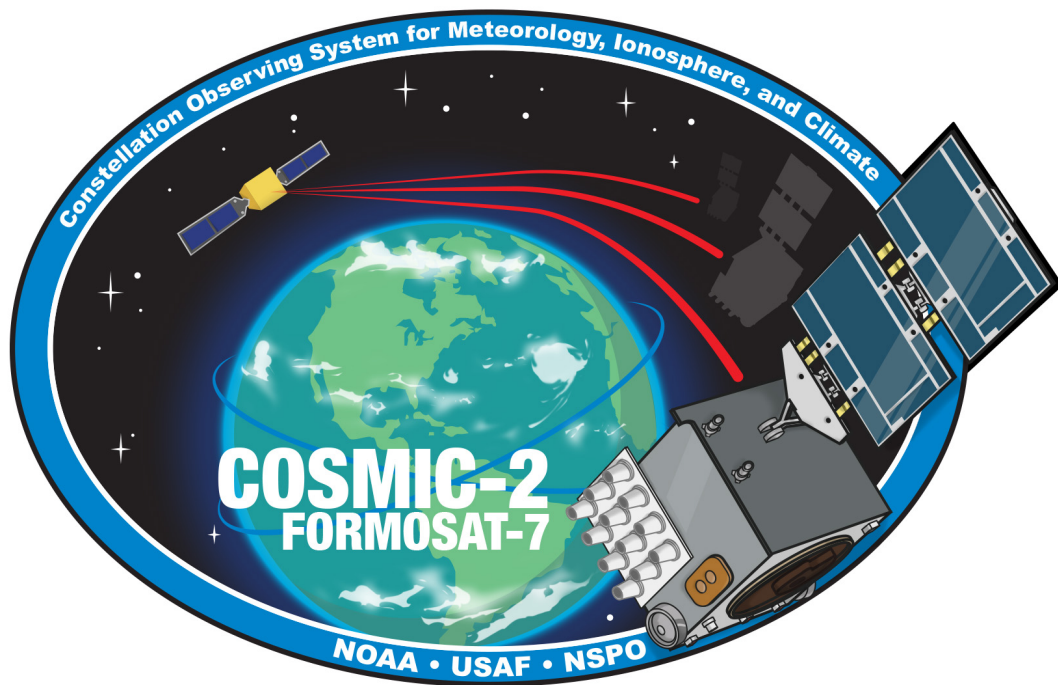


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FORMOSAT-7/COSMIC-2  
Neutral Atmosphere Provisional Data Release 1

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December 10, 2019



Submitted by:

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# 1 Background

The US Air Force Space Test Program successfully 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 research. Following spacecraft system activation and checkout, instruments were first activated on July 16, 2019. Each F7C2 satellite has three instruments: the primary Tri-GNSS Radio-occultation System (TGRS) payload, Ion Velocity Meter, and Radio Frequency Beacon. This data release encompasses only TGRS data and neutral atmosphere products. Ionospheric data and products will be released at a later date.

TGRS data and neutral atmosphere products from October 1, 2019 and forward are included in this release. This start date is chosen because all TGRS units operated using consistent flight software and configuration, and because radio occultation (RO) counts are relatively consistent. As such the dataset is useful for evaluation in numerical weather prediction (NWP) systems to assess quality and impacts of the F7C2 data. All data are processed as if in near real-time. The following data types are released:

- Level 0  
Raw TGRS binary data files
- Level 1a  
Precise orbit determination antenna measurements (RINEX v2 format)  
Satellite attitude measurements (leoAtt format)  
High rate RO measurements (opnGns format)
- Level 1b  
Precise orbit determination solutions (SP3 format)  
Atmospheric excess phase (conPhs format)
- Level 2  
Atmospheric profiles as atmPrf (RO retrieval), wetPf2 (1D-var retrieval), and BUFR

See Section 6 for the data download locations and file format descriptions.

## 2 Provisional Maturity Definition

1. Product performance has been demonstrated through analysis of a large, but still limited (i.e. not necessarily globally or seasonally representative) number of independent

measurements obtained from selected locations, time periods, or field campaign efforts.

2. Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.
3. Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists.
4. Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.

### 3 Justification for Provisional Data Release

The F7C2 team supporting calibration and validation of TGRS neutral atmosphere products consists of experts from Aerospace Corp., Central Weather Bureau (CWB), Jet Propulsion Laboratory (JPL), National Central University (NCU), National Oceanic and Atmospheric Administration (NOAA), National Space Organization (NSPO), and University Corporation for Atmospheric Research (UCAR). The team has worked intensively to evaluate instrument performance and optimize processing algorithms since launch. Metrics evaluated for this data release include RO profile counts and distribution, bending angle noise from 60-80km altitude, bending angle/refractivity/temperature comparison to global NWP forecasts/analyses, evaluation of 1D-var retrieval products, inter-comparisons with other RO missions (KOMPSAT-5, MetOp, PAZ) and radiosondes, NWP assimilation system observation-background statistics, and a limited set of NWP impact studies. In general, the team finds F7C2 product quality to be at least as good as FORMOSAT-3/COSMIC-1, KOMPSAT-5, and PAZ. Detailed initial results are shown in five recent conference presentations [1, 2, 3, 4, 5].

All TGRS instrument data in this release were collected with v4.3.2 or later flight software. The v4.3.2 software was uploaded to all flight instrument in late September 2019. This addressed issues related to reboots, occasional periods without data collection, and adjusted rising occultation tracking parameters.

Figure 1 shows quality controlled RO profile counts and the number of satellites/instruments contributing each day in October 2019. There are more than 3000 GPS and GLONASS profiles for the majority of days. However due to operational spacecraft and instrument issues the counts are not consistently this high across the released time series.

## 4 Provisional Data Caveats

We note the following caveats to provisional data users:

- L2P rising occultations

In model comparisons, GPS L2P rising occultation bias and standard deviation are higher than setting occultations from approximately 19-29km altitude, as illustrated in Figure 2. The TGRS v4.3.2 flight software reduced but did not eliminate this feature, and the team continues to investigate. Some NWP analyses have ignored rising L2P profile data above 18km to avoid potential negative effects, while others have used the complete profiles. On the date of this memo, the affected GPS PRNs are 2, 4, 11, 13, 14, 16, 18, 19, 20, 21, 22, 23, 28.

- Precise orbit determination (POD) antenna phase center offset

Empirical acceleration estimated in precise orbit determination post-processing indicate there may be an error in the specification of the POD antenna phase center offsets. This is still under investigation. The vector offset error magnitude appears to be no more than a few cm. Since this error most likely results in a bias in the orbit estimates it should not affect RO retrievals. We expect to correct this in a future data release.

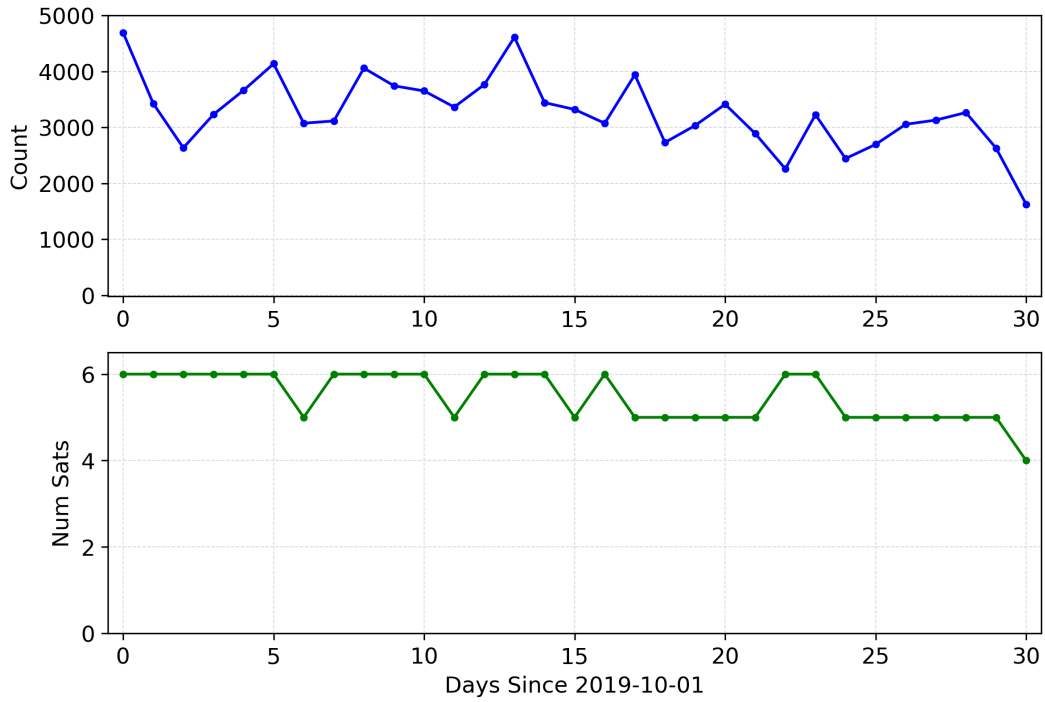
## 5 Path Forward

The F7C2 team is working on several tasks:

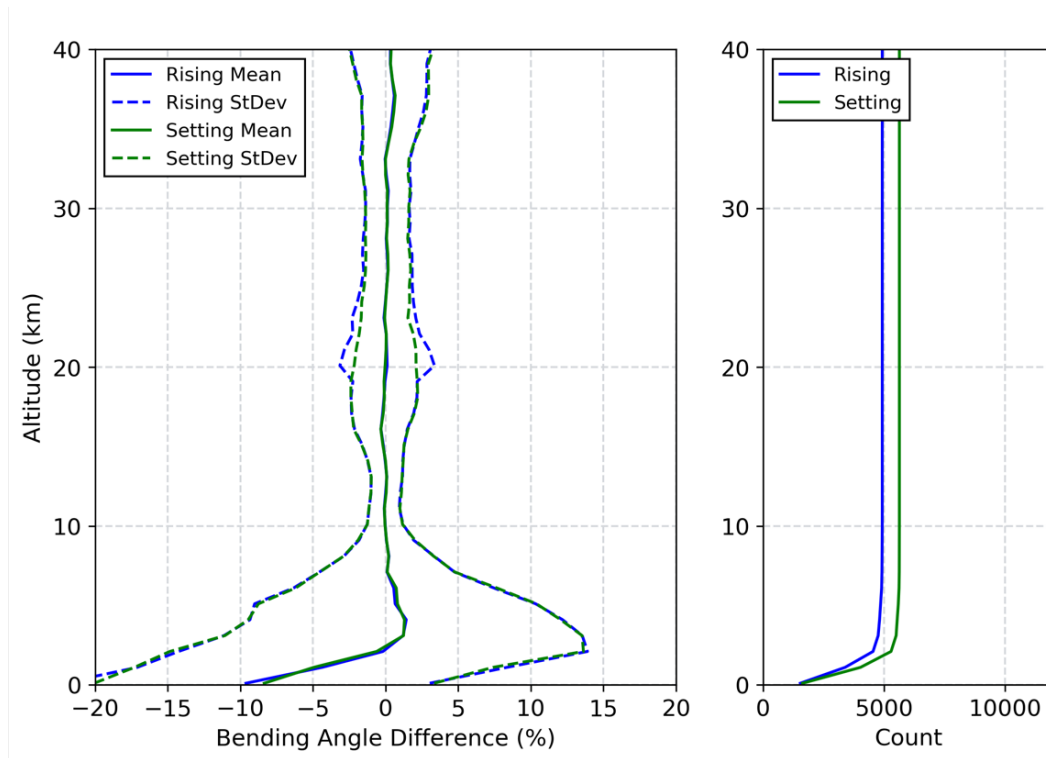
- Reprocess mission data prior to October 1, 2019 in a manner consistent with this release, document features, and make available to the public (expected early 2020).
- Update TGRS flight software to v4.3.3, to address an issue affecting occultation counts.
- Continue investigating noted rising L2P occultation tracking and POD antenna phase center offset issues, and adjust processing as needed.

We plan to release future provisional data approximately biweekly. Operational constraints may, however, cause occasional delays. If significant processing changes impacting product quality are made, we will increment the provisional release version, make the corresponding download area subdirectory, and provide release notes describing the changes.

F7C2 neutral atmosphere initial operational capability is currently expected in February 2020. Upon reaching this milestone, data and products will be released on a daily basis, by 0200 UTC for the prior day.



**Figure 1:** Good quality controlled (QC) neutral atmosphere occultation counts.



**Figure 2:** Rising/setting GPS occultation bending angle compared to ECMWF global NWP.



## 6 Links

- F7C2 neutral atmosphere provisional data download  
<https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional>  
<https://tacc.cwb.gov.tw/v2/download.html>
- COSMIC Data Analysis and Archive Center  
<https://cdaac-www.cosmic.ucar.edu/>
- 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>
- RINEX v2 format  
<ftp://igs.org/pub/data/format/rinex211.txt>
- leoAtt format  
[https://cdaac-www.cosmic.ucar.edu/cdaac/cgi\\_bin/fileFormats.cgi?type=leoAtt](https://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=leoAtt)  
[https://tacc.cwb.gov.tw/cdaac/cgi\\_bin/fileFormats.cgi?type=leoAtt](https://tacc.cwb.gov.tw/cdaac/cgi_bin/fileFormats.cgi?type=leoAtt)
- opnGns format  
[https://cdaac-www.cosmic.ucar.edu/cdaac/cgi\\_bin/fileFormats.cgi?type=opnGns](https://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=opnGns)  
[https://tacc.cwb.gov.tw/cdaac/cgi\\_bin/fileFormats.cgi?type=opnGns](https://tacc.cwb.gov.tw/cdaac/cgi_bin/fileFormats.cgi?type=opnGns)
- SP3 format  
<ftp://igs.org/pub/data/format/sp3c.txt>
- conPhs format (same as atmPhs, except nav bits have been applied)  
[https://cdaac-www.cosmic.ucar.edu/cdaac/cgi\\_bin/fileFormats.cgi?type=atmPhs](https://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=atmPhs)  
[https://tacc.cwb.gov.tw/cdaac/cgi\\_bin/fileFormats.cgi?type=atmPhs](https://tacc.cwb.gov.tw/cdaac/cgi_bin/fileFormats.cgi?type=atmPhs)
- atmPrf RO retrieval format  
[https://cdaac-www.cosmic.ucar.edu/cdaac/cgi\\_bin/fileFormats.cgi?type=atmPrf](https://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=atmPrf)  
[https://tacc.cwb.gov.tw/cdaac/cgi\\_bin/fileFormats.cgi?type=atmPrf](https://tacc.cwb.gov.tw/cdaac/cgi_bin/fileFormats.cgi?type=atmPrf)
- wetPf2 1D-var retrieval format (same as wetPrf)  
[https://cdaac-www.cosmic.ucar.edu/cdaac/cgi\\_bin/fileFormats.cgi?type=wetPrf](https://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=wetPrf)  
[https://tacc.cwb.gov.tw/cdaac/cgi\\_bin/fileFormats.cgi?type=wetPrf](https://tacc.cwb.gov.tw/cdaac/cgi_bin/fileFormats.cgi?type=wetPrf)

- BUFR format

[https://cdaac-www.cosmic.ucar.edu/cdaac/cgi\\_bin/fileFormats.cgi?type=bfrPrf](https://cdaac-www.cosmic.ucar.edu/cdaac/cgi_bin/fileFormats.cgi?type=bfrPrf)

[https://tacc.cwb.gov.tw/cdaac/cgi\\_bin/fileFormats.cgi?type=bfrPrf](https://tacc.cwb.gov.tw/cdaac/cgi_bin/fileFormats.cgi?type=bfrPrf)

## References

- [1] Chen et al., *Typhoon Predictions with GNSS RO Data Assimilation in the MPAS-GSI System*, Severe Weather and TAHOPE Planning Workshop, Taipei, Taiwan, Oct. 14-15, 2019.  
[https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional/references/chen\\_2019.pdf](https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional/references/chen_2019.pdf)
  
- [2] Fong et al., *From FORMOSAT-3/COSMIC to FORMOSAT-7/COSMIC-2 Mission: A New Era of Operational GNSS Radio Occultation Constellation Observing System*, ROM-SAF IROWG Workshop, Helsingør, Denmark, Sep. 19-25, 2019.  
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- [3] Schreiner et al., *Performance Assessment and Requirement Verification of COSMIC-2 Neutral Atmospheric Radio Occultation Data*, ROM-SAF IROWG Workshop, Helsingør, Denmark, Sep. 19-25, 2019.  
[https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional/references/schreiner\\_2019.pdf](https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional/references/schreiner_2019.pdf)
  
- [4] Shao et al., *GNSS-RO data assimilation advancement and implementation at JCSDA and NCEP*, ROM-SAF IROWG Workshop, Helsingør, Denmark, Sep. 19-25, 2019.  
[https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional/references/shao\\_2019.pdf](https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional/references/shao_2019.pdf)
  
- [5] Weiss and Xia-Serafino, *FORMOSAT-7/COSMIC-2 Mission Status and Initial Results*, ROM-SAF IROWG Workshop, Helsingør, Denmark, Sep. 19-25, 2019.  
[https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional/references/weiss\\_2019.pdf](https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional/references/weiss_2019.pdf)

## Acronyms

**BUFR** binary universal form for the representation of meteorological data

**CDAAC** COSMIC Data Analysis and Archive Center

**CWB** Central Weather Bureau

**ECMWF** European Centre for Medium-Range Weather Forecasts

**F3C1** FORMOSAT-3/COSMIC-1

**F7C2** FORMOSAT-7/COSMIC-2

**GLONASS** Globalnaya Navigatsionnaya Sputnikovaya Sistema (Russia)

**GPS** Global Positioning System (USA)

**IVM** Ion Velocity Meter

**JPL** Jet Propulsion Laboratory

**NCU** National Central University

**NOAA** National Oceanic and Atmospheric Administration

**NSPO** National Space Organization

**NWP** numerical weather prediction

**POD** precise orbit determination

**PRN** pseudorandom noise sequence

**QC** quality controlled

**RFB** Radio Frequency Beacon

**RO** radio occultation

**TACC** Taiwan Analysis Center for COSMIC

**TGRS** Tri-GNSS Radio-occultation System

**UCAR** University Corporation for Atmospheric Research

**UTC** Coordinated Universal Time