COSMIC-2 Data for Atmospheric Soundings

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ABSTRACT

FORMOSAT-7/COSMIC-2 is a joint mission between the United States (NOAA,USAF) and Taiwan (NSPO) to provide operational radio occultation (RO) data. A follow on to the successful FORMSAT-3/ COSMIC mission, COSMIC-2 observations are vital to numerical weather prediction (NWP) and other science applications. In addition to temperature and moisture profiles for the neutral atmosphere, COSMIC-2 also provides total electron content profiles for the ionosphere as well as ionospheric scintillation indices for space weather applications.

The six COSMIC-2 satellites launched on June 24, 2019. Following spacecraft and payload checkout, the RO receivers on-board each satellite have been collecting atmospheric soundings. COSMIC-2 data is processed by UCAR/CDAAC and provided to both NWP centers and science users. After an intensive calibration and validation period, the quality of the data was deemed to be provisional in December 2019. The initial operational capability of the COSMIC-2 neutral atmosphere data was reached in February of 2020.

Figure 1. The launch of COSMIC-2 as part of STP-2 on-board a SpaceX Falcon Heavy, Image credit: NOAA and SpaceX.

BACKGROUND

Radio Occultation (RO) is a limb sounding technique that measures atmospheric profiles by making use of the signals transmitted by Global Navigation Satellite System (GNSS) satellites. These signals are refracted by the Earth's atmosphere by varying angles due to density gradients. An occultation occurs when a GNSS satellite is observed rising or setting behind the disk of the Earth from the perspective of a receiving satellite in low earth orbit (LEO). Receivers on-board the six COSMIC-2 satellites capture the radio signals and record a series of the time delay introduced by the bent path at various altitudes. From the degree of bending, temperature and moisture profiles of the atmosphere can be retrieved.

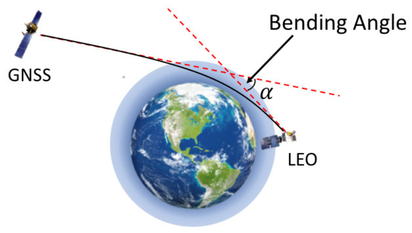

Figure 2. A schematic depicting the geometry of an occultation and the bending angle that is derived.

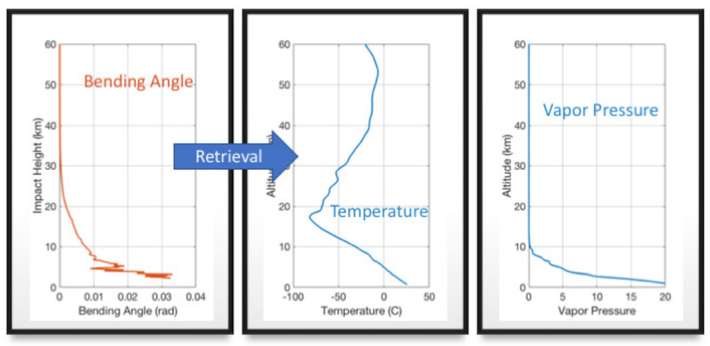

Figure 3. From the bending angle profile, temperature and moisture profiles can be retrieved.

TGRS: NEXT GENERATION RO RECEIVER

The primary COSMIC-2 payload is the Tri-GNSS Radio-occultation System (TGRS) instrument. The TGRS includes a number of technological advancements over the heritage receiver on-board COSMIC-1, including:

- The ability to receive new, modernized GNSS signals from multiple GNSS constellations including GPS and GLONASS;
- The ability to update both software and firmware to improve data quality and acquisition;
- Multiple digital beam steering to simultaneously direct multiple beams for high SNR especially at low and high atmospheric altitudes and maximized for each satellite tracked individually ;
- Multi-lag processing allowing for use of multiple range and Doppler models to more reliably capture rising occultations;
- Time delayed processing that stores RO data so that it can be reprocessed if a better model can be produced;
- Blueshift Algorithm allowing for tracking when SNR is low, improving both lower atmosphere and rising occultations.

COSMIC-2 CONSTELLATION

Figure 4. A schematic of the low inclination orbits of the six COSMIC-2 satellites. Image courtesy of NSPO.

The final COSMIC-2 mission constellation will put the six satellites into low inclination LEO orbits with altitudes of about 550 km. The Walker 6/6/4 constellation will allow for as much uniformity in geographic distribution of occultations as possible. The low inclination orbits result occultations between 45° North and 45° South where cyclogenesis occurs and the improved data collection techniques will help to capture the highly variable moisture structure. Nine ground stations allow for data latency of less than 45 minutes.

The satellites were launched into parking orbits at 720km. Each is lowered one at a time into the mission orbit to allow for proper spacing and phasing. At this time, two of the six satellites are in their mission orbits, and a third is being lowered. The final mission constellation will be realized in February 2021.

References:
1. Weiss, J.P. & Schreiner, W.S. (December 10, 2020) FORMOSAT-7/COSMIC-2 Neutral Atmosphere Provisional Data Release 1. Retreived from https://data.cosmic.ucar.edu/gnss-ro/cosmic2/provisional/F7C2_NA_Provisional_Data_Release_1_Memo.pdf
2. Schreiner, W. S., et al.(2020). COSMIC-2 radio occultationconstellation: First results.GeophysicalResearch Letters,47, e2019GL086841. https://do.rg/10.1029/2019GL086841
3: Ho, Shu-peng, Xinjia Zhou, Stanislav Kireev, Loknath Adhikari, 2019b, NESDIS RO Science Studies and Quality Assurance through the STAR Integrated Cal/Val System: Initial Validation of COSMIC2 Data, IROWG Workshop, https://www.romsaf.org/romsaf-irowg-2019/en/open/1570202501.3acc71ecd45aa34b643a194c5d451c98.pdf/Ho__2019_09_IROWG_ICVS_C2_talk_BenHo.pdf

PROVISIONAL DATA RELEASE

Following an intensive commissioning and calibration/validation period, the COSMIC-2 data were declared provisional on December 10, 2020. The data processed by UCAR/CDAAC is publicly available at the following website:

https://data.cosmic.ucar.edu/gnss-ro/cosmic2/

- > 4000 Occultations Per Day

By receiving signals from both GPS and GLONASS satellites, COSMIC-2 is able to capture upwards of 4000 occultations per day.

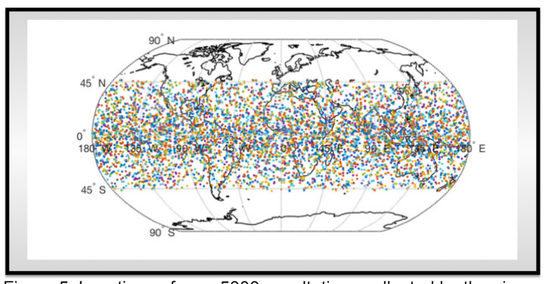

Figure 5. Locations of over 5800 occultations collected by the six COSMIC-2 satellites on Feb. 5, 2019.

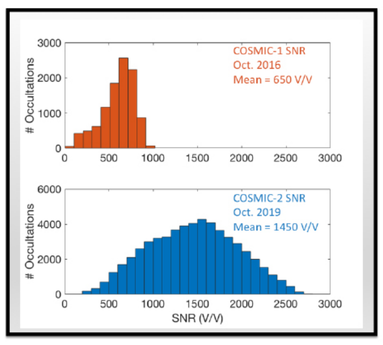

Figure 6. The distributions of the L1 SNR at 80km for occultations collected by COSMIC-1 in October 2016 (top panel) and similarly, for those collected by COSMIC-2 in October 2019 (bottom panel).

- High Signal to Noise Ratio (SNR)

COSMIC-2 has by far the highest SNR of any RO mission. The impacts of SNR on data quality and penetration depth are active areas of study, as are the best ways to utilize the enhanced measurement capability.

- Deep Profile Penetration

Over 80% of COSMIC-2 profiles penetrate below 1.2km. Tropospheric ducting where super-refractivity occurs can be detected (see Schreiner et al. 2020).

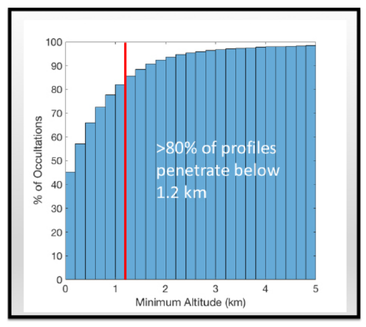

Figure 7. The cumulative distribution of the minimum altitude of occultations from October 2019.

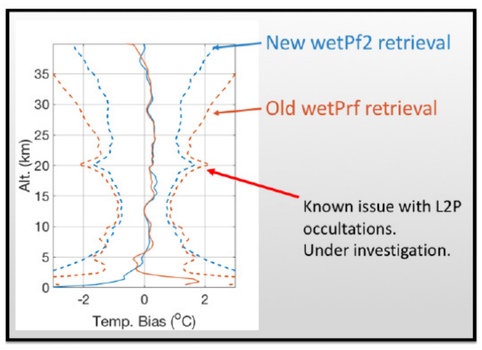

Figure 8. The means (solid curves) and standard deviations (dashed curves) of the old wetPrf retrieved (orange) and new wetPf2 retrieved temperatures compared to ECMWF forecasts.

- New Temperature and Moisture Retrieval Algorithm

The new 1D-VAR retrieval algorithm was implemented by UCAR/CDAAC for the COSMIC-2 data. This retrieval utilizes a Control-Variable Transform formulation and variational Abel transforms for both the observation operator an optimization of the bending angle. The wetPf2 profiles offer higher vertical resolution than the previous wetPrf version.

STAR RO ICVS

STAR has extended the monitoring capabilities of the Integrated Calibration and Validation system (ICVS) to radio occultation data from multiple missions including COSMIC-2. The ICVS is a web-based system that supports instrument performance monitoring, inter-comparisons with other independent measurements, and data assimilation in collaboration with data users. Capabilities for RO include:

- Near real time and long-term monitoring of instrument status and performance;
- Near real time and long-term monitoring of data product quality;
- Anomaly detection and diagnosis;
- Assurance of the integrity of the climate data records;
- Routine comparisons with other satellite observations and retrievals, e.g. MW and IR;
- Routine comparisons of profiles with those from Radiosondes;
- Dynamic web interface with many capabilities;
- Long-term monitoring of RO parameters.

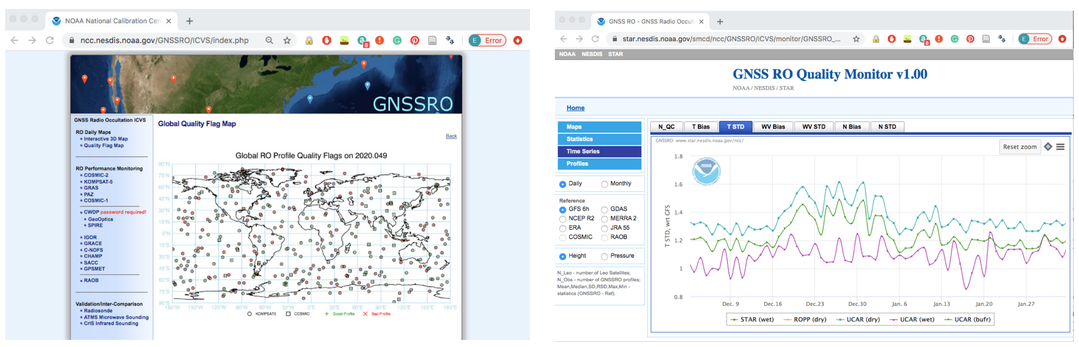

Figure 9. Screen-captures of the STAR RO ICVS website. Many RO missions are monitored, including COSMIC, MetOp GRAS, Commercial Data providers (not public), and COSMIC-2. The right panel shows trending of the standard deviation of temperature compared to GFS forecasts for COSMIC-2.

COSMIC-2 Data have reached Provisional Maturity and are suitable for operational use in Numerical Weather Prediction (NWP) and other science applications.