



European Gravity Service for Improved Emergency Management

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

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

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42<sup>nd</sup> COSPAR Scientific Assembly, PSD.1

14-22 July, 2018, Pasadena, California

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# Introduction



# EGSIEM European Gravity Service for Improved Emergency Management

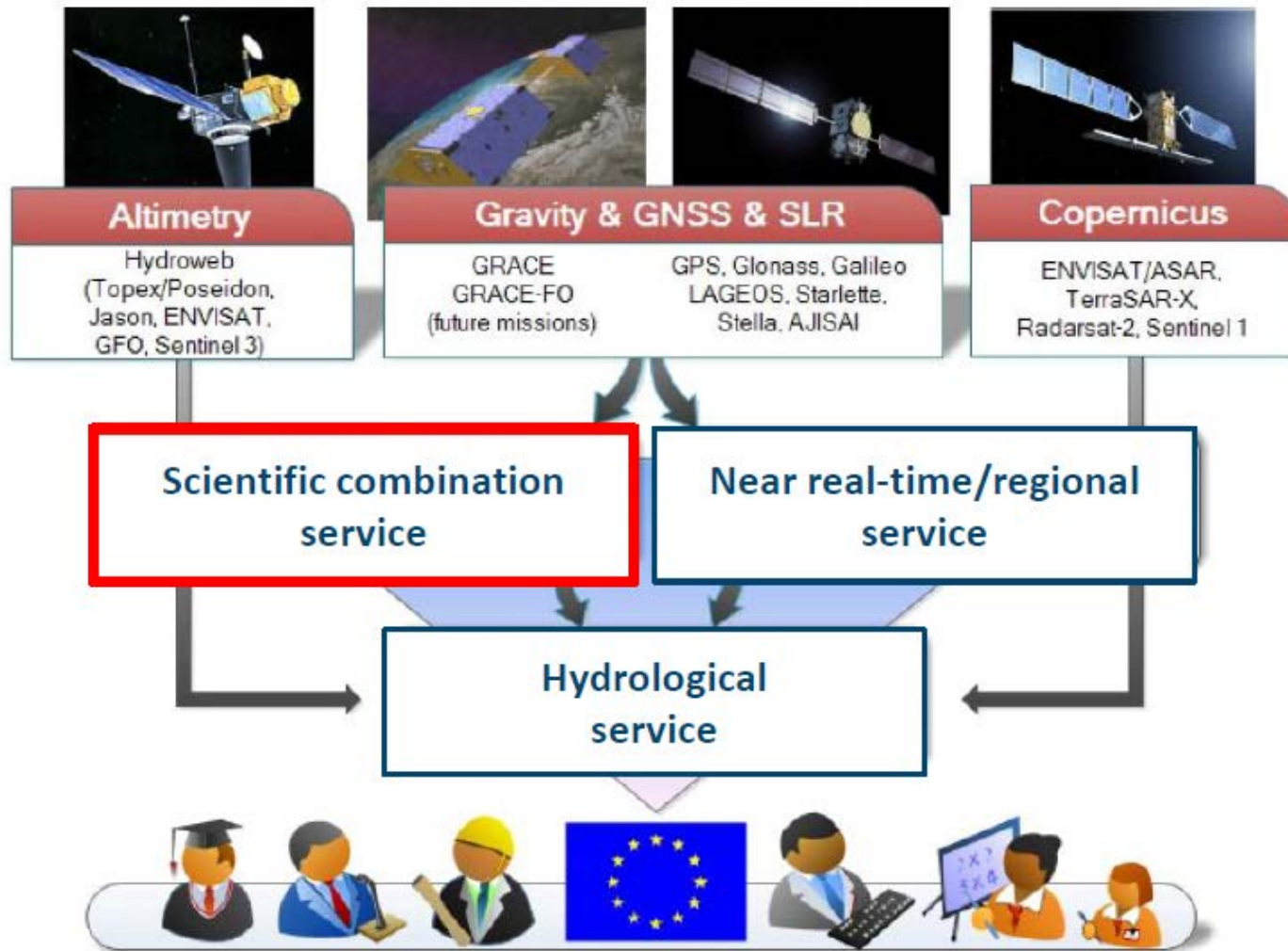
was a H2020 project running 2015-2017 with the partners:



and several associated members:

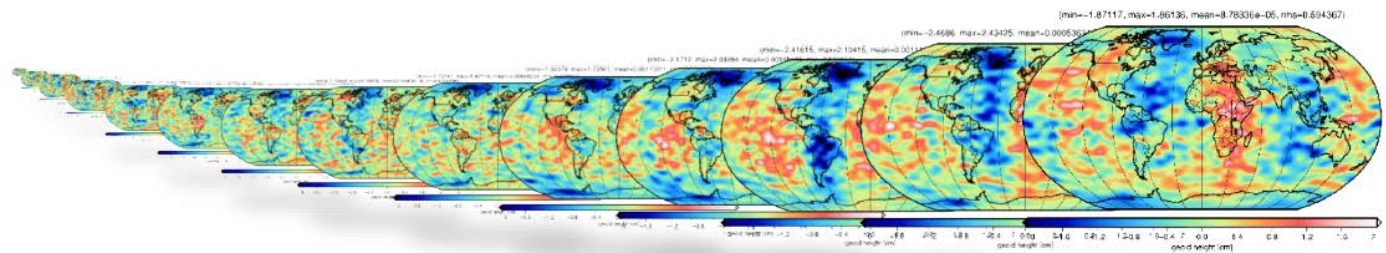
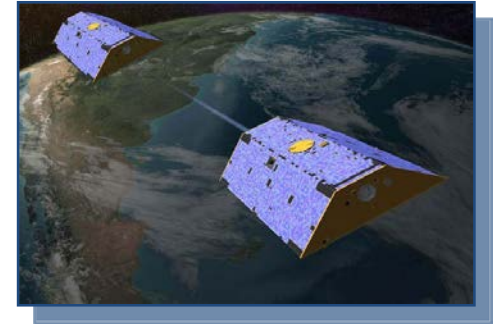


# EGSIEM: Three Prototype Services were established



# Why a combination service?

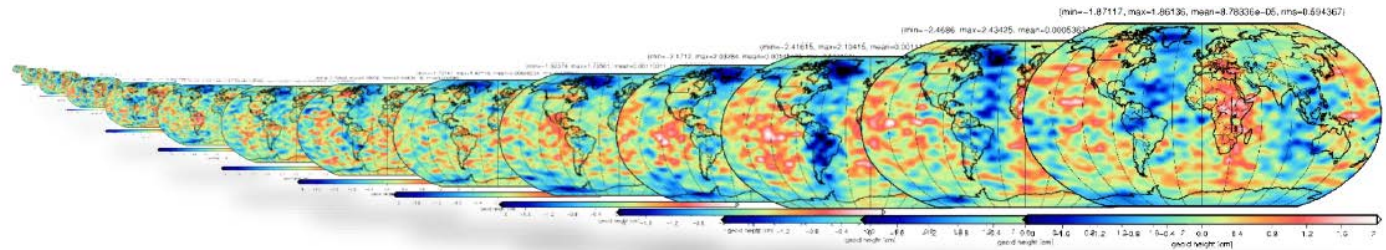
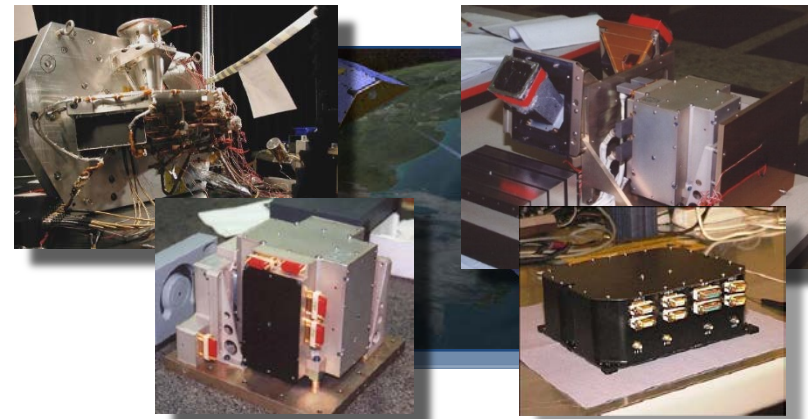
- Process GRACE / GRACE-FO data to a time series of monthly gravity field solutions
- Processing is challenging





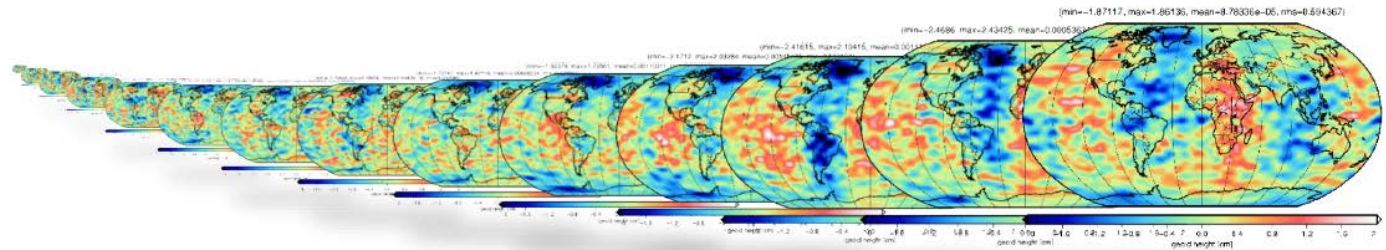
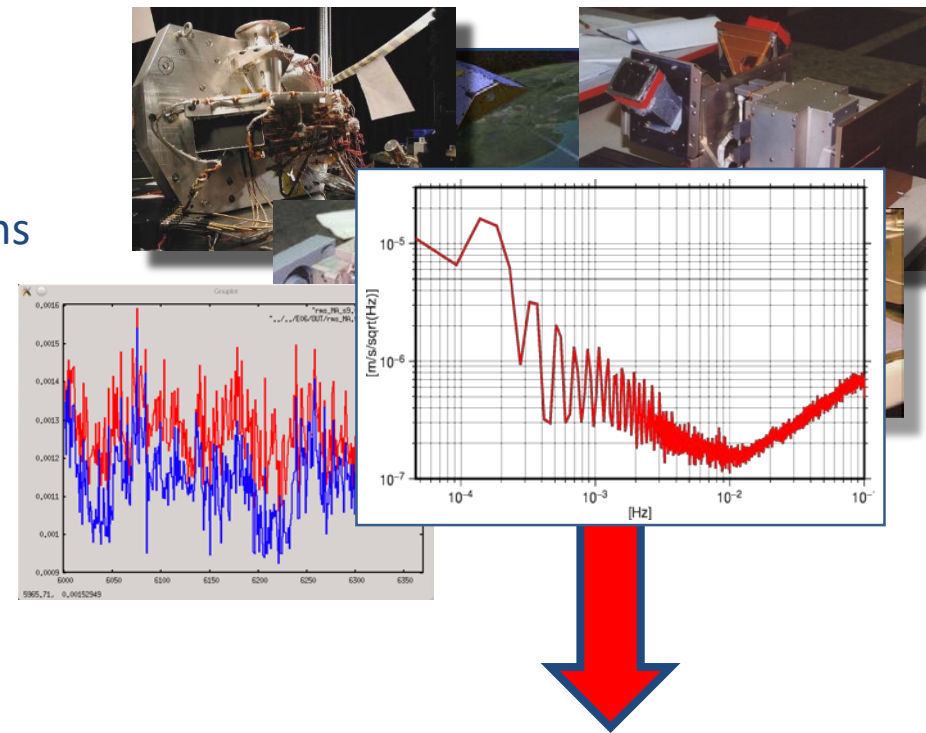
# Why a combination service?

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



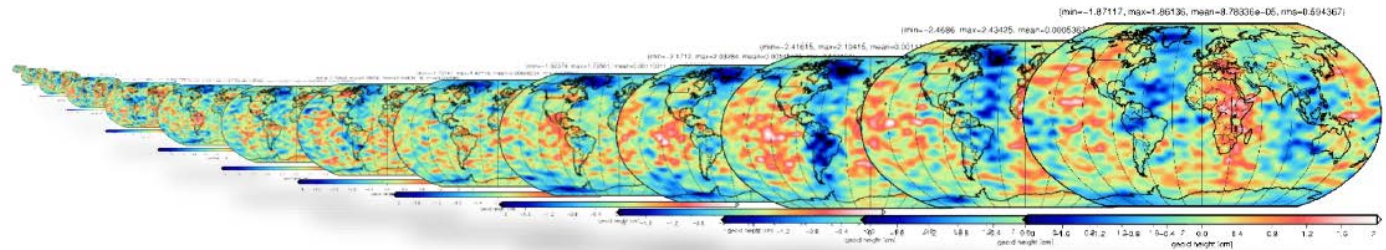
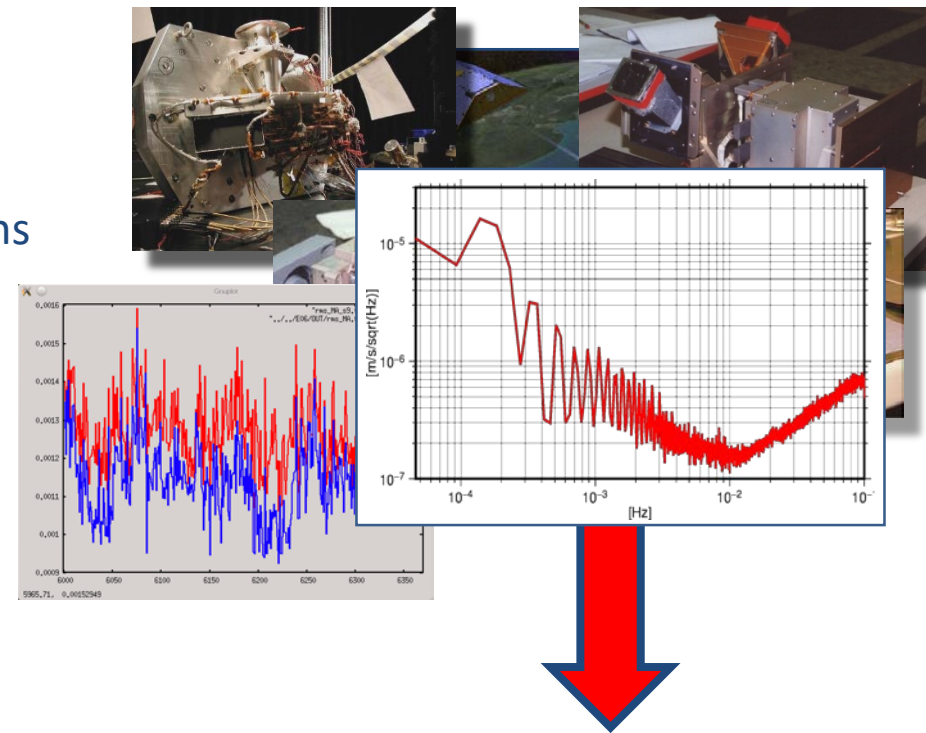
# Why a combination service?

- 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?

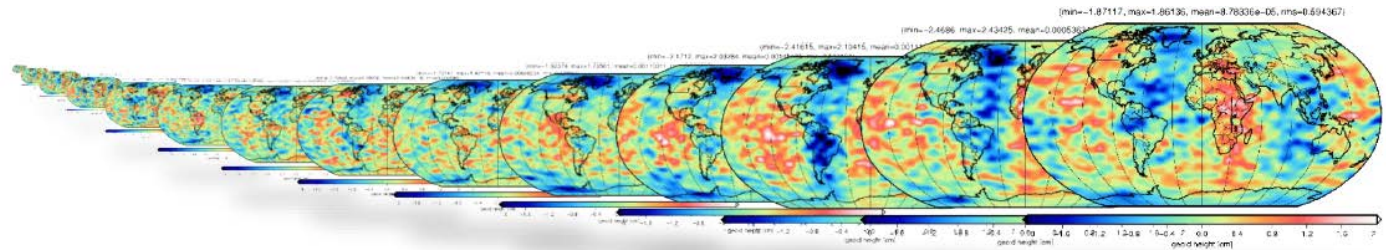
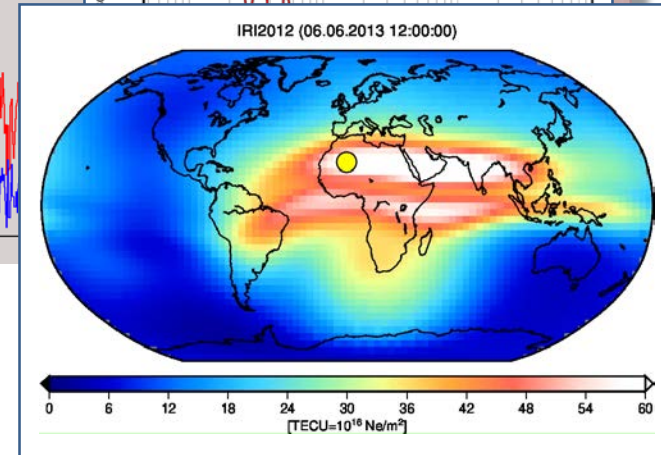
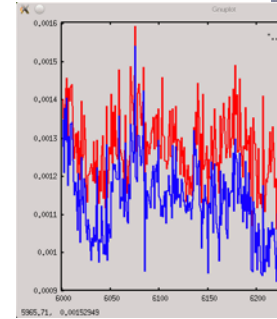
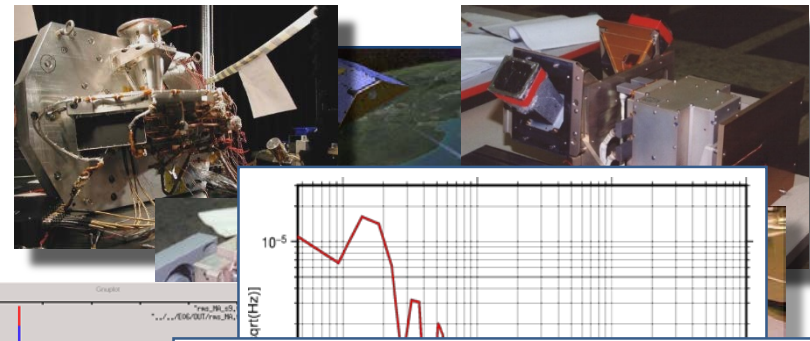
- Process GRACE / GRACE-FO data to a time series of monthly gravity field solutions
- Processing is challenging
  - Interaction of multiple instruments
  - Different noise characteristics
  - Environmental disturbances





# Why a combination service?

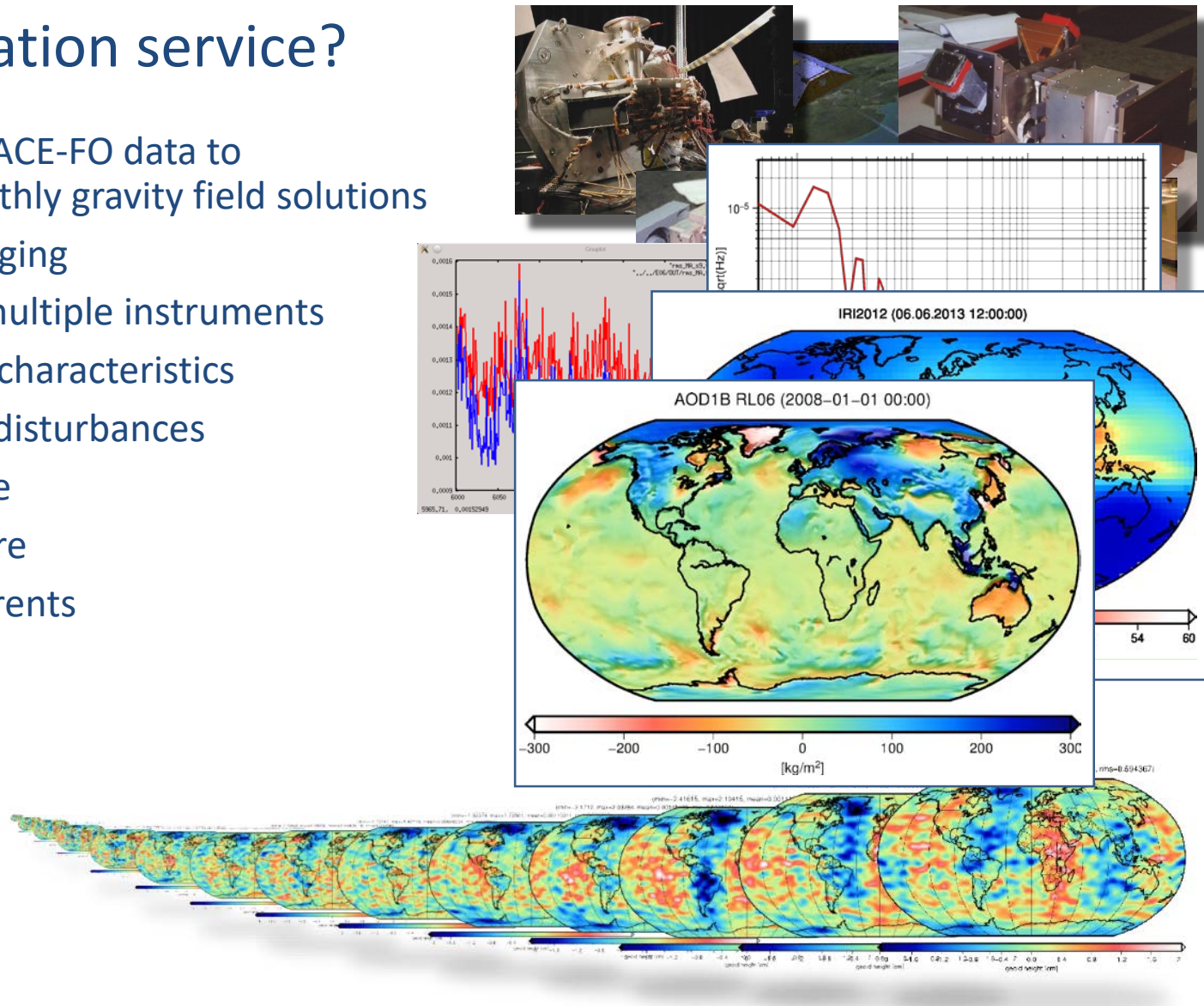
- Process GRACE / GRACE-FO data to a time series of monthly gravity field solutions
- Processing is challenging
  - Interaction of multiple instruments
  - Different noise characteristics
  - Environmental disturbances
    - Ionosphere





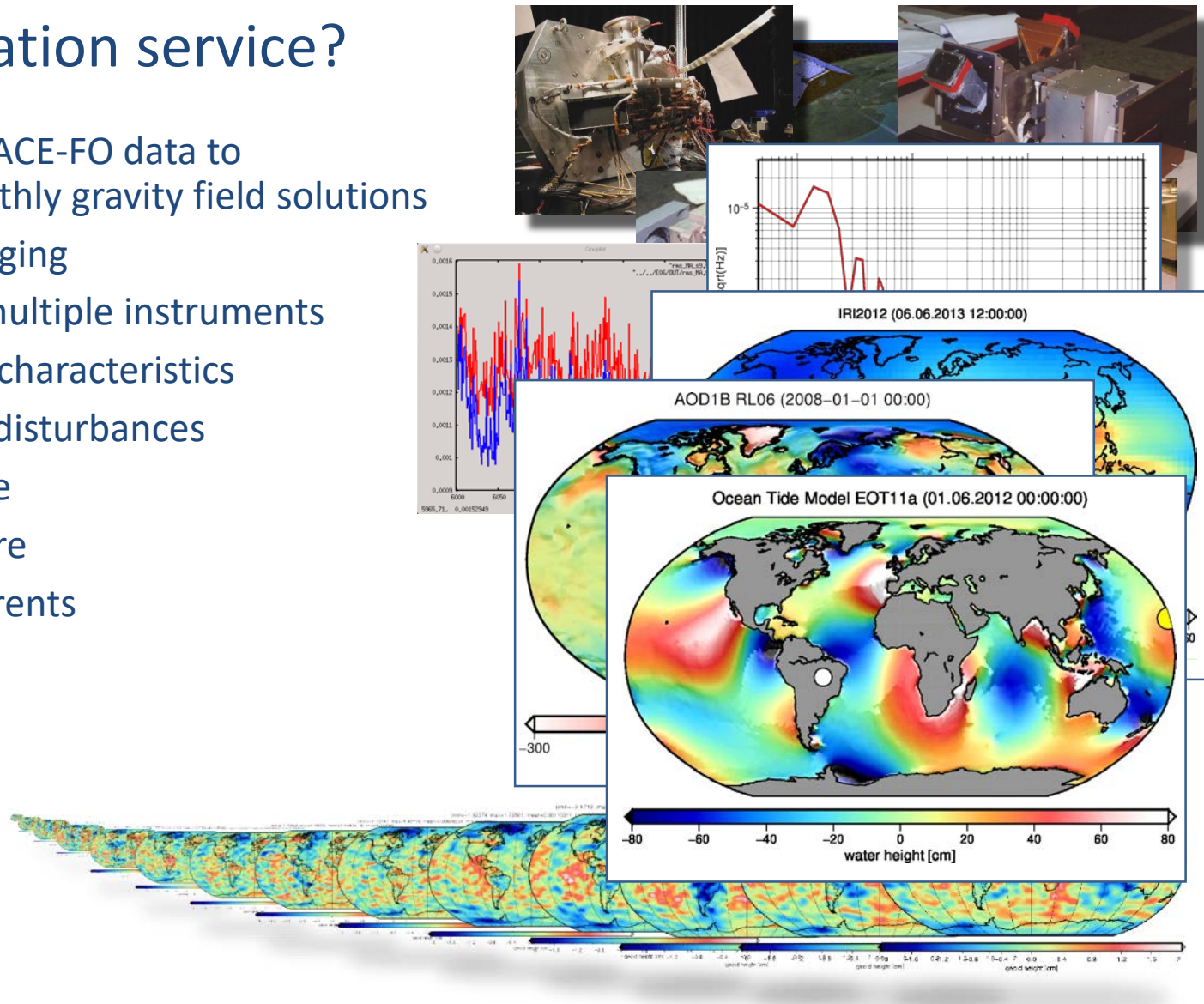
# Why a combination service?

- 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



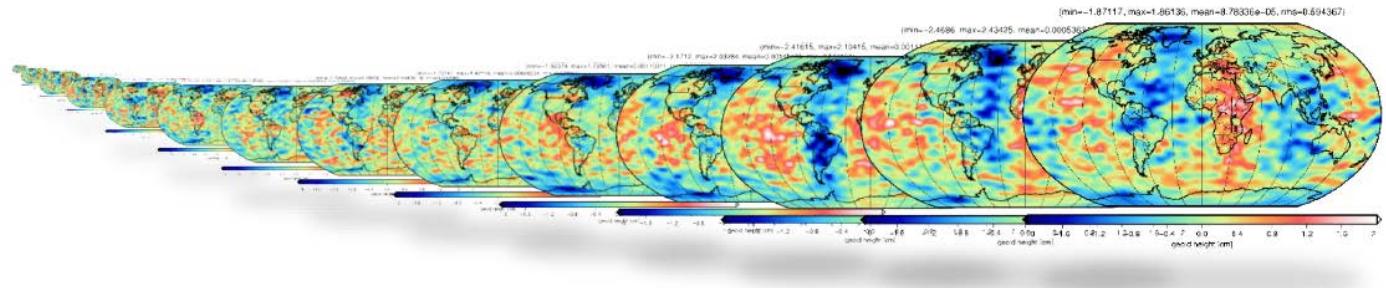
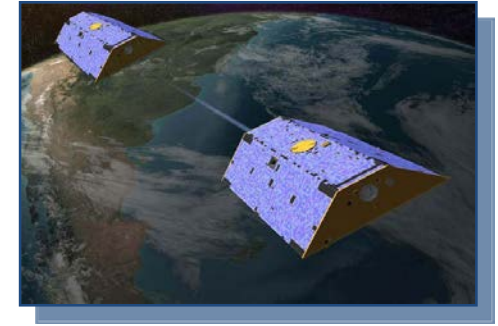
# Why a combination service?

- 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
- EGSIM Analysis Centers (ACs):
  - GFZ
  - CNES
  - AIUB
  - TUG





# Harmonization of Processing Standards

- ~~Consistent reference and GPS consistent~~
- 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
```

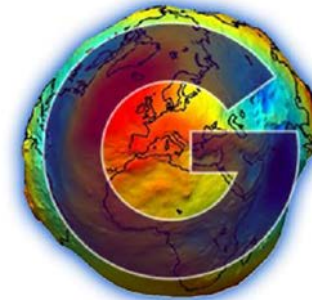


*EO-1-2014: New ideas for Earth-relevant space applications  
Research and Innovation Action*

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

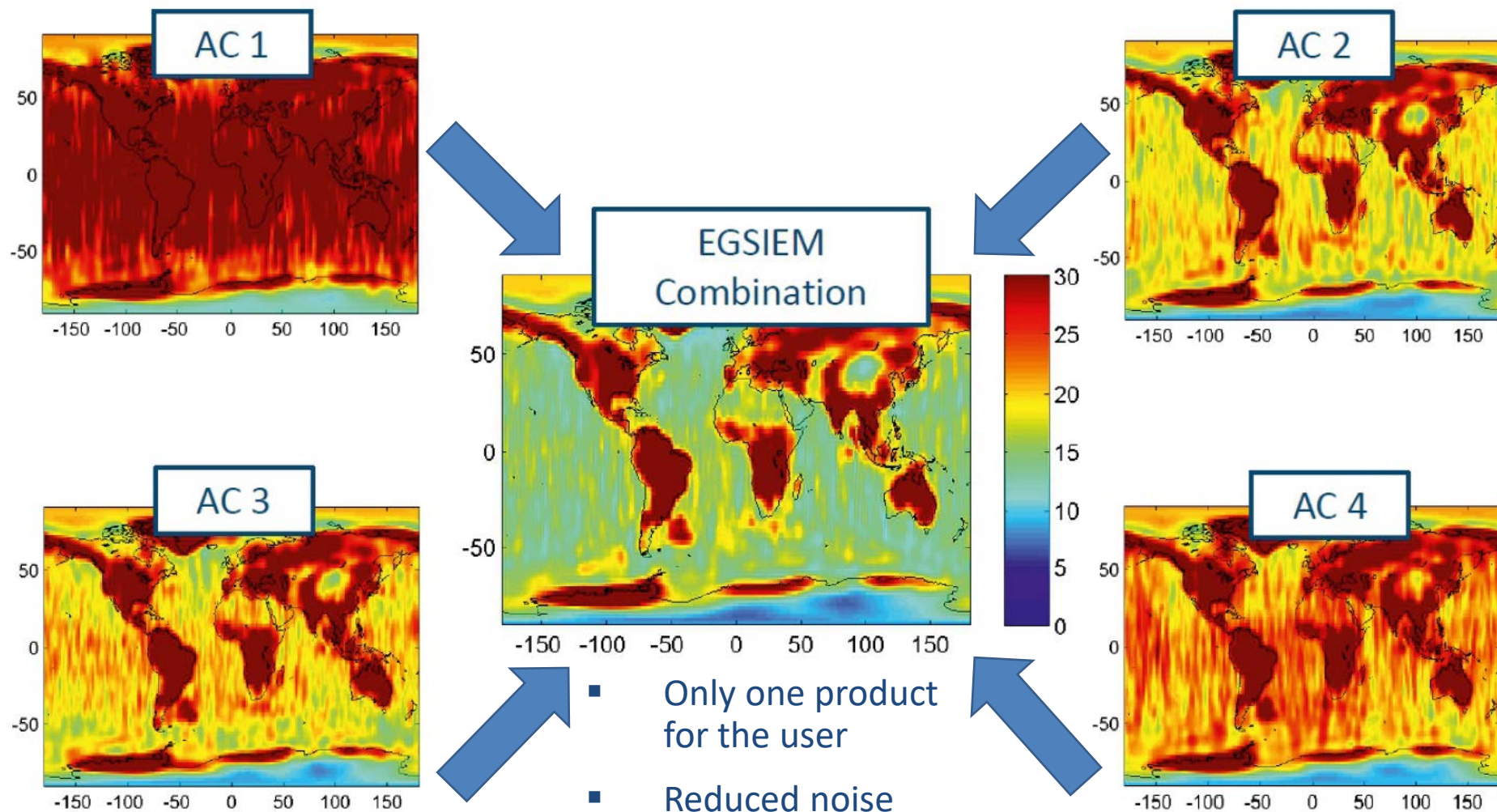
Deliverable 2.1  
Processing Standards

Date: 27/02/2015

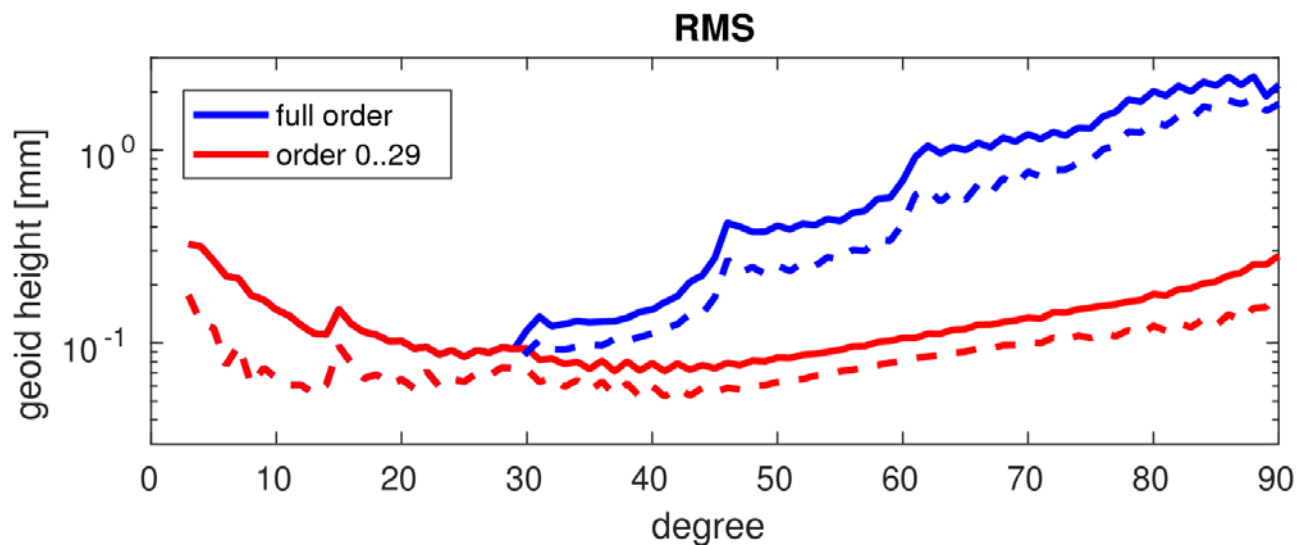


Prepared by: U. Meyer

# Scientific Combination Service



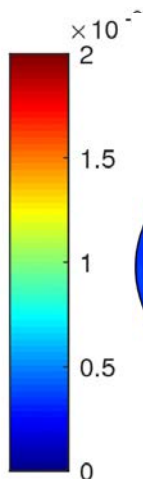
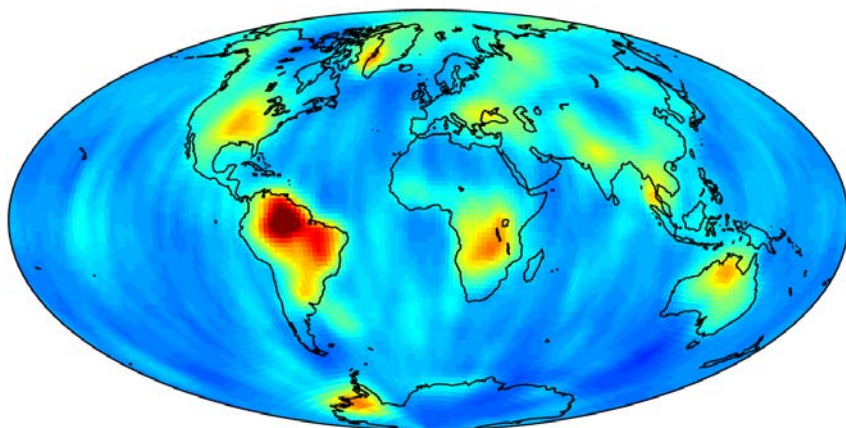
# Noise Assessment



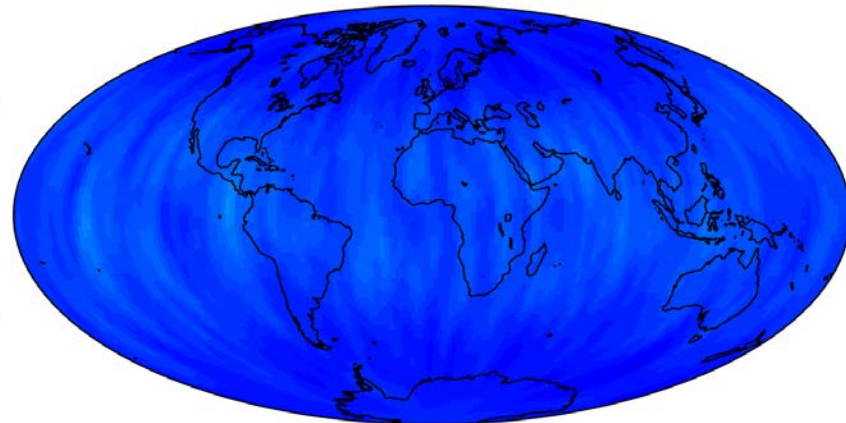
Differences to mean  
to derive relative  
weights. — — —

Anomalies over quite  
regions to indepently  
assess quality. — — —

**RMS of anomalies**



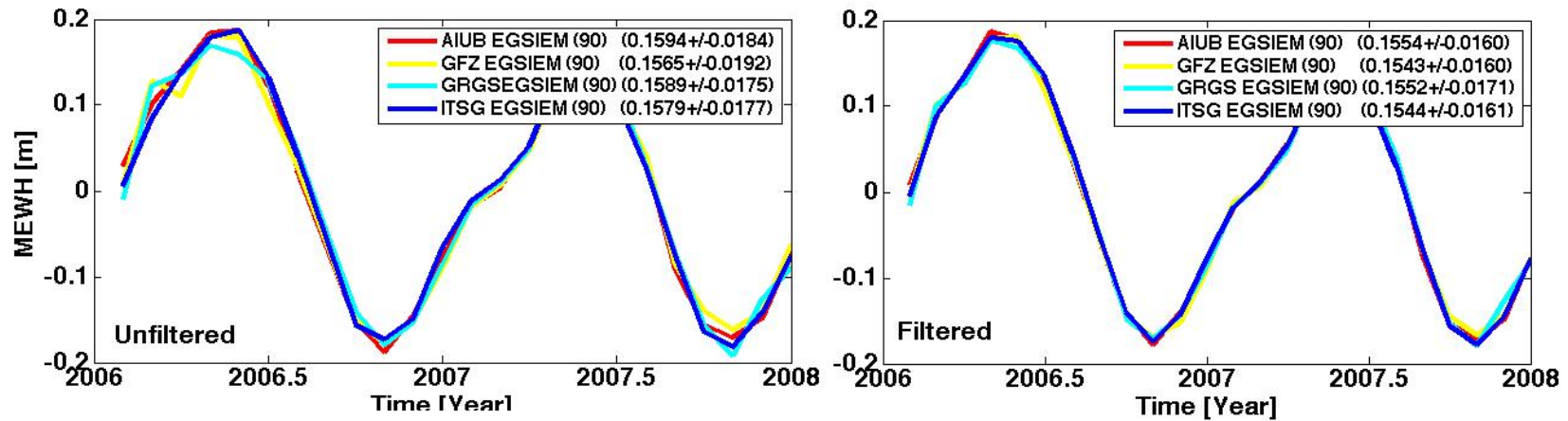
**RMS of differences to mean**





# Pre-Processing: Signal and Noise Assessment

## MEWH over large river basins:

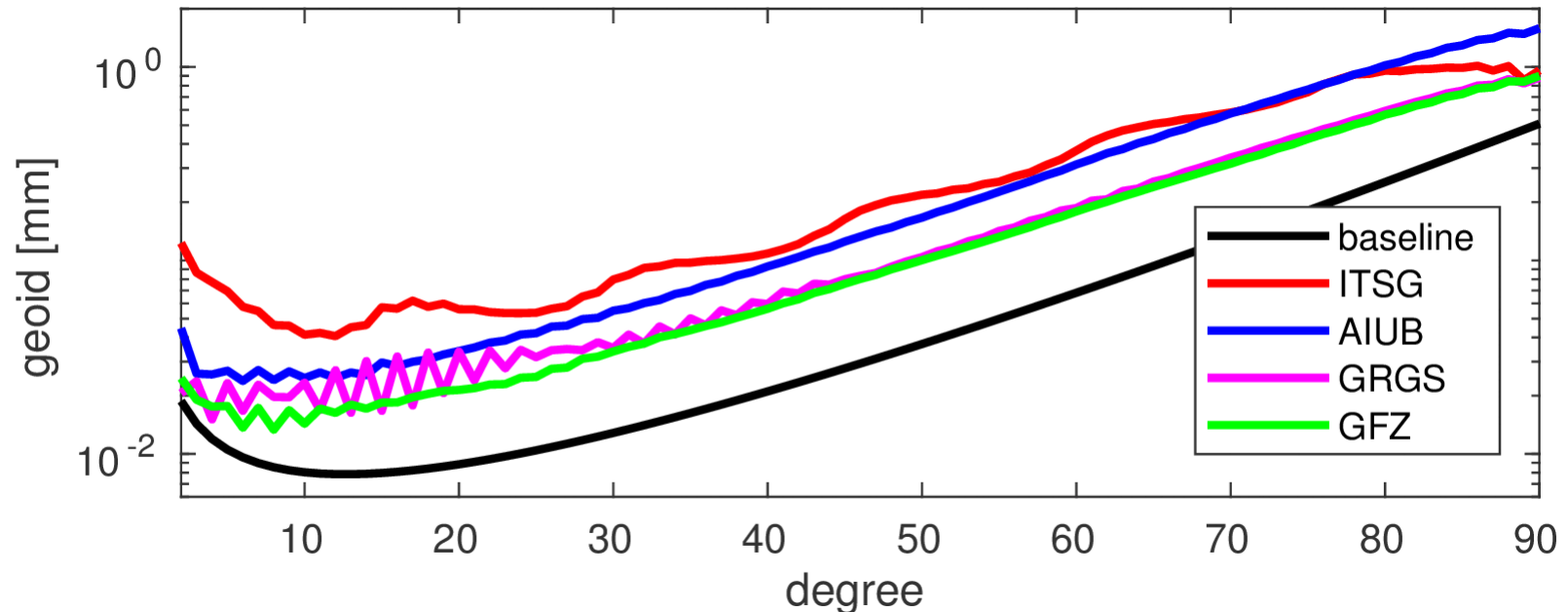


## wSTD over oceans:



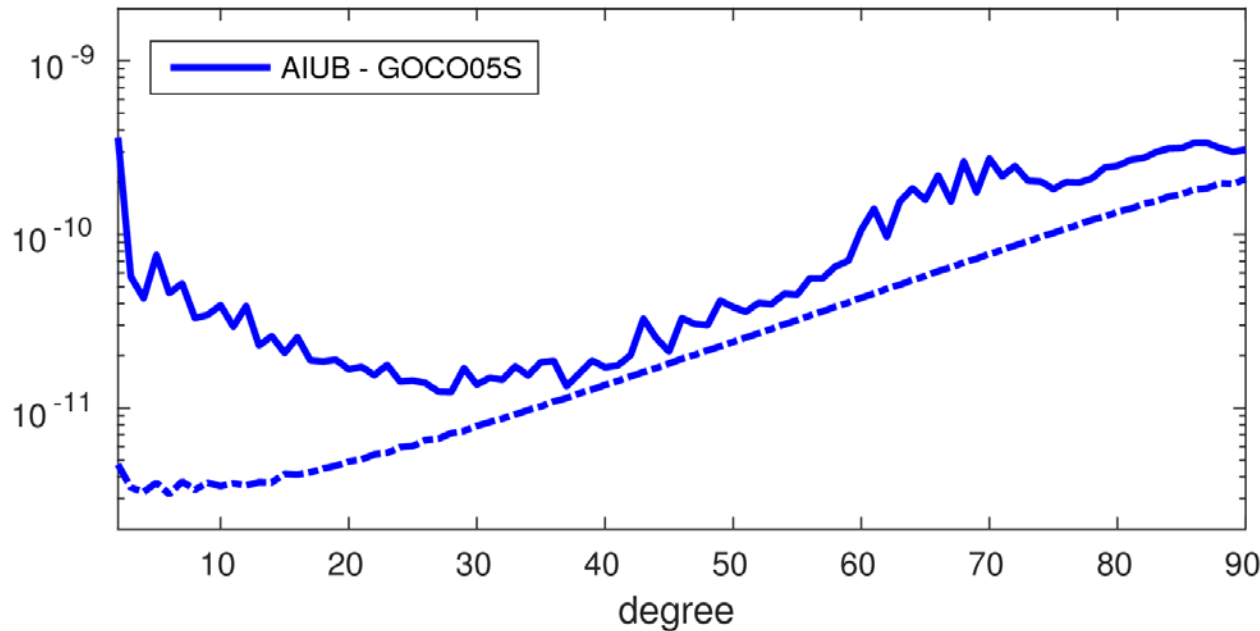
# Motivation and Challenge for Combination

- 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

2006/01

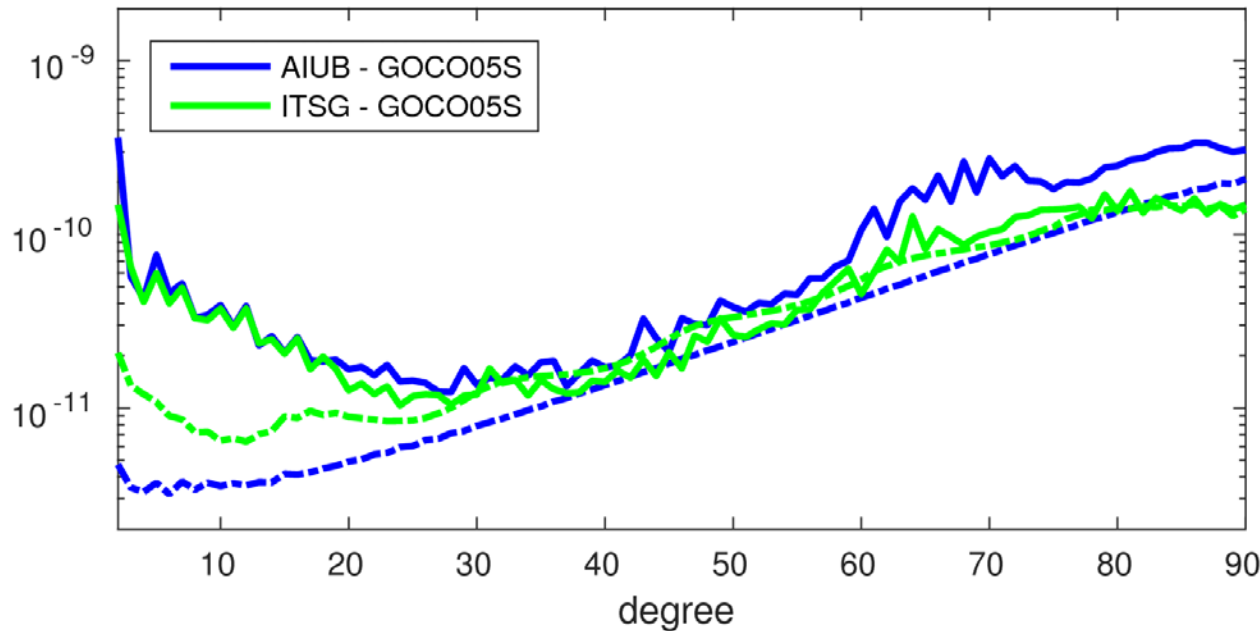


- **AIUB:** Dynamic approach (with pseudo-stochastic accelerations)
  - ~ 500'000 KRR observations per month
  - ~ 500'000 kinematic positions (30s) per month



# Individual Contributions: ITSG

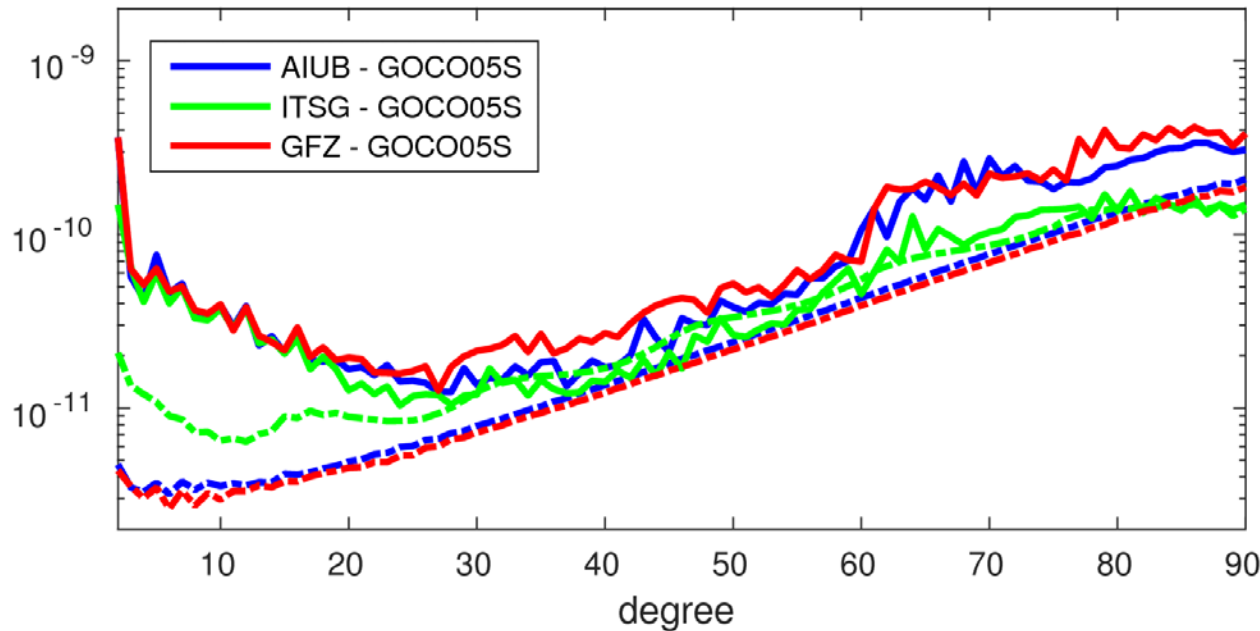
2006/01



- **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

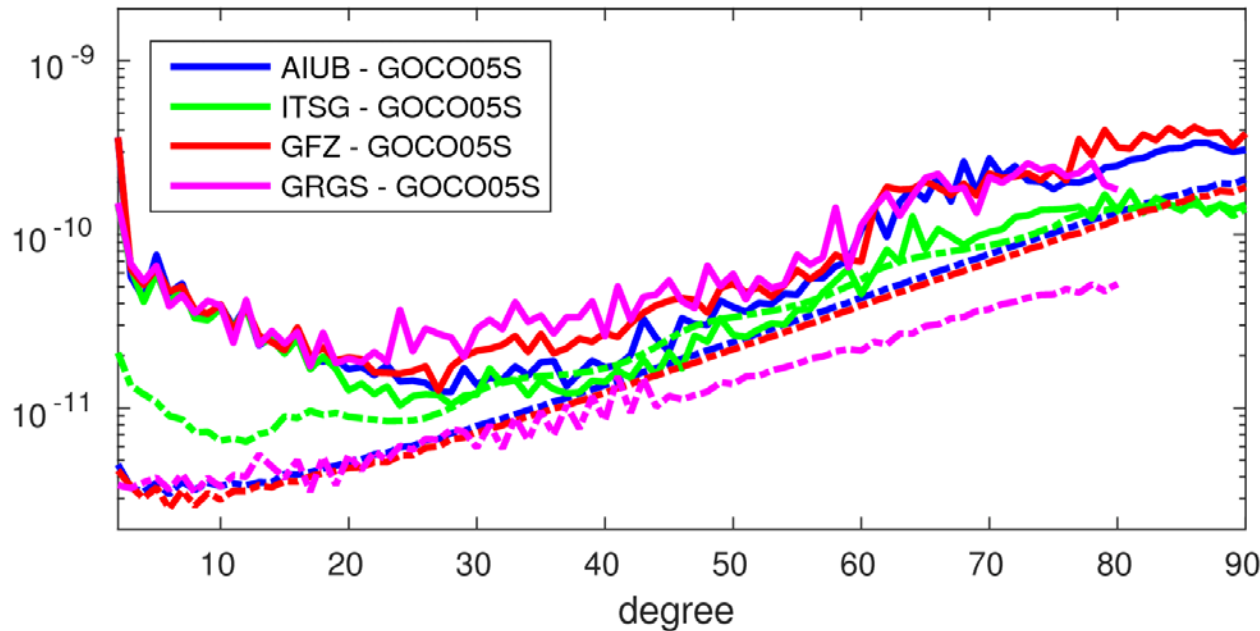
2006/01



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

# Individual Contributions: GRGS

2006/01



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



# Combination on Solution Level

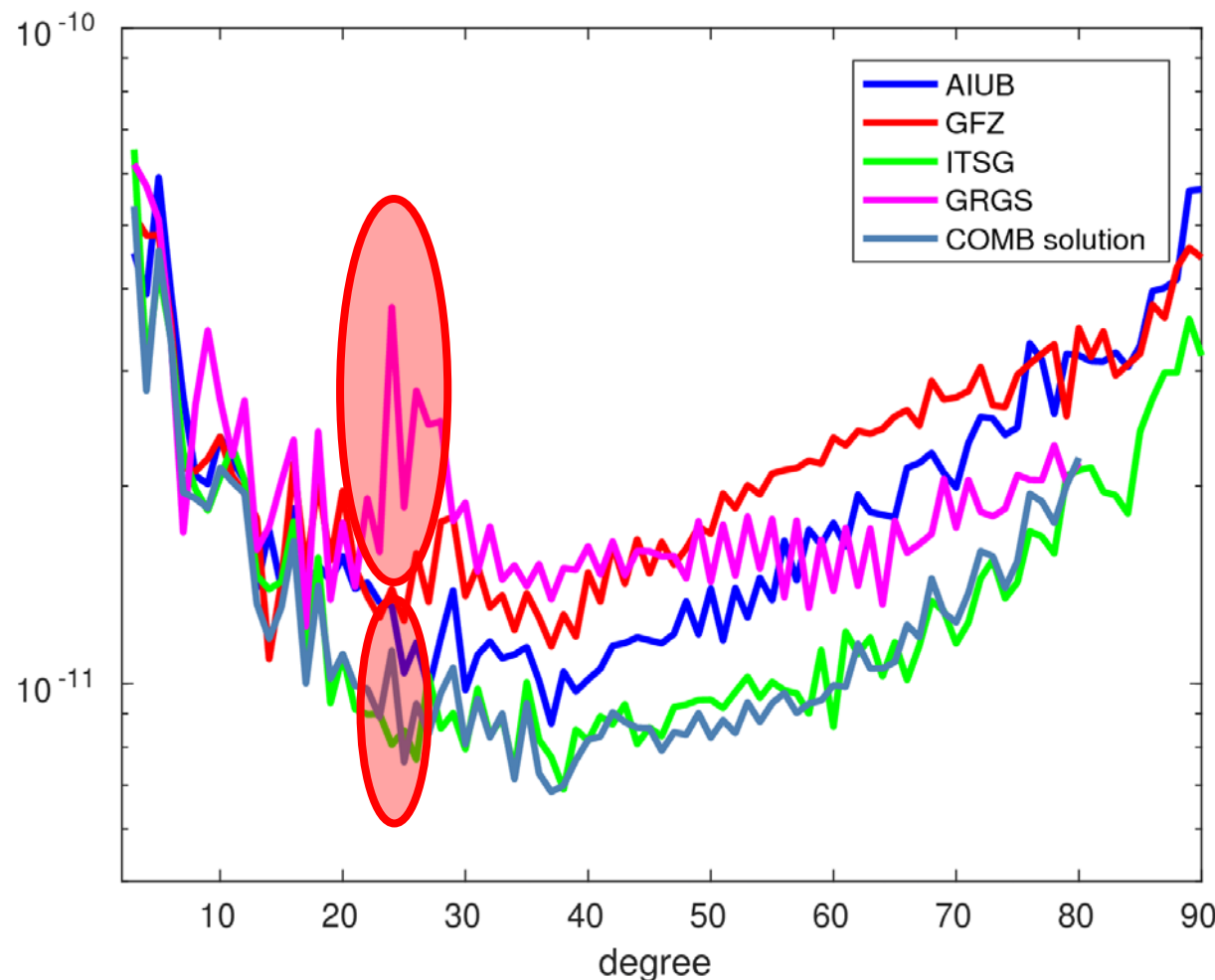
Formulas of Variance Component Estimation (VCE) may be adopted to the resulting (trivial) normal equations when using SH coefficients from individual ACs to compute the combined solution by a simple weighted average. The following explicit formulas result:

$$\begin{array}{ll} \text{Iteration 0} & \hat{\mathbf{x}}_0 = \frac{1}{n} \sum_k \mathbf{x}_k \quad \text{with} \quad w_{k,0} = \frac{1}{n} \quad \forall k, \quad k = 1, \dots, n \\ \\ \text{Iteration } i > 0 & \hat{\mathbf{x}}_i = \frac{1}{\sum_k w_{k,i}} \sum_k w_{k,i} \mathbf{x}_k \quad \text{with} \quad w_{k,i} = \left(1 - \frac{w_{k,i-1}}{\sum_k w_{k,i-1}}\right) / \text{RMS}(\mathbf{d}_{k,i-1})^2 \\ & \mathbf{d}_{k,i-1} = \mathbf{x}_k - \hat{\mathbf{x}}_{i-1} \quad \text{Differences to the combined solution from } \hat{\mathbf{x}}_{i-1} \\ & \quad \quad \quad \text{the previous iteration} \end{array}$$

**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

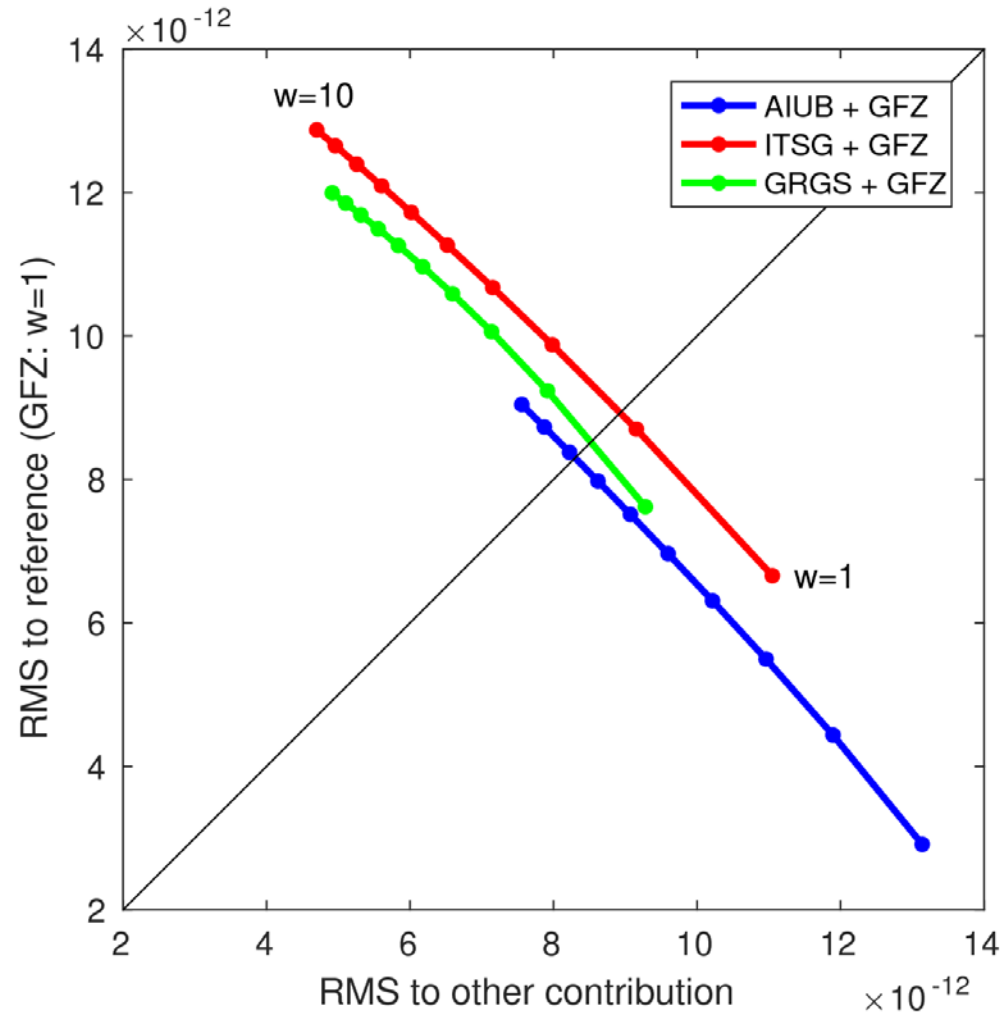


The procedure usually works already well. Smaller weights are assigned to inferior solutions.

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

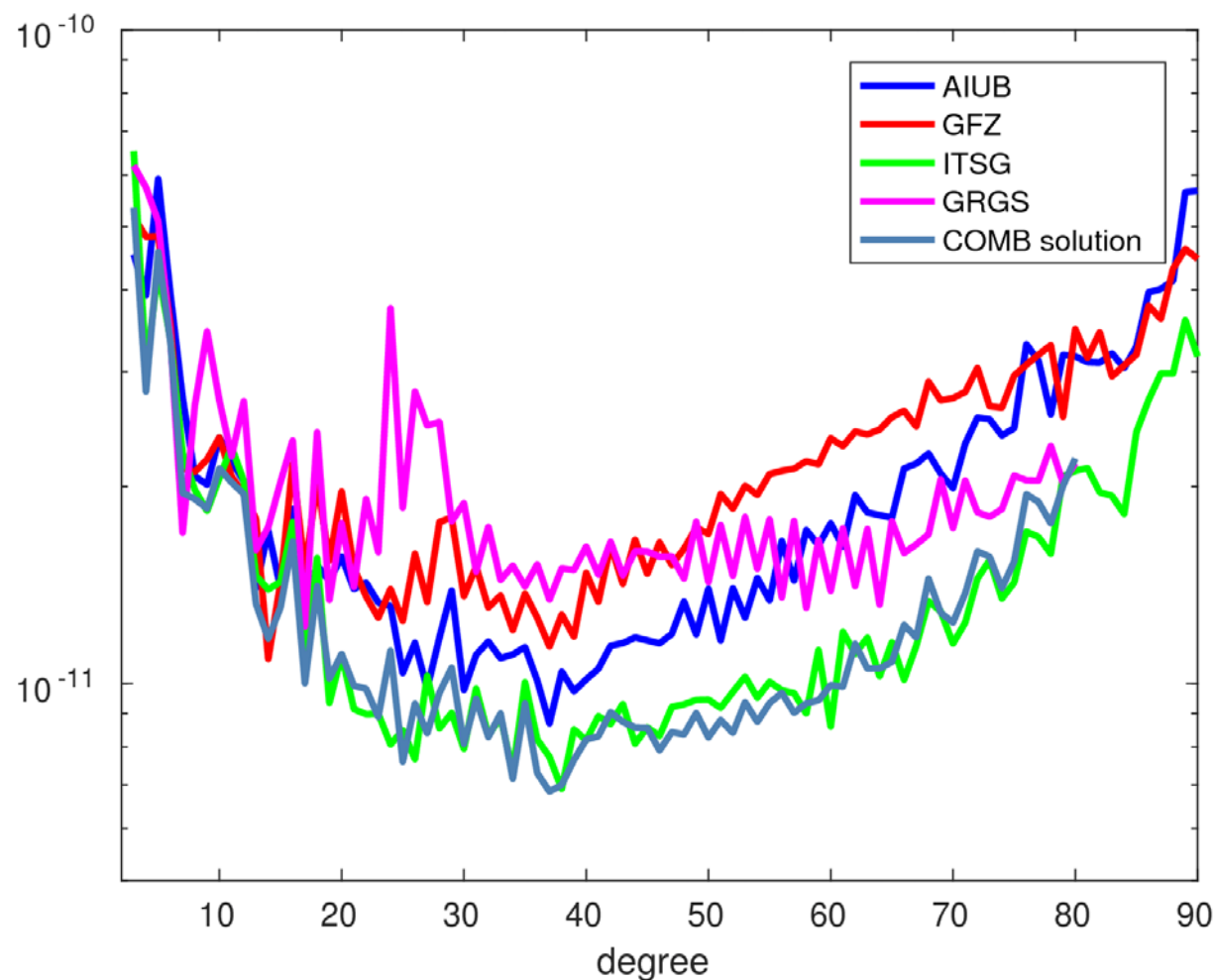


Empirical rescaling to achieve an equal impact is first needed

## equalizing weight

GRGS	1.60
GFZ	1.00
AIUB	7.81
ITSG	2.21

# Combination on Normal Equation Level

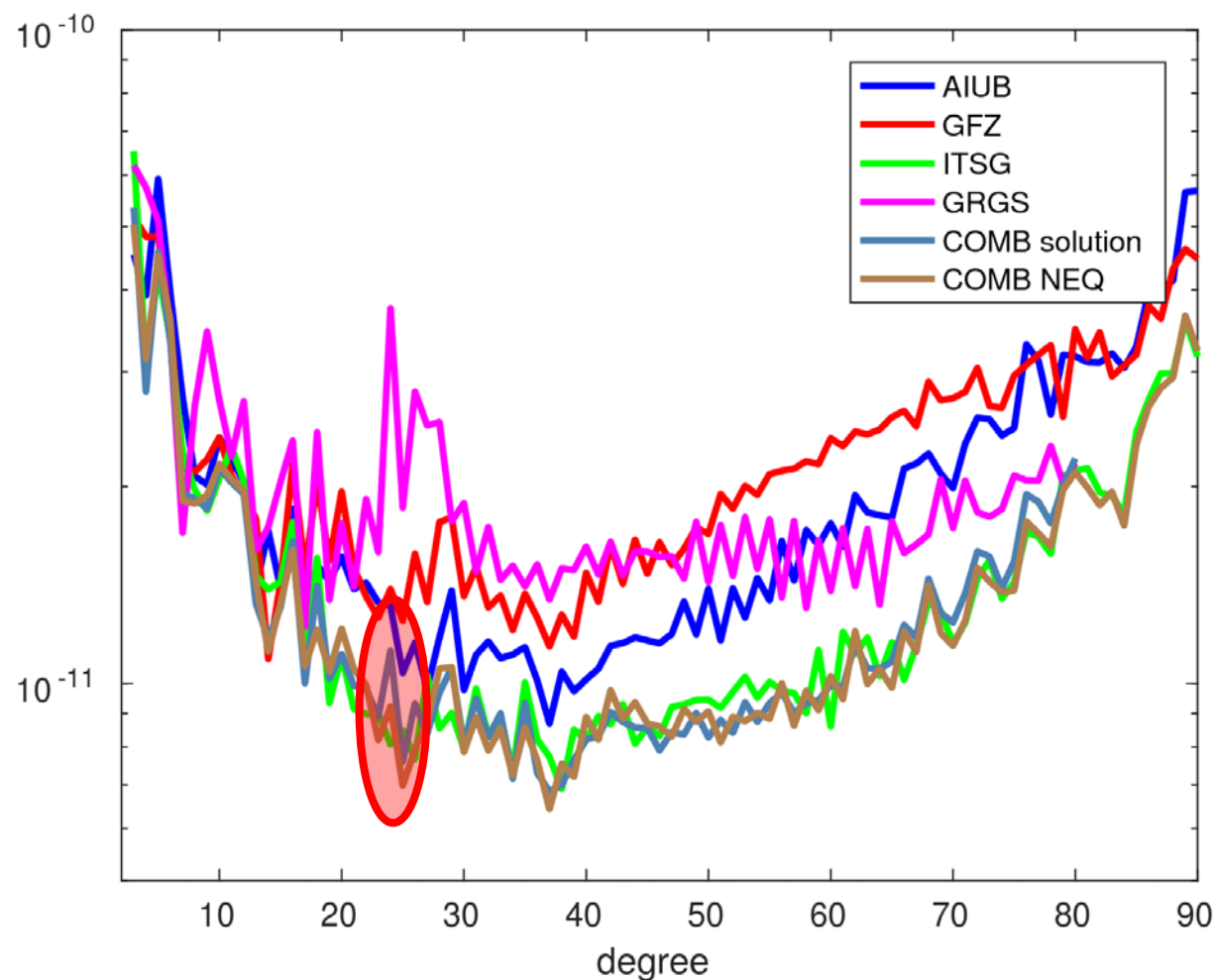


The weights are thus first derived on the solution level using a VCE scheme:

Solution:	weight
GRGS	0.14
GFZ	0.19
AIUB	0.29
ITSG	0.38



# Combination on Normal Equation Level



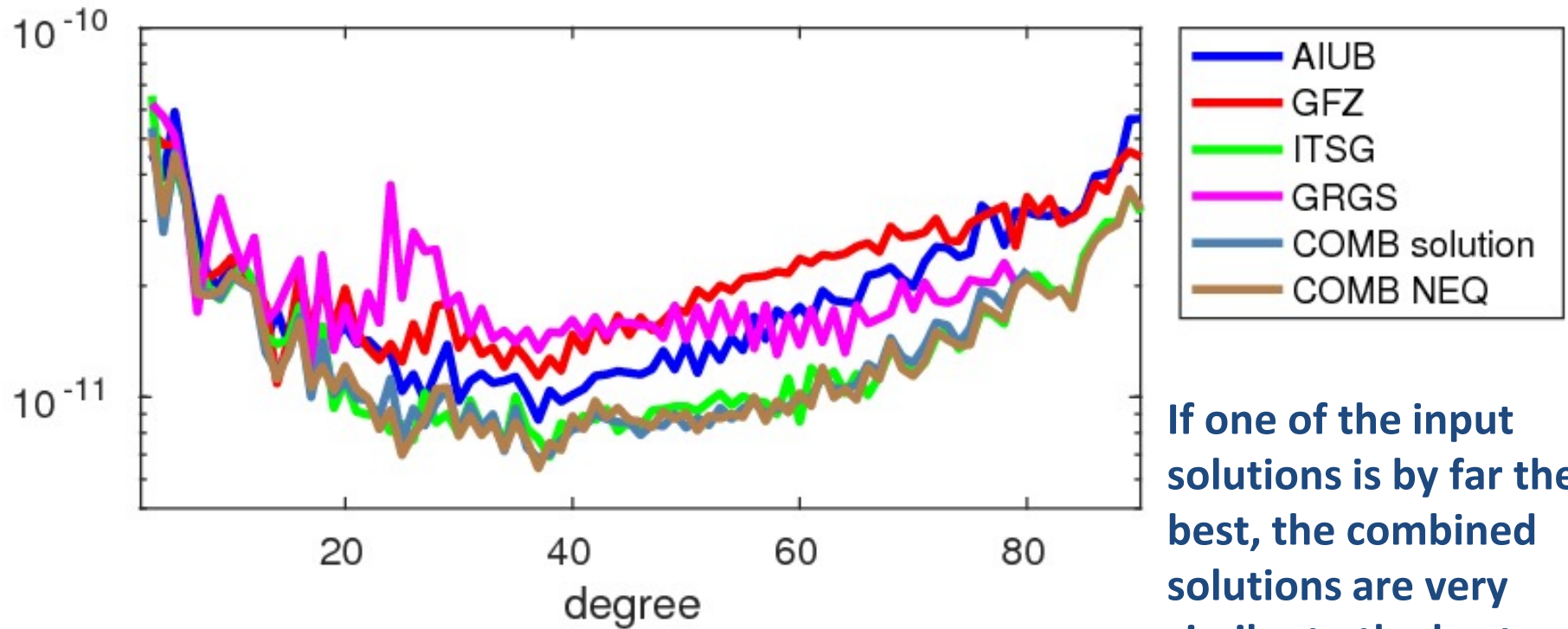
## equalizing weight

GRGS	1.60
GFZ	1.00
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## Solution: weight

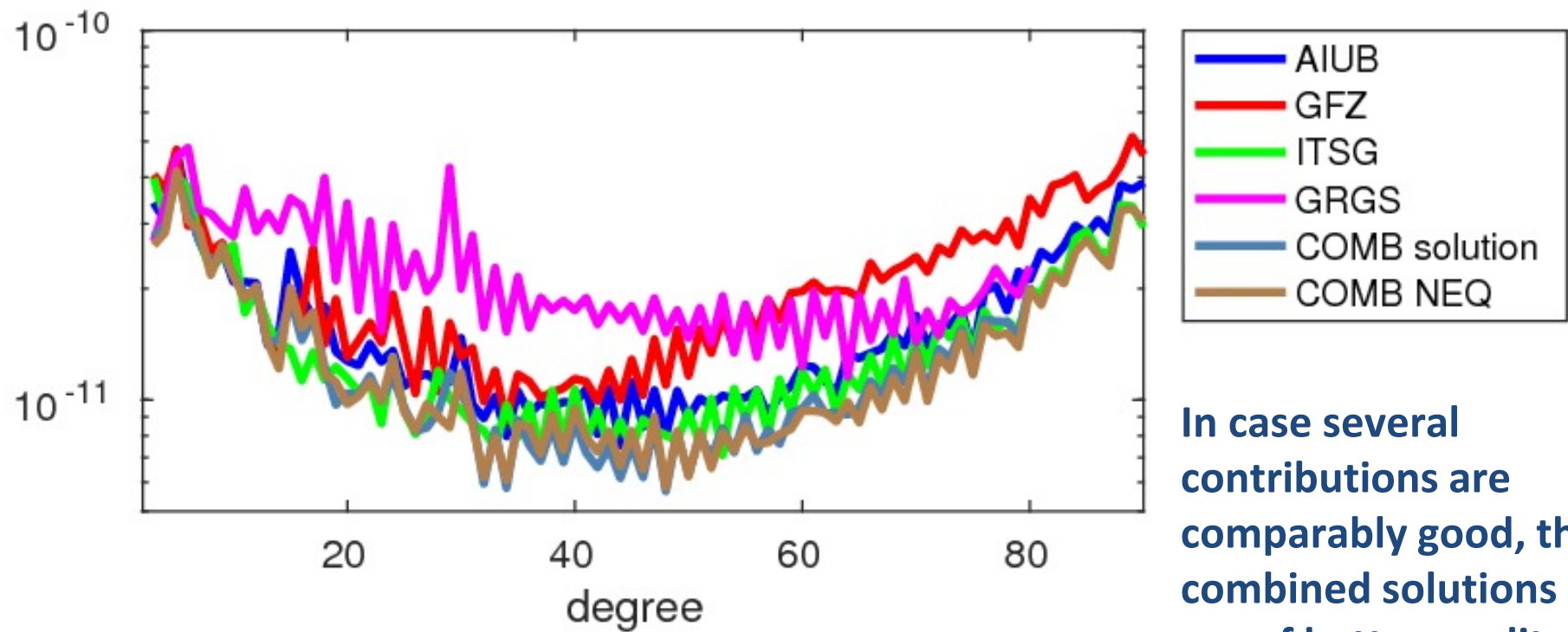
GRGS	0.14
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AIUB	0.29
ITSG	0.38

# 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.

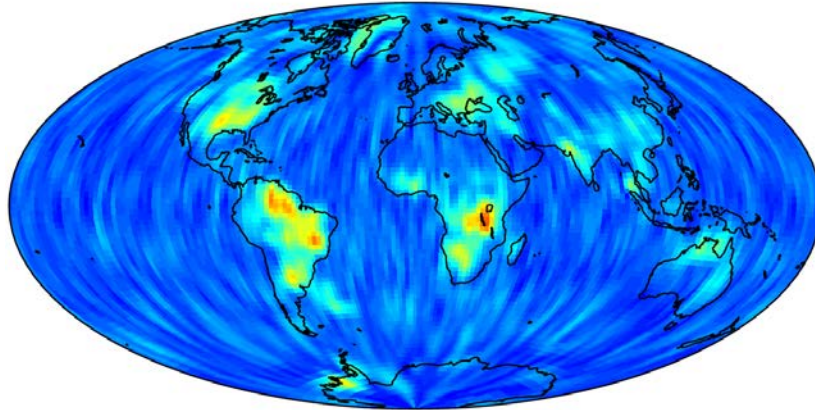
# Combination Examples – Case II



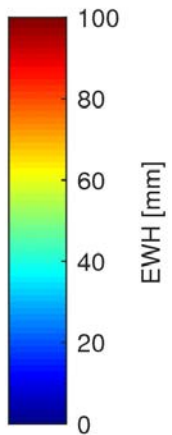
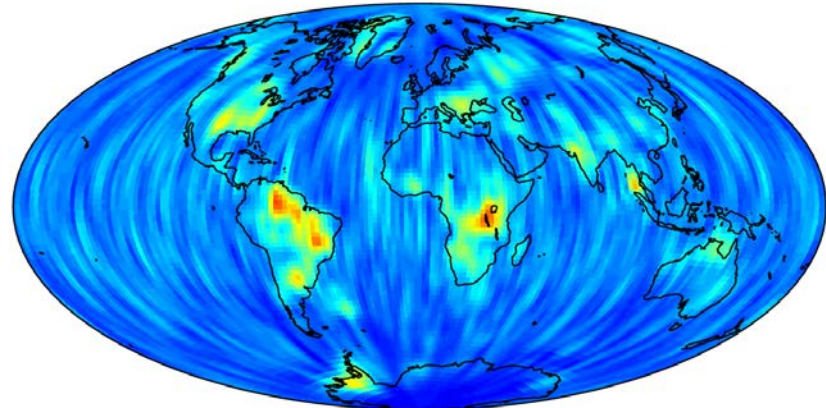
**In case several contributions are comparably good, the combined solutions are of better quality.**

# Validation in the Spatial Domain

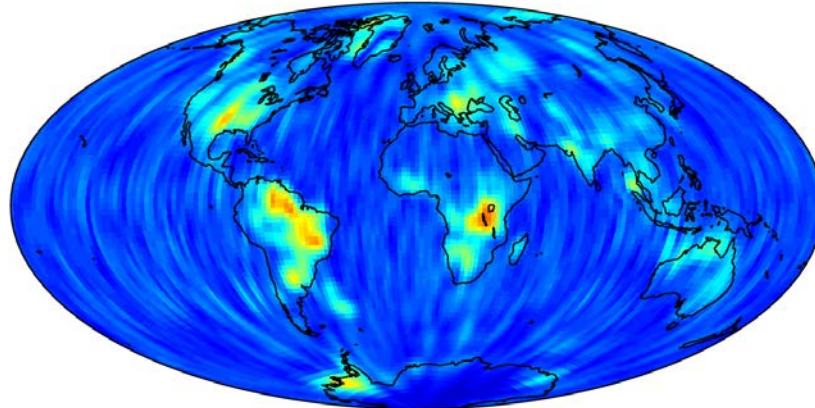
JPL-RL05



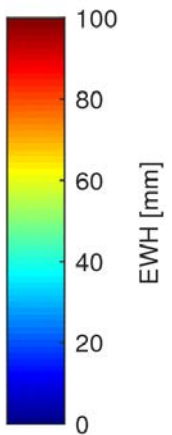
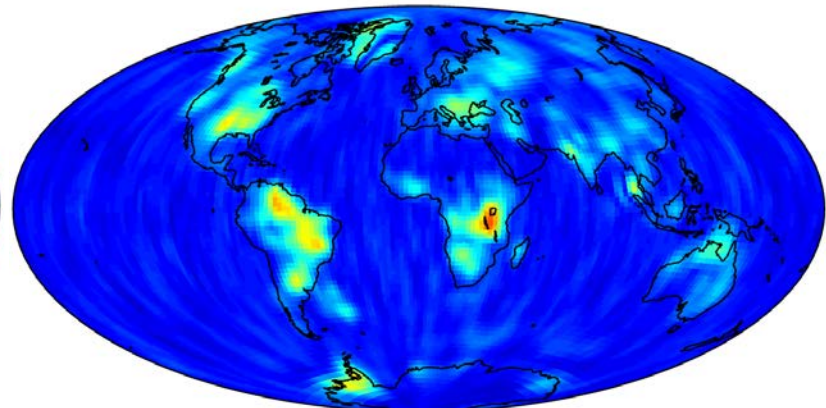
GFZ-RL05a



CSR-RL05

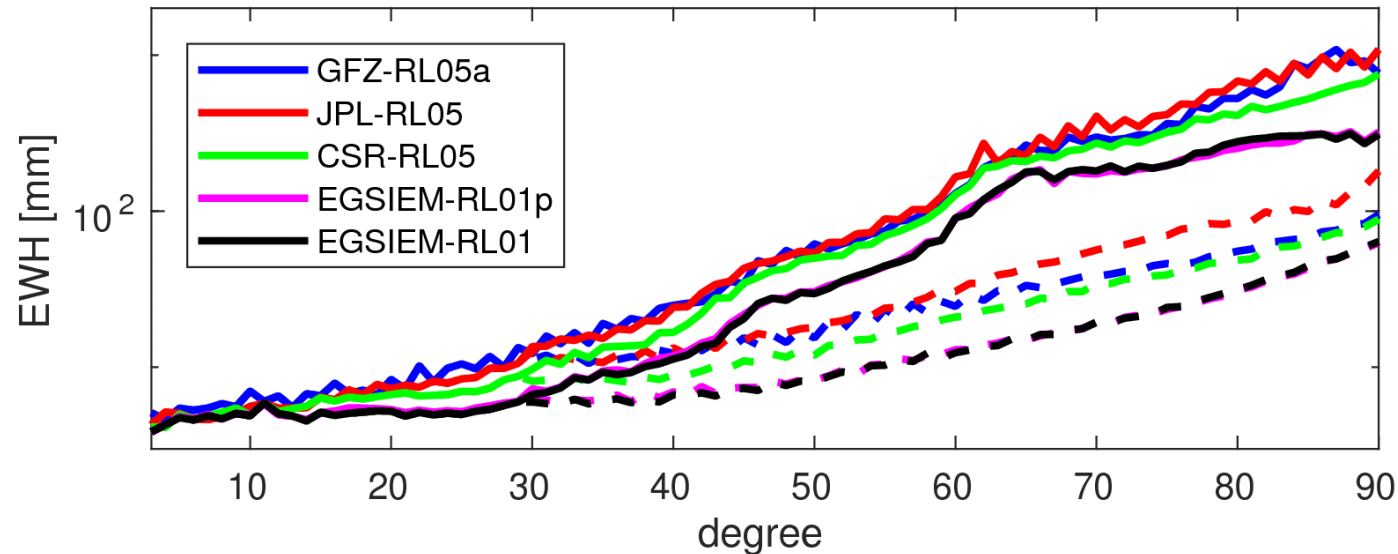


EGSIEM-RL01

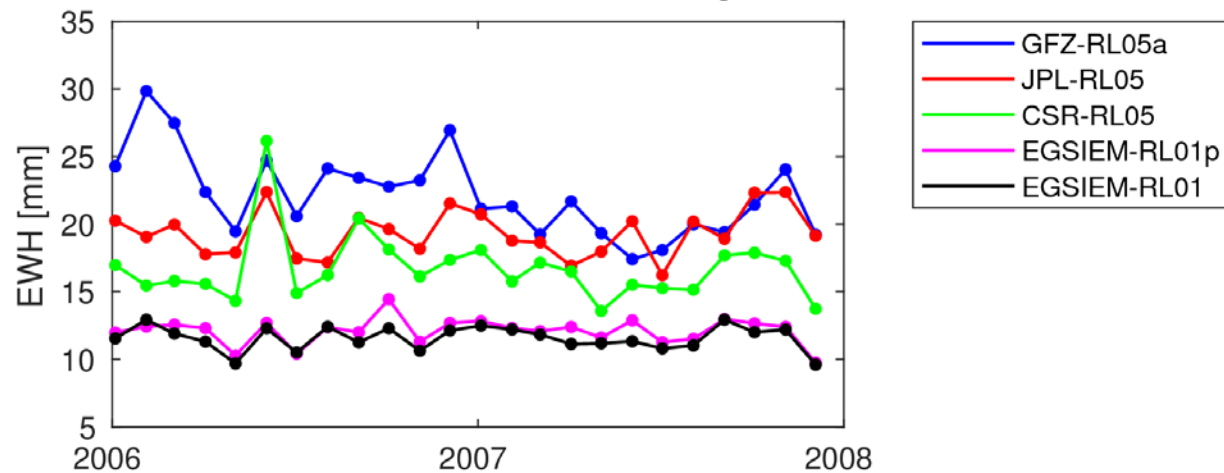




# Validation in the Spectral and Time Domain



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):**

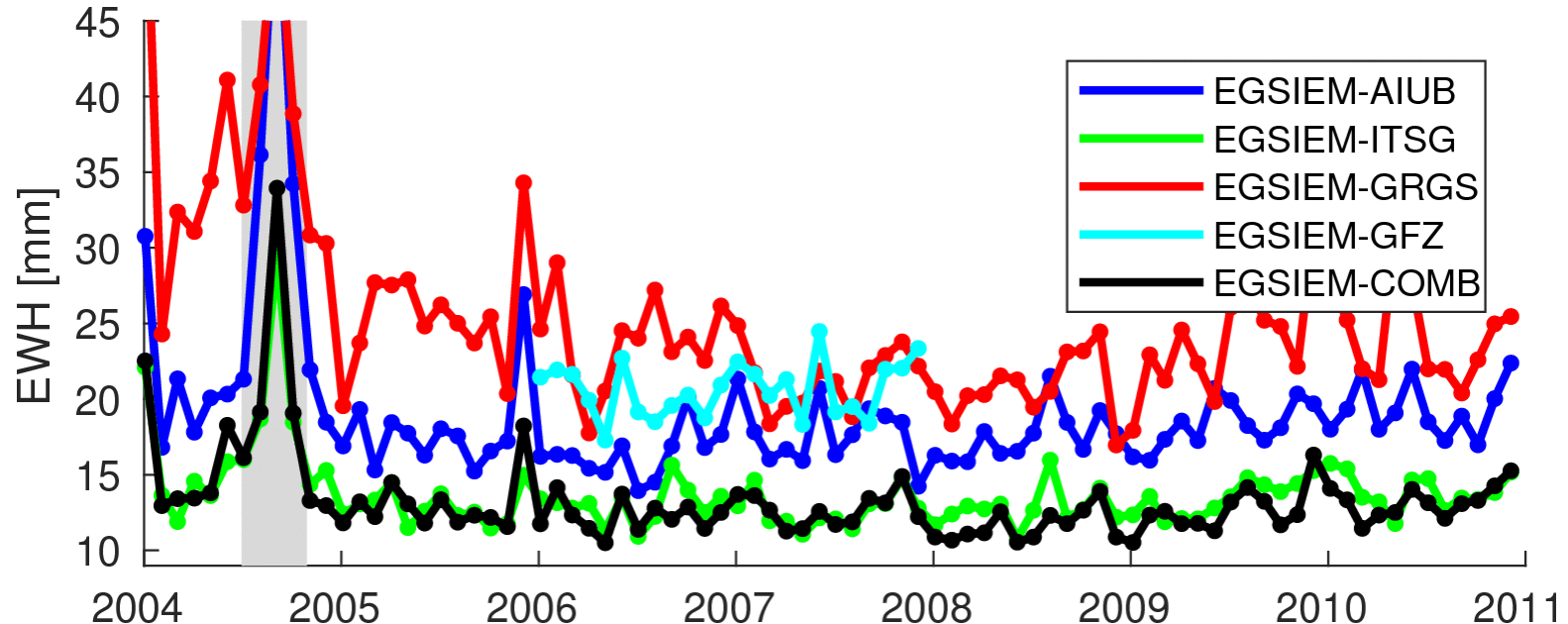
- **AIUB**
- **CSR**
- **CNES**
- **GFZ**
- **JPL**
- **TUG**

**and maybe even more in the future ...**

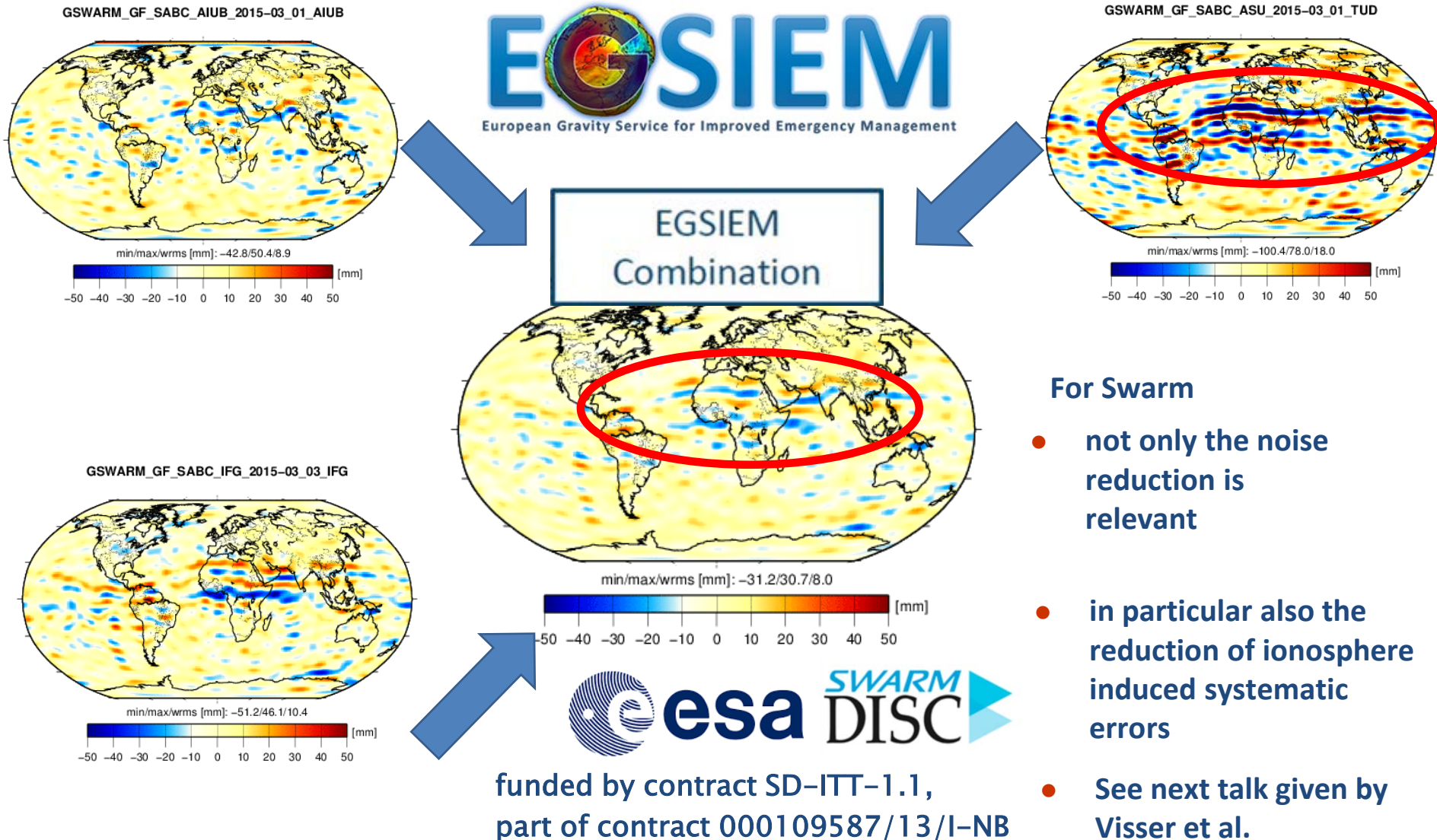
- The EGSIM Scientific Combination Service will be continued as **COST-G** (**CO**mbination **S**ervice of **T**ime-variable **G**ravity field solutions). COST-G will be a Product Center of the International Gravity Field Service (**IGFS**) of the International Association of Geodesy (**IAG**).
- The 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 EGSIM 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





# 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!