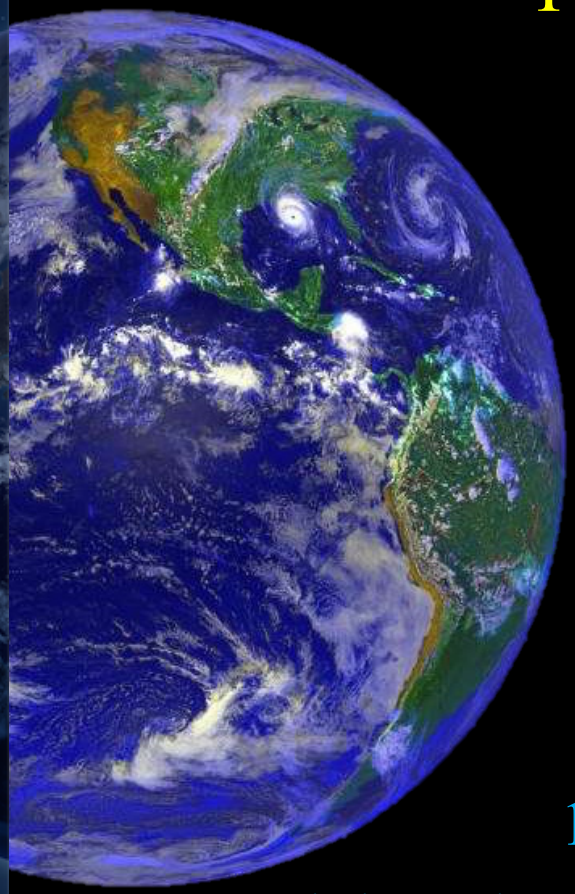
Sentinel-6 Mission: US Payload and Performance



Parag Vaze
John Oswald

14th May 2019

Living Planet Symposium

Milan, Italy

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Sentinel-6 (S6) Mission Overview

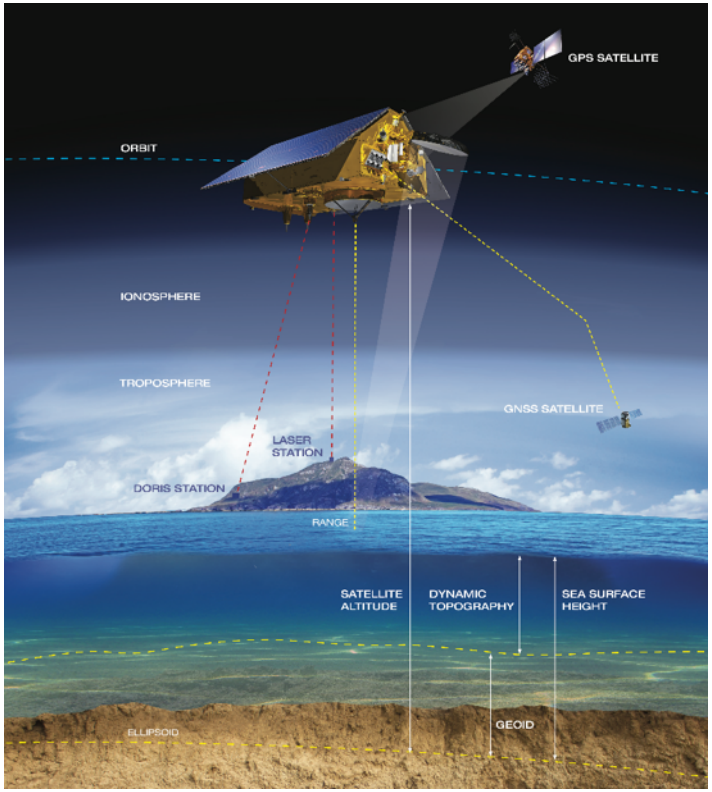
Mission Objectives

- 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)

NASA responsible items in BLUE



Mission Overview

- Target Launch Dates: Nov 2020 & (tbd) 2025
- Launch Vehicle: SX F9 for S6-A
- Project: Cat II
- Risk Class: B for (AMR-C & LRA); C for GNSS-RO
- Spacecraft Bus (Airbus: Cryosat Heritage)
- Mission life of 5 ½ years (goal of 7 ½ years)
- 1336 km Orbit, 66° Inclination

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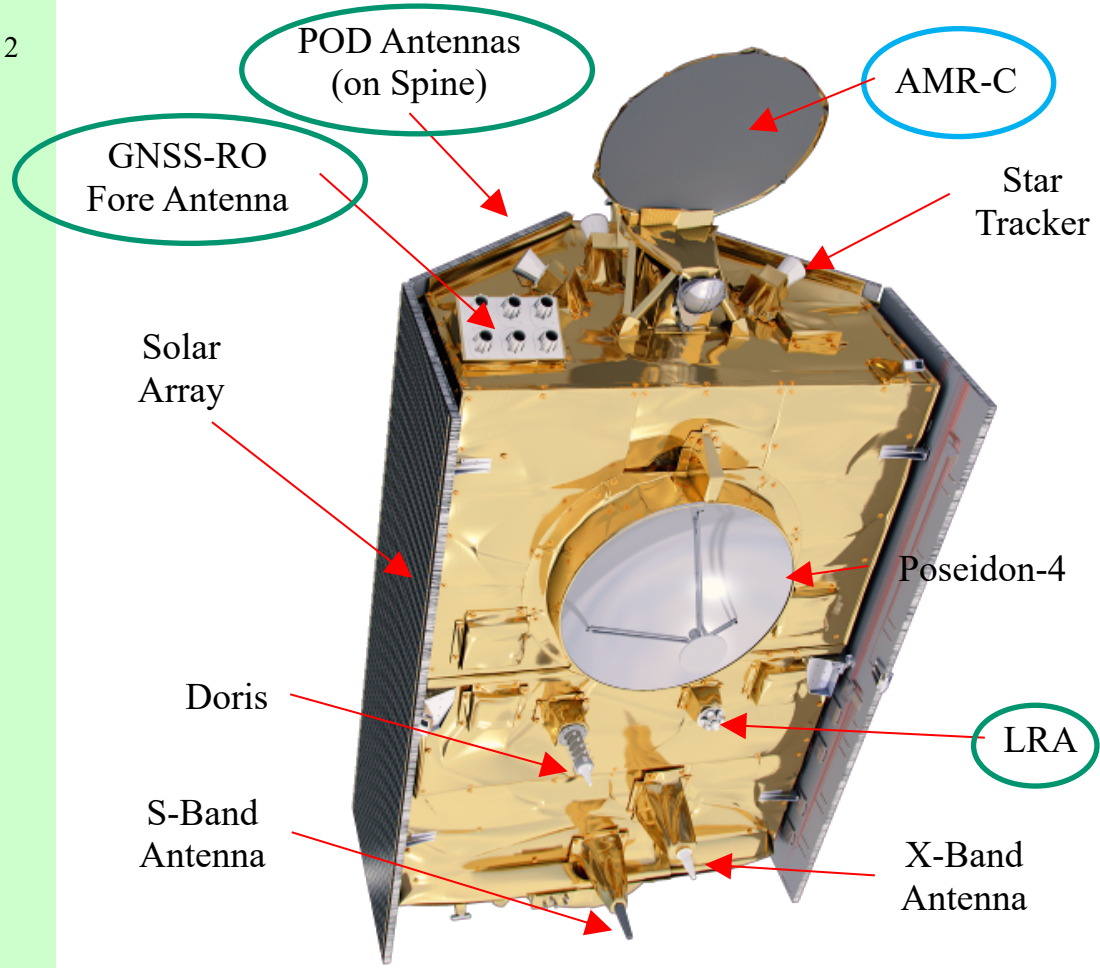
Flight System Overview

- Jason-CS mission implemented by two Sentinel-6 satellites.
- Series of 2 satellites, each with 5.5 years nominal lifetime + 2 years consumables.
- Ocean Topography as Primary Mission.
- Radio Occultation as Secondary Mission.
- Instruments:
  - Poseidon-4 Radar Altimeter
    - Heritage from Jason-3 and Sentinel-3
    - Ku and C-band
    - "Interleaved" SAR mode (SAR + LRM simultaneously)
  - AMR-C Microwave Radiometer
    - Jason-2/3 heritage
    - "Climate Quality" through additional calibration mechanism
  - Precise Orbit Determination
    - GNSS-POD Receiver (Sentinel-3 heritage)
    - DORIS Receiver (Jason-2/3 and Sentinel-3 heritage)
    - LRA Laser Reflector (Jason-2/3 heritage)
  - Radio Occultation
    - GNSS-RO Receiver (COSMIC-2 heritage)
- Launch Vehicle: SpaceX Falcon 9



NASA contributions in BLUE text

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AMR-C Instrument Overview

- Measures single polarization, radiometric brightness temperatures to provide “wet” tropospheric path delay correction for the Altimeter range measurement which is critical to meet science requirements.
- Same basic functional and radiometric performance requirements as OSTM, Jason-3, and SWOT AMR with some mission-unique enhancements.
  - Traditional (Jason-2/3) three frequency (18.7, 23.8, 34 GHz) radiometer (heritage architecture).
  - Enhanced science objective to measure path delay with absolute stability of 1mm/year (was goal on Jason-3 to a requirement). This drives the addition of a on-board Supplemental Calibration System (SCS).
  - Experimental addition of three high-frequency (90, 130, and 168 GHz) channels (as tech demo, non-mission critical). This High Resolution Microwave Radiometer (HRMR) provides high resolution path delay correction in coastal regions where heritage AMR measurements are degraded by land contamination.

Jason-3 AMR

S6 AMR-C

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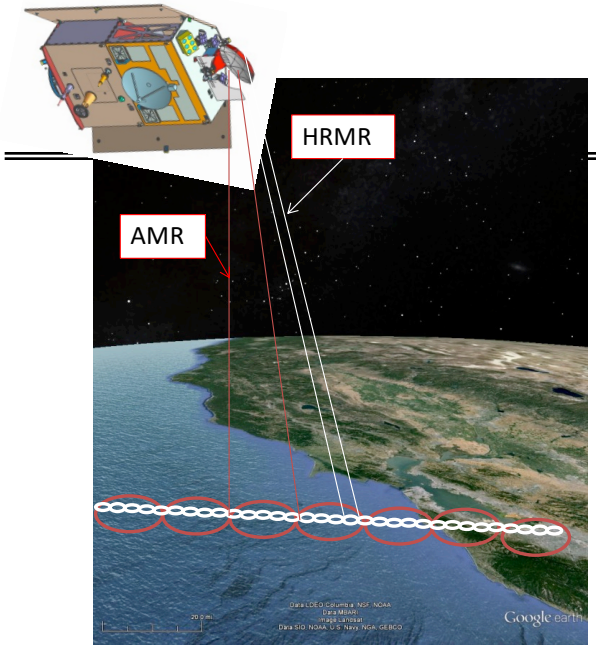
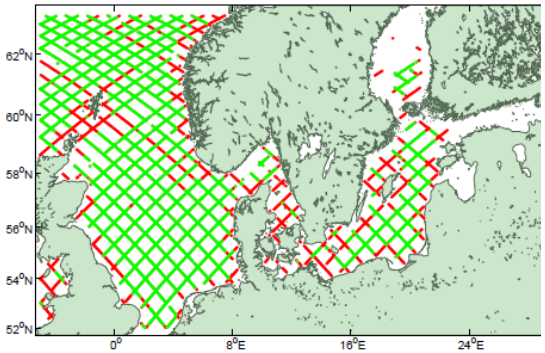
HRMR - Coastal Altimetry





Performance *Goal*:
Measure the wet tropospheric path delay of the nadir altimeter signal over ocean with an objective uncertainty of *1.0 cm* within 5-50km of the coast

Measure the relative change in brightness temperature at 90, 130 and 168 GHz over 60s with an uncertainty of 0.2K

- Experimental high frequency radiometer (90, 130 & 168 GHz) integrated into classical AMR (18, 23, 34 GHz) structure sharing the main 1-m reflector
- Objective to measure wet tropospheric Path Delay to better than 1 cm with ~5x smaller spatial footprint (compared to AMR)
  - Complements high-resolution radar altimeter on-board S6 for improved characterization of important coastal processes (e.g. coastal currents, upwelling, estuaries)
  - No formal performance requirements for HRMR; only goals
- HRMR expected to achieve better than 0.7 cm Path Delay correction

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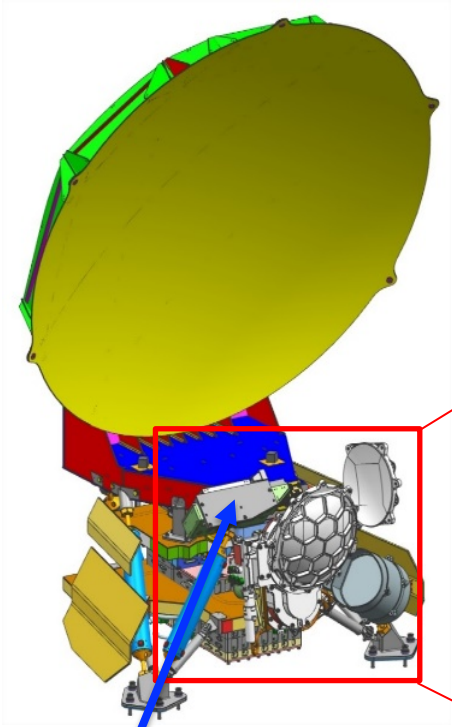
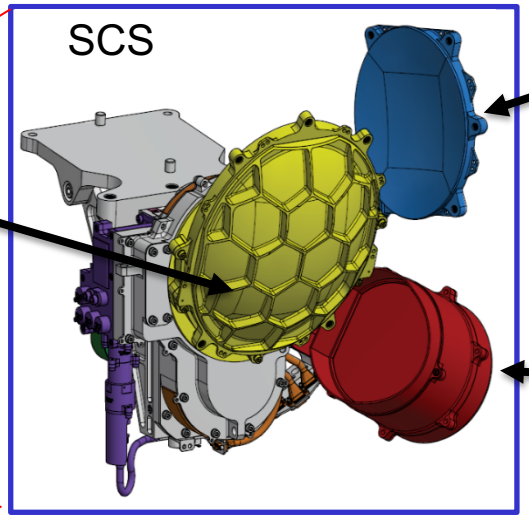
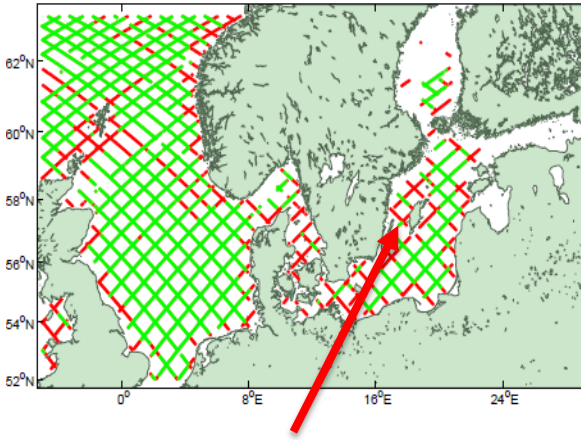
Mission Enhancements: AMR-C
Climate Quality



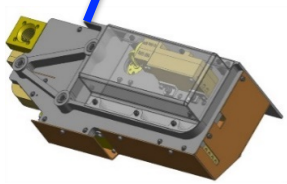
Provides wet tropospheric path delay (Pd) correction by way of heritage performance as Jason-3 with 18.7, 23.8 and 34.0 GHz bands

New On-board calibrator (**SCS**) redirects beam to provide 2-point (warm, cold) stable reference to meet new requirement to maintain path delay drift correction to less than 0.7 mm/year (was a goal for Jason-3)





HRMR new measurement coverage



High Resolution Microwave Radiometer (HRMR) *All new*

HRMR (High Resolution Microwave Radiometer): Complements the High Res Alt SAR mode

- High-frequency channels (90,130,168 GHz) demonstrate capability of high-frequency radiometer for extending the wet path delay measurement into the coastal zone

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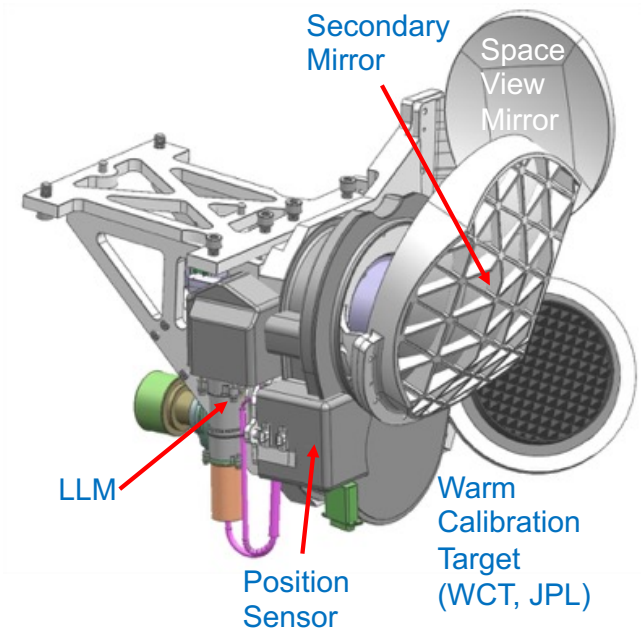
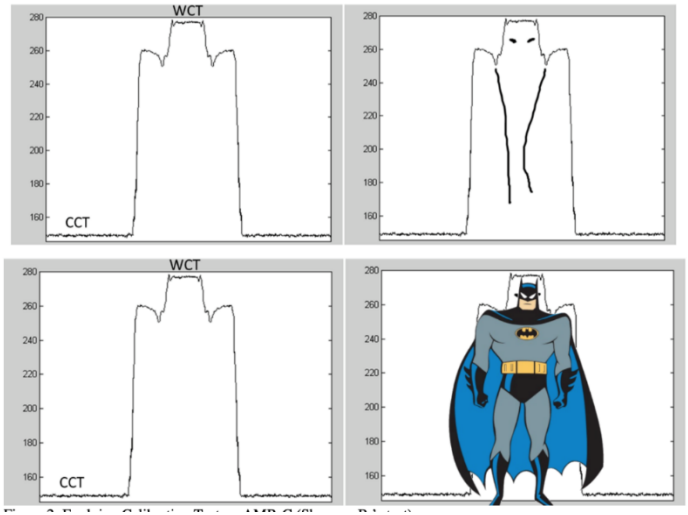
Supplemental Calibration System (SCS)

- SCS introduced as a significant upgrade to heritage AMR's enabling on-board calibration
- A secondary reflector is connected to a drive system to steer the instrument beam from the science position (nadir-pointing) through a cold space mirror, to a warm target, and then back again to science position
- Calibrations are planned every 5 days in orbit to support S6's enhanced mean sea level measurement stability requirement over much shorter time-scales (< 60 days) than what has ever been achievable on prior Jason satellites
- SCS has been fully demonstrated to meet calibration objectives during recent Instrument TVAC testing





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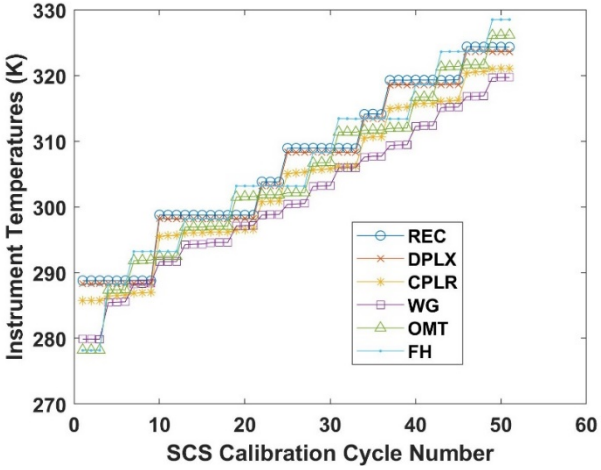
AMR Performance

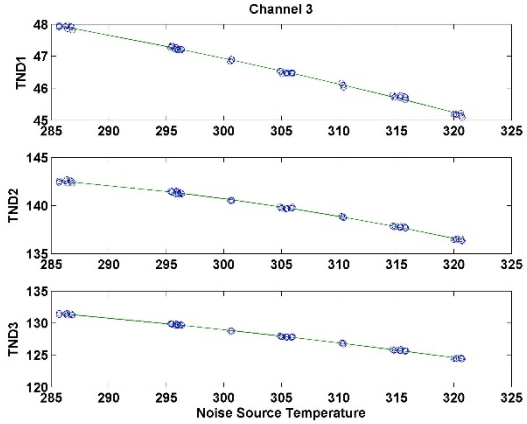
- Introduced variable gradients along radiometer front-end to characterize path loss
- SCS used to cycle between warm calibration target and cryogenic absorber at each plateau
- **Verifies measurement noise and antenna temperature calibration error terms**

- *Calibration residuals in-family with JA2/JA3 AMR*

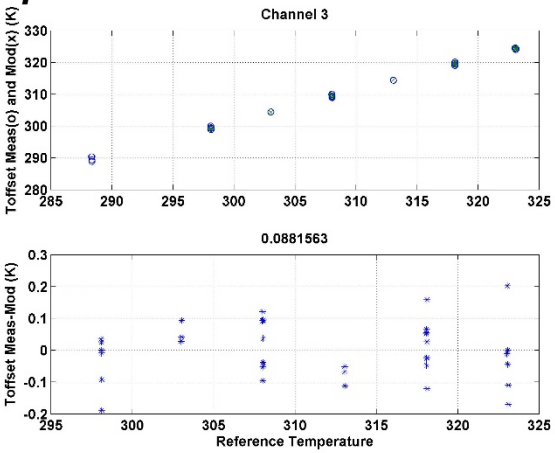


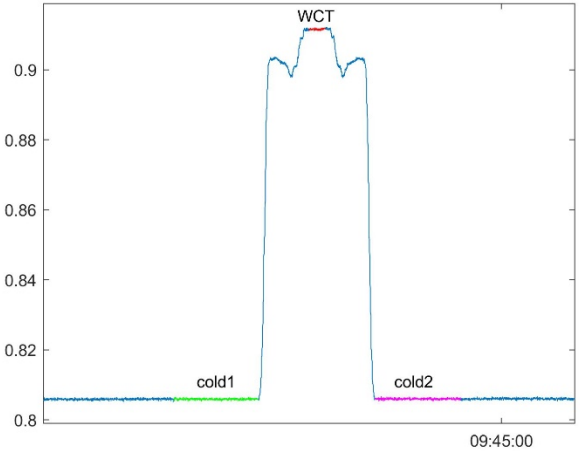
Front-end temperatures

Noise diode brightness vs Temperature



Front-end correction over thermal plateaus





Radiometer voltage during calibration cycle

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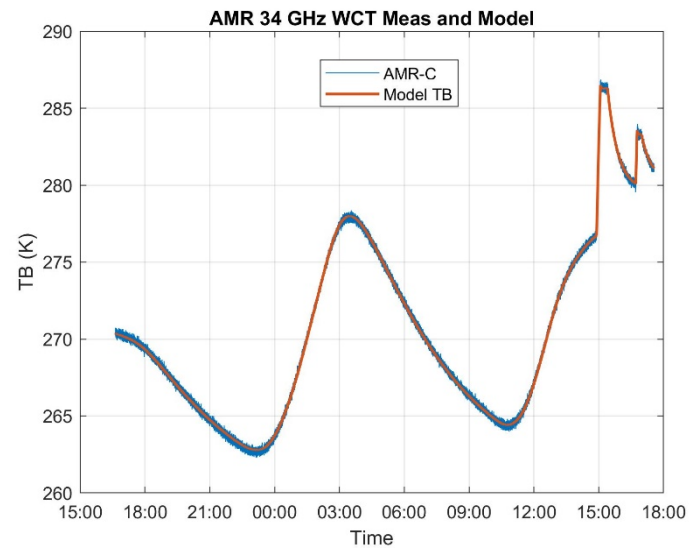
AMR Error Budget (Long Term Drift)

- Warm target TB uncertainty updated to include temperature knowledge characterization from TVAC data
- Cold sky reflector pattern uncertainty analysis verified by range test, slew time updated for final SCS speed
- SCS predicted to provide long term stability to 0.07 K/yr relative to 0.1 K/yr requirement based on 5-day SCS calibration cadence



Measured and modeled warm target TB during TVAC characterization test

TB Stability Error Budget	Error Allocation	CBE	Basis
Cold Target TB Uncertainty	0.2 K	0.1 K	Analysis, supported antenna model/range data
Hot Target TB Uncertainty	0.2 K	0.15 K	Target return loss meas, TVAC characterization, thermal predicts
Maximum Cold Target TB	100 K	3.1 K	Analysis, supported antenna model/range data
Minimum Hot Target TB	200 K	220 K	Thermal analysis
Internal Calibration RMS Stability	0.2 K	0.1 K	Thermal repeatability testing & Jason-2/Jason-3 in-orbit stability
Calibration Frequency	At least once per 5 days	Qualified to once every 2 days	
Antenna pattern correction (seasonal component)	0.03 K	0.03 K	Analysis, supported antenna model/range data

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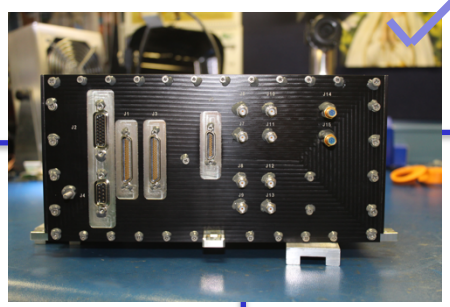
The GNSS-RO instrument will provide radio occultation measurements used for weather prediction.

- Installed on S/C at Airbus in Oct, 2018
- Shipping to Airbus March 2019

Zenith facing Precise Orbit Determination antenna purchased from RUAG

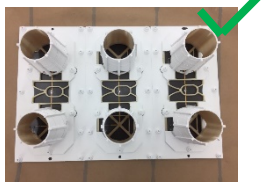
Single Band Pass Filter and Low Noise Amplifier Assembly.

JPL provides RF cables.



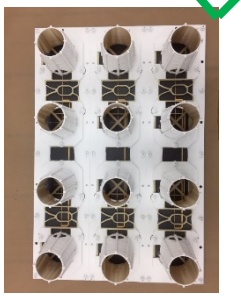
Receiver electronics

Triple BPF/LNA Assembly. Same elements as single BPF/LNA on one plate.



Fore RO Antenna
(Half sized Aft RO Antenna).

Airbus to provide power, 1553, and RS-422 (test) cable.



Aft RO antenna:
Based on Cosmic-2 with printed circuit board combiner

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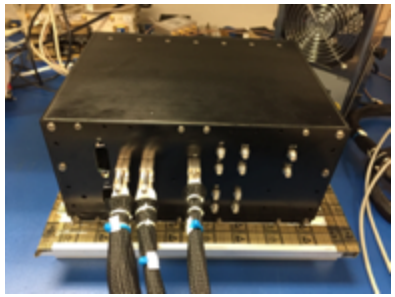
GNSS-RO Status and LRA Status

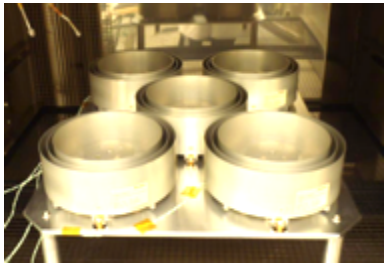
GNSS-RO (Radio Occultation measurements for numerical weather modelling)

- POD and RO Antennas complete
- GNSS receiver electronics built and flight software testing in-progress
- Delivery by end 2018



GNSS Receiver Electronics

GNSS RO Antenna



GNSS POD Antennas

Laser Retroreflector Array (LRA): Complete & ready for installation on spacecraft

SpaceX Launcher development well underway. Completing early interface and mission analysis

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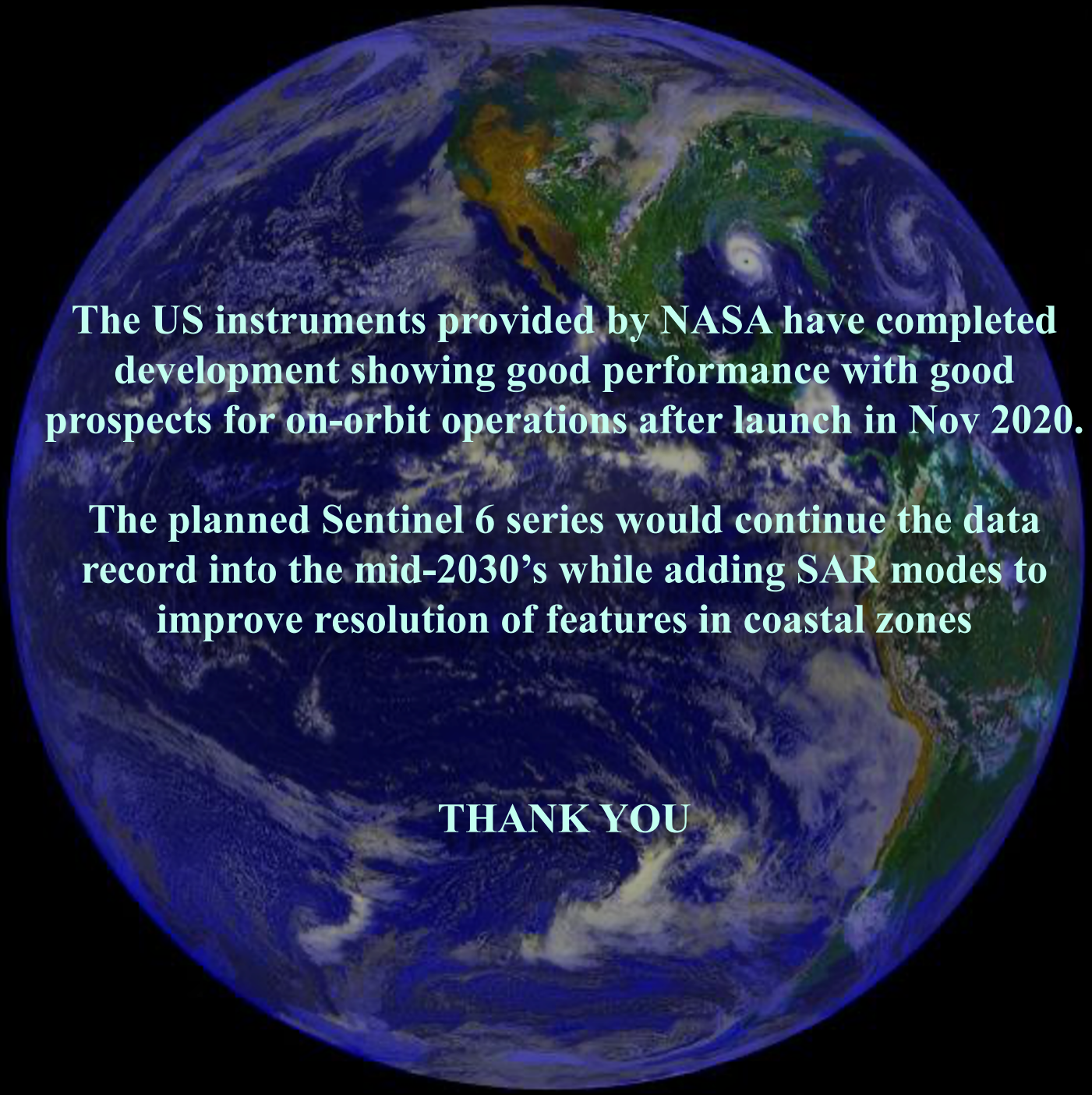

The US instruments provided by NASA have completed development showing good performance with good prospects for on-orbit operations after launch in Nov 2020.

The planned Sentinel 6 series would continue the data record into the mid-2030's while adding SAR modes to improve resolution of features in coastal zones

THANK YOU