The Solar Radiation Pressure Modelling and Parameter Analysis for BeiDou Satellites

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1 Introduction

The solar radiation pressure (SRP) perturbation is difficult to be accurately modeled due to the complicated and changing satellite attitude and surface material characteristics. Therefore, it becomes the most important error source in the precise orbit determination(POD) and forecast of GNSS satellites. For BeiDou satellite navigation system (BDS) a SRP model is necessary for high precise applications especially with Global BDS establishment in future. The BDS accuracy for broadcast ephemeris need be improved. So, we adopted the radiation transfer theory and corresponding physical concept, simplified satellite body configuration and calculated SRP perturbation through the solar radiation intensity and flux. A box-wing theoretical SRP model with fine structure was established. Then, the initial model was adjusted to fit better for the measured data and finally form the two models, one is the semi-empirical model based on the structure and physical properties of satellites, the other is called adjustment model without empirical parameters. By using the geometry and physical properties of satellites we highlight the benefit of an accurate SRP modelling versus conventional methods such as a Cannonball-like model or a purely empirical approach(BERN/ECOM model). The analysis shows that the implementation of a detailed satellite geometry allows for better orbit precision of final results and prediction, especially for local satellite system or Insufficient amount of data.

2 Simple BOX-WING model parameter adjustment

Generally the surface shape of satellite equipped with panels is more complicated when it needs to be modelled for orbit determination, and often use a called Box-Wing simplified model. In this model, the main body of the satellite is seen as a cuboid, while the solar panels are treated as rectangle around the Y-axis rotation of the satellite. The other approach is a precise modelling, which surface is divided into more blocks that the size of each block, reflection and scattering rates are measured respectively. For modelling solar radiation pressure, the interaction between the various parts of block is also needed to be considered, which is relatively complex to model. In the process of Box-Wing modelling for similar cuboid satellite, six faces of main body and two solar panel are considered separately. So direct solar radiation can be written as below, parameters are multiple shapes of different parts, area, reflectivity, specularity, orbital angle, and directions in the Body Fixed coordinate System(Fig. 1). The absorption and diffuse reflection coefficient are estimated in the direction of each panel, specular reflection coefficient, and scaling factor, Y-axis bias, and B-axis experience parameters.

At first we have estimated 15 parameters, however, through the study found that, the correlations among some of the parameters are very strong. So strong related parameters are removed, and the panels in the same line direction adopt same two comprehensive parameters(absorption plus diffuse reflection part and specular reflection part). We have done tests with nine parameters and six parameters version, at last, we have tested a reduced five parameters, they are D-scale, Y-bias, solar panel, box x-axis and z-axis.

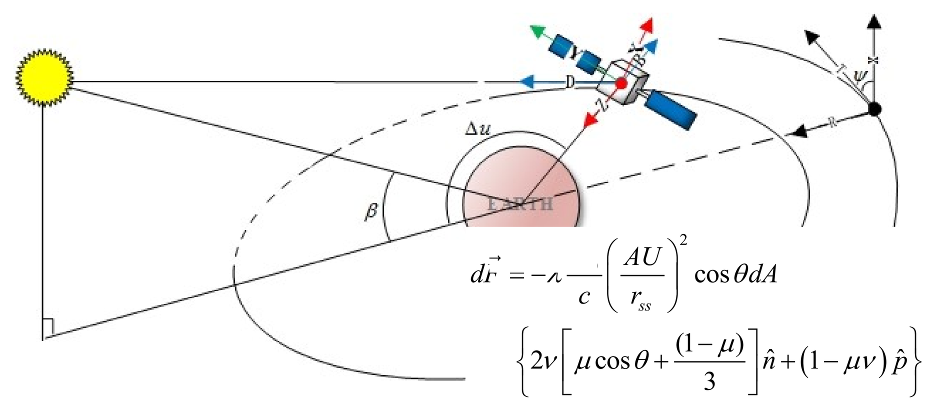


Fig. 1 Satellite coordinate system and geometric parameter relations

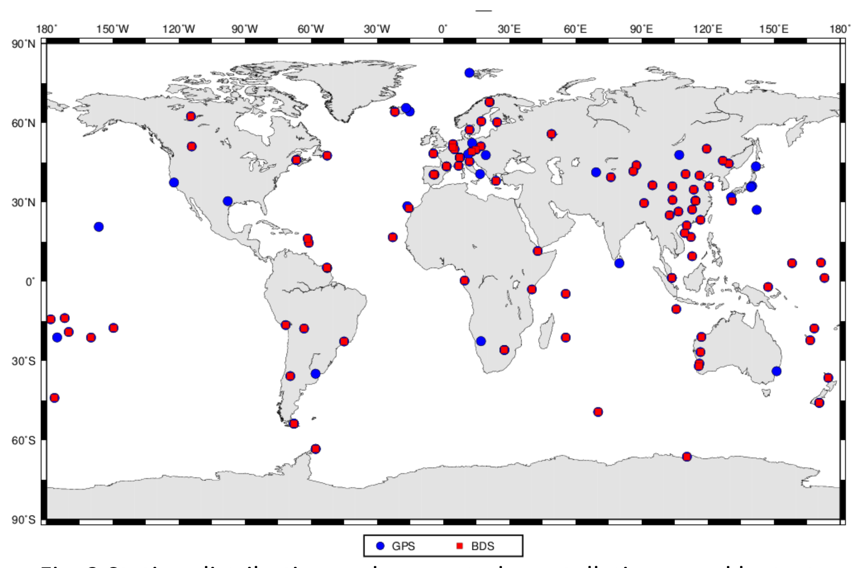


Fig. 2 Station distribution and supported constellations used by tests

3 Test data and solve strategies

Orbit determination process, mainly includes batch mode and filtering method, two methods have their own advantages. Currently, the batch mode is widely used in non-real-time orbit determination whose main theoretical contents include the linearization of the reference state and the partial derivatives of estimated state. In the process of orbit determination, SRP scale factor is estimated together with other parameters. Error correction models considered are listed in Tab. 1, solar radiation pressure parameters which BERN model estimates five Bernese parameters and IIF model estimates an SRP scale parameter, and, the satellite clock error, station clock error, ambiguous parameters, troposphere ZTD parameters of each station per one hour and EOP parameters.

(1) In the test, one month of 59 and 168 global IGS stations' GPS data from July 31 to August 31 in 2013 are used for IIF model validation test, which estimate only one parameters.

(2) SRP models(ADBOXW) with more complex structures and more parameters designed for BDS satellites were validated with MGEX data(Fig. 2) in 2015, if only BDS, use 3 days arc; or use GPS + BDS 1 day arc, see Table 1.

Tab. 1 Main Dynamical orbit models and observation models involved in multi-GNSS POD

Item	Applied models
Geopotential	EGM96 model (12 × 12)
M-body gravity	Sun, Moon and planets
Tidal forces	Solid Earth, pole, ocean tide IERS conventions 2003
Solar radiation pressure	ADBOXW model refer to ECOM with 5 parameters
Relativistic effects	IERS conventions 2003
Basic observables	Un-differenced ionosphere-free combination of code and phase based on GPS L1/L2, BDS B1/B2
Processing sampling	300 s
Cutoff elevation	7°
Weighting	Elevation-dependent weight
Satellite antenna phase center	PCOs and PCVs for GPS from igs08_wtMGEX.atx.
Receiver phase center	igs08.atx for GPS, none for BDS
Phase wind-up	Wu et al. (1993)
Earth rotation parameters	Estimated with tight constraint

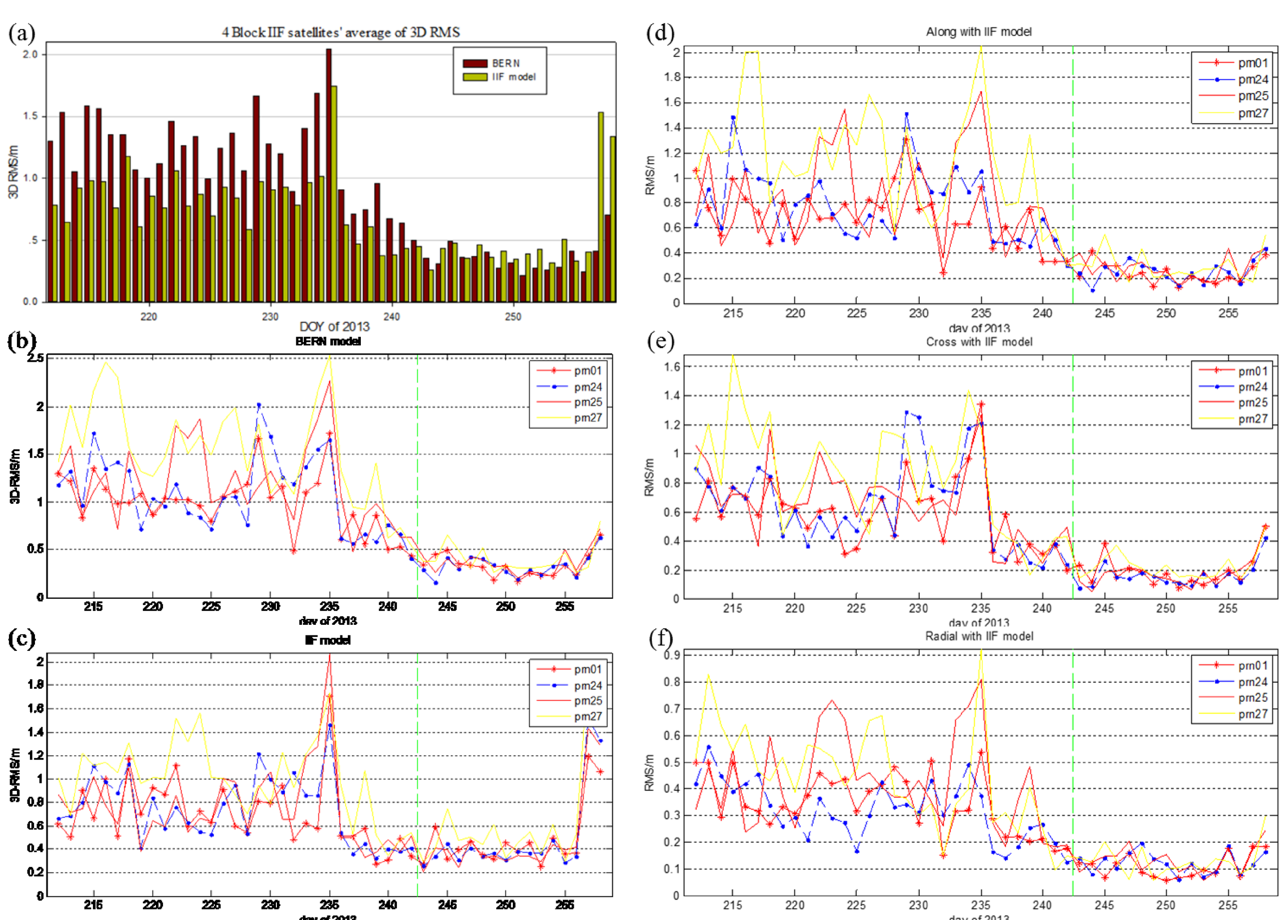


Fig. 3 The statistical results of orbit determination using 1parameter IIF model and BERN model, and different station numbers: 2013,DOY 212~242 with 59 stations, 243~258 with 168 stations.

4 Orbit prediction

The orbital prediction processing schema is to see Figure 4 . As can be seen Figure 5 the orbit prediction RMSE of four GPS Block IIF satellites using the BERN model for 1 day, 3 days, 7 days is approximately 0.9 m, 5.5 m, 30 m, and about 0.4 m, 2.0 m, 10.0 m for using IIF model.

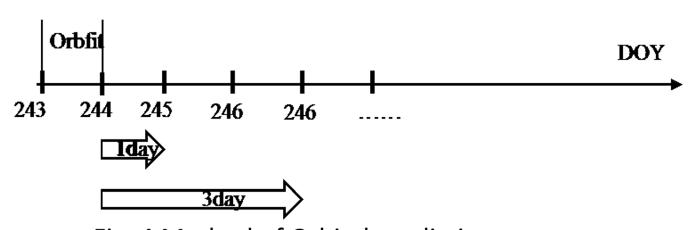


Fig. 4 Method of Orbital prediction tests

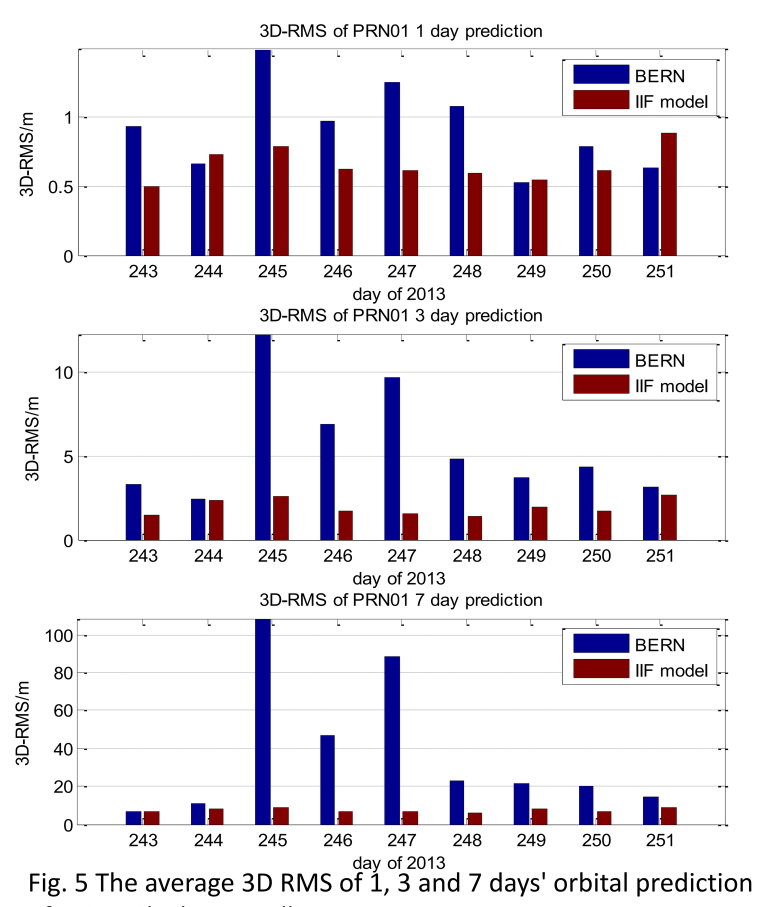


Fig. 5 The average 3D RMS of 1, 3 and 7 days' orbital prediction of 4 GPS Block IIF satellites

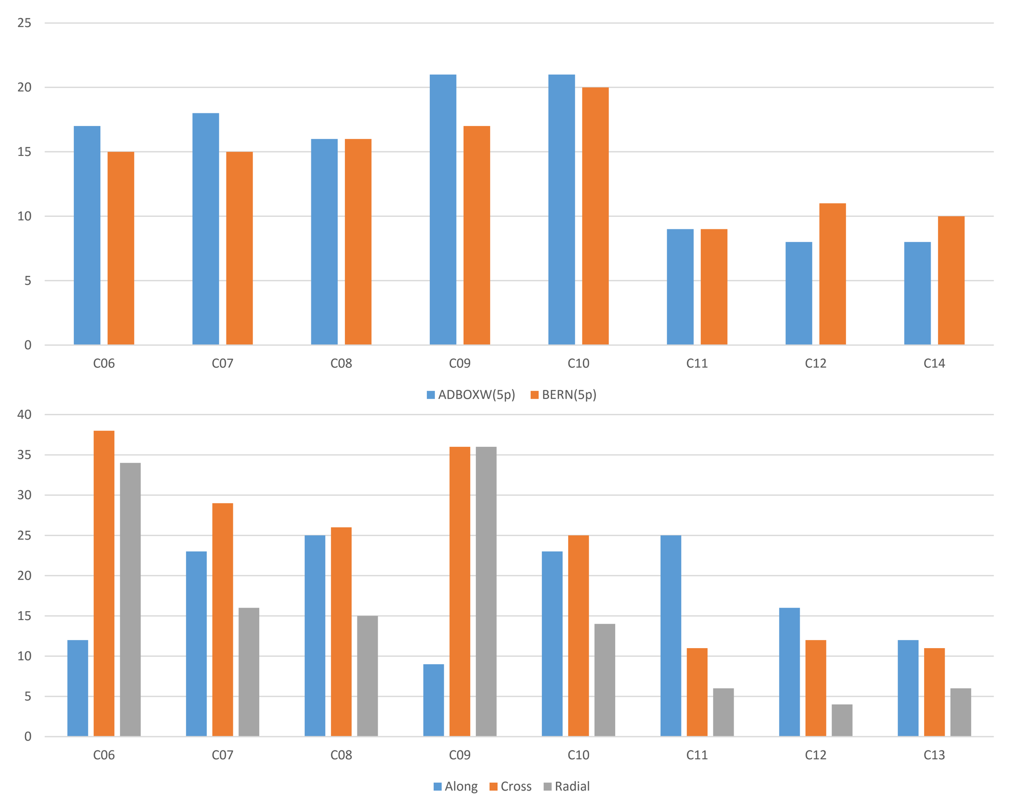


Fig. 6 [1] RMS of orbit residuals with 5 parameters' ADBOXW model and 5 parameters' ECOM(BERN) model, 011/2015, unit: cm; [2] FITRMS of Along, Cross and Radial track direction compared to GBM products.

5 SLR validation of BDS orbits

The BDS LRAs were constructed by the Shanghai Astronomical Observatory and are similar in design to the other satellites. Four in-Orbit satellites (PRN C01, C08, C10, C11) were equipped with LRA. The values of center of mass refer to the International Laser Ranging Service (ILRS). Figure 7 shows the omc residuals of SLR validation to BDS (C08, C10, C11) 1-day satellite arcs. The solutions shows the similar offset about C08 and C11, however C10 when using ECOM model is worse than ADBOXW model. It is not difficult to find that the offset of the two models about C11 tend to be negatively correlated with reference to the results of GFZ, which are some problems of this new physical model needed further research.

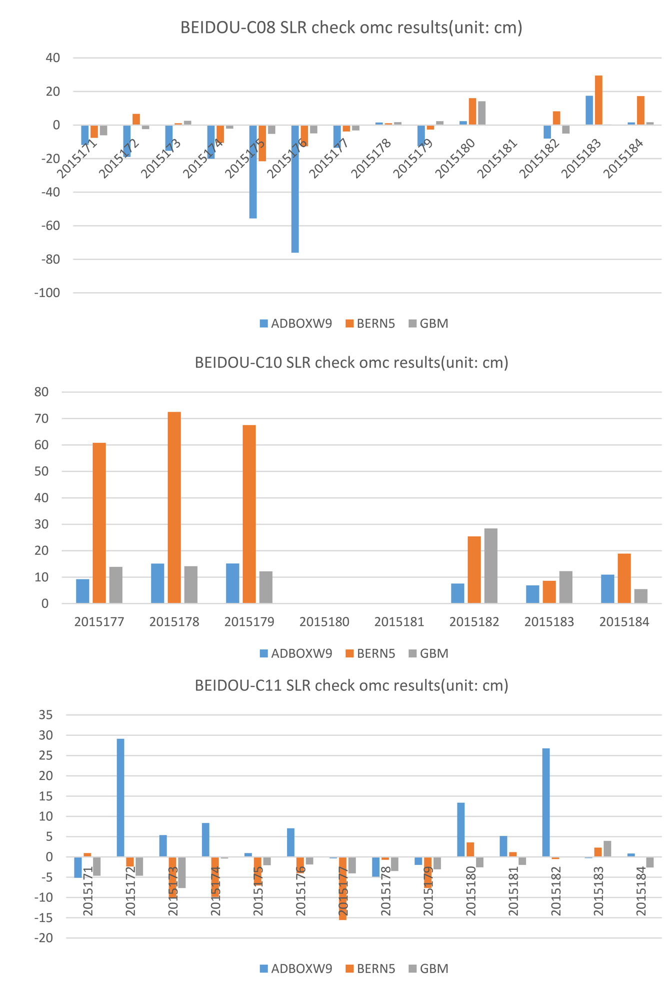
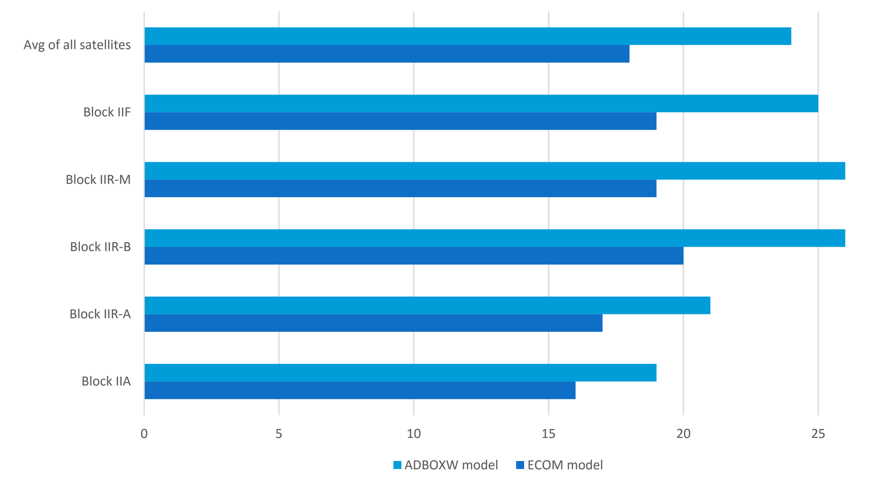


Fig. 7 -> SLR validation of BDS satellites orbits and compared with GFZ products(GBM). (TOP) C08, (MIDDLE) C10, (BOTTOM) C11. ADBOXW model has the best performance in the C10 satellite.



<- Fig. 8 Orbit residuals of all GPS satellite using ADBOXW model and ECOM model. It shows that ECOM model has better results about 5mm than ADBOXW model. Error results of Block IIR* and IIF type satellites is larger because of the larger amounts of quantity and complexity.

6 Conclusion

Based on the physical principles of modeling the solar radiation pressure, the factors of influencing the solar radiation pressure perturbation are discussed and analyzed, and a brief analysis of the changes in orbit of solar radiation pressure is taken into account. Then, the physical analysis model of GPS Block IIF satellites is established, namely IIF model and the validation is that the RMSE of precise orbit determination is about 0.2 m through a lot of in-orbit data. And then Adjusted BOXWING model(ADBOXW) was built and tested for BDS satellites. Compared with BERN model which is the most commonly used, the tests results show that IIF and ADBOXW models take advantage of physical models when data is not sufficient, but it would be slightly worse than the BERN model when data is sufficient and number of stations is enough, however, IIF model has the much higher accuracy for orbit prediction which is more advantageous to predict orbit and broadcast ephemeris which is also applicable for BDS satellites, such as IGSO and MEO satellites. The method of modelling solar radiation pressure in this article provide a reliable reference for high precision orbit determination and positioning of China's BeiDou navigation satellite system, especially for the construction of the new navigation satellite systems with little satellites and insufficient data.

7 References

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