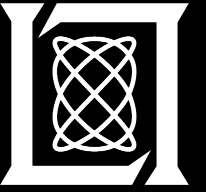
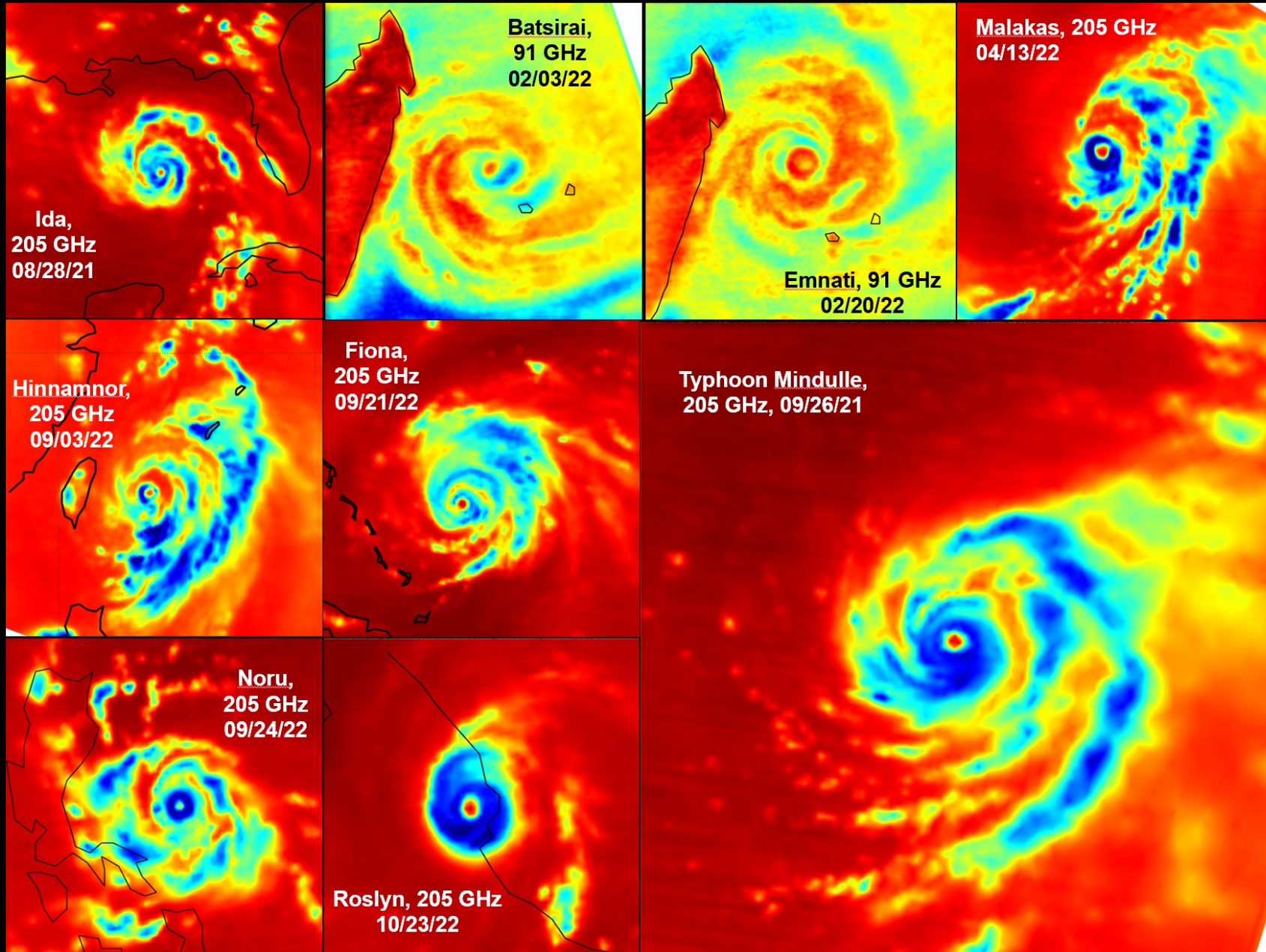
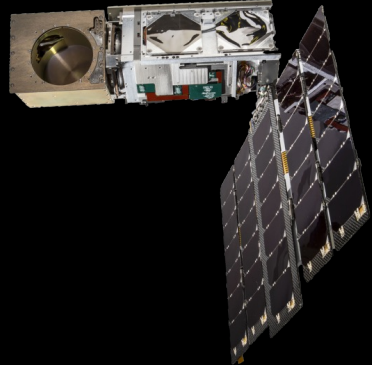


TROPICS Pathfinder On-orbit Results and Status of the NASA TROPICS Constellation Mission



William J. Blackwell
MIT Lincoln Laboratory
and co-authors

March 1, 2023
LEO Precip Workshop



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Author List

William J. Blackwell
Massachusetts Institute of
Technology, Lincoln Laboratory
Lexington, MA
USA

R. Vincent Leslie
Massachusetts Institute of
Technology, Lincoln Laboratory
Lexington, MA
USA

Ralf Bennartz
Vanderbilt university
nashville, TN
USA

Thomas Joseph Greenwald
CIMSS
Madison, WI
USA

Nick Zorn
Massachusetts Institute of
Technology, Lincoln Laboratory
Lexington, MA
USA

Scott A. Braun
NASA
Greenbelt, MD
USA

Chris Velden
CIMSS
Madison, WI
USA

Derrick C. Herndon
CIMSS
Madison, WI
USA

Mark DeMaria
CIRA
Fort Collins, CO
USA

Robert M. Atlas
NOAA/AOML
Miami, FL
USA

Jeff Hawkins
UW CIMSS
Madison, WI USA

Frank D. Marks
AOML
Miami, FL
USA

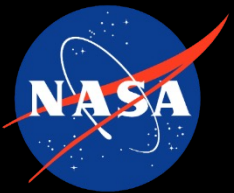
Kerri Cahoy
MIT Aero/Astro & EAPS
Cambridge, MA
USA

Galina Chirokova
CIRA
Fort Collins, CO
USA

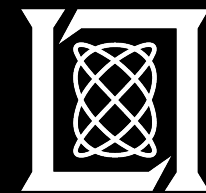
Jason P. Dunion
Univ. of Miami/Cooperative
Institute for Marine and
Atmospheric Studies and
NOAA/AOML/HRD
Miami, FL
USA

Robert F. Rogers
Hurricane Research Division,
AOML
Miami, FL
USA

Brittany Anne Dahl
Univ. of Miami Rosenstiel School
of Marine and Atmospheric
Science
Miami, FL
USA



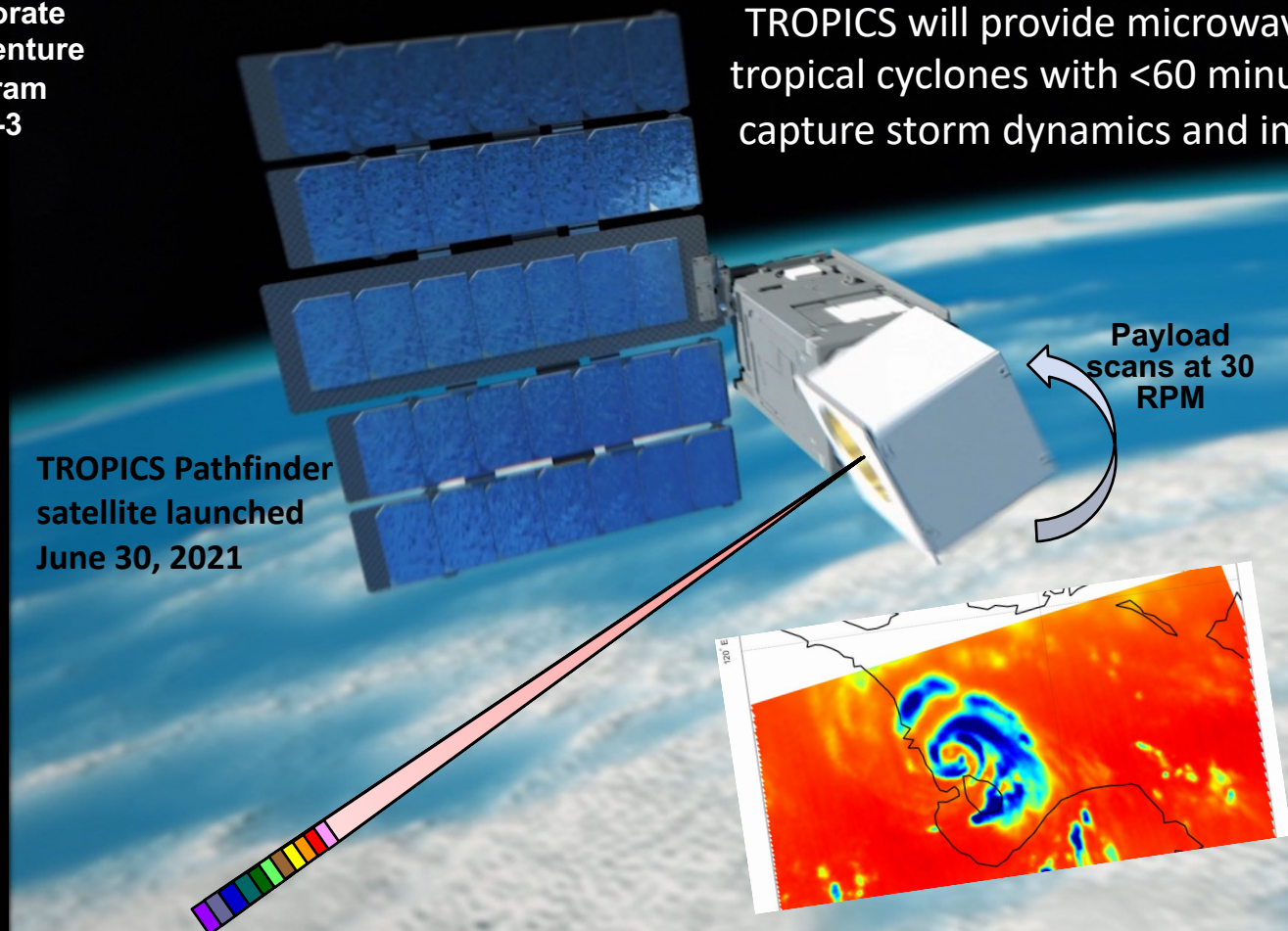
TROPICS: Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsat



William J. Blackwell (MIT LL), Principal Investigator Scott A. Braun (NASA GSFC), Project Scientist

Science Mission
Directorate
Earth Venture
Program
EVI-3

TROPICS will provide microwave observations of tropical cyclones with <60 minute revisit to better capture storm dynamics and improve forecasting



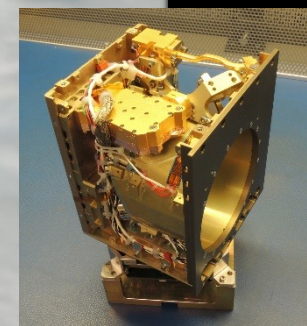
TROPICS Pathfinder satellite launched June 30, 2021

Payload scans at 30 RPM

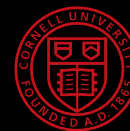
High-resolution microwave data resolves tropical cyclone eye and rain structure

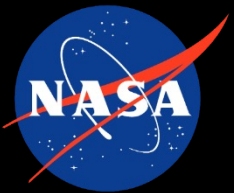


Constellation of Four 3U CubeSats
MIT LL payload; BCT bus; KSAT downlink

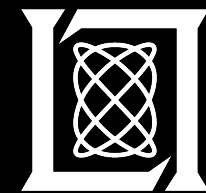


TROPICS Microwave Sounder
12 channels (90-205 GHz)
Temperature, Moisture, Rain Rate





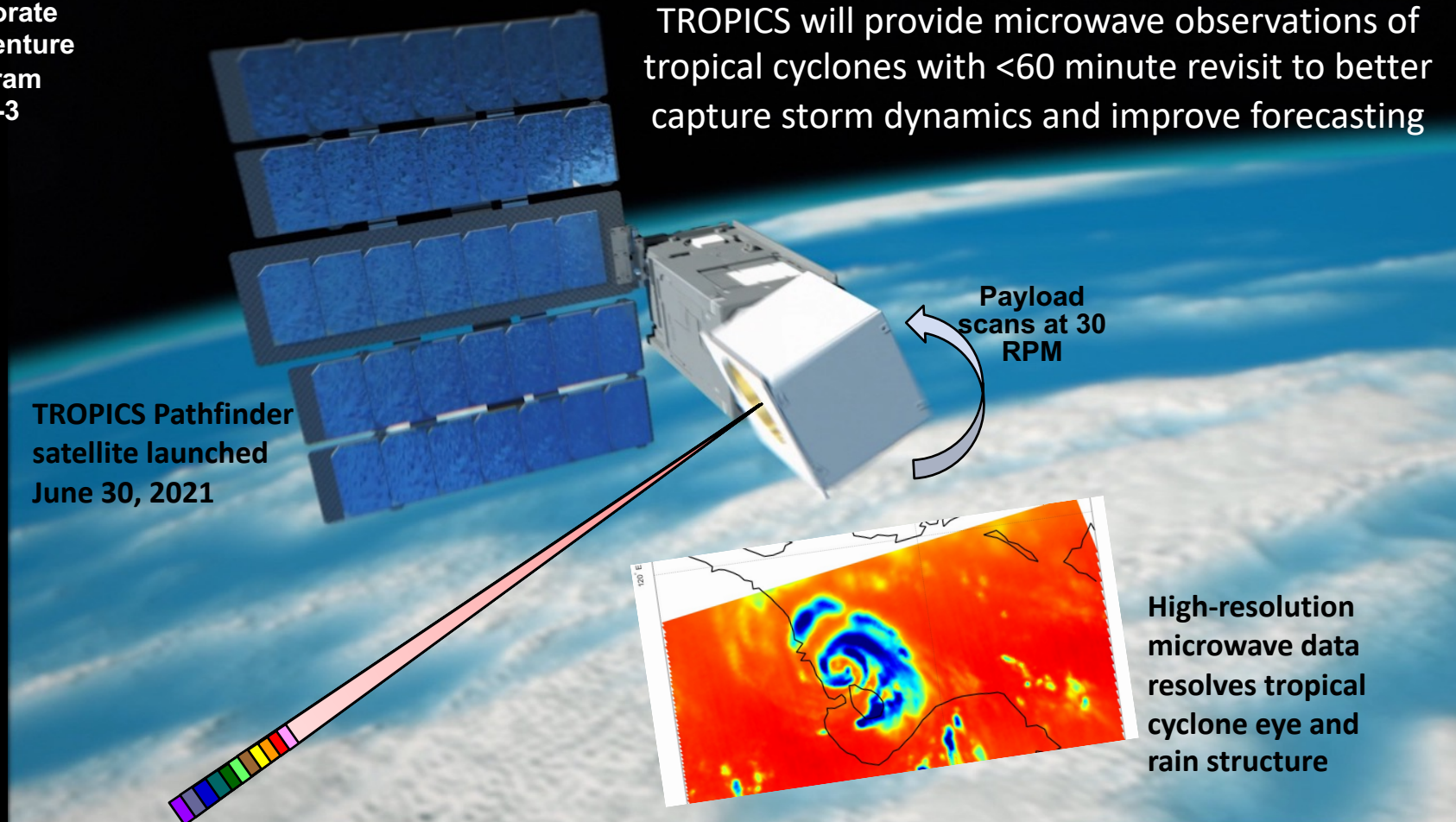
TROPICS: Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsat



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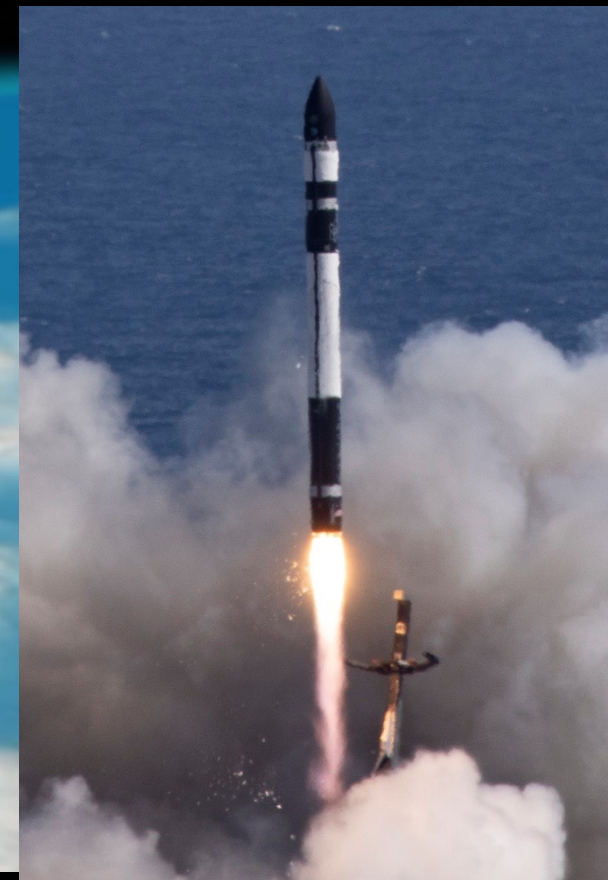
TROPICS will provide microwave observations of tropical cyclones with <60 minute revisit to better capture storm dynamics and improve forecasting



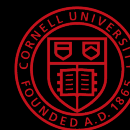
TROPICS Pathfinder satellite launched June 30, 2021

Payload scans at 30 RPM

High-resolution microwave data resolves tropical cyclone eye and rain structure



Two upcoming launches by Rocket Lab
No earlier than May 2023

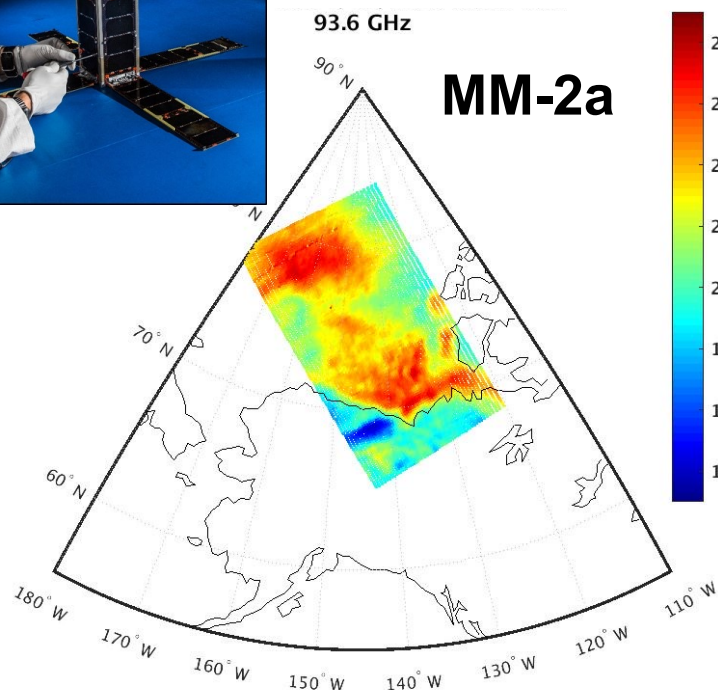
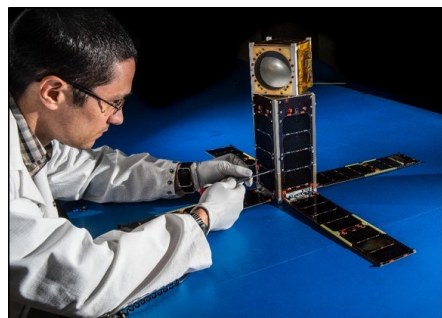




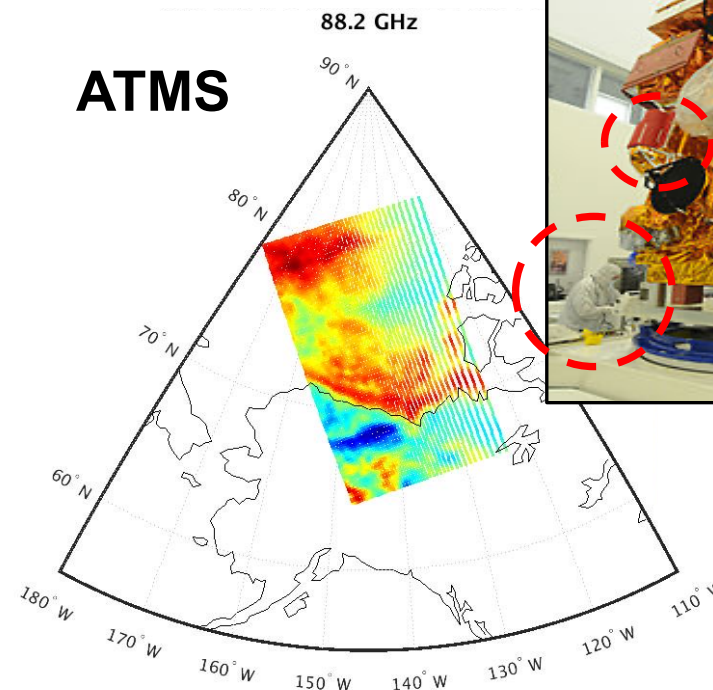
FIVE-YEAR ANNIVERSARY

MIT LL demonstrates the first CubeSat Sounder: MicroMAS-2a

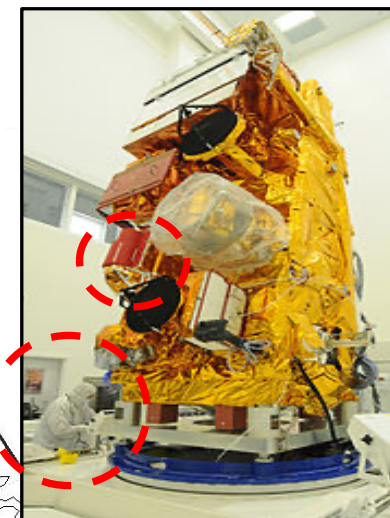
Enabling CubeSat Sounder
Demonstration: MM-2a



January 2018



Suomi-NPP

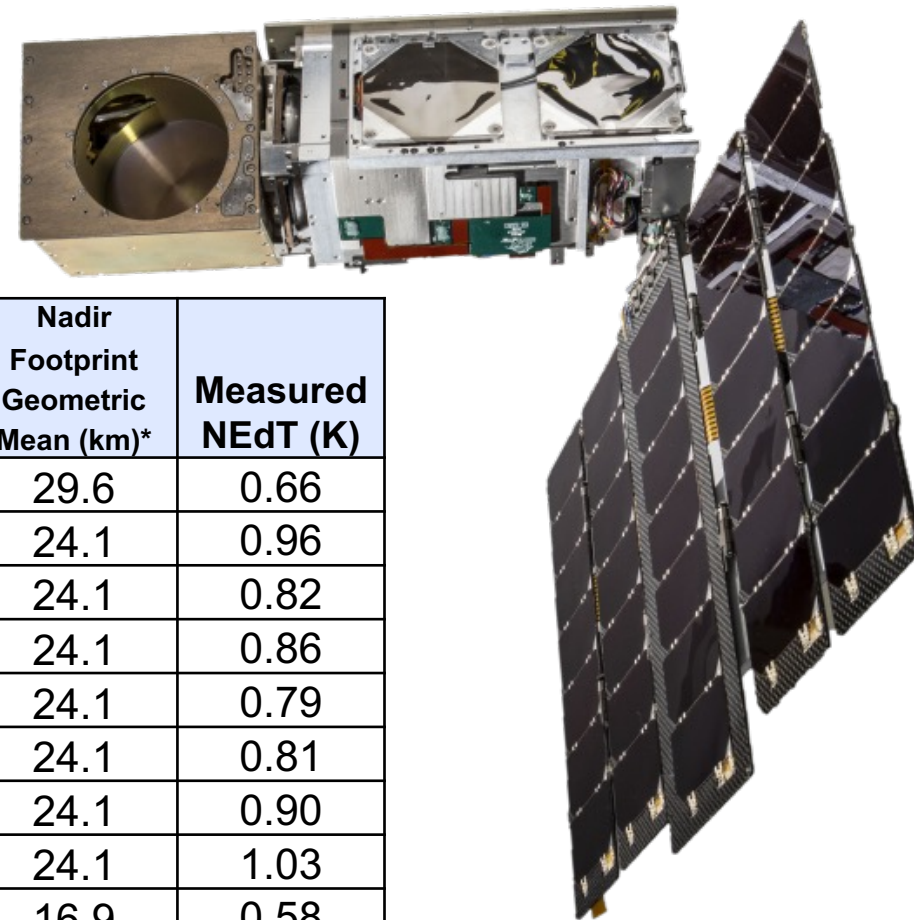


A. Crews, W. Blackwell, et al., "Initial Radiance Validation of the Microsized Microwave Atmospheric Satellite-2A," in *IEEE Transactions on Geoscience and Remote Sensing*, doi: 10.1109/TGRS.2020.3011200.



TROPICS Satellite (“CubeSat”) (TROPICS Millimeter-wave Sounder = TMS)

- 3U CubeSat: 10 cm x 10 cm x 36 cm
- Mass: 5.4 kg; Power: 15 W (payload is 3W)
- Blue Canyon Technologies bus
- LL passive millimeter-wave payload
- Innoflight SCR-100 S-band radio



TMS Channel	Central frequency	ATMS Channel	MHS Channel	MWHS-2 Channel
1	91.655±1.4 GHz	88.2 GHz	89.0 GHz	89.0 GHz
2	114.50 GHz	-	-	118.75±5.0
3	115.95 GHz	-	-	118.75±3.0
4	116.65 GHz	-	-	118.75±2.5
5	117.25 GHz	-	-	118.75±1.1
6	117.80 GHz	-	-	118.75±0.8
7	118.24 GHz	-	-	118.75±0.3
8	118.58 GHz	-	-	118.75±0.2
9	184.41 GHz	183.31±1.0	183.31±1.0	183±1.0
10	186.51 GHz	183.31±3.0	183.31±3.0	183±3.0
11	190.31 GHz	183.31±7.0	190.31	183±7.0
12	204.8 GHz	-	-	-

Beamwidth (degrees) Down/Cross	Nadir Footprint Geometric Mean (km)*	Measured NEdT (K)
3.0/3.17	29.6	0.66
2.4/2.62	24.1	0.96
2.4/2.62	24.1	0.82
2.4/2.62	24.1	0.86
2.4/2.62	24.1	0.79
2.4/2.62	24.1	0.81
2.4/2.62	24.1	0.90
2.4/2.62	24.1	1.03
1.5/1.87	16.9	0.58
1.5/1.87	16.9	0.55
1.5/1.87	16.9	0.53
1.35/1.76	15.2	0.52



TROPICS Pathfinder (Qualification Unit) Launched June 30, 2021

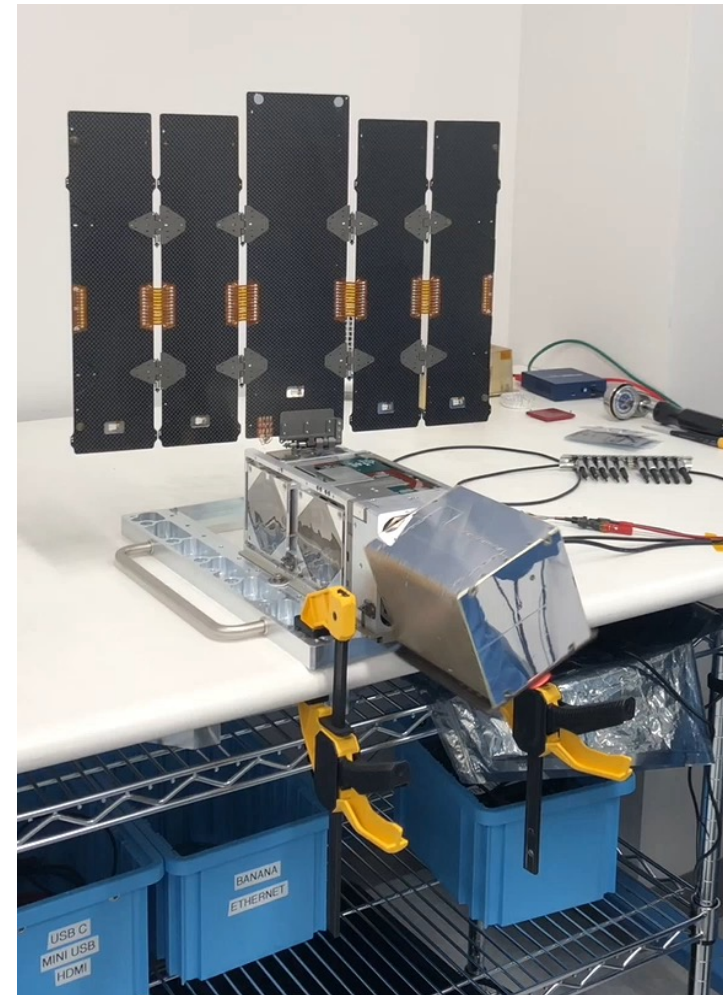


Pathfinder “precursor” mission provided checkout of operations, ground links, data processing & science

Detailed cal/val indicates that radiometric calibration performance is better than 1 K in all channels

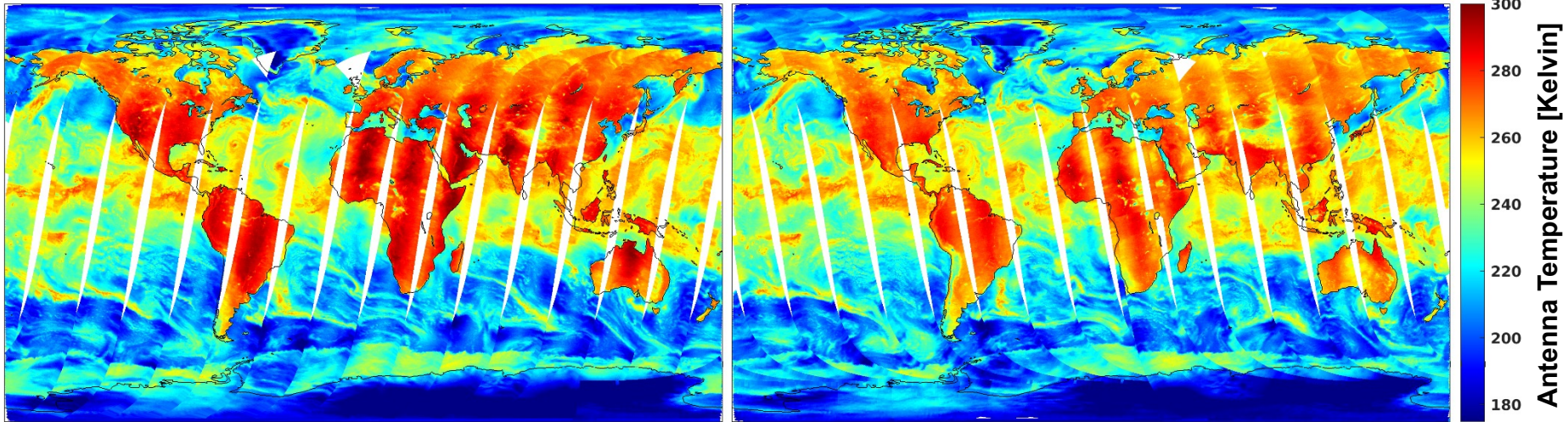
NOAA-funded low-latency experiment conducted in April 2022

Provisional (beta) data now available to general public via GES-DISC (validated data coming soon)

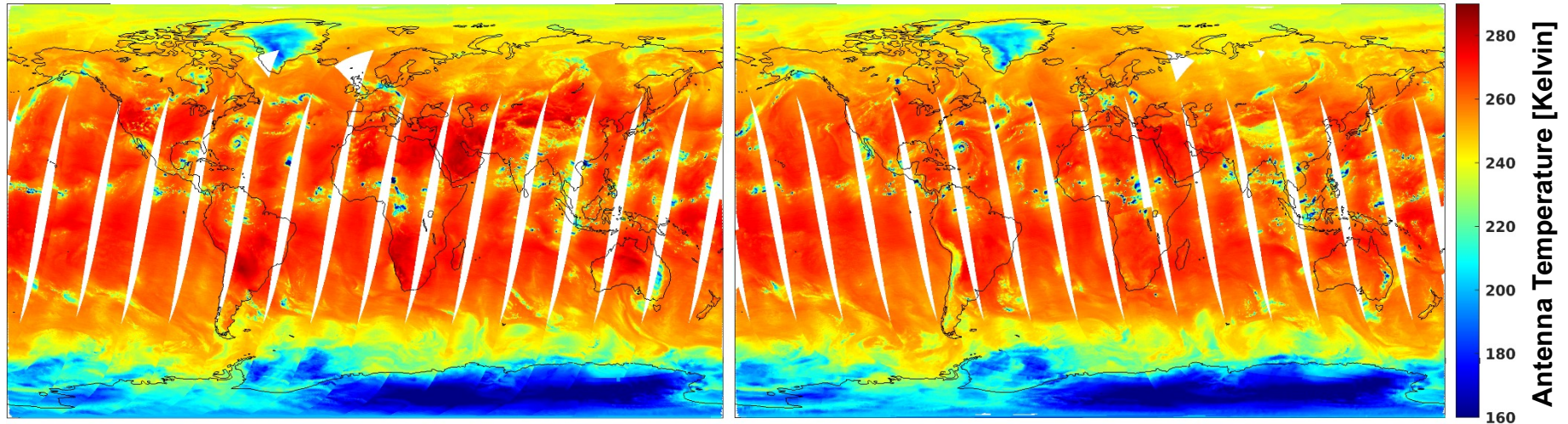




Pathfinder's Twice-Daily Global Collections



91.656 GHz – Channel 1 (W) – Daytime and Nighttime Mosaics



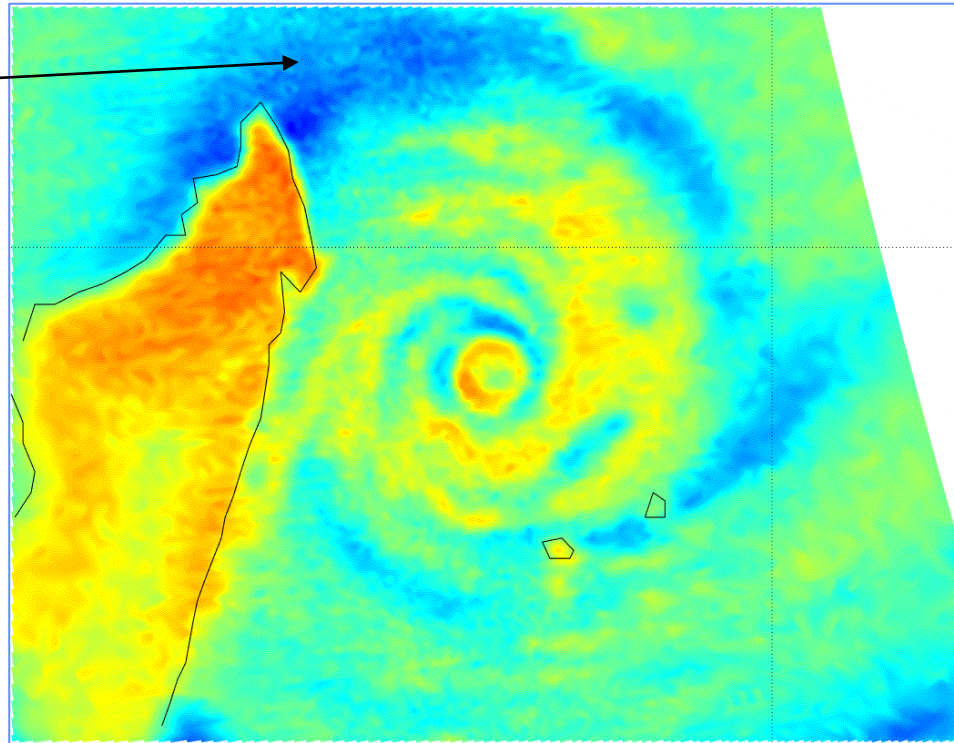
204.8 GHz – Channel 12 (G4) – Daytime and Nighttime Mosaics



TROPICS Data Addresses Critical Science Questions

What is the relationship between environmental conditions and storm intensification?

Changing environmental conditions near edge of tropical cyclone



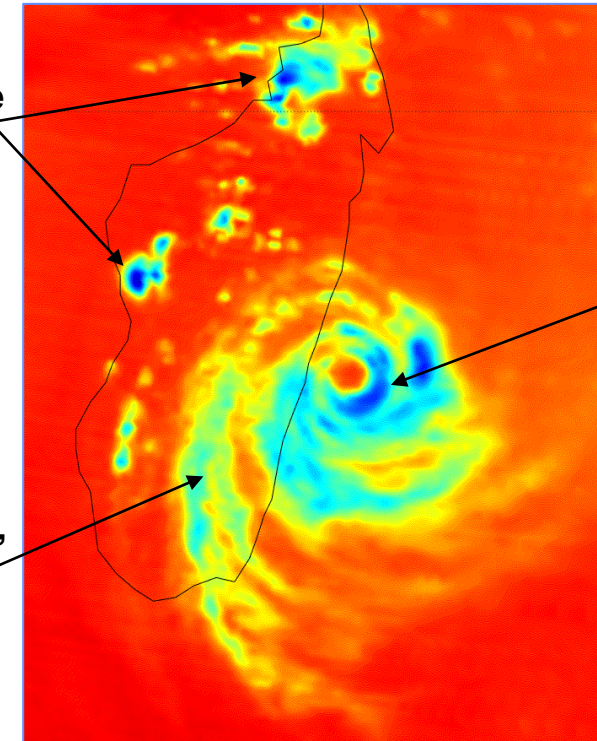
TC Emnati, Feb 10, 2022, 92 GHz

What is the relationship between structural features of the storm and intensification?

Convective cores

Strong eyewall convection on other side of storm

Spiral "arm" on one side of storm



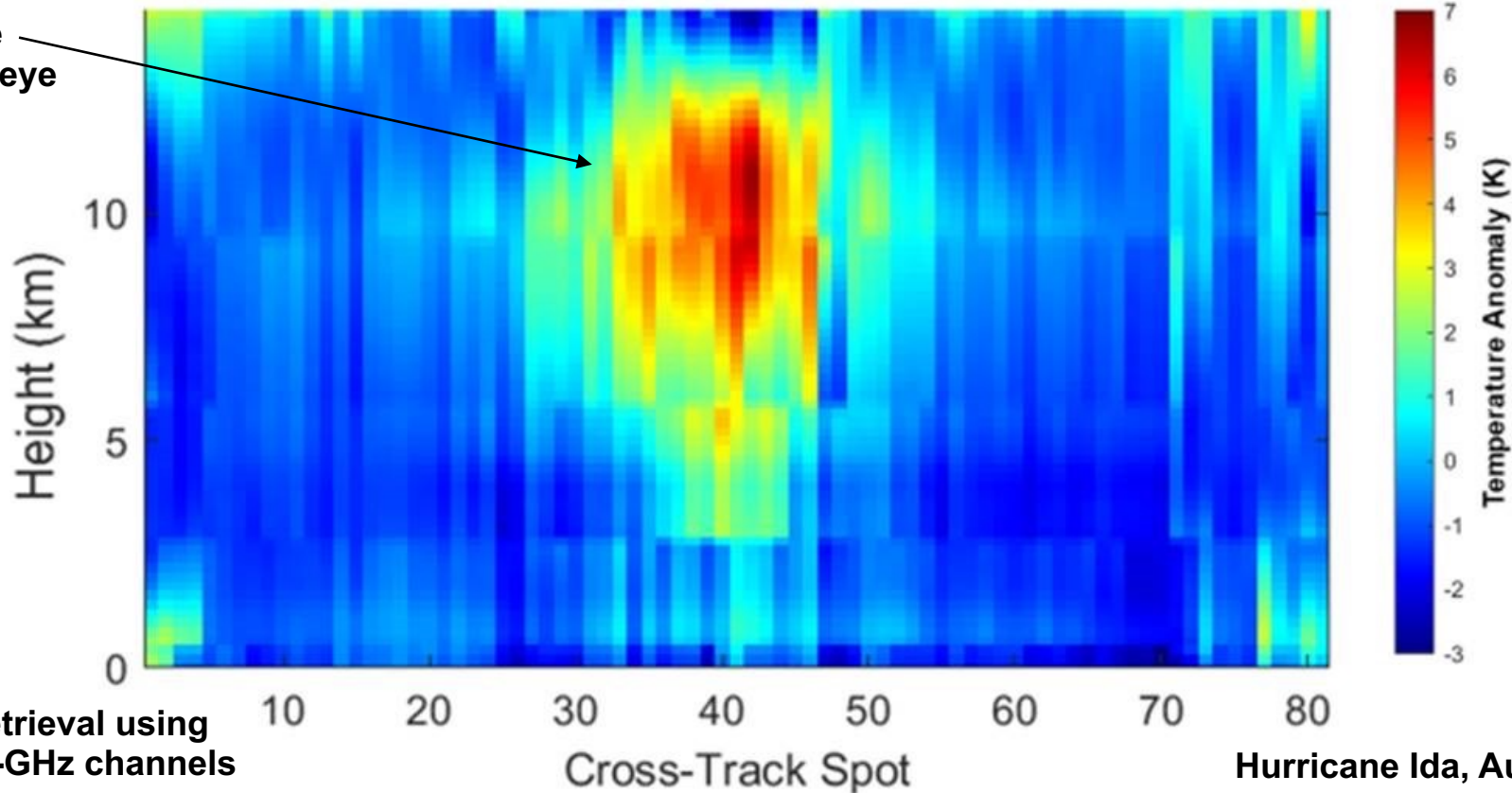
TC Batsirai, Feb 5, 2022, 205 GHz



TROPICS Data Addresses Critical Science Questions

What is the relationship between structural evolution and warm core evolution and what role does the diurnal cycle play?

Warming aloft in the inside of the hurricane eye



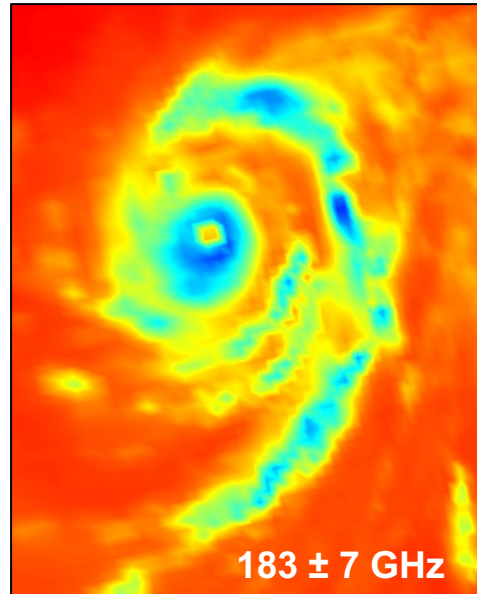
Ultimately, we want to show that TROPICS data will improve forecasting of tropical cyclone track and intensity



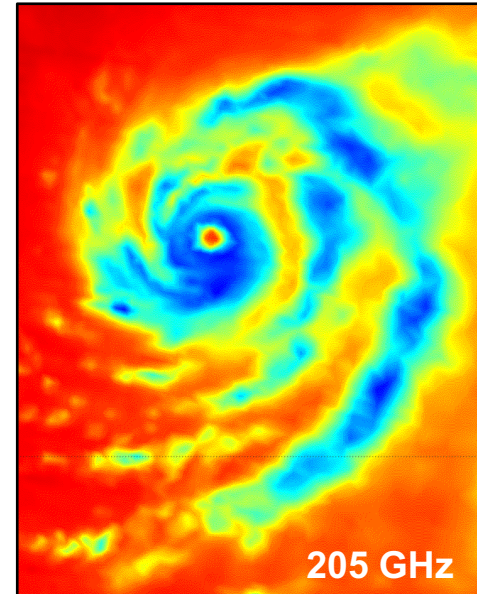
TROPICS Pathfinder Data Compares Favorably to State-of-the-Art Sensors

Super Typhoon Mindulle (Sep 26, 2021)

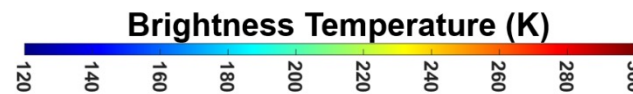
SNPP Satellite (ATMS)
>2000 kg



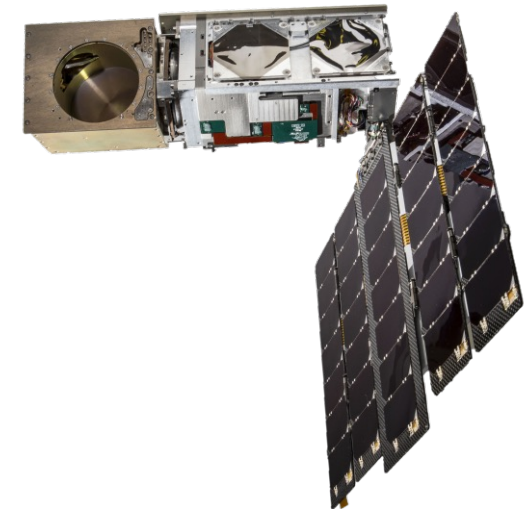
9/26/2021 03:48 UTC



9/26/2021 05:21 UTC

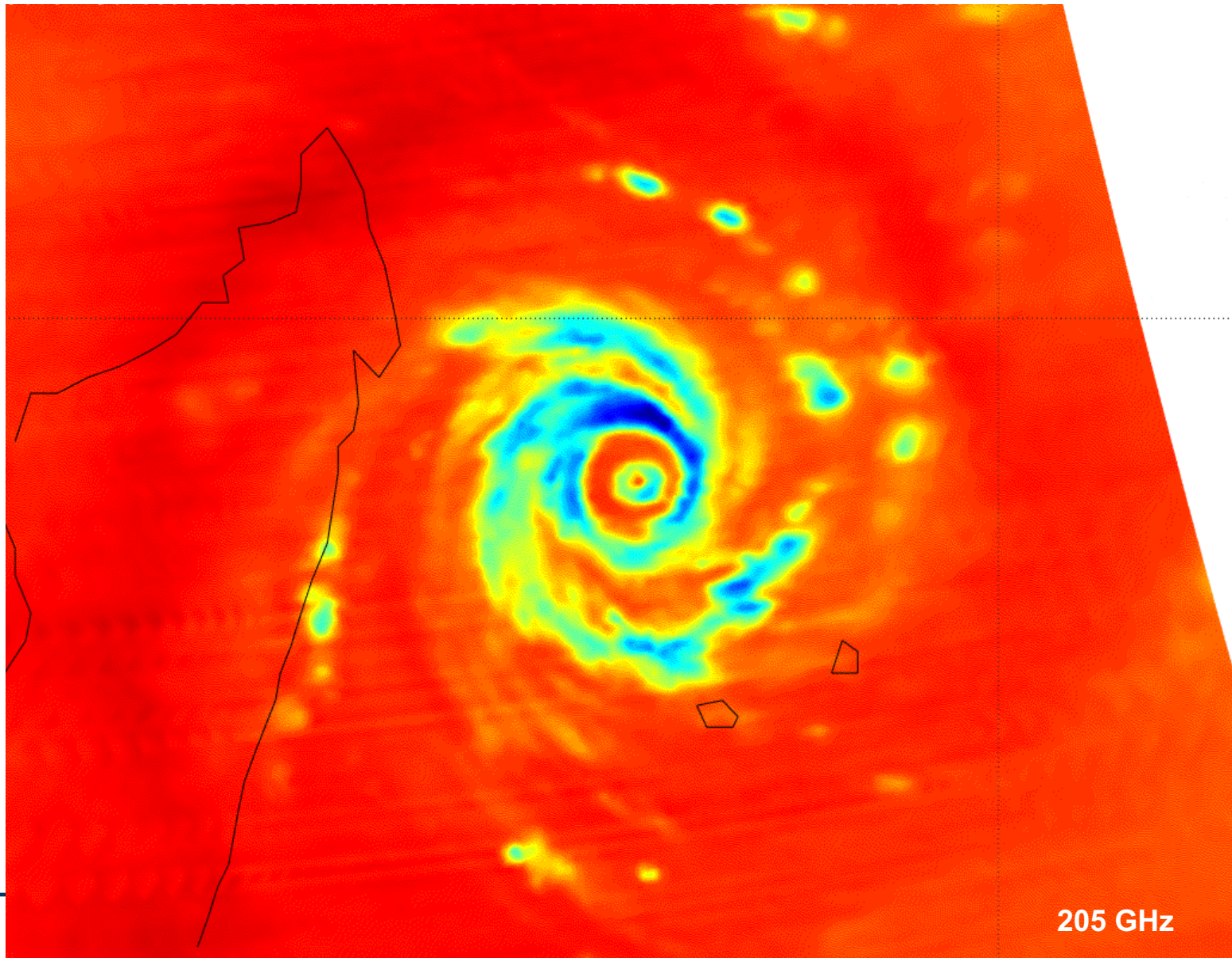


TROPICS Pathfinder Satellite
5.4 kg





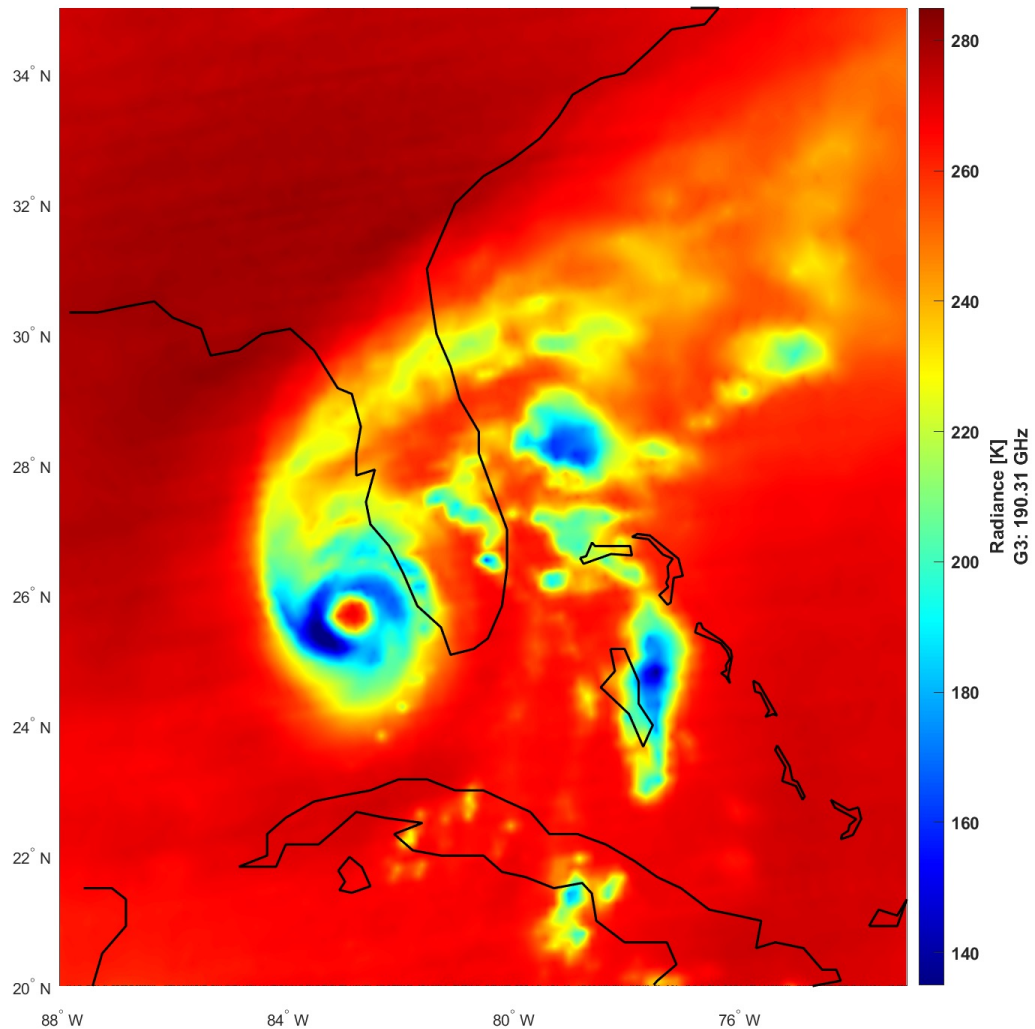
TROPICS Pathfinder Observations of Cyclone Emnati Able to Resolve Eyewall Replacement Cycle!



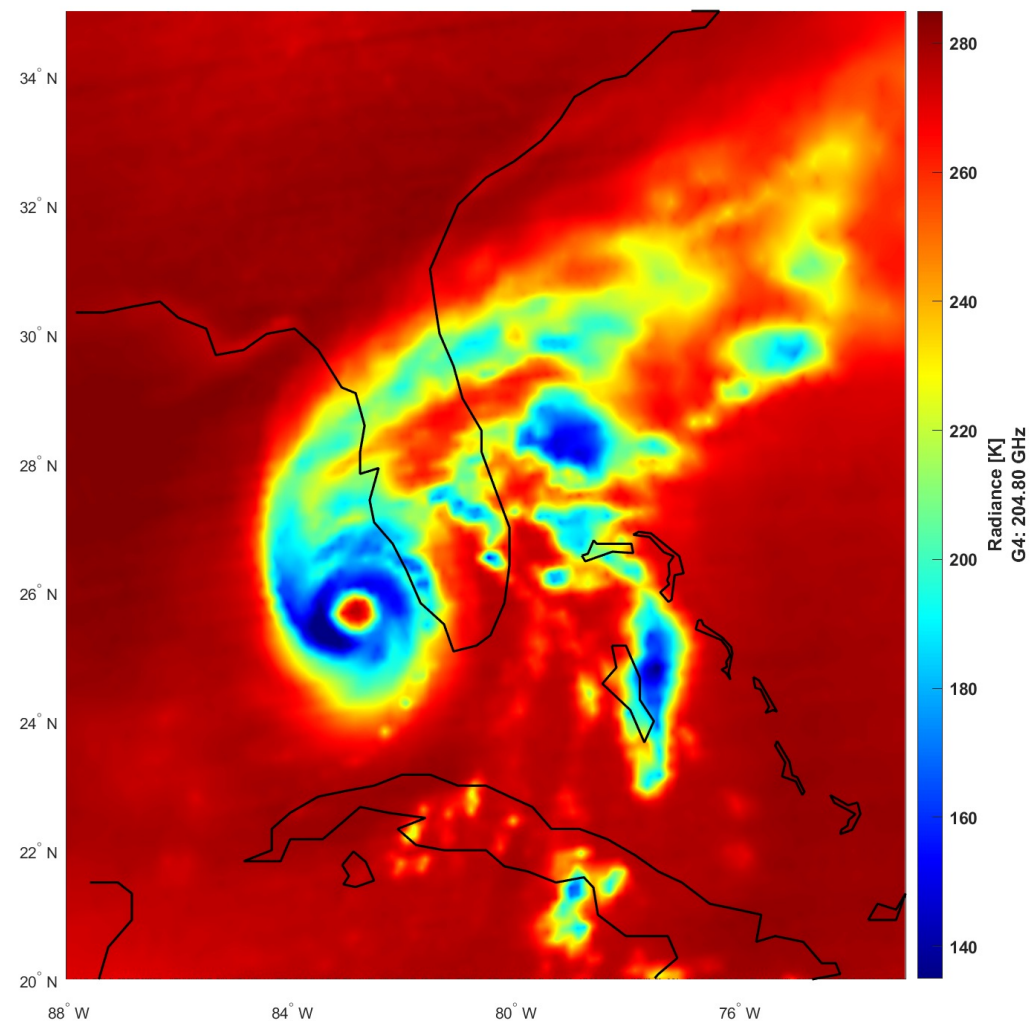


TROPICS Pathfinder Observations of Hurricane Ian 9/28/2022 07:21 UTC

190 GHz

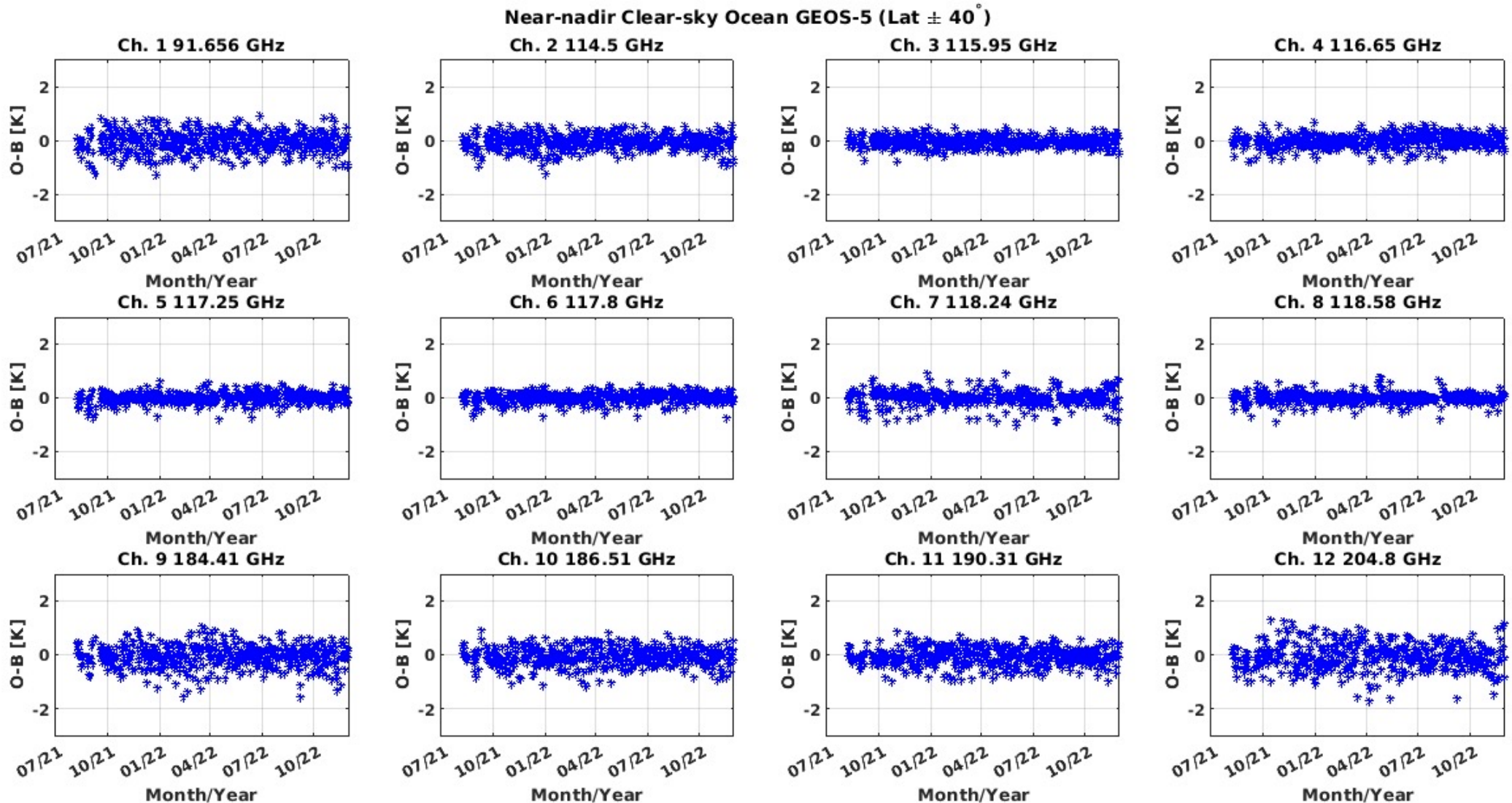


205 GHz





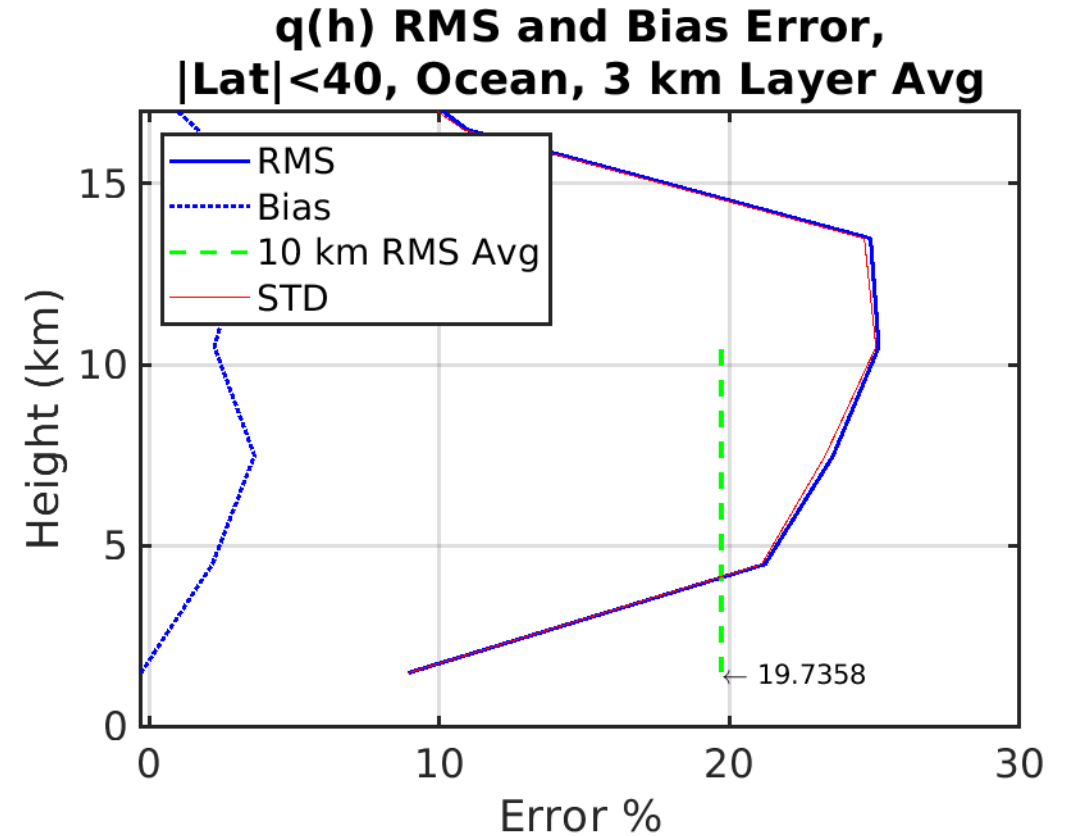
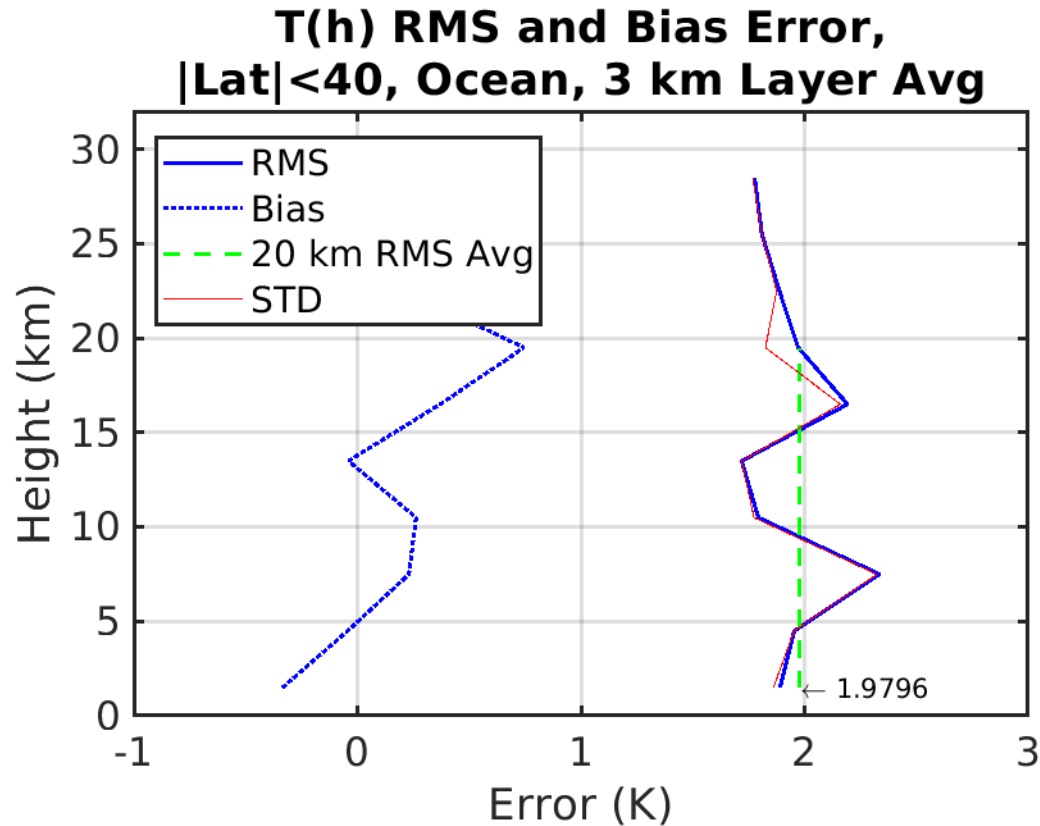
Preview of “Validated” Level 1B Product (Available Soon!) 18+ Months of TROPICS Pathfinder Calibration Trending





Temperature and Moisture Retrievals Meet Requirements (Cloudy, mostly non-precipitating atmospheres)

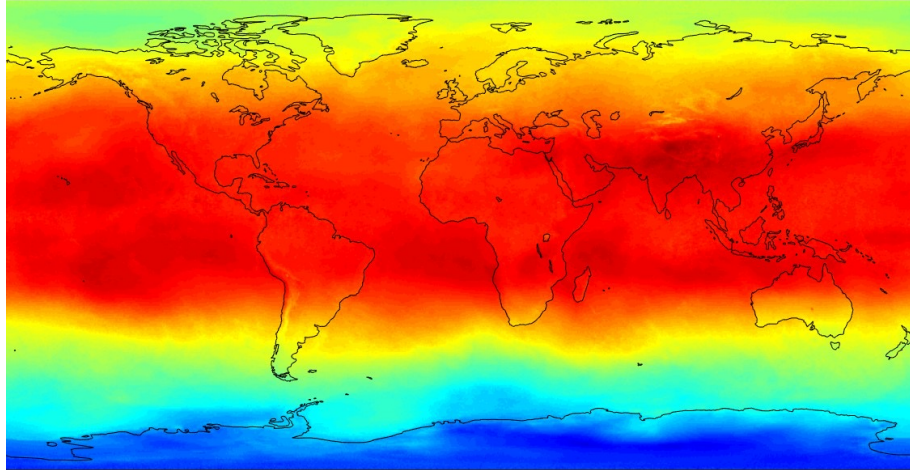
TROPICS Pathfinder



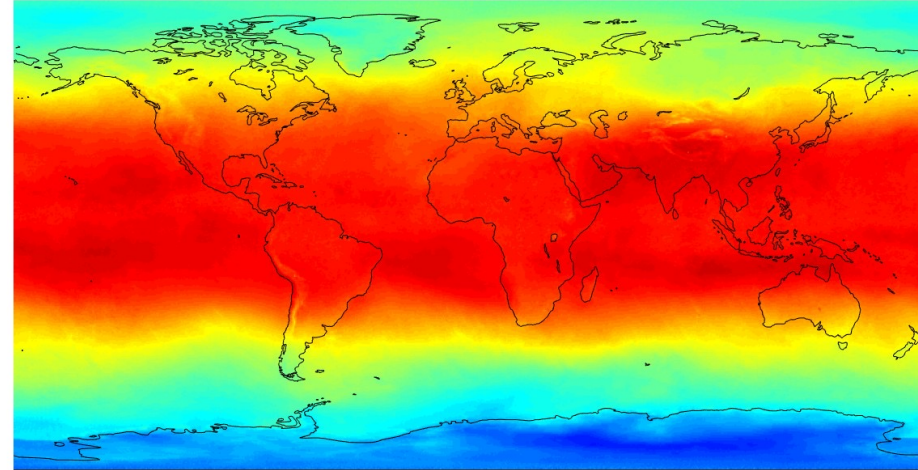


TROPICS Long-term Data Records: MidTrop Temperature

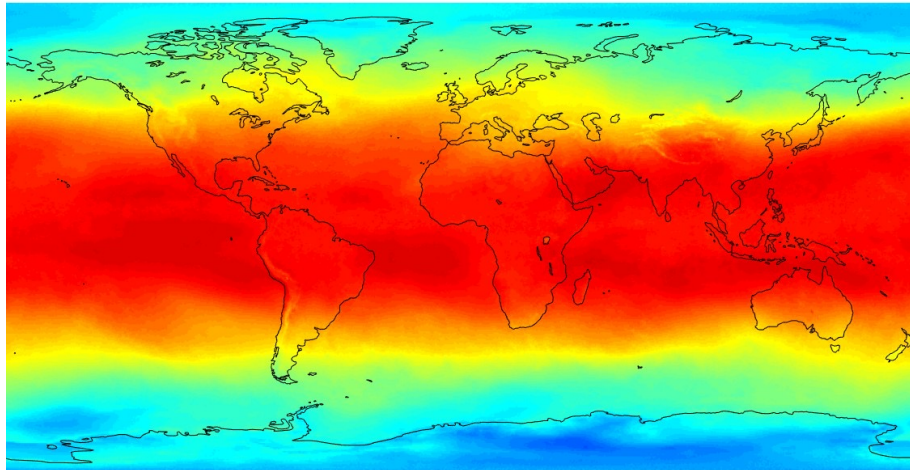
Temperature August 2021



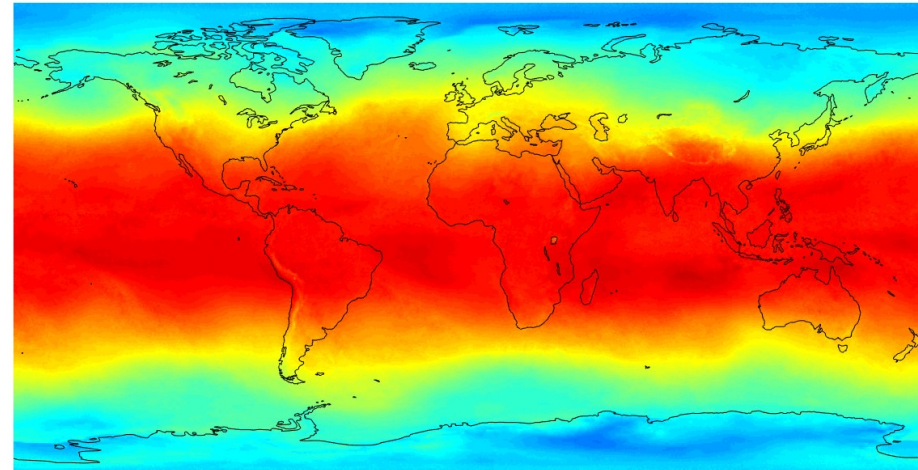
Temperature September 2021



Temperature October 2021



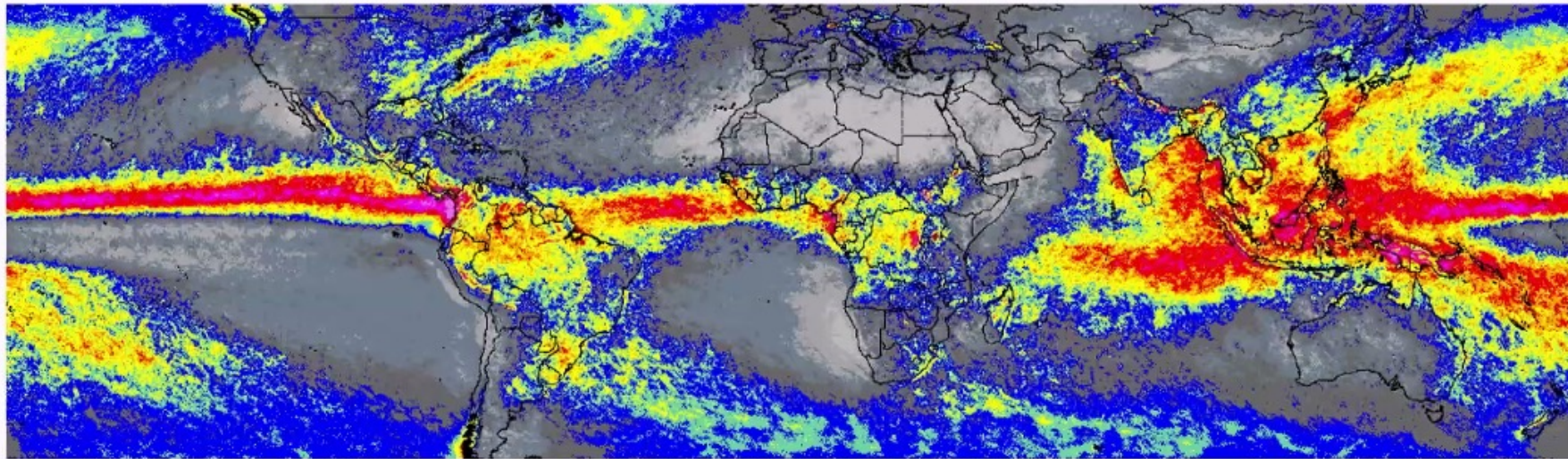
Temperature November 2021





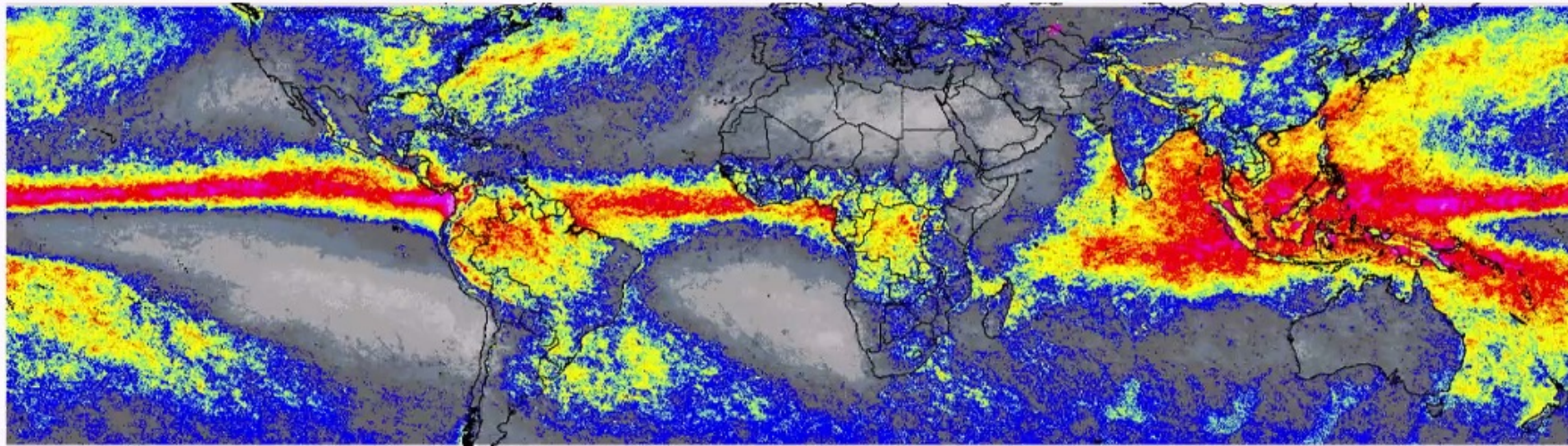
TROPICS Pathfinder Mean Annual Precipitation Compares Well with NOAA-19 and other Sounders

GPROF
NOAA-19
MHS

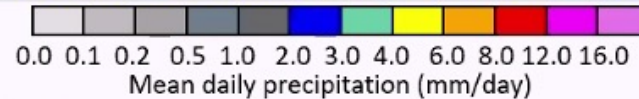


2021.08.01
-
2022.07.31

PRPS
TROPICS
TMS

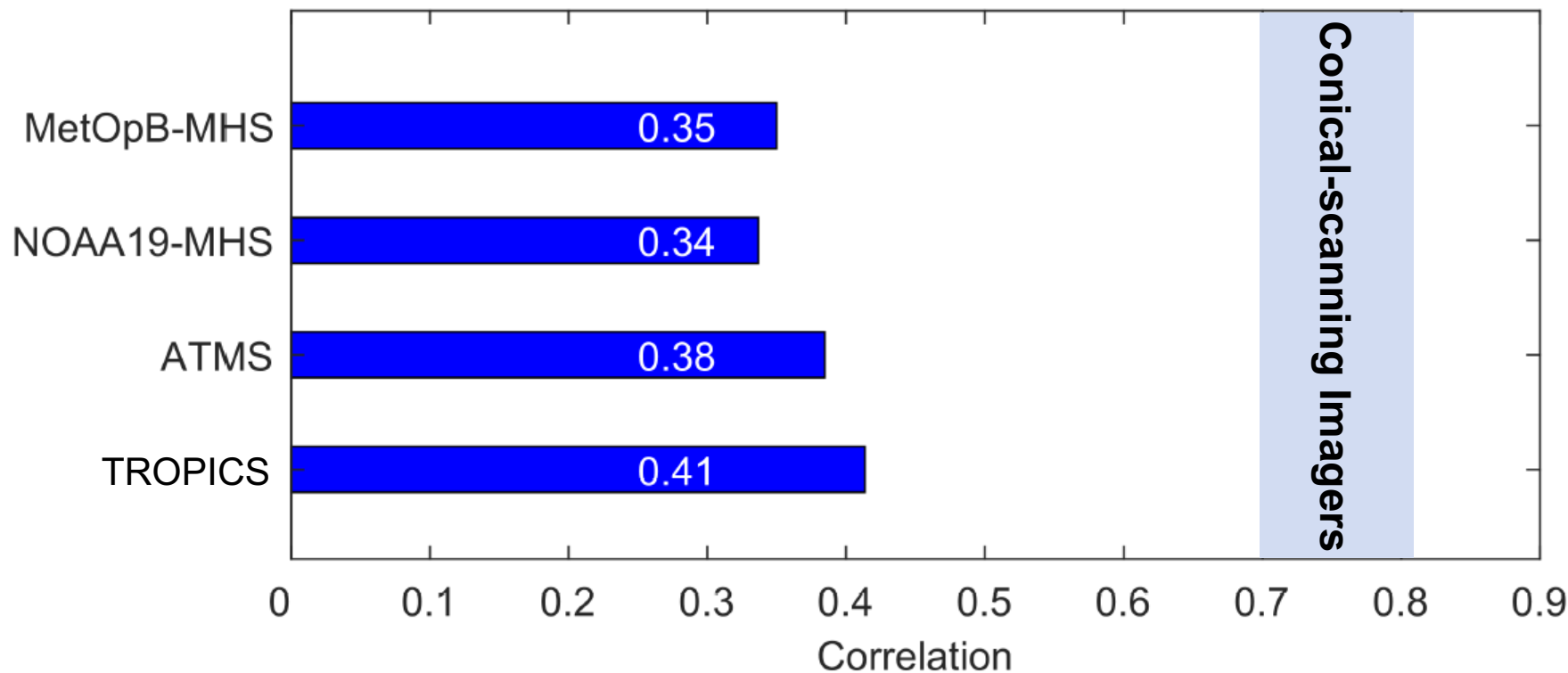


2021.08.08
-
2022.07.31





Correlation Between Coincident Retrievals from GMI and Cross-track Sounders Over Ocean

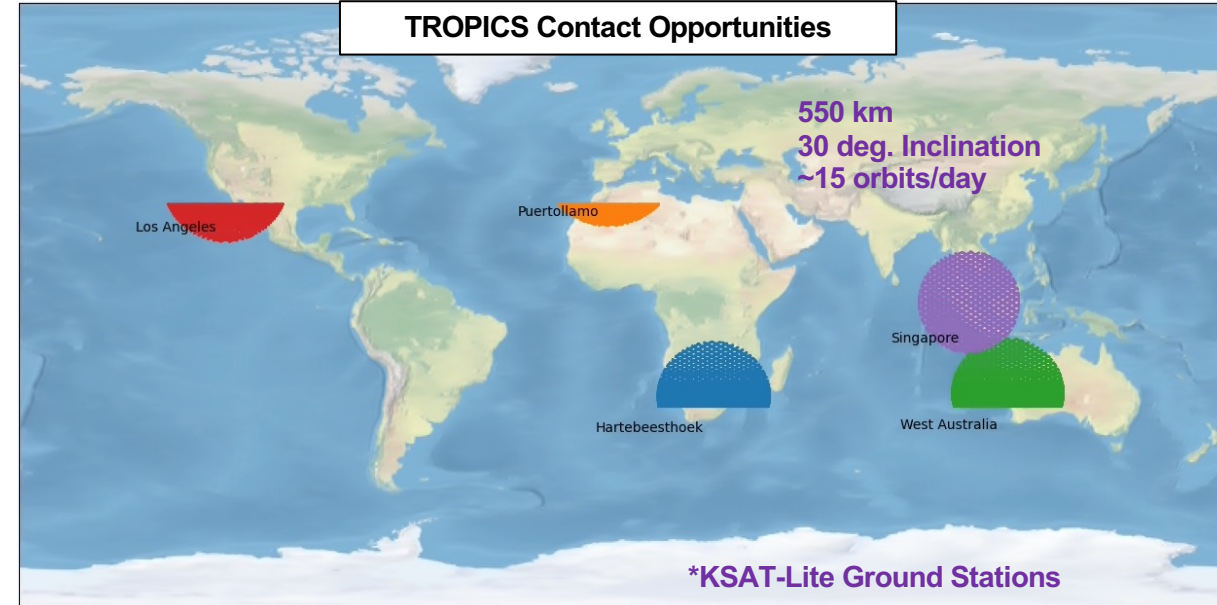


Reference: Y. You, "Evaluating and Improving TROPICS Millimeter-Wave Sounder's Precipitation Estimates over Ocean," JGR: Atmospheres, under review



Low-Latency Potential for TROPICS Constellation

- The Pathfinder low-latency demo results will be mapped to constellation orbit to understand potential constellation stats
 - Incorporate demo lessons learned
 - Estimate constellation low latency cost
- Constellation frequency authorizations obtained
- Funding from NOAA and ONR to improve TROPICS latency gratefully acknowledged
- Average latency estimate: **45 minutes**



Preliminary Pathfinder analysis indicates that the low latency mode for the constellation is very manageable



TROPICS Technology Transfer

- The TROPICS Pathfinder satellite showed the compact TROPICS design performs comparably to state-of-the-art sounders
 - Lessons learned will help commission and operate constellation
- Boston-based Tomorrow.io has funded a Cooperative Research and Development Agreement with MIT LL to improve the payload, host on 6U bus, and deploy an initial constellation of 18 satellites



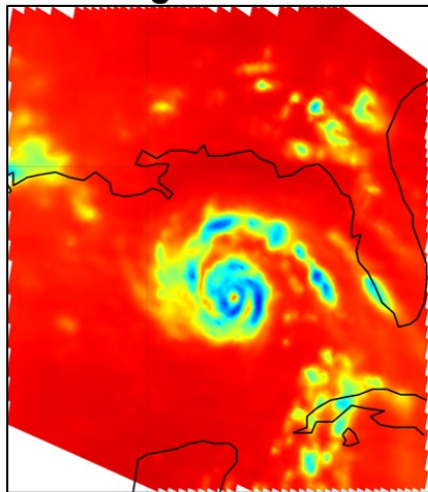


Summary and Path Forward

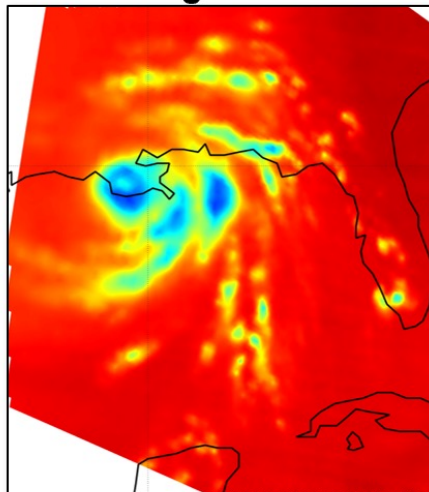
- **TROPICS will provide the first high-revisit microwave observations of precipitation, temperature, and humidity**
- **TROPICS CubeSats delivered with excellent performance**
- **Pathfinder mission has demonstrated all mission elements and provided new tropical cyclone imagery; 9000+ orbits and counting!**
- **Two constellation launches planned for May 2023**

Hurricane Ida

28 Aug 20:07 UTC



29 Aug 19:55 UTC



30 Aug 08:06 UTC

