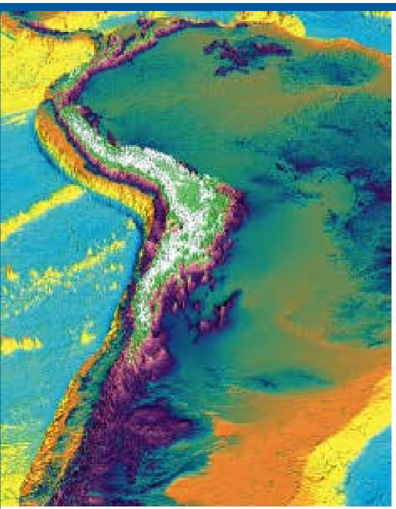
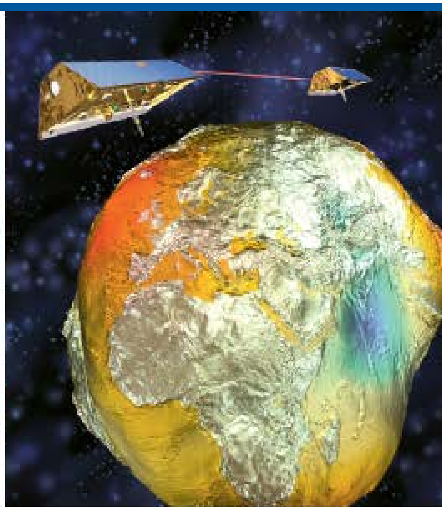
GFZ GERMAN RESEARCH CENTRE FOR GEOSCIENCES

GFZ
Helmholtz Centre
POTSDAM







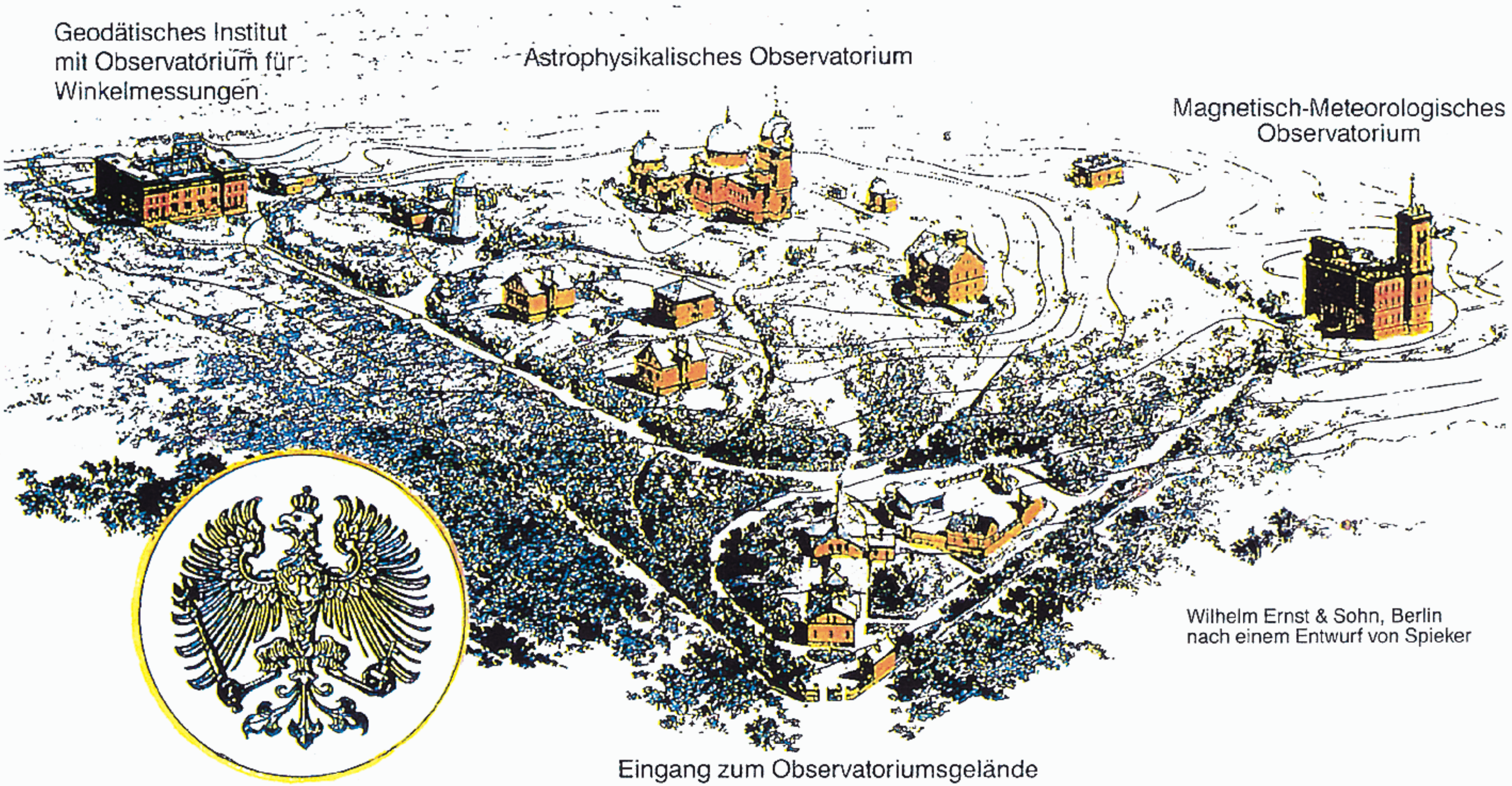
OVERVIEW

F. Flechtner

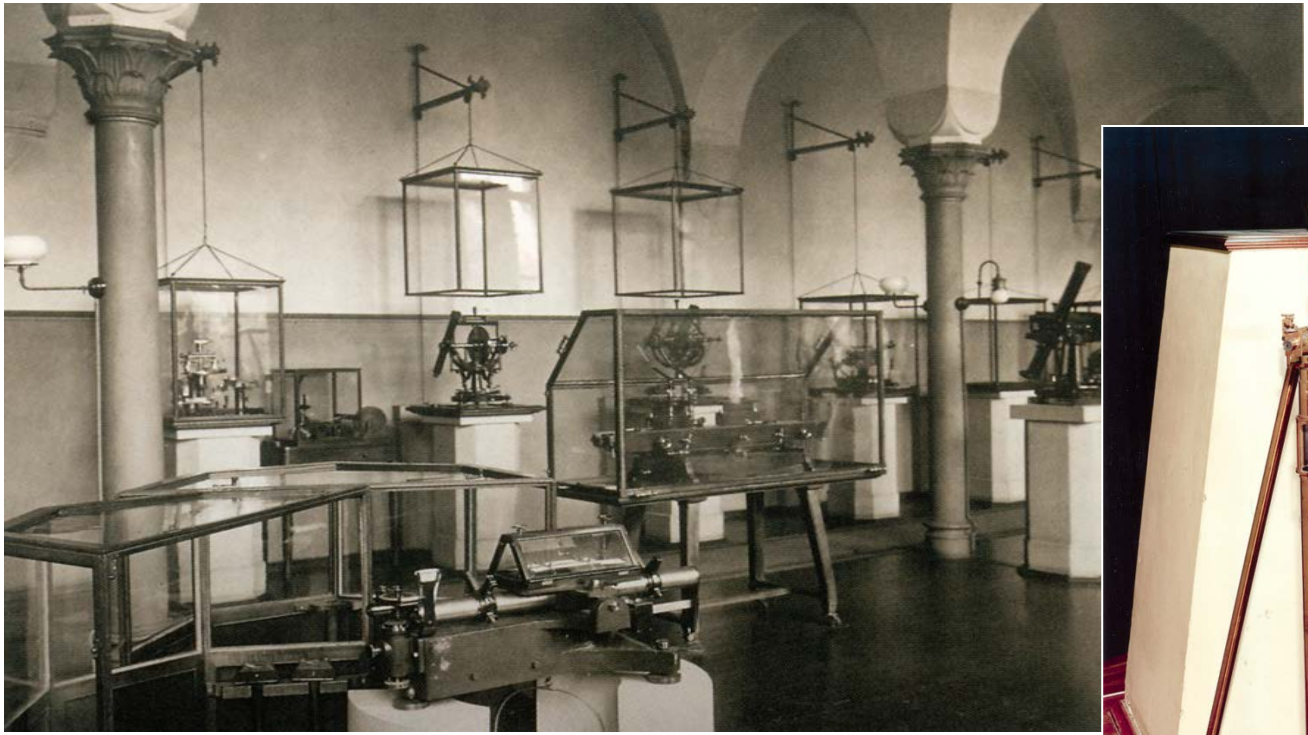
June 2016

HELMHOLTZ
ASSOCIATION

Die Königlich Preußischen Observatorien bei Potsdam
auf dem Telegraphen-Berge (um 1892)

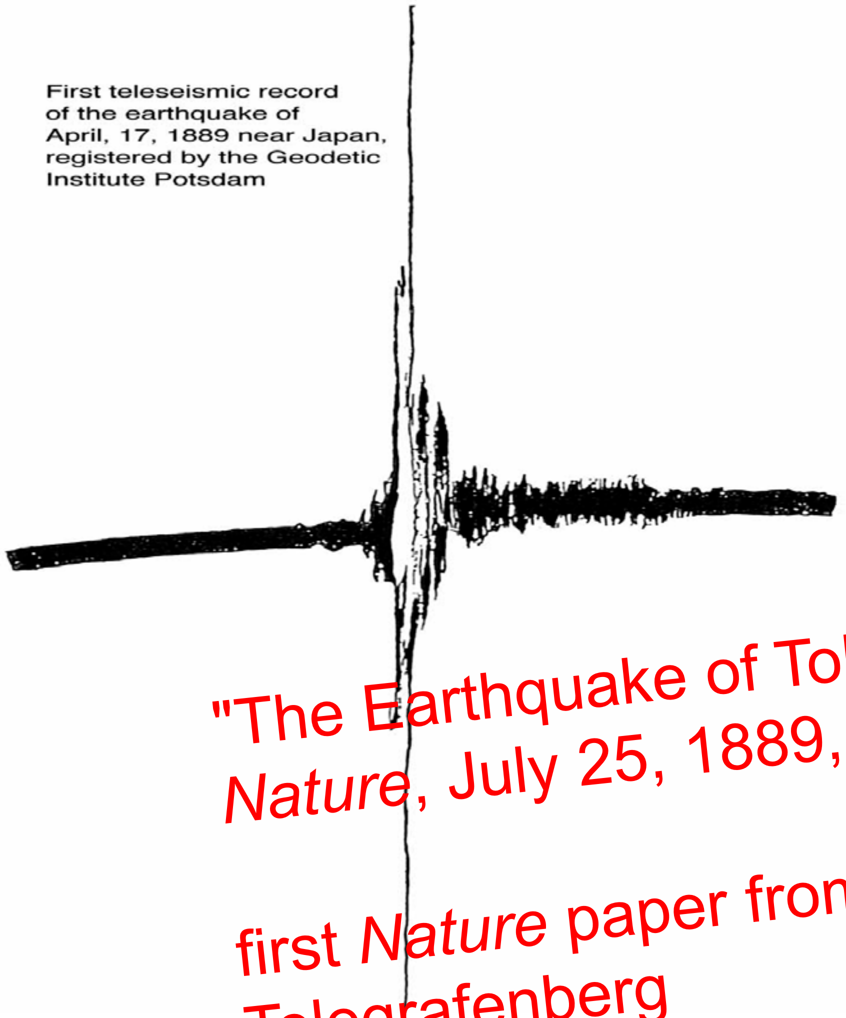


Geodetic Institute Potsdam



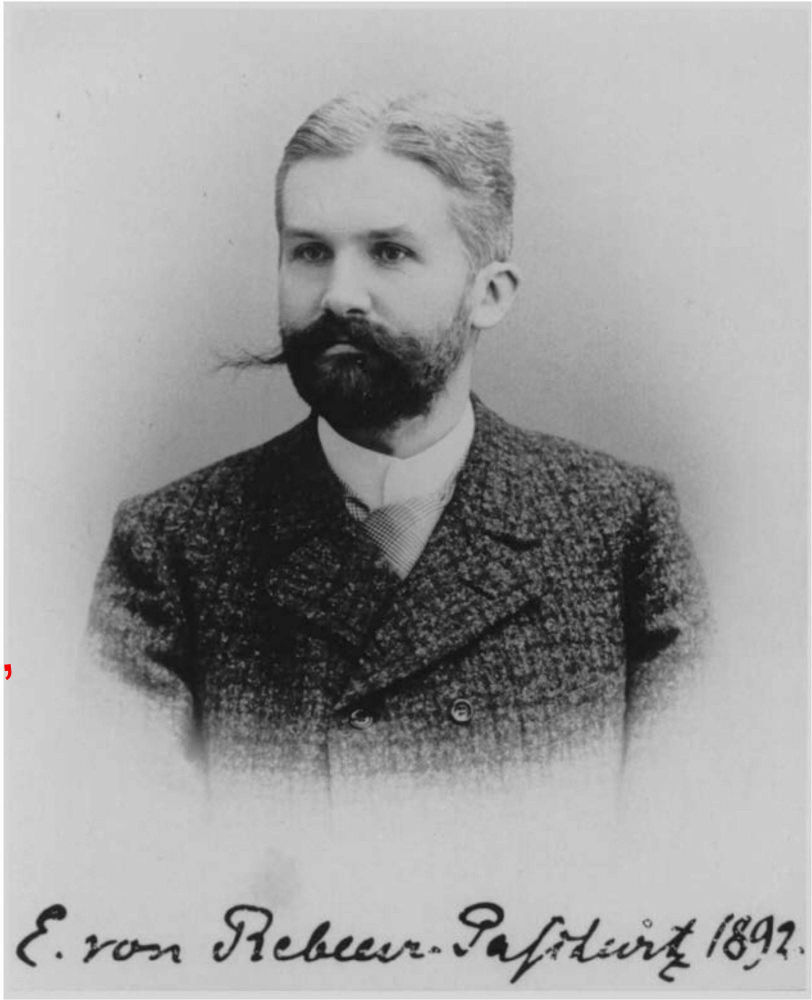
Measurements of the absolute gravity value in Potsdam which in 1909 is accepted as the international reference (until 1971)

World's first teleseismic record, 1889

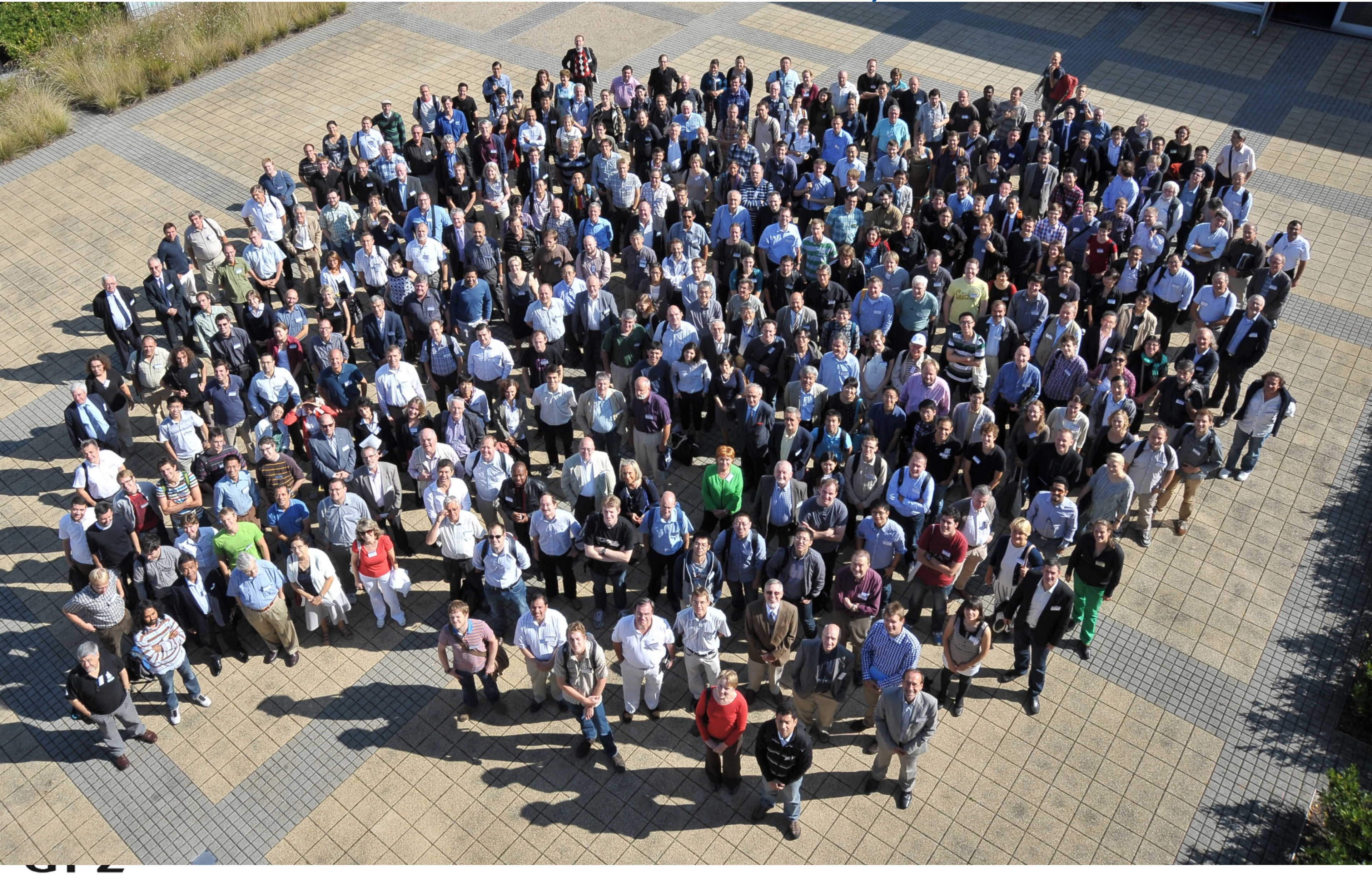


"The Earthquake of Tokio", *Nature*, July 25, 1889,

first *Nature* paper from Telegrafenberg



IAG SCIENTIFIC ASSEMBLY, SEPT. 2013



Science campus Telegrafenberg, Potsdam

GFZ Locations

Main research centre: Potsdam

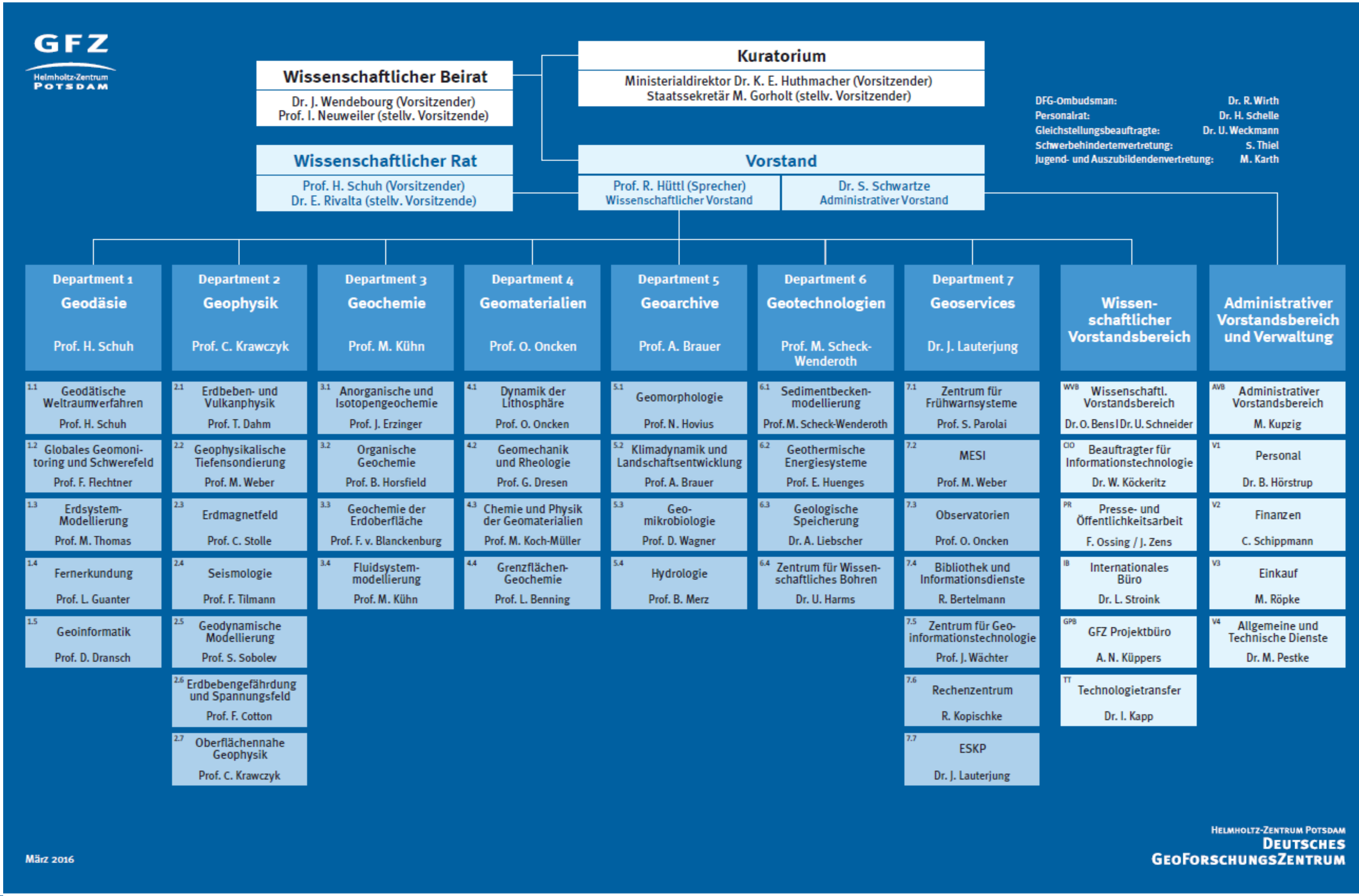
Branch offices:

- Adolf-Schmidt-Observatory for Geomagnetism, Niemegk
- KTB Deep Crustal Lab, Windischeschenbach
- Department 1, Section 1.2 Oberpfaffenhofen (Wessling)

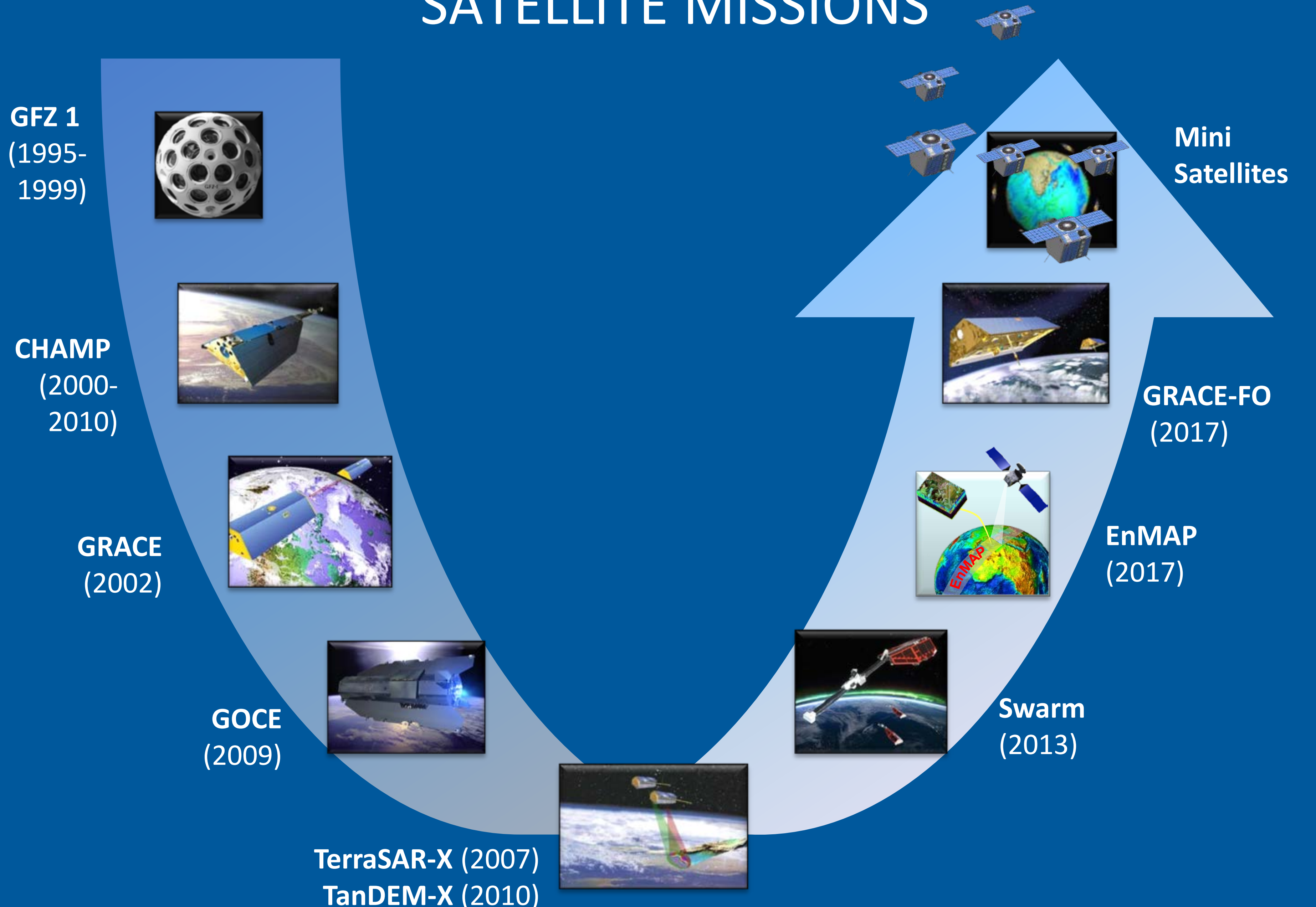
Further research sites e.g.:

- Magnetic Observatory Wingst
- Geothermal in situ Research Lab, Groß Schönebeck
- CO_2 Storage Research Lab, Ketzin
- Underground-Lab Freiberg
- Central Asian Institute for Applied Geosciences CAIAG, Kyrgyzstan

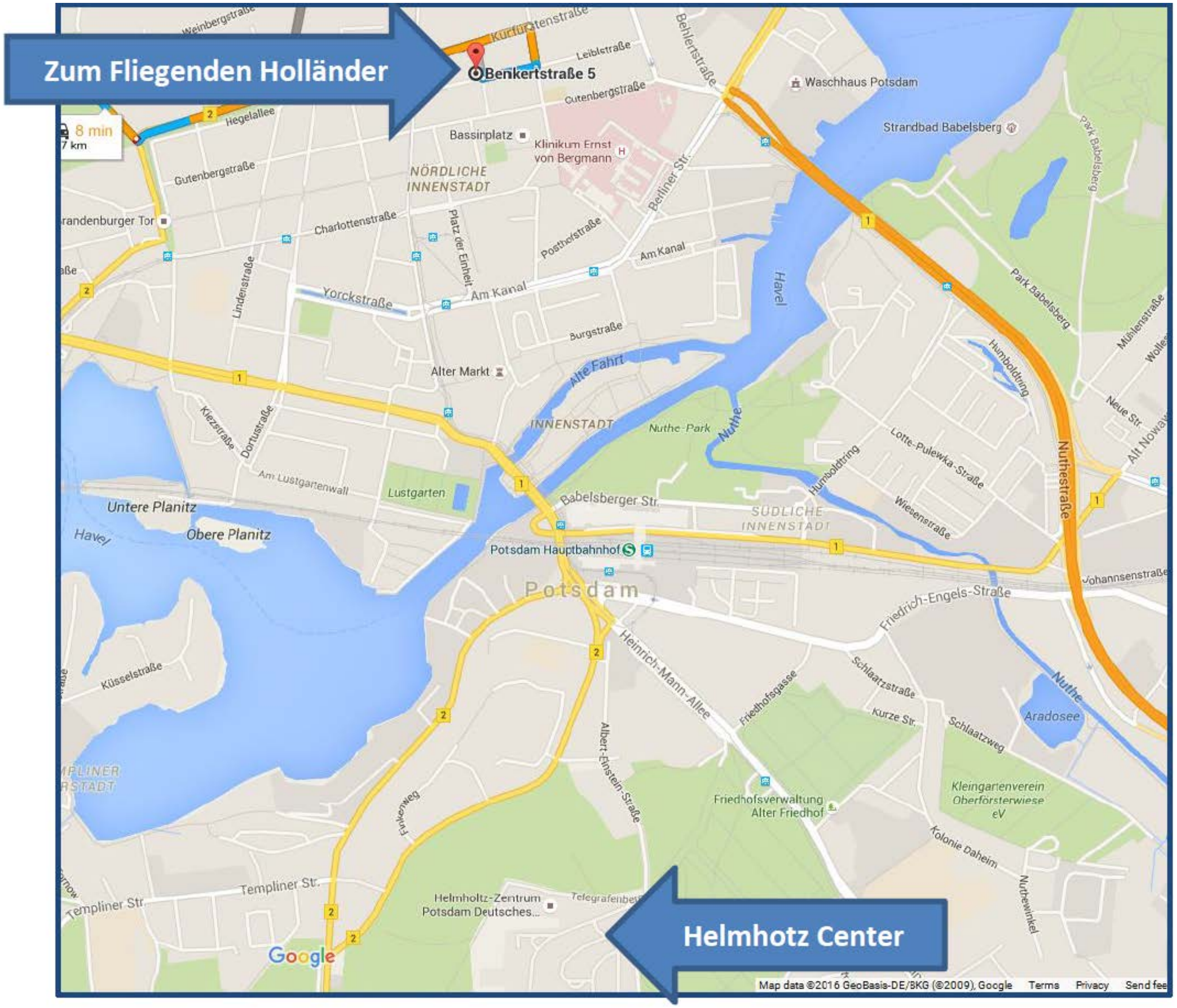
GFZ matrix structure



SATELLITE MISSIONS



Dinner at „Fliegender Holländer" 19:00



EGSIEM

European Gravity Service for Improved Emergency Management

EGSIEM Progress Meeting # 3

GFZ Potsdam

June 2 – 3, 2016

Purpose of the meeting

European Gravity Service for Improved Emergency Management

Status of the reprocessing

- Progress made in the first half year of 2016
- Discussion on the treatment of background models

Concept of Scientific Service

- Status, Future perspectives
- Discussions

Discussion of any other emerging topics

- ...

EGSIEM

European Gravity Service for Improved Emergency Management

Upcoming Deliverables & Action Items

Adrian Jäggi (AIUB)

EGSIEM Progress Meeting # 3

GFZ Potsdam

June 2 – 3, 2016

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
2.2	GRACE/GRACE-FO Product Report	2	TUG	R	PU	M18
4.1	Concept of Scientific service	4	UBERN	R	PU	M18

Upcoming Milestones

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

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	31.03.2015
011	EGSIEM	GFZ (AG), DLR, CNES	Establish the interfaces between ZKI, Hydrology, and CNES to clarify the possibility to derive flood volumes and the potential role of altimetry (Hydroweb).	30.09.2015
012	EGSIEM	EGSIEM ACs	Each AC to provide a test SINEX file of a monthly GRACE solution (NEQ information). Still waiting for NEQ from CNES.	31.07.2015
013	EGSIEM	GFZ (FF), UL, GFZ (AG)	Compile a list of EGSIEM L3 products, Compile a list of sources for degree 1 terms and C20	30.09.2015
014	EGSIEM	CNES	Validation of GRACE solutions over oceans using altimetry and ocean surface topography	31.12.2015
015	EGSIEM	UL	Check availabilities of GRACE movies and possibilities (persons) to update them	31.12.2015

HORIZON 2020

Action Items Status

EGSIEM
European Gravity Service for Improved Emergency Management

016	EGSIEM	All	Milestone 002 (*Implementation and Preparation Review)* to be completed.	29.02.2016
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

EGSIEM

European Gravity Service for Improved Emergency Management

WP1: Management Update

Keith Cann-Guthauser
Astronomisches Institut, Universität Bern

EGSIEM Project Meeting

2-3. June 2016, Potsdam

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

WP1: Management

Overview

- Reporting
- Review
- Payments

WP1: Management

Reporting

Our first reporting period (**1.1.2015 – 31.12.2015)** has now ended;

We submitted the first periodic report on 28th February 2016 (so, within the 60 days deadline).

EGSIEM

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WP1: Management

Reporting

- Part A (1) was generated by the SyGMa grant management section (*Continuous Reporting*) within the Participant Portal (updated by UBERN)
- Part A (2) is the Periodic Technical Report, a separate .doc which received input from <u>all</u>
- Part B is the periodic financial report which each partner completed and submitted online

WP1: Management

Reporting

- Technical report was 60 (sixty) pages in length
- Covered the work undertaken up to the end of the first year of EGSIEM
- As well as dissemination and exploitation activities
- Can be downloaded from the Participant Portal
- Do we want this as an internal doc on egsiem.eu?

WP1: Management

Review

The EU Project Officer invited the WP leaders to present the progress of the project in Brussels on 7. March 2016

Research Executive Agency
RESEARCH EXECUTIVE AGENCY
Space Research

EGSIEM

European Gravity Service for Improved Emergency Management

637010

Mid-Term Review Meeting

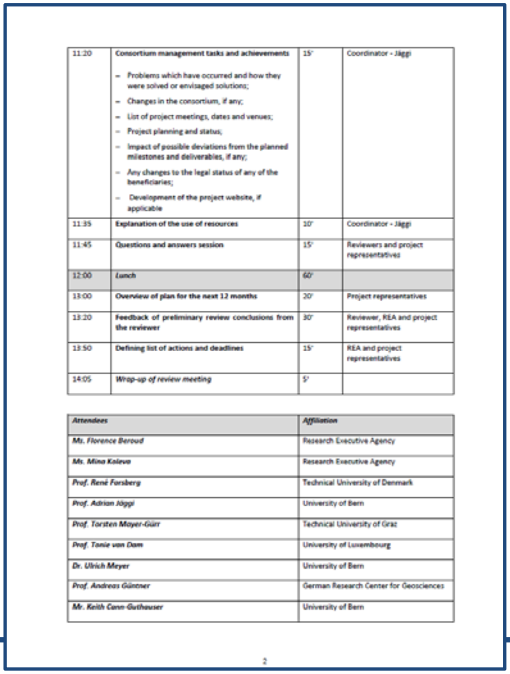
Date: Monday, 7th March 2016

Meeting venue: 18 / SDRA, Covent Garden Building, REA, Place Rogier, Brussels

AGENDA

Time (approx..)	Topic	Time	Presenter
09:00	*Opening of the review meeting*	5'	REA
09:05	**Overview** – Introduction to the objectives of the project; – Specific objectives in Year 1;	10'	Coordinator - Jäggi
09:15	**Detailed feedback per WP:** ***WP1 Management*** ***WP2 Gravity Field Analysis*** ***WP3 Integration of Complementary Data*** ***WP4 Scientific Service*** ***WP5 NRT and Regional Service*** ***WP6 Hydrological Service*** ***WP7 Dissemination and Exploitation*** Progress and achievements in Year 1; overview of work completed; problems encountered and proposed solutions; deliverables and milestones	15' per WP	WP leaders Cann-Guthauser Mayer-Gürr van Dam Meyer Flechtner (Mayer-Gürr) Güntner Jäggi/Cann-Guthauser
11:00	*Coffee / short break*	20'	

Agence exécutive pour la recherche/Research Executive Agency,
1049 Bruxelles/Brussel, BELGIQUE/BELGIË
Tel. +32 22991111



11:20	**Consortium management tasks and achievements** – Problems which have occurred and how they were solved or envisaged solutions; – Changes in the consortium, if any; – List of project meetings, dates and venues; – Project planning and status; – Impact of possible deviations from the planned milestones and deliverables, if any; – Any changes to the legal status of any of the beneficiaries; – Development of the project website, if applicable	15'	Coordinator - Jäggi
11:35	**Explanation of the use of resources**	10'	Coordinator - Jäggi
11:45	**Questions and answers session**	15'	Reviewers and project representatives
12:00	***Lunch***	60'	
13:00	**Overview of plan for the next 12 months**	20'	Project representatives
13:20	**Feedback of preliminary review conclusions from the reviewer**	30'	Reviewer, REA and project representatives
13:50	**Defining list of actions and deadlines**	15'	REA and project representatives
14:05	*Wrap-up of review meeting*	5'	

Attendees	*Affiliation*
Ms. Florence Beroud	Research Executive Agency
Ms. Mina Koleva	Research Executive Agency
Prof. René Forsberg	Technical University of Denmark
Prof. Adrian Jäggi	University of Bern
Prof. Torsten Mayer-Gürr	Technical University of Graz
Prof. Tonie van Dam	University of Luxembourg
Dr. Ulrich Meyer	University of Bern
Prof. Andreas Güntner	German Research Center for Geosciences
Mr. Keith Cann-Guthauser	University of Bern

2

WP1: Management
Review

Annex 1 – List of deliverables

Del. no.	Deliverable name	Status	Comments
D1.1 (WP1)	Management guidelines	Accepted	Clear, good model for other projects
D2.1 (WP2)	Processing standards and models	Accepted	Fine
D3.1 (WP3)	Reference frame product UL report	Accepted	Fine, SLR/GNSS state of the art
D5.1 (WP5)	Concept of NRT service	Accepted	Concise and nice to read
D7.1 (WP7)	EGSIEM project website	Accepted	Nice and well-organized
D7.2 (WP7)	EGSIEM project brochure	Accepted	Nice, handed out at meeting
D7.3 (WP7)	Teaser lecture	Accepted	Looked ok

WP1: Management
Review

Has the plan for exploitation of results, in particular with regards intellectual property rights, been appropriately planned and executed, as described in the DoA? Has the exploitation plan been updated?	Partially
IPR rights and DOI of data sets discussed at mid-term evaluation meeting. Some (minor) action required. The completely open data policy is a good thing, and in line with earlier very successful geodetic services (e.g. the International GNSS Service)	
[Option for projects taking part in the Open research data pilot **Has the Data Management Plan (DMP) been appropriately executed? Give details if an update of the DMP is needed.** *]*	N/A
Project so far not in the "Open research data pilot" (as I understand it). However as the project is apparently in line with the objectives of the EU pilot, it should take the necessary steps to join, by issuing a DMP and consulting the REA on possible other steps.	

WP1: Management

Payments

The payments from EGSIEM are due/have been sent as follows;

- January 2015 - Pre-Financing, paid out in 2 x instalments; the first 70% of this figure was received by 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)

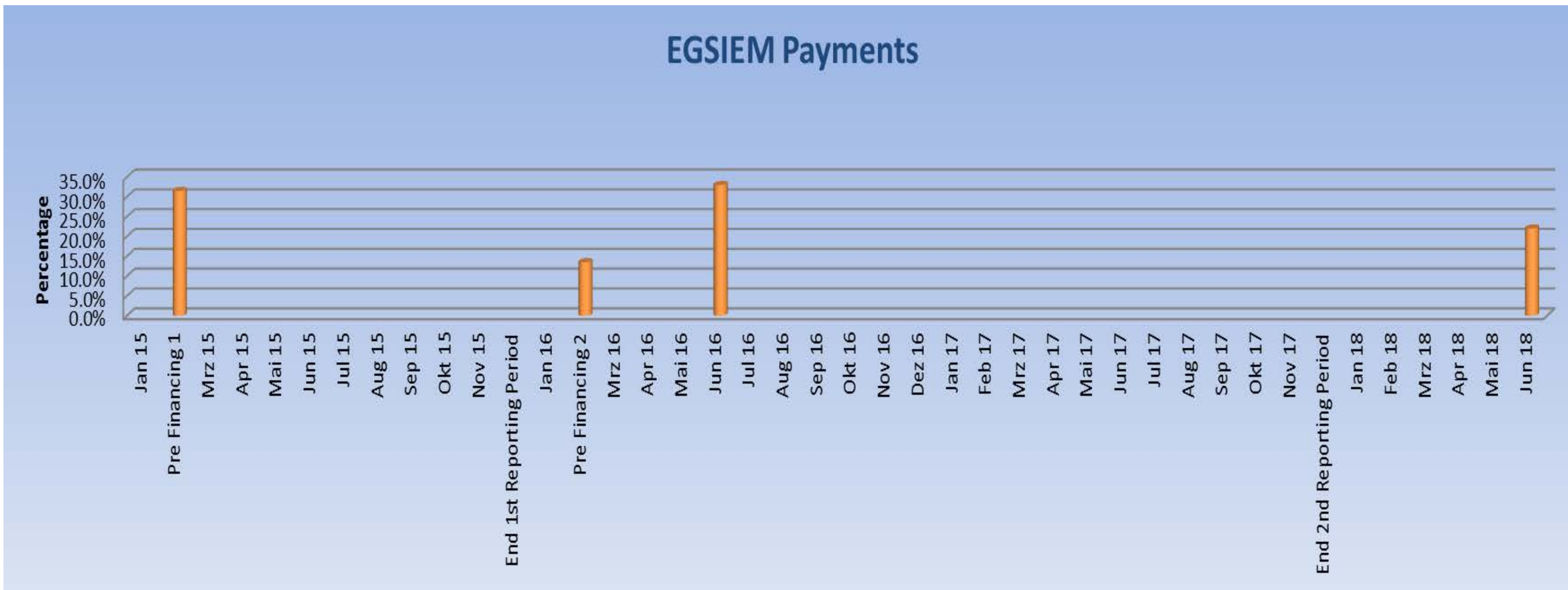
This was received in May – payments will be made (hopefully) next week.

- mid 2018 - Final Payment, 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

Payments

Chart shown at previous meetings.



EGSIEM

HORIZON 2020

EGSIEM

European Gravity Service for Improved Emergency Management

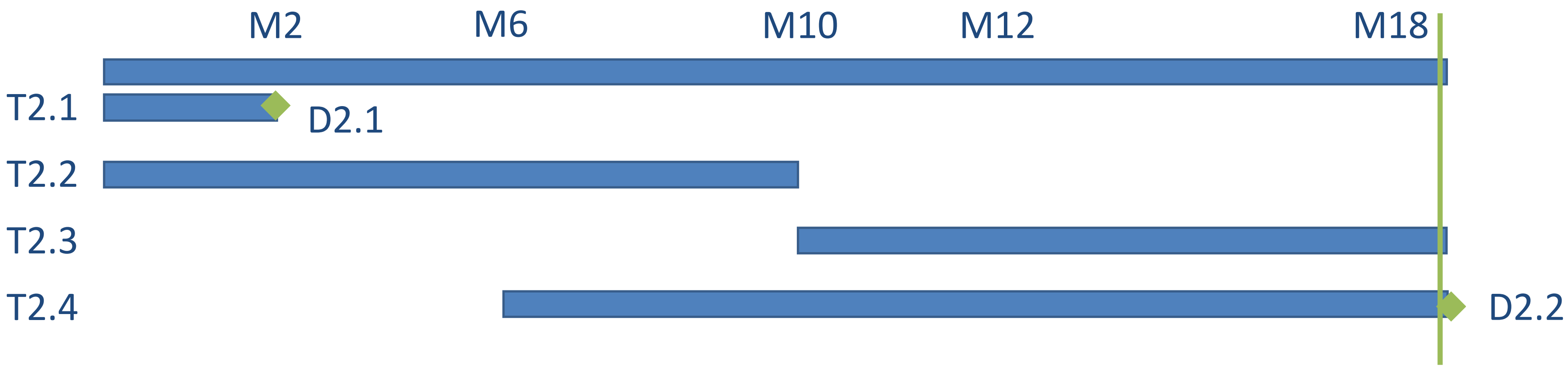
Title: **WP2 Gravity field analysis**

Presenter: TMG and all ACs

Affiliation: TUG

EGSIEM Meeting Potsdam,
02.06.2016 - 03.06.2016

WP2 Gravity field analysis – Time Table



T2.1 Processing Standards and Models

T2.2 Improved processing tools

T2.3 Data analysis

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

T2.3 Reprocessing

- Reprocessing of two years (2006 – 2007) of GRACE data
  - AIUB
  - GFZ
  - TUG
  - CNES/GRGRS
  - ULux
- Based on document
  D2.1_Processing Standards and Models_02.03.2015.pdf
- Based on AIUB GPS orbit and clock constellation
  or AIUB kinematic orbits
- 5 x 24 monthly normal equations in SINEX format
- What is about the additional Level 2 products: GAA, GAB, GAC, GAD ?

T2.3 Reprocessing: SINEX format

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

Should contain the ICGEM header
earth_gravity_constant
radius
max_degree
tide_system

All information are related to the reduced observations

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

Monthly mean of ~~all~~/standard background models

- static, trend, (semi-) annual
- AOD1B
- Earth-, ocean-, pole tides

T2.3 Reprocessing: Apriori

APRIORI includes the reduced static gravity field, trend, annual, semiannual signal

Tides not included, AOD1B not included

⇒ Result is standard GSM file

⇒ Need also the combination of different GAA - GAD files

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

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

TUG: ITSG-Grace2016 public available (ifg.tugraz.at/itsg-grace2016)

- Normal equations (degree 90) in SINEX for all months 2002-2016
- Monthly mean of all background models

EGSIEM

European Gravity Service for Improved Emergency Management

Status of processing

Ulrich Meyer (AIUB)

EGSIEM Progress Meeting # 3

GFZ Potsdam

June 2 – 3, 2016

AIUB-NEQs and solutions

	REPRO (GPS-orbits, clocks)	Standards (relativity, planets)	Geometric KRR-correction smoothed	ATM-tides	Bernese -> gfc	Bernese -> SINEX
2006	no	yes	no	no	yes	no
2007	yes	yes	yes	no	yes	no

Slides were shown in progress meeting 2006/01

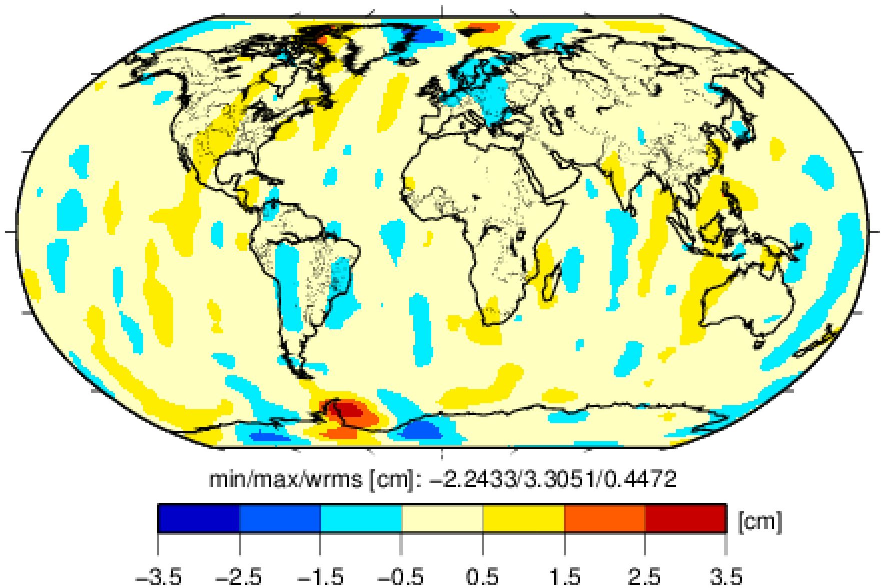
Level 2 Products at GFZ: General

EGSIEM
European Gravity Service for Improved Emergency Management

- Current operational release: GFZ RL05a (152 monthly solutions from 04/2002-03/2016)
- RL06 shall be published June 2017 (SDS RR), EGSIEM L2 can be seen as “precursor”
- Improvements from RL05 to RL06 comprise
  - New (improved) background models
    - FES2014 (see next slides)
    - AOD1B RL06 (currently internally tested at GFZ and within GRACE SDS)
  - Modifications in processing strategy
    - stochastic modeling of KBR observations (first tests with promising results)
    - parameterization of KBR observations (still to be investigated)
    - relative weighting KBR vs GPS (still to be investigated)
    - Use of AIUB GPS constellation (EPOS SW prepared for testing)
    - handling/parameterization of accelerometer observations (see next slides)

Level 2 Products at GFZ: FES2014

Difference between official GFZ RL05a 12/2007 solution (with EOT11a) and alternative solution (with FES2014, everything else remained unchanged), expressed in equivalent water height and smoothed with DDK2 filter:

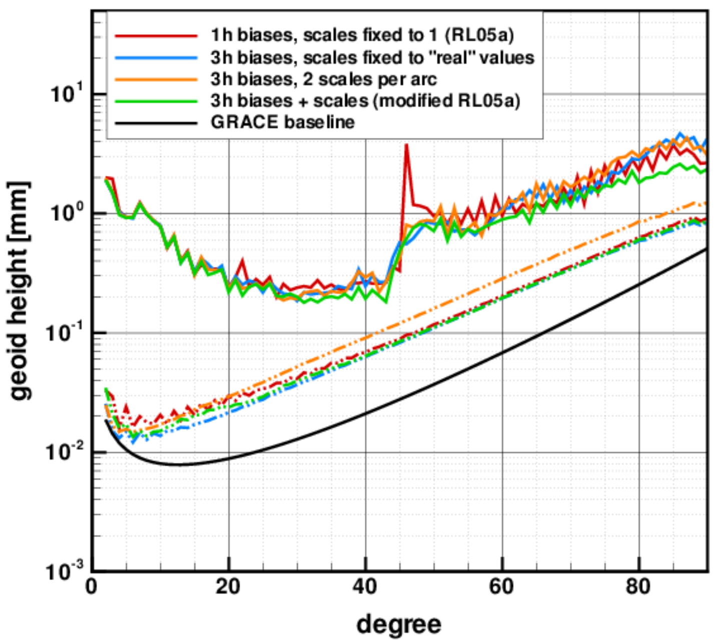


- regional effects are clearly visible
- largest differences occur where EOT11a is known to be less accurate (see Stammer et al. 2014, Rev Geophys)

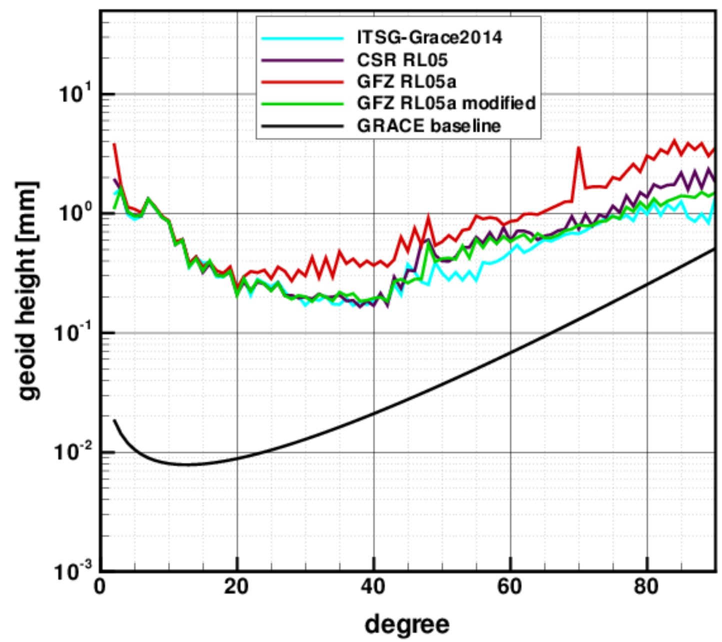
Level 2 Products at GFZ: ACC Parametrization

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)

Level 2 Products at GFZ: Schedule

- Agreed 2 years (2006 and 2007) will be reprocessed till June 30
- Remark: GFZ would not be happy if the June 2016 solution is the „final EGSIEM contribution“ to a combination product. We xpect further improvements in the next 6 months and suggest to reapeat the procedure for the next PM in January 2017!

EGSIEM

European Gravity Service for Improved Emergency Management

Title: **Improved processing tools at TUG**

Presenter: BK

Affiliation: TUG

EGSIEM Meeting Potsdam,
02.06.2016 - 03.06.2016

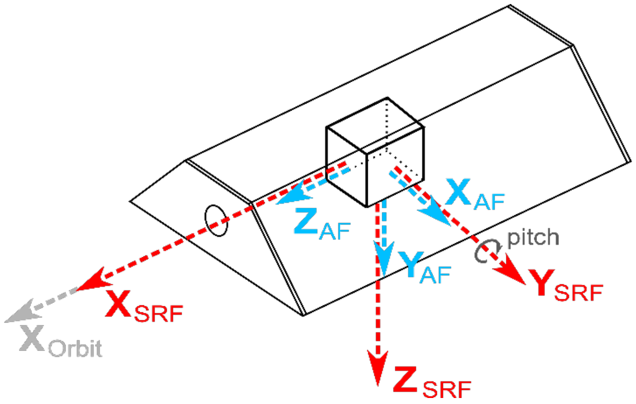
Universität Bern | Université du Luxembourg | GFZ Helmholtz Centre Potsdam | TU Graz Graz University of Technology | Leibniz Universität Hannover | cnes | DLR | géode & cie | Horizon2020

Accelerometer calibration

SuperSTAR accelerometer

Error sources:

- **Instrument bias & scale**
- **Thermal variations**
- **Misalignment between SRF and AF**
- **Non-orthogonality of accelerometer axes**
- Noise
- Center of mass offset
- Attitude determination errors
- …



⇒ Sensor errors and satellite-induced disturbances (activation and de-activation of heaters, thermal control)

Accelerometer calibration

Accelerometer biases & scale factors:

- Two-step approach: a-priori calibration for data screening
- Calibration equation: $\mathbf{a}_{\text{cal}} = \underline{\mathbf{S}}\ \mathbf{a}_{\text{obs}} + \underline{\mathbf{b}}$

with $\mathbf{S} = \begin{bmatrix} s_x & \alpha + \zeta & \beta - \epsilon \\ \alpha - \zeta & s_y & \gamma + \delta \\ \beta + \epsilon & \gamma - \delta & s_z \end{bmatrix}$

- Main-diagonal elements
- Shear parameter
- Rotational parameter

(1) Bias:

- Estimation: once per day
- Parameterization: uniform cubic basis splines (UCBS), with a 6h knot interval

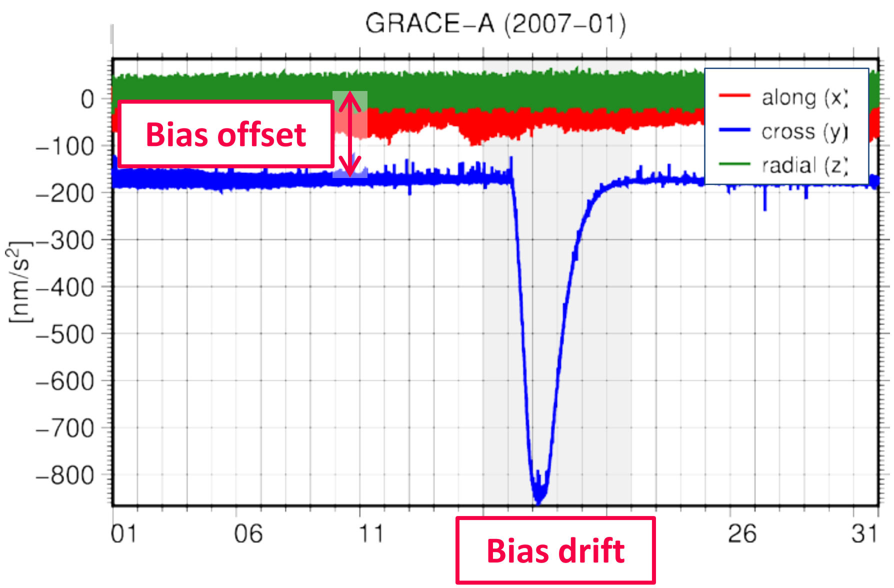
(2) Scale factors:

- Estimation: once per day
- Parameterization: fully-populated scale factor matrix
- Off-diagonal elements: non-orthogonality of accelerometer axes (cross-talk), misalignment between SRF and AF

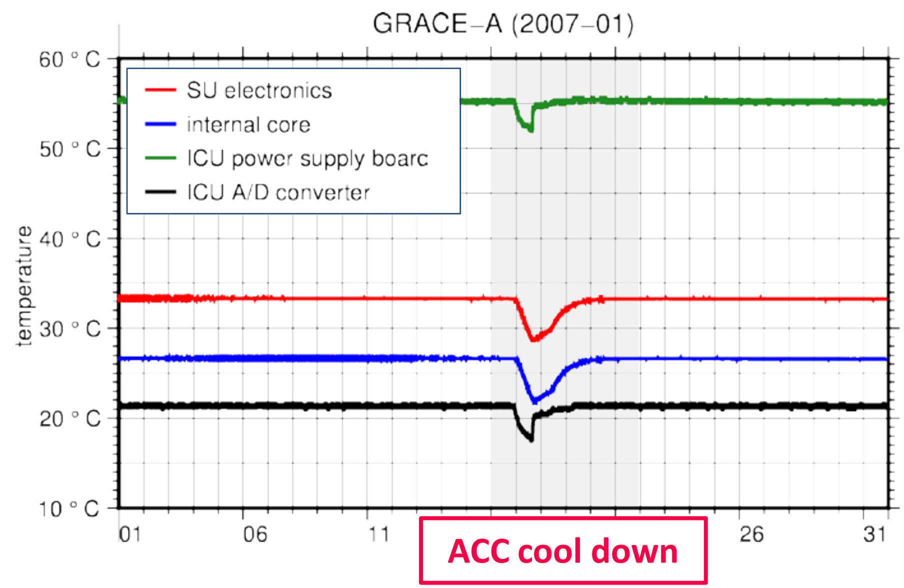
Accelerometer calibration

- Temperature-dependent behavior (biases & scale factors)
- Parameterization significantly affects C20 coefficients

Accelerations - ACC1B
(calibrated according to TN-02)



Temperature - AHK1B



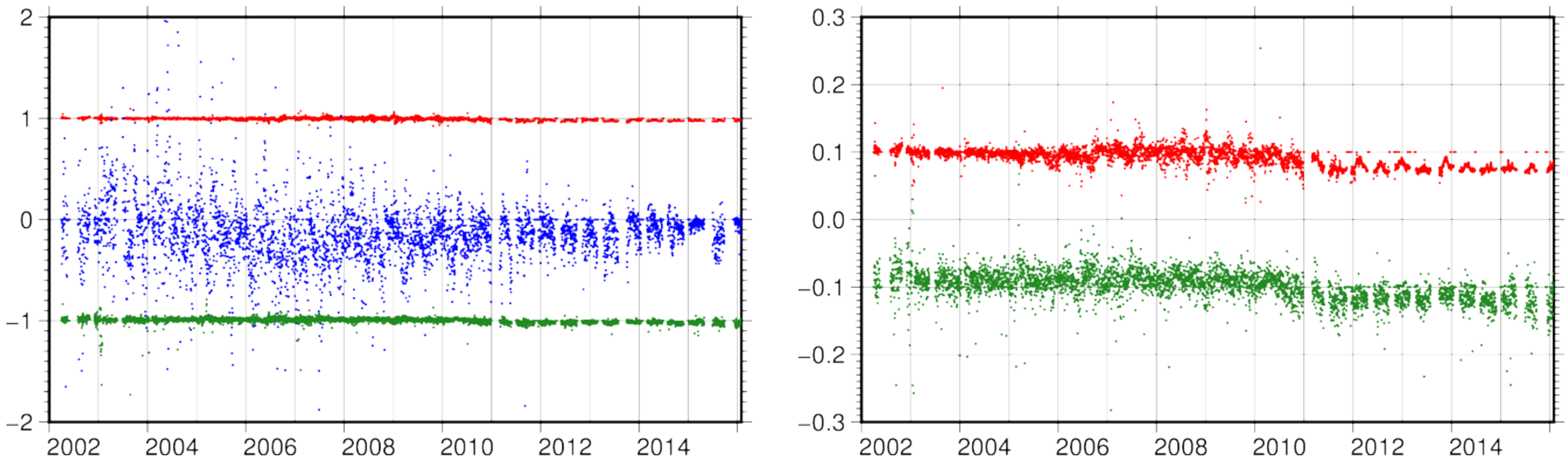
Scale factor matrix

Main diagonal elements:

- Scale factors: along (x), cross-track (y), radial (z)

$$\mathbf{S} = \begin{bmatrix} s_x & \alpha + \zeta & \beta - \epsilon \\ \alpha - \zeta & s_y & \gamma + \delta \\ \beta + \epsilon & \gamma - \delta & s_z \end{bmatrix}$$

Scale factors (GRACE-A)



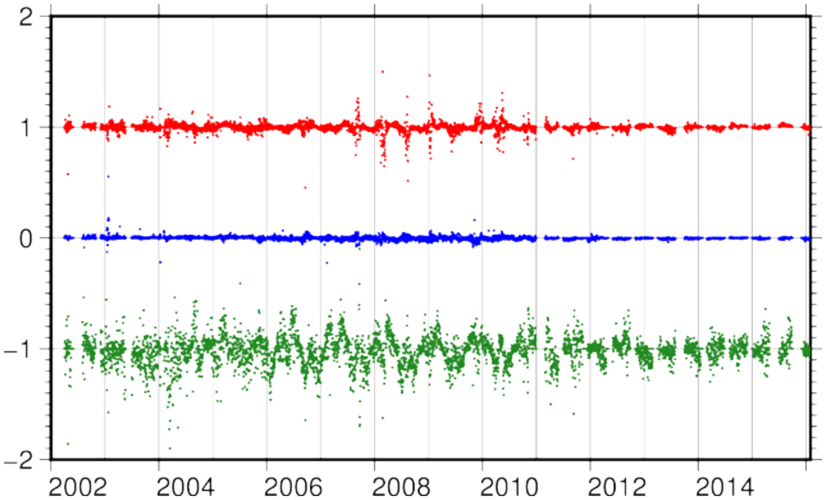
Scale factor matrix

Off-diagonal elements: xy, xz, yz

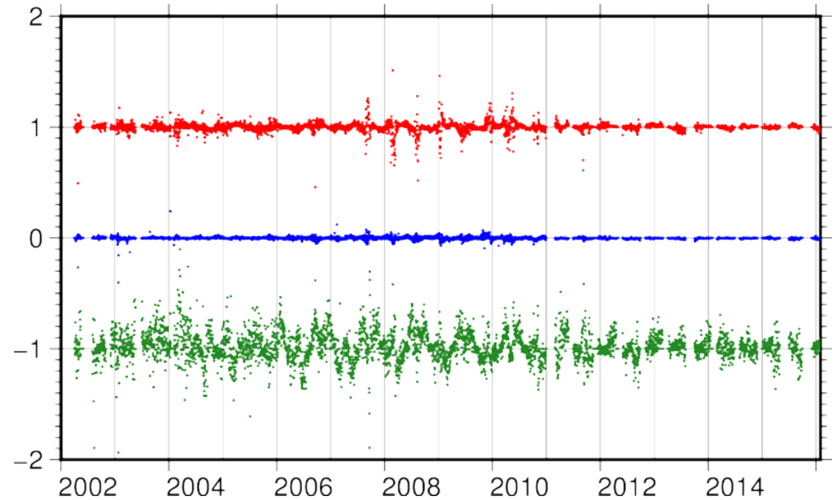
- Shear parameter: α, β, γ
- Rotational parameter: ζ, ε, δ

$$\mathbf{S} = \begin{bmatrix} s_x & \alpha + \zeta & \beta - \epsilon \\ \alpha - \zeta & s_y & \gamma + \delta \\ \beta + \epsilon & \gamma - \delta & s_z \end{bmatrix}$$

Shear parameter (GRACE-A)



Rotational parameter (GRACE-A)



EGSIEM
European Gravity Service for Improved Emergency Management

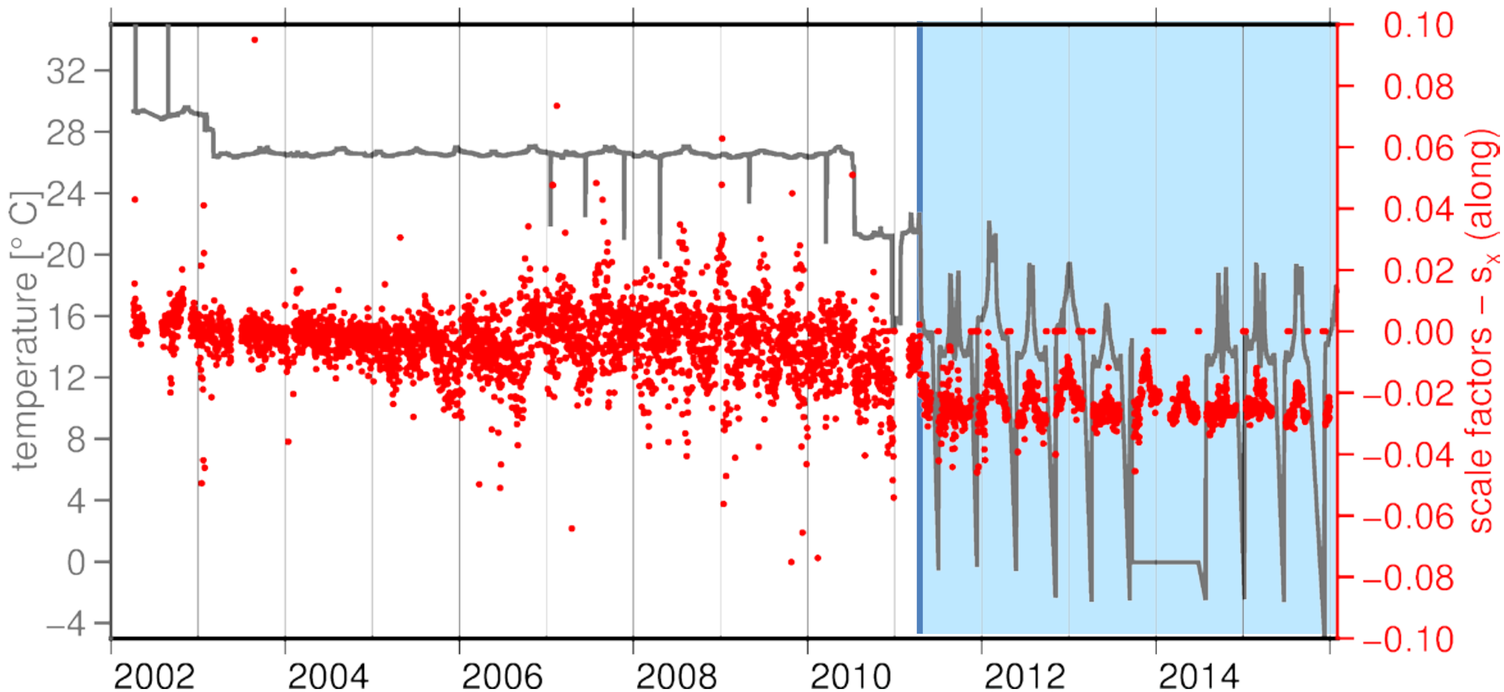
EGSIEM Meeting Potsdam, 02.06.2016 - 03.06.2016

Horizon2020

Temperature-dependency

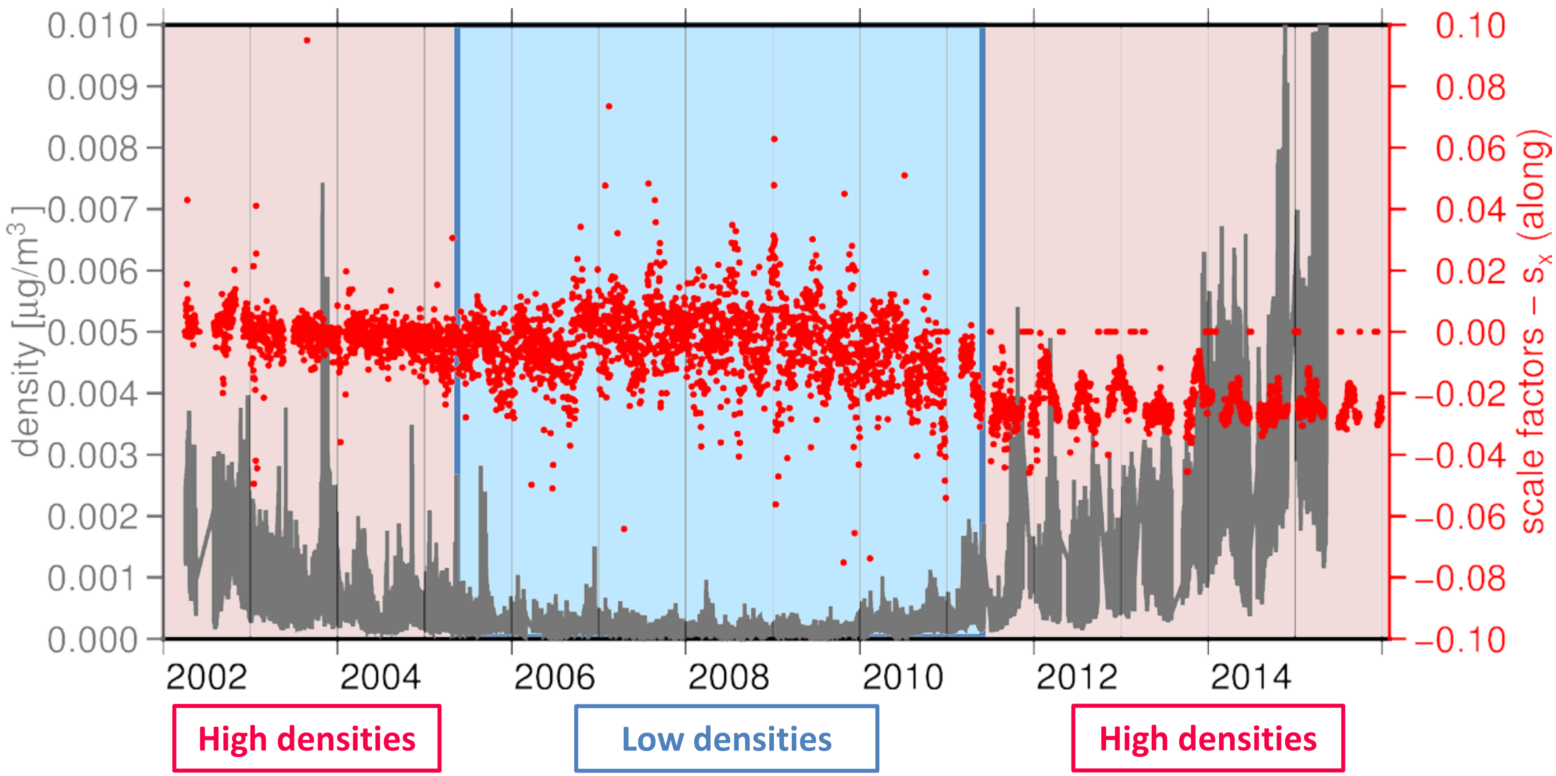
April 2011 - present:

- Scale factors highly correlated with temperature variations



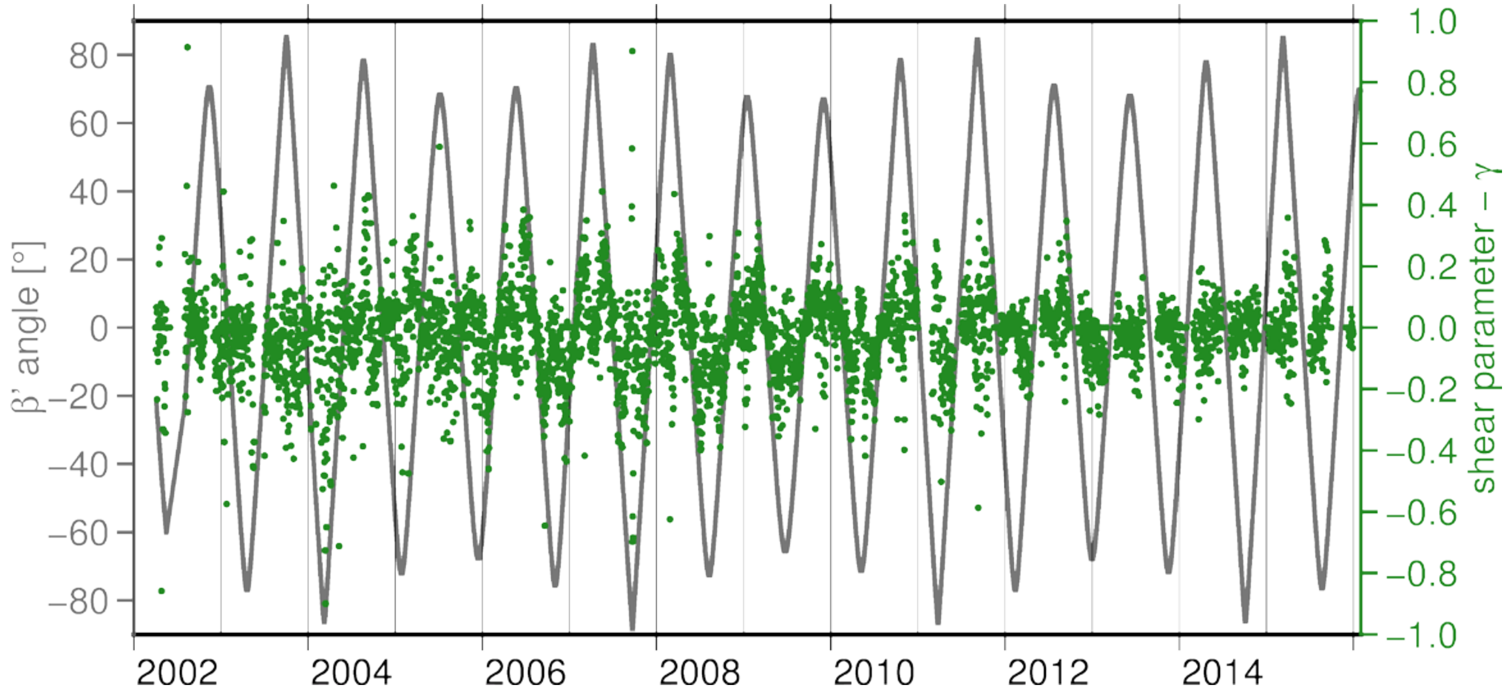
Atmospheric density (DTM2013)

- Scale factors better estimable for periods with higher atmospheric densities (non-gravitational signal)
- Variations depend on solar activity, geomagnetic activity and altitude



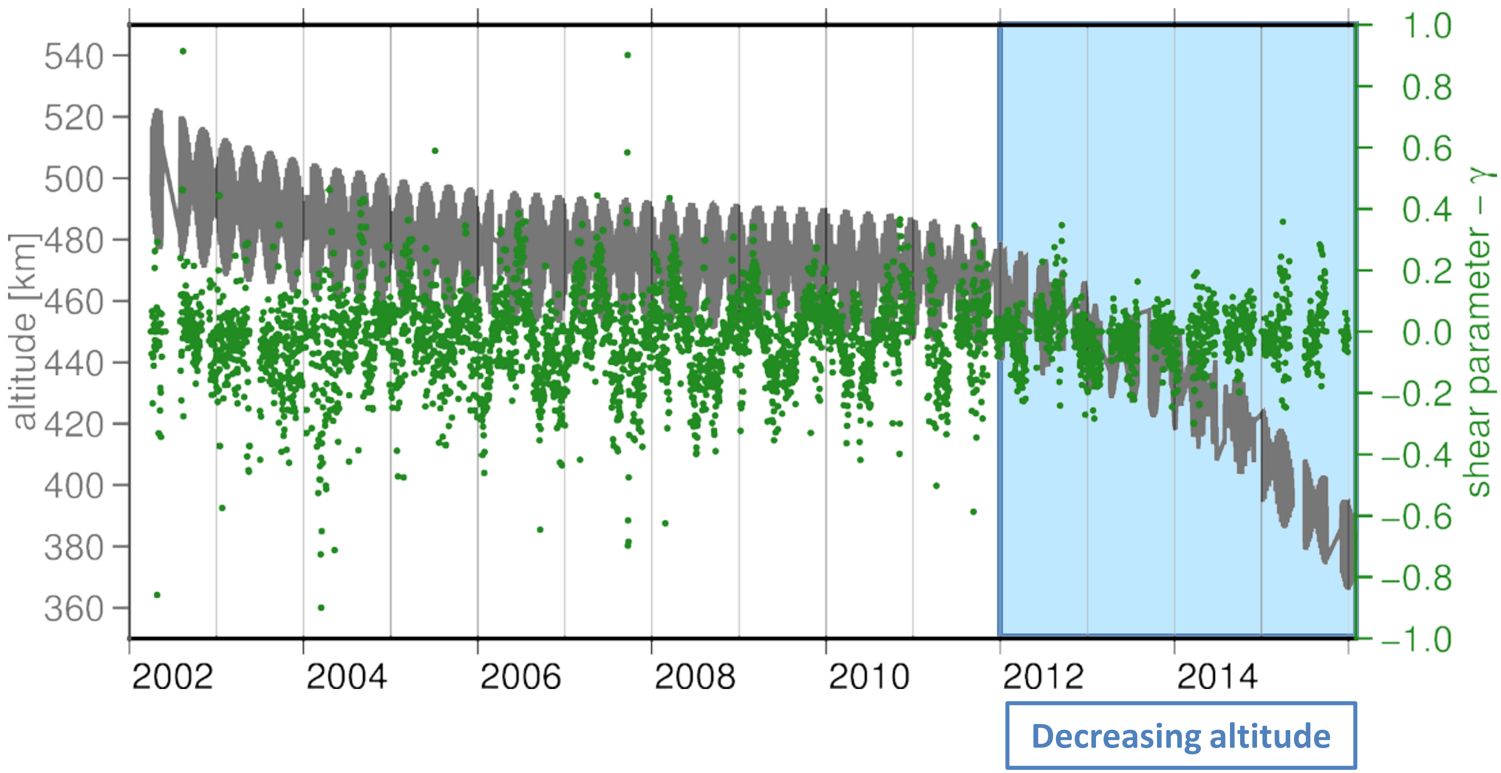
Beta prime angle (β‘)

- 161-day periodic signal



Altitude

- **Interference from other axis components:** magnitude dependent on magnitude of the actual non-gravitational accelerations



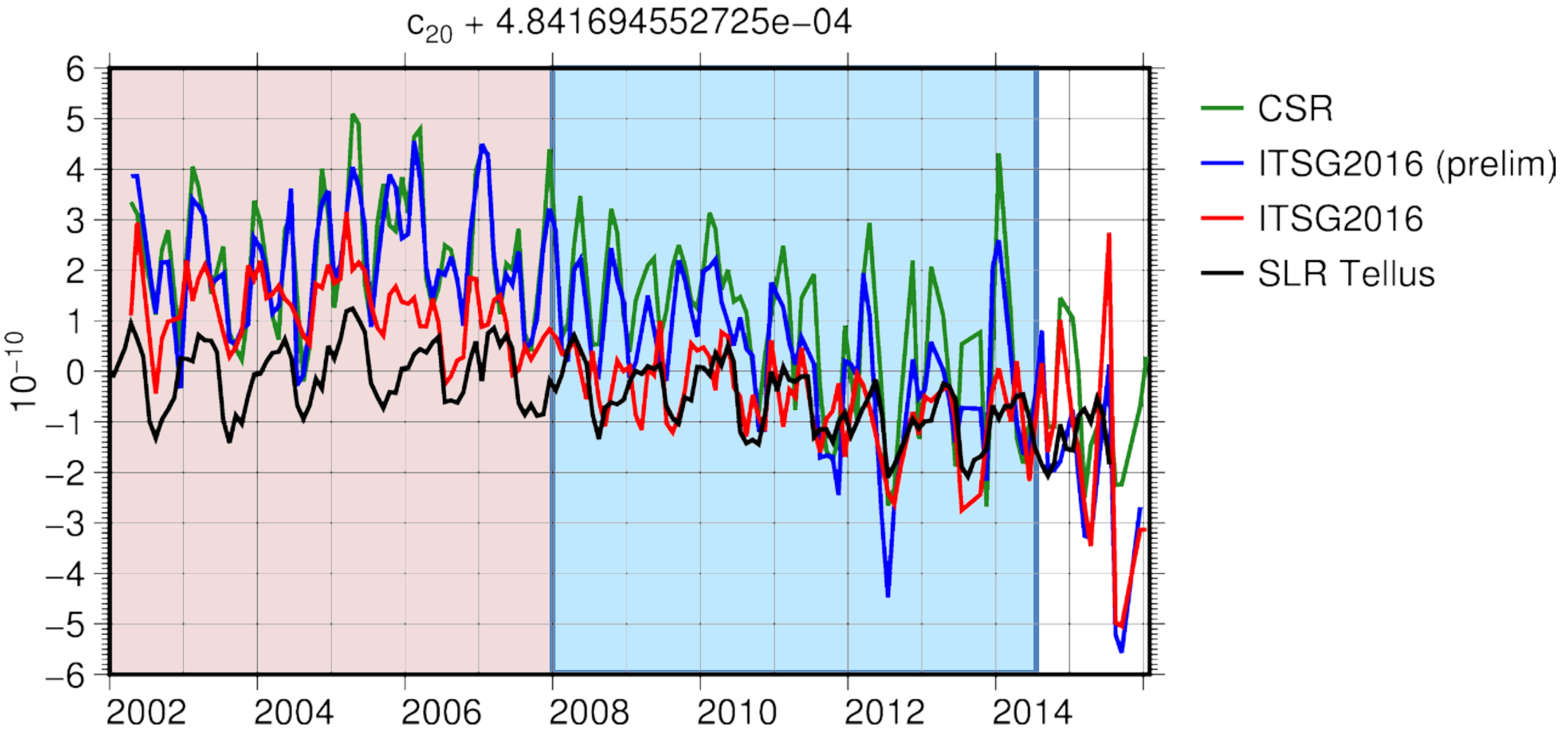
Impact on C20

ITSG-Grace2016 (prelim):

- Main diagonal elements only

ITSG-Grace2016:

- Fully-populated scale factor matrix



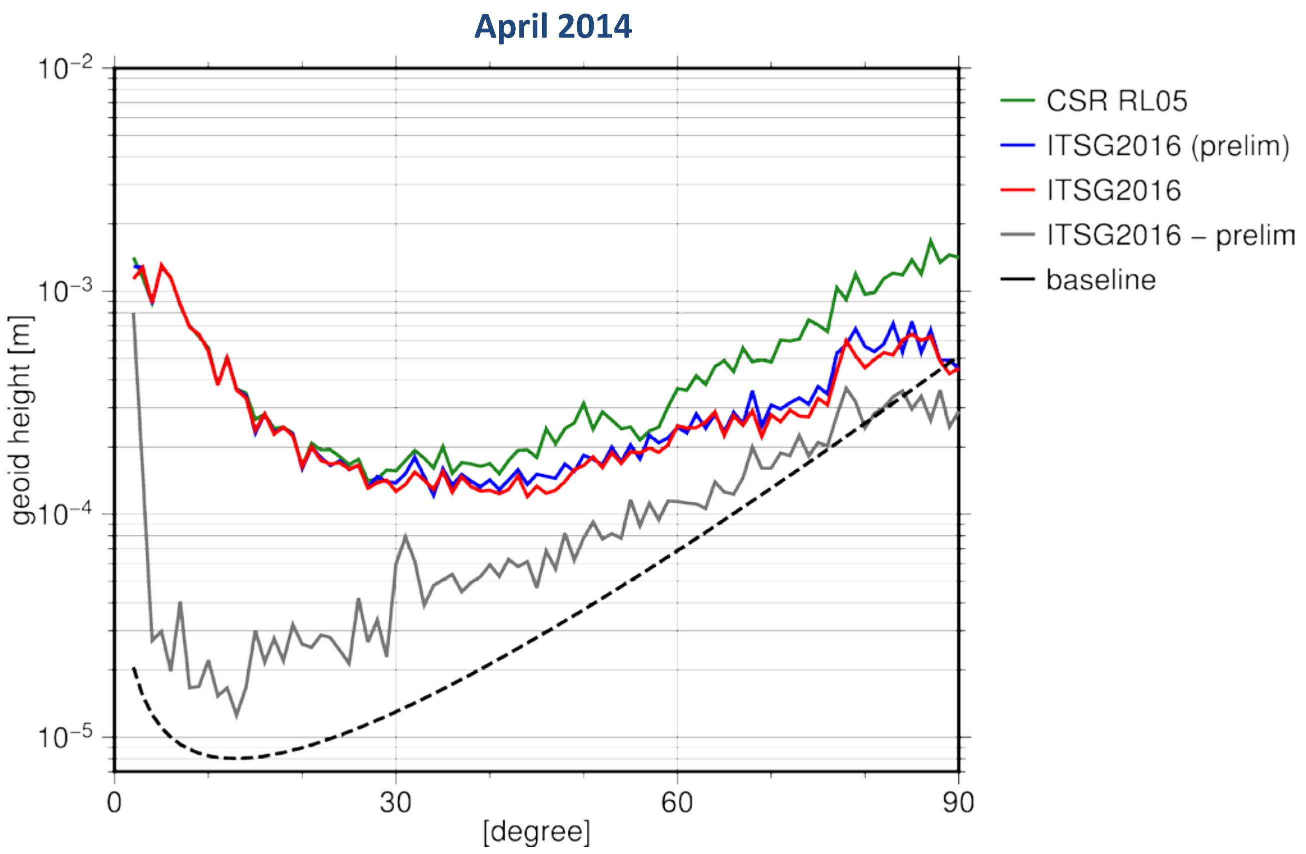
Impact on C20

ITSG-Grace2016 (prelim):

- Main diagonal elements only

ITSG-Grace2016:

- Fully-populated scale factor matrix

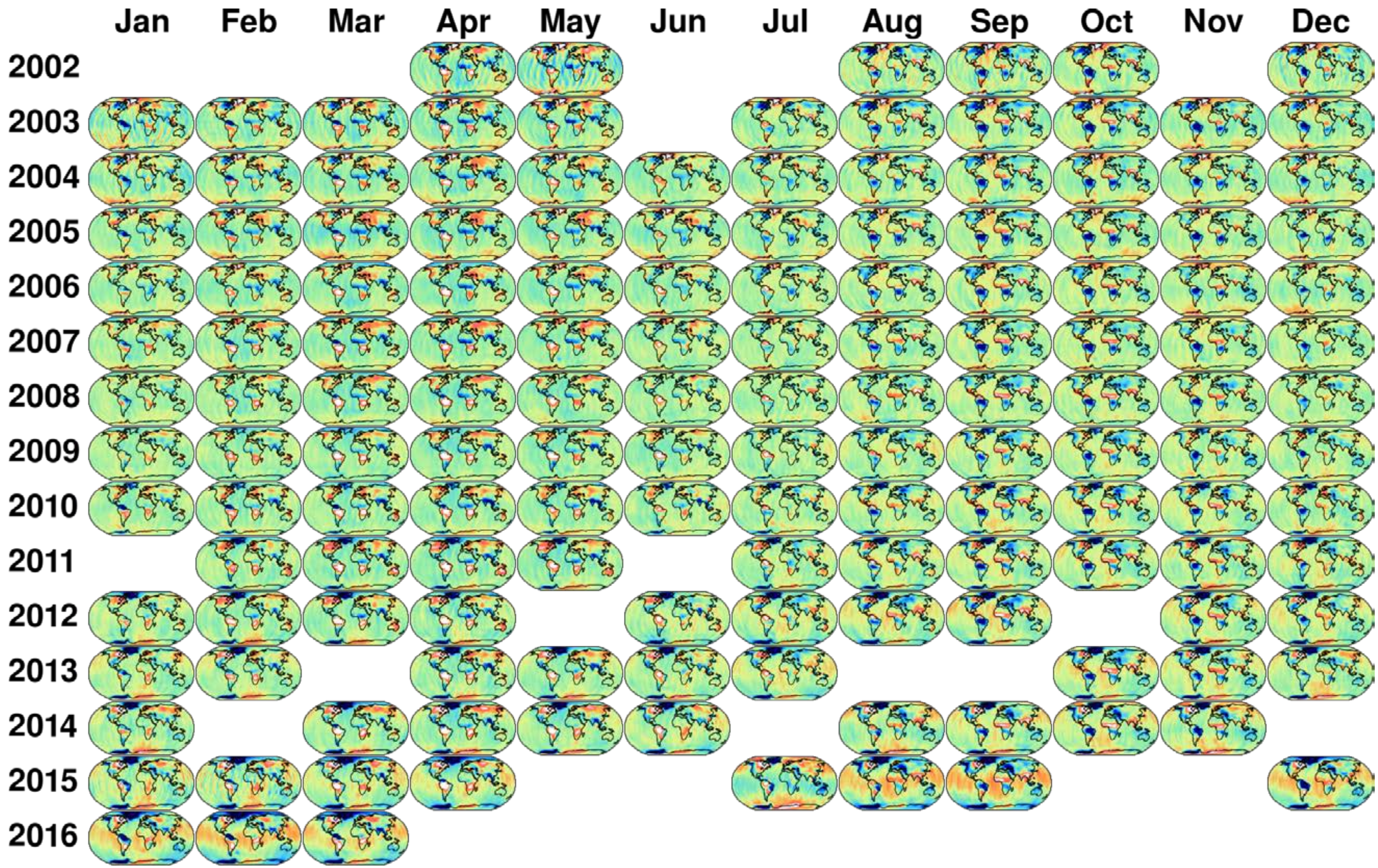


Summary & Conclusions

- GRACE accelerometers are extremely sensitive to satellite-internal temperature variations
- Temperature-induced variations of calibration parameters (biases & scale factors)
- Fully-populated scale factor matrix significantly improves estimates of C20 coefficients (w.r.t SLR data)
- Further analysis: ideal parametrization of calibration equation

ITSG-Grace2016

ITSG-Grace2016 Monthly Solutions



ITSG-Grace2016 Monthly solutions

Method:

- Variational equations
- 24h arc length, 3h covariance length

Input:

- GRACE Level-1B data from 2002-04 to 2016-03
- ITSG orbit product (Zehentner et al. 2015)
- Improved satellite attitude (Klinger et al. 2014)

Unconstrained monthly solutions:

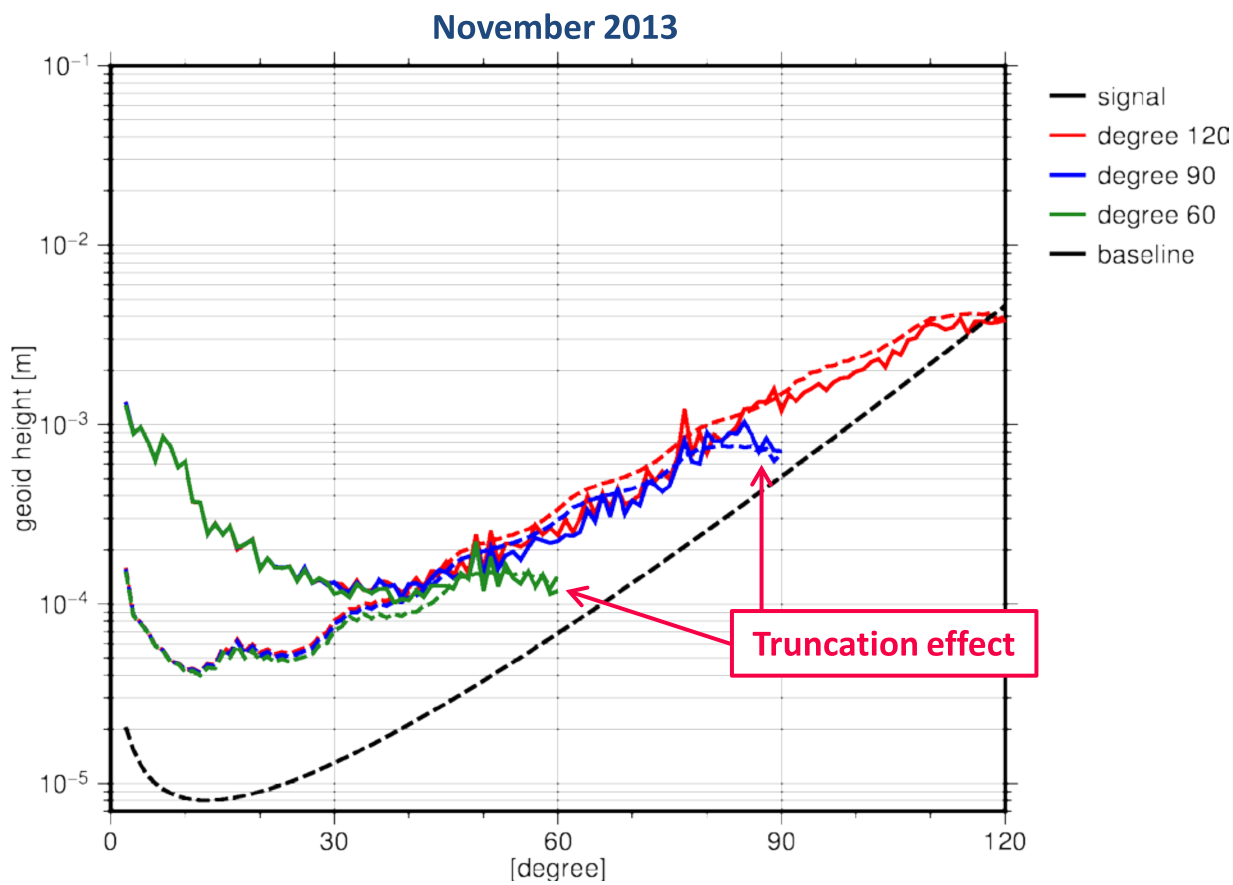
- Degree 60, 90, 120

Non-gravity parameters:

- Once per day: satellite state vector, accelerometer bias per axis (basis splines), accelerometer scale factors

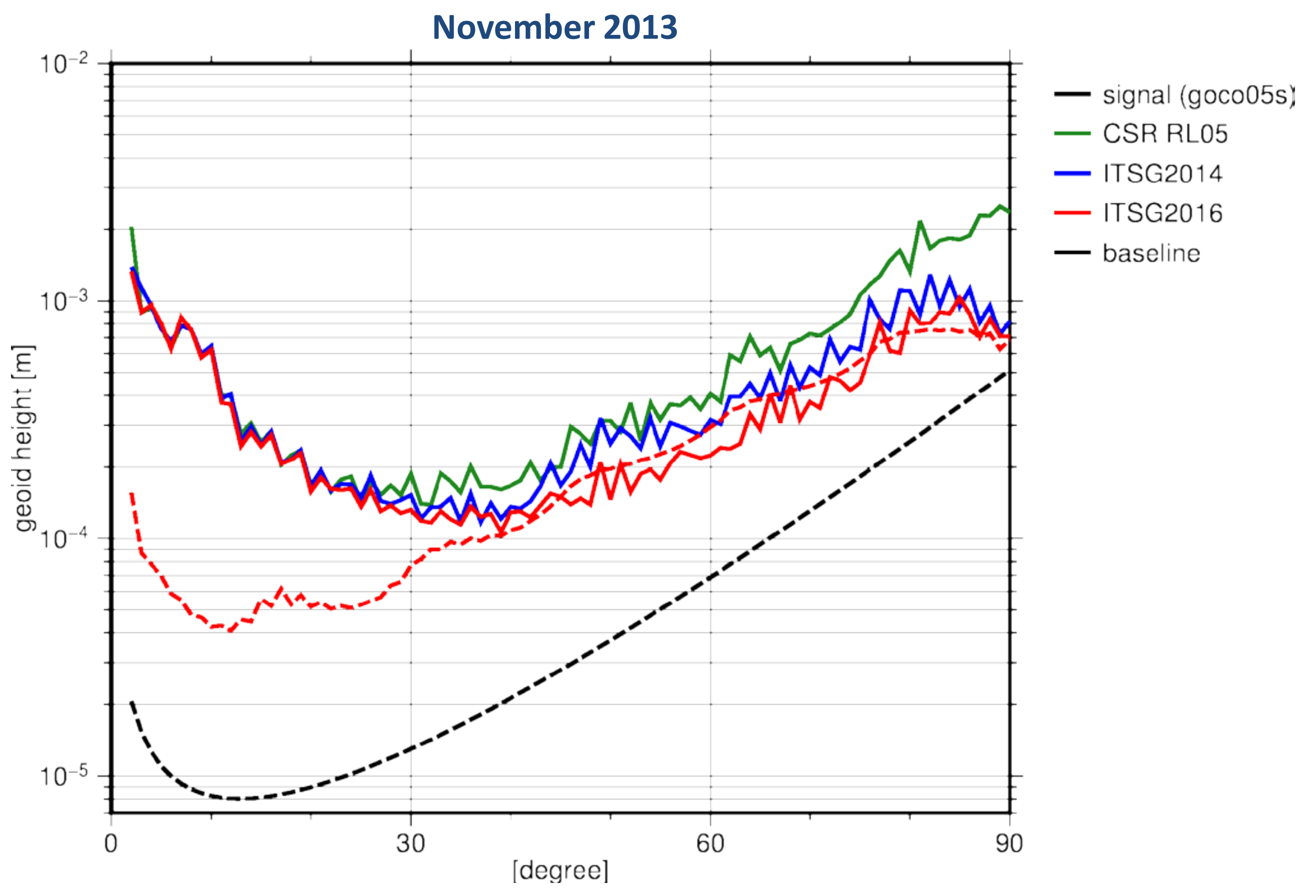
ITSG-Grace2016 Monthly Solutions

- **Unconstrained monthly solutions:** degree 60, 90 and 120



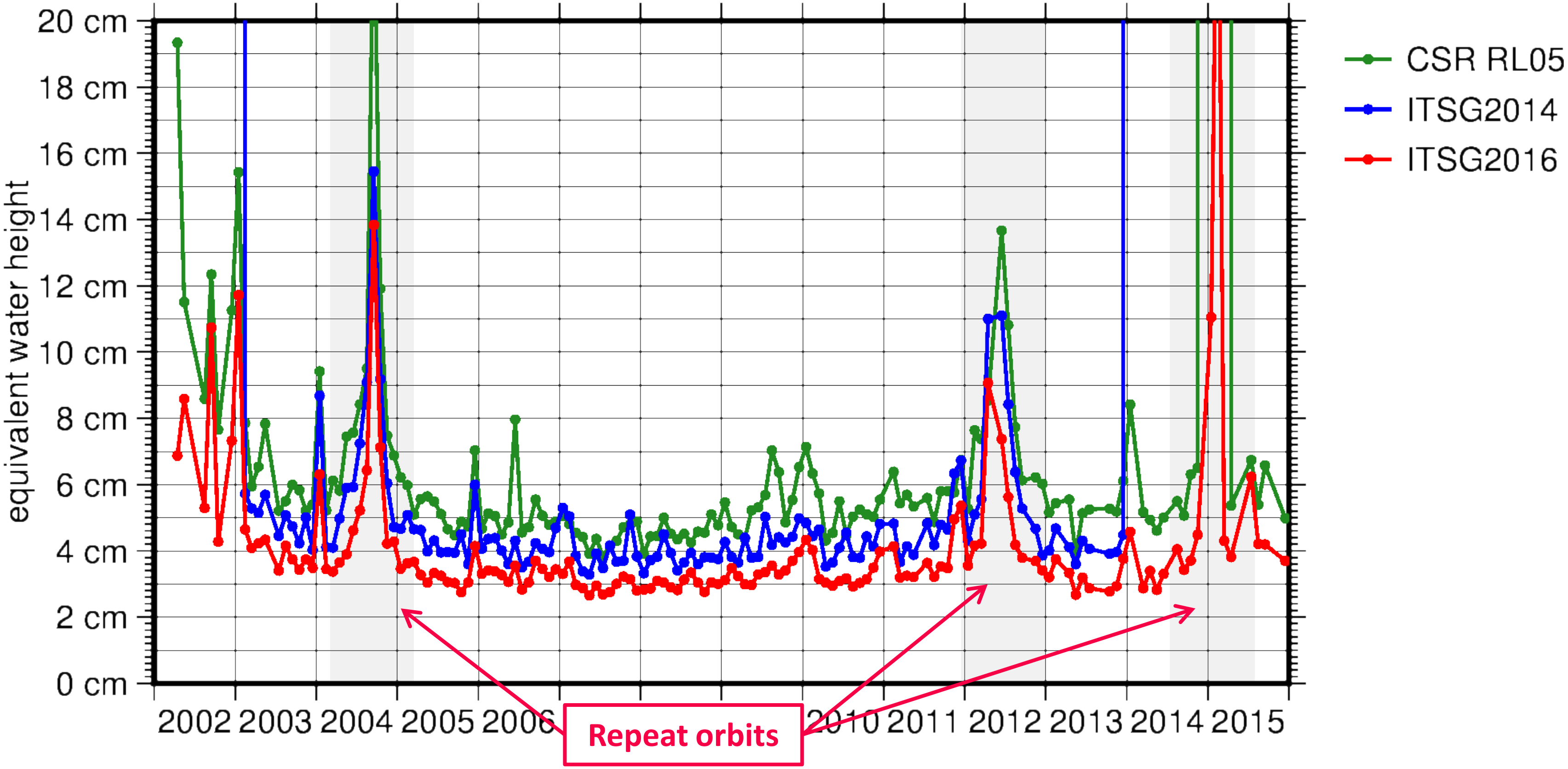
ITSG-Grace2016 Monthly Solutions

- **Unconstrained monthly solutions:** degree 60, 90 and 120

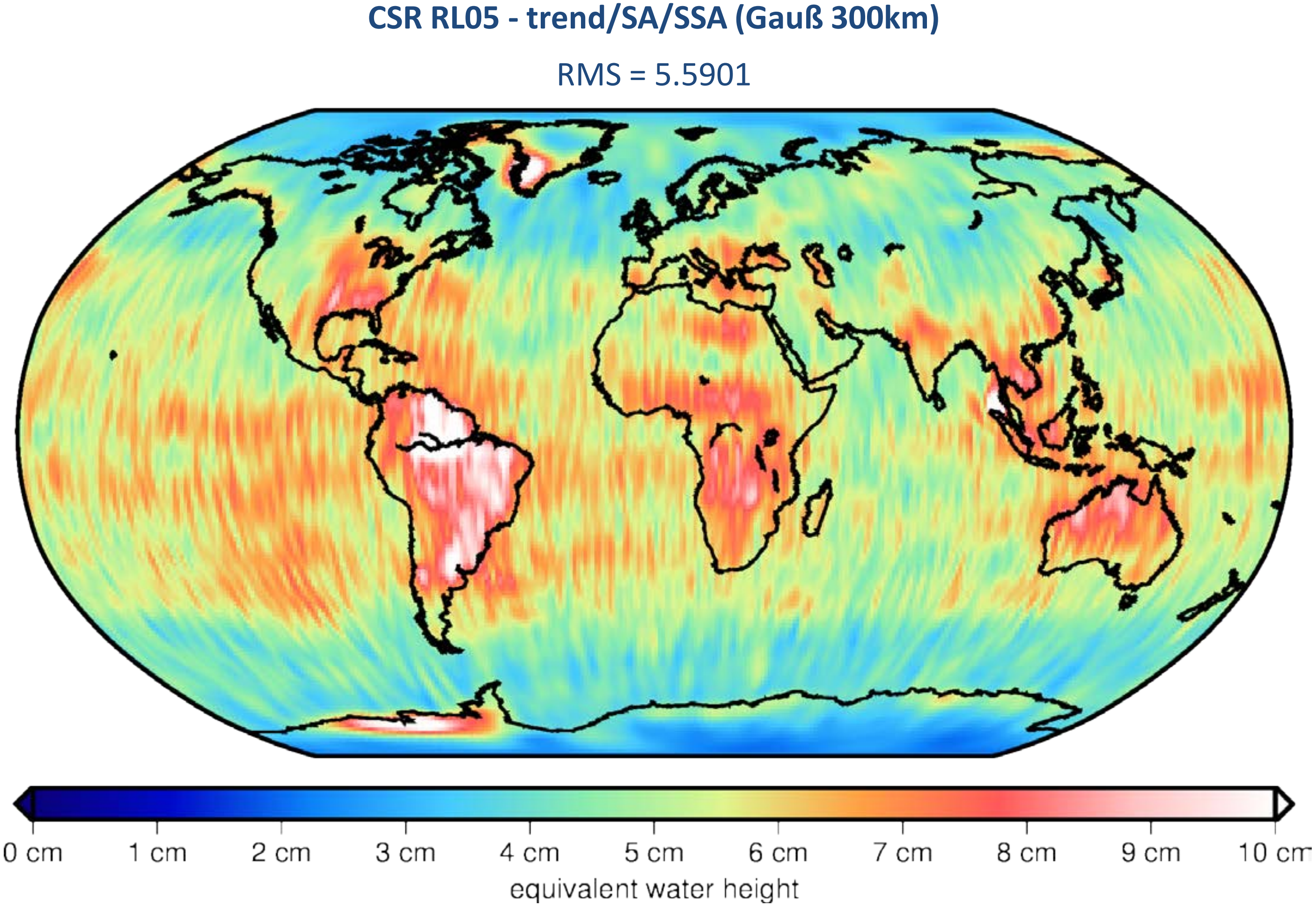


Variability over the Oceans

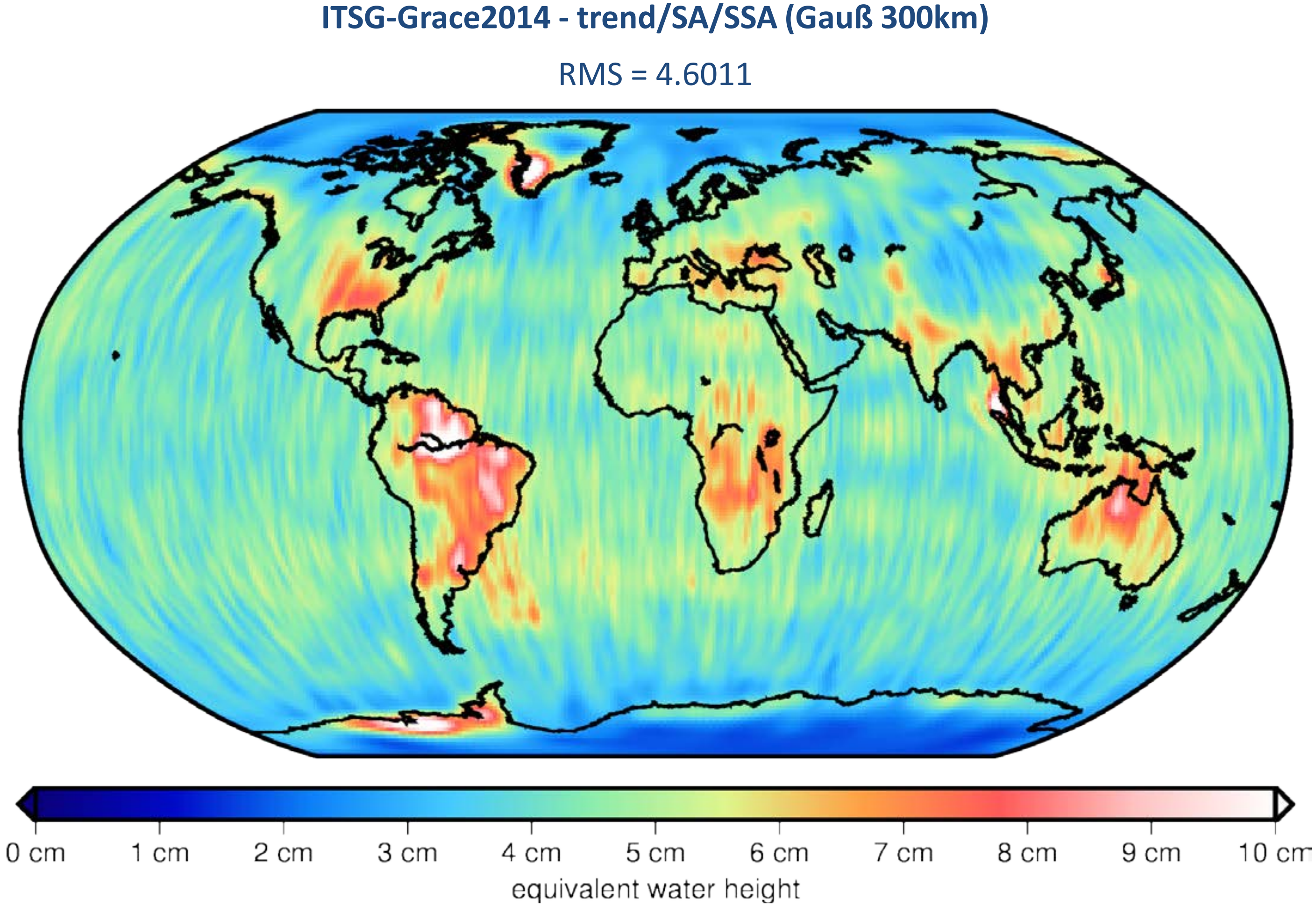
Trend/Annual/Semiannual reduced (Gauß 300km)



Temporal RMS



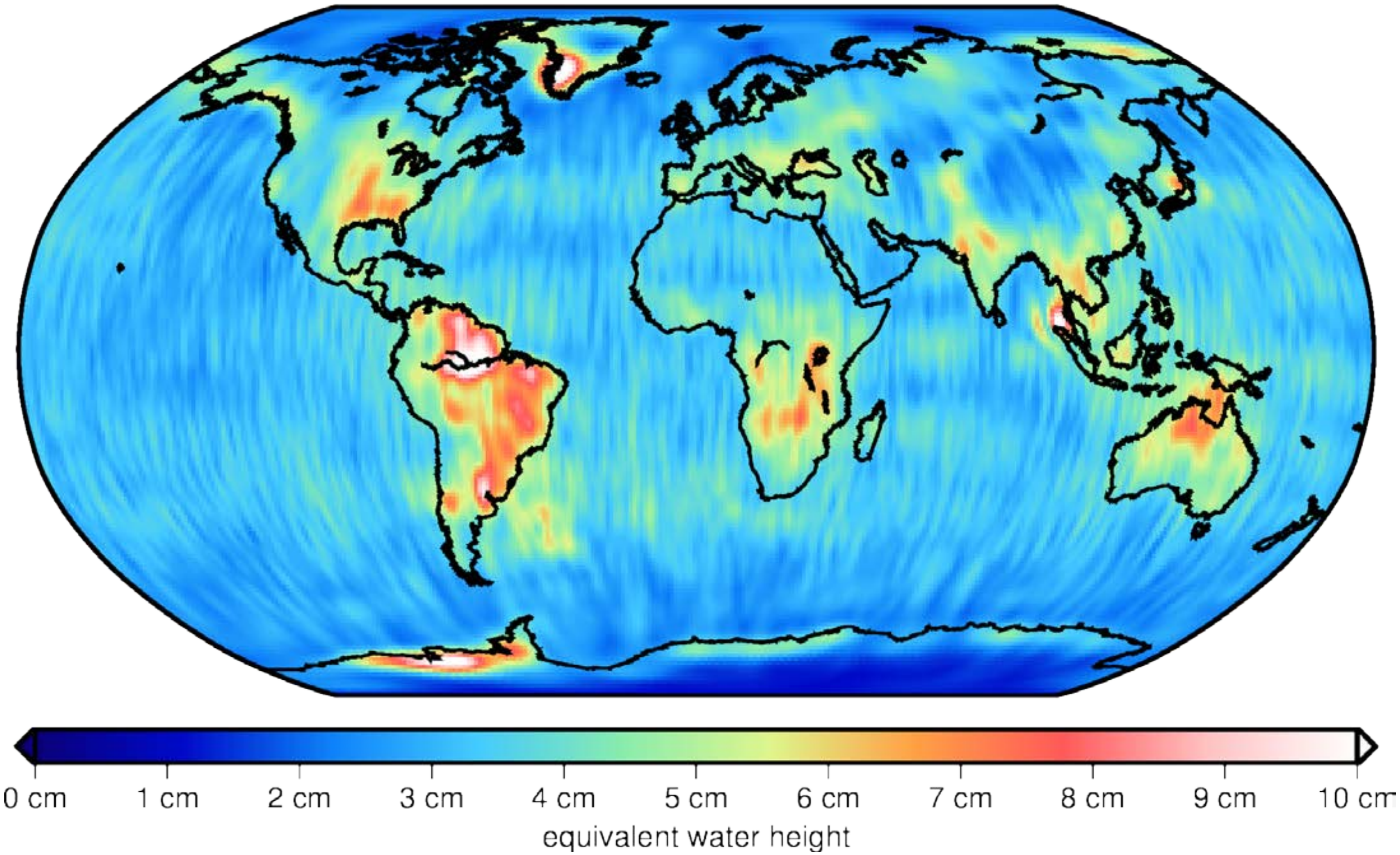
Temporal RMS



Temporal RMS

ITSG-Grace2016 - trend/SA/SSA (Gauß 300km)

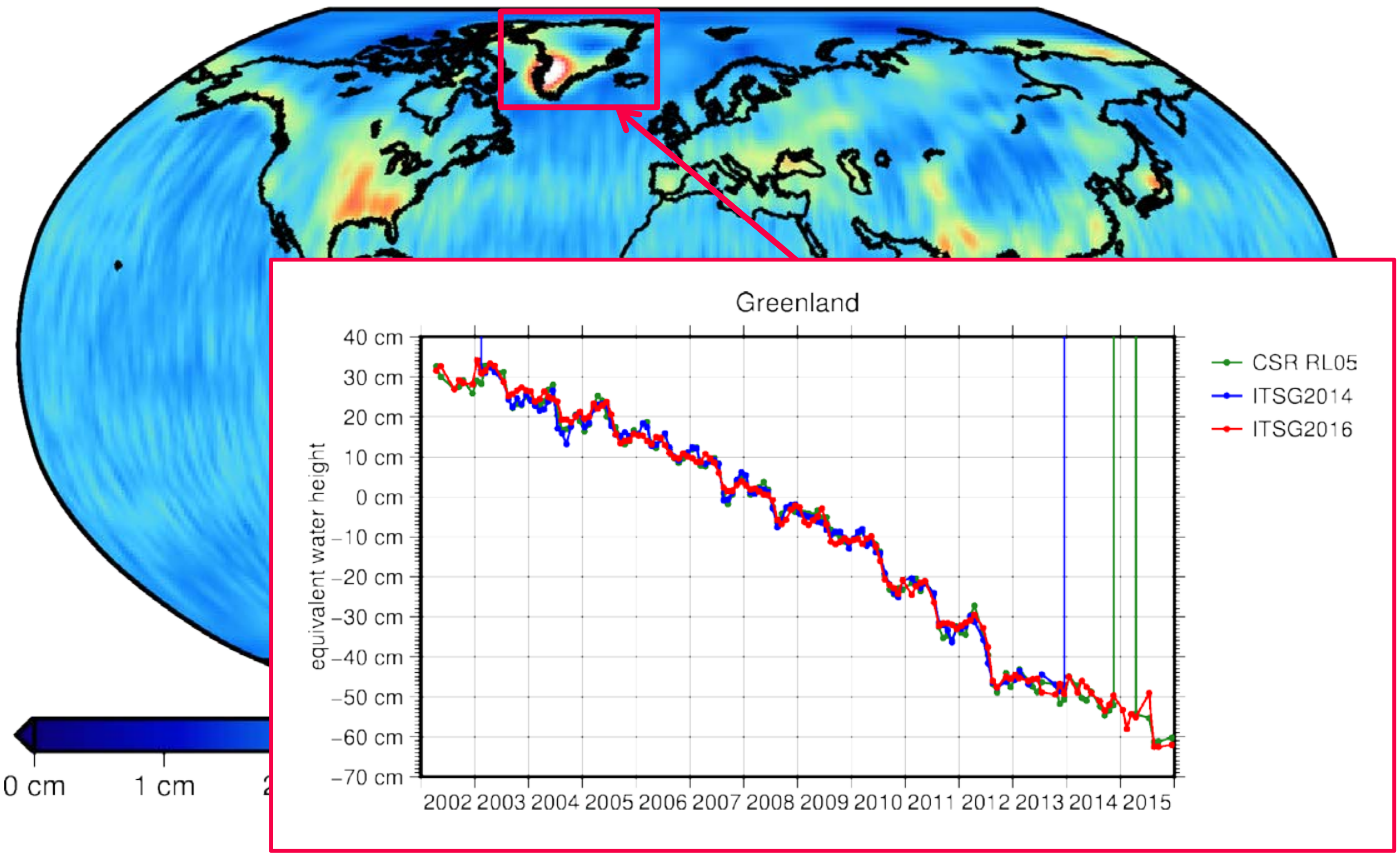
RMS = 3.7209



Comparison of signals

ITSG-Grace2016 - trend/SA/SSA (Gauß 300km)

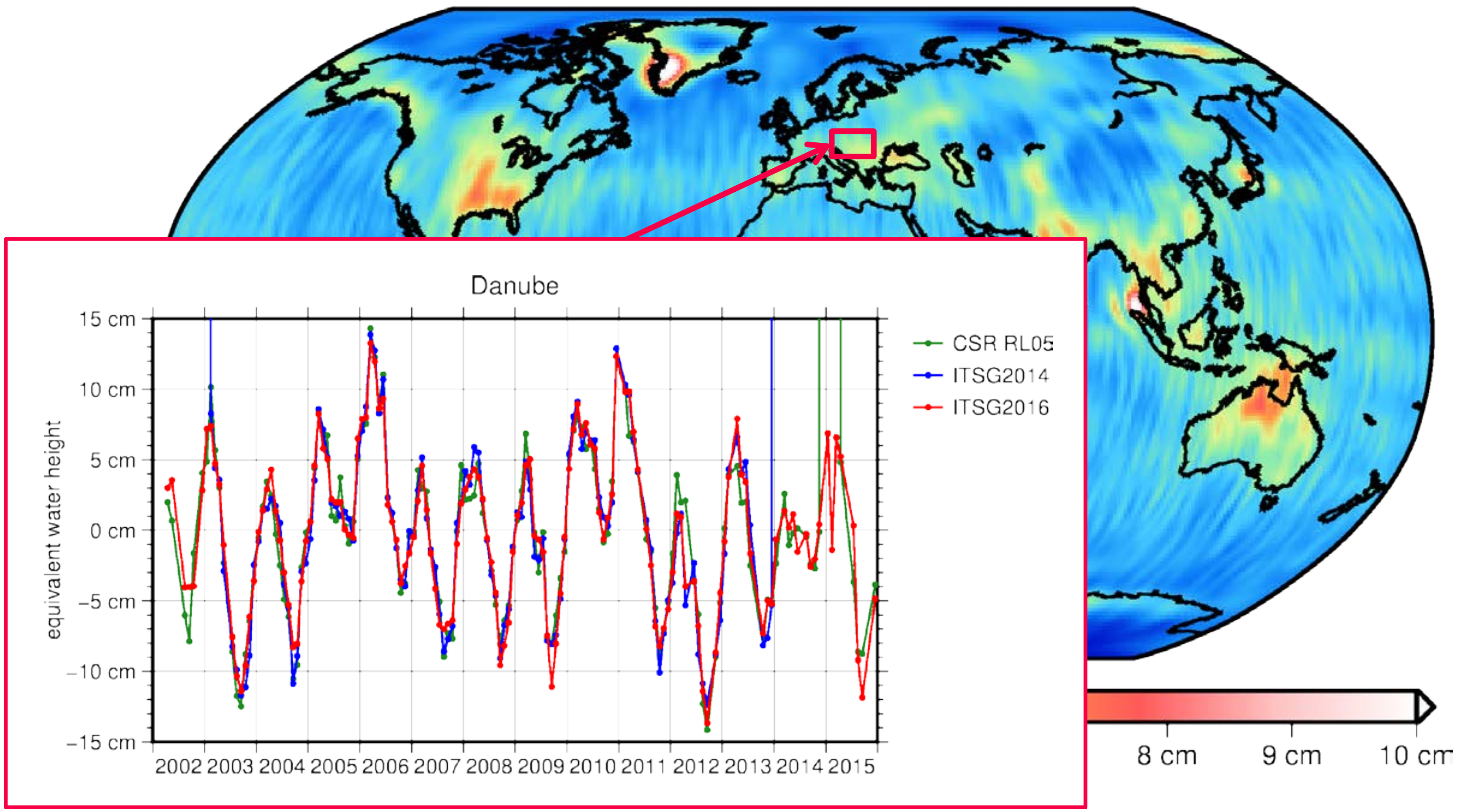
RMS = 3.7209



Comparison of signals

ITSG-Grace2016 - trend/SA/SSA (Gauß 300km)

RMS = 3.7209



Summary & Conclusions

ITSG-Grace2014 vs. ITSG-Grace2016:

- Improved processing (data screening, accelerometer calibration, orbit integration, covariance function, …) contributes to overall accuracy of monthly gravity field solutions
- Noise reduction w.r.t ITSG-Grace2014 in the order of
  - 20% for n = 15-25
  - 40% for n = 25-40
  - 25% for n = 40-90 (Horwath et al., 2016)
- Fully-populated scale factor matrix significantly improves C20 coefficients

ITSG-Grace2016

Unconstrained monthly solutions:

- Degree 60, 90 and 120
- Full normal equations in SINEX format are published

Daily Kalman smoothed solutions:

- Degree 40

New ITSG-Grace2016 Release available at:

- ifg.tugraz.at/ITSG-Grace2016

EGSIEM

European Gravity Service for Improved Emergency Management

EGSIEM - WP2
CNES/GRGS GRACE processing

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

(1) CNES/GRGS, Toulouse, France

(2) GET/UMR5563/OMP/GRGS, Toulouse, France

(3) Géode & Cie, Toulouse, France

Summary

1. Report on 2006-2007 NEQs processing
2. Problems at the poles in our RL03-v1: solved in RL03-v2

Report on 2006-2007 NEQs processing

- The years 2006-2007 have been processed and the NEQs computed.
- They will be uploaded on the ftp server at Bern very soon
- The unconstrained solutions will be provided at the same time as the NEQs
- We have also computed a 4-SLR-sat monthly time series of NEQs over 2002-2016 (Lageos-1, Lageos-2, Starlette and Stella). It is available to EGSIEM members

Report on 2006-2007 NEQs processing

- Processing standards:
  - A priori sigma for KBRR: 1.e-7 m/s
  - A priori sigma for GPS phase: 2.e-2 m
  - A priori sigma for GPS code: 1. m
  - GPS measurements density: 1 epoch every 30"
  - The GPS partial derivatives are computed only up to degree 40

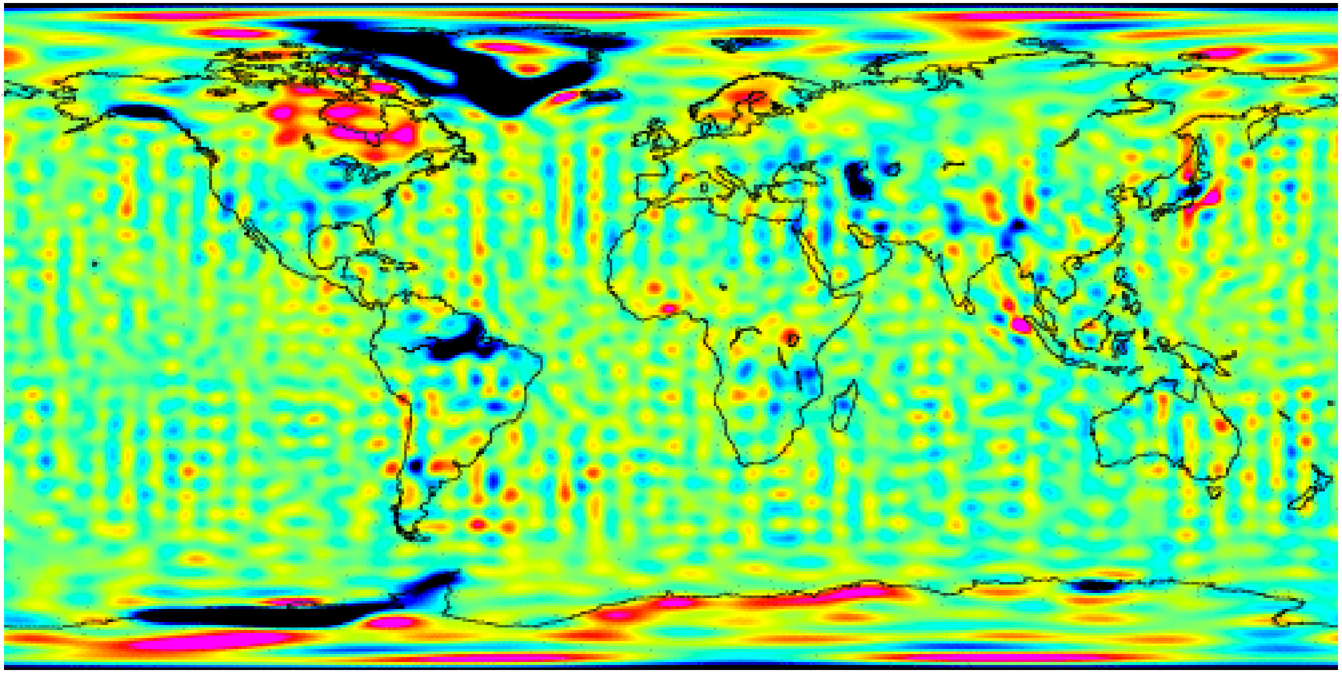
GPS KBR weighting

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

GPS KBR weighting

- A priori sigma GPS : 8 mm (high weight)

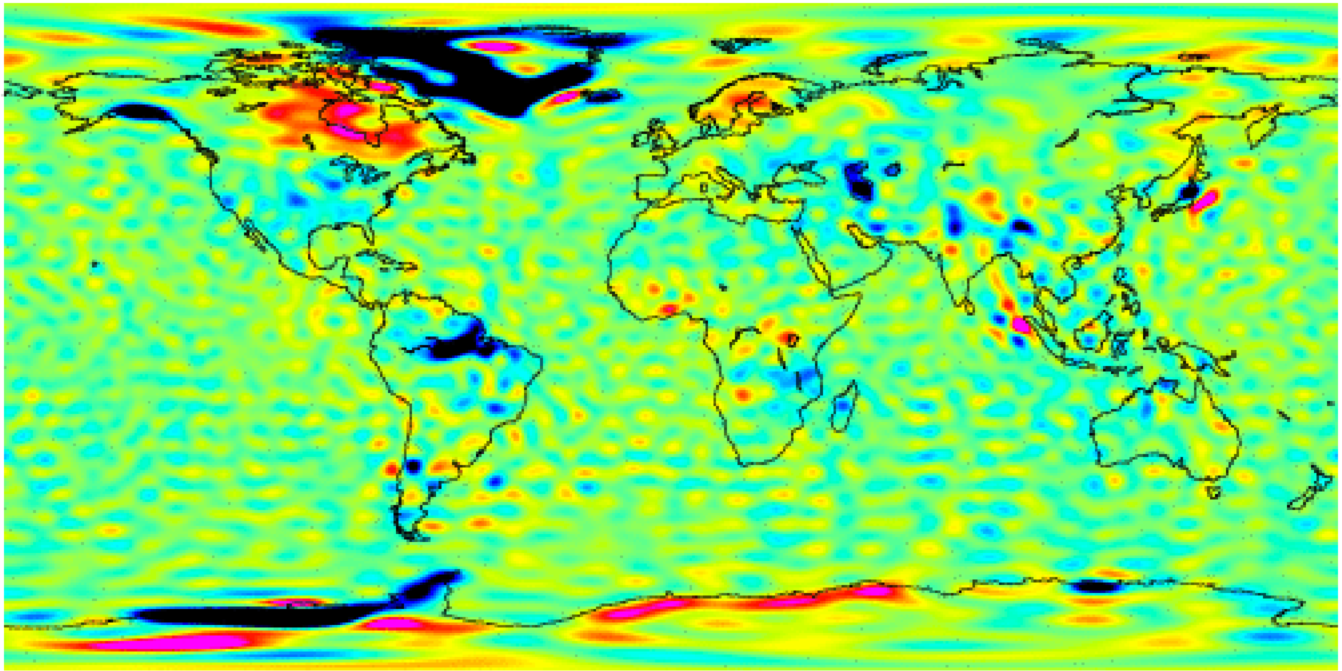
Typical monthly solution



GPS KBR weighting

- **A priori sigma GPS : 20 mm (low weight)**

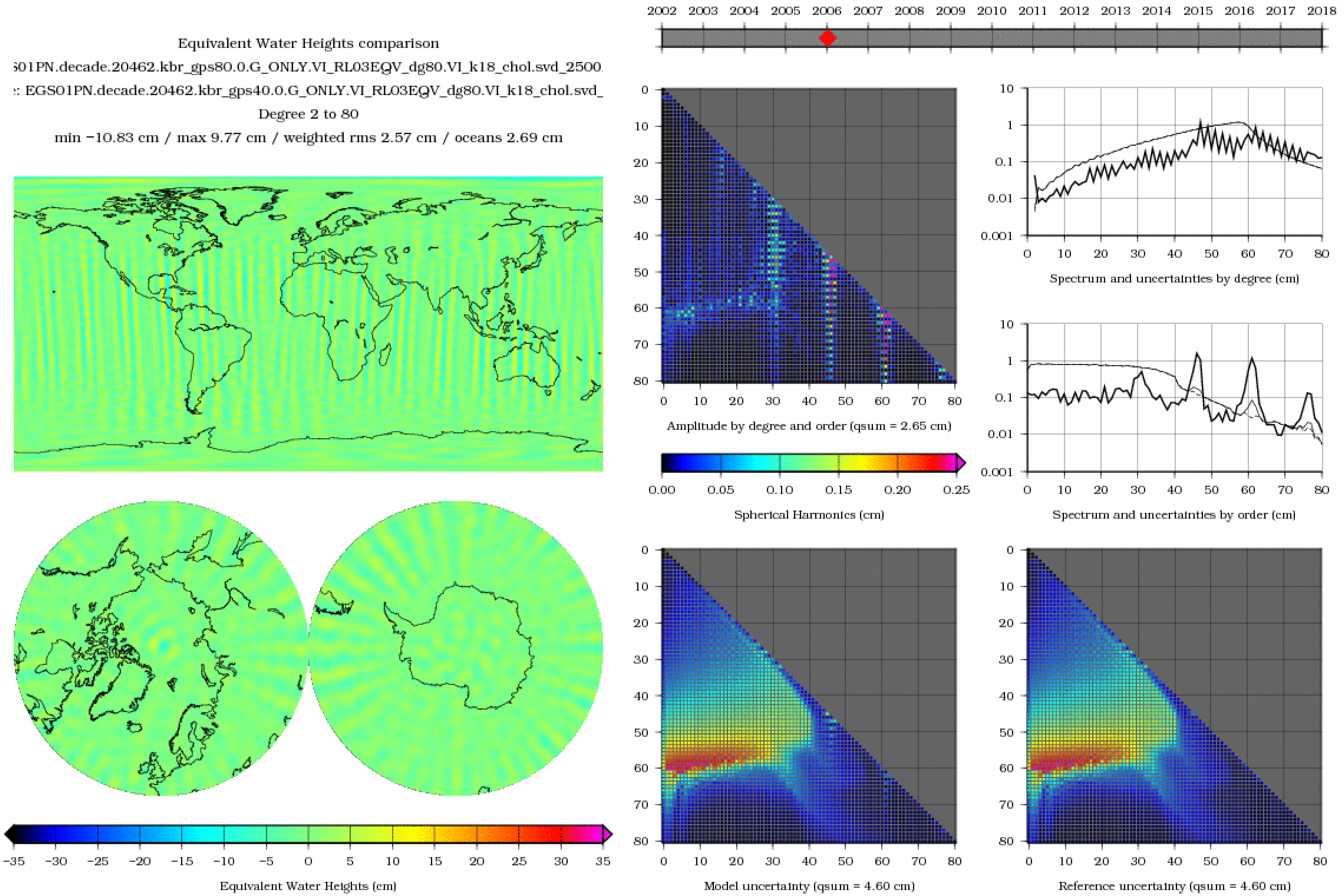
Typical monthly solution



GPS KBR weighting

- **Best solution:**
  - **high density, low weight, and cut GPS equation to degree 40**

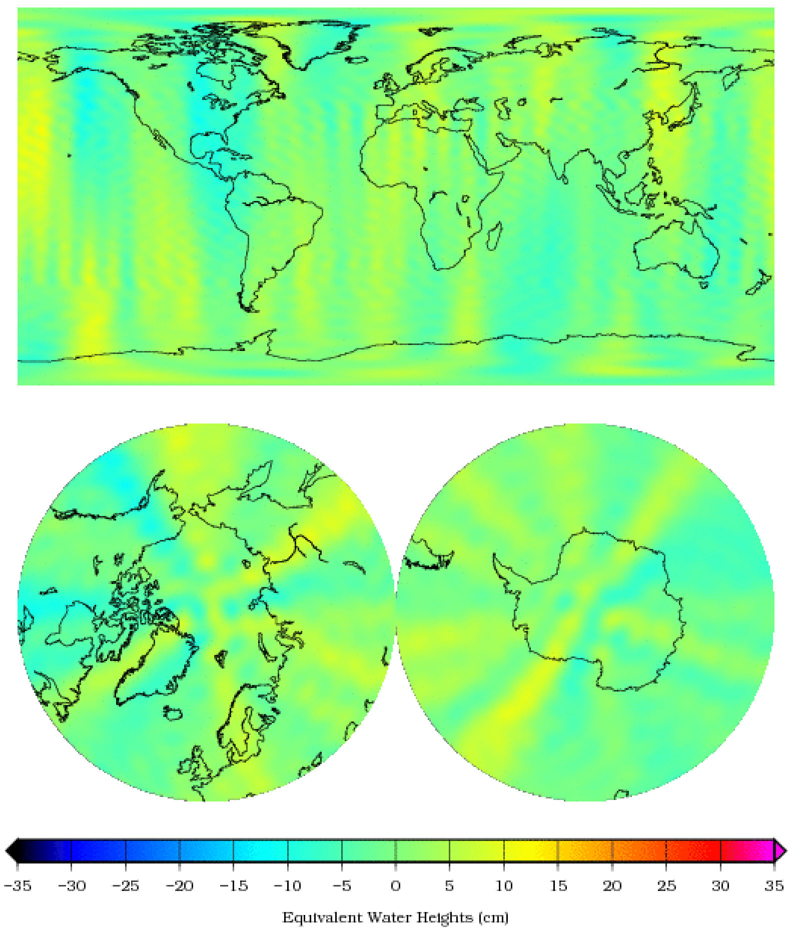
Truncation of GPS partials

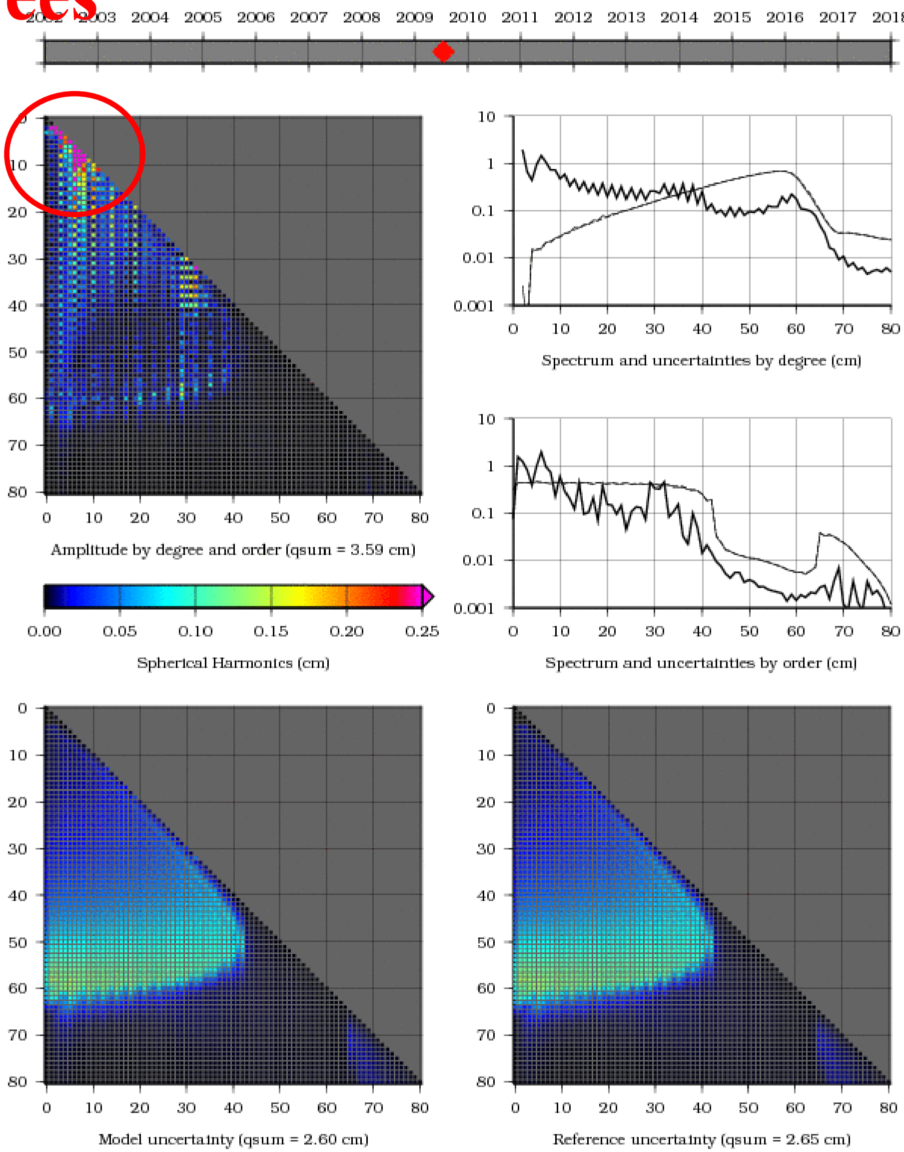


Truncation of GPS partials

Up to 40 improves low degrees

Gravity field solution:
High vs. Low GPS weight

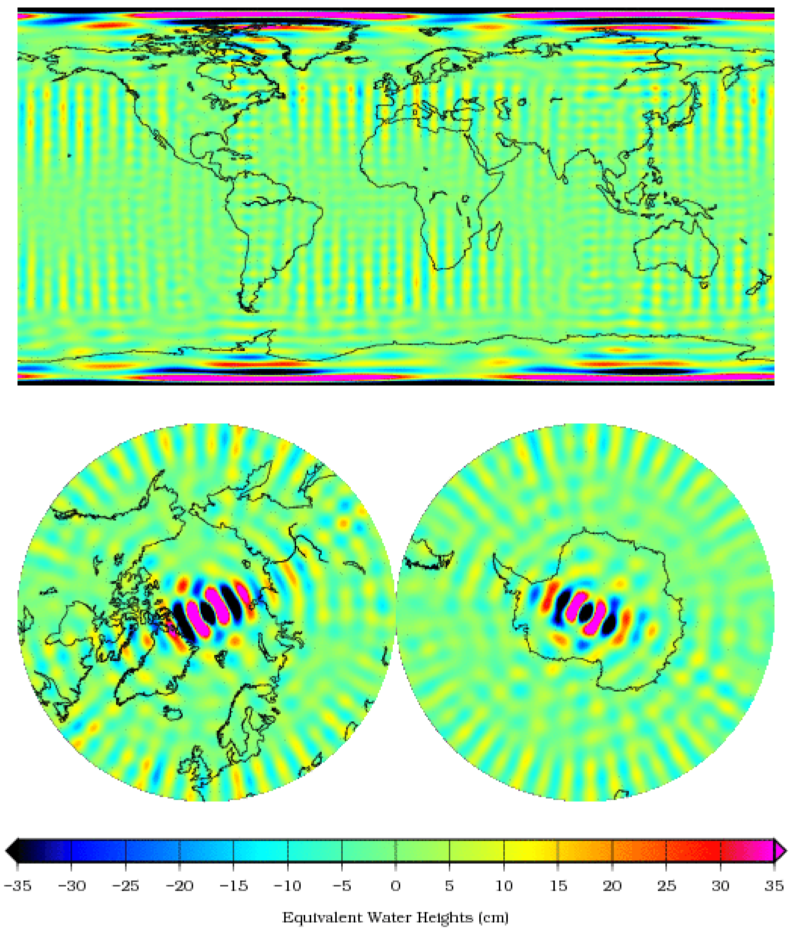


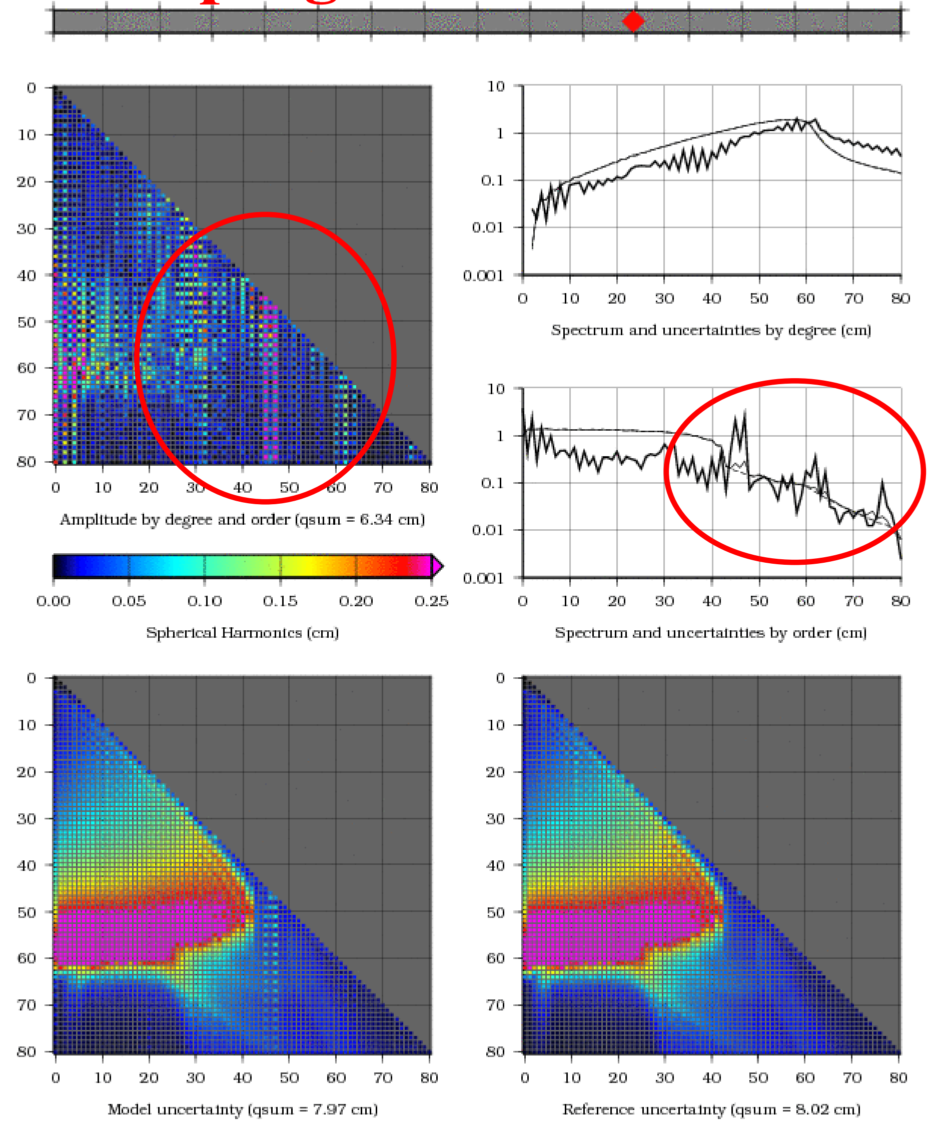


Truncation of GPS partials

From 40 to 80 adds noise and striping

Gravity field solution:
High vs. Low GPS weight

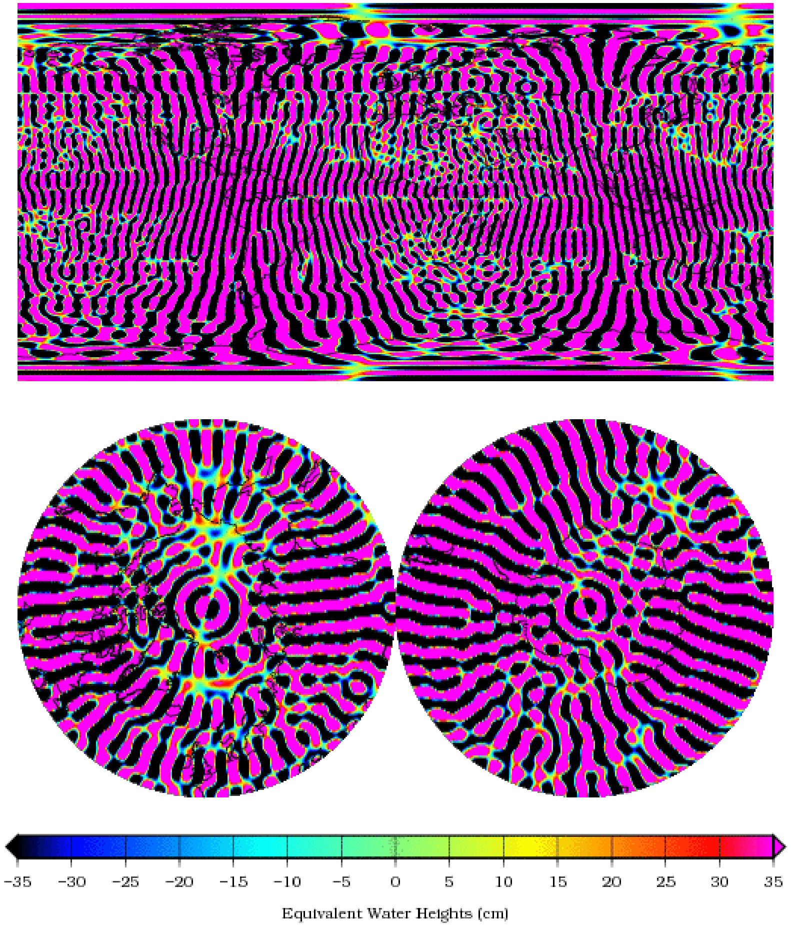


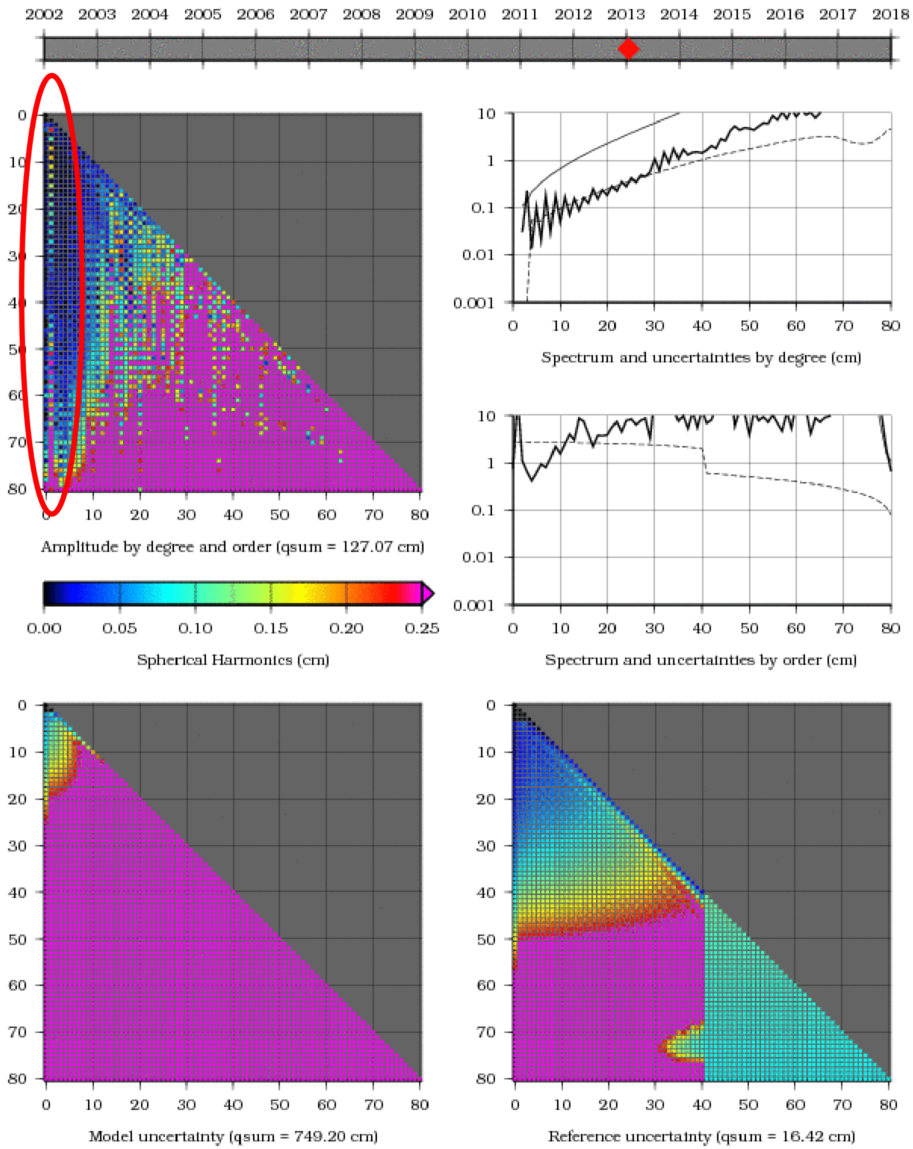


- Problems at the poles
  - They are not immediately related to GPS
  - Appear when low sectorial coefficients are wrong (compensation on higher orders). This can be the case when those are fixed, or with SVD
- Example
  - Choleski inversion (no constraint), with degree 1 fixed or solved

Degree 1 fixed

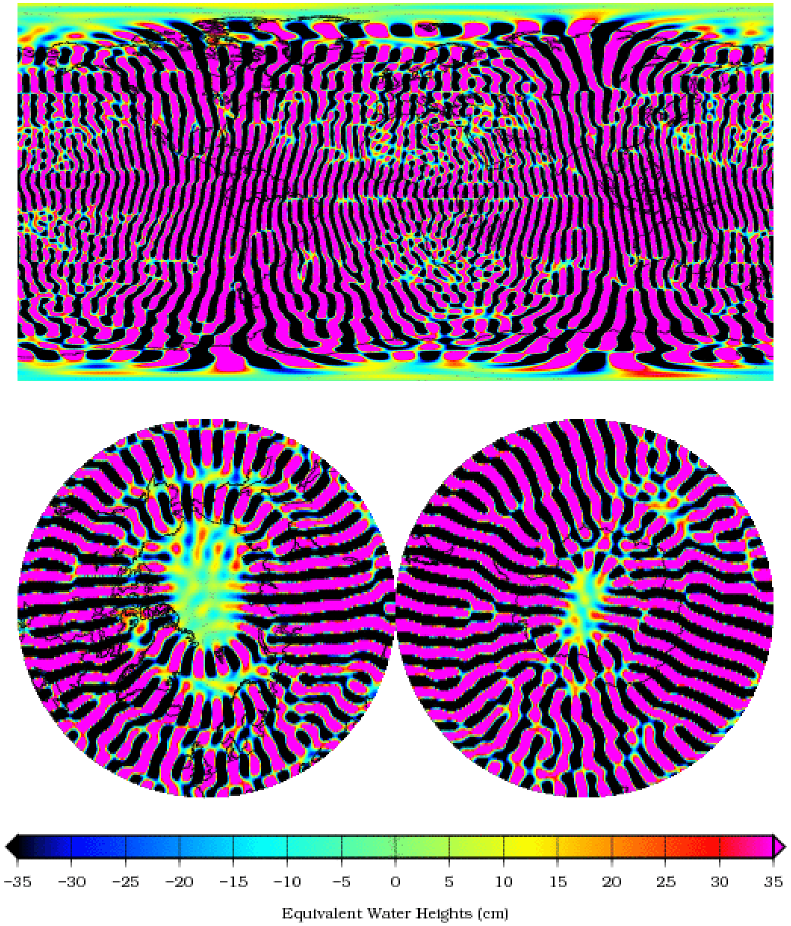
Unconstrained gravity field solution
Degree 1 FIXED (December 2012)

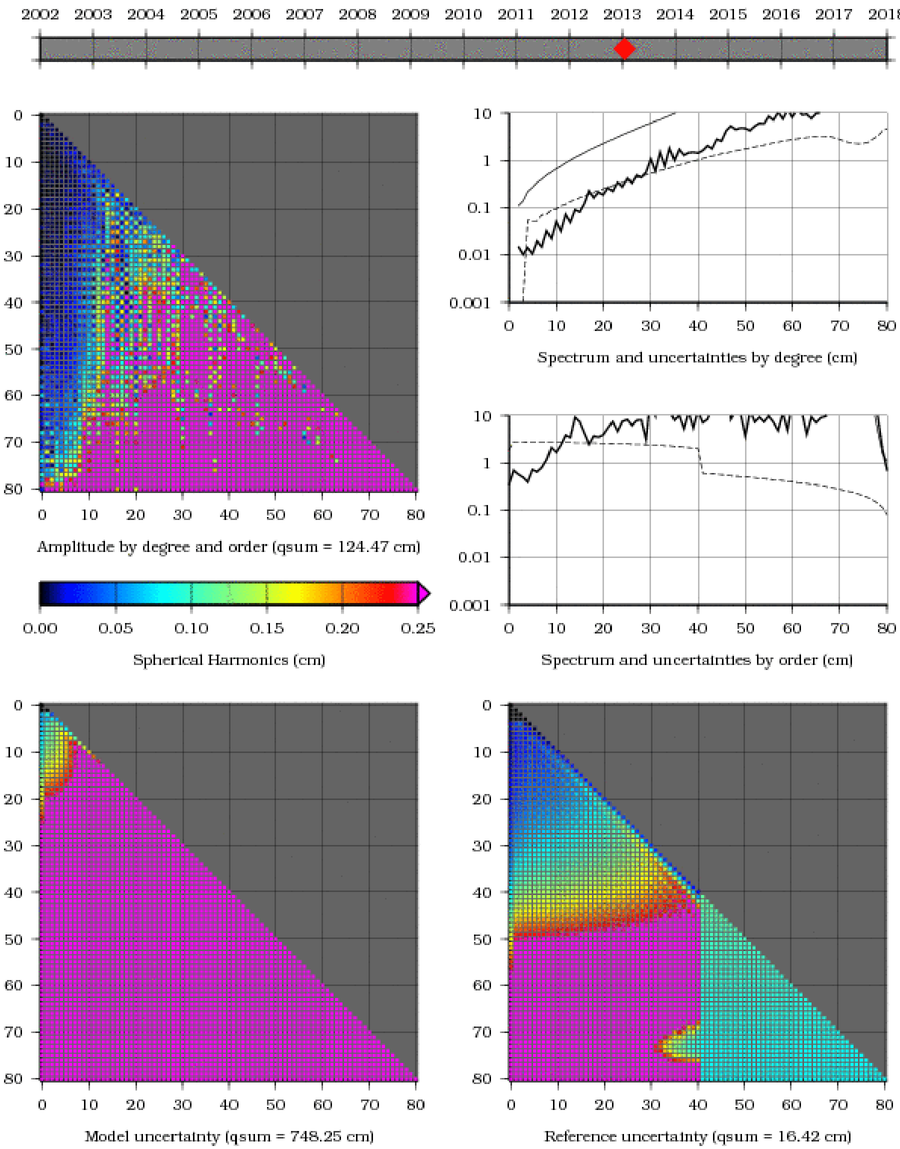




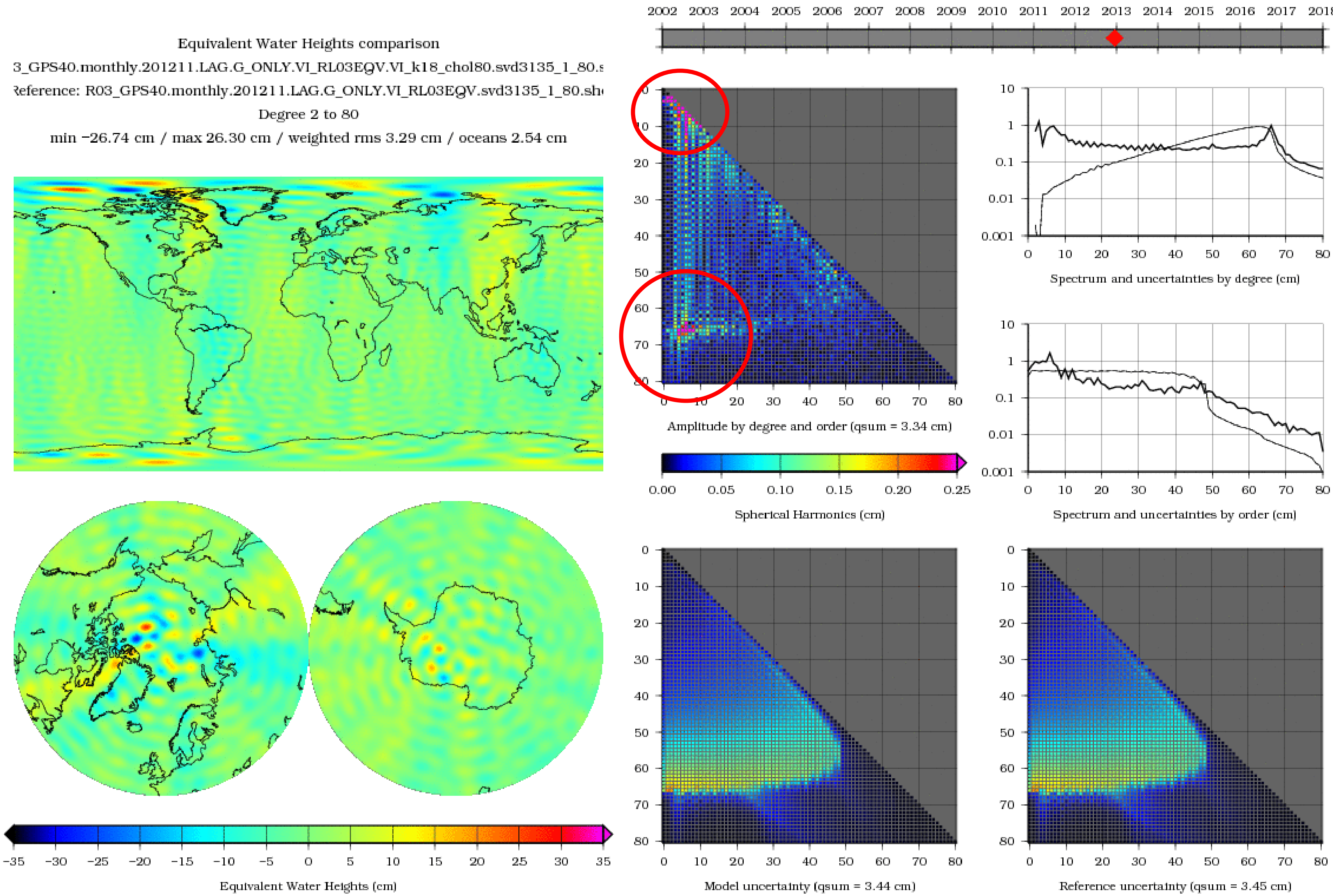
Degree 1 solved

Unconstrained gravity field solution
Degree 1 FREE (December 2012)

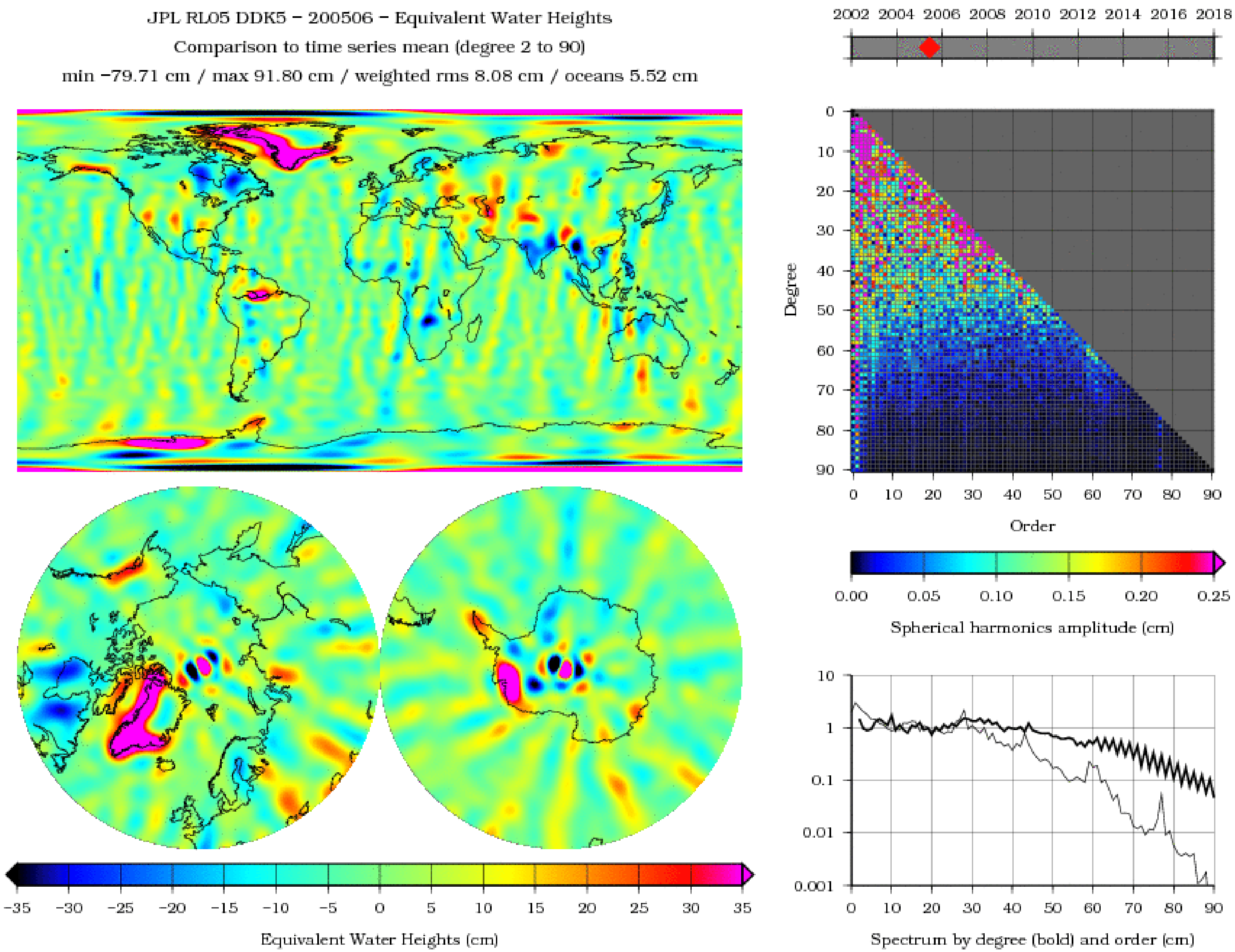




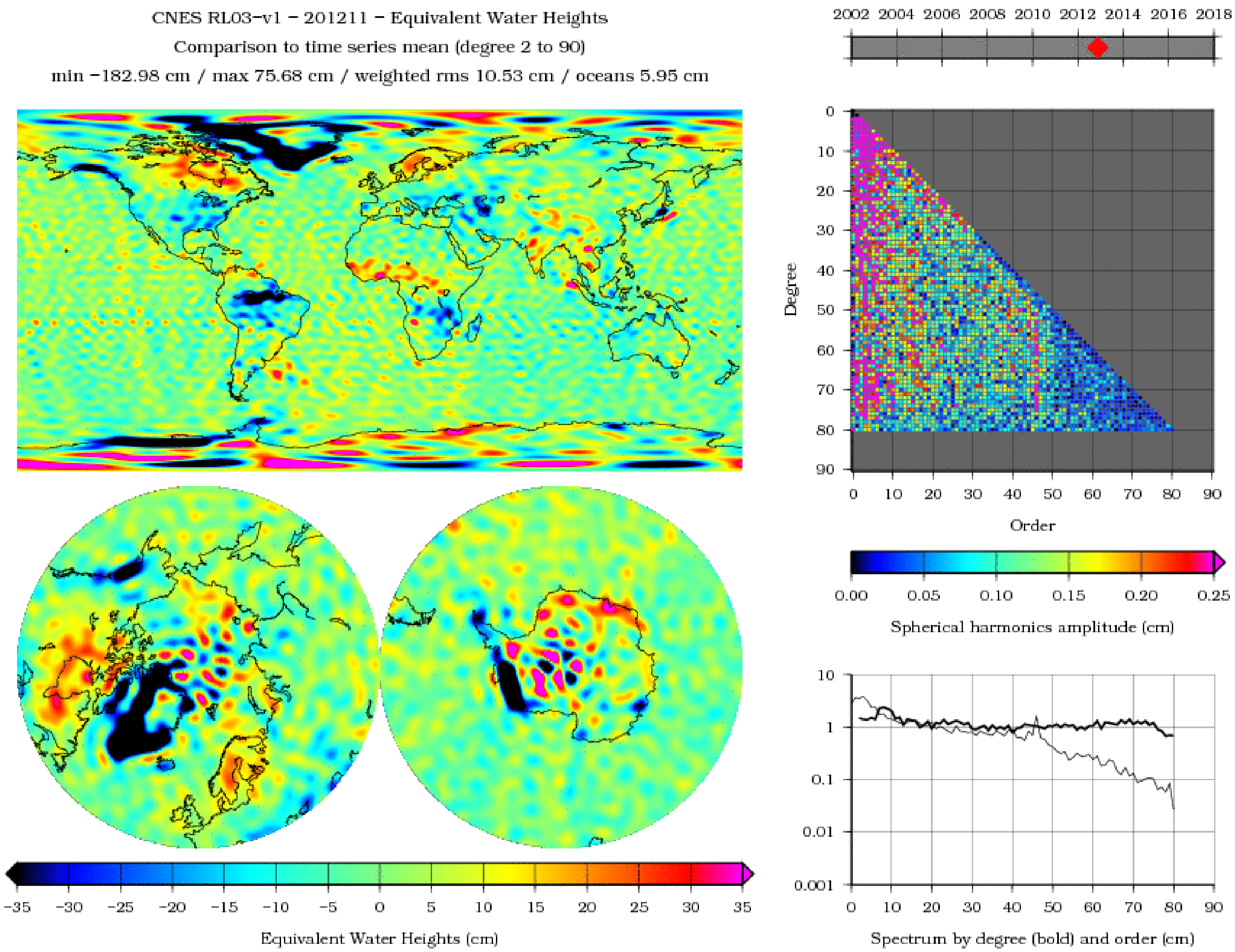
Impact of wrong low-degree sectorials

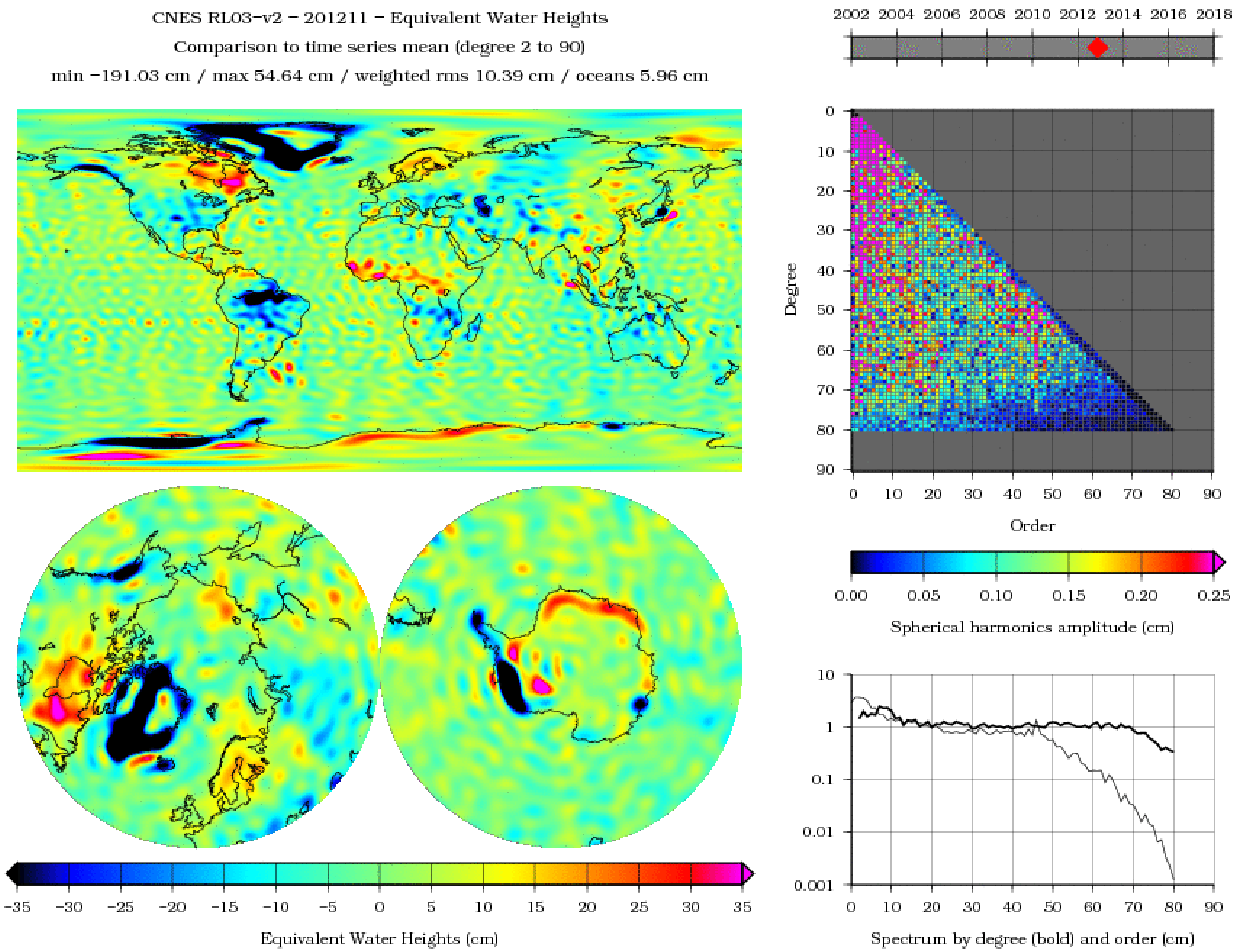


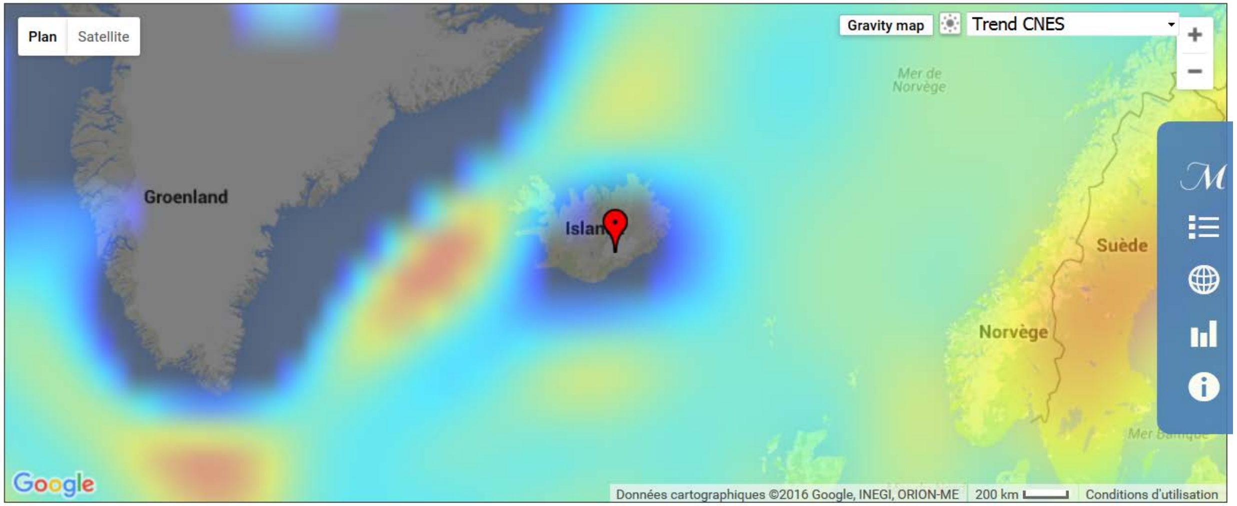
JPL solution



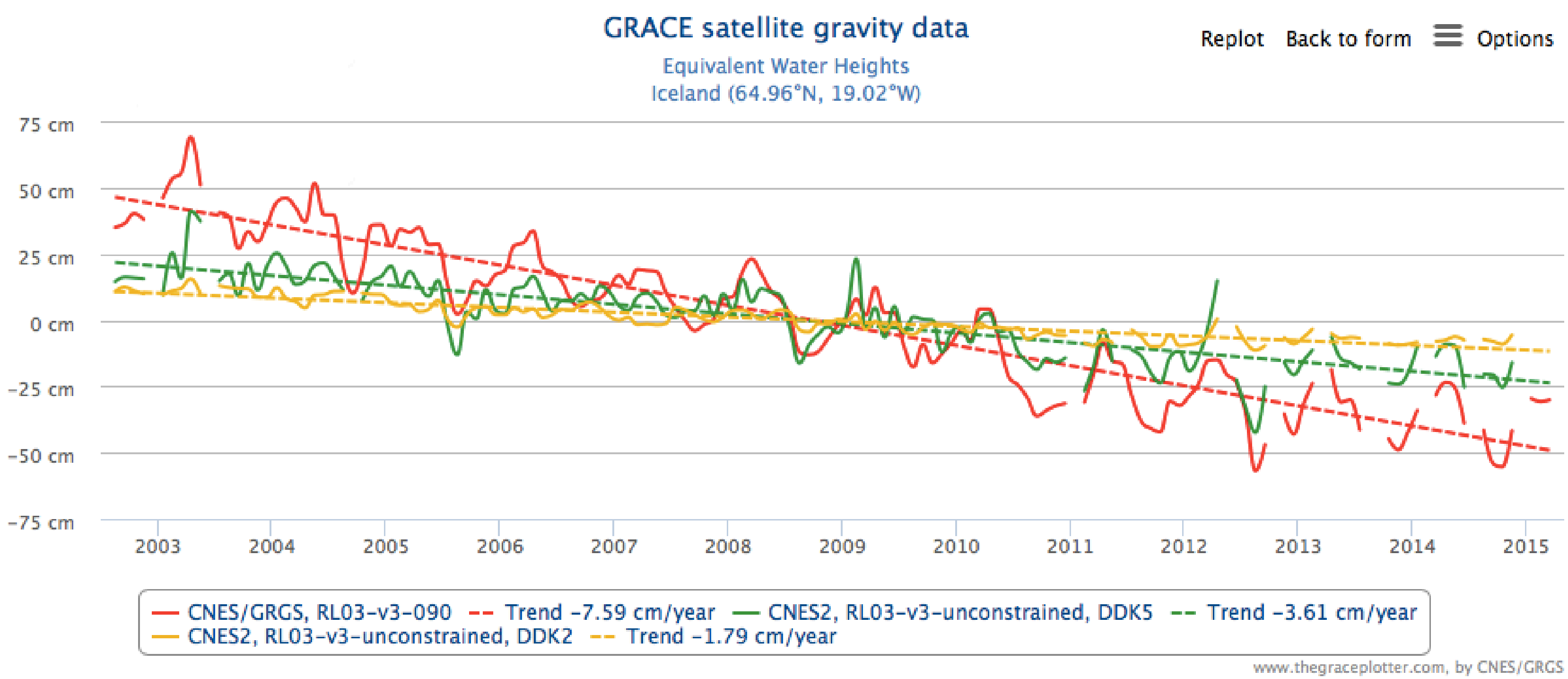
RL03-v1


CNES RL03−v1 − 201211 − Equivalent Water Heights
Comparison to time series mean (degree 2 to 90)
min −182.98 cm / max 75.68 cm / weighted rms 10.53 cm / oceans 5.95 cm
2002 2004 2006 2008 2010 2012 2014 2016 2018
Degree
0 10 20 30 40 50 60 70 80 90
Order
0 10 20 30 40 50 60 70 80 90
0.00 0.05 0.10 0.15 0.20 0.25
Spherical harmonics amplitude (cm)
10 1 0.1 0.01 0.001
0 10 20 30 40 50 60 70 80 90
Spectrum by degree (bold) and order (cm)
−35 −30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30 35
Equivalent Water Heights (cm)


CNES RL03−v2 − 201211 − Equivalent Water Heights
Comparison to time series mean (degree 2 to 90)
min −191.03 cm / max 54.64 cm / weighted rms 10.39 cm / oceans 5.96 cm
2002 2004 2006 2008 2010 2012 2014 2016 2018
Degree
Order
0 10 20 30 40 50 60 70 80 90
0.00 0.05 0.10 0.15 0.20 0.25
Spherical harmonics amplitude (cm)
10 1 0.1 0.01 0.001
Spectrum by degree (bold) and order (cm)
−35 −30 −25 −20 −15 −10 −5 0 5 10 15 20 25 30 35
Equivalent Water Heights (cm)

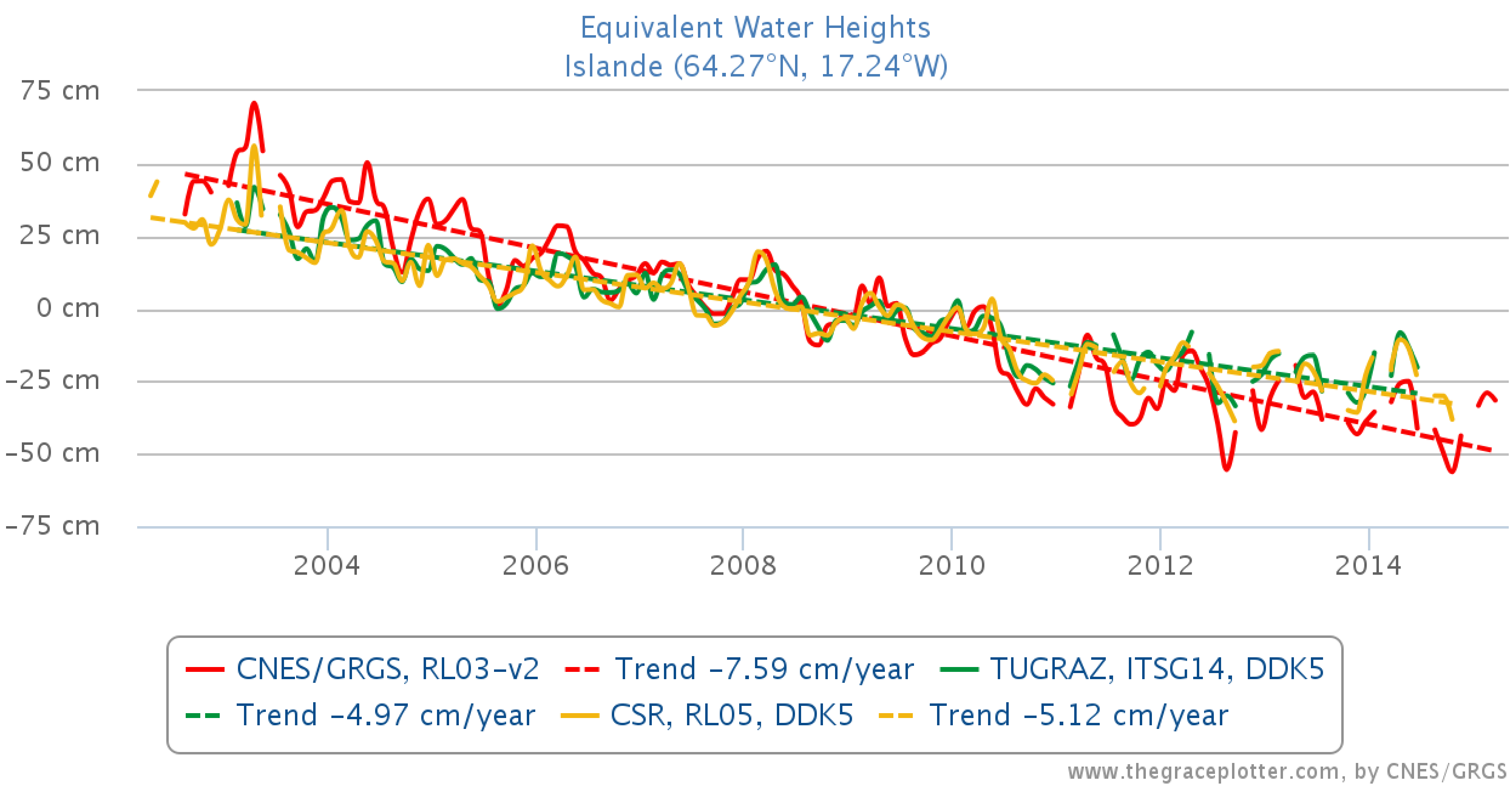


Plan
Satellite
Gravity map
Trend CNES
Mer de Norvège
Groenland
Islan
Suède
Norvège
Google
Données cartographiques ©2016 Google, INEGI, ORION-ME
200 km
Conditions d'utilisation

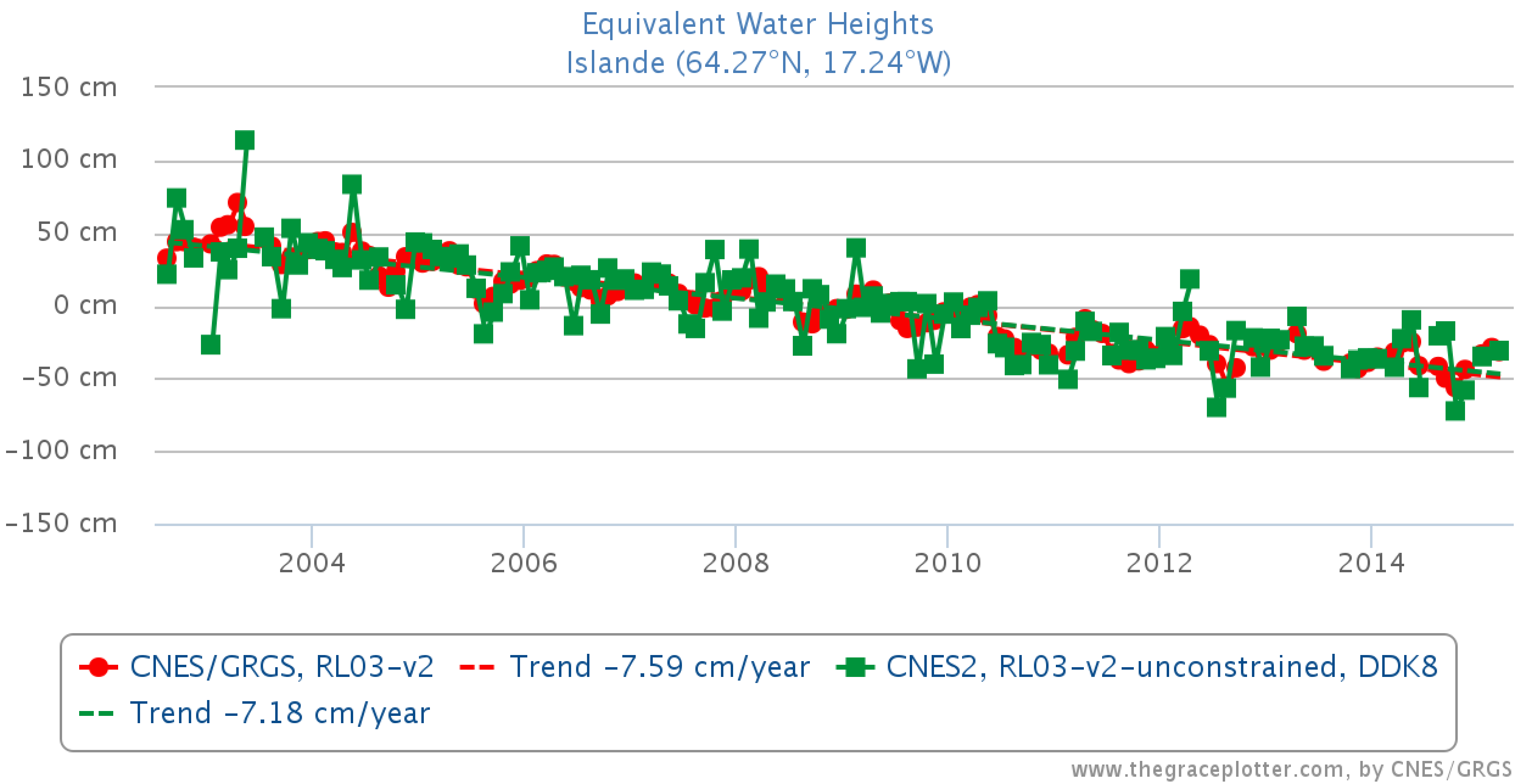


GRACE satellite gravity data
Equivalent Water Heights
Iceland (64.96°N, 19.02°W)
Replot
Back to form
Options
75 cm
50 cm
25 cm
0 cm
-25 cm
-50 cm
-75 cm
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
CNES/GRGS, RL03-v3-090
Trend -7.59 cm/year
CNES2, RL03-v3-unconstrained, DDK5
Trend -3.61 cm/year
CNES2, RL03-v3-unconstrained, DDK2
Trend -1.79 cm/year
www.thegraceplotter.com, by CNES/GRGS

GRACE satellite gravity data



GRACE satellite gravity data



CONCLUSION

The choice of the inversion method for producing the combined solution is VERY VERY important

EGSIEM
European Gravity Service for Improved Emergency Management

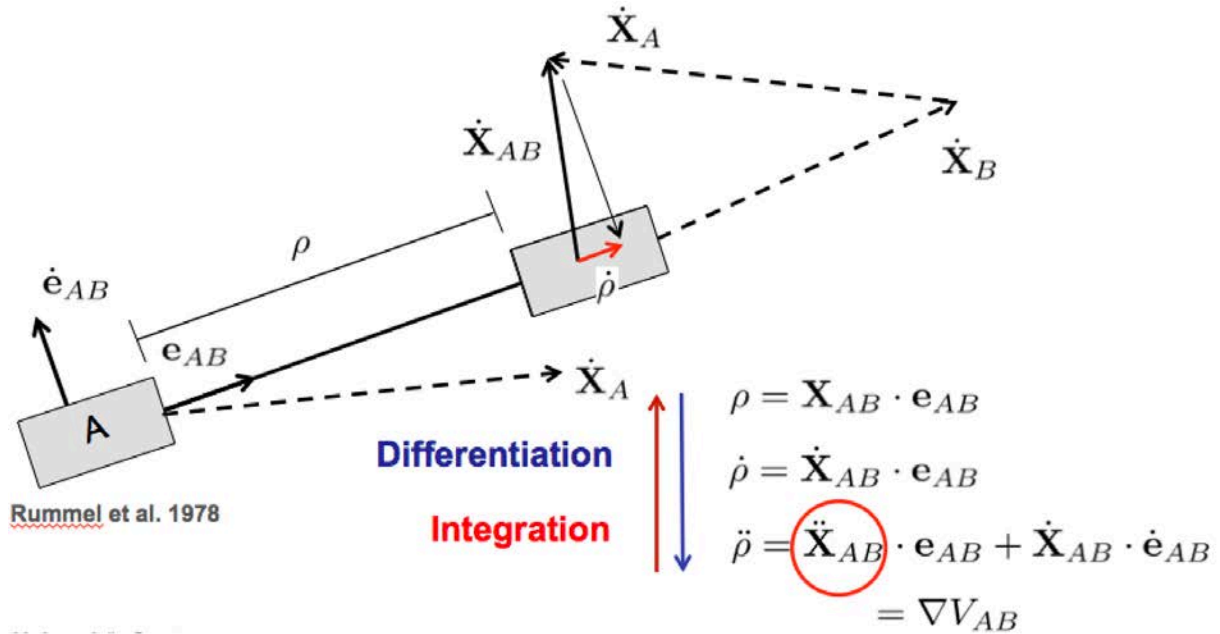
Implementation of the rigorous acceleration approach

Ulux progress on WP2

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

– **Concept:** link kinematic observations to forces based on Newton‘s equation of motion



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

$10\,{}^{\mathrm{nm}}/_{\mathrm{s}^2}$ $\quad 1\,\mu\mathrm{m}$ $\quad 0.1\,{}^{\mathrm{mm}}/_{\mathrm{s}}$ $\quad 0.1\,{}^{\mu\mathrm{m}}/_{\mathrm{s}}$

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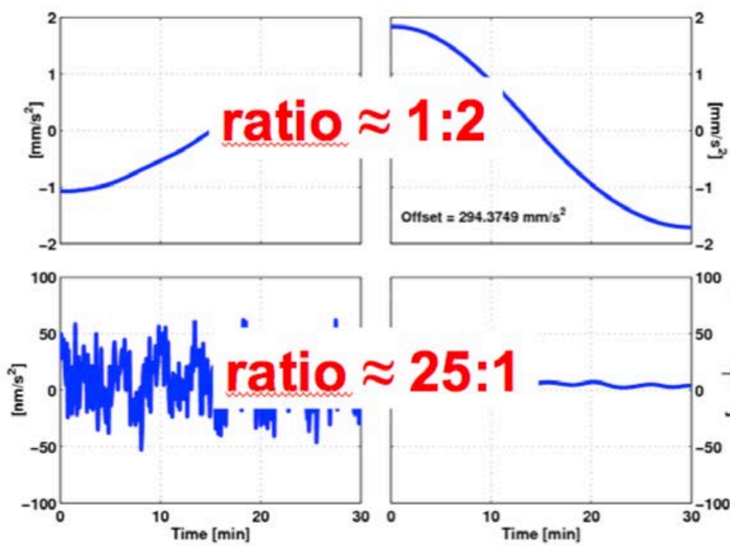
The acceleration approach-an alternative way of processing GRACE data

– Advantage
  - No accumulation of numerical integration errors or model errors
  - Allows for a point-wise application (especially suitable for regional and local applications)
– Downside
  - requires range acceleration and centrifugal component (GPS observations)

Approximate solution

– Reducing the observations to residual quantities

$\ddot{\rho}$



$$-\frac{1}{\rho}\left(\dot{\mathbf{X}}_{AB}\cdot\dot{\mathbf{X}}_{AB}-\dot{\rho}^2\right)$$

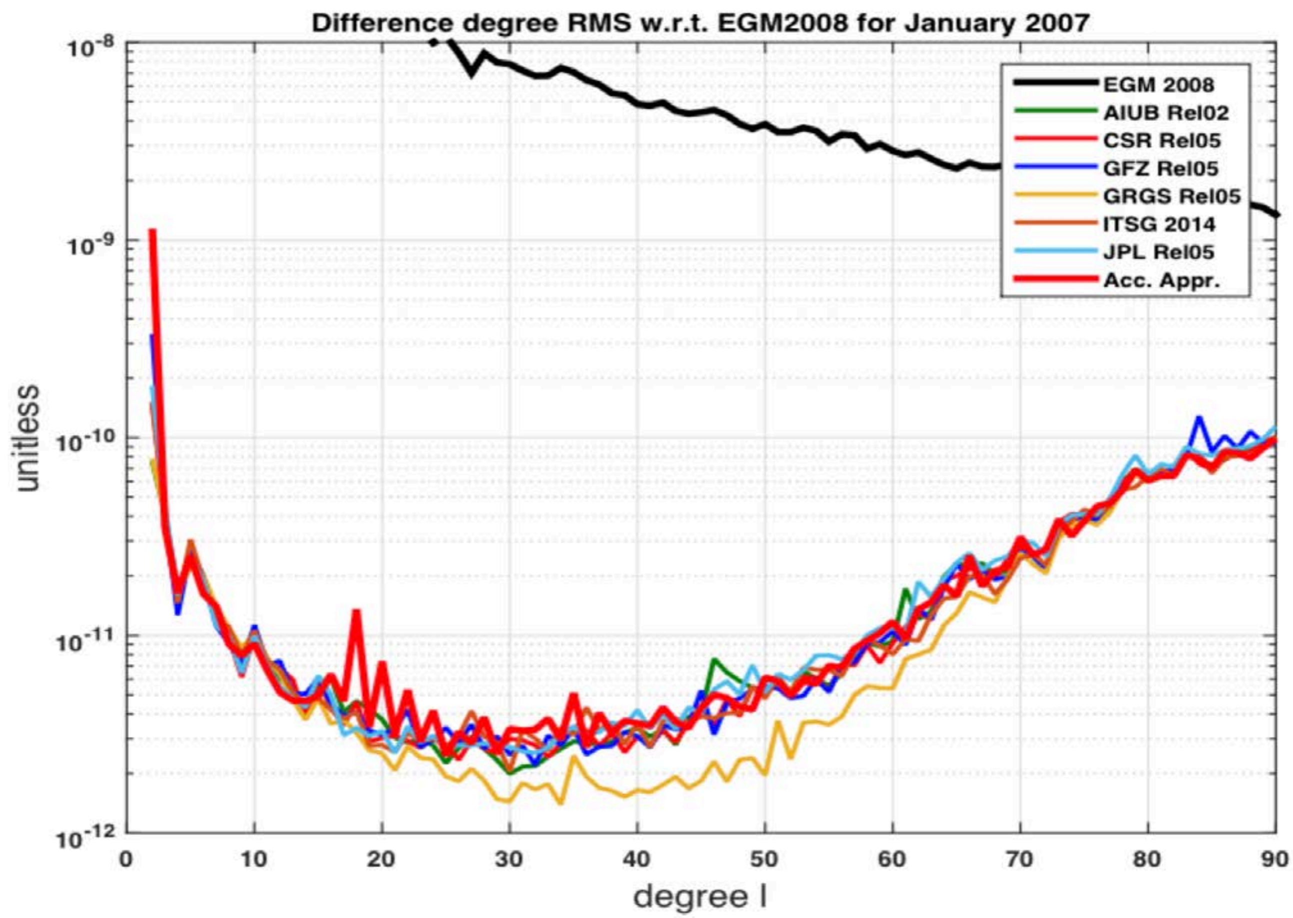
$\ddot{\rho}-\ddot{\rho}_0$

$$-\frac{1}{\rho}\left(\dot{\mathbf{X}}_{AB}\cdot\dot{\mathbf{X}}_{AB}-\dot{\rho}^2\right)+\frac{1}{\rho_0}\left(\dot{\mathbf{X}}_{AB,0}\cdot\dot{\mathbf{X}}_{AB,0}-\dot{\rho_0}^2\right)$$

– Neglecting the residual terms

$$\ddot{\rho}-\ddot{\rho}^0\approx\left(\nabla V_B-\nabla V_A\right)\cdot\mathbf{e}^{\mathrm{a}}_{\mathrm{AB}}-\left(\nabla V^0_B-\nabla V^0_A\right)\cdot\mathbf{e}^{\mathrm{a},0}_{\mathrm{AB}}$$

Approximate solution



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Rigorous solution

- Assumption degrades the solution
- Error at degree 2 and around degree 16 (number of revolutions per day for GRACE)
- Improvement: Rigorous approach

$$
\begin{aligned}
\ddot{\rho} &= \ddot{\mathbf{x}}_{\mathrm{AB}} \cdot \mathbf{e}^{\mathrm{a}}_{\mathrm{AB}} + \frac{1}{\rho}\dot{\mathbf{x}}_{\mathrm{AB}} \cdot \dot{\mathbf{x}}_{\mathrm{AB}} - \frac{\dot{\rho}^2}{\rho} \\
&= (\nabla V_B - \nabla V_A) \cdot \mathbf{e}^{\mathrm{a}}_{\mathrm{AB}} + \frac{1}{\rho}\dot{\mathbf{x}}_{\mathrm{AB}} \cdot \dot{\mathbf{x}}_{\mathrm{AB}} - \frac{\dot{\rho}^2}{\rho} \\
&= f + g_1 + g_2
\end{aligned}
$$

Rigorous solution

– Introduce a priori observation and reduce the equation system to residual quantities (fit an “Observed“ orbit and approximate a dynamic orbit)

$$\ddot{\rho} - \ddot{\rho}^0 = (\nabla V_B - \nabla V_A)\cdot \mathbf{e}^{\mathrm{a}}_{\mathrm{AB}} + \frac{1}{\rho}\left(\dot{\mathbf{x}}_{\mathrm{AB}}\cdot\dot{\mathbf{x}}_{\mathrm{AB}} - \dot{\rho}^2\right)$$
$$- \left(\nabla V_B^0 - \nabla V_A^0\right)\cdot \mathbf{e}^{\mathrm{a},0}_{\mathrm{AB}} - \frac{1}{\rho^0}\left(\dot{\mathbf{x}}^0_{\mathrm{AB}}\cdot\dot{\mathbf{x}}^0_{\mathrm{AB}} - \left(\dot{\rho}^0\right)^2\right)$$

– Linearize the right-hand side of the above equation

$$\ddot{\rho} - \ddot{\rho}^0 \approx \sum_i \frac{\partial f}{\partial p_i}\Delta p_i + \sum_i \frac{\partial g_1}{\partial p_i}\Delta p_i + \sum_i \frac{\partial g_2}{\partial p_i}\Delta p_i$$

$$(\nabla V_B - \nabla V_A)\cdot \mathbf{e}^{\mathrm{a}}_{\mathrm{AB}} - \left(\nabla V_B^0 - \nabla V_A^0\right)\cdot \mathbf{e}^{\mathrm{a},0}_{\mathrm{AB}} = \sum_i \frac{\partial f}{\partial p_i}\Delta p_i + \hbar^2$$
$$\frac{1}{\rho}\dot{\mathbf{x}}_{\mathrm{AB}}\cdot\dot{\mathbf{x}}_{\mathrm{AB}} - \frac{1}{\rho^0}\dot{\mathbf{x}}^0_{\mathrm{AB}}\cdot\dot{\mathbf{x}}^0_{\mathrm{AB}} = \sum_i \frac{\partial g_1}{\partial p_i}\Delta p_i + \hbar^2$$
$$-\frac{\dot{\rho}^2}{\rho} + \frac{\left(\dot{\rho}^0\right)^2}{\rho^0} = \sum_i \frac{\partial g_2}{\partial p_i}\Delta p_i + \hbar^2,$$

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Rigorous solution

- Solve the variational equations using the variation of constant approach (Jäggi, 2007)
  - Variational equation for the initial conditions (homogeneous solution)

$$\frac{d}{dt}\begin{pmatrix} \Phi \\ \dot{\Phi} \end{pmatrix} = \begin{pmatrix} \dot{\Phi} \\ F(\mathbf{x}, \dot{\mathbf{x}}) \cdot \Phi \end{pmatrix}$$

  - Variation of constants (inhomogeous solution)

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

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

- Connect the above derivatives to the linearized mathematical model by applying the chain rule

Rigorous solution

- Belongs to another implimentation of the variational equations
- Theoretically give identical results as the other approaches implemented within the EGSIEM project
- Practically different processing schemes come with their particular advantages and disadvantages. By combining the different solutions would be able to benefit from the advantages and to mitigate the disadvantages.

Current implementation status at UL

- **Already finished:**
  - **Data screening for Grace A and B using GNV1B data**
  - **Testing the covariance information of Grace A and B for positive definiteness**
  - **Correcting the non-linear behavior in the accelerometer data**
  - **synchronization of the GRACE A and B**
  - **Orbit adjustment for Grace A and B (done, but may have problems…)**
- **Under going:**
  - **Combined adjustment of Grace A, B and K-Band data (Stucked)**

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Problems to be solved

- **Orbit adjustment:**
  - **Different iterations on different computers (result in different input orbit for later combined adjustment):**
    - **Desktop (matlab R2015b), stopped at the 3rd iteration**
    - **Mac (matlab R2014b), stopped at the 5th iteration**
    - **Different initial conditions reaching 1cm**
- **Combined adjustment:**
  - **Different N matrix for range bias (3), acc scale (3) and bias (3), I think both are wrong, since there are negative diagal values**
    - **Desktop, acc scale negative**
    - **Mac, acc bias negative**
  - **Different b (observed range-xAB)**

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Problems to be solved

13.7910	-13.8353	0.1207	1.7464	1.3008e...	-0.0036	2.5945e...	0.0332	-1.3877e...
-13.8368	31.0844	-17.2634	0.1868	-1.2647e...	5.1209e-...	7.2726e...	-0.0125	1.7153e...
0.1535	-17.2606	17.0356	-0.0962	-1.9881e...	0.0042	8.1848e...	6.2128e-...	7.7294e...
1.5583	0.1901	-0.0559	9.8670	2.9159e...	-0.0885	-1.2257e...	0.1573	-1.4768e...
7.7435e...	-1.2291e...	-3.3769e...	2.9861e...	-1.0137e...	2.0991e...	9.5364e...	2.6439e...	5.2431e...
-0.0016	3.7908e-...	0.0069	-0.0811	2.0238e...	3.0603e...	-2.0963e...	-7.0171e...	-9.1545e...
-7.0405e...	-1.5969e...	-5.7634e...	2.0623e...	-3.4731e...	8.0361e...	3.0603e...	2.1586e...	1.6700e...
0.0483	-0.0117	0.0066	0.2000	7.9280e...	-0.0023	-9.2404e...	3.0603e...	-3.9403e...
2.3891e...	2.9537e...	2.4107e...	1.0134e...	4.7995e...	-1.2651e...	-6.7151e...	1.4826e...	3.0603e...

					6	7	8	9
14.2034	-13.8100	0.3611	1.6289	1.6609e+05	-0.0398	-4.7538e+05	0.0441	-7.5025e+07
-13.8004	31.0866	-17.2423	0.1813	795.2148	-0.0027	-5.7141e+04	-0.0114	-4.7882e+06
0.4269	-17.2438	17.1961	-0.1428	8.1739e+04	-0.0201	-4.0645e+05	0.0082	-4.1503e+07
-0.7945	0.1786	-0.1666	-3.4022	-1.4276e+05	0.0398	1.6883e+05	-0.0521	7.0000e+07
1.3187e+05	-933.4834	7.4365e+04	-1.2214e+05	4.8220e+10	-1.1095e+04	-2.4011e+11	2.1811e+03	-2.2768e+13
-0.0301	-0.0020	-0.0160	-0.0059	-1.0726e+04	3.0603e+14	4.9976e+04	-8.8021e-04	5.2093e+06
-3.1423e+05	-2.8476e+04	-1.7537e+05	2.3113e+04	-1.1596e+11	2.7780e+04	3.0603e+22	-8.6715e+03	5.6223e+13
0.0076	-0.0124	-1.3789e-04	0.0207	-1.2281e+03	2.6636e-04	9.0431e+03	3.0603e+14	6.1184e+05
-7.4817e+07	-3.8779e+06	-3.6945e+07	-5.9276e+07	-2.5416e+13	6.1884e+06	1.1191e+14	-3.0806e+06	3.0603e+22

EGSIEM

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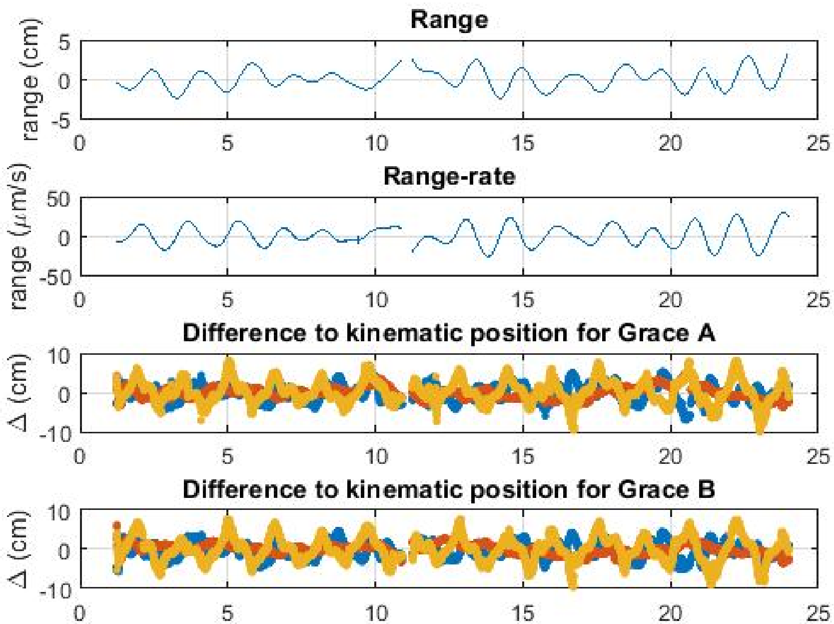
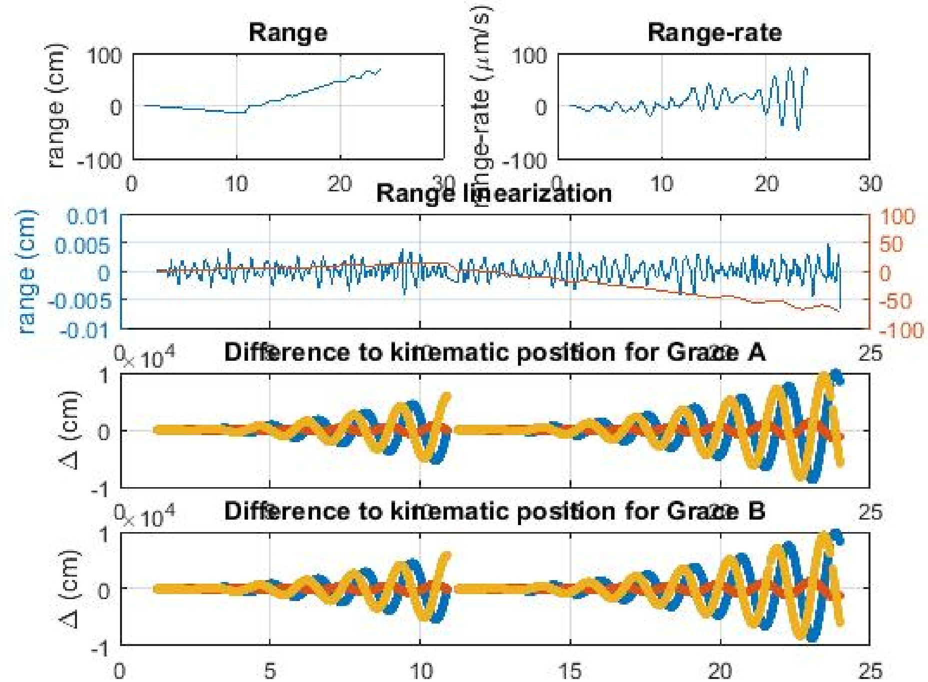
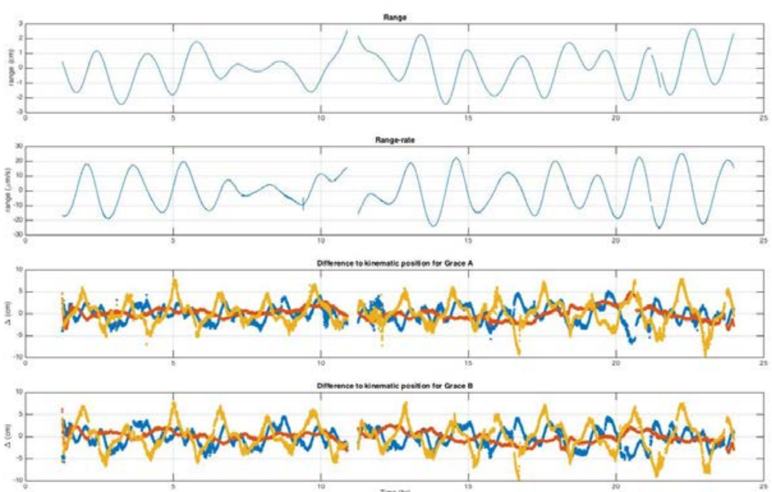
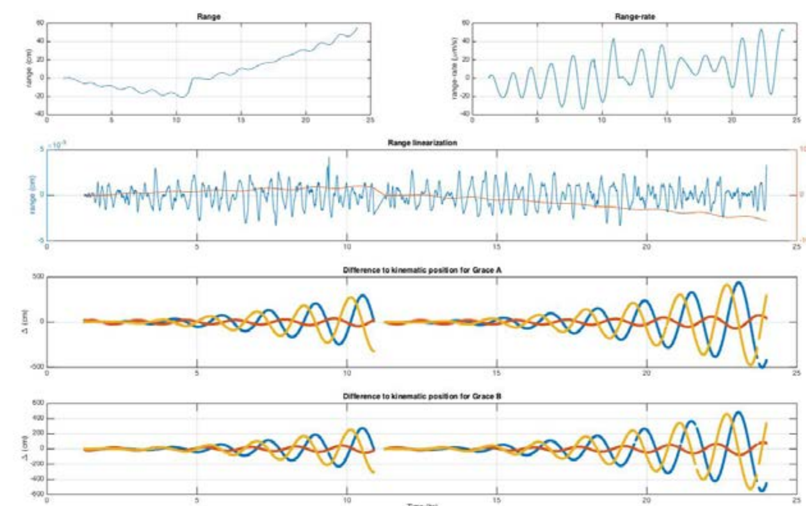
Comparison

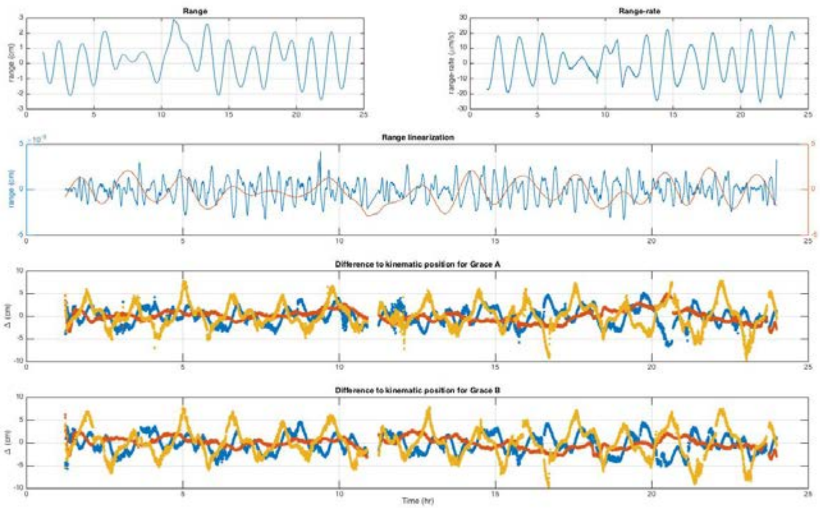

Range
range (cm)
Range-rate
range (μm/s)
Difference to kinematic position for Grace A
Δ (cm)
Difference to kinematic position for Grace B
Δ (cm)

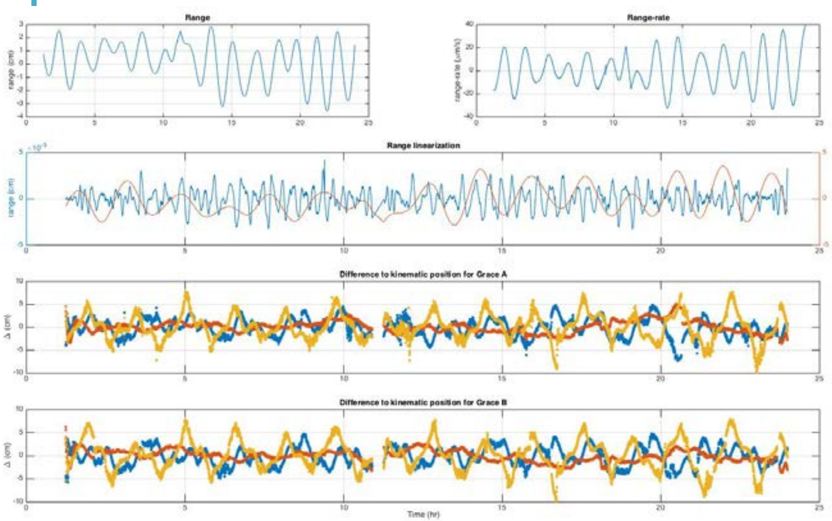

Range
range (cm)
Range-rate
range-rate (μm/s)
Range linearization
range (cm)
Difference to kinematic position for Grace A
Δ (cm)
Difference to kinematic position for Grace B
Δ (cm)

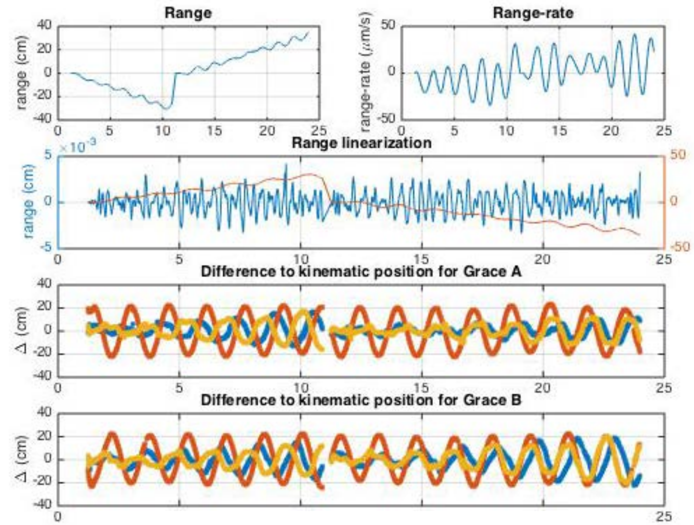

Range
Range-rate
Difference to kinematic position for Grace A
Difference to kinematic position for Grace B
Time (hr)

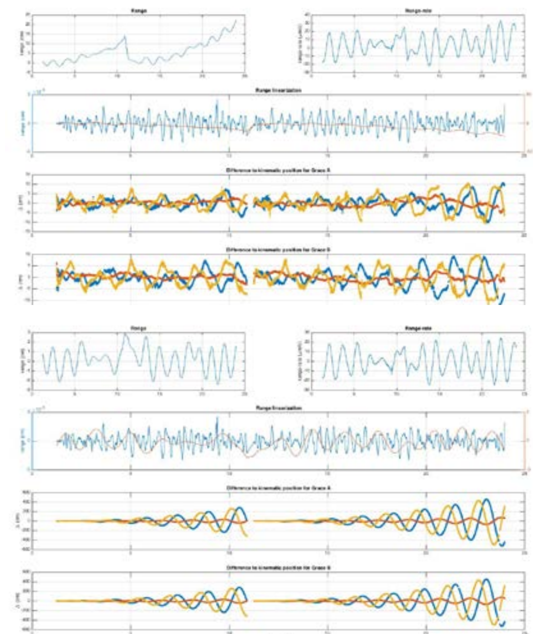

Range
Range-rate
Range linearization
Difference to kinematic position for Grace A
Difference to kinematic position for Grace B
Time (hr)

Comparison









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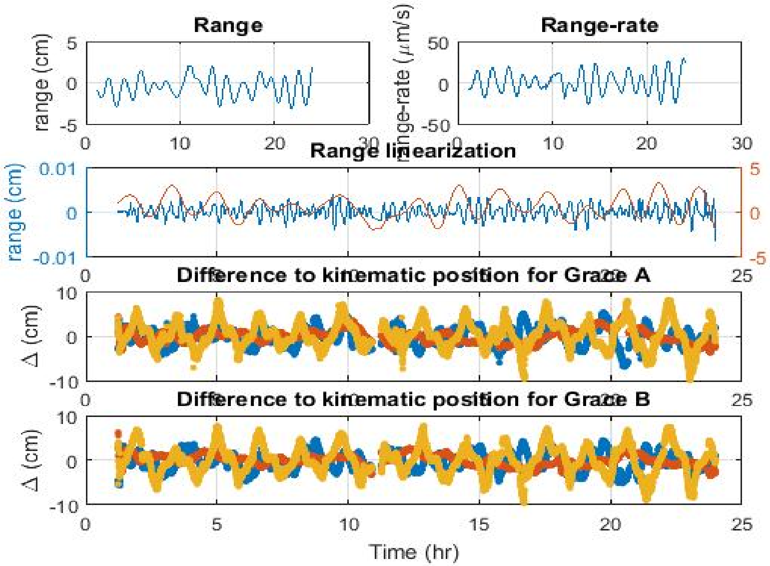
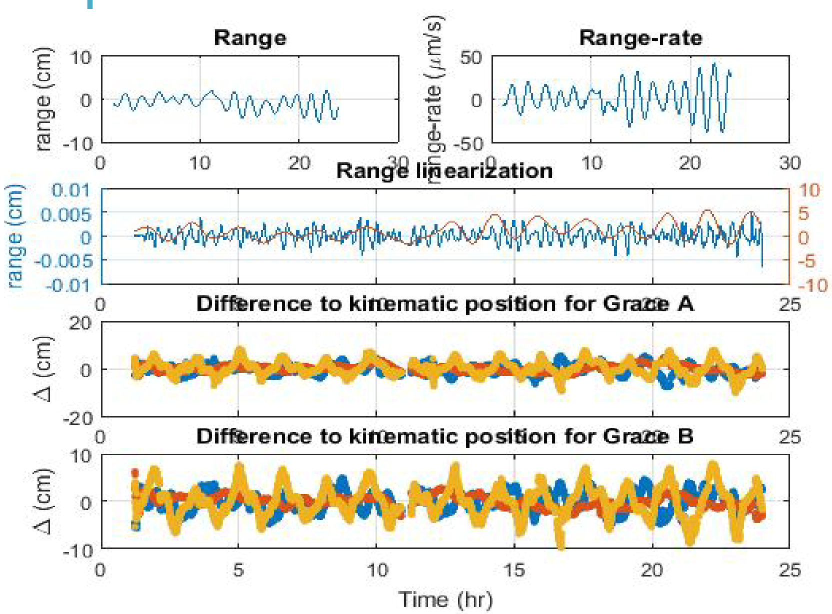
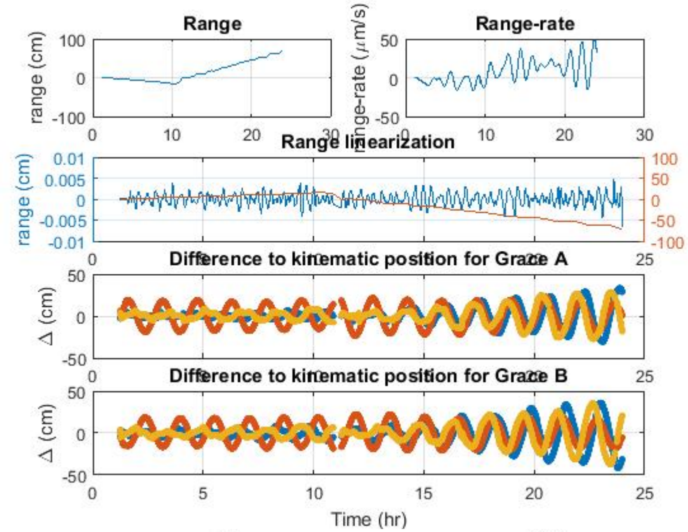
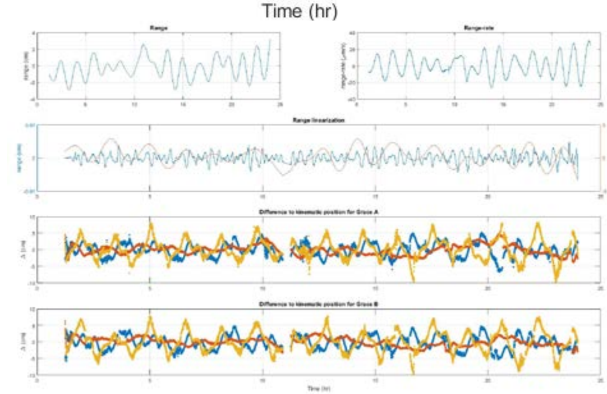
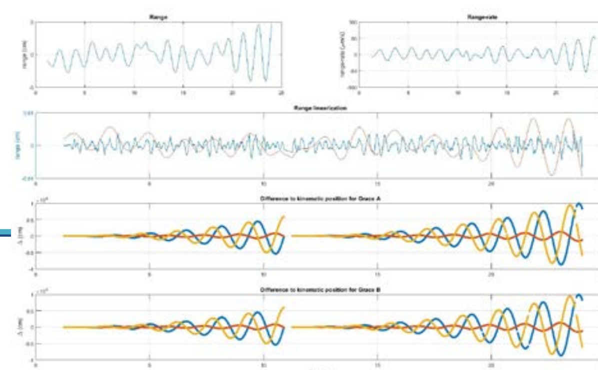
Comparison











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HORIZON 2020

Our strategies

- **Orbit adjustment:**
  - **Common parameter**
    - **Acc scale + bias**
  - **Arc specific parameter**
    - **Empirical linear acc (15min), initial conditions (no constrains)**
- **Combined adjustment:**
  - **Common parameter**
    - **Range bias + Acc scale + bias (9)**
  - **Arc specific parameter**
    - **Empirical linear acc (15min), initial conditions**
- **Constraining values:**
  - **Empirical linear acc: 5e-9**
  - **Acc scale: 1e-4**
  - **Acc bias: 1e-8**
  - **Pos: 1e-1**
  - **Vel: 1e-2**
  - **Scaling factor for y and z components (emp acc,, acc scale and bias) : 1e-16**

EGSIEM

European Gravity Service for Improved Emergency Management

Title: **Test of the preliminary AOD1B RL6**

Presenter: TMG

Affiliation: TUG

EGSIEM Meeting Potsdam,
02.06.2016 - 03.06.2016

Horizon2020

ITSG-Grace2016 processing scheme

3 years of monthly solutions (2006 – 2008)

- Estimation of monthly n=2..60
- Co-estimation of constrained daily n=2..40

ITSG-Grace2016

- AOD1B RL5 (degree 100)
- Ocean tide EOT11a w/o S1
- Atmospheric S1/S2 tide removed from AOD1B

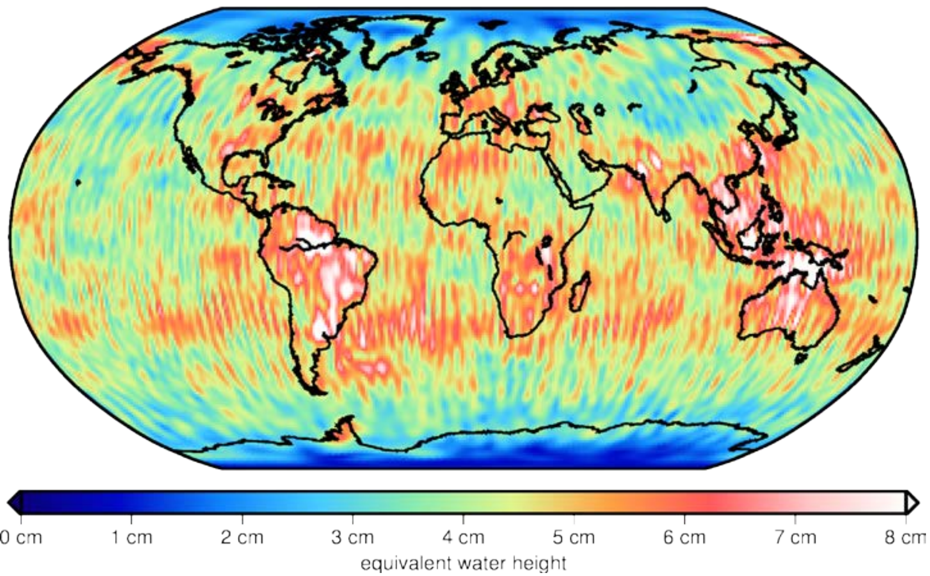
Test version

- AOD1B RL5.9 (degree 180)
- Ocean tide EOT11a with S1
- (not to apply)

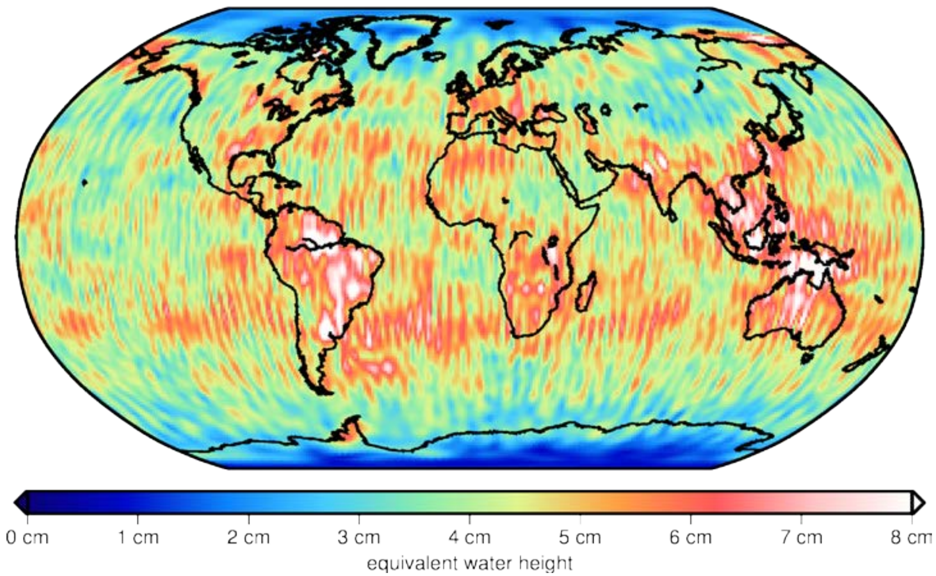
Comparison of monthly solutions

Monthly: Temporal RMS, annual/semiannual/trend reduced, Gaussian 200km

Old: AOD1B RL5



New: AOD1B RL5.9

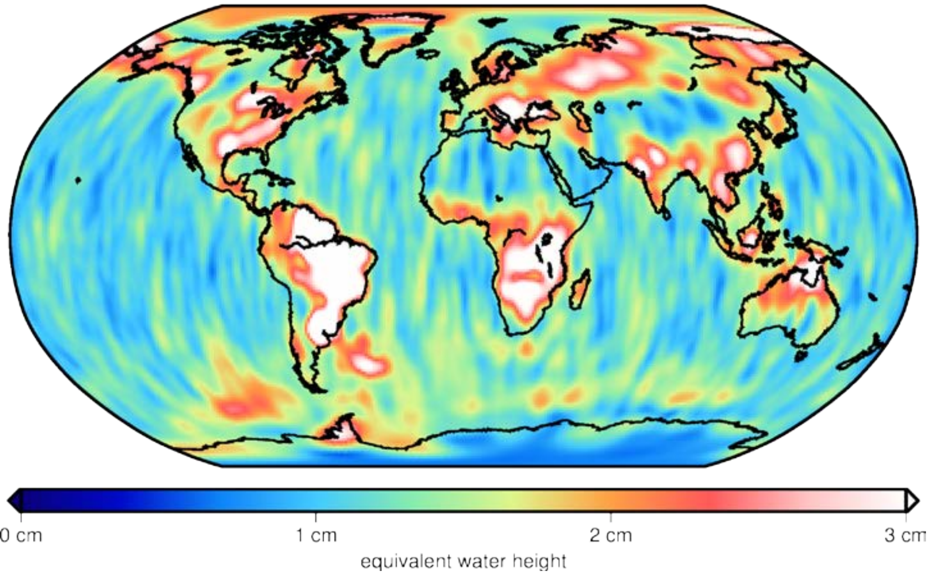


=> No significant difference

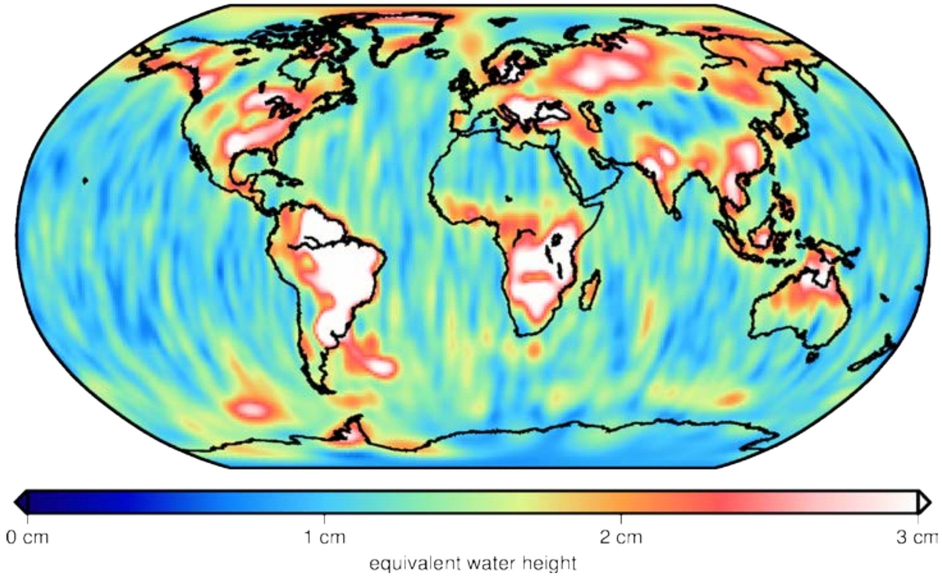
Comparison of monthly solutions

Monthly: Temporal RMS, annual/semiannual/trend reduced, Gaussian 400km

Old: AOD1B RL5



New: AOD1B RL5.9



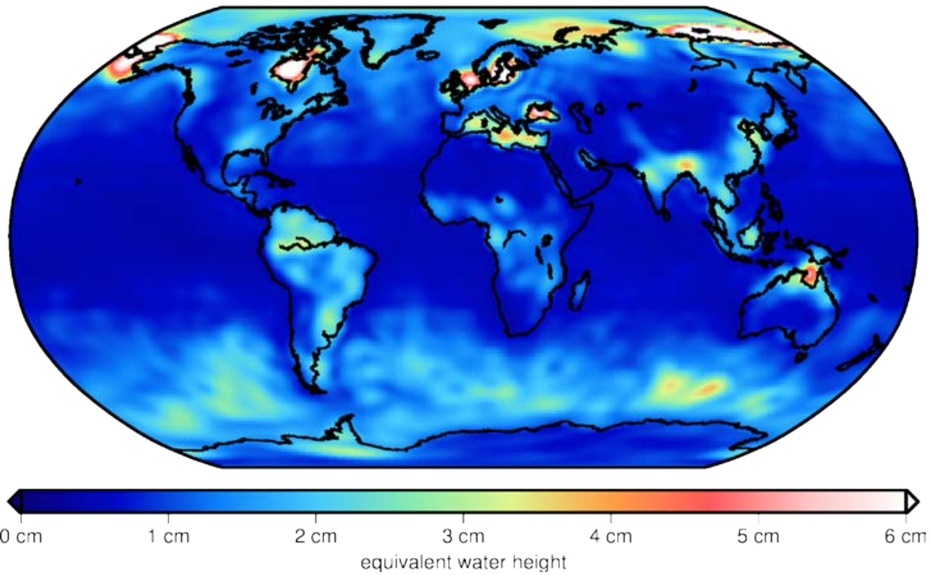
=> No significant difference

Co-estimation of daily gravity fields
(signals between 1 .. 30 days)

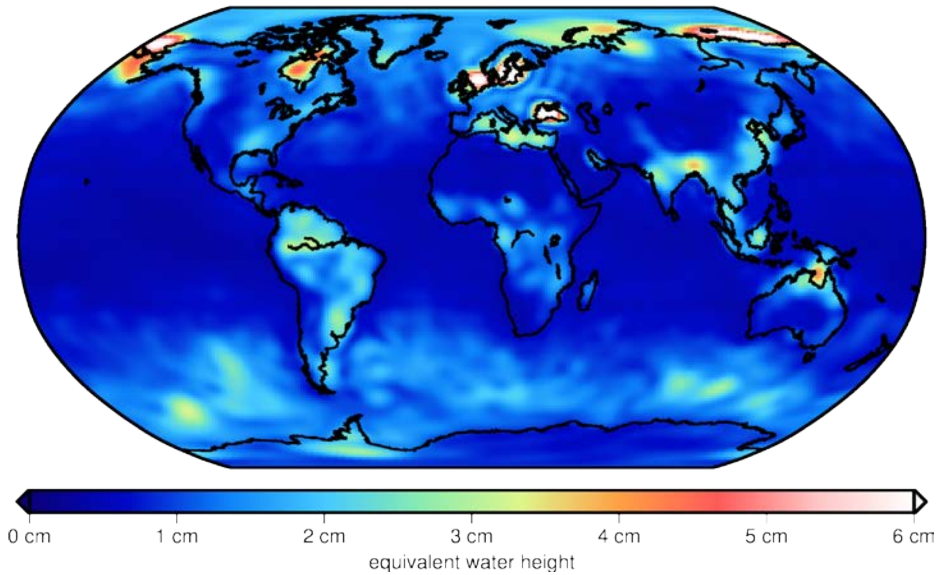
Comparison of daily solutions

Constrained daily: Temporal RMS

Old: AOD1B RL5



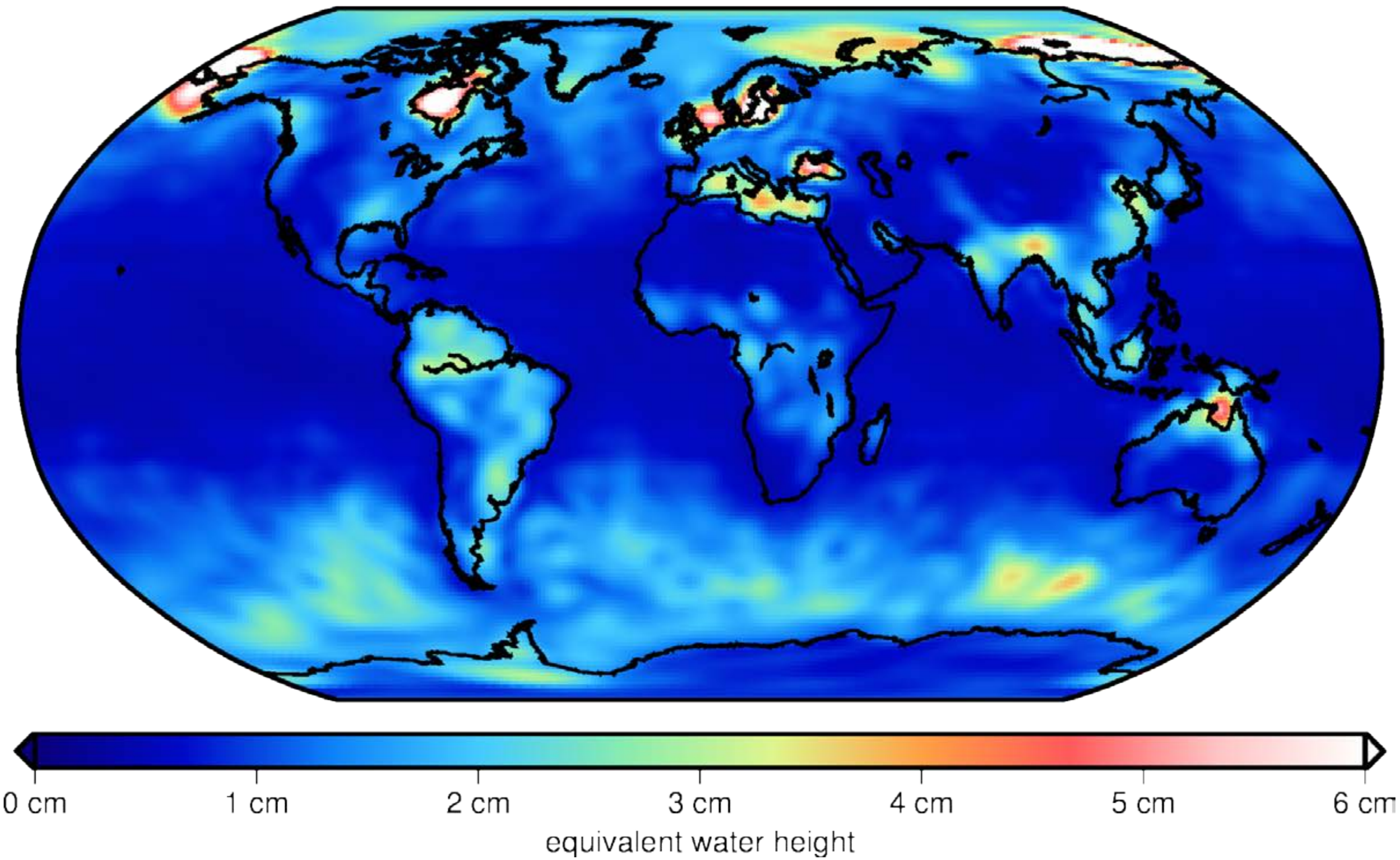
New: AOD1B RL5.9



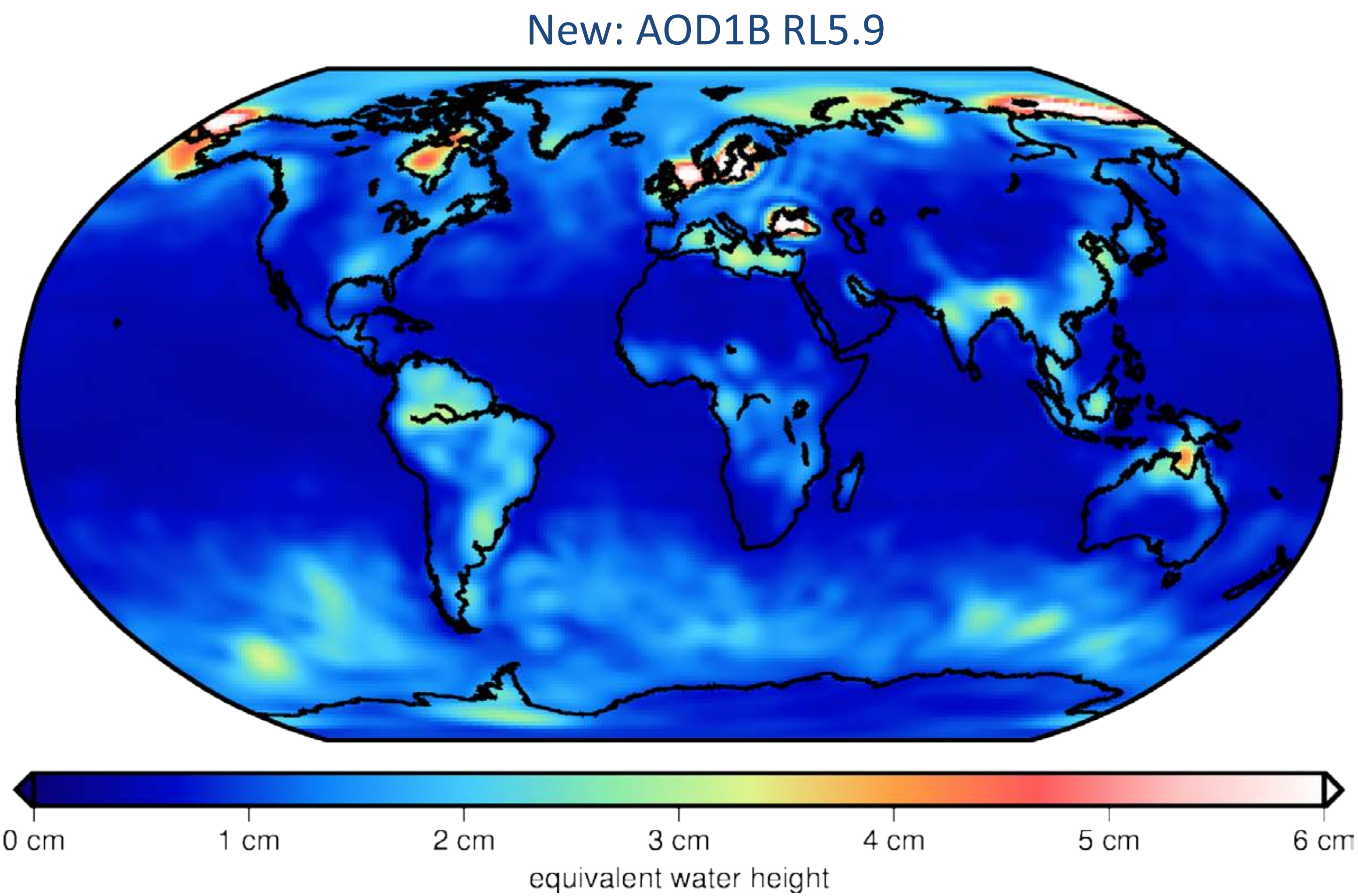
=> Reduced RMS ~10%

Comparison of daily solutions

Old: AOD1B RL5

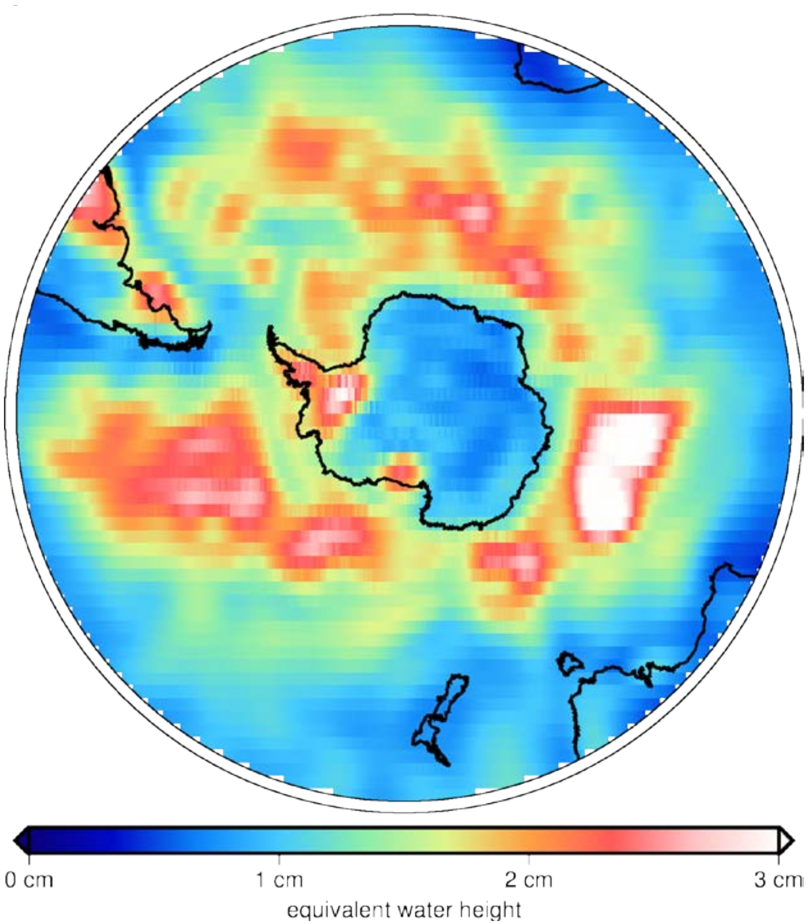


Comparison of daily solutions

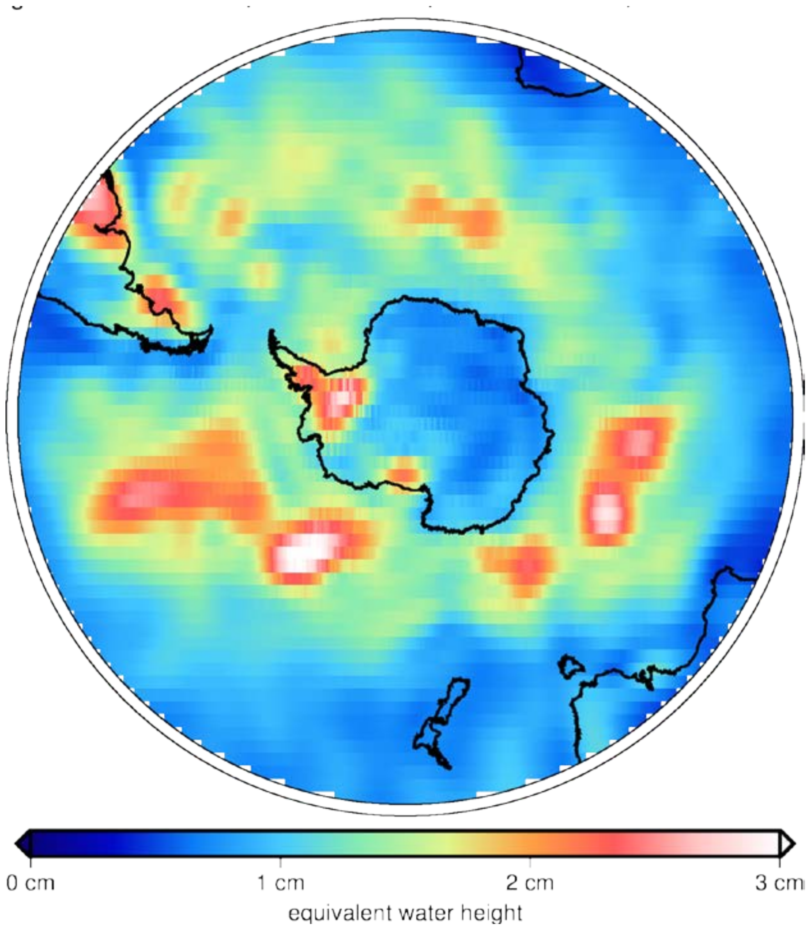


Comparison of daily solutions

Old: AOD1B RL5

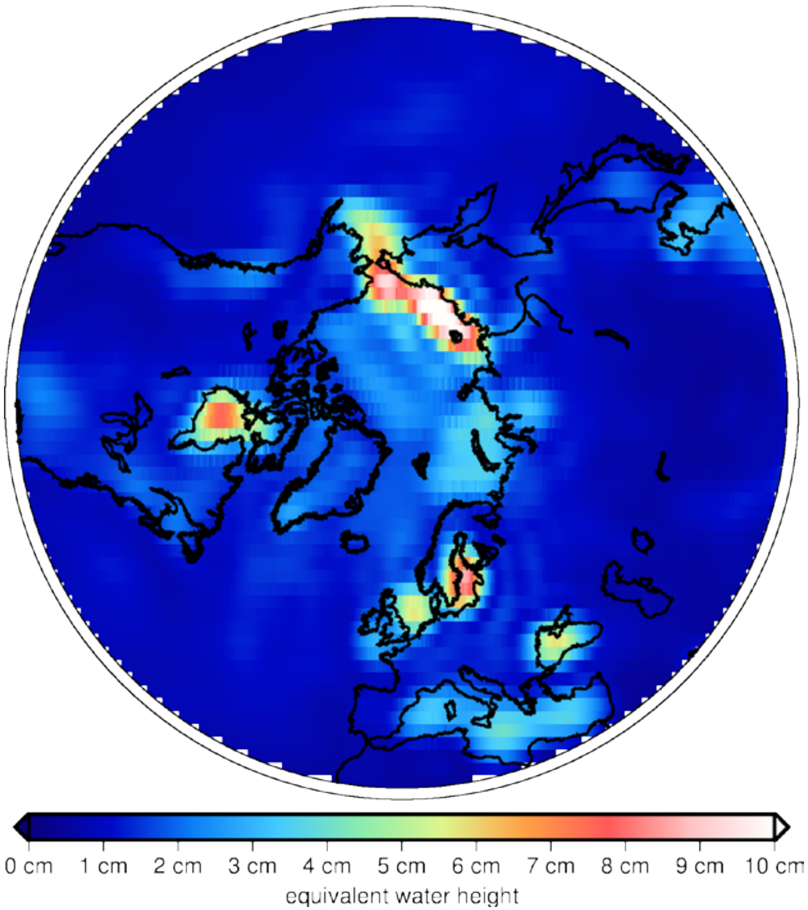


New: AOD1B RL5.9

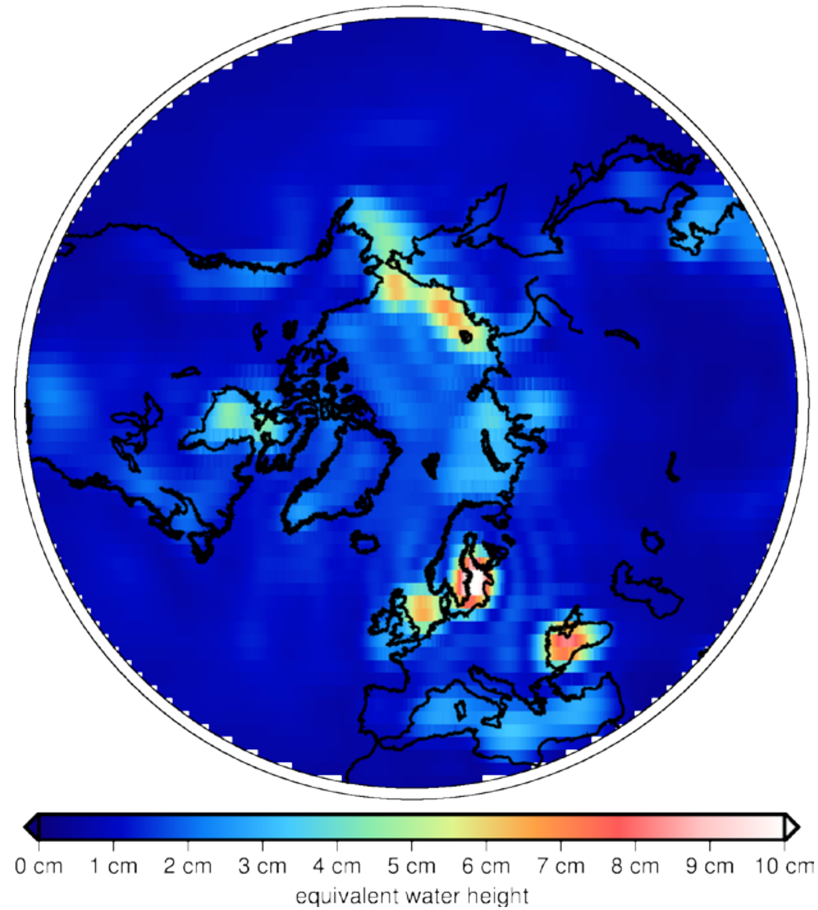


Comparison of daily solutions

Old: AOD1B RL5

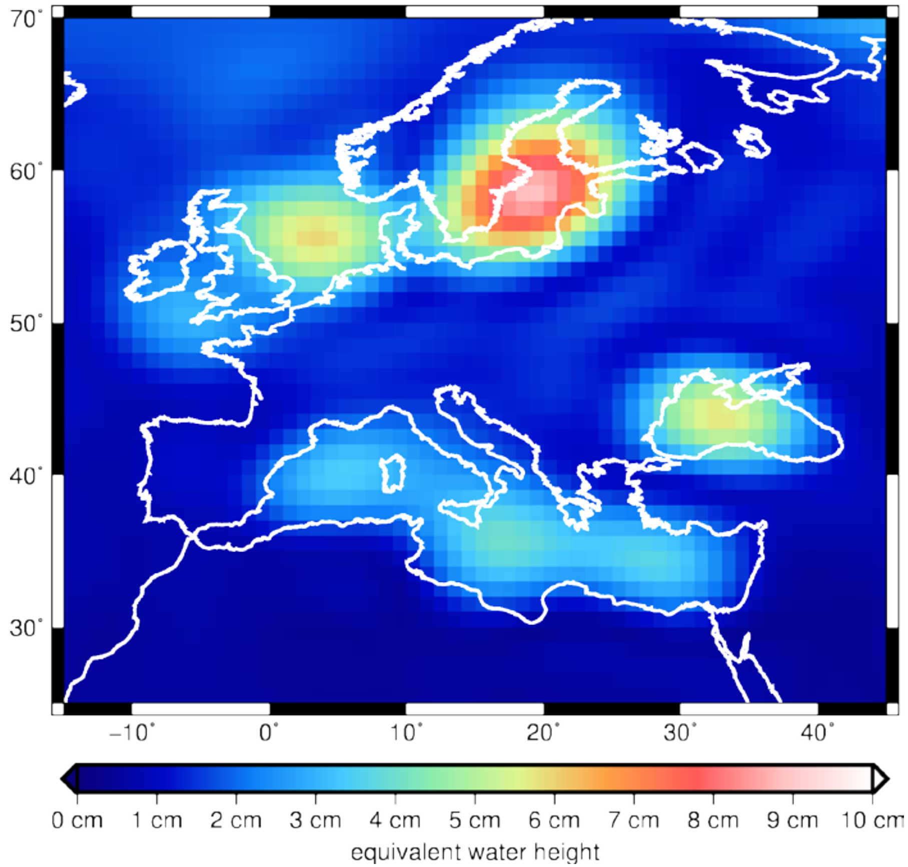


New: AOD1B RL5.9

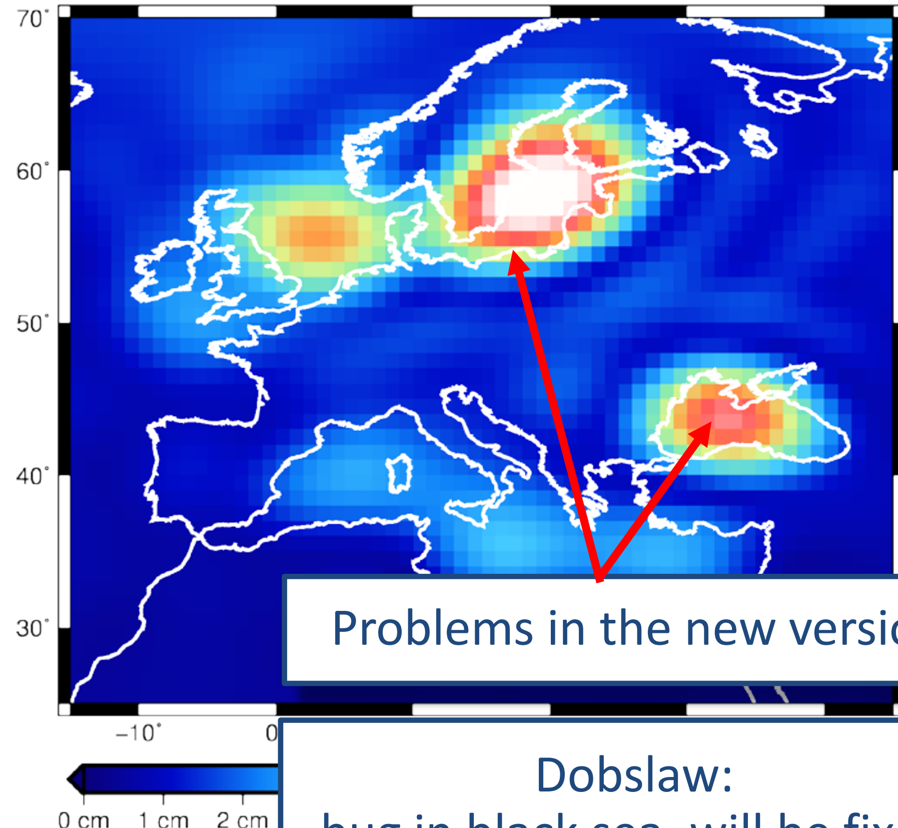


Comparison of daily solutions

Old: AOD1B RL5



New: AOD1B RL5.9



Problems in the new version

Dobslaw:
bug in black sea, will be fixed
in the final release

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European Gravity Service for Improved Emergency Management

WP3 Integration of complementary data

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

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: presented in January and in progress
- T3.6: Validation of GRACE gravity products with Ocean Bottom Pressure GFZ
  - M25-M36: presented in January
- T3.7: Preparation for Hydroweb data CNES
  - M01-M10
- T3.8 GIA for Hydrology LM
  - M11-M36: presented in January
- T3.9: Compilation of representative historical flood situations DLR
  - M01-M10: presented in January

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European Gravity Service for Improved Emergency Management

Validation with GNSS loading

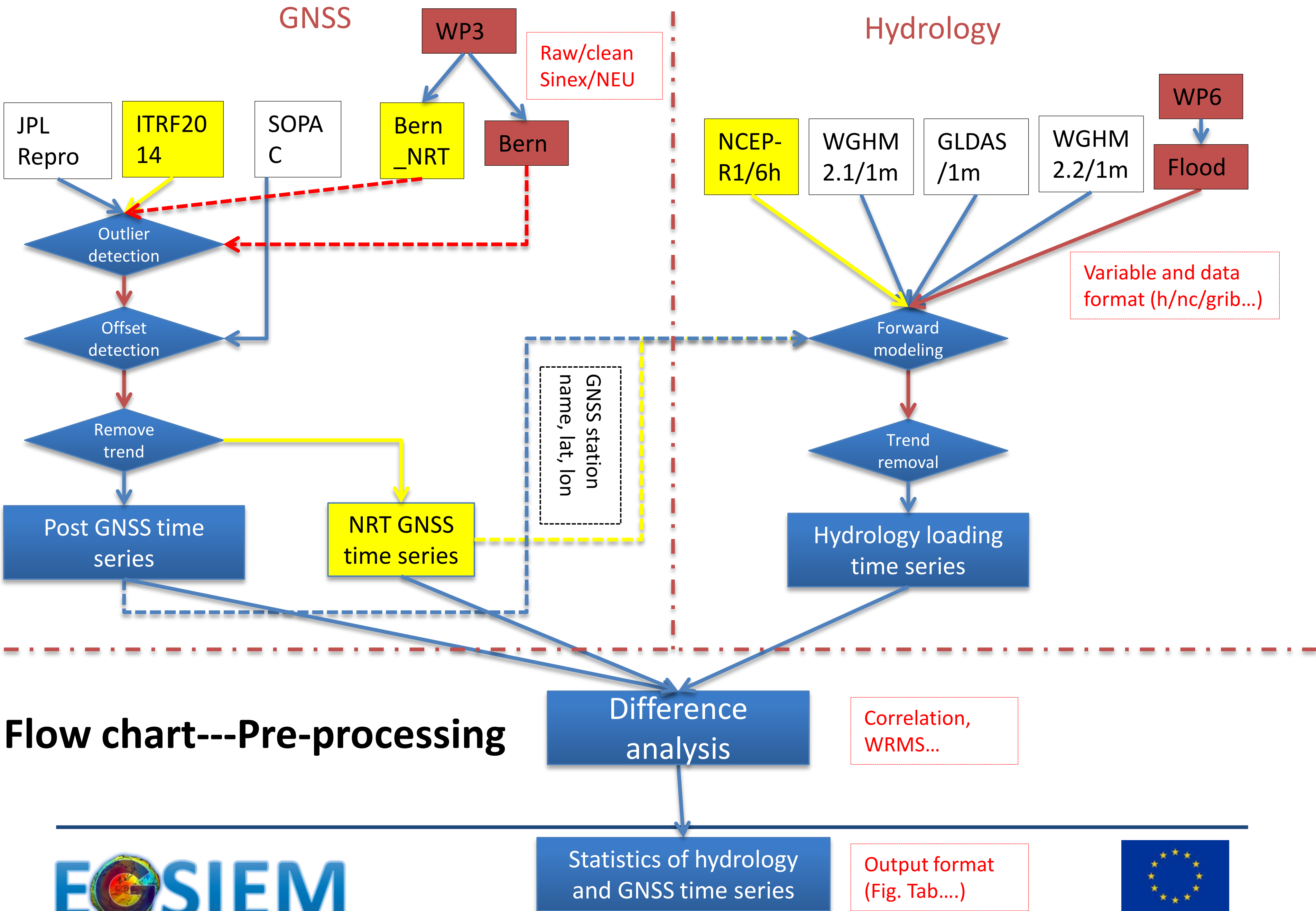
Ulux progress on WP3 T3.5

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

Validation with GNSS loading

- 3-step concept
  - Data pre-processing
  - Data processing
  - Output (Correlation coefficient and WRMS reduction ...)

Flow chart---Pre-processing



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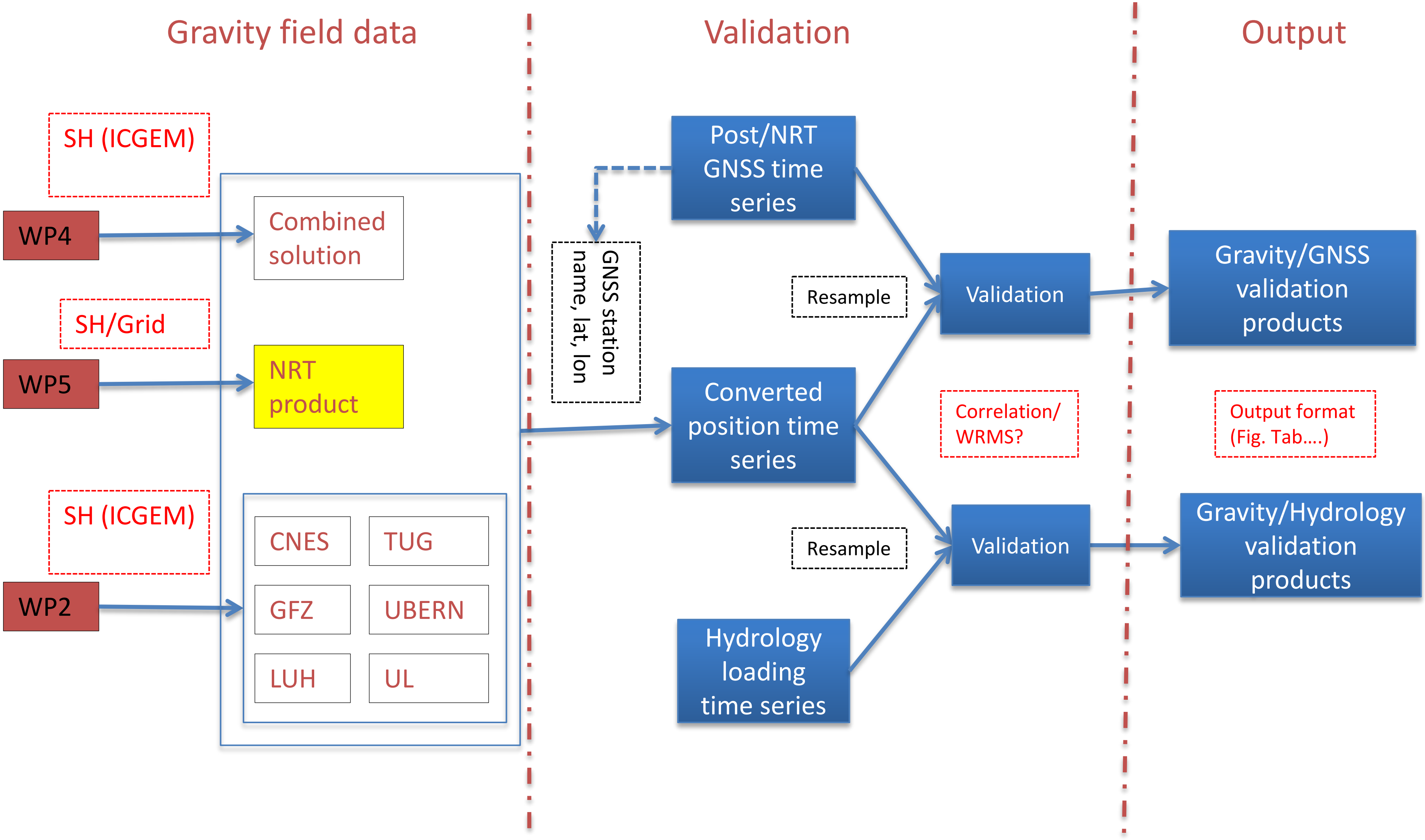
Flow chart---Data-processing and output



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Data

- GNSS data
  - Latest global daily GNSS time series from JPL (1094 stations) and SOPAC (918 stations) (ftp://garner.ucsd.edu/pub/timeseries/measures/ats/Global)
    - Cleaned, detrended, outlier removed
    - Nearly real time
  - Latest ITRF2014 GNSS residuals (IGN), 1054 stations
    - Rigorously stacking the latest IGS repro2 solutions
  - Stations with less than 2-year data abandoned
- Continental Water Storage Models
  - GLDAS, monthly, 3-4m latency
  - WGHM_2.1f6, monthly, 2002-12/2013
  - WGHM_2.2_STANDARD, latest official version, 2002-10/2010, m and d
  - WGHM_2.2_STANDARD_CRU, a modification of 2.2standard, 2002-12/2012,but not calibrated for the climate input
- Gravity model
  - EGSIEM combined solution, 2003-2014
  - GRACE Release 5 from GFZ (RL05a), CSR and JPL (RL05.1)
  - 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

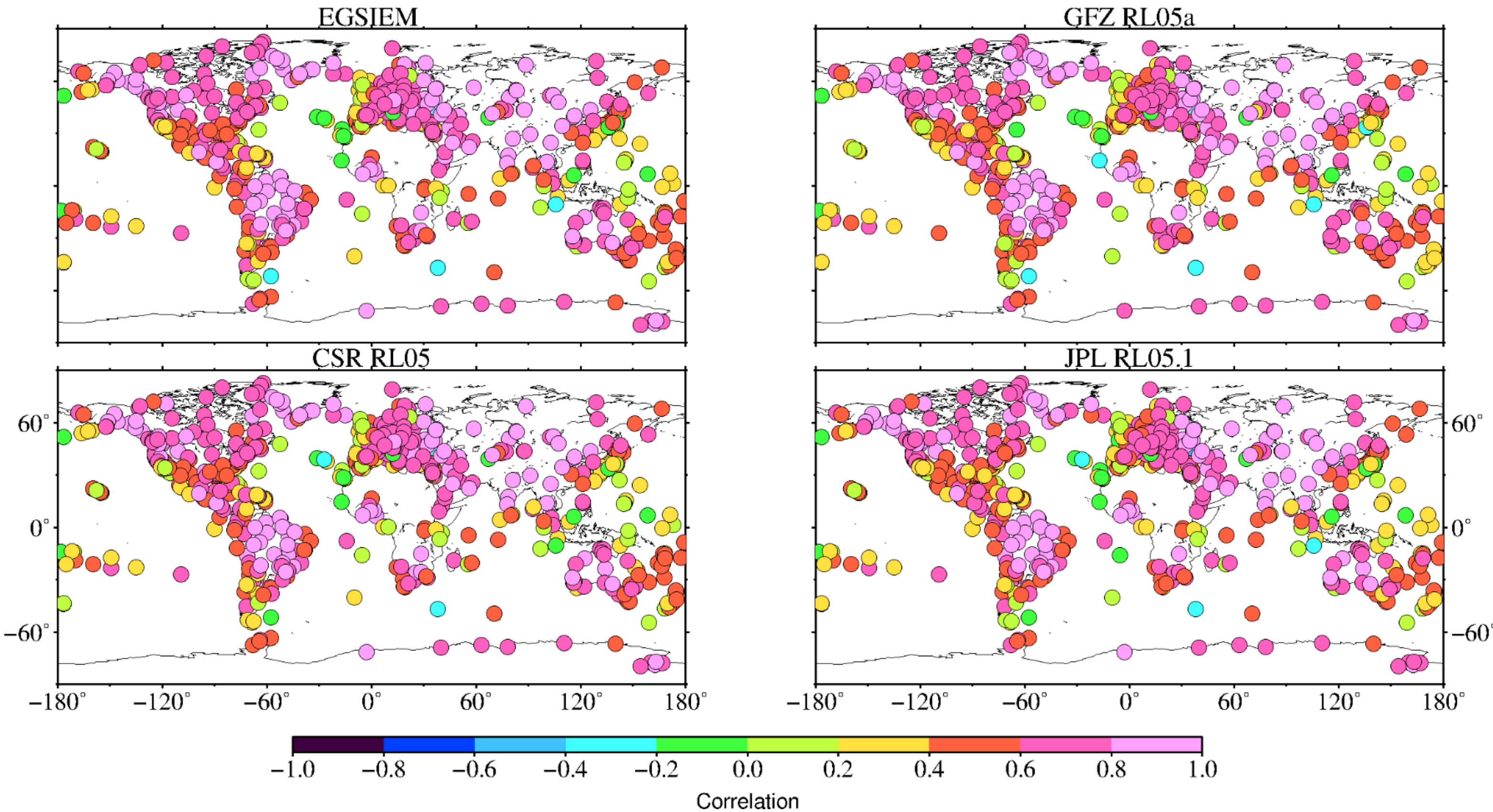
Recap from last meeting

- The GNSS observed and the EGSIEM derived displacements are in strong agreement. The ITRF2014 solutions provide the better performance than the JPL and SOPAC GNSS solutions.
- Agreement between the four hydrological models and the three GNSS solutions is good as well and better agreement is found with the ITRF2014 time series than the JPL and SOPAC time series
- With respect to the three GNSS position time series, EGSIEM shows better statistics than the hydrological models.

see EGU Poster Li et al., (2016)

GRACE .VS. ITRF2014

- In a comparison to 949 ITRF2014 GNSS stations: correlation
- High correlations are observed between the GRACE-derived displacements and the ITRF2014 solutions



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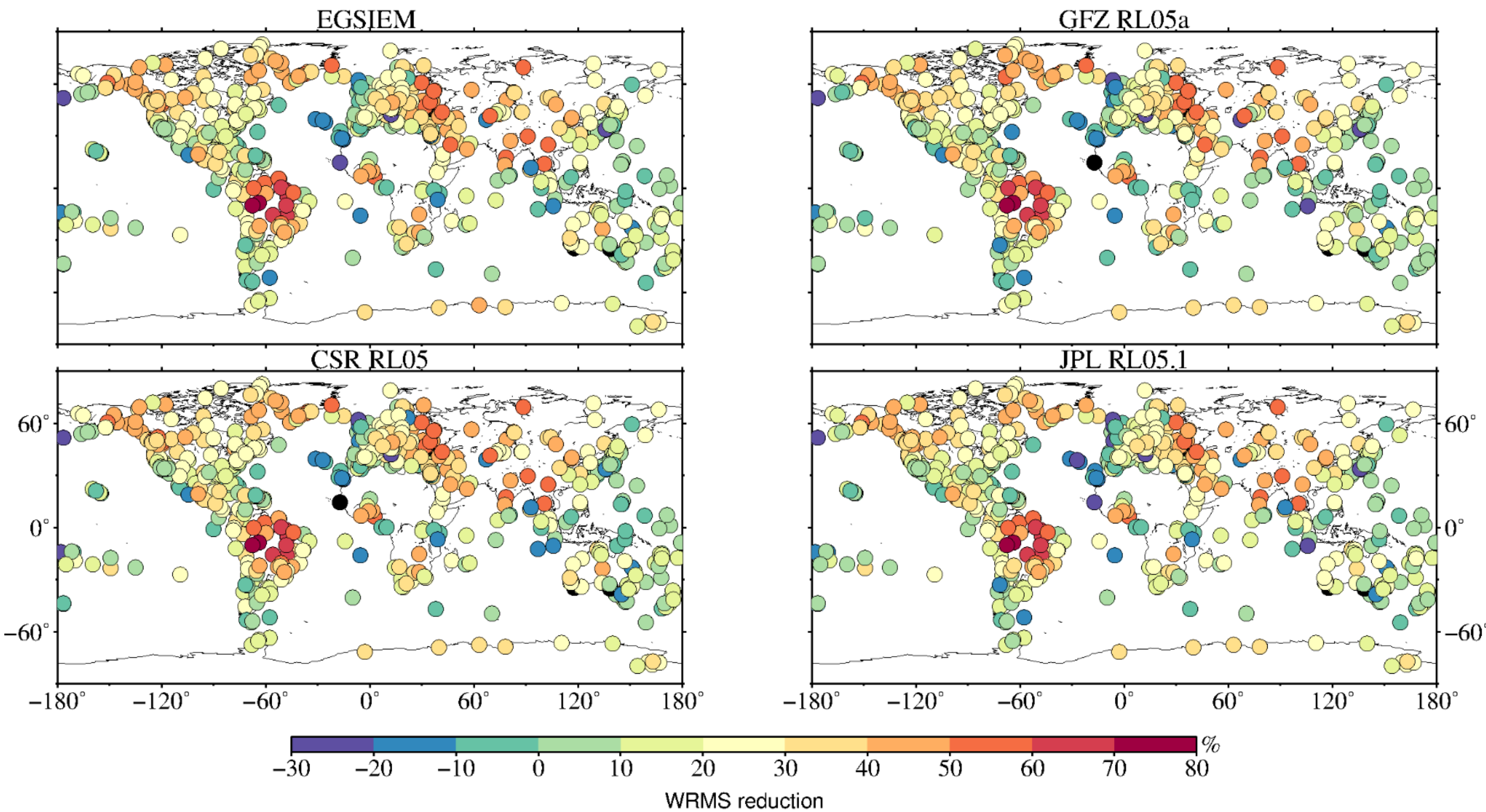
GRACE .VS. ITRF2014

- In a comparison to 949 ITRF2014 GNSS stations: WRMS reduction
- Up to around 75% of WRMS reduction at POVE station (Porto Velho, Brazil)



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GRACE .VS. ITRF2014

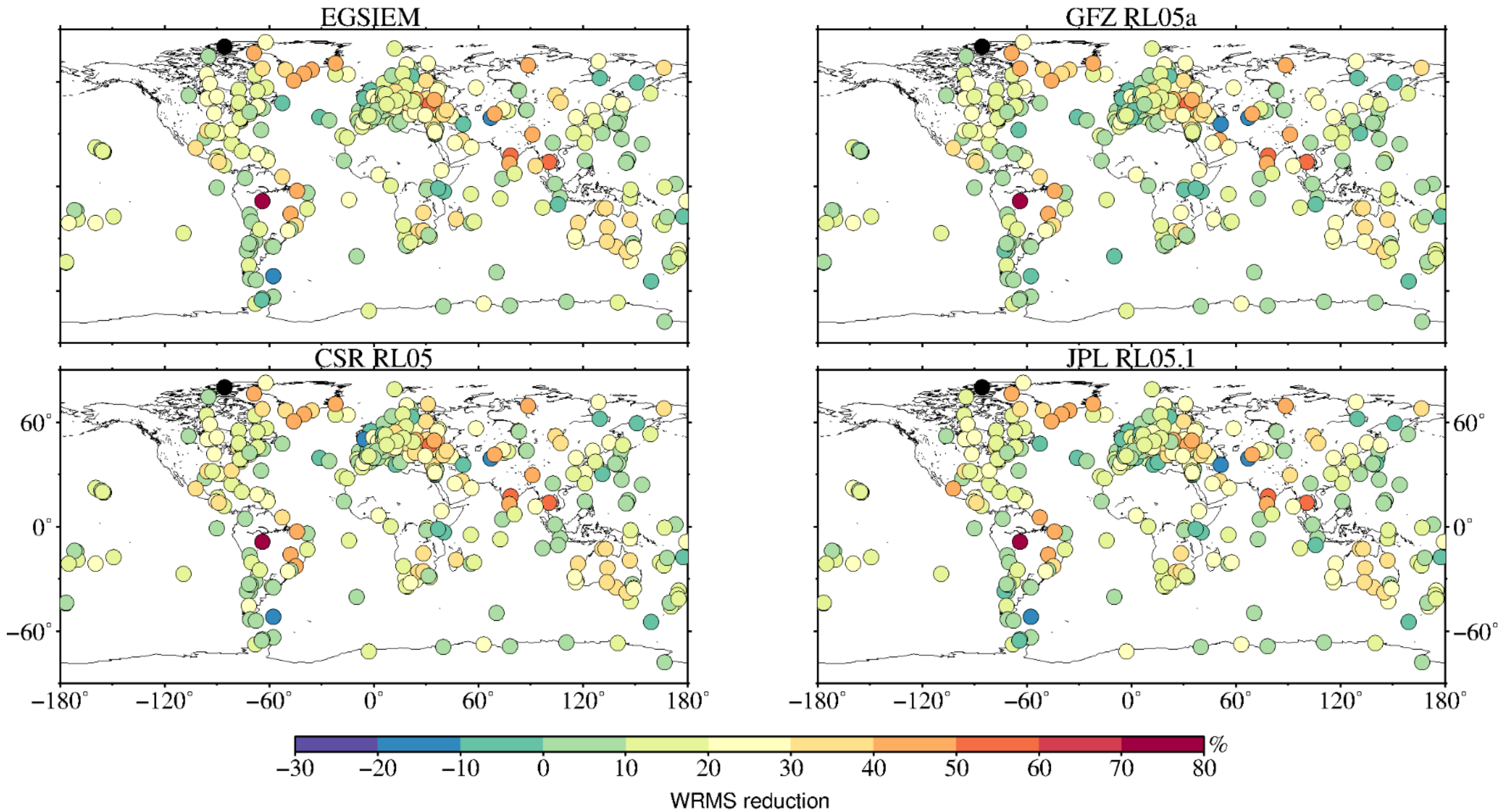
Table 1: *Statistics between GRACE and ITRF2014 solutions. High percentages of stations with positive WRMS reductions are observed using the four different GRACE products.*

	Correlation			Stations with correlation> 0.6 [%]	WRMS reduction [%]			Stations with positive WRMS reduction [%]
	min	max	mean		min	max	mean	
GFZ RL05a	-0.40	0.97	0.55	48.68	-55.67	74.46	17.69	84.93
CSR RL05	-0.40	0.97	0.57	52.90	-50.80	74.44	19.68	88.41
JPL RL05.1	-0.43	0.97	0.55	47.95	-58.50	73.95	17.99	87.04
EGSIEM	-0.39	0.97	0.57	53.74	-47.83	74.56	19.70	88.72

- All four GRACE products display good agreements with the ITRF 2014 solutions
- EGSIEM provides the best performance in terms of both correlation and WRMS reduction in a comparison to 949 ITRF2014 GNSS stations

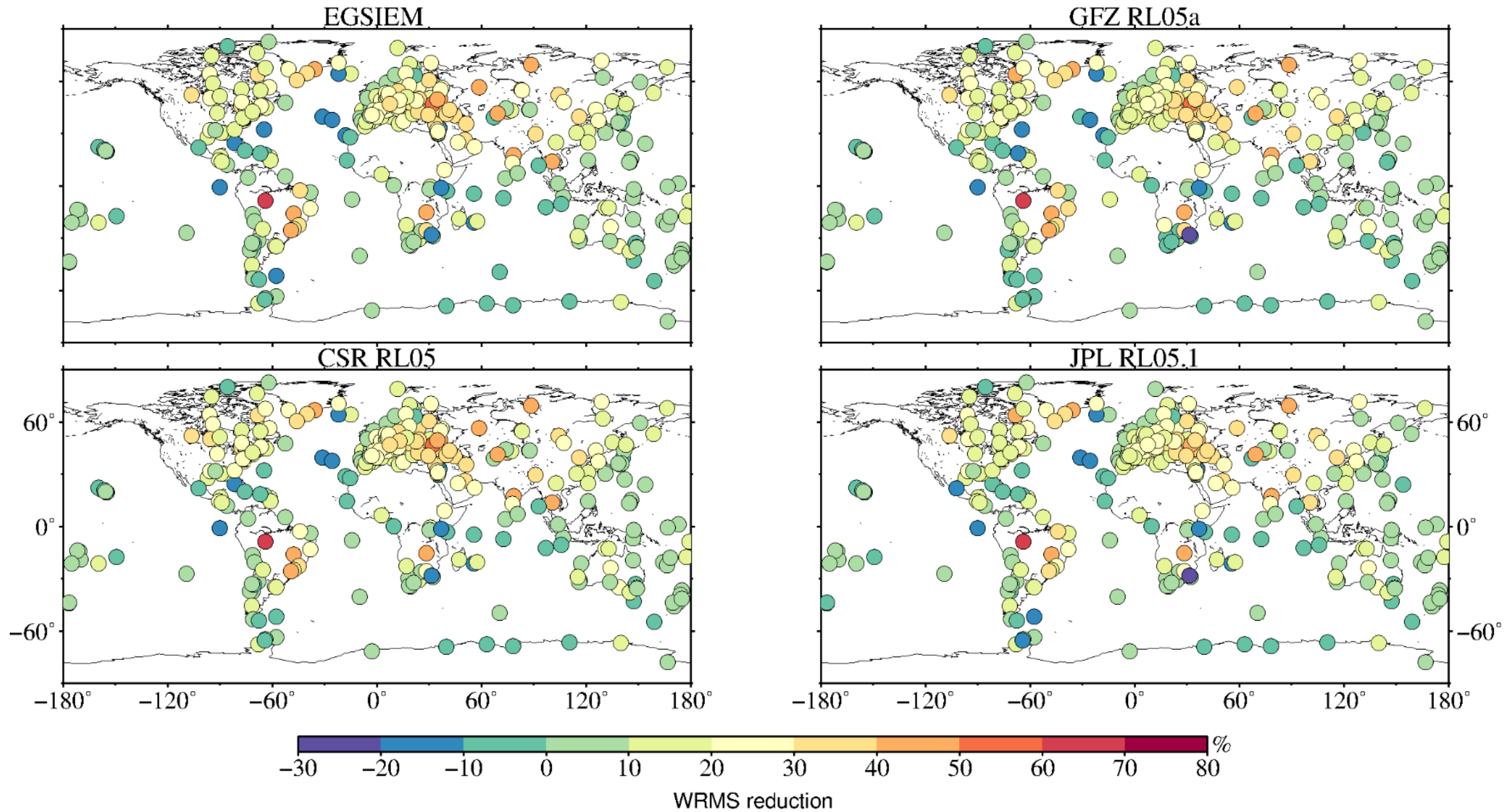
GRACE .VS. GNSS (JPL)

- In comparison to 394 common GNSS stations from JPL, SOPAC and ITRF2014 solutions



GRACE .VS. GNSS (SOPAC)

- In comparison to 394 common GNSS stations from JPL, SOPAC and ITRF2014 solutions



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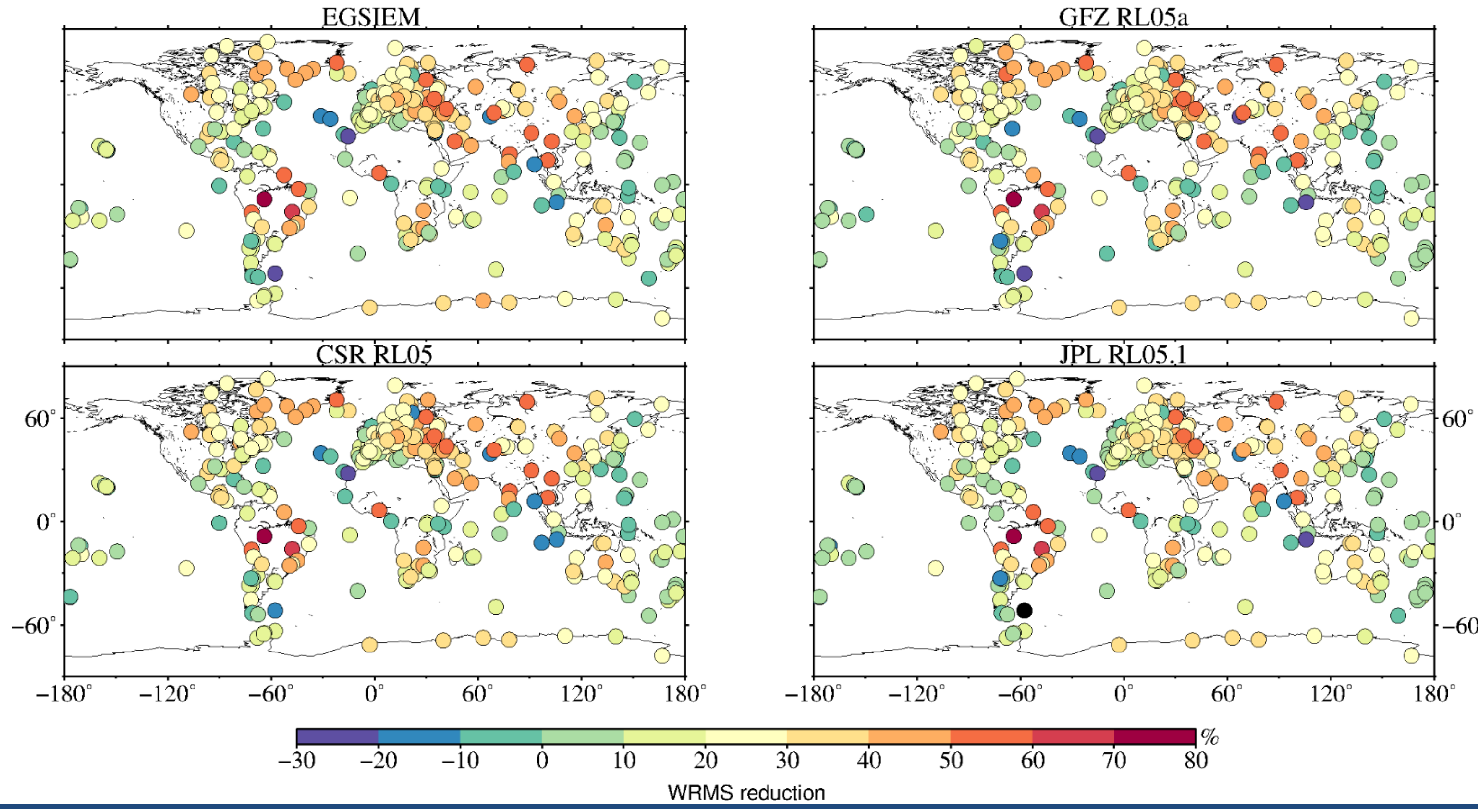
GRACE .VS. GNSS (ITRF2014)

- In comparison to 394 common GNSS stations from JPL, SOPAC and ITRF2014 solutions



GRACE .VS. GNSS

Table 2: *The metric of WRMS reduction between four GRACE products and three GNSS solutions.*

	JPL		SOPAC		ITRF2014	
	mean WRMS reduction [%]	positive WRMS reduction [%]	mean WRMS reduction [%]	positive WRMS reduction [%]	mean WRMS reduction [%]	positive WRMS reduction [%]
GFZ RL05a	14.97	88.32	13.18	81.98	20.49	87.06
CSR RL05	16.42	91.62	14.38	85.03	22.35	88.58
JPL RL05.1	15.64	89.85	13.12	83.50	20.64	88.83
EGSIEM	16.64	92.13	14.07	84.77	22.14	88.32

- In comparison to 394 common GNSS stations from JPL, SOPAC and ITRF2014 solutions
- ITRF2014 performs better than other two GPS solutions
- EGSIEM and CSR RL05 provide close performance and they beat both GFZ RL05a and JPL RL05.1

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Conclusions

- ITRF2014 solutions provide the best agreements with the four considered GRACE products.

- Generally, both four GRACE products are in good agreements with the three GNSS Solutions. More than 80% stations (out of 394 stations) have positive WRMS reduction.

- Comparing to the three GNSS solutions, close performances are observed between EGSIEM and CSR RL05. They show slightly better statistics than GFZ RL05a and JPL RL05.1.

Future work

- Adding other GRACE products into validation against the latest GNSS products
  - ITSG-GRACE 2016
  - AIUB Release 02
  - GRGS Release 03
- Validation on daily data level
  - Daily hydrological model data
  - Daily GNSS time series
- Near real time (NRT) validation
  - CWS: NCEP-R1, WGHM
  - GNSS: SOPAC, JPL
  - Gravity: waiting …

Thanks for your attention!

EGSIEM

European Gravity Service for Improved Emergency Management

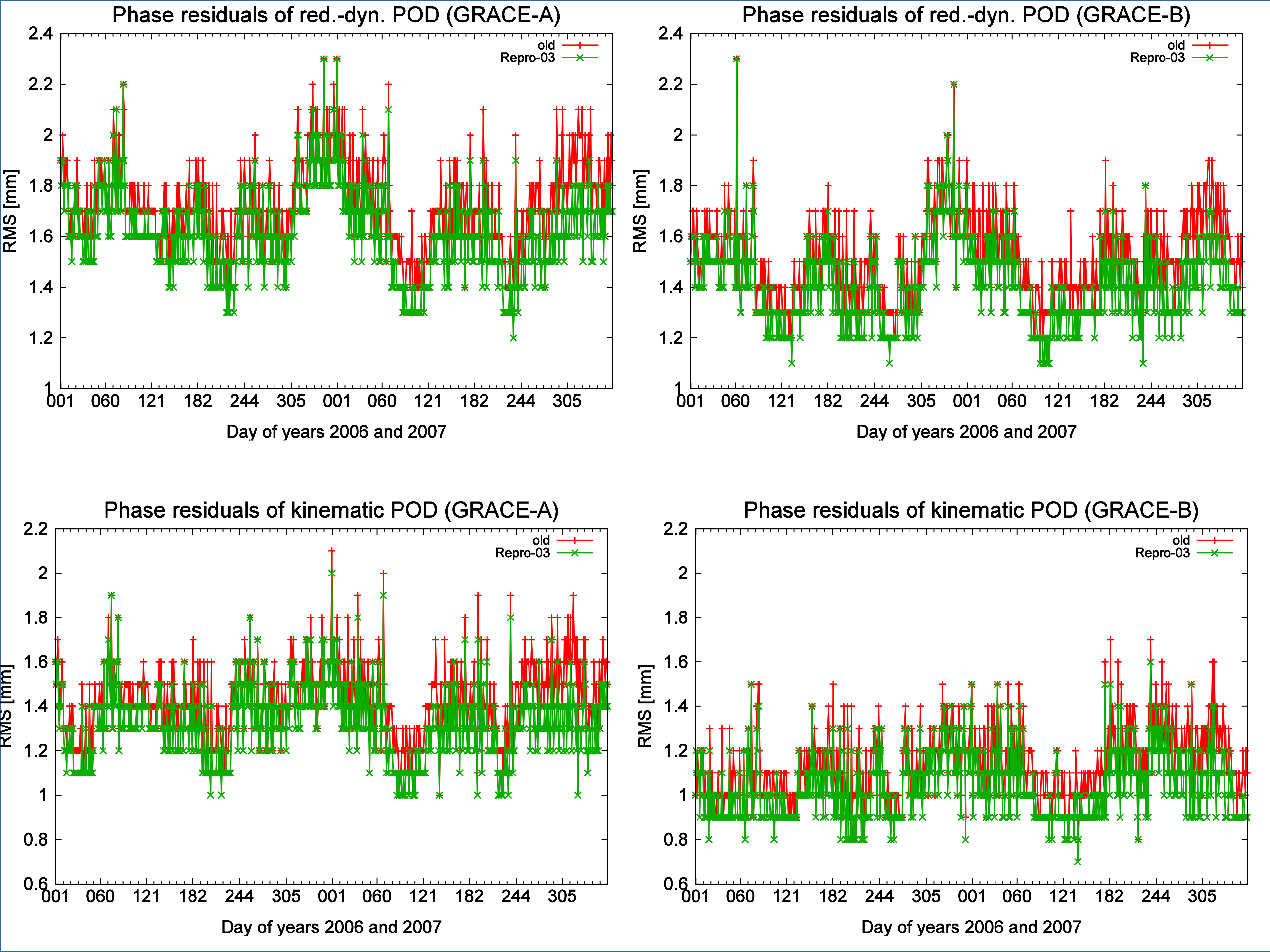
Reference Frame Products

Andreja Susnik

Current status

European Gravity Service for Improved Emergency Management

- Task 3.1 Reference Frame Reprocessing (M03-M10) closed
- Deliverable 3.1: "Reference Frame Product Report", was submitted to the Project Officer at the end of October 2015
- products referring to years 2006 and 2007 provided to the consortium at the beginning of the January 2016
- validation of the products, with LEO POD and SLR was performed by AIUB


Phase residuals of red.-dyn. POD (GRACE-A)
Phase residuals of red.-dyn. POD (GRACE-B)
Phase residuals of kinematic POD (GRACE-A)
Phase residuals of kinematic POD (GRACE-B)
old
Repro-03
RMS [mm]
Day of years 2006 and 2007
001
060
121
182
244
305
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6

Current status

Since March, products are avalible at:

- GNSS Satellite clocks (RFPHyyddd.CLK - 30 second, high-rate products and RFPUyyddd.CLK -5 second, ultra-high-rate products):
- http://dl.aiub.unibe.ch/data/egsiem/private/Repro-15/YYYY/CLK

- GNSS Orbits (RFPyyddd.PRE) and Earth rotation parameters (RFPyyddd.ERP):
- http://dl.aiub.unibe.ch/data/egsiem/private/Repro15/YYYY/ORB/

Currently only 2006 and 2007 products on the server, however if any group is interested we have products for 2003-2011 period – only SLR validation performed at AIUB !

European Gravity Service for Improved Emergency Management

Gravity field coefficients from SLR data

Andrea Maier, Adrian Jäggi

HORIZON 2020

Procedure (1)

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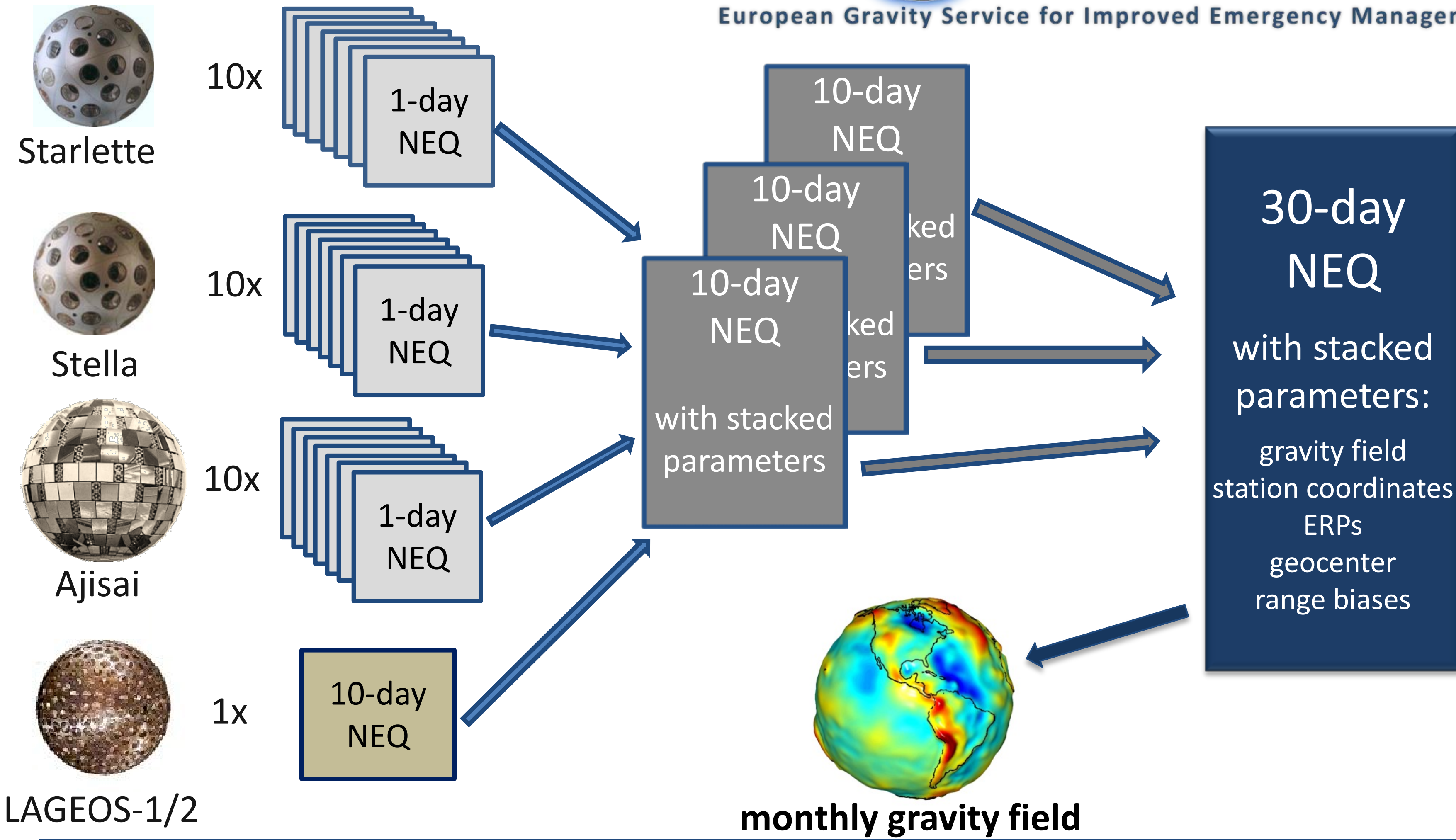

Procedure (2)

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Reference frame	SLRF2008
A priori gravity field model	AIUB-GRACE03 (up to d/o 30 for LAGEOS, up to d/o 90 for LEOs)
Ocean tide model	EOT11a (up to d/o 30)
AOD applied at observation level	RL05
Atmospheric drag model (LEOs)	NRLMSISE-00
Albedo	monthly reflectivity coefficients in a 2.5 x 2.5 degree grid (CERES mission)
…	…
Weighting of satellite-specific NEQs	LAGEOS: 8mm Ajisai: 25mm Starlette/Stella: 20mm

Procedure (3)

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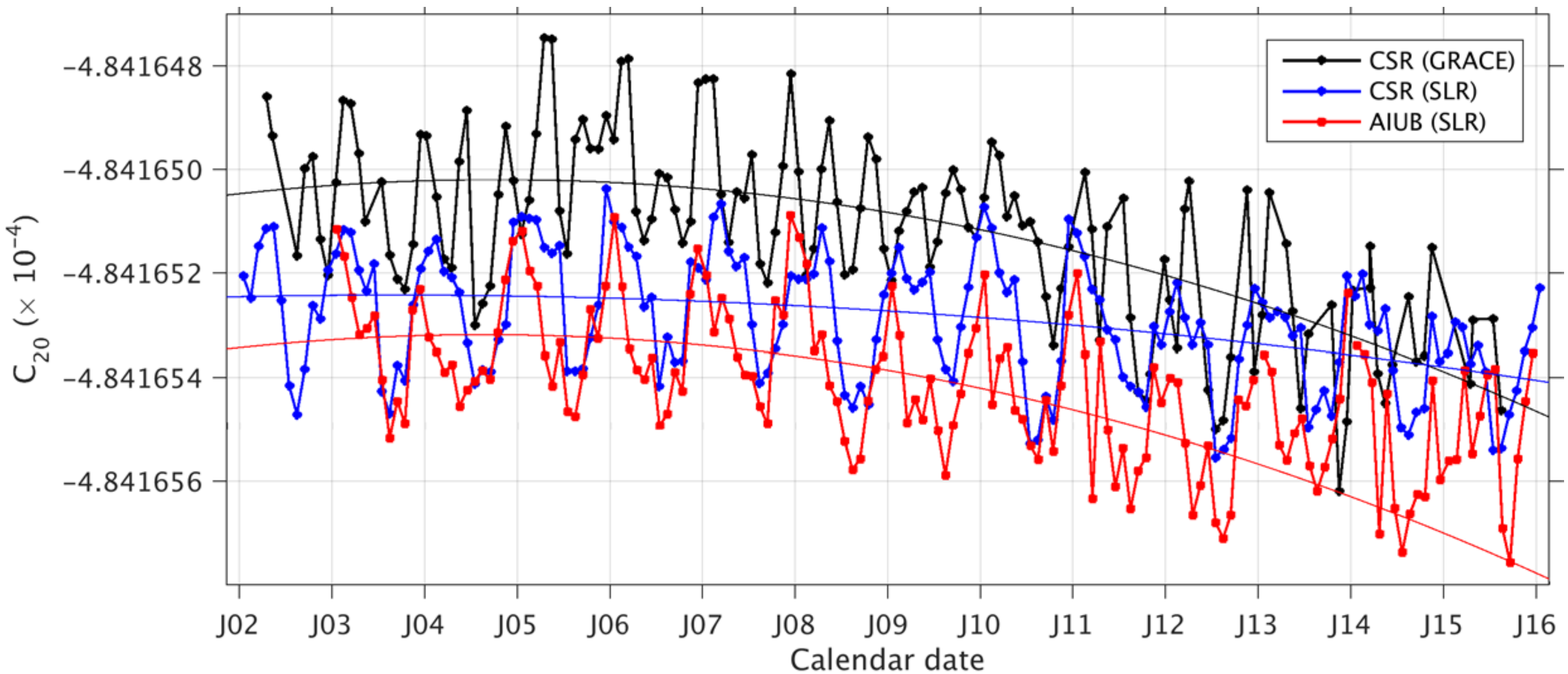
		SLR solutions
Estimated parameters		LAGEOS-1/2, Starlette, Stella, Ajisai (LEOs)
Orbits	Osculating elements	a, e, i, Ω, ω, u_0 (LAGEOS: 1 set per 10 days, LEOs: 1 set per day)
	Dynamical parameters	LAGEOS: const. and 1/rev along track (1 set per 10 days) LEOs: const. and 1/rev along track, 1/rev cross track (daily)
	Pseudo-stochastic pulses	LAGEOS: none LEOs: 1/rev in along track
Earth rotation parameters		X_P, Y_P, UT1-UTC (piecewise linear, 1 set per day)
Geocenter coordinates		1 set per 30 days
Earth gravity field		up to d/o 6 (1 set per 30 days)
Station coordinates		1 set per 30 days
Range biases		LAGEOS: for selected stations (1 set per 30 days) LEOs: for all stations (1 set per 30 days)

Results (EGU)

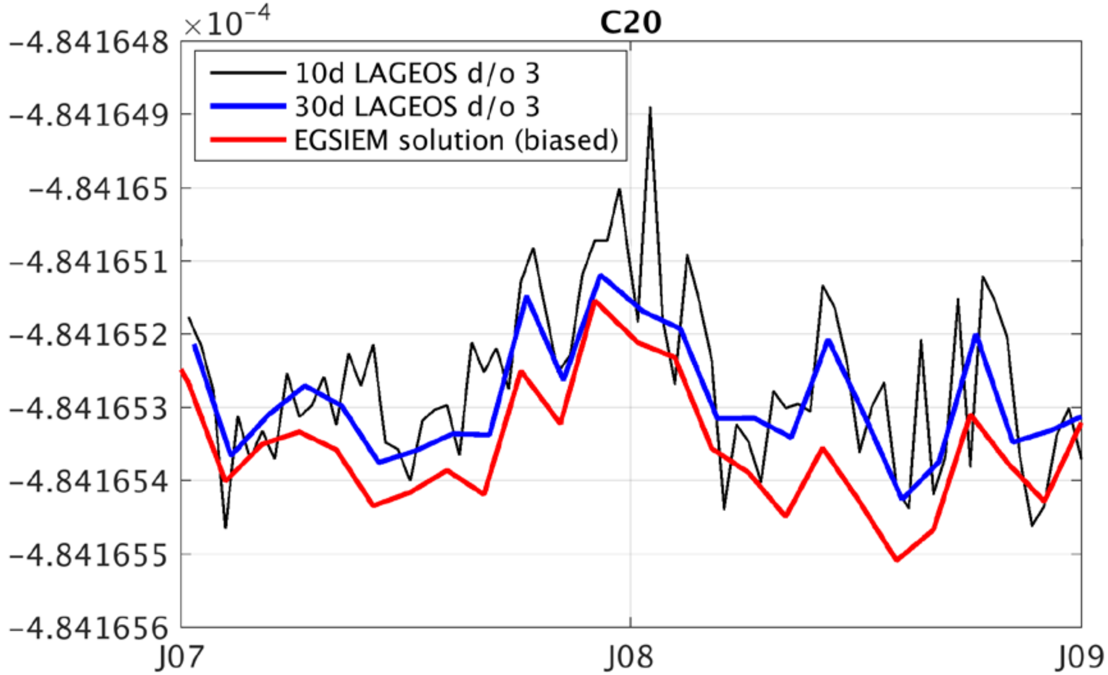


→ 1. bias of ~1.e-10 between our solution and CSR

2. the long-term trend of our solution is similar to the GRACE-based solution of CSR but not to the SLR-based solution of CSR

Latest results

- the estimated number of gravity field coefficients was reduced from degree and order (d/o) 6 to d/o 3
- a LAGEOS-only solution was set up



Next steps

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- combine LAGEOS with LEOs
- find the issue that is responsible for the bias between the biased EGSIEM solution (LAGEOS+LEOs) and the new unbiased LAGEOS-only solution
- find the reason for the differernt long-term behaviour of C20 computed at AIUB and CSR

EGSIEM

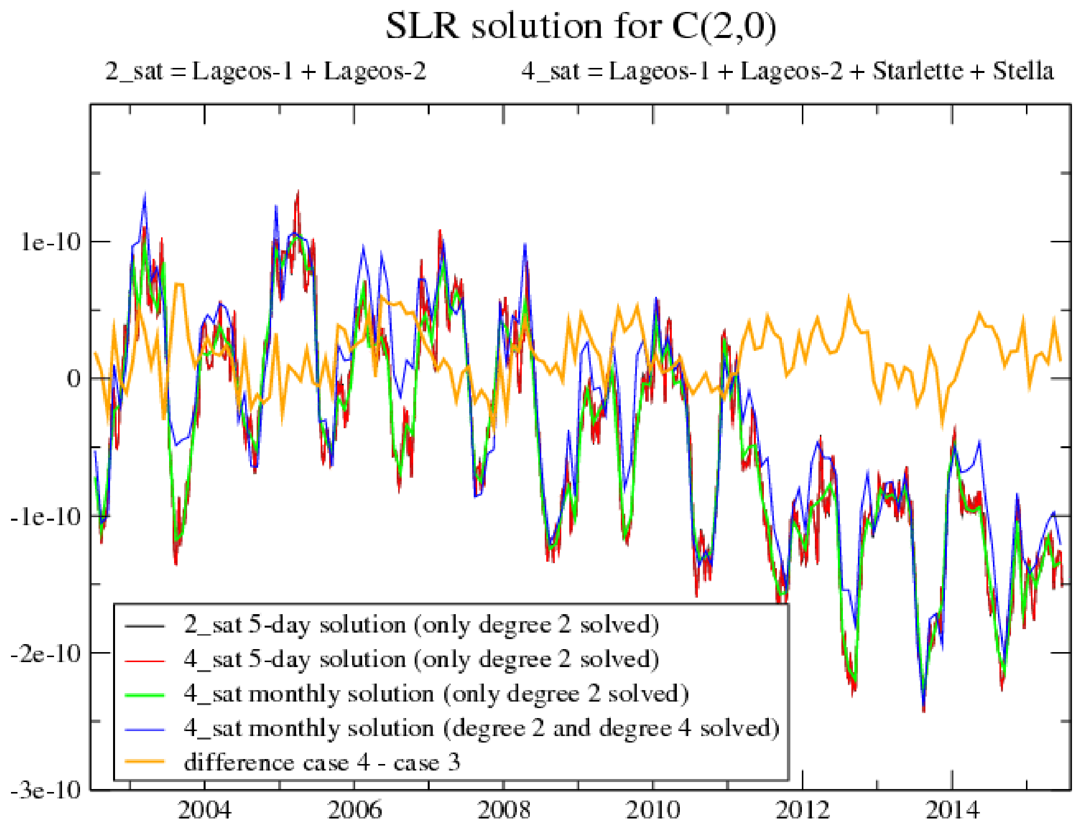
European Gravity Service for Improved Emergency Management

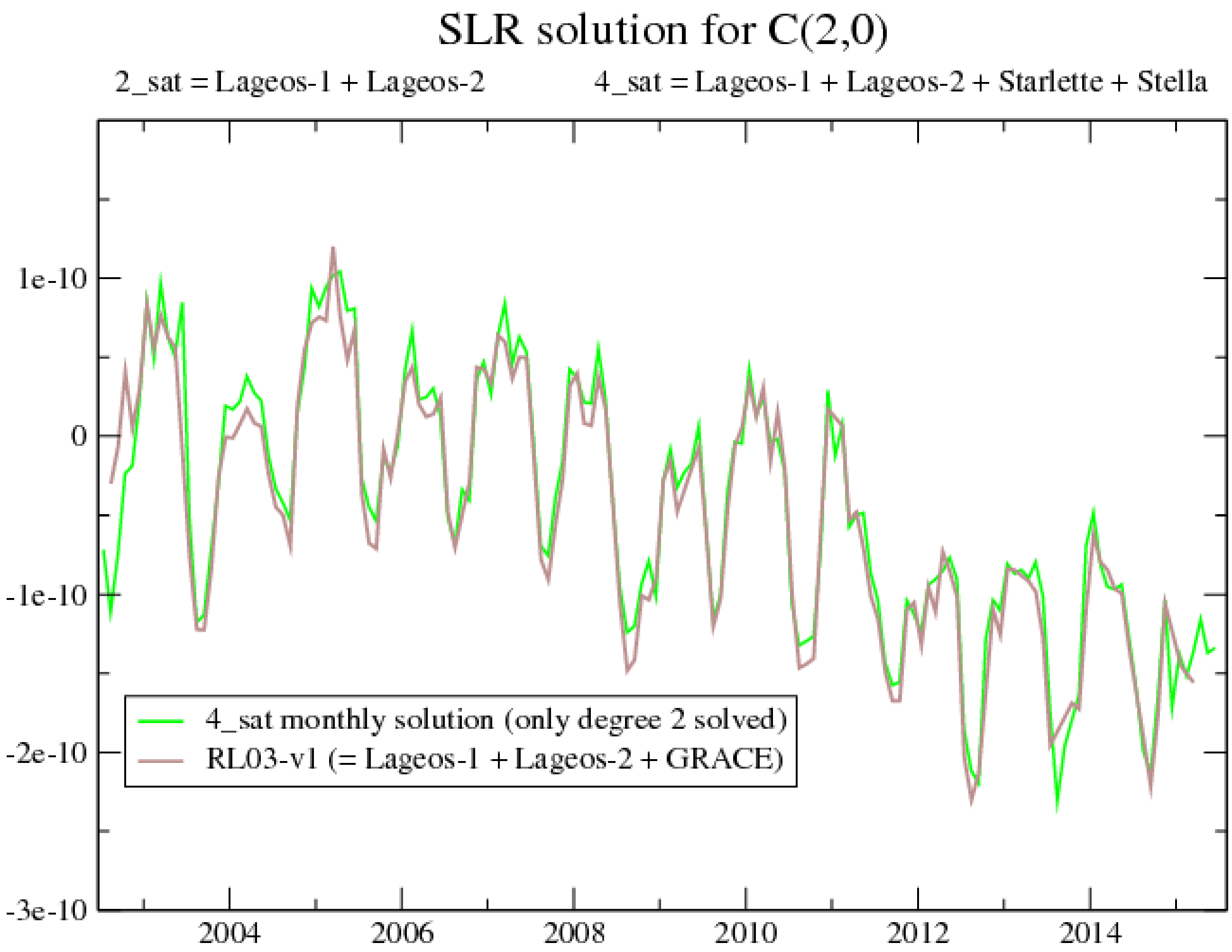
EGSIEM – WP3
CNES/GRGS SLR processing

J.M. Lemoine [(1)], F. Reinquin [(1)], S. Bruinsma [(1)]

(1) CNES/GRGS, Toulouse, France

❖ 15 years have been processed (2002-2016) on 4 satellites: Lageos-1, Lageos-2, Starlette, Stella




SLR solution for C(2,0)
2_sat = Lageos-1 + Lageos-2
4_sat = Lageos-1 + Lageos-2 + Starlette + Stella
1e-10
0
-1e-10
-2e-10
-3e-10
2004
2006
2008
2010
2012
2014
4_sat monthly solution (only degree 2 solved)
RL03-v1 (= Lageos-1 + Lageos-2 + GRACE)

EGSIEM

European Gravity Service for Improved Emergency Management

Oceanographic validation of time variable gravity solutions from GRACE

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

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

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

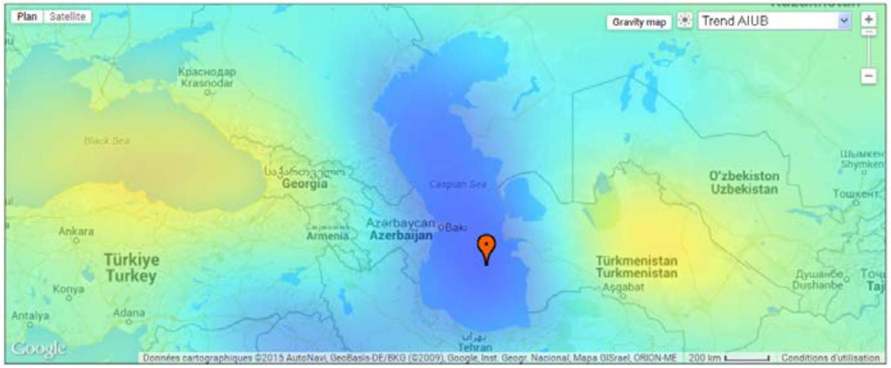
Summary

- **Interest of using some oceanic areas as a validation tool for GRACE products:**
  - Availability of precise and densely sampled time series from altimetry
  - The oceanic structures are usually larger than the continental ones → more compatible with GRACE resolution
- **Conditions:**
  - The presence of noticeable mass signal in the GRACE solutions
  - Altimeter heights have to be corrected for the steric component and for the loading effect

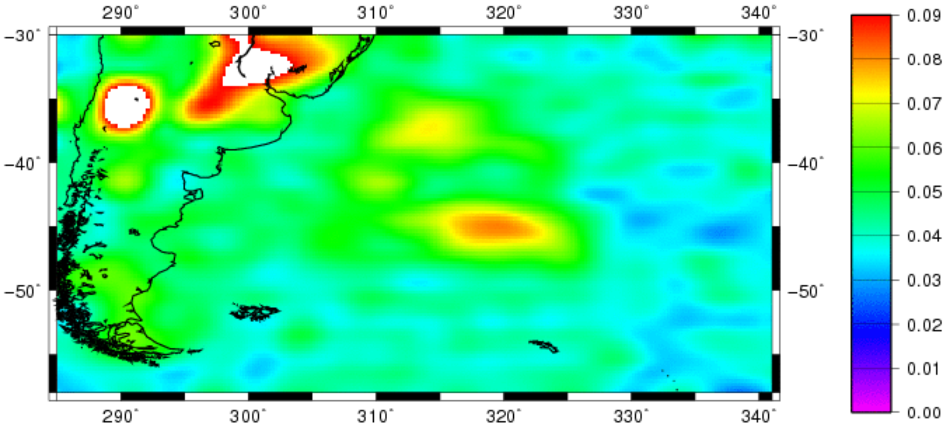
Summary

❖ **Test zones:**

➢ **Inland sea: the Caspian sea**



➢ **Open ocean: the Zapiola gyre**



Summary

❖ Data used:

➢ Altimetry:

- open ocean: **AVISO+** (Multi-satellite Gridded Sea Level Anomalies SSALTO/Duacs) daily
- inland seas: **HYDROWEB** (Cretaux et al. 2011) 10-day

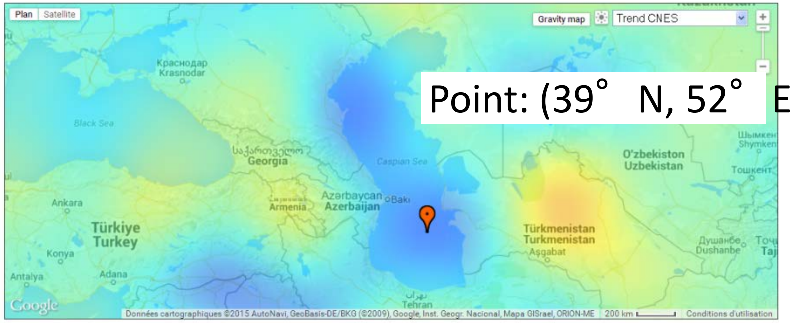
➢ GRACE time series (monthly solutions)*:

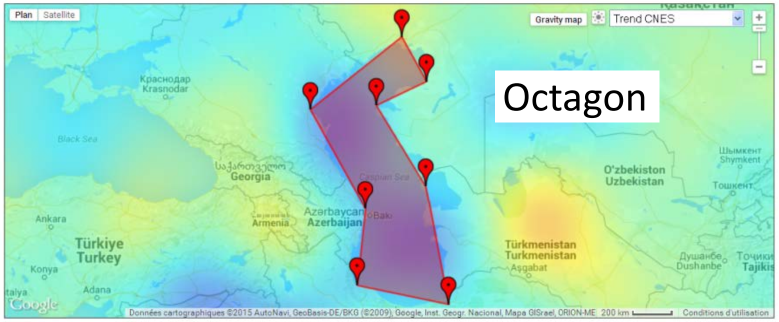
AIUB RL02	(DDK-5 filtered)
CNES/GRGS RL03-v1	(unfiltered)
CSR RL05	(DDK-5 filtered)
GFZ RL05a	(DDK-5 filtered)
JPL RL05	(DDK-5 filtered)
TUGRAZ ITSG14	(DDK-5 filtered)

* All available from the ICGEM web site in unfiltered and DDK-1/2/3/4/5 versions

1- Caspian sea

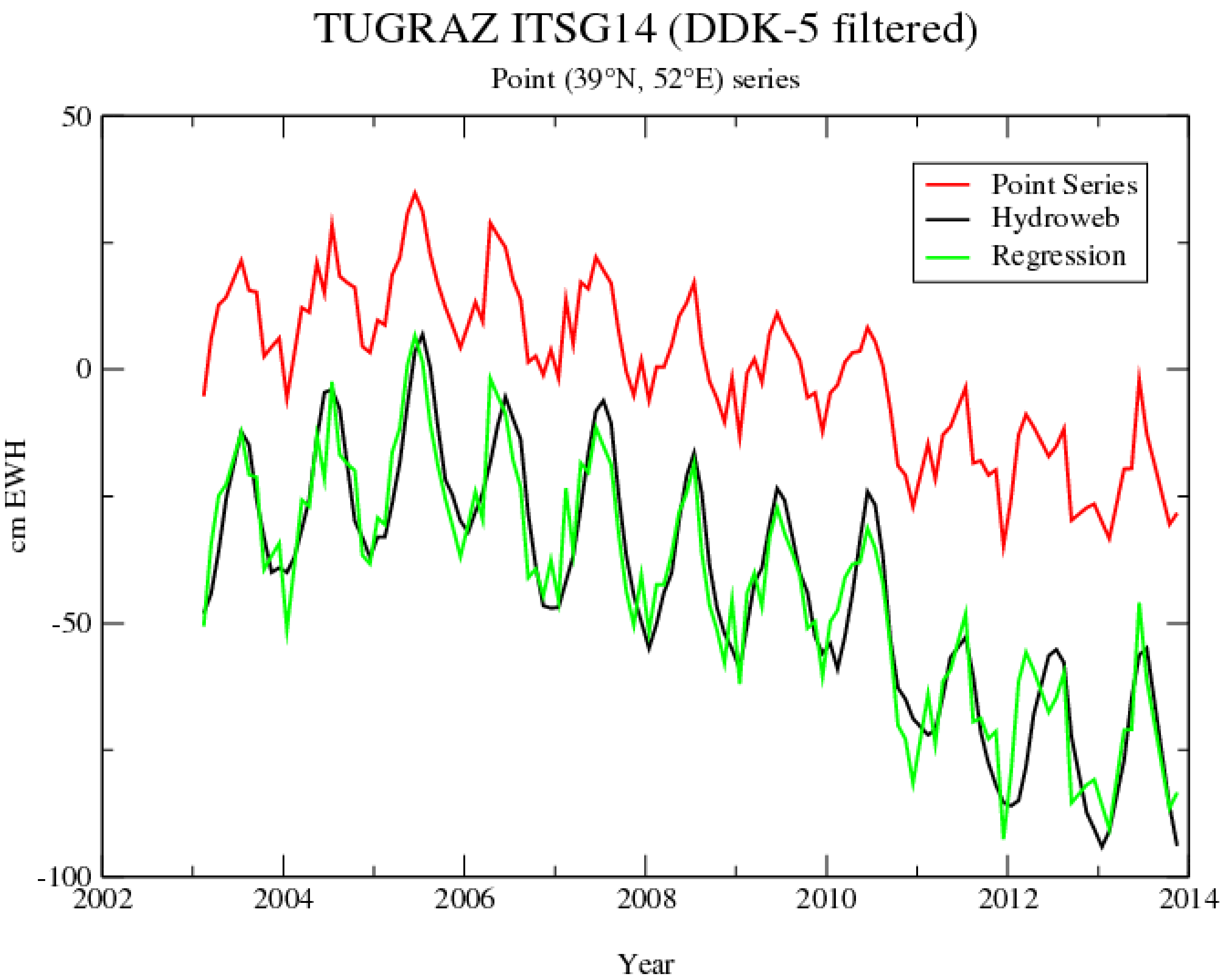
- The largest enclosed inland body of water on Earth: 370,000 km^2 (400 x 900 km)
- Accurate altimeter time series
- Can test the ability of the GRACE solutions to provide spatially pertinent information
- GRACE point-wise and basin-wise time series are tested:





- Test mostly valid in a relative sense; an absolute calibration would require more sophisticated methods (averaging kernel, land hydrology and steric effect removal, cf. Swenson & Wahr 2007)

1- Caspian sea



1- Caspian sea

	Correlation		Scale Factor	
	Point	Basin	Point	Basin
AIUB RL02	0.91	0.94	1.32	1.67
CNES/GRGS RL03-v1	0.96	0.98	1.27	1.75
CSR RL05	0.91	0.93	1.37	1.68
GFZ RL05a	0.86	0.80	1.28	1.39
JPL RL05	0.89	0.89	1.28	1.53
TUGRAZ ITSG14	0.95	0.96	1.43	1.69

- Correlation is slightly better for basin-average than for point

→ **Less noise in the basin-average than in the point time series**

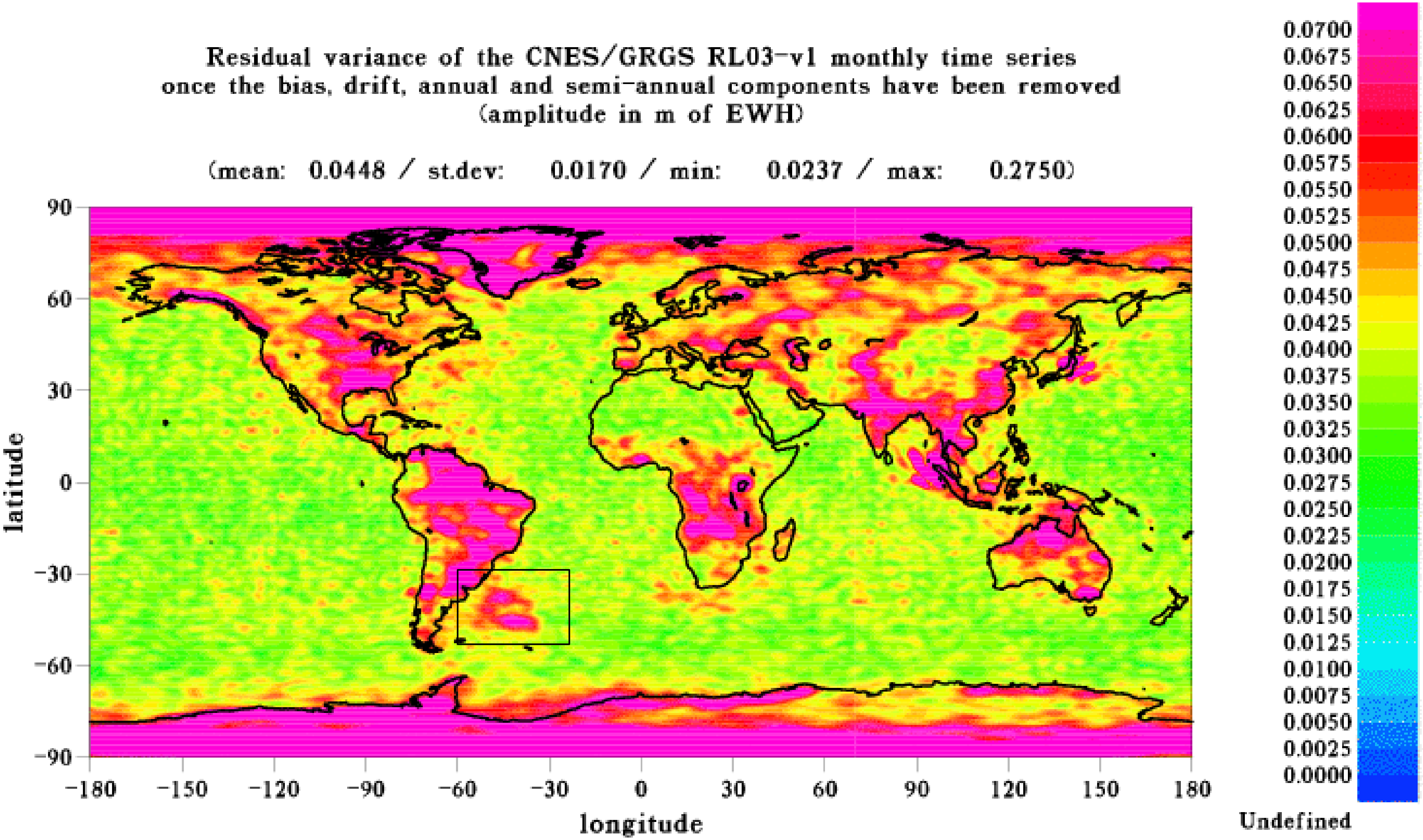
- BUT scale factor is much higher for basin-average than for point

→ **The point time series is closer to the actual sea level**

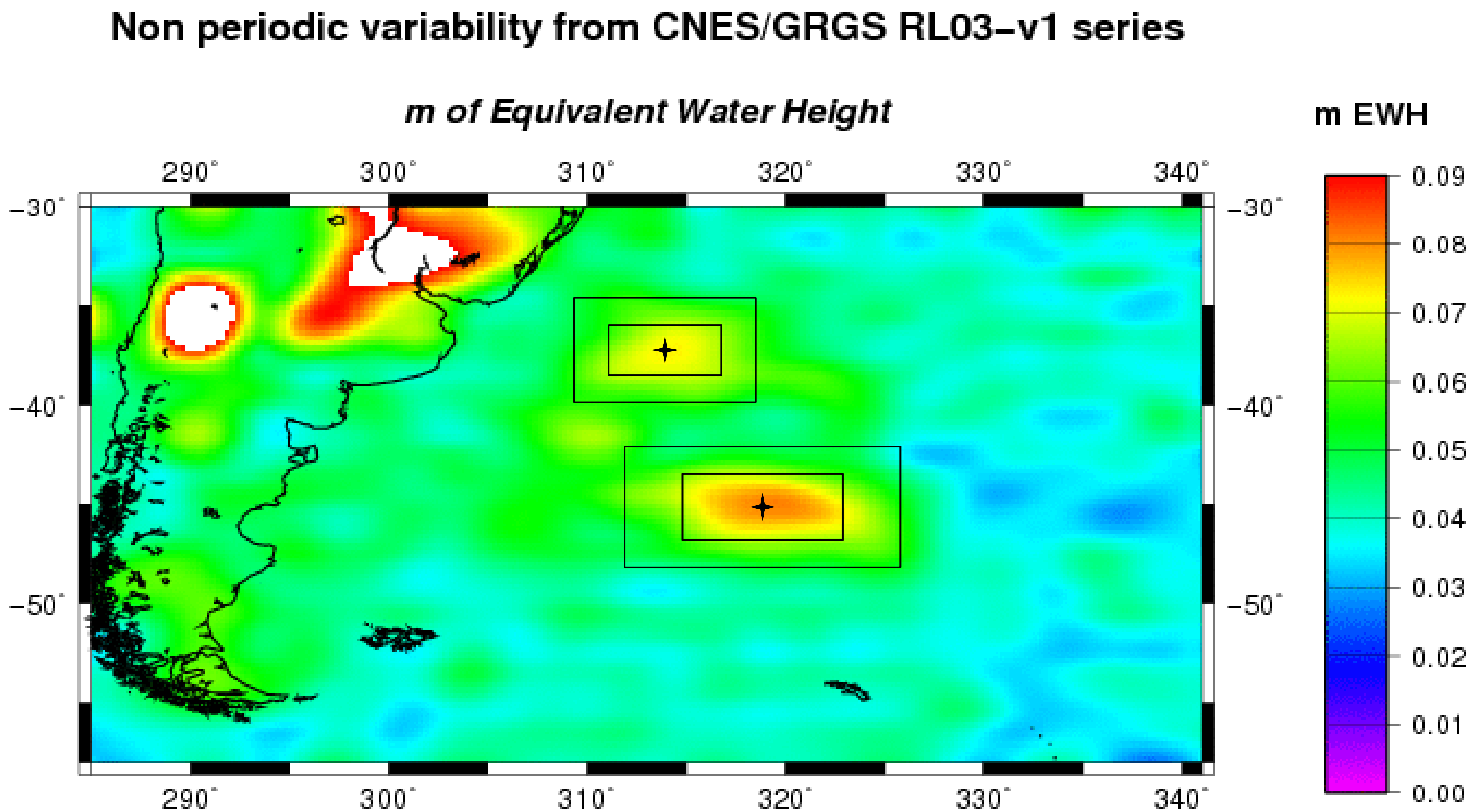
Best correlation is 98 %, best scale factor is 1.27

2- Zapiola gyre

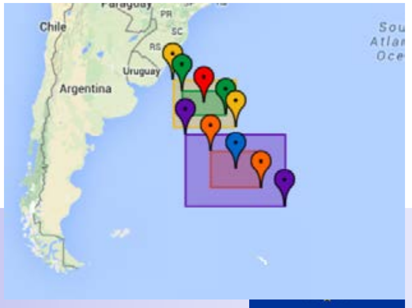
❖ **Large non-periodic mass signal in the GRACE series**



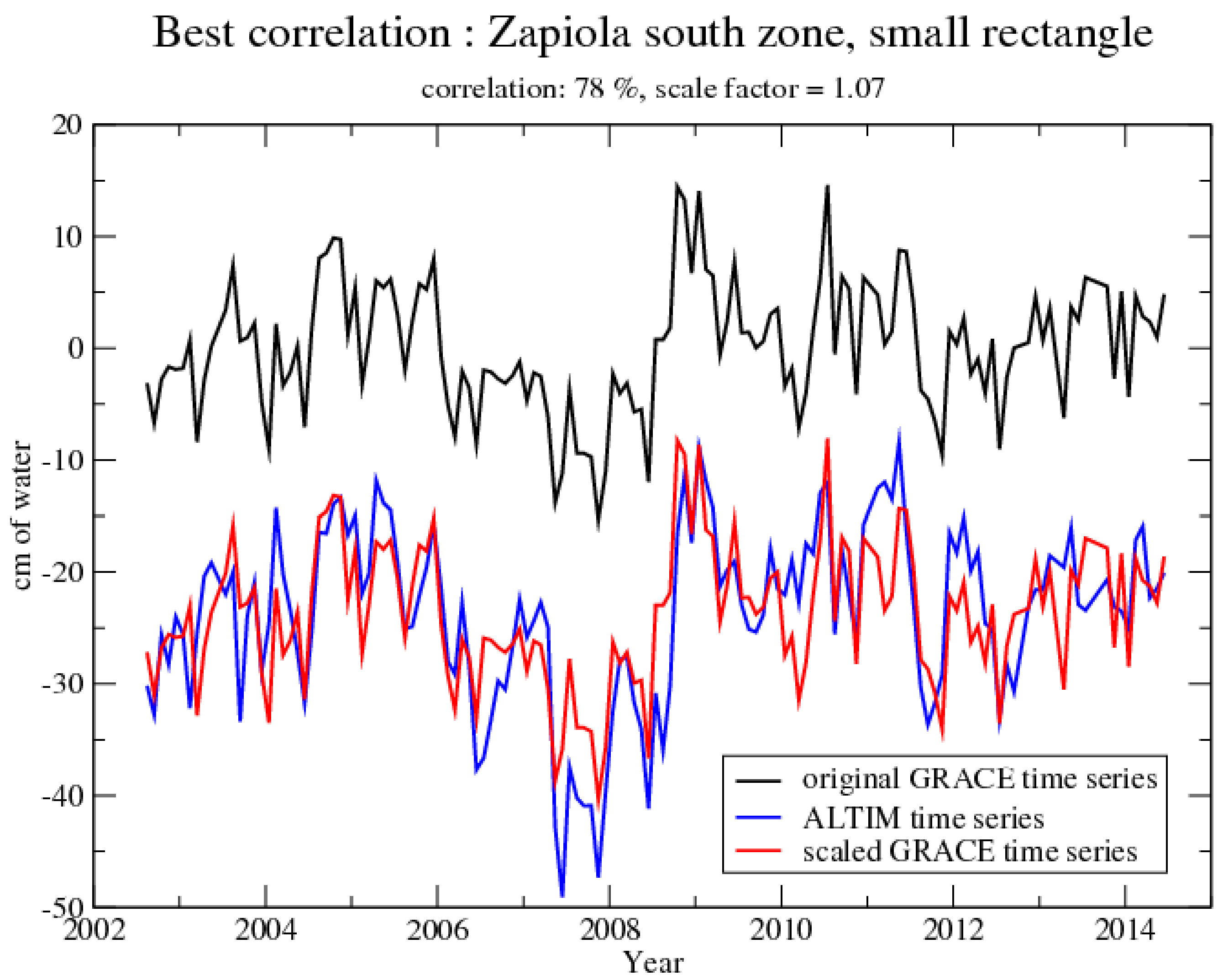
2- Zapiola gyre



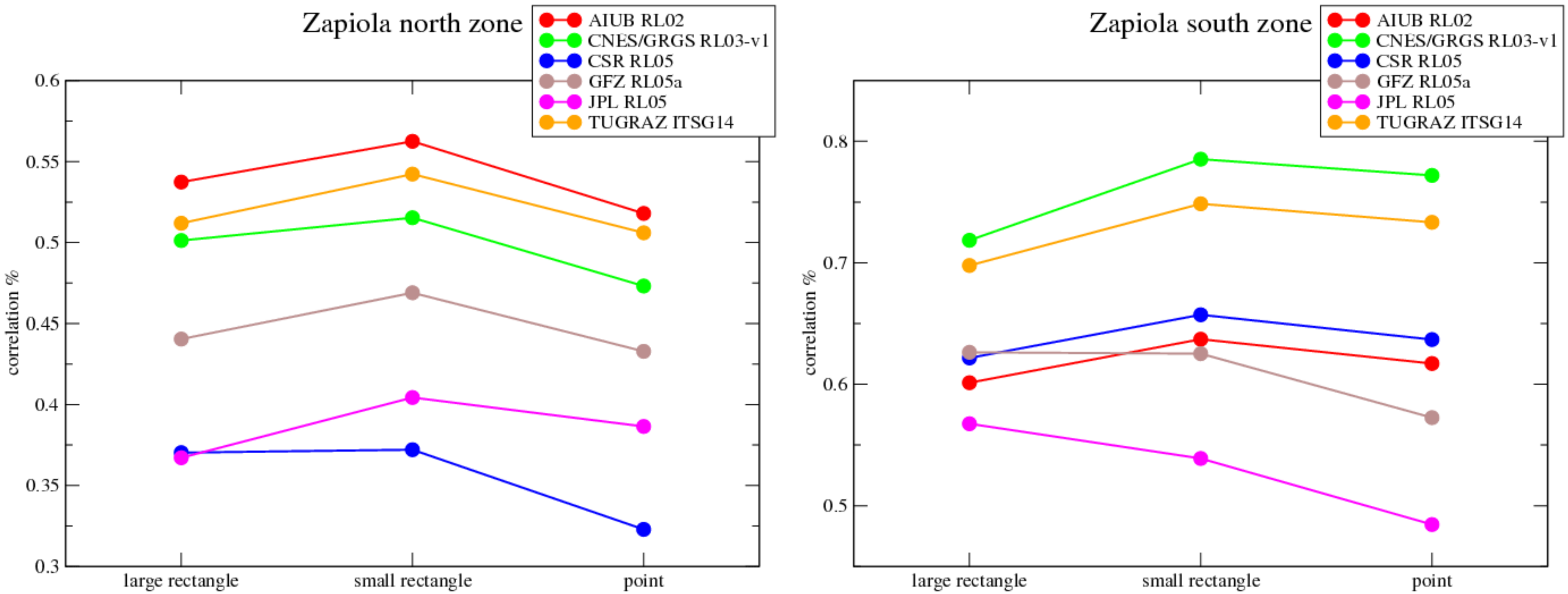
- Point coordinates: (37° S, 46° W) and (45° S, 41° W)
- Small rectangle area: north ~ 316,000 km², south ~ 280,000 km²
- Large rectangle area: north ~ 592,000 km², south ~ 1,120,000 km²



2- Zapiola gyre



2- Zapiola gyre



- **The best coherence between altimetry and GRACE is achieved for areas ~ 300,000 km^2**
- **Agreement is much better for the south zone than for the north zone**
- **Best coherence in the south zone = 79 % with a scale factor of 1.07**
- **Worst coherence in the north zone = 37 % with a scale factor of 0.66**

Conclusion

- Altimetry can be a precious tool for GRACE solutions validation
- The selected oceanic areas must present a large mass signal
- They can be far off-coast and therefore escape contamination from continental hydrology
- In the Caspian sea we can reach a very high level of coherence between altimetry and GRACE (98 %) although it is an enclosed sea
- For some time series, the low correlations do not come from the smoothing by DDK-5, but from the intrinsic noise of the time series
- In the Zapiola gyre the variability of the ocean is higher than in the Caspian – spatially and temporally - and is more difficult to capture it with monthly time series from GRACE (max. correlation 79 %)
- The example of the Zapiola gyre shows that in some cases (Zapiola north) the monthly time sampling is not sufficient
  We must go to a shorter time sampling…

Thank you for your attention

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 Progress Meeting # 3

GFZ, Potsdam

June 02 – 03, 2016

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

Introduction

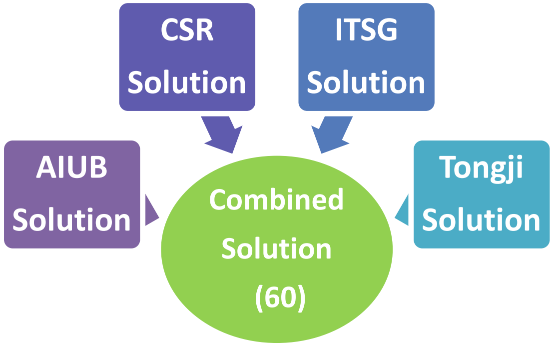
- In WP4 at AIUB
  - Scientific Combination Service :

    Combination of GRACE Monthly Gravity Field Solutions

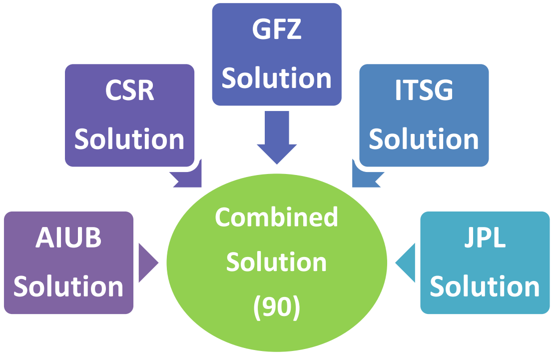
- Contents
  - Review:
    - Comparison and Combination of GRACE Monthly Solutions on Solution Level
    - Validation of a Combined Solution: Hydrology, Cryology, GIA, GPS Loading
  - Simulation Study on the Combination
  - Combined Solution using New Weighting Schemes

Review (1/2): Combination of GRACE Monthly Solutions

- GRACE Monthly Solutions
  - The solutions available at ICGEM website



- Comparison
  - Signal: MEWH of river basins
  - Variability: wSTD over the oceans
  - Spherical Harmonic Coefficients



- Combination
  - Weighting schemes: 1/(Solution - Arithmetic Mean) ^{2}
  - Weighted combined solutions:

    One weight/month/gravity field

Review (2/2): Validation of Combined Solutions

- Combined solution: Single weight/month/gravity field (degree 90)

  : in gfc file format and L3 grids (Thanks to *TU Graz*'s prompt conversion assistance)

Slightly better correlation with a hydrological model

Hydrology

(Andreas Güntner, Ben Gouweleeuw)

Hydrological Events

- Combined Solution: 0~60
- Combined vs. ITSG: 60~90

Cryology

(Martin Horwath)

Ice Mass in Antarctica

Combined Solution

Better fit to the center of rebound than CSR solution

GIA

(Holger Steffen)

Fennoscandia, Canada

Station-related results

GPS Station Loading

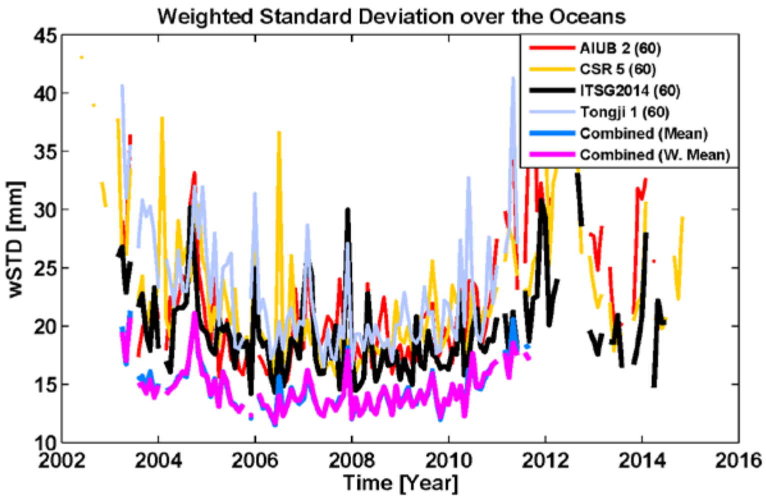
(Tonie van Dam)

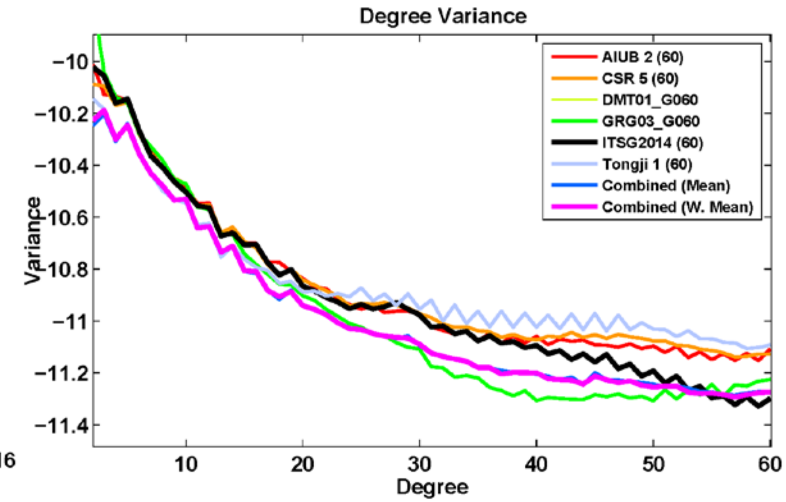
GPS stations

[Simulation Study] Motivation

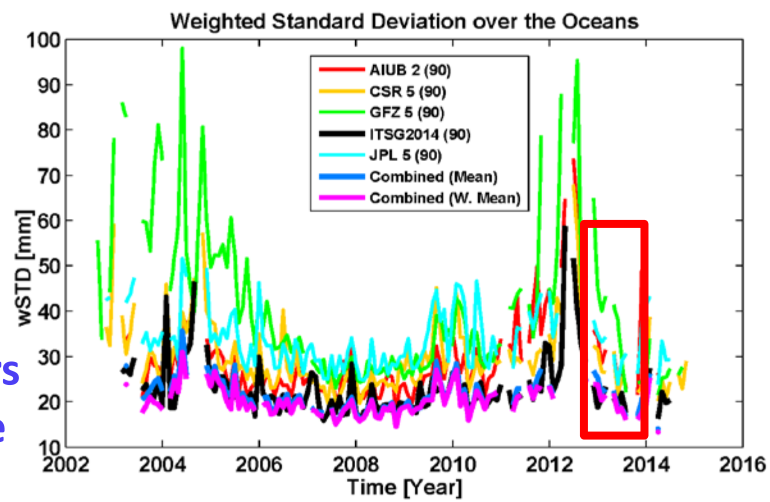
Degree 60

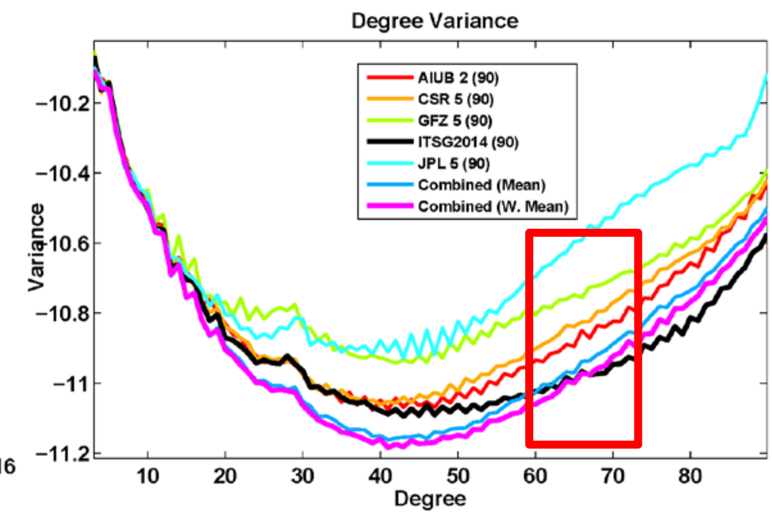
Median of time series of





Degree 90





Strange behaviors in degree 90 case

[Simulation Study] Objectives

- To investigate
  - **Impact of an Individual Solution** with
    - Very different levels of noise
    - Attenuated Signal
  - **Weighting schemes**
    - Another weighting scheme to overcome the limitations of current weighting schemes
- Presented in *EGU General Assembly 2016* (April 2016)

A Newly Tested Weighting Scheme

- In the last meeting, about the limits of current weighting schemes
  - Assumption: the ***arithmetic mean*** is close to the truth.
  - However, the ***reality*** may be not like that.
  - How to ***improve*** the weighting scheme?

- **Variance Component Estimation (VCE)**
  - Iterative process
  - Replacing **Arithmetic Mean → Weighted Mean**
    in computation of weights in each iteration step
  - Updating weights in each iteration step

[Simulation Study] Simulated Gravity Field Solutions

- **Reference gravtiy field**: extracted from a model

$$\hat{X}_{lm}(t) = \underbrace{a_{0_{lm}}}_{\text{Offset}} + \underbrace{a_{1_{lm}} \Delta t}_{\text{Trend}} + \underbrace{a_{2_{lm}} \sin \omega \Delta t + b_{2_{lm}} \cos \omega \Delta t}_{\text{Annual Signal}}$$

- **Simulated Individual Solutions**

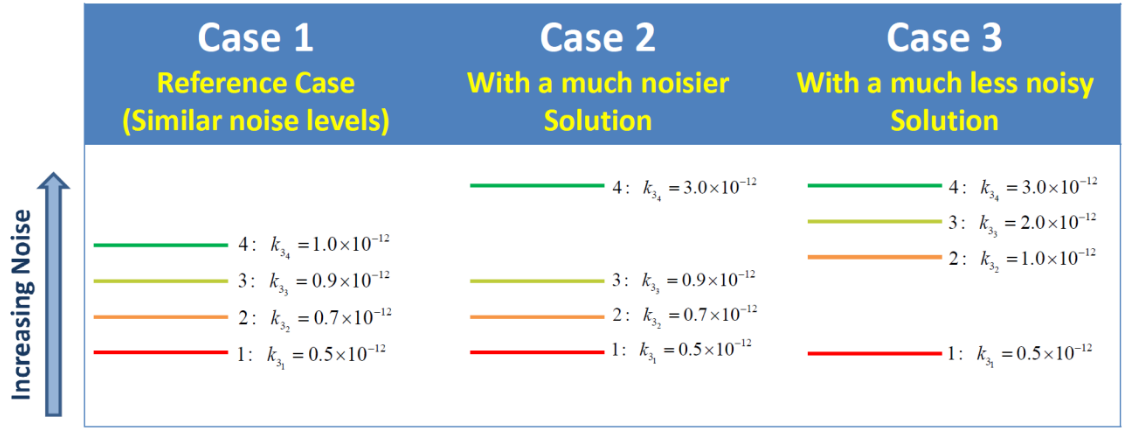
$$X_{i_{lm}}(t) = \mathbf{k_0} a_{0_{lm}} + \mathbf{k_1} a_{1_{lm}} \Delta t + \mathbf{k_2} (a_{2_{lm}} \sin \omega \Delta t + b_{2_{lm}} \cos \omega \Delta t) + \mathbf{k_3} \epsilon$$

Coefficient	Term	Scale Factor	In the simulation
a_0	Offset	k_0	Fixed
a_1	Slope (Trend)	k_1	Fixed
a_2, b_2	**Annual Signal**	**k_2**	**Varied**
1	**Random Error**	**k_3**	**Varied**

[Simulation Study] Cases (Four Indiv. Simul. Solutions / Case)

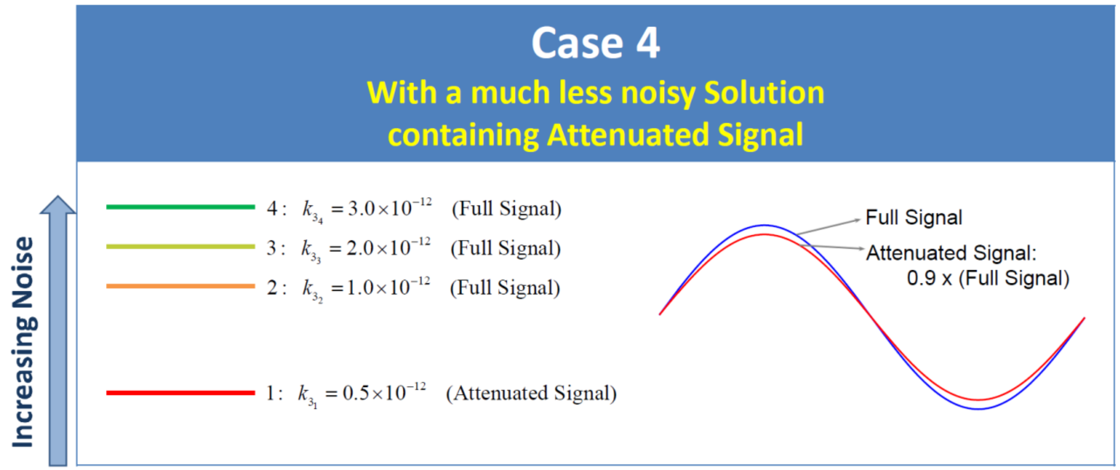
Noise :

Deviated Level of Noise

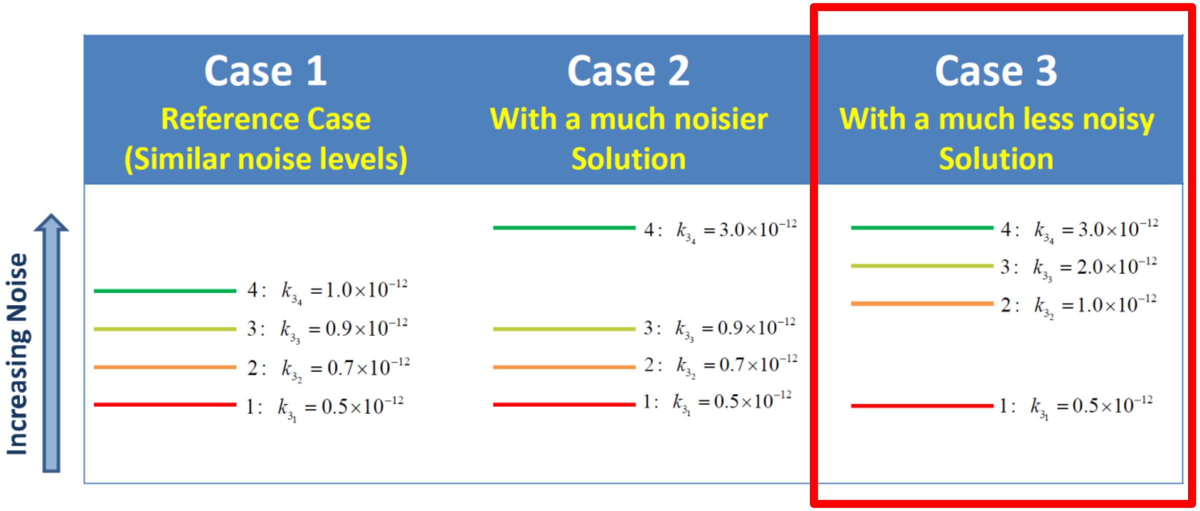


Systematic Error :

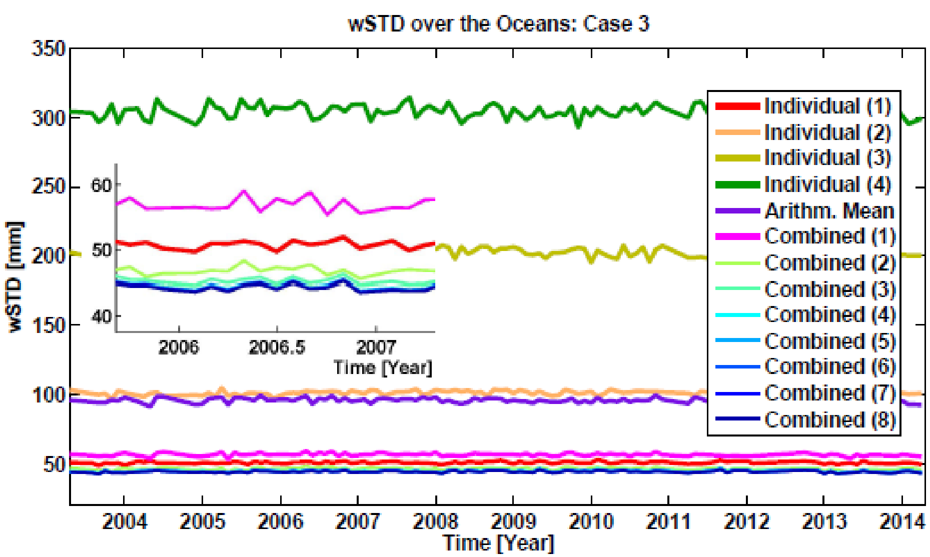
Attenuated Signal

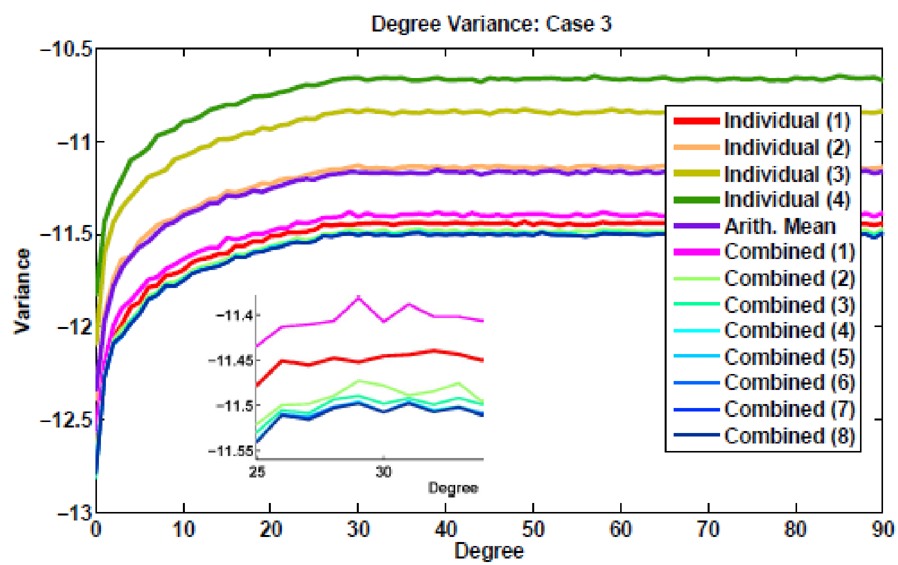


Case 3: With a Much-Less-Noisy Solution

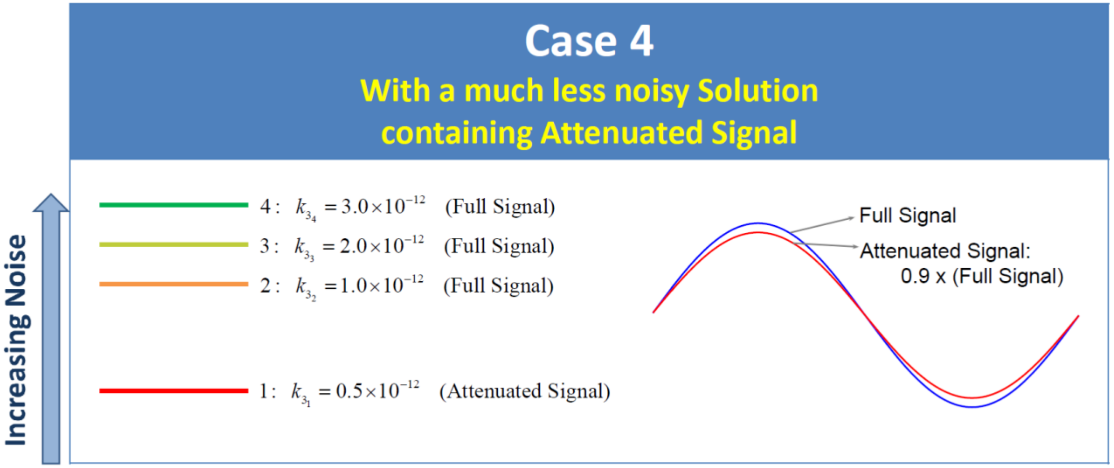


- Combined solutions after iterations have less noise than the individual solution with the least noise.

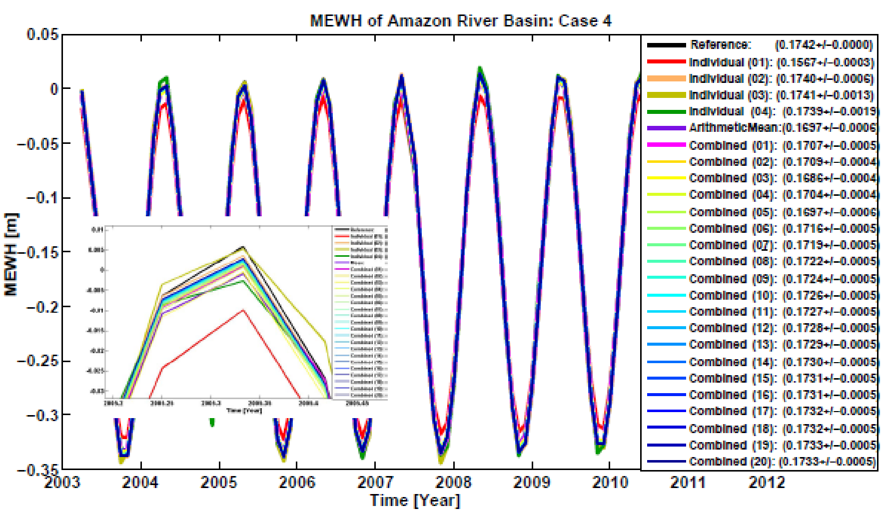


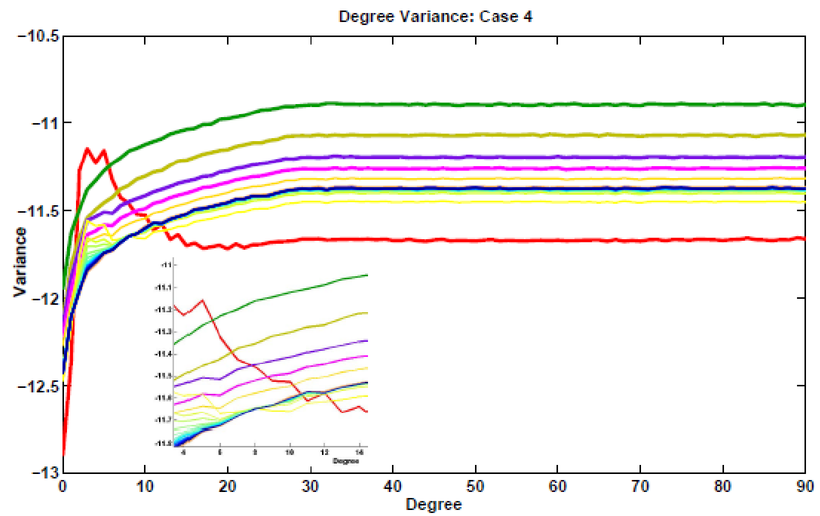


Case 4: Attenuated Signal



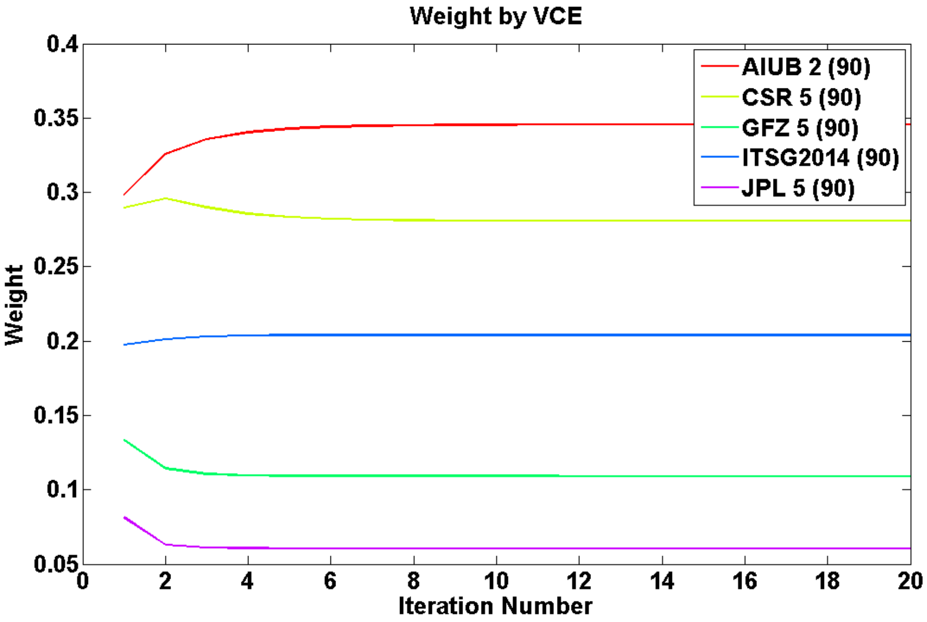
- Combined solutions after iterations have less noise than the individual solution with the second least noise.

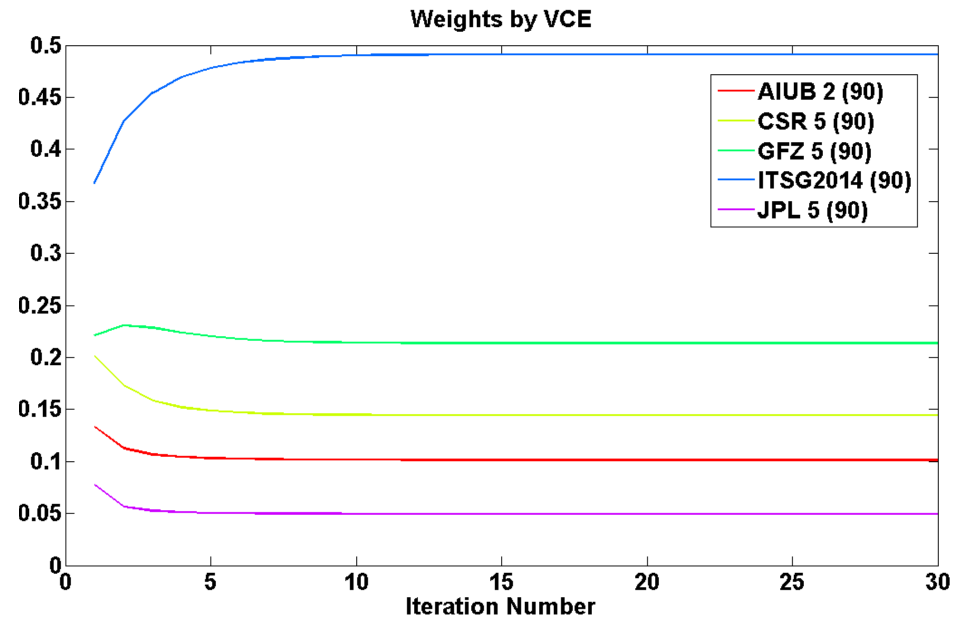




Real Combined Solutions using *VCE* Weighting Scheme

- Weights: (almost) Converging

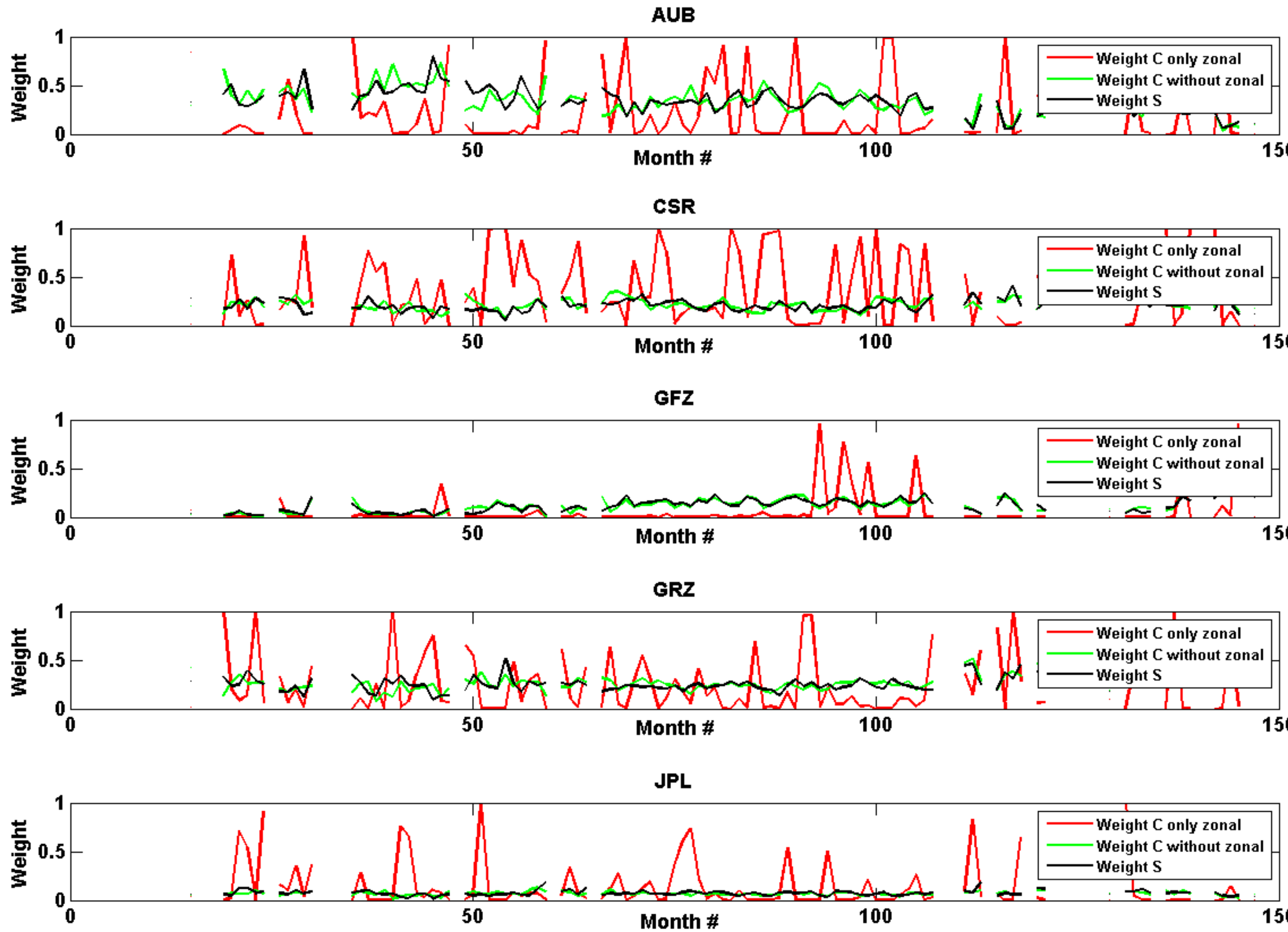




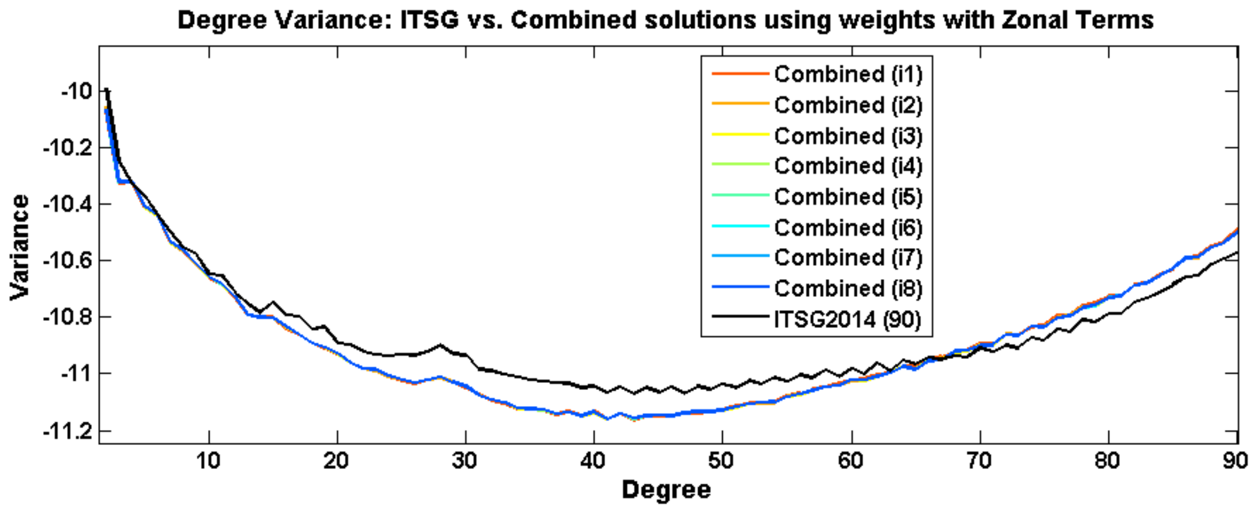
2007/08 **2014/03**

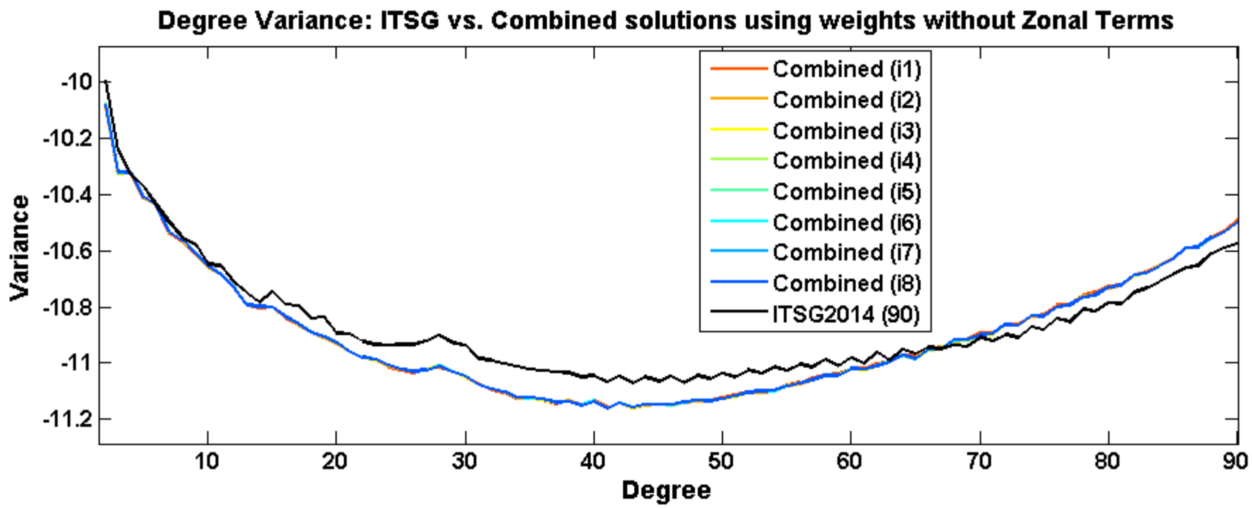
Weights using (*Only C*), (*Only S*), (*Only Zonal Terms*)

- Weights by **C coefficients (w/o Zonal Terms)** and that by **S coefficients** are similar.
- However, the **weights by only zonal terms** are very different.

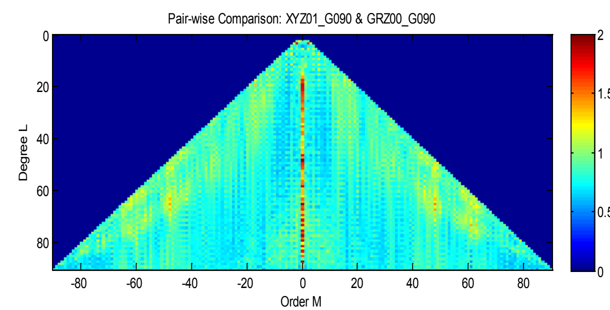


Weights *with* and *without* Zonal Terms



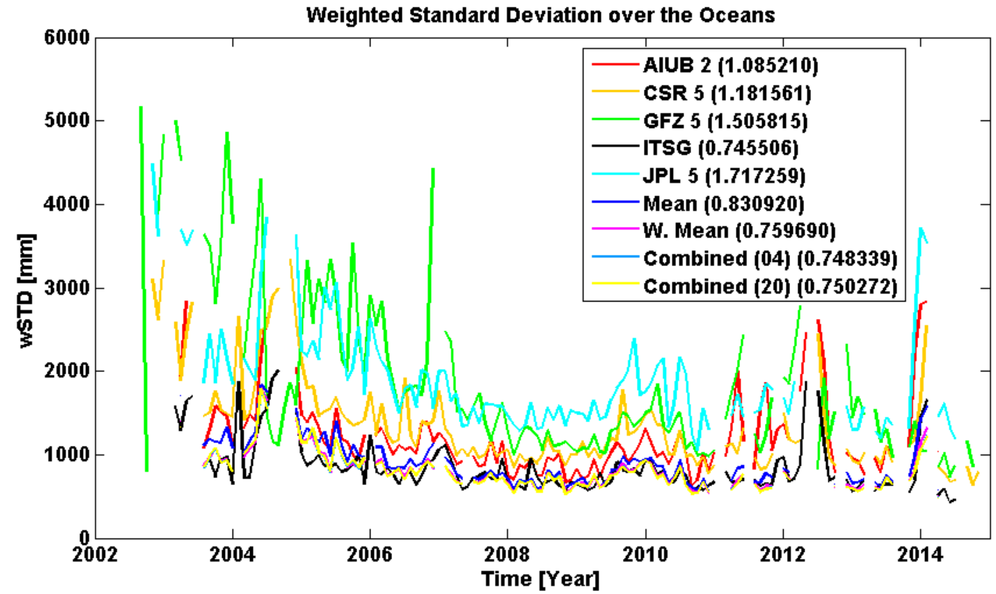


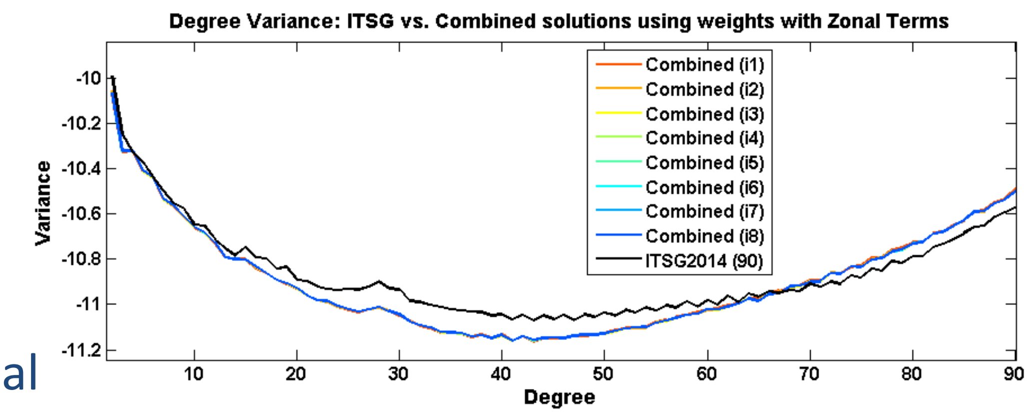
- Almost similar
- # of zonal coefficients: ***90***
- # of whole coefficients: ***4186***



Real Combined Solutions using VCE

Solution	Median of wSTD over the Oceans
AIUB	1.085210
CSR	1.181561
GFZ	1.505815
ITSG	**0.745506**
JPL	1.717259
Combined 01	0.756438
Combined 02	0.750095
Combined 03	0.750446
Combined 04	**0.748339**
Combined05	0.748382

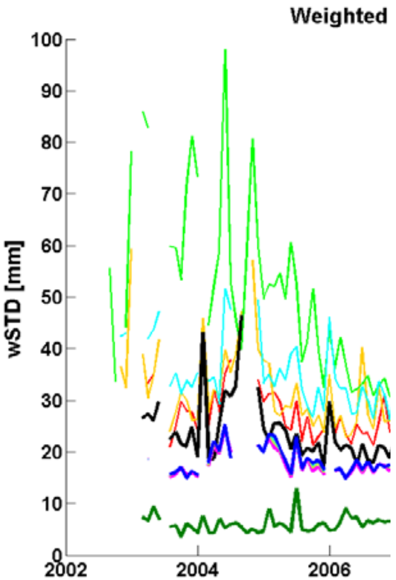


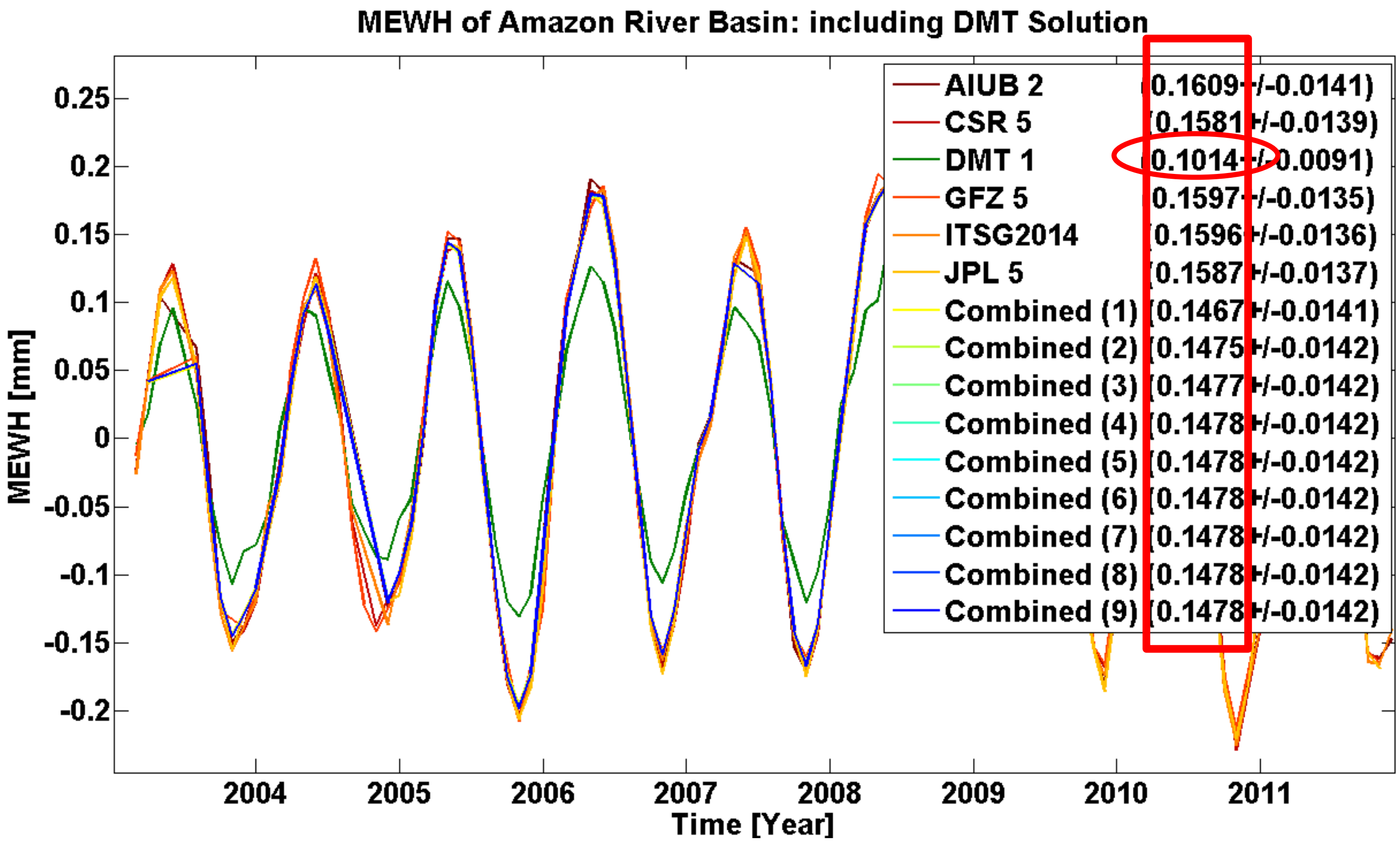


Combined solution using rough empirical weights (before optimization): **0.648336**

Inclusion of DMT Solution in Combination

- In *Simulation*: the attenuated signal could be recovered by VCE.
- In *this real case*: the attenuated signal cannot be fully recovered by VCE.



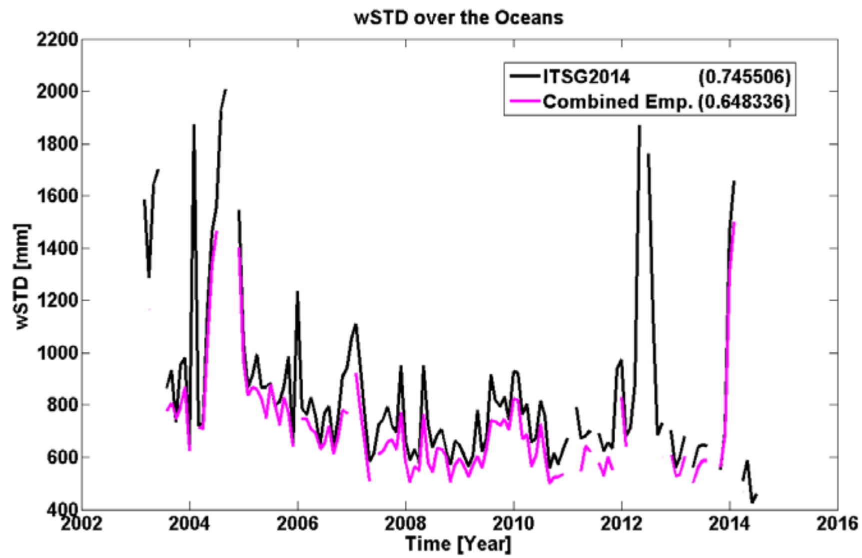


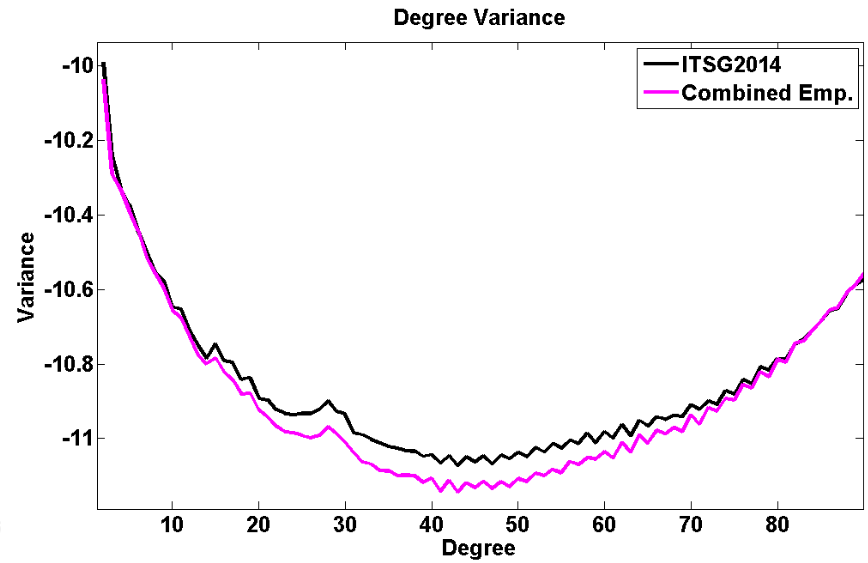
Conclusions: in Simulation and in Reality

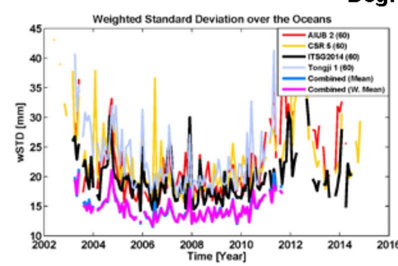
- A solution containing attenuated signal can
  - cause strange behavior from certain degree: cross point

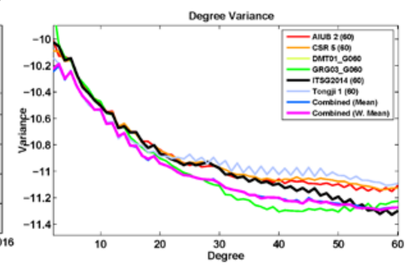
- Weighting scheme
  - In simulation study, the VCE works well. (only white noise)
  - In real case, benefits of VCE are limited due to systematic effect in noise.

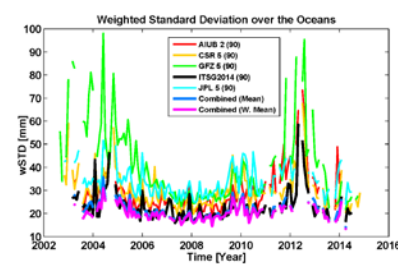
Combined Solution using Rough Empirical Weights

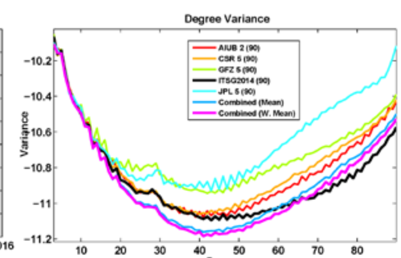












- Even before optimization:
  0.745506 vs. ***0.648336***
- Degree 90 combined solutions can be further improved.
- Mathematics + Signal contents

Final Report of WP 4.1 (~M18)

- Content related to **combination on solution level**
  - Availability and Preprocessing of GRACE Monthly Solutions
  - Comparison of GRACE Monthly Solutions
  - Combination of GRACE Monthly Solutions
  - Evaluation of GRACE Monthly Combined Solutions

Presentations / Publications

- Presentation in the EGU 2015 (Apr. 2015)
- Presentation in the Geodätische Woche 2015 (Sep. 2015)
- Contribution to presentation by Prof. Adrian Jäggi in the AGU meeting 2015 (Dec. 2015)
- Presentation in the EGU 2016 (Apr. 2016)

In progress:

- Manuscript for a journal article (to be submitted in the first half of 2016)
- Final Report of WP4.1 (until M18: End of June 2016)

Level 3 Products at GFZ

EGSIEM
European Gravity Service for Improved Emergency Management

Workshop on May 31 at GFZ with participants from GFZ, TU Dresden & AWI

Driven by the fact that

- AWI will support GRACE-FO backup launcher funding and shall receive scientific responsibilities (mainly for ice L3 products)
- With TU Dresden GFZ had planned earlier a cooperation on ice product generation

Objectives

- Define reasonable Level-3 products (which may be not just a copy of JPL Tellus) and responsibilities
- Timeline till SDS Readiness Review (June 2017)
- Next meeting October 4

Level 3 Products at GFZ

EGSIEM
European Gravity Service for Improved Emergency Management

Auxiliary products
- Degree-1 (CD)
- C20 (CD)
- GIA (Spher.Harm.) (VK)
- Consistent Love numbers (proposed by VK)
- Land/ocean/ice masks (AOD1B)

Global grid
- 1x1 (CD)
- [combination of land/ocean/ice grids]

Ocean (IB, HD)
- Global barostatic sea level
- Sea level pattern (1x1 grids)
- Ocean dynamics (1x1 grids)

Hydrology (CD, LZ, HD, AG)
- 1x1 grids
- basins
- [customized basins]
- [Separation of individual storage compartments]

Solid Earth (VK)
- Elastic deformation
- GIA trends

Ice (IS, MH, VK)
- Greenland, Antarctica
- [Major glaciers & ice caps]
- Basins
- Polar-stereographic grid

Verification & Error estimation
- should be done by corresponding product generators

EGSIEM

European Gravity Service for Improved Emergency Management

Title: **Improved Level 2 products**

Presenter: TMG

Affiliation: TUG

EGSIEM Meeting Potsdam,
02.06.2016 - 03.06.2016

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

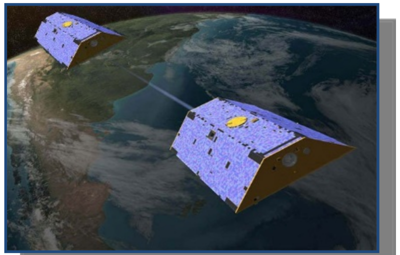
Motivation

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

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

GRACE observations

GRACE observes the total mass change



Level 2 should reflect this

Level 2 should include additional models for signal seperation

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

Ice

Ocean

Atmosphere

Solid Earth

A possible new definition of Level 2 products

GRACE Level 2 product (GSM)

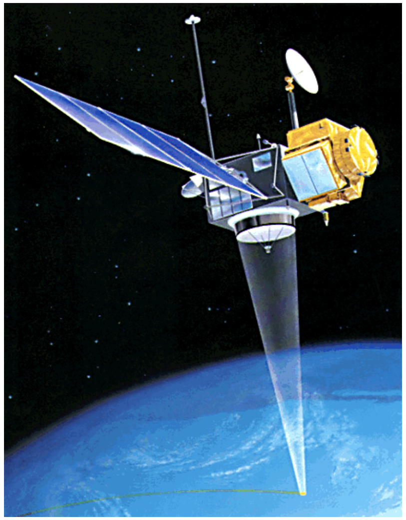
- Gravitational potential generated by the complete mass of the Earth

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

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

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

- Inverse barometric effect
- Ocean tides
- Geoid



Definition

In the reference system community:
Distinction between:

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

GRACE: only realizations without theoretical definition

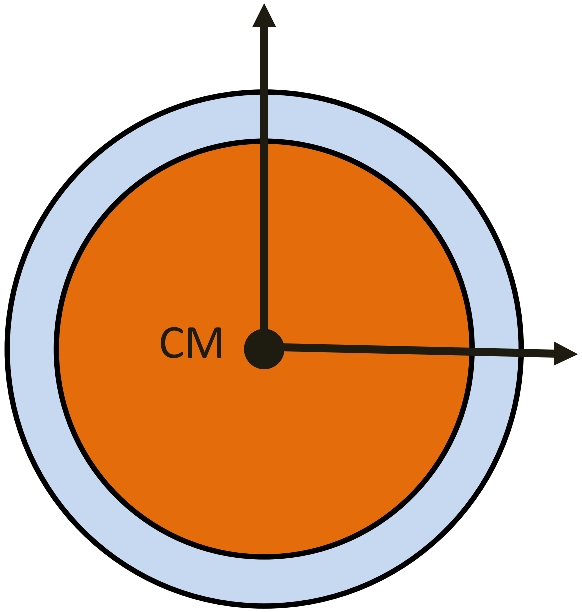
Proposal of a theoretical definition:
GRACE monthly solution (GSM)

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

Geocenter motion

Center of mass (CM)

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



Geocenter motion

Center of mass (CM)

- The degree 1 terms of the sum of all masses do not change (set to zero)
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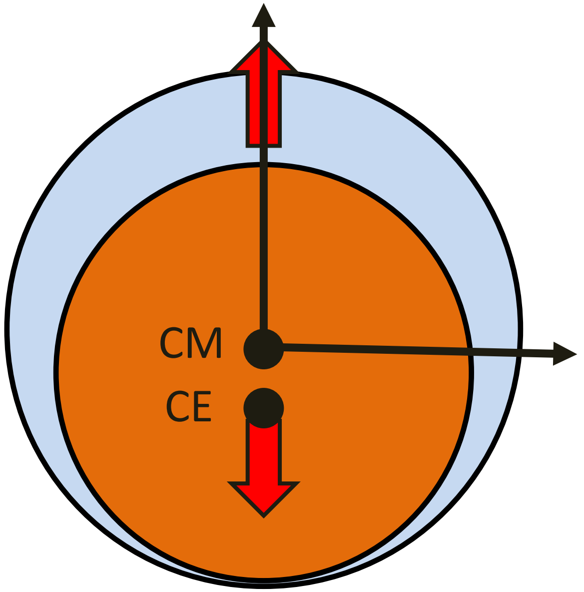

Center of solid Earth (CE) / Center of figure (CF)

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

Transformation from CM to CE

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

$\Rightarrow$ Signal separation problem
$\Rightarrow$ Cannot provided by GRACE only
$\Rightarrow$ Model / external data needed

For hydrology apps.: remove solid earth and ocean

For ocean apps.: remove solid earth and hydrology

Geocenter motion

Center of mass (CM)

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

Center of sol

- The degre
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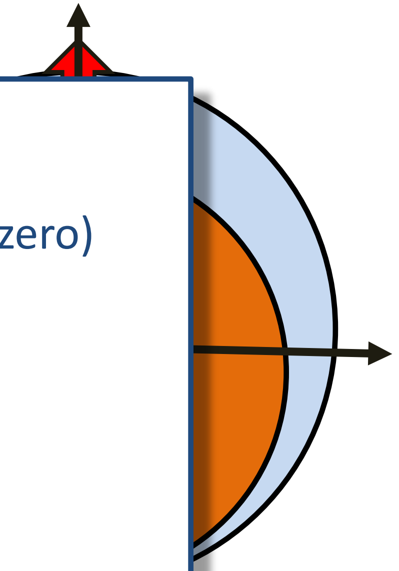
Transformati

Must remove
the degree 1
⇒ Signal sep
⇒ Cannot provided by GRACE only
⇒ Model / external data needed



GRACE Level 2:

- GRACE monthly solution (GSM) in CM (degree 1 set to zero)
  - Contains all mass variations
- Additional degree 1 products for signal separation
  - Solid earth
  - Ocean
  - Hydrology
  - Atmosphere

  (Provided by Tellus already)

For hydrology apps.: remove solid earth and ocean

For ocean apps.: remove solid earth and hydrology

Definition

In the reference system community:
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Proposal of a theoretical definition:
GRACE monthly solution (GSM)

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- Origin is the center of mass (CM)
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- Mean mass distribution of the complete month

Temporal average

Current definition

Average over all days with GRACE data

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

Proposal of a new definition

Average over the complete month

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

What is the consequence?

Example usage of GRACE: Validation/Comparison with other data

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

$\Rightarrow$ Computation the temporal average

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

Which definition did you used?

(Almost) all users treat GRACE products as monthly means

$\Rightarrow$ **Level 2 should respect this**

Temporal average

Current definition
Average over all days with GRACE data

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

Proposal of a new definition
Average over the complete month

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

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

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

Summary

We should make the GRACE Level 2 products more user friendly

- With a clear theoretical definition

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

- With additional monthly mean of models for signal separation

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

EGSIEM

European Gravity Service for Improved Emergency Management

Combination on Normal Equation Level

Ulrich Meyer (AIUB)

EGSIEM Progress Meeting # 3

GFZ Potsdam

June 2 – 3, 2016

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

Contents

- Why?
- How?
- First results!

Combination on Normal Equation Level

- To fully take into account correlations between gravity field, orbit, instrument and stochastic parameters, solutions have to be combined on normal equation level.
- All NEQs are based on common standards on reference frames, Earth orientation, relativity, and third bodies.
- Processing approaches, parametrization and background models are not harmonized.

Combination on NEQ-level is the special thing about the EGSIEM combination service!!!

NEQ-Format: SINEX

The information is stored in the following blocks:

- FILE/REFERENCE
- FILE/COMMENT
- SOLUTION/STATISTICS
- SOLUTION/ESTIMATE
- SOLUTION/APRIORI
- SOLUTION/NORMAL_EQUATION_VECTOR
- SOLUTION/NORMAL_EQUATION_MATRIX

SINEX: COMMENT and STATISTICS

- FILE/COMMENT:
  - earth_gravity_constant 3.9860044150e+14
  - radius 6.3781363000e+06
  - tide_system zero_tide / tide_free

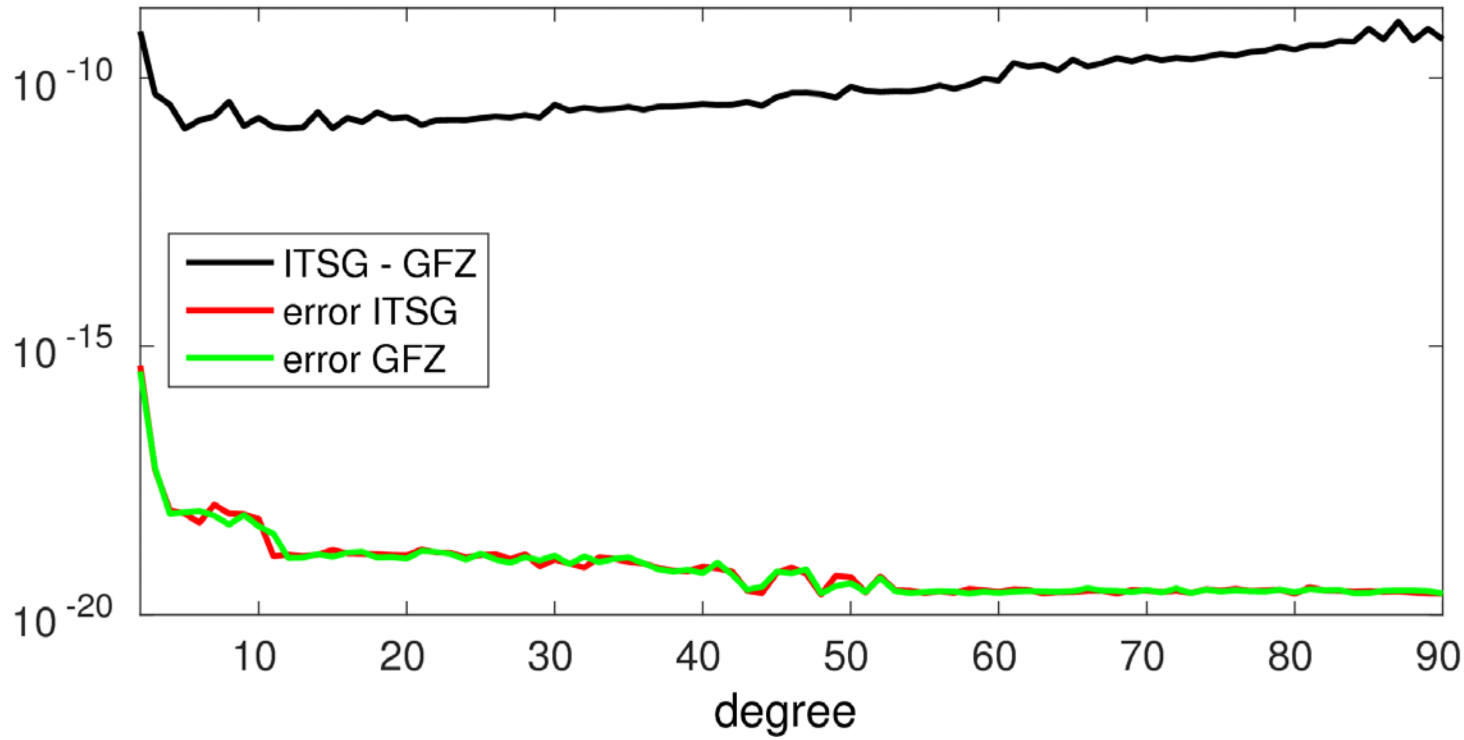
- SOLUTION/STATISTICS
  - NUMBER OF OBSERVATIONS 540481
  - NUMBER OF UNKNOWNS 8277
  - NUMBER OF DEGREES OF FREEDOM 532204
  - WEIGHTED SQUARE SUM OF O-C 5.1761025e+05

SINEX: Data

- SOLUTION/ESTIMATE
  - 1 CN 2 -- 0 06:016:43200 ---- 2 -4.84169160788564e-04 1.39923e-11
  - 2 CN 2 -- 1 06:016:43200 ---- 2 -3.41480150232469e-10 8.80419e-12
  - 3 SN 2 -- 1 06:016:43200 ---- 2 1.46383672520029e-09 8.37504e-12
- SOLUTION/APRIORI
  - 1 CN 2 -- 0 06:016:43200 ---- 2 -4.84169219812195e-04
  - 2 CN 2 -- 1 06:016:43200 ---- 2 -2.87591948230532e-10
  - 3 SN 2 -- 1 06:016:43200 ---- 2 1.47690500410210e-09
- SOLUTION/NORMAL_EQUATION_VECTOR
  - 1 CN 2 -- 0 06:016:43200 ---- 2 4.04254781162723e+11
  - 2 CN 2 -- 1 06:016:43200 ---- 2 -6.85974043792560e+11
  - 3 SN 2 -- 1 06:016:43200 ---- 2 7.71101358350703e+10

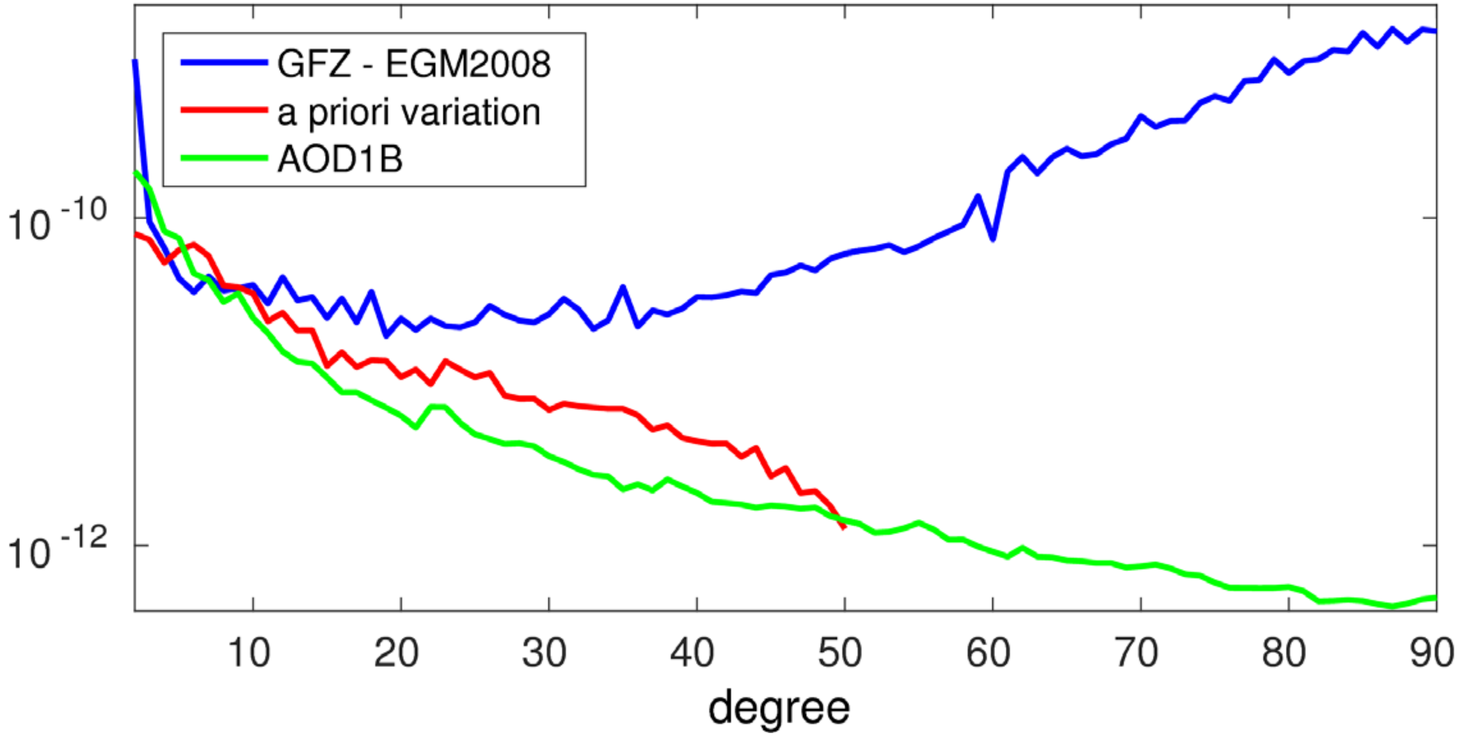
Test of consistency

NEQs are converted from SINEX to NQ0 and inverted by ADDNEQ2. The solution is compared to SOLUTION/ESTIMATE.



A priori values

- SOLUTION/APRIORI contains the a priori static gravity field (plus monthly mean of a priori temporal variations).
- Monthly mean of background or dealiasing models may be added (development during operational service phase).



Observables

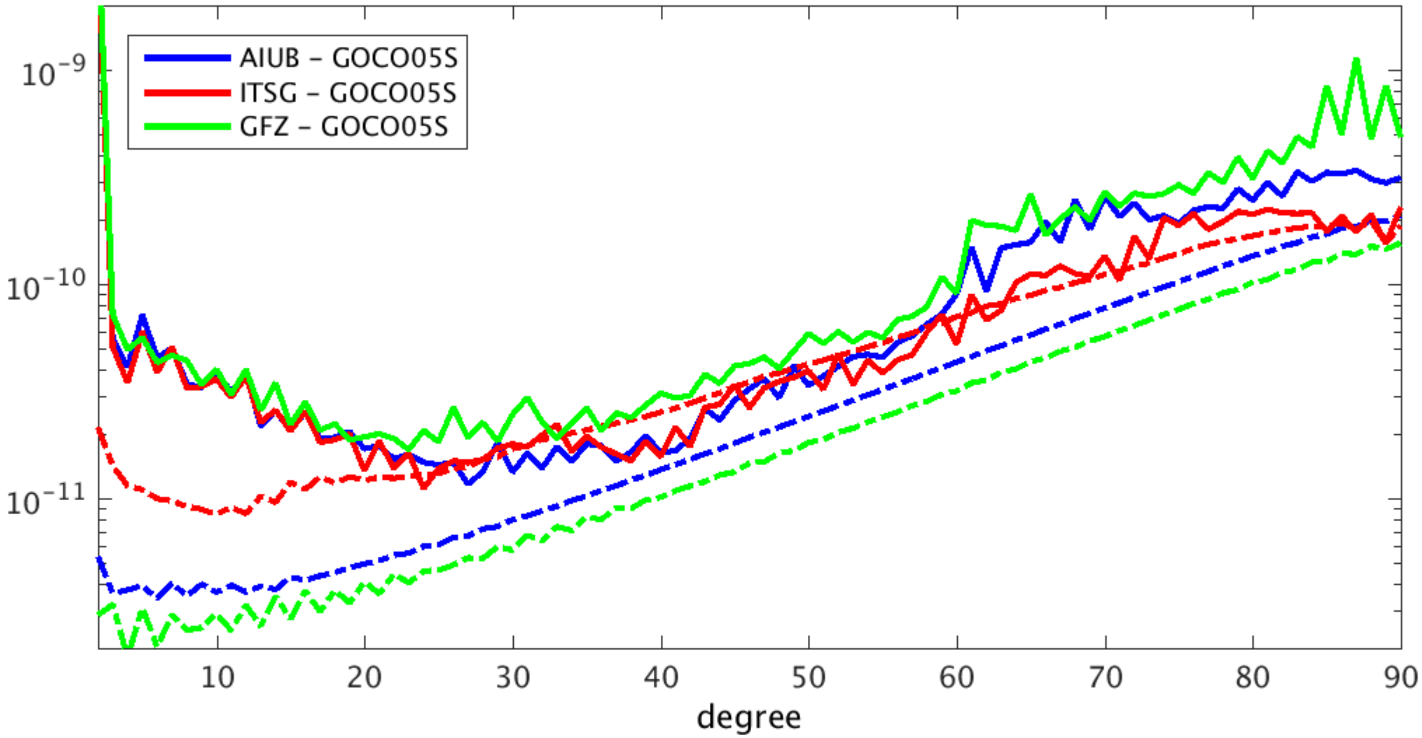
The individual NEQs are based on GPS phases (**GPS**) or kinematic satellite orbits (**POS**), K-band range-rates (**KRR**) (and pseudo-observations of instrument or arc-specific parameters).

f=15	S0	W_{KRR}	W_{GPS}	W_{POS}	W_{norm}
KRR	$S0_{KRR}$ = 3e-7 m s^{-1}	1	$S0_{GPS}^2 / S0_{KRR}^2$ = 1e10	$S0_{POS}^2 / S0_{KRR}^2$ = 1e12	$1 / S0_{KRR}^2$ = 1.11e13
GPS	$S0_{GPS}$ = f*2e-3 m = 0.03 m	$S0_{KRR}^2 / S0_{GPS}^2$ = 1e-10	1		$1 / S0_{GPS}^2$ = 1111.11
POS	$S0_{POS}$ = f*2e-2 m = 0.3 m	$S0_{KRR}^2 / S0_{POS}^2$ = 1e-12		1	$1 / S0_{POS}^2$ = 11.11
STOCH. ACCEL.	$S0_{cons}$ = 3e-9 s^{-2}	$S0_{KRR}^2 / S0_{cons}^2$ = 1e4	$S0_{GPS}^2 / S0_{cons}^2$ = 1e14	$S0_{POS}^2 / S0_{cons}^2$ = 1e16	$1 / S0_{cons}^2$ = 1.11e17

Observation types, sampling rates and relative weighting of observations may vary. For combination NEQs are normalized.

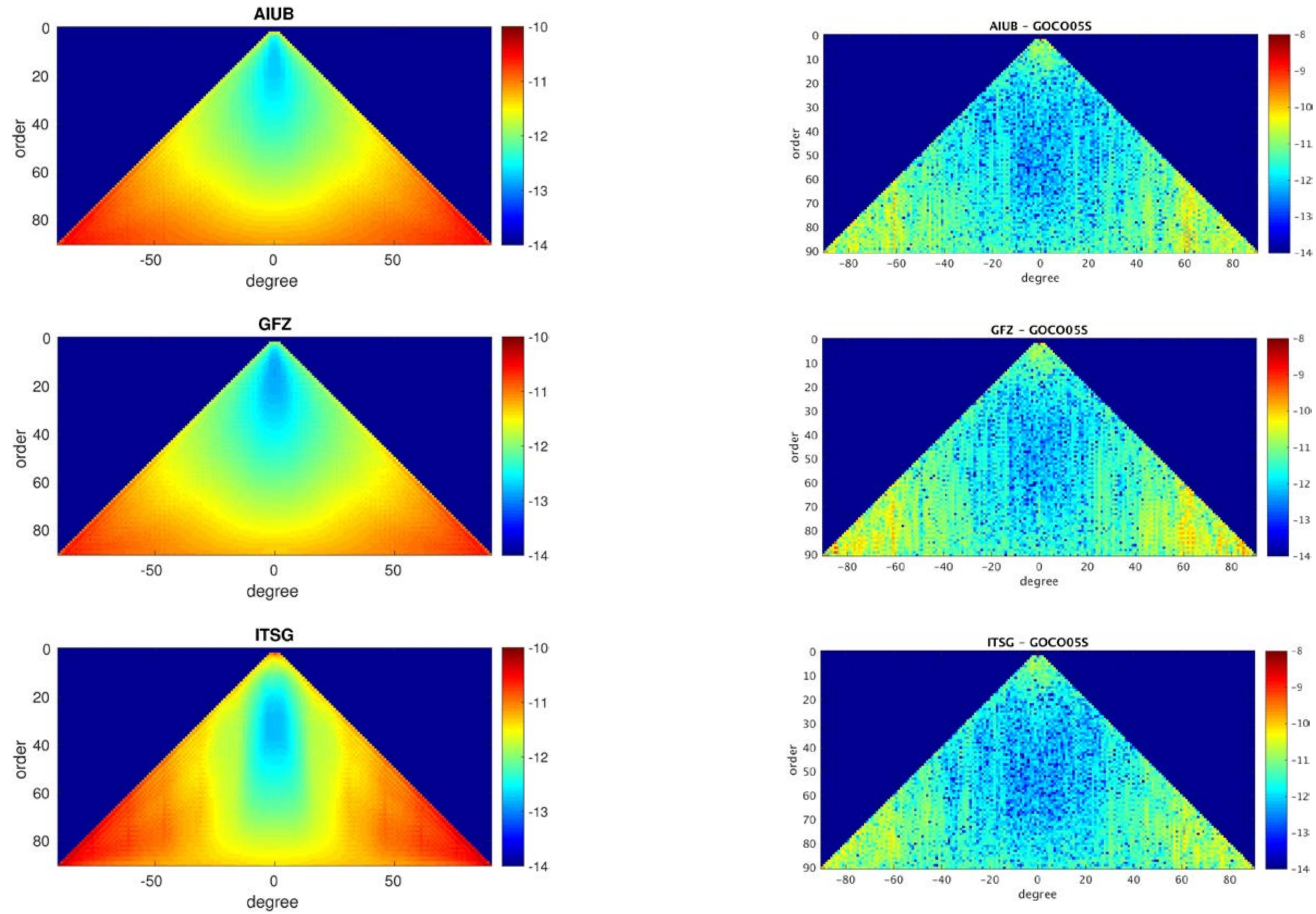
Noise model

Noise models and consequently formal errors vary significantly.

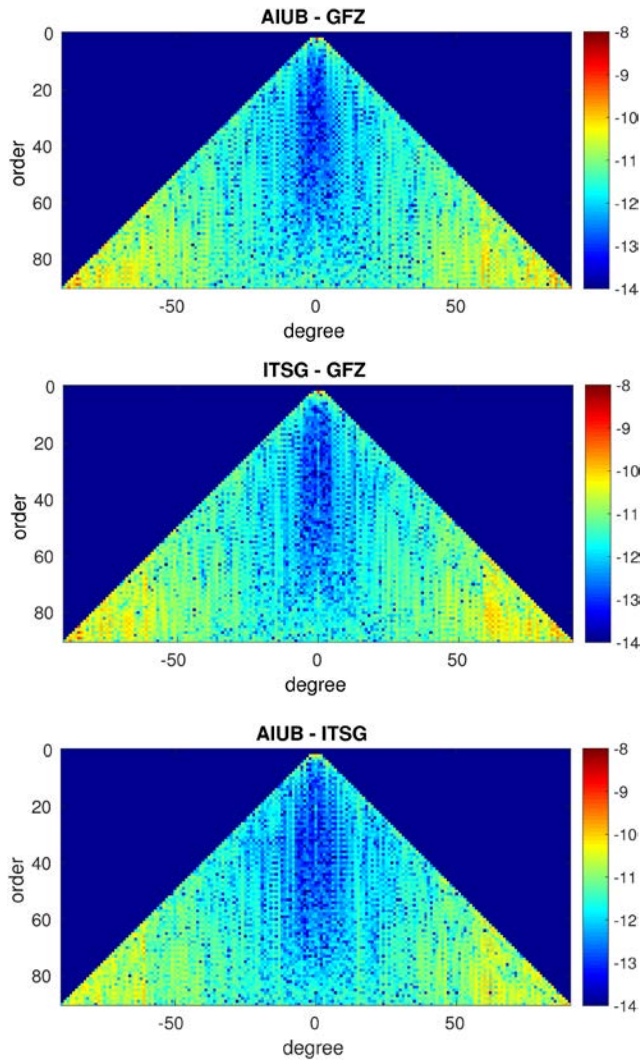


ITSG applies empirical co-variances, leading to realistic formal errors.

Formal Errors and Differences to GOCO05S

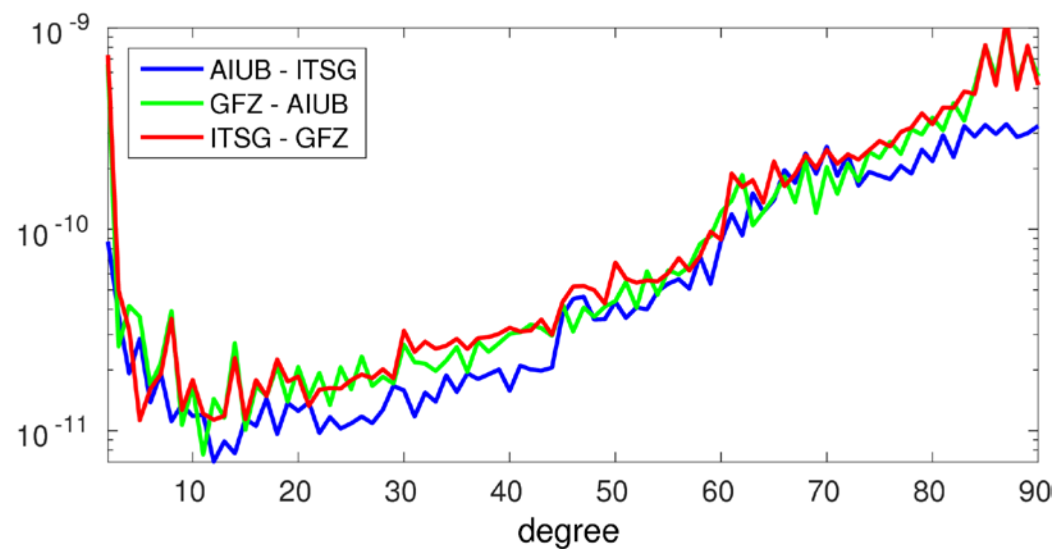


Comparison at solution level



- The consistency between AIUB and ITSG is higher than to GFZ.

- ITSG zonal coefficients differ due to sensor fusion ATT + ACC.



Individual contributions: AIUB, GFZ, ITSG

Observables:

- AIUB: 1016763 (POS at 30s, KRR at 5s)
- GFZ: 2691802 (GPS at 30s, KRR at 5s)
- ITSG: 540481 (POS at 300 s, KRR at 5s)

Parameters:

- 8277 (gravity field coefficients of degrees 2 to 90)

All orbit, instrument or stochastic parameters are pre-eliminated (**and statistics corrected accordingly**).

Degree 1 terms have to be handeled consistently. They may be set to zero / fixed at their specific a priori values (**0**) by AIUB.

Relative weights from NEQ statistics

Relative weights are based on a posteriori RMS:

$W = S_0^2 / RMS^2 = 1 / RMS^2$ (in case of normalization)

$RMS^2 = \mathbf{v^T P v} / DOF$

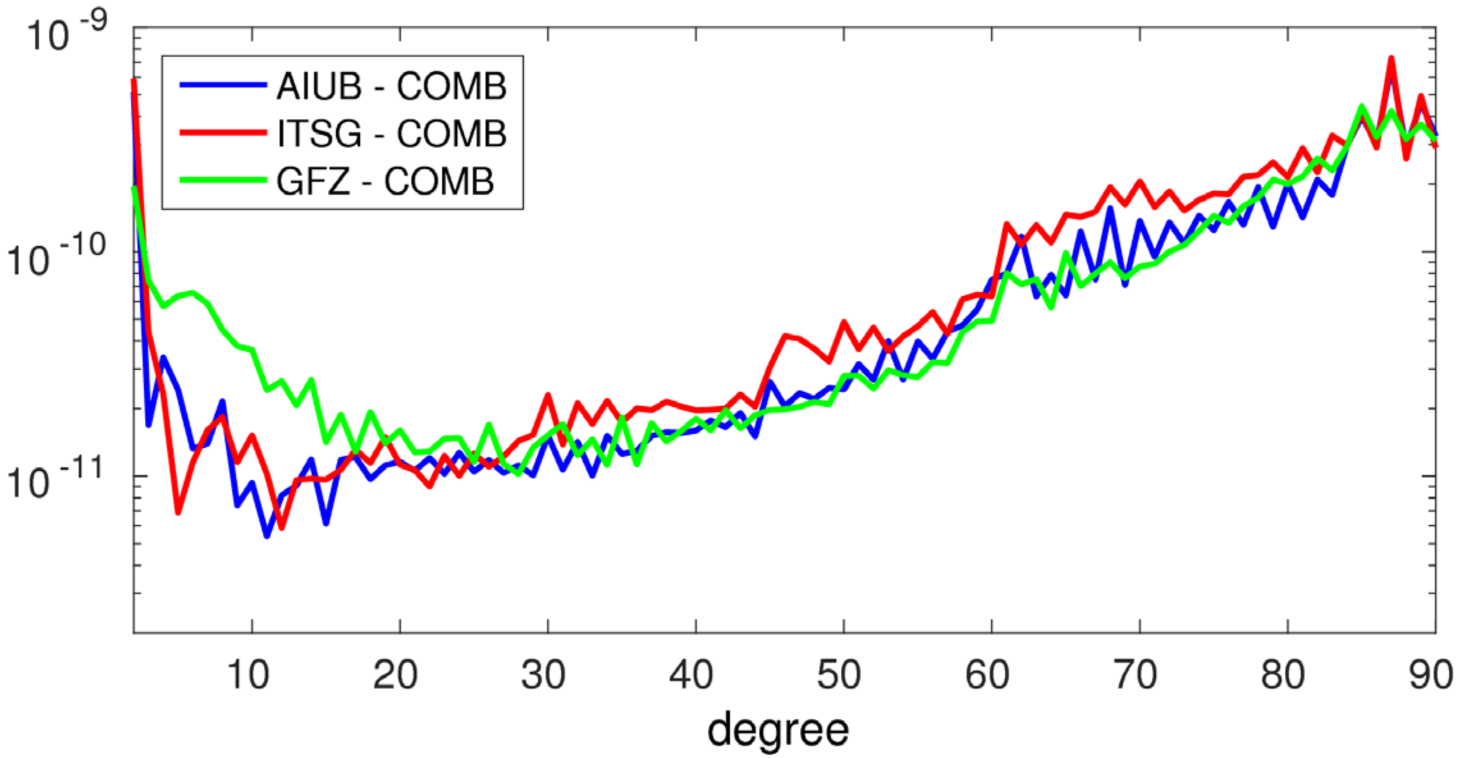
$DOF = n_{obs} - n_{par}$ (corrected for pseudo-observations /pre-eliminated parameters)

$\mathbf{v^T P v} = \mathbf{l^T P l} - \mathbf{dx^T b}$ with **v** = residuals, **l** = observations, **P** = weights, **dx** = ESTIMATE – APRIORI, **b** = NORMAL_EQUATION_VECTOR

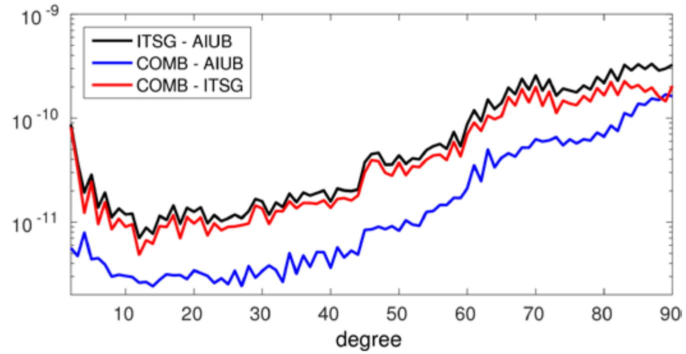
$S_0 = 1$	DOF	$l^T P l$	$v^T P v$	RMS	S_0^2/RMS^2
AIUB	1008486	178615	161893	0.40	6.25
GFZ	2683525	2599539	2065152	0.88	1.30
ITSG	532204	517610	495045	0.96	1.08

Combination: AIUB + GFZ + ITSG

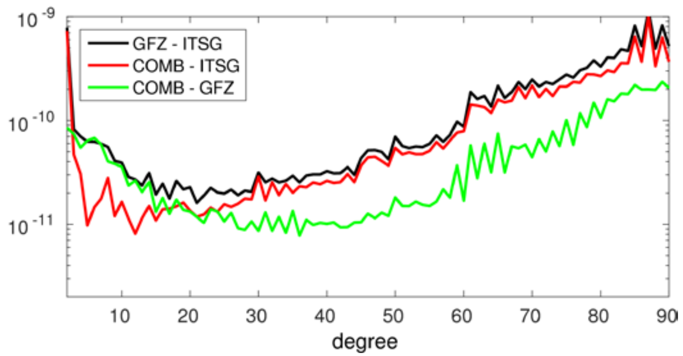
- A combination based on NEQ-statistics leads to a down-weighting of ITSG relative to AIUB and GFZ.
- GFZ contributes less to low degree coefficients.



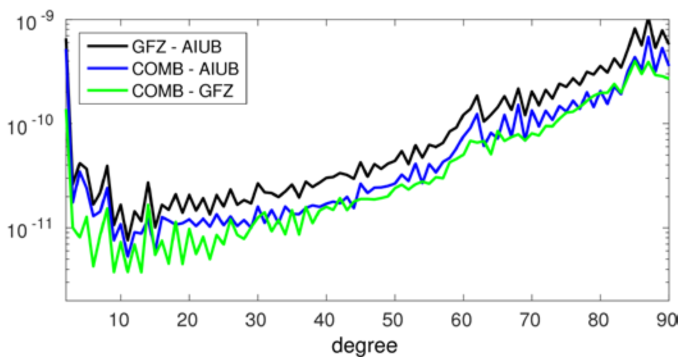
Combination: individual contributions



AIUB and ITSG contributions run parallel, but ITSG is punished for realistic error levels.



GFZ contributes little at low degrees to combination with ITSG, but dominates middle to high degrees.

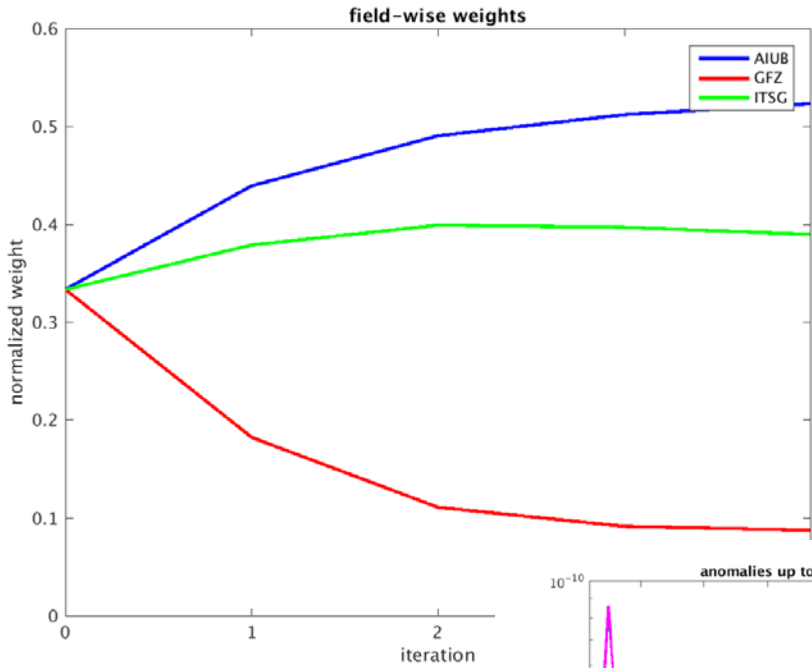


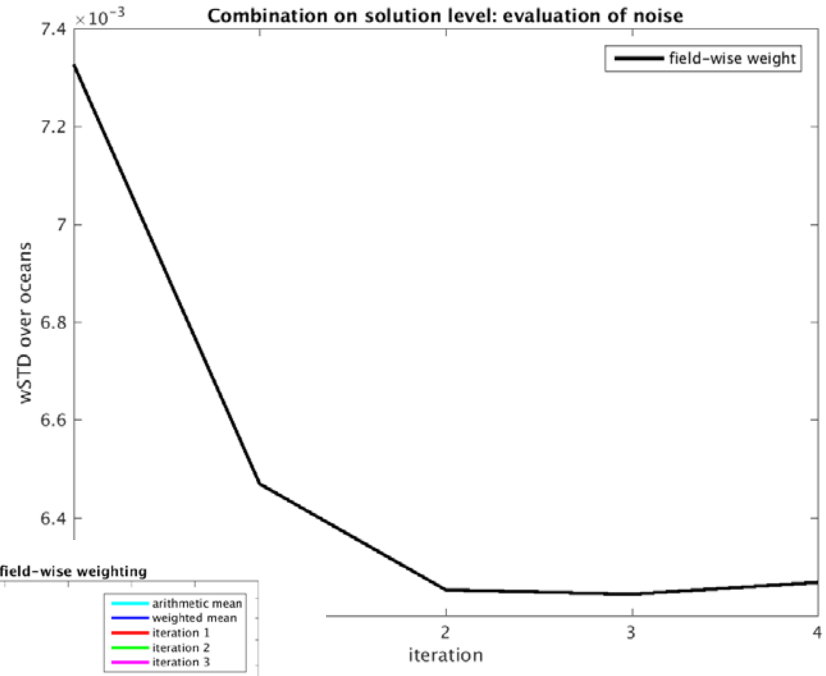
Weights perform best for AIUB + GFZ combination, individual contributions correspond to relative levels of formal errors.

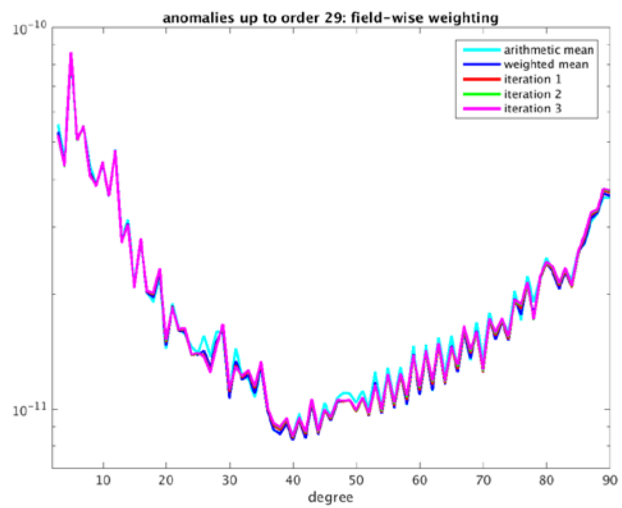
Combination Results

- Solution level
- NEQ level

Combination on solution level: weights (VCE)



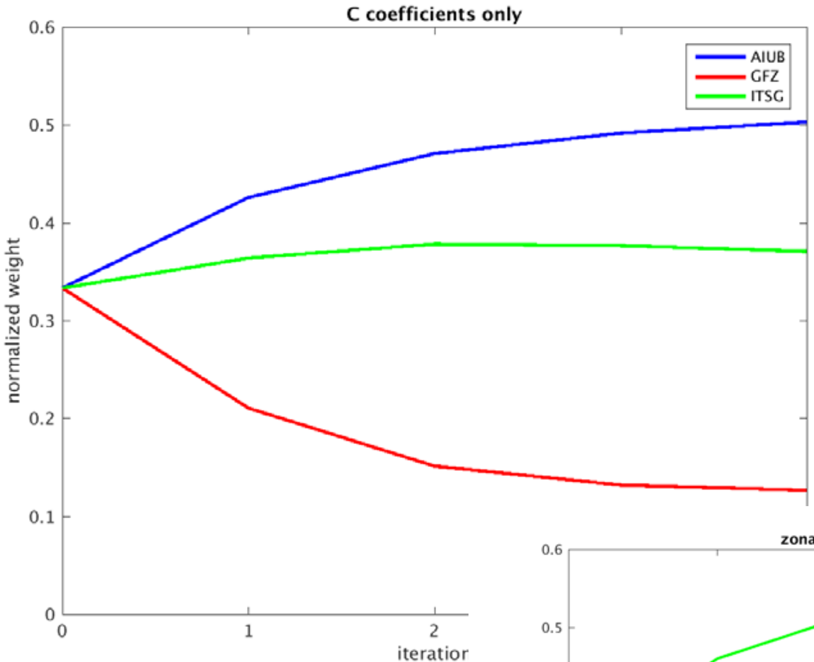




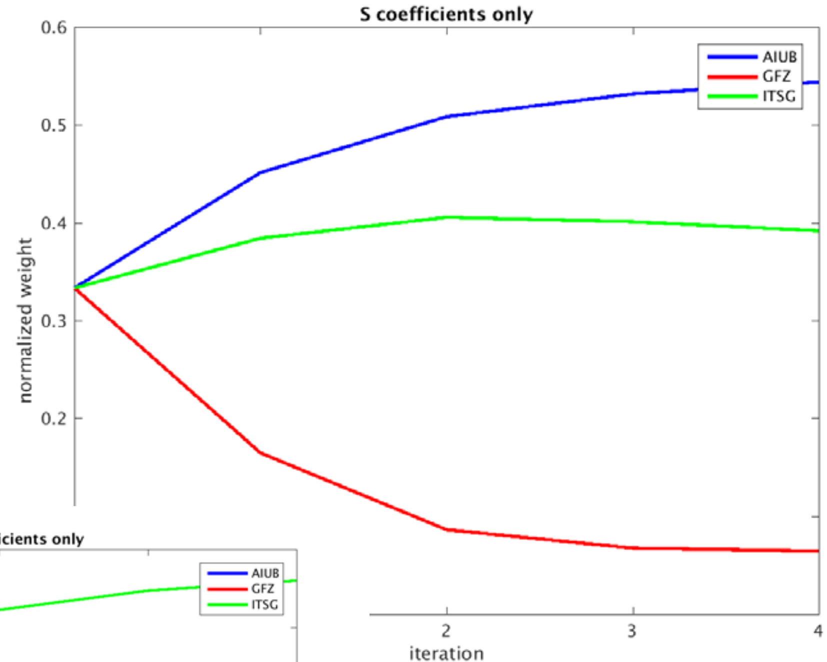
wSTD oceans:

- AIUB: 8.2e-3
- GFZ: 14.4e-3
- ITSG: 5.5e-3

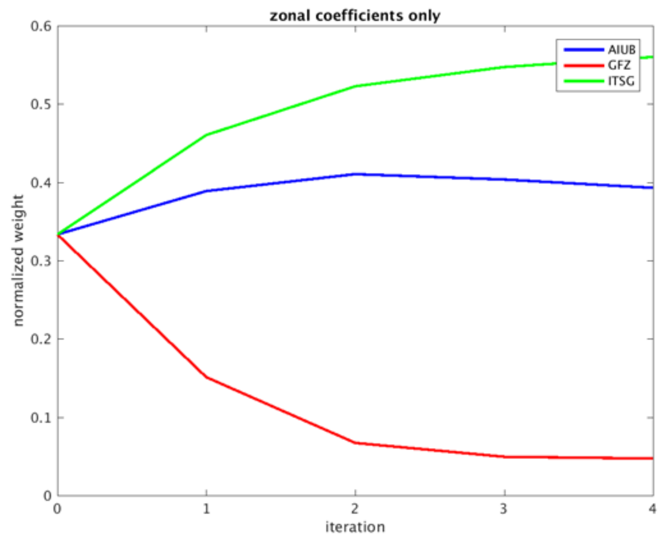
Are the weights characteristic for whole spectrum?



4094 coefficients



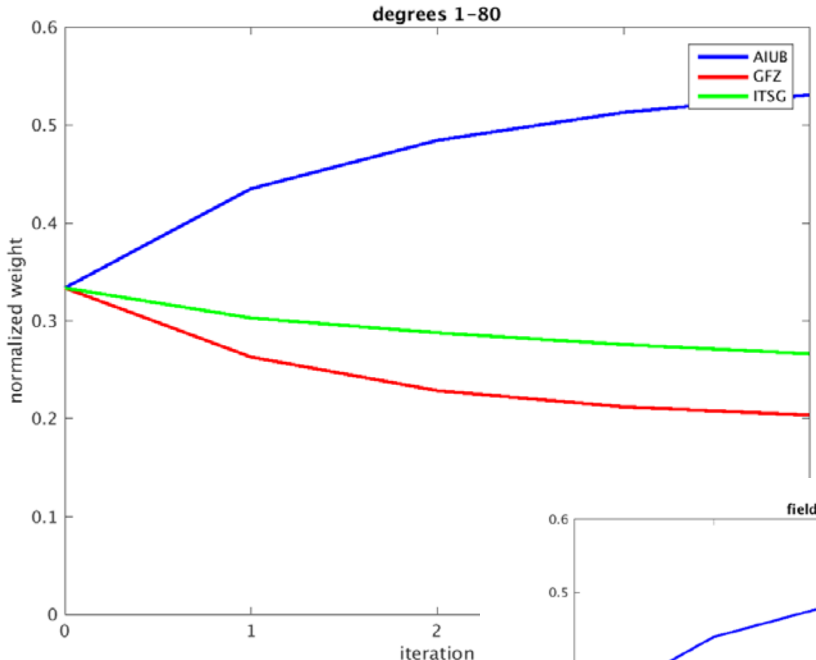
4094 coefficients



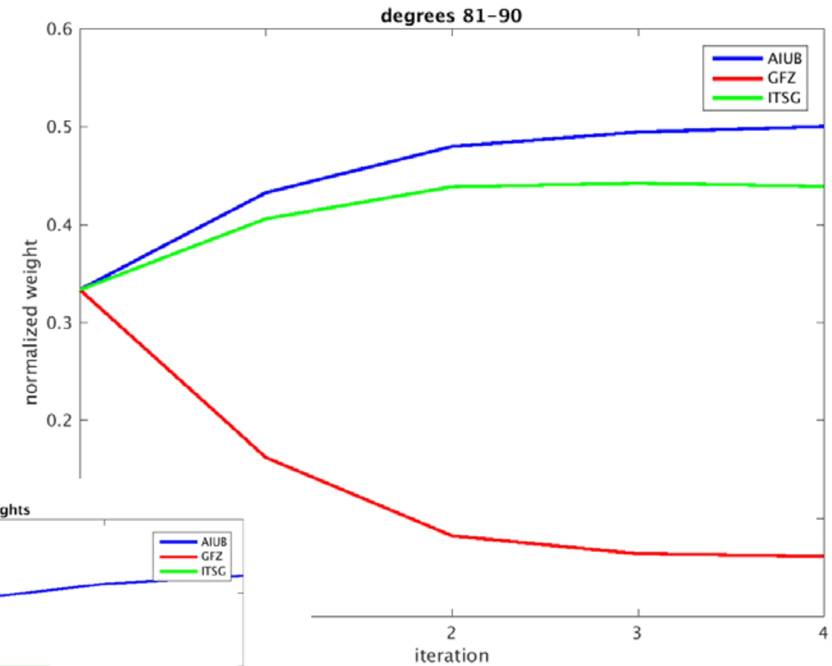
89 coefficients

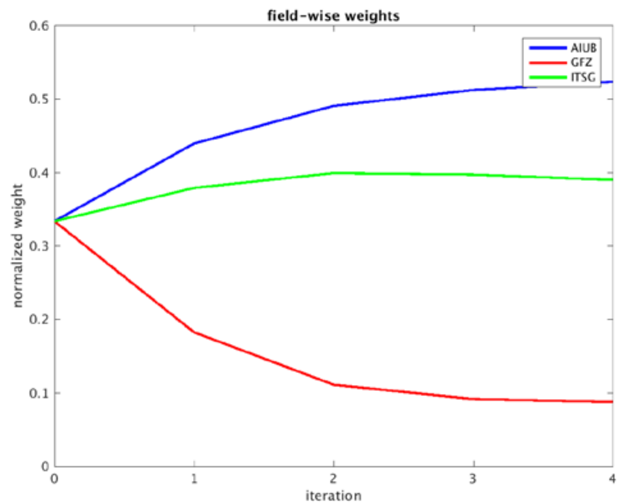
Are the weights characteristic for whole spectrum?

6557 coefficients



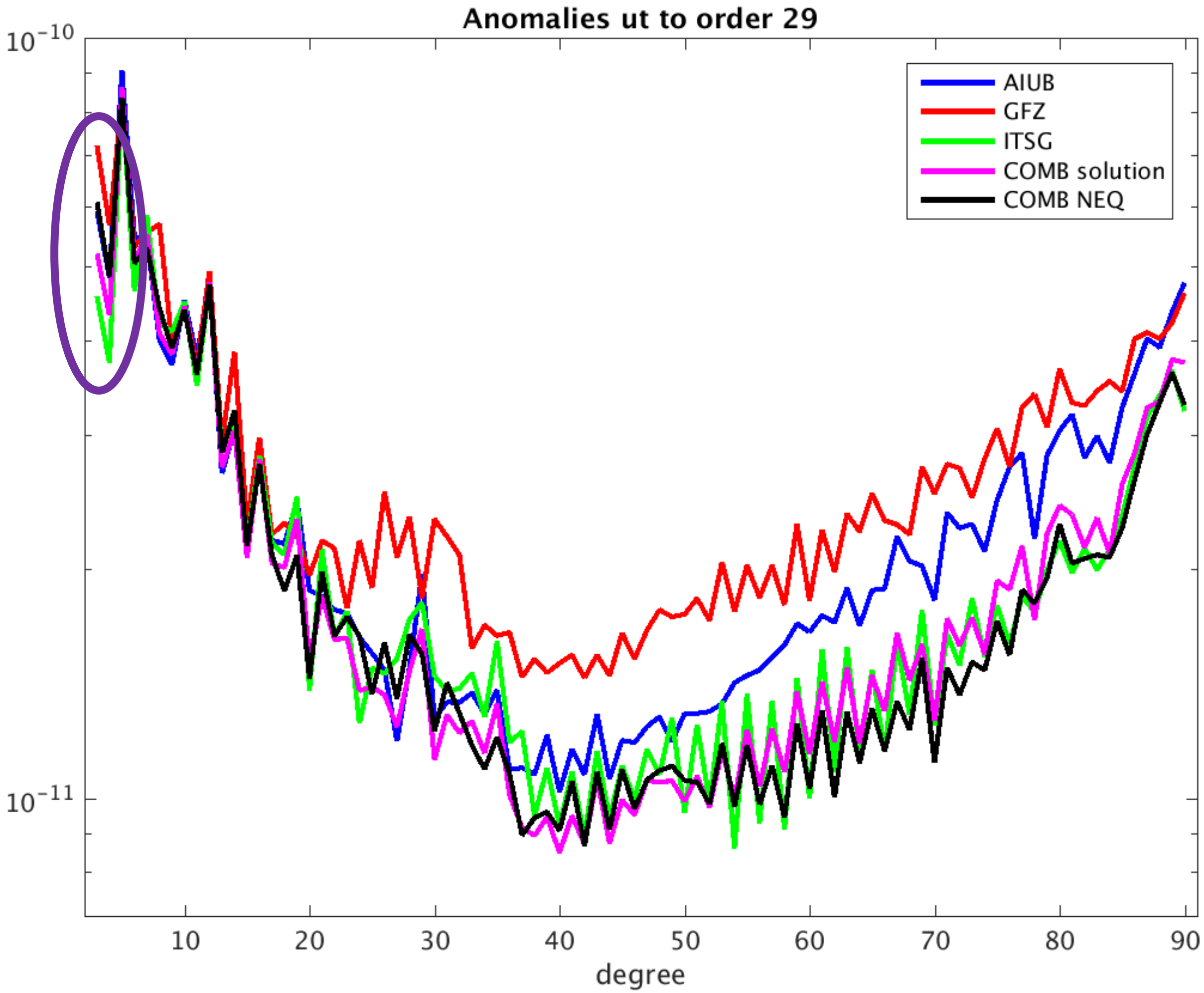
1720 coefficients





All (8277) coefficients

Combination on NEQ level: weights from solutions

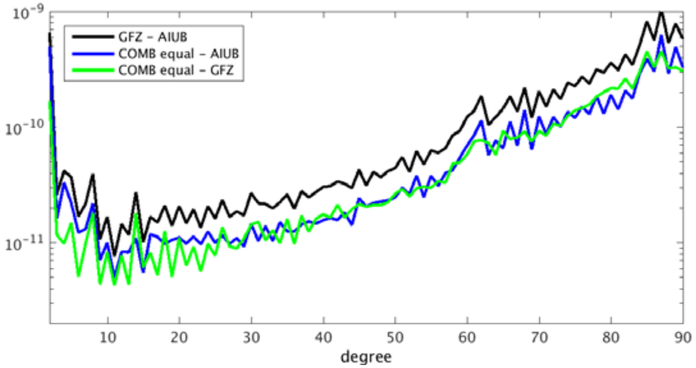


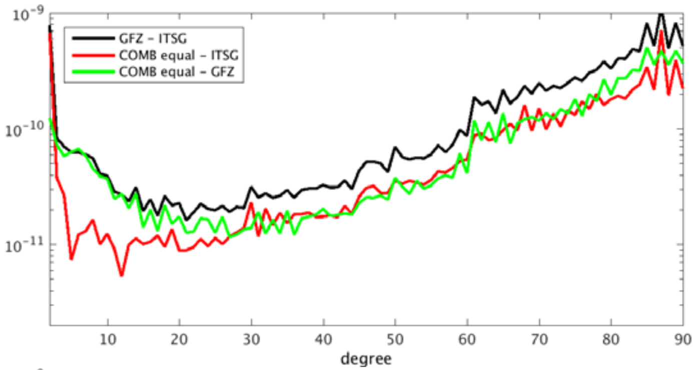
wSTD oceans:

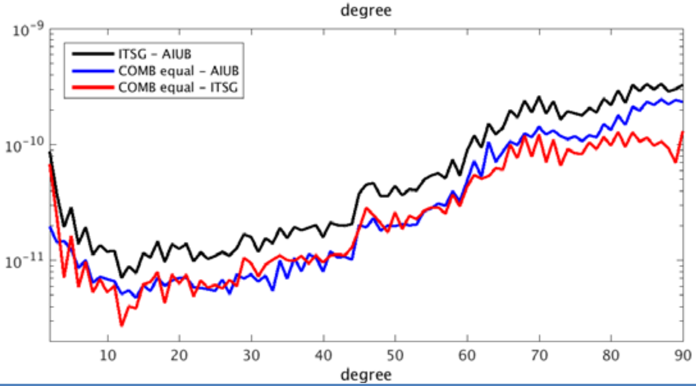
- AIUB: 8.2e-3
- GFZ: 14.4e-3
- ITSG: 5.5e-3

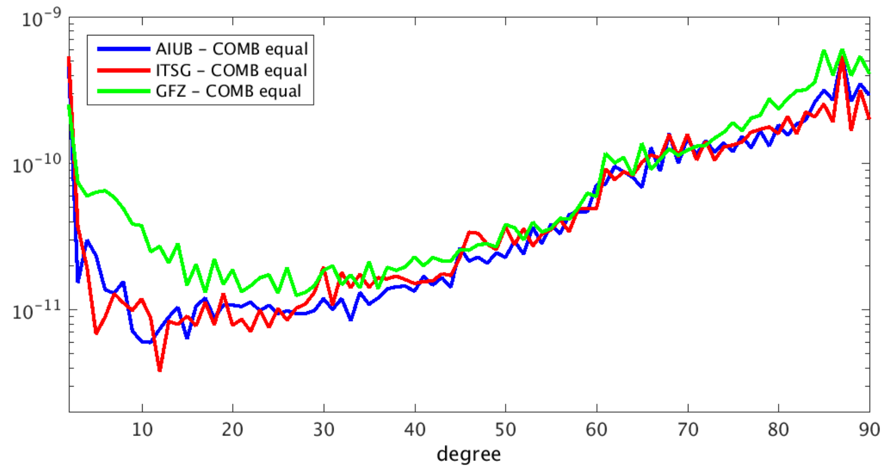
- SOL: 6.3e-3
- NEQ: 7.7e-3

# Equal contribution by empirical weighting









Empirical * solution derived relative weights

Equal contribution is approx. reached for relative weights of

- AIUB: 6.25
- GFZ: 1 (instead of 1.30)
- ITSG: 5 (instead of 1.08)

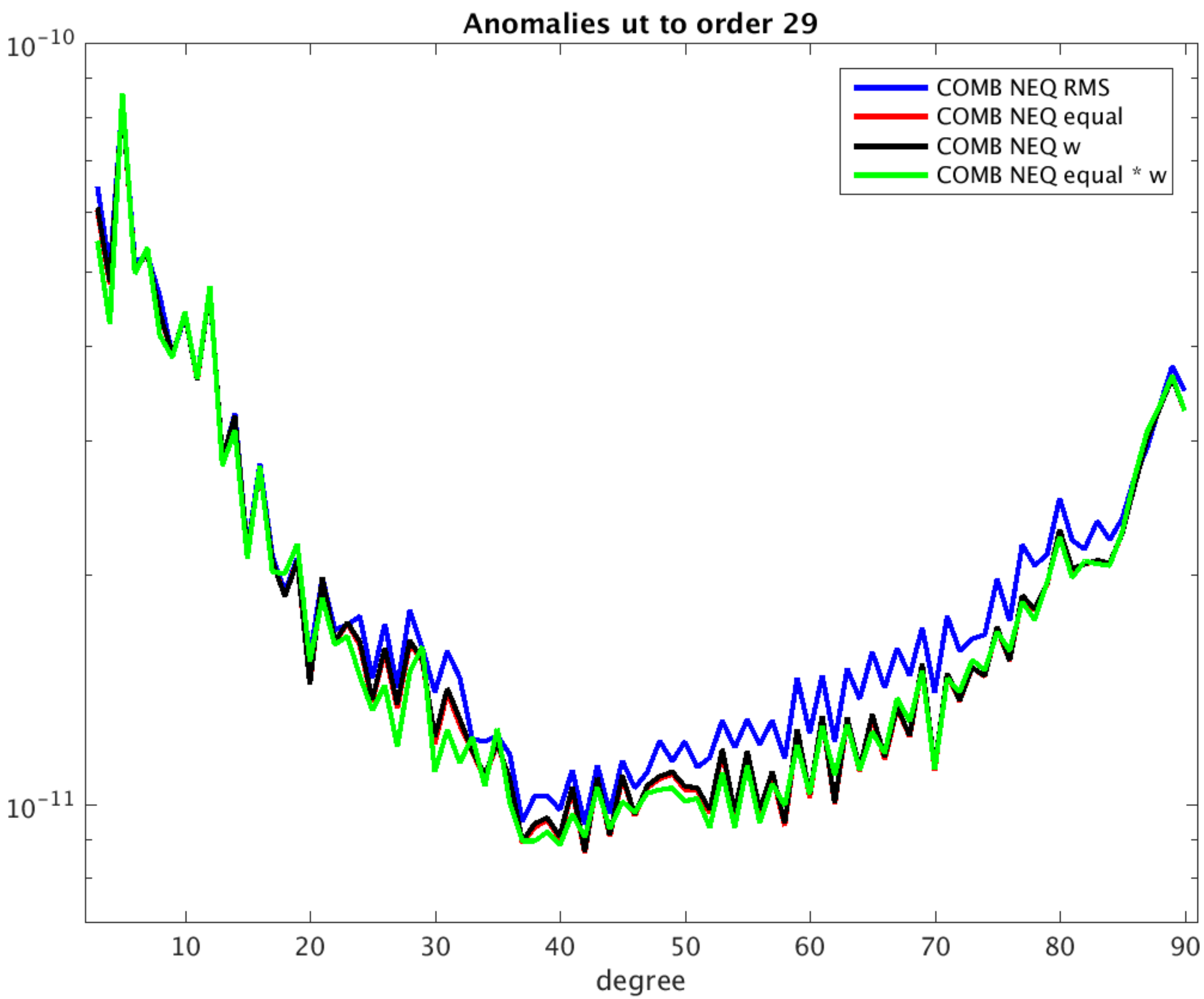
Comparison at solution level leads to

- AIUB: 0.51 ≙ 5.67
- GFZ: 0.09 ≙ 1
- ITSG: 0.40 ≙ 4.44

Weighting corresponding to solution level is reached by

- AIUB: 6.25 * 5.67 = 35.44
- GFZ: 1
- ITSG: 5 * 4.44 = 22.20

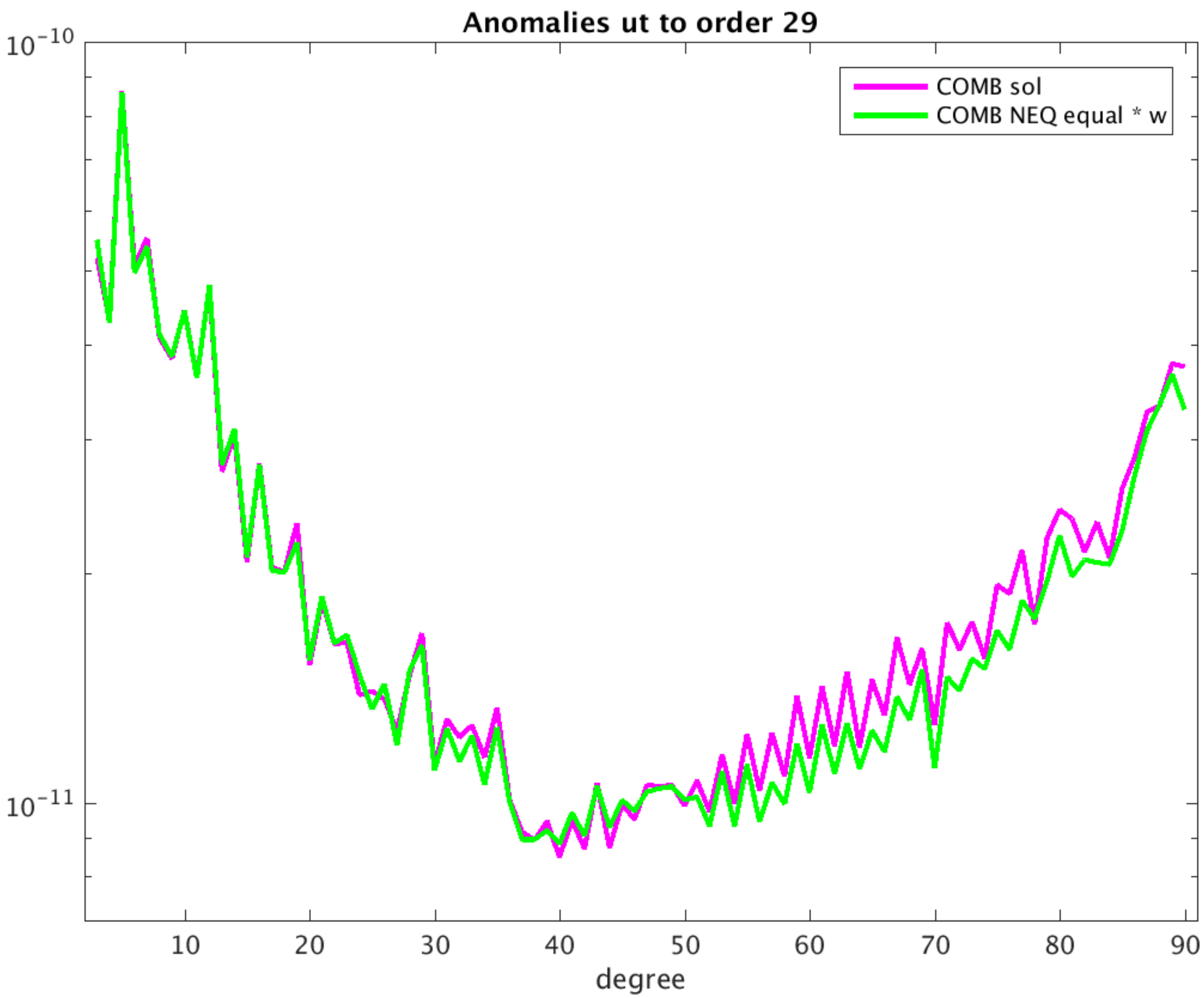
Combination on NEQ level



wSTD oceans:

- RMS: 9.5e-3
- equal: 7.5e-3
- equal*w: 5.9e-3

Comparison NEQ / SOL - combination



wSTD oceans:

- SOL: 6.3e-3
- NEQ: 5.9e-3

Signal-dominated part is consistent.

Noise-dominated part is better!

Conclusions

- It‘s working!
- Outomated process to reach comparable contribution of indiviual NEQs is needed.
- Contribution analysis
- Scaling of NEQs to common R is still missing (effect mainly on degree 2).
- Format transformation of NEQs Bernese – SINEX is still missing.

European Gravity Service for Improved Emergency Management

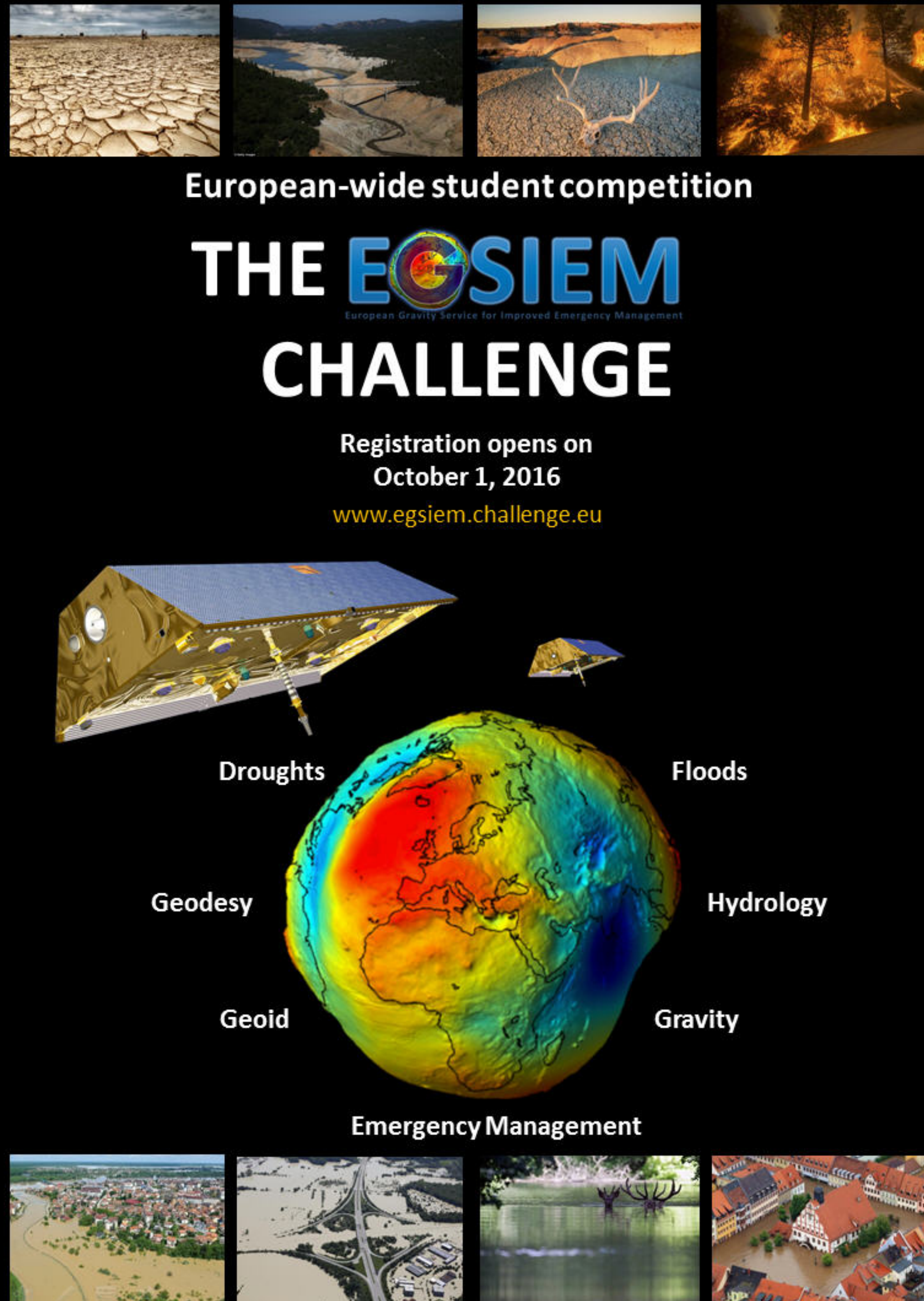
High-School Competition

Akbar Shabanloui and Jakob Flury

Institut für Erdmessung

Leibniz Universität Hannover

GFZ-Potsdam @03.06.2016


European-wide student competition
THE EGSIEM CHALLENGE
European Gravity Service for Improved Emergency Management
Registration opens on October 1, 2016
www.egsiem.challenge.eu
Droughts
Floods
Geodesy
Hydrology
Geoid
Gravity
Emergency Management

The Goals

European Gravity Service for Improved Emergency Management

- **Education:** Geodesy, Hydrology and Emergency services with focus on EGSIEM research topics
- **Attention:** The importance of Earth Observations Programs (Satellites, Systems and Services) for motoring and forecasting of natural hazards
- **Curiosity:** To awake students' interest about the EGSIEM
- **Opportunity:** To give students some opportunities in terms of summer school or a research internship!

EGSIEM

HORIZON 2020

Target Group

European Gravity Service for Improved Emergency Management

- **University Students:**

  - Undergraduate and Graduate [B.Sc. &M.Sc.]

  - Focusing on Geodesy, Hydrology and Geophysics students, but others are welcome!

  - [19 – 29] years old

  - EU & CH residents [foreign students]

What should be learned?

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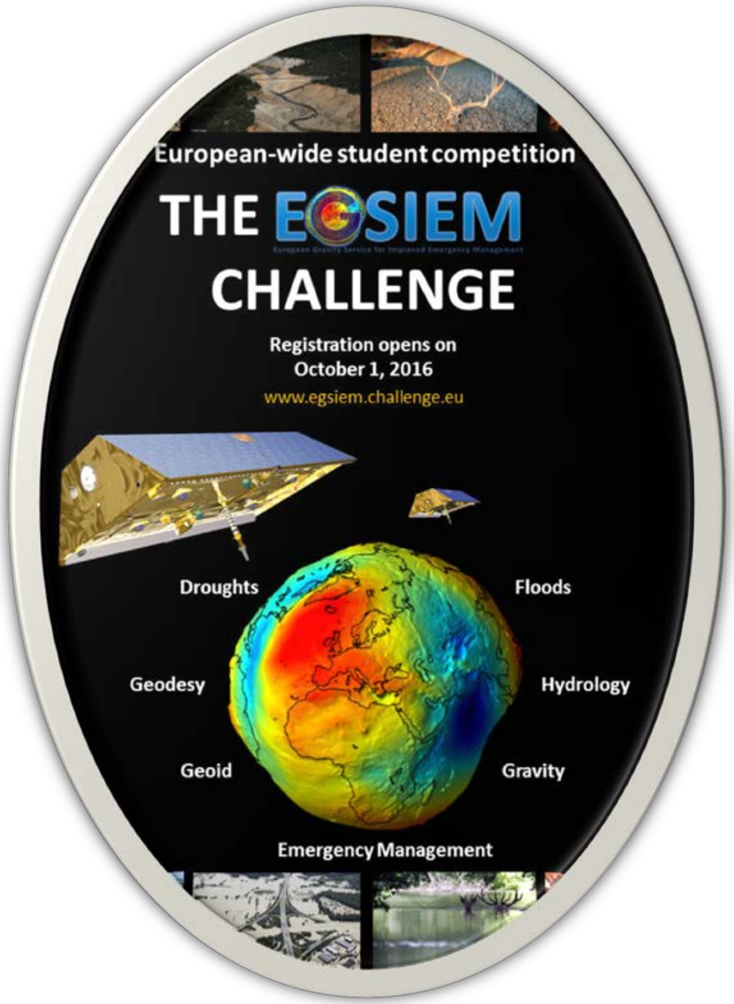
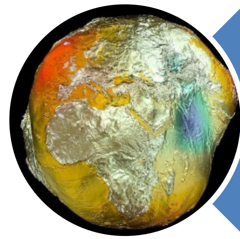
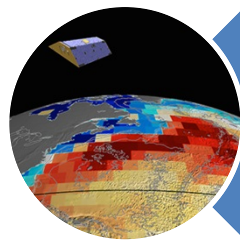




Earth Gravity Field



GRACE - Hydrology

Floods and Droughts Monitoring

Competition Rounds

European Gravity Service for Improved Emergency Management

- **1ST ROUND:**
  - 20 questions
  - Multiple-choice
  - The online and offline materials:
    - EGSIEM website and its partners
    - GRACE Analysis Centers e.g. GFZ, CSR and JPL
    - Other relevant sources

- **Anybody who solves 75% of the problems [15+]**
- **They pass automatically to the 2st Round**

HORIZON 2020

Competition Rounds

European Gravity Service for Improved Emergency Management

- **2ST ROUND:**
  - Deeper understanding of the topic
  - 20 open questions
  - The materials (online or offline):
    - EGSIEM website and its partners
    - GRACE Analysis Centers e.g. GFZ, CSR and JPL
    - Introducing some relevant books

- **Anybody who solves 60% of the problems [12+]**
- **If nobody reached 60%, the candidate who answered as many as ques.?**

Schedule

EGSIEM

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Launch

- Registration opens @01.10.2016
- 1st Round questions publish on EGSIEM

1st Round

- End of Submission period @10.11.2016
- The winners announcement @11.11.2016

2st Round

- Opens @12.11.2016
- End of Registration @20.12.2016

Hospitation

- Announcement of final winners @ 22.12.2016
- Preparation for Research-Internships/Summer School

Awards

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1st

Two Internships

- At one EGSIEM Member Ins.
- 6 - 8 Weeks
- Travel Expenses
- Health Accident & Personal Liability Insu.
- Monthly Allowance

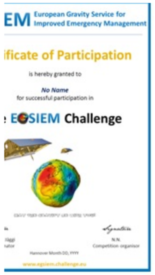
2nd

Two Scholarships

- Participation at EGSIEM Summer School
- Health Expenses, Personal Liability insurances

Awards

European Gravity Service for Improved Emergency Management



Successfully passed 1st Round

- Certificate
- Giveaways
  - Travel mug with the Egisem logo

1ST ROUND QUESTIONS ?

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1. **What are the fundamental observation techniques of the Gravity Recovery and Climate Experiment (GRACE) mission, based on which the Earth's gravity field is recovered?**
   a) *GPS positioning, microwave inter-satellite ranging, ultra-sensitive accelerometer*
   b) Gravitational gradiometry, GPS positioning
   c) radar altimetry, GPS positioning
   d) laser inter-satellite ranging, GPS positioning, ultra-sensitive gradiometry

2. **What is the precision level of the distance measurement between the two GRACE spacecraft?**
   a) *Micrometer*
   b) Millimeter
   c) decimeter
   d) meter

3. **The GRACE monthly geo-potential models are distributed as spherical harmonic coefficients usually up to degree and order 60. How many coefficients does one such model contain?**
   a) *3721*
   b) 60
   c) 3600
   d) 1860

4. **The gravity field variations inform about ...**
   a) *mass distribution and mass transport in the Earth's system*
   b) structure of the Earth interior
   c) current weather situation
   d) geological structure of the lithosphere

COMMUNICATIONS

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European Gravity Service for Improved Emergency Management

www.egsiem.eu

www.egsiem.challenge.eu

COMMUNICATIONS

EGSIEM

European Gravity Service for Improved Emergency Management

- E-MAIL LIST OF UNIVERSITIES WITH FOCUS ON GEODESY

29 COUNTRIES
69 UNIVERSITIES
139 CONTACT PERSONS

PLAN

EGSIEM
European Gravity Service for Improved Emergency Management

- DEFINITION OF THE COMPETITION ☑
- RULES ☑
- PRIZES ☑
- QUESTIONS 1ST ROUND ☑
- QUESTIONS 2ND ROUND ☐ (in progress)
- INTERNAL REVIEW ☒ (to be done) : Feedbacks (15.06.2016)
- ADVERTISEMENT ☐ (in progress
- WEBSITE (WWW.EGSIEM.CHALLANEG.EU) ☒ (to be done) : 15.09.2016

Open Questions

European Gravity Service for Improved Emergency Management

- **Prizes**
  - Research Internships should be at LUH?
  - How about the summer school, date is fixed?
- **Website**
  - Website programming (Joomla)
    - Creating the sub-link www.egsiem.cahllenge.eu
    - Creating contact formula
    - Appearing questions randomly
    - Security issues
    - …

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Visibility to Copernicus

Adrian Jäggi (AIUB)

EGSIEM Progress Meeting # 3

GFZ Potsdam

June 2 – 3, 2016

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

Visibility to Copernicus

- Copernicus user survey for Next Generation Sentinels has been filled out by several (hopefully all?) 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 participated in the GEO PROJECTS WORKSHOP this week
- EGSIEM provided input to ESA for the Climate Change Workshop in Brussels on 11 March

Next steps

- Most recent Copernicus user survey for the Emergency Management Service at https://spacetec.typeform.com/to/GdhVSg should be answered by all institutions (see e-mail from 23 May 2016).
- How can we further increase our visibility at Copernicus events? How do we share the workload?
- How could we establish a gravity teaser talk?

The Gravity Community needs to be visible to Copernicus if a future gravity mission shall ever become a future Sentinel mission

Feedback from ESA

- ESA is closely following the progress of EGSIEM and considers it as an excellent project to promote gravity data in the frame of Copernicus. EGSIEM has the potential to become an important "voice" of the gravity community.

- For this purpose EGSIEM first of all needs to be successful. If not, it will be difficult to get successor projects in the frame of H2020 (Copernicus Service Evolution Calls).

- In addition EGSIEM needs to visible for Copernicus. Every institution has to contribute to the "lobbying".

"Satellite missions are not for free". All our efforts are needed.

Feedback from ESA

- ESA (Pierluigi Silvestrin, Roger Haagmans) promised to keep us informed about upcoming Copernicus events where they think EGSIEM should contribute.

- Next such event is the Copernicus Polar and Snow Cover Applications Workshop that will be held on 23 June in Brussels. It is another event to gather user requirements to contribute to the design of the Next Generation Copernicus Space Component.

- Should EGSIEM participate? If yes, who could do it?

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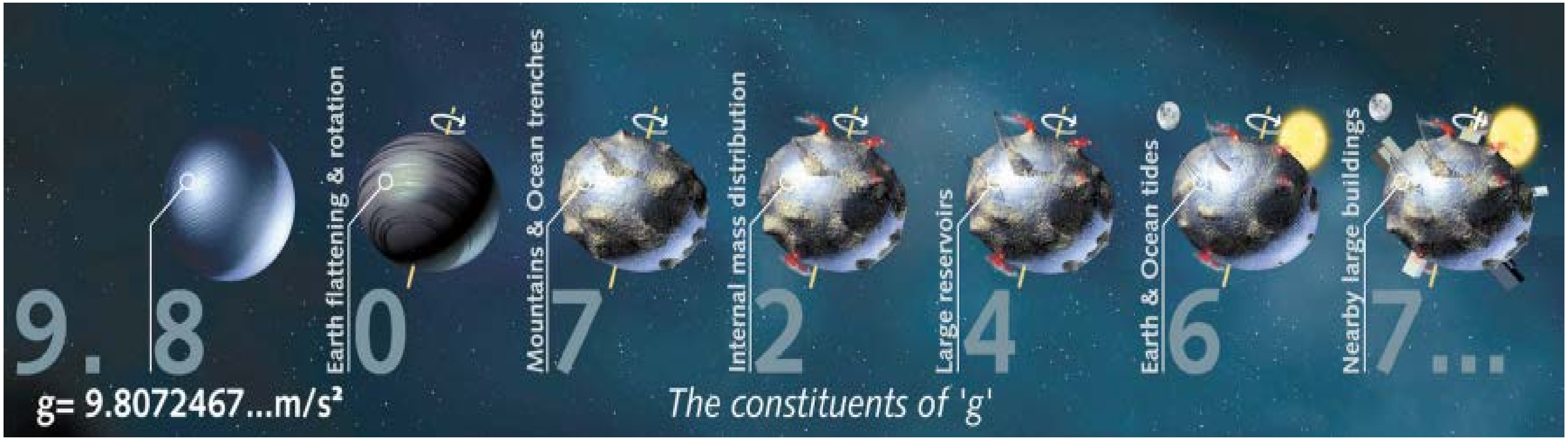
Sensing total mass change by gravity observations – a (missing) key element of ECVs

Dr. Matthias Weigelt
on behalf of the EGSIEM team

What is gravity and how do we observe ECVs with it?

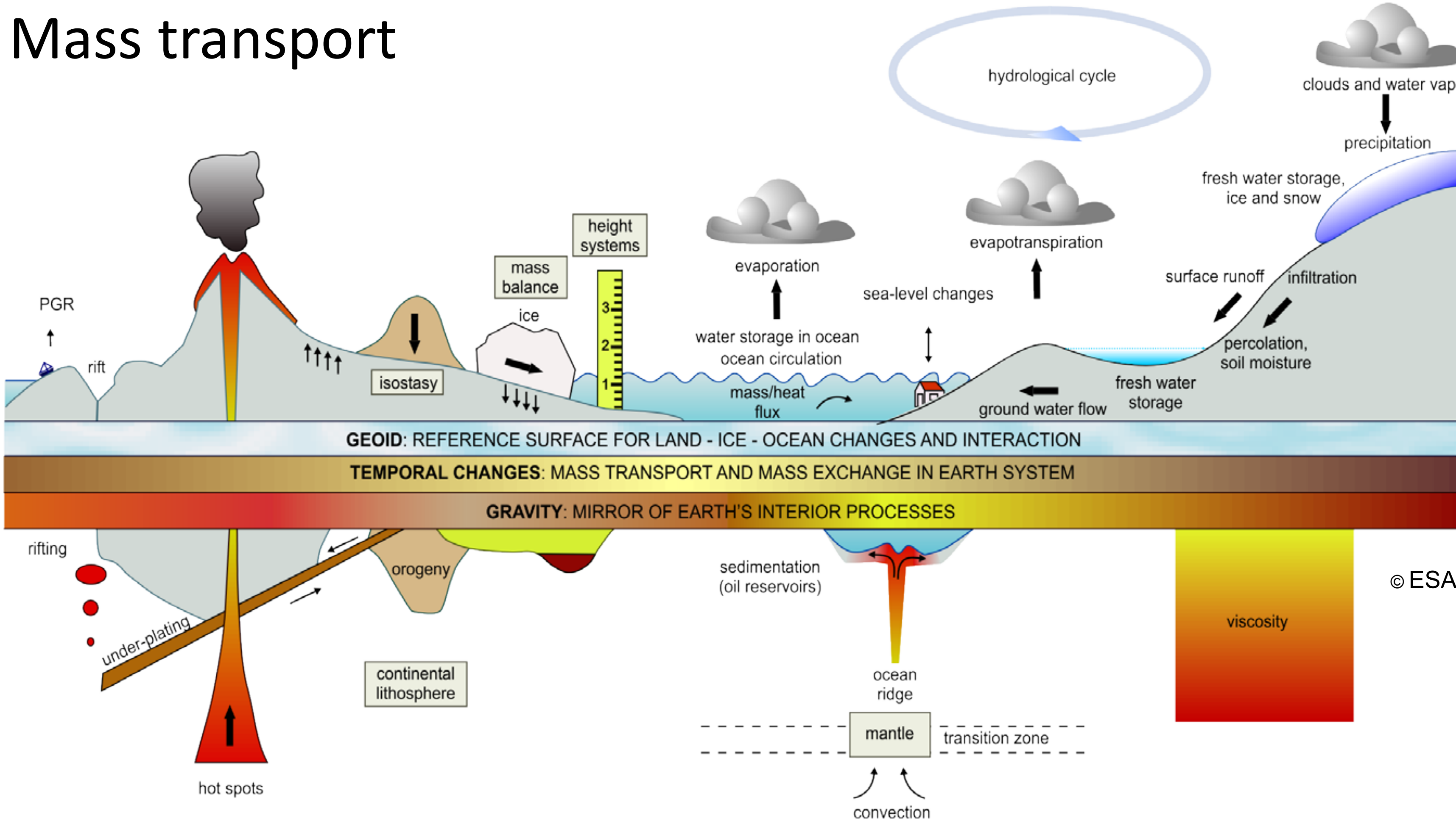
You already know gravity ...



Gravity describes the
mass distribution of the Earth

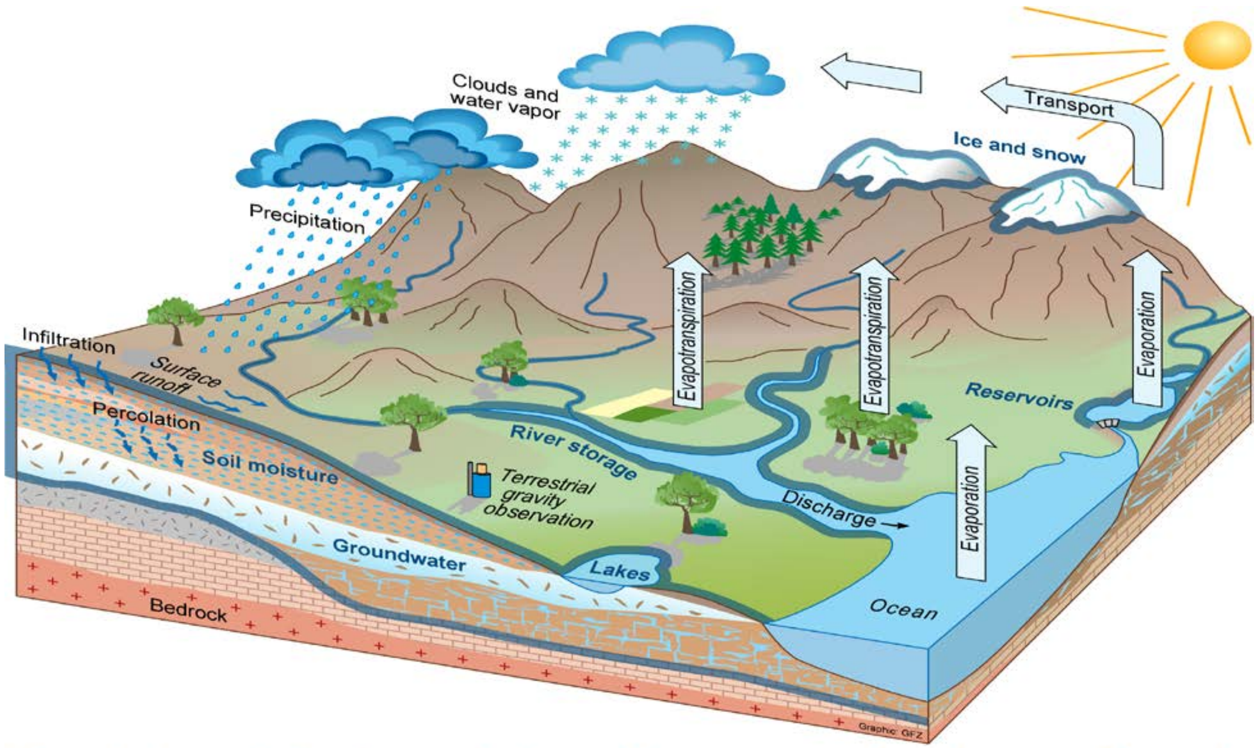
Mass **RE-distribution (=transport)** causes
variations in the gravity field

Mass transport



On short time scales, mass transport is almost exclusively caused by water transport

The global water cycle

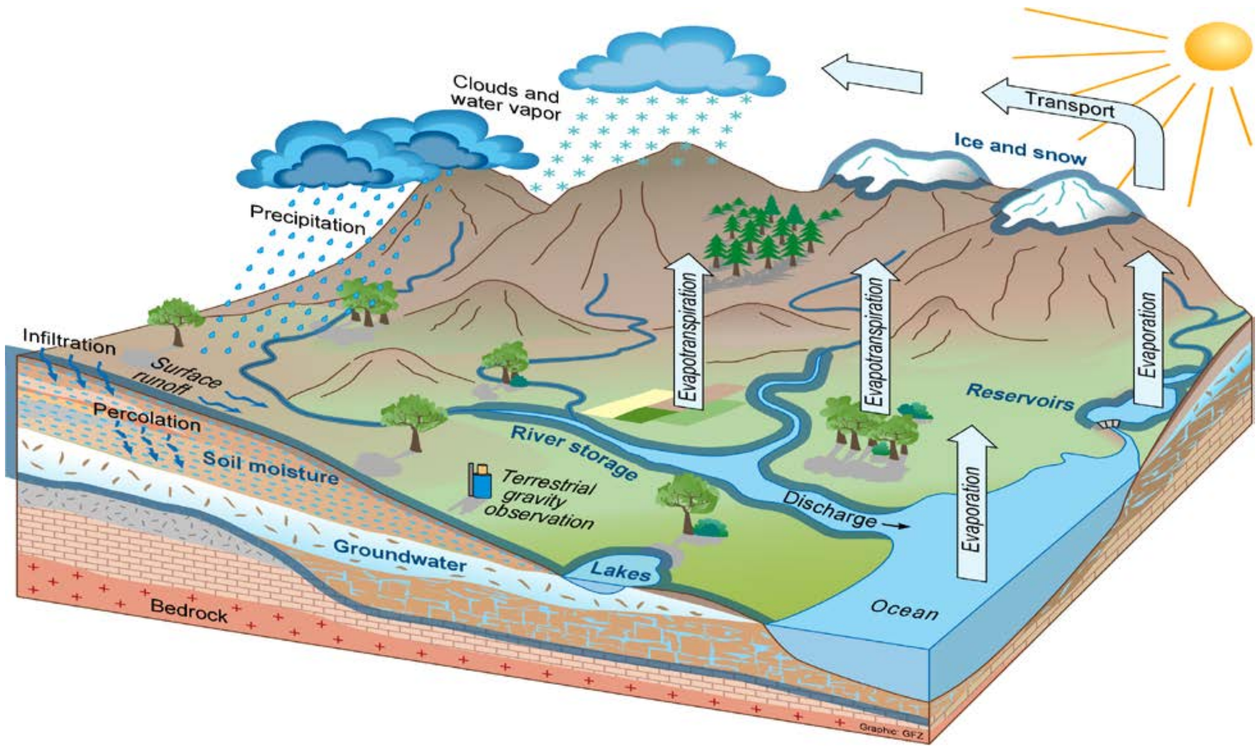


Continental water balance

$$P = ET + Q + \Delta S$$

P:	Precipitation
ET:	Evapotranspiration
Q:	Runoff
ΔS:	Storage change

Continental water storage variations



Groundwater | Soil moisture | Lakes | River storage | Ice and snow | Reservoirs

→ TOTAL WATER STORAGE

Local to global water balances:

- → Water resources
- → Flood generation
- → Sea level change
- → Weathering, gas fluxes

Continental water balance

$$P = ET + Q + \Delta S$$

P: Precipitation
ET: Evapotranspiration
Q: Runoff
ΔS: Storage change

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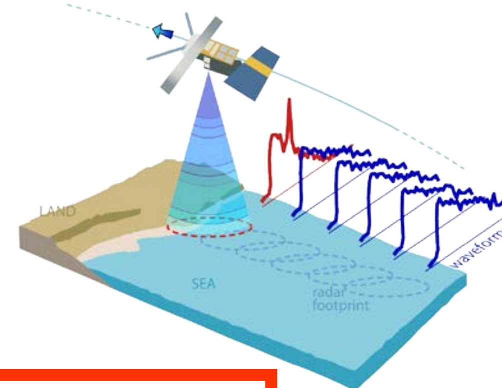
Monitoring water storage



G

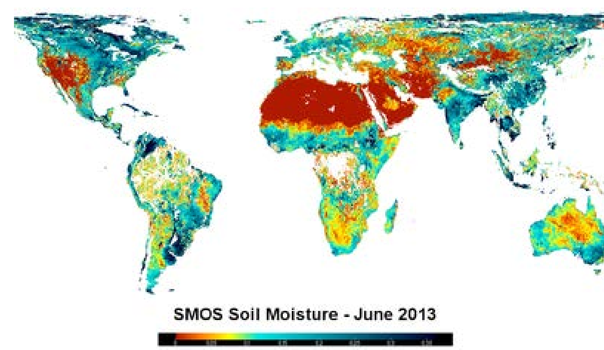
nland water
es

Soil m

moisture

Limitation:

- **single storage compartments**
- **point measurements**



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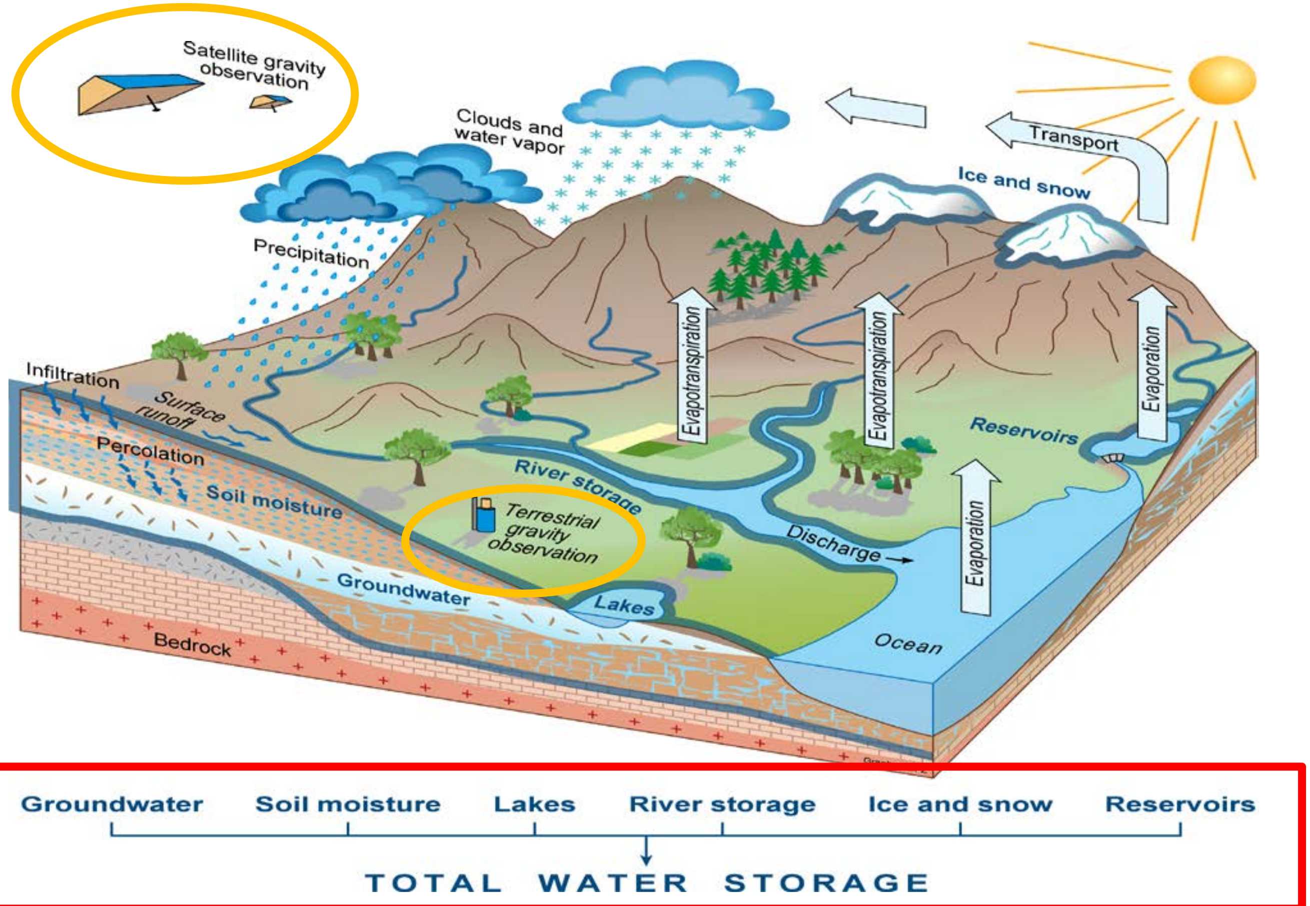
The global water cycle



Continental water balance

$$P = ET + Q + \Delta S$$

P:	Precipitation
AET:	Evapotranspiration
Q:	Runoff
ΔS:	Storage change

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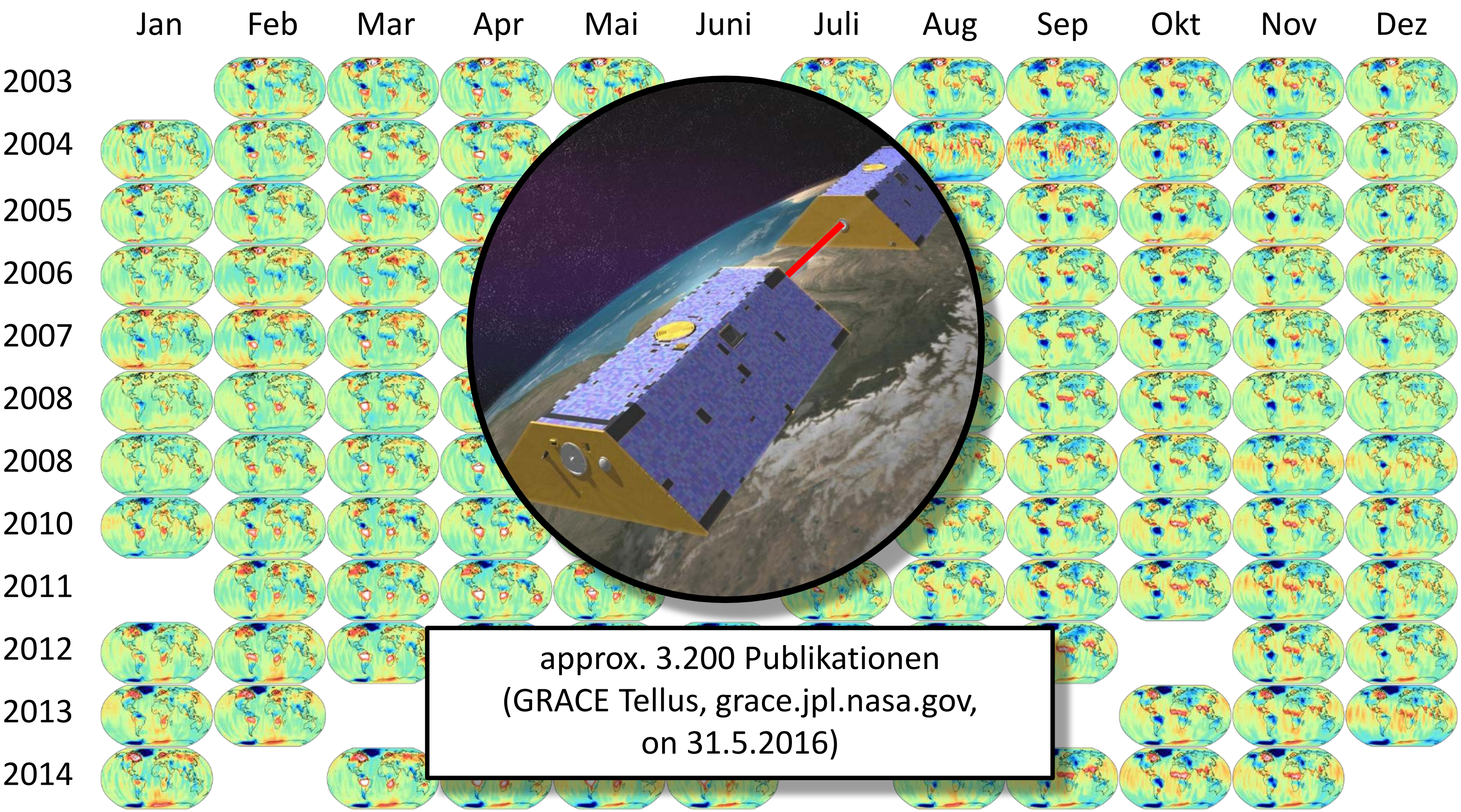
How to observe it?

GRACE – Gravity Recovery And Climate Experiment

GRACE products



approx. 3.200 Publikationen
(GRACE Tellus, grace.jpl.nasa.gov,
on 31.5.2016)

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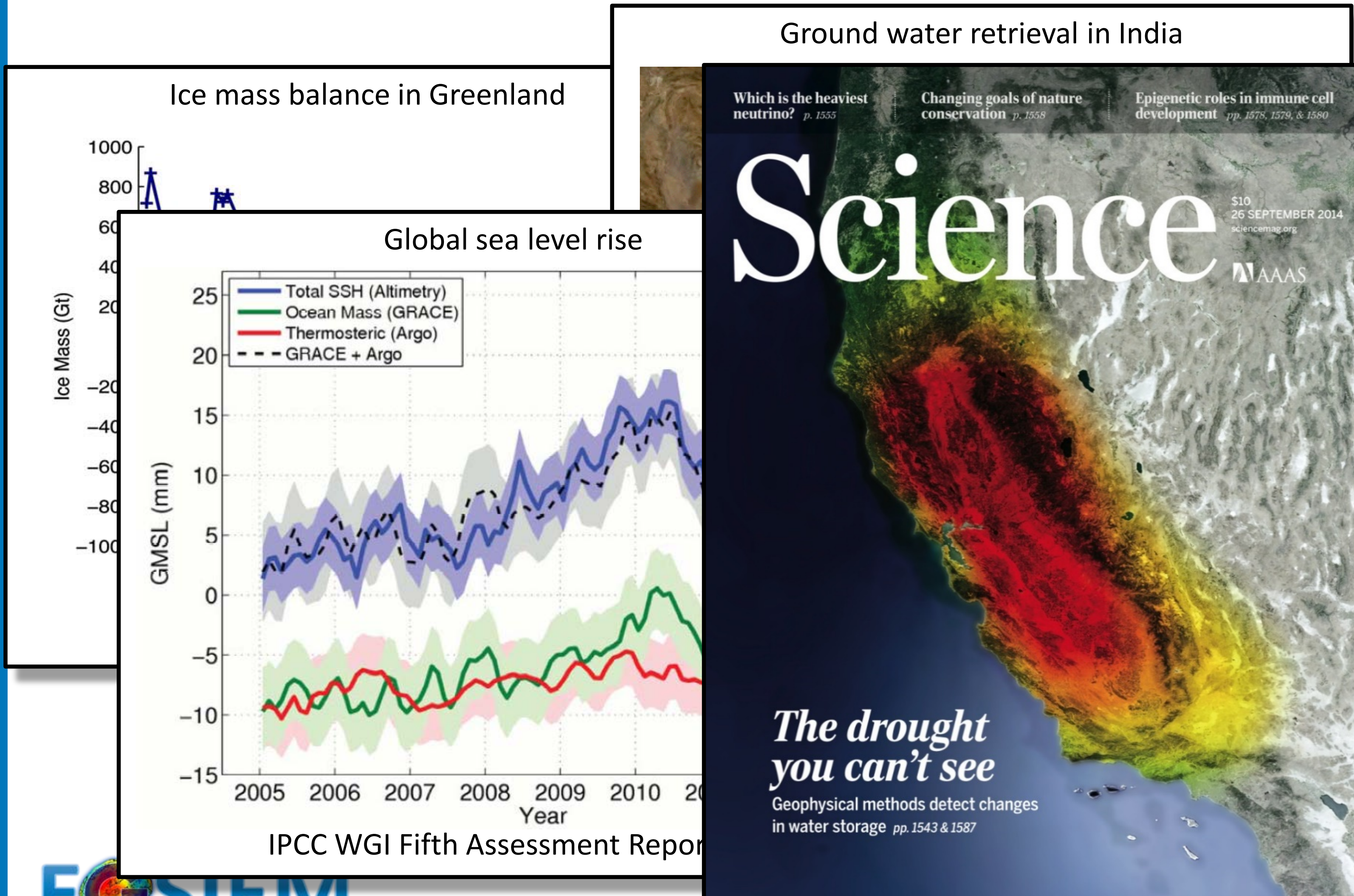
Applications, applications, applications …



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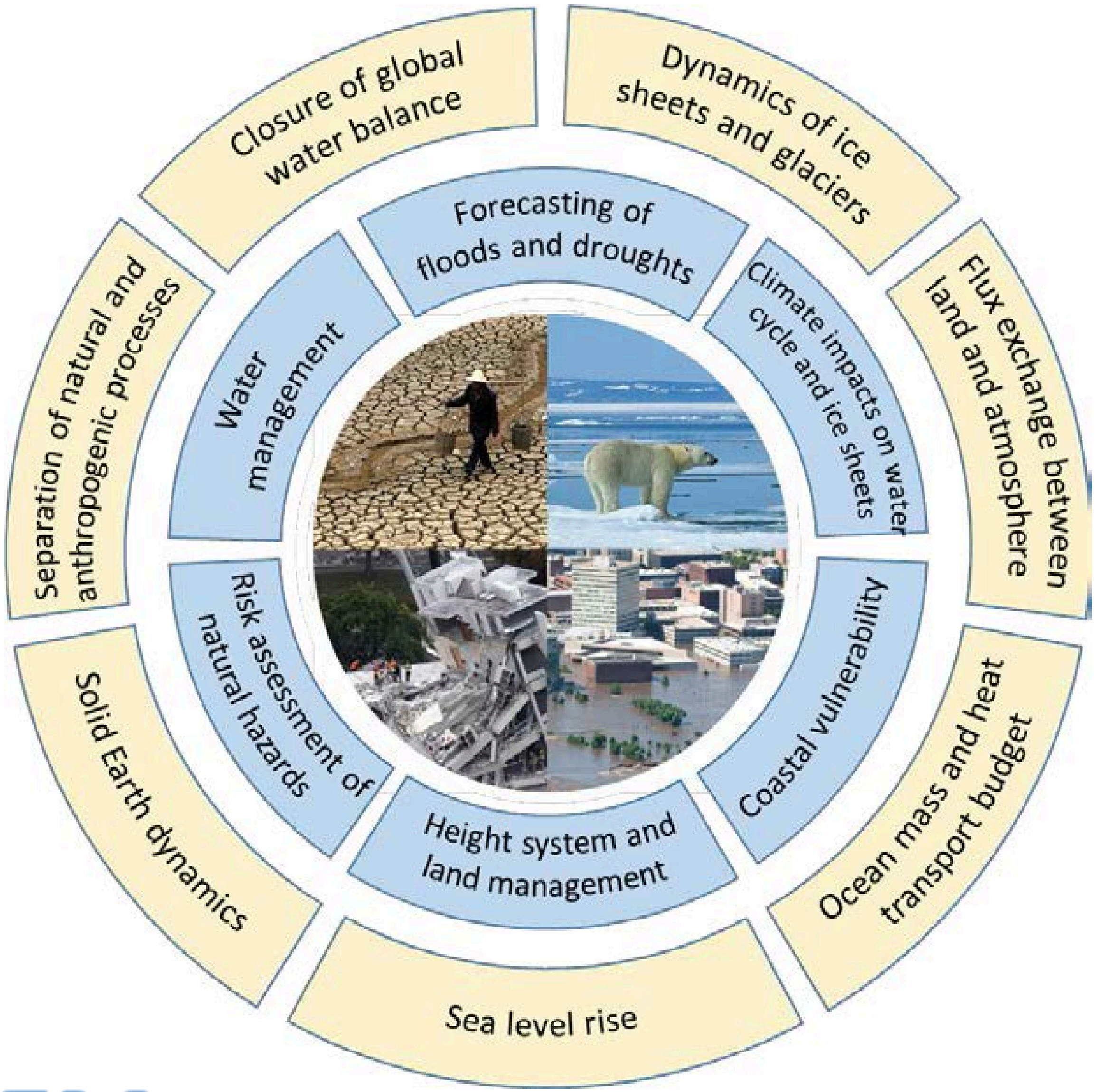
Numerous benefits ...



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Challenges

- Limited spatial (> 250 km) and temporal (1 month) resolution
- Latency of 2-3 month
- Complex post-processing necessary (gridding, filtering, …)
- Multiple processing centers with inhomogeneous processing

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is our response to the challenges …

A proposal for the project

EGSIEM European Gravity Service for Improved Emergency Management

has been submitted last spring to the EO-1 Space Call of the Horizon 2020 Framework Program for Research and Innovation.

UNIVERSITÄT BERN

UNIVERSITÄT LUXEMBURG

GFZ Helmholtz Centre POTSDAM

TU Graz

Leibniz Universität Hannover

DLR

cnes

géode & cie

LANTMÄTERIET

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE
Directorate H - Institute for Environment and Sustainability
Climate Risk Management

IAG GGOS

TECHNISCHE UNIVERSITÄT MÜNCHEN

THE UNIVERSITY OF TEXAS AT AUSTIN

universitätbonn igg

EUROPEAN GEOSCIENCES UNION

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EGSIEM project overview

EGSIEM is a EU Horizon 2020 project and has officially started on January 1, 2015.

The three main objectives of EGSIEM are to

- deliver the best gravity products for applications in Earth and environmental science research
- reduce the latency and increase the temporal resolution of the gravity and therefore mass redistribution products
- develop gravity-based indicators for extreme hydrological events and demonstrate their value for flood and drought forecasting and monitoring services

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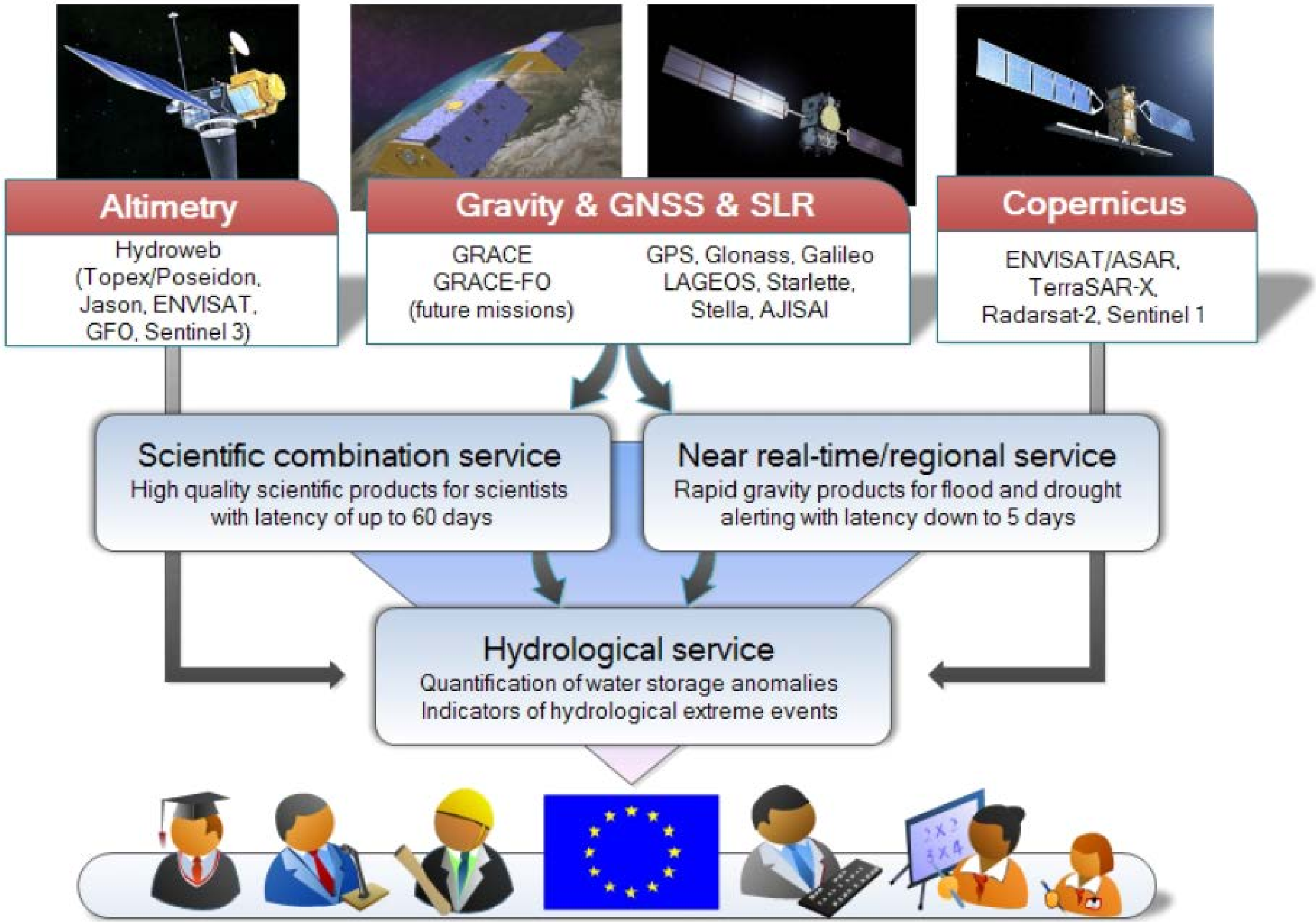
EGSIEM project overview

Three dedicated services shall be established:



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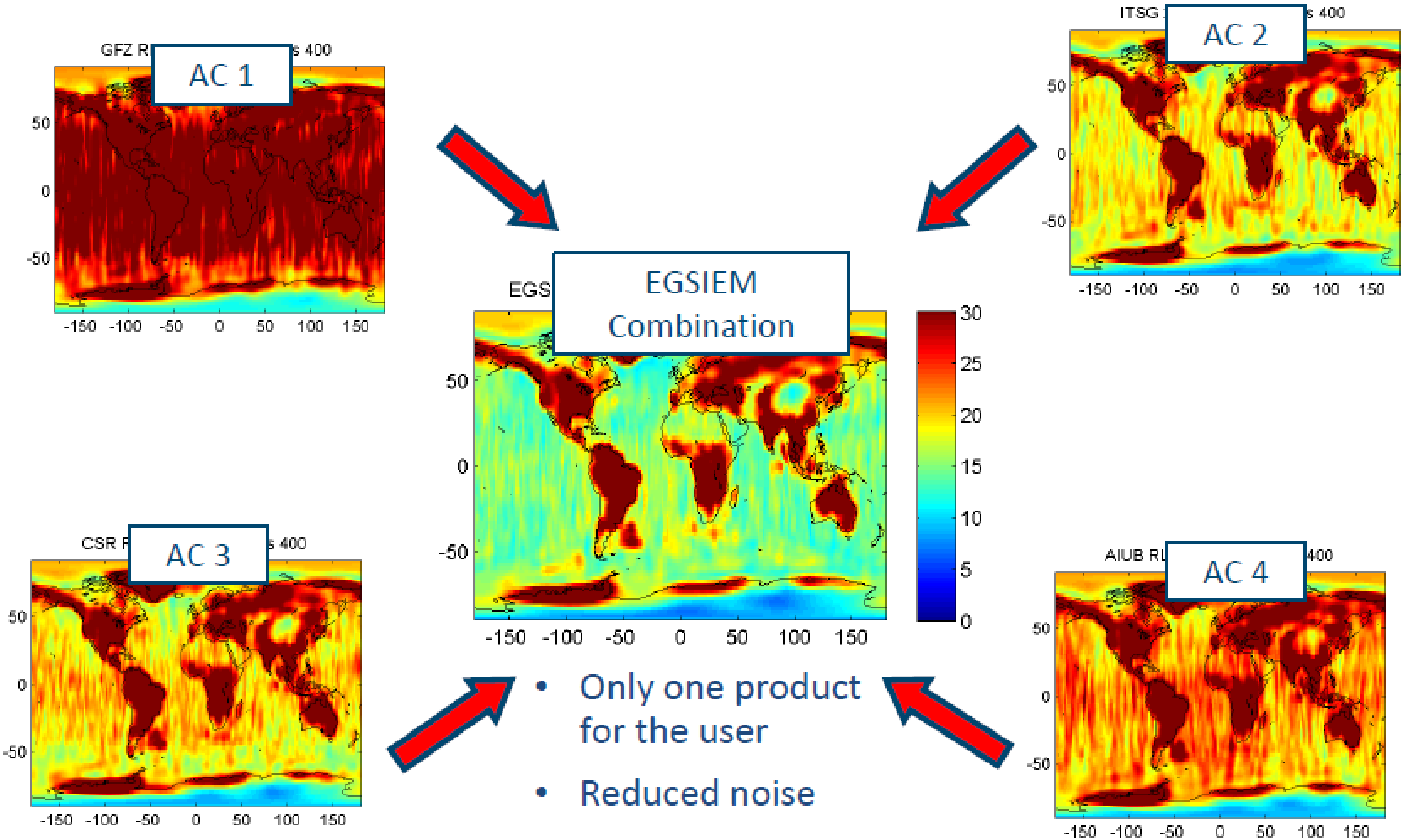
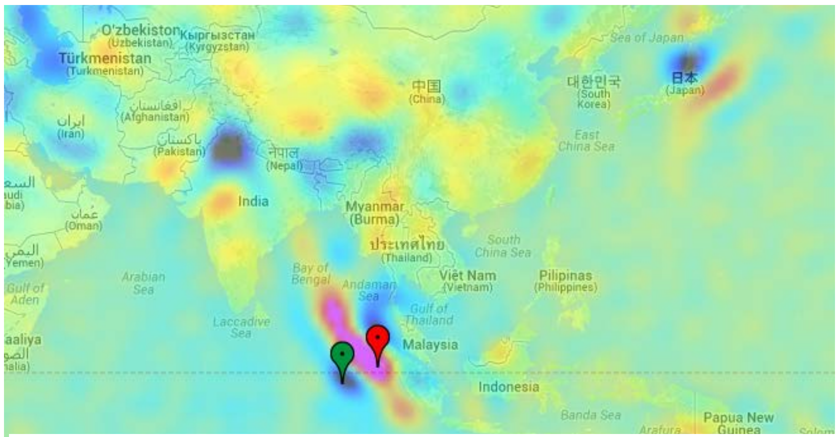
Scientific service

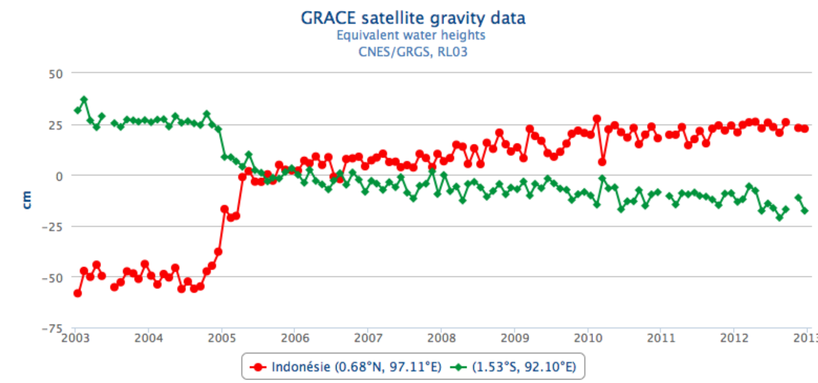


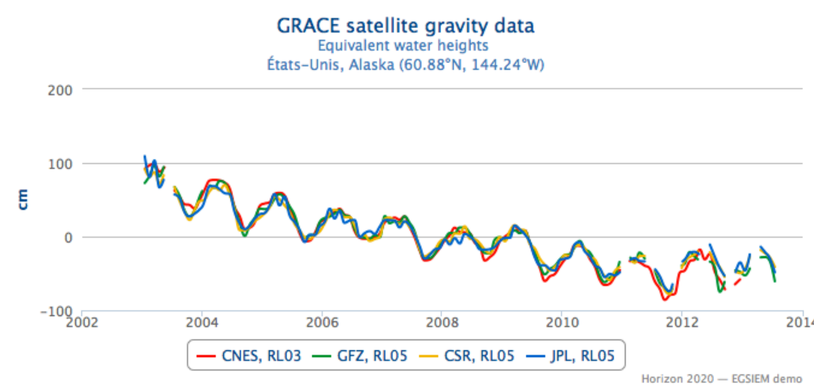
- Only one product for the user
- Reduced noise

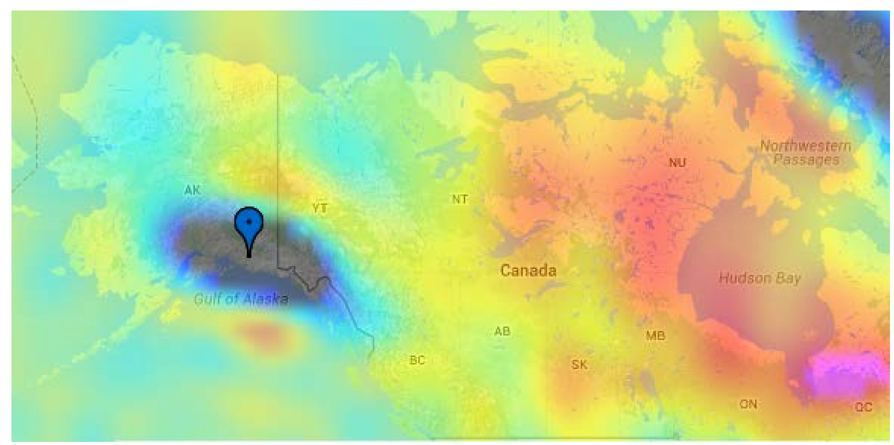
Dissemination and Exploitation

EGSIEM plotter: interactive, fast and user-friendly visualization of results for scientific evaluation.









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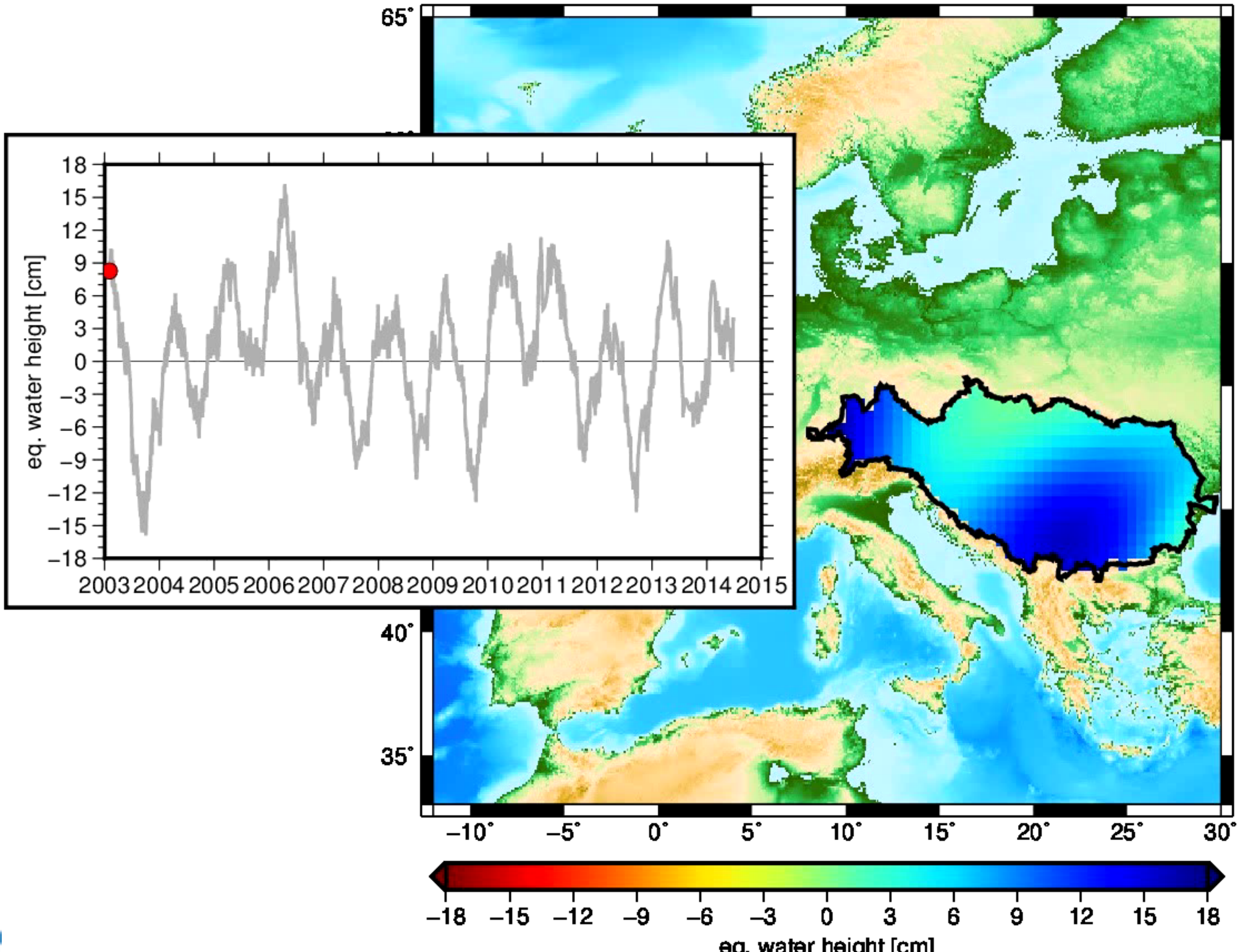
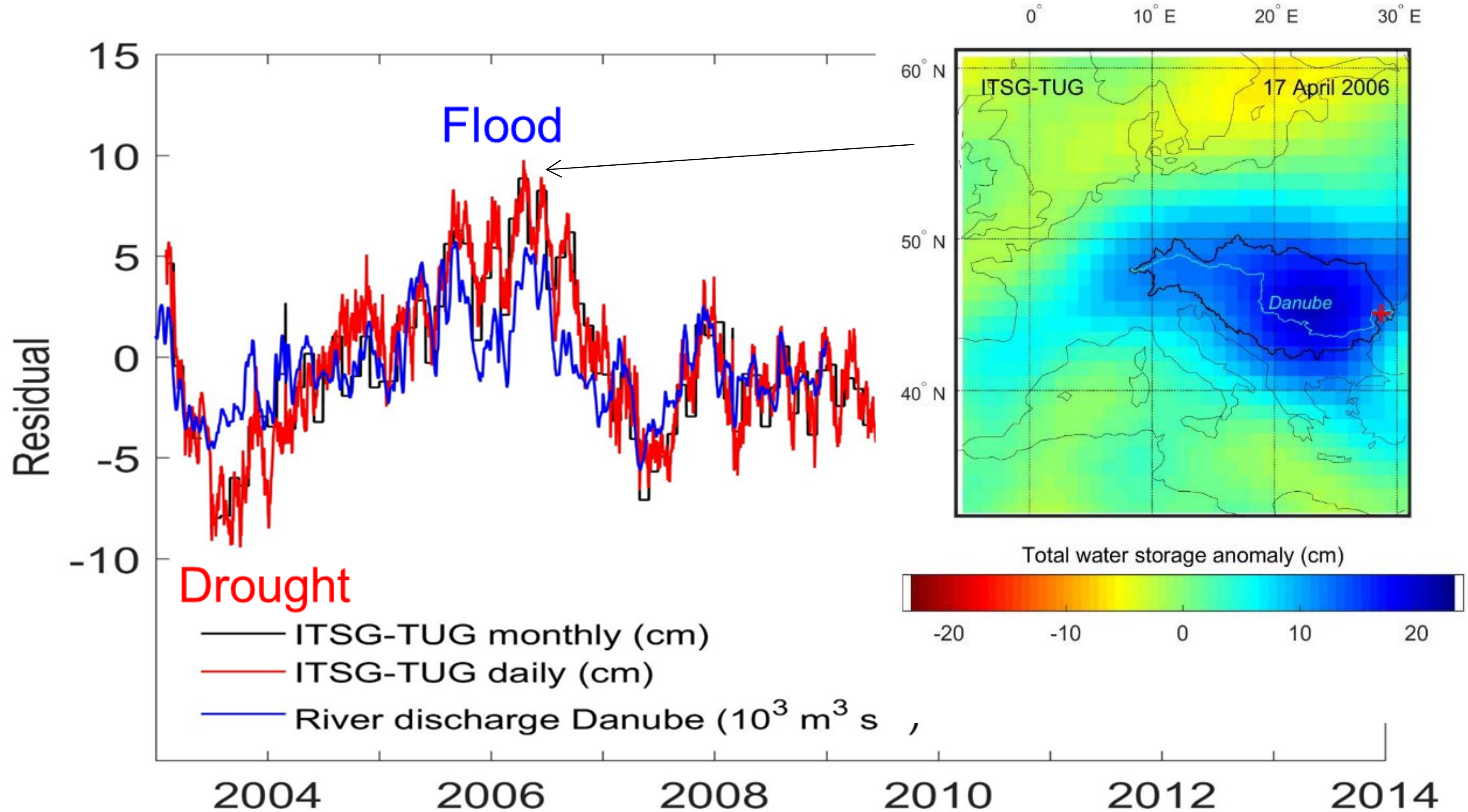
Near-realtime service

Daily updated solution with max. 5 days delay



Daily total water storage in the Danube basin based on ITSG-Grace2014, TU Graz

Near-realtime service: flood and drought



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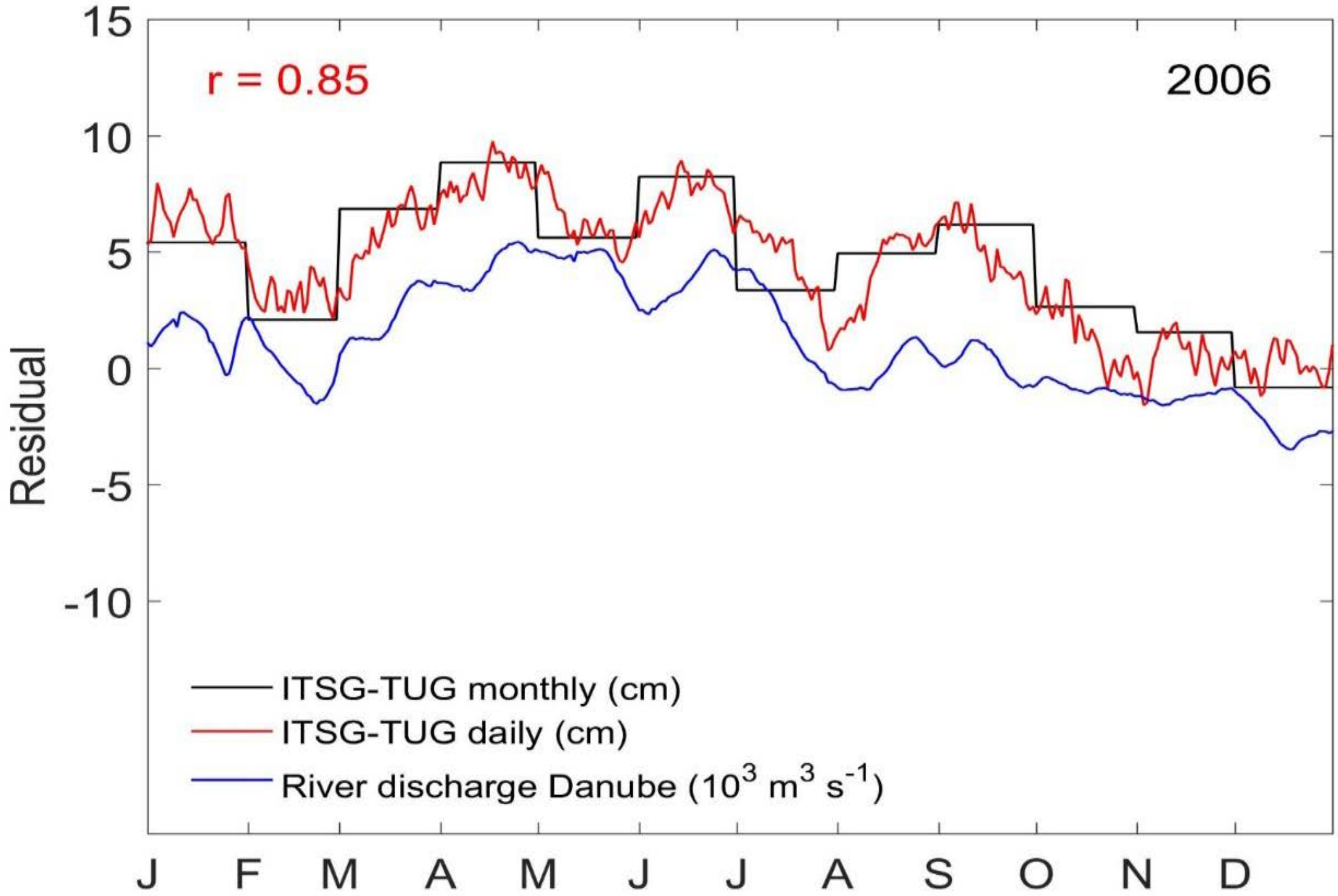
Hydrological service



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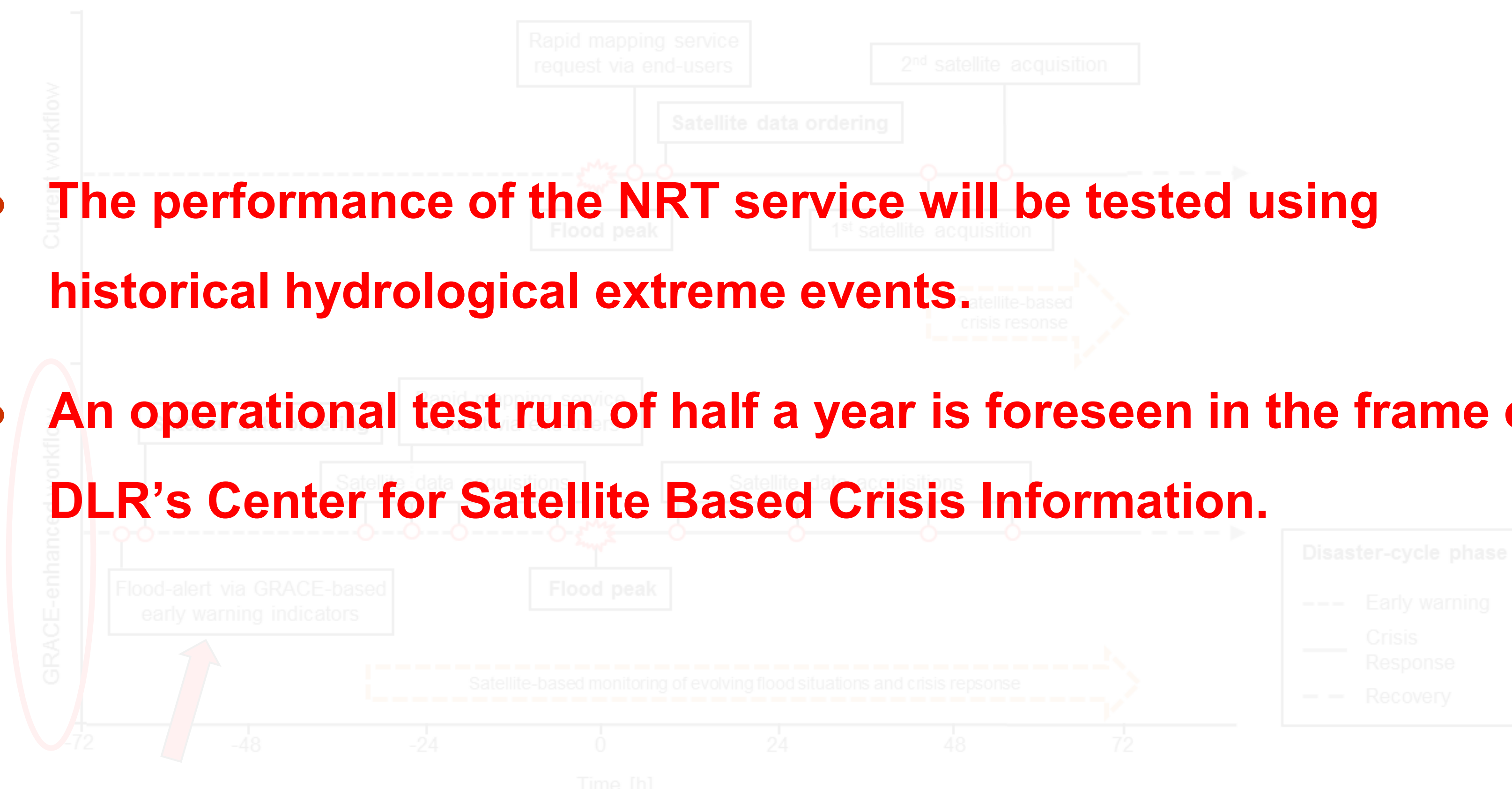
Hydrological Service

- **Improved rapid mapping using on-demand satellite acquisitions**
- **Integration into automatic flood emergency management services**



- **The performance of the NRT service will be tested using historical hydrological extreme events.**
- **An operational test run of half a year is foreseen in the frame of DLR's Center for Satellite Based Crisis Information.**

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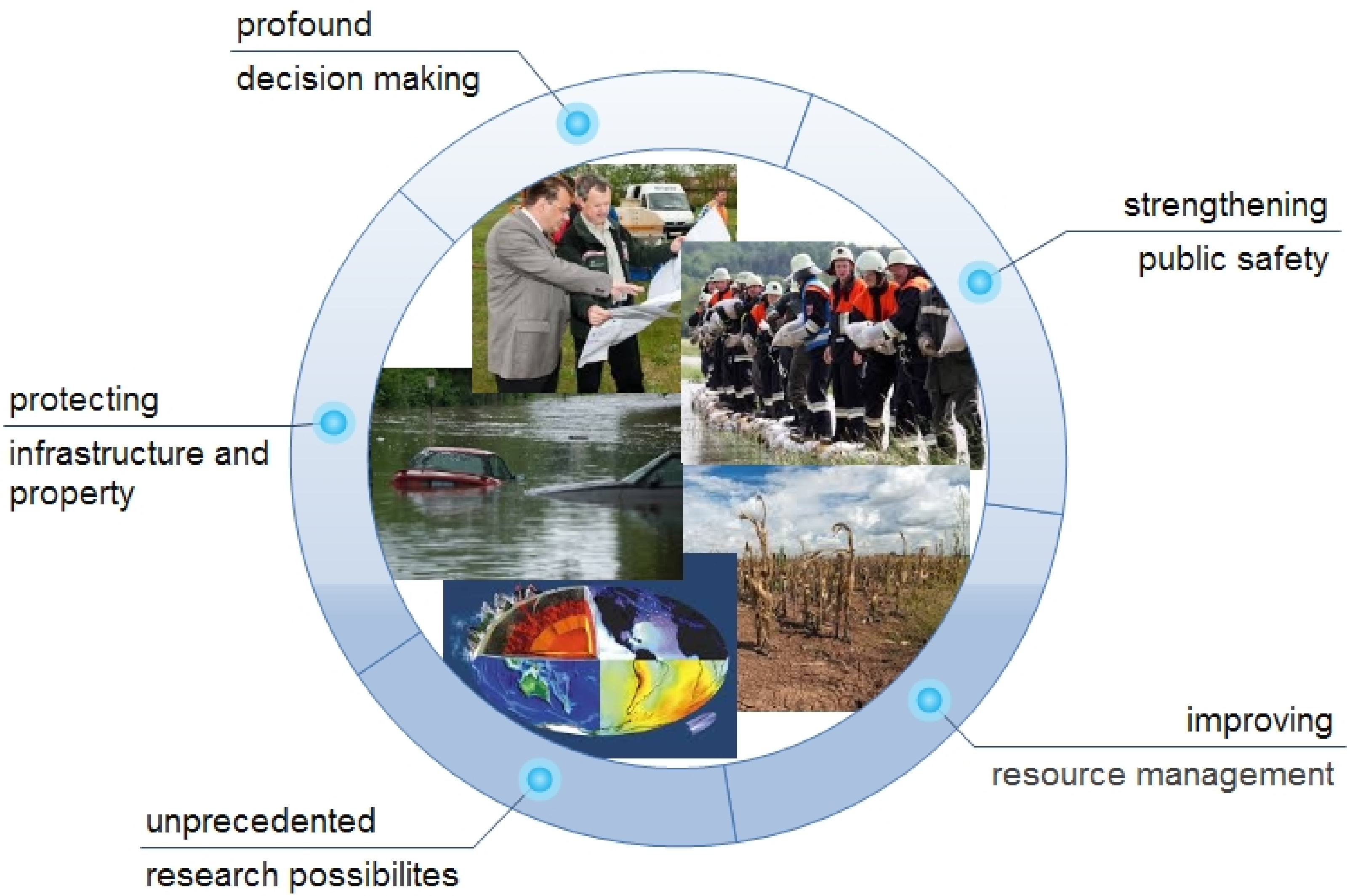
Impact to society



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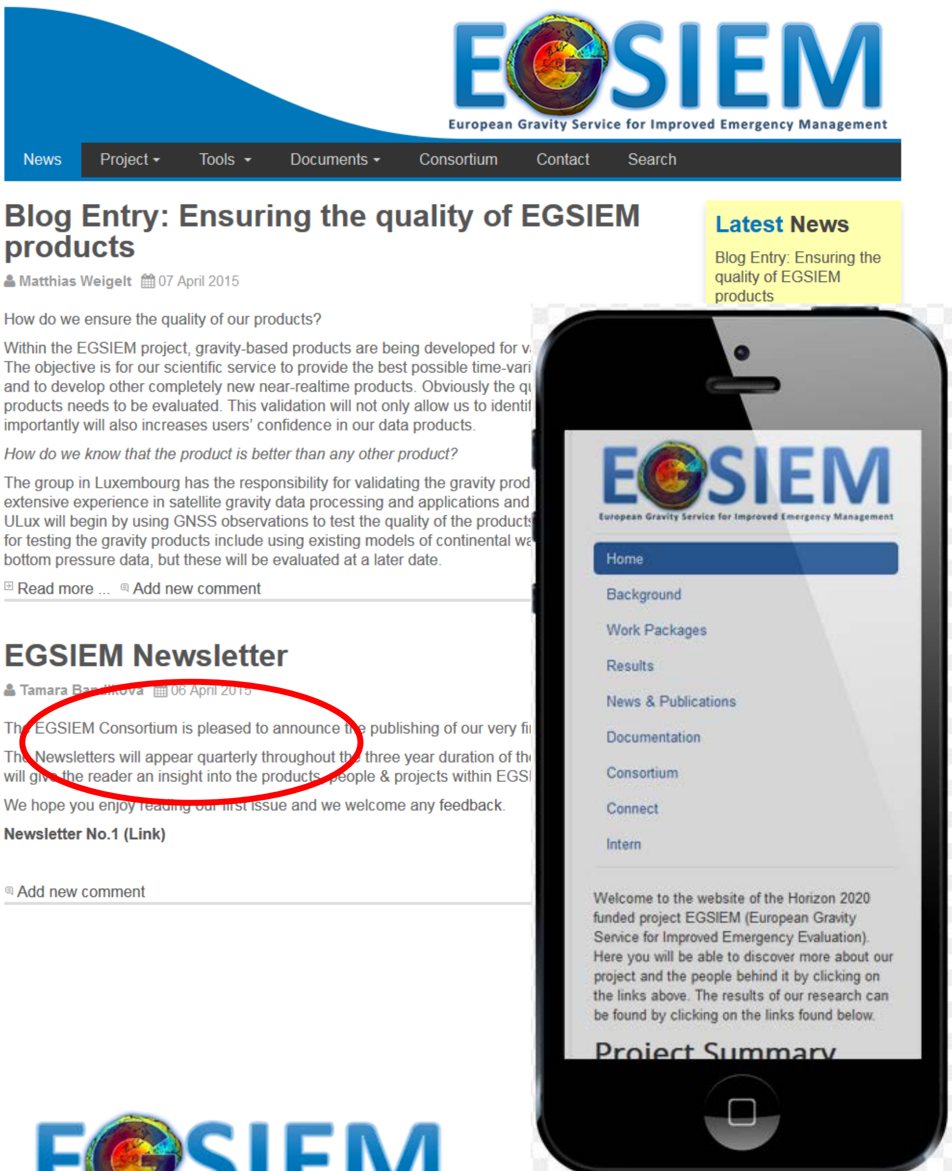
Take home messages

- Observing gravity changes allows to observe water/mass transport and thus contributes substantially to a number of essential climate variables.
- EGSIEM dedicates its efforts to deliver the best gravity products with reduced latency and higher temporal and spatial resolutions.
- EGSIEM products are freely available to the public and have diverse impact on the society, especially disaster resilience and water resource management

Stay in touch ...



EGSIEM will have an open data policy with respect to all data generated within the project. Accessibility to all levels will be guaranteed via the project website:

www.egsiem.eu

EGSIEM is also present on social media:

https://twitter.com/EGSIEM
www.facebook.com/egsiem
https://egsiem.wordpress.com

GRACE Videos

GRACE Videos from internet

Title of video	Link	Length	Quality	Description	Purpose
GRACE mission measures global ice mass changes	http://www.jpl.nasa.gov/video/details.php?id=1062	1'48	720P	The animation shows the location of mountain glaciers and ice caps around the world with data from the GRACE mission to show recent trends in ice mass loss or gain.	Application
GRACE sees groundwater losses around the world	http://grace.jpl.nasa.gov/resources/9/	4'25	360P	The animation displays trends in total water storage measured by GRACE from 2003.01 to 2009.12	Application
Scale in the sky	http://grace.jpl.nasa.gov/resources/26/	1'42	1080P	The animation introduces the principle of gravity and GRACE	Education
GRACE data over the United States	http://grace.jpl.nasa.gov/resources/5/	1'45	360P	This animation illustrates the highs and lows of the Earth's gravity field as water in the basins of the U.S. changes from 2003 to 2013	Application
GRACE: Tracking Water from Space	https://www.youtube.com/watch?v=hDtyhTCXpbA	7'09	1080P	The video shows the principle of GRACE missions with interviews over two scientists	Education
Gravity Recovery and Climate Experiment from WizScience.com	https://www.youtube.com/watch?v=Vd2GBZPUBgc	2'08	1080P	This animation was made by WizScience to introduce climate change and the principle of GRACE missions to children of all ages	Education
GRACE Satellite shows Greenland mass loss	https://www.youtube.com/watch?v=hE9_o-RSHjw	0'50	1080P	GRACE satellite shows Greenland mass loss from 2004.01 to 2014.06	Application
GRACE Satellite shows Antarctic mass loss	https://www.youtube.com/watch?v=gbCoi51q4m0	0'43	1080P	GRACE Satellite shows Antarctic mass loss from 2004.01 to 2014.06	Application
Groundwater Depletion in India Revealed by GRACE	https://www.youtube.com/watch?v=DvdzWbtAlKo	1'06	1080P	This video shows groundwater depletion from 2003 to 2013 in India revealed by GRACE	Application
NASA shows severity of California's drought	https://www.youtube.com/watch?v=GIlHSY6CVr0	0'21	1080P	NASA shows severity of California's drought from 2002.09 to 2013.11	Application
Ocean bottom pressure from GRACE	https://www.youtube.com/watch?v=bsHiOB86-no	1'14	720P	This video shows ocean bottom pressure from 2002.10 to 2012.04	Application
Global terrestrial water storage anomaly	https://www.youtube.com/watch?v=FLEc2sSzxqQ&index=7&list=PL6vzpF_OEV8kjbo-U1MWh_tEEMe3CfWeX	0'14	1080P	This video shows a global map of water storage anomaly.	Application

A summary of the videos

- The GRACE Data used in the videos are not up to date and the latest is up to June, 2014.

- Each GRACE application related video shows only one aspect of the application of GRACE, e.g. ice mass change in Greenland, or shows the application in one specific region, e.g. groundwater depletion in India. No video compiles all the potential applications of GRACE.

- No video shows the application of GRACE over Europe.

- No video shows the potential application of GRACE for a near-real time regional service or a hydrological warning service.

Your comments???

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EGSIEM Summer School

Adrian Jäggi (AIUB)

EGSIEM Progress Meeting # 3

GFZ Potsdam

June 2 – 3, 2016

Status of summer school planning

- Proposal for a EGSIEM Summer School to Wilhelm and Else Heraeus (WHE) foundation has been rejected. The topic was considered to be too special for a WHE Summer School. This is a pity, funding by the WHE foundation would have been very generous.

- Currently there are no competing alternatives at hand. Options might be the Klaus Tschira Stiftung in Germany, the Schweizer Studienstifung in Switzerland.

- Are there any other alternatives?

If we do not find an attractive funding for the EGSIEM Summer School, this might all become rather expensive.

Feedback from ESA

- ESA is closely following the progress of EGSIEM and considers it as an excellent project to promote gravity data in the frame of Copernicus. EGSIEM has the potential to become an important "voice" of the gravity community.

- For this purpose EGSIEM first of all needs to be successful. If not, it will be difficult to get successor projects in the frame of H2020 (Copernicus Service Evolution Calls).

- In addition EGSIEM needs to visible for Copernicus. Every institution has to contribute to the "lobbying".

Satellite missions are not for free. All our efforts are needed.

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WP7: Website Update

Keith Cann-Guthauser

Astronomisches Institut, Universität Bern

EGSIEM Project Meeting

2-3. June 2016, Potsdam

WP7: Website update

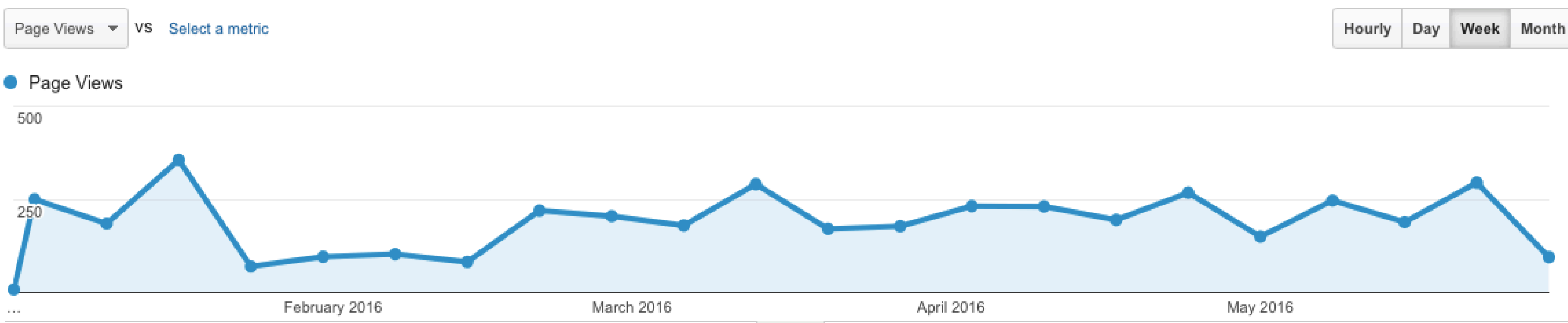
- Website was briefly discussed at the Review Meeting on 7. March in Brussels
- Overall a very positive feedback was received – particularly liked the constant updated nature.

WP7: Website update

Period shown, January – June 2016

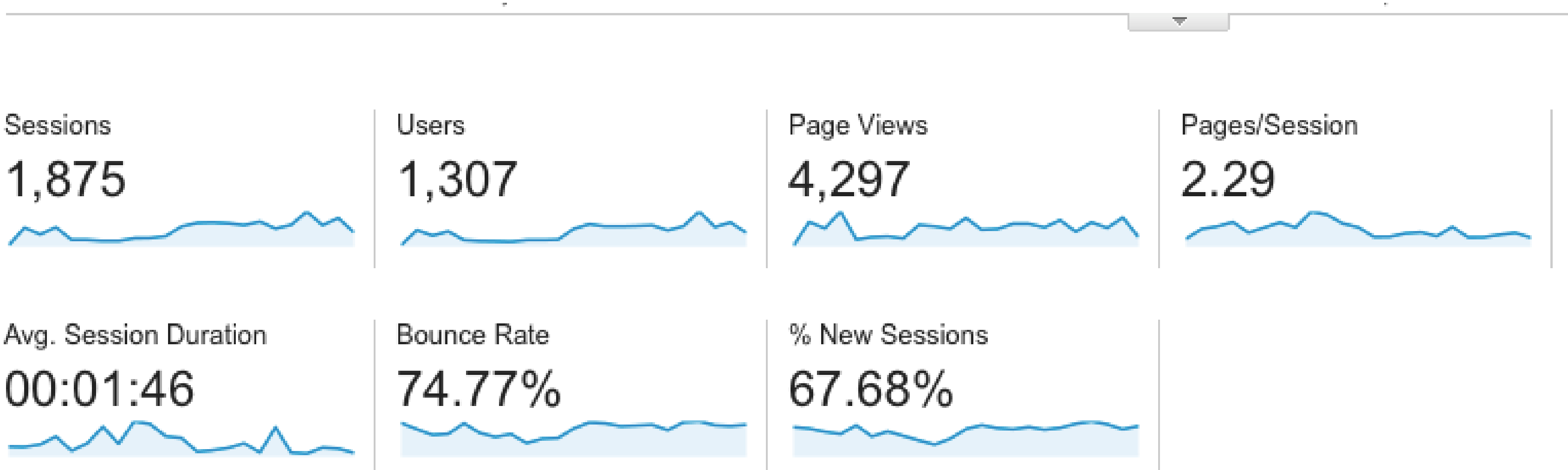
Total page views **4’297**

March – December figure was 9’761



WP7: Website update

Period shown, January – June 2016



WP7: Website update

Period shown, January – June 2016

	Country	Sessions	% Sessions
1.	Russia	623	33.23%
2.	Switzerland	258	13.76%
3.	Germany	211	11.25%
4.	United States	84	4.48%
5.	Luxembourg	82	4.37%
6.	Austria	73	3.89%
7.	Brazil	62	3.31%
8.	France	62	3.31%
9.	(not set)	51	2.72%
10.	United Kingdom	37	1.97%

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EGSIEM dissemination activities: status

J. Flury, A. Shabanloui

General Assembly, 2-3 Jun 2016

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

Newsletter

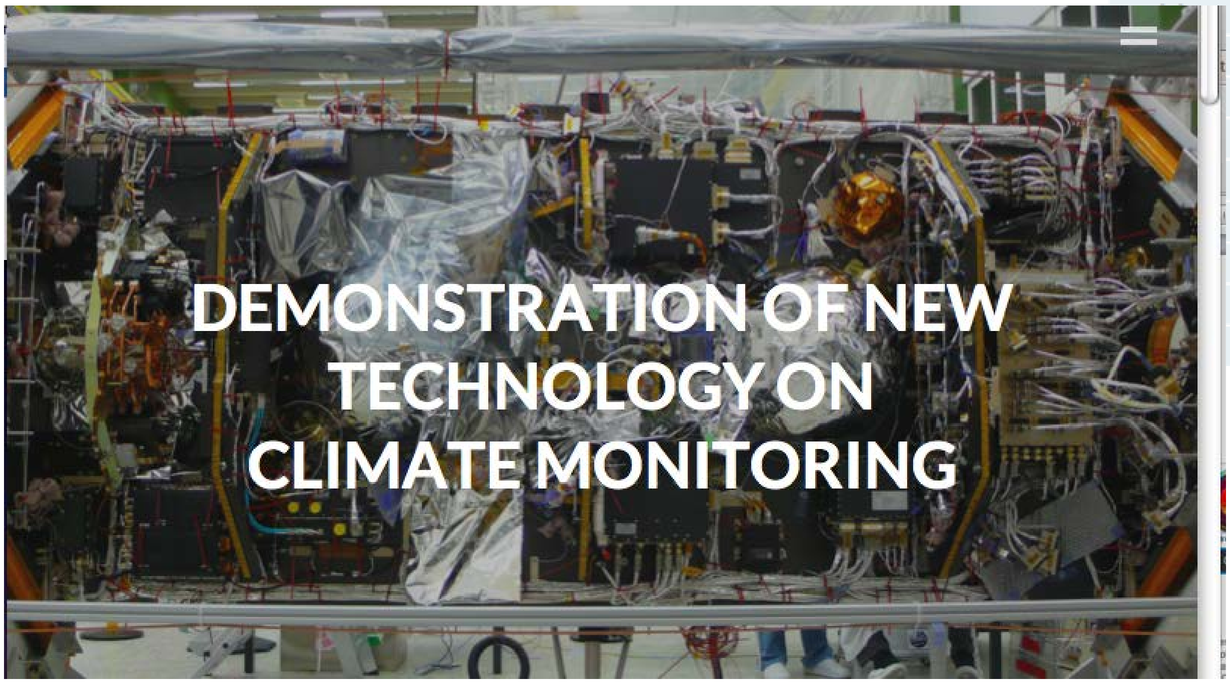
- No 1 Apr 2015
- No 2 Jul 2015
- No 3 Oct 2015
- No 4 Jan 2016
- No 5 Apr 2016
- No 6 tbc

Blog

European Gravity Service for Improved Emergency Management

www.egsiem.eu - news

2015	week 1	week 2	week 3	week 4
Jan	-	-	-	-
Feb	-	-	-	-
	Ubern	DLR	CNES	TUG
	LU	G&C	GFZ	LUH
	Ubern	DLR	CNES	TUG
	LU	G&C	GFZ	LUH
	Ubern	DLR	CNES	TUG
	LU	G&C	GFZ	LUH
	Ubern	DLR	CNES	TUG
	LU	G&C	GFZ	LUH
	Ubern	DLR	CNES	TUG



Conference contributions

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- AGU 2015
- EGU 2016
- Living Planet 2016
- GEO meeting Jun 1, 2016
- COSPAR Jul 30 – Aug 7, 2016 Istanbul?
- GGHS Sep 19-23, 2016 Thessaloniki
- GSTM Oct 5-7, Potsdam
- AGU 2016?
- others?

Journal papers

European Gravity Service for Improved Emergency Management

Teaser lectures

European Gravity Service for Improved Emergency Management

done in Bern

next steps?

Press

European Gravity Service for Improved Emergency Management

Facebook

European Gravity Service for Improved Emergency Management

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Other

- EGSIEM brochure
- Twitter
- Hot stories

European Gravity Service for Improved Emergency Management

Title: **Status of NRT & Regional Service at TUG**

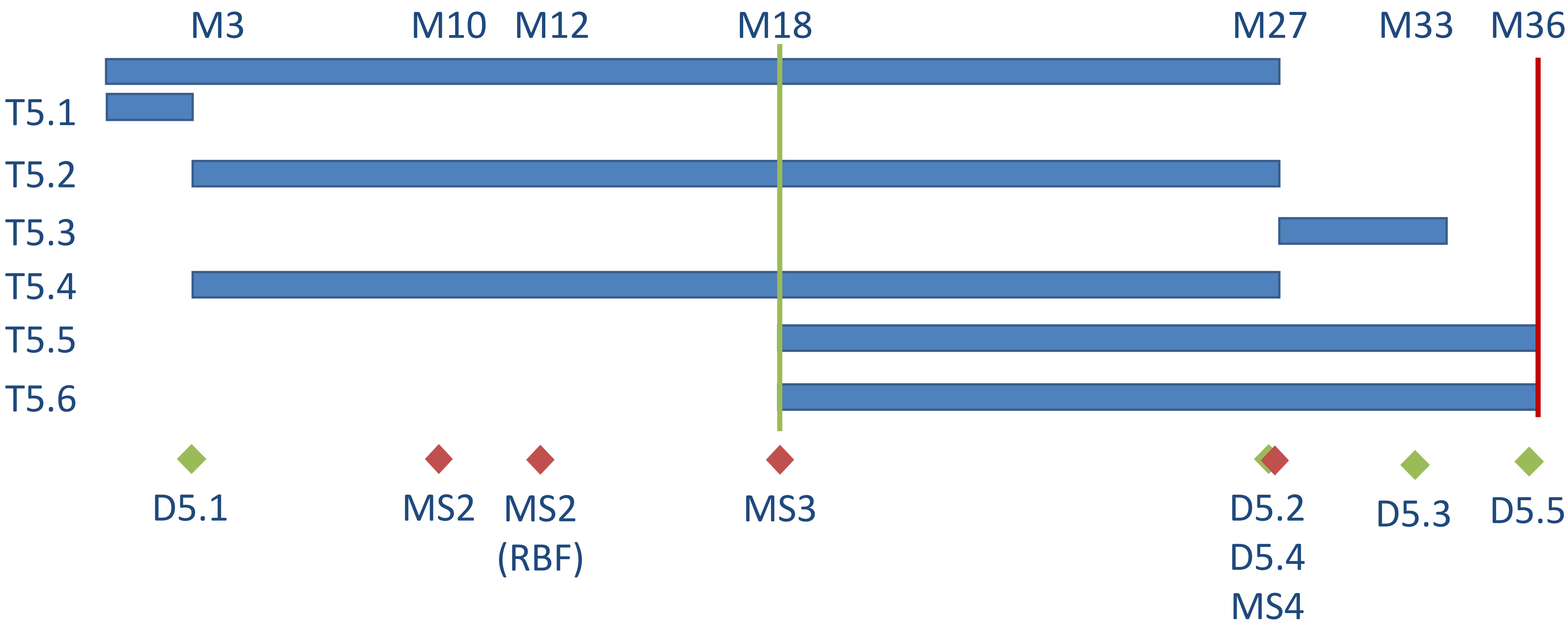
Presenter: AK

Affiliation: TUG

EGSIEM Meeting Potsdam,
02.06.2016 - 03.06.2016

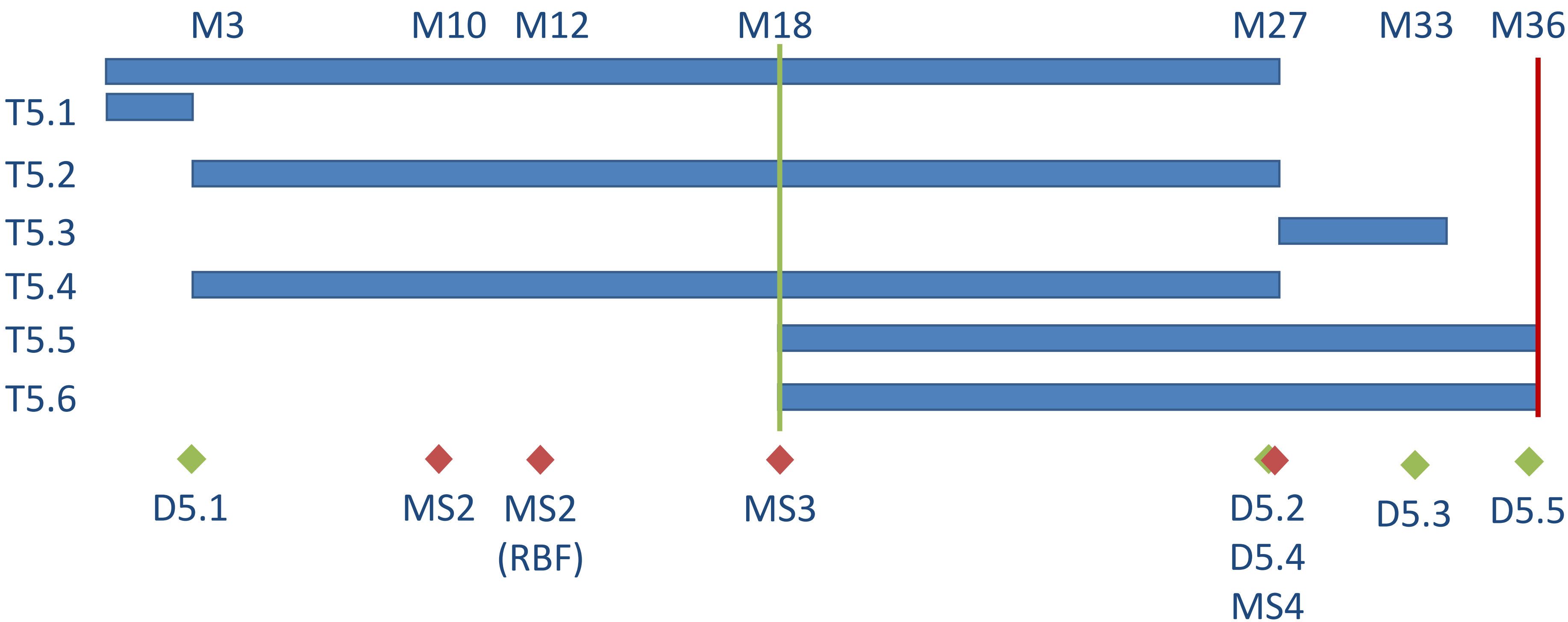
Status of NRT – Time Table and Milestones

Status of NRT – Time Table and Milestones



- Milestone 3: Service Readiness, M18
  - Marks the begin of T5.5 (Generation of Area Mean Values, M19) and T5.6 (Validation/Feedback, M19)
  - Software for NRT capability is implemented

Status of NRT – Time Table and Milestones

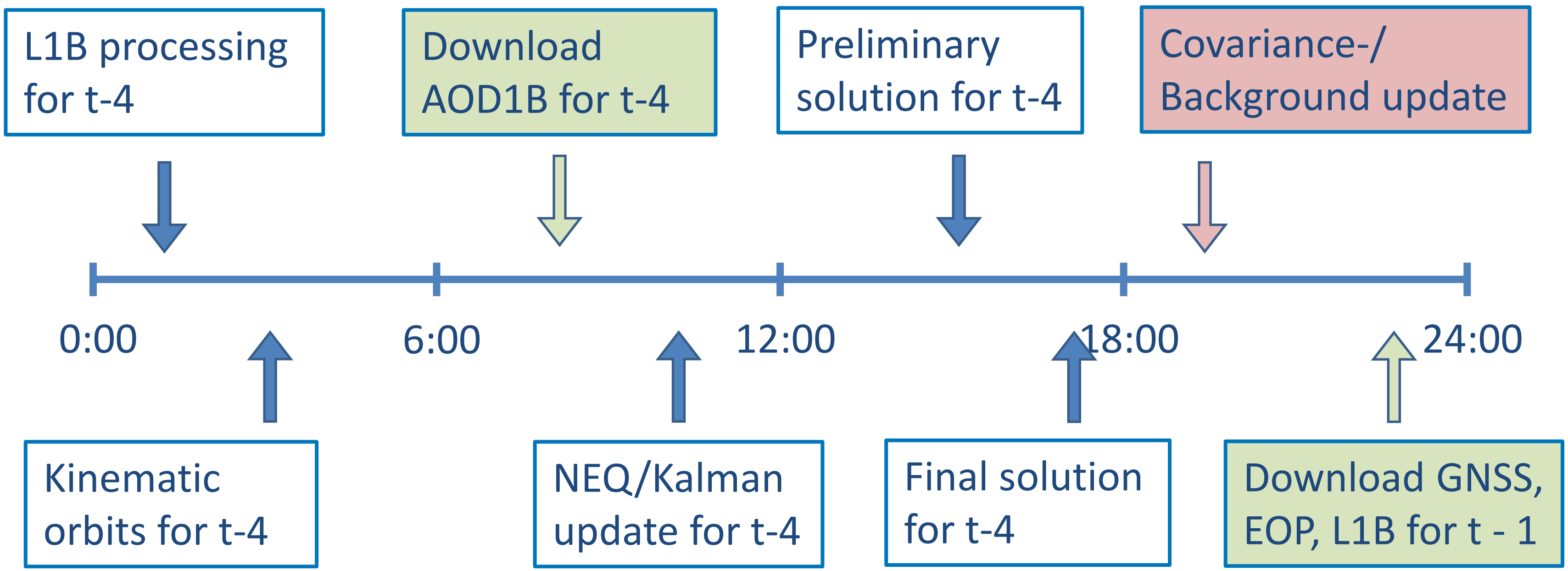


- Next milestones/deliverables:
  - D5.2: NRT Service Product Report (M27)
  - D5.4: Regional Solution Product Report (M27)

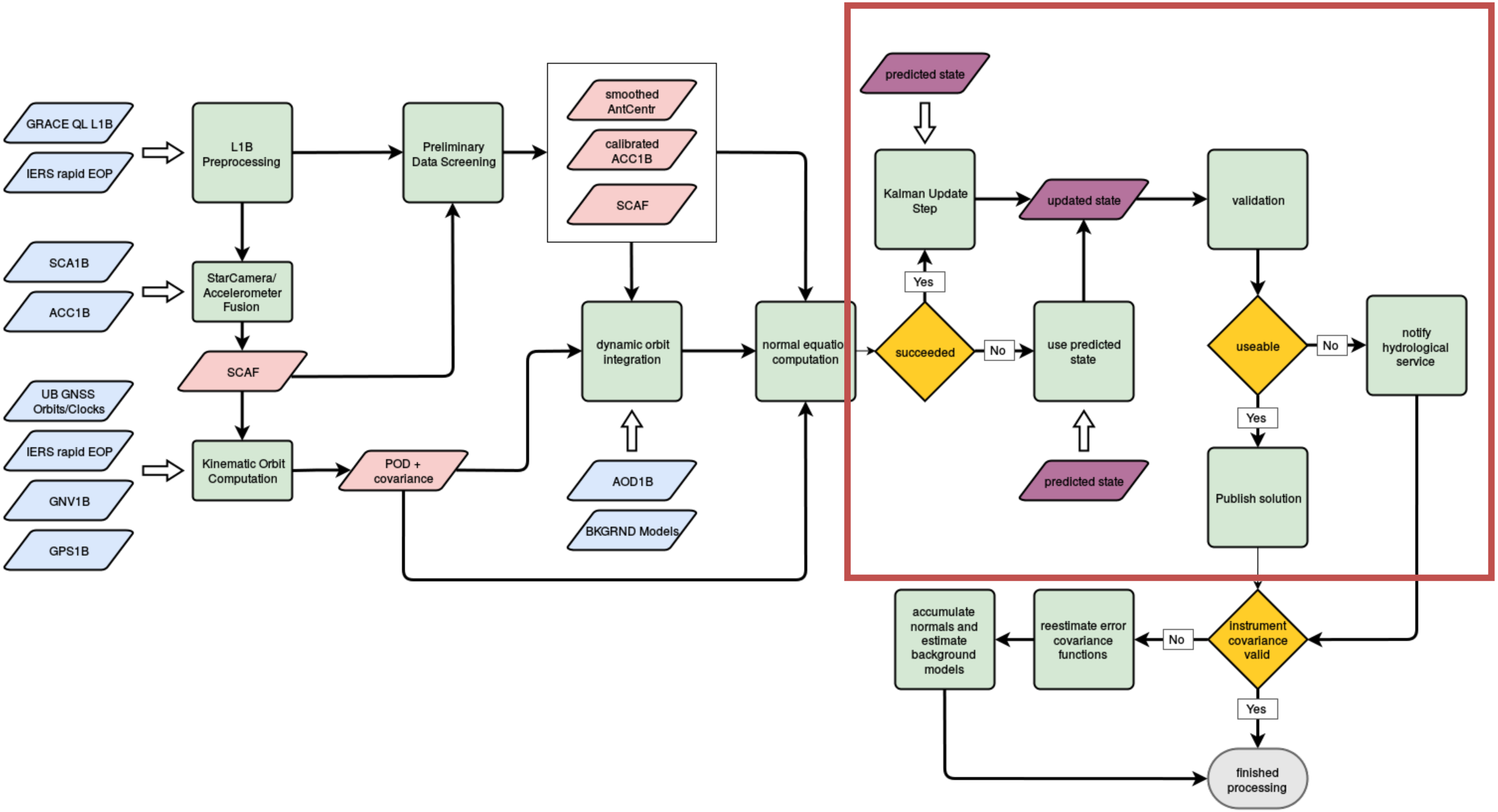
  - MS4: Operational NRT Service (M27)

Status of NRT – Processing Schedule

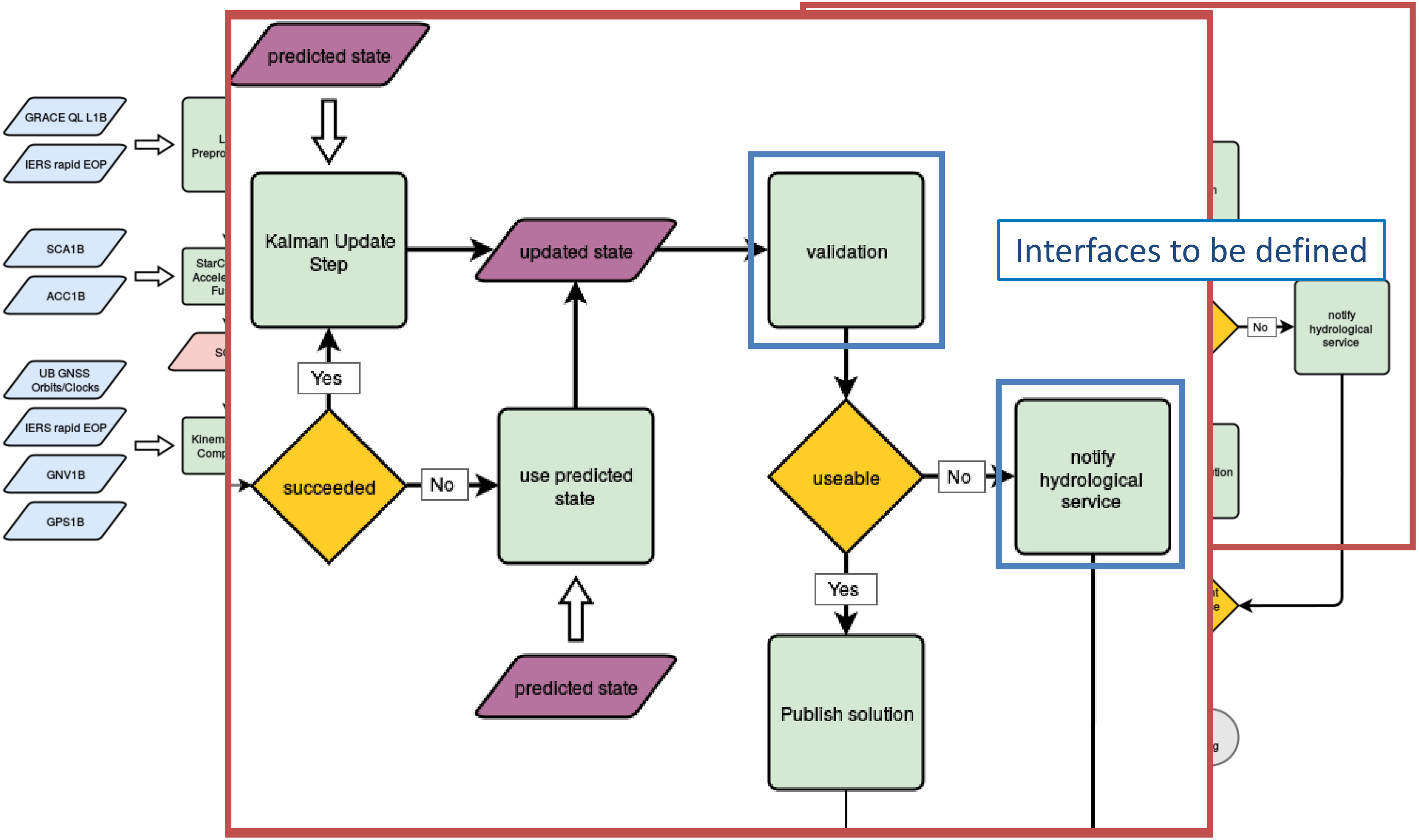
- Processing sequence executed daily
- Slight departure from D5.1:
  - Data acquisition is detached from processing



Status of NRT – Processing Schedule



Status of NRT – Processing Schedule

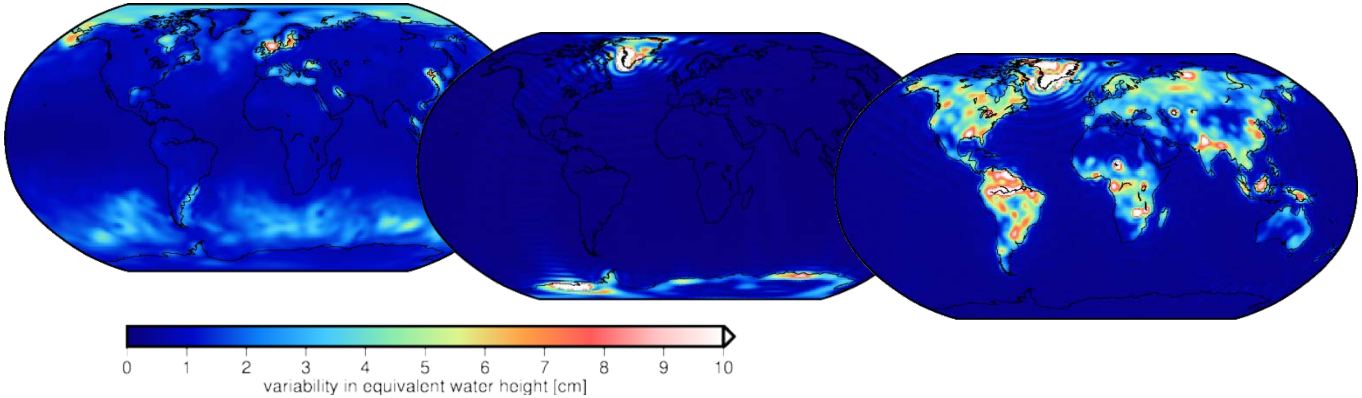


Post Processing Results

Post processing results – ITSG-Grace2016

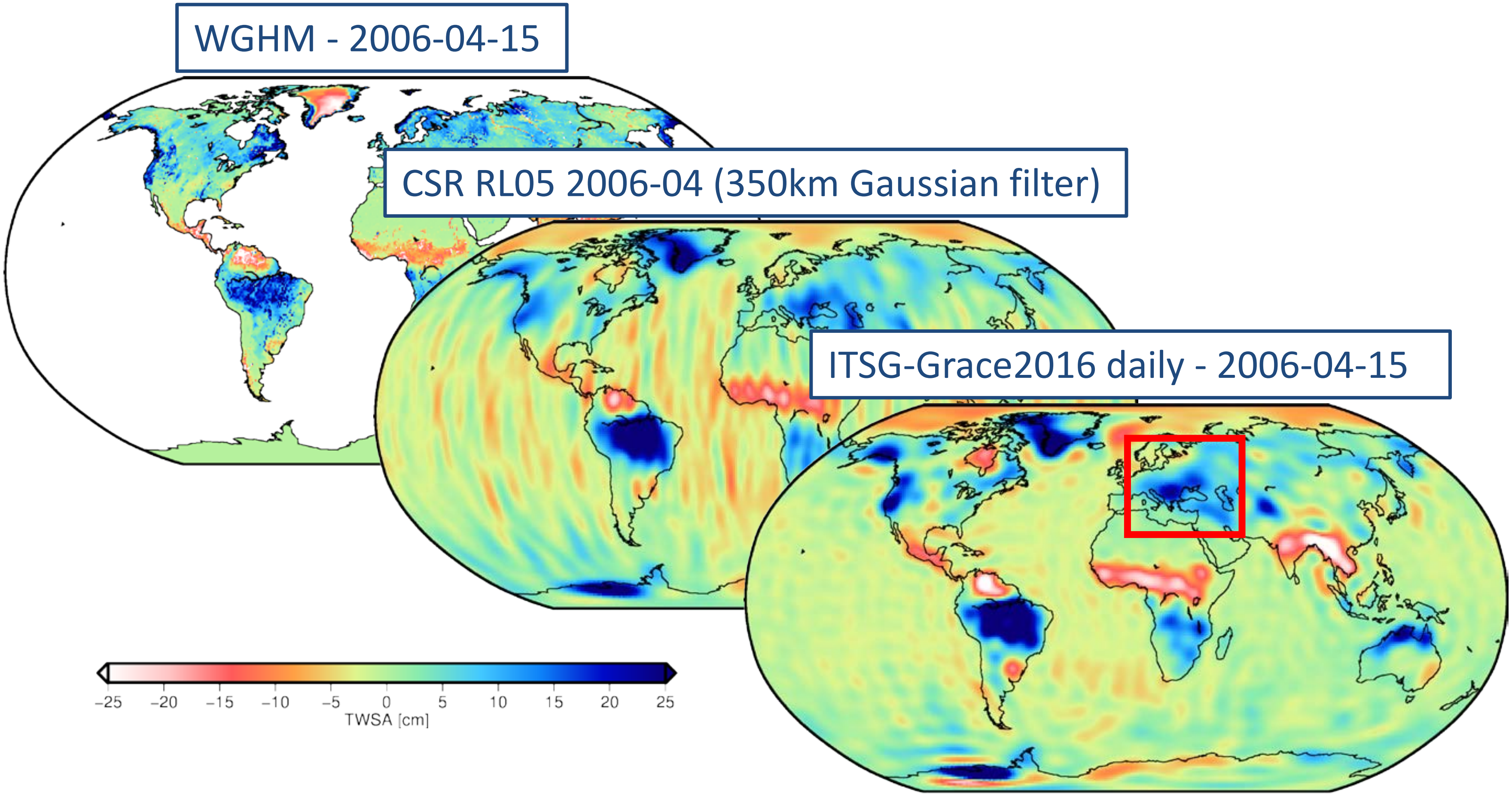
- GRACE time series (2002 to 2016) processed and continually updated
  - 5053 daily solutions (4258 days with GRACE contribution)

- Process model derived from WGHM (hydrosphere) and ESA ESM (cryosphere, residual atmosphere/ocean)

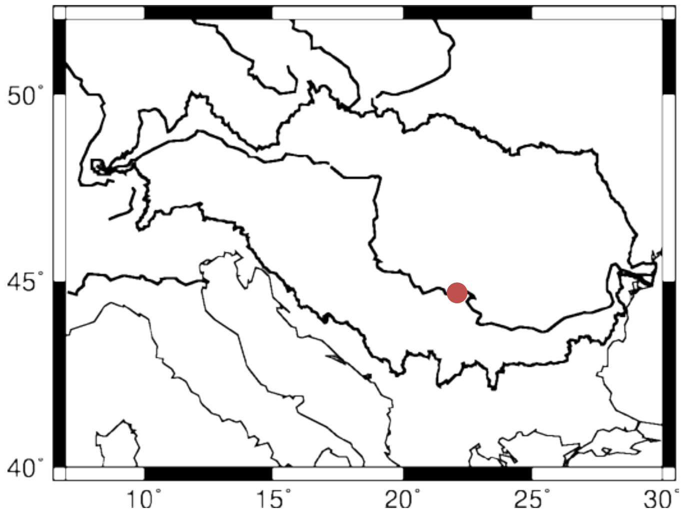


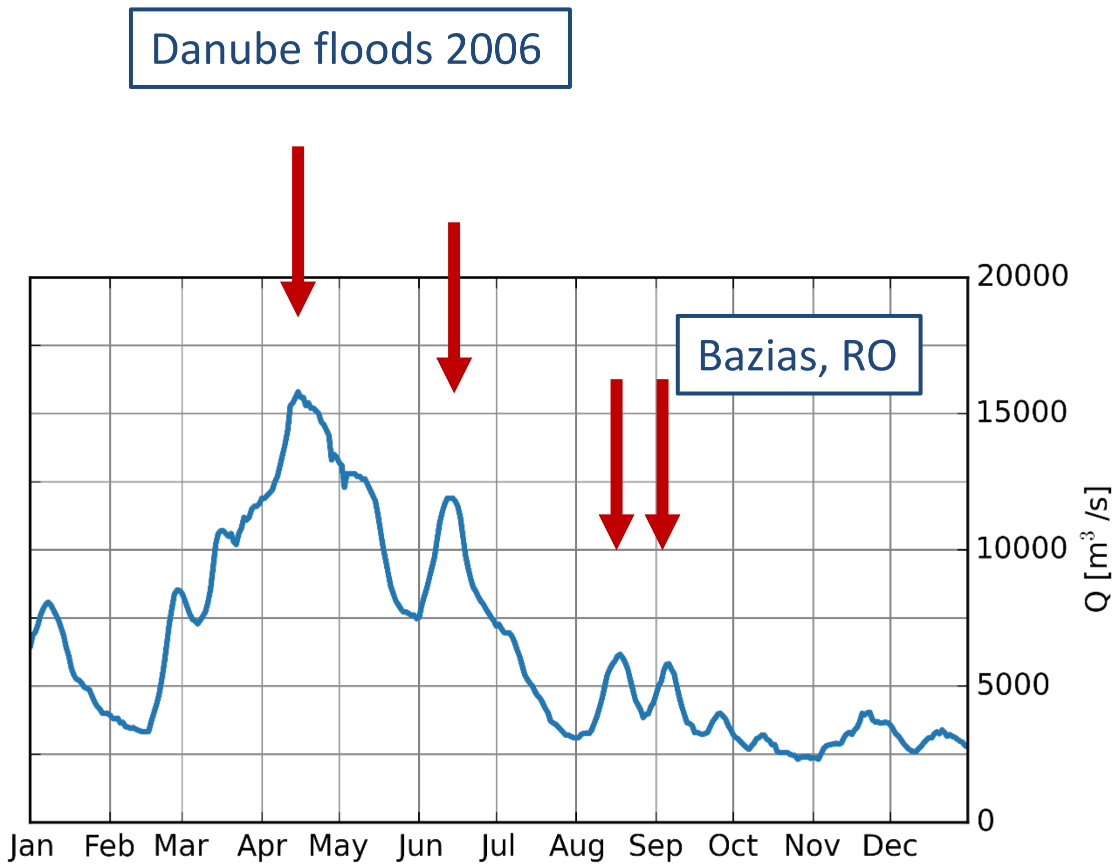
- GRACE processing details: Klinger et al. - Towards a new ITSG-Grace release: improvements within the processing chain, Session G4.2 - Wednesday, 9am

Post processing results – ITSG-Grace2016

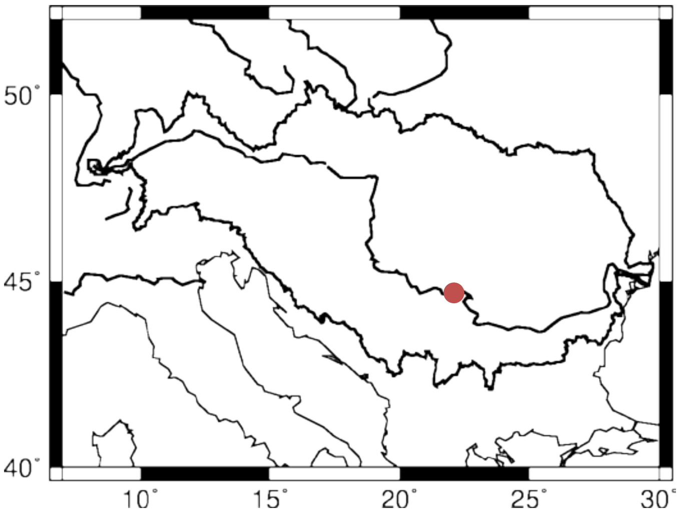


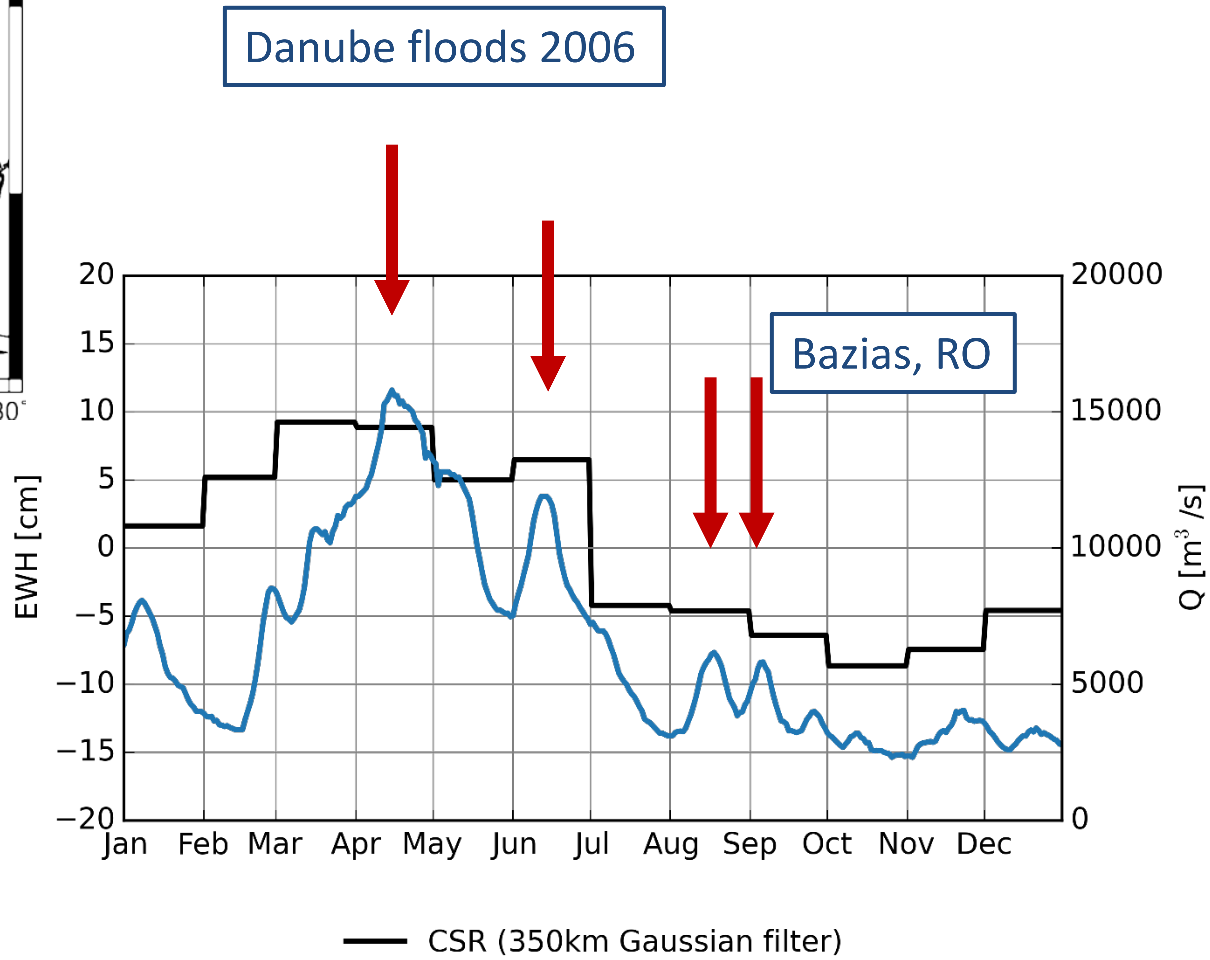
Post processing results – ITSG-Grace2016



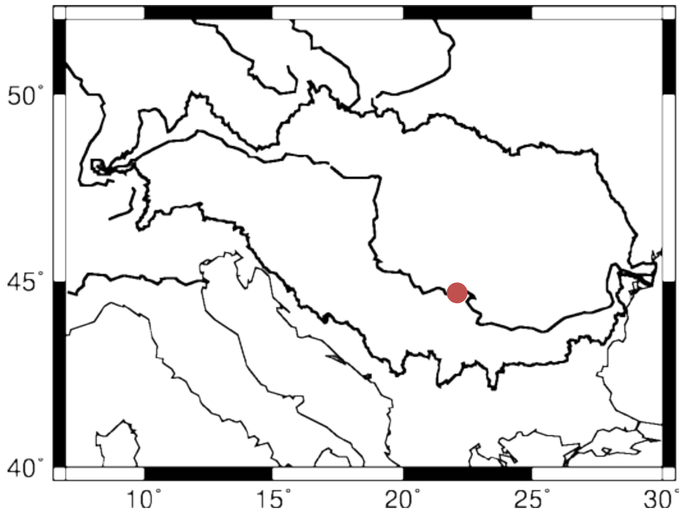


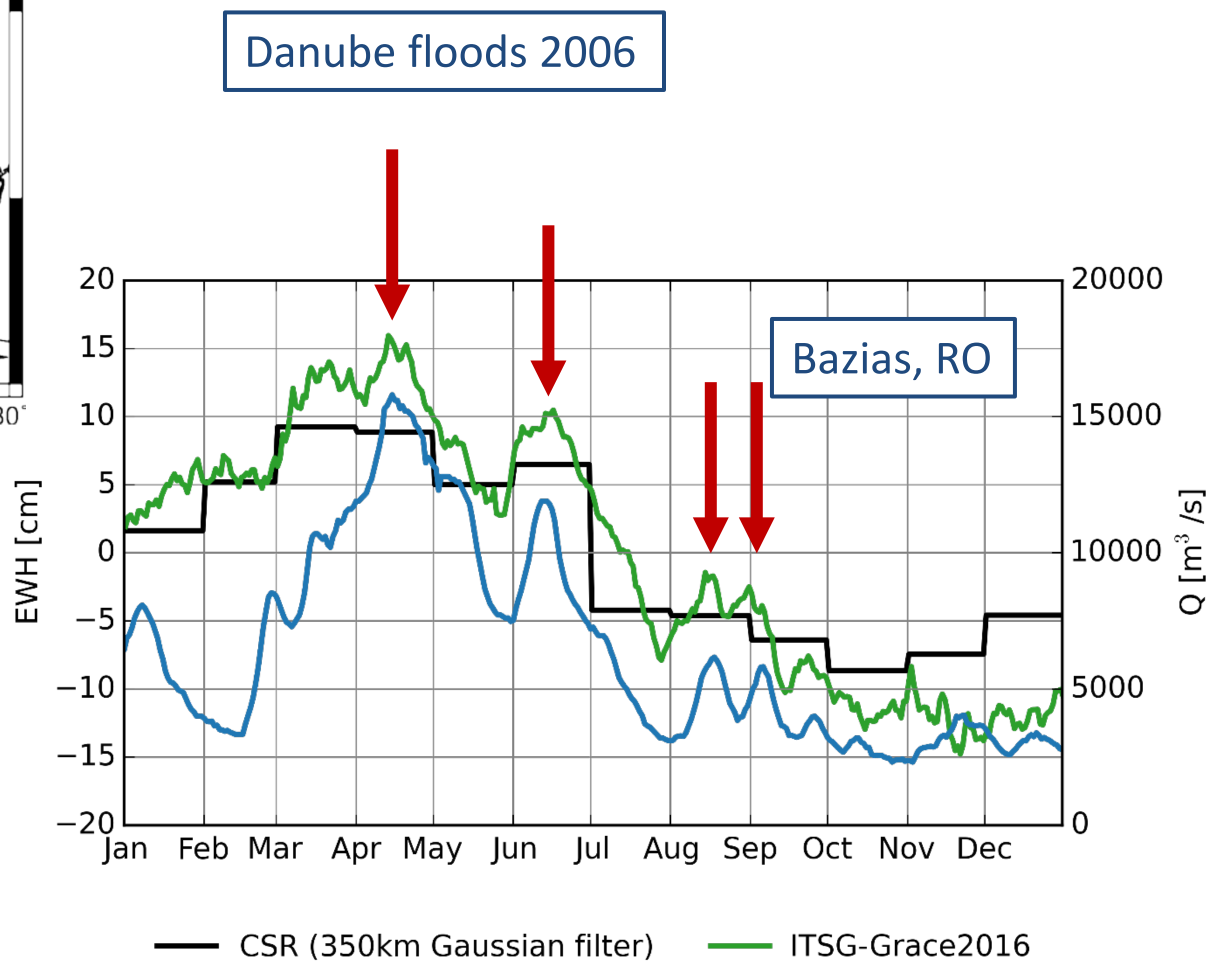
Post processing results – ITSG-Grace2016





Post processing results – ITSG-Grace2016





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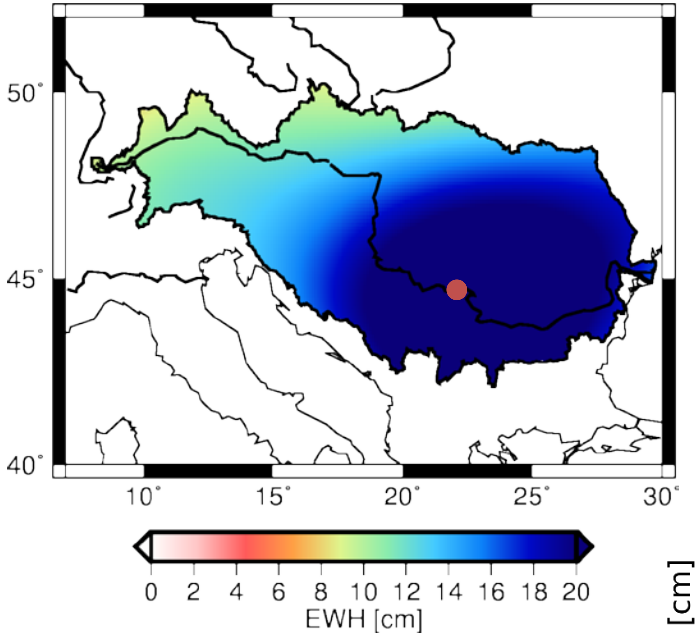
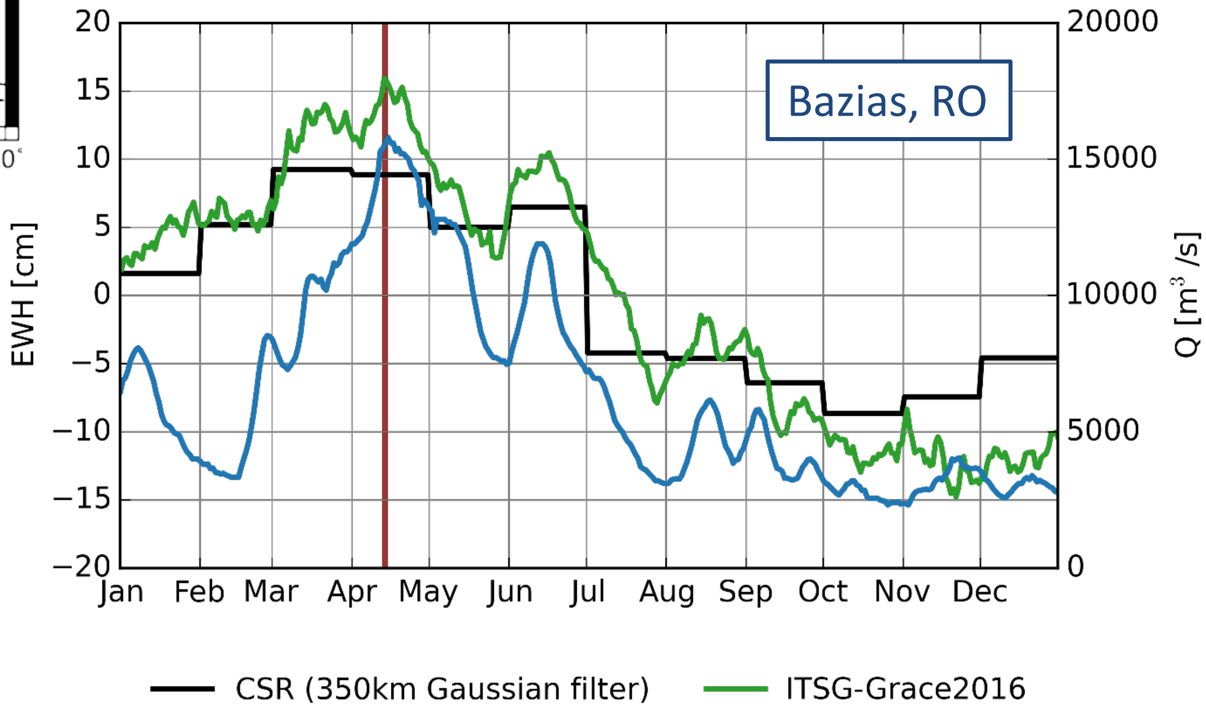
Post processing results – ITSG-Grace2016



Danube floods 2006



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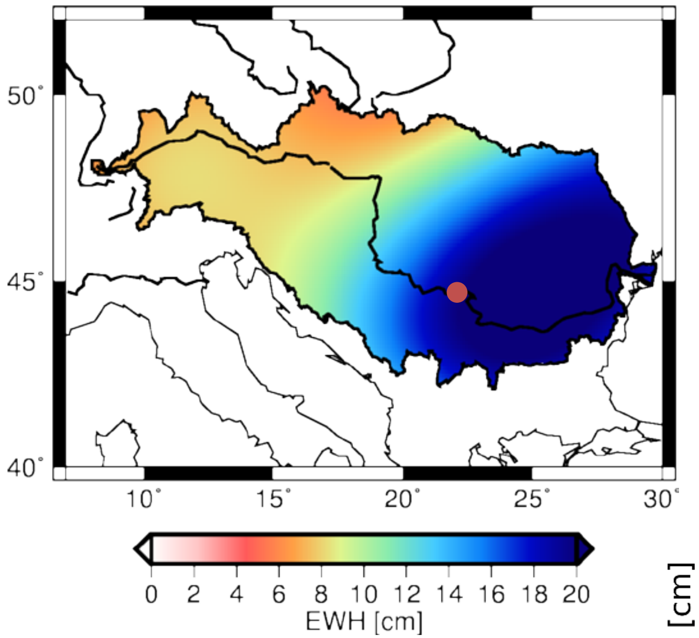
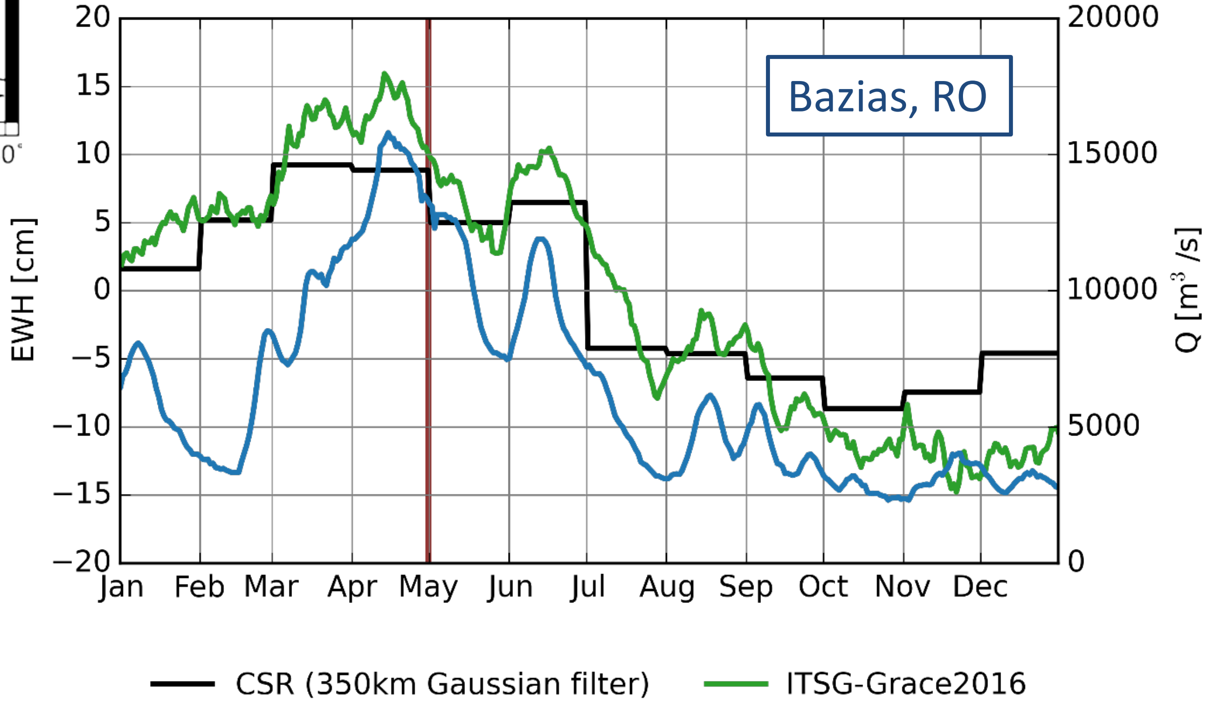


Danube floods 2006



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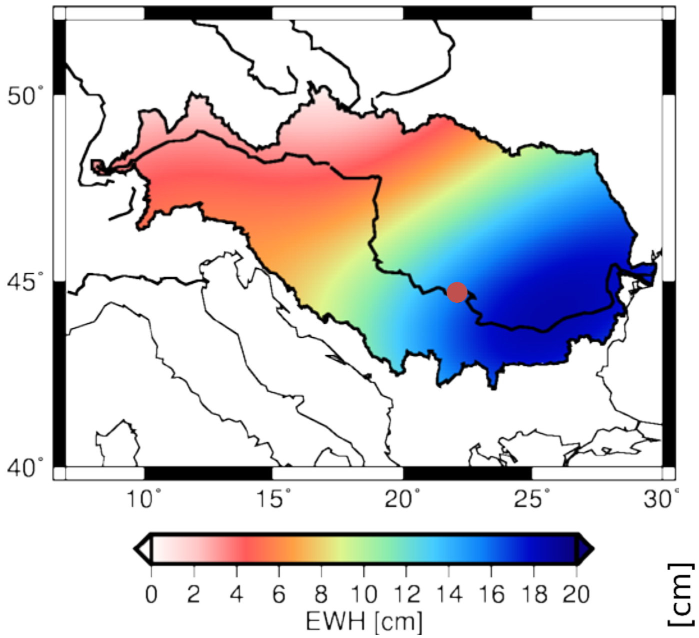
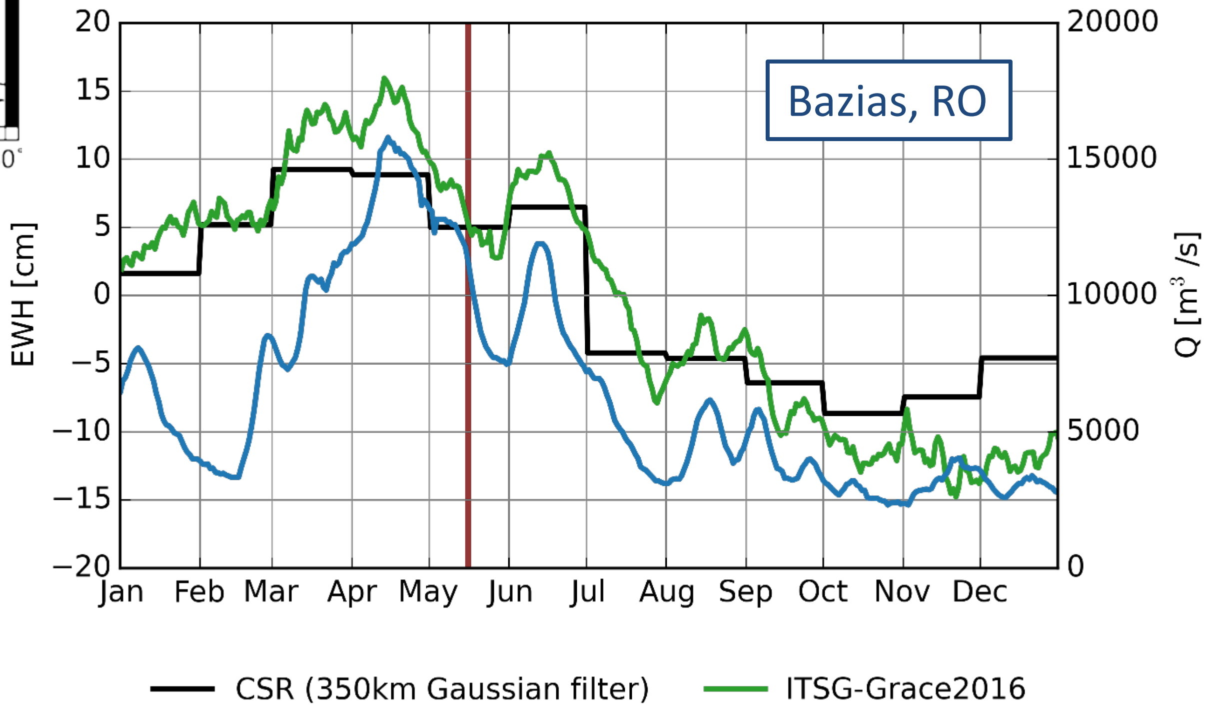
Post processing results – ITSG-Grace2016



Danube floods 2006



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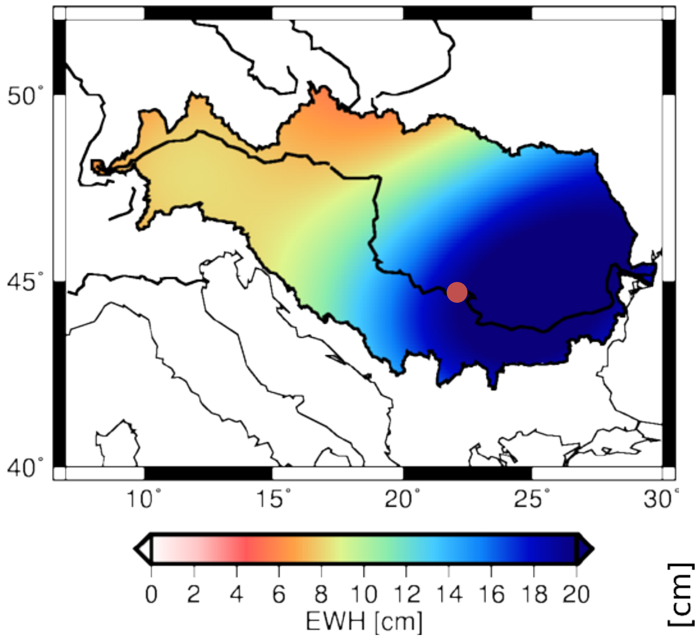
Post processing results – ITSG-Grace2016



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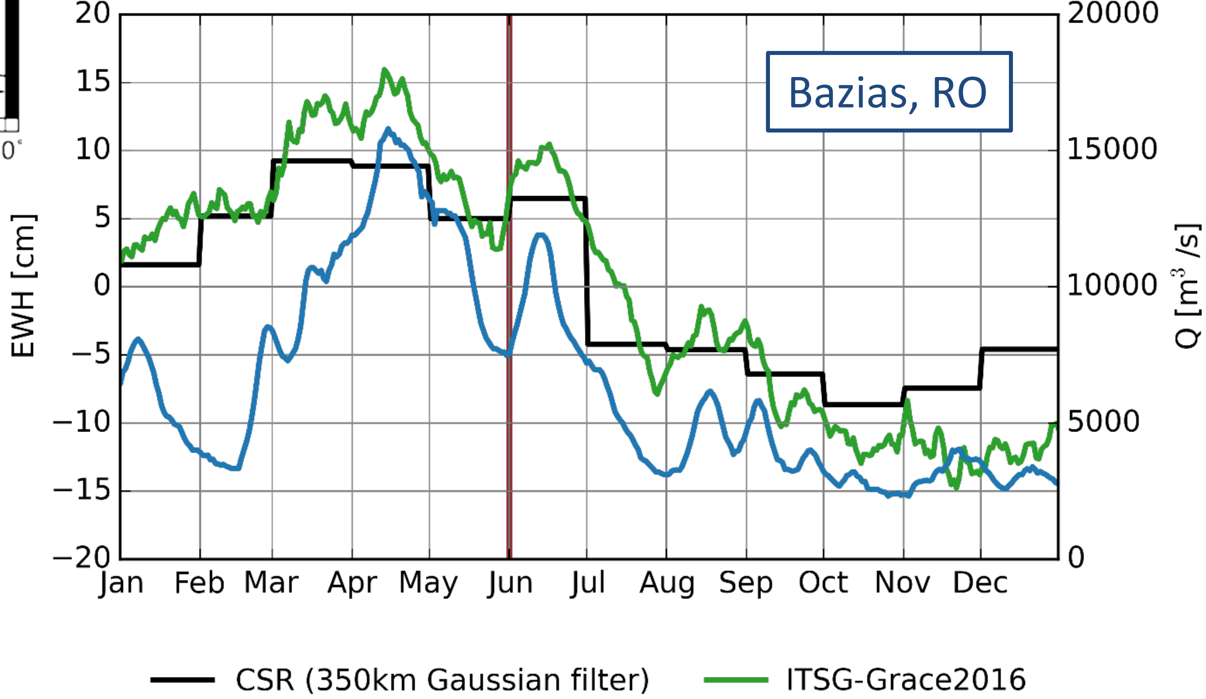
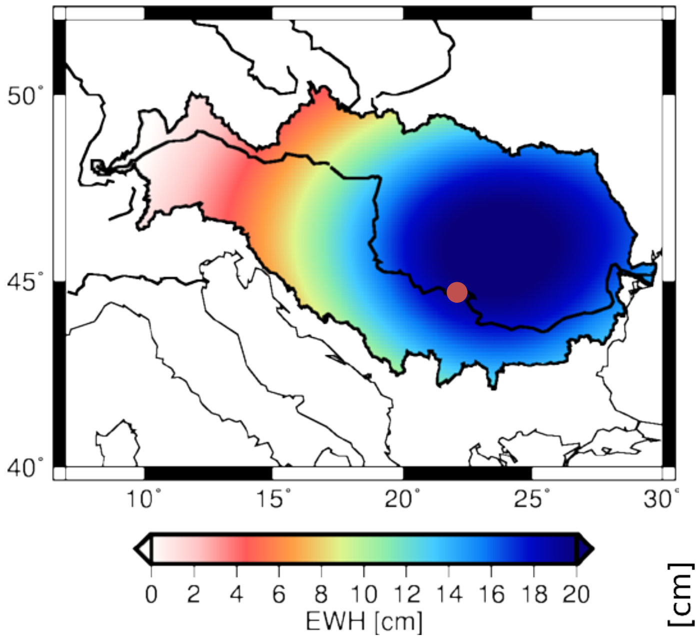


Post processing results – ITSG-Grace2016



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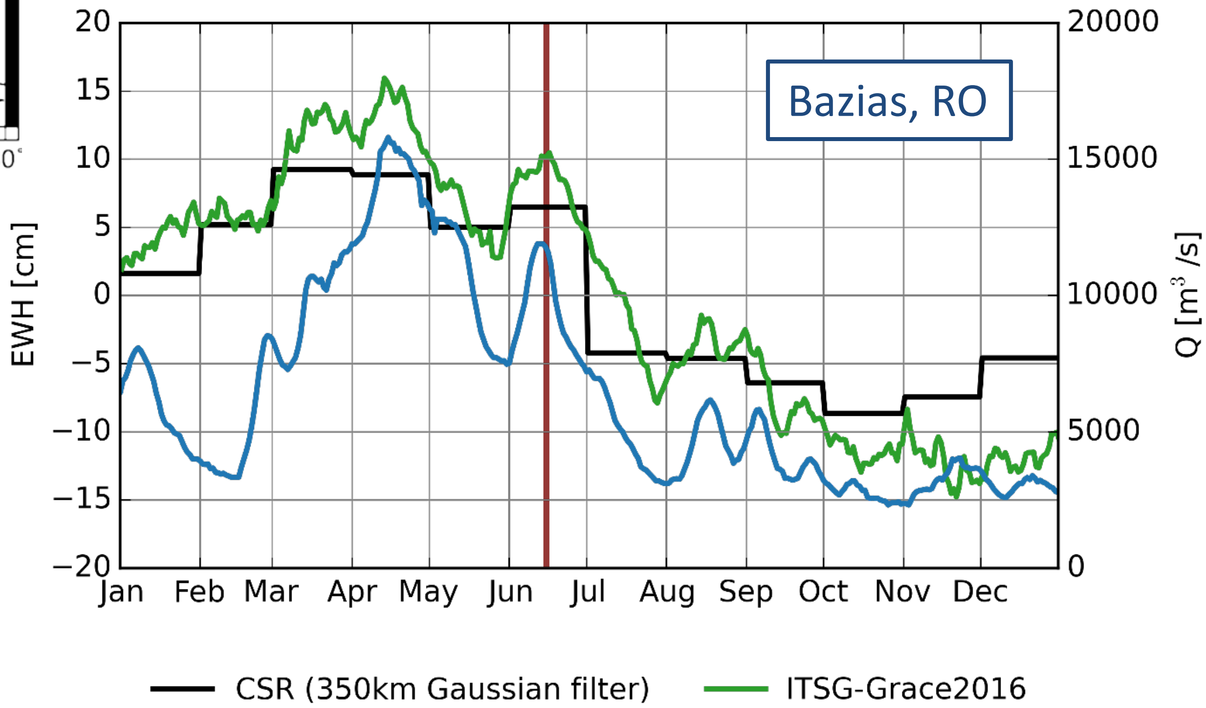

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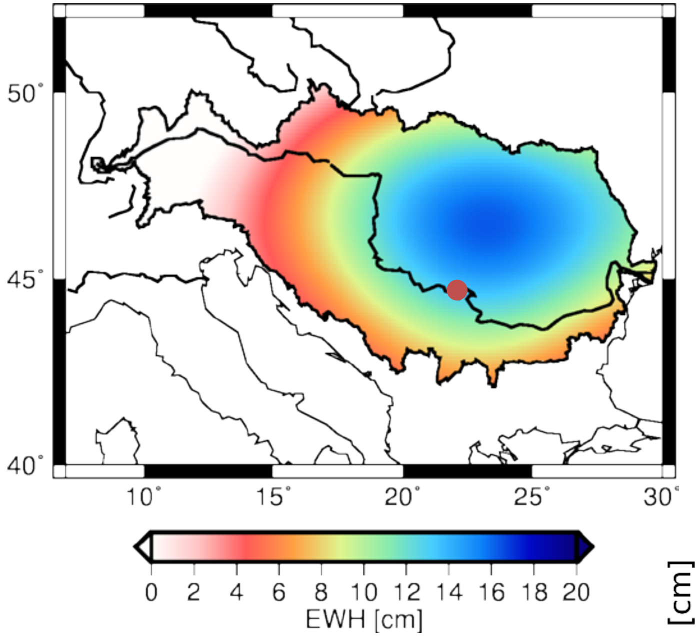

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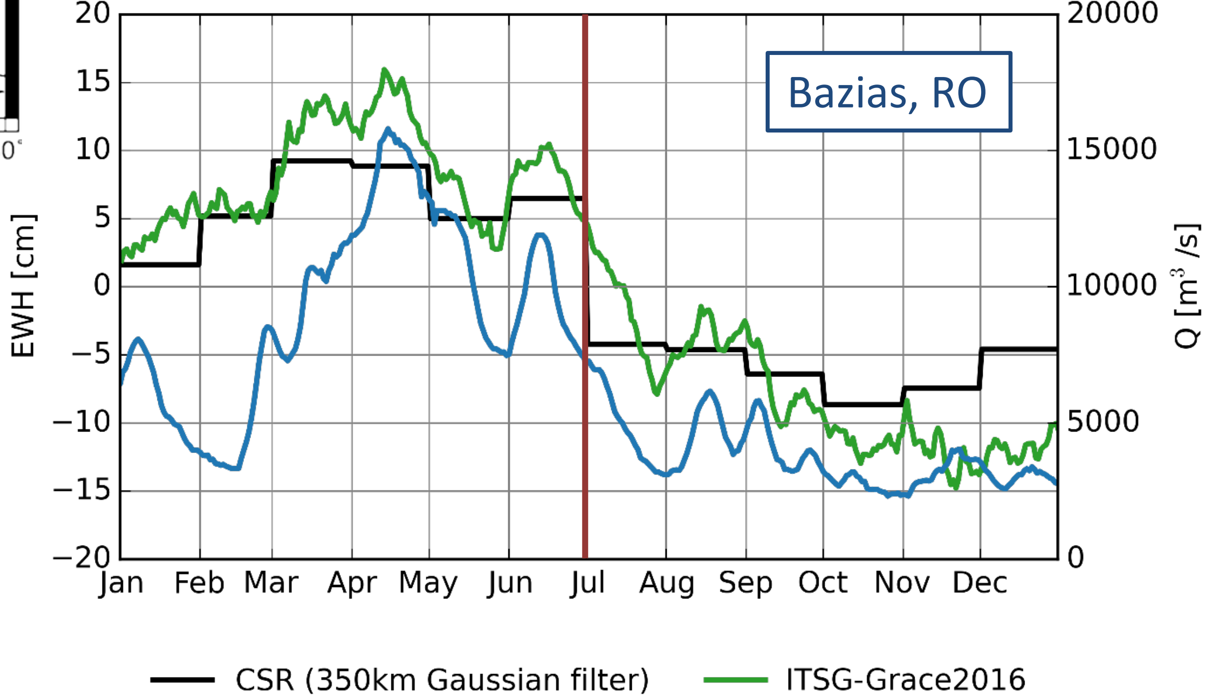

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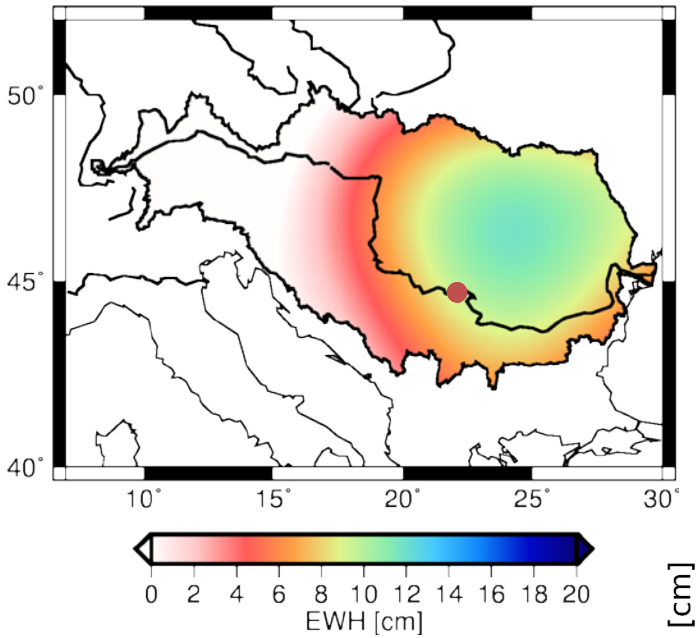

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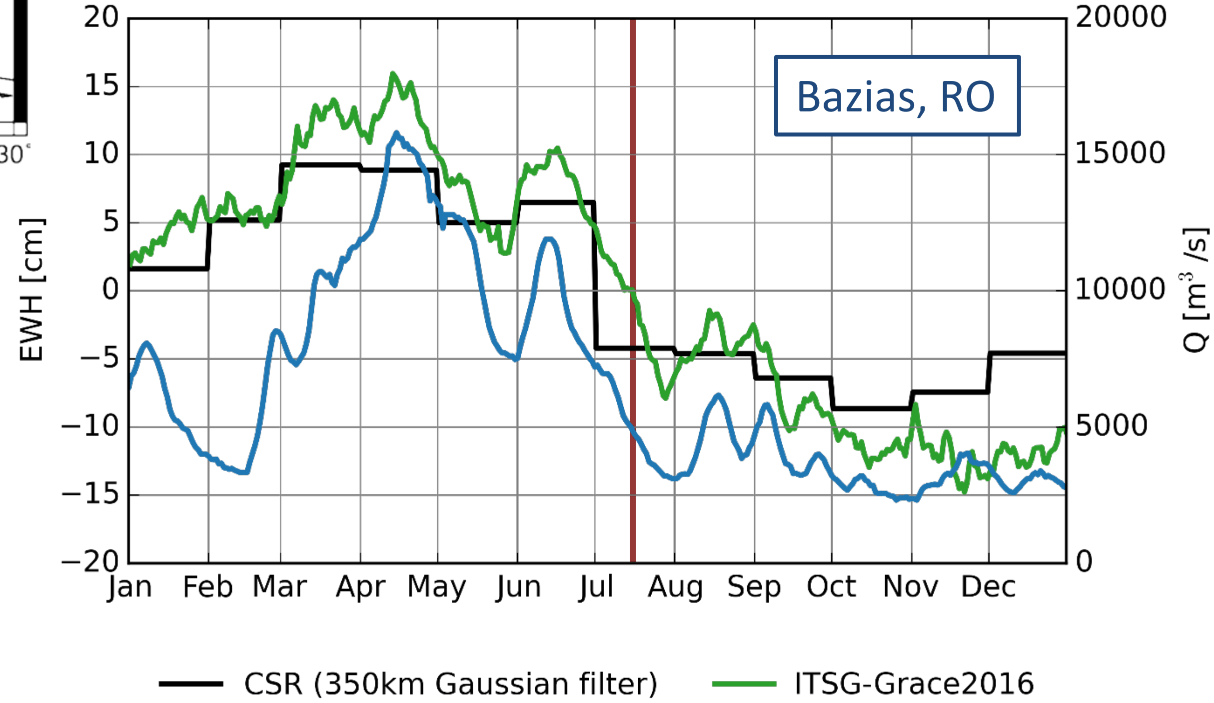

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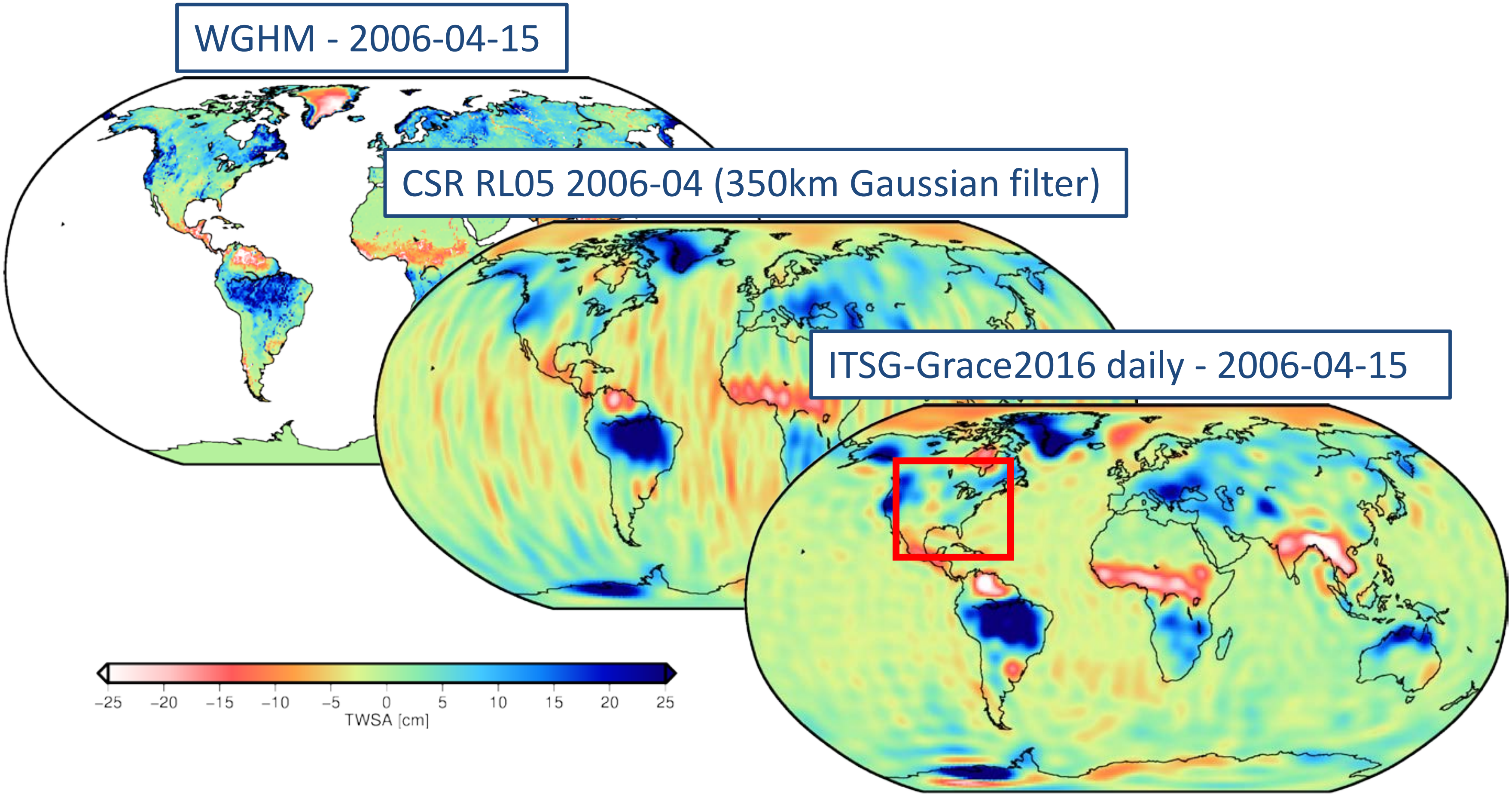

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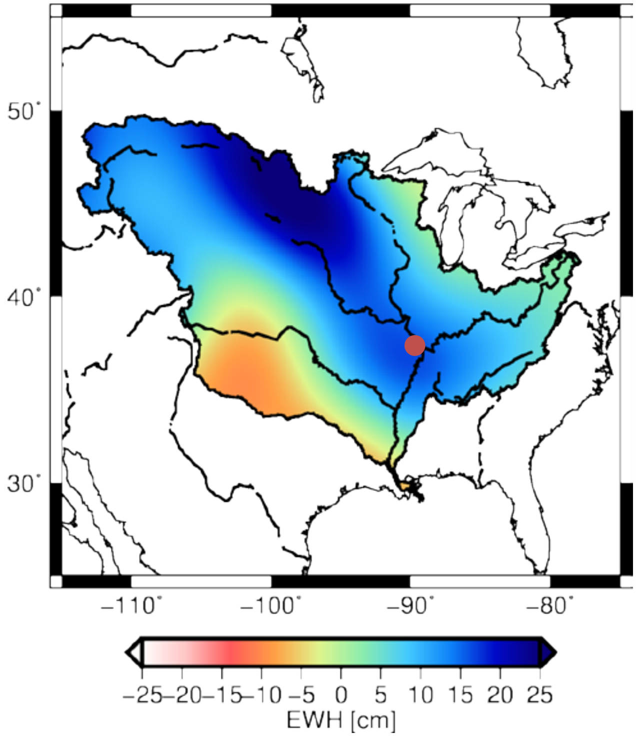
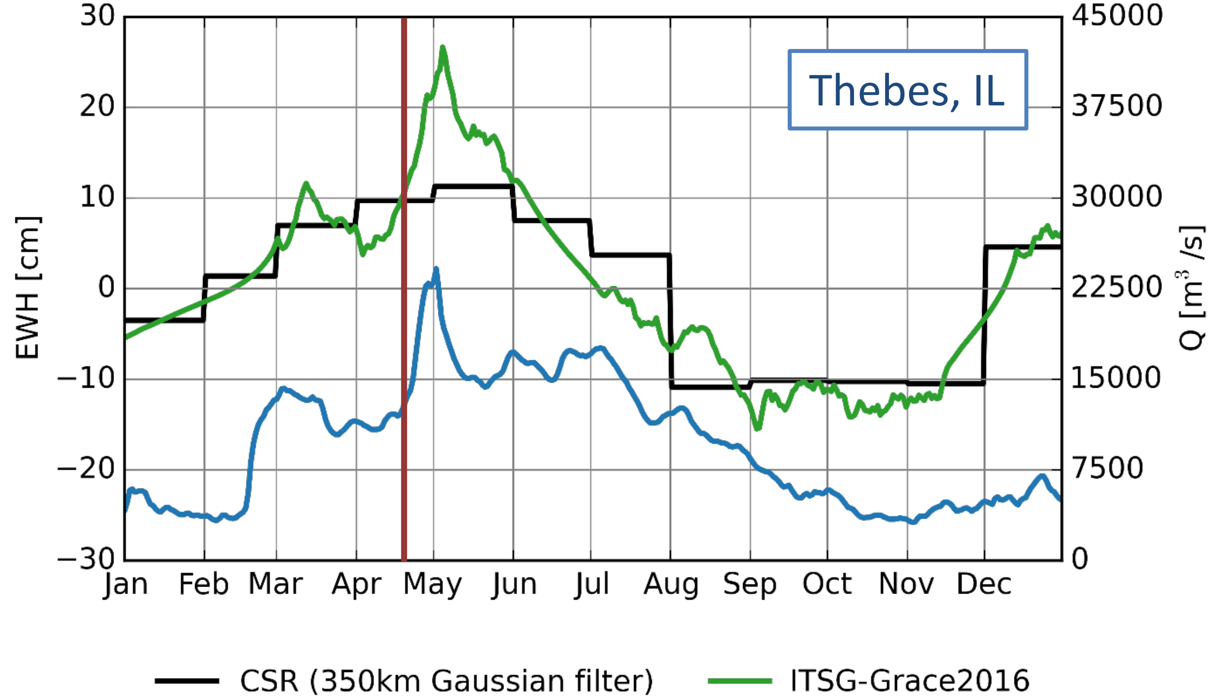


Great Mississippi Flood of 2011



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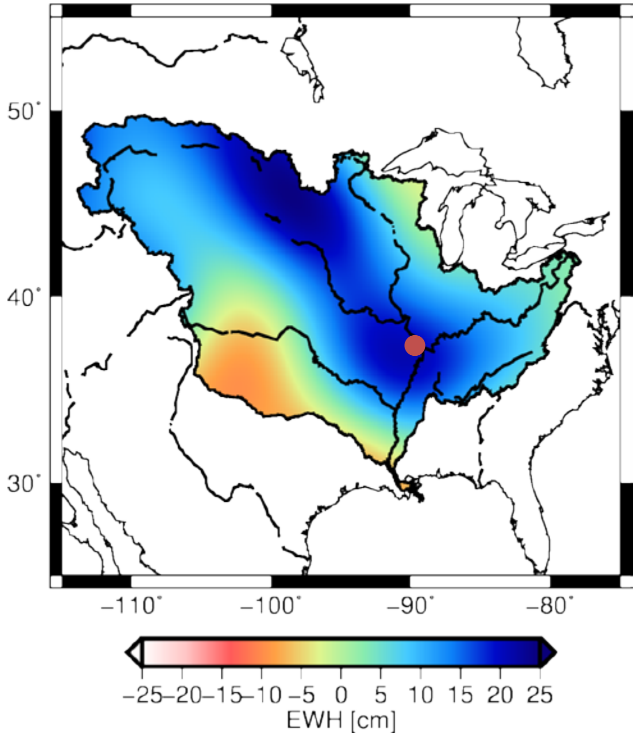

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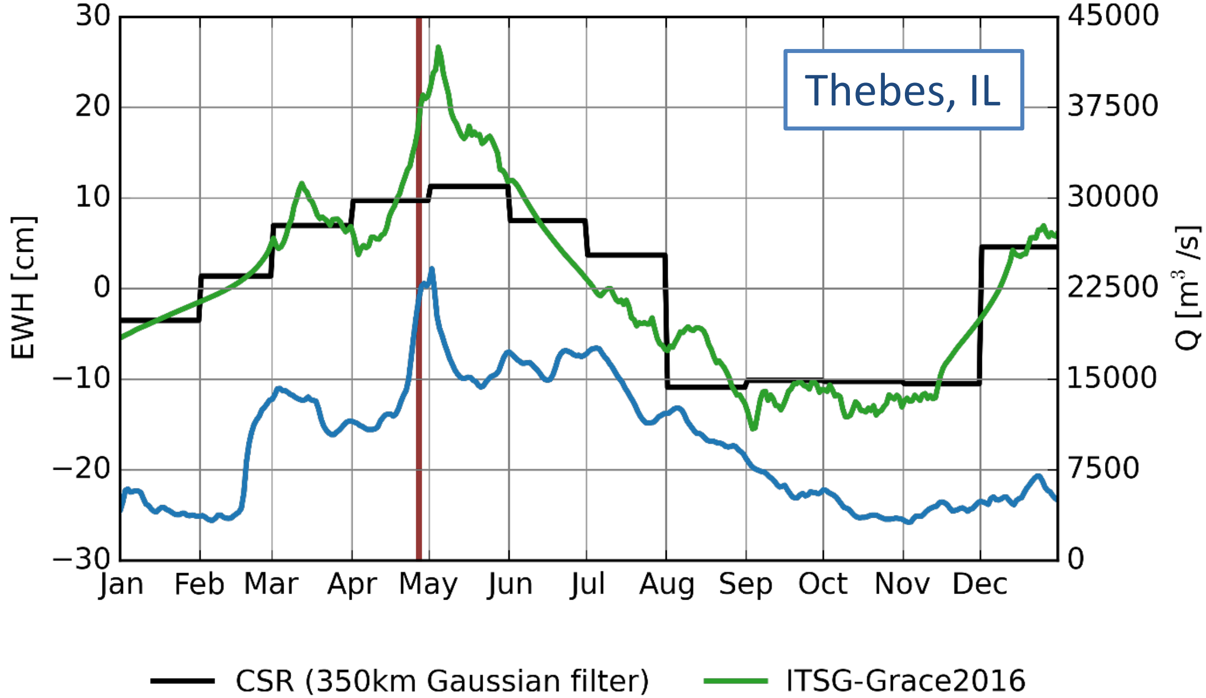

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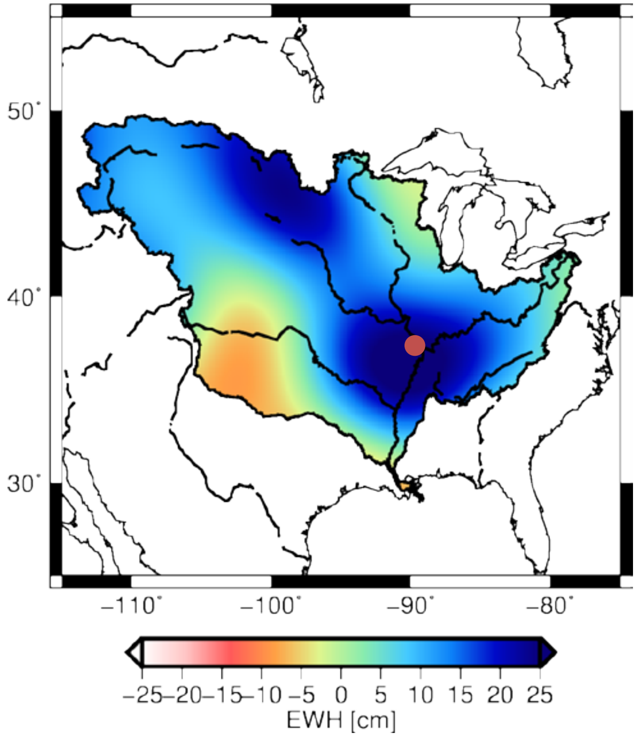
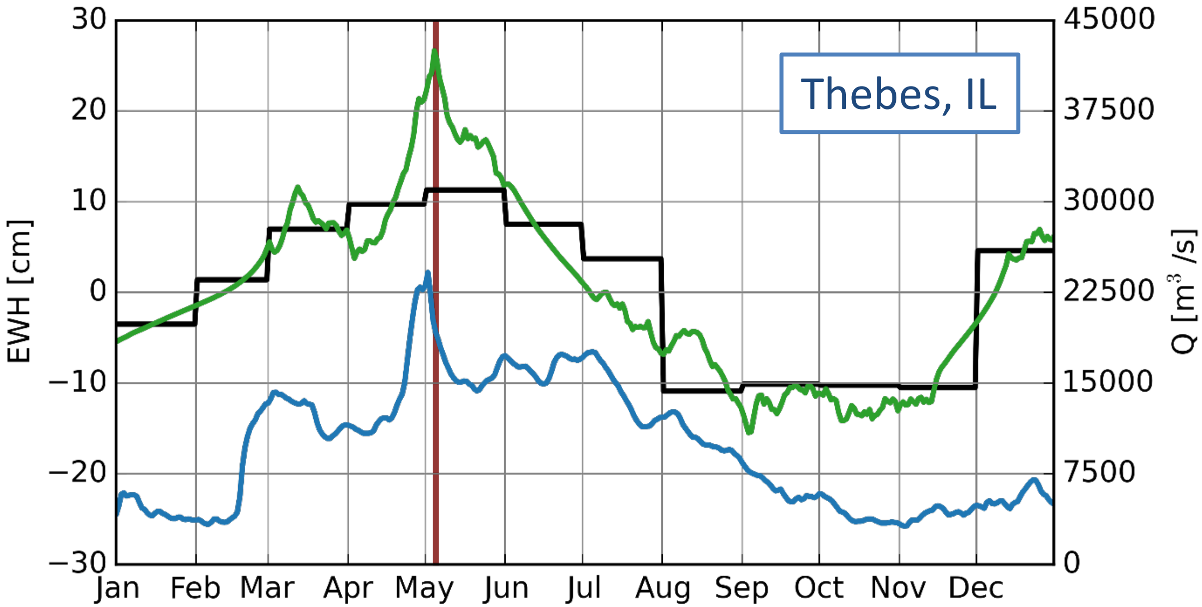
Post processing results – ITSG-Grace2016



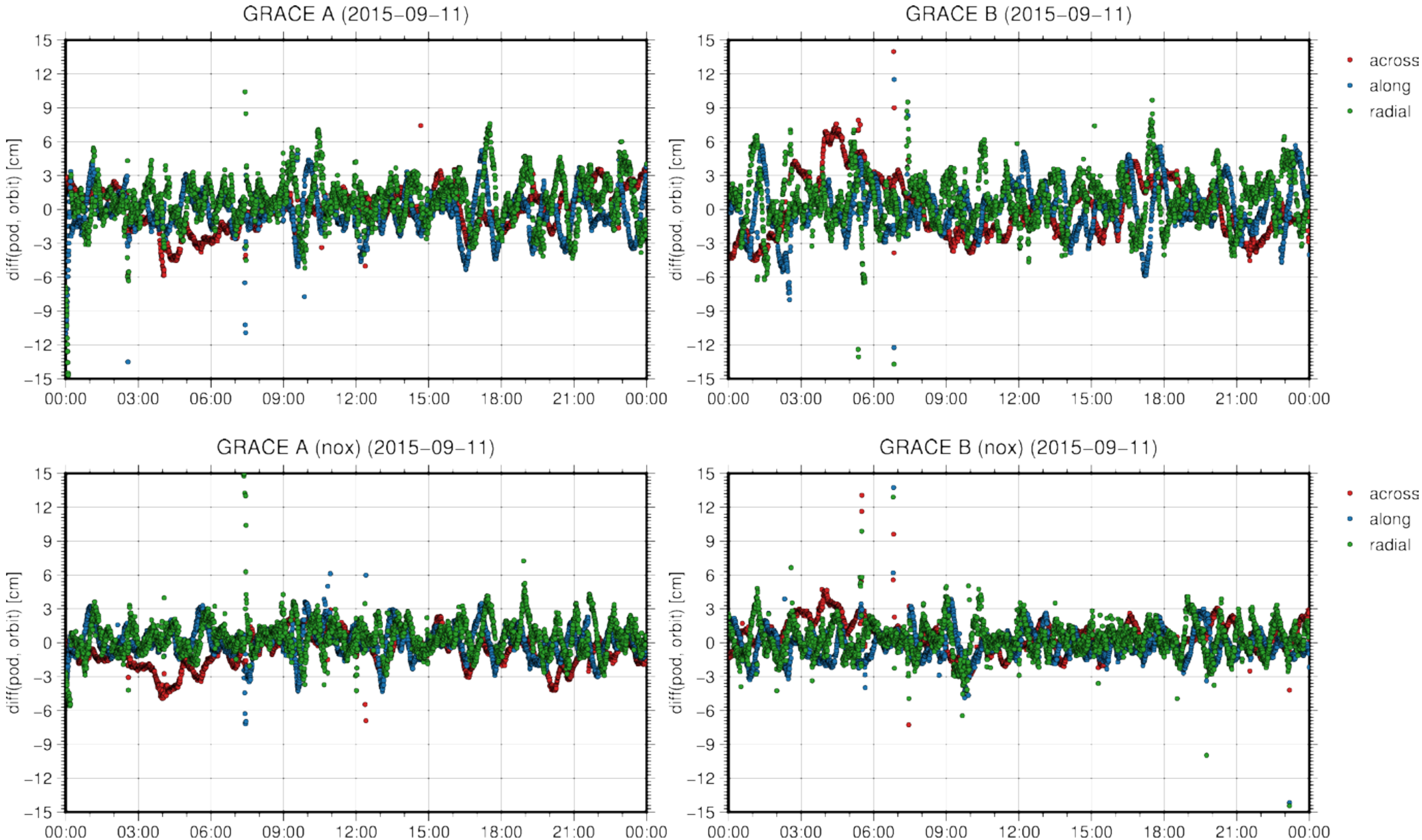


Rapid GNSS Input Data

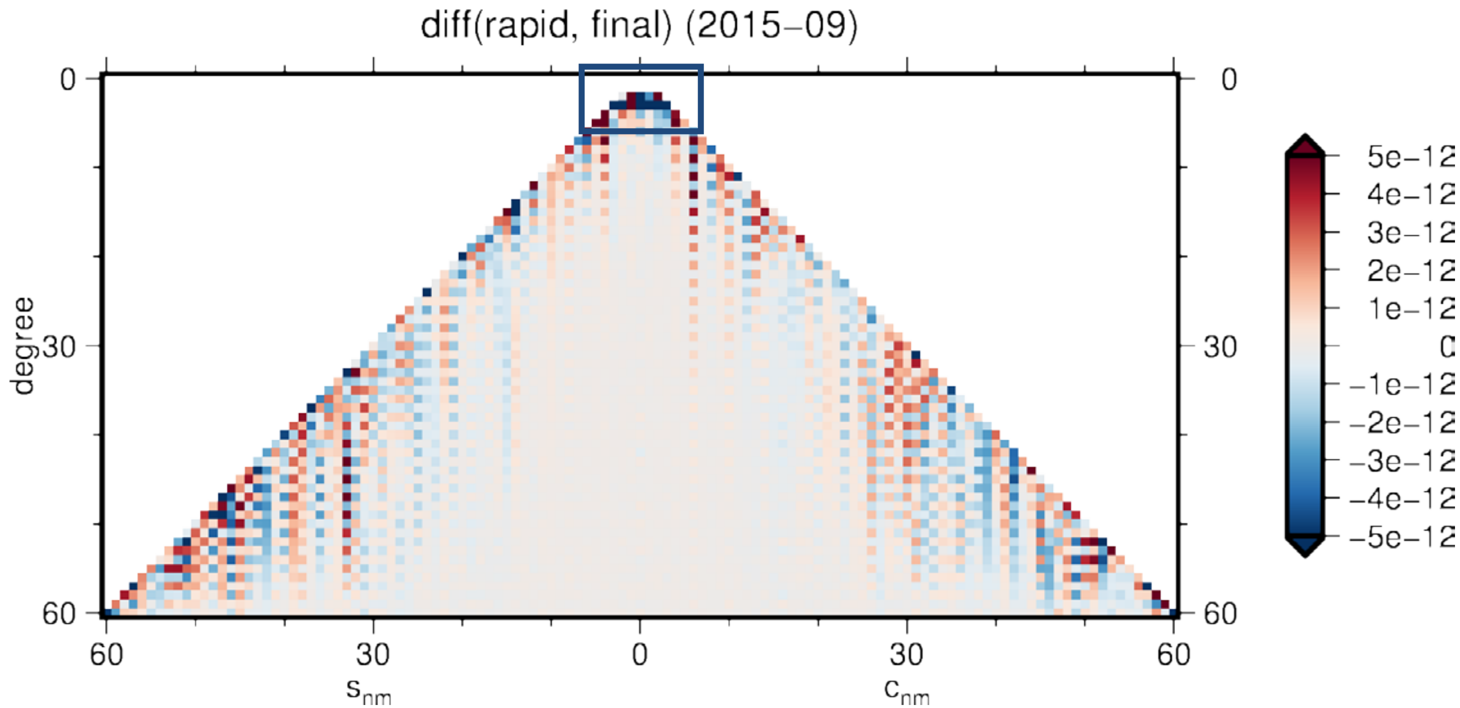
Status of NRT – Rapid Input Data

CODE rapid

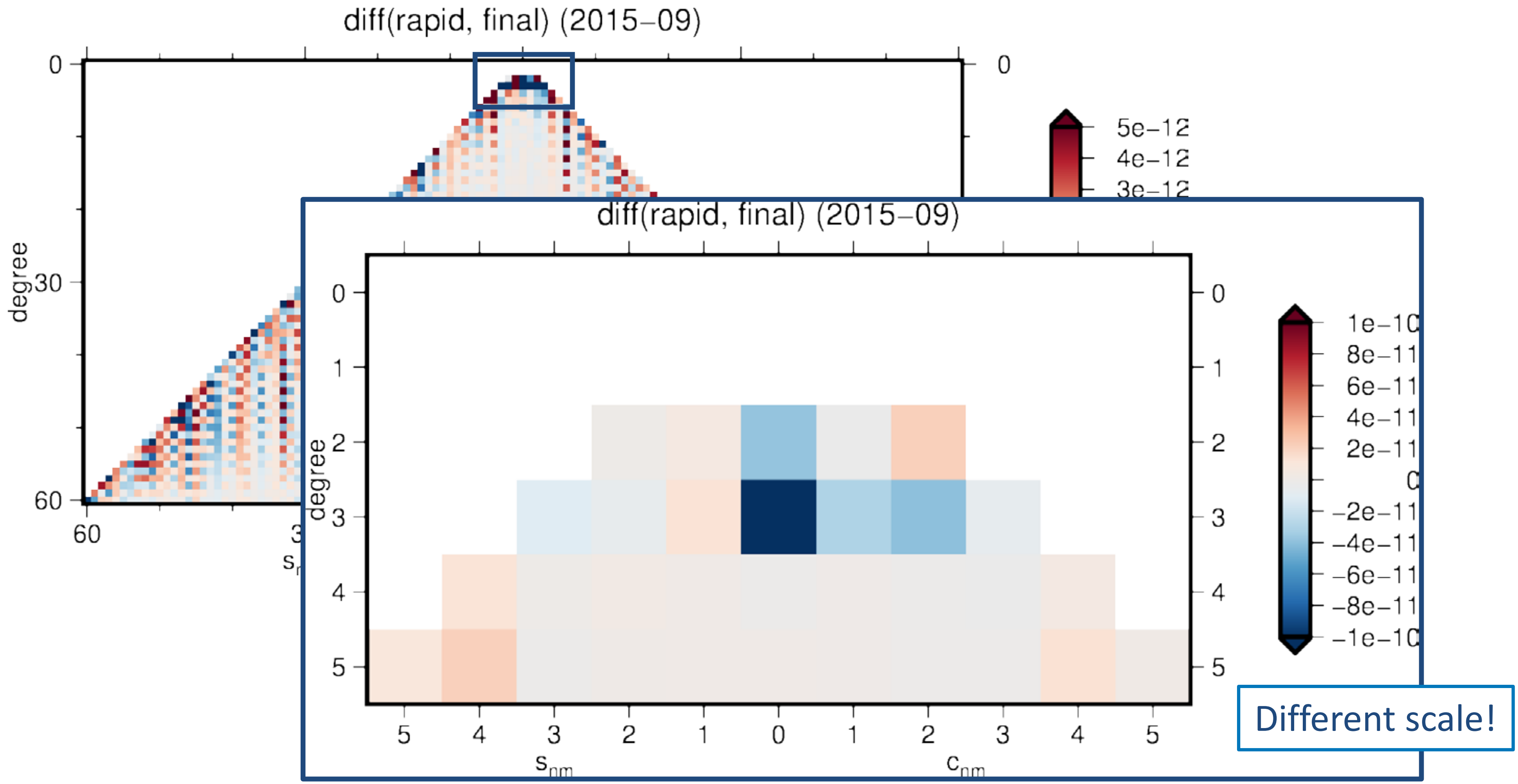
CODE final



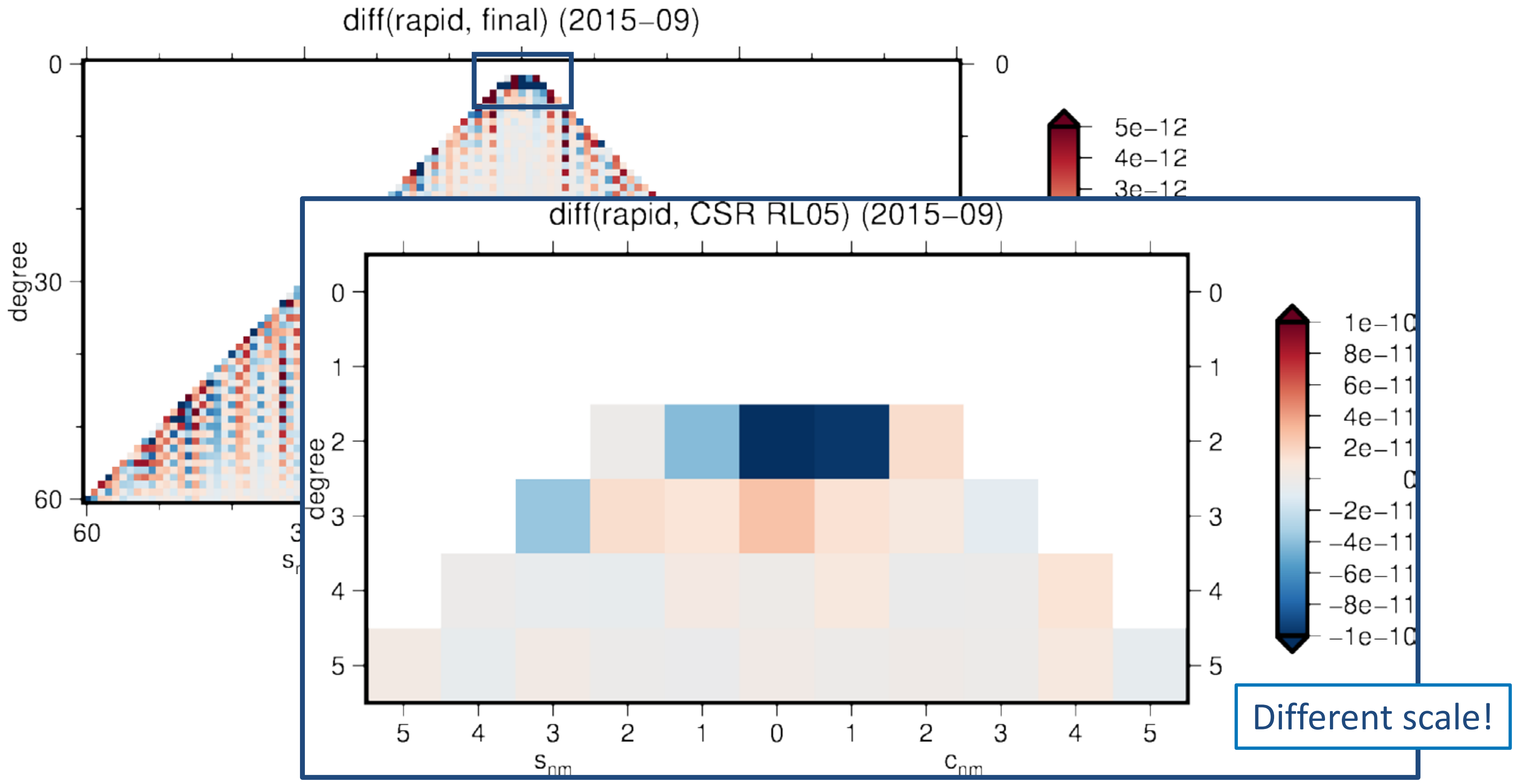
Status of NRT – Rapid Input Data



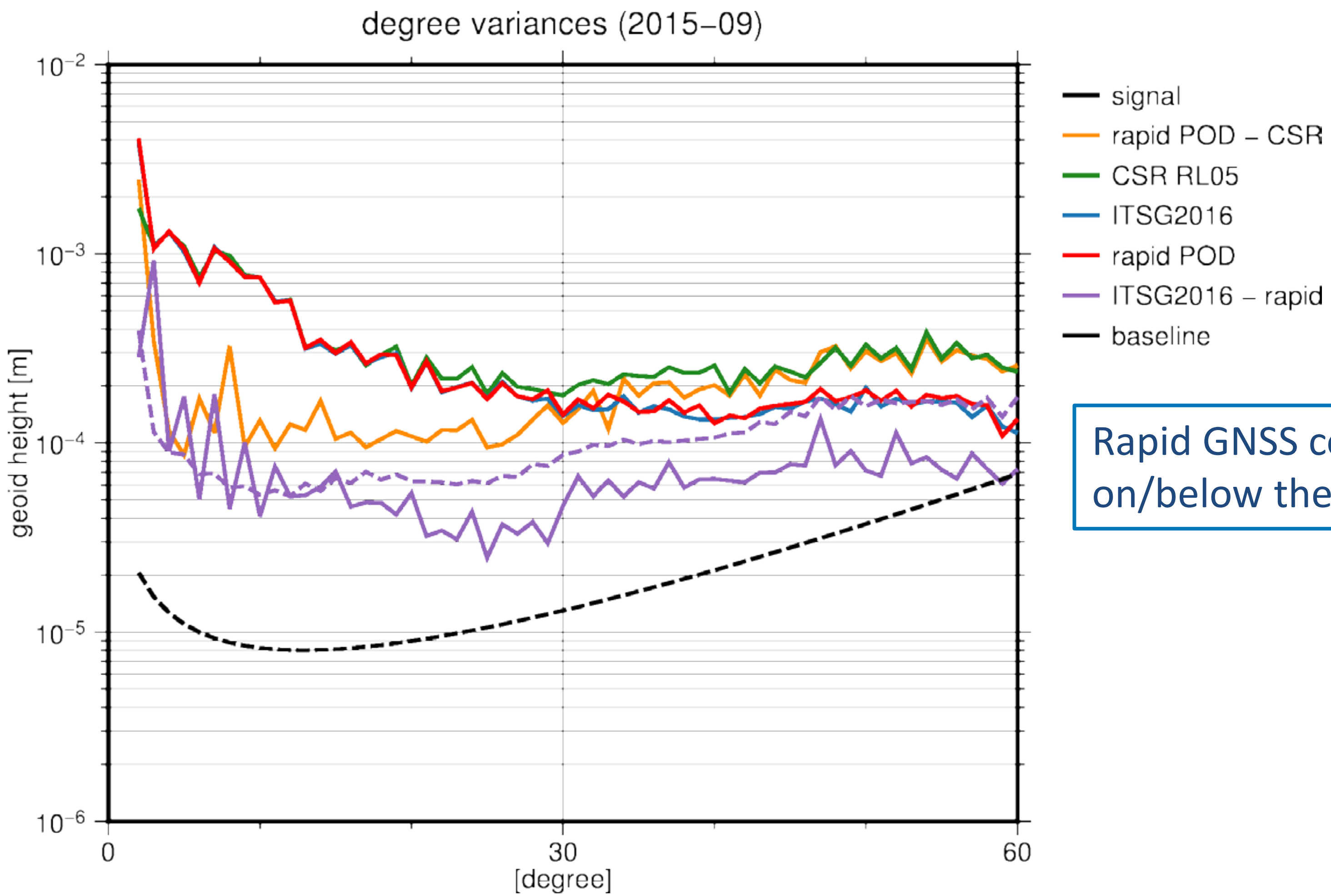
Status of NRT – Rapid Input Data



Status of NRT – Rapid Input Data



Status of NRT – Rapid Input Data



Rapid GNSS constellation is on/below the formal errors

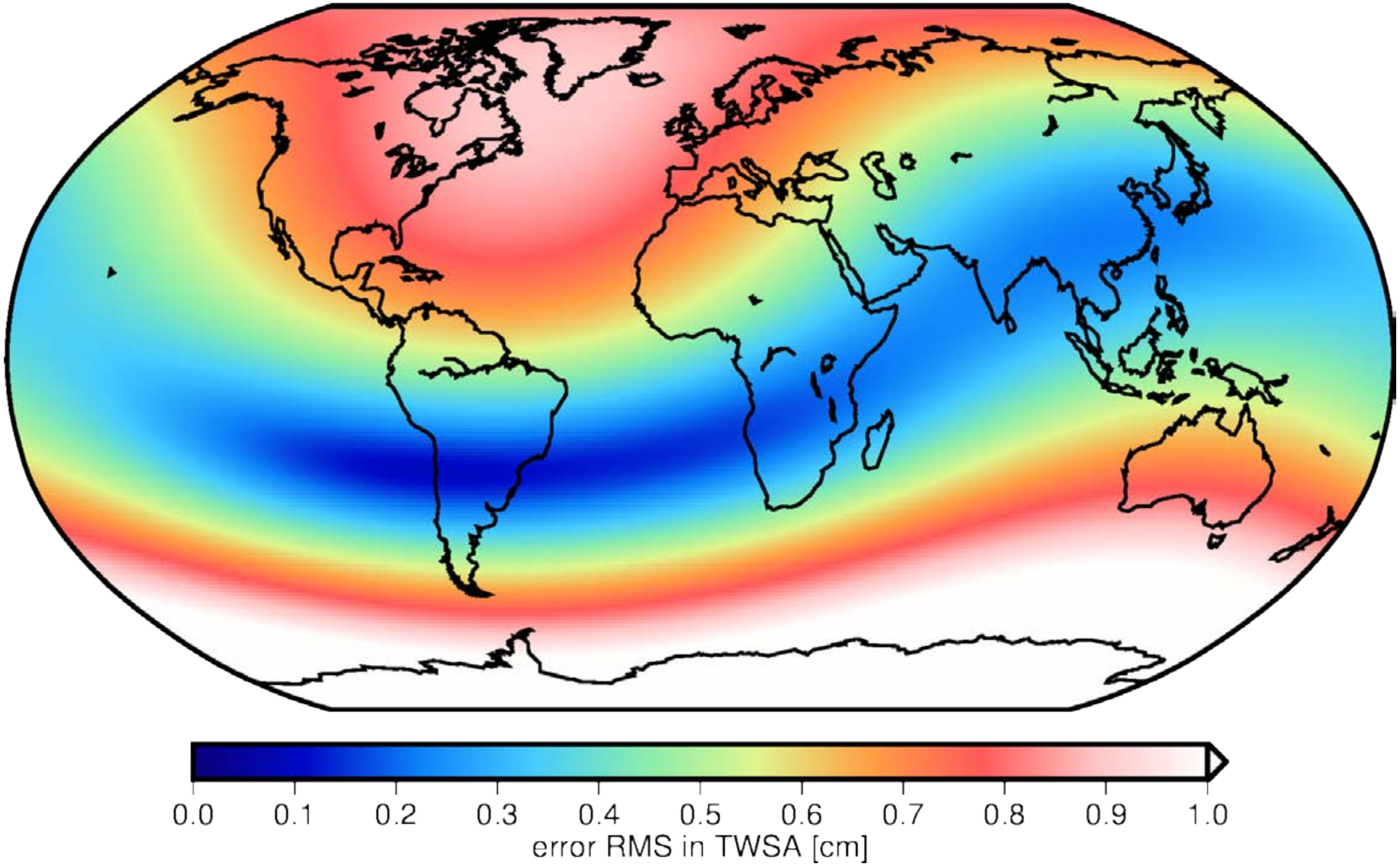
Gridded Total Water Storage

Status of NRT – Gridded Total Water Storage

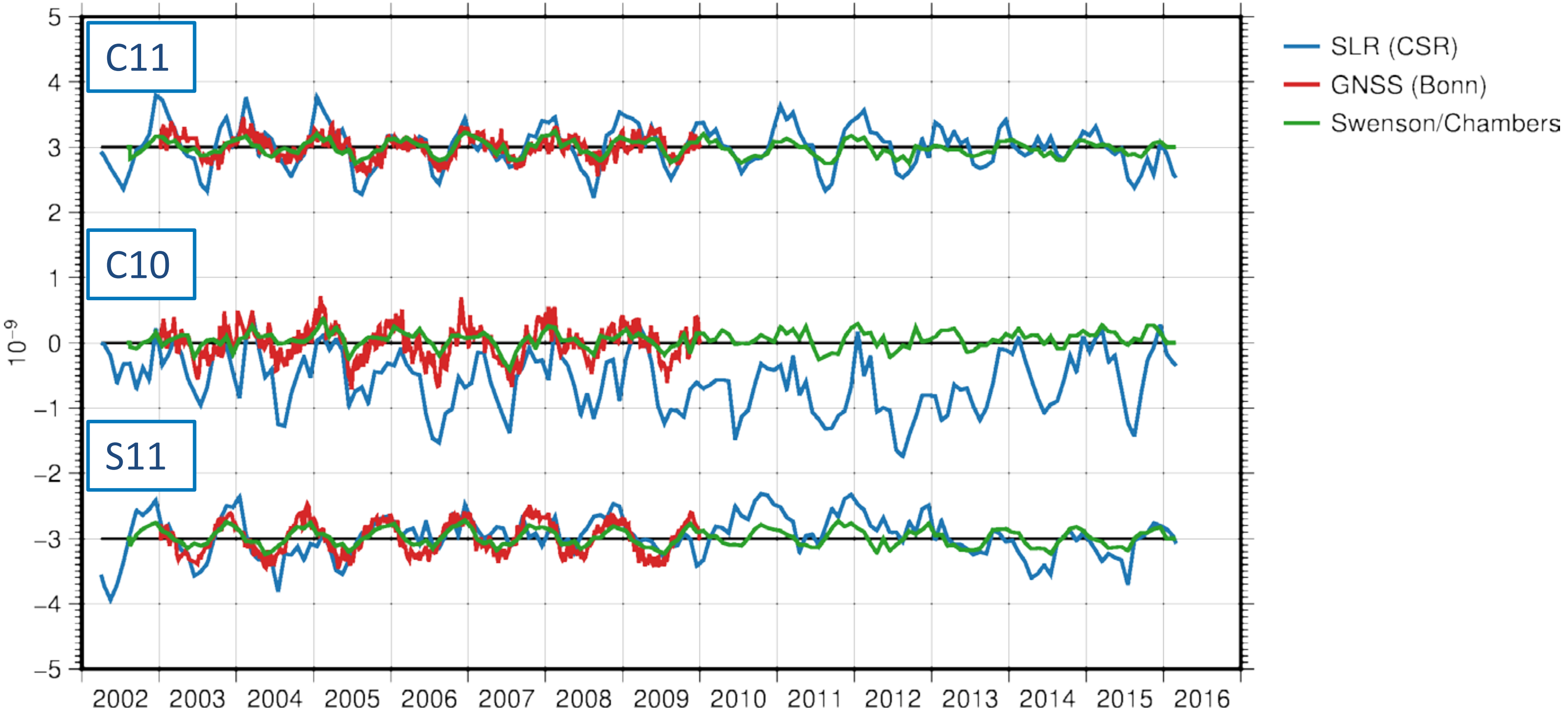
- Required external input: degree 1 terms (geocenter motion), c20 coefficient
- Mass variations in center of figure required for
  - Hydrological service
  - GNSS validation
- No operational NRT product available (to our knowledge)
- Proposal: extrapolation with major constituents

Status of NRT – Gridded Total Water Storage

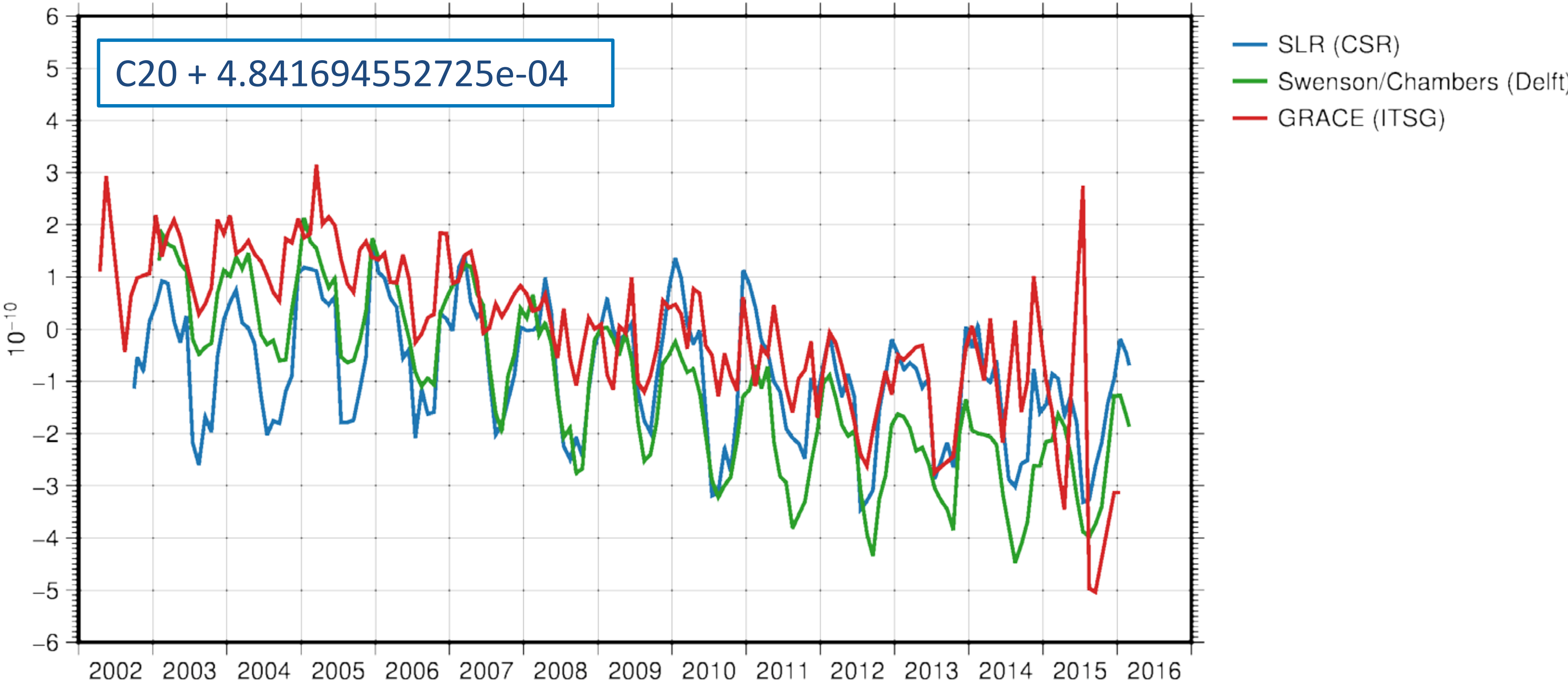
Approximation with SA/SSA/trend – 4 months extrapolated



Status of NRT – Gridded Total Water Storage



Status of NRT – Gridded Total Water Storage



Which product to use?

Impact of Process Dynamic on Kalman Solutions

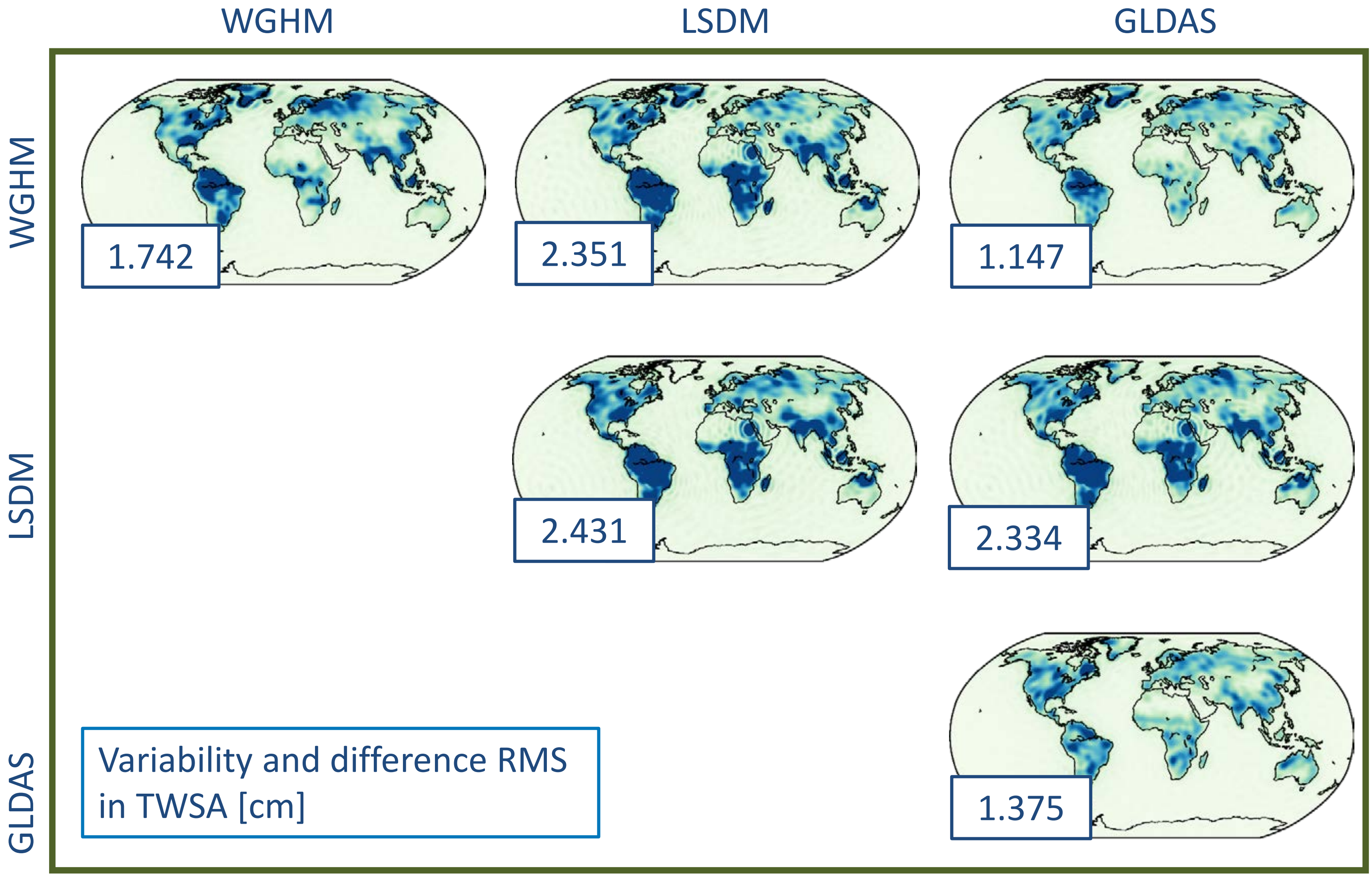
Daily Solutions – Impact of Background Models

- How much prior information is contained in the Kalman solutions?

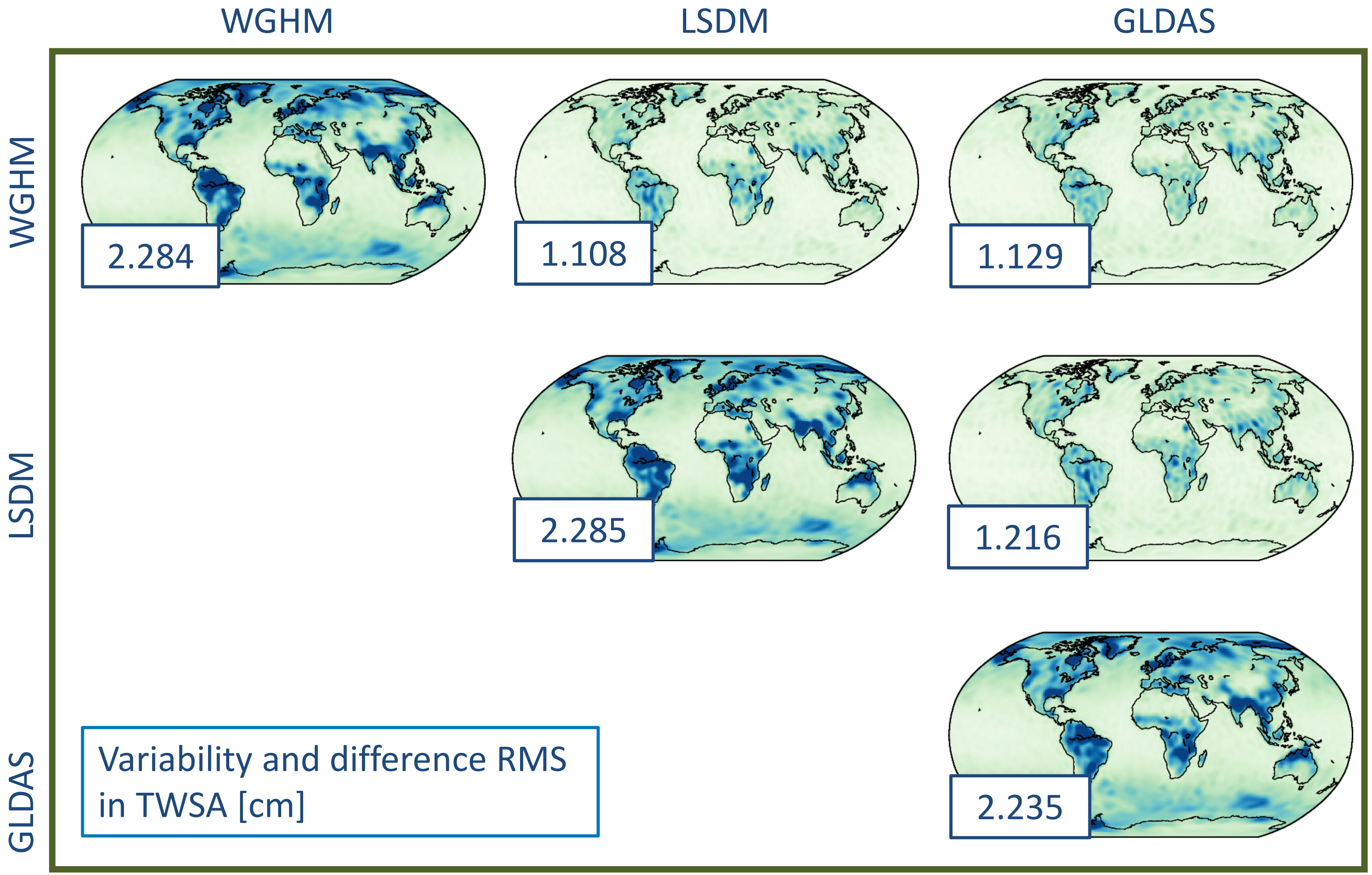
- Study setup:
  - Process dynamic from three different hydrological models
  - one set of GRACE normal equations (ITSG-Grace2014)
    → three Kalman filter solutions

- Cross comparison of:
  - model ↔ model
  - GRACE ↔ GRACE
  - GRACE ↔ model

Daily Solutions – Impact of Background Models

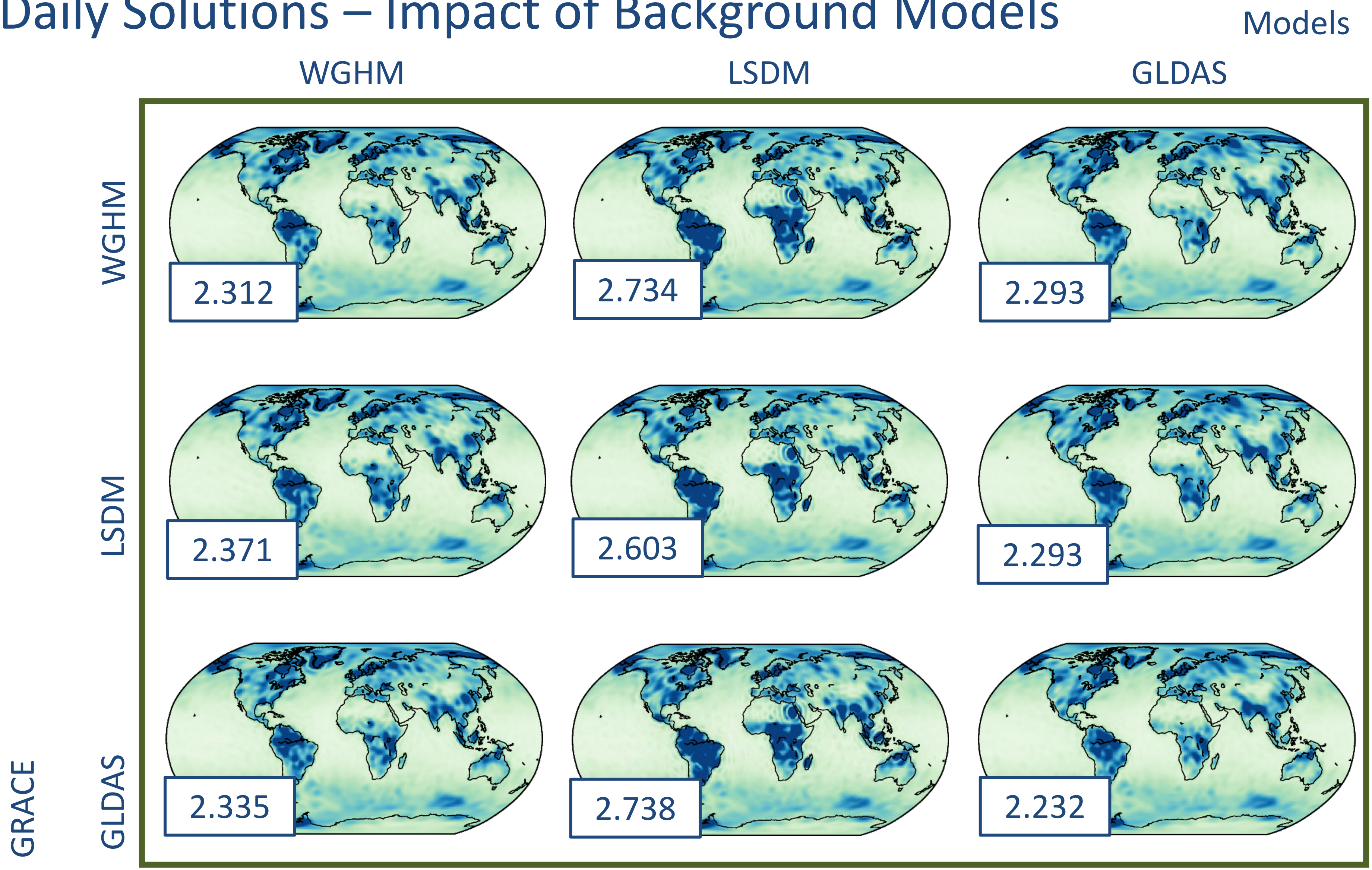


Daily Solutions – Impact of Background Models



Variability and difference RMS in TWSA [cm]

Daily Solutions – Impact of Background Models



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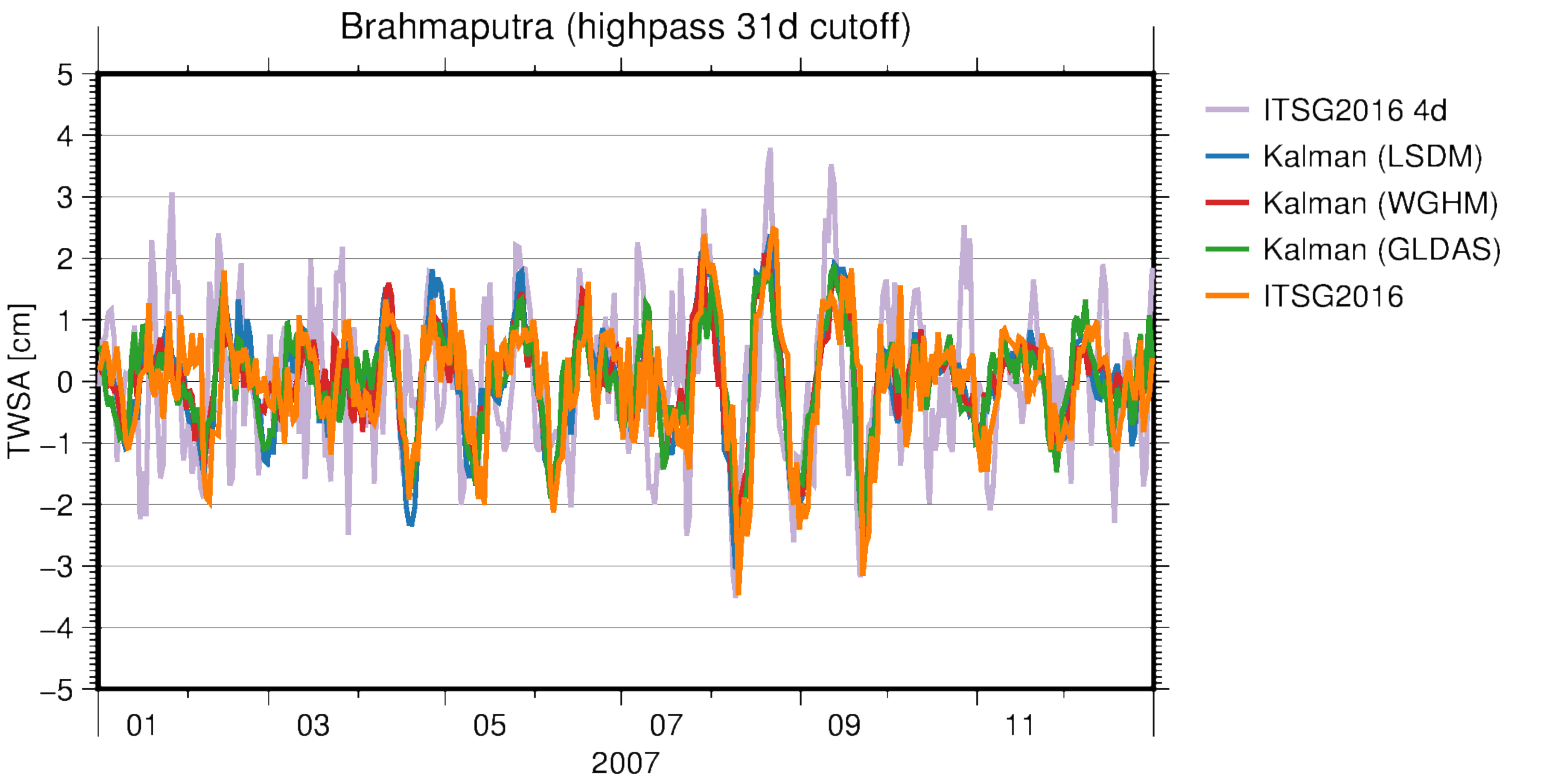
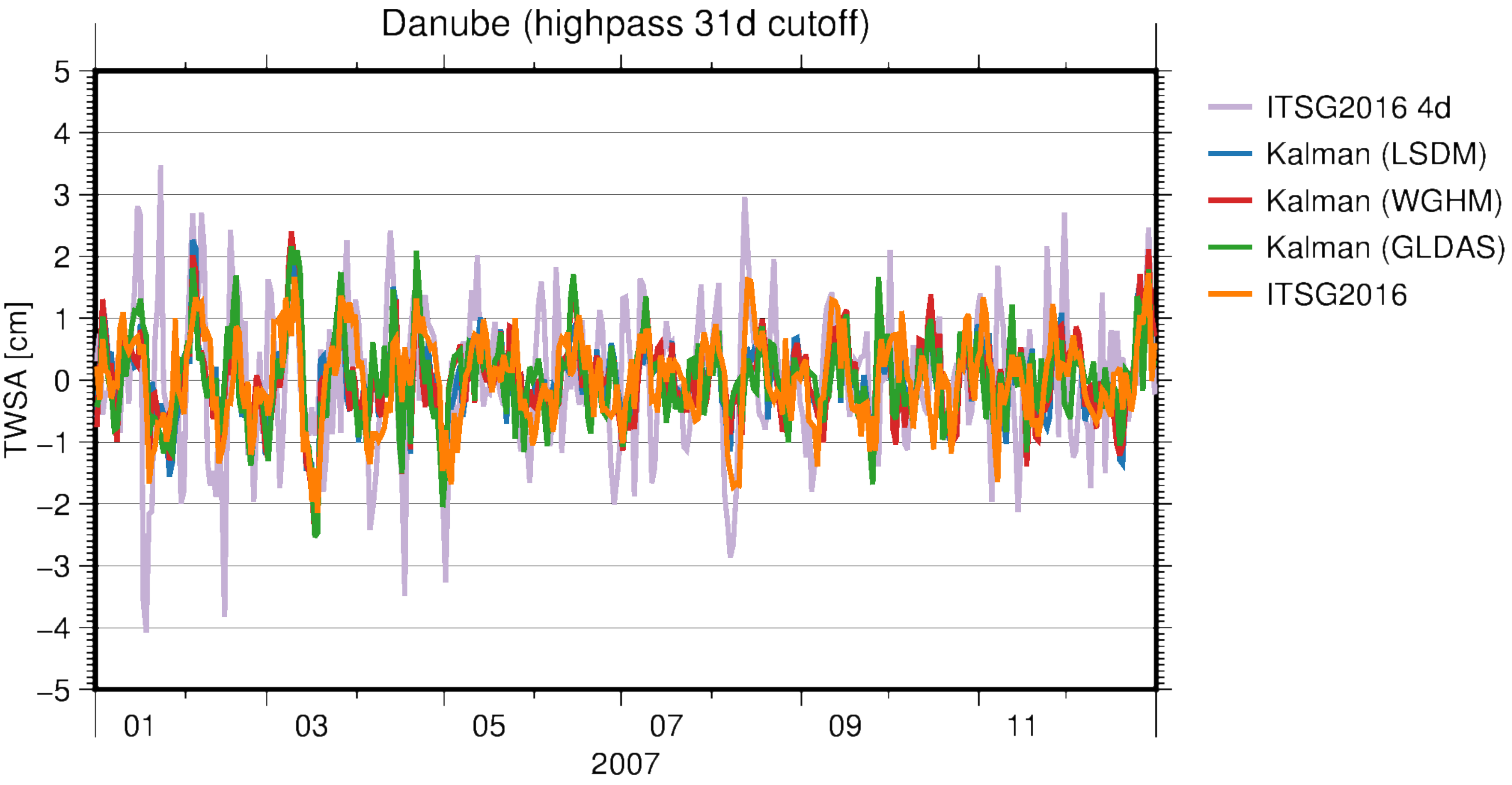
Daily Solutions – Impact of Background Models

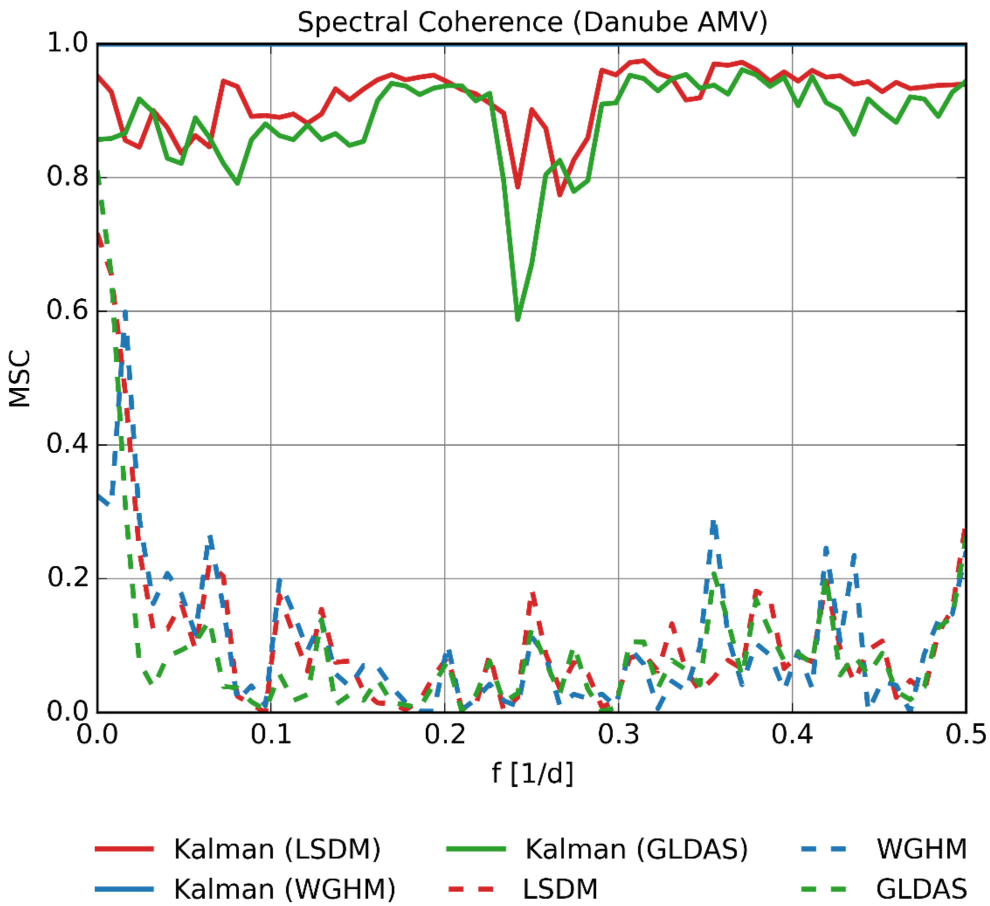


Daily Solutions – Impact of Background Models



Daily Solutions – Impact of Background Models

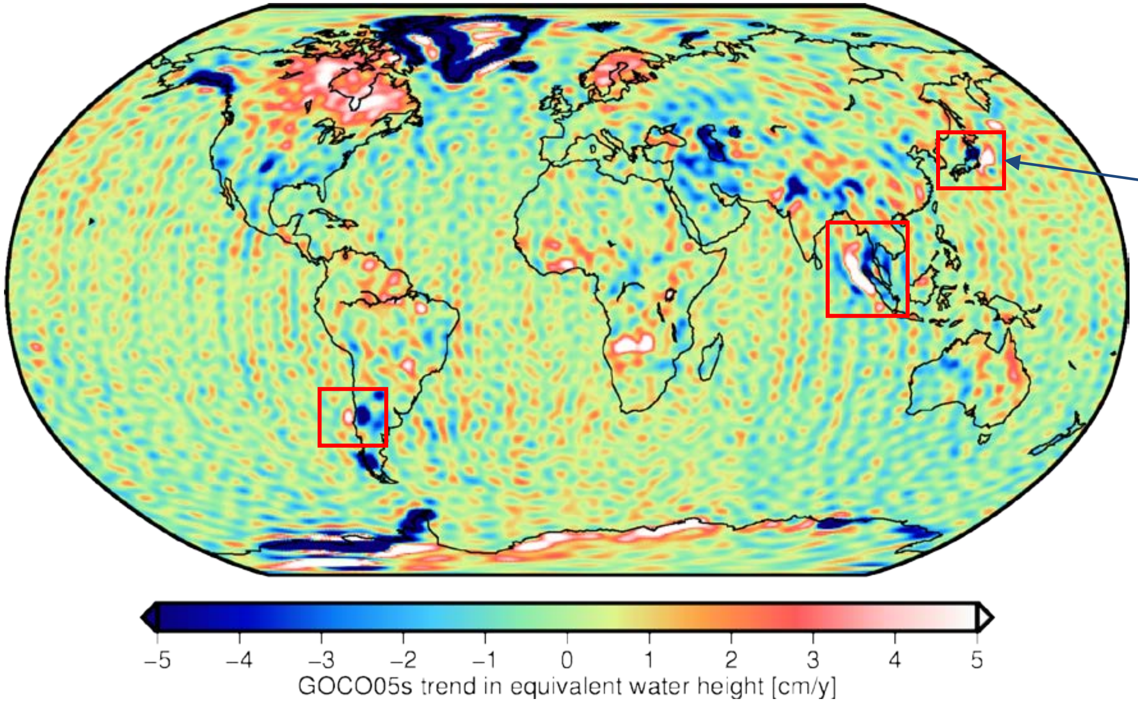
- GRACE solutions exhibit better consistency than models
- No clear bias towards the used process model visible

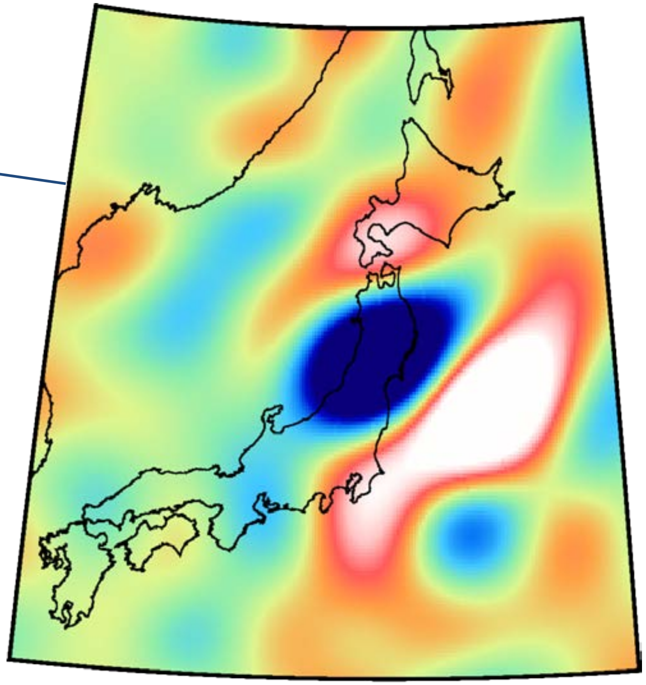


Plans Towards Operational Phase

Plans Towards Operational Phase

- New static GRACE model (ITSG-Grace2016s, ITSG-Grace2016k)
  - Piecewise linear trend
  - Co-estimation of SA/SSA
  - Tides?





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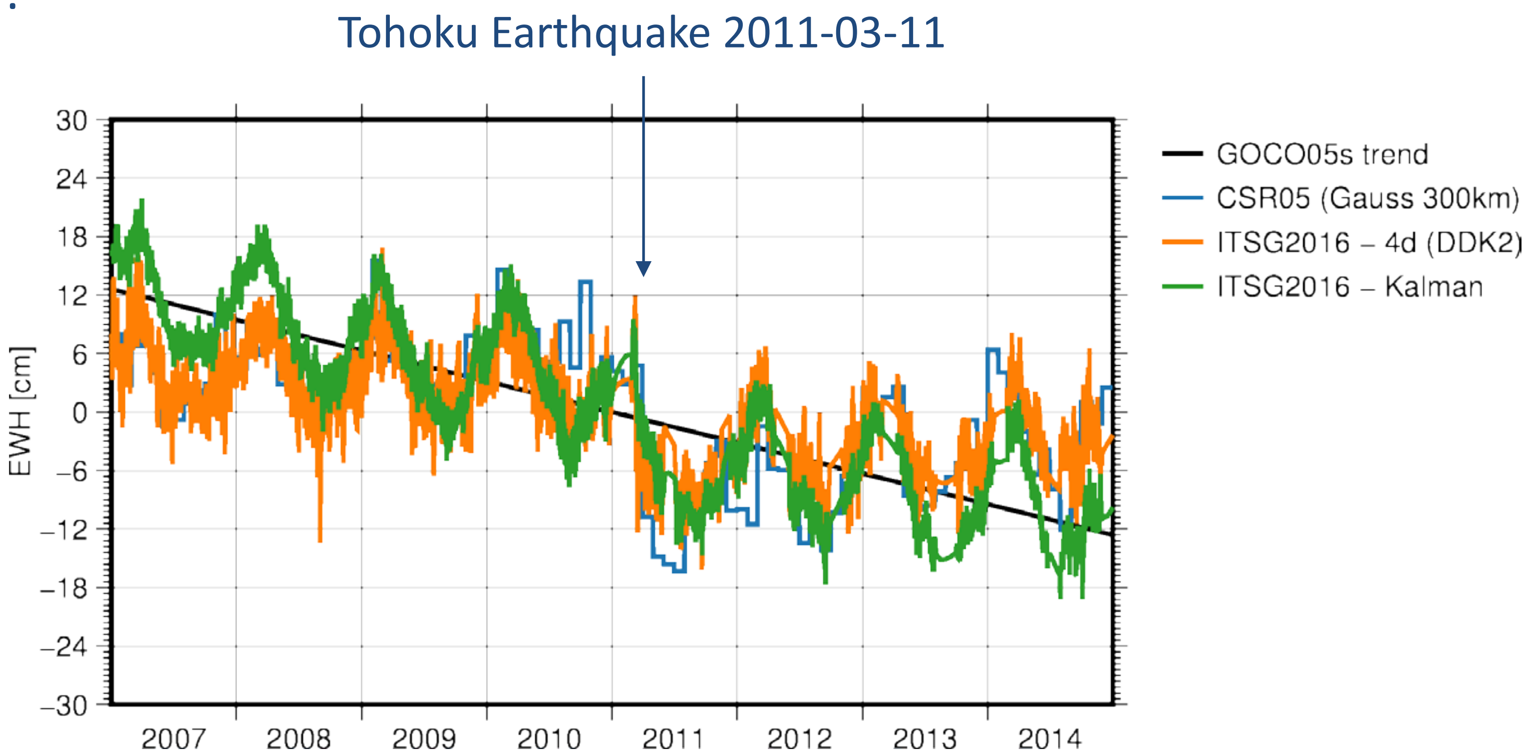

Plans Towards Operational Phase

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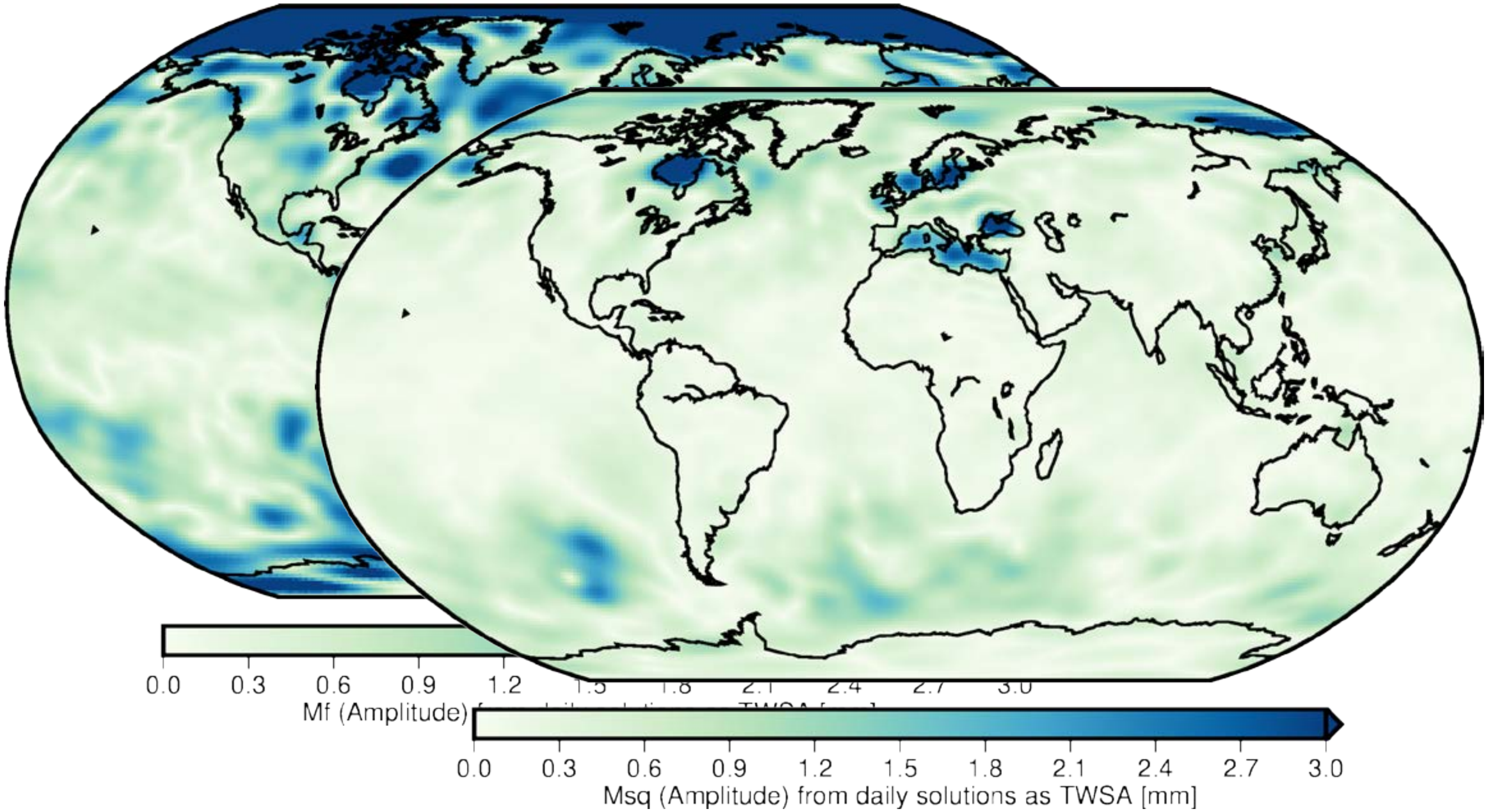
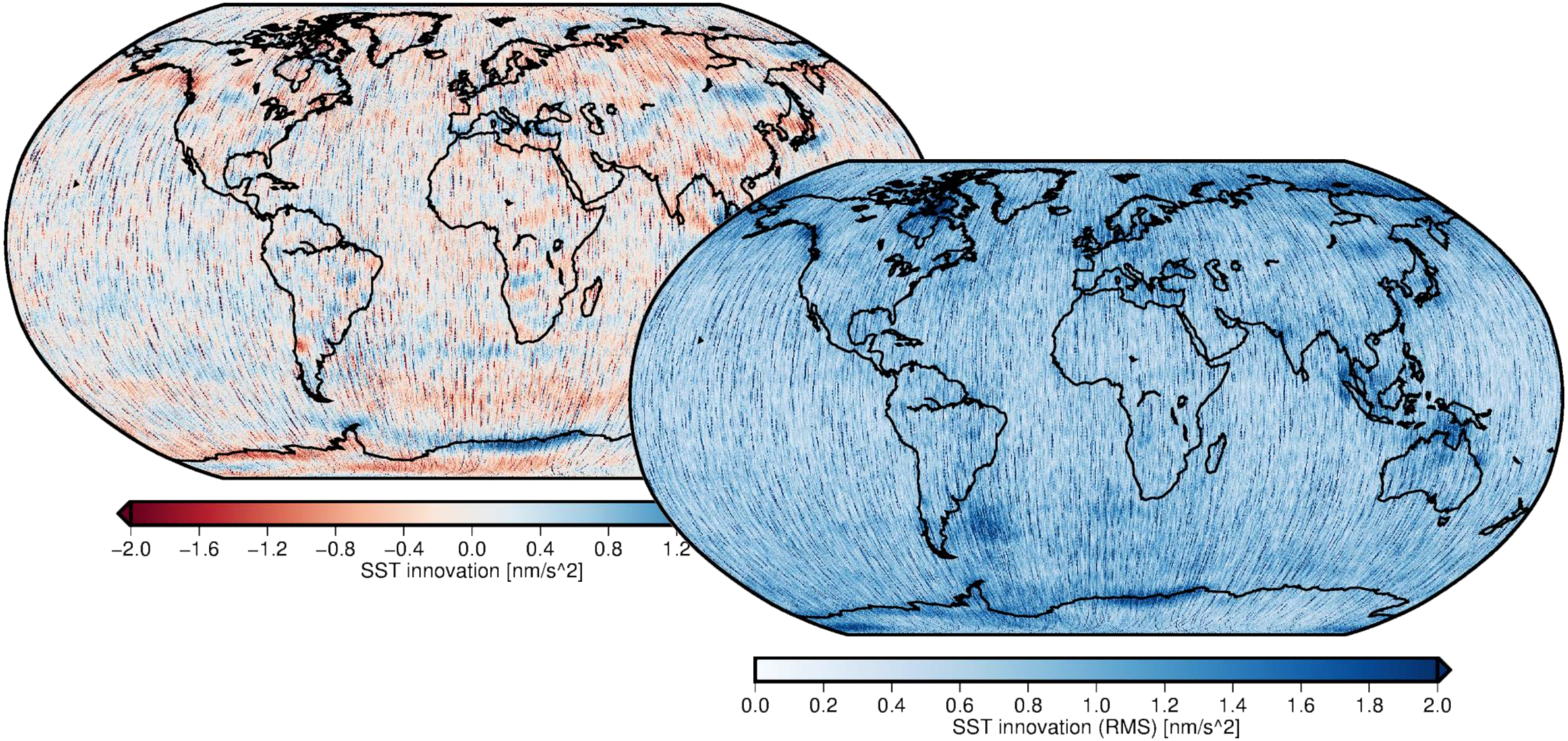


Plans Towards Operational Phase

- Internal consistency checks using system innovation:
  How well does the prediction fit the GRACE observations?



Plans Towards Operational Phase

- Evaluation of Swenson/Chambers method for NRT geocenter estimation

- Continuation of time lagged service run (currently seven years in the past)
  - Move towards a more recent time span → long data gaps

Summary

- Software packages for NRT operations are implemented → MS3
- Start of T5.3, T5.5 → Interfaces need to be defined
- Points for discussion:
  - NRT Level 3 product input data
  - Machine readable validation result
  - Interfaces to the outside world

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European Gravity Service for Improved Emergency Management

WP5: Status & Milestones

Christian Gruber - GFZ

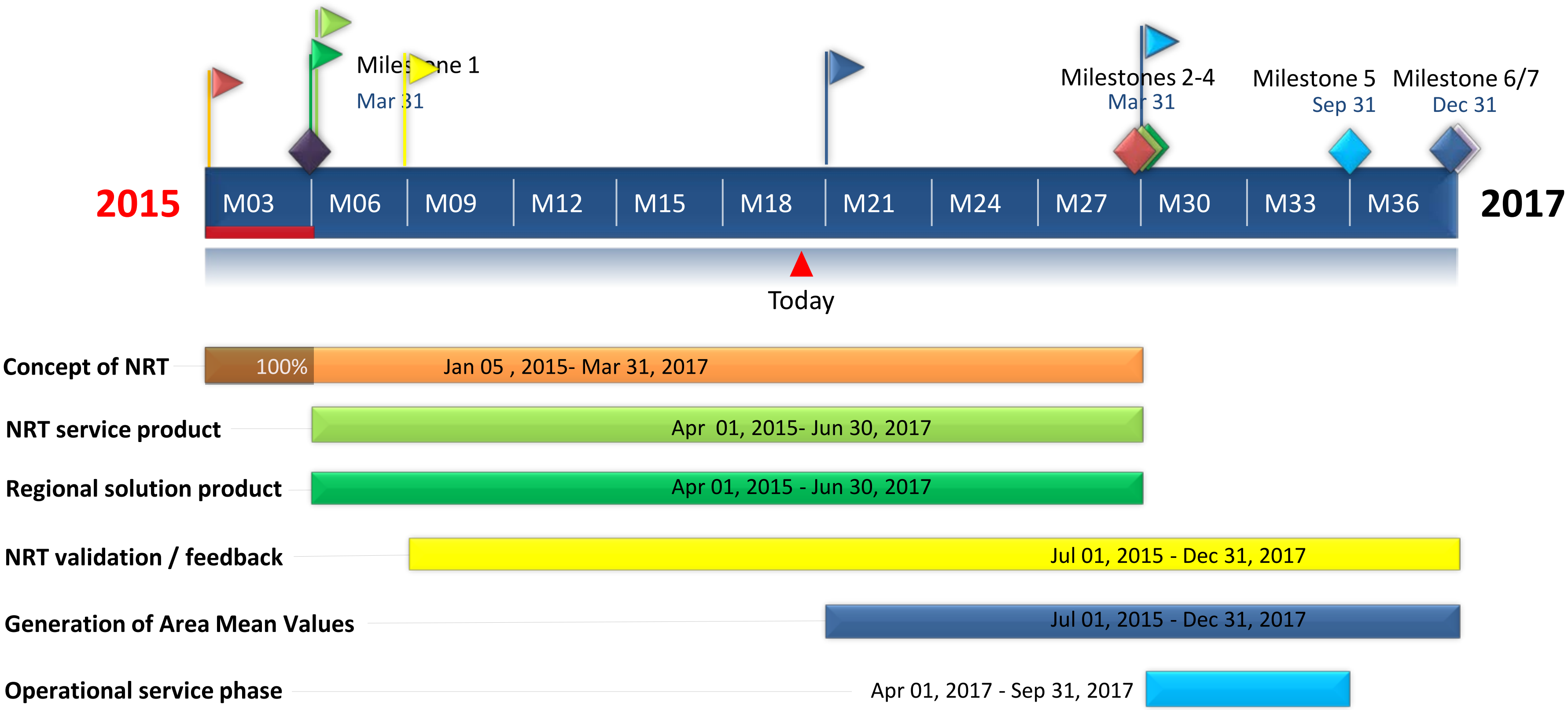
EGSIEM Meeting, GeoForschungsZentrum, Potsdam

Jun 2 – Jun 3, 2016

u^b UNIVERSITÄT BERN · uni.lu UNIVERSITÉ DU LUXEMBOURG · GFZ Helmholtz Centre Potsdam · TU Graz · Leibniz Universität Hannover · cnes · DLR · géode&cie · HORIZON 2020

Project Plan

European Gravity Service for Improved Emergency Management



Input data and latencies

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Product	Source	Current Latency (IP)	Required Latency (OP)
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	1 day
Dealiasing Product (AOD1B) Specific hydrological basin (upon request)	GFZ WP3/6	7 days Not available	3-4 days 1 day

Production-flow

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Last day 00:00

1. GFZ GPS constellations 13:00
   UB: CODE constellations, EOPs 18:00
2. L1B data availability 18:00

first day 00:00

3. GFZ: preliminary dynamic orbit 1d+12:00
4. LSC/ Kalman update preliminary, QL 1d+18:00

second-fourth day 00:00

5. 3-hourly Atmosphere and Ocean Estimates 4d+8:00
6. GFZ: final dynamic orbit 4d+12:00
   TUG: kinematic orbit
7. LSC/ Kalman update final 4d+12:00
8. plausibility test/ evaluation 4d+16:00
9. grid release /SH –coefficients 4d+18:00

RBF Status

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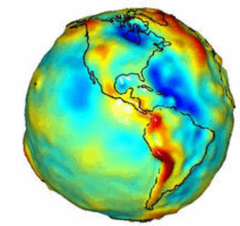
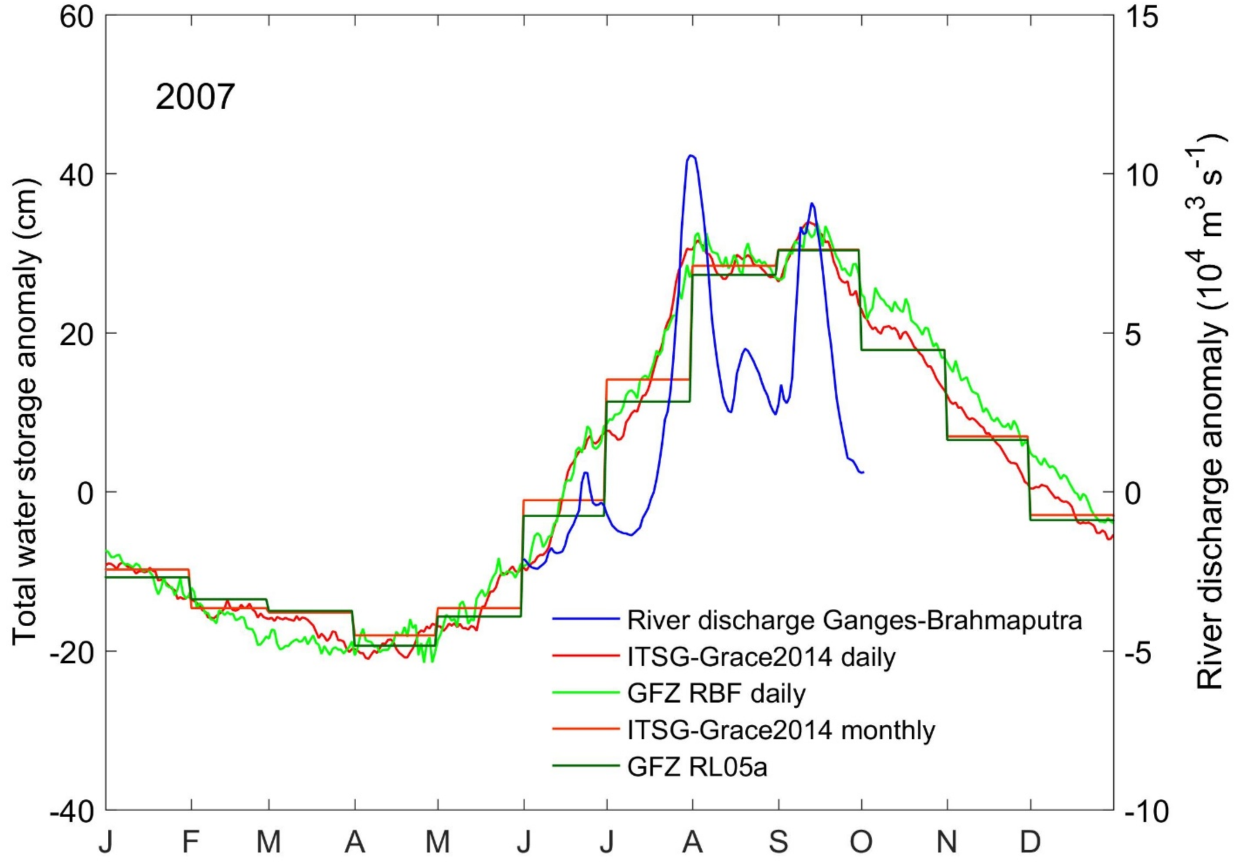


- good news: the RBF solution works and is well on its way to provide a full time series of GRACE days
- main keys to success:
  - limit observation de-correlation to < 5 rev. (5000epochs)
  - vast limitation of (previously considered) outliers: none
  - accelerometer calibration
  - some improvements to the process model (stability)
- all necessary NRT interfaces for service readiness have been developed
  - ftp, shell/perl scripts, conversions, formating, etc.

RBF Success


2007
Total water storage anomaly (cm)
River discharge anomaly (10^4 m^3 s^{-1})
60
40
20
0
-20
-40
15
10
5
0
-5
-10
J F M A M J J A S O N D
River discharge Ganges-Brahmaputra
ITSG-Grace2014 daily
GFZ RBF daily
ITSG-Grace2014 monthly
GFZ RL05a

Service mode

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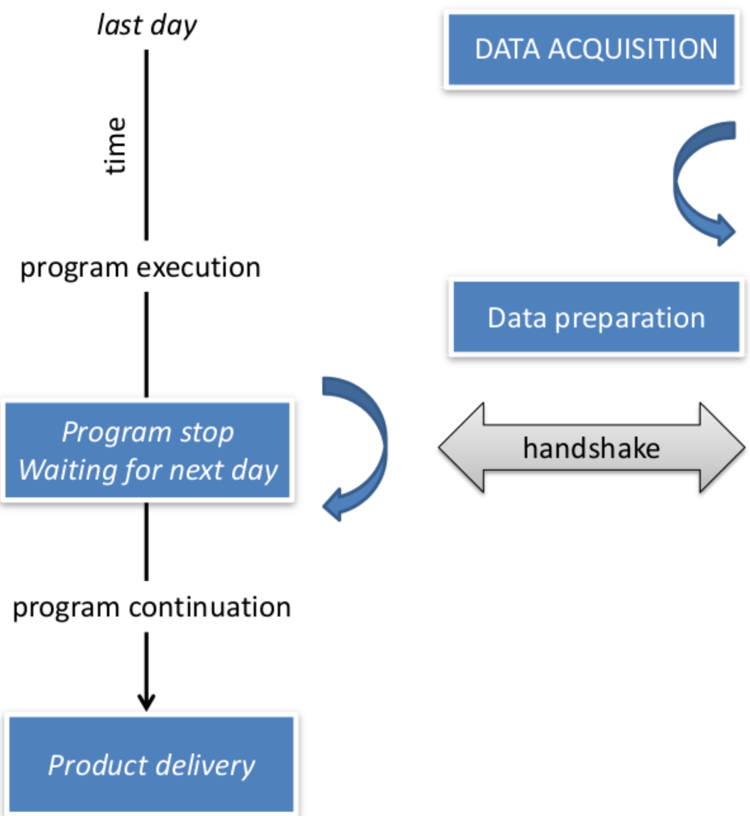

daily [perl script]
+ NRT L1B (ftp)
+ orbit auxiliaries (ftp)
  PRNs, clocks, EOPs
+ NRT AOD (ftp)

EPOS-OC
+ predicted orbits
+ rapid orbit generation

[shell script]
+ deploy ORB
+ deploy KBR
+ log-entry

monthly
+ update GAC
+ update SDS fields (GFZ)
+ update Deg 2 (ftp)

Background models

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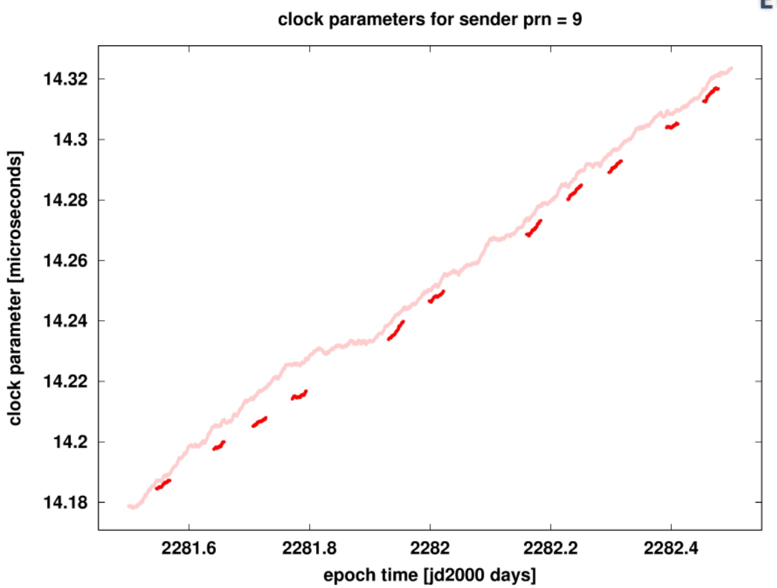
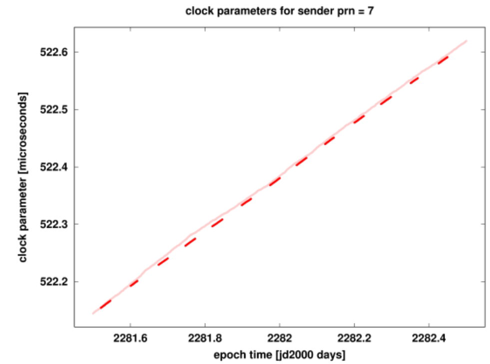
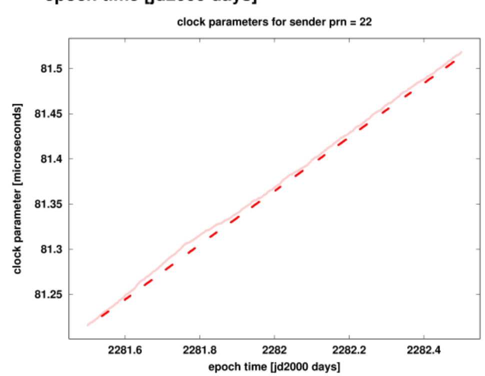
- Ocean tides (EOT11a),
- Atm tides S1,S2 (Bode/Biancale)
- Solid Earth & Pole Tides (Desai)
- 3rd body ephemerides (JPL de421)
- EOP’s (Susnik et al.)
- GPS clock’s (Susnik et al.)
- no nutation/precession correction terms ($\Delta\varepsilon/\Delta\psi$)
- GAC (glo, daily, *RL6*: 3D-Earth)
- WGHM (Döll et al., 2002-2013)
- GRACE RL05a (2002-2015)

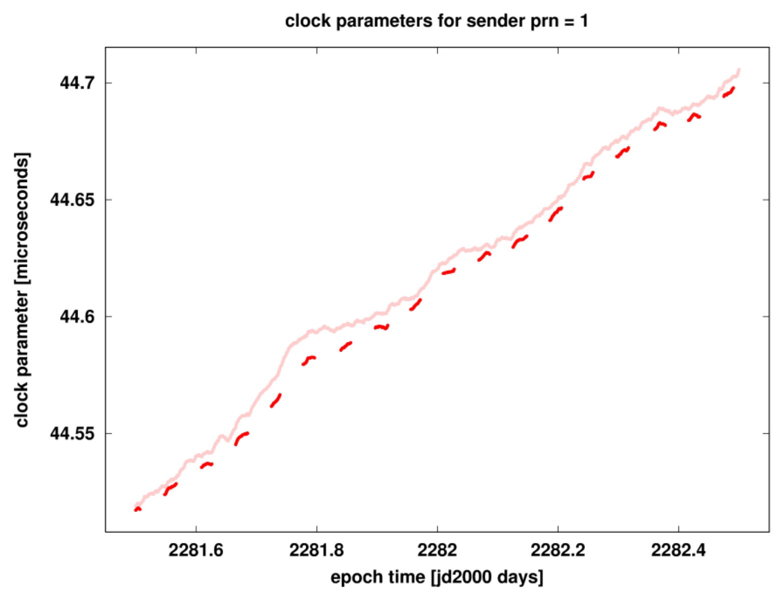
NRT CLOCKs





Offset: *1e-8* sec





Output

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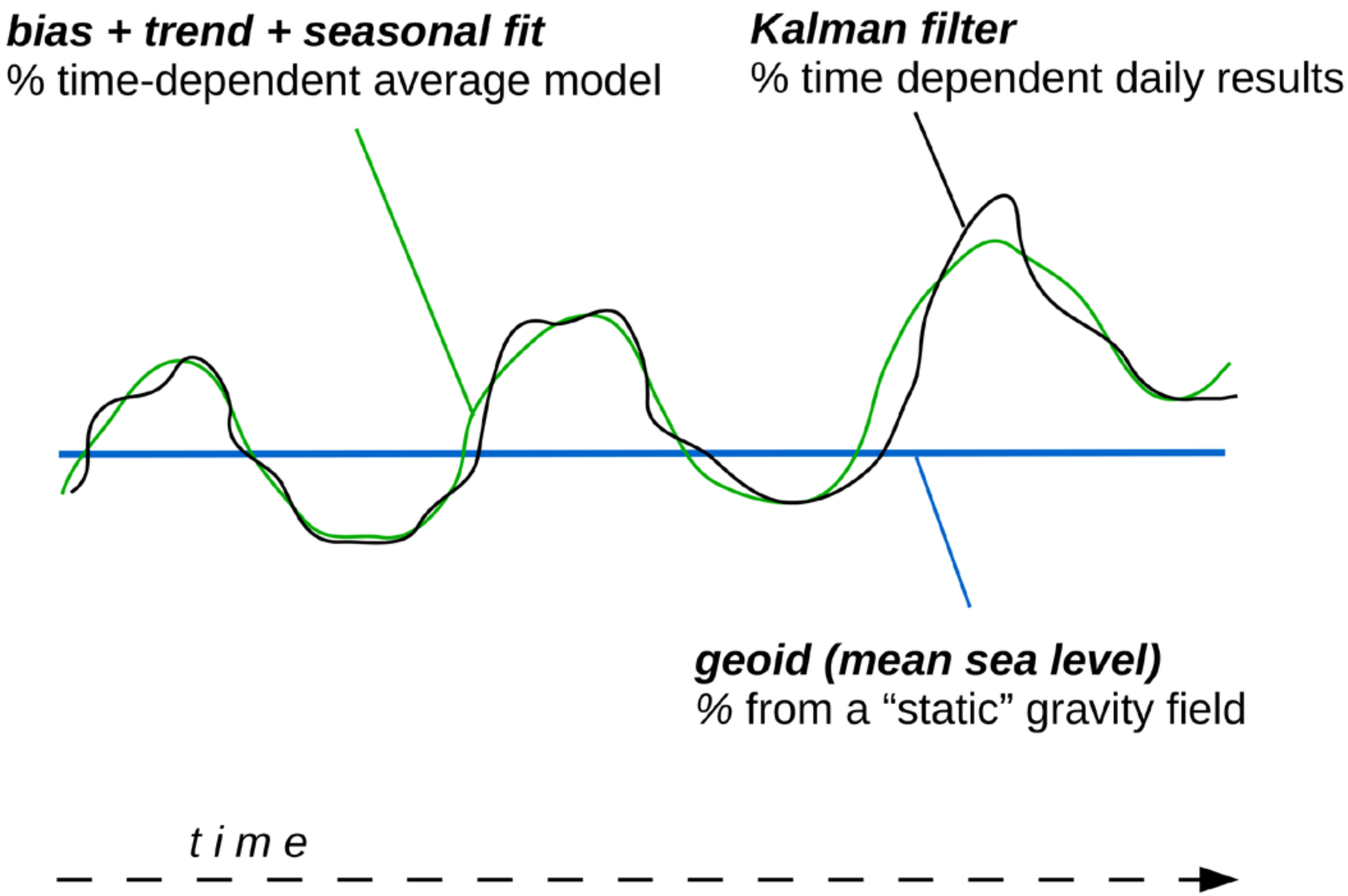
- daily solution on 2x2 deg grid (in ewh)
- 2x2 deg operational anomaly w.r.t average model
- 2x2 deg operational average model
- 1x1 deg grid regional product for defined areas of interest
- error estimates for solution vector / grid values

Linear system Equations

- integration grid (~Reuter), corresponding to 2x2 deg
  - conversion between Spherical Harmonics/grid
- radial basis functions assembly in grid points
- cov-estimation
  - obs auto-correlations for weighting/filtering
  - monthly auto/cross covariances for LS prediction
- Kalman filtering
- monthly inversion

Kalman solutions



Process noise

auto/cross covariance estimates (isotropic average operator)

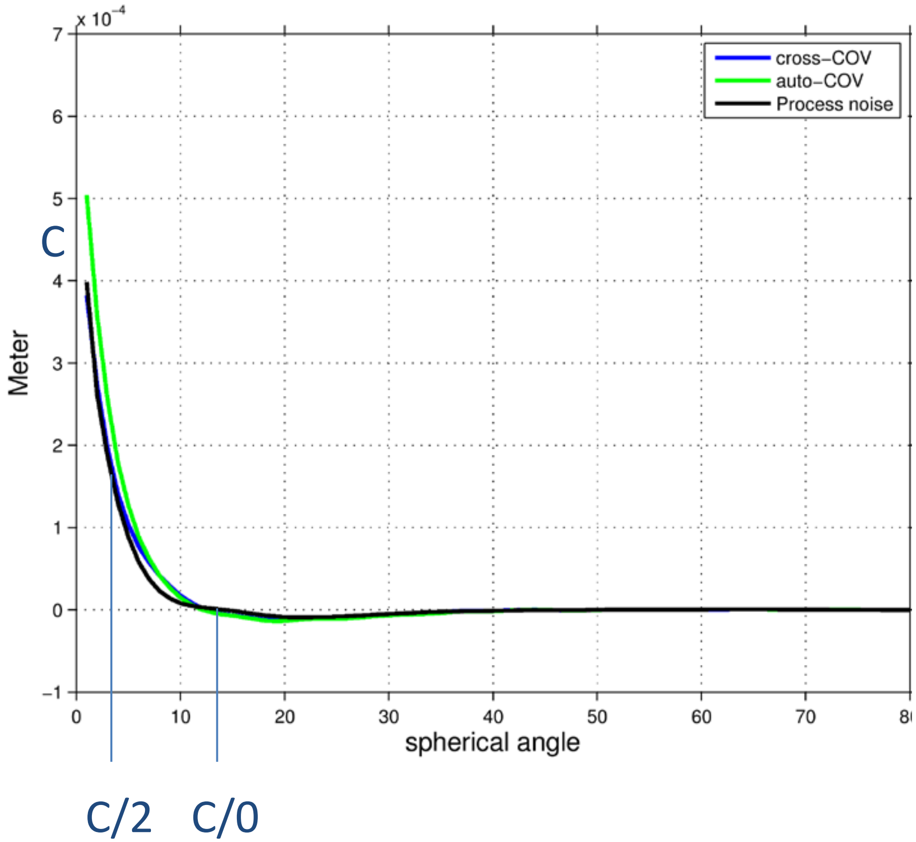
- mean{ GAC(daily) – meanGAC } → 30%
- de-seasoned hydrology model → 20%
- GRACE residuals w.r.t average model → 50%

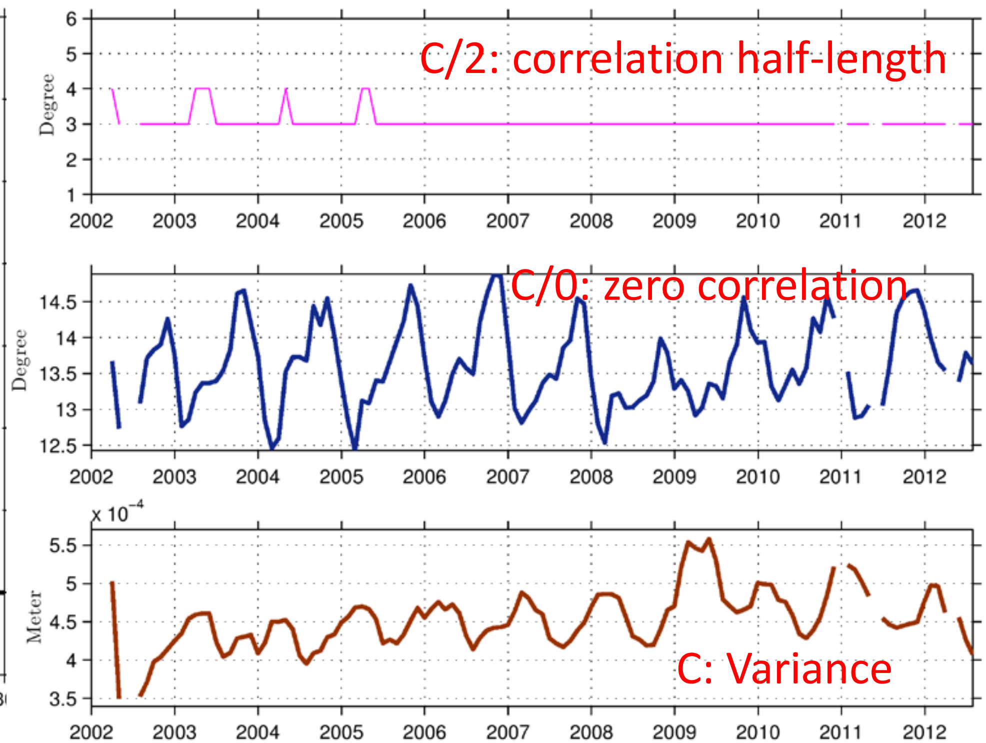
Use of GRACE average model stochastic for process noise estimates

Additional signal RMS to construct non- stationary variances

- average model = fitted secular/ seasonal function over available GRACE years

Covariances over time





Evaluation

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- Envisat/Jason arc-overlaps/SLR/Doris-fits
- WGHM basin coherence
- GPS-GreenlandNET(*Abbas-Khan*), GPS-CODE
- SLR deg2
- OBP evaluation (*Poropat et al.*)
- EGSIEM evaluation

Envisat orbit

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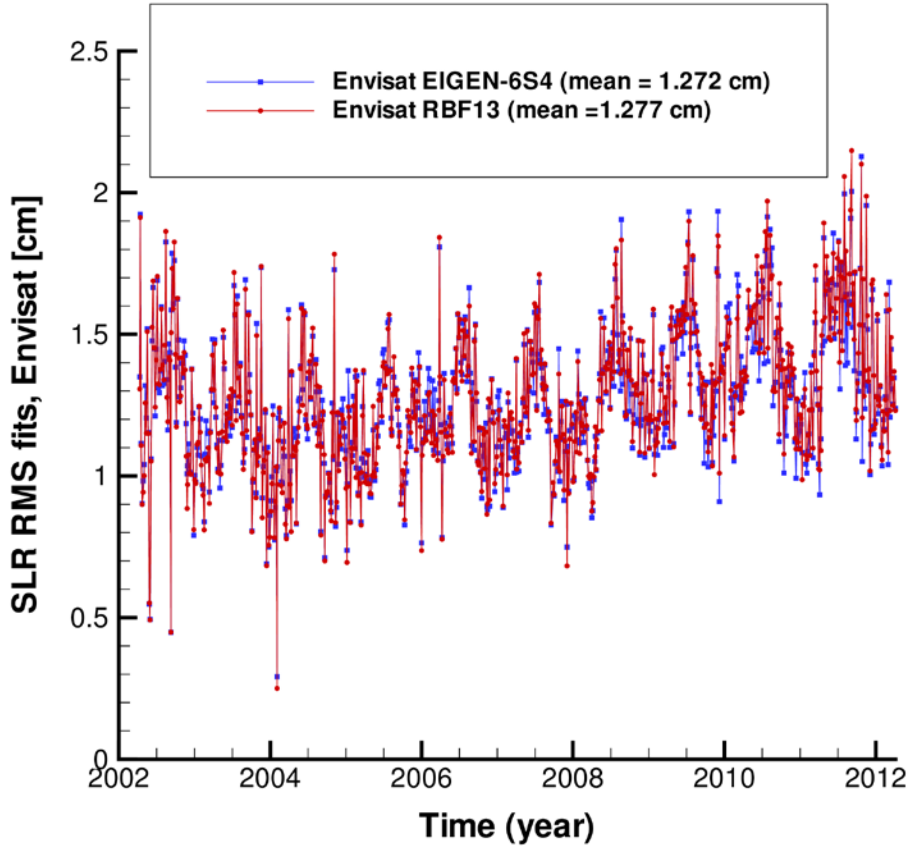
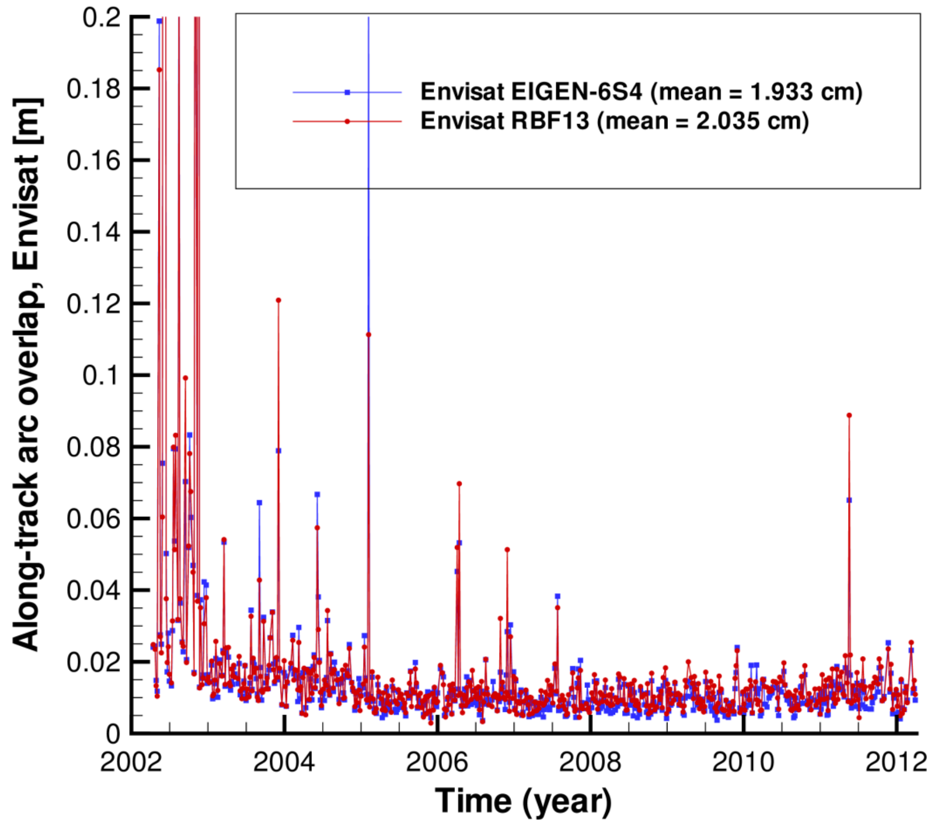
SLR RMS fits

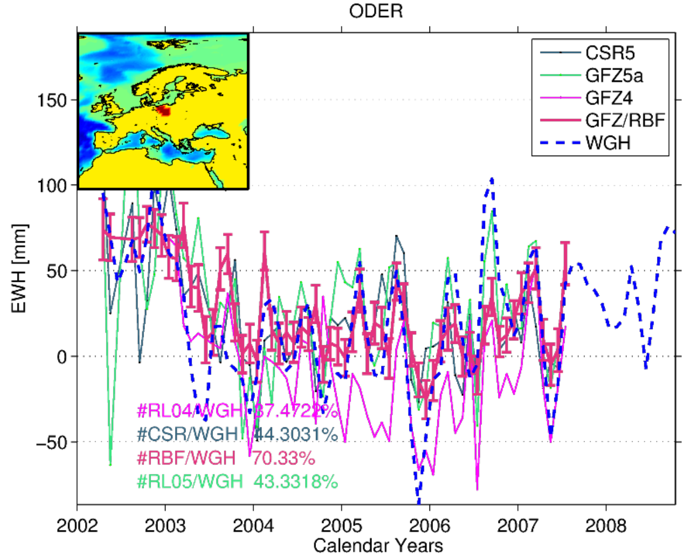


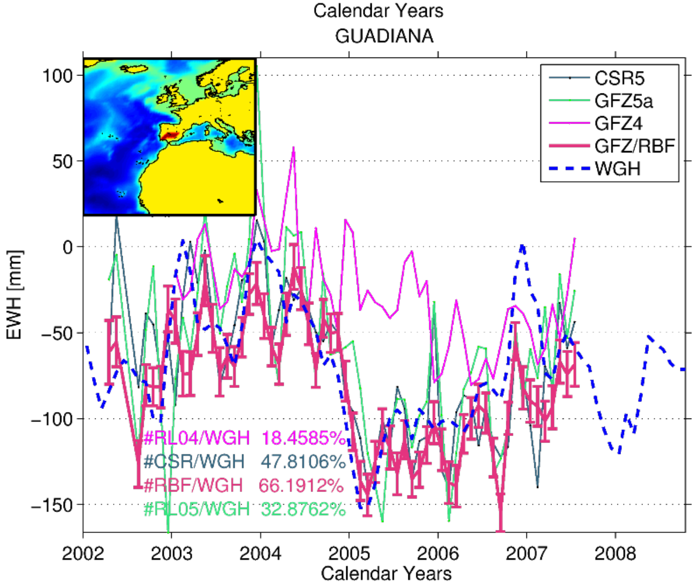
Envisat orbits

Arc overlaps, along-track



Hydro-basin comparison





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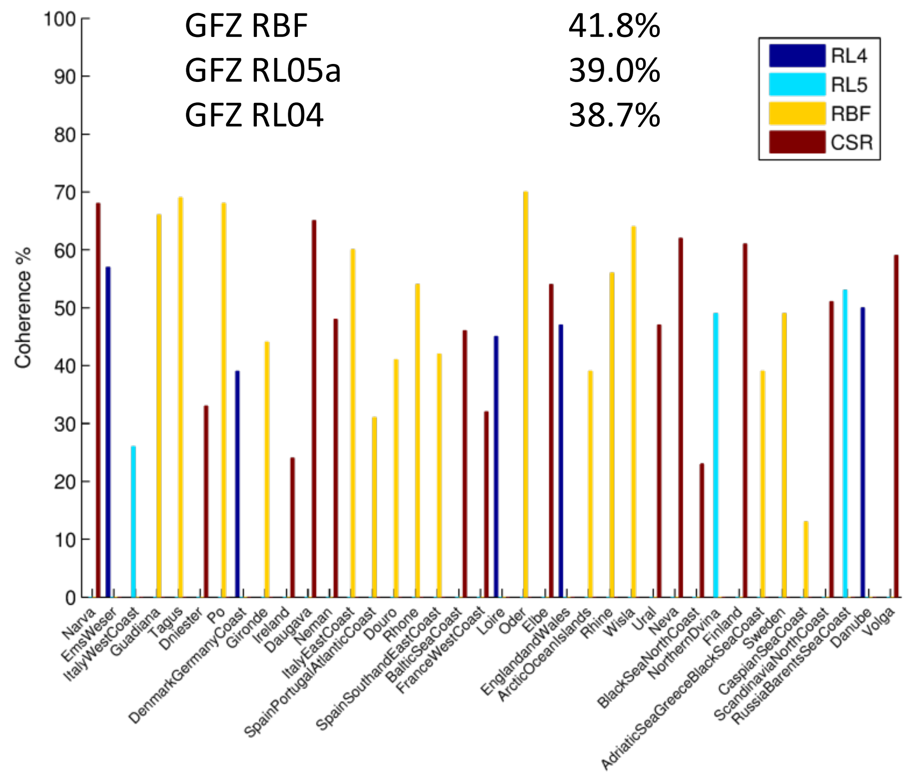
Averaged coherence for Europe
(de-seasoned, weighted by basin size)

CSR RL05	44.7%
GFZ RBF	41.8%
GFZ RL05a	39.0%
GFZ RL04	38.7%



GPS Validation

Greenland station network (GNET):

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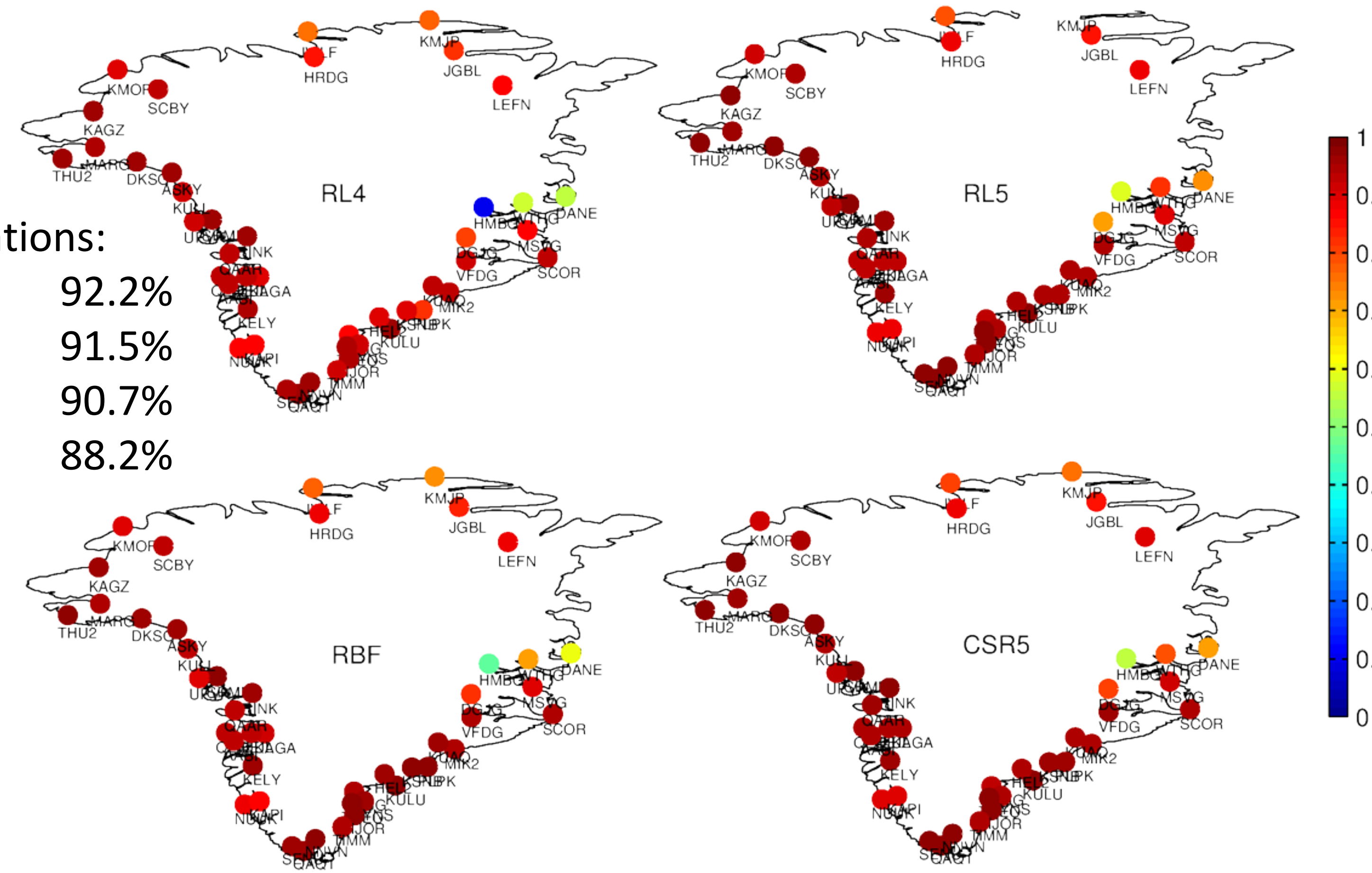
averaged correlations:

CSR RL05	92.2%
GFZ RL05a	91.5%
GFZ RBF	90.7%
GFZ RL04	88.2%



Monitor

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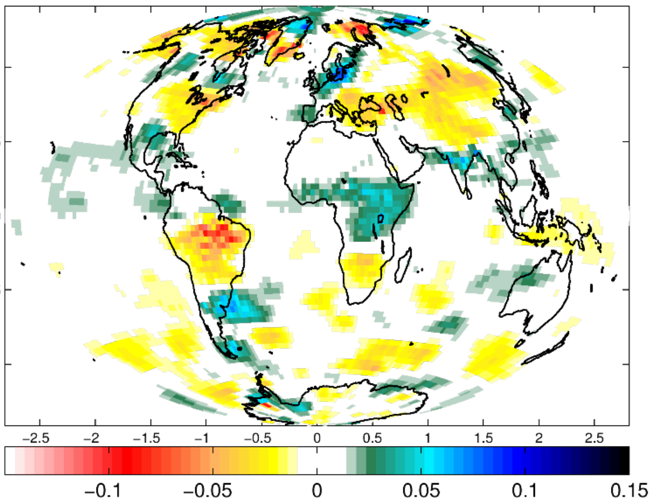
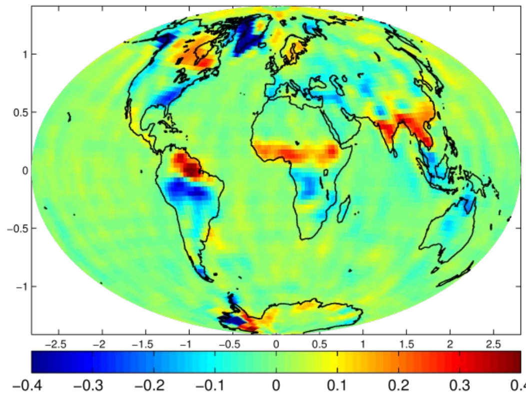
A N O M A L I E S



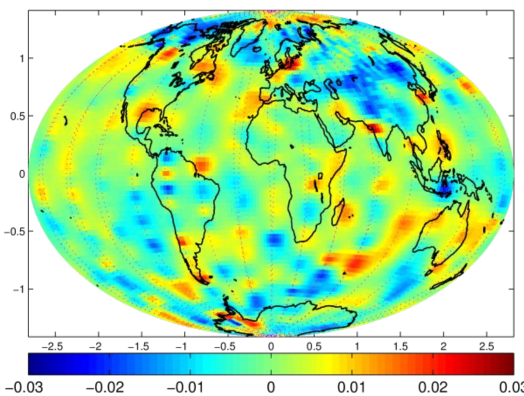
2007/09/30 height [m]



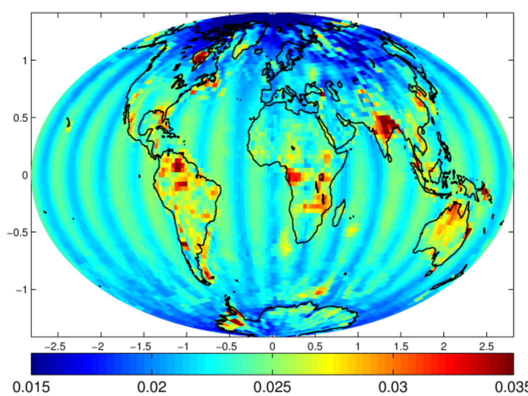
2007/09/30 height [m]

Full State
After restore

Last Day
(measurement update)



2007/09/30 height [m]



2007/09/30 rms [m]

formal RMS
error

Plans

until operational readiness (M27) focus will be put on:

- convergence of daily results and used stochastic models between Graz and GFZ
- further research on the impact of seasonal Covariance functions
- quantify difference between using NRT data vs. historical data
- what is the impact of the iterated dynamic orbit with the actual (Kalman) day against using the average background ?
- show the convergence of regularized solutions w.r.t the monthly (SDS) fields w/o regularization

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Data will be soon available

ftp://egsiem@gfzop.gfz-potsdam.de

Hydro-basin comparison

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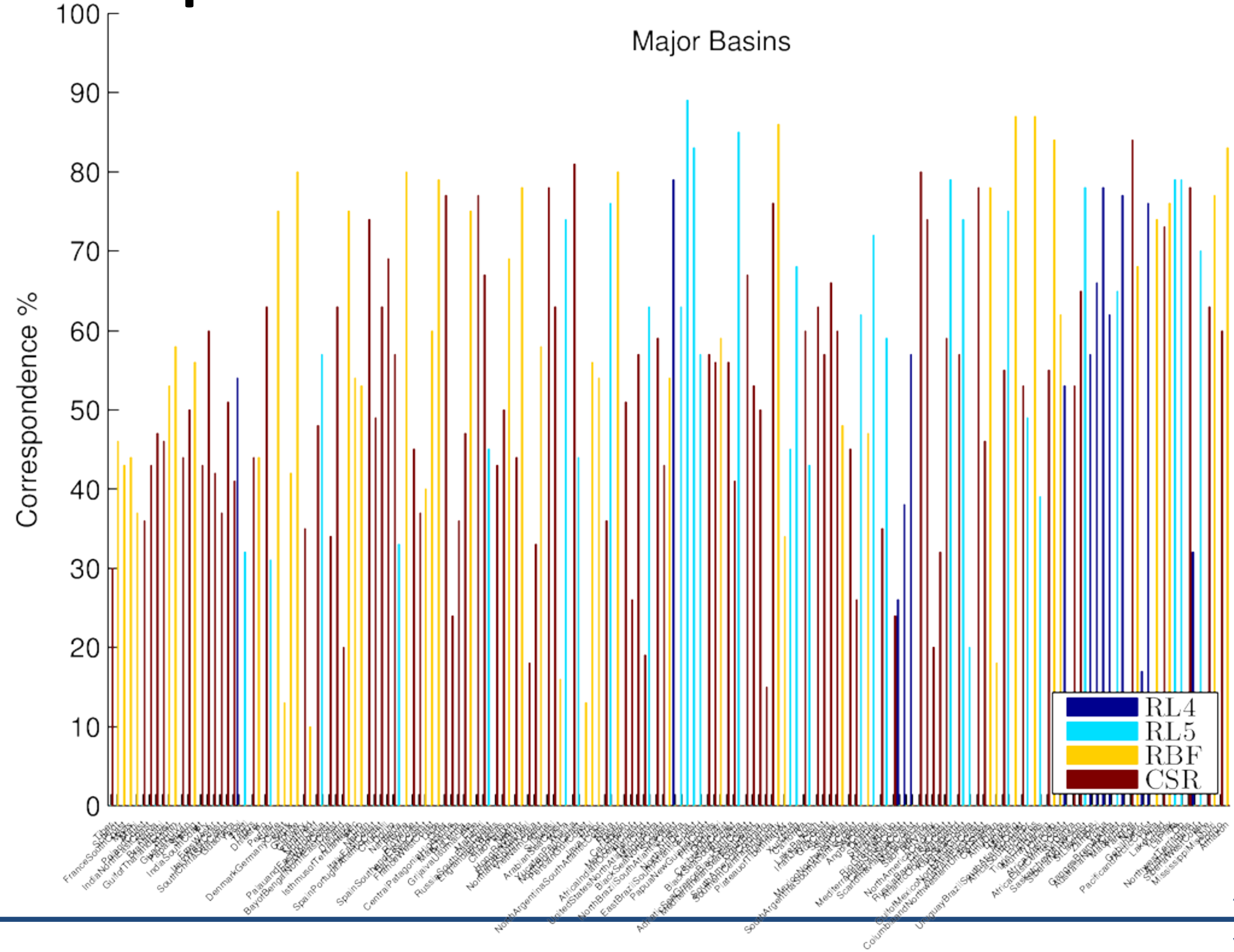

Monthly COV

- GRACE de-saisoned + sec/seas. model errors
- WGHM, de-seasoned
- VAR{GAC-mean(GAC)}

additional (non-stationary) signal

- 30% GRACE, 20% HYD, 15% GAC

Program start

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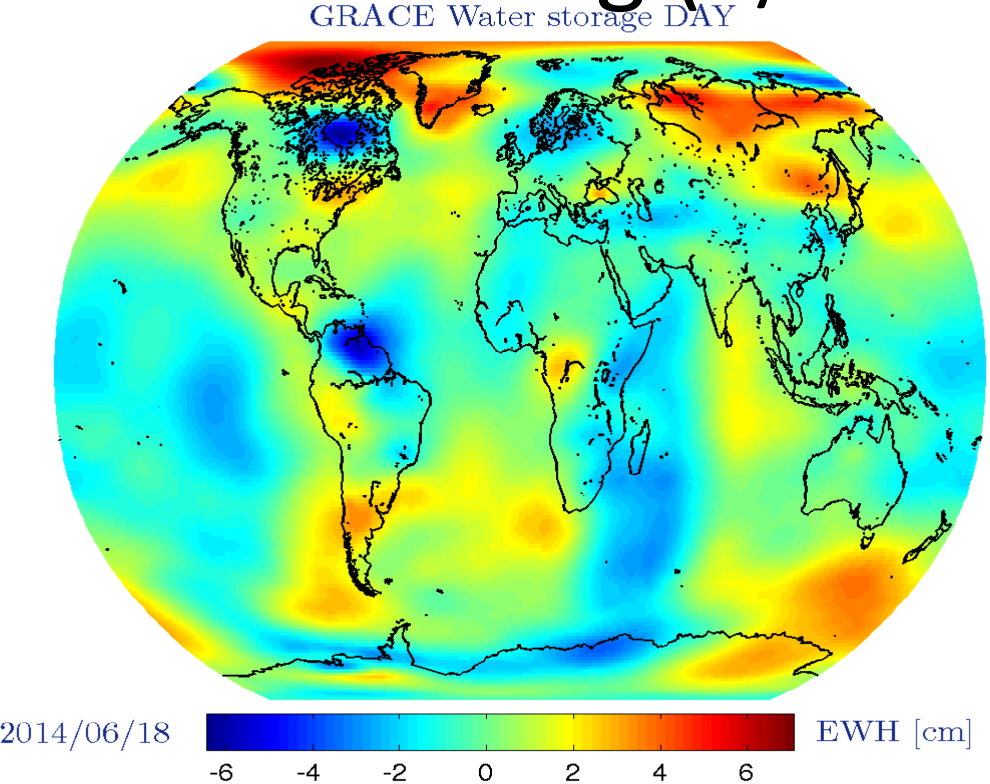
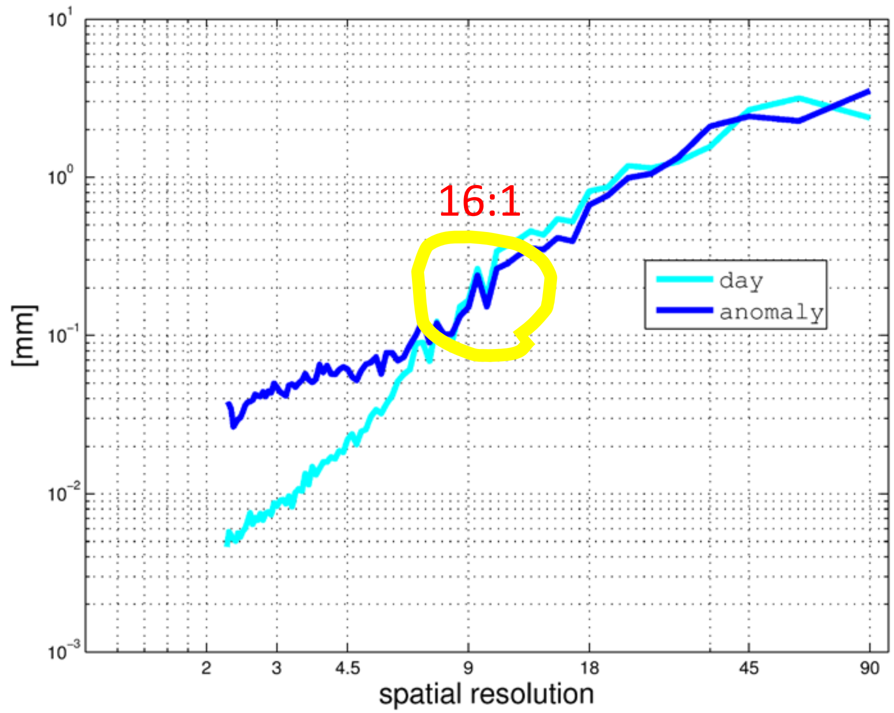
- Data acquisition
  - date/time, perturbation forces (*acc/o-tides/e-tides/lunisol/aod*), coordinates(*cis/cts*), Kband ranges
- Blunder detection (*acc*)
- Background model (gravity)
  - Static, SLR deg2, time-var (sec/seas. GRACE model: 50%, last Kalman day 50%)
- Proxy observation assembly I (pert. forces, sec/seas. model)
- Blunders, cycle/rev-param estimation (*kim*)

GRACE Day vs. TV- modeling (7yr – sec/seas.)





Least Squares Prediction

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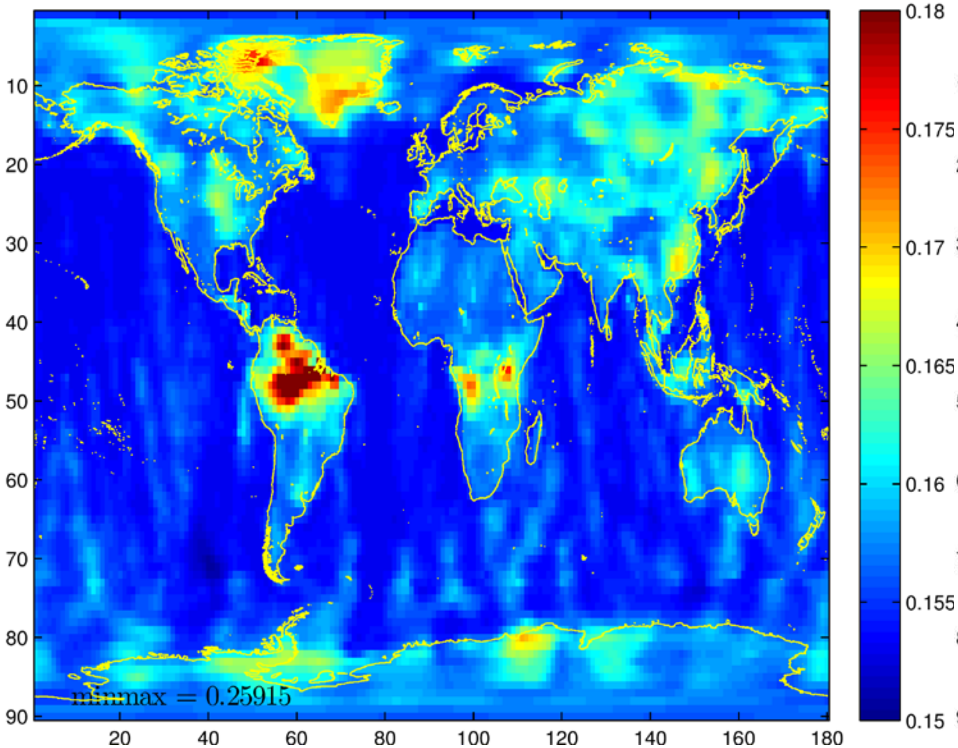
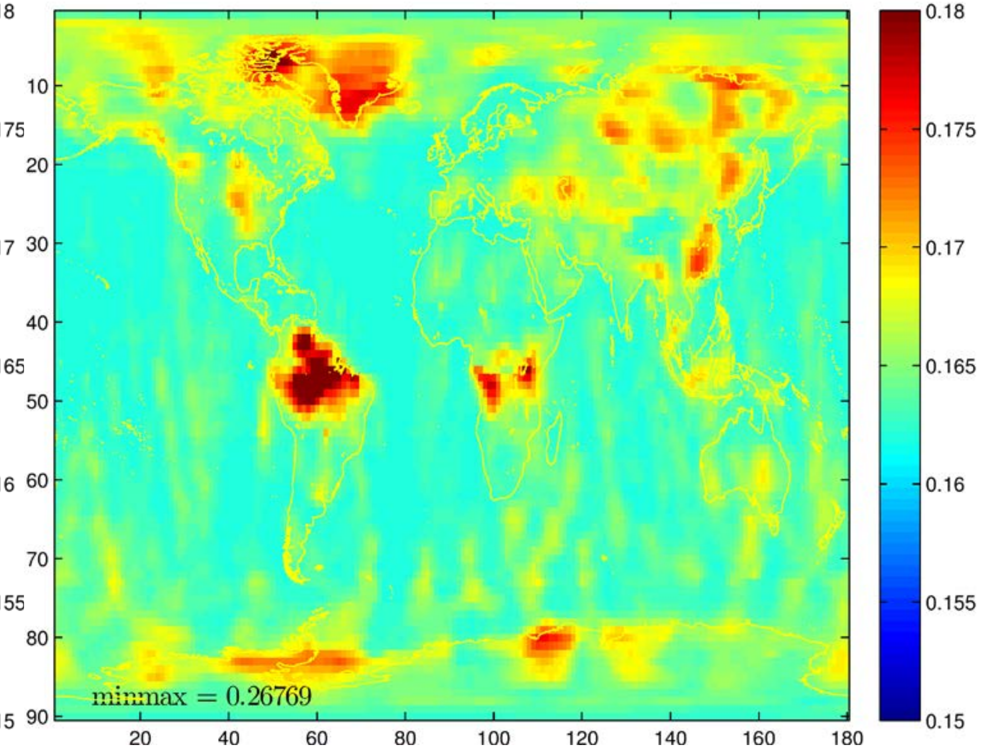


Cross-Co/Variances (06/2005)



Auto-Co/Variances (06/2005)

Anomalies vs. TV- modeling (7yr – sec/seas.)

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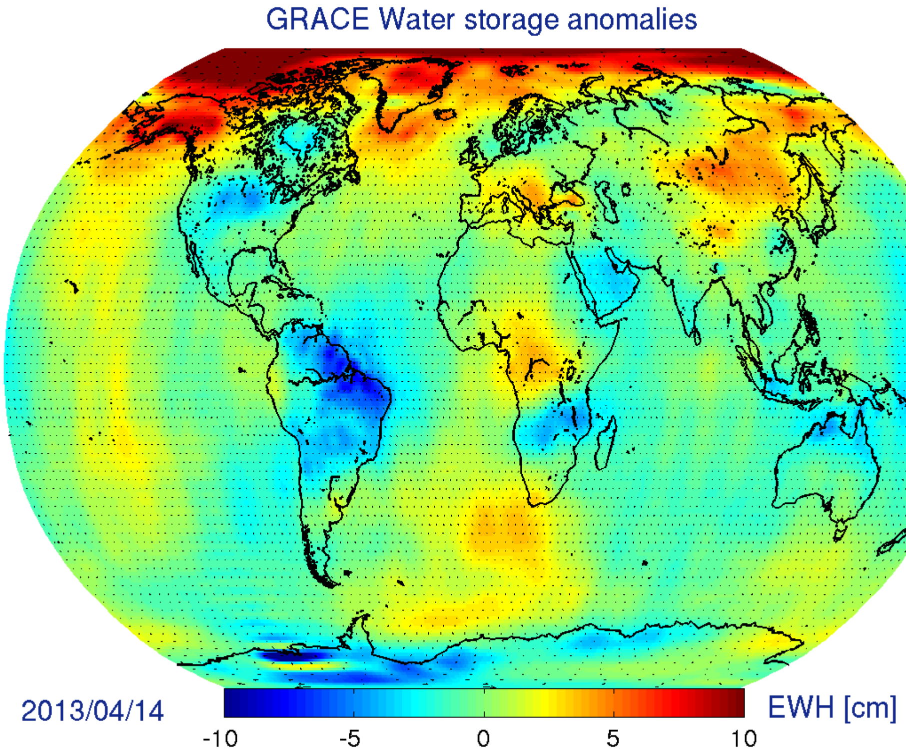

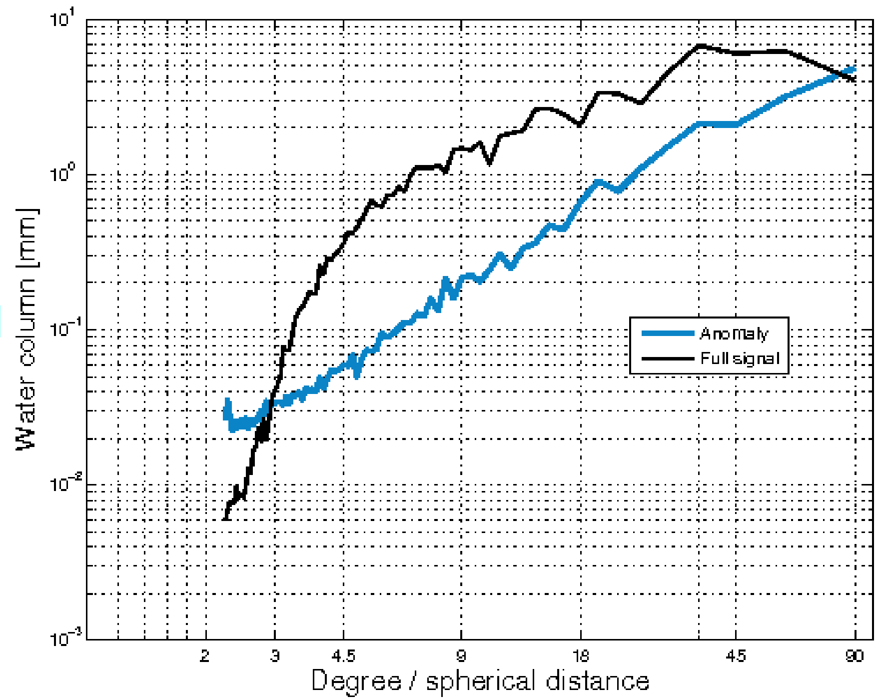

GPS sites comparison

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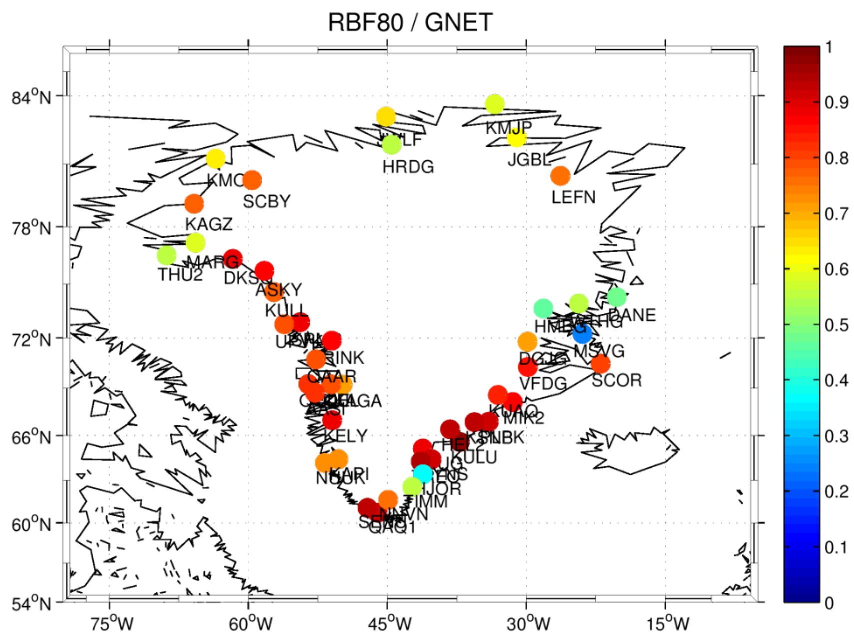
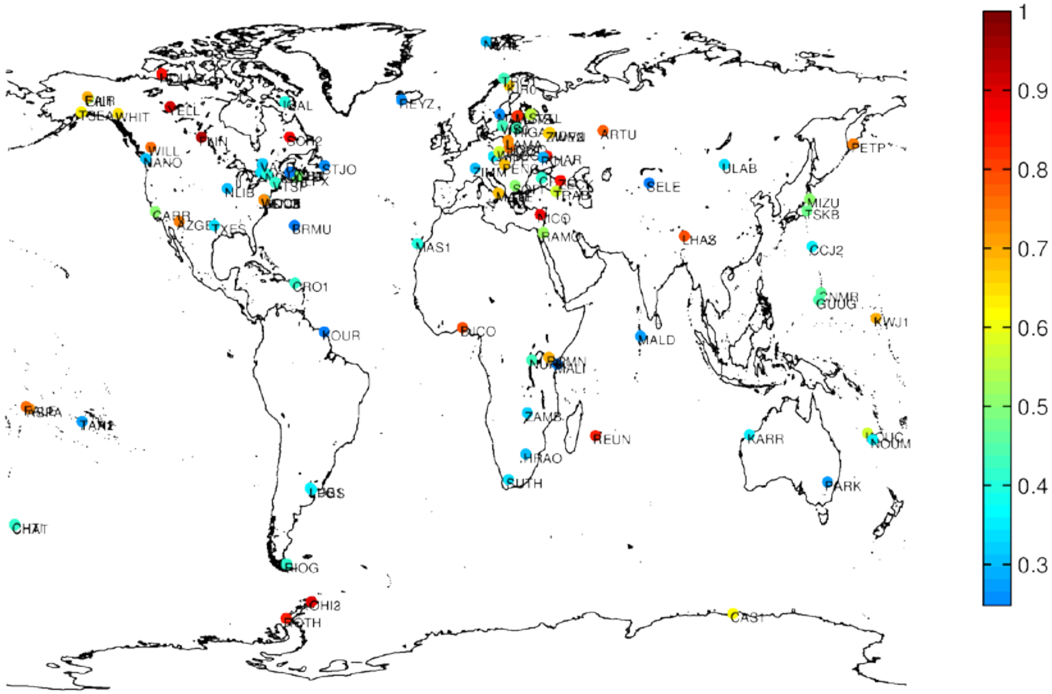


Greenland Network



CODE Network

NRT@GFZ

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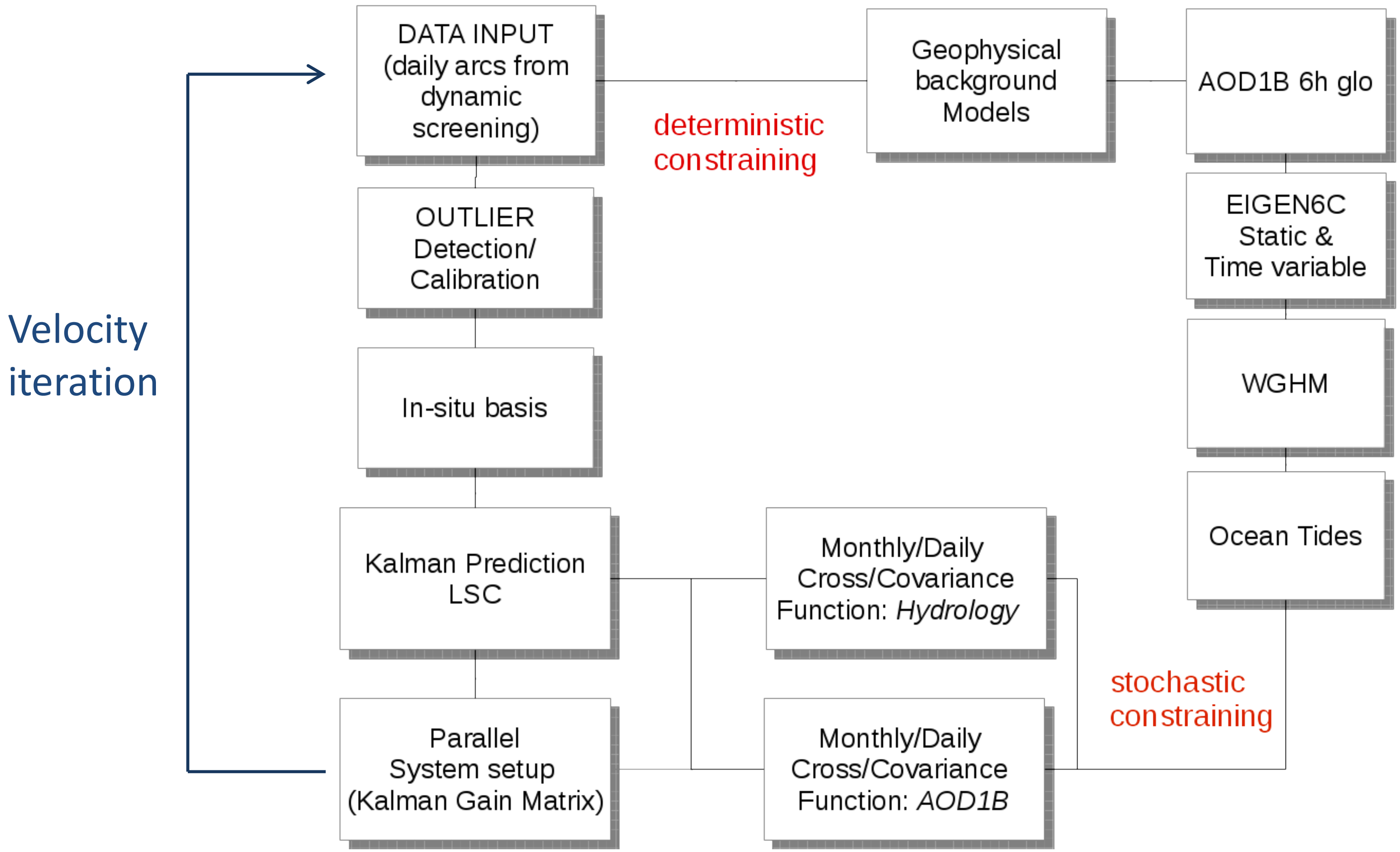

Kalman Process

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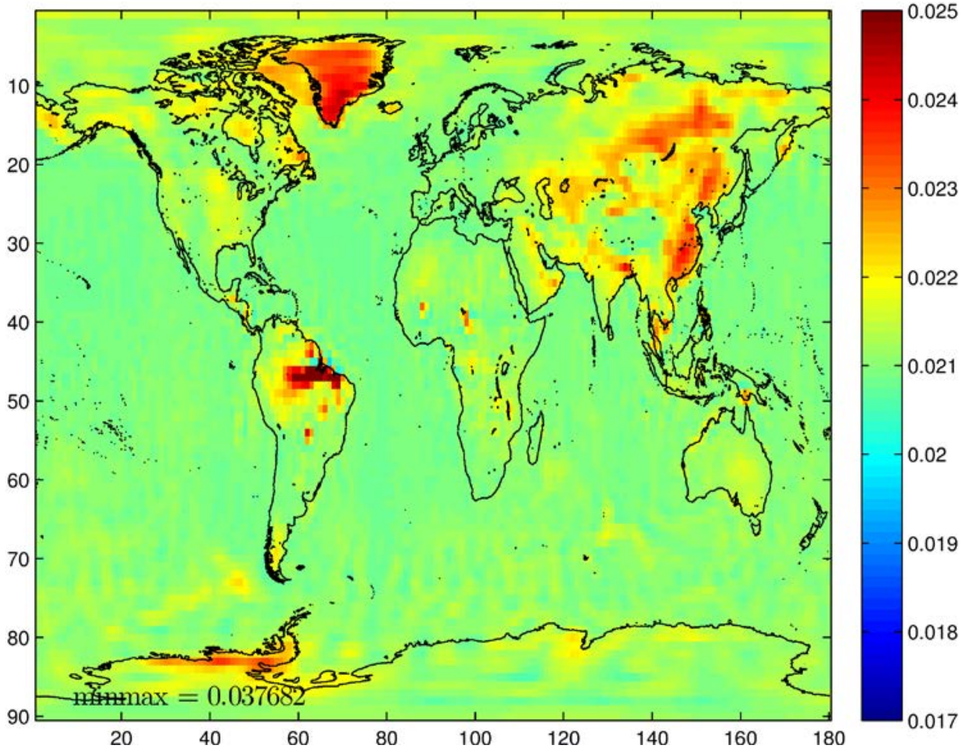
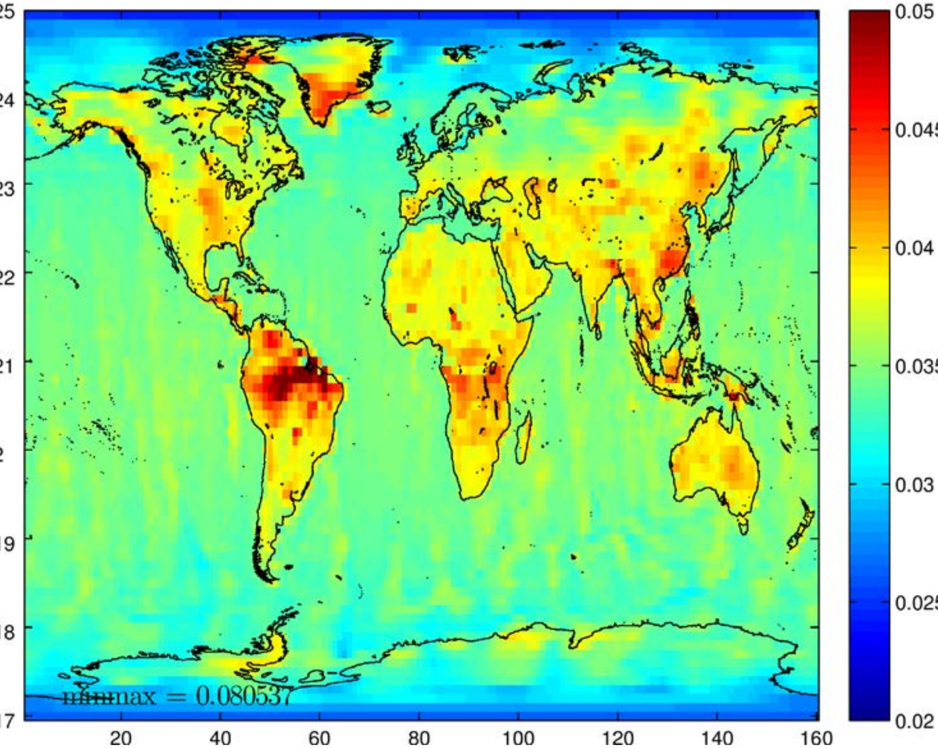


Kalman process-variances (06/2005)



Kalman state-variances (2005/06/13)
after measurement update

EGSIEM WP5 Discussion

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- Generation of area mean values (T5.5) M19-M36 (GFZ)

"We will derive for all areas of interest and all flooded regions area mean values (AMV) based on gridded equivalent water heights of gravity field time series derived in WPs 2, 4 and 5 and masks defined in WP3. Resulting AMVs will be used in WP6 e.g. for derivation of flooding indicators and will be visualised in WP7."
Output: *area mean values for all selected areas of interest*

Questions:
- Who is responsible? GFZ 1.2 or GFZ 5.4?
- What is the definition of "gridded equivalent water heights"? "Simplified" L3 product? Final GFZ product will only be available at M30 (June 2017)

EGSIEM WP5 Discussion

- (NRT) Validation/Feedback from GNSS and hydrological models (T5.6) M19-M36 (UL)

“The gravity field solutions from T5.2, T5.3, T5.4 are validated with hydrological models, e.g. GLDAS, WGHM, and with independent GNSS loading time series. For the latter approach the representations of mass redistributions are converted to site displacements. Atmospheric and ocean-contributions will be added using state-of-the-art models according to D2.1. The procedure will be automated to allow for a just-in-time validation of the NRT service products.

Questions:

– When do we get first results to get impression what GNSS and hydrological models can provide as validation?
– Is it really possible to provide this on a daily NRT 5d basis?
– What are the results? Maps will not be useful to provide an ok or not ok. Have to define values like correlation coefficients
– Need more discussions between GFZ, TUG and UL

EGSIEM WP5 Discussion

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- Validation/Feedback from historical flood events (T6.1) M07-M30 (GFZ, DLR)

Input: *List of flood events and flood masks from T3.9, water level time series from T3.6, GIA-based trends from T3.8, combined solution products for geophysical applications from T4.2, NRT solutions from T5.2, regional solutions from T5.4*

- Validation and evaluation of the daily, near-real time and regional gravity products on water storage anomalies for selected flood events by a combination of complementary observation data sets and hydrological/hydraulic modelling

So far we are focusing only on very few events such as Ganges/Bhramaputra or Danube. For a real validation of TUG and GFZ NRT solutions we will need much more test scenarios / better statistics.

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Title: WP6 (Hydrological Service)

Ben Gouweleeuw, Andreas Güntner (GFZ)

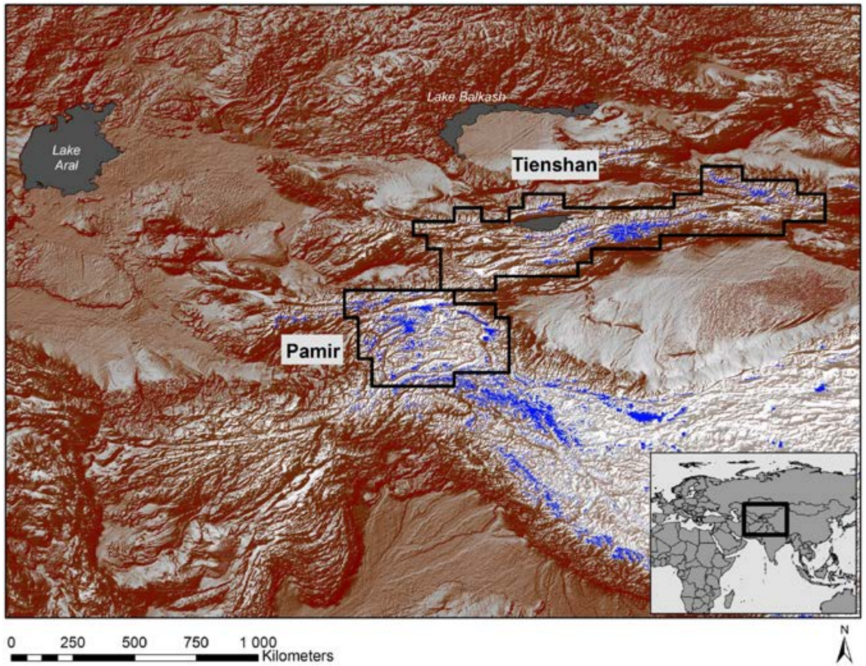
Henryk Zwenzner, Sandro Martinis (DLR)

EGSIEM Meeting

GFZ Potsdam

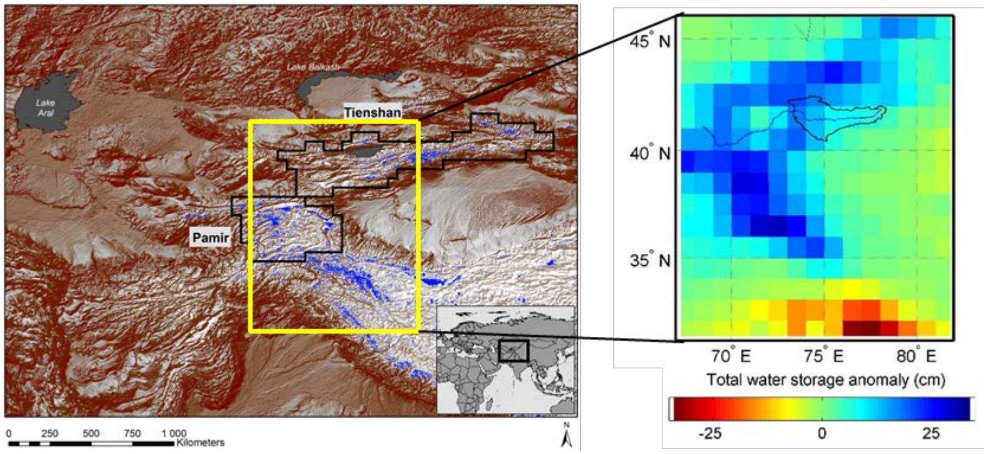
June 2-3 2016

Seasonal forecasting of summer streamflow in Central Asia



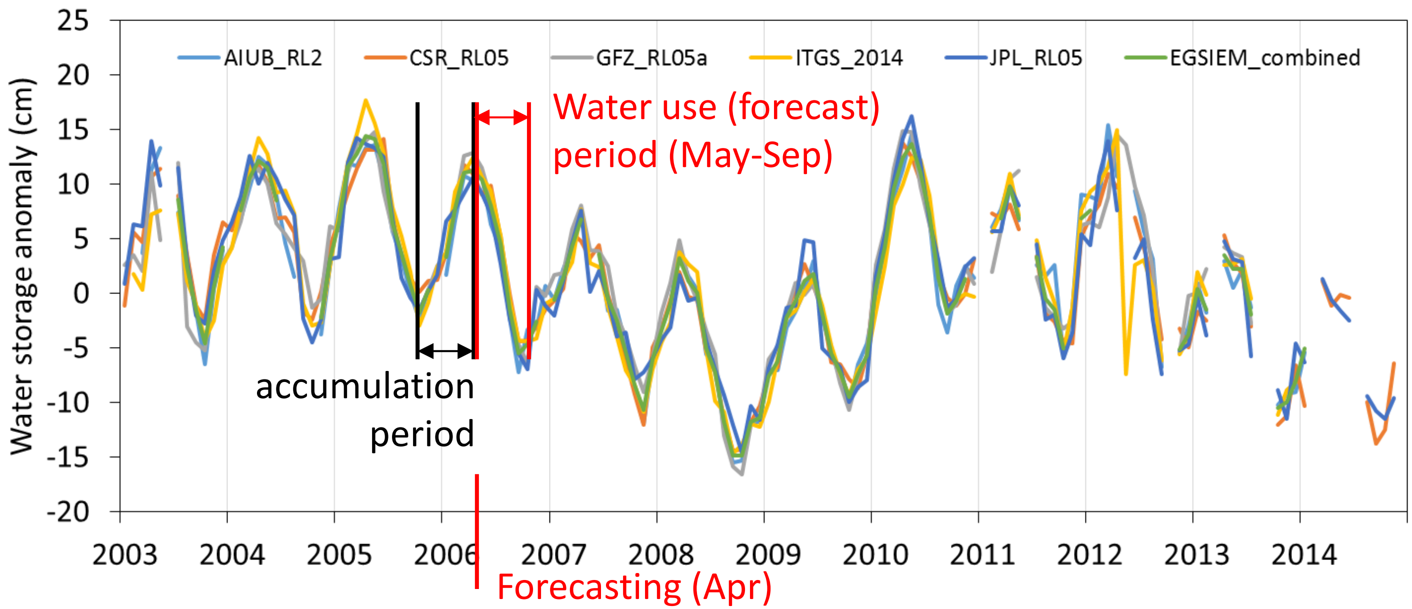
Water resources in Central Asia depend on snowmelt and glacier melt from mountain ranges such as Pamir and Tien Shan

Seasonal forecasting of summer streamflow in Central Asia



Naryn river basin
River gauging station Uchterek
Basin size ~50000km²

April 2010 total water storage (TWS) anomaly



Seasonal forecasting of summer streamflow in Central Asia

Linear forecast models

Forecast variable:

- Summer streamflow (May-Sep)

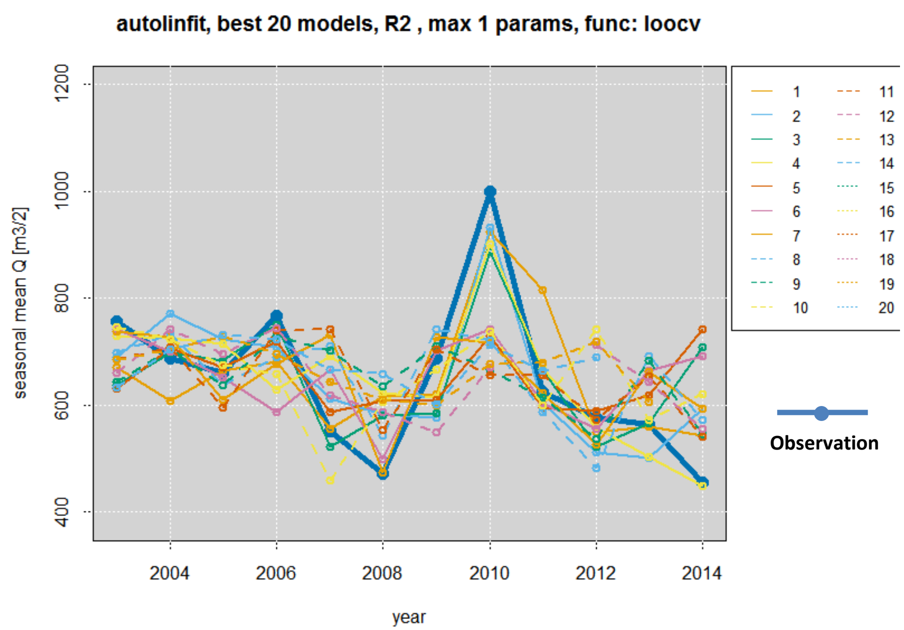
Predictors (winter conditions):

- Precipitation
- Standardized Precipitation Index (SPI)
- Air temperature
- River discharge
- Snow cover
- GRACE TWS anomaly

Seasonal forecasting of summer streamflow in Central Asia

Linear forecast model (1 predictor) (2003-2014)

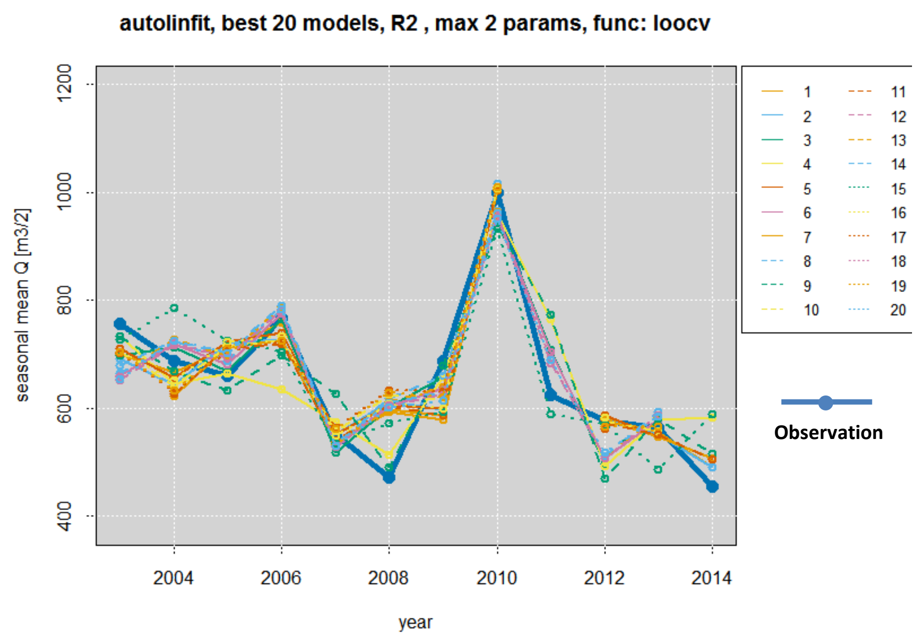
	Predictor	R^2 cross-validation
1	precip_feb	0.655
2	precip_janmar	0.645
3	precip_janfeb	0.602
4	precip_febmar	0.493
5	precip_jan	0.311
6	temp_jan	0.286
7	temp_janfeb	0.274
8	temp_janmar	0.202
9	temp_febmar	0.152
10	snowcov_mar	0.086
11	temp_feb	0.083
12	JPL_RL05_1_DDK2s_grav_jan	0.034
13	JPL_RL05_1_DDK2s_grav_feb	0.025
14	GFZ_RL05a_DDK2s_grav_mar	0.011



Seasonal forecasting of summer streamflow in Central Asia

Linear forecast model (2 predictors) (2003-2014)

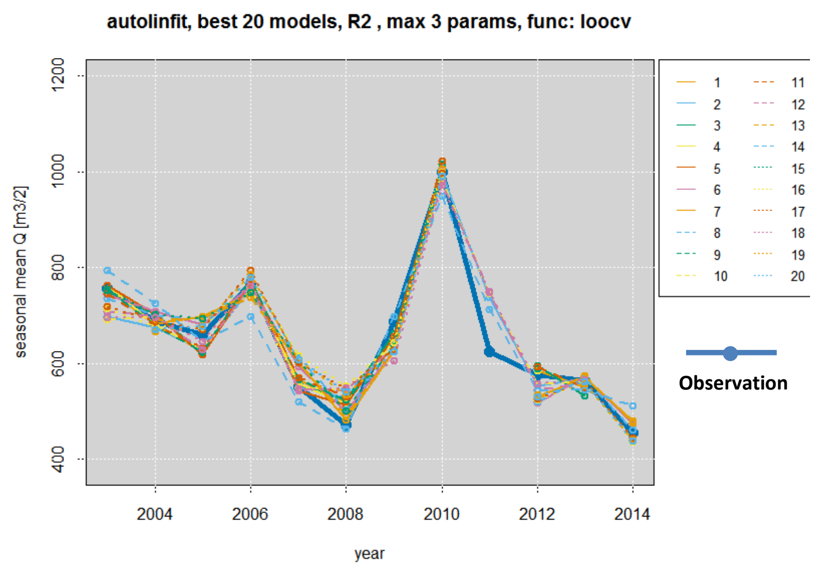
	Predictor	R^2 cross-val
1	JPL_RL05_1_DDK2s_grav_jan + precip_feb	0.773
2	CSR_RL05_DDK2s_grav_jan + precip_feb	0.756
3	GFZ_RL05a_DDK2s_grav_mar + precip_janfeb	0.752
4	temp_jan + precip_feb	0.747
5	JPL_RL05_1_DDK2s_grav_janfeb + precip_feb	0.742
6	GFZ_RL05a_DDK2s_grav_feb + precip_janfeb	0.732
7	EGSIEM2_DDK3s_grav_jan + precip_feb	0.732
8	GFZ_RL05a_DDK2s_grav_janmar + precip_janfeb	0.725
9	temp_janfeb + precip_feb	0.722
10	CSR_RL05_DDK2s_grav_janfeb + precip_feb	0.721
11	EGSIEM2_DDK2s_grav_jan + precip_feb	0.719
12	CSR_RL05_DDK2s_grav_feb + precip_janfeb	0.698
13	GFZ_RL05a_DDK2s_grav_janfeb + precip_janfeb	0.696
14	CSR_RL05_DDK2s_grav_janfeb + precip_janfeb	0.689
15	snowcov_mar + precip_janmar	0.682
16	JPL_RL05_1_DDK2s_grav_janmar + precip_feb	0.675
17	GFZ_RL05a_DDK2s_grav_janmar + precip_feb	0.674
18	EGSIEM2_DDK2s_grav_feb + precip_janfeb	0.673
19	GFZ_RL05a_DDK2s_grav_janfeb + precip_feb	0.671
20	EGSIEM2_DDK3s_grav_feb + precip_janfeb	0.663



Seasonal forecasting of summer streamflow in Central Asia

Linear forecast model (3 predictors) (2003-2014)

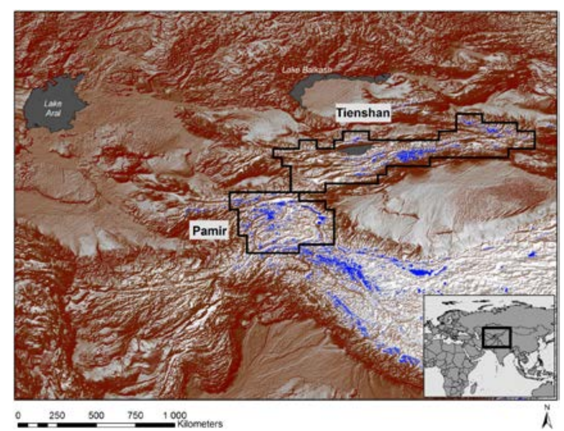
	Predictor	R^2 cross-val
1	CSR_RL05_DDK2s_grav_janfeb + temp_mar + precip_janfeb	0.928
2	CSR_RL05_DDK2s_grav_feb + temp_mar + precip_janfeb	0.918
3	GFZ_RL05a_DDK2s_grav_janfeb + temp_mar + precip_janfeb	0.915
4	CSR_RL05_DDK2s_grav_janmar + temp_mar + precip_janfeb	0.908
5	GFZ_RL05a_DDK2s_grav_janmar + temp_mar + precip_janfeb	0.904
6	JPL_RL05_1_DDK2s_grav_jan + temp_janfeb + precip_feb	0.871
7	EGSIEM2_DDK3s_grav_jan + temp_janfeb + precip_feb	0.867
8	CSR_RL05_DDK2s_grav_jan + temp_janfeb + precip_feb	0.861
9	JPL_RL05_1_DDK2s_grav_janmar + temp_mar + precip_janfeb	0.861
10	EGSIEM2_DDK3s_grav_feb + temp_mar + precip_janfeb	0.861
11	JPL_RL05_1_DDK2s_grav_janfeb + temp_mar + precip_janfeb	0.860
12	EGSIEM2_DDK2s_grav_feb + temp_mar + precip_janfeb	0.848
13	EGSIEM2_DDK2s_grav_jan + temp_janfeb + precip_feb	0.847
14	snowcov_mar + temp_janfeb + precip_feb	0.845
15	JPL_RL05_1_DDK2s_grav_janfeb + temp_janfeb + precip_feb	0.844
16	CSR_RL05_DDK2s_grav_jan + temp_feb + precip_feb	0.839
17	JPL_RL05_1_DDK2s_grav_jan + temp_feb + precip_feb	0.833
18	JPL_RL05_1_DDK2s_grav_feb + temp_mar + precip_janfeb	0.829
19	EGSIEM2_DDK3s_grav_jan + temp_feb + precip_feb	0.821
20	EGSIEM2_DDK2s_grav_jan + temp_feb + precip_feb	0.815



Seasonal forecasting of summer streamflow in Central Asia

Summary

- GRACE TWS alone is not a good predictor for summer streamflow
- But forecasts can be improved by GRACE TWS as additional predictor (in addition to, e.g., precipitation, temperature)
- EGSIEM combined monthly solution performs similar or slightly worse than individual solutions



EGSIEM

European Gravity Service for Improved Emergency Management

Title: WP6 (Hydrological Service)

Ben Gouweleeuw (GFZ)

EGSIEM Project Meeting

GFZ potsdam

June 2-3.2016

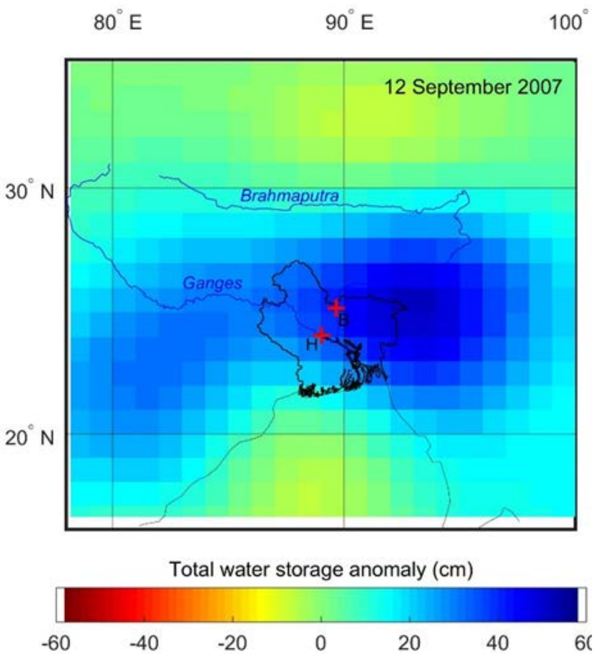
Universität Bern · Université du Luxembourg · GFZ Helmholtz Centre Potsdam · TU Graz · Leibniz Universität Hannover · cnes · DLR · géode&cie · HORIZON 2020

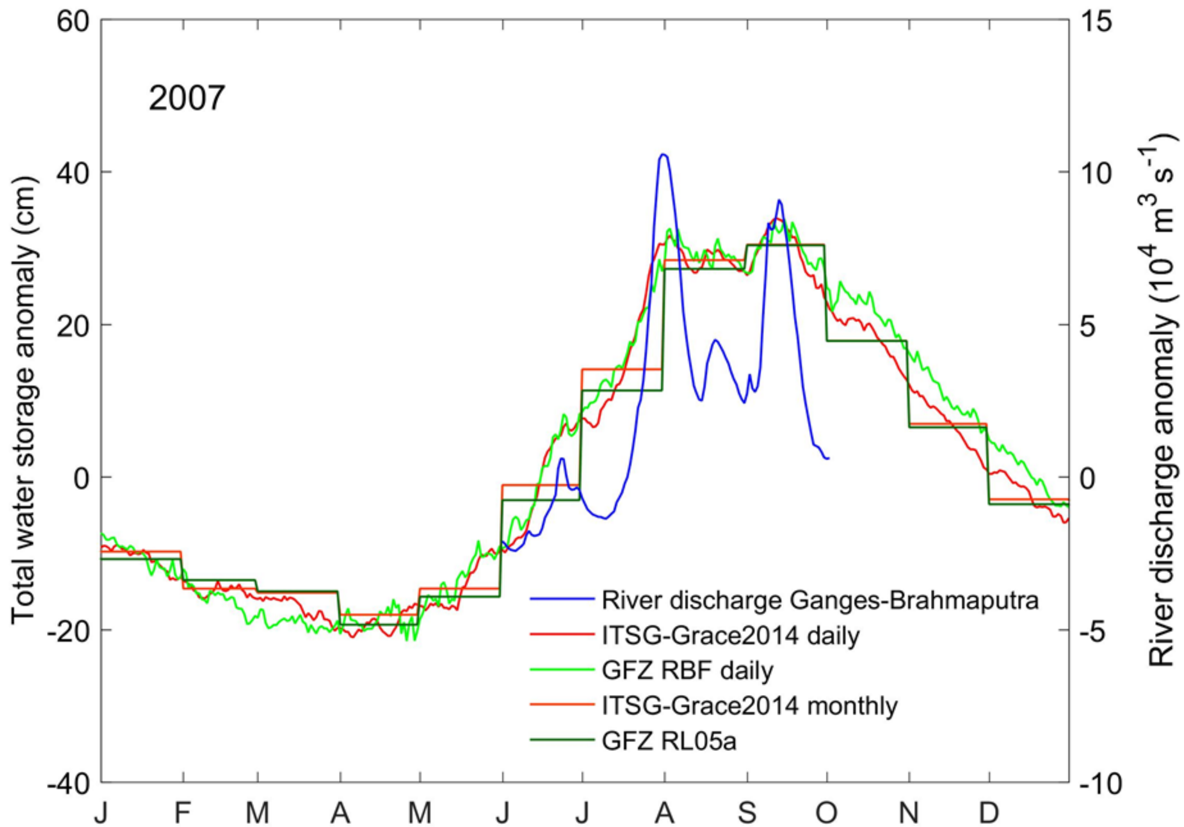
Other activities & outlook

- Paper on evaluation of GRACE daily gravity solutions for hydrological extremes in selected river basins (Gouweleeuw et al., GRL, in prep.)

WP6: Hydrological Service

European Gravity Service for Improved Emergency Management





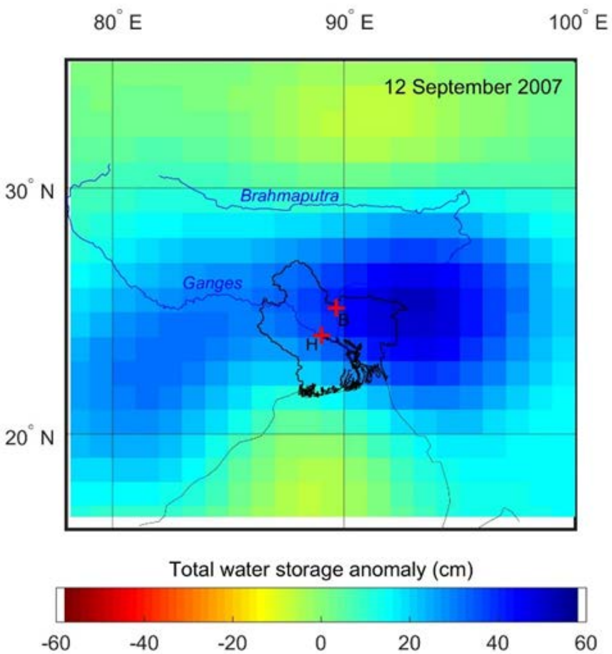
Gouweleeuw et al. (in review): Daily GRACE gravity solutions track major flood events in the GB Delta

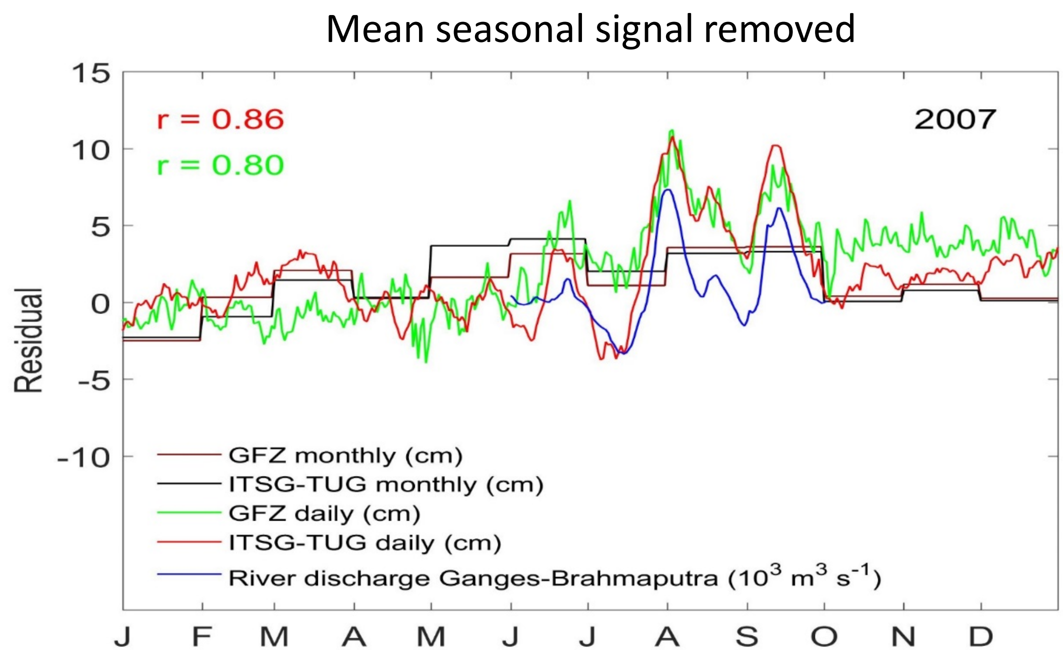
Key reviewers' comments

- Demonstrate (quantitatively) additional value of the daily solutions
- Information GRACE observations vs. hydrological model
- Noise level of the daily solutions
- Flood monitoring vs. flood forecasting

WP6: Hydrological Service

EGSIEM
European Gravity Service for Improved Emergency Management





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

- Collection of complimentary hydrological data (groundwater level, surface water level, river discharge) for Ganges-Brahmaputra Delta.

Other activities & outlook of last meeting

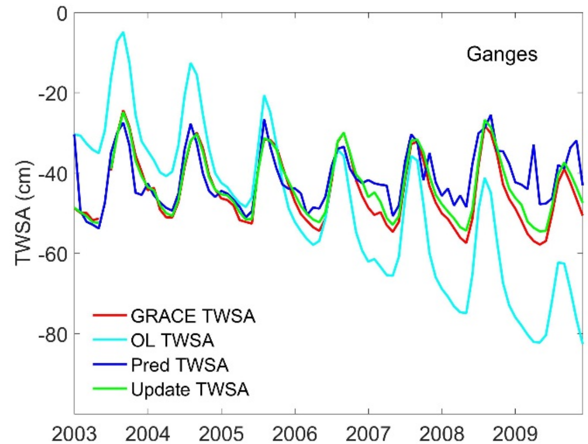
- Planned research stay at IGG, Bonn to set up DA framework for assimilation of EGSIEM data products into WGHM for Ganges-Brahmaputra Basin.

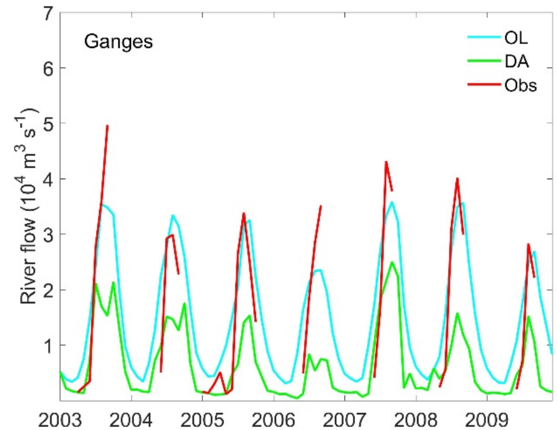
WP6: Hydrological Service

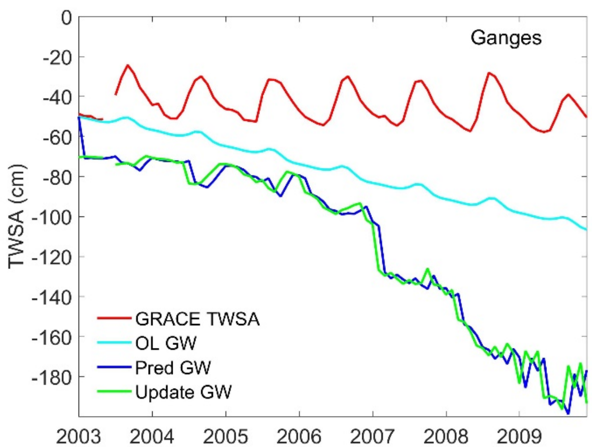
European Gravity Service for Improved Emergency Management

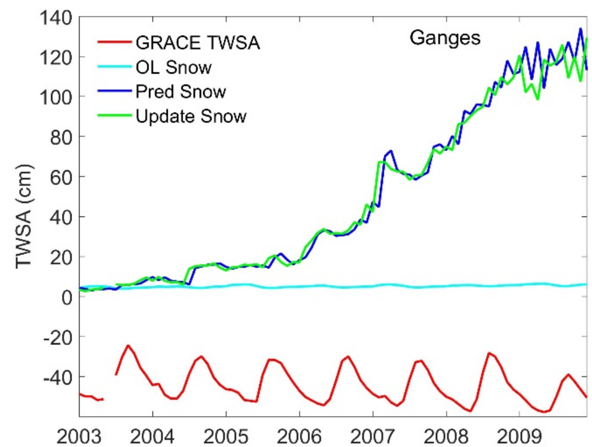
Ganges

European Gravity Service for Improved Emergency Management









HORIZON 2020

Brahmaputra

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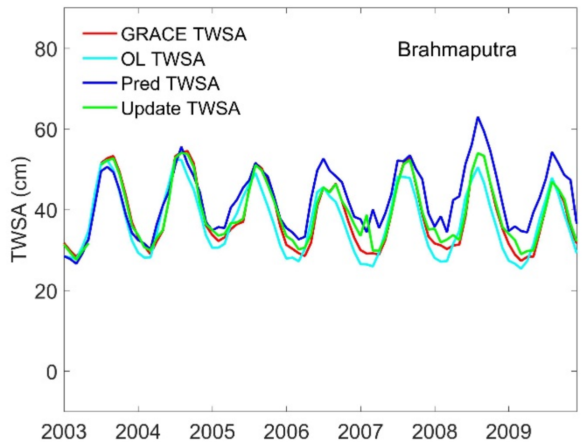

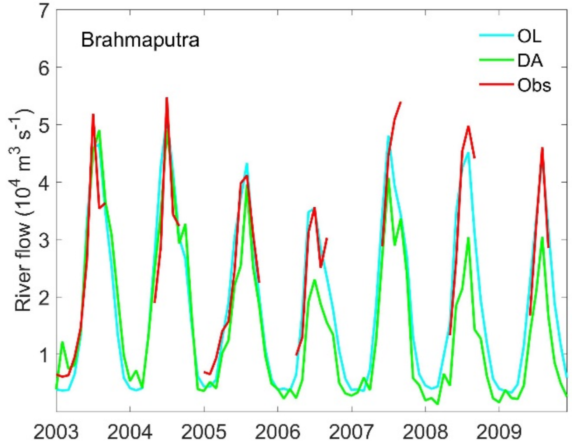

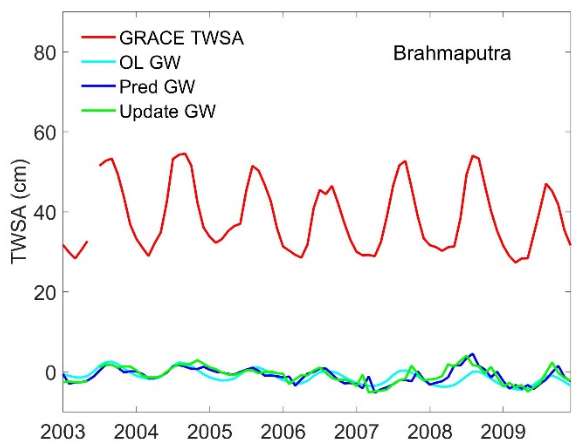

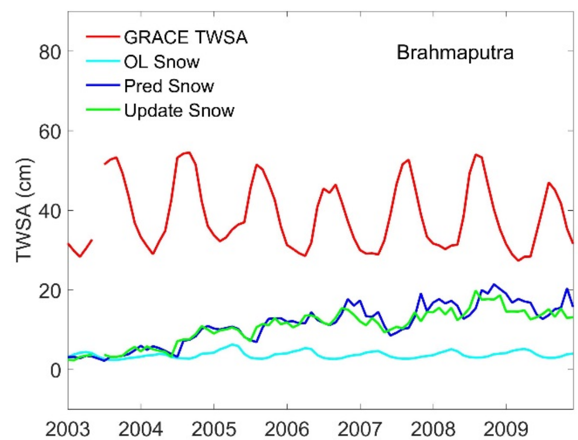

Meghna

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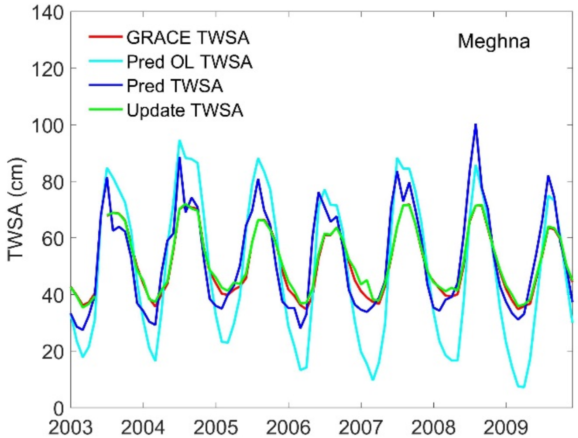

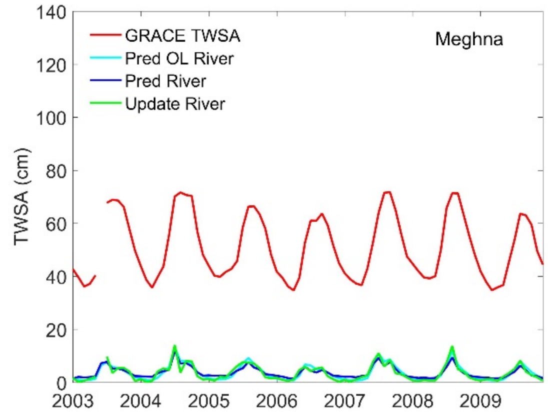

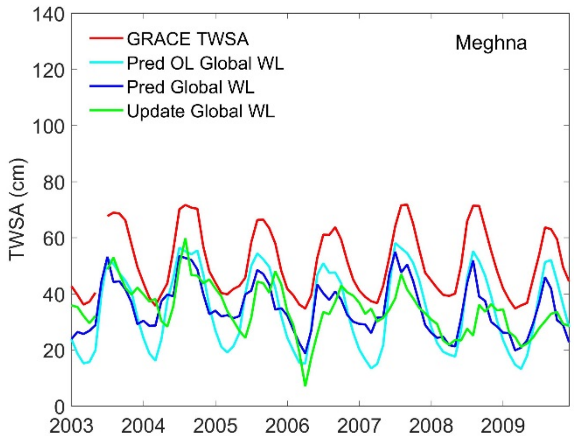

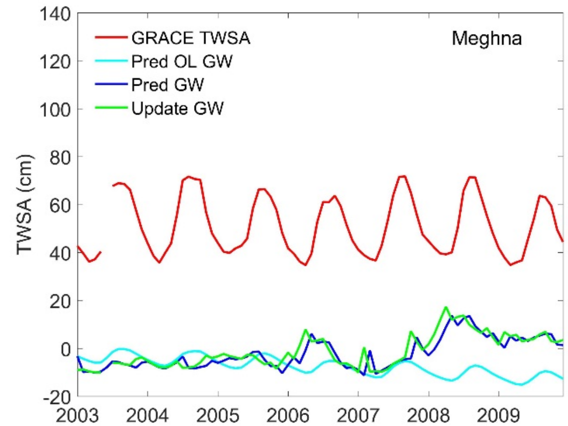

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WP6: Hydrological Service

EGSIEM

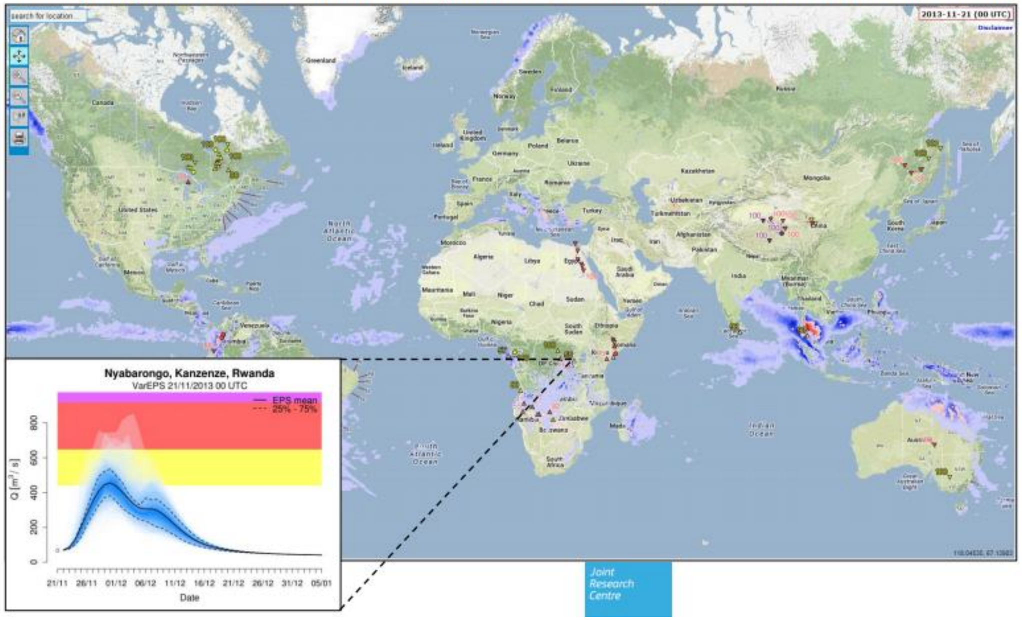
European Gravity Service for Improved Emergency Management

European Commission

Global Flood Awareness System (GloFAS)

Flood early warnings for large river basins around the world

Developed by: Joint Research Center of the European Commission & European Center for Medium Range Weather Forecasting



Forecast lead time:
Up to 20 days

Minimum river basin size:
10.000 km²

Forecast frequency:
Daily

Forecast type:
Probabilistic

Joint Research Centre

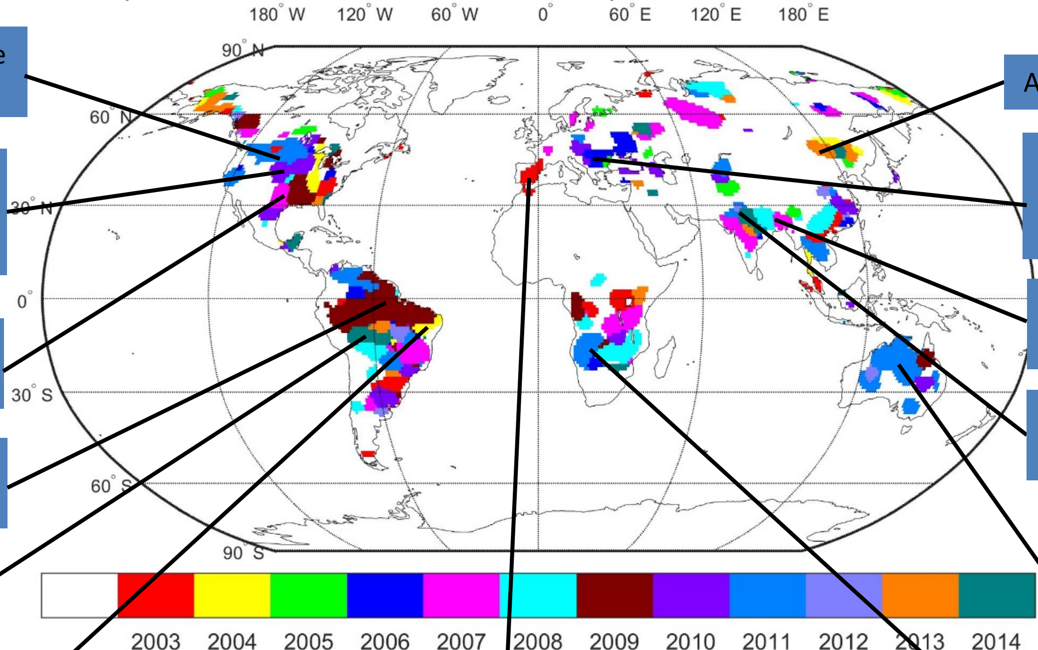
WP6: Hydrological Service

EGSIEM

European Gravity Service for Improved Emergency Management

Wettest Year on record, 2003-2014 (threshold > 10 cm)

Year of maximum monthly TWS of the EGSIEM combined product, linear trend and seasonal cycle removed



2011: Record flooding across the U.S. Northern Plains

March 2010: Heavy rain and snowmelt cause flooding in Upper Mid-West U.S.

June-Aug 2007: Heavy rain and flooding in Texas

2009: Devastating floods in NE Brazil

Jan-May 2014: Torrential rain and floods in Bolivia

2004: Major flooding in Eastern Brazil in Jan-Feb

2003: Flooding in Ebro river basin (March) and heavy rain in southern Spain (Nov)

March-April 2011: Severe flooding in Namibia and Angola

Aug 2013: Flooding in NE China

April 2006 and May 2010: Major flooding in central and lower Danube river basin

Aug-Sept 2007: Major flooding in Ganges-Brahmaputra Delta

August 2014: Widespread flooding in northern India

2011: Summer 2010-2011 second wettest on record across Australia

EGSIEM

The wettest year observed by GRACE may reflect an exceptionally wet period or flood

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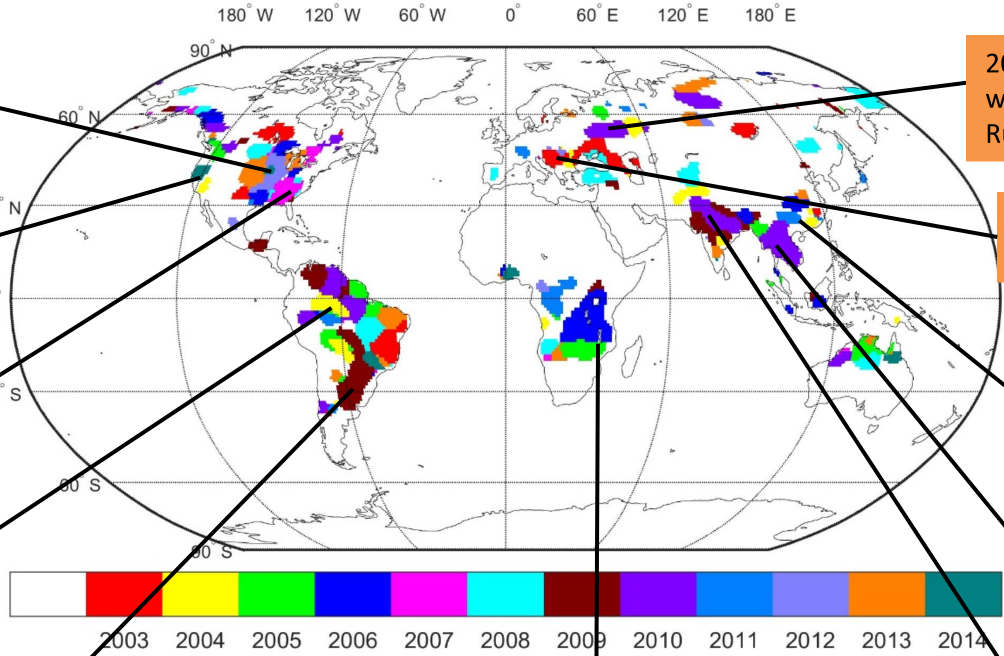
WP6: Hydrological Service

EGSIEM
European Gravity Service for Improved Emergency Management

Drought periods (3 months and longer), 2003-2014

Year of maximum TWS deficit of the EGSIEM combined product (threshold -10 cm)



2012: Widespread drought grips the U.S. and persists in Central U.S. in 2013

2014: Continuing extreme drought in California

2007: Severe drought in Southern and Eastern U.S.

2004: Drought in western Amazonia

2008-2009: Drought in the La Plata basin, Argentina

2005-2006: Near end of long term drought in East Central Africa

2009-2010: Drought conditions in northern India

2010: Drought in SE Asia prior to onset of heavy monsoon rains

2004: Worst drought in 50 years threatens drinking water supplies in SE China

2003: Heatwave and dry conditions in Europe

2010: Record heat exacerbates worst drought since 1972 in Russia

EGSIEM

Water storage deficit is the negative residual of the de-trended GRACE TWS and the seasonal cycle

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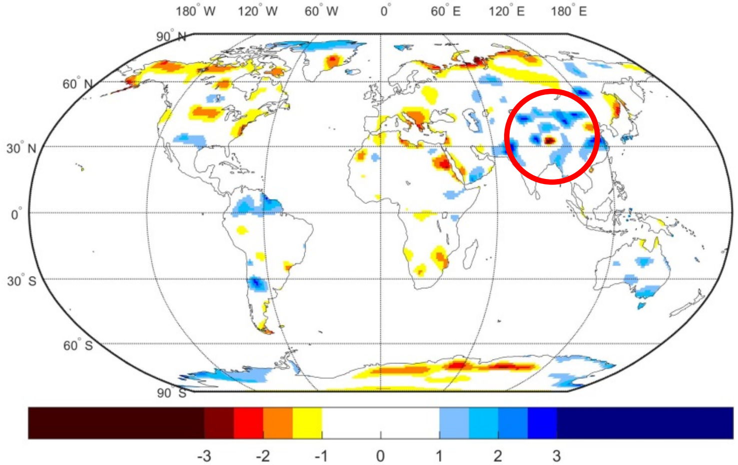
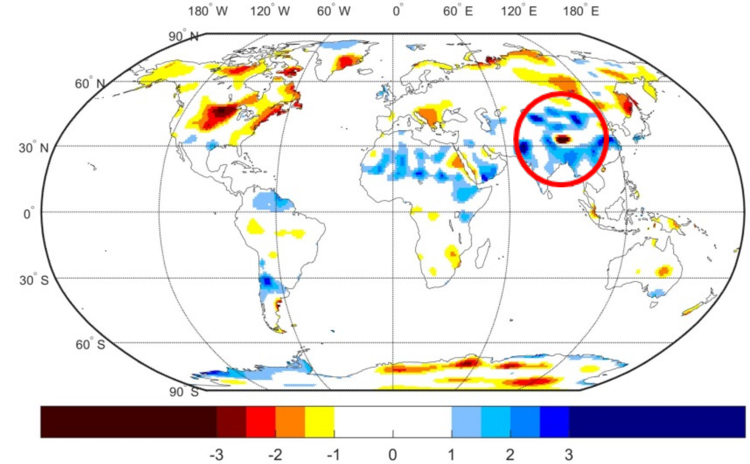
Flood and drought indicator – normalized TWSA

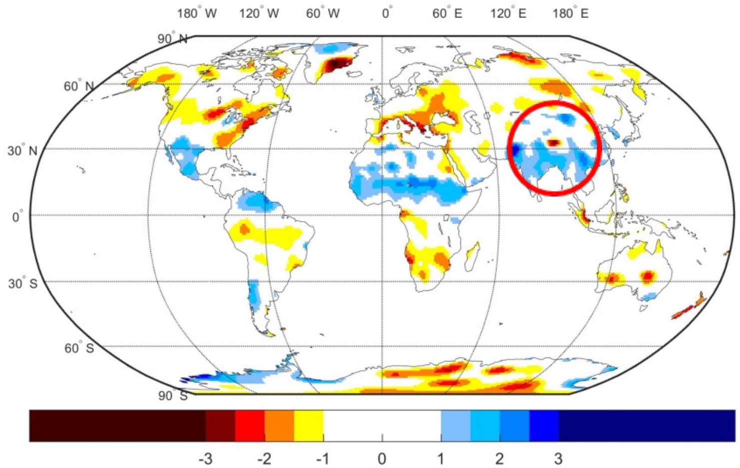
19 July 2007



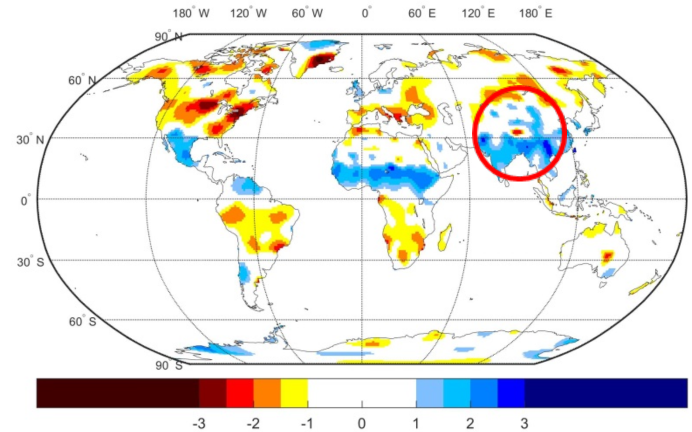
3 August 2007



28 August 2007



12 September 2007



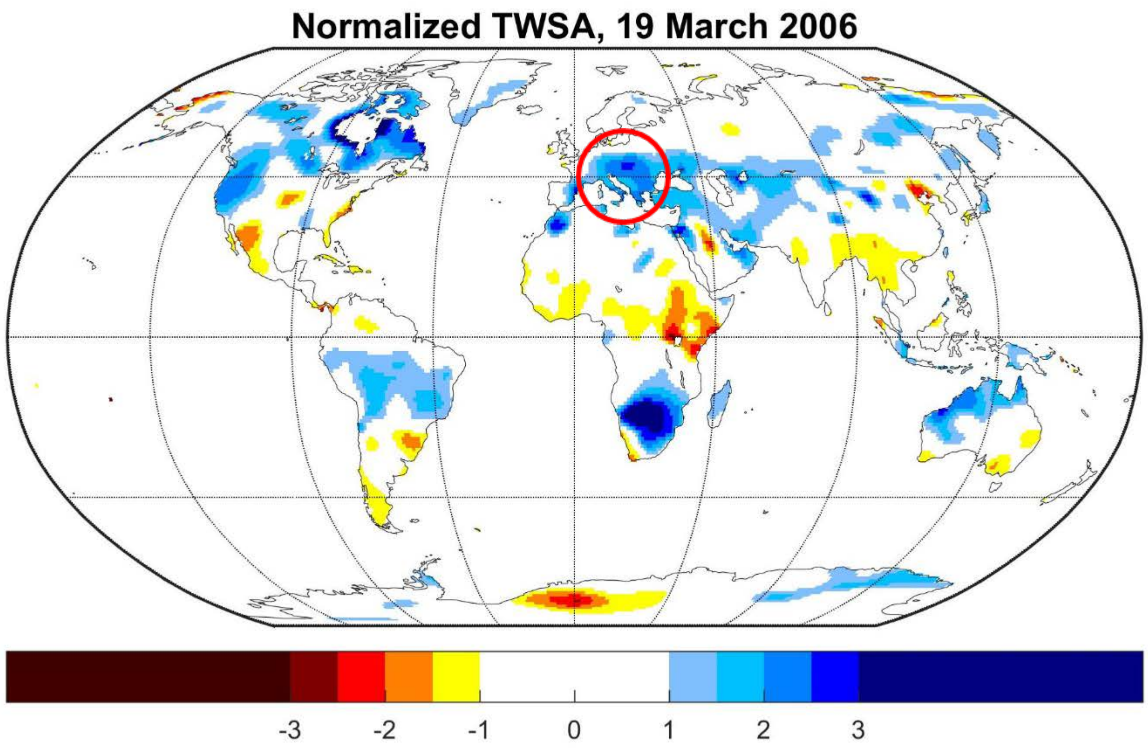
EGSIEM

Ganges-Brahmaputra Delta flood

HORIZON 2020

Danube basin

European Gravity Service for Improved Emergency Management



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.

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)
- Analyse and extend DA assimilation for Ganges-Brahmaputra-Meghna basin incl. analysis of complimentary hydrological data (groundwater level, surface water level, river discharge).
- Further development and refinement of global drought and flood indexing in preparation of real-time test.

EGSIEM
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Flood volume estimation based on EO data

- Ganges-Brahmaputra test case -

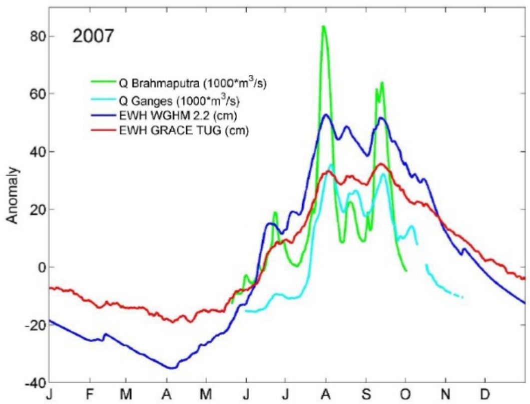
WP6 – T6.1

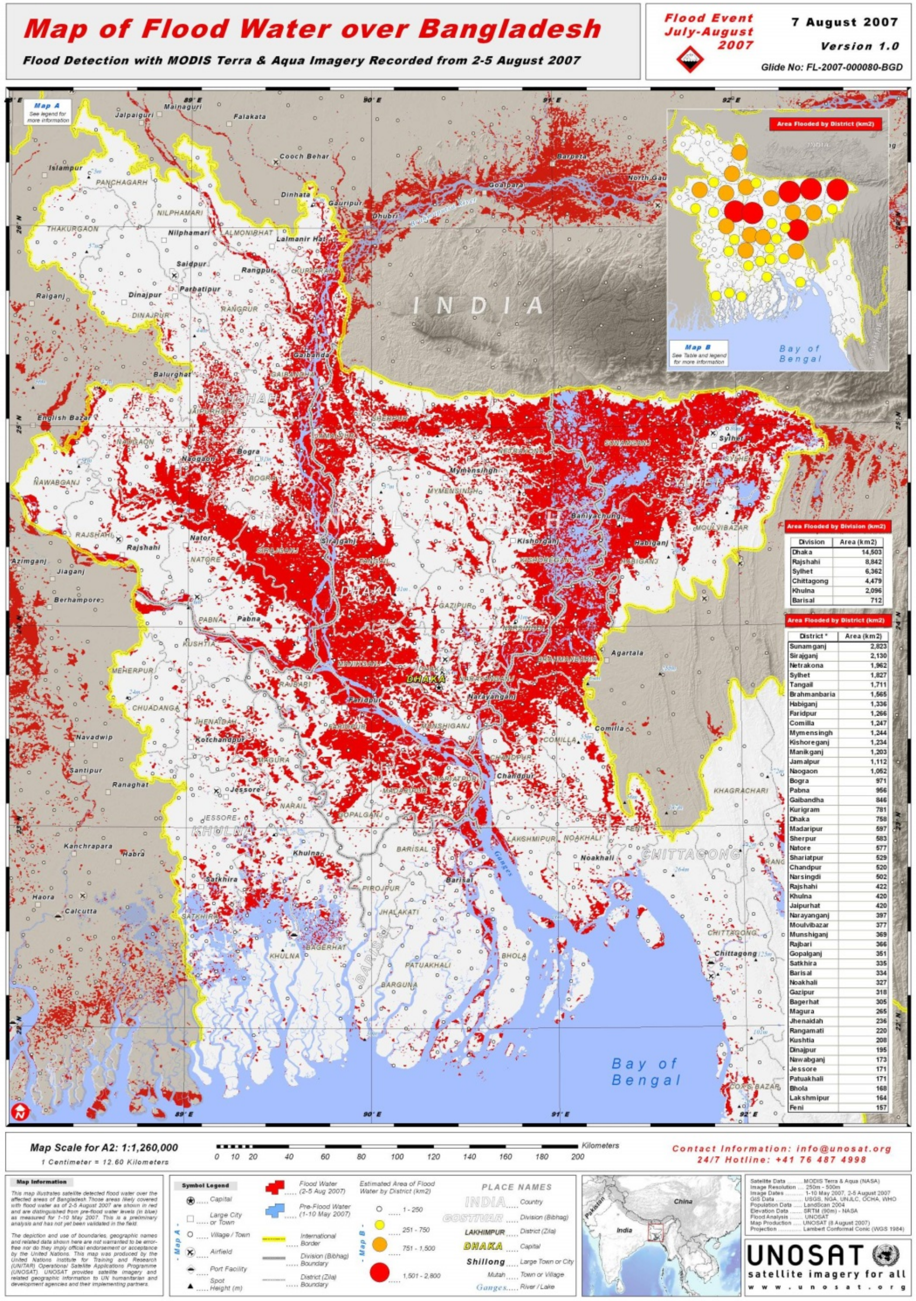
Hendrik Zwenzner - DLR

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

Ganges/Brahmaputra

- Extreme flood event during 2007
- Size: ca. 220.000 km²





EOSIEM

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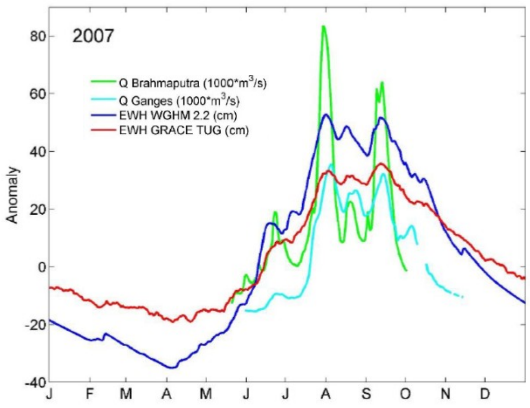
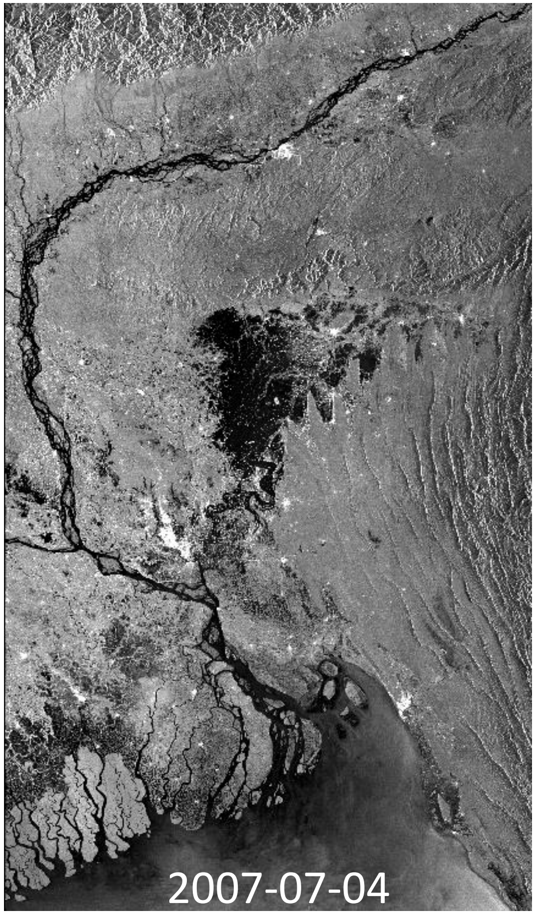
European Gravity Service for Improved Emergency Management

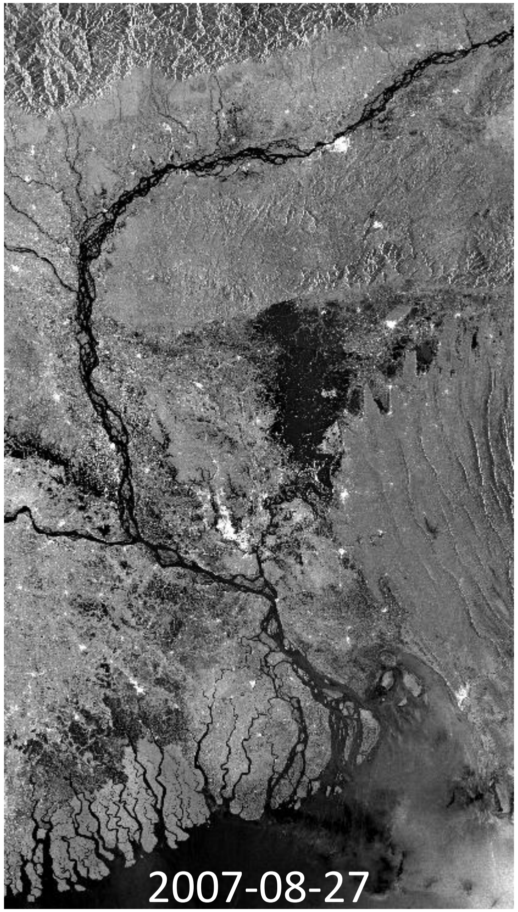
Ganges/Brahmaputra

ENVISAT-ASAR wideswath (150m)

Id	Mission	Sensor	date	track	pass
1	ENVISAT-1	ASAR/WS	2007-07-04	319	D
2	ENVISAT-1	ASAR/WS	2007-07-23	90	D
3	ENVISAT-1	ASAR/WS	2007-08-11	362	D
4	ENVISAT-1	ASAR/WS	2007-08-27	90	D
5	ENVISAT-1	ASAR/WS	2007-09-04	212	A
6	ENVISAT-1	ASAR/WS	2007-09-07	255	A
7	ENVISAT-1	ASAR/WS	2007-09-23	484	A
8	ENVISAT-1	ASAR/WS	2007-10-09	212	A

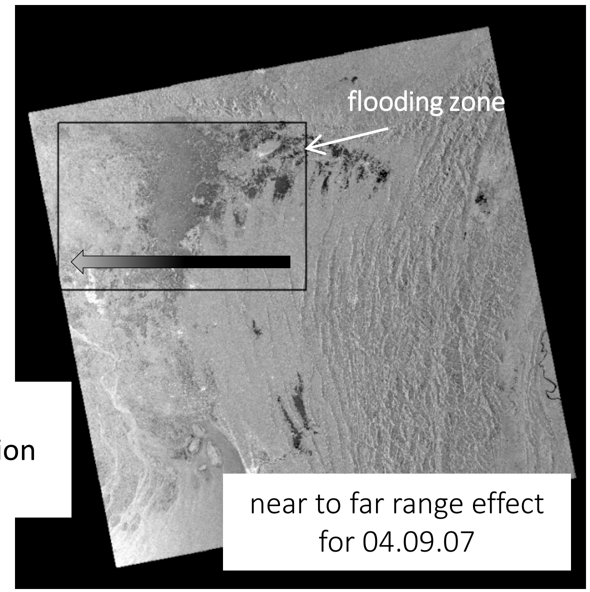




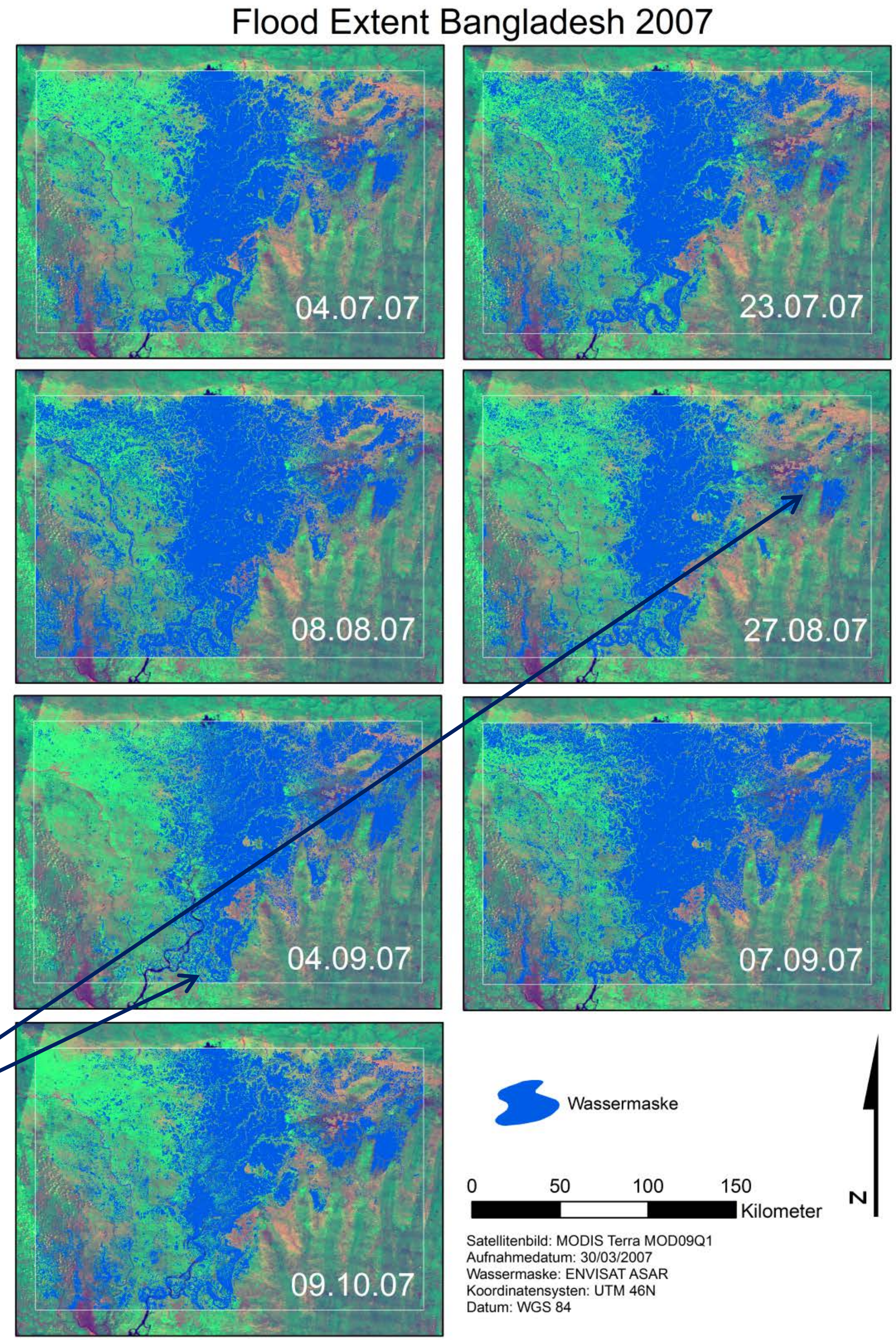


HORIZON 2020

Water Extent: Floodingzone



attempts of brightness correction weren't satisfying

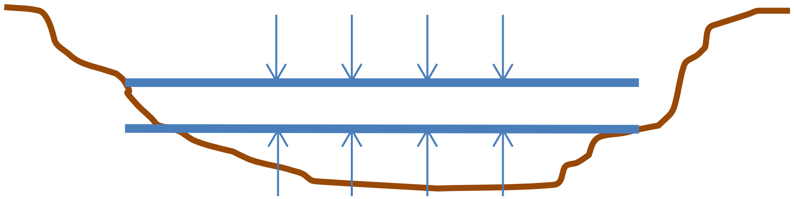


The difference in brightness due to the near & far range effect leads to an inaccurate water mask in the western flooding zone for the 4th of September and eastern for 27th August. Water pixel are not recognized, the water extent is underestimated and thus the volume.

Data integration

European Gravity Service for Improved Emergency Management

- Combination of flood mask and DEM (both datasets resampled to 30m)

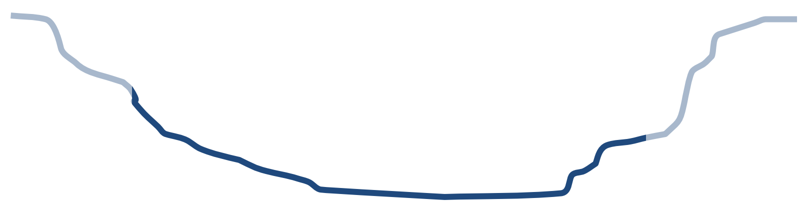


Plain water surface is assumed (no slope)

- Coarse resolution and inconsistencies between both datasets do not allow for accurate determination of vertical water profile

Data integration

- Combination of flood mask and DEM (both datasets resampled to 100m)



Plain water surface is assumed (no slope)

- Coarse resolution and inconsistencies between both datasets do not allow for accurate determination of vertical water profile

Histogram

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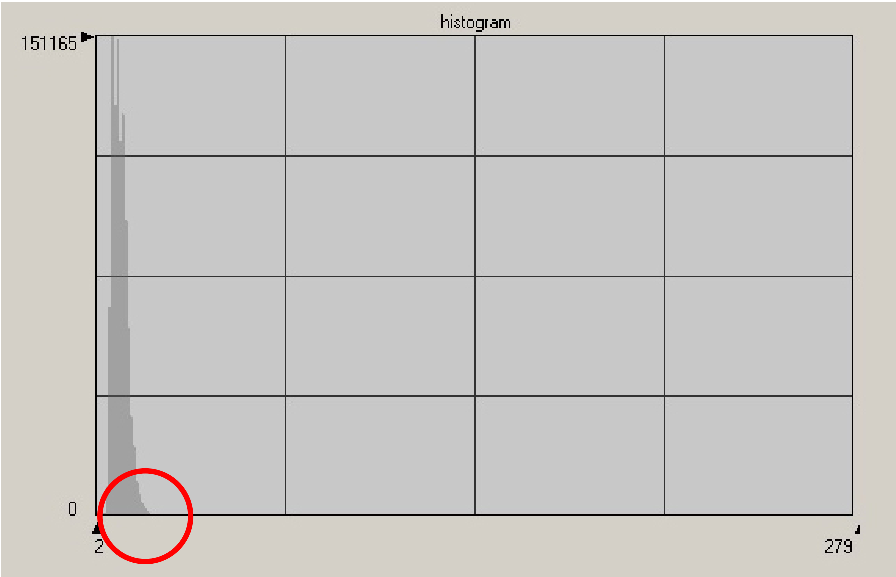
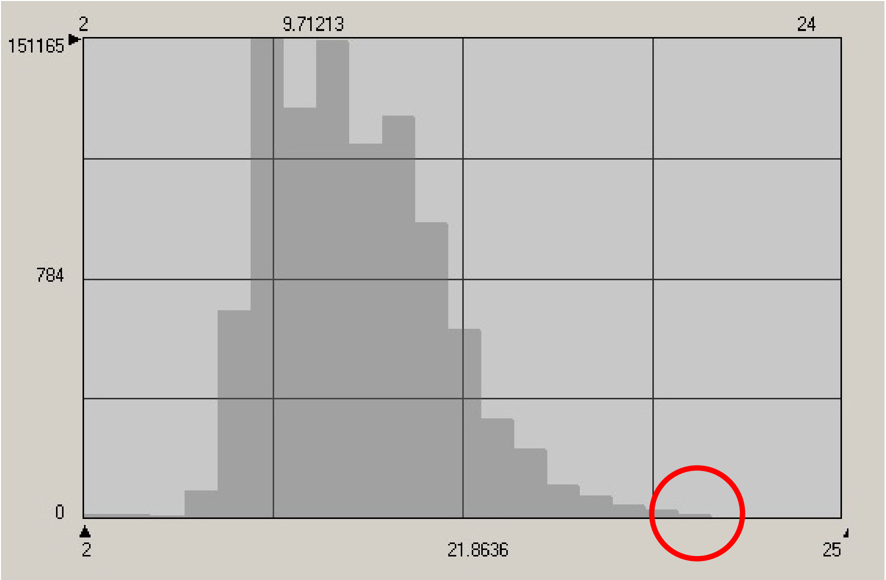
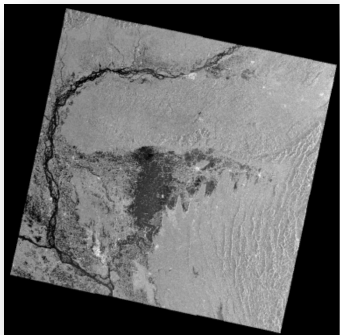




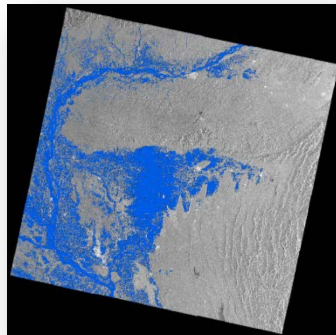
- Histogram shows distribution of elevation of flood pixels
- Flood water level is defined by land-water-boundary
- optimal threshold to be found (due to classification errors, etc.)

Workflow

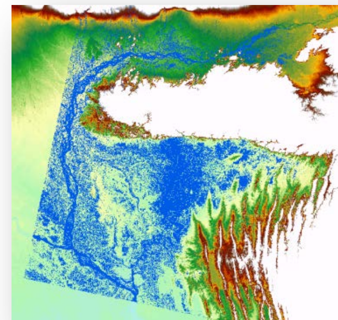
SAR-Scene



Water classification



Clip SRTM 30 m for water mask



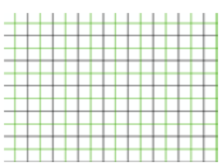
clipped DEM
(height only for flood pixels)

ArcGIS Model

(Toolbox: Fishnet & Zonal Histogram)

Input

Grid Cell Size
(adjustable)



Output

Grid Cell ID

LABEL	OID_2377	OID_2378	OID_2379	OID_2380
2	0	8781	0	0
3	0	695	1367	4333
4	0	955	976	1615
5	0	3604	789	4733
6	2490	30522	18417	27717
7	10756	30773	30672	21427
8	29417	8546	17577	13513
9	8050	1592	6295	6375
10	3778	230	2139	2340
11	986	47	798	720
12	296	6	310	284
13	112	0	144	92
14	19	2	74	49
15	9	2	28	19
16	5	0	17	8
17	1	0	10	7
18	0	0	5	2
19	0	0	5	2
20	0	0	2	1

DEM Value

Histogram for one grid cell

Volume calculation with R

R-Script

```
for(a in 1:length(filename)){        #iterates every .dbf file in the folder

  #file <- read.dbf(filename[a])
  file <- read.table(filename[a], sep=",", header=T)  # use for txt file
  TOTAL <- matrix(nrow=1,ncol= 0)
  rownames(file)<- file$LABLE # rownames are now the terrain elevation value
```

calculates threshold and sums up the volume for each grid cell

Volume

12,518 Gt

Thresholding (I)

A **threshold of 15%** leads to promising results. However, water levels do not fit to gauge/altimetry data due to:

- Time difference between altimetry measurement and satellite data acquisition
- Point measurement vs. Extensive coverage of satellite image

Each OID represents a certain grid cell

Number of pixels with a water level of 12 m

07.09.2007	Ganges_P	Ganges_R	Ganges_Q	Ganges_S	Ganges_D	Ganges_BWDB	Brah_BWDB
DEM elevation	OID_5009	OID_4912	OID_4719	OID_4428	OID_3528	OID_3909	OID_5568
1					7130	0	
2	0	0	0	0	6729	0	
3	0	0	0	0	207	2000	
4	0	0	0	0	340	3111	
5	0	0	0	0	428	3046	
6	0	0	0	0	434	198	
7	0	19095	0	0	713	139	
8	2944	20394	5239	0	715	439	
9	36870	10184	9012	34396	789	285	
10	7938	3607	18474	8049	592	371	
11	2615	1245	6957	3639	4353	673	0
12	1000	448	3557	1077	2807	320	0
13	366	167	1817	338	930	354	0
14	143	67	898	91	438	355	0
15	68	24	422	21	283	377	7453
16	26	12	190	10	143	341	4817
17	9	7	82	3	84	184	326
18	3	4	25	0	36	279	247
19	2	6	10	0	7	63	293
20	2	2	4	0	2	27	331
21	1	0	0	0	0	28	1546
22	1	0	0	0	0	15	11532
23	0	0	0	0	1	10	8098
24	0	0	0	0	1	7	3497
25	0	0			1	5	1436
26	0	0			1	8	456
27	0	0			0	0	141
28	0	0			0	1	34
29	0	0			1	3	16
30	0				0	2	9
31	0				1	3	9
32	0				0	0	6
33					0	8	6
34					1	2	1
Date	**15.09.2007**	**15.09.2007**	**15.09.2007**	**15.09.2007**	**02.09.2007**		**08.08.2007**
Gauge Data/ Altimeter	7.44	7.28	6.65	6.53	11.03	13.25	20.46
Korrigiert für WGS84	10.574	10.445	9.506	8.947	8.424	NO	NO
Summe	51988	55262	46687	47624	27168	12665	40264
5%	2599.4	2763.1	2334.35	2381.2	1358.4	633.25	2013.2
10%	5199	5526	4669	4762	2717	1267	4026
15%	7798	8289	7003	7144	4075	1900	6040
20%	10398	11052	9337	9525	5434	2533	8053
	12174	15773	7005	5179	999	125	5618
Ergebnis 5%	11	10	12	11	12	11	24
Ergebnis 10%	10	9	11	10	12	5	23
Ergebnis 15%	9	9	10	10	11	5	23
Ergebnis 20%	9	8	10	9	2	5	23

Thresholding (II)

Results depend on grid cell size. Which size of the grid cells and which threshold fits best?

Threshold fits best here

- (green) Resulting threshold equals(± 0.5 m) the gauge measurement
- (red) Resulting threshold deviates from the gauge measurement > 4 m

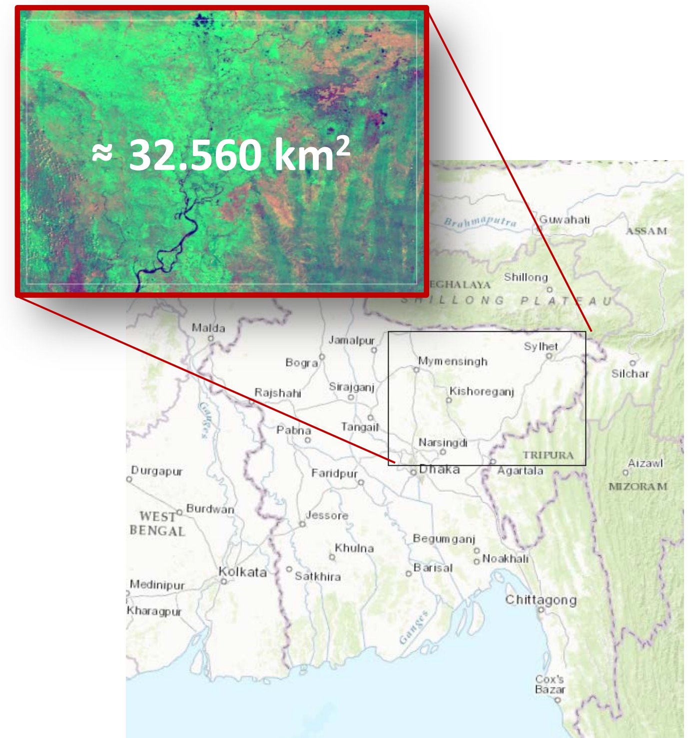
Gauge	Ganges_P	Ganges_R	Ganges_Q	Ganges_S	Gan_337	Ganges_D	Gan_524	Gan_982low	Ganges_BWDB	Brah_BWDB	Gan_438		
Water Mask: 07.09.07	OID_5009	OID_4912	OID_4719	OID_4428	OID_3528	OID_3528	OID_3909	OID_3529	OID_3908	OID_5568	OID_2956		
Date of measurement	15.09.2007	15.09.2007	15.09.2007	15.09.2007	28.07.2007	02.09.2007	08.09.2007	24.09.2007	07.09.2007	07.09.2007	05.09.2007		
height in meters	7.44	7.28	6.729	6.53	10.728	11.03	14.14	9.915	13.25	20.46	6.14		
corrected for EGM96	10.574	10.445	9.506	8.947	11.243	8.424	14.364	10.457	NO	NO	6.859		
50km 5%	10	10	12	10	12	12	18	12	12	24	10	2	0
50km 10%	10	9	11	10	11	11	4	11	4	23	9	2	2
50km 15%	9	8	10	9	11	11	4	10	3	23	8	4	2
50km 20%	9	8	10	9	2	2	4	1	3	22	8	2	5
75km 5%	11	10	12	11	12	12	15	12	15	24	9	3	
75km 10%	10	9	11	10	12	12	5	12	5	23	9	1	2
75km 15%	9	9	10	10	11	11	5	11	5	15	8	2	2
75km 20%	9	8	10	10	11	11	5	11	5	15	8	2	2
100km 5%	11	10	12	11	12	12	11	13	11	24	9	2	0
100km 10%	10	9	11	10	12	12	5	12	5	23	8	2	2
100km 15%	9	9	10	10	11	11	5	12	5	23	8	2	2
100km 20 %	9	8	10	9	2	2	5	11	5	23	8	2	4

➔ Threshold of 15% and Grid Cell Size of 50 km fits best to the reference data.

Volume: Flooding zone

Date	Volume in Gt Grid Cell 30 x 30 km	Volume in Gt Grid Cell 75 x 75 km	Volume in Gt Grid Cell 100 x 100 km
04.07.07	13,809	15,340	15,784
23.07.07	15,364	17,152	17,520
08.08.07	19,027	20,883	21,262
27.08.07	12,518	14,158	14,034
04.09.07	13,426	14,394	14,293
07.09.07	19,679	21,511	21,545
09.10.07	13,024	14,563	14,488

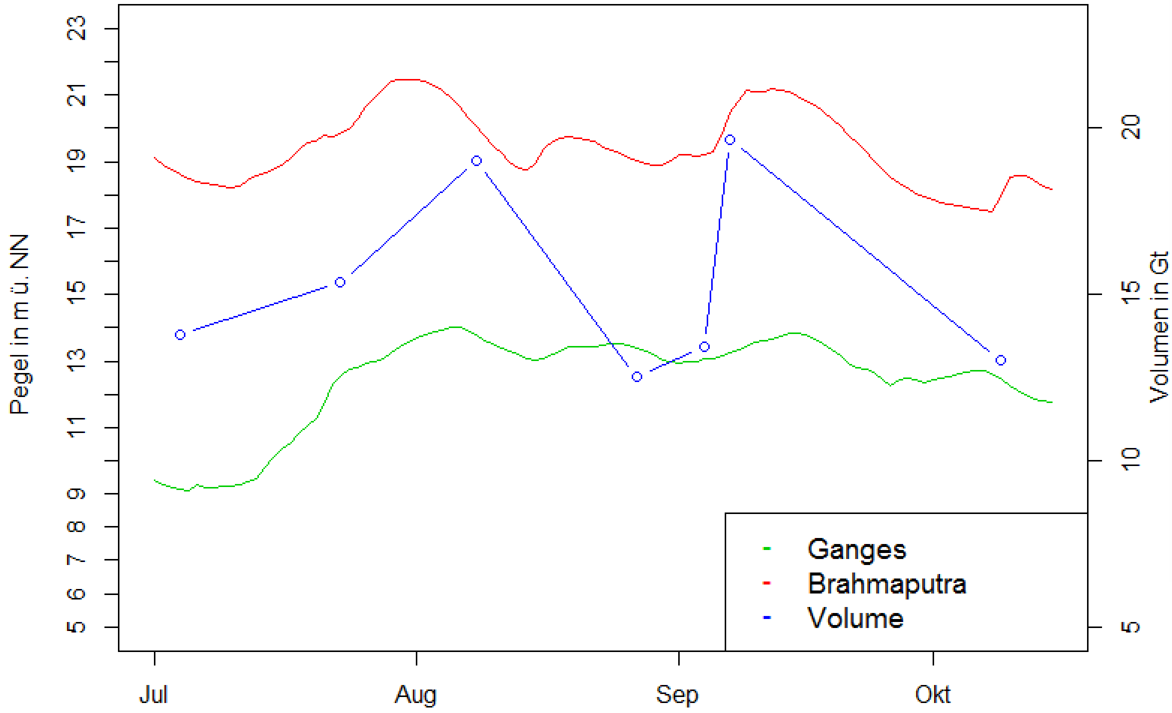
Flooding Zone
(covered by every scene)

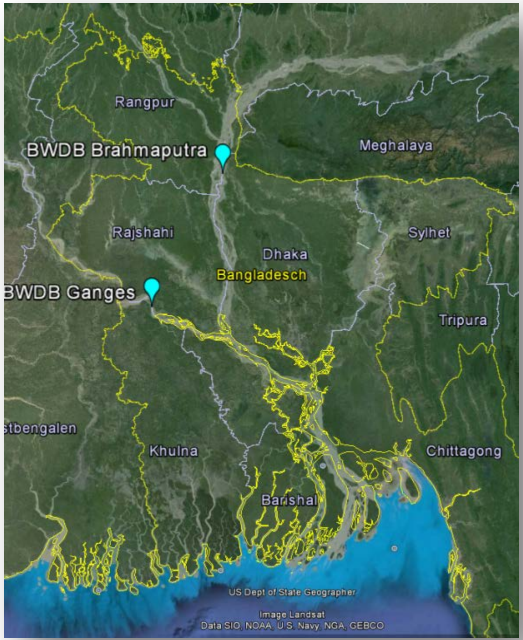


Size of the grid cell determines flood volume.
Flood peak: ~ 7 Sep. 2007
Threshold: 15 %
For comparison: ca. 160 Gt for the whole of Bangladesch (ca. 100 Gt ground water) → 60 Gt surface water
(STECKLER et al. 2010)

Volume: Flooding zone

Daily water gauge measurements from BWDB (Bangladesh Water Development Board) for Ganges & Brahmaputra (1st July to 15th Oktober) as well as calculated flood volumes for 7 Envisat ASAR szenes





Location of water gauges (google earth)

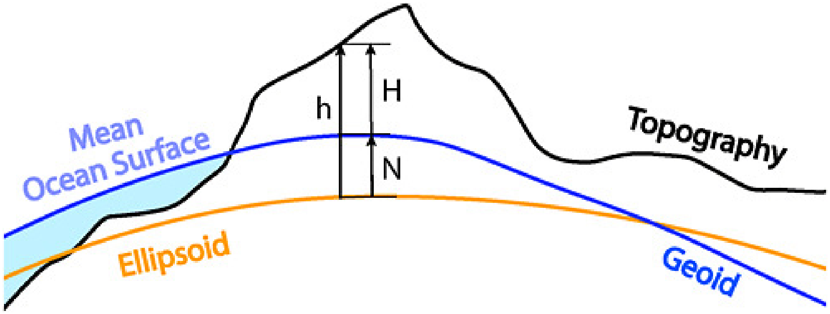
The temporal resolution of the volume data is much lower than the one of the gauges. Still it is possible to see higher amounts of volume for the two peaks in the gauge data (begin of August & mid of September)

Next Steps

European Gravity Service for Improved Emergency Management

- The threshold must be more accurate
  - Integrate more reference measurements
  - Different method for threshold calculation
- Processing and flood volume calculation for entire ENVISAT ASAR scene for better comparison with GRACE daily solutions

Appendix: Geoid-Reference



nap.edu

- SRTM 30 m: WGS84 EGM96
- ENVISAT: Ganges & Brahmaputra
  - Grace Ellipsoid GGM02C
- ENVISAT: Ganges: EGM2008

→There are several online tools for conversion of EGM96 into EGM2008, Basis WGS84 Ellipsoid

→GGM02C and many others: http://icgem.gfz-potsdam.de/ICGEM/