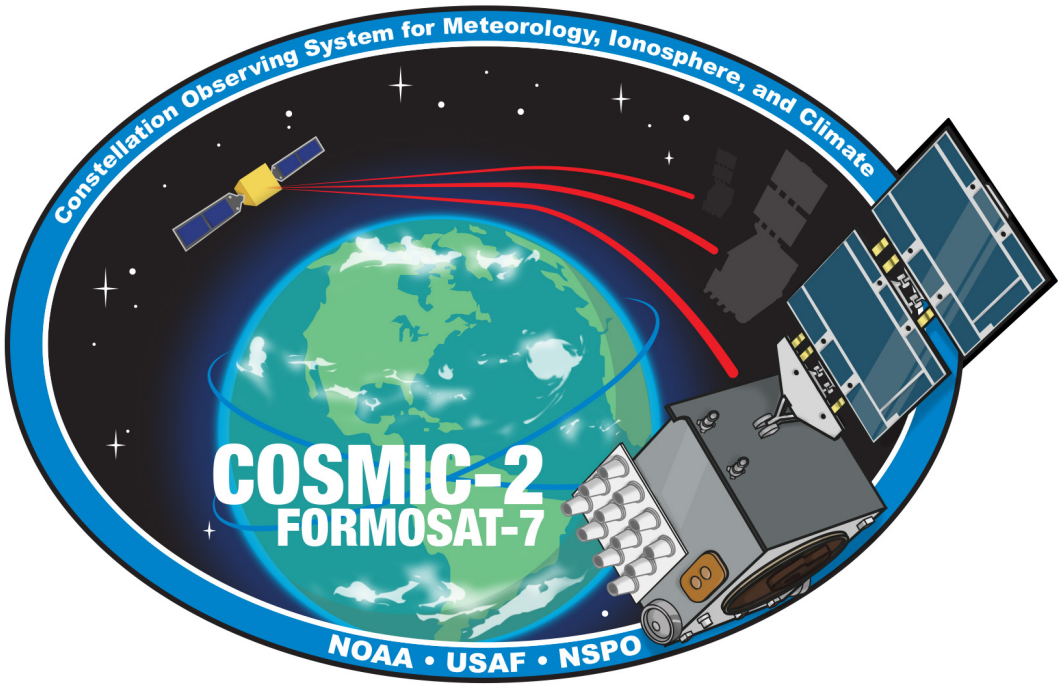
FORMOSAT-7/COSMIC-2
Space Weather Data Release 3

January 29, 2021



Submitted by:

Paul R Straus

Dr. Paul Straus
FORMOSAT-7/COSMIC-2 Space Weather Cal/Val Lead
The Aerospace Corporation

Concurred by:

Bill Schreiner Digitally signed by Bill Schreiner
Date: 2021.01.27 21:41:55 -07'00'

Dr. William Schreiner
FORMOSAT-7/COSMIC-2 Mission Scientist
Director, COSMIC Program
University Corporation for Atmospheric Research

Concurred by:

SANTIAGO.JOSEPH.MICHAEL.JR.1290239458 Digitally signed by SANTIAGO.JOSEPH.MICHAEL.JR.12902394 58
Date: 2021.01.27 17:55:02 -08'00'

Lt. Joseph Santiago
FORMOSAT-7/COSMIC-2 Payload Mission Manager
United States Space Force

Approved by:

Elsayed R. Talaat Digitally signed by Elsayed R. Talaat
Date: 2021.01.29 05:54:01 -05'00'

Dr. Elsayed Talaat
Director, Office of Projects, Planning, and Analysis
National Environmental Satellite, Data, and Information Service
National Oceanic and Atmospheric Administration

Approved by:

Dr. Chun-Liang Lin
Director General
National Space Organization

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 the absolute Total Electron Content (TEC) derived from TGRS measurements of GLONASS satellite signals.

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), 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 absolute GLONASS TEC. 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. Absolute GPS TEC data products were released operationally on Sept 8, 2020. Provisional TGRS data products including scintillation amplitude index (S4) and electron density profiles on March 30, 2020 remain unchanged. See section 6 for the data download locations and file format descriptions.

All TGRS instrument data in this release were collected with v4.3.4 or later flight software. This software was uploaded to the six F7C2 TGRS flight instruments beginning on February 7, 2020 and finishing on March 23, 2020. This software update addressed issues related to ionospheric arc and occultation scheduling, and high rate scintillation data collection. While the Cal/Val team has focused on validation using v4.3.5 TGRS firmware, the

team believes that data collected with both v4.3.4 and v4.3.5 are suitable for release. We will evaluate data collected prior to v4.3.4 and release that data when the team can comment on the overall accuracy of those data products.

3 Justification for Data Release

Release of data as operational indicates that the space weather Cal/Val team has verified the data quality meets the operational requirements of both the USSF and NOAA. Specifically, the GLONASS absolute TEC have been shown to meet the Level 1 mission requirements of being accurate to better than 3 TEC Unit (TECU). GLONASS TEC data were verified using collocated GPS TEC observations. GPS TEC data were previously validated using data from the Swarm-B satellite. F7C2 data were determined to be collocated if they were collected at the exact same time and the transmitting GNSS satellites were separated by less than 2 deg. Figure 1 shows a scatter plot of collocated GPS and GLONASS TEC data for each of the six F7C2 satellites. The figure shows results for data collected between 2020.296 and 2020.325. There were 844 collocated measurements from the six F7C2 instruments. A histogram of these collocated measurements is shown in Figure 2. The mean and standard deviation of the collocated TEC differences are 0.251 and 1.916 TECU, respectively. An error analysis of data from the Swarm-B, F7C2 GPS, and F7C2 GLONASS TEC allowed for an independent assessment of both GPS and GLONASS errors. This analysis indicates that the GPS TEC data are accurate to 2.54 TECU and the GLONASS TEC data are accurate to 2.59 TECU.

4 Data Caveats

We note the following caveats to data users:

- GLONASS Multipath Corrections
  The GLONASS TEC data products do not include multipath corrections. UCAR has determined that GLONASS TEC data are not significantly impacted by multipath and that all operational requirements can be met without these corrections.

- Release of Data Prior to V4.3.4
  Data collected with flight software v4.3.4 or greater are included in this release. Data collected prior to v4.3.4 will be released separately after the data quality has been evaluated by the Cal/Val team.

5 Path Forward

The F7C2 Space Weather Cal/Val team is working on developing and evaluating TGRS scintillation data products and associated quality control software. Provisional release of the TGRS ionospheric high rate data and associated phase scintillation product is currently planned for April 2021.

The release of IVM sensor in-situ density products has been delayed due to COVID-19 impacts that have prevented timely ground truth data collection. The Cal/Val team is currently targeting February 2021 for release of these products. Provisional release of IVM ion drifts from FM1, FM2, FM4, are also expected in Feb 2021. An updated provisional release of improved IVM ion drifts for satellites FM3 and FM5 is expected in April 2021. All remaining IVM products are planned for operational release in June 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.

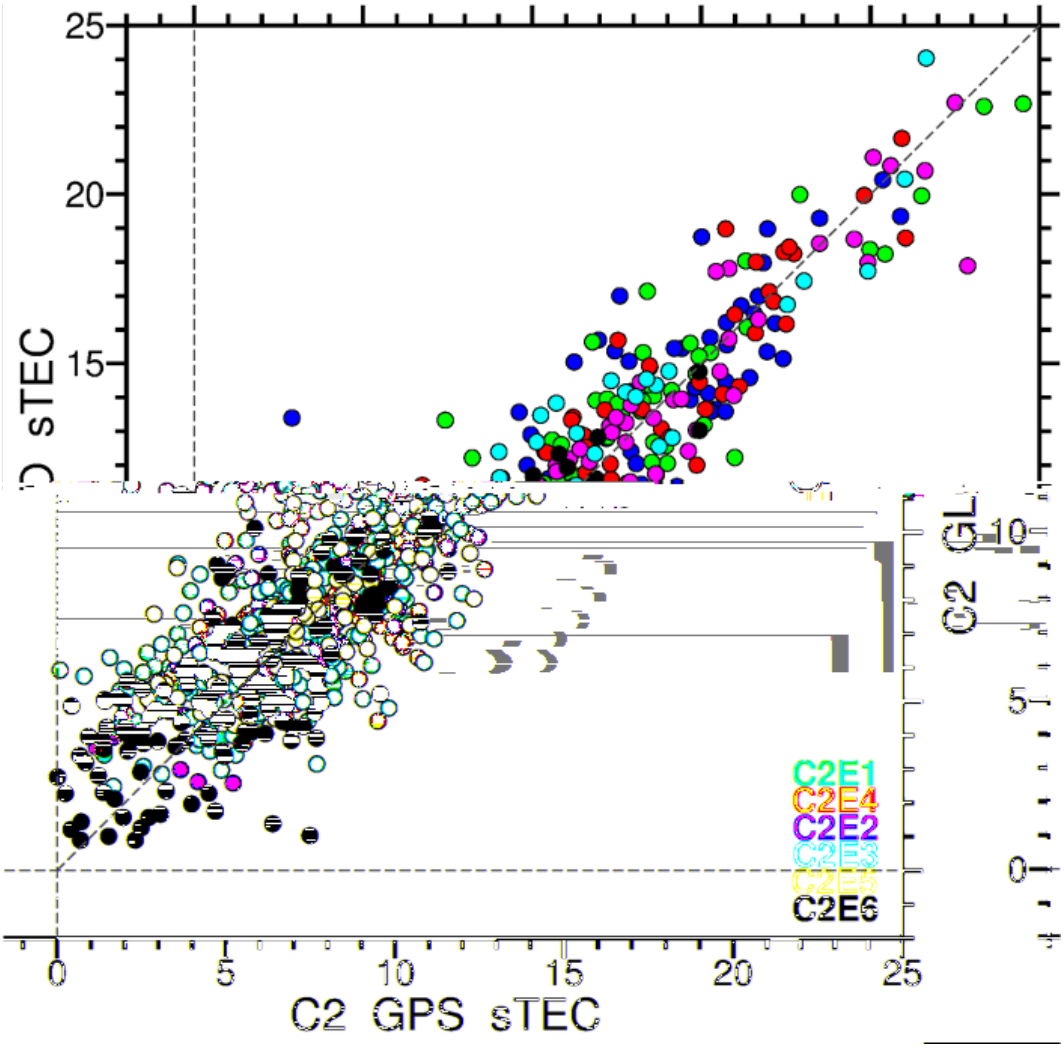


Figure 1: Scatterplot of collocated GPS and GLONASS TEC measurements. Results from all six F7C2 satellites are shown. Data collected between 2020.296 and 2020.325.

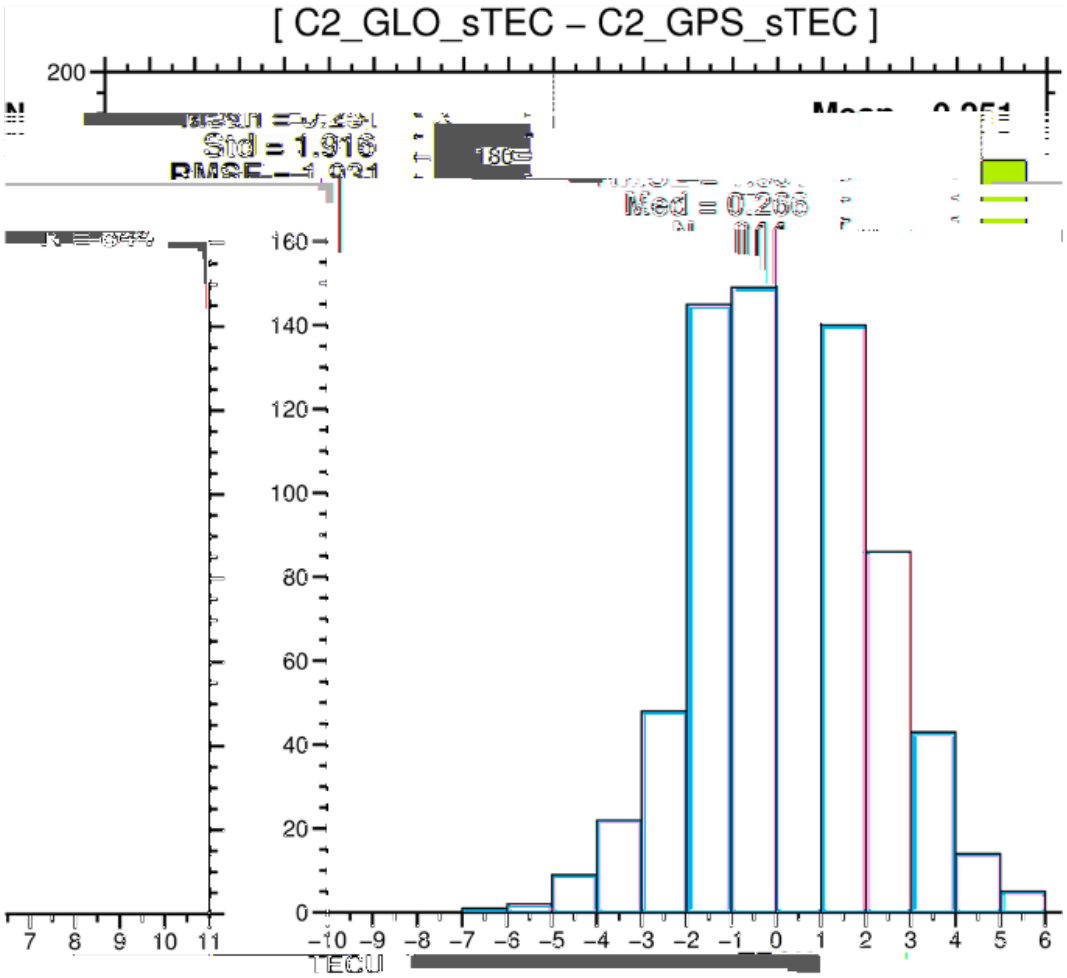


Figure 2: Histogram of differences in collocated measurements of absolute TEC for GPS and GLONASS measurements.

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
- podTc2 format
  https://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=podTc2
  https://tacc.cwb.gov.tw/v2/en/fileformat.html#podTc2
- ionPrf format
  https://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=ionPrf
  https://tacc.cwb.gov.tw/v2/en/fileformat.html#ionPrf

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.