Combination Service for Time-Variable Gravity Field Solutions (COST-G):

Transition from an EGSIEM prototype service into a product center of the IGFS

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14-22 July, 2018, Pasadena, California

Horizon2020

Introduction

EGSIEM

European Gravity Service for Improved Emergency Management

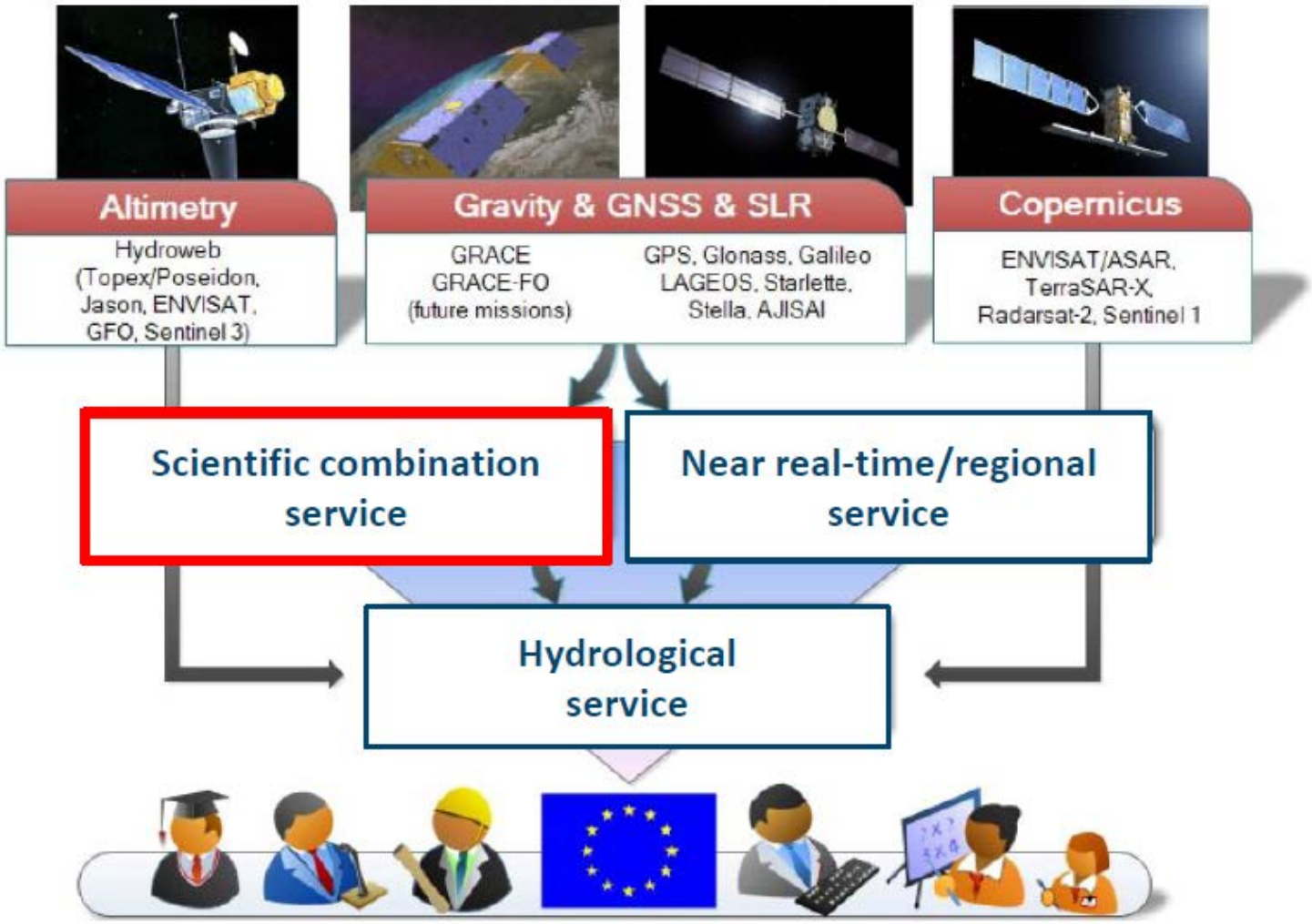
EGSIEM European Gravity Service for Improved Emergency Management

was a H2020 project running 2015-2017 with the partners:

and several associated members:

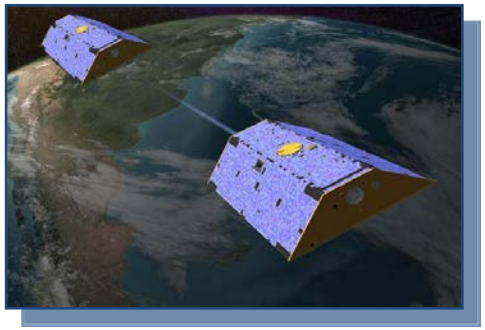
EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE
Directorate H - Institute for Environment and Sustainability
Climate Risk Management

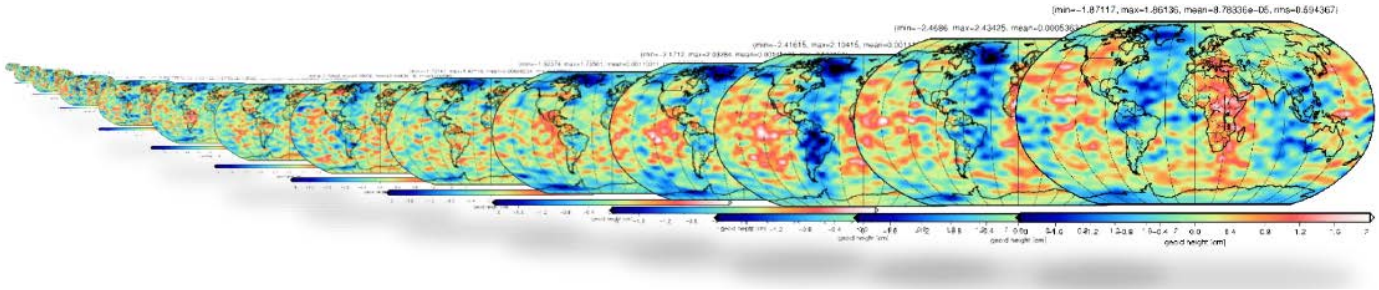
EGSIEM: Three Prototype Services were established



Why a combination service?

- Process GRACE / GRACE-FO data to a time series of monthly gravity field solutions
- Processing is challenging





Why a combination service?

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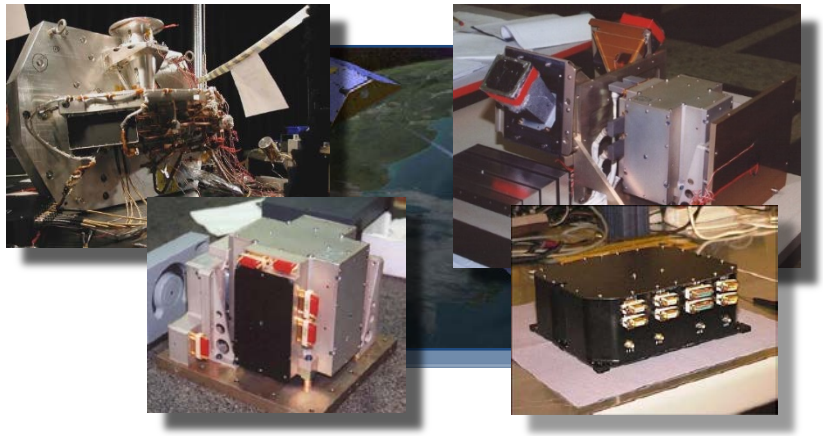
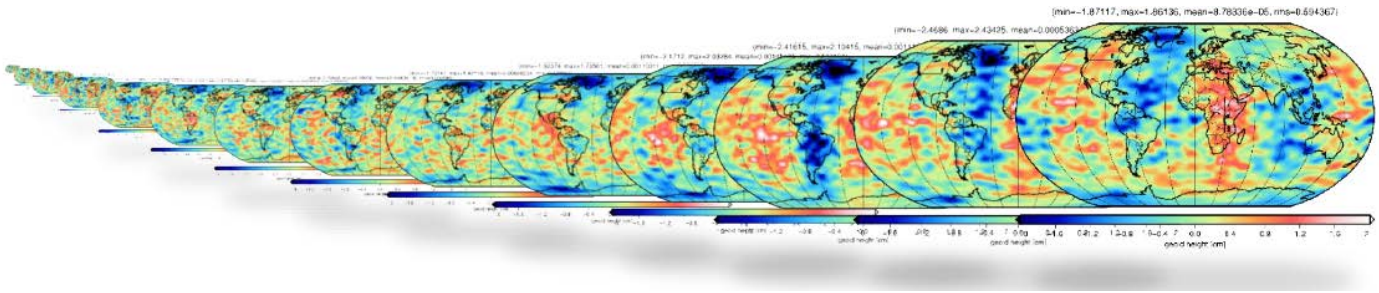
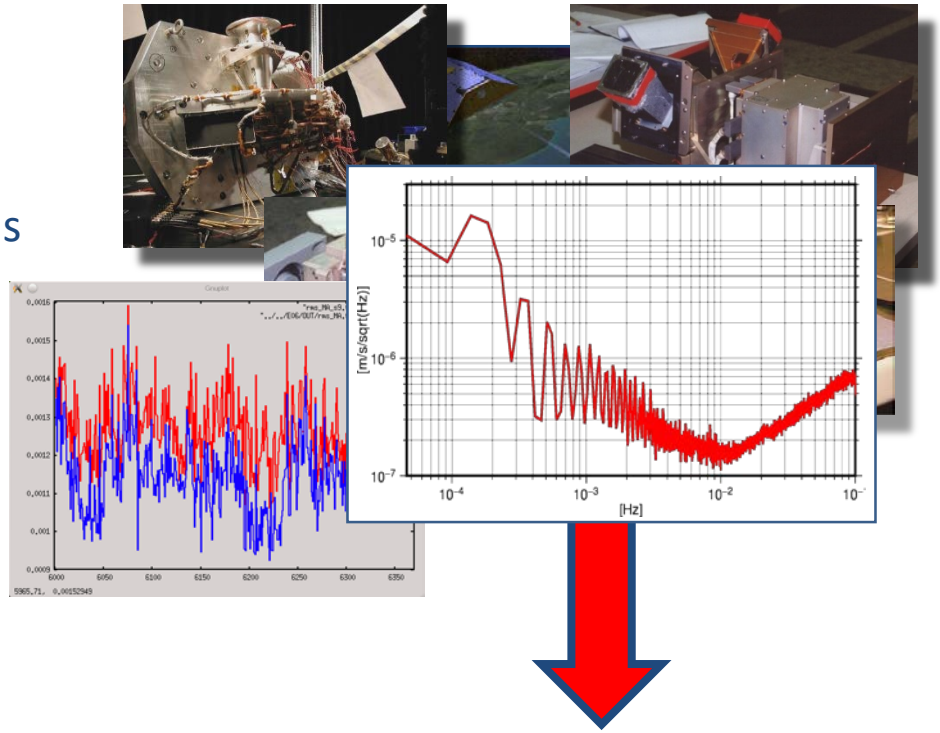
  - Interaction of multiple instruments

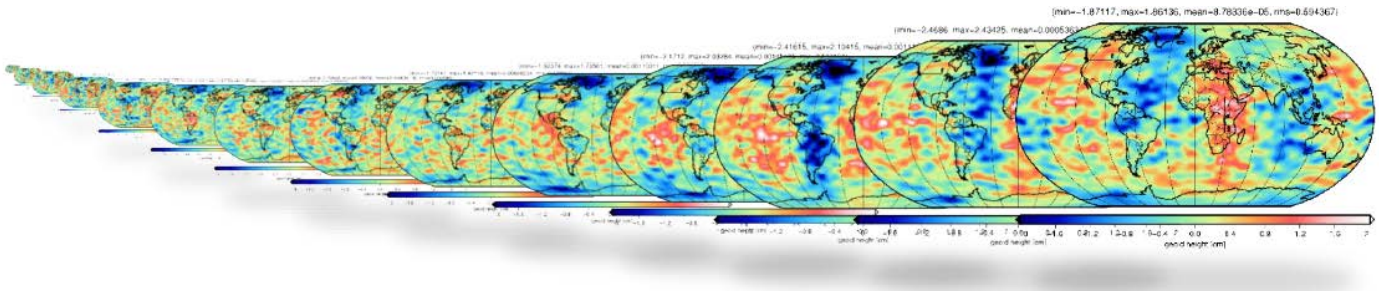




Why a combination service?

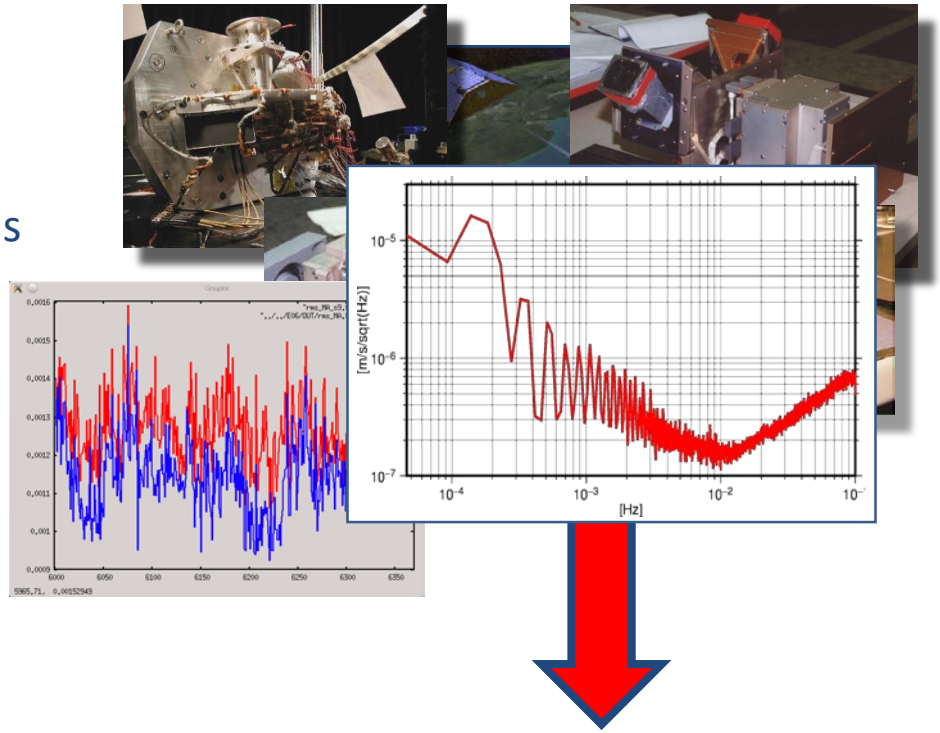
- Process GRACE / GRACE-FO data to a time series of monthly gravity field solutions
- Processing is challenging
  - Interaction of multiple instruments
  - Different noise characteristics

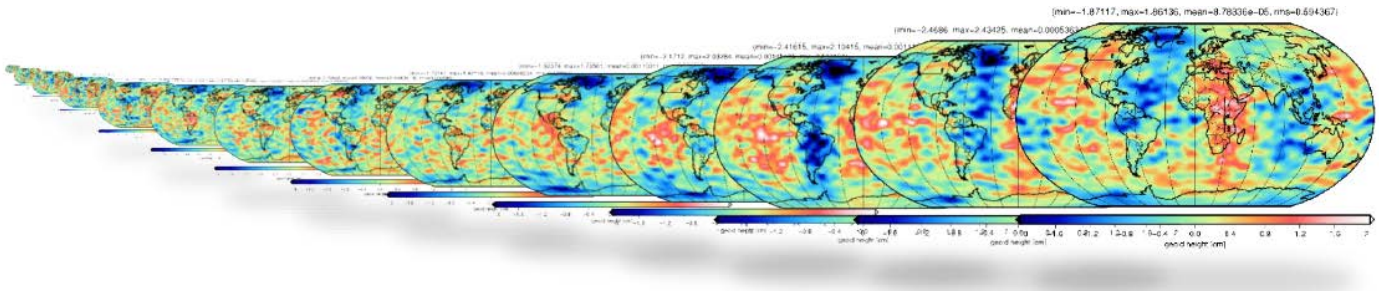




Why a combination service?

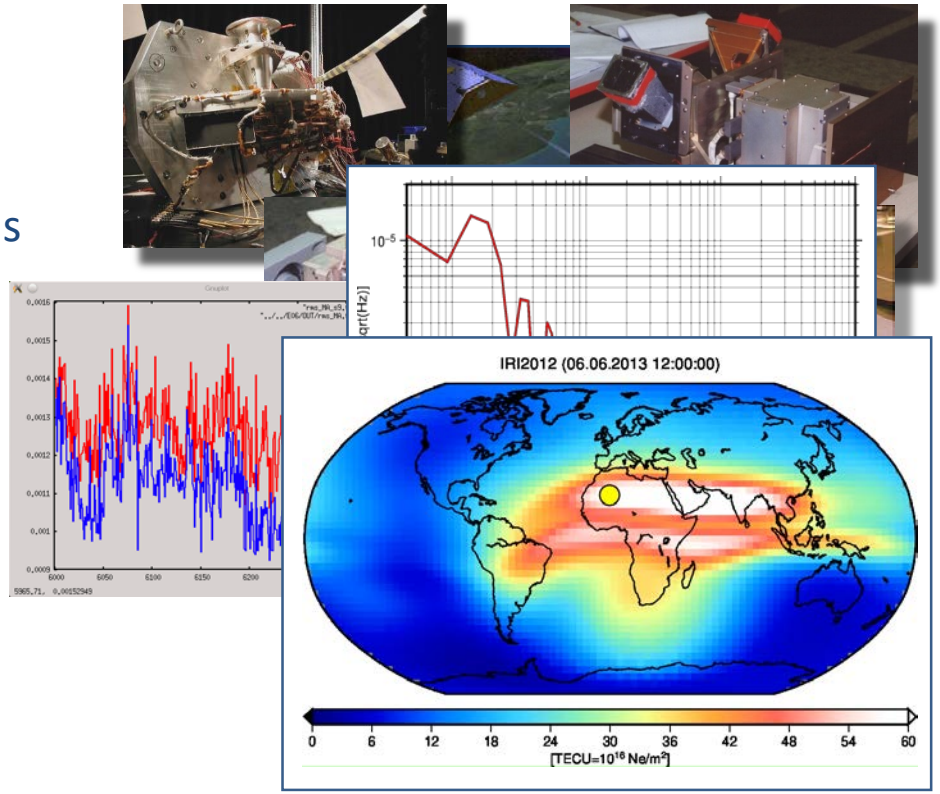
- Process GRACE / GRACE-FO data to a time series of monthly gravity field solutions
- Processing is challenging
  - Interaction of multiple instruments
  - Different noise characteristics
  - Environmental disturbances

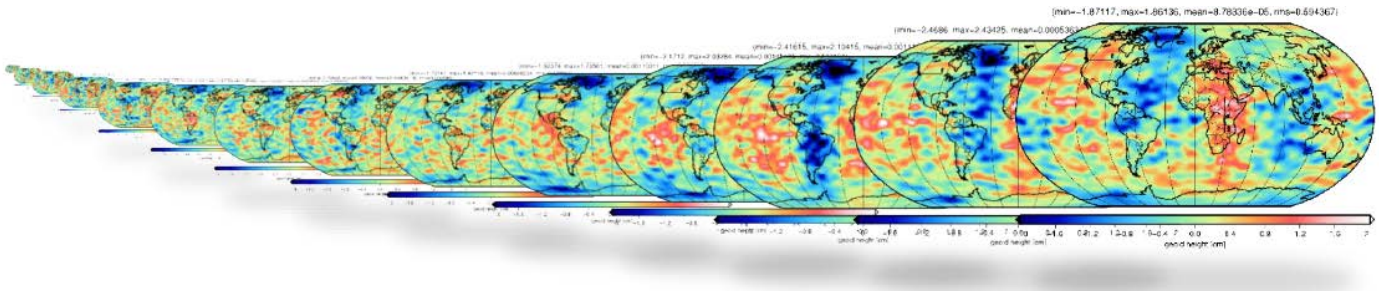




Why a combination service?

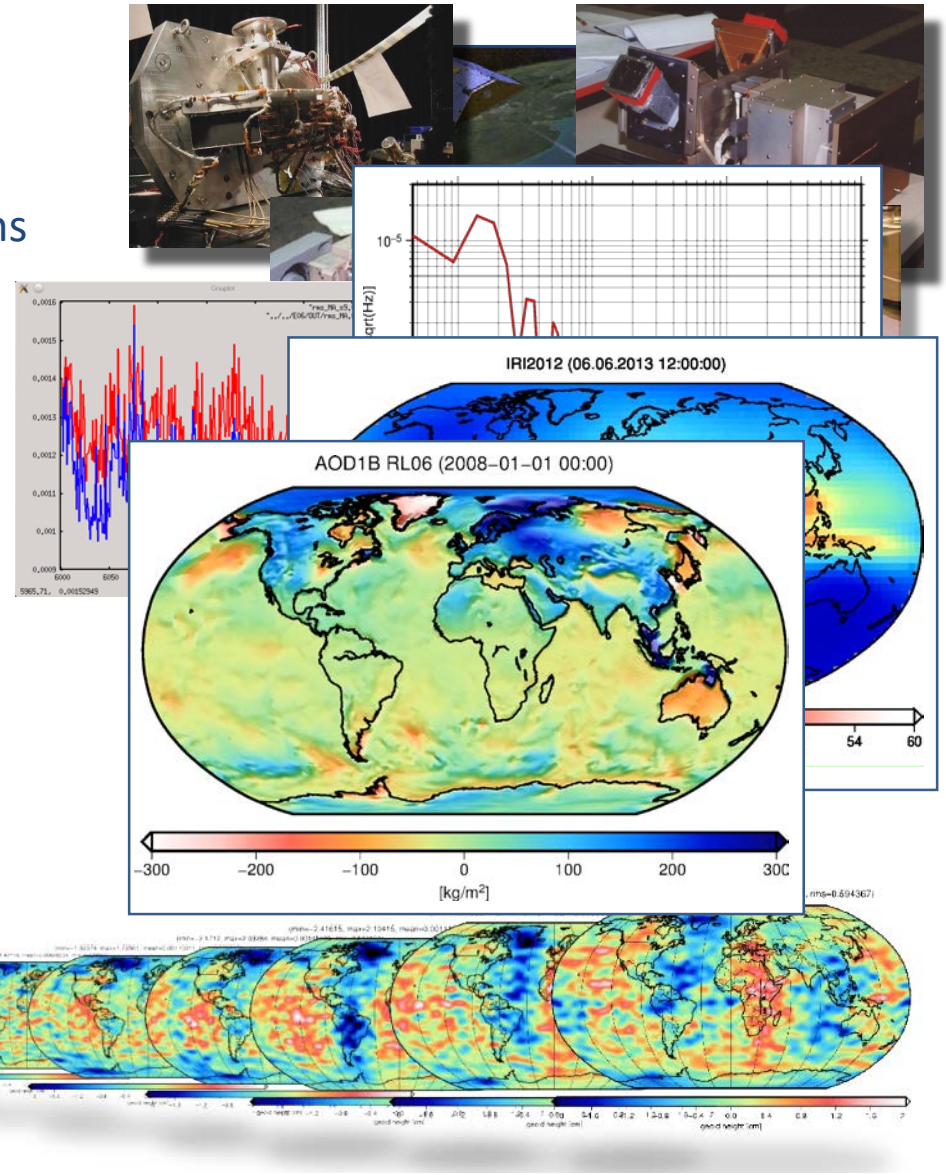
- Process GRACE / GRACE-FO data to a time series of monthly gravity field solutions
- Processing is challenging
  - Interaction of multiple instruments
  - Different noise characteristics
  - Environmental disturbances
    - Ionosphere





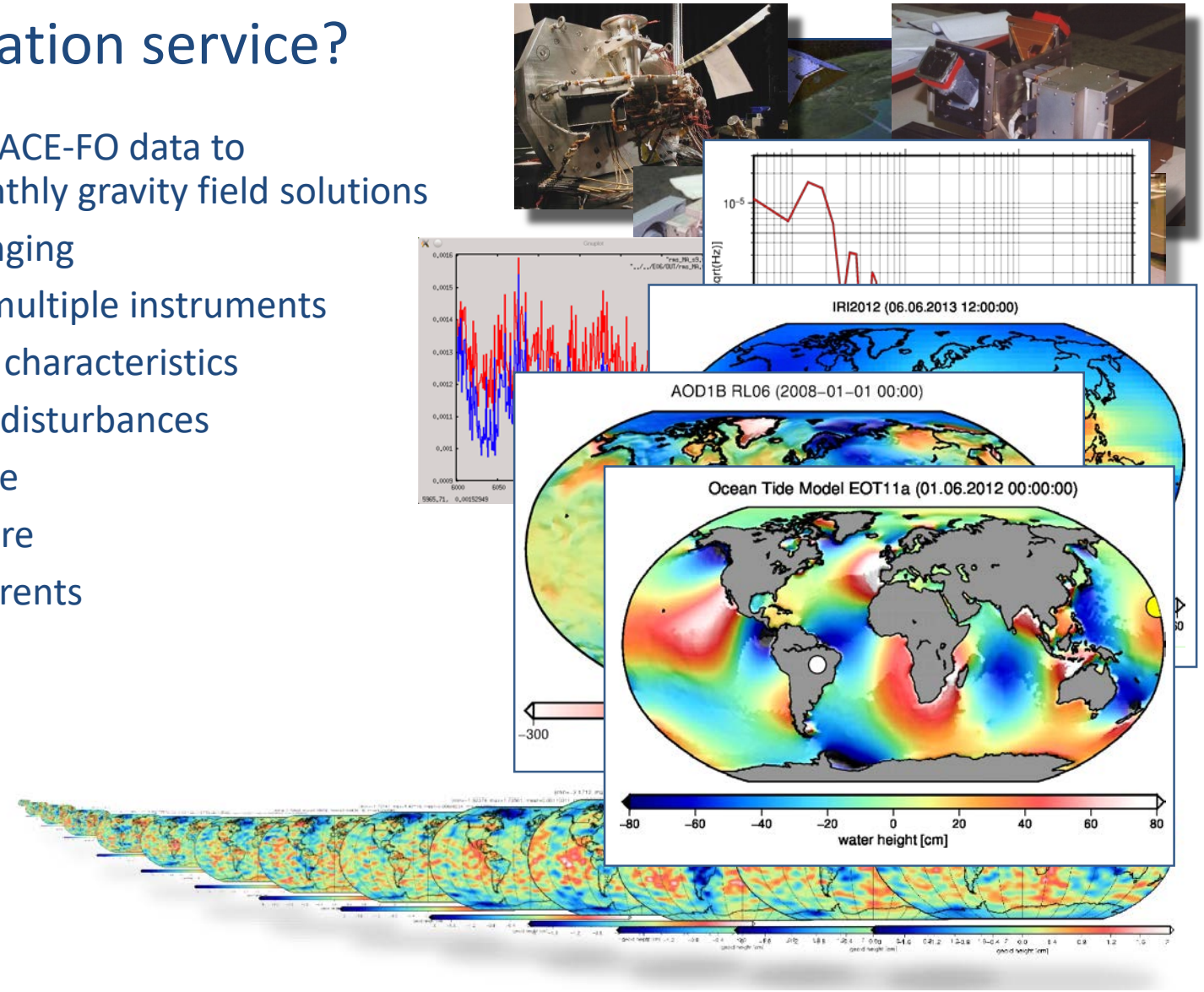
Why a combination service?

- Process GRACE / GRACE-FO data to a time series of monthly gravity field solutions
- Processing is challenging
  - Interaction of multiple instruments
  - Different noise characteristics
  - Environmental disturbances
    - Ionosphere
    - Atmosphere
    - Ocean currents

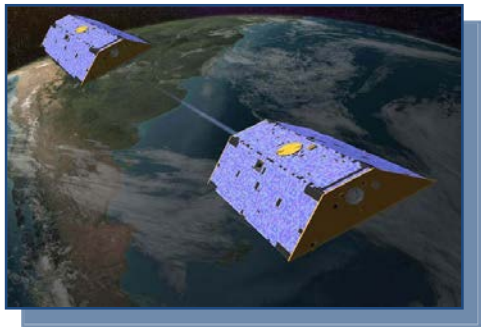


Why a combination service?

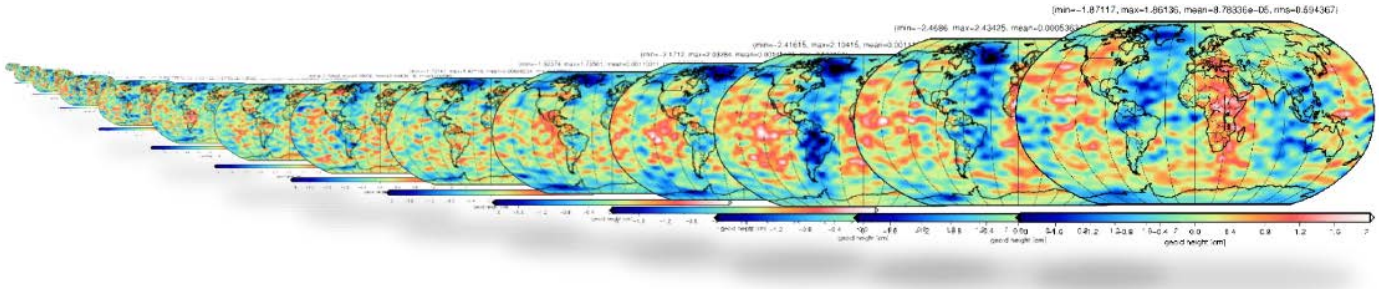
- Process GRACE / GRACE-FO data to a time series of monthly gravity field solutions
- Processing is challenging
  - Interaction of multiple instruments
  - Different noise characteristics
  - Environmental disturbances
    - Ionosphere
    - Atmosphere
    - Ocean currents
    - Tides



Why a combination service?



- Process GRACE / GRACE-FO data to a time series of monthly gravity field solutions
- Processing is challenging
- => There is not only one truth solution
- Computation of different solutions (ensembles) from different Analysis Centers (ACs) using different software packages and adopting different approaches
- EGSIEM Analysis Centers (ACs):
  - GFZ
  - CNES
  - AIUB
  - TUG



Harmonization of Processing Standards

- ~~Co[illegible]eferen[illegible]e and GPS [illegible]onsiste[illegible]~~
- Ensemble of different background models
- Distribution of solutions at normal equation level in standard 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
```

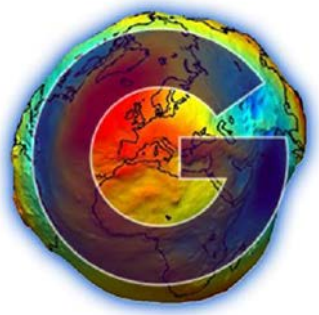
EGSIEM
European Gravity Service for Improved Emergency Management
HORIZON 2020

EO-1-2014: New ideas for Earth-relevant space applications
Research and Innoation Action

Action Acronym:	EGSIEM
Action full title:	European Gravity Service for improved Emergency Management
Grant agreement no:	637010

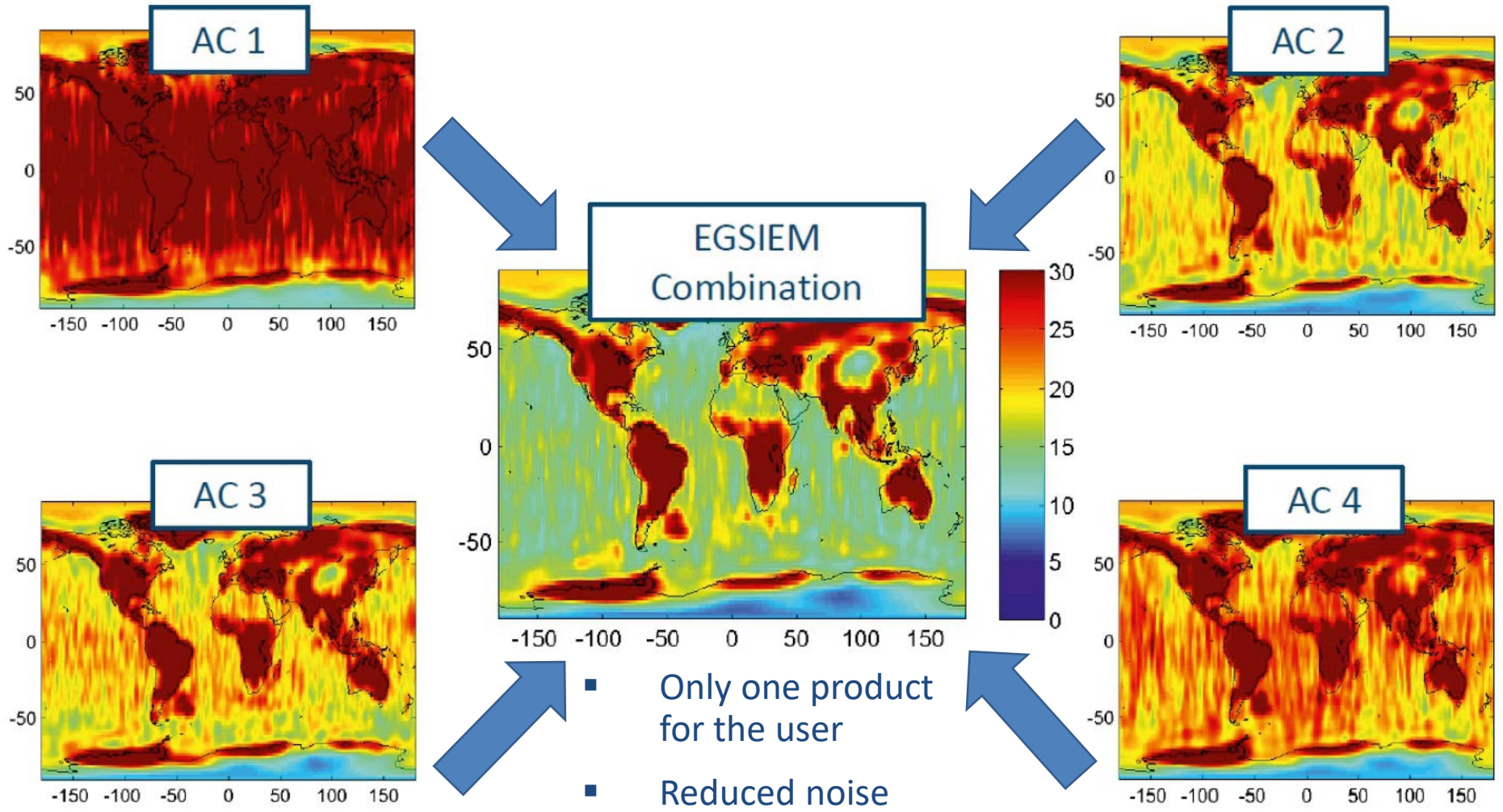
Deliverable 2.1
Processing Standards

Date: 27/02/2015



Prepared by: U. Meyer

Scientific Combination Service



- Only one product for the user
- Reduced noise

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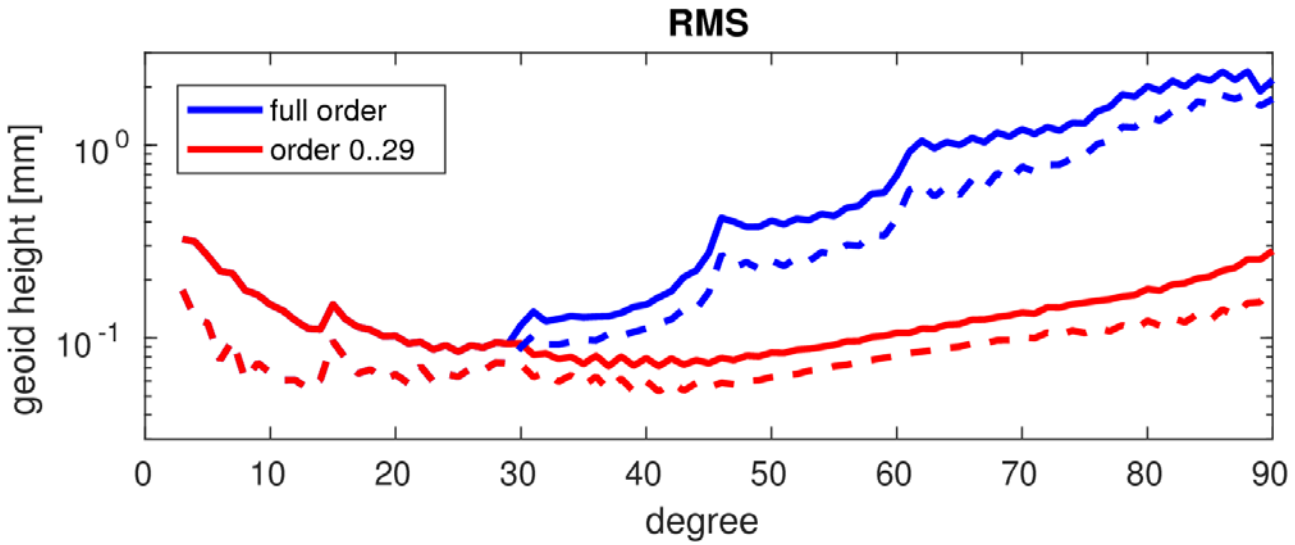
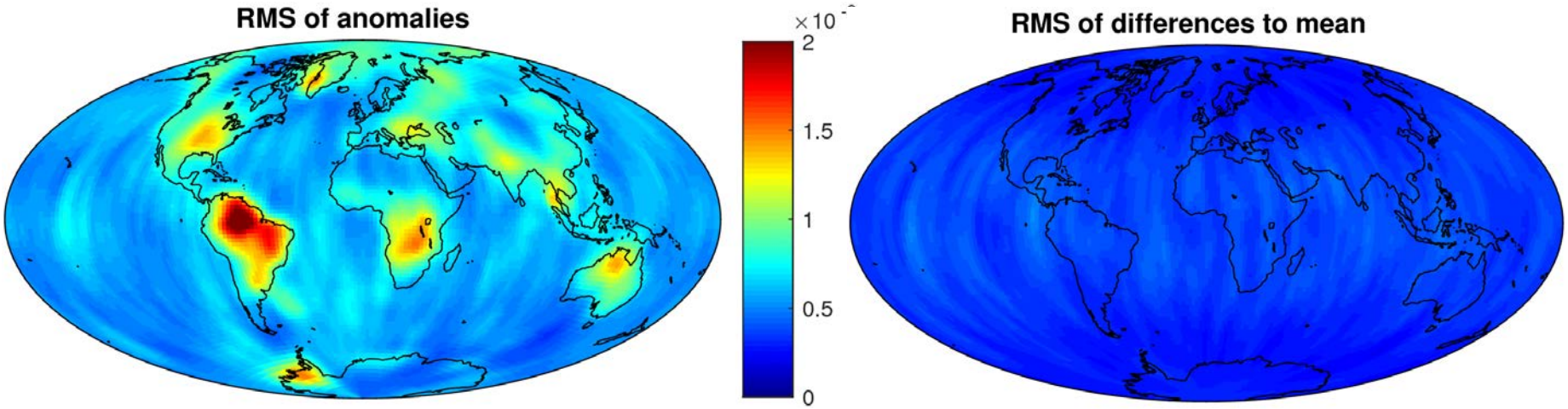
Noise Assessment



Differences to mean to derive relative weights.

Anomalies over quite regions to indepently assess quality.



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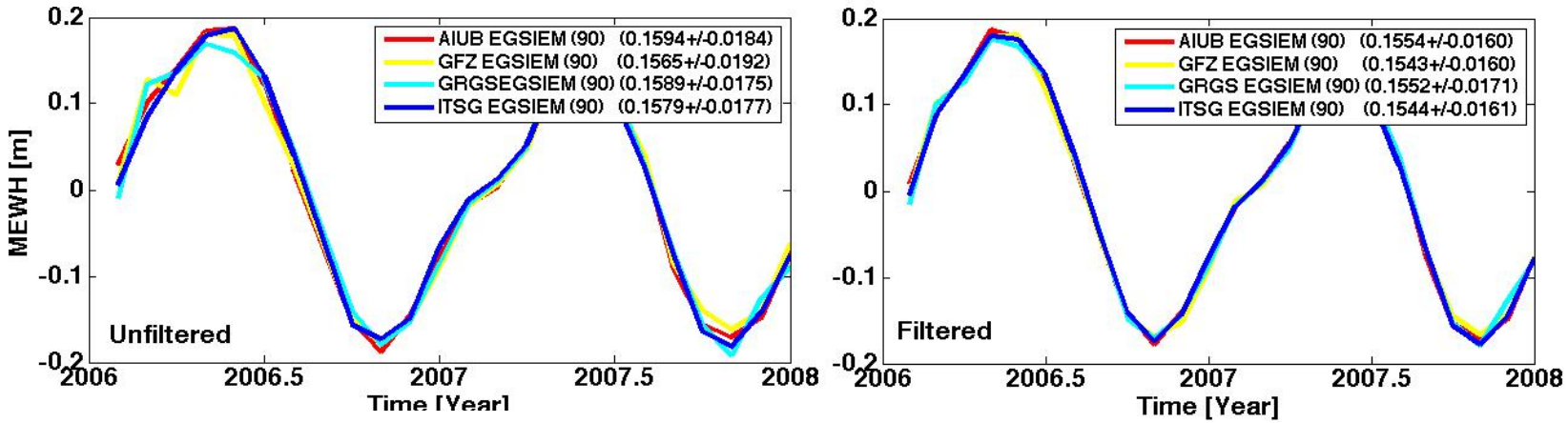
Pre-Processing: Signal and Noise Assessment

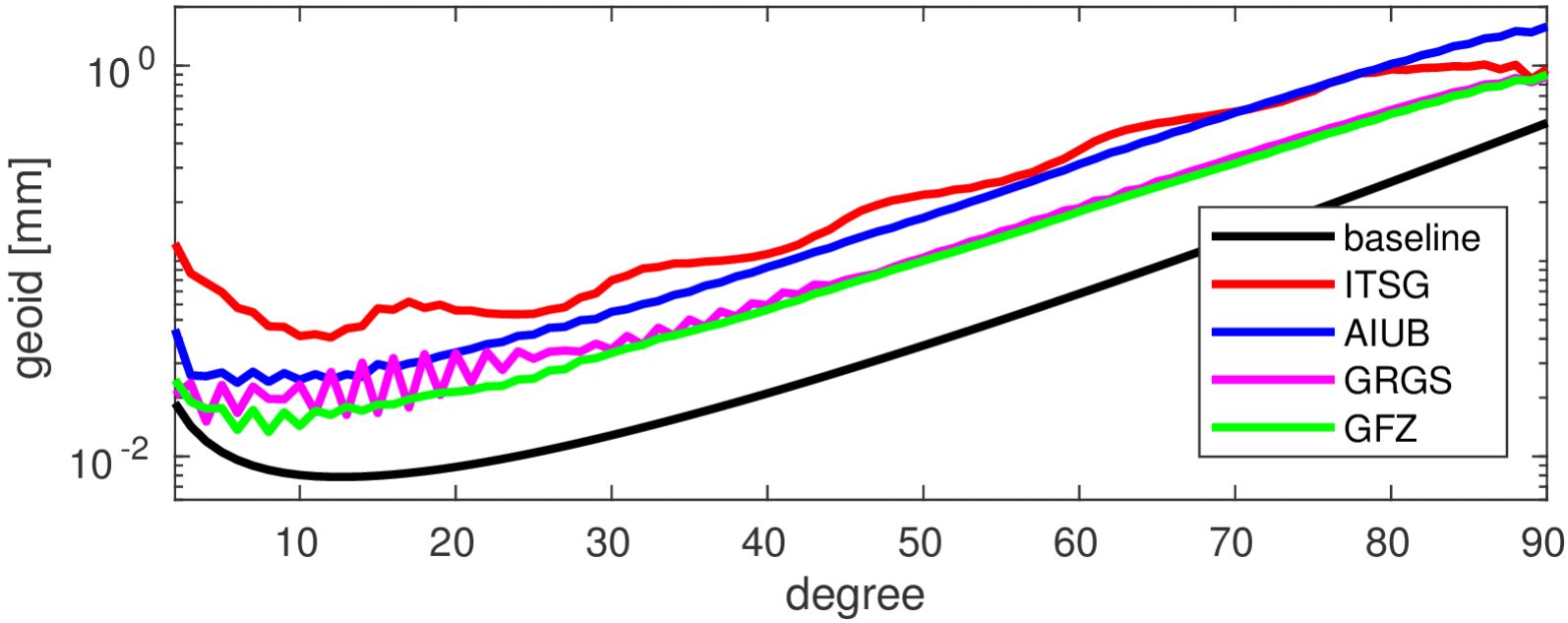
MEWH over large river basins:



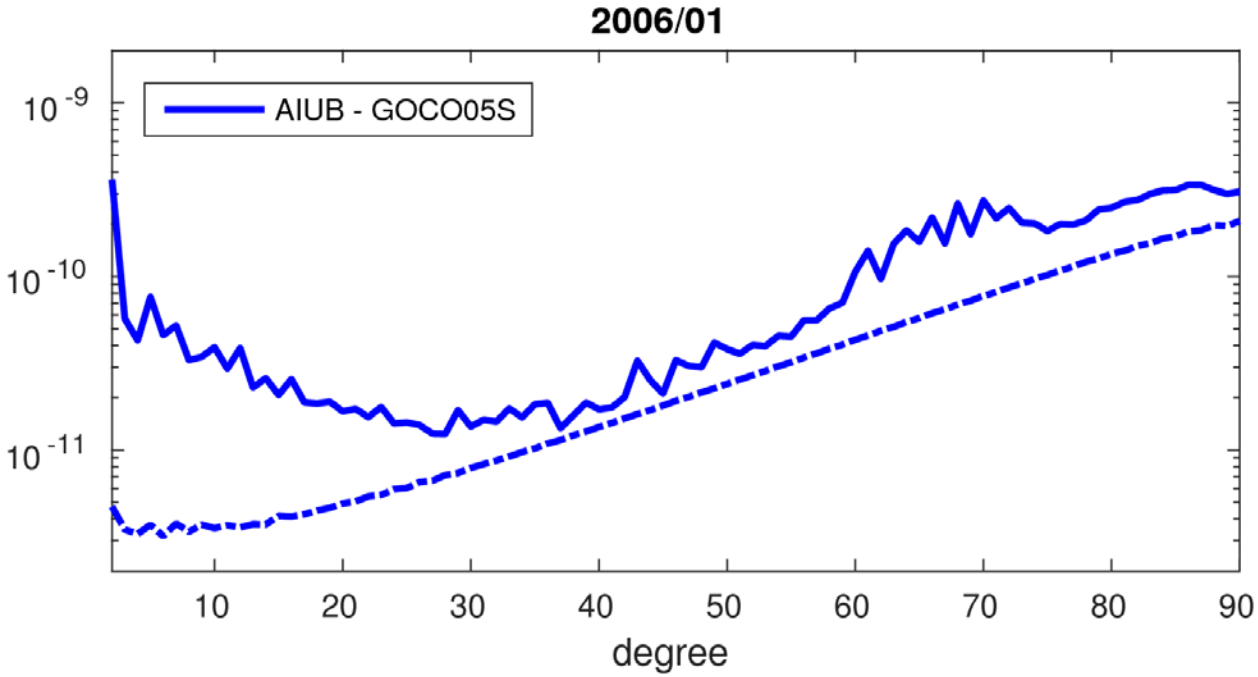
wSTD over oceans:

Motivation and Challenge for Combination

- Errors in spherical harmonic gravity fields do **not** represent observation noise (see baseline) but are governed by signal aliasing, background model errors and AC-specific analysis noise.
- Normal equations (NEQs) cannot be combined by VCE “just like this”, because formal errors (shown are below the mean formal errors of August 2007) very much depend on the choice of the used observables and noise models adopted by the individual Acs in the processing.

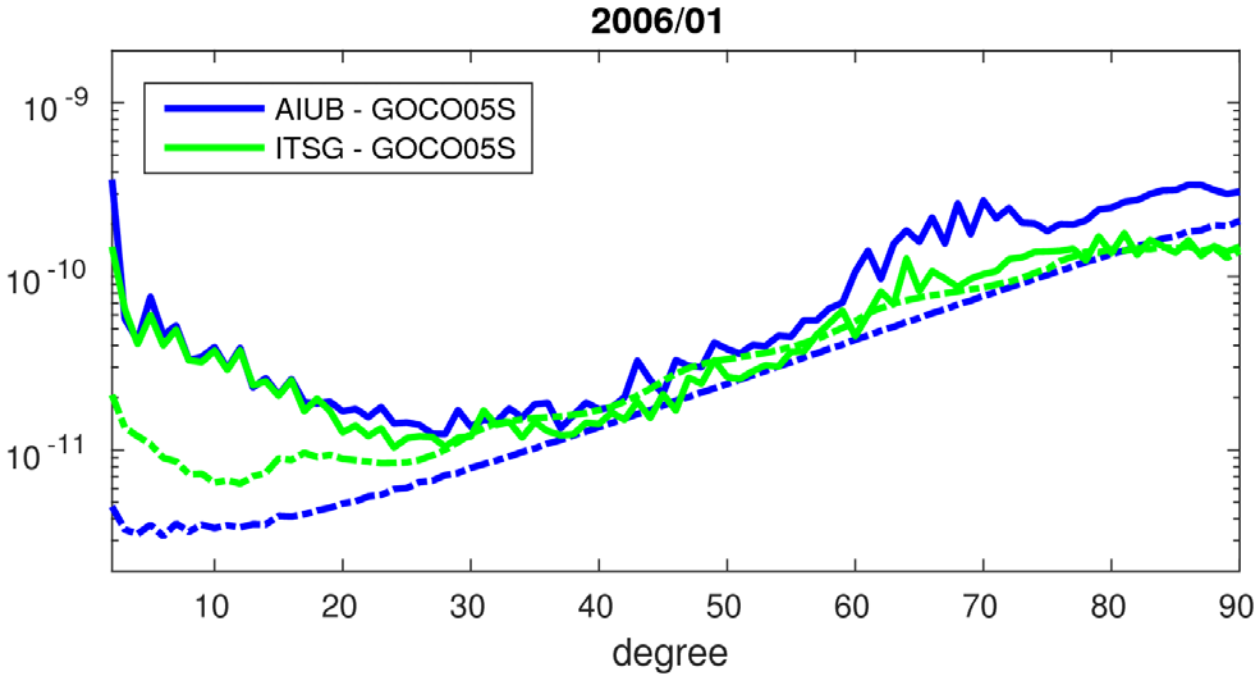


Individual Contributions: AIUB



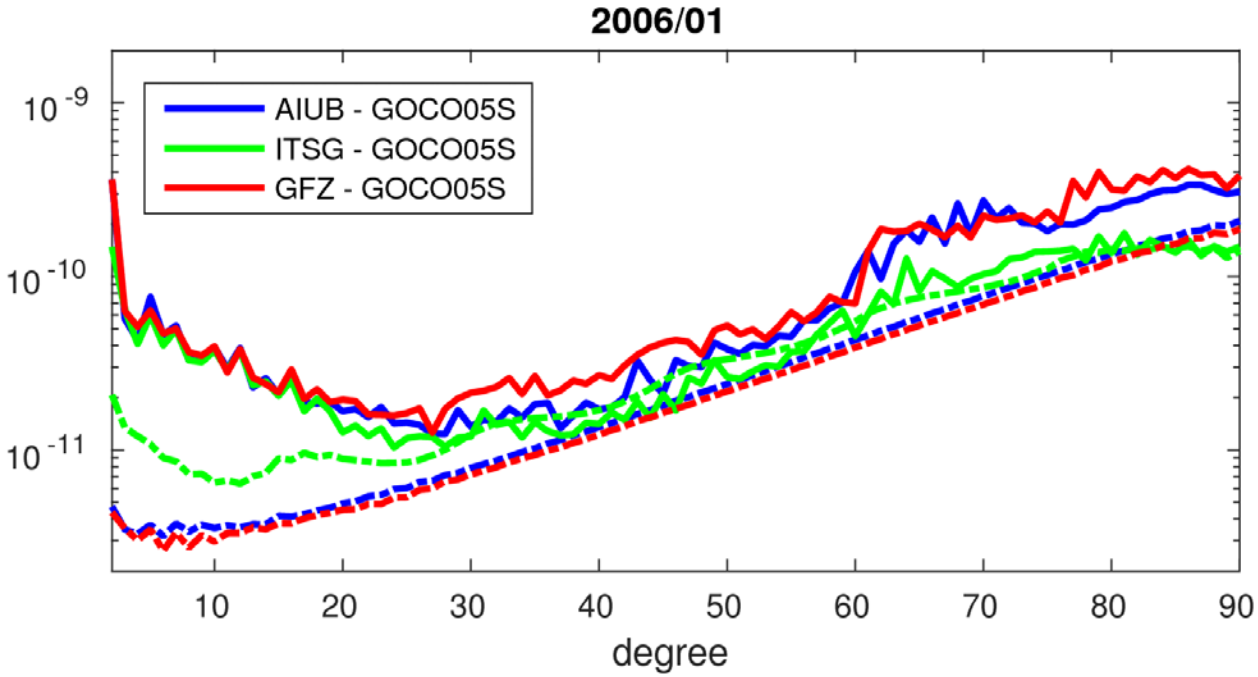
- **AIUB:** Dynamic approach (with pseudo-stochastic accelerations)
  - **~ 500‘000 KRR observations per month**
  - **~ 500‘000 kinematic positions (30s) per month**

Individual Contributions: ITSG



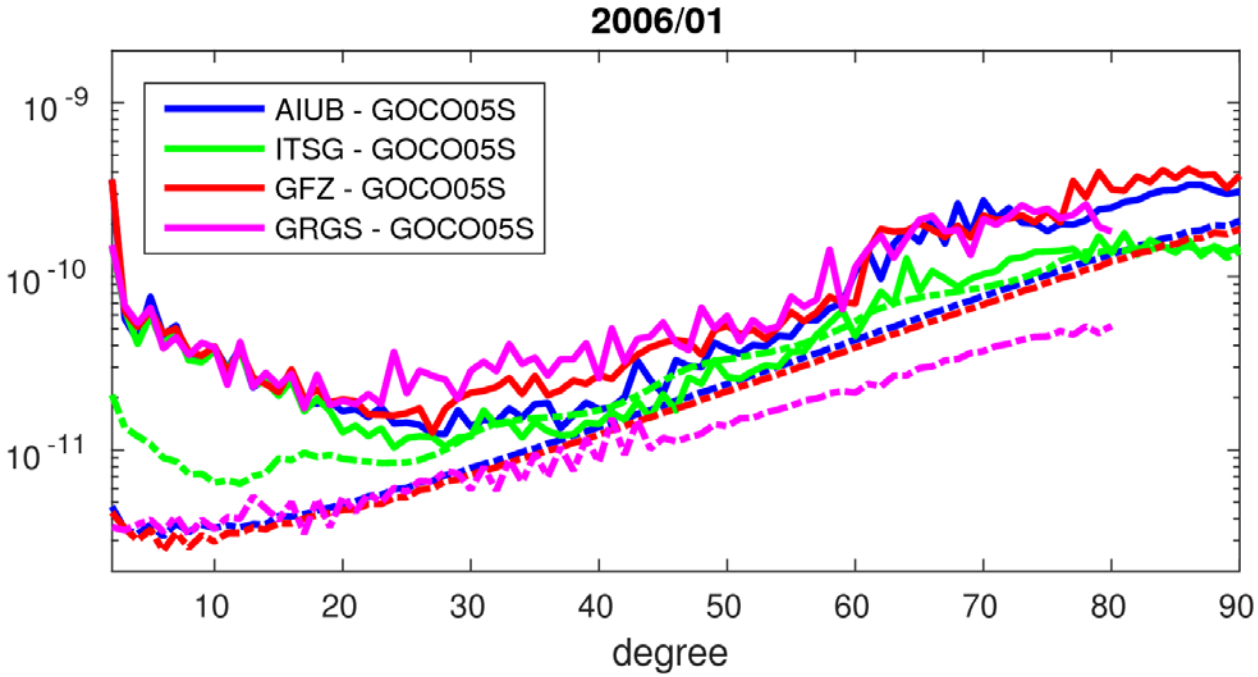
- **ITSG:** Originally a short arc approach, empirical noise models used
  - **~ 500‘000 KRR observations per month**
  - **~ 50‘000 kinematic positions (300s) per month**

Individual Contributions: GFZ



- **GFZ:** Dynamic approach, dense accelerometer parametrization
  - **~ 500‘000 KRR observations per month**
  - **~ 2‘500‘000 GPS observations per month**

Individual Contributions: GRGS



- **GRGS:** Yet another dynamic approach
  - **~ 500‘000 KRR observations per month**
  - **~ 2‘500‘000 GPS observations per month**

Combination on Solution Level

Formulas of Variance Component Estimation (VCE) may be adopted to the resulting (trivial) normal equations when using SH coefficients from individual ACs to compute the combined solution by a simple weighted average. The following explicit formulas result:

Iteration 0

$$\hat{\mathbf{x}}_0 = \frac{1}{n}\sum_k \mathbf{x}_k \qquad \text{with} \qquad w_{k,0} = \frac{1}{n} \quad \forall k,\ k = 1,\ldots,n$$

Iteration $i > 0$

$$\hat{\mathbf{x}}_i = \frac{1}{\sum_k w_{k,i}}\sum_k w_{k,i}\mathbf{x}_k \qquad \text{with} \qquad w_{k,i} = \left(1 - \frac{w_{k,i-1}}{\sum_k w_{k,i-1}}\right) / \mathrm{RMS}(\mathbf{d}_{k,i-1})^2$$

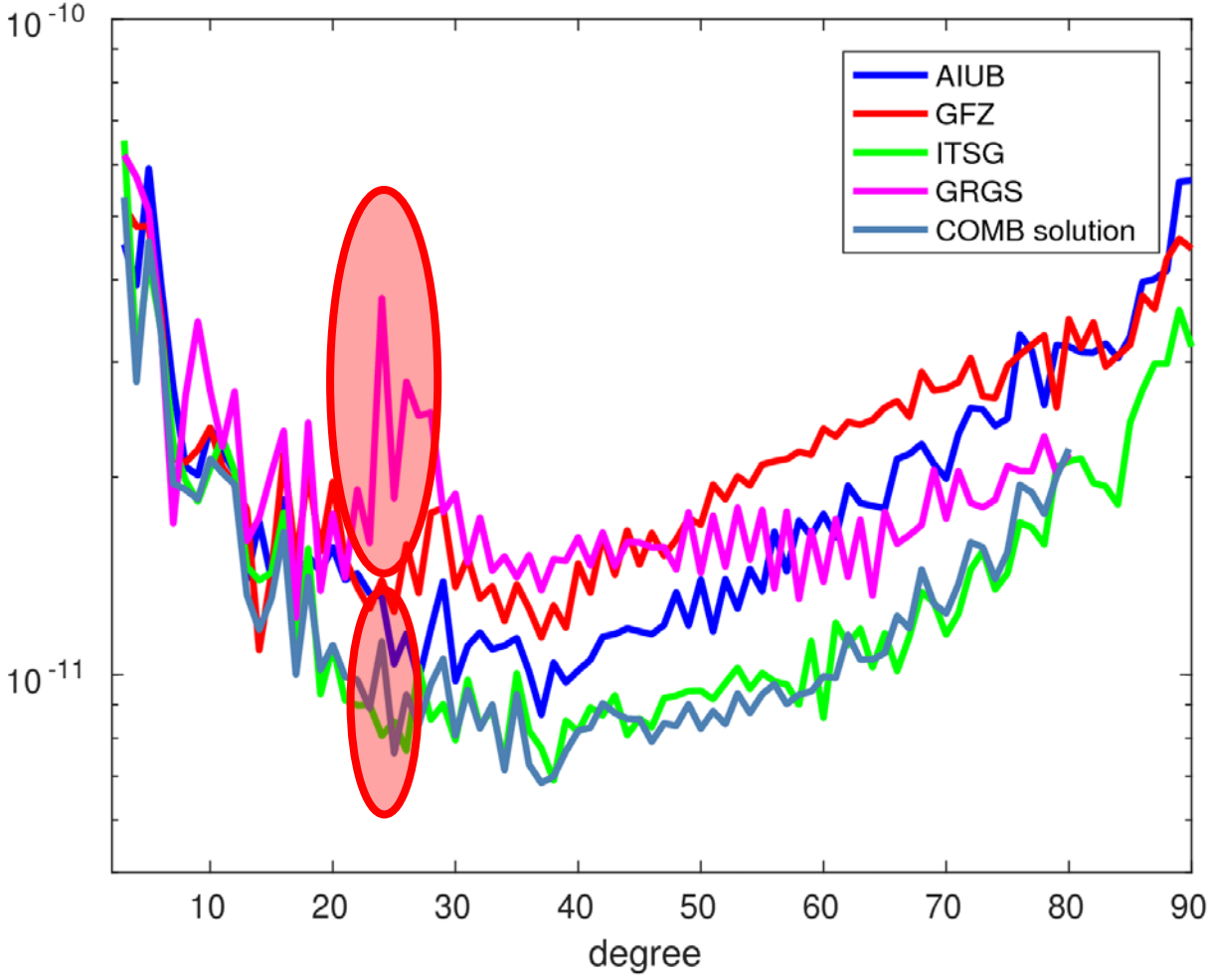
$$\mathbf{d}_{k,i-1} = \mathbf{x}_k - \hat{\mathbf{x}}_{i-1}$$

Differences to the combined solution from $\hat{\mathbf{x}}_{i-1}$ **the previous iteration**

Iteration 0 is equivalent to a simple average, iteration 1 is equivalent to the simple weighted average. Further iterations are required until the procedure converges.

The formulas assume that the stochastic behavior of the SH coefficients is the same for all input solutions and that they are furthermore uncorrelated among each other.

Combination on Solution Level

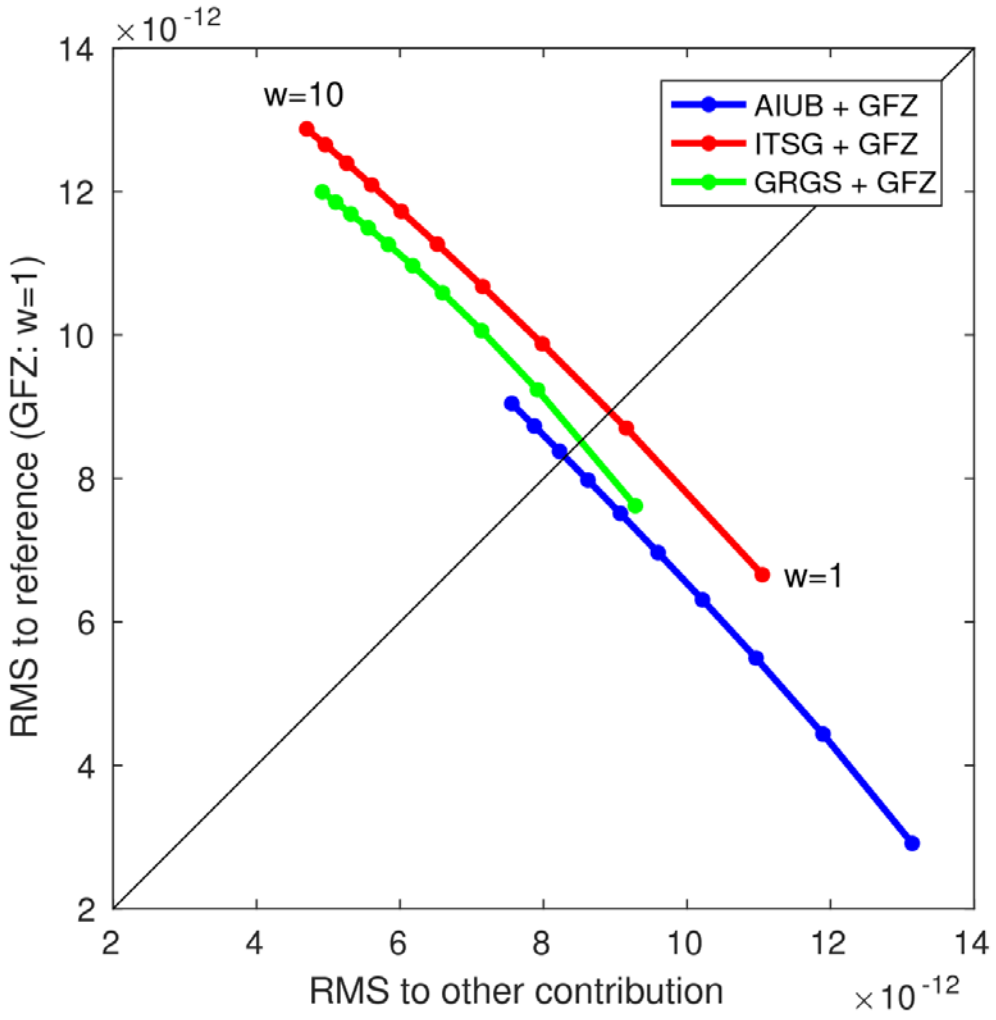


The procedure usually works already well. Smaller weights are assigned to inferior solutions.

Solution:	weight
GRGS	0.14
GFZ	0.19
AIUB	0.29
ITSG	0.38

It can happen, however, that issues of individual solutions propagate to the combined solution.

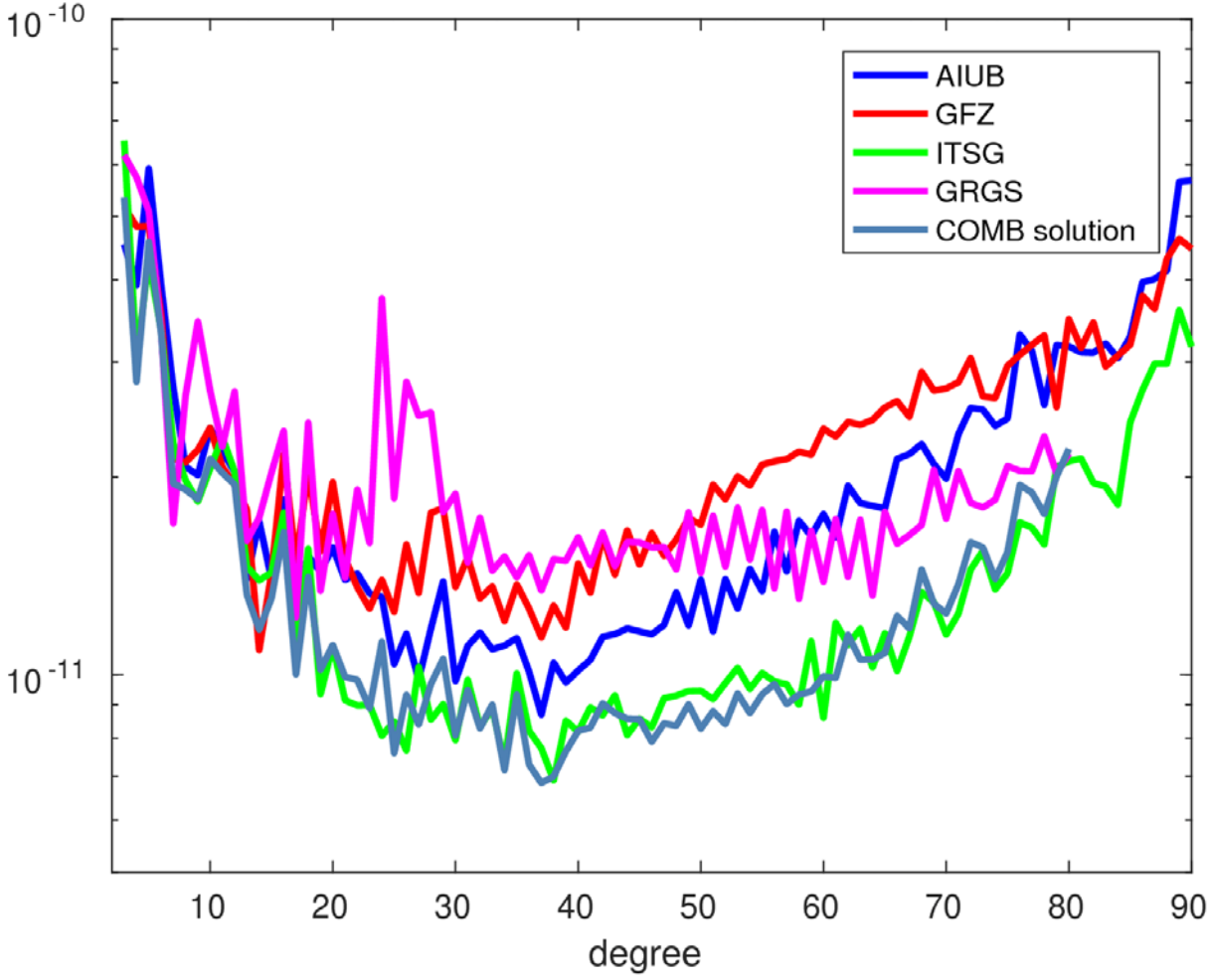
Combination on Normal Equation Level



Empirical rescaling to achieve an equal impact is first needed

equalizing weight	
GRGS	1.60
GFZ	1.00
AIUB	7.81
ITSG	2.21

Combination on Normal Equation Level



The weights are thus first derived on the solution level using a VCE scheme:

Solution:	weight
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GFZ	0.19
AIUB	0.29
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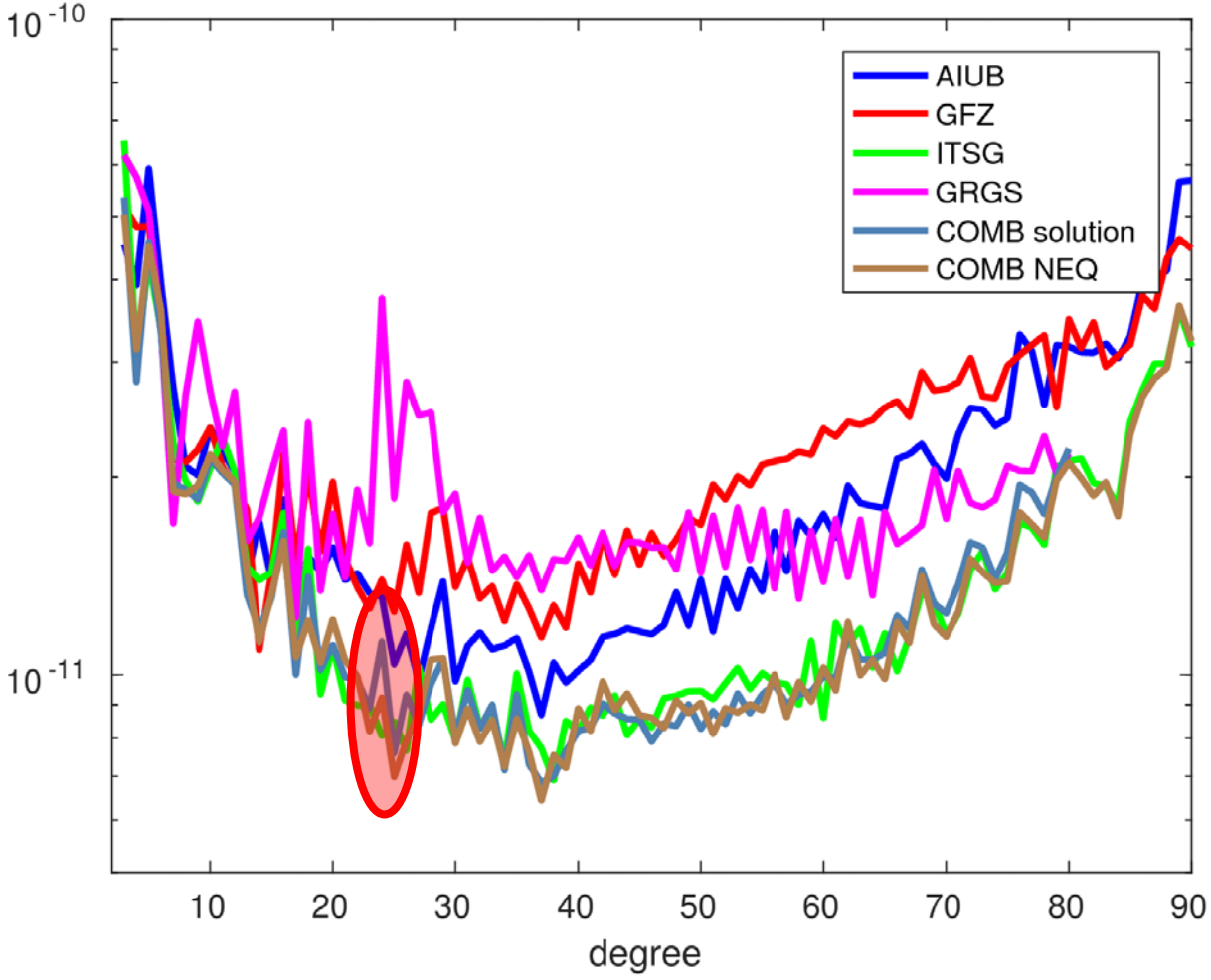
Combination on Normal Equation Level



equalizing weight	
GRGS	1.60
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Solution:	weight
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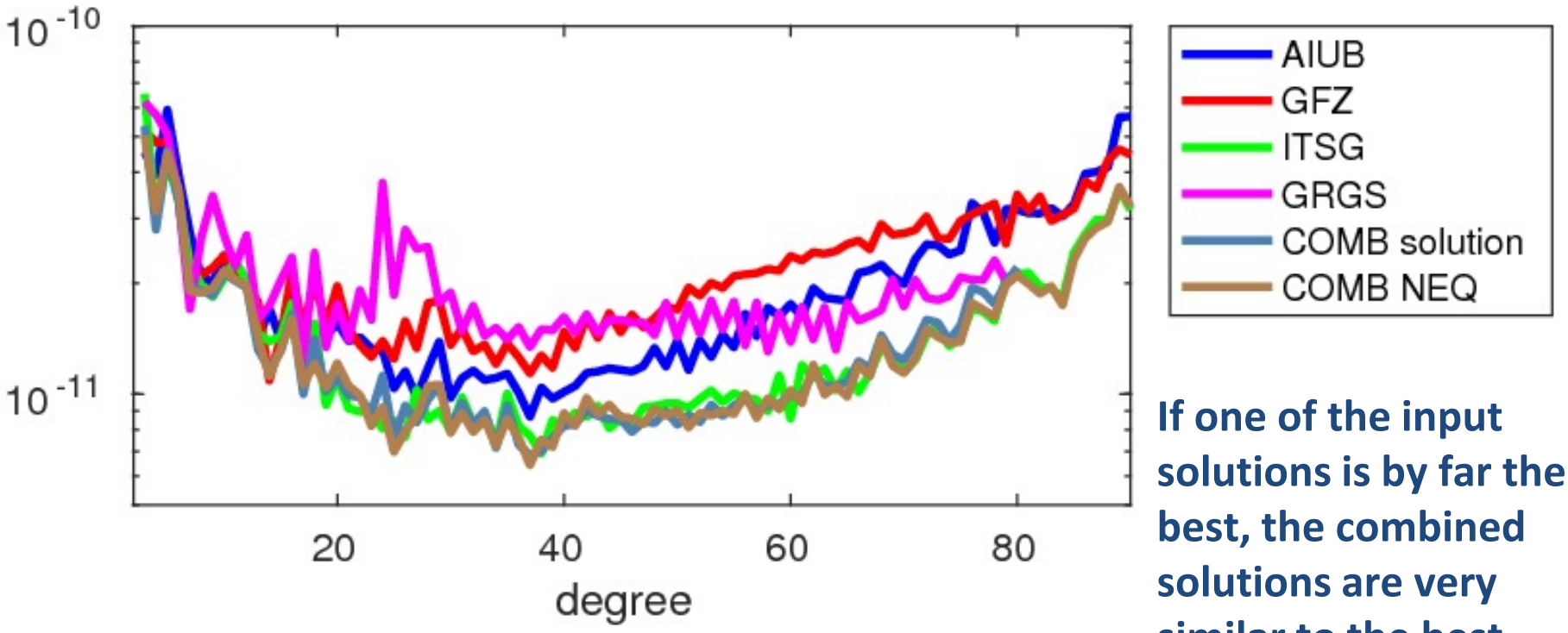
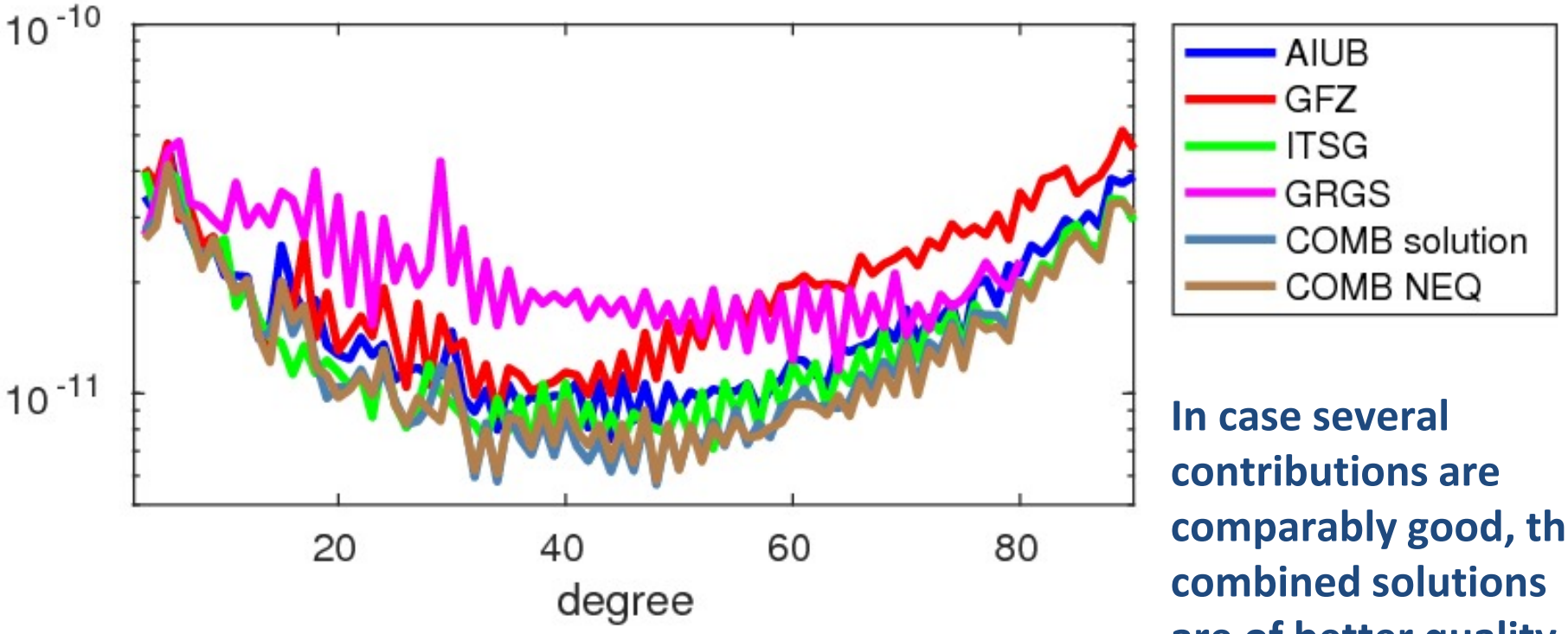
Combination Examples – Case I



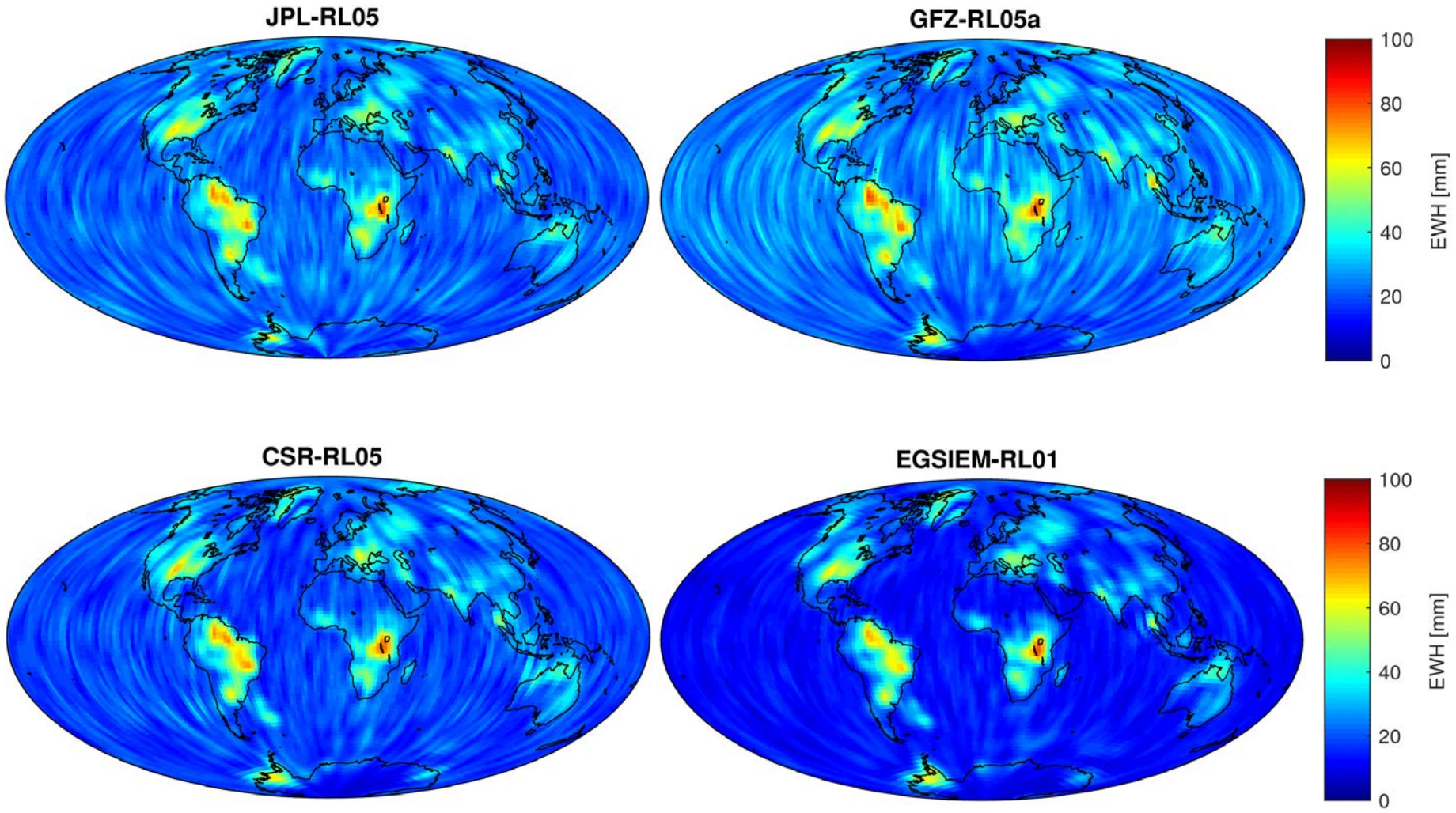
If one of the input solutions is by far the best, the combined solutions are very similar to the best solution.

Combination Examples – Case II

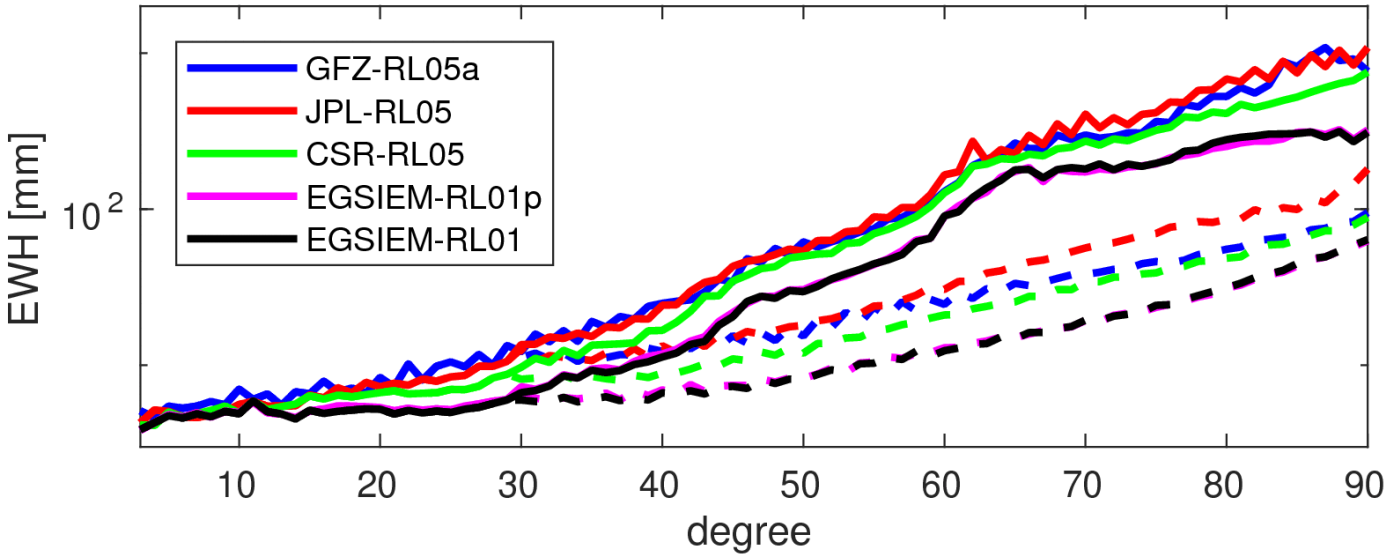


In case several contributions are comparably good, the combined solutions are of better quality.

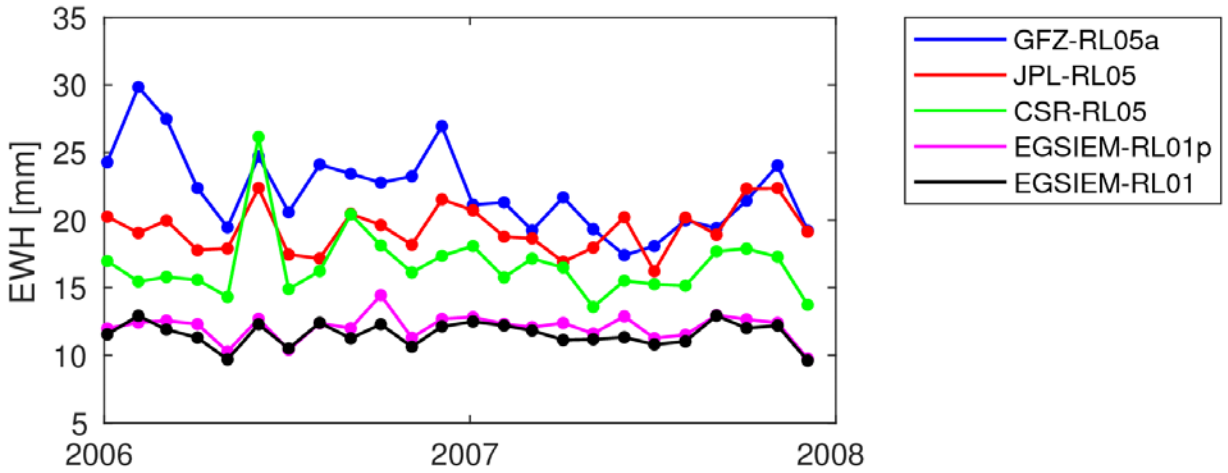
Validation in the Spatial Domain



Validation in the Spectral and Time Domain



Degree amplitudes of anomalies (all orders / orders 0-29).



RMS of anomalies in ocean areas (smoothed by 400 km Gauss filter).

Continuation as an IAG Service

COST-G Analysis Centers (confirmed):

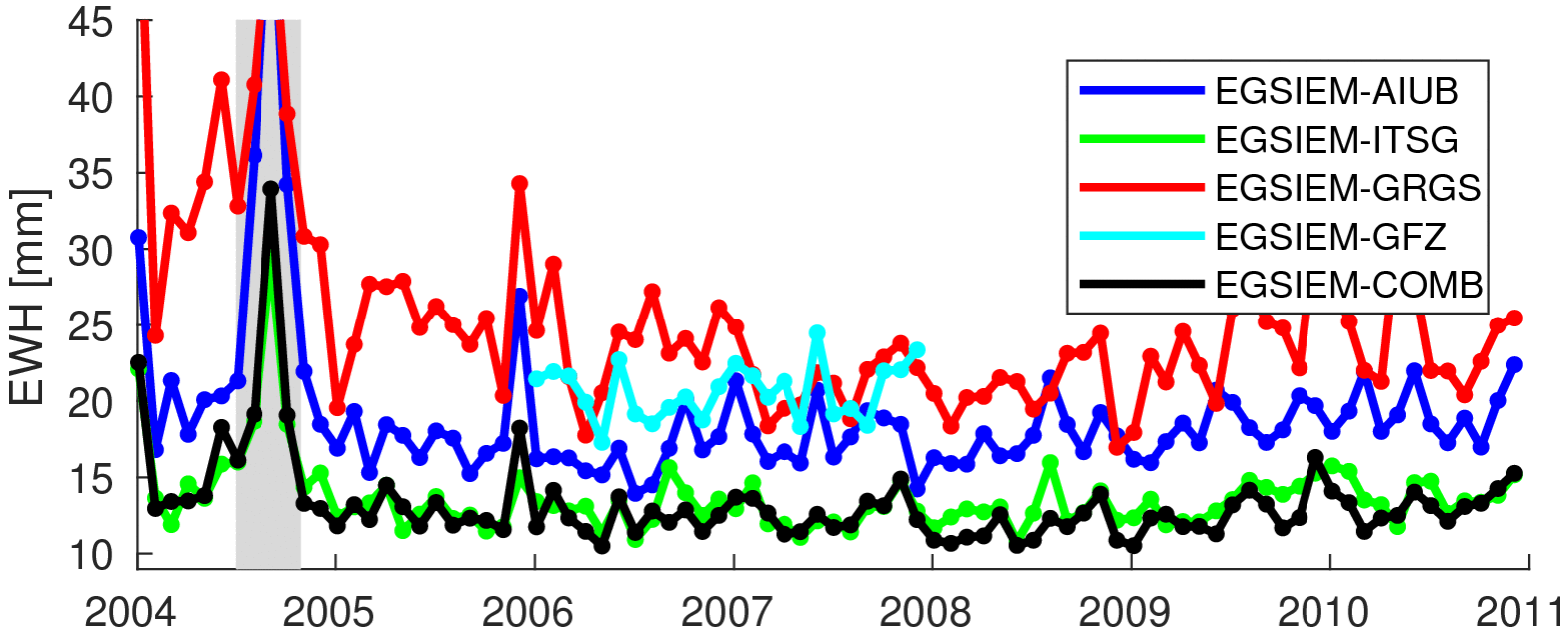
- **AIUB**
- **CSR**
- **CNES**
- **GFZ**
- **JPL**
- **TUG**

and maybe even more in the future …

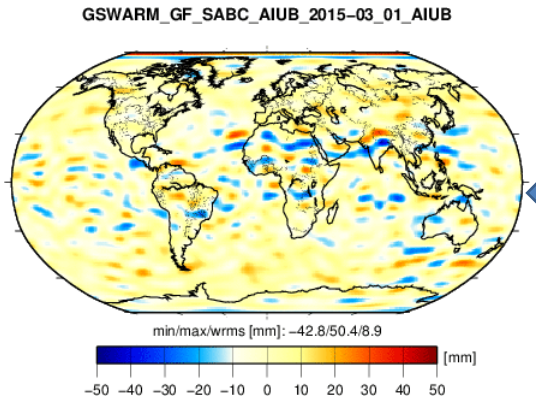
- The EGSIEM Scientific Combination Service will be continued as **COST-G** (**CO**mbination **S**ervice of **T**ime-variable **G**ravity field solutions). COST-G will be a Product Center of the International Gravity Field Service (**IGFS**) of the International Association of Geodesy (**IAG**).
- The NRT Service as well as the Hydrological Service will be continued on a best effort basis when GRACE-FO data will become available.

Current Activities: Extending the GRACE Combination

- The so far released EGSIEM combined series is spanning 2006-2007. The combination is done on the level of **Normal Equations**.
- The series is currently being extended. 7 years based on 3 ACs are already available.
- Shown is the RMS of anomalies in oceanic regions, smoothed by a 400 km Gauss filter.



Current Activities: Swarm Combination



EGSIEM

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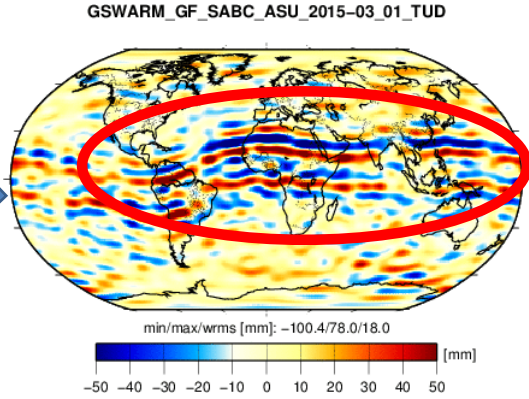
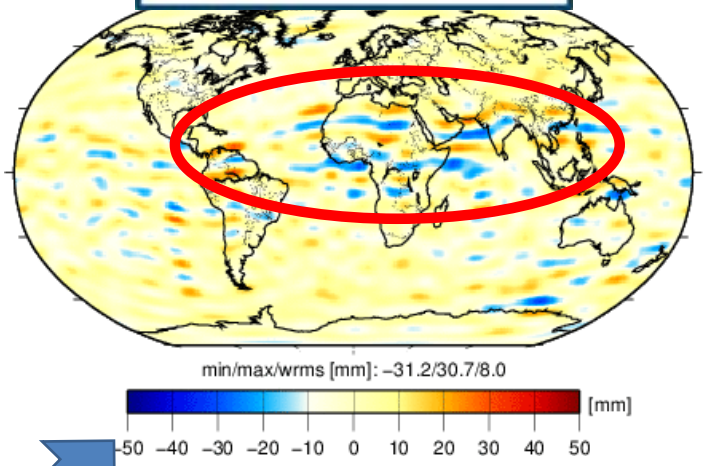
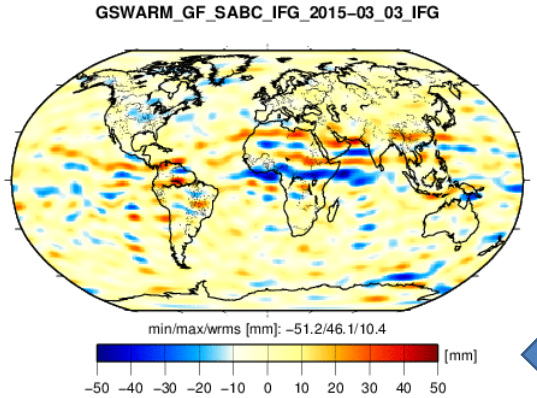


EGSIEM Combination





esa SWARM DISC

funded by contract SD-ITT-1.1,
part of contract 000109587/13/I-NB

For Swarm

- not only the noise reduction is relevant
- in particular also the reduction of ionosphere induced systematic errors
- See next talk given by Visser et al.

Summary and Future Perspectives

- EGSIEM was running for three years (2015-2017).
- Integration of the EGSIEM Combination Prototype Service as the new **Product Center** for time-variable gravity fields of IAG's International Gravity Field Service (IGFS) has been formally achieved.
- Combined time-variable gravity fields shall be regularly computed in the future from data of the following satellites:
  - Dedicated gravity missions (**GRACE-FO**)
  - Selected non-dedicated missions (**Swarm**)
  - Maybe spherical SLR satellites (studies are initiated)
- A full time series of combined **GRACE** solutions is planned to be computed as soon as possible (time frame fully depends on the contributing ACs).

Thanks a lot for your attention!