IAG 2021 Beijing June 28–July 2 2021
Geodesy for a sustainable Earth
Scientific Assembly of the International Association of Geodesy
Beijing • June 28-July 2, 2021

Precise Orbit Determination of CubeSats Using a Proposed Observations Weighting Model

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Introduction CubeSats are small low-cost and low-power satellites that can be used for many space missions. Precise orbit Determination (POD) of CubeSats is essential for some missions such as radio-occultation, InSAR, satellite altimetry, and gravity field recovery, and future mega-constellations LEO satellites that are proposed as augmentation systems for positioning and navigation [1]. In this study, we analysed the POD of seventeen 3U-CubeSats from the Spire Global Constellation. The data, processing information and models in the POD processing are provided in Table1.

Table 1

Item	Description
Gravity field / Earth tide / Relativity /Other planets	EGM 2008 /FES2004 / IERS 2010 / DE405
Observation Combination	1Hz dual-frequency GPS Ionosphere-Free (IF)
Priori code and phase sigma	0.1 m, 1 mm (Zenith, L1)
Empirical acceleration	Stochastic pulses, Piecewise constant accelerations
Attitude info, Quaternions, Antenna PCO & PCV	Provided by Spire Co.
Weighting Model	Elevation-dependent and SNR-based models

Weighting Models Equal weighting of GNSS observations are generally considered for LEO POD. However, this is not optimal due to the different effective factors such as higher order ionosphere, scintillation, near filed multipath, hardware delays, etc. One may suggest using the elevation dependant weighting models. Analysis of residuals reveal that this type of models does not reflect the actual noise level of the observations (See the last figure). Besides, the CubeSat should effectively record the quaternions to estimate the receiving signal elevation angels correctly. This may not be possible for low-power budget CubeSats. Hence, we propose to weight the observations (Φ_i) based on the following Signal-to-Noise-Ratio (SNR) model:

$$W(\Phi_i) = \left(0.1 + 0.9 * \left(\frac{\Delta SNR_{i,min}}{\Delta SNR_{max,min}}\right)\right)^2$$

Where $\Delta SNR_{i,min}$ is the differences between the observation SNR value and minimum SNR in all observations, and $\Delta SNR_{max,min}$ is the difference between maximum and minimum SNR values among all observations. Figure 1 compares the weighs generated from applying different weighting models for different elevation angels for one month of CubeSat PRN-099 observations.

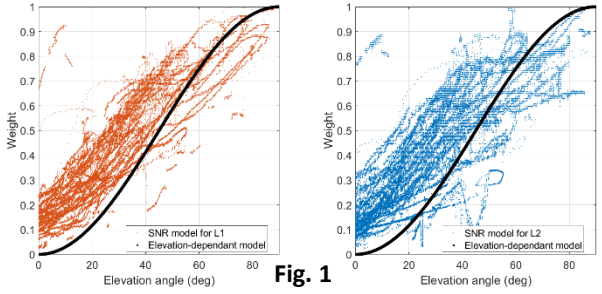

Fig. 1

POD Results: All pieces of observations of 3U-CubeSats from the Spire Constellation (each piece has around 1.5 hour 1-Hz dual-frequency GPS data) are processed in both reduced-dynamic (RD) and kinematic (KIN) POD. The results are compared in **Figure 2** in Radial (R), along-track (S), and cross-track (W) directions.

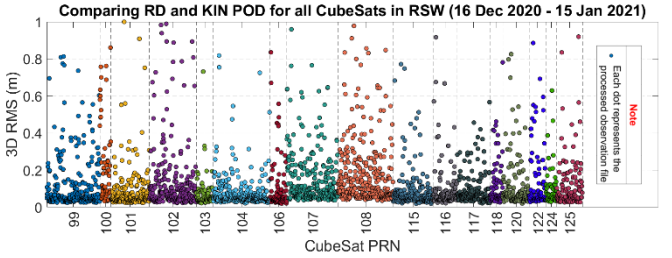

Fig. 2

POD Validation: The internal methods including the overlapping arcs, residuals analyses, and posterior variance factors are used to validate the POD results. The overlapping differences are less than 5 cm for all directions. The posteriori sigma of all CubeSats are plotted in **Figure 3**. They are doubled in the case of using only an elevation-dependent weighting model.

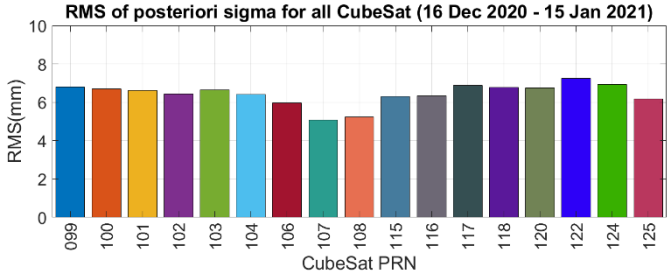

Fig. 3

The GPS IF phase residuals for CubeSat PRN-099 are plotted in **Figure 4**. The residuals decreasing is obvious in the case of using the SNR-based model. Similar trends are observed for other CubeSats.

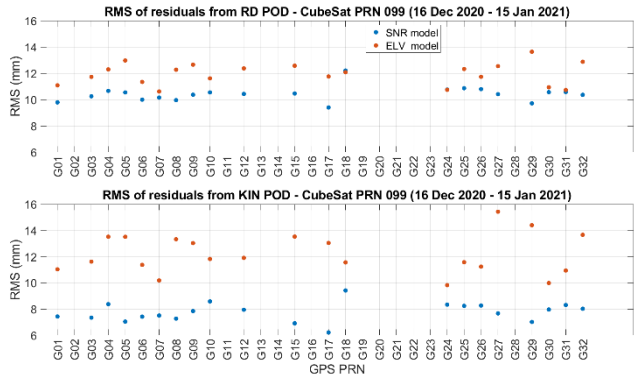

Fig. 4

Conclusion The proposed SNR-based weighting model reduced the IF phase residuals compared to the traditional elevation-dependent model. The internal validation including comparing overlapping arcs and the posteriori sigma confirmed the improved performance CubeSat's POD using this weighting model. The generated CubeSats obits fulfil the requirements of different space and Earth science applications. The impact of using such weighting model on ambiguity resolution is our next study.

Reference

[1] Allahvirdi-Zadeh, A., Wang, K. & El-Mowafy, A. POD of small LEO satellites based on precise real-time MADOCA and SBAS-aided PPP corrections. GPS Solut 25, 31 (2021). https://doi.org/10.1007/s10291-020-01078-8