FORMOSAT-3/COSMIC-1
2021 Reprocessing Data Release

November 29, 2022

1 Background

The FORMOSAT-3/COSMIC-1 (COSMIC-1) radio occultation (RO) mission was developed and operated in partnership between Taiwan's National Space Organization (NSPO), National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), and University Corporation for Atmospheric Research (UCAR). COSMIC-1 launched into a circular low-Earth orbit from Vandenberg Air Force Base on April 15, 2006 and retired in May, 2020. COSMIC-1 data products have significantly impacted many areas of scientific research including the following:

- Meteorology
  Demonstrated value for weather prediction.
  Detailed global moisture distribution.
  Monitoring of the tropopause and lower stratosphere temperature profiles with high resolution.
  All-weather data for joint analysis with other systems like GOES.
  First RO mission making the research to operations transition.

- Ionosphere (space weather)
  Demonstrates operational value for monitoring global electron density field.
  Demonstrates operational value for scintillation monitoring.
  Provides electron density fields for model testing and development.
  Develops predictive models.
  Magnetospheric studies of auroral oval.

- Climate
  Provides a global "self-calibrating" data set for climate monitoring and model test.
  Provides water vapor distribution, especially in the tropics.
  Studies of ozone depletion.
  Studies of troposphere/stratosphere exchange.
  Studies of volcanic effects.

Since the conclusion of the mission, the UCAR COSMIC Data Analysis and Archive Center (CDAAC) team has worked to reprocess the entire data series using consistent algorithms and configuration to create a definitive set of COSMIC-1 data products for the scientific community.

2 Datasets

The reprocessing encompasses both neutral atmosphere and space weather data and products derived from the Integrated GPS and Occultation Receiver (IGOR) receivers on the COSMIC-1 satellites. These are:

- Level 0
  Raw IGOR Receiver binary data files

- Level 1a
  Precise orbit determination (POD) antenna measurements (RINEX v2.11 format)
  Satellite attitude measurements (leoAtt format)
  High rate RO measurements (opnGps format)

- Level 1b
  POD solutions (SP3 format)
  Total electron content (TEC) on slant paths to the Global Positioning System (GPS) transmitters (podTec format)
  Neutral atmosphere excess phase (conPhs format)
  Ionospheric excess phase (ionPhs format)
  Scintillation indices (scnLv1 format)
  GPS navigation data message bit information (gpsBit format)

- Level 2
  Atmospheric profiles as atmPrf (RO retrieval), wetPf2 (1D-var retrieval), and binary universal form for the representation of meteorological data (BUFR)
  Atmospheric profiles generated from model data (echPrf, er5Prf, erFprf, gfsPrf)
  Electron density profiles (EDPs) as ionPrf (standard retrieval) and igaPrf (gradient assisted)

See Section 3 for the data download locations and file format descriptions.

2.1 Processing Notes

The 2021 reprocessing differs from 2013 COSMIC-1 reprocessing in the following main ways:

- We utilized an entirely new, in-house developed excess phase code. Previously, we relied on modules from the Bernese GNSS Software to compute excess phase. The new software generates conPhs files instead of atmPhs files.
- We utilized the latest NewROAM retrieval software [1].
- Utilizing MIT final GNSS orbits, clock, and Earth orientation products. The 2013 reprocessing used CODE GNSS products.
- ERA5 short-term forecasts used as background for 1D-var processing with our latest retrieval software [2].
- COSMIC 2021 adds monthly gradient-assisted electron density products.

The COSMIC 2021 data span the entire mission and are compatible with CDAAC's COSMIC-2 datasets.

2.2 Results

The COSMIC 2021 reprocessing generated a total of 6,913,411 neutral atmosphere profiles, 6,971,017 TEC tracks, and 4,619,386 EDPs. A time series of counts is shown in Figures 1 and 2.

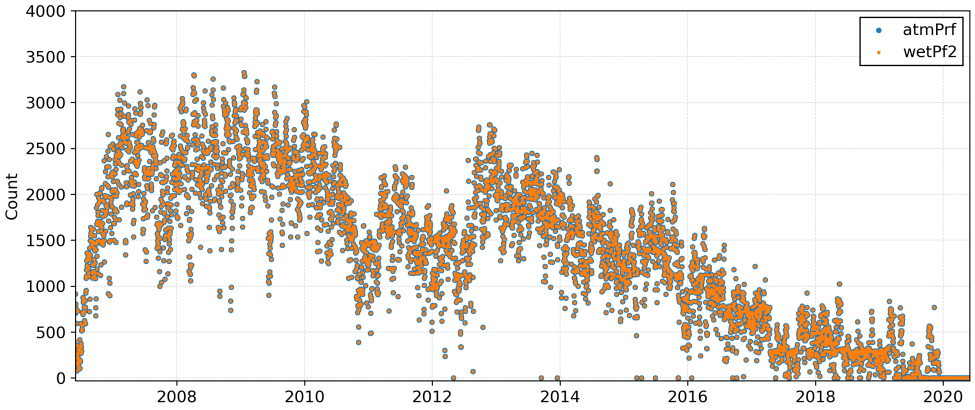

Figure 1: Neutral atmosphere counts (includes profiles flagged as good and bad QC).

The calibration and validation team has evaluated the COSMIC 2021 neutral atmosphere data and verified they are consistent with COSMIC 2013 metrics. Figure 3 compares COSMIC 2021 and COSMIC 2013 bending angle statistics to ECMWF analysis.

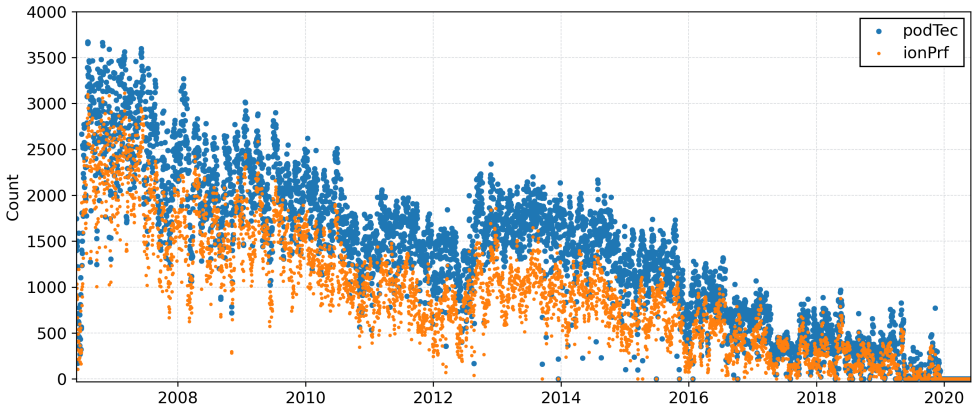

Figure 2: TEC track and EDP counts.

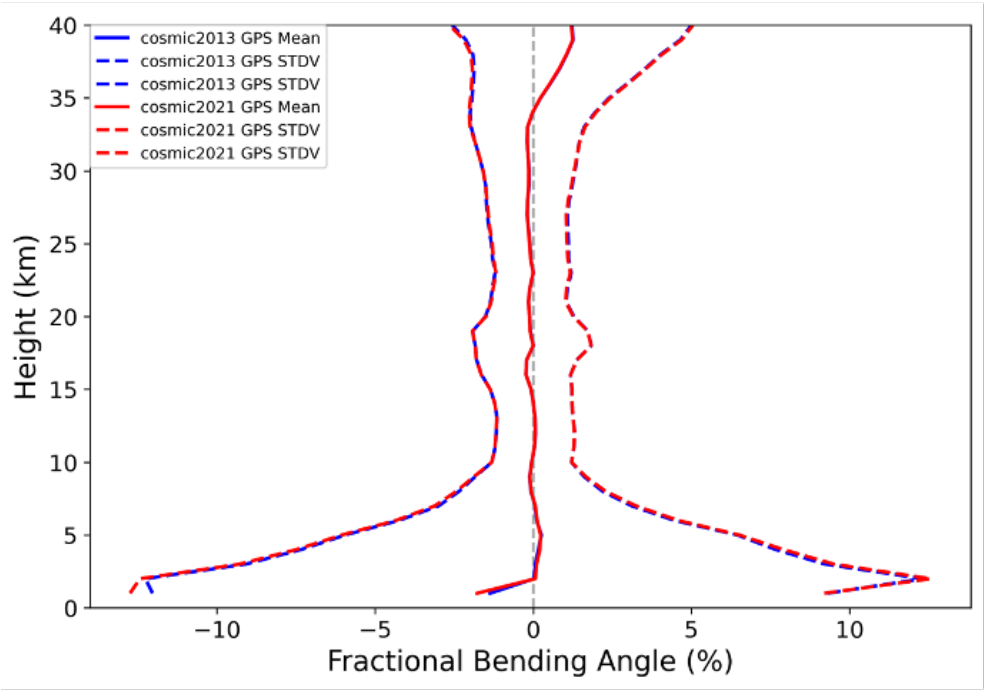

Figure 3: Good quality control (QC) Bending angle statistics for COSMIC 2013 and COSMIC 2021 vs. ECMWF.

TEC was evaluated by way of slant and vertical TEC distributions and differential code bias (DCB) stability. Sample TEC distributions are shown in Figure 4 and the negative TEC fractions for 3 years are summarized in Table 1.

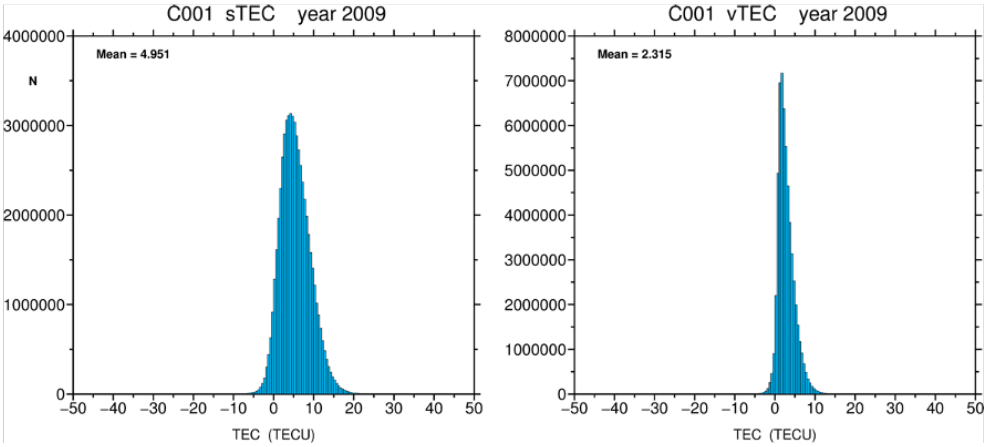

Figure 4: TEC distributions for FM1 in 2009.

Table 1: Negative slant TEC fractions for 3 years.

FM	% in 2009	% in 2012	% in 2015
1	12.5	3.0	3.6
2	7.5	2.3	6.6
3	9.7	–	–
4	7.0	1.0	1.2
5	13.6	3.5	4.8
6	11.3	3.5	4.2

3 Links

- COSMIC-1 data formats and download information
  `https://www.cosmic.ucar.edu/what-we-do/cosmic-1/data/`

- CDAAC user support forum
  `https://groups.google.com/a/ucar.edu/forum/#!forum/cdaac-users`

References

[1] Sokolovskiy, S. (2021), *Standard RO Inversions in the Neutral Atmosphere 2013 - 2020 (Processing Steps and Explanation of Data)*, `https://www.cosmic.ucar.edu/sites/default/files/2021-09/cdaac_ro_retrieval_description_v1.pdf`.

[2] Wee, T.-K., R. A. Anthes, D. C. Hunt, W. S. Schreiner, Y.-H. Kuo (2022), Atmospheric GNSS RO 1D-Var in use at UCAR: Description and Validation, *Remote Sensing*, 14(21):5614, `https://doi.org/10.3390/rs14215614`.