GOCE orbit determination using accelerometer data

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PSD.1

39th COSPAR Scientific Assembly

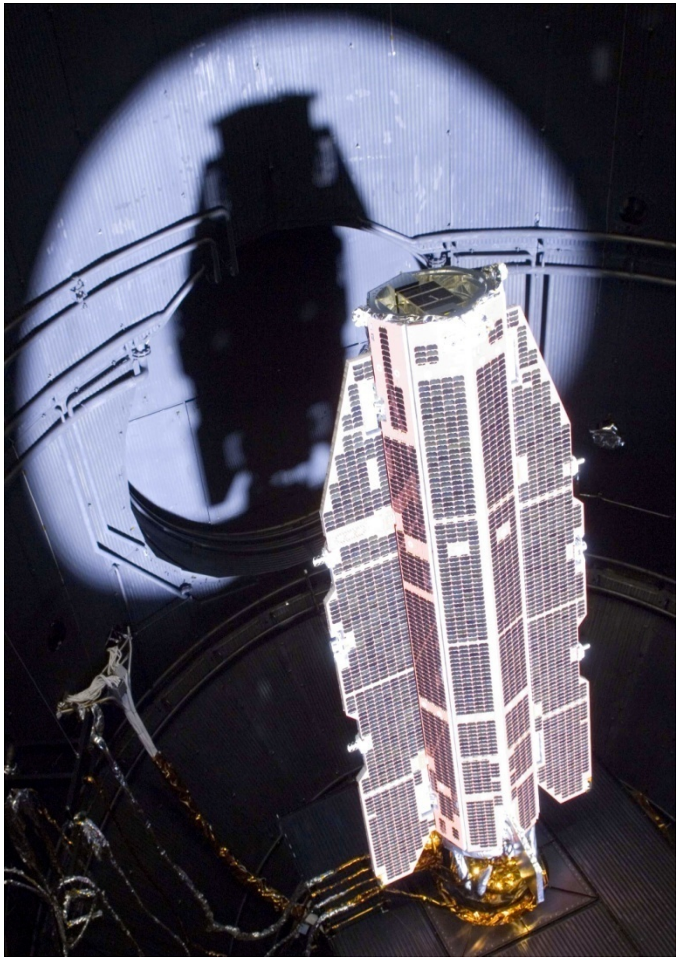
14–22 July 2012

Mysore, India

Outline

- Motivation
- GOCE accelerometer data
  - Characteristics and filtering
- Orbit determination using accelerometer data
  - Description of solutions
  - Comparison and validation
- Summary and outlook

Motivation



Courtesy:ESA

- The GOCE satellite is equipped with a gradiometer for gravity field recovery.
- On one hand, gravity gradients are derived from the measurements of the three pairs of accelerometers (differential mode) and, on the other hand,
- non-gravitational forces acting on the satellite are derived as well (common mode)
- in along-track direction used for drag compensation by thruster pulses.
- Common mode accelerometer data may also be used for orbit determination.

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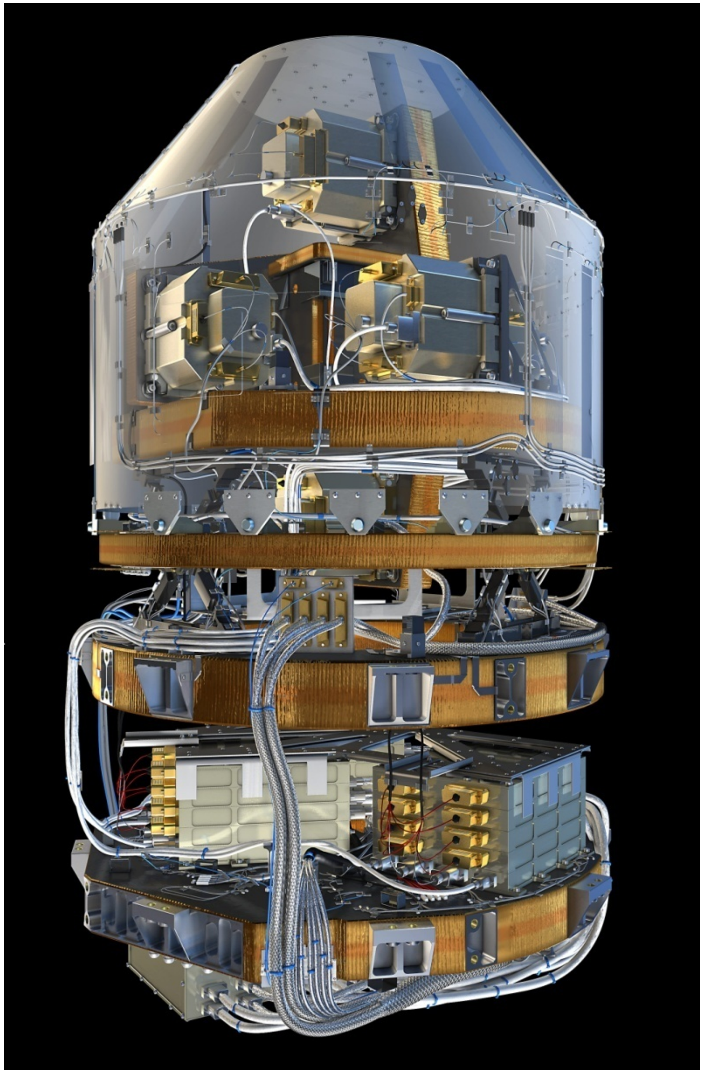

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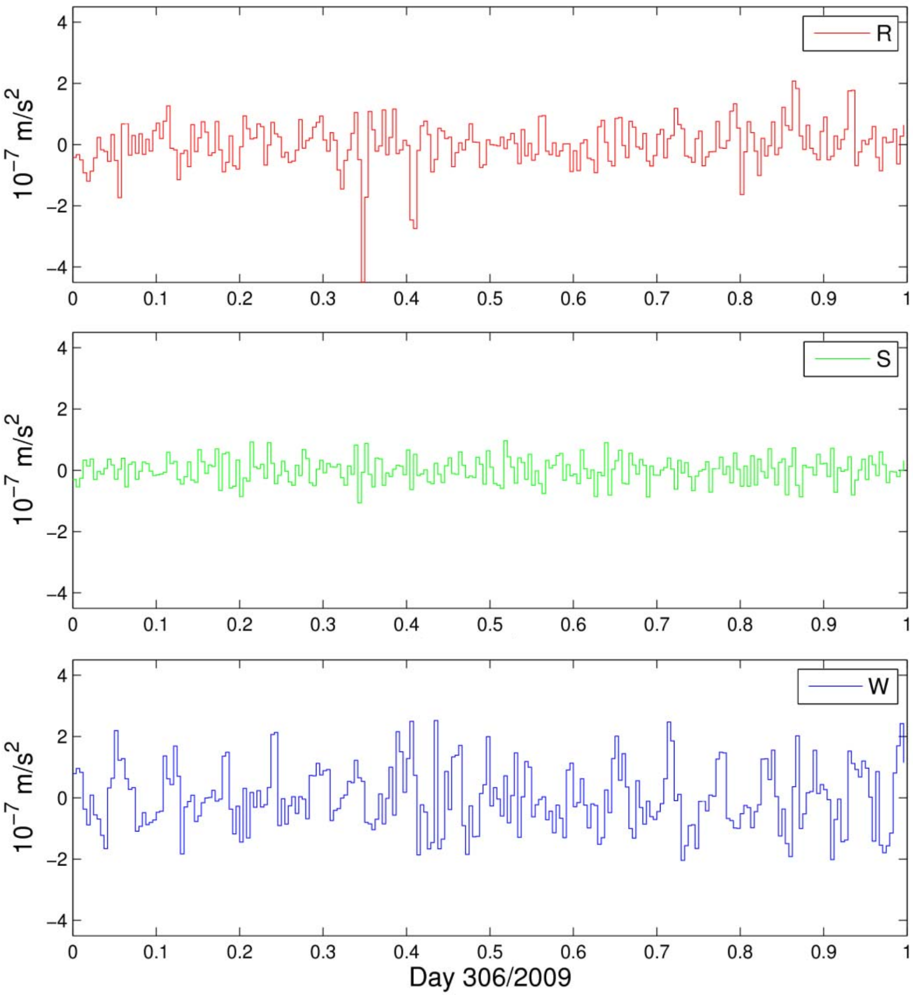
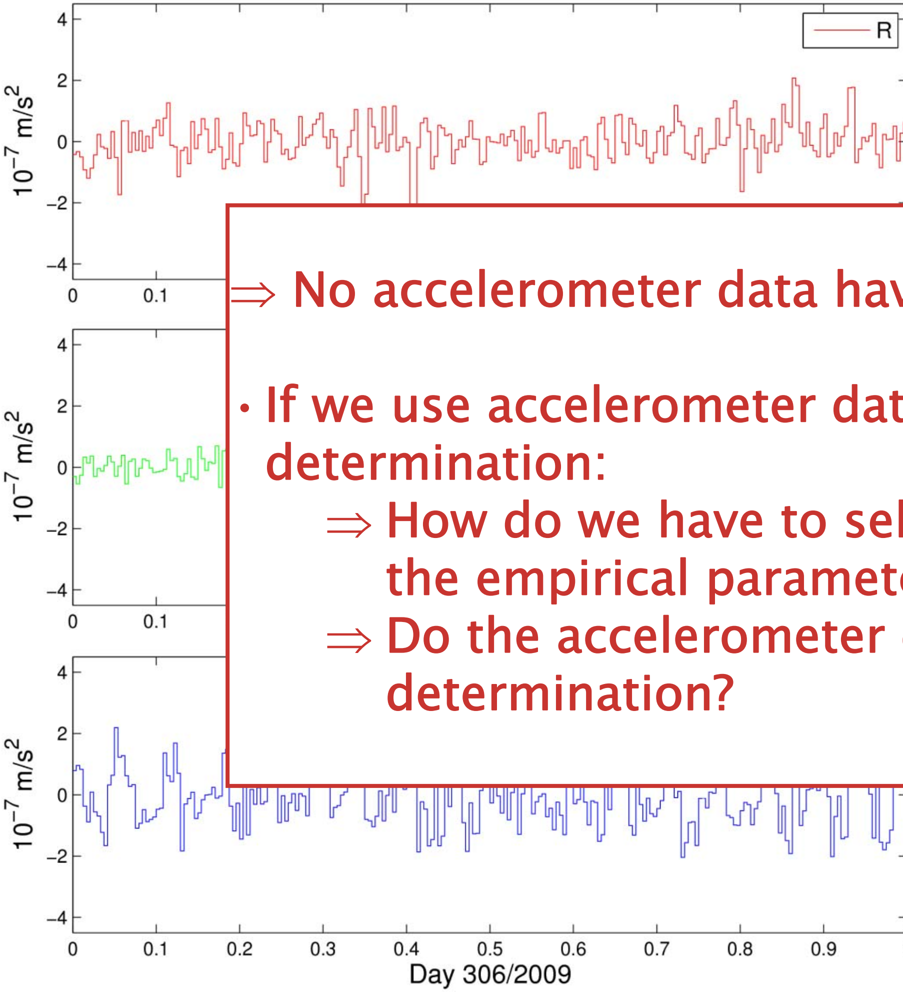


- Official reduced-dynamic orbit solution is based on:
- Most important background models:
  - Gravity field: EIGEN5S (120x120)
  - Ocean tides: FES2004 (50x50)
- No models for non-gravitational forces
- Parameters:
  - six initial orbital elements
  - three constant offsets in RSW
  - piece-wise constant accelerations (6 min) in RSW, constrained with $\sigma=2.0*10^{-8}$ m/s^2

Motivation



- Official reduced-dynamic orbit solution is based on:

kground

N5S (120x120)

004 (50x50)

-gravitational

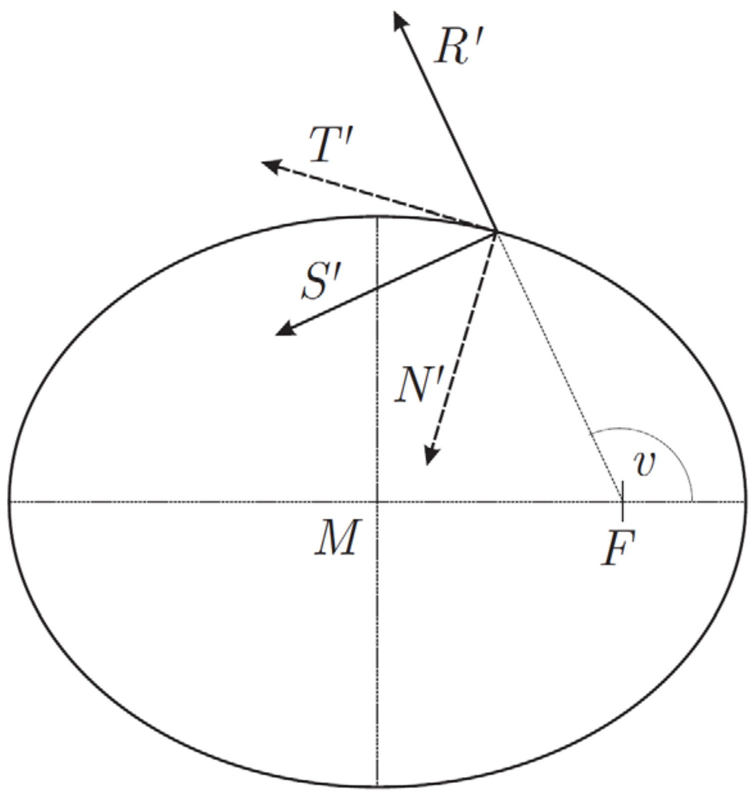
elements

- three constant offsets in RSW
- piece-wise constant accelerations (6 min) in RSW, constrained with $\sigma=2.0*10^{-8}$ m/s^2

⇒ No accelerometer data have been used until now

- If we use accelerometer data for orbit determination:
  - ⇒ How do we have to select the constraints for the empirical parameters?
  - ⇒ Do the accelerometer data improve the orbit determination?

Explanation of RSW–system



Co–Rotating Orbital Frames

R, S, W unit vectors are pointing:

- into the radial direction
- normal to **R** in the orbital plane
- normal to the orbital plane (cross–track)

T, N, W unit vectors are pointing:

- into the tangential (along–track) direction
- normal to **T** in the orbital plane
- normal to the orbital plane (cross–track)

For small eccentricities: **S~T** (velocity direction)

GOCE accelerometer data

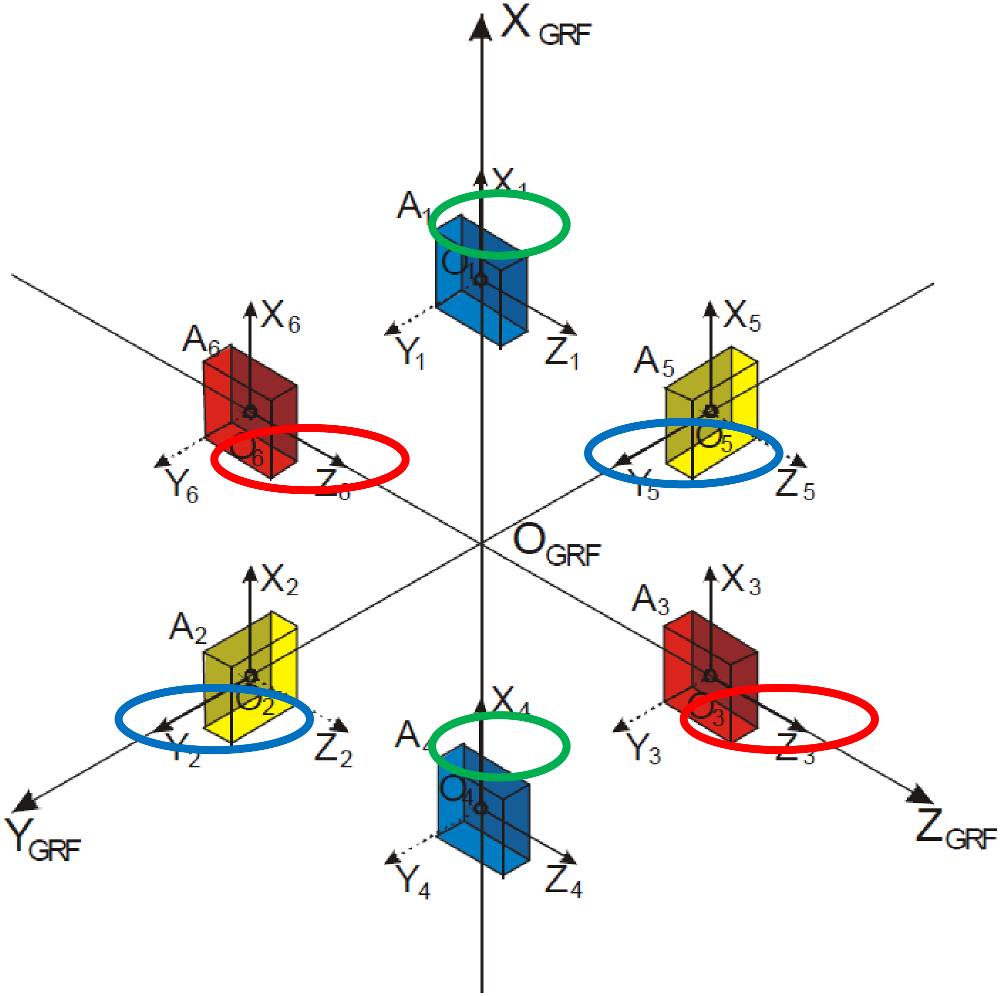
GRF: Gradiometer reference frame

X: flight direction

Z: nadir direction

- Common mode accelerations provide a measure of the non-gravitational forces acting on the satellite

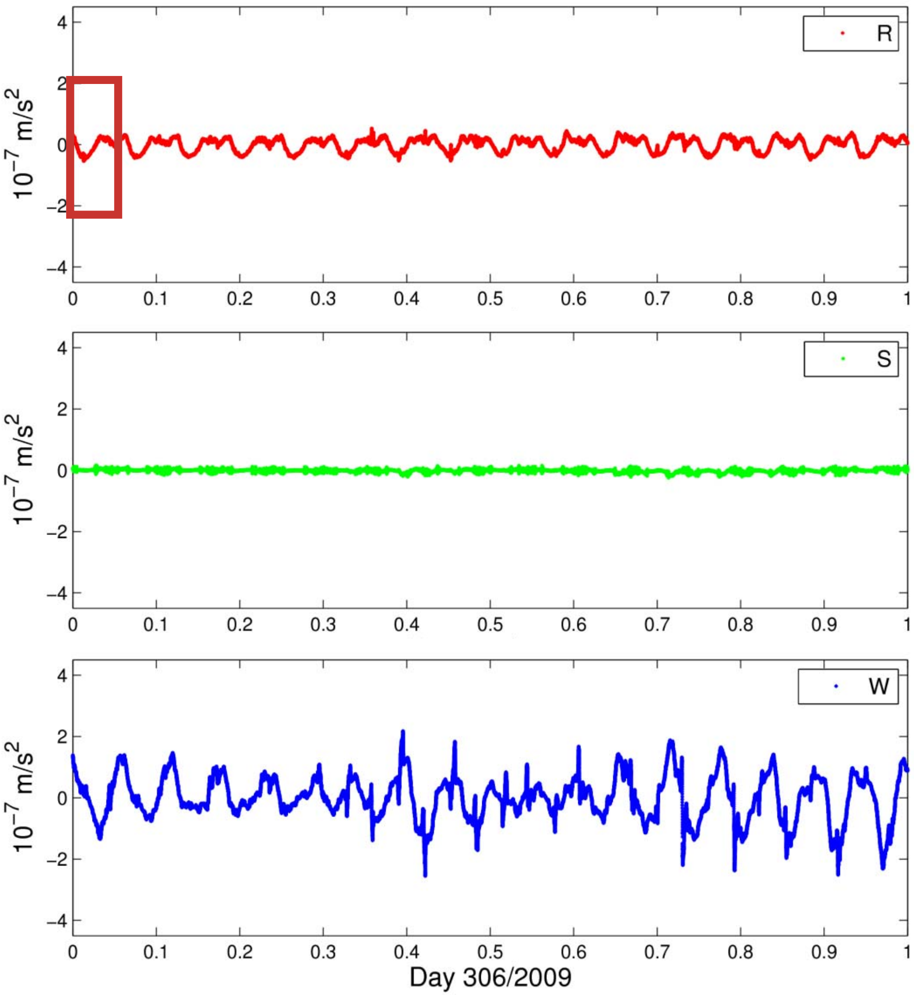
Schematic view of GOCE gradiometer



Common Mode:

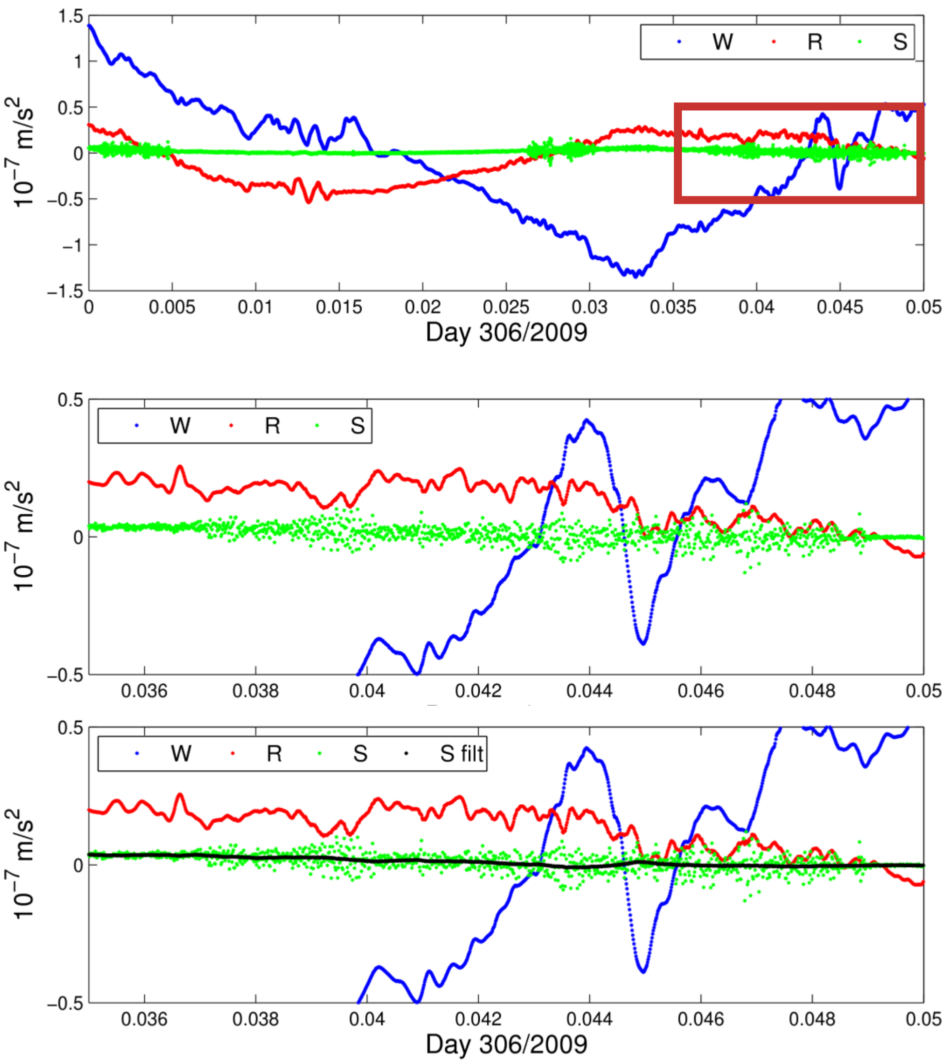
$$a_{c,k,l,i} = \frac{1}{2}(a_{k,i} + a_{l,i})$$

GOCE accelerometer data – characteristics



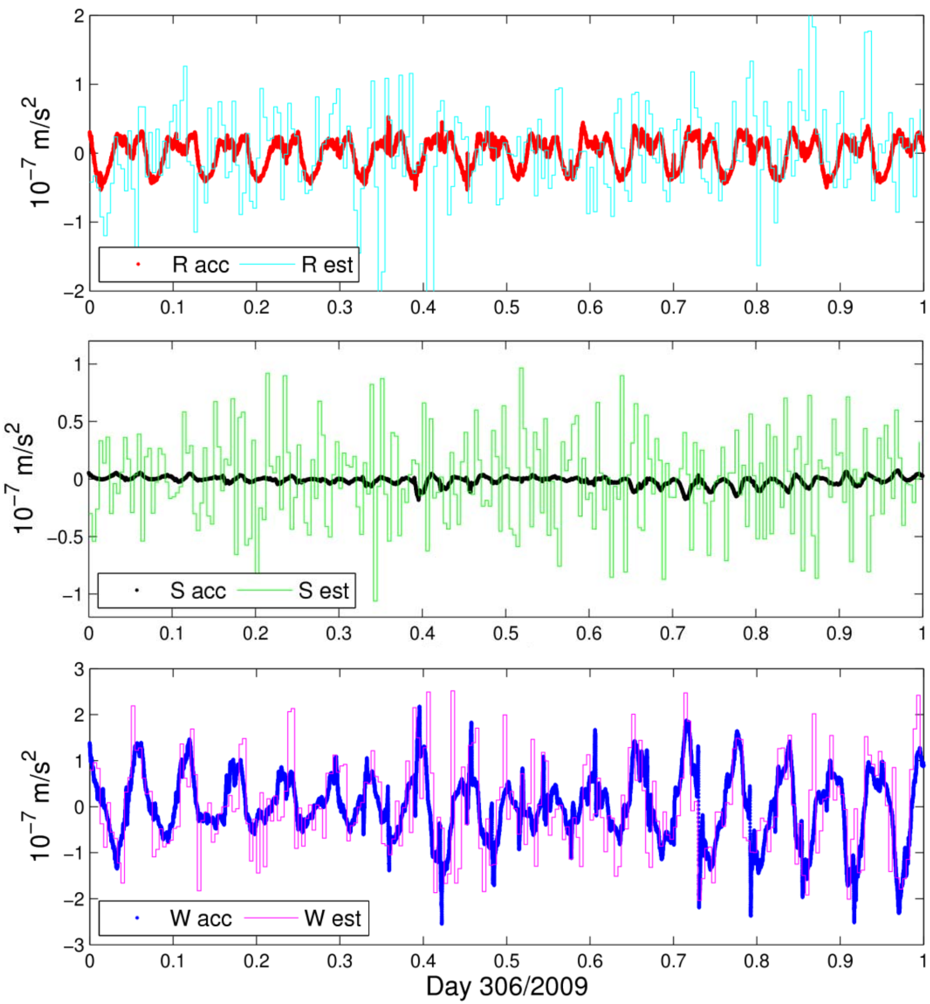
- Attitude and orbit information is needed
- Mean offset is removed (drift and scale are ignored)
- S is very small due to atmospheric drag compensation
- R shows variations proportional to thruster pulses (~3% cross-coupling)
- W shows largest variations due to attitude motion (up to 5 degree) => atmospheric drag acting on the satellite body

GOCE accelerometer data – filtering



- Very clean data, no outliers
- Only S-component shows noisy parts
- S-component is filtered

GOCE accelerometer data – characteristics



Different scaling !!!

- Comparison of accelerometer data with estimated piece-wise constant accelerations shows
  - small correlation for R
  - no correlation for S
  - high correlation for W
- How do we have to select the constraints for the empirical parameters?
- Do the accelerometer data improve the orbit determination?

Orbit determination – data set

- Data set: 306–364/2009, w/o 323, 324 (57 days)
- Solution A0 => reference orbits: GOCE "official" reduced-dynamic orbit solution, 24h instead of 30h batches
  - EIGEN5S (120x120), FES2004 (50x50)
  - Six initial orbital elements
  - Three constant offsets in RSW
  - Piece-wise (6 min) constant accelerations in RSW $\sigma=2.0*10^{-8}$ m/s^2
- SLR validation: Mean 0.35 cm, RMS 2.01 cm

Orbit determination – alternative solutions

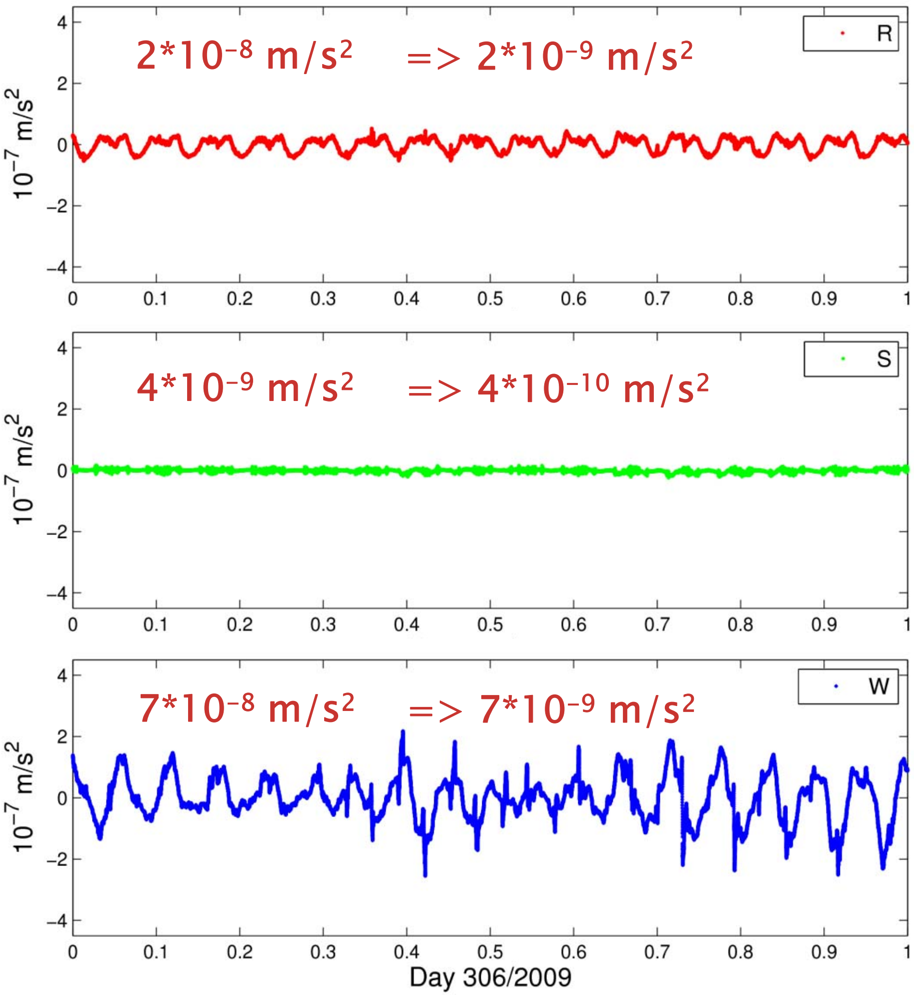
Different models:

- A: EIGEN5S (120x120), FES2004 (50x50)
  w/o accelerometer data
- B: EIGEN5S (120x120), FES2004 (50x50) with acc
- C: GOCO03Sp (120x120), EOT08A (50x50) with acc
- D: GOCO03Sp (160x160), EOT08A (50x50) with acc

Different constraints:

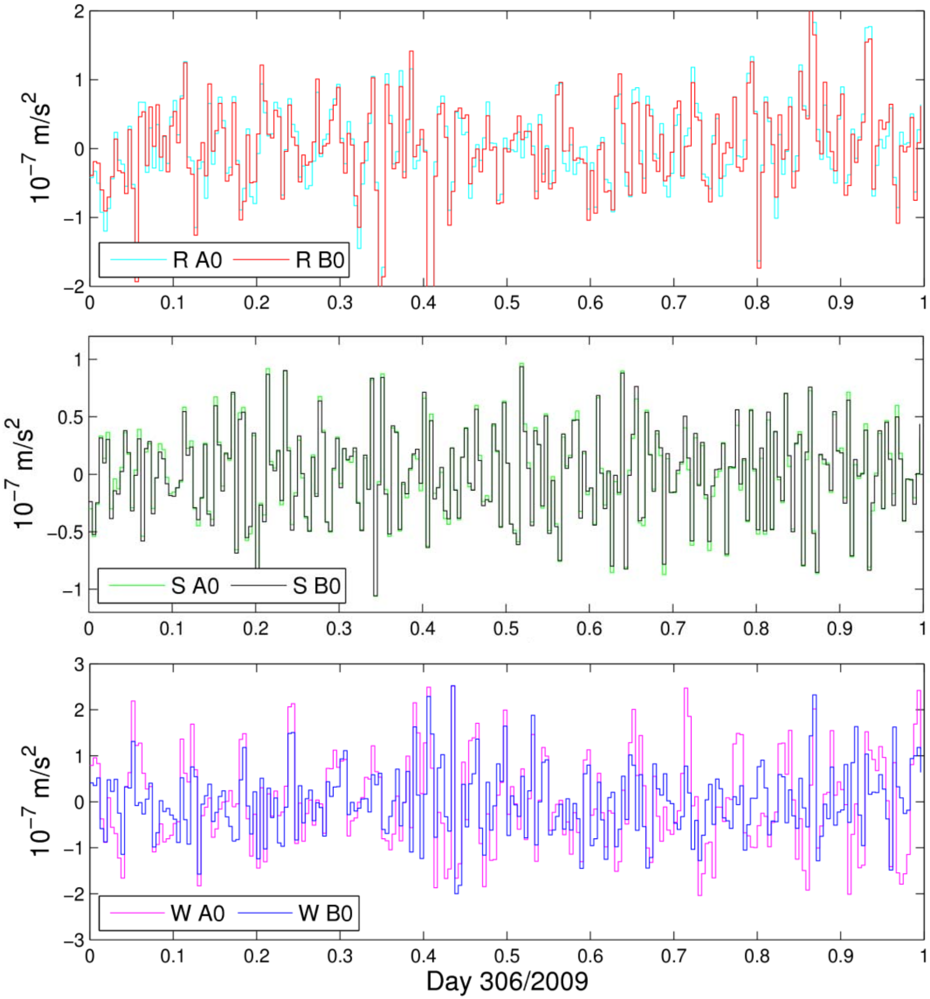
- 0: $\sigma_R = \sigma_S = \sigma_W = 2.0*10^{-8}$ m/s²
- 1: $\sigma_R = \sigma_S = \sigma_W = 5.0*10^{-9}$ m/s²
- 2: with acc $\sigma_R = 2.0*10^{-9}$ m/s² w/o acc: $2.0*10^{-8}$ m/s²
  with acc $\sigma_S = 4.0*10^{-10}$ m/s² w/o acc: $4.0*10^{-9}$ m/s²
  with acc $\sigma_W = 7.0*10^{-9}$ m/s² w/o acc: $7.0*10^{-8}$ m/s²

Deriving constraints from accelerometer data



- The variations of the accelerometer differ very much in R, S, W.
- Use of different constraints for the three directions might be reasonable.
- Constraints, if no accelerometer data are used, are derived from:
  - Mean values for 6-min bins
  - RMS of these mean values => stable for the 57 days
- Constraints, if accelerometer data are used
  - 10 % – assuming that background models are sufficient

Comparison of estimated accelerations

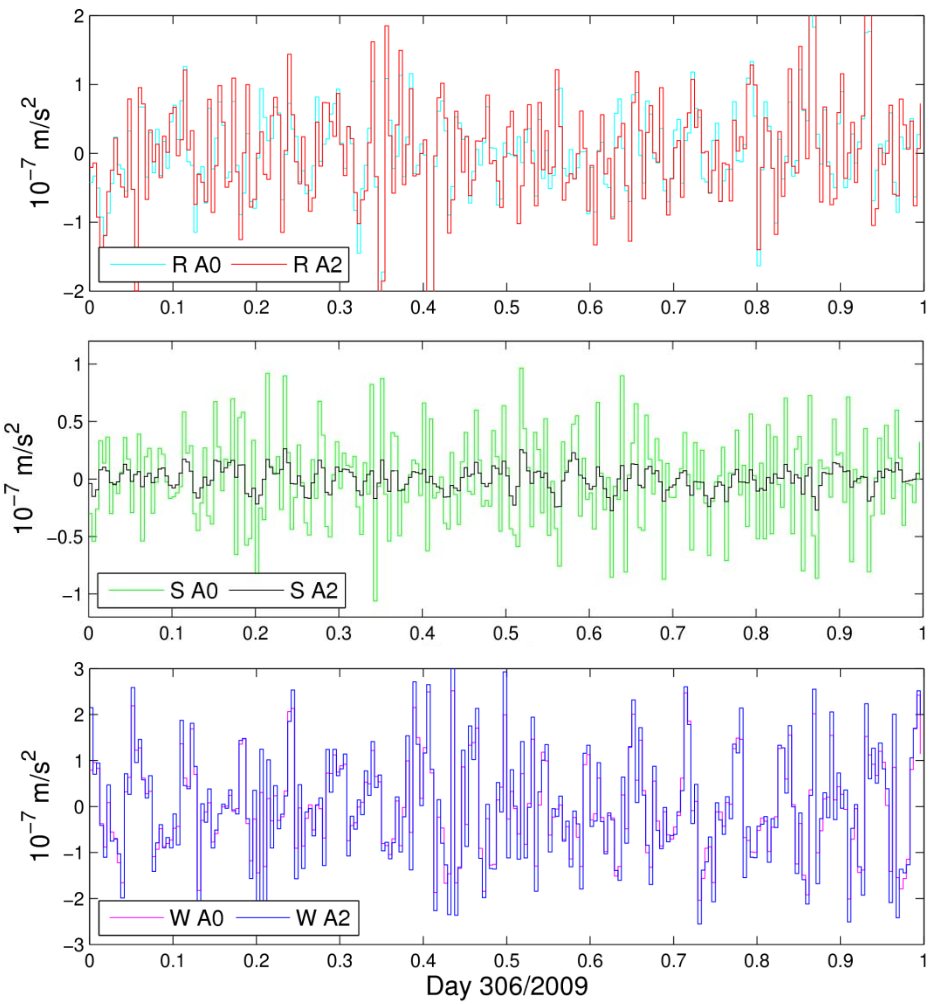


Different scaling !!!

- Comparison A0 ⇔ B0
  - Difference: use of accelerometer data for B0
- R+S: no/small reduction of size of empirical parameters
- W: reduction of size is visible

=> Use of accelerometer data with the same parametrization in R,S,W has only impact on estimated accelerations in W

Comparison of estimated accelerations

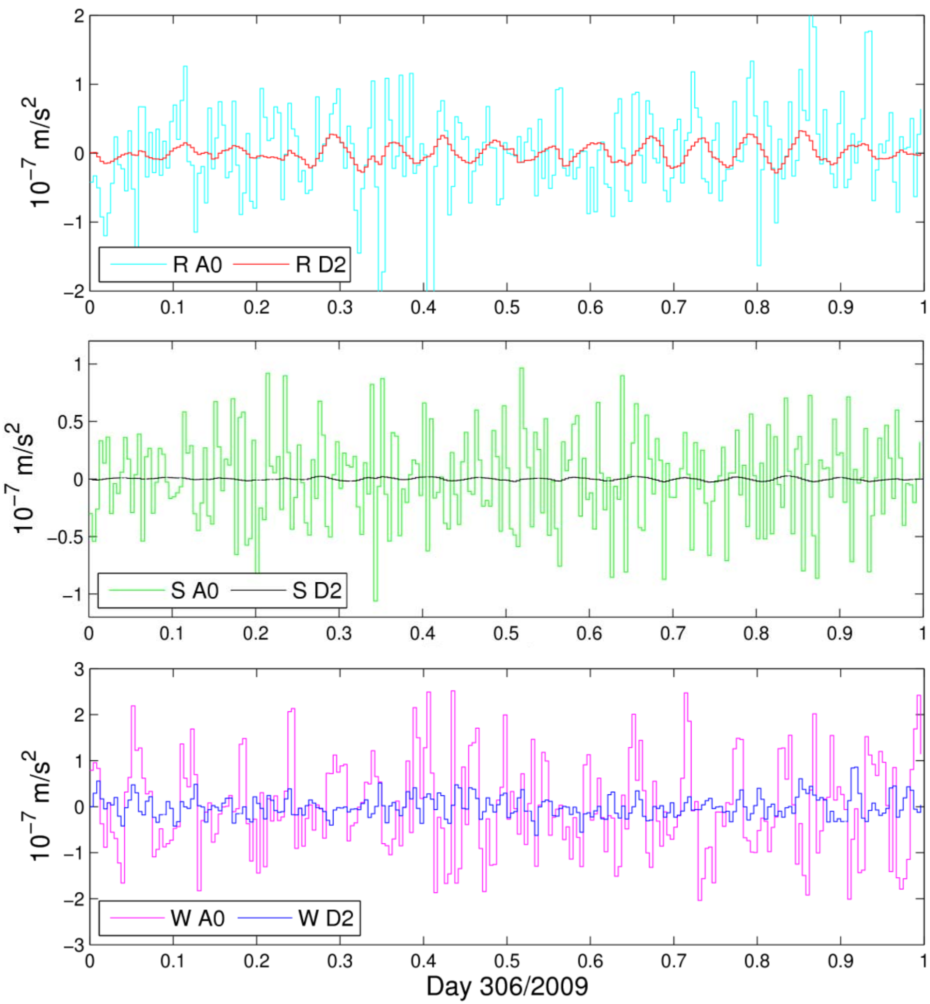


Different scaling !!!

- Comparison A0 ⇔ A2
  - Difference: realistic constraints for A2
- R: few differences
- S: high reduction of size
- W: slight increase of size

=> Use of realistic constraints has impact on the size of the accelerations related to looser or tighter constraints

Comparison of estimated accelerations

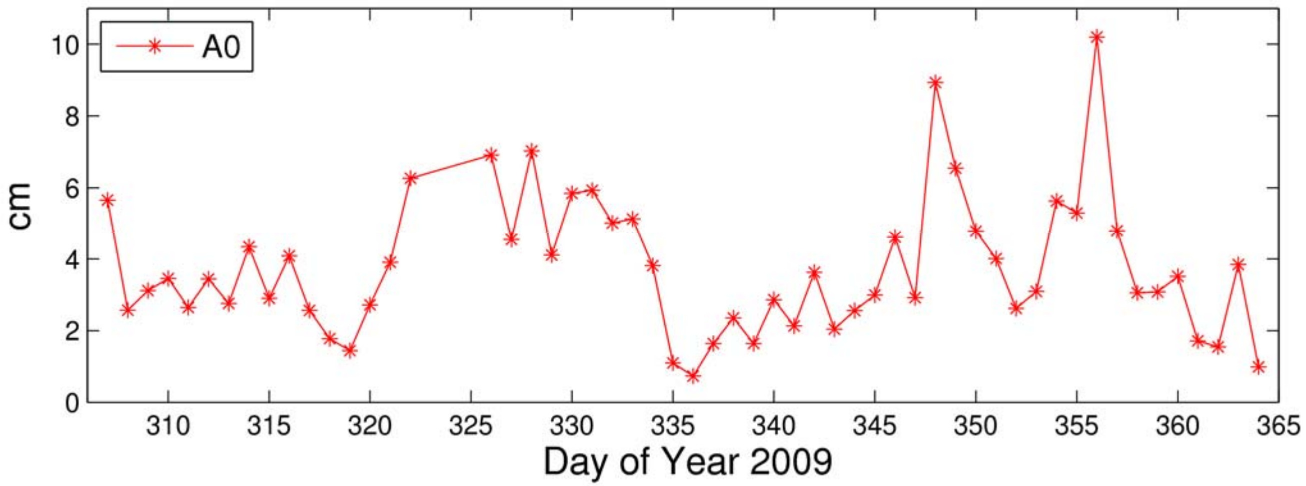


Different scaling !!!

- Comparison A0 ⇔ D2
  - Difference: use of accelerometer data + "best possible" background models + realistic constraints (10%)
- High reduction for all components

=> Use of accelerometer data+realistic constraints has impact on the size of the accelerations related to tighter constraints

Validation of orbit quality



- 3D-position difference of orbits at midnight
- Differences compared to A0:
  - Use of accelerometer data, different background models (C0, D0)

=> No significant difference in the orbits

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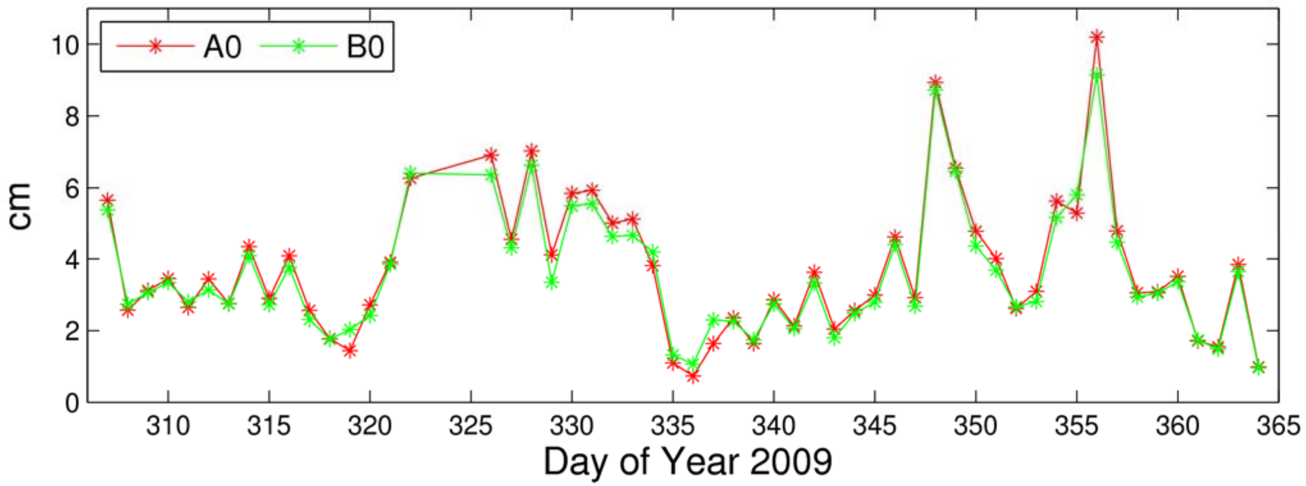

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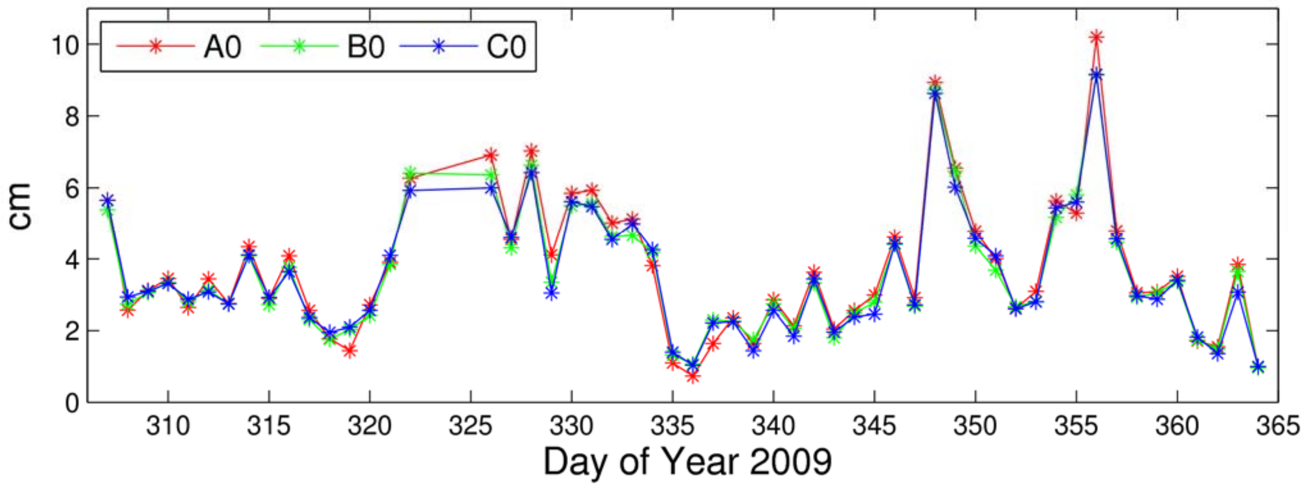

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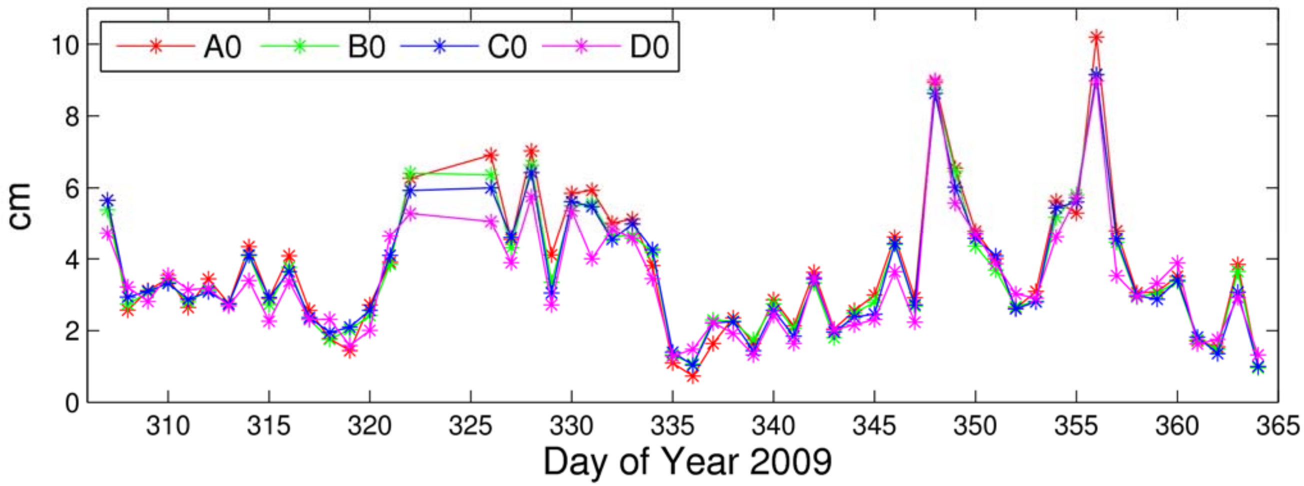

SLR validation

Mean (cm)	RMS (cm)
0.35	2.01
0.32	1.99
0.33	1.99
0.34	1.98

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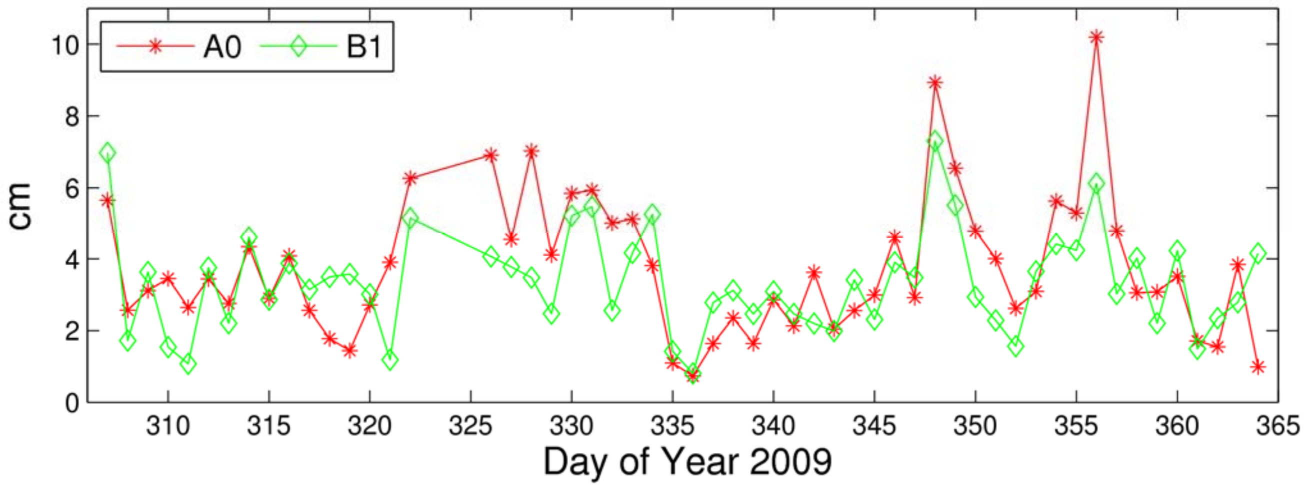
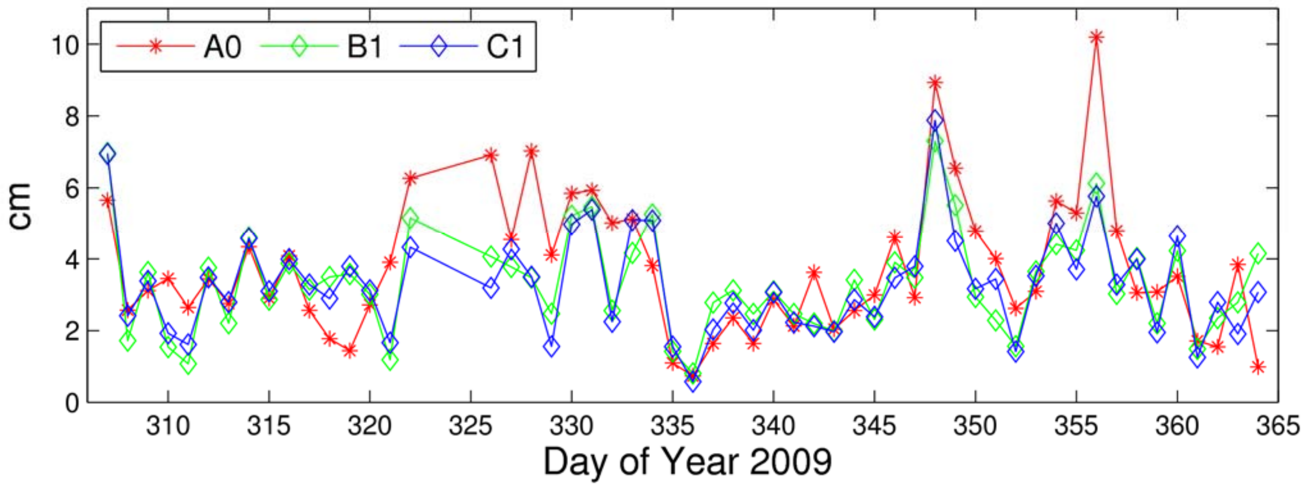


- Differences compared to A0:
  - Use of accelerometer data, different background models (C1, D1), tighter constraint for all components

=> Positive impact on orbit quality: The better the background models, the better the orbits.

Validation of orbit quality



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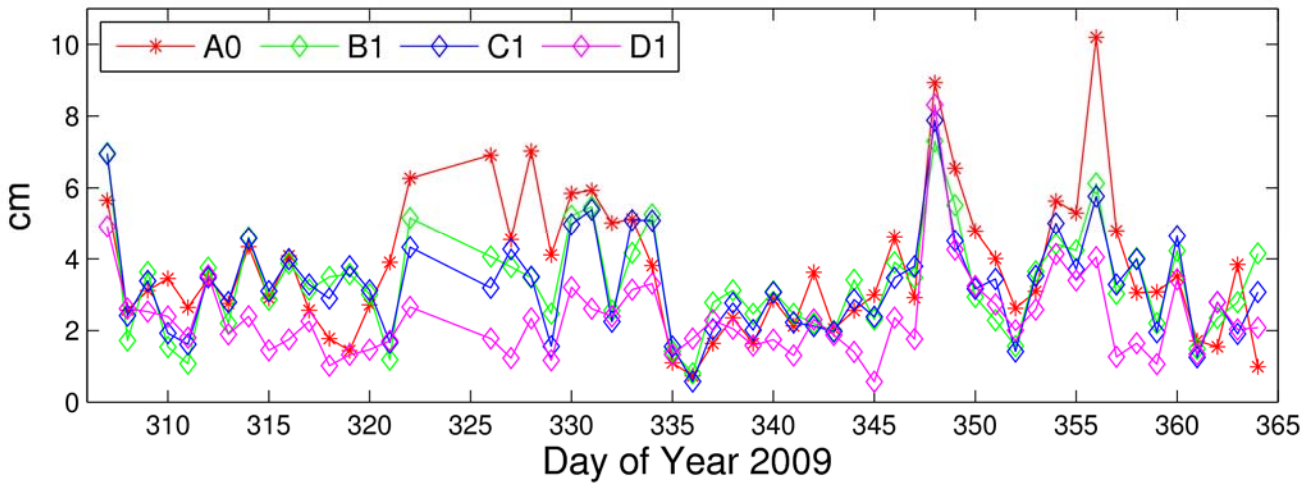

SLR validation

Mean (cm)	RMS (cm)
0.35	2.01
0.23	2.01
0.22	1.98
0.28	1.89

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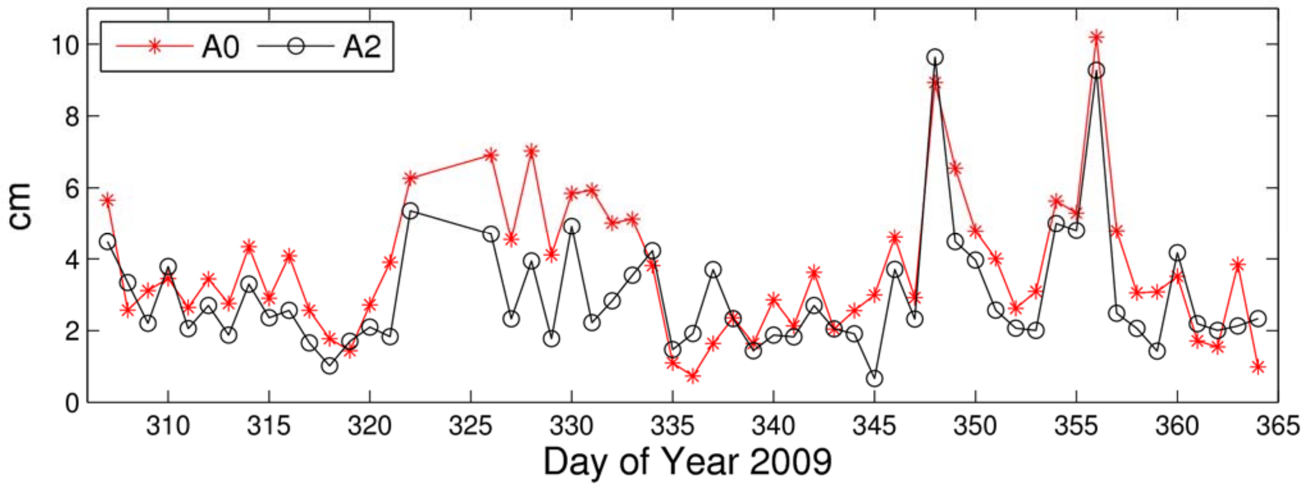
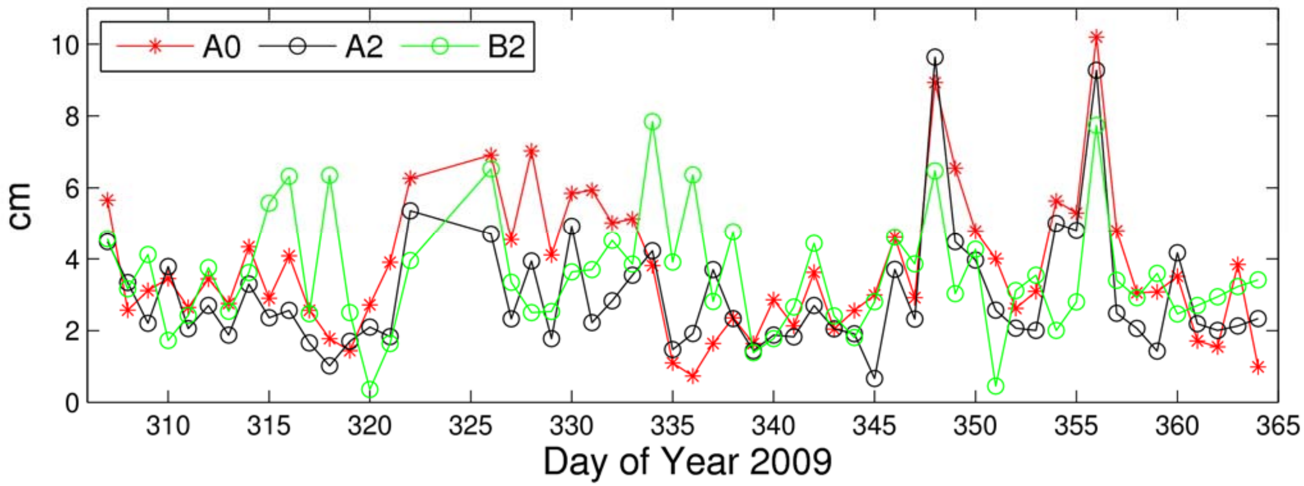


- Differences compared to A0:
  - A2: realistic constraints
  - B2.C2,D2: use of accelerometer data, different background models (C2, D2), 10% of realistic constraints

⇒Positive impact on orbit quality: The better the background models, the better the orbits.

⇒10% of constraints not sufficient for B2 and C2

Validation of orbit quality



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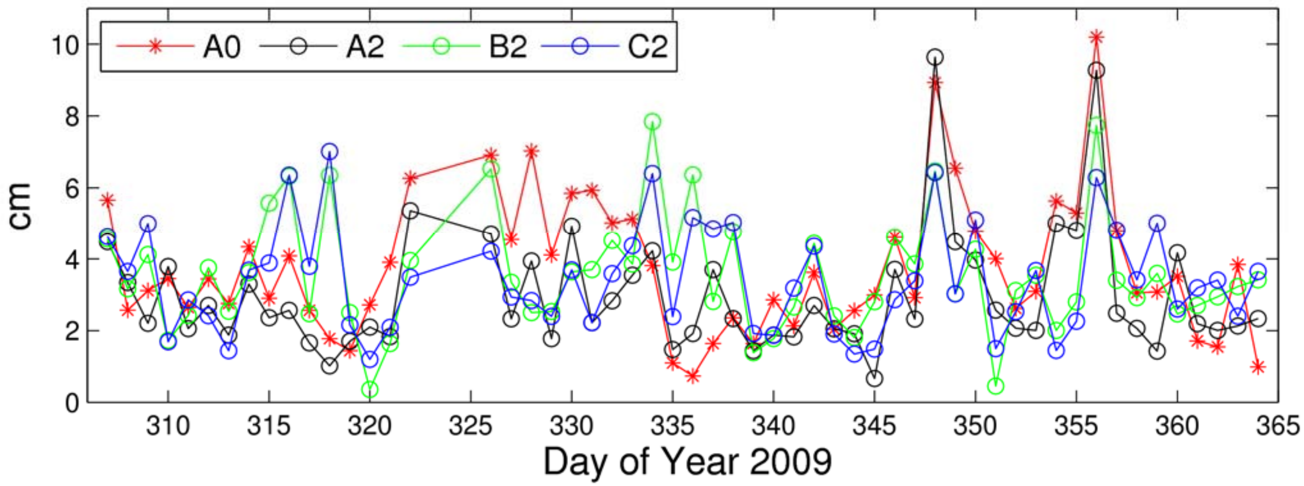

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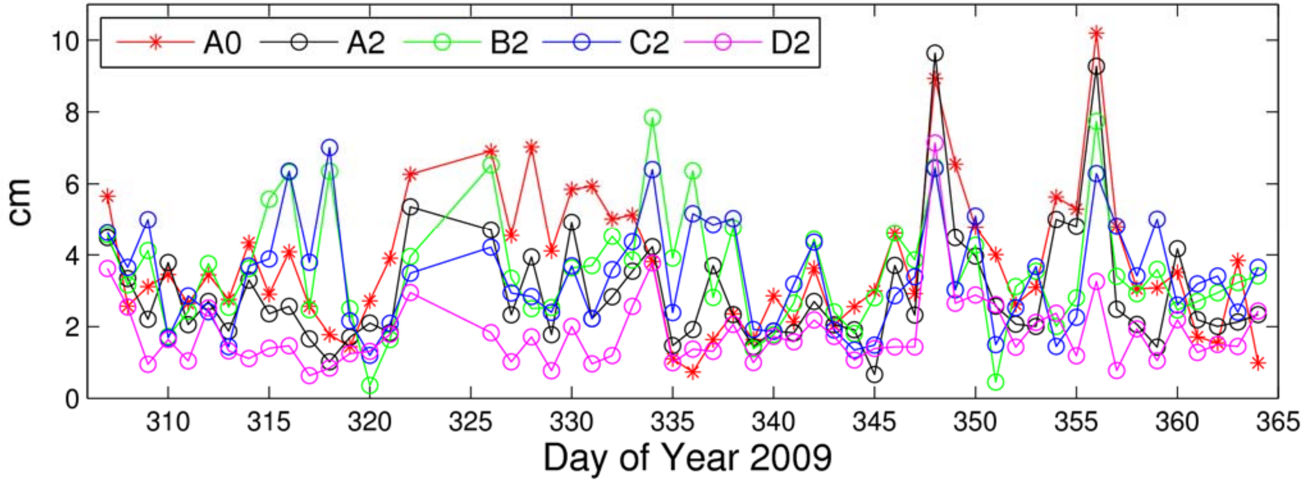

SLR validation

Mean (cm)	RMS (cm)
0.35	2.01
0.31	1.90
0.17	2.02
0.18	1.96
0.22	1.79

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Summary

- GOCE accelerometer data provide a measure for the non-gravitational forces acting on the satellite.
- The data may be used for orbit determination.
- The data are very clean. No outliers were seen.
- The data can improve current official orbit determination results, provided that background models are improved as well.
- Even orbit solutions without using the accelerometer data may be improved by realistic constraints derived from the accelerometers.

Outlook

- Further investigations on best selection of constraints and background models
- Check performance of accelerometer data in non drag-free periods
- Study scale of accelerometer data
- ...

Thank you for your attention!