Orbit and Gravity Field Solutions from Swarm GPS Observations

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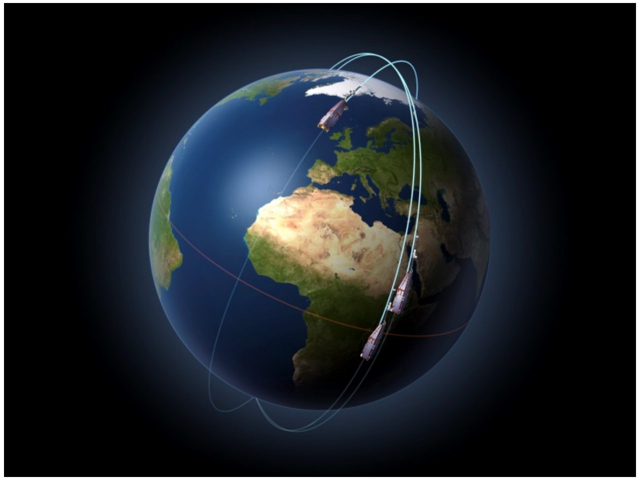
The Swarm Mission

- **Orbit:**
  - Low Earth Orbiter; near-polar
  - Swarm-A/C: h=460-300 km, i=87.3°, 1.4° side-by-side sep.
  - Swarm-B: 530 km altitude, i=88°
  - 90° difference in orbital plane between lower pair and higher satellite after 3 years



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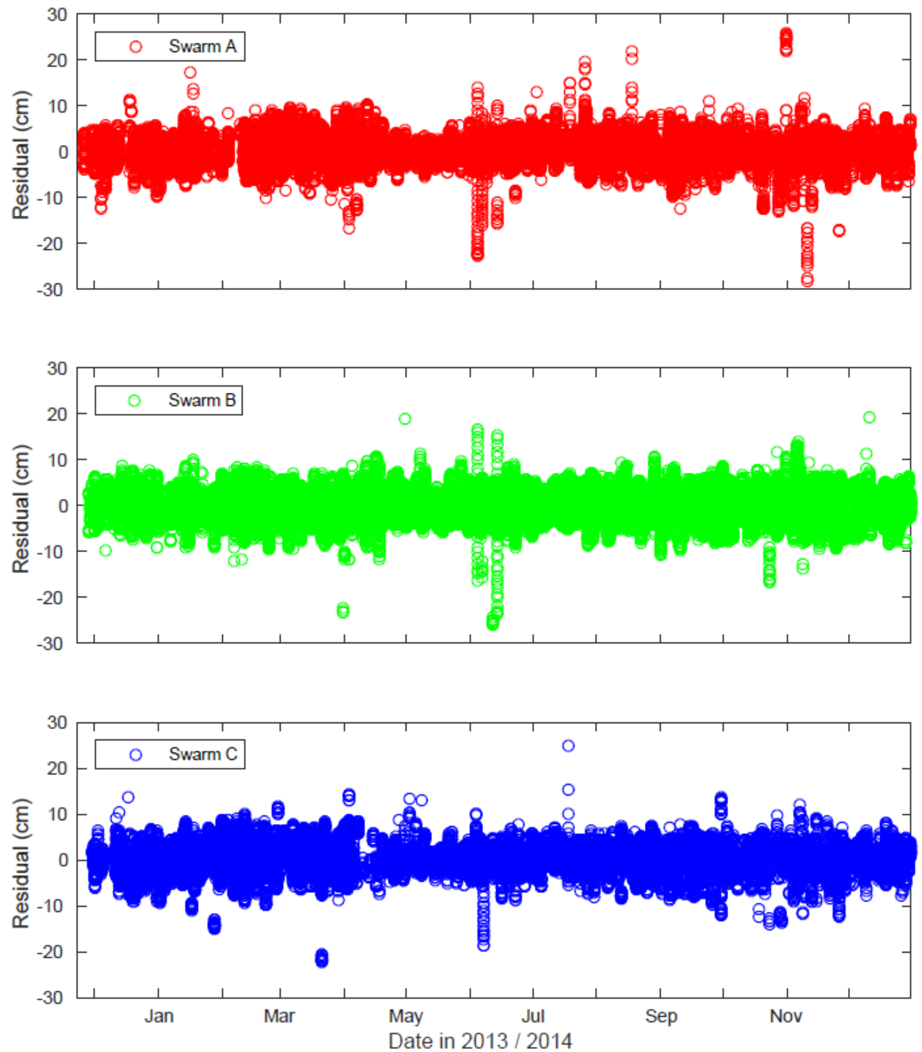
- **Payload:**
  - Magnetometers, electric field instrument, GPS receiver, accelerometer, star-trackers, laser retro-reflector
- **Secondary mission objective:**
  - Measuring the Earth's gravity field (GPS hl-SST observing system)

SLR Validation of Kinematic Swarm Orbits



Mean = 2.7 mm

RMS = 32.5 mm

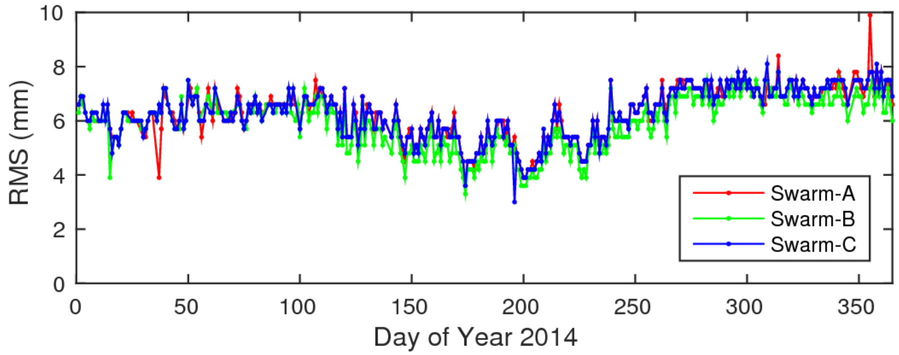
Mean = 1.0 mm

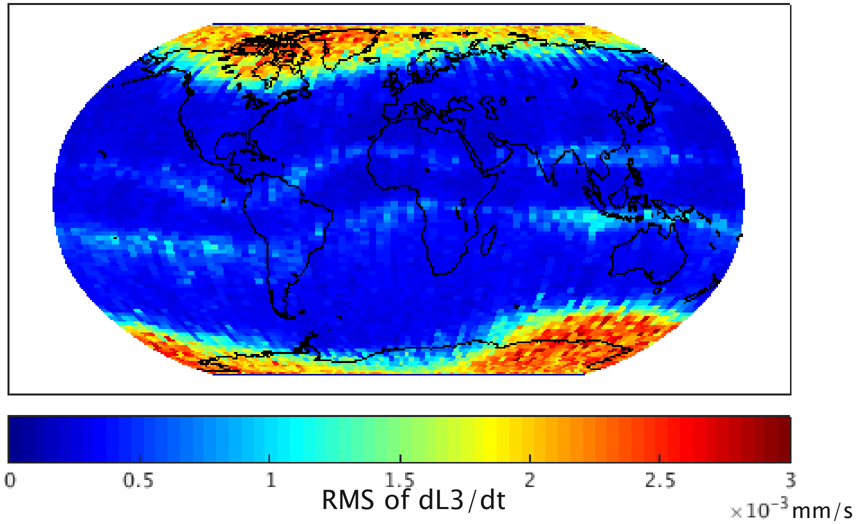
RMS = 27.4 mm

Mean = 0.6 mm

RMS = 31.1 mm

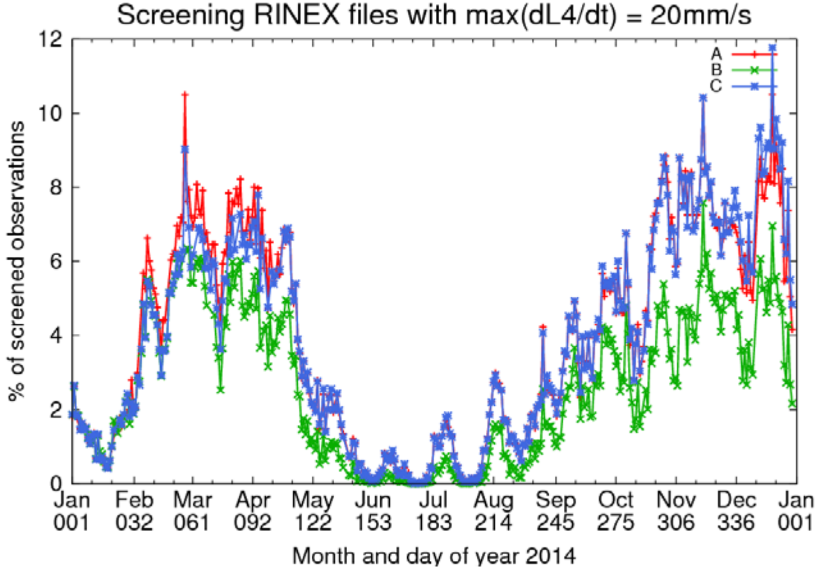
Ionosphere Disturbances





- Random errors:
  - Overall RMS is rather high
  - Dominated by polar areas

- Systematic errors:
  - Along geomagnetic equator
  - May be reduced by additional data screening (dL4/dt criterion)



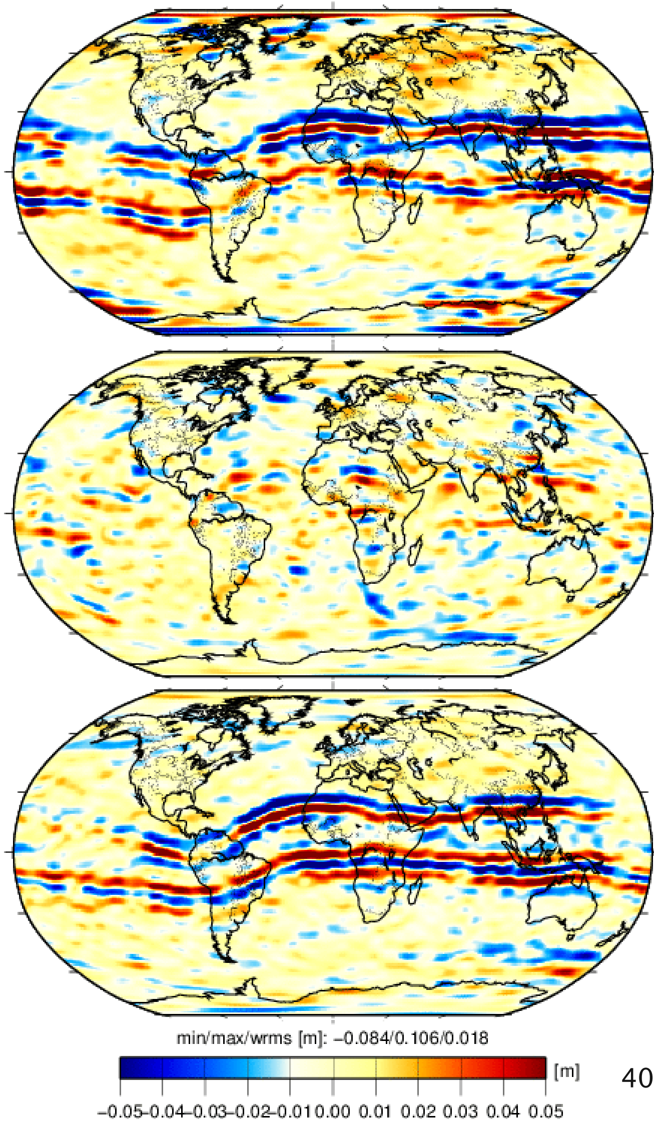
Processing Method

- Celestial Mechanics Approach
  - Orbit, gravity field and stochastic parameters are estimated simultaneously
  - Kinematic orbit positions are used as pseudo-observations (weighted with epoch-wise covariance information)
- Models:
  - Earth gravity: EGM2008 (up to d/o 90x90)
  - Ocean tides: FES2004
- Estimated Parameters:
  - Initial states at beginning of each 24-hour arc
  - Constant empirical accelerations over 24 hours
  - 15-minute piecewise constant empirical accelerations (constrained)
  - Gravity field coefficients up to d/o 90x90

Bi-Monthly Gravity Field Solutions up to d/o 90

Original GPS Data

Screened GPS Data



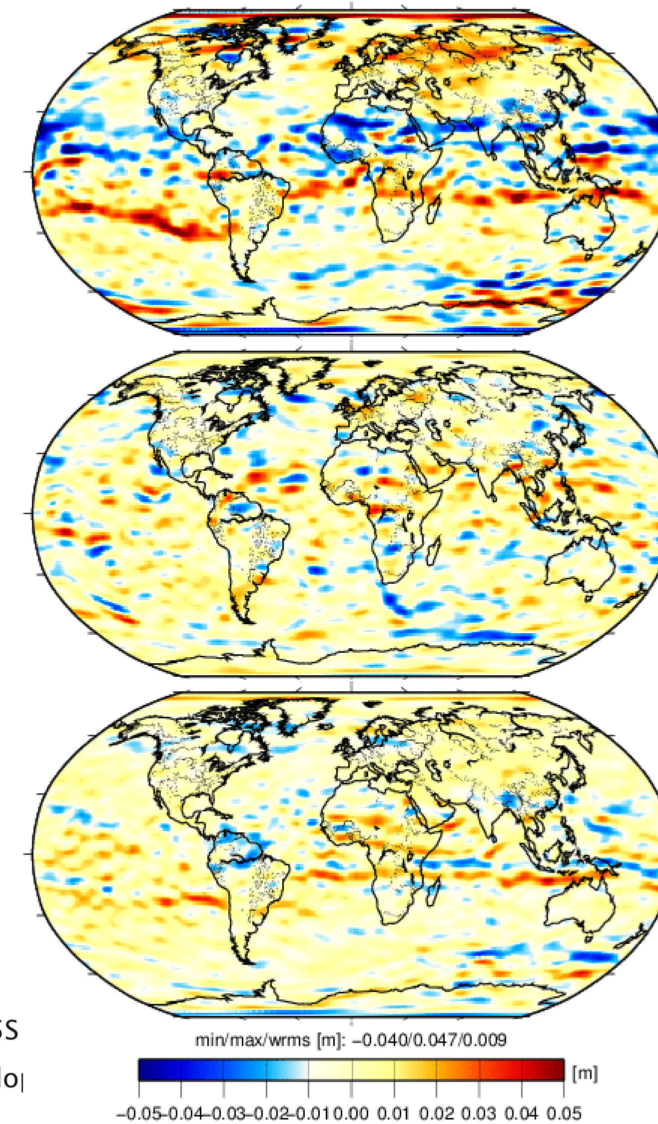
Mar/Apr 2014

Jun/Jul 2014

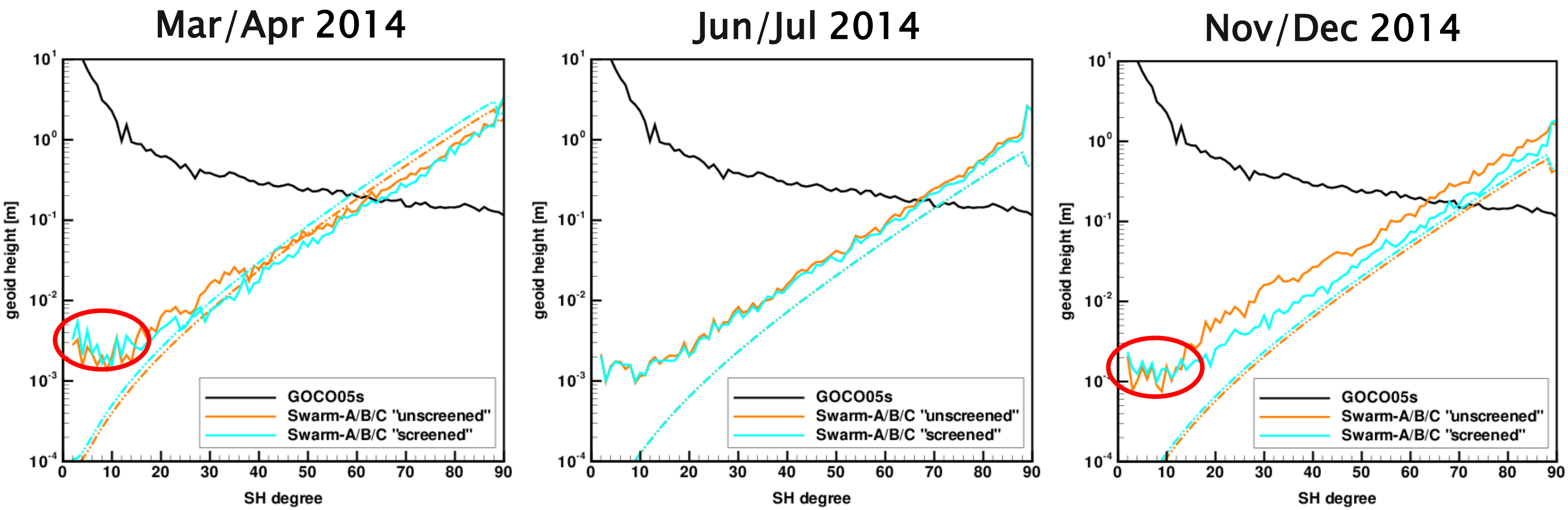
Nov/Dec 2014

Differences wrt GOCO05S

400 km Gauss smoothing ado



Bi-Monthly Gravity Field Solutions

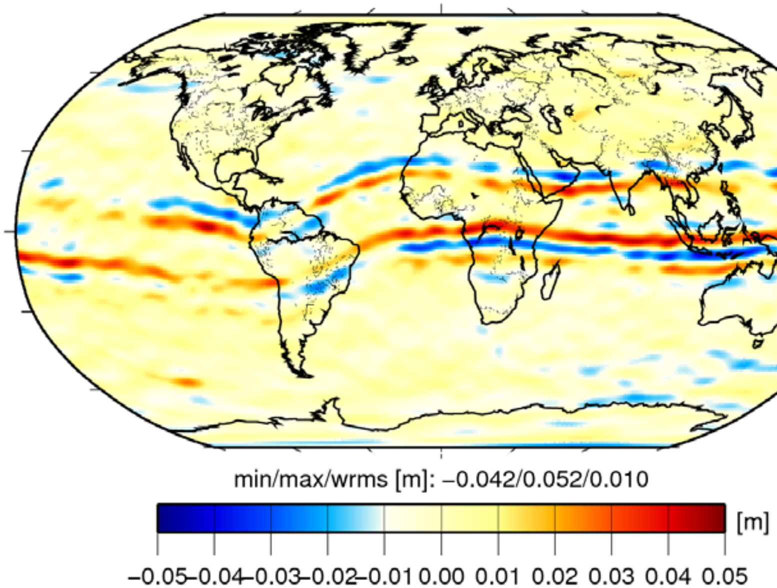


Impact of screening the raw RINEX GPS data files (dL4/dt criterion):

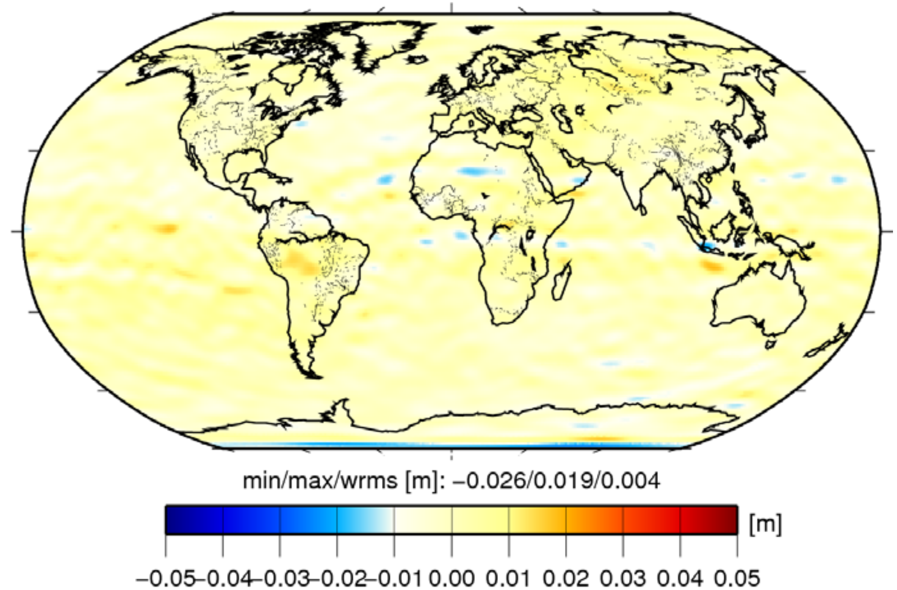
- Difference degree amplitudes are significantly improved, especially for periods with strong ionosphere conditions (spring, fall).
- Very low degrees (n < 15) tend to be weakened due to the very "crude" data screening.

Static Gravity Field Solutions

Original GPS Data
(13 months)



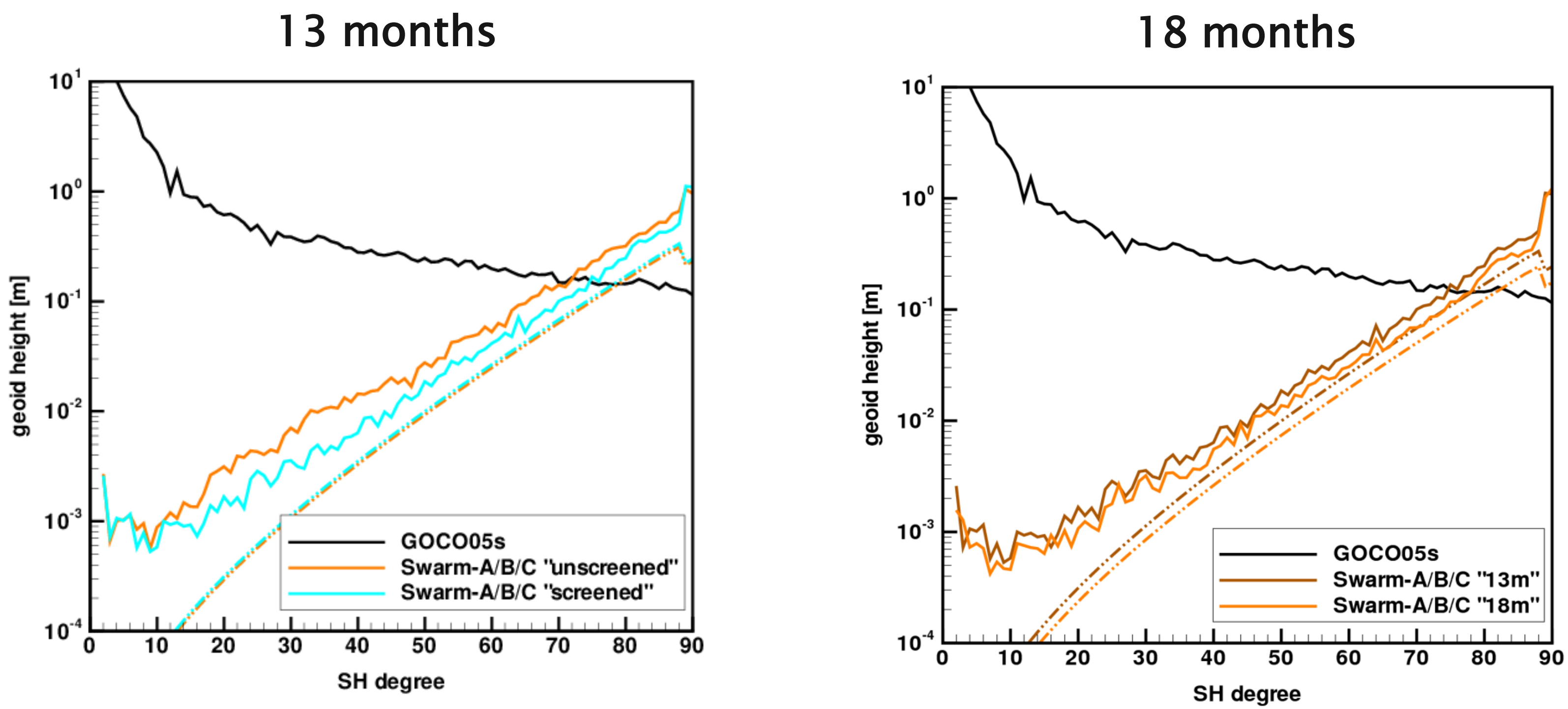
Screened GPS Data
(18 months)



(Differences wrt GOCO05S, 400 km Gauss smoothing adopted)

Systematic signatures along the geomagnetic equator may be efficiently reduced for static Swarm gravity field recovery when screening the raw RINEX GPS data files with the dL4/dt criterion.

Static Gravity Field solutions



(Differences wrt GOCO05S)

Systematic signatures along the geomagnetic equator cause the artificial "bumps" and may be reduced for static Swarm gravity field recovery when screening the raw RINEX GPS data files with the dL4/dt criterion.

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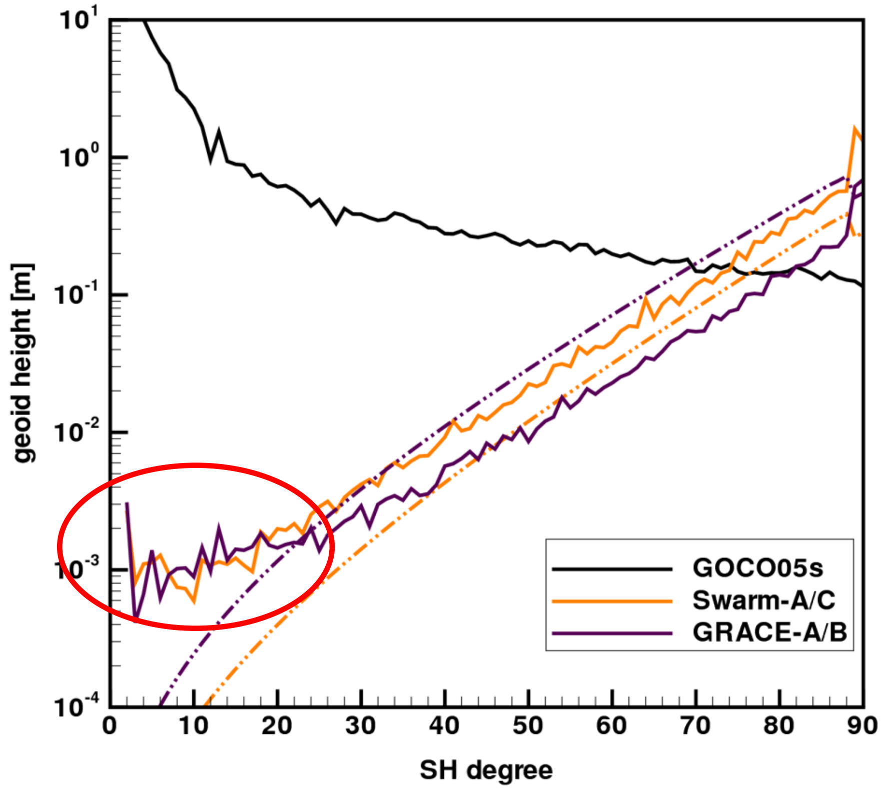
Comparison with GRACE hl-SST Solutions



Processed data:

- Dec 2013 – Nov 2014
- Swarm-A/C (screened)
- GRACE-A/B (GPS-only) (original L1B data)

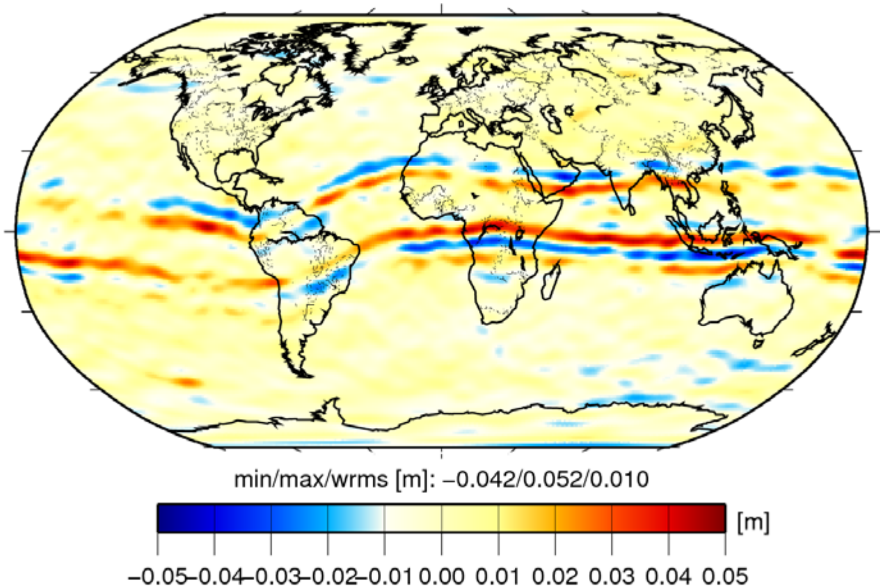
Results:

- Similar performance for long wavelengths
- Worse performance for short wavelengths

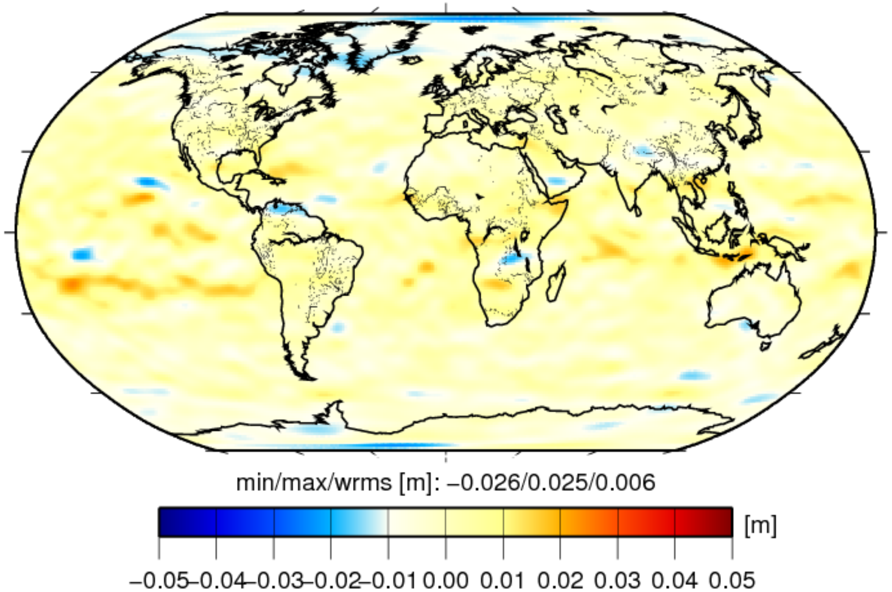
Worse performance for higher degrees can be explained to some extent by higher orbital altitude, but probably is mainly caused by the higher noise of the Swarm GPS data.

Comparison with GRACE hl-SST Solutions

Original GPS Data
(Swarm)



Original GPS Data
(GRACE)

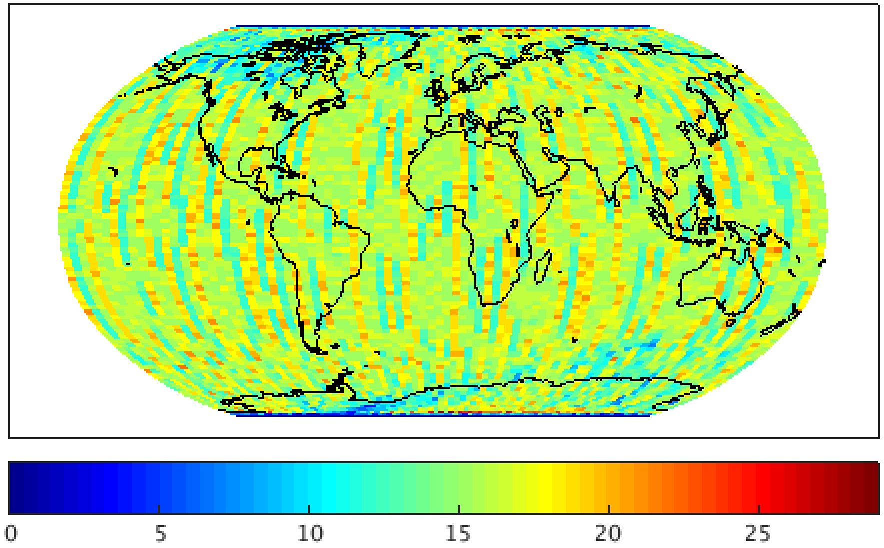


(Differences wrt GOCO05S, 400 km Gauss smoothing adopted)

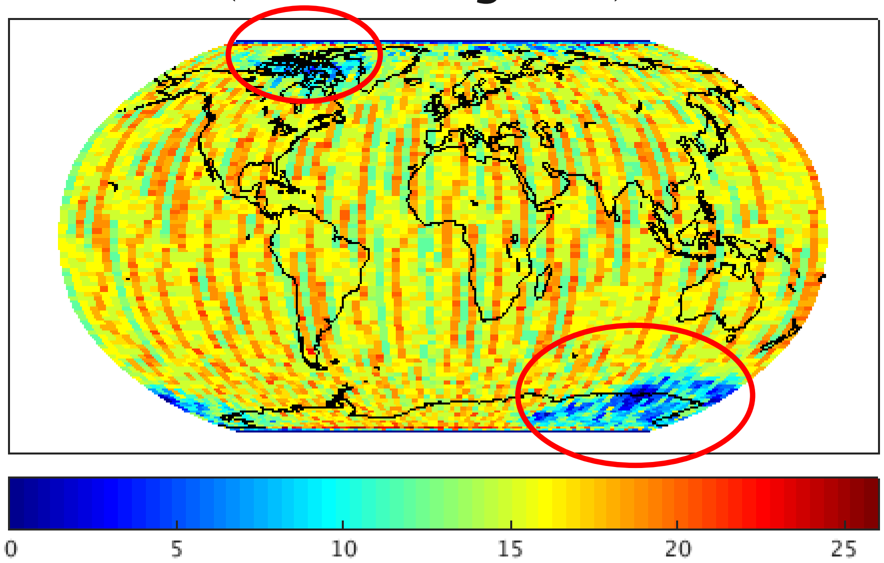
Systematic signatures along the geomagnetic equator are almost not visible in GRACE solutions when using official L1B GPS data.

Number of available Kinematic Positions

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



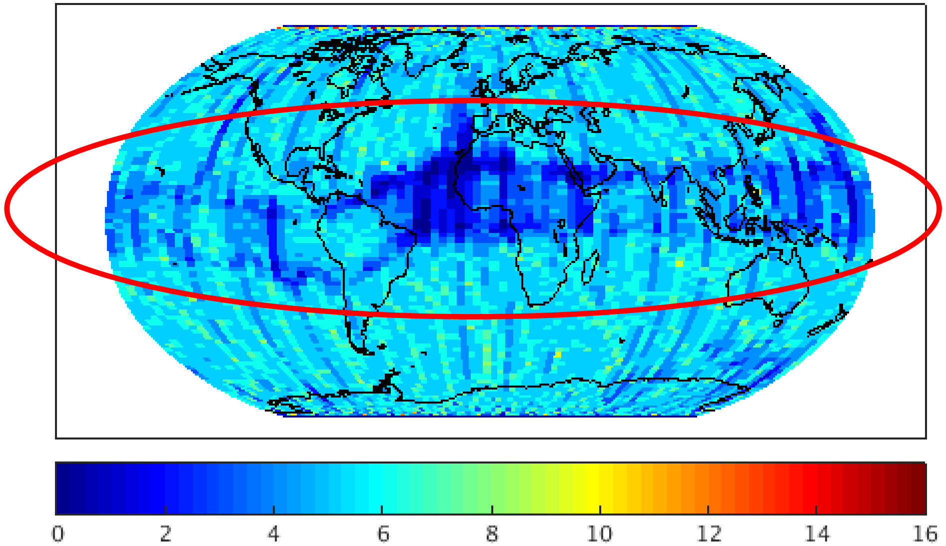
Swarm-A, doy 060-090, 2014
(descending arcs)



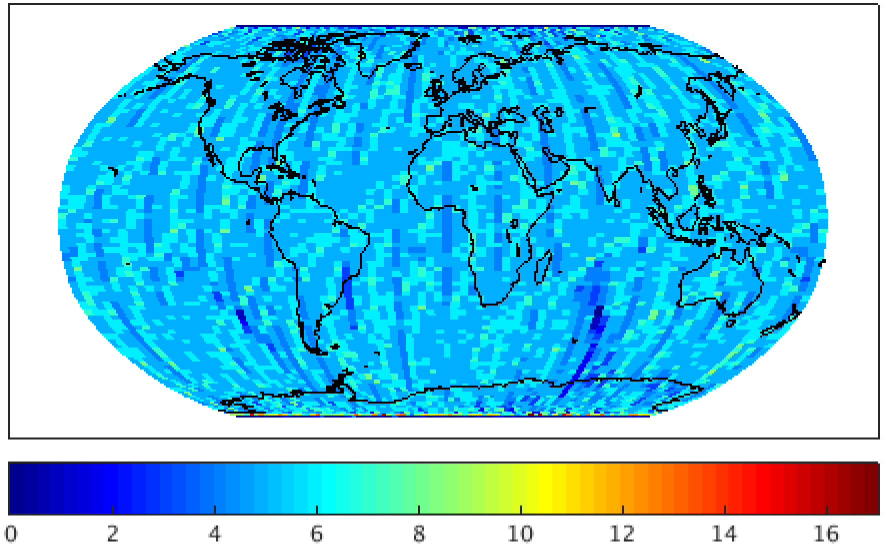
- For the selected period descending arcs are predominantly affected by ionosphere disturbances.
- Missing kinematic positions are found over the geomagnetic poles, but not along the geomagnetic equator.

Number of available Kinematic Positions

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



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

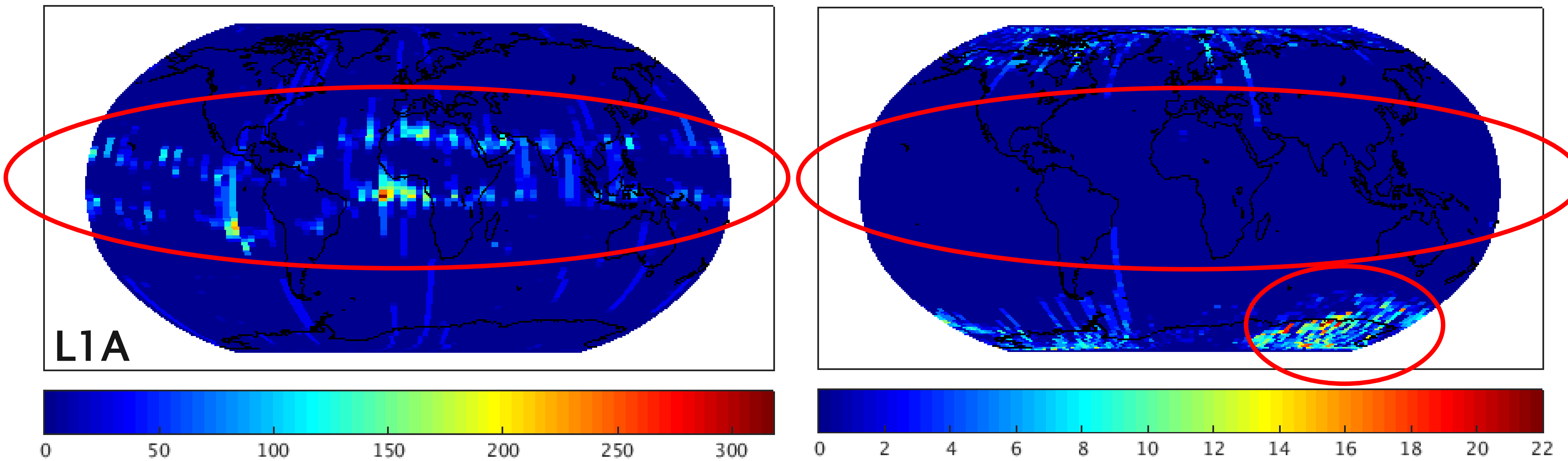


- For the selected period ascending arcs are predominantly affected by ionosphere disturbances (nodes happen to be separated by ~180°).
- Missing kinematic positions are found along the geomagnetic equator => problematic signatures cannot be present in the gravity field.

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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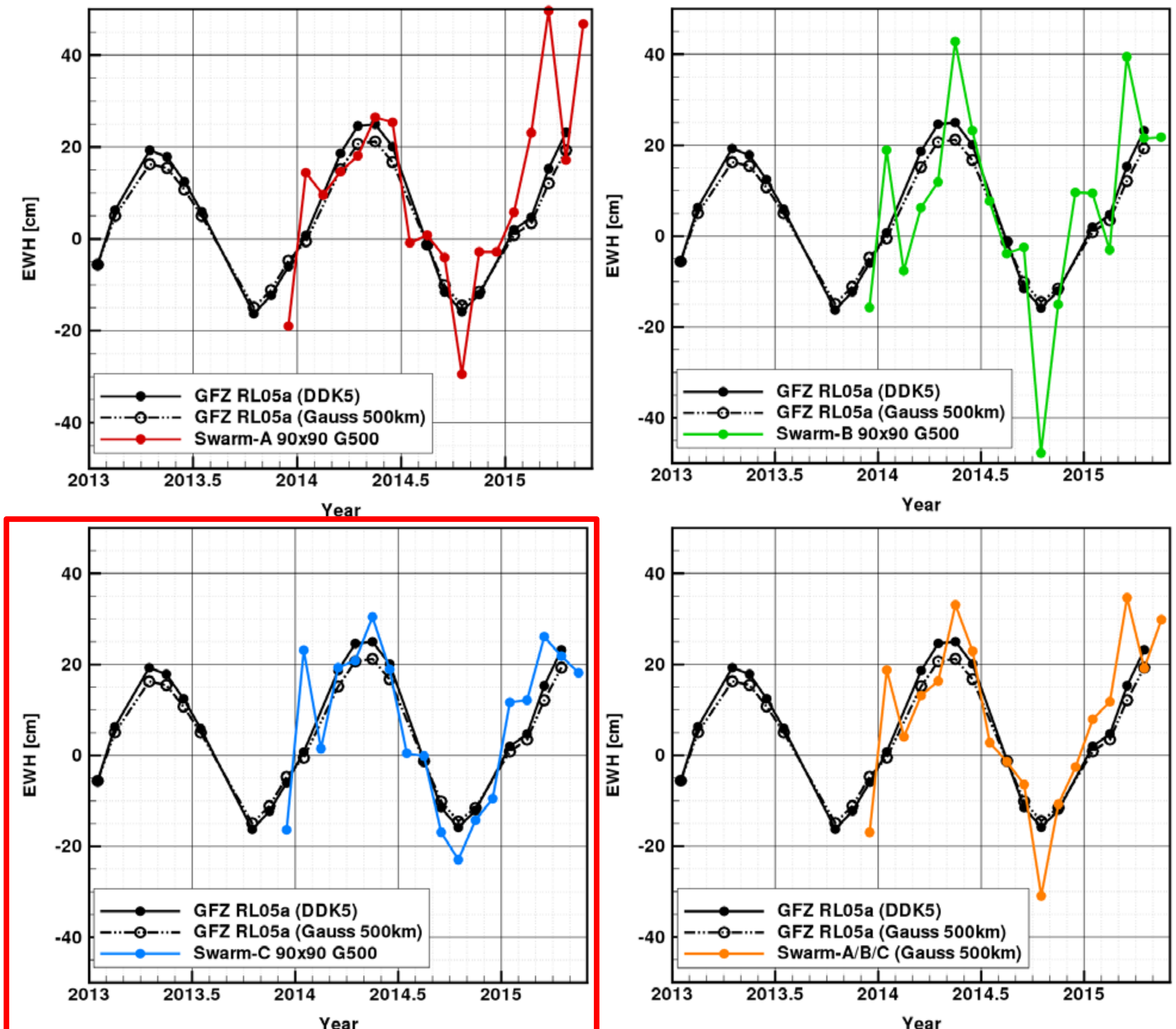
Time-Variable Gravity (Amazon)



"True" signal:

- GFZ-RL05a (DDK5-filtered)

"Comparison" signal:

- GFZ-RL05a (500km Gauss)

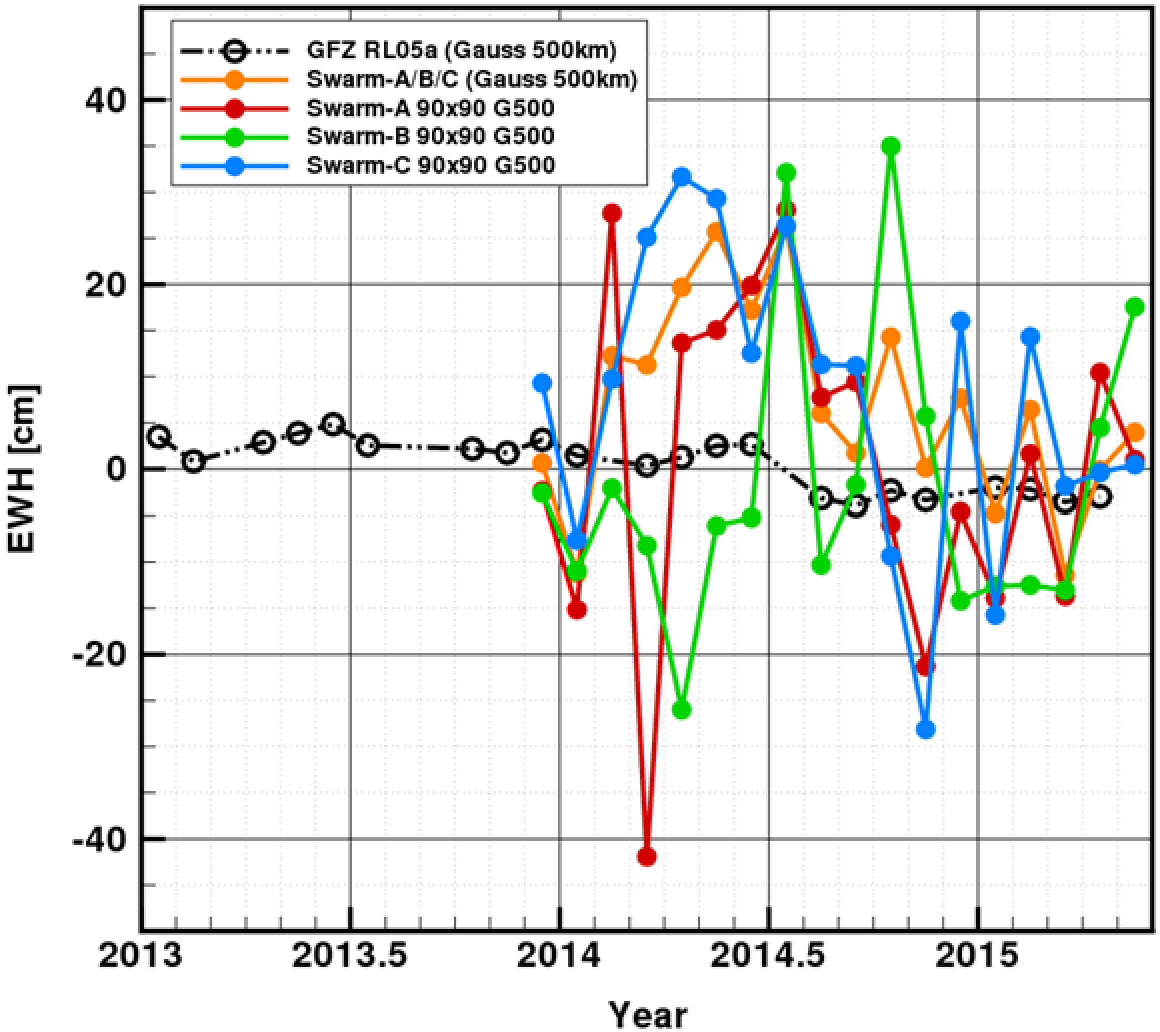
Swarm signal:

- 90x90 solutions (Gauss-filtered)

Result:

- Best agreement for Swarm-C
- Some outliers to be investigated

Time–Variable Gravity (Greenland)



"Comparison" signal:

- GFZ–RL05a (500km Gauss)

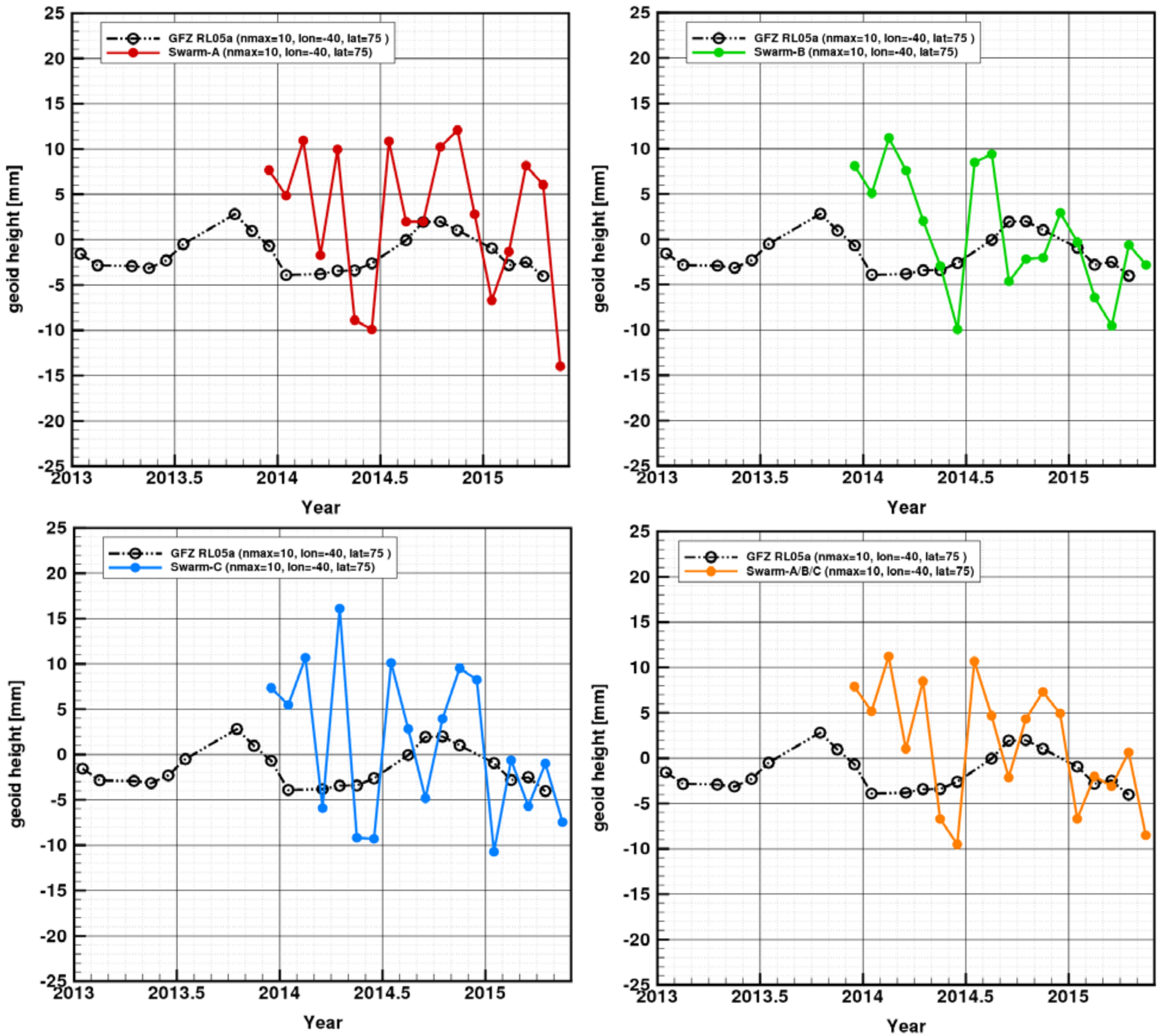
Swarm signal:

- 90x90 solutions (Gauss–filtered)

Result:

- Very noisy series, trends are hardly recognized. Not very promising.

Time-Variable Gravity (Greenland)



"True" signal:

- GFZ-RL05a (truncated at 10)

Swarm signal:

- 90x90 solutions (truncated at 10)

Nicer, but:

- It is a point-wise evaluation of the truncated field, expressed in geoid heights instead of EWH.

Summary (1/2)

- SLR RMS of 3cm for Swarm kinematic orbits.
- Ionosphere disturbances affect orbit and gravity field solutions.
- GPS data screening for large ionosphere changes helps to reduce the geomagnetic signatures, but also weakens low degrees.
- Very low degree coefficients are of similar quality as from GRACE GPS hl-SST.
- Different behavior of GRACE solutions is related to missing GPS data along the geomagnetic equator.

Summary (2/2)

- Preview on time-variable signals is encouraging for largest annual signals, but trend estimates seem to remain a challenging task.

- For more information, see upcoming paper:

  A. Jäggi et al, "Swarm kinematic orbits and gravity fields from 18 months of GPS data", Adv. Space Res. (accepted after minor revision)