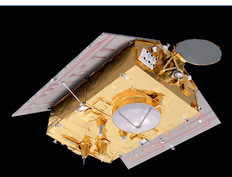

Sentinel-6 Status and Updates

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IROWG-10 2024 Boulder, CO
September 12-18, 2024

National Aeronautics and Space Administration

Poster No. 3

The Sentinel-6 Michael Freilich (MF) satellite was launched on November 21, 2020 and has been tracking GPS and GLONASS radio occultations (ROs) routinely since January 2021. The status of the RO mission and processing is presented as well as the current plans to augment the RO capabilities in orbit and on the ground.

Sentinel-6 Mission

Primary mission is to provide continuity of ocean topography measurements beyond Jason-3 for determining ocean circulation, climate change, and sea-level rise.

- Partners: NASA, EUMETSAT, NOAA, and ESA (with support from CNES)
- Two-satellite mission ("Michael Freilich" and "B")
- 1336 km orbit at 66º inclination
- Orbits Earth every 2 hours with the ground track repeating every 10 days
- Mission life of 5.5 years (goal of 7.5 years) per satellite

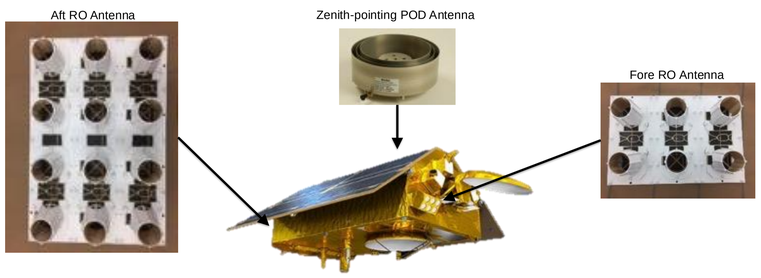
Secondary mission is to track GNSS radio occultations to provide global, high-vertical resolution profiles sensitive to temperature and water vapor for weather and climate applications.

Partner responsibilities for RO mission:
- JPL provides the GNSS-RO instrument hardware and maintains the software
- JPL is responsible for near-real-time (NRT) processing for distribution to NWP centers
- NOAA is responsible for distributing received JPL NRT BUFR products to NWP centers via GTS
- EUMETSAT is responsible for non-time-critical processing for climate and atmosphere studies

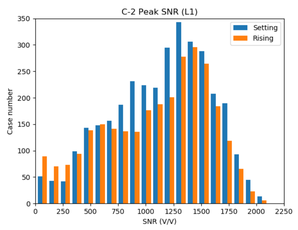
Instrumentation and Antennas

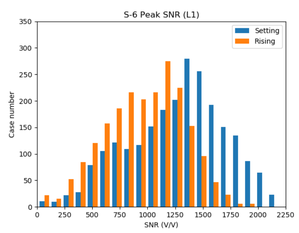
Sentinel-6 leverages the lengthy GNSS-RO instrumentation heritage incubated at JPL by using the Tri-GNSS (TriG) sounder and RO antennas developed for COSMIC-2. *See Garth Franklin's poster (#11) for more details.*

Instrumentation:
- Currently tracks setting and rising GPS and GLONASS occultations
- Tracks GPS satellites for precise orbit determination
- Has capability to track ionosphere occultations, grazing reflections, and Galileo occultations



Antennas:
- Leverages design used for COSMIC-2
- Beam-steering is enabled to digitally combine multiple arrays for increased SNRs
- Have similar performance as COSMIC-2 for setting occultations
- Fore antenna is half the size as aft antenna due to footprint constraints from nearby instrumentation, which yields lower peak SNRs than COSMIC-2 for rising occultations (see plots below)

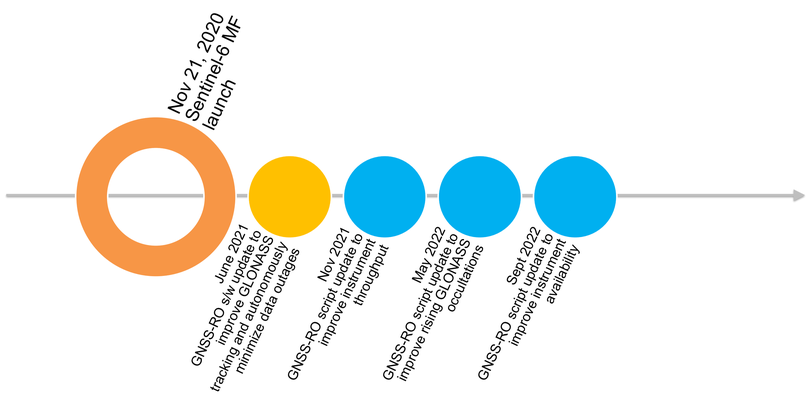




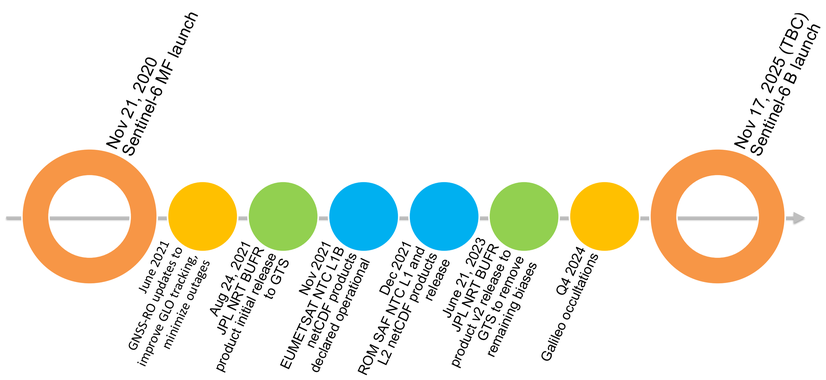
Instrument Performance and Updates

The GNSS-RO instrument (TriG) has been performing well since launch without encountering any major issues.

- **Currently tracks around 1050 GPS and GLONASS setting and rising occultations per day**
- Setting occultations are tracked down to -350 km (line-of-sight altitude) within +/- 40º latitude to facilitate detection of atmosphere ducting
- On-board instrument updates have improved availability, stability, and performance in tracking ROs (from GLONASS, especially)



Major Events Timeline

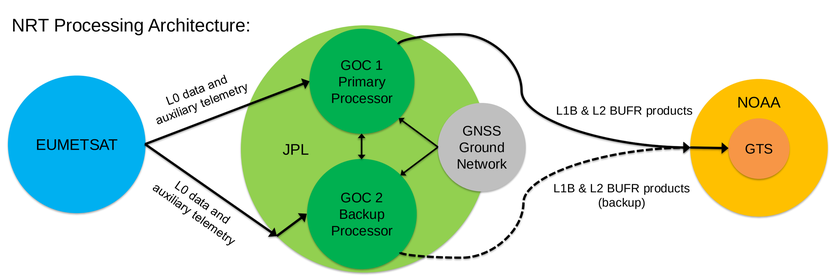


Ground Data Processing

RO NRT Processing System

JPL's NRT processing leverages existing JPL GDGPS Operations Centers (GOCs) for:
- Real-time 1-second POD solutions for GNSS orbits, clocks, and attitudes
- Majority-voted GNSS navigation message data bits
- Distributed, hot-redundant architecture
- Search for document CL22-5995 at https://dataverse.jpl.nasa.gov to find more details about the JPL GDGPS system

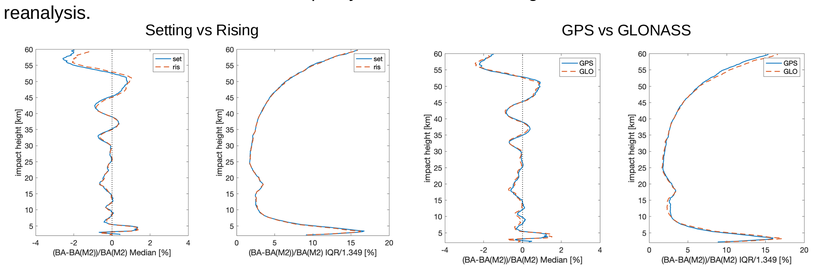
NRT Processing Architecture:



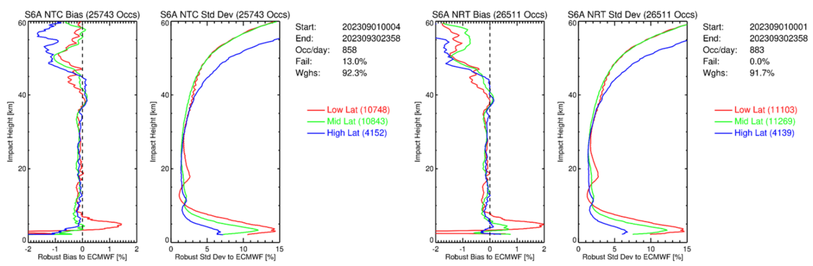
JPL's NRT processor uses the Radio Occultation Atmospheric Retrieval System (ROARS):
- Leverages retrieval and inversion algorithms developed at JPL and applied to multiple past missions (CHAMP, COSMIC, GRACE, etc.)
- Processes occultations from multiple GNSS constellations
- Uses JPL's GipsyX/RTGx software for rapid on-line NRT LEO POD processing
- Retrieves atmospheric profiles in parallel to significantly reduce NRT processing latencies

Bending Angle Assessments

Sentinel-6 RO retrievals have similar quality as COSMIC-2 and agree well with NASA MERRA-2 reanalysis.



EUMETSAT NTC and JPL NRT retrieved bending angle profiles agree well with each other with some notable differences at high altitude, likely due to differences in orbits and clocks.



Sentinel-6 RO NRT data have been evaluated and assimilated operationally at ECMWF and other weather centers since January 2022.

Product Releases

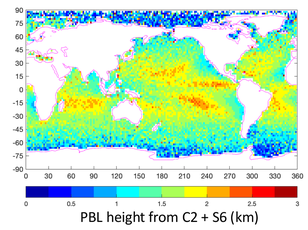
JPL NRT BUFR products released initially to GTS on August 24, 2021
- A time-dependent bias between rising and setting bending angle profiles was observed
- Cause identified in the processor and fixed
- Subsequent analysis of updated BUFR products revealed an underlying small (0.2%) constant bias in rising and setting bending angles between about 20-40 km
- After a lengthy investigation, the cause was identified in the processor and fixed
- Updated BUFR products were released to GTS on June 21, 2023

EUMETSAT NTC L1B netCDF products became operational in November 2021.
ROM SAF NTC netCDF products were released in December 2021.

Science

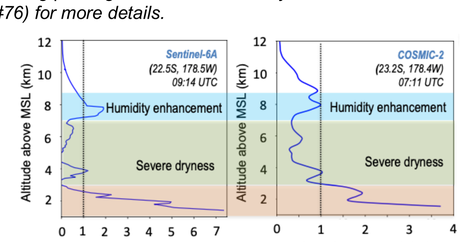
Planetary Boundary Layer

Sentinel-6 profiles penetrate much deeper into the Planetary Boundary Layer (PBL) than COSMIC-1 and its global distribution complements the low latitude distributions of COSMIC-2. *See Chi Ao's invited talk on Monday, Sept 16, 2024 for more details.*



2022 Tonga Volcanic Eruption

Sentinel-6 MF and COSMIC-2 occultations captured extreme tropospheric dryness southwest of the Tonga eruption indicating prolonged convection activity hours after the event. *See Panagiotis Vergados' poster (#76) for more details.*



Looking Forward

Galileo on Sentinel-6 Michael Freilich

The Sentinel-6 project is preparing to start tracking Galileo occultations, which will:
- Increase profile coverage and number of profiles
- Make up for reduced number of occultations during periods when GLONASS orbital planes are obscured by the Earth's limb (approximately every 2 months)
- **Increase the total counts to almost 1500 occultations per day**

Currently planning for tracking Galileo to be enabled in orbit on S6 MF in Q4 2024:
- EUMETSAT and JPL are preparing to process Galileo occultations with NTC and NRT latencies
- An email will be sent at the appropriate time to the IROWG mailing list announcing the details of this enhancement.

Sentinel-6 B

The mission partners are actively preparing to launch Sentinel-6 B on November 17, 2025 (TBC):
- The second satellite was built at the same time as the first and contains the same instrumentation
- The GNSS-RO instrument will track GPS, GLONASS, and Galileo occultations after launch

S6 B will fly in tandem with S6 MF, trailing in orbit by about 30-seconds during the months-long commissioning phase:
- Due to the proximity of the orbits, NRT products from S6 B will be nearly the same as those from S6 MF and may not be released immediately on GTS (to be coordinated with NWP partners)
- After commissioning phase ends, both satellites will drift apart and S6B NRT products will be distributed on GTS
- S6 MF and B are expected to have a period of overlapping operations (duration is TBD)

Almost 3000 occultations per day are anticipated from both satellites during overlapping operational period

Ionosphere occultations are planned to be collected and analyzed during commissioning phase to assess performance and to query potential user feedback.

Sentinel-6 C

Planning for a third satellite, Sentinel-6 C, is underway:
- May include GNSS-RO as a secondary mission
- To be launched no earlier than 2030
- Stay tuned for updates about this exciting development!

Conclusion

The Sentinel-6 RO mission continues to provide routinely more than 1000 occultations per day and shows similar quality of performance with COSMIC-2 profiles. The planned addition of Galileo in Q4 2024 is expected to increase this number by about 500 occultations per day. With the ongoing operations of the "Michael Freilich" satellite and the launches of the B (late 2025) and C (no earlier than 2030) satellites, occultations from the Sentinel-6 series could provide ongoing global coverage with RO for years to come, possibly through 2037.

Where to find Sentinel-6 RO products:
- JPL's NRT L1B and L2 BUFR products: WMO's GTS
- EUMETSAT's NTC L1B netCDF products: https://user.eumetsat.int/data-access/data-centre
- ROM SAF's NTC netCDF products: https://rom-saf.eumetsat.int
- JPL's NRT and NTC L1B and L2 netCDF validation products, to be released in Q4 2004: https://disc.gsfc.nasa.gov/ (NASA/GES DISC archive)

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.