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The NASA Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) Mission: Results from the Pathfinder Demonstration and Look Ahead to the Constellation Mission

William J. Blackwell, David Crompton, Andrew Cunningham, Shawn Donnelly, James Eshbaugh, Vincent Leslie, Brian Powers, Nicholas Zorn
Lincoln Laboratory, Massachusetts Institute of Technology
244 Wood St. Lexington, MA 02421; 781-981-7973
WJB@LL.MIT.EDU

Kerri Cahoy, Amelia Gagnon, Samantha Hasler
Department of Aeronautics and Astronautics, Massachusetts Institute of Technology

Daniel Adams, Owen Hart, Jostein Johansen
Kongsberg Satellite Services AS (KSAT)

Ian Murray
Astra Space

Benjamin Kim, William McCarty
NASA Headquarters

Garrett Skrobot, Genevieve Taylor
NASA Kennedy Space Center

Stuart Cooke, Michael Grant
NASA Langley Research Center

Scott Braun
NASA Goddard Space Flight Center

ABSTRACT

The NASA Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission will provide nearly all-weather observations of 3-D temperature and humidity, as well as cloud ice and precipitation horizontal structure, at high temporal resolution to conduct high-value science investigations of tropical cyclones. TROPICS will provide rapid-refresh microwave measurements (median refresh rate of approximately 50 minutes for the baseline mission) over the tropics that can be used to observe the thermodynamics of the troposphere and precipitation structure for storm systems at the mesoscale and synoptic scale over the entire storm lifecycle. The TROPICS constellation mission comprises six CubeSats in three low-Earth orbital planes. Each CubeSat will host a high-performance radiometer to provide temperature profiles using seven channels near the 118.75 GHz oxygen absorption line, water vapor profiles using three channels near the 183 GHz water vapor absorption line, imagery in a single channel near 90 GHz for precipitation measurements (when combined with higher resolution water vapor channels), and a single channel at 205 GHz that is more sensitive to precipitation-sized ice particles. TROPICS spatial resolution and measurement sensitivity is comparable with current state-of-the-art observing platforms. Launches for the TROPICS constellation mission are planned in 2022. NASA's Earth System Science Pathfinder (ESSP) Program Office approved the separate TROPICS Pathfinder mission, which launched into a sun-synchronous orbit (2:00pm LTDN, 530 km) on June 30, 2021, in advance of the TROPICS constellation mission as a technology demonstration and risk reduction effort. The TROPICS Pathfinder mission has provided an opportunity to checkout and optimize all mission elements prior to the primary constellation mission. In this paper, we describe the instrument checkout and calibration/validation plans and progress for the TROPICS Pathfinder mission and discuss first light mission results. All spacecraft and radiometer systems are fully operational as of Launch + 11 months.

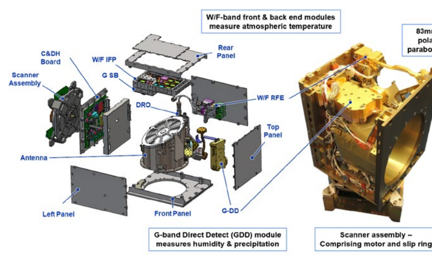
OVERVIEW OF THE TROPICS SPACECRAFT

The 5.4 kg TROPICS flight 3U spacecraft is shown in Fig. 1. The spacecraft bus was developed by Blue Canyon Technologies, and the payload was developed by MIT Lincoln Laboratory. Spacecraft dimensions are approximately 10 x 10 x 36 cm. A full-duplex S-band Innoflight SCR-100 radio is used to downlink data to the ground, where it is processed and relayed to the NASA GES DISC for download. DC power consumption for the radiometer payload and scanning assembly is less than 5 W, permitting 100% duty cycle operation. Dual star trackers provide excellent attitude knowledge, enabling the geolocation uncertainty better than 1/20 of a footprint.

Figure 1. TROPICS satellite (left), showing the rotating payload connected to the satellite bus via a rotary joint. Also shown in the image on the left is the articulating solar array, which rotates (as does the satellite bus) to track the sun to maximize power output. The six satellites that will comprise the constellation are shown on the right. (Photo credit: Blue Canyon Technologies)

DESCRIPTION OF THE TROPICS RADIOMETER INSTRUMENT

The radiometer payload provides observations in 12 channels spanning approximately 90 to 206 GHz. 81 footprints are measured in a swath subtending ±60 degrees from nadir across the satellite track as the payload rotates at 30 RPM. Given the Pathfinder orbit altitude of approximately 530 km, this results in a swath width of almost 2000 km. The Pathfinder was launched into a sun synchronous orbit with local time of the descending node of approximately 2:00pm. The calibration of the radiometer is achieved by: 1) injecting noise (generated by a weakly coupled noise diode) into the radiometer front end, and 2) measuring the cold cosmic background radiation. These calibrations are performed once per payload scan (every 2 seconds). The TROPICS radiometer payload is shown in Fig. 2. Key components are highlighted, and spectral/spatial properties are given. The spatial resolution of each channel (at nadir) is given in Fig. 2 for the nominal constellation orbital altitude of 550 km (slightly higher than the Pathfinder orbit of 530 km). The constellation orbits will not be sun synchronous, instead, there will be three, equally-spaced (in RAAN) orbits, each with inclination of 30°. Each constellation orbit will contain two satellites. The G-band (180-206 GHz) channels exhibit a noise-equivalent delta temperature (NEDT) of 0.4-0.6 K, and the 90-120 GHz channels exhibit an NEDT of 0.6-1.0 K. The NEDT values are generally stable over time, even over frequent radiometer downtime early in the mission when the spacecraft was being commissioned and updated. Radiometer uptime is now routinely 100%, with only infrequent restarts due to radiation single event effects. For example, the radiometer operated 100% of the time in February, 2022 with zero downtime, and this is representative of current performance. Radiometric calibration accuracies, determined by comparing to GEOS-5 atmospheric fields, is also quite good, with deviations less than 1 K for all non-surface-impacted channels and all instrument temperatures. The temperature sounding channels show accuracies of better than 0.6 K, with negligible residual calibration drift over the course of the mission. Scan biases are less than 1 K within scan angles of ±45°. Geolocation accuracies have been determined to be better then 1/20th of a footprint diameter for all channels by comparing a large number of coastline crossings.



Channel	Band	Channel Span (GHz)	Sensor Bandwidth (GHz)	550km Nadir Footprint Diameter (km)
1	W	89.756-90.756, 92.556-93.556	1	27.7
2	F1	114.00-115.00	1	23.1
3	F2	115.55-116.35	0.8	23.1
4	F3	116.35-116.95	0.6	23.1
5	F4	116.95-117.55	0.6	23.1
6	F5	117.55-118.05	0.5	23.1
7	F6	118.05-118.43	0.38	23.1
8	F7	118.43-118.73	0.3	23.1
9	G1	183.41-185.41	2	16.1
10	G2	185.51-187.51	2	16.1
11	G3	189.31-191 .31	2	16.1
12	G4	203.80-205.80	2	15.6

Figure 2. Overview and characteristics of the TROPICS radiometer payload.

OVERVIEW OF THE TROPICS GROUND SEGMENT

Mission data flow is shown in Fig. 3. Data is first downlinked over an S-band link to ground stations operated by Kongsberg Satellite Services (KSAT). Hartebeshtook, South Africa is the primary ground station for the constellation satellites, and the Pathfinder satellite uses Svalbaard as its ground station location. Blue Canyon Technologies operates the Mission Operations Center (MOC), MIT Lincoln Laboratory operates the Science and Payload Operations Center (SPOC), and the University of Wisconsin creates the geophysical data products at the Data Processing Center (DPC).

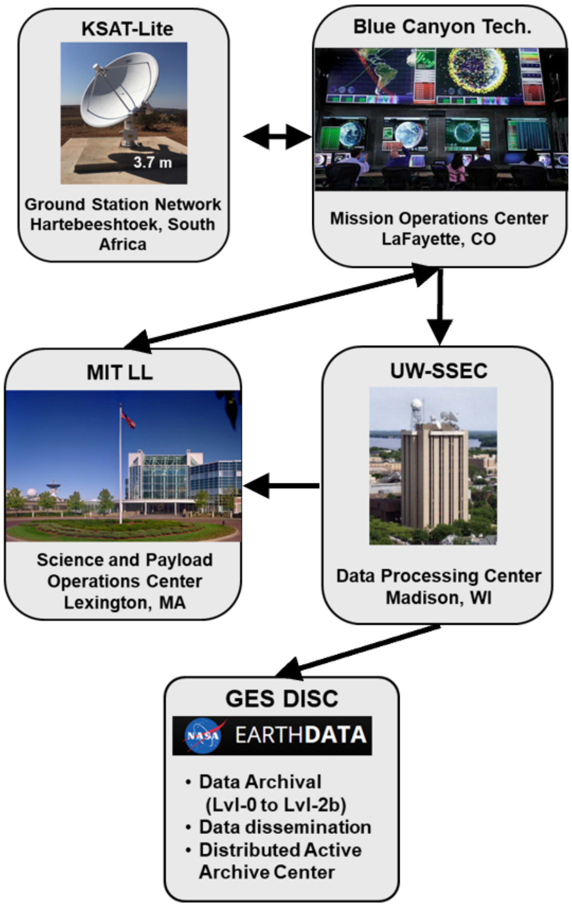


Figure 3. TROPICS mission data flows down from the spacecraft to KSAT-Lite ground stations, through BCT mission operations, to data processing at U. Wisconsin-Madison, and finally out to the generally public through the NASA GES-DISC.

TROPICS PATHFINDER ON-ORBIT COMMISSIONING RESULTS

The TROPICS Pathfinder satellite has been operating almost continuously for the last eleven months and has collected many extraordinary images of tropical cyclones. Of particular interest is imagery collected by the 205 GHz channel, the first of its kind on a spaceborne cross-track sounder. For example, Super Typhoon Mindulle was observed by the TROPICS Pathfinder on Sep 26, 2021, as shown in Fig. 4. Very clear and distinct storm structure is revealed by the TROPICS Pathfinder observations at 205 GHz, including rain bands and eyewall. Another example is Cyclone Batsirai, shown in Fig. 5 as observed by TROPICS Pathfinder at 205 GHz. Again, detailed storm structure is revealed in these images, showing a relatively large, clear eye and spiral rain band structure. Finally, Fig. 6 shows Cyclone Gombe observed on March 10, 2022 is it made landfall near Madagascar.

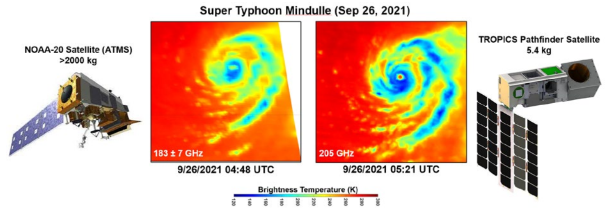


Figure 4. Super Typhoon Mindulle as observed by the Advanced Technology Microwave Sounder (ATMS) on the NOAA-20 satellite and by the TROPICS Pathfinder satellite.

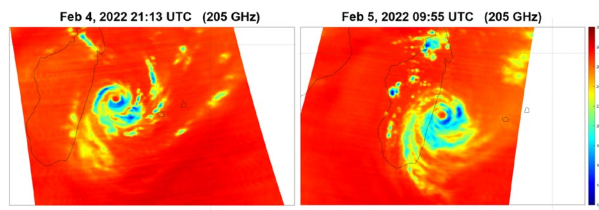


Figure 5. Cyclone Batsirai as observed by the TROPICS Pathfinder at 205 GHz on February 4 and 5, 2022. The colorbar indicates the brightness temperature in units of Kelvins.

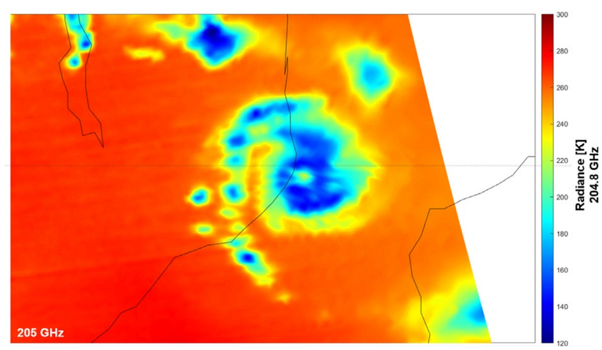


Figure 6. Cyclone Gombe as observed by the TROPICS Pathfinder at 205 GHz on March 10, 2022 (22:24 UTC).

SUMMARY AND LOOK AHEAD TO THE CONSTELLATION MISSION

The TROPICS Pathfinder precursor mission has demonstrated exceptional capabilities of the radiometers that will fly as part of the six-satellite TROPICS constellation later in 2022. Spacecraft performance and reliability has been demonstrated, as has radiometer calibration, stability, and geolocation. All aspects of the ground and data processing elements are fully checked out and ready for implementation as part of the constellation mission.

The six constellation vehicles are scheduled to be launched into three separate orbital planes by Astra Rocket 3.3 vehicles (see Fig. 7). The orbit altitude will be approximately 550 km and the inclination will be 30 degrees. The three orbital planes will be approximately equally space in Right Ascension of the Ascending Node (RAAN).

Figure 7. Photo of the three Astra Rocket 3.3 launch vehicles that will shuttle the six TROPICS satellites into orbit (Photo credit: Astra Space).

We expect the new, high-revisit capabilities of TROPICS with performance demonstrated by Pathfinder will provide invaluable information to better understand and predict severe storms, and many similar systems are expected to be developed and deployed to further extend and improve the record of small-satellite microwave sounding, started by the launch of the MicroMAS-2 mission in January 2018. These new observations will complement and augment the planned operational enterprise of microwave observations by NOAA, EUMETSAT, and others.

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