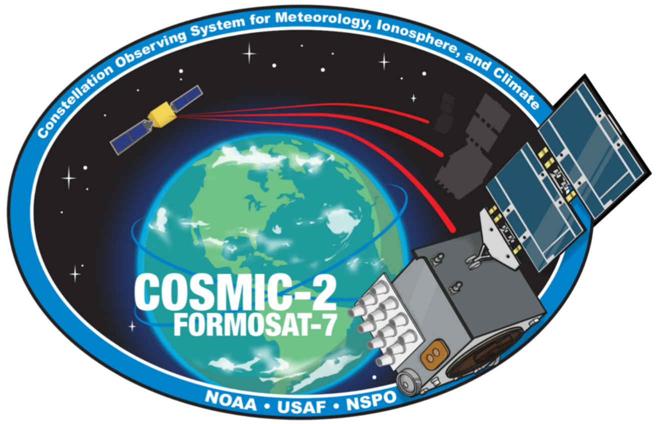

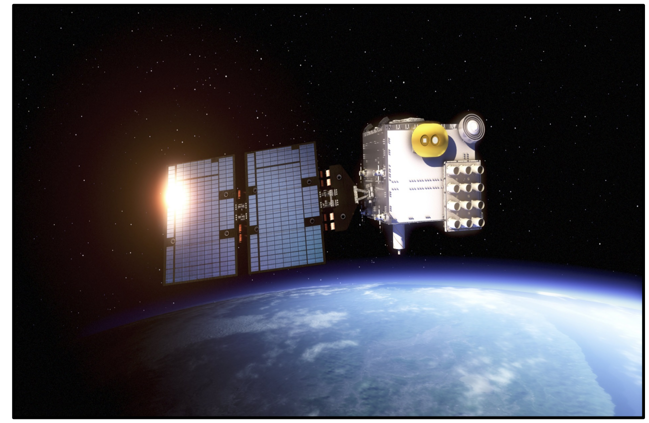

COSMIC-2 Precise Orbit Determination Results

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May 5, 2020

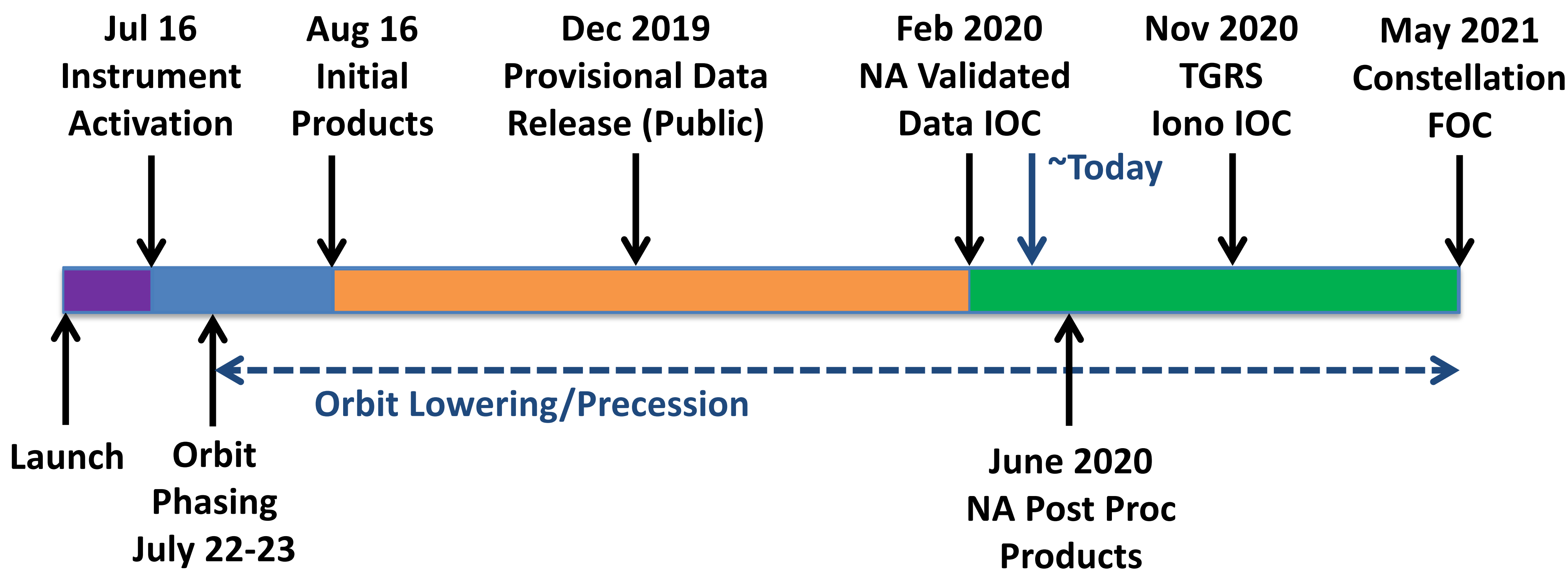
Outline

- Mission and instrument overview
- Post-processing POD strategy and results
- Summary and next steps

Mission Overview

- FORMOSAT-7/COSMIC-2 (COSMIC-2, C2) follows on the successful COSMIC-1 mission launched in 2006
- Six satellite constellation around the equator
  - 24 degree inclination orbit
  - ~750 km initial, ~525 km final altitude
- 5 year mission life to provide 4000+ radio occultation soundings per day for improved numerical weather prediction, space weather monitoring, trending of climate change
- All weather, uniform coverage over oceans and land with 30 min median data latency
- Each satellite has 3 payloads provided by USAF
  - Tri GNSS Radio-occultation System (TGRS) – primary payload
  - Ion Velocity Meter (IVM) – secondary payload
  - RF Beacon – secondary payload

COSMIC-2 Mission Schedule

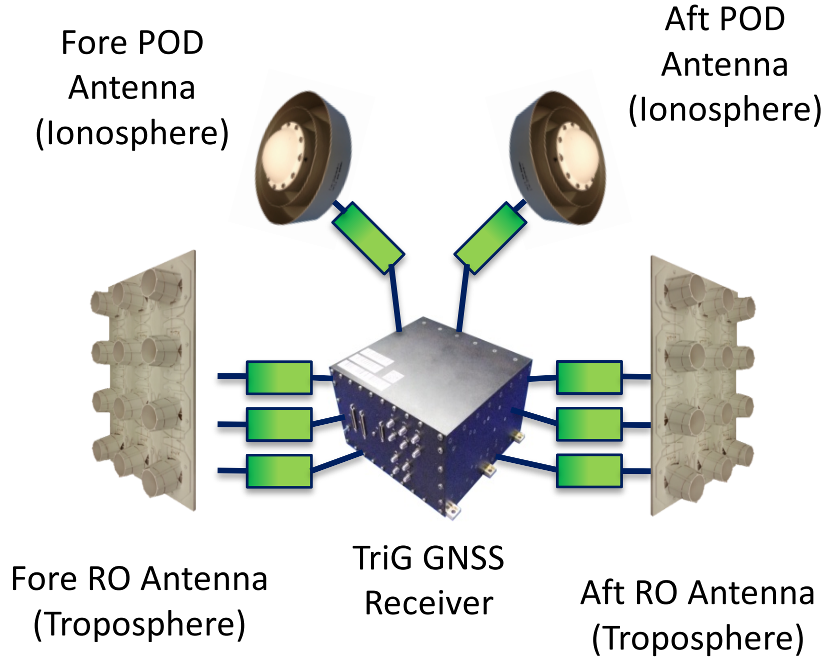


- Launch and early orbit operations
- Checkout and commissioning
- Weather cal/val
- Weather operations

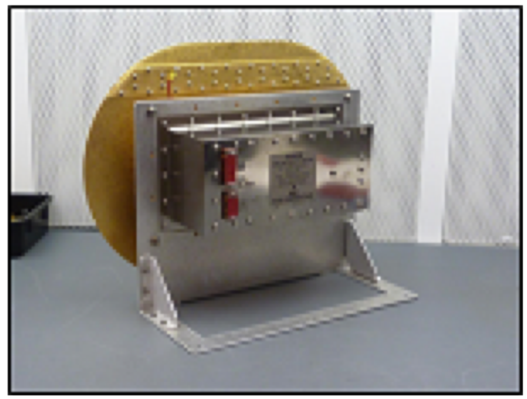
NA = Neutral Atmosphere
Iono = Ionosphere
IOC = Initial Operational Capability
FOC = Full Operational Capability

COSMIC-2 Instruments

This Talk



TGRS

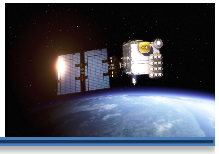


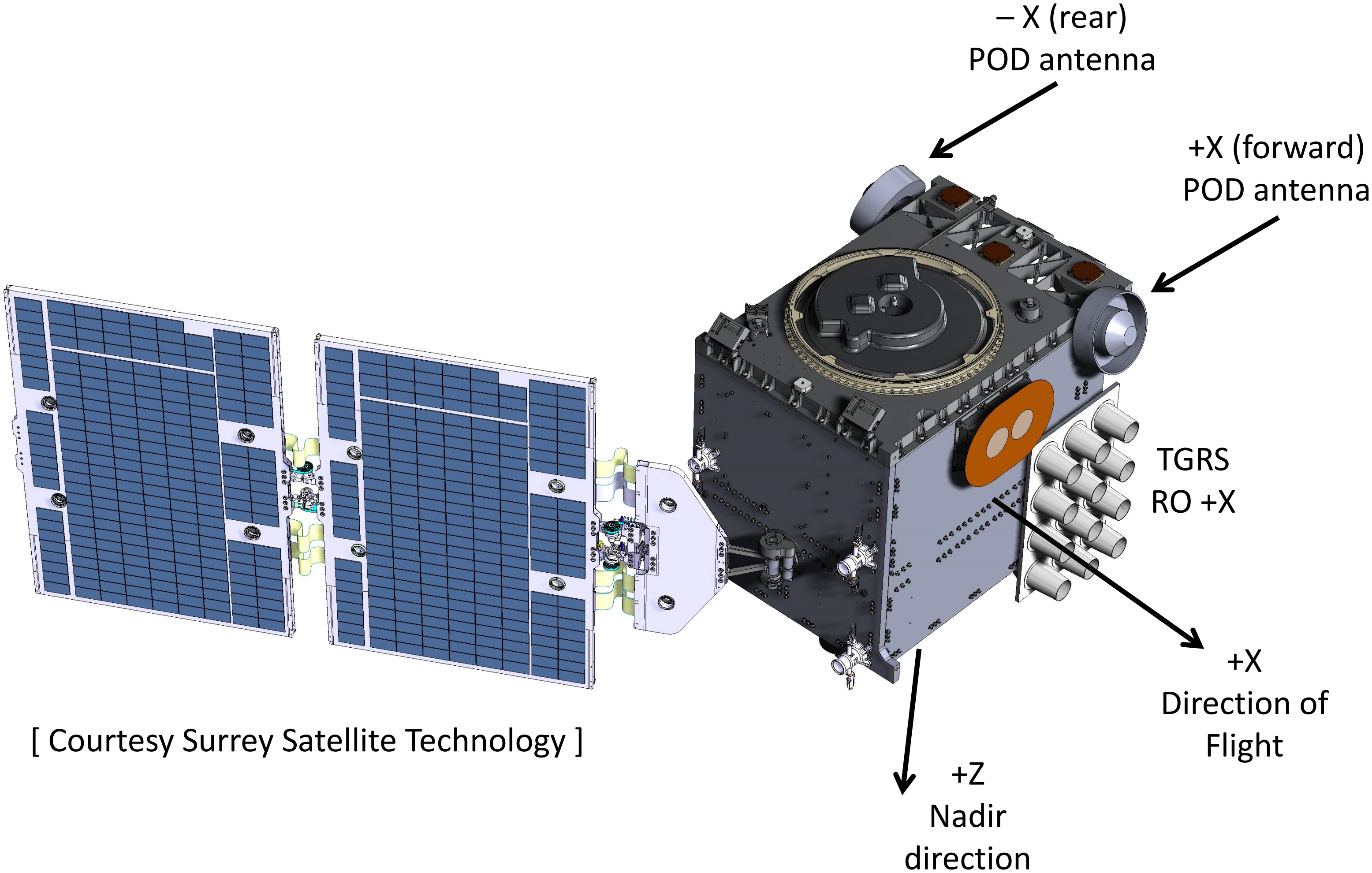
IVM

RFB

Mission Payload	TGRS (Tri-GNSS Radio occultation System)	To measure the amplitude and phase/group delay of GNSS (GPS, GLONASS) signals
Science Payload	IVM (Ion Velocity Meter)	To measure in-situ ion density, drifts (Electric fields), temperature & composition
	RFB (Radio Frequency Beacon)	To measure total electron content and ionospheric scintillation.

COSMIC-2 Spacecraft Diagram





[Courtesy Surrey Satellite Technology]

- POD antennas tilted 75 deg from zenith to allow for ionospheric profiling
- Normally use rear antenna for POD since more observations scheduled here

POD Overview

- This presentation focuses on post-processing solutions for 24 hour arcs
- Evaluating data collected October 1-31, 2019
  - Consistent receiver flight software and configuration
  - Some improvements over initial launch configuration (related to observation scheduling and GLONASS pseudorange noise)
- Three solution sets
  - 1) Antenna 1 (rear), GPS data only
  - 2) Antenna 1 (rear), GPS + GLONASS data
  - 3) Antenna 2 (forward), GPS data only
- Using Bernese GNSS Software

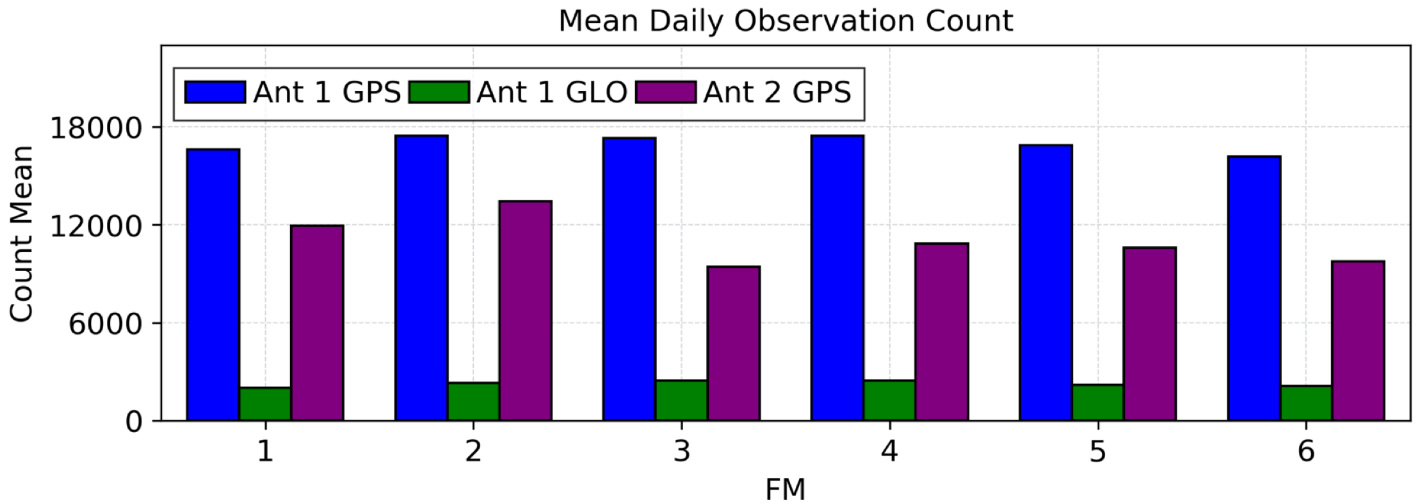
POD Strategy

- Table summarizes key POD parameters

Category	Key Parameters
Observation data	L1 and L2 pseudorange and carrier phase
GNSS orbit/clocks	CODE final product
Orbit arc	24 hours
Data interval	30 sec
Antenna calibrations	Transmitter: IGS14 standard applied LEO: offsets only, phase center variations not considered
Apriori LEO orbit	Dynamic fit pseudorange only kinematic solution
Dynamic orbit solution estimated parameters	Epoch state Constant and 1/rev acceleration in radial, cross-track, along-track
Reduced dynamic orbit solution estimated parameters	Epoch state Constant and 1/rev acceleration in radial, cross-track, along-track Stochastic acceleration in radial, cross-track, along-track every 10 min, with apriori sigma 5 nm/s^2 Carrier phase data only
Receiver clock	White noise stochastic estimated every 30 sec

Data Volume

- The figure below shows the average daily number of of 30 sec phase observations by antenna and GNSS

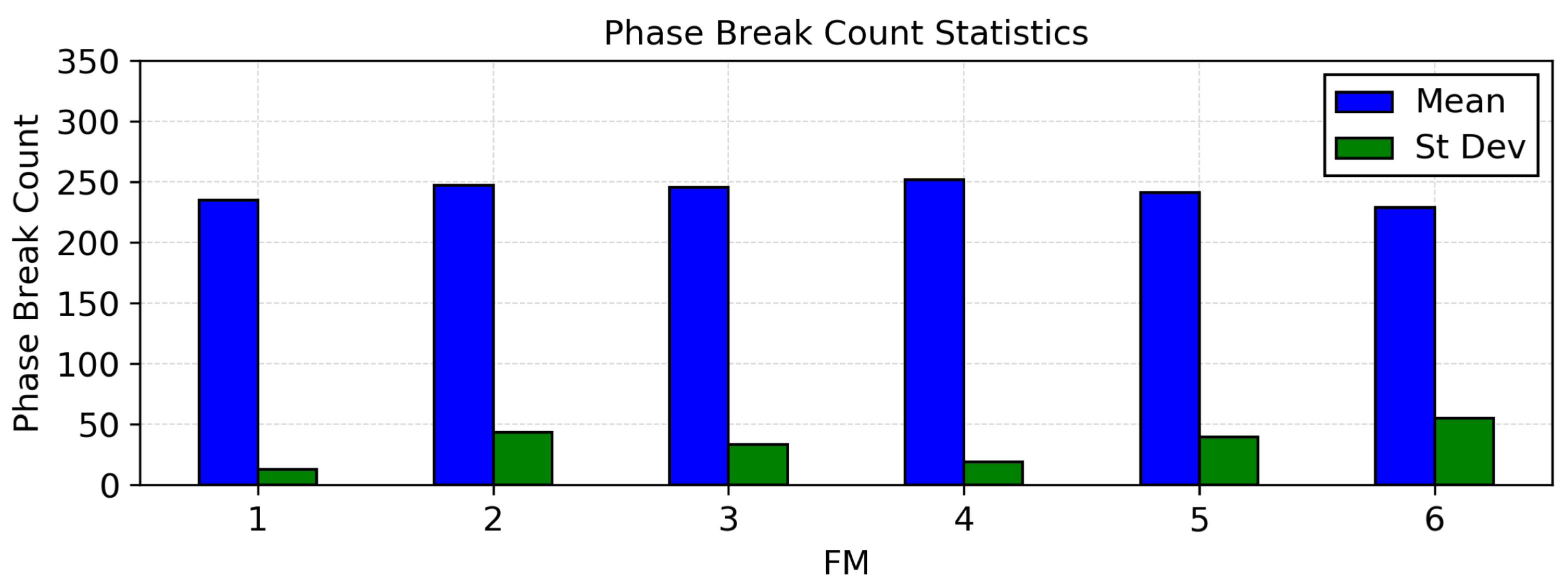


- Due to operational or POD processing issues, solutions are not generated on all days, as summarized in the table; fewer observations are scheduled on antenna 2, so fewer processed days are expected

FM	1	2	3	4	5	6
Number of days antenna 1	31	31	30	31	30	27
Number of days antenna 2	28	25	20	23	24	16

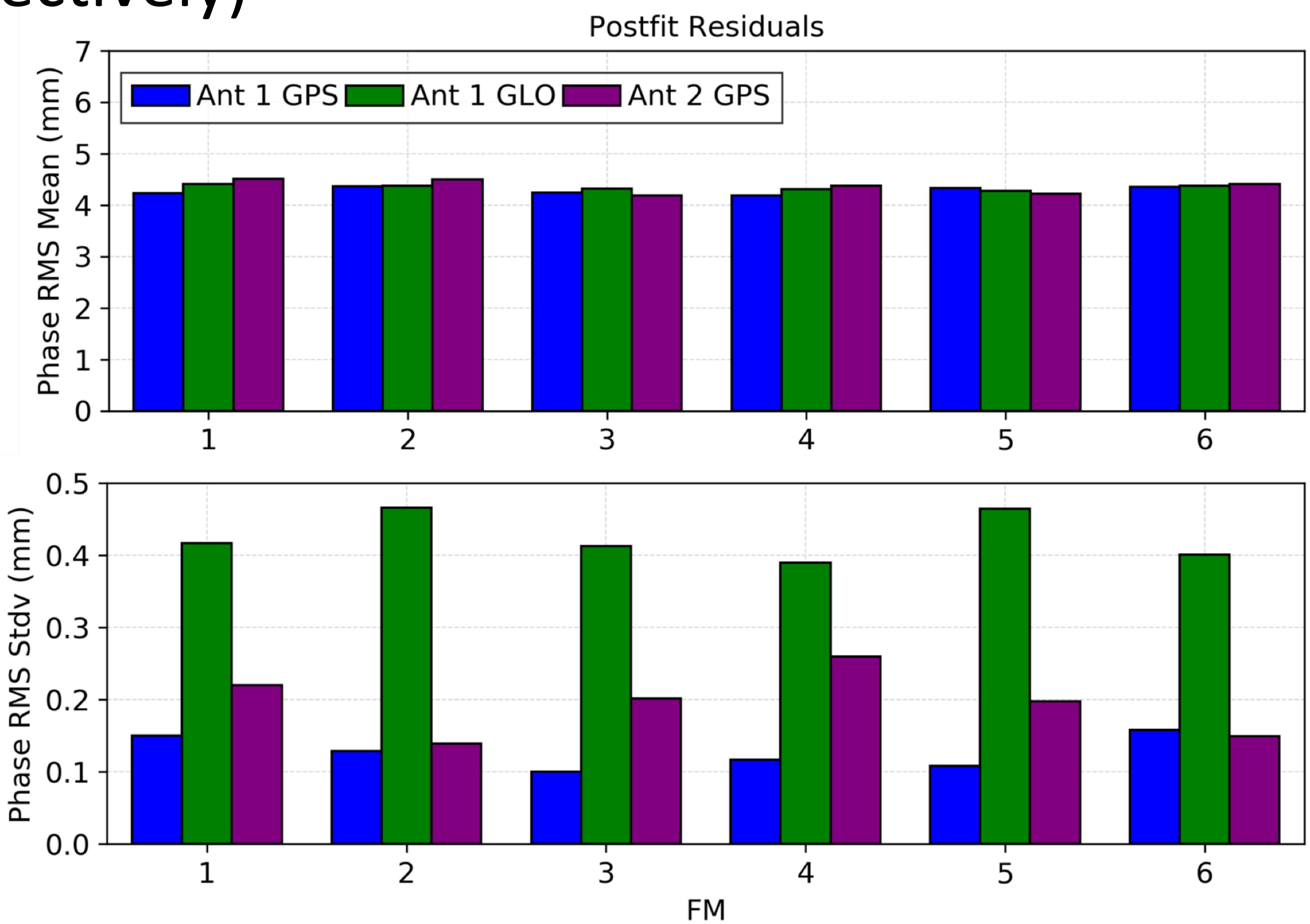
Phase Break Counts (Ant 1 GPS)

- Multiple techniques (e.g. widelane, M-W combination) applied to detect phase breaks in observation data
- The figure below shows the mean and st. dev. of detected phase breaks for all FMs for the days processed
  - Approximately 250 phase breaks detected on average each day for all FMs, with st. dev. below 55
- Considering nearly 18000 phase observations per day on average, small number of breaks is of no concern

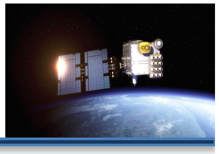


Postfit Residuals

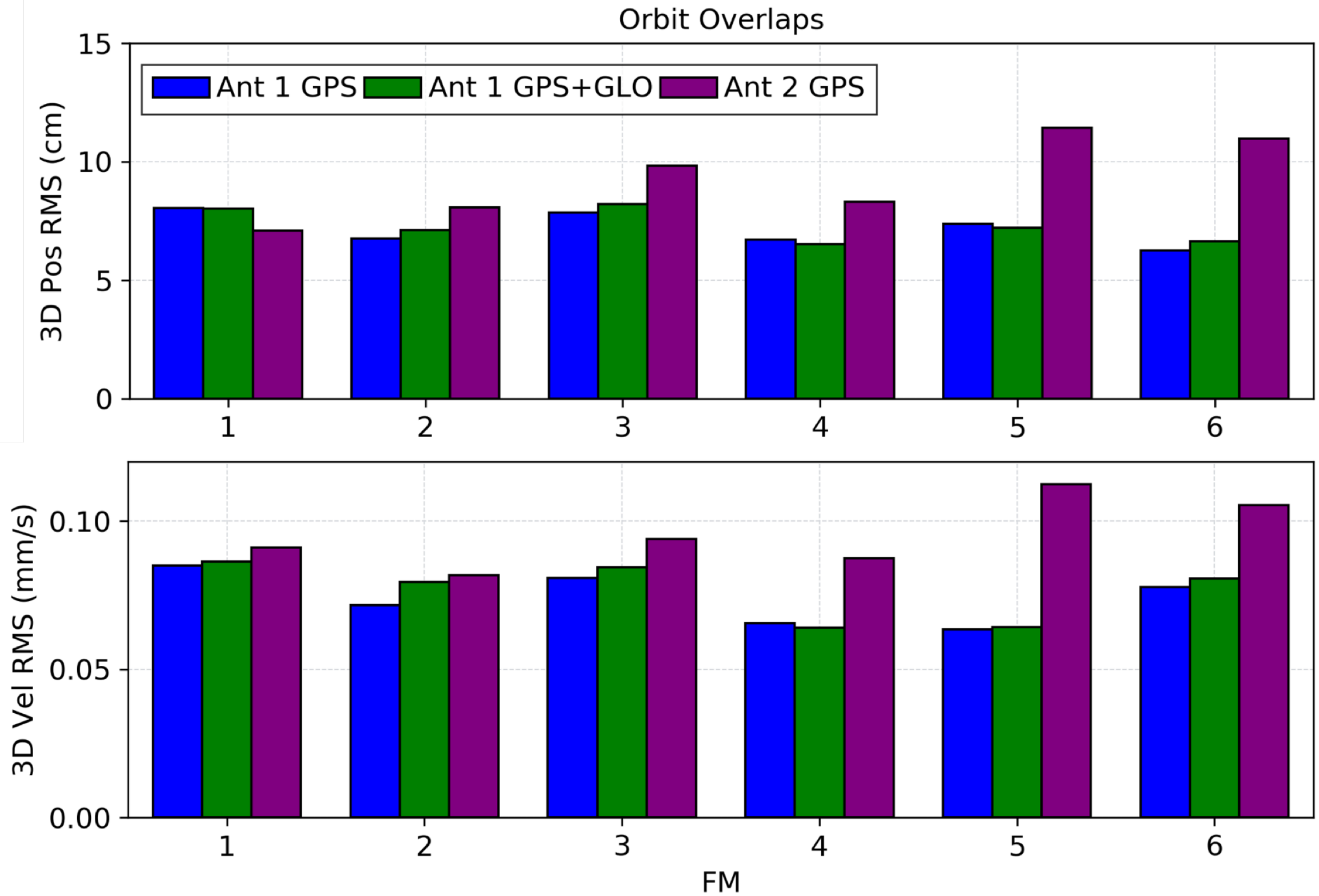
- The average and st. dev. of the daily phase residual RMS are shown below
- In general, all solutions are very consistent in terms of mean of daily RMS, while GLONASS and antenna 2 GPS residuals show more variation (~0.4 mm and ~0.2 mm 1-σ, respectively)



Orbit Overlaps



- Single point (so pessimistic) internal orbit overlaps are computed across the month and summarized by their RMS value
- Position and velocity results for antenna 1 are below the 10 cm and 0.1 mm/s mission requirements for post-processed solutions
- The standalone antenna 2 solutions are generally a bit worse, as expected due to the lower data volume



Issue Noted

- Center of mass to antenna reference point offset vector spacecraft body-fixed Z-component is likely incorrect
  - Infer this from empirical radial acceleration estimated in reduced dynamic orbit solution
  - Magnitude of radial acceleration is around 1.5-3 x 10^{-6} nm/s^2
  - Such large acceleration is not estimated in cross- and along-track components
- It is likely that this acceleration is absorbing a Z-component antenna offset error
  - Corresponds to few cm Z-offset error based on quick sensitivity test
- We have reviewed the calculation of the offset vector and plan to engage with the spacecraft vendor/integrator for further evaluation

Summary and Next Steps

- All six satellites perform consistently in terms of data volume collected, postfit residual statistics, orbit precision metrics, and detected phase breaks
  - Requirements for precise orbit determination metrics are already met
  - Uncovered likely antenna offset issue
- POD next steps
  - Combined processing of the antenna 1 and 2 data (work in progress)
  - Apply phase center variation calibrations (minor impact expected)
  - Ambiguity resolved processing
  - These improvements will mainly benefit post- and re-processing applications where the highest accuracy is desired

Backup

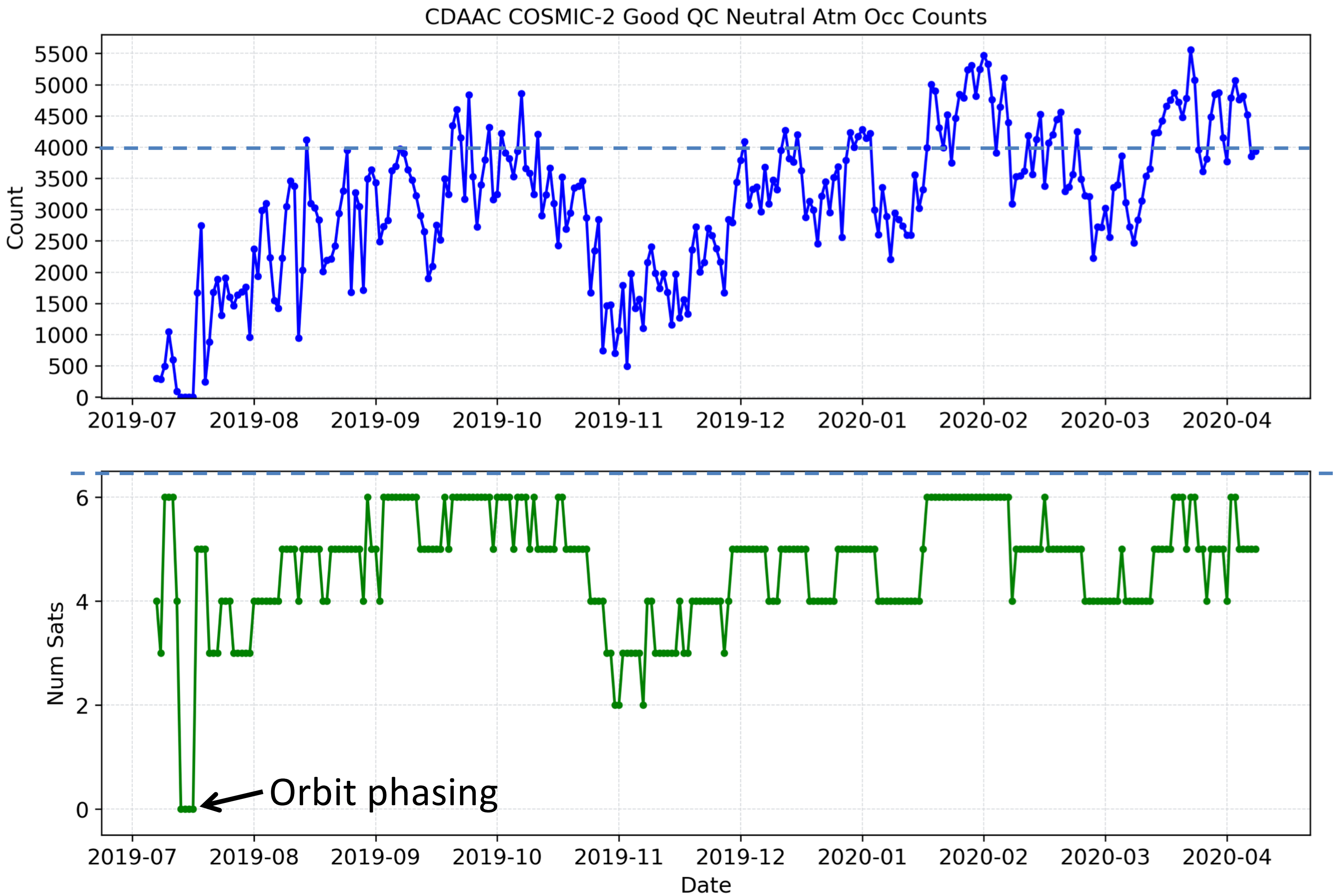
C2 Product Availability

Type	Available	Notes
Precise orbits	Yes	podCrx
Excess phase	Yes	conPhs
Neutral atm retrieval	Yes	atmPrf
1D var retrieval	Yes	wetPf2
BUFR files	Yes	bfrPrf
Relative TEC	Yes	podTc2
Electron density profiles	Yes	ionPrf
Scintillation indices	Yes	Onboard S4, podTc2
Absolute TEC	No	Pending DCB validation, multipath calibration
High rate scintillation indices	No	Pending TGRS s/w update validation

Data products available at:
https://data.cosmic.ucar.edu/gnss-ro/cosmic2
https://tacc.cwb.gov.tw

Neutral Atm Occultations Counts

- Showing post-QC counts and satellites participating since instrument activation on July 16
- Easily meeting 4000 occ requirement when all instruments operating



High Occultation Count Day

- 5556 good QC occultations on March 27, 2020
  - Map shows 24 hr geographic coverage