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Introduction to the special issue on Exploring the terrestrial and space weather using an operational radio occultation satellite constellation - A FORMOSAT-7/COSMIC-2 Special Issue after 1-year on orbit

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ABSTRACT

Launched on 25 June 2019, the Formosa Satellite Mission 7 and Constellation Observing System for Meteorology, Ionosphere, and Climate and Formosa Satellite Mission 2 (FORMOSAT-7/COSMIC-2, F7/C2) is the first operational global navigation satellite system (GNSS) radio occultation (RO) mission for the weather and space weather forecast that is focusing on mid-latitude and tropical regions. F7/C2 is a bi-lateral satellite constellation mission between Taiwan and the United States. Launched to the low inclination orbit of 24 degrees, the constellation consists of six satellites equipped with GNSS receivers, the advanced Tri-GNSS Radio-occultation System (TGRS), capable of receiving GPS, GLONASS, and Galileo signals. Alongside TGRS, there are two additional space weather-related instruments, the Ion Velocity Meter (or IVM) and the Radio Frequency Beacon (or RF Beacon) provided by U. S. Air Force. IVM observes *in-situ* ion species, densities, temperatures, and velocities; RF Beacon transmits beacon signals with three frequencies (400, 965, and 2200 MHz) to ground-based receivers for the derivation of the ionosphere electron content (IEC) and SNR of the radio signals. Both IVM and RF Beacon observations provide information on plasma irregularities of the ionosphere.

1. INTRODUCTION TO THE SPECIAL ISSUE

Each satellite of F7/C2 mission is equipped with the TGRS that has a high signal-to-noise ratio (SNR) and can receive signals penetrating to lower altitudes of the atmosphere, enabling it to collect more observations closer to the lower troposphere for the meteorological weather forecast model. The constellation receives ~5000 RO profiles of meteorological parameters to lower altitudes than previous RO missions between ±45°N latitudes (Chu et al. 2021) and has an important impact on the terrestrial weather analyses. Anthes et al. (2021) show that the RO retrievals of temperature and water vapor have an accuracy comparable to the atmospheric model reanalyses. The F7/C2 can provide accurate temperature and water vapor profiles even in the environment of an intense hurricane, indicating its essential characteristic of being relatively unaffected by cloud and precipitation. Comparing the RO and *in-situ* radiosonde observations (RAOB) helps quantify the temperature and humidity biases among different sensor types and between different RO retrieval algorithms. Shao et al. (2021) compare the temperature and humidity profiles independently retrieved by University Corporation for Atmospheric Research (UCAR) and NOAA Center for Satellite Applications and Research (STAR) from F7/C2 RO data with the *in-situ* Vaisala RS41 and RS92 RAOBs. The F7/C2 temperature retrievals by UCAR and STAR are consistent with each other above 12.5 km. Over 8 to 11 km, the temperature difference between RO retrievals and RAOBs is more significant than other

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heights. The UCAR and STAR RO humidity retrievals are generally very similar in the troposphere above 4.8 km. Shao et al. (2021) identified a clear day-night humidity bias below 4.2 km between the RO retrieval and RS92 RAOB, related to the dry biases of RS92 in the daytime.

For the ionosphere space weather application, TGRS observations at the low-latitude region will be affected by the electron density gradient of the crests of the equatorial ionization anomaly. Comprehensive validation of the RO ionosphere profiles is given by Lee et al. (2021a), showing the high correlation coefficients between the RO profiles and nearby ground-based ionosondes with 0.94 for NmF_2 and 0.84 for hmF_2. Lee et al. (2021a) further show that the biases of NmF_2 and hmF_2 are 10^4 # cm^{-3} and a few kilometers, respectively. According to their study, the accurate RO profiles benefit the data assimilation model of the ionosphere. Following the validations of TGRS, Lee et al. (2021b) investigate the ionosphere structures using F7/C2 RO observations for various local time sectors and compare them with the low latitude ionosphere structure as revealed by tens of thousands of RO profiles provided by its predecessor FORMOSAT-3/COSMIC (F3/C). The high quality of abundant RO observations of the ionosphere offers the opportunity to study the day-to-day variability of the ionosphere. Rajesh et al. (2021) assimilate F7/C2 RO total electron contents (TECs) to the data assimilation based global ionosphere specifications and find that there are significant daily variations over dayside low latitudes, yielding about 10 - 20% standard deviation in equinoxes, 20 - 30% in solstices, reaching 40 - 50% in winter. The nighttime deviations could be 30 - 60%, being largest in solstices. Day-to-day variations are also observed in the longitudinal wave-4 structures.

Efforts are also made to validate IVM observations. Chou et al. (2021) compare the collocated TGRS and IVM observations for each of the F7/C2 satellites at ~715 and ~540 km during 2020. They find that the TGRS and IVM density observations have high correlation coefficients of 0.92 - 0.96 for each satellite, demonstrating a good agreement between the independent TGRS and IVM observations. They further compare the general morphology of the topside ionosphere as revealed separately by ROs, and *in-situ* IVM measured densities and indicate the similar topside structure provided by the two instruments. Chen et al. (2021a) apply the IVM measured electron density to validate the topside electron density retrieved by RO soundings and discuss the condition where the RO retrieved topside density might have deviations due to the Abel inversion.

As GNSS signals traverse ionosphere irregularities they suffer from reductions of signal strength causing scintillations, the signal-to-noise indices, S4, from TGRS provides good opportunities to observe the distribution of the ionosphere irregularities. Chen et al. (2021b) examine the empirical scintillation model built based on F3/C observations with the S4 observations of F7/C2, showing promising agreements. The global morphologies of S4 given by F3/C and F7/C2 are validated by the rate of TEC index (ROTI) derived from the phase variations of the ground-based GNSS receivers of a global network (Chen et al. 2021b).

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