Adjustable box-wing model for solar radiation pressure impacting GPS satellites

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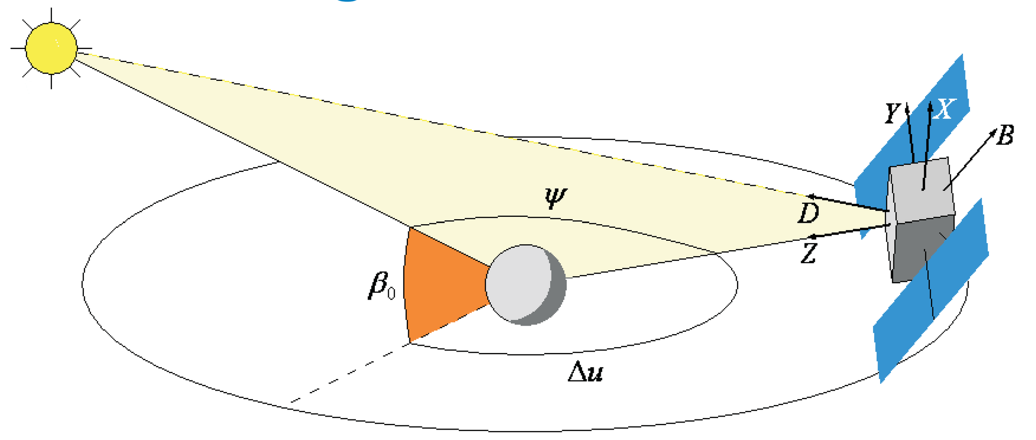
1. Introduction

GPS satellites are at a distance from the Earth where the solar radiation pressure is the main non-gravitational orbit perturbation. While the solar radiation impacting the satellites is simple to model, the perturbing acceleration depends on the structure of the satellite and on the optical properties of each surface facing the Sun. Furthermore the satellite is constantly changing its orientation with respect to the Sun to maintain its nominal attitude, making the modelling of solar radiation pressure a complex task.

2. The CODE Model

To compensate for solar radiation pressure, the IGS (International GNSS Service) Analysis Centers usually estimate empirical parameters which fit best the tracking data obtained from a global network of GNSS ground stations. This has allowed computing orbits at an accuracy level of 2.5 cm for GPS satellites. The Center for Orbit Determination in Europe (CODE) estimates five parameters (per satellite and per day) in a satellite-Sun fixed reference frame. These parameters are three constants in the D, Y and B directions and two peridic (once per revolution) in the B direction. Additionally, three pseudo-stochastic pulses are estimated once per revolution in the radial, along-track and cross-track directions. The acceleration of the a priori CODE model (updated, Springer et al., 1999) is introduced.

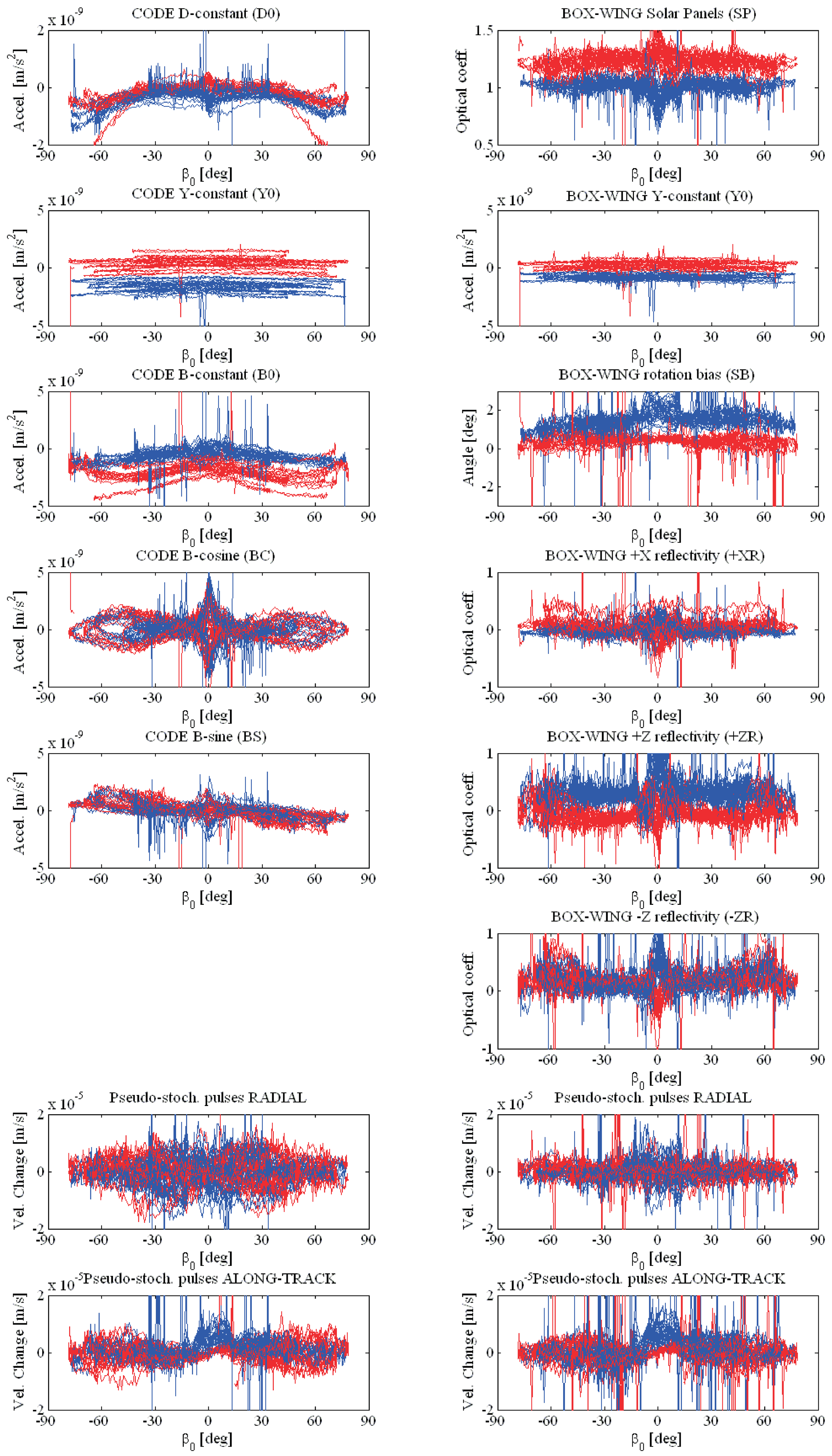
3. The Box-Wing Model



For this study an analytical box-wing model has been derived based on the physical interaction between the solar radiation and a satellite consisting of a bus (box shape) and solar panels. Furthermore some of the parameters of the box-wing model can be adjusted to fit the GPS tracking data, namely the optical properties of the satellite surfaces. A similar approach has been applied by Marshall and Luthcke (1994) for the Topex/Poseidon satellite. Additionally a parameter related to a rotation angle bias of the solar panel array around its rotation axis was included in the box-wing model. The orientation error of the GPS satellite's solar panels was previously investigated by Kuang et al. (1996).

There are also accurate physical models for the non-conservative forces affecting the GPS satellites such as the ROCK models developed by Fliegel et al. (1992, 1996) for Block IIA and Block IIR. However, current models fail to predict the real orbit behaviour with sufficient accuracy, mainly due to deviations from nominal attitude, from inaccurately known optical properties, or from aging of the satellite surfaces. The basis of the box-wing model for this study are the areas and optical properties reported by Fliegel et al. (1992, 1996).

4. Parameter Estimation



GPS satellite orbits were generated from one year of tracking data (2007) from the global IGS network and involving the box-wing model implemented into the Bernese GPS Software, with the processing scheme derived from the one used at CODE. The solar radiation pressure parameters of the CODE and the box-wing model were estimated once per day and per satellite. In the figure above the estimated parameters are shown for all satellites (separately by Block IIA and Block IIR) as a function of the angle β_0, the Sun elevation angle above the orbital plane.

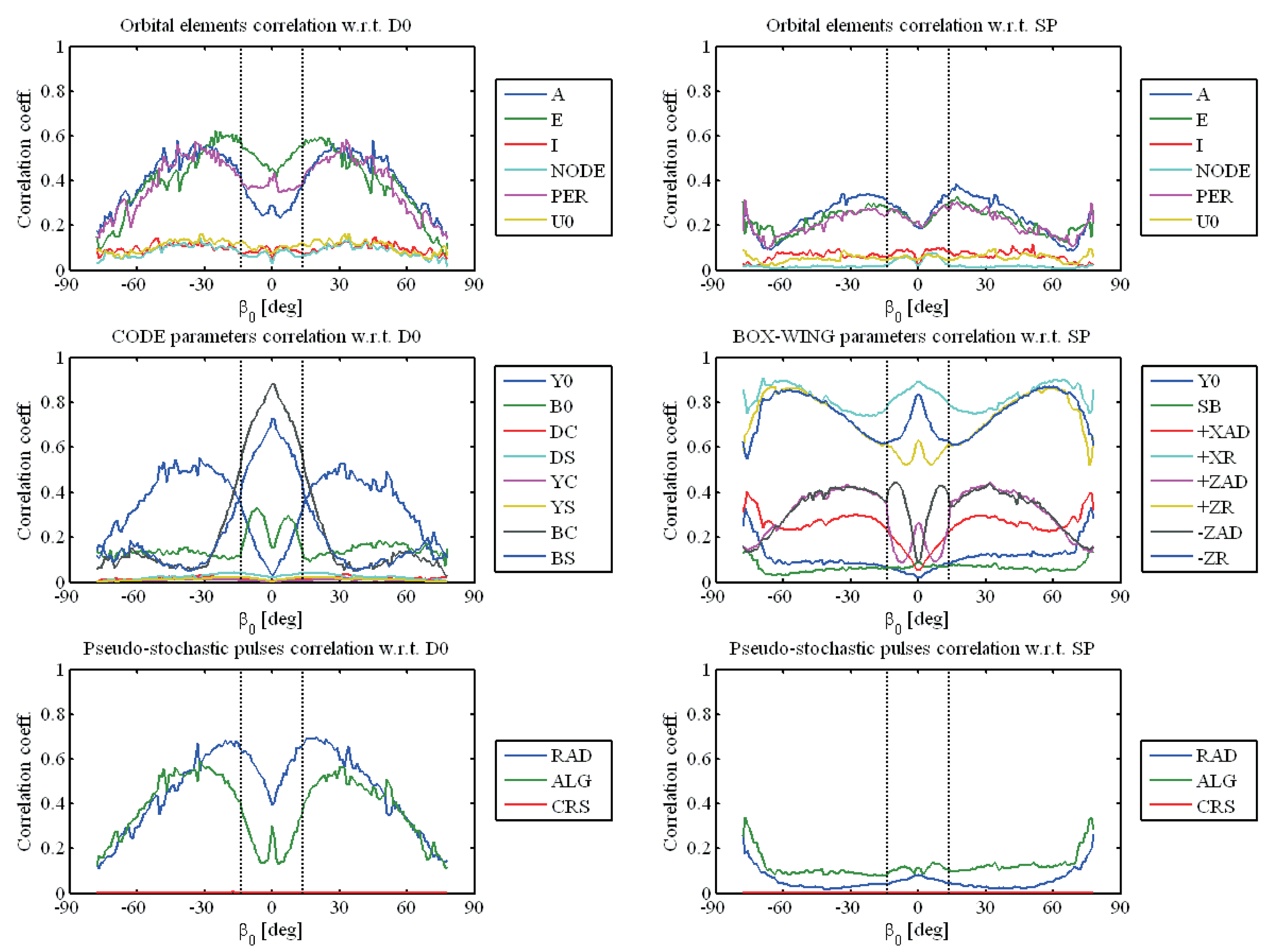
The variability of the parameters of the box-wing model is higher as for the CODE model. Note however that the estimated Y0 and radial pseudo-stochastic pulses are reduced by using the box-wing model. In both models a clear dependency with the angle β_0 is observed, which may indicate mismodeling problems, like in the case of Block IIA for which attitude is not nominal during eclipse seasons ($-13.5° < \beta_0 < 13.5°$, Bar-Sever, 1996).

5. Parameter Correlation

The correlation between the parameters of the radiation pressure models was investigated using one year of data. The figure shows the correlation coeffcients (absolute) averaged over all satellites as a function of β_0, the Sun elevation angle above the orbital plane.

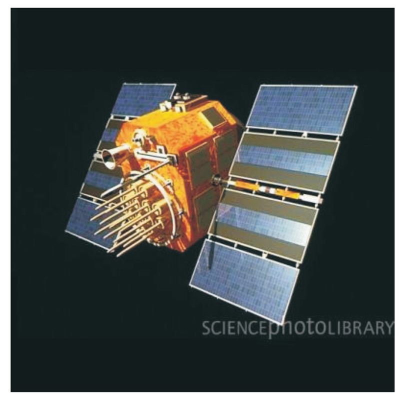
The correlation is shown for the parameter D0 (constant in D-direction) of the CODE model and the parameter SP (optical coefficient of solar panels) of the box-wing model, with respect to the other parameters used in the orbit determination procedure: Keplerian elements, radiation pressure parameters and pseudo-stochastic parameters. For the box-wing model, AD means absorption plus diffusion for each satellite surface, these parameters were highly constrained.

In general the correlation within the parameters of the box-wing model is higher than for the CODE model, which is at the moment the major problem to be solved. Note also the change of the correlation if the satellites are in eclipse season ($-13.5° < \beta_0 < 13.5°$, doted lines)



6. Impact on Satellite Orbits

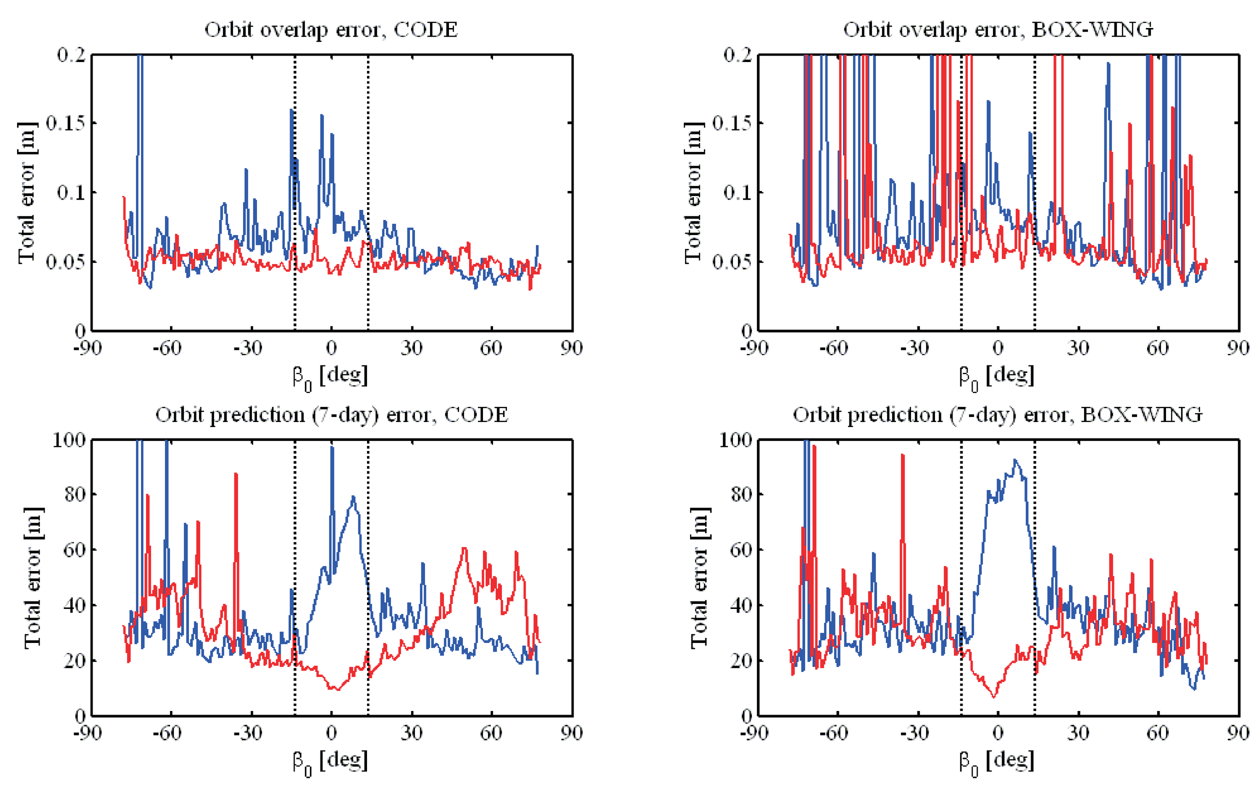
Block IIA



Block IIR

The impact on the GPS satellite orbits, due to the different solar radiation pressure models, was investigated by computing overlap (of consecutive days) and prediction (after 7 days) errors during one year. The figure below shows the total error averaged over all satellites of the same type (Block IIA and Block IIR) as a function of the angle β_0 (the Sun elevation angle above the orbital plane).

Note that the box-wing model performs almost as good as the CODE model, except for the larger number of outliers that can be seen for the box-wing model.



7. Conclusions

An analytical box-wing satellite has been developed for GPS satellites and was tested using one year (2007) of GPS tracking data. The performance of the new model is comparable to the CODE empirical model, when looking at the orbit overlap and prediction errors. The parameters derived from the box-wing model have, however, the big advantage of having a physical meaning (optical properties and rotation bias angle) since the box-wing model is based on the physical interaction between the solar radiation pressure and the satellite structure.

The dependency of both models, CODE and box-wing, with the angle β_0 (the Sun elevation angle above the orbital plane) may indicate mismodeling problems. In particular for the box-wing there should be no dependency on β_0, since the optical properties may change with time (due to aging) but not with β_0.

The box-wing model is still under development. Future work will focus on decorrelating the box-wing parameters among themselves and on taking into account the non-nominal attitude of the satellites during eclipse seasons.

Finally, this study has shown that it is possible to compute GPS orbits at the level of precision required by the IGS, but using a physical model (capable of adjusting to the tracking data) instead of a purely empirical model.

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EGU 2011