Non-conservative GNSS satellite modeling: long-term orbit behavior

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1. Solar radiation pressure ➡ box-wing model

The main non-gravitational orbit perturbation acting on GNSS satellites is the solar radiation pressure. There are two main approaches to model this force:

1) adjusting empirical parameters that fit best the GNSS tracking data, and
2) computing the a priori force from analytical models based on the detailed satellite structure and information available on ground.

The first one is not based on the physical interaction between solar radiation and the satellite, while the second one can not be easily adjusted to the real on-orbit behaviour of the satellites, e.g., changes due to aging of optical properties or deviations from nominal attitude.

In this study an intermediate approach is used, an analytical box-wing model based on the physical interaction between the solar radiation and a satellite consisting of a bus (box shape) and solar panels (Rodriguez-Solano et al., 2012). Furthermore, some of the parameters of the box-wing model can be adjusted to fit the GNSS tracking data, namely the optical properties of the satellite surfaces.

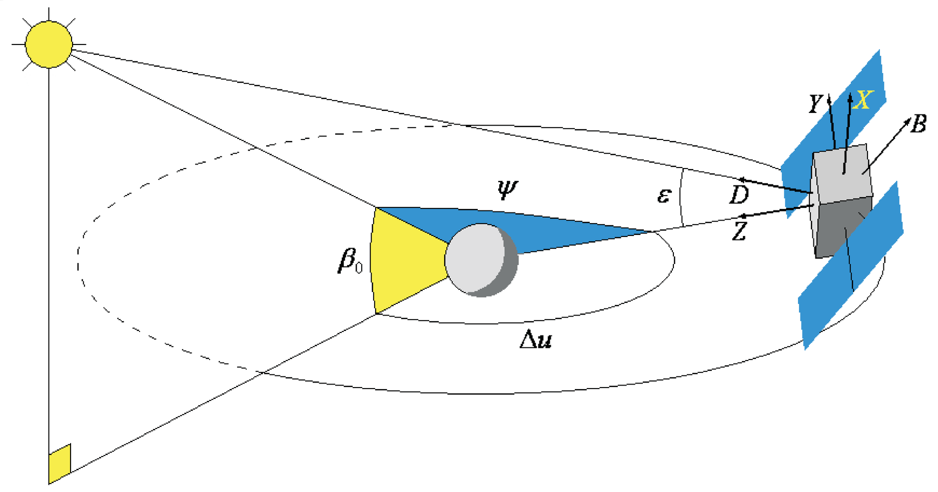
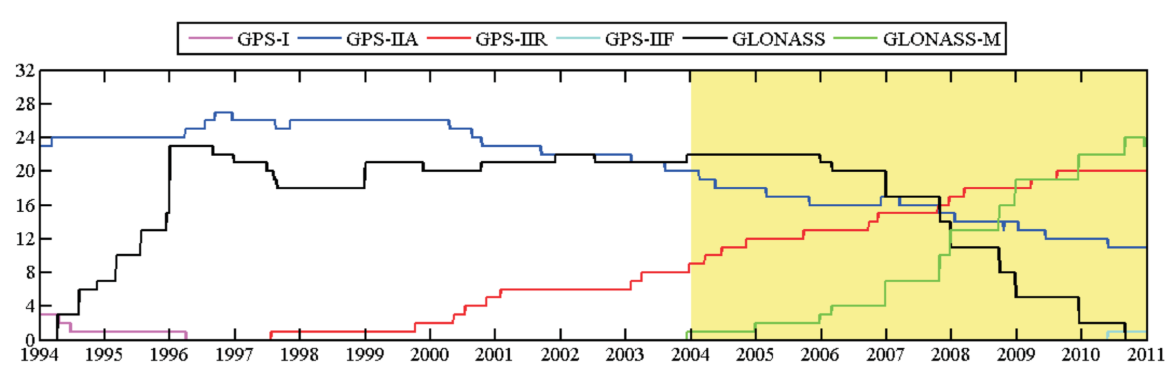
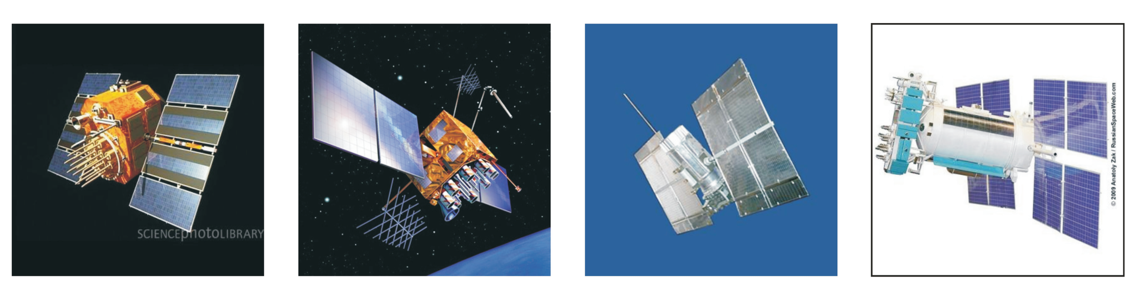


Fig. 1: Relative geometry of Sun, Earth and satellite. Illustration of DYB (Sun-fixed) and XYZ (body-fixed) frames.

In this study, two multi-year (2004-2010, Fig. 2) GPS/GLONASS solutions have been computed, using a processing scheme derived from CODE (Center for Orbit Determination in Europe). The first solution uses the CODE empirical radiation pressure model (Beutler et al., 1994) and the second one uses the adjustable box-wing model. Furthermore, Earth radiation pressure and antenna thrust are included as a priori acceleration.

This multi-year solution allows studying the long-term behavior of satellite orbits, box-wing parameters and geodetic parameters, e.g. station coordinates. Moreover, the accuracy of GNSS orbits is assessed by using SLR data.





GPS IIA G06 / SVN 36 — **GPS IIR** G28 / SVN 44 — **GLONASS** R22 / SVN 791 — **GLONASS-M** R24 / SVN 713

Fig. 2: The top figure shows the number and block type of GNSS satellites from 1994 to 2010. The years 2004-2010 were selected to study the main types of GNSS satellites (shown at the bottom figure together with specific spacecraft selected for this work).

2. On-orbit optical properties

The daily estimates of the adjustable box-wing model are shown in the following figures, the main parameters of the model are:

- SP: solar panel scaling factor
- SB: solar panel rotation lag
- Y0: Y-bias acceleration
- +XR: reflection coefficient of +X bus
- +ZR: reflection coefficient of +Z bus
- -ZR: reflection coefficient of -Z bus

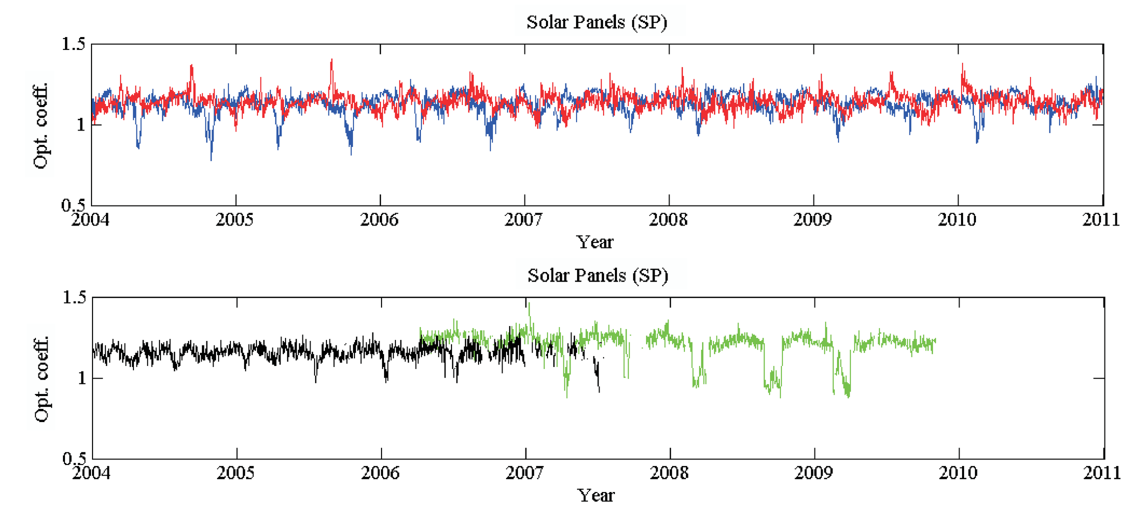


Fig. 3: Solar panel scaling factor as function of time for selected spacecrafts (Fig. 2, bottom). The periods where the values of SP are low for SVN 36 (GPS IIA) and SVN 713 (GLONASS-M), correspond to periods with $|\beta_0| < 13.5°$ (eclipse seasons) and $|\beta_0| < 22.5°$ respectively.

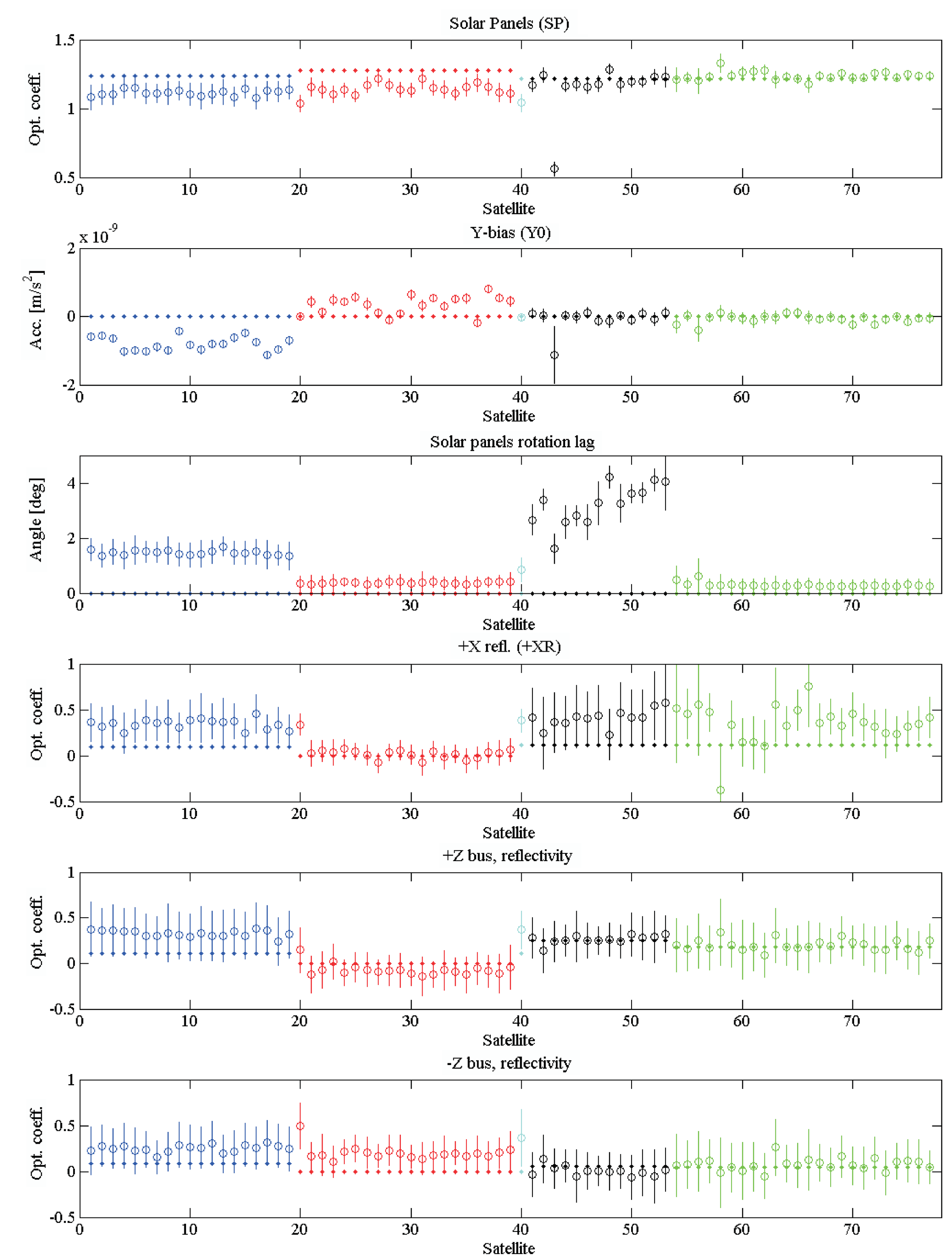


Fig. 4: Mean and standard deviation of the parameters of the adjustable box-wing model for the 77 satellites available during 2004-2010 (GPS IIA, GPS IIR, GPS IIF, GLONASS and GLONASS-M). A priori values are shown with dots.

3. SLR orbit validation

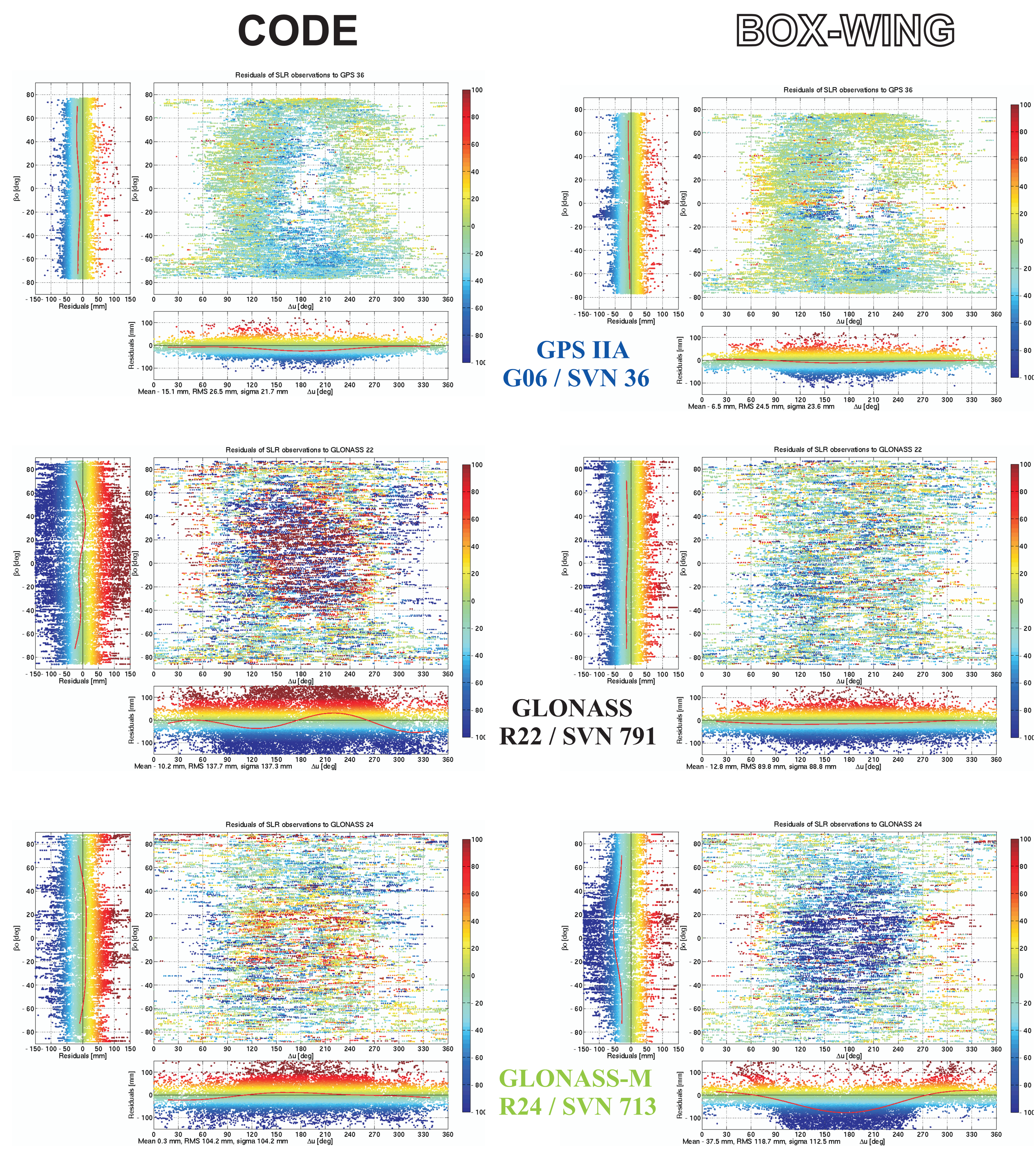


Fig. 5: SLR residuals in millimeters for selected satellites in a Sun-fixed reference frame (see Fig. 1). The SLR resdiuals show particular patterns when plotted in this reference frame. The patterns are reduced for most satellites when using the box-wing model, with the exception of SVN 713 which exhibits a different behavior than other satellites for $|\beta_0| < 22.5°$ (see Fig. 3).

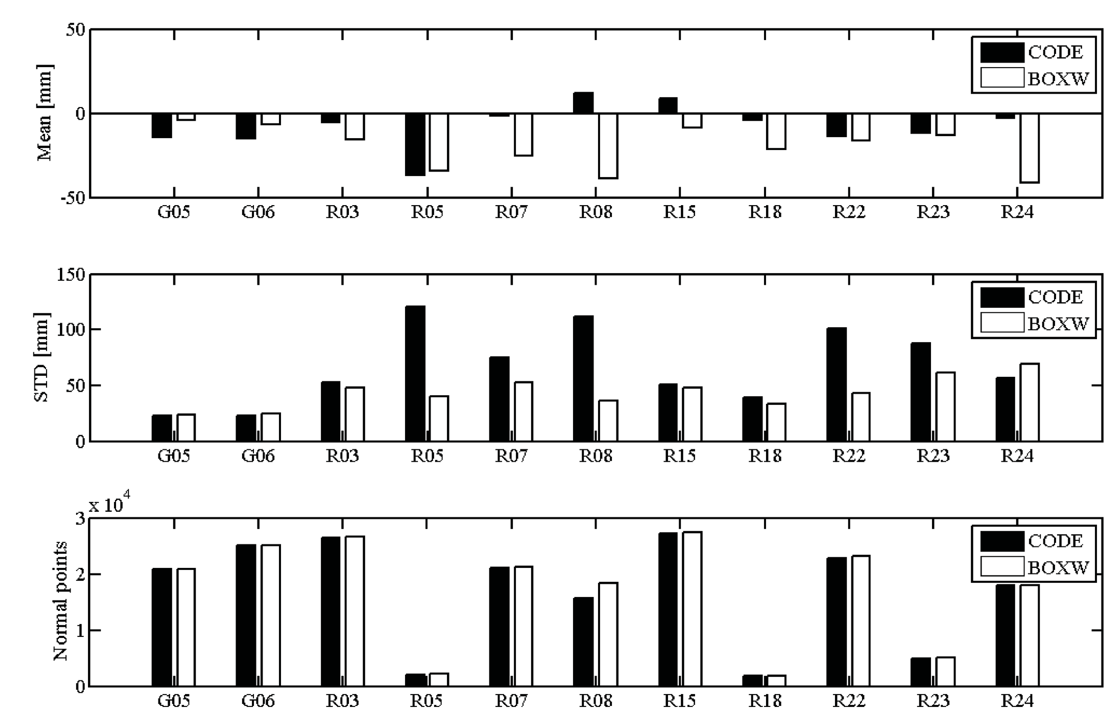


Fig. 6: Mean and standard deviation of SLR residuals and number of SLR normal points for the satellites tracked during 2004-2010. Thresholds of 150 mm and 300 mm were used to exclude outliers from the SLR residuals, for GPS and GLONASS respectively. The box-wing model mainly reduces the GPS-SLR bias to -4.1 mm and -6.5 mm for G05 / SVN 35 and G06 / SVN 36 respectively. In the case of GLONASS satellites the box-wing model mainly reduces the standard deviation of the SLR residuals, except for R24 / SVN 713.

4. Comparison between SRP models

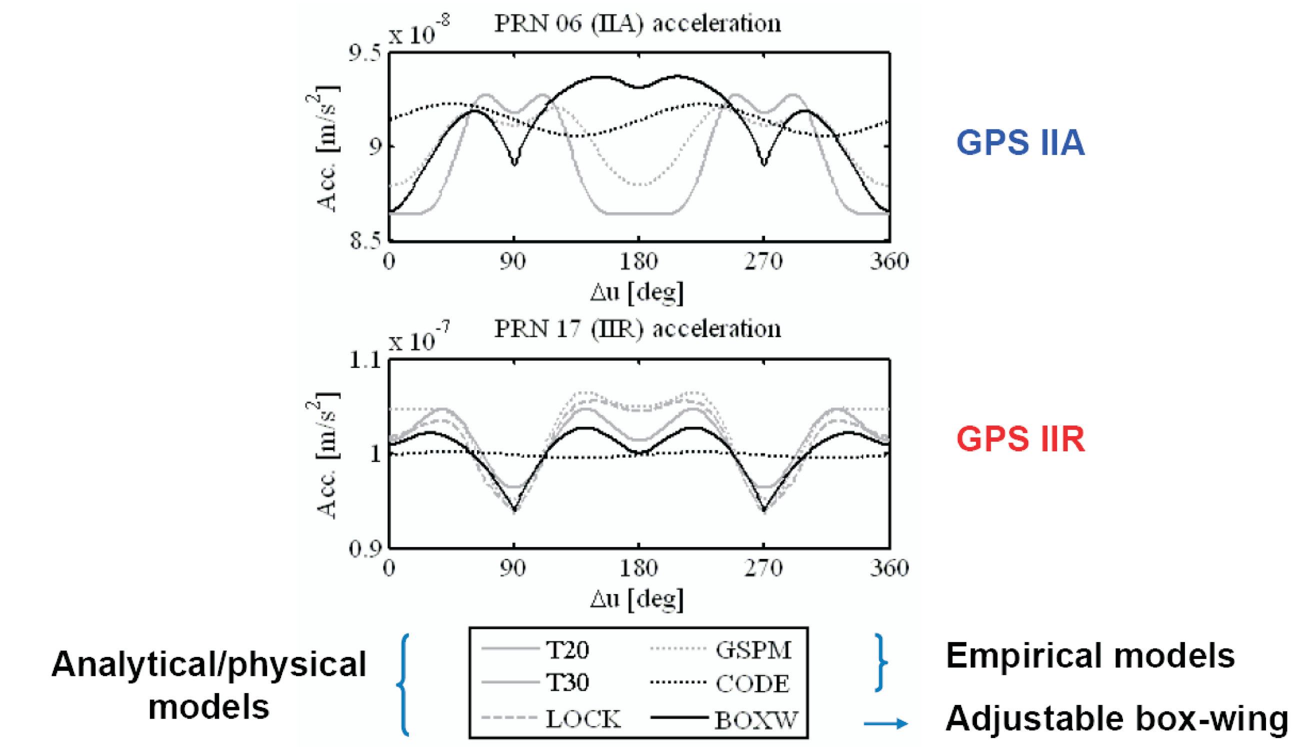


Fig. 7: Reconstructed total acceleration due to solar radiation pressure (SRP) for the box-wing model and comparison with existing models, for $\beta_0 \sim 15°$ (Rodriguez-Solano et al., 2012). Note the large differences between models for GPS IIA and $90° < \Delta u < 270°$. The SLR residuals (Fig. 5) also differs the most for $90° < \Delta u < 270°$, in the case of GPS IIA.

5. Impact on station coordinates

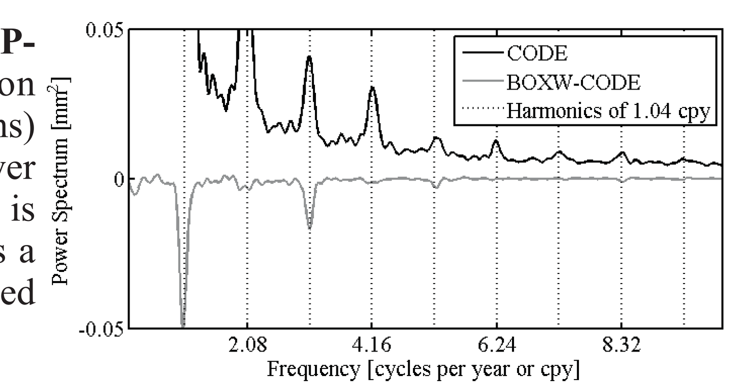


Fig. 8: Average power spectrum of the **UP-component** of GNSS daily position estimates (266 ground tracking stations) from 2004 to 2010. The difference of power spectrum between box-wing and CODE is shown in gray, a negative sign indicates a reduction of the power spectrum achieved by the box-wing model.

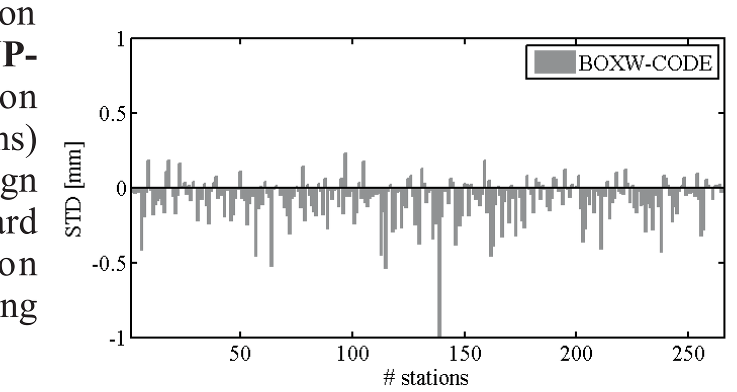


Fig. 9: Difference of standard deviation (between box-wing and CODE) for the **UP-component** of GNSS daily position estimates (266 ground tracking stations) from 2004 to 2010. A negative sign indicates a reduction of the standard deviation (improvement of station repeatability) achieved by the box-wing model.

6. Impact on geocenter ➡ talk on session G2.3 (Thursday, 11:00)

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DFG project *"LEO orbit modeling improvement and application for GNSS and DORIS LEO satellites"*

DFG project *"Geodätische und geodynamische Nutzung reprozessierter GPS-, GLONASS- und SLR-Daten"*

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