The Adjusted Optical Properties of GNSS Satellites and Applications in Precise Orbit Determination and Prediction

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Abstract

Solar Radiation Pressure (SRP) is the dominant non-gravitational perturbation for GNSS satellites. In the absence of precise surface models, the Empirical CODE Orbit Models (ECOM, ECOM2) are widely used in GNSS satellite orbit determination. Based on previous studies, the use of an a priori box-wing model enhances the ECOM model, especially if the spacecraft is a stretched body satellite. However, system providers of GNSS satellites so far have not yet all published the metadata. To ensure a precise use of the a priori box-wing model, we estimate the optical parameters of GNSS satellites based on the physical processes from SRP to acceleration. The resulting optical parameters of all the satellites are introduced into an a priori box-wing model, which is jointly used with ECOM and ECOM2 model in the orbit determination. Results show that combined with the a priori box-wing model the ECOM model (ECOM+BW) results in the best Galileo, BeiDou-2 GEO and QZS-1 orbits.

Current Status of GNSS Optical Properties

- GPS: Not yet officially published.
- GLONASS: Not yet officially published.
- GALILEO: Detailed metadata information were officially published by www.gsc-europa.eu in 2017
- BeiDou: Not yet officially published.
- QZSS: QZS-2, QZS-3, QZS-4 system providers published all the metadata in October 2018, but declared that optical parameters of QZS-1 were still under investigation (http://qzss.go.jp).

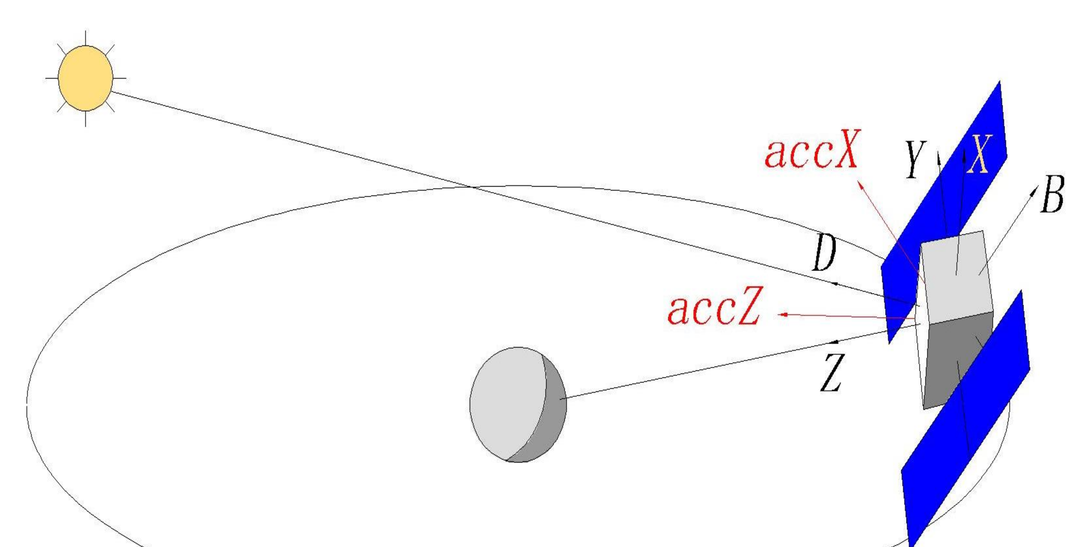
✓ For GPS and BeiDou satellite optical parameters, Fliegel[1] et al. (1996), Rodriguez[2] et al. (2012), Guo[3] et al. (2017) suggested initial values.

SRP Accelerations

The physical optical properties of a satellite surface comprise absorbed (α), reflected (ρ) and diffusely (δ) scattered photons. Milani[4] et al. (1987) formulated the physical interaction between SRP of each panel and acceleration in the following way:

$$\mathbf{acc} = -\frac{A}{M}\frac{S_0}{c}\cos\theta\left[(\alpha+\delta)\mathbf{e}_D + 2\left(\frac{\delta}{3}+\rho\cos\theta\right)\mathbf{e}_N\right] \quad (1)$$

If considering that the energy absorbed by the satellite surface is instantaneously re-radiated back into the space, equation (1) expresses as :



$$\mathbf{acc} = -\frac{A}{M}\frac{S_0}{c}\cos\theta\left[(\alpha+\delta)\left(\mathbf{e}_D+\frac{2}{3}\mathbf{e}_N\right)+2\rho\cos\theta\,\mathbf{e}_N\right] \quad (2)$$

where A denotes the surface area, M the total mass of the satellite, S_0 the solar flux at 1 AU, c the vacuum velocity of light, e_D the unit vector in Sun direction, e_N the normal vector of the satellite surface, and θ the angle between both vectors.

In our adjustment, equation (1) is applied for solar panel while equation (2) is adopted for satellite body surfaces. For each surface there are two adjusted optical parameters: $\mathrm{AD}(\alpha+\delta)$ and $\mathrm{R}(\rho)$.

Modeling Options and Settings

Items	Value
Software	Bernese 5.3 modified
Observations	Zero-difference Code&Phase
Data arc	1 day
Sampling	5 min
Optical and empirical parameters	Yaw-steering: lag, Y-bias, SP, +XAD, +XR, ±ZAD, ±ZR Orbit-normal: SPR, ±XAD, ±XR, ±YAD, ±YR, ±ZAD, ±ZR
Earth albedo	Considered
Station coordinate	Fixed on GPS PPP
Troposphere	Fixed on GPS PPP
Receiver clock	Fixed on GPS PPP
Satellite clock	Estimated
Receiver system bias	Estimated

* lag, the solar panel rotation lag * SP, the direct radiation pressure
* AD and R, the adjusted two optical parameters of each panel

GPS PPP (CODE orbits and clocks)

↓

Optical parameter estimation (Galileo/BDS/QZSS)

↓

Stack normal equations of half a year eliminating all the other parameters except the optical parameters

↓

Introduce the adjusted parameters into an a priori box-wing mode and jointly used with ECOM/ECOM2

Validation of Orbit Prediction

1. Fit precise gbm orbits from GFZ of one day to generate precise initial condition at the end of the day.
2. Predict orbit arc length of 7 days by using box-wing model based on the adjusted and initial parameters.
3. Compare the predicted orbits with the precise gbm orbits.

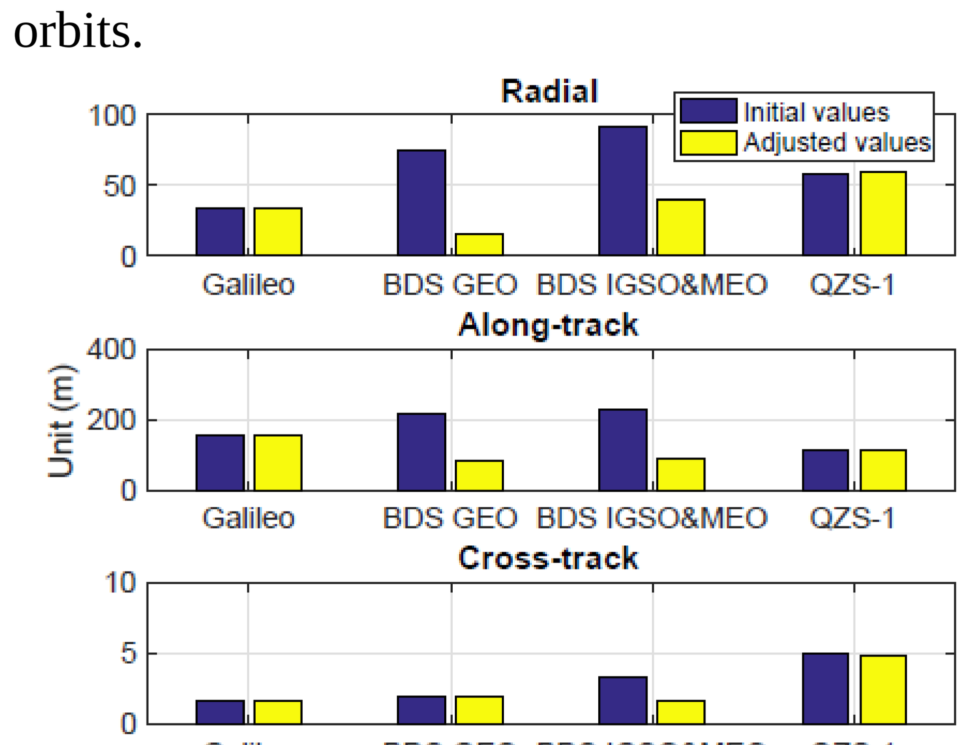
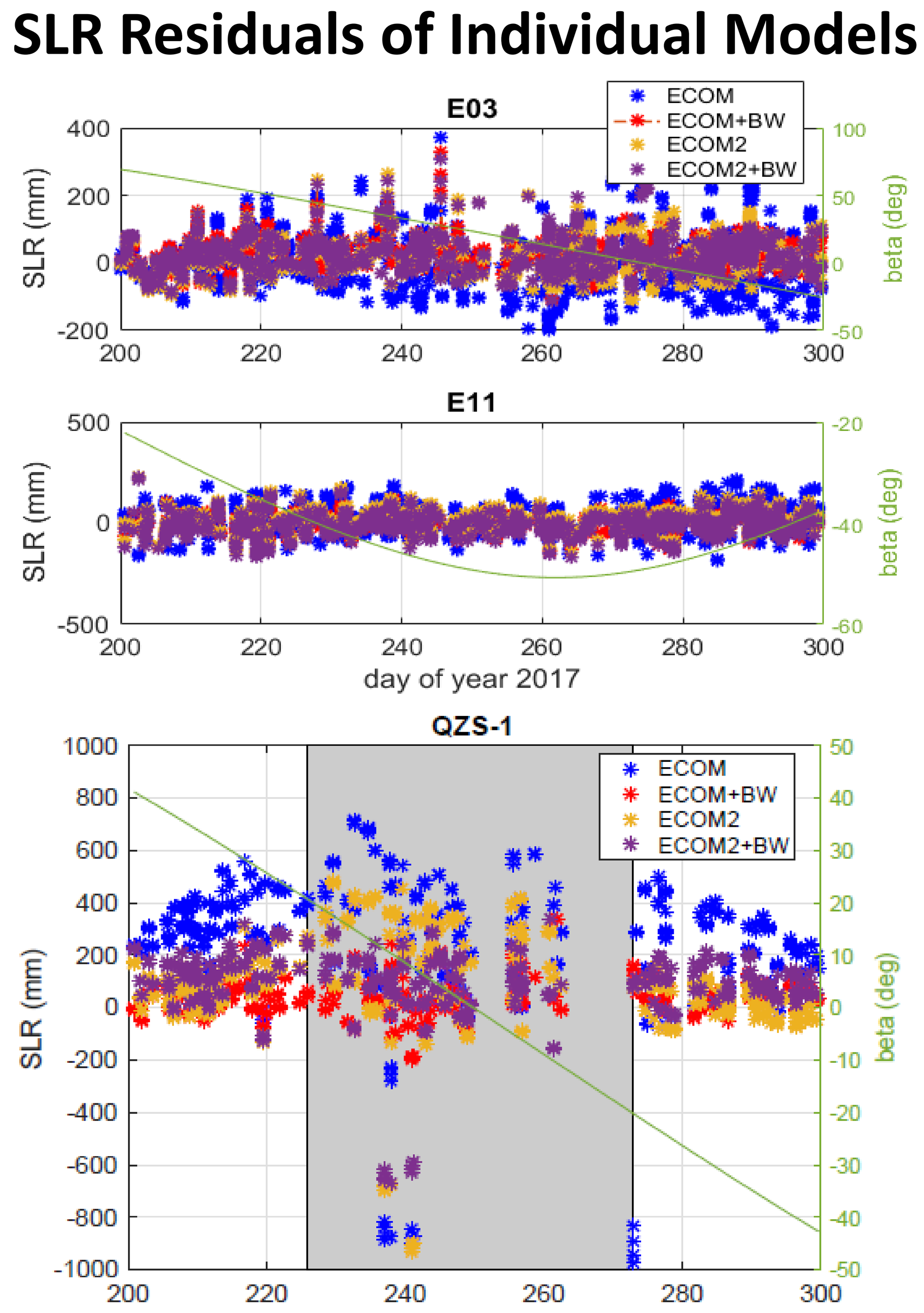


Figure1. Averaged RMS of predicted orbits based on the initial (blue) and the adjusted (yellow) optical properties

SLR Residuals of Individual Models



STD of SLR residuals for all the satellites (cm)

	ECOM	ECOM+BW	ECOM2	ECOM2+BW
Galileo	8.2	4.2	5.4	5.2
BDS GEO	21.2	17.7	18.3	17.2
BDS IGSO (YS)	10.0	10.8	14.1	16.4
BDS IGSO (ON)	12.3	12.3	15.9	16.5
BDS MEO (YS)	12.2	13.1	15.3	16.5
BDS MEO (ON)	16.4	17.4	20.0	21.4
BeiDou-3e	14.7	12.5	18.2	12.7
QZS-1 (YS)	19.9	4.8	8.2	7.4
QZS-1 (ON)	33.7	10.5	28.2	19.3
QZS-2	27.0	19.1	29.1	30.4

* YS, yaw-steering mode
* ON, orbit-normal mode
* ECOM model parameters in YS and ON are differently defined, which refers to Duan[5] et al . (2018)
* BDS denotes BeiDou-2

Conclusions

Our estimation procedure reproduces the published Galileo parameters fairly well. Validation of orbit prediction proves that the adjusted parameters of Galileo and QZS-1 satellites show almost the same performances as the corresponding published or "guess" values, whereas, an improvement of more than 60% is pointed out for BDS satellites.

Combined with the box-wing model that bases on the adjusted parameters the ECOM model benefits more than the ECOM2 model. STD of SLR residuals reduces by about 20% for Galileo orbits, while the reductions are 40% and 60% for QZS-1 orbits in YS and ON mode respectively. BDS IGSO and MEO orbits do not benefit from the box-wing model, while that of BDS GEO orbits still show some improvements.

Regarding the ECOM+BW model, QZS-2 and BeiDou-3e orbits show an improvement of 30% and 20% in radial direction.

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4. Milani A., Nobili A M, Farinella P (1987) Non-gravitational perturbations and satellite geodesy. Adam Hilger, Bristol, UK.
5. Duan B, Hugentobler U, Selmke I (2018) The Adjusted Optical Properties for Galileo/BeiDou-2/QZS-1 Satellites and Initial Results on BeiDou-3e and QZS-2 satellites.

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