Data-driven Atmospheric Drag and Radiation Pressure Models Based on GRACE-C Accelerometer Measurements for the Study of the Upper Atmosphere

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Abstract

The atmospheric drag and the Radiation Pressure are the dominant forces acting on LEO satellites. Many different approaches have been followed for the modelling of these non-gravitational forces, based on the physics and the satellite characteristics, but in many cases large inconsistencies are present between the models and the accelerometer measurements. Atmospheric drag is considered as the most difficult force to model, and the Radiation Pressure models show large deviations from the measurements depending on the b' angle and the position of the satellite near the entrance and the exit from the Earth's shadow. Numerous models have been presented for GRACE satellites but none for GRACE-FO. The innovation of this study is the development of an atmospheric drag and a Radiation Pressure data-driven model based only on the accelerometer measurements of GRACE-C satellite, using least squares principles. The atmospheric drag is modelled using accelerometer measurements from the shadow segment of the orbit. An additional weighted constraint is that near the middle of the sun segment of the orbit, the drag in the x-direction should be equal to the actual measurements due to Radiation Pressure being nearly zero. Subsequently, we subtract the modelled drag from the real measurements in order to estimate the Radiation Pressure which, consequently, is modelled using a least squares frequency-domain analysis. The residual series proceeded from the subtraction of these two models from the actual measurements of GRACE-C accelerometer, are analyzed by taking into consideration the local time, the spatial information and the variations of b′ angle, as well as their connection with electromagnetic changes in the upper atmosphere. The proposed models have been tested for different time periods in the last three years of GRACE C and the rms of the residual series along the x and the z axes of the accelerometer is ˜2.5 nm/s^2, while the y-axis exhibits an rms of ˜1 nm/sˆ2.

GRACE-FO accelerometer data: An alternative approach using Least Squares Spectral Analysis

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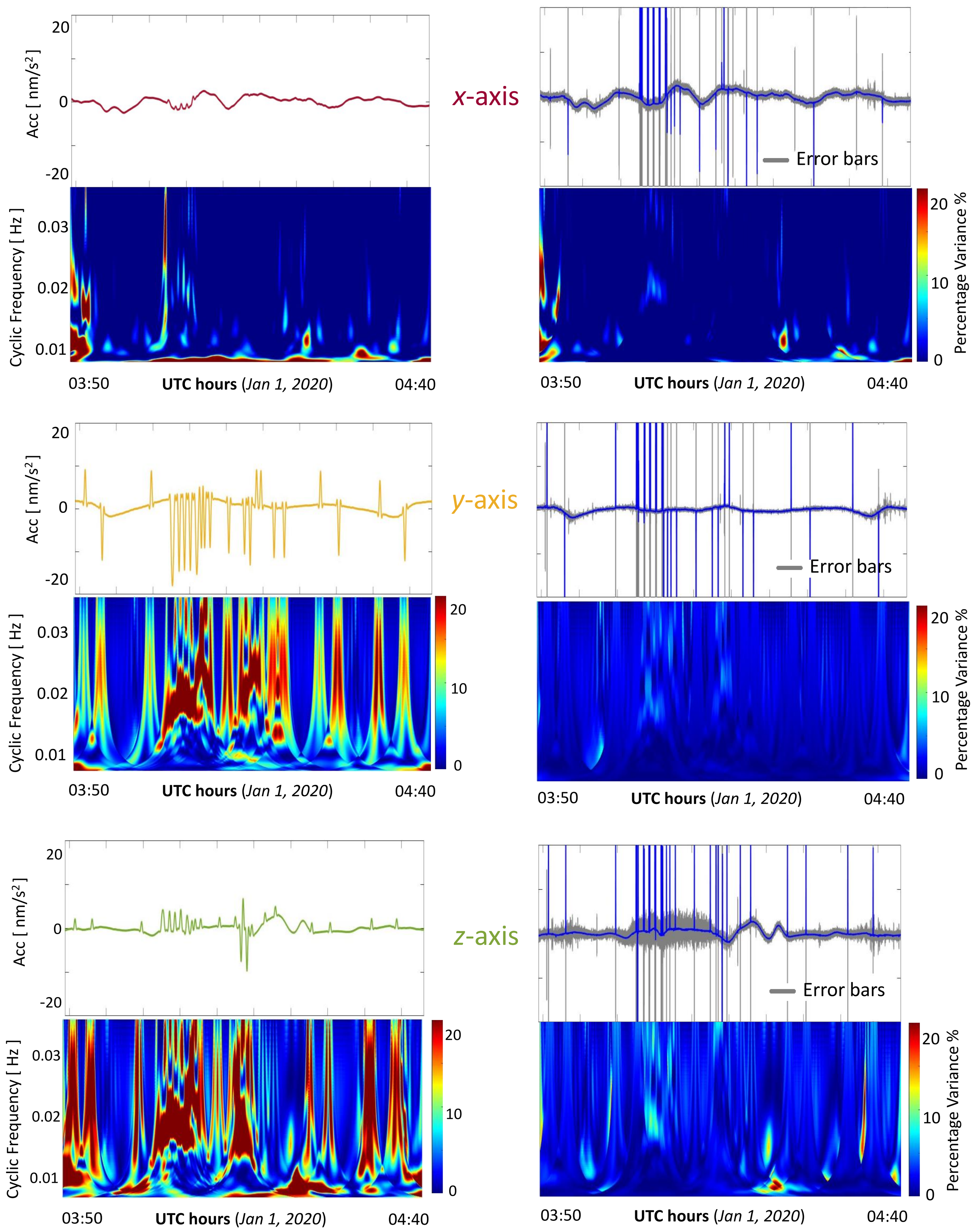
What can be really seen from GRACE C acceleration measurements? An analysis based solely on real measurements using LSSA.

ACW1B: An alternative Level 1B dataset for GRACE-FO

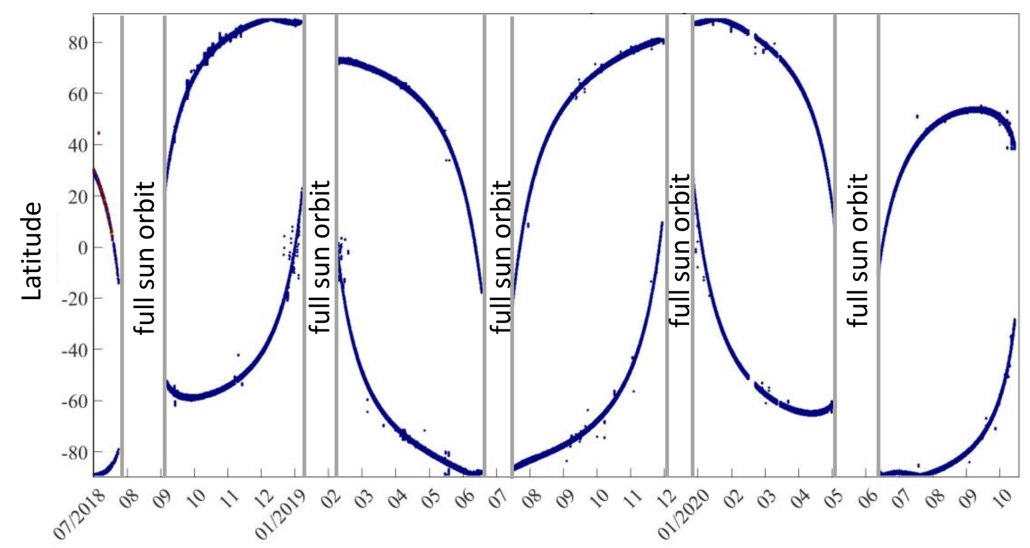
- **Weighted Gaussian filter** with a cut-off frequency of 35mHz is applied to ACC1A dataset.
- **Errors of filtered values** are estimated using the ACF within each Gaussian window.
- **No data points** are **removed** or **interpolated**.
- The **time correction** has been made according to Wu *et al.* (2006).
- The ACT1B dataset (Bandikova *et al*., 2019) is used for comparisons.
- Spikes on the ACW1B dataset don't affect any estimations either in time or frequency domain.
- Interpolation or removal of the spikes introduces aliasing effects in the frequency domain, especially in the cross–track and radial acceleration components.

LS Spectrograms of the residual series after the removal of the dominant orbital frequencies **ACT1B** (left) and **ACW1B** (right)



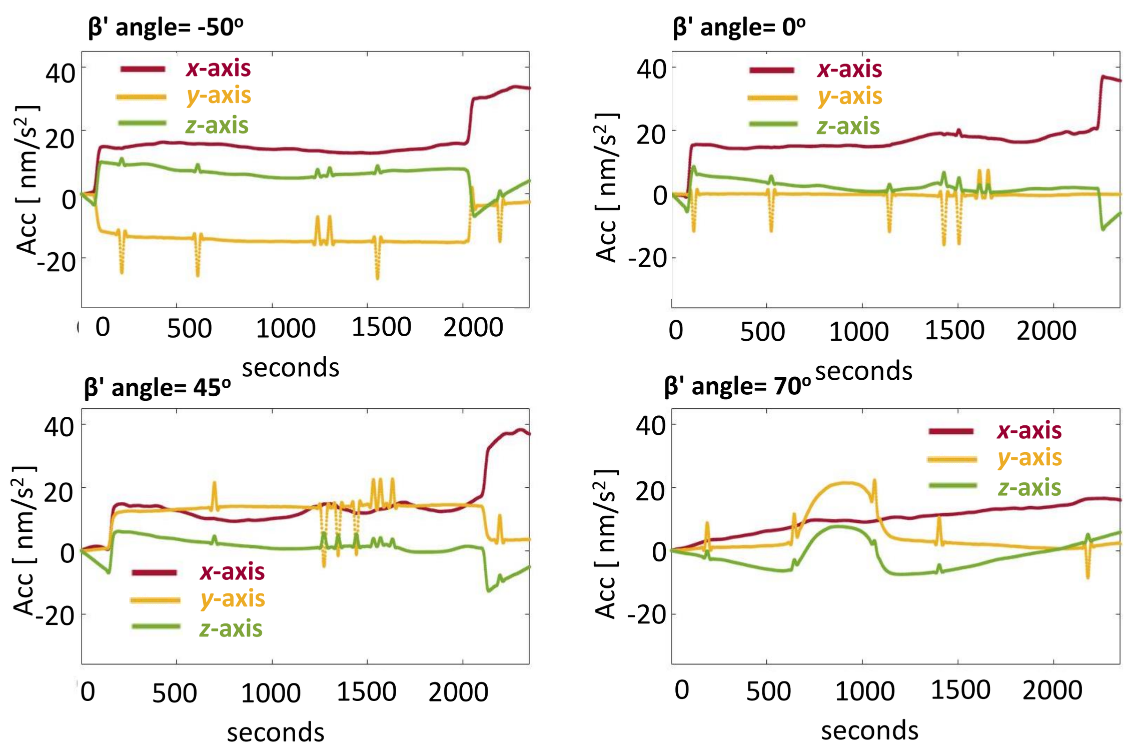
Penumbra Transitions of GRACE-FO

- Acceleration measurements present jumps when the satellites **enter and leave the Earth's shadow** (penumbra transitions).
- The **transitions are not present simultaneously in all three axes** for all β' angles.
- When **β' angle=0°** SRP is maximum, and **the cross-track component is not affected.**
- Penumbra locations are estimated using latitudinal information and a threshold applied on the first derivative of acceleration measurements **directly from GFO data (July 2018 – September 2020).**



Quantification of the time and the latitude that penumbra transitions occur at the x-axis of SRF of GRACE C from July 2018 – September 2020).

Penumbra transitions measured in each axis of SRF

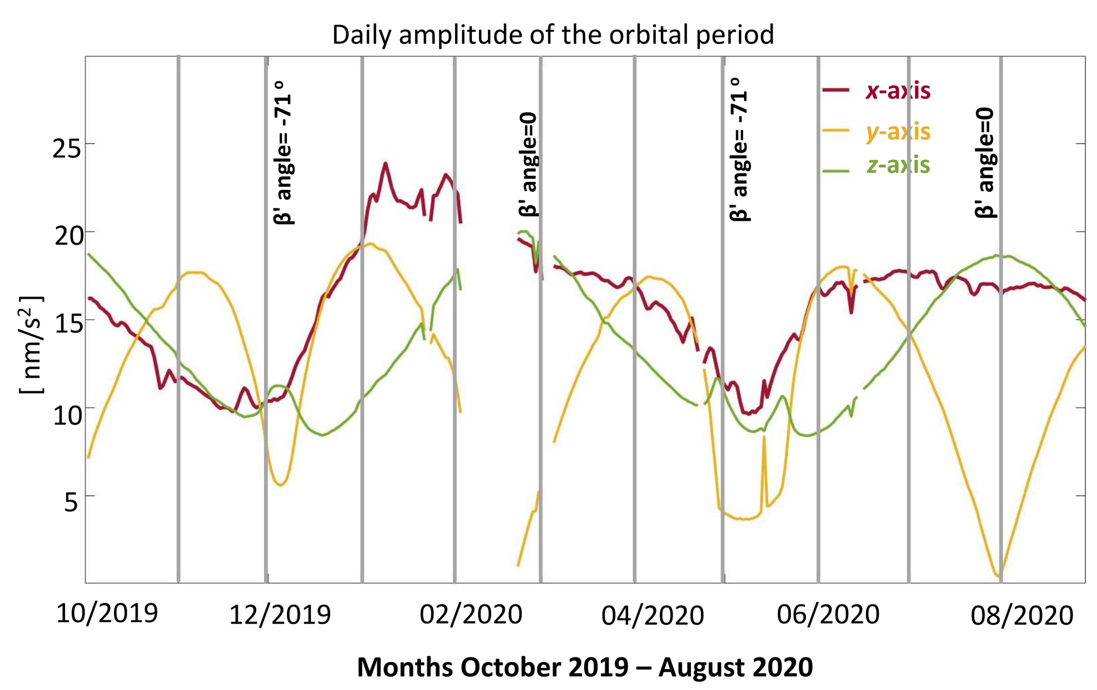


β' angle=0°: the satellite spends half of its revolution time to the shadow of the Earth. The **cross-track component does not present penumbra transitions.**

β' angle=~70°: no penumbra transitions are present **in the along-track axis.**

β' angle= ~-50° or ~45°: Penumbra transitions are **present at the three axes.**

- Accurate estimation **(from observations)** of the penumbra transitions and their time variability is **critical**.
- Investigation on **how the transitions affect each axis** is crucial. The discrepancy of the actual eclipse geometry with the models could introduce errors to the calibration of the instrument, the SRP modelling and the estimation of neutral winds.
- **Daily variations in the amplitudes of the period**, estimated from LSSA, **present a periodic signal of ~160 days** which is connected to the appearance of penumbra transitions and the temperature variations.

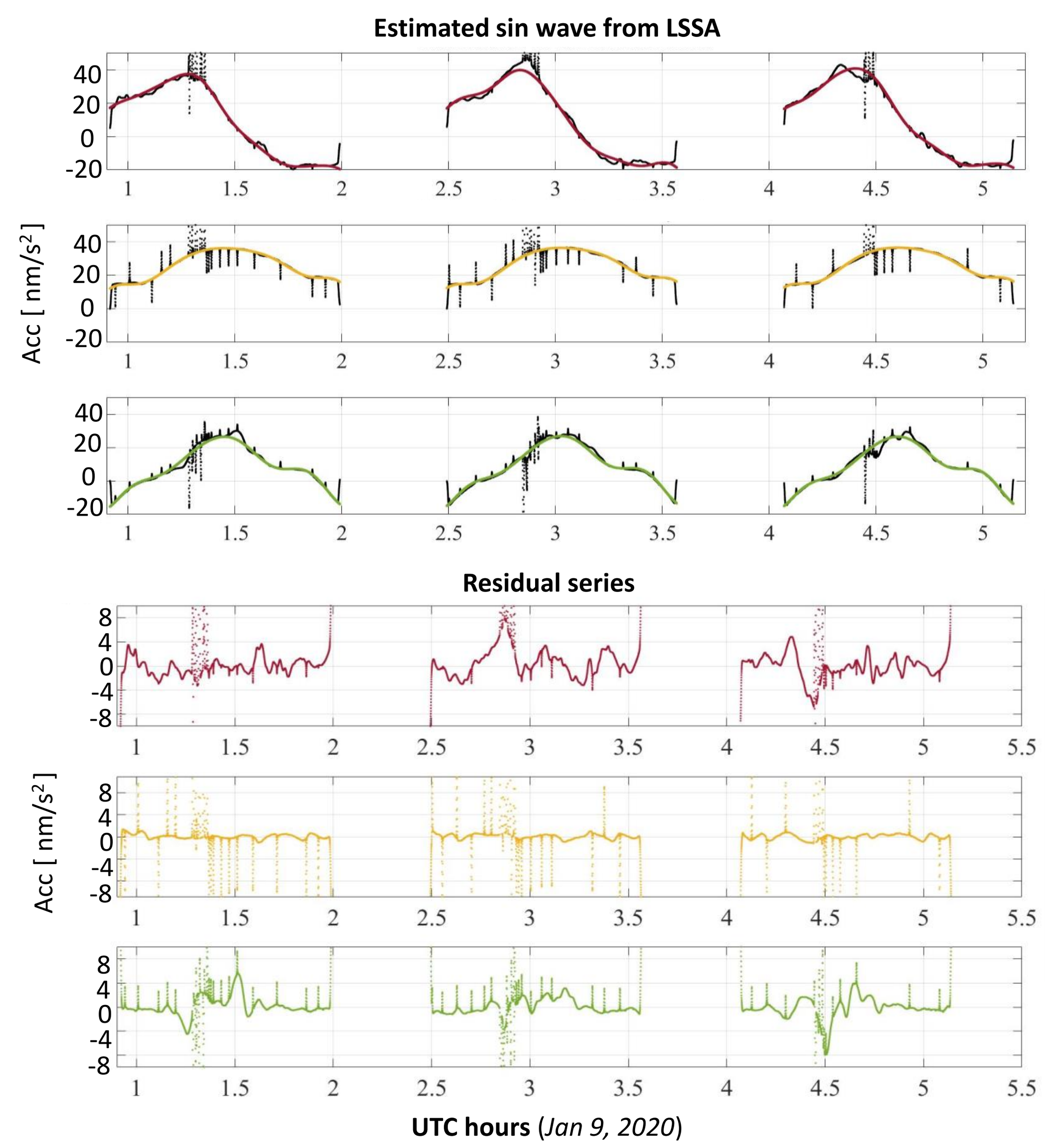


- Variations in the amplitudes of along and radial components are similar.
- Cross-track component present the minimum amplitude when β=0 and β= ~71° (no penumbra transitions in the cross-track).

Analysis of the residual series during the sun part of the orbit - January 9, 2020 (GRACE C)

- Estimation of non-gravitational accelerations in measurements, requires an **accurate determination of the jumps**.
- The estimated components agree with the SRP models.
- The residual series show correlation with electromagnetic disturbances.
- The **residual series in the cross-track is close to 0 both in the sun and shadow parts of the orbit.**
- Along-track and radial component present **high correlation with the changes in the solar wind speed and the Interplanetary Magnetic field components B_t and B_z.**

Sun parts of the ACW1B dataset



The radiation pressure for the sun parts of the orbit is calculated after the **correction of the penumbra transitions** and the **removal of the orbital frequency and its 4 harmonics**.

04:31 UTC h: Interplanetary field decreased 5nT. (NOAA – SWPC)

06:00-09:00 UTC: Kp index = 4-

07:41 UTC h: increase in solar wind speed ~700 km/sec

Conclusions

The above analysis is based only on the GRACE C ACC1A data. For the estimation of the non-gravitational forces **only the measurements** and **their standard deviations** are used.

To avoid aliasing in the frequency domain, an **alternative dataset ACW1B for GRACE-FO is proposed** with error estimates of each value. This dataset could be used to investigate the response of the accelerometer in **thermospheric disturbances**.

A **penumbra transition data driven model** is presented. Penumbra transitions are measured differently on each axis of SRF. **Examine the behavior of the transitions could enhance the gravity field models**. (~161 days in agreement with C20 signal)

Residual series derived from LSSA at the along-track and radial component of SRF, show **high correlation with the electromagnetic disturbances**.

Deciphering the DRAG from the RP components directly from the data will be investigated further and could be used for **orbit determination** and estimation of **neutral winds**.