthPacific Ocean
FES2012 (black) / FES2014 (red)

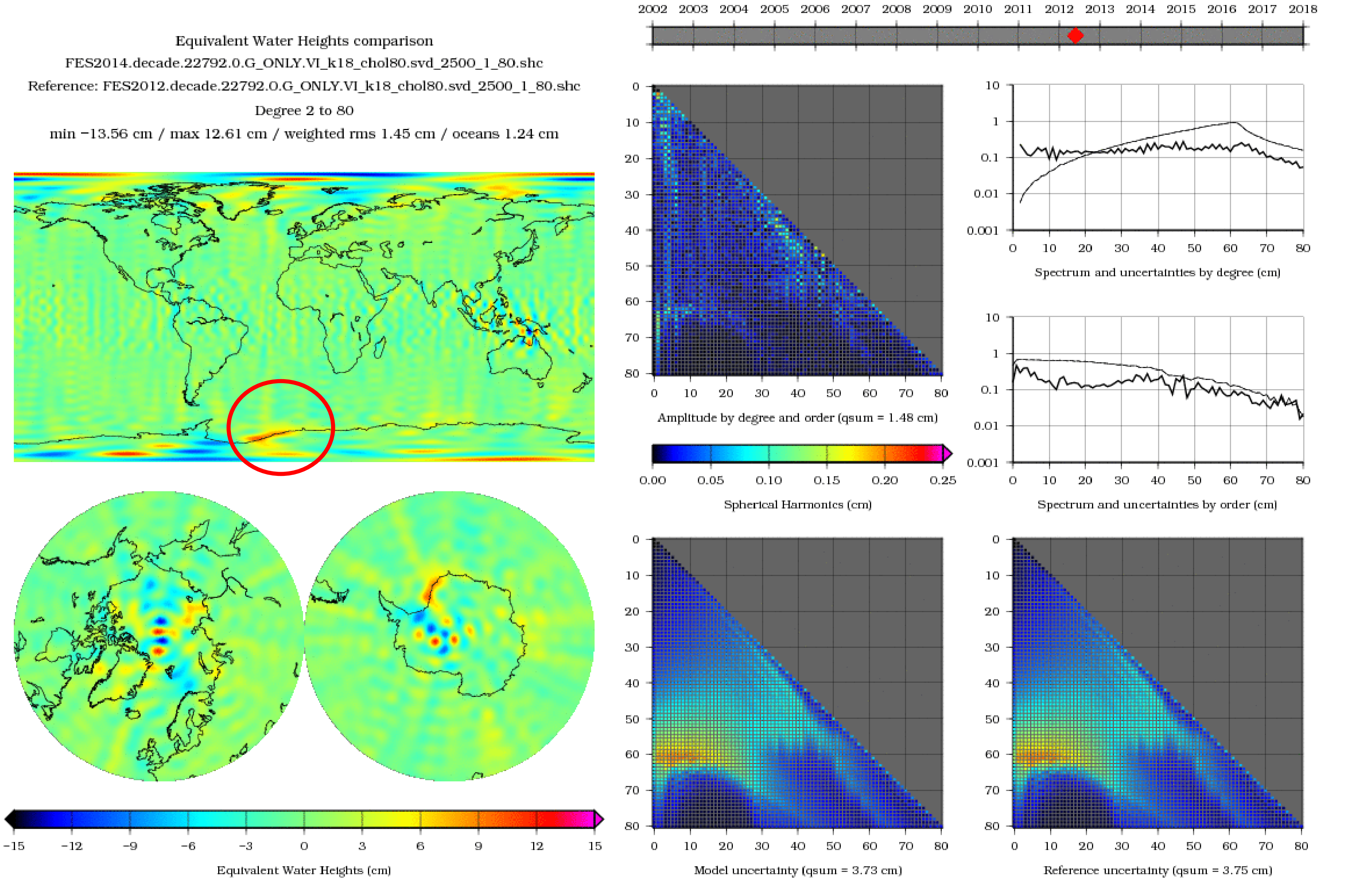


FES2014: Gravity field differences

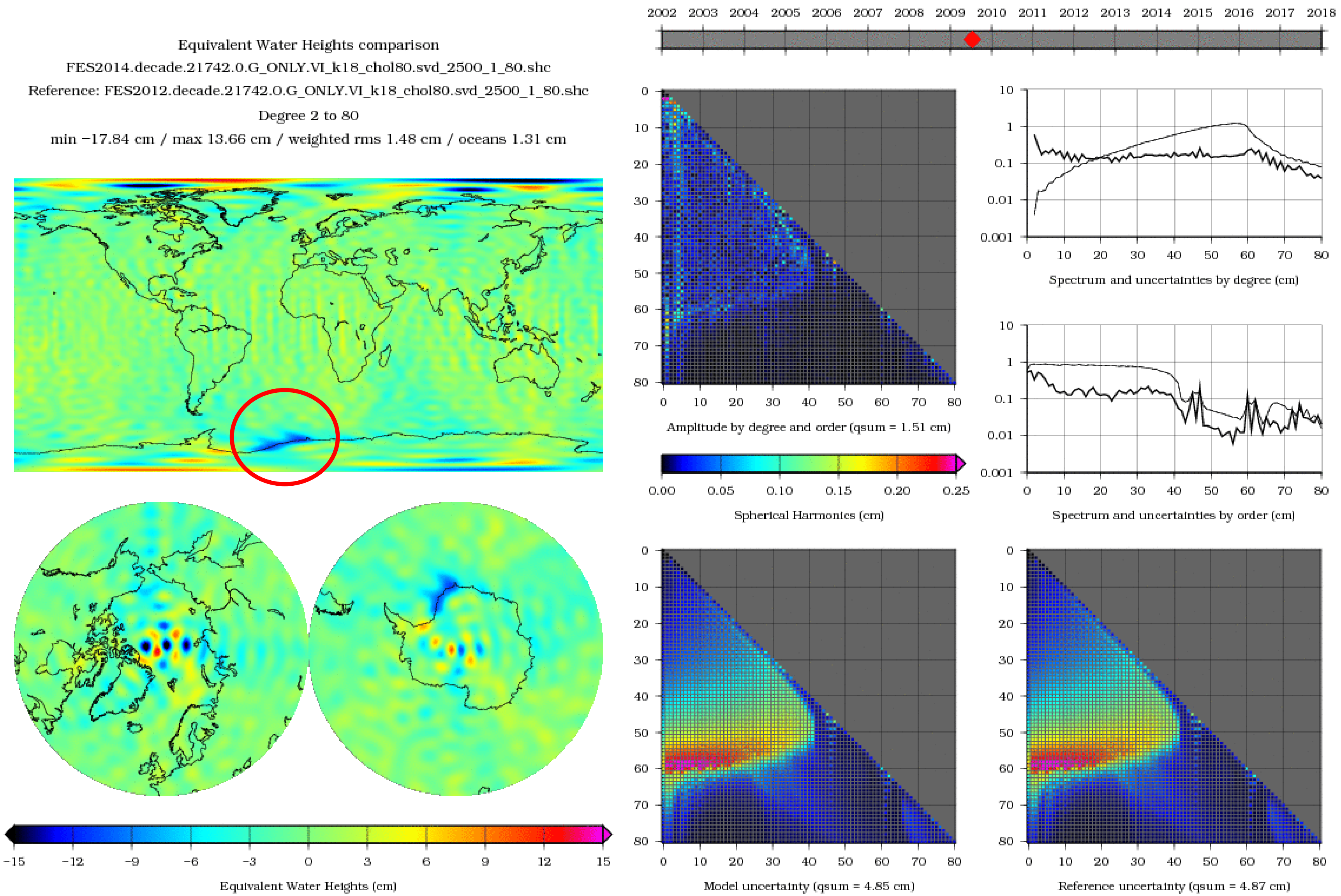
❖ Gravity field restitution : differences are light



FES2014: Gravity field differences (zoom)



FES2014: Gravity field differences (zoom)



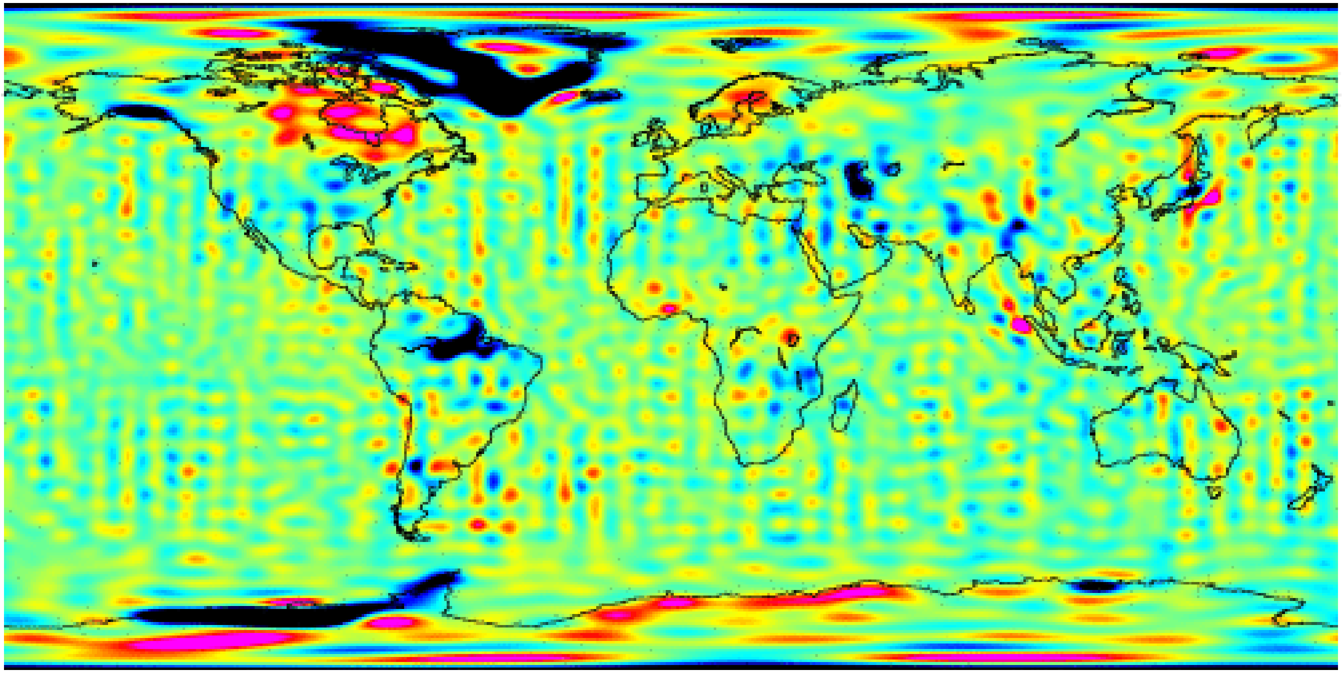
GPS KBR weighting

- **GPS KBR relative weighting**
  - **Weights in orbit restitution step**
  - **Density of measurements (30s or 300s)**
  - **Weight in stacking of normal equations step**
  - **Choice of degree of normal equations for each measurement type**

- **Effects of relative weighting**
  - **GPS weight too high: too much striping in the solution (resonances)**
  - **GPS weight too low: orbit errors, and low sectorial coefficients badly determined**

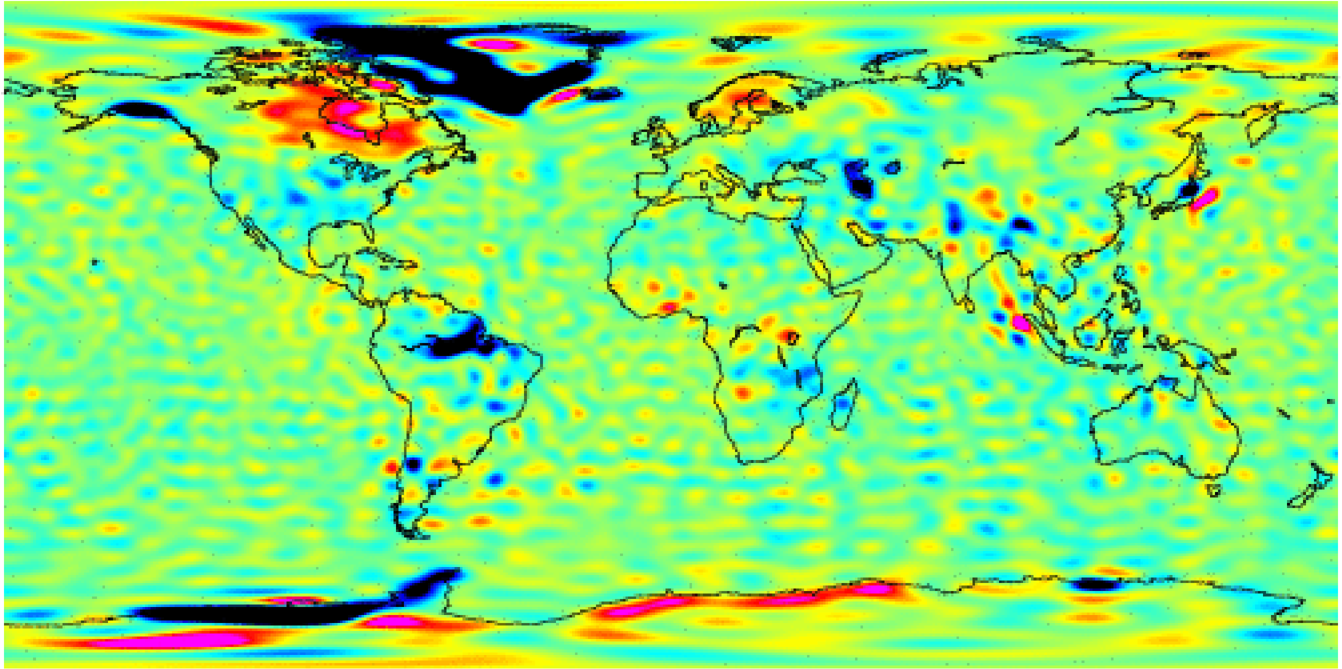
GPS KBR weighting

❖ **Sigma GPS : 8 mm (high weight)**



GPS KBR weighting

❖ **Sigma GPS : 2 cm (low weight)**



GPS KBR weighting

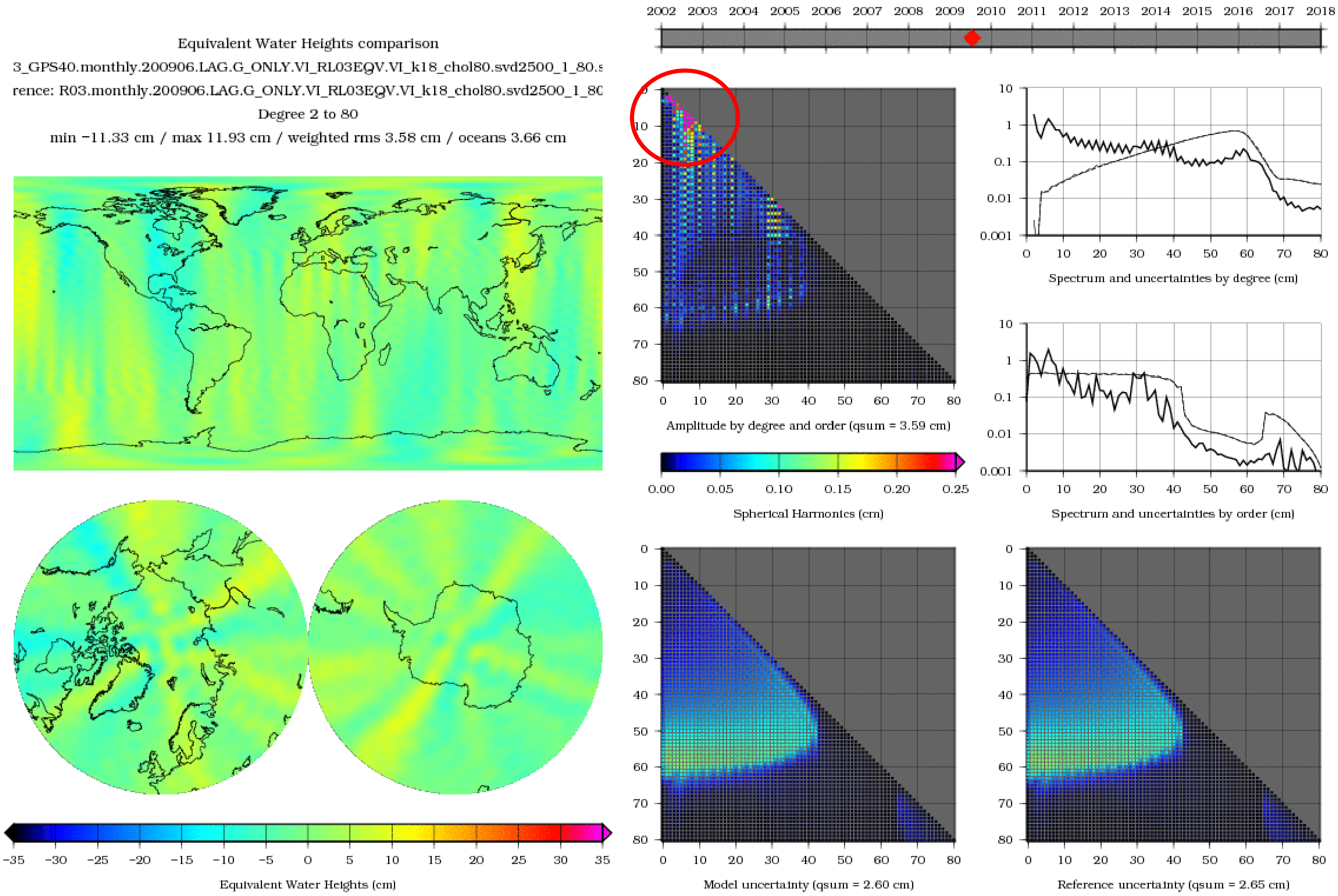
- Tests
  - [High/low density] x [high/low weight]
  - Separation of normal equations with different weights
  - Degree of GPS equation cut to 40

- Best solution
  - Best compromise : high density, low weight
  - Even better : cut GPS equation to degree 40, then the weight is not a problem anymore

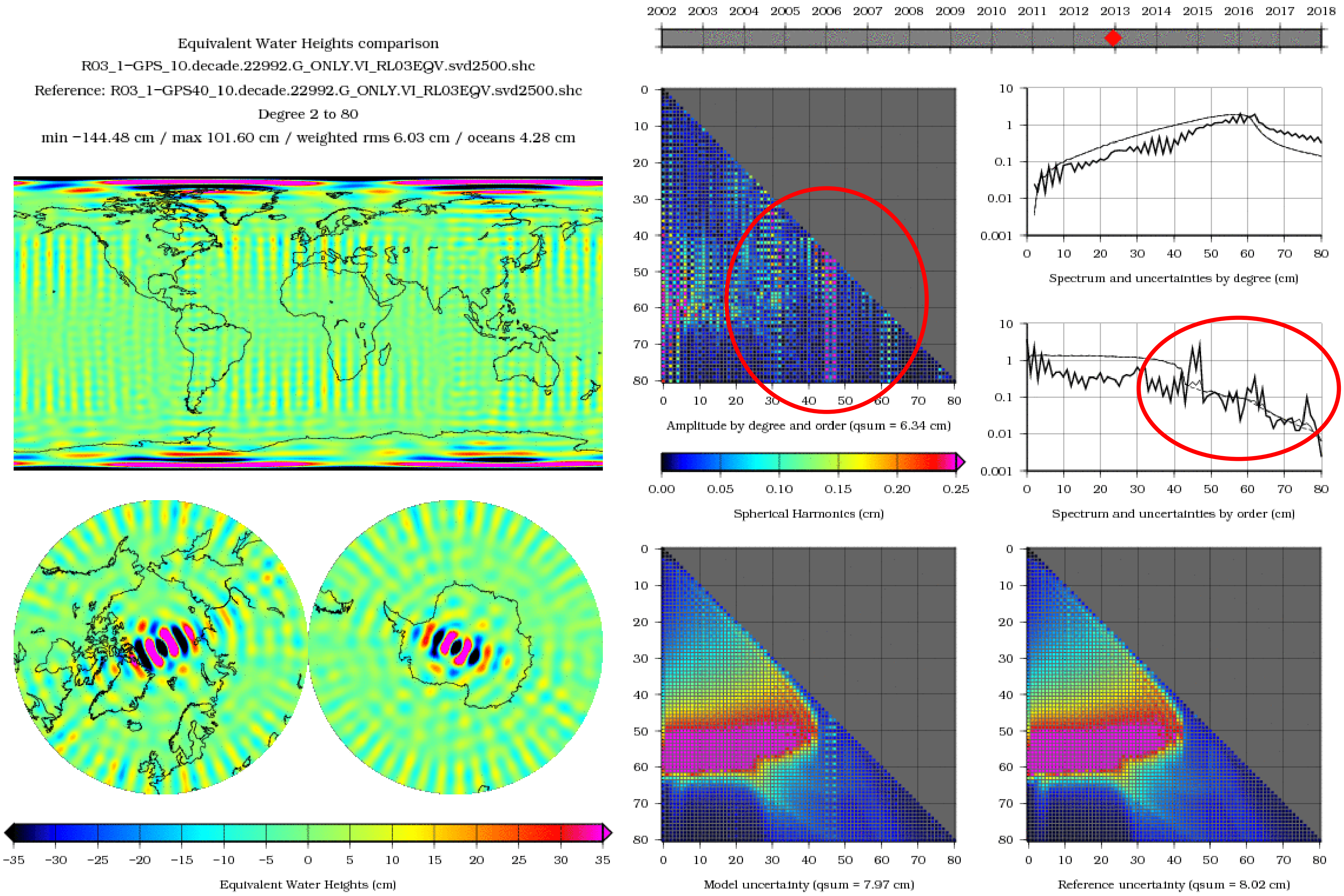
GPS KBR weighting

- From our RL03 equations (underweighted GPS)
    - Stack of GRACE-GPS normal equation up to 40
    - Stack of GRACE-GPS normal equation up to 80

Up to 40 : improves low degrees



From 40 to 80 : adds noise and striping

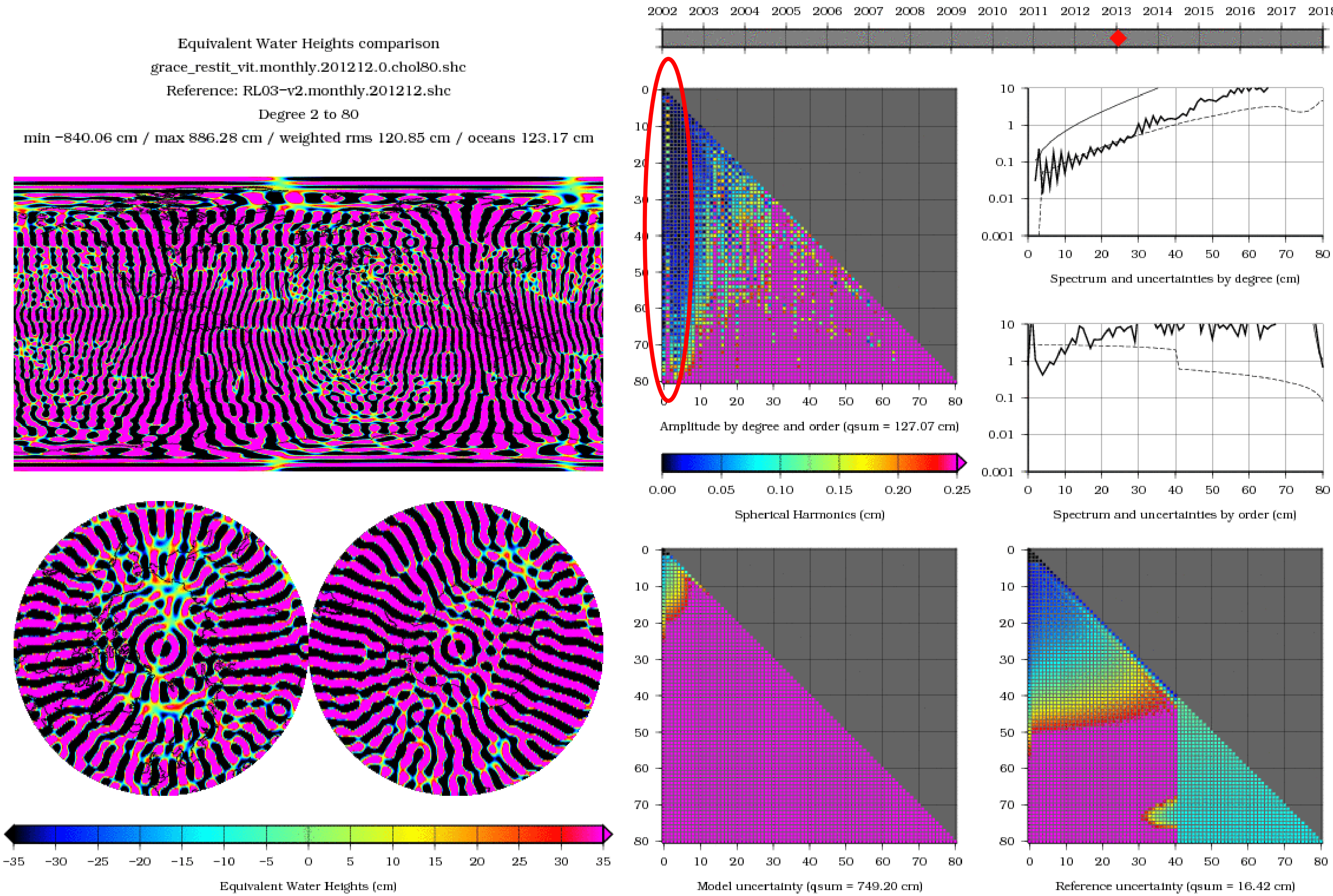


Problems at the poles

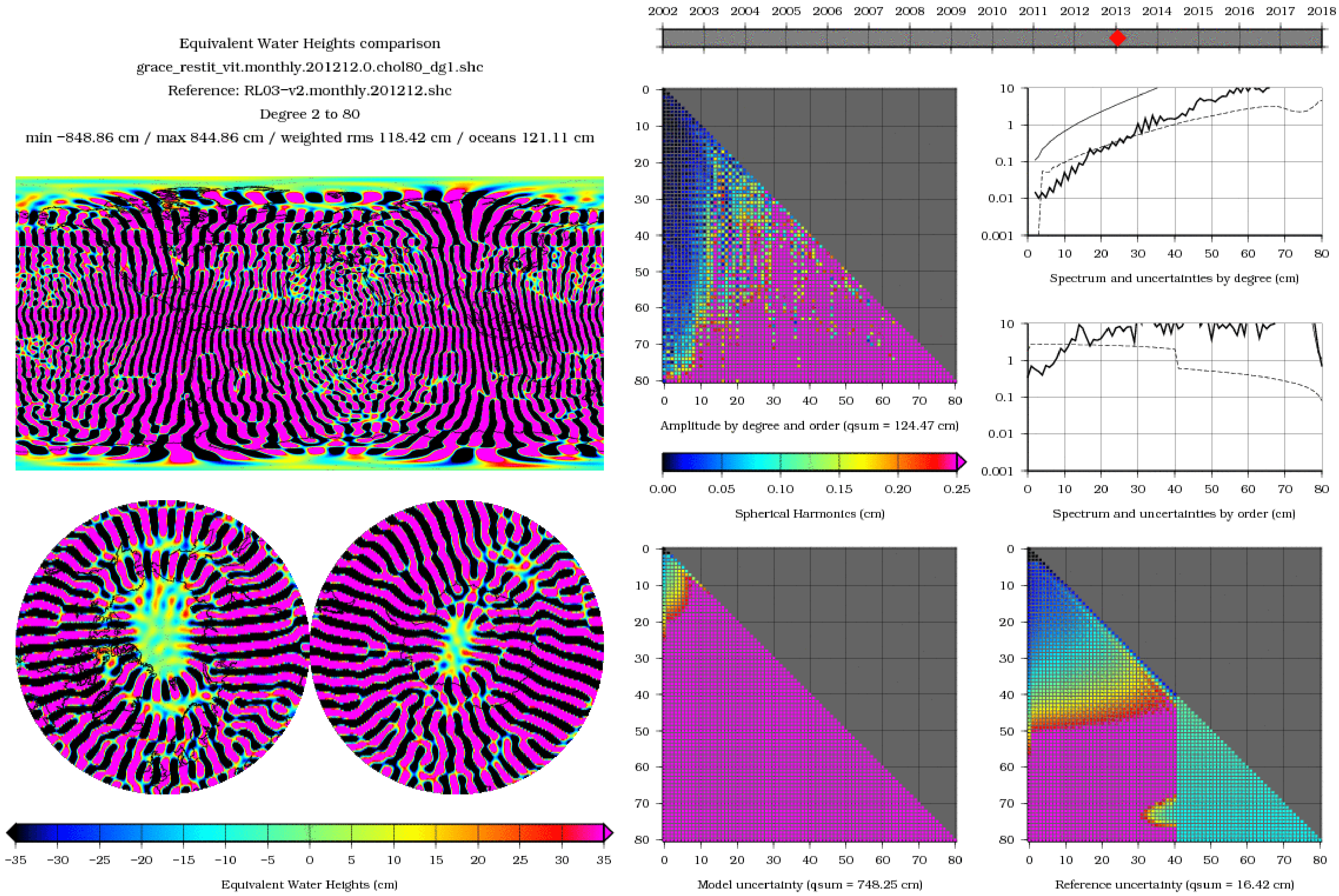
- Problems at the poles
  - They are not immediately related to GPS
  - Appear when low sectorial coefficients are wrong (compensation on higher orders). This can be the case when those are fixed, or with SVD

- Examples
  - Cholesky inversion (no constraint), with degree 1 fixed or solved
  - Two step inversion (Cholesky + SVD)

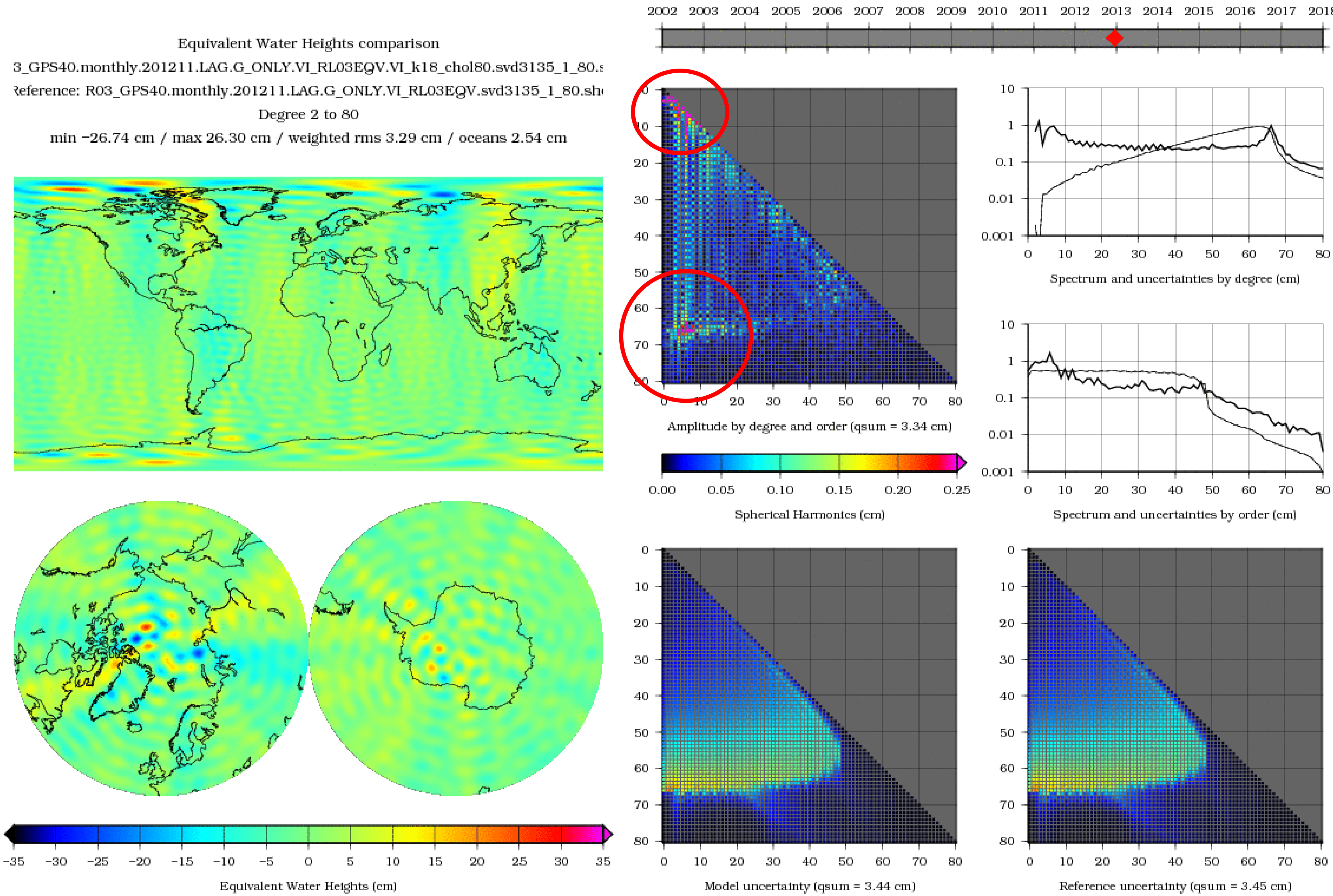
Degree 1 fixed



Degree 1 solved



Impact of wrong low-degree sectorials



Conclusions

❖ Conclusions

- ❖ FES2014 brings a clear improvement to the processing standards
- ❖ Cutting the GPS equations to degree 40 eliminates most of unwanted noise
- ❖ Problems are the pole can be avoided if low degree sectorials are correctly solved

European Gravity Service for Improved Emergency Management

Title: **ULux processing**

Presenter:

Affiliation: ULux

EGSIEM

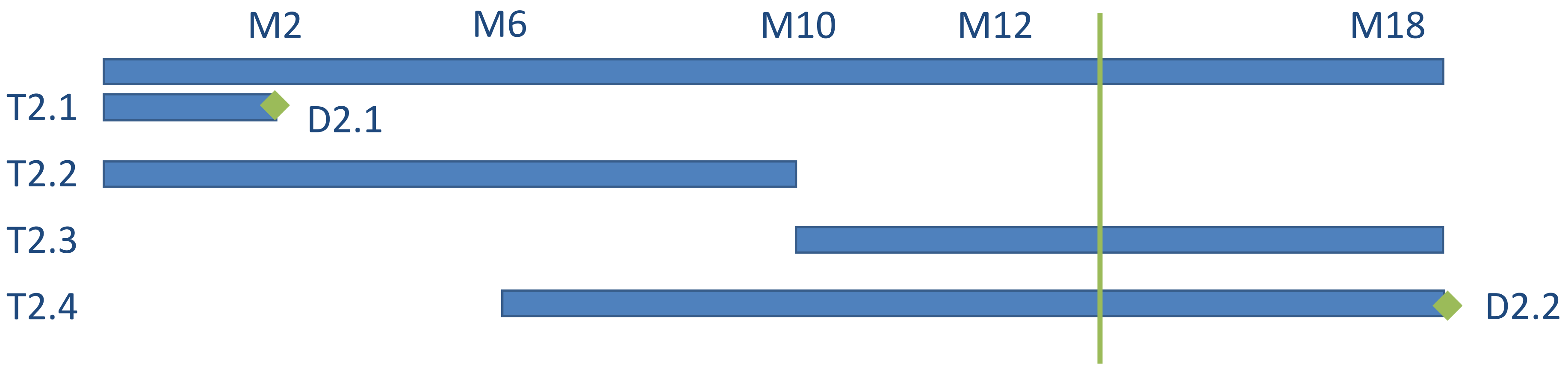
European Gravity Service for Improved Emergency Management

Title: **GRACE Reprocessing**

Presenter: TMG

Affiliation: TUG

WP2 Gravity field analysis – Time Table



T2.1 Processing Standards and Models

Document delivered

T2.2 Improved processing tools

Presentation of results today: AIUB, GZF, TUG,CNES/GRGS, ULux

T2.3 Data analysis

Discussion today

T2.4 Instrumental behavior and End-to-end Simulator

T2.3 Reprocessing

- Reprocessing of two years (2006 – 2007) of GRACE data
  - AIUB
  - GFZ
  - TUG
  - CNES/GRGRS
  - ULux

- Based on document
  D2.1_Processing Standards and Models_02.03.2015.pdf

- Based on AIUB GPS orbit and clock constellation
  or AIUB kinematic orbits

- 5 x 24 monthly normal equations in SINEX format

- What is about the additional Level 2 products: GAA, GAB, GAC, GAD ?

T2.3 Reprocessing: SINEX format

```
%=SNX 2.02
+FILE/REFERENCE
+FILE/COMMENT
+SOLUTION/STATISTICS
+SOLUTION/NORMAL_EQUATION_VECTOR
+SOLUTION/NORMAL_EQUATION_MATRIX U
+SOLUTION/ESTIMATE
+SOLUTION/APRIORI
%ENDSNX
```

Should contain the ICGEM header
earth_gravity_constant
radius
max_degree
tide_system

All information are related to the reduced observations

Must be added to **SOLUTION/ESTIMATE** to get the full solution

Monthly mean of all (?!) background models
- static, trend, (semi-) annual
- AOD1B
- Earth-, ocean-, pole tides

T2.3 Reprocessing: Apriori

APRIORI includes the reduced static gravity field, trend, annual, semiannual signal
And additional three options:

1.) Tides not included, AOD1B not included
- ⇒ Result is standard GSM file
- ⇒ Need also the combination of different GAA - GAD files

2.) Tides not included, AOD1B included
- ⇒ Selection of a GAA - GAD files for publication (OMCT vs MOG2D)

3.) Monthly mean of all models included (my preference)
- ⇒ Straight forward combination
- ⇒ Selection of a GAA - GAD files for publication

All centers should provide monthly mean of all reduced background models (ICGEM-format) for internal consistency check

- Earth tides, Pole tides, Ocean tides, Ocean pole tides
- Atmosphere, Ocean

EGSIEM

European Gravity Service for Improved Emergency Management

Title: **New definition of GRACE Level2produtcs**

Presenter: Torsten Mayer-Gürr

Affiliation: TUG

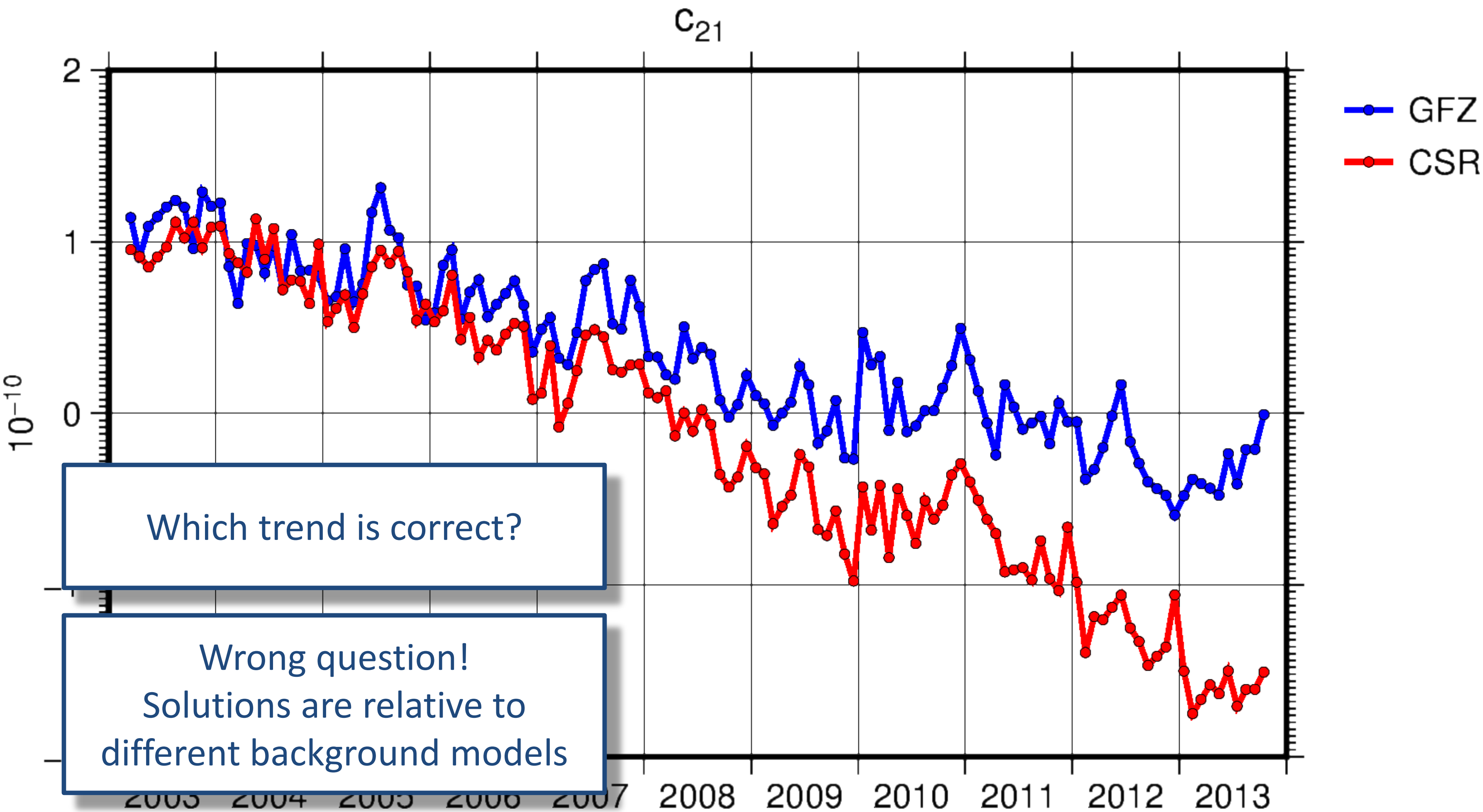
Motivation

GRACE Level 2 products are complicated to use!
$\Rightarrow$ Generation of user friendly Level 3 products

Can we make the Level 2 products more user friendly too?

Two examples about problems…

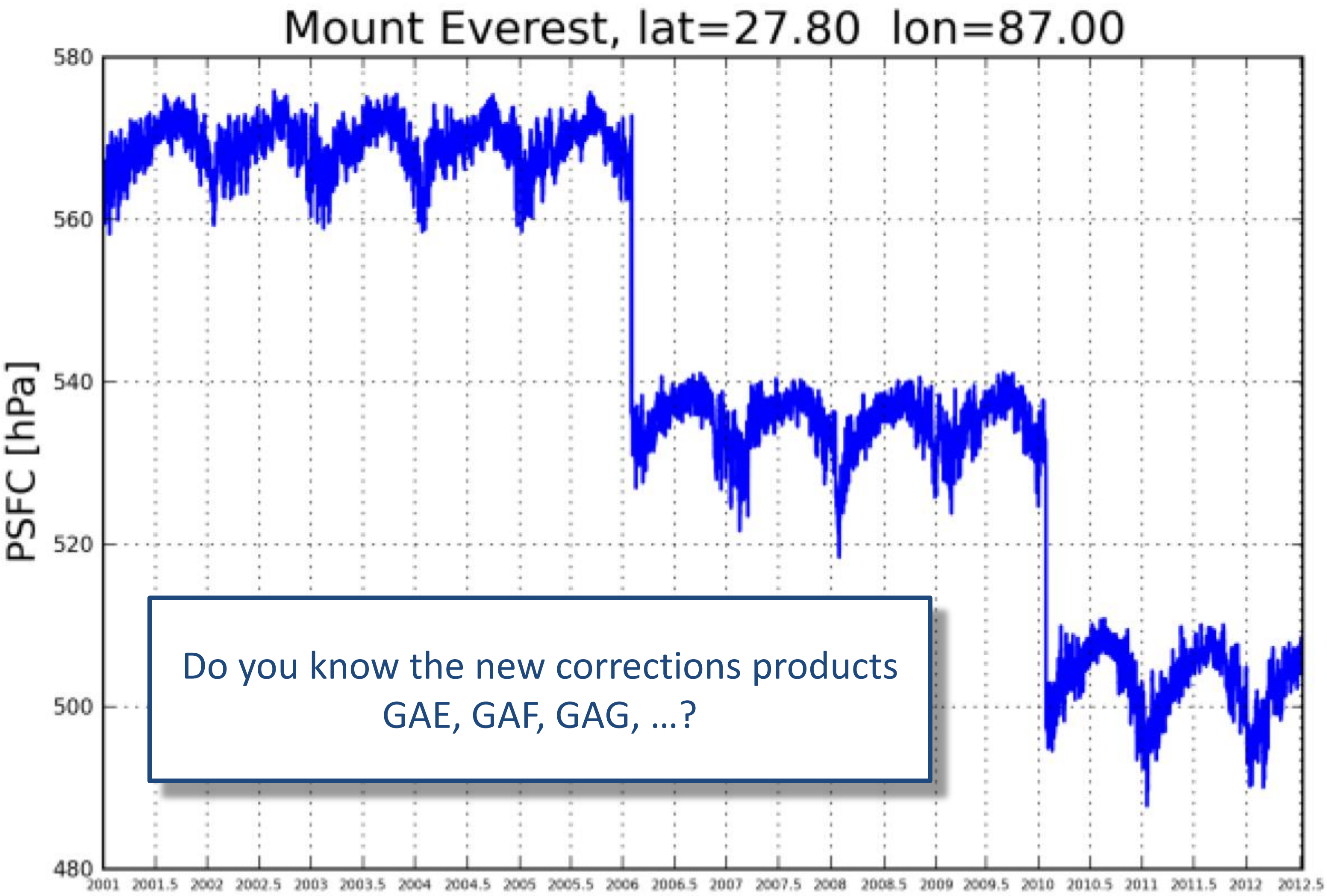
Trends in level 2 RL05 products



Which trend is correct?

Wrong question!
Solutions are relative to
different background models

Jumps in the Level 2 products



Do you know the new corrections products GAE, GAF, GAG, …?

Definition

GRACE Level 2 products are not GSM files only

Level 2 products consists of monthly

- GSM: Reduced GRACE coefficients
- GAA: Monthly mean of atmosphere
- GAB: Monthly mean of ocean
- GAC: GAA + GAB
- GAD: Monthly mean of ocean bottom pressure

Additionally jump corrections are provided

- GAE
- GAF
- GAG

Mass transports – a simulated world

- Hydrology
- Ice sheets
- Glaciers
- Permanent frost
- Ocean tides
- Ocean pole tides
- Barotropic ocean circulation
- Sea level rise (?)
- Atmospheric tides (S1, S2)
- Atmospheric mass redistribution
- Solid Earth tides
- Rotational deformation (pole tides)
- Glacial isostatic adjustment
- Loading deformation
- Degree 1 mass redistribution
- Earthquakes

Ice

Ocean

Atmosphere

Solid Earth

Mass transports – a simulated world

Hydrology	WGHM, LSDM, GLDAS, …
Ice sheets	RACMO2
Glaciers	Glaciers
Permanent frost	???
Ocean tides	EOT11a, FES2014, …
Ocean pole tides	Desai 2004
Barotropic ocean circulation	OMCT, MOG2D, ECCO, …
Sea level rise (?)	Altimetry - ARGO
Atmospheric tides (S1, S2)	Van Dam, 2010
Atmospheric mass redistribution	ECMWF, NCEP, …
Solid Earth tides	IERS 2010
Rotational deformation (pole tides)	IERS 2010
Glacial isostatic adjustment	Klemann 2008, …
Loading deformation	Love numbers, Farell 1972, …
Degree 1 mass redistribution	SLR, Joint inversion model, …
Earthquakes	Sabadini, Vermeersen, 1997

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- Earthquakes

=

Total mass change

(Observable by GRACE)

The equation is not exactly fullfilled as the models and the GRACE are not free of errors

Anyway the equation can be reordered…

Mass transports – a simulated world

- Hydrology

=

Total mass change

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Signal separation

Different ways to separate the hydrological signal from other signals:

- Spatial patterns
- Frequency patterns
- Principal components
- …
- but in general models are needed

Hydrology is not the only interesting sinal, so the equation can be reordered to separate other signals

Mass transports – a simulated world

- Hydrology

=

Total mass change
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- Earthquakes

(uncountable …)

Mayer-Gürr et al 2012,
Killett 2011
Han et al 2010, …

Landerer et al 2015
Makowski et al 2015
Piecuch 2015, …

Dieng et al 2015
IPCC 2015, …

Martinec et al 2015
Root et al 2015
Sutterley et al 2014, …

Wahr et al 2015

Bergmann-Wolf et al 2014
Wu et al 2012
Rietbroek et al 2012, …

Broerse et al 2015
Zhang et al 2015
Tanaka et al 2015
Li et al 2015
Shahrisvand et al 2015
Han et al 2015, …

Mass transports – a simulated world

- Hydrology

=

Total mass change
- Ice sheets
- Glaciers
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The equation can be reordered once more …

Mass transports – a simulated world

- Hydrology
- Ice sheets
- Glaciers
- Permanent frost
- Sea level rise (?)
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=

Total mass change
– Ocean tides
– Ocean pole tides
– Barotropic ocean circulation
– Atmospheric tides (S1, S2)
– Atmospheric mass redistribution
– Solid Earth tides
– Rotational deformation (pole tides)

Application: hydrology
⇒ GIA must be reduced (not part of level 2)
⇒ Degree 1 terms (not part of level 2)

Application: oceanography
⇒ Ocean model must be added back
⇒ GIA must be reduced (not part of level 2)
⇒ Degree 1 terms (not part of level 2)

Level 2 product (GSM)

⇒ Mixture of observations and models

⇒ Unclear why some models are reduced and others are not

Mass transports – a simulated world

- Hydrology
- Ice sheets
- Glaciers
- Permanent frost
- Ocean tides
- Ocean pole tides
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=

Total mass change

A possible new definition of Level 2 products

GRACE Level 2 product (GSM)

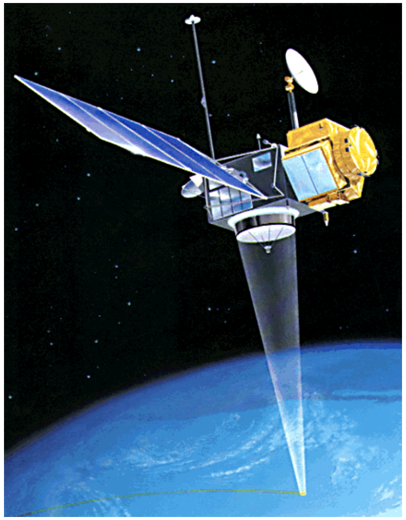
- Gravitational potential generated by the complete mass of the Earth

Part of the Level 2 products:
Monthly mean of models for signal separation

- Solid Earth tides
- Rotational deformation (pole tides)
- Glacial isostatic adjustment
- Degree 1 mass redistribution
- Ocean tides
- Ocean pole tides
- Barotropic ocean circulation
- Atmospheric mass redistribution
- Continental hydrology

Regularly used for Altimeter data. Each observation is supplemented by geophysical models, e.g.

- Inverse barometric effect
- Ocean tides
- Geoid



A possible new definition of Level 2 products

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- Ocean tides
- Ocean pole tides
- Barotropic ocean circulation
- Atmospheric mass redistribution
- Continental hydrology

Advantages

- Separation of obs. and models (Signals and noise/errors)
- Models can be exchanged without reprocessing
- Solutions of different ACs are comparable and combinable
- Future safe: new models can simply provided

Disadvantages

- Changed definition compared to release 5

But: Changes between releases, e.g.

- Pole tide model included
- Baroclinic to barotropic ocean model

Models for dealiasing and linearization

We still need models in the frame of GRACE processing!
Models for dealiasing: < 1month
Models for signal separation: > 1 month

Models used in processing:

1. Reduced and monthly mean provided as additional product
   - Atmosphere
   - Ocean
2. Reduced and monthly mean not provided
   - Earth tides
   - Ocean tides
   - Pole tides
3. Reduced but monthly mean added back
   - Static
   - Annual
   - Semiannual

Consistent method for all models

- Reduction
- Add back monthly mean
- Monthly mean as additional product

First Summary

- We need a discussion about the models used in GRACE processing!
  It should be clear beforehand which models are reduced and which are not.

- Level 2 should include the models needed for signal separation
  (these models are needed for Level 3 products too)
    - Glacial isostatic adjustment
    - Solid Earth degree 1 mass redistribution
    - Continental hydrology
    - …

Following slides:
Details about
- Geocenter
- Averaging interval (monthly mean)

Definition

In the reference system community:
Distinction between:

- “System”: Theoretical definition (Goal: products without noise/errors/problems)
- “Frame”: Realization (Instruments noise, Complicated space-time pattern, Aliasing)

GRACE: only realizations without theoretical definition

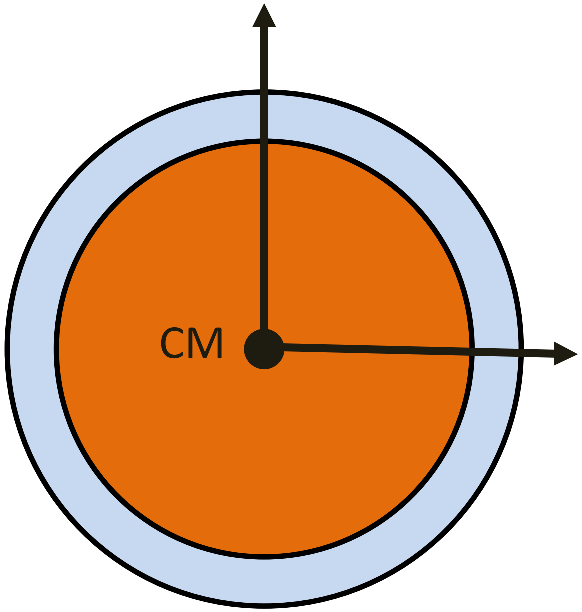
Proposal of a theoretical definition:
GRACE monthly solution

- Gravitational potential generated by the complete mass of the Earth
- Origin is the center of mass (CM)
- Orientation is aligned to ITRS
- Mean mass distribution of the complete month

Geocenter motion

Center of mass (CM)

- The degree 1 terms of the sum of all masses do not change (set to zero)
- If the degree 1 terms of the fluid envelope (ocean, atmosphere, hydrology, …) changes, the degree 1 terms of the solid Earth changes too



Geocenter motion

Center of mass (CM)

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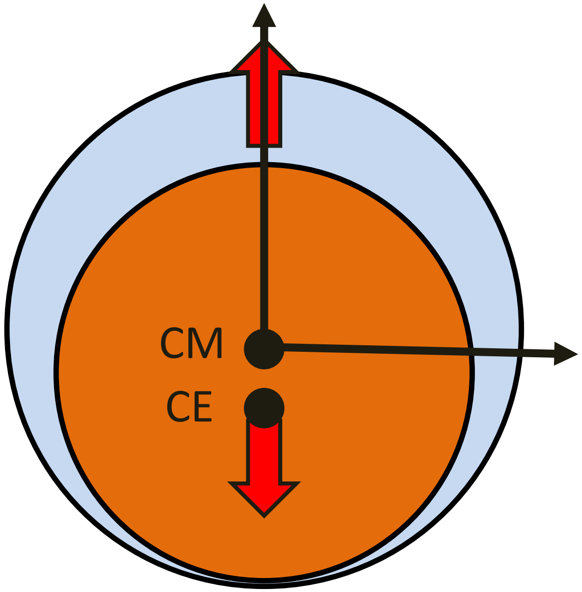

Center of solid Earth (CE) / Center of figure (CF)

- The degree 1 terms of the solid Earth do not change
- (only the terms of the fluid envelope changes)

Transformation from CM to CE

Must remove the degree 1 terms of the solid Earth from the degree 1 of the complete mass

⇒ Signal separation problem

⇒ Cannot provided by GRACE only

⇒ Model / external data needed

Temporal average

Current definition

Average over all days with GRACE data

$$\bar{c}_{nm} = \sum_{i \text{ with } GRACE} \int_{t_i}^{t_{i+1}} c_{nm}(t)\, dt$$

Proposal of a new definition

Average over the complete month

$$\bar{c}_{nm} = \int_{t_0}^{t_1} c_{nm}(t)\, dt$$

Concerning only the mean of the background models (GAA, GAB, GAC, …)

GRACE processing: Observation model assumes constant gravity field coefficients
Trying to remove all high frequent (submonthly) variations by models
$\Rightarrow$ Reduced Gravity field (GSM) should be constant within the month regardless which days are observed

Example usage of GRACE: Validation/Comparison with other data

- Altimetry
- Ocean bottom pressure recorder
- GPS loading deformation
- Hydrological model

$\Rightarrow$ Computation the temporal average
$\Rightarrow$ Must use the same time span as GRACE data

Which definition did you used?

Summary

We should make the GRACE Level 2 products more user friendly

- With a clear theoretical definition

Theoretical definition:
GRACE monthly solution
- Gravitational potential generated by the complete mass of the Earth
- Origin is the center of mass (CM)
- Orientation is aligned to ITRS
- Mean mass distribution of the complete month

- With additional monthly mean of models for signal separation

• Glacial isostatic adjustment • Degree 1 mass redistribution • Barotropic ocean circulation • Atmospheric mass redistribution • Continental hydrology	• Solid Earth tides • Pole tides • Ocean tides • Ocean pole tides