EGSIEM: scientific combination service for monthly gravity fields

IGSW 2017: PS07-10
International GNSS Service Workshop
University of Paris-Diderot
3 - 7 July 2017, Paris, France

U. Meyer, Y. Jean, D. Arnold and A. Jäggi

Astronomical Institute
University of Bern, Bern, Switzerland

1 EGSIEM: Gravity Field Combination Service

The Horizon 2020 project European Gravity Service for Improved Emergency Management (EGSIEM) is coordinated by the Astronomical Institute of the University of Bern (AIUB) that also provides the scientific combination service. This service aims at consistent, reliable and validated monthly gravity fields that are combined on solution and on Normal Equation (NEQ) level taking into account contributions of all associated Analysis Centers (ACs), namely

- Astronomical Institute University of Bern (AIUB),
- Groupe de Recherche de Géodésie Spatiale (GRGS),
- Helmholtz Centre Potsdam (GFZ), and
- Institute of Geodesy, Graz (ITSG).

Currently, gravity fields are derived from GRACE K-band and GPS data, but EGSIEM is being extended to also include GPS-only and Satellite Laser Ranging (SLR) solutions. EGSIEM is open to all interested ACs.

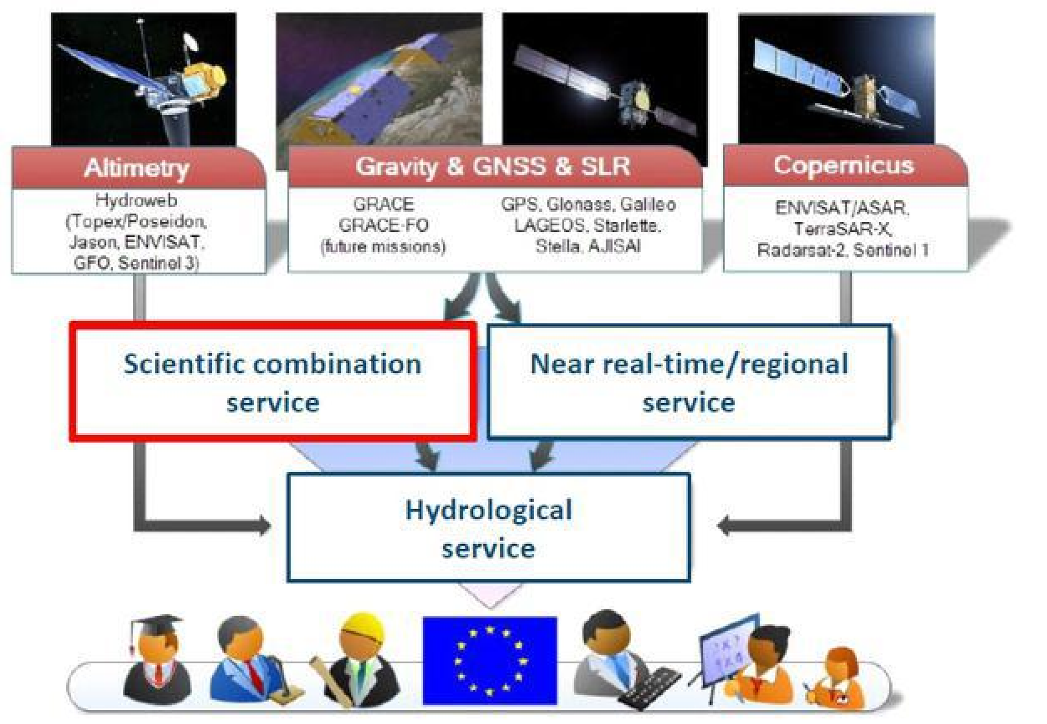


Fig. 1: EGSIEM is installing three services related to temporal gravity field variations. The main goal is early warning in case of floods to improve emergency management.

2 Common Standards

To ensure consistency of the individual contributions, EGSIEM defines common standards on:

- reference frame and orientation,
- satellite geometry,
- relativistic effects and third bodies.

The different ACs are free to use their specific approaches and parametrization and the a priori and background models of their choice of:

- ocean, solid Earth and pole tides,
- atmosphere and ocean de-aliasing (AOD).

In this sense the situation in EGSIEM is comparable to IGS.

3 File Formats

NEQs with gravity field coefficients are exchanged in the Solution INdependent EXchange (SINEX) format. Additional information on Earth Radius, GM and tide system is provided in the SOLUTION/COMMENT block. Monthly gravity fields are provided in spherical harmonic coefficients in the GFC-format maintained by the International Center for Global Earth Models (http://icgem.gfz-potsdam.de/ICGEM-format-2011.pdf).

4 Formal Errors

The formal errors provided by the individual ACs strongly depend on the applied noise models and generally are optimistic and very diverse. Only ITSG is deriving empirical covariances based on K-band residuals, thereby calibrating their formal errors.

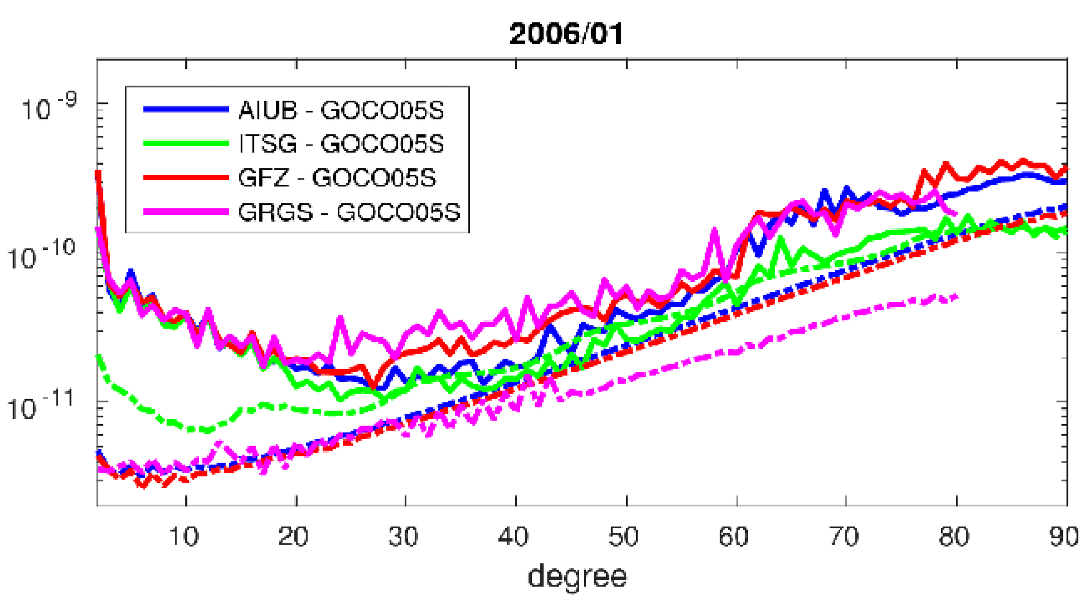


Fig. 2: Degree variances with respect to static reference GOCO05S and formal errors (dashed) of the individual contributions.

5 Noise Assessment

Since formal errors do not represent true noise levels, other measures have to be identified for relative weighting and quality control. We assume that all contributions contain similar signal, but different noise. Relative weights are derived by pair-wise comparison to the monthly mean. Independent quality control is based on anomalies (non-secular, non-seasonal variations) over the oceans or in the high-degree part of the spherical harmonics spectrum.

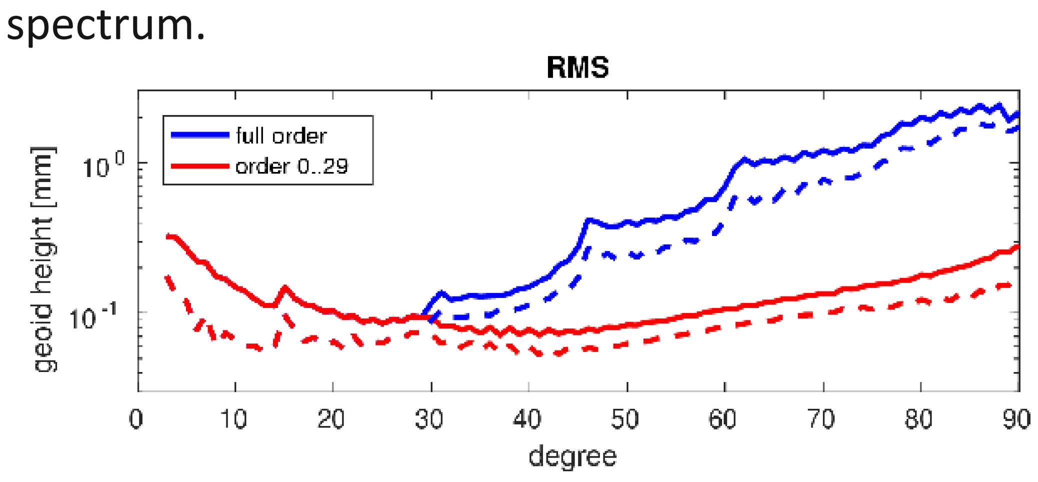


Fig. 3: Spectral representation of anomalies (solid) or differences to mean (dashed) by the RMS of monthly degree amplitudes.

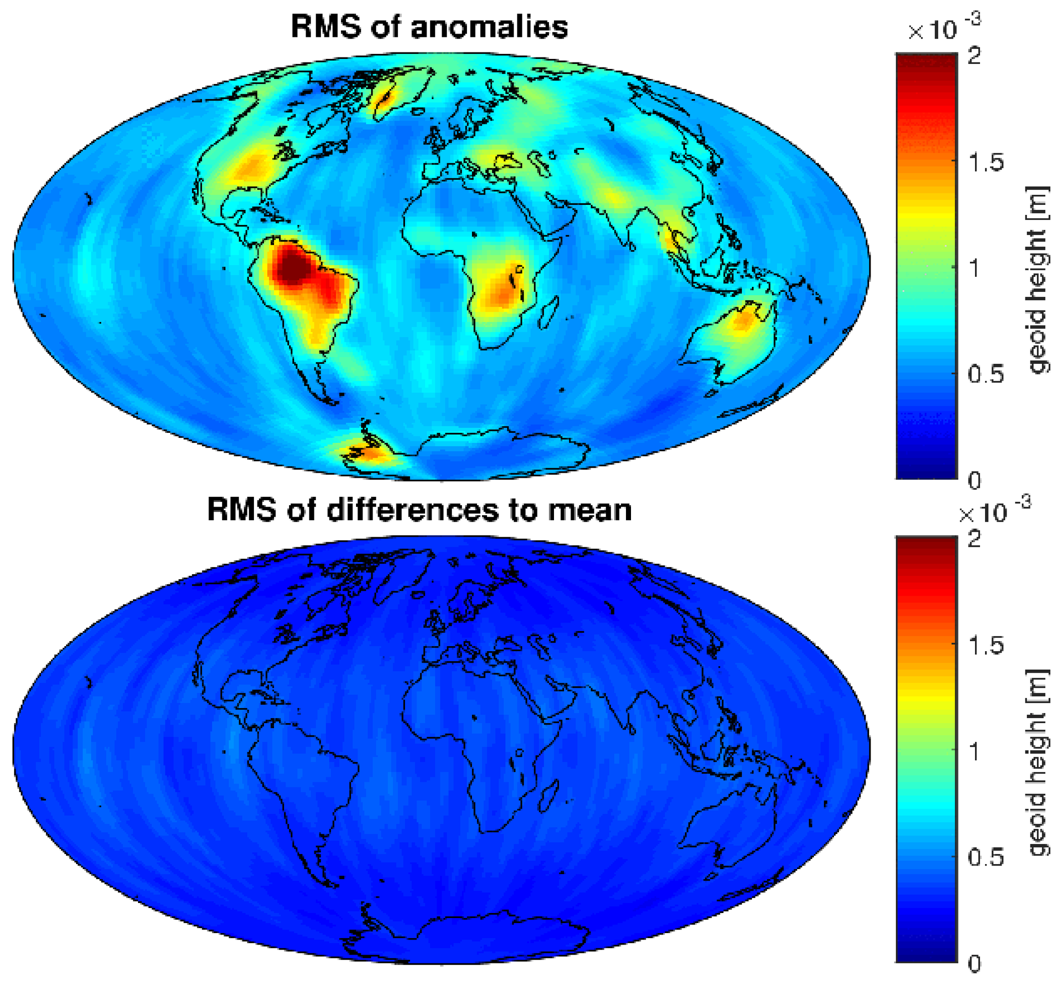


Fig. 4: Spatial distribution of non-secular, non-seasonal signal (anomalies, top) or differences to the arithmetic mean (bottom).

6 Combination on Solution Level

After quality control (tests on signal strength and outlier screening) the monthly gravity fields are first combined on solution level applying field-wise weights derived by Variance Component Estimation (VCE). Therefore simple observation equations are set up:

$$\boldsymbol{A_i x_i} = \boldsymbol{l_i}, \text{ with } \boldsymbol{A_i} = \boldsymbol{I}$$

and the number of observations n_i equal to the number of unknowns m_i. Consequently

$$\boldsymbol{N_i} = \boldsymbol{A_i}^T \boldsymbol{P_i} \boldsymbol{A_i} = \boldsymbol{I}$$

with the simplest possible stochastic model $\boldsymbol{P_i} = \boldsymbol{I}$

Stacking several sets of observations we can compute partial redundancies

$$r_i = m_i - w_i \,\mathrm{Tr}(\boldsymbol{N_i N}^{-1}) = n_i\left(1 - \frac{w_i}{\sum_i w_i}\right)$$

$$\text{with } N = \sum_i w_i \boldsymbol{N_i}$$

The square sum of residuals is

$$\boldsymbol{v_i}^T \boldsymbol{P_i} \boldsymbol{v_i} = \sum (x_i - \bar{x})^2$$

and the iterated weights consequently become

$$\hat{w}_i = \frac{r_i}{\boldsymbol{v_i}^T \boldsymbol{P_i} \boldsymbol{v_i}} = \frac{n_i\left(1 - \frac{w_i}{\sum_i w_i}\right)}{\sum (x_i - \bar{x})^2}$$

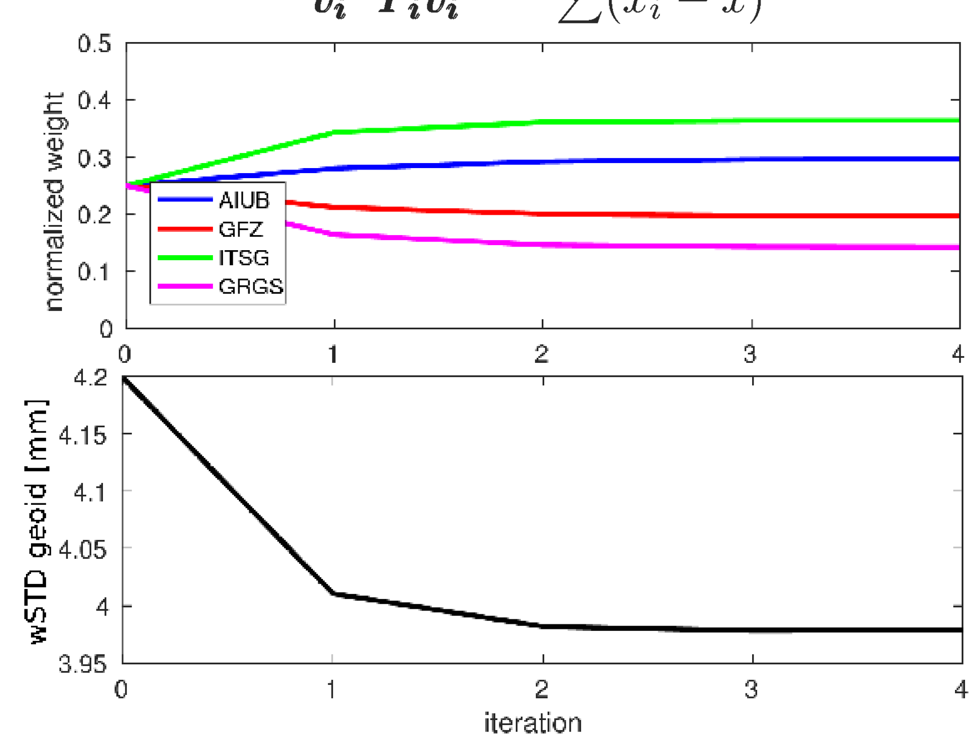


Fig. 5: Weights on solution level are derived iteratively (top). The weighted STD of anomalies over the oceans indicates noise.

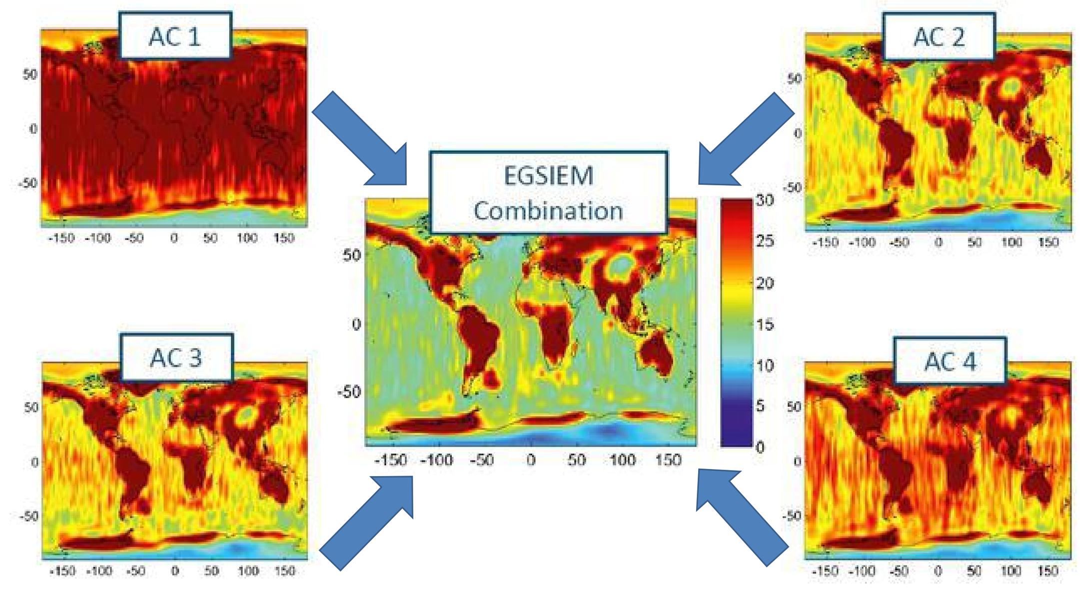


Fig. 6: Noise reduction (visible over oceans) achieved by combination of monthly gravity fields.

The combined fields already show significant improvement in terms of the noise level over the oceans, while the signal strength over the continents is maintained due to rejection of regularized solutions (quality control). This iterative combination is in principle also applicable to IGS orbit or clock products.

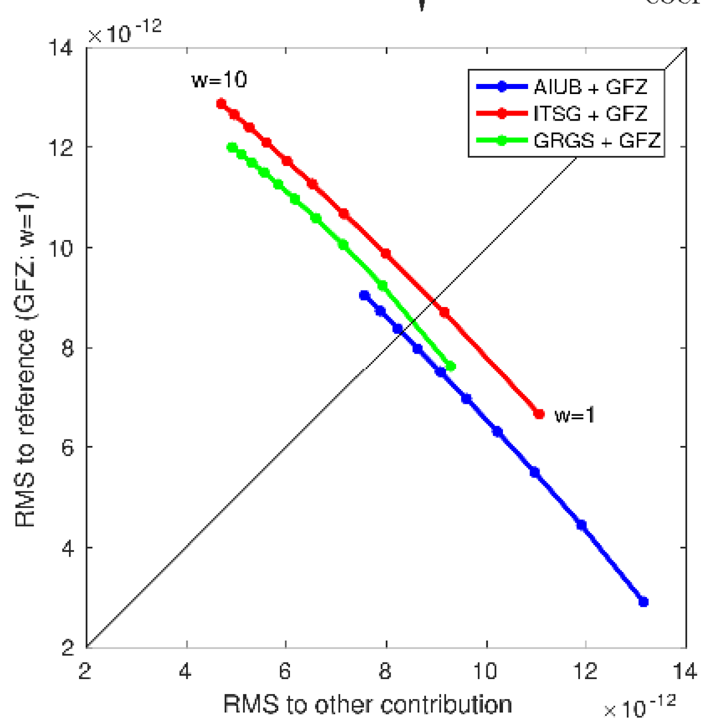
7 Combination of Normal Equations

In the final combination of NEQs, the relative weights derived by noise analysis on solution level are applied. Prior to this combination the impact of each NEQ $\boldsymbol{N_i}$ on the combination is equalized by empirical weights w_i based on the analysis of pair-wise combinations:

$$(\boldsymbol{N}_{\mathrm{ref}} + w_i \boldsymbol{N}_i)\boldsymbol{dx} = \boldsymbol{b}_{\mathrm{ref}} + w_i \boldsymbol{b}_i$$

The impact of an individual contribution on the combination is computed as the RMS of all differences between the spherical harmonic coefficients $K_{l,m}$ of the combined and the individual gravity fields:

$$\mathrm{RMS}_i = \sqrt{\frac{\sum_{l,m}(K_{l,m}^{\mathrm{comb}} - K_{l,m}^i)^2}{n_{\mathrm{coef}}}}$$



Equal impact is achieved for:

$$\frac{\mathrm{RMS}_i}{\mathrm{RMS}_{\mathrm{ref}}} = 1$$

Fig. 7: Equal contribution of individual NEQs is achieved prior to final combination by empirical tests of pair-wise combinations.

NEQ combination in IGS is realized for CRD and ERP.

8 Combination Results

The two years 2006 and 2007 were chosen to develop and test the combination strategy and to validate the results. In case of heterogeneous quality the combined fields reach at least the quality of the best individual contribution. In case of more homogeneous quality both, the combinations on solution level and on NEQ level, are clearly superior to the individual contributions in terms of noise. The combination on NEQ level is slightly more robust against artifacts in an individual contribution.

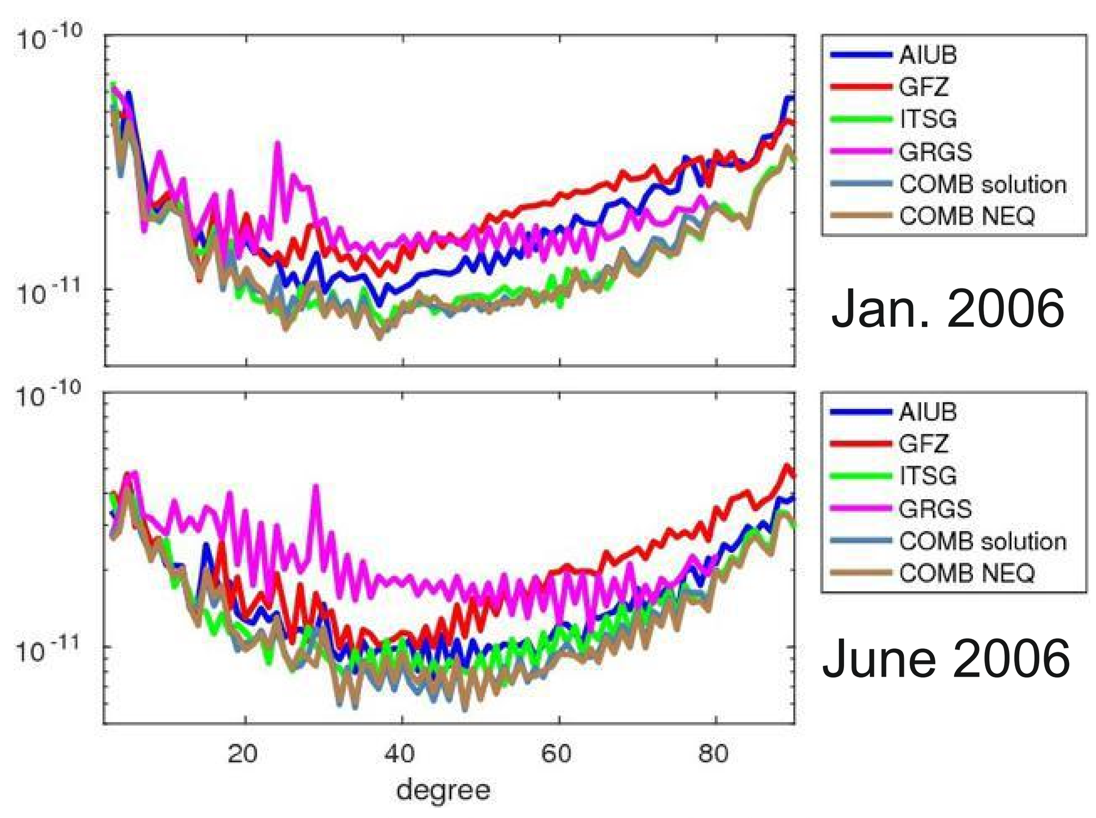


Fig. 8: Degree amplitudes of anomalies of individual contributions and combined monthly gravity fields for January 2006 (top) and June 2006 (bottom).

References: Jean Y, Meyer U, Jäggi A (2017): Combination of GRACE monthly gravity field solutions from different processing strategies. Submitted to JoG.

AIUB

Posters and other publications from the AIUB Satellite Geodesy Group: http://www.bernese.unibe.ch/publist

UNIVERSITÄT BERN

Acknowledgment: This research was supported by the European Union's Horizon 2020 research and innovation program under the grant agreement No. 637010. All views expressed are those of the authors and not of the Agency.

European Commission

EGSIEM