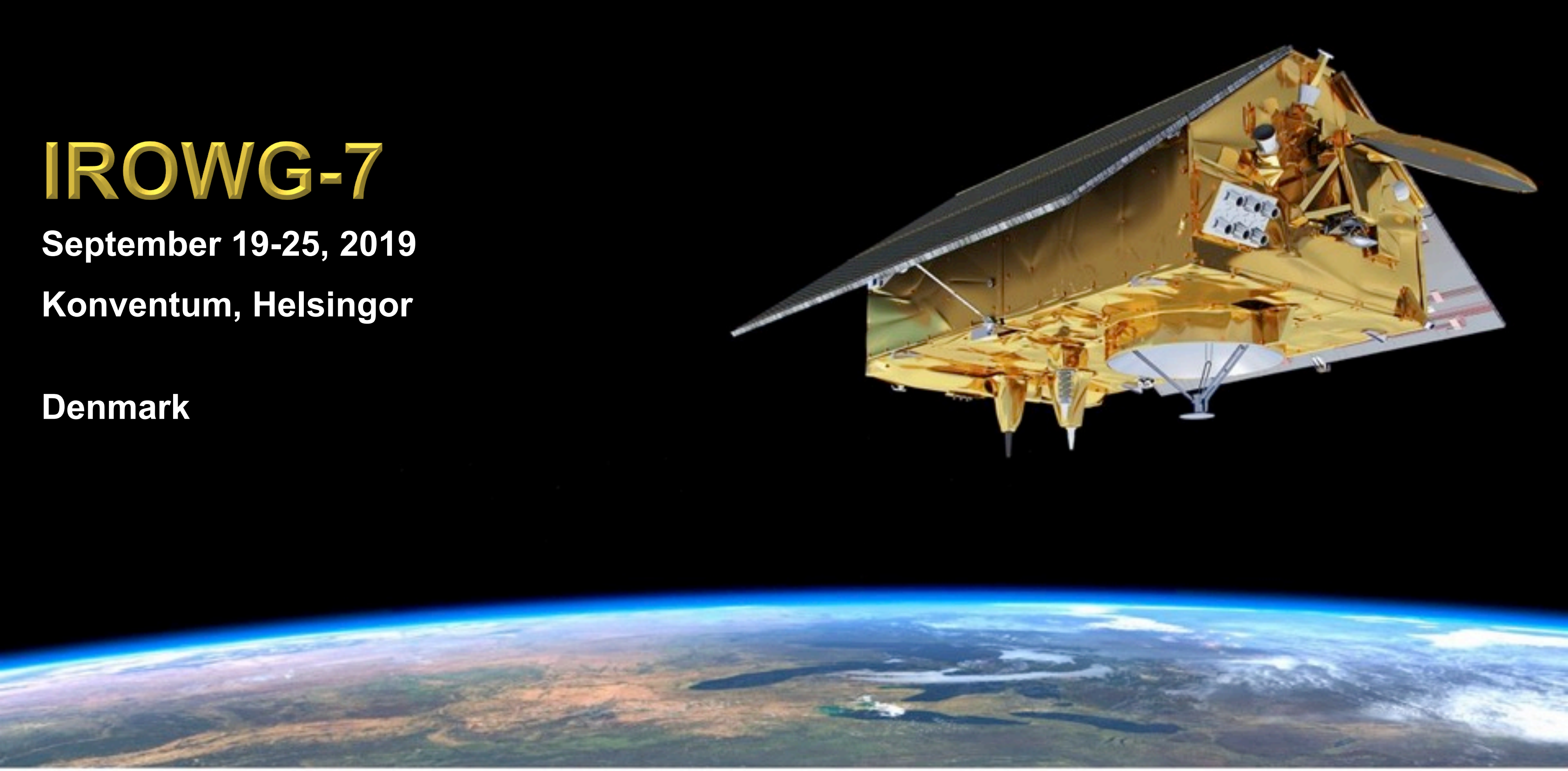
IROWG-7

September 19-25, 2019

Konventum, Helsingor

Denmark



Jason-CS/Sentinel-6 GNSS Radio Occultation Instrument Overview and Performance

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Axel Von Engeln (EUMETSAT)

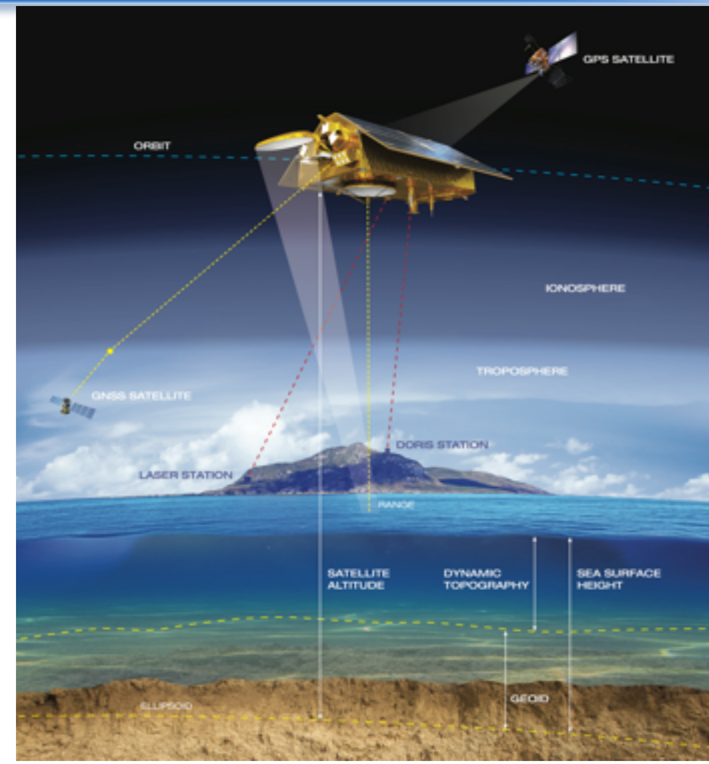
Jason-CS/Sentinel-6 Mission Summary

Mission Objectives

- Operational ocean altimetry to provide continuity of ocean topography measurements beyond Jason-3
- Global sea surface height to an accuracy of ≤ 4 cm every 10 days, for determining ocean circulation, climate change and sea level rise
- NASA, EUMETSAT, ESA and NOAA partnership with CNES providing technical support
- Operational mission as part of *a two-satellite* EUROPEAN Copernicus/Sentinel program

Instruments

- Ku/C-Band Radar Altimeter (Next gen Poseidon: Thales)
- DORIS (Precise Orbit Determination System)
- GNSS Receiver (POD System)
- Advanced Microwave Radiometer – Climate Quality (AMR-C)
- GNSS-Radio Occultation (GNSS-RO)
- Laser Retro-Reflector Array (LRA)



Mission Overview

- Target Launch Dates: Nov 2020 & (tbd) 2025
- **Launch Vehicle: SpaceX Falcon 9 FT**
- Project: Cat II
- Risk Class: B for (AMR-C & LRA); C for GNSS-RO
- Spacecraft Bus (Airbus: Cryosat Heritage)
- Alti Mission life: 5 ½ years (goal of 7 ½ years)
- RO Mission life: **3 years**
- 1336 km Orbit, 66º Inclination

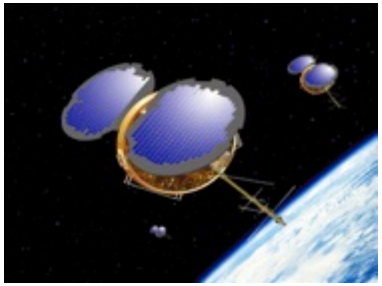
GNSS RO Level 1 Science Requirements

- Sentinel-6 payload includes a GNSS receiver/antenna system provided by NASA/JPL for measuring **bending angles** of GNSS signals occulted by Earth's atmosphere, with **sufficient accuracy and coverage** for numerical weather prediction and other applications.

Profiles per day	**770**			
Altitude Range	**Vertical Resolution (km)**	**Bending Angle Uncertainty**		
		Requirement (μrad)	CBE (μrad)	Margin
10-20 km	**0.15**	**30**	20.4	32%
20-30 km	**1.5**	**3**	1.65	45%
30-60 km	**1.5**	**2**	1.10	45%

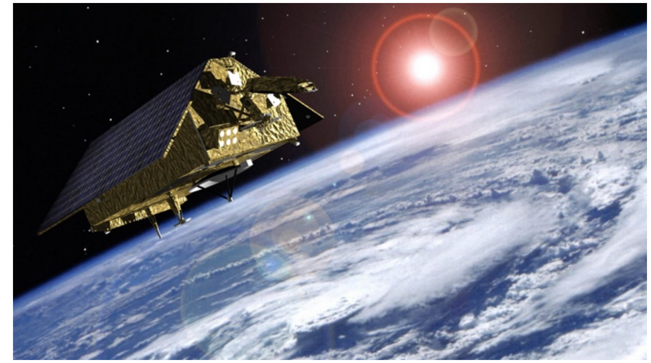
- RO measurements satisfy secondary mission objectives and are not connected in any way to the primary altimetry mission.
  - No Project threshold requirements and no Mission Success Criteria associated with RO
  - RO mission lifetime is 3 years (rather than 5.5-year lifetime of altimetry mission)

The GNSS-RO Radio Occultation Instrument derives heritage from Cosmic-1 and Cosmic-2



Cosmic-1
Number of Satellites: 6
Launch Date: April 15, 2006

Cosmic-2
Number of Satellites: 6
Launched June 25, 2019



Sentinel-6
Number of Satellites: 2
Launch Date: 2020 and 2025

Electronics

POD antenna (patch)

RO antenna (patch array)

	Cosmic-2	Sentinel-6
Orbit Altitude	540 km	1330 km
Inclination Angle	24	66
Mission Life	5 Years	5.5-7.5 Years

Fore

Aft

The S-6 fore antenna size is limited by spacecraft constraints.

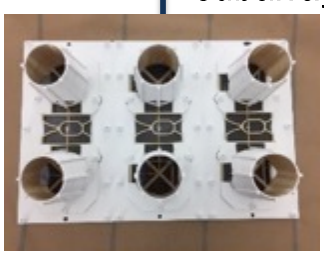
Fore

Aft

The GNSS-RO instrument will provide radio occultation measurements from GPS L1/L2 and GLONASS FDMA L1/L2 at the Sentinel-6 Orbit

Zenith facing Precise Orbit Determination (POD) antenna (RUAG PEC).

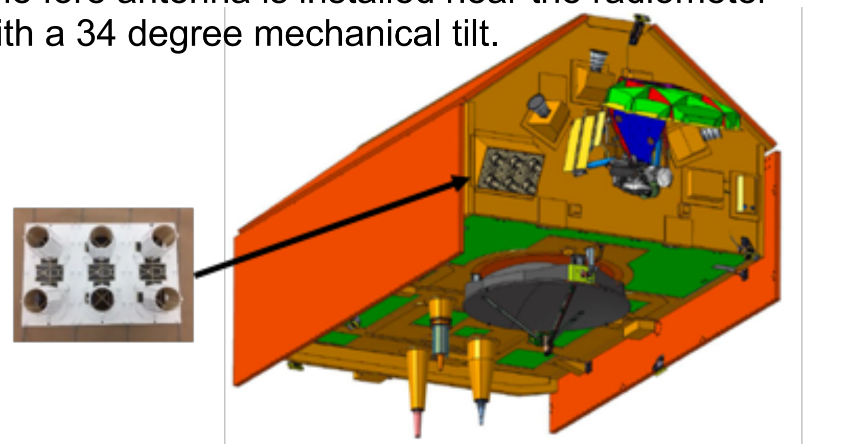
Inherited Cosmic-2 Electronics with 1553 digitally samples each subarray.

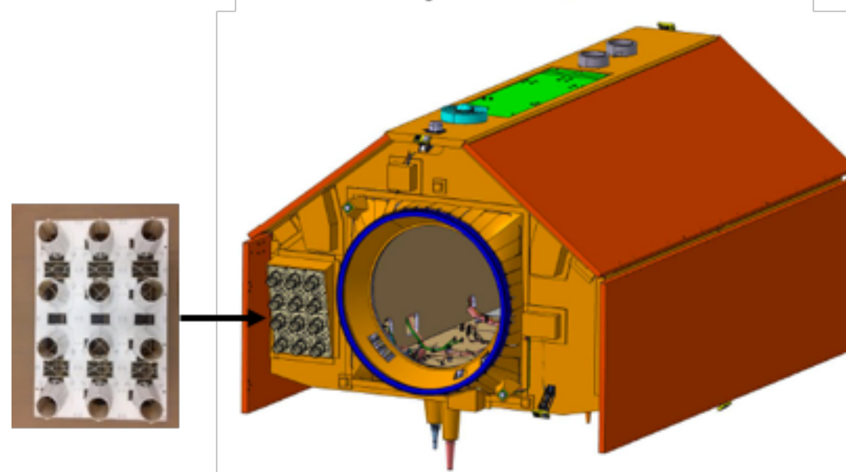


The Fore RO antenna consists of 3 subarrays of 2 helices with max gain at boresite.

The Aft RO antenna consists of 3 subarrays of 4 helices with max gain at 22 degrees from boresite.

The fore antenna is installed near the radiometer with a 34 degree mechanical tilt.

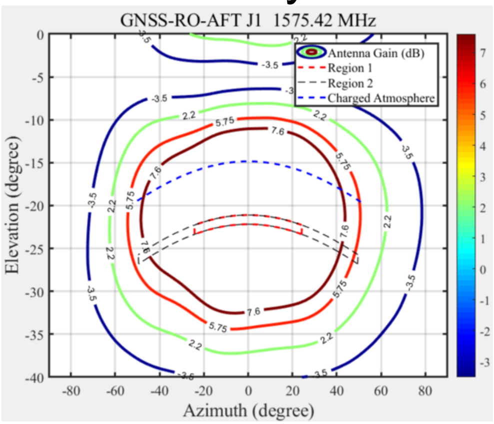


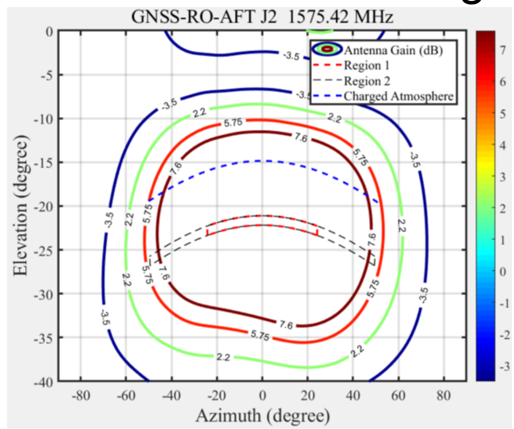


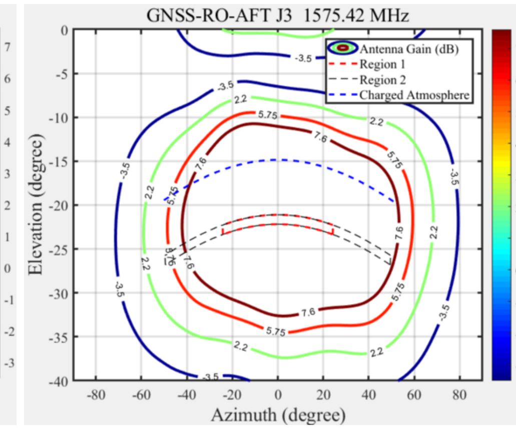
The Aft antenna is installed near the launch ring with a 12 degree mechanical tilt.

Each subarray of the Aft antenna provides +/- 55 deg of azimuth in the neutral and charged atmosphere.

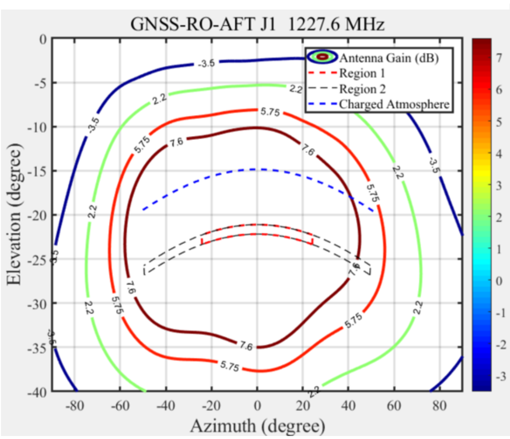
The sub arrays are tuned for GPS L1. Peak gain > 12.0 dBi for each subarray at L1.

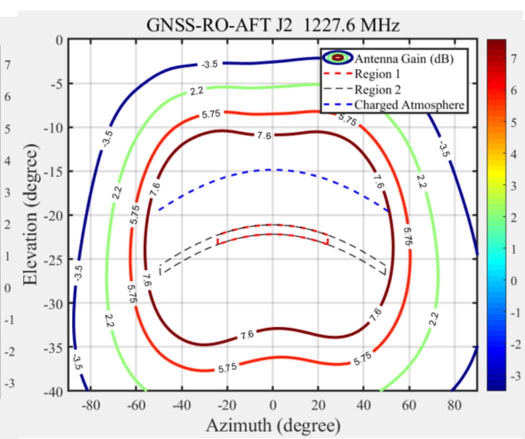


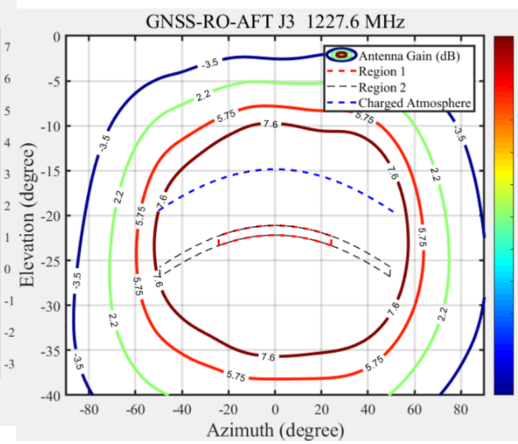


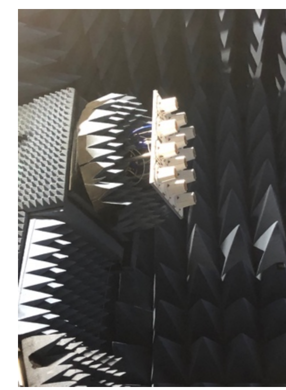


The antenna is wide band to cover GPS L1/L2 and GLONASS FDMA L1/L2





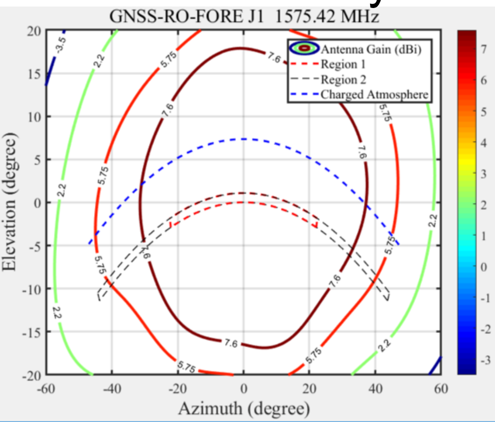


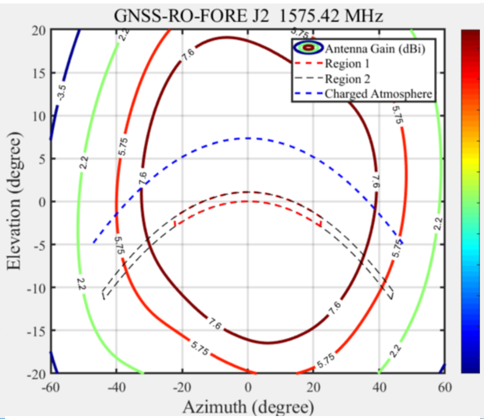


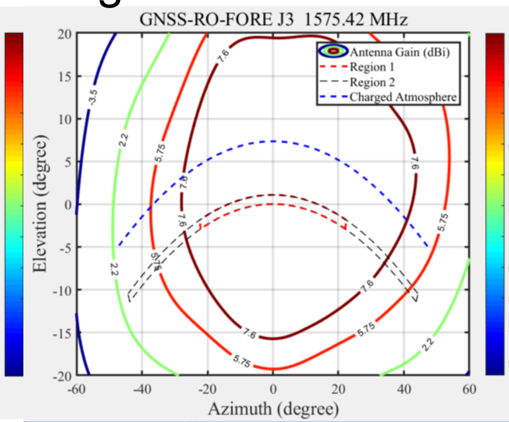
Gains were measured in the anechoic chamber.
The antenna is capable of measuring GPS L5, Galileo E1/E5A, and Beidou signals.

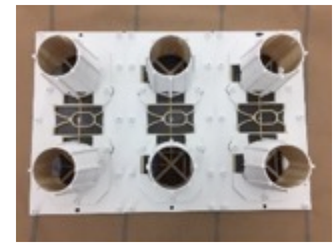
The smaller Fore antenna provides +/- 55 deg of azimuth field of view in the neutral and charged atmosphere and nearly equivalent gain over the region.

The sub arrays are tuned for GPS L1. Peak gain > 10.5 dBi for each subarray at L1.

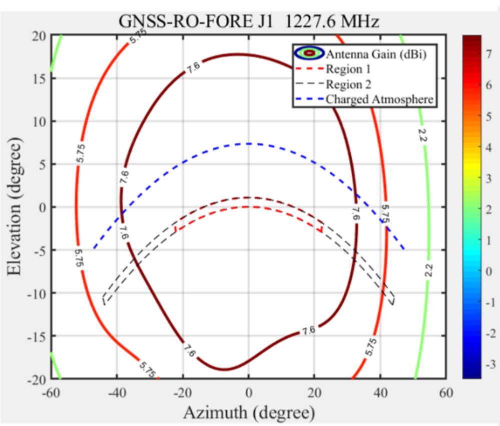


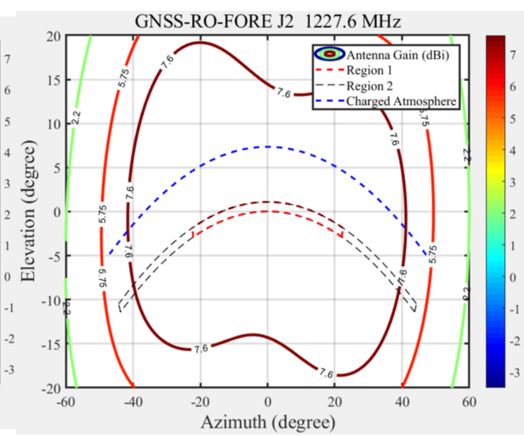


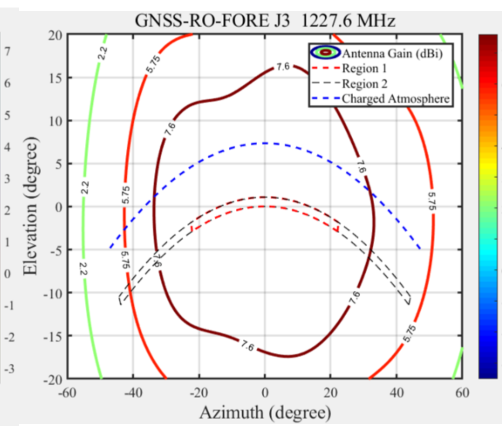




The antenna is wide band to cover GPS L1/L2 and GLONASS FDMA L1/L2

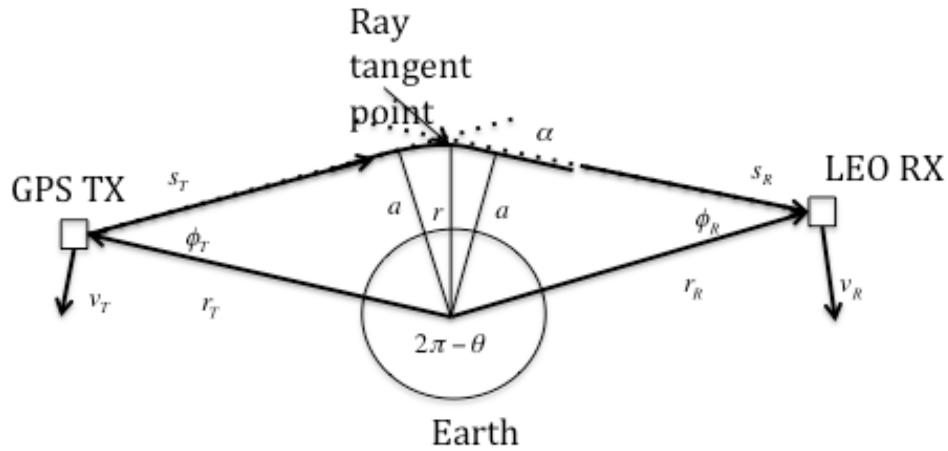






Gains were measured in the anechoic chamber.
The antenna is capable of measuring GPS L5, Galileo E1/E5A, and Beidou signals.

Performance Validation via Analysis and Simulation

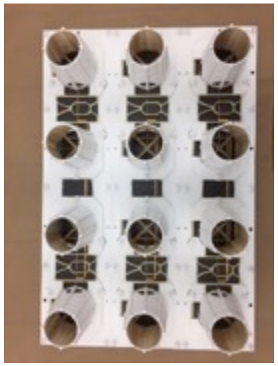


To estimate measurement error requires only a 2D (circular) orbit simulation. Developed by W. Williamson, C. Ao, L. Young.

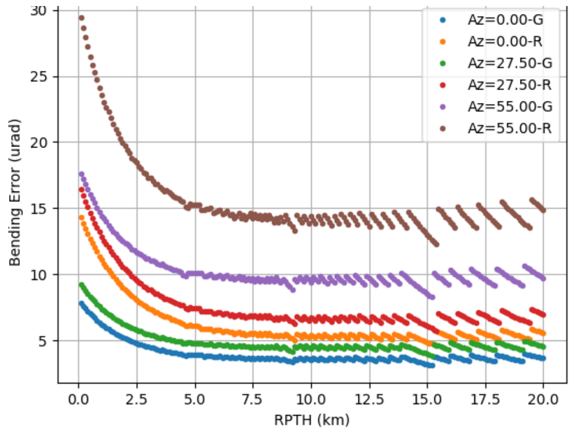
2D Orbit Sim for S-6 and GNSS Constellation → Atmosphere model → Antenna model (Gain and thermal noise as a function of azimuth and elevation) → Receiver Model (NF, tracking errors for dual frequency receivers) → Measurement Error

- **2D Orbit Sim for S-6 and GNSS Constellation:** Assumes circular orbits. Use orbit altitude as input parameter. ***Using on orbit power.***
- **Atmosphere model:** Used Eumetsat provided profiles. *Used ray tracing algorithm to derive bending angles.*
- **Antenna model:** Azimuth used as an input parameter. Uses Friis equation and atmosphere loss to calculate received signal to noise ratio.
- **Receiver Model:** NF and GNSS frequencies define code and phase tracking performance.
- **Measurement Error:** Bending angle error calculated.

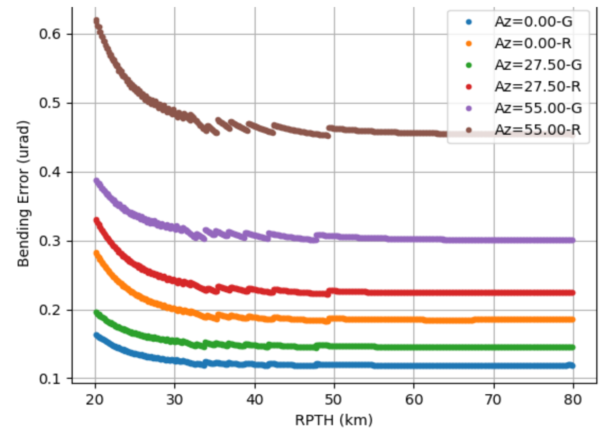
The simulation study provides an estimate of the error for each antenna with beam forming turned on

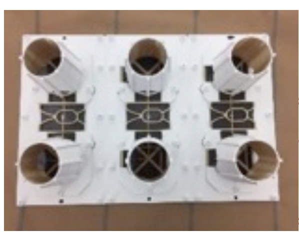


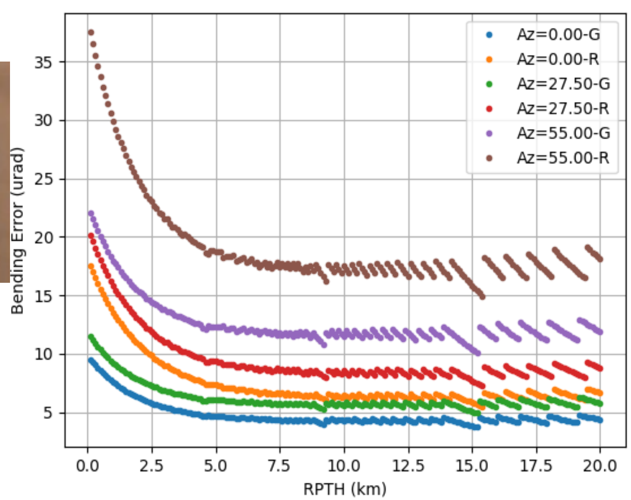
RPTH 0 – 20 km assumed
150m vertical resolution

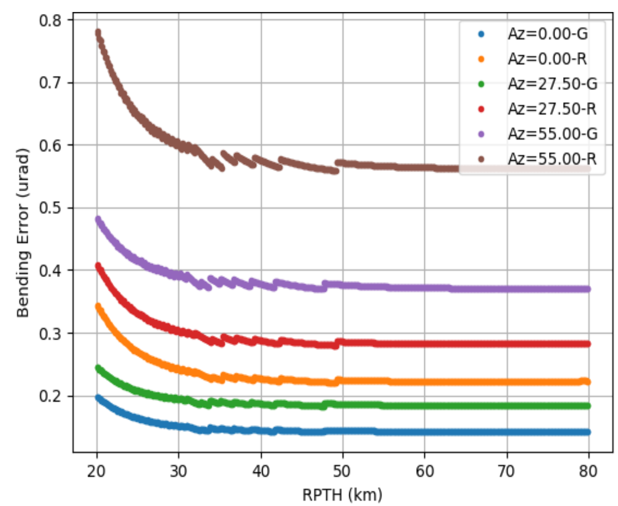


RPTH 20 – 60 km assumed
1.5 km vertical resolution





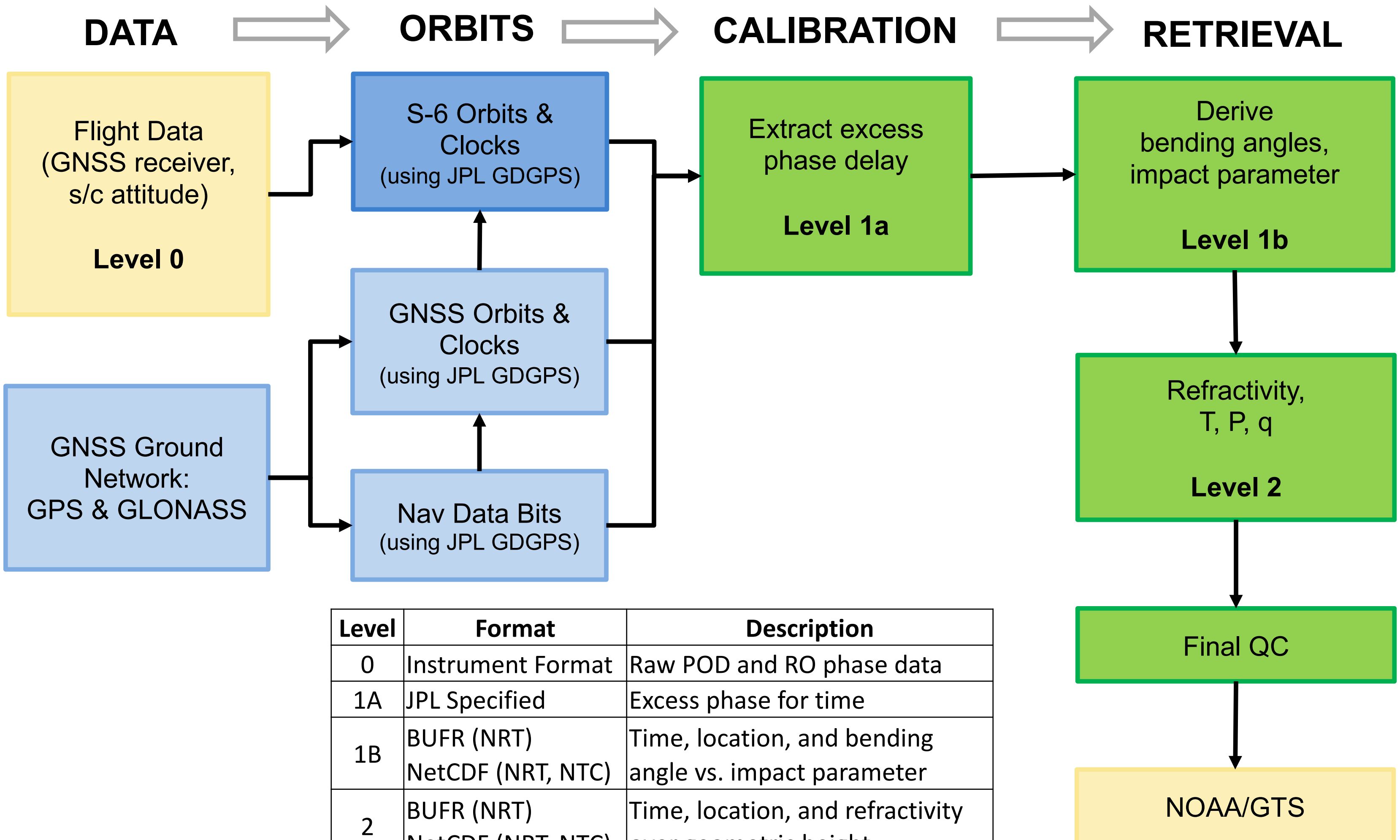




Assumes zero differencing, Historical GPS power, ICD GLONASS power, beam forming, exponential atmosphere.

JPL will provide data near real time data products for weather forecasting.

Sentinel-6 will leverage algorithms from JPL's autonomous legacy RO processing system, which has processed data from multiple missions.



Level	Format	Description
0	Instrument Format	Raw POD and RO phase data
1A	JPL Specified	Excess phase for time
1B	BUFR (NRT) NetCDF (NRT, NTC)	Time, location, and bending angle vs. impact parameter
2	BUFR (NRT) NetCDF (NRT, NTC)	Time, location, and refractivity over geometric height

Summary

- Sentinel-6 will provide continuity of radio occultation data from 2021-2031 using two different spacecraft.
  - Both spacecraft are in fabrication
- The GNSS-RO instrument is based on the Cosmic-2 instrument
  - Same electronics and software capability.
  - Similar antennas with wide field of view.
  - Performance is expected to be as good as Cosmic-2.
- Data processing for the mission:
  - Near Real Time (NRT) products will be generated by JPL and distributed by NOAA on the GTS for weather forecasting.
  - Non Time Critical (NTC) data products will be generated by EUMETSAT & JPL and available for climate studies and research using improved orbit and clock data at ROM SAF and NASA's GES DISC archive.
- Sentinel-6 will provide 20%-25% of its occultations above 40° latitude (N and S) and will provide 100% of the global occultations at certain local times in this latitude range

Acknowledgements

- This work was funded by NASA.

- Special thanks to the NASA JPL Sentinel-6 Project Team:
  - Parag Vaze (PM), John Oswald (DPM), Mike Kilzer (SE), Alex Murray (PLSE), Guy Zohar (PLSE), Shawn Kang (MAM).

- Special thanks to ESA and Airbus for providing an excellent spacecraft.