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Solar Radiation Pressure Model Performance Test Using GNSS Precise Ephemeris

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1. Summary

The solar radiation pressure (SRP) is one of many forces acting on orbiting satellites. It has been the most difficult force to model for satellites at altitude higher than Low Earth Orbit (LEO) and hence the biggest error source in GNSS orbit determination. Most of GNSS satellites are orbiting at Medium Earth Orbit (MEO) with exception of BeiDou, which has satellites at Inclined Geosynchronous Orbit (IGSO) and Geostationary Orbit (GEO) as well as MEO.

NGS uses 5 parameter Reduced Empirical CODE Orbit Model (ECOM-Re), to model SRP acting on GPS satellites. However, several researchers have shown its deficiency in modeling SRP acting on other GNSS satellites, especially Galileo and BeiDou satellites. To address this deficiency in the traditional ECOM model, a new model, called Extended ECOM (ECOM-Ex), has been proposed in [Arnold, 2015]. The Extended ECOM introduces more parameters to represent SRP acting on GNSS satellite in the satellite-Sun direction.

We have tested the performance of the NGS implementation of the Extended ECOM model on GNSS orbit determination by making use of the approach called orbit fit analysis. In orbit fit analysis, the performance of force models is evaluated by comparing the propagated ephemeris to the high quality precise ephemeris products. In this study, we used GNSS precise ephemeris products from IGS MGEX working group.

Analysis results show that NGS propagated orbits using ECOM-Ex agree to the MGEX products much better than those using ECOM-Re. However, relatively bigger disagreements still exist with BeiDou satellites. This could be attributed to 1) poorer quality of BeiDou precise ephemeris products 2) the Orbit Normal mode that BeiDou satellites employ during low-beta angle period, but was not considered in this study. This needs to be further investigated.

2. Data Used

Precise ephemeris products from IGS MGEX (Multi-GNSS Experiment) working group [Montenbruck 2017] for days from 2017-09-01 to 2017-08-31 were used for this study. Five analysis centers provided products and their products contains ephemeris for the following GNSS satellites (QZSS not considered in this study):

- COD (CODE) : GPS, GLONASS, Galileo, BeiDou (except GEO)
- GBM (GFZ) : GPS, GLONASS, Galileo, BeiDou
- GRM (CNES/CLS) : GPS, GLONASS, Galileo
- TUM (TUM) : Galileo
- WUM (Wuhan Univ): GPS, GLONASS, Galileo, BeiDou

3. Ephemeris Comparison Results

To show the quality of MGEX precise ephemeris products, differences in the ephemeris have been computed and their mean values of daily RMS are presented below in cm. Two Galileo-2 satellites in elliptical orbits are denoted as GAL-2E.

	COD	GBM	GRM	TUM	WUM
COD		3.4	2.8	X	3.4
GBM			4.1	X	2.3
GRM				X	3.9
TUM	GPS-IIR				X
WUM	Overall = 3.3 cm (std=0.6)				

	COD	GBM	GRM	TUM	WUM
COD		2.6	2.9	X	2.7
GBM			3.2	X	2.2
GRM				X	3.2
TUM	GPS-IIF				X
WUM	Overall = 2.7 cm (std=0.3)				

	COD	GBM	GRM	TUM	WUM
COD		8.2	6.7	X	8.4
GBM			7.9	X	4.5
GRM				X	7.9
TUM	GLO-M				X
WUM	Overall = 7.2 cm (std=1.3)				

	COD	GBM	GRM	TUM	WUM
COD		6.2	5.1	X	6.0
GBM			6.0	X	3.8
GRM				X	6.0
TUM	GLO-K1				X
WUM	Overall = 5.5 cm (std=0.8)				

	COD	GBM	GRM	TUM	WUM
COD		4.1	8.2	11.0	5.6
GBM			8.1	11.0	4.8
GRM				12.4	9.1
TUM	GAL-1				11.4
WUM	Overall = 8.5 cm (std=2.7)				

	COD	GBM	GRM	TUM	WUM
COD		4.3	7.1	8.0	5.0
GBM			7.3	8.1	4.8
GRM				10.3	8.0
TUM	GAL-2				9.1
WUM	Overall = 7.2 cm (std=1.8)				

	COD	GBM	GRM	TUM	WUM
COD		6.0	8.2	9.6	6.7
GBM			7.5	9.8	6.0
GRM				11.3	9.0
TUM	GAL-2E				10.3
WUM	Overall = 8.4 cm (std=1.7)				

	COD	GBM	GRM	TUM	WUM
COD		9.8	X	X	10.1
GBM			X	X	7.9
GRM				X	X
TUM	BDS-2M				X
WUM	Overall = 9.2 cm (std=0.9)				

	COD	GBM	GRM	TUM	WUM
COD		16.5	X	X	16.3
GBM			X	X	11.8
GRM				X	X
TUM	BDS-2I				X
WUM	Overall = 14.8 cm (std=2.1)				

	COD	GBM	GRM	TUM	WUM
COD		X	X	X	X
GBM			X	X	289.8
GRM				X	X
TUM	BDS-2G				X
WUM	Overall = 289.8 cm (N/A)				

4. Solar Radiation Pressure Model

The ECOM (Empirical CODE Orbit Model) decomposes the perturbing accelerations into three orthogonal vectors: e_D unit vector points the satellite-Sun direction, e_Y unit vector points along the satellites' solar panel axes, e_B unit vector completes the orthogonal system. Now, the perturbing acceleration can be represented using these unit vectors:

$$\hat{a} = \hat{a}_0 + D(u) \cdot \hat{e}_D + Y(u) \cdot \hat{e}_Y + B(u) \cdot \hat{e}_B$$

where *u* is the satellite's argument of latitude and *D(u)*, *Y(u)* and *B(u)* are defined as:

$$D(u) = D_0 + D_c \cdot cos(u) + D_s \cdot sin(u)$$
$$Y(u) = Y_0 + Y_c \cdot cos(u) + Y_s \cdot sin(u)$$
$$B(u) = B_0 + B_c \cdot cos(u) + B_s \cdot sin(u)$$

NGS is currently using the so-called reduced ECOM (ECOM-Re) in rapid and final orbit processing to model the solar radiation pressure on GPS satellites, in which some of the parameters in the original parameters are constrained to be zero. In this model, the formulation above becomes:

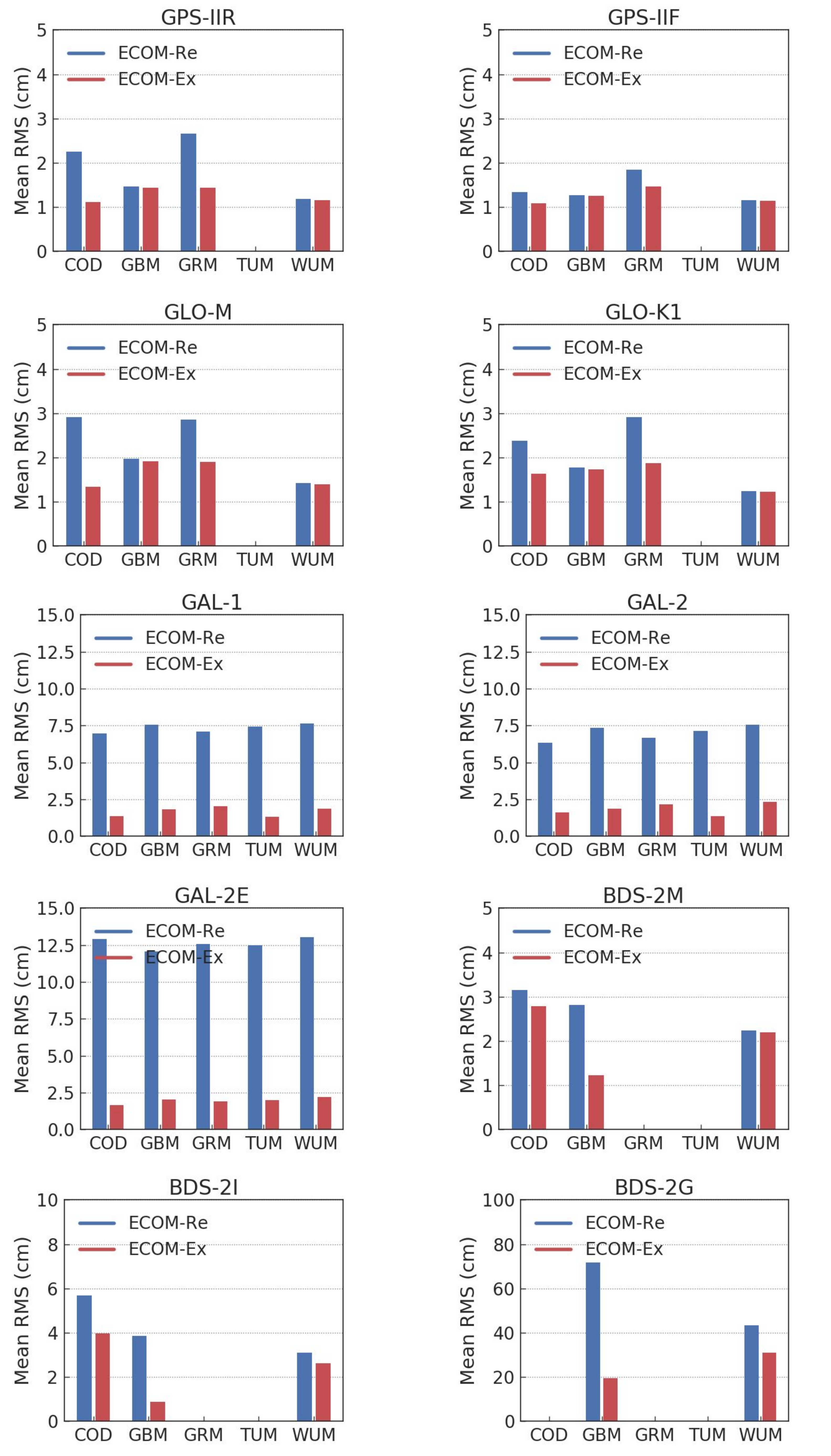
$$D(u) = D_0$$
$$Y(u) = Y_0$$
$$B(u) = B_0 + B_c \cdot cos(u) + B_s \cdot sin(u)$$

[Arnold, 2015] proposed to extend the original ECOM formulation with additional even number periodic terms in *D(u)* direction (ECOM-Ex) as below:

$$D(u) = D_0 + (D_{2C} \cdot cos(2u) + D_{2S} \cdot sin(2u)) + (D_{4C} \cdot cos(4u) + D_{4S} \cdot sin(4u))$$
$$Y(u) = Y_0$$
$$B(u) = B_0 + B_c \cdot cos(u) + B_s \cdot sin(u)$$

5. Orbit Fit Analysis Results

Orbit fit analysis is a method to assess the quality of satellite dynamic models by comparing the propagated orbits using a set of force models against a high quality precise ephemeris. In this study, two propagated orbits, one using ECOM-5 model and the other using ECOM-Ex model as well as other force models being used within NGS, are compared to MGEX precise ephemeris products described in the Section 2. The plotted values are mean values of daily RMS values between NGS propagated orbits and precise ephemeris products from the denoted analysis centers



6. References

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2. Arnold, D, et. al., CODE's new solar radiation pressure model for GNSS orbit determination, Journal of Geodesy (2015) 89:775-791