EGSIEM combination of GRACE monthly gravity fields

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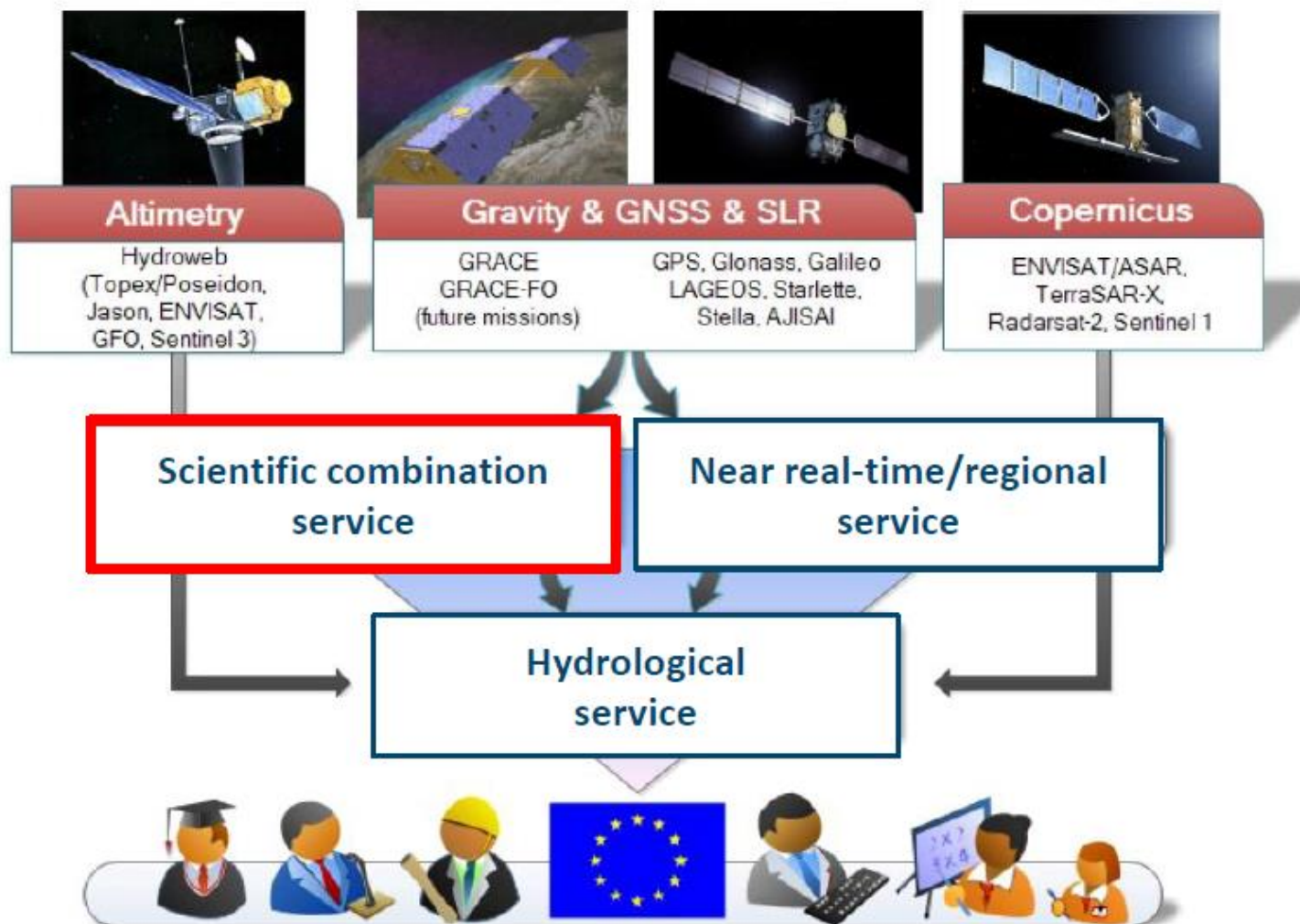[3] Institute for Theoretical and Satellite Geodesy, TU Graz
[4] Groupe de Recherche de Géodésie Spatiale, Toulouse
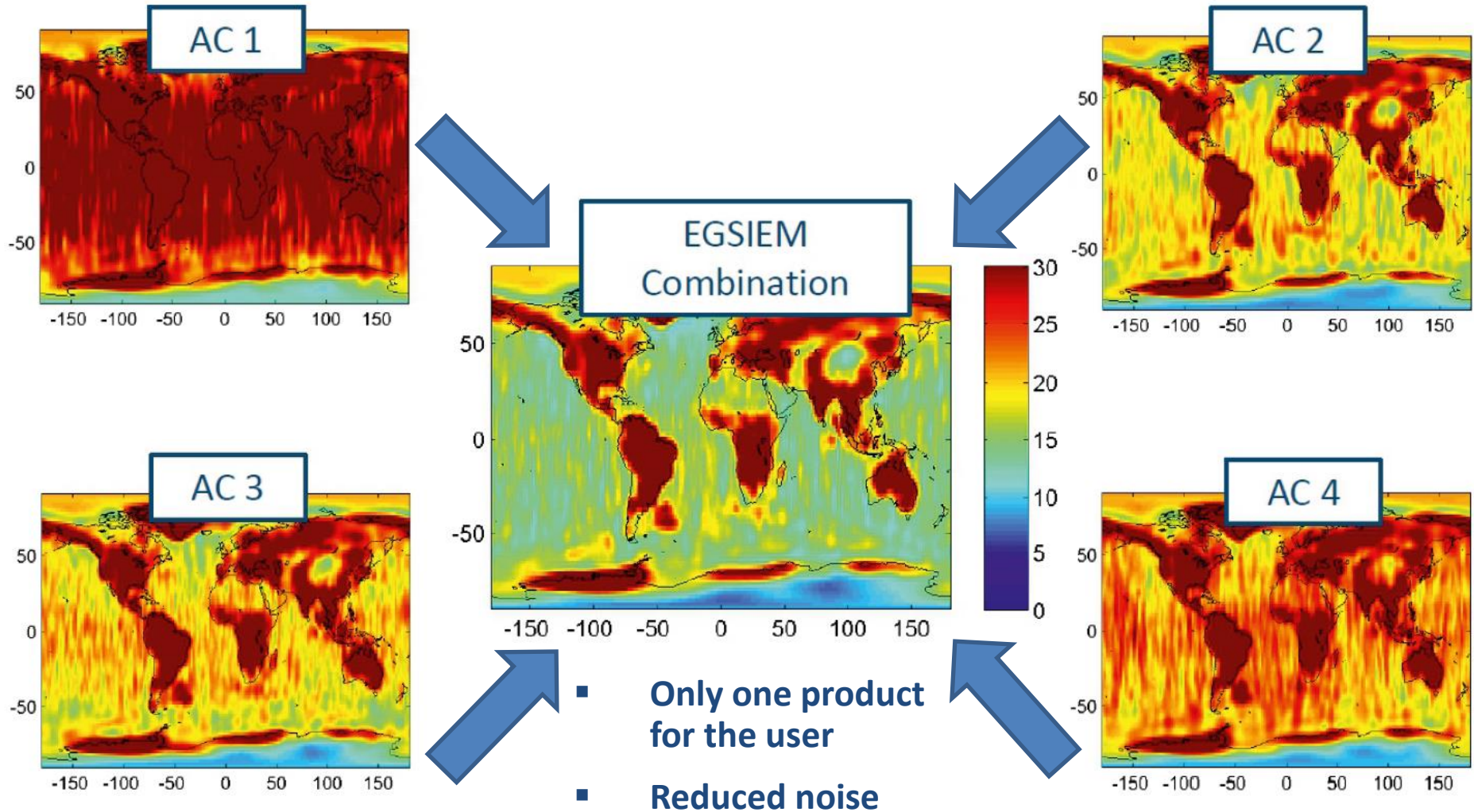
GRACE Science Team Meeting 2016

GFZ Potsdam
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EGSIEM Project – Three services shall be established

Scientific Combination Service

AC 1

AC 2

EGSIEM Combination

AC 3

AC 4

- Only one product for the user
- Reduced noise

Scientific Combination Service

- The EGSIEM combination service provides monthly GRACE K-band gravity fields combined on solution / normal equation (NEQ) Level.

- To ensure consistency, a set of common standards for reference frame, Earth rotation, force model and satellite geometry were defined.

- EGSIEM lately was extended to also include SLR and GPS-only NEQs.

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

EGSIEM Standards

- Reference frame: reprocessed GPS-constellations and high-rate clock corrections.

- Earth rotation: IERS 2010

- Force model:
    - relativistic corrections (Schwarzschild, Lense-Thirring, de Sitter)
    - Sun and all planets as point masses

- Satellite geometry: common antenna reference points

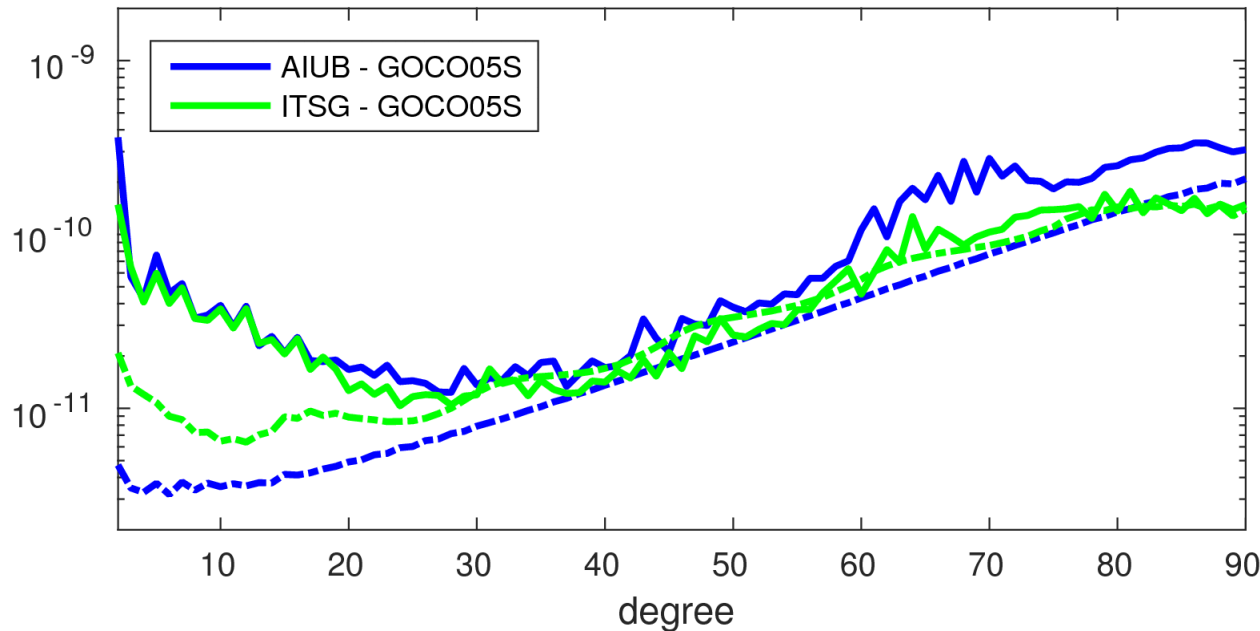# Individual Contributions: AIUB

2006/01
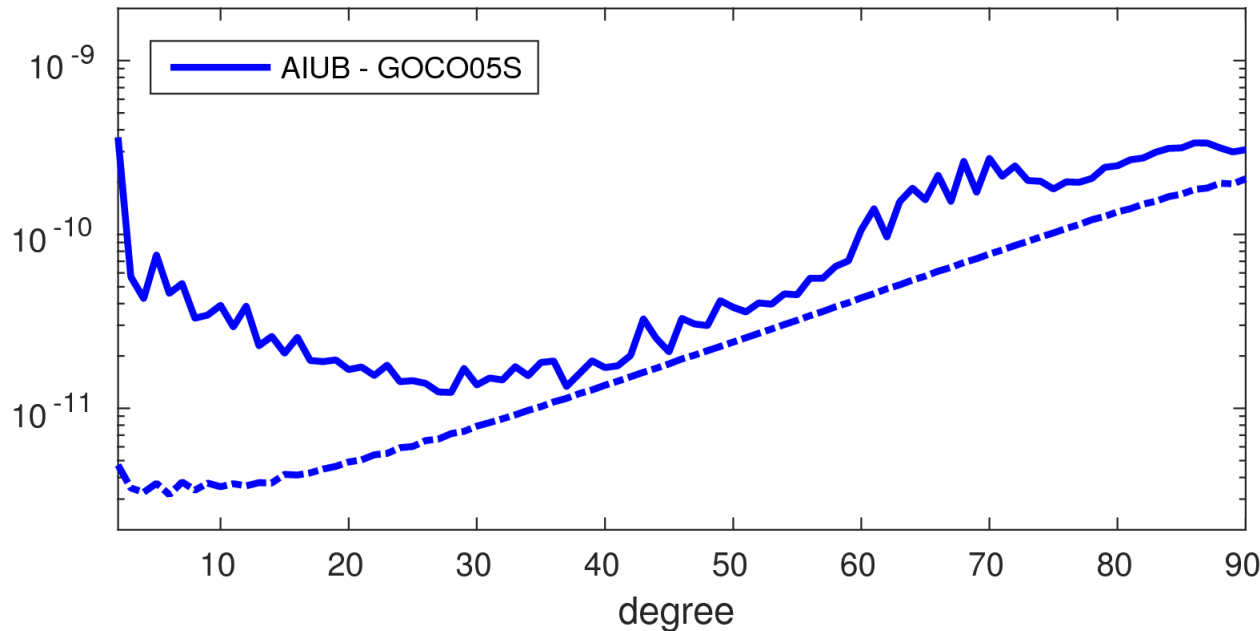
- **AIUB:** Celestial mechanics approach (dynamic approach relying on frequent pseudo-stochastic accelerations)
  - approx. 500000 KRR observations and
  - 500000 kinematic positions (30s) / month
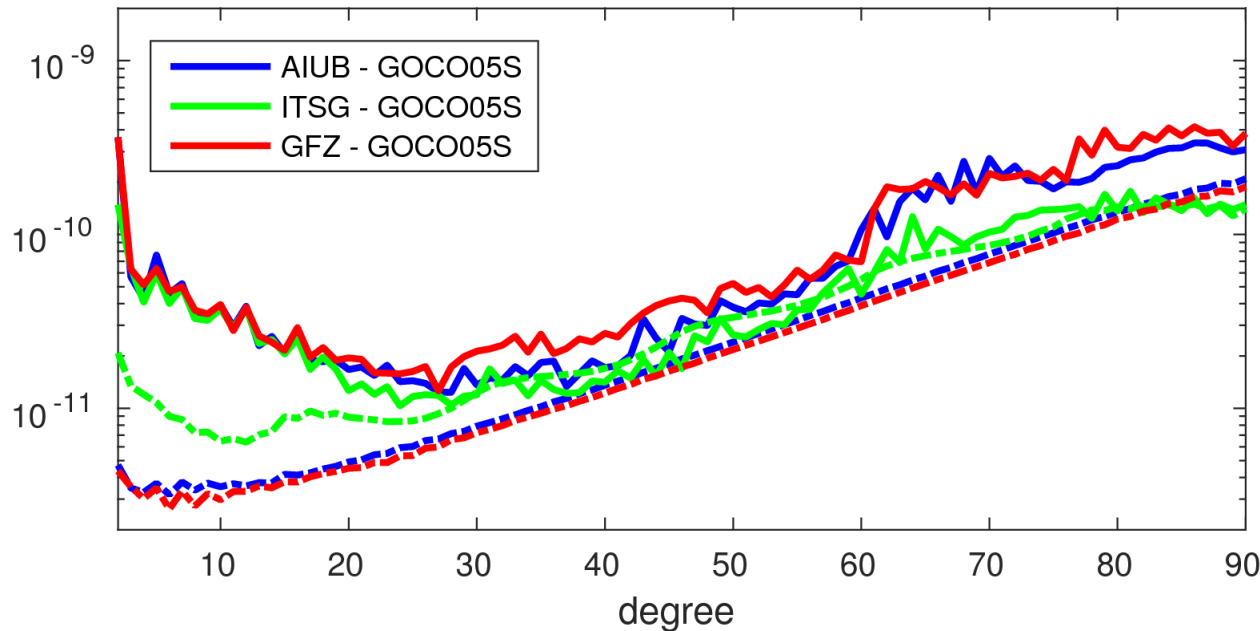
Individual Contributions: ITSG

2006/01

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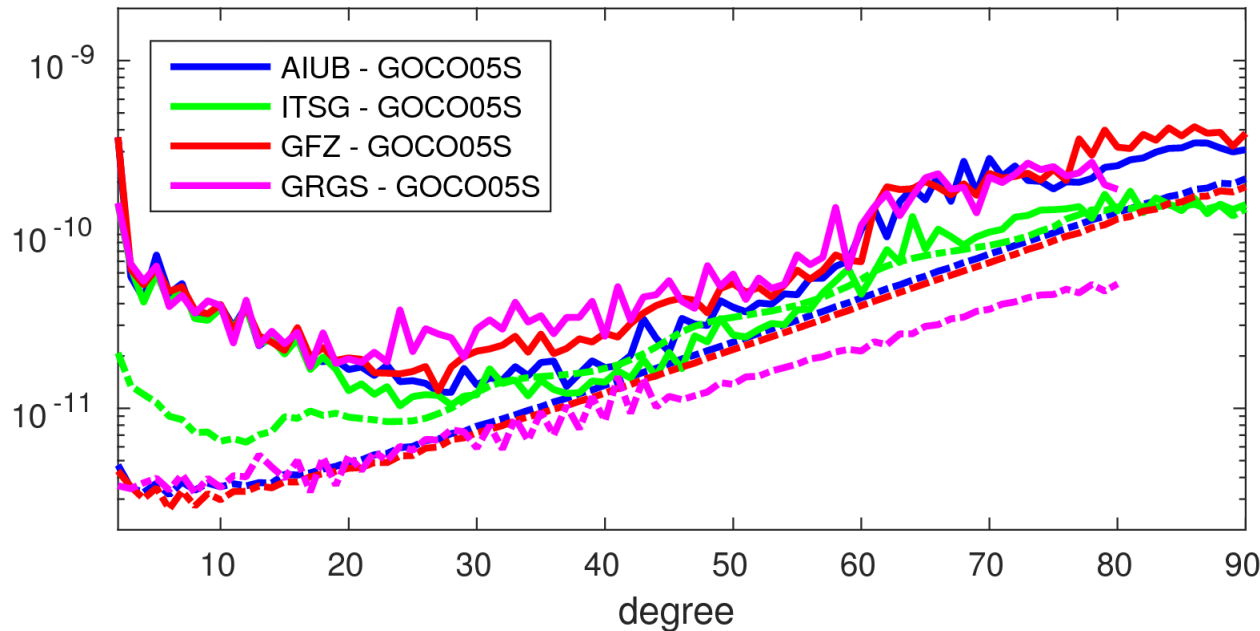
Individual Contributions: GFZ

2006/01

- **GFZ:** dynamic approach, dense accelerometer parametrization
  - **approx. 500000 KRR observations and**
  - **> 2500000 GPS observations (30s) / month**
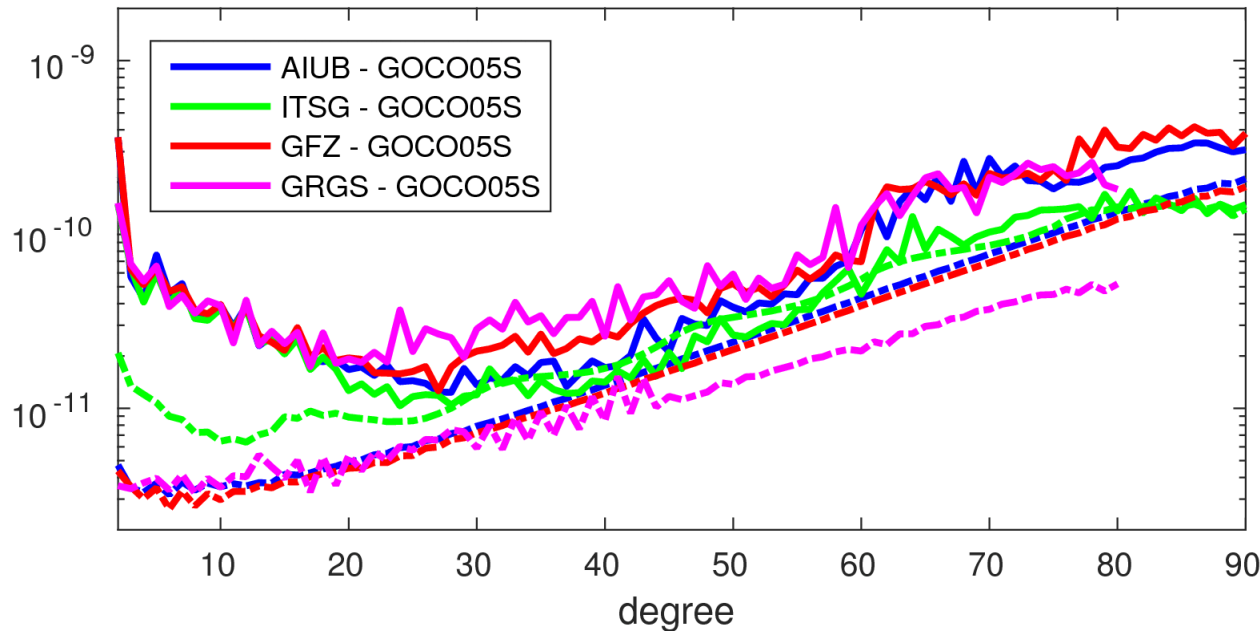
Individual Contributions: GRGS

2006/01

- **GRGS:** magic approach … but we got free (unconstrained) normal equations and solutions for combination!

    – **approx. 500000 KRR observations**

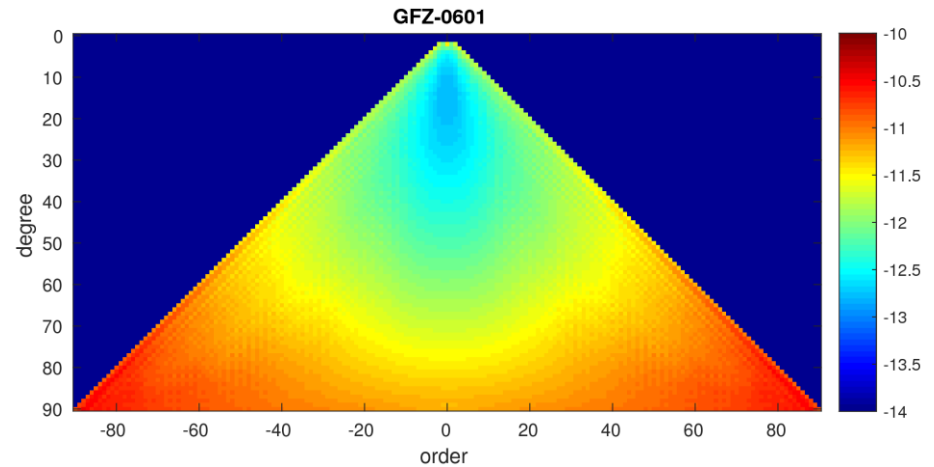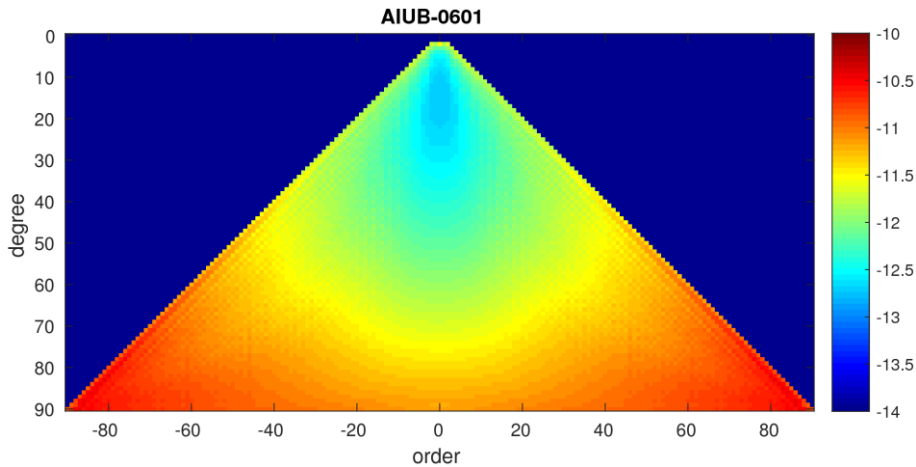   – **500000 kinematic positions (30s) / month**

Individual Contributions: U Lux

2006/01

- **U Lux:** acceleration approach, still under development …

Formal errors: 2006/01

AIUB-0601

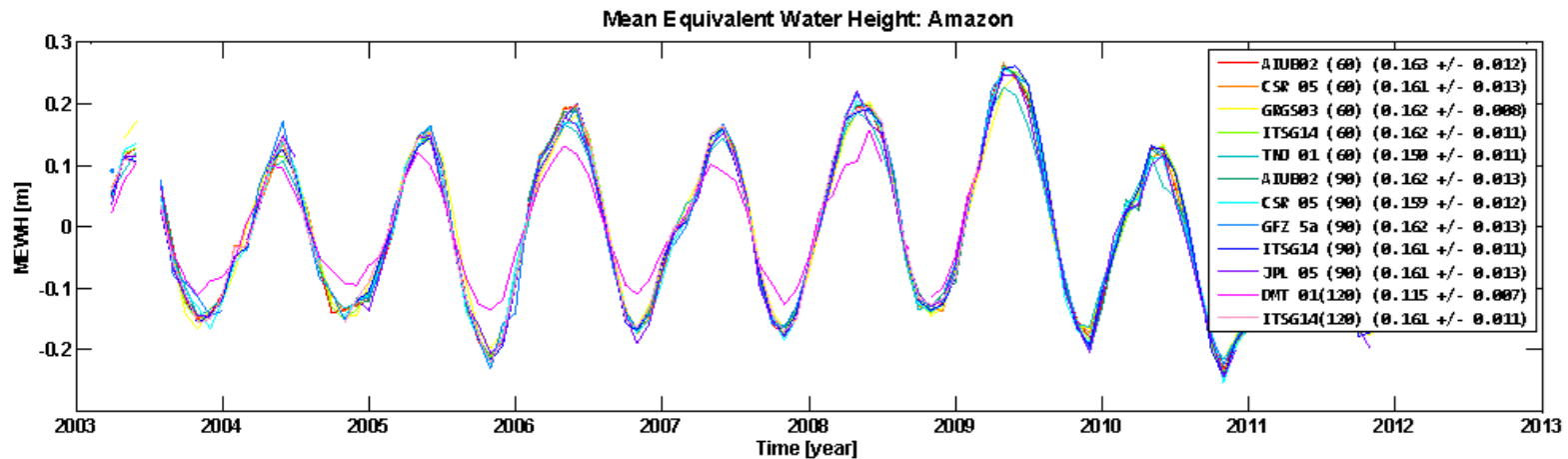GFZ-0601

Contains main part of signal
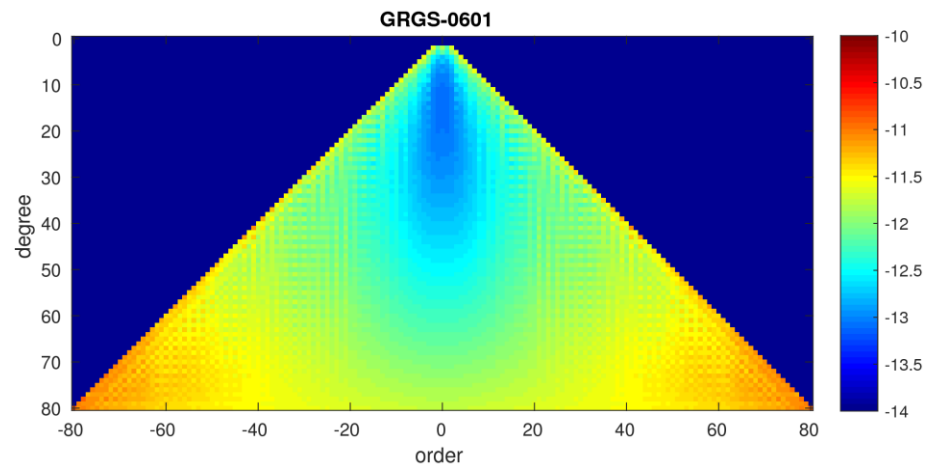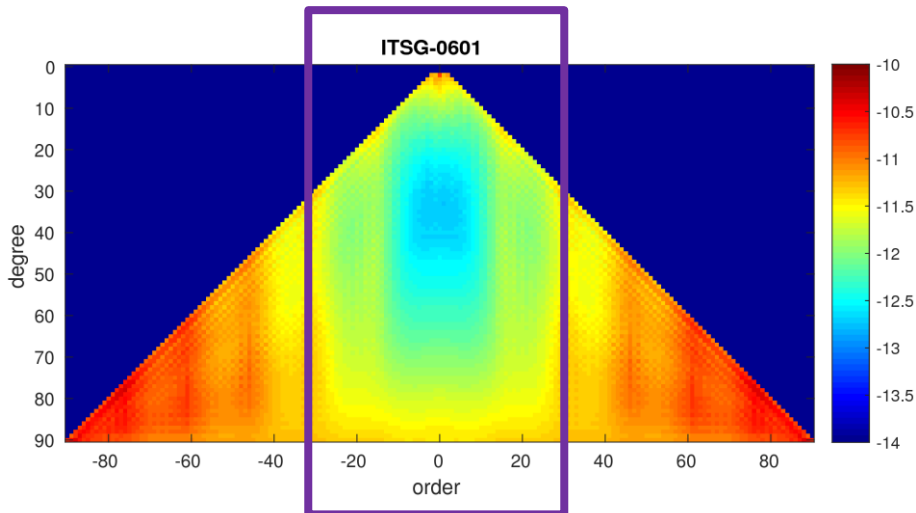
ITSG-0601

GRGS-0601

Combination on Solution Level

- ## Comparison of individual contributions
  - ### Signal content: river basins, Greenland, west Antarctica

Mean Equivalent Water Height: Amazon

Combination on Solution Level

- ## Comparison of individual contributions
  - **Signal content: river basins, Greenland, west Antarctica**
  - **Noise level: weighted STD of anomalies (with respect to model: bias + trend + annual + semian.) over the oceans**

wSTD over the Oceans (Unfiltered, Degree 60)

Legend:
- AIUB 02   (60)   (0.125423)
- CSR 05   (60)   (0.134465)
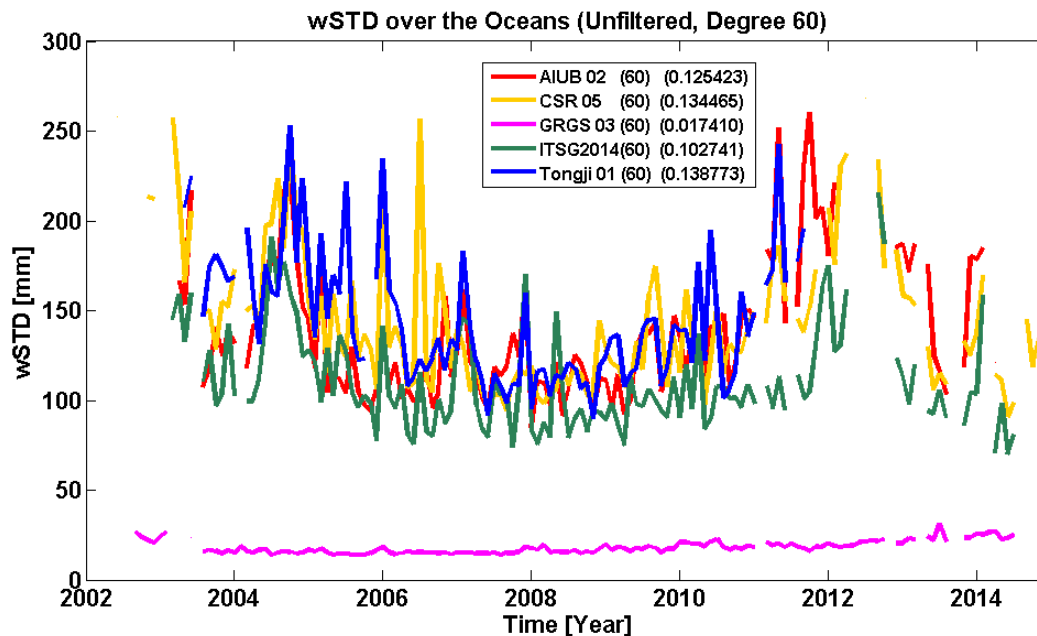- GRGS 03 (60) (0.017410)
- ITSG2014(60) (0.102741)
- Tongji 01 (60) (0.138773)

Combination on Solution Level

- Comparison of individual contributions
  - **Signal content: river basins, Greenland, west Antarctica**
  - **Noise level: weighted STD of anomalies (with respect to model: bias + trend + annual + semian.) over the oceans**

- Rejection of biased series of gravity fields (regularized, pre-filtered)

- Screening of noisy monthly gravity fields

- Relative weights based on comparison to mean

- Iteration using Variance Component Estimation

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.
- **But:** different noise models make combination difficult. Relative weighting by variance factors is not possible!

$$W = S_0^2 * DOF / v^T P v$$
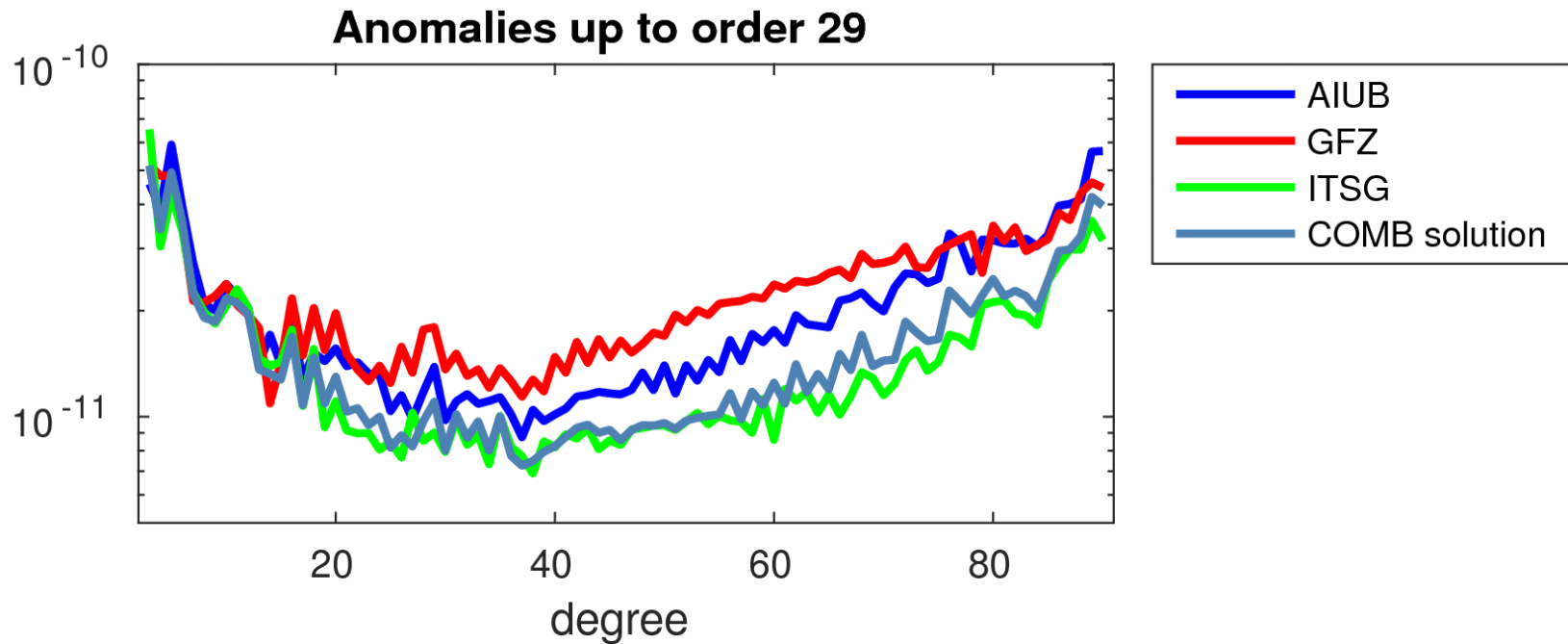
Combination: 2006/01

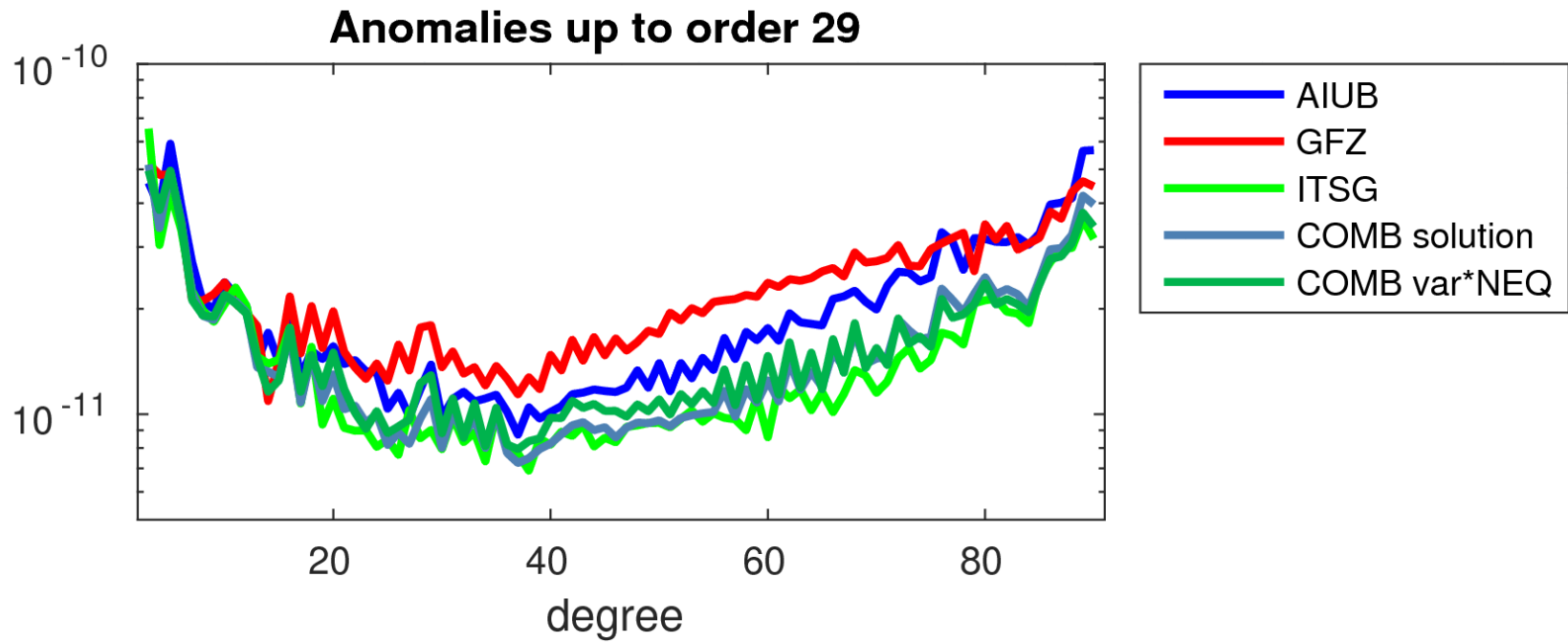Anomalies up to order 29
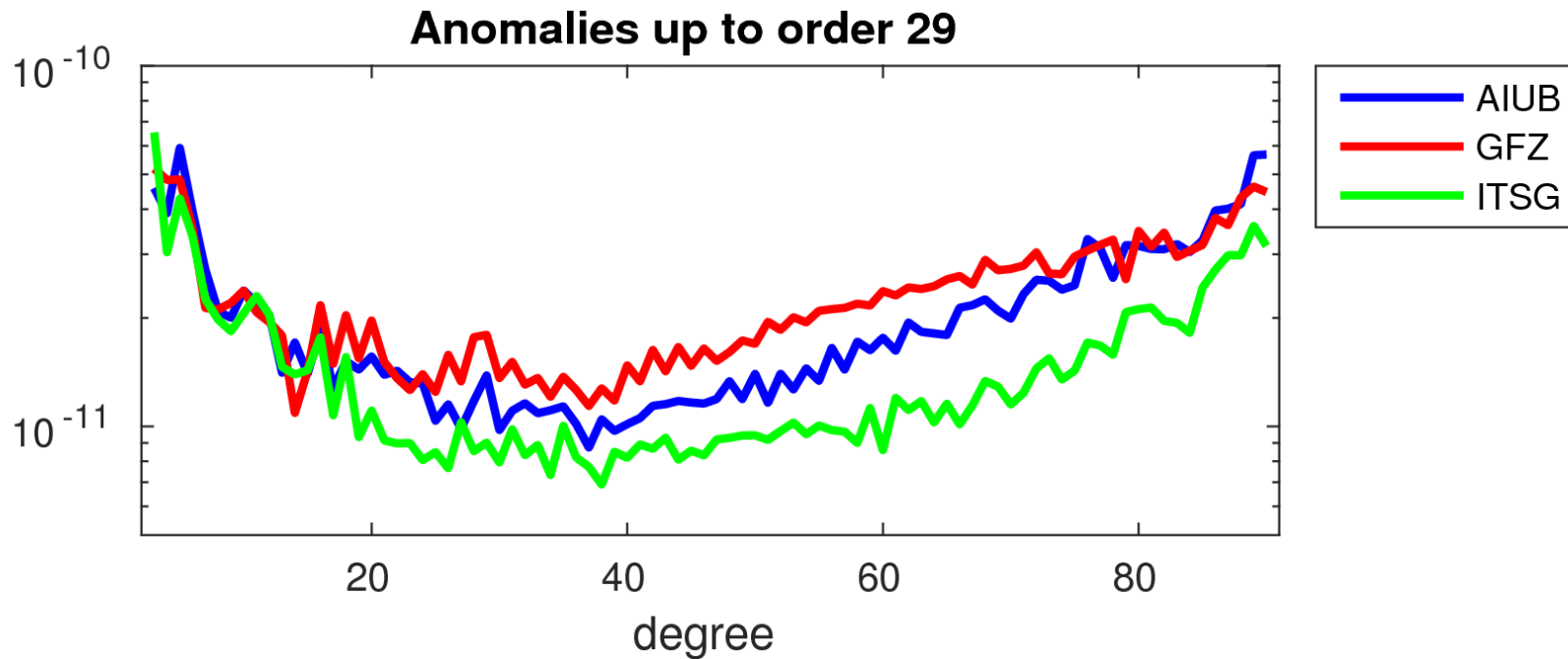
	AIUB	GFZ	ITSG	COMB sol	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.45	0.22	0.33				
wSTD	7.7 mm	9.6 mm	4.7 mm				

Combination: 2006/01

Anomalies up to order 29

	AIUB	GFZ	ITSG	COMB sol	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.45	0.22	0.33				
wSTD	7.7 mm	9.6 mm	4.7 mm	5.8 mm			

Combination: 2006/01

Anomalies up to order 29

	AIUB	GFZ	ITSG	COMB sol	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.45	0.22	0.33				
wSTD	7.7 mm	9.6 mm	4.7 mm	5.8 mm	6.6 mm		

Individual contributions (variance factors): 2006/01
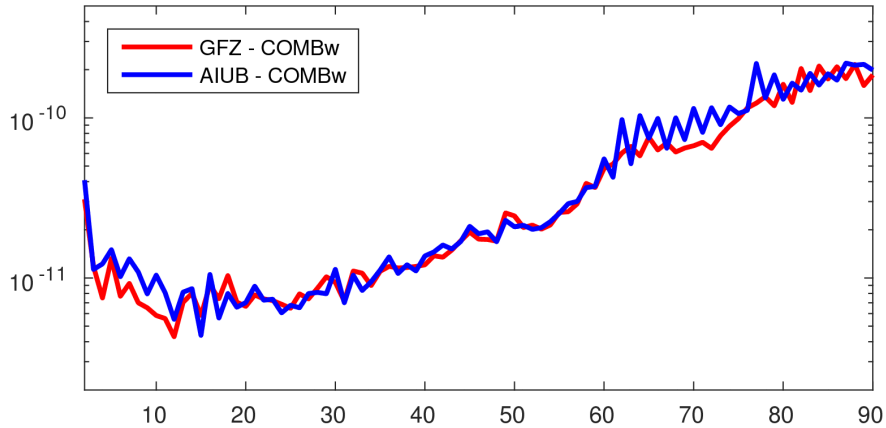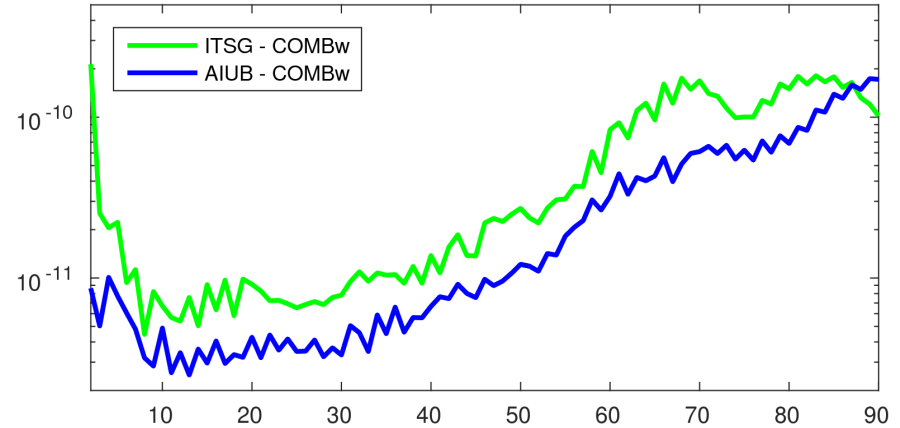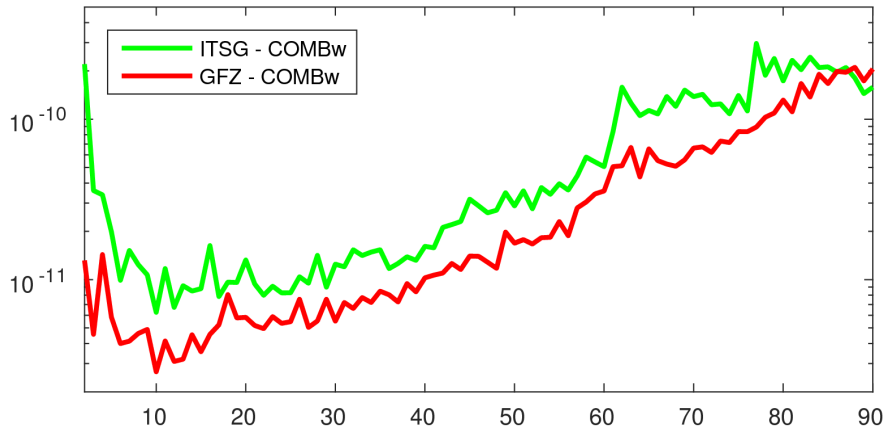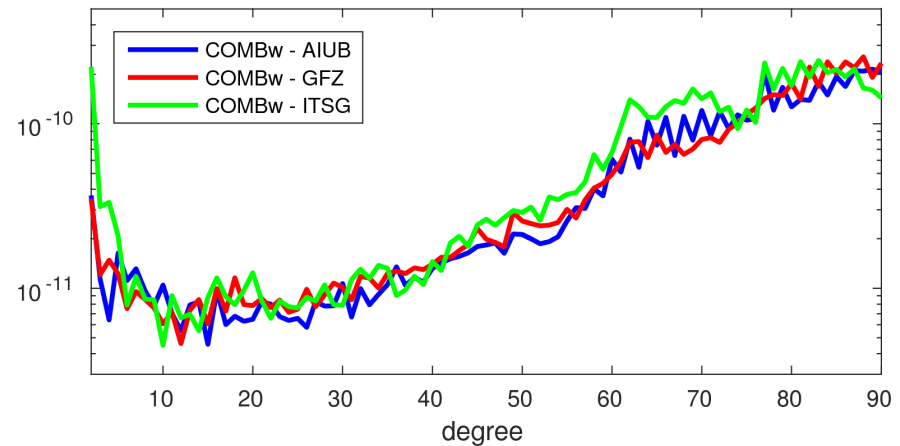
Individual contributions (equalized): 2006/01
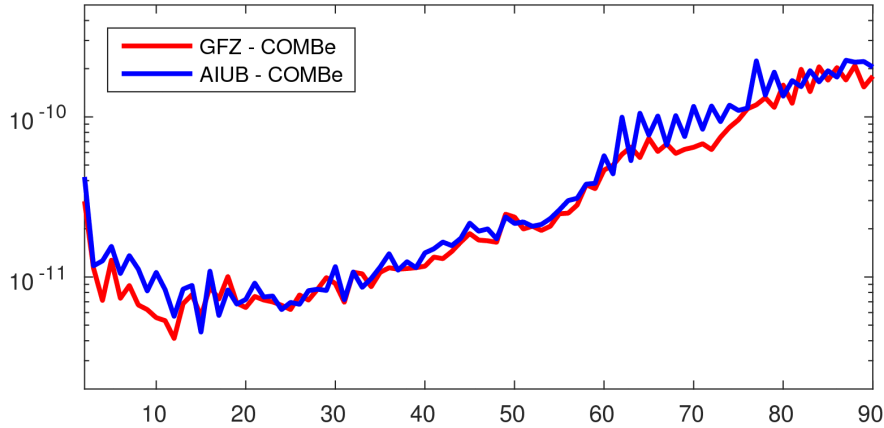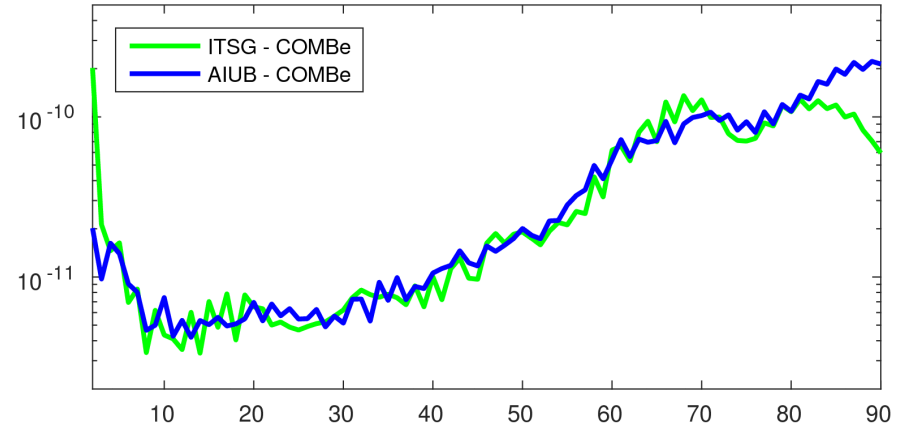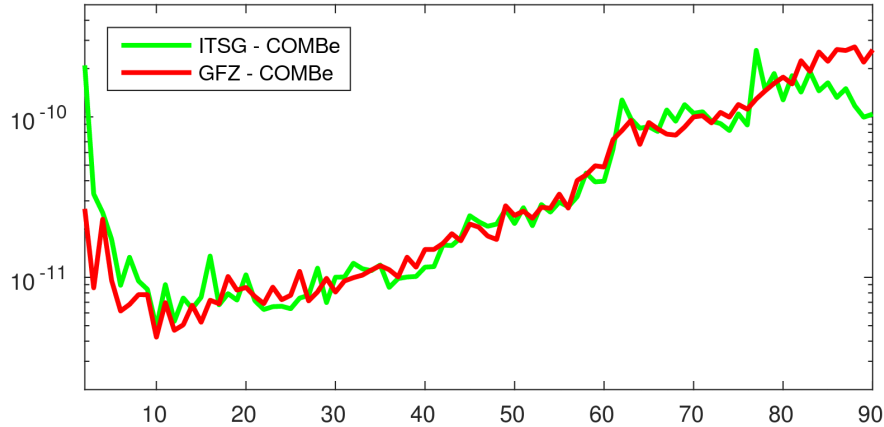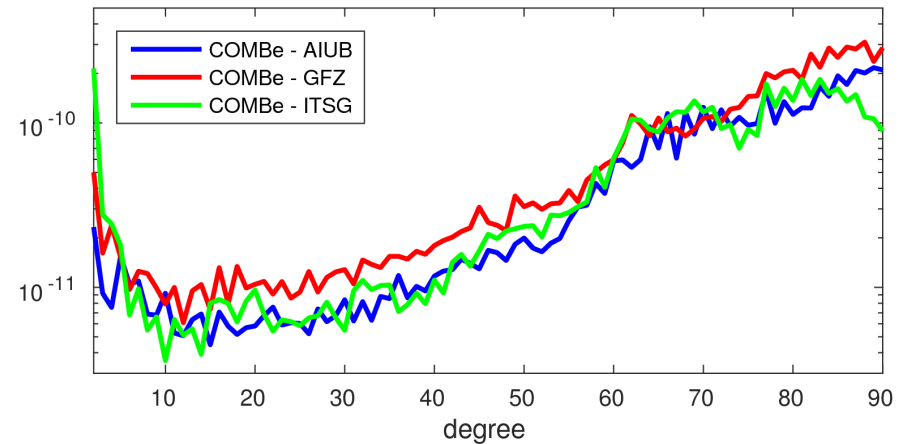
Combination: 2006/01
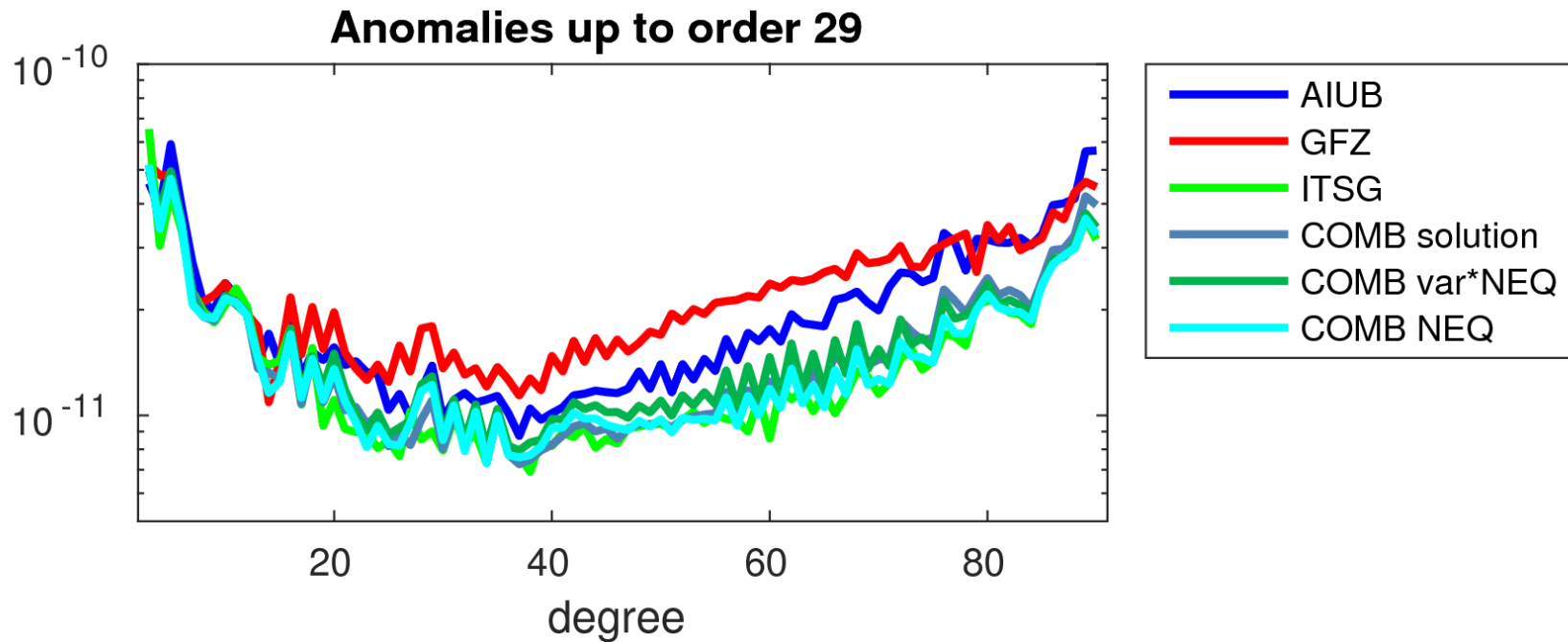
Anomalies up to order 29

	AIUB	GFZ	ITSG	COMB sol	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.45	0.22	0.33				
wSTD	7.7 mm	9.6 mm	4.7 mm	5.8 mm	6.6 mm	5.9 mm	

Combination: 2006/01
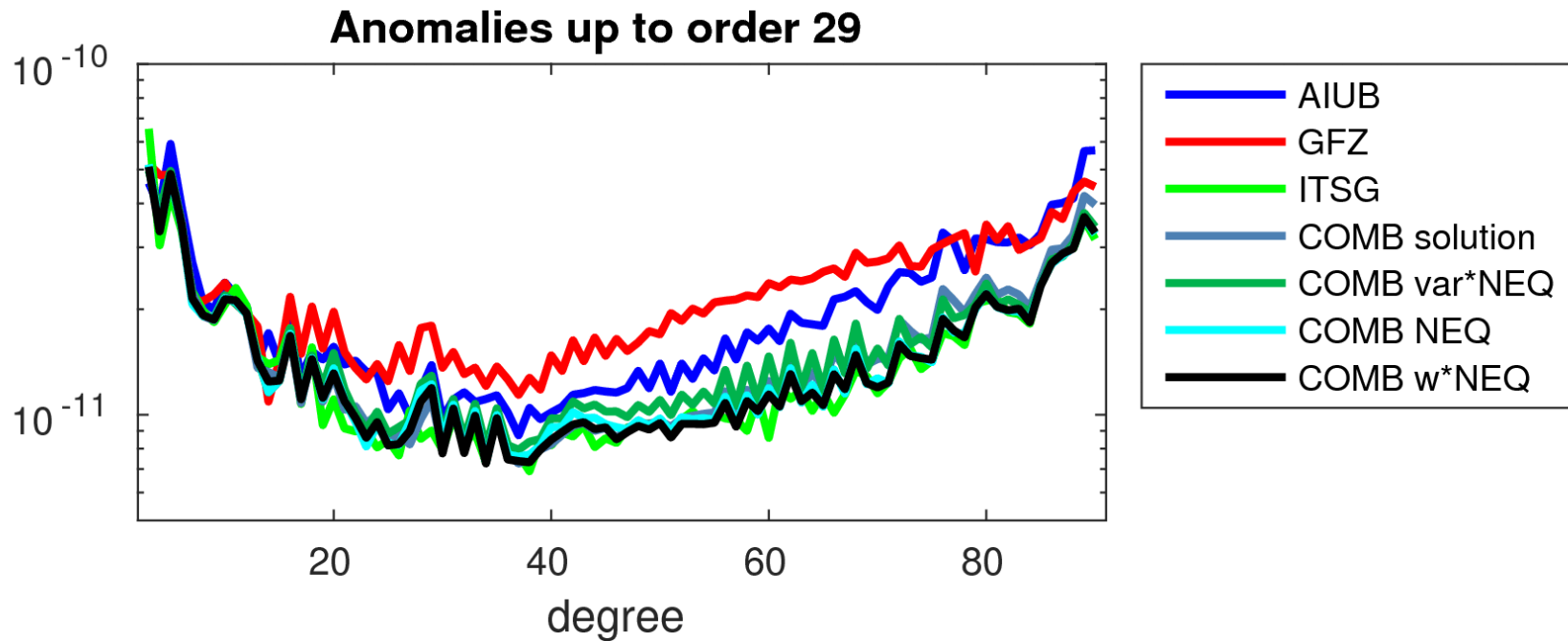
Anomalies up to order 29

	AIUB	GFZ	ITSG	COMB sol	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.45	0.22	0.33				
wSTD	7.7 mm	9.6 mm	4.7 mm	5.8 mm	6.6 mm	5.9 mm	5.7 mm

Combination: 2006/01

Anomalies up to order 29

Signal: we want to keep that

Noise: we want to reduce that

Legend:
- AIUB
- GFZ
- ITSG
- COMB solution
- COMB w*NEQ
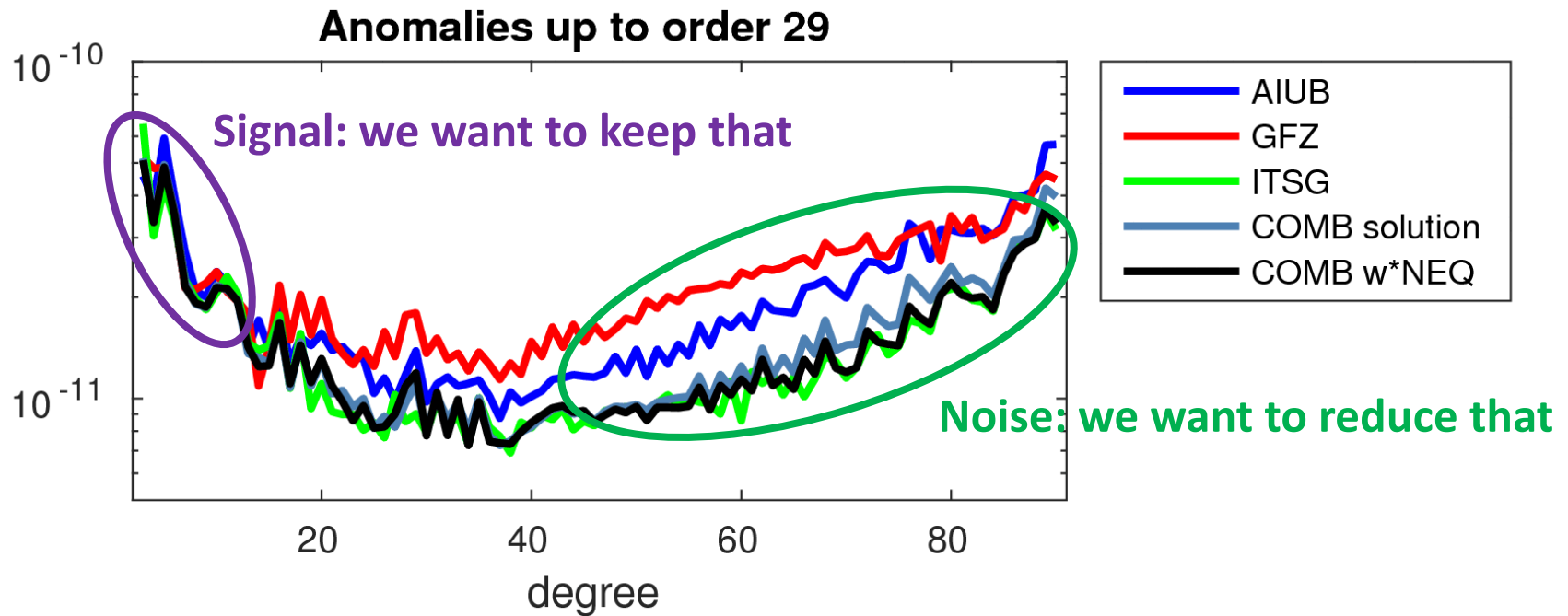
	AIUB	GFZ	ITSG	COMB sol	COMB w * NEQ
weight	0.45	0.22	0.33		
wSTD	7.7 mm	9.6 mm	4.7 mm	5.8 mm	5.7 mm

EGSIEM

Horizon2020

Combination: 2006/02

Anomalies up to order 29

Legend:
- AIUB (blue)
- GFZ (red)
- ITSG (green)
- COMB solution (gray)
- COMB w*NEQ (black)

NEQ-combination is less sensitive to crap in an individual contribution.
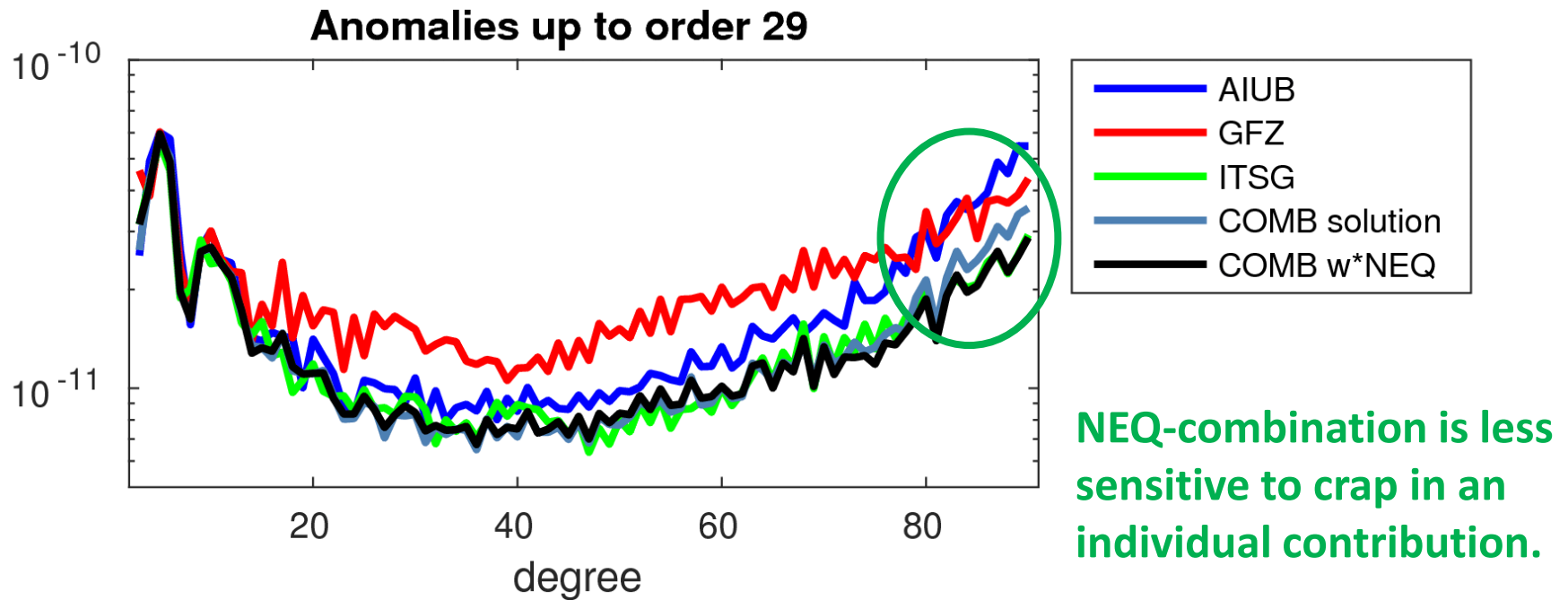
	AIUB	GFZ	ITSG	COMB sol	COMB w * NEQ
weight	0.45	0.23	0.32		
wSTD	8.0 mm	9.8 mm	4.5 mm	5.9 mm	6.0 mm

Combination: 2006/03

Anomalies up to order 29

Legend:
- AIUB (blue)
- GFZ (red)
- ITSG (green)
- COMB solution (grey)
- COMB w*NEQ (black)
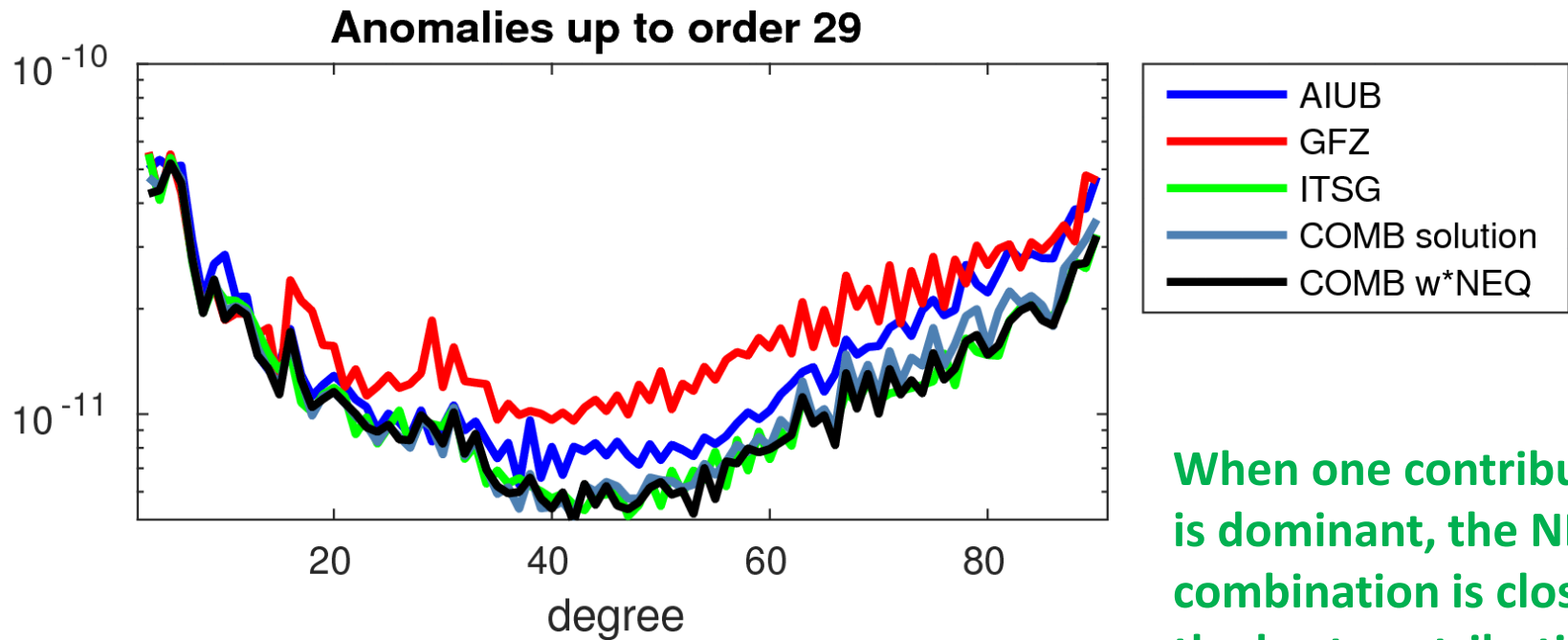
When one contribution is dominant, the NEQ-combination is close to the best contribution.

	AIUB	GFZ	ITSG	COMB sol	COMB w * NEQ
weight	0.45	0.24	0.31		
wSTD	7.8 mm	9.6 mm	4.3 mm	5.9 mm	5.7 mm

Combination: 2006/04

Anomalies up to order 29

Legend:
- AIUB (blue)
- GFZ (red)
- ITSG (green)
- COMB solution (gray)
- COMB w*NEQ (black)

x-axis: degree; y-axis from 10^{-11} to 10^{-10}
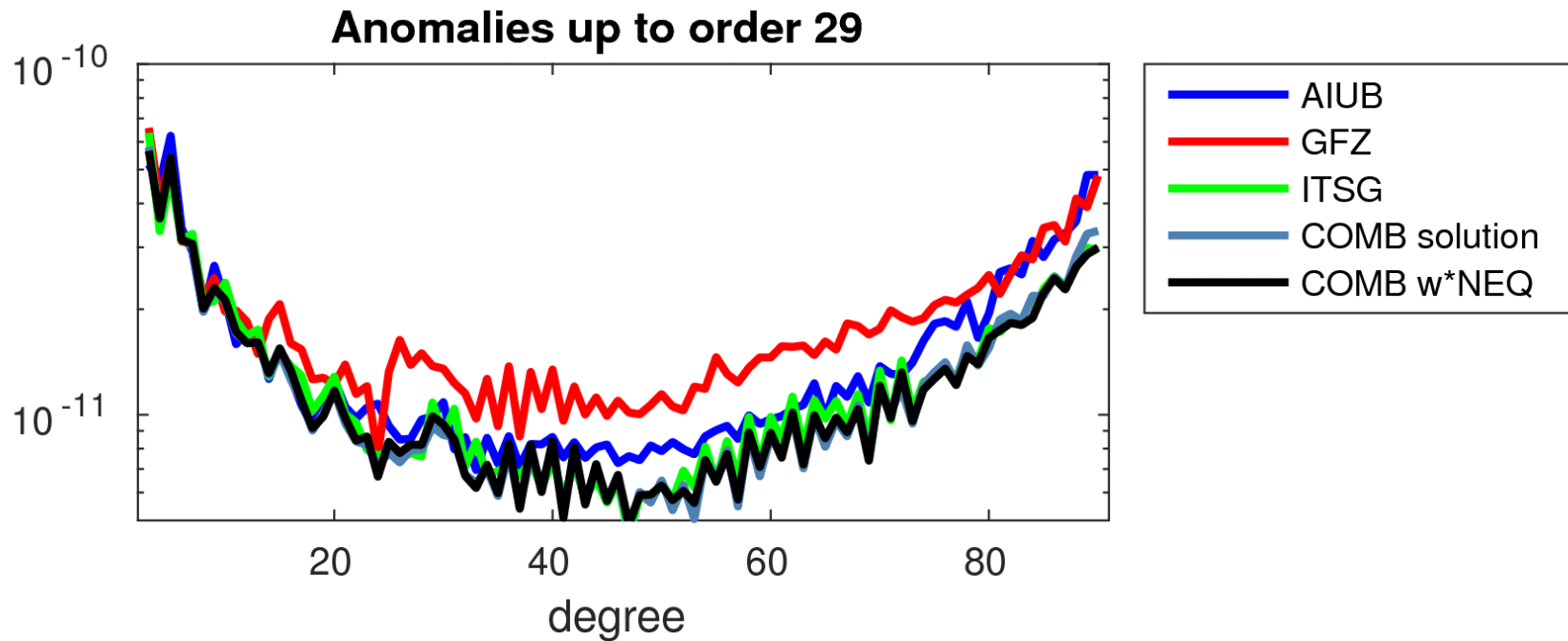
	AIUB	GFZ	ITSG	COMB sol	COMB w * NEQ
weight	0.36	0.22	0.32		
wSTD	6.4 mm	7.7 mm	4.2 mm	4.3 mm	4.3 mm

Combination: 2006/05

Anomalies up to order 29

When several contributions are comparably good, the combination is better!
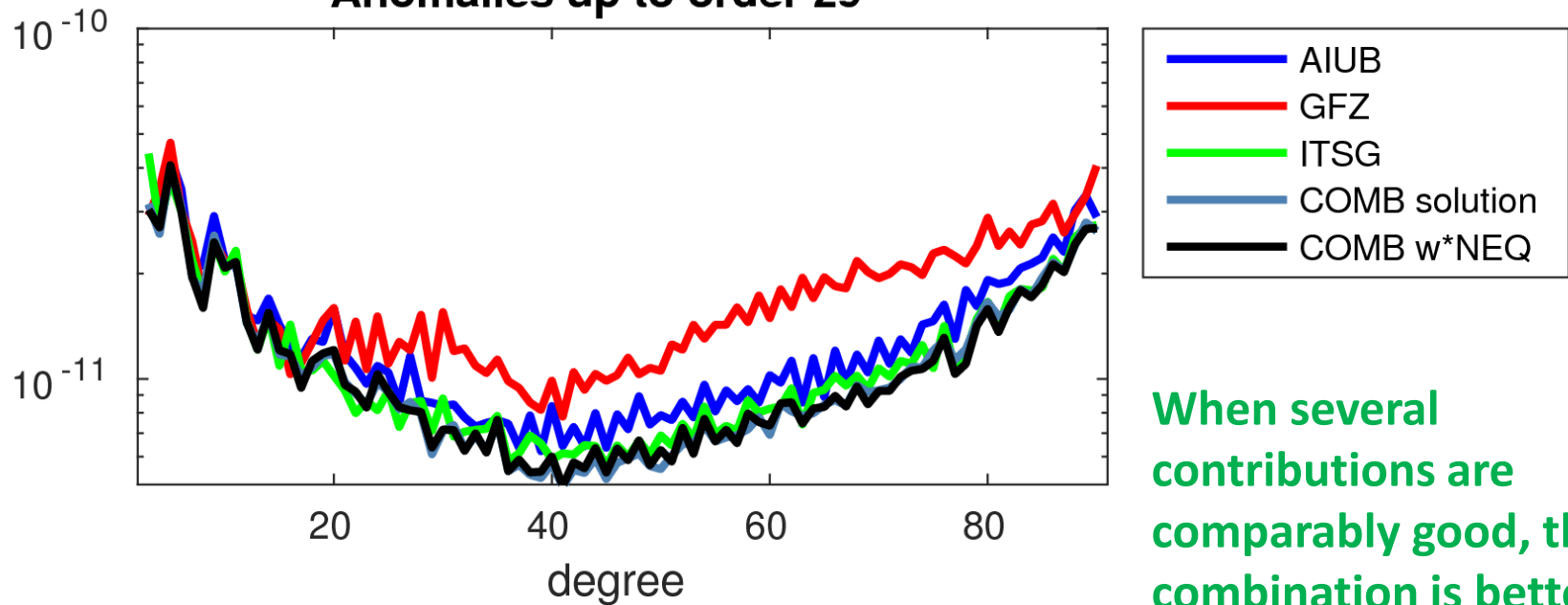
	AIUB	GFZ	ITSG	COMB sol	COMB w * NEQ
weight	0.40	0.25	0.35		
wSTD	7.1 mm	7.5 mm	4.0 mm	5.0 mm	4.6 mm

Combination: 2006/06

Anomalies up to order 29
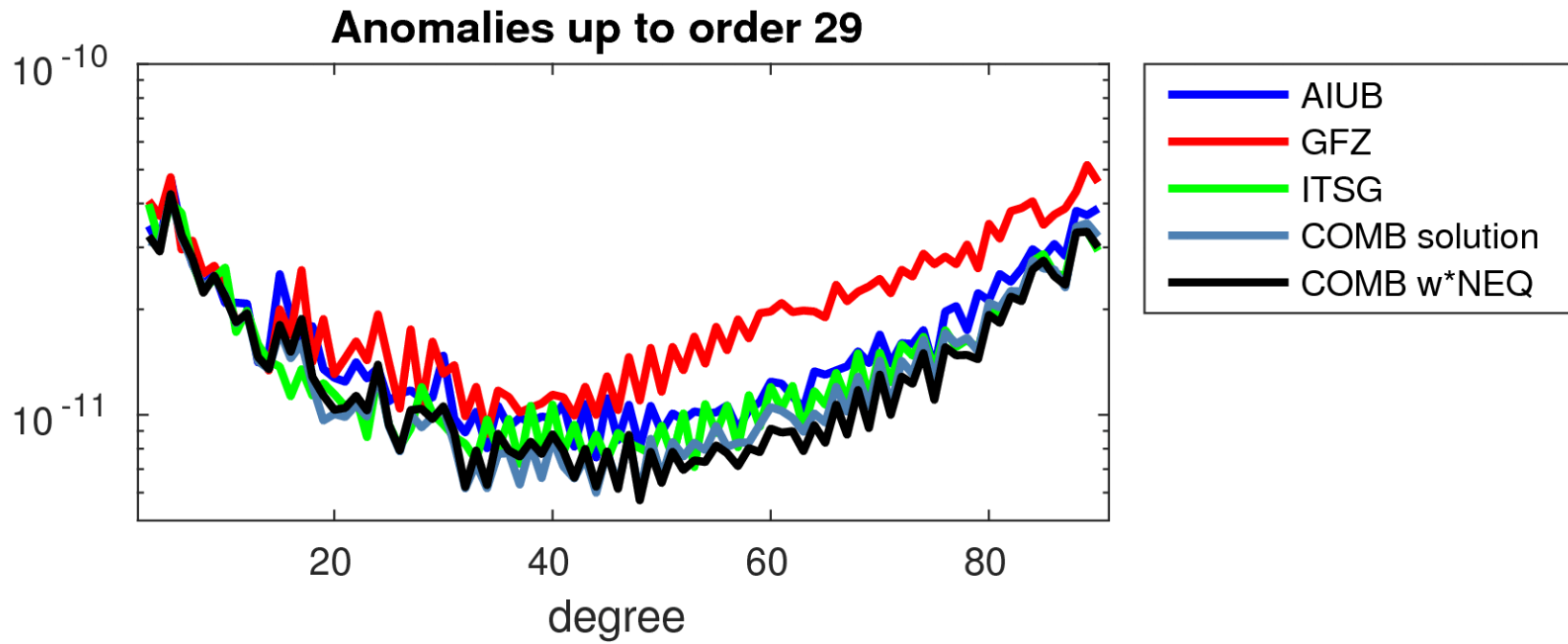
	AIUB	GFZ	ITSG	COMB sol	COMB w * NEQ
weight	0.34	0.27	0.339		
wSTD	7.3 mm	7.5 mm	4.6 mm	5.0 mm	4.6 mm

Combination including GRGS: 2006/01
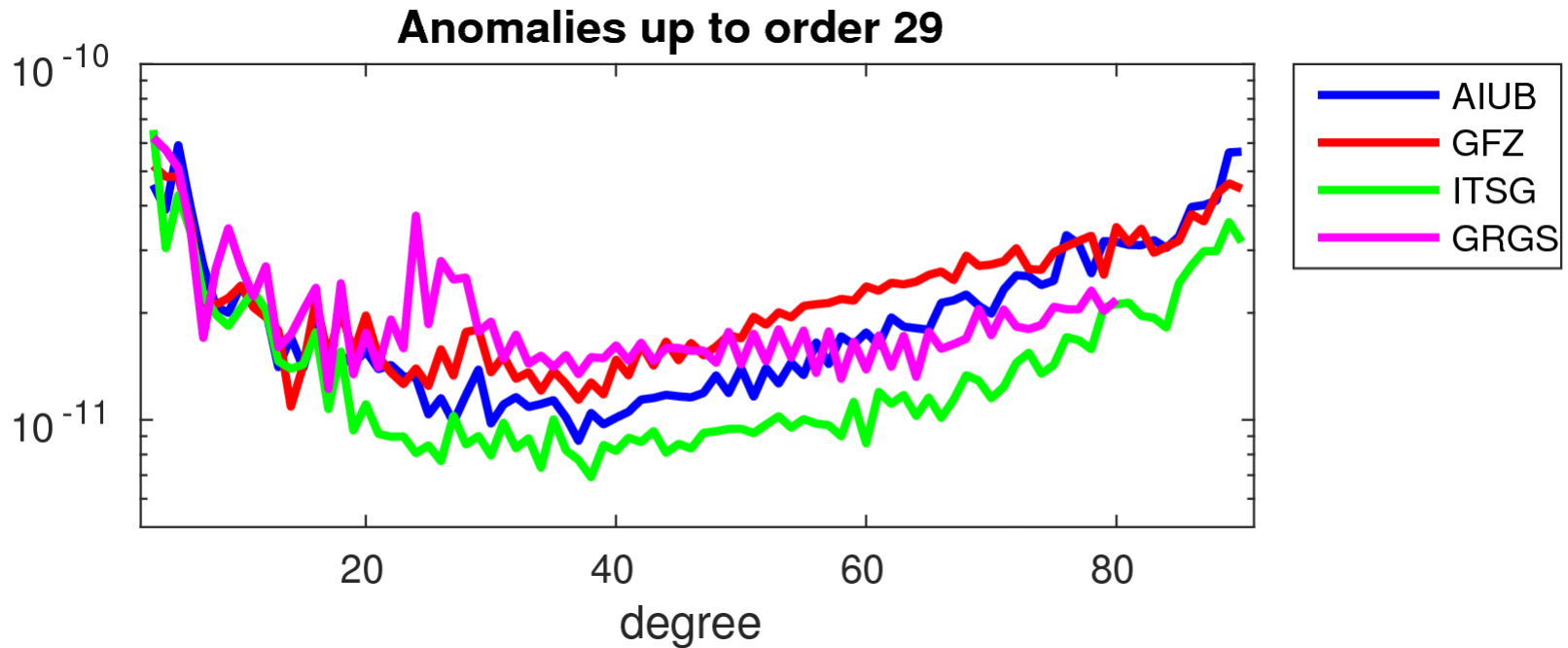
Anomalies up to order 29

$l_{max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.29	0.19	0.38	0.14				
wSTD	5.6 mm	6.6 mm	3.5 mm	6.4 mm				

Combination including GRGS: 2006/01
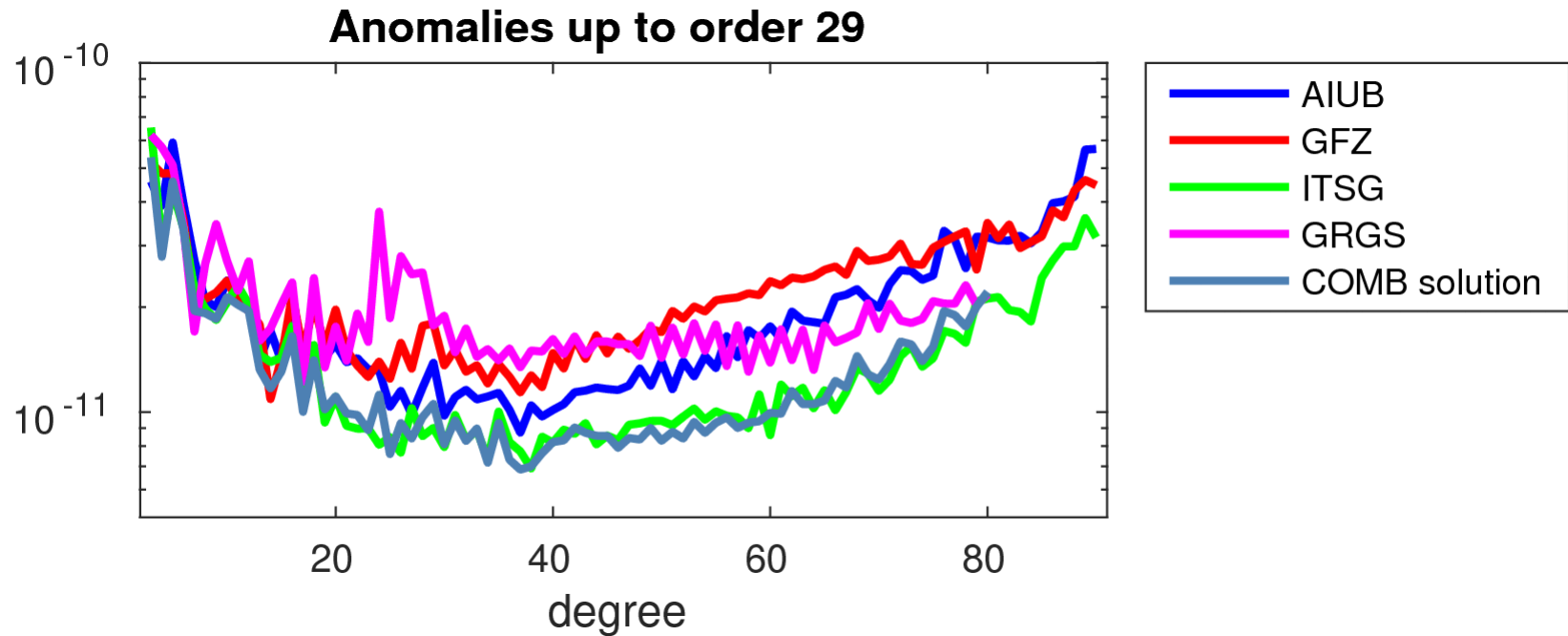
Anomalies up to order 29

l_{max} = 80	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.29	0.19	0.38	0.14				
wSTD	5.6 mm	6.6 mm	3.5 mm	6.4 mm	3.9 mm			

Combination including GRGS: 2006/01
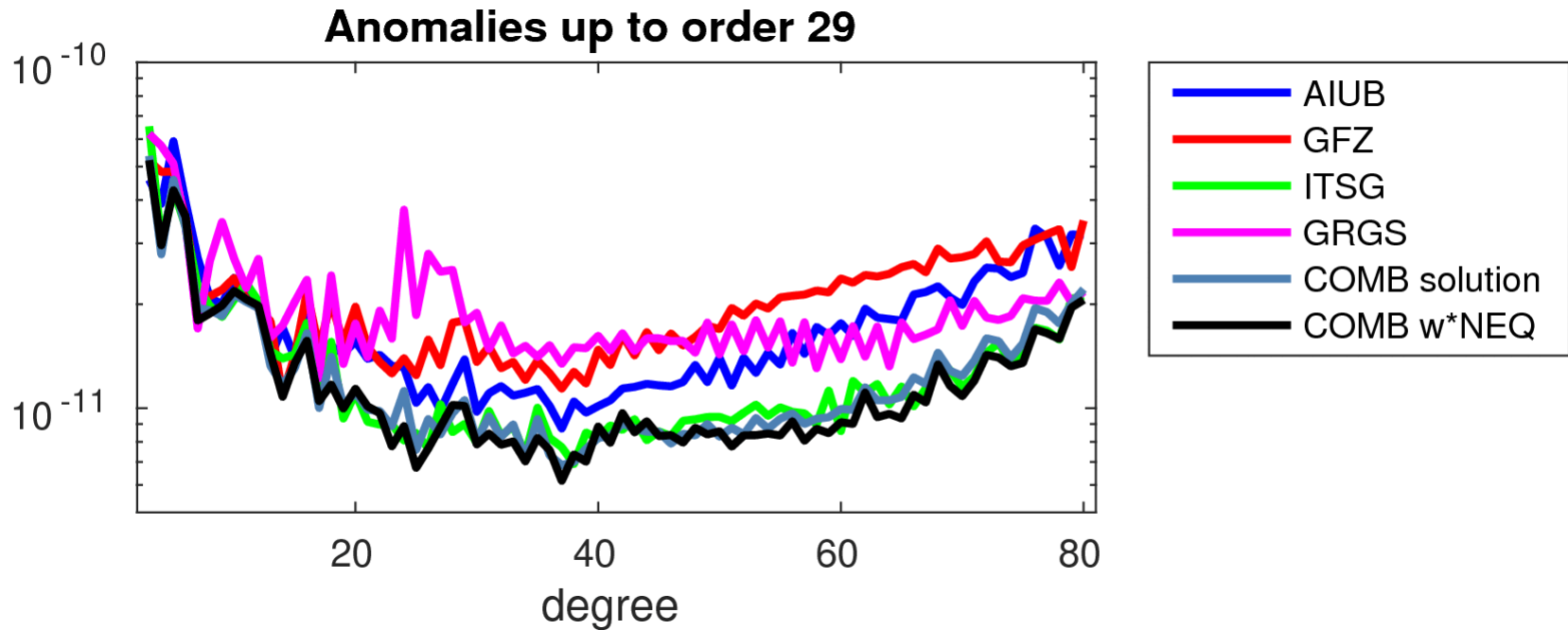
Anomalies up to order 29

l_{max} = 80	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.29	0.19	0.38	0.14		
wSTD	5.6 mm	6.6 mm	3.5 mm	6.4 mm	3.9 mm	3.9 mm

Combination including GRGS: 2006/02

Anomalies up to order 29
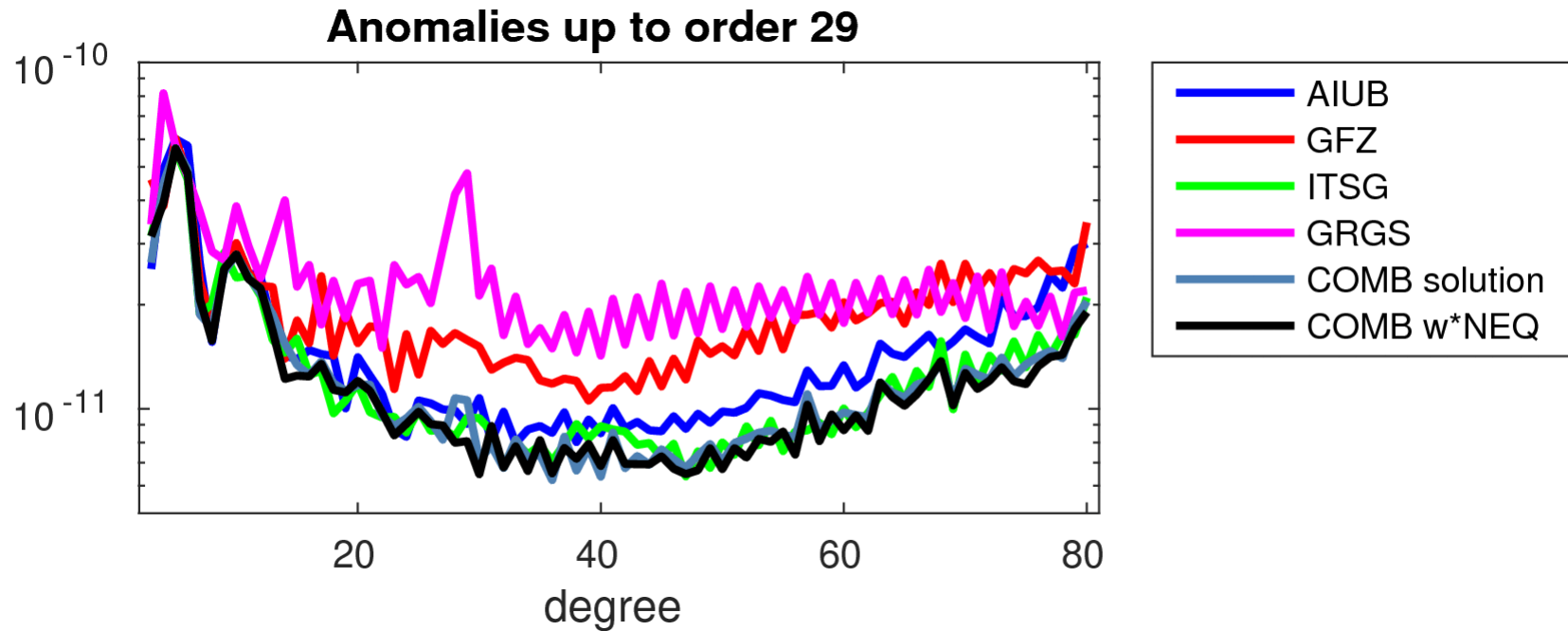
l_{max} = 80	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.36	0.21	0.27	0.16		
wSTD	5.6 mm	6.3 mm	3.4 mm	5.4 mm	4.1 mm	3.9 mm

Combination including GRGS: 2006/03

Anomalies up to order 29
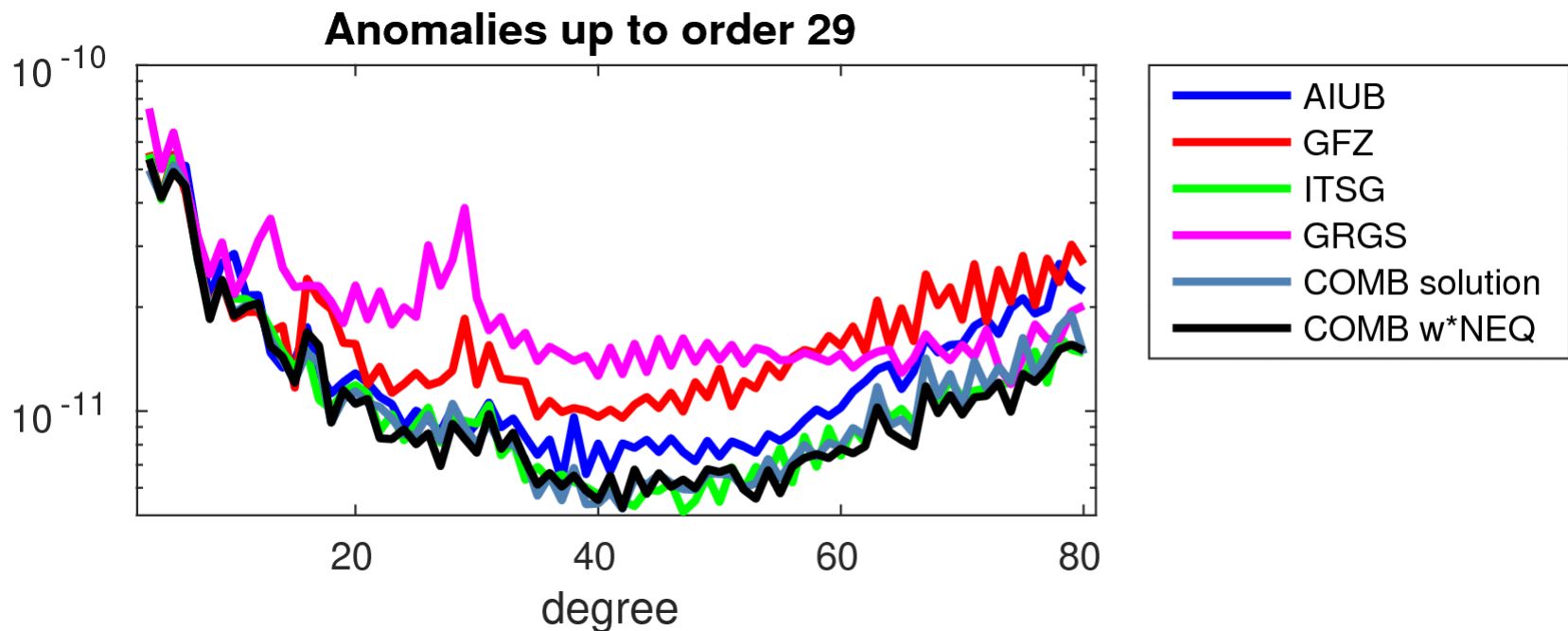
$l_{max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.37	0.22	0.27	0.14		
wSTD	5.3 mm	6.5 mm	3.4 mm	6.1 mm	4.0 mm	4.0 mm

Combination including GRGS: 2006/04

Anomalies up to order 29
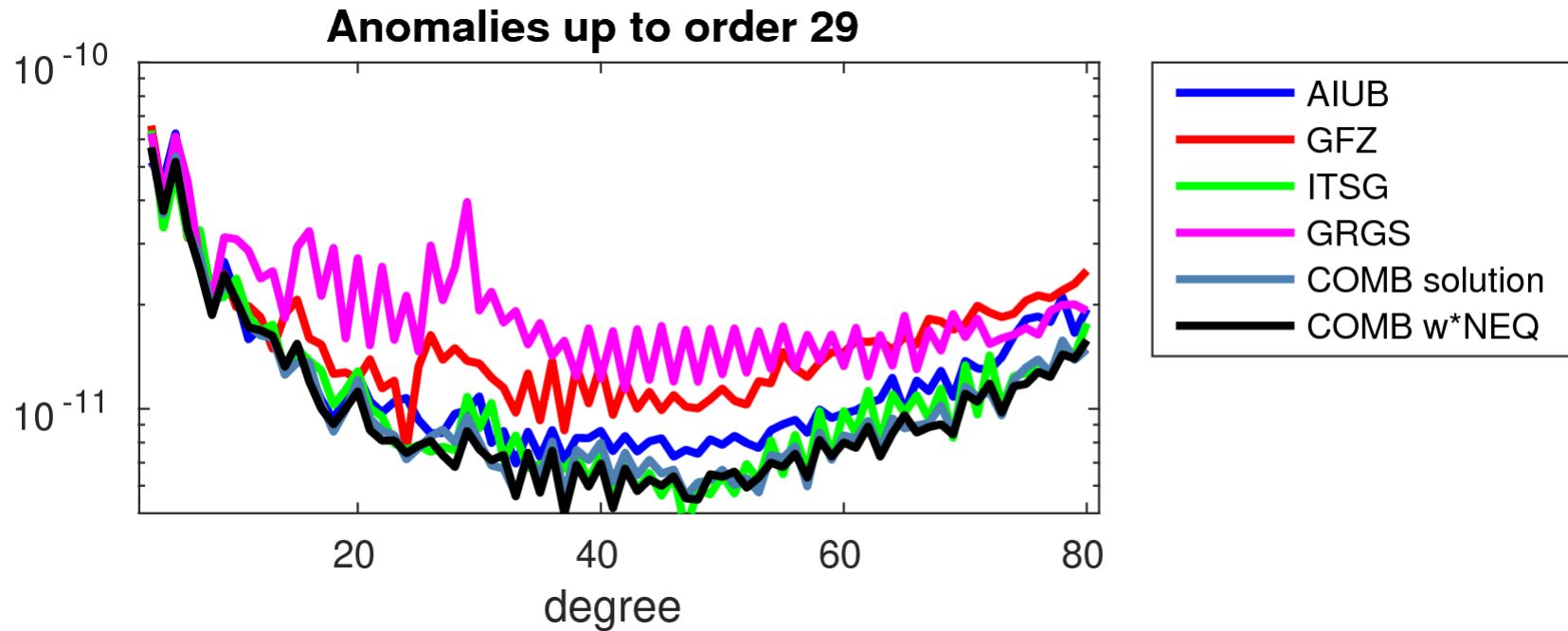
$l_{max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.37	0.22	0.29	0.12		
wSTD	4.4 mm	5.2 mm	3.2 mm	5.3 mm	3.3 mm	3.4 mm

Combination including GRGS: 2006/05

Anomalies up to order 29
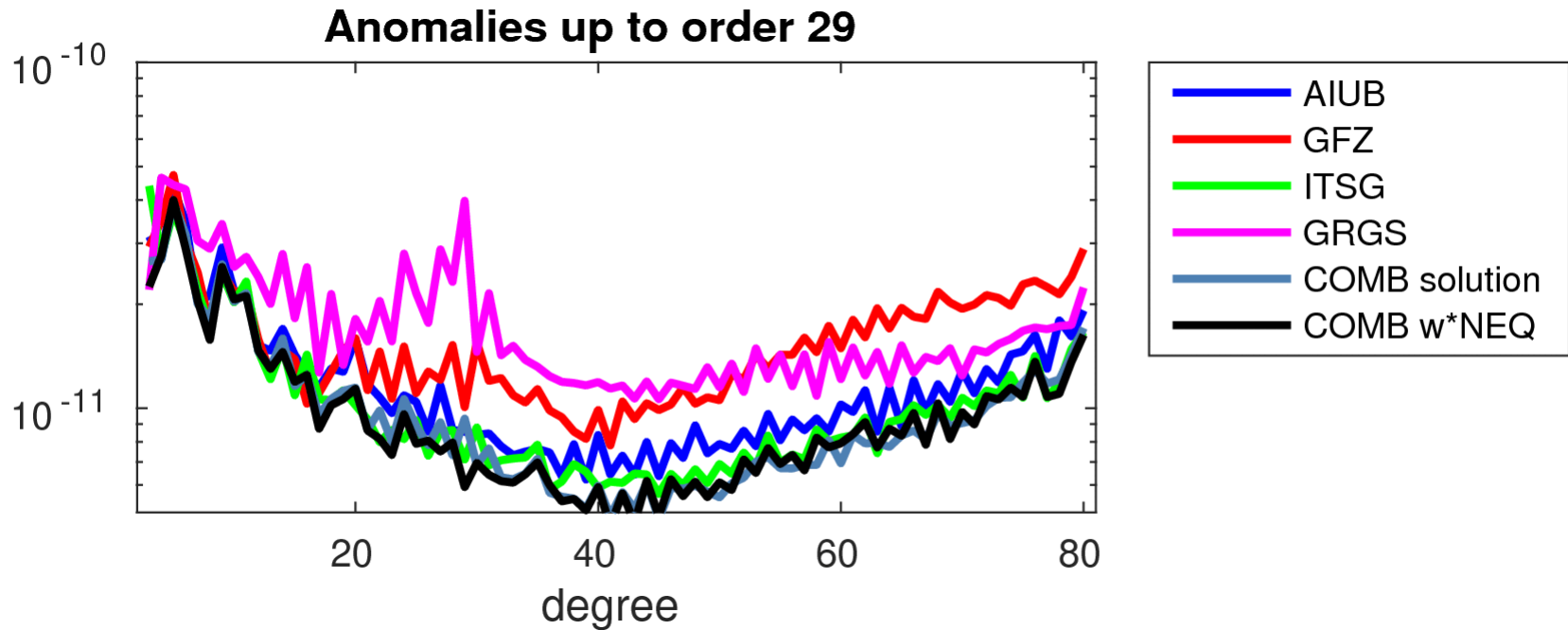
$l_{max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.27	0.26	0.31	0.16		
wSTD	5.0 mm	5.2 mm	3.2 mm	4.9 mm	3.5 mm	3.2 mm

Combination including GRGS: 2006/06

Anomalies up to order 29
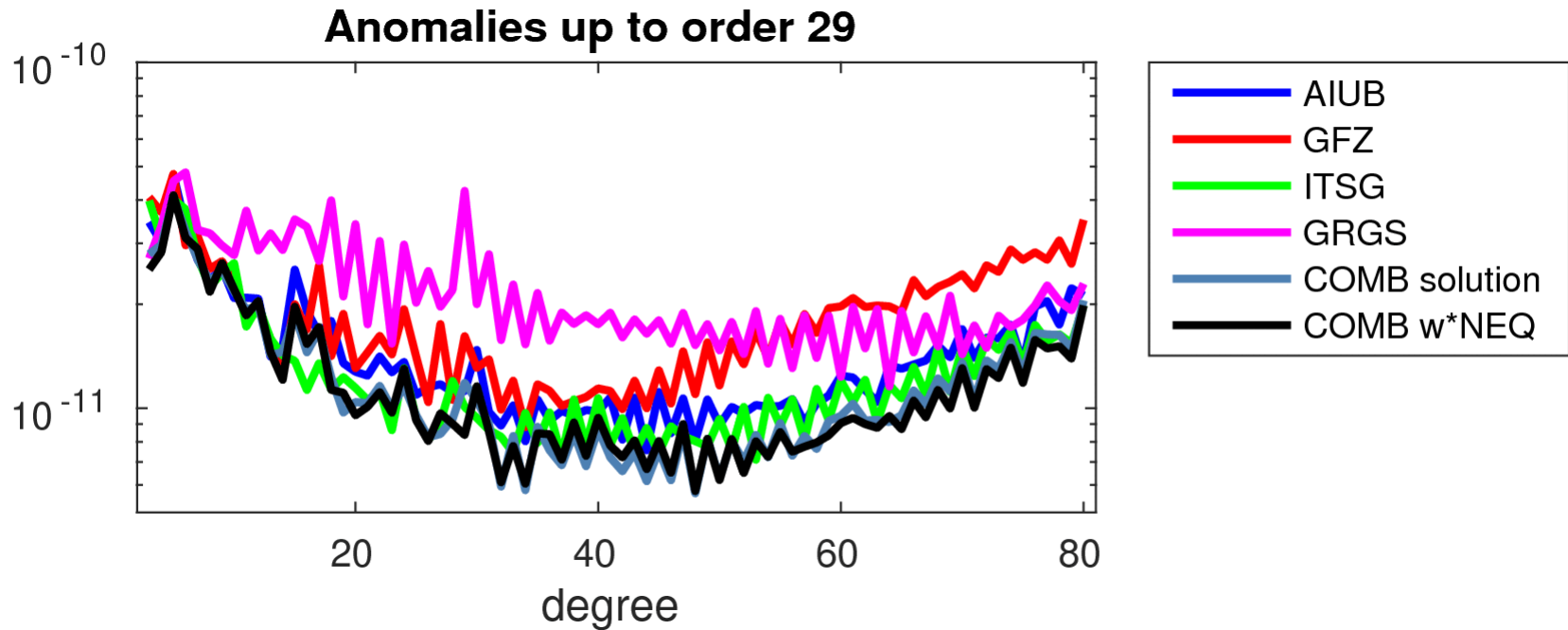
$l_{max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.30	0.26	0.30	0.14		
wSTD	5.0 mm	5.2 mm	3.4 mm	5.4 mm	3.6 mm	3.4 mm

Combination including GRGS: 2006/10

Anomalies up to order 29
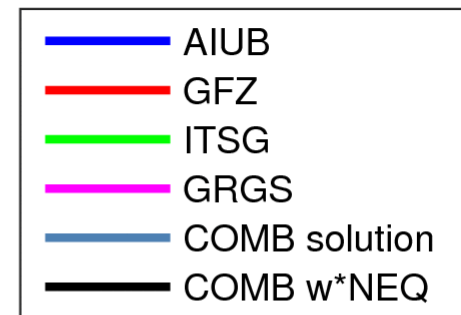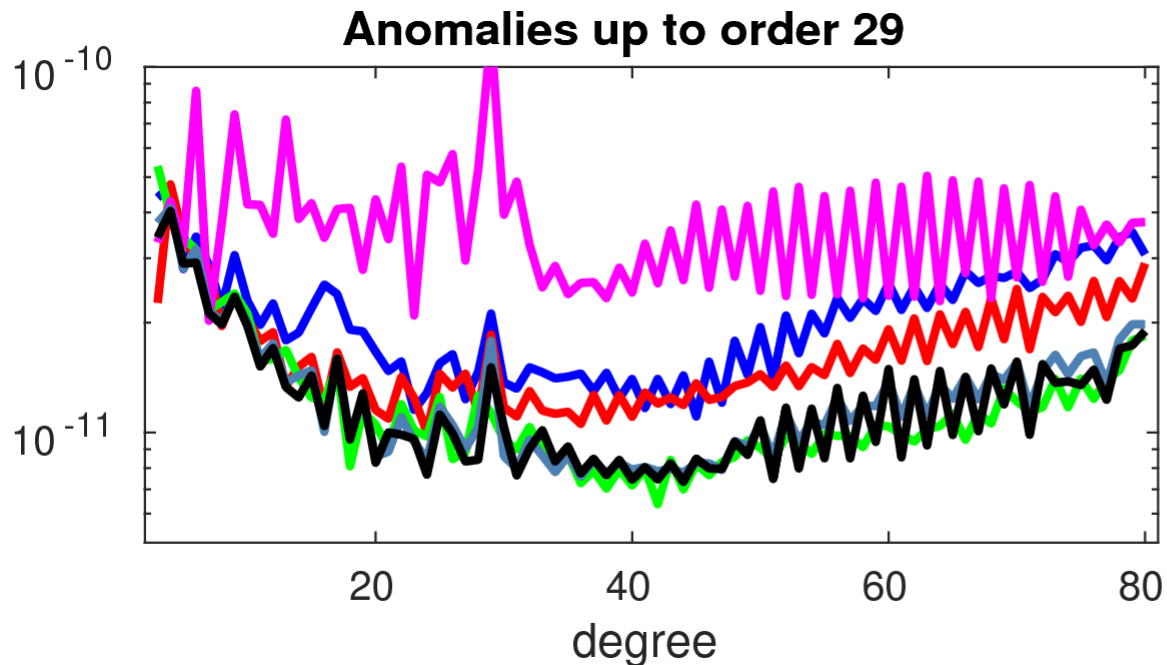
Combination is statistics, not magic -> screening (or improve individual contributions!!)

l_max = 80	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.25	0.29	0.40	0.06		
wSTD	6.3 mm	6.1 mm	3.2 mm	10.0 mm	4.0 mm	3.8 mm

Conclusions

- The EGSIEM combination service is close to operational (Level-3-grids and GA...-products are still missing).

- Careful validation and screening of individual contributions => combinations are
  - robust
  - reliable

- Combined monthly gravity fields reach level of best individual contributions or outperform them.

- Combination on NEQ-level seems to be more robust against problems in individual contributions.