EGSIEM

European Gravity Service for Improved Emergency Management

Upcoming Deliverables & Action Items

Adrian Jäggi (AIUB)

EGSIEM General Assembly

University of Bern

January 19 – 20, 2017

UNIVERSITÄT BERN · UNIVERSITÉ DU LUXEMBOURG · GFZ Helmholtz Centre Potsdam · TU Graz Graz University of Technology · Leibniz Universität Hannover · cnes · DLR · géode & cie · HORIZON 2020

Upcoming Deliverables

EGSIEM

European Gravity Service for Improved Emergency Management

Deliverable (number)	Deliverable name	Work package number	Short name of lead participant	Type	Dissemination level	Delivery date
5.2	NRT service product report	5	GFZ	R	PU	M27
5.4	Regional solution product report	5	GFZ	R	PU	M27
6.1	Hydrological Service Product Report	6	GFZ	R	PU	M30

Upcoming Milestones

EGSIEM
European Gravity Service for Improved Emergency Management

Milestone number	Milestone name	Related work package(s)	Estimated date	Means of verification
1	Finalisation of Processing Standards	WP 3	2	D2.1 is available
2	Implementation and preparation Review	WP 2,3,5	10	Implementation and preparation work finished, T2.2, T3.1, T3.2 finished, T5.2 and T5.4 implementations finished
3	Service Readiness	WP4,5,6	18	Scientific, NRT and Hydrological service set up, T4.1, T5.1 finished, T5.2 and T5.4 ready for service run
4	Operational NRT Service Readiness	WP5,6	27	Preparation work for operational NRT service finished
5	Final Review	WP 1-7	36	All work packages finished

Action Items Status

EGSIEM
European Gravity Service for Improved Emergency Management

Action Item Status List (open and new AI's)				
A.I.	**Originator**	**Actionee**	**Action Description**	**Due Date**
006	EGSIEM	WP Managers	Collect ideas for paper topics to set up a publication plan	Continuous
017	EGSIEM	TUG	TMG to provide a plan for the removal or restoration of background models	02.06.2016
018	EGSIEM	UBERN	SLR processing standard text will be added to Deliverable 2.1	02.06.2016
019	EGSIEM	UBERN	UBERN to draft a plan on how to incorporate SLR data and how to welcome new contributors.	02.06.2016
020	EGSIEM	UL	Submission plan to be created for dedicated sessions at conferences (see Task 7.5)	31.3.2016
021	EU/EGSIEM	UBERN	Present work undertaken on DOI numbers (at UBERN & GFZ) and draft Data Plan.	20.01.2017

AI #018 & #019

European Gravity Service for Improved Emergency Management

- Sub-group on SLR activities with new Associated Members has been established (led by M. Blossfeld).
- Dedicated splinter meeting will be held today

5a	16:00	Blossfeld	EGSIEM SLR/DORIS Processing Standards Exakte Wissenschaft Building Room 216, 2nd Floor Sidlerstrasse 5 • M. Blossfeld • K. Sosnica • D. König • A. Grahsl
** Splinter Group Meeting **			

AI #018 & #019

EGSIEM
European Gravity Service for Improved Emergency Management

- Status will be reported tomorrow by M. Blossfeld.

8	11:45	All	Associate Member Presentations • Combined SLR-derived gravity fields for EGSIEM (MB)

AI #021

EGSIEM
European Gravity Service for Improved Emergency Management

- Products of the CODE Analysis Center of the IGS are meanwhile referenced by DOI numbers that are assigned by the Bern Open Repository and Information System (BORIS) maintained by University of Bern

  Example:
  http://www.bernese.unibe.ch/publist/publist_code.php

- Similar procedures are probably offered by other institutions/ universities as well

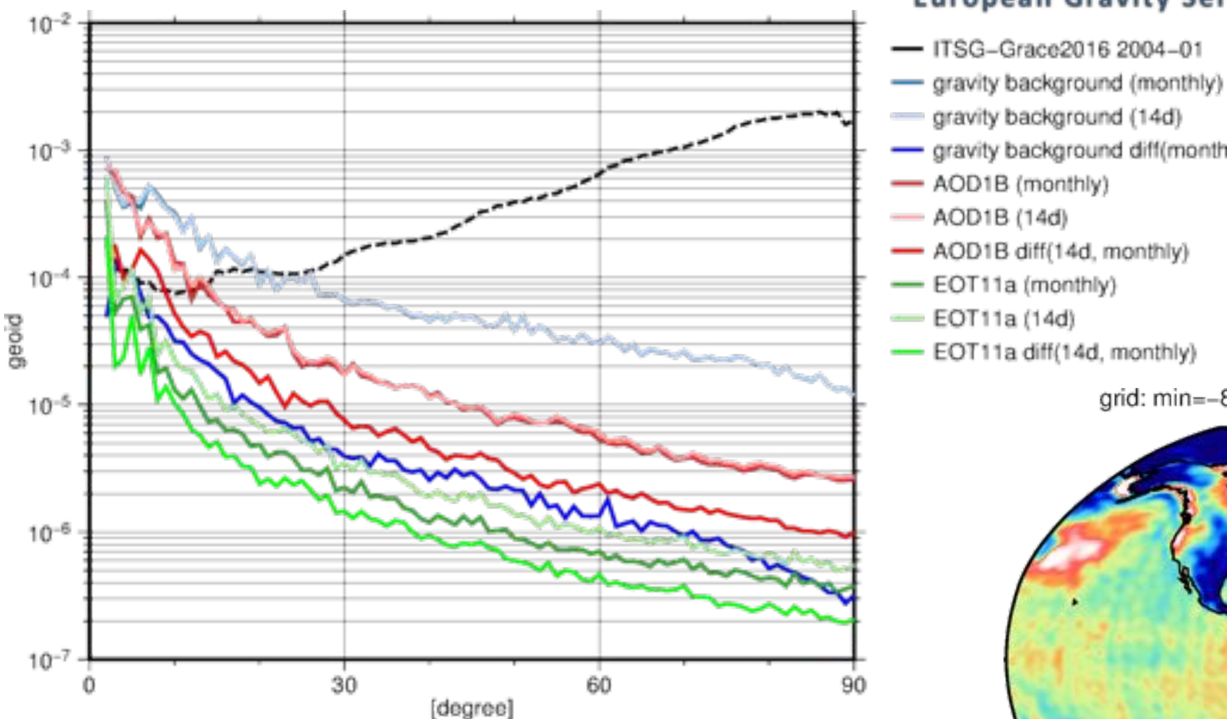
Action Item Status

European Gravity Service for Improved Emergency Management

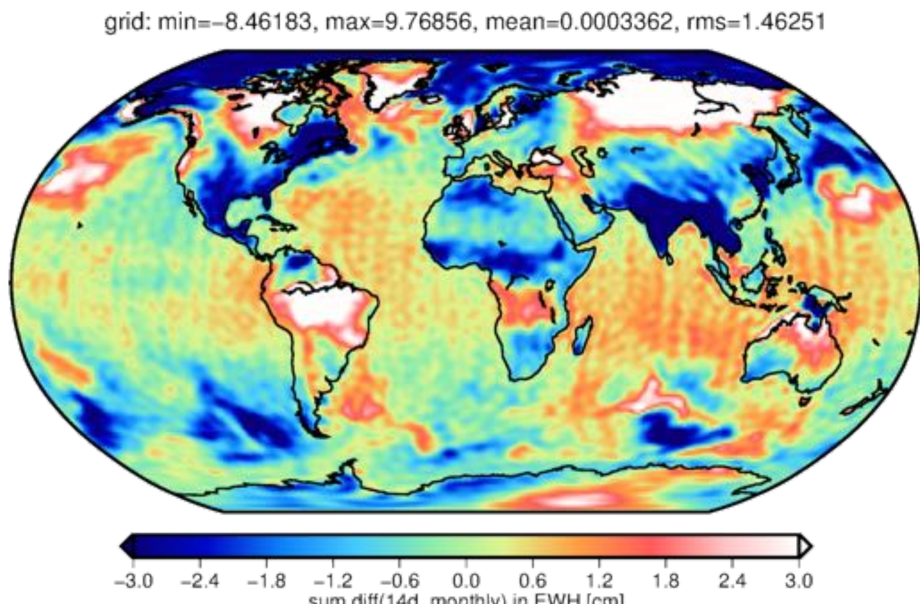
022	EGSIEM	GFZ/FF	Consortium to be informed about the future generation of L3 products at the next GRACE user meeting.	31.10.2016
023	EGSIEM	TUG	Data collection exercise comparing simplified monthly GRACE day calculation (Monthly Mean comparison)	30.06.2016
024	EGSIEM	AIUB	Secure EGSIEM Competition URL	30.06.2016

AI #023

European Gravity Service for Improved Emergency Management



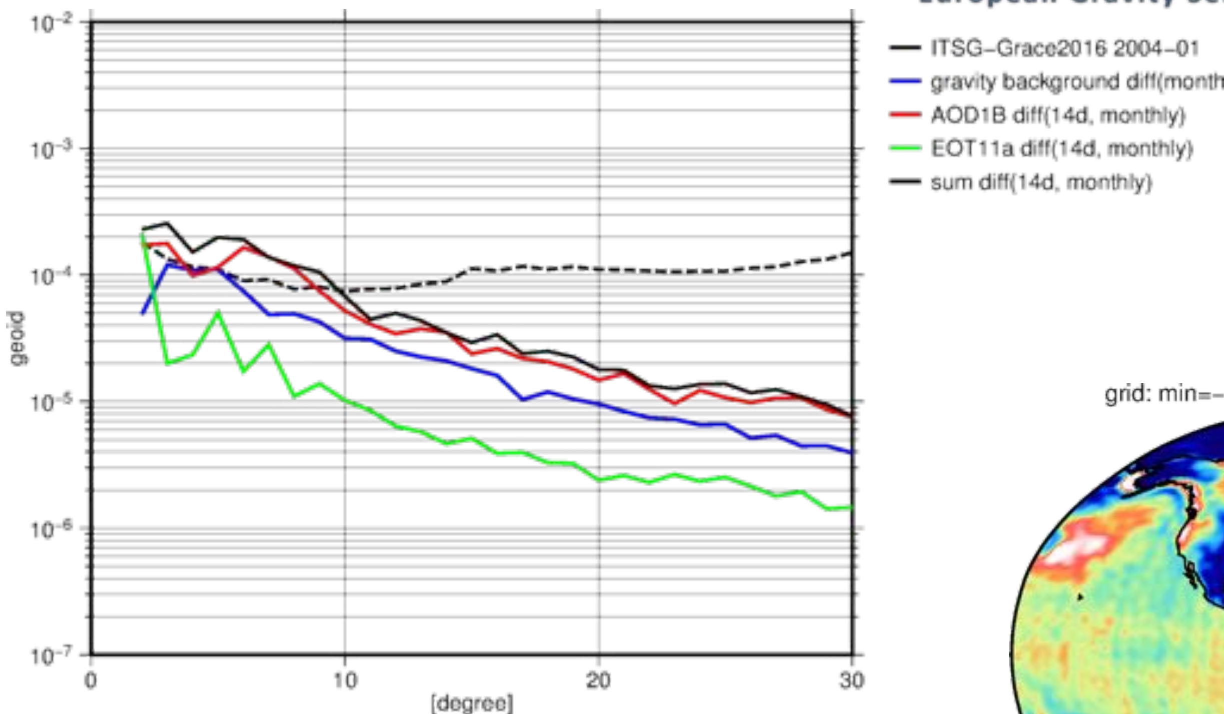
Figures from e-mail sent by A. Kvas on 9 Dec 2016



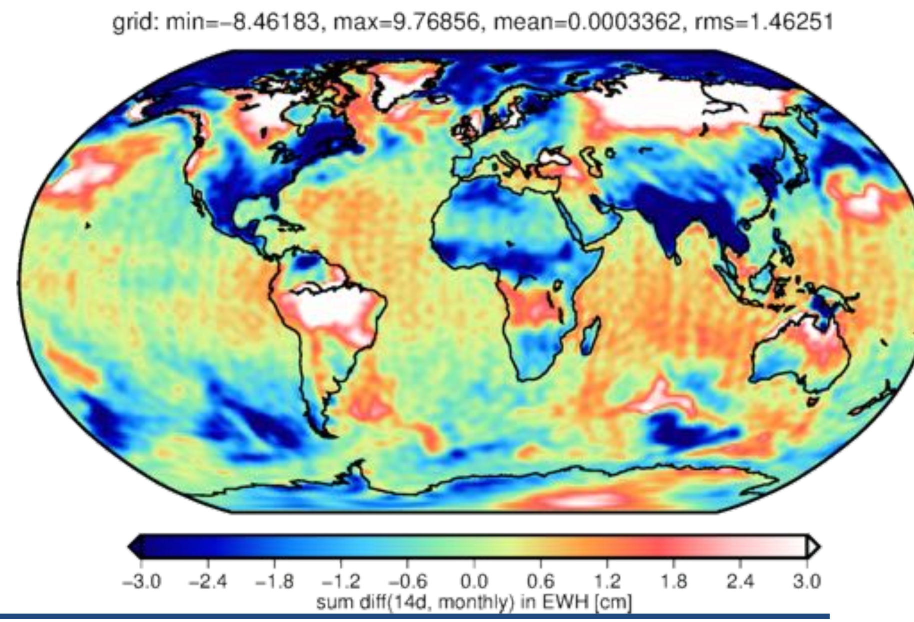
The difference between all background models (tidal and non-tidal) is larger than 3cm EWH in some regions, and also exceed the formal errors below degree 10. Since the differences are not negligible, the discussion should focus on the strict definition of the EGSIEM solutions.

AI #023

European Gravity Service for Improved Emergency Management



Figures from e-mail sent by A. Kvas on 9 Dec 2016



The difference between all background models (tidal and non-tidal) is larger than 3cm EWH in some regions, and also exceed the formal errors below degree 10. Since the differences are not negligible, the discussion should focus on the strict definition of the EGSIEM solutions.

EGSIEM

HORIZON 2020

EGSIEM

European Gravity Service for Improved Emergency Management

Title: **WP2 Gravity field analysis**

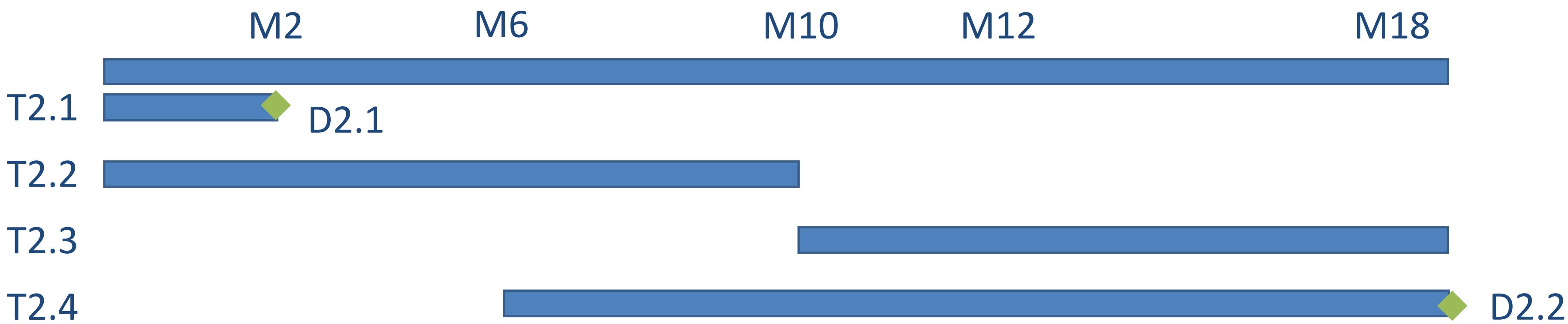
Presenter: TMG and all ACs

Affiliation: TUG

EGSIEM Meeting Bern,
19.01.2017 – 20.01.2017

Horizon2020

WP2 Gravity field analysis – Time Table



June 2016

T2.1 Processing Standards and Models

T2.2 Improved processing tools

T2.3 Data analysis

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

⇒ WP2 finished

WP2 Gravity field analysis

- All analysis centers (AC) delivered monthly normal equations in SINEX (2006-2007)
  - except Ulux, see talk by Zhao Li,
    Implementation of the rigorous acceleration approach and its preliminary results

- Deliverable 2.2 GRACE/GRACE-FO Product report

- Periodic report

EGSIEM
European Gravity Service for Improved Emergency Management

Status of TUG ITSG-GRACE processing

Torsten Mayer-Gürr (TUG)

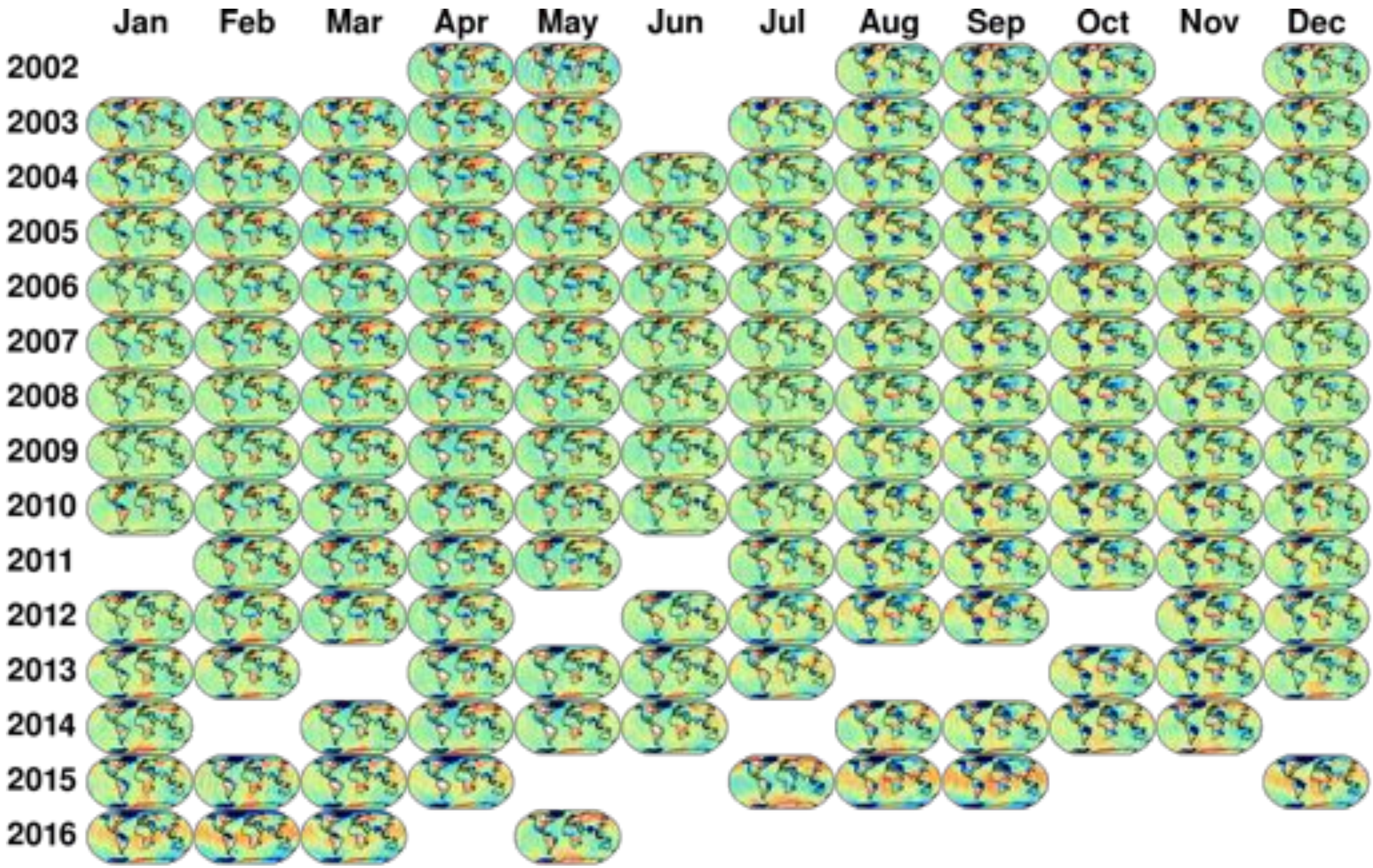
EGSIEM General Assembly

AIUB Bern

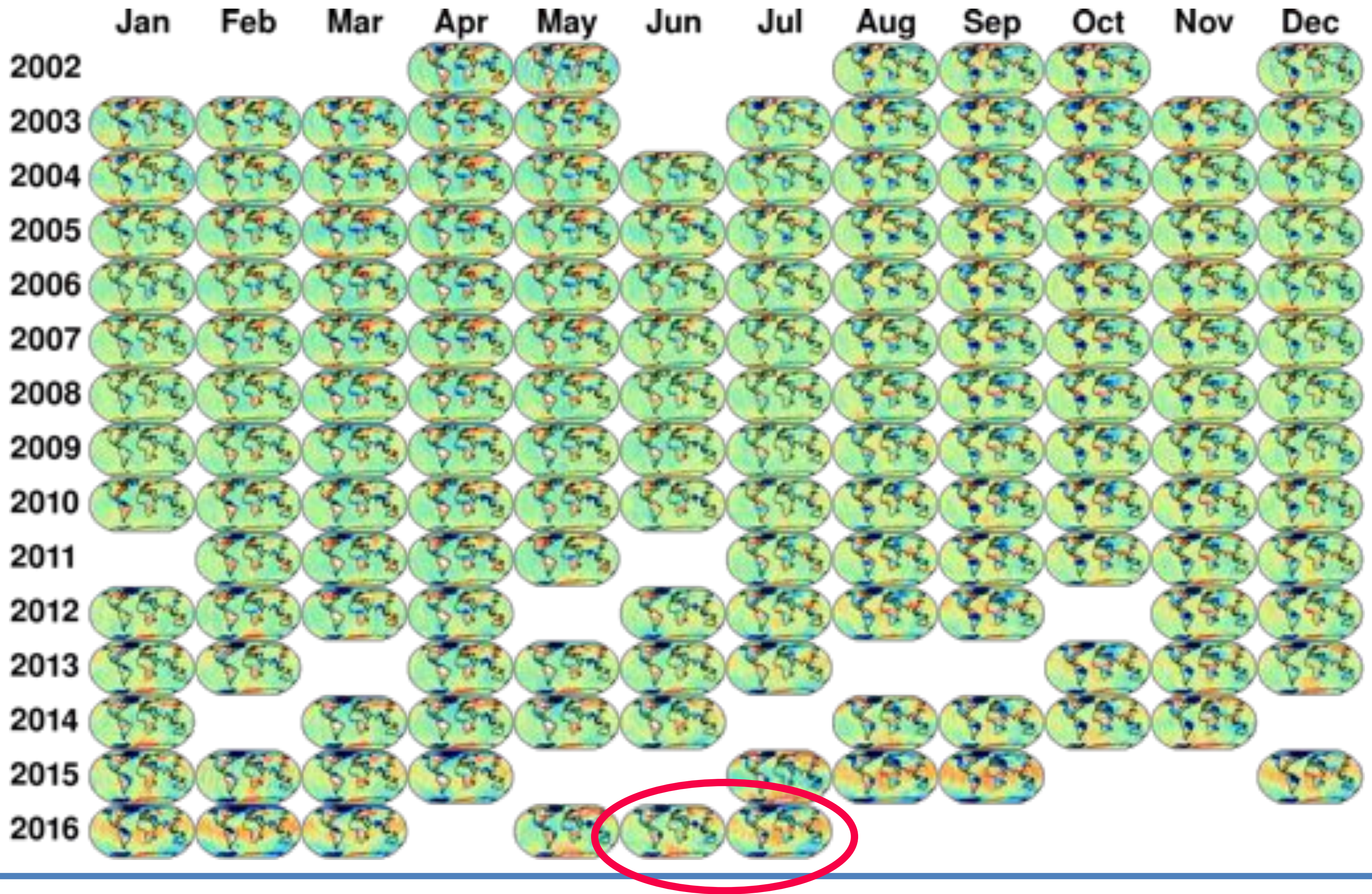
January 19 - 20, 2017

Universität Bern · Université du Luxembourg · GFZ Helmholtz Centre Potsdam · TU Graz – Graz University of Technology · Leibniz Universität Hannover · cnes · DLR · géode&cie · Horizon2020

Status TU Graz: ITSG-Grace2016



Status TU Graz: ITSG-Grace2016



Status TU Graz

- Delivered monthly normal equations in SINEX (2006-2007)
- Normals of all other months are ready and can be uploaded on request

- TUG has now access to level 1-a data for some months: planned tests
  - Improved star camera and angular acceleration fusion
  - Improved outlier detection

Austrian Research Promotion Agency (FFG) Project

CAKAO **Combined analysis of kinematic orbits and loading observations to determine mass redistribution**

- Improved kinematic GRACE orbits by ambiguity resolution
- Geocenter motion by GPS station loading

Status TU Graz

EGSIEM
European Gravity Service for Improved Emergency Management

AIUB monthly GRACE K-Band gravity models

Ulrich Meyer (AIUB)

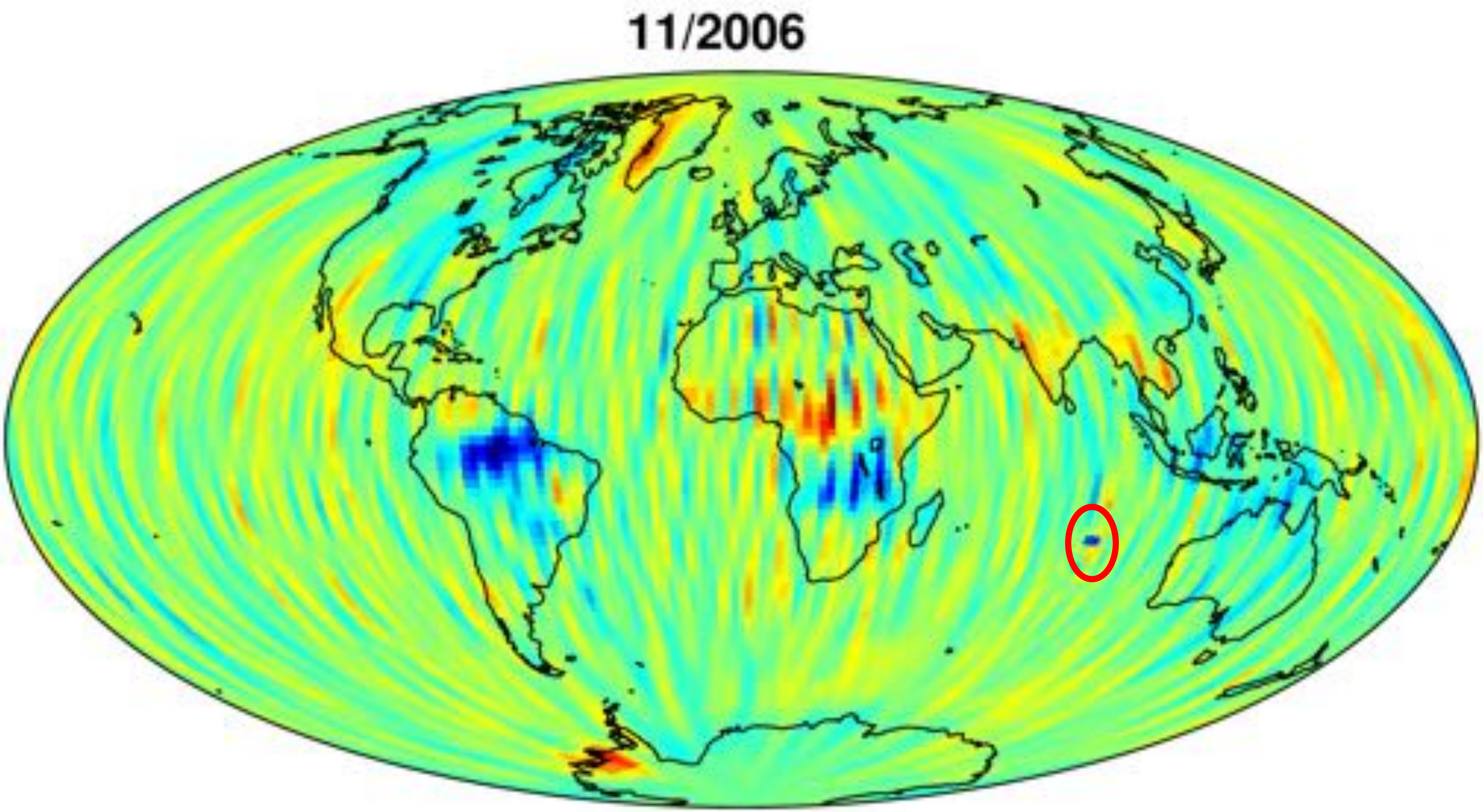
EGSIEM General Assembly

AIUB Bern

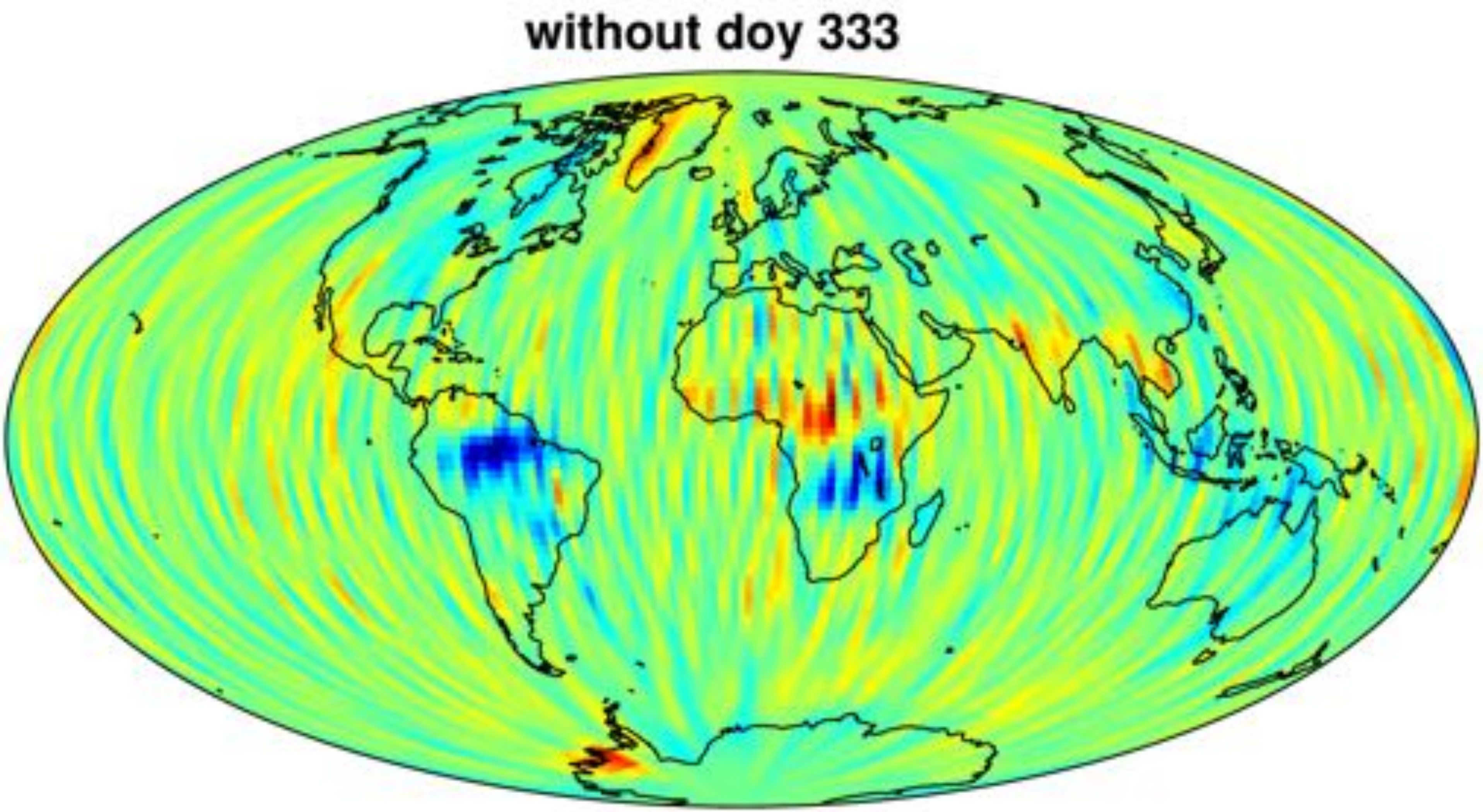
January 19 - 20, 2017

Universität Bern | Université du Luxembourg | GFZ Helmholtz Centre Potsdam | TU Graz Graz University of Technology | Leibniz Universität Hannover | cnes | DLR | géode&cie | Horizon2020

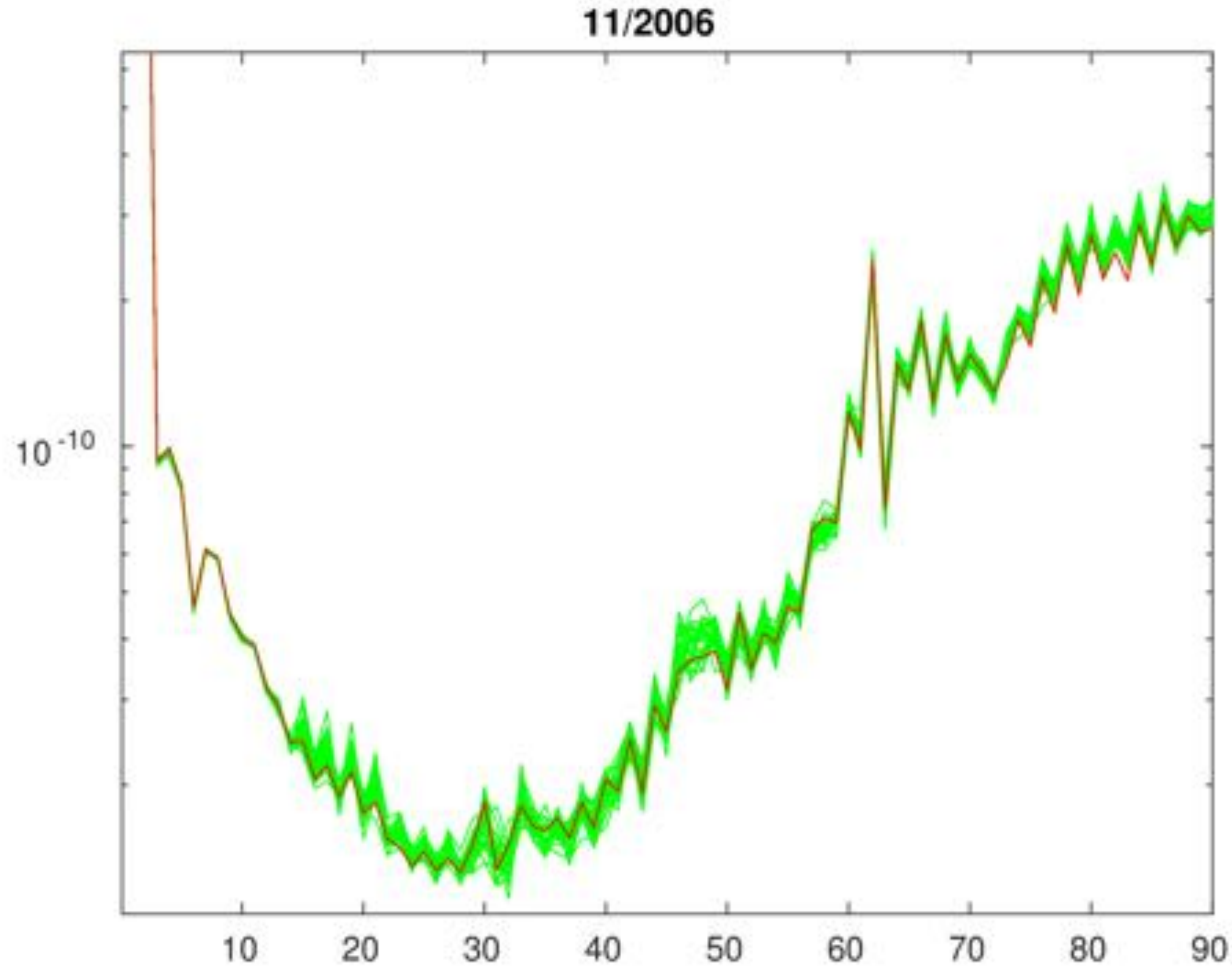
Artifact in monthly solution 11/2006



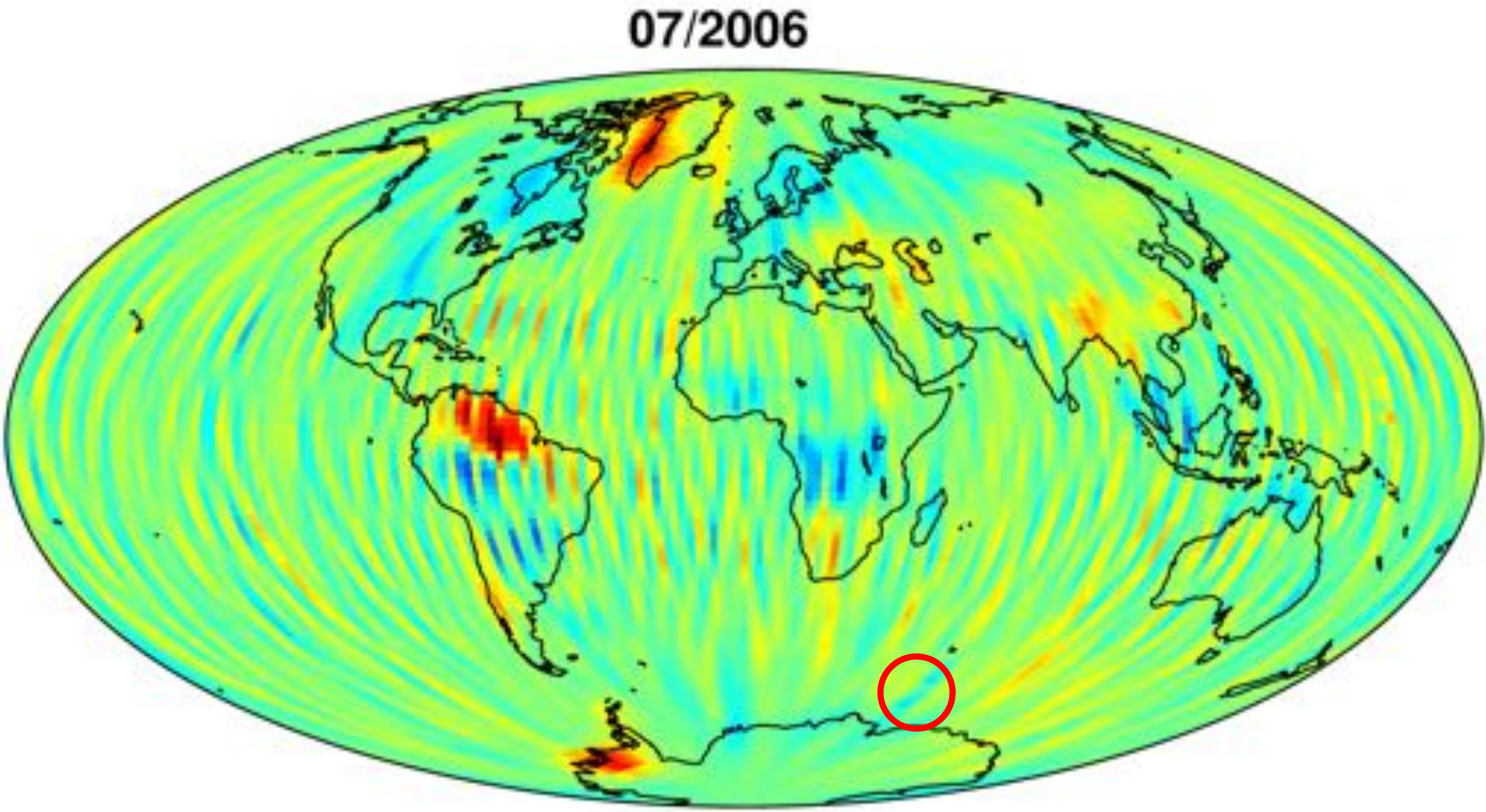
Artifact in monthly solution 11/2006



not noticeable in spectral representation …

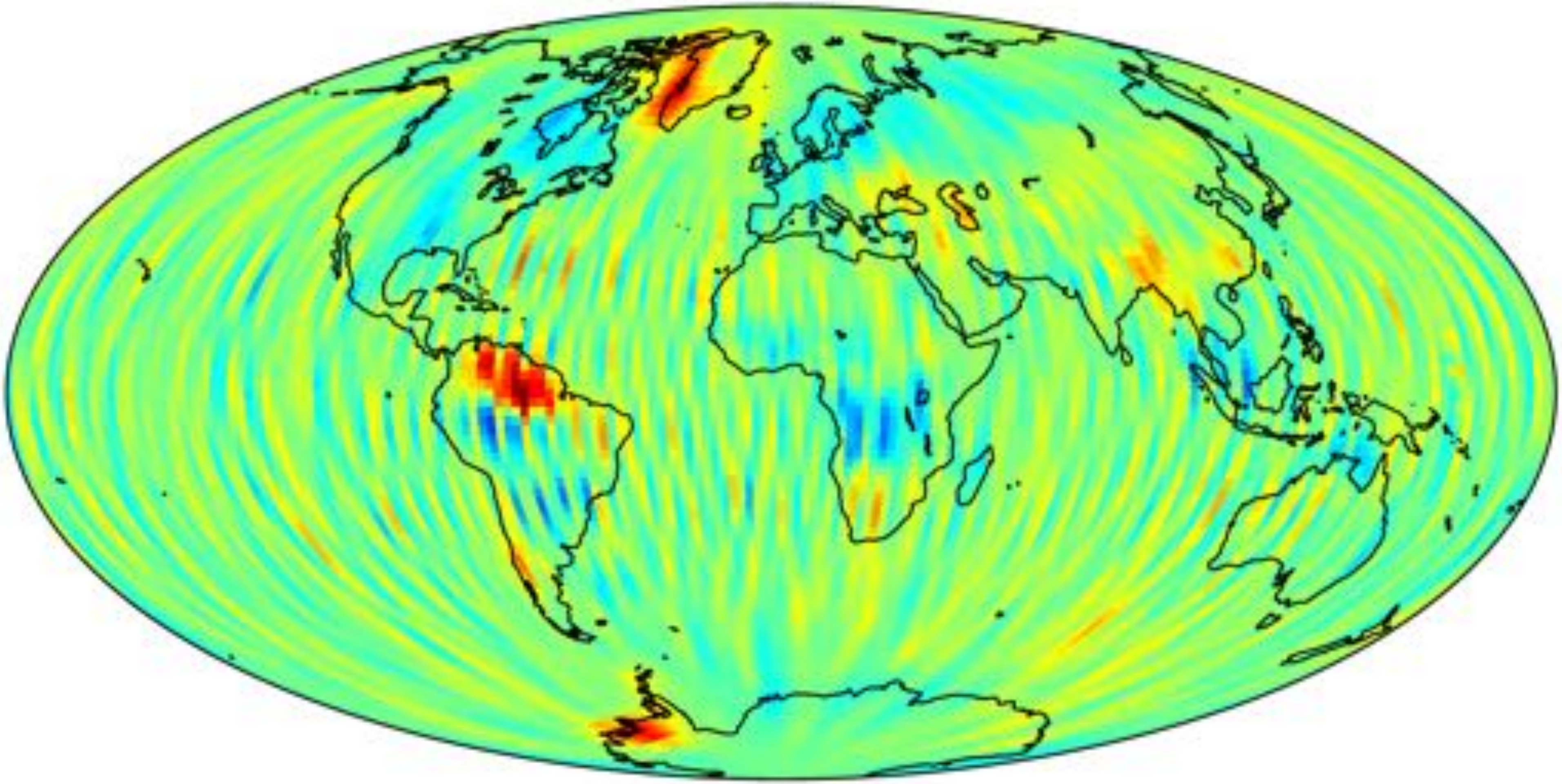


Artifact in monthly solution 07/2006

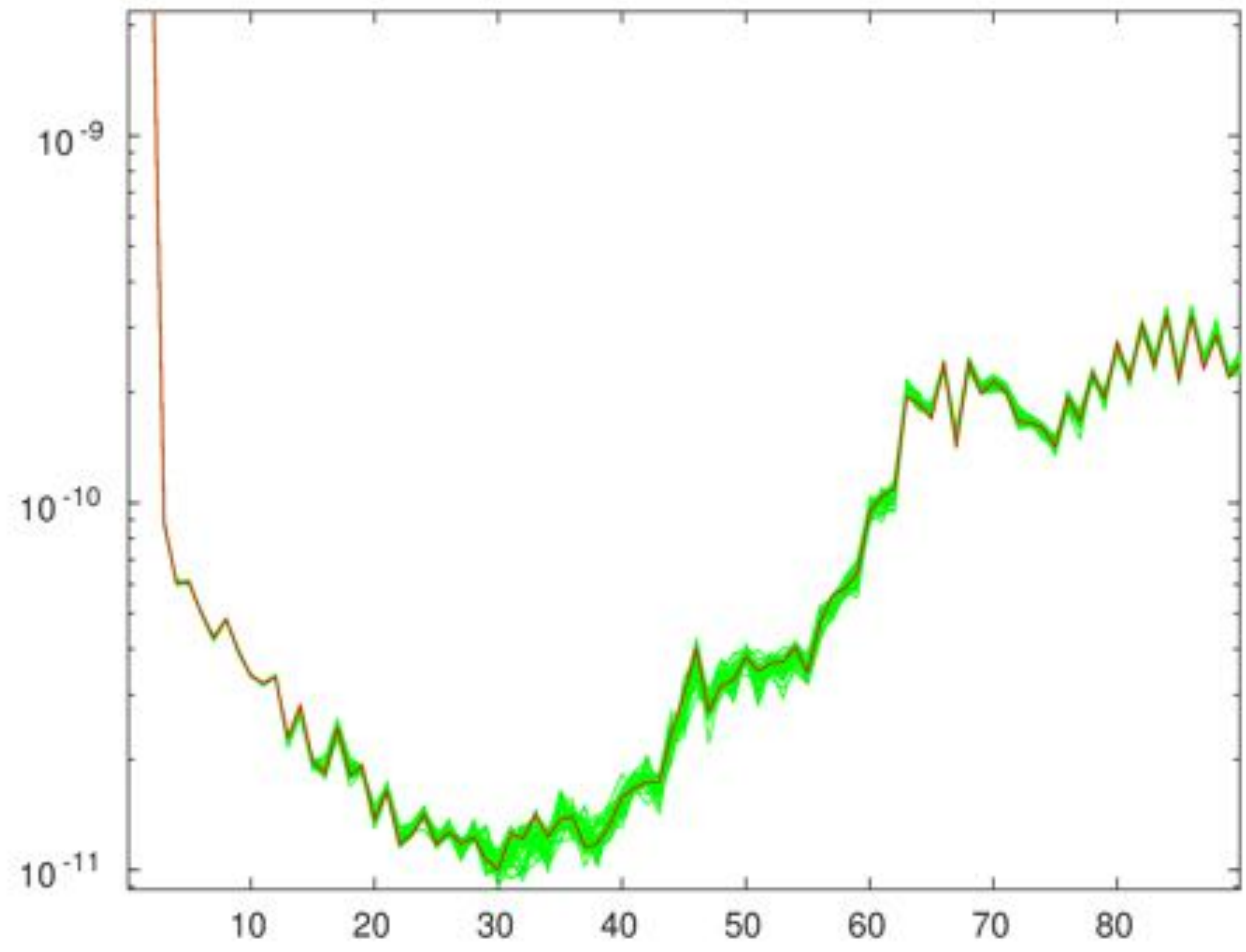


Artifact in monthly solution 07/2006

without doy 190



not noticeable in spectral representation …



EGSIEM
European Gravity Service for Improved Emergency Management

WP2: Status GFZ Monthly Solutions

Christoph Dahle, Frank Flechtner

EGSIEM General Assembly, AIUB, Bern, Switzerland

Jan 19-20, 2017

Level 2 Products at GFZ: General

European Gravity Service for Improved Emergency Management

- Current operational release: GFZ RL05a (156 monthly solutions from 04/2002-08/2016)
- Years 2006 & 2007 have been reprocessed for EGSIEM and delivered to WP4 as
  - Monthly Level-2 products (SH coefficients) up to d/o 90x90
  - Monthly NEQs in SINEX format
- RL06 shall be published Nov 2017 (SDS RR), EGSIEM L2 can be seen as “precursor”

Level 2 Products at GFZ: General

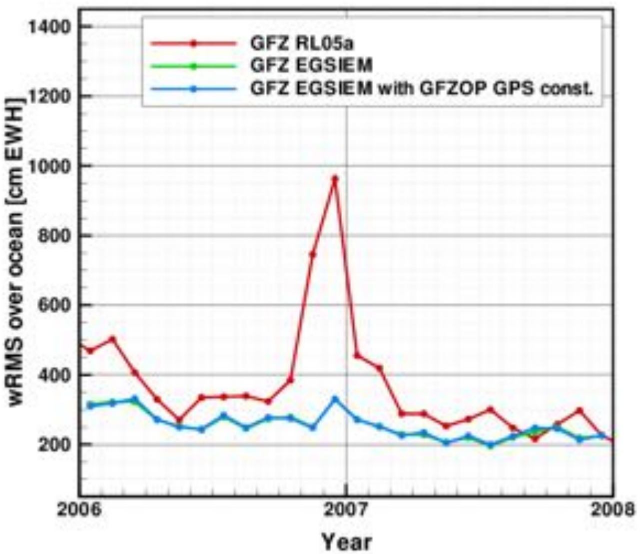
- Improvements from RL05 to RL06 will comprise (EGSIEM applied in red) e.g.
  - Reprocessed RL03 L1B data
    - First set of data recently made available within SDS
  - New (improved) background models
    - ocean tide model: e.g. FES2014, GOT+GRACE, … (tbd)
    - AOD1B RL06 (see next slides)
  - Modifications in processing strategy
    - stochastic modeling of KBR observations (first tests with promising results)
    - relative weighting KBR vs GPS
      - GPS has been slightly down-weighted (a priori sigma 0.7 cm -> 1 cm)
      - use of arc-wise KBR weights (ongoing research)
    - use of AIUB GPS constellation (for EGSIEM only, see next slides)
    - handling/parameterization of accelerometer observations (see next slides)
      - ACC biases as splines (currently under investigation)
    - parameterization of KBR observations (still to be investigated)

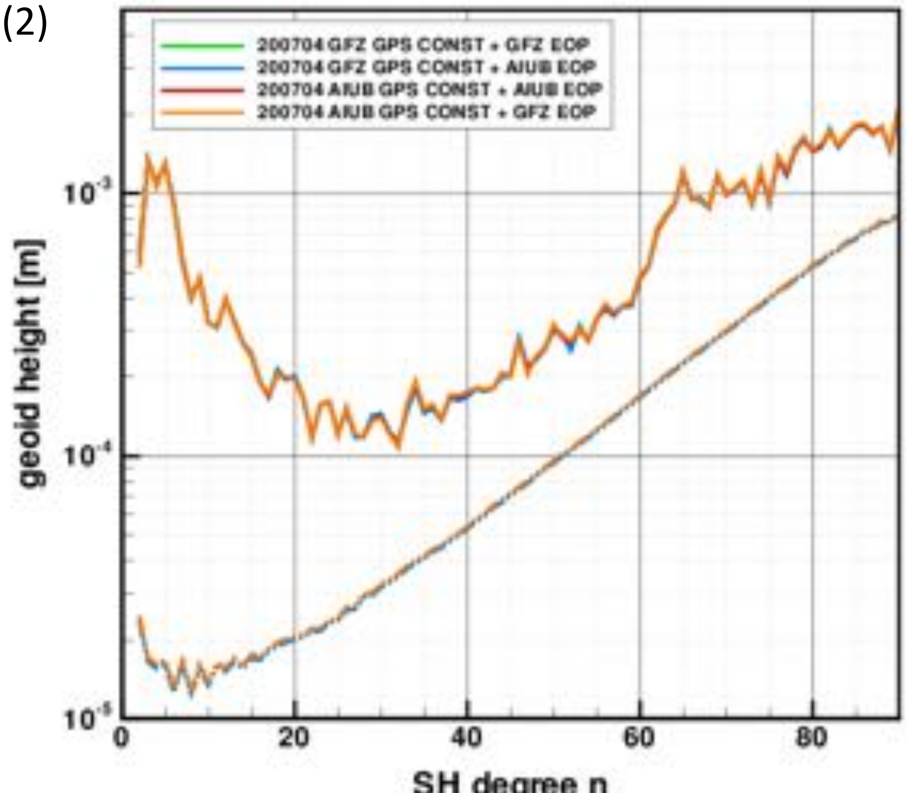
Level 2 Products at GFZ:
GPS Constellation

European Gravity Service for Improved Emergency Management

Impact on monthly gravity field solution

- Using the GPS constellation by (1) AIUB and (2) GFZ yields the same results
- Even inconsistent EOPs have no impact
    - AIUB GPS orb/clocks + GFZ EOPs
    - GFZ GPS orb/clocks + AIUB EOPs





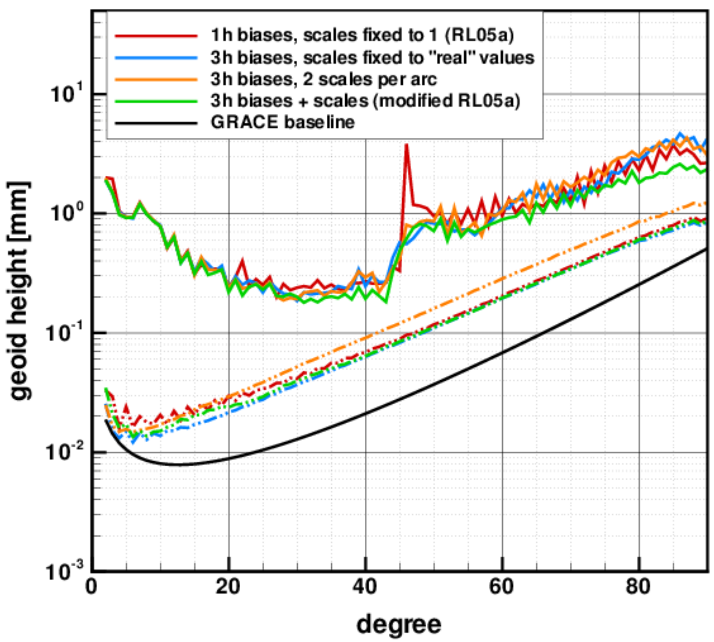
EGSIEM

HORIZON 2020

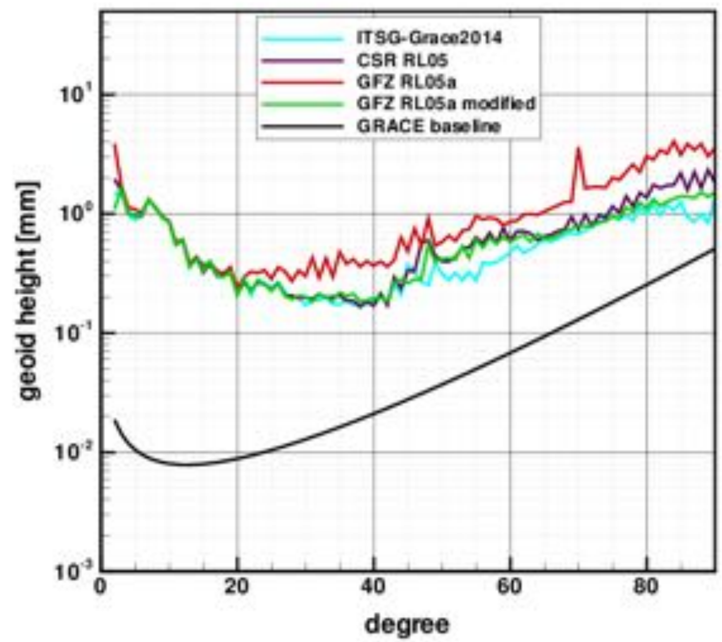
Level 2 Products at GFZ: ACC Parametrization

European Gravity Service for Improved Emergency Management

07/2012: comp. of different ACC parametrization



12/2012: comparison of different Aanalysis Centres



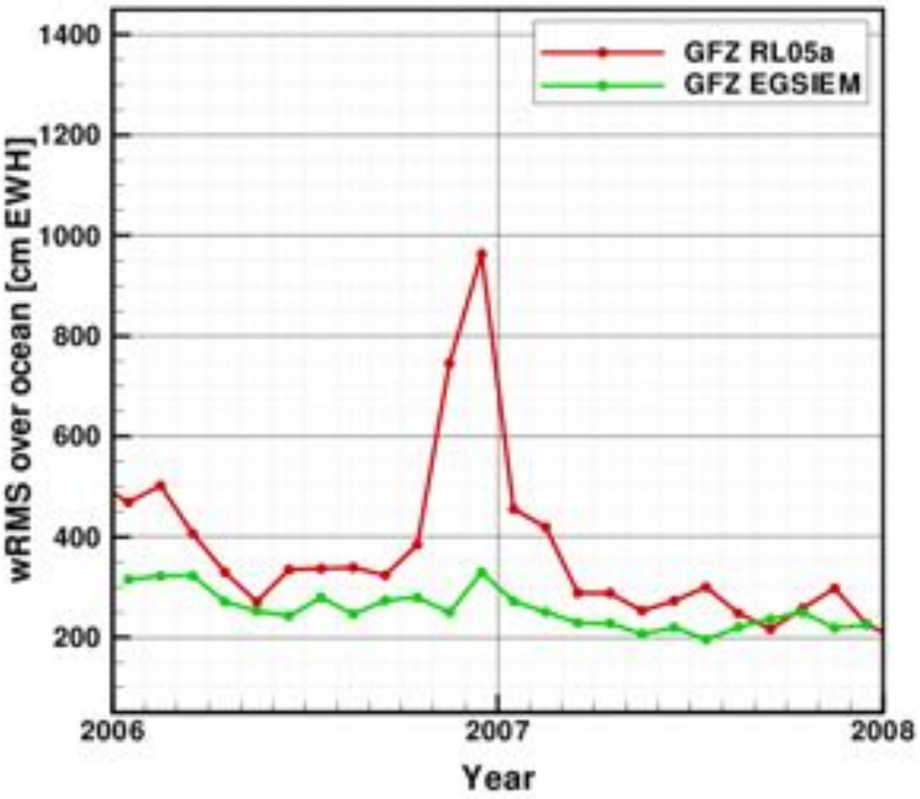
- 3h biases + scales least noisy (left Fig.), puts GFZ RL05a solution on a level comparable with CSR RL05 and ITSG2014 (right Fig.)
- Proper treatment of accelerometer observations crucial during early mission (higher solar activity) and during last years (reduced thermal control, again higher solar activity + lower orbit)
- => Tests are still onging (got suggestions from CSR, are interested in TUG results)

HORIZON 2020

Level 2 Products at GFZ: EGSIEM 2006/2007

European Gravity Service for Improved Emergency Management

- Significant noise reduction and increased consistency w.r.t. GFZ RL05a:



Level 2 Products at GFZ: AOD1B RL06

European Gravity Service for Improved Emergency Management

Differences between AOD1B RL05 and RL06:

- RL06 has higher spatial and temporal resolution (max d/o 180 instead 100, 3h instead 6h)
- (atmospheric & oceanic) tidal signals are removed from AOD1B products in RL06
- RL06 uses ERA-Interim data until 2006 (RL05: 2000) & op. ECMWF data since 2007 (RL05: 2001)
- Surface pressure is reduced to op. ECMWF orography from 2014 in RL06 (no reference orography in RL05)
- RL06 uses MPIOM ocean model (RL05: OMCT)
- No ocean signals beneath Antarctic ice shelves in RL06 (RL05: ocean dynamics from Padman et al. 2002)

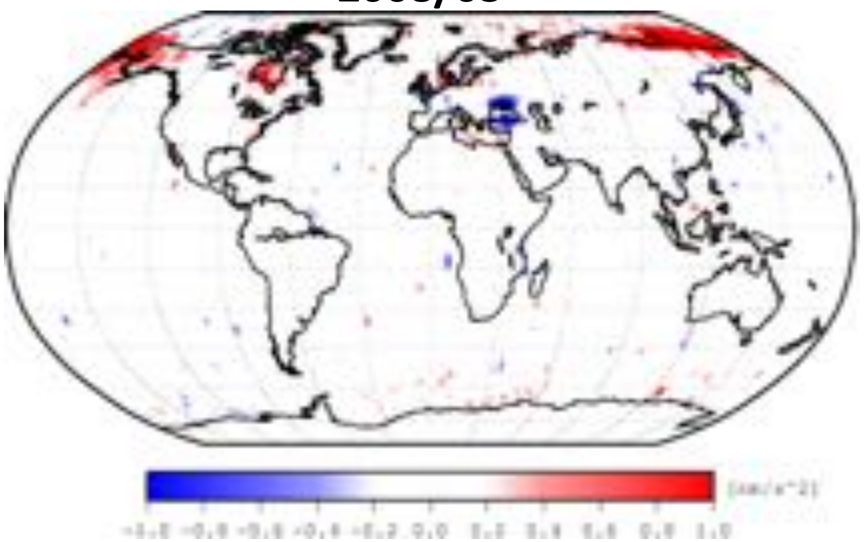
Level 2 Products at GFZ:
AOD1B RL06

European Gravity Service for Improved Emergency Management

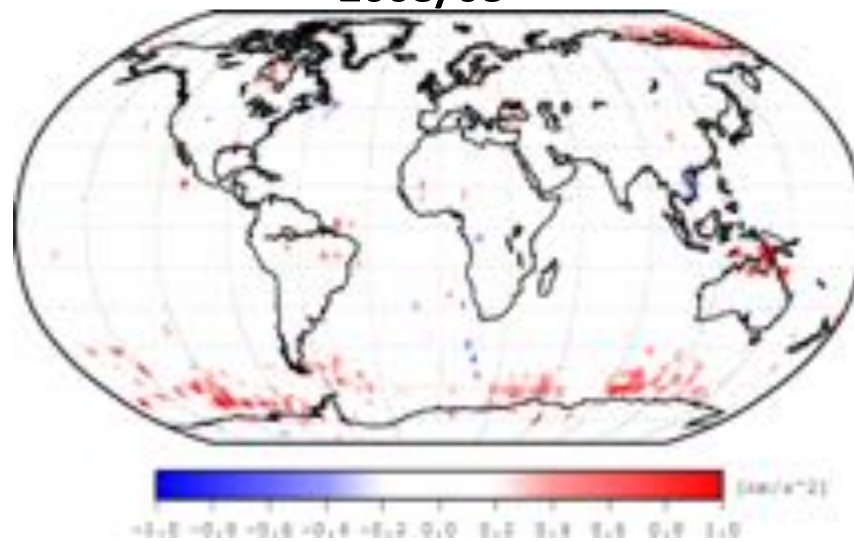
Variance reduction of K-band range-acceleration residuals

Differences between GFZ GRACE solutions using (1) AOD1B RL05 and (2) AOD1B RL06 (red indicates AOD1B RL06 is better, blue AOD1B RL05 is better)

2008/03



2008/08



- Generally improvements by AOD1B RL06
- Years investigated so far: 2008 & 2014 (similar conclusions can be drawn from all months)

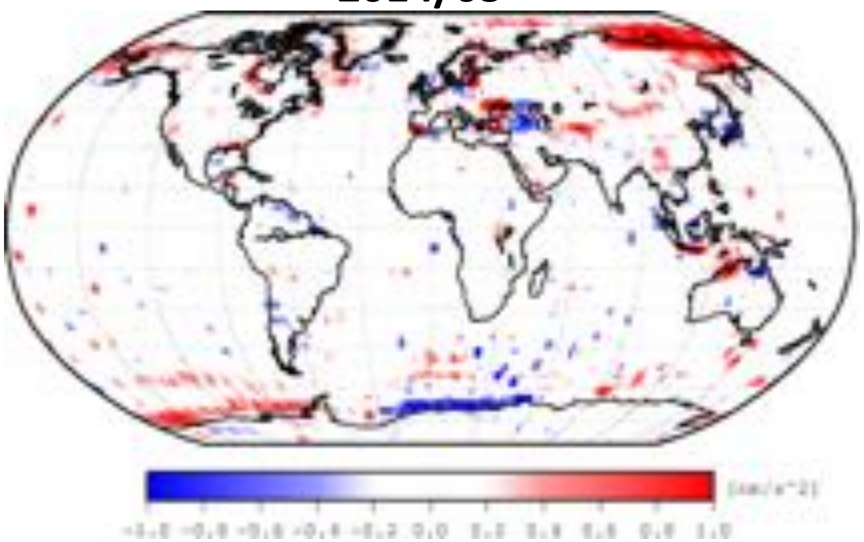
Level 2 Products at GFZ: AOD1B RL06

EGSIEM
European Gravity Service for Improved Emergency Management

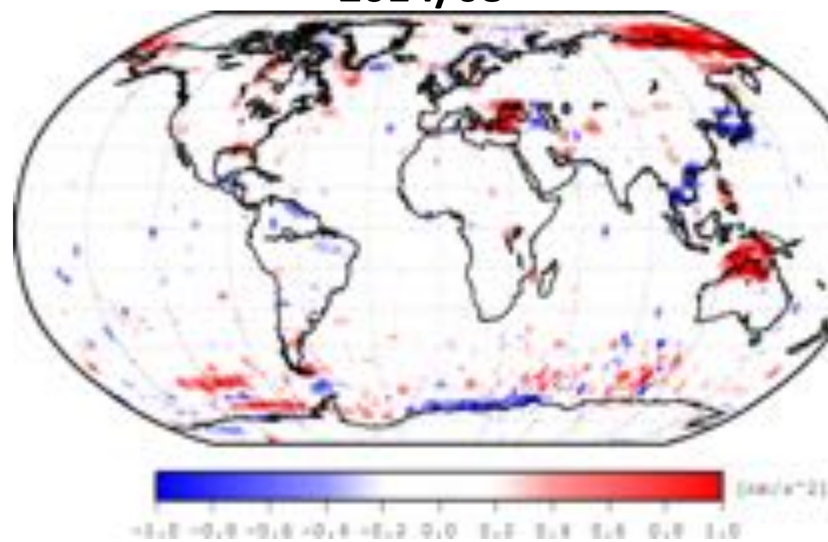
Variance reduction of K-band range-acceleration residuals

Differences between GFZ GRACE solutions using (1) AOD1B RL05 and (2) AOD1B RL06 (red indicates AOD1B RL06 is better, blue AOD1B RL05 is better)

2014/03



2014/08



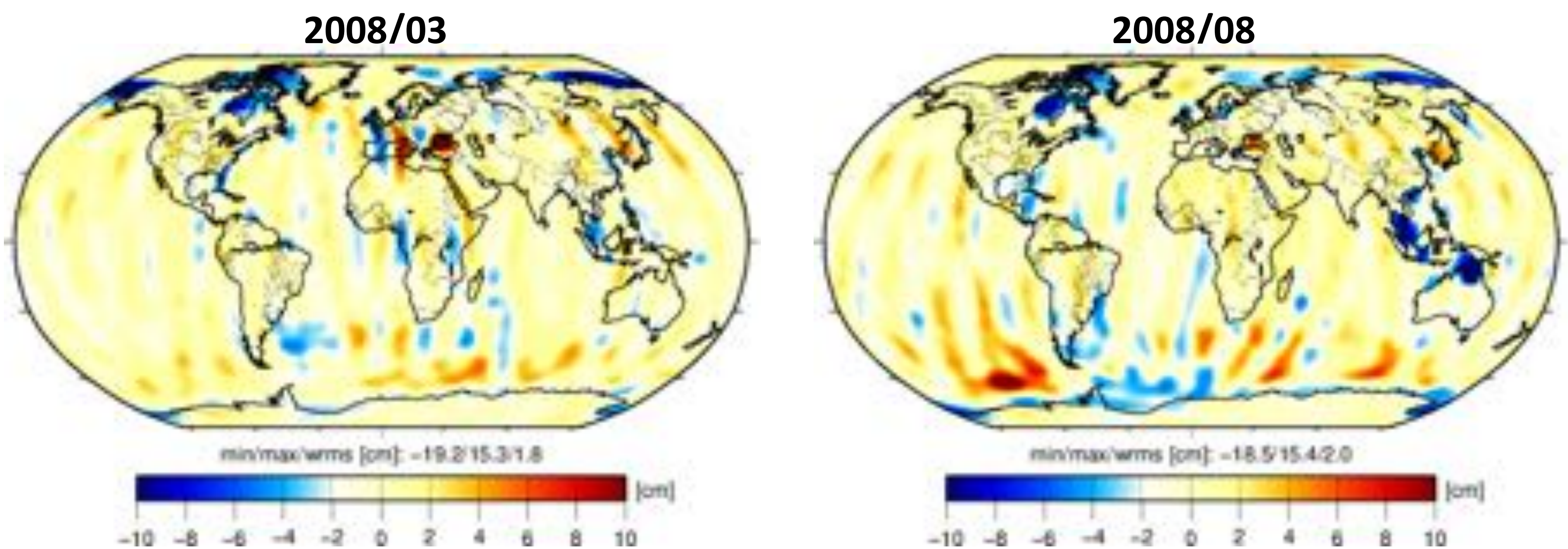
- Generally improvements by AOD1B RL06
- Years investigated so far: 2008 & 2014 (similar conclusions can be drawn from all months)

Level 2 Products at GFZ: AOD1B RL06

EGSIEM
European Gravity Service for Improved Emergency Management

Impact on monthly gravity field solutions

EWH differences [cm] (DDK3 filtered) between GFZ GRACE solutions using (1) AOD1B RL05 and (2) AOD1B RL06 (red indicates AOD1B RL06 has smaller values, blue AOD1B RL05 has smaller values)



- RMS differences of ~2cm, but also up to ~20 cm in certain regions!

Level 2 Products at GFZ: AOD1B RL06

European Gravity Service for Improved Emergency Management

Impact on monthly gravity field solutions: wRMS over ocean (EWH [cm], unfiltered):

	AOD1B RL05	AOD1B RL06
2008/01	**186.7**	**177.5 (-5%)**
2008/02	**200.8**	**192.4 (-4%)**
2008/03	**198.2**	**191.7 (-3%)**
2008/04	**200.8**	**197.5 (-2%)**
2008/05	**189.5**	**186.7 (-1%)**
2008/06	**213.5**	**211.7 (-1%)**
2008/07	**208.1**	**199.7 (-4%)**
2008/08	**215.1**	**210.8 (-2%)**
2008/09	**213.2**	**214.2 (+0%)**
2008/10	**190.3**	**186.2 (-2%)**
2008/11	**195.0**	**188.9 (-3%)**
2008/12	**195.5**	**187.6 (-4%)**

Level 2 Products at GFZ: Remark

European Gravity Service for Improved Emergency Management

- GFZ is planning to provide (at least) a (draft) RL06 2006/2007 solution for the EGSIEM Combination Service in September 2017.

EGSIEM

European Gravity Service for Improved Emergency Management

GRACE Gravity Field Determination using Refined Acceleration Approach: Preliminary results

ULUX—WP2 progress

UNIVERSITÄT BERN
UNIVERSITÉ DU LUXEMBOURG
GFZ Helmholtz Centre POTSDAM
TU Graz
Leibniz Universität Hannover
cnes
DLR
géode&cie

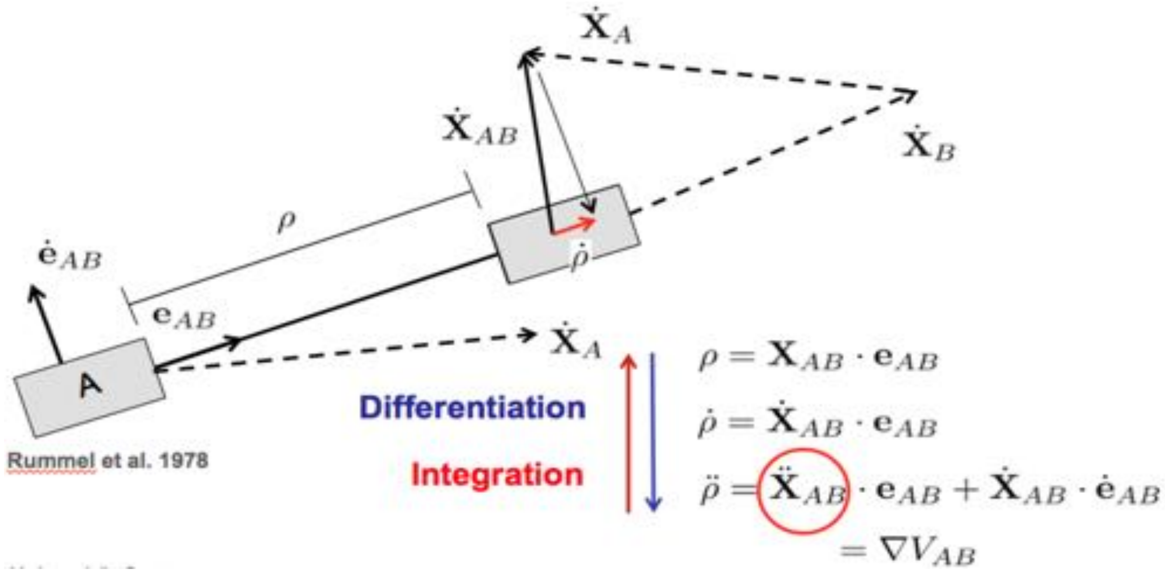
HORIZON 2020

The acceleration approach-an alternative way of processing GRACE data

- Direct Link between kinematics (obs) and dynamics (force)
- Existing GRACE gravity field solutions based on acceleration approach:
  - Mean acceleration approach
    - DMT-1 (Liu et al., 2010)
    - Tongji_Acc RL01 (Chen et al., 2015)
  - Point-wise acceleration approach
    - WHIGG-GEGM01S (Cheng et al., 2012)
- An alternative way: connect the range accelerations with gradient of the gravitational potential

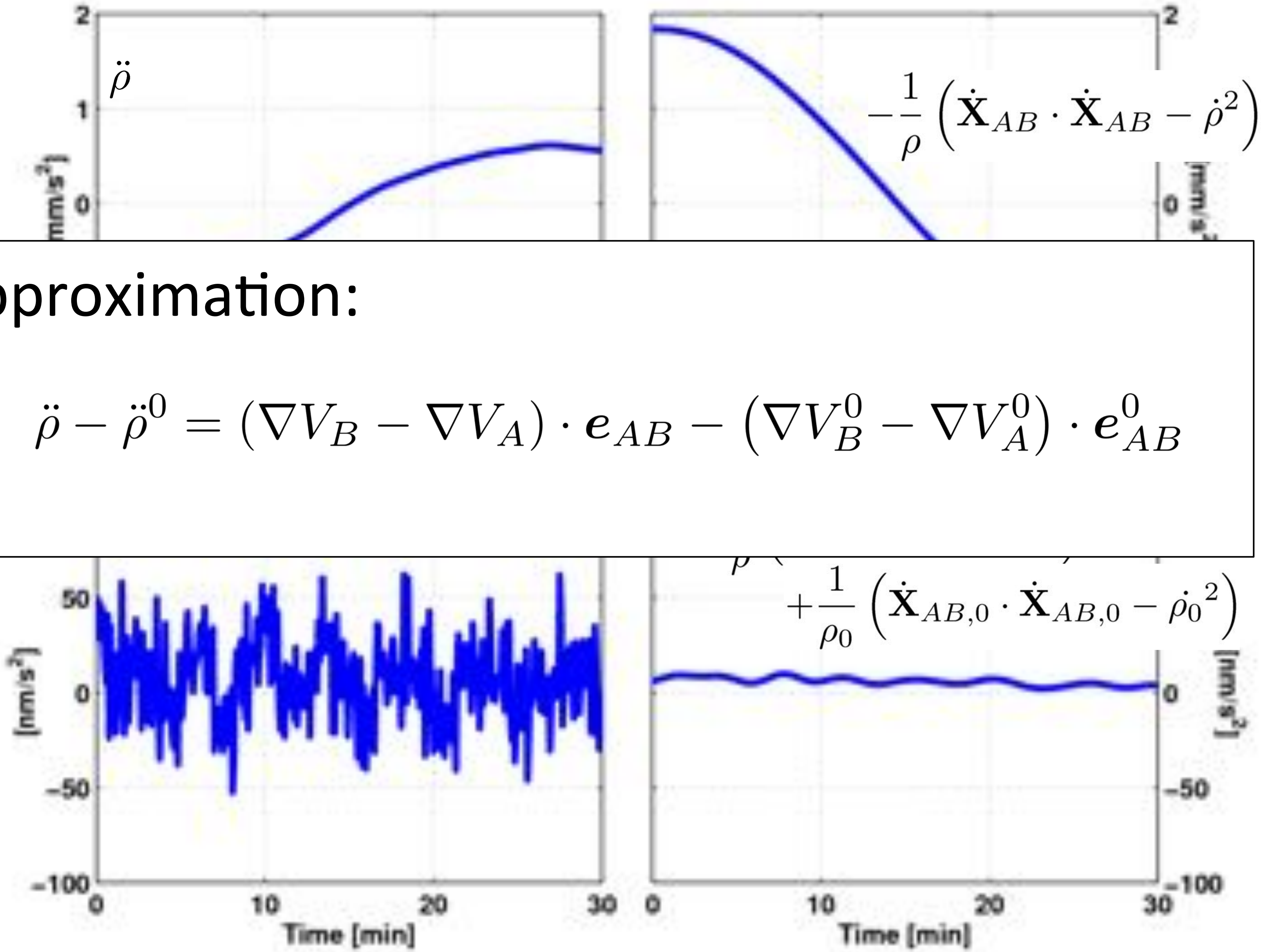
Recall the functional model of the classical acceleration approach

For the GRACE ll-SST case,



$$\nabla V_{AB} \cdot \mathrm{e}_{\mathrm{AB}}^{\mathrm{a}} = \ddot{\rho} - \frac{1}{\rho}\left(\dot{\mathrm{x}}_{\mathrm{AB}} \cdot \dot{\mathrm{x}}_{\mathrm{AB}} - \dot{\rho}^2\right)$$

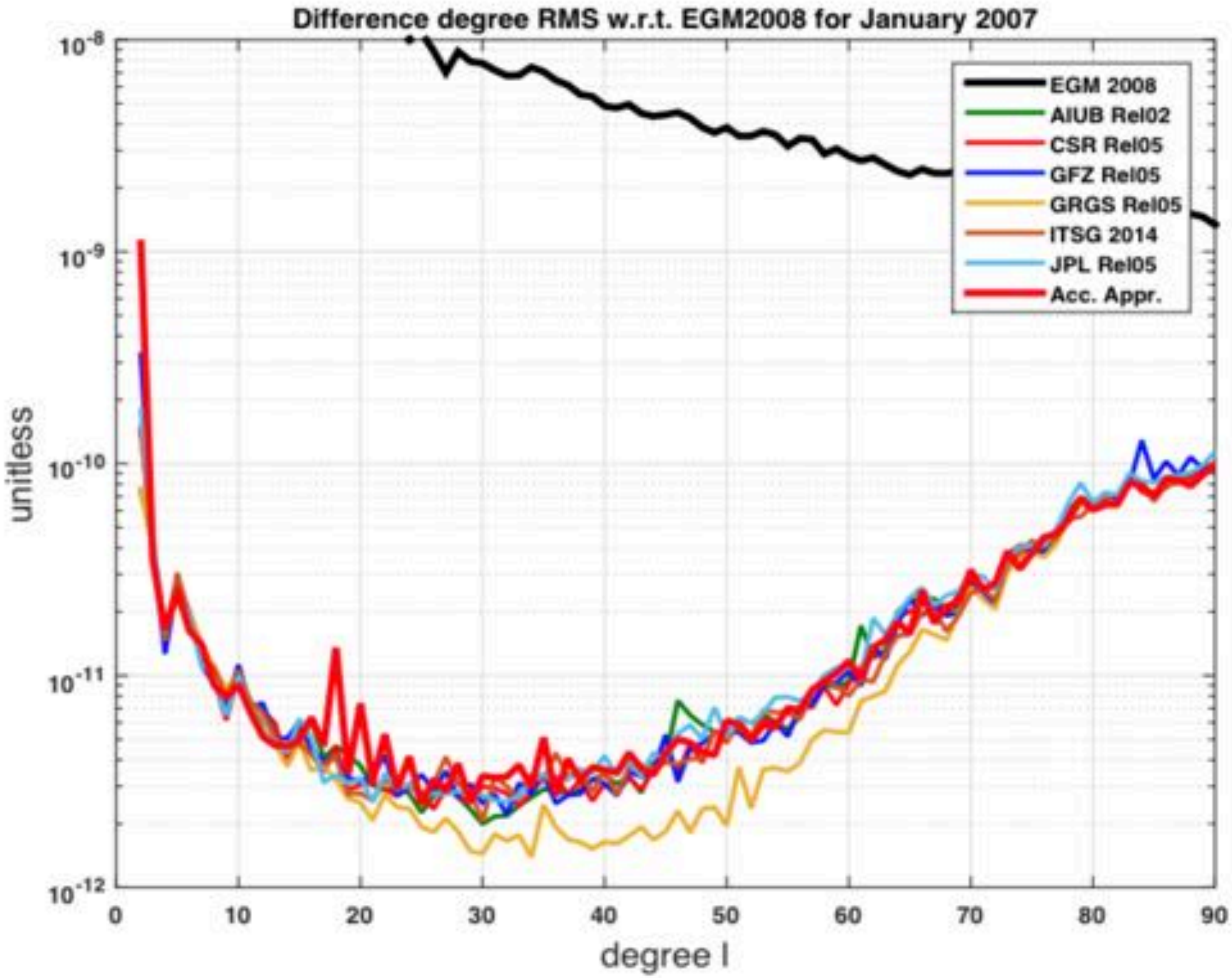
Approach: $\nabla V \cdot \boldsymbol{e}_{AB} = \ddot{\rho} - \frac{1}{\rho}\left(\|\dot{\boldsymbol{X}}_{AB}\|^2 - \dot{\rho}^2\right)$



Approximation:

$$\ddot{\rho} - \ddot{\rho}^0 = (\nabla V_B - \nabla V_A)\cdot \boldsymbol{e}_{AB} - \left(\nabla V_B^0 - \nabla V_A^0\right)\cdot \boldsymbol{e}_{AB}^0$$

Approximate solution



EGSIEM

HORIZON 2020

Refinement (Rigorous solution)

- Full expression:

$$\ddot{\rho} - \ddot{\rho}^0 = (\nabla V_B - \nabla V_A) \cdot \boldsymbol{e}_{AB} - \left(\nabla V_B^0 - \nabla V_A^0\right) \cdot \boldsymbol{e}_{AB}^0 + \frac{1}{\rho}\left(\dot{\boldsymbol{X}}_{AB} \cdot \dot{\boldsymbol{X}}_{AB} - \dot{\rho}^2\right) - \frac{1}{\rho^0}\left(\dot{\boldsymbol{X}}_{AB}^0 \cdot \dot{\boldsymbol{X}}_{AB}^0 - \left(\dot{\rho}^0\right)^2\right)$$

- Applying linearization yields:

$$\begin{aligned} \nabla V_{AB} \cdot \boldsymbol{e}_{AB} - \nabla V_{AB}^0 \cdot \boldsymbol{e}_{AB}^0 &= \sum_i \frac{\partial f_1}{\partial s_i}\Delta s_i + \sum_i \frac{\partial f_2}{\partial s_i}\Delta s_i + \hbar^2 \\ \frac{1}{\rho}\|\dot{\boldsymbol{X}}_{AB}\|^2 - \frac{1}{\rho^0}\|\dot{\boldsymbol{X}}_{AB}^0\|^2 &= \sum_i \frac{\partial g_1}{\partial s_i}\Delta s_i + \hbar^2 \\ -\frac{\dot{\rho}^2}{\rho} + \frac{\left(\dot{\rho}^0\right)^2}{\rho^0} &= \sum_i \frac{\partial g_2}{\partial s_i}\Delta s_i + \hbar^2 \end{aligned}$$

- f1 is the relative gravity vector and f2 is the line of sight unit vector

Refinement (Rigorous solution)

- Partial derivatives for f1 toward Clm and Slm can be derived analytically:

$$\frac{\partial f_1}{\partial \overline{C}_{lm}} = \frac{\partial(\partial V_B/\partial x_E)}{\partial \overline{C}_{lm}} \cdot e^0_{AB,x_E} + \frac{\partial(\partial V_B/\partial y_E)}{\partial \overline{C}_{lm}} \cdot e^0_{AB,y_E} + \frac{\partial(\partial V_B/\partial z_E)}{\partial \overline{C}_{lm}} \cdot e^0_{AB,z_E}$$
$$- \frac{\partial(\partial V_A/\partial x_E)}{\partial \overline{C}_{lm}} \cdot e^0_{AB,x_E} - \frac{\partial(\partial V_A/\partial y_E)}{\partial \overline{C}_{lm}} \cdot e^0_{AB,y_E} - \frac{\partial(\partial V/\partial z_E)}{\partial \overline{C}_{lm}} \cdot e^0_{AB,z_E}$$

$$\frac{\partial f_1}{\partial \overline{S}_{lm}} = \frac{\partial(\partial V_B/\partial x_E)}{\partial \overline{S}_{lm}} \cdot e^0_{AB,x_E} + \frac{\partial(\partial V_B/\partial y_E)}{\partial \overline{S}_{lm}} \cdot e^0_{AB,y_E} + \frac{\partial(\partial V_B/\partial z_E)}{\partial \overline{S}_{lm}} \cdot e^0_{AB,z_E}$$
$$- \frac{\partial(\partial V_A/\partial x_E)}{\partial \overline{S}_{lm}} \cdot e^0_{AB,x_E} - \frac{\partial(\partial V_A/\partial y_E)}{\partial \overline{S}_{lm}} \cdot e^0_{AB,y_E} - \frac{\partial(\partial V/\partial z_E)}{\partial \overline{S}_{lm}} \cdot e^0_{AB,z_E}$$

- All the other partials are formed by chain rule and linked to the partial derivatives of position and velocity of each satellite toward the unknowns

- Variational equations need to be solved! More work than considering range/range rate observations because of g1 and g2

Variation of constant approach (Jaeggi, 2007)

- Variational equations for the initial conditions (homogeneous solution):

$$
\frac{d}{dt}\begin{bmatrix}
\frac{\partial x}{\partial x_0} & \frac{\partial x}{\partial y_0} & \cdots & \frac{\partial x}{\partial \dot{y}_0} & \frac{\partial x}{\partial \dot{z}_0} \\
\frac{\partial y}{\partial x_0} & \frac{\partial y}{\partial y_0} & \cdots & \frac{\partial y}{\partial \dot{y}_0} & \frac{\partial y}{\partial \dot{z}_0} \\
\frac{\partial z}{\partial x_0} & \frac{\partial z}{\partial y_0} & \cdots & \frac{\partial z}{\partial \dot{y}_0} & \frac{\partial z}{\partial \dot{z}_0} \\
\frac{\partial \dot{x}}{\partial x_0} & \frac{\partial \dot{x}}{\partial y_0} & \cdots & \frac{\partial \dot{x}}{\partial \dot{y}_0} & \frac{\partial \dot{x}}{\partial \dot{z}_0} \\
\frac{\partial \dot{y}}{\partial x_0} & \frac{\partial \dot{y}}{\partial y_0} & \cdots & \frac{\partial \dot{y}}{\partial \dot{y}_0} & \frac{\partial \dot{y}}{\partial \dot{z}_0} \\
\frac{\partial \dot{z}}{\partial x_0} & \frac{\partial \dot{z}}{\partial y_0} & \cdots & \frac{\partial \dot{z}}{\partial \dot{y}_0} & \frac{\partial \dot{z}}{\partial \dot{z}_0}
\end{bmatrix}
=
\begin{bmatrix}
0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 \\
\frac{\partial^2 V}{\partial x^2} & \frac{\partial^2 V}{\partial x \partial y} & \frac{\partial^2 V}{\partial x \partial z} & 0 & 0 & 0 \\
\frac{\partial^2 V}{\partial y \partial x} & \frac{\partial^2 V}{\partial y^2} & \frac{\partial^2 V}{\partial y \partial z} & 0 & 0 & 0 \\
\frac{\partial^2 V}{\partial z \partial x} & \frac{\partial^2 V}{\partial z \partial y} & \frac{\partial^2 V}{\partial z^2} & 0 & 0 & 0
\end{bmatrix}
\cdot
\begin{bmatrix}
\frac{\partial x}{\partial x_0} & \frac{\partial x}{\partial y_0} & \cdots & \frac{\partial x}{\partial \dot{y}_0} & \frac{\partial x}{\partial \dot{z}_0} \\
\frac{\partial y}{\partial x_0} & \frac{\partial y}{\partial y_0} & \cdots & \frac{\partial y}{\partial \dot{y}_0} & \frac{\partial y}{\partial \dot{z}_0} \\
\frac{\partial z}{\partial x_0} & \frac{\partial z}{\partial y_0} & \cdots & \frac{\partial z}{\partial \dot{y}_0} & \frac{\partial z}{\partial \dot{z}_0} \\
\frac{\partial \dot{x}}{\partial x_0} & \frac{\partial \dot{x}}{\partial y_0} & \cdots & \frac{\partial \dot{x}}{\partial \dot{y}_0} & \frac{\partial \dot{x}}{\partial \dot{z}_0} \\
\frac{\partial \dot{y}}{\partial x_0} & \frac{\partial \dot{y}}{\partial y_0} & \cdots & \frac{\partial \dot{y}}{\partial \dot{y}_0} & \frac{\partial \dot{y}}{\partial \dot{z}_0} \\
\frac{\partial \dot{z}}{\partial x_0} & \frac{\partial \dot{z}}{\partial y_0} & \cdots & \frac{\partial \dot{z}}{\partial \dot{y}_0} & \frac{\partial \dot{z}}{\partial \dot{z}_0}
\end{bmatrix}
$$

- Variation of constant (inhomogeneous solution):

$$
\boldsymbol{\alpha}_{p_i}(t) = \int_{t_0}^{t} \Phi^{-1}(\tau) \cdot \frac{\partial \mathbf{h}(\tau)}{\partial p_i} d\tau
$$

$$
\phi_{p_i}(t) = \Phi(t) \cdot \boldsymbol{\alpha}_{p_i}(t) .
$$

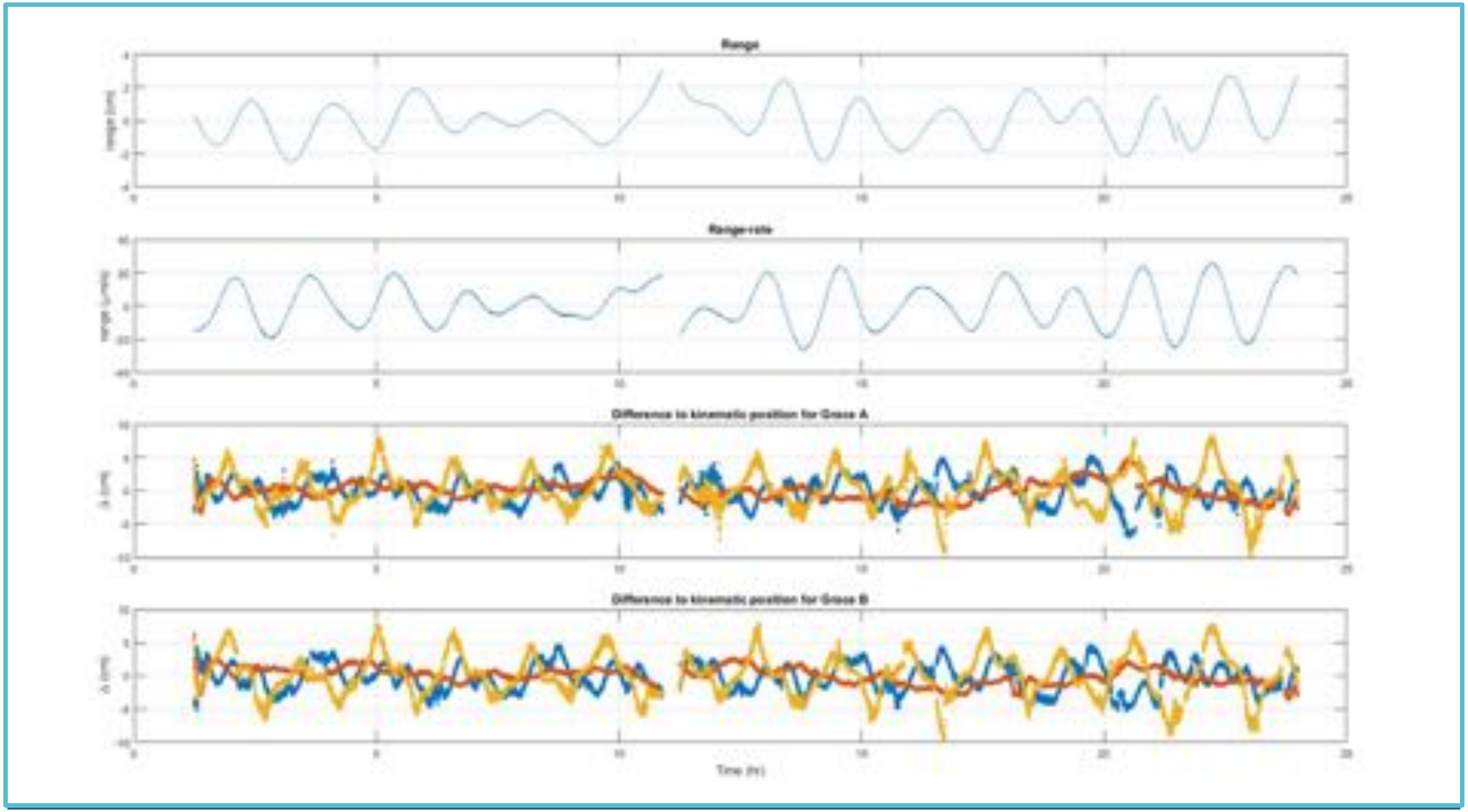
- Partial derivatives toward the unknowns could then be established via chain rule using the above solutions

Current implementation status at UL

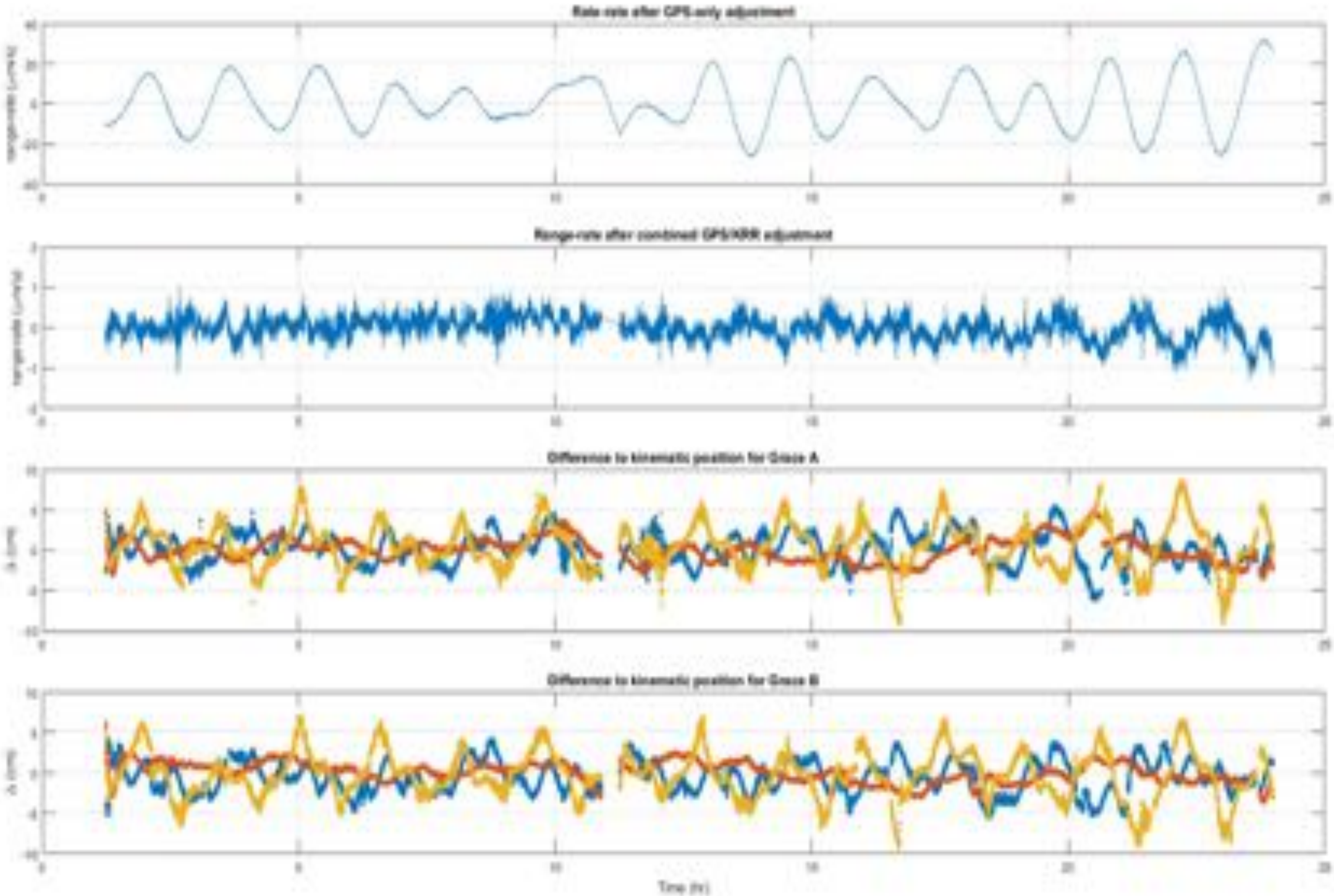
- **Codes for the rigorous approach have almost been finished. They are now under the test stage**

- **A priori orbit of Grace A and B for later gravity field determination (iteration)**
  - **Method: CMA, totally follow AIUB (Beutler et al., 2010)**
  - **Input data: LIB GRAZ Kin, Nav, KRR, accelerometer and star camera data**
  - **Arc-length: 24 hours**
  - **Parameterization: 6 initial state vectors per arc, empirical piece-wise constant acceleration every 15min per axis per arc, accelerometer scale and bias per axis per day**
  - **Constraints: pos 0.3, vel 0.03, emp acc 3e-9, acc scale 1e-4, acc bias 1e-8, during combined adjustment, p1 and p2 applied with different constraints: 3e-9 and 3e-11**
  - **Scaling ratio of krr/gps is calculated ∂krr2/ ∂gps2**
  - **Background model:**
    - **Tide-system: Tide-free**
    - **Goco05s is used as the a priori gravity model**
    - **EGM2008 is used for correcting the impact of coefficients from maximum degree (60 or 90) to 250**
    - **Solid earth and pole tide: IERS 2003**
    - **Ocean pole tide: Desai model complete to degree and order 120**
    - **Ocean tide: EOT11a, degree and order 120**
    - **Atmospheric tides: only S2, degree and order 8 (Biancale & Bode 2006, GFZ from ECMWF model)**
    - **High frequency atmosphere and ocean mass redistribution: AOD1B RL05, complete to degree and order 100 (Flechtner & Dobslaw 2013), remove the S2 part**
    - **Body tides: moon, sun, mercury, venus, mars, Jupiter, Saturn, Uranus, Neptune, DE421 used (Folkner et al 2008)**
    - **Relativistic effect: IERS 2010**
    - **Earth rotation: IERS 2010**

Orbit adjustment result for Grace A and B on 2006-01-01



KRR contribution for Grace A and B on 2006-01-01



EGSIEM

HORIZON 2020

Current implementation status at UL

- **Solve for orbit and the gravity field parameters using our rigorous acceleration approach(no iteration)**

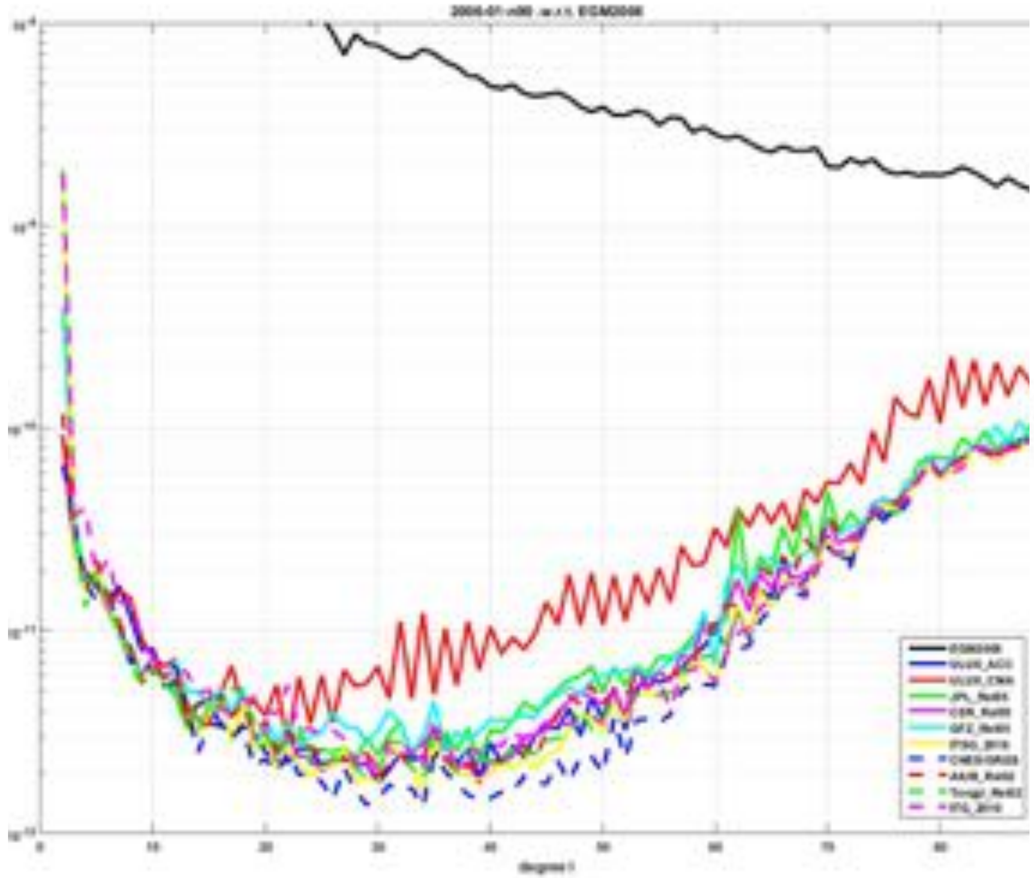
- **Only ll-SST considered so far, the observation equation is:**

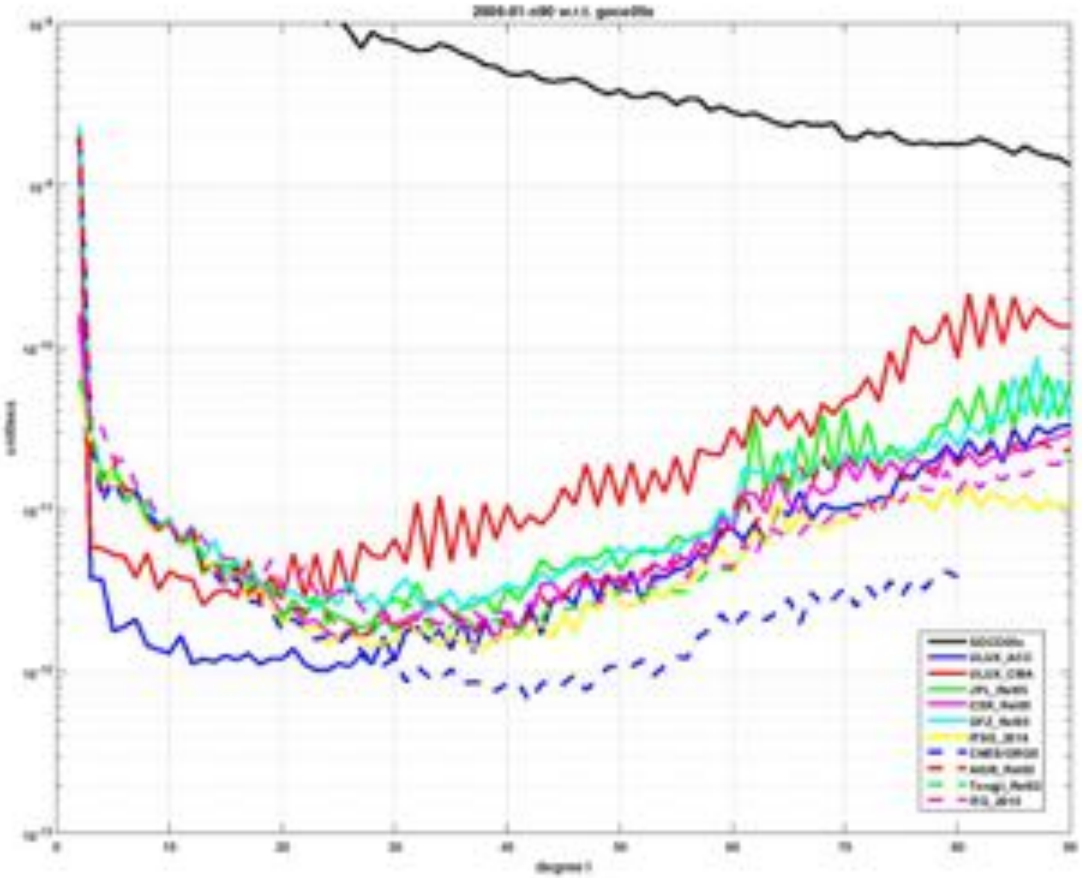
$$
\begin{aligned}
\ddot{\rho} - \ddot{\rho}^0 &= (\nabla V_B - \nabla V_A) \cdot \boldsymbol{e}_{AB} - \left(\nabla V_B^0 - \nabla V_A^0\right) \cdot \boldsymbol{e}_{AB}^0 \\
&+ \frac{1}{\rho}\left(\dot{\boldsymbol{X}}_{AB} \cdot \dot{\boldsymbol{X}}_{AB} - \dot{\rho}^2\right) - \frac{1}{\rho^0}\left(\dot{\boldsymbol{X}}_{AB}^0 \cdot \dot{\boldsymbol{X}}_{AB}^0 - \left(\dot{\rho}^0\right)^2\right)
\end{aligned}
$$

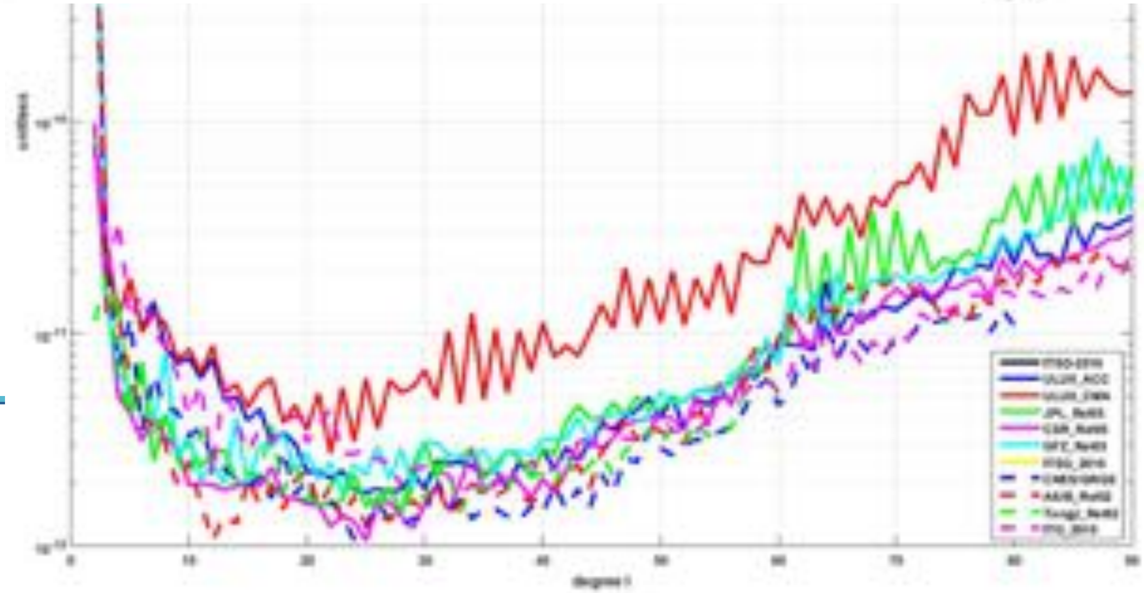
- **Position and range-rate also needed to form normal equations**

- **The rigorous acceleration approach is just another implementation of the variational equations**

Test gravity coefficient results for 01/2006 until degree 90



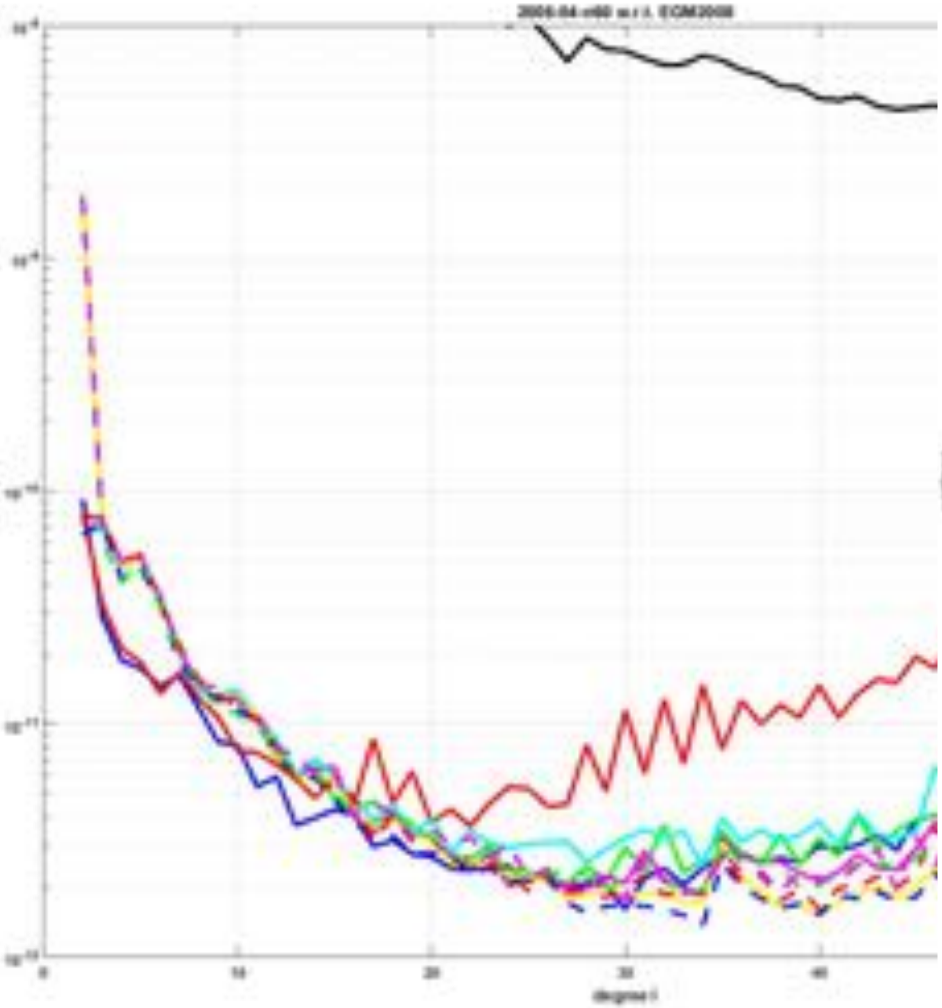


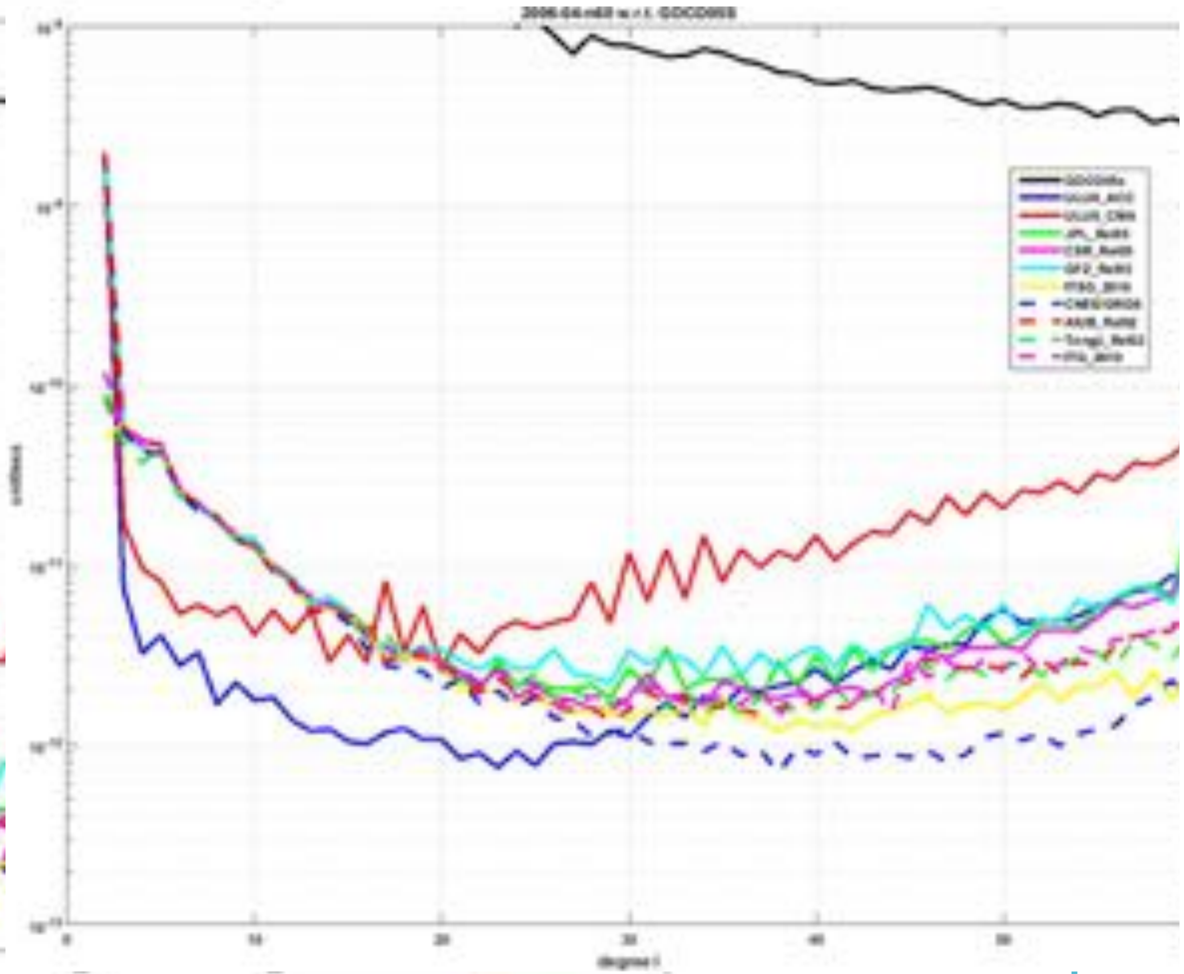


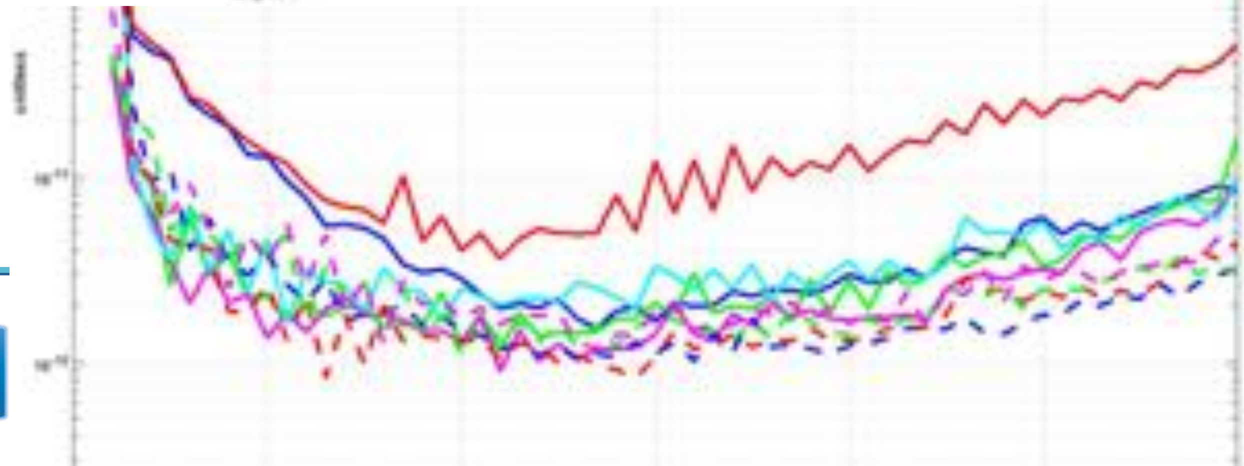
EGSIEM

HORIZON 2020

Test gravity coefficient results for 04/2006 until degree 60

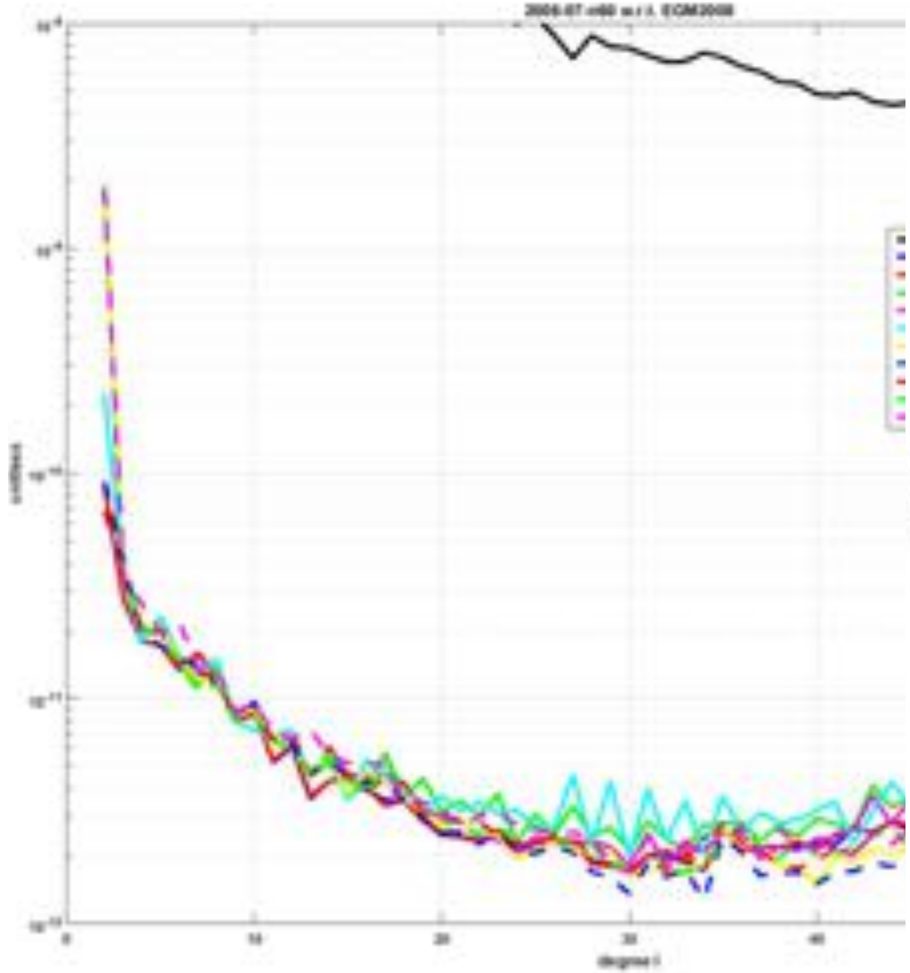


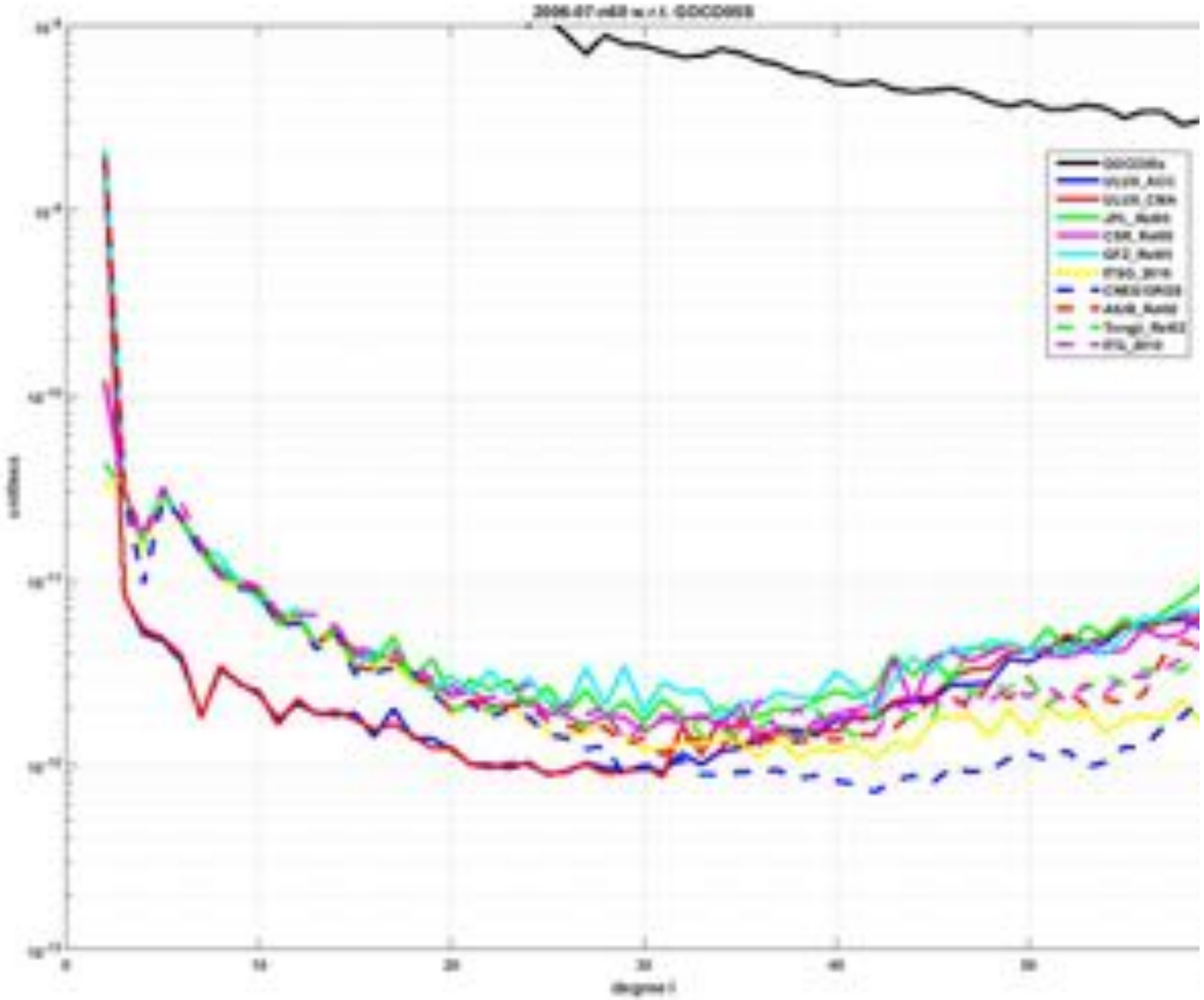


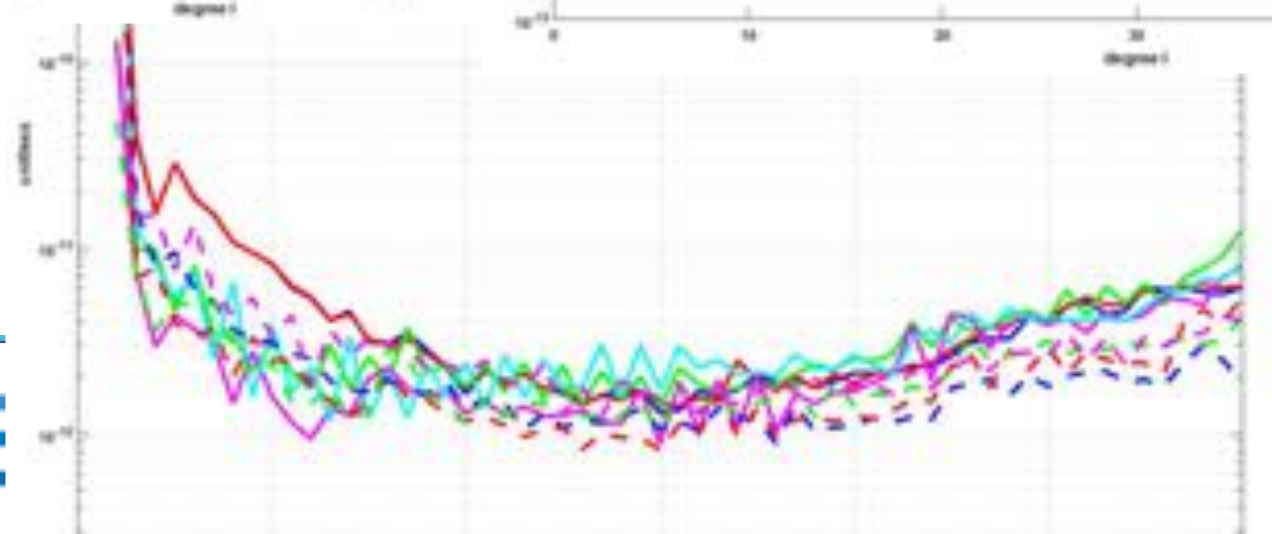


HORIZON 2020

Test gravity coefficient results for 07/2006 until degree 60

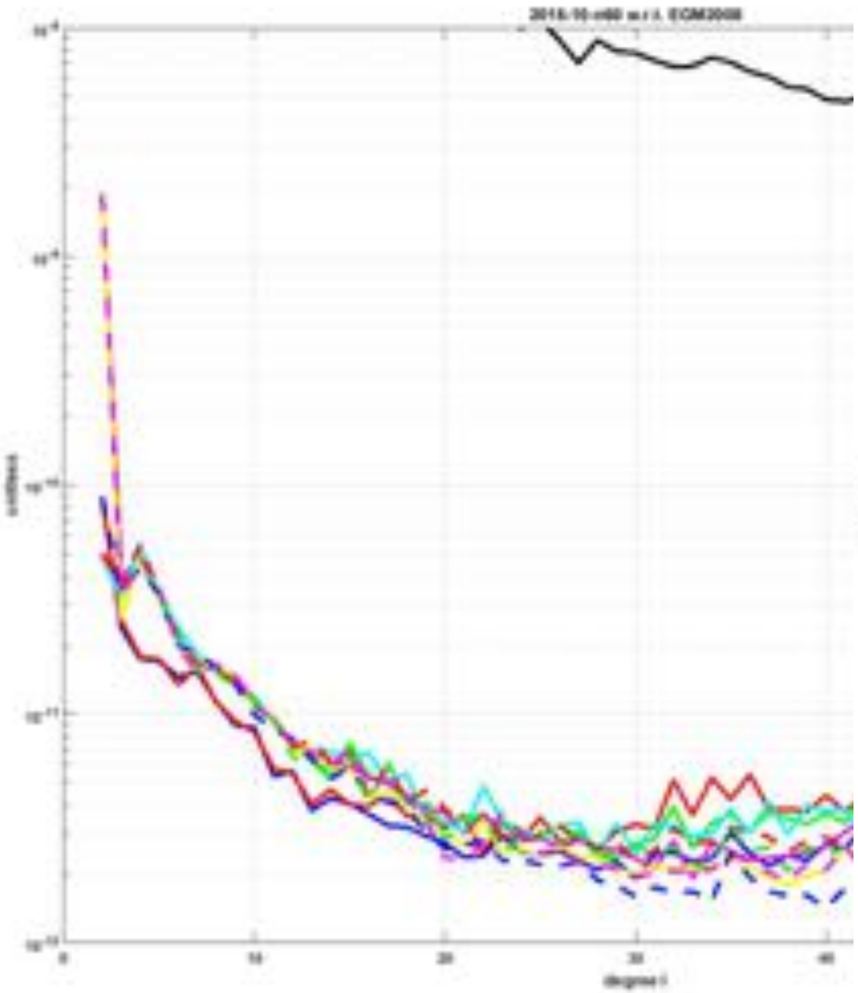


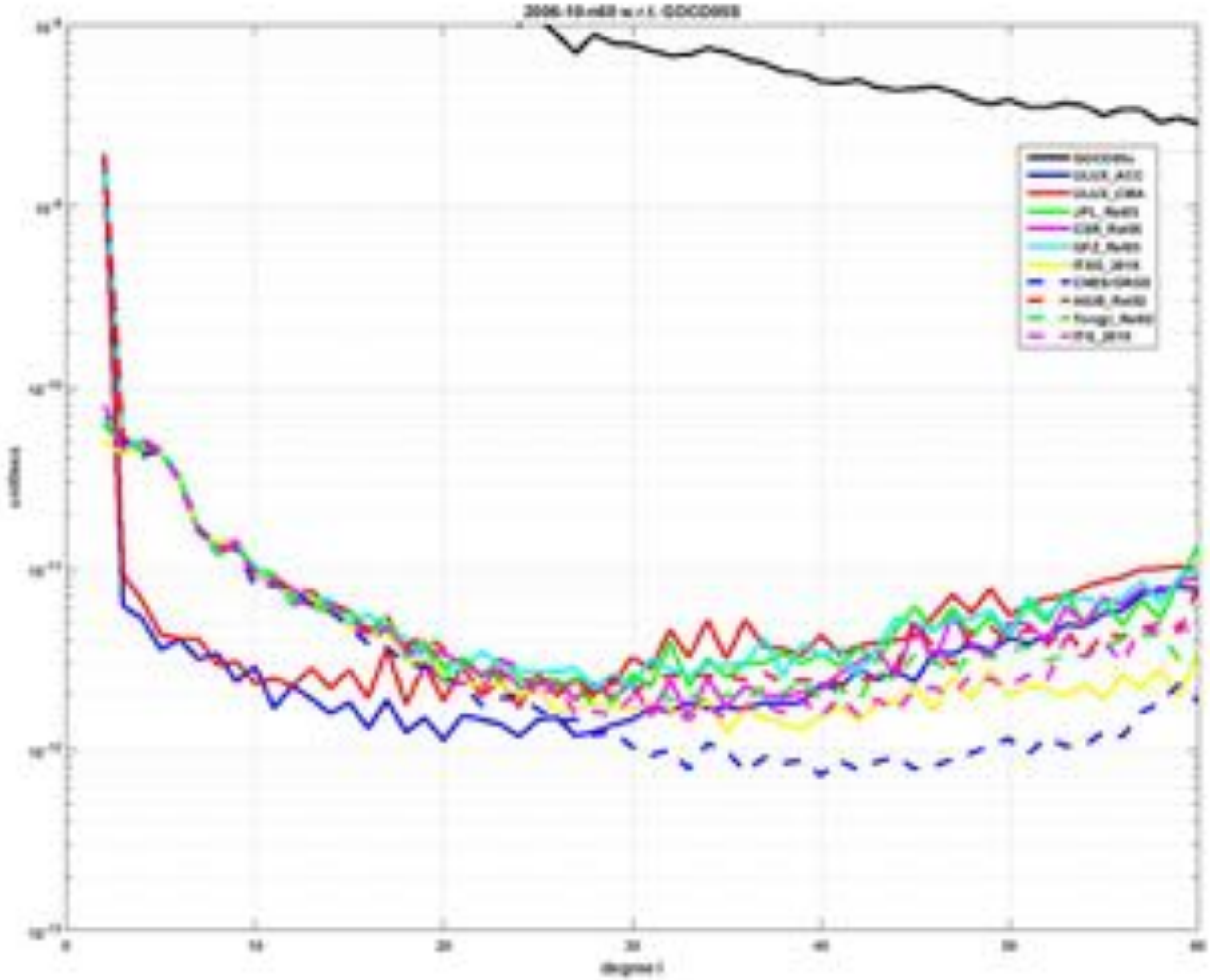


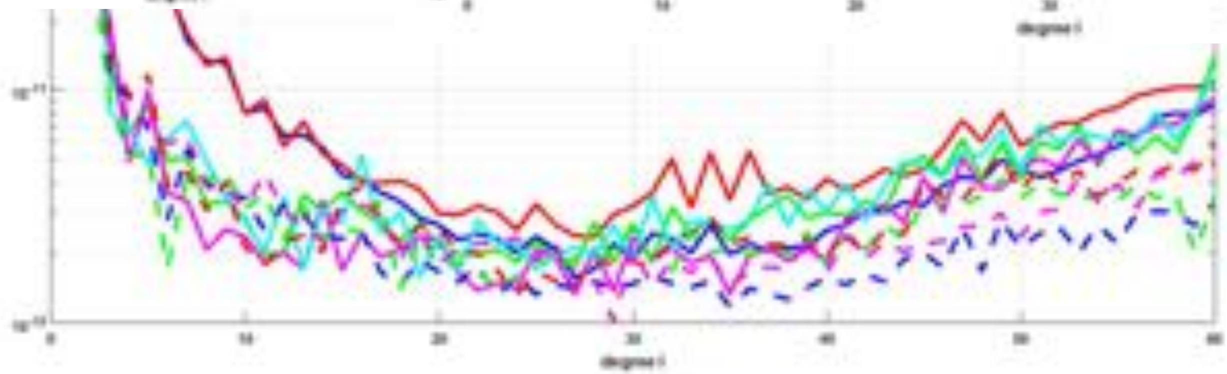


HORIZON 2020

Test gravity coefficient results for 10/2006 until degree 60







HORIZON 2020

Work plan in 2007

- The implementation has been improved and we are getting more closer.
- Still issues to be solved
  - Some of the orbit are not good enough
    - Shorter arc length, piece wise linear acc,…
    - Better integrator
    - Parameterization
    - …
  - Solution biased toward GOCO05S
- More detailed analysis and comparison with the other analysis centers
  - Validation with hydrology
  - Validation with GPS leveling and displacement
- Good news is that ULUX is progressing, and we are confident to deliver full solution for 2006-2007 at the end of June

Thank you very much!

EGSIEM

HORIZON 2020

EGSIEM
European Gravity Service for Improved Emergency Management

WP1: Management Update

Keith Cann-Guthauser
Astronomisches Institut, Universität Bern

EGSIEM Assembly

19-20. January 2017, Bern

WP1: Management
Overview

- Reporting
- Payments
- Data Management Plan

WP1: Management

Reporting

Our first financial reporting period was between **1.1.2015 – 31.12.2015** and we submitted the first periodic report on 28th February 2016 (so, within the 60 days deadline).

WP1: Management

Reporting

In year 2 (01.01. – 31.12.2016) we provided a Progress Report

No financials details were necessary* other than where there was a significant divergence from the budget.

The report template was identical to that which was completed for the first periodic report.

The report provides an overview of what has happened in each WP since the end of 2015

* UBERN will need to complete their own finances to their local funder.

WP1: Management

Reporting

- The WP Leaders coordinated each relevant section
- All other areas written by UBERN (with significant input from you all)
- During 2016 all WPs were active
- Progress Report can be downloaded from SyGMa (EU Participant Portal)* or from egsiem.eu
- Our next report will be due in Feb 2018 (Second Periodic Report)

* Is it?

WP1: Management

Reporting/Deliverables

Deliverables

For each Deliverable, a single file (max 10MB) can be uploaded

WP No.	Del.Rel. No.	Del.No.	Title	Lead Beneficiary	Nature	Dissemination Level	Est. Del. Date (annex I)	Receipt Date	Approval Date	Status
WP1	D1.1	D1	Management guidelines	UBERN	Report	Confidential, only for members	28 Feb 2015	30 Jul 2015		Submi...
WP2	D2.1	D2	Processing standards and models	TU GRAZ	Report	Public	28 Feb 2015	30 Jul 2015		Submi...
WP5	D5.1	D10	Concept of NRT service	GFZ	Report	Public	31 Mar 2015	30 Jul 2015		Submi...
WP7	D7.1	D16	EGSIEM project website	UBERN	Websites, patents fil	Public	31 Mar 2015	30 Jul 2015		Submi...
WP3	D3.1	D4	Reference frame product report	UL	Report	Public	31 Oct 2015	01 Nov 2015		Submi...
WP7	D7.2	D17	EGSIEM brochure	UBERN	Websites, patents fil	Public	29 Feb 2016	19 Oct 2015		Submi...
WP7	D7.3	D18	Teaser lecture	UBERN	Websites, patents fil	Public	31 Mar 2016	18 Mar 2016		Submi...
WP2	D2.2	D3	GRACE/GRACE FO product report	TU GRAZ	Report	Public	30 Jun 2016	30 Jun 2016		Submi...
WP4	D4.1	D7	Concept of scientific service	UBERN	Report	Public	30 Jun 2016	30 Jun 2016		Submi...
WP1	D1.2	D21	Interim progress report	UBERN	Report	Public	31 Dec 2016	31 Dec 2016		Submi...
WP5	D5.2	D11	NRT service product report	GFZ	Report	Public	31 Mar 2017			Pending
WP5	D5.4	D13	Regional solution product report	GFZ	Report	Public	31 Mar 2017			Pending
WP6	D6.1	D14	Hydrological service product report	GFZ	Report	Public	30 Jun 2017			Pending
WP4	D4.2	D8	Scientific service product report	UBERN	Report	Public	30 Sep 2017			Pending
WP4	D4.3	D9	Validation Report	UBERN	Report	Public	30 Sep 2017			Pending
WP5	D5.3	D12	Operational NRT service product report	GFZ	Report	Public	30 Sep 2017			Pending
WP3	D3.2	D5	Scientific product validation report	UL	Report	Public	31 Dec 2017			Pending
WP3	D3.3	D6	NRT validation report	UL	Report	Public	31 Dec 2017			Pending
WP6	D6.2	D15	Operational hydrological service product report	GFZ	Report	Public	31 Dec 2017			Pending
WP7	D7.4	D19	Summer school lecture notes	UBERN	Websites, patents fil	Public	31 Dec 2017			Pending
WP7	D7.5	D20	Plan for exploitation and dissemination of results	UBERN	Report	Public	31 Dec 2017			Pending

10 of 21 Deliverables submitted so far.

EGSIEM

HORIZON 2020

WP1: Management Reporting/Deliverables

Publications are being updated within the participant portal, however, the consortium needs to know at least 45 days in advance of any **planned** publication.

EGSIEM Consortium Agreement, Section 8.3.1.1

HORIZON 2020

WP1: Management

Payments

Lots of Deliverables and a report!

EGSIEM

HORIZON 2020

WP1: Management

Payments

The payments from EGSIEM have been/will be sent as follows;

- January 2015 - Pre-Financing, paid out in 2 x instalments; the first 70% of this figure was sent in early March 2015
- Feb/March 2016 - Pre-Financing (2), the remainder (30%) of the above was sent to everyone on 18.03.2016

EGSIEM Consortium Agreement, Section 7.3.2

- Mid 2016 - Interim Payment based on the expenditure reported in the first periodic report (uploaded in the EC's Participant Portal in Feb 2016)

Payment was made on **18.07.2016** – apologies for the delay!

- **Mid 2018 - Final Payment expected, remaining budget (including the 5% guarantee fund that the EU held back from the Pre-Financing), this figure is based on the total expenditure reported**

WP1: Management

Data Management Plan

- It was recommended at the Mid-Term Review (Brussels, March 2016) that the question of the release of datasets and solutions should be looked into.
- This was briefly discussed at the last project meeting (Potsdam, June 2016 – Action Item 021)

WP1: Management

Data Management Plan

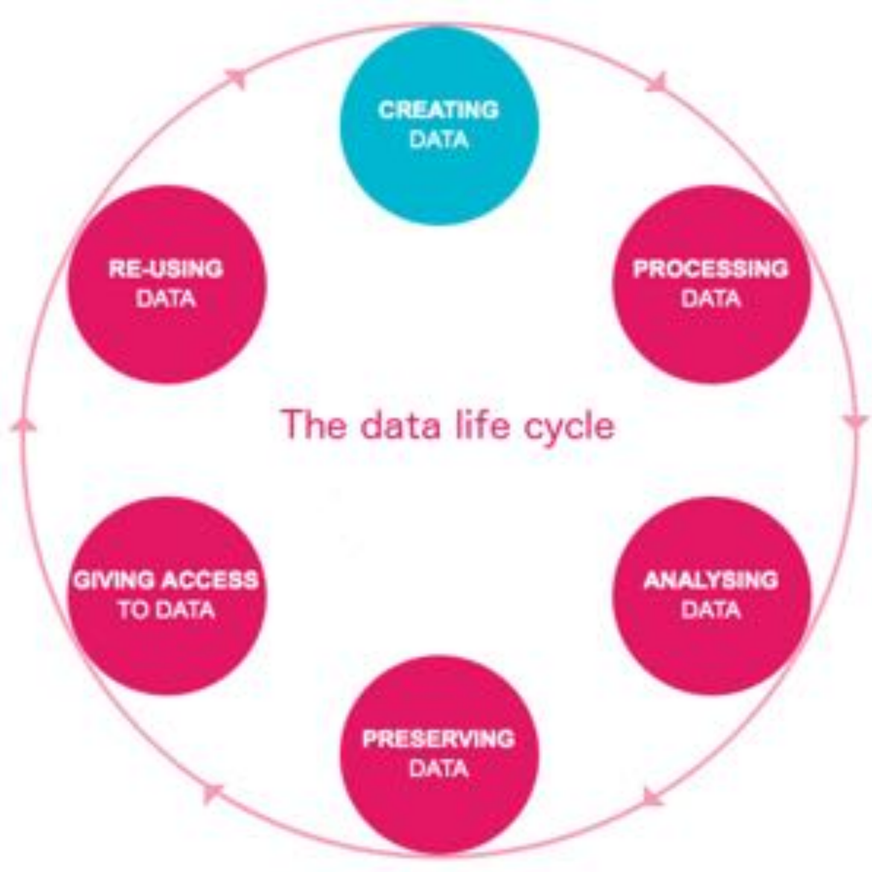


Figure 1 - Data lifecycle according to UK Data Archives (www.data-archive.ac.uk/create-manage/life-cycle)

WP1: Management

Data Management Plan

A DMP should include information on:

- the handling of research data during and after the end of the project
- what data will be collected, processed and/or generated
- which methodology and standards will be applied
- whether data will be shared/made open access and
- how data will be curated and preserved (including after the end of the project)

A DMP is required for all projects participating in the extended ORD pilot, unless they opt out of the ORD pilot. **However, projects that opt out are still encouraged to submit a DMP on a voluntary basis.**

http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hi-oa-data-mgt_en.pdf

WP1: Management

Data Management Plan

The utilisation of data was already foreseen in the original application (*Management of research data*, p. 31).
What the DMP is designed to provide is a structured way of dealing with this data now, and in the future.

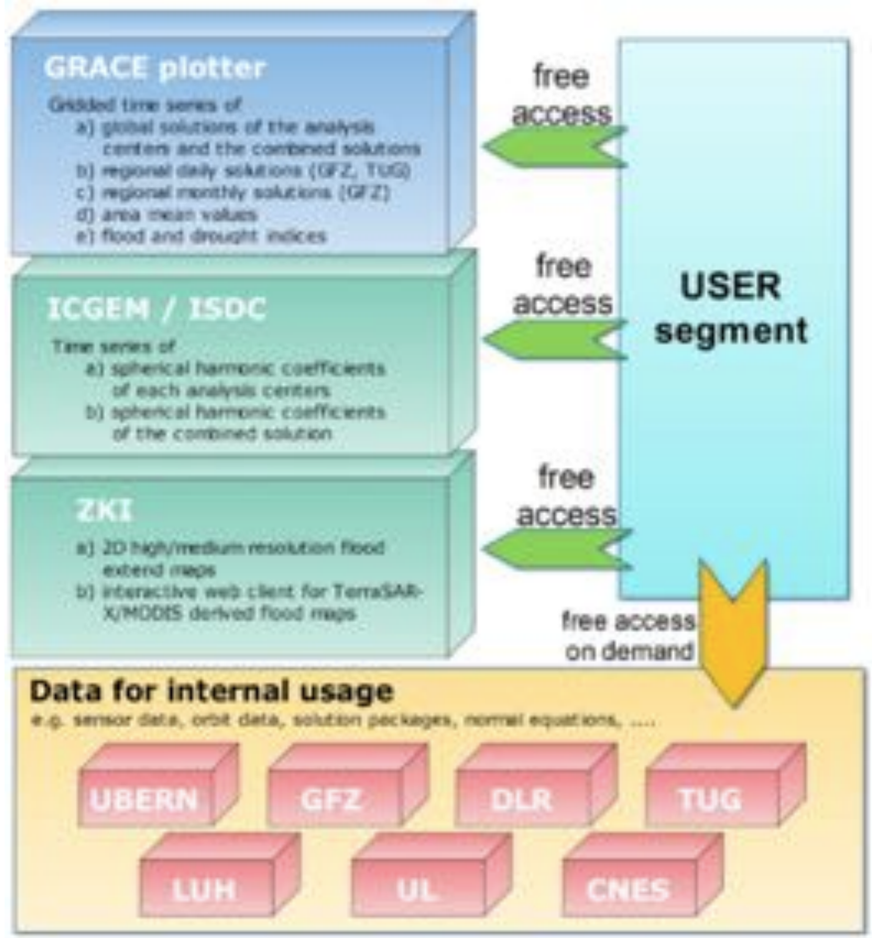
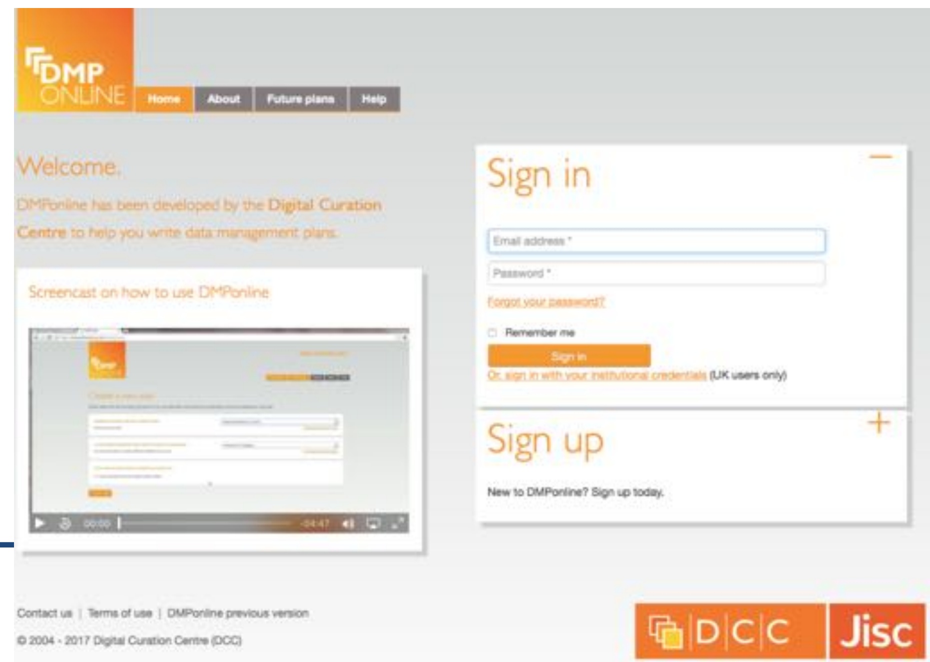


Figure 2.2-5 from the EGSIEM DoA

WP1: Management

Data Management Plan

- As a first step I have registered EGSIEM with the DMP online tool, developed by the UK-based Digital Curation Centre which includes a H2020 template
- I can add users to the EGSIEM account (such as G&C)



WP1: Management

Data Management Plan

- But… what are we putting in here?
- The DoA states that L3 products will be *accessible* via the EGSIEM Plotter and that L2 products will continue to be made available via ICGEM etc
- Stéphane has already assisted with answers to some of the more technical questions but he is not responsible for the source data

WP1: Management

Data Management Plan

The questions for me are:

- At what level do we need to present a DMP for EGSIEM (Plotter/individual ACs)?
- Would standardisation of metadata and formats be possible across the consortium?
- Can we agree a licensing structure (eg Creative Commons Attribution-NonCommercial 4.0 International Public License) across all partners?
- Can we guarantee that we are free to release this data (do we need to acknowledge anyone else)?

WP1: Management

Data Management Plan

[Attribution-NonCommercial 4.0 International (CC BY-NC 4.0)]

You are free to:

Share — copy and redistribute the material in any medium or format

Adapt — remix, transform, and build upon the material

The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:

Attribution — You must give **appropriate credit**, provide a link to the license, and **indicate if changes were made**. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

NonCommercial — You may not use the material for **commercial purposes**.

No additional restrictions — You may not apply legal terms or **technological measures** that legally restrict others from doing anything the license permits.

WP1: Management

Data Management Plan

EGSIEM

HORIZON 2020

WP3 Integration of complementary data

Working progress

- T3.1: Reference Frame reprocessing UBERN
  - M03-M10
- T3.2: SLR normal equations UBERN
  - M07-M09
- T3.3: NRT Reference Frame processing UBERN
  - M03-M06
- T3.4: Operational NRT Reference Frame processing UBERN
  - M28-M33
- T3.5: Validation of GRACE gravity products with GNSS UL
  - M19-M36: will presented today by Q. Chen
- T3.6: Validation of GRACE gravity products with Ocean Bottom Pressure GFZ
  - M25-M36: will presented today by L. Poropat
- T3.7: Preparation for Hydroweb data CNES
  - M01-M10
- T3.8 GIA for Hydrology LM
  - M11-M36: will presented today by H. Steffen
- T3.9: Compilation of representative historical flood situations DLR
  - M01-M10

EGSIEM

European Gravity Service for Improved Emergency Management

WP3. Integration of complementary data

Validation with GNSS loading

Qiang Chen

Faculty of Science, Technology and Communication

University of Luxembourg

EGSIEM Progress Meeting # 4

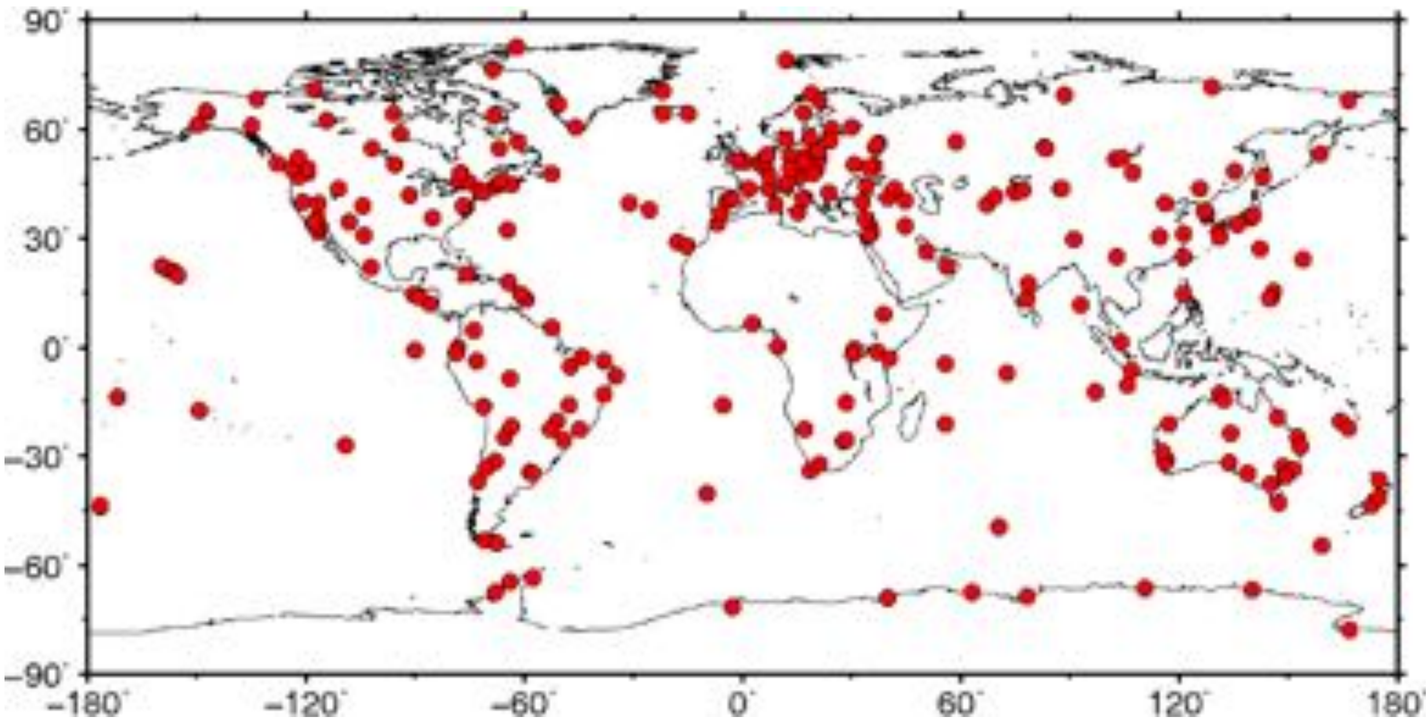
January 19 – 20, 2017

Data

- GNSS data
  - Reference frame data from UBERN (Repro 3)
    - Raw data in SINEX format
  - Latest daily ITRF2014 GNSS residuals (IGN), 1054 stations
    - Rigorously stacking the latest IGS repro2 solutions, averaged into monthly
  - Latest global daily GNSS time series from JPL (1094 stations)
    - Cleaned, detrended and outlier removed, averaged into monthly
- Gravity models
  - EGSIEM combined solution, 2003-2014
  - Official GRACE Release 5 from GFZ (RL05a), CSR and JPL (RL05.1)
  - Addition GRACE products from AIUB (RL2), ITSG (2016) and CNES (GRGS RL03v3)
  - Standard GRACE data processing
    - Replacing C20 term (Cheng et al., SLR) and adding back degree-1 coefficients (Swenson et al., 2008)
    - The Gaussian filtering with a smoothing radius of 500 km
    - Adding back GAC products when comparing to GNSS
    - Converting into displacements using the spherical harmonic approach in the vertical component

Processing Repro3

- Reference frame data (Repro3, GNSS position time series) provided by UBERN in SINEX format from 2003 to 2014
  - 312 stations for further processing (393 stations in total with 81 stations removed due to short time span, very big gaps or very bad data)



EGSIEM

HORIZON 2020

Processing Repro3

- Processing procedure
  - Coordinate transformation from XYZ to NEU
  - Offsets detection and removal
  - Removing outliers
  - Average daily data into monthly data

Processing Repro3

- Offsets detection and removal
  - Including jumps, coseismic offsets and postseismic relaxation
    - 264 out of 312 stations with offsets (84.62%)
    - 33 out of 264 stations with postseismic relaxation
  - No efficient automatic way to detect (Gazeaux et al., 2013)
  - Visual inspection and detection with offset datasets from NGL, JPL and SOPAC
    - An offset dataset for Repro3 and potentially for near-real-time validation using rapid solutions
  - Extended Trajectory Model to remove postseismic relaxation (Bevis and Brown, 2014)

$$
\begin{aligned}
\mathbf{x} = & \sum_{i=0}^{n_P} \mathbf{p}_i (t - t_R)^i + \sum_{i=1}^{n_J} \mathbf{b}_j H(t - t_j) \\
& + \sum_{i=1}^{n_F} \mathbf{s}_i \sin(\omega_i t) + \mathbf{c}_i \cos(\omega_i t) \\
& + \sum_{i=1}^{n_T} \mathbf{e}_i (1 - \exp(-(t - t_i)/T_i)) + \\
& + \sum_{k=1}^{n_L} \mathbf{a}_k \log(1 + (t - t_k)/T_k))
\end{aligned}
$$

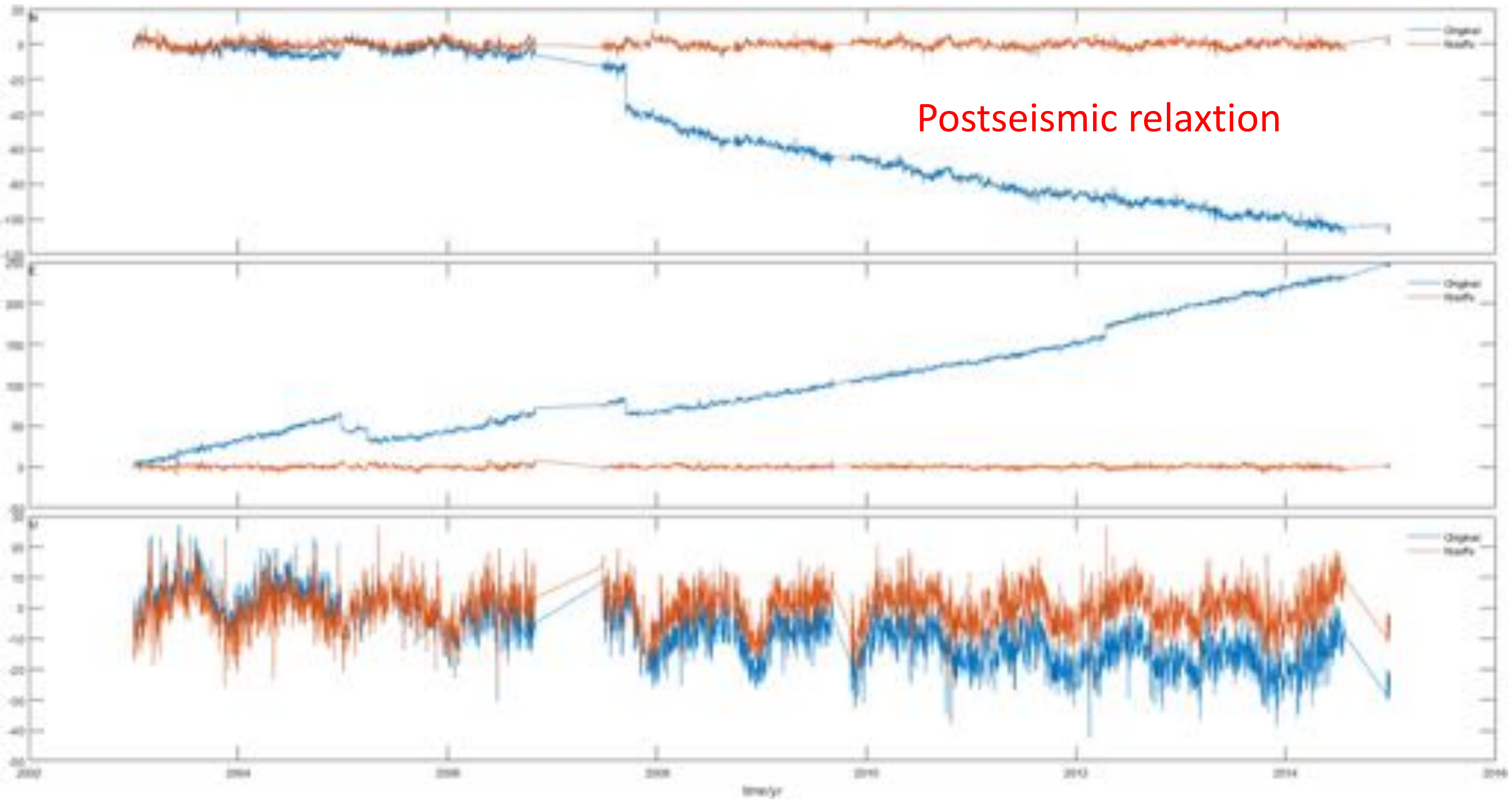
T_i and T_k from JPL model

EGSIEM

HORIZON 2020

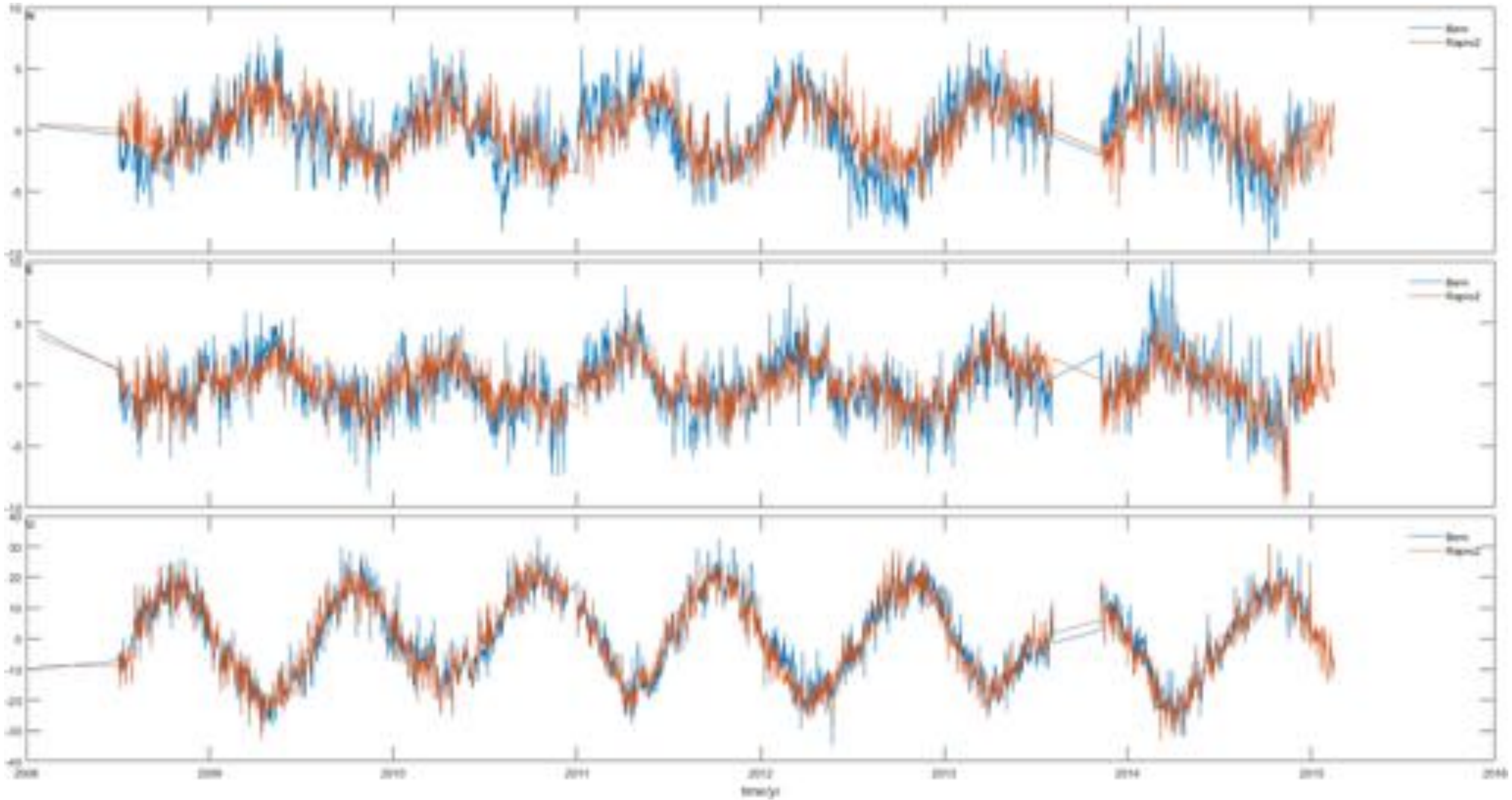
Processing Repro3

- Example of Offsets detection and removal: NTUS



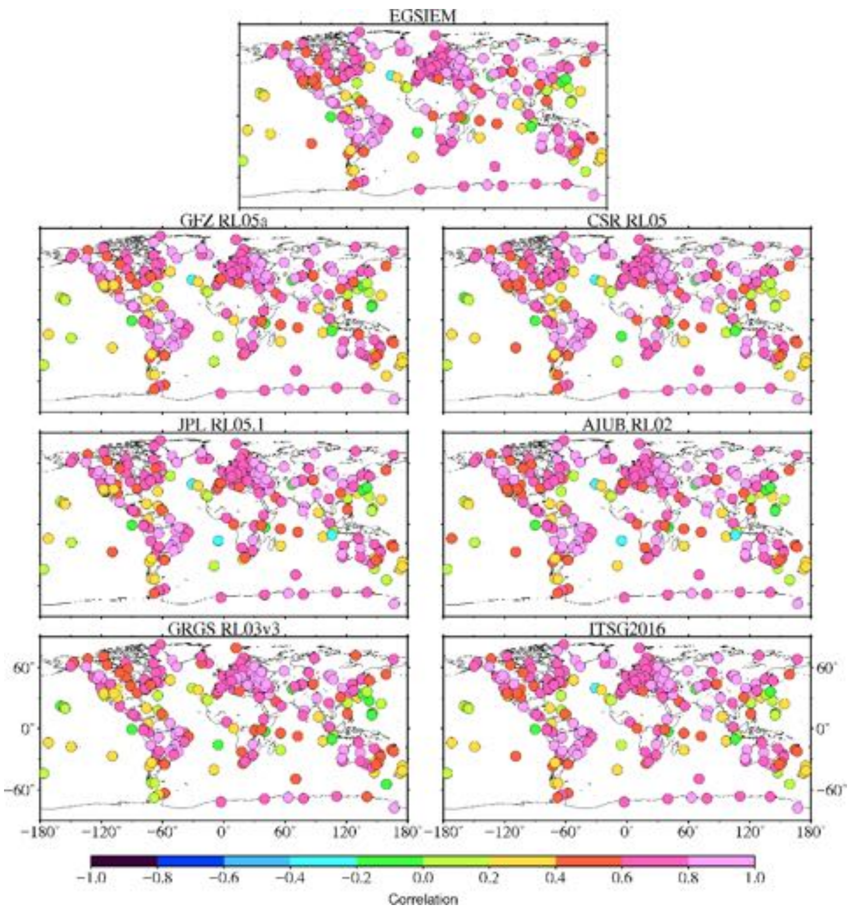
Processing Repro3

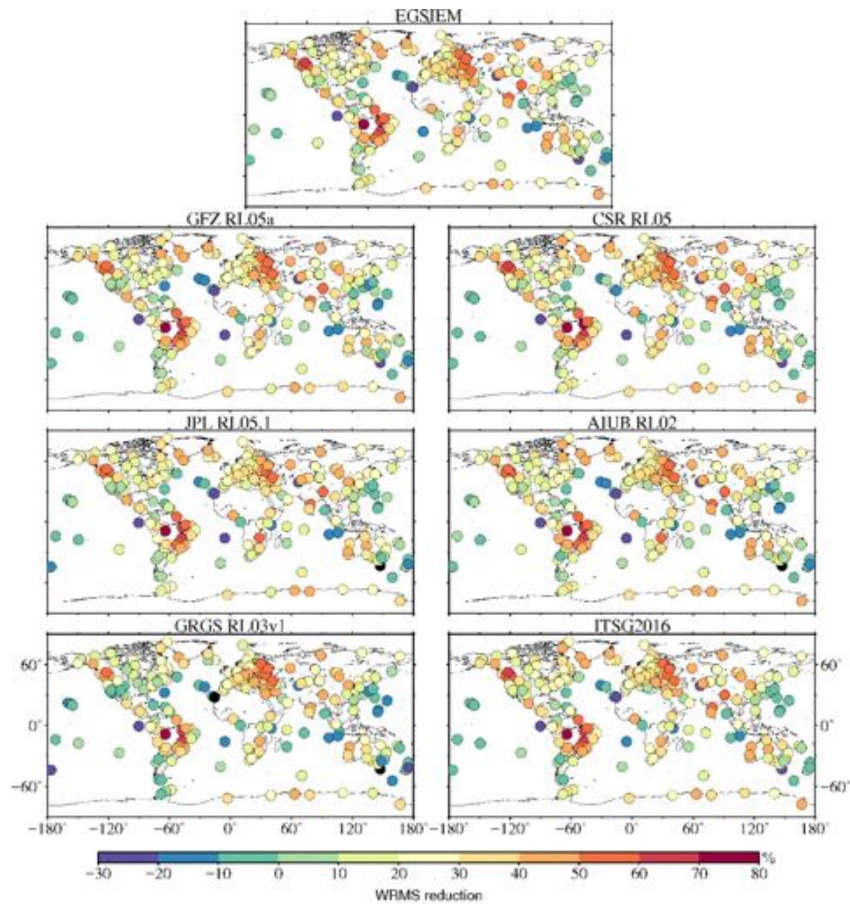
- Comparison with respect to the ITRF2014 residuals: POVE



Validation with Repro3

- In a comparison to 312 GNSS stations: correlation (left) and WRMS reduction (right)





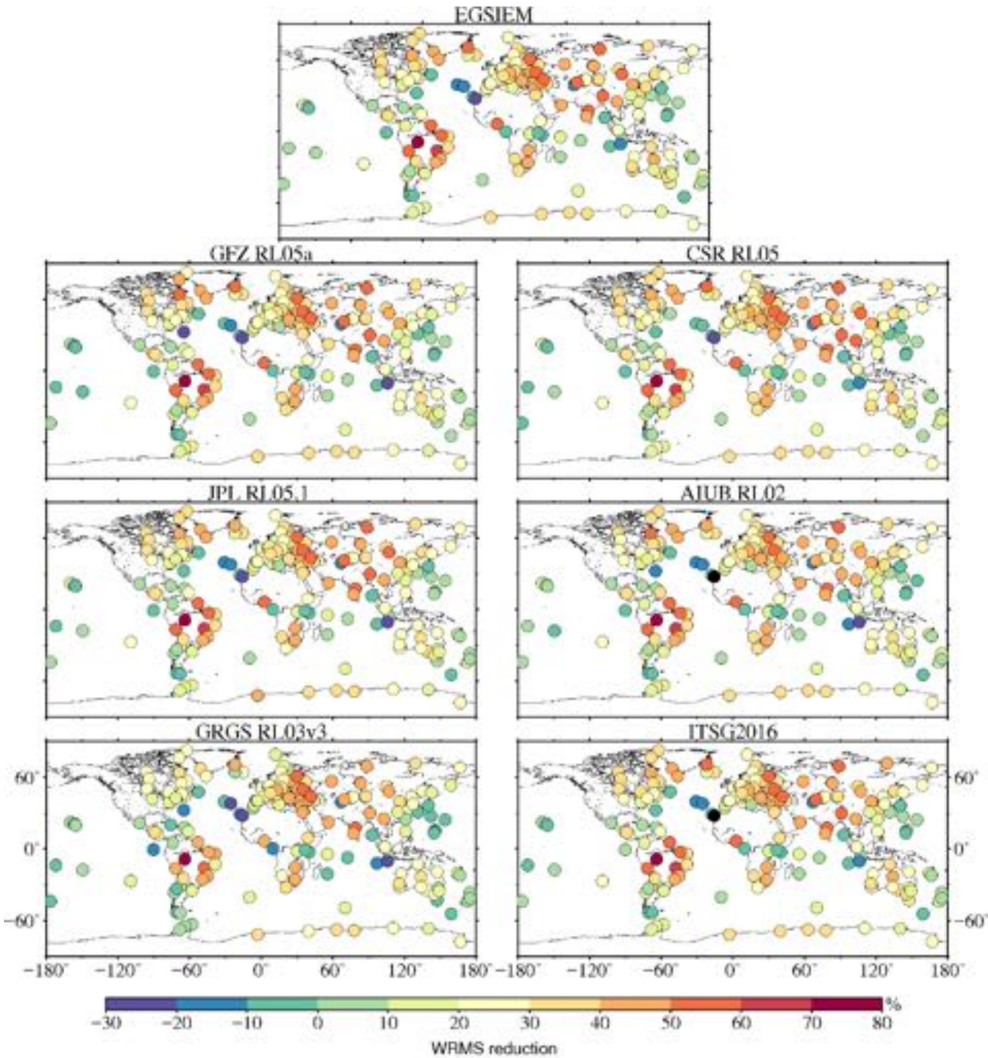
Validation with Repro3

	Correlation			Stations with correlation> 0.6 [%]	WRMS reduction [%]			Positive WRMS reduction [%]
	min	max	mean		min	max	mean	
GFZ RL05a	-0.24	0.98	0.60	62.18	-26.82	76.48	22.23	86.86
CSR RL05	-0.28	0.99	0.62	66.67	-28.07	78.87	24.22	88.14
JPL RL05.1	-0.37	0.98	0.60	63.78	-31.19	77.05	22.52	87.18
AIUB RL02	-0.30	0.99	0.60	63.78	-34.87	78.56	22.80	87.50
GRGS RL03v3	-0.25	0.98	0.57	56.41	-33.49	78.48	20.26	81.41
ITSG2016	-0.29	0.98	0.61	66.03	-27.44	78.38	23.91	87.18
EGSIEM	-0.30	0.99	0.62	66.99	-28.76	78.57	24.05	89.42

- All seven GRACE products display good agreements with the Repro3 solutions
- EGSIEM, CSR RL05 and ITSG2016 provide close performances and slightly better than others

GRACE .VS. GNSS (ITRF2014)

- In comparison to 236 common GNSS stations from ITRF2014, Repro3 and JPL solutions: WRMS reduction

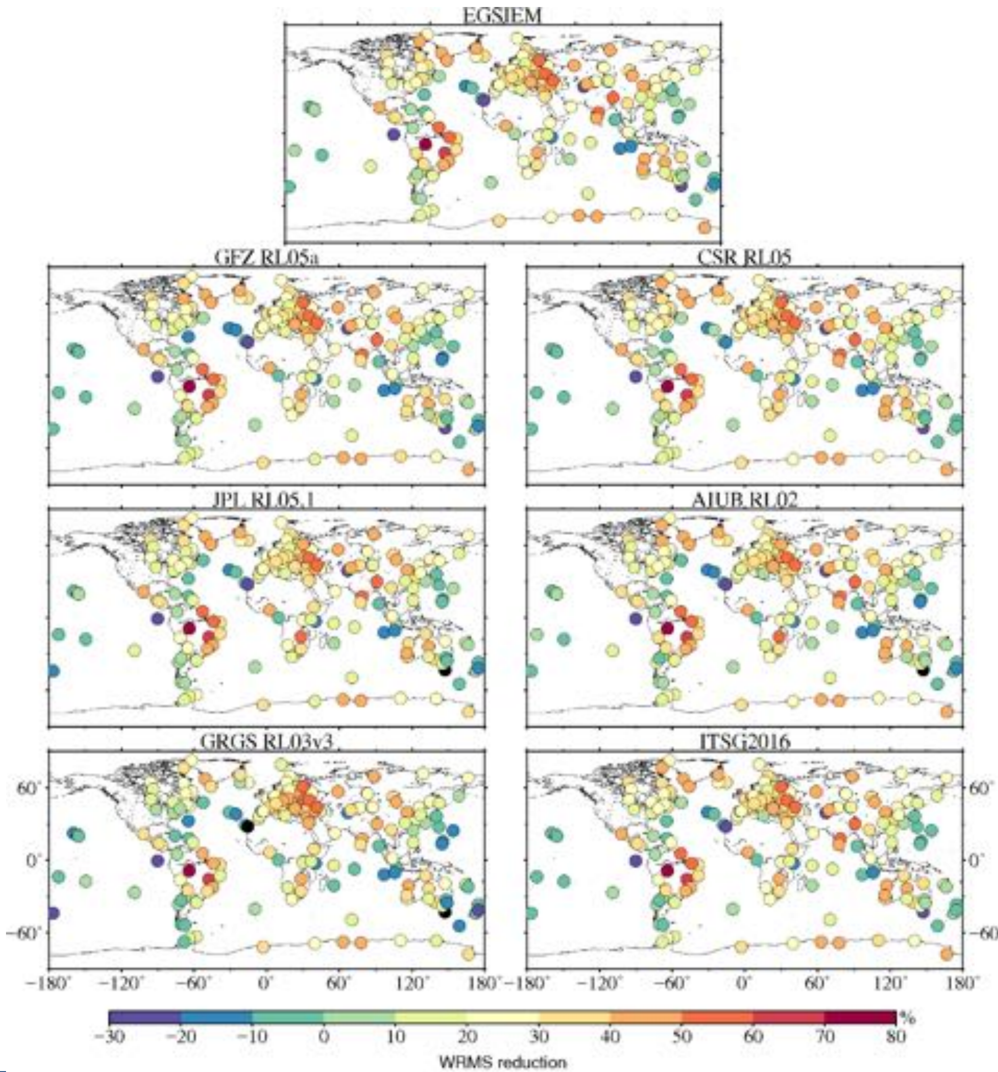


EGSIEM

HORIZON 2020

GRACE .VS. GNSS (Repro3)

- In comparison to 236 common GNSS stations from ITRF2014, Repro3 and JPL solutions: WRMS reduction

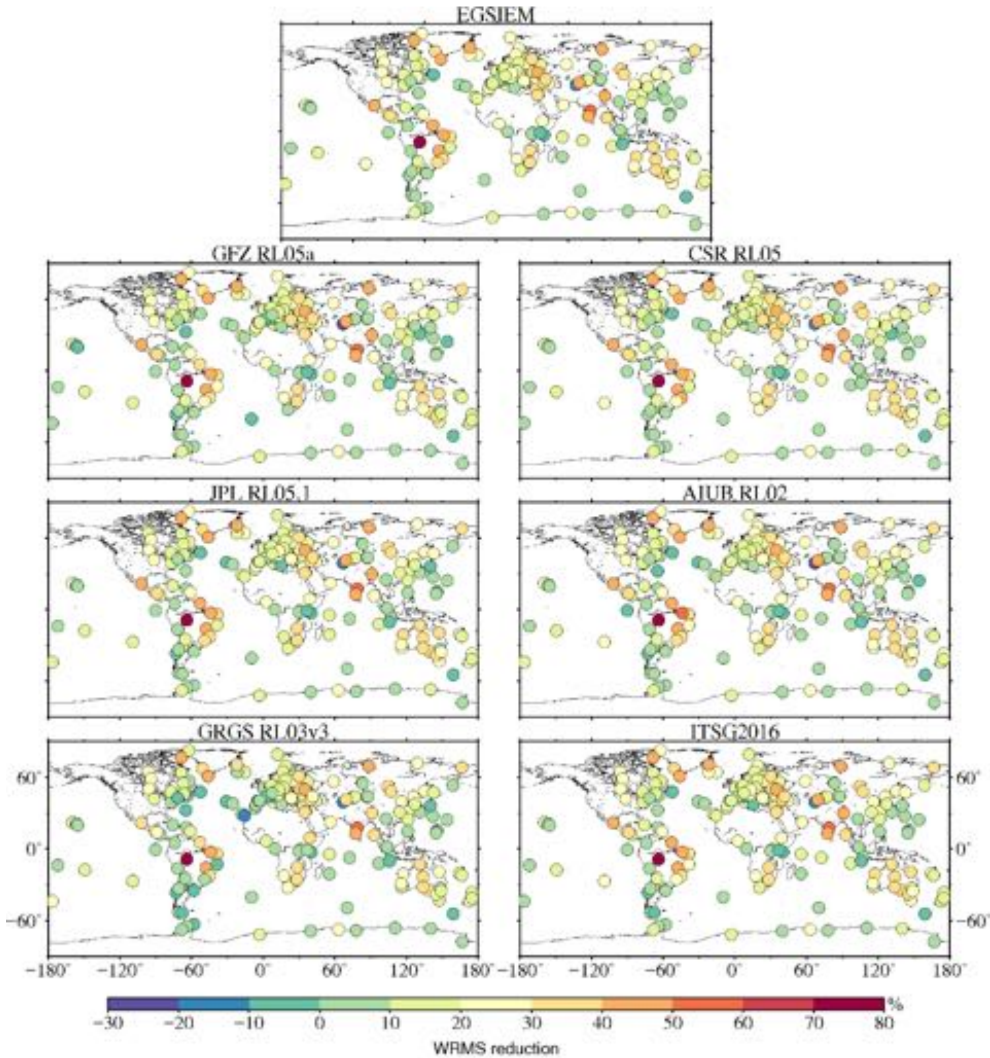


EGSIEM

HORIZON 2020

GRACE .VS. GNSS (JPL)

- In comparison to 236 common GNSS stations from ITRF2014, Repro3 and JPL solutions: WRMS reduction



EGSIEM

HORIZON 2020

GRACE .VS. GNSS

	Repro3		JPL		ITRF2014	
	mean [%]	positive [%]	mean [%]	positive [%]	mean [%]	positive [%]
GFZ RL05a	21.68	85.59	17.33	91.95	23.71	87.71
CSR RL05	23.58	87.29	18.75	94.92	25.50	89.41
JPL RL05.1	21.78	85.59	18.13	93.64	24.04	89.41
AIUB RL02	22.00	85.59	18.09	92.80	24.01	88.98
GRGS RL03v3	20.36	80.51	16.33	89.83	21.83	85.17
ITSG2016	23.12	85.59	18.61	93.64	25.08	89.83
EGSIEM	23.36	88.56	19.07	94.92	25.50	89.41

- In comparison to 236 common GNSS stations from Repro3, JPL and ITRF2014 solutions
- Repro3 performs between ITRF2014 and JPL solutions
- Again, EGSIEM, CSR RL05 and ITSG2016 provide close performance and better than others

Conclusions

- Generally, all seven GRACE products are in good agreements with the three GNSS Solutions. More than 80% stations (out of 236 stations) have positive WRMS reduction.

- Comparing to the three GNSS solutions, close performances are observed among EGSIEM, CSR RL05 and ITSG2016. They show slightly better statistics than other gravity models.

- Our Repro3 solution provides very close performances to the latest ITRF2014 residuals.

Thanks for your attention!

Validation of monthly GRACE gravity field solutions against in situ ocean bottom pressure measurements

Lea Poropat, Inga Bergmann-Wolf,
Henryk Dobslaw, Frank Flechtner

German Research Centre for Geosciences (GFZ)
Department 1: Geodesy
Section 1.3: Earth System Modelling
poropat@gfz-potsdam.de

Motivation

Motivation

gravity

Motivation

gravity

Validation against independent measurements is required!

Motivation

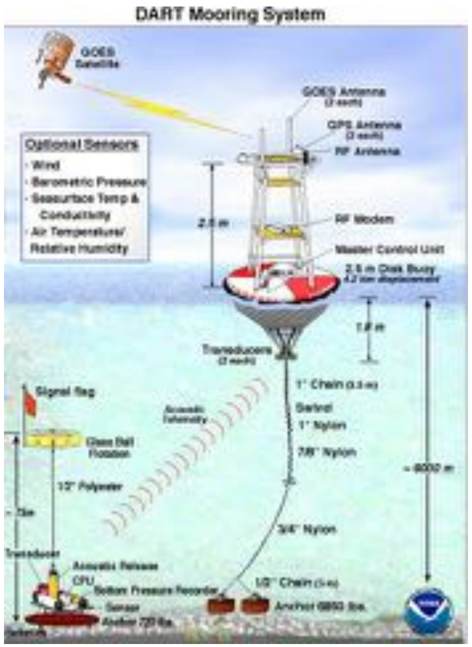
Validation against independent measurements is required!

gravity → mass

Motivation

Validation against independent measurements is required!

gravity → mass ← ocean bottom pressure



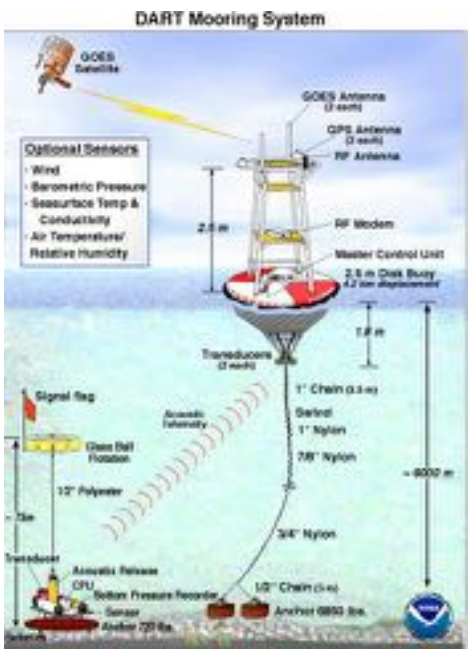
Motivation

Validation against independent measurements is required!

gravity → mass

ocean bottom pressure → mass

validation



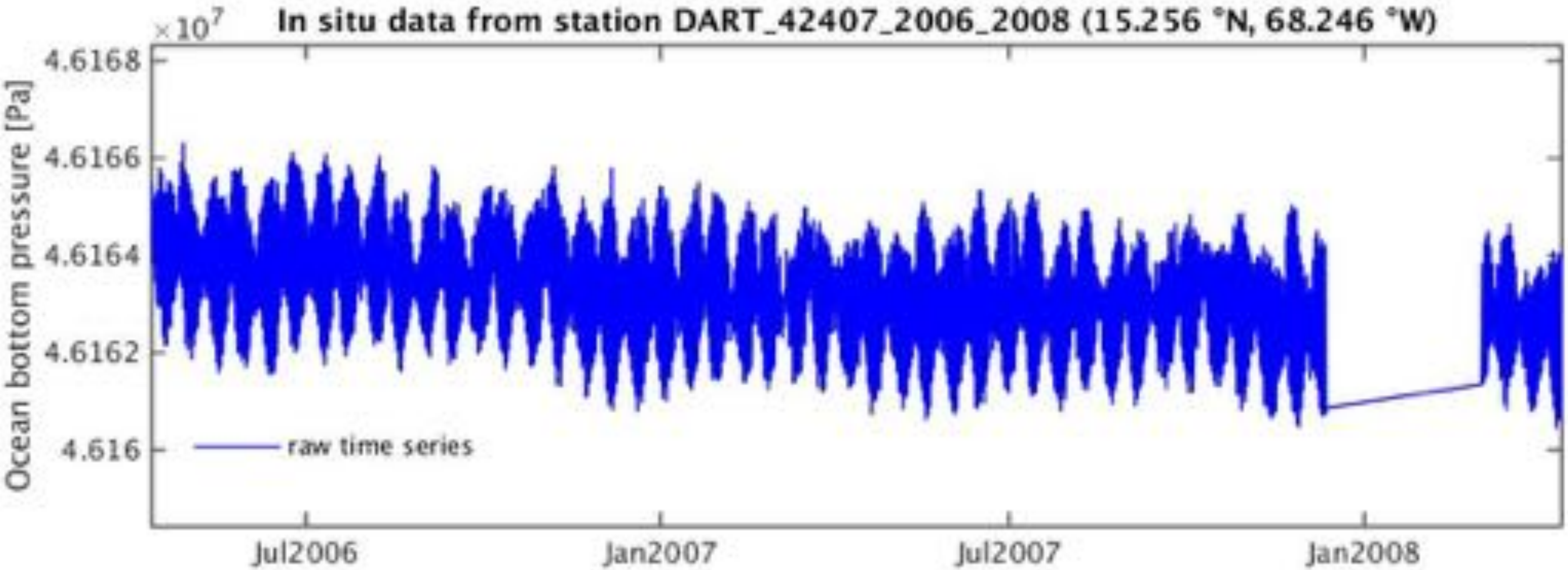
Preprocessing of in situ data

Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour

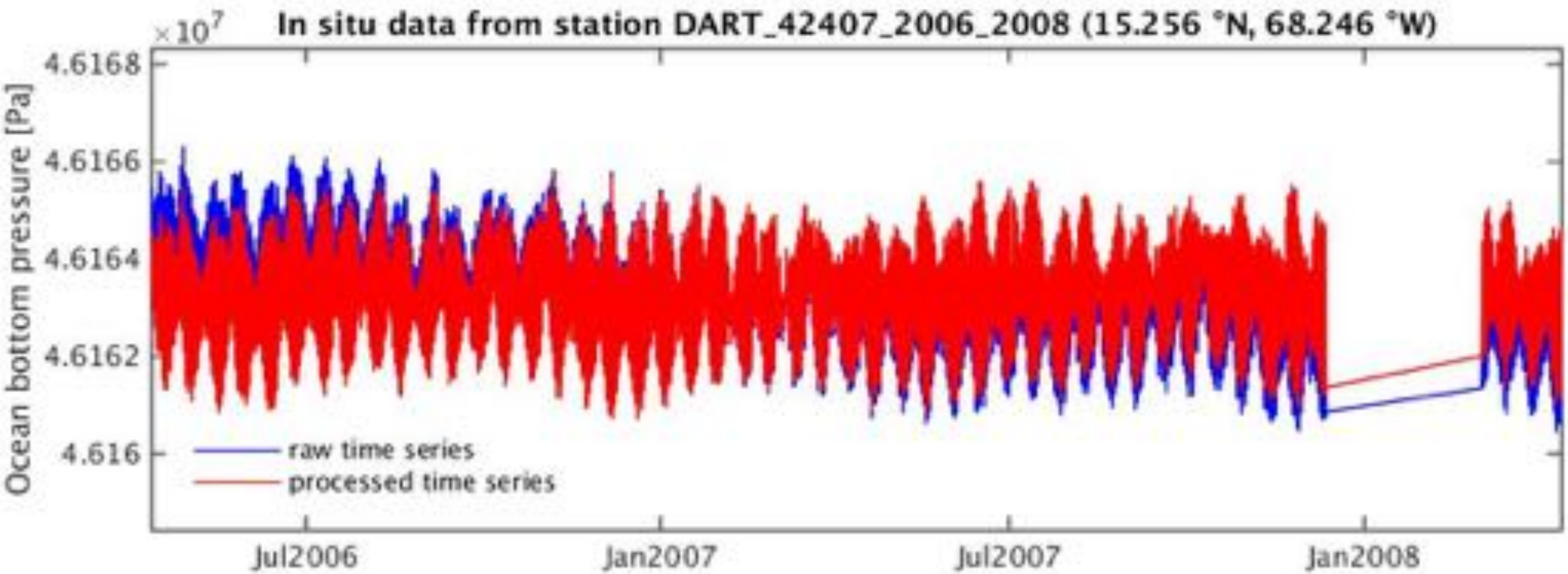
Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour



Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour



Preprocessing of in situ data

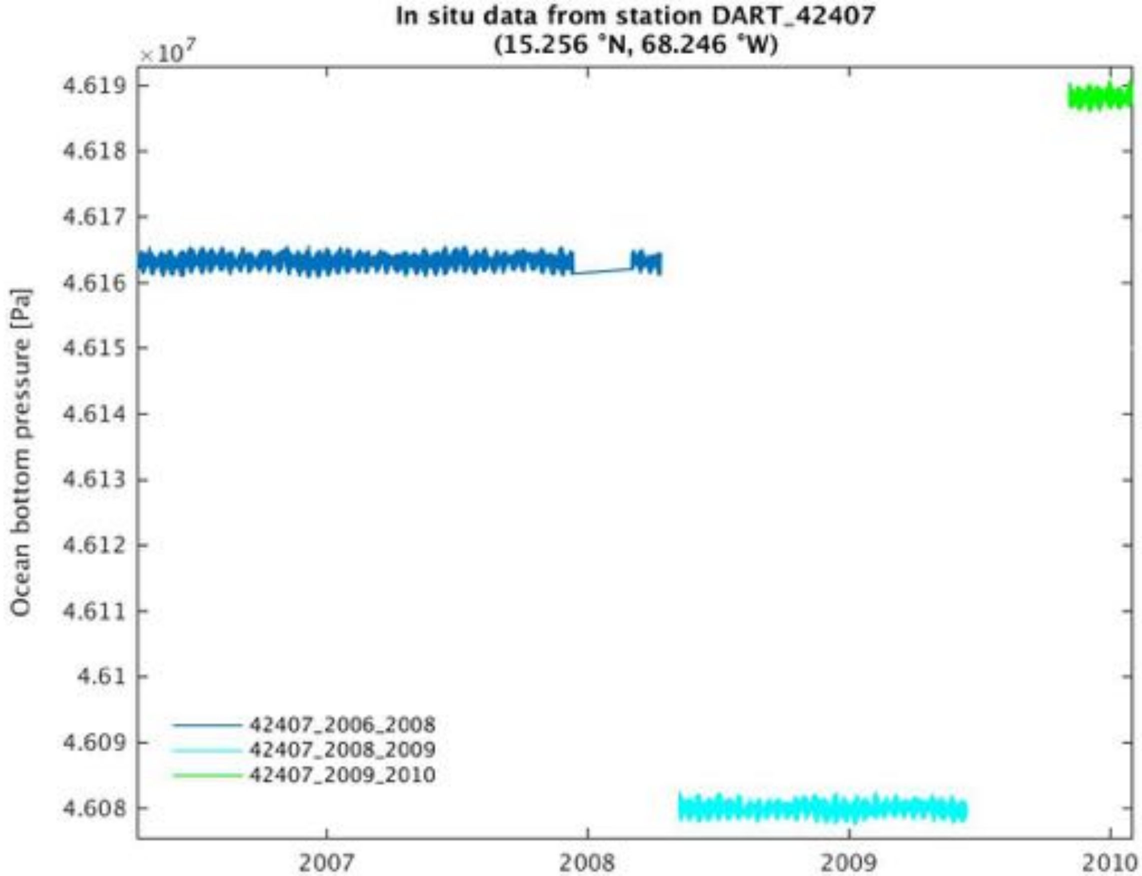
- removing outliers, drifts, jumps and trends
- changing time step to 1 hour

Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station

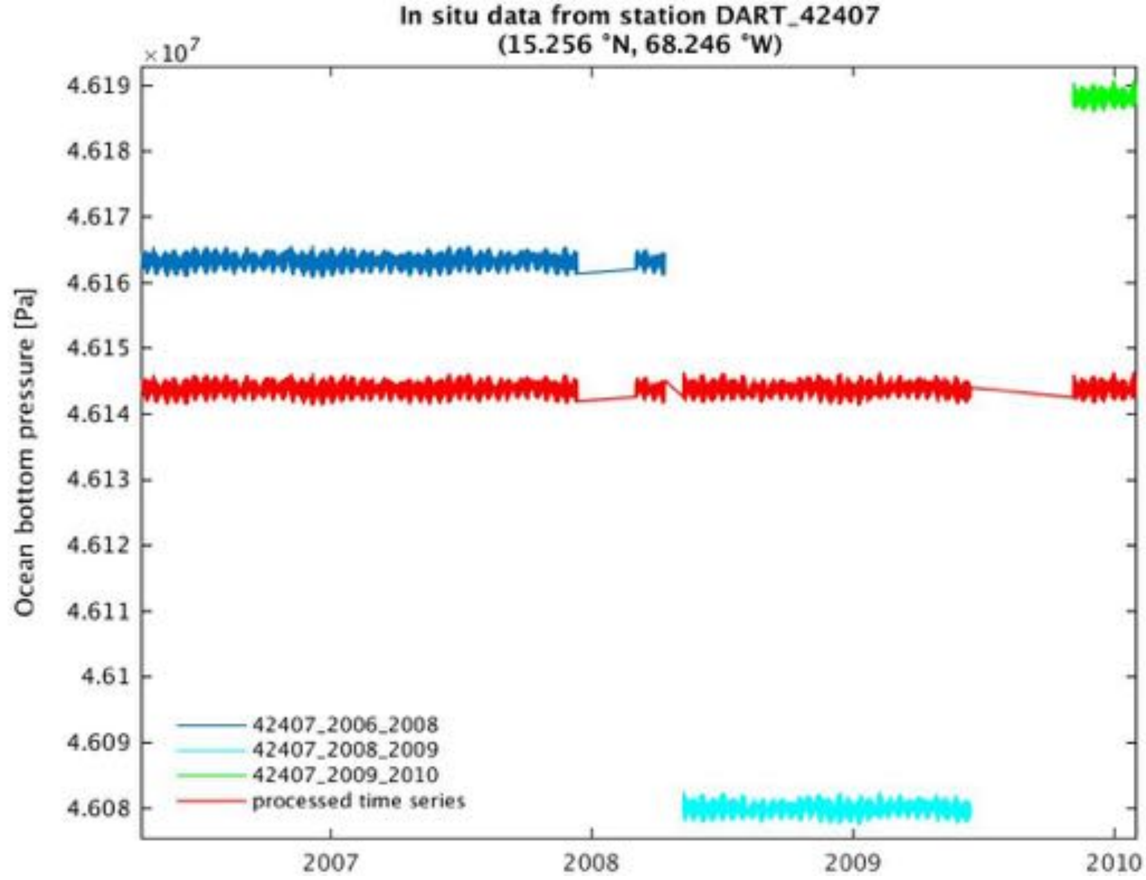
Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station



Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station



Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station

Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station

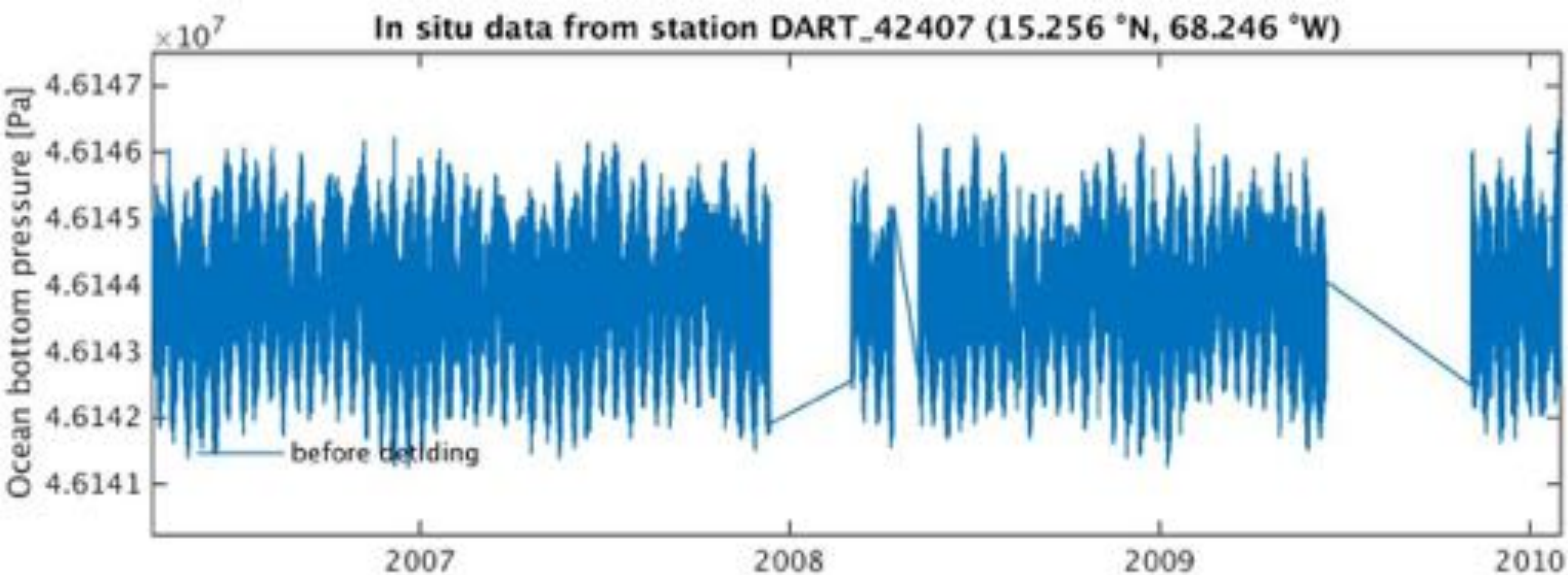
- removing tidal signal

T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]

Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station
- removing tidal signal

T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]

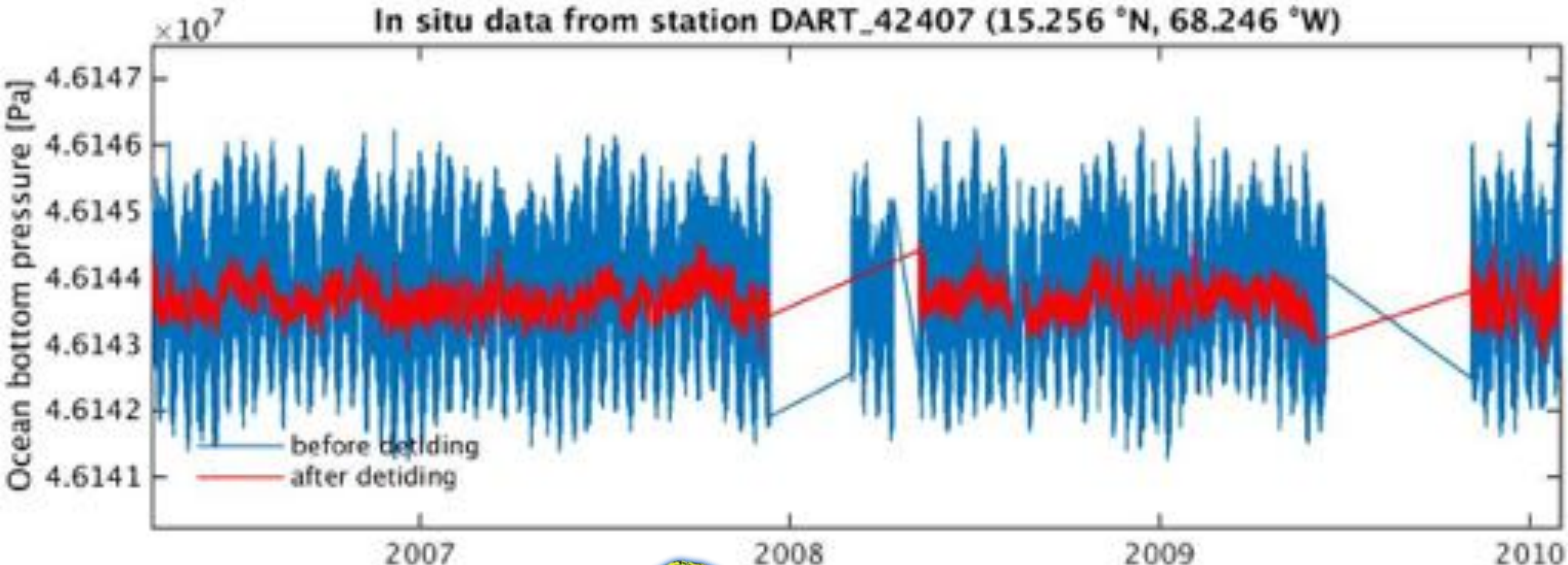


GFZ Helmholtz Centre Potsdam
EGSIEM
HELMHOLTZ ASSOCIATION

Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station
- removing tidal signal

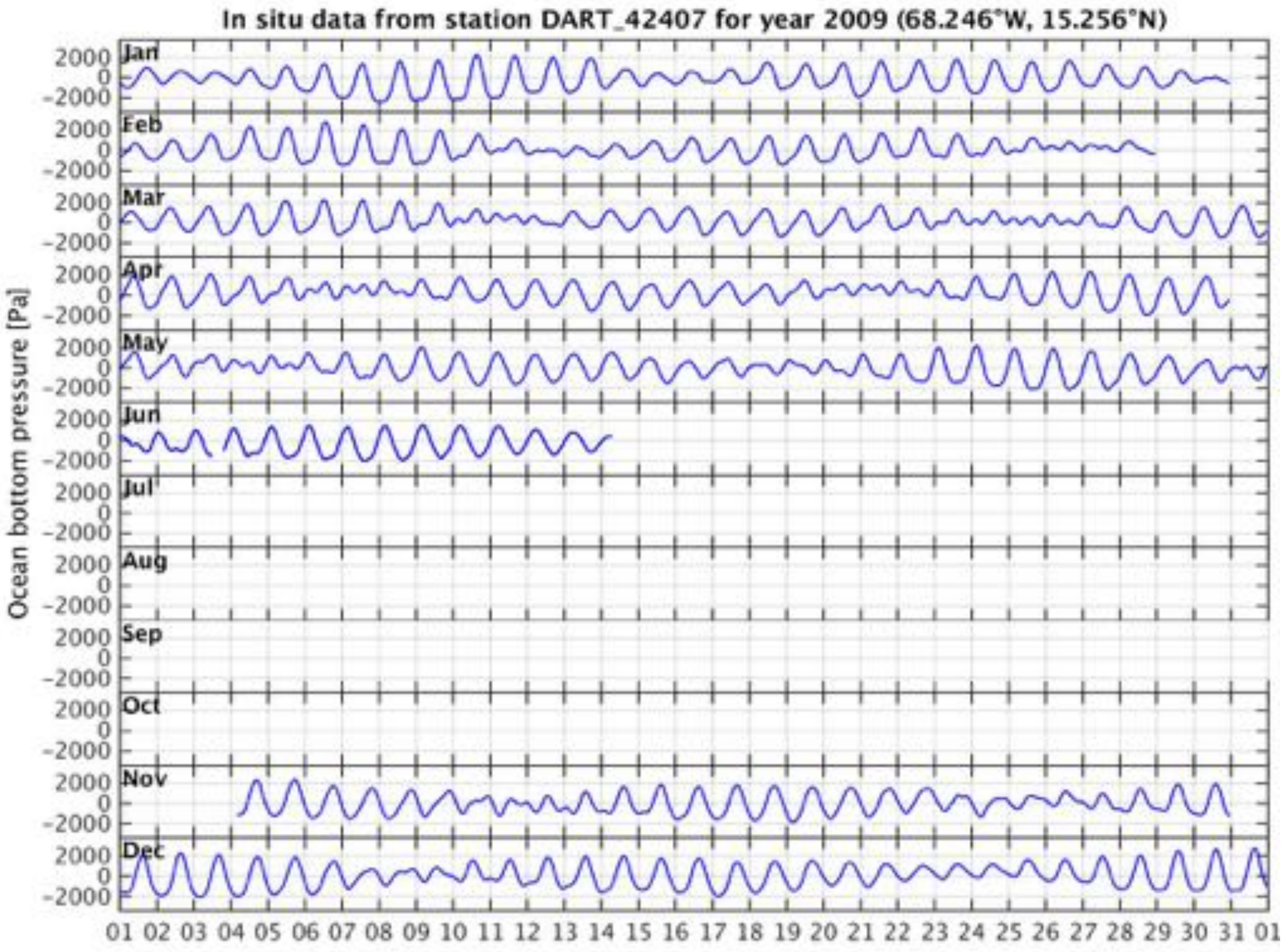
T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]



Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- removing tidal signal

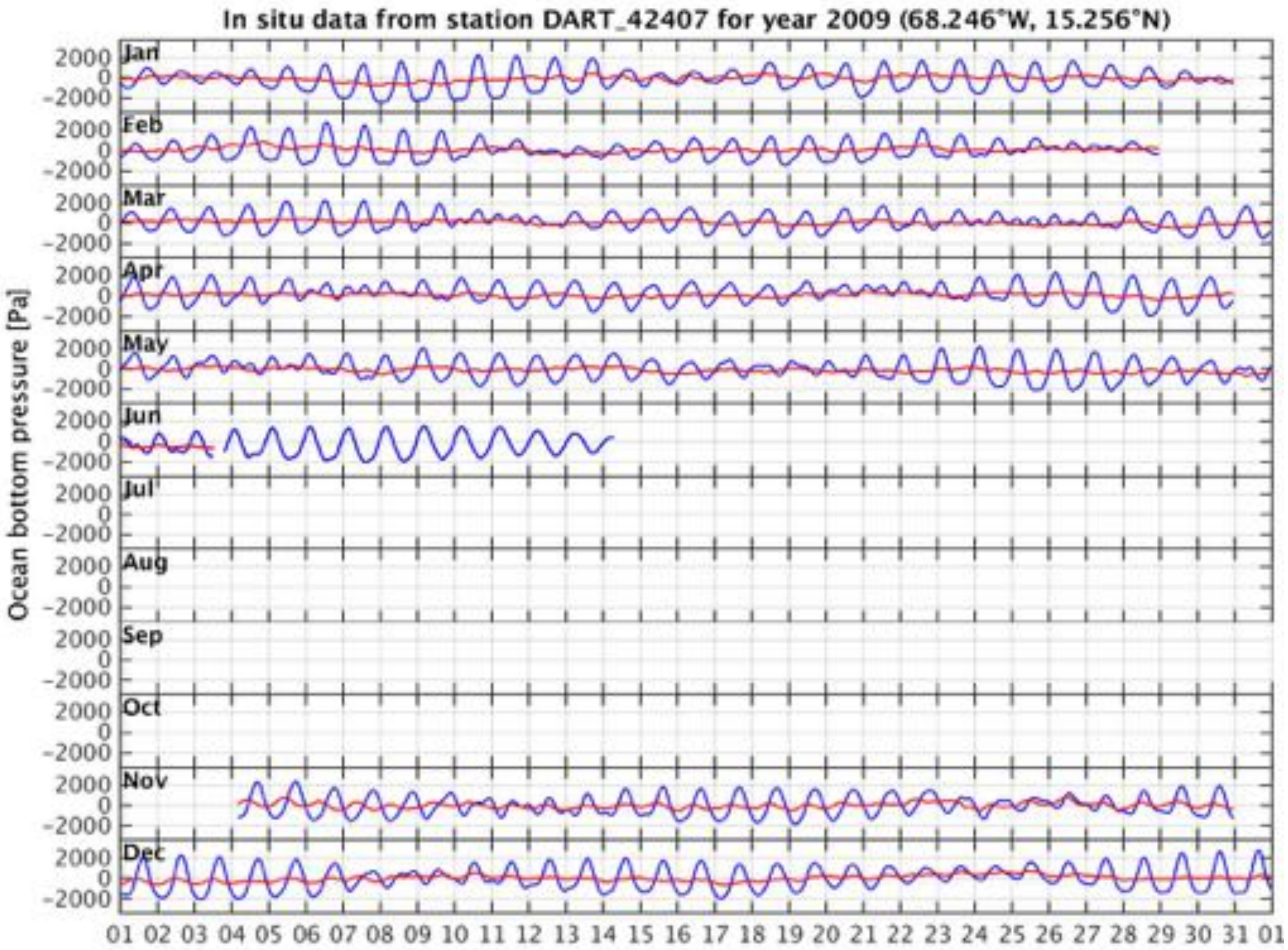
T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]



Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- removing tidal signal

T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]



Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station
- removing tidal signal

T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]

Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station

- removing tidal signal
- filtering data

Butterworth low pass filter

T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]

Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station

- removing tidal signal
- filtering data

Butterworth low pass filter

T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]

3 frequency bands:

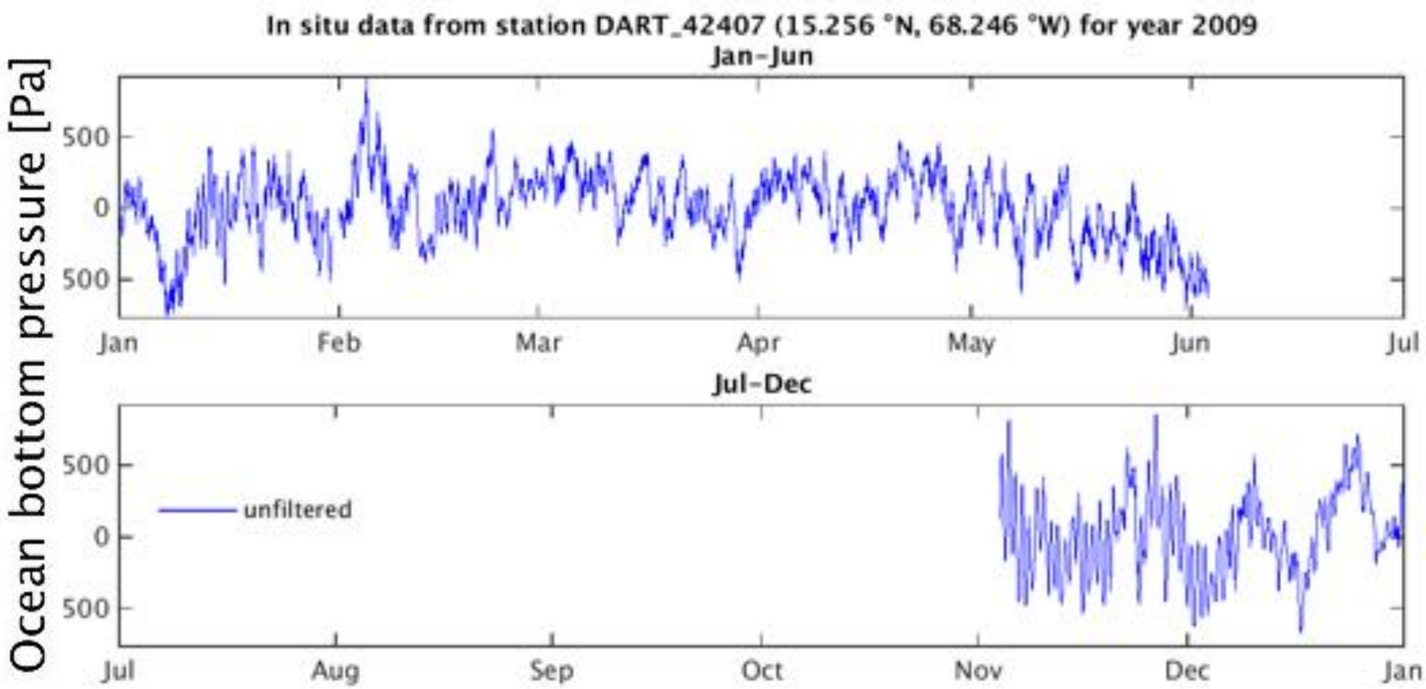
Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station

- removing tidal signal
- filtering data

Butterworth low pass filter

T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]



3 frequency bands:

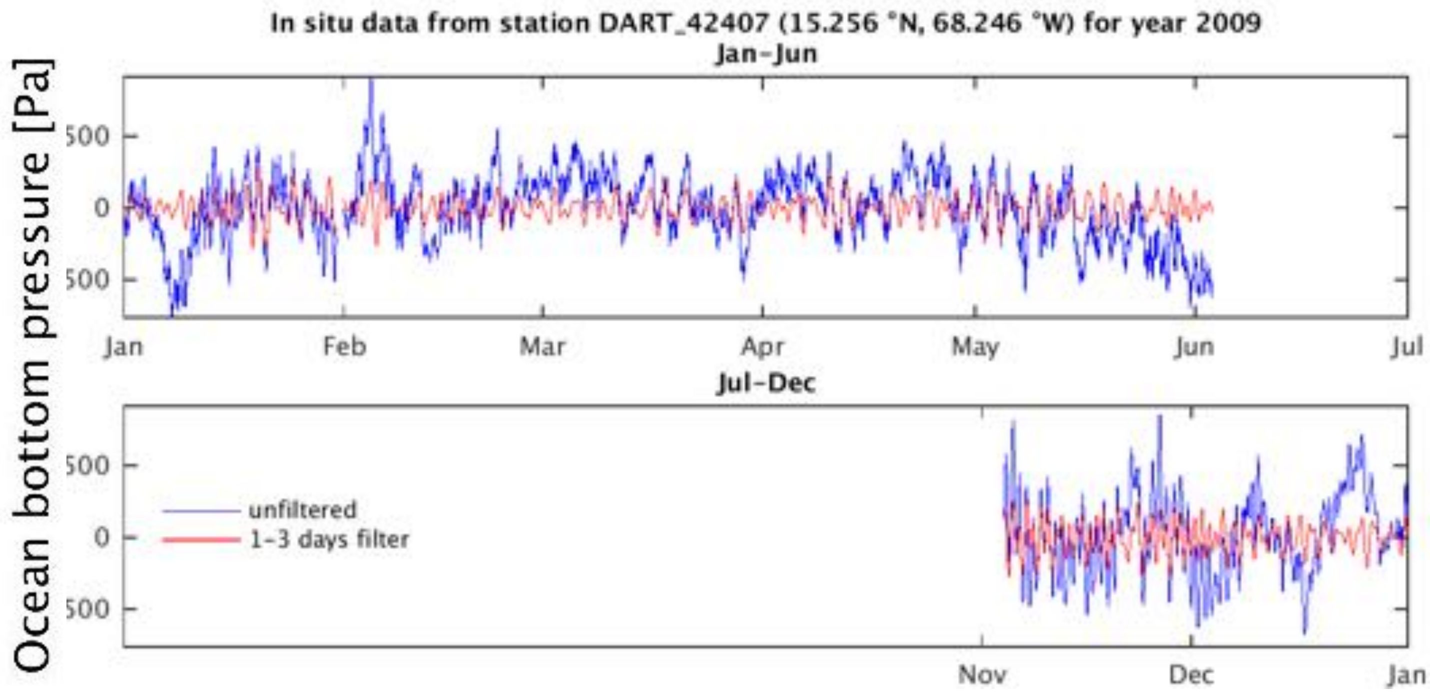
Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station

- removing tidal signal
- filtering data

Butterworth low pass filter

T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]



3 frequency bands:
- 1-3 days

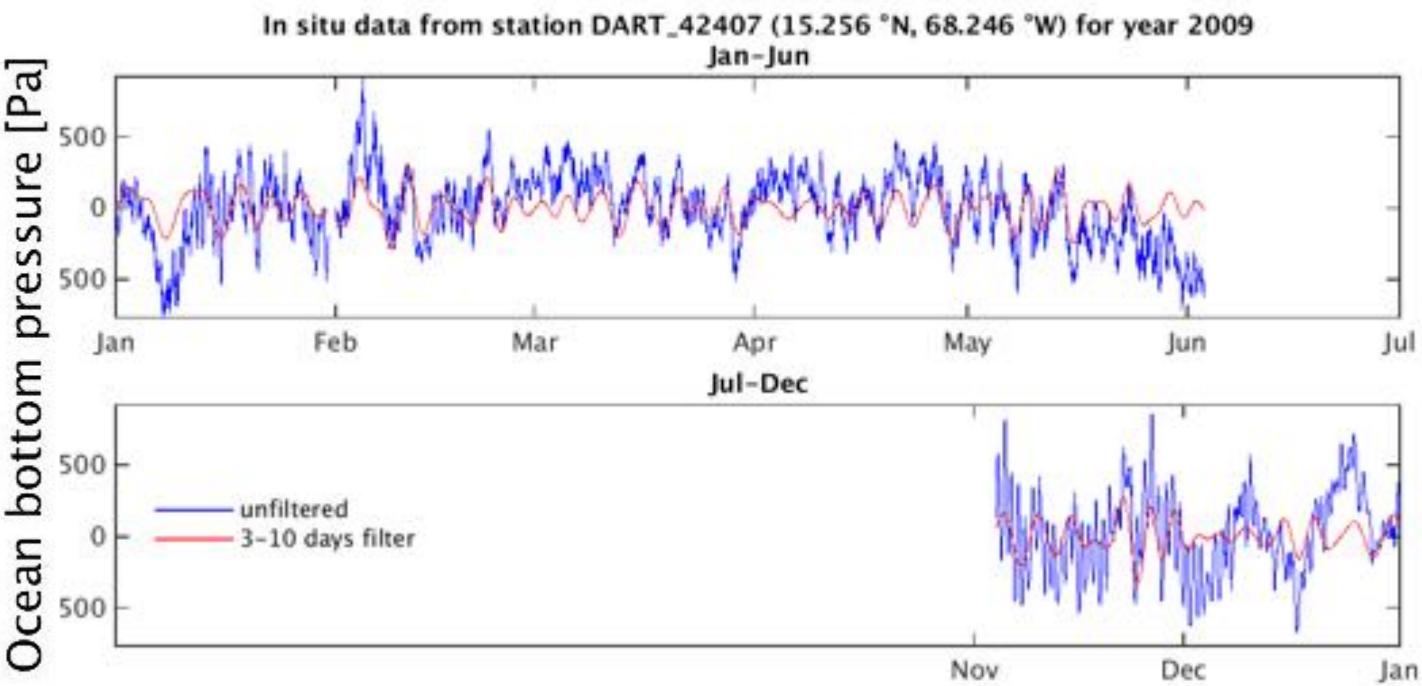
Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station

- removing tidal signal
- filtering data

Butterworth low pass filter

T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]



3 frequency bands:

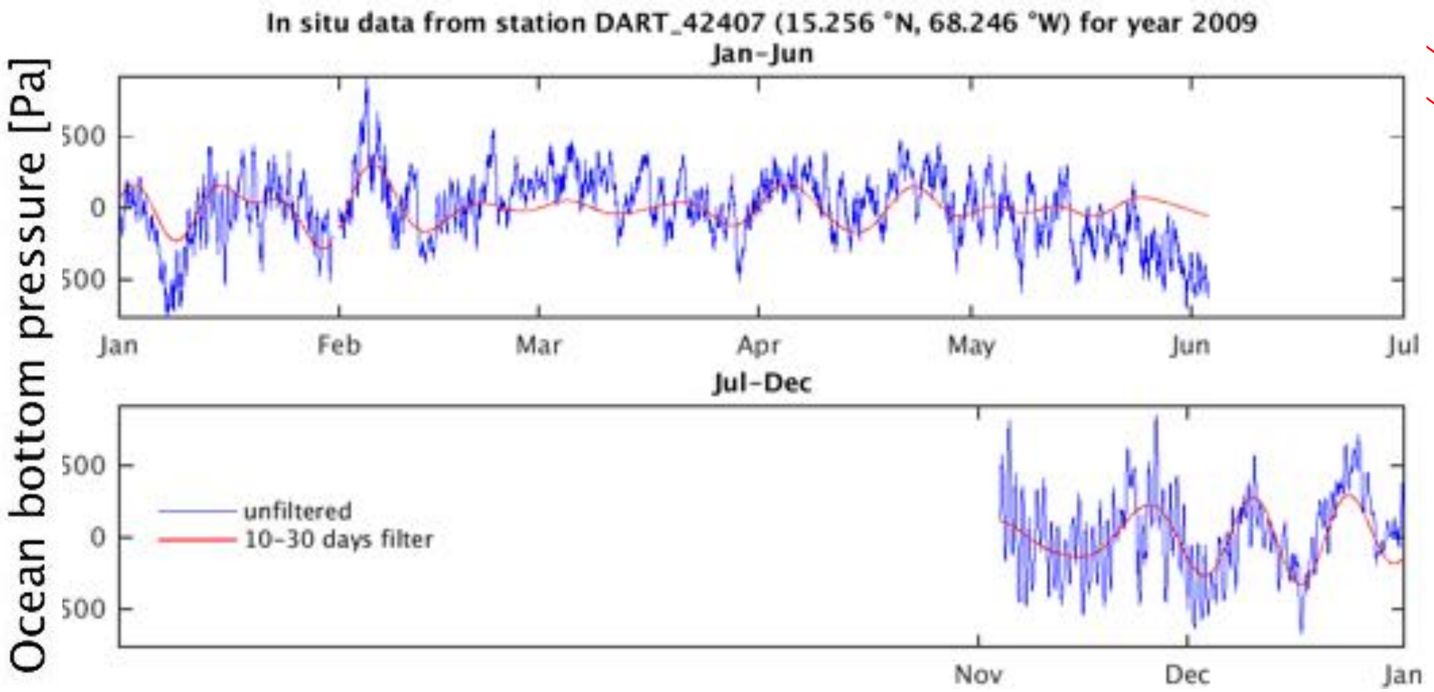
- 1-3 days
- 3-10 days

EGSIEM

Preprocessing of in situ data

- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station

- removing tidal signal → T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]
- filtering data → Butterworth low pass filter



3 frequency bands:
- 1-3 days
- 3-10 days
- 10-30 days

Preprocessing of in situ data

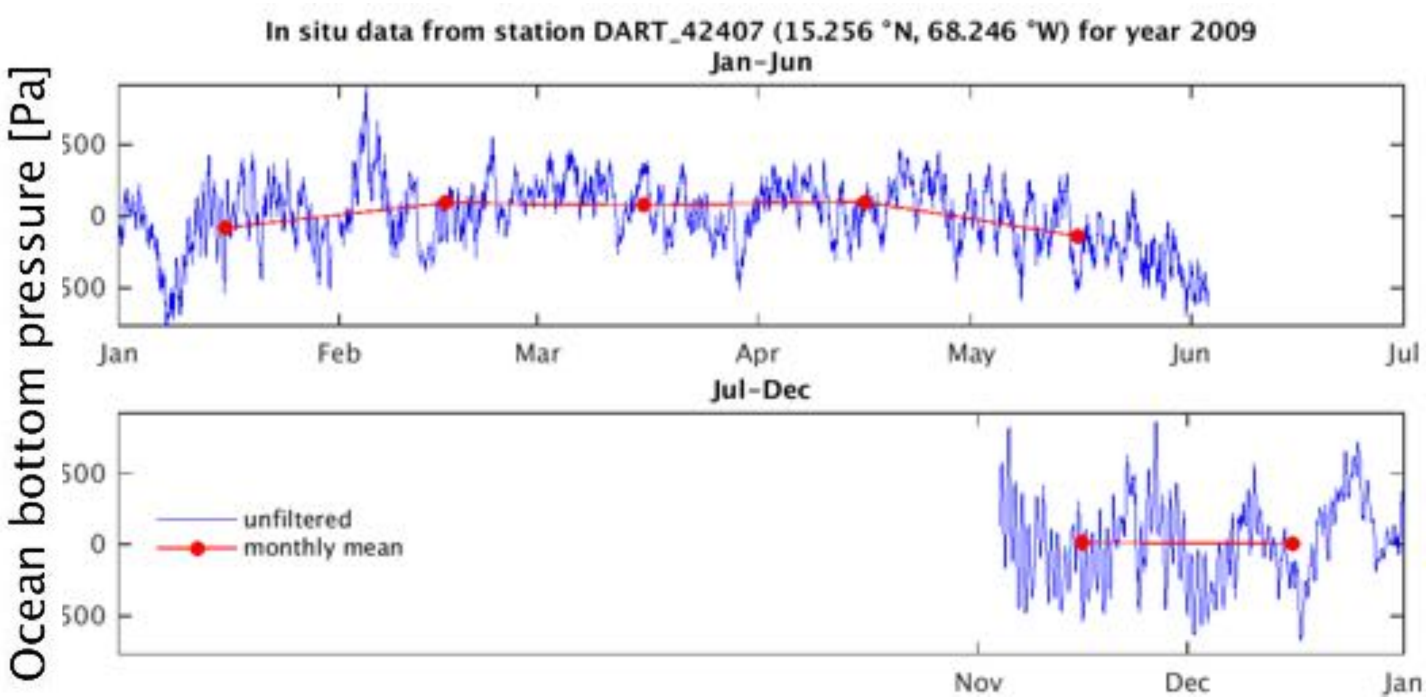
- removing outliers, drifts, jumps and trends
- changing time step to 1 hour
- stacking time series from the same station

- removing tidal signal
- filtering data

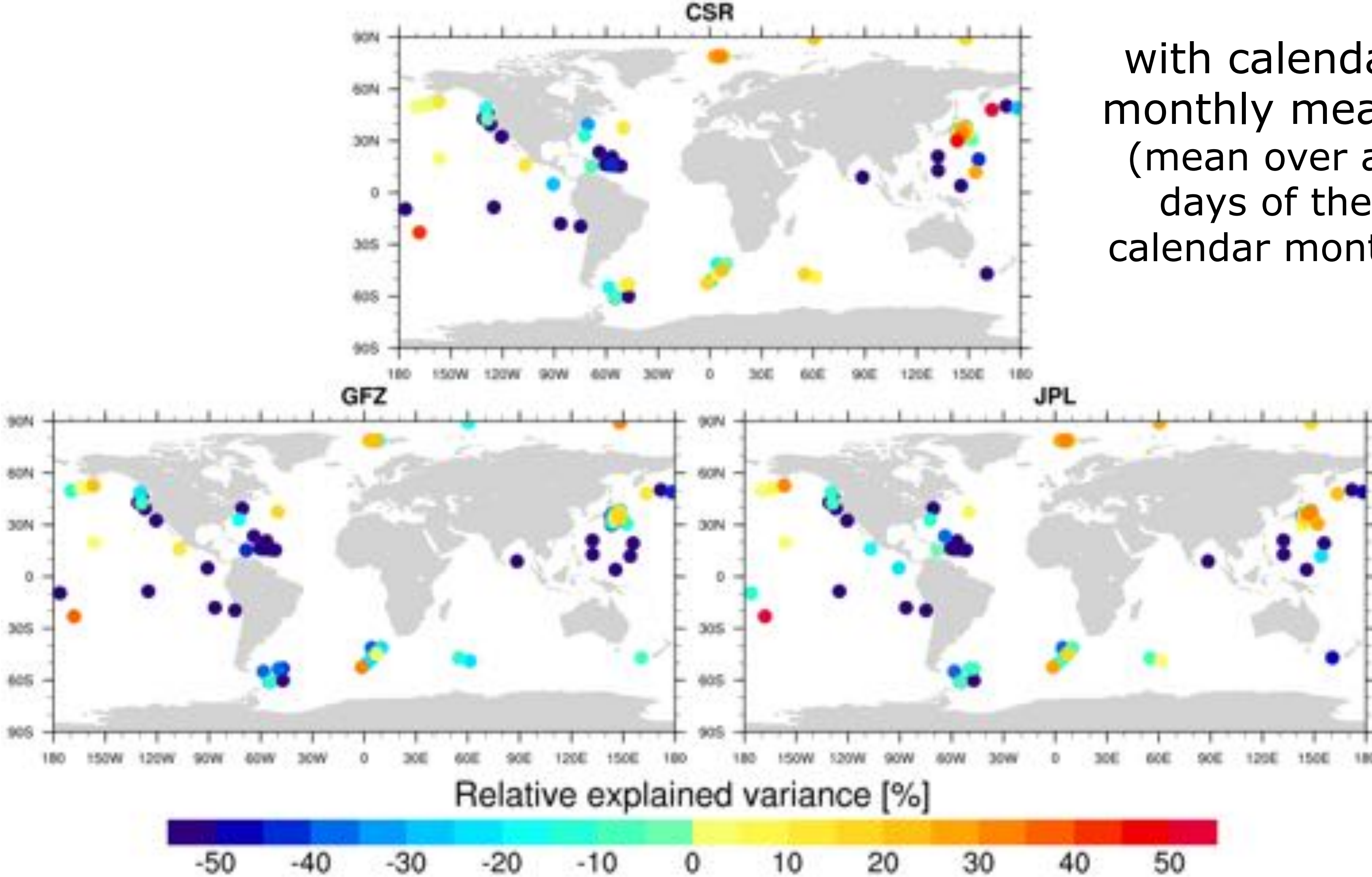
or

- monthly mean

T_TIDE MATLAB package for classical harmonic analysis [Pawlowicz et al., 2002]

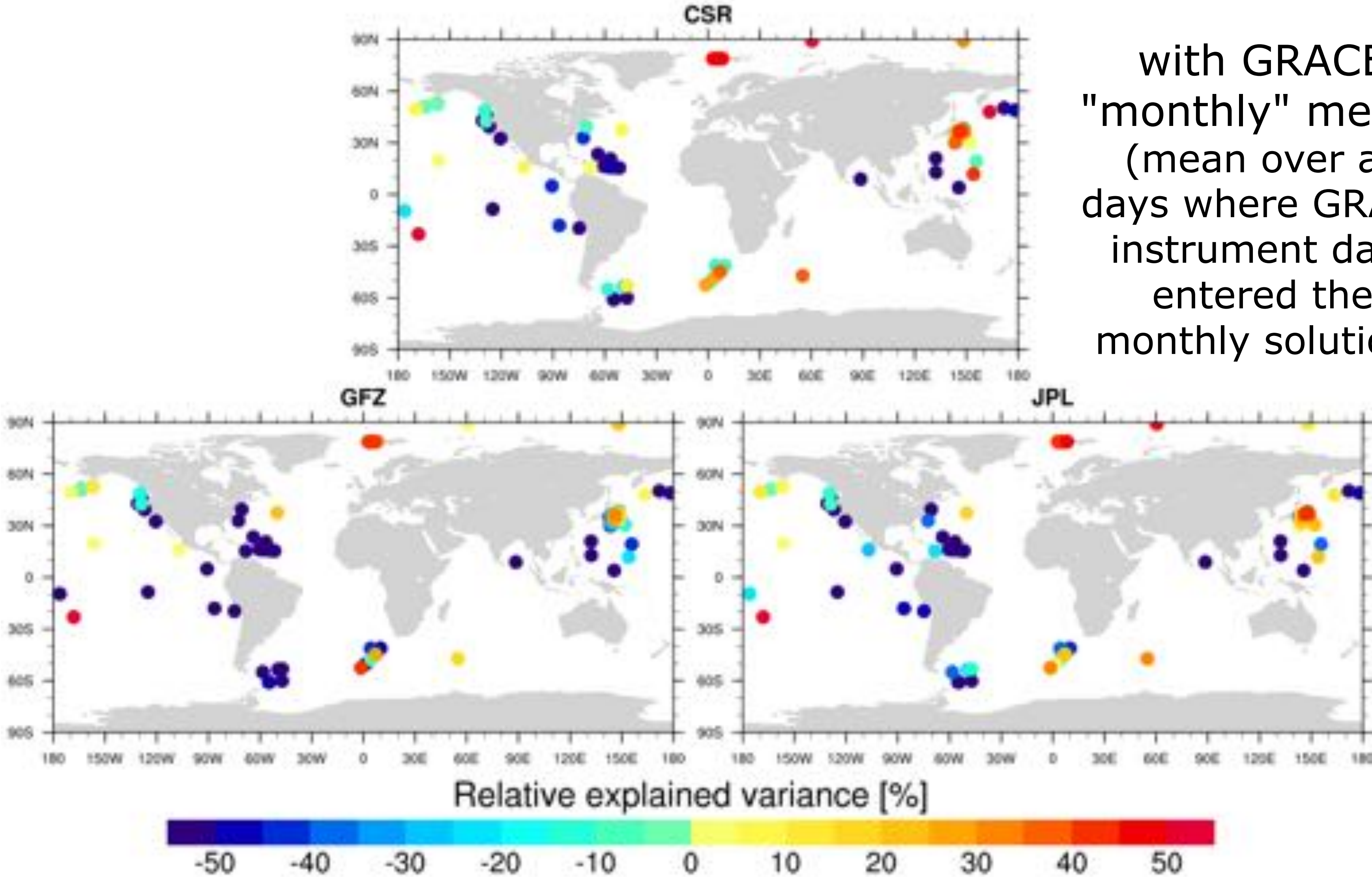


Validation of Tellus monthly solutions



with calendar monthly means (mean over all days of the calendar month)

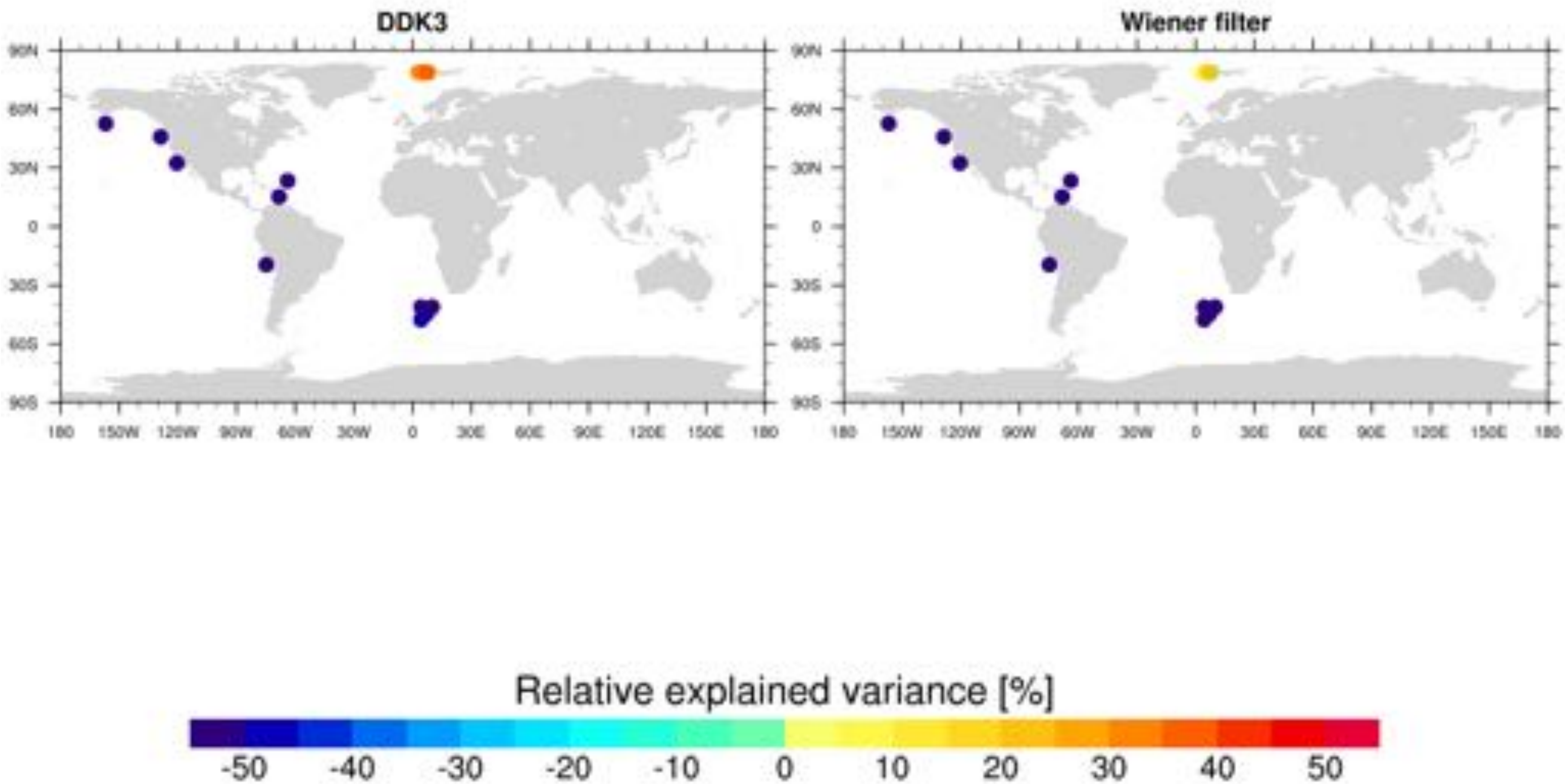
Validation of Tellus monthly solutions



with GRACE "monthly" means (mean over all days where GRACE instrument data entered the monthly solution)

Validation of EGSIEM preliminary ocean grids

GRACE solution only for years 2006-2007 → only 16 stations provide sufficient data (12 monthly means) in that time span



Summary and outlook

Summary and outlook

- a database of ~ 100 in situ OBP timeseries is available for validation of GRACE monthly solutions, new stations are to be added to cover also recent years

Summary and outlook

- a database of ~ 100 in situ OBP timeseries is available for validation of GRACE monthly solutions, new stations are to be added to cover also recent years
- the actual days that entered a GRACE monthly solution should be also averaged from the in situ data to improve the fit

Summary and outlook

- a database of ~ 100 in situ OBP timeseries is available for validation of GRACE monthly solutions, new stations are to be added to cover also recent years
- the actual days that entered a GRACE monthly solution should be also averaged from the in situ data to improve the fit
- GRACE monthly solutions are quite noisy in the tropics, but show moderate skills in less stratified oceans at higher latitudes

Summary and outlook

- a database of ~ 100 in situ OBP timeseries is available for validation of GRACE monthly solutions, new stations are to be added to cover also recent years
- the actual days that entered a GRACE monthly solution should be also averaged from the in situ data to improve the fit
- GRACE monthly solutions are quite noisy in the tropics, but show moderate skills in less stratified oceans at higher latitudes
- 2 years of monthly-mean test data is certainly too short to draw robust conclusions out of the OBP validation

Summary and outlook

- a database of ~ 100 in situ OBP timeseries is available for validation of GRACE monthly solutions, new stations are to be added to cover also recent years
- the actual days that entered a GRACE monthly solution should be also averaged from the in situ data to improve the fit
- GRACE monthly solutions are quite noisy in the tropics, but show moderate skills in less stratified oceans at higher latitudes
- 2 years of monthly-mean test data is certainly too short to draw robust conclusions out of the OBP validation

Thank you!

References

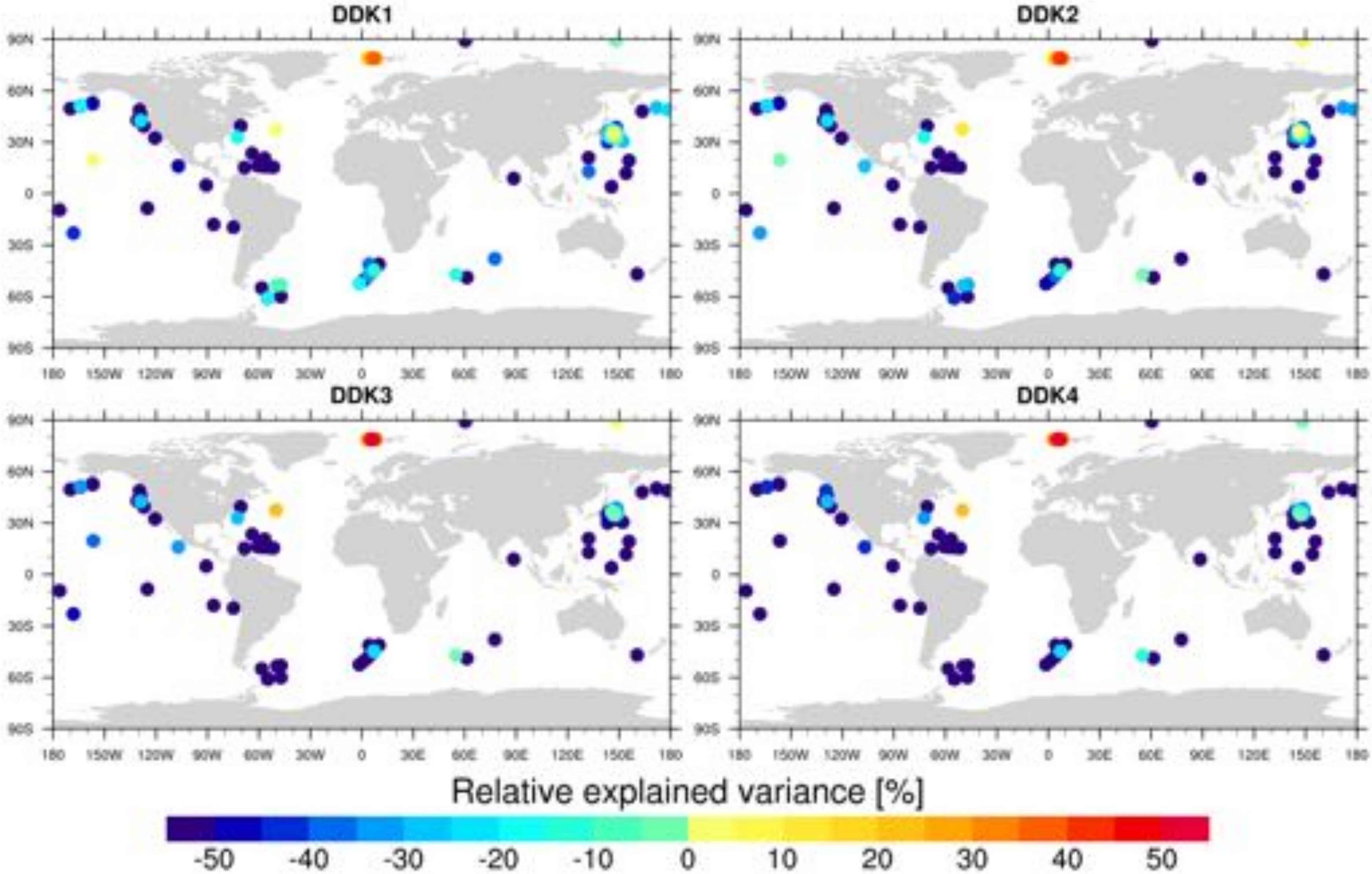
- Macrander, A., Boening, C., Boebel, O., Schroeter, J. (2010), Validation of GRACE gravity fields by in-situ data of ocean bottom pressure, System Earth via Geodetic-Geophysical Space Techniques, Springer, Berlin
- Pawlowicz, R., Beardsley, B. & Lentz, S. (2002), Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE, Computers & Geosciences, 28, 929-937, doi: 10.1016/S0098-3004(02)00013-4
- Cheng, M., Ries, J.C. & Tapley, B.D. (2011), Variations of the Earth's figure axis from satellite laser ranging and GRACE, J. Geophys. Res., 116, B01409, doi:10.1029/2010JB000850
- Paulson, A., Zhong, S. & Wahr, J. (2007), Inference of mantle viscosity from GRACE and relative sea level data, Geophys. J. Int., 171, 497–508, doi:10.1111/j.1365-246X.2007.03556.x
- Bergmann-Wolf, I., Zhang, L. & Dobslaw, H. (2014), Global Eustatic Sea-Level Variations for the Approximation of Geocenter Motion from GRACE, J. Geod. Sci., 4, 37–48, doi:10.2478/jogs-2014-0006
- Wahr, J., Molenaar, M. & Bryan, F. (1998), Time variability of the Earth’s gravity field: Hydrological and oceanic effects and their possible detection using GRACE, J. Geophys. Res., 103, 30,205–30,229, doi:10.1029/98JB02844
- Kusche, J. (2007), Approximate decorrelation and non-isotropic smoothing of time-variable GRACE-type gravity field models, J. Geod., 81, 733–749, doi:10.1007/s00190-007-0143-3

Relative explained variance

Explained variance – variance of in situ measurements explained by the model

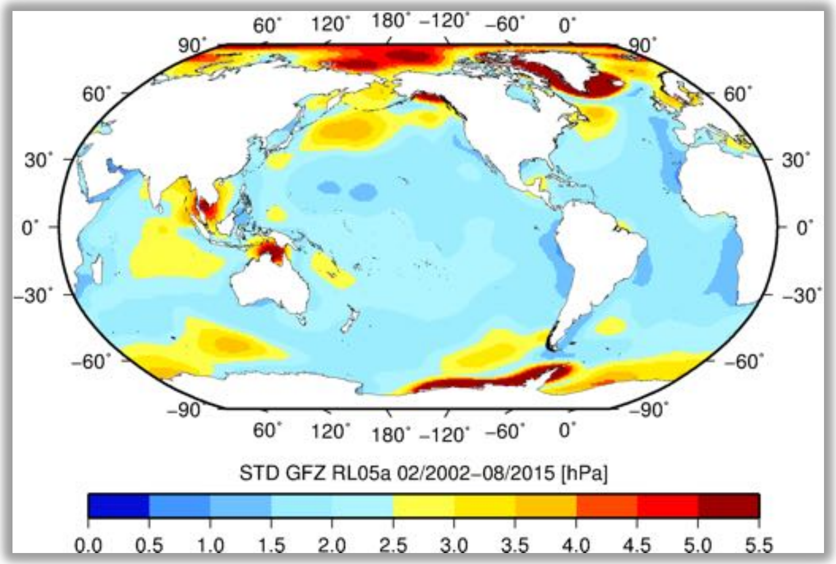
$$V = \frac{\langle obs \rangle - \langle obs - \mathrm{mod} \rangle}{\langle obs \rangle}$$

Validation of ITSG 2016 monthly solutions



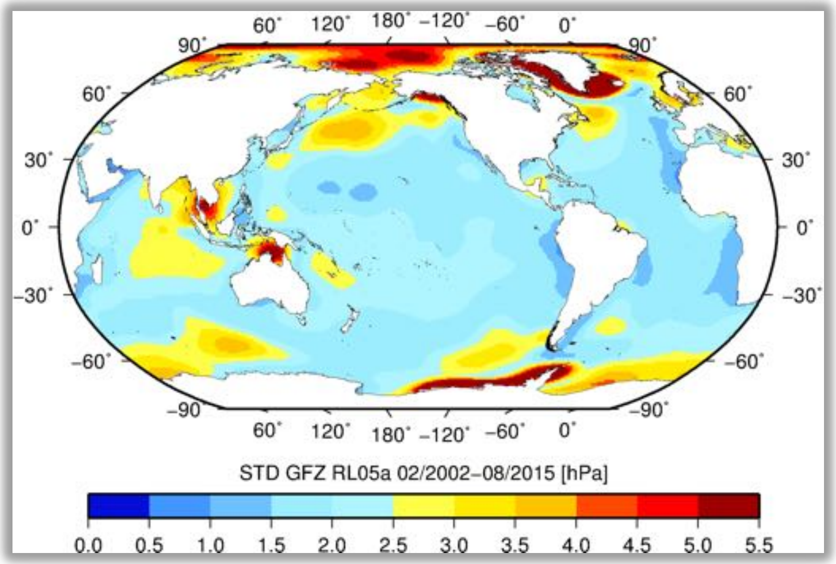
OBP fields from GRACE GFZ RL05a

Work in progress



- improve leakage correction
- remove Sumatra-Andaman earthquake signature
- reconsider GIA model
- residual tidal signal assessment: Gulf of Carpentaria
- reconsider level of smoothing (DDK2, DDK3)

OBP fields from GRACE GFZ RL05a



- 04/2002 – 08/2015
- up to d/o=90
- atmospheric jumps corrected with GAE & GAF
- C20 replaced (Cheng et al., 2011)
- GIA correction (Paulson et al., 2007)
- Geocenter variations included acc. to Bergmann-Wolf et al. (2014)
- land leakage reduction acc. to Wahr et al. (1998)
- GAD added back
- Filtering with DDK1 (Kusche, 2007)
- grid: 1° x 1°

GFZ Helmholtz Centre POTSDAM

HELMHOLTZ ASSOCIATION

EGSIEM
European Gravity Service for Improved Emergency Management

Task 3.8 – GIA (correction) for hydrology Status January 2017

Holger Steffen, Evan Gowan, Erik Ivins, Benoit Lecavalier, Glenn Milne, Anthony Purcell, Lev Tarasov, Pippa Whitehouse & Patrick Wu

holger.steffen@lm.se

Glacial Isostatic Adjustment model

- Once developed to determine mantle viscosity for convection models and to describe sea-level variations, nowadays quite complex
- Two major parts: (I) Earth (Rheology) model and (II) ice model
- Other information: Topography model (for time-dependent ocean function)
- Mathematical-physical theory relating the physics of the ice-earth-ocean changes to observational quantities
  - Earth and ice models are coupled via the sea-level equation
- Needs (III) observations for tuning
- Can take different processes/effects into account:
  - Deformation
  - Mass redistribution (ice, water, earth, (sedimentation))
  - Earth rotation
  - Geoid & sea-level changes
  - Stress changes
- A well-fitting GIA model for one quantity may NOT fit another quantity well!

Task 3.8 (from the proposal)

T3.8: GIA for Hydrology LM (covered by SLA, see Sect. 3.3.4) M11-M36
Input: *D2.1, Gravity field solutions from T2.3, combined solution from T4.2, NRT solutions from T5.2 and T5.3, regional solutions from T5.4*
Efficient monitoring tools of the available water resources on regional and local scales need to take global interactions into account. In northern latitudes, e.g. in Fennoscandia, the tilting due to the GIA will be modelled by applying the latest GIA models. This is necessary because it strongly affects groundwater flow and lake surface control. The consortium will benefit from the latest developments in GIA modelling through the associated member Lantmäteriet.
Output: *GIA models; When?*

Sect. 3.3.4 (from the proposal)

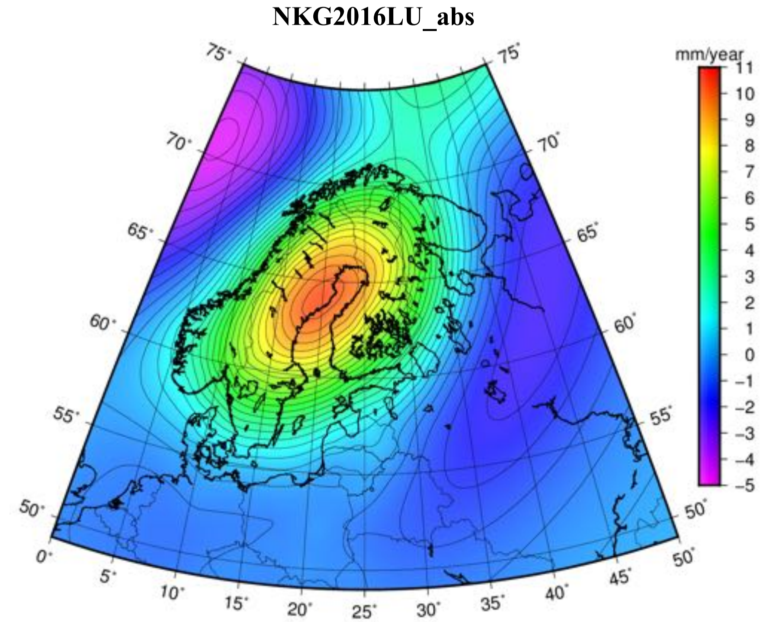
LM will provide a sophisticated global GIA model to the project, whose Fennoscandian part will be used at LM for corrections of the Swedish reference network (SWEREF99), and national height (RH2000) and gravity models (RG2000). This model part will be publicly released by 2015 as part of LM's strategic geodesy plan for the decade 2010-2020. It will include station and grid values (1x1 degree or finer) of velocities, geoid, geoid changes, and gravity changes. A global velocity field of 1x1 degree grid will substitute a 2x2 degree grid field that was made accessible to the GIA community through the COST action ES0701. (…)

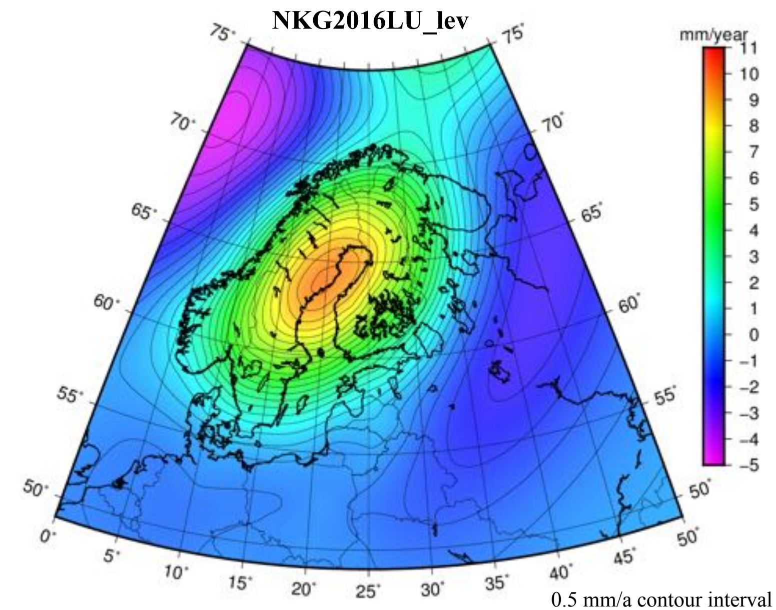
Status of Fennoscandian part

- Uplift model NKG2016LU released June 2016, GIA model part NKG2016GIA_prel0306 available on request
- Geoid model NKG2015 released October 2016
- Velocity model NKG_RF17vel to be processed this year, release hopefully summer 2017, GIA model part NKG2016GIA_prel0907 done
- NKG2016LU_gdot gravity change model to be processed this year, release end of 2018
- No official geoid change model planned, but geoid change component of NKG2016GIA_prel0306 available on request

NKG2016LU

- Semi-empirical land uplift model computed in Nordic-Baltic cooperation in the NKG Working Group of Geoid and Height Systems
- Vertical land uplift rate in two different ways (high resolution of 10′ long./5′ lat.):
  - **NKG2016LU_abs**: Absolute land uplift in ITRF2008 (i.e. relative to the Earth's centre of mass)
  - **NKG2016LU_lev**: Levelled land uplift, i.e. uplift relative to the geoid
- NKG2016LU has been computed based on
  - An **empirical land uplift model** computed by Olav Vestøl based on geodetic observations
  - The preliminary geophysical GIA model **NKG2016GIA_prel0306** (next slide) computed by Steffen et al. (2016) in the NKG WG of Geodynamics

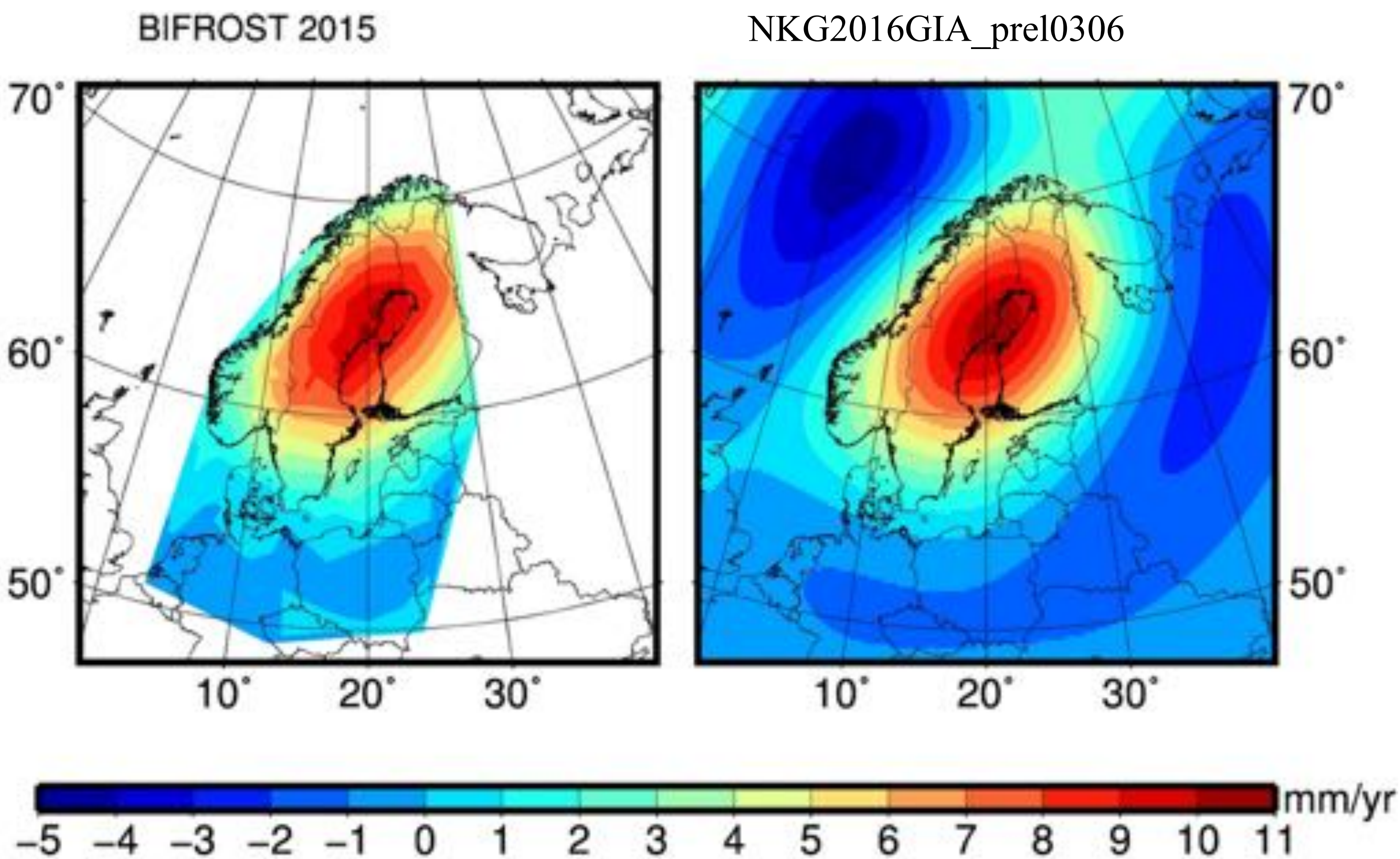




0.5 mm/a contour interval

Best fitting model to GNSS and RSL observations

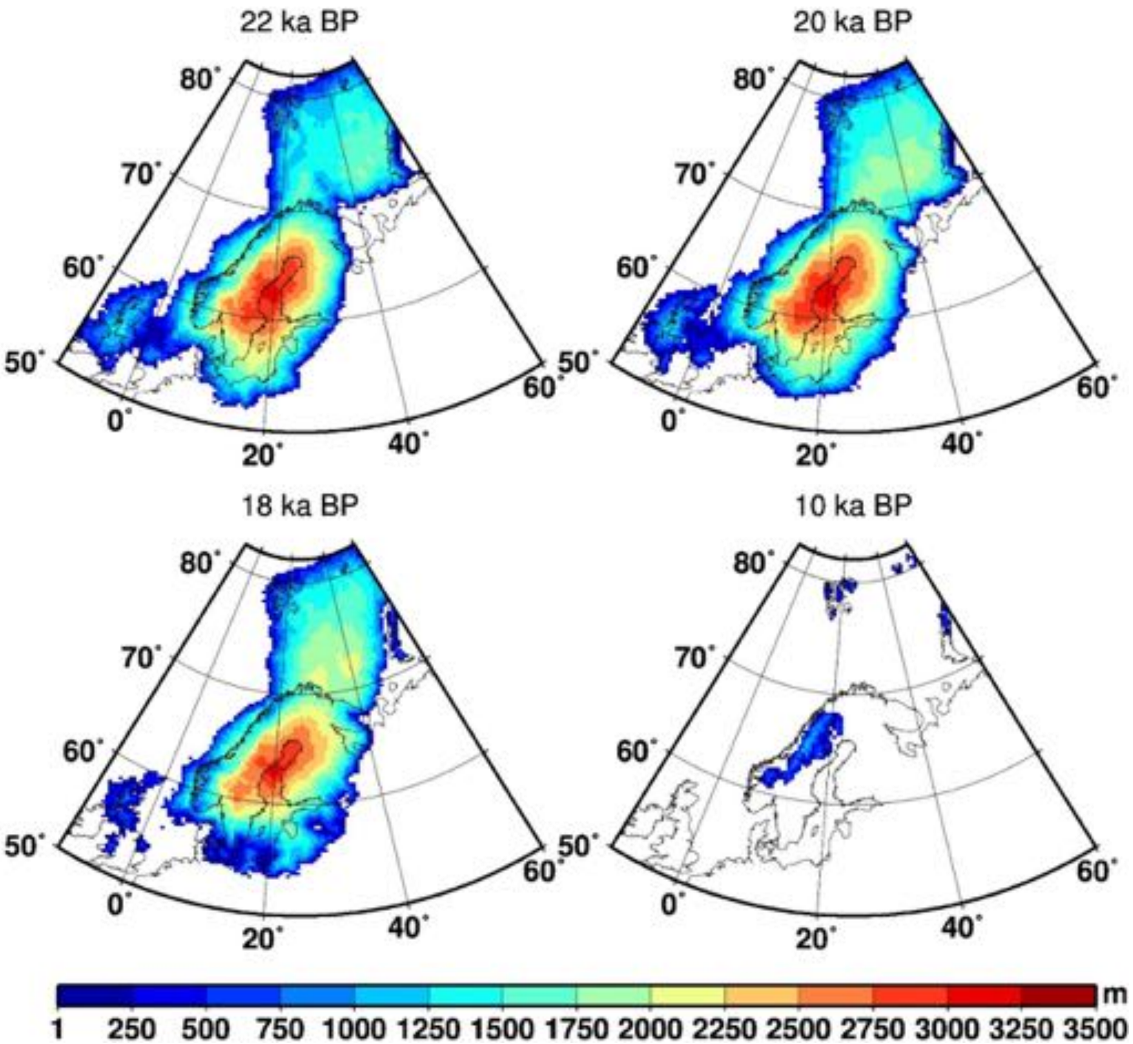
160 km lith. thick., 7 x 10^{20} Pa s upper mantle visc., $7x10^{22}$ lower mantle visc.



EGSIEM

HORIZON 2020

Best ice model GLAC-71340

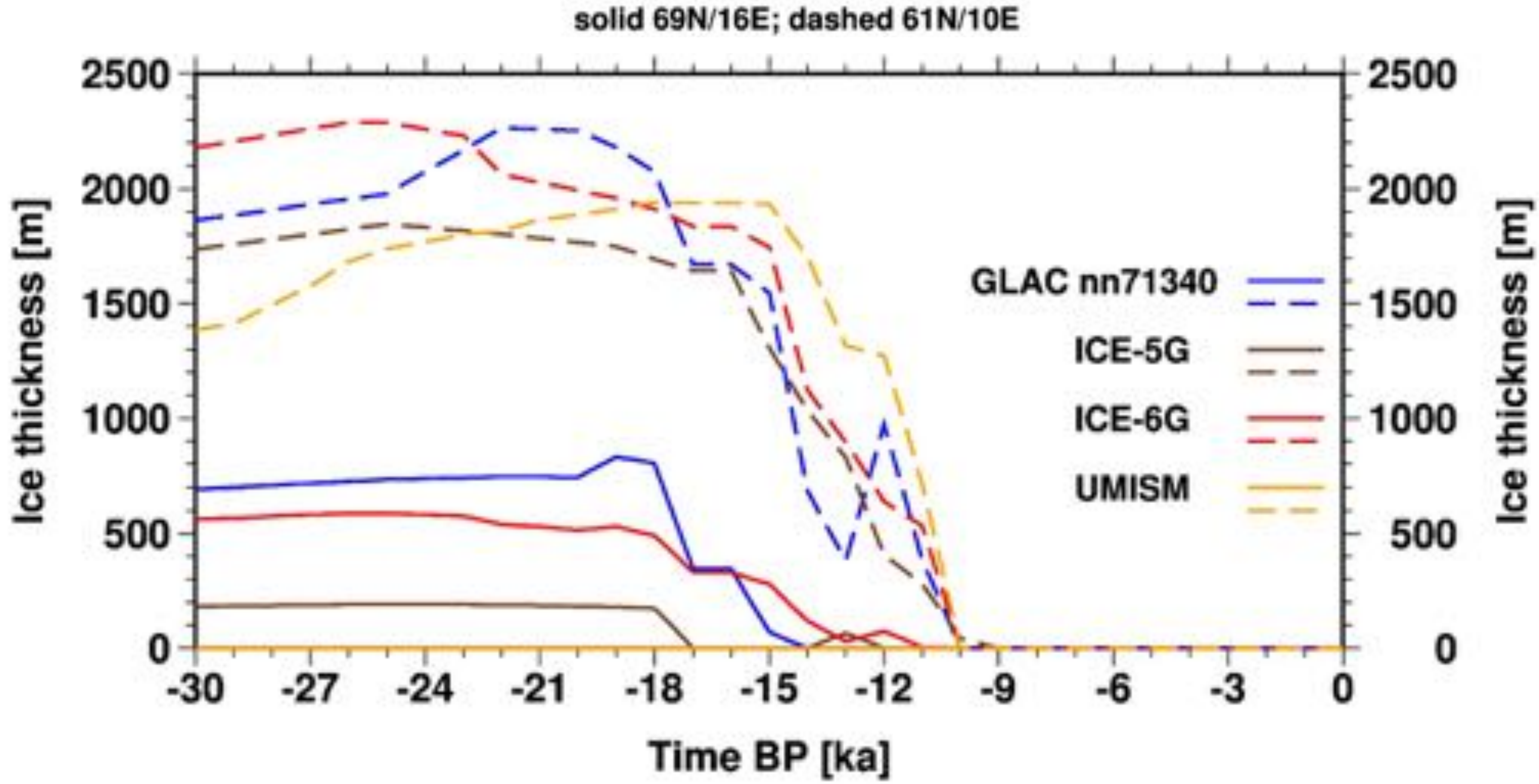


- Glaciological Systems Model (GSM) results kindly provided by Lev Tarasov, Memorial University of Newfoundland, Canada, to NKG
- 3D thermo-mechanically coupled glaciological model calibrated against ice margin information, present-day uplift, relative sea-level records
- 39 ensemble parameters (the majority related to the climate forcing) subject to Bayesian calibration
- Calibration done with Peltier's VM5a earth model
- Takes uncertainties in the constraints into account → generates posterior probability distributions for past ice sheet evolution (Tarasov et al., 2012)

EGSIEM

HORIZON 2020

GLAC vs. other ice models



Model set-up for first EGSIEM GIA correction

- Ice models:
  - Best GLAC (#71340) for Fennoscandia/Barents Sea, GLAC for North America, GLAC for Antarctica, HUY3 for Greenland, *IJ04 for Patagonia*, rest (Iceland, HMA, Siberia, Tibet) from ANU-ICE
- Earth model:
  - *Dedicated earth model for each region*, Maxwell rheology, using Wu (2004) 3D spherical FE model approach
  - Other model parameters (ice/water density, Earth radius, moments of inertia, π, etc.) as used in COST benchmark activity (see Spada et al. 2010)
- Observations (to be done):
  - Global RSL data
  - GNSS in North America and northern Europe
  - EGSIEM GRACE result (?)

Ice models

A series of regional ice models was kindly provided by colleagues for this purpose:

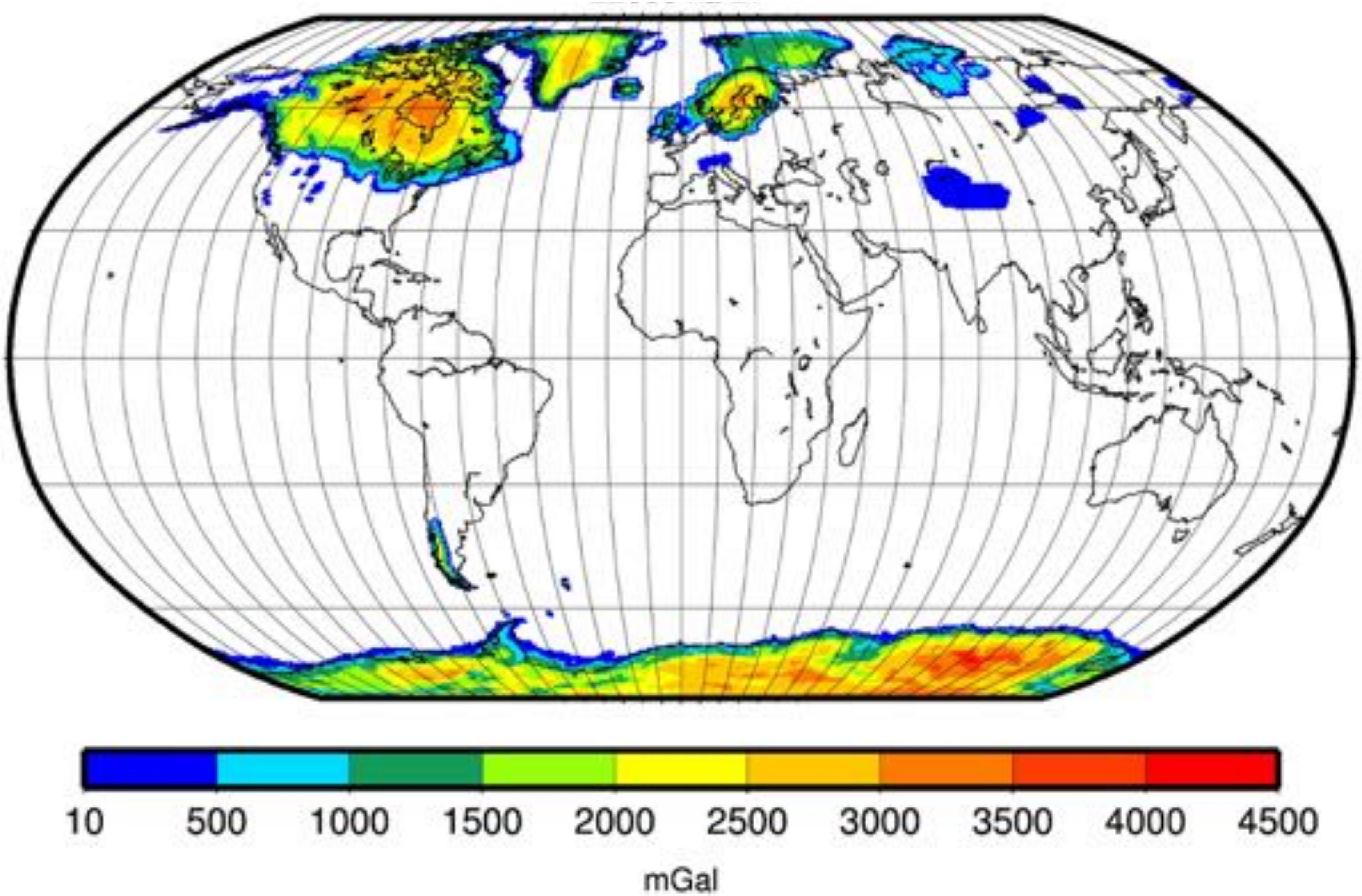
- Greenland (2): HUY3 (Lecavalier et al. 2014), ANU-ICE (Lambeck et al. 2014)
- Fennoscandia and Barents Sea (2): GLAC (Hughes et al. 2015, Nordman et al. 2015, Root et al. 2015; updated chronologies from Lev Tarasov), ANU-ICE (Lambeck et al. 2010)
- North America (3): GLAC (Tarasov et al. 2012), NAIce (Gowan et al. 2016), ANU-ICE (Lambeck et al. 2017)
- Antarctica (including Antarctic Peninsula) (4): W12 (Whitehouse et al. 2012), IJ05_R2 (Ivins et al. 2013), GLAC (Briggs et al. 2014), ANU-ICE (unpublished)
- Patagonia (2): updated IJ04 (Ivins & James 2004), ANU-ICE (Lambeck et al. 2014)
- High Mountain Areas, Iceland, Siberia, Tibet & small SH glaciers (1): ANU-ICE (Lambeck et al. 2014)

Ice model combination is not easy

- Different grids (e.g. 0.5x0.25 vs. 0.7x0.7)
- Different start & end times, # time steps and time intervals
- **The global combination will most likely not fit the expected sea-level equivalent of at least 120 m at LGM (missing ice problem)**

Model			ANU_ICE					GLAC			NAICE	HUY3	W12	IJ05_R2	ICE-6G_C
Region	skan+bar	brit	na+green	nh_glac	sh_glac	ant	skan+bar+brit	na	ant	global	na	green	ant	ant	global
Version/ Number	16	10	19	12	12	12	71340	9894	4041	skan90227 +na9894 +ant6005 +green	2	(3)	(1)	(2)	(6)
Resolution Grid	0.5x0.25	0.25x0.125	0.5x0.25	1x0.5	1x0.5	1x1	0.5x0.25	0.5x0.25	1x0.5	1x0.5	0.5x0.25	0.7x0.7	0.7x0.7	0.7x0.7	1x1
Start-End-Grid (lon/lat/lon /lat)	0/83/ 115/50.25	-10.25/58.75/ 4/51.5	-139/84.5 / -7/38	-179/80.5 / 180/35	-75/-38/ -36/-62.5	-179/-61.5/ 180/-89.5	-12.75/48.125/ 119.25/83.125	-172.5/34.75/ -42.5/84.75	0.5/-89.75/ 359.5/-52.75	global	-166/83/ -51.5/37.5	global	global	-180/-57.2/ 179.3/-89.5	global
Start-End Time	240000-9650	195000-6000	240000-6800	240000-0	240000-0	250000-0	120000-0	120000-0	200000-0	120000-0	200000-5000	122000-+500	122000-+500	21000-2200	26000-0
Timesteps	76	74	64	48	48	49	97	97	117	391	40	68	57	9	48
Reference	Lambeck et al. 2010, Boreas	?	Lambeck et al. 2017, QSR	unpubl.	unpubl.	unpubl.	Nordman et al. 2015, GJI	Tarasov et al. 2012, EPSL	Briggs et al. 2013, Cryosphere	unpubl.	Gowan et al. 2016, GMD	Lecavalier et al. 2014, QSR	Whitehouse et al. 2012, QSR	Ivins et al. 2013, JGR	Peltier et al. 2015, JGR

First model: Ice thickness at 22 ka BP



EGSIEM

HORIZON 2020

Model set-up for first EGSIEM GIA correction

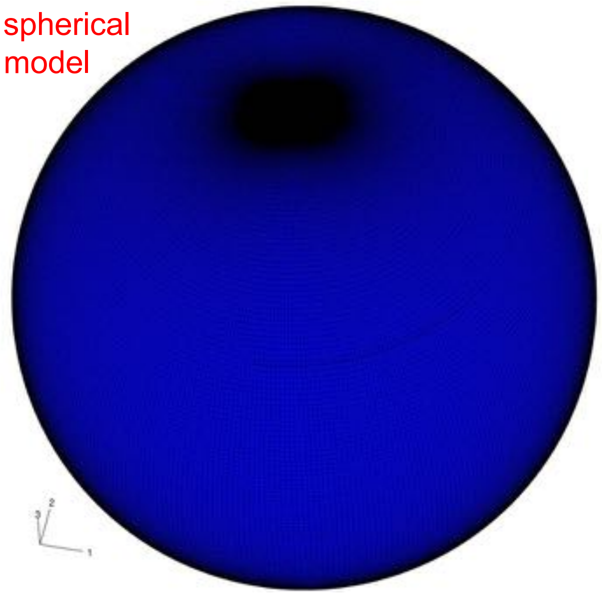
- Ice models:
  - Best GLAC (#71340) for Fennoscandia/Barents Sea, GLAC for North America, GLAC for Antarctica, HUY3 for Greenland, *IJ04 for Patagonia*, rest (Iceland, HMA, Siberia, Tibet) from ANU-ICE
- Earth model:
  - *Dedicated earth model for each region*, Maxwell rheology, using Wu (2004) 3D spherical FE model approach
  - Other model parameters (ice/water density, Earth radius, moments of inertia, π, etc.) as used in COST benchmark activity (see Spada et al. 2010)
- Observations (to be done):
  - Global RSL data
  - GNSS in North America and northern Europe
  - EGSIEM GRACE result (?)

3D modelling

- Using model approach by Wu (2004)
- Global model, 0.5x0.5 degrees
- Lateral variations in lithospheric thickness and mantle viscosity possible
- Rotational feedback (in test mode)
- Compressibility (in test mode)
- Time-dependent coastlines

- Problems:
  - Sea-level equivalent from ice model
  - Run time (reduces time steps)

3D spherical
FE model



Earth model combination is not easy either

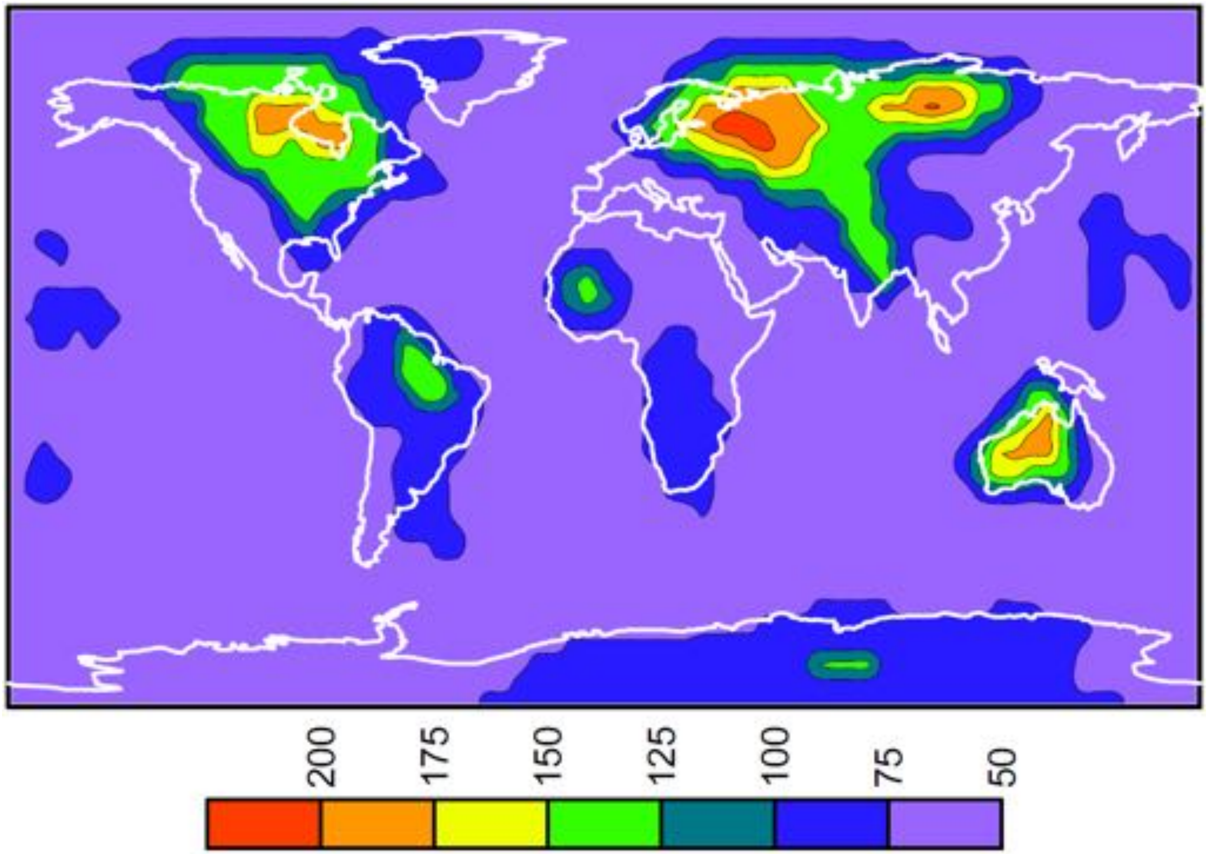
Corresponding Earth models to the ice models:

- Different lithospheric thicknesses
- Different mantle viscosities, different layers (number and/or depth interval)

Plan: Each model will be implemented in the GIA model with its ~corresponding Earth model → lateral variation in lithospheric thickness and mantle viscosity!

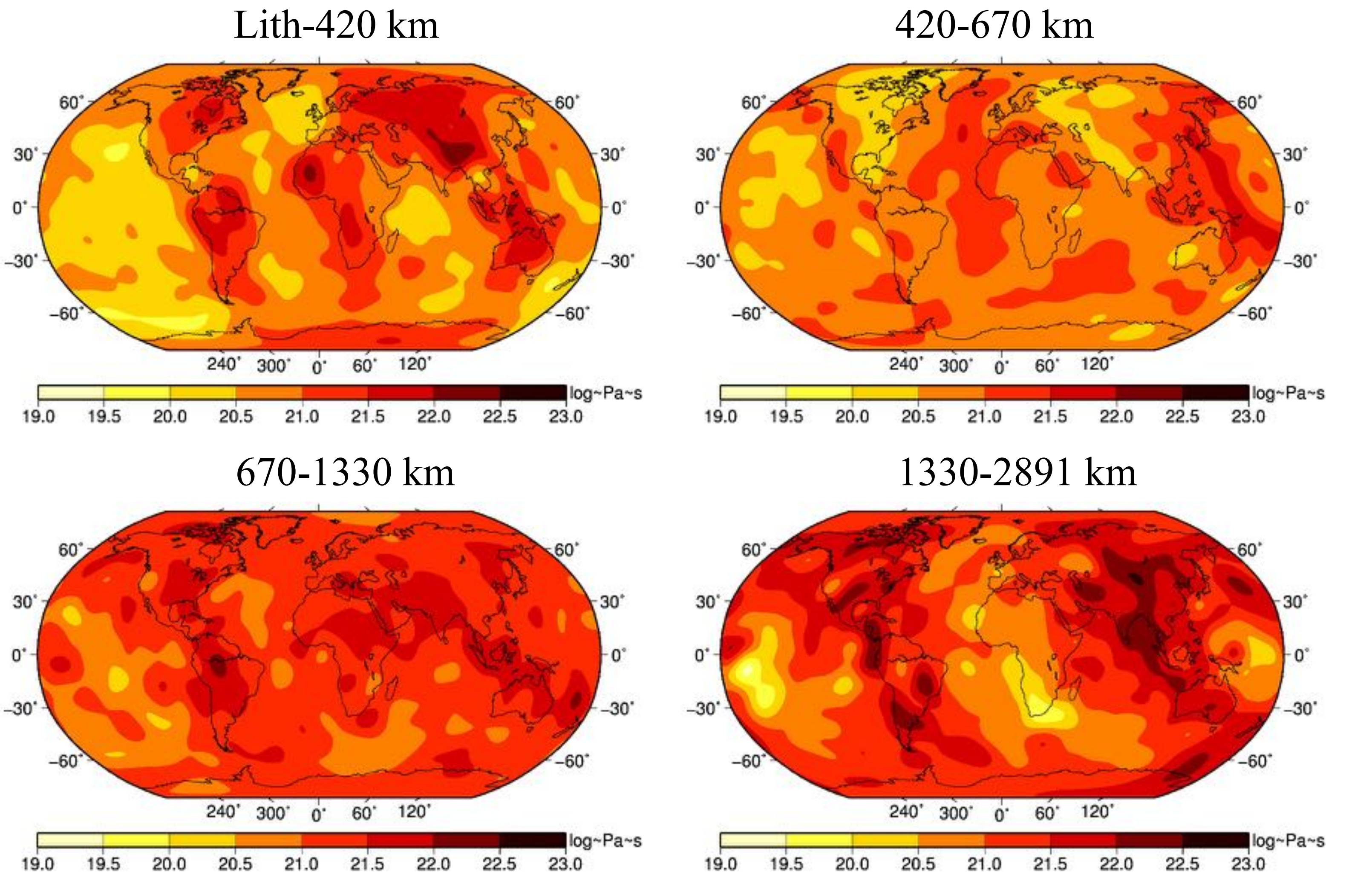
- Which thicknesses and viscosities for the rest of the world?
- Shall we treat oceanic lithosphere separately?
- Inclusion of plate boundaries?
- Shall we use Maxwell rheology only?

3D modelling alternative: 3D lithosphere



(Wang & Wu 2006, EPSL)

3D modelling alternative: 3D viscosity



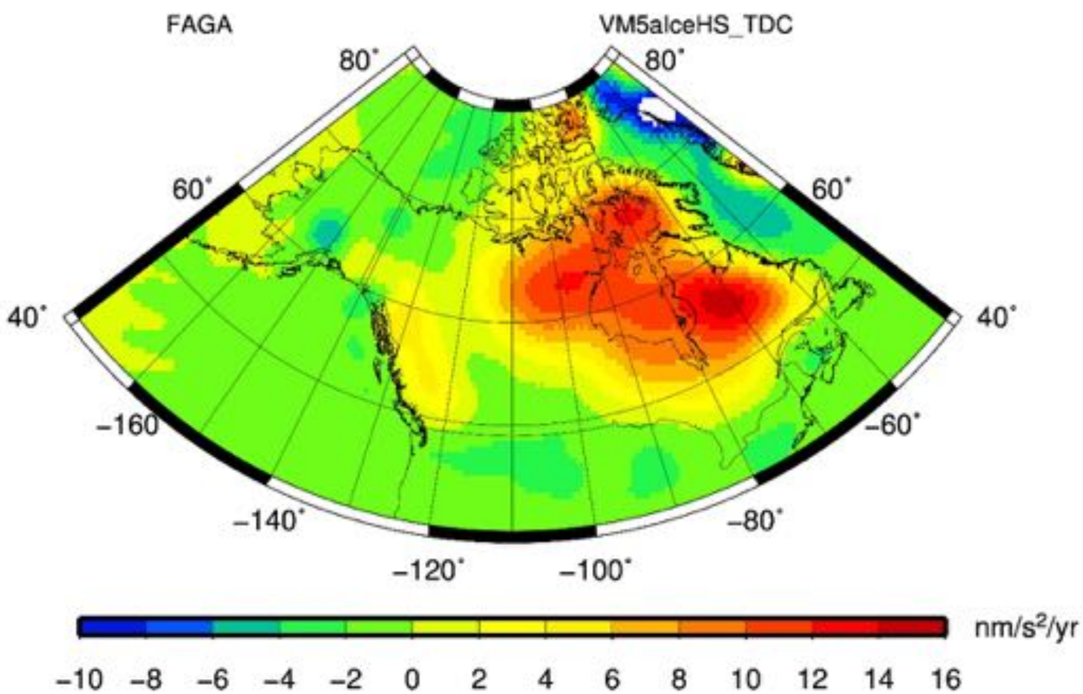
(Based on Grand et al. 1997)

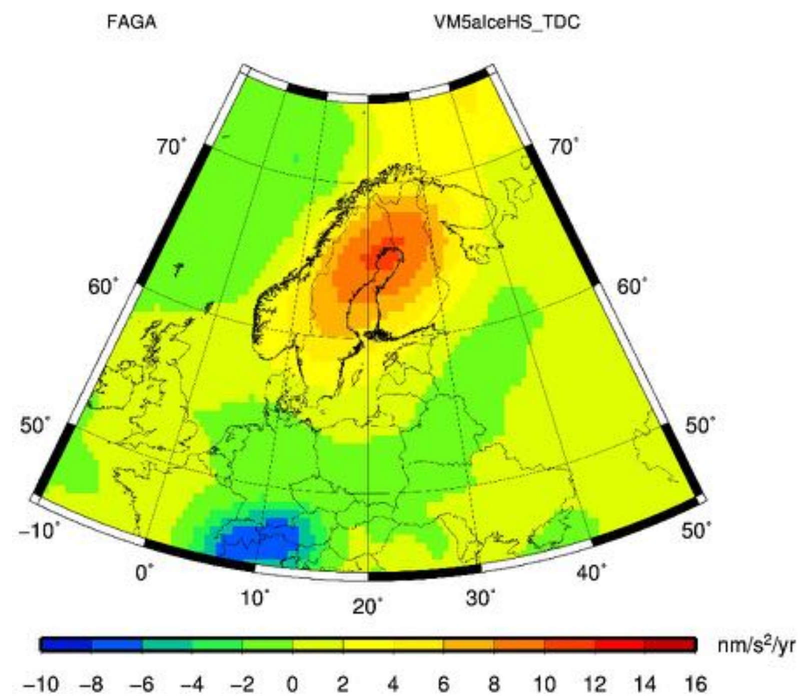
EGSIEM

HORIZON 2020

First results (to be continued in 2017)

- Ice model as outlined except Patagonia from ANU-ICE, 0.5x0.5 deg resolution, 53 time steps
- VM5a Earth model





Work in progress (a bit delayed)!

EGSIEM

European Gravity Service for Improved Emergency Management

Combination on Normal Equation Level

Ulrich Meyer (AIUB)

EGSIEM General Assembly

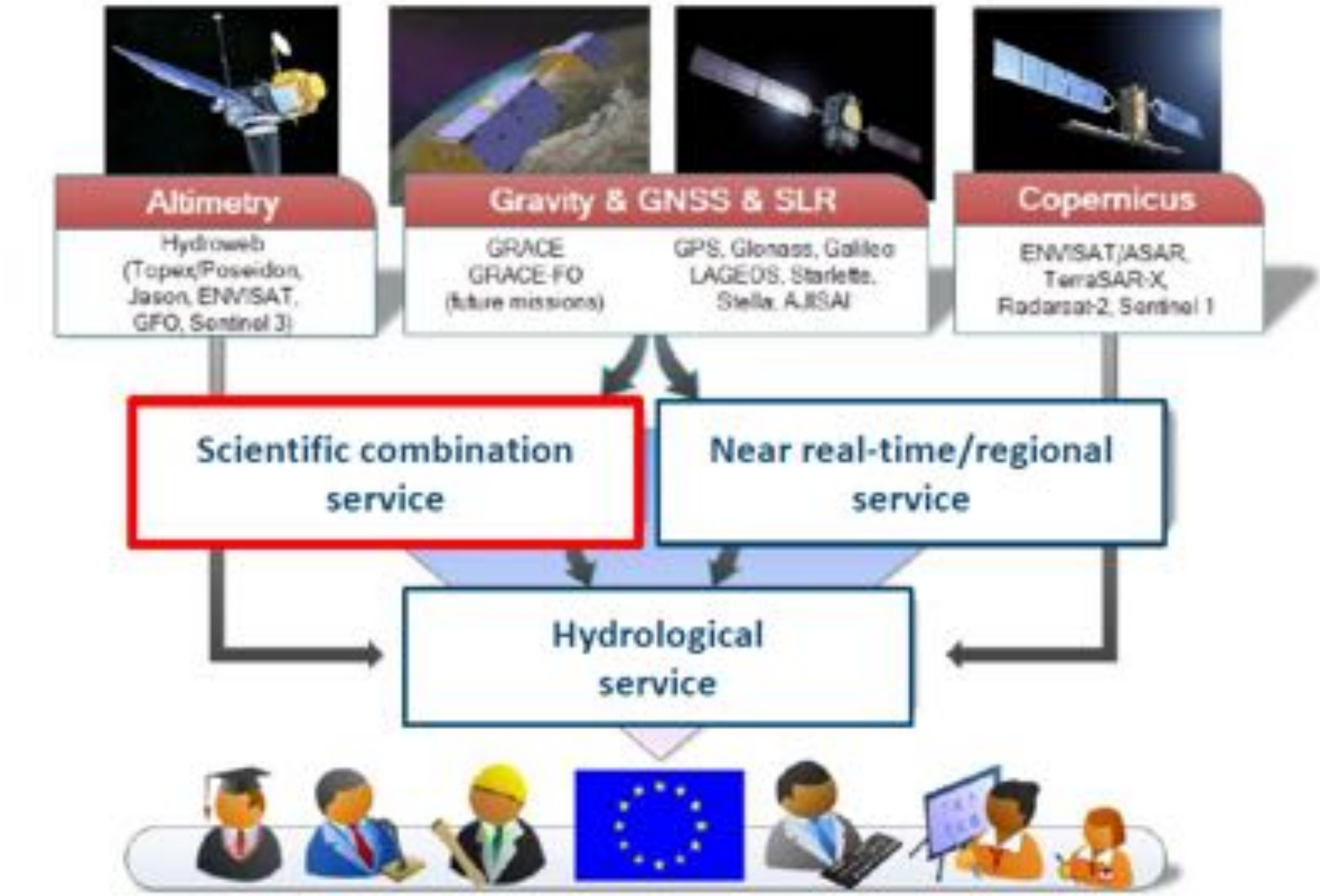
AIUB Bern

January 19 - 20, 2017

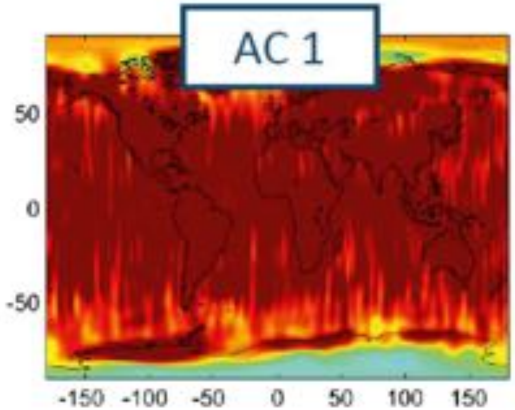
Contents

- Motivation for NEQ-combination
- Weighting schemes
- Combination results

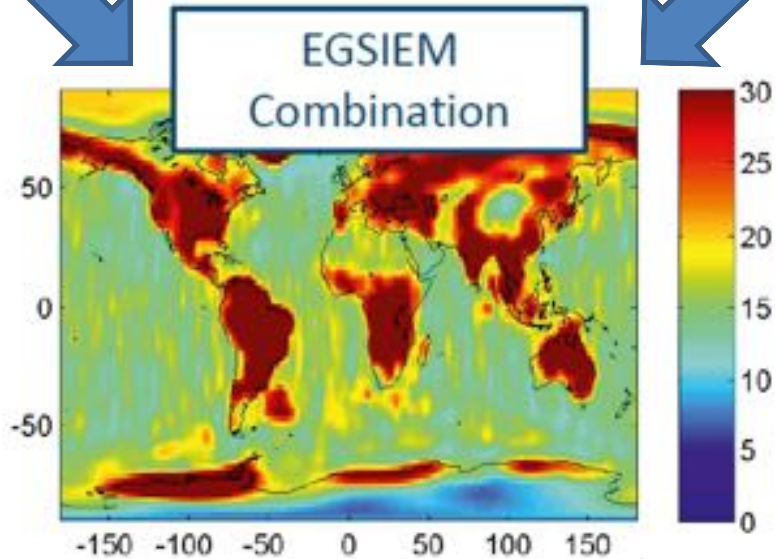
EGSIEM Project – Three services are beeing established

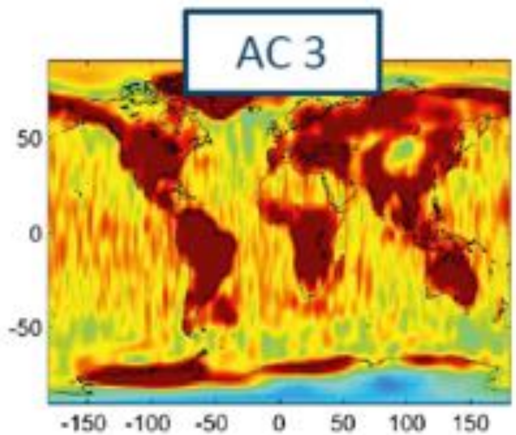


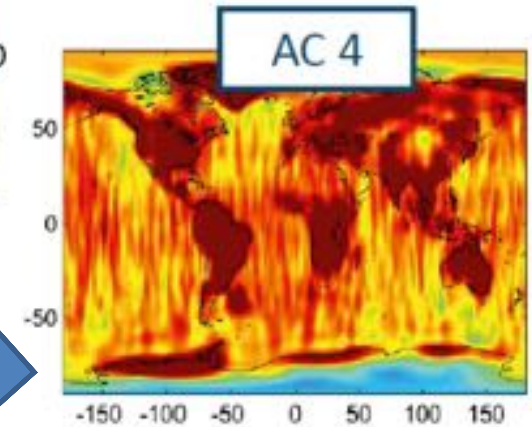
Scientific Combination Service



This image cannot currently be displayed.







- **Only one product for the user**
- **Reduced noise**

Scientific Combination Service

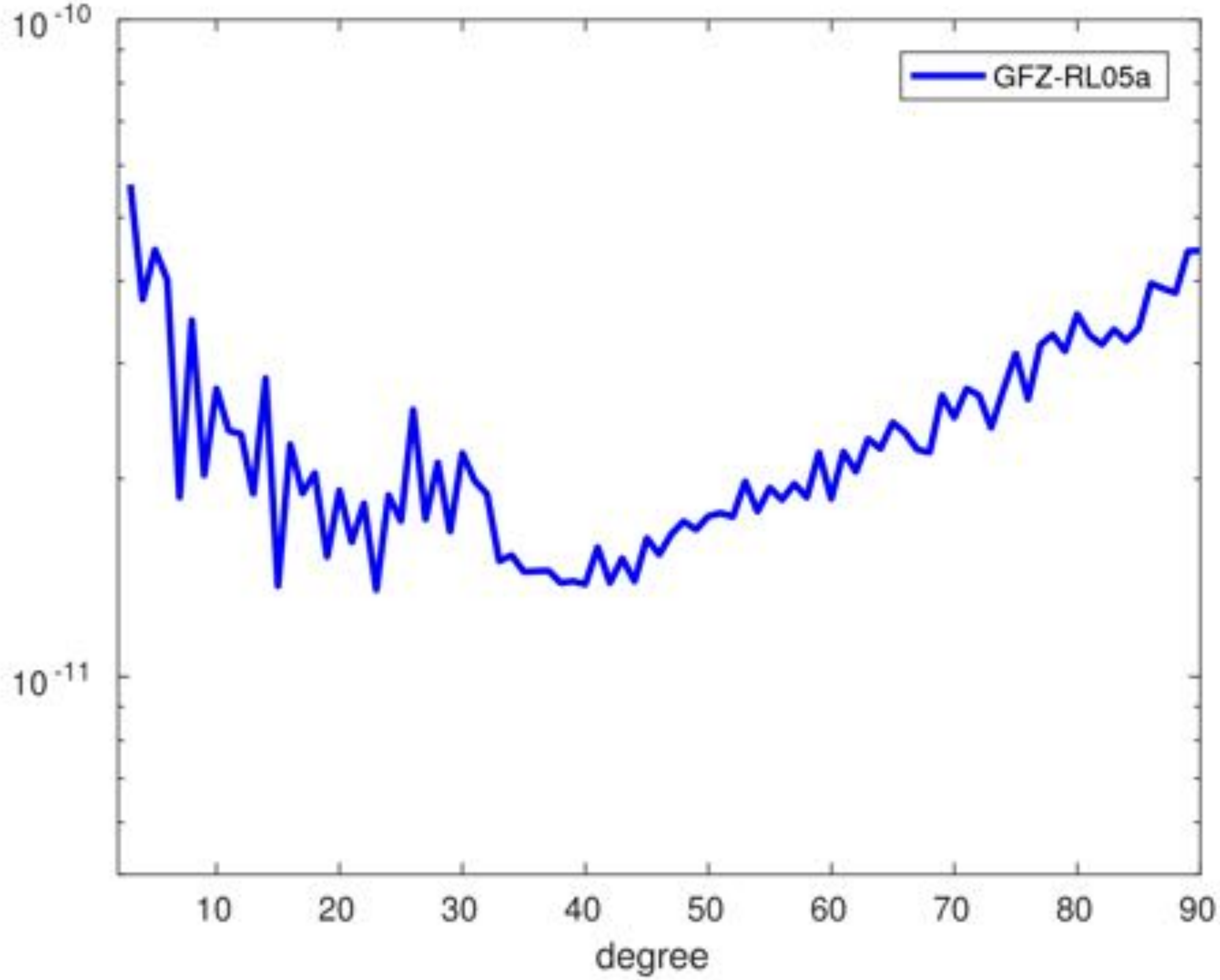
- The EGSIEM combination service provides monthly GRACE K-band gravity fields combined on solution / normal equation (NEQ) Level.
- To ensure consistency, a set of common standards for reference frame, Earth rotation, force model and satellite geometry were defined.
- EGSIEM lately was extended to also include SLR and GPS-only NEQs.

Why combine results based on the same observations?
Errors in GRACE monthly gravity fields are still dominated by analysis and background model noise, not observation noise!

Motivation for NEQ-Combination

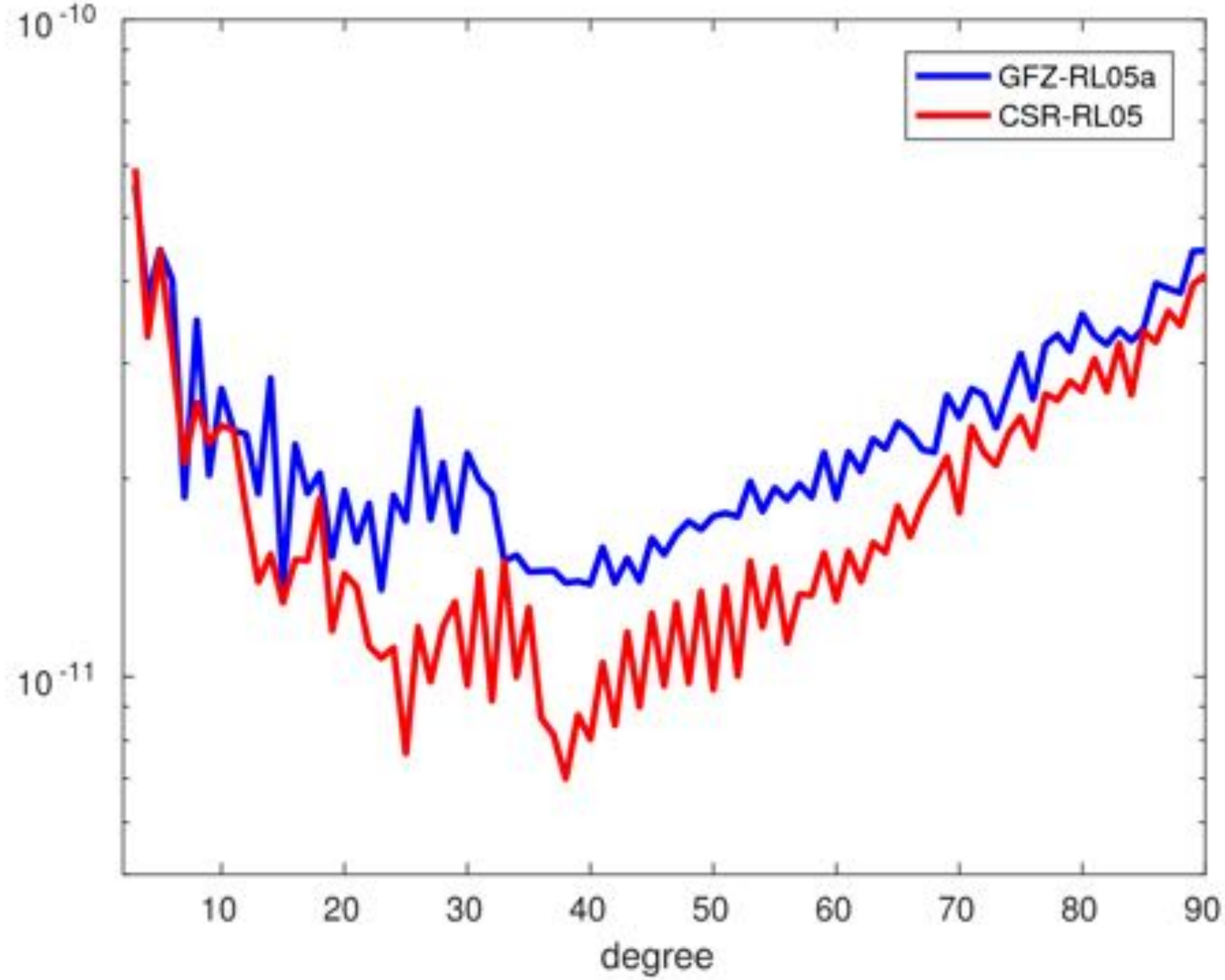
- Correlations are correctly taken into account, even with pre-eliminated parameters.
- In principle corrections are estimated for the original observations, not the intermediate individual model parameters.

Comparison to official solutions 2006/01



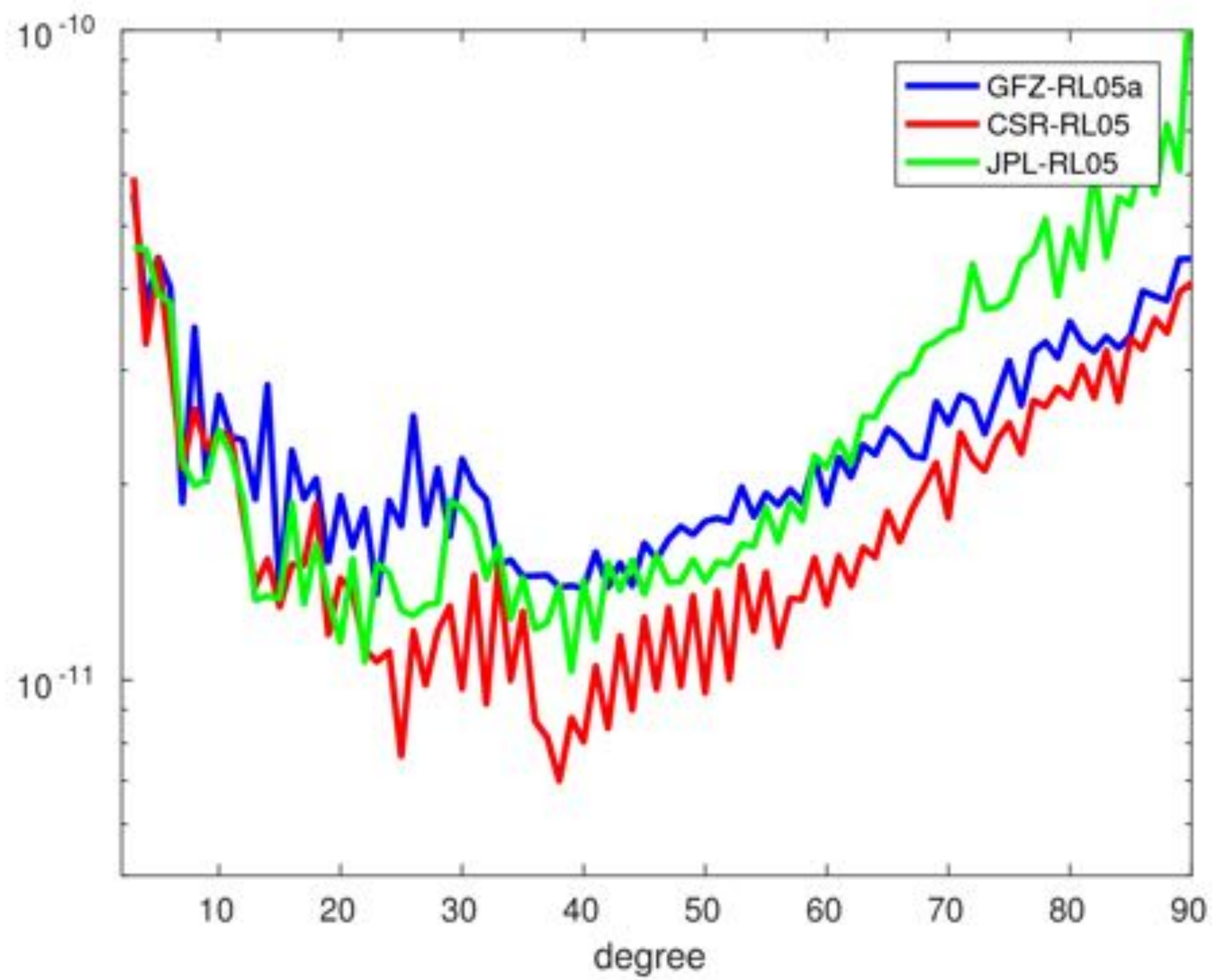
- Degree amplitudes of anomalies with respect to modeled secular and seasonal variations (based on ICGEM dataset).
- Only orders 0..29 are considered: evaluation of part of the spectrum that is determined meaningful.

Comparison to official solutions 2006/01



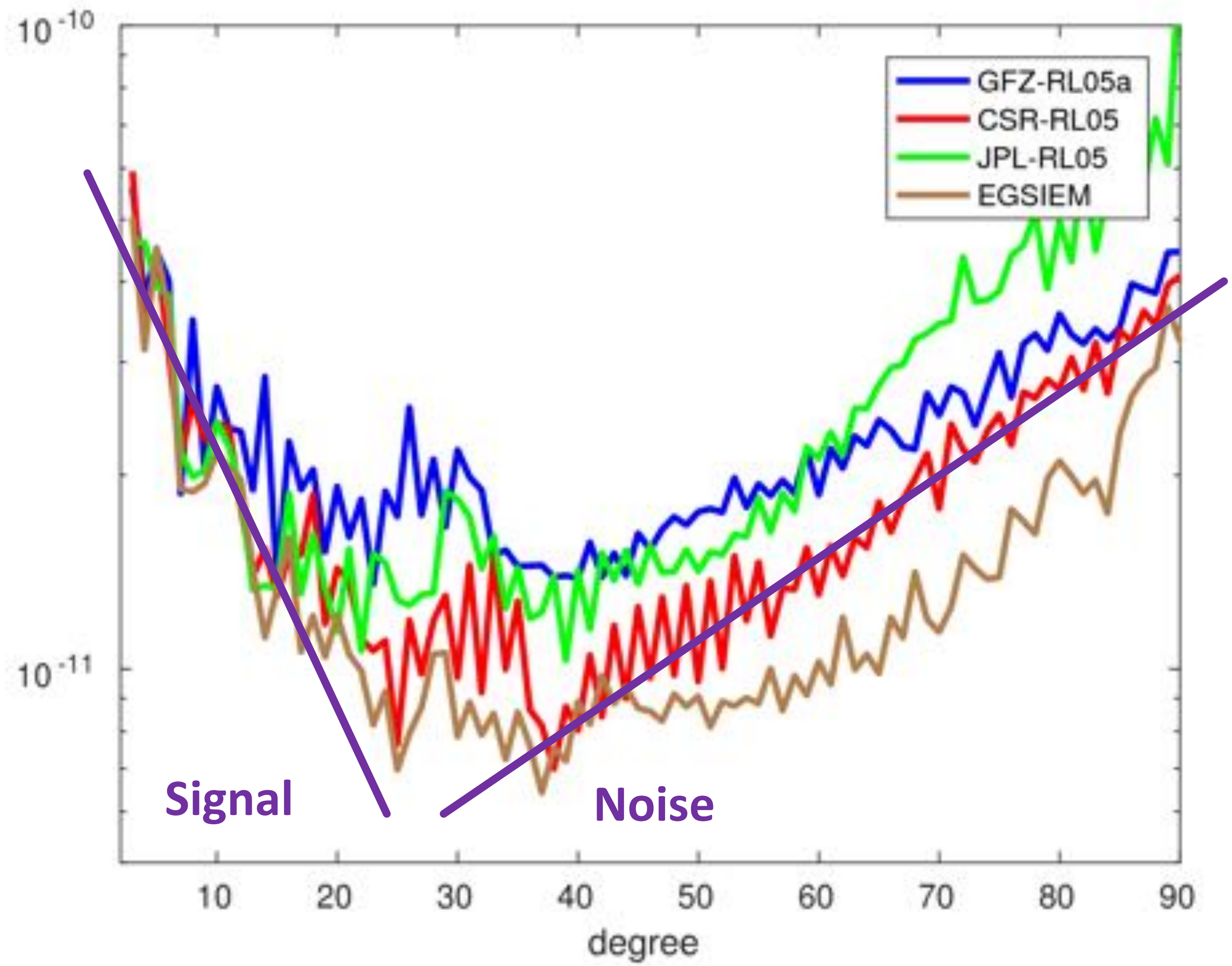
- Degree amplitudes of anomalies with respect to modeled secular and seasonal variations (based on ICGEM dataset).
- Only orders 0..29 are considered: evaluation of part of the spectrum that is determined meaningful.

Comparison to official solutions 2006/01



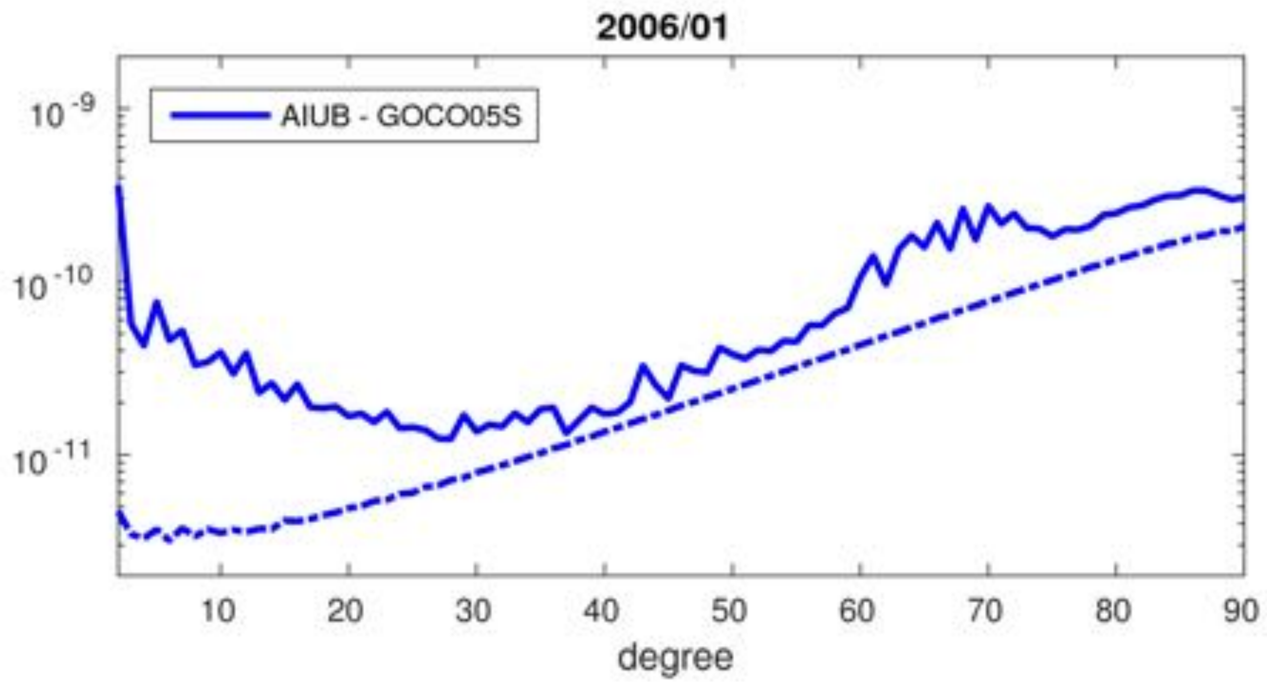
- Degree amplitudes of anomalies with respect to modeled secular and seasonal variations (based on ICGEM dataset).
- Only orders 0..29 are considered: evaluation of part of the spectrum that is determined meaningful.

Comparison to official solutions 2006/01



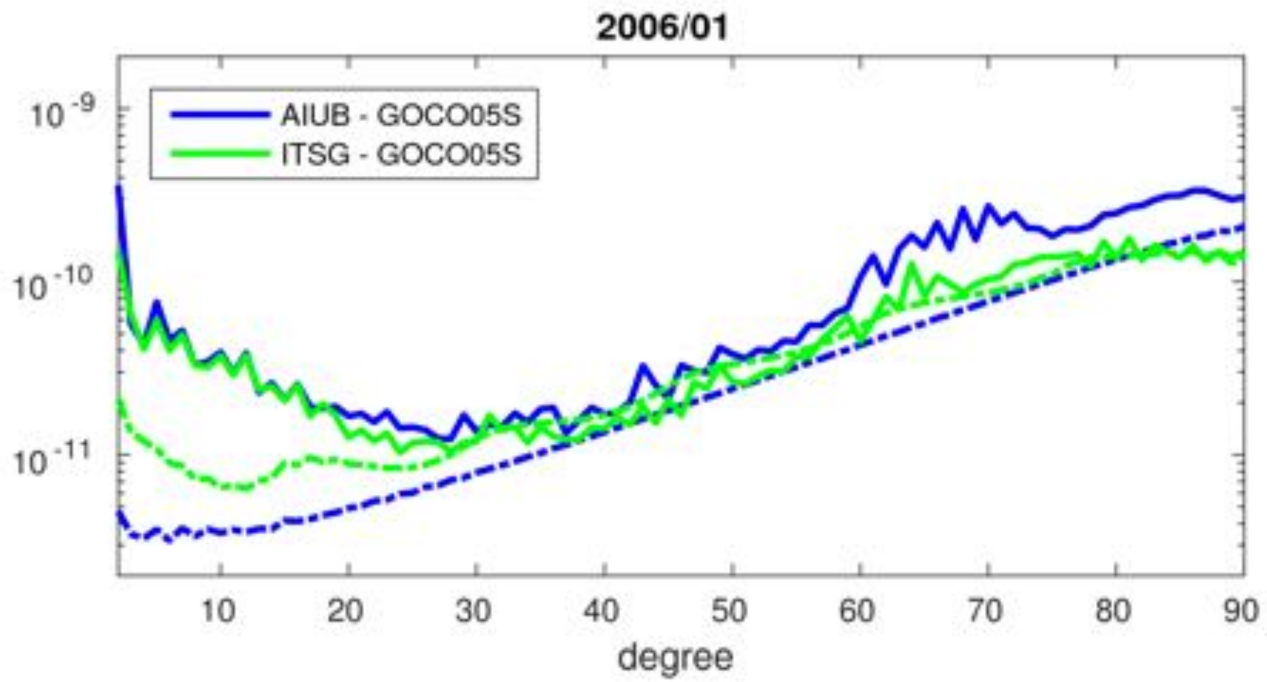
- Degree amplitudes of anomalies with respect to modeled secular and seasonal variations (based on ICGEM dataset).
- Only orders 0..29 are considered: evaluation of part of the spectrum that is determined meaningful.

Individual Contributions: AIUB



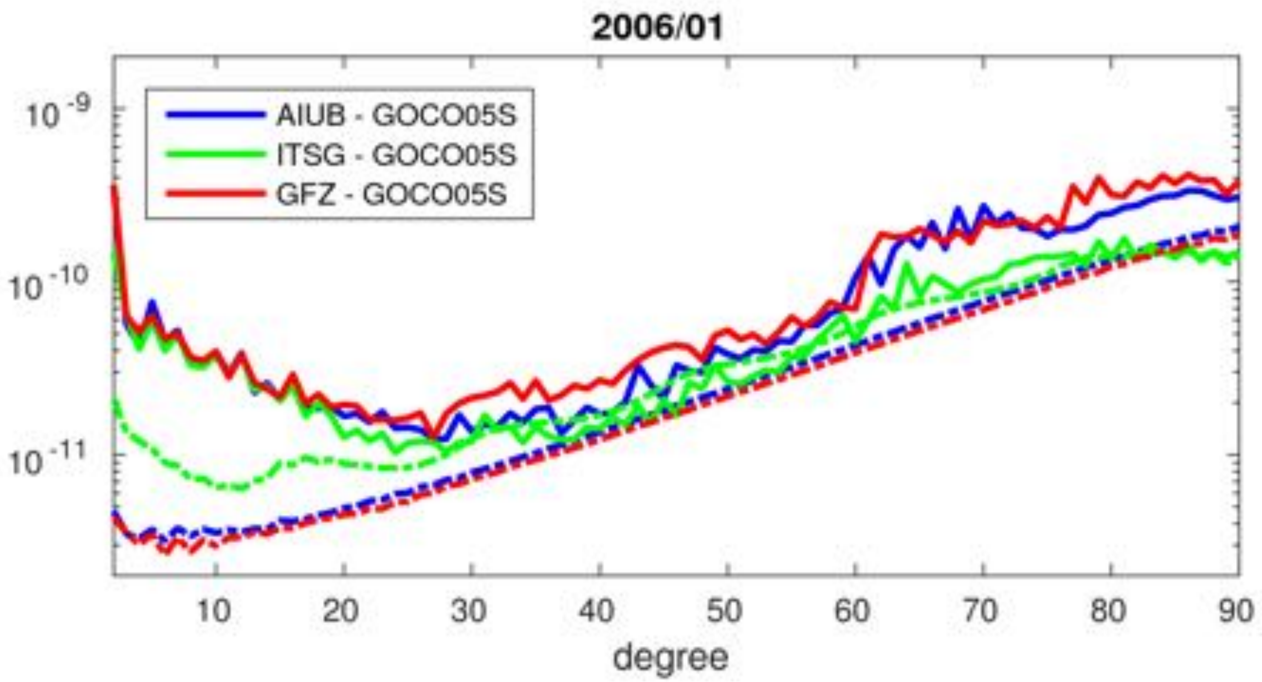
- **AIUB:** Celestial mechanics approach (dynamic approach relying on frequent pseudo-stochastic accelerations)
  - **approx. 500000 KRR observations and**
  - **500000 kinematic positions (30s) / month**

Individual Contributions: ITSG



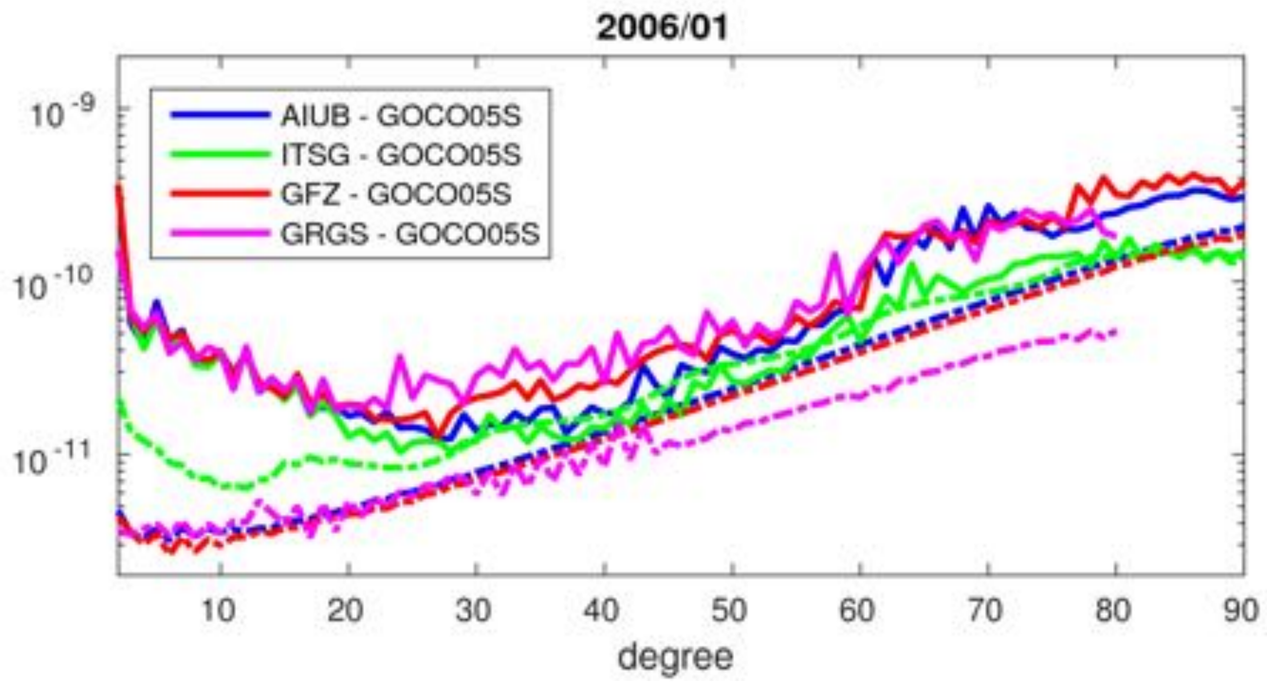
- **ITSG:** originally short arc approach, empirical noise model
  - **approx. 500000 KRR observations and**
  - **50000 kinematic positions (300s) / month**

Individual Contributions: GFZ



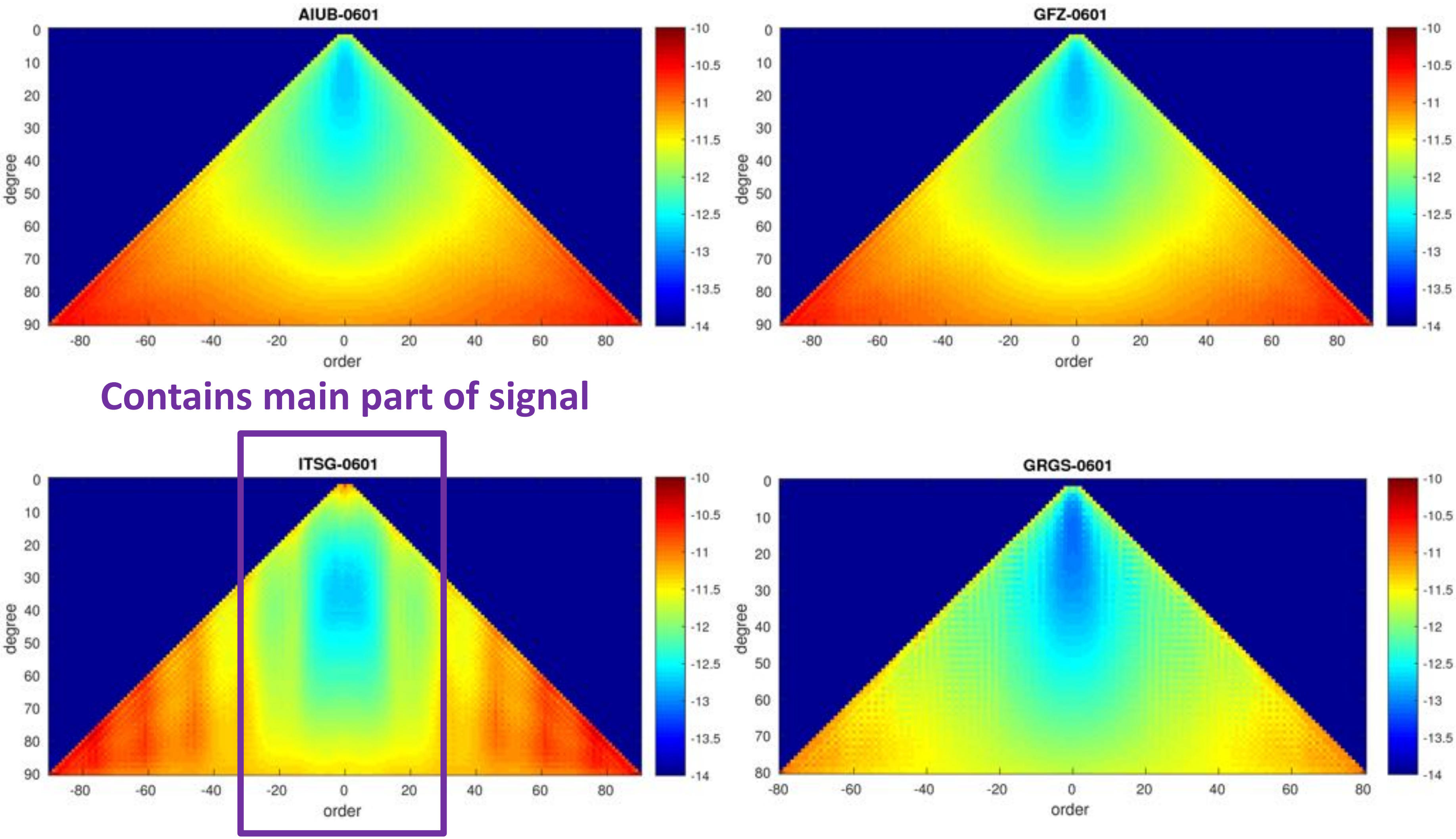
- **GFZ:** dynamic approach, dense accelerometer parametrization
  - **approx. 500000 KRR observations and**
  - **approx. 2500000 GPS observations / month**

Individual Contributions: GRGS



- **GRGS:** magic approach
  - **approx. 500000 KRR observations and**
  - **approx. 2500000 GPS observations / month**

Formal errors: 2006/01



Variance Component Estimation

Iterative determination of weights:

$$w_{i,0} = 1 / \sigma_{i,0}^2 \; ; \; \sigma_{i,0}^2 = 1$$

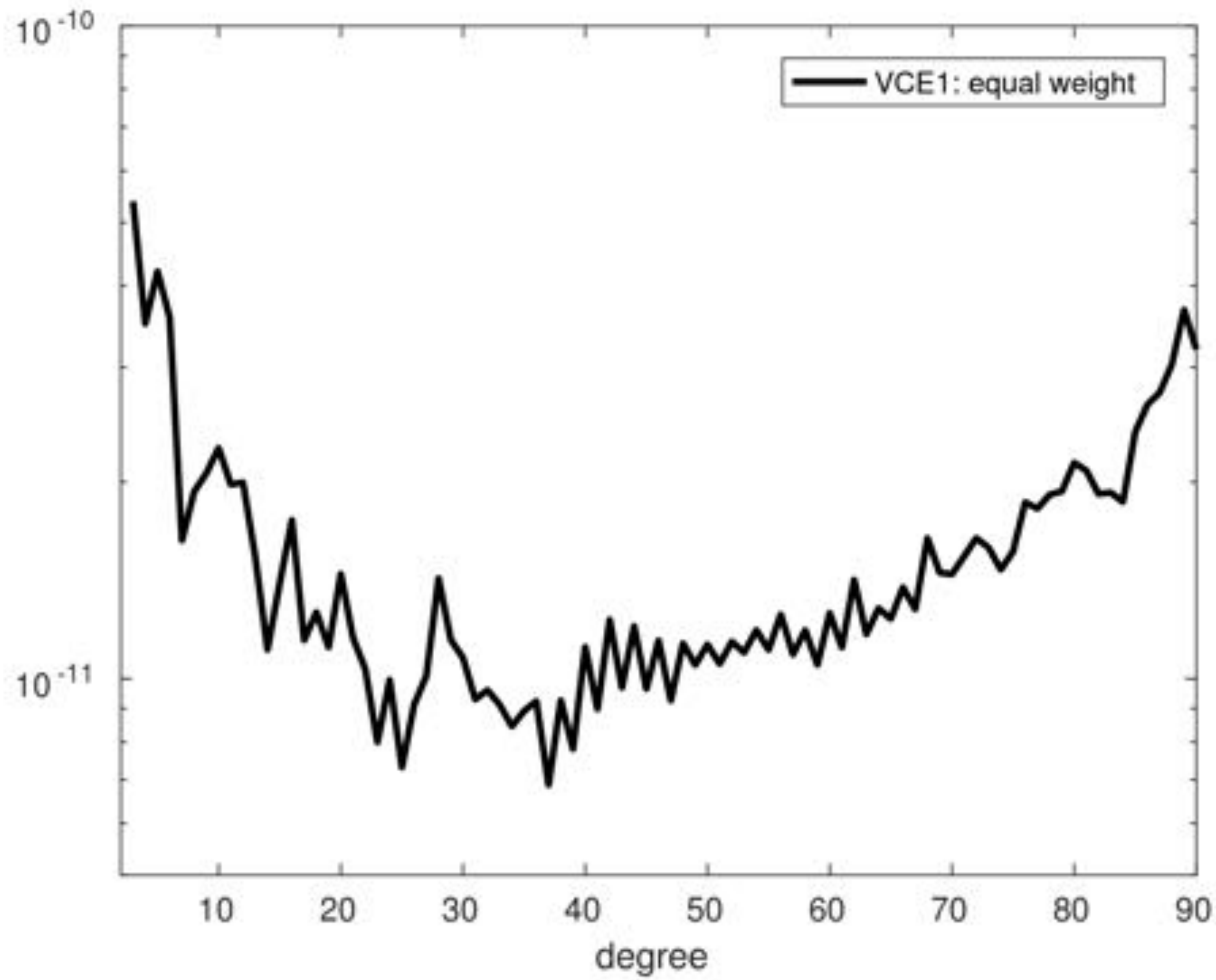
$$(\textstyle\sum_i w_{i,k} \mathbf{N}_i)\, \mathbf{dx} = \textstyle\sum_i w_{i,k} \mathbf{b}_i \; ; \; \mathbf{l}_{i,k}^T \mathbf{P}_{i,k} \mathbf{l}_{i,k} = w_{i,k} \mathbf{l}_i^T \mathbf{P}_i \mathbf{l}_i$$

$$\sigma_{i,k+1}^2 = \mathbf{v}_{i,k}^T \mathbf{P}_i \mathbf{v}_{i,k} / r_i$$

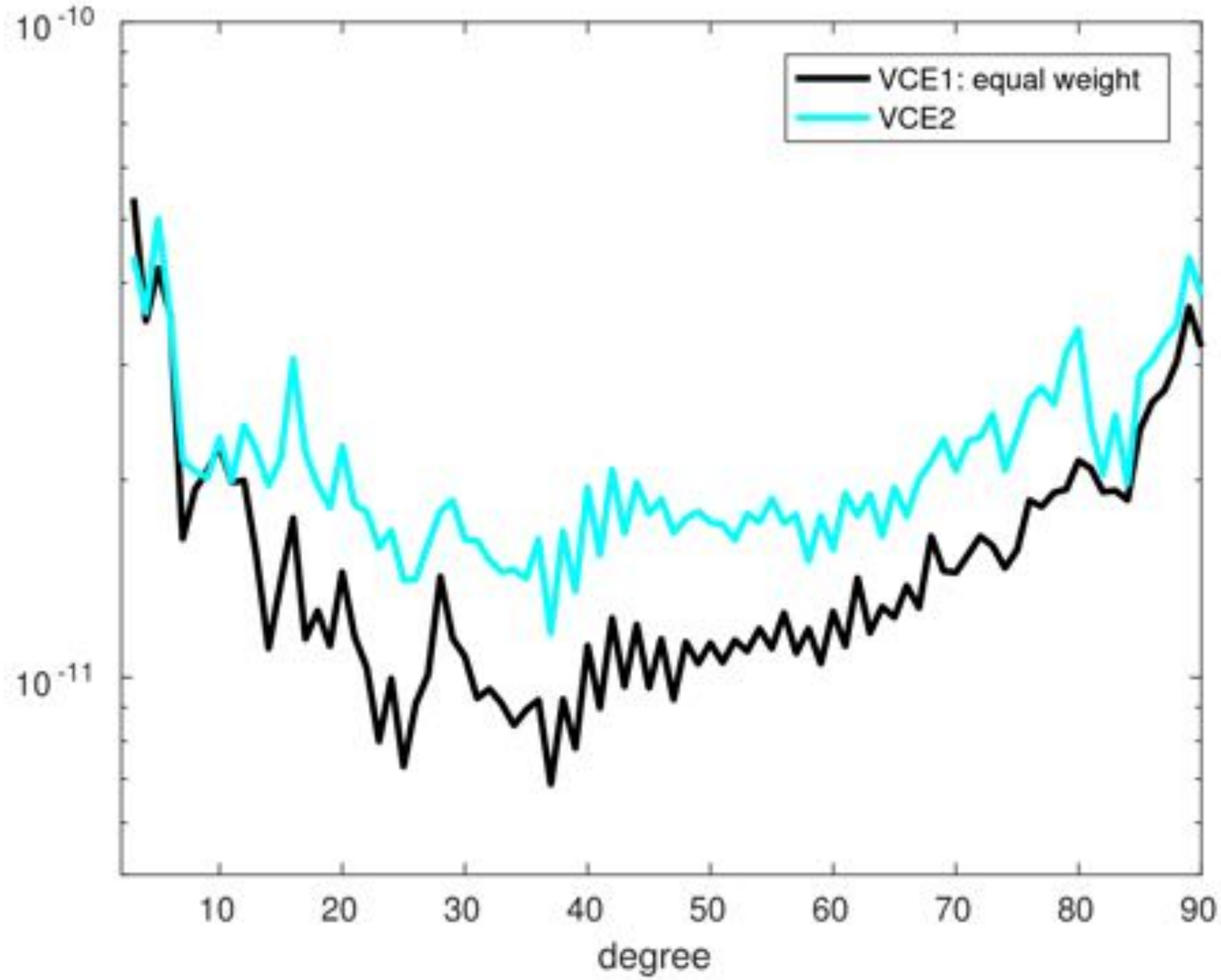
Square sum of residuals: $\mathbf{v}_{i,k}^T \mathbf{P}_i \mathbf{v}_{i,k} = \mathbf{l}_i^T \mathbf{P}_i \mathbf{l}_i - \mathbf{b}_i^T \mathbf{dx}_k$

Partial redundancy: $r_i = n_i - m$

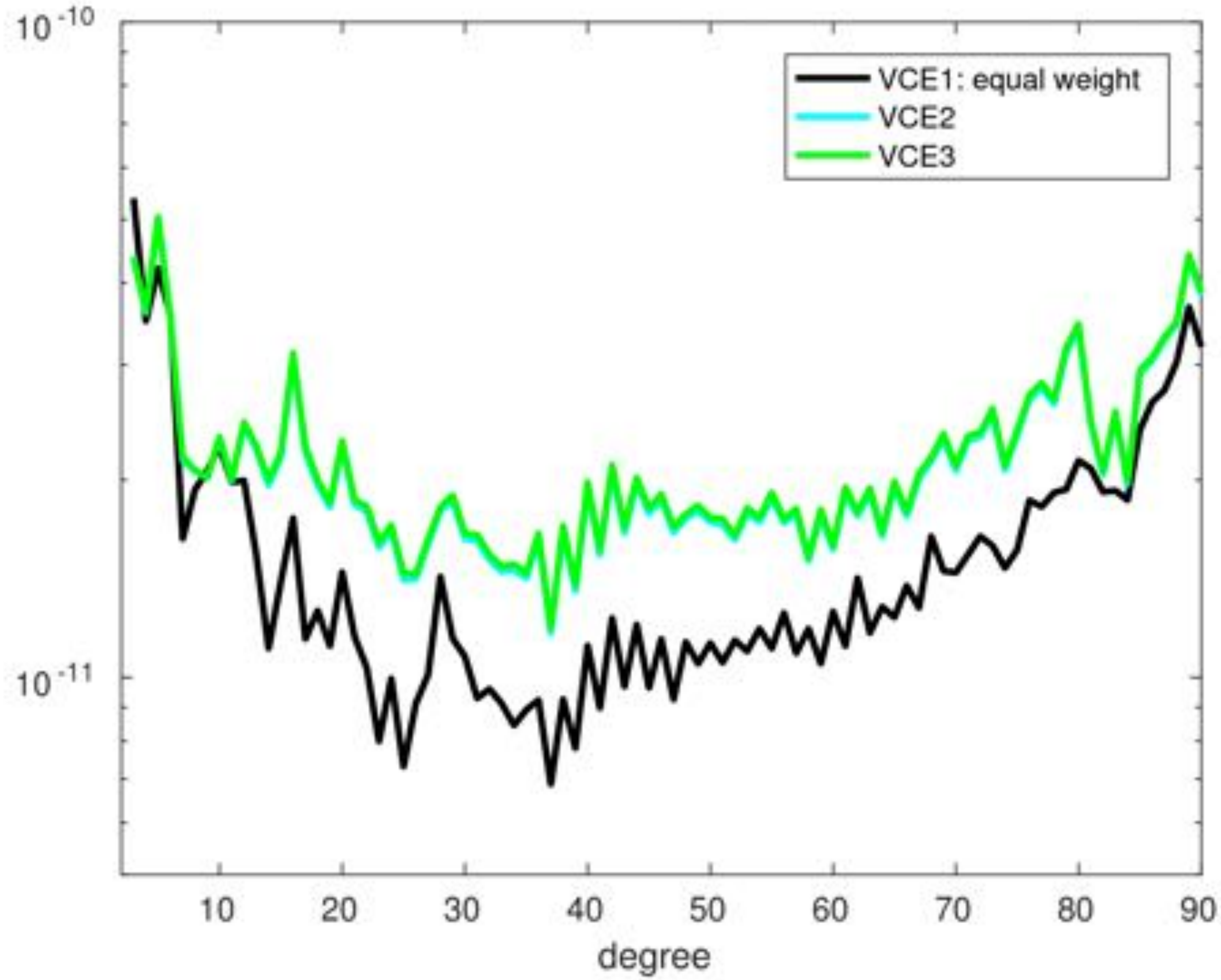
Variance Component Estimation (0)



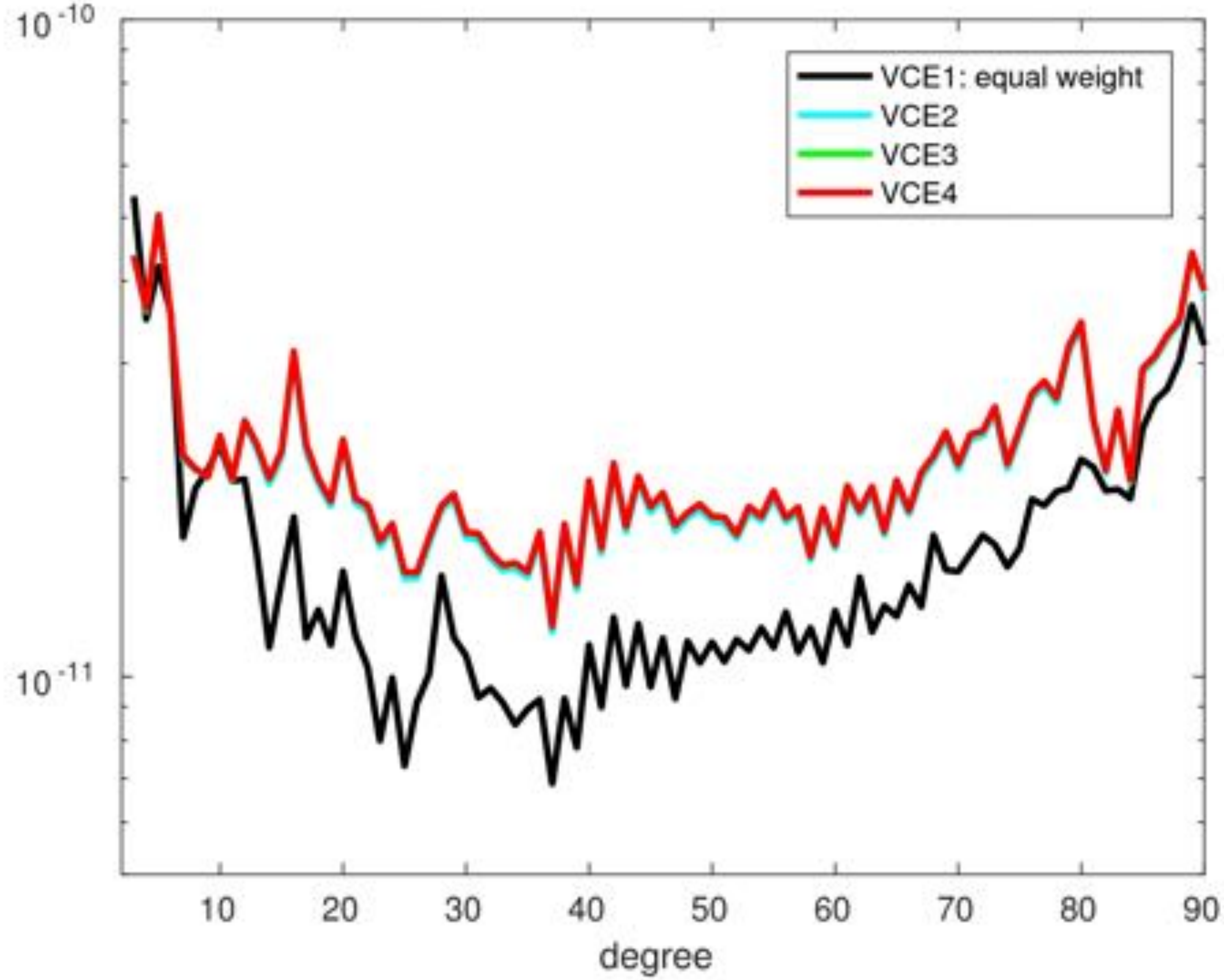
Variance Component Estimation (1)



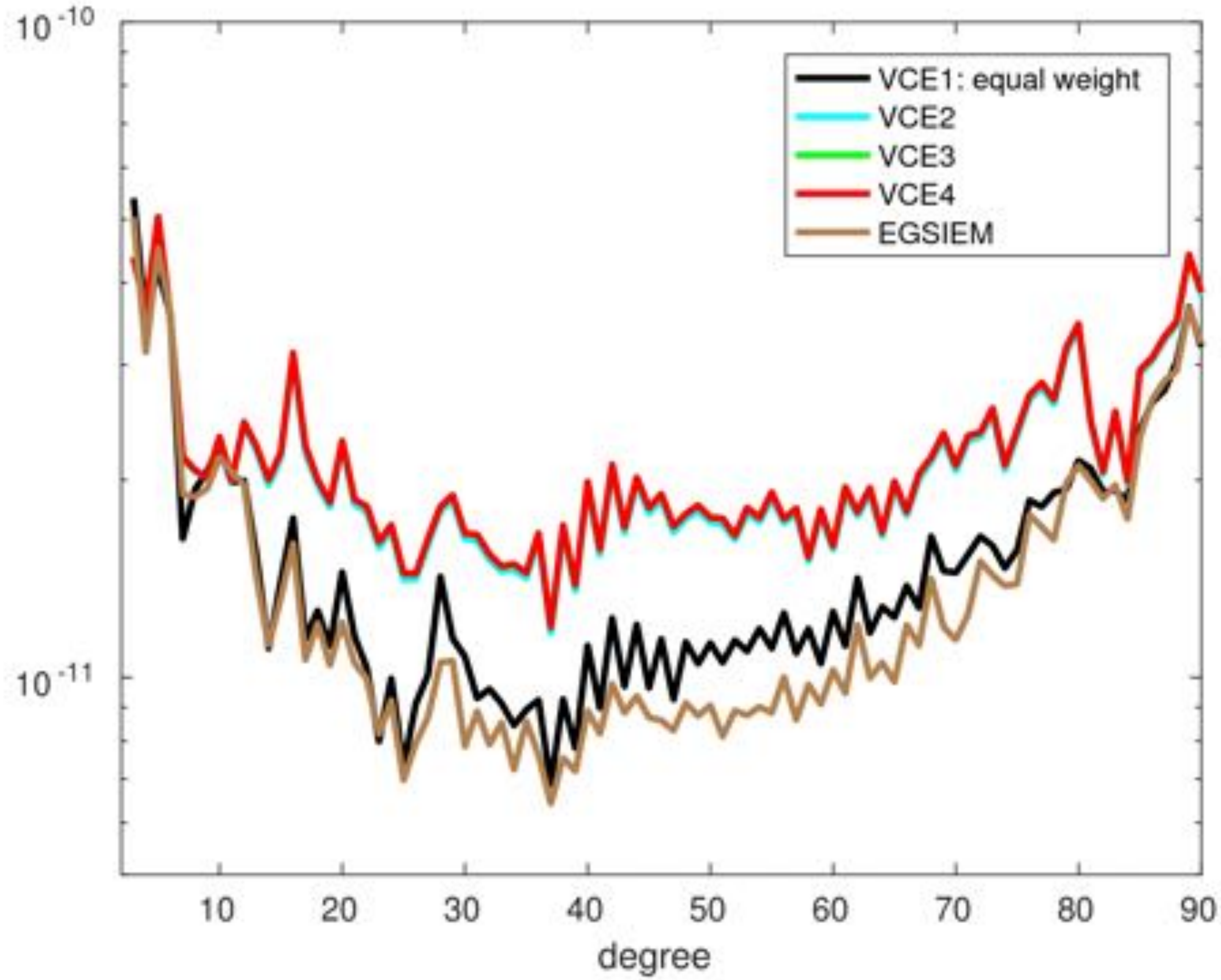
Variance Component Estimation (2)



Variance Component Estimation (3)

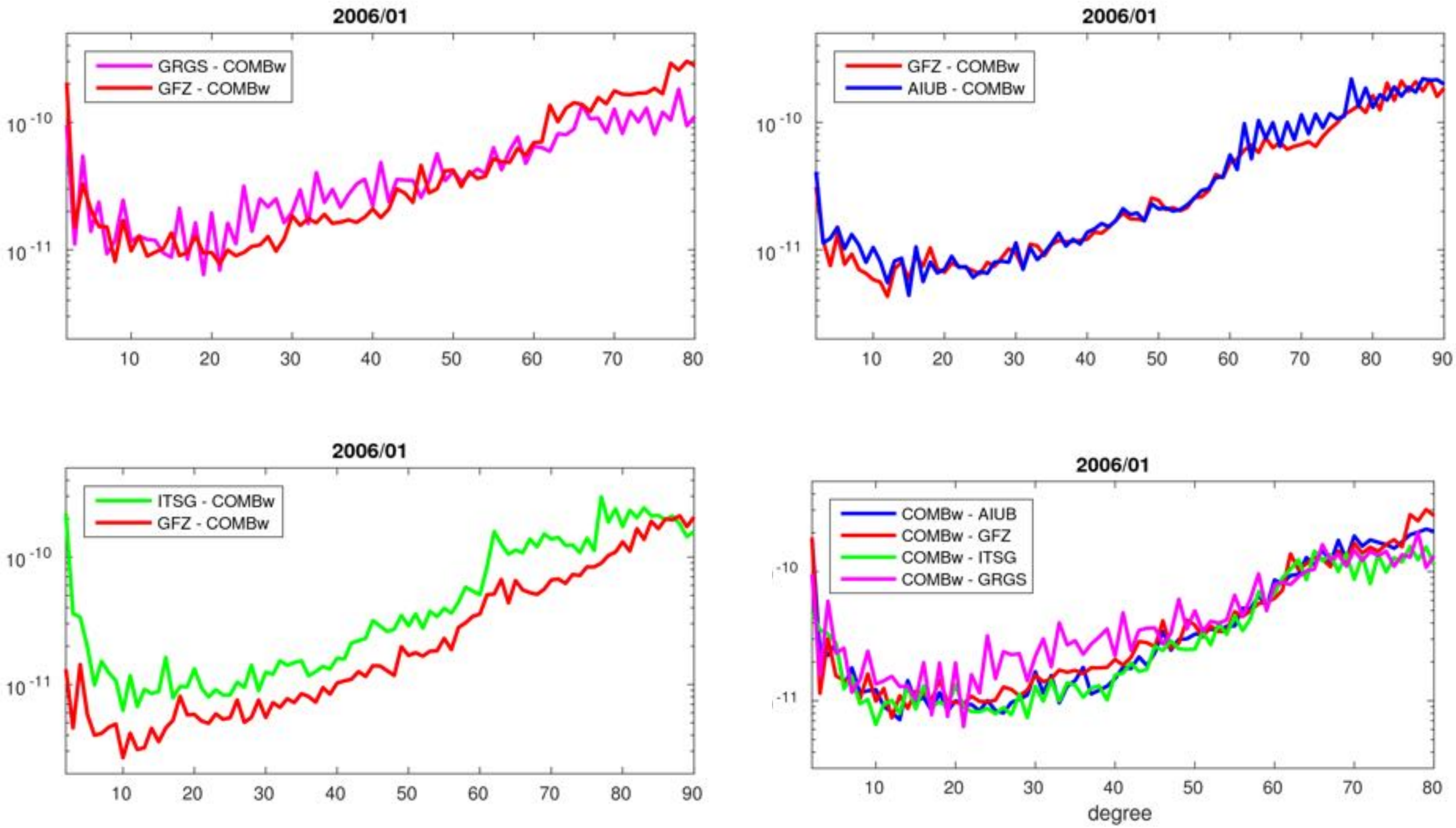


Variance Component Estimation (4)



VCE	weight
GRGS	3.23
GFZ	0.87
AIUB	5.88
ITSG	1.08

Individual contributions (variance factors): 2006/01



Empirical rescaling to achieve equal impact

A straight-forward empirical approach is to search for weights w_i that equalize the impact of individual contributions on pairwise combinations:

$$(\mathbf{N}_{ref} + w_i\, \mathbf{N}_i)\, \mathbf{dx} = \mathbf{b}_{ref} + w_i\, \mathbf{b}_i$$

The impact is measured by:

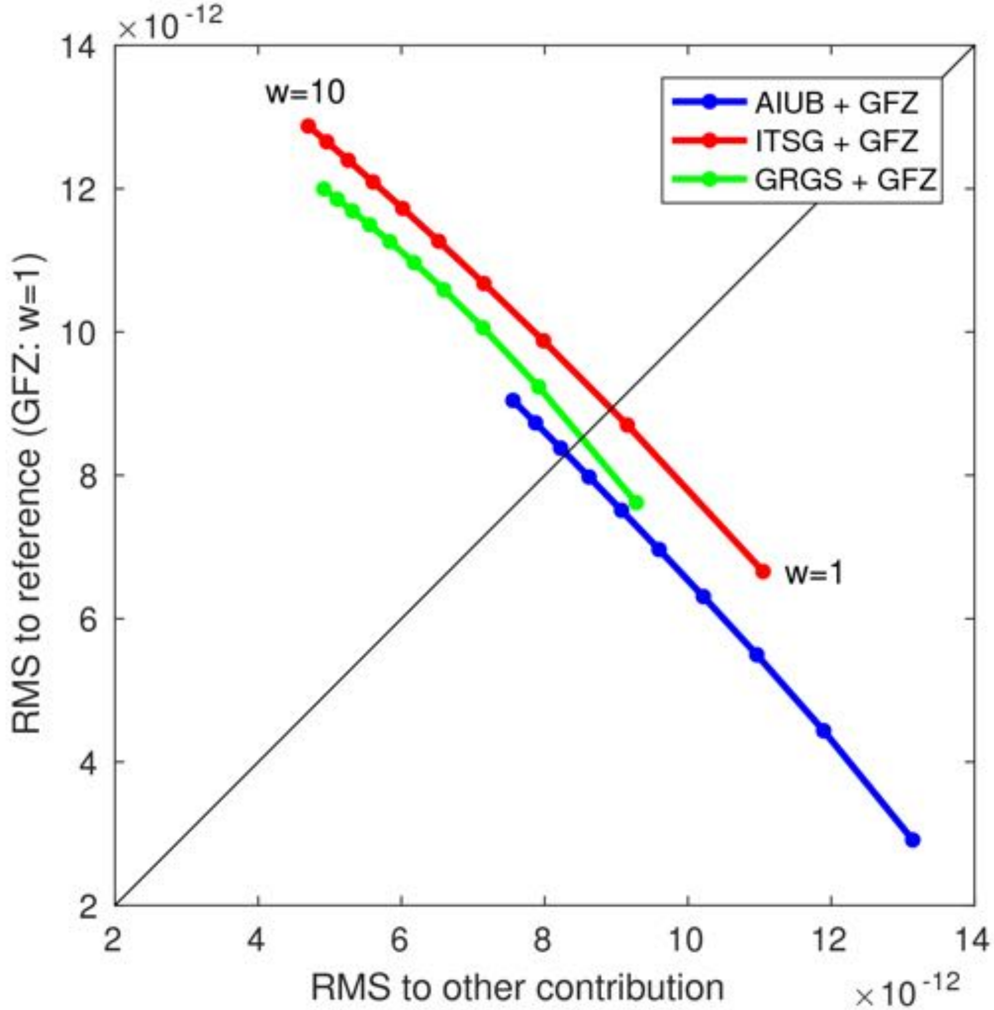
$$RMS_i = SQRT(\sum_{l,m}(K_{l,m}{}^{comb} - K_{l,m}{}^{i})^2/n_{coef})$$

Equal impact is achieve for:

$$RMS_i/RMS_{ref} = 1$$

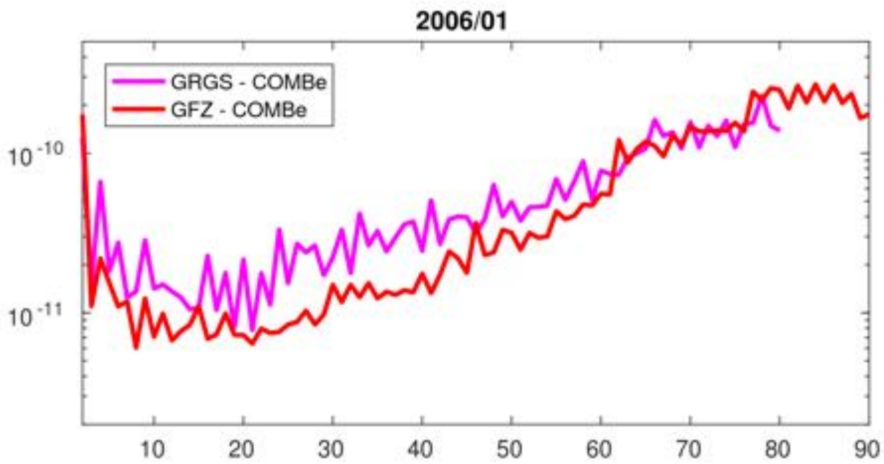
Consequently weights derived on solution level are applied.

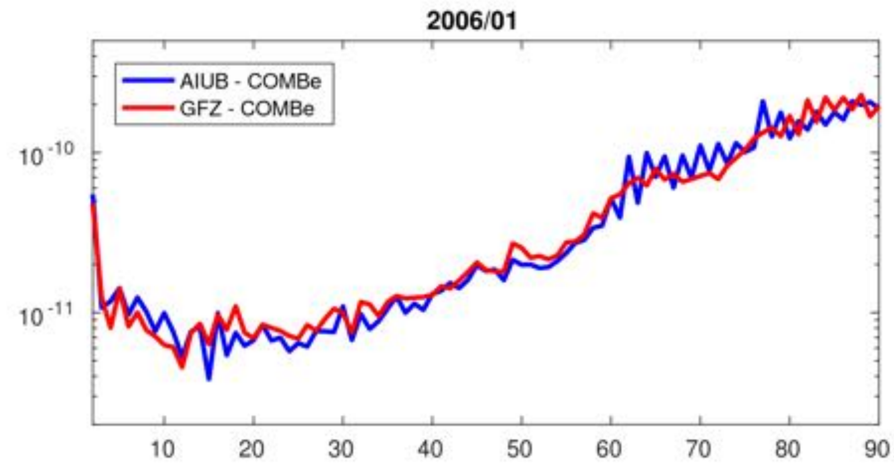
Empirical rescaling to achieve equal impact

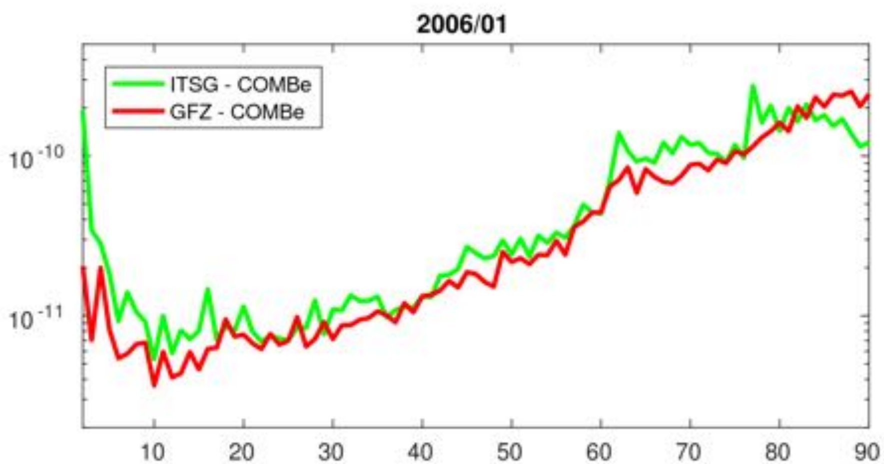


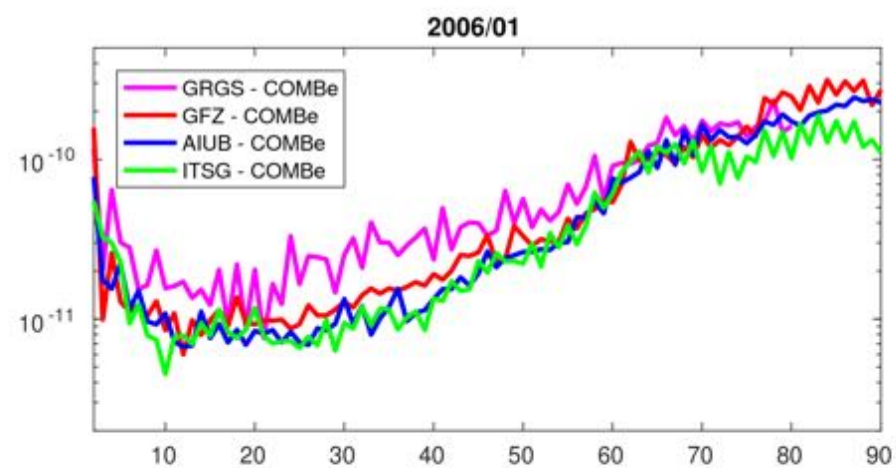
equalizing weight	
GRGS	1.60
GFZ	1.00
AIUB	7.81
ITSG	2.21

Individual contributions (equalized): 2006/01

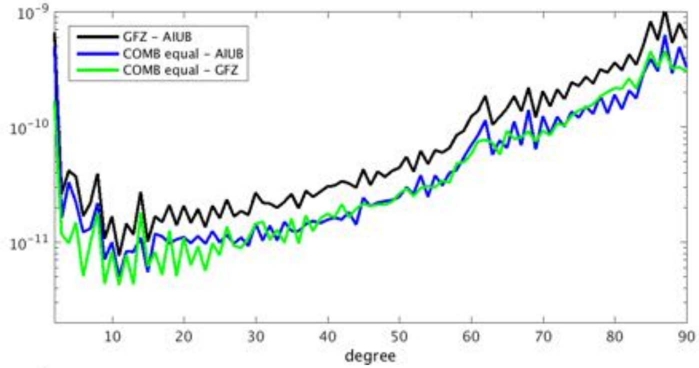


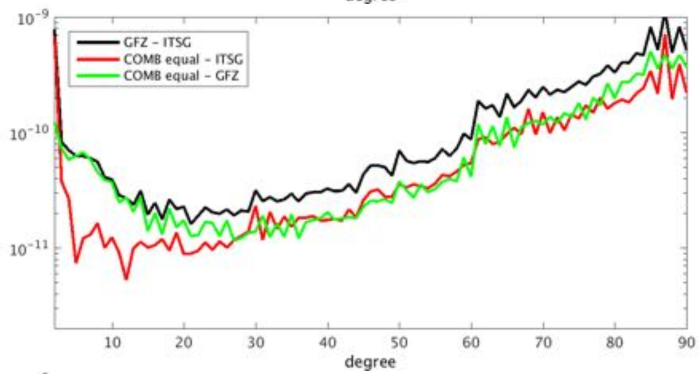


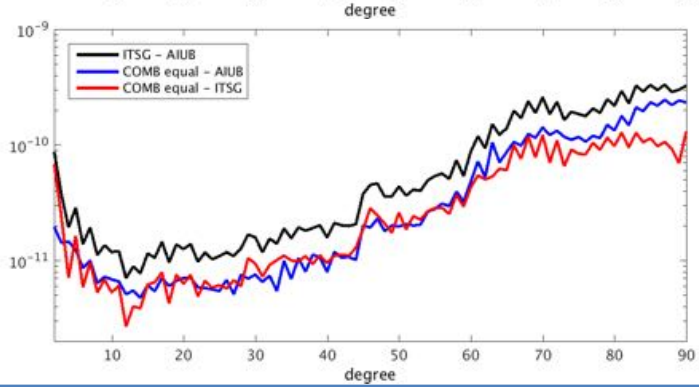


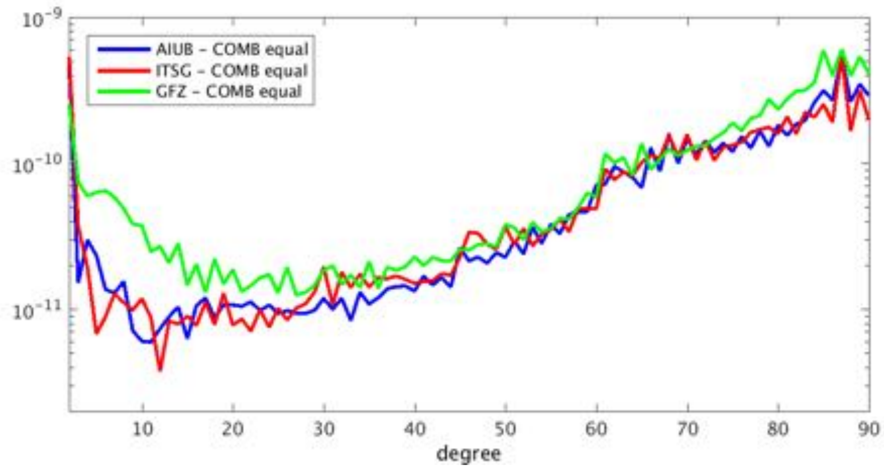


# Equal contribution by empirical weighting

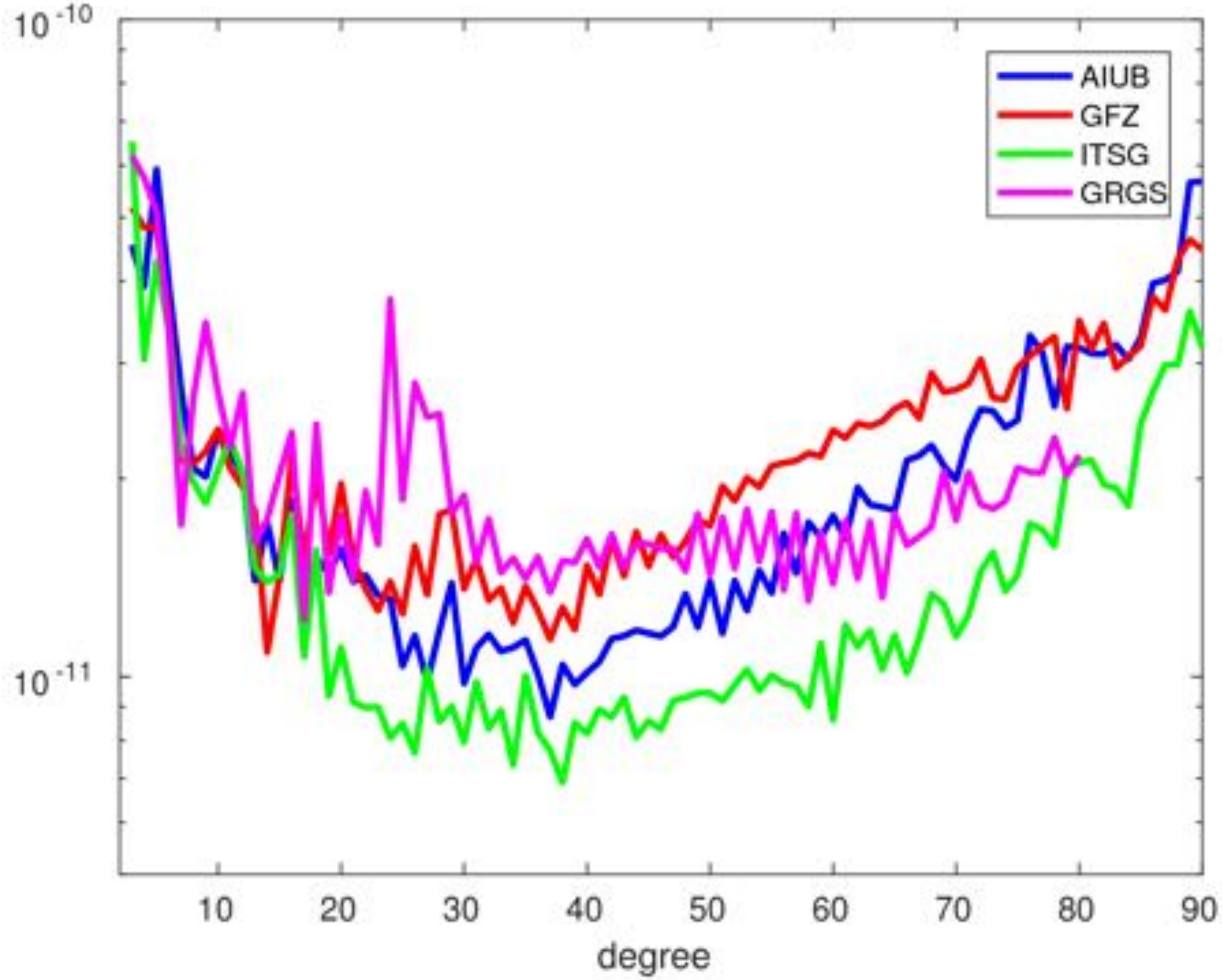




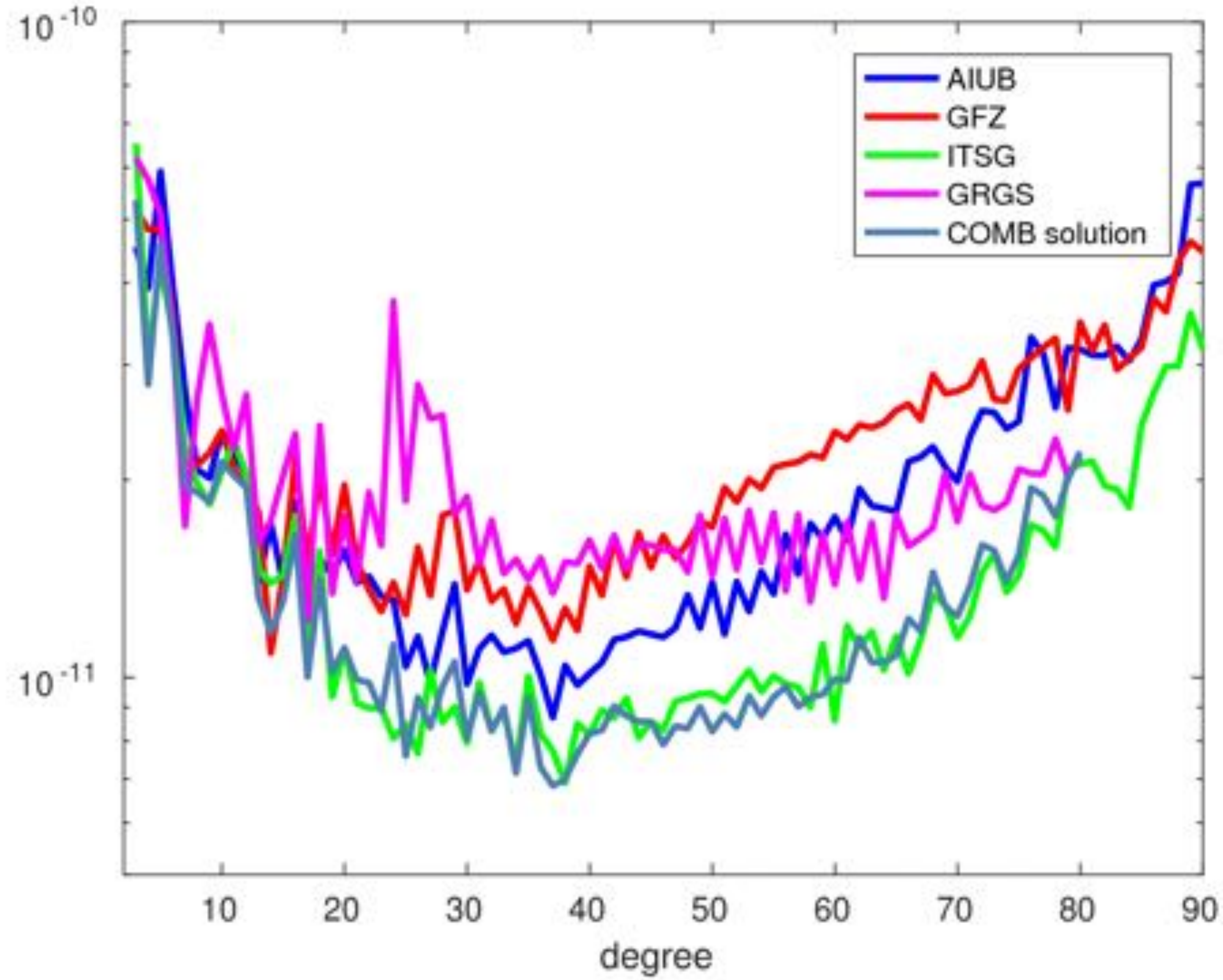




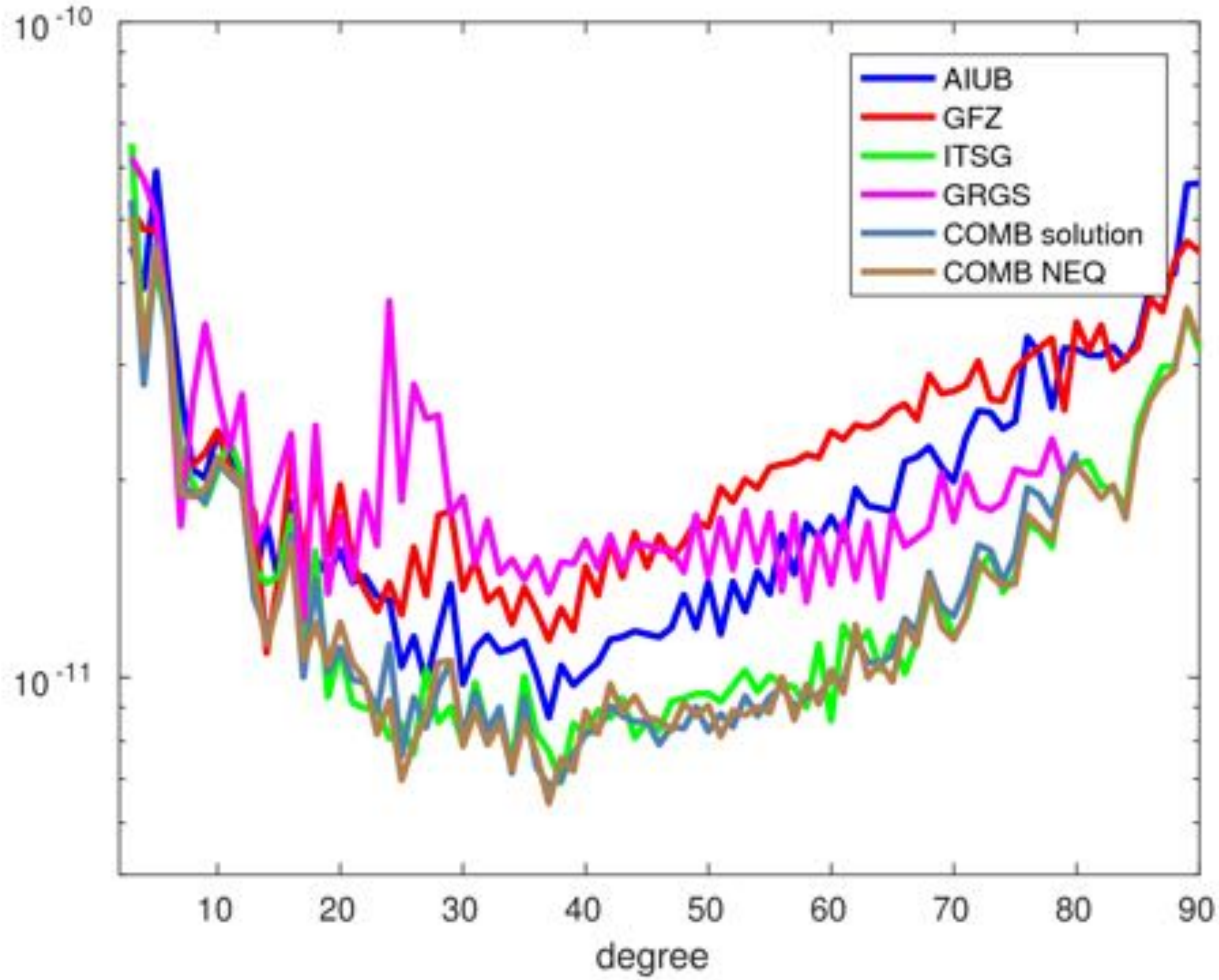
Individual Solutions 2006/01



Weighted Combination on Solution Level



Weighted Combination on NEQ-level



equalizing weight	
GRGS	1.60
GFZ	1.00
AIUB	7.81
ITSG	2.21

Solution:	weight
GRGS	0.14
GFZ	0.19
AIUB	0.29
ITSG	0.38

Weighting schemes: comparison

equal

GRGS	0.25
GFZ	0.25
AIUB	0.25
ITSG	0.25

VCE

GRGS	0.29
GFZ	0.08
AIUB	0.53
ITSG	0.10

=

equalizing

GRGS	0.13
GFZ	0.08
AIUB	0.62
ITSG	0.17

* **VCE**

GRGS	0.49
GFZ	0.21
AIUB	0.18
ITSG	0.12

=

GRGS	0.29
GFZ	0.08
AIUB	0.53
ITSG	0.10

* **solution level**

GRGS	0.14
GFZ	0.19
AIUB	0.29
ITSG	0.38

=

GRGS	0.07
GFZ	0.05
AIUB	0.65
ITSG	0.23

Combination on Normal Equation Level

What can we do to a normal equation without changing the individual solution:

$$\mathbf{N}\,\mathbf{dx} = \mathbf{b}\ ;\ \mathbf{x} = \mathbf{x}_0 + \mathbf{dx}$$

Scalar scaling: $f\,\mathbf{N}\,\mathbf{dx} = f\,\mathbf{b}$

Matrix scaling: $\mathbf{F}^T\,\mathbf{N}\,\mathbf{F}\,\mathbf{F}^{-1}\,\mathbf{dx} = \mathbf{F}^T\,\mathbf{b}\ ;\ \mathbf{x}_0' = \mathbf{F}^{-1}\,\mathbf{x}_0$

Transformation to different a priori values:

$$\mathbf{x}_0' = \mathbf{x}_0 + \mathbf{dx}_0\ ;\ \mathbf{N}\,(\mathbf{dx} - \mathbf{dx}_0) = \mathbf{b} - \mathbf{N}\,\mathbf{dx}_0$$

Rescaling of formal errors

Cofactor matrix: $\mathbf{Q}' = \mathbf{S\ Q\ S}$; $s_{ii} = \sigma_{ii} / \sigma_{ii,ref}$; $s_{ij} = 0$

Normal matrix: $\mathbf{F}^T \mathbf{N\ F} = (\mathbf{S\ Q\ S})^{-1}$

Cholesky decomposition: $\mathbf{N} = \mathbf{G\ G}^T$

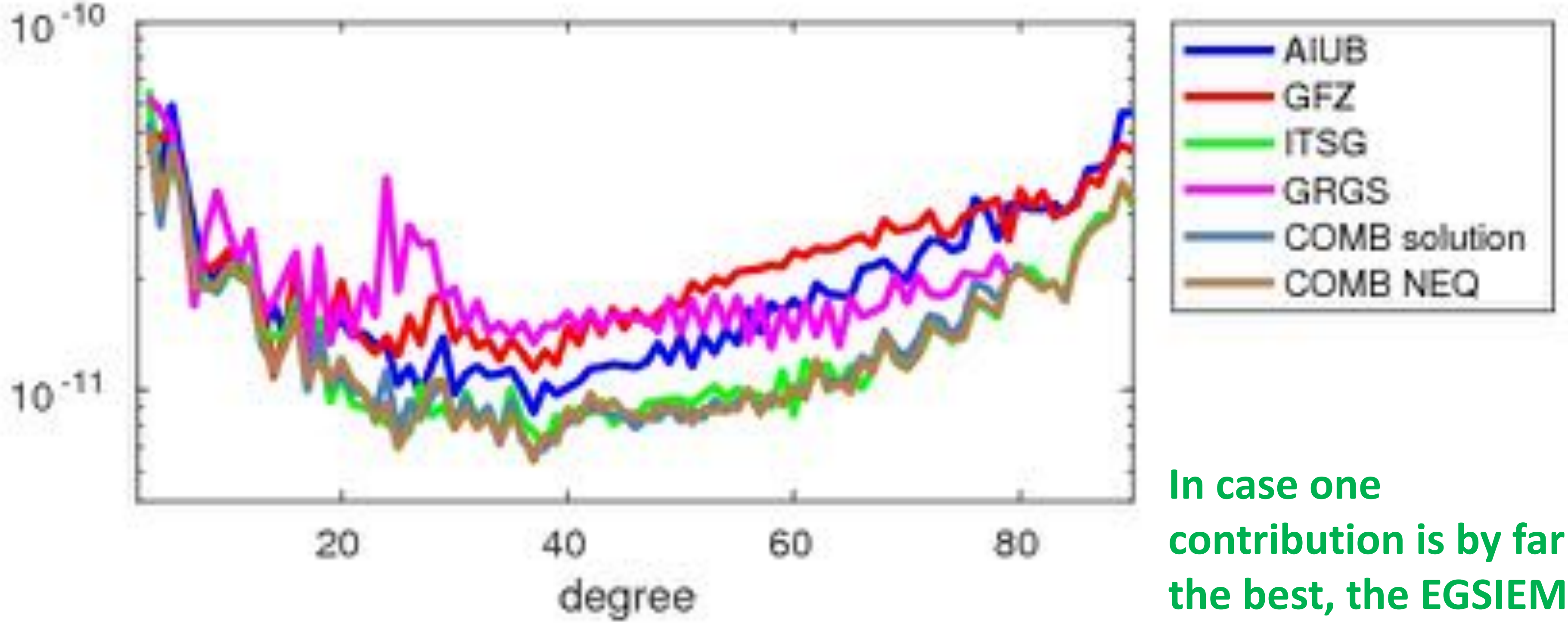
$(\mathbf{S\ Q\ S})^{-1} = \mathbf{H\ H}^T$

$$\mathbf{F}^T \mathbf{G\ G}^T \mathbf{F} = \mathbf{H\ H}^T \quad \Rightarrow \quad \mathbf{F}^T = \mathbf{H\ G}^{-1}$$

Resulting NEQ: $\mathbf{N}'\ \mathbf{dx}' = \mathbf{b}'$

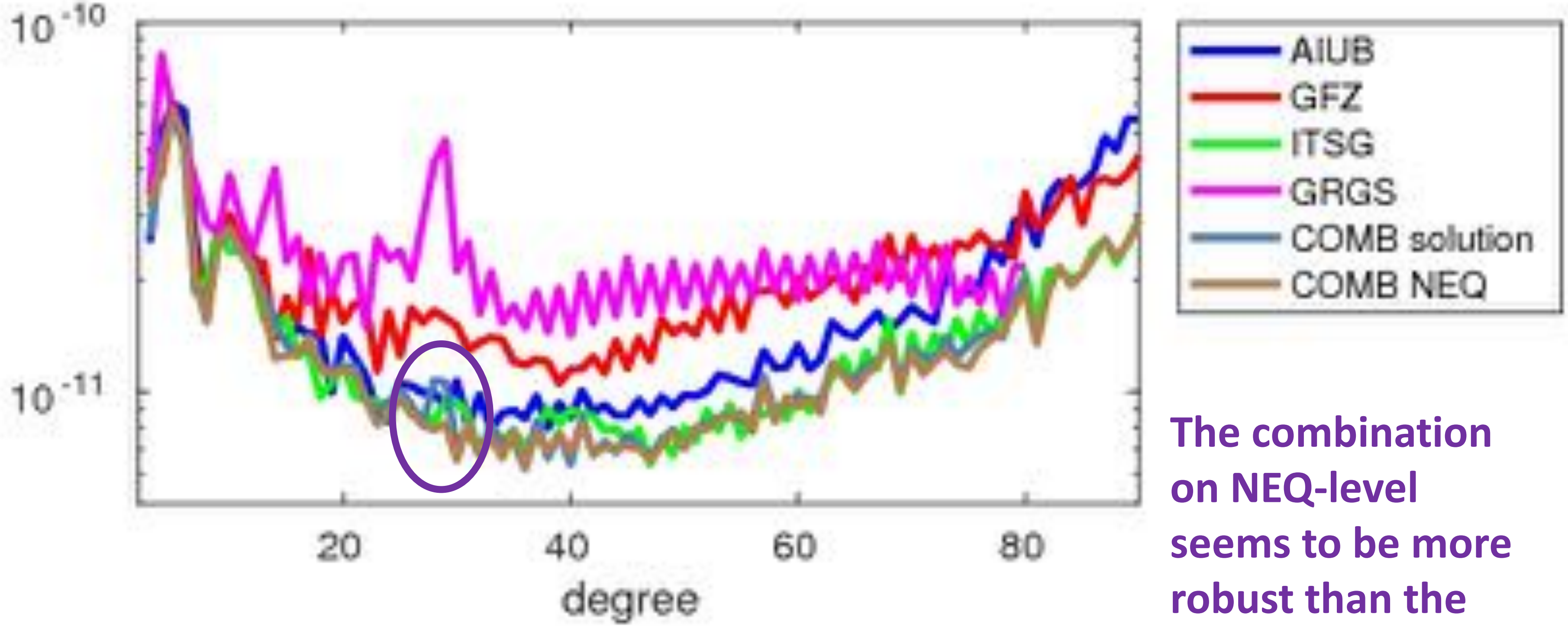
with $\mathbf{N}' = \mathbf{F}^T \mathbf{N\ F}$, $\mathbf{b}' = \mathbf{F}^T\mathbf{b}$, $\mathbf{dx}' = \mathbf{F}^{-1}\mathbf{dx}$ and $\mathbf{x_0}' = \mathbf{F}^{-1} \mathbf{x_0}$

2006/01



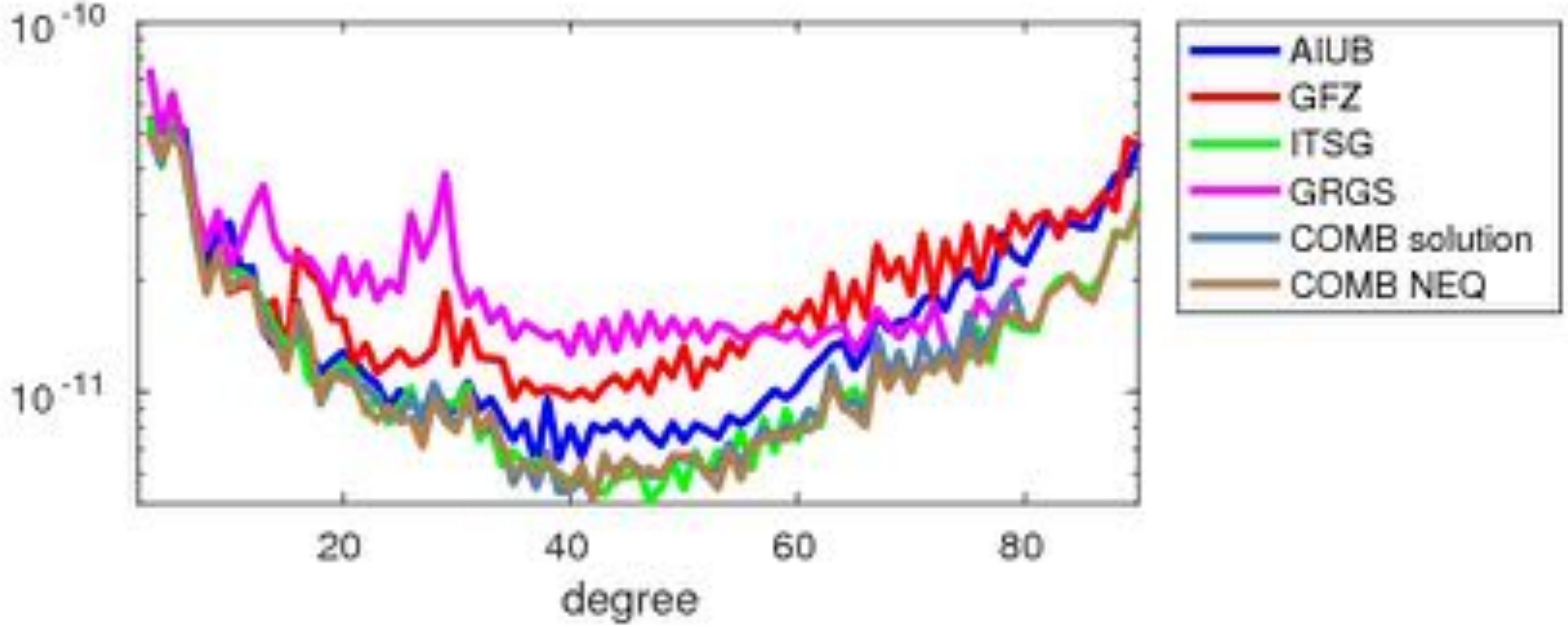
In case one contribution is by far the best, the EGSIEM-combinations are close to it.

2006/02



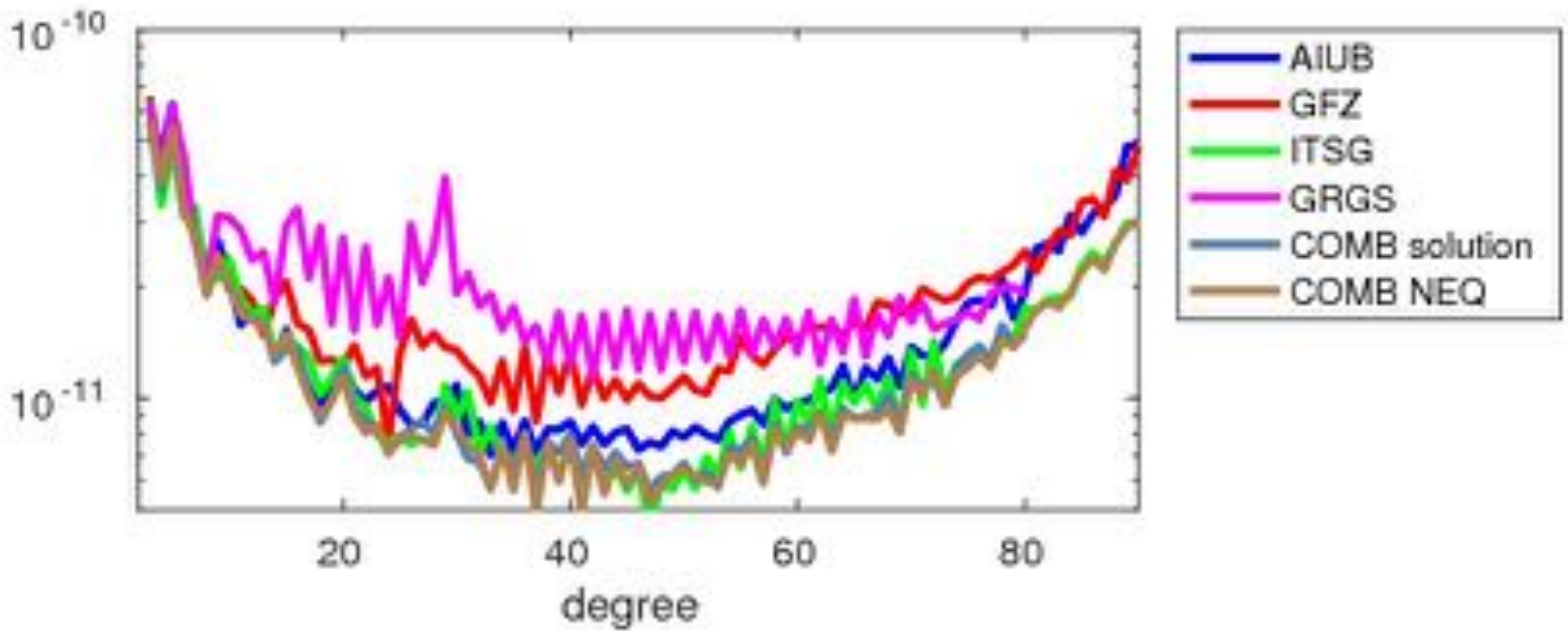
The combination on NEQ-level seems to be more robust than the combination on solution level.

2006/03



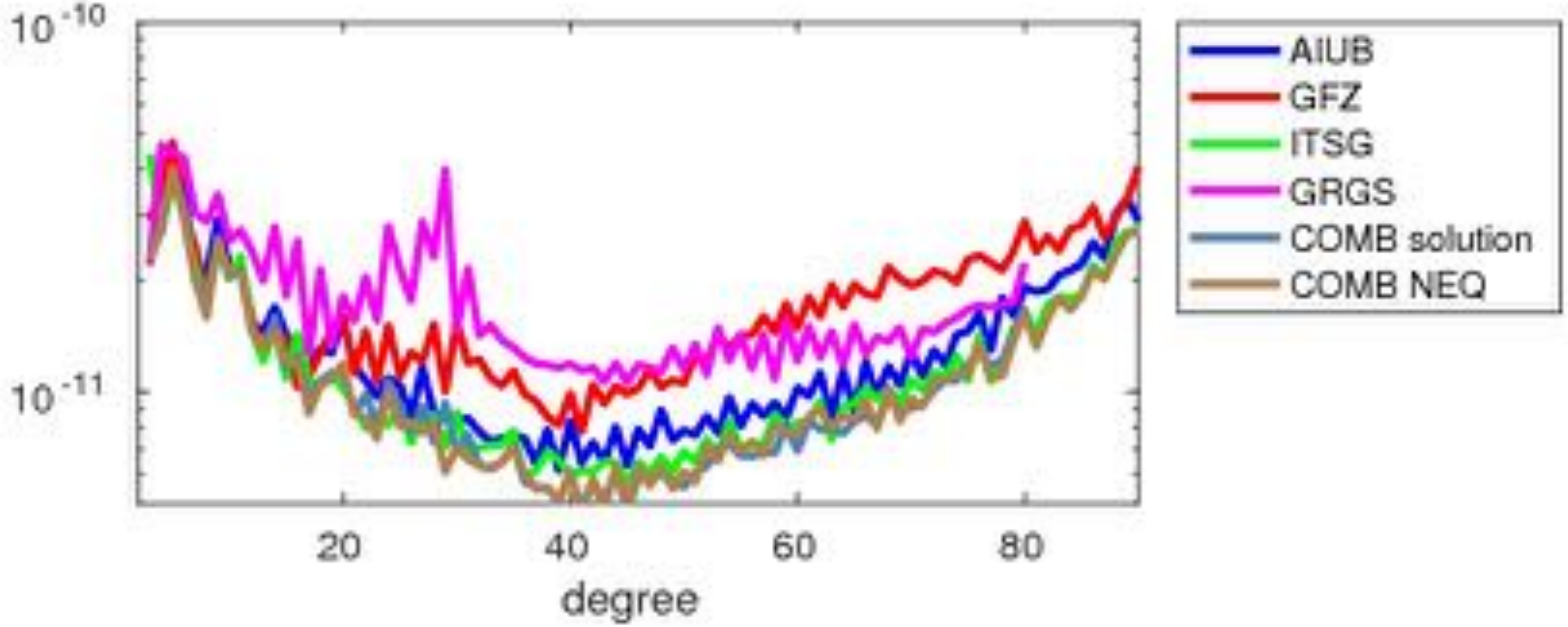
10^-10
10^-11
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2006/04

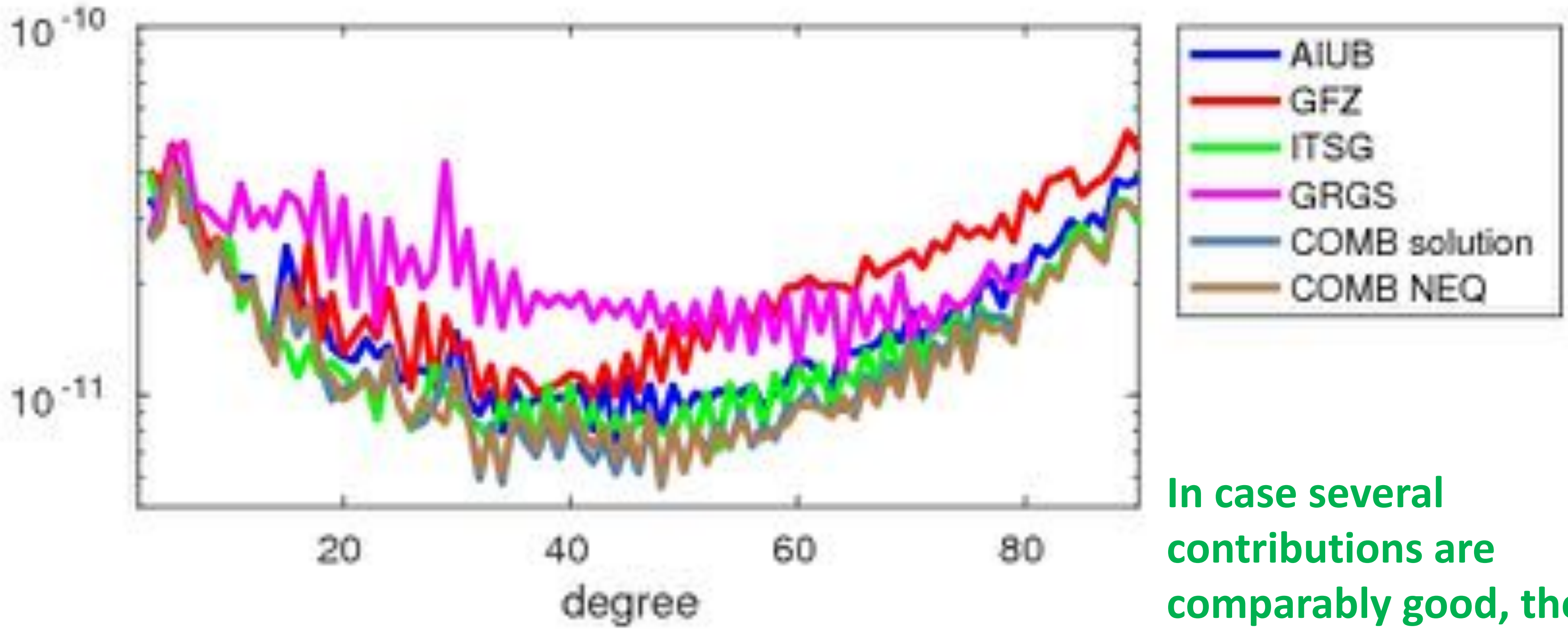


10^{-10}
10^{-11}
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2006/05

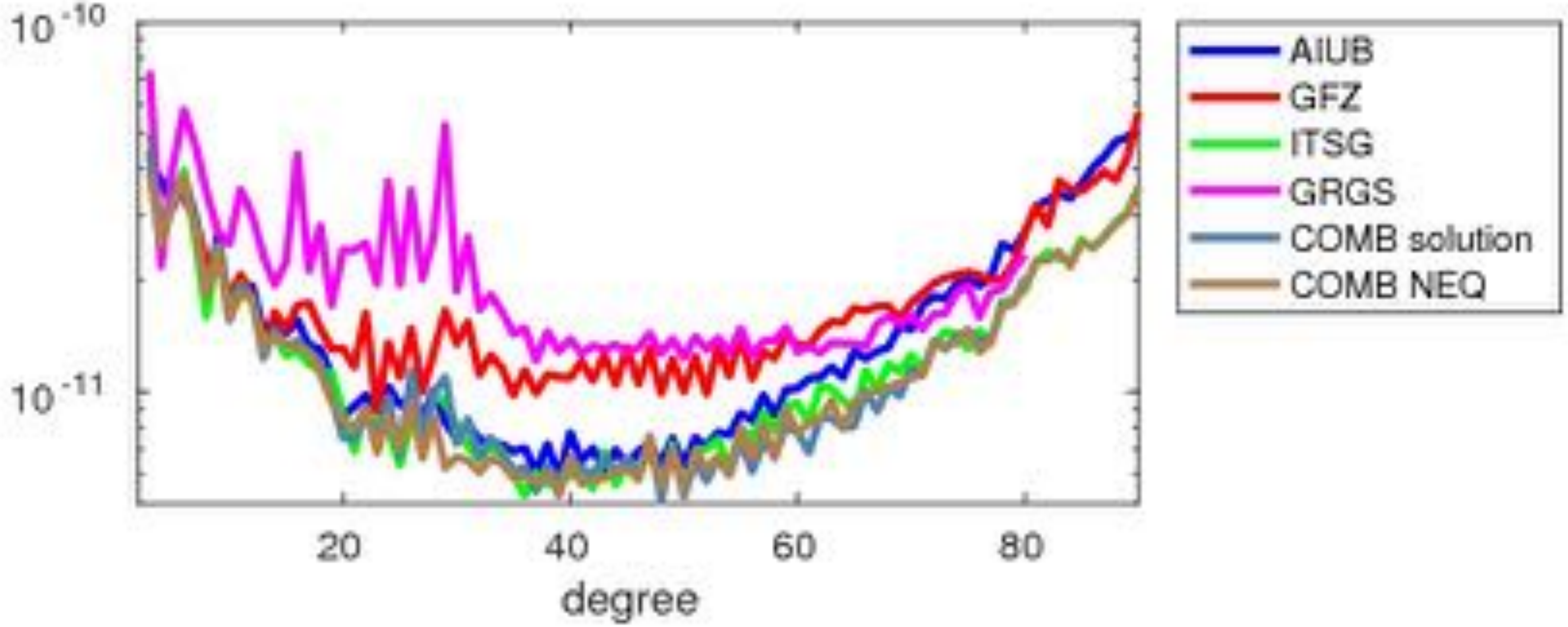

10^-10
10^-11
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2006/06



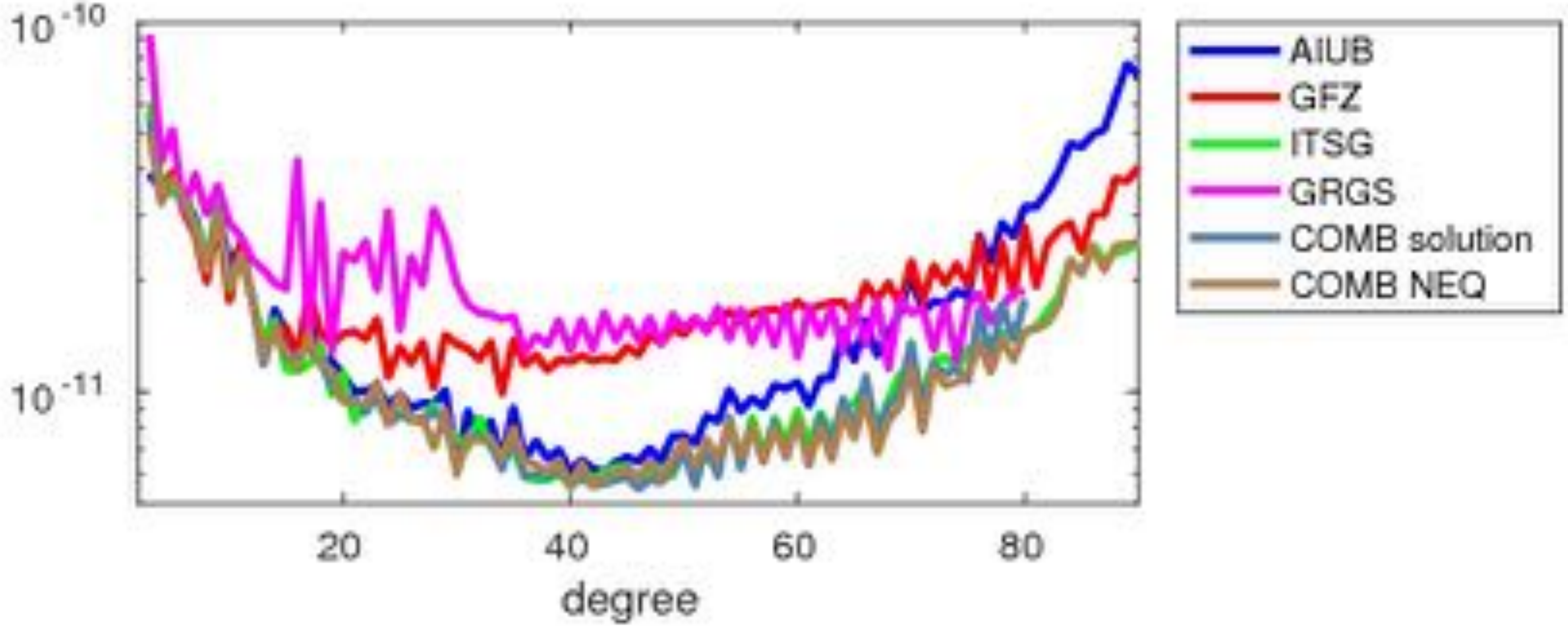
In case several contributions are comparably good, the EGSIEM-combinations are better!

2006/07



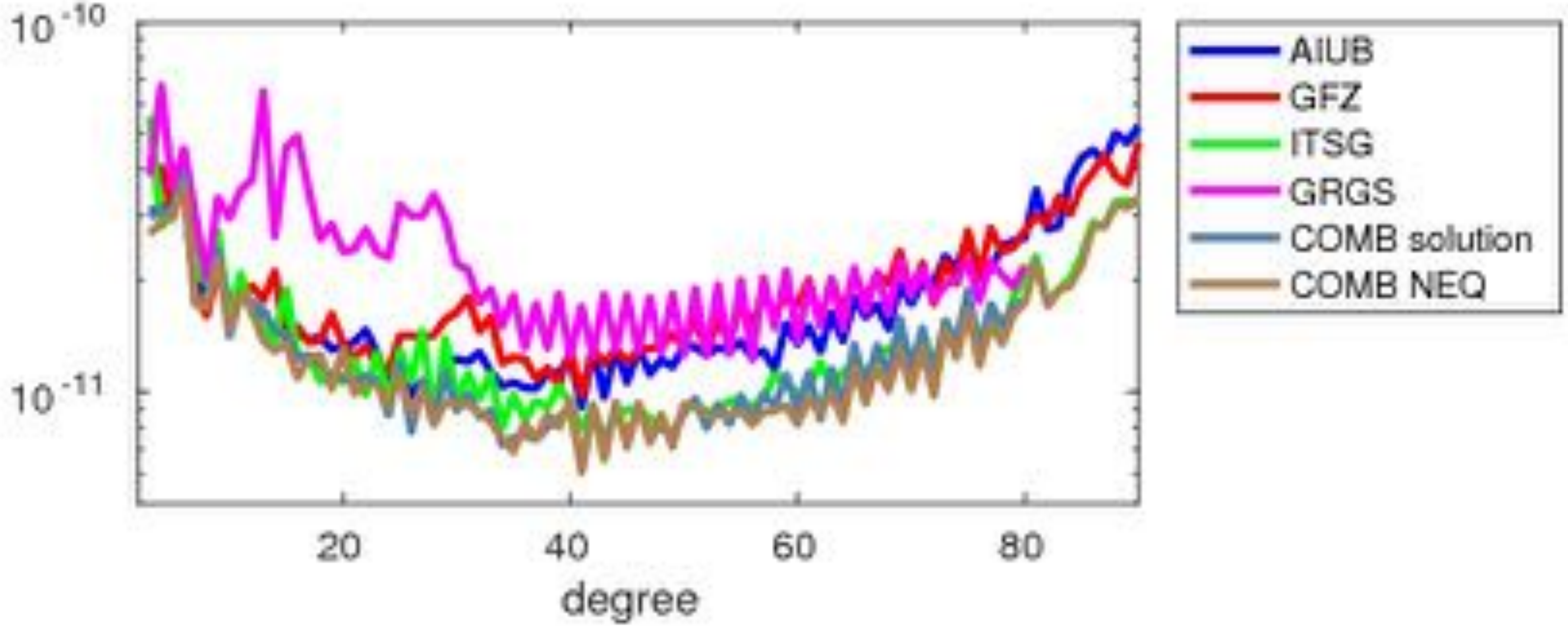
10^{-10}
10^{-11}
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2006/08



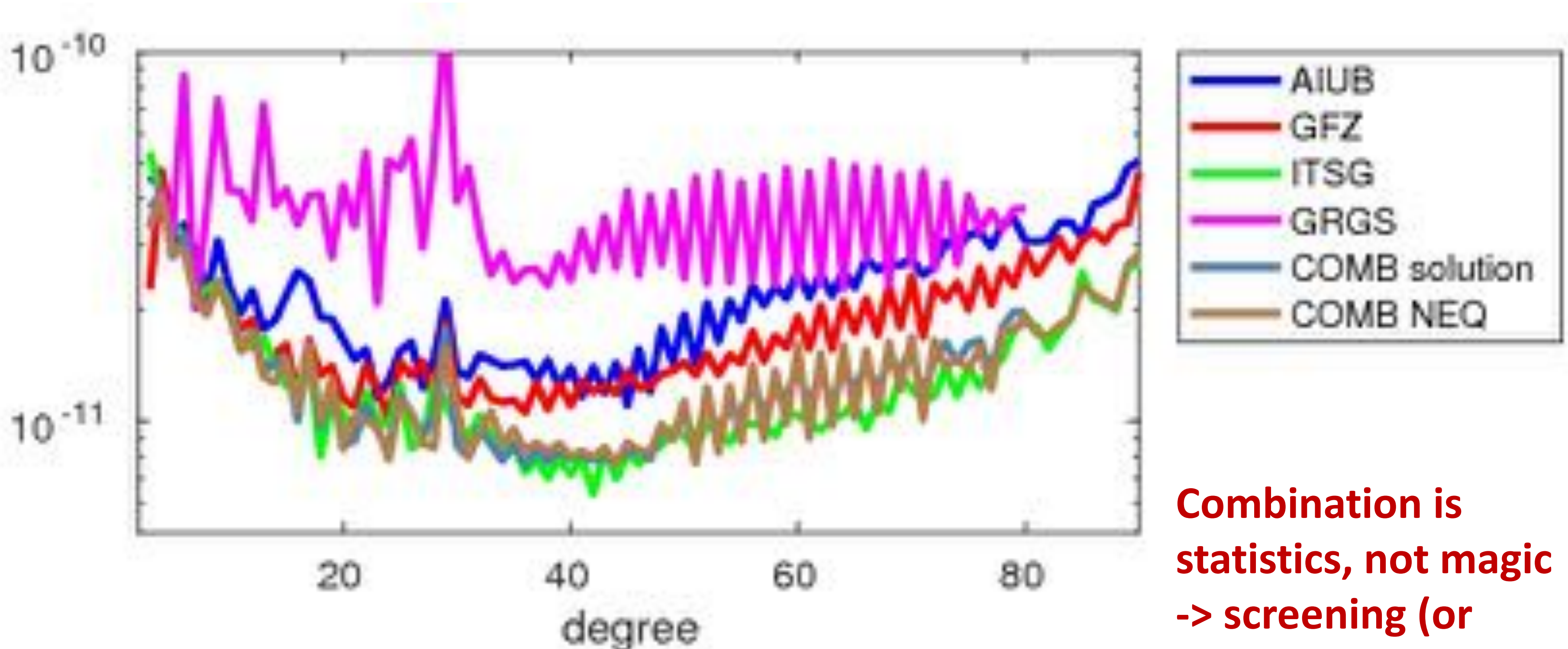
10^{-10}
10^{-11}
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2006/09



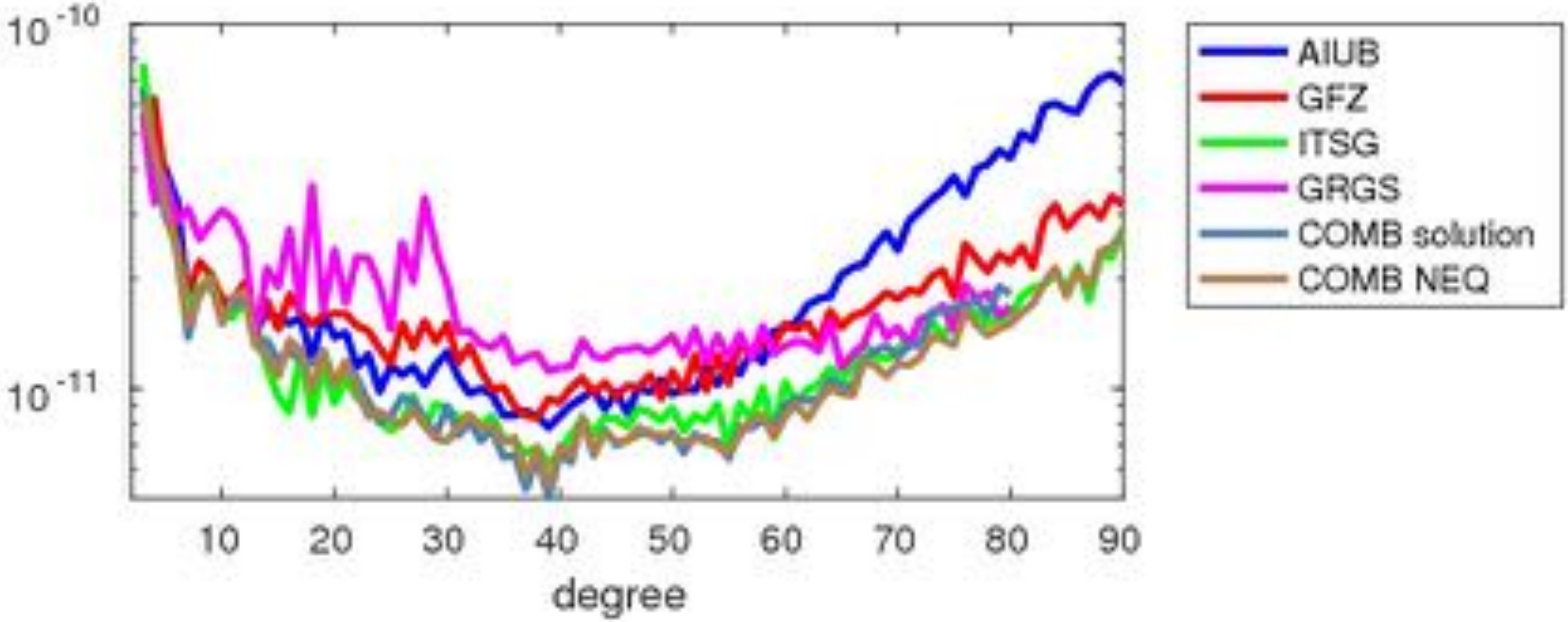
10^-10
10^-11
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2006/10



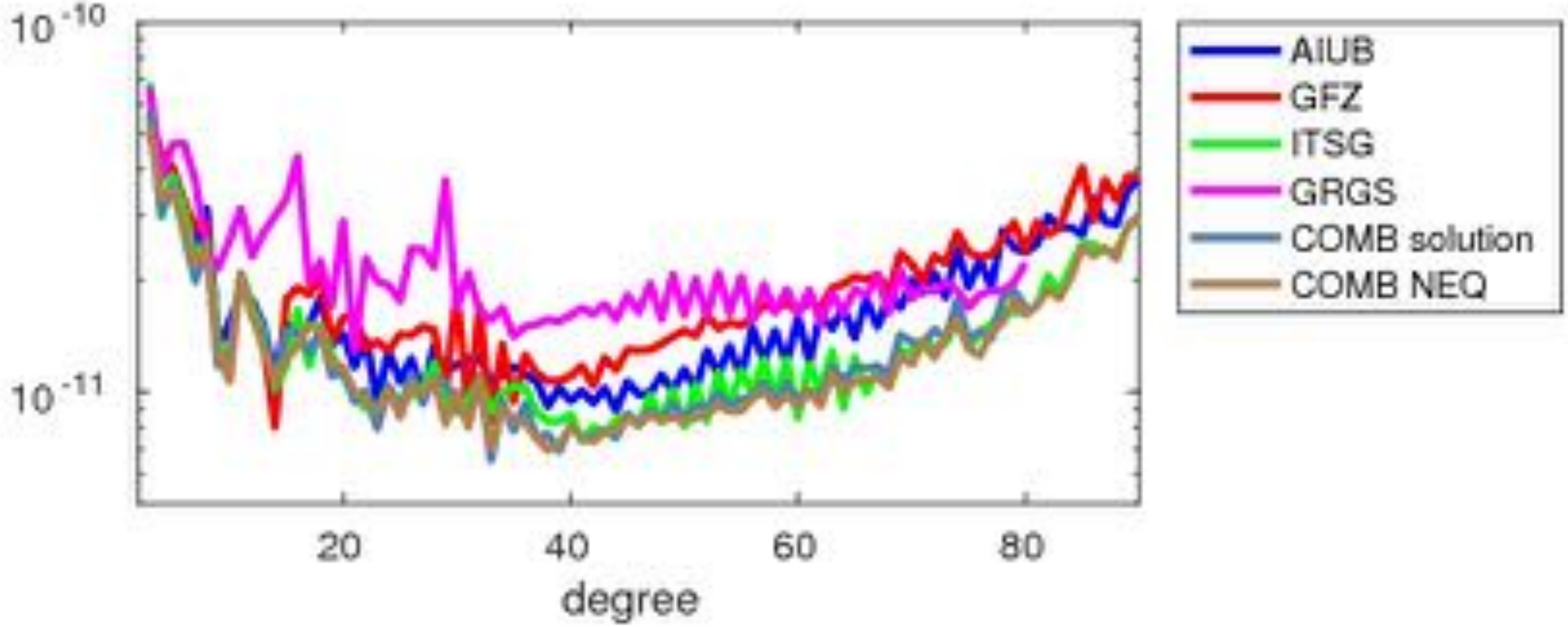
Combination is statistics, not magic -> screening (or improve individual contributions!!)

2006/11



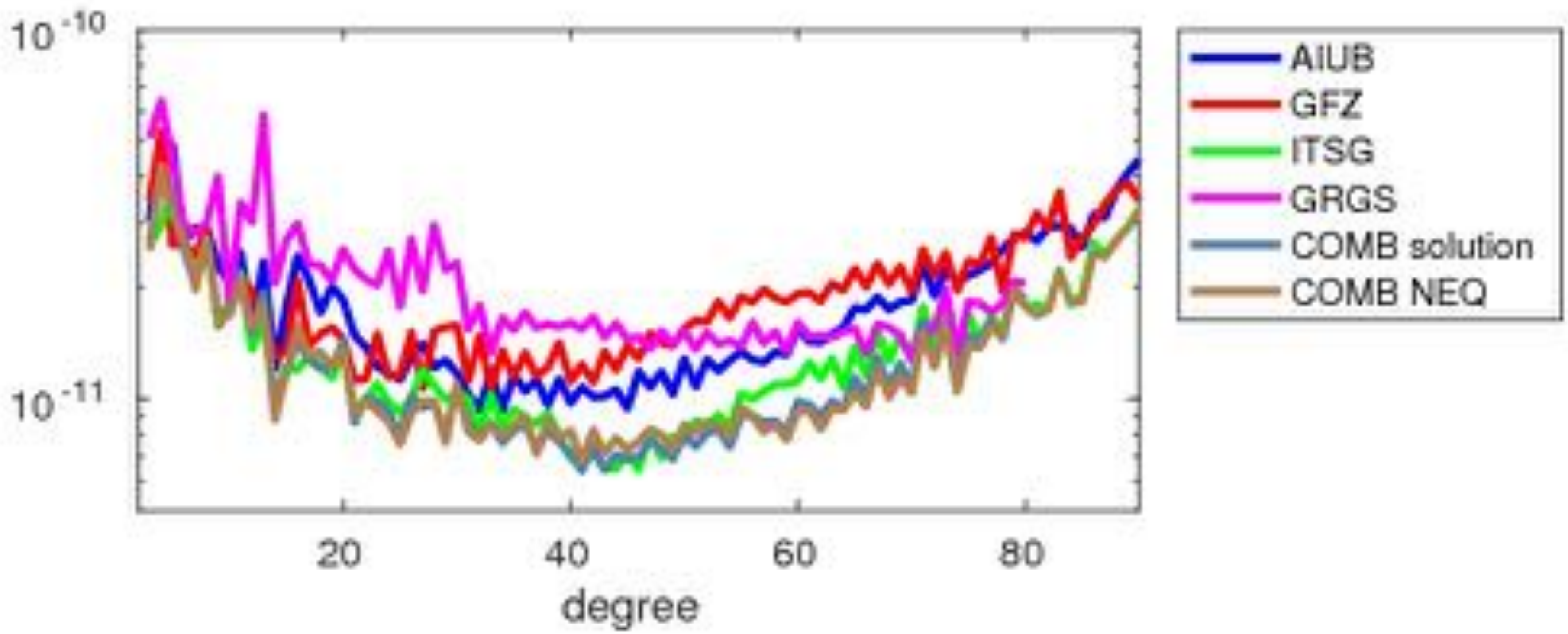
10^-10
10^-11
10
20
30
40
50
60
70
80
90
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2006/12



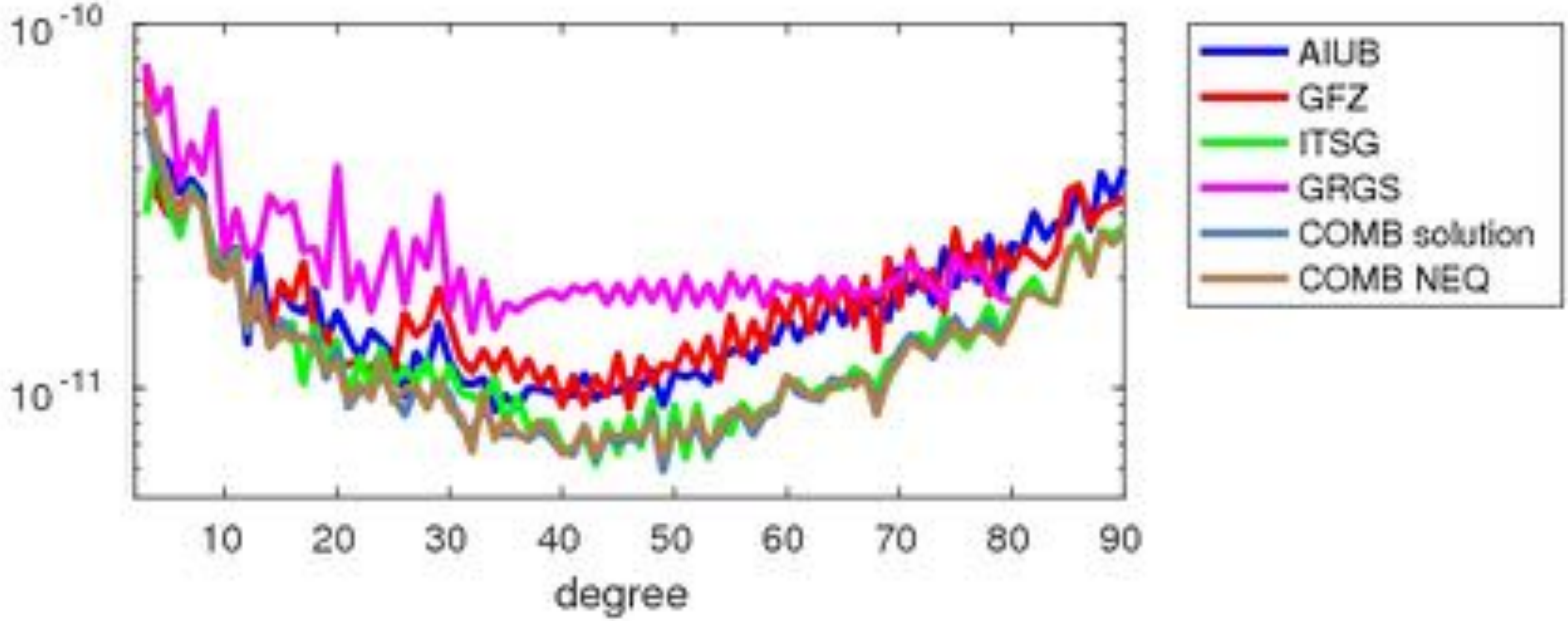
10^-10
10^-11
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/01



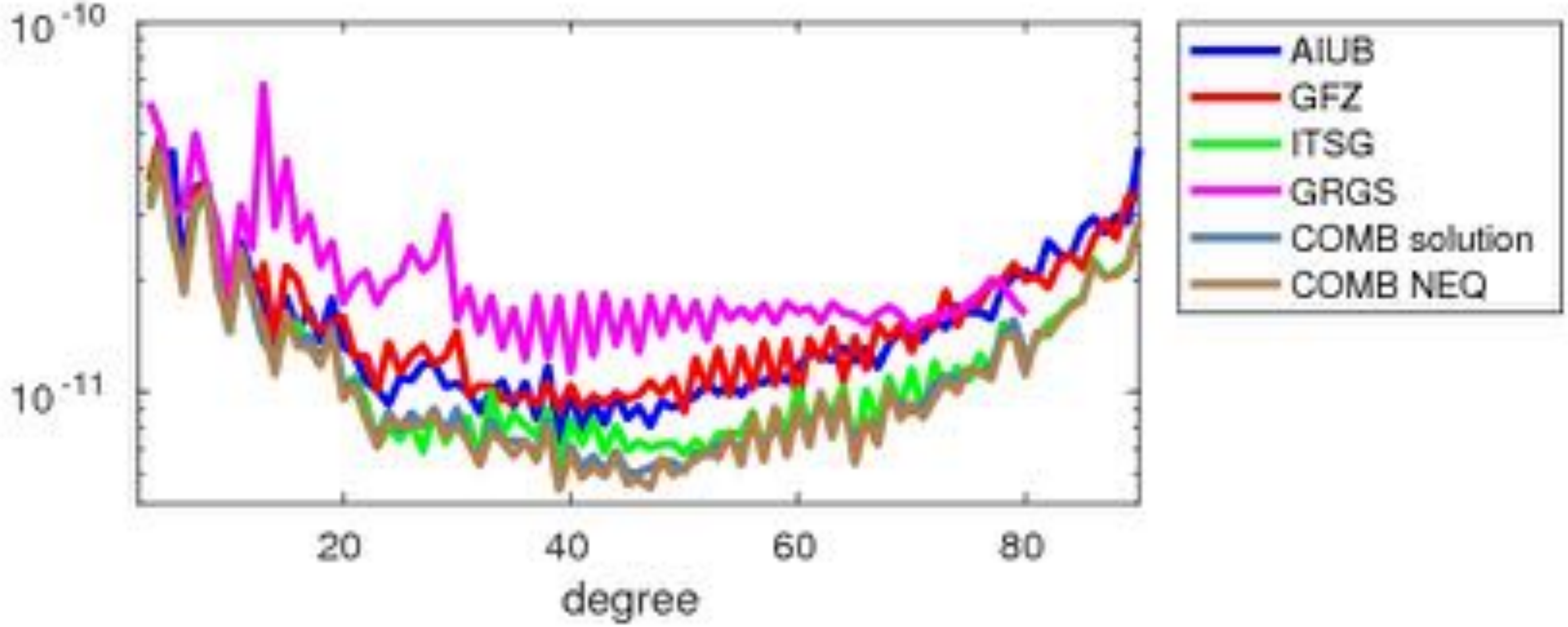
10^{-10}
10^{-11}
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/02



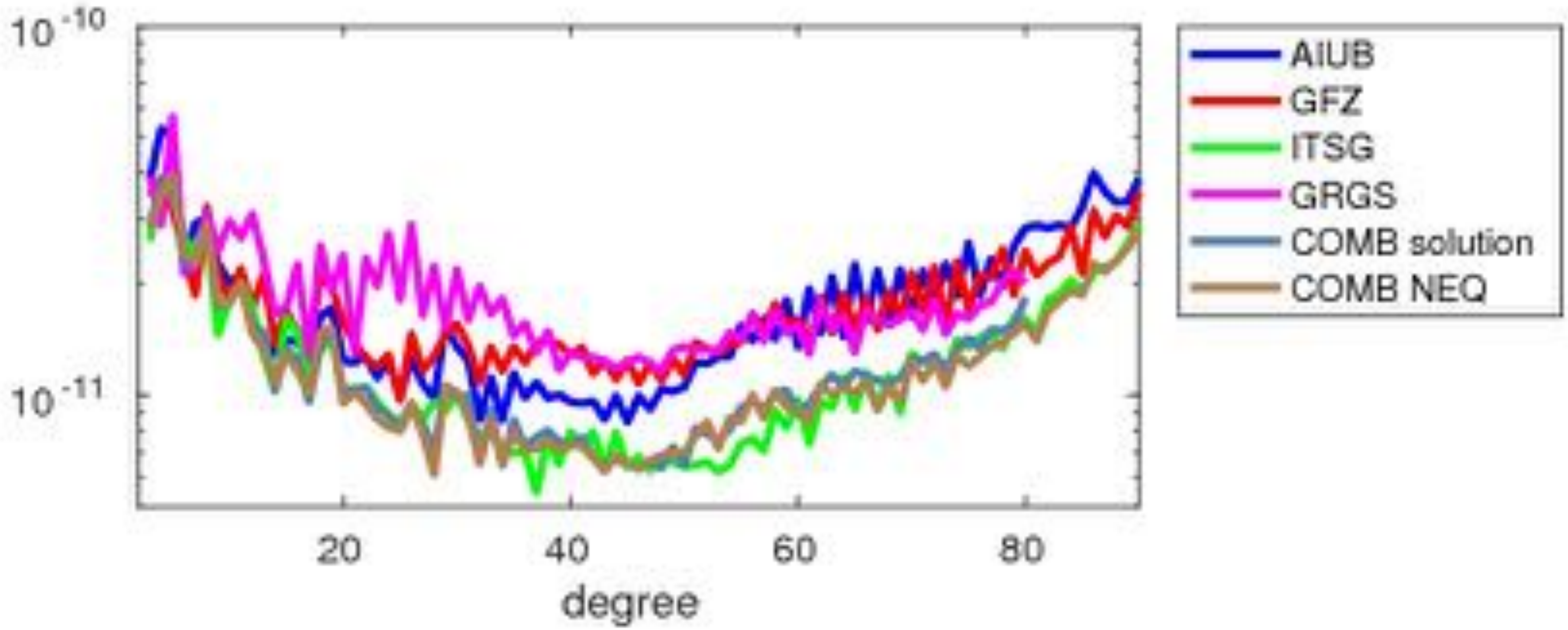
10^{-10}
10^{-11}
10
20
30
40
50
60
70
80
90
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/03



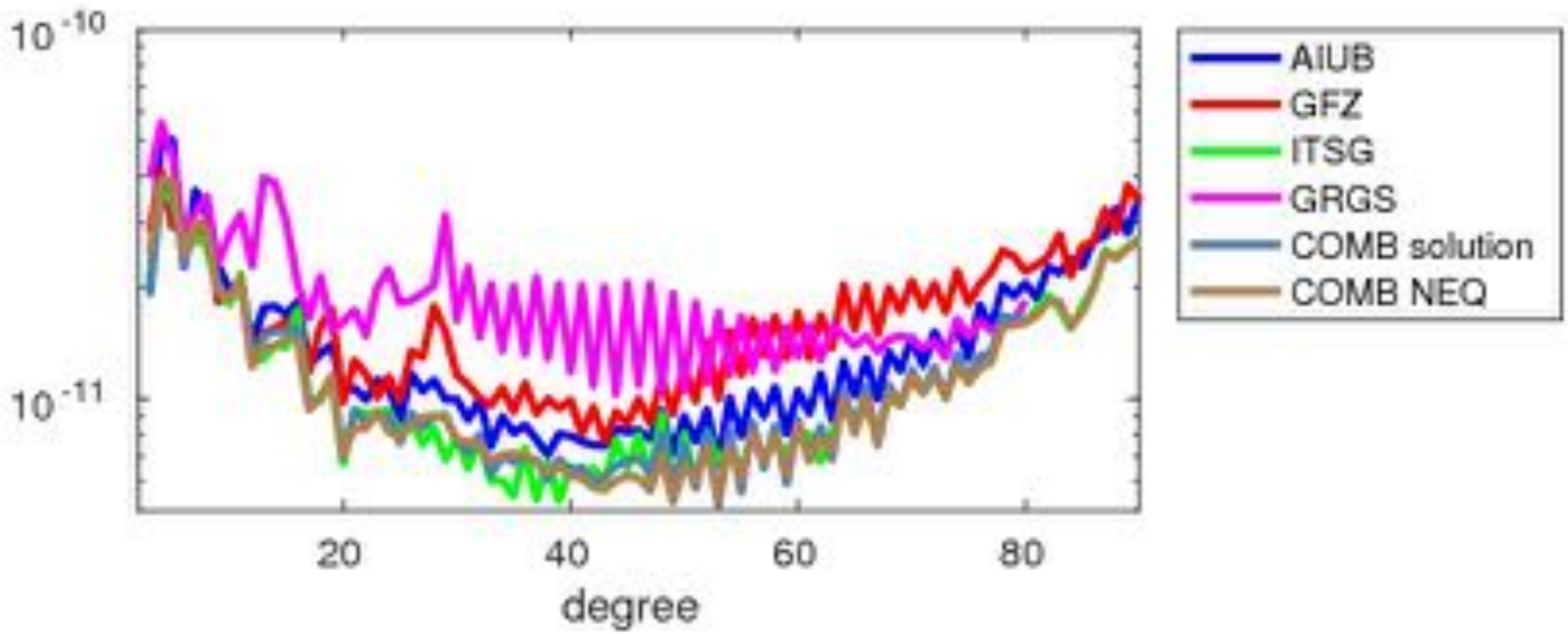
10^{-10}
10^{-11}
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/04



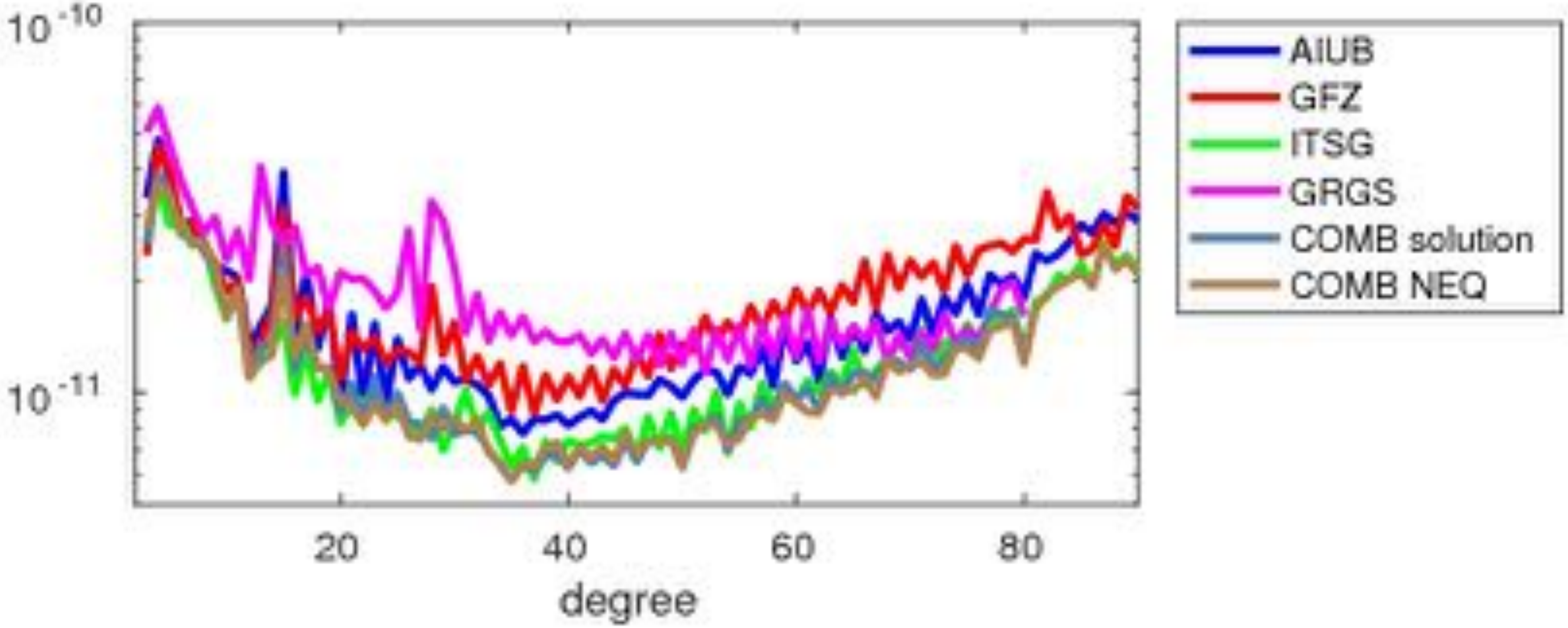
10^{-10}
10^{-11}
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/05



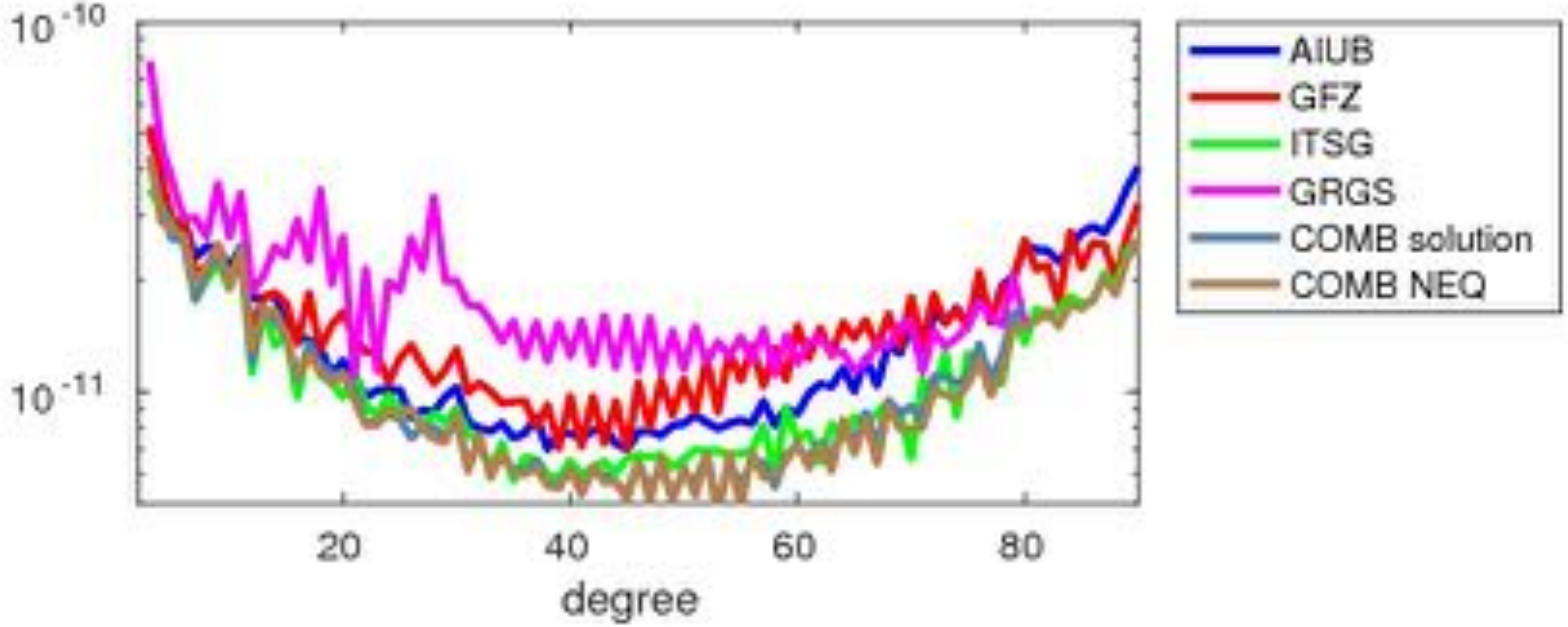
10^-10
10^-11
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/06

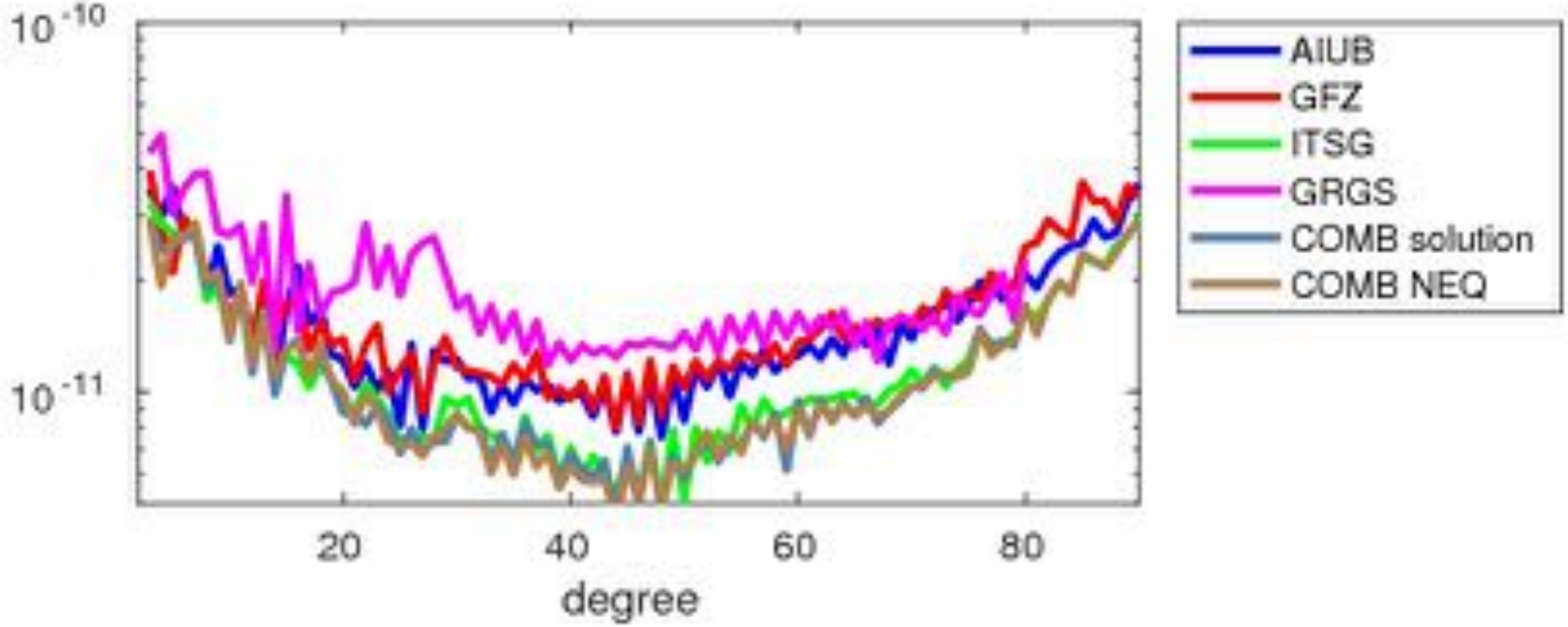


10^-10
10^-11
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/07

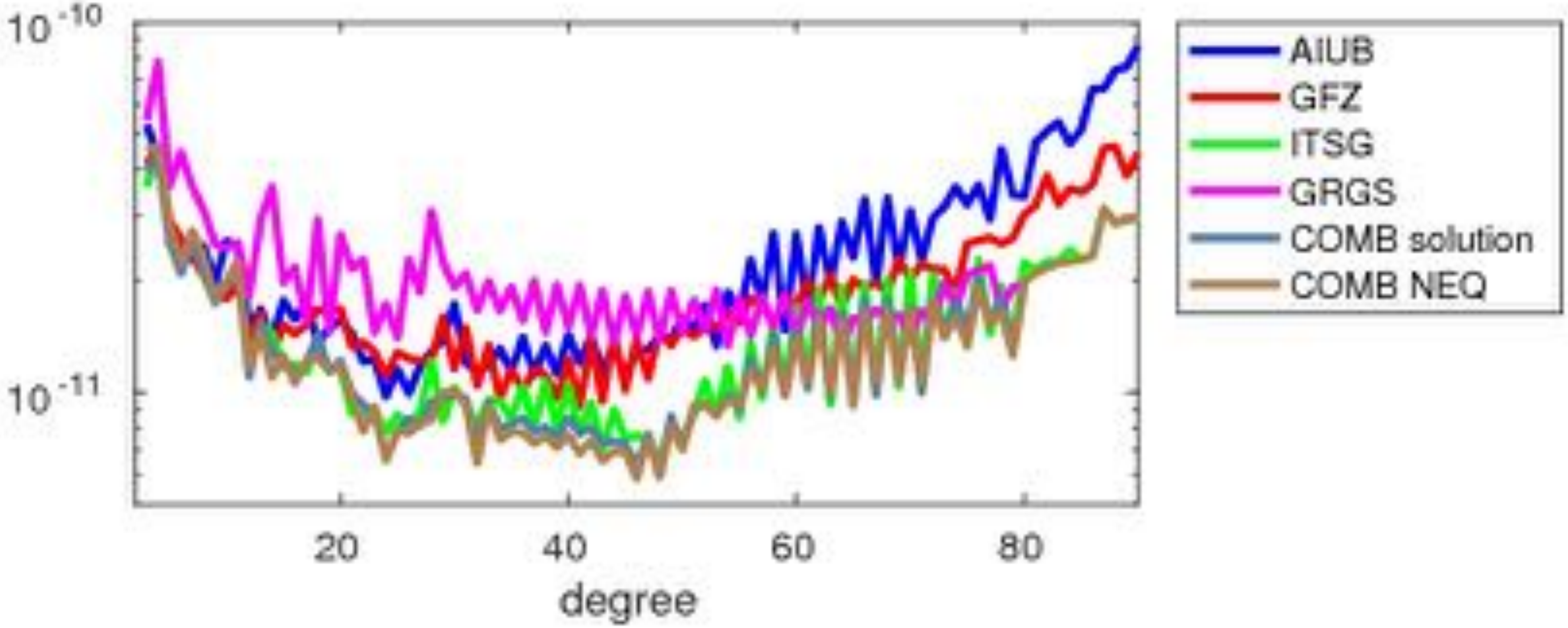

10^-10
10^-11
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/08



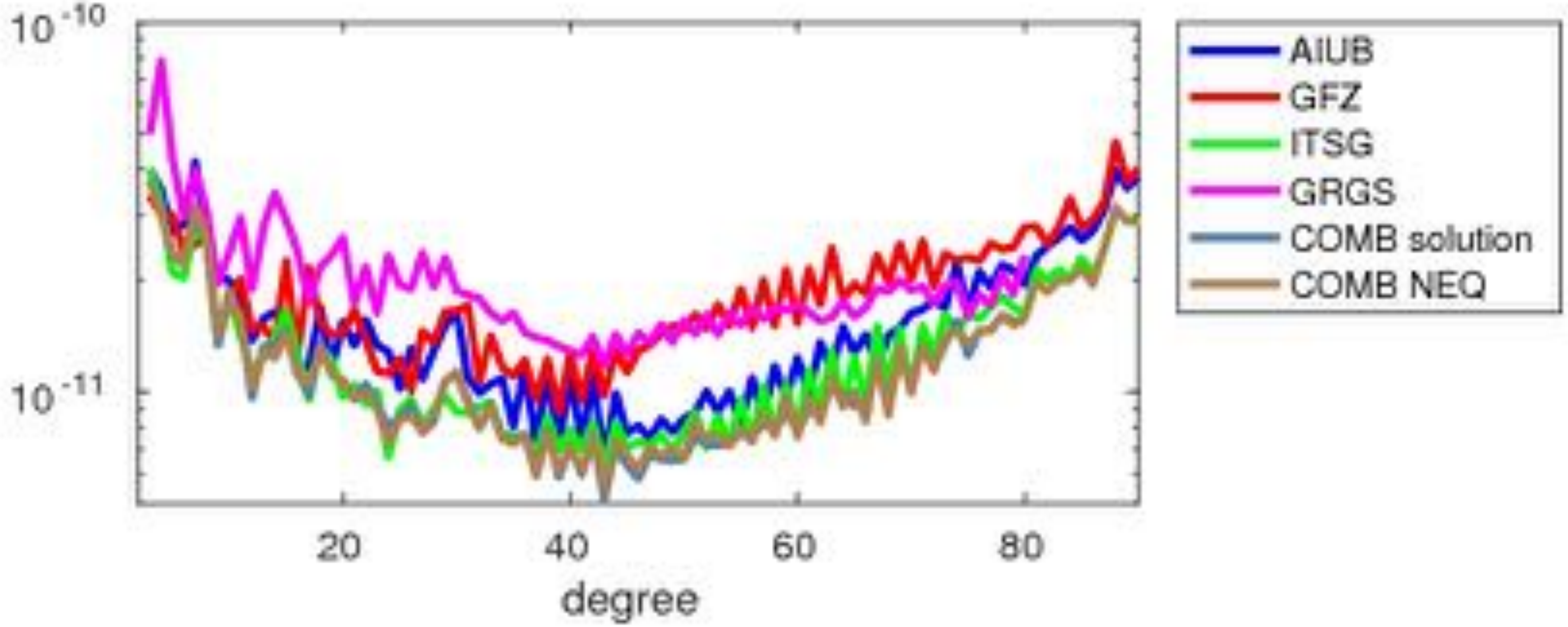
10^-10
10^-11
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/09



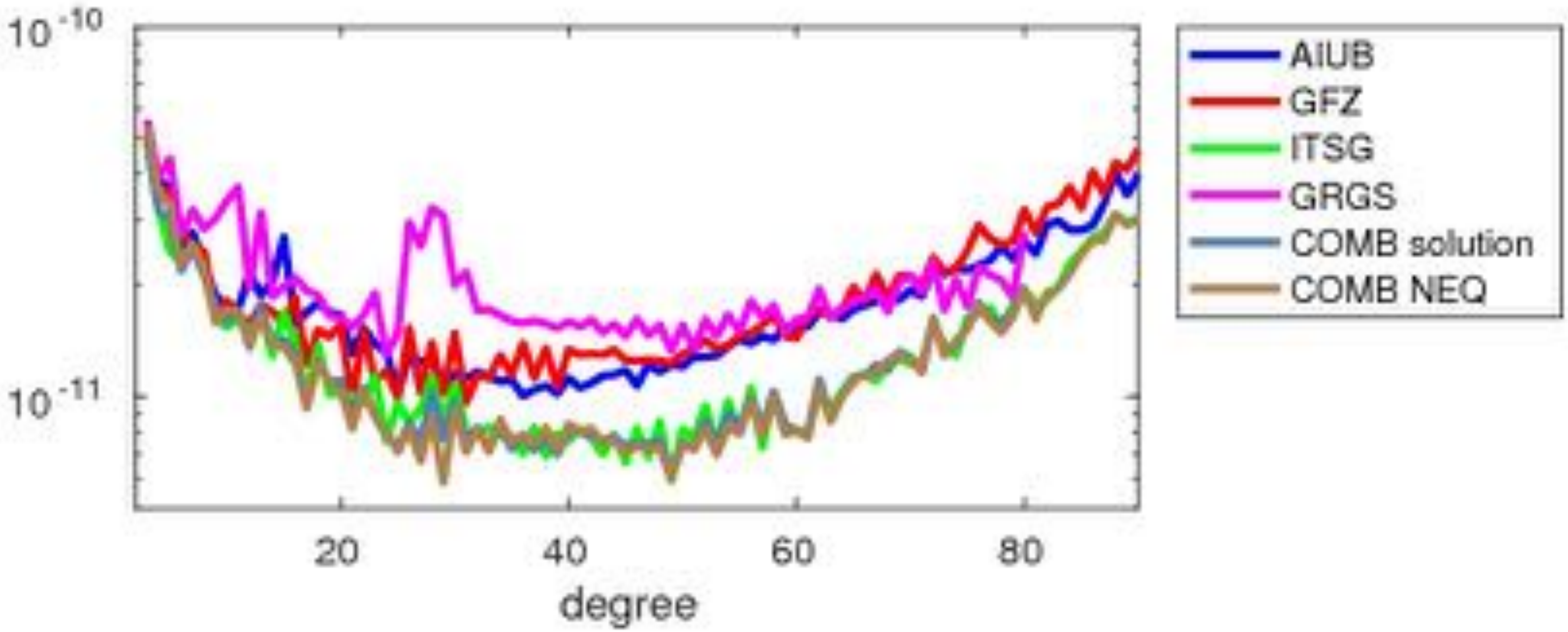
10^{-10}
10^{-11}
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/10



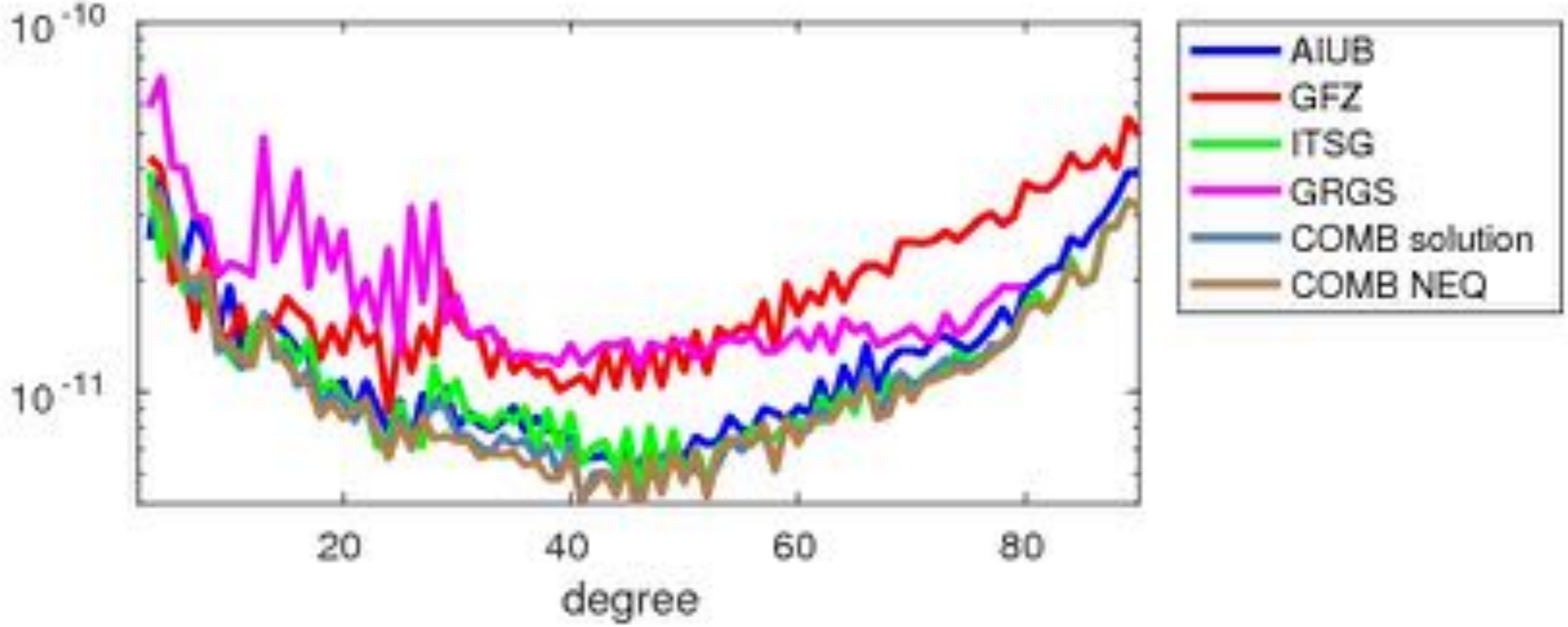
10^{-10}
10^{-11}
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/11



10^-10
10^-11
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

2007/12


10^{-10}
10^{-11}
20
40
60
80
degree
AIUB
GFZ
ITSG
GRGS
COMB solution
COMB NEQ

EGSIEM

European Gravity Service for Improved Emergency Management

WP4. Scientific Combination Service

Combination of GRACE Monthly Gravity Field Solutions

Yoomin Jean

Astronomical Institute, University of Bern

EGSIEM General Assembly

University of Bern

January 19 – 20, 2017

Horizon2020

Introduction

- In **WP4** at **Univeristy of Bern**
  - Scientific Combination Service:
    Combination of GRACE Monthly Gravity Field Solutions
- Contents
  - **EGSIEM Combined Solutions on Solution Level**
  - **Evaluation** of Combined Solutions using **Reservoir Cases**

Input from the EGSIEM Analysis Centers

GRACE Monthly Gravity Field Solutions (L2)

refered to the ***EGSIEM Processing Standard***:

Analysis Center	Max. Degree	Period
AIUB	90	2006/01 – 2007/12 (2 years)
GFZ	90	
GRGS	*80*	
ITSG	90	

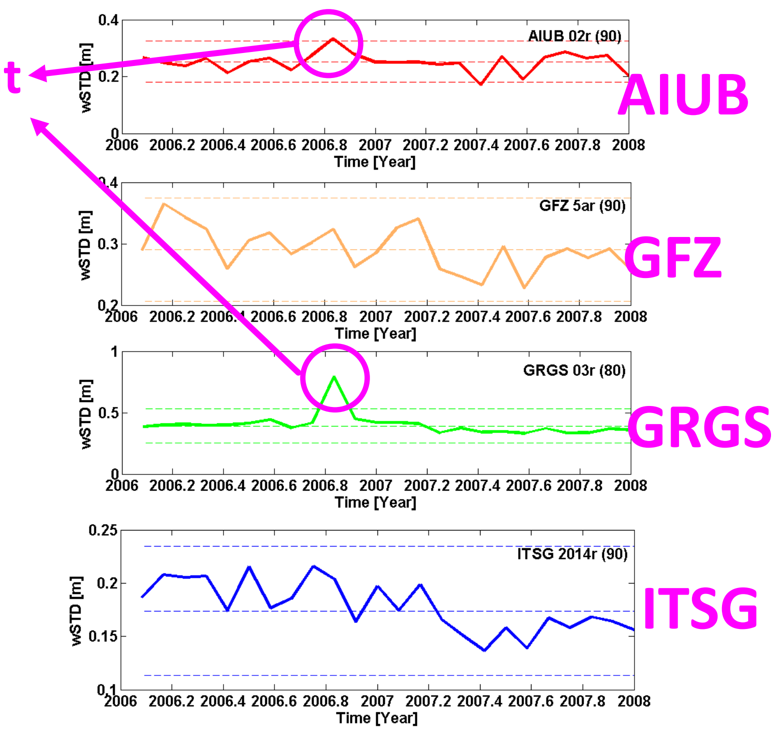
FTP Server:

`http://dl.aiub.unibe.ch/data/egsiem/private/Gravity/`

Preprocessing (1): Scaling and Screening

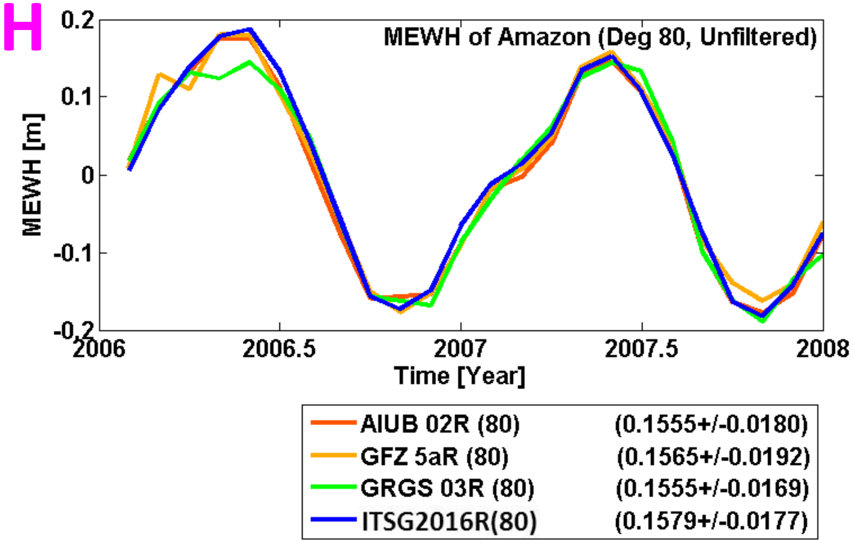
- **Rescaling** of ***Earth radius, Gravitational parameter***
- **Correction** of **C20 bias** (w.r.t. Tide-free system)
- **Screening** of outliers
  - Criterion: Median + 3MAD using *wSTD over the oceans* (Quality Measure)

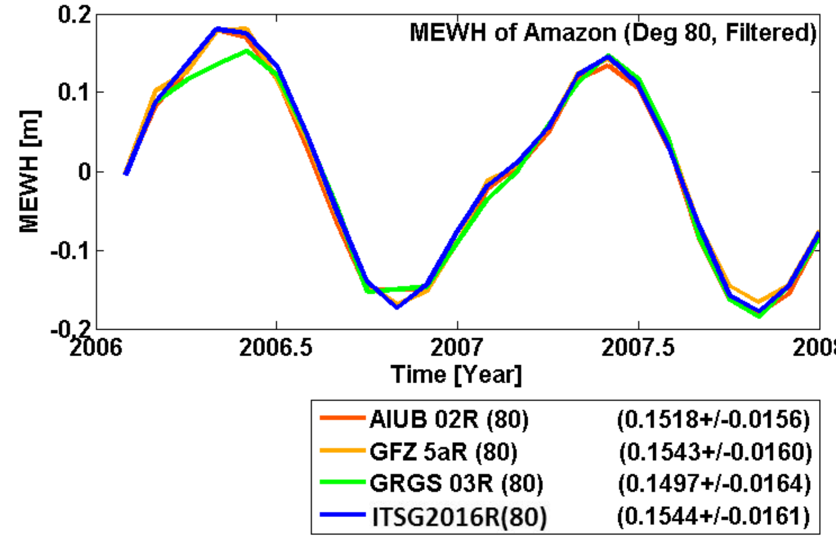
Analysis Center	Max. Degree	Screened Monthly Solution
AIUB	90	2006/10
GFZ	90	None
GRGS	*80*	2006/10
ITSG	90	None



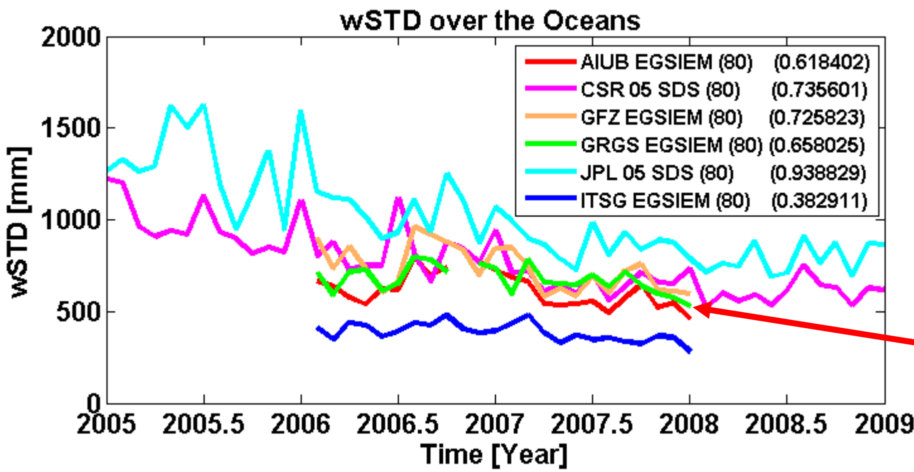
Preprocessing (2): Signal and Noise Comparison

MEWH

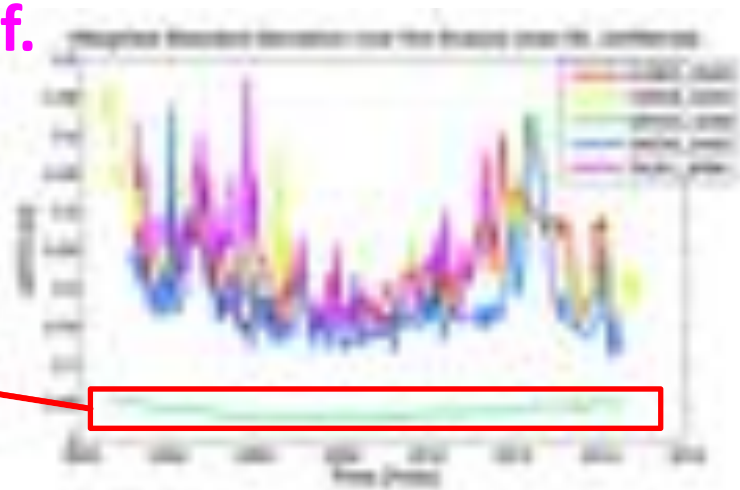




wSTD Oceans

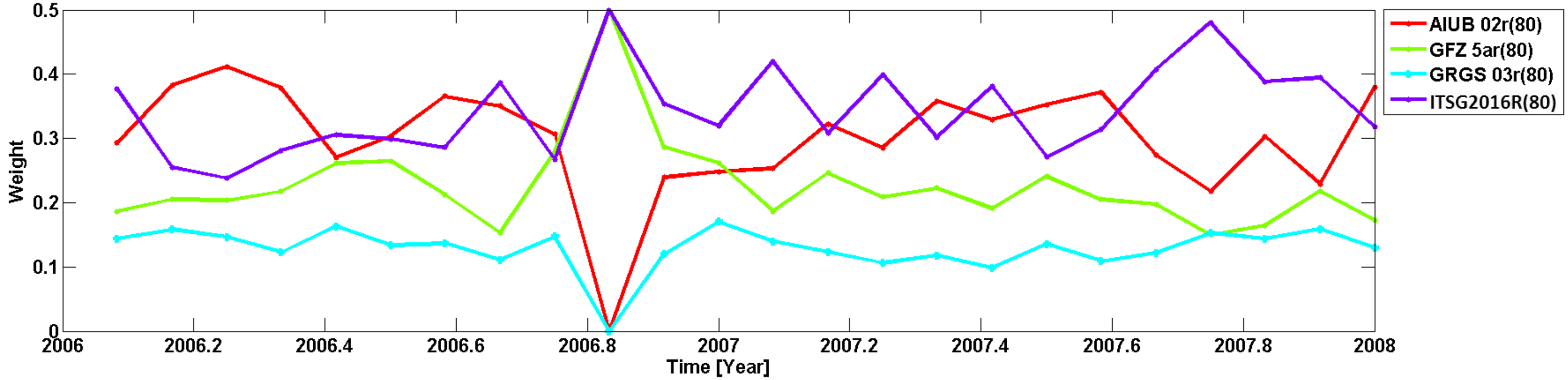


cf.



Weights

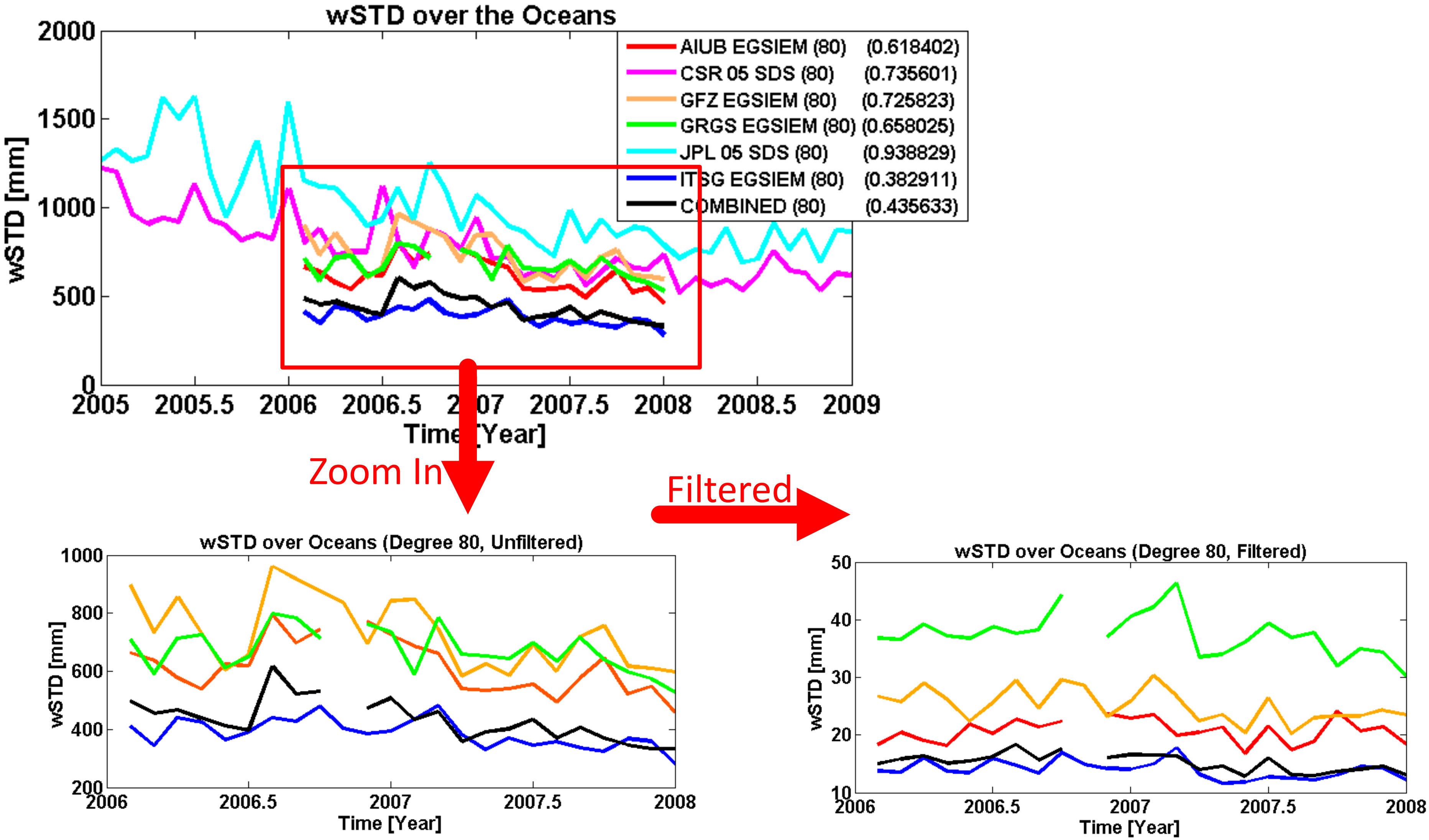
- Weights from *iterative* process using the *Variance Component Estimation (VCE)* method



Screened out: AIUB, GRGS in October 2006 =2006.833 [year]

→ Only GFZ and ITSG solutions were combined in this month.

Combined Solutions: wSTD over Oceans

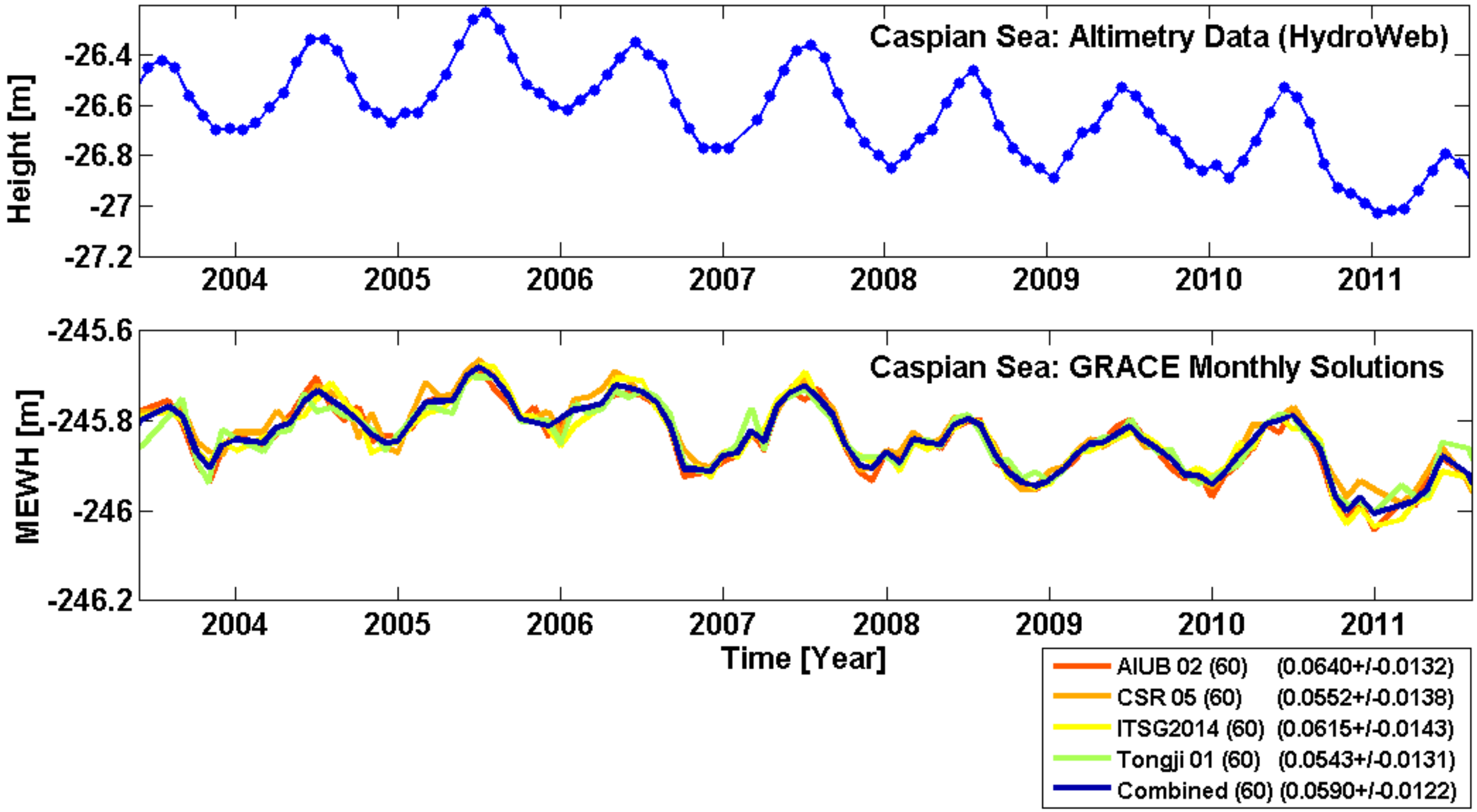


Evaluation using Reservoir Cases

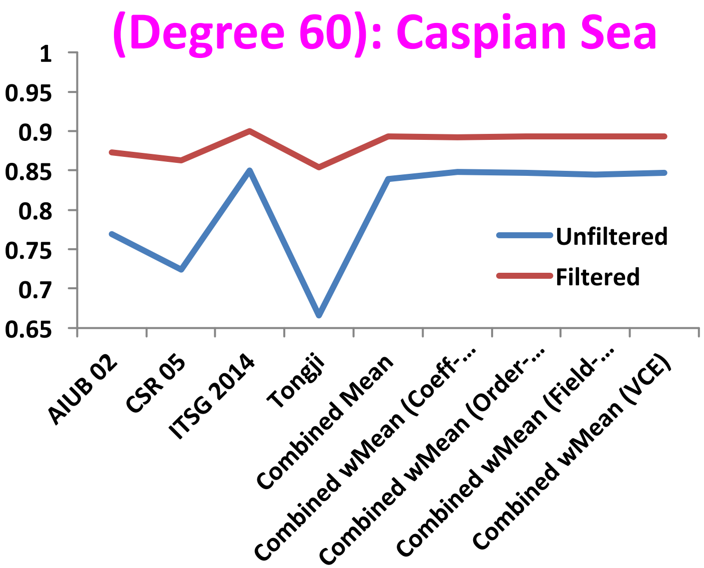
- Suggestion **by Prof. J. Kusche** (Advisory Board)
  in last meeting in January 2016
  - Evaluation using **reservoir** cases:
    - **Caspian Sea**: huge signal
    - **Lake Volta**: much smaller, but still visible signal
  - Altimetry data by **Hydroweb**
    - From **satellite images** + **radar alitmetry**
    - TOPEX/POSEIDON, Jason (1,2,3), GFO, ENVISAT, SARAL
    - By ***Legos***, Toulouse, France
- Combined GRACE monthly gravity field solutions
  - (Solution level) AIUB, GFZ, GRGS, ITSG

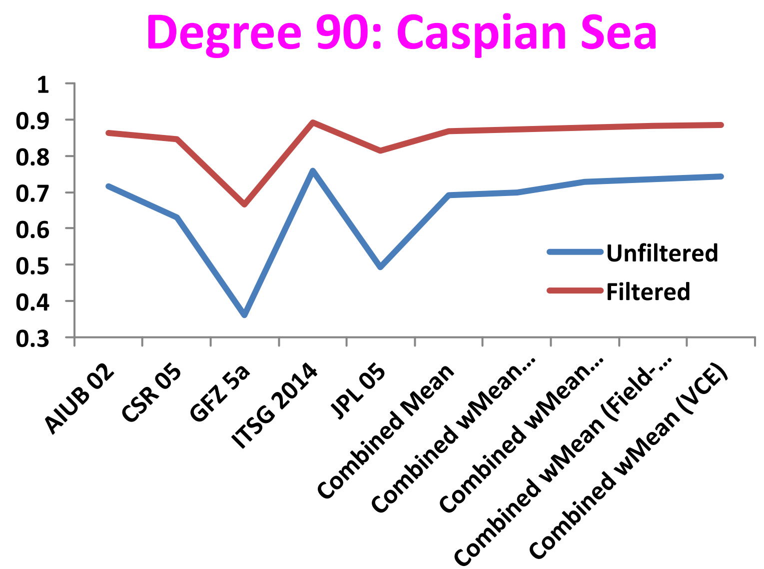
Water Heights by Altimetry and GRACE (1)

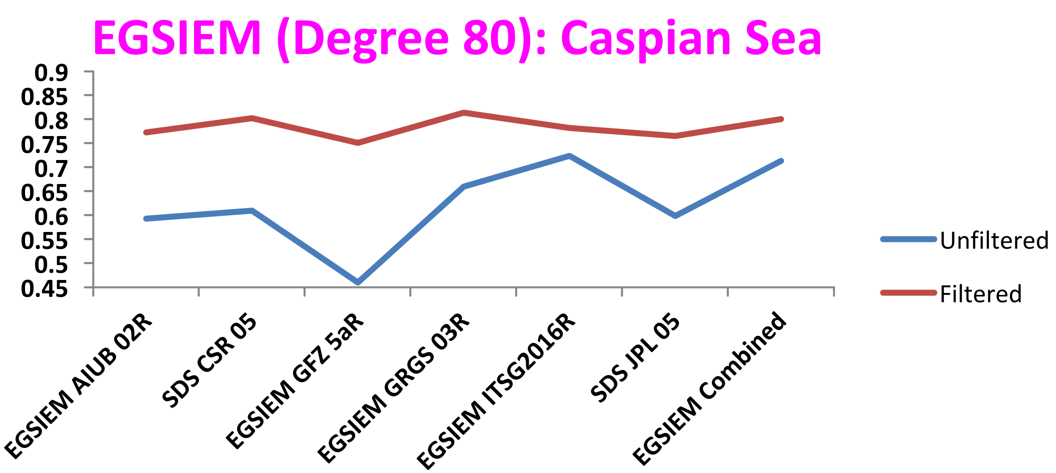
- **Caspian Sea**



Correlation Coefficients: Caspian Sea







European Gravity Service for Improved Emergency Management

WP4. Scientific Service

Validating two-year EGSIEM combined GRACE products

Qiang Chen

Faculty of Science, Technology and Communication

University of Luxembourg

EGSIEM Progress Meeting # 4

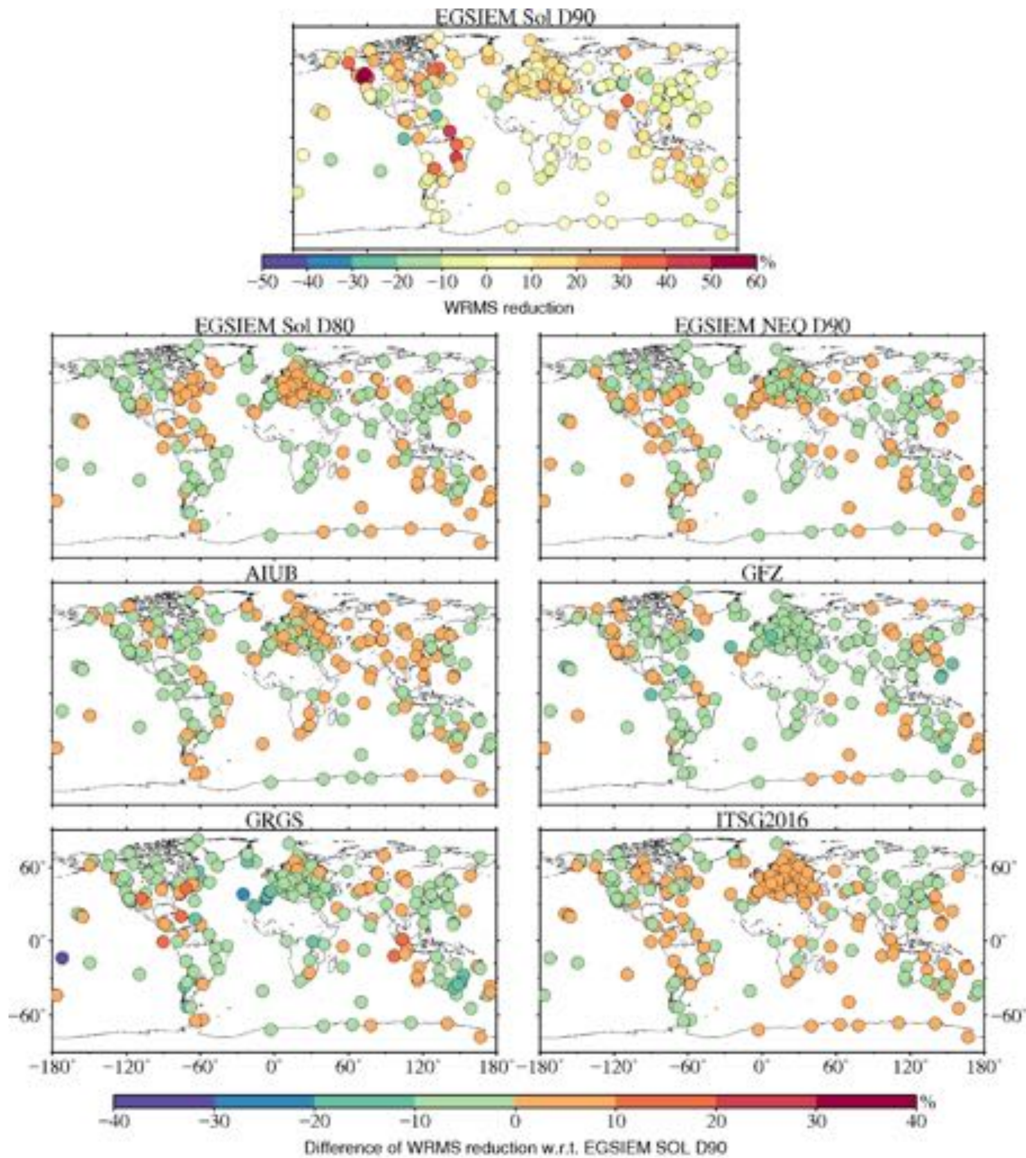
January 19 – 20, 2017

Data

- GNSS data
  - Reprocessed daily UBERN GNSS time series (Repro3)
    - Cleaned, detrended, outlier and offsets removed, averaged into monthly
  - Latest daily ITRF2014 GNSS residuals (IGN)
    - Rigorously stacking the latest IGS repro2 solutions, averaged into monthly
- Gravity models
  - 4 two-year (2006&2007) GRACE gravity models from 4 ACs (AIUB, GFZ, ITSG, GRGS)
  - 3 two-year (2006&2007) combined EGSIEM solutions both at NEQ level and Solution level (max degree 80&90)
  - Standard GRACE data processing
    - Replacing C20 term (Cheng et al., SLR) and adding back degree-1 coefficients (Swenson et al., 2008)
    - The Gaussian filtering with a smoothing radius of 500 km
    - Converting spherical harmonics into displacements in the vertical component at GNSS stations

GRACE .VS. Repro3

- In a comparison to 258 GNSS stations: WRMS reduction
- Differences of WRMS reduction w.r.t EGSIEM Sol D90 are within the range of ±10% for EGSIEM Sol D80, EGSIEM NEQ D90, AIUB and ITSG2016
- Bigger differences are seen for GFZ and GRGS
- More negative than positive differences of WRMS reduction are observed for all except ITSG2016



EGSIEM

HORIZON 2020

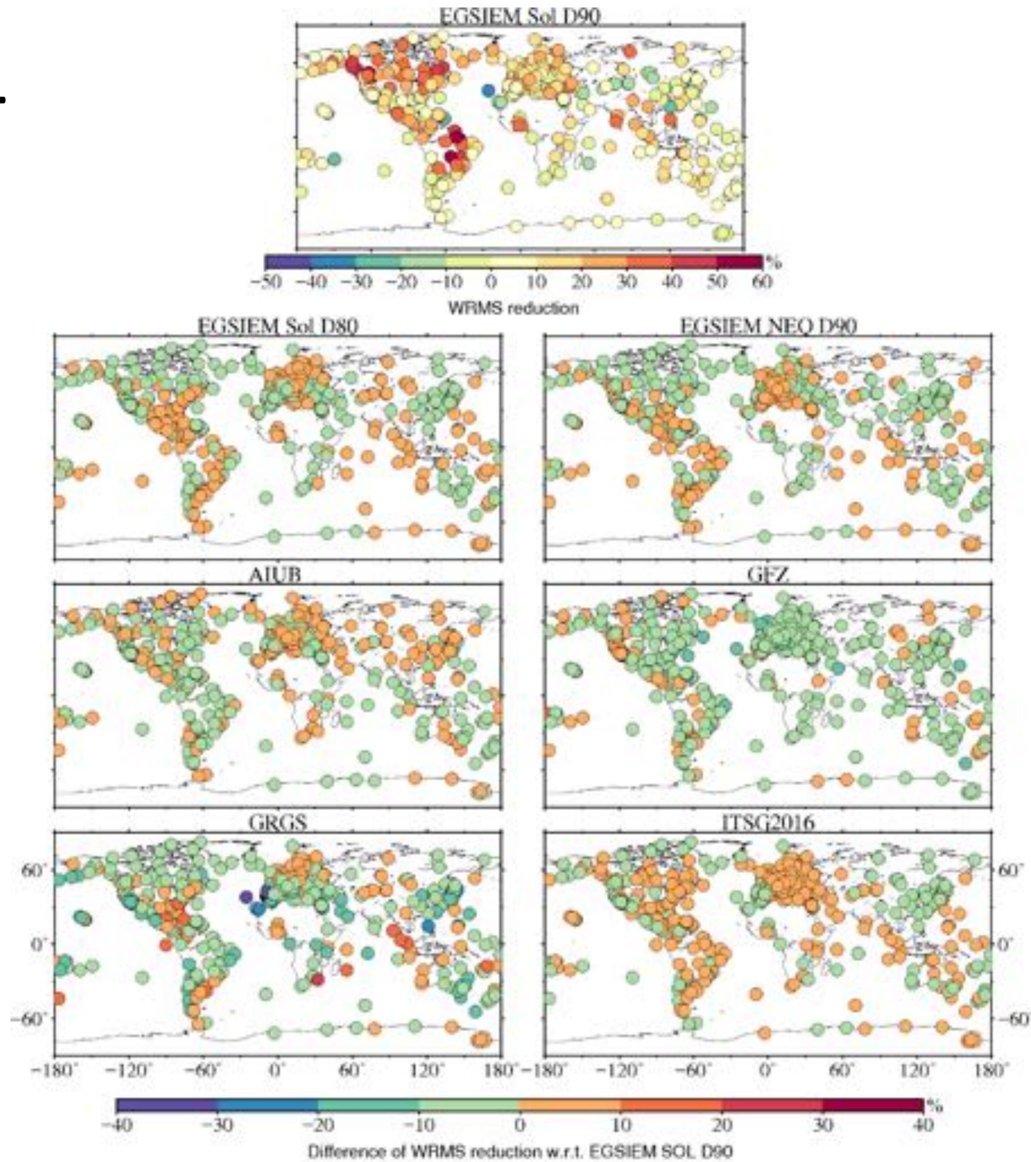
GRACE .VS. Repro3

	WRMS reduction [%]				Positive WRMS reduction [%]
	min	max	mean	median	
AIUB	-27.88	54.07	7.71	7.24	75.19
GFZ	-41.08	55.41	4.82	3.69	65.89
GRGS	-43.64	51.54	5.11	4.68	64.34
ITSG	-27.21	54.75	8.24	8.28	74.03
EGSIEM Sol D80	-30.91	54.12	7.85	7.52	74.42
EGSIEM Sol D90	-29.57	54.78	7.78	7.56	75.58
EGSIEM NEQ D90	-34.13	53.37	7.42	7.05	72.48

- ITSG performs slightly better than the EGSIME combined solutions
- EGSIEM NEQ D90 seems to not provide better statistics than the combined solution level
- Two-year GFZ and GRGS solutions seem to slightly worse than other solutions

GRACE .VS. ITRF2014

- In a comparison to 626 GNSS stations: WRMS reduction
- Differences of WRMS reduction w.r.t EGSIEM Sol D90 are within the range of ±10% for EGSIEM Sol D80, EGSIEM NEQ D90, AIUB and ITSG2016
- Bigger differences are seen for GFZ and GRGS
- More negative than positive differences of WRMS reduction are observed for all except ITSG2016



EGSIEM

HORIZON 2020

GRACE .VS. ITRF2014

	WRMS reduction [%]				Positive WRMS reduction [%]
	min	max	mean	median	
AIUB	-40.97	57.43	11.24	10.09	81.15
GFZ	-54.68	59.54	8.62	8.03	73.96
GRGS	-74.08	56.37	7.90	8.29	69.65
ITSG	-47.13	59.67	12.10	11.58	82.11
EGSIEM Sol D80	-42.56	58.49	11.69	10.77	81.47
EGSIEM Sol D90	-39.84	58.82	11.63	10.83	81.79
EGSIEM NEQ D90	-43.20	58.52	11.38	10.59	81.31

- Slightly better statistics than Repro3 but with the same conclusions as Repro3

Future work

- Validation with improved version of the combined solutions
  - NEQ level
  - Solution level

- Longer time span for better validation?

Thanks for your attention!

EGSIEM

European Gravity Service for Improved Emergency Management

Title: **Preliminary L3 Products**

Presenter: AK

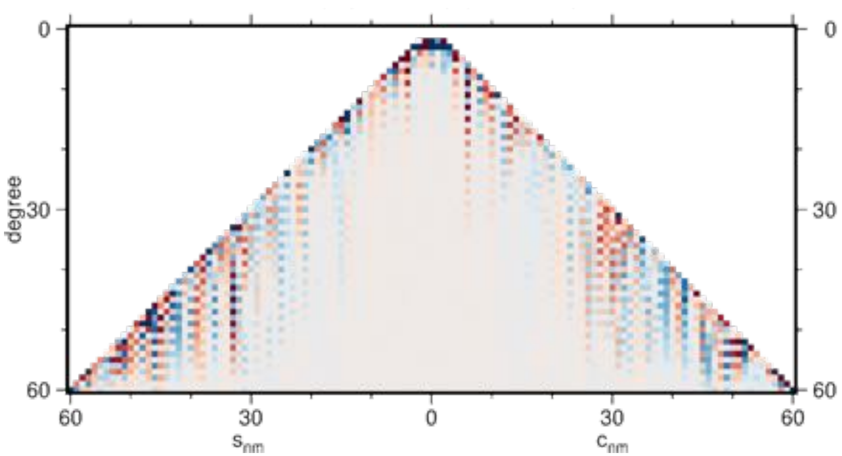
Affiliation: TUG

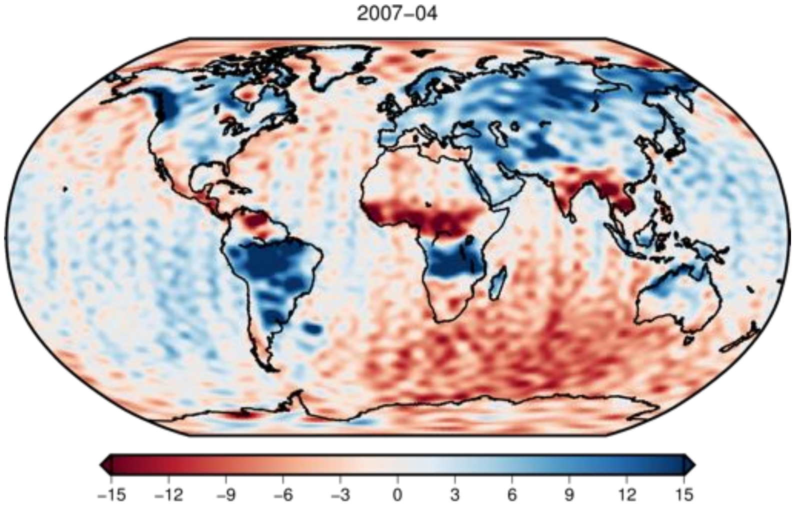
EGSIEM Meeting Bern,
18.01.2017 - 19.01.2017

Preliminary L3 Products - Overview

Preliminary L3 Products - Overview

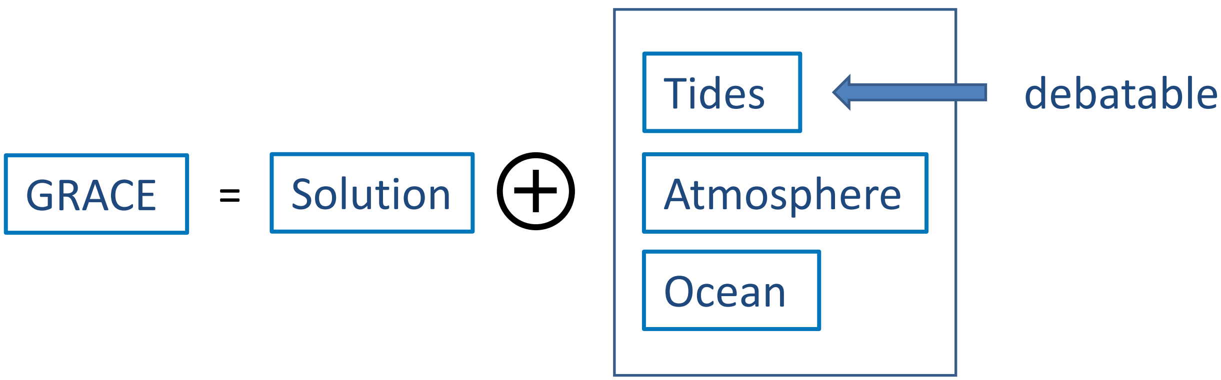
- Definition: user friendly data products derived from potential coefficients
- Generally: gridded mass anomalies (deviations from long term mean) in terms of liquid water equivalent





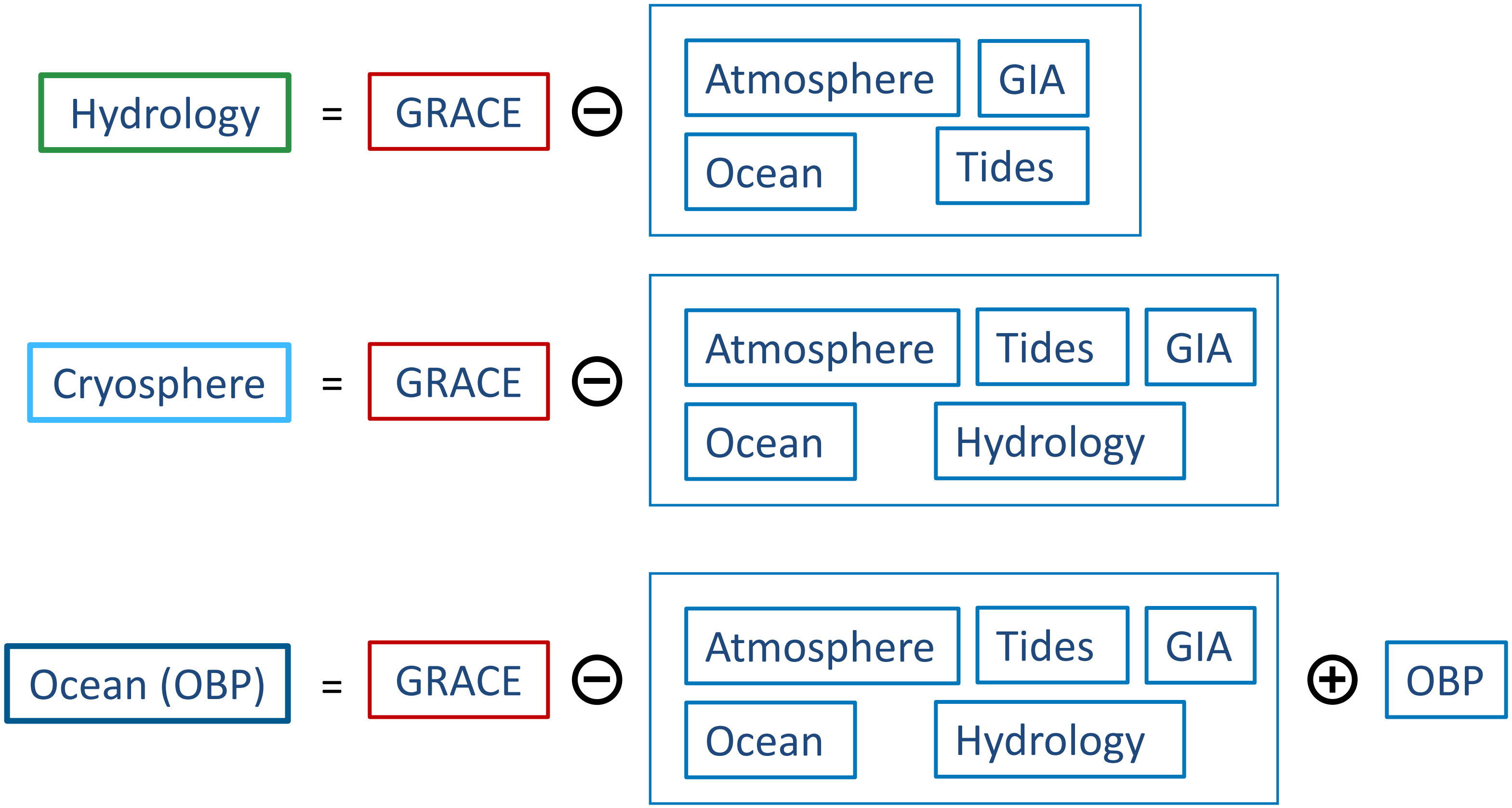
Preliminary L3 Products - Approach

- GRACE measures the total mass change in all geophysical subsystems
  - Signal separation requires models
- GRACE solutions are dominated by high frequency noise
  - Spatial low pass filter required
- GRACE “observation”: estimated monthly solution with all background models restored, transformed to center of figure (CF)



Preliminary L3 Products - Approach

- Gridded mass products will be available for hydrology, cryosphere and ocean applications



Preliminary L3 Products - Used Models

Constituent	Model	Temporal Mean
Hydrology	WGHM	Estimate
Cryosphere	-	-
Ocean	GAB	Estimate
Atmosphere	GAA	Estimate
OBP	GAD	Estimate
GIA	Geruo A (Tellus)	Zero
Ocean Tides	EOT11a	Zero
Pole Tide/Ocean Pole Tide	IERS 2010	Zero
Transformation CM to CF	SLR (AIUB)	Estimate

Preliminary L3 Products – Spatial Filter

Preliminary L3 Products - Spatial Filter

- Anisotropic filter using full GRACE covariance matrix
  - Equivalent to Kaula-constrained monthly solution

- Signal covariance is expressed as Kaula-type function (similar to DDK filters)

⊕

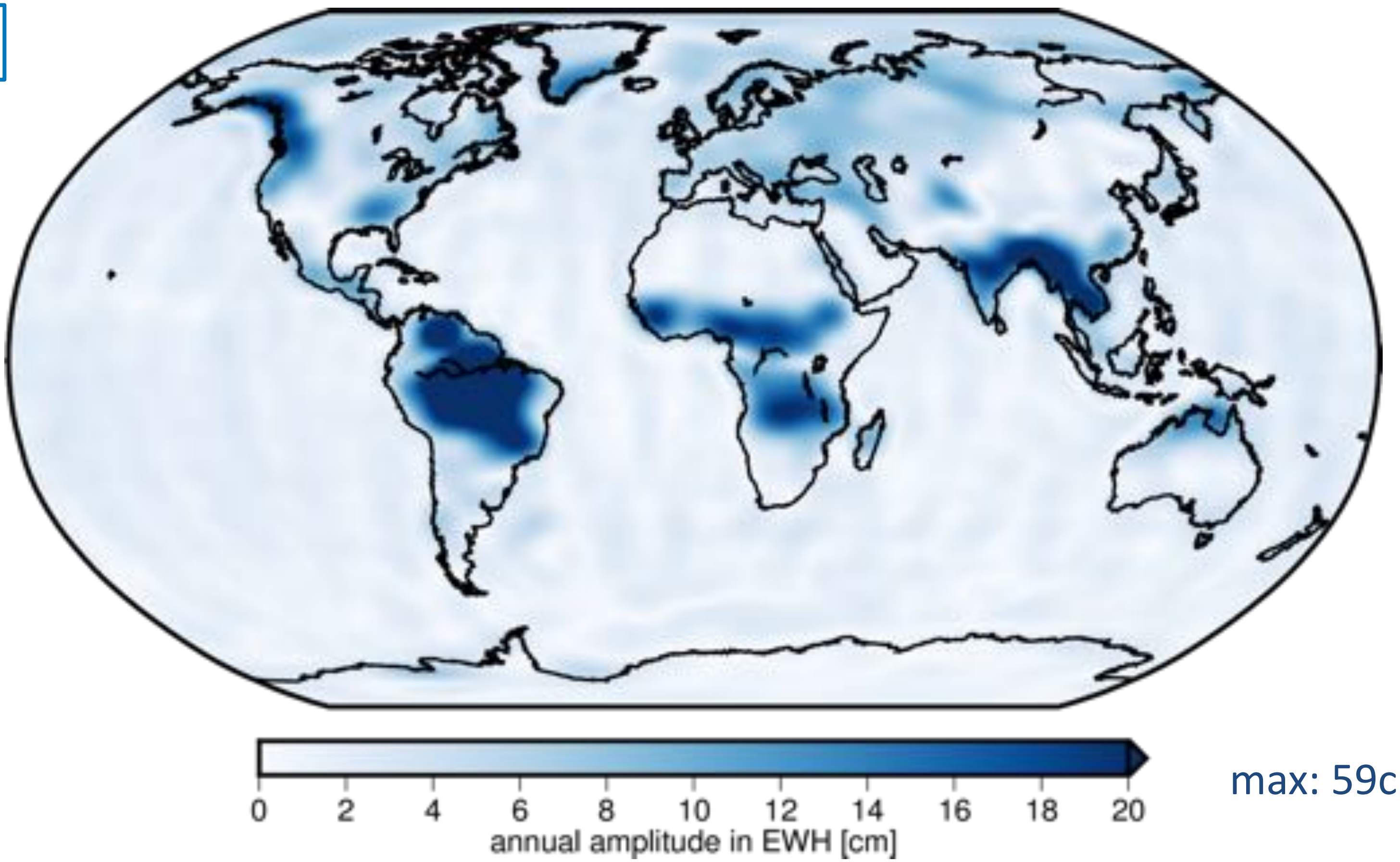
- Time varying
- Takes into account instrument noise, data gaps and orbit

⊖

- Time varying
- Large filter matrix (upper triangle ~ 250Mb)

Preliminary L3 Products - Spatial Filter

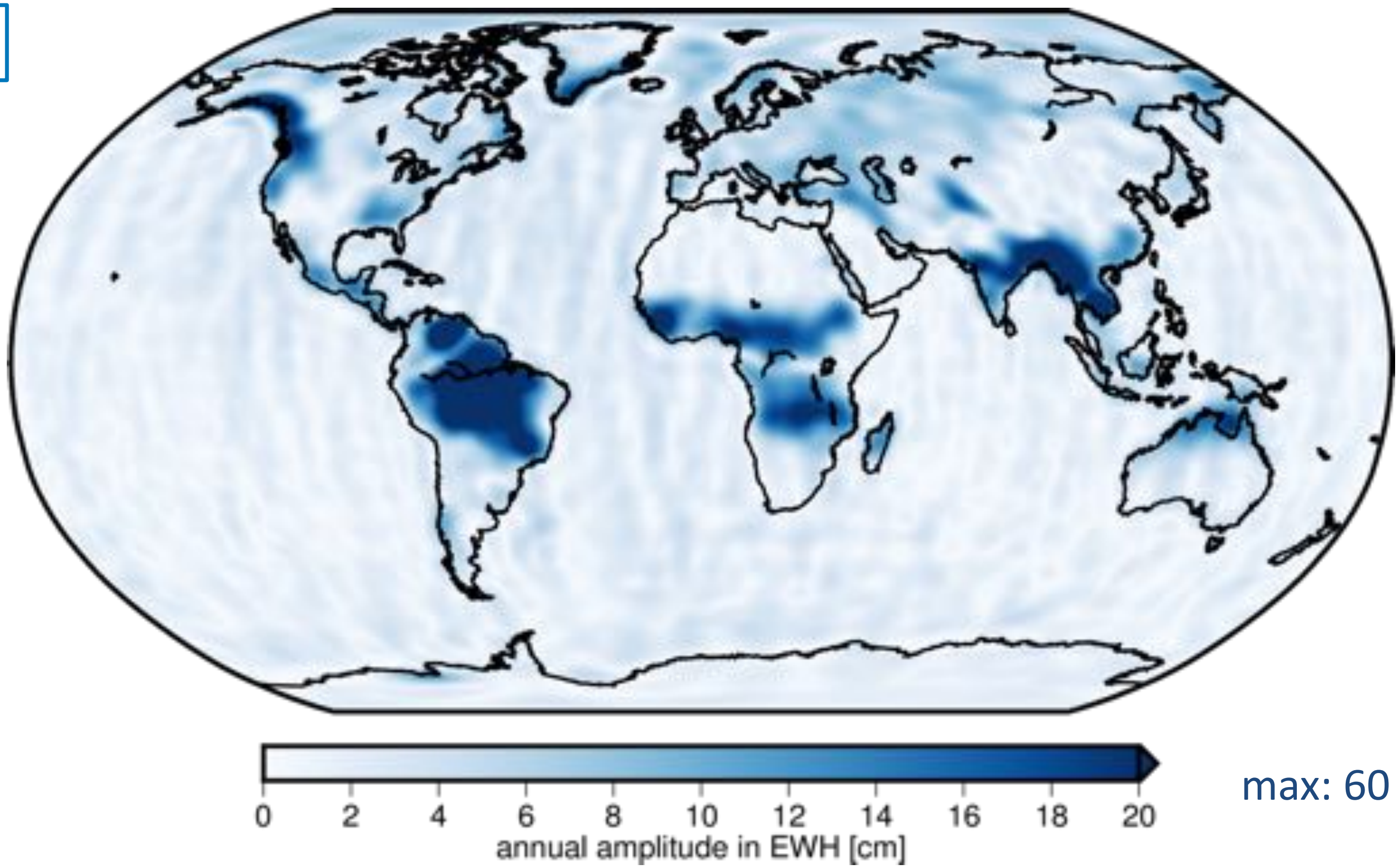
DDK3



max: 59cm

Preliminary L3 Products - Spatial Filter

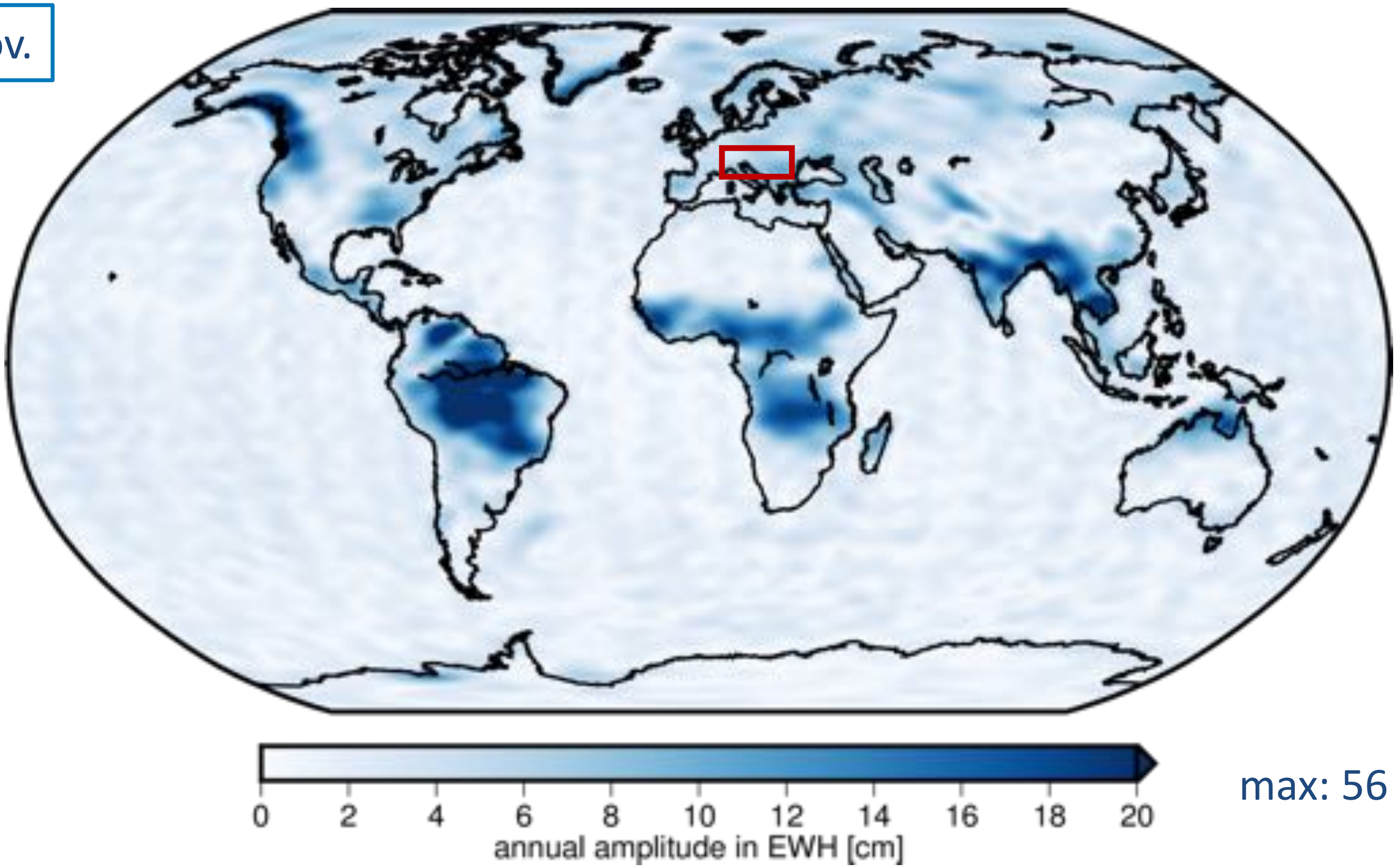
DDK4



max: 60 cm

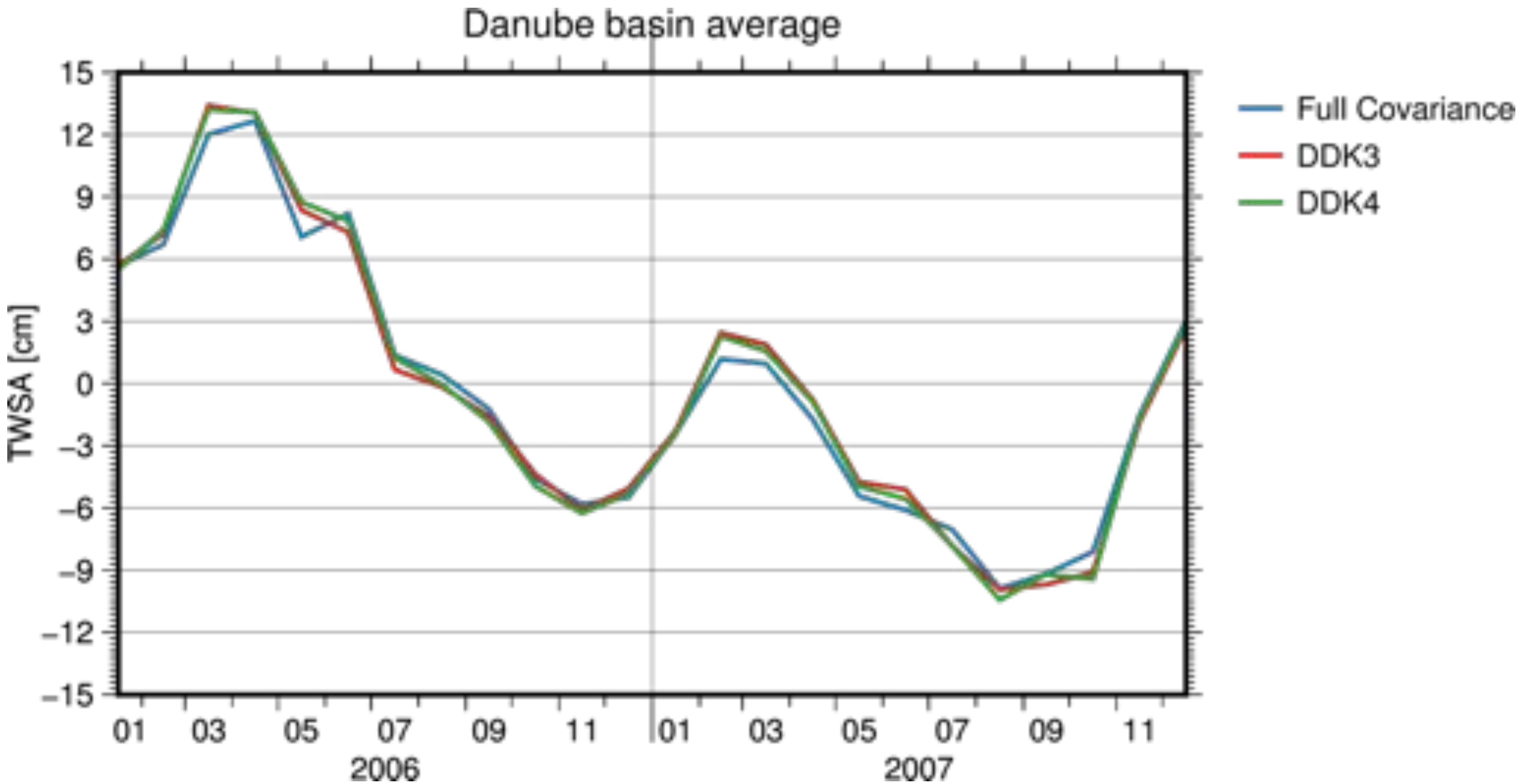
Preliminary L3 Products - Spatial Filter

Full Cov.



max: 56 cm

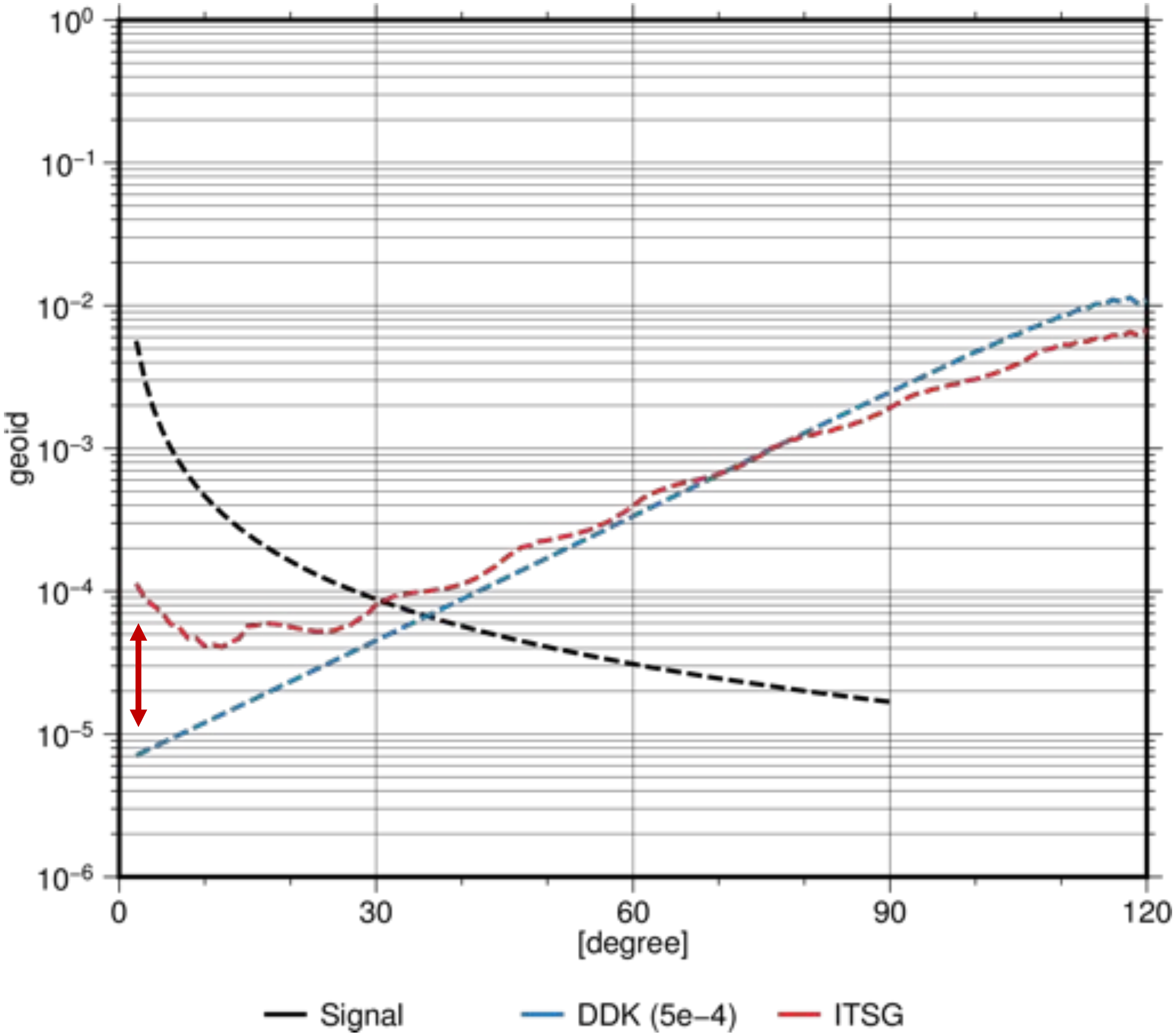
Preliminary L3 Products - Spatial Filter



Generally: slightly smaller amplitudes when using full covariance

Preliminary L3 Products - Spatial Filter

Significantly lower SNR



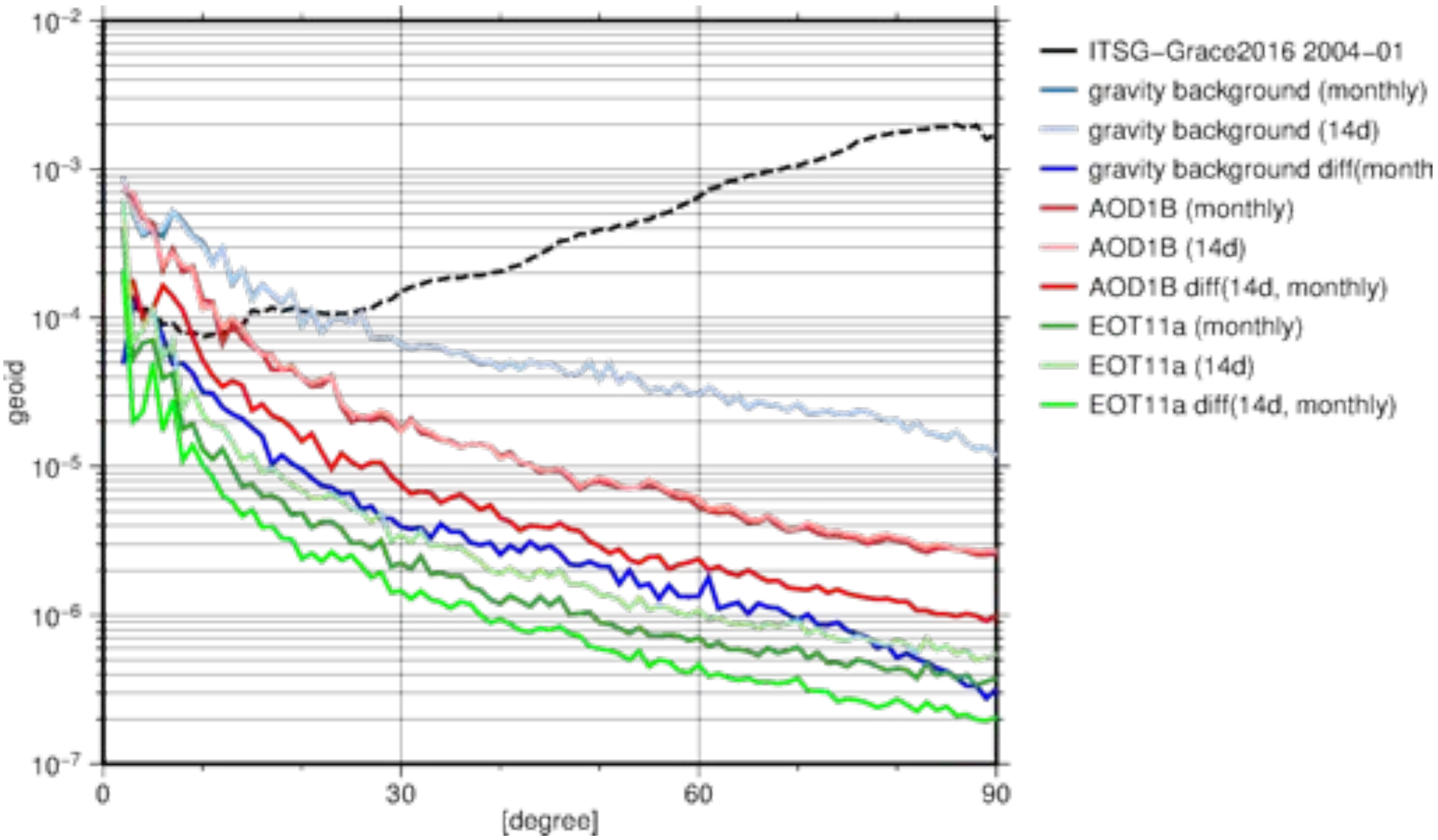
Restoring Background Models

Preliminary L3 Products – Monthly Mean

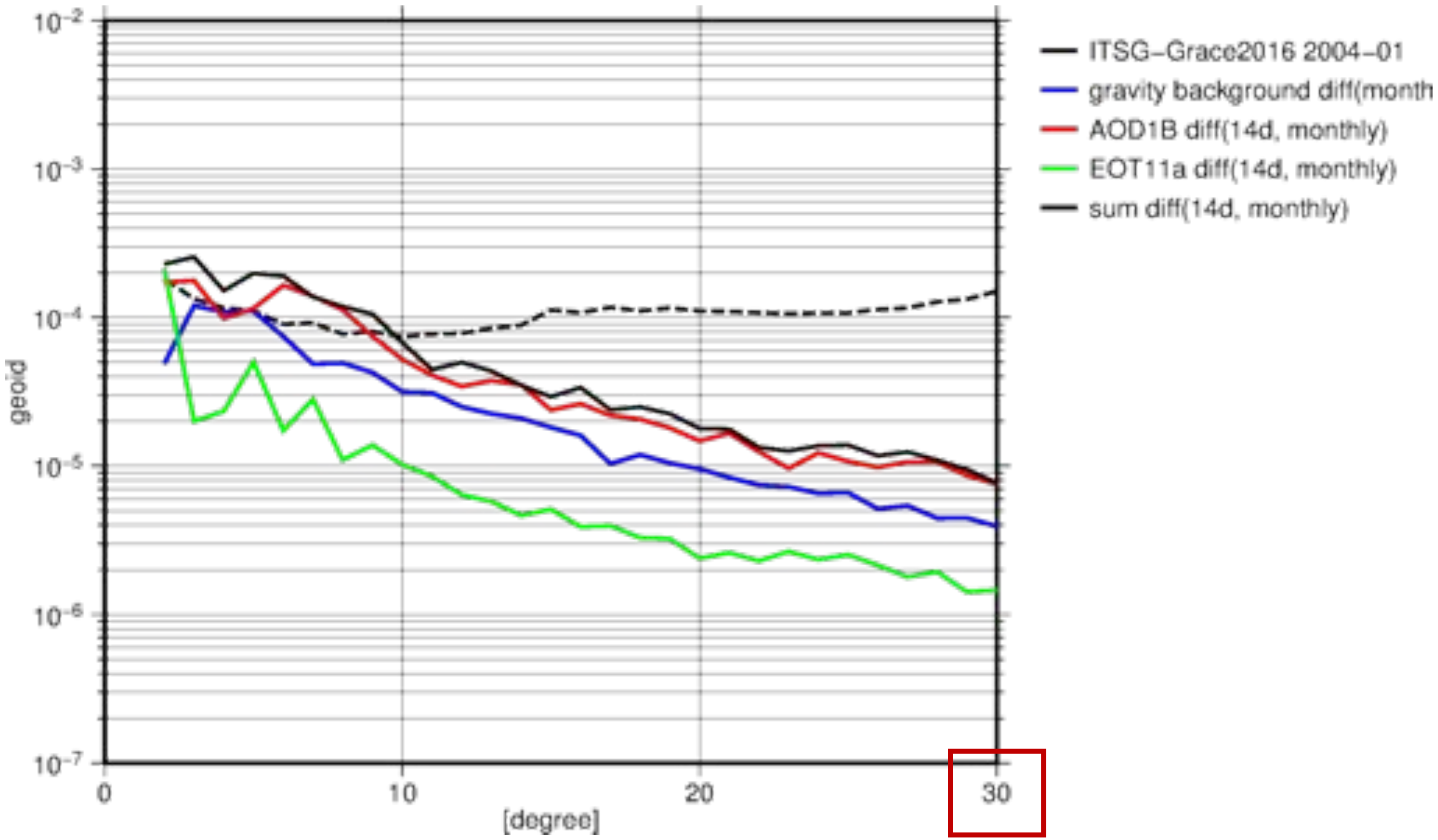
- Multiple ways of restoring background models possible:
  - Whole month
  - Individual days
  - First day with GRACE data till last day with GRACE data (i.e. gaps not considered)

- In extreme cases the difference is significantly higher than the measurement uncertainty

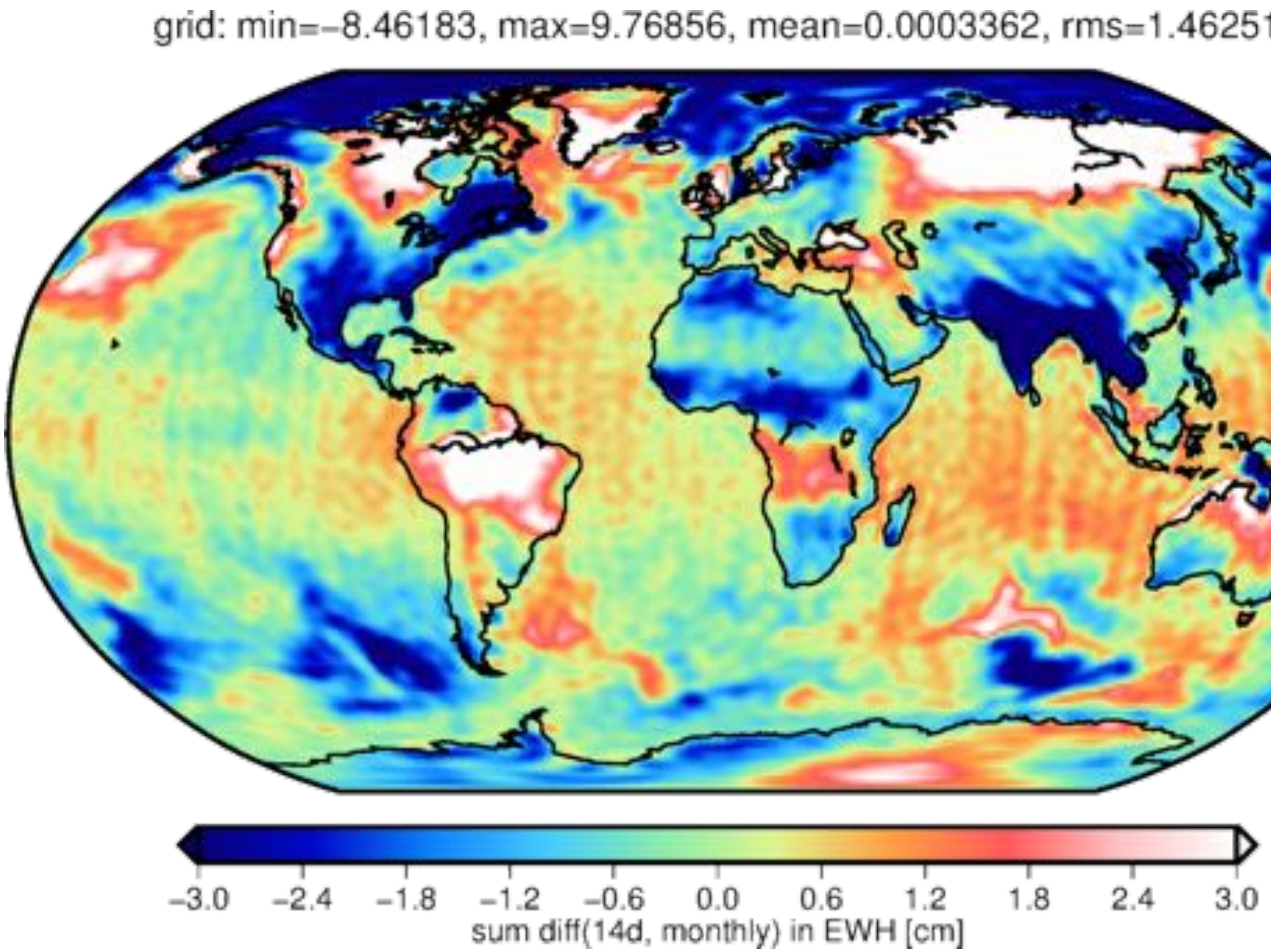
Preliminary L3 Products – Monthly Mean



Preliminary L3 Products – Monthly Mean



Preliminary L3 Products – Monthly Mean



Summary

Summary

- Gridded mass anomalies are available for terrestrial hydrology, cryosphere and ocean applications

- Data sets are **preliminary**
  - Validation feedback and suggestions are welcome

- Points of discussion:
  - C20 replacement
  - Joint inversion with SLR
  - Restoring background models

EGSIEM

European Gravity Service for Improved Emergency Management

Title: **Preliminary L3 Products**

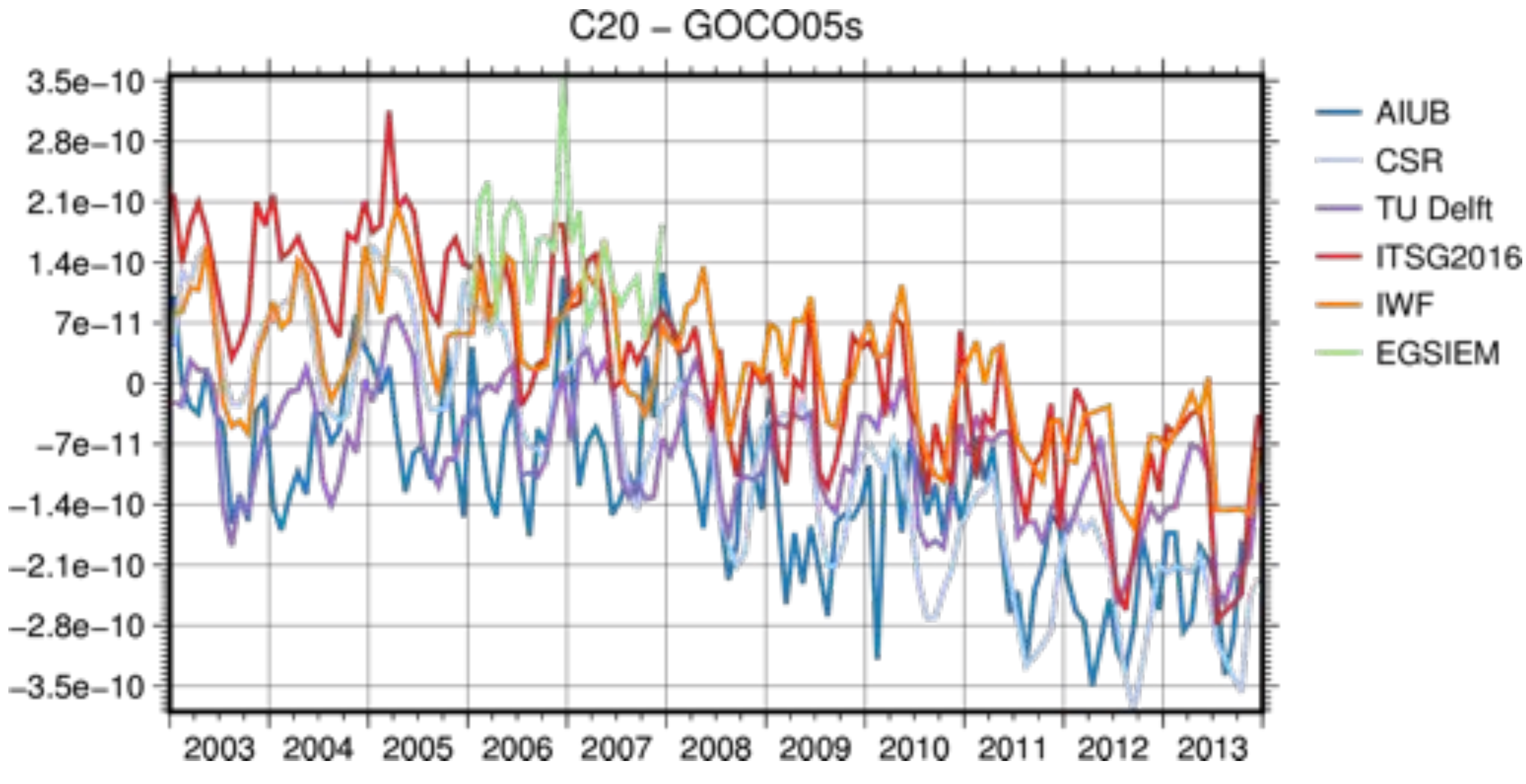
Presenter: AK

Affiliation: TUG

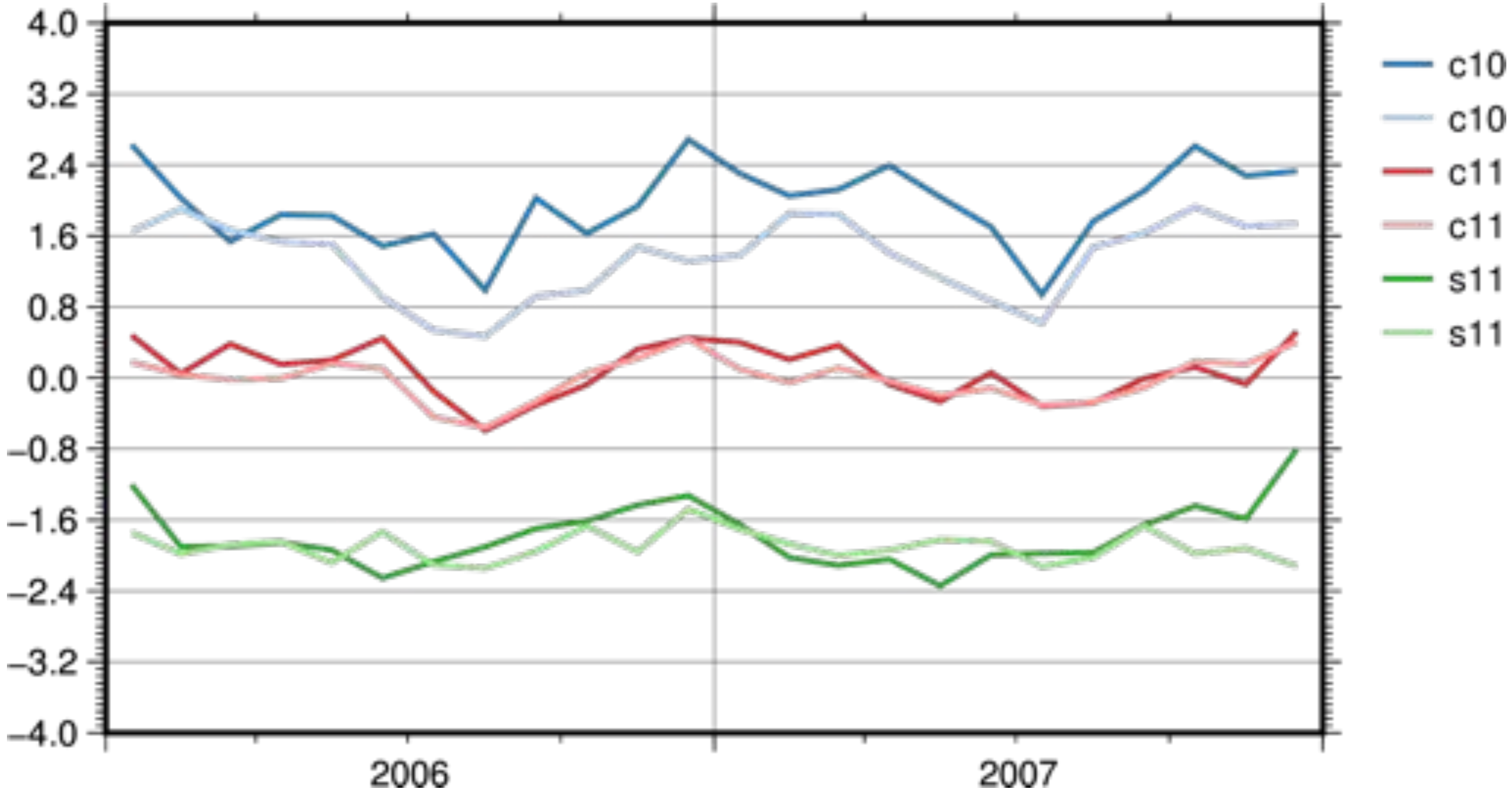
EGSIEM Meeting Bern,
18.01.2017 - 19.01.2017

Universität Bern | Université du Luxembourg | GFZ Helmholtz Centre Potsdam | TU Graz Graz University of Technology | Leibniz Universität Hannover | cnes | DLR | géode & cie | Horizon2020

Preliminary L3 Products – C20



Preliminary L3 Products – Degree 1



WP5 Introduction

European Gravity Service for Improved Emergency Management

- Contributing: TU Graz and GFZ
- Goal: Provide to the Hydrological Service (WP6)
  - Daily and in NRT (<5d) mass redistribution products for all areas of interest
  - Regional gravity solutions with increased spatial resolution
- T5.1 (Requirements and Concept, M01-M03):
  - Deliverable Document D5.1 „Concept of NRT Service" (@M03)
- T5.2 (NRT Solutions, M04-M27):
  - Based on daily Kalman filter modeling (TUG) and Radial Base Functions (GFZ)
  - Reprocessed Solutions for complete GRACE mission period available and provided to partners for validation (GNSS, OBP) and application (Hydrological Service)
  - Important Milestone 1 @M18: Service Readiness (NRT service set up)
  - Important Milestone 2 @M27: Operational NRT Service Readiness (Preparation work for operational NRT Service finished)
  - Upcoming: Deliverable Document D5.2 „NRT Service Product Report" (@M27)

WP5 Introduction

European Gravity Service for Improved Emergency Management

- T5.3 (Operational NRT Solutions, M28-M33):
  - 6 months test run (together with WP6 Hydrological Service) at DLR/ZKI
  - Open: Are GRACE data still completely available between April and September? Impact of reduced L1B quality? Use historical flood events as backup scenario?
- T5.4 (Regional Solutions: Concept and Processing, M04-M27):
  - Not yet completely finished, further work needed till M28
- T5.5 (Generation of Area Mean Values, M19-M36):
  - Area Mean Values have been generated for a number of selected medium to large-scale river basins, which have experienced widespread flooding since the start of the GRACE mission and for which daily discharge observations are available, e.g. the Danube, Rhine, Elbe (Europe), Mississippi (North-America) and Mekong and Ganges-Brahmaputra (South-East Asia).
- T5.6 (Validation/Feedback, M19-M36):
  - Historical events and NRT validation based on GNSS and in-situ/modeled OBP

WP5 Presentations

European Gravity Service for Improved Emergency Management

WP5: NRT & Regional Service

- Introduction to WP5 (FF)
- Status of NRT and Regional Solutions at TUG (AK)
- Status of NRT and Regional Solutions at GFZ (CG)
- Validation of daily NRT time series using OBP data (HD)
- Validation of daily NRT time series using GNSS data (QC)
- Discussion

EGSIEM
European Gravity Service for Improved Emergency Management

WP5: Daily gravity field solutions in near real time

Christian Gruber

EGSIEM General Assembly, AIUB

Jan 19-20, 2017

Outline

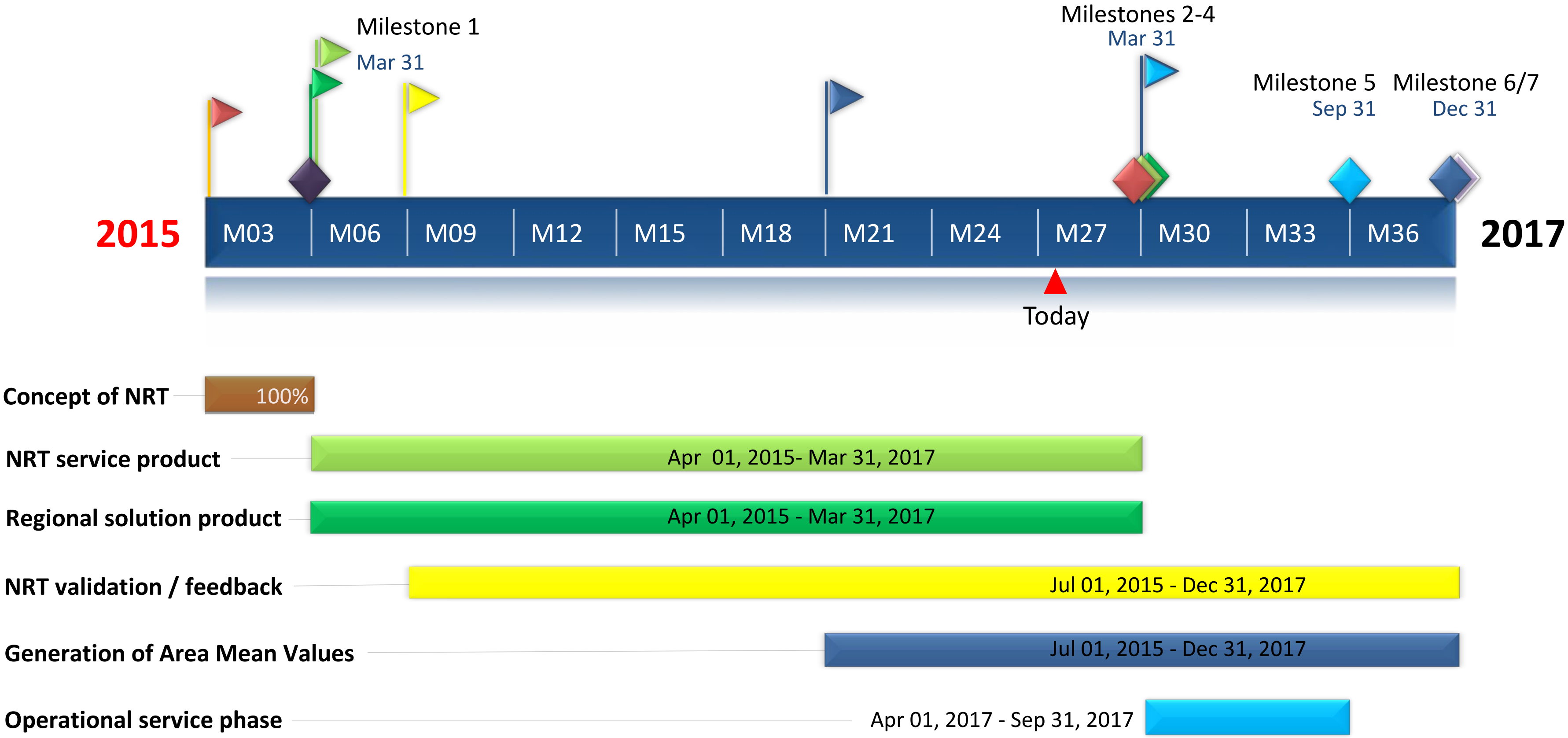
European Gravity Service for Improved Emergency Management

- Project status / milestones
- Radial Basis Functions & Kalman Filtering for daily updates
- Coherence with WGHM

- Near Real time processing
  - Orbit comparison from NRT PRNs, clocks, EOPs
  - Impact on gravity field solution

Project Plan

EGSIEM
European Gravity Service for Improved Emergency Management



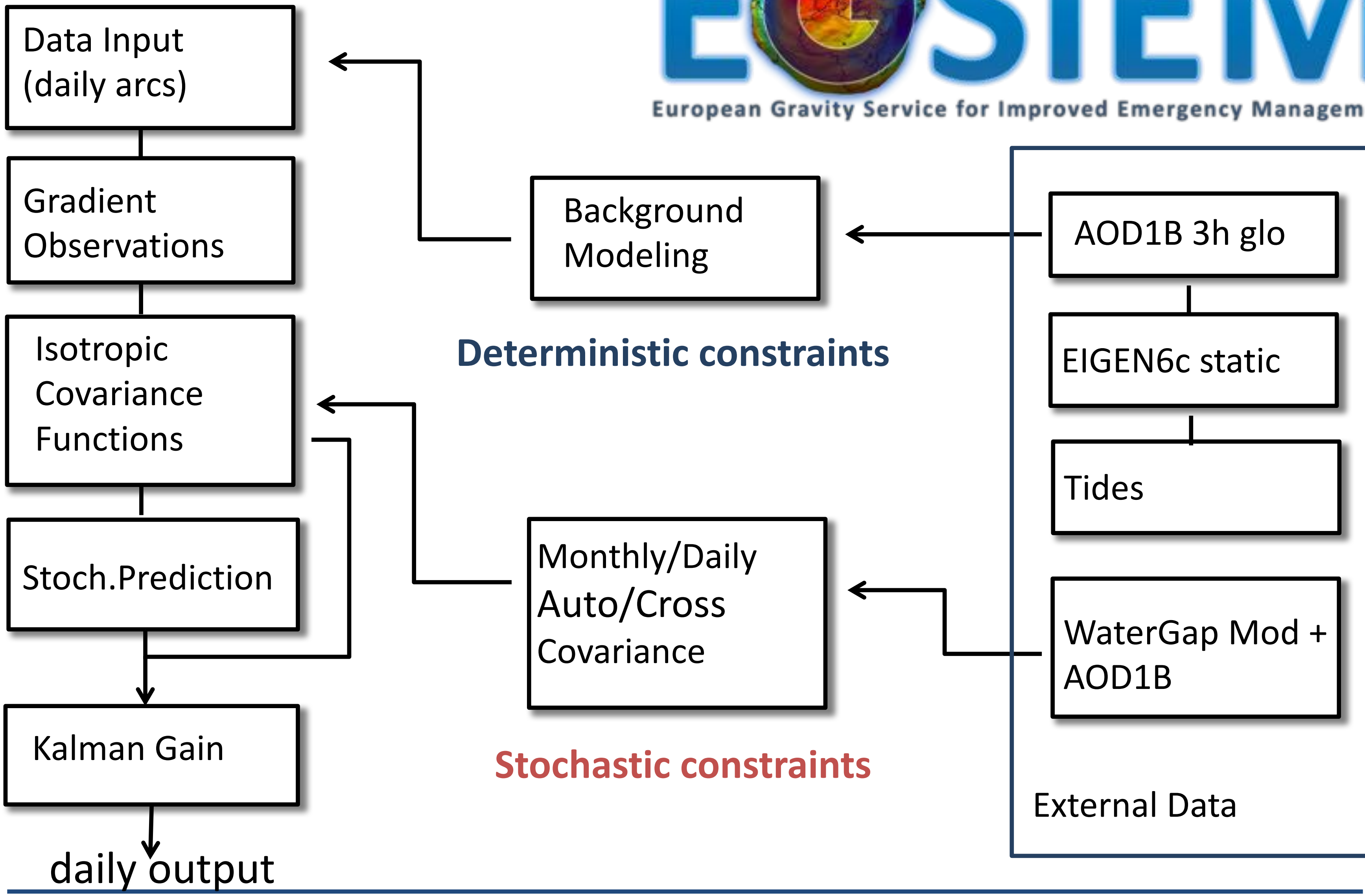
Data and latencies

European Gravity Service for Improved Emergency Management

Product	Source	Current Latency	Required Latency
EOP	IERS/UBERN	IERS: 1-3 days, UBERN: 14 days	IERS: 1-3days, UBERN: **17 hours**
GPS Orbits/Clocks	UBERN (T3.4)	14 days	**17 hours**
GRACE L1B Data	JPL, Backup: GFZ	11 days	**18 hours**
Dealiasing Product (AOD1B)	GFZ	7 days	**2-4 days**
Monthly gravity field (global)	GFZ/ TU Graz	~ 2 month	**3-5 days (Daily products)**
Specific hydrological basin or region (upon request)	WP3/6	not available	additional **1 day**

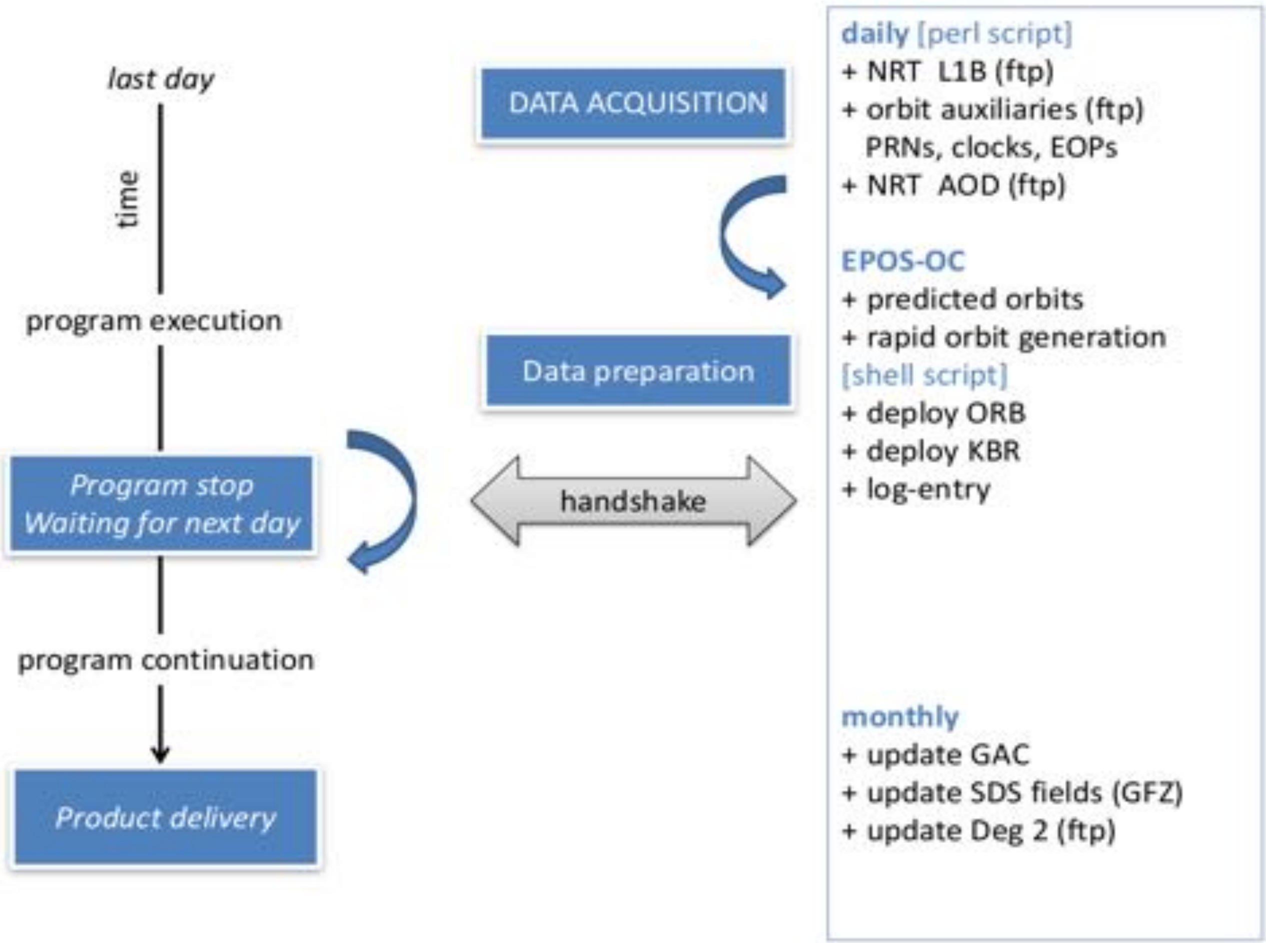
EGSIEM

European Gravity Service for Improved Emergency Management



Service mode

European Gravity Service for Improved Emergency Management



Production-flow

EGSIEM
European Gravity Service for Improved Emergency Management

Last day 24:00

1. GFZ GPS constellations +13:00
   UB: CODE constellations, EOPs +17:00
2. L1B data (KBR, etc.) available +18:00

first day 24:00

3. GFZ: preliminary dynamic orbit **1d**+12:00
4. Stochastic prediction **1d**+18:00

second-fourth day 00:00

5. 3-hourly AOD1B **4d**+8:00
6. GFZ: final dynamic orbit (iterated) **4d**+12:00
   TUG: kinematic orbit
7. final Kalman update step **4d**+12:00
8. plausibility test/ evaluation **4d**+16:00
9. grid release /SH –coefficients **4d**+18:00

GFZ daily solutions

EGSIEM
European Gravity Service for Improved Emergency Management

- Scalar gradient differences from GPS velocities and K-Band accelerations
- Outlier detection (strongly reduced)
- Accelerometer drifts: currently removed by high-pass filtering
- de-correlation length: 2.5 x orbital revolution
- Background modeling (average time-variable model)
  - break points for the linear fits are 2005/01, 2008/06, 2011/03 (Earth quake events)
- Process model derivation is based on
  - hydrology (WGHM), GAC and 15 years of GRACE
  - specific masks for individual contributions, e.g. north/southern hemisphere, land-ocean decoupling, distant dependent damping
  - monthly updated isotropic covariance functions

  \+ additional rms errors on diagonal ca. 1.5cm
- Process covariance is derived in spatial domain

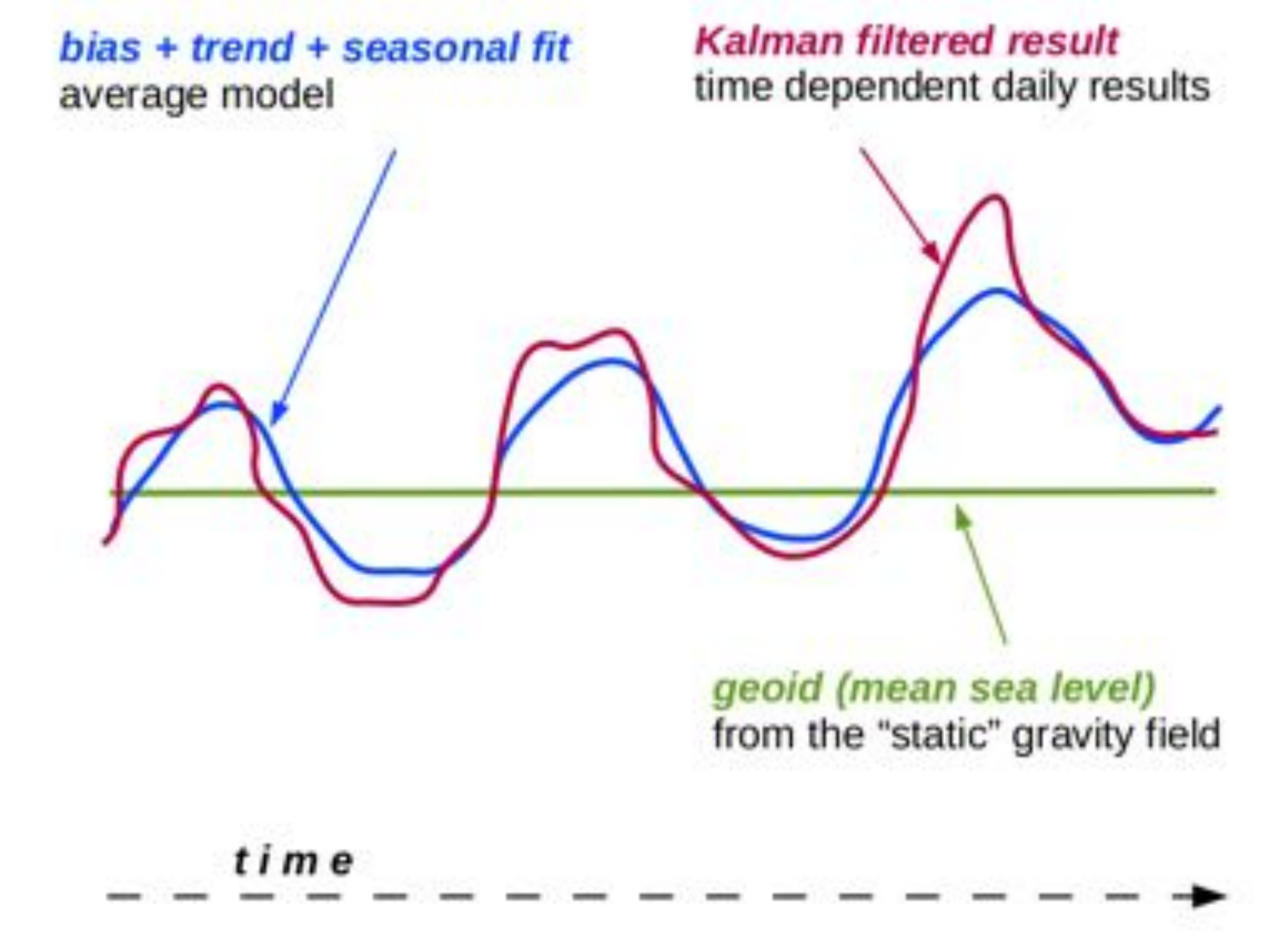
Linear Equation Systems

European Gravity Service for Improved Emergency Management

- integration grid (2x2 deg equal areal): 10540 surface tiles
- conversion between surface grid respresentations
- radial basis functions assembly in observation points
- covariance - estimation
  - observation de-correlations
  - external auto/cross covariances for stochastic prediction
- Stochastic prediction
- Daily Kalman filtering
- monthly inversion (under revision for lesser constraining)

Daily Kalman Filter

EGSIEM
European Gravity Service for Improved Emergency Management



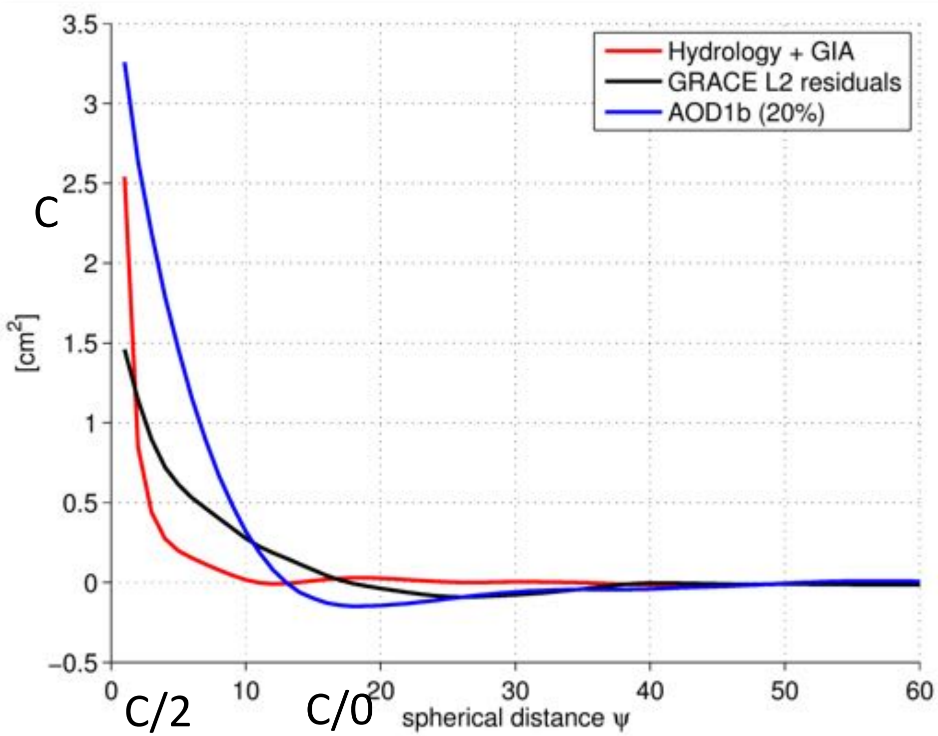
Background models

- Ocean tides (EOT11a),
- Atm tides S1,S2 (Bode/Biancale)
- Solid Earth & Pole Tides (Desai)
- 3rd body ephemerides (JPL de421)
- EOP's, GPS clock's / PRN's (EGSIEM, Susnik et al.)
- AOD1B (RL5 → RL6)
- **Bias/ trend and annual signal fit with respect to EIGEN-6C**
- **Stochastic modeling**, built of: GAC (2002-2016), WGHM (2002-2013) and GRACE RL05a (2002-2016)

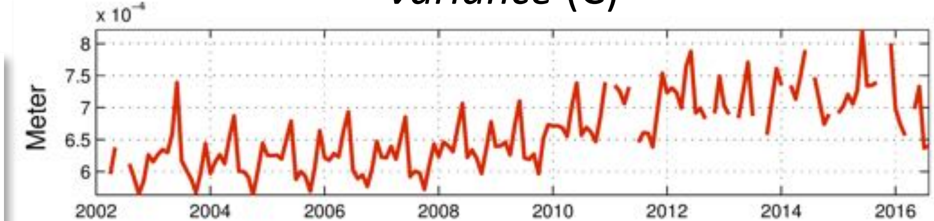
Process covariances

EGSIEM

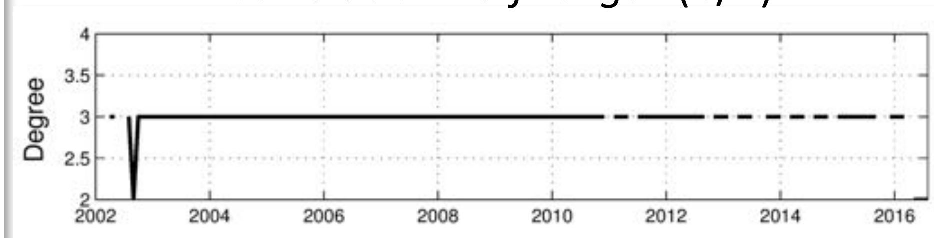
European Gravity Service for Improved Emergency Management



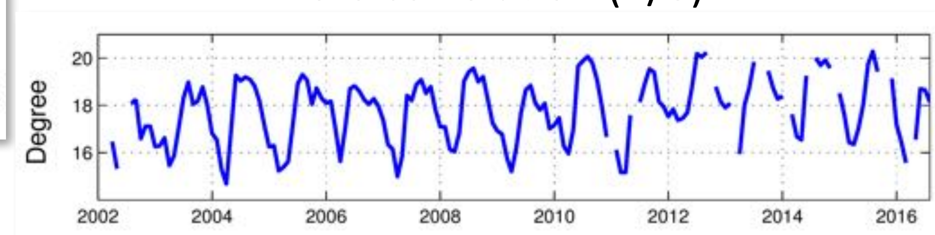
variance (C)



correlation half-length (C/2)



zero correlation (C/0)



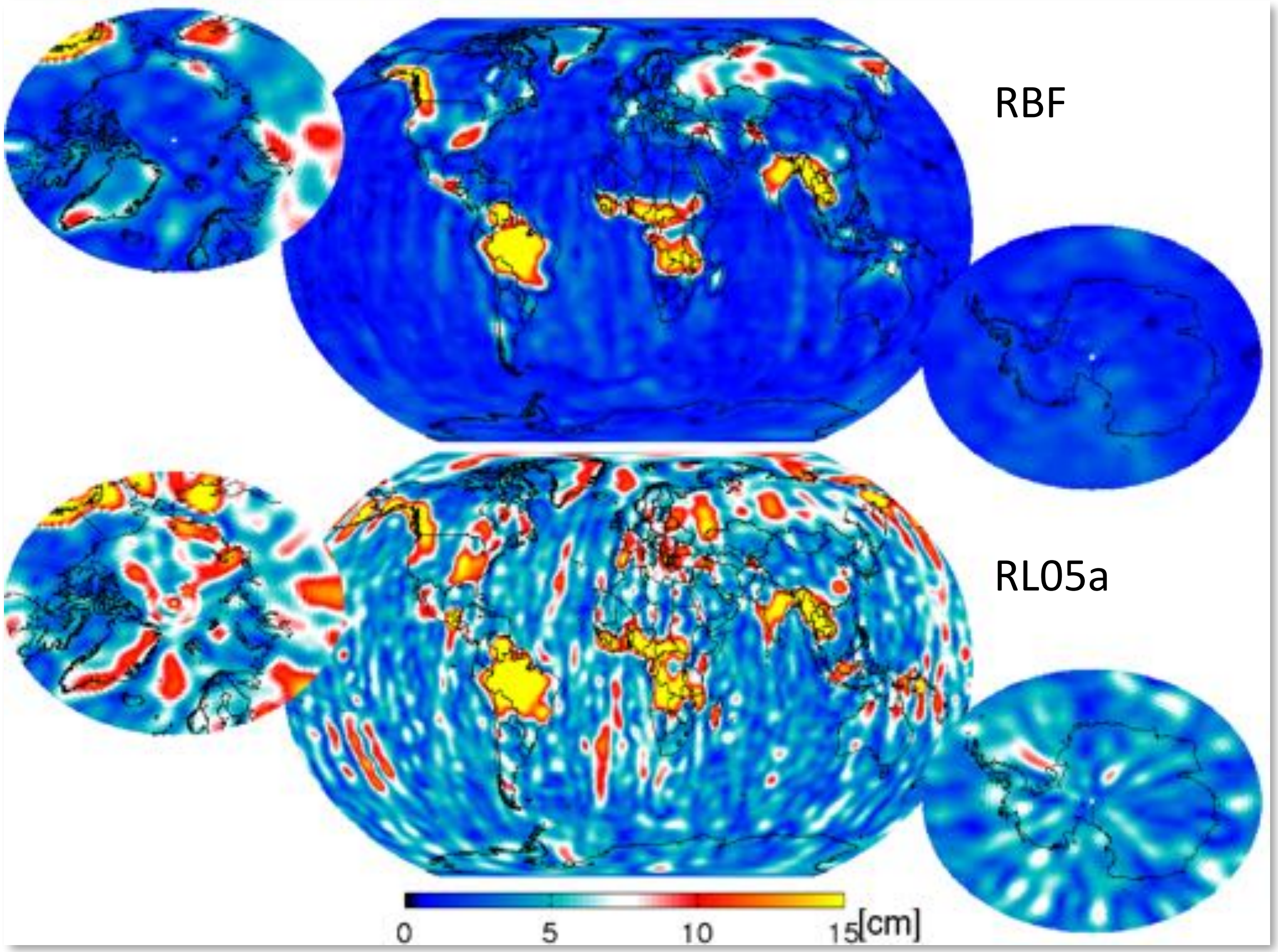
Output products

European Gravity Service for Improved Emergency Management

- Global daily solution on 2x2 deg grid (water equivalent)
- Global 2x2 deg operational average model
- 1x1 deg grid regional product for defined areas of interest (not yet available)
- error estimates for the grid values

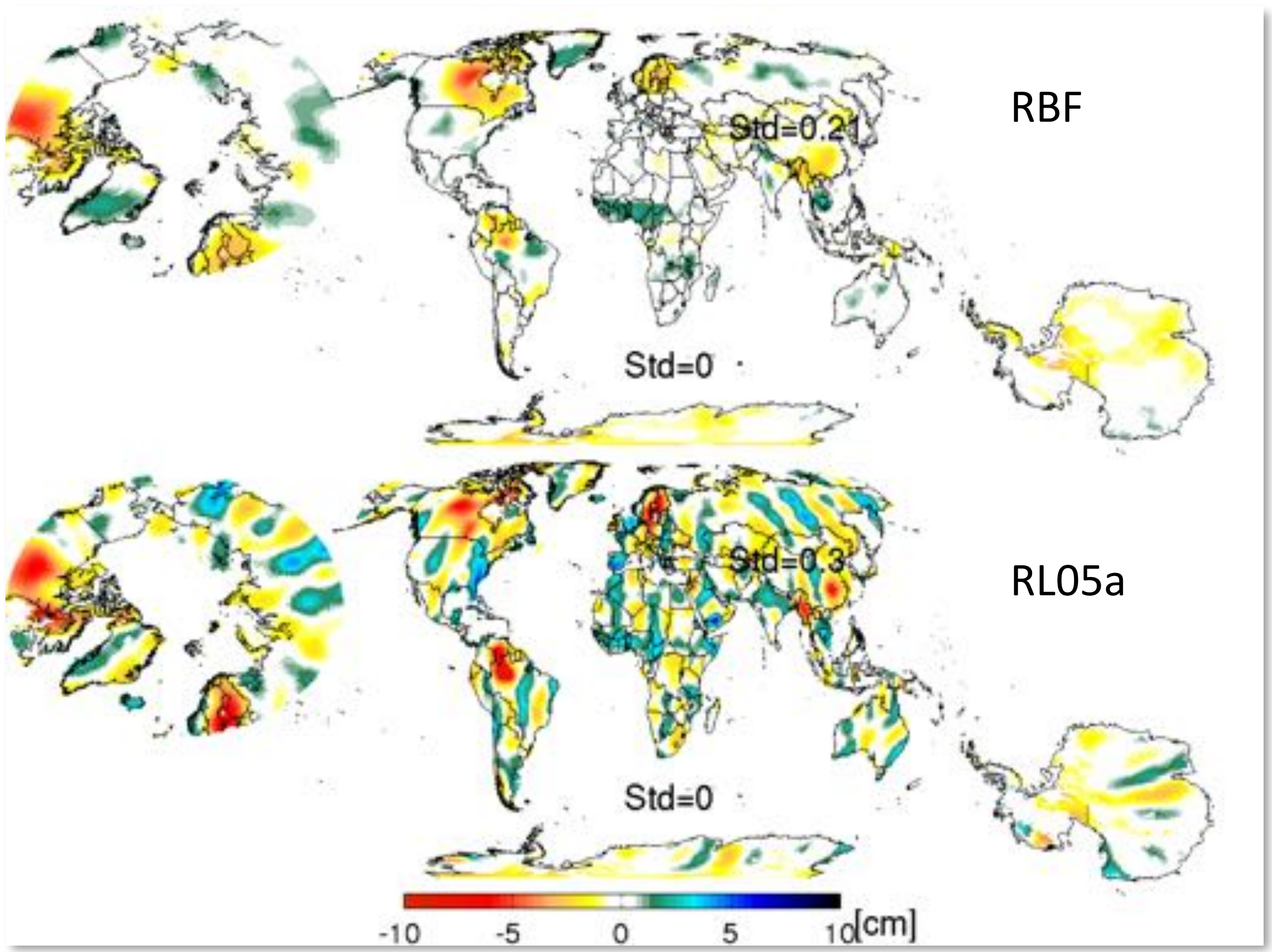
RMS (2002)

EGSIEM
European Gravity Service for Improved Emergency Management



Trend (2002)

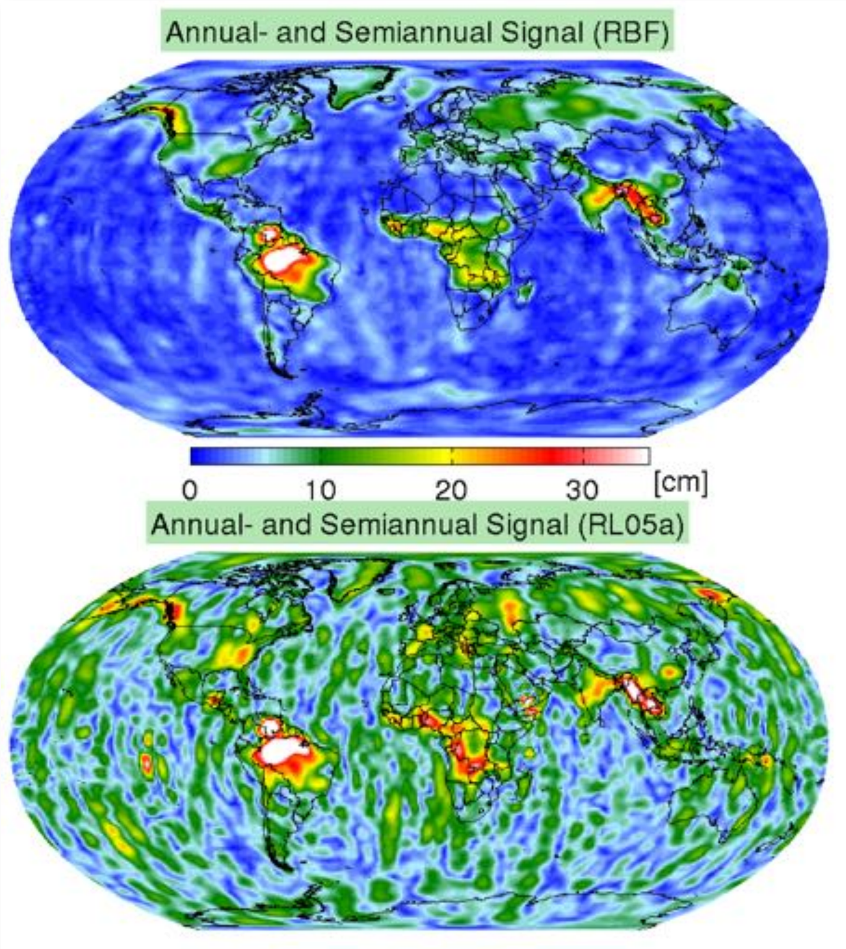
European Gravity Service for Improved Emergency Management



RBF

RL05a

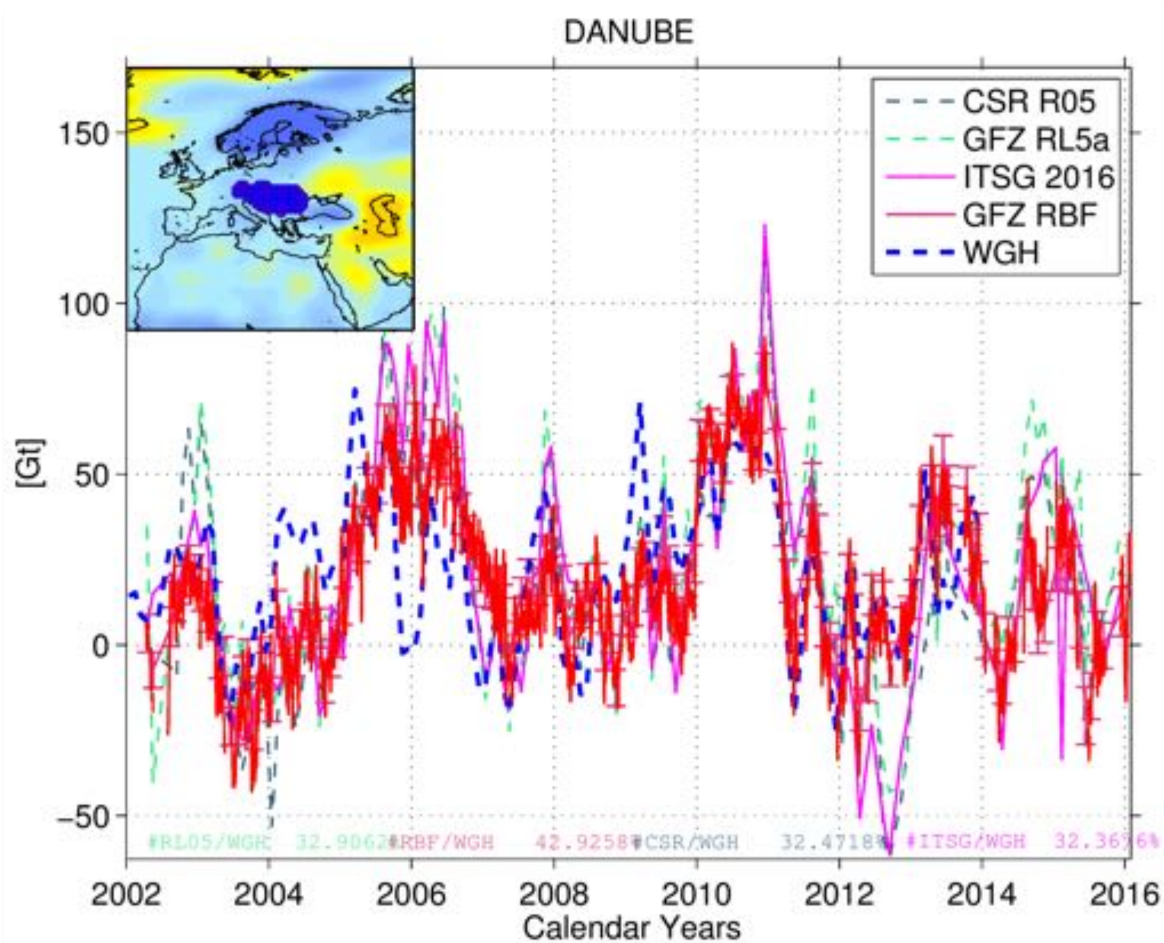
Annual-/Semi year (2002)



European Gravity Service for Improved Emergency Management
HORIZON 2020

WGHM Coherence

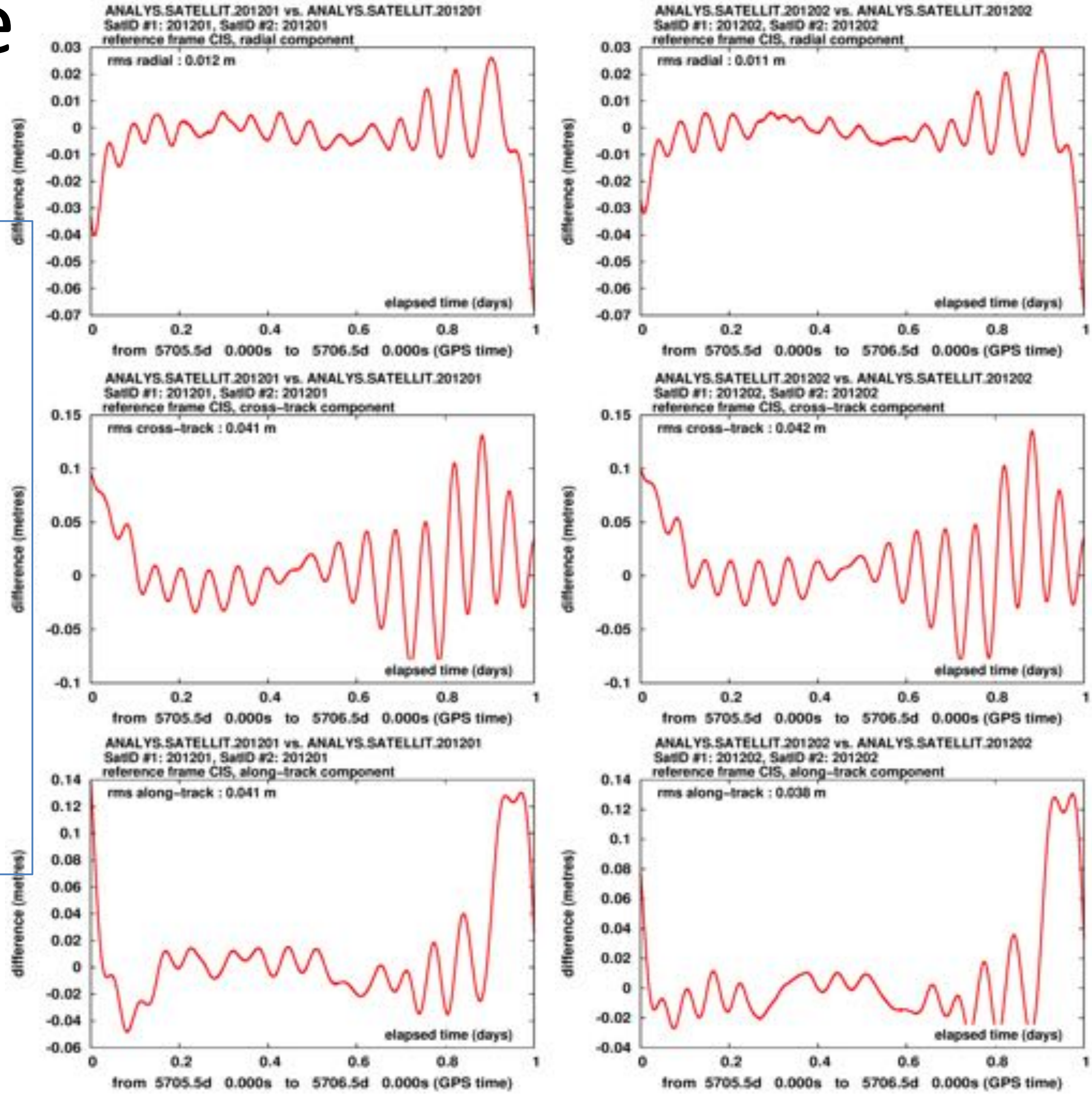
De-seasoned (annual/semi annual) time Series



Near Real Time ORBIT

- NRT clocks & GPS constellation from AIUB
- EOPs (AUIB)
- Iterative orbit fit to GPS /observations & K-Band
- substantial differences to original in the respective components (RTN-system)

  3D- orbit : several [cm]
- However, the GPS base-line is in a fair agreement



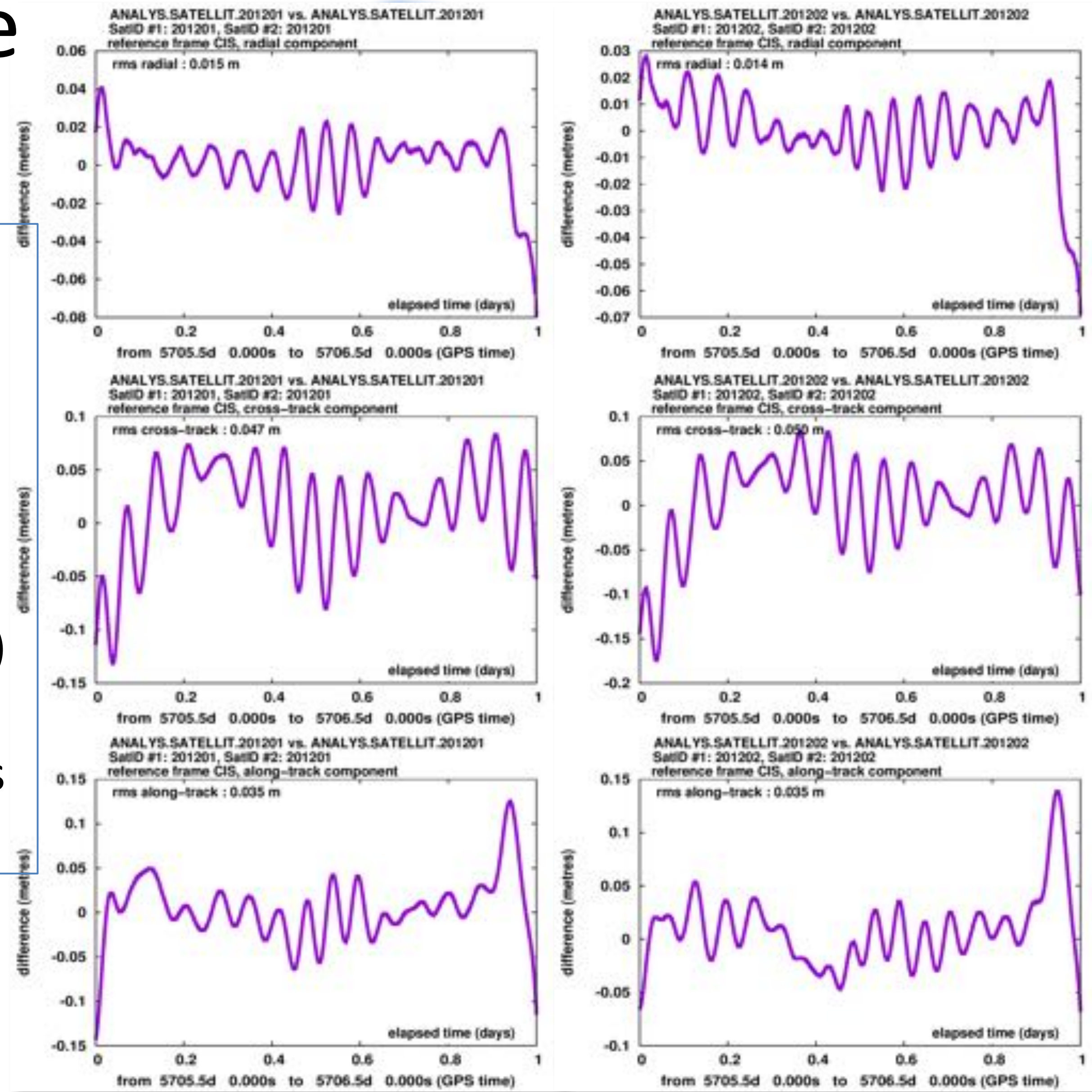
GRACE A

GRACE B

Near Real Time ORBIT

- NRT clocks & GPS constellation from AIUB
- Predicted EOPs (BGI)
- Iterative orbit fit to GPS /observations & K-Band
- substantial differences to original in the respective components (RTN-system)

  3D- orbit : several [cm]
- Again, the GPS base-line is in a fair agreement



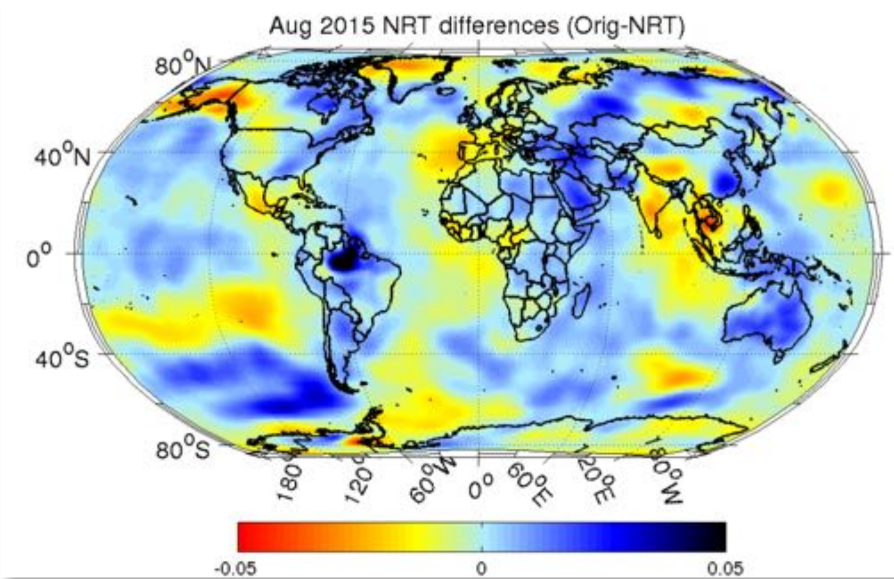
GRACE A

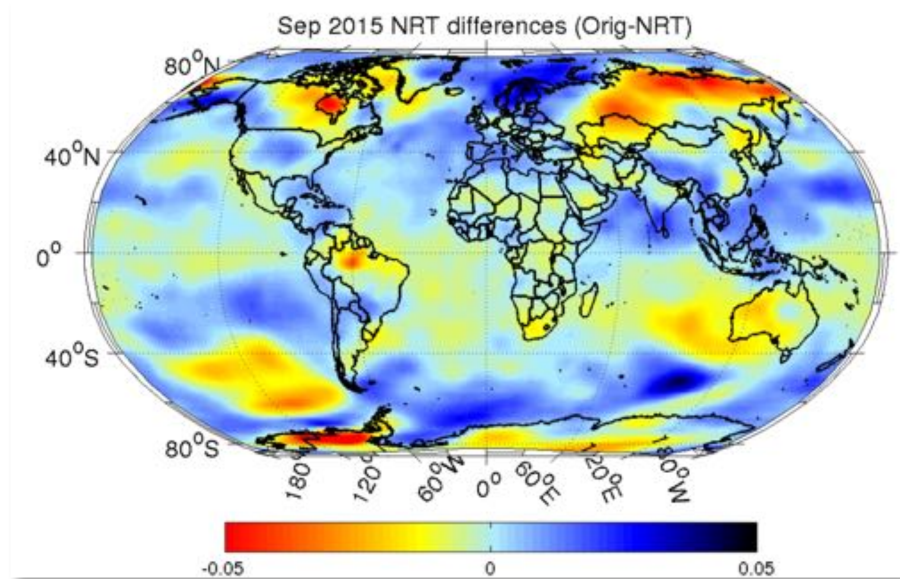
GRACE B

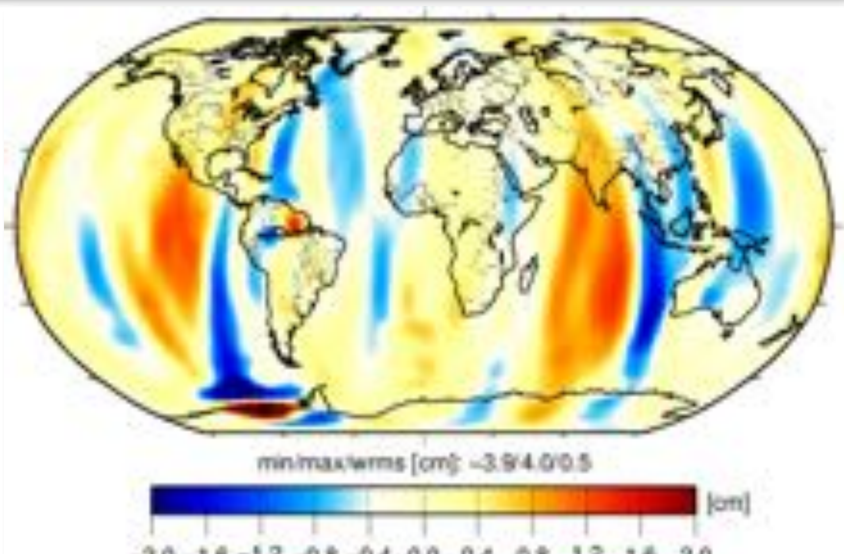
HORIZON 2020

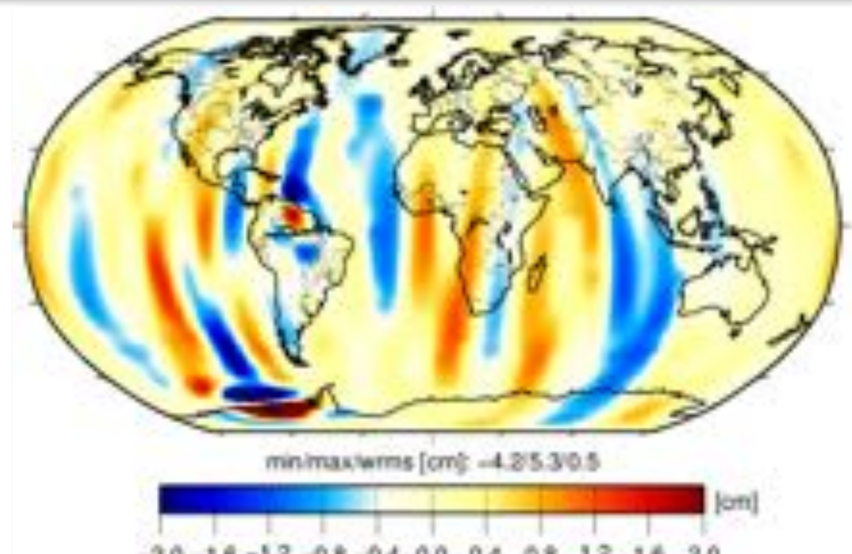
Differences caused by NRT- orbits

EGSIEM
European Gravity Service for Improved Emergency Management









Outlook

European Gravity Service for Improved Emergency Management

until operational readiness (M27):

- Minimize differences between NRT input data vs. standard data processing, work is ongoing
- Investigate the impact of the iterated dynamic orbit using the actual (Kalman) day against using the average background model
- comparisons of (Kalman) regularized solutions w.r.t standard monthly (SDS) fields
- Minor fixes (grid conversions, process model derivation) → /v201
- Compute the regional refinements (1 x 1 deg) in selected basins

Grace RBF results are accessible:

Index of ftp://egsiem@gfzop.gfz-potsdam.de/v200/

Up to higher level directory

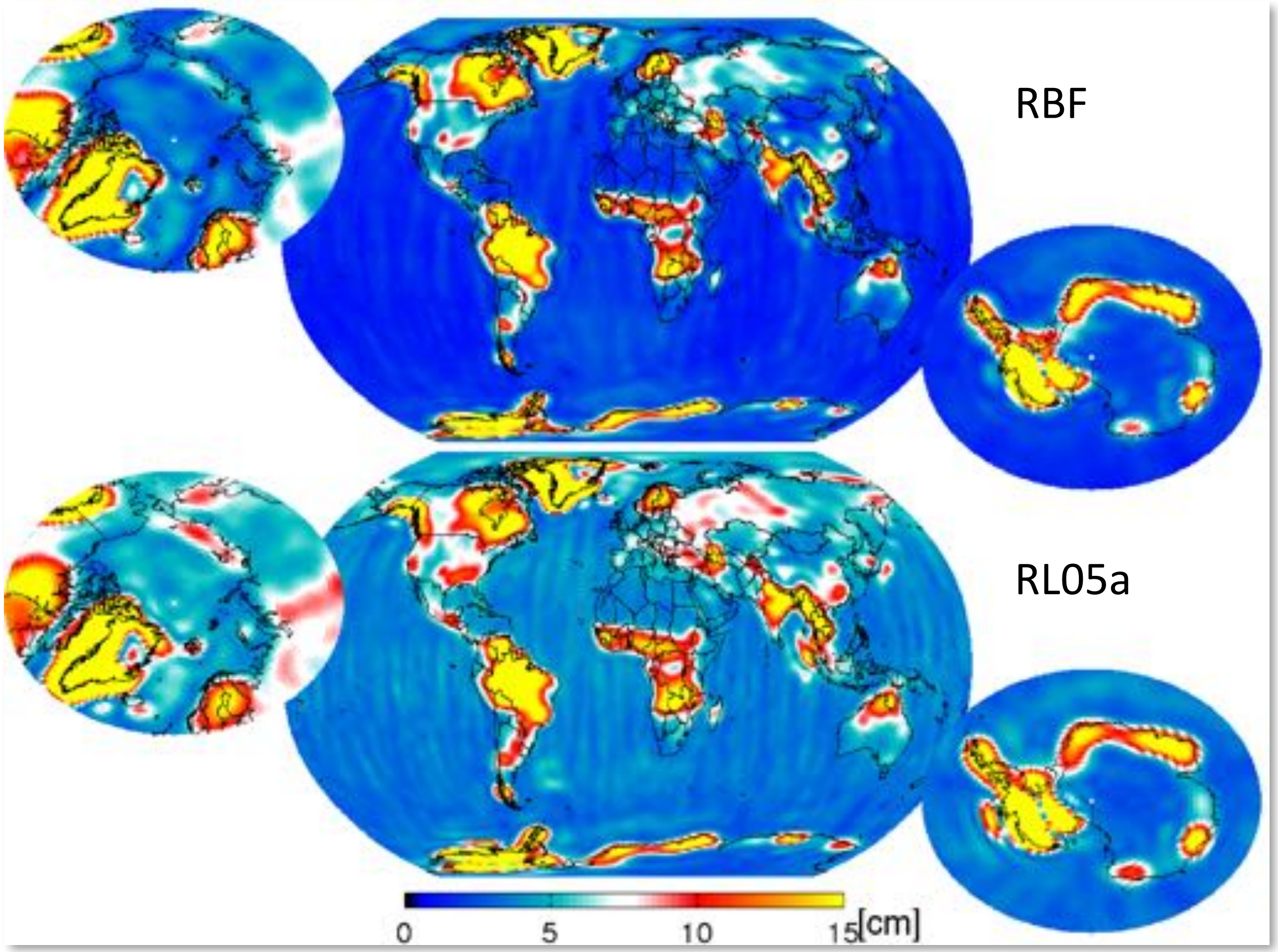
Name	Size	Last Modified	
2002		12/15/2016	09:50:00 AM
2003		12/15/2016	03:37:00 PM
2004		12/17/2016	12:31:00 PM
2005		12/18/2016	10:09:00 AM
2006		12/19/2016	07:29:00 PM
2007		12/21/2016	08:25:00 AM
2008		12/22/2016	05:36:00 PM
2009		12/25/2016	11:38:00 AM
2010		12/25/2016	04:03:00 PM
2011		12/26/2016	04:31:00 PM
2012		12/28/2016	10:03:00 AM
2013		12/29/2016	09:59:00 AM
2014		12/30/2016	09:22:00 AM
2015		12/31/2016	09:51:00 AM
2016		12/31/2016	10:00:00 AM

European Gravity Service for Improved Emergency Management

Thanks for your attention!

Global RMS

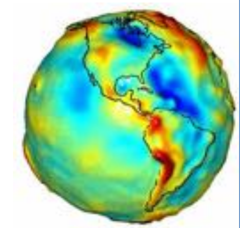
European Gravity Service for Improved Emergency Management



RBF Status

EGSIEM

European Gravity Service for Improved Emergency Management



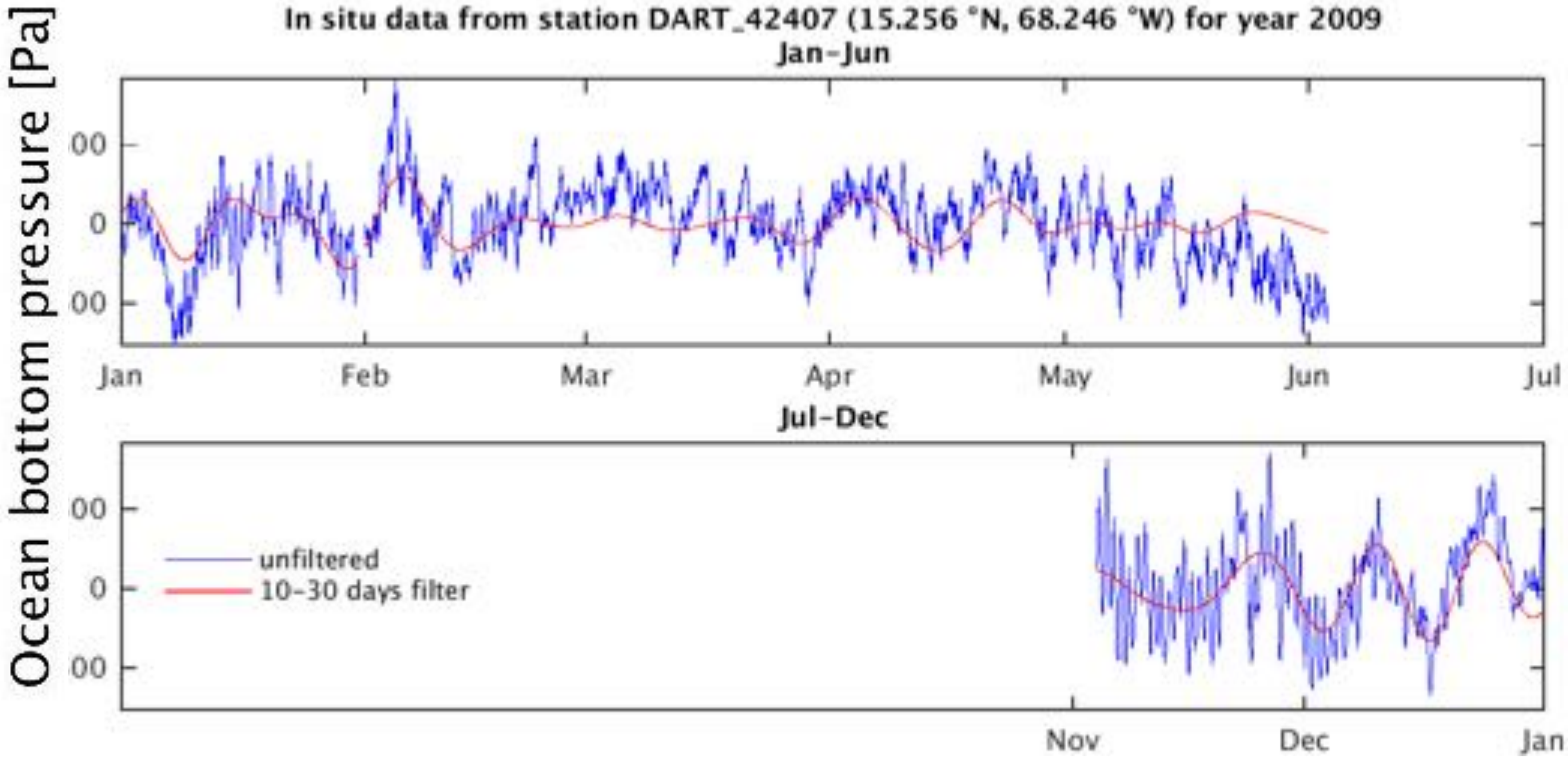
- Kalman/RBF time series of available GRACE days has been produced!
- main keys to success:
  - observation de-correlation reduced to < 2.5 rev.
  - vast limitation of outliers: only very few observations are discarded
  - accelerometer pre-processing for all 3 axis (high-pass)
  - modifications of the process model (stability)
- interfaces for NRT service readiness are developed
  - ftp, shell/perl scripts, conversions, formatings, etc.

Validation of Daily GRACE Time-Series with in situ Ocean Bottom Pressure Observations

Henryk Dobslaw and Lea Poropat

GFZ Potsdam
Department 1: Geodesy
Section 1.3: Earth System Modelling

Introduction



1. Validation of ocean model experiments for AOD1B
2. Validation of quasi-daily GRACE gravity field solutions:
- **ITSG-Grace2016_Kalman**
- **GFZ daily RBF solutions v100 & v200**

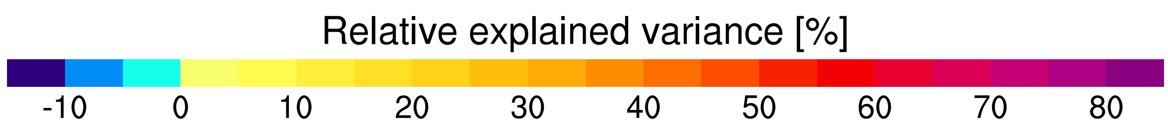
Validation Metric: Rel. Explained Variance

pressure (anomaly) observed by in situ OBP gauge

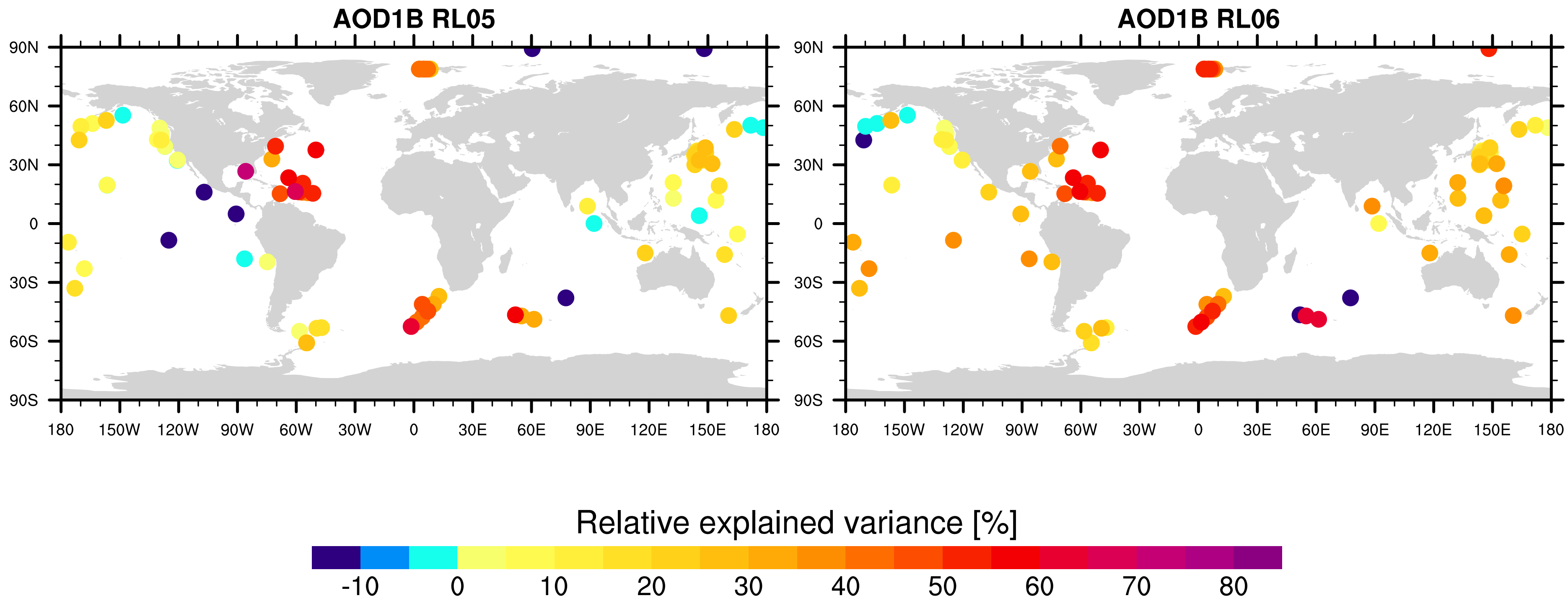
pressure (anomaly) predicted by a numerical model / gravity field model

$$\mathrm{exp_p} = \frac{< \mathrm{p_o^2} > - < (\mathrm{p_o} - \mathrm{p_m})^2 >}{< \mathrm{p_o^2} >}$$

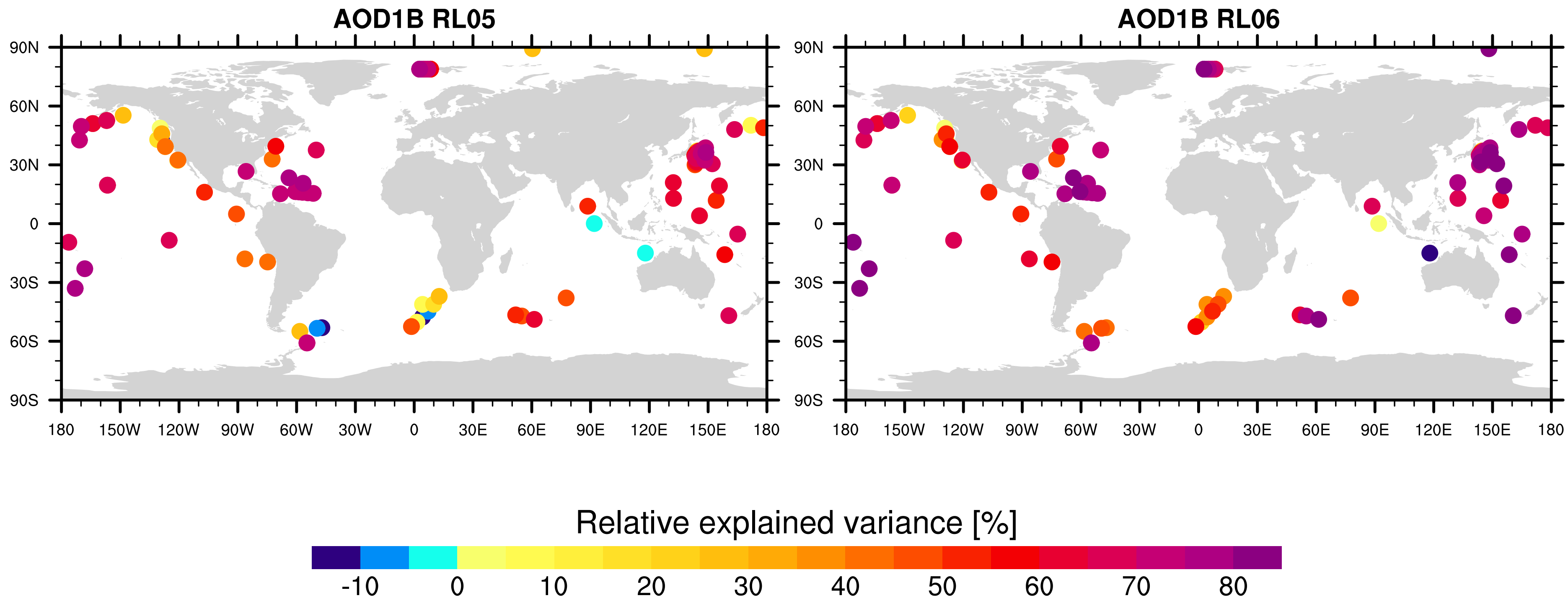
fraction of variance of the observation explained by the model



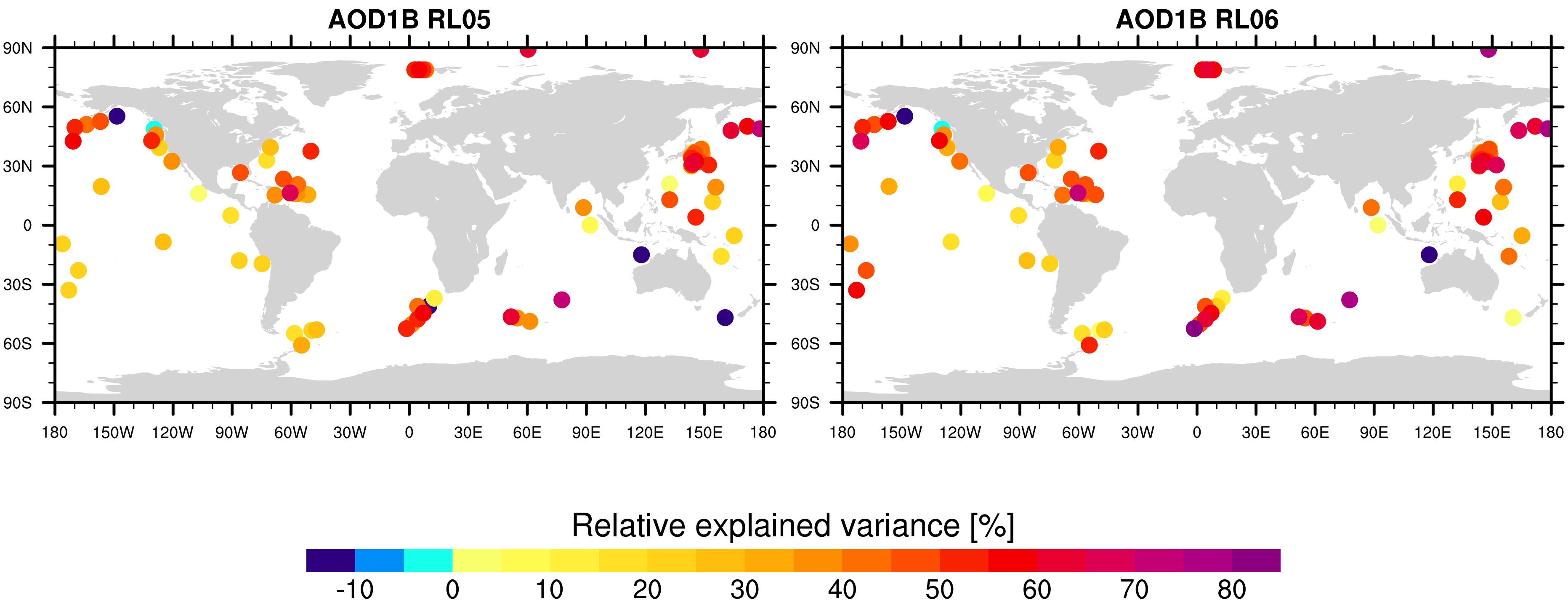
AOD1B: High-Frequency Signals (≤ 3 days)



AOD1B: Weekly Signals (3 – 10 days)



AOD1B: Sub-Monthly Signals (10 – 30 days)



Status of AOD1B RL06

- AOD1B RL06 processing is completed (1976 – 2017)
- 3h sampling; d/o=100 until 1999, d/o=180 since 2000
- improved long-term stability: no GAE/GAF products required
- tidal signals at 12 frequencies are provided in separate sets of coefficients (i.e. sin/cos terms per frequency)
- AOD1B RL06 Documentation already available at ISDC & PO.DAAC:

  ftp://isdcftp.gfz-potsdam.de/grace/DOCUMENTS/Level-1

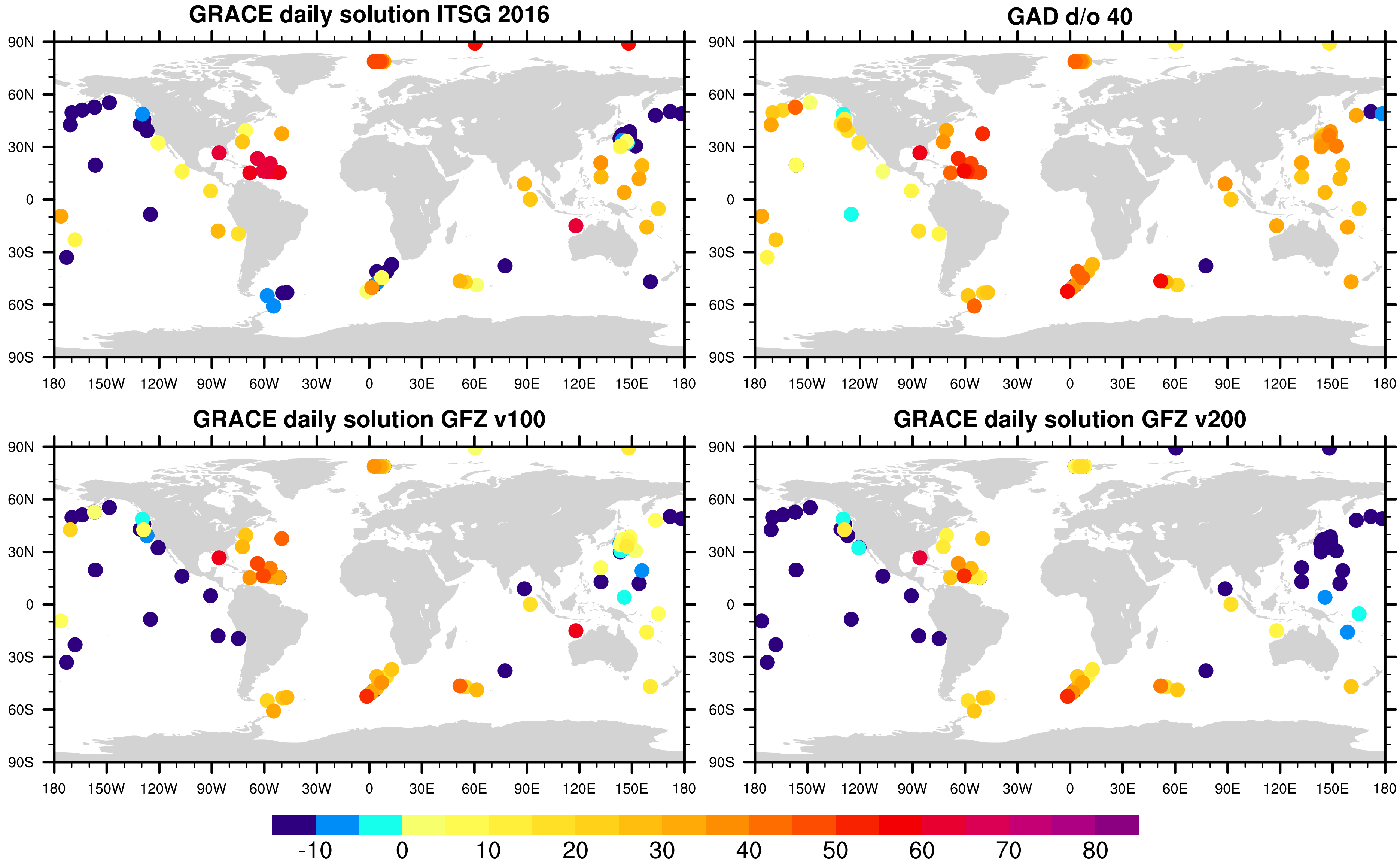
- Daily updates at about 11:00 UTC for the previous day
- AOD1B forecasts (3h; d/o=50; no upper-air signals) are processed daily for 6 days into the future

  http://www.gfz-potsdam.de/en/esmdata/

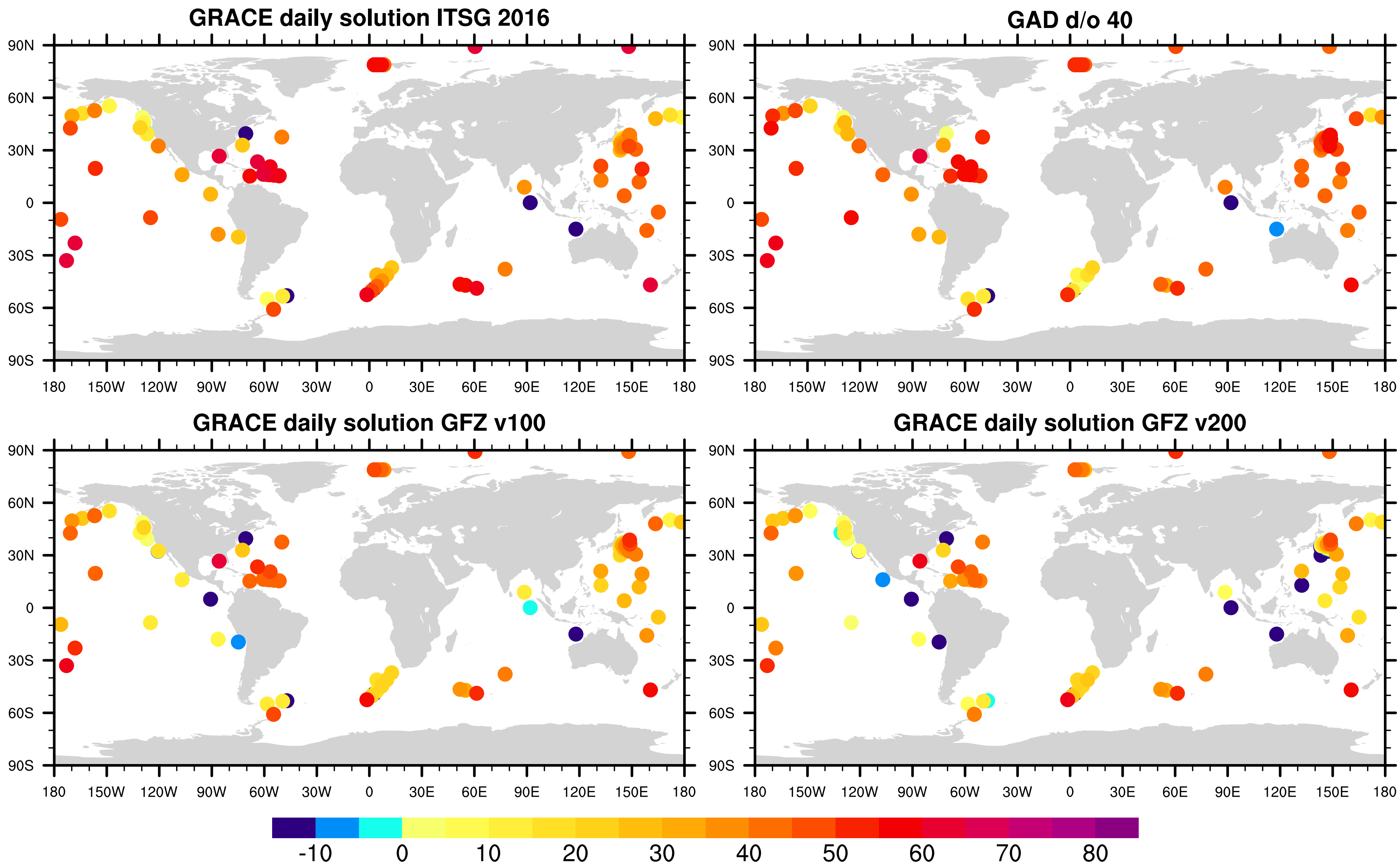
GRACE Level-2 Post-processing

	ITSG-Grace2016 Kalman n=40	GFZ daily RBF solutions v100 & v200
• replace C20 from SLR	-	-
• subtract a priori GIA model	X	-
• approximate degree-1 (Swenson et al., 2008)	X	-
• apply DDK-x filter (Kusche et al., 2009)	-	-
• reduce continental leakage (Wahr et al., 1998)	-	-
• add GAD product removed during De-Aliasing	X	(X)
• synthesize to grid	X	-
• fit & remove time-mean & trend	X	X

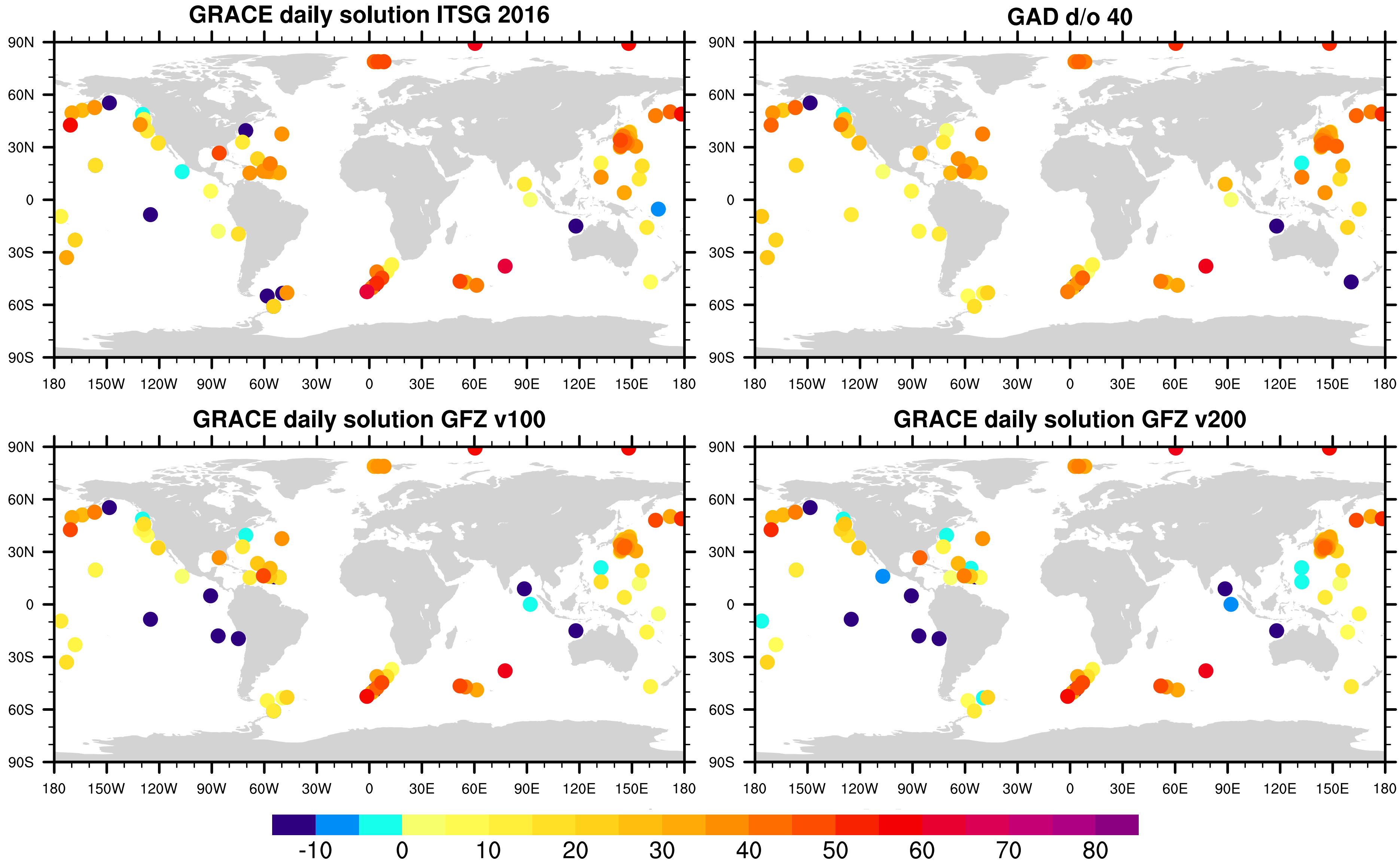
GRACE: High-Frequency Signals (1 – 3 days)



GRACE: Weekly Signals (3 – 10 days)



GRACE: Sub-Monthly Signals (10 – 30 days)



Summary

- in situ OBP database maintained at GFZ contributes to the validation of both AOD1B and GRACE gravity field time-series
- ITSG-Grace2016_Kalman has skill wrt. AOD1B_RL05/GAD in particular at higher latitudes and at weekly periods and longer
- GFZ daily RBF solutions are more noisy wrt. ITSG-Grace2016_Kalman, but might benefit from a specifically tailored post-processing not yet available
- GFZ daily RBF v100 performs better than v200 in terms of OBP in situ validation

ftp://isdcftp.gfz-potsdam.de/grace/DOCUMENTS/Level-1

http://www.gfz-potsdam.de/en/esmdata/

- Back Up -

Release 05 (2012)	Release 06 (2017)
1976 – 2016, 6 hourly, d/o = 100	1976 – 2016, 3 hourly, d/o = 180
ERA-40 (1976 – 1978); ERA-Interim (1979 – 2000); op. ECMWF (since 2001)	ERA-40 (1976 – 1978); ERA-Interim (1979 – 2006); op. ECMWF (since 2007)
tidal signals included and partly aliased (S2 standing wave pattern)	tidal signals estimated and removed for S1, S2, S3, M2 + annual modulations
no reference orography for surface pressure anomalies	surface pressure reduced to op. ECMWF orography from 2014
OMCT (Thomas et al. 2001), configuration R10L20; 6 hourly atmospheric forcing	MPIOM (Jungclaus et al. 2013), code revision #3932; configuration TP10L40; 3 hourly forcing; modifications to source code based on OMCT experience
ocean dynamics beneath Antarctic iceshelves with Padman et al. (2002) bathymetry	no ocean signals beneath iceshelves included

EGSIEM

European Gravity Service for Improved Emergency Management

WP5. NRT and regional Service

Validation of daily GRACE products and preparation for NRT

Qiang Chen

Faculty of Science, Technology and Communication

University of Luxembourg

EGSIEM Progress Meeting # 4

January 19 – 20, 2017

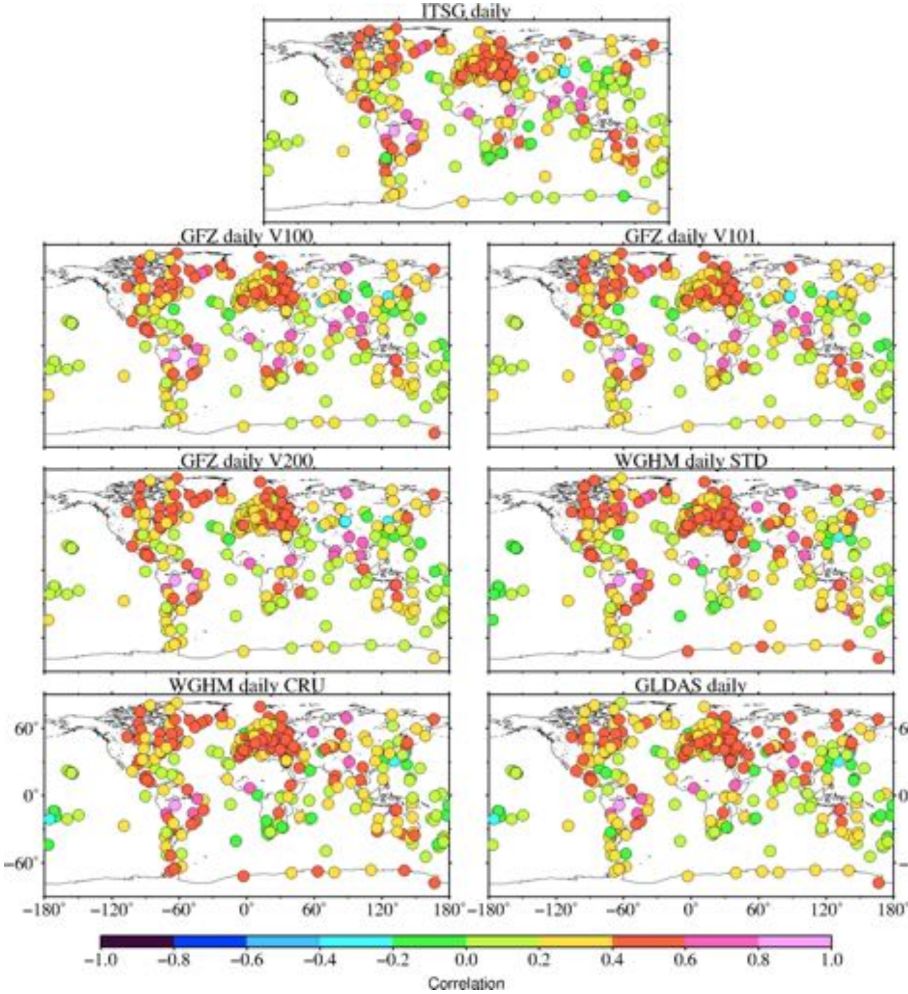
Universität Bern · Université du Luxembourg · GFZ Helmholtz Centre Potsdam · TU Graz · Leibniz Universität Hannover · cnes · DLR · géode&cie · HORIZON 2020

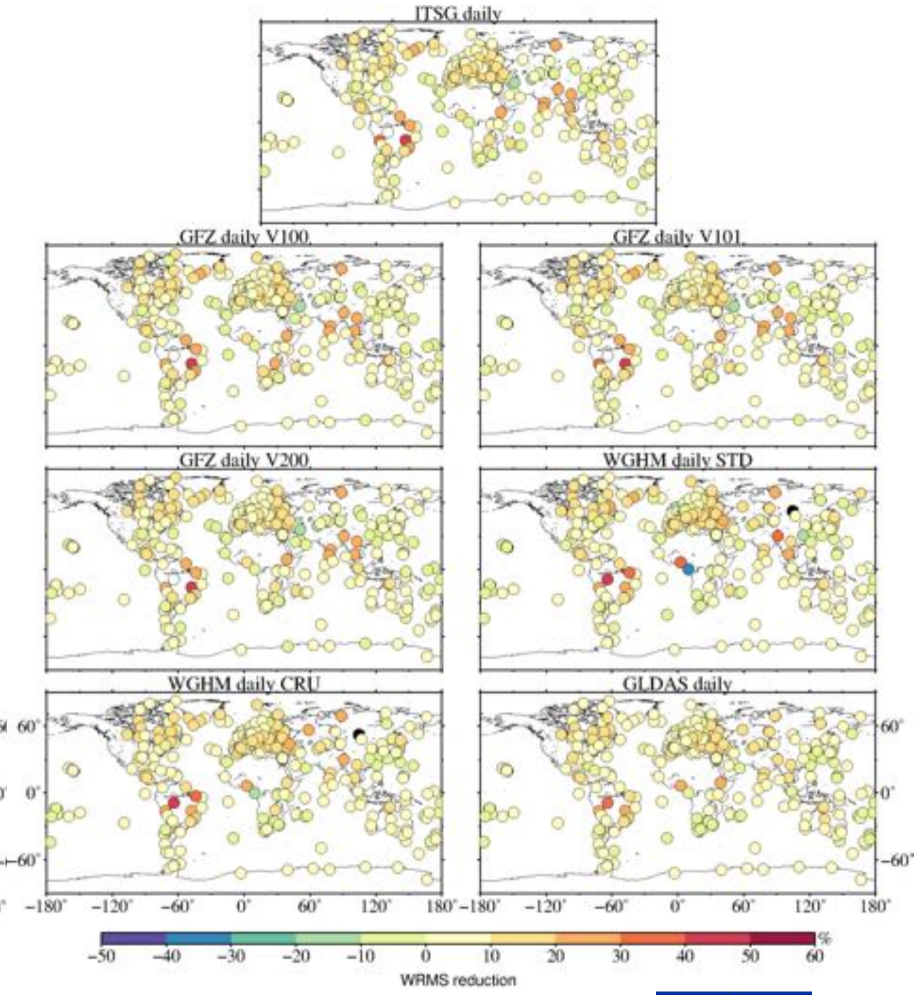
Data

- GNSS data
  - Reprocessed daily UBERN GNSS time series (Repro3)
    - Cleaned, detrended, outlier and offsets removed
  - Latest daily ITRF2014 GNSS residuals (IGN)
    - Rigorously stacking the latest IGS repro2 solutions
- Continental Water Storage Models
  - GLDAS, daily
  - WGHM_2.2_STANDARD, latest official version, 2002-10/2010, daily
  - WGHM_2.2_STANDARD_CRU, 2002-12/2012, daily
    - a modification of 2.2standard,but not calibrated for the climate input
- Gravity models
  - Daily GRACE products from GFZ, version 100, version 101 and version 200
  - Daily GRACE products from ITSG2016

Validation with ITRF2014

- Without de-aliasing products: correlation (left) and WRMS reduction (right)



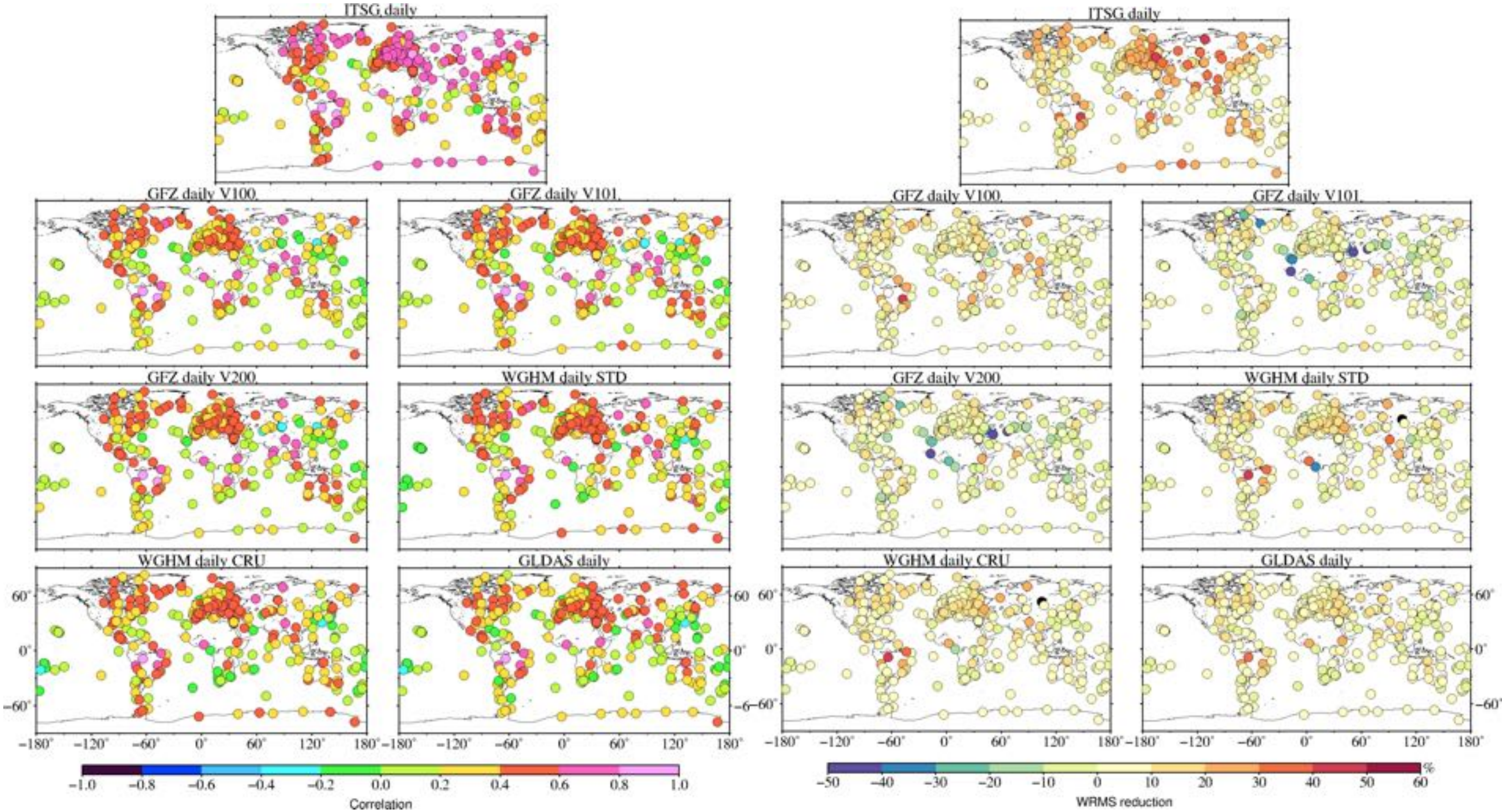


EGSIEM

HORIZON 2020

Validation with ITRF2014

- With de-aliasing products: correlation (left) and WRMS reduction (right)



HORIZON 2020

Validation with ITRF2014

	WRMS reduction [%]				Positive WRMS reduction [%]
	min	max	mean	median	
GFZ V100	-16.45	63.42	5.79	4.31	84.52
GFZ V101 (without dealiasing)	-16.65	63.97	5.78	4.34	85.79
GFZ V200 (without dealiasing)	-17.33	64.12	5.52	4.00	82.23
ITSG (without dealiasing)	-17.32	64.21	6.10	4.88	84.77
ITSG (with dealiasing)	-12.80	66.45	14.73	14.47	93.40
GLDAS	-12.54	33.42	5.09	3.45	80.92
WGHM STD	-18.61	44.96	5.31	4.10	78.96
WGHM CRU	-14.83	42.80	5.53	4.44	84.48

- Both GFZ and ITSG daily GRACE models are better than hydrological models
- De-aliasing products are important in terms of daily solution validation

Preparation for NRT at ULux

- Automatic downloading and processing daily GRACE data is taking shape
  - Server for all the data: EGSIEM server?

- Question mark about GNSS data?
  - Latencies of JPL and SOPAC data
  - GNSS stations
  - Quality of UBERN rapid GNSS data

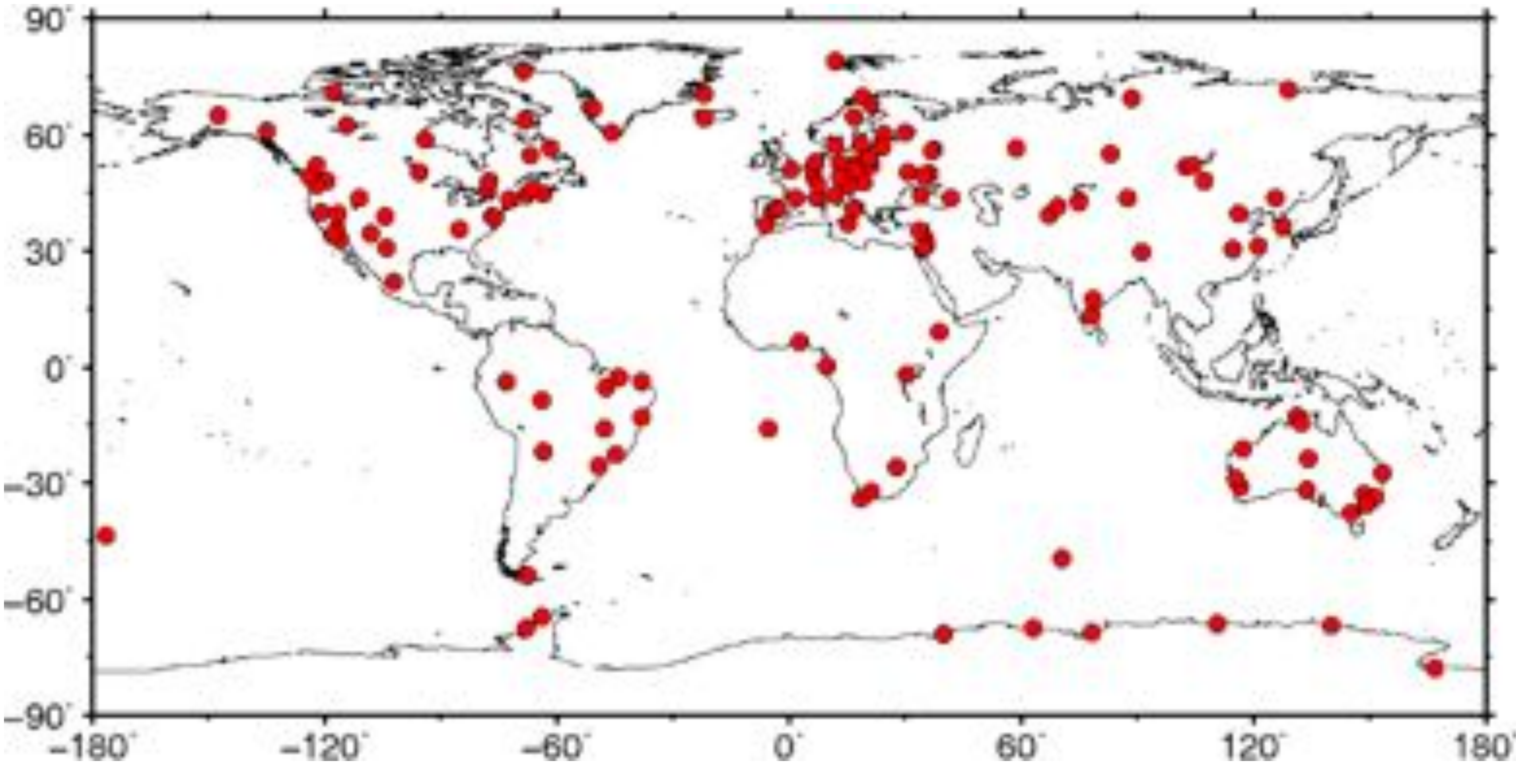
Preparation for NRT at ULux

- JPL and SOPAC GNSS time series with more than 12-day latency

File Name from JP and SOPAC	Update time	The Newest data	Latency (day)
GLB_Clean_DetrendNeuTimeSeries_jpl_20161104	11/4/16, 2:27:00 PM	2016.10.22	13
GLB_Clean_DetrendNeuTimeSeries_sopac_20161104	11/4/16, 8:09:00 PM	2016.10.22	13
GLB_Clean_DetrendNeuTimeSeries_jpl_20161110	11/10/16, 2:56:00 PM	2016.10.29	12
GLB_Clean_DetrendNeuTimeSeries_sopac_20161110	11/10/16, 9:41:00 PM	2016.10.29	12
GLB_Clean_DetrendNeuTimeSeries_jpl_20161117	11/17/16, 9:23:00 PM	2016.11.05	12
GLB_Clean_DetrendNeuTimeSeries_sopac_20161118	11/18/16, 12:47:00 PM	2016.11.05	13
GLB_Clean_DetrendNeuTimeSeries_jpl_20161123	11/24/16, 1:23:00 AM	2016.11.12	12
GLB_Clean_DetrendNeuTimeSeries_sopac_20161124	11/24/16, 4:16:00 PM	2016.11.05	19
GLB_Clean_DetrendNeuTimeSeries_jpl_20161205	12/5/16, 12:04:00 PM	2016.11.19	15
GLB_Clean_DetrendNeuTimeSeries_sopac_20161205	12/5/16, 4:14:00 PM	2016.11.05	30
GLB_Clean_DetrendNeuTimeSeries_jpl_20161209	12/9/16, 4:28:00 PM	2016.11.26	13
GLB_Clean_DetrendNeuTimeSeries_sopac_20161209	12/9/16, 8:36:00 PM	2016.11.05	34
GLB_Clean_DetrendNeuTimeSeries_jpl_20161215	12/15/16, 1:29:00 PM	2016.12.03	12
GLB_Clean_DetrendNeuTimeSeries_sopac_20161215	12/15/16, 6:37:00 PM	2016.11.05	40
GLB_Clean_DetrendNeuTimeSeries_jpl_20161225	12/25/16, 3:55:00 PM	2016.12.10	15
GLB_Clean_DetrendNeuTimeSeries_sopac_20161225	12/25/16, 9:40:00 PM	2016.11.05	50
GLB_Clean_DetrendNeuTimeSeries_jpl_20161230	12/30/16, 9:16:00 PM	2016.12.17	13
GLB_Clean_DetrendNeuTimeSeries_sopac_20161231	12/31/16, 7:46:00 PM	2016.11.05	56
GLB_Clean_DetrendNeuTimeSeries_jpl_20170108	1/9/17, 12:45:00 AM	2016.12.24	16
GLB_Clean_DetrendNeuTimeSeries_sopac_20170109	1/9/17, 12:29:00 PM	2016.12.24	16
GLB_Clean_DetrendNeuTimeSeries_jpl_20170114	1/15/17, 2:48:00 AM	2016.12.31	15
GLB_Clean_DetrendNeuTimeSeries_sopac_20170115	1/15/17, 4:26:00 PM	2016.12.31	15

Preparation for NRT at ULux

- Pre-selected 155 GNSS stations
  - Low possibilities of offsets based on the processed reference frame data provided by UBERN



EGSIEM

HORIZON 2020

Preparation for NRT at ULux

- Further preparations to be done
  - Test the rapid GNSS position time series solutions from UBERN
  - Try to find an automatic way to deal with offsets in the GNSS time series
  - Try to find better metrics for validation results as WRMS reduction and correlation do not work in the NRT mode
  - Integrate the whole validation system

I expect your inputs and thank you for your attention!

EGSIEM

European Gravity Service for Improved Emergency Management

WP6 (Hydrological Service)

Ben Gouweleeuw, Andreas Güntner (GFZ)

Henryk Zwenzner, Sandro Martinis (DLR)

EGSIEM Genrtsl Assembly

University of Bern

January 19-20, 2017

UNIVERSITÄT BERN · UNIVERSITÉ DU LUXEMBOURG · GFZ Helmholtz Centre POTSDAM · TU Graz · Leibniz Universität Hannover · cnes · DLR · géode&cie · HORIZON 2020

WP6: Hydrological Service

EGSIEM
European Gravity Service for Improved Emergency Management

Task 6.1

Evaluation of historical flood events (M07-M30)

Task 6.2

Development and evaluation of gravity-based indicators for flood forecasting and drought monitoring (M01-M36)

Task 6.3

Rapid mapping concept (M07-M36)

WP6: Hydrological Service

EGSIEM
European Gravity Service for Improved Emergency Management

Deliverables

6.1 Hydrological Service Product Report (M30)

6.2 Operational Hydrological Service product report (M36)

Milestones

- Operational NRT Service Readiness (WP5 and 6, M27)

EGSIEM
European Gravity Service for Improved Emergency Management

Title: WP6 (Hydrological Service)

Ben Gouweleeuw (GFZ)

EGSIEM General Assembly

U Bern

Jan 18-19.2017

UNIVERSITÄT BERN · UNIVERSITÉ DU LUXEMBOURG · GFZ Helmholtz Centre Potsdam · TU Graz · Leibniz Universität Hannover · cnes · DLR · géode&cie · HORIZON 2020

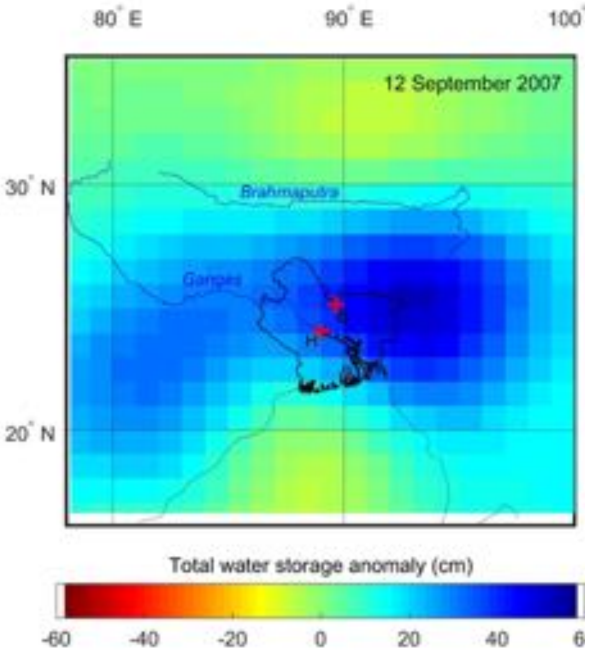
Other activities & outlook

- Revise and re-submit paper on evaluation of GRACE daily gravity solutions for hydrological extremes in selected river basins (Gouweleeuw et al., GRL, in review)

WP6: Hydrological Service

EGSIEM
European Gravity Service for Improved Emergency Management

Hydrology and Earth System Sciences
An interactive open-access journal of the European Geosciences Union



MS Records

hess-2016-653 Submitted on 09 Dec 2016
Daily GRACE gravity field solutions track major flood events in the Ganges-Brahmaputra Delta
Ben Gouweleeuw, Andreas Kvas, Christian Gruber, Animesh Gain, Thorsten Mayer-Gürr, Frank Flechtner, and Andreas Güntner

First Contact: Ben Gouweleeuw, bingo@gfz-potsdam.de
Second Contact: Andreas Güntner, andreas.guentner@gfz-potsdam.de

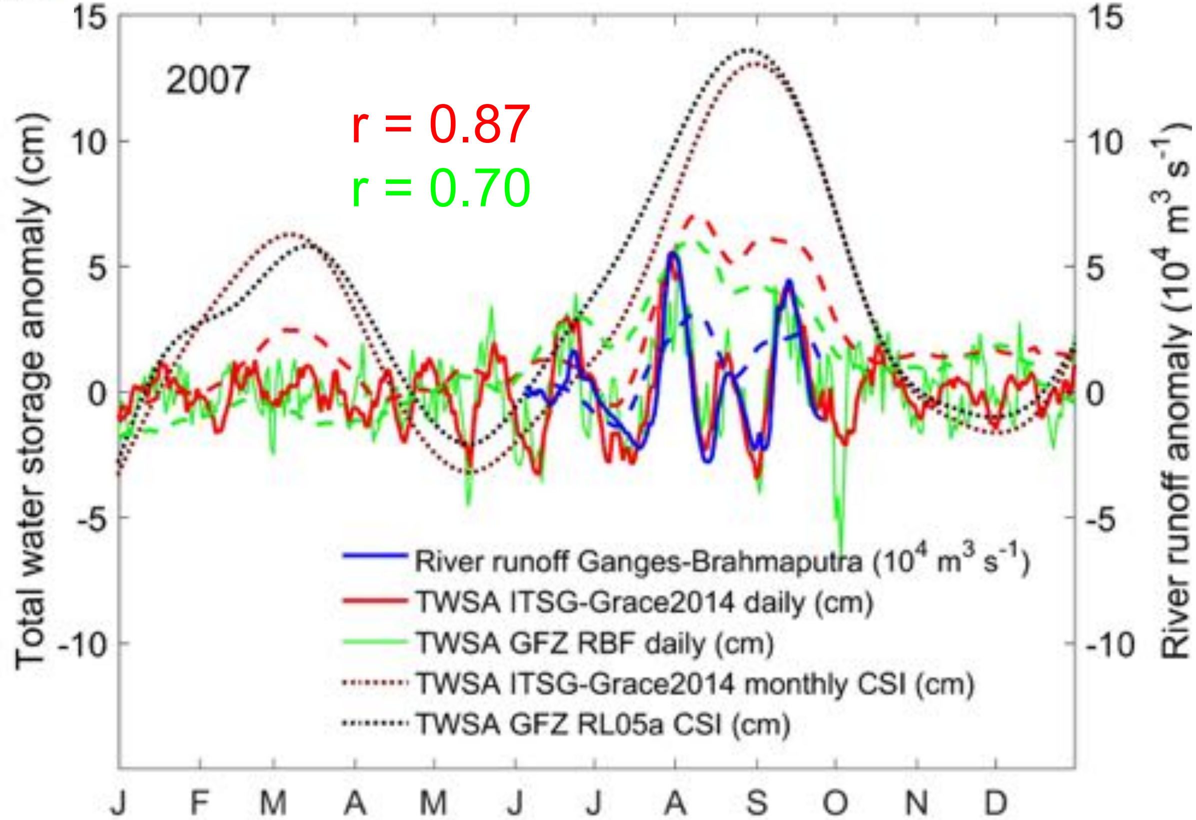
Institutional Payment: Helmholtz Association \ German Research Centre for Geosciences - GFZ

FundRef: Name of Funder: Horizon 2020
Framework programme: Horizon 2020
EC funded project: EGSIEM (637010)

Manuscript Type: Research article

Status: Editor Assignment (HESS Discussions) **Iteration: Initial Submission**

High Pass Filter, 31-day cut off



Reflects trends over periods of a few days

EGSIEM

Gouweleeuw et al. (in review): Daily GRACE gravity solutions track major flood events in the GB Delta

HORIZON 2020

Other activities & outlook of last meeting

- Analyse and extend DA assimilation for Ganges-Brahmaputra-Meghna basin incl. analysis of complimentary hydrological data (groundwater level,

WP6: Hydrological Service

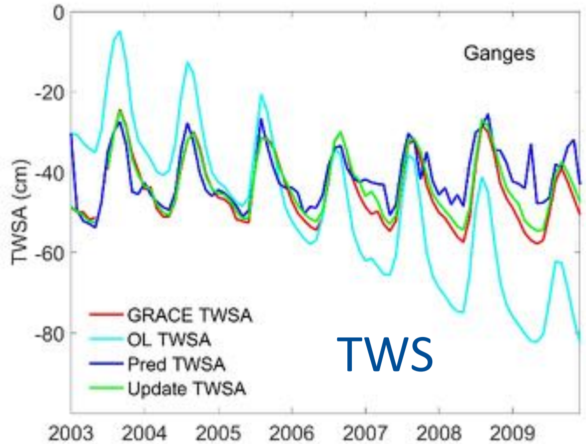
EGSIEM
European Gravity Service for Improved Emergency Management

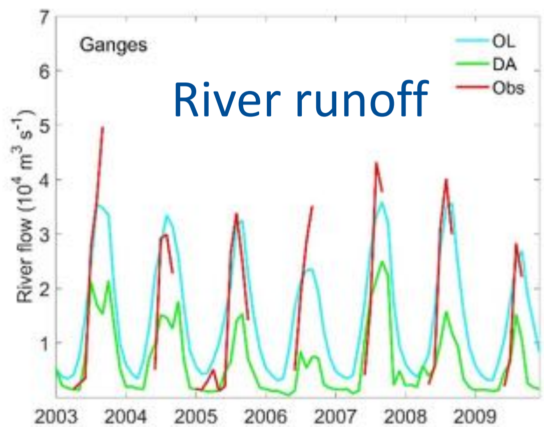
EGSIEM

European Gravity Service for Improved Emergency Management

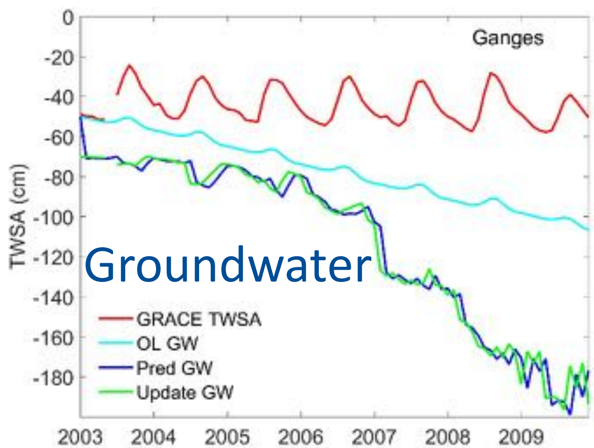
Ganges

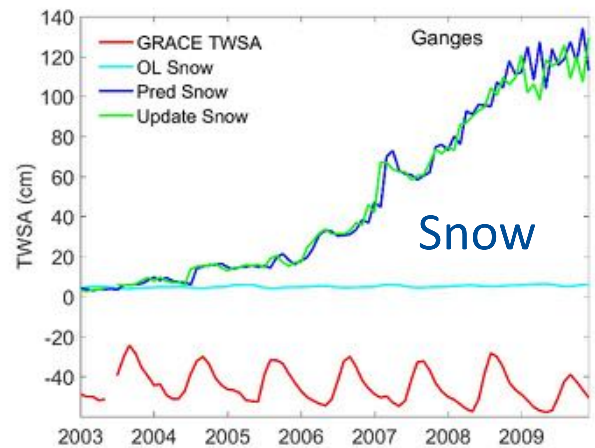
of last meeting





1. Ensemble size
   30 (100)
2. Groundwater use
   yes (no)
3. Initial conditions
   (no) groundwater use



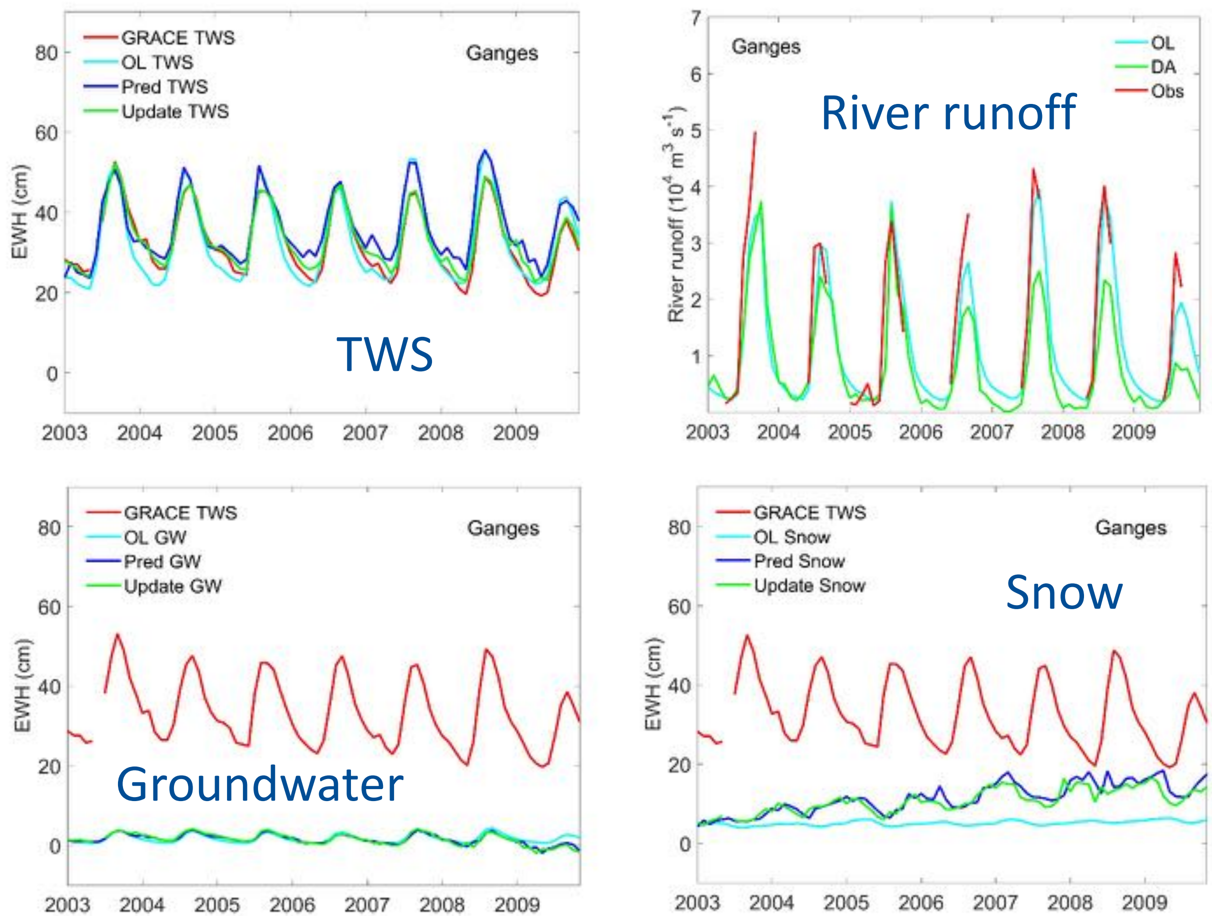


EGSIEM

HORIZON 2020

Ganges

EGSIEM
European Gravity Service for Improved Emergency Management



1. Ensemble size
   30
2. Groundwater use
   no
3. Initial conditions
   no groundwater use

Way forward:

- simultaneous C/DA for relevant/sensitive model parameters (GW-1, SL-1, SN-2,..)

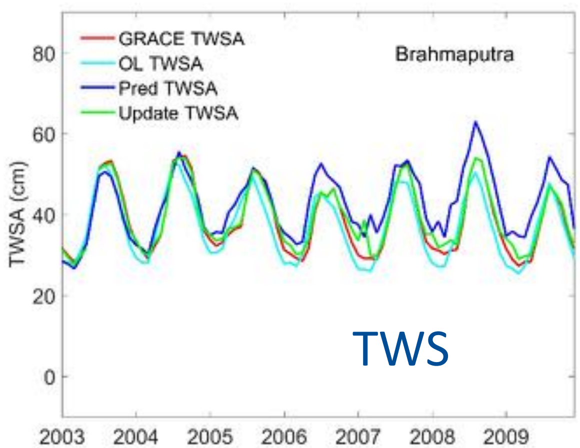
EGSIEM

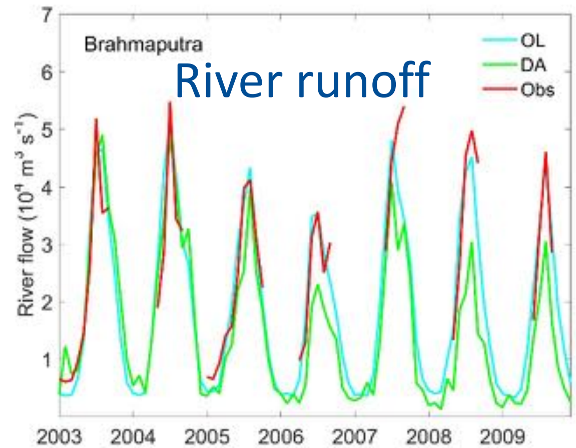
HORIZON 2020

European Gravity Service for Improved Emergency Management

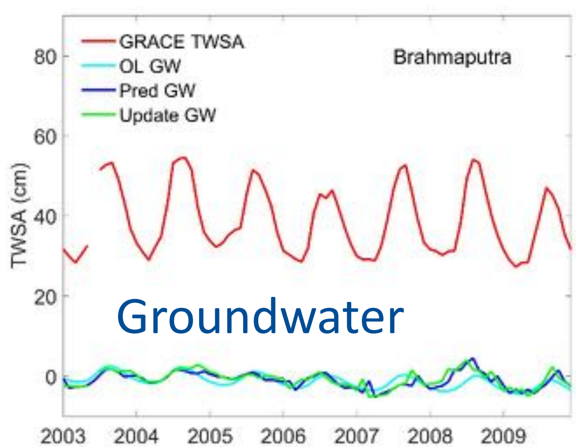
Brahmaputra

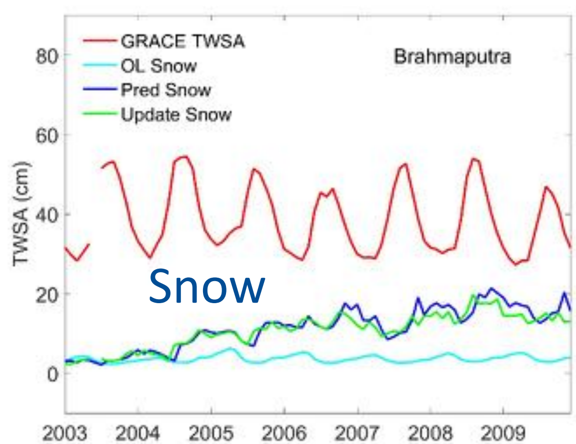
of last meeting





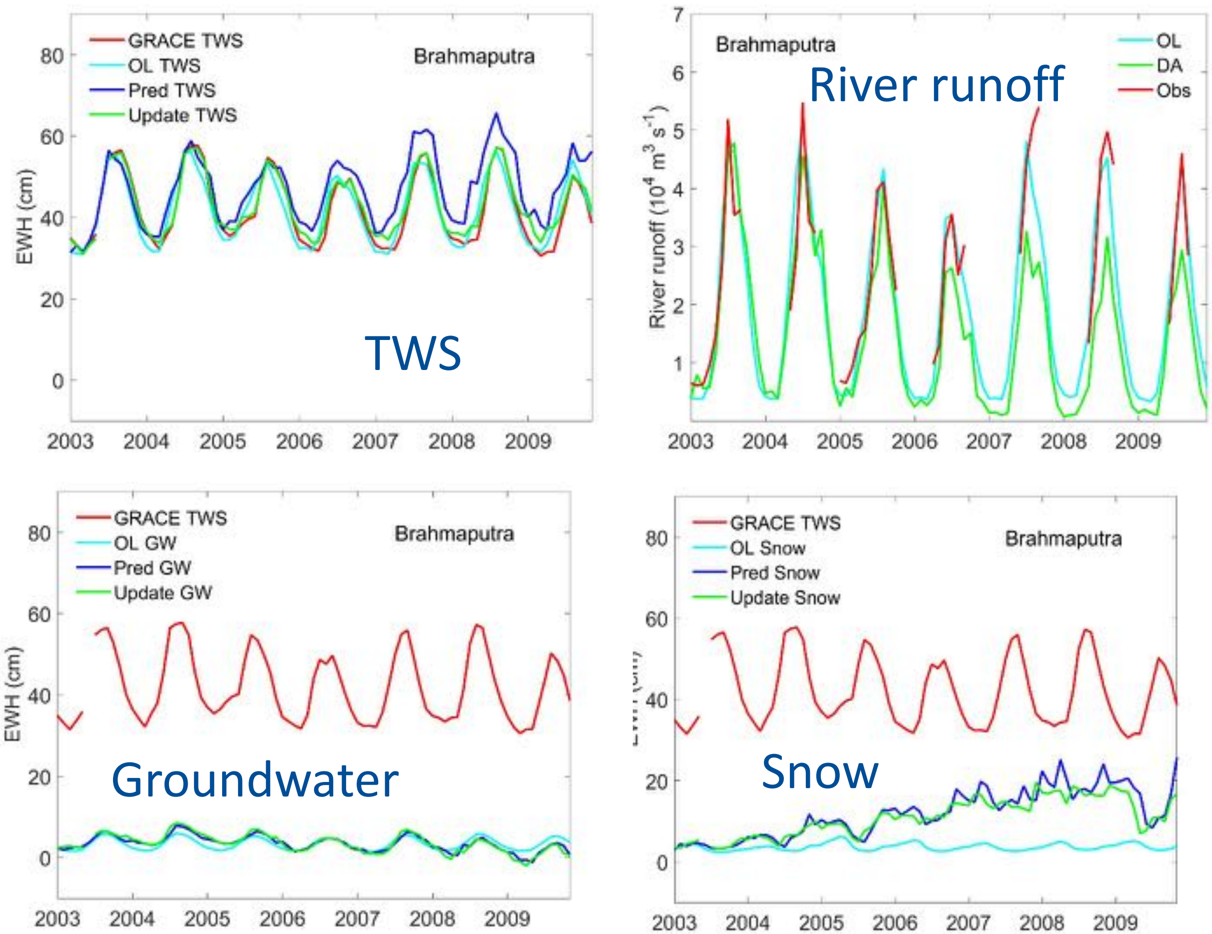
1. Ensemble size
   30 (100)
2. Groundwater use
   yes (no)
3. Initial conditions
   (no) groundwater use





Brahmaputra

EGSIEM
European Gravity Service for Improved Emergency Management



Ensemble size

30

Groundwater use

no

Initial conditions

no groundwater use

EGSIEM

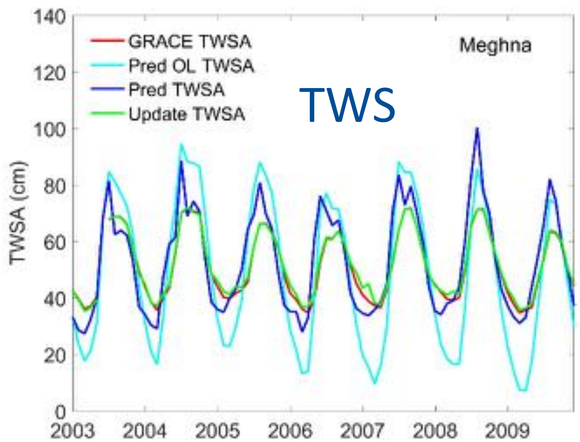
HORIZON 2020

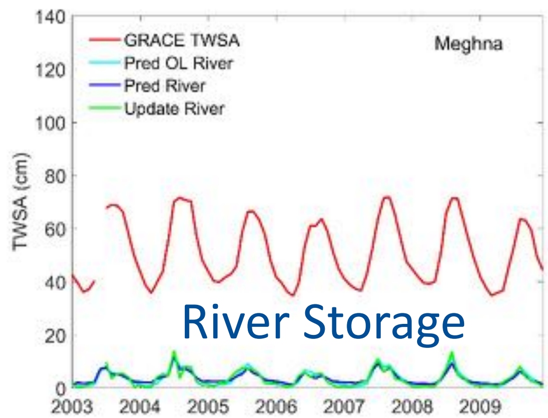
Meghna

of last meeting

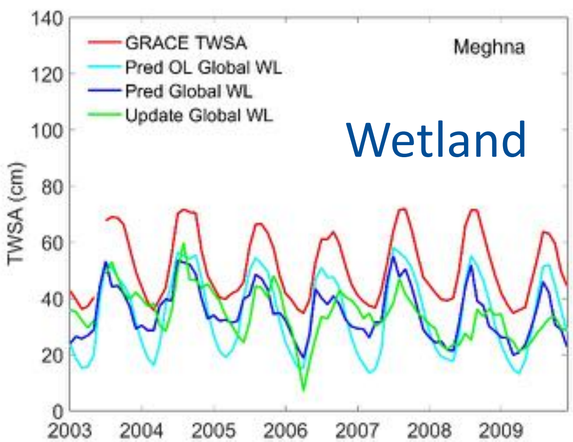
EGSIEM

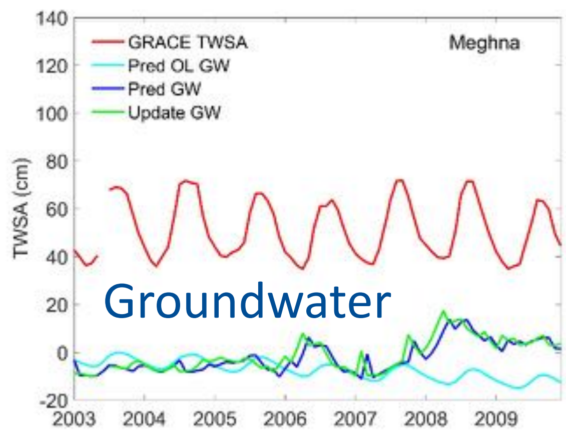
European Gravity Service for Improved Emergency Management





1. Ensemble size
   30 (100)
2. Groundwater use
   yes (no)
3. Initial conditions
   (no) groundwater use





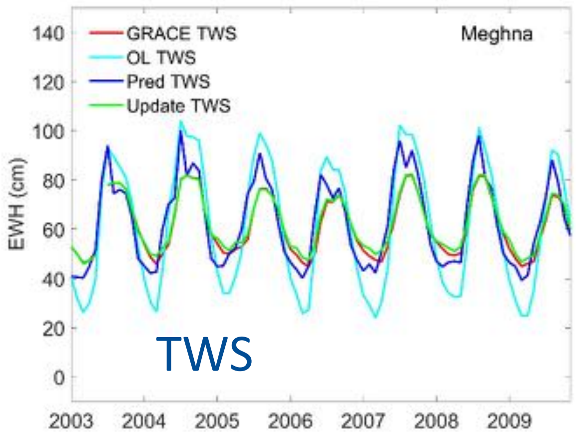
EGSIEM

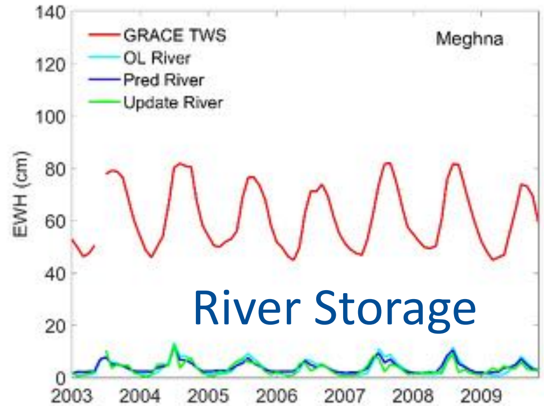
HORIZON 2020

EGSIEM

European Gravity Service for Improved Emergency Management

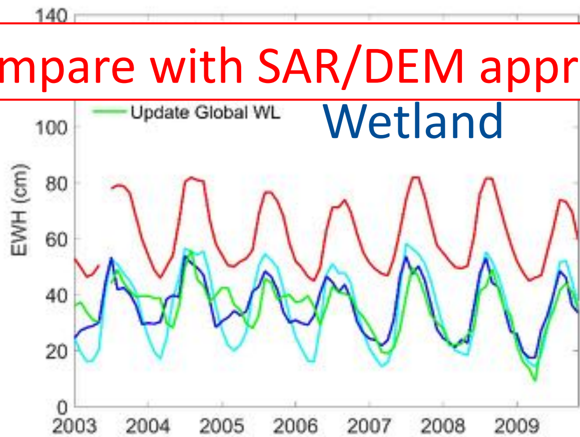
Meghna

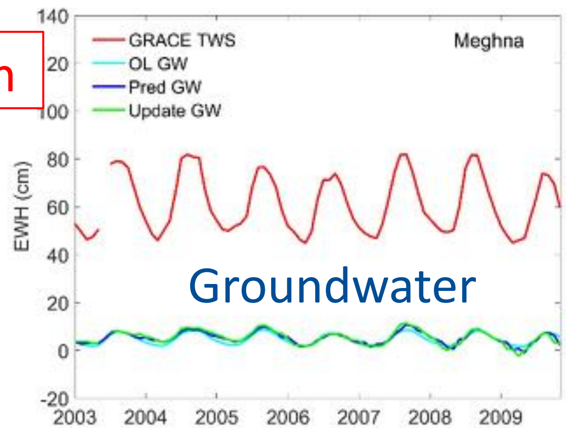




1. Ensemble size
   30
2. Groundwater use
   no
3. Initial conditions
   no groundwater use

Compare with SAR/DEM approach





Why again?

- Individual water storage components
- Run model in forward mode & Extend time series (backward)

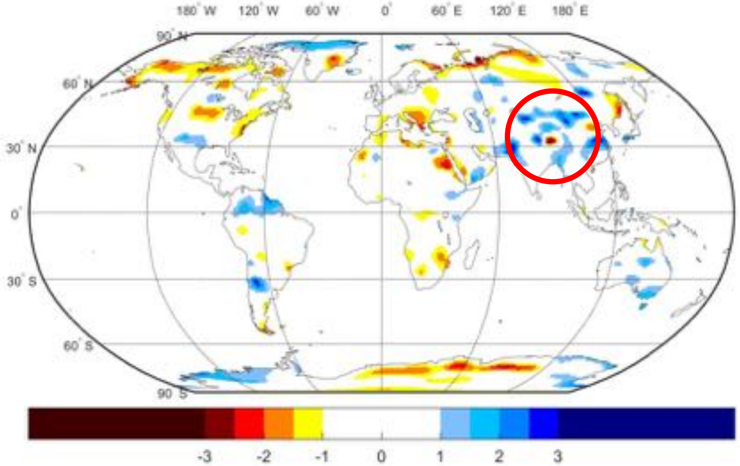
Other activities & outlook of last meeting

- Further development and refinement of global drought and flood indexing in preparation of real-time test.

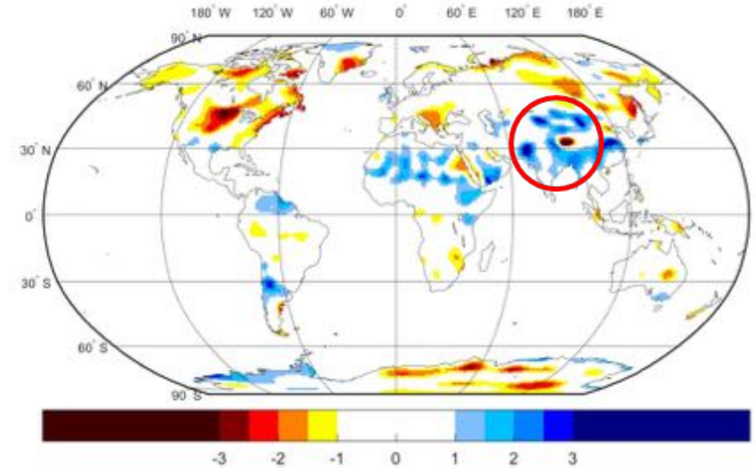
Flood and drought indicator – normalized TWSA

Last meeting

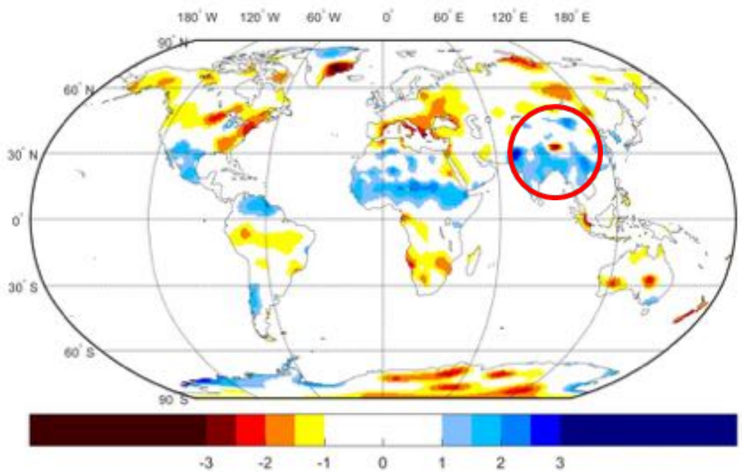
19 July 2007



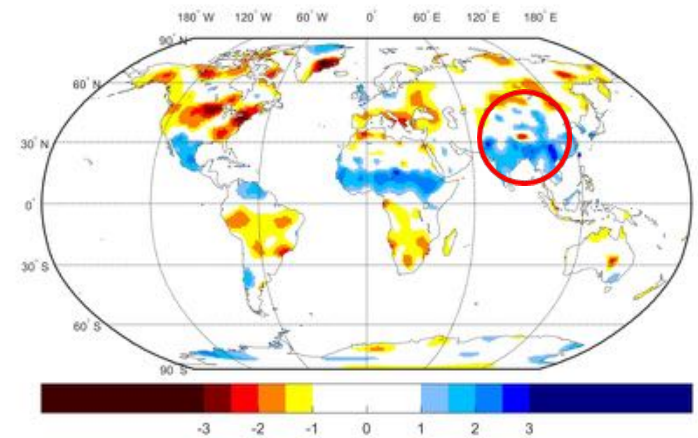
3 August 2007



28 August 2007



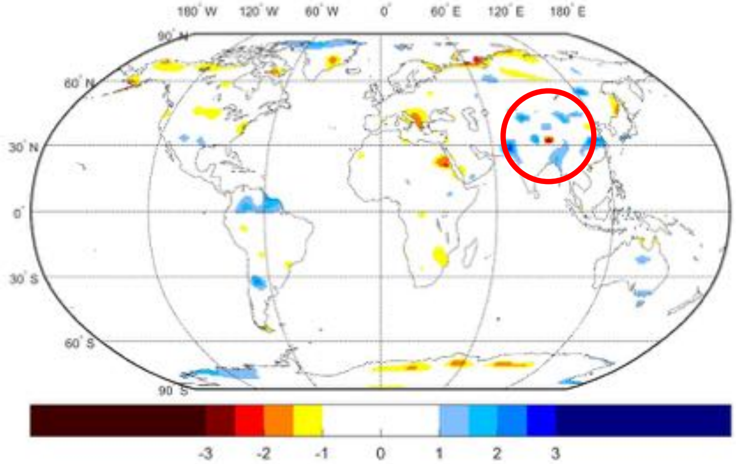
12 September 2007



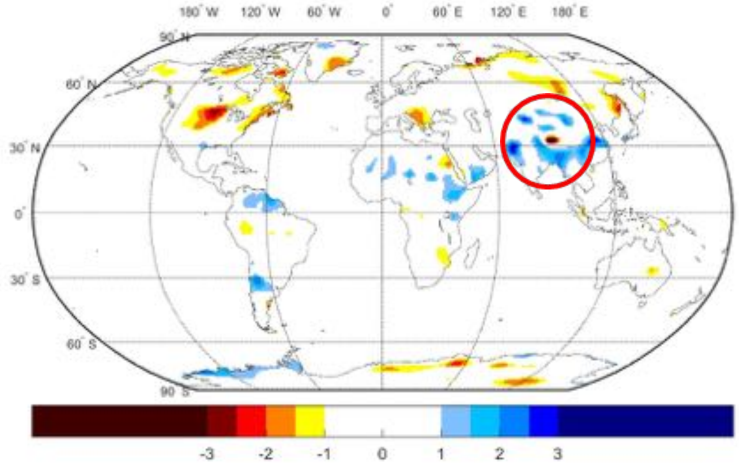
Flood and drought indicator – normalized TWSA

Noise reduction

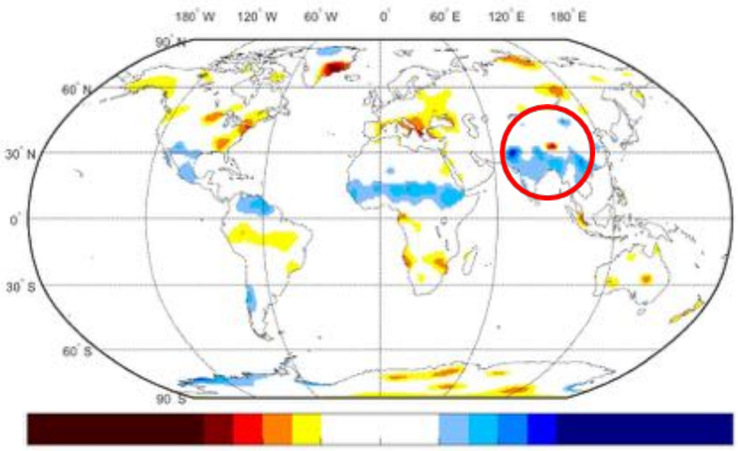
19 July 2007



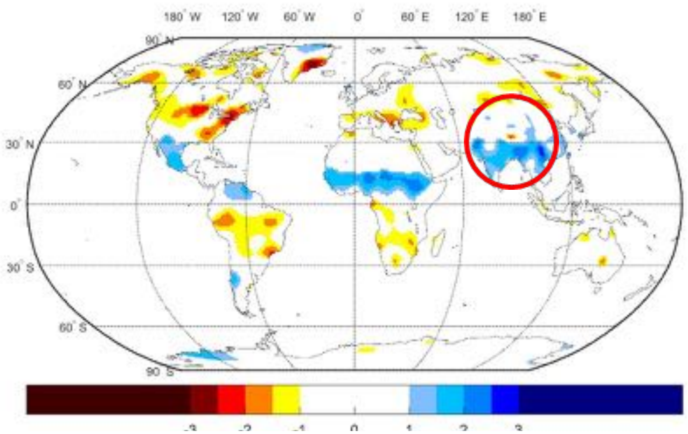
3 August 2007



28 August 2007



12 September 2007



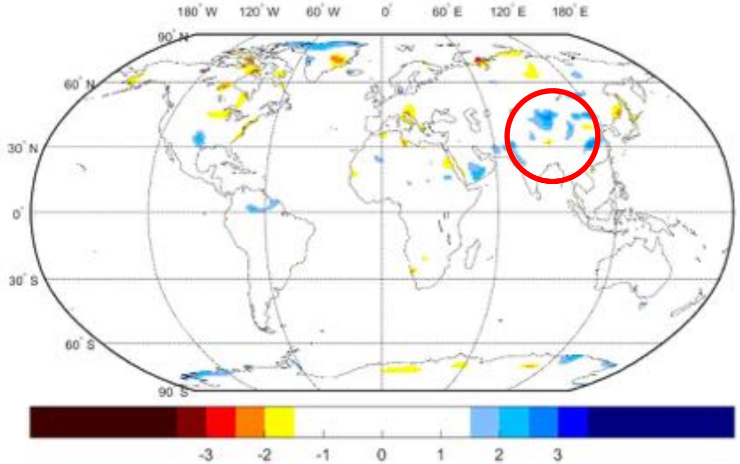
EOSIEM Ganges-Brahmaputra Delta flood

HORIZON 2020

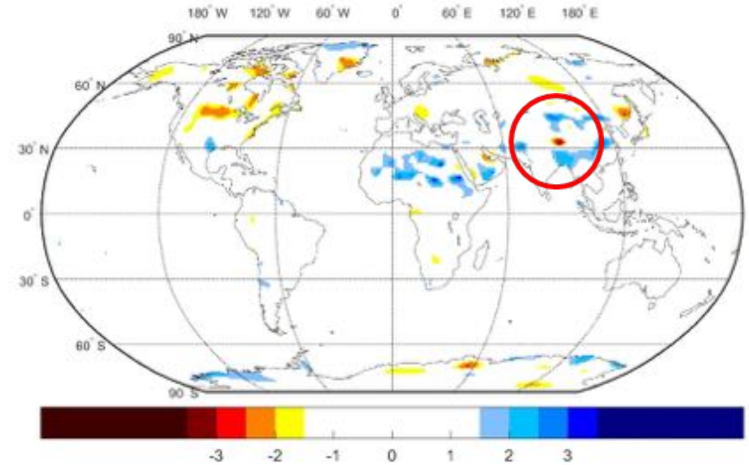
Flood and drought indicator – normalized TWSA

Lower threshold

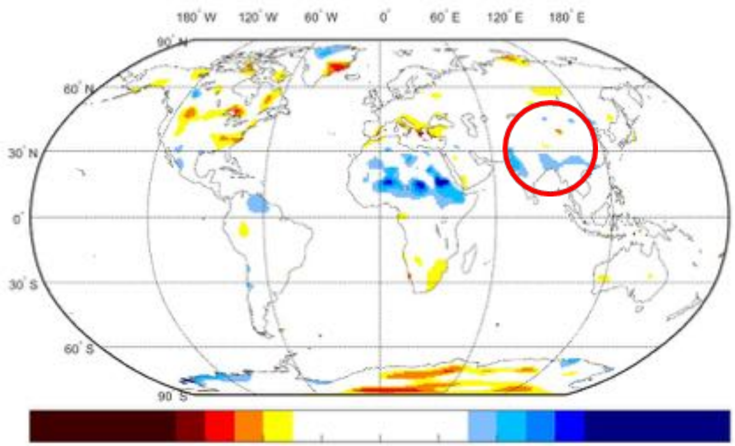
19 July 2007



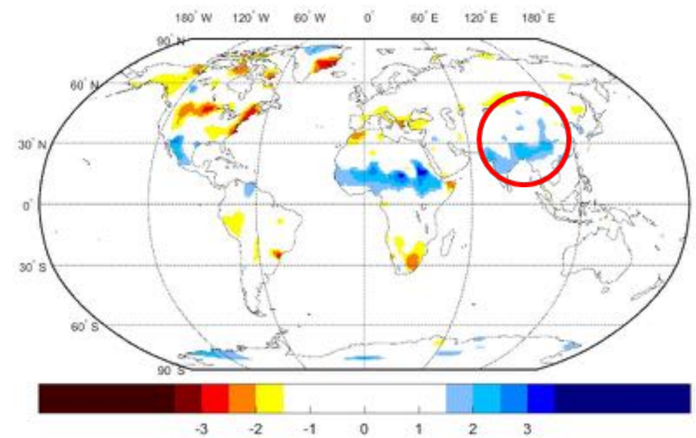
3 August 2007



28 August 2007



12 September 2007



WP6: Hydrological Service

SQL database GLOBAL validation

EGSIEM
European Gravity Service for Improved Emergency Management

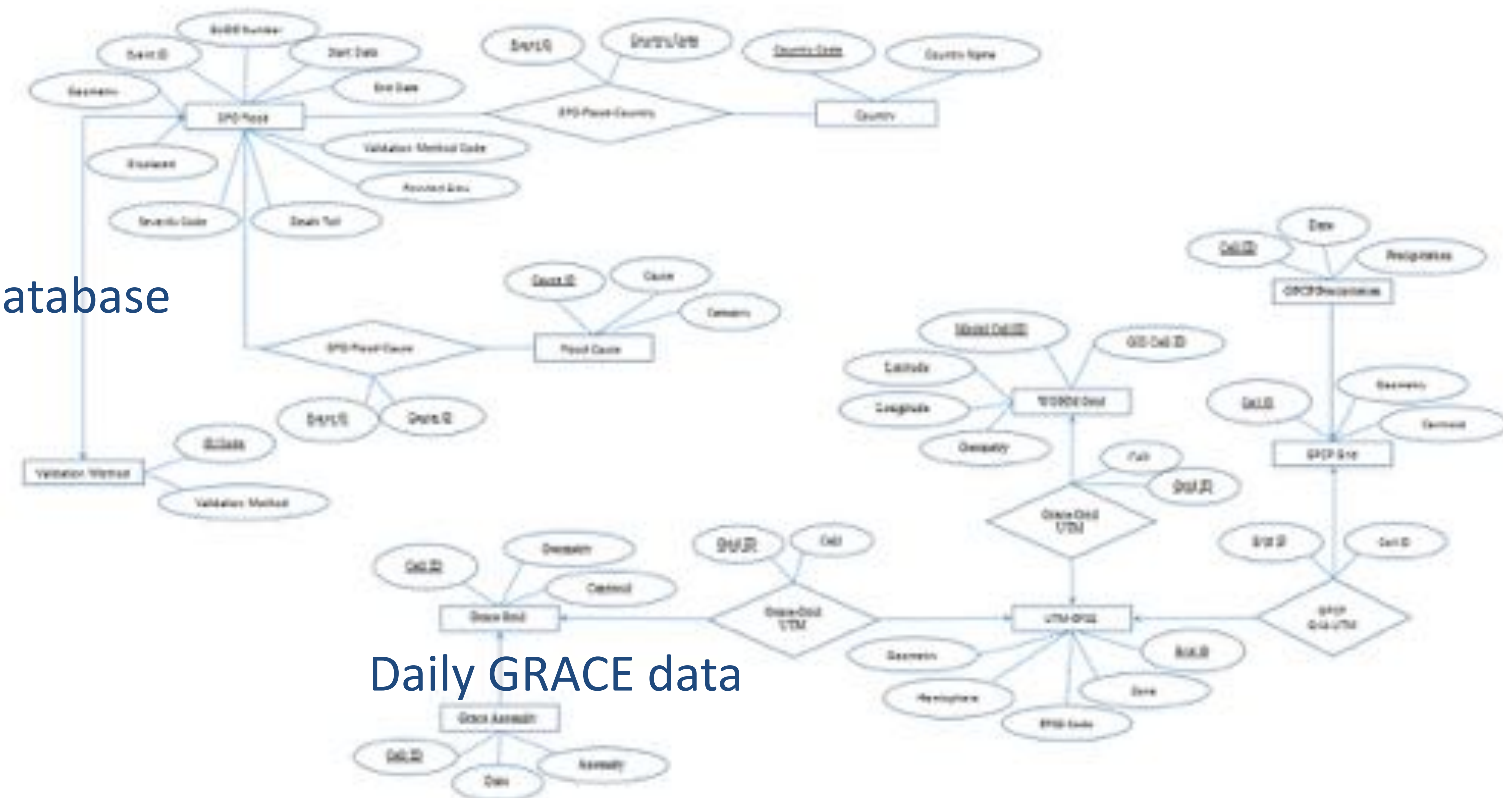


Figure 1: E-R Diagram of Flood Database

WP6: Hydrological Service

European Gravity Service for Improved Emergency Management

Preliminary results

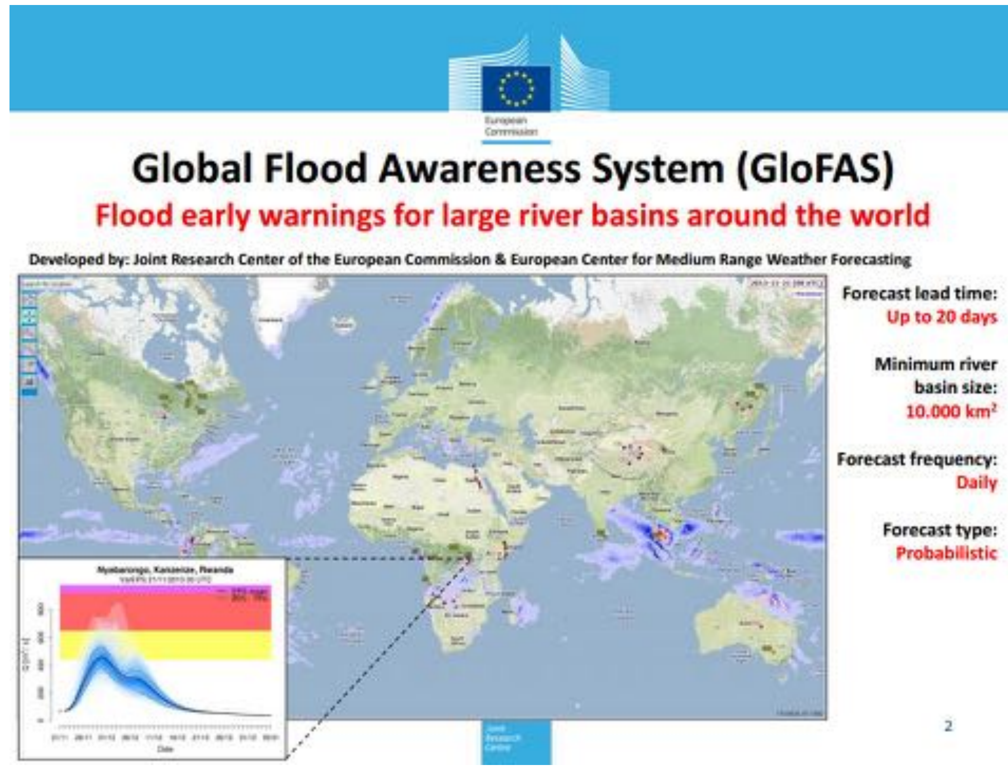
- Signals for large extreme floods related to heavy/monsoonal rainfall in the Southern Hemisphere and lower Northern Hemisphere (Africa, S-America, Australia, S-Asia) picked up very well.
- Extreme floods in Northern Hemisphere (Russia) related to snow melt often not flagged. Possibly related to lack of mass movement over long distances, e.g. due to river ice blocking.

WP6: Hydrological Service

EGSIEM
European Gravity Service for Improved Emergency Management

Further testing

- GloFAS through WMS-T (near-real time test, DLR)
  - Other databases (EDO, EM-DAT)



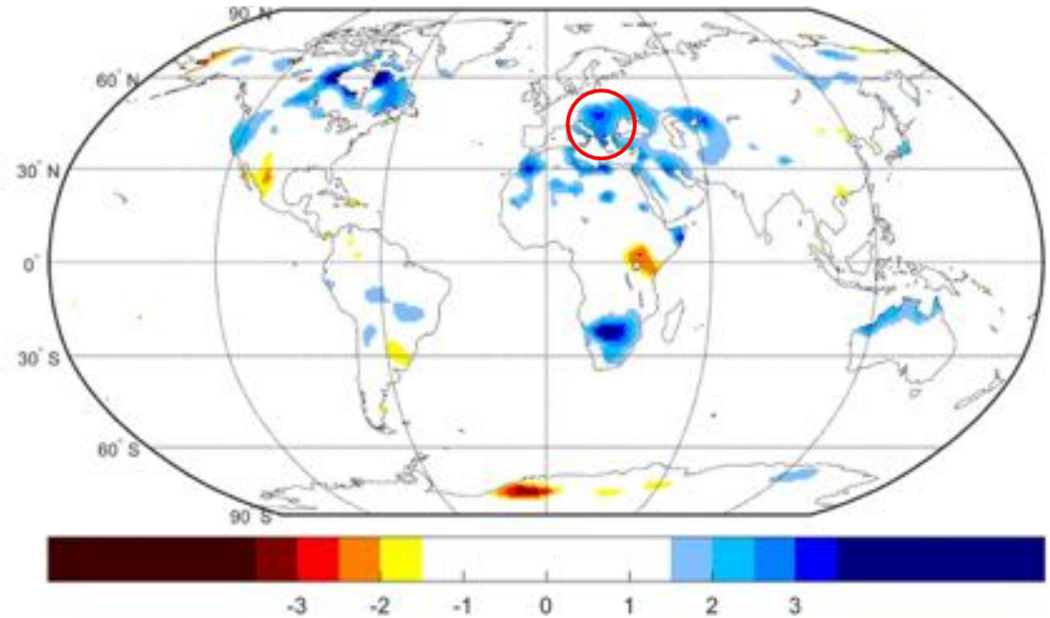
Other activities & outlook

- Extend DA assimilation for Ganges-Brahmaputra-Meghna basin to include model parameter calibration and comparison to complimentary hydrological data (e.g., SAR/DEM approach to estimate surface water).
- Further development and testing (SQL, GloFAS, EDO) of global gravity-based wetness index in preparation of near-real time test, including logistics (WMS-T).

Danube basin

EGSIEM
European Gravity Service for Improved Emergency Management

Normalized TWSA, 19 March 2006

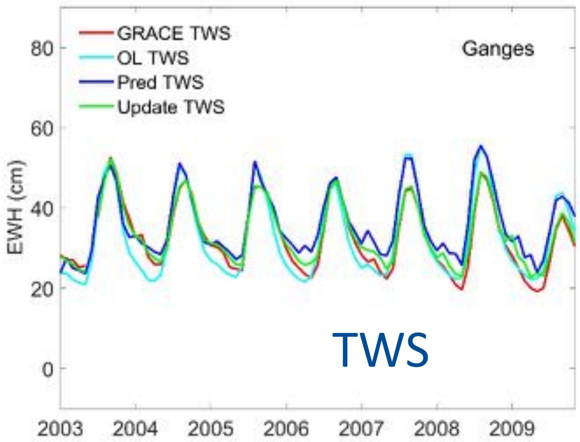


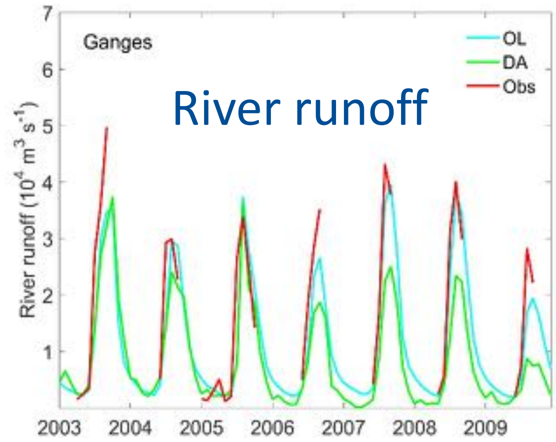
Wetter than normal conditions (2.5-3 times the standard deviation) are indicated for the Danube basin in March 2006, just before the April 2006 flood.

Ganges

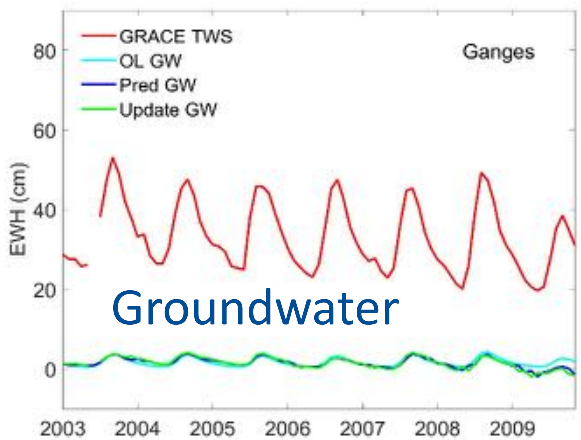
EGSIEM

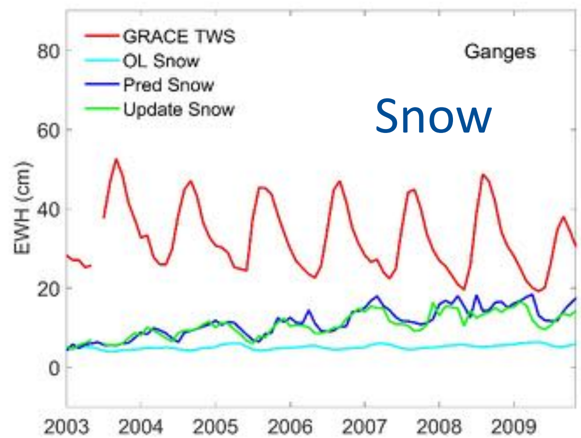
European Gravity Service for Improved Emergency Management





1. Ensemble size
   30
2. Groundwater use
   no
3. Initial conditions
   no groundwater use



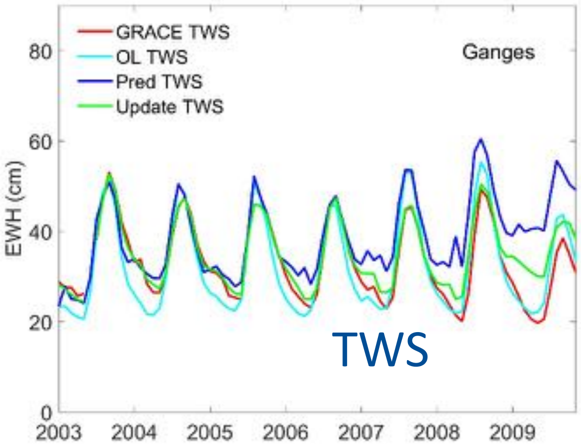


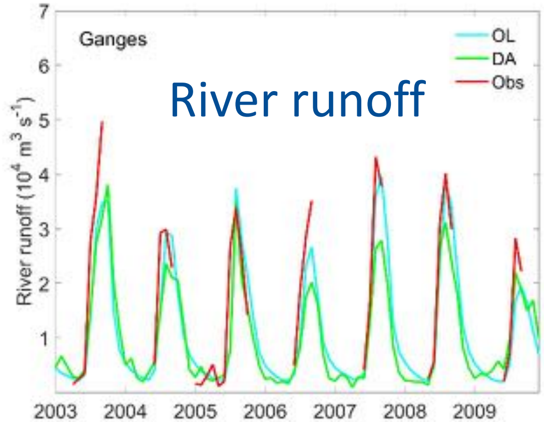
EGSIEM

HORIZON 2020

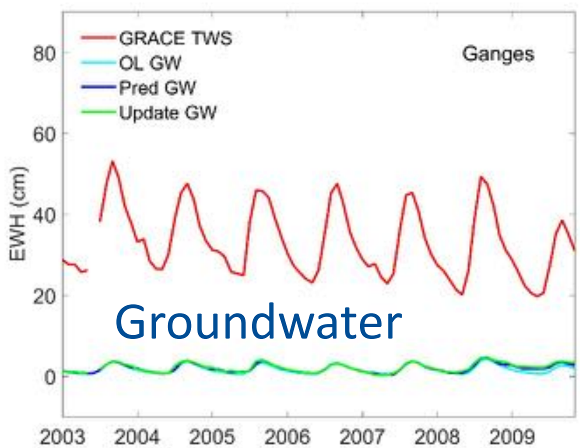
European Gravity Service for Improved Emergency Management

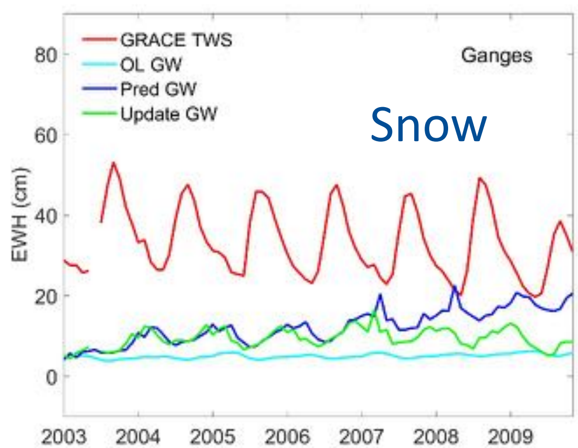
Ganges





1. Ensemble size
   100
2. Groundwater use
   no
3. Initial conditions
   no groundwater use

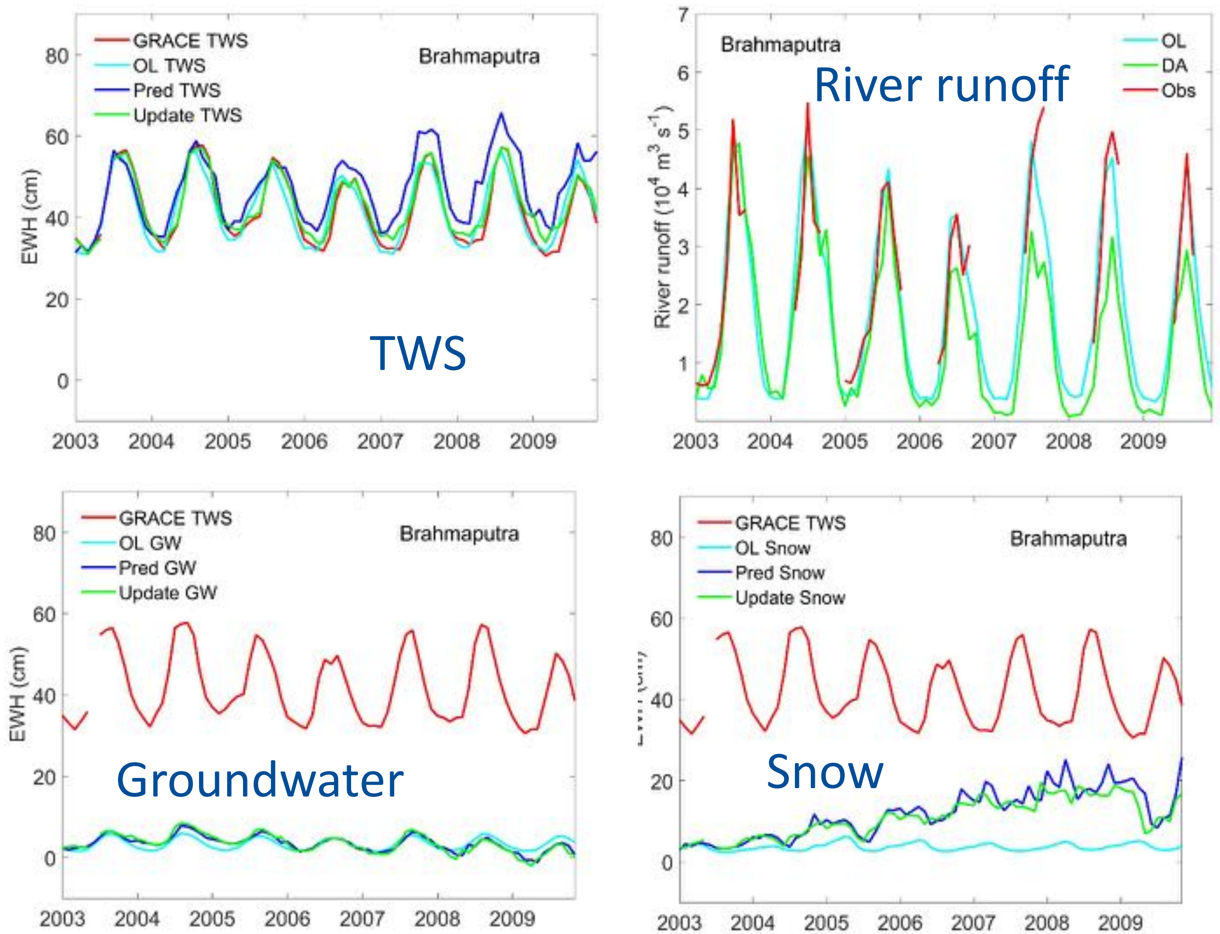




HORIZON 2020

Brahmaputra

European Gravity Service for Improved Emergency Management



Ensemble size

30

Groundwater use

no

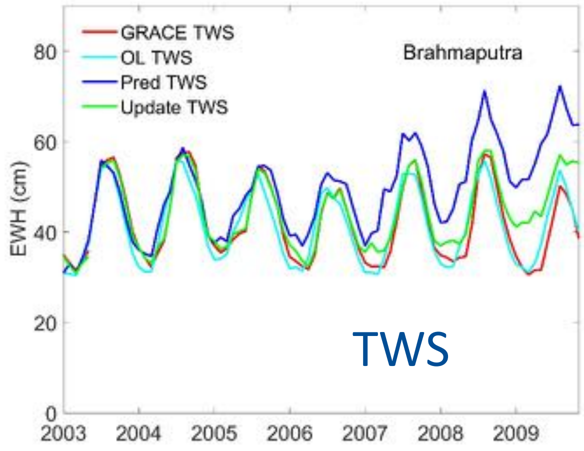
Initial conditions

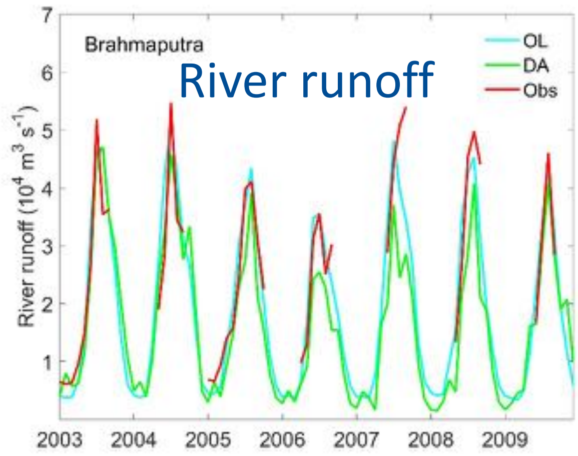
no groundwater use

EGSIEM

European Gravity Service for Improved Emergency Management

Brahmaputra





Ensemble size

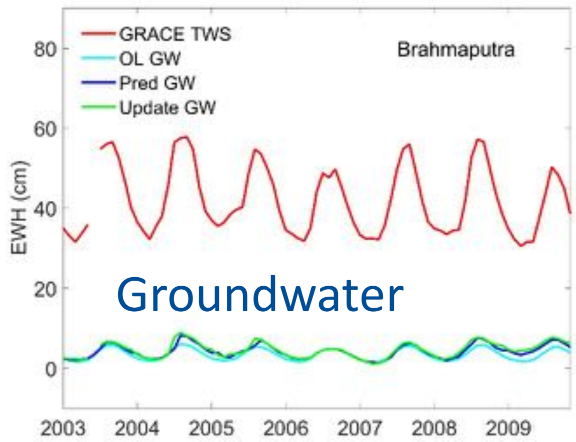
100

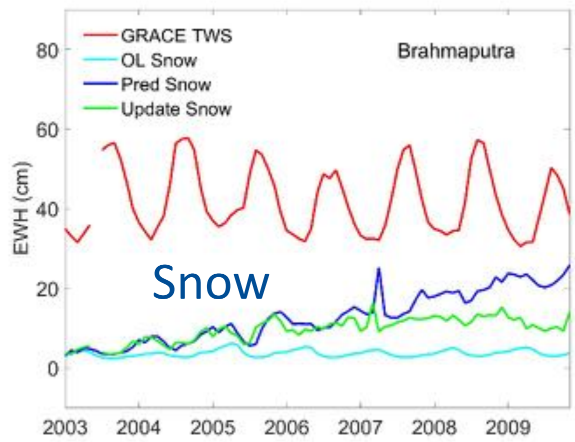
Groundwater use

no

Initial conditions

no groundwater use

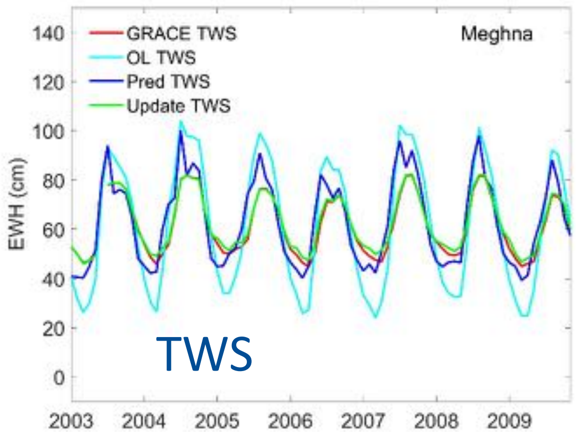


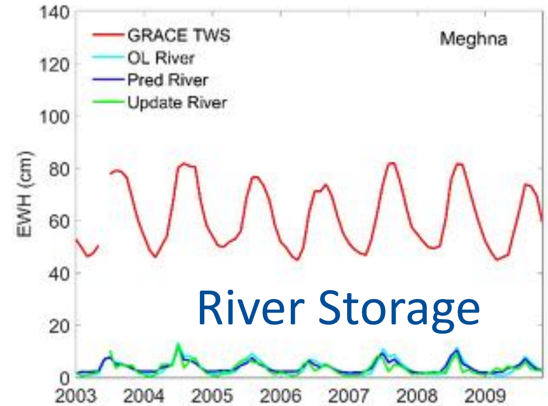


Meghna

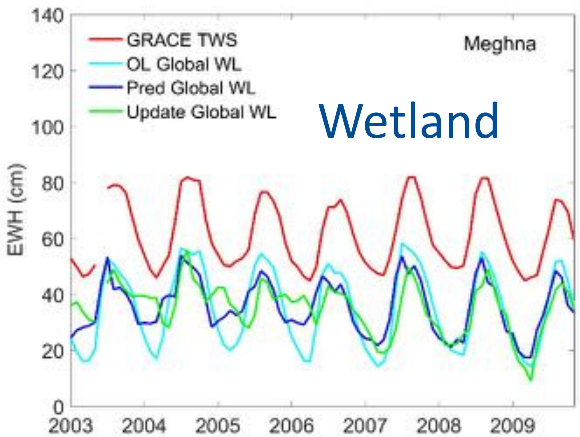
EGSIEM

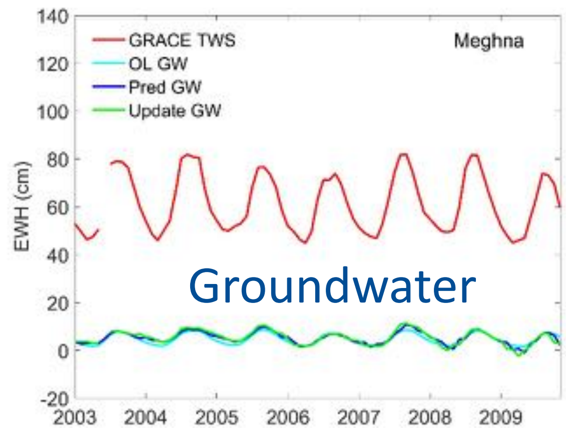
European Gravity Service for Improved Emergency Management





1. Ensemble size
   30
2. Groundwater use
   no
3. Initial conditions
   no groundwater use

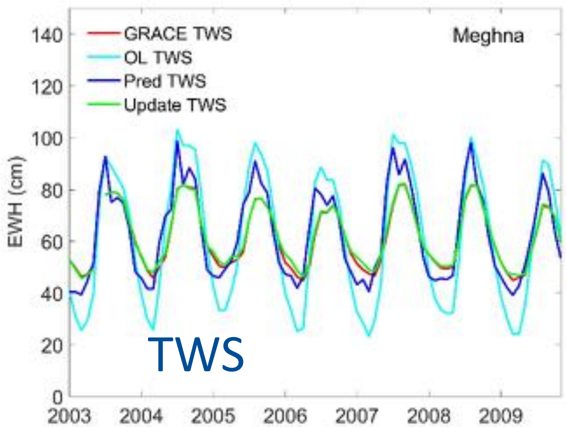


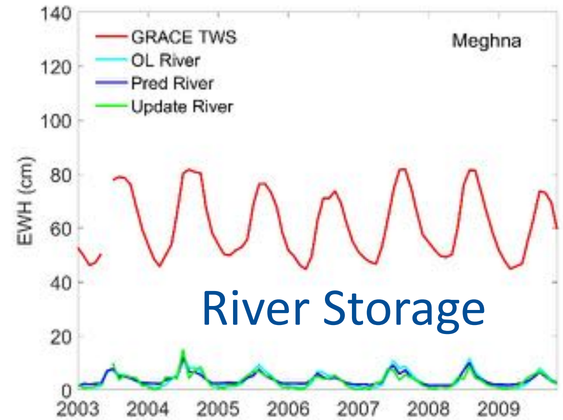


EGSIEM

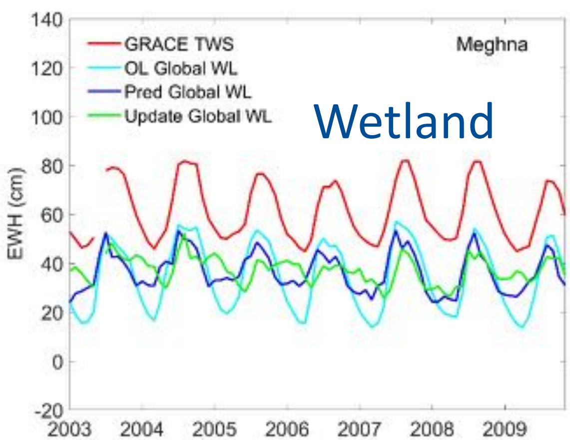
HORIZON 2020

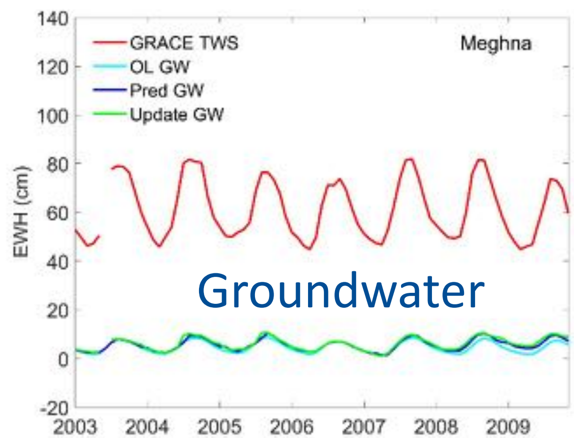
Meghna





1. Ensemble size
   100
2. Groundwater use
   no
3. Initial conditions
   no groundwater use





EGSIEM

European Gravity Service for Improved Emergency Management

WP6: An automated approach to estimate flood volumes based on SAR satellite imagery and DEMs

Hendrik Zwenzner

DLR

EGSIEM General Assembly
University of Bern
January 19. – 20. 2017

Objectives

- Establish a method for flood volume estimation for large scale floods based on EO data and DEMs
  - Higher level product compared to 2-D flood masks
  - Can be compared to gravity measurements from space
- Implement gravity based flood indicators into the operational workflow of DLR's Center for Satellite-based Crisis Information
  - Early-warning component for potential large scale flood events
  - Reduce lead time in satellite tasking (e.g. TerraSAR-X)

Introduction

- Flood depth & volume estimations are mostly done by hydraulic modelling (1-D, 2-D)

  > BUT the more complex & precise they get :
  - computational cost increases
  - study areas get smaller
  - more input parameters are needed

→ sometimes complex hydraulic models are not suitable for real-world flood risk analysis (BATES 2012)

BATES (2012:2515) *„... argued that the use of remote sensing data had allowed a significant breakthrough to be made in flood inundation modelling.“*

-> in terms of higher resolutions, shorter revisit times, better availability

-> improving terrain data resolution leads to better performances than improving the hydraulic model!

Flood volumes without hydraulic modelling

but with improved remote sensing data?

Few publications tried to estimate flood volumes only with remote sensing data or a combination of RS data and hydraulic modelling before:

- HORRIT 1999: **Snake algorithm** for delineation
- NÉELZ et al 2006: **Airborne** SAR data & LiDAR, inundation extent delineation
- MASON et al. 2007: **Waterline delineation** with ERS SAR & LiDAR, hydraulic model
- MATGEN et al. 2007: SAR water mask extent, hydraulic modelling for flood depths
- ZWENZNER & VOIGT 2009: heights from **cross sections** for each river bank
- SCHUMANN et al. 2009: Flood depths from airborne photography and LiDAR, **SAR too coarse**
- KAWAK et al. 2013 flood volume & depths modeled with 1-D hydraulic model, **optical data**, low resolution (500 m)
- HUANG et al. 2014: inundation extent & LiDAR => **shift small tiles till they fit the DEM**

=> So far no study for large scale flood volumes & depths derived from SAR derived flood masks & DEMs with world wide coverage

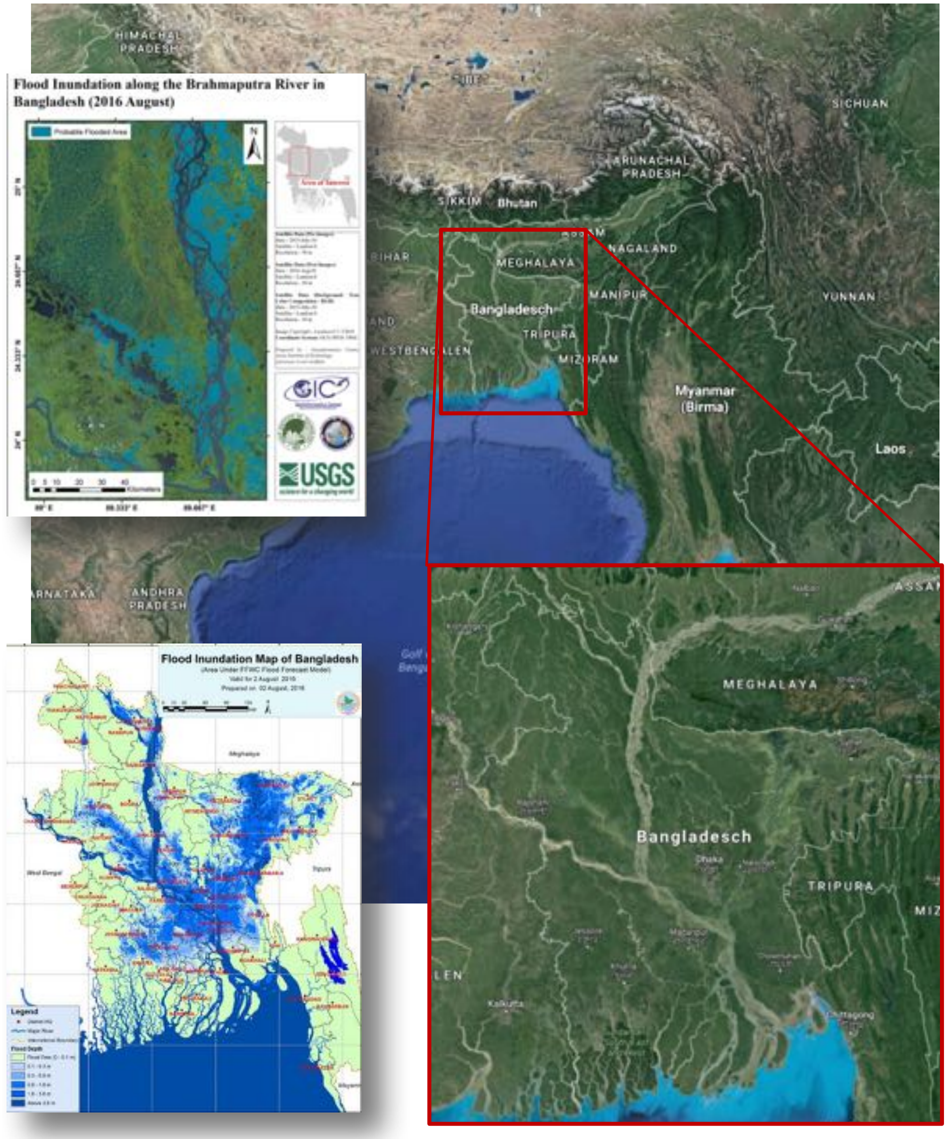
Study Area: Bangladesh

- Seasonal flooding due to monsoonal precipitation
- Regular Charter activations
- Huge affected area

<u>Selected Event:</u>

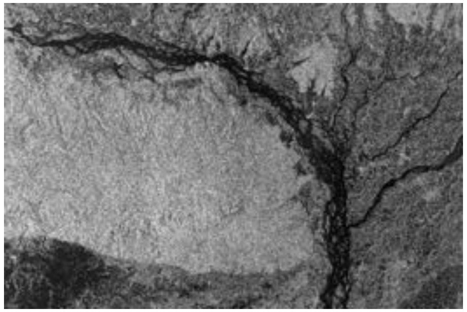
Activation of the International Charter on 1st of August 2016

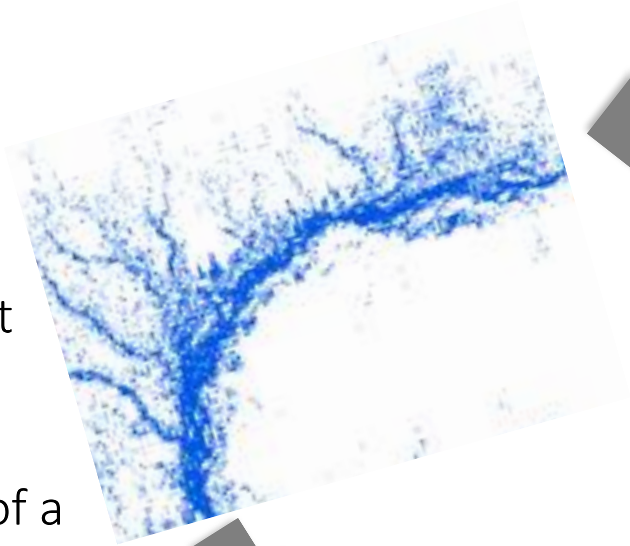
- 16 people killed
- 1.5 million people affected
- flooding of Ganges and Brahmaputra due to heavy rainfalls for several days



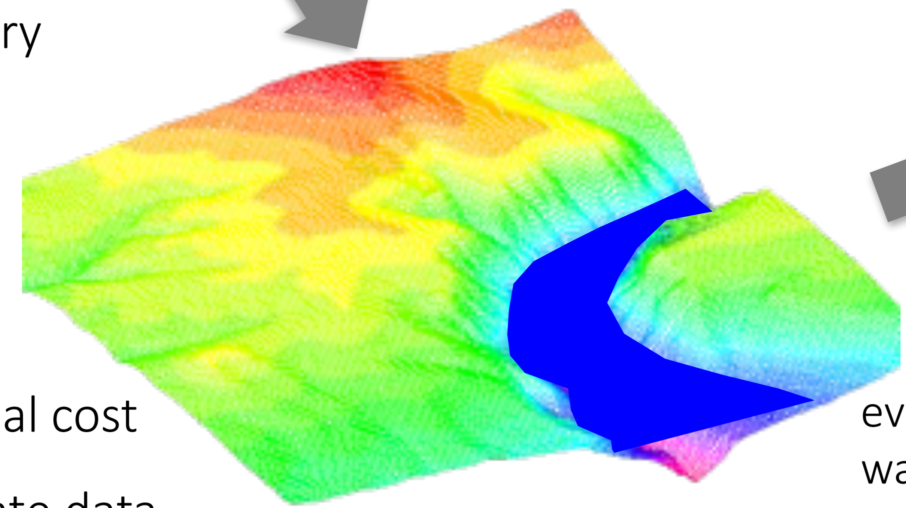
Horizon2020

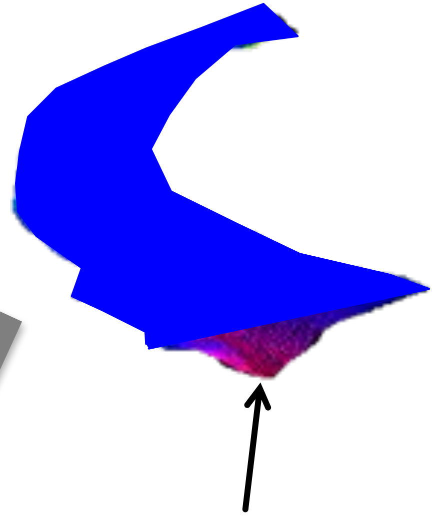
Method





Develop a method to get accurate flood volumes through a combination of a DEM and SAR imagery





everything in-between the water surface and the DEM is flood volume

<u>Important criteria:</u>

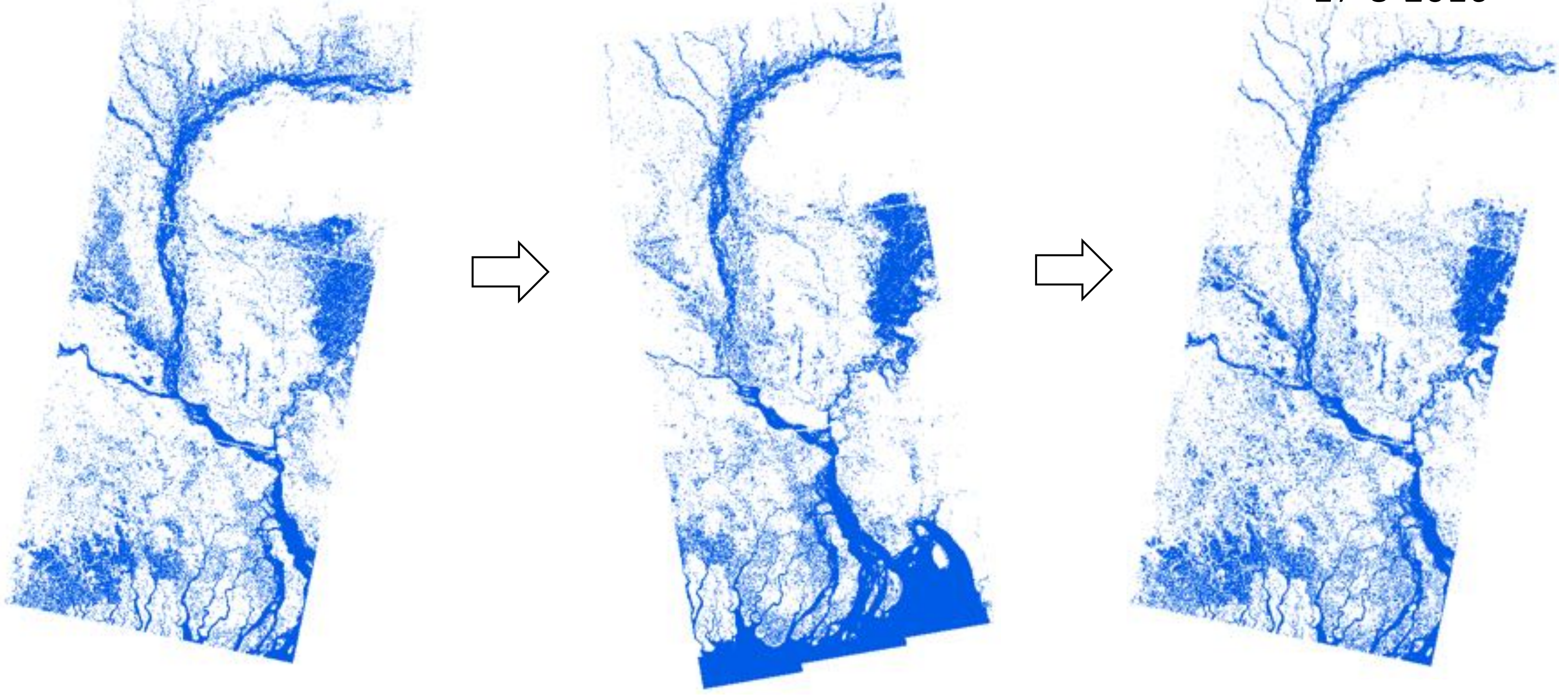
- low computational cost
- usage of up to date data

Input data

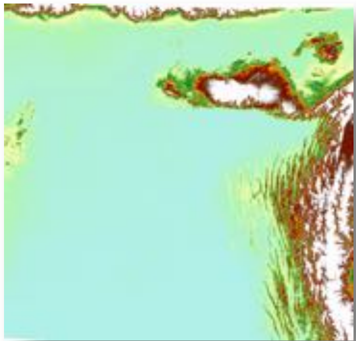
Flood Masks

- Sentinel-1 Scenes (SAR-Data) for Pre- & Post-Flooding, time-series
- ENVISAT ASAR

Pre-Flood 24-7-2016 | **Post-Flood** 03-8-2016 | **Post-Flood** 17-8-2016



Input data



Digital Elevation Models (DEM)

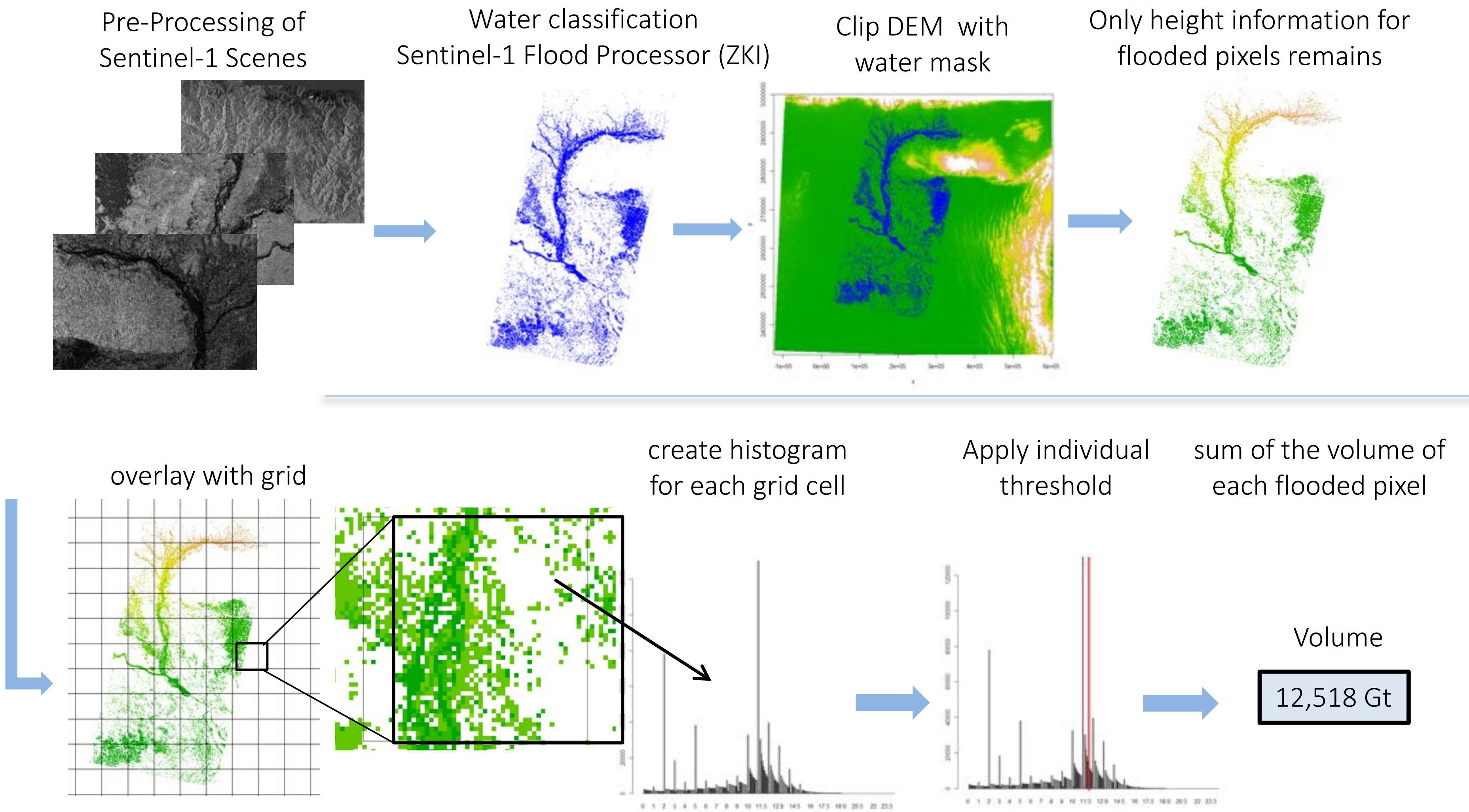
- SRTM 30 m integer
- SRTM 30 m interpolated to 32-bit float (still height artefacts)
- TanDEM-X 30 m 32-bit float (Proposal submitted)

www.legos.obs-mip.fr

Gauge Validation Data

- Water level data for automatic in situ stations from the Bangladesh Water Development Board (BWDB)
- Altimeter data from Jason-2 for virtual gauges

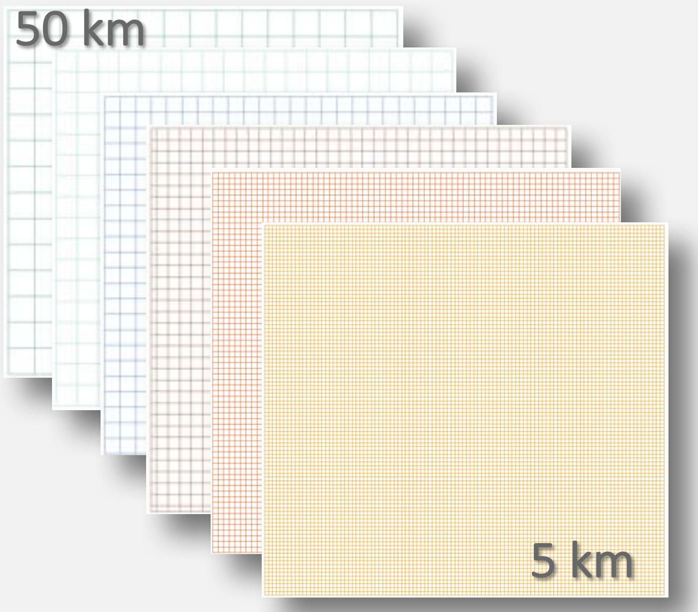
Workflow



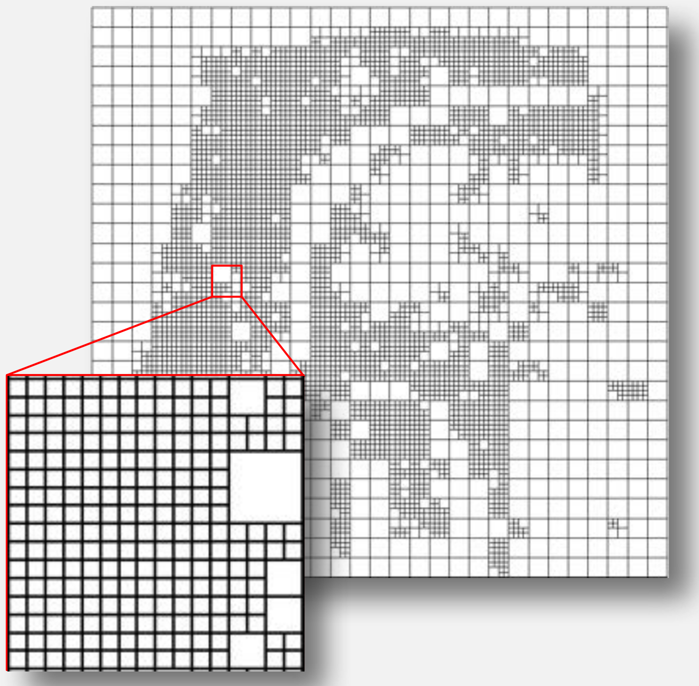
Pre-Processing of Sentinel-1 Scenes
Water classification Sentinel-1 Flood Processor (ZKI)
Clip DEM with water mask
Only height information for flooded pixels remains
overlay with grid
create histogram for each grid cell
Apply individual threshold
sum of the volume of each flooded pixel
Volume
12,518 Gt

Raster approach

Classic Fishnet
with different cellsizes



Sub-Tiles
created by slope-dependent threshold



Threshold I
apprupt change

Histogram for one grid cell

DEM values
=> height information

	07.09.07
	Gan_524
	OID_3909
1	0
2	0
3	2000
4	3111
5	3046
6	198
7	139
8	439
9	285
10	371
11	673
12	320
13	354
14	355
15	377
16	341
17	184
18	279
19	63
20	27
21	28
22	15
23	10

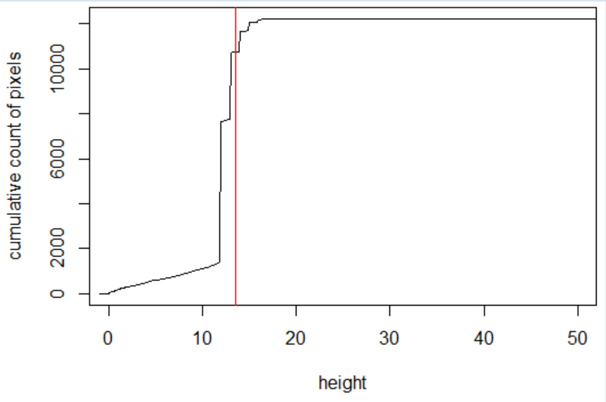
WATER

EXCLUDED PIXELS

get the point of drastic change
=> **Water height is 5 m**

Threshold II
cummulative

1. Sum up the pixel counts of the histogram
2. Set threshold until pixels are included
3. **70 %** of pixels is a good value



=> Still not appropriate for all grid cells

Threshold I
apprupt change

Histogram for one grid cell

DEM values
=> height information

	07.09.07
	Gan_524
	OID_3909
1	0
2	0
3	2000
4	3111
5	3046
6	198
7	139
8	439
9	285
10	371
11	673
12	320
13	354
14	355
15	377
16	341
17	184
18	279
19	63
20	27
21	28
22	15
23	10

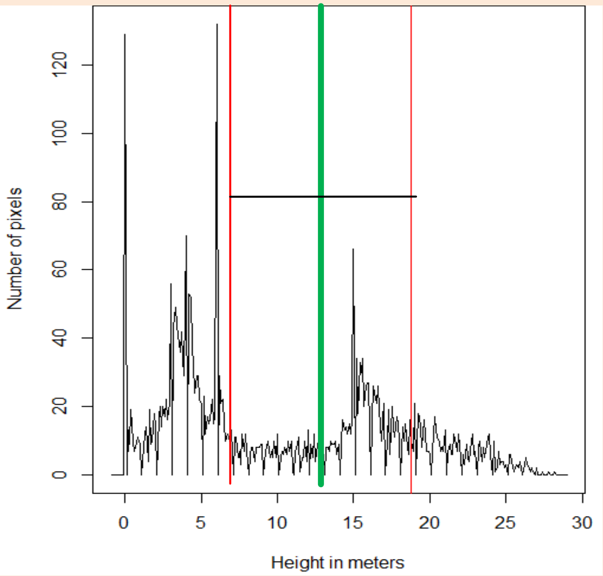
WATER

EXCLUDED PIXELS

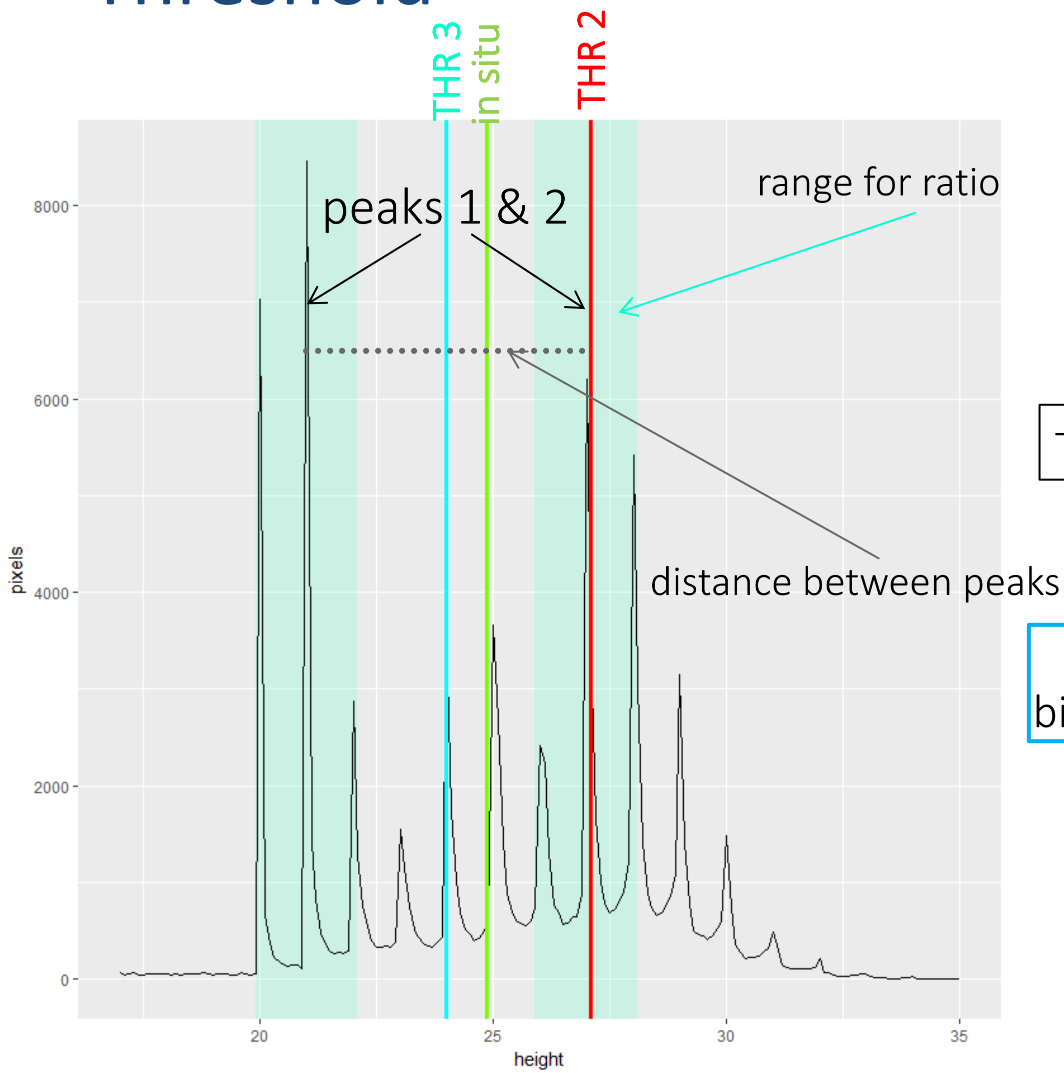
get the point of drastic change
=> **Water height is 5 m**

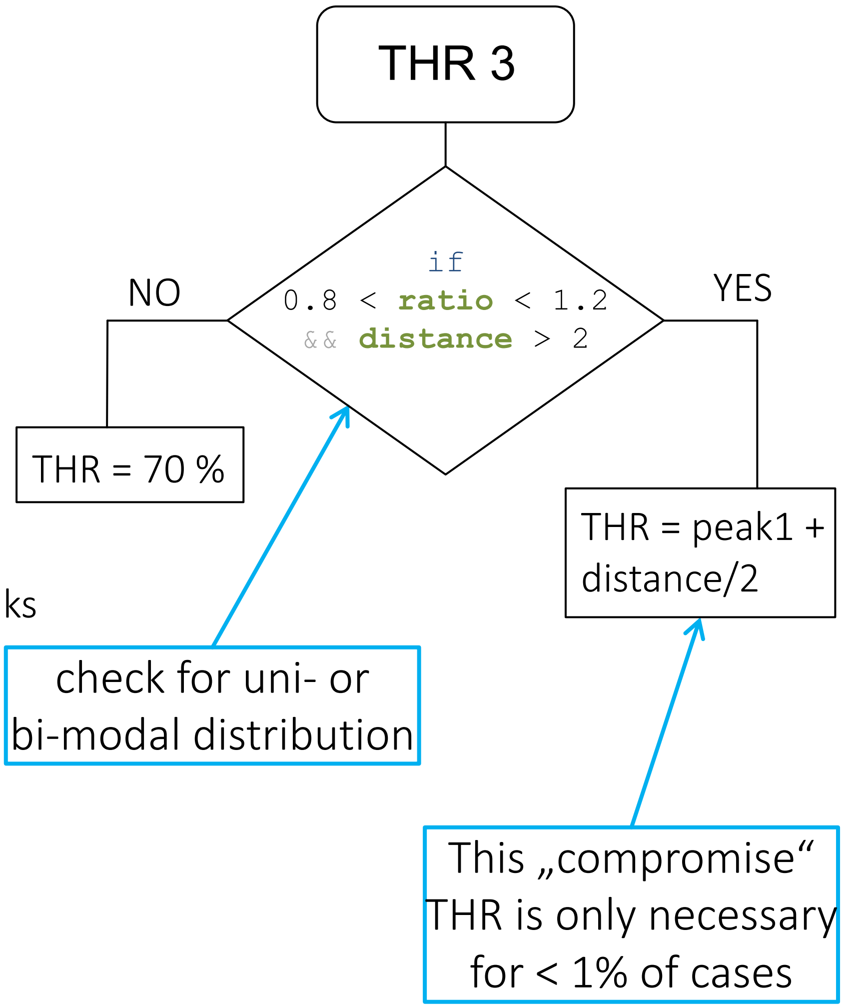
Threshold III
advancement of THR 2

Difficulty to handle bi-modal distributions
⇒ Actually two thr‘s needed
Compromise for lower level



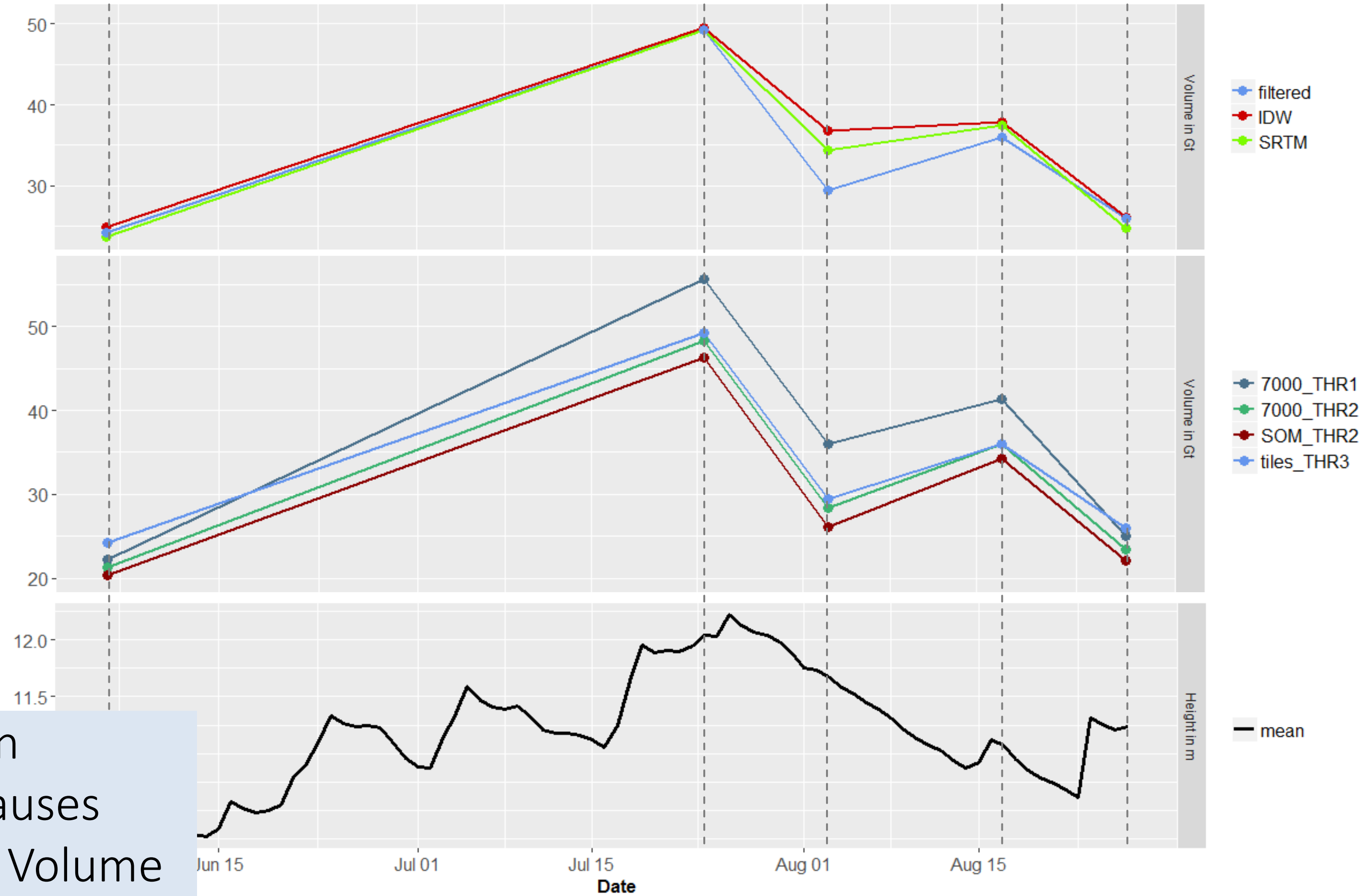
Threshold


THR 3
in situ
THR 2
peaks 1 & 2
range for ratio
distance between peaks
8000
6000
4000
2000
0
pixels
20
25
30
35
height


THR 3
NO
YES
if
0.8 < ratio < 1.2
&& distance > 2
THR = 70 %
THR = peak1 + distance/2
check for uni- or bi-modal distribution
This „compromise“ THR is only necessary for < 1% of cases

Results

Calculated volumes compared to the mean of water level gauge measurements

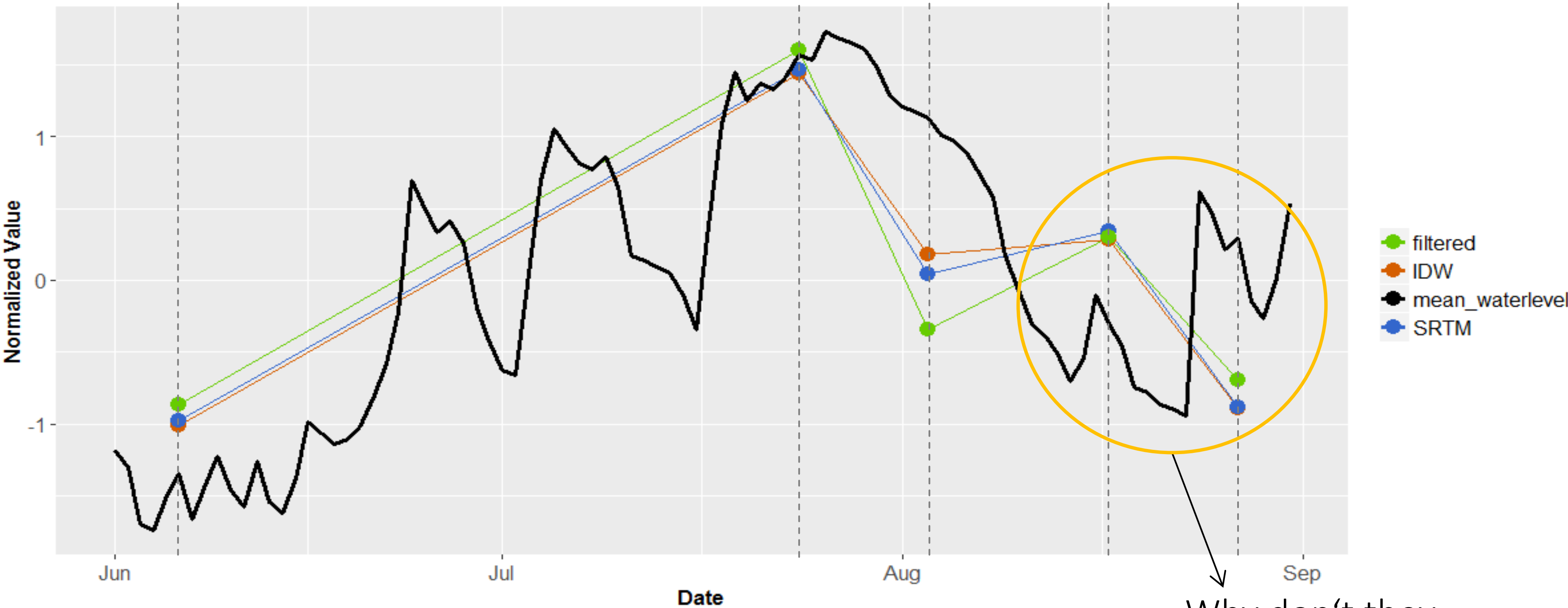


=> Impact of choosen threshold and grid causes higher differences in Volume than the impact of the DEM

Discussion

Normalized volumes & mean water levels

For comparison, the mean value of seven water level gauges in Bangladesh is displayed.



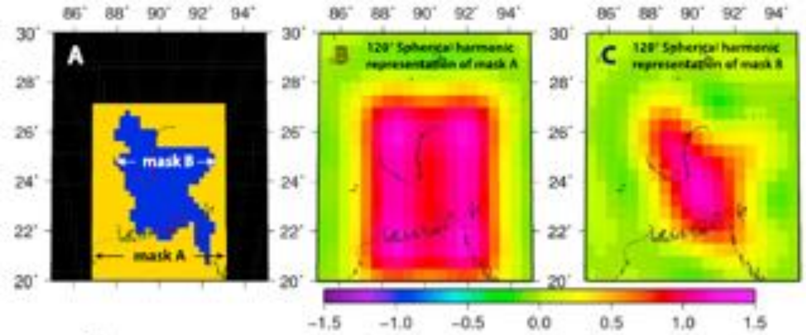
Why don't they match with the gauge measurement?

Uncertainties

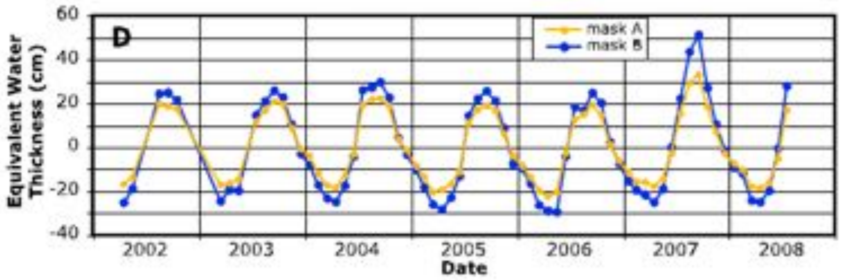
- Inaccurately orthorectified imagery
- Errors in the DEM (*absolute* ***vertical accuracy is better than 9 m)***
- Errors in the gauge measurements
- Inaccuracy of the altimeter measurements (especially over rivers)
- Comparison from point to area values
- Wrong threshold/ grid size
- Inaccuracy in the correction for the same geoid/ellipsoid, ground lowering/deformation(STECKER et al. 2010)
- Zero of mean sea level of the gauge in Calcutta
- Inaccuracy of in situ water level measurements (but rather cm than meters)
- Time shift in gauge measurement and aquisiton of SAR scene
- Change in elevation of river bed -> braided river!
- ……

Reference Study

Mask used for volume estimations with GRACE



Relative change in water thickness



<u>Comparing results :</u>

STECKER et al. (2010:10):

*„Both sets of data indicate that in an average year just over **100 GT** of water is stored within Bangladesh. The Storage can reach **150 GT** during exeptional floods…"*

⇒ Up to 50 Gt are stored due to flooding

⇒ Results show 45 to 55 Gt of flood volumes depending on DEM and THR

⇒ still accuracy in range of Gt is not accurate enough!

Conclusions

- So far, it is possible to calculate inundation depth to an **accuracy of ≈2 m** compared to water level measurements
- The volume estimations fit to the results of other values in literature in a range of Gt
  - the **kind and size of a grid** has highly influences the results => a dynamic fishnet grid derived best results
  - **THR 3 delivered best results** as it can handle bi-modal distributions
  - Different DEMs deliver different results, full magnitude will be defined by TanDEM-X data
- The volume estimation is automated, as the script is fully automatic

EGSIEM

European Gravity Service for Improved Emergency Management

EGSIEM Student Challenge 2016 | Status Report

Akbar Shabanloui, Jakob Flury

Institut für Erdmessung (IfE)

Leibniz Universität Hannover (LUH)

EGSIEM General Assembly

Bern, 2017-01-20

CHALLENGE!

EGSIEM
European Gravity Service for Improved Emergency Management

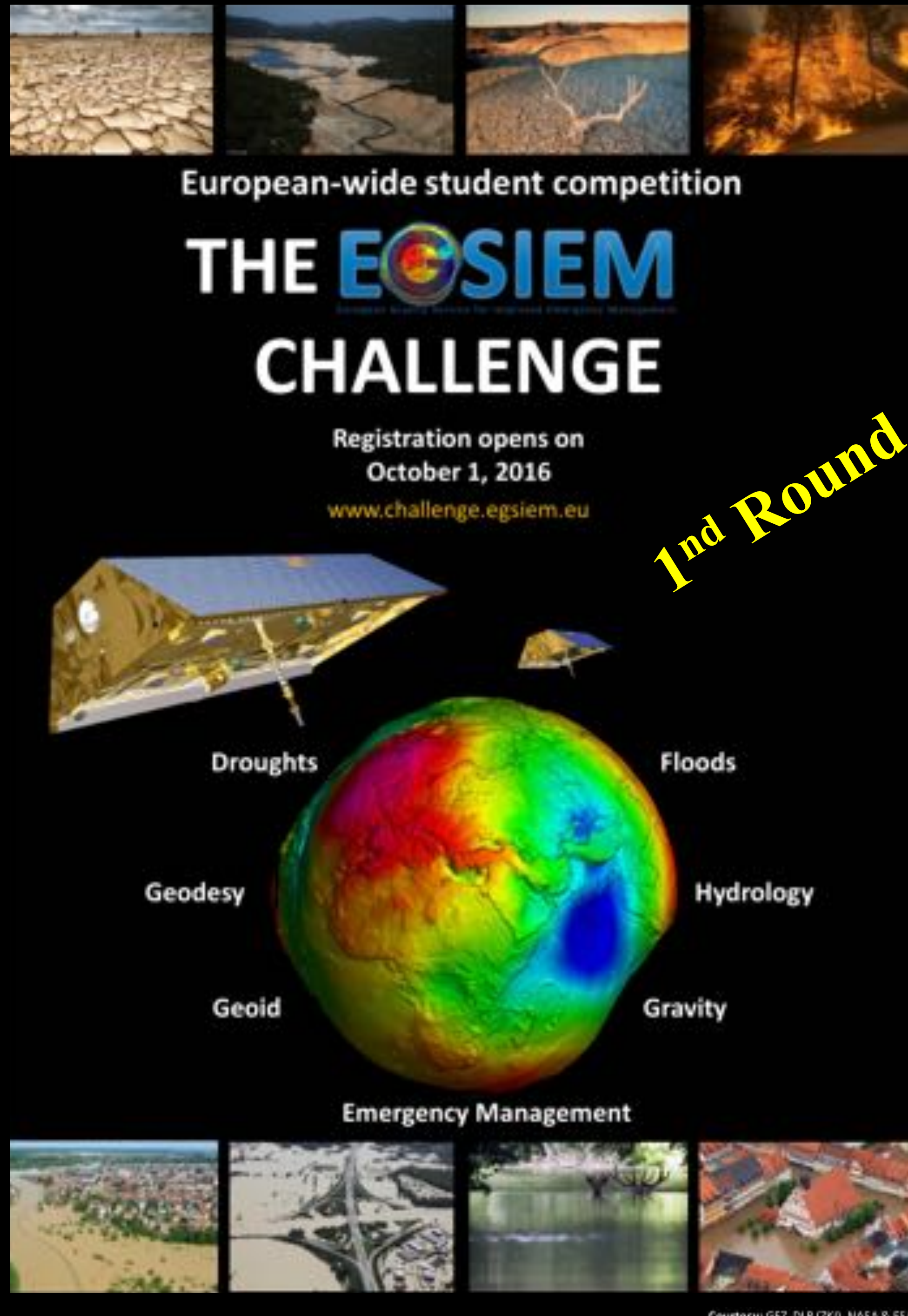
SOURCE:AWAKEEARLY.COM

EGSIEM Student Challenge 2016 | Schedule

European Gravity Service for Improved Emergency Management

Important Events	October				November						December				January	
	1	**8**	**15**	**22**	**1**	**8**	**11**	**12**	**15**	**22**	**1**	**15**	**22**	**31**	**1**	**15**
1st Round | **Online**																
1st Round | **Registration**																
1st Round | **Offline**																
1st Round | **Winners Announcement**																
2nd Round | **Online**																
1st Round | **Prizes**																
2nd Round | **Offline**																
2nd Round | **Winners Announcement**																

HORIZON 2020


European-wide student competition
THE EGSIEM
CHALLENGE
Registration opens on
October 1, 2016
www.challenge.egsiem.eu
Droughts
Floods
Geodesy
Hydrology
Geoid
Gravity
Emergency Management
Courtesy: GFZ, DLR (ZKI), NASA & ESA

1nd Round

Target Group

- **Students:**
  - Undergraduate students [B.Sc. & M.Sc.]
  - Focusing on Geodesy, Hydrology and Geophysics students, but others are welcome!
  - [19 – 29] years old
  - EU & CH residents [foreign students]

COMMUNICATIONS | ADVERTISEMENT

European Gravity Service for Improved Emergency Management

www.challenge.egsiem.eu | www.egsiem.eu

400 contact persons

EGSIEM STUDENT CHALLENGE | 1ND ROUND

EGSIEM
European Gravity Service for Improved Emergency Management

- **1ST ROUND:**
  - **Registration**
  - **20** questions | available after registration on www.challenge.egsiem.eu
  - Multiple-choice | to be solved in **6** hours
  - Started at **1.10.2016** – **11.11.2016**
  - Online & offline materials:
    - EGSIEM website and its partners
    - GRACE analysis centers e.g. GFZ, CSR and JPL
    - Other relevant sources
    - …

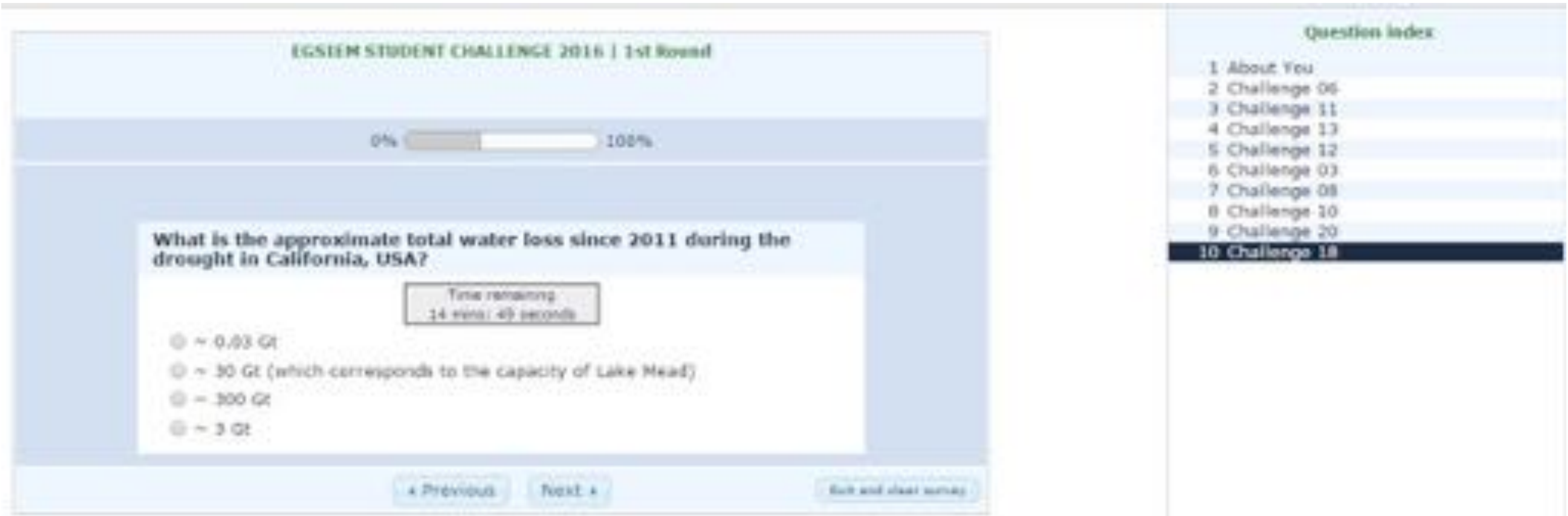
EGSIEM STUDENT CHALLENGE | 1ND ROUND

- **1ST ROUND | REGISTRATION**

EGSIEM STUDENT CHALLENGE | 1ND ROUND

European Gravity Service for Improved Emergency Management

- **1ST ROUND | QUESTIONS**
  - 20 multiple-choice questions | Online at www.challenge.egsiem.eu



EGSIEM STUDENT CHALLENGE | 1ND ROUND

EGSIEM
European Gravity Service for Improved Emergency Management

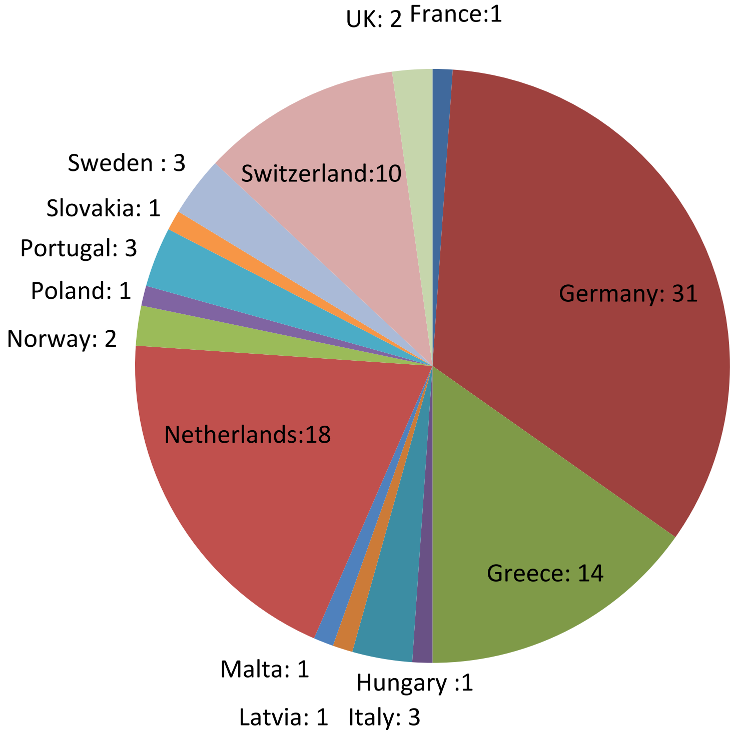
- **1ST ROUND | QUESTIONS | SUBMISSION**
  - 20 multiple-choice questions | Online at www.challenge.egsiem.eu

EGSIEM STUDENT CHALLENGE | 1ND ROUND

EGSIEM
European Gravity Service for Improved Emergency Management

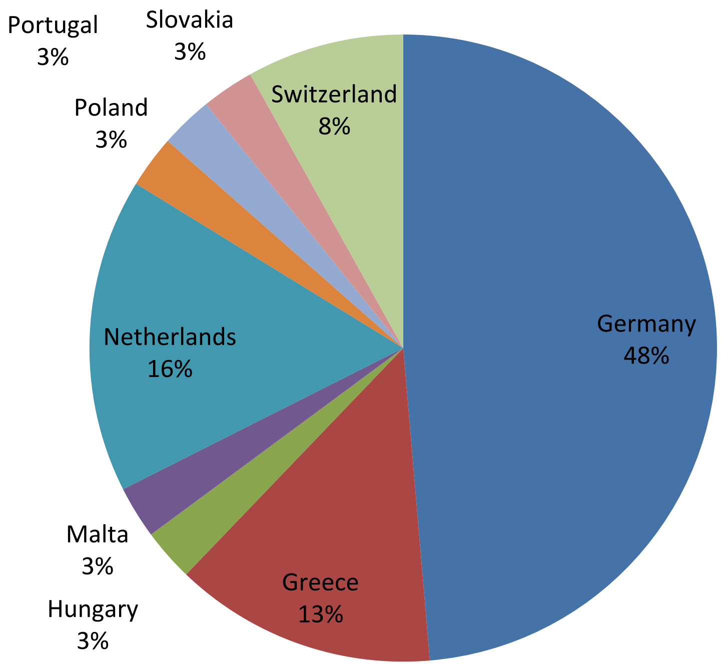
- 1ST ROUND | STATISTICS

# of registered participants : 92

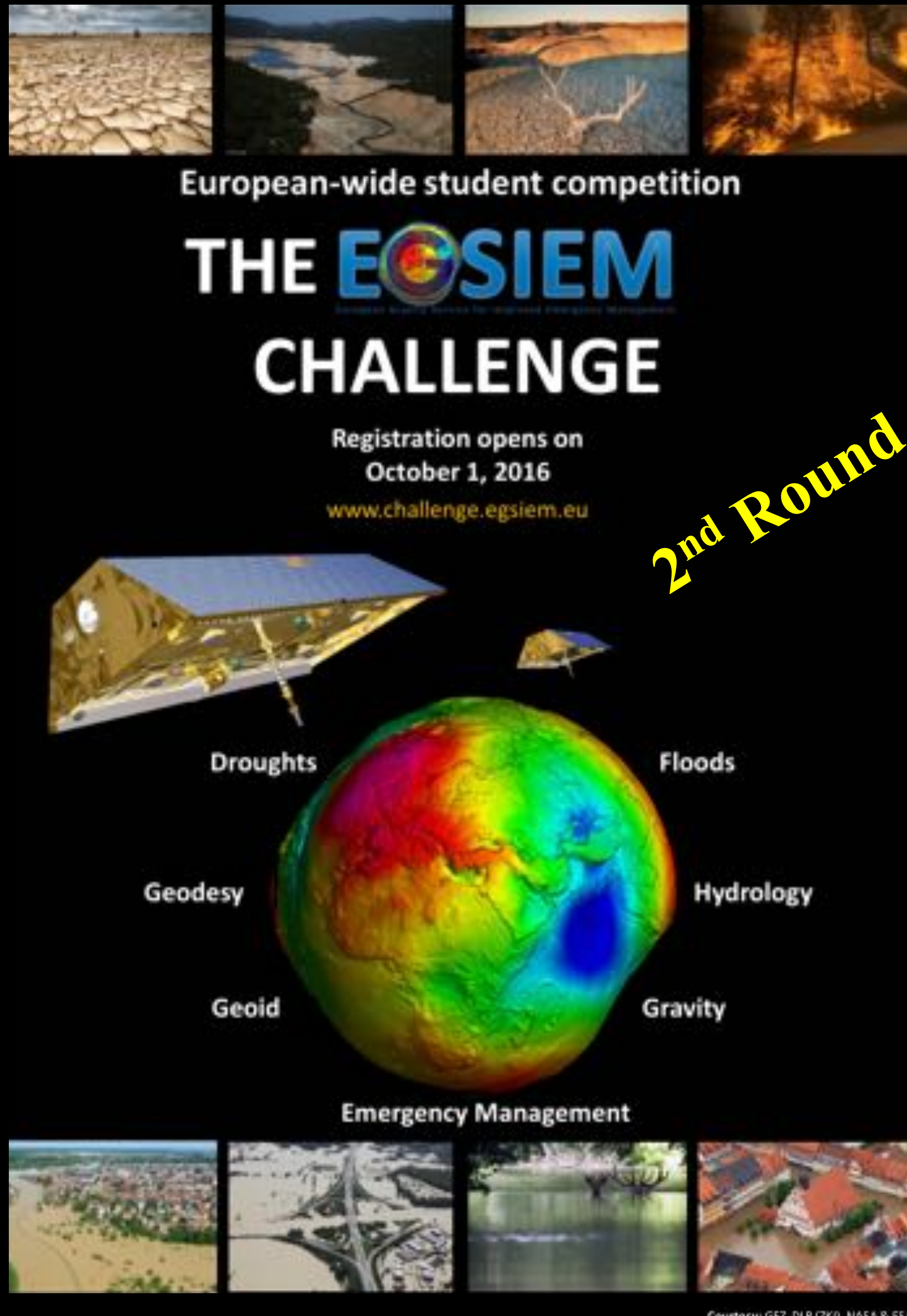


- 1ST ROUND | SUCCESSFULLY PASSED

37 of participant passed the first round | 12+ correctly



HORIZON 2020


European-wide student competition
THE EGSIEM
CHALLENGE
Registration opens on
October 1, 2016
www.challenge.egsiem.eu
2nd Round
Droughts
Floods
Geodesy
Hydrology
Geoid
Gravity
Emergency Management
Courtesy: GFZ, DLR (ZKI), NASA & ESA

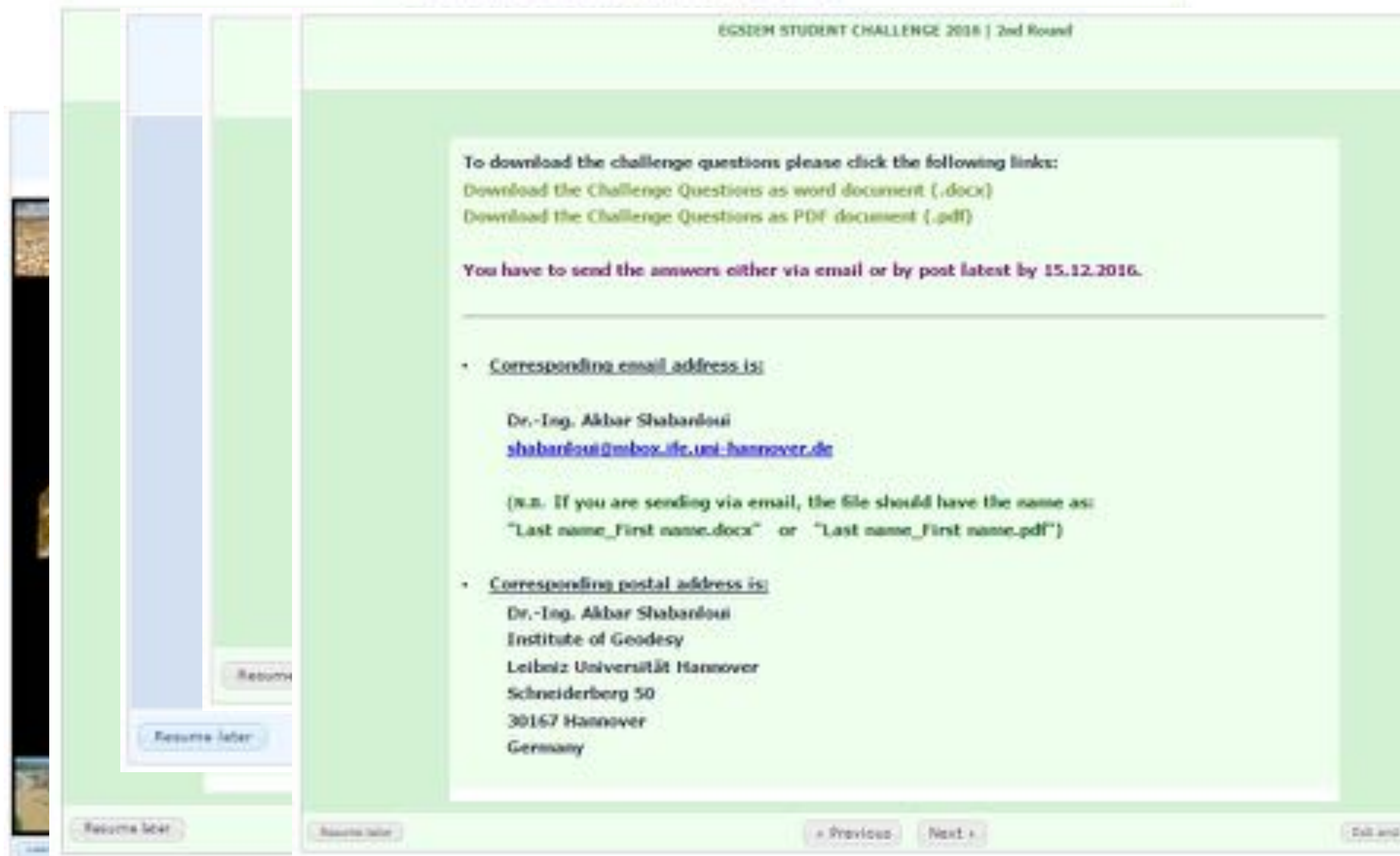
EGSIEM STUDENT CHALLENGE | 2ND ROUND

European Gravity Service for Improved Emergency Management

- **2ND ROUND:**
  - **20** written questions | available at www.challenge.egsiem.eu | Password
  - to be solved in **30** days
  - Started at **15.11.2016** – **15.12.2016**
  - The online and offline materials:
    - EGSIEM website and its partners
    - GRACE analysis centers e.g. GFZ, CSR and JPL
    - Other relevant sources
    - …

EGSIEM STUDENT CHALLENGE | 2ND ROUND

European Gravity Service for Improved Emergency Management



EGSIEM STUDENT CHALLENGE | 2ND ROUND

European Gravity Service for Improved Emergency Management

- **2ND ROUND | QUESTIONS (DOC | PDF)**

20. Could you propose some ideas about the measurement concepts for the next generation gravimetric missions? How we can benefit from current/future techniques to improve gravimetric approach for emergency management?

EGSIEM STUDENT CHALLENGE | WINNERS

EGSIEM
European Gravity Service for Improved Emergency Management

B.Sc. Philippa Higgins

Institute of Hydrology and Meteorology, TU Dresden

Dresden - Germany

B.Sc. Julian Rodriguez Villamizar

ESPACE, Technical University of Munich (TUM)

Munich - Germany

B.Sc. Peizo Cheng Rachel

UNESCO-IHE, Institute for Water Education

Delft - Niederlands

B.Sc. Alexandros Kazantzidis

Thessaloniki University, Department of Surveying

Thessaloniki - Greece

EGSIEM Student Challenge | Awards

EGSIEM
European Gravity Service for Improved Emergency Management

Two Internships

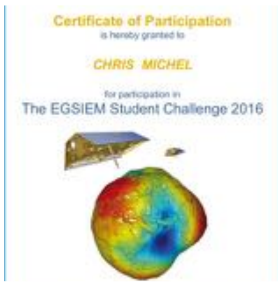
- 6 – 8 Weeks
- @ one of EGSIEM Member Institutes
- Travel Expenses
- Insurances (Including Health Accident & Personal Liability Insurances)

Two Scholarships

- 1 Week
- Participation @ Summer School (?)
- Travel and Health Expenses, Personal Liability insurances

Awards | Post

European Gravity Service for Improved Emergency Management



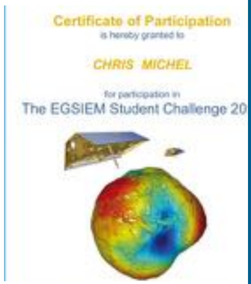
Successfully passed 1st Round

- Certificate
- Giveaways
  - Travel mug
  - Lanyard| LUH Log
  - Pen | LUH Log
  - EGSIEM Brochure

HORIZON 2020

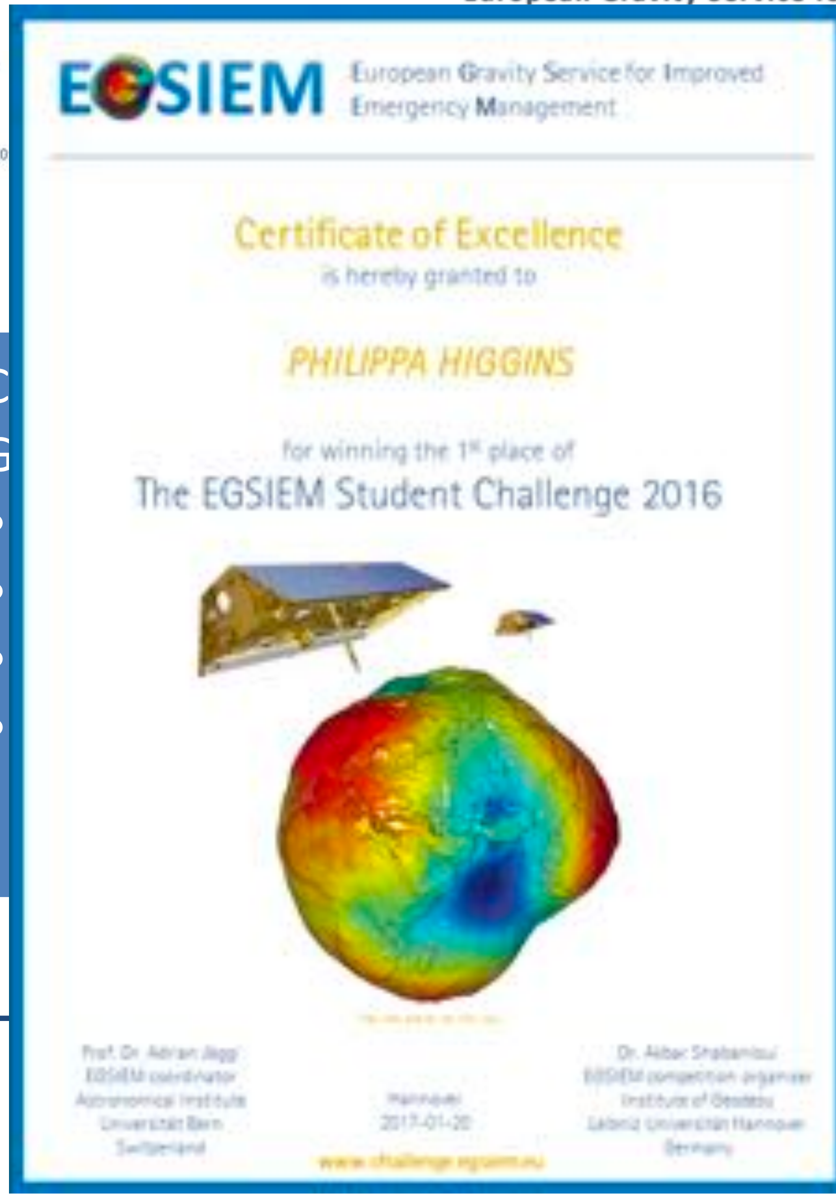
AWARDS | POST

EGSIEM
European Gravity Service for Improved Emergency Management



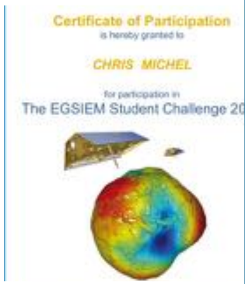
SUCCESSFULLY PASSED
1ST ROUND

- C
- G



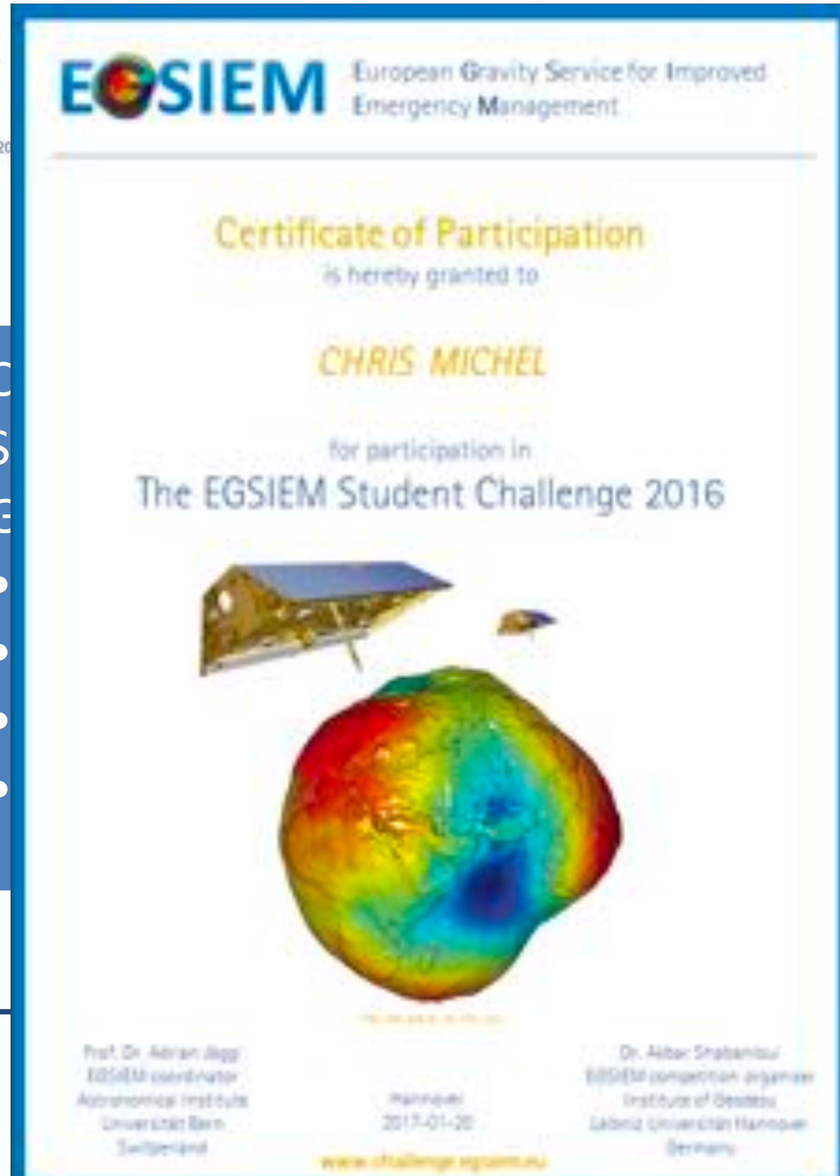
Awards | Post

European Gravity Service for Improved Emergency Management



Successfully passed
2nd Round

- C
- S
- G
  -
  -
  -
  -



-Michel

Open Questions?

European Gravity Service for Improved Emergency Management

- **Prizes**
  - Research **Internships** | **Which** Institutes are ready to host the winners?
  - How about the **summer school** | Date and Place**?**
- **Website**
  - **Publishing** the winners on the EGSIEM Portal| Confirmed by the winners
  - **Deactivation** of the EGSIEM Student Challenge Portal!
  - # of **visitors** during EGSIEM Student Challenge

- **FEEDBACKS**
  - **Students** were very strong motivated to participate in the challenge!
  - **Running** the similar challenge | **Platform** incl. all materials are available!
  - **Public Relation (PR)** | Outreach activities (e.g. STAG@LUH ,
    Friday Lecture@Bern or EGSIEM meet students) | Geodesy

NEWSLETTER

European Gravity Service for Improved Emergency Management

- **ISSUES**
  - **Inputs:** interesting news, updates, toolbox …
  - **EGSIEM introduces itself** | missing people ?
  - **Last page** of the newsletter!

EGSIEM

European Gravity Service for Improved Emergency Management

EGSIEM Summer School

Adrian Jäggi (AIUB)

EGSIEM General Assembly

University of Bern

January 19 – 20, 2017

UNIVERSITÄT BERN · UNIVERSITÉ DU LUXEMBOURG · GFZ Helmholtz Centre Potsdam · TU Graz Graz University of Technology · Leibniz Universität Hannover · cnes · DLR · géode & cie · HORIZON 2020

Status of summer school planning

- EGSIEM Summer School will take place at GFZ Potsdam from **11 – 15 September 2017**
- Additional support by 10 kEUR by BMBF
- Reorganization of the original program submitted to WEH foundation will be needed in the upcoming months:

DATE	Morning	Afternoon	Evening
Sunday		Welcome Program	Introduction to school **EGSIEM** Adrian Jäggi
Monday	Core topic 1 **GRACE Analysis I** Torsten Mayer-Gürr	Core topic 1 **GRACE Analysis II** Ulrich Meyer	**Loading** Tonie van Dam
Tuesday	Core topic 2 **Hydrology I** Andreas Güntner	Core topic 2 **Hydrology II** Annette Eicker	**GIA** Holger Steffen
Wednesday	Core topic 3 **Ice sheet signals** Martin Horwath	**Visit to the German Federal Institute of Hydrology, Koblenz**	**Heraeus Evening**
Thursday	Core topic 4 **Remote Sensing I** Hendrik Zwenzer	Core topic 4 **Remote Sensing II** Sandro Martinis	**GRACE FO** Frank Flechtner
Friday	Practical: EGSIEM tools Stephane Bourgogne / Matthias Weigelt	Group challenge Matthias Weigelt, all	Group presentations all
Saturday	Departure		

EGSIEM

European Gravity Service for Improved Emergency Management

Visibility to Copernicus

Adrian Jäggi (AIUB)

EGSIEM General Assembly

University of Bern

January 19 – 20, 2017

Visibility to Copernicus

- Copernicus user surveys for Next Generation Sentinels have been filled out by several EGSIEM partners and further institutions from the gravity community
- EGSIEM letter has been formulated to respond to the stakeholder consultation for the H2020 work program 2018-2020 on Earth Observation
- EGSIEM has provided input to ESA for the Climate Change Workshop in Brussels

The Draft Scoping Papers of upcoming Calls nevertheless do not directly contain keywords relevant for the Gravity Community

Improvement of the situation

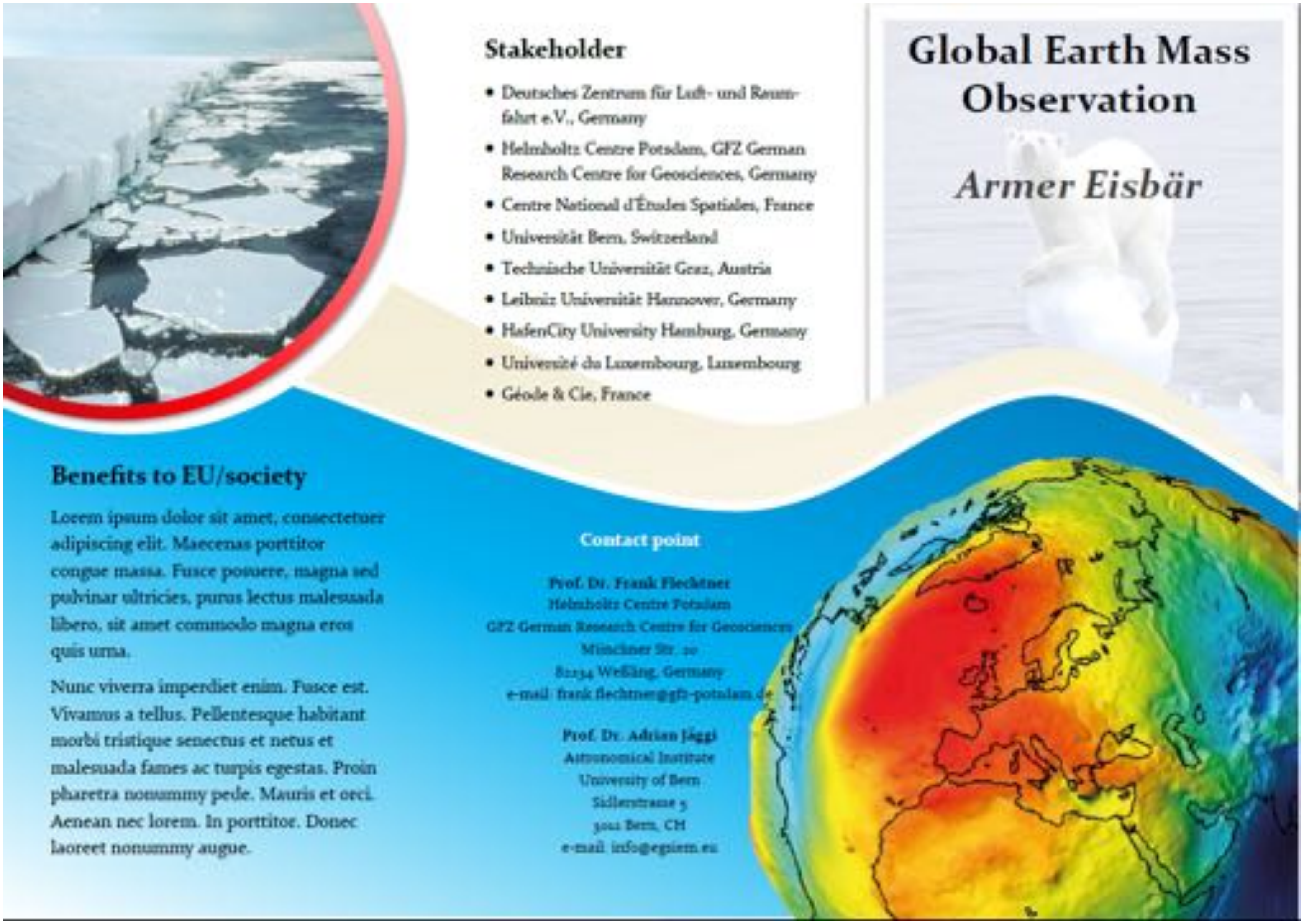
- A lobby event shall be organized in Brussels with the help of the Helmholtz Office in Brussels, SwissCore, the GFZ EU Project Office, and EUResearch to further promote satellite gravimetry in view of the upcoming GRACE-FO mission.

- Potential dates are 2nd , 6th or 14th March (TBC)

- Info material (short talks, flyers, position papers) are currently prepared by the EGSIEM EB to inform the participants of this event on satellite gravimetry and its applications

- The target audience are program coordinators, project officers, national delegates of the program committees, etc.

Layout of Flyers



EGSIEM

HORIZON 2020

Layout of Flyers

EOSIEM

HORIZON 2020

Topics for Flyers

- Principle of Satellite Gravimetry
- Climate Change
- Water and Resiurce Management
- Hazard Monitoring
- Synergies between Copernicus and Satellite Gravimetry

Combined SLR-derived gravity fields for EGSIEM

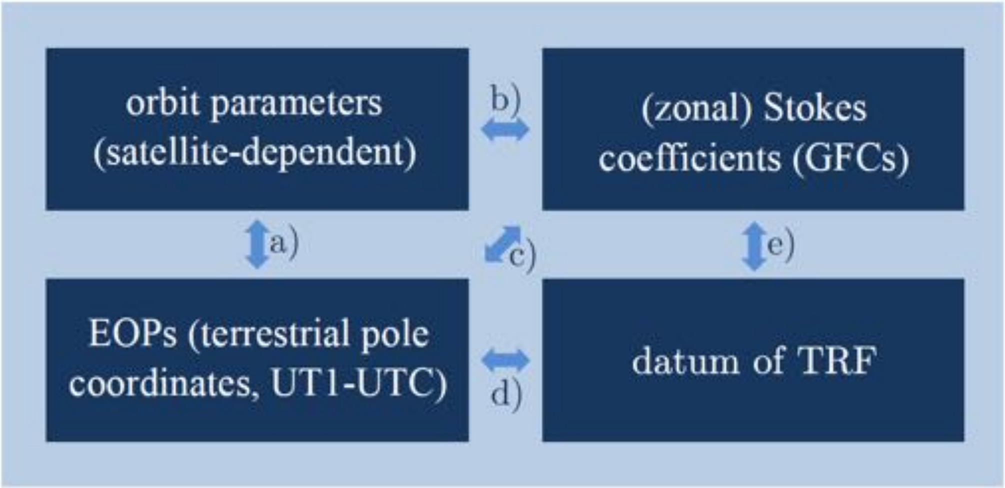
Mathis Bloßfeld, Andrea Grahsl, Daniel König, Krzysztof Sosnica, Sandro Krauss, Rolf König, Jean-Michel Lemoine, Toshimichi Otsubo

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

EGSIEM consortium meeting
Bern, Switzerland, 20 January 2017

Motivation

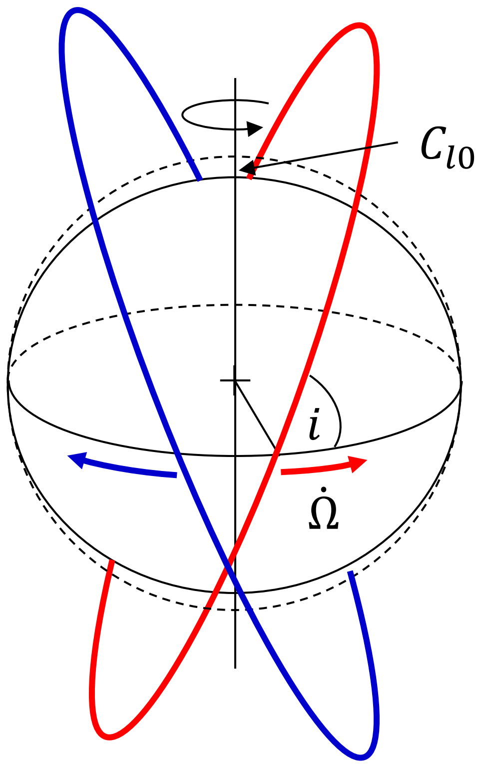
- Due to the high sensitivity of SLR observations to the fundamental geodetic parameters, correlations falsify reliable estimates

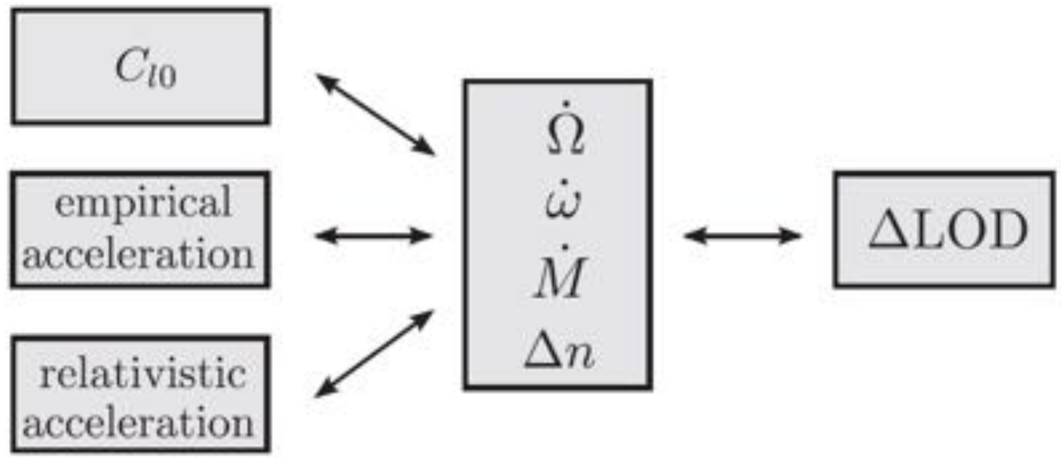


- Correlations related to Stokes coefficients
  - b) correlations of orbit parameters and Stokes coefficients
  - c) correlations of LOD and C_{l0}; x_p/y_p with C_{21}/S_{21}
  - e) correlation of TRF scale with C_{00}; origin with $C_{10}/C_{11}/S_{11}$; orientation with $C_{21}/S_{21}/C_{22}/S_{22}$

Motivation

- Single-satellite solution: high correlation of various parameters (especially between zonal coefficients, satellite orbit parameters and LOD)





- Multi-satellite solution (MSS): de-correlation of parameters due to combination of inclinations (e.g. C_{l0} and Ω) → reliable estimates of zonal coefficients

SLR decorrelation and sensitivity tests (I)

- ❑ In order to obtain reliable estimates of the Stokes coefficients, it is essential to de-correlate the orbital parameters and the coefficients of the Earth‘s gravitational field.

- ➢ **Test 1**: De-correlation of orbit parameters and C_{20} (taken from Bloßfeld et al., 2015)

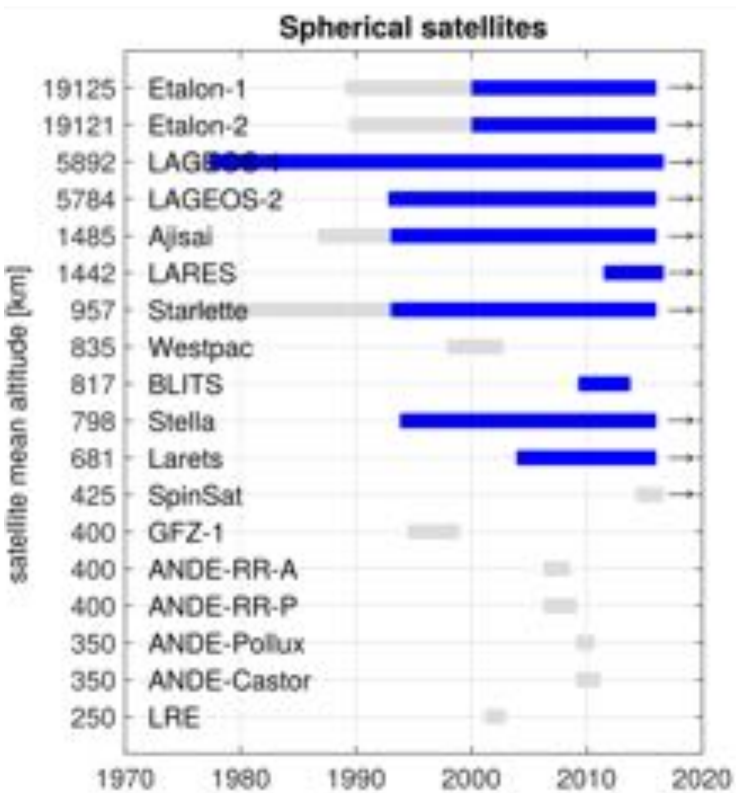


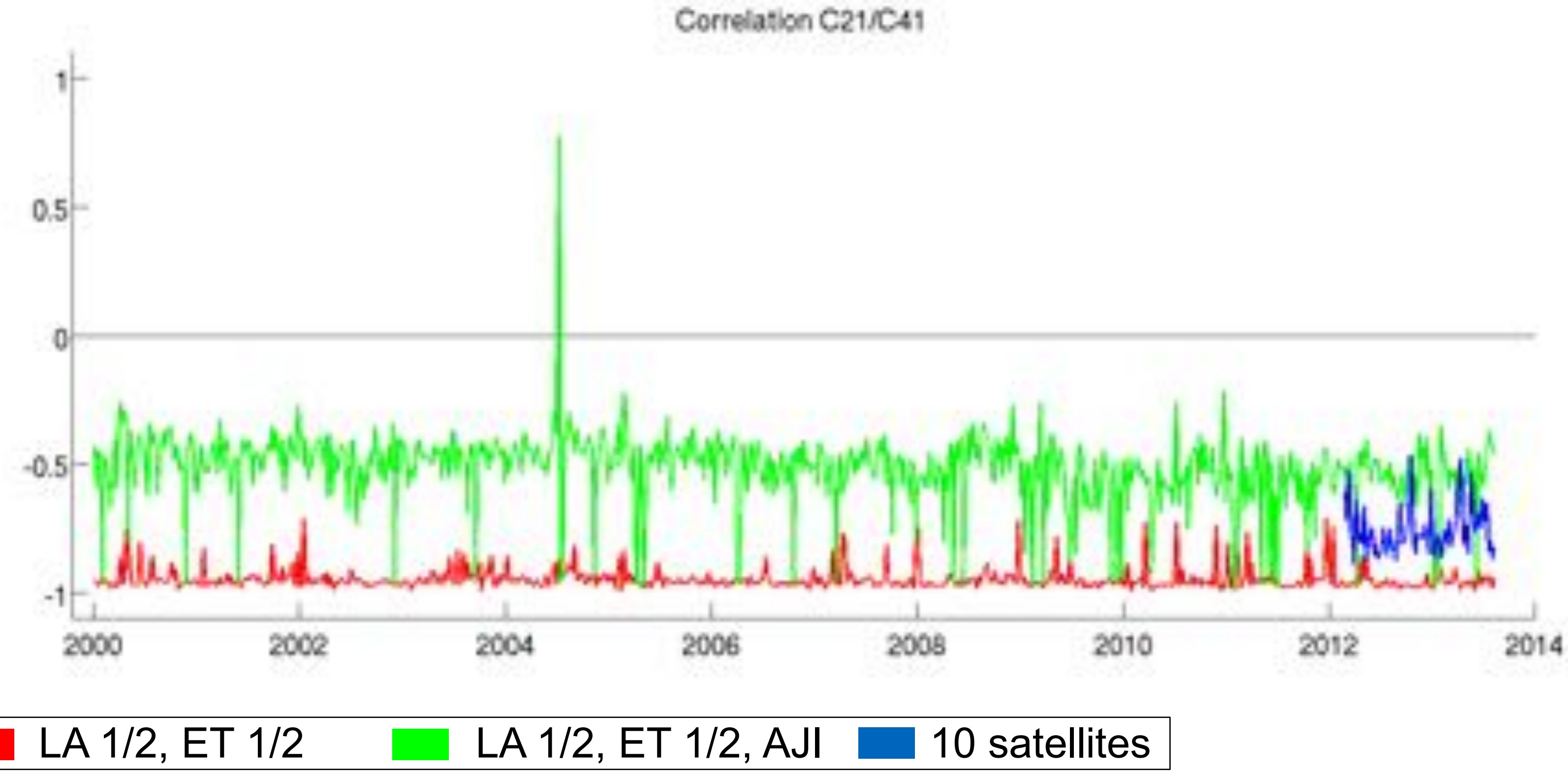
Table 8 Correlation coefficients of C_{20} and the right ascension of the ascending node of LA1 (Ω_{LA1}) at CW 51 of 2012

solution	correlation coefficient
LA1	1.00
2-sat.	0.44
4-sat.	0.44 (current ILRS setup)
4-sat. + AJI	0.24
4-sat. + STA	0.28
4-sat. + STE	0.31
4-sat. + LTS	0.41
4-sat. + BTS	0.43
4-sat. + LRS	0.24 (future ILRS setup)
6-sat.	0.24
7-sat.	0.22
8-sat.	0.21
9-sat.	0.21
10-sat.	0.08

SLR decorrelation and sensitivity tests (II)

- ❑ In order to obtain reliable estimates of the Stokes coefficients, it is essential to de-correlate the orbital parameters and the coefficients of the Earth's gravitational field.

- ➢ **Test 2**: De-correlation of different Stokes coefficients using multi-satellite SLR solution



SLR decorrelation and sensitivity tests (III)

- ❑ In order to obtain reliable estimates of the Stokes coefficients, it is essential to de-correlate the orbital parameters and the coefficients of the Earth‘s gravitational field.

- ➢ **Test 3**: Sensitivity analysis w.r.t. Stokes coefficients

- ➢ This test is based on the PhD thesis of R. Floberghagen (2002);

$$[0; 1] \epsilon \; diag(N^{-1}N) = (A^T PA + \alpha K)^{-1}(A^T PA)$$

- ➢ **Important:** sensitivity coefficient equal to one means that the Stokes coefficient is fully determinable from the observations

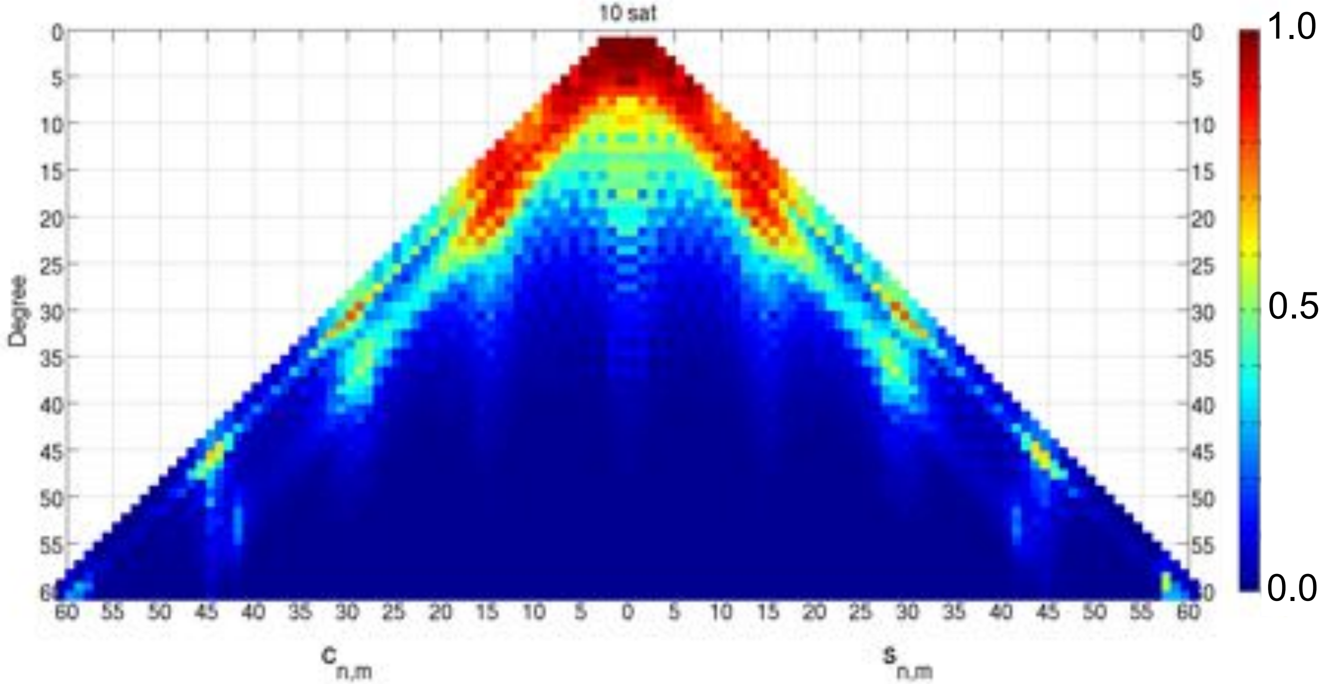
- ➢ **BUT:** some coefficients are highly correlated (Haberkorn et al., 2014) and therefore only a linear combination of them (Kaula, 1966) can be estimated (e.g., even zonal low degree Stokes coefficients)

SLR decorrelation and sensitivity tests (III)

- In order to obtain reliable estimates of the Stokes coefficients, it is essential to de-correlate the orbital parameters and the coefficients of the Earth‘s gravitational field.

➢ **Test 3**: Sensitivity analysis w.r.t. Stokes coefficients

LA 1/2
+ ET 1/2
+ AJI
+ STA
+ STE
+ LTS
+ BTS
+ LRS
+ JA2



Possible contributions to EGSIEM (by DGFI-TUM)…

- DGFI-TUM can provide SLR normal equations (NEQs) …
  … which comprise SLR observations to **numerous spherical** and/or **non-spherical satellites**
  … which cover the time interval from **1978 until 2017** (laser data)
  … which are based on various arc lengths (**weekly, 2-weekly, monthly**)
  … which include station coordinates/EOP/**Stokes coefficients**/etc…
  … which are based on **numerous different a priori models** (solid Earth/ocean tides, non-tidal loading effects, relativistic effects, etc…

- BUT: not only DGFI-TUM is able to contribute to EGSIEM with SLR data!
- A. Jäggi invited a group of (European) institutes which have SLR expertise to contribute to EGSIEM

TECHNISCHE UNIVERSITÄT MÜNCHEN | UNIVERSITÄT BERN | Bundesamt für Kartographie und Geodäsie | UNIVERSITAS RERUM NATURALIUM WRATISLAVIENSIS | ÖAW | GFZ Helmholtz-Zentrum POTSDAM | GRGS GROUPE DE RECHERCHE DE GEODESIE SPATIALE | HITOTSUBASHI UNIVERSITY

EGSIEM SLR processing standards

- ❑ in order to be most consistent with the EGSIEM processing standards for GRACE, we compiled a table summarizing all existing SLR solution setups

institutions:

- ➢ DGFI-TUM (Germany)
- ➢ AIUB/BKG (Switzerland/Germany)
- ➢ GFZ (Germany)
- ➢ WUELS (Poland)
- ➢ OEAW (Austria)
- ➢ GRGS (France)

- ➢ Hitotsubashi University (Japan)

for comparison:

- ➢ NASA GSFC (USA)
- ➢ CSR (USA)

EGSIEM SLR processing standards

- in order to be most consistent with the EGSIEM processing standards for GRACE, we compiled a table summarizing all existing SLR solution setups

advantageous for combination

- 5+1 SLR software packages

main fields (colored) in the comparison

- general information
- SLR-specific corrections and solution setup
- station coordinates, gravitational perturbation, dynamic a priori models
- non-gravitational perturbations
- EOP

EGSIEM SLR processing standards

- in order to be most consistent with the EGSIEM processing standards for GRACE, we compiled a table summarizing all existing SLR solution setups

- **General information**
  - institution, software package, contact, online availability, major reference

- **SLR-specific corrections and solution setup**
  - time span, SLR (+DORIS) satellites, arc length, covariance information, weighting of observations, integrator details (step size), polynomial representation degree, tropospheric model, CoM correction at satellite, applied relativistic effects, applied empirical accelerations, Earth gravity field estimates

- **Station coordinates, gravitational perturbation, dynamic a priori models**
  - a priori station coordinates, range/time biases (SLR specific), applied constrain on station coordinates, station-dependent weighting of observations, solid Earth tides (gravity + loading), ocean tides (gravity + loading), atmospheric tides (gravity + loading), ocean pole tides (gravity + loading), a priori gravity model (static + time-variable part), C21/S21 a priori values, equatorial radius, non-tidal loading corrections (gravity + loading), lunar gravity, ephemerides

EGSIEM SLR processing standards

- in order to be most consistent with the EGSIEM processing standards for GRACE, we compiled a table summarizing all existing SLR solution setups

- **Non-gravitational perturbations**
  - solar radiation, satellite drag modelling, Earth albedo, atmospheric/ thermospheric model for LEOs, thermal dissipation, used satellite macromodels

- **EOP**
  - LOD, terrestrial mean pole, terrestrial pole

- rough cross-checking with GRACE processing standards (together with U. Meyer)

EGSIEM SLR processing standards

- potential important (critical) issues w.r.t. EGSIEM GRACE processing standards

institution	estimate d/o 1 terms	maximum d/o	apply AOD at observation level	non-unify a priori dynamic models	constrain GFCs	number of satellites	maximum time span
DGFI-TUM	no	5 + C61/S61	possible (gravity + loading)	EOT11a	unconstrained	13	1978.6 – now
AIUB/BKG	no	10	possible (gravity + loading)	EOT11a	constrained for d/o > 6	12	2002.0 – now
GFZ	yes	50	not applied	FES2004	unconstrained	6	2002.0 – now
WUELS	?	6	possible (gravity + loading)	EOT11a	?	6	?
OEAW							
GRGS							
Hitotsubashi University	no	4	loading (ERA -> ATM/ CWS, ECCO -> OCN)	EOT11a	unconstrained	6	1992.8 – now
CSR	no	5 + C61/S61	not clear what was applied	?	unconstrained	4	1992.8 – 2011.4
NASA GSFC	no	5 + C61/S61	ECMWF based	GOT4.8	unconstrained	7 (SLR) + 6 (DORIS)	1992.8 – now

(yes)	**10 (in 1st iteration) and more**	**any NT-L model applied (gravity + loading)**	**any**	**unconstrained**	**4 - 13**	**2006.0 – 2008.0**

Roadmap for SLR contribution to EGSIEM

- How will the SLR contribution to EGSIEM be organized?
  - Collect solution setups of SLR ACs and discuss potential/necessary unification at EGSIEM meeting in Bern (**mid of January 2017**) → send SLR processing standards to A. Jäggi
  - 1st reprocessing of singular NEQs of 2006/2007 using common standards and submission (SINEX file with NEQ and SOLUTION/ESTIMATE block) to DGFI-TUM (**end of February 2017**)
  - Generation of solutions and 1st comparisons; potential re-iteration with ACs (**end of April 2017**)
  - 2nd reprocessing (if necessary) and submission of final singular NEQs to DGFI-TUM (**mid of June 2017**)
  - Final evaluation of solutions and submission of individual AC SLR-NEQs to AIUB (including weight suggestions) for combination at NEQ level with GRACE (**end of July 2017**)
  - (Extension of time series to maximum time span)

Combined SLR-derived gravity fields for EGSIEM

Mathis Bloßfeld, Andrea Grahsl, Daniel König, Krzysztof Sosnica, Sandro Krauss, Rolf König, Jean-Michel Lemoine, Toshimichi Otsubo

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

EGSIEM consortium meeting
Bern, Switzerland, 20 January 2017

Estimation of white noise in a mass anomaly time-series and modelling the geocenter motion

P. Ditmar, Y. Sun, and R. Riva

Delft University of Technology, The Netherlands

Estimation of white noise

Tikhonov regularization of GRACE-based mass anomaly time-series

Penalty functional:

$$\Phi[H] = \sum_i \left(H(t_i) - H_i^{(\mathrm{obs})} \right)^2 + \alpha \Omega[H]$$

Regularized time-series (to be found)

Original time-series

Regularization parameter

Regularization functional

Regularization functional

Let $H(t) = \begin{pmatrix} h_1(t) \\ h_2(t) \\ \dots \\ h_K(t) \end{pmatrix}$

- $h_1(t)$ ← Mass anomalies in year 1
- $h_2(t)$ ← Mass anomalies in year 2
- $h_K(t)$ ← Mass anomalies in year K

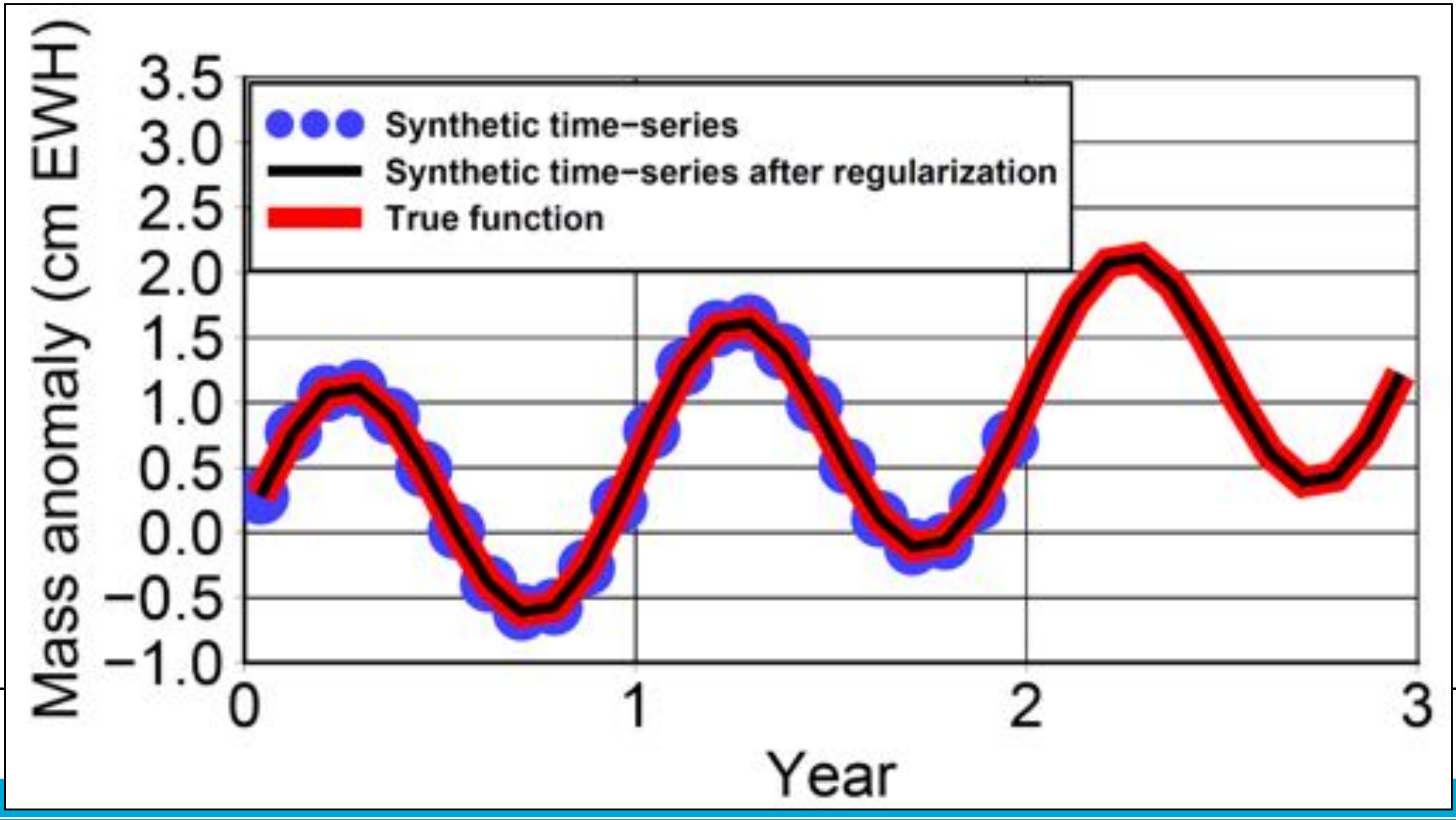
$$\Omega[H] = \sum_{k=1}^{K-1} \int_0^1 \left(\dot{h}_{k+1}(t) - \dot{h}_k(t)\right)^2 dt$$

(t – time in years)

Example: Regularization in the absence of noise and penalized signals

$$H(t) = \sin 2\pi t + 0.5 \cdot t$$

t – time in years
$H(t)$ – Equivalent water heights (EWH) in cm



Regularization parameter

$$\alpha = \frac{\sigma^2_{\text{GRACE}}}{\sigma^2_{\text{Signal}}}$$

Noise variance (characterizes random noise in GRACE-based mass anomalies)

Signal variance (characterizes deviations of the actual signal from a non-penalized one)

Variance Component Estimation (see, e.g., Koch & Kusche, JoG, 2002)

Estimation of geocenter motion

Basic idea

- Goal: estimate temporal variations of degree-1 and C_{20} coefficients, as well as the stochastic description of their errors (full covariance matrices)

- Data:
  - GRACE SH coefficients (except for degree-1 and C_{20} coefficients), cleaned from GIA signal
  - Residual OBP estimates (mean monthly values)

- Methodology: statistically-optimal data combination

Statistically-optimal data combination

General format of combining two data sets $\mathbf{d}_1$ and $\mathbf{d}_2$:

$$\mathbf{x}_c = (\mathbf{A}_1^T \mathbf{C}_1^{-1} \mathbf{A}_1 + \mathbf{A}_2^T \mathbf{C}_2^{-1} \mathbf{A}_2)(\mathbf{A}_1^T \mathbf{C}_1^{-1} \mathbf{d}_1 + \mathbf{A}_2^T \mathbf{C}_2^{-1} \mathbf{d}_2),$$

$\mathbf{x}_c$ is the re-estimated data set; $\mathbf{A}_{1,2}$ are design matrices; $\mathbf{C}_{1,2}$ are error co-variance matrices. In case of combining GRACE data (spectral domain) and OBP data (spatial domain):

$$\mathbf{x}_c = (\mathbf{T}^T \mathbf{C}^{-1} \mathbf{T} + \mathbf{S} \mathbf{Y}^T \mathbf{P} \mathbf{Y} \mathbf{S})^{-1} (\mathbf{T}^T \mathbf{C}^{-1} \mathbf{x}_g + \mathbf{S} \mathbf{Y}^T \mathbf{P} \mathbf{h}).$$

Note that all the other coefficients are re-estimated.

- ✓ $\mathbf{x}_g$: Vector containing GRACE coefficients.
- ✓ $\mathbf{C}$: Full error covariance matrix of GRACE data.
- ✓ $\mathbf{T}$: Truncated unit matrix.
- ✓ $\mathbf{Y}$: Transformation from spatial to spectral domain.
- ✓ $\mathbf{h}$: Vector containing OBP data.
- ✓ $\mathbf{S}$: Matrix transforming dimensionless coefficients into mass coefficients.
- ✓ $\mathbf{O}$: Ocean function, equals 1 over ocean and 0 over land.
- ✗ $\mathbf{C}_o$: Error covariance matrix of OBP data (diagonal). $(C_o = P^{-1})$

Input data

- GRACE CSR RL05 solutions (including error covariance matrices)
- GIA model of A et al. (2012)
- Noise in AOD1B product (Dobslaw et al, 2015)

Estimation of C_o
(noise is assumed to be stationary)

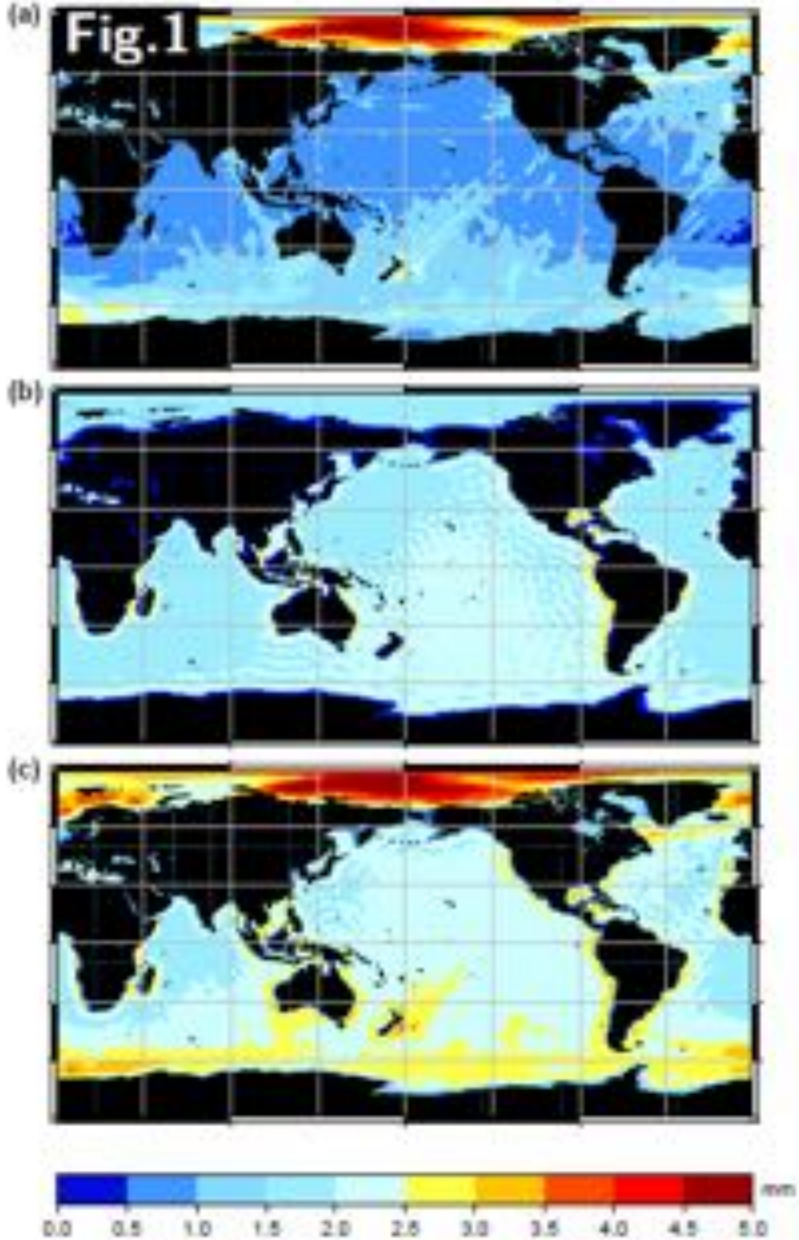
SD of noise in AOD1B product

+

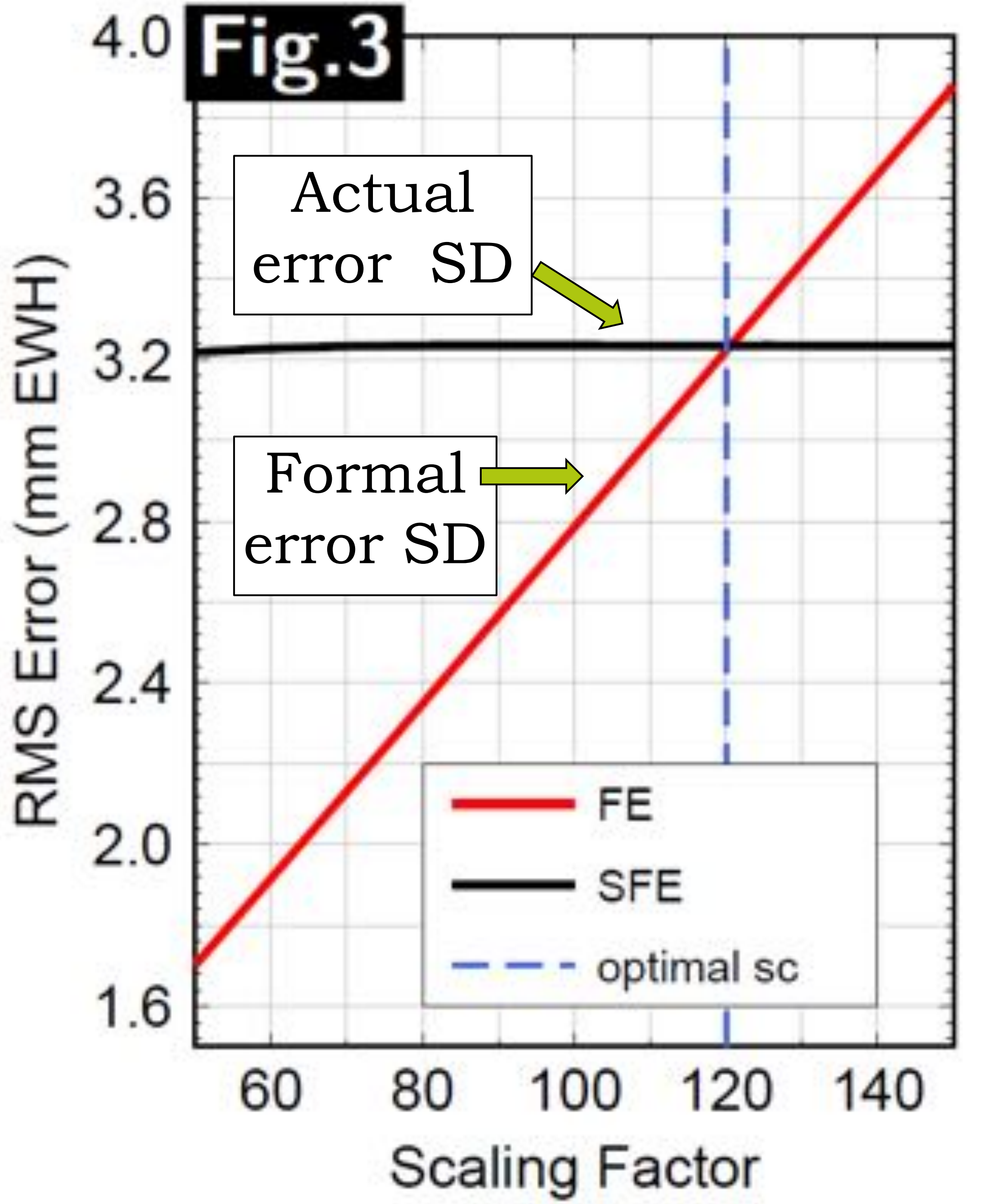
SD of noise in fingerprint estimates (based on GRACE error covariance matrices)

=

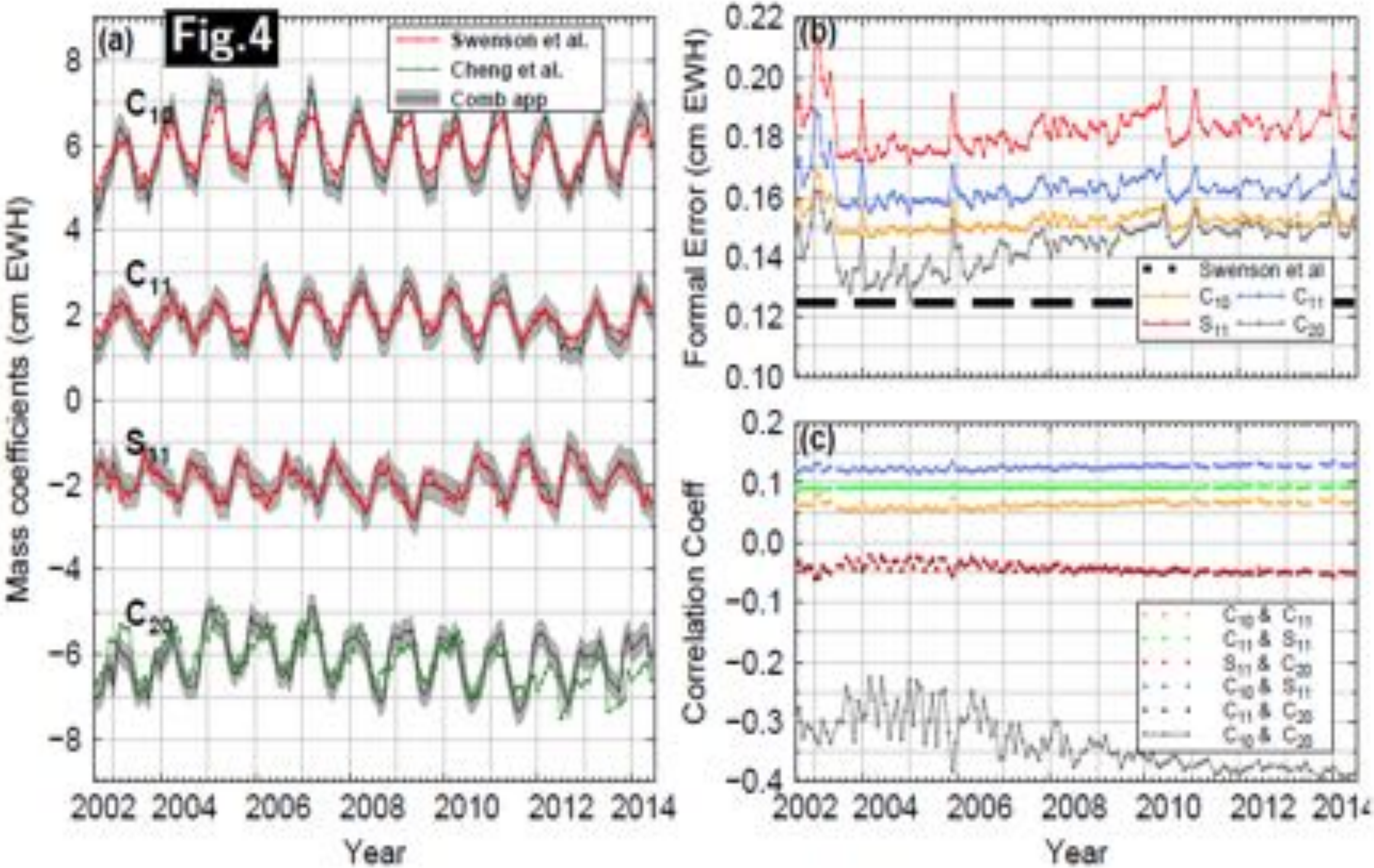
Total noise SD



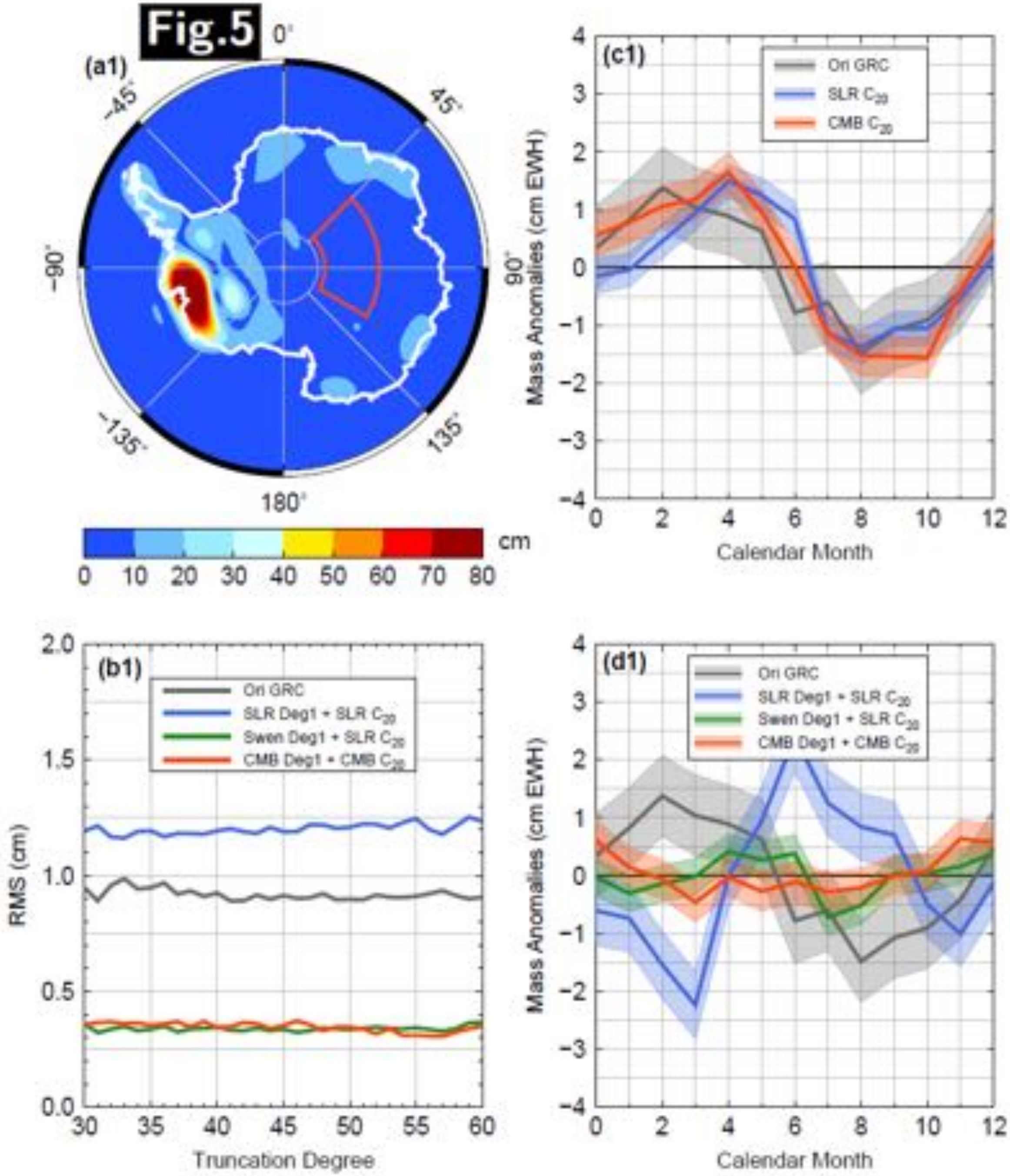
Upscaling of C_o



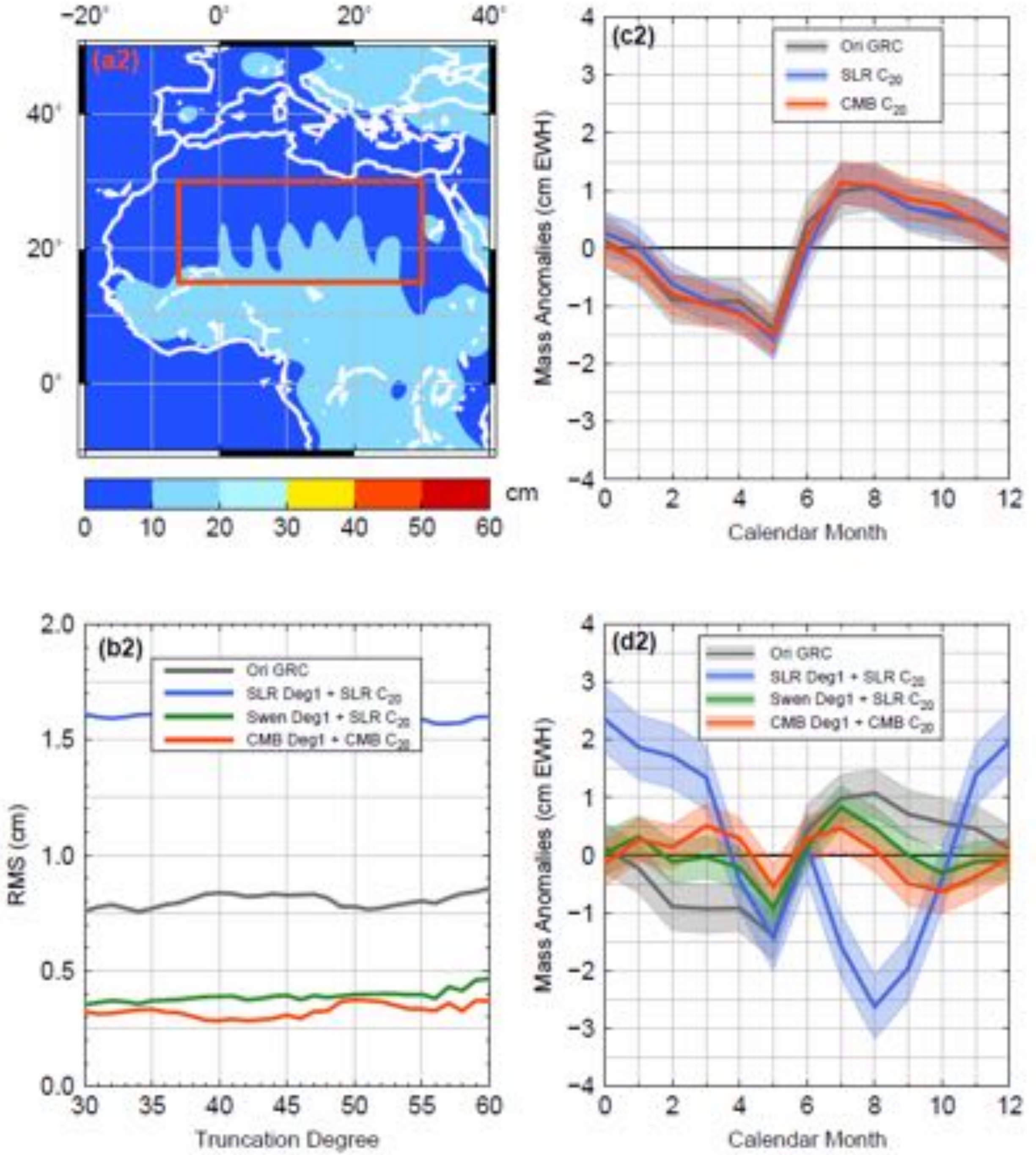
Final product



Validation: East Antarctica



Validation: Sahara



The produced time-series of degree-1 and C_{20} coefficients will be available from:

http://www.citg.tudelft.nl/deg1&c20