COSMIC2 Performance, Operation, and Data Loss

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Abstract

The FORMOSAT-7/Constellation Observing System for Meteorology Ionosphere and Climate -2 (COSMIC-2) (FS7/C2) mission began operation in 2019. The COSMIC-2 constellation consists of six satellites each carrying three scientific payloads. The three payloads consist of a Tri-GNSS Radio-occultation System(TGRS), an ION Velocity Meter (IVM), and a Radio Frequency Beacon (RFB). The TGRS unit produces Radio Occultation (RO) profiles which are measurements of bending in radio waves through the Earth's atmosphere. Since mission launch, the constellation has increased its operational performance based on a measured increase in RO profile counts.

In this presentation we show a quantitative increase in performance (roughly 20% increase in occultation counts) and identify the lead cause of this increase as onboard software updates over the mission life. The presentation shows incremental improvement with each new software version. Increased RO profile counts means increased data for the scientific community studying Earth's atmosphere.

We additionally present a measurable decrease in data loss on the two primary payloads (the TGRS and IVM). This analysis defines contributors to the decreased loss including a reduction in both missed ground station contacts and spacecraft related data loss events which represent the two largest categories of data loss. The spacecraft related data loss events can be further classified into seven subcategories. These categories include Single Event Upsets (SEU), occurring either within or outside the South Atlantic Anomaly, spacecraft maneuvering, collision avoidance, spacecraft flight software, spacecraft anomalies and maintenance, and unknown outages.

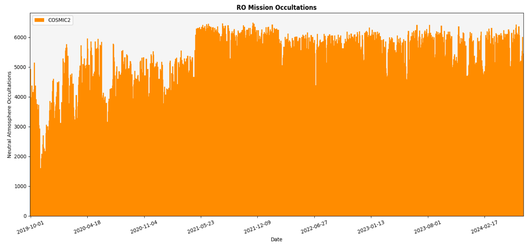
Lastly we present some State of Health (SOH) metrics monitored throughout the mission life. While not specific contributors to improved performance, analysis of these monitors provides an indication that the spacecraft is operating as expected. Monitoring of the solar panel array position and the TRIG temp monitor both display a healthy and expected pattern over the mission life for equatorial orbit. The above data was gathered with the help of the US Data Processing Center (USDPC) as well as the Taiwan Space Agency and provides various methods for measuring RO system performance. The breakdown of data loss into categories also provides an understanding of where major barriers can exist in optimizing data collection by an RO system for future mission operations.

Lead Taiwan Agency Spacecraft Command & Control

Payloads Launch RF Beacon ground system RF Beacon/IVM ground processing

Occultation Profile Counts

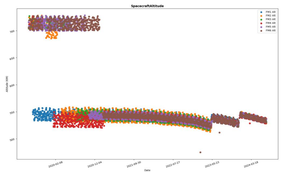
Figure 1



- Radio Occultation (RO) profiles provide the primary data products of the FORMOSAT7/COSMIC2 satellite system. The count of profiles per day provides a representation of data provided to operational users
- Improvements in the FS7/C2 system have lead to an increase in profile counts since mission launch
- The mission has a requirement to provide at least 4000 occultations per day to operational users

Spacecraft Altitude

Figure 11



- Spacecrafts were originally separated from the launch vehicle at ~700km.
- Spacecrafts were lowered to roughly ~550km on a schedule to spread the spacecraft equally around the equator.
- As of 6/30/24 two major raising events have occurred with a 3rd planned for July 2024 in order to maintain altitude
- Figure 11 shows the altitude of all 6 spacecraft over the mission life

Ground Station Contacts

Figure 5: F7/C2 Contacts

Figure 6: Received Contacts vs Scheduled Contacts

Figure 7: Ground Station Comparison

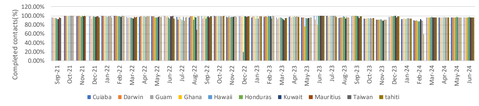
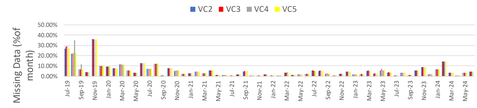


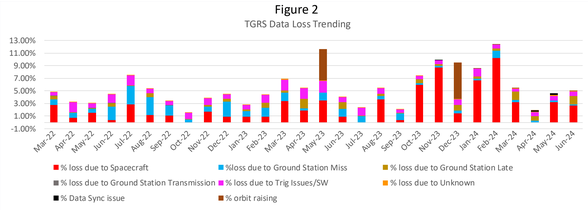
Figure 8: Data Missed in Downlinks by File type



- FS7/C2 downlinks occur at ten locations with contacts provided from government partners and commercial ground stations as a service GSaaS
- Throughout the course of the mission, the number of downlinks has been increased to improve product latency
- Increased scheduling has occurred through a combination of enhancements in the scheduling system, addition of ground stations, and improvements in coverage
- Following the spacecraft reaching the final orbit configuration in 2021, the ratio of received vs scheduled contacts has remained consistent
- Figure 6 shows the individual reliability of specific ground stations over time. Note that accurate monitoring of this type of information had not been perfected until September of 2021
- Downlinks contain four virtual channel (VC) filetypes related to the payloads that are delivered to the ground site and sent on to the USDPC
- VC2 files contain data from the TGRS
- VC3 files contain data from an Ion Velocity Meter (IVM) payload
- VC4 files contain data from a Radio Frequency Beacon (RFB) payload
- VC5 files contain state-of-health data from the spacecraft itself
- Figure 7 shows a break down the specific file types that were scheduled but not actually received by the ground stations

TGRS Data Loss

Figure 2

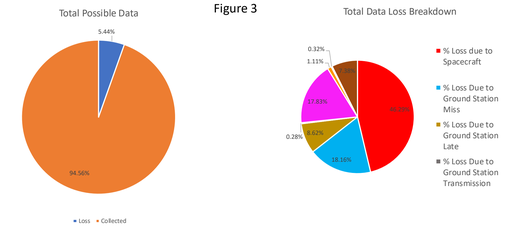


- The Tri-GNSS RO System (TGRS) is the primary payload on FS7/C2. Data from this instrument provides the primary products for operations and science users
- TGRS continuously collects data at rate of 1 Hz - 50 Hz. Data loss is calculated as the fraction of the missing points to the expected data rate
- TGRS data loss is tracked across 6 categories. Some of these categories have further sub-classifications

TGRS Data Loss Categories:

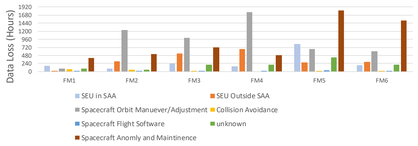
1. **Spacecraft:** Outages caused by spacecraft systems anomalies, orbit maneuvering, or flight software uploads
2. **Ground station misses:** Failed downlinks at ground stations
3. **Ground station late:** Data from ground station did not reach the US Data Processing Center (USDPC) quickly enough to be utilized in real-time ops
4. **Ground station transmission:** Errors in data transfer from the station to USDPC
5. **TGRS issues:** TGRS anomalies including reboots, internal data gaps, and TGRS data timestamp inconsistencies
6. **Unknown:** Loss source cannot be characterized or is unknown

Figure 3



Spacecraft Related Data Loss

Figure 4: FS7/C2 Spacecraft Safe Modes and Outages (Hours)



Spacecraft Outages:

- Spacecraft related events account for the most significant of data loss source for FS7/C2
- The majority of spacecraft outages are due to anomalies with the spacecraft leading to safe modes
- A large subset of the spacecraft anomalies are caused by Single Event Upsets (SEUs)
- Any anomaly with in a spacecraft subsystem requiring payloads to power down are also in this category
- The second largest source of loss is orbit maneuvering as any time the spacecraft maneuvers all payloads are powered down
- Maneuvers can occur for orbit adjustments or to avoid collision with other objects in space

Impacts of FS7/C2 Performance

- FORMOSAT-7/COSMIC-2 has maintained a monthly data availability of 92.45% or higher on the TGRS units since Full Operational Capability (9/15/2021)
  - Only exception to data availability are during major constellation orbit maneuvers
- Numerous tools are currently employed at the USDPC to monitor payload performance and health
- Identification of the largest contributors to data loss provide a basis on most impactful areas for improvement
- Lessons learned based on FORMOSAT7/COSMIC2 performance can be used in future missions for instrument and spacecraft design, ground network, and systems architecture

TGRS Flight Software

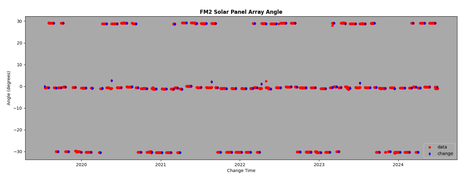
- The flight software (FSW) on TGRS has been progressively updated on FS7/C2 throughout the mission
- FSW updates have added numerous capabilities and enhancements to TGRS that have led to an increase in the RO count performance of the instrument

TGRS Firmware Update Log

Version #	FMs	Upload Period
V4.3.2	1	9/11/19
	2	9/17/2019-9/18/2019
	3	9/19/2019-9/20-2019
	4	9/24/2019-9/25/2019
	5	9/18/2019-9/20/2019
	6	9/23/2019-9/24/2019
V4.3.3	1	11/21/2019
	2	12/3/2019
	3	12/3/2019
	4	1/30/2020
	5	12/5/2019
	6	12/10/2019
V4.3.4	1	2/10/2020
	2	3/24/2020
	3	2/24/2020
	4	2/24/2020
	5	3/2/2020
	6	2/25/2020
V4.3.5	1	8/18/2020-8/19/2020
	2	8/31/2020-9/1/2020
	3	8/25/2020-8/26/2020
	4	8/25/2020-8/26/2020
	5	8/25/2020-8/26/2020
	6	9/9/2020-9/10/2020
V4.3.6	1	3/8/2021-3/11/2021
	2	4/24/2021
	3	4/27/2021
	4	4/27/2021-4/29/2021
	5	5/4/2021
	6	5/4/2021
V4.4	1	9/6/2021
	2	11/17/2021
	3	11/17/2021
	4	11/18/2021
	5	11/18/2021
	6	11/18/2021
V4.4.1	1	12/1/2021
	2	2/15/2022
	3	2/8/2022
	4	2/8/2022-2/23/2022
	5	2/8/2022
	6	2/15/2022
V4.4.2	1	10/26/2022-10/27/2022
	2	7/7/2022
	3	10/26/2022
	4	10/27/2022
	5	10/26/2022
	6	10/31/2022-11/1/2022
V4.5	1	6/27/2023-6/29/2023
V4.5.1	1	1/10/2024-1/11/2024

Solar Array

Figure 9: Solar Array β angle for FS702

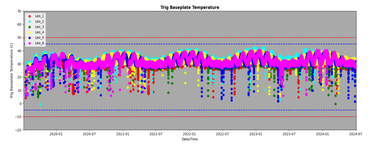


	Array β Angle (% of Mission Life)		
Spacecraft	-30°	0°	+30°
FS701	26.16	46.93	26.90
FS702	27.54	46.64	28.80
FS703	25.59	46.65	27.75
FS704	29.59	45.05	25.36
FS705	24.59	49.77	25.64
FS706	23.87	49.61	26.52

- FS7/C2 spacecraft have a single solar panel array that is rotated through three positions (-30º, 0º , +30º) to optimize charging as the spacecraft orbits precess
- As shown in Figure 9 the solar array follows a pattern over the course of the mission changing the angle of the solar panel array
- All satellites exhibit similar patterns
- In all cases the solar array returns to 0º between +30º or -30º
- The solar panel array of each satellite spends roughly half of the mission time at 0º and 25% of the mission at -30º and 30º as shown in Figure 9

TRIG Temp

Figure 10: TriG Temperatures



- TGRS has a Tri-GNSS receiver (TriG) contained within the center of the spacecraft bus
- The temperature of the TriG is tracked by a thermocouple on the baseplate of the instrument
- Figure 10 shows a periodic trend displayed by all six satellites at the baseplate temperature of the trig unit

Acknowledgements

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