GOCE orbit determination using accelerometer data

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Outline

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

- 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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- Common mode accelerometer data may also be used for orbit determination.
Motivation

- Official reduced–dynamic orbit solution is based on:
- Most important background models:
  - Gravity field: EIGEN-5S (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 $\sigma=2.0\times10^{-8}\ m/s^2$
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Motivation

- 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

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

- 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?

Different scaling !!!
 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
  \[ \sigma = 2.0 \times 10^{-8} \text{ m/s}^2 \]
- **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**: \( \sigma_R = \sigma_S = \sigma_W = 2.0 \times 10^{-8} \text{ m/s}^2 \)
- **1**: \( \sigma_R = \sigma_S = \sigma_W = 5.0 \times 10^{-9} \text{ m/s}^2 \)
- **2**: with acc \( \sigma_R = 2.0 \times 10^{-9} \text{ m/s}^2 \) w/o acc: \( 2.0 \times 10^{-8} \text{ m/s}^2 \)
  - with acc \( \sigma_S = 4.0 \times 10^{-10} \text{ m/s}^2 \) w/o acc: \( 4.0 \times 10^{-9} \text{ m/s}^2 \)
  - with acc \( \sigma_W = 7.0 \times 10^{-9} \text{ m/s}^2 \) w/o acc: \( 7.0 \times 10^{-8} \text{ m/s}^2 \)
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 $\Rightarrow$ stable for the 57 days

- Constraints, if accelerometer data are used
  - $10\%$ – assuming that background models are sufficient
Comparison of estimated accelerations

- 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

- 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

Different scaling !!!
Comparison of estimated accelerations

- 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

Different scaling !!!
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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<table>
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<th>Day of Year 2009</th>
<th>A0</th>
<th>B0</th>
<th>C0</th>
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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
Validation of orbit quality

- 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.
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<td>2.01</td>
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<td>0.23</td>
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<td>0.22</td>
<td>1.98</td>
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<td>0.28</td>
<td>1.89</td>
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</tbody>
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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

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10% of constraints not sufficient for B2 and C2
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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!