Orbit/SRP Modelling for Long Term Prediction

DEFENCE AND SPACE

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Orbit/SRP Modelling for Long Term Prediction

Solar Radiation Pressure (SRP) and Thermal re-radiation are known to have a significant impact the accuracy of orbit and clock precise determination by the IGS centers.

This presentation provides the outcomes of the first phase of the ESA study « ORBIT/SRP Modelling for Long Term Prediction » which targets improvement of long term and short term orbit prediction accuracy for Galileo.

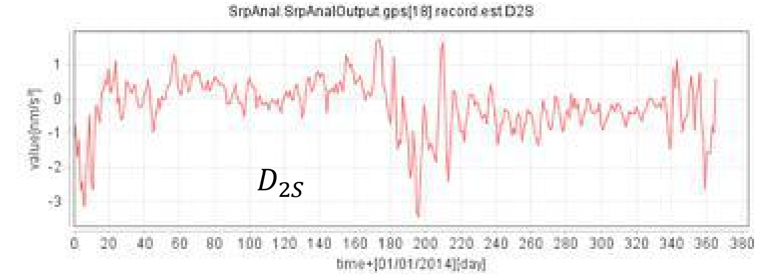
The proposed methodology:

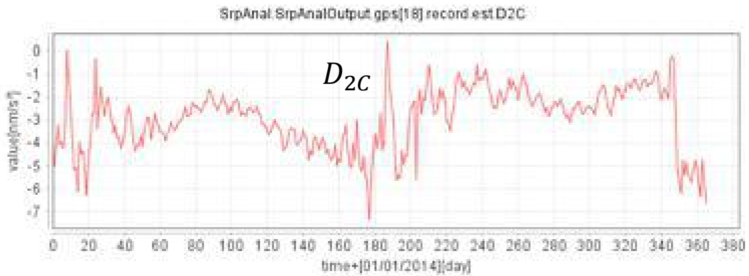
- Develop high accuracy model of SRP forces using 3D model of the spacecraft (FOC) and BoxWing (GPS, Galileo IOV)
- Predict the evolution of the residual observed (but unmodelled) forces based on observation within each class of GNSS satellites.

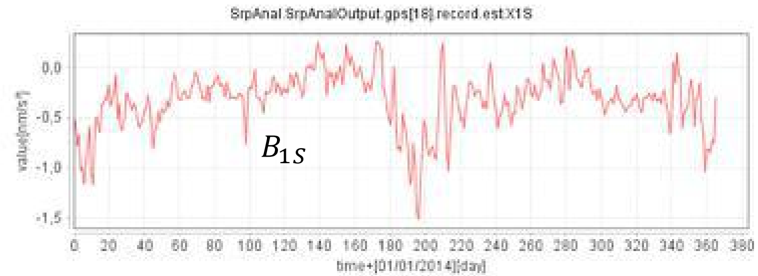
Analysis limited to GPS IIR, GPS IIF, Galileo IOV, Galileo FOC

EECOM estimation analysis

EECOM parameter estimation shows strong correlation between some parameters, especially during eclipse season.







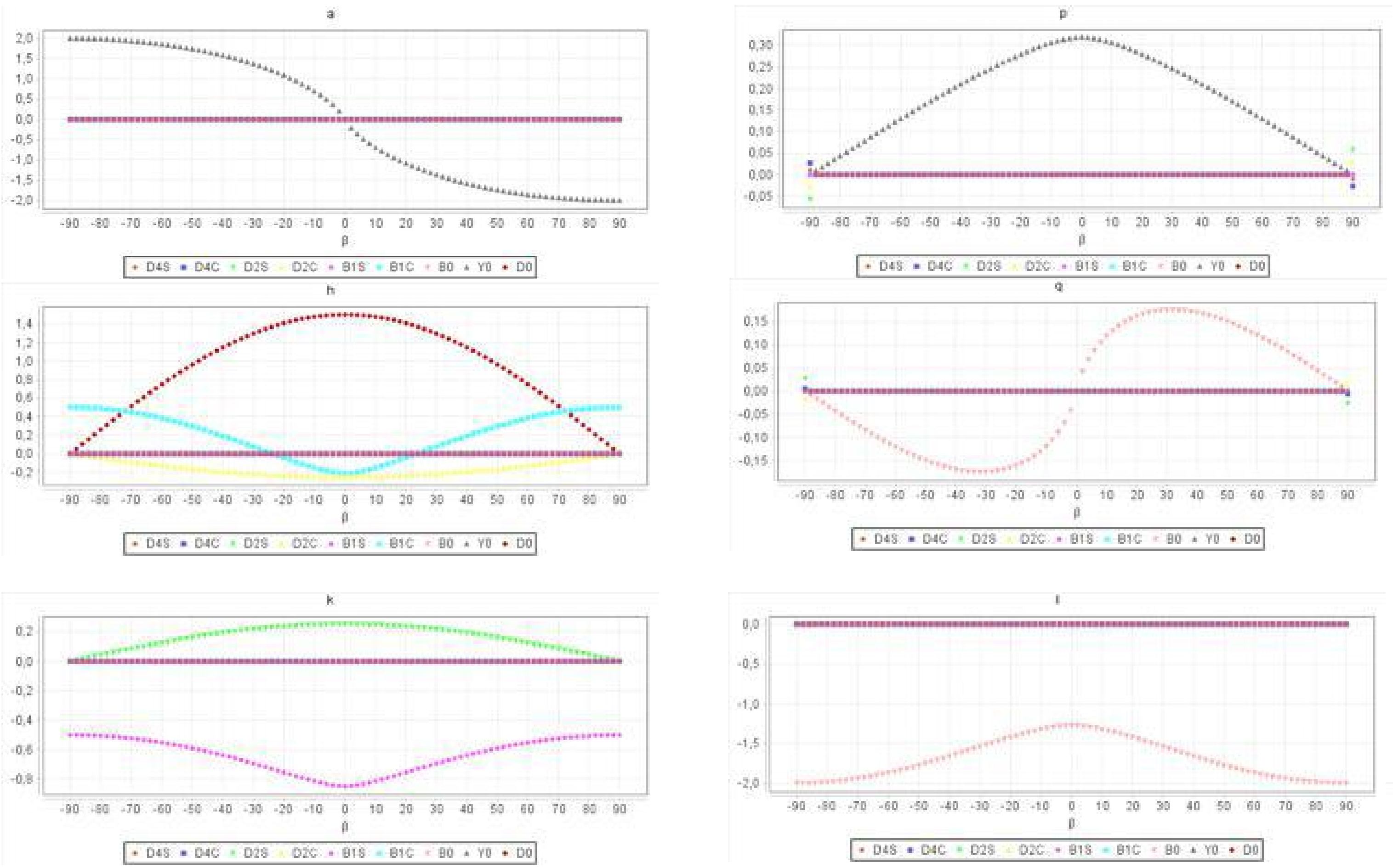
Orbit equinoctial parameters drift analysis

- SRP forces will make some the orbit mean parameters drift.
- Several parameters have the same long term effect (D_0, D_{2C}),(B_{1S}, D_{2S}) explaining the observed correlation.
- Some parameters affects (alone) two different parameters ($Y_0 \rightarrow \mathrm{a,p}$), ($B_0 \rightarrow \mathrm{q,l}$)

Coefficient	Equinoctial Parameter Drift
D_0	h (eccentricity) drift.
Y_0	a (semi major axis) and p (inclination) drift.
B_0	q (inclination) and l (longitude) drift.
B_{1C}	h (eccentricity) drift.
B_{1S}	k (eccentricity) drift.
D_{2C}	h (eccentricity) drift.
D_{2S}	k (eccentricity) drift.
D_{4C}	None
D_{4S}	None

Orbit equinoctial parameters drift analysis

Orbit Equinoctial Parameters Drift per day
(Scaled to equivalent meters)



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Equinoctial Parameter Drift Reconstruction

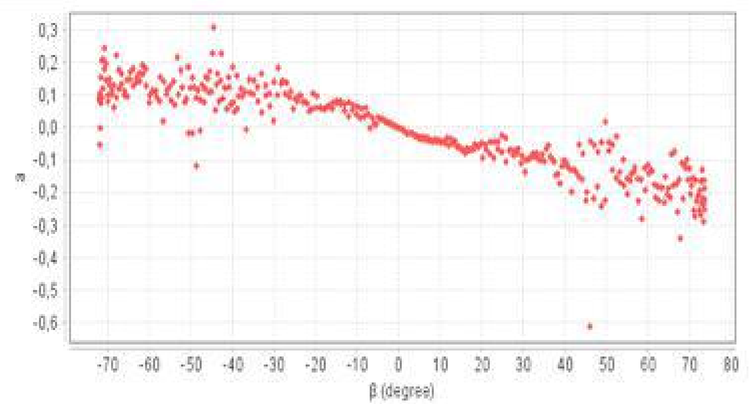
Galileo IOV Semi major axis drift per day (meters) as a function of the Sun elevation angle β

Equinoctial parameter drift reconstruction allows to evaluate the impact of SRP on the orbit.

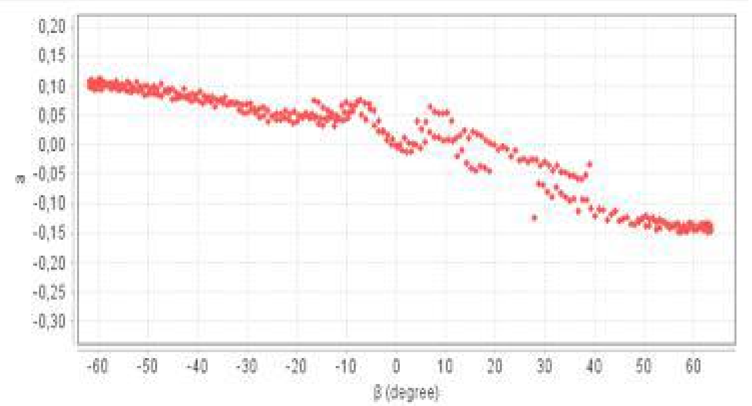
Stochastic pulses (not taken into account in the reconstruction) add noise.

=> Stochastic pulses were removed from estimation

Reconstruction with stochastic pulses (but ignored in the reconstruction)



Reconstruction without stochastic pulse

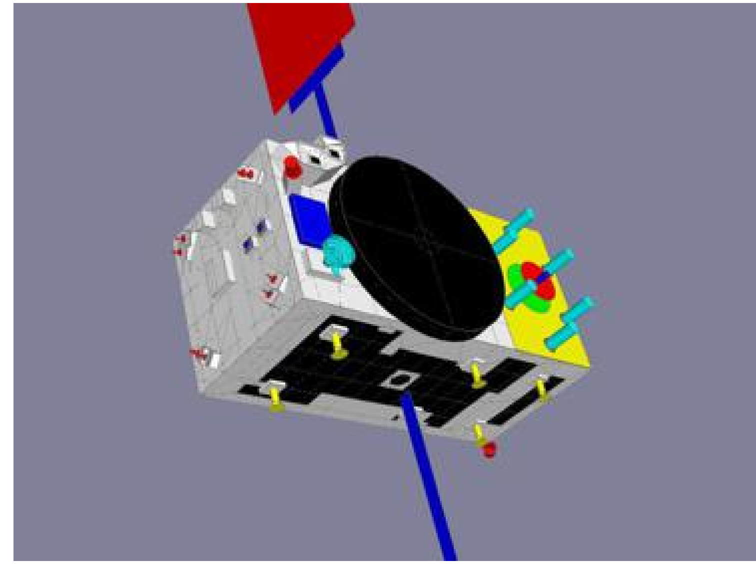


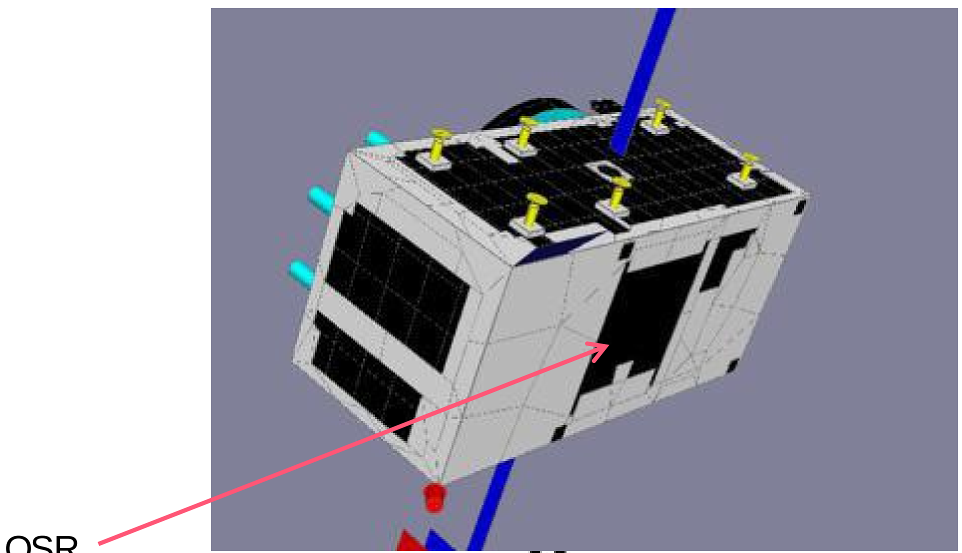
3D and BoxWing Model

3D model surfaces properties have to be hand tuned to take into account thermal re-radiation.

Remains one unknown: What is the power rejected by **O**ptical **S**urface **R**eflectors?

- Y radiators are rejecting along Y and are captured by Y_0.
- Z radiators will produce a D_{1C} component (at low β) not included in the EECOM set of coefficients.

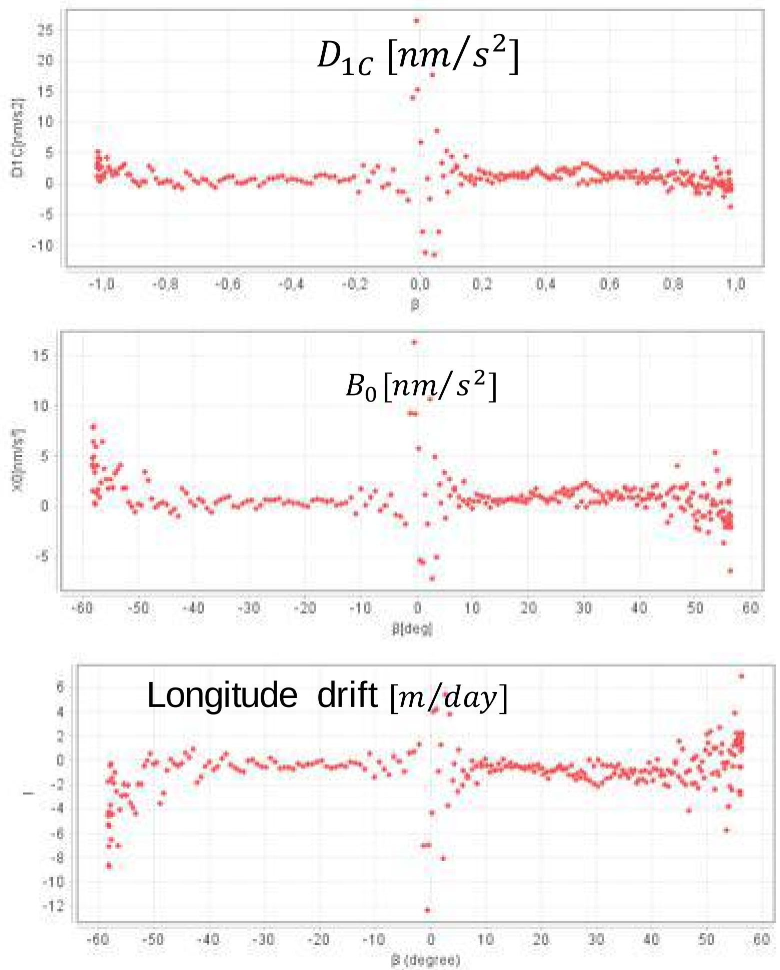




D0,Y0,B0,B1C,B1S,D2C,D2S,D1C,D1S

To check if any D_{1C} component is present, D_{4C} and D_{4S} have been replaced by D_{1C} and D_{1S}.

The experiment did result in strong errors in semi major axis, longitude drift and strong correlation between D_{1C}, B_0.



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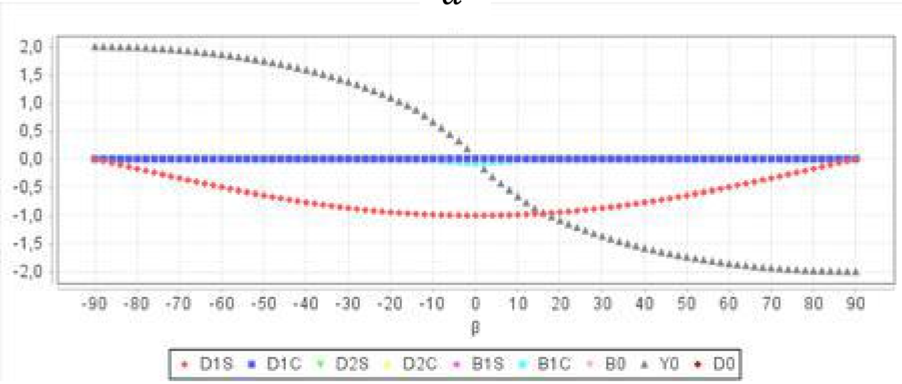
D0,Y0,B0,B1C,B1S,D2C,D2S,D1C,D1S

Analysis of equinoctial parameter drift explains this result:

- $Y_0, D_{1S} \rightarrow a, p$
- $B_0, D_{1C} \rightarrow \mathrm{q,l}$
- Eccentricity unchanged.

Failure of observing D_{1C} is due to its contribution to longitude drift.

a



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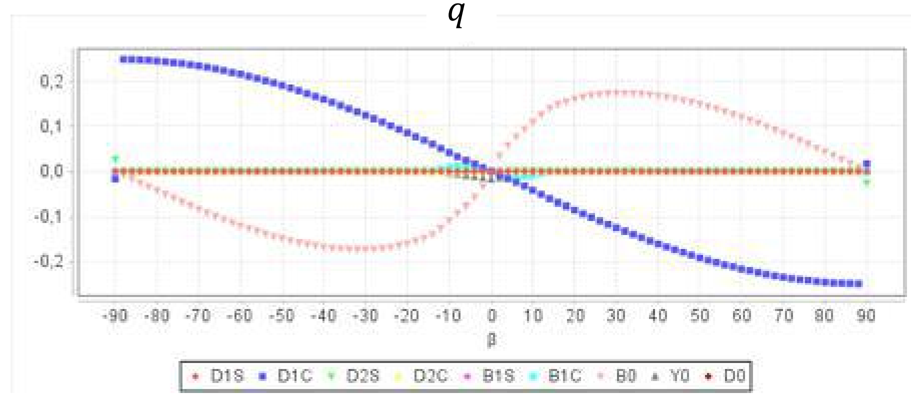

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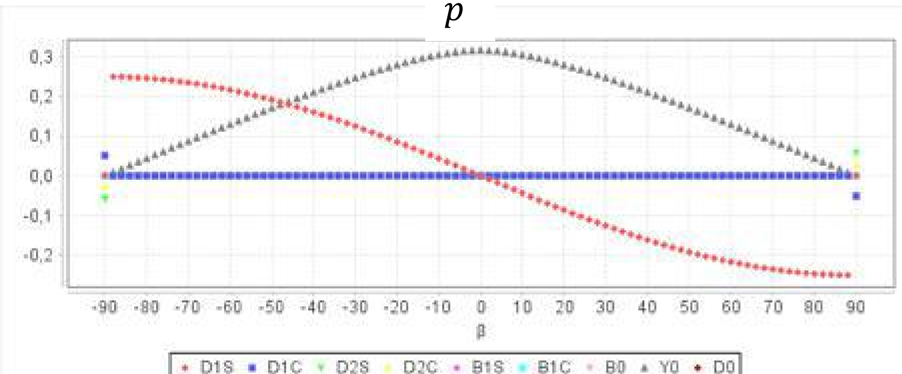

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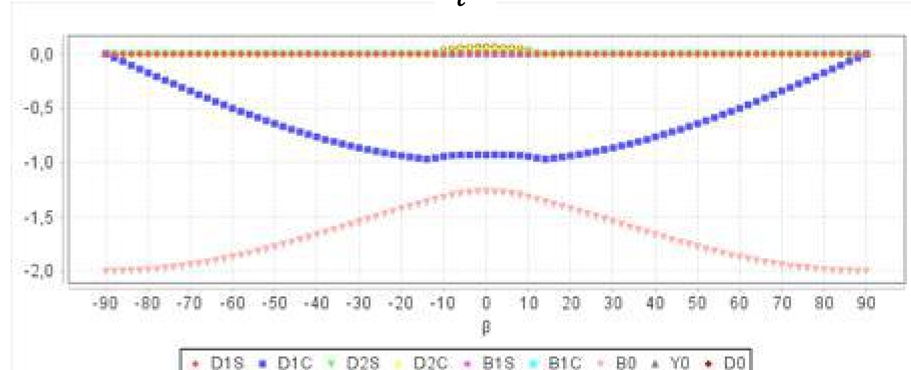


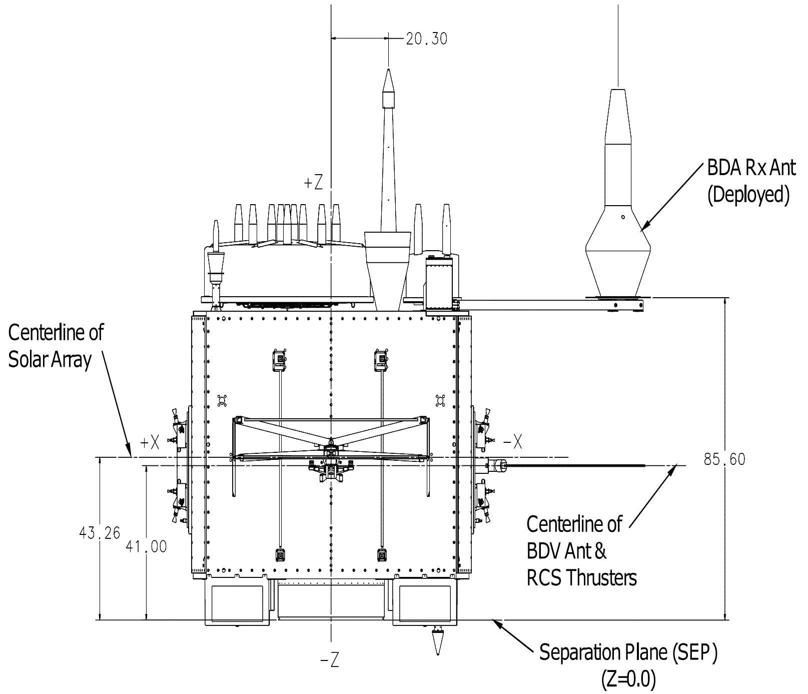
Box Wing Model Tuning Methodology

Perform first guess from ICD known shape.

Estimate EECOM parameter shape as a function of the β angle by simulation.

Tune box shape to match observation, mainly thanks to D_0 and D_{2C}.

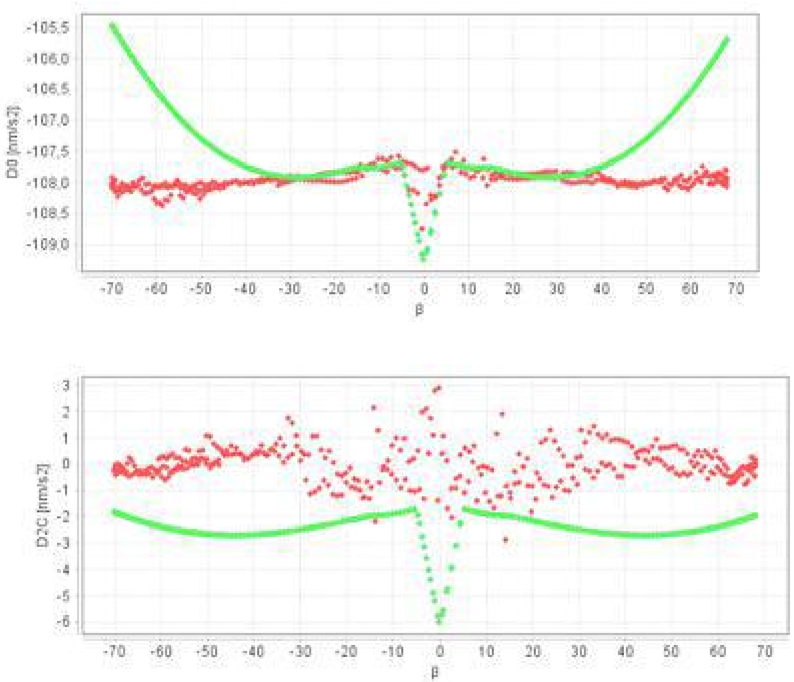
Fine tune with deterministic EECOM parameters.



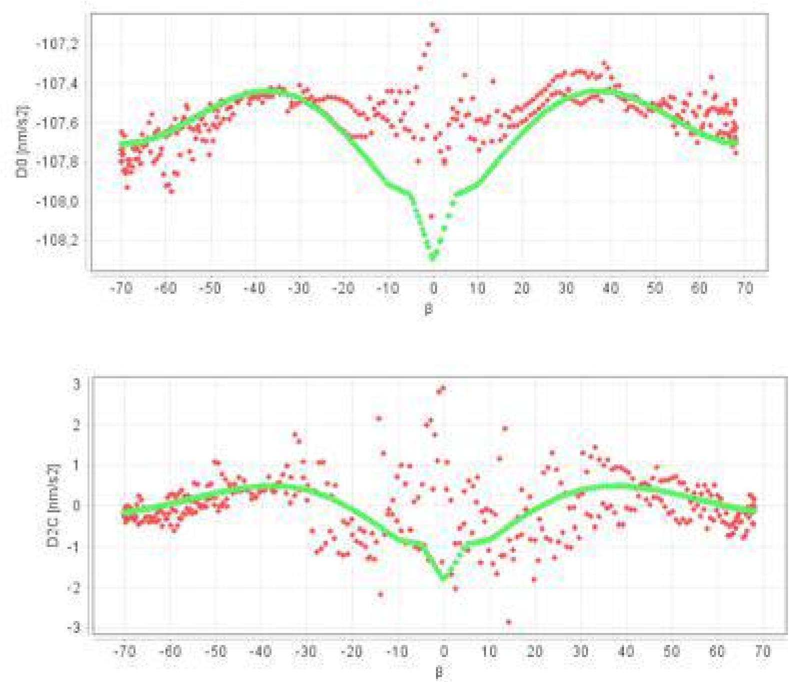
GPS IIF equivalent « Box » difficult to tune without tuning with respect to observation.

Box Wing Model Tuning Methodology (GPS IIF)

EECOM prediction from Published Dimensions Box Wing model compared to EECOM measurements.



EECOM prediction from Tuned Box Wing model compared to EECOM measurements.



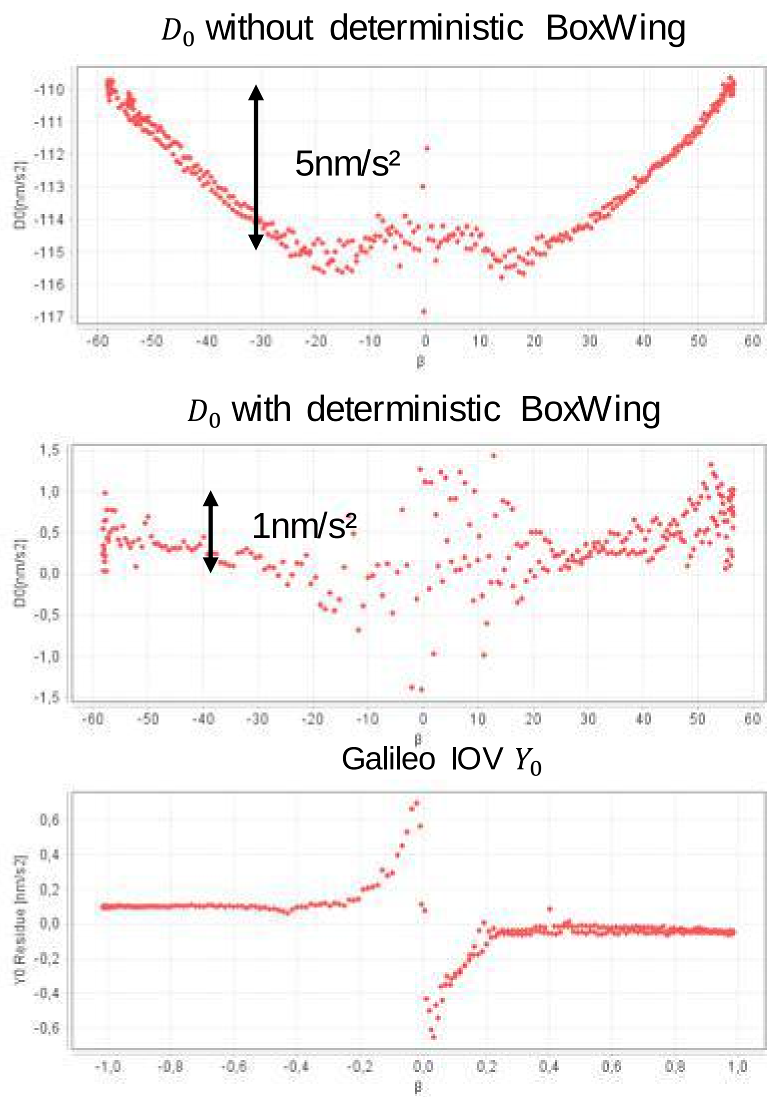
BW=D0,Y0,B0,B1C,B1S,D2C
BW5=D0,Y0,B0,B1C,B1S

Two new estimations performed with BoxWing as a deterministic model:

- One with D_{2C} to validate BoxWing model efficiency in reducing this component.
- One with only the 5 classical ECOM parameters.

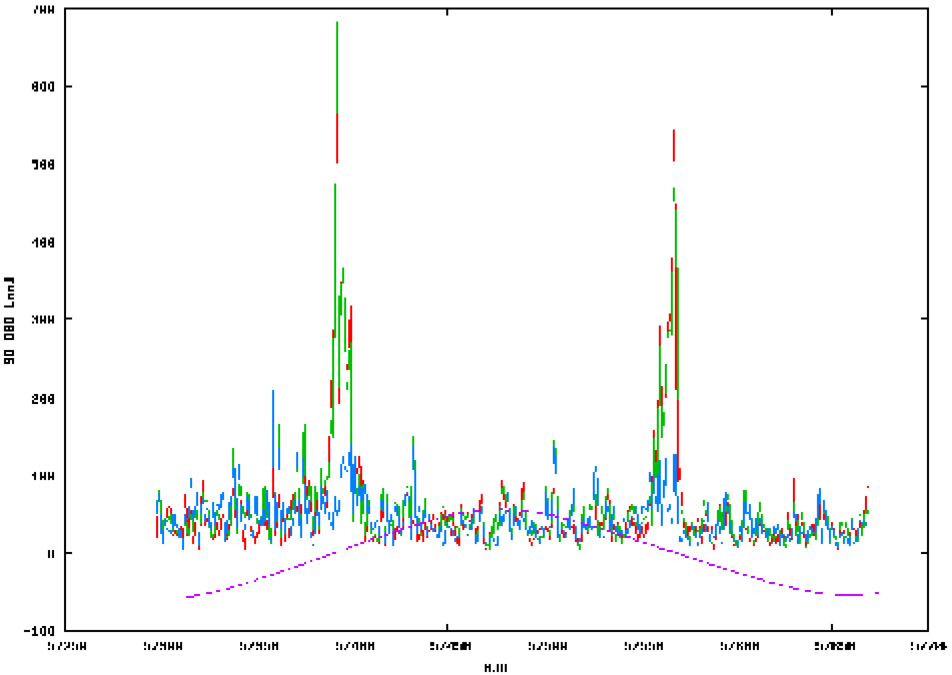
Main results:

- Strong reduction of some parameter estimation noise on Galileo.
- As expected, ECOM parameters estimate as a function of β is now almost flat.
- Strange Galileo IOV Y_0 parameter shape: Very flat out of eclipse period with « exponential growth » in eclipse when $\beta \to 0$



The Eclipse Period Problem

- Orbit estimation discontinuity comparison shows:
- No improvement thanks to BoxWing
- Performance out of eclipse similar with the reduced set and coefficients of our BW and BW5 models and the full EECOM + SP.
- Large modelling error in eclipse without stochastic pulses (The main reason for their introduction).
- GPS has much smaller errors than Galileo.



FOC orbit estimation discontinuities with BoxWing

Red: with BW models, D0, Y0, X0,X1C,X1S,D2C, no albedo/RF, no pulses

Green: without BW models, D0, Y0, X0,X1C,X1S,D2S,D2C, no albedo/RF, no pulses

Blue: without BW models, D0, Y0, X0,X1C,X1S,D2S,D2C, with albedo/RF, with pulses at midnight.

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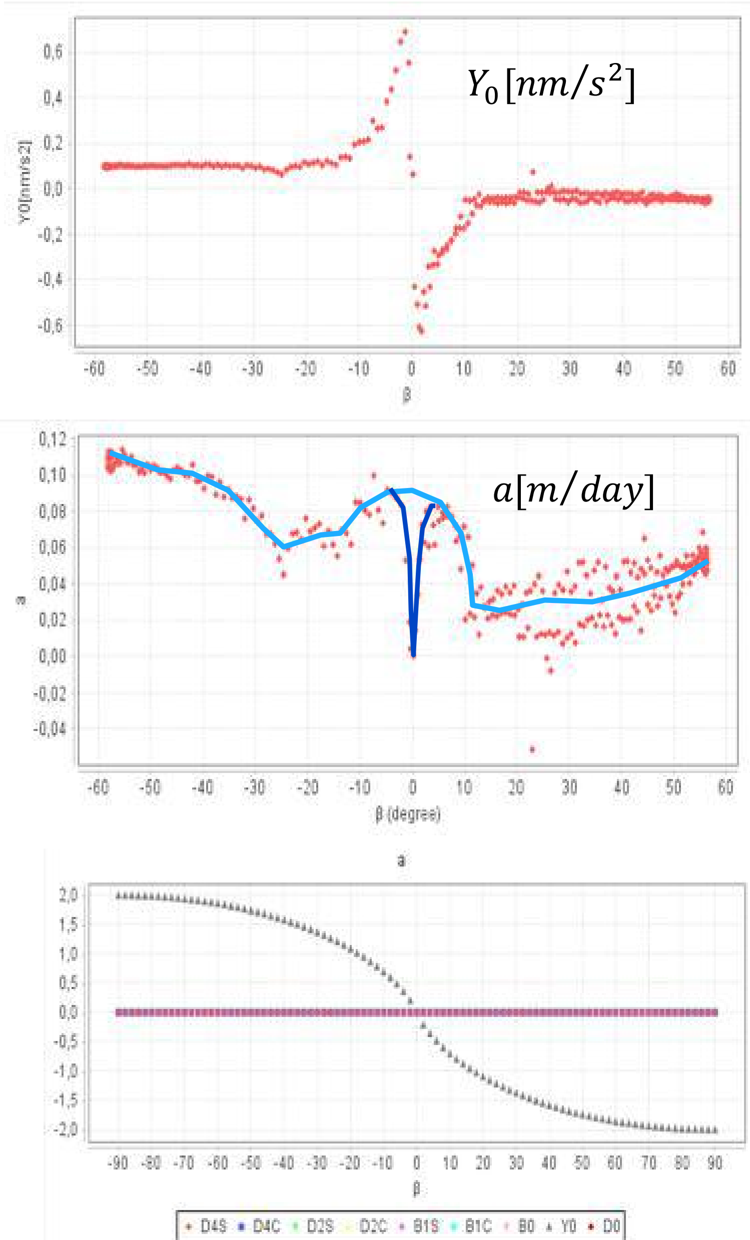
The Eclipse Period Problem

After (many) unsuccessful try to apply forces and search for similar signature, Galileo and GPS IIF together with the orbit drift reconstruction give some hint on what may happen.

- A « bump » in the semi major axis drift can be observed during eclipses.
- The reconstruction exhibit a drop due to the fact that the EECOM model has no impact on the semi major axis at $\beta = 0$
- The reality is probably something like the light blue curve.

- A semi major axis drift occurs during eclipse periods while EECOM do not allow for such drift.



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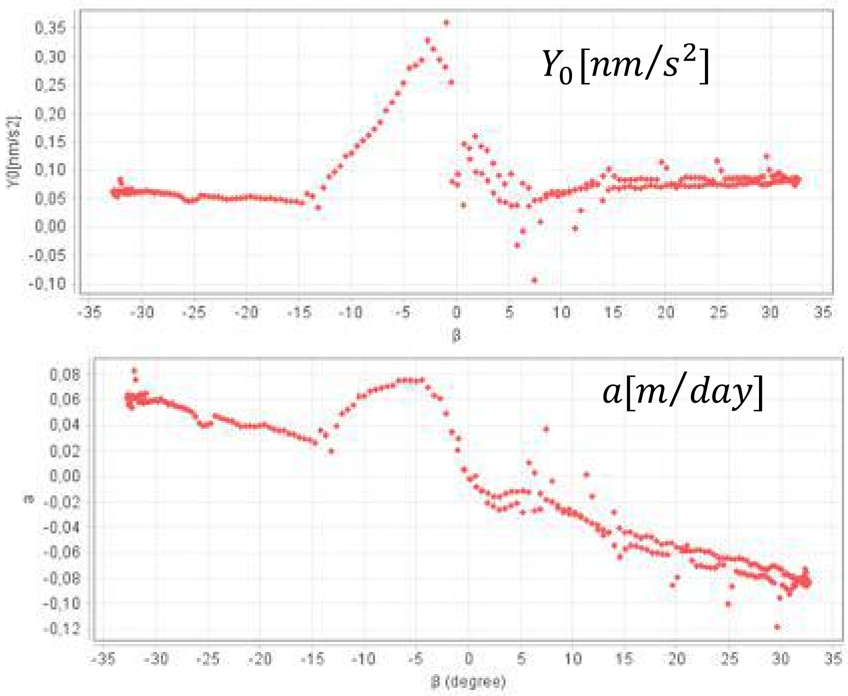
Candidate Explanation

No obvious source for this semi major axis drift increase during eclipse has been found.

The unsymmetrical shape on GPSIIF and Galileo FOC lead us to think that it is related to yaw pointing error.

Candidate	Discussion
Solar Array Thermal transient (Heating and Battery Charge)	Would lead to semi-major axis increase, but symmetrical.
Yaw Error at eclipse exit	Would require larger error than expected.
Small Pointing Unbalance over the whole orbit.	Prefered

GPS Block IIF signature is unsymmetrical



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Proposed Model

Without any detailed knowledge of the AOCS design, it is difficult to know where the force apply.

It occurs once per orbit -> D_{1C} and D_{1S} could account for the long term effect of these impulses.

- D_{1C} has no effect on the semi-major axis and has already be identified as almost unobservable (from GNSS measurements only).
- D_{1S} can absorb the semi major axis drift.

Proposed Model: BW+ D0,Y0,B0,B1S,B1C,D2C,D1S

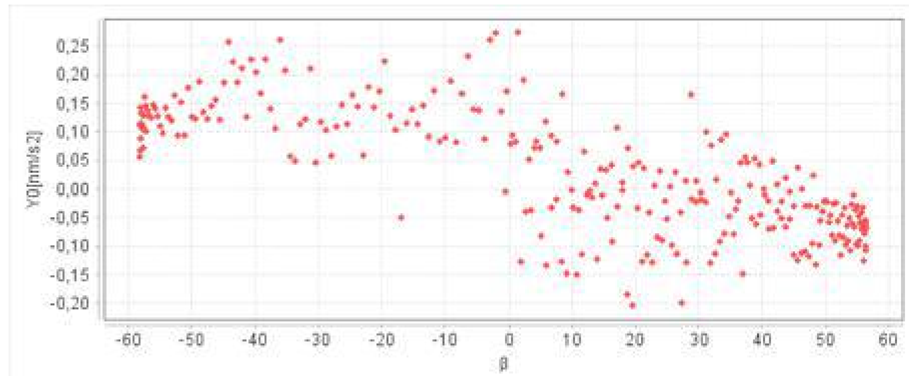
BW+ D0,Y0,B0,B1S,B1C,D2C,D1S

First results confirm the good/promising performance of this model.

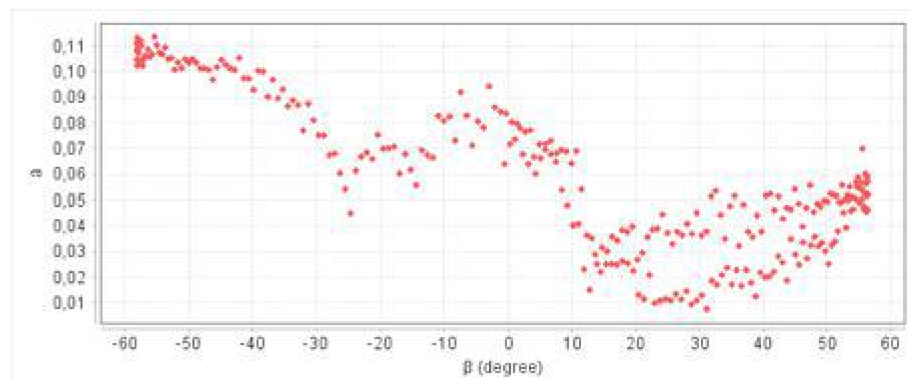
The strength of this model is:

- Forces are close to the expected ones.
- Allow for drift of all orbit parameters (except longitude) independently (robust to mismodelling).

Exponential growth of Galileo IOV Y0 disappear



Drop of semi major axis drift around $\beta = 0$ removed



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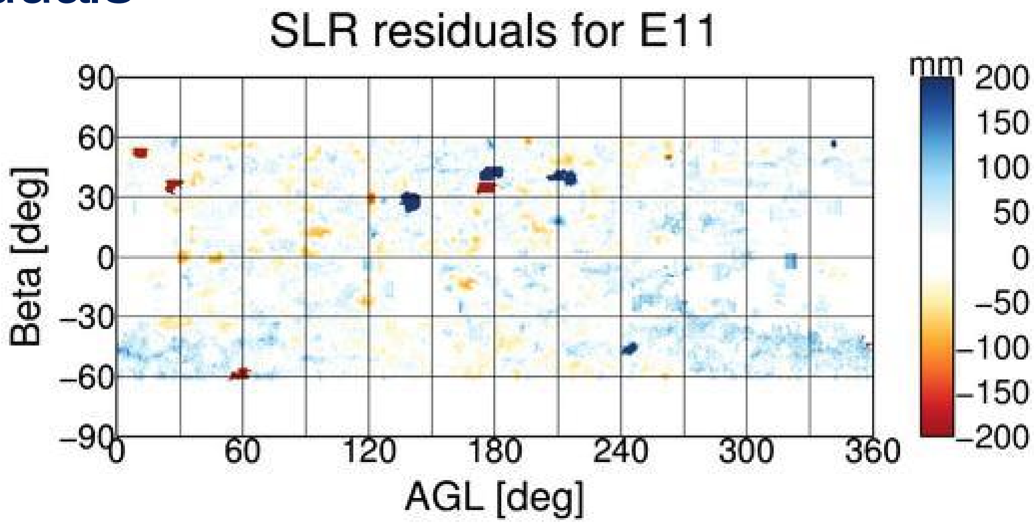
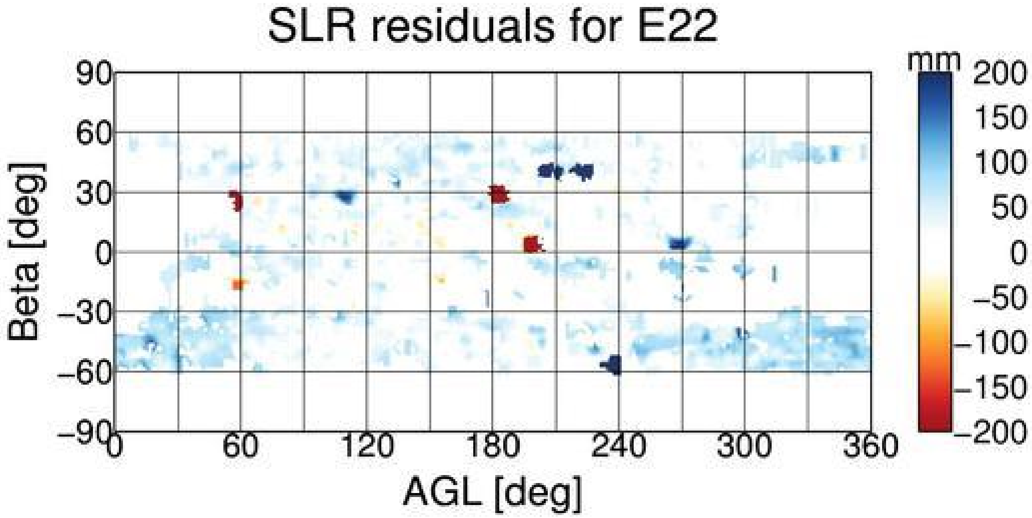
BW+ D0,Y0,B0,B1S,B1C,D2C,D1S
SLR Residuals





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D1C Contribution

Analysis of Satellite Laser Ranging Residuals (FOC) exhibit a bias (estimated orbit lower than the real one, like if the RF pressure and Albedo have been overestimated).

Existence of D_{1C} force is more than probable. (Higher reflectivity of Z- than Z+) and could be one contributor to this bias.

As for RF and albedo cannot be estimated by GNSS measurements only.

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Summary And Conclusion

- The lower amplitude of GPS orbit discontinuity metric is likely due to the 12H period more than due to a more accurate control.

- The large observed orbit discontinuity during eclipse period is likely due to the Yaw error at eclipse exit leading to unbalanced semi major axis drift.

- This error at orbital period is not correctly captured by classical EECOM coefficients. The D_{1S} coefficient adds the required degree of freedom to capture this drift.

- The reflective dissymmetry between the front and back Z faces has a significant impact on the (short term) performance but cannot be estimated with GNSS measurements only. As for the RF pressure and Albedo, we must rely on models or SLR measurements.

Thank you

Annex: ECOM Empirical Model

ECOM Empirical Model

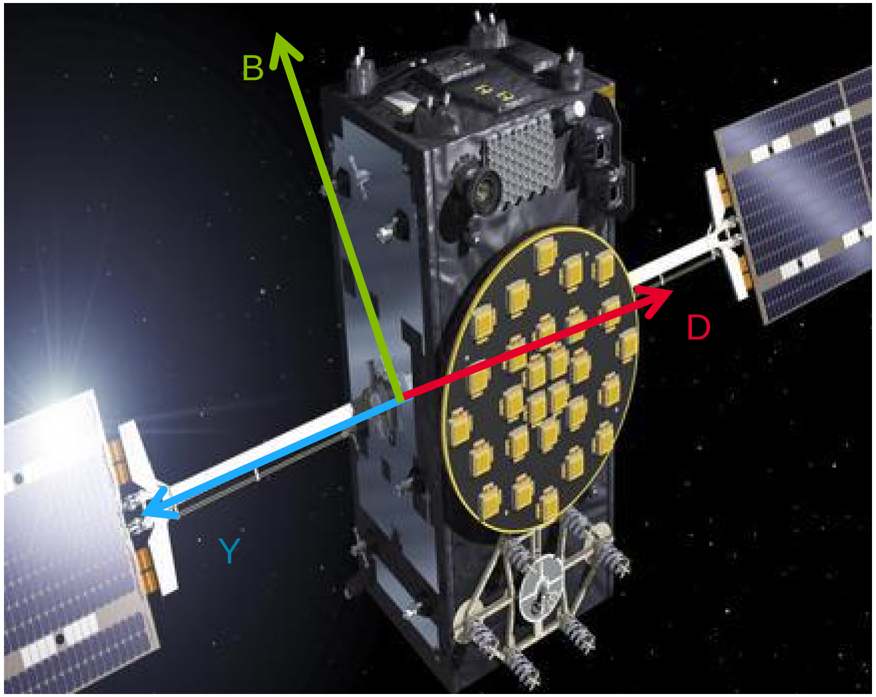
ECOM Empirical model are currently used to model SRP.

ECOM model coefficients are estimated together with the orbit parameters.

They are expressed in the DYB frame linked to the Solar arrays.

- D in the Spacecraft->Sun direction
- Y along the solar array axis.
- B completing the right handed frame in the solar array plane

In this frame, the main force is along –D sue to the SRP force on the solar arrays and spacecraft body.



ECOM	EXTENDED ECOM
$D = D_0$ $Y = Y_0$ $B = B_0 + B_{1C}cos(u) + B_{1S}\sin(u)$	$D = D_0 + D_{2C}cos(2\Delta u) + D_{2S}\sin(2\Delta u) + D_{4C}cos(4\Delta u) + D_{4S}\sin(4\Delta u)$ $Y = Y_0$ $B = B_0 + B_{1C}cos(\Delta u) + B_{1S}\sin(\Delta u)$

ECOM Empirical Model

Most of the coefficients can be explained by the shape of the satellite.

Extended ECOM model is a good approximation of GNSS satellites boxwing shape.

Stochastic pulses have been added to « absorb » model deficiencies. (One pulse at middle of the day, three axes)

Coefficient	Main Origin
D_0	SRP Pressure on SA and mean force on body
Y_0	SA out of plane misalignment
B_0	SA pointing bias
B_{1C}	Reflectivity of Body, « strechendness » of body shape.
B_{1S}	None
D_{2C}	« Cubicness » and « strechendness » of body shape
D_{2S}	None
D_{4C}	« Cubicness » body shape
D_{4S}	None

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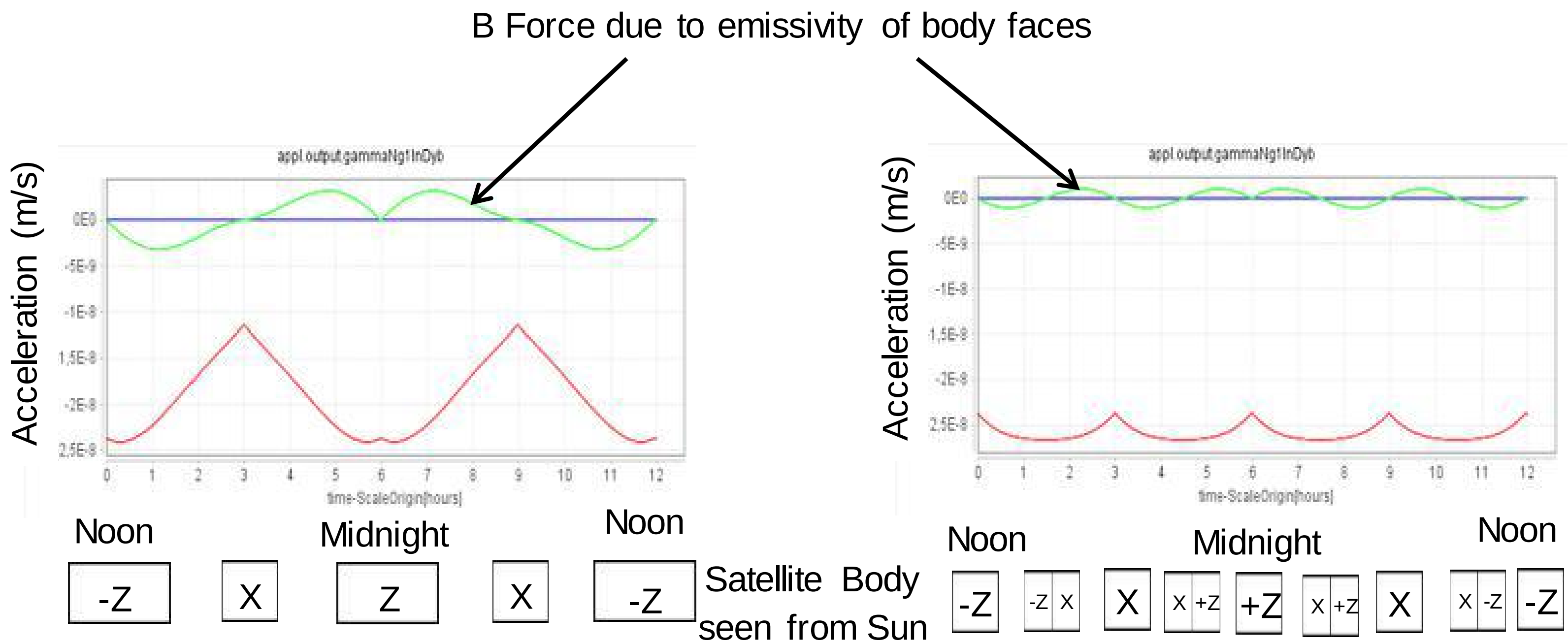
ECOM Empirical Model



Elongated shape (FOC Like) creates D2C and D4C
D2C much more stronger

Square shape creates D4C only due to increased surface when seen from 45°.