# BOX-WING MODEL APPROACH FOR SOLAR RADIATION PRESSURE IN A MULTI-GNSS SCENARIO

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## 1 INTRODUCTION

The solar radiation pressure force is the largest orbital perturbation after the gravitational effects and the major source of error affecting GNSS orbits and clock estimation. The impact of these non-gravitational forces is larger in the Galileo constellation whose satellites have a larger surface-to-mass ratio with respect to GPS.

A wide range of approaches to compensate for the solar radiation pressure have been developed which vary from purely empirical to purely analytical. Intermediate solutions allow maximizing the advantages of both approaches.

Consolidated Solar radiation empirical models, such as CODE's ECOM or the enhanced ECOM2, have shown that they provide an accurate estimation of these effects. However, both models are limited by the estimation effort required for the parameter adjustment. In order to alleviate this estimation effort we propose to use an analytical box-wing model based on the satellite properties which can provide an a-priori accurate estimation to an empirical model, ECOM.

A three-month period has been analyzed to evaluate the performances of the consolidated ECOM model, the enhanced ECOM2 and the proposed approach: An analytical box-wing model as an a priori estimate for the ECOM model. The effort has been initially focused on the Galileo constellation.

## 2 CODE SRP EMPIRICAL MODELS

CODE's ECOM model is based on the estimation of 5 SRP parameters, meanwhile ECOM2 implies estimating 9 parameters. The formulation in Sun-Earth oriented frame is given by:

$$D(u) = D_0 + D_{2C}\cos(2\Delta u) + D_{2S}\sin(2\Delta u) + D_{4C}\cos(4\Delta u)\ D_{4S}\cos(4\Delta u)$$

$$Y(u) = Y_0$$

$$B(u) = B_0 + B_C\cos(\Delta u) + D_S\sin(\Delta u)$$

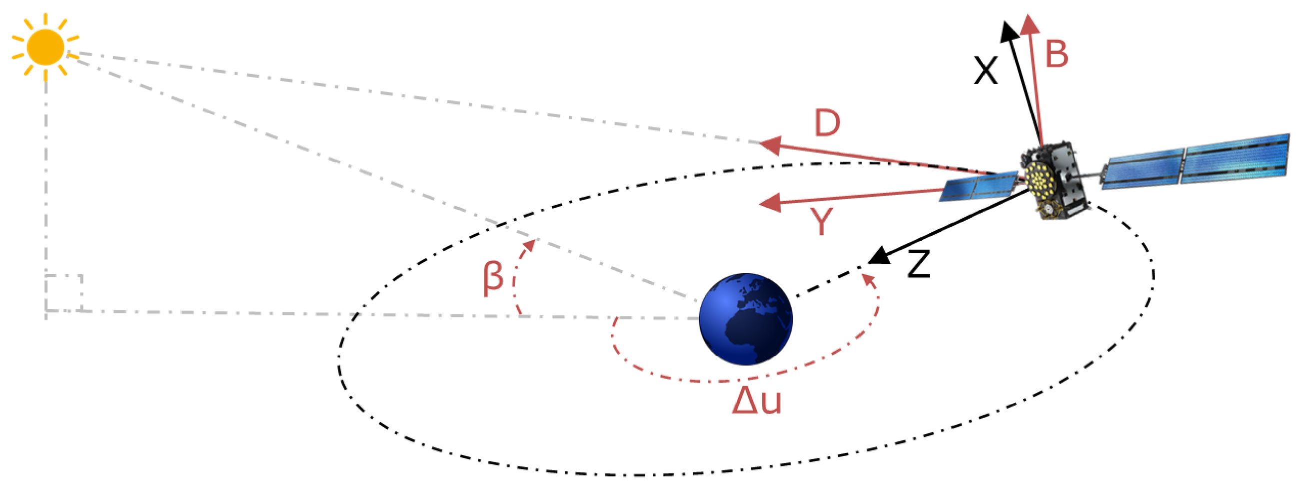



**Fig. 1 Nominal yaw-steering attitude as a function of the Earth-Sun position**

## 2 ANALYTICAL BOX-WING MODEL

The analytical box-wing model is based on the assumption that the satellite structure can be simplified to a box shape bus and flat solar panels. Neither heating effects nor shadowing of one surface to another are considered. The formulation is based on the superposition of the interaction of the solar radiation and a flat surface which models the solar panel and each of the box faces.

## 3 IMPLEMENTED APPROACH

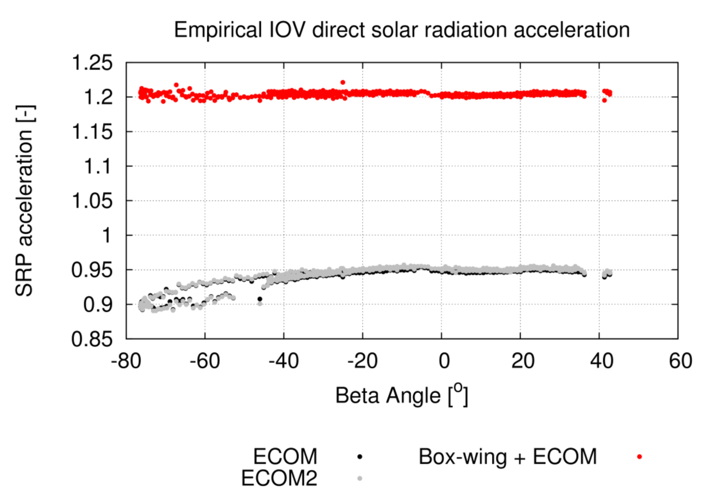
An analytical box-wing model provides an accurate a-priori solar radiation acceleration. In order to account for the unconsidered effects, such as the acceleration in the solar panel direction, the ECOM model is used to refine the a-priori calculation. Note that the a-priori acceleration allows the 5 parameters of the ECOM model to properly fit the in-orbit data without requiring the higher estimation cost of the ECOM2 model. The solar radiation pressure acceleration is given by:

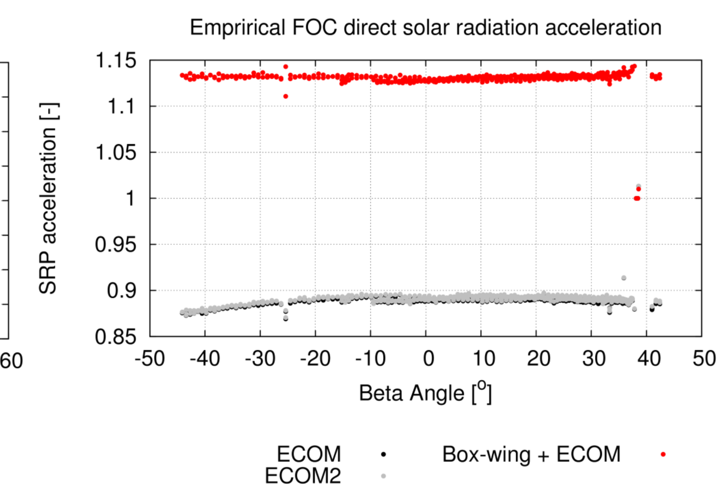
$$\boldsymbol{a}_{SRP} = \frac{1\ AU^2}{r^2_{Earth-Sun}}(\boldsymbol{a}_{box-wing} + \boldsymbol{a}_{ECOM})$$

The performances of the implemented approach are assessed for the Galileo constellation in terms of the behavior of the solar radiation pressure coefficients and the impact in the Satellite Laser Ranging Residuals, the restituted clocks and the orbit prediction error.

## 4 SOLAR RADIATION PRESSURE COEFFICIENTS

The impact of using the a priori model in the Empirical direct solar acceleration ($D_0$) is analyzed. The box-wing model approach removes the dependency with β . The difference with the non a-priori models is more remarkable in IOV and non eccentric FOC satellites.



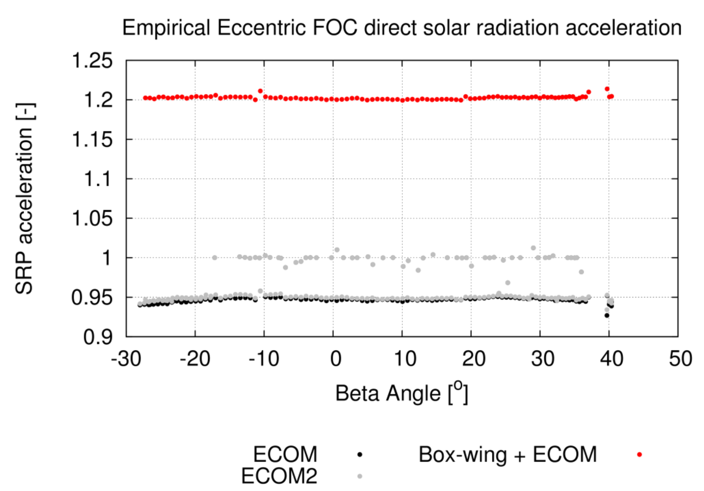
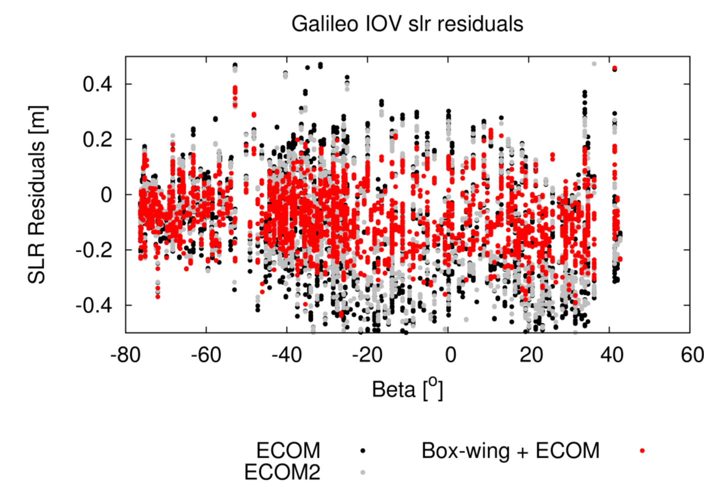
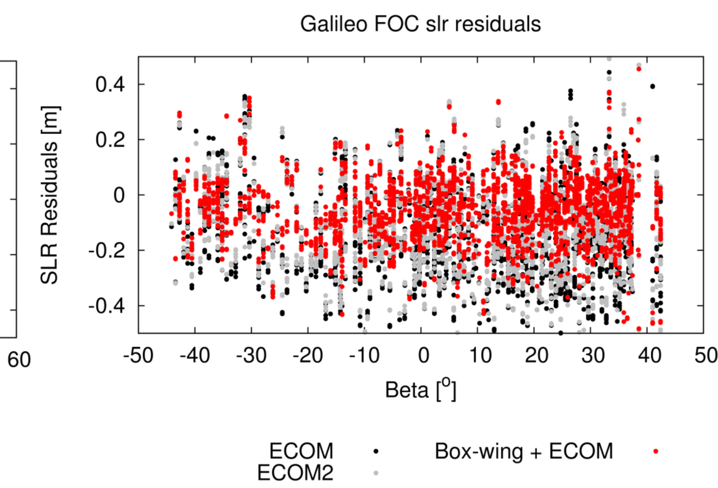




**Fig. 2 Empirical direct solar radiation acceleration for IOV, FOC and eccentric FOC satellites of Galileo constellation. Dimensionless values are shown.**

## 5 IMPACT ON SATELLITE LASER RANGING RESIDUALS

Satellite laser ranging (SLR) measurements from the International Laser Ranging Service have been processed un-weighted within the POD processing to assess the orbit estimation improvement when using a simple box-wing model for the IOV and FOC satellites.



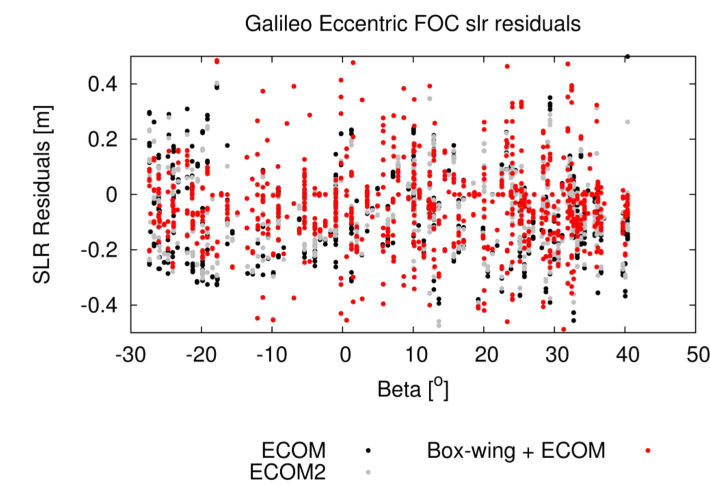




**Fig. 3 SLR residuals for Galileo**

**Tab 1. RMS and AVE of the SLR residuals**

| RMS | IOV | FOC | FOC(e) |
|---|---|---|---|
| ECOM | 0.240 | 0.212 | 0.450 |
| ECOM2 | 0.212 | 0.197 | 0.443 |
| BW | 0.146 | 0.150 | 0.445 |
| **AVE** | | | |
| ECOM | -0.104 | -0.113 | -0.049 |
| ECOM2 | -0.095 | -0.101 | -0.045 |
| BW | -0.073 | -0.043 | -0.034 |

## 6 IMPACT ON GALILEO RESTITUTED CLOCKS

Systematic 1-per orbital revolution effects are observed in the Galileo satellite clock estimates and have been analyzed for quite some time. These effects have been linked to orbit determination errors as well as possible thermal bias variations within the Galileo satellites. In this regard, the different analyzed SRP modelling approaches have been used to evaluate the orbit estimation errors in the amplitude of the aforementioned periodic fluctuations.

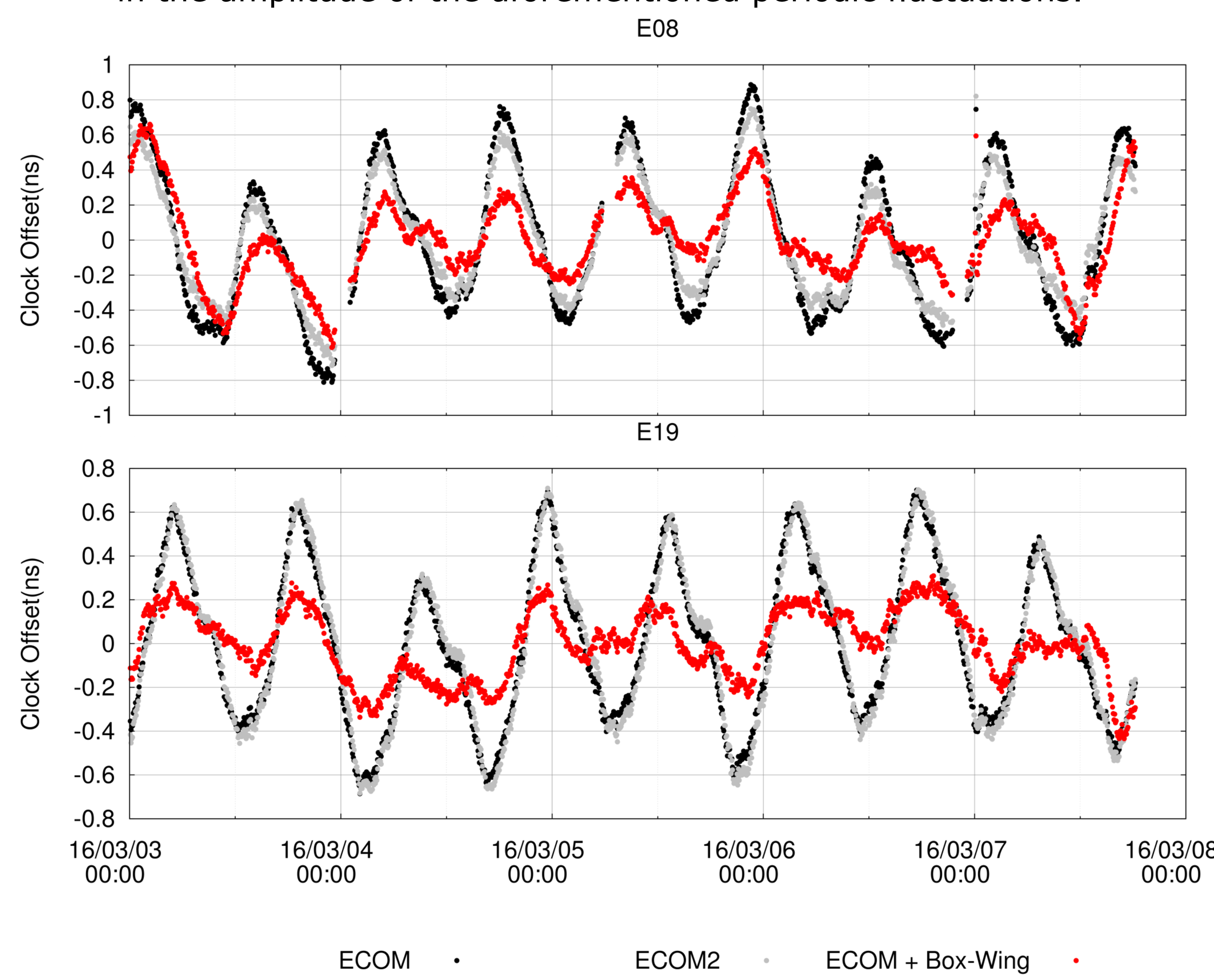



**Fig. 4 Restituted Galileo clocks for a 5-day estimation arc**

## 7 IMPACT ON GALILEO PREDICTED ORBITS

The impact of each solar radiation pressure approach has been evaluated for the long-term orbit prediction error (15-day prediction arc), where the reference orbits have been computed by means of a 5-day estimation arc, weighting the SLR measurements within the POD process.

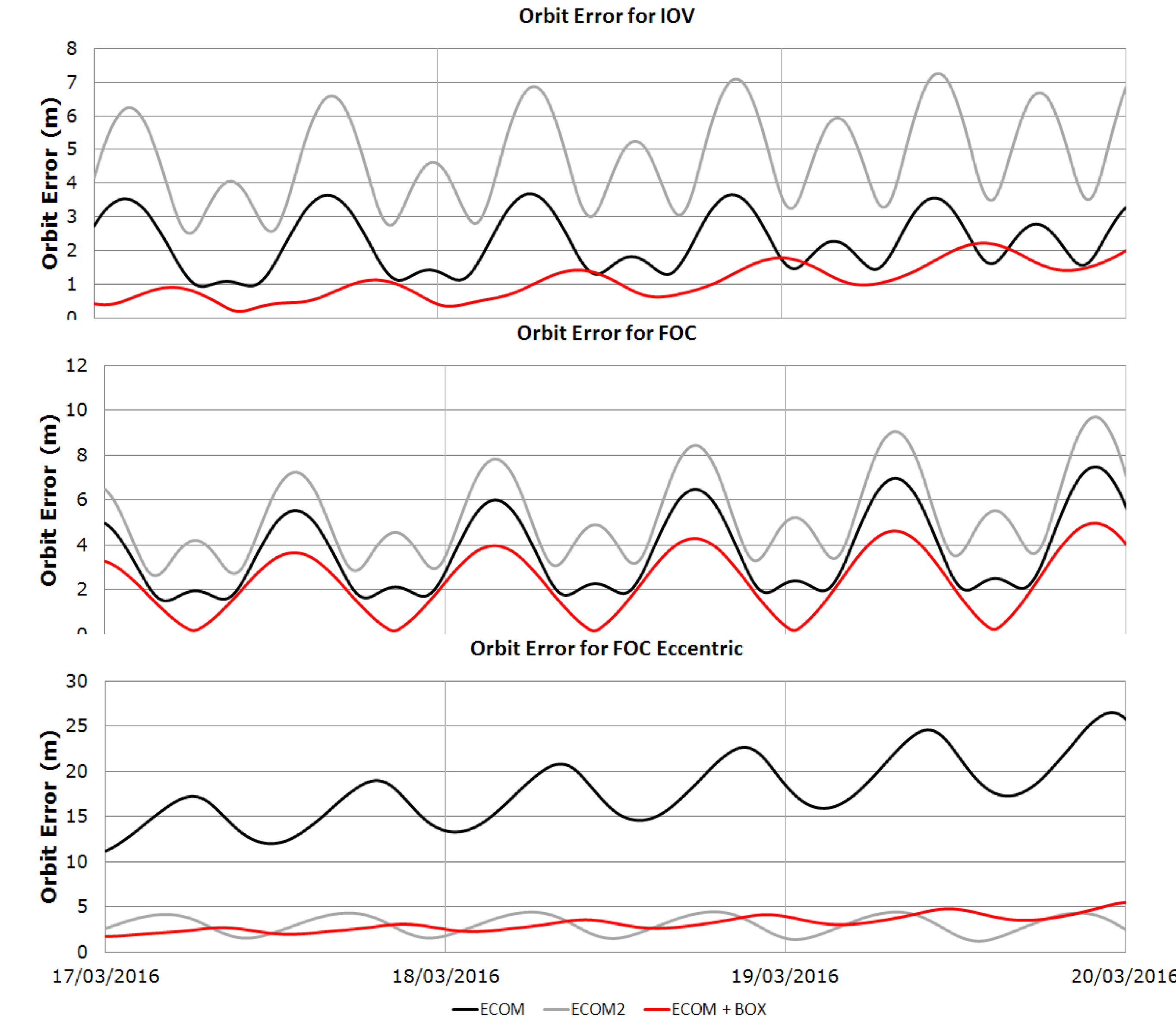



**Fig. 5 Orbit prediction error at 15 days. (3 last days are shown)**

## 8 CONCLUSIONS

- A simple box-wing model has been implemented for Galileo. This model has been tested against 2 purely empirical SRP models; ECOM and ECOM2.
- Although the results are quite preliminary (only 3 months of data have been analyzed), there is a potential improvement for the Galileo POD which has been assessed by means of SLR residuals and evaluating the long-term prediction errors.
- The ECOM2 model has proven to provide a remarkable improvement with respect to ECOM for the eccentric FOC satellites, even close to the performances of the implemented box-wing model.
- If the box-wing model approach is to be fully exploited, detailed information about the Galileo satellites is required.

## REFERENCES

**Rodriguez-Solano CJ, Hugentobler U, Steigenberger P (2012)** *Adjustable box-wing model for solar radiation pressure impacting GPS satellites.* Adv Space Res 49(7):1113–1128

**O. Montenbruck · P. Steigenberger · U. Hugentobler (2015)** *Enhanced solar radiation pressure modeling for Galileo satellites.* J Geod (2015) 89:283–297