

FORMOSAT-7/COSMIC-2

Program Overview and Status



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IROWG #9

Outline

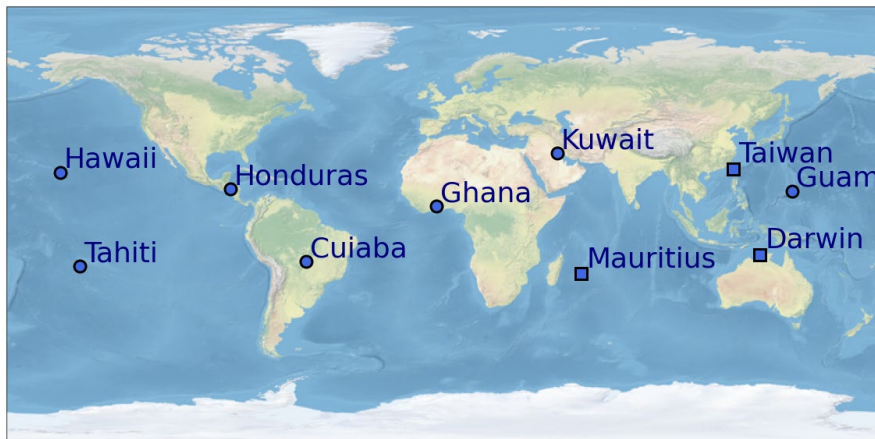


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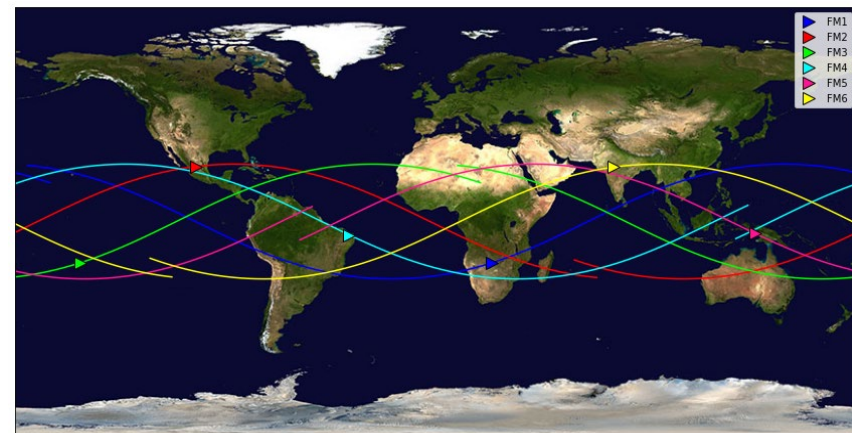
Program Overview



- Partnership: National Oceanic and Atmospheric Administration (NOAA), Taiwan National Space Organization (NSPO), US Air Force/Space Force (USAF/USSF)
- 5 year mission, launched on 6/25/2019, SpaceX Falcon Heavy (USAF STP-2 Mission)
- 6-satellite constellation in six evenly-spaced orbit planes to provide uniform equatorial coverage
- 10 ground stations for downlink support
- Each satellite has 3 instruments provided by USSF
 - Tri-GNSS Radio Occultation System (TGRS) –Primary Instrument
 - Ion Velocity Meter (IVM) – Secondary Instrument
 - Radio Frequency Beacon (RFB) – Secondary Instrument
- Providing > 5000 daily radio occultation for weather forecasting
- Providing ~12,000 daily ionospheric soundings for space weather monitoring
- Median latency <30 min (neutral atmosphere (NA) and space weather, 45 min/30 min requirement)

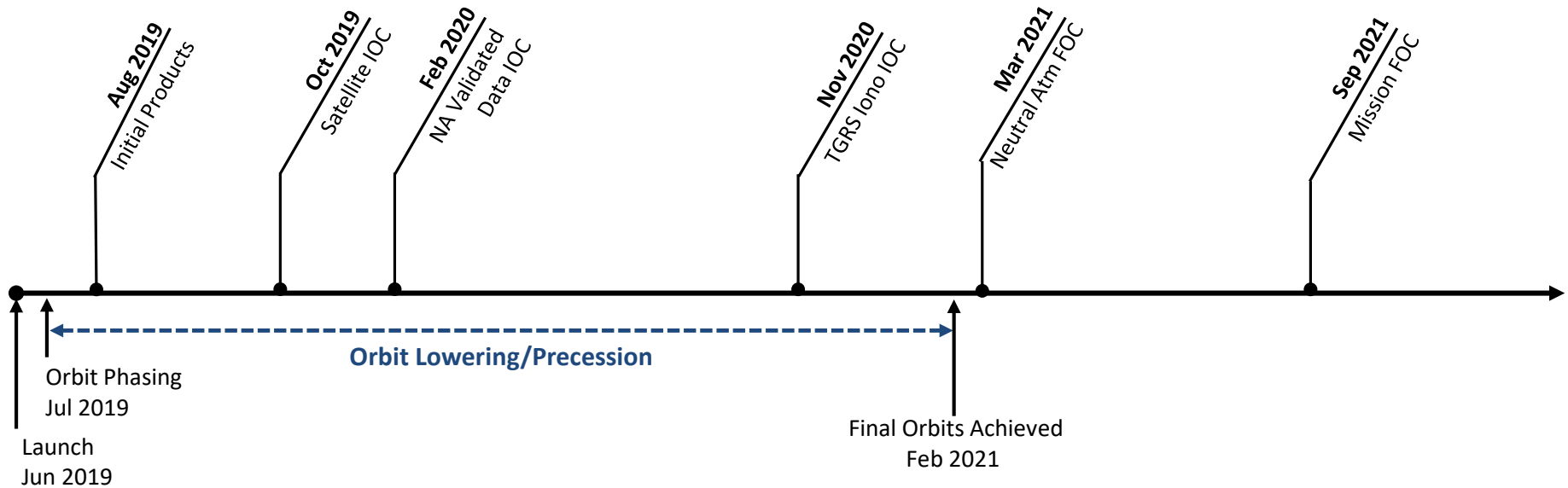


COSMIC-2 Ground Site locations



Mission Constellation Orbit

Major Post Launch Program Milestones



Major Program Achievements

- All satellites in final mission orbits (550 km altitude, 24° inclination, 60° RAAN separation)
- >5000 NA RO profiles/day with a precision better than 2 micro-radian from 30-60 km altitude
- Nearly 12,000/day Total Electron Content (TEC) occs and arcs with accuracy better than 3 TECU
- IVM density accuracy is at or below the 5% mission requirement
- Daily NA product and TEC latency from observation to product creation below 30 min median
- Data products delivered in Near Real Time (NRT) to multiple operational weather and space weather centers and openly available to the research community
- New ionosphere products specifying the presence, absence, and location of scintillation are under development and planned for release in the near-future

Mission Operations



Spacecraft

- NSPO Responsibility
 - Command upload
 - Ephemeris Generation
 - Collision Avoidance
 - Orbit Maintenance
 - Contact Schedule

Ground Stations

- NOAA Responsibility
- 10 ground stations
 - 2 Telemetry and Command
 - 8 Telemetry Only
 - 1 emergency command
 - Partner and US Commercial
 - ~300 contacts per day

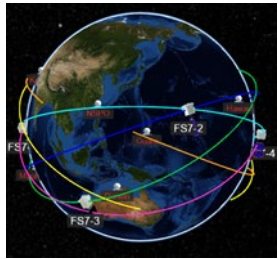
Instruments

- USSF Responsibility
 - Payload commanding
 - Flight Software Updates
 - Payload Monitoring
 - Product Calibration/Validation (Cal/Val)

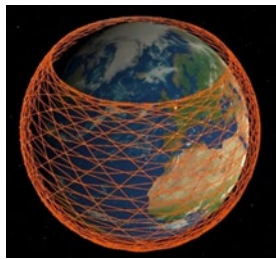
Data

- Processing/Management Centers
 - UCAR
 - Taiwan
- Distribution
 - NOAA GTS
 - UCAR
 - Taiwan
- Archival
 - NOAA NCEI
 - UCAR
 - Taiwan

Collision Avoidance with Starlink Satellites



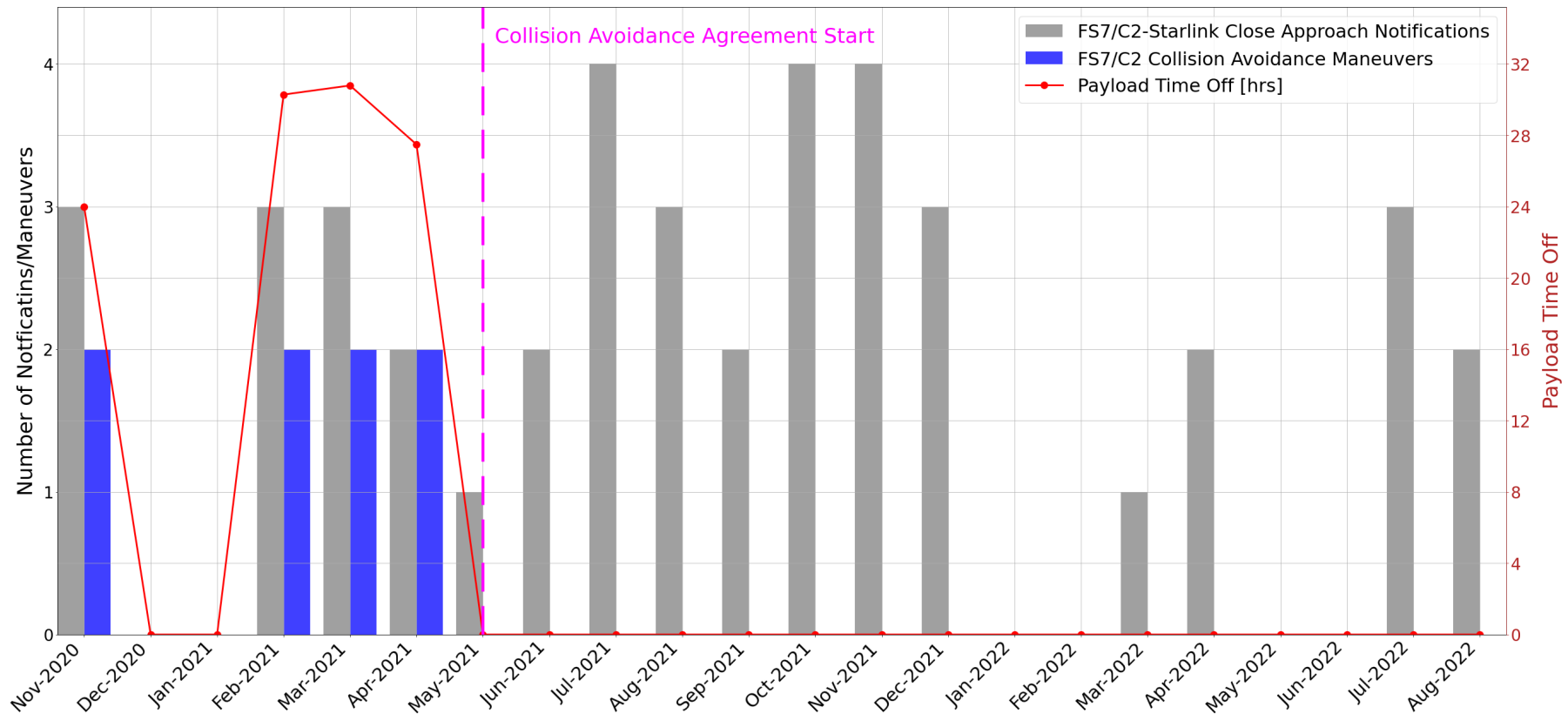
FS-7/C-2



Starlink

- Starlink: 2000+ spacecraft at 540-570-km altitude
- FORMOSAT-7/COSMIC-2 payloads average downtime during a collision avoidance is 14 hours
- 430+ hours FS-7/C-2 payload downtime avoided with the collision avoidance agreement in place since May 2021

FORMOSAT-7/COSMIC-2 and Starlink Conjunctions



COSMIC-2 Products



The COSMIC-2 team has worked to progressively release products as Cal/Val completes throughout the mission life and improve products and production through progressive updates to the payloads.

Data Releases

Neutral Atmosphere:

1. Provisional Products
 - Dec 2019
2. Operational Products
 - Mar 2020

Space Weather:

1. Provisional TEC, EDP, S4
 - Mar 2020
2. TGRS GPS Absolute TEC
 - Sep 2020
3. TGRS GLONASS Absolute TEC
 - Jan 2021
4. IVM Plasma Density
 - Mar 2021
5. Scint High-Rate data & Indices, IVM Comp, Temp and early Drift
 - Mar 2022

TGRS	
Atmospheric Profiles (Mar 2020)	Wet Profiles (Mar 2020)
GPS Absolute TEC (Sep 2020)	GLONASS Abs TEC (Jan 2021)
Electron Density Prof (Mar 2020)	<i>Rel. GPS/GLONASS TEC (Mar 2020)</i>
Scint Amp Index (S4) (Mar 2022)	Scint Phase Index (σ_ϕ) (Mar 2022)
Scint High Rate Data (Mar 2022)	Scintillation All-Clear (Sep 2022)
Scintillation Bubble Map (TBD)	Scintillation Geolocation (TBD)
IVM	
Plasma In-situ Density (Apr 2021)	Plasma Comp & Temp (Mar 2022)
Plasma In-Track Drifts (TBD)	Plasma Cross-Track Drifts (TBD)
RFB	
<i>Relative TEC (TBD)</i>	Scint Amplitude Index (S4) (TBD)
Scint Phase Index (σ_ϕ) (TBD)	

All NRT and post-processed products are available from [UCAR's website](#)

Operational User Status



NOAA National Center for Environmental Prediction (NCEP)

- Operational use of neutral atmosphere products since May 2020

NOAA Space Weather Prediction Center (SWPC)

- Began operational use of absolute TEC in Mar 2022

557th Weather Wing

- Operational use of neutral atmosphere products began July 2022
- Operational use of ionosphere products since Jan 2021

Taiwan Central Weather Bureau (CWB)

- Bending angle data assimilated in CWB Global Forecast System since Sep 2020
- Refractivity data assimilated into CWB regional model since June 2021
- Ionospheric profiles assimilated into CWB Global Ionospheric Specification and Ionospheric Space Weather Forecast System since Feb 2020

Neutral Atmosphere and Ionosphere Requirements



- The selected TGRS NA science requirements relate to RO profile counts per day after quality control (QC) and retrieved bending angle and refractivity precision
- Important TGRS ionosphere requirements are the TEC occultation and combined occultation and arc counts per day and absolute TEC uncertainty

Description	Requirement	Verification Status
Good QC Neutral Atmosphere profiles/day	> 4,000	Met, typically > 5,000
Daily NA profile median product latency	< 45 min (NA)	Met, typically <28 min
Bending angle uncertainty, 30-60 km	2 mrad	Met, 1.6 mrad
Refractivity uncertainty, 10-20 km	0.1 N units	Met, 0.076 N units
TEC occultations per day	> 6,000	Met 33% of days Jan.-May 2022, and 42% of days in May 2022. Average Jan.-May 2022 is 5797 and May 2022 is 5870. Waiver issued for compliance.
Combined TEC arcs and occultations per day	> 12,000	Met 31% of days Jan.-May 2022, and 65% of days in May 2022. Average Jan.-May 2022 is 11626 and May 2022 is 11948. Waiver issued for compliance.
Absolute TEC uncertainty	3 TECU	Met, estimated 2.5 TECU for GPS and 2.6 TECU for GLONASS
Daily TEC median product latency	< 30 min	Met, typically <28 min
IVM in-situ plasma density accuracy	5%	Met

Open Work – TGRS and IVM



- **TGRS scintillation Cal/Val and products development**
 - Geolocation
 - Bubble Map
 - All Clear

New TGRS ionosphere products specifying the presence or absence of scintillation events will provide additional important information to space weather centers.

- **Flight software and ground processing updates**
 - Performance enhancement
 - Galileo capability (neutral atmosphere and ionosphere)
 - Ground software improvement/enhancement

Incremental flight software and ground processing updates will further enhance the quantity and quality of both neutral atmosphere and ionosphere data products.

- **IVM**
 - Validate FS702/FS704 early mission drifts
 - Validate full mission in-track drifts
 - Investigation into root cause of drift meter anomaly
 - Develop improved photo-electron correction for early mission drifts

Summary

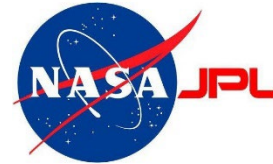


- All six spacecraft and payloads are operating nominally
- Program has reached Mission Full Operational Capability Sept 2021
- >5000 Neutral Atmosphere Profiles per day
- Approximately 12000 TEC arcs and occultations per day
- NA profile and TEC daily median latency <30 minutes
- NA data products in operational use at NCEP and USAF
- Iono. data products in operational use at SWPC and USAF
- COSMIC-2 making clearly positive impacts to operational weather and space weather specification and prediction
- COSMIC-2 contributing high quality data to science applications in the areas of weather, space weather, and climate
- New scintillation data products are under development
- Advances in RO techniques for scintillation detection are providing science and operational communities with an unprecedented ability to monitor equatorial ionospheric scintillation

Acknowledgements



Thanks to the FS-7/C-2 Program partners!



Back Up



System Element and Data Flow

