NASA TROPICS Earth Venture Mission: Payload Characteristics and Data Products

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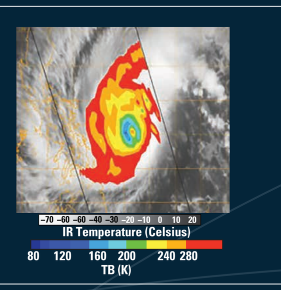
Mission Overview

The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission was selected by NASA as part of the Earth Venture–Instrument (EVI-3) program. The overarching goal for TROPICS is to provide nearly all-weather observations of 3D 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. Launch readiness is currently projected for late 2019 (Blackwell 2018).

Science Objectives

- Relate precipitation structure evolution, including diurnal cycle, to the evolution of the upper-level warm core and associated intensity changes
- Relate the occurrence of intense precipitation cores (convective bursts) to storm intensity evolution
- Relate retrieved environmental moisture measurements to coincident measures of storm structure (including size) and intensity
- Assimilate microwave observations in mesoscale and global numerical weather prediction models to assess impacts on storm track and intensity



12/05/14 0600Z 22W HAGUPIT
12/05/14 0800Z MTSAT-2 IR
12/05/14 Super Typhoon Hagupit
Sounding channel at 183 ± 7 GHz reveals precipitation structure

Typhoon Hagupit, Dec 5, 2014: GMI observations (183.31 ± 7 GHz) degraded to TROPICS resolution are shown

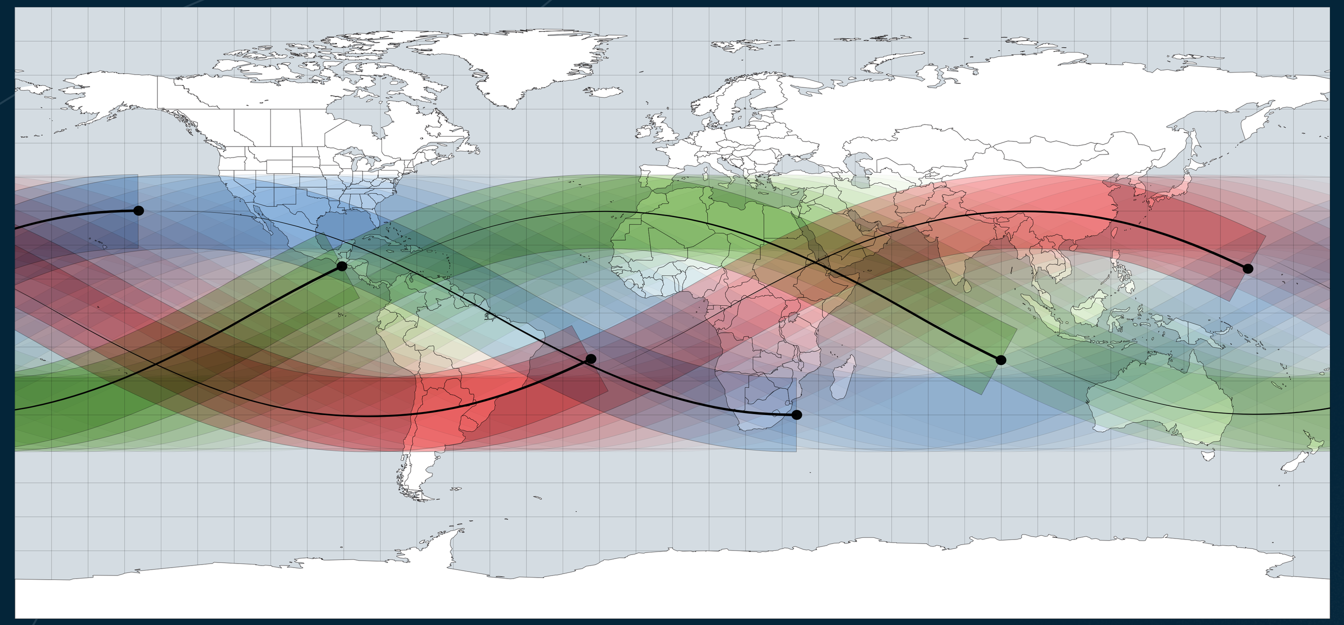
Naval Research Laboratory
http://www.nrlmry.navy.mil/sat_products.html

Constellation

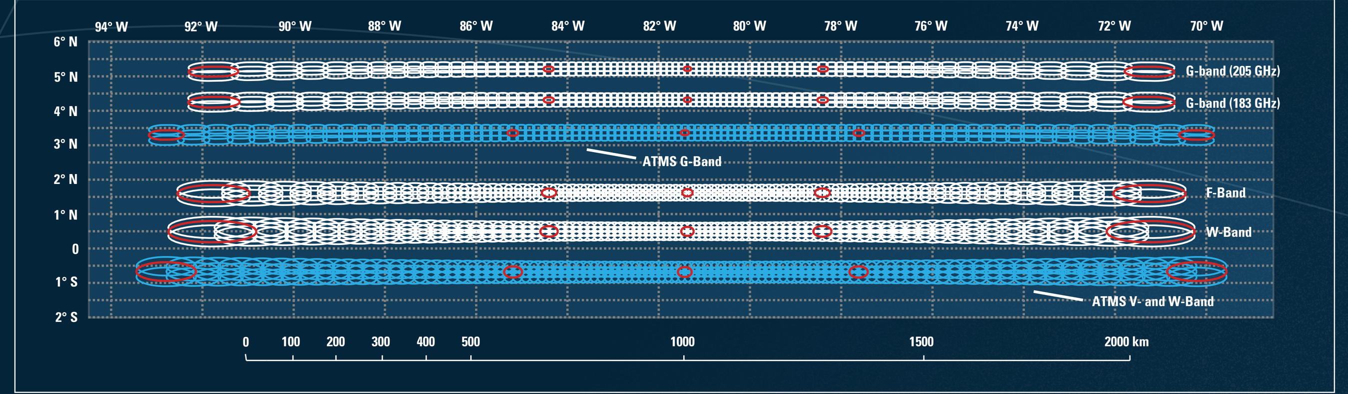
TROPICS comprises of at least six CubeSats in three low-Earth orbital planes. TROPICS will provide rapid-refresh microwave measurements (median refresh rate better than 60 minutes for the baseline mission) that can be used to observe the thermodynamics of the troposphere and precipitation structure for storm systems at the mesoscale and synoptic scale over the entire storm lifecycle. This observing system offers an unprecedented combination of horizontal and temporal resolution to measure environmental and inner-core conditions for tropical cyclones on a nearly global scale and is a major leap forward in the temporal resolution of several key parameters needed for assimilation into advanced data assimilation systems capable of utilizing rapid-update radiance or retrieval data.

- Number of planes: 3
- Satellites per plane: 2
- Inclination: 30 ± 3°
- Altitude: 550 ± 50 km
- RAAN spacing: 120 ± 30°
- All launches within 60-day window

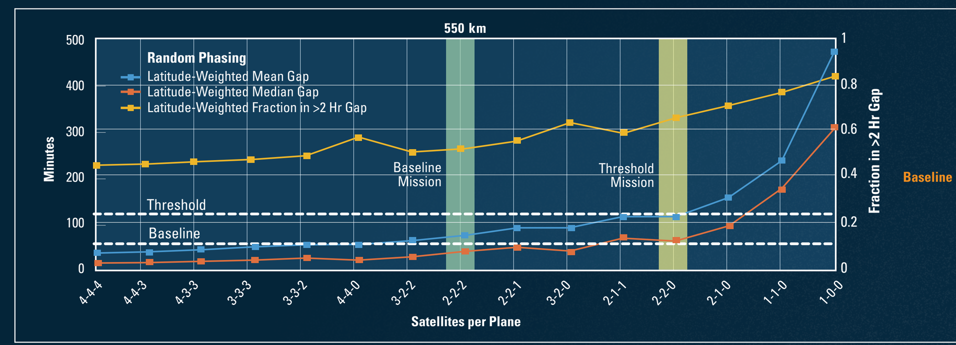
CS-F-1



CS-F-2



CS-F-3



	Average (min)	Median (min)	Frequency of Gaps <2 Hr
8 satellites	60	30	55%
6 satellites	75	40	45%
4 satellites	120	70	25%

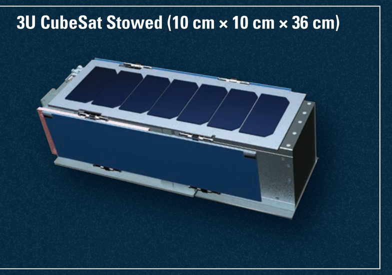
Space Vehicle

Each SV in the six-member TROPICS constellation is an identical 3U CubeSat consisting of an MIT Lincoln Laboratory (MIT LL)-built spectrometer payload integrated into a commercially procured bus from Blue Canyon Technologies (Boulder, CO).

The spectrometer payload consists of a rotating passive radio frequency (RF) antenna measuring spectral radiance as it rotates about the SV velocity vector. The payload is based upon a similar payload previously designed by MIT LL for the MicroMAS-2 mission (Blackwell 2017).

3U CubeSat Deployed

3U CubeSat Stowed (10 cm × 10 cm × 36 cm)



Payload

Each CubeSat will host a high-performance radiometer to provide temperature profiles using seven channels near the 118.75 GHz oxygen absorption line (F-band), water vapor profiles using three channels near the 183 GHz water vapor absorption line (G-band), imagery in a single channel near 90 GHz for precipitation measurements (W-band), and a single channel near 205 GHz that is more sensitive to cloud-sized ice particles (G-band). The W/F receiver front-end was provided by Neal Erickson from UMass Amherst, and the G-band is a direct-detect receiver from Virginia Diodes, Inc. (VDI).

Figure PL-F-1 is the block diagram for the CAD drawing of the rotating payload in Figure PL-F-2. The channel set for the block diagram is in Table PL-T-1. Figures PL-F-3 and PL-F-4 illustrate the passbands and weighting functions for the U.S. 1976 Standard Atmosphere. Also shown are the temperature weighting functions and water vapor burden. Table PL-T-2 has details on the scan profile of the payload that produces the footprints in Figure CS-F-2. Using the orbital parameters in the Constellation section and the antenna pattern beamwidths from Table PL-T-1 provides the ground spatial resolution information in Table PL-T-3. Figure PL-F-5 has the scan pattern design with four sectors: 1) Earth view, 2) calibration using noise diode, 3) solar and lunar intrusion of calibration trending, and 4) calibration using deep space. The TROPICS has a unique polarization from the traditional cross-track sounders. Due to the rotating payload with a fixed parabolic reflector, the polarization is also fixed. Figure PL-F-6 shows an illustration of the polarization and the resulting equation. Also shown are ocean surface emissivity model outputs. The W- and F-band polarization is 70 degrees from the velocity vector, and G-band is ~20 degrees.

PL-T-1

Chan.	Center Freq. (GHz)	Bandwidth (GHz)	RF Span (GHz)	Beamwidth (degrees) Down/Cross	Nadir Footprint Geometric Mean (km)	Expected NEdT (K)
1	91.655 ± 1.4	1.000	89.756–90.756, 92.556–93.556	3.0/3.17	29.6	0.40
2	114.50	1.000	114.00–115.00	2.4/2.62	24.1	0.55
3	115.95	0.800	115.55–116.35	2.4/2.62	24.1	0.60
4	116.65	0.600	116.35–116.95	2.4/2.62	24.1	0.70
5	117.25	0.600	116.95–117.55	2.4/2.62	24.1	0.70
6	117.80	0.500	117.55–118.05	2.4/2.62	24.1	0.75
7	118.24	0.380	118.05–118.43	2.4/2.62	24.1	0.85
8	118.58	0.300	118.43–118.73	2.4/2.62	24.1	1.00
9	184.41	2.000	183.41–185.41	1.5/1.87	16.1	0.60
10	186.51	2.000	185.51–187.51	1.5/1.87	16.1	0.60
11	190.31	2.000	189.31–191.31	1.5/1.87	16.1	0.60
12	204.8	2.000	203.8–205.8	1.4/1.76	15.2	0.60

PL-T-2

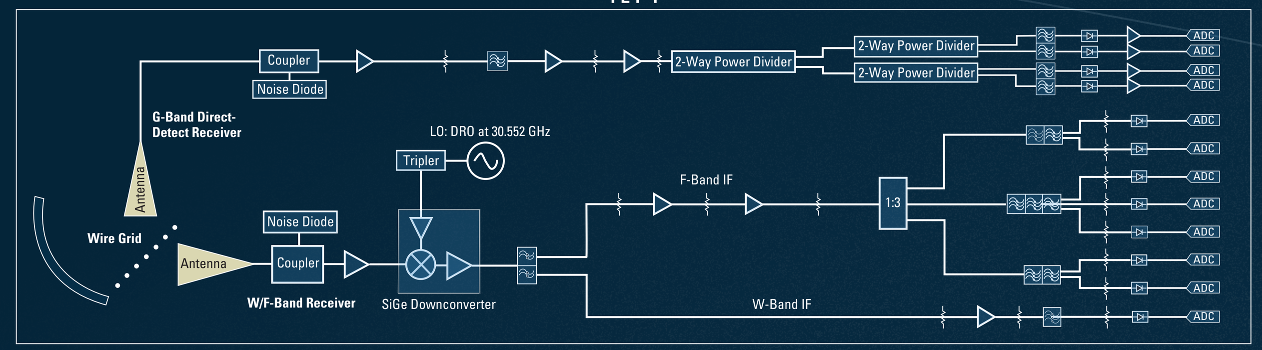
Characteristic	Units	Value
Rotation Period	Seconds	2
Maximum Earth View Sector Angle	Degrees	±60
Scan Type	N/A	Constant velocity (scanning during integration)
Integration Time	Seconds	1/120
Number of Earth View Sector Measurements	N/A	81 per scan (one at nadir)

PL-T-3

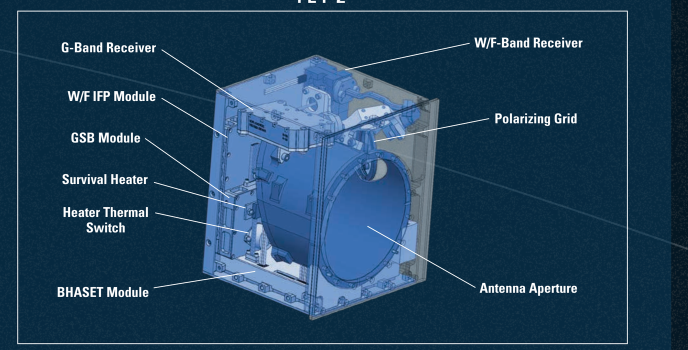
Band	Nadir	Scan Mean
W (90 GHz)	29.6	42.9
F (118 GHz)	24.1	34.9
G (183 GHz)	16.1	23.3
G (205 GHz)	15.2	22.1

TROPICS spatial resolution (shown in km) for W-, F-, and G-band channels are shown at nadir and averaged over the 81 footprints in the swath.

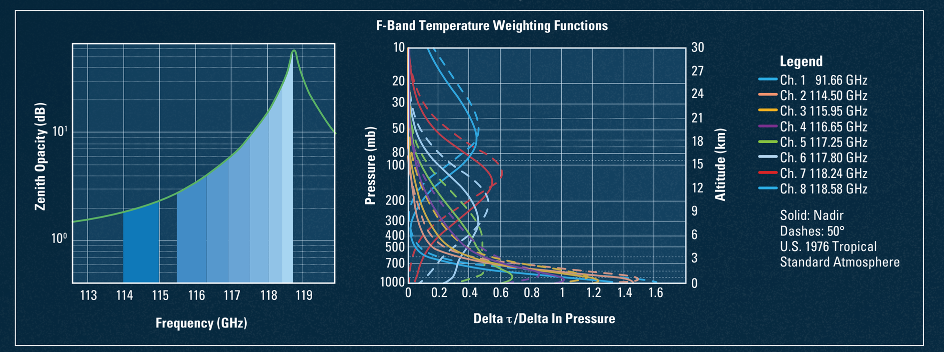
PL-F-1



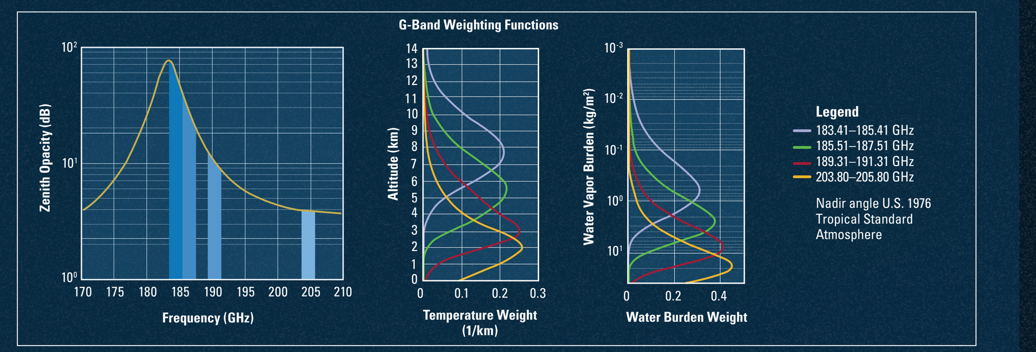
PL-F-2



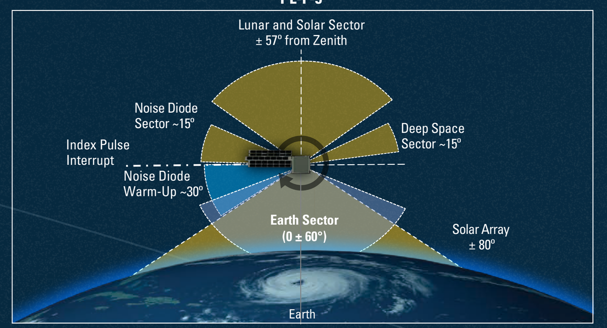
PL-F-3



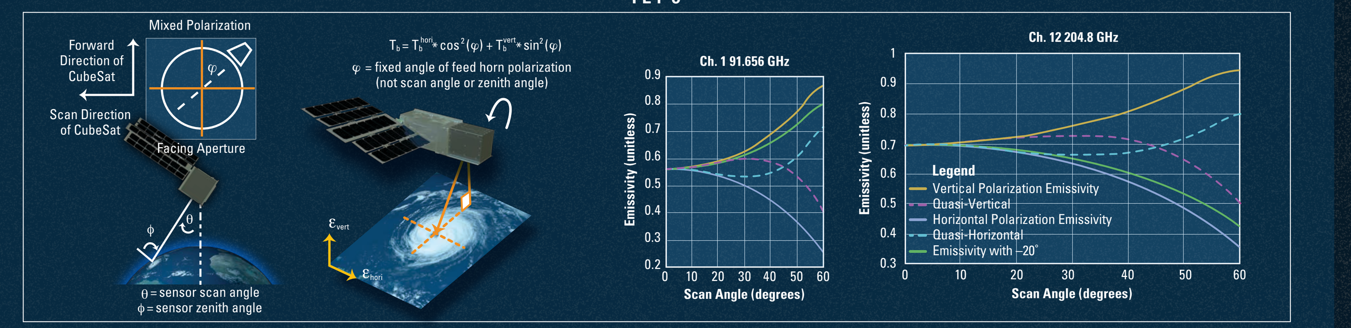
PL-F-4



PL-F-5



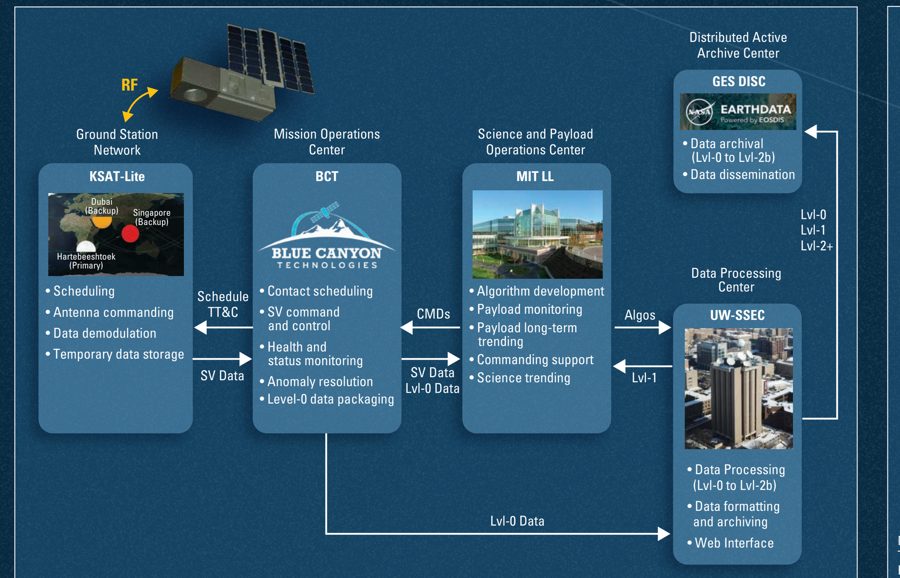
PL-F-6



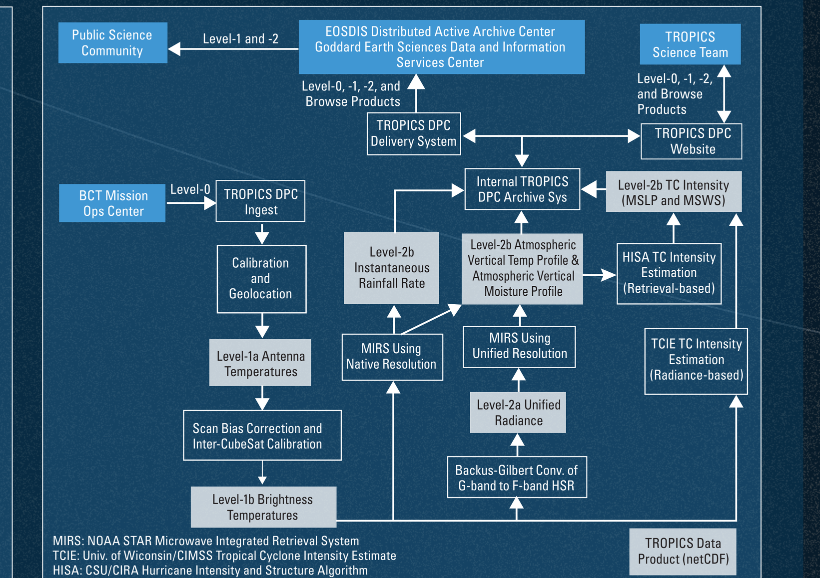
Ground Segment

The TROPICS SVs will interface with the ground station network, Kongsberg Satellite Services AS (KSAT), to allow for SV command and control and downlink of bus and payload telemetry for each member of the constellation. The SV prime contractor, Blue Canyon Technologies, will run the Mission Operations Center (MOC) out of their offices in Boulder, CO. Stored mission data will be downlinked at S-band. The MOC will provide the data to the Data Processing Center (DPC) for processing the data from raw data (Level-0) to radiances (Level-1) and finally geophysical parameters (Level-2). The DPC is lead by the University of Wisconsin Space Science and Engineering Center (UW-SSEC). TROPICS will archive the data to the Goddard Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Center in a format approved by NASA Earth Science Data Systems. MIT LL hosts the TROPICS Science and Payload Operations Center to monitor payload performance and trend data products.

GS-F-1



GS-F-2



Data Products

The TROPICS observatory will provide a set of products as shown in Table DP-T-1, including raw (uncalibrated) radiometric counts, calibrated and geolocated radiances, temperature and moisture profiles, rain rate, and tropical cyclone intensity indicators. Details on these products and their use in the TROPICS science program are described below.

Table DP-T-2 is the latest estimated performance of the TROPICS data products using the various data sets. Two proxy data sets used by the team are A) Hurricane Nature Run (Nolan 2013) and Community Radiative Transfer Model (CRTM) combination, and B) FY-3C MWHS-2 radiance measurements at 118 and 183 GHz.

Table DP-T-3 is a list of the TROPICS documents that will be available to the public along with the heritage of the algorithms.

Proxy Data

A) Simulated HNR

- Hurricane Nature Run 1 (Nolan 2013), over 4 TC over life cycle
- Community Radiative Transfer Model
- Simulated TROPICS spec. (along with simulated ATMS spectral)
- Mean revisit rate simulated through orbital parameters
- Final releases will be in final data format for ground segment testing
- All algorithms will use this proxy data for performance and checkout

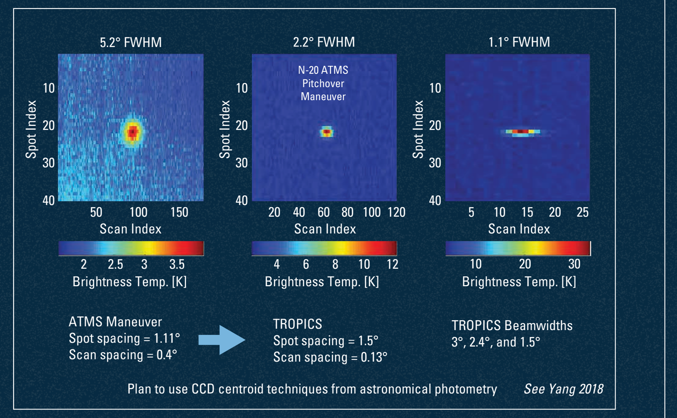
B) FY-3C MWHS-2

- Actual 118 and 183 GHz TC measurements
- FY-3C MWHS-2 specifications (e.g., Horizontal Spatial Resolution)
- TROPICS channels can be simulated by differencing MWHS-2 channels
- ~400 TC global overpasses from 2013 to 2017 (have ATMS overpasses to compare)
- Matched overpasses with ATCF hurricane database
- Primarily for TC intensity performance (TCIE)

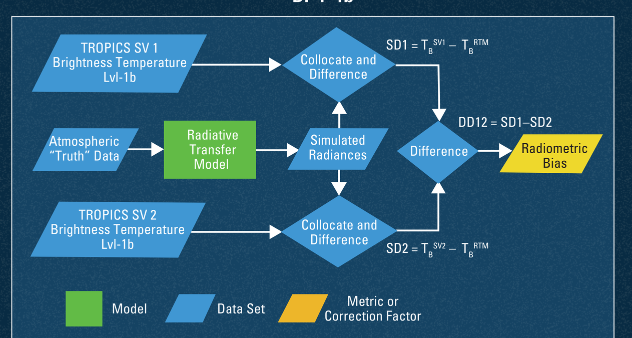
Data Product Algorithm Highlights—Level-1 Radiance Algorithm:

- **Level-1a Antenna Temperature**
  - Timestamped and geolocated
  - Calibrated antenna temperature using deep space and noise diode
  - Static nonlinearity correction (derived from TVac calibration)
- **Level-1b Brightness Temperature**
  - First-principle scan-bias correction (static)
    - Uses antenna patterns and model with contributions from Earth, deep space, and spacecraft
    - Uses two terms: multiplicative and additive (number of spots × number of channels)
  - Daily dynamic empirical scan-bias correction
    - GMAO GOES-5 NWP residual scan bias
    - Additive term only (number of spots × number of channels)
  - Daily dynamic noise diode correction (derived from lunar/solar intrusion; see Figure DP-F-1a)
  - Each of the three L-1b corrections will be included as separate variables in the data to be removed by users if they want

DP-F-1a



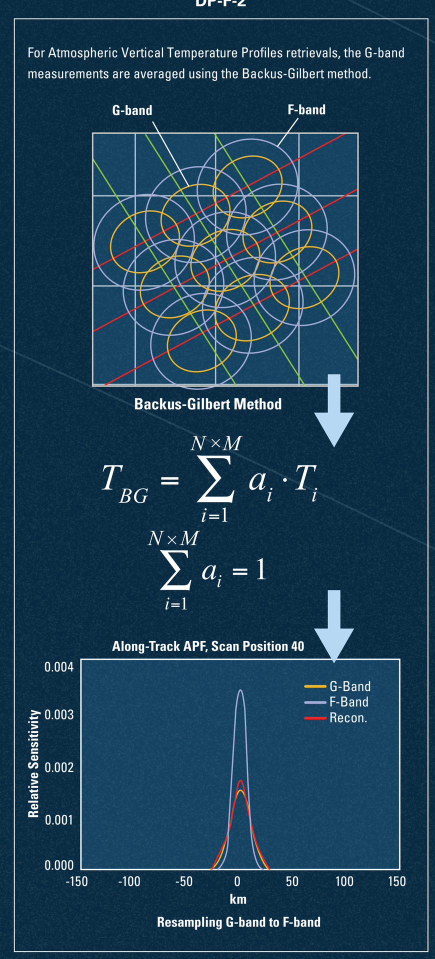
DP-F-1b



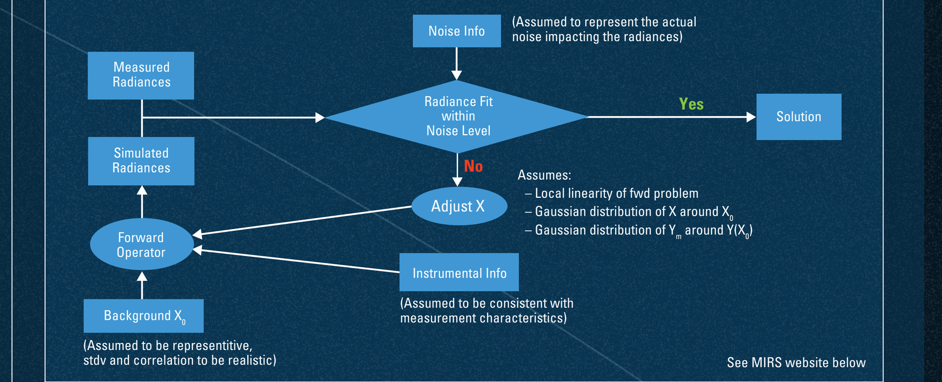
DP-T-2

Product	Threshold Requirement (Uncertainty)	Baseline Requirement (Uncertainty)	Expected Performance (CBE) (Uncertainty)
Temperature Profile	2.5 K	2.0 K	1.5 K
Moisture Profile	35%	25%	18.3%
Rain Rate	50%	25%	18.3%
Min Sea-Level Pressure	12 hPa	10 hPa	7.8 hPa
Max Sustained Wind	8 m/sec	6 m/sec	5.4 m/sec

DP-F-2



DP-F-3



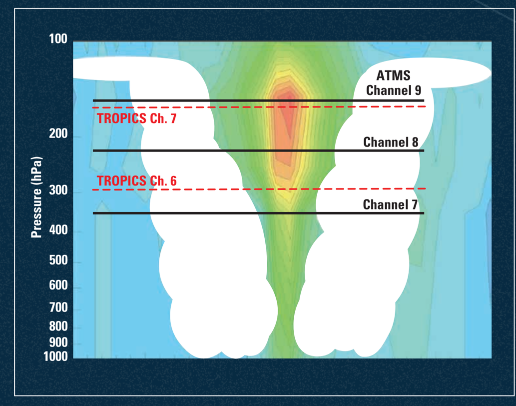
The TROPICS Atmospheric Vertical Temperature and Moisture Profiles (AVTP and AVMP) and Instantaneous Surface Rain Rate (ISRR) will leverage existing algorithms that meet requirements, have been extensively tested and proven robust in operations, and save development cost. TROPICS has adapted the NOAA/NESDIS/STAR Microwave Integrated Retrieval System (MIRS) to the TROPICS payload (Boukabara 2011). The MIRS 1DVAR approach to the retrieval problem incorporates a sophisticated forward operator, which the heritage algorithms do not have, that fully assimilates all sensor radiance measurements (see Figure DP-F-3). For TROPICS, the background state, i.e., initial guess, will use deep learning trained on an NWP and radiosonde data set (Blackwell 2009).

Tropical cyclone intensity algorithms estimate two primary variables: Minimum Sea Level Pressure (MSLP) and Maximum Sustained Winds (MSW). Two independent intensity estimation methods are included: 1) the Tropical Cyclone Intensity Estimate (TCIE) algorithm developed at the University of Wisconsin/CIMSS (Herndon and Velden 2018) that uses native microwave brightness temperatures, and 2) the Hurricane Intensity and Structure Algorithm (HISA) developed at Colorado State University/CIRA (Demuth 2006) that uses microwave retrievals of temperature, moisture, and integrated quantities. In addition to MSW and MSLP, HISA also provides estimates of surface wind radii and 2D winds at standard pressure levels.

In general, both approaches rely on the well-established hydrostatic relationship between the warm core that appears as a TC develops, and its concurrent surface intensity (MSLP and MSW). The TCIE approach is to take observed brightness temperature (Tb) anomalies from selected microwave channels in the middle- to upper-troposphere (i.e., Fig. DP-F-4) and use them to estimate the TC intensity. While the sounder-observed Tb anomaly is nearly always a fraction of the true temperature anomaly (20–50% for existing sounders), a sufficient signal exists with the appropriate corrections to calibrate it and derive estimates of TC intensity.

The HISA approach utilizes retrieved fields of temperature and moisture to derive the TC intensity and structure parameters (Demuth et al., 2006). This method will integrate AVTP and AVMP retrievals combined with Global Forecast System (GFS, GFS 2017) model boundary conditions to provide the azimuthally averaged potential height field and solve the gradient wind equation. Using the symmetrical height, temperature, and wind field, HISA will then use a multiple regression approach to obtain the objective estimates of MSW and MSLP.

DP-F-4



Level-1 Radiance Validation

- Direct radiance comparisons:
  - Intra-TROPICS overpasses (not necessarily nadir)
  - Cross-instrument SNO or Double Difference:
    - W- and G-band can be compared with operational instruments
    - F-band can be compared against Chinese FY3C and FY3D MWHS-2
- Simulated radiances comparisons
  - Use CRTM and in-line radiative transfer models
  - Radiosondes
    - Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN)
    - The NOAA IGRA
  - GNSS-RO (opaque F-band channels)
  - NWP (best option for scan bias monitoring)

Summary and Acknowledgments

Summary

TROPICS is a cost-effective science mission utilizing CubeSats to learn more on the dynamics of Tropical Cyclones. With an estimated launch in late 2019 or early 2020 of six space vehicles (two in three orbital planes), TROPICS will offer unprecedented revisit rates of passive microwave radiometry over TCs. NASA and TROPICS are committed to providing the public the mission data and documentation.

Acknowledgments

The authors would like to thank the MIT LL TROPICS bus and payload leads: Andy Cunningham (Bus), Jay Eshbaugh (Payload RF), Jeff Shultz (Payload Electronics), and Dave Crompton (Chief Engineer); the TROPICS Instrument Team: Kerri Cahoy (MIT SSL), Angie Crews (MIT SSL), and Mike Grant (NASA Langley), the TROPICS Ground Segment lead: Shawn Donnelly, and the TROPICS management: Kris Clark (PM), Steven Michael (DPM), Tom Roy (DPM), and Linda Fuhrman (PSE).

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This material is based upon work supported by the National Aeronautics and Space Administration under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.