ION GNSS+ 2016

Galileo Simple Box-Wing Model Plus ECOM for Improving Orbit and Clock Prediction Performances

September 15TH , 2016

Session E4: Modernization of GNSS 2

A. García, D. Luque, **P. F. Navarro**, G. Tobías, **GMV, Spain;**

INNOVATING SOLUTIONS

Introduction

- Solar radiation pressure force is the largest orbital perturbation after gravitational effects. Galileo satellites are more affected than GPS ones due to the higher surface-to-mass ratio

- A wide range of approaches to account for this effect have been proposed. They vary from purely empirical to purely analytical

Introduction

- 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 in accuracy and by the estimation effort required for the parameter adjustment

- Analytical box wing models may provide a better modelling, by computing the force from first principles
  - Physics
  - Shape and properties of surfaces in the satellite

- A simple analytical box wing model is proposed

- Not possible to get perfect analytical model, so it will be refined by an empirical model such as CODE's ECOM

Proposed approach

- Use an analytical box-wing model to calculate an accurate value of the solar radiation pressure acceleration
- Use the ECOM model to account for the unconsidered effects such as the effect on Y component

$$\boldsymbol{a}_{SRP} = \frac{1\,AU^2}{d_{SUN}^2}\left(\boldsymbol{a}_{BOX-WING} + \boldsymbol{a}_{ECOM}\right)$$

- IOV/FOC Galileo satellite properties have been determined

- Performance of the proposed model along with the performances of ECOM and ECOM2 are analysed

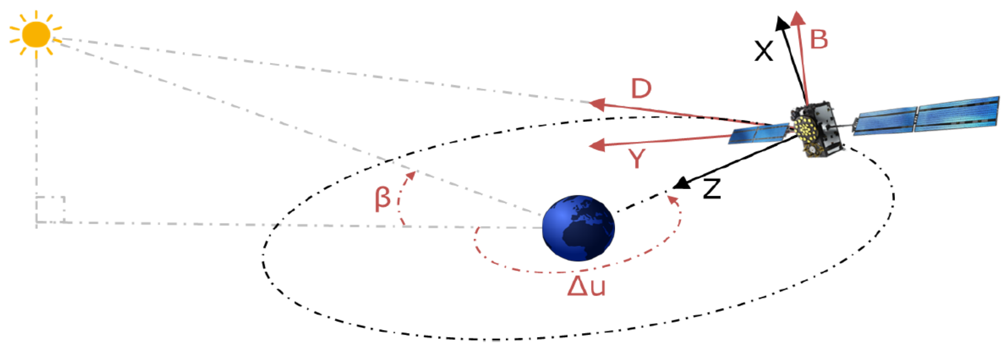
SRP Empirical models

- CODE's ECOM model is based on 5 SRP parameters, while ECOM2 uses 9 parameters. The formulation in Sun-Earth oriented frame is given by:

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

$$Y(u) = Y_0$$

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



Analytical Box-wing

- Assuming the satellite bus as n flat panels with different properties:

$$\vec{f}_{SRP} = \sum_{i=1}^{i=n} \left(-\frac{A_i}{M} \frac{S_0}{c} \cos\theta_i \left[(\alpha_i + \delta_i) \left(\vec{e}_D + \frac{2}{3} \vec{e}_N \right) + 2\rho_i \cos\theta_i \right] \right)$$

where $\alpha_i + \delta_i + \rho_i = 1$

- The interaction of each surface/material depends on two parameters: the effective area A_i and the material properties $\alpha_i + \delta_i$ or ρ_i

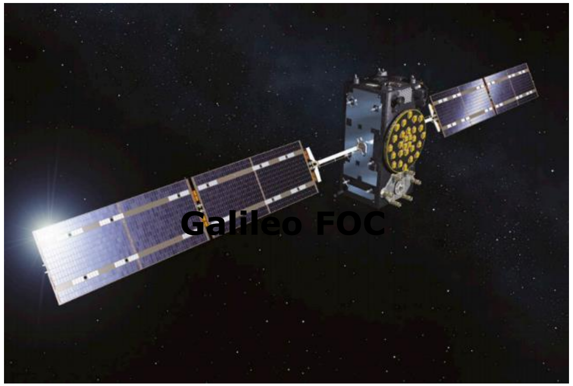
- n not necessarily limited by the number of flat surfaces. Different materials are expected in each face and, therefore, superposition principle will be applied to the surfaces.

- Considering non-eclipse periods the attitude law is driven by the yaw-steering mode. Therefore, only ±z and +x faces contribute to the SRP.

Parameter determination

Initial condition

- An a-priori value of the surface areas of the different faces is known
- The visual inspection of the satellite surfaces suggests using some of the optical properties of GPS IIR satellites
- References [Montenbruck et al, 2015]



Parameter determination

Variation

- Introduce additional layers in faces +z and +x

  - $A_{+x1} = A_x - \boldsymbol{\Delta A_{+x}}$
  - $A_{+x2} = \Delta \boldsymbol{A}_{+x}$
  - $A_{+z1} = A_z - \boldsymbol{\Delta A_{+z}}$
  - $A_{+z2} = \Delta \boldsymbol{A}_{+z}$
  - $A_{-z} = A_z$

  - $\rho_{+x1} = \rho_{+x}$
  - $\rho_{+x2} = \boldsymbol{\rho'}_{+x}$
  - $\rho_{+z1} = \rho_{+z}$
  - $\rho_{+z2} = \boldsymbol{\rho'}_{+z}$
  - $\rho_{-z} = 0$

- The parameters to be determined are:

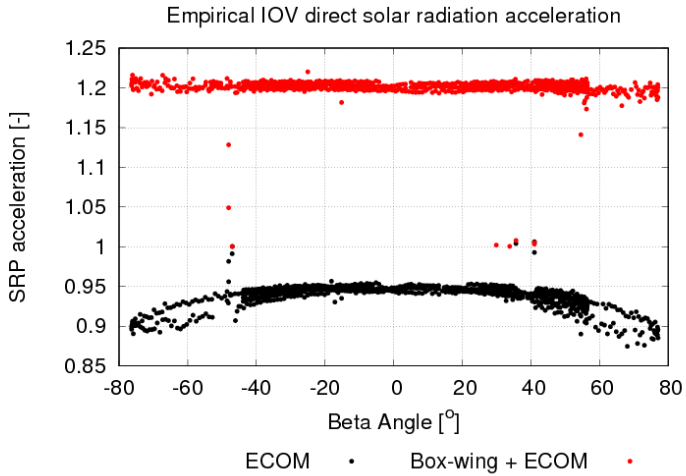
$$\Delta \boldsymbol{A}_{+x} \quad \Delta \boldsymbol{A}_{+z} \quad \Delta \boldsymbol{\rho}_{+x} \quad \Delta \boldsymbol{\rho}_{+z}$$

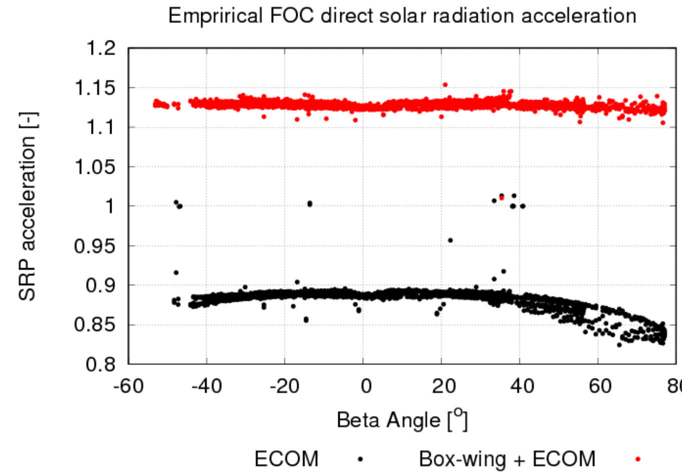
- IOV and FOC satellites are assumed to have the same properties. The parameters have been obtained by iterative adjustments

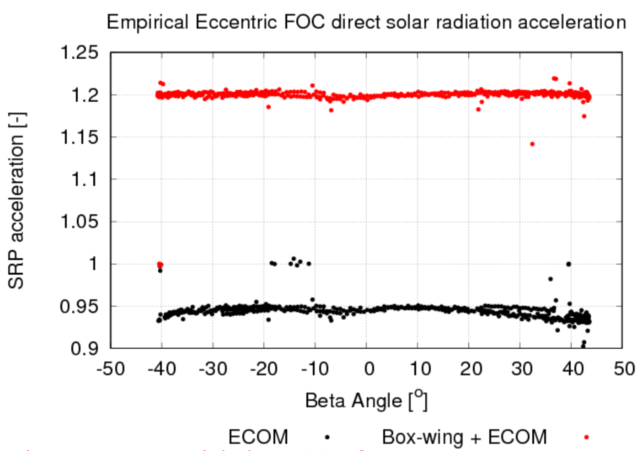
Model validation

- The model has been validated over a 9-month period (Dec 2015 – Aug 2016)
- Both IOV and FOC performances are assessed
- magicGnss suite over which the model has been implemented has been used in order to execute the validation process
- The performance are compared to those obtained by ECOM and ECOM2 in the same scenarios
- 1-day scenarios have been executed with a global network of 55 stations
- The behavior of SRP parameters, SLR residuals, estimated clocks and predicted orbits have been assessed

Results: SRP coefficients

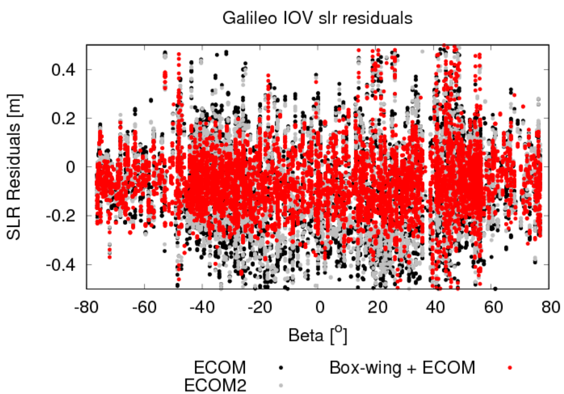


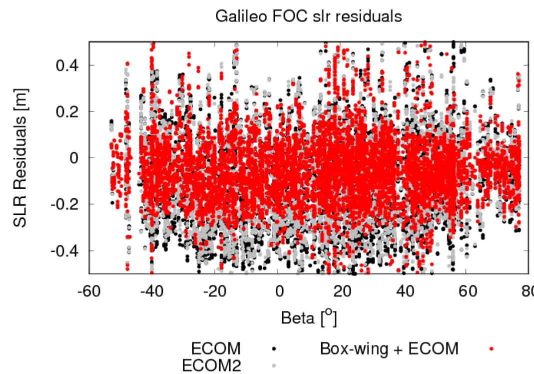


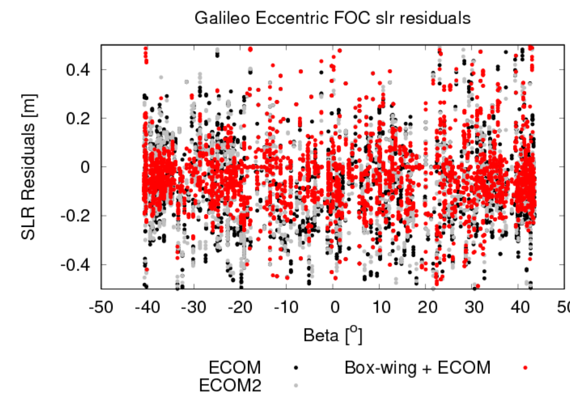


The impact of using the a priori model in the Empirical direct solar acceleration (D_0) is analyzed. The box-wing model approach removes the dependency with β . The difference with the non a-priori models is more remarkable in IOV and non eccentric FOC satellites.

Results: SLR residuals



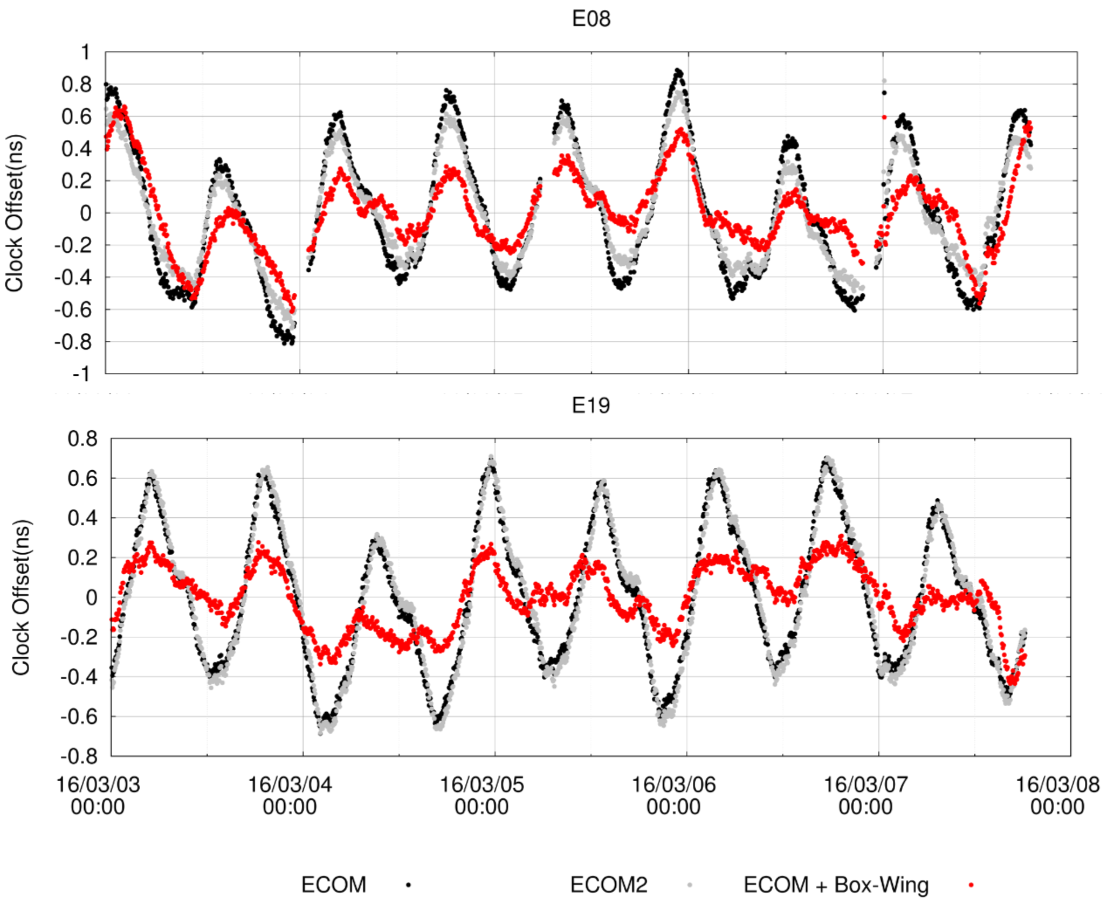




Satellite laser ranging (SLR) measurements from the International Laser Ranging Service have been processed un-weighted within the POD processing to assess the orbit estimation improvement when using a simple box-wing model for the IOV and FOC satellites.

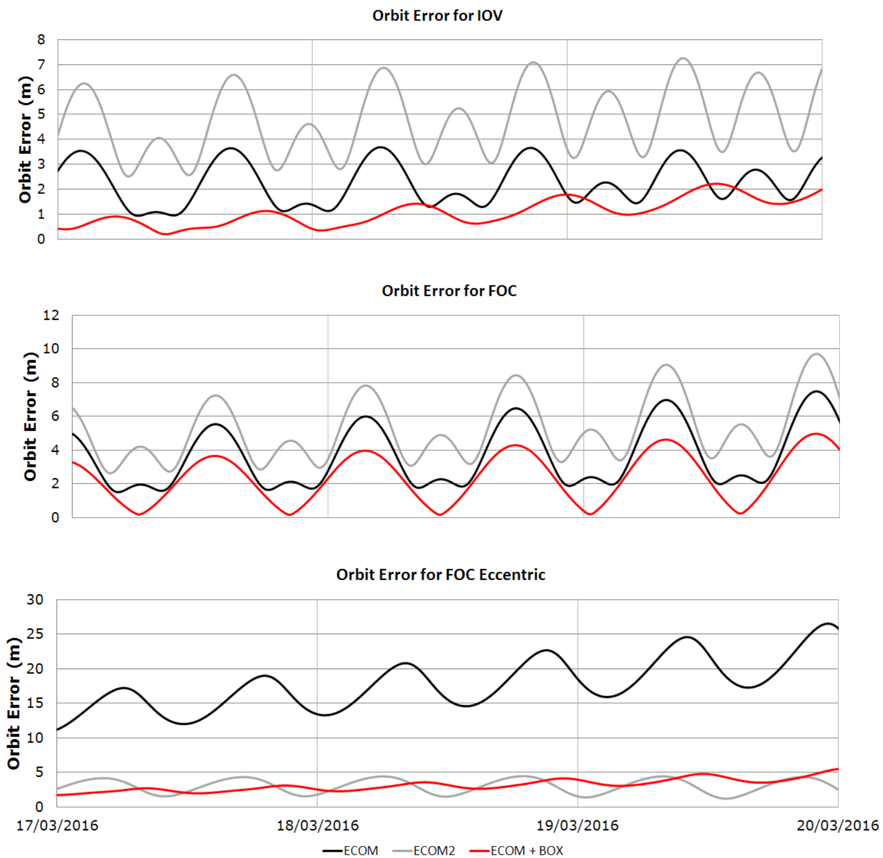
RMS	IOV	FOC	FOC(e)
ECOM	0.240	0.212	0.405
ECOM2	0.212	0.197	0.401
BW	0.146	0.150	0.380
AVE			
ECOM	-0.104	-0.113	-0.049
ECOM2	-0.095	-0.101	-0.045
BW	-0.073	-0.043	-0.034

Results: Impact on 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.

Results: Impact on 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.

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.

www.gmv.com

THANK YOU

Visit us at booth 508

www.facebook.com/infoGMV

@infoGMV

gmv