UNIVERSITÄT BERN

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

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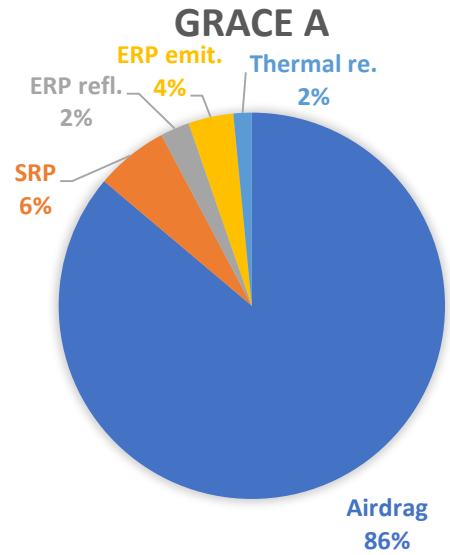
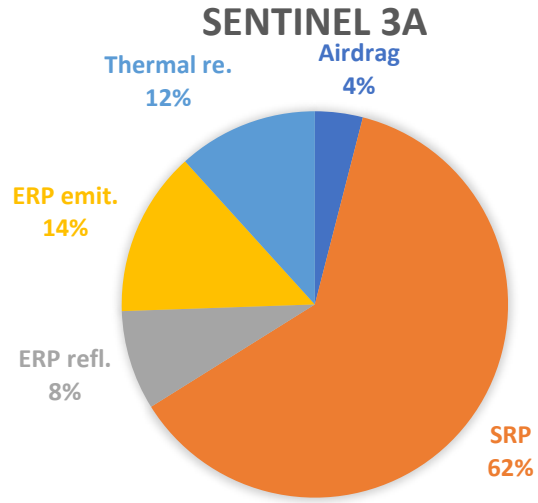
Context

Force	Acceleration (m/s^2)
Central term of Earth's gravity field	8.42
Oblateness of Earth's gravity filed	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

~ 425 km

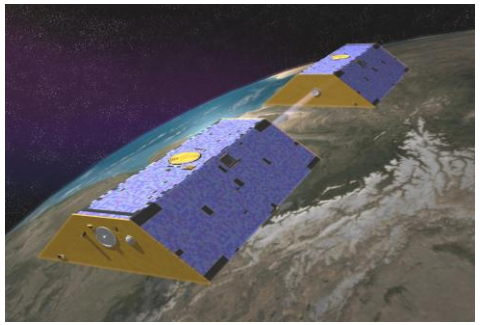
~ 825 km





Spacecraft surface modelling

GRACE A&B

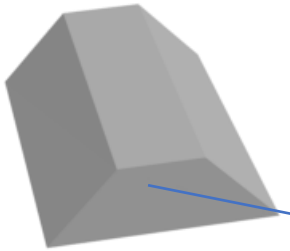


Courtesy: Astrium GmbH

Sentinel 3A

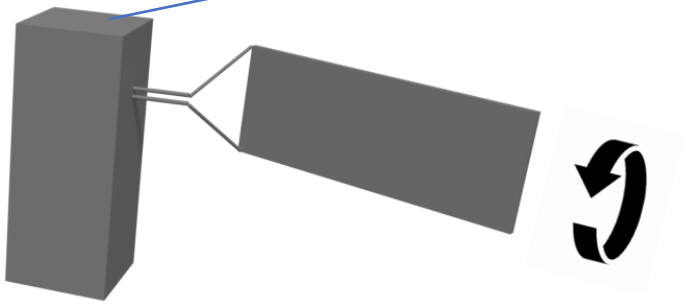
Courtesy: ESA

Static macromodel



Each panel

Dynamic macromodel

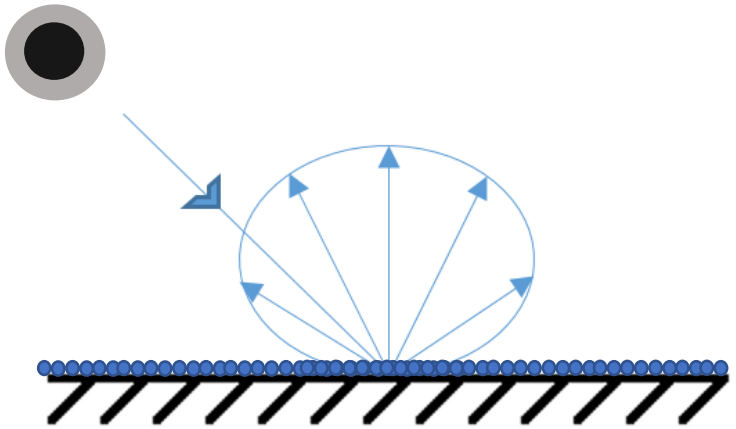


Each panel

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.

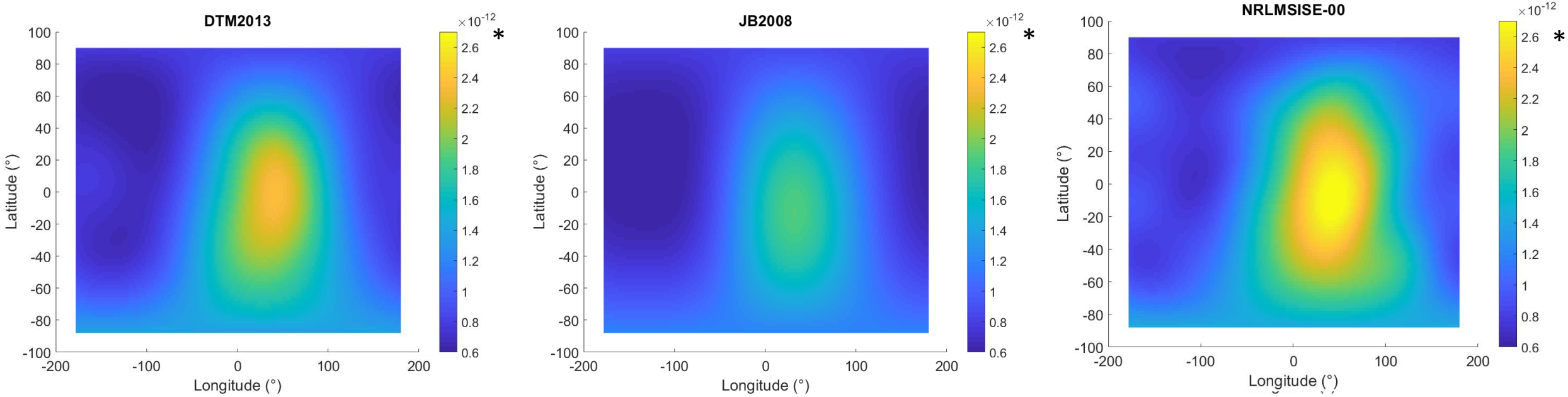


Diffuse reflection
(based on Sentman's method*)

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

Atmospheric model output: GRACE altitude

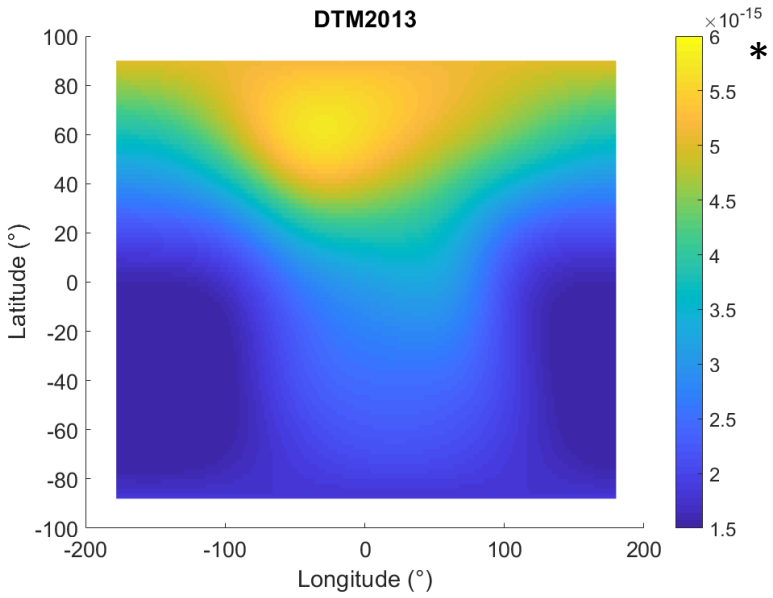
Altitude : 425 km

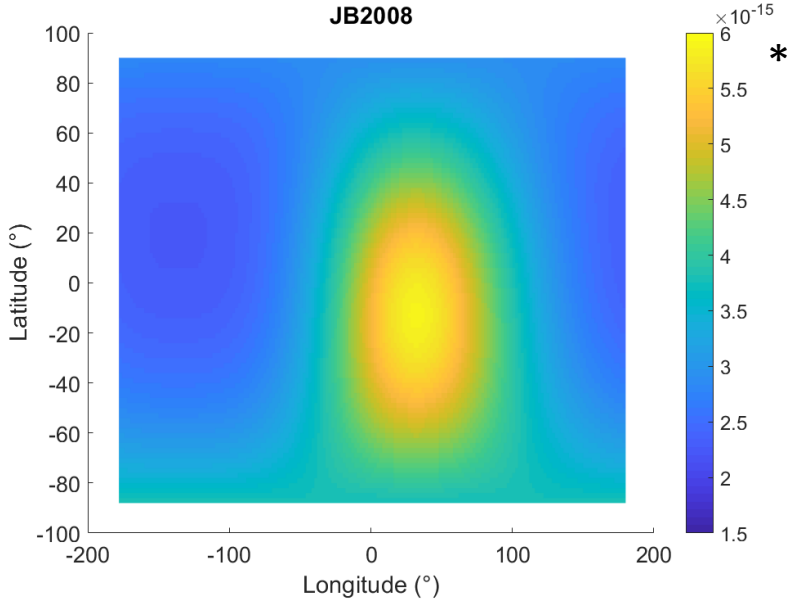


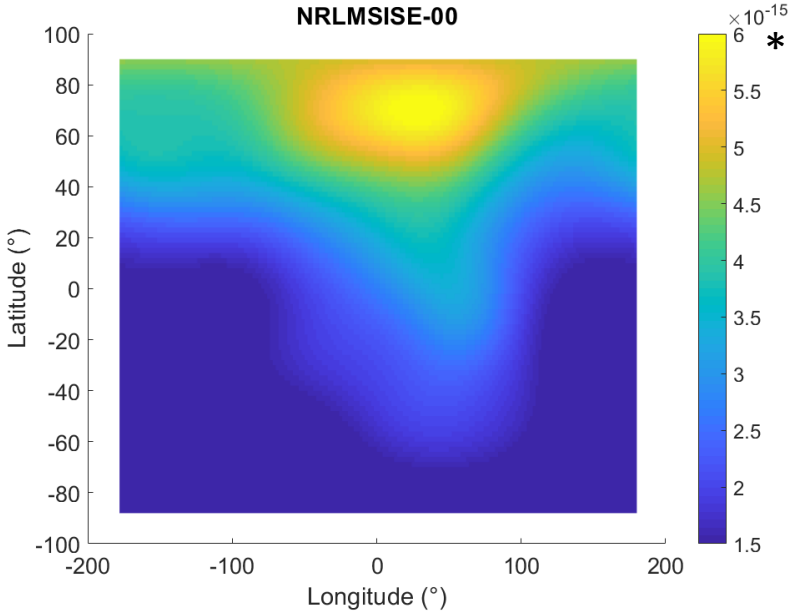
* Temperature (K) * Density (kg/m^3)

Atmospheric model output: Sentinel 3A altitude

Altitude : 825 km

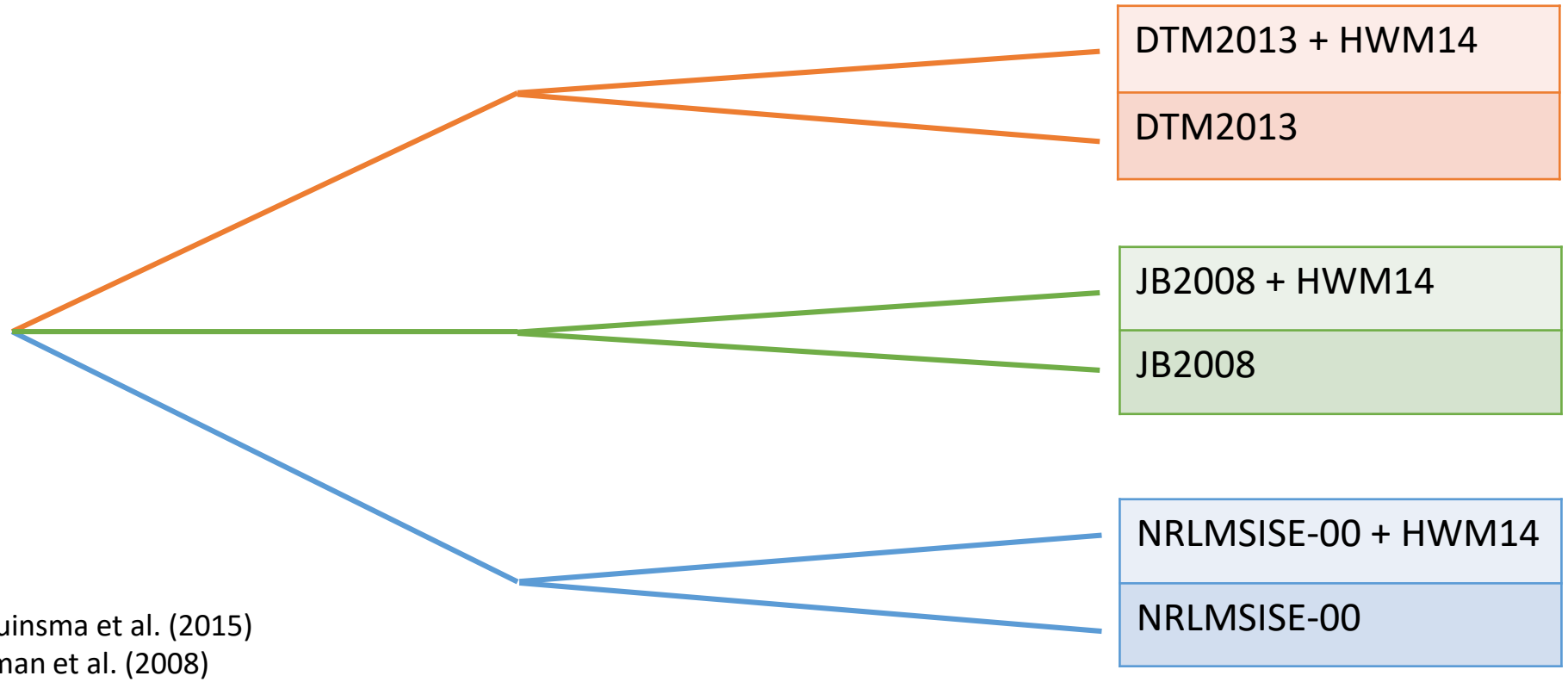






* Temperature (K) * Density (kg/m^3)

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.

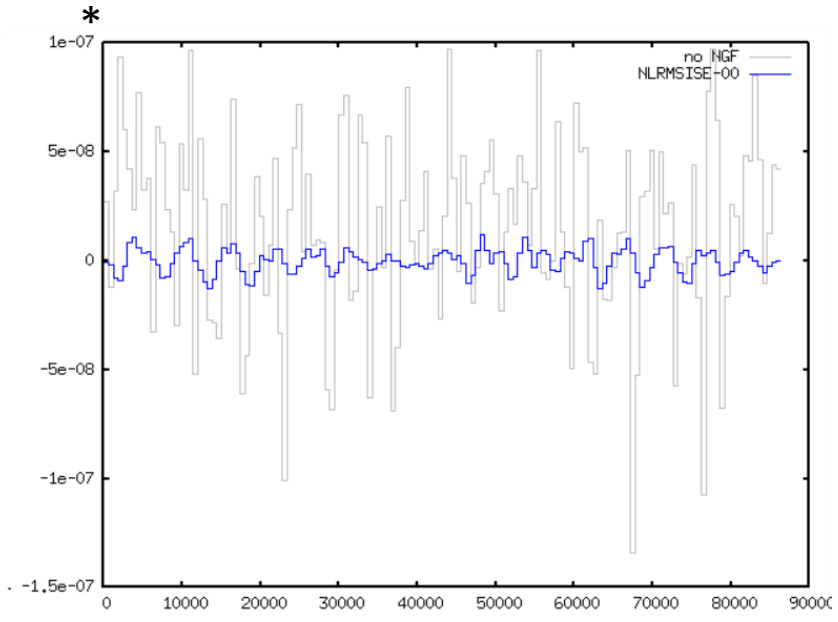
Reduced-dynamic orbit using Piecewise Constant Accelerations (PCAs)

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

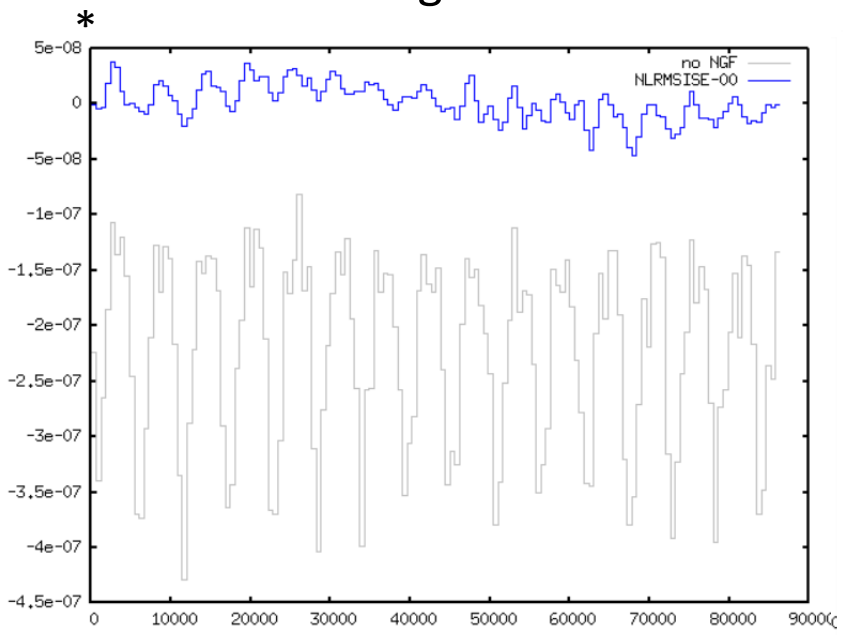
DTM2013
JB2008
NRLMSISE-00

Radial



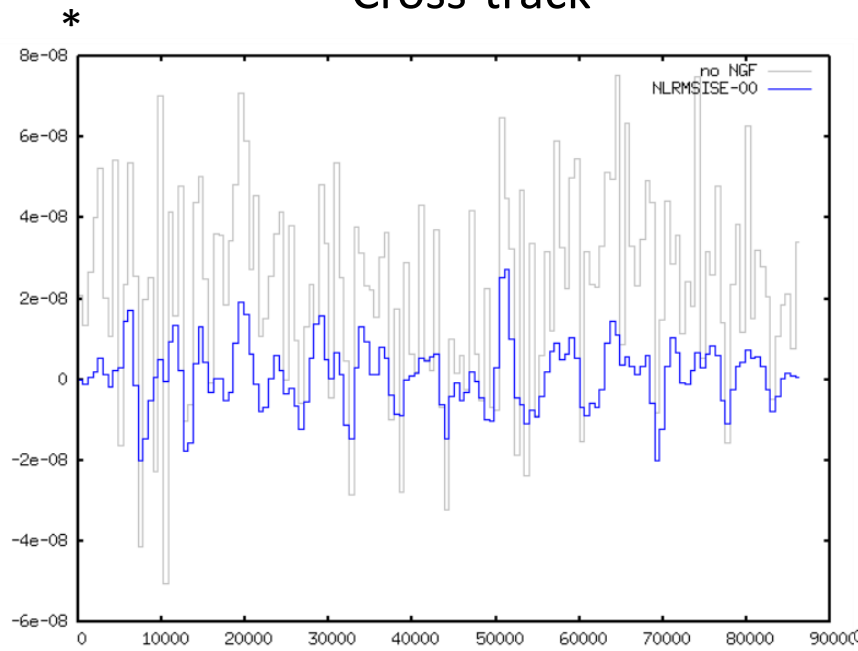
Epoch (s), doy 222 year 2014

Along-track



Epoch (s), doy 222 year 2014

Cross-track



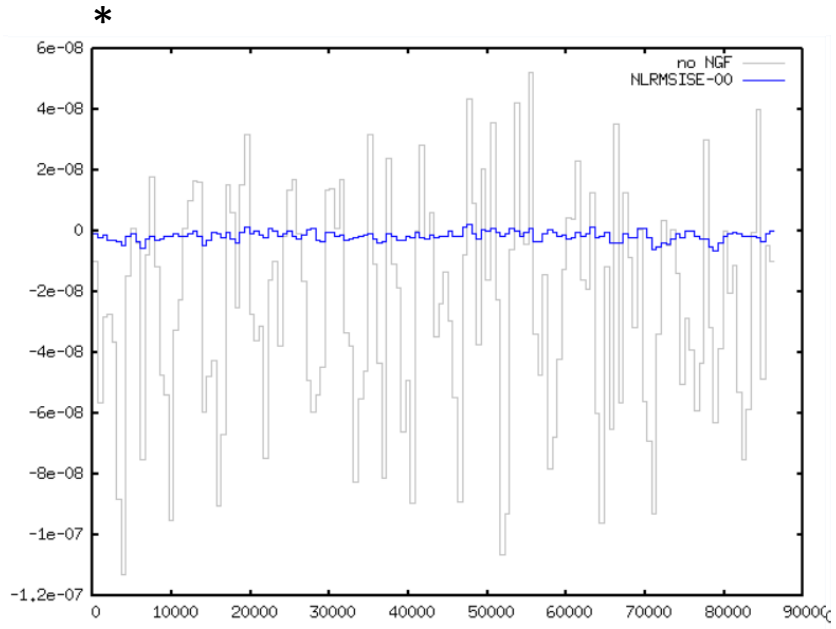
Epoch (s), doy 222 year 2014

* Accelerations (m/s^2)

Piecewise Constant Accelerations: Sentinel 3A

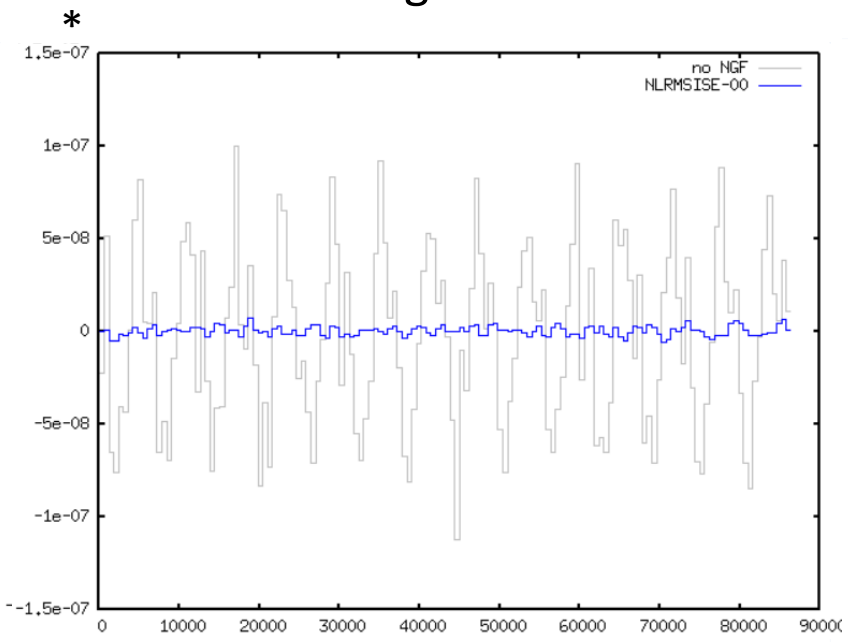
DTM2013
JB2008
NRLMSISE-00

Radial



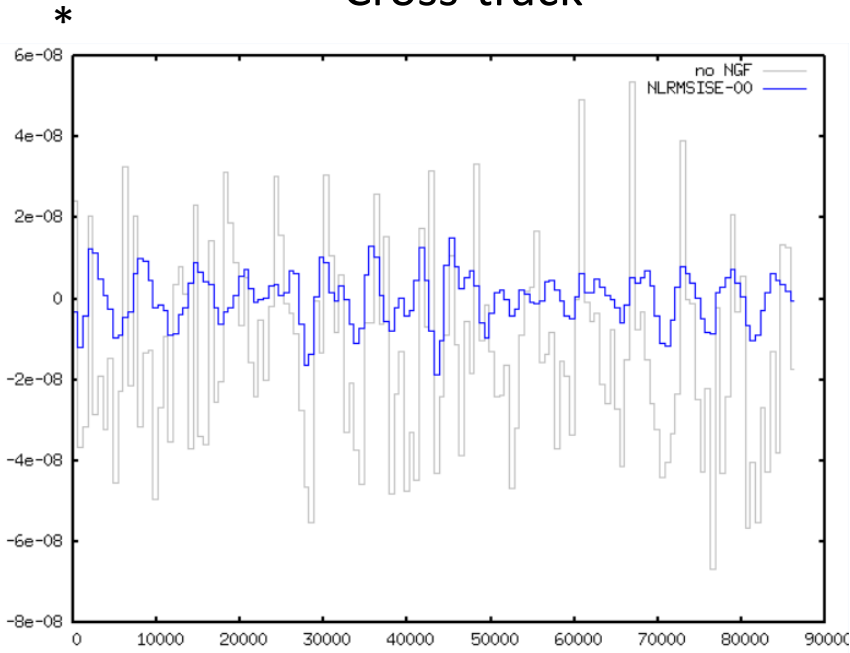
Epoch (s), doy 222 year 2016

Along-track



Epoch (s), doy 222 year 2016

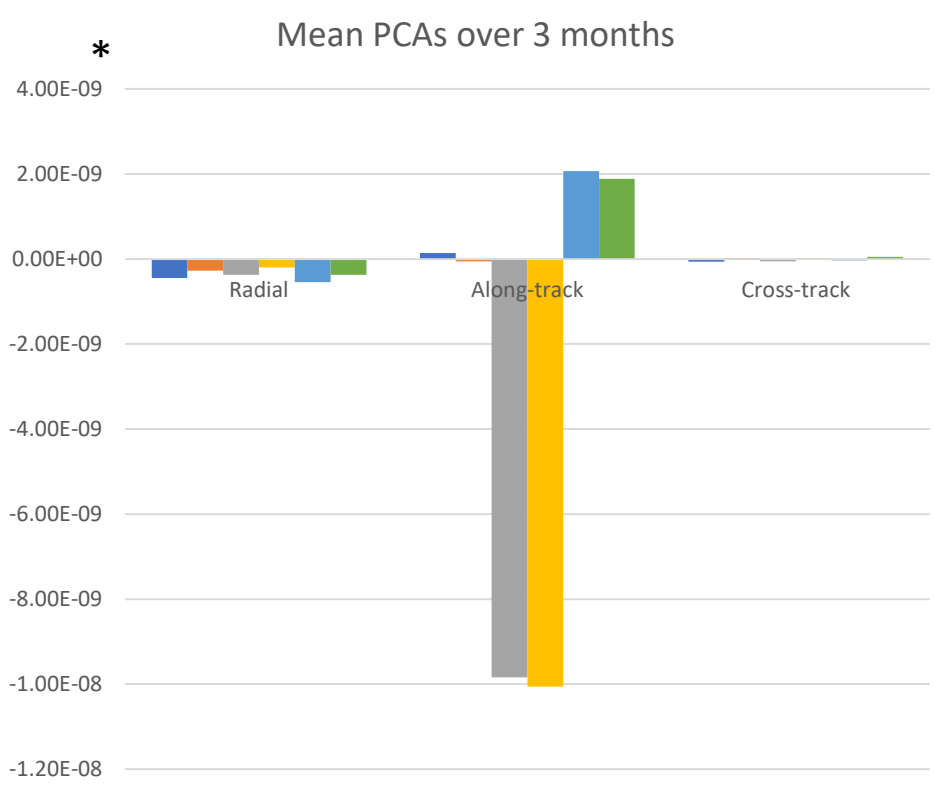
Cross-track

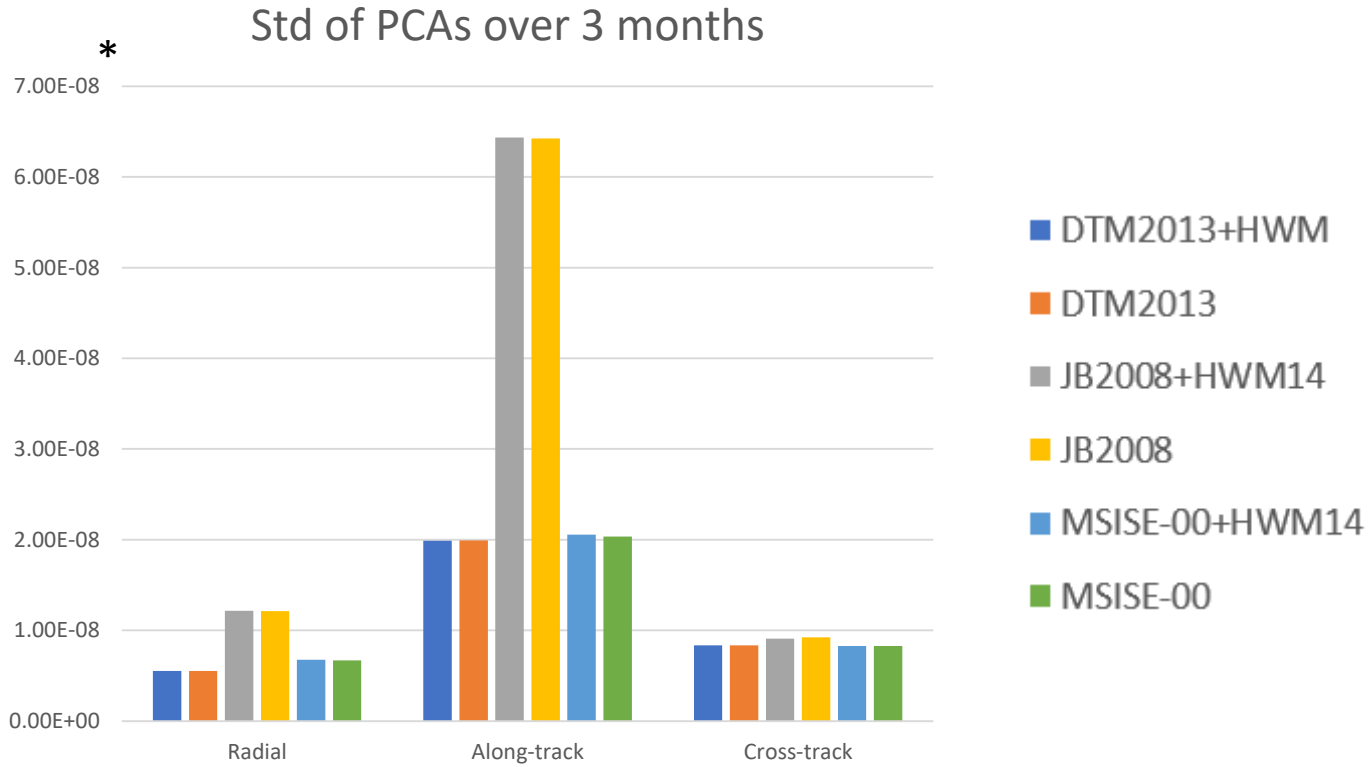


Epoch (s), doy 222 year 2016

* Accelerations (m/s^2)

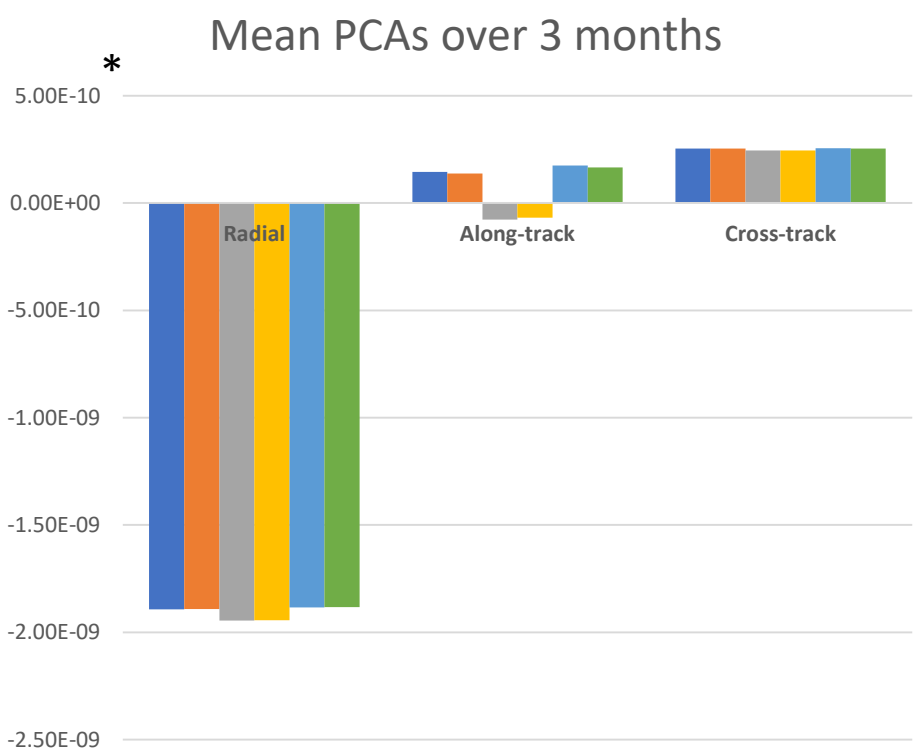
Piecewise Constant Accelerations: Statistics for GRACE A

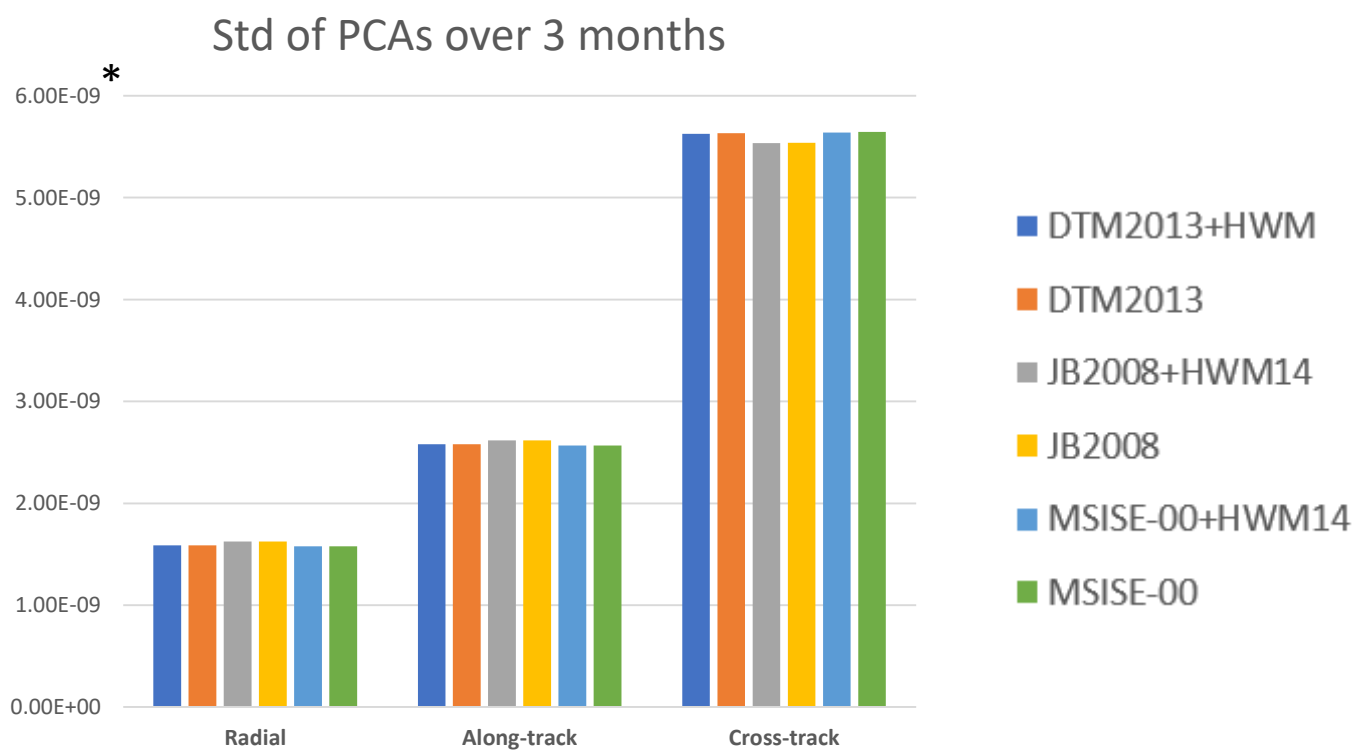




* Accelerations (m/s^2)

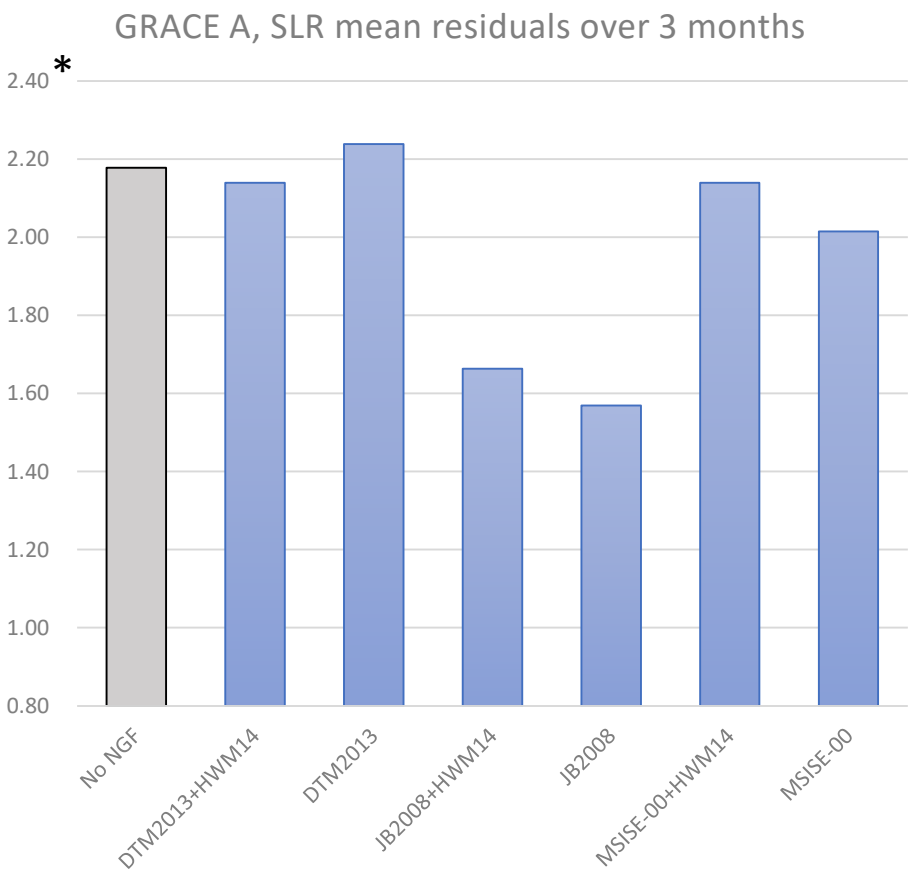
Piecewise Constant Accelerations: Statistics for Sentinel 3A

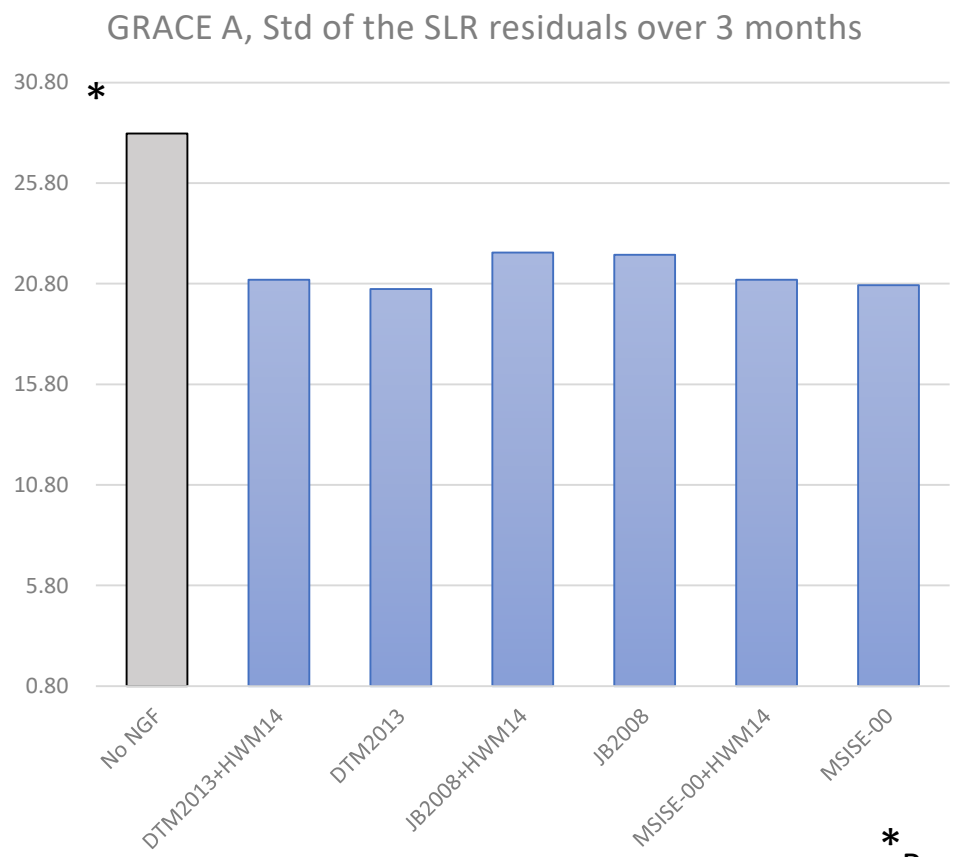




* Accelerations (m/s^2)

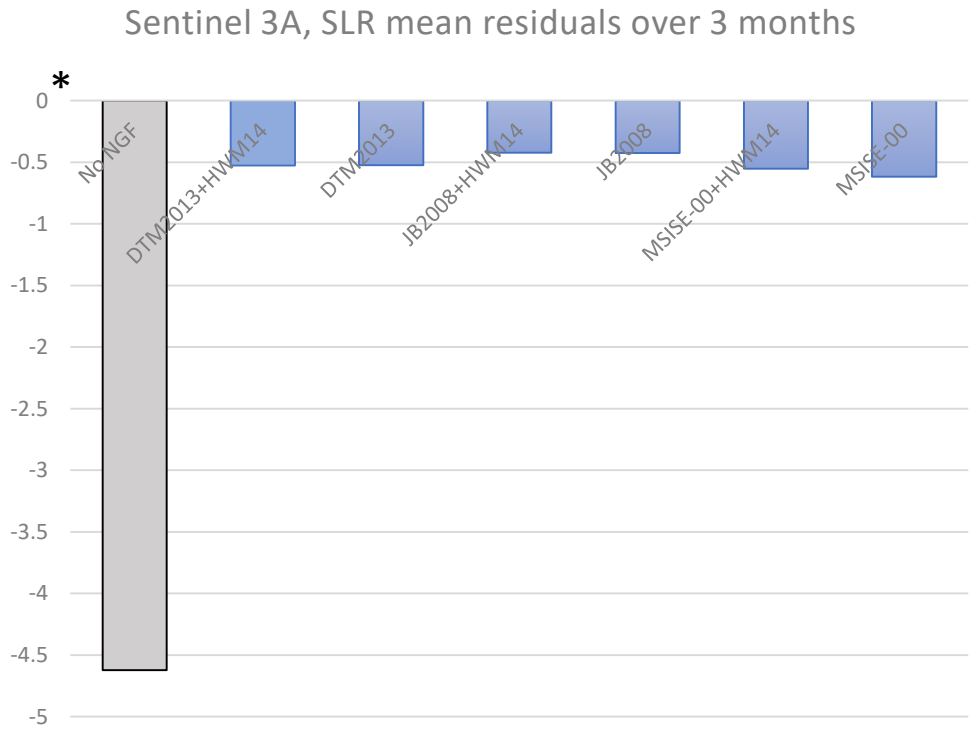
Satellite Laser Ranging: Statistics for GRACE A

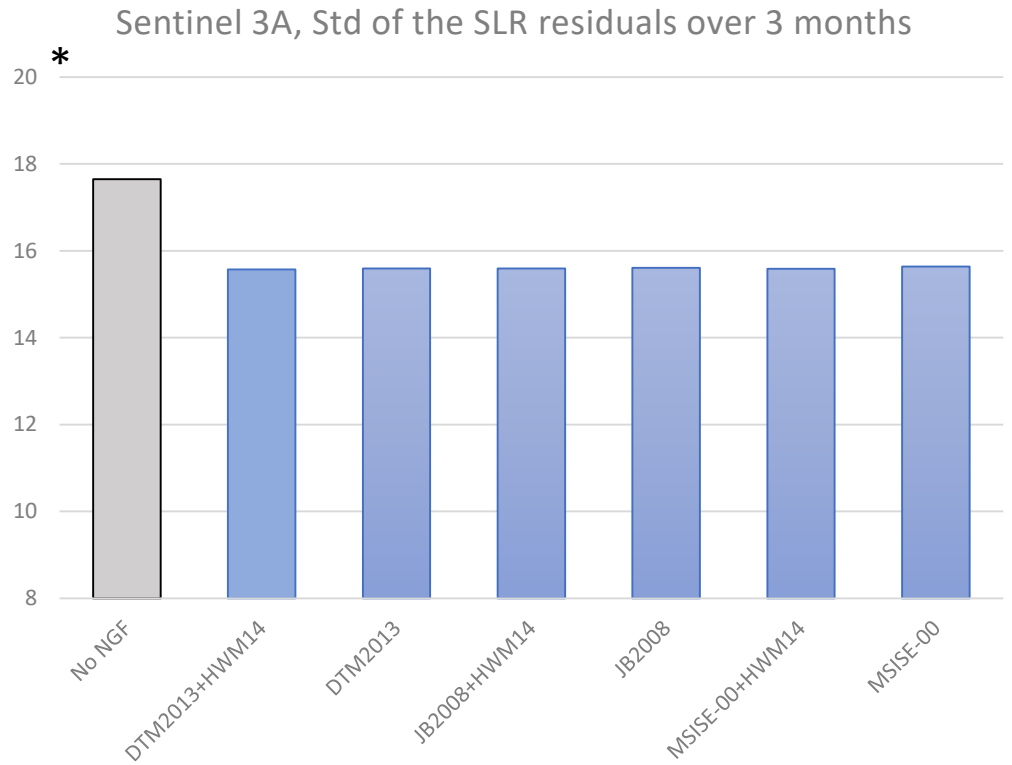




* Range residuals (mm)

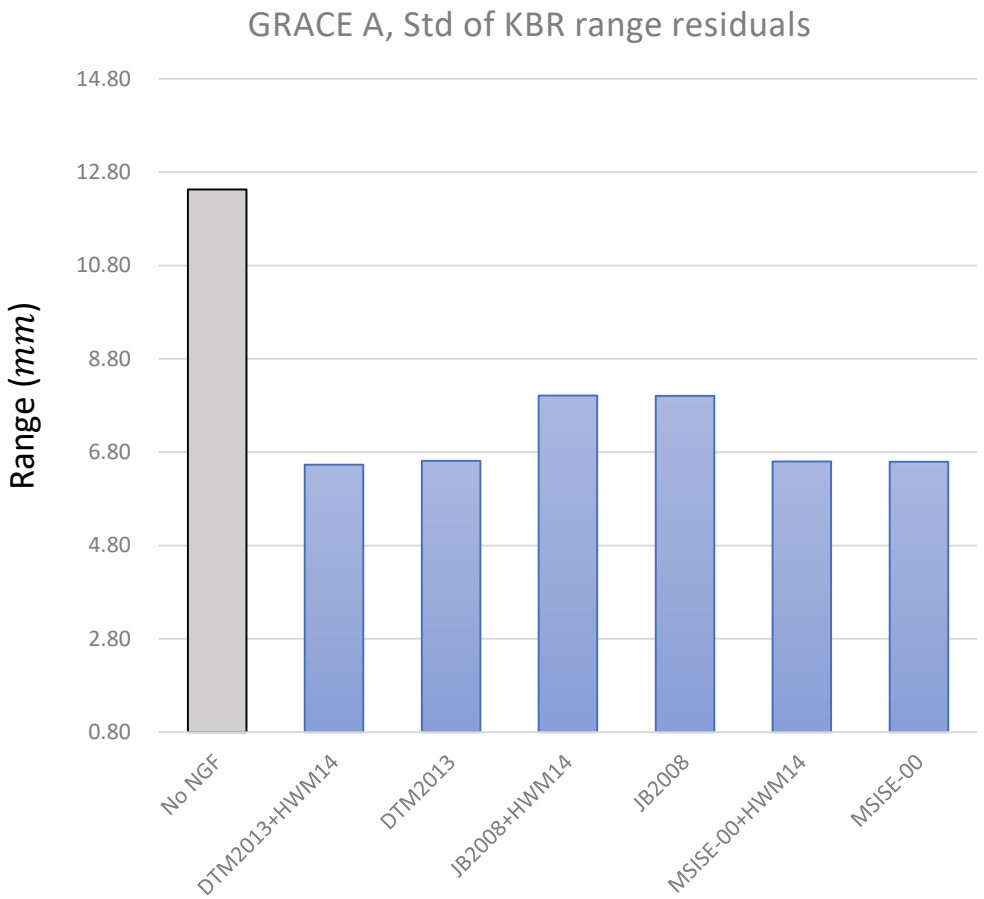
Satellite Laser Ranging: Statistics for Sentinel 3A

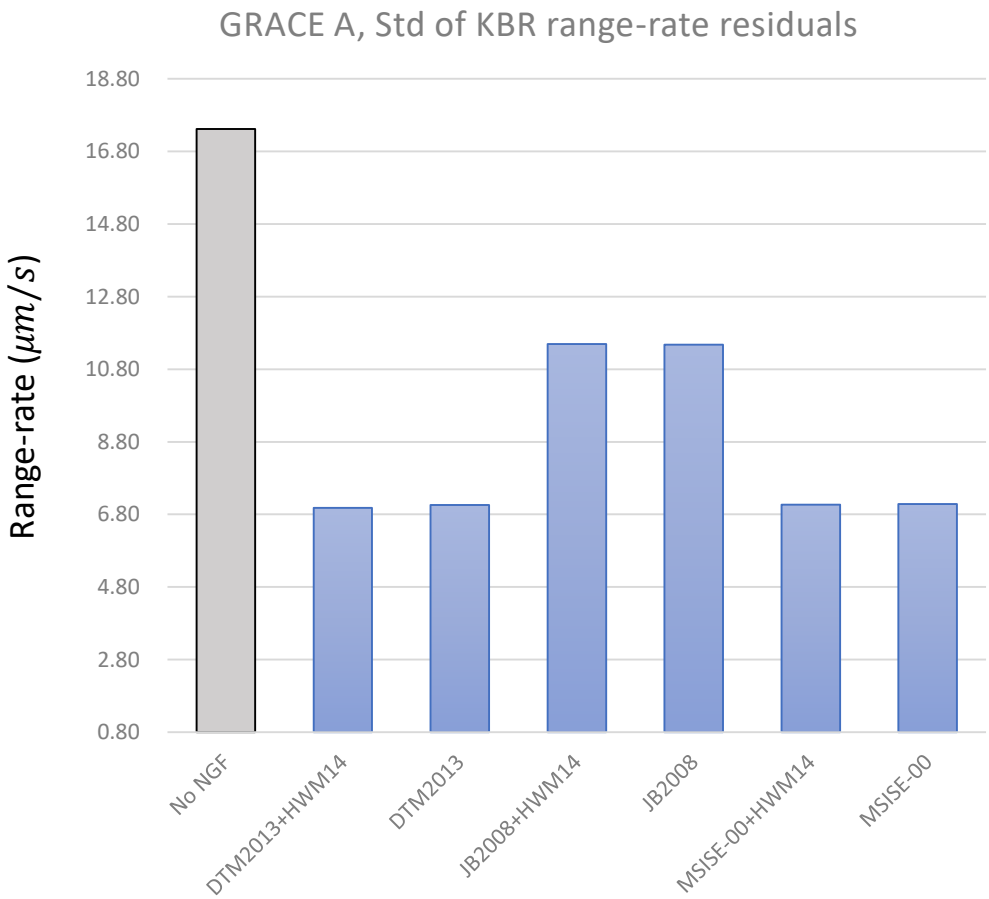




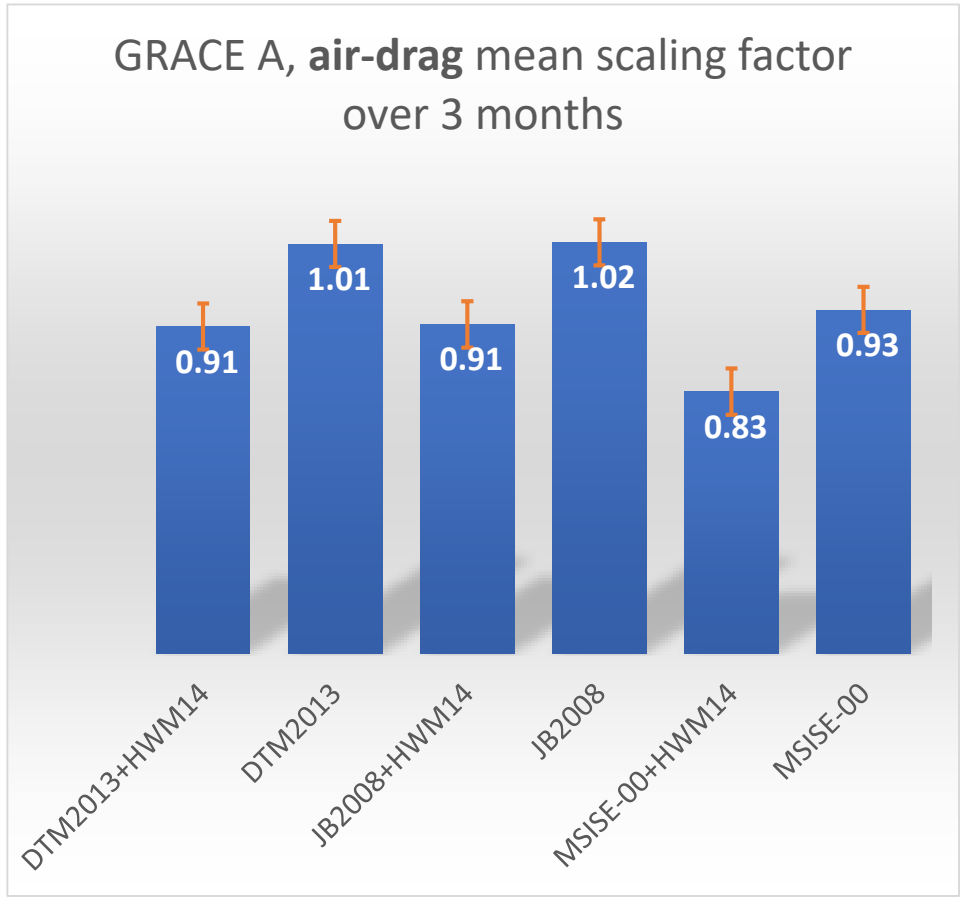
* Range residuals (mm)

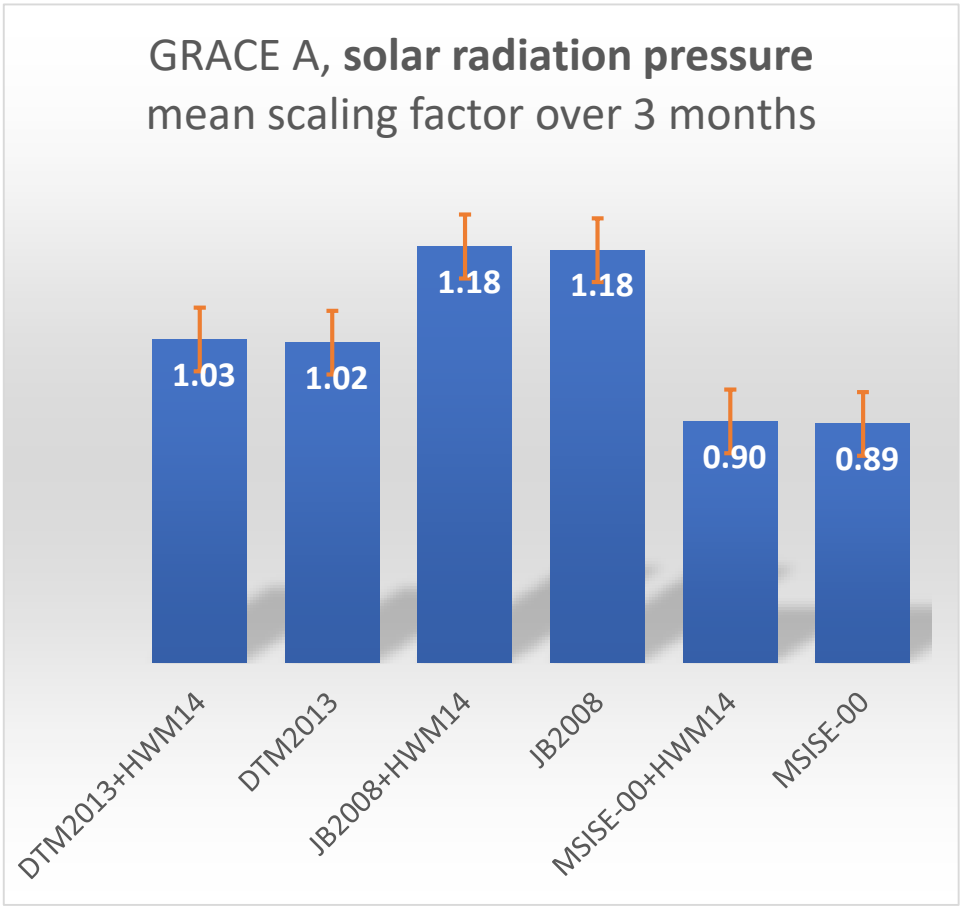
K-band: Statistics for GRACE A&B



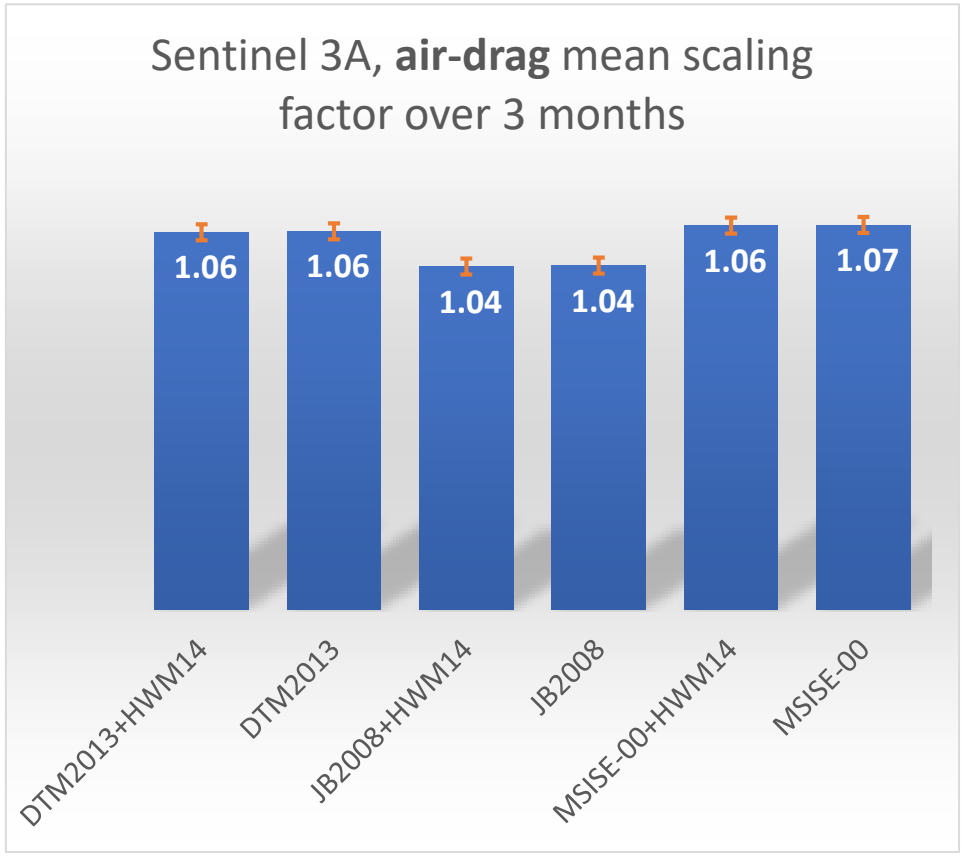


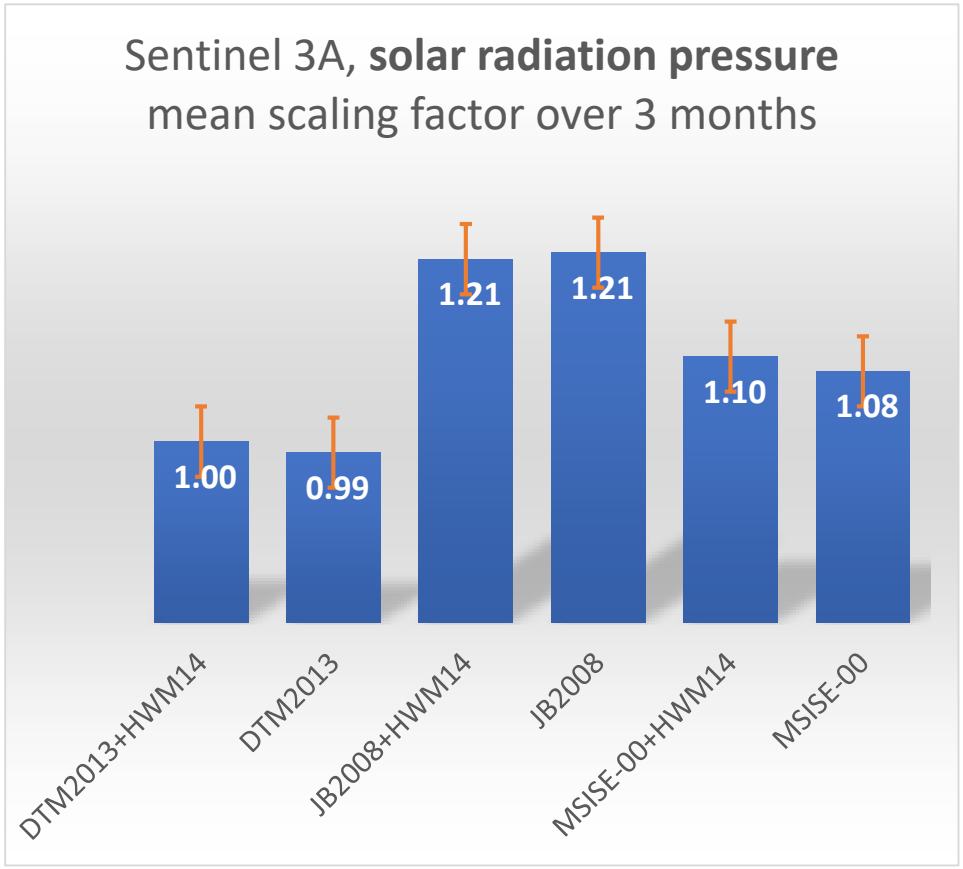
Scaling factors: GRACE A





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