Gravity field recovery from hl-SST: latest results from Swarm and other satellites

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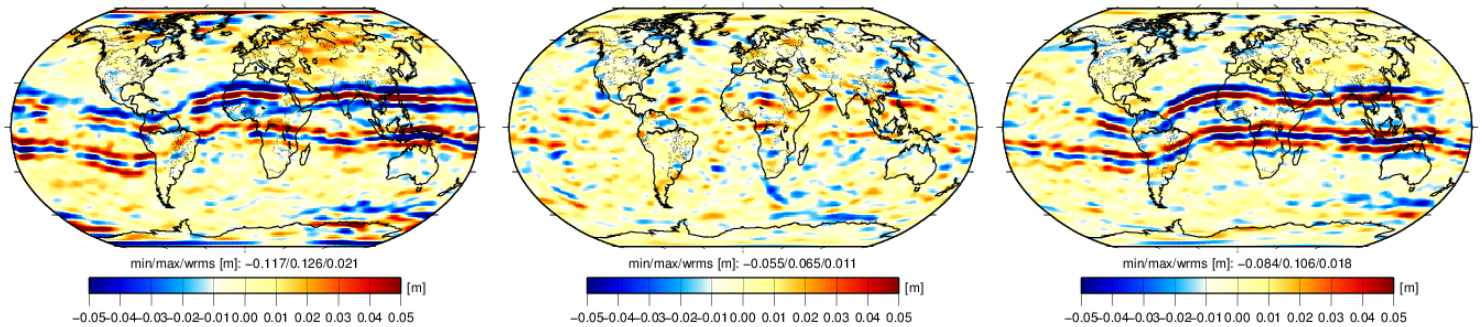
Potsdam

Recap

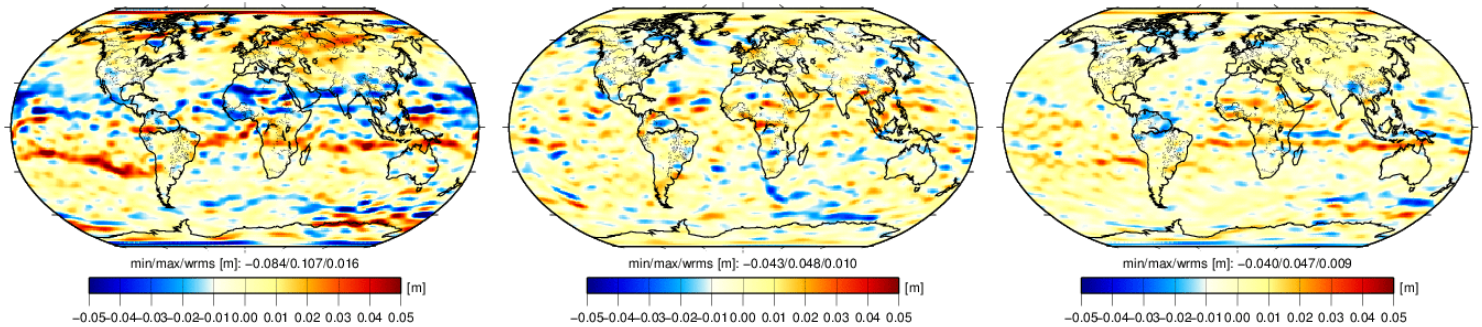
- **Ionosphere disturbances affect orbit and gravity field solutions:**
  - Systematic errors along geomagnetic equator
  - Magnitude of errors depending on ionospheric activity
  - May be reduced by additional data screening (dL_{gf}/dt criterion)

Original GPS Data



Mar/Apr 2014 | Jun/Jul 2014 | Nov/Dec 2014

Screened GPS Data



Differences wrt GOCO05S, 400 km Gauss smoothing adopted

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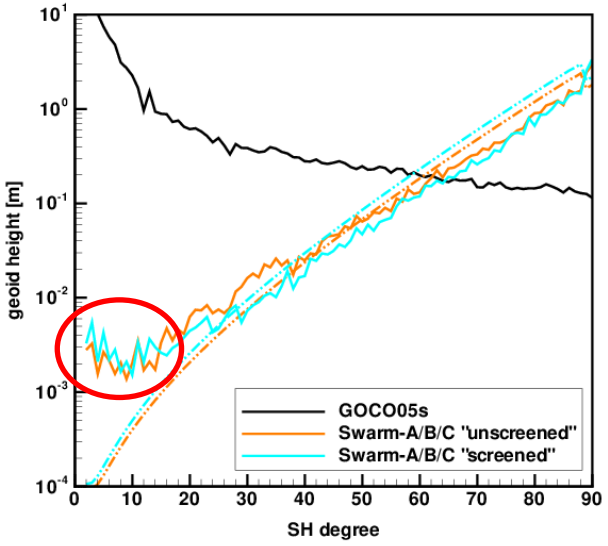
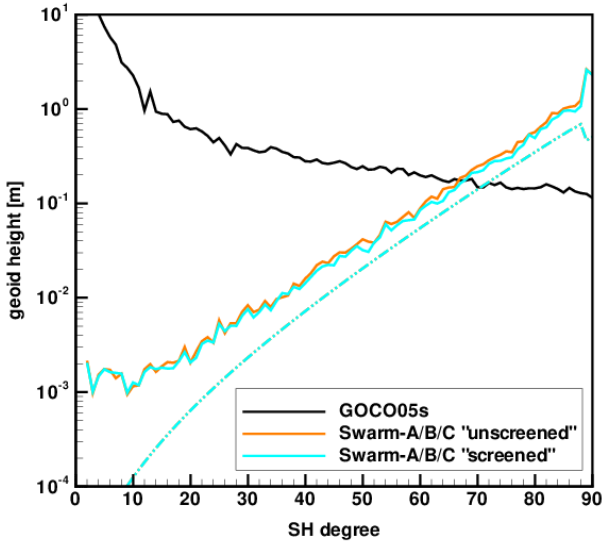
Recap

- Ionosphere disturbances affect orbit and gravity field solutions:
  - Systematic errors along geomagnetic equator
  - Magnitude of errors depending on ionospheric activity
  - May be reduced by additional data screening (dL_{gf}/dt criterion)
- **GPS data screening for large ionosphere changes helps to reduce the geomagnetic signatures, but also weakens low degrees**

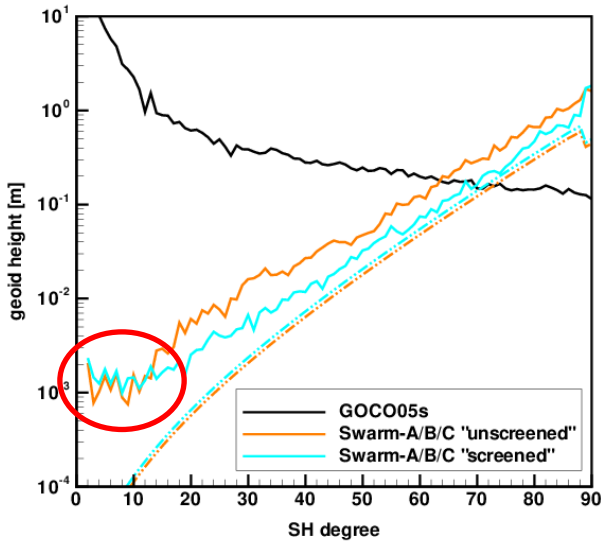
Mar/Apr 2014



Jun/Jul 2014



Nov/Dec 2014



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Updated Swarm GPSR Settings

- Stepwise modification of the tracking loops of the GPS receiver
- Wider carrier loop bandwidths increase the robustness of carrier phase tracking against ionospheric scintillations

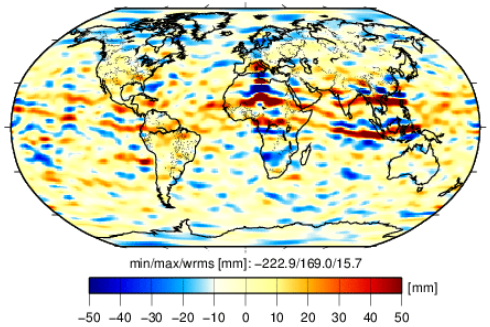
L2 carrier loop bandwidth updates (copyright: ESA)

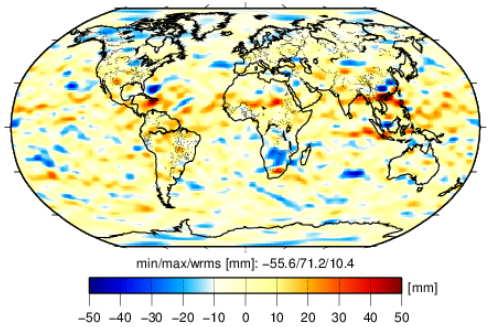
	Swarm A	Swarm B	Swarm C
Before 6 May 2015	0.25Hz	0.25Hz	0.25Hz
6 May 2015			0.25Hz → 0.5Hz
8 October 2015	0.25Hz → 0.5Hz		
10 October 2015		0.25Hz → 0.5Hz	
23 June 2016			0.5Hz → 0.75Hz
11 August 2016	0.5Hz → 0.75Hz		0.75Hz → 1.0Hz

Updated Swarm GPSR Settings

Impact on Gravity Field Solutions (June 2015)

Original GPS Data

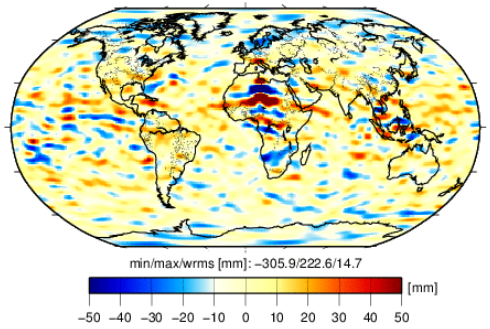


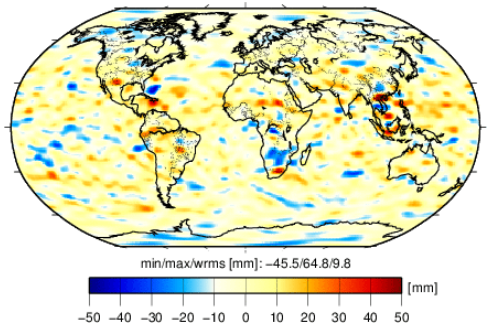


Swarm-A

Swarm-C

Screened GPS Data





After 1st tracking loop update (6 May 2015): Systematics markedly reduced in gravity field derived from Swarm-C, even when using original GPS data!

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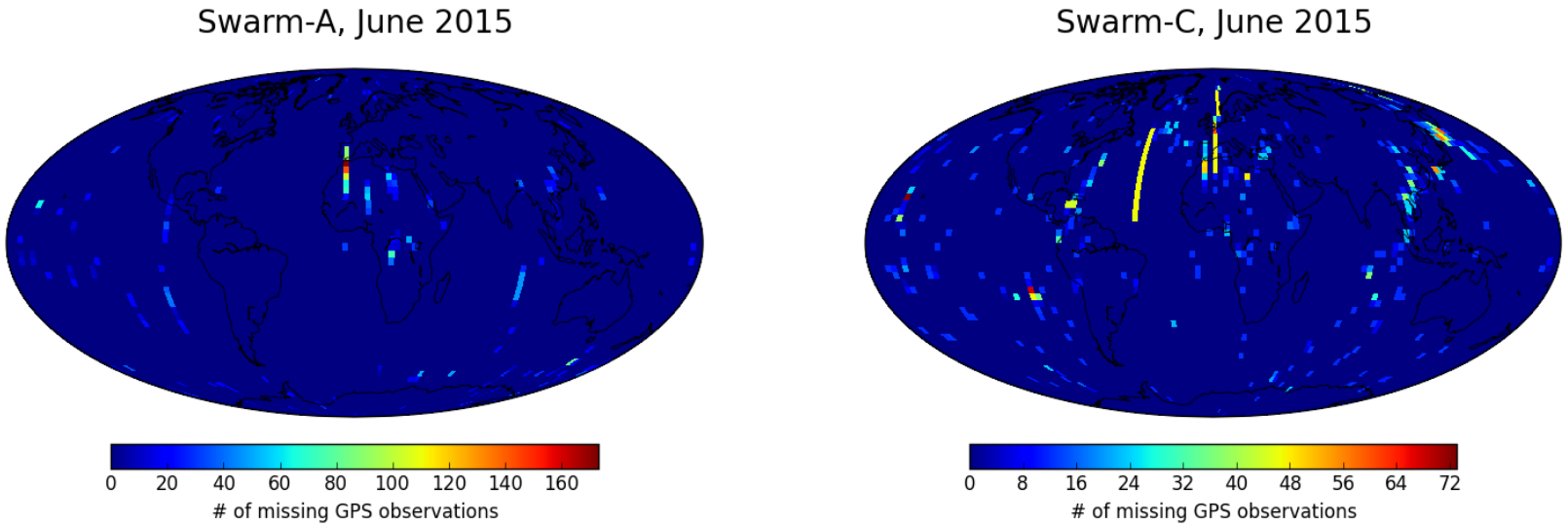
Updated Swarm GPSR Settings

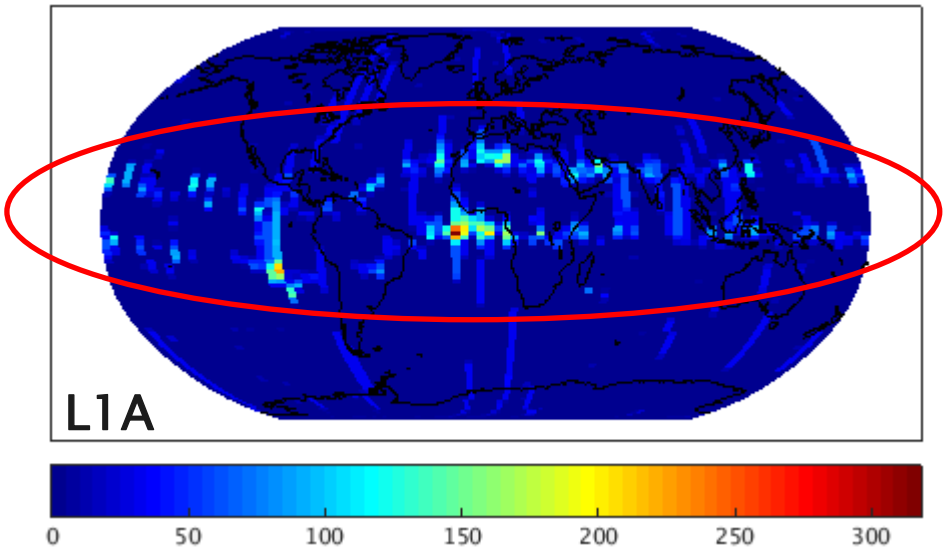
Missing observations (June 2015)



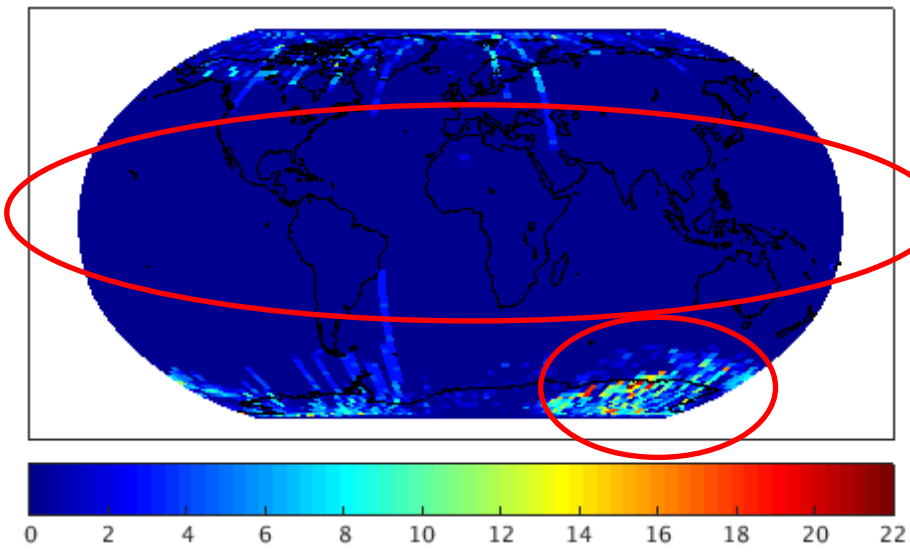
- No obvious gaps for Swarm-C along geomagnetic equator.
- Reduction of artefacts in gravity field solutions is therefore not due to data gaps along geomagnetic equator (as observed for GRACE).
- This indicates that the equatorial GPS data were indeed “corrupted” before the tracking loop changes. With improved settings of the tracking loop the problem seems to be largely mitigated.

Number of missing Observations in RINEX files

GRACE-B, doy 060-090, 2014
(all arcs)



Swarm-A, doy 060-090, 2014
(all arcs)



- Significant amounts of data are missing in GRACE L1B RINEX files
  => problematic signatures cannot propagate into gravity field.
- Swarm RINEX files are more complete (gaps only over the poles)
  => problematic signatures do propagate into the gravity field.

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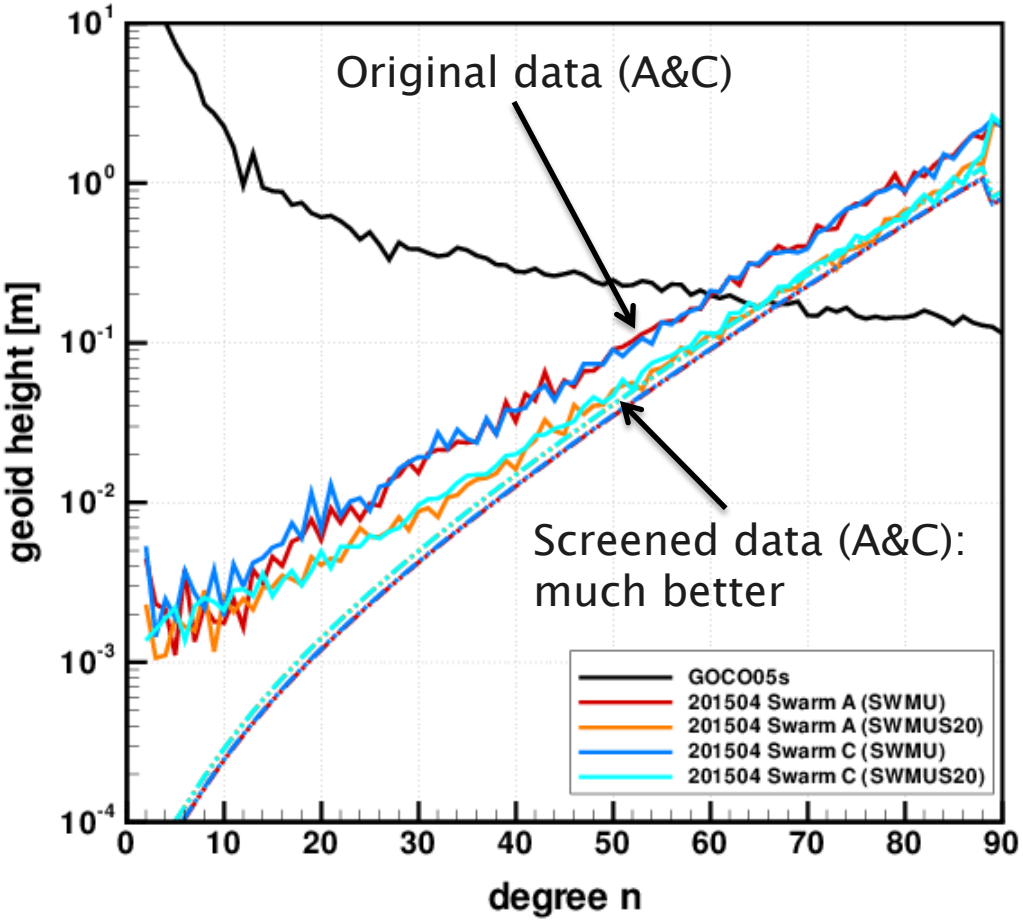
Updated Swarm GPSR Settings

Degree amplitudes: April 2015

(Swarm-A: 0.25 Hz, Swarm-C: 0.25 Hz)



- **Swarm-A and -C very similar**
- **Screening improves gravity field significantly**

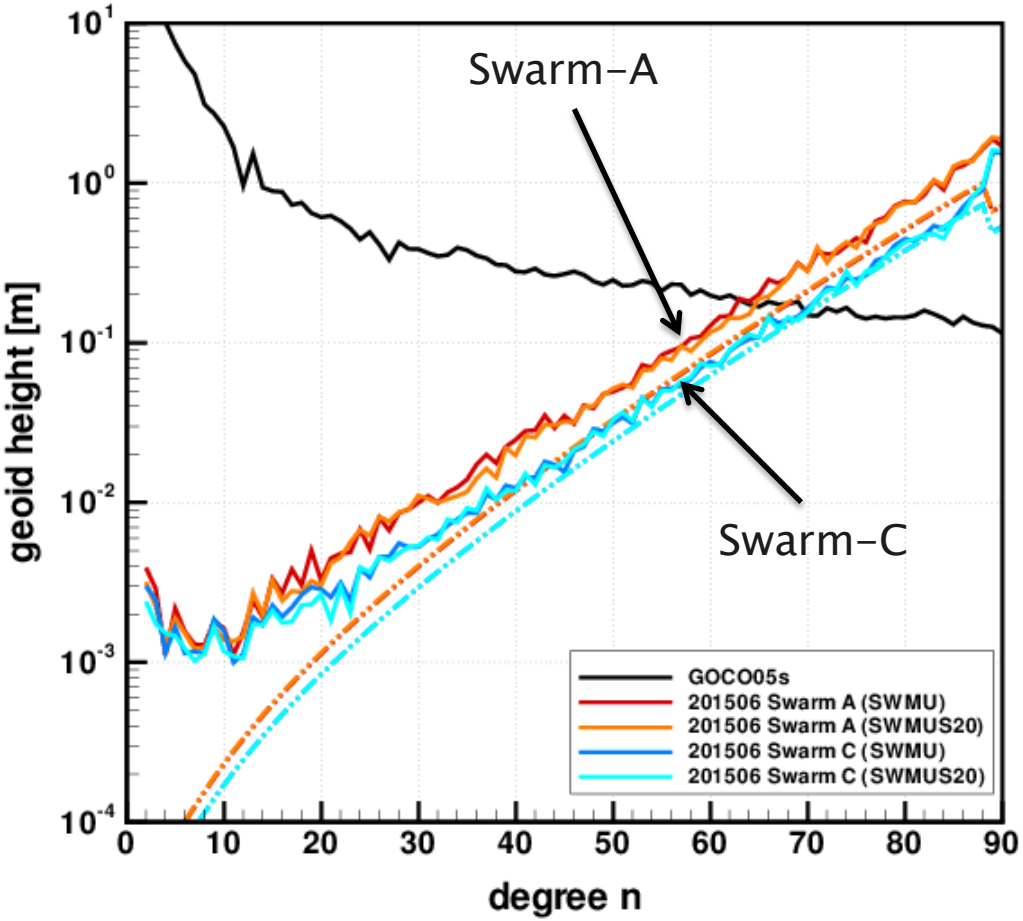
Percentage of missing kinematic positions in „screened“ solutions wrt. „original“ solutions:

Swarm-A: 13.9%
Swarm-C: 13.8%

Updated Swarm GPSR Settings

Degree amplitudes: June 2015

(Swarm-A: 0.25 Hz, Swarm-C: 0.5 Hz)



- **Swarm-A worse than Swarm-C**
- **Screening does not help a lot, neither for Swarm-A, nor for Swarm-C**
- **The applied screening is not as beneficial as tracking loop update (under investigation)**

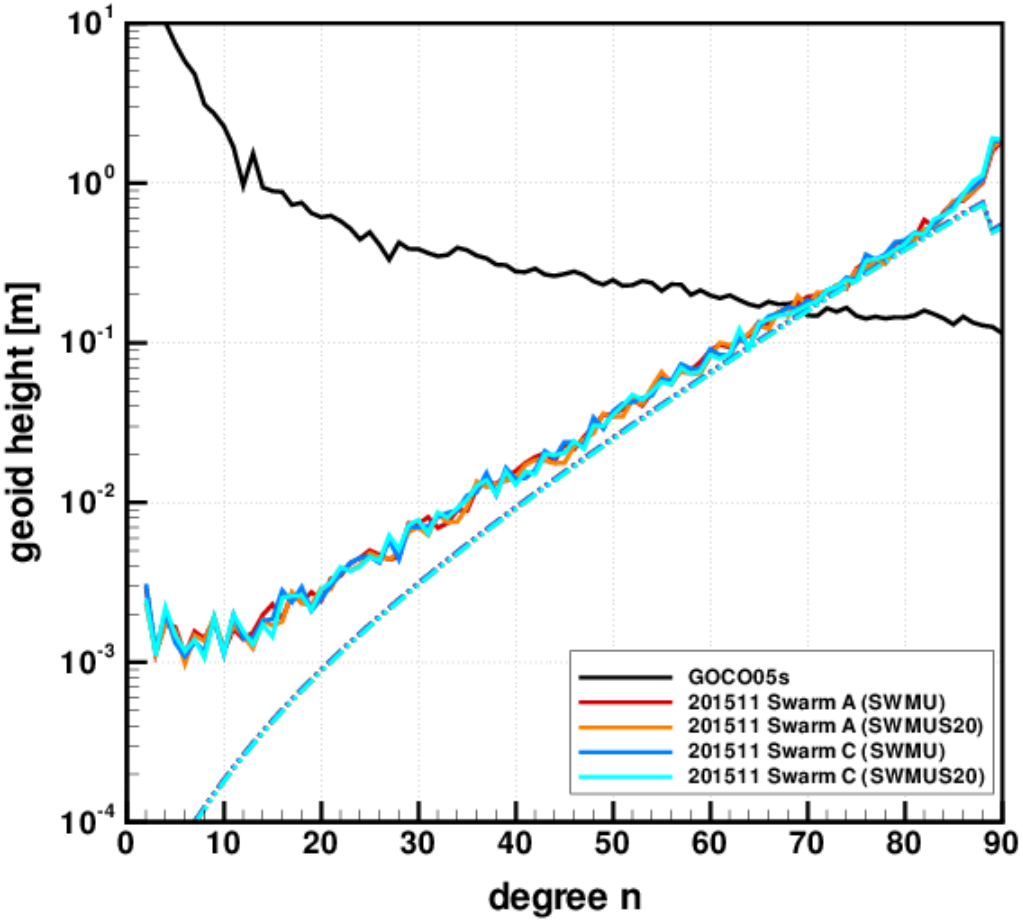
Percentage of missing kinematic positions in „screened“ solutions wrt. „original“ solutions:

Swarm-A: 3.0%
Swarm-C: 1.5%

Updated Swarm GPSR Settings

Degree amplitudes: November 2015

(Swarm-A: 0.5 Hz, Swarm-C: 0.5 Hz)



- Swarm-A and -C very similar again
- Screening does not help

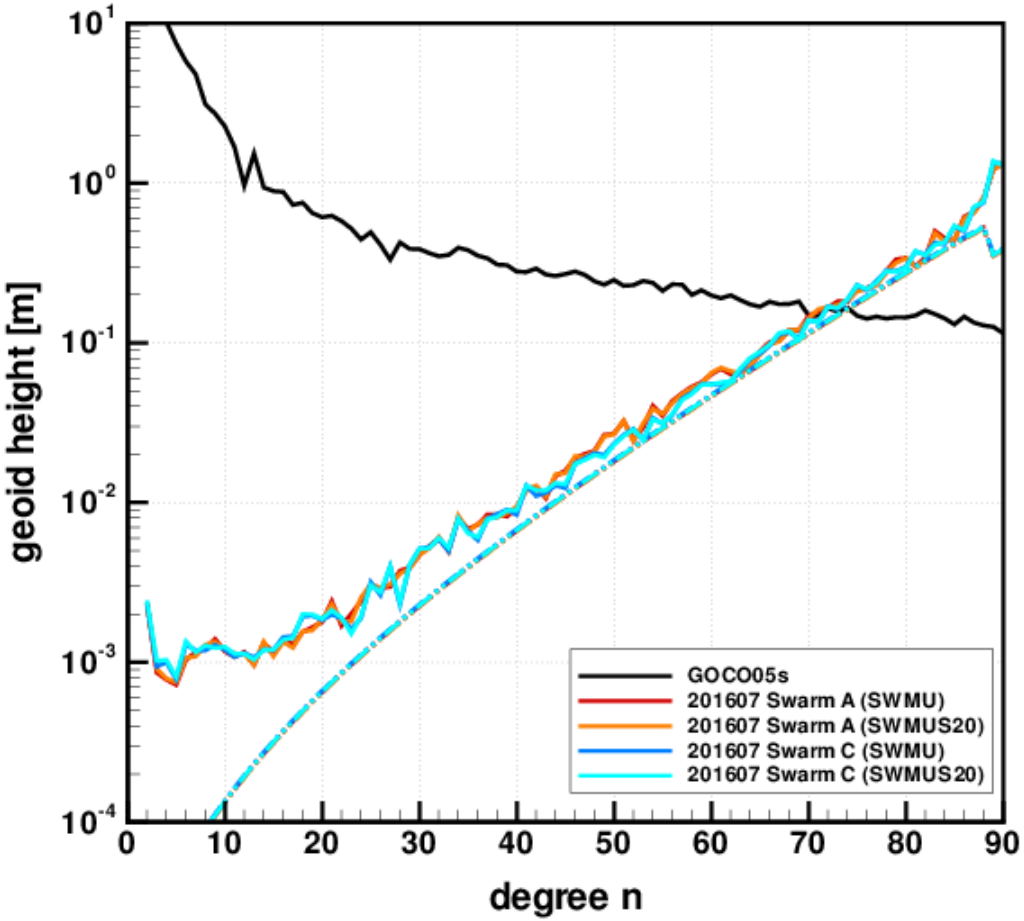
Percentage of missing kinematic positions in „screened“ solutions wrt. „original“ solutions:

Swarm-A: 2.2%
Swarm-C: 2.2%

Updated Swarm GPSR Settings

Degree amplitudes: July 2016

(Swarm-A: 0.5 Hz, Swarm-C: 0.75 Hz)



- No obvious improvement for Swarm-C due to the June 2016 tracking loop update
- Screening does not help

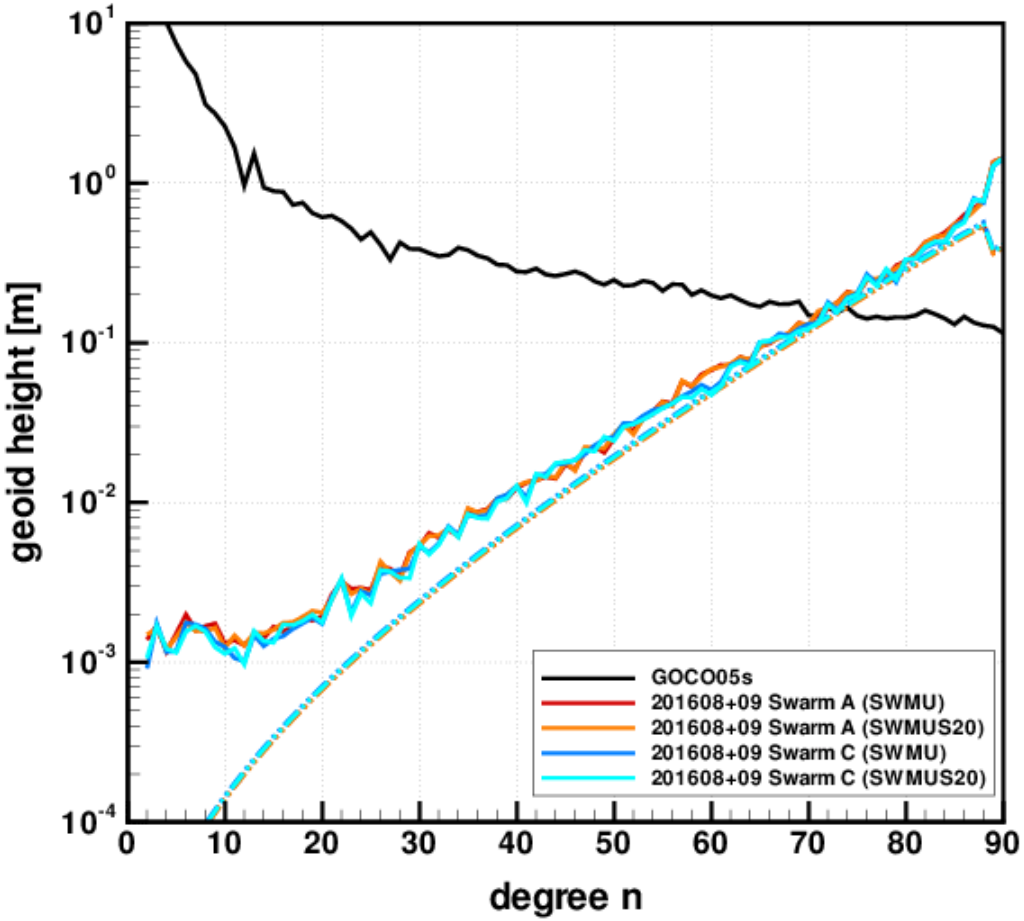
Percentage of missing kinematic positions in „screened“ solutions wrt. „original“ solutions:

Swarm-A: 0.1%
Swarm-C: 0.1%

Updated Swarm GPSR Settings

Degree amplitudes: 12 Aug – 10 Sep 2016

(Swarm-A: 0.75 Hz, Swarm-C: 1.0 Hz)



- No obvious improvement for Swarm-C due to the August 2016 tracking loop update
- Screening does not help

Percentage of missing kinematic positions in „screened“ solutions wrt. „original“ solutions:

Swarm-A: 0.2%
Swarm-C: 0.3%

Comparison of different hl-SST solutions

Consistent processing of hl-SST solutions from Swarm, GRACE and Sentinel-1A

- same standards, force models and processing strategy
- same observation type:
  - kinematic positions (10s-sampling)
- same type of noise model:
  - observations are considered as uncorrelated in time
  - constrained stochastic accelerations absorb model deficiencies

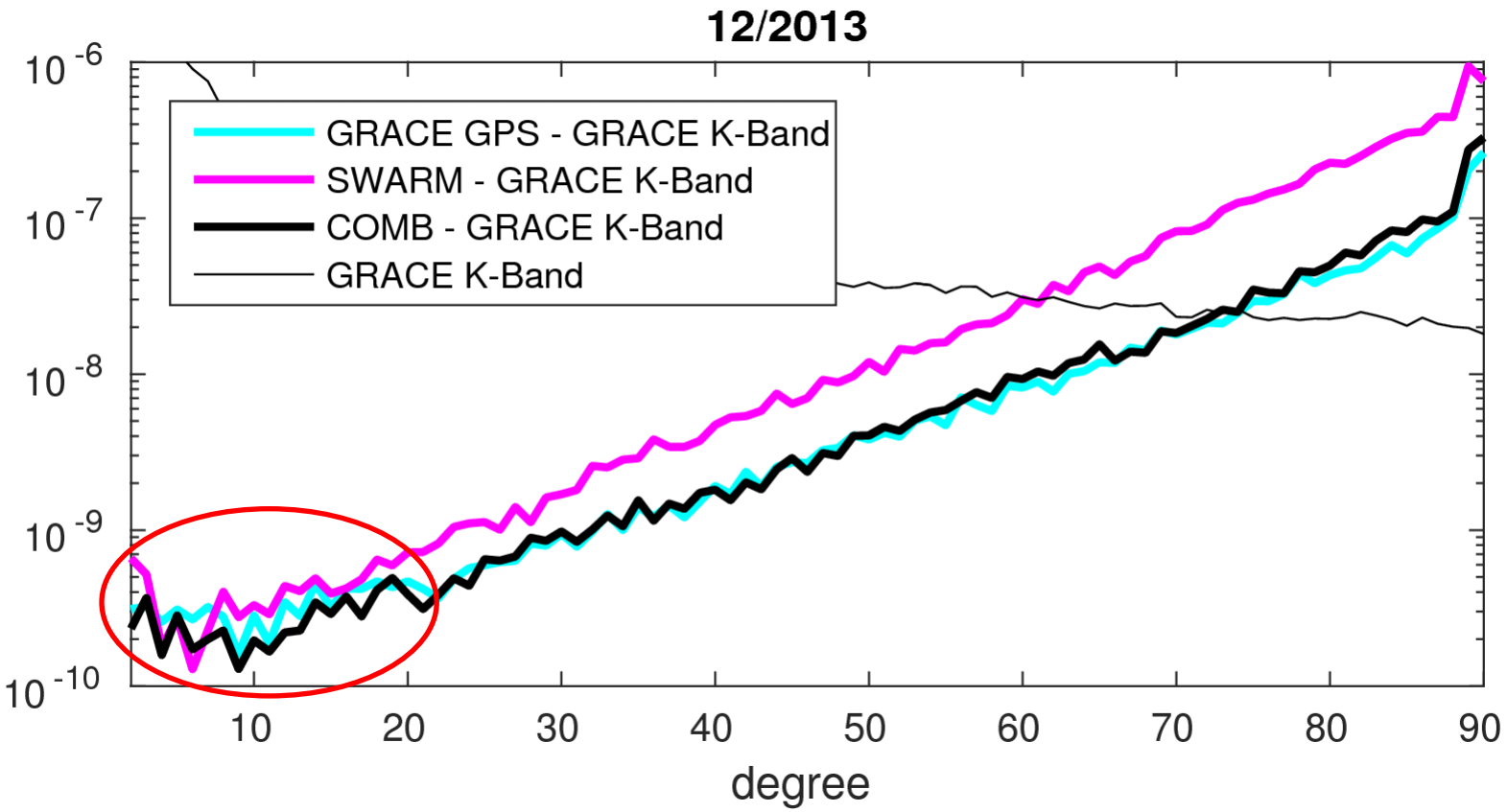
⇒ NEQs from these LEOs can be combined „just like that“ as long as sampling rate of kinematic positions is the same

⇒ this is the case here till 06/2014

⇒ different sampling rate of SWARM (1s since July 2014) leads to over-weighting of SWARM from 07/2014 onwards

Comparison of different hl-SST solutions

Swarm & GRACE:



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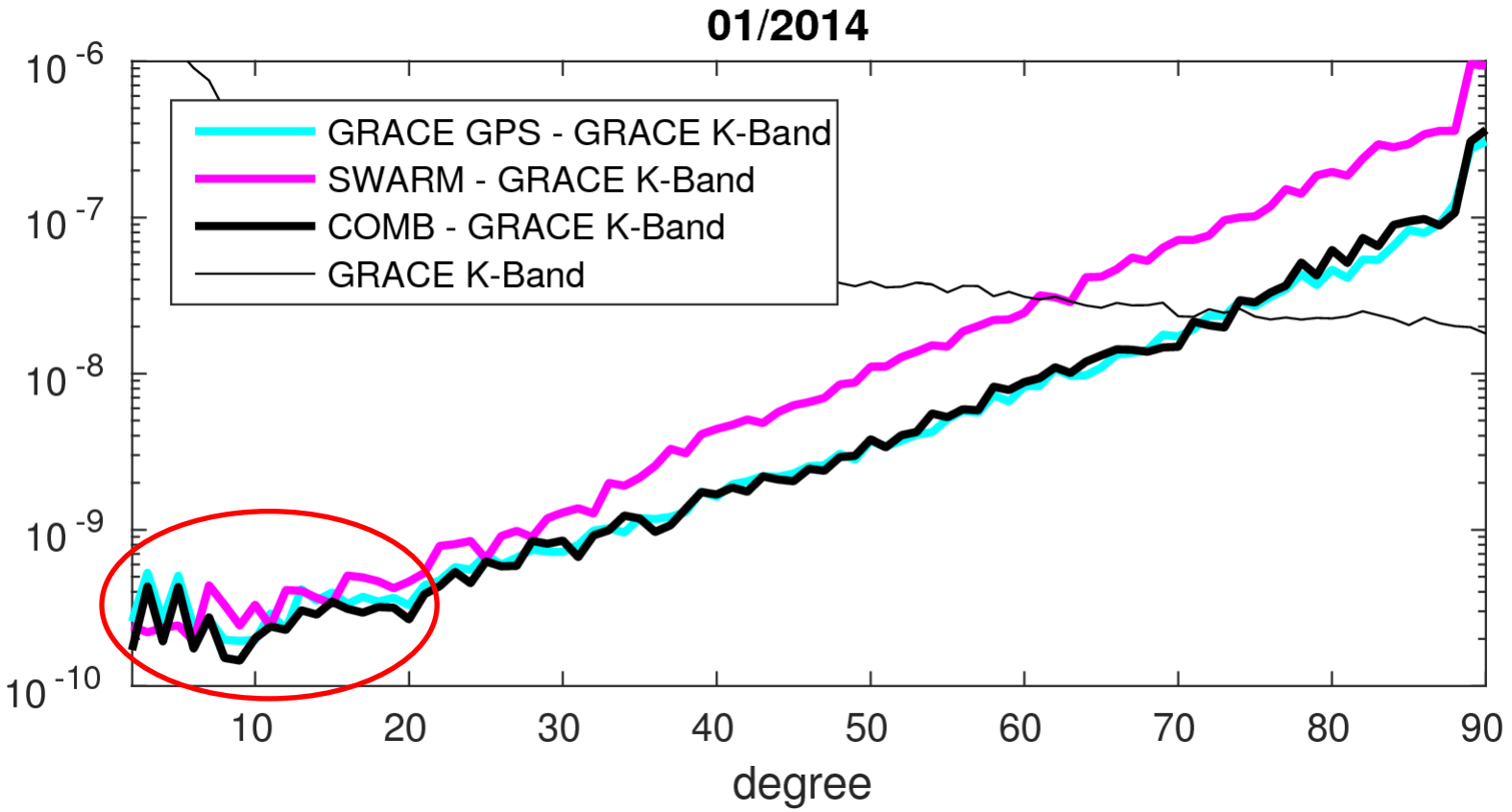

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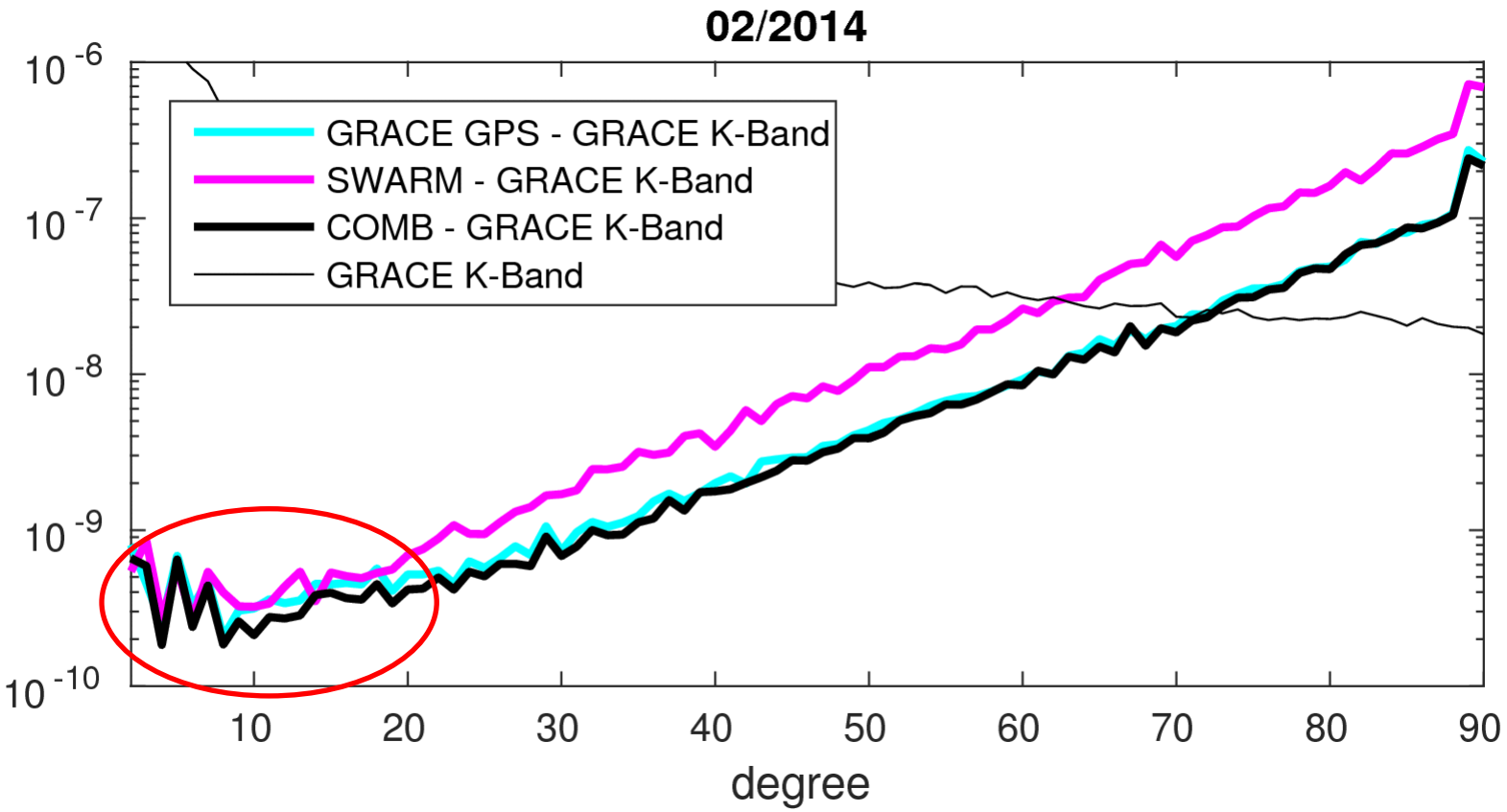

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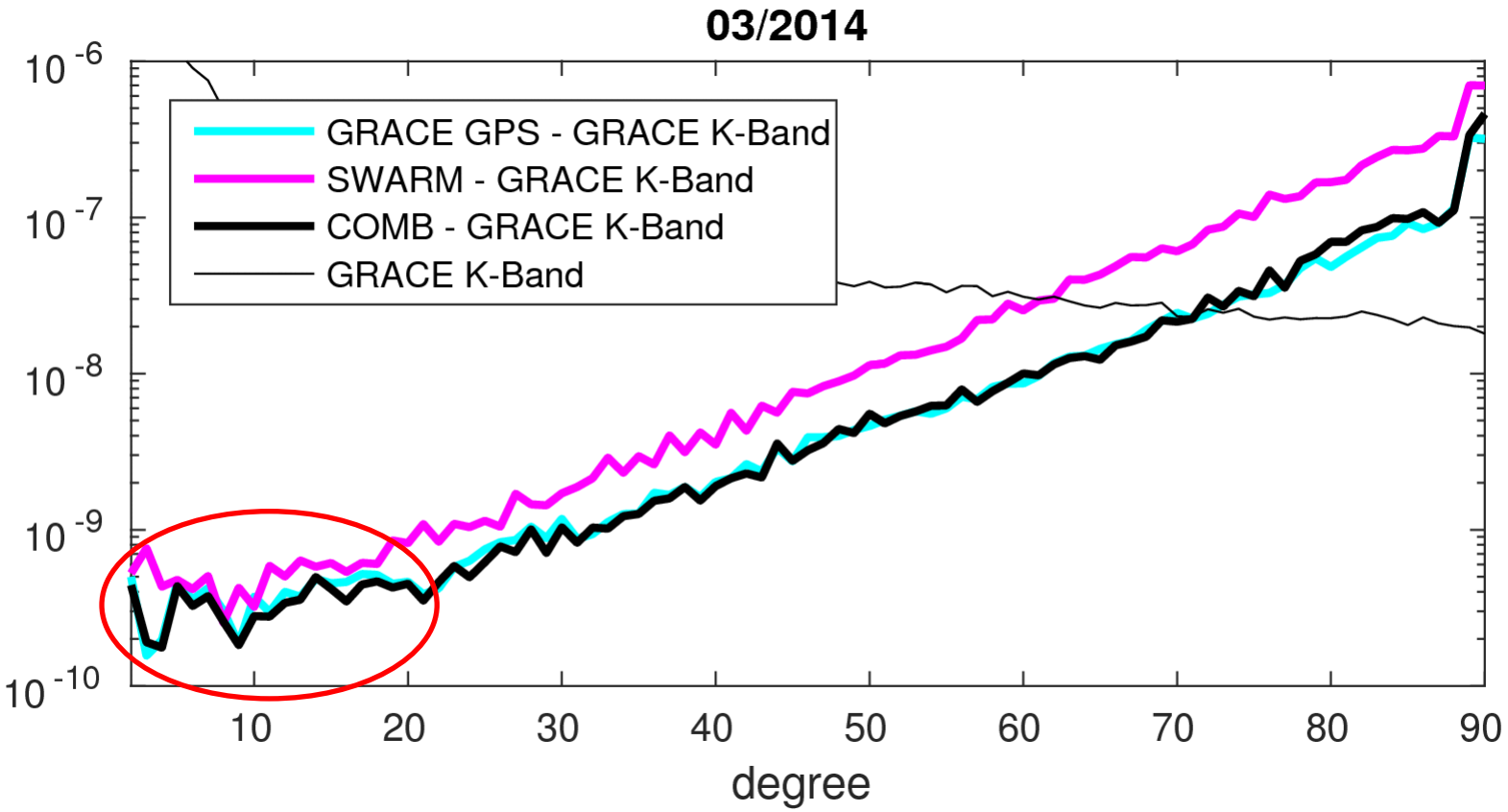

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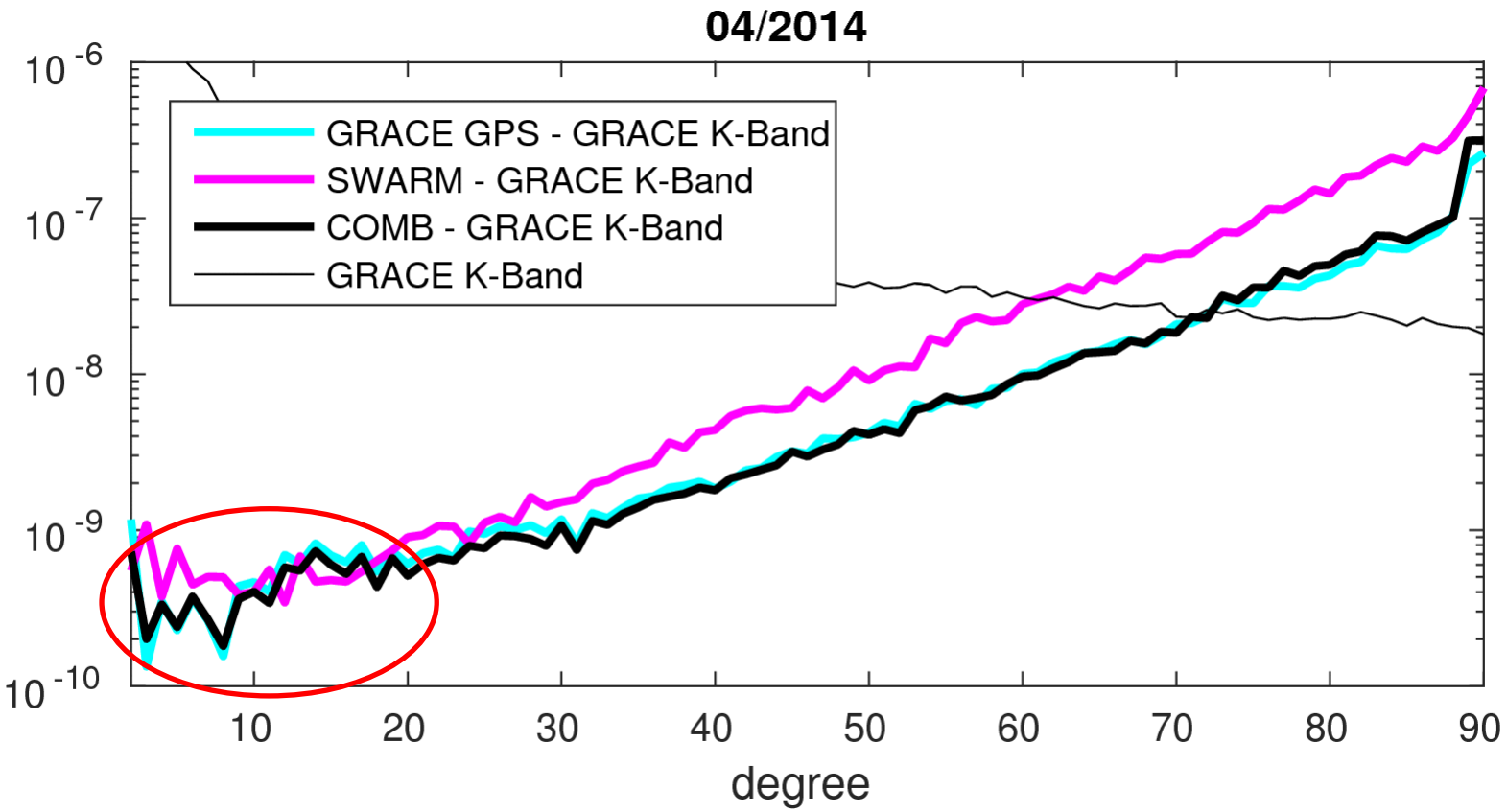

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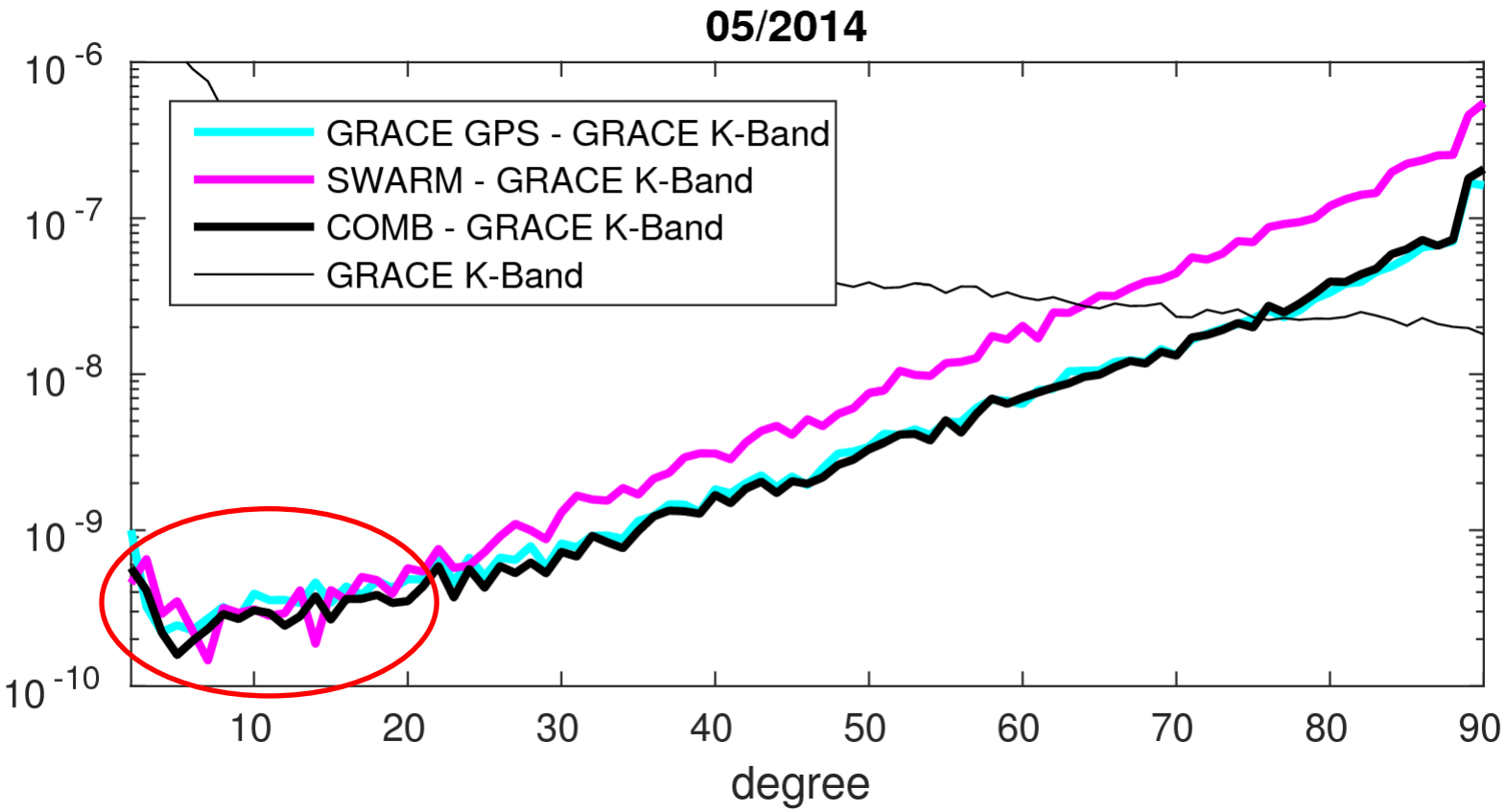

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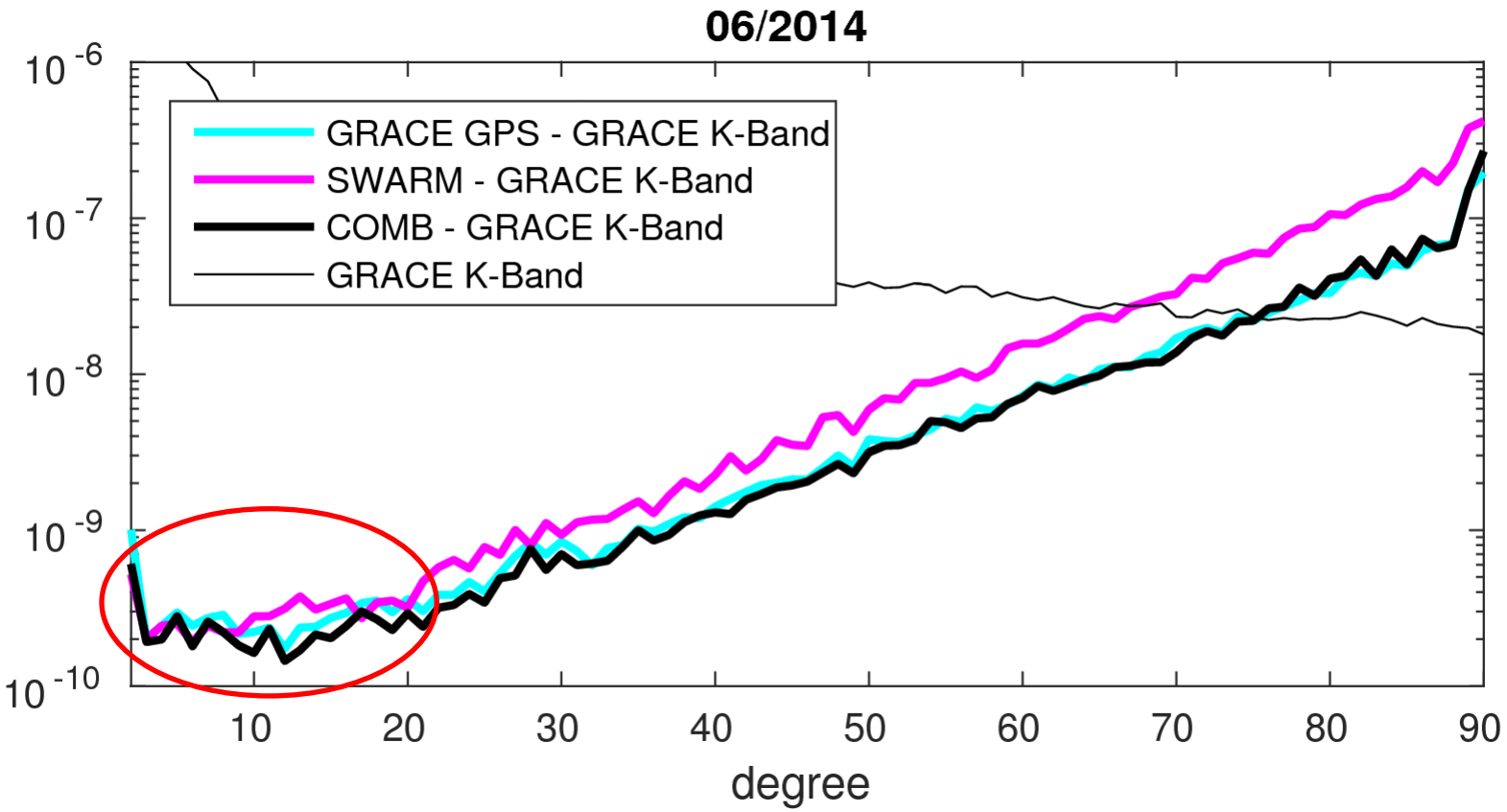

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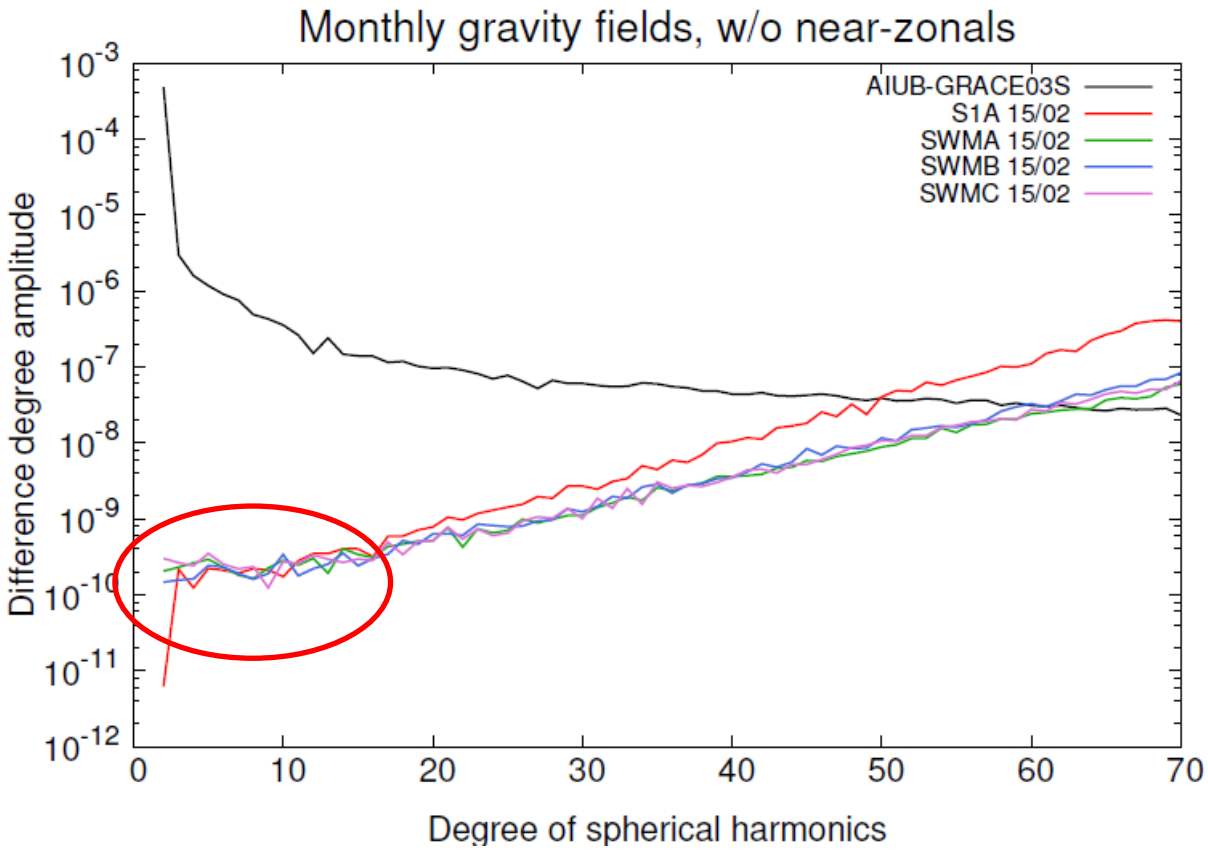
Comparison of different hl-SST solutions

Swarm & Sentinel-1A:

Sentinel-1A:

Sun-synchronous, near-polar orbit (h=690km, i=98°)

- Leaving out near-zonal coefficients according to van Gelderen and Koop
- similar to Swarm gravity fields up to d/o 15

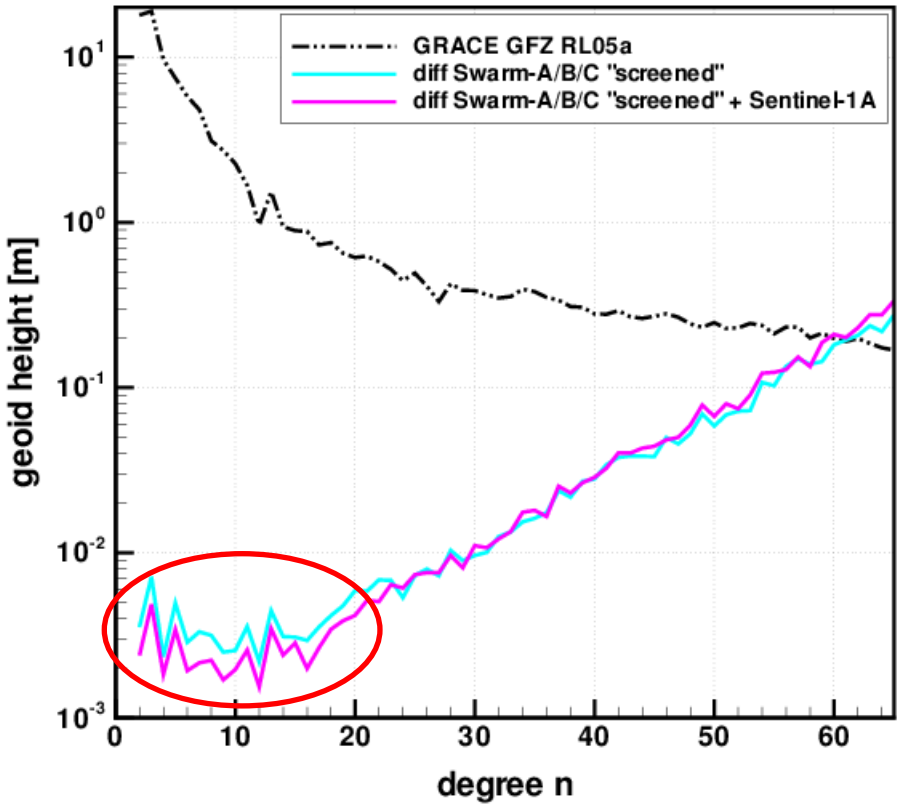


Comparison of different hl-SST solutions

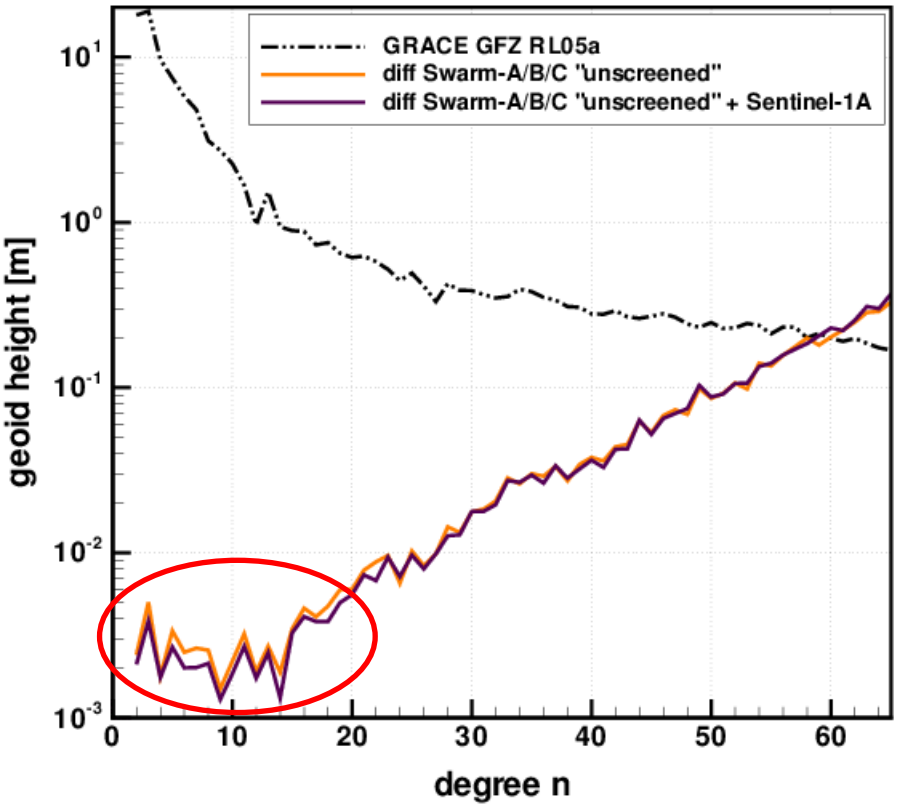
Swarm & Sentinel-1A:

04/2014

Swarm: Screened GPS Data



Swarm: Original GPS Data

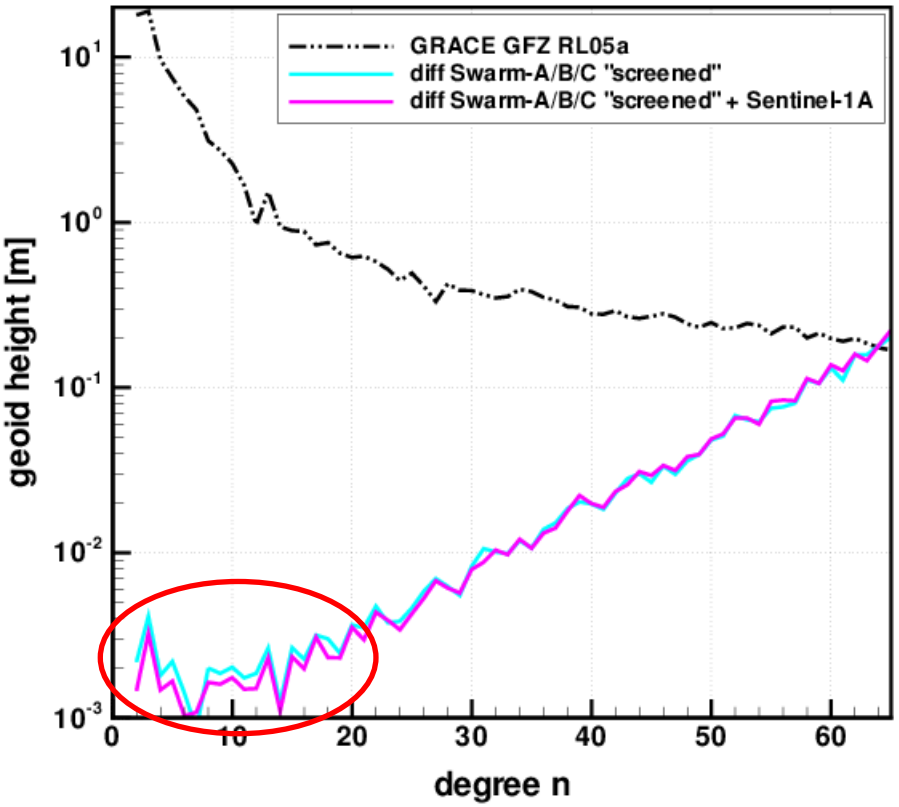


Comparison of different hl-SST solutions

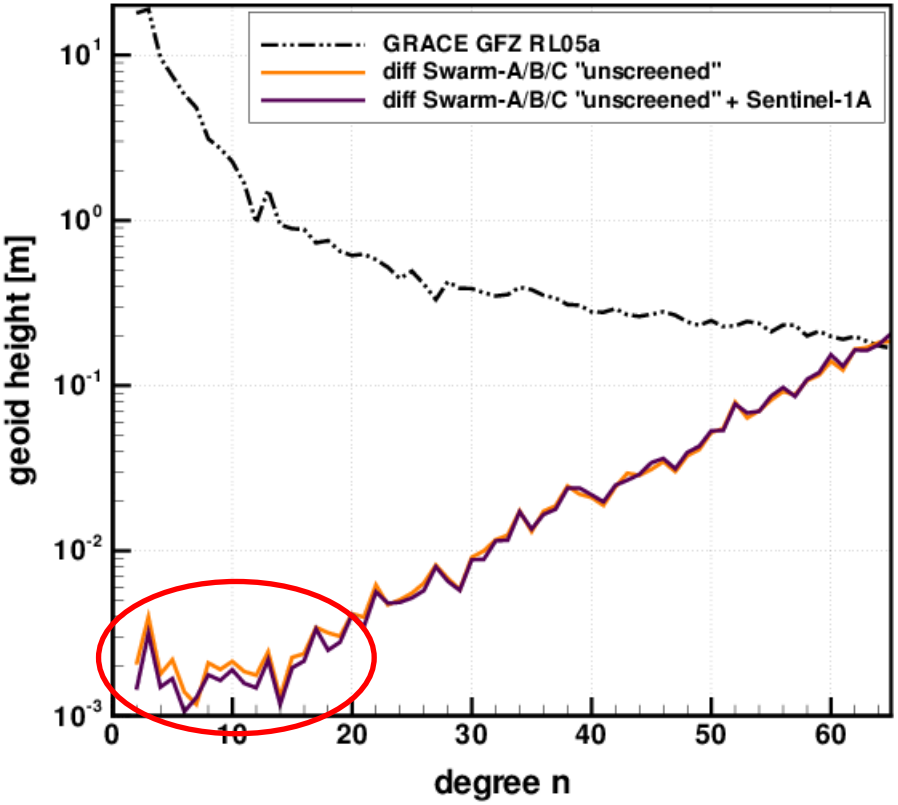
Swarm & Sentinel-1A:

05/2014

Swarm: Screened GPS Data



Swarm: Original GPS Data

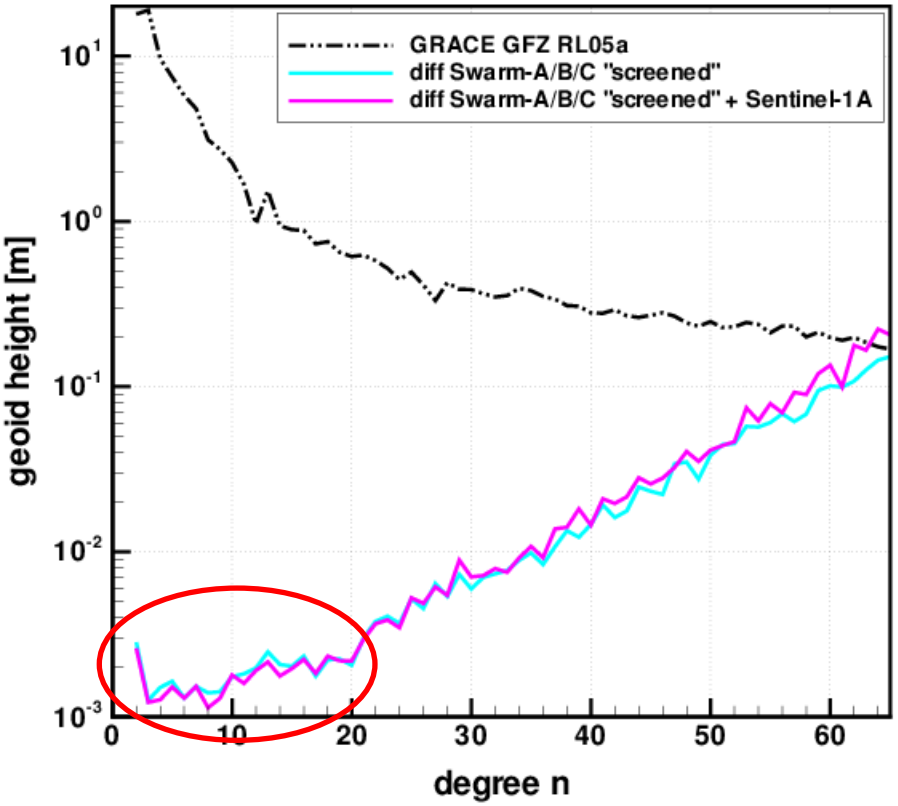


Comparison of different hl-SST solutions

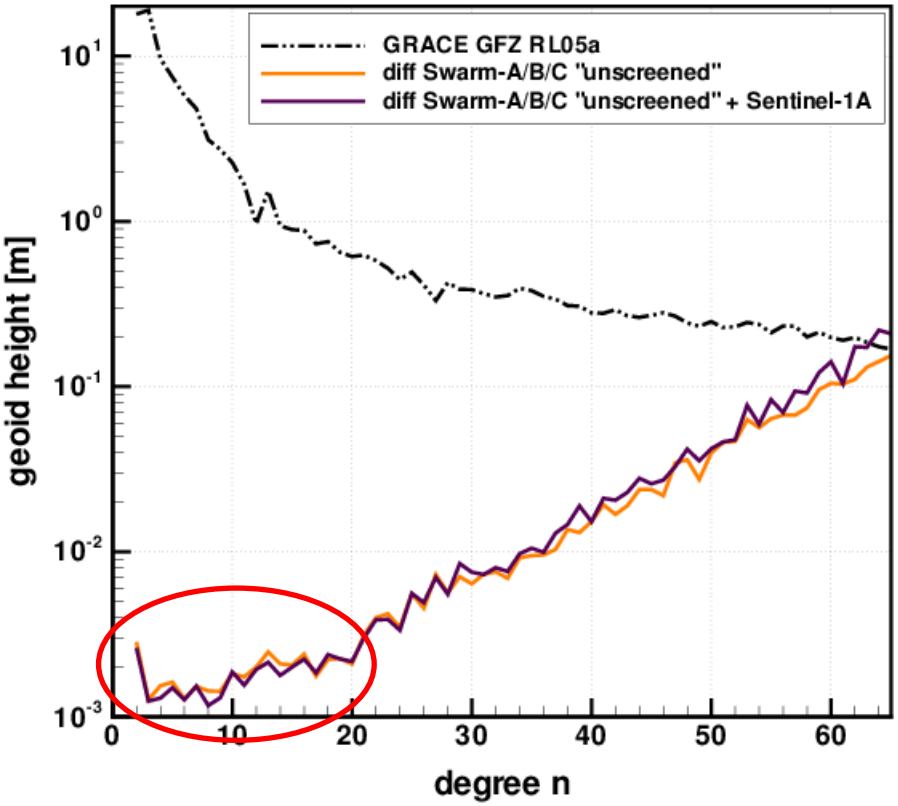
Swarm & Sentinel-1A:

06/2014

Swarm: Screened GPS Data



Swarm: Original GPS Data



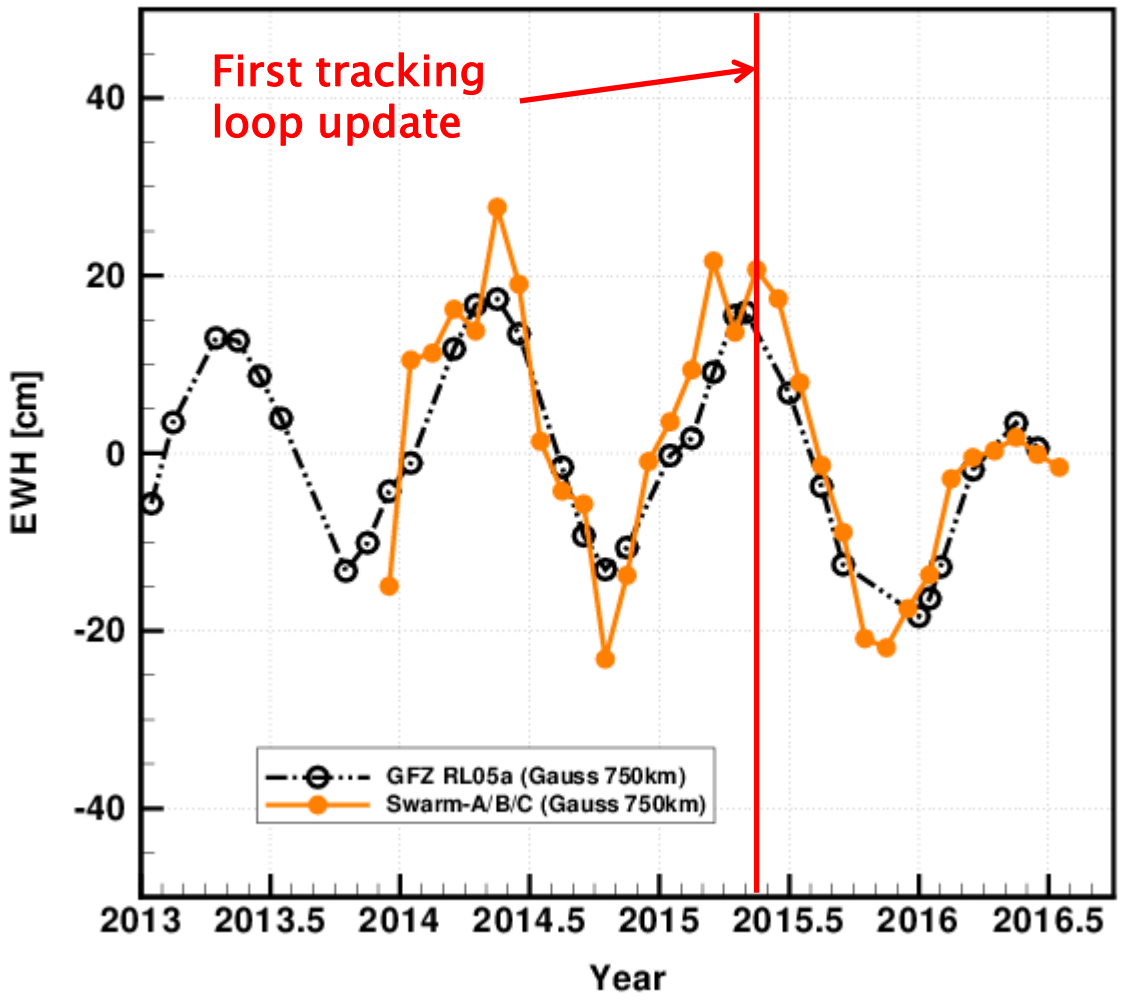
Quality Assessment of monthly Swarm solutions

Swarm Initiative led by Joao Encarnacao (TU Delft):

- Participating institutes and persons:
  - TU Delft: J. Encarnacao, E. Doornbos, J. van den Ijssel, P. Visser
  - AIUB: D. Arnold, C. Dahle, A. Jäggi
  - ASU: A. Bezdek, J. Sebera
  - TU Graz: T. Mayer-Gürr, N. Zehentner
- Encarnacao et al., "Gravity field models derived from Swarm GPS data", Earth, Planets and Space (2016), doi:10.1186/s40623-016-0499-9
  - time period considered: Sep 2014 till Sep 2015
  - Swarm monthly solutions are able to describe time-variable signals up to degree & order 12 (1666 km spatial resolution)
  - compared to GRACE KBR: RMS difference over land 2-4 mm geoid height, spatial correlation between 0.6 and 0.7
  - combined solutions consistently better than individual solutions
- Combination service: extension of EGSIEM project intended

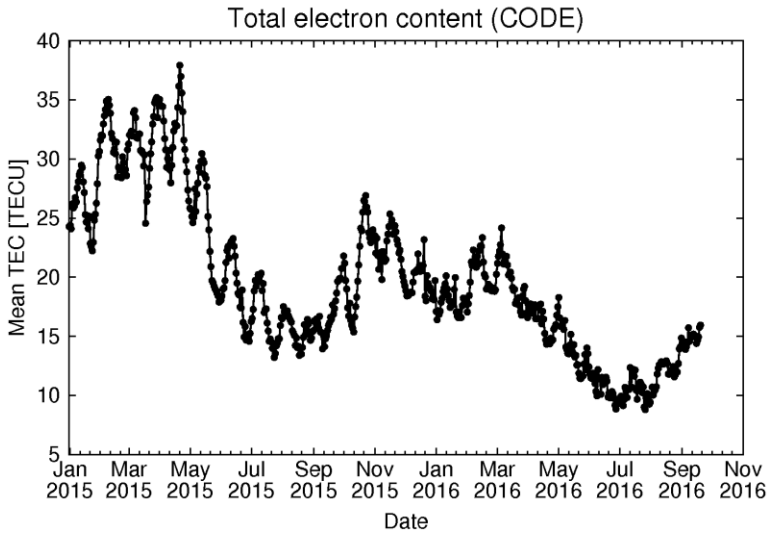
Quality Assessment of monthly Swarm solutions

Basin Average Amazon



- Combined Swarm-A/B/C solution based on screened GPS data
- 750 km Gaussian smoothing applied

- Improvement in recent months more due to
  - GPSR settings?
  - Lower ionospheric activity?



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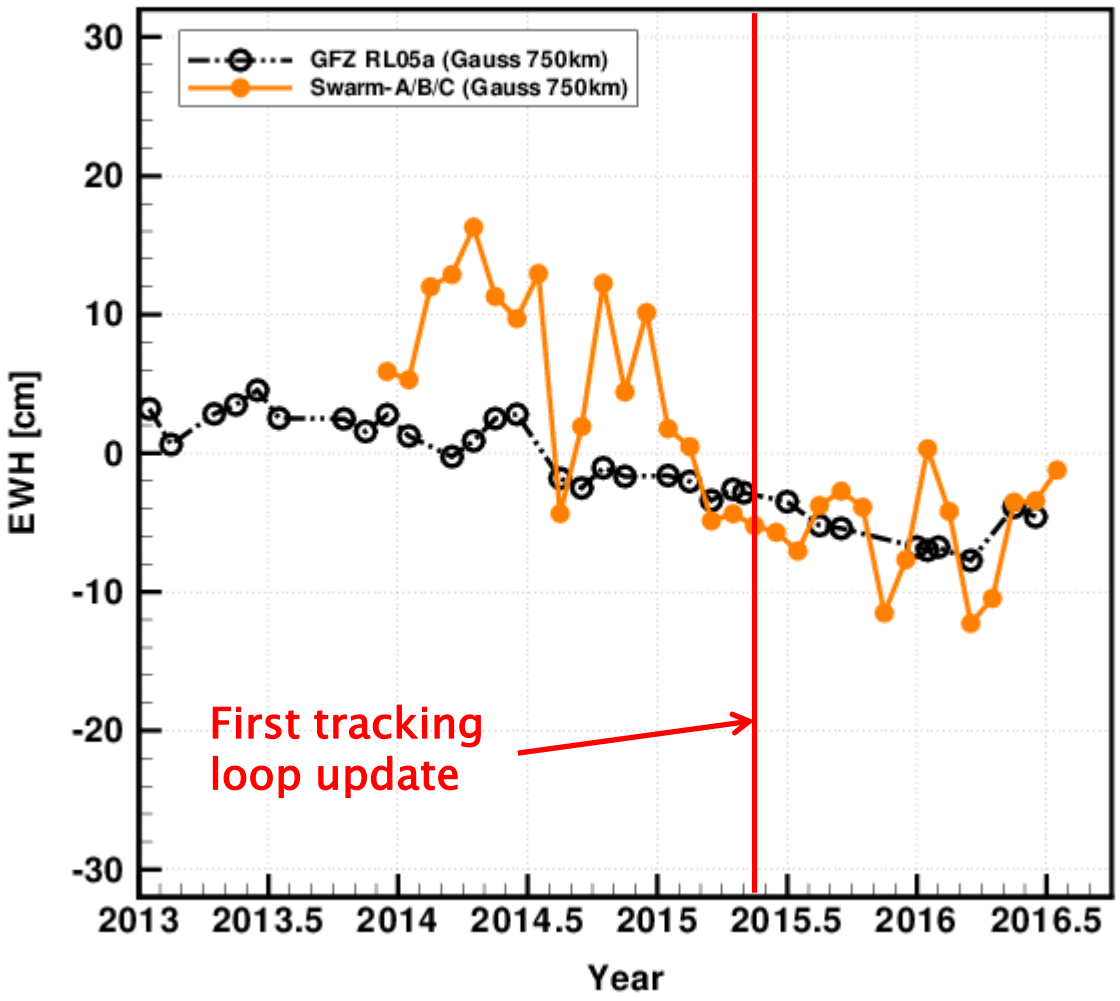
Quality Assessment of monthly Swarm solutions

Basin Average Greenland



- Combined Swarm-A/B/C solution based on screened GPS data
- 750 km Gaussian smoothing applied

- Also here: improvement in recent months, but still larger deviations

Summary

- Swarm solutions affected by ionospheric disturbances, but tracking loop updates are very beneficial
  - Rather crude GPS data screening not necessary anymore (or can at least be weakened)
  - Effect of latest settings needs to be checked when higher ionospheric activity is present again
- Combination of Swarm with GRACE or Sentinel-1A can improve the low degrees at least in periods with high ionospheric activity
  - Multi-LEO hl-SST solution favourable to fill the gap between GRACE and GRACE-FO
- Monthly Swarm time series able to capture large-scale signals
  - Quality seems to have improved recently due to improved GPS receiver settings and lower ionospheric activity
  - Detailed analysis for a larger number of basins still to be done