University of Bremen

EGU 2022 G5.1

Ionosphere, thermosphere and space weather: monitoring and modelling

Accelerometer calibration for thermospheric neutral density estimation with GRACE data by dynamic Precise Orbit Determination (POD) with tailored parametrization.

Florian Wöske, Benny Rievers

Vienna, 23. May 2022

CENTER OF
APPLIED SPACE TECHNOLOGY
AND MICROGRAVITY
ZARM

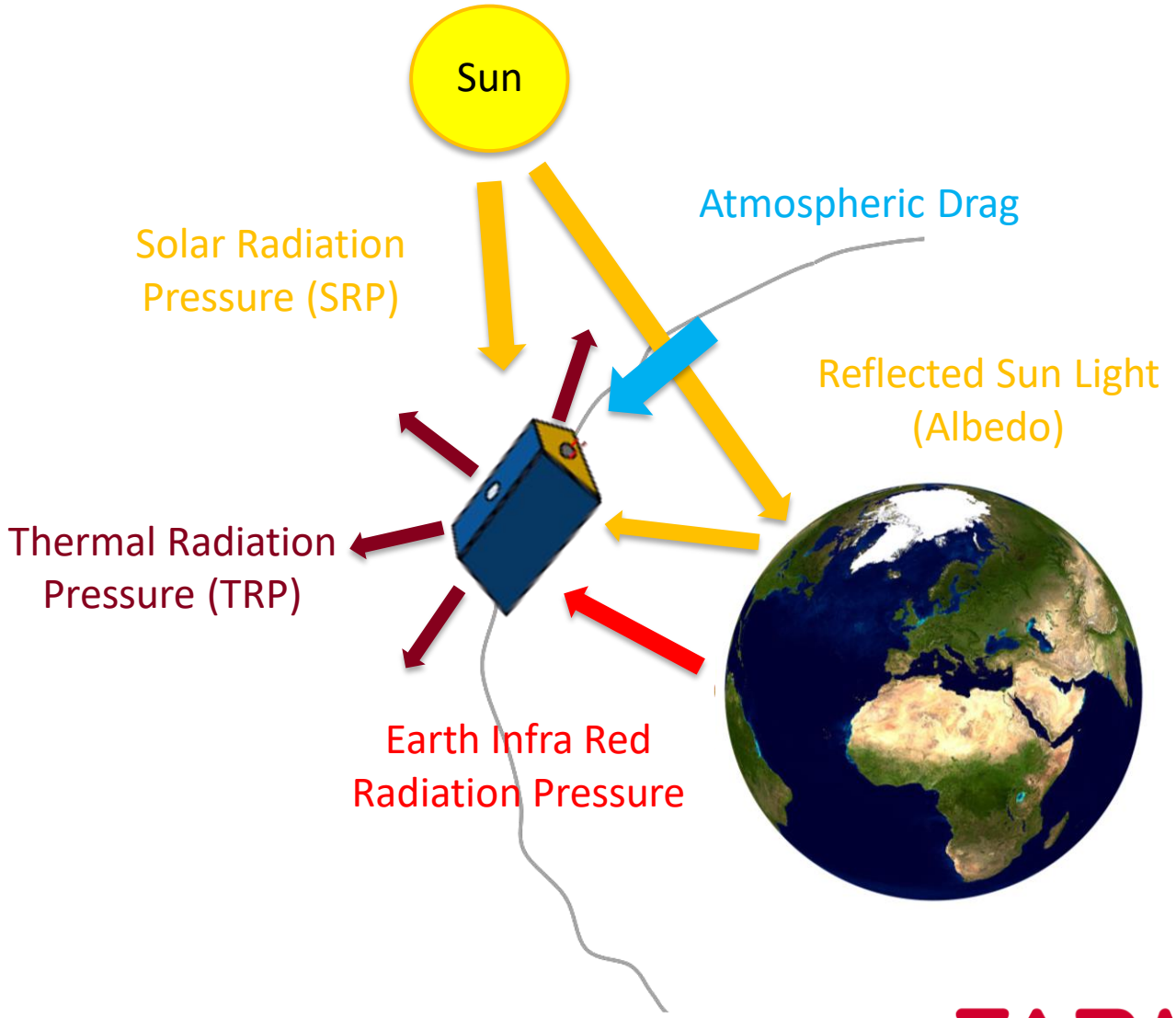
Density Estimation from Accelerometer Measurements

Overview

Idea:

- Accelerometer (ACC) measures sum of all non-gravitational accelerations acting on satellite
- Precise modelling of all radiative accelerations
- $\vec{a}_{drag} = ACC_{meas} - \vec{a}_{sim,rad}$
- Then the atmospheric density follows:
- $\rho = \frac{2\,|\vec{a}_{drag}|\,m_{sat}}{C_D\,A_{proj}\,|\vec{v}_{inc}|^2}$

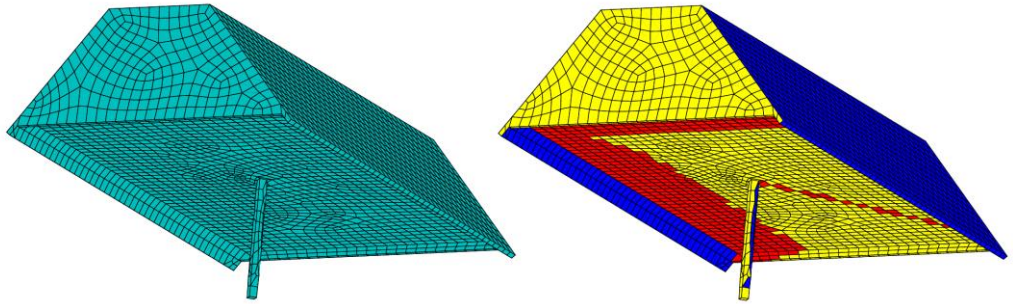
- → Radiative forces can be modeled much more accurate than the density

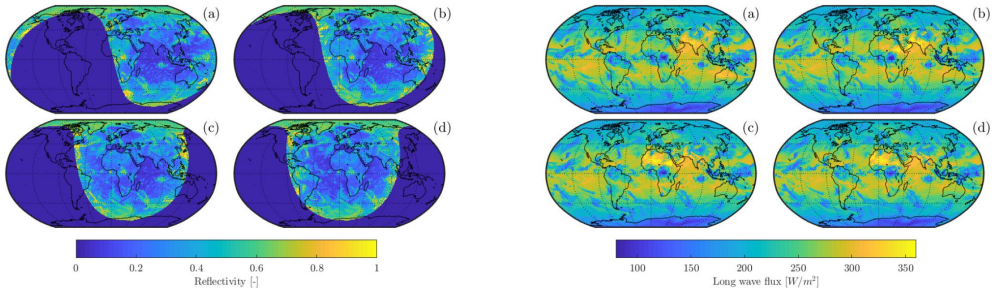


Non-Gravitational Force Modeling

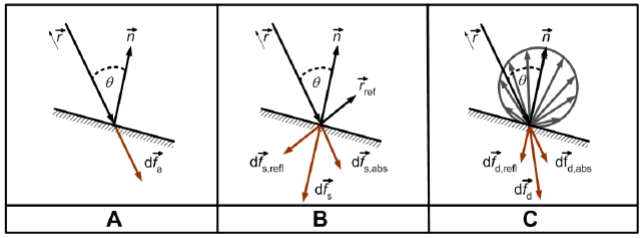
Comprehensive Overview

- Computation of each force with FE Model, including shadowing
- Hourly CERES data for Earth‘s reflectivity and infra red radiation on 360°*180° grid
- Well known geometric conditions, attitude of satellite, and intensity of the Sun
- Optical parameters of satellite surfaces known relatively well from ground testing

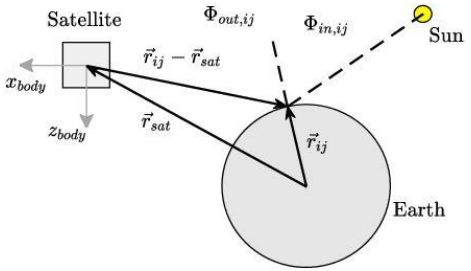


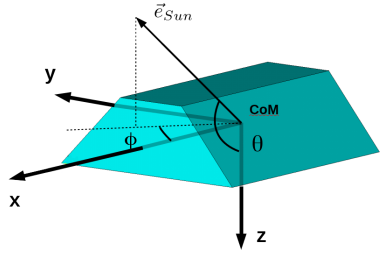


Treatment of optical properties:



A: Absorption, B: Spec. Reflection, C: Diff. Reflection

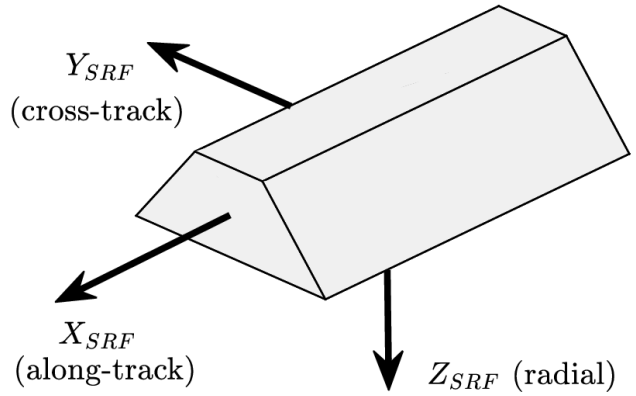


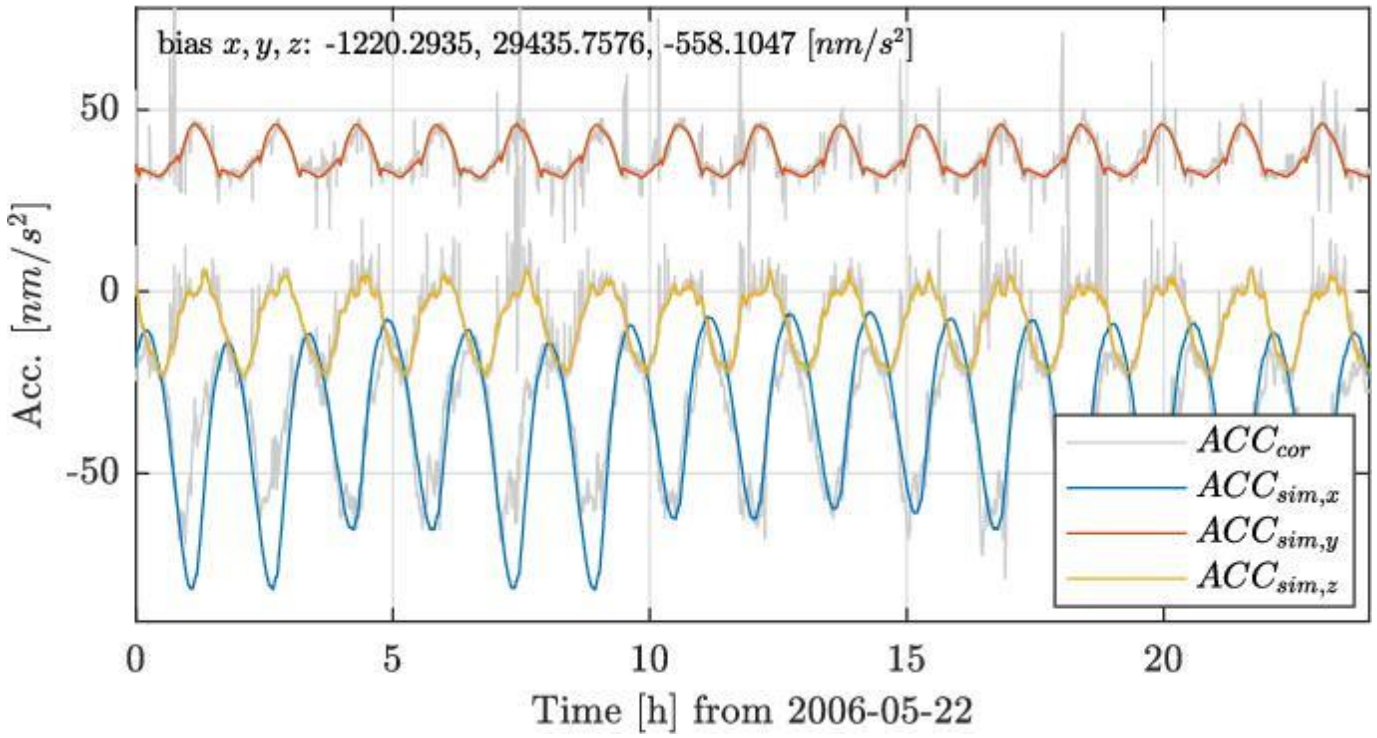


Non-Gravitational Force Modeling

Comparison with GRACE ACC Data

- X_{SRF} axis closely aligned with orbital velocity direction
- → Y- and z-axis barely contain any drag acceleration





Simulated non-grav. accelerations and calibrated ACC data (daily bias for each axis), GRACE A. All spikes refer to attitude thruster firings

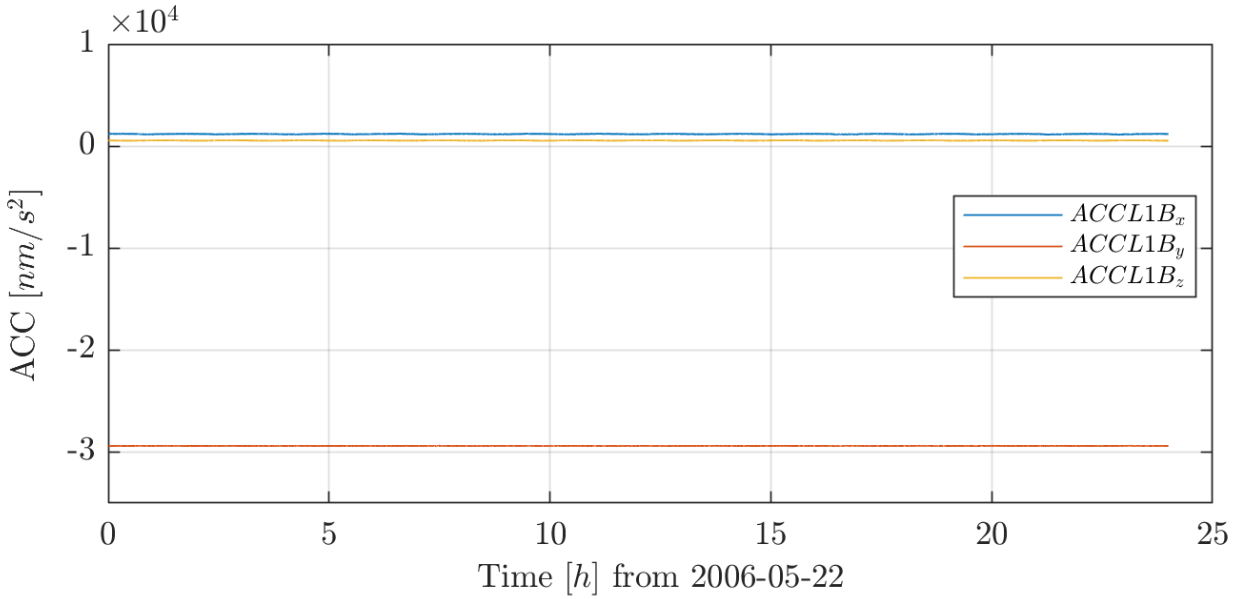
Accelerometer Data Need to Be Calibrated

Overview

But:

- Calibration of Accelerometer data necessary
- $\vec{a}_{ng} = \vec{s} * ACC_{meas} + \vec{b} + \vec{d} * t$
- $\Leftrightarrow \vec{a}_{ng} = \vec{s} * \left(ACC_{meas} + \vec{b}./\vec{s} + \vec{d} * t./\vec{s}\right)$

- In case the satellite would **not** rotate with orbital frequency, calibration and density could be estimated iteratively from solely simulated data
- → A bias can not be distinguished from an offset of the acceleration
- Calibration from different source
  - Precise Orbit Determination (POD)
  - Gravity Field Recovery (GFR)



Raw accelerometer data ACC L1B, GRACE A

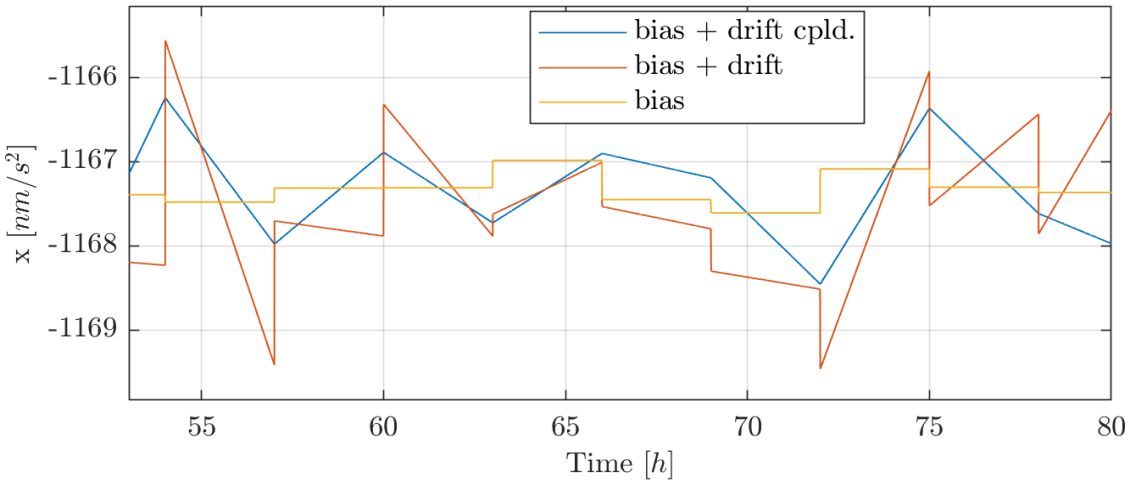
Accelerometer Data Need to Be Calibrated

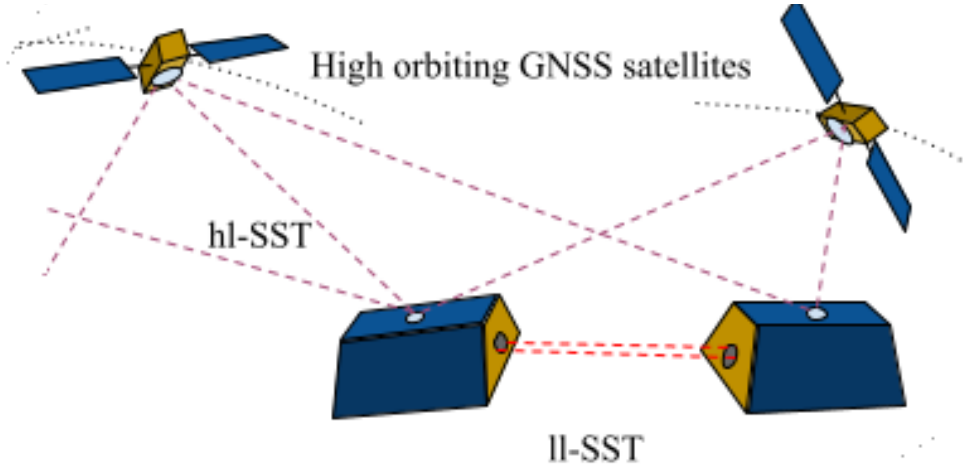
Calibration by dynamic POD or GFR

But:

- Calibration of Accelerometer data necessary
- $\vec{a}_{ng} = \vec{s} * ACC_{meas} + \vec{b} + \vec{d} * t$
- $\Leftrightarrow \vec{a}_{ng} = \vec{s} * \left(ACC_{meas} + \vec{b}./\vec{s} + \vec{d} * t./\vec{s}\right)$

- Parametrization with POD and GFR
  - Which parameter
  - Global and local parameters
  - Arc length for glob. and loc. parameters
  - Couple parameters between arcs
- Observation data
  - GNSS position data (GNV L1B or KOS - Kinematic Orbit Solution from TU Graz)
  - ll-Satellite-to-Satellite Tracking (KBR L1B)





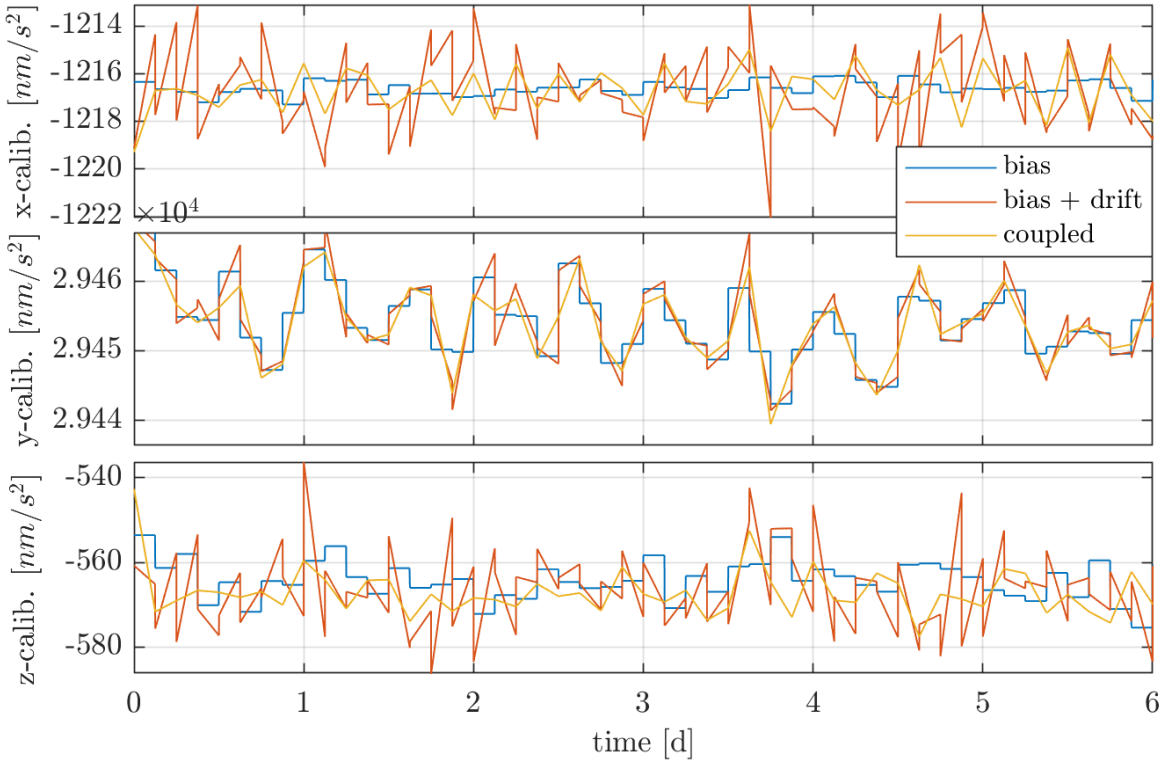
Results: Estimated Bias and Drift

Different Parametrizations

- Local arc length of 3h
- Resulting calibrations follow same trend
- Bias + drift higher variability

  → just bias parametrization
- Accelerations in along-track axis (x) have strongest influence on orbit

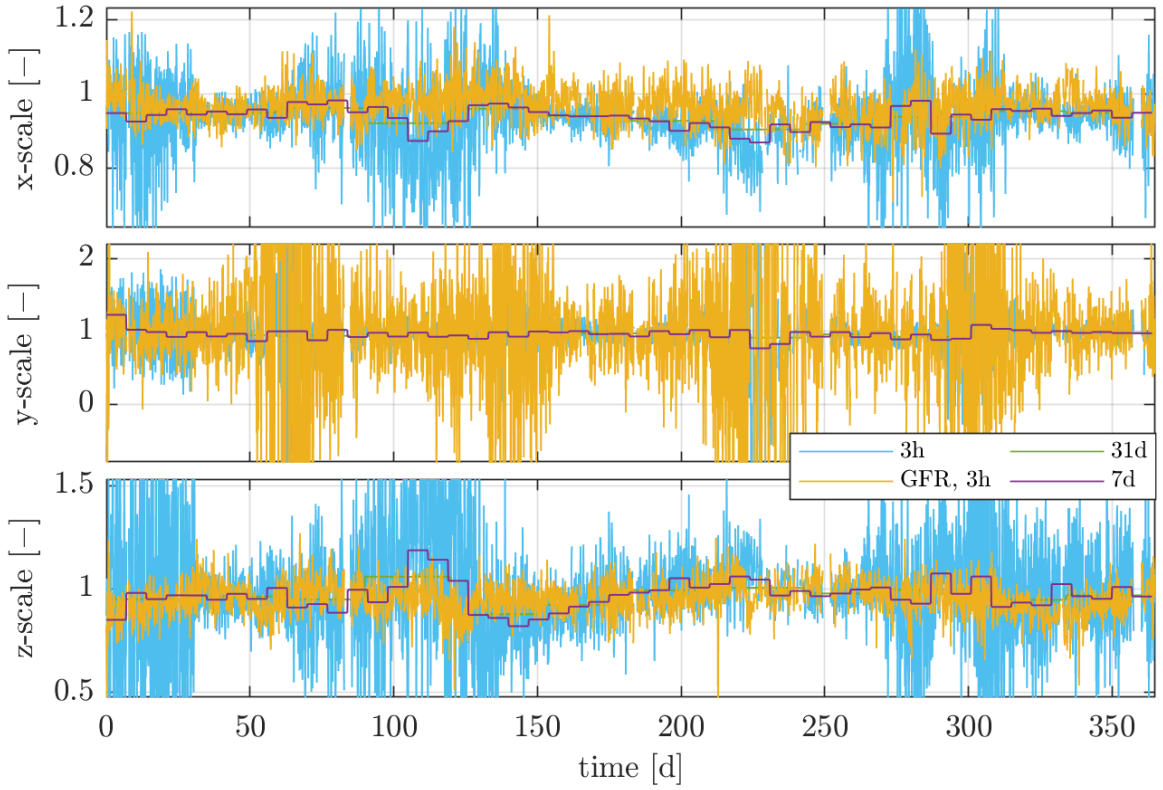
  → Parameter can be determined more accurately



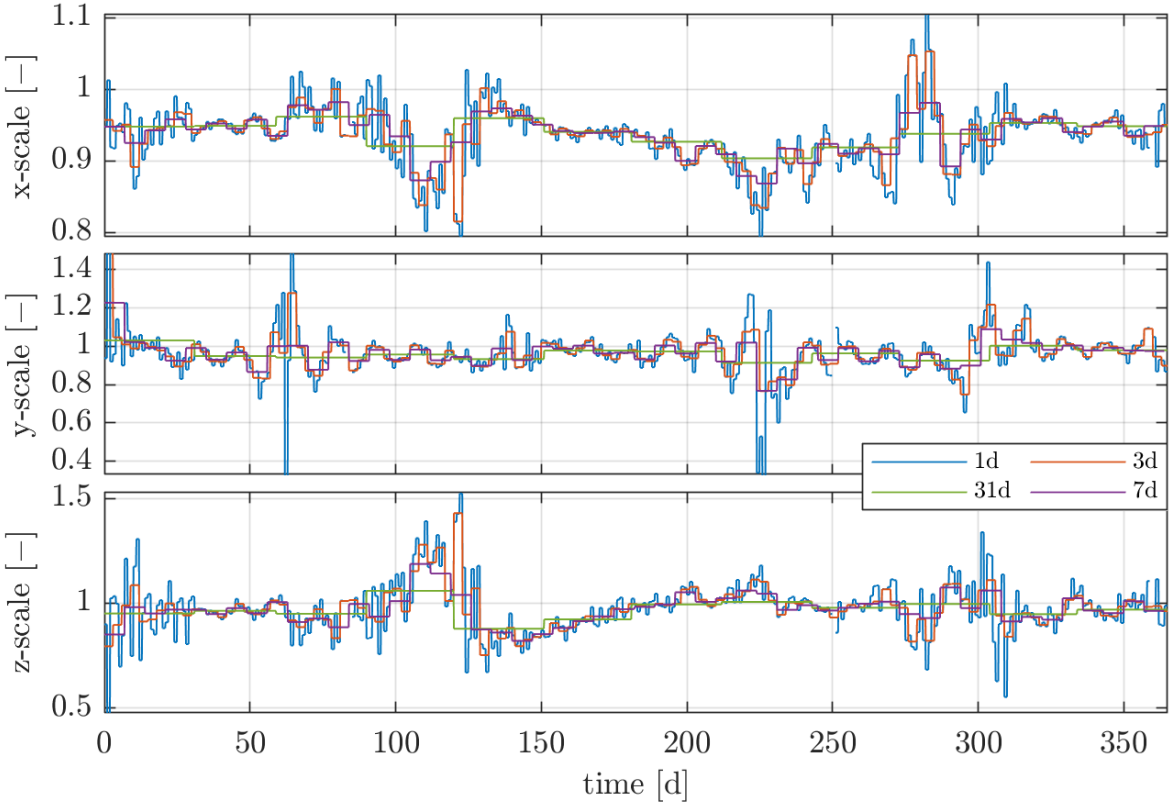
Exampel of calibration with bias, bias+drift and coupled bias+drift estimation

Results: Estimated Scale Factors

Different Parametrizations



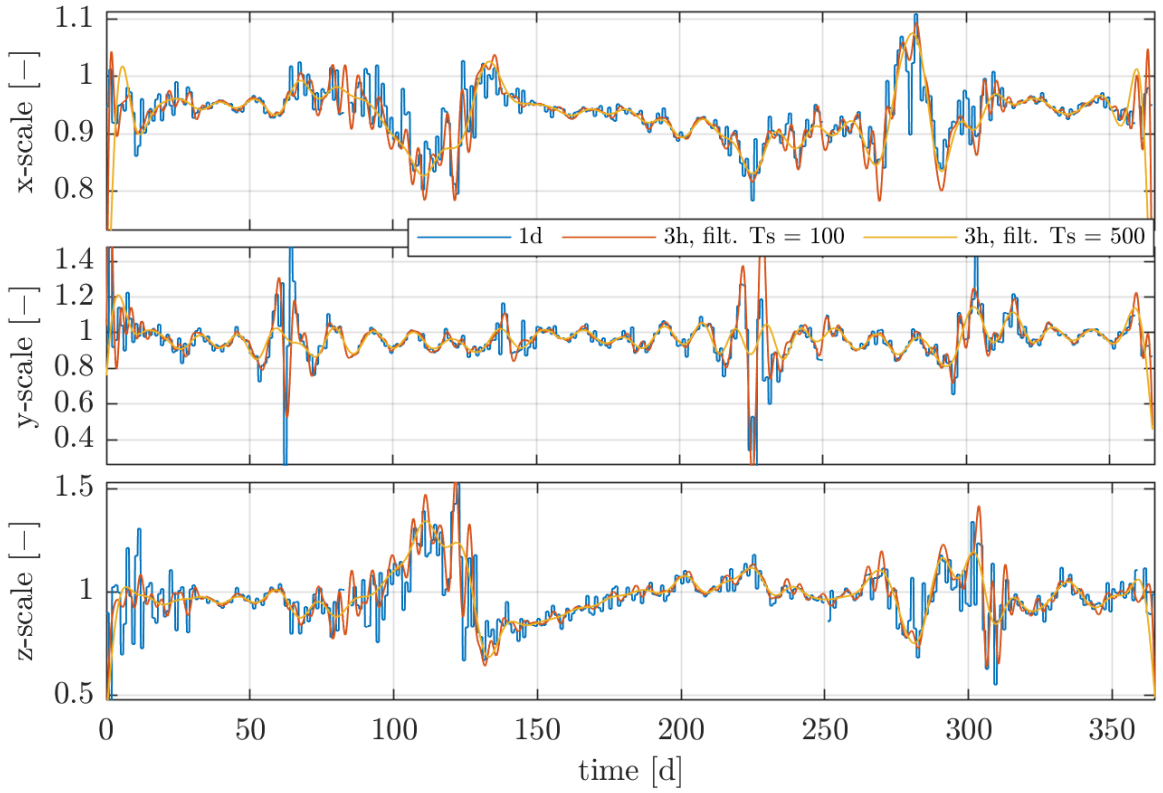
Local (3h arcs) estimated scale from POD and GFR, 2006, GRACE A



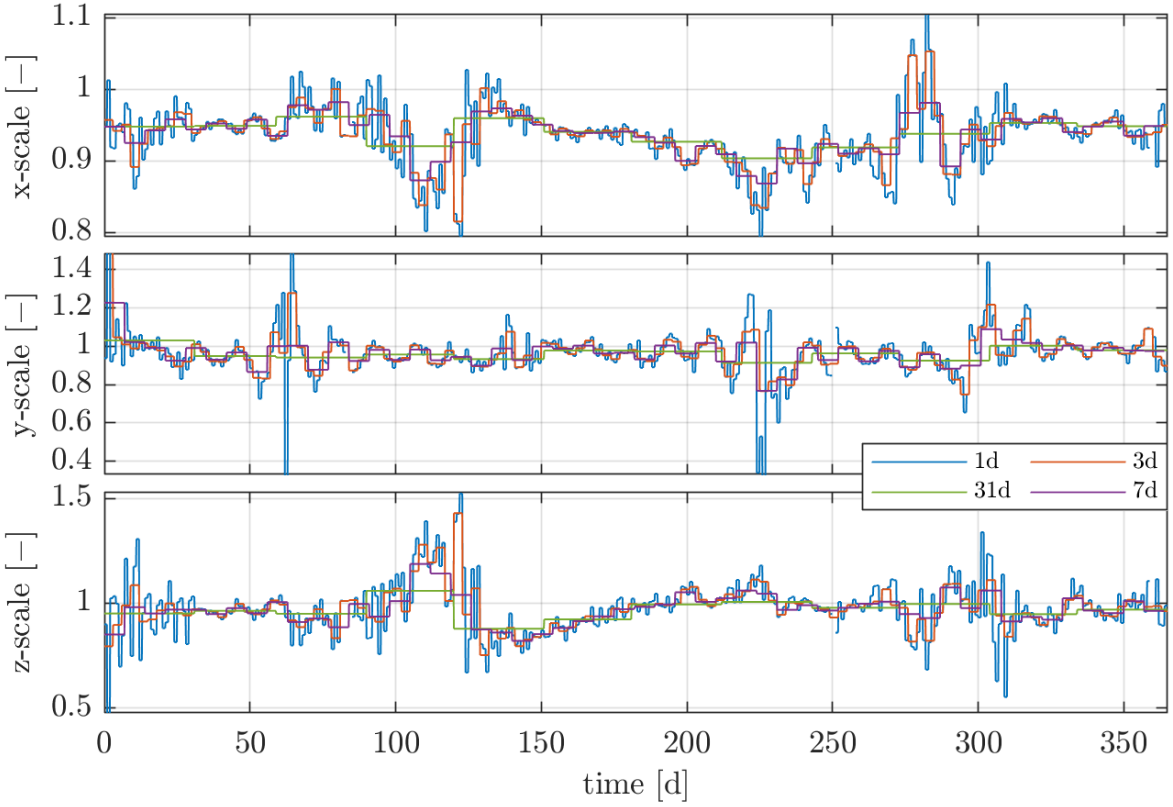
Global estimated scale with arc length of 1, 3, 7, 31 days 2006, GRACE A

Results: Estimated Scale Factors

Different Parametrizations



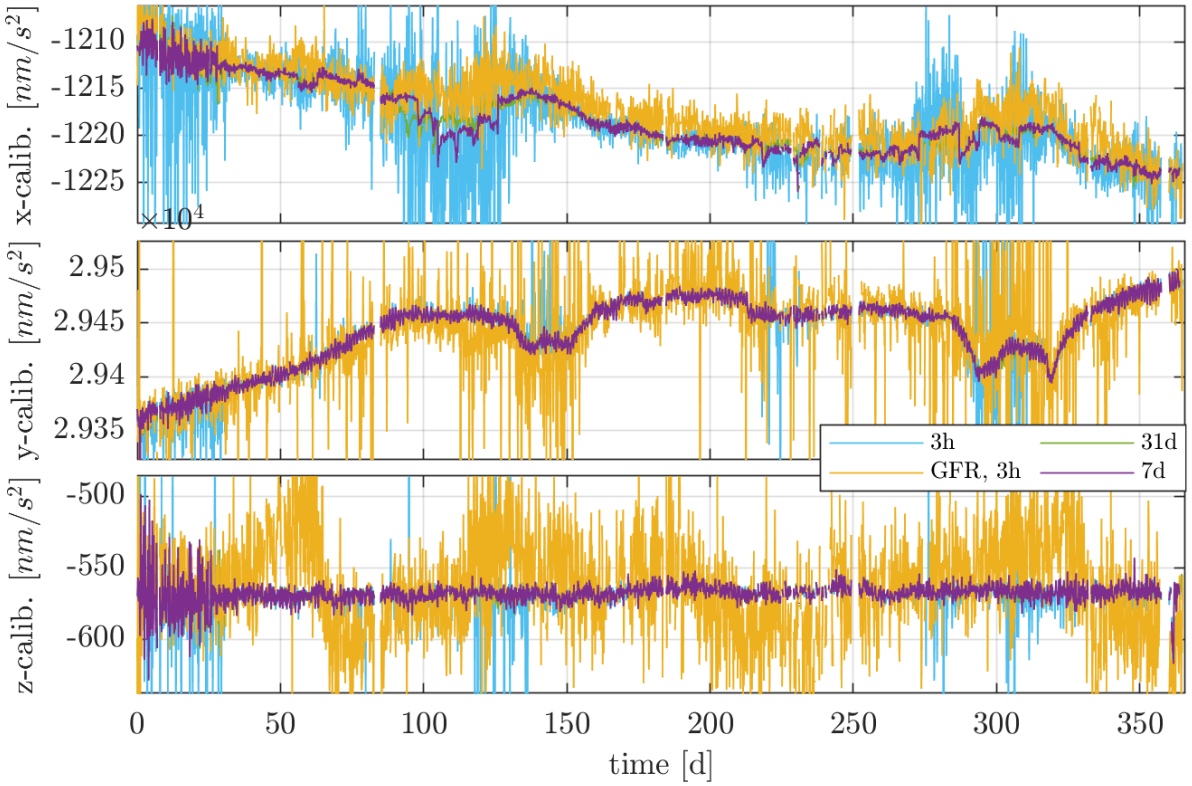
Local (3h arcs) estimated scale from POD and GFR, 2006, GRACE A



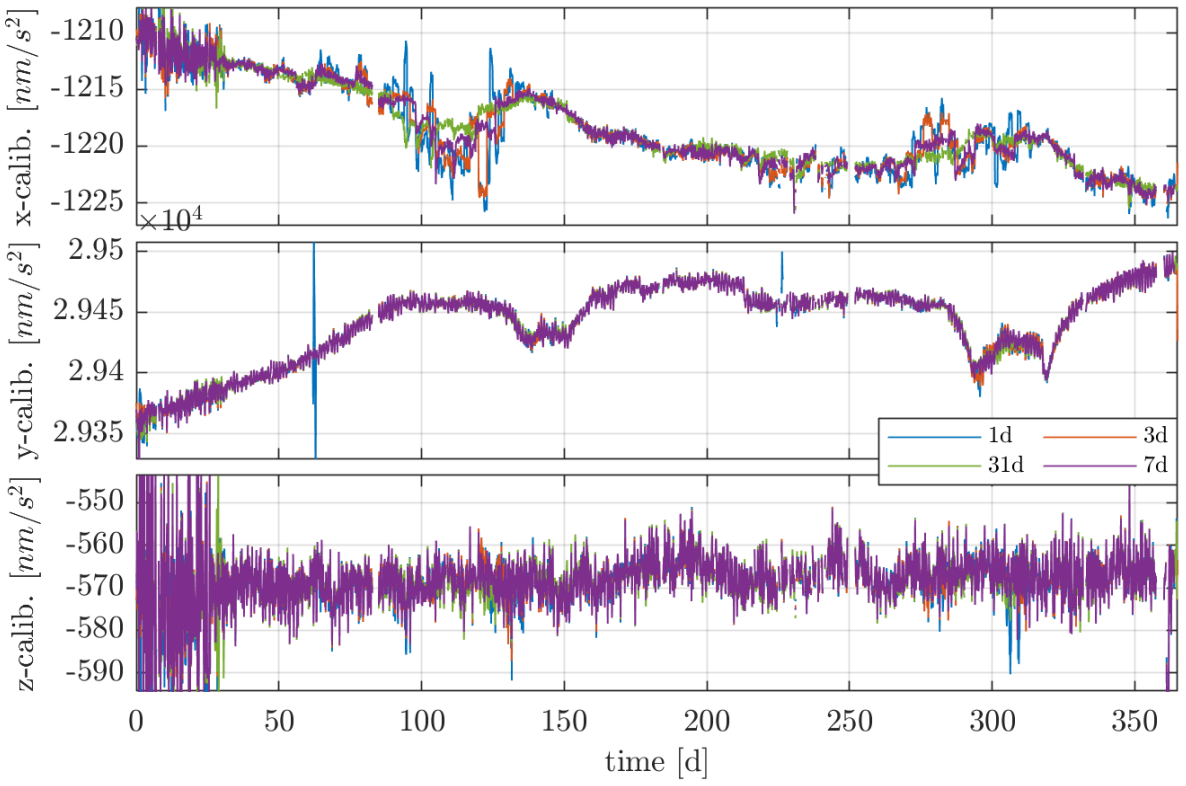
Global estimated scale with arc length of 1, 3, 7, 31 days 2006, GRACE A

Results: Estimated Bias

Different Parametrizations



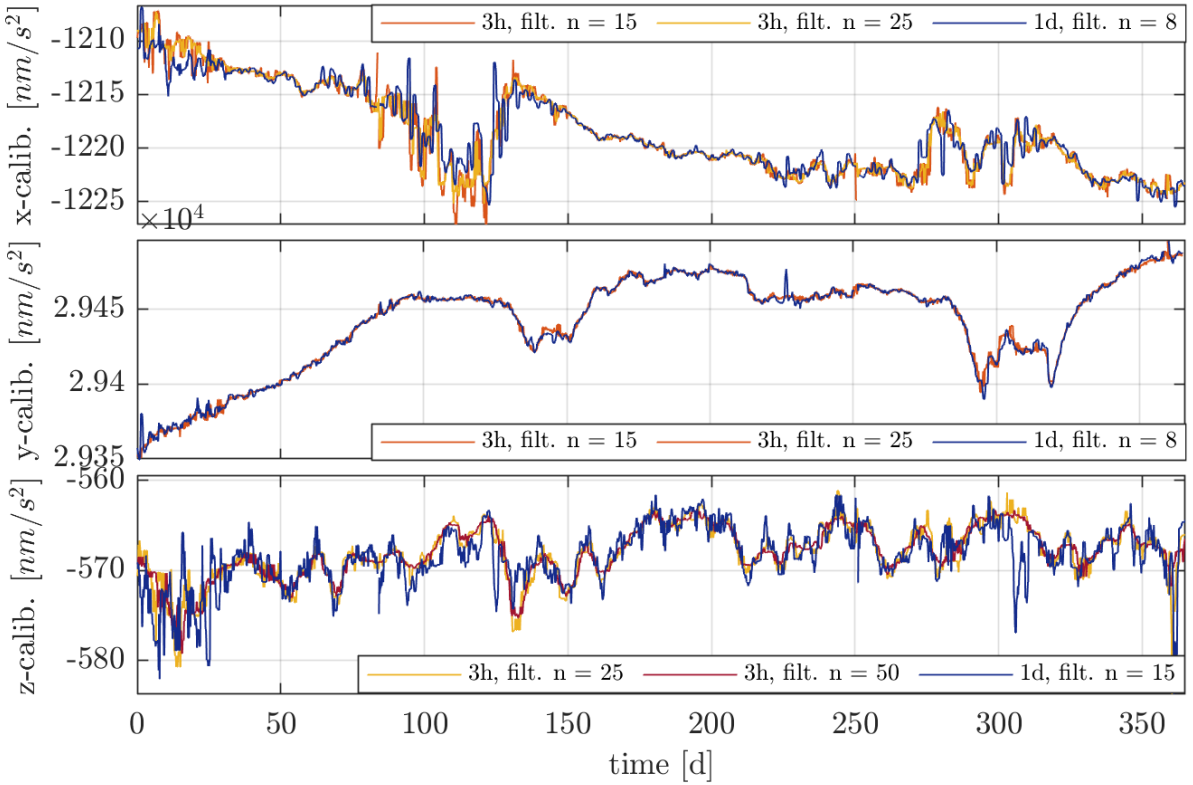
Estimated bias with local (3h) scale parametrization from POD and GFR, for comparison 7d glob., 2006, GRACE A



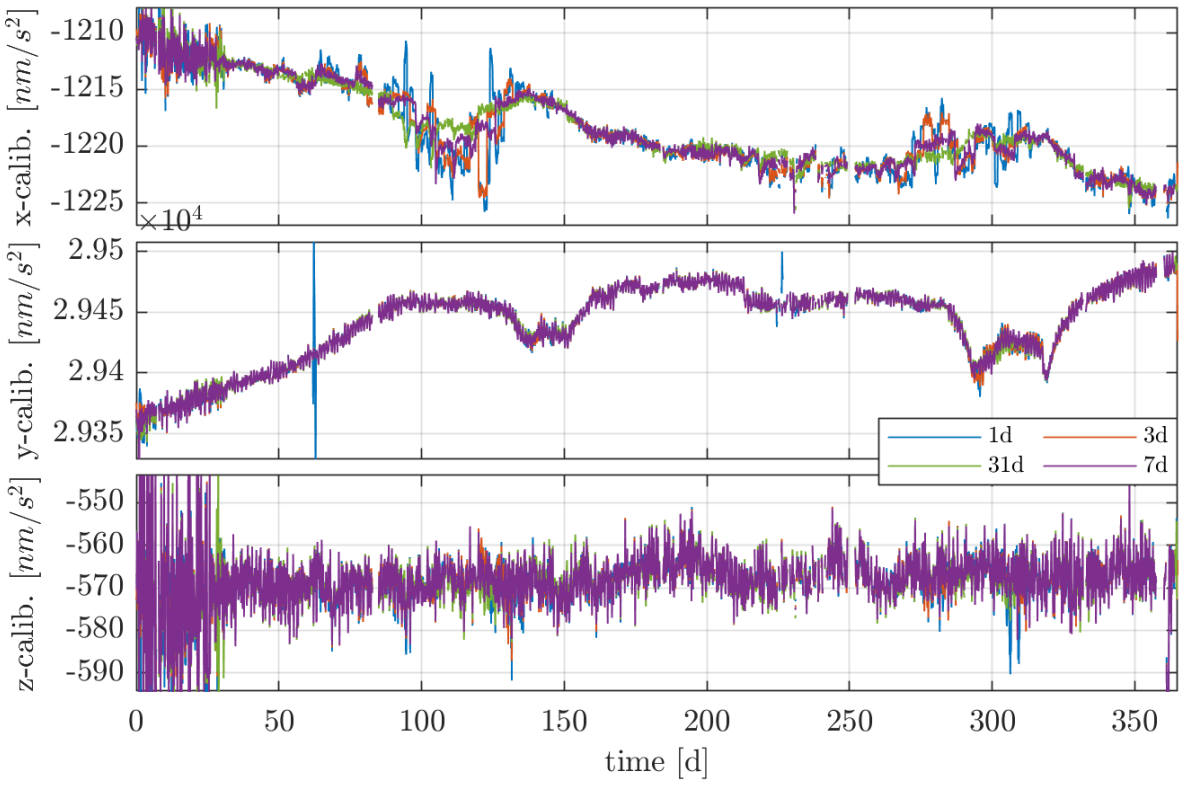
Estimated bias with global scale parametrization from POD with arc length of 1, 3, 7, 31 days 2006, GRACE A

Results: Estimated Bias

Different Parametrizations



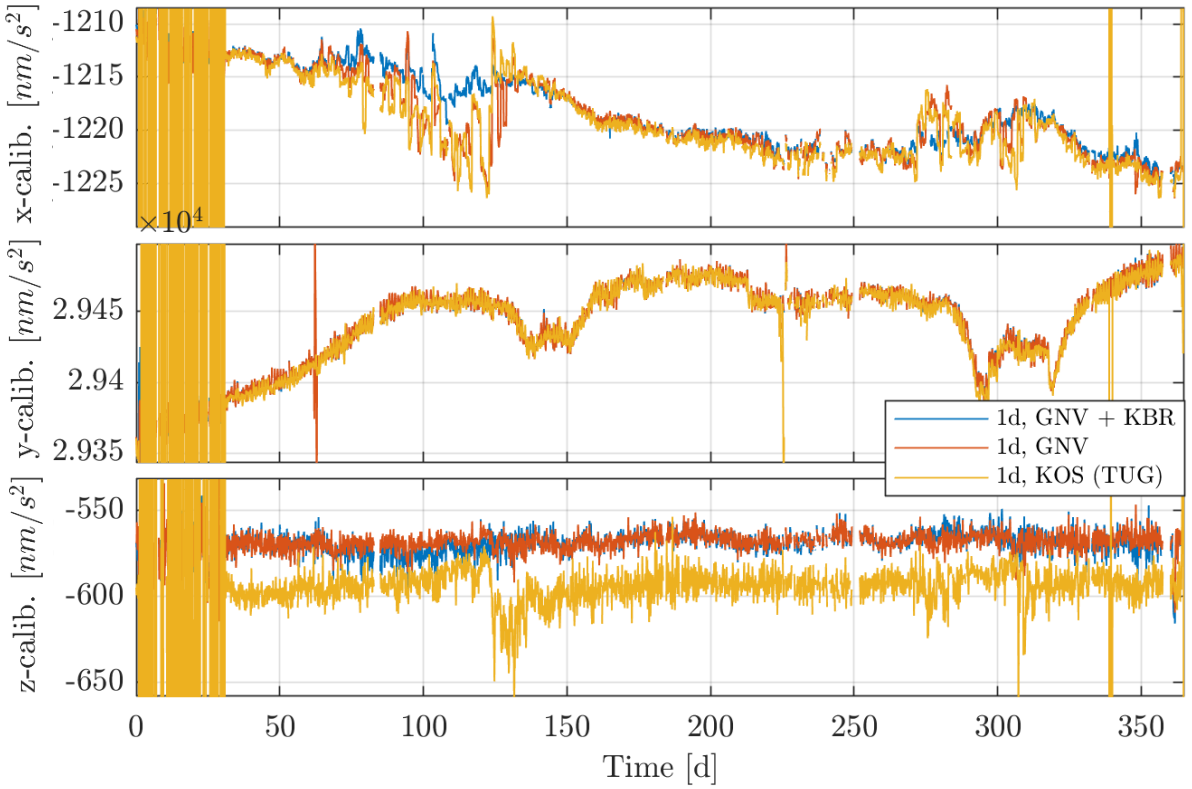
Median filtered bias (red, yellow) from POD with loc. scale parametrization, and global scale with 1d for comparison, 2006, GRACE A



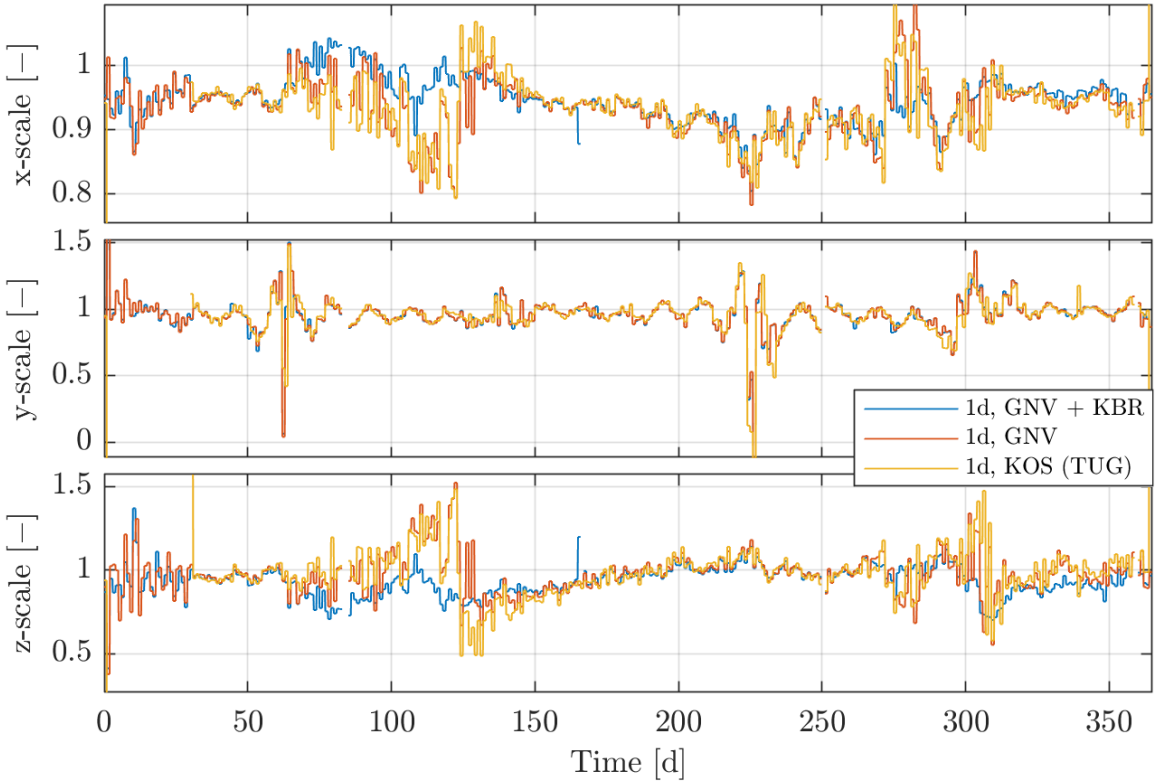
Estimated bias with global scale parametrization from POD with arc length of 1, 3, 7, 31 days 2006, GRACE A

Results: Estimated Bias and Scale

Different Observations



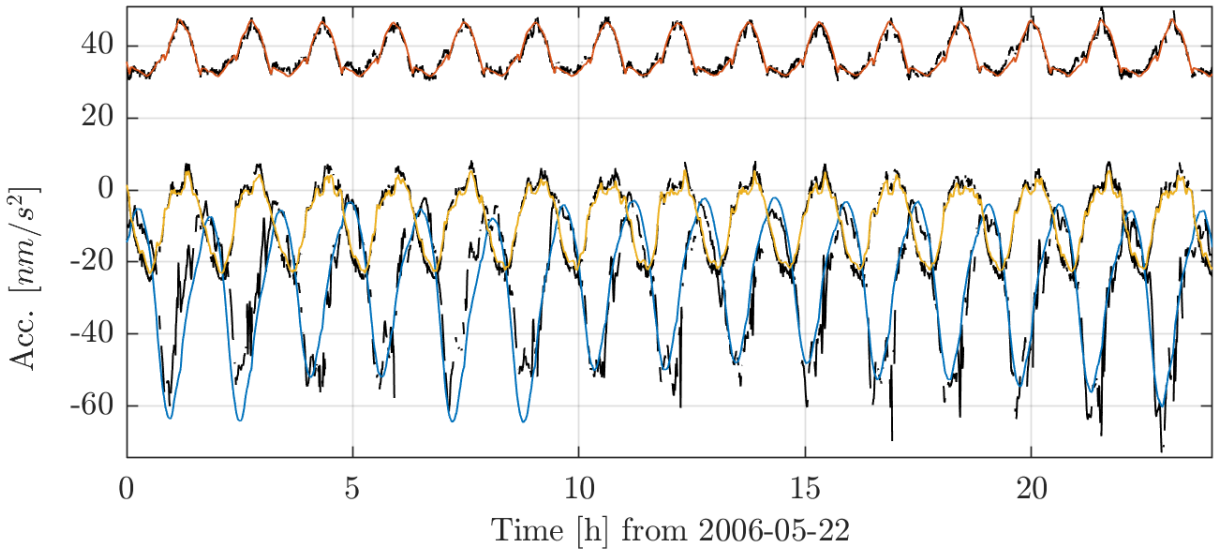
Estimated bias with global scale scale parametrization (1d), using GNV + KBR, GNV and KOS (from TU Graz) observations in POD, 2006, GRACE A



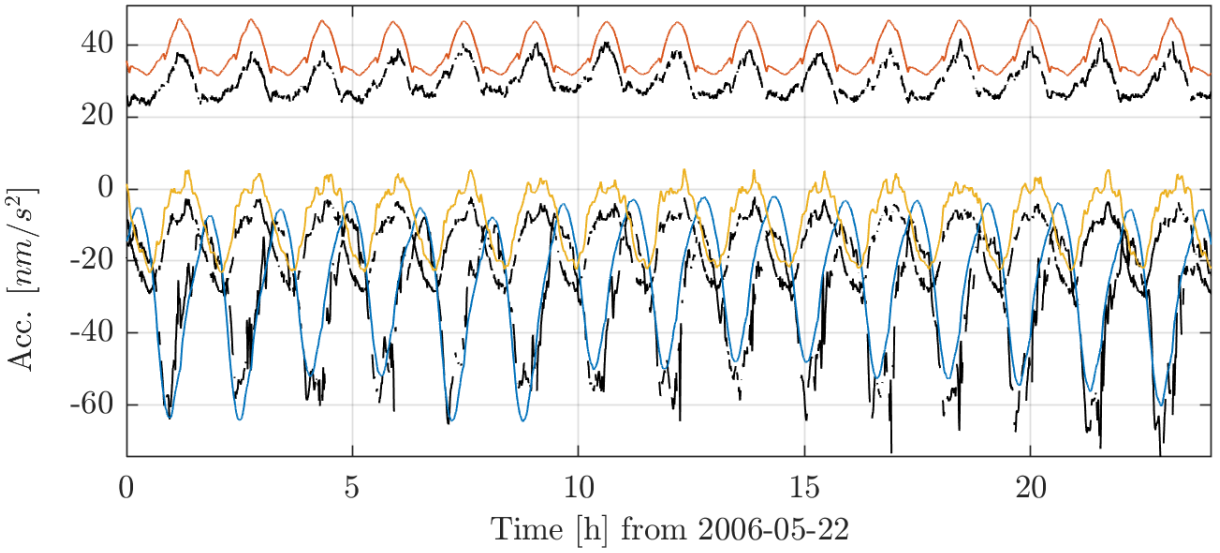
Estimated global scale (1d), using GNV + KBR, GNV and KOS (from TU Graz) observations in POD, 2006, GRACE A

How to Validate the Different Results

Comparison with the Simulated Data



As reference: ACC calibration with simulated data, daily bias.
RMS residuals in x, y, z: 7.05, 1.12, 1.62 nm/s^2

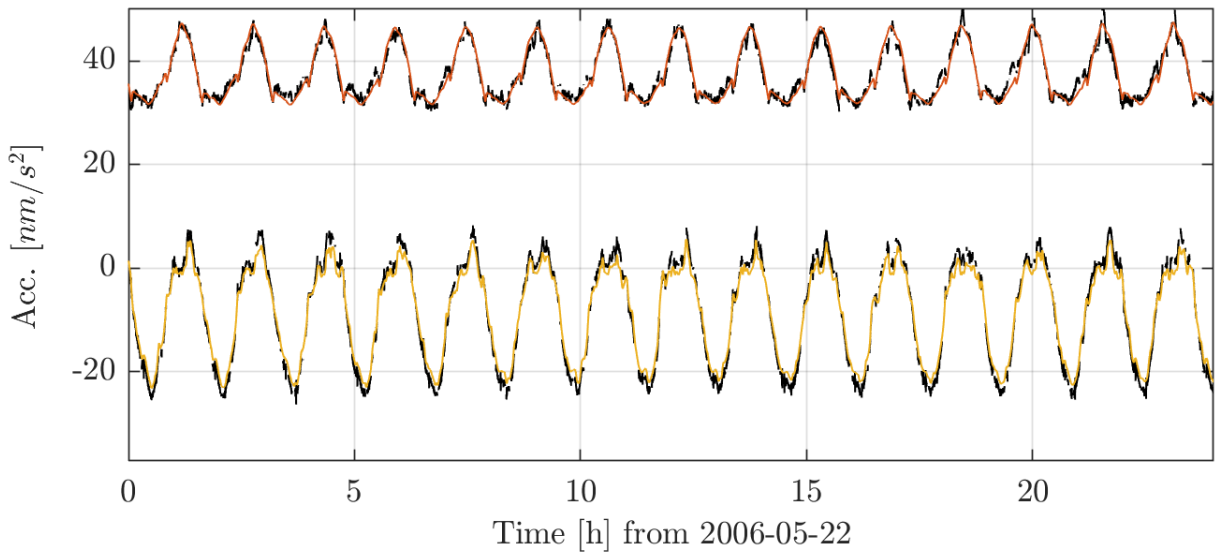


Using POD calibration: Global scale (1d), bias filtered.
RMS residuals in x, y, z: 8.63, 7.51, 7.23 nm/s^2

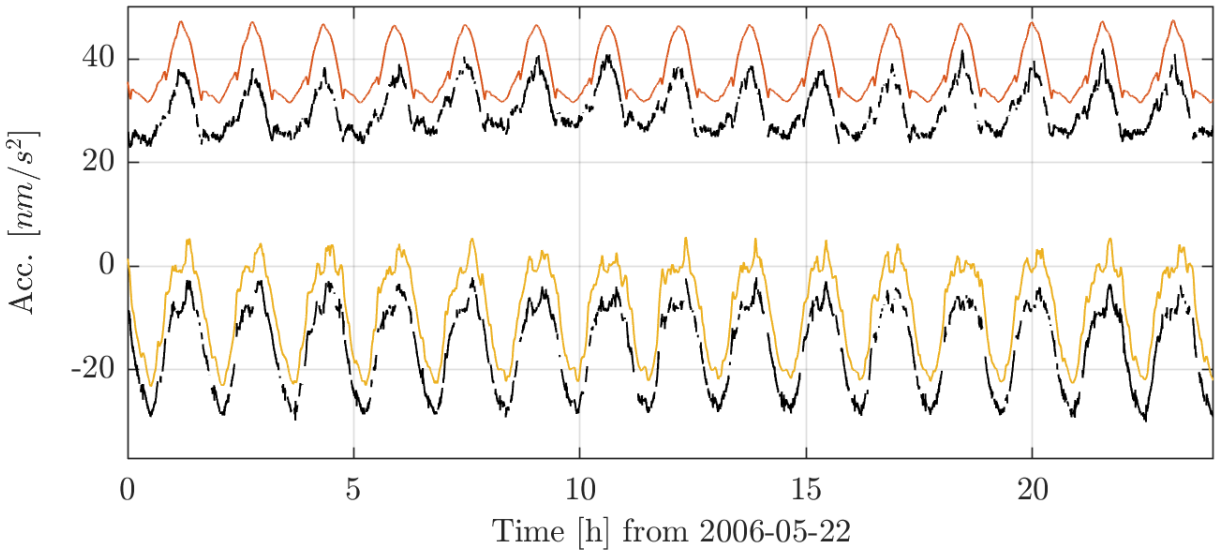
- X-axis not so interesting for comparison, because big uncertainties in modelling
- Not realistic that simulated data have ≈25% error
- Not possible to draw a conclusion from Y-, Z-axis bias calibration to X-axis
- -> But assess time variability of scale factor

How to Validate the Different Results

Comparison with the Simulated Data



As reference: ACC calibration with simulated data, daily bias.
RMS residuals in x, y, z: 7.05, 1.12, 1.62 nm/s^2

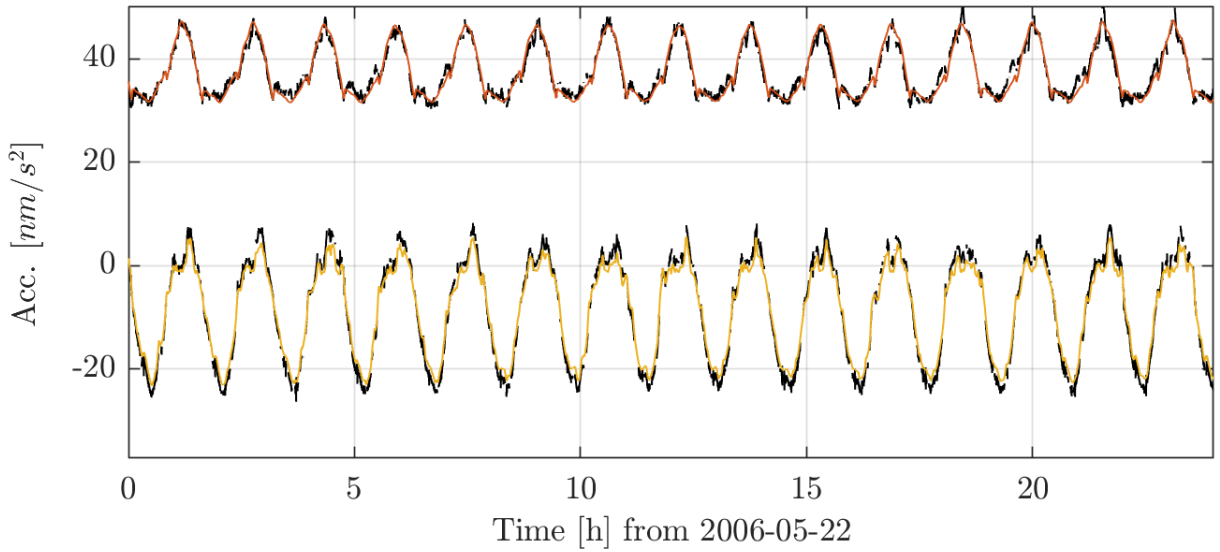


Using POD calibration: Global scale (1d), bias filtered.
RMS residuals in x, y, z: 8.63, 7.51, 7.23 nm/s^2

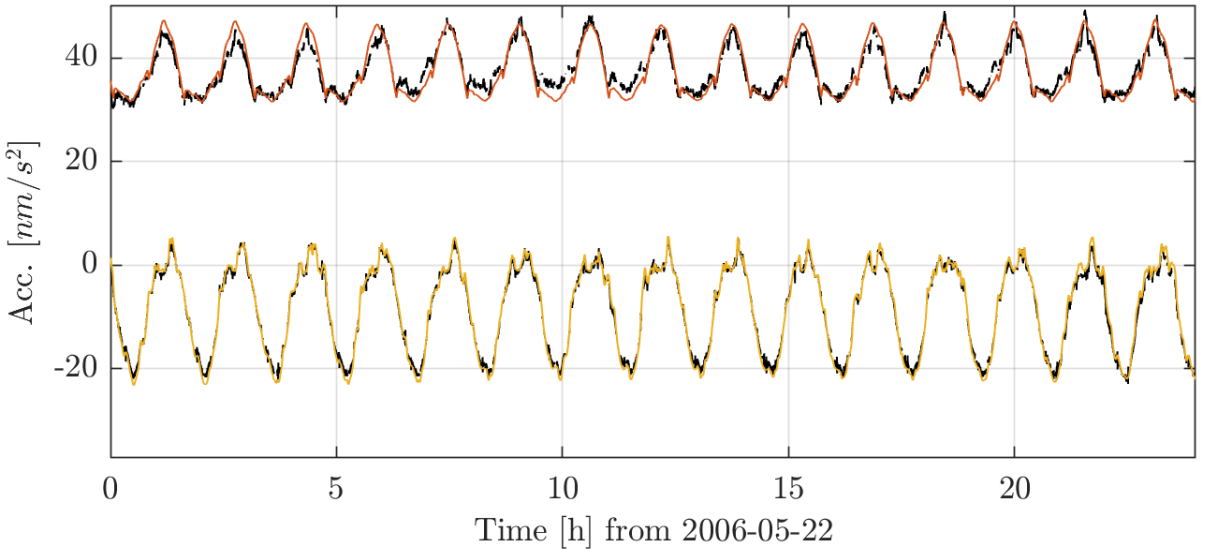
- X-axis not so interesting for comparison, because big uncertainties in modelling
- Not realistic that simulated data have ≈25% error
- Not possible to draw a conclusion from Y-, Z-axis bias calibration to X-axis
- -> But assess time variability of scale factor

How to Validate the Different Results

Comparison with the Simulated Data



As reference: ACC calibration with simulated data, daily bias.
RMS residuals in x, y, z: 7.05, 1.12, 1.62 nm/s^2

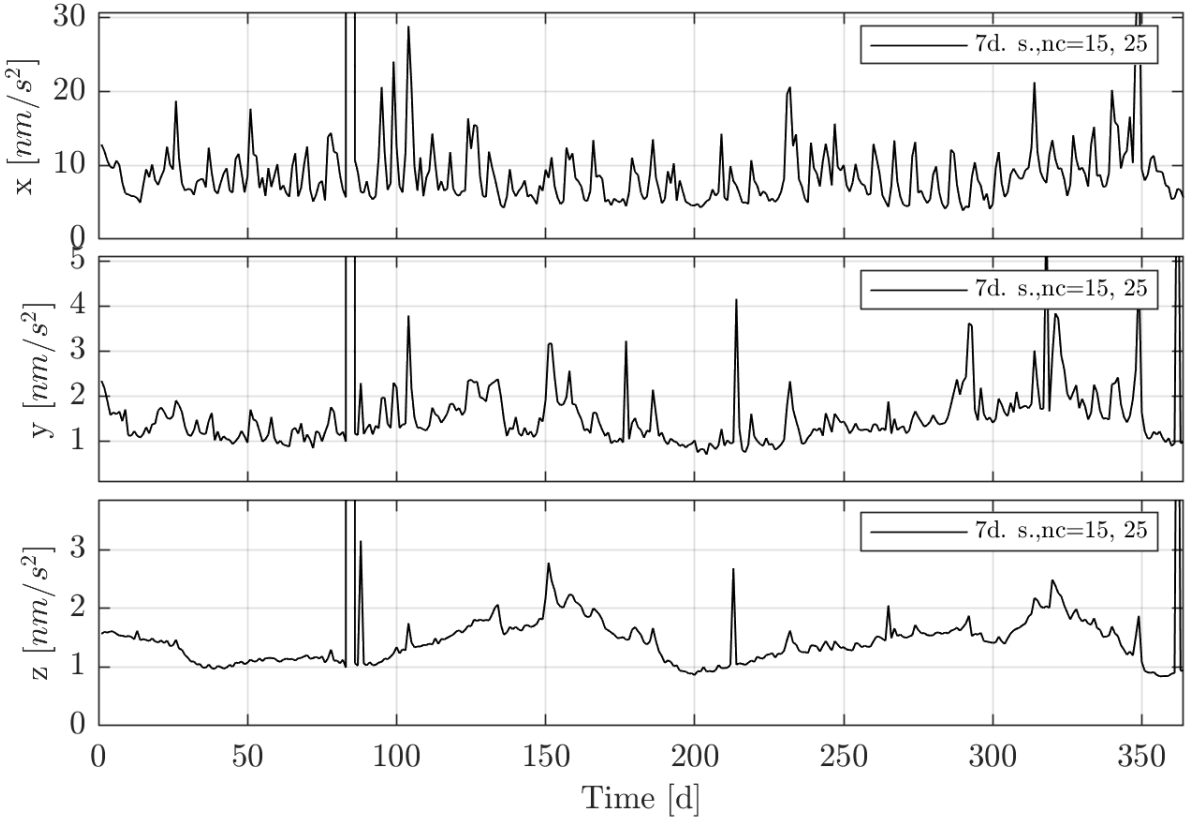


Calibrated ACC data shifted to optimally match simulated data, global scale (1d), bias filtered.
RMS residuals in x, y, z: 7.02, 1.58, 0.86 nm/s^2

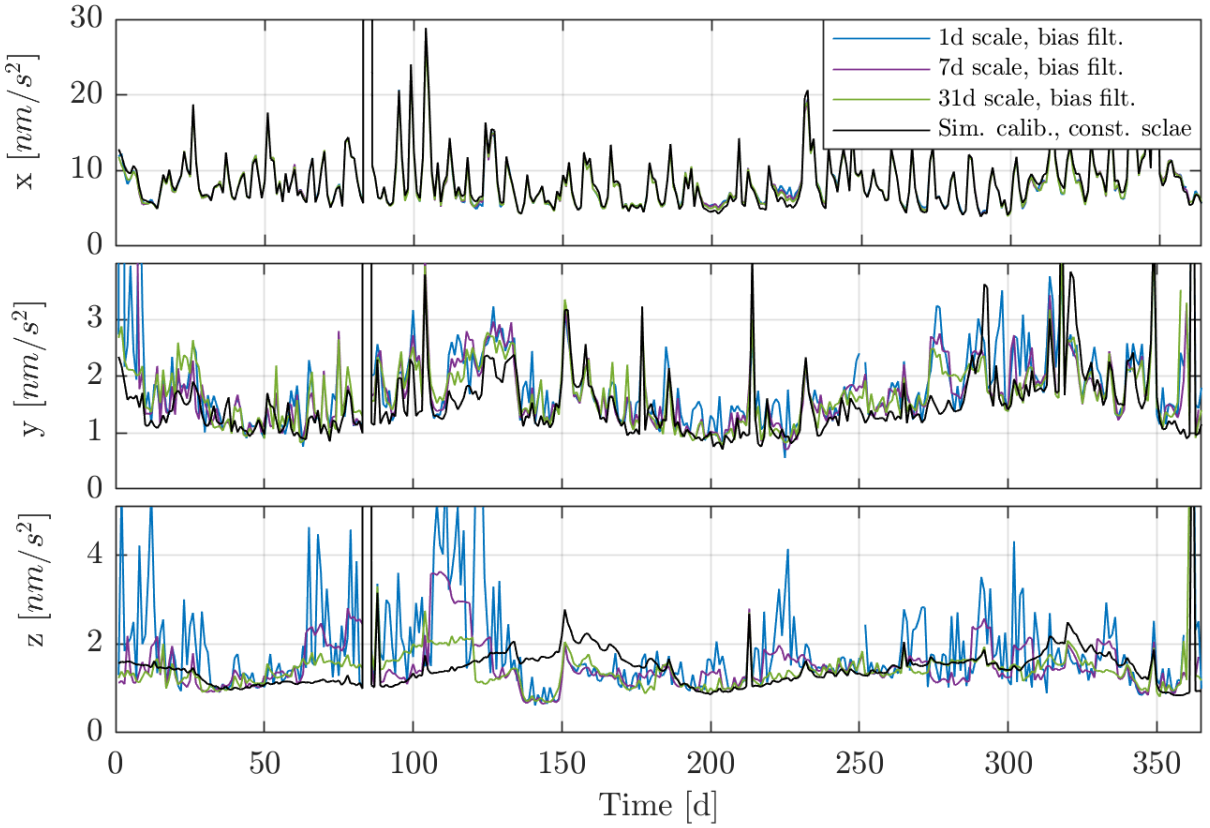
- Shifting the POD calibration to optimally match the simulated data

How to Validate the Different Results

Comparison with the Simulated Data



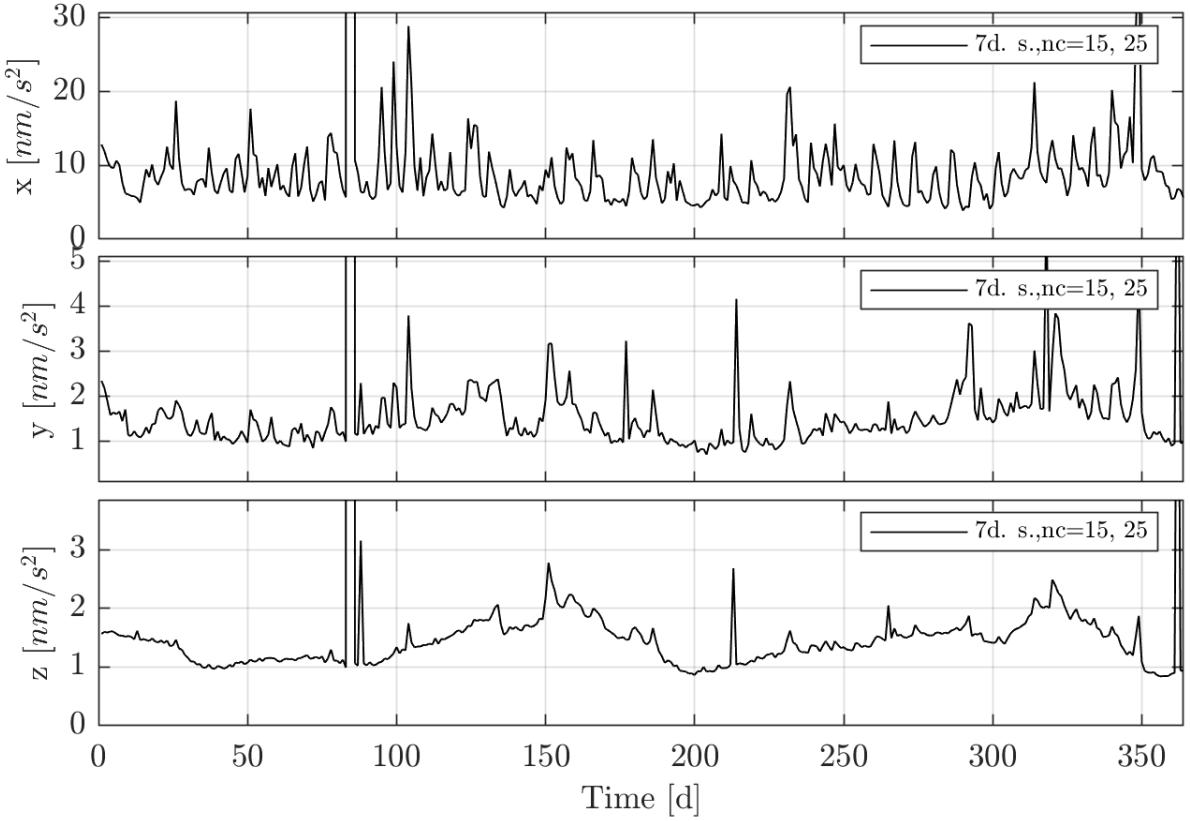
RMS residuals of ACC calibration with simulated data, (daily bias), 2006, GRACE A



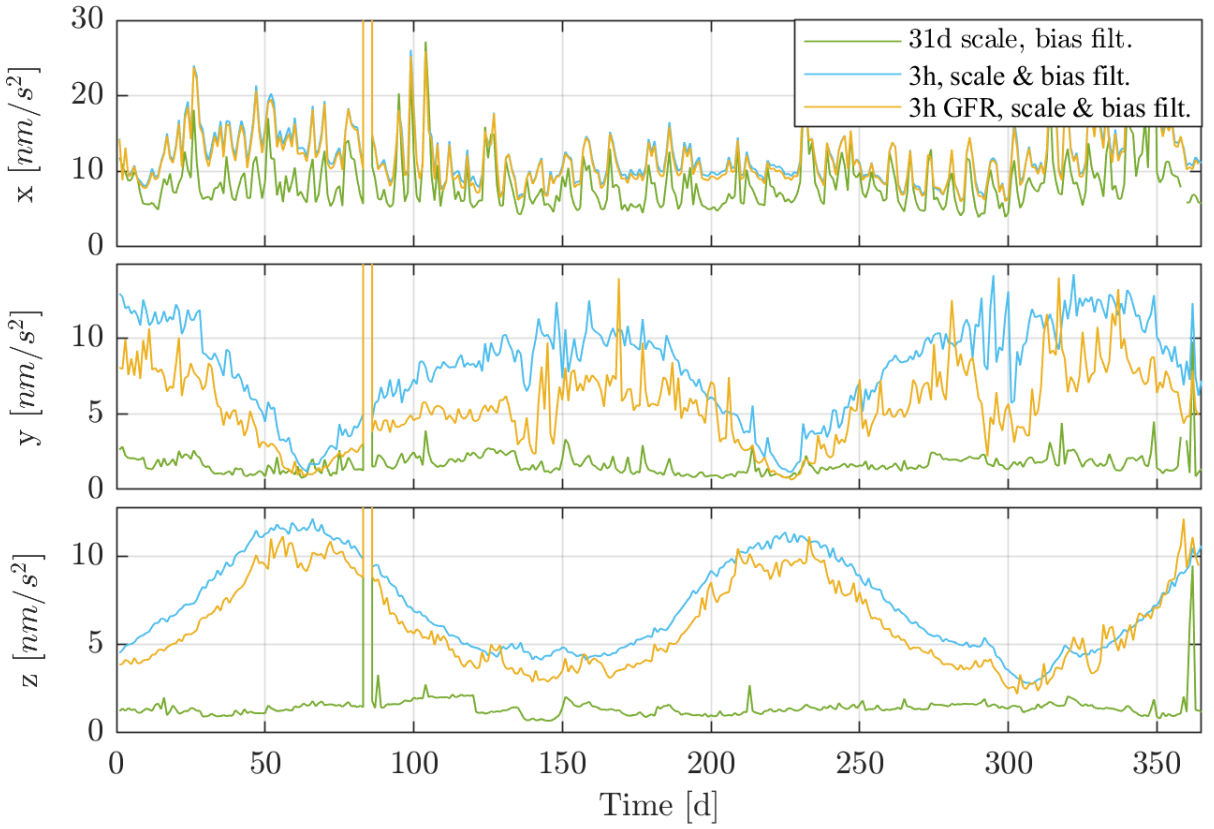
RMS difference of calibrated ACC data shifted to optimally match simulated data, for global scale parametrization with 1, 7, 31 days, 2006, GRACE A

How to Validate the Different Results

Comparison with the Simulated Data



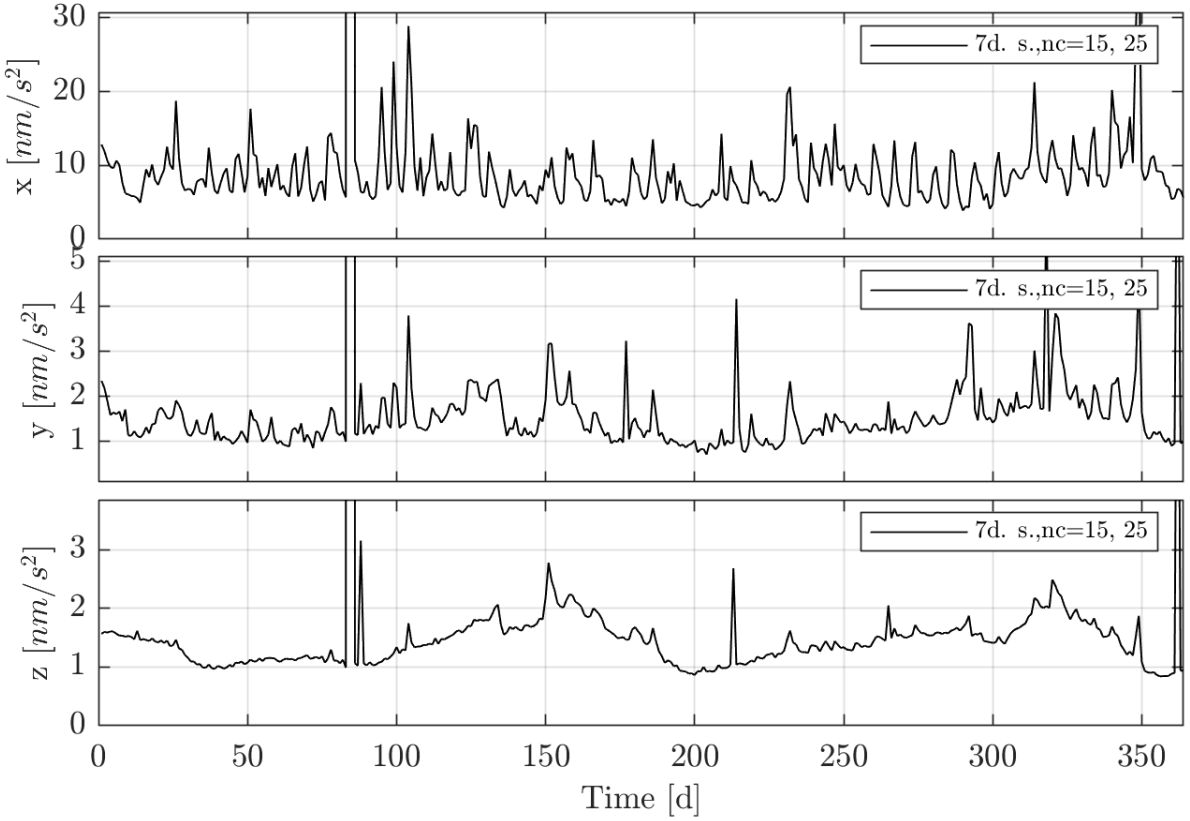
RMS residuals of ACC calibration with simulated data, (daily bias), 2006, GRACE A



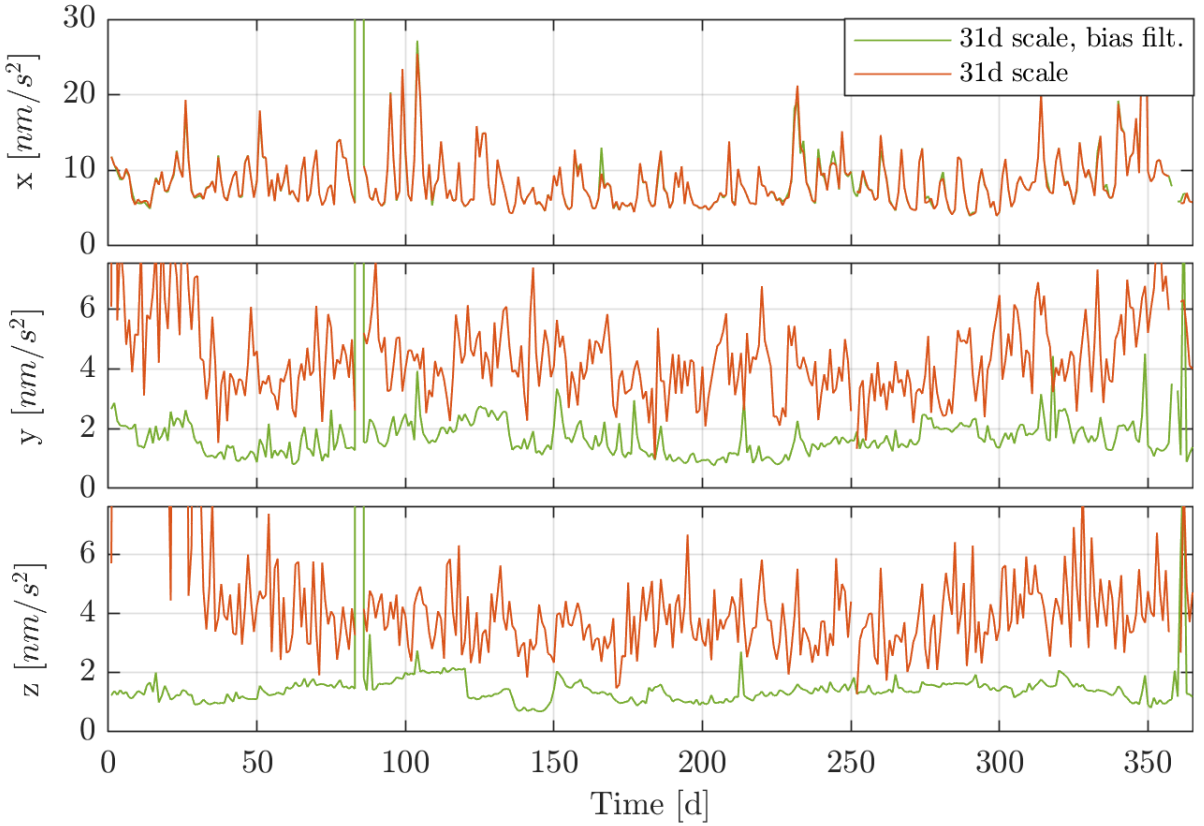
RMS difference of calibrated ACC data shifted to optimally match simulated data, with local (3h) scale parametrization for POD from POD and GFR, 31d global scale for comaprison, 2006, GRACE A

How to Validate the Different Results

Comparison with the Simulated Data



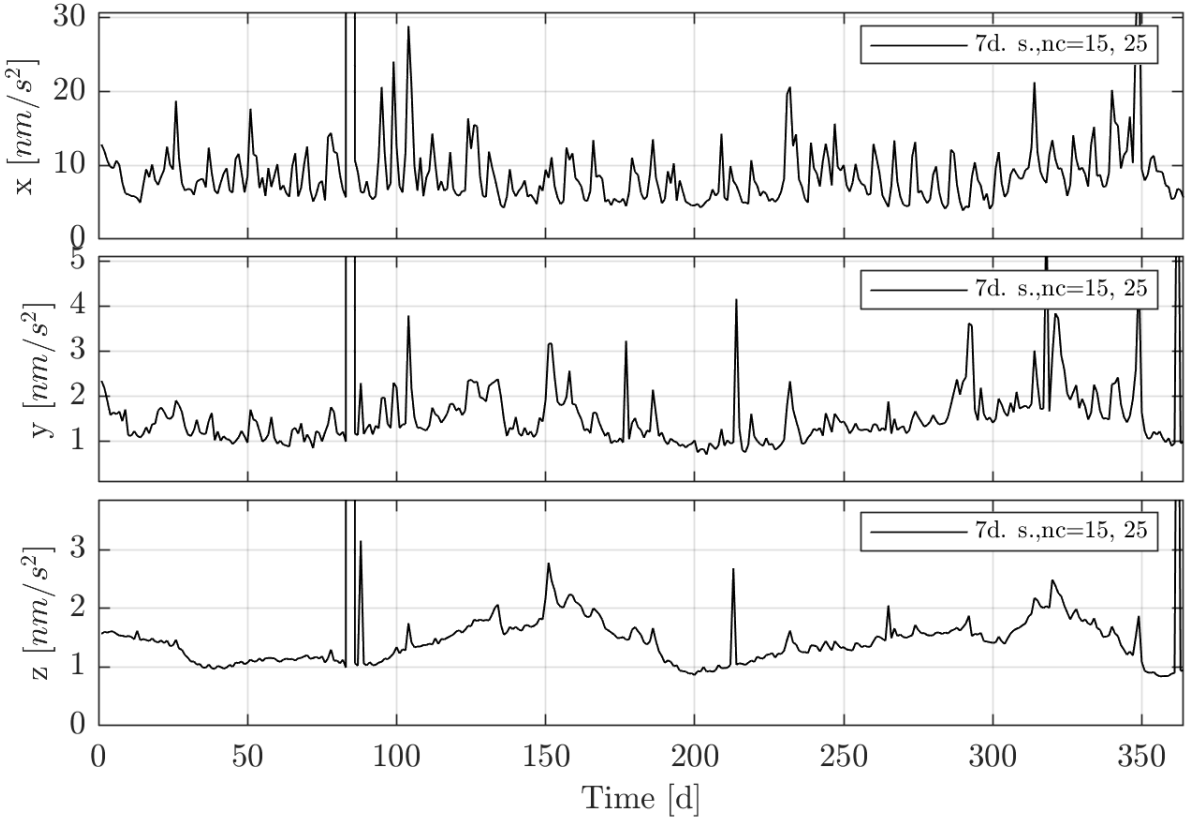
RMS residuals of ACC calibration with simulated data, (daily bias), 2006, GRACE A



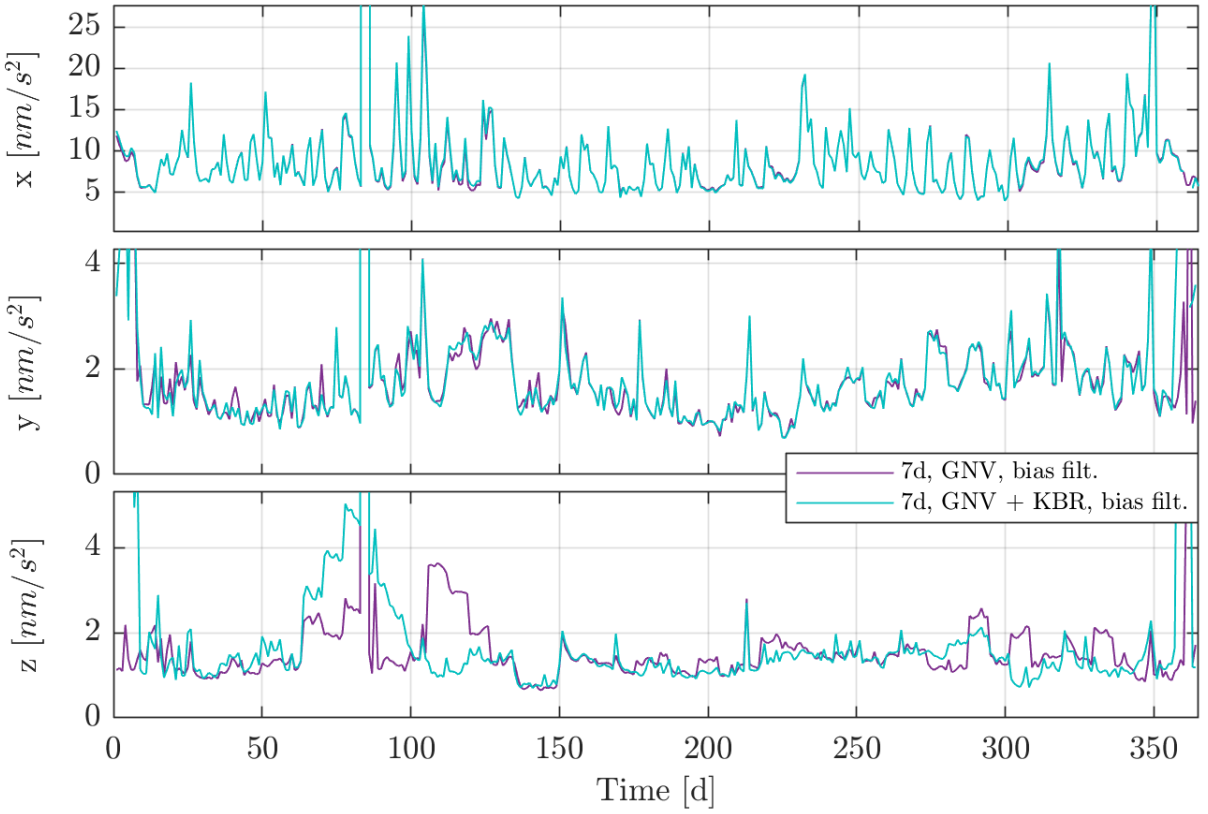
RMS difference of calibrated ACC data shifted to optimally match simulated data, with filtered and unfiltered bias, 2006, GRACE A

How to Validate the Different Results

Comparison with the Simulated Data



RMS residuals of ACC calibration with simulated data, (daily bias), 2006, GRACE A



RMS difference of calibrated ACC data shifted to optimally match simulated data, using GNV or GNV + KBR data as observations, 2006, GRACE A

Conclusions

- Calibration by POD and GFR is ambiguous, dependent on many options
- Especially the scale factor shows high sensitivity towards different options
- Validation not so easy
- Nevertheless, X-axis much more sensitive and decisive for density estimation
- Estimation of thermospheric wind very troublesome because of huge uncertainty in Y- and Z-axis in POD estimation

Outlook

- Completion of analysis over the whole time span of GRACE and GRACE-FO
- Density estimation with all data

University of Bremen

Thank You!

zarm.uni-bremen.de/

florian.woeske@zarm.uni-bremen.de

CENTER OF
APPLIED SPACE TECHNOLOGY
AND MICROGRAVITY

ZARM