

Non-gravitational forces acting on spacecraft: impact of different atmospheric models on LEO orbits

V. Girardin

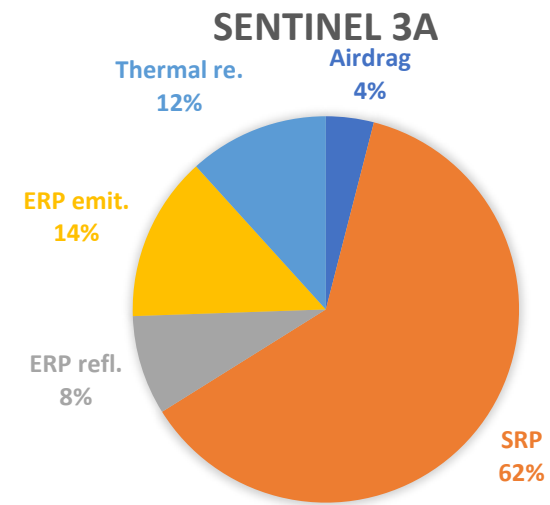
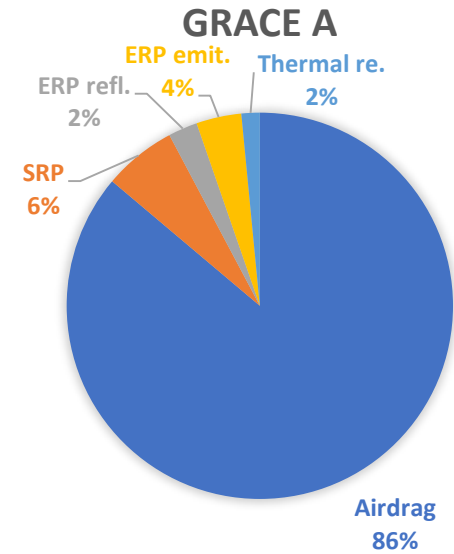
D. Arnold

S. Bertone

A. Jäggi

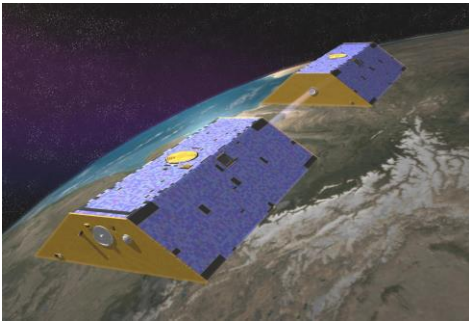
Context

| Force | Acceleration (m/s ²) |
|--|----------------------------------|
| Central term of Earth's gravity field | 8.42 |
| Oblateness of Earth's gravity field | 0.015 |
| Higher order terms of Earth's gravity field | 0.00025 |
| Attraction from the Moon | 0.0000054 |
| Attraction from the Sun | 0.000000097 |
| Non-gravitational forces acting on GRACE A | 0.000000306 |
| Non-gravitational forces acting on Sentinel-3A | 0.000000050 |



Spacecraft surface modelling

GRACE A&B



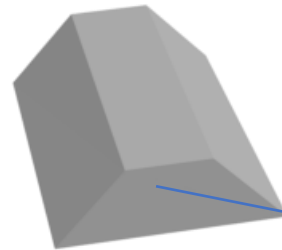
Courtesy: Astrium GmbH

Sentinel 3A



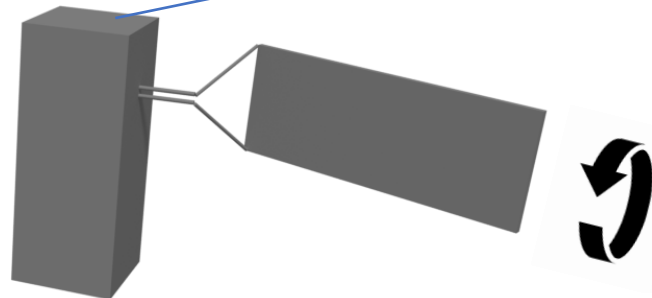
Courtesy: ESA

Static macromodel



Each panel

Dynamic macromodel

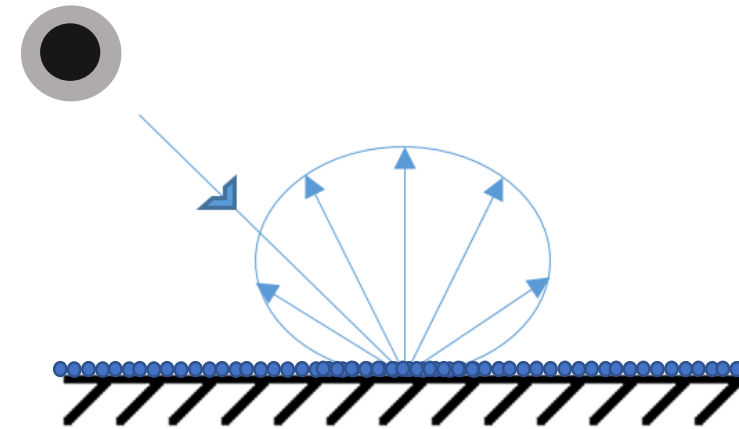


Each panel

| |
|--------------------|
| Orientation |
| Area |
| Optical properties |
| Temperature |
| ... |

Atmospheric drag modelling

- Caused by a complex gas-surface interaction between atmospheric particles and spacecraft surface.
- Atmospheric density, chemical composition and temperature are required.
- Spacecraft velocity is with respect to the atmosphere.

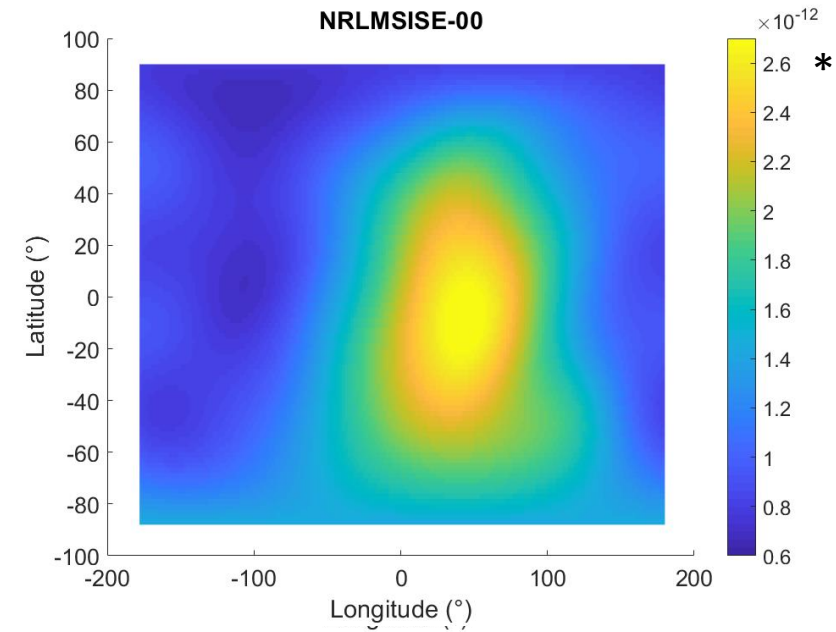
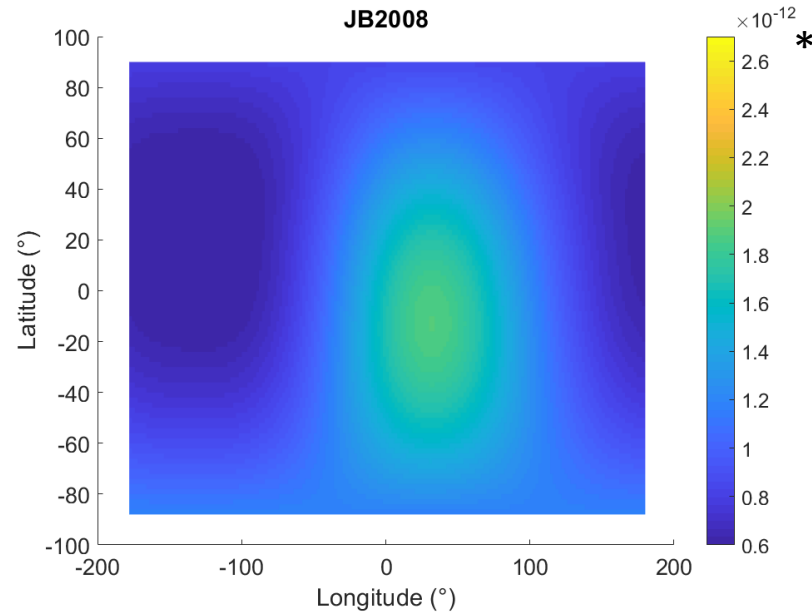
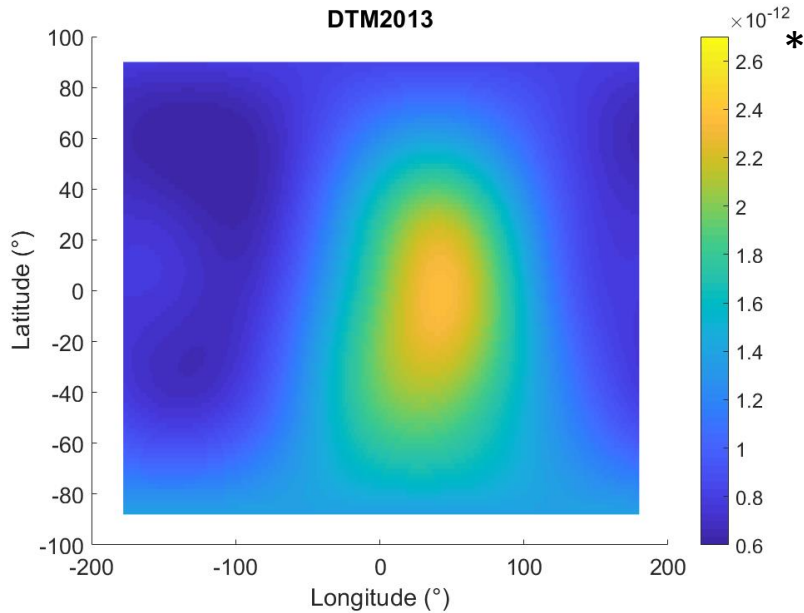


Diffuse reflection
(based on Sentman's method*)

*L. H. Sentman, Free molecule flow theory and its application to the determination of aerodynamic forces, Tech. Rep. (1961)

Atmospheric model output: GRACE altitude

Altitude : 425 km

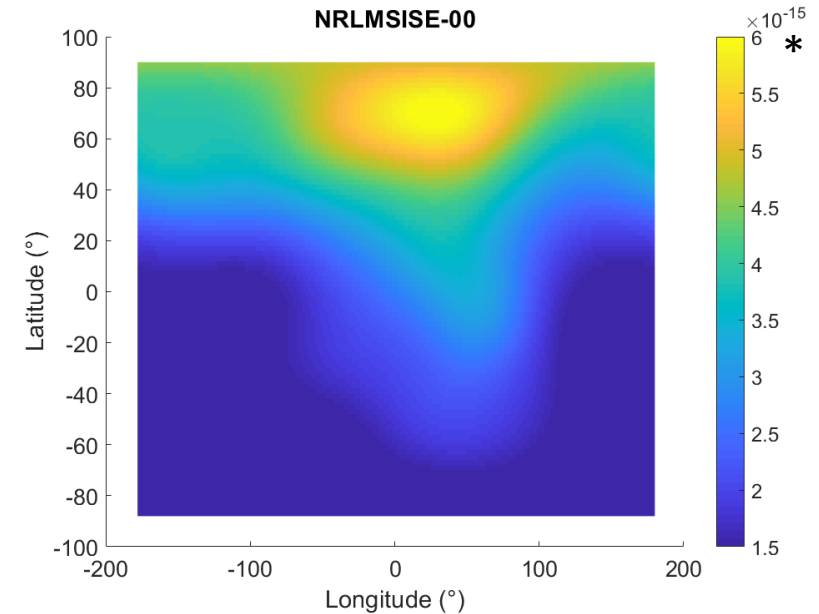
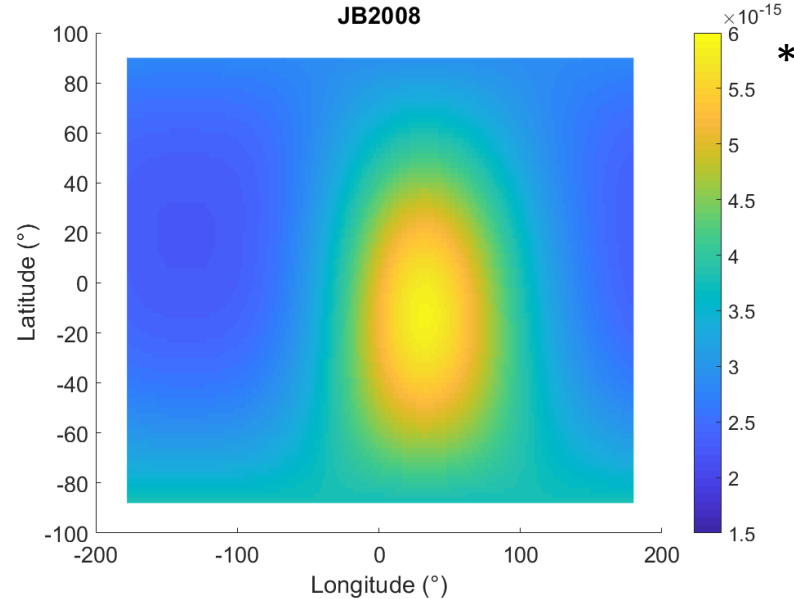
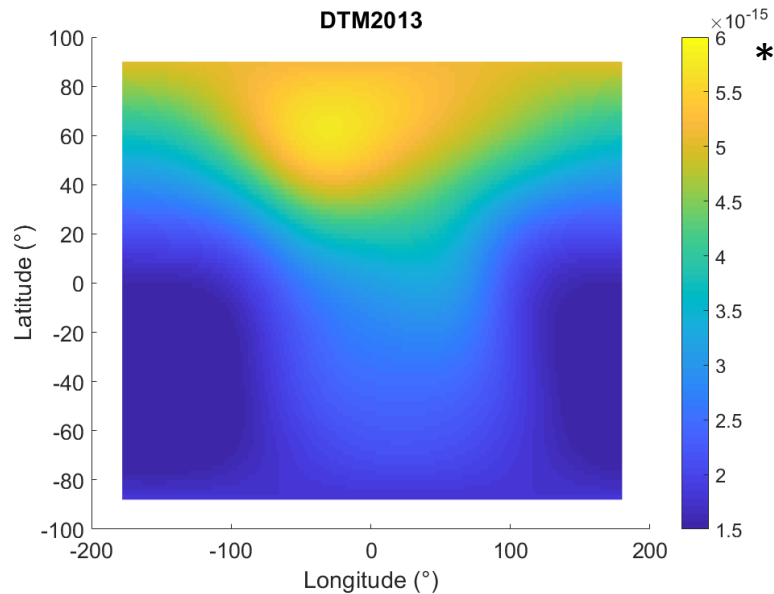


* Temperature (K)

* Density (kg/m^3)

Atmospheric model output: Sentinel 3A altitude

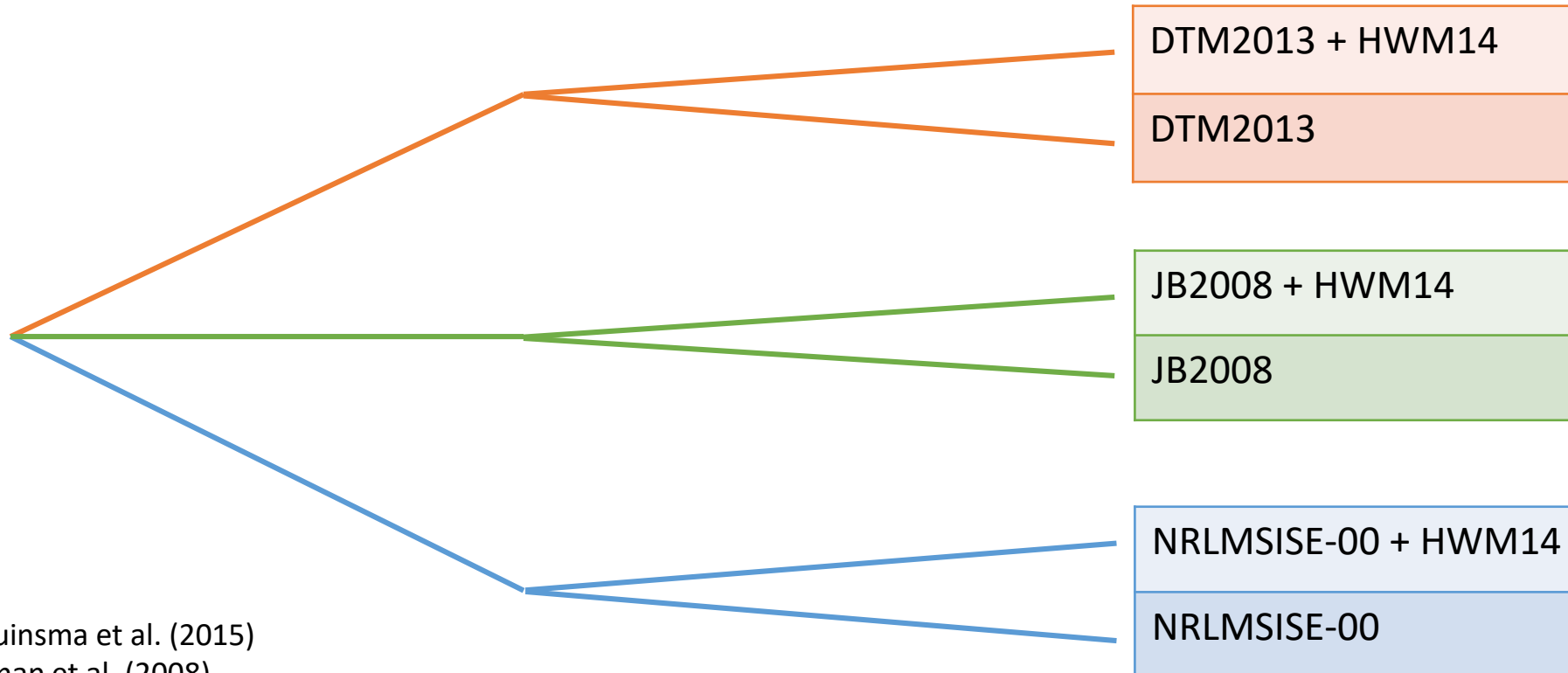
Altitude : 825 km



* Temperature (K)

* Density (kg/m^3)

Summary of the studied cases



References:

- DTM2013: Bruinsma et al. (2015)
- JB2008: Bowman et al. (2008)
- NRLMSISE-00: Picone et al. (2002)
- HWM14: Drop et al. (2015)

Set-up

- Orbit determination
 - Based on GPS-phase data.
 - Reduced-dynamic orbit with estimated PCAs.
 - No constant accelerations.
 - Arc length of one day.
- Data
 - GRACE A & B: 90 days from doy 153 to 242 of year 2014.
 - Sentinel 3A: 90 days from doy 153 to 242 of year 2016.
- Non-gravitational forces modelling
 - Earth local albedo (2 deg. resolution) from CERES data.
 - Cone-based partial eclipse modelling.
 - Drag coefficient modelled using an accommodation coefficient based on hard sphere theory.

Reduced-dynamic orbit using Piecewise Constant Accelerations (PCAs)

| Spacecraft | Case | Std PCA (constraint) | Sampling | Scaling factor estimation of the Non-gravitational forces |
|-------------|-----------------------------------|----------------------|----------------------|---|
| Sentinel 3A | Reference orbit | 1.0 E-08 | 10 min (144 per day) | no |
| Sentinel 3A | Non-gravitational forces modelled | 1.0 E-09 | 10 min (144 per day) | 2 : air-drag and solar radiation pressure |
| GRACE A&B | Reference orbit | 1.0 E-08 | 10 min (144 per day) | no |
| GRACE A&B | Non-gravitational forces modelled | 1.0 E-09 | 10 min (144 per day) | 2 : air-drag and solar radiation pressure |

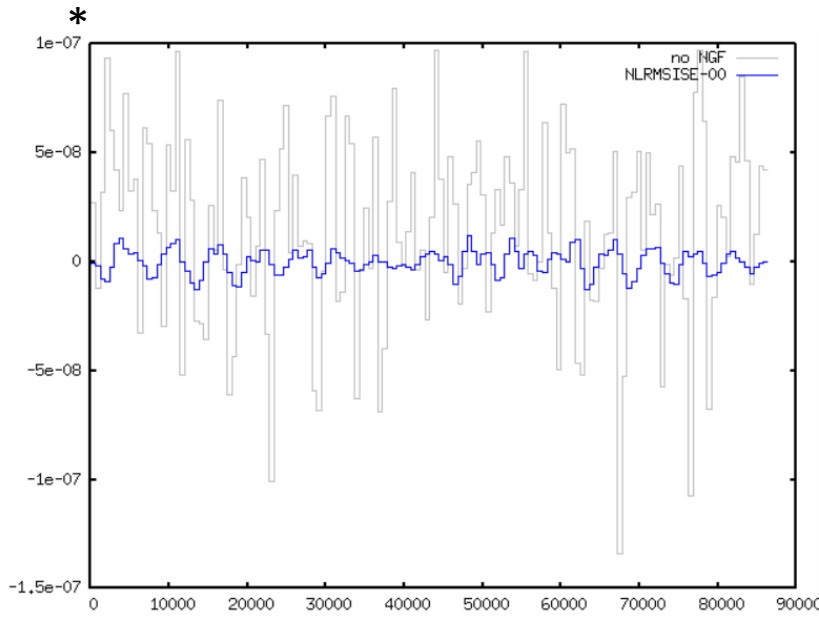
Piecewise Constant Accelerations: GRACE A

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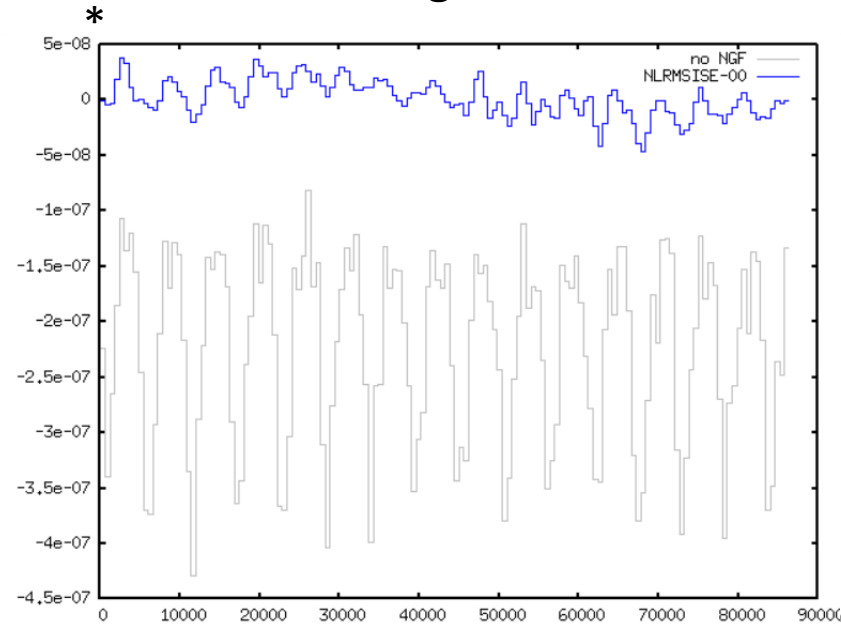
DTM2013
JB2008
NLRMSISE-00

Radial



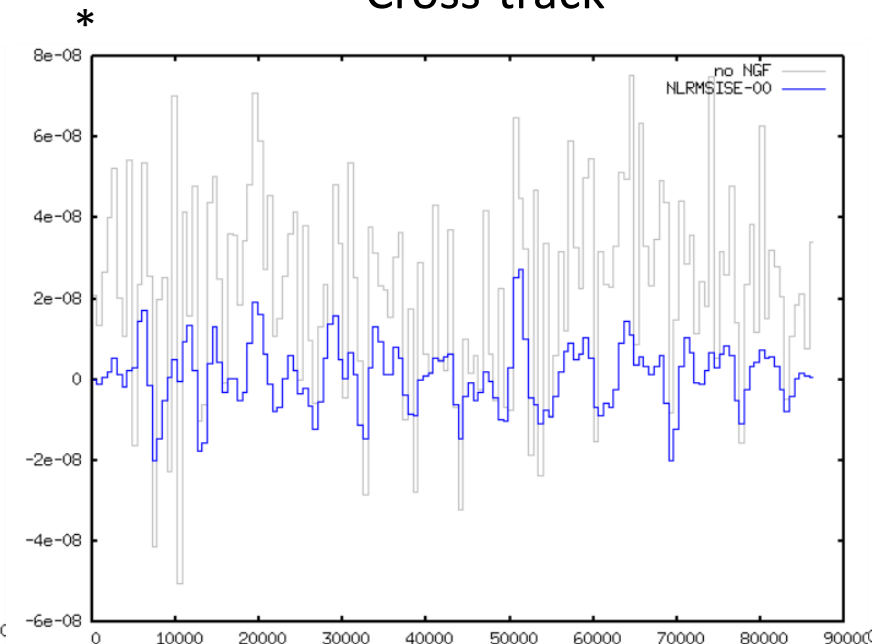
Epoch (s), doy 222 year 2014

Along-track



Epoch (s), doy 222 year 2014

Cross-track



Epoch (s), doy 222 year 2014

* Accelerations (m/s^2)

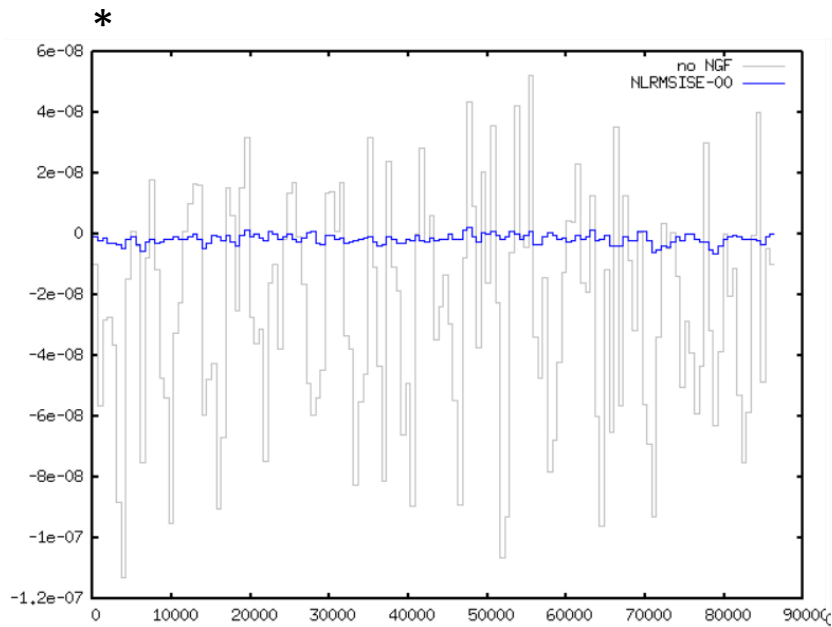
Piecewise Constant Accelerations: Sentinel 3A

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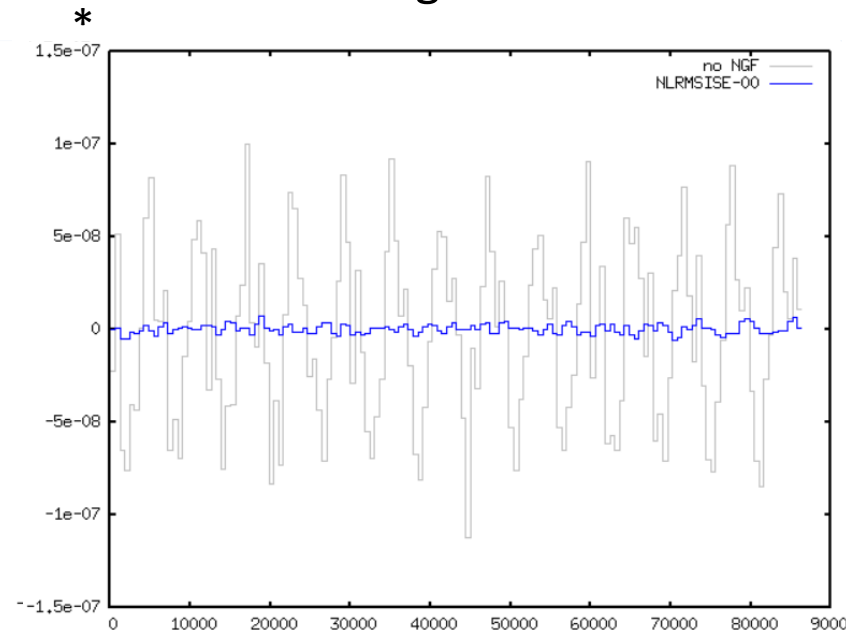
DTM2013
JB2008
NLRMSISE-00

Radial



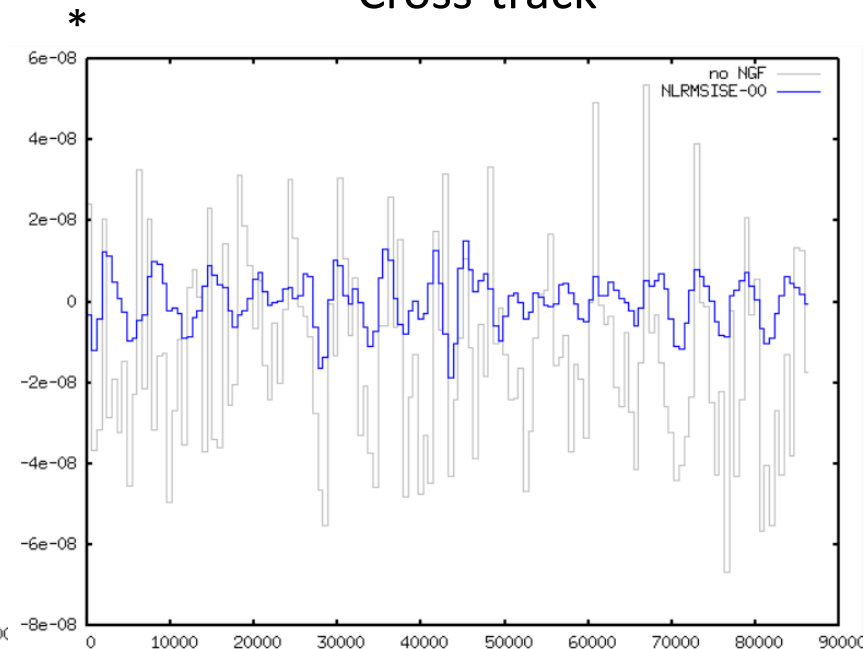
Epoch (s), doy 222 year 2016

Along-track



Epoch (s), doy 222 year 2016

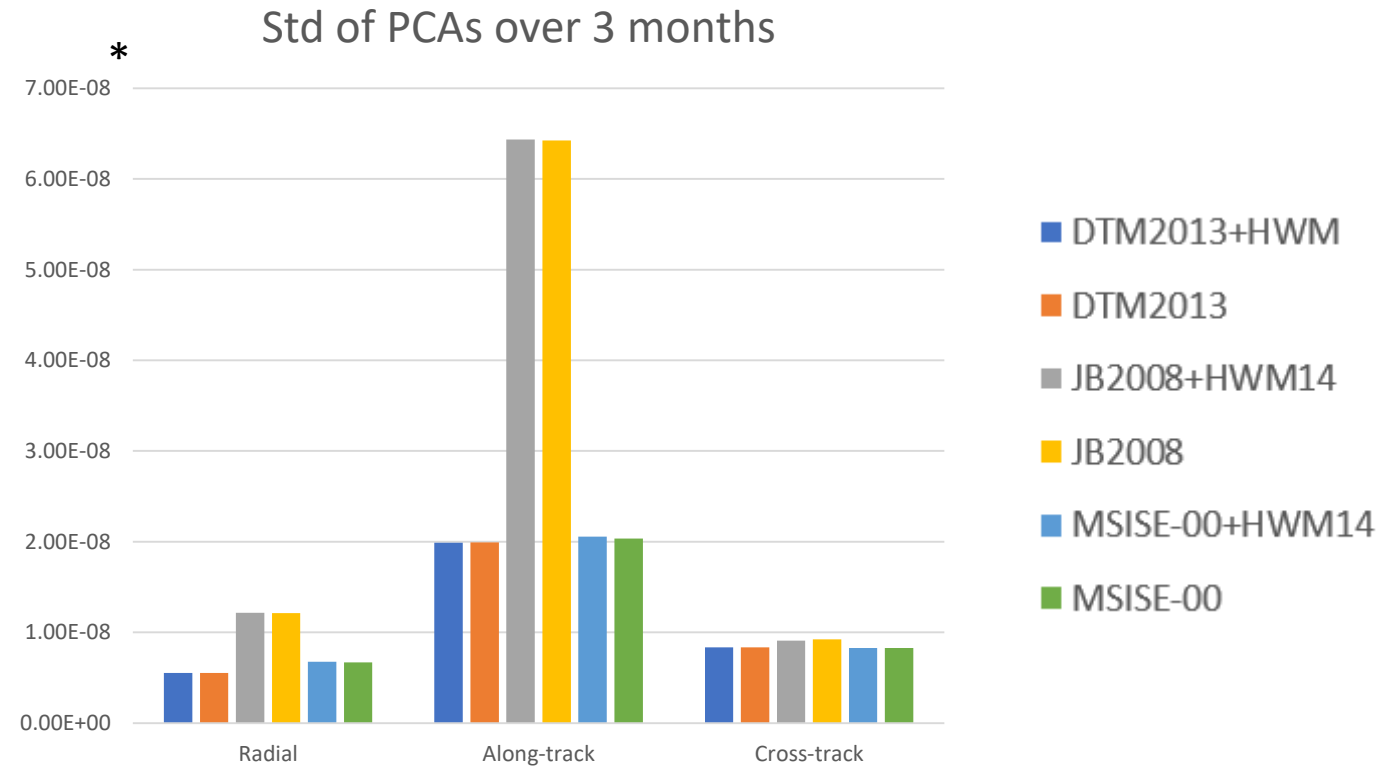
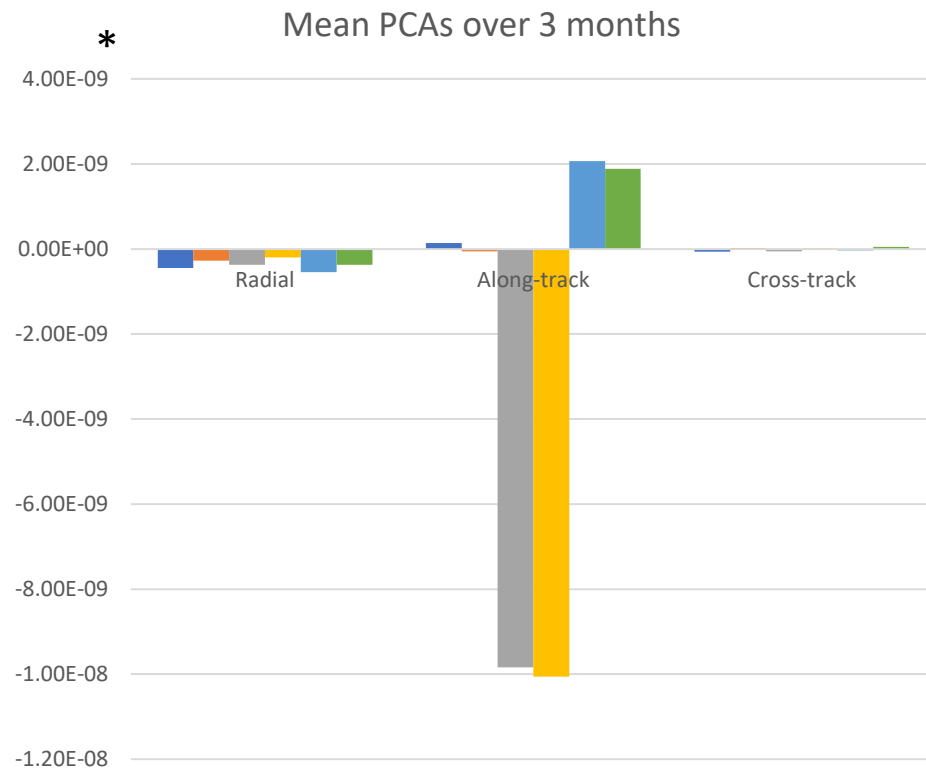
Cross-track



Epoch (s), doy 222 year 2016

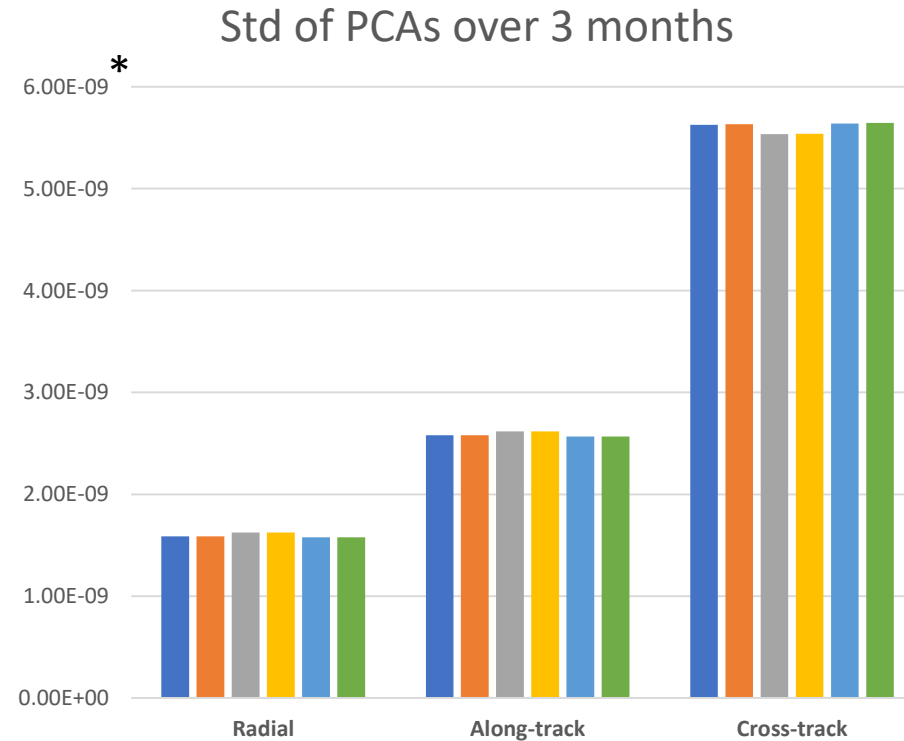
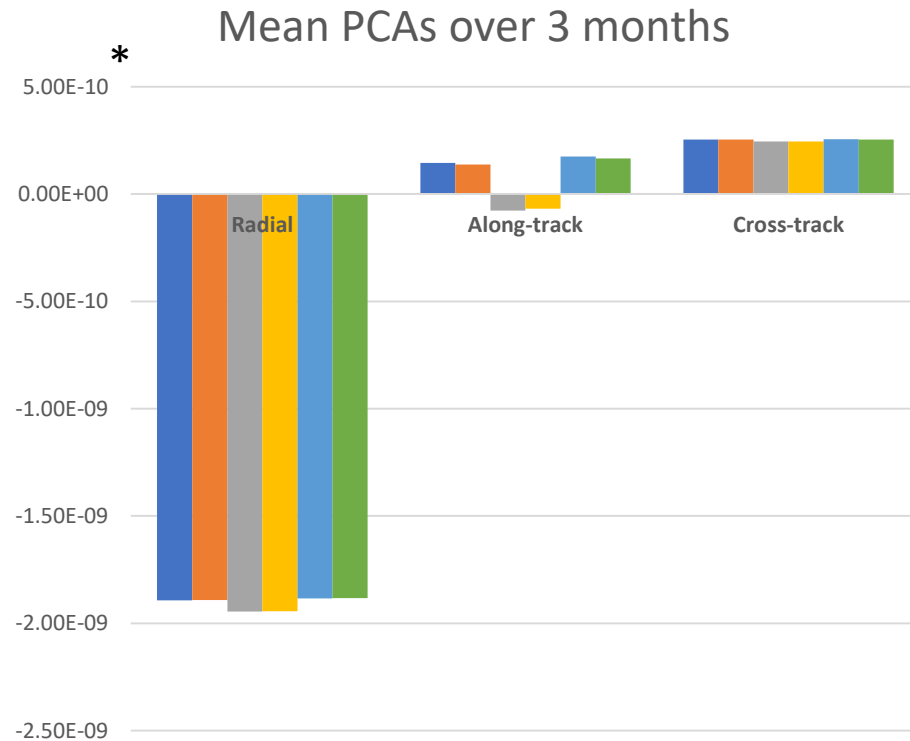
* Accelerations (m/s²)

Piecewise Constant Accelerations: Statistics for GRACE A



* Accelerations (m/s²)

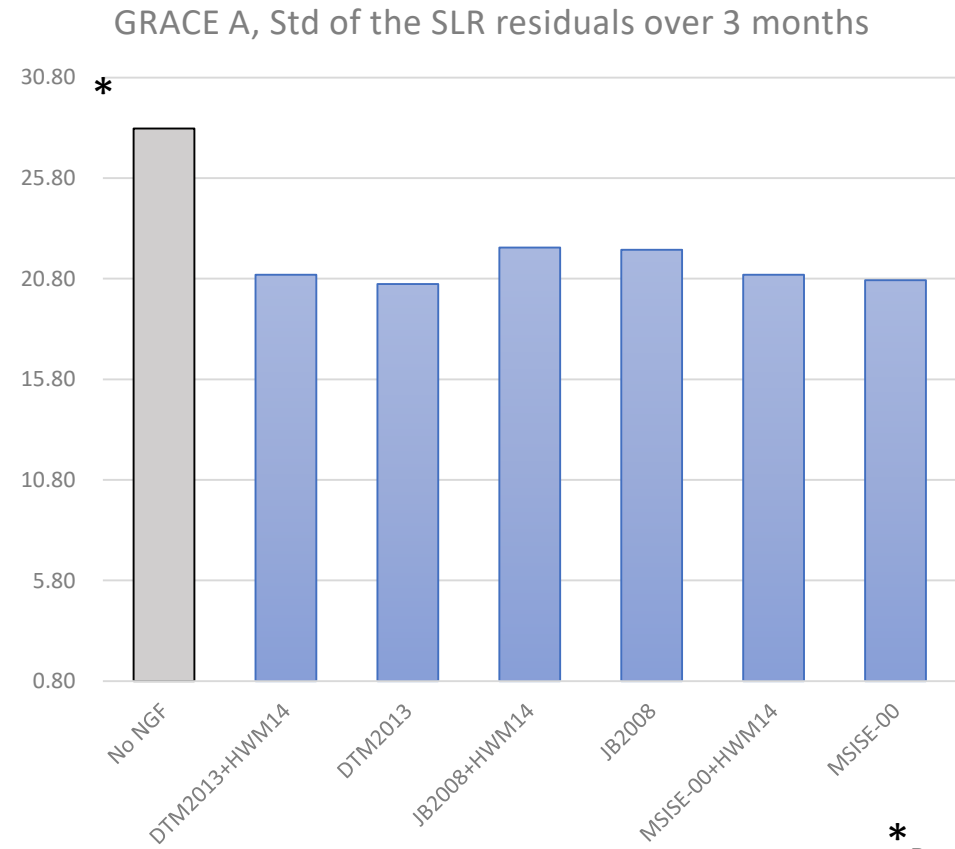
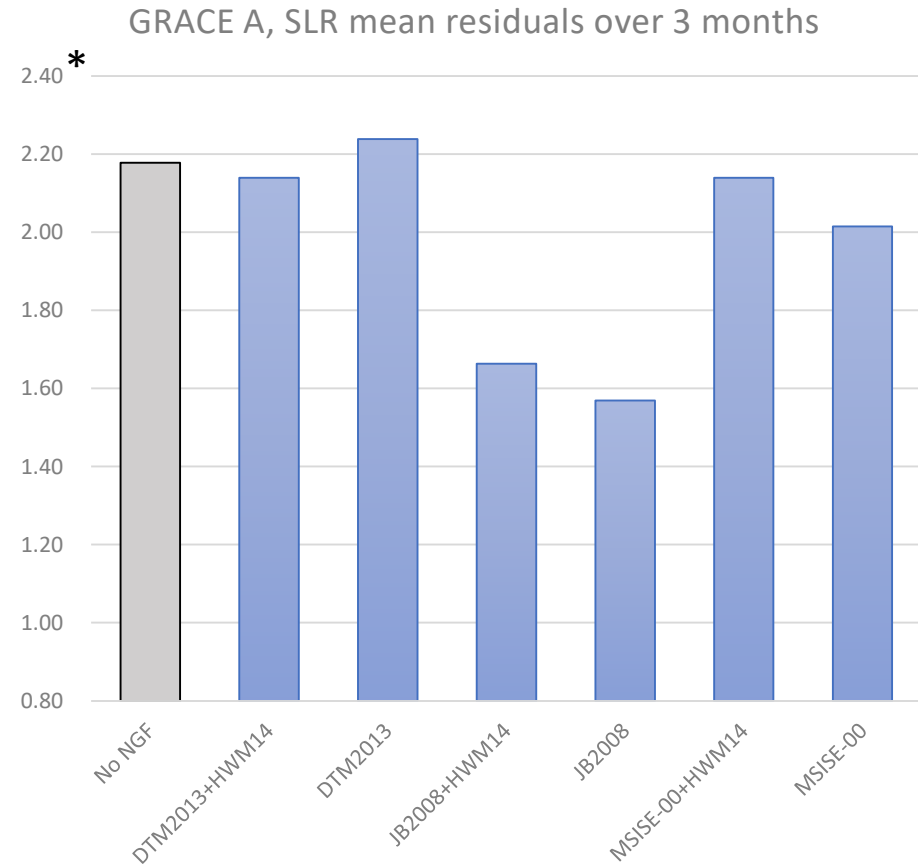
Piecewise Constant Accelerations: Statistics for Sentinel 3A



- DTM2013+HWM
- DTM2013
- JB2008+HWM14
- JB2008
- MSISE-00+HWM14
- MSISE-00

* Accelerations (m/s²)

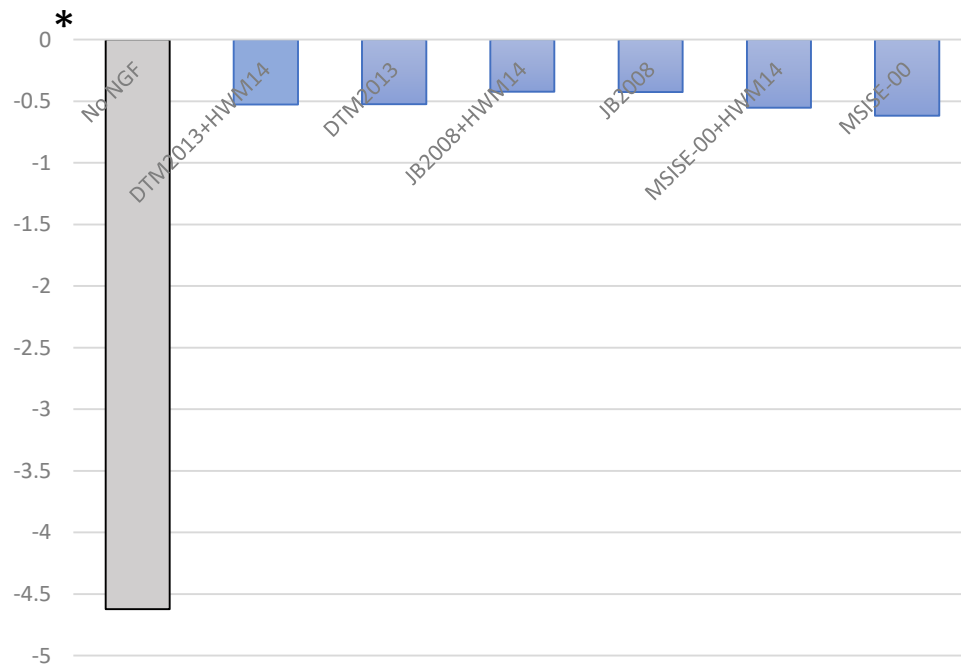
Satellite Laser Ranging: Statistics for GRACE A



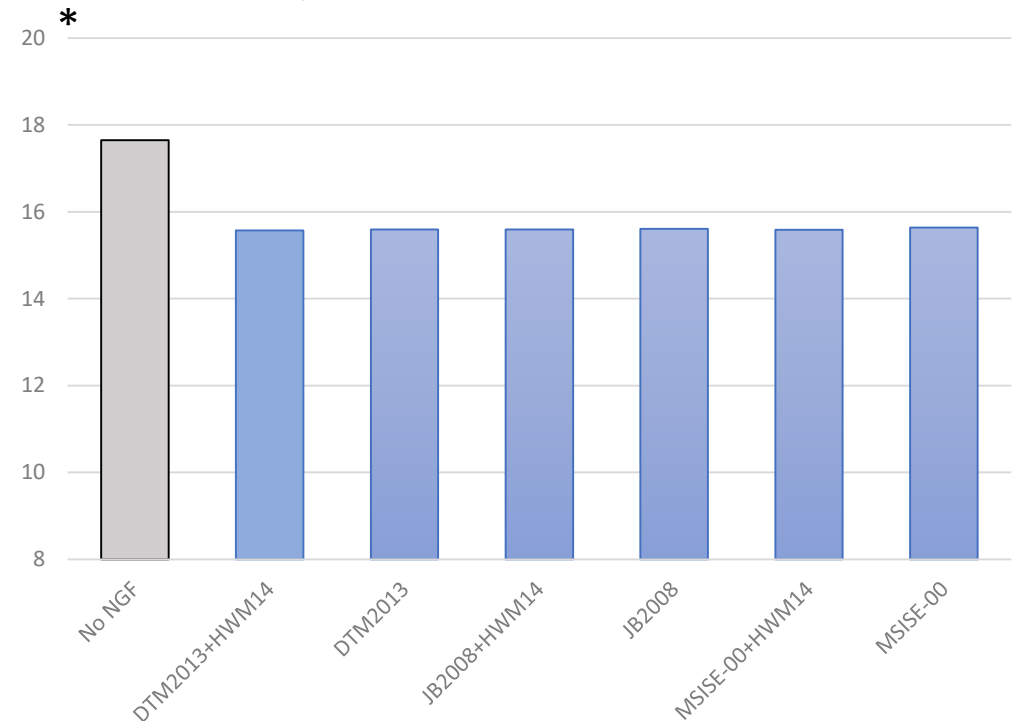
* Range residuals (mm)

Satellite Laser Ranging: Statistics for Sentinel 3A

Sentinel 3A, SLR mean residuals over 3 months



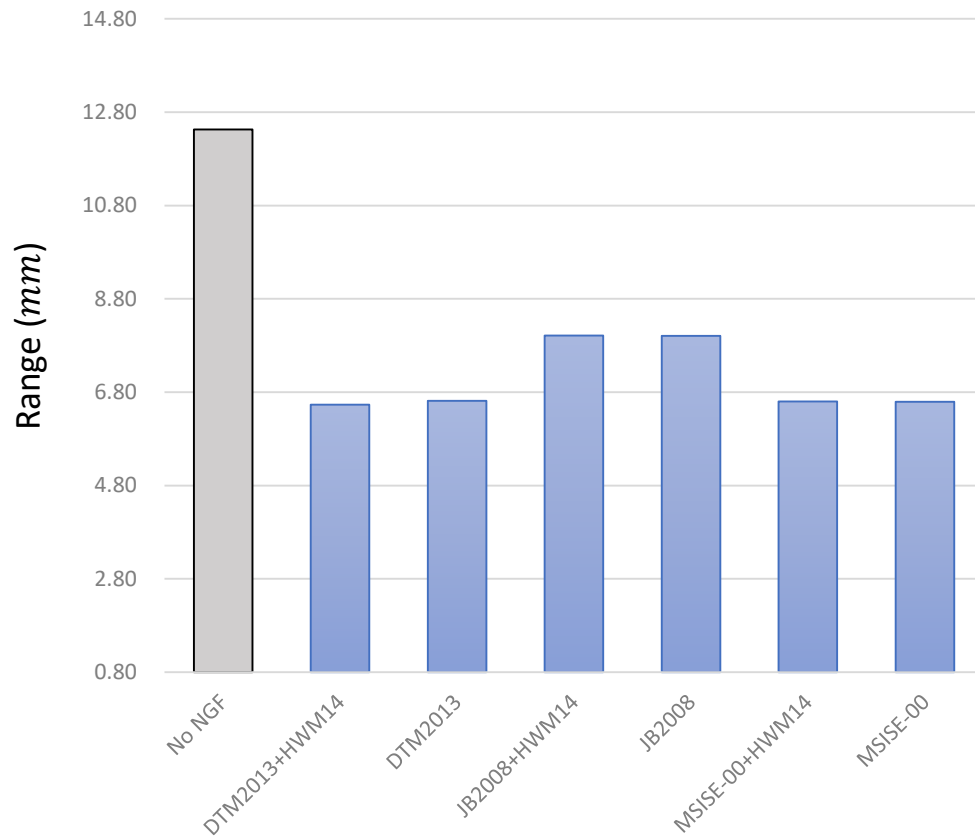
Sentinel 3A, Std of the SLR residuals over 3 months



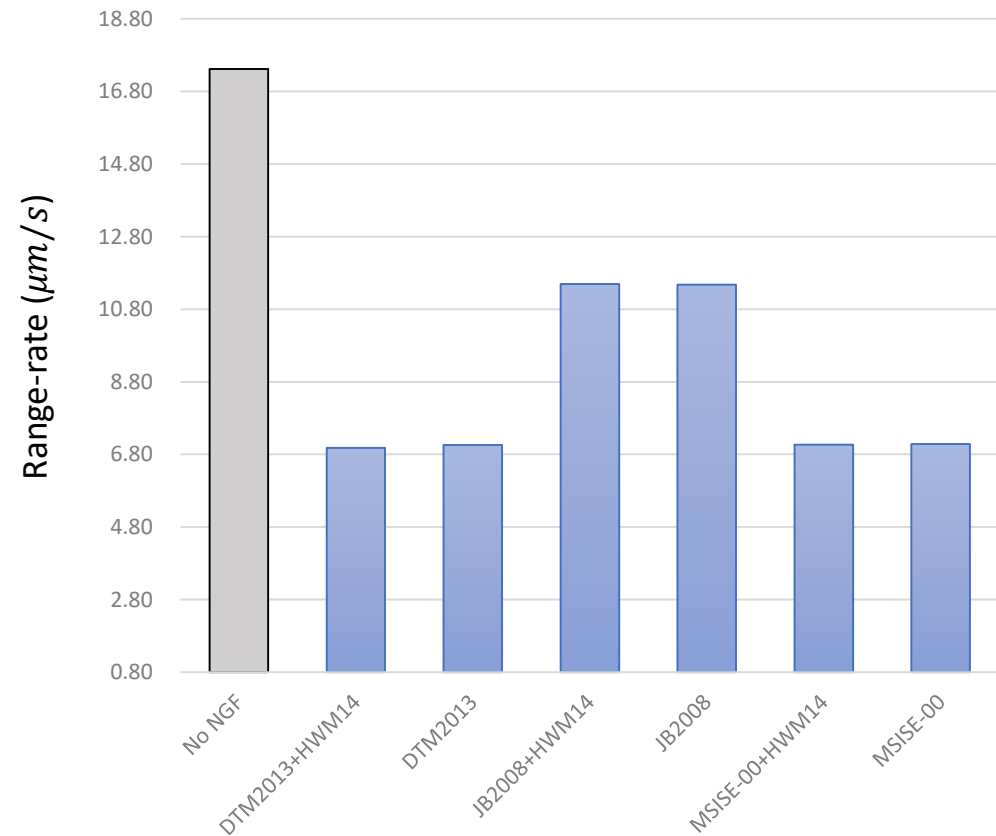
* Range residuals (mm)

K-band: Statistics for GRACE A&B

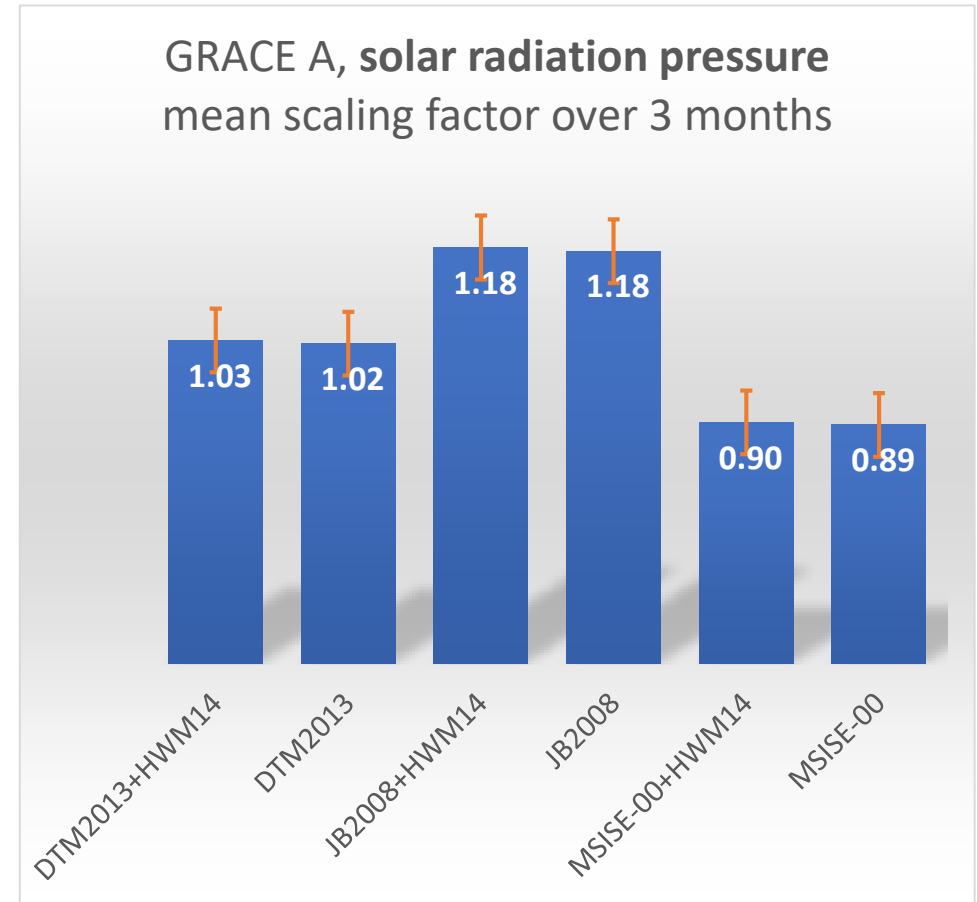
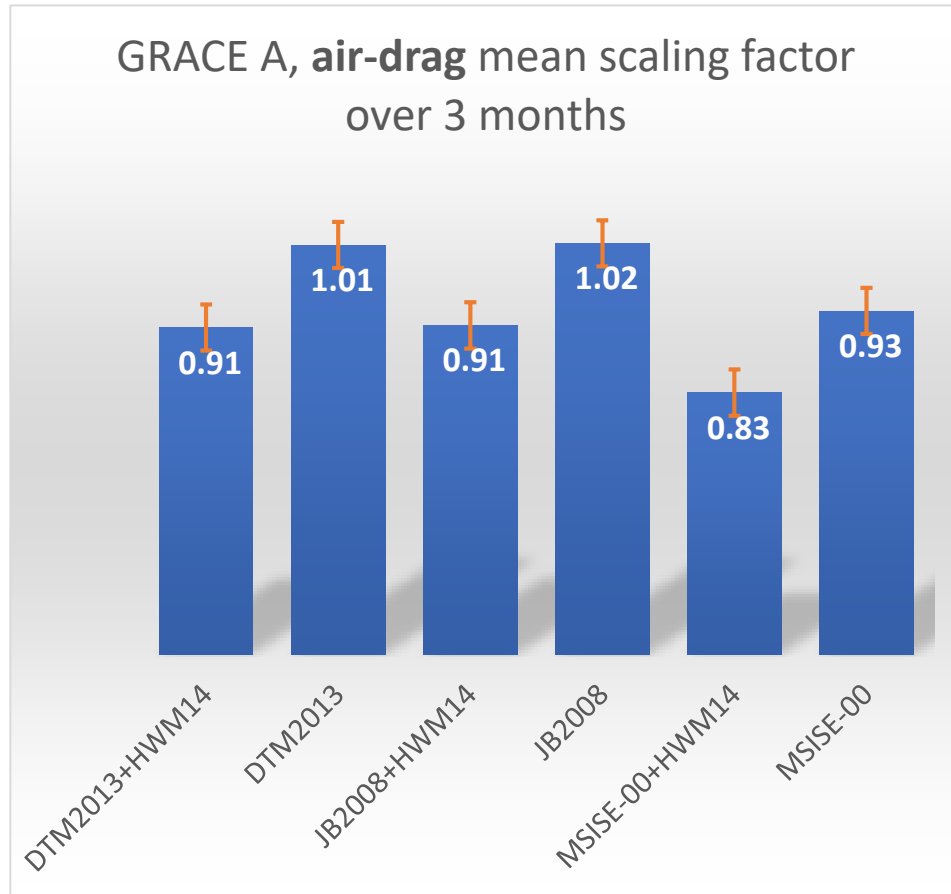
GRACE A, Std of KBR range residuals



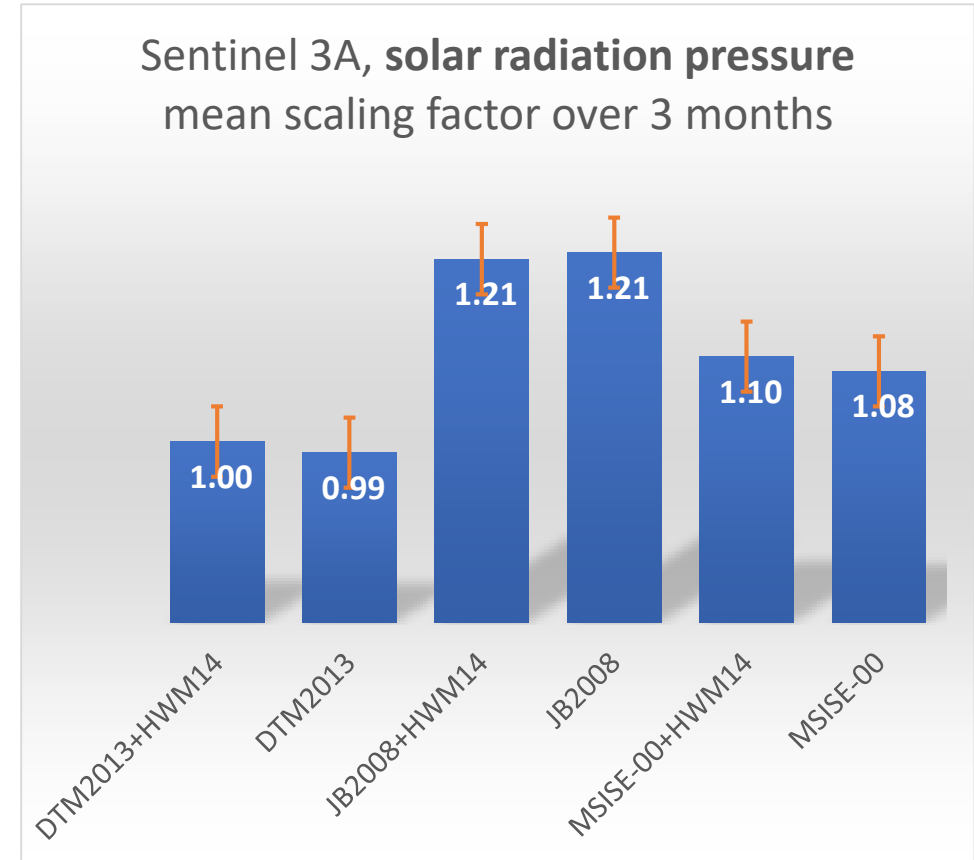
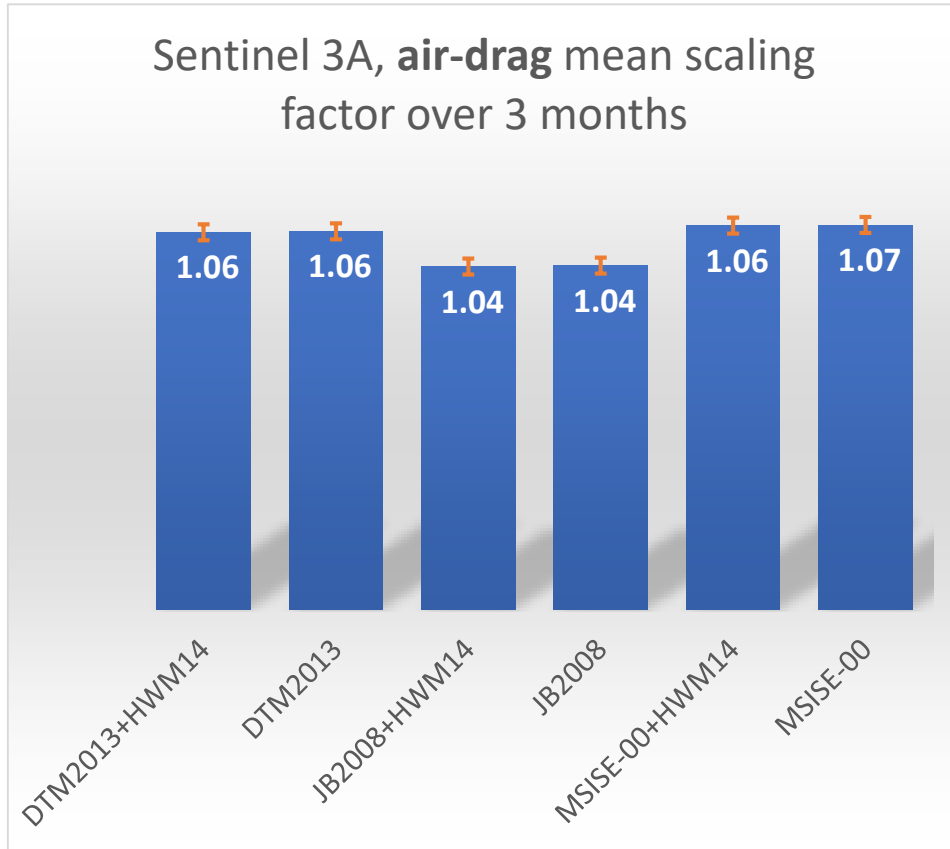
GRACE A, Std of KBR range-rate residuals



Scaling factors: GRACE A



Scaling factors: Sentinel 3A



Conclusion

- Altitude difference
 - ✓ GRACE A and Sentinel 3A outcomes are mostly consistent.
 - The impact of the different atmospheric model on the orbit is very small for Sentinel 3A.
- DTM2013
 - ✓ Smallest PCAs.
 - ✓ Smallest Std of the SLR residuals.
 - ✓ Smallest KBR residuals (both range and range-rate).
 - ✓ Mean scaling factor of solar radiation pressure closest to 1.
- JB2008
 - ✓ Smallest mean SLR residuals.
 - ✗ Much larger PCAs than the other models.
 - ✗ Much larger KBR residuals than the other models.
 - ✗ Scaling factor of solar radiation pressure farthest to 1 (~1.2)
- NRLMSISE-00
 - ✓ SLR mean and Std as good as the DTM.
 - ✓ Smallest KBR residuals (both range and range-rate).
 - ✓ PCAs reduction close to DTM but slightly worse.
 - ✗ Mean scaling factor of the air-drag farthest to 1 (0.83 for GRACE A)
- HWM14
 - Small impact on the orbit.
 - ✗ Improve the orbit precision in few cases.
 - Different outcome for GRACE and Sentinel.
 - ✗ Large impact on the air-drag scaling factor, bringing it further to 1.

Thank you for your attention

