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Satellite Operation in Special Space Weather - Cross-Platform Satellite Operation Control (XPSOC) -

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Abstract

The FORMOSAT-7/COSMIC-2 is a cooperation satellite mission between Taiwan and USA to measure atmospheric profiles and space weather parameters with six satellite constellations. It is a busy and complex task for operation, due to the data latency requirements within 45/30 min average for weather/space weather data assimilation and six satellites flying in space simultaneously. There are ten ground stations are used to downlink the measurements to achieve this goal. XPSOC (Cross-Platform Satellite Operation Control), a satellite monitoring and commanding system, has been completed to establish Taiwan's technical capabilities in satellite operation and control. After more than a year of verifications, XPSOC has proven it can fully support the mission operations of the FORMOSAT-7 constellation.

One of the most important tasks in satellite operation control is the accurate prediction of the satellite position and velocity information. However, according to solar activity increases, the density of neutral air will become denser and the variation of neutral air will become sharp in the next few years. These uncertainties cause challenges to predict two-line elements (TLE) for satellite operation. A spike in radio emission (F10.7) had happened around the end of March 2022, causing the downlink data loss of FORMOSAT-7/COSMIC-2 in early April 2022. This study tries to figure out the relationship between space weather and precise of satellite orbit and find a better operation to avoid the data loss again. The parameters of two lines elements (TLE) are tuned for satellite tracking with using air drag derived from FORMOSAT-7/COSMIC-2 precise orbit.

Keywords: XPSOC, FORMOSAT-7/COSMIC, BSTAR, Air Drag

Acronyms/Abbreviations

Cross-Platform Satellite Operation Control (XPSOC), FORMOSAT-7/COSMIC-2 (FS-7/C-2), Low Earth Orbit (LEO), Two Line Elements (TLE). TAiwan Space Agency (TASA).

1. Introduction

FORMOSAT-7 satellites were launched into space on June 25, 2019. Then the Darwin Ground Station in Australia successfully acquired the satellite signals at 173 minutes after the launch, which was the first time that FORMOSAT-7 satellites were communicated with the ground station. In the meantime, the satellite operations control system XPSOC (Cross Platform Satellite Operation Control) takes over the activity of mission operation, XPSOC include the command uplink, command encoding, telemetry data downlink, telemetry decoding, data monitoring and archiving for each satellite of FORMOSAT-7. Until now, the operation team has executed satellite constellation contact activity via the User Interface of XPSOC over 0.1 million times in 40 months, supported the payload data downlink over 6 million products, and assisted the orbit transfer of 6 satellites to the mission orbit. Combing the above activities, the reliability of XPSOC system achieves 99.9%. In addition to continuous assistance in the operation of FORMOSAT-7, XPSOC system will be updated and upgraded as the general platform of the satellite operations and control system. The ground system of each satellite mission in the Taiwan's Long-Term National Space Technology Development Program (The Third Phase) is expected to be developed on the basis of this system.

Figure 1. The function of XPSOC

XPSOC (Cross-Platform Satellite Operation Control) is a 100% Taiwan-made multi-satellite control system. Compared with the past foreign systems, TASA (Taiwan Space Agency) can not only modify the needs more flexibly but also save more than $1.6 million per decade for maintenance costs. The XPSOC system had been used to support the Taiwan-US cooperation mission FS-7/C-2 launched in June 2019, supporting the launch and early orbit phase, command uplink and data downlink, six satellites orbital deployment, the system had been proven to be a stable and reliable system. TASA is continuing to upgrade and integrate the system to support the next serious missions of FORMOSAT-8, 9 and 10, commercial communication satellites (B5G). TASA also are committing on foreign technology transfer or commercial services in the future.

Satellite Communications technologies have achieved remarkable breakthrough efficiencies and increases in performance in nearly a half century [3]. The major satellites manufacture includes SpaceX, Telesat, Oneweb, and Amazon. According to the satellite industry data provided by Market Intelligence & Consulting Institute [MIC, https://ctee.com.tw/news/stocks/763202.html], the estimated number of satellites in 2022 is 2,825, and the total number from 2025 to 2027 will reach 7,518. SpaceX lost up to 40 brand-new Starlink internet satellites due to a geomagnetic storm in Feb. 2022, onboard GPS suggests the escalation speed and severity of the storm caused atmospheric drag to increase up to 50 percent higher than during previous launches. (https://www.space.com/spacex-starlink-satellites-lost-geomagnetic-storm), it demonstrate that the air-drag will be an important key for low earth orbital satellite control. The maximum of upcoming solar cycle 25 will arrive around 2024, and the maximum should be larger than cycle 24, as strong as cycle 23. The sharper variation and denser density of neutral should be a challenge for LEO operation for the next few year. Due to the real-time operation need, except using NORAD form CelesTrak product, XPSOC is planning to derive BSATR from the precise orbit of FS-7/C-2 to optimize the TLE products of XPSOC. The sections 2 will introduce the operation achievement of XPSOC and the sections 3 will introduce how XPSOC uses the FS-7/C-2 onboard GNSS position to derive the BSTAR coefficient and show the comparison with CelesTrak products..

2. Achievement of XPSOC

The FS-7/C-2 is a constellation of satellites for meteorology, ionosphere, climatology, and space weather research. It is a powerful tool to monitor the climate and space weather in ionosphere. The biggest challenge of this mission is to provide enough profiles to data assimilation for weather/space weather forecast [https://tacc.cwb.gov.tw/v2/TACC & https://swoo.cwb.gov.tw/V2/]. 10 ground stations are used to downlink the data to fulfil the latency requirements.

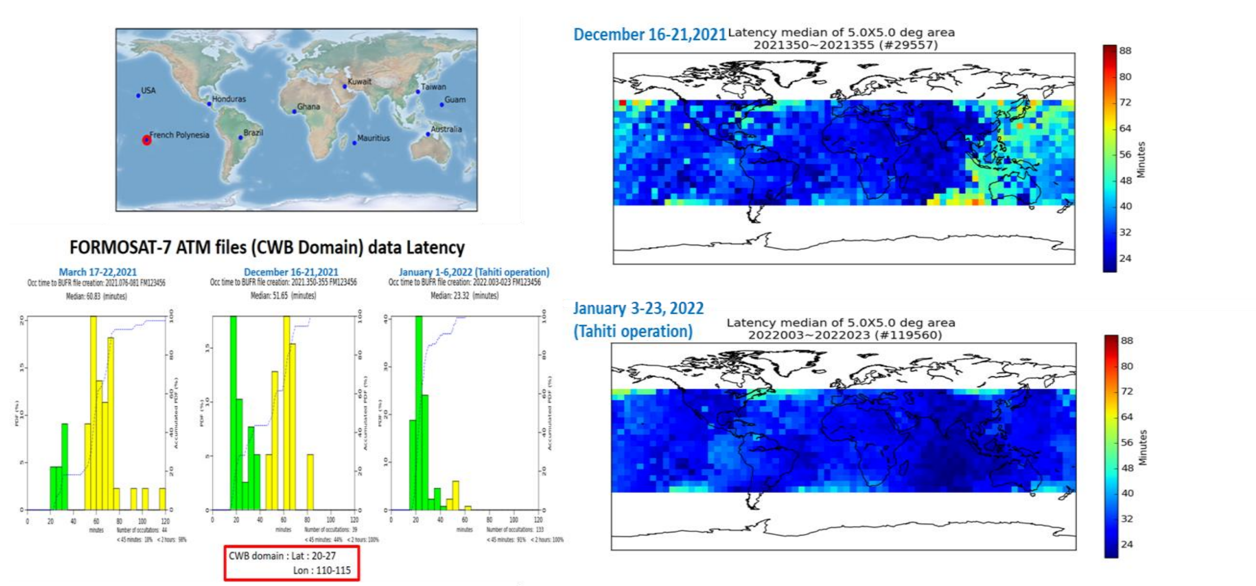

Figure 2. FS-7/C-2 Ground stations and Data Latency

XPSOC uses Taiwan and Darwin ground stations to uplink the commands to maintain satellite operations, and downlink the observed data with additional 8 ground stations, schedule 2-4 times to downlink the data per orbit for each satellite, usually the total downlink times is over 300 times per day. The Tahiti joined the ranks of FS-7/C-2 data downlink from Jan. 3rd 2022. In Figure 2, the upper left map show the positions of the 10 ground stations, and the red spot is the location of Tahiti. The right two panels show the data latency before and after Tahiti started downloading. The main difference between panels locates around Taiwan area, the latencies in Taiwan/Global is 70/28 minutes before and after Tahiti started downloading. The lower left panels show the latency during 3 periods, before, testing and after Tahiti started downloading. That results have great benefit for data assimilation to weather forecast on real need.

3. BSTAR derived from FS-7/C-2

Each satellite of FS-7/C-2 is equipped with two precise GNSS antennas sited on forward and backward separately. The precise position of FS-7/C-2 satellites could be got less than 35 mins averagely with 4 mm standard deviation. The high precise position enables us to derive the situ neutral density from satellite orbit. The results could help us to check the TLE accuracy and find a way to improve the accuracy of orbit prediction.

The Eq.1 presents the satellite acceleration is [1]

$$\bar{a} = -\frac{\mu}{r^3}\bar{\mathbf{r}} + \bar{a}_{non-spherical} + \bar{a}_{3-body} + \bar{a}_{ocean.tides} + \bar{a}_{solid.tides} + \bar{a}_{albedo} + \bar{a}_{srp} + \bar{a}_{air.drag} \quad (1)$$

Each item on the right side of the equal sign represents spherical gravitational force, non-spherical gravitational force, third body force, ocean tide, solid tide, albedo effect reflected from earth surface, solar radiation pressure, and air drag respectively. In this study, we calculate the mechanical energy lost rate from precise orbit position and velocity, remove the non-spherical gravitational force by gif48 model [https://grace.jpl.nasa.gov/data/get-data/], ocean tide by FES2004 model [https://datastore.cls.fr/catalogues/tide], solid tide by IERS report [2]. Removing solar pressure and albedo will be our next challenge to get better results. Although some perturbation forces are not removed yet, XPSOC still could derive the BSTAR currently due to the fact that the other unremoved perturbations might be kind of sinusoidal forces, but air drag is a secular force. Figure 3 shows the acceleration of air-drag derived form FS-7/C-2 precise orbit and the blue curve shows the F10.7 parameter, which has high correlation with the air drag.

The acceleration of air drag is given by

$$\bar{a}_{air.drag} = -\frac{C_d A}{2m}\rho v \bar{\mathbf{v}} \quad (2)$$

where ρ is the air density, C_d is the drag coefficients, A is the frontal area, m is mass of satellite, and v is the velocity of satellite in inertial frame. The starred ballistic (BSTAR) coefficient:

$$\mathrm{B}^* = \frac{\rho_o C_d A}{2m} \quad (3)$$

Here, ρ_o is density (assumed to be 2.461e-5 kg/m^2/ER). With equation (2), the expression for the BSTAR is

$$\mathrm{B}^* = \frac{\rho_o}{\rho v^2} a_{airdrag} \quad (4)$$

The Figure 4 compares the BSTAR values from different sources. The black dots are the BSTAR from the CelesTrak website (marked as NORAD) [https://celestrak.org/NORAD/], the red dot present the BSTAR derived from FS-7/C-2 precise orbit (mentioned later by XPSOC*), the blue curve shows the solar radiation parameter F10.7, and the right

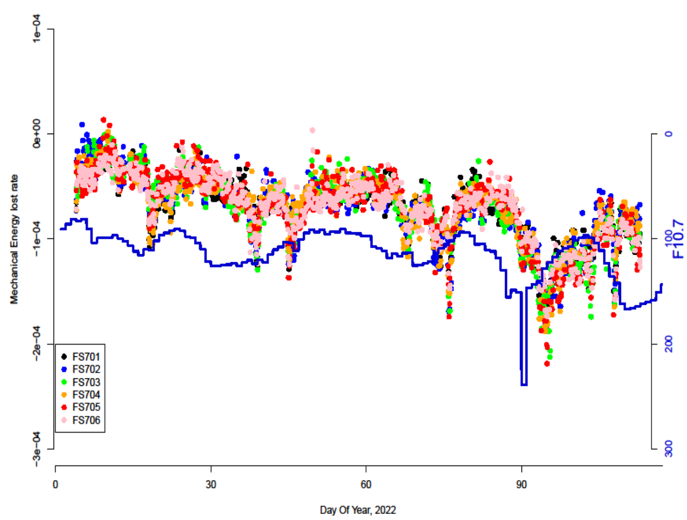

Figure 3. Mechanical Energy lost rate derived from precise orbit

panel shows the six FS-7/C-2 satellites for validation. The results show the XPSOC* has good consistent performance with the NORAD, and the BSTAR has positive correlation with F10.7. The Starlink launched 49 satellites on Feb. 3rd 2022 (DOY 34), up to 40 re-entered the Earth's atmosphere. The BSTAR in Figure 3 also shows a peak around DOY 35. We lost few contacts on DOY 95 due to the contact time difference, and there is magnetic storm on DOY 91. XPSOC hopes more precise BSTAR could improve the accuracy of predicted orbit and reduce the times of missing contact and data lost.

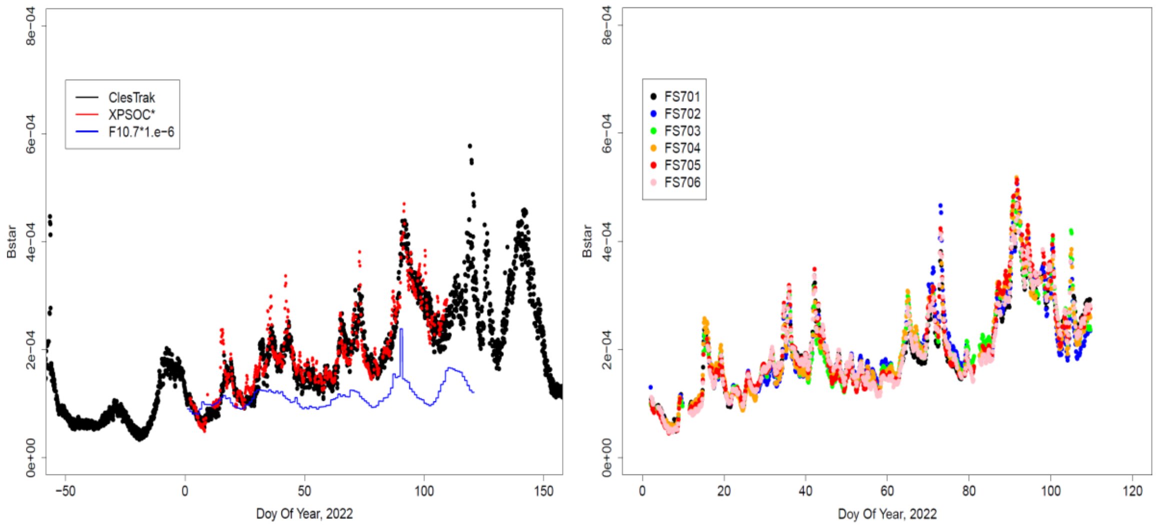

Figure 4. The right panel compares XPSOC* (red dots) with CelesTrak (black dots). Blue curve present the solar activity parameter F10.7. The left panel shows the XPSOC* from six FS-7/C-2 satellites for co-validation.

4. Conclusions

XPSOC had run FS-7/SC-2 mission for 3.5 years, the status is very stable and reliable. The mission had provided 6.3 million and 4.6 million profiles for weather and space weather forecast with data latency less than 30 min. Facing the next solar active cycle, we are figuring out a way to improve the accuracy of TLE for satellite real-time operation. The results have shown that XPSOC* have good consistent results with NORAD of Celestrak.

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