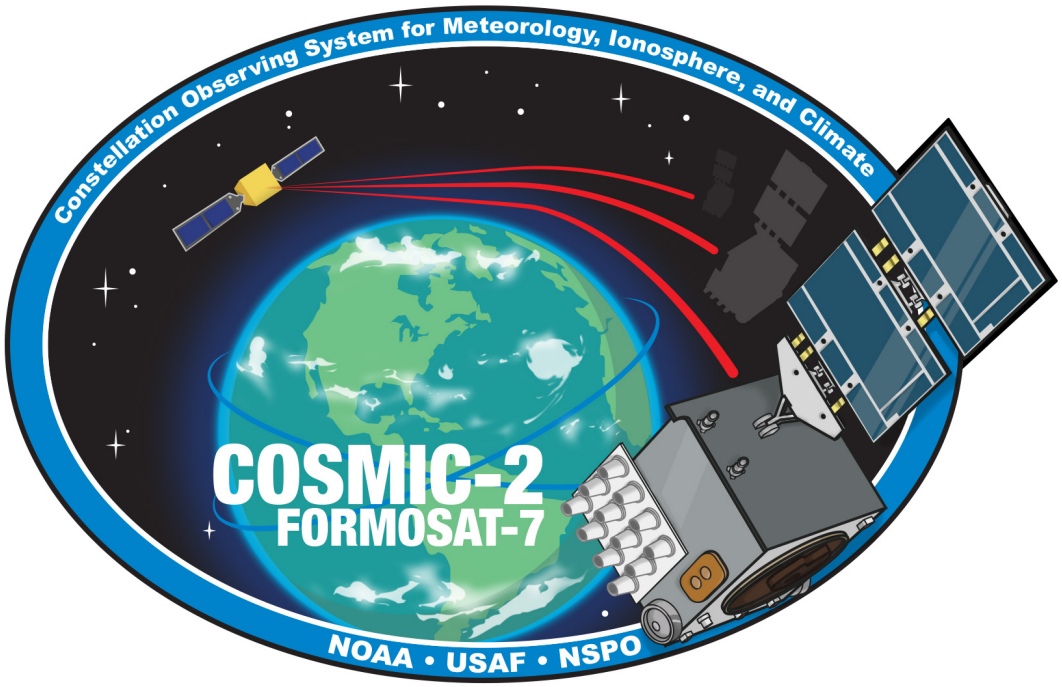
FORMOSAT-7/COSMIC-2
Space Weather Data Release 4

March 29, 2021



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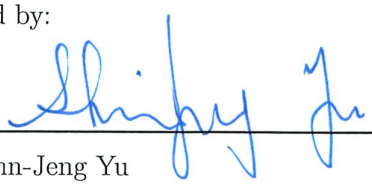

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Acting Director General
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1 Background

The United States Air Force (USAF) Space Test Program launched six FORMOSAT-7/COSMIC-2 (F7C2) satellites into a 24 deg inclination low Earth orbit on June 25, 2019. The primary F7C2 mission objective is to continuously and uniformly collect atmospheric and ionospheric data as the inputs to daily near-real-time weather forecasts, climate studies, and space weather monitoring and forecasting. Each F7C2 satellite has three payloads. The primary instrument is the Tri-GNSS Radio-occultation System (TGRS) payload. Secondary science instruments include the Ion Velocity Meter (IVM), and Radio Frequency Beacon (RFB) science payloads. Following spacecraft system activation and checkout, the primary and science payloads were first activated on July 16, 2019. This data release is focused on in-situ ion density measurements derived from the IVM science payloads.

2 Summary of Data Release

The F7C2 space weather calibration and validation effort is led by the United States Space Force (USSF) and assisted by experts from the USSF, The Aerospace Corporation (AERO), Central Weather Bureau (CWB), Jet Propulsion Laboratory (JPL), National Cheng Kung University (NCKU), National Central University (NCU), National Oceanic and Atmospheric Administration (NOAA), National Space Organization (NSPO), University of Texas at Dallas (UTD) and University Corporation for Atmospheric Research (UCAR). Summaries of space weather early orbit and calibration and validation (Cal/Val) activities are described in [1] and [2]. The team has worked to evaluate instrument performance and optimize processing algorithms since launch. This document summarizes the operational release of in-situ ion density from the IVM payloads. A description of the IVM instrument is described in [4]. Release of data as operational indicates that the space weather Cal/Val team has verified that the data quality meets the operational requirements of the USSF, NOAA, and CWB.

3 Justification for Data Release

IVM in-situ density data were validated using TGRS Total Electron Content (TEC) derived density measurements collected within 0.5 degrees of either the velocity or anti-velocity direction of the spacecraft. An example time series of IVM density and TGRS derived density is shown in figure 1. Scatter plots of density collected at a nominal orbit altitude of 550 km are shown from TGRS and IVM for satellites 1-5 are shown in figure 2. No data from satellite 6 is shown because it had not been lowered into the final orbit prior to data

release. Based on these comparisons, the IVM density measurements were corrected with a scaling factor to remove the 3-6% overestimation of ion density from the IVM instruments (an average correction from satellites 1-5 was used for satellite 6 after orbit lowering). A scatter plot of corrected IVM density measurements is shown in figure 3. A histogram of differences between IVM and TEC derived density is shown in figure 4. Data collected at the orbit insertion altitude of 720 km had a separate correction factor applied to remove an underestimation of ion density between 7-15% from the IVM instruments (figures not shown). Based on these corrected measurements, the IVM density products have been deemed to have a measurement precision of better than 1% for measurements averaged over 110 Km intervals with density values greater than $8x10^3 cm^{-3}$. After accounting for spatial averaging and constraining for low densities, the IVM density products have been deemed suitable for operational use and public release.

4 Data Caveats

We note the following caveats to data users:

- IVM composition and temperature measurements
  Composition and temperature measurements from the IVM instruments have been removed from all ivmL2m data products until they have been fully validated by the Cal/Val team.

- IVM drift measurements
  Drift measurements from the IVM instruments have been removed from all ivmL2m data products until they have been fully validated by the Cal/Val team.

- Corrected and uncorrected IVM density
  As mentioned in section 3, IVM density measurements were corrected based upon the validation results using the TEC derived density process. Both the corrected and uncorrected data products are included in the ivmL2m files.

- Data formats ivmLv2 vs ivmL2m
  IVM data products are being released with a file type designated as ivmL2m. The format of this file type is identical to the ivmLv2 format with unverified data fields being masked with NaN values until the Cal/Val team is able to finish validation of composition, temperature and drift products.

5 Path Forward

The F7C2 Space Weather Cal/Val team continues to work to validate and release data products for operational use. Provisional release of IVM drift, temperature, and composition products has been delayed to allow UTD to complete its analysis and verification process. All remaining IVM products are planned for operational release in June 2021. TGRS scintillation data products and associated quality control software continue to be developed. Provisional release of the TGRS ionospheric high rate data and associated phase scintillation product is currently planned for April 2021.

All space weather data products described in this memo are expected to be released daily. Operational constraints may, however, cause occasional delays. While not anticipated, if significant processing changes impacting product quality are made, we will increment the release version, make a corresponding data download area subdirectory, and provide release notes describing the changes.

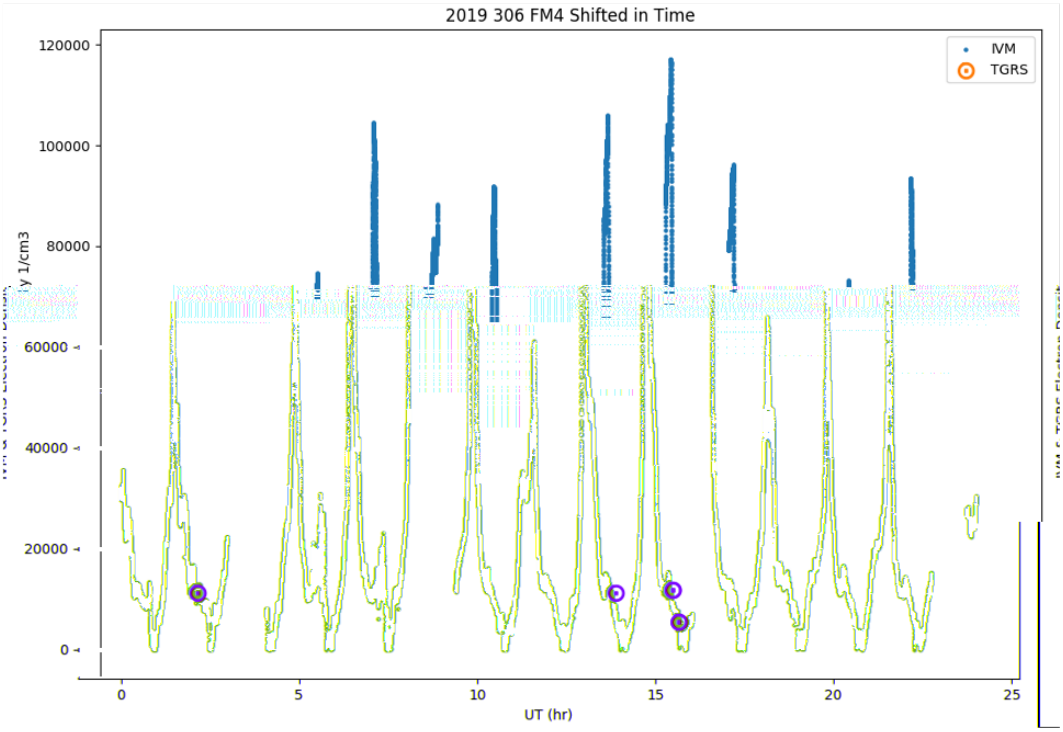

Figure 1: Timeseries of IVM density observations for F7C2 FM06 on day 2019.306. TGRS TEC derived density measurements within 0.5 degree of the spacecraft RAM or anti-RAM direction are also shown.

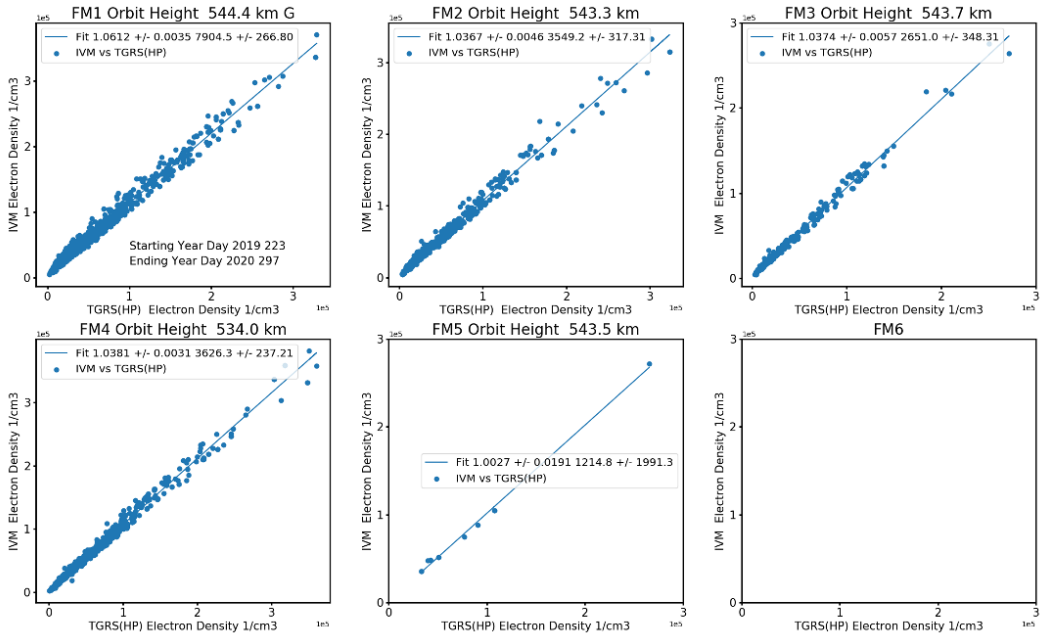

Figure 2: Scatterplot of IVM and TEC derived density for satellites in 550 km orbit before calibration correction.

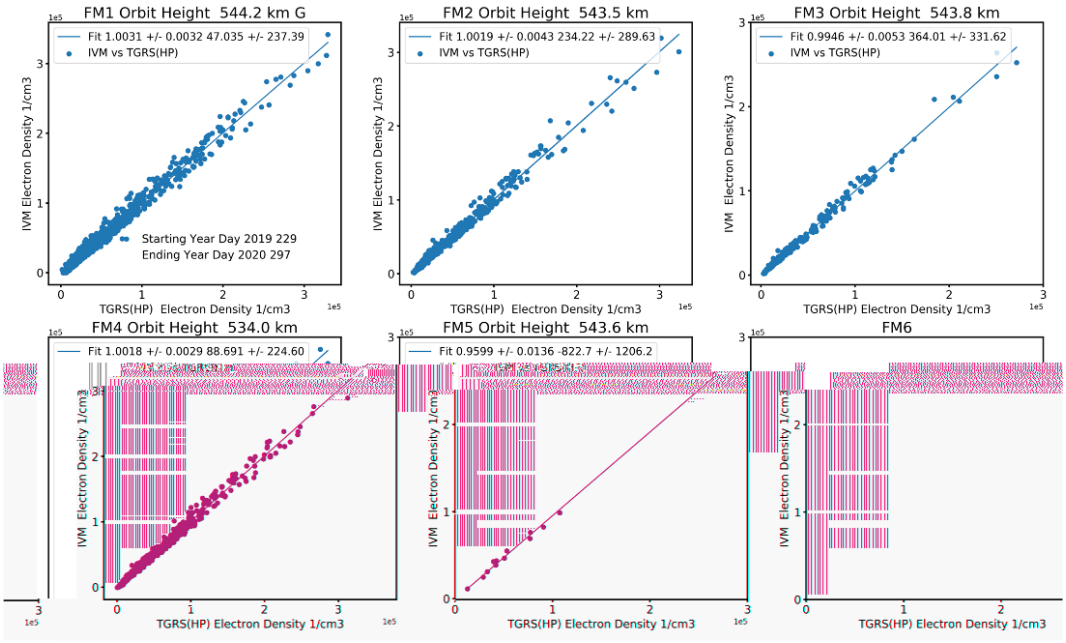

Figure 3: Scatterplot of IVM and TEC derived density for satellites in 550 km orbit after calibration correction.

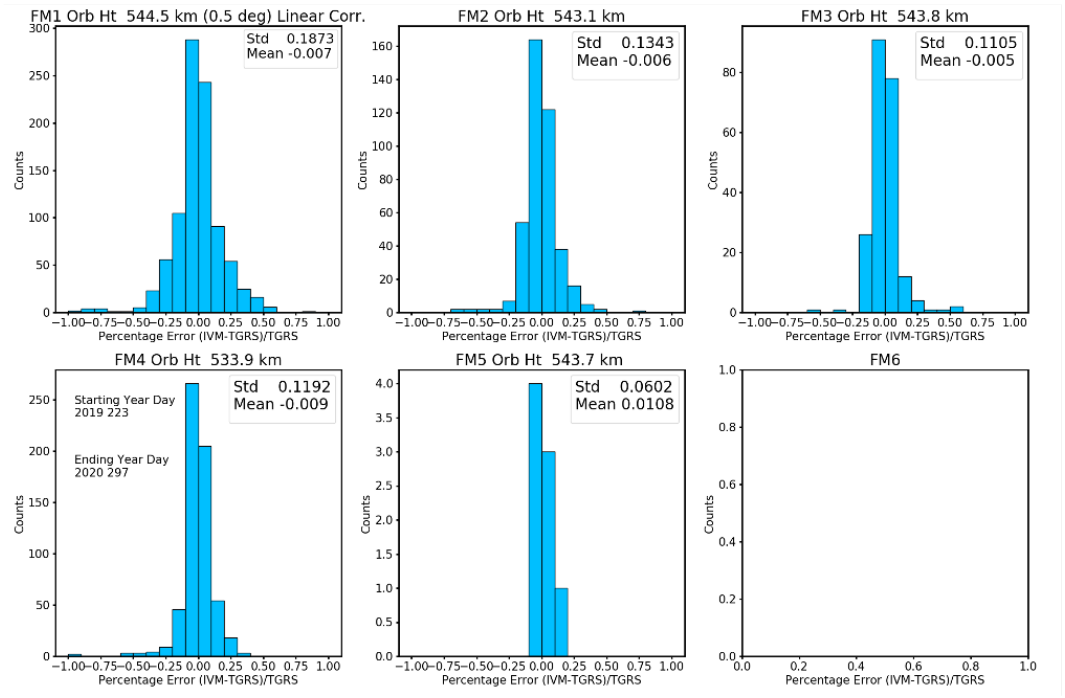

Figure 4: Histogram of differences in IVM and TEC derived density for satellites in 550 km orbit after calibration correction.

6 Links

- F7C2 space weather data download
  https://www.cosmic.ucar.edu/what-we-do/cosmic-2/data/
  https://tacc.cwb.gov.tw/v2/download.html
- COSMIC Data Analysis and Archive Center
  https://www.cosmic.ucar.edu/what-we-do/data-processing-center/
- Taiwan Analysis Center for COSMIC
  https://tacc.cwb.gov.tw
- CDAAC user support forum
  https://groups.google.com/a/ucar.edu/forum/#!forum/cdaac-users
- Algorithms for inverting radio occultation signals in the ionosphere
  https://cdaac-www.cosmic.ucar.edu/cdaac/doc/documents/gmrion.pdf
- ivmLv2/ivmL2m format
  https://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=ivmLv2
  https://tacc.cwb.gov.tw/v2/en/fileformat.html#ivmLv2

References

[1] Braun et al., *Performance of the FORMOSAT-7/COSMIC-2 Tri-GNSS Radio Occultation System (TGRS) Instrument During Early Orbit Operations for Space Weather Applications*, Fall AGU, San Francisco, USA, December, 2019.

[2] Straus et al., *Validation of COSMIC-2 Space Weather Science Products*, AMS Annual Meeting, USA, January, 2020.

[3] Liu et al., *FORMOSAT-7/COSMIC-2 Mission and Preliminary Results*, Fall AGU, San Francisco, USA, December, 2019.

[4] Heelis, R. A., R. A. Stoneback, M. D. Perdue, M. D. Depew, W. A. Morgan, M. W. Mankey, C. R. Lippincott and L. L. Harmon and B. J. Holt, *Ion Velocity Measurements for the Ionospheric Connections Explorer*, Space Science Reviews, doi:10.1007/s11214-017-0383-3,2017.

Acronyms

AERO The Aerospace Corporation

CDAAC COSMIC Data Analysis and Archive Center

CWB Central Weather Bureau

F7C2 FORMOSAT-7/COSMIC-2

IVM Ion Velocity Meter

JPL Jet Propulsion Laboratory

NCKU National Cheng Kung University

NCU National Central University

NOAA National Oceanic and Atmospheric Administration

NSPO National Space Organization

RFB Radio Frequency Beacon

TACC Taiwan Analysis Center for COSMIC

TEC Total Electron Content

TGRS Tri-GNSS Radio-occultation System

UCAR University Corporation for Atmospheric Research

USAF United States Air Force

USSF United States Space Force

UTD University of Texas at Dallas