

EGSIEM combination of GRACE monthly gravity fields

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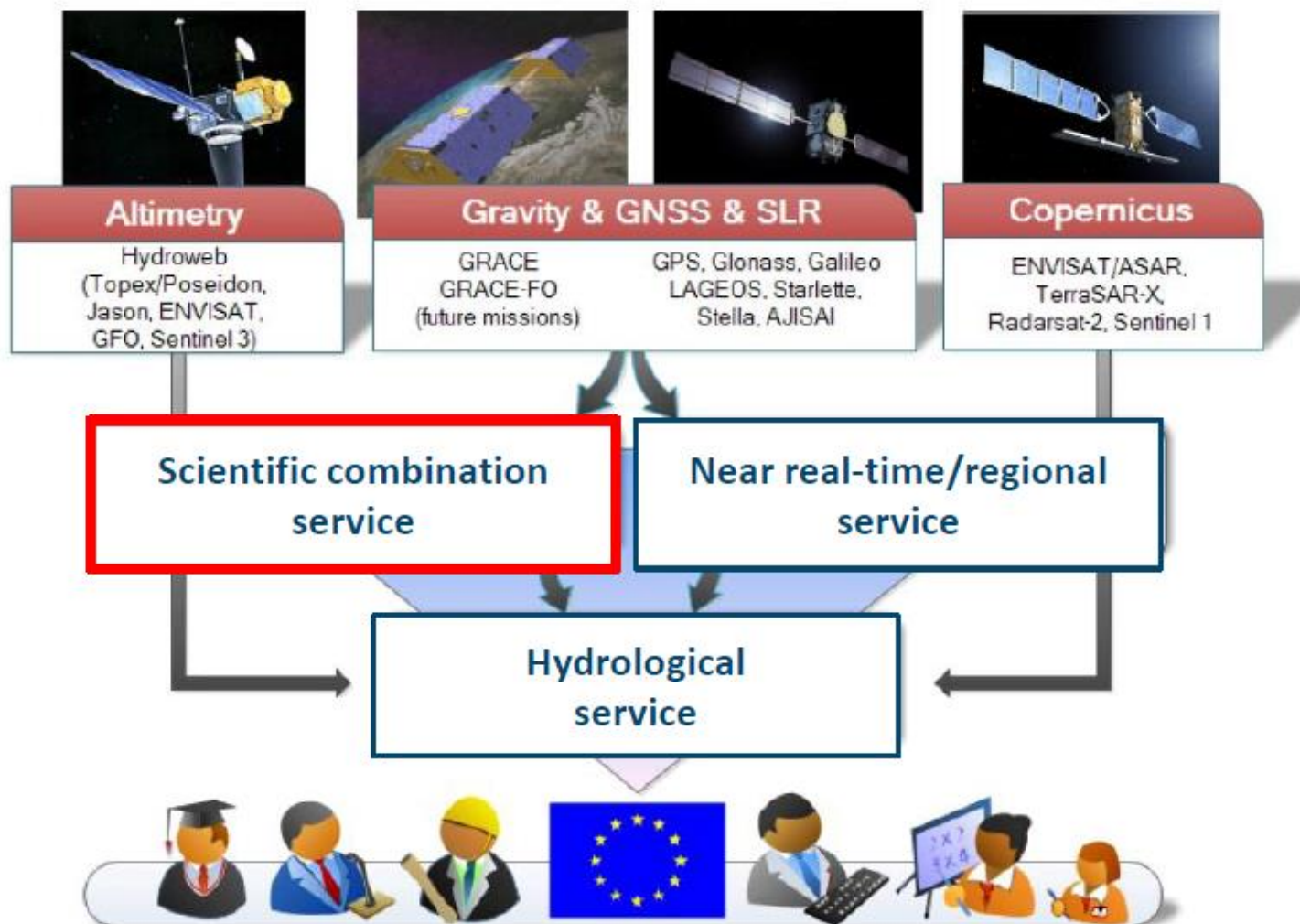
⁴ Groupe de Recherche de Géodésie Spatiale, Toulouse

GRACE Science Team Meeting 2016

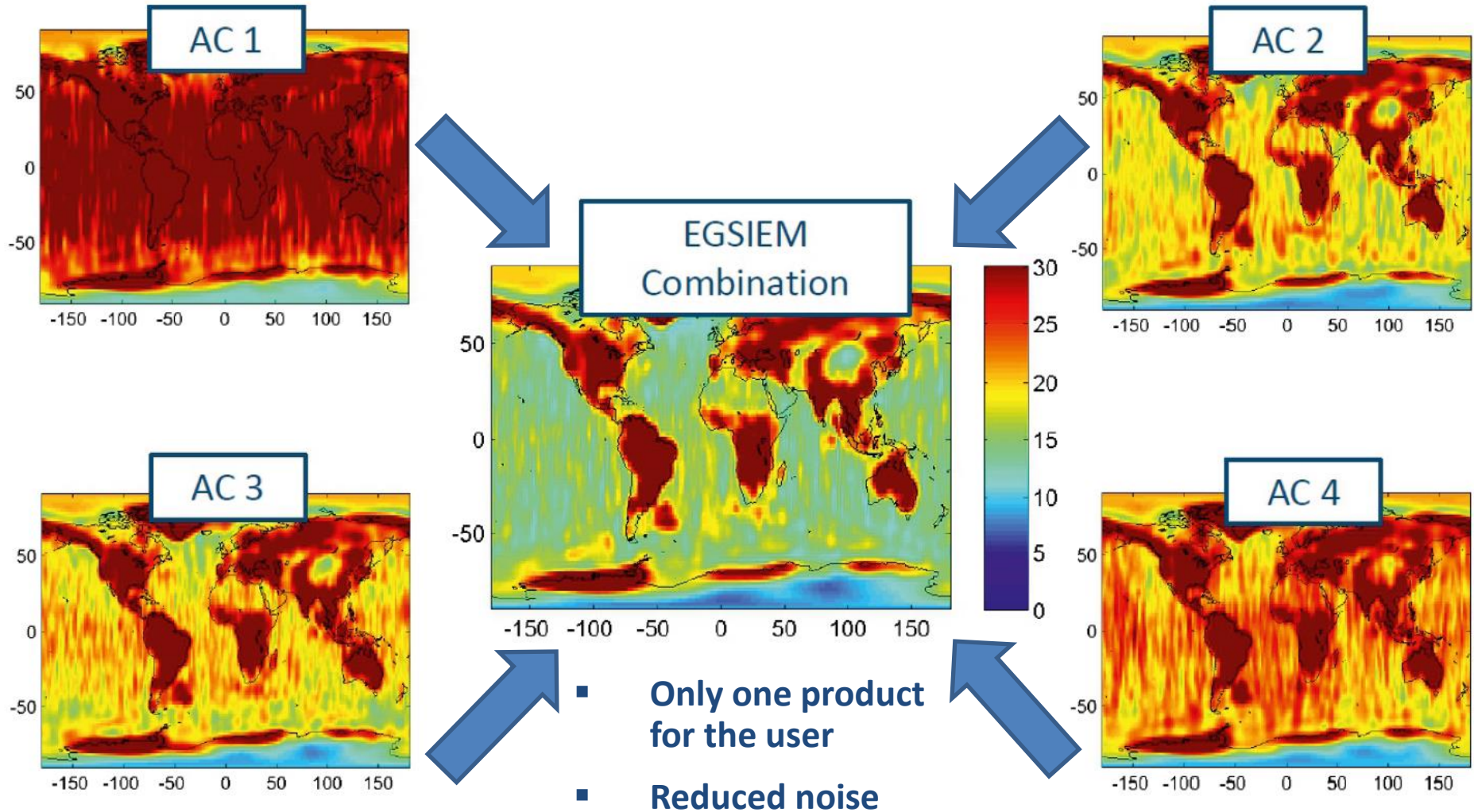
GFZ Potsdam

October 5-7, 2016

EGSIEM Project – Three services shall be established



Scientific Combination Service



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?

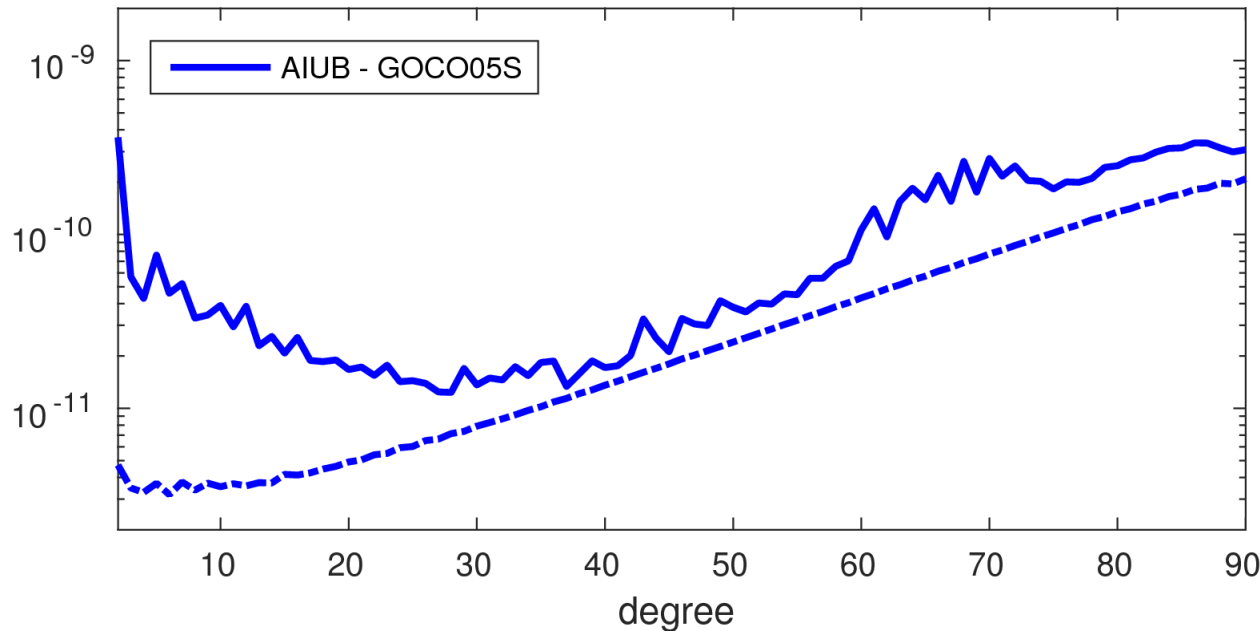
Errors in GRACE monthly gravity fields are still dominated by analysis and background model noise, not observation noise!

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

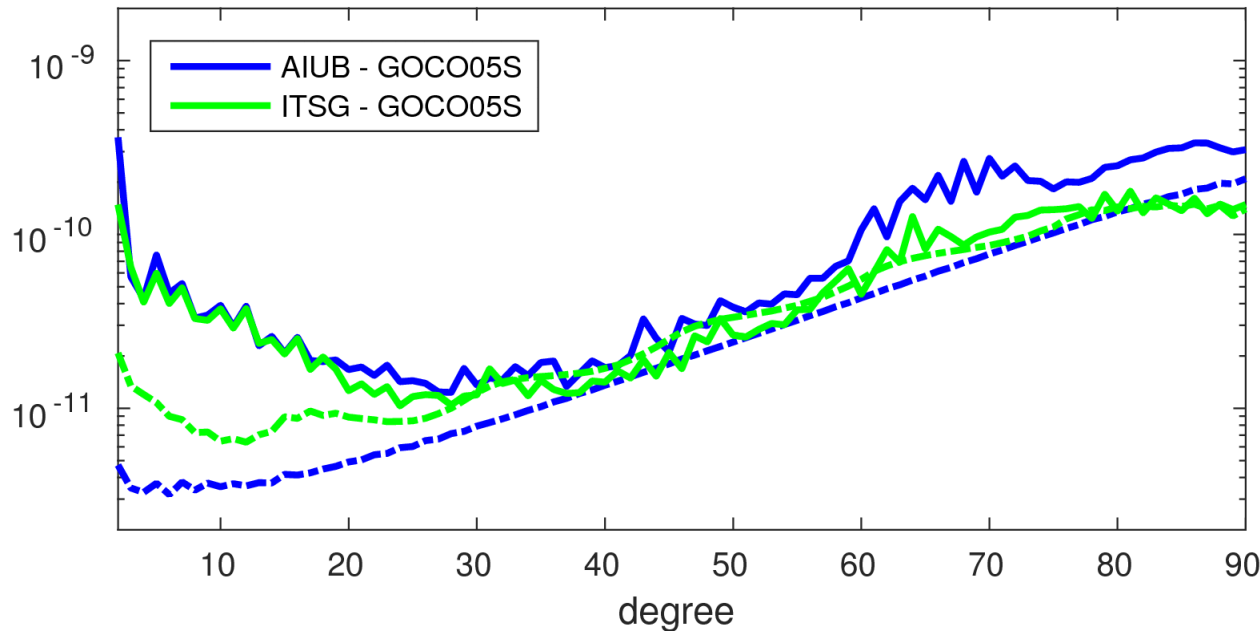
2006/01



- **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

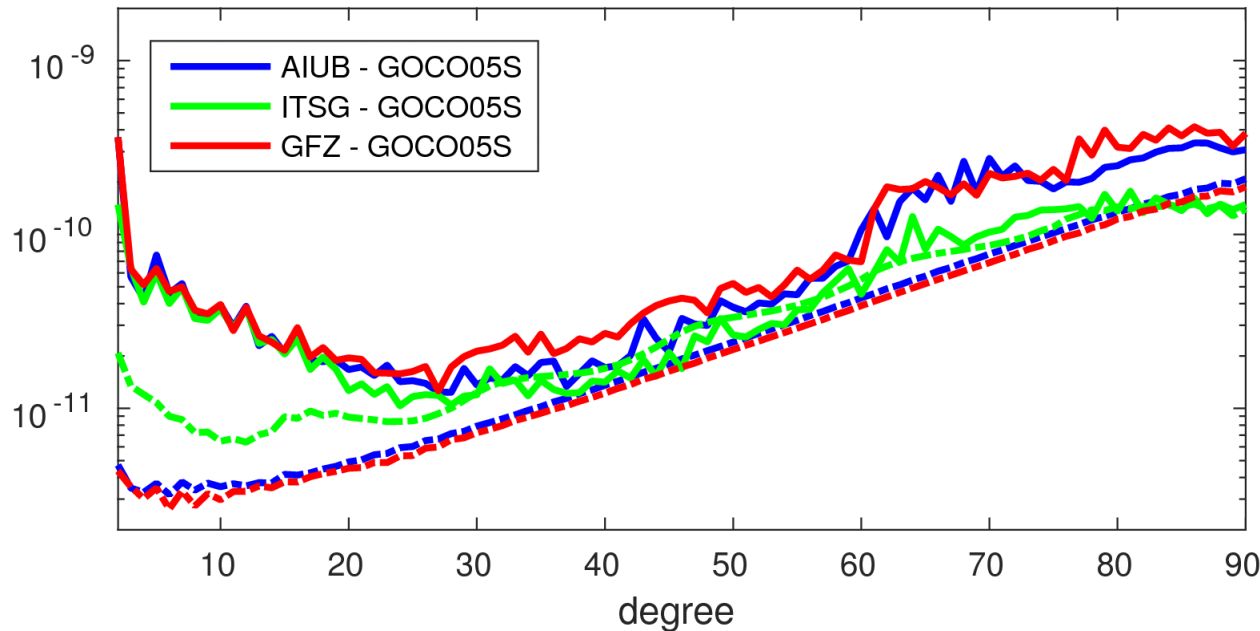
2006/01



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

Individual Contributions: GFZ

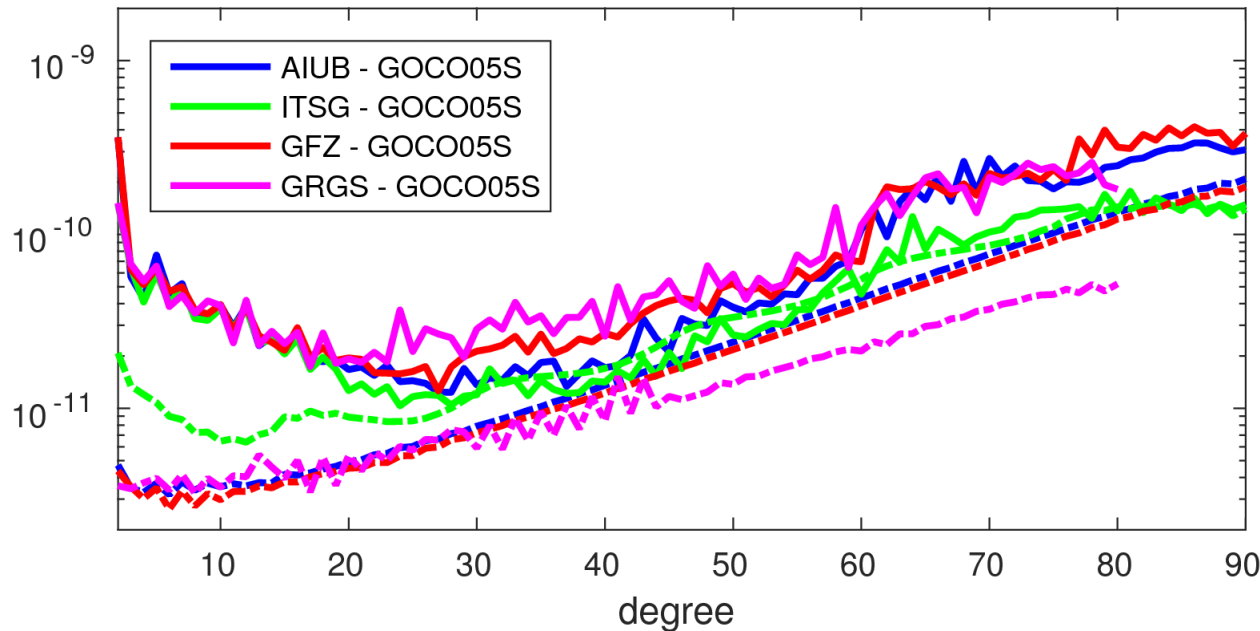
2006/01



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

Individual Contributions: GRGS

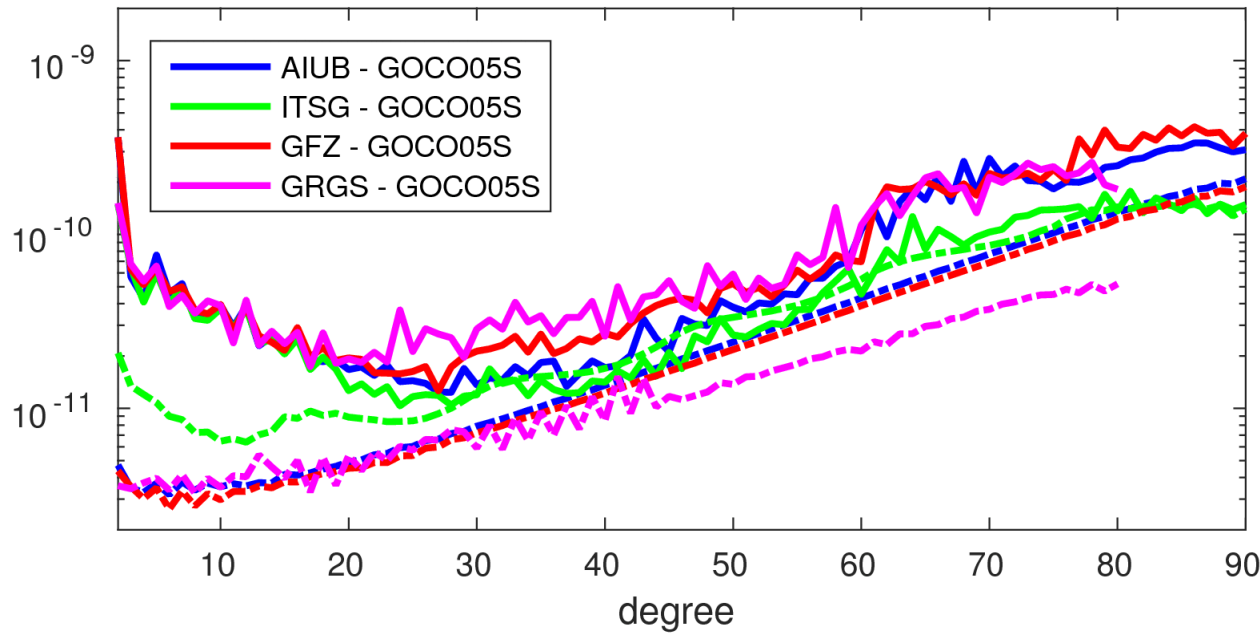
2006/01



- **GRGS:** magic approach ... but we got free (unconstrained) normal equations and solutions for combination!
 - approx. 500000 KRR observations
 - 500000 kinematic positions (30s) / month

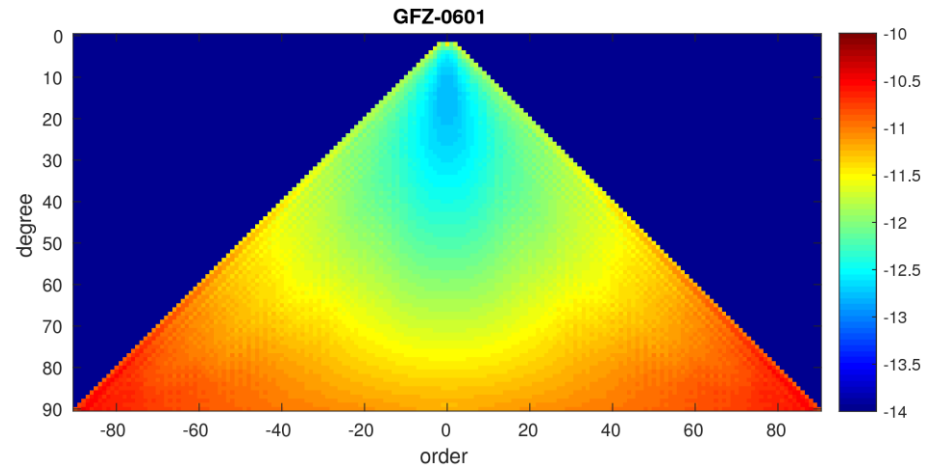
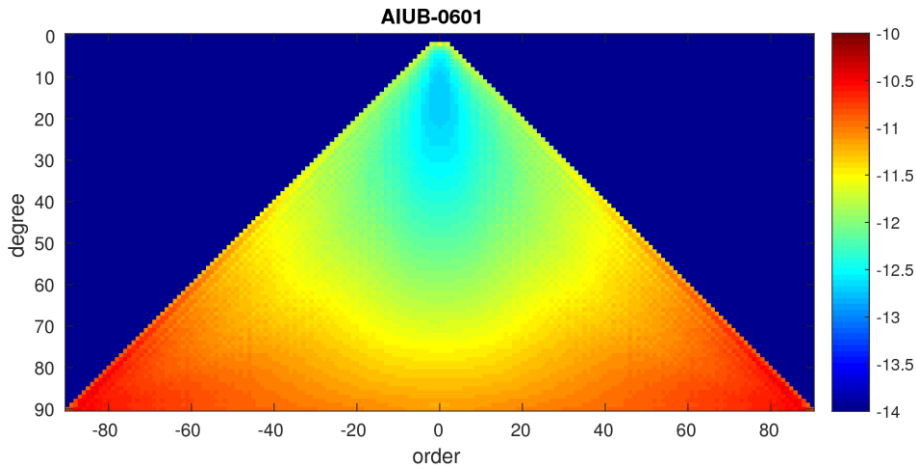
Individual Contributions: U Lux

2006/01

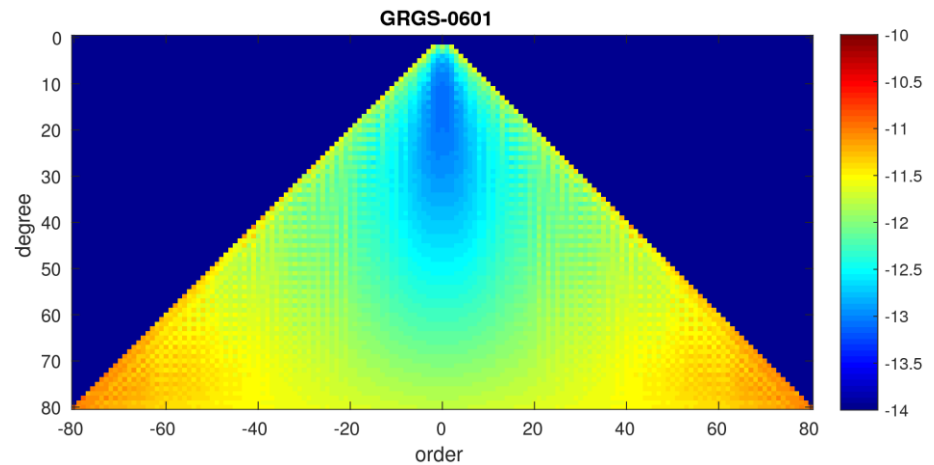
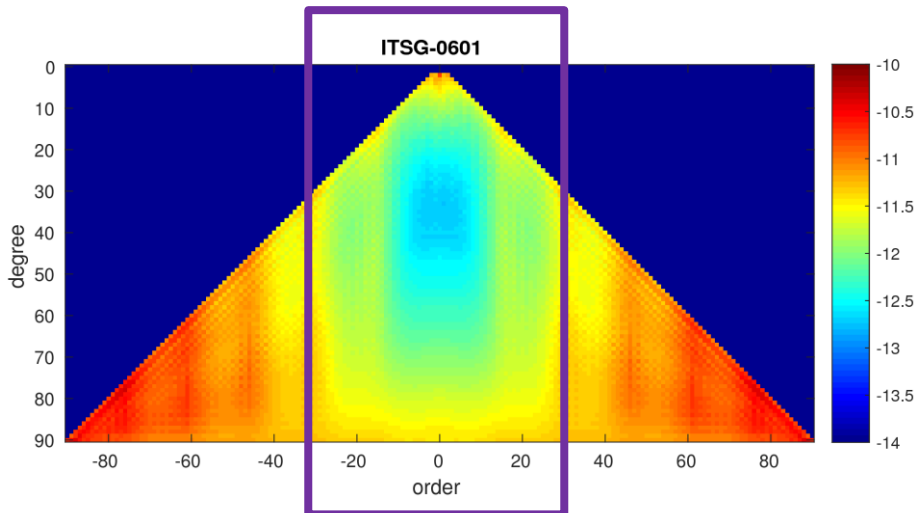


- **U Lux:** acceleration approach, still under development ...

Formal errors: 2006/01

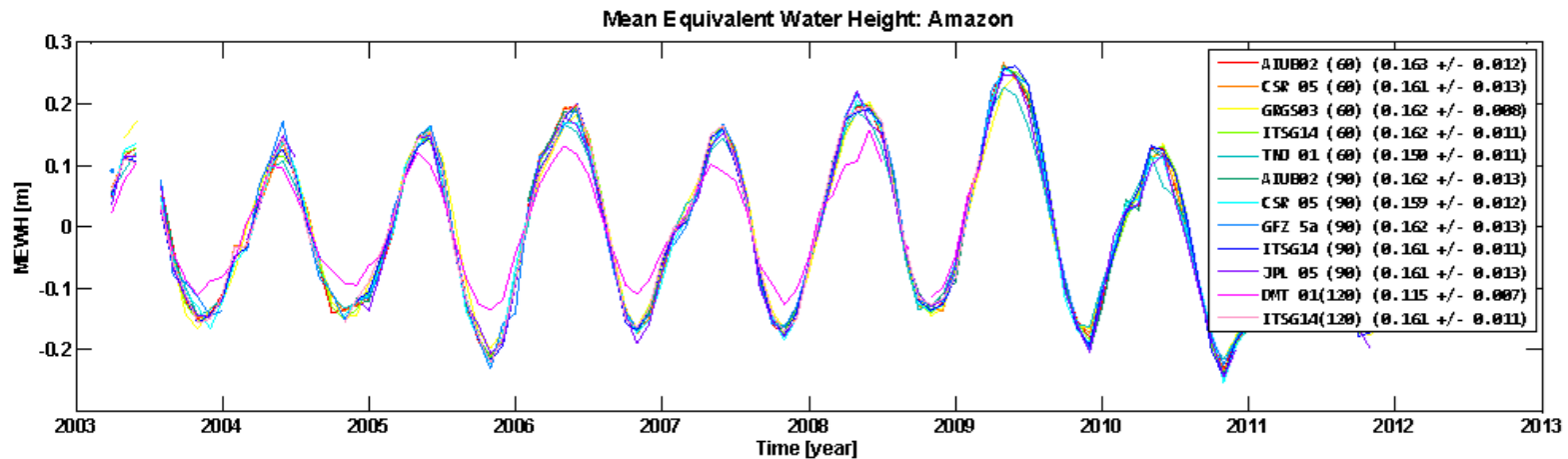


Contains main part of signal



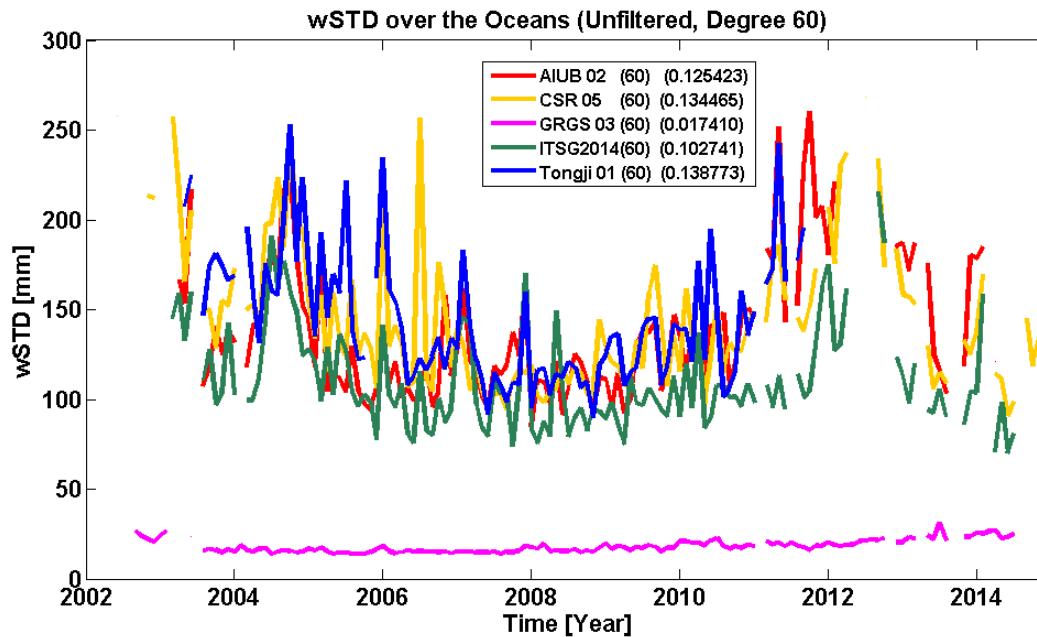
Combination on Solution Level

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



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



Combination on Solution Level

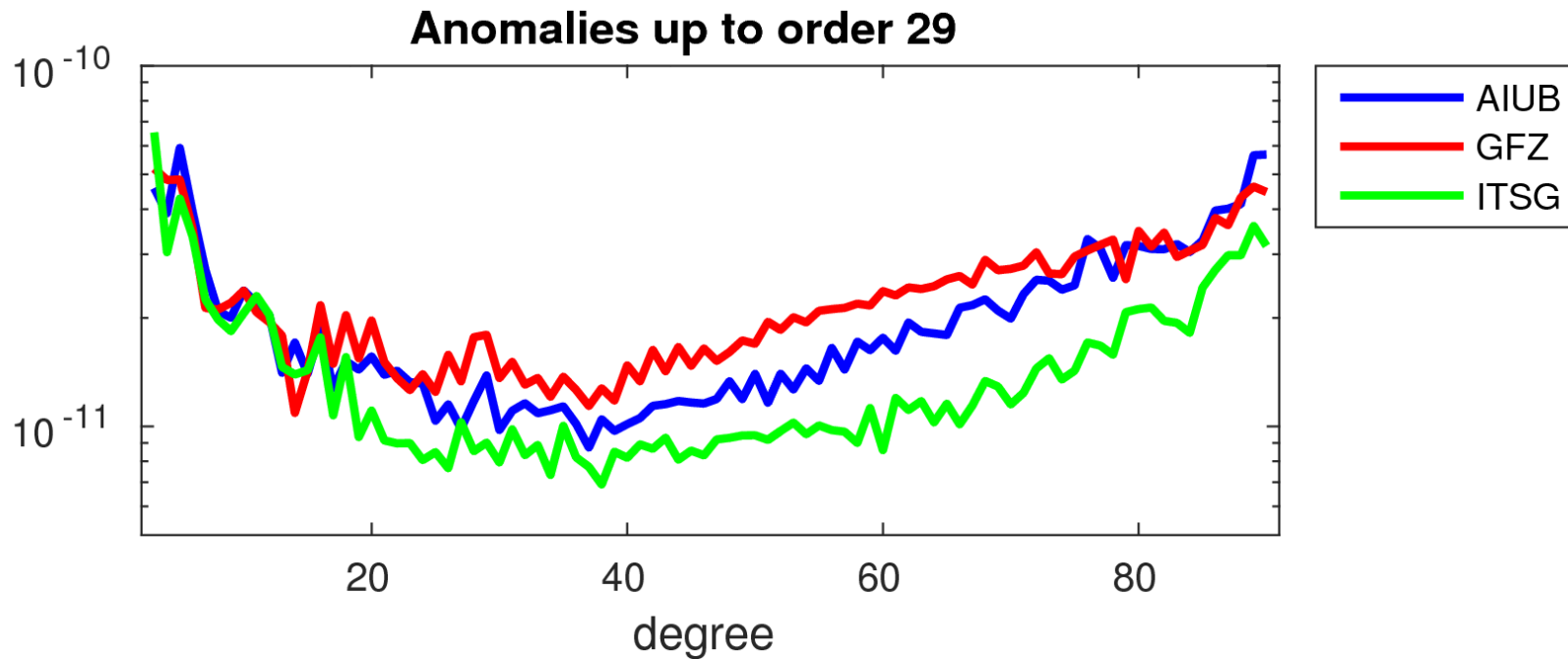
- Comparison of individual contributions
 - Signal content: river basins, Greenland, west Antarctica
 - Noise level: weighted STD of anomalies (with respect to model: bias + trend + annual + semian.) over the oceans
- Rejection of biased series of gravity fields (regularized, pre-filtered)
- Screening 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!

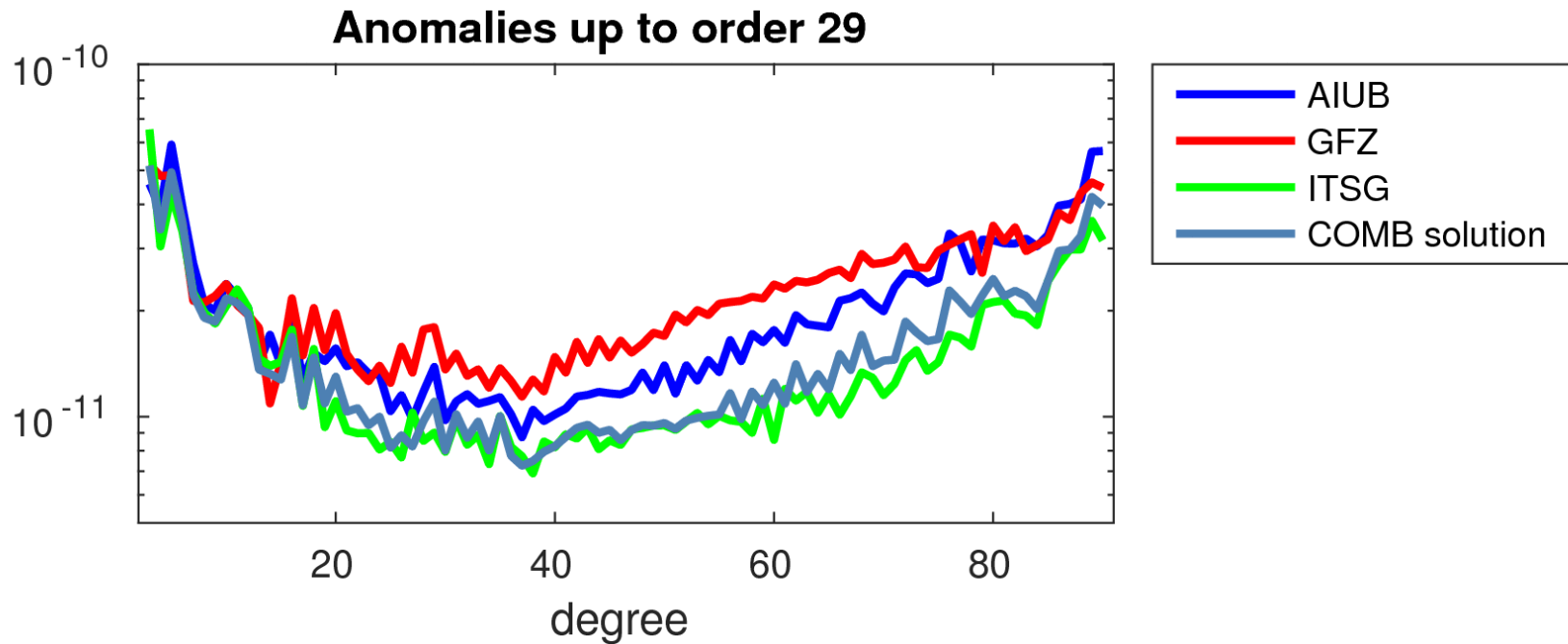
$$~~W = \sigma_0^2 * \text{DOF} / v^T P v~~$$

Combination: 2006/01



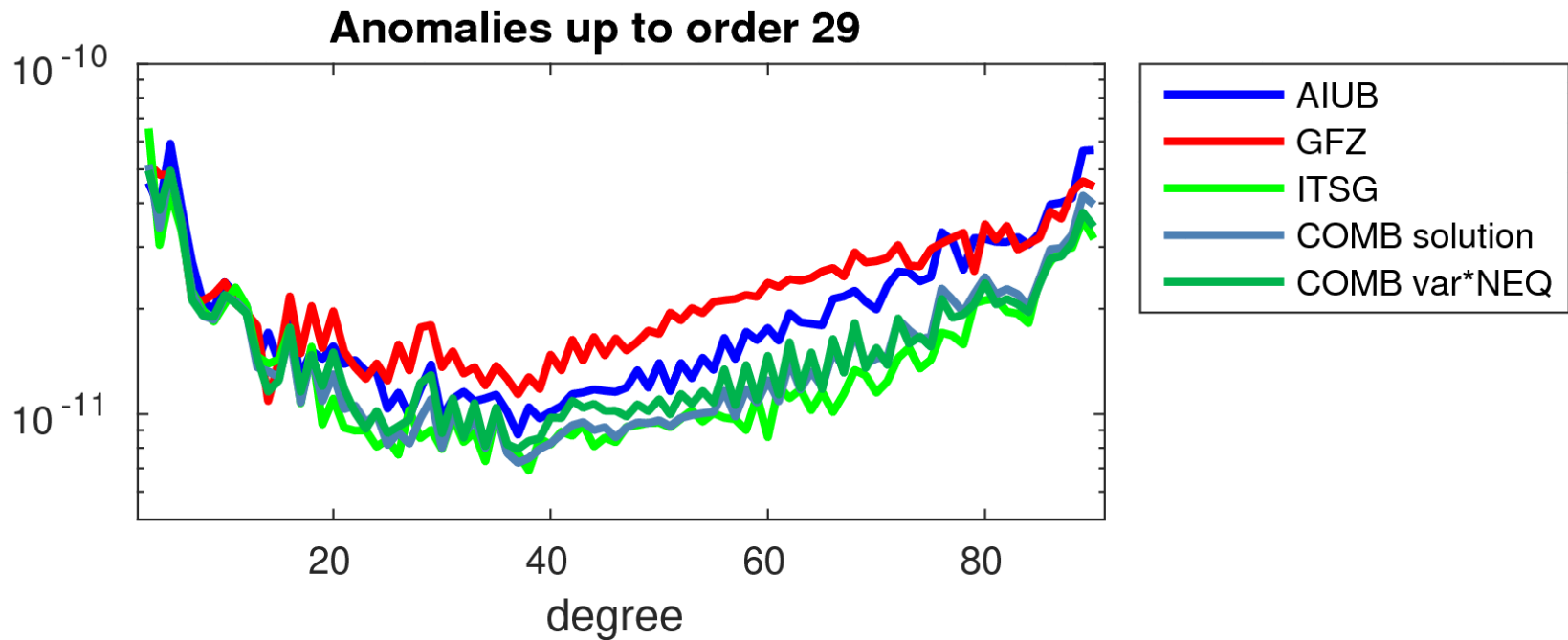
	AIUB	GFZ	ITSG	COMB sol	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.45	0.22	0.33				
wSTD	7.7 mm	9.6 mm	4.7 mm				

Combination: 2006/01



	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			

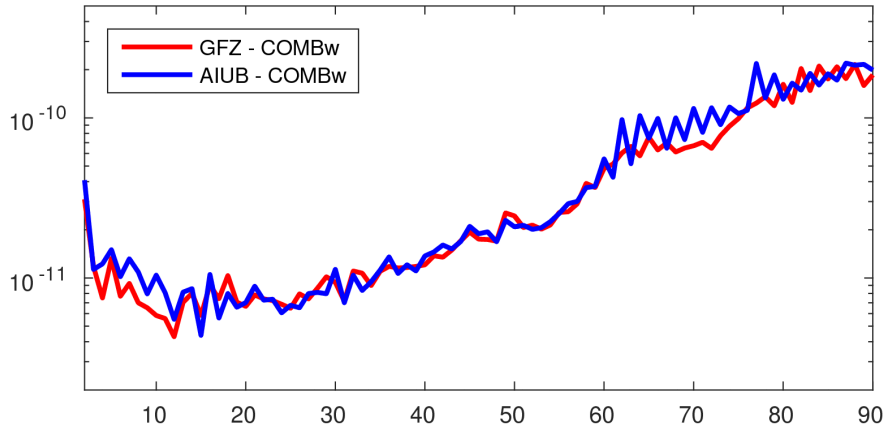
Combination: 2006/01



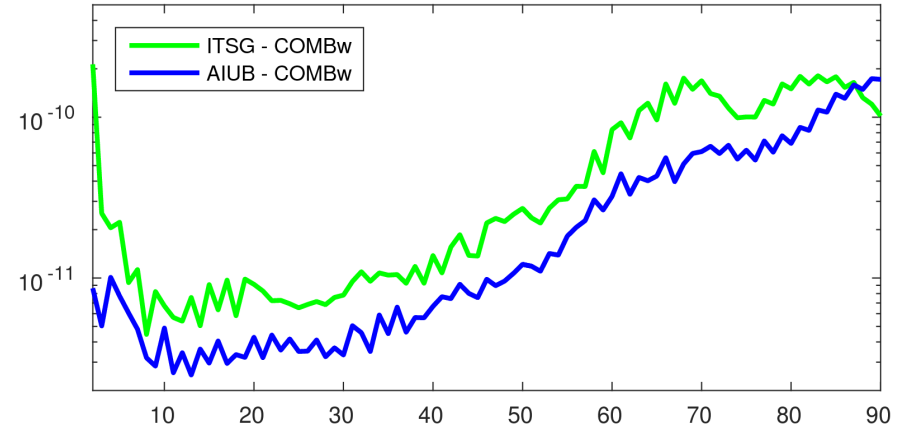
	AIUB	GFZ	ITSG	COMB sol	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.45	0.22	0.33				
wSTD	7.7 mm	9.6 mm	4.7 mm	5.8 mm	6.6 mm		

Individual contributions (variance factors): 2006/01

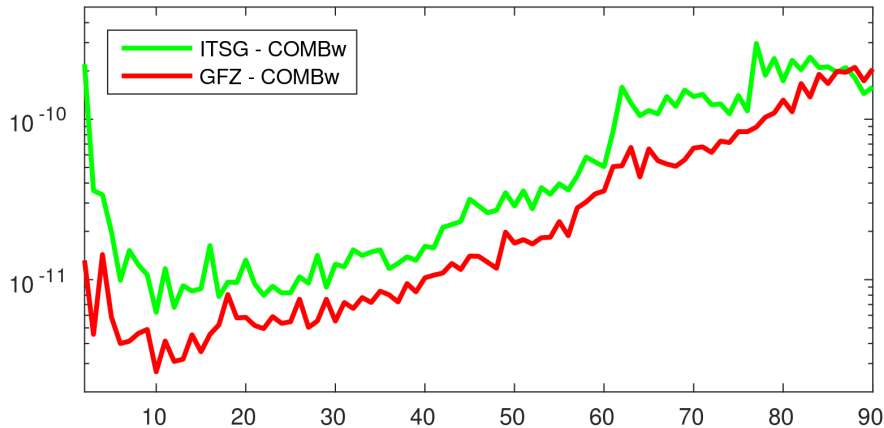
2006/01



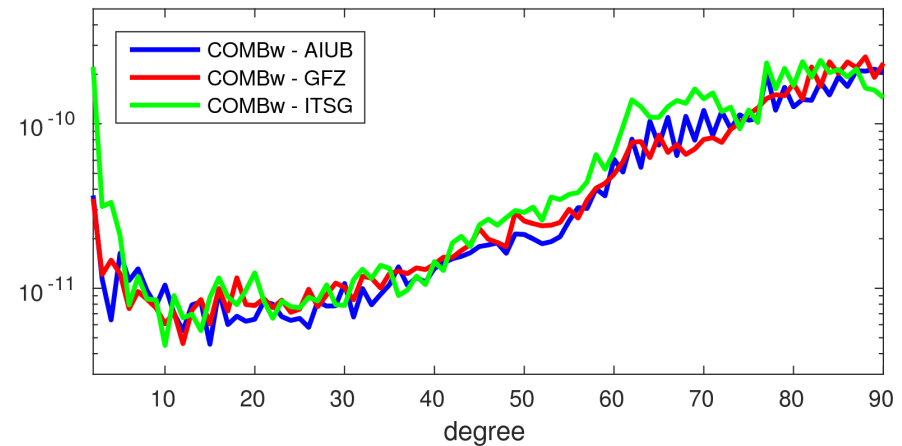
2006/01



2006/01

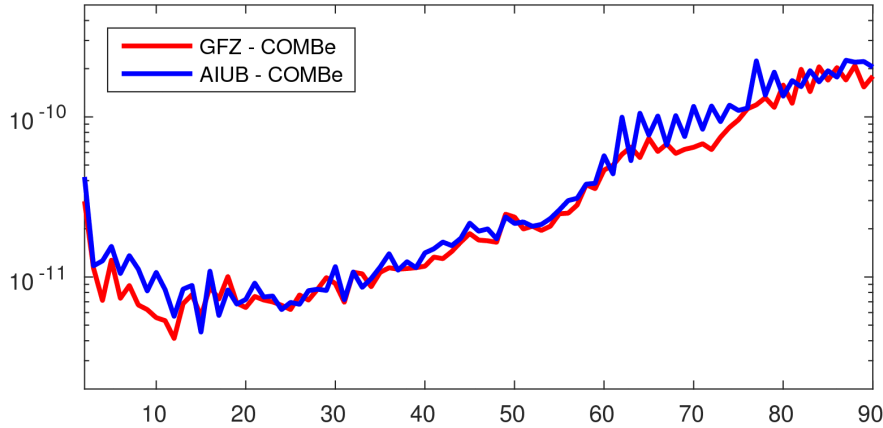


2006/01

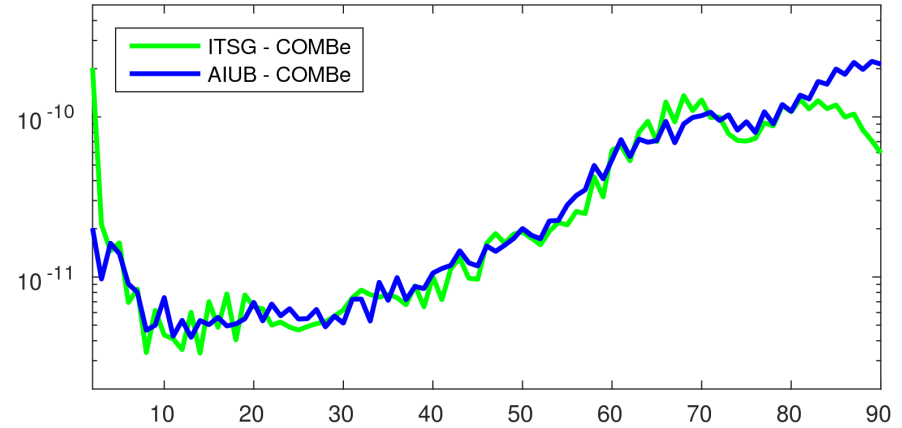


Individual contributions (equalized): 2006/01

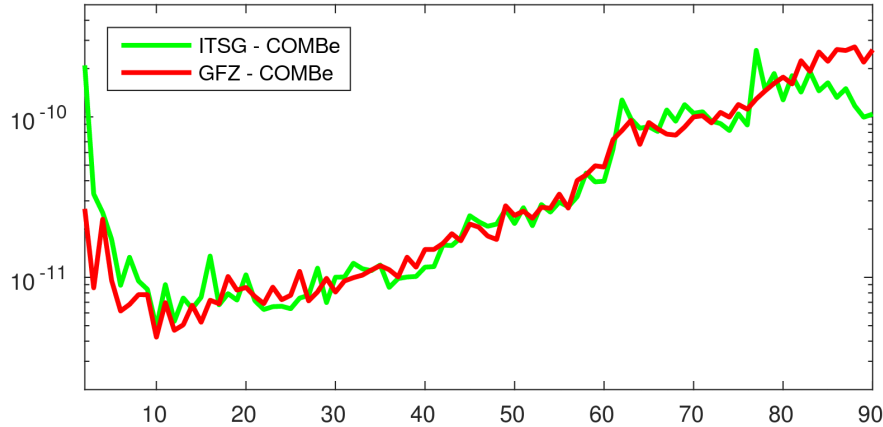
2006/01



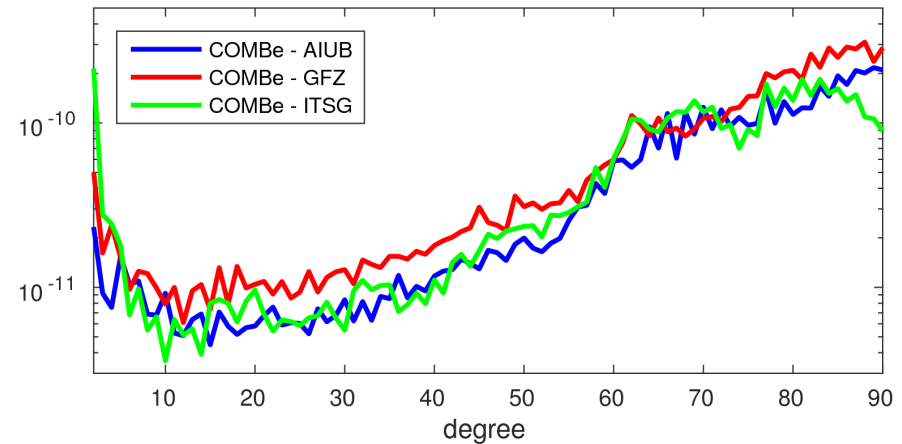
2006/01



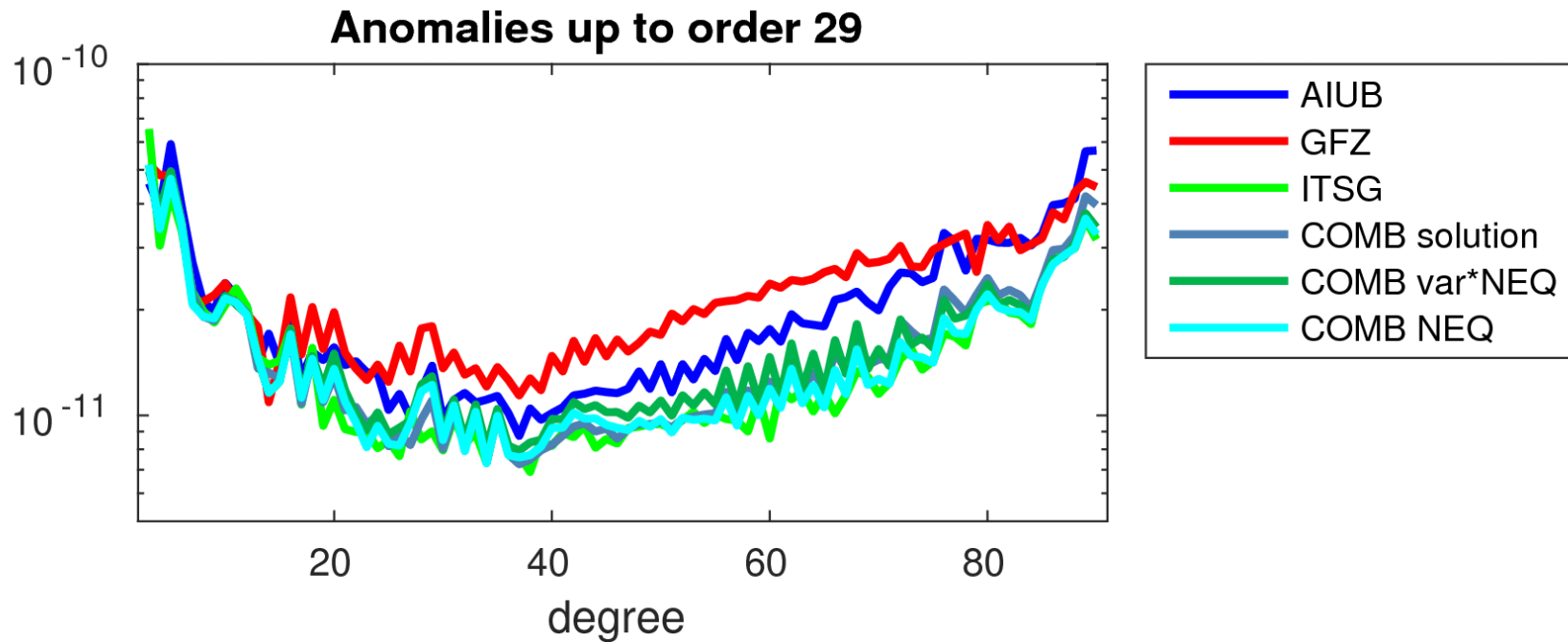
2006/01



2006/01

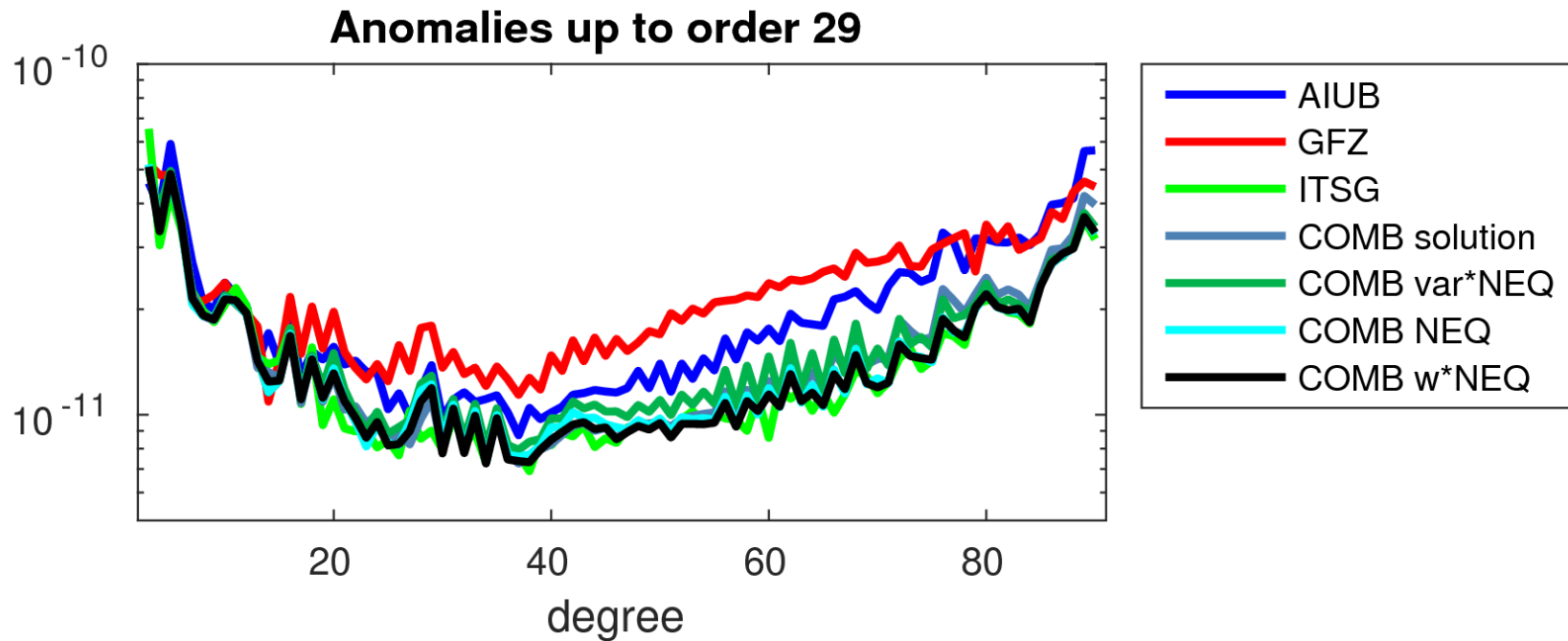


Combination: 2006/01



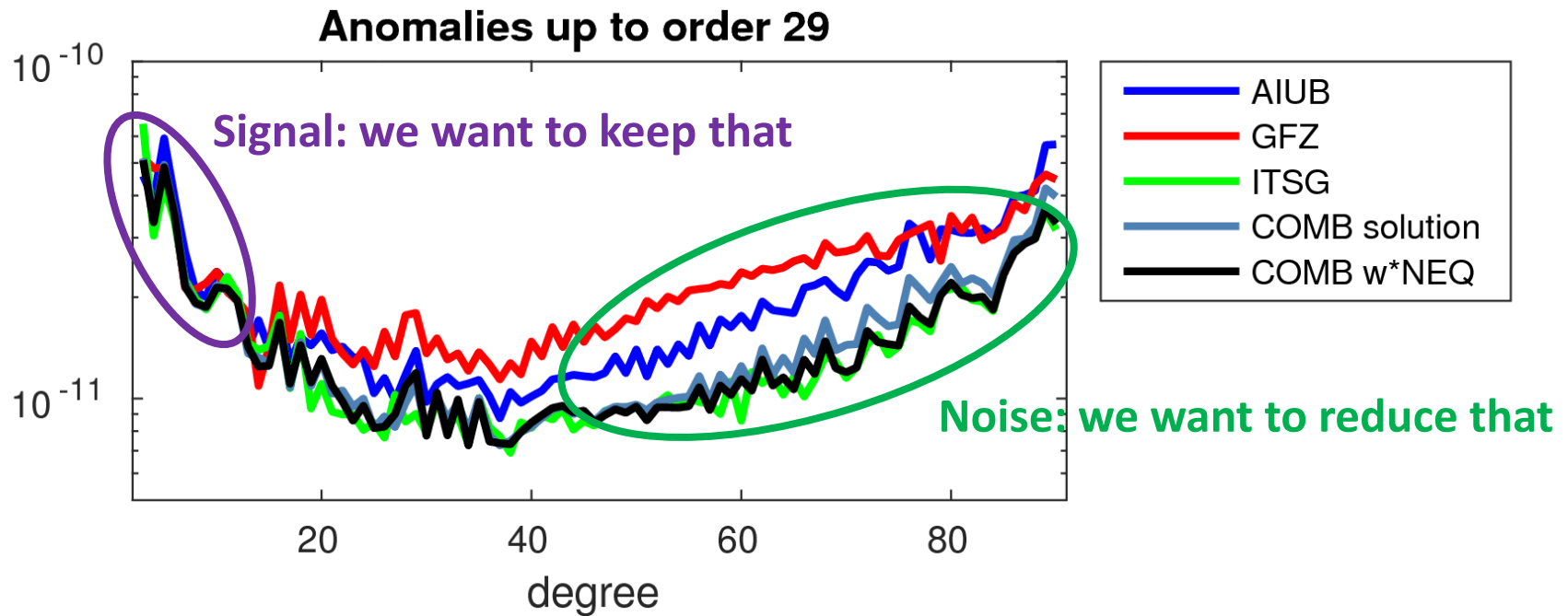
	AIUB	GFZ	ITSG	COMB sol	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.45	0.22	0.33				
wSTD	7.7 mm	9.6 mm	4.7 mm	5.8 mm	6.6 mm	5.9 mm	

Combination: 2006/01



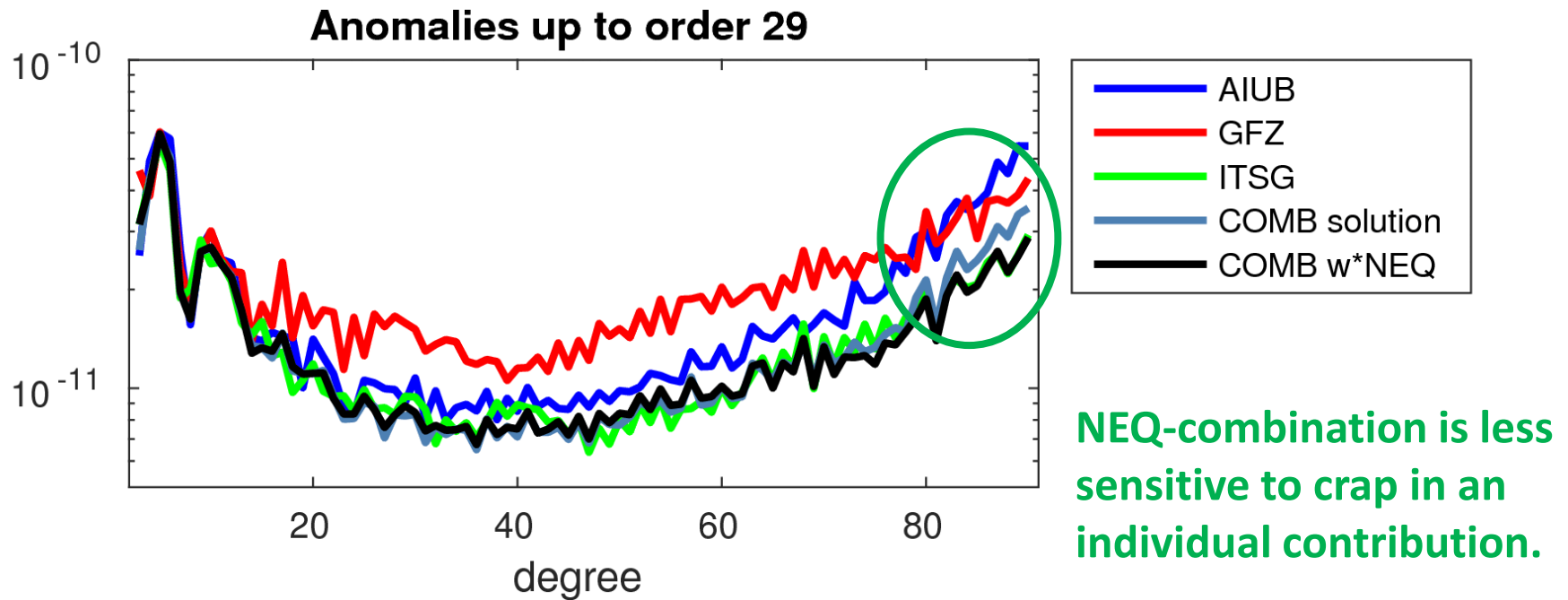
	AIUB	GFZ	ITSG	COMB sol	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.45	0.22	0.33				
wSTD	7.7 mm	9.6 mm	4.7 mm	5.8 mm	6.6 mm	5.9 mm	5.7 mm

Combination: 2006/01



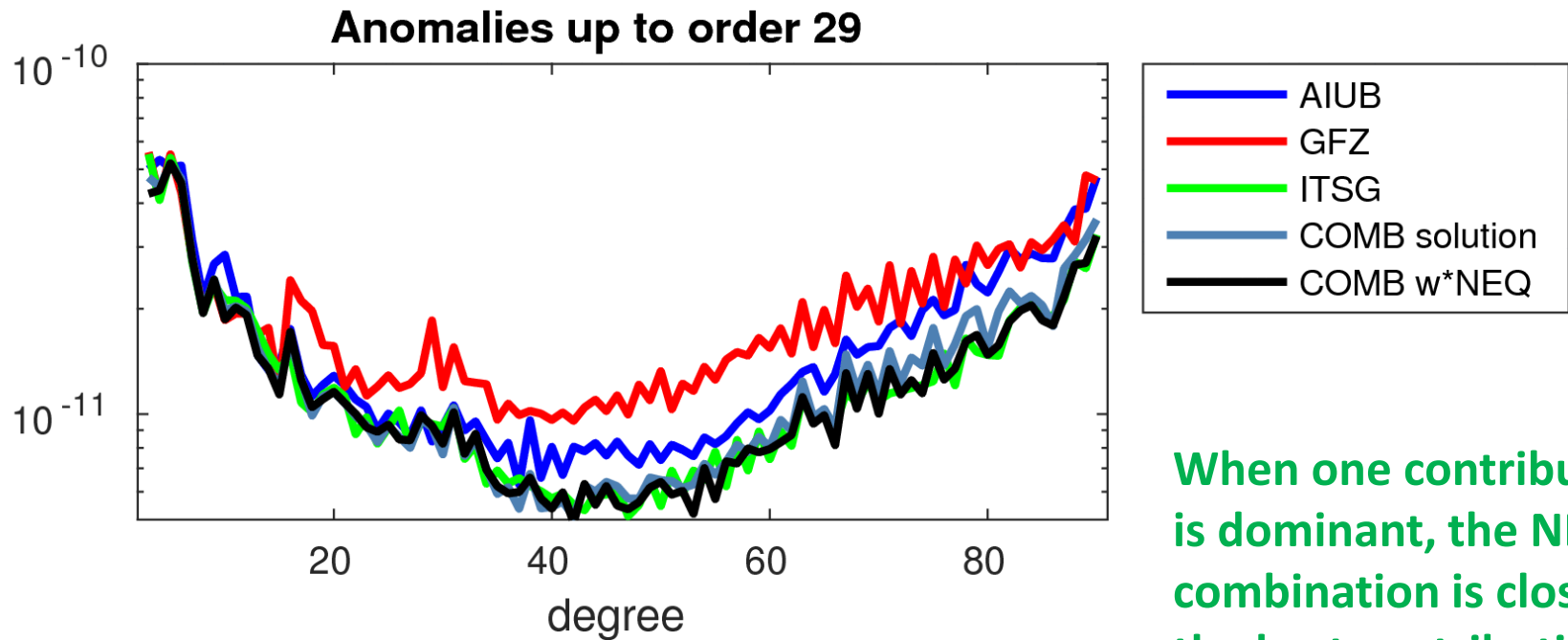
	AIUB	GFZ	ITSG	COMB sol	COMB w * NEQ
weight	0.45	0.22	0.33		
wSTD	7.7 mm	9.6 mm	4.7 mm	5.8 mm	5.7 mm

Combination: 2006/02



	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

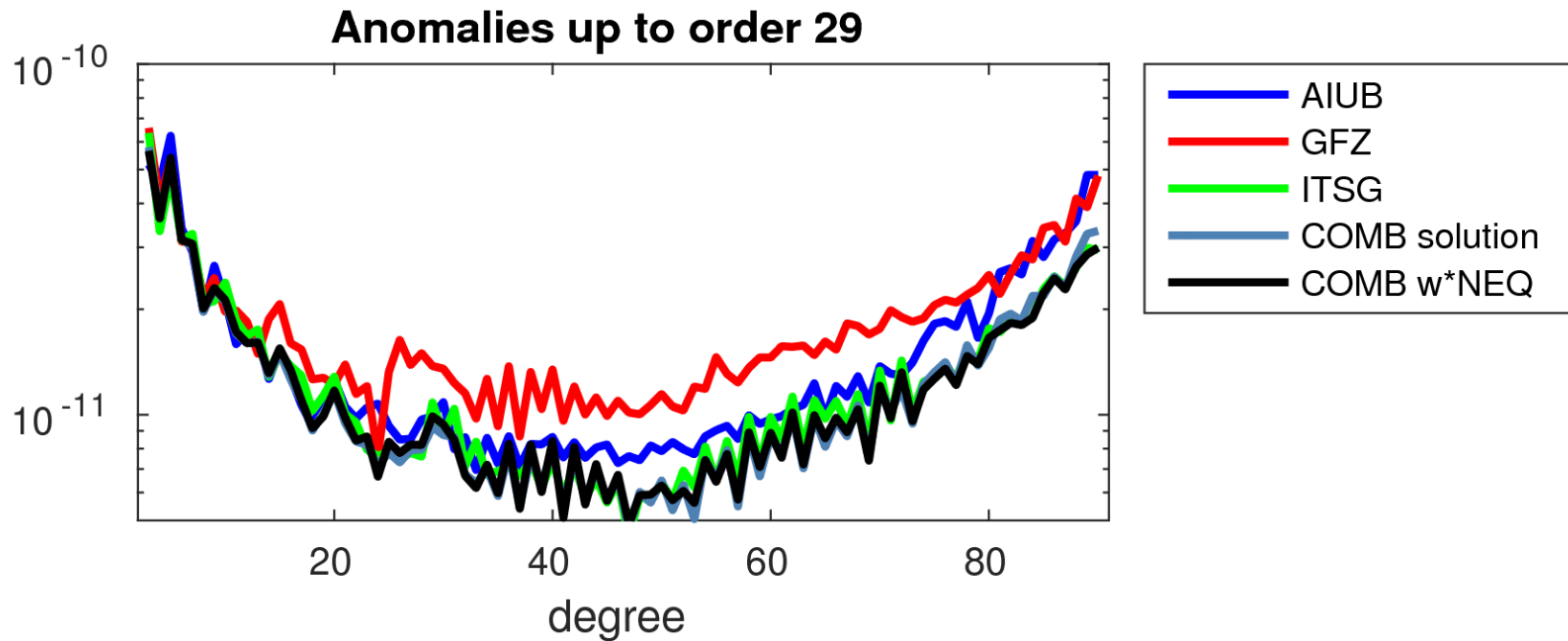
Combination: 2006/03



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

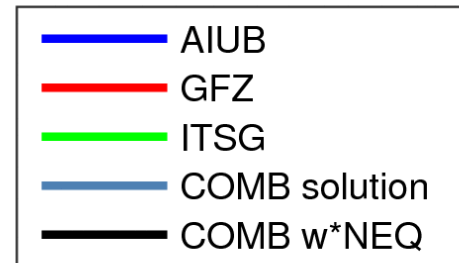
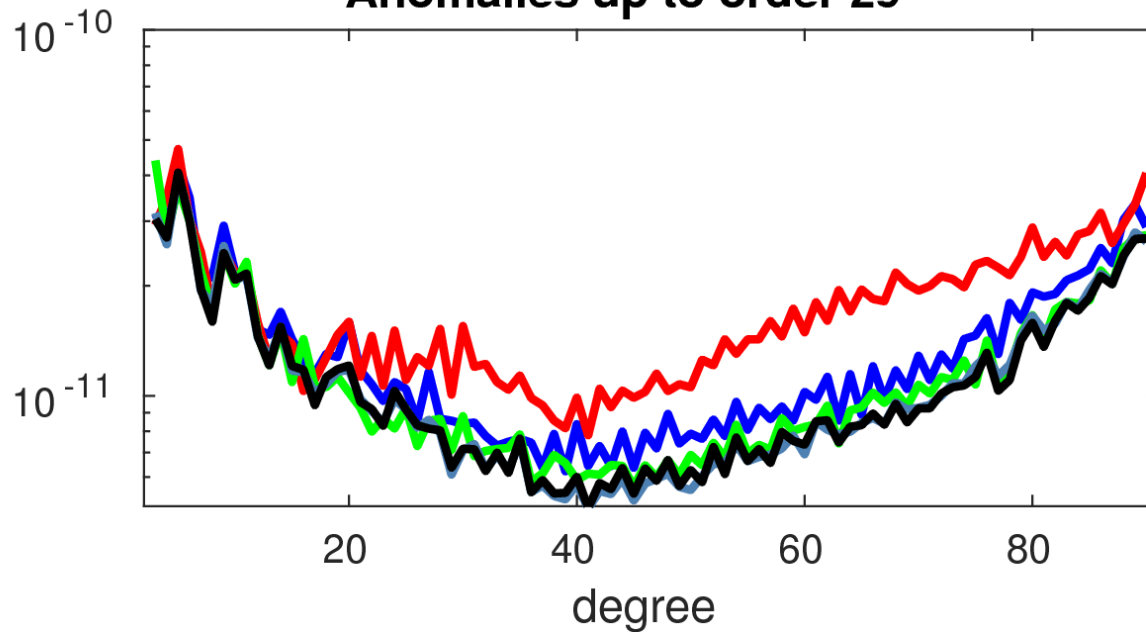
Combination: 2006/04



	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

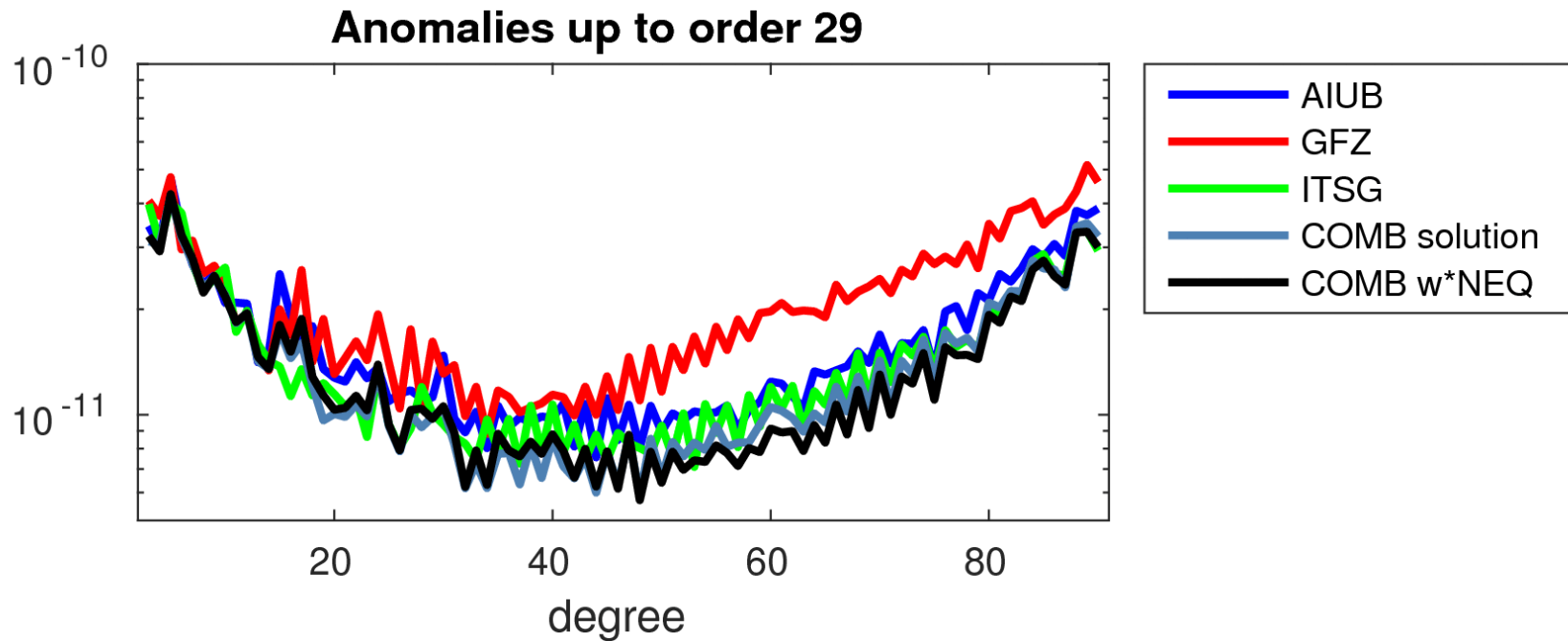
Anomalies up to order 29



When several contributions are comparably good, the combination is better!

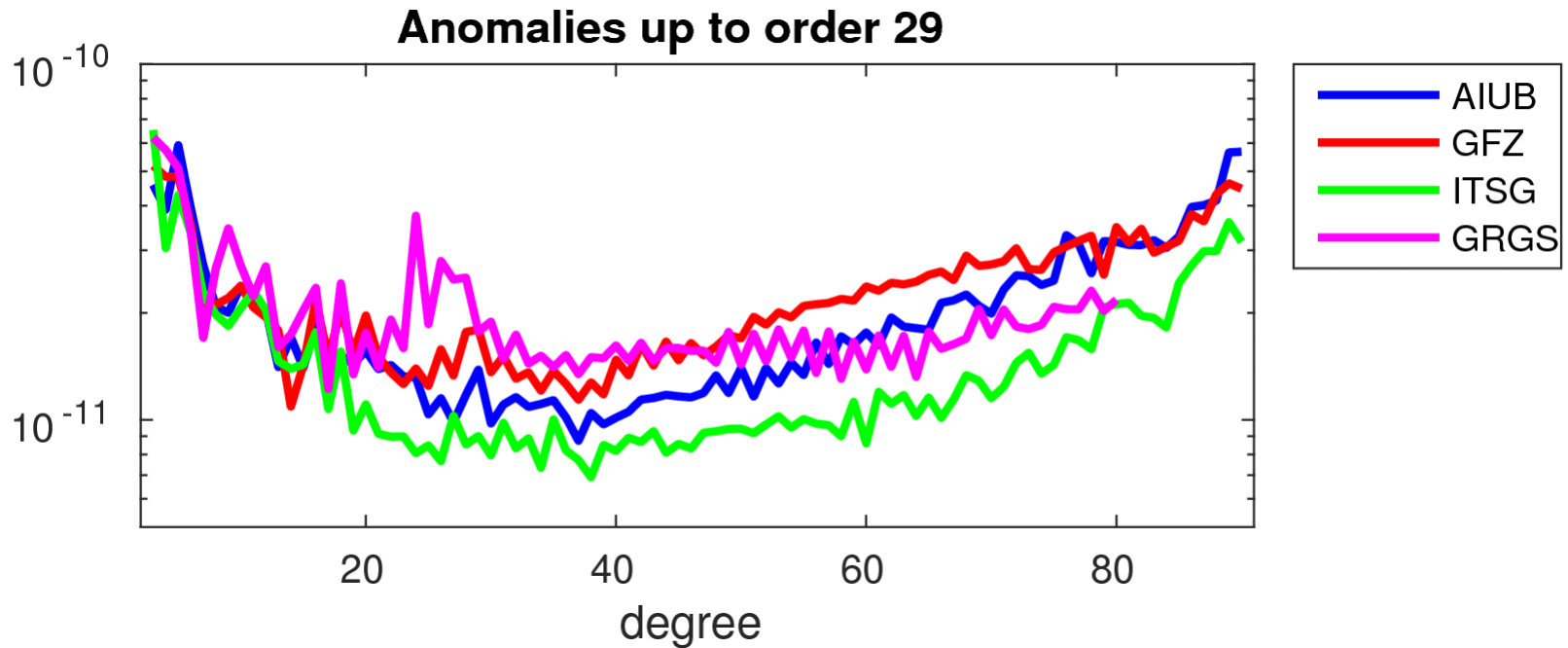
	AIUB	GFZ	ITSG	COMB sol	COMB w * NEQ
weight	0.40	0.25	0.35		
wSTD	7.1 mm	7.5 mm	4.0 mm	5.0 mm	4.6 mm

Combination: 2006/06



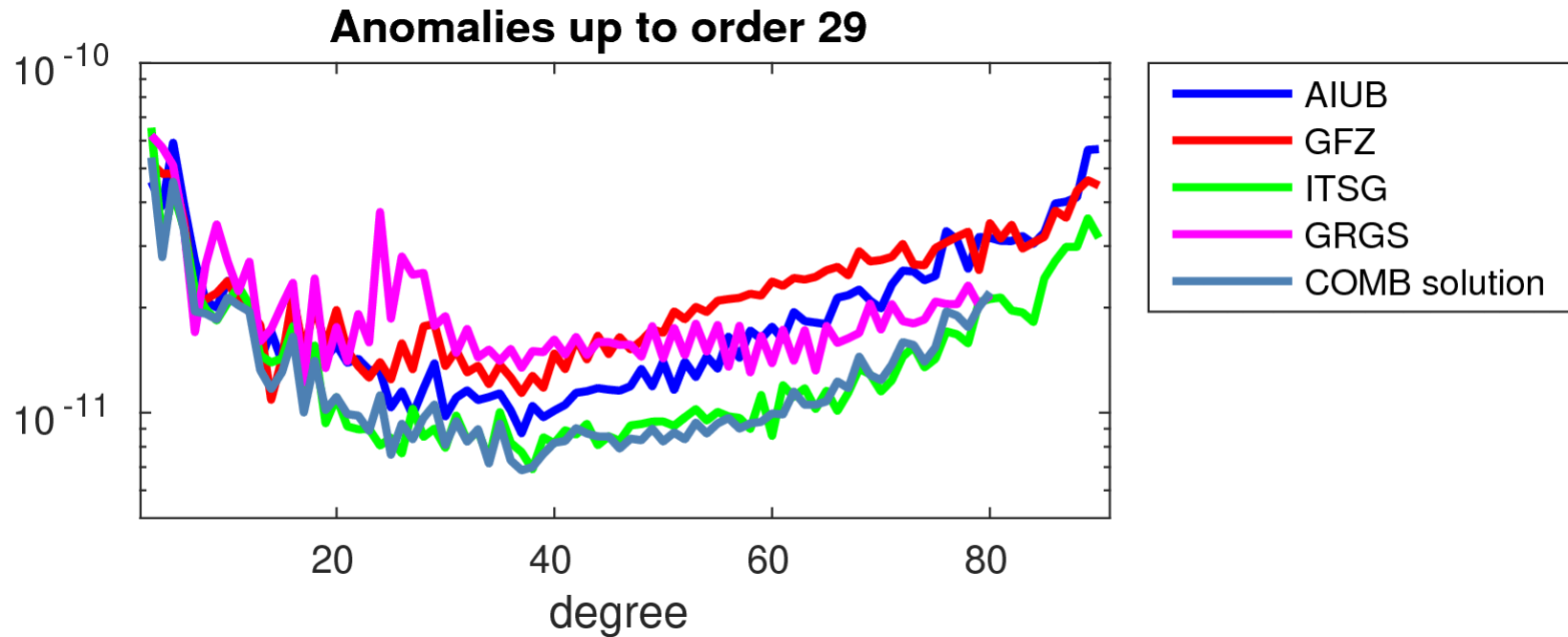
	AIUB	GFZ	ITSG	COMB sol	COMB w * NEQ
weight	0.34	0.27	0.339		
wSTD	7.3 mm	7.5 mm	4.6 mm	5.0 mm	4.6 mm

Combination including GRGS: 2006/01



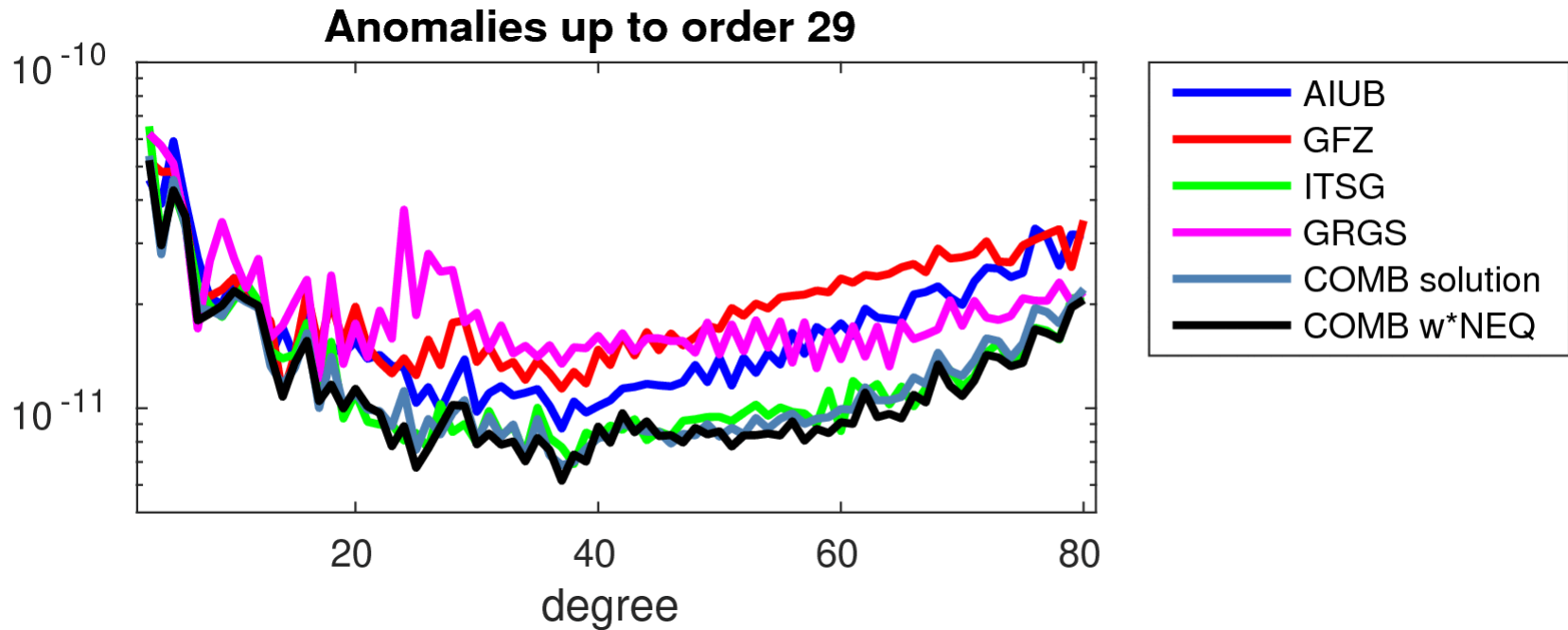
$l_{\max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.29	0.19	0.38	0.14				
wSTD	5.6 mm	6.6 mm	3.5 mm	6.4 mm				

Combination including GRGS: 2006/01



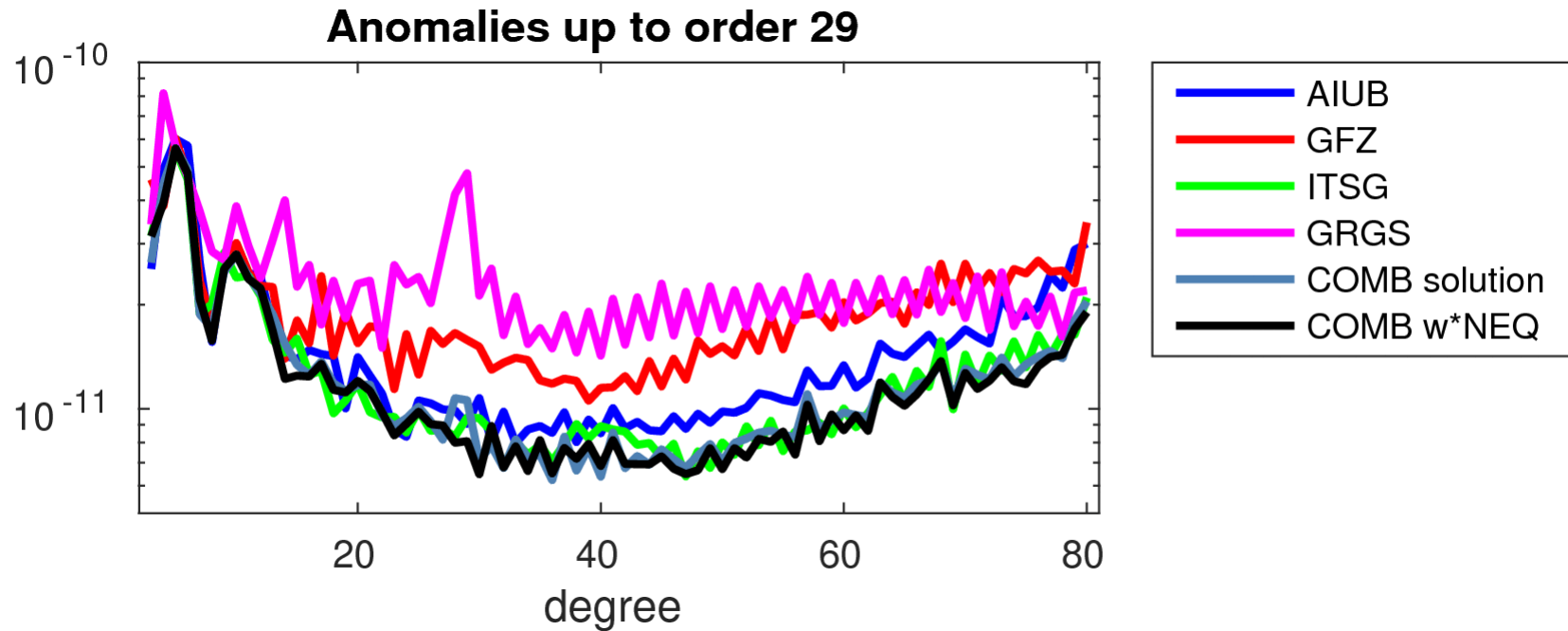
$l_{\max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB F * NEQ	COMB NEQ	COMB w * NEQ
weight	0.29	0.19	0.38	0.14				
wSTD	5.6 mm	6.6 mm	3.5 mm	6.4 mm	3.9 mm			

Combination including GRGS: 2006/01



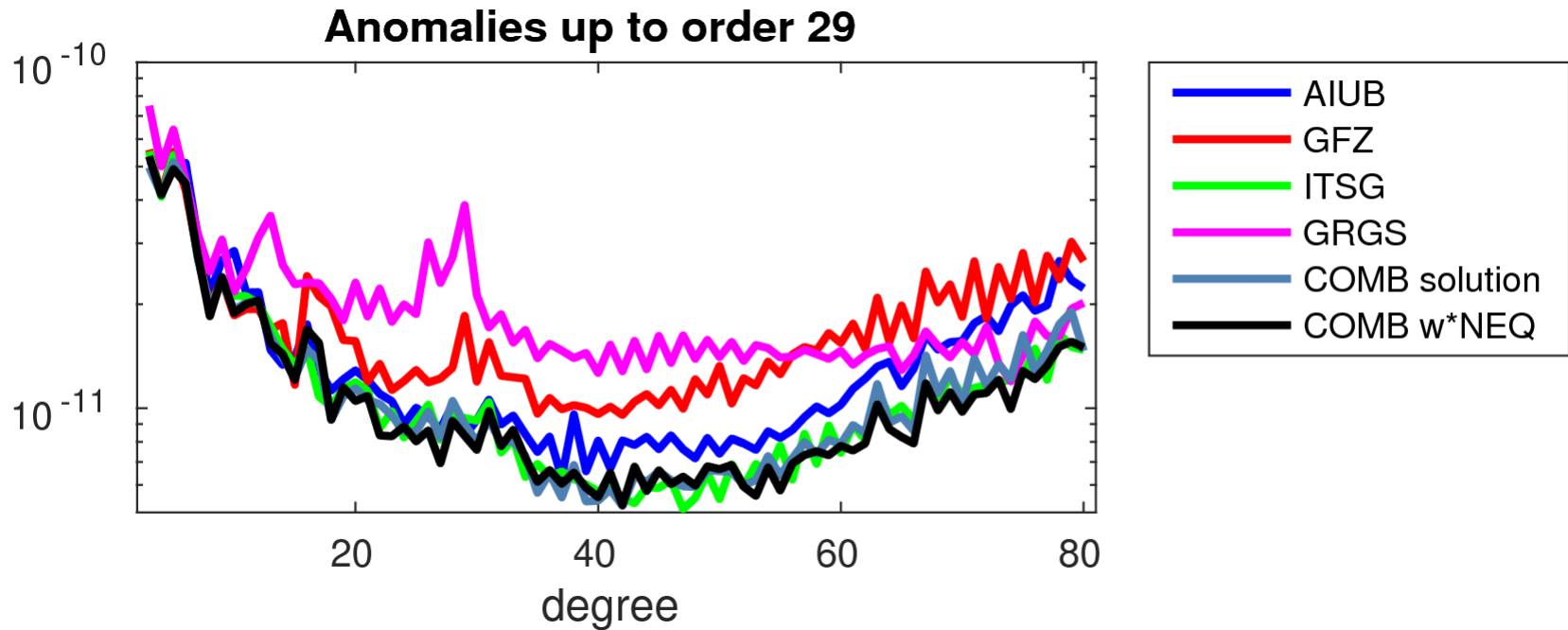
$l_{\max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.29	0.19	0.38	0.14		
wSTD	5.6 mm	6.6 mm	3.5 mm	6.4 mm	3.9 mm	3.9 mm

Combination including GRGS: 2006/02



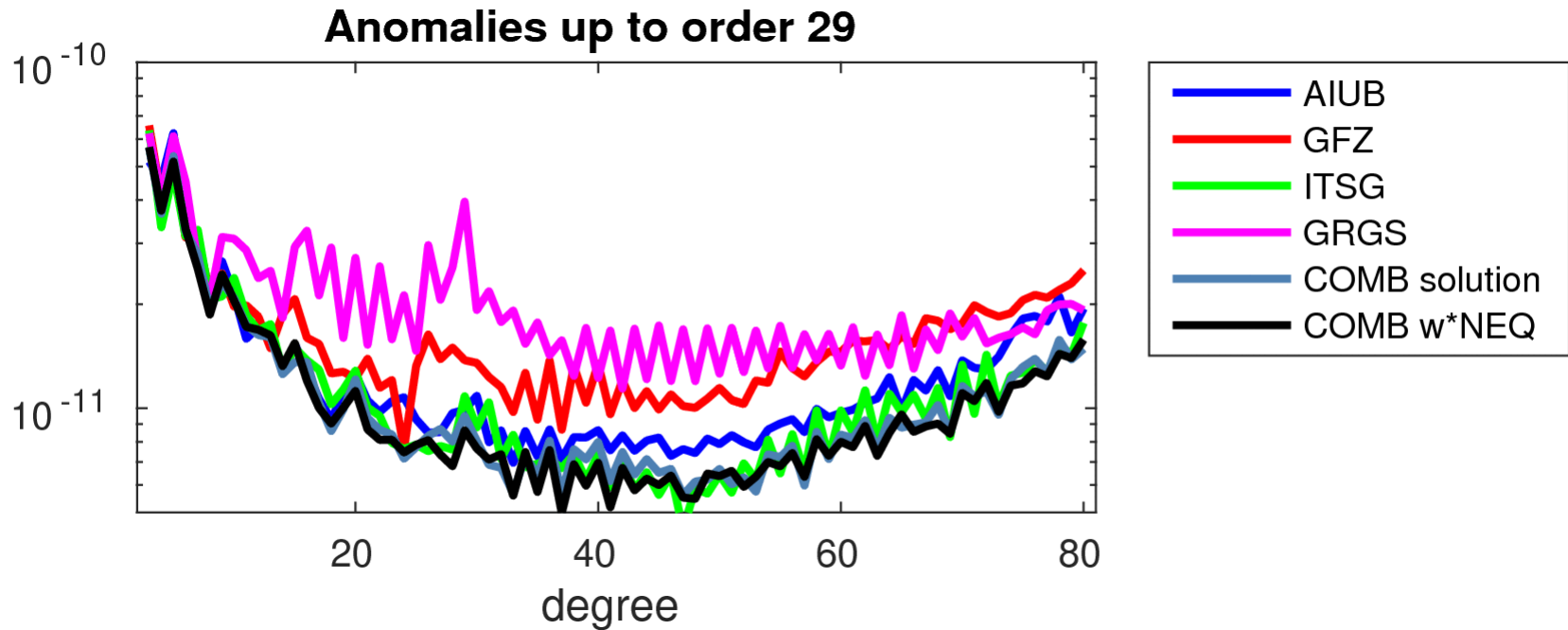
$l_{\max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.36	0.21	0.27	0.16		
wSTD	5.6 mm	6.3 mm	3.4 mm	5.4 mm	4.1 mm	3.9 mm

Combination including GRGS: 2006/03



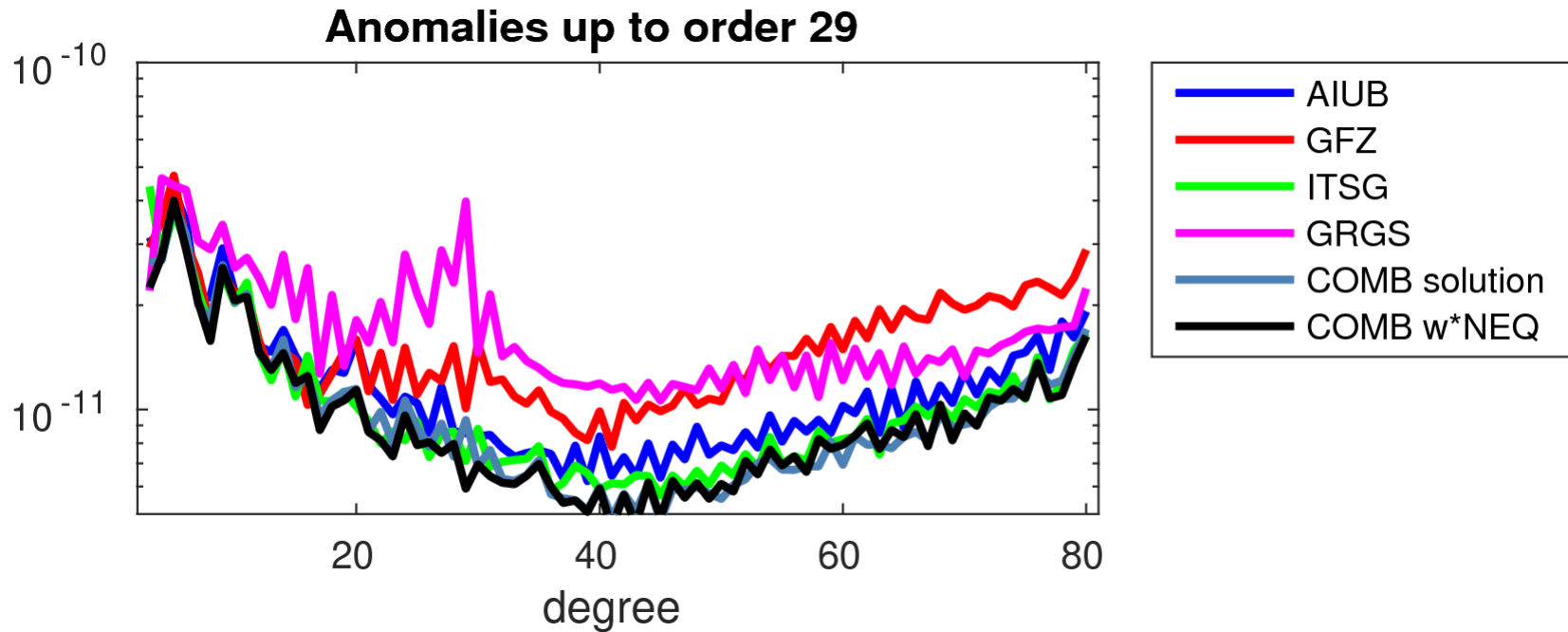
$l_{\max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.37	0.22	0.27	0.14		
wSTD	5.3 mm	6.5 mm	3.4 mm	6.1 mm	4.0 mm	4.0 mm

Combination including GRGS: 2006/04



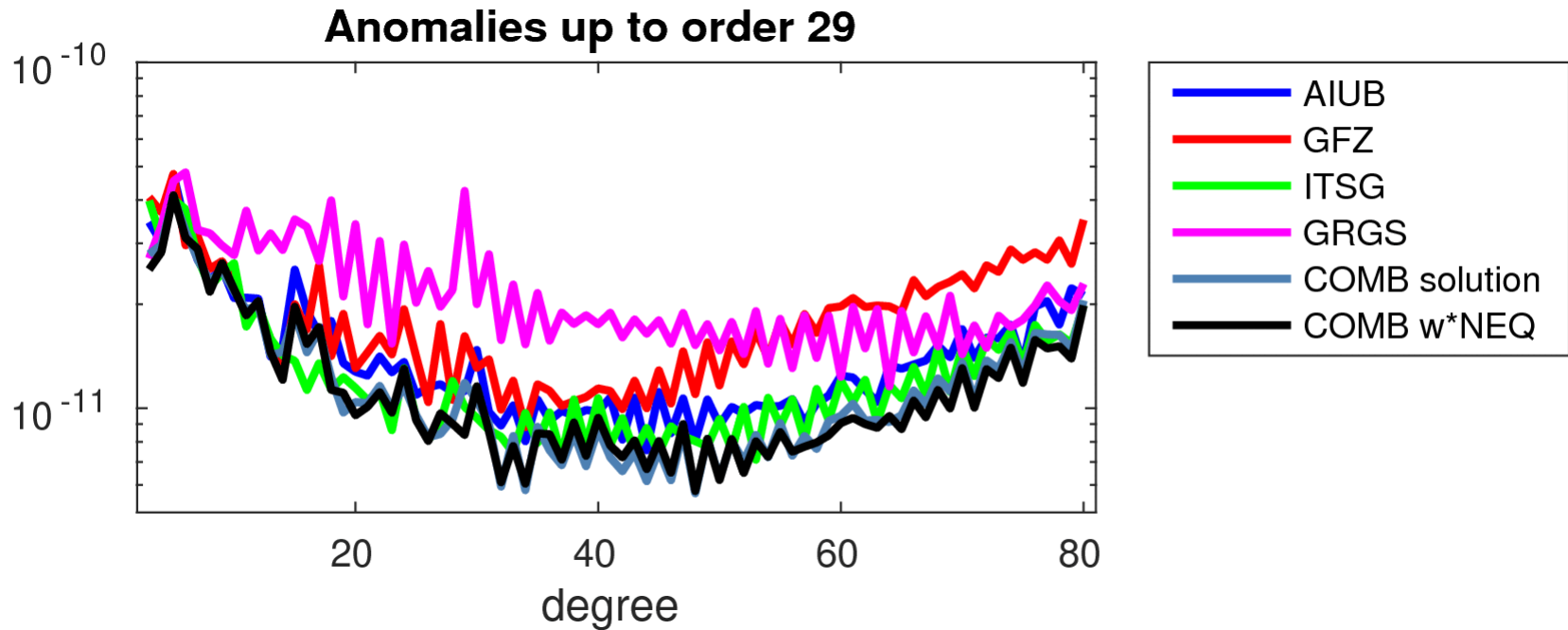
$l_{\max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.37	0.22	0.29	0.12		
wSTD	4.4 mm	5.2 mm	3.2 mm	5.3 mm	3.3 mm	3.4 mm

Combination including GRGS: 2006/05



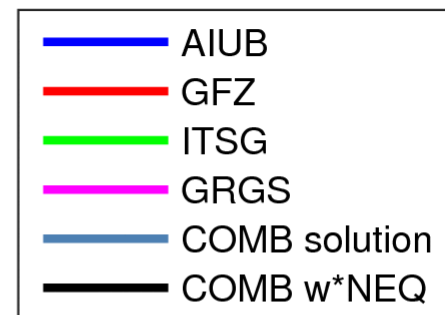
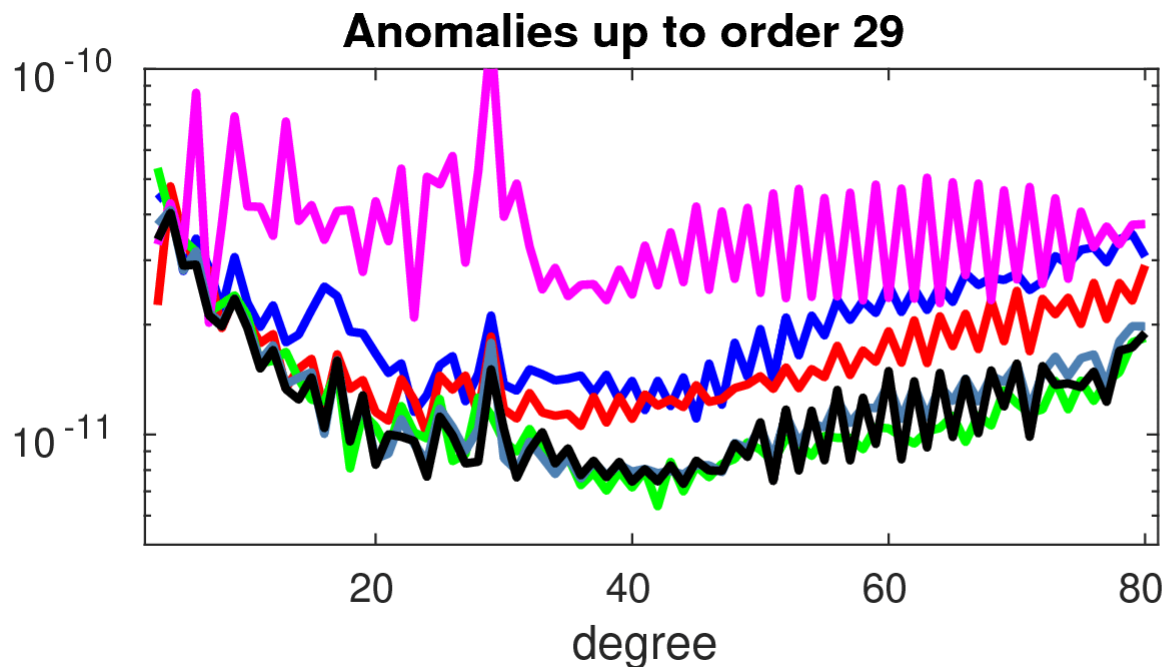
$l_{\max} = 80$	AIUB	GFZ	ITSG	GRGS	COMB solution	COMB w * NEQ
weight	0.27	0.26	0.31	0.16		
wSTD	5.0 mm	5.2 mm	3.2 mm	4.9 mm	3.5 mm	3.2 mm

Combination including GRGS: 2006/06



$l_{\max} = 80$	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



**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.