Kinematic Space–Baselines and their Use for Gravity Field Recovery

A. Jäggi[1], C. Dahle[2], D. Arnold[1], U. Meyer[1] , H. Bock[1]

[1] *Astronomical Institute, University of Bern, Switzerland*

[2] *German Research Centre for Geosciences, Potsdam, Germany*

PSD.1

40th COSPAR Scientific Assembly

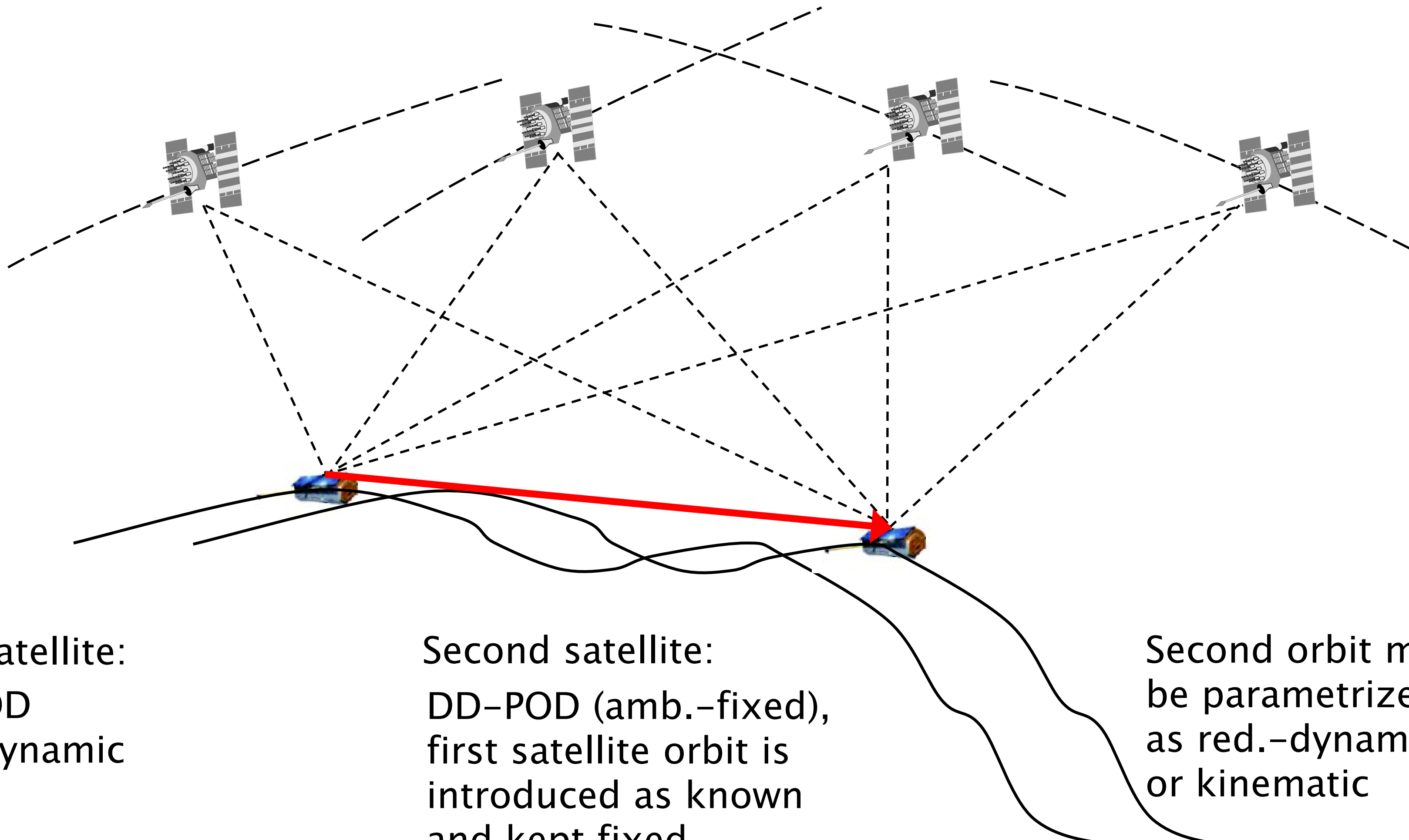
2–10 August 2014

Moscow, Russia

Content

- Motivation and performance of space-baselines
  - GRACE
  - Swarm
- Current issues with Swarm gravity field recovery
- Space baselines for gravity field recovery
  - Observation Equation Approach
  - GRACE-type approach
- Summary

Principle of space-baseline determination



First Satellite:

ZD–POD
red.–dynamic

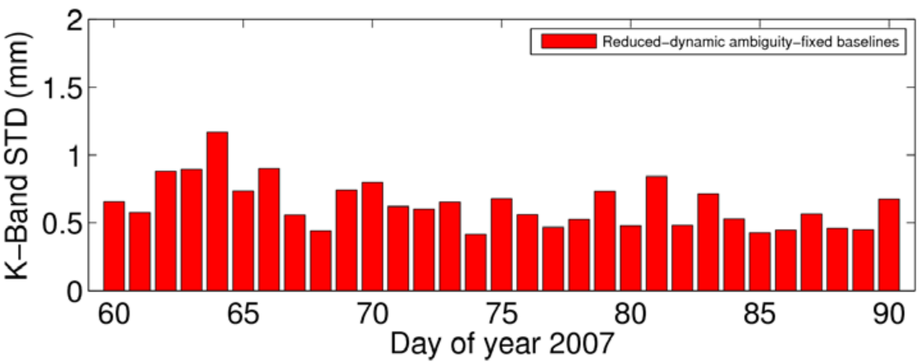
Second satellite:

DD–POD (amb.–fixed), first satellite orbit is introduced as known and kept fixed

Second orbit may be parametrized as red.–dynamic or kinematic

Motivation to use space-baselines

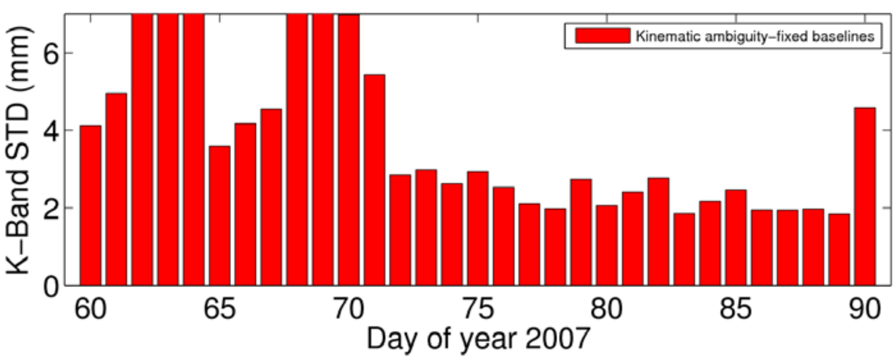
Differential GPS with ambiguity-resolution substantially improves the accuracy of space-baselines from cm- to mm-accuracy.



GRACE reduced-dynamic baselines:

K-Band validation confirms sub-millimeter precision in the line-of-sight direction:

Mean K-Band STD: 0.63 mm



GRACE kinematic baselines:

K-Band validation confirms few-millimeter precision in the line-of-sight direction:

Mean K-Band STD: 4.66 mm

Gains of a factor of 10 are sometimes predicted in simulation studies of gravity field recovery when using baseline- instead of position-observables.

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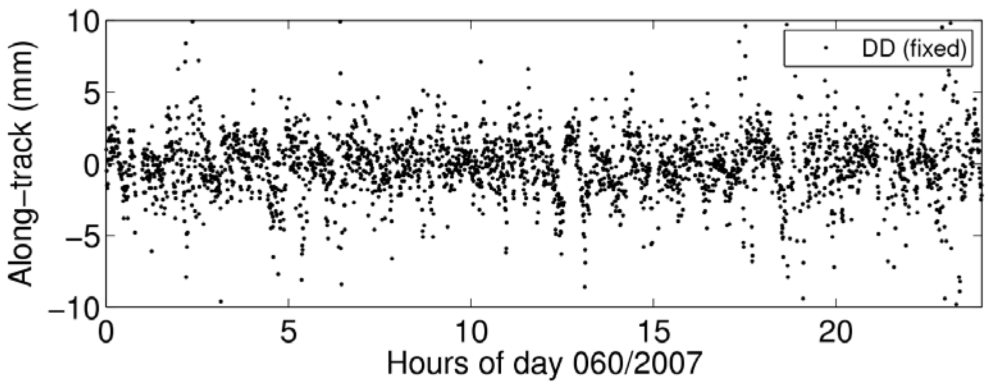
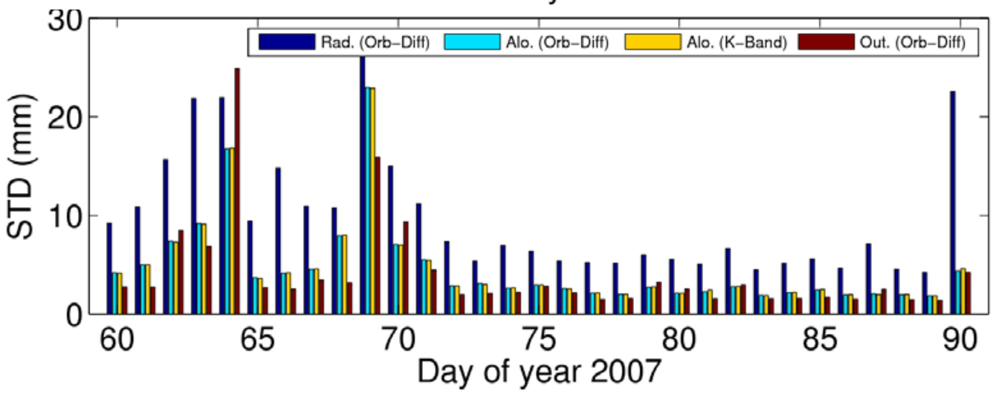
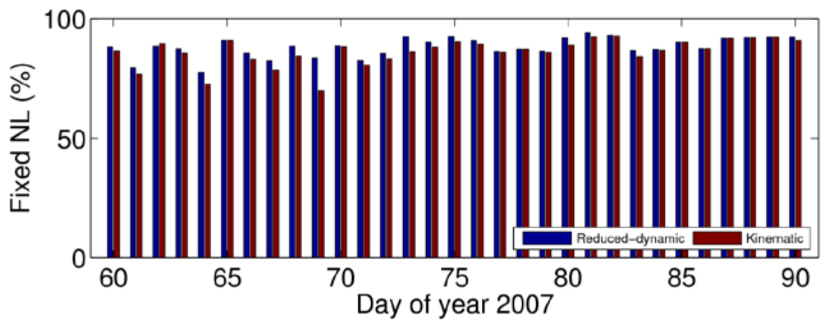
Performance of GRACE baselines







Zero–difference orbit and baseline solutions are usually prone to long wavelength systematic errors.

Double–difference baseline solutions have the potential to reduce them …

… or even eliminate them.

Ambiguity resolution is crucial for the removal. Success may be assessed by inspecting the differences of estimated positions of the second satellite between kinematic and reduced–dynamic amb.–fixed baseline solutions.

~ 87% of the narrow–lane ambiguities could be fixed for both solutions. The mean STD of the orbit differences are 9.75mm, 4.66mm, 4.10mm

Note the agreement with K–Band: 4.66mm

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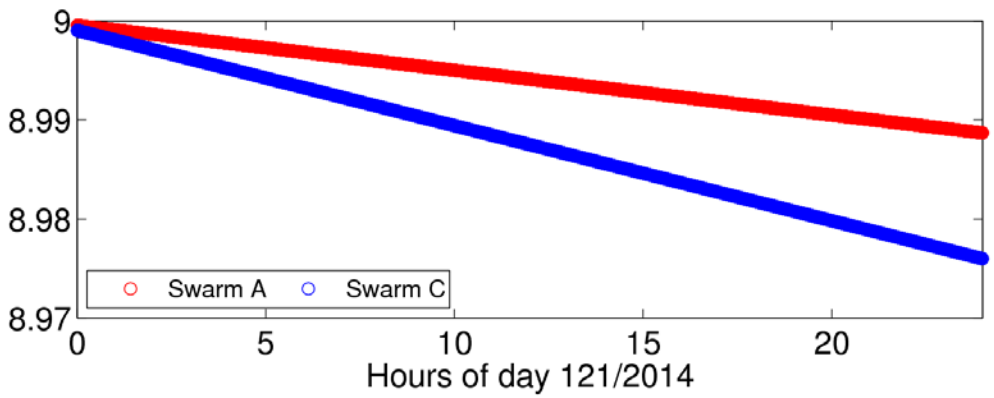
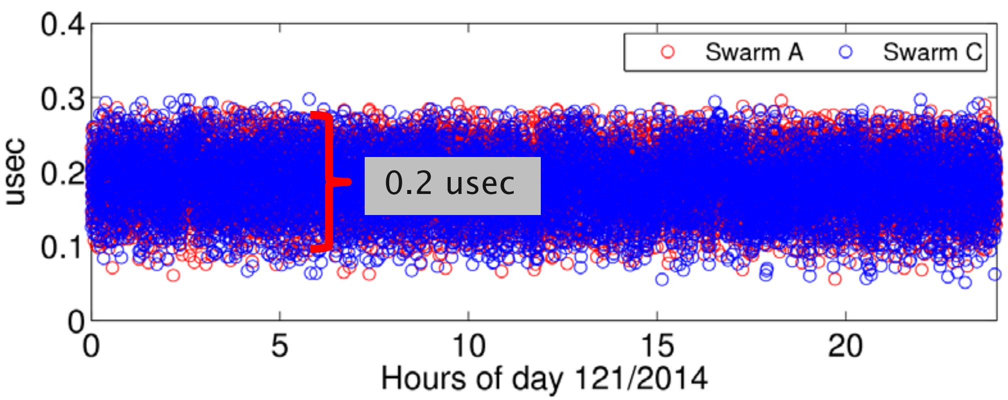
Differences for Swarm: clock synchronization



Measurement epochs in 0.1Hz RINEX data files (receiver time):

Since 2 March Swarm A & C track both at sec 9, 19, 29, etc. (lucky coincidence).

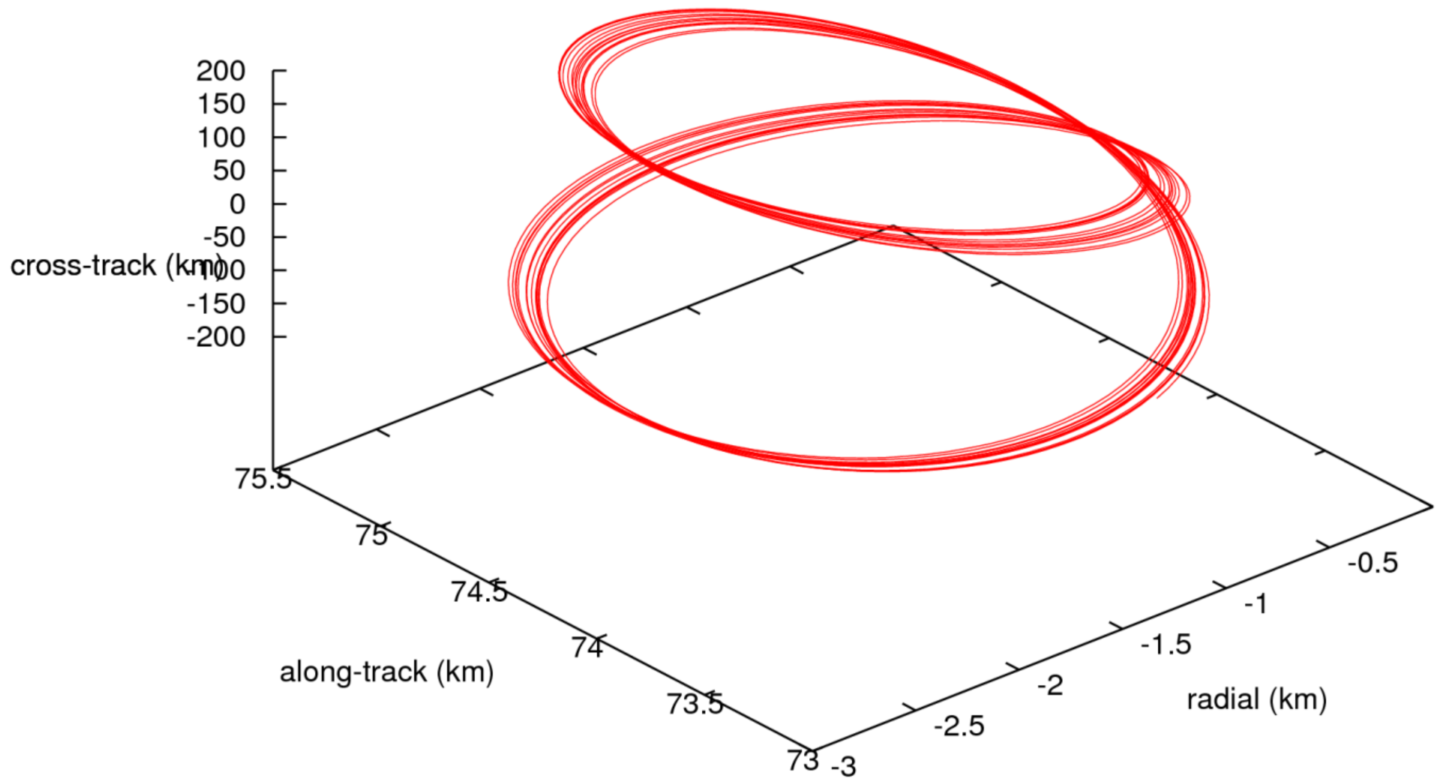


Fractional parts of measurement time in GPS time (after correction of receiver clock) do not differ by more than 0.2 usec.

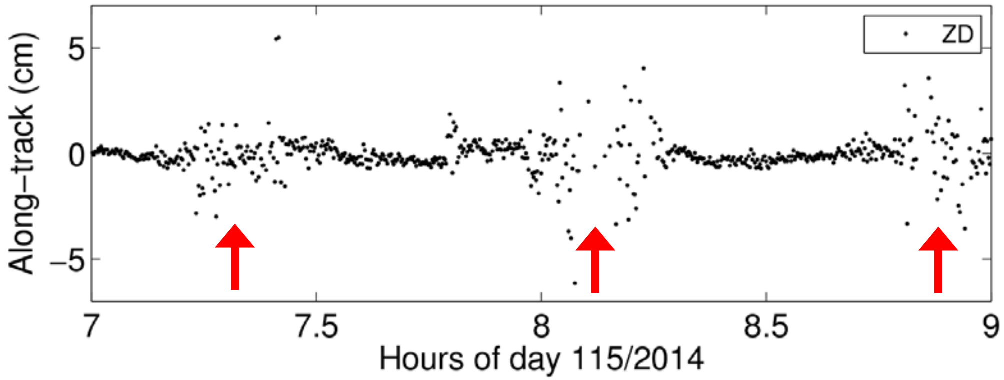
This level of clock synchronization is sufficient to keep phase modeling errors small for reduced-dynamic/kinematic baseline determination. Since 15 July all Swarm satellites even deliver 1 Hz RINEX data files.

Differences for Swarm: baseline geometry

- The baseline of GRACE is always in along–track direction
- The baseline of Swarm A & C is not “fixed” in one direction

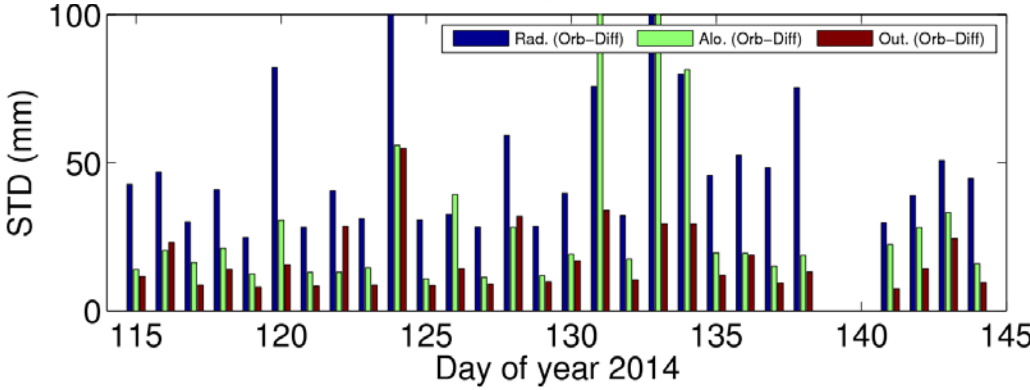


Performance of Swarm baselines



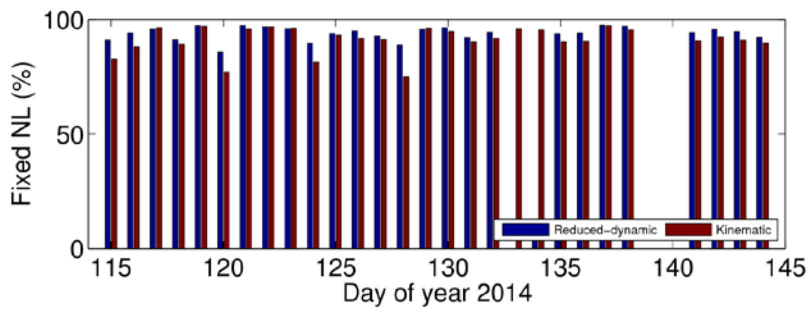
Zero−difference and double−difference float Swarm solutions show considerably larger signals than observed for GRACE.

Double−difference ambiguity−fixed solutions are partly able to reduce them, but large excursions are observed twice per revolution over the geomagnetic poles.



Although ambiguity fixing seems to be quite successful, the statistics is governed by the problems over the polar regions: 57.57mm, 32.44mm, 17.27mm

This is significantly worse than for GRACE!



~ 89% of the narrow−lane ambiguities could be fixed for both solutions for most of the days.

Some problematic days remain and need to be further investigated.

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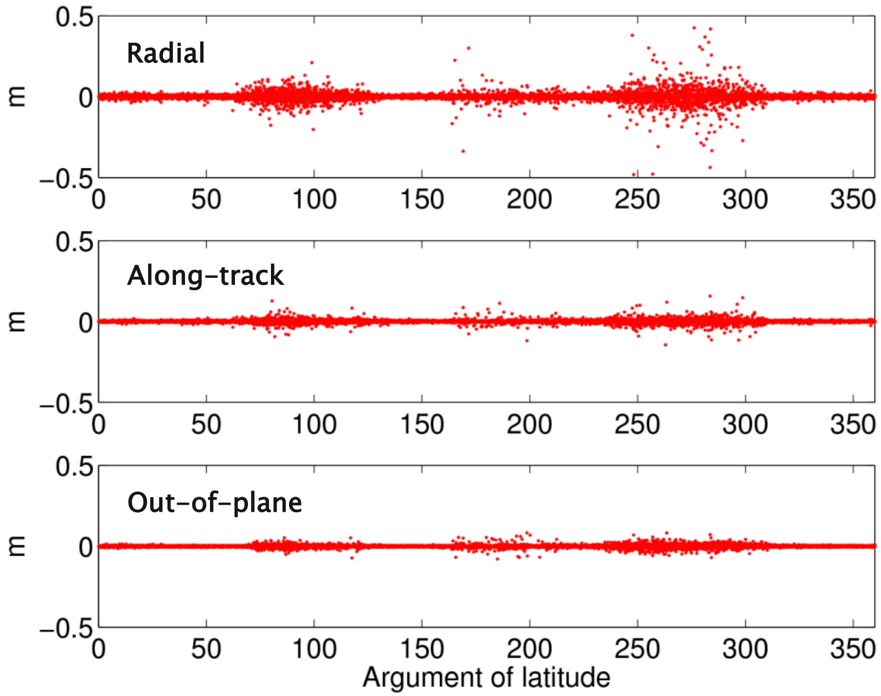
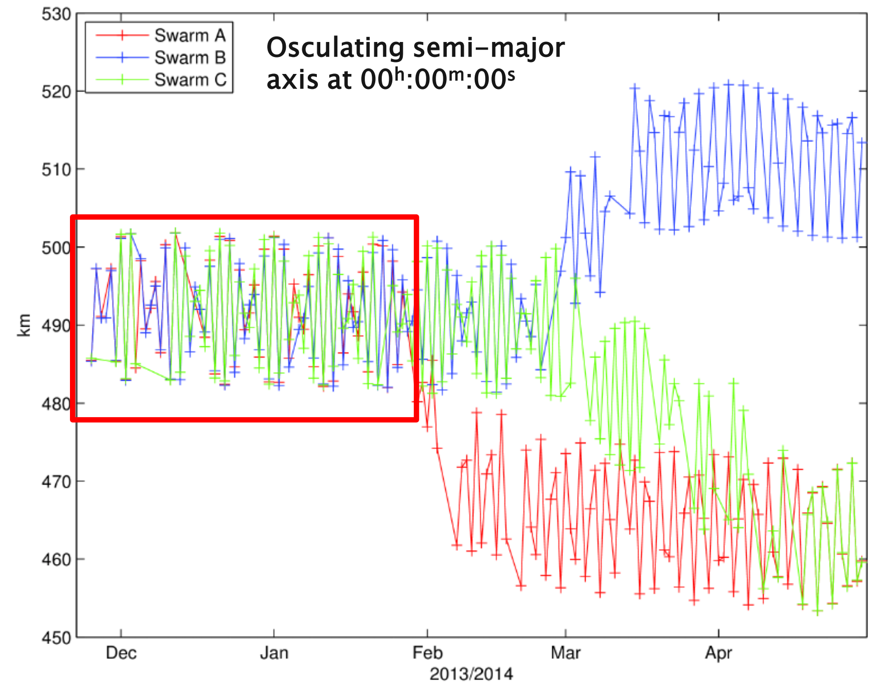
Issues in Swarm kinematic positions





Similar to the GOCE mission, larger noise is also observed for kinematic positions over the polar regions and along the geomagnetic equator.

What are the consequences for gravity field determination?

Based on the Swarm orbit configuration two test periods are selected for gravity field tests based on kinematic positions:

1 Dec 2013 – 31 Jan 2014 (2 months)

1 Dec 2013 – 31 Apr 2014 (5 months)

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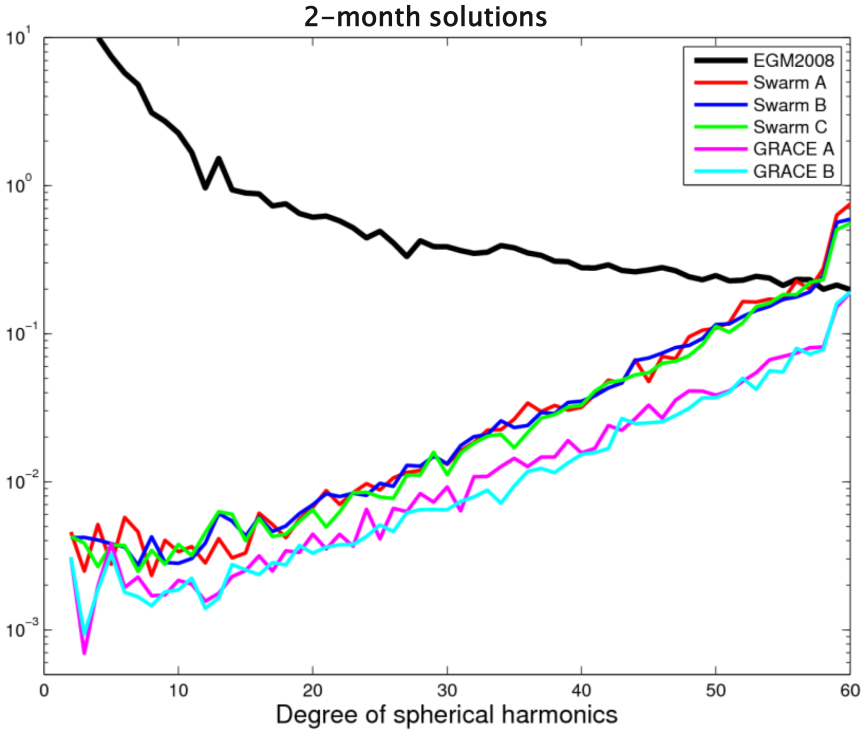
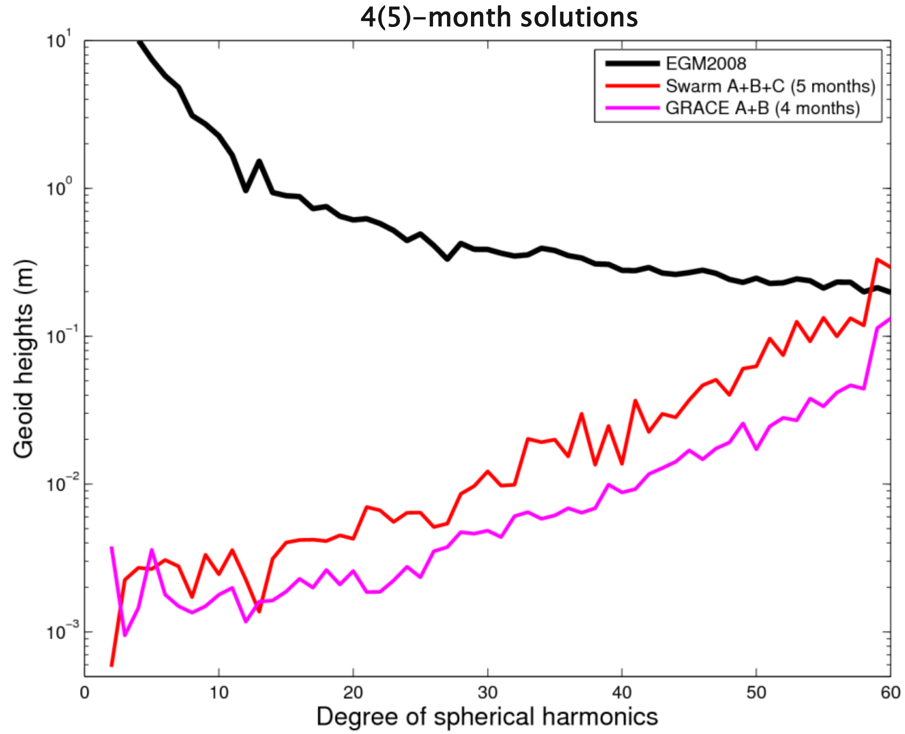
Swarm solutions based on positions





Individual 2-month solutions based on kinematic positions show a comparable quality for all three Swarm satellites.

The performance is significantly worse than for GRACE solutions based on kinematic positions.

Combined Swarm A+B+C over longer time intervals are also significantly worse than GRACE A+B solutions.

Some improvement for degree 2 is observed.

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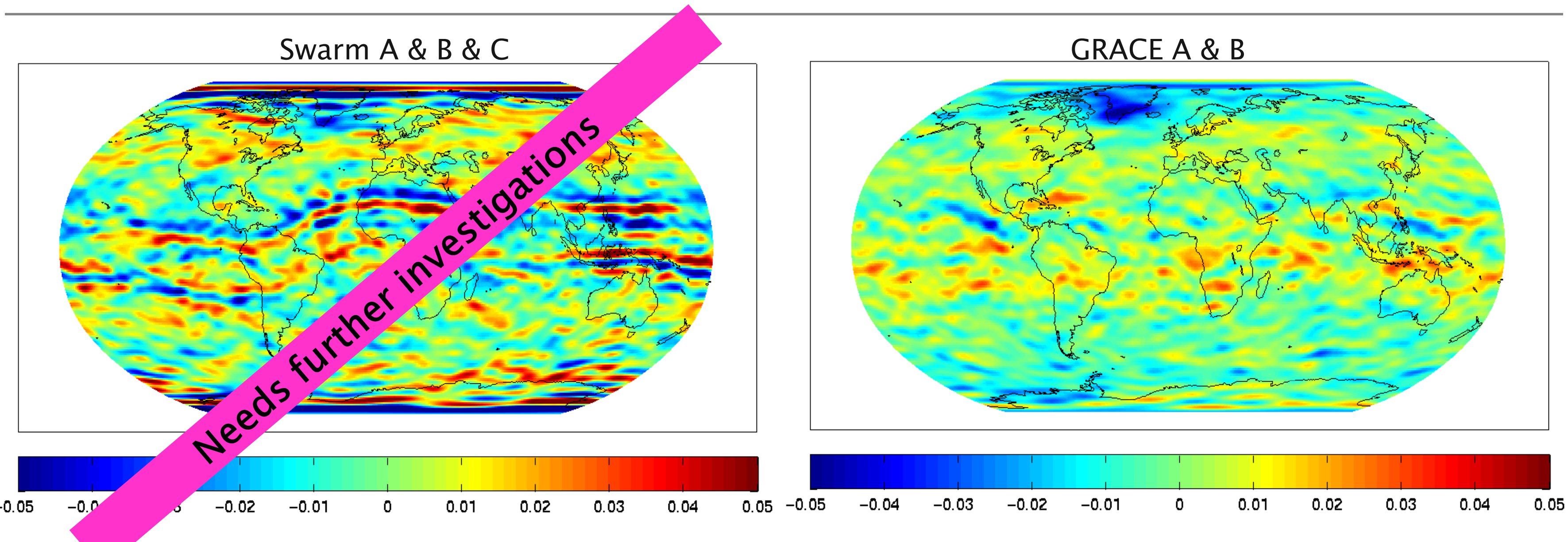
Comparison of Swarm and GRACE solutions



Differences between the solutions:

- **Swarm 3 satellites, GRACE 2 satellites**
- **Swarm satellites are on higher altitude**
- **Swarm kinematic orbits are of worse quality**
  - **Swarm tracks max. 8 satellites, GRACE max. 10**
  - **Swarm has tracking problems over the pole and around the geomagnetic equator**
  - **Elevation cut-off: Swarm 10 degrees, GRACE 0 degrees**
  - **GRACE provides L1C, which has lower noise than L1P**
- **Different inclinations 87 ⇔ 89 degrees**

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Using space baselines for gravity field recovery

- "Observation equation approach"
  - Establish individual observation equations for both satellites based on positions of the two endpoints of the baseline
  - Form differences of the two individual observation equations (fix orbit parameters of one satellite to a priori values)
  - Form normal equations
- "GRACE-type approach"
  - Establish individual observation and normal equations for both satellites based on ZD kinematic positions
  - Establish observation and normal equations for vector differences or baseline lengths based on DD kinematic baselines (set up orbit parameters for both satellites)
  - Combine normal equations
- …

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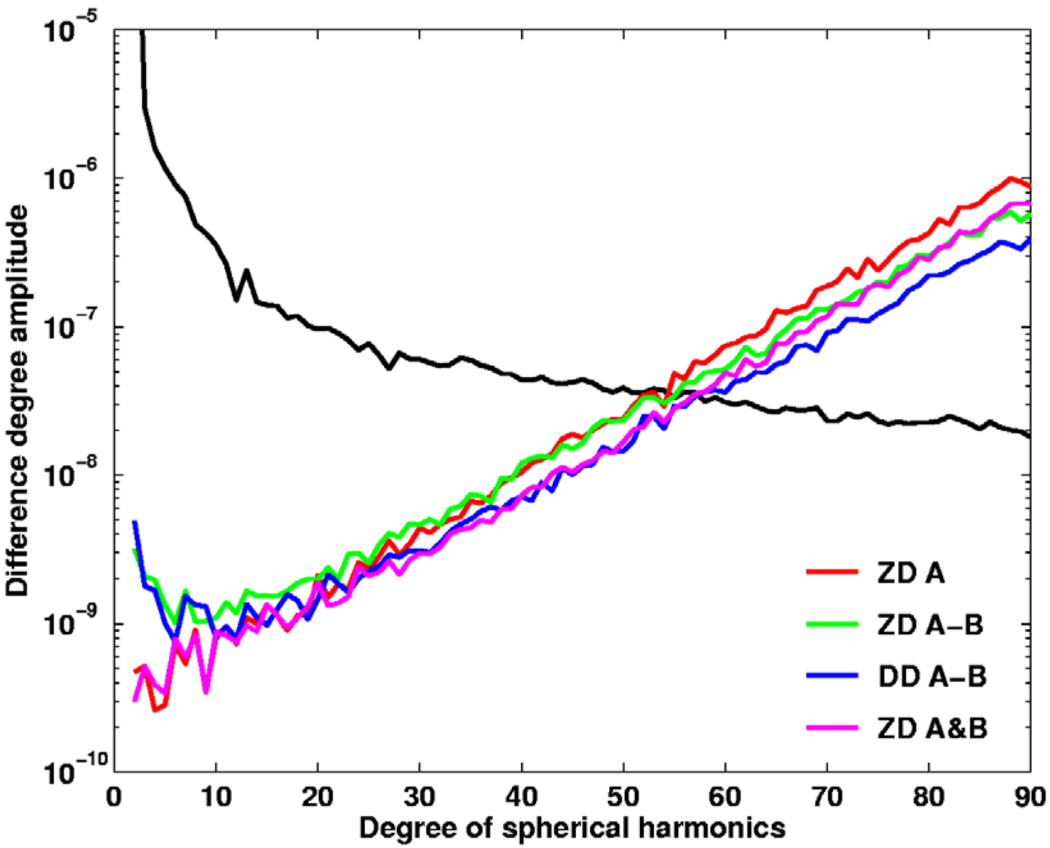
Observation equation approach



ZD A:
ZD kinematic positions of GRACE–A

ZD A–B:
Baselines formed from kinematic ZD positions of GRACE–A and GRACE–B

DD A–B:
Baselines formed from kinematic DD float solutions

ZD A&B:
ZD positions of GRACE–A and GRACE–B.

No dramatic improvement is observed when using baseline-type observations.

Possibly a slightly more favorable slope is seen for the DD A-B solution

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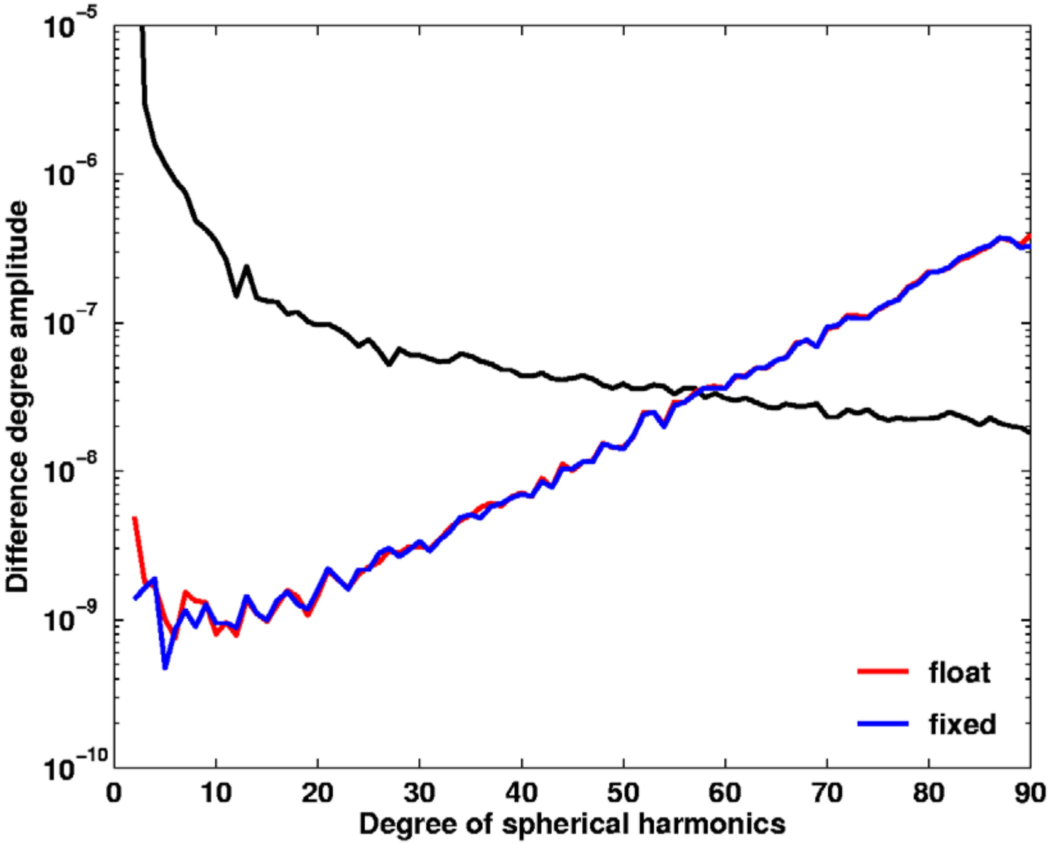
Impact of ambiguity-fixing



DD A−B:
Baseline formed from kinematic DD float solutions

Ambiguity−float baselines

Ambiguity−fixed baselines

Ambiguity resolution does only affect the very low degress.

Not relevant when baseline results are not combined with position solutions.

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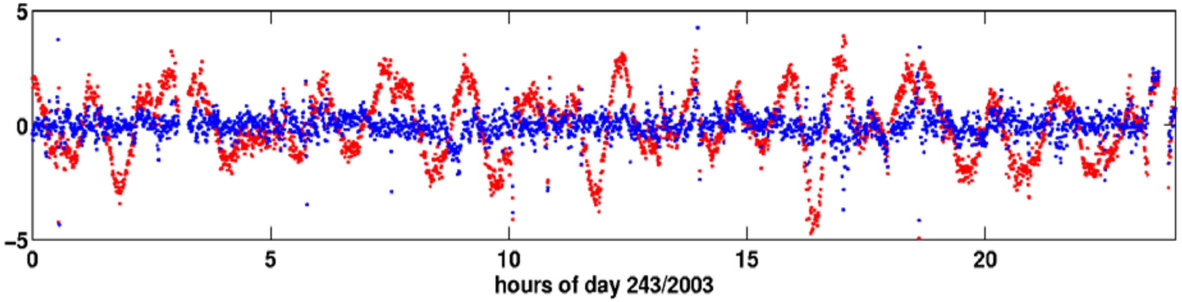
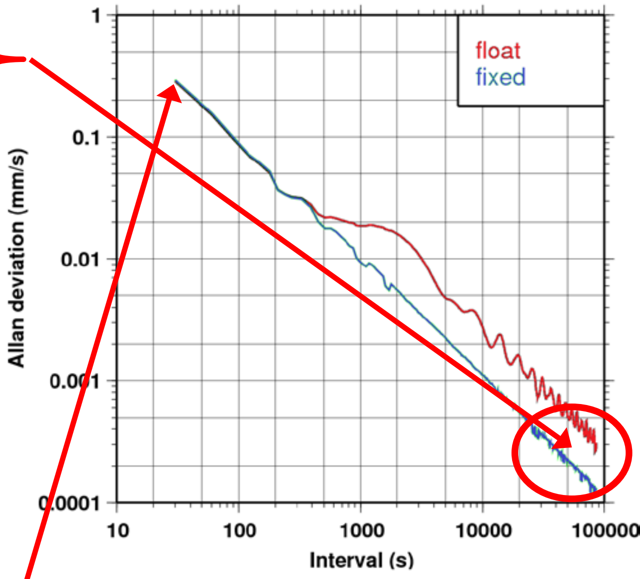
Impact of ambiguity-fixing

Original K-Band residuals:

KBR RMS: 14.41 mm 5.78 mm

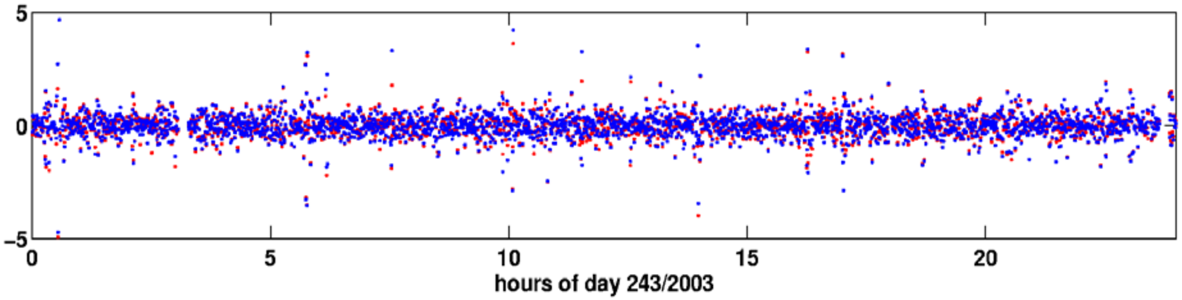


Allan deviation:



Time-differenced K-Band residuals:

KBR RMS: 6.10 mm 6.10 mm



Ambiguity resolution only reduces long wavelength excursions (colored noise) but not the noise in the relative positions.

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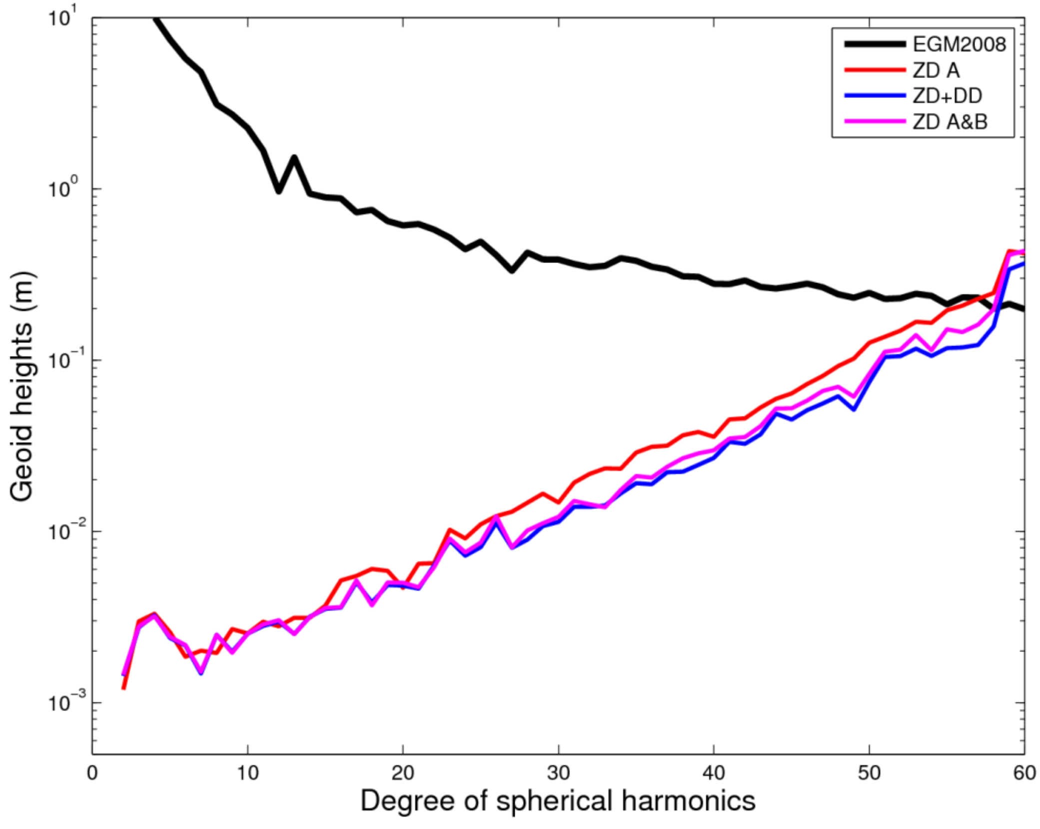
GRACE-type approach



ZD A:
ZD kinematic positions of GRACE-A

ZD+DD:
Individual normal equations set up from ZD positions of GRACE-A and GRACE-B and from baseline lengths from kinematic DD fixed solutions

ZD A&B:
ZD positions of GRACE-A and GRACE-B.

Similar to previous slides: no dramatic improvement when using baselines

Work in progress: Only baseline length used so far, not individual vector components

Moreover: Different weighting not yet exploited, covariance information not yet used

Summary

- **Swarm offers a unique opportunity to exploit kinematic space-baselines for gravity field determination**
- **First Swarm baselines have been formed**
  - **data problems over geomagnetic poles and along geomagnetic equator are limiting the quality. Needs to be further investigated**
- **GRACE baselines were used to test several processing options for gravity field recovery**
  - **Observation Equation Approach**
  - **GRACE-type approach (only baseline length used so far)**
- **Only small advantages seen so far**
  - **individual weighting needs to be investigated**
  - **use of covariances needs to be investigated**

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