TROPICAL CYCLONE OBSERVATIONS USING A CUBESAT CONSTELLATION: RECENT RESULTS FROM THE NASA TROPICS MISSION

W. Blackwell, A. Cunningham, M. Diliberto, S. Donnelly, V. Leslie, G. Perras, J. Prince, and N. Zorn

Lincoln Laboratory, Massachusetts Institute of Technology, 244 Wood St, Lexington, MA 02421

ABSTRACT

CubeSat and SmallSat constellations are transforming the way data are collected and communicated in space, and the cost and schedule barriers to the development, launch, and operations of these high-performance systems have been substantially lowered in recent years. Here we present the NASA TROPICS Earth Venture (EVI-3) CubeSat constellation, which is currently providing new microwave observations of tropical cyclones at unprecedented revisit rates. Four satellites were successfully launched into orbit on May 8 and May 25, 2023 (two 3U CubeSats in each of the two launches), and TROPICS is now providing 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 is providing rapid-refresh microwave measurements (median refresh rate of approximately 60 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 [1].

1 INTRODUCTION

The TROPICS constellation mission comprises four 3U CubeSats (5.4 kg each) in two low-Earth orbital planes inclined at approximately 33 degrees with a 550-km altitude. Each CubeSat comprises a Blue Canyon Technologies bus and a high-performance radiometer payload 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. Data is downlinked to the ground via the KSAT-Lite ground network with latencies better than one hour. The TROPICS Pathfinder satellite launched into a sun-synchronous orbit (2pm descending node) on June 30, 2021, in advance of the TROPICS constellation mission as a technology demonstration and risk reduction effort. The TROPICS Pathfinder satellite has yielded useful data for 30+ months of operation (up until December 2023) and has provided an opportunity to checkout and optimize all mission elements prior to the primary constellation mission.

2 OVERVIEW OF THE TROPICS OBSERVATORY

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 geolocation uncertainty better than a small fraction of a footprint as demonstrated by the Pathfinder satellite and shown in Figure 2.

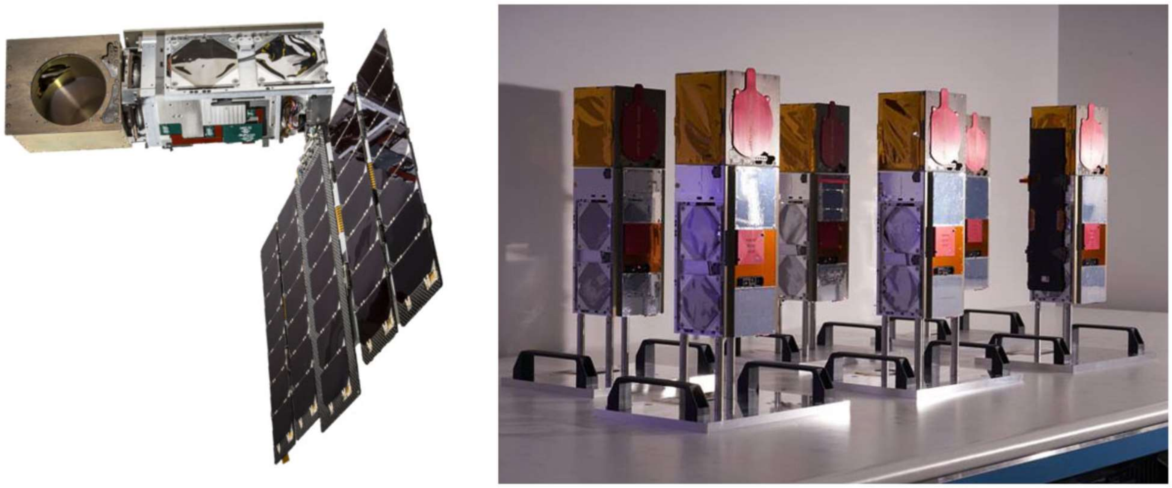


Figure 1. TROPICS Pathfinder satellite (left), showing the rotating payload connected to the satellite bus via a rotary joint. Also shown in the image on the left is the articulating solar array, which rotates (as does the satellite bus) to track the sun to maximize power output. The six satellites delivered for the constellation are shown on the right. Two of the satellites were lost in a launch failure in June 2022. (Photo credit: Blue Canyon Technologies)

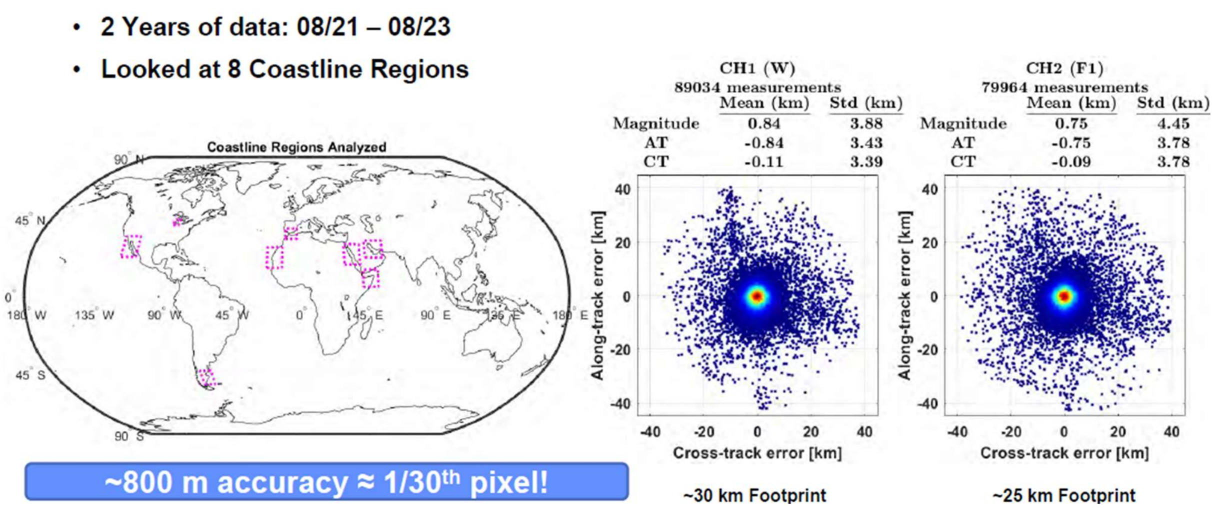
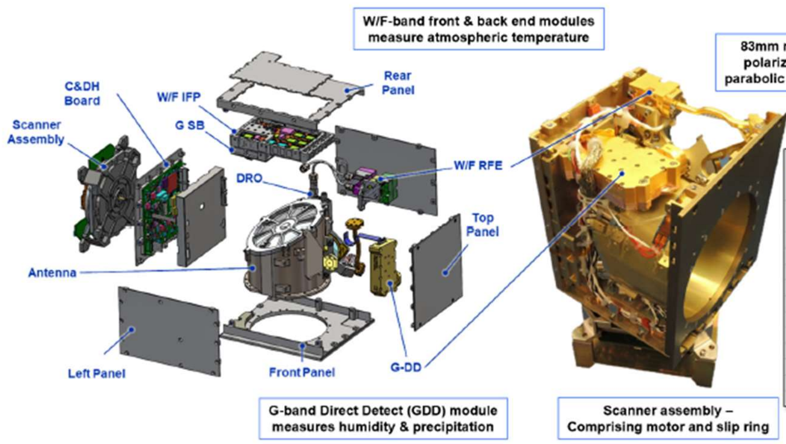


Figure 2. Observations of coast-line crossings made by the TROPICS Pathfinder satellite over two years were used to assess the geolocation performance, which has been excellent.

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 TROPICS orbit altitude of approximately 530 km, this results in a swath width of approximately 2000 km. 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. 3. Key components are highlighted, and spectral/spatial properties are given. The spatial resolution of each channel (at nadir) is given in Fig. 3 for the nominal constellation orbital altitude of 550 km (slightly higher than the Pathfinder orbit of 530 km). The constellation orbits are not sun synchronous, instead, there are two, equally-spaced (in RAAN) orbits, each with inclination of 33°. Each constellation orbit contains 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 down-time early in the mission when the spacecraft was being commissioned and updated. Radiometer uptime has been routinely near 100%, with only infrequent restarts due to radiation single event effects. Radiometric calibration accuracies, determined by comparing to GEOS-5 atmospheric fields, is also quite good, with deviations less than 1 K for all nonsurface-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°.



Channel	Band	Channel Span (GHz)	Sensor Bandwidth (GHz)	550km Nadir Footprint Diameter (km)
1	W	89.756-90.756, 92.556-92.556	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 3. Overview and characteristics of the TROPICS radiometer payload.

3 SELECTED TROPICS RESULTS

Hundreds of high-resolution images of tropical cyclones have been captured thus far by the TROPICS mission, revealing detailed structure of the eyewall and surrounding rain bands. The new 205-GHz channel in particular (together with a traditional channel near 92 GHz) is providing new information on the inner storm structure, and, coupled with the relatively frequent revisit and low downlink latency, is already informing tropical cyclone analysis at operational centers. Two examples of the new utility provided by the 205-GHz channel are shown in Fig. 4, where the TROPICS Pathfinder 205-GHz imagery is compared to the highest frequency channel on the NOAA Advanced Technology Microwave Sounder (ATMS), 183 ±7 GHz. The 205-GHz channel responds much more strongly to scattering from cloud hydrometeors (indicated by cold/blue regions in the figure) and therefore clearly reveals more structural details at higher spatial resolution than does the ATMS imagery. The high spatial resolution and sensitivity of the TROPICS 205-GHz channel has resolved many interested tropical cyclone structural features, including eyewall replacement cycles.

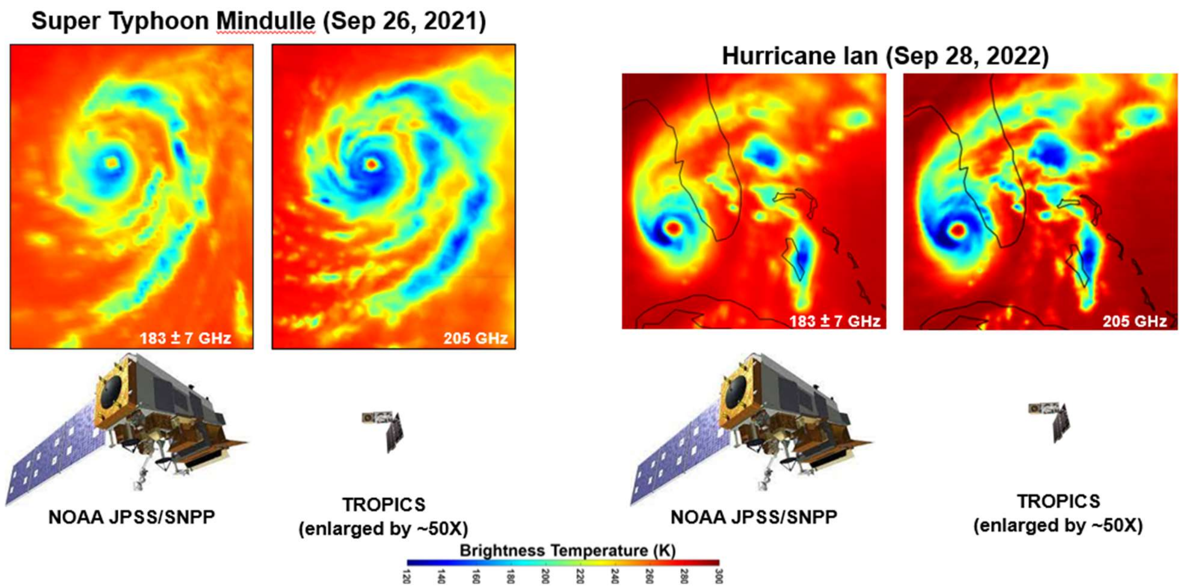


Figure 4. Comparisons of TROPICS Pathfinder 205-GHz tropical cyclone imagery with ATMS 183 ±7 GHz imagery (one of 22 ATMS channels) over Super Typhoon Mindulle (2021) and Hurricane Ian (2022) with similar temporal coincidence. The 205-GHz channel clearly reveals more structural details at higher spatial resolution than does the ATMS imagery.

The TROPICS constellation satellites observed Hurricane Idalia as it made landfall on the Gulf Coast of Florida on August 30, 2023. Shown in Fig. 5 are three images taken in three successive orbits of the TROPICS-3 satellite.

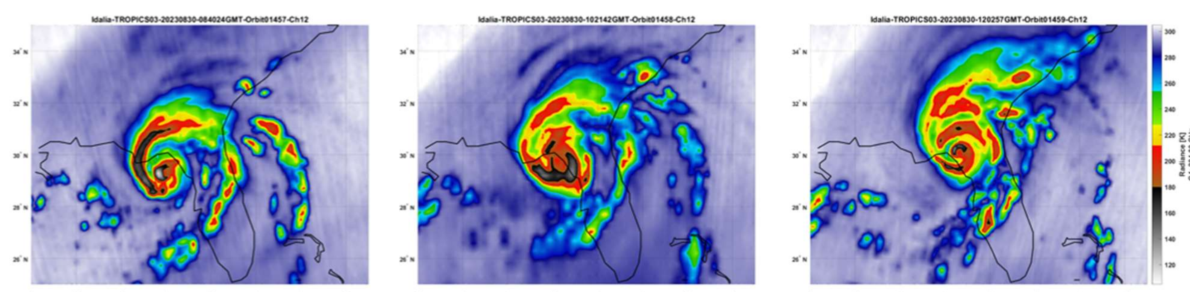


Figure 5. TROPICS constellation observations of Hurricane Idalia making landfall in the Southeastern United States on August 30, 2023. These images taken in rapid succession demonstrate the new capability of TROPICS to capture evolving storm dynamics.

The TROPICS constellation has also made many observations of convective storms [2]. One example is shown in Fig. 6, where convective activity over the Midwestern United States was observed. The figure shows images from four of the TROPICS channels (near 90, 118, 183, and 205 GHz) on March 14, 2024 for a single orbital pass.

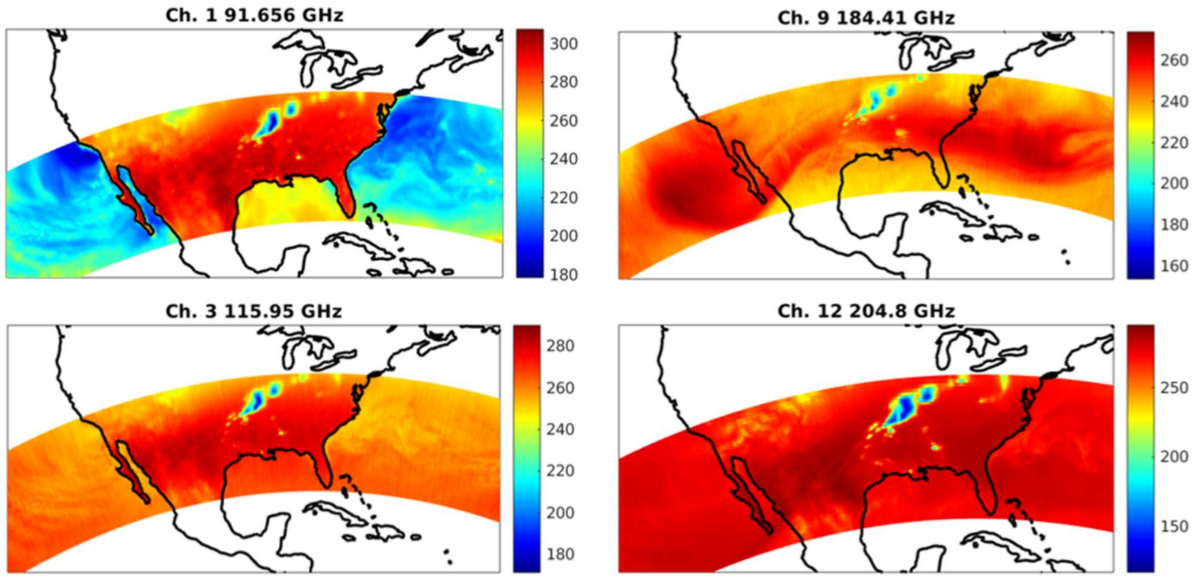


Figure 6. TROPICS Constellation observations of convective activity over the Midwestern United States on March 14, 2024 in four of the 12 TROPICS channels.

4 SUMMARY AND FUTURE OUTLOOK

The TROPICS constellation and Pathfinder data sets are currently undergoing final stages of calibration and validation. Data sets are now being released on the GES DISC archive (https://disc.gsfc.nasa.gov/information/data-release), and all TROPICS Level 1 (radiance) and Level 2 (temperature/moisture profiles, tropical cyclone intensity, and instantaneous rain rate) products are on track to meet mission requirements. TROPICS observations are now being used in data assimilation trials to assess utility for tropical cyclone forecasting, and operational centers are now using TROPICS data to inform tropical cyclone analysis and forecasting guidance.

5 ACKNOWLEDGMENTS

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6 REFERENCES

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