National Aeronautics and Space Administration
Goddard Earth Science Data Information and Services Center (GES DISC)

User Guide for TROPICS Data Products

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https://tropics.ll.mit.edu

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1.0 Introduction

This document provides information for using the data products available from the "Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats" (TROPICS) mission. The TROPICS mission will produce a range of data products that will be available at the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC).

The data products will be produced at the TROPICS Data Processing Center (UW-M SSEC), and consist of Level-1 radiances (antenna and brightness temperatures), Level-2a unified resolution radiance, Level-2b Atmospheric Vertical Temperature Profiles (AVTP), Level-2b Atmospheric Vertical Moisture Profiles (AVMP), Level-2b Instantaneous Surface Rain Rate (ISRR), and Level-2b Tropical Cyclone (TC) intensity algorithms to 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 algorithm (TCIE) developed at the University of Wisconsin/CIMSS using native microwave brightness temperatures and 2) the Hurricane Intensity and Structure Algorithm (HISA) developed at Colorado State University/CIRA using 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. TROPICS is adapting the NOAA STAR Microwave Integrated Retrieval System (MIRS) to retrieve the AVTP and AVMP data products. The ISRR algorithm uses the NASA Goddard Precipitation Retrieval and Profiling Scheme (PRPS).

1.1 Mission Description

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 three-dimensional 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 to address these 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

TROPICS comprises a constellation of six identical Space Vehicles (SVs) conforming to the 3U form factor and hosting a passive microwave spectrometer payload. The six 3U small satellites are divided into three low-Earth orbital planes to make up the constellation and are due to launch in early 2022. A single 3U small satellite, named Pathfinder and TROPICS-01, launched ahead of the constellation in June 2021, but has a different orbital plane (sun-synchronous).

1.1.1 Launch Segment

The constellation members will be flown in a circular Low Earth Orbit (LEO) in nearly equally-spaced orbital planes, with a pair of satellites populating each orbital plane. Each orbit inclination will be roughly 30°. 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.

Astra Space Inc. was awarded the TROPICS constellation launches. The three constellation launches from the Cape Canaveral are scheduled for early 2022. A seventh TROPICS space vehicle, called the Pathfinder, launched on the SpaceX Transporter 2 into a sun-synchronous orbit (LTAN 02:05 on 1Aug2021 with approximately -30 second drift per month), which was provided by Maverick Space Systems. Figure 1 illustrates the orbital path of the six space vehicle constellation. Table 1 contains the orbital parameters of the constellation and the Pathfinder.

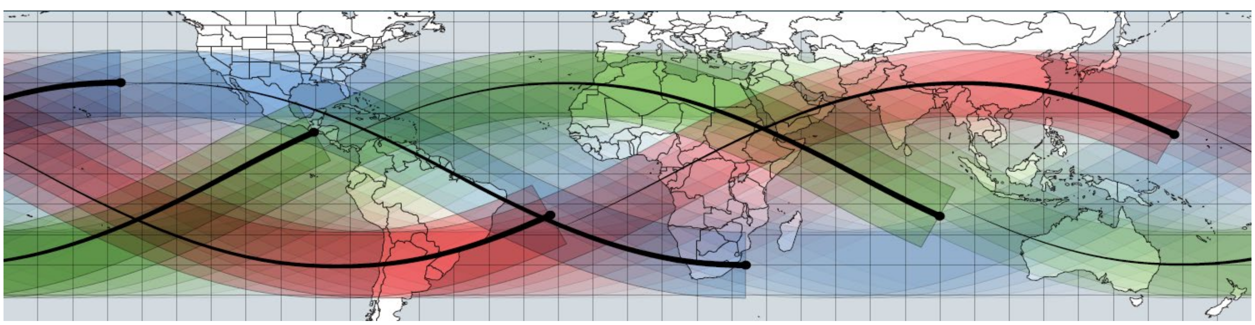


Figure 1 – Illustration of the six space vehicle constellation. Each color is a separate orbital plane (~30˚inclination) with two space vehicles each. The width of the colored bar is approximately the surface covered by the passive microwave instrument (i.e., swath width).

Table 1 – Constellation and Pathfinder Orbital Parameters

Orbit Parameter	Pathfinder	Constellation Launch #1	Constellation Launch #2	Constellation Launch #3
SV ID	1	2 & 4	5 & 6	3 & 7
Altitude (km)	528.8 – 544.2	550±20	550±20	550±20
Inclination (deg.)	97.51	30±3˚	30±3˚	30±3˚
Longitude of the ascending node (deg.)	330.29	TBD (L1)	L1 + 120±10	L1+240±10
Launch date/time yyyy-mm-dd HH:MM:SS.SSS	2021-06-30 T19:31:00.178Z	Mar. 1, 2022 (TBC)	Apr. 1, 2022 (TBC)	May 1, 2022 (TBC)
NORAD ID	48901	TBD	TBD	TBD

1.1.2 Space Segment

Each identical SV has a passive TROPICS Millimeter-wave Sounder (TMS) instrument with an antenna mounted on a rotating axis that spins about the long axis of the SV. The long axis is aligned to the satellite velocity vector such that the spectrometer will record measurements along a line perpendicular to the satellite velocity in a "pushbroom" fashion that maximizes the area scan rate of the instrument. Each SV records the raw passive microwave data (100% duty cycle) and relays the raw data to the ground, where the data will be processed to produce the temperature and moisture profiles.

The TMS instruments was designed and built by MIT Lincoln Laboratory (MIT LL) and the spacecraft bus will be built by Blue Canyon Technologies. The TROPICS core instrument is a cross-track scanning passive millimeter-wave spectrometer that provides measurements of upwelling thermal emission and scattering of the Earth's atmosphere. Measurements are taken in twelve channels near atmospheric absorption features of oxygen and water vapor. Processing of the raw radiance values measured by the spectrometer yields atmospheric temperature, moisture, rain rates, and other information relevant to precipitation structure and storm intensity. Instrumentation needed to make these measurements has been used in space for decades and 3ultra-compact instrumentation for small satellite implementation is now available with a high technology readiness level.

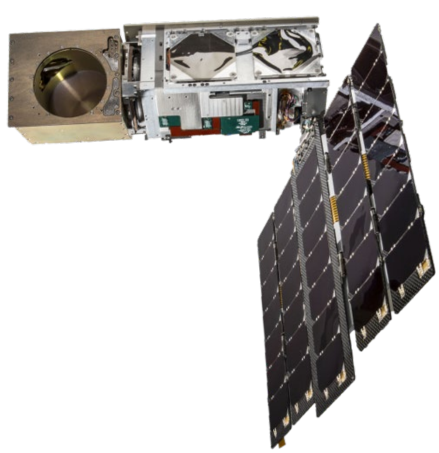


Figure 1 – TROPICS Space Vehicle (SV)

1.1.3 Ground Segment

The TROPICS ground operations mission is comprised of five different entities: Ground Station Network (GSN), Mission Operations Center (MOC), Science & Payload Operations Center (SPOC), Data Processing Center (DPC), and Distributed Active Archive Center (DAAC). Figure 2 shows the mission operations functional flow between the five entities.

The TROPICS mission partners are:

- GSN (KSAT-Lite): The GSN functions as the Radio Frequency (RF) interface to the TROPICS Space Vehicles (SVs).
- MOC (Blue Canyon Technologies (BCT)): The MOC provides mission operations for all stages of the TROPICS mission life cycle.
- SPOC (MIT Lincoln Laboratory (MIT LL)): The SPOC supports both payload operations and science data processing.
- DPC (University of Wisconsin - Madison (UW-M)): The DPC supports the processing of Level 1a to Level 2b data products.
- DAAC (Goddard Earth Sciences Data and Information Services Center (GES DISC)): The DAAC provides long term archival of all data products collected from the TROPICS program. The DAAC also provides access to the public for Level 1a to Level 2b science data.

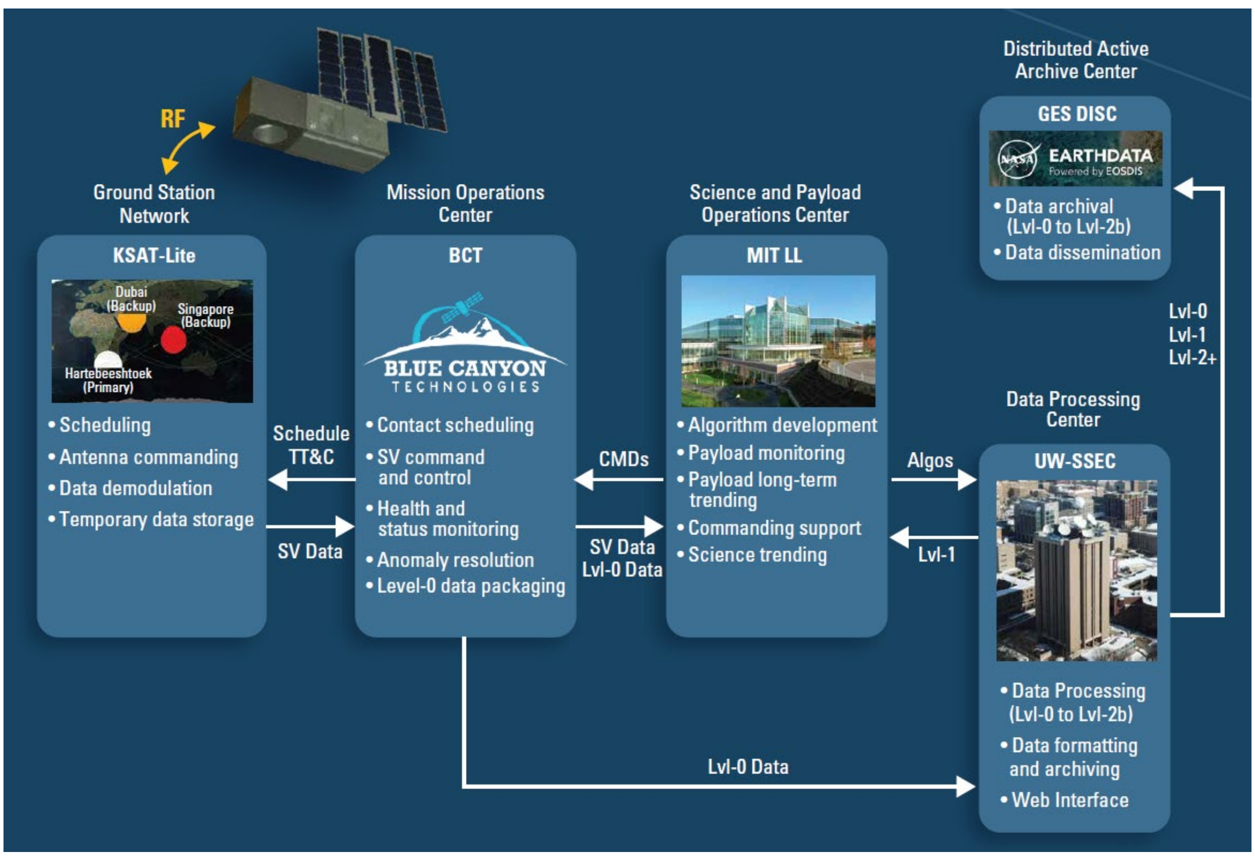


Figure 2 – Mission Operations Functional Flow

The TROPICS DPC processes all data products for the TROPICS mission. The TROPICS Science Team provided the L2 algorithms and the TROPICS Instrument Team provided the L0 and L1 algorithms. DPC integrated the algorithms into their processing architecture and prepare the data to be transferred to the GES DISC DAAC with all supporting information for archiving and dissemination. Figure 3 shows the interdependencies of the various TROPICS data products.

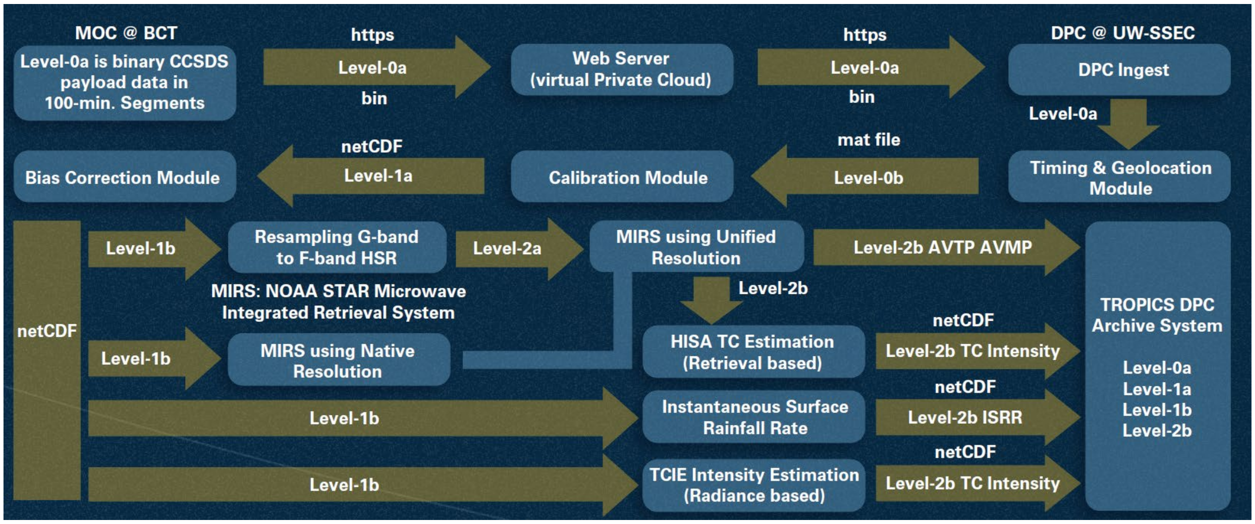


Figure 3 TROPICS data product flow chart throughout the DPC showing interdependencies between the various TROPICS data products. Inputs come from the BCT MOC and outputs go to the GES DISC DAAC.

1.2 Instrument Description

Each SV hosts an identical high-performance spectrometer named the TROPICS Millimeter-wave Sounder (TMS) that will 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 near 205 GHz that is more sensitive to cloud-sized ice particles. For further description of the payload, pre-launch accuracy and precision (i.e., NEDT), please see the TROPICS L1 Radiance Algorithm Theoretical Basis Document.

1.2.1 Spectral Characteristics

To properly retrieve temperature and moisture profiles, each channel's spectral characteristics are carefully chosen to optimize the atmospheric weighting functions. For more details, see the TROPICS Atmospheric Vertical Profile Algorithm Theoretical Basis Document (ATBD). Table 2 has each channel's center frequency and bandwidth goal, but due to manufacturing variability, each TMS will have a different spectral response.

The TMS instrument team measured the spectral response of all seven SVs and produced digitized parameters that were given to the Joint Center for Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM) team. The team produced individual CRTM coefficients for each TROPICS SV. When using CRTM, make sure to use the appropriate CRTM coefficients for SV data. The European RTTOV (Radiative Transfer for TOV) also has coefficients using the spectral response functions. See the L1 Radiance ATBD for more information on the spectral response functions.

The TROPICS G-band or moisture sounding channels are not the typical double-sideband hardware implementation from the heritage sensors like the Advanced Technology Microwave Sounder (ATMS). It should be noted that TROPICS channel 9 is closest to the absorption line and most similar to the 183±1 GHz channel. Furthermore, TROPICS channel 10 and 11 are most similar to 183±3 GHz and 183±7 GHz, respectively. The F-band channel's absorption line is at 118.75 GHz, so the most opaque (highest peaking weighting function is channel 8).

Table 2 – TROPICS spectral, spatial, and NEdT characteristics (Footprint from 550-km altitude)

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	0.60
2	114.50	1.000	114.00-115.00	2.4/2.62	24.1	1.00
3	115.95	0.800	115.55-116.35	2.4/2.62	24.1	0.90
4	116.65	0.600	116.35-116.95	2.4/2.62	24.1	0.90
5	117.25	0.600	116.95-117.55	2.4/2.62	24.1	0.90
6	117.80	0.500	117.55-118.05	2.4/2.62	24.1	0.90
7	118.24	0.380	118.05-118.43	2.4/2.62	24.1	0.90
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

1.2.2 Spatial Resolution

The TMS spatial resolution is primarily due to the antenna pattern Full-Width Half Maximum (FWHM) beam width, space vehicle altitude, and the integration time and spin rate of the payload. Table 2 has the general beam width for each channel and the resulting geometric mean of the nadir spot. The cross-track beam width includes the smearing of the antenna pattern during the 1/120 second integration period. There are 81 measurements or "spots" measured on the Earth, which produces a swath from each scan that is 2200 km wide. See Figure 4 for an illustration of the resulting measurement pattern on the Earth's surface. The forward SV velocity will produce a 15.2 km spacing between scan (i.e., payload rotations). The integration period of the constant velocity scan will produce a 14.4 km spacing between spots within a scan (near nadir).

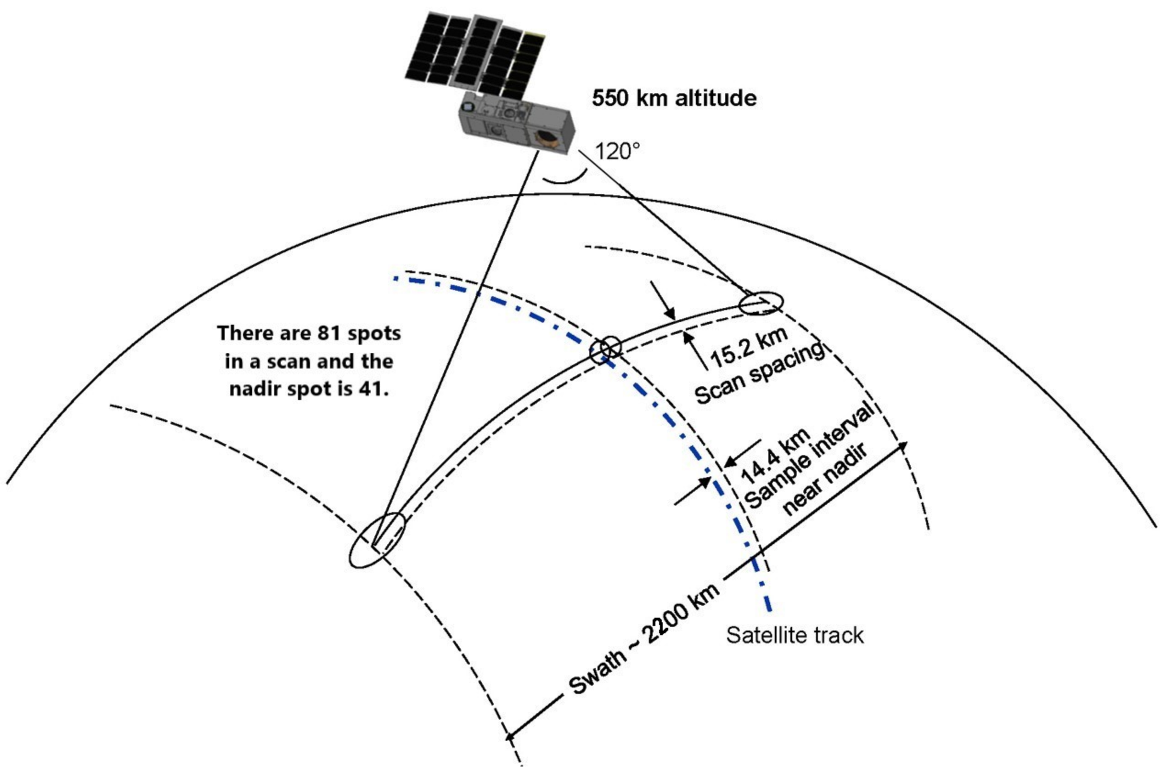


Figure 4 – Illustration of the radiometric measurements projected on to the surface of the Earth. The cross-track spacing is 14.4 km and the along-track spacing is 15.2 km.

Table 3 contains a summary of the changing spatial resolution throughout the scan with the smallest resolution near the nadir spot. For footprint dimensions of each spot, see the L1 Radiance ATBD appendix. Cross-track means the direction of the scan that is perpendicular to the SV velocity vector and Down-track (or along-track) is the direction of the SV velocity vector. There has been no attempt at this time to interpolate the 81 spots on the Earth's surface to a standardized grid.

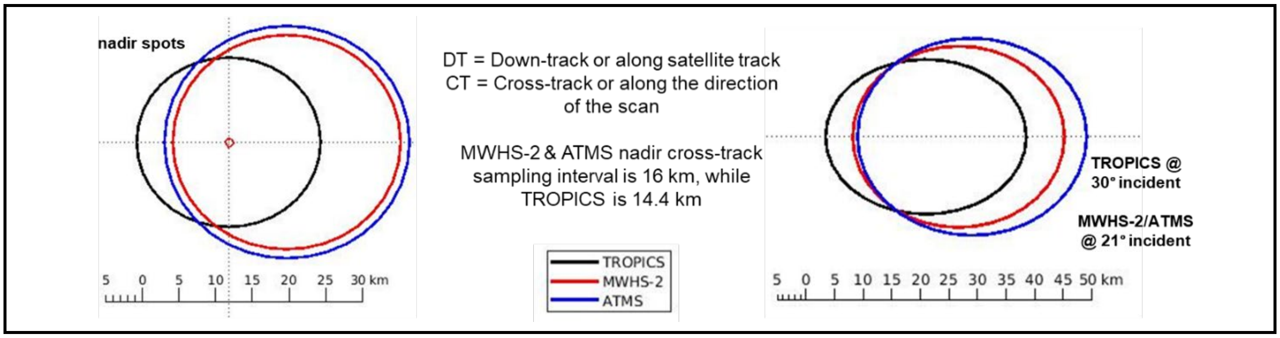
Table 3 – TROPICS Native Spatial Resolution Summary

Channels	Band	Geometric mean diameter of nadir Spot 41 (km)	Geometric mean diameter of Spot 20 or 61 with Cross-track/Down-track diameter (km)	Geometric mean diameter of Spot 1 or 81 with CT/DT diameter (km)
1	W-band	29.6	38.9 (32/44)	121.1 (215/68)
2-8	F-band (Unified Temperature)	24.1	27.5 (37/28)	98.3 (177/55)
9-12	G-band (Moisture)	16.1	21.1 (26/17)	65.4 (126/34)

It is common with new sensors to compare them against the heritage sensors. Table 4 has a comparison between TROPICS and the Advanced Technology Microwave Sounder (ATMS) on the NOAA polar-orbiting satellites and the MicroWave Humidity Sounder 2 (MWHS-2) on the China Meteorological Administration (CMA)'s Feng Yun (FY)-3C polar orbiting satellite. Even though ATMS doesn't have F-band channels, the roughly similar V-band temperature sounding channels are shown. There are illustrations of a couple of spots at the bottom of the table.

Table 4 – Spatial Resolution Comparison with ATMS and MHWS-2

Band	TROPICS Nadir Resolution (km)		MWHS-2 Nadir Resolution (km)		ATMS Nadir Resolution (km)	
	DT	CT	DT	CT	DT	CT
W-band (90 GHz)	27.2	28.9	29.2	31.2	31.6	33.6
F- or V-band 118 or 50 GHz (AVTP)	23.0	25.2	29.2	31.2	31.6	33.6
G-band 183 GHz (AVMP)	14.4	17.9	16.1	20.0	15.8	19.8



1.2.3 Granulation

Each TROPICS NetCDF file contains a granule of data with 81 spots and approximately 2880 scans with exception of the TC intensity algorithms that only perform estimates on tracked TCs. TROPICS defines a granule as an orbit's worth of data. Granule start and end times are defined by the time that the SV has an ascending equatorial crossing, which covers an orbital period of approximately 97 minutes or approximately 2880 scans. TROPICS also supplies an orbit number that starts on the release time of the SV. An example can be seen in Figure 7 with the beginning ascending equatorial crossing on the right and the end ascending equatorial crossing on the left.

1.3 Data Products

1.3.1 Data Product Overview

The TROPICS data products are listed below. Descriptions of the spatial sampling and resolution can be found in Section 1.2.2. The data products are provided individually for each space vehicle. Presently, there are no plans to provide combined space vehicle data products (i.e., multiple SV measurements in the same file). Descriptions of the algorithms can be found in the five standalone Algorithm Theoretical Basis Documents (ATBDs). The TROPICS ATBDs are L1 Radiance covering the L1a and L1b; L2a Unified Resolution Radiometric Product; L2b Atmospheric Vertical Profiles covering the temperature profiles, moisture profiles, and integrated water vapor (i.e., Total Precipitable Water); L2b Instantaneous Surface Rain Rate; and L2b TC Intensity covering the maximum sustained wind speed and minimum sea-level pressure metric of TC intensity.

- **Level-1a Antenna Temperatures** – geolocated antenna temperatures (radiance) in units of kelvins that are timestamped to UTC and are reported at native spatial resolutions
- **Level-1b Brightness Temperatures** – geolocated brightness temperatures (radiance) in units of kelvins that are timestamped to UTC and are reported at native spatial resolutions
- **Level-2a Unified Resolution Brightness Temperatures** – geolocated brightness temperature with the water vapor sounding channels (Ch. 9 to 12) converted from their native G-band resolution to the temperature sounding channel (F-band) native resolution (i.e., all measurements at the same unified larger resolution). This product is used in the Atmospheric Vertical Temperature Profile (AVTP) retrievals to gain the benefit of averaging the G-band

channels (i.e., noise reduction) while maintain the F-band (AVTP) spatial resolution. The conversion uses the Backus-Gilbert technique.

- **Level-2b Atmospheric Vertical Temperature Profiles (AVTP)** – vertical retrievals of temperature are made in non-precipitating conditions from surface to 20-km altitude at the F-band spatial resolution in units of kelvins. The TROPICS retrievals adapted the NOAA/NESDIS/STAR Microwave Integrated Retrieval System (MIRS) to the TROPICS payload.
- **Level-2b Atmospheric Vertical Moisture Profiles (AVMP)** – vertical retrievals of moisture (i.e., water vapor) are made in non-precipitating conditions from surface to 10-km altitude at the G-band spatial resolution in units of g/kg. The TROPICS retrievals adapted the NOAA/NESDIS/STAR Microwave Integrated Retrieval System (MIRS) to the TROPICS payload. The only other geophysical retrieval provided from the MIRS algorithm is the Total Precipitable Water (mm) at the G-band spatial resolution.
- **Level-2b Instantaneous Surface Rain Rate (ISRR)** – retrievals of instantaneous surface rain rate in units of mm/hr at G-band spatial resolution. The algorithm was adapted from the NASA Goddard Precipitation Retrieval and Profiling Scheme (PRPS).
- **Level-2b Maximum Sustained Wind Speed (MSWS)** – Tropical Cyclone (TC) intensity algorithm that estimates MSWS in units of m/s. Retrieval target TC are obtained from the respective warning agency TC bulletin information (CARQ file or ATCF working best track). TROPICS provides two estimates of MSWS: Tropical Cyclone Intensity Estimate algorithm (TCIE) developed at the University of Wisconsin/CIMSS and Hurricane Intensity and Structure Algorithm (HISA) developed at Colorado State University/CIRA.
- **Level-2b Minimum Sea-Level Pressure (MSLP)** – Tropical Cyclone (TC) intensity algorithm that estimates MSLP in units of hPa. Retrieval target TC are obtained from the respective warning agency TC bulletin information (CARQ file or ATCF working best track). TROPICS provides two estimates of MSLP: 1) Tropical Cyclone Intensity Estimate algorithm (TCIE) developed at the University of Wisconsin/CIMSS and 2) Hurricane Intensity and Structure Algorithm (HISA) developed at Colorado State University/CIRA.

1.3.2 Data Product Maturity

TROPICS data products will follow a similar maturity progress as the NASA SMD process. The data maturity levels for TROPICS will proceed through beta, provisional, validated stage 1, and validated stage 2. Each product on each space vehicle will go through maturity levels. The status of the various Pathfinder data product maturity levels can be found at this DPC website: https://tropics.ssec.wisc.edu/42-2/ , which will be updated for the constellation at a later date.

1.4 Data Latency

The objectives of the TROPICS mission are to answer the scientific questions in Section 1.1 and, therefore, did not have a "measurement to ground station" or space latency requirement like an operational mission would have. The project's latency requirement is a ground latency (versus the space latency), which covers from the ground station to the DAAC and has a current best estimate of three hours. Once Pathfinder is on-orbit and the DPC is running, this value will be updated with actual statistics.

With limited funding and without a space latency requirement, the TROPICS mission plans to have a nominal two ground station contacts per day, which will approximately provide the previous twelve hours of data. This will mean the space latency can be up to approximately twelve hours, which will need to add the ground latency.

2.0 Obtaining the Products

The TROPICS data products are developed by the TROPICS Instrument and Science Team and processed in collaboration with the University of Wisconsin - Madison. The raw data is downlinked from the TROPICS mission satellites, routed through the TROPICS Data Processing Center for processing, then transferred to the long-term archive at the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC). https://disc.gsfc.nasa.gov. Use the ECS Shortnames found in Table 5 for the search string to find the TROPICS data products.

Table 5 – TROPICS data products Shortnames and descriptions. See Table 3 for spatial resolution summary. (0? is the space vehicle ID, e.g., Pathfinder is 01)

Short Name	Description
TROPICS0?ANTTL1A	Geolocated antenna temperature (radiance) in kelvins at native spatial resolution
TROPICS0?BRTTL1B	Geolocated brightness temperature (radiance) in kelvins at native spatial resolution
TROPICS0?URADL2A	Unified resolution radiometric product that resamples the G-band channels to match the F-band spatial resolution
TROPICS0?MIRSL2B	1) Geophysical retrieval of atmospheric vertical temperature (kelvins) at the larger unified F-band resolution. 2) Retrieval of vertical moisture (g/kg) at the finer G-band spatial resolution 3) Total Precipitable Water (mm) at the finer G-band spatial resolution.
TROPICS0?PRPSL2B	Instantaneous surface rain rate (mm/hr) at the finer G-band spatial resolution

Short Name	Description
TROPICS0?TCIEL2B	Tropical Cyclone (TC) intensity algorithm that estimates two primary variables: Minimum Sea Level Pressure (MSLP) and Maximum Sustained Winds (MSW). This is the Tropical Cyclone Intensity Estimate algorithm (TCIE) developed at the University of Wisconsin/CIMSS that uses native microwave brightness temperatures
TROPICS0?HISAL2B	Tropical Cyclone (TC) intensity algorithm that estimates two primary variables: Minimum Sea Level Pressure (MSLP) and Maximum Sustained Winds (MSW). This is the Hurricane Intensity and Structure Algorithm (HISA) developed at Colorado State University/CIRA 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.

2.1 GES DISC Data Services

Located at the Goddard Space Flight Center in Greenbelt, Maryland, GES DISC is one of twelve NASA Science Mission Directorate Data Centers that provide Earth science data, information, and services to research scientists, applications scientists, applications users, and students. GES DISC archives and supports data sets applicable to several NASA Earth Science Focus Areas including: Atmospheric Composition, Water & Energy Cycles, and Climate Variability.

If you need assistance or wish to report a problem:
Email: gsfc-dl-help-disc@mail.nasa.gov
Voice: 301-614-5224
Fax: 301-614-5268
Address:
Goddard Earth Sciences Data and Information Services Center NASA Goddard Space Flight Center Code 610.2 Greenbelt, MD 20771 USA

2.1.1 How-To Articles

The GESDISC web site contains many articles under the "How To Section", "FAQ" (frequently asked questions), "News", "Glossary", and "Help." A sample of these articles includes:

- Earthdata Login for Data Access
- How to Download Data Files from HTTPS Service with wget
- How to Obtain Data in NetCDF Format via OPeNDAP
- Quick View Data with Panoply

- How to Read Data in NetCDF Format with R
- How to Read Data in HDF-5 or netCDF Format with GrADS
- How to read and plot NetCDF MERRA-2 data in Python
- How to Subset Level-2 Data
- How to use the Level 3 and 4 Subsetter and Regridder

2.2 Filename Convention

TROPICS data products will be following the filename nomenclature outlined below. Examples are given in Table 6. Two filenames are defined as:

TROPICS<*spacevehicle_id*>.<*algorithm*>**.L**<*level*>**.Orbit**<*orbit*>**.V**<*version*>**.ST**<*start*>**.ET**<*end*>**.CT**<*creation*>**.nc**

TROPICS<*spacevehicle_id*>.<*algorithm*>**.L**<*level*>**.Orbit**<*orbit*>**.V**<*version*>**.OT**<*overpass*>.<*ATCF id*>**.CT**<*creation*>**.nc**

where:

spacevehicle_id	launch order of the satellite (01-07)
algorithm	algorithm or data product name (ANTT, BRTT, URAD, MIRS, PRPS, TCIE, & HISA)
level	level identifier product name (1A, 1B, 2A, & 2B)
orbit	orbit number with five digits
version	algorithm version number XX-YY following XX.YY semantic versioning methodology, with XX is the major version number and YY is the minor version number
start	data start time in YYYYMMDD-HHMMSS UTC date/time format
end	data end time in YYYYMMDD-HHMMSS UTC date/time format
overpass	overpass time in YYYYMMDD-HHMMSS UTC date/time format
ATCF id	ATCF ID taken from the ATCF -a/b deck files used to generate the product. The ATCF ID includes the basin abbreviation (AL, EP, CP, WP, IO, SH), the storm number, and the year. The storm number is always a 2-digit number between 01 and 49. For invests, the number is from 90 to 99. The year is in YYYY format.
creation	file creation time YYYYMMDD-HHMMSS UTC date/time format

Table 6 – TROPICS data products Shortnames with example filenames (note 0? is replaced by SV ID)

Short Name	Example Filename
TROPICS0?ANTTL1A	TROPICS01.ANTT.L1A.Orbit00119.V01-00.ST20190408-204530.ET20190408-222035.CT20210101-214129.nc

TROPICS0?BRTTL1B	TROPICS03.BRTT.L1B.Orbit00119.V01-00.ST20190408-204530.ET20190408-222035.CT20210101-214129.nc
TROPICS0?URADL2A	TROPICS01.URAD.L2A.Orbit00000.V01-00.ST20050806-052500.ET20050806-053458.CT20201028-170800.nc
TROPICS0?MIRSL2B	TROPICS01.MIRS.L2B.Orbit00000.V01-00.ST20050804-054500.ET20050804-055458.CT20201109-162852.nc
TROPICS0?PRPSL2B	TROPICS01.PRPS.L2B.Orbit00000.V01-00.ST20050805-053500.ET20050805-054458.CT20200810-193035.nc
TROPICS0?TCIEL2B	TROPICS01.TCIE.L2B.Orbit00000.V01-00.OT20050804-011500.AL012019.CT20201001-121314.nc
TROPICS0?HISAL2B	TROPICS01.HISA.L2B.Orbit00000.V01-00.OT20050804-011500.AL012019.CT20201001-121314.nc

2.3 File Format and Structure

The TROPICS files are in Network Common Data Form, Version 4.7.3 / Hierarchical Data Format Version 5 (NetCDF4/HDF5) format (NetCDF=4.7.3 HDF5=1.8.12). NetCDF is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data that was developed by UCAR/Unidata.

http://doi.org/10.5065/D6H70CW6

https://www.unidata.ucar.edu/software/netcdf/

2.4 Data Product Availability

TROPICS data products availability will be monitored and reported by the TROPICS DPC website: https://sips.ssec.wisc.edu/dawg2-availability/main, but all data products will only be available to the public through the GES DISC DAAC (see next section).

2.5 Worldview Quicklooks

TROPICS data products will be made available on the NASA Worldview website. Worldview is a software tool designed for interactively browsing and downloading imagery from NASA's Earth observing satellites. Building upon a set of open source mapping and user interface libraries, it provides an environment to visually discover interesting phenomena as observed by NASA satellites then download the data for further analysis. The tool was originally designed to address the needs of the near real-time applications community to provide relevant information for time-critical scenarios such as wildfire and flood management. Satellite imagery is available for viewing in Worldview within four hours of observation. The imagery can be viewed in its highest, or native, resolution and the imagery can be panned and zoomed rapidly through space and time to find the most relevant information available.

NASA Worldview website: https://worldview.earthdata.nasa.gov/

2.6 Data Disclaimer

The TROPICS data products are released to the public as is. Every effort has been made to properly represent the data for which this document describes.

2.6.1 Data User Acknowledgement

MIT Lincoln Laboratory: William J. Blackwell (2021), TROPICS Level [Data Product Level and Name] V[Version ID], Greenbelt, MD, Goddard Earth Sciences Data and Information Services Center (GES DISC) Accessed: [Data Access Date]

Example:

MIT Lincoln Laboratory: William J. Blackwell (2021), TROPICS Level 1b Brightness Temperatures V02.00, Greenbelt, MD, Goddard Earth Sciences Data and Information Services Center (GES DISC) Accessed: 31 July 2021

2.6.2 Contact

For more information, questions, or concerns with the TROPICS data products or this document, contact Vince Leslie at: lesliev@LL.mit.edu

2.7 What's New?

This is the initial public release of the data products. All previous versions were pre-launch versions and will not be detailed in this document. All sequential versions will have their highlights documented here.

3.0 Options for Reading the Data

3.1 Command Line Utilities

3.1.1 ncdump

The ncdump tool can be used as a simple browser for HDF data files to display the dimension names and sizes; variable names, types, and shapes; attribute names and values; and optionally, the values of data for all variables or selected variables in a netCDF file. The most common use of ncdump is with the –h option, in which only the header information is displayed.

ncdump [-c|-h] [-v ...] [[-b|-f] [c|f]] [-l len] [-n name] [-d n[,n]] filename

Options/Arguments:

[-c] Coordinate variable data and header information

[-h] Header information only, no data

[-v var1[,...]] Data for variable(s) <var1>,... only data

[-f [c|f]] Full annotations for C or Fortran indices in data

[-l len] Line length maximum in data section (default 80)

[-n name] Name for netCDF (default derived from file name)

[-d n[,n]] Approximate floating-point values with less precision

filename File name of input netCDF file

For more information, refer to the website:
https://www.unidata.ucar.edu/software/netcdf/workshops/2011/utilities/Ncdump.html

3.1.2 HDFView

HDFView is a Java-based graphical user interface created by the HDF Group, which can be used to browse HDF files. The utility allows users to view all objects in an HDF file hierarchy, represented as a tree structure. See the links below for additional information about HDFView and HDF.

HDFView: https://support.hdfgroup.org/products/java/hdfview/

HDF: https://portal.hdfgroup.org/display/support

3.2 Tools/Programming

The product files can be read and queried using the NetCDF4 library and tools maintained by Unidata (http://www.unidata.ucar.edu/software/netcdf/). Support for reading NetCDF is offered in many programming languages, including Python, Matlab, IDL, C/C++ and Fortran. NetCDF4 files are legal HDF5 files with additional bookkeeping information managed by the NetCDF4 library. It is therefore possible to inspect and copy data out of the NetCDF4 files by using the HDF5 utilities and libraries maintained by the HDF Group, or by using the HDF5 interface in your favorite programming language. However, the two libraries should not be considered fully interchangeable.

HDF Group: https://www.hdfgroup.org/products/hdf5_tools/index.html

5.2.1 Python

The following code snippet shows how to read the variable lat, lon, and nh3_vmr from the dataset with the name "filename". Also shown are some basic information about the size of the variables' arrays.

```
import netCDF4
from netCDF4 import Dataset

nc_fid = netCDF4.Dataset( filename ,mode='r',format='NETCDF4')

#read in the variables
lat = nc_fid.variables['lat'][:]
lon = nc_fid.variables['lon'][:]
nh3 = nc_fid.variables['nh3_vmr'][:]

# print out the minimum, maximum, and dimensions for the three variables
print("-- lat  Min/Max values", lat[:].min(), lat[:].max())
print("lat.shape:", lat.shape)
print("-- lon Min/Max values:", lon[:].min(), lon[:].max())
print("lon.shape:", lon.shape)
print("-- nh3 Min/Max values:", nh3[:].min(), nh3[:].max())
print("nh3.shape:", nh3.shape)
```

3.2.1 Matlab NetCDF Reader

Matlab can read in the NetCDF/HDF5 format. The code below is a generic NetCDF function that will scan the NetCDF file for attributes and variables then read them into a Matlab structure.

```
function Struct=NetCDF_reader(DIR,filename)
% Struct=NetCDF_reader(DIR,filename)
% This is generic NetCDF file reader.
%
% Input: DIR is the directory of the input file
%        filename is the full name of the NetCDF filename,
%        e.g.,TROPICS07.ANTT.L1A.Orbit00102.V02-03.ST20210901-
034304.ET20210901-051824.CT20210509-205323.nc
%
% Output: Struct is a Matlab structure with the attributes and variables
of
% the input file.
%
% DISTRIBUTION STATEMENT A. Approved for public release. Distribution is
unlimited.
%
```

```
% 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.
%
% Copyright 2021 Massachusetts Institute of Technology.
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% The software/firmware is provided to you on an As-Is basis
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% Delivered to the U.S. Government with Unlimited Rights, as defined in
DFARS Part 252.227-7013 or 7014 (Feb 2014).
% Notwithstanding any copyright notice, U.S. Government rights in this
work are defined by DFARS 252.227-7013 or
% DFARS 252.227-7014 as detailed above. Use of this work other than as
specifically authorized by the U.S. Government
% may violate any copyrights that exist in this work.


% Print filename to screen
display([DIR filename])

% Get a list of the variables in file
Fncinfo=ncinfo([DIR filename]);

% Read in the variables
for VarL=1:length(Fncinfo.Variables)
eval(['Struct.' Fncinfo.Variables(VarL).Name ' = ncread([DIR filename],'''
Fncinfo.Variables(VarL).Name ''');']);
end

% Read in attributes
for AttL=1:length(Fncinfo.Attributes)
    AttN=Fncinfo.Attributes(AttL).Name;
    eval(['Struct.' AttN(~isspace(AttN)) ' = ncreadatt([DIR
filename],''/'',''' Fncinfo.Attributes(AttL).Name ''');']);
end

clear VarL AttL FilInd
end
```

4.0 Radiance Data Products

This section describes the radiance data products of the TROPICS mission. The TROPICS radiance products consist of the L1a antenna temperatures, L1b brightness temperatures, and L2a unified resolution brightness temperatures.

4.1 Algorithm Background

The TROPICS L1 Radiance Algorithm Theoretical Basis Document (ATBD) contains the algorithm background for the L1 radiance data products. The background for the L2a unified resolution radiance is found in the TROPICS L2 Unified Resolution Radiometric Product ATBD. The information below may be specific to a particular data product, which is commented in the description, but most variables are common to all of the radiance data products.

4.2 Data Contents

This section contains the attributes and variables of the radiance data products.

4.2.1 File Attributes (Metadata)

Files store global metadata in addition to variables. Some metadata are required by standard conventions, some are present to meet data provenance requirements and others as a convenience to users of TROPICS data products. Table 7 provides a summary of global attributes present in all radiance files.

Table 7 – List of Radiance Global Attributes

Global Attribute	Type	Description
SpaceVehicleID or Source	uint8	Spacecraft Identifier from 01 to 07
OrbitNumber or orbit	uint16	number of orbits since launch
L0b_SW_Ver	string	Release version number of the L0b algorithm in VXX.YY.ZZ format.
L1a_SW_Ver	string	Release version number of the L1a algorithm in VXX.YY.ZZ format
L1b_SW_Ver	string	Release version number for the L1b algorithm in VXX.YY.ZZ format
PayloadDriver_SW_Ver	uint32	Build date of the payload driver used to make each scan. When converted to HEX this is a human readable date.
BandsToChannel	string	Maps the variable frequency bands to channels. Band 1 = Ch. 1; Band 2 = Ch. 2-4; Band 3 = Ch. 5-8; Band 4 = Ch. 9-11; Band 5 = Ch. 12
_NCProperties	string	NetCDF versions
project	string	NASA Time-Resolved Observations of Precipitation structure and storm intensity with a Constellation of Smallsats (TROPICS) Mission

Global Attribute	Type	Description
ShortName	string	See Table 5 for list of TROPICS ShortNames
LongName or title	string	Longer, more descriptive name for data product
ProcessingLevel	string	L1a, L1b, or L2a
Orbit	string	00119 format
GranuleID or filename	string	file name, e.g., TROPICS03.ANTT.L1A.Orbit00119.V01-00.ST20190408-204530.ET20190408-222035.CT20210301-183149.nc
ProductionDateTime	string	YYYY-MM-DD HH:MM:SS.SSSS format
RangeBeginningTime	string	HH:MM:SS.SSSSS format
RangeBeginningDate	string	YYYY-MM-DD format
RangeEndingTime	string	HH:MM:SS.SSSSS format
RangeEndingDate	string	YYYY-MM-DD format
license	string	http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/
creator_name	string	TROPICS Data Processing Center (DPC)
creator_email	string	sips.support@ssec.wisc.edu
creator_url	string	https://sips.ssec.wisc.edu
creator_institution	string	Space Science & Engineering Center, Univ. of Wisconsin – Madison
publisher_name	string	GES DISC
publisher_email	string	gsfc-dl-help-disc@mail.nasa.gov
publisher_url	string	https://disc.gsfc.nasa.gov
publisher_institution	string	NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC)
dpc_software_delivery_id	string	Science Team algorithm delivery ID (e.g., 20210128-1)
dpc_version	string	DPC architecture version
inputs	string	All input filenames
BoundingBox_GPolygon	string	Latitude & longitude bounding box of the data
Collection	string	DAAC collection ID representing a collection of algorithm

Global Attribute	Type	Description
		versions running at DPC
identifierProductDOIAuthority	string	https://dx.doi.org
IdentifierProductDOI	string	DOI
L0b_File_Creation_Date	string	L0b file's creation time yyyy-MMM-dd HH:mm:ss.SSS UTC
L1a_File_Creation_Date	string	L1a file's creation time yyyy-MMM-dd HH:mm:ss.SSS UTC
L1b_File_Creation_Date	string	L1b file's creation time yyyy-MMM-dd HH:mm:ss.SSS UTC

4.2.2 Dimensions

Table 8 provides a description of the variable dimensions associated with the radiance data products.

Table 8 – List of Variable Dimensions

Dimension	Description
scalar	Used as scalar dimension
spots	Number of measurements or spots on the Earth's surface every rotation of the payload. Equal to 81 with 41 is the nadir spot.
scans	Number of rotations or scans in this file.
channels	Number of radiometric channels or frequency bins. Equal to 12.
bands	Bands are groups of similar channels. See global attribute Bands to Channels for conversion.
coord	Coordinates for the ECEF position. Equal to three.
coord2	Coordinates for the quaternion. Equal to four.
sensors	Number of physical temperature sensors in the data. Equal to three.

4.2.3 Variable Data Attributes

A summary of variable attributes is presented in Table 9.

Table 9 – List of variable attributes

Attribute	Descriptions
Short name	Variable's short name

Dimensions	Variable’s dimensions (e.g., number of spots)
Data Type	Data type (e.g., float, double, ubyte)
Long name	Variable’s longer, more descriptive name
Description	Explanation of the variable
Units	Variable’s units
Fill value	Some units have fill values, which are all set to -999
Valid Range	Valid range of values for the variable

4.2.4 Radiometric Variables

Table 10 contains the radiometric-related variables in the radiance files. This includes the geometry between the radiometric spot on the surface and the payload aperture.

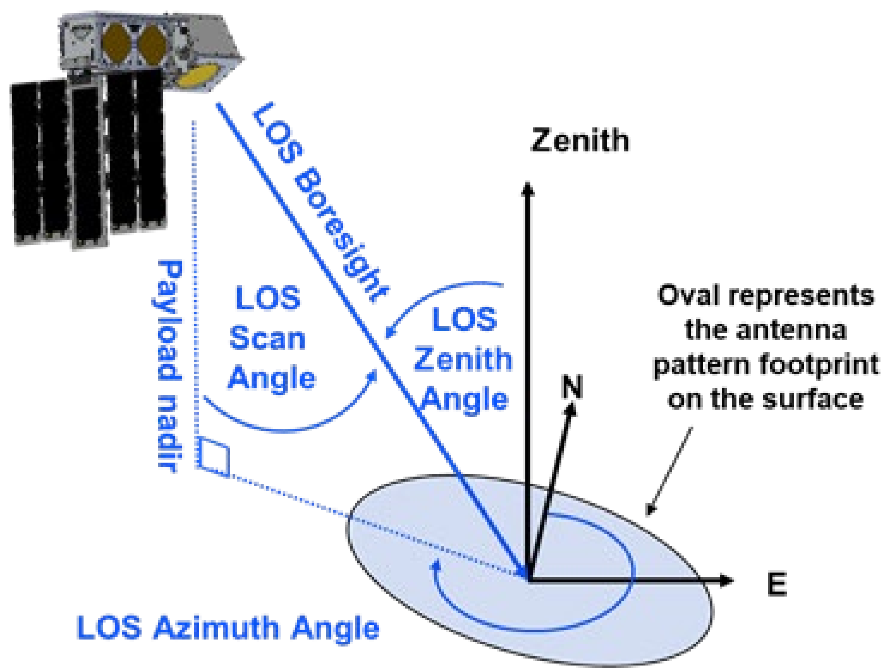

Figure 5 – Illustration of the geometry for the line-of-sight (LOS) projection of the antenna pattern electrical boresight on to the Earth’s surface. Blue ellipse is the projection of the antenna pattern onto the surface of the Earth with the boresight in the middle of the projection.

Table 10 – List of Radiometric Variables

Long Name	Short Name	Dimen-sions	Data Type	Description	Units (Range)
Earth radiometric antenna temperature	tempAntE_K	spots x scans x channels	single	Planck blackbody equivalent antenna temperatures of the Earth scene measurements. (L1a only)	kelvins (0 to 350)
Earth radiometric brightness temperature	tempBrightE_K	spots x scans x channels	single	Planck blackbody equivalent brightness temperatures of the Earth scene measurements. (L1b and L2a only)	kelvins (0 to 350)
Level-2a Earth radiometric brightness temperature	tempBright_l2a	spots x scans x channels	single	Level-2A Earth radiometric brightness temperature at 118 GHz or F-band resolution (G-band converted to F-band resolution) (L2a only)	kelvins (0 to 350)
Time of Earth radiometric measurements	timeE	spots x scans	double	TROPICS Epoch Time (TET) which is the number of atomic seconds elapsed since January 1, 2000 00:00:00.000 TAI. These correspond to the middle of each spot's integration period.	Seconds
UTC year	Year	scans	unit16	UTC year of the nadir spot (41)	years (2015-2030)
UTC month	Month	scans	unit8	UTC month of year for nadir spot	months (1-12)
UTC day	Day	scans	uint8	UTC day of month for nadir spot	days (1-31)
UTC hour	Hour	scans	uint8	UTC hour of day for nadir spot	hours (0-23)
UTC minute	Minute	scans	uint8	UTC minute of hour for nadir spot	minutes (0-59)
UTC second	Second	scans	uint8	UTC second of minute for nadir spot	seconds (0-59)

Long Name	Short Name	Dimen-sions	Data Type	Description	Units (Range)
UTC millisecond	Millisecond	scans	uint16	UTC millisecond of second for nadir spot	milliseconds (0-999)
Line of sight scan angle	losScan_deg	spots x scans x bands	single	The angle between the local nadir at the satellite and the line-of-sight vector of the measurement to the surface.	Degrees (0 to 180)
Line of sight azimuth angle	losAzi_deg	spots x scans x bands	single	The angle between the local north vector at the LOS earth intersection point and the inverse LOS vector (a vector pointing toward the satellite from earth)	degrees (0 to 360)
Line of sight zenith angle	losZen_deg	spots x scans x bands	single	The angle between the local zenith at the LOS earth intersection point and the inverse LOS vector (a vector pointing toward the satellite from earth). Fill values will be used when there is no LOS intersection point.	Degrees (0 to 90)

4.2.5 Geolocation Variables

Table 11 lists the variables related to geolocation of the radiances and the position and orientation of the SV. Figure 5 illustrates the variables related to the geolocation of the radiances measurements on the Earth's surface.

Table 11 – List of Geolocation Related Variables

Long Name	Short Name	Dimen-sions	Data Type	Description	Units (Range)
Latitude: line-of-sight to Earth intersection	losLat_deg	spots x scans x bands	single	Geodetic latitude of the line-of-sight intersection point with Earth for each spot. These correspond with the middle of each spot's integration period. Fill values will be used to indicate no intersection. WGS84	degrees (-90 to 90)
Longitude: line-of-sight to Earth intersection	losLon_deg	spots x scans x bands	single	Geodetic longitude of the line-of-sight intersection point with Earth for each spot. These correspond with the middle of each spot's integration period. Fill values will be used to indicate no intersection. WGS84	degrees (-180 to 179.9999)

Long Name	Short Name	Dimen-sions	Data Type	Description	Units (Range)
Spacecraft ECEF Position	scPosECEF	scans x coord	single	The spacecraft position in ECEF coordinate system. The first dimension is [x,y,z]. WGS84 Use 41st spot of variable timeE for timestamp.	Km (-10,000 to 10,000)
Spacecraft Body-to-ECEF Quaternion	scQuatECEF	scans x coord2	single	The unit length quaternion that rotates from spacecraft body coordinate system to ECEF coordinate system. The second dimension is [i,j,k,r], where r is the scalar element of the quaternion. WGS84 Use 41st spot of variable timeE for timestamp.	norm one (0 to 1)

4.2.6 Ephemeris Variables

Table 12 contains a list of the variables related to the relationship between the radiometric spot on the surface and the sun or moon. Figure 6 illustrates the geometry of the ephemeris variables.

Table 12 – List of Ephemeris Variables

Long Name	Short Name	Dimen-sions	Data Type	Description	Units (Range)
Line of sight lunar azimuth angle	losLunAzi_deg	spots x scans x bands	single	The angle between the local north vector at the LOS earth intersection point and a vector pointing at the center of the Moon. Fill values will be used when there is no LOS intersection point.	degrees (0 to 360)
Line of sight lunar zenith angle	losLunZen_deg	spots x scans x bands	single	The angle between the local zenith at the LOS earth intersection point and a vector pointing at the center of the Moon. Fill values will be used when there is no LOS intersection point.	degrees (0 to 180)
Line of sight solar azimuth angle	losSolAzi_deg	spots x scans x bands	single	The angle between the local north vector at the LOS earth intersection point and a vector pointing at the center of the Sun. Fill values will be used when there is no LOS intersection point.	degrees (0 to 360)
Line of sight solar zenith angle	losSolZen_deg	spots x scans x bands	single	The angle between the local zenith at the LOS earth intersection point and a vector pointing at the center of the Sun. Fill values will be used when there is no LOS intersection point.	degrees (0 to 180)

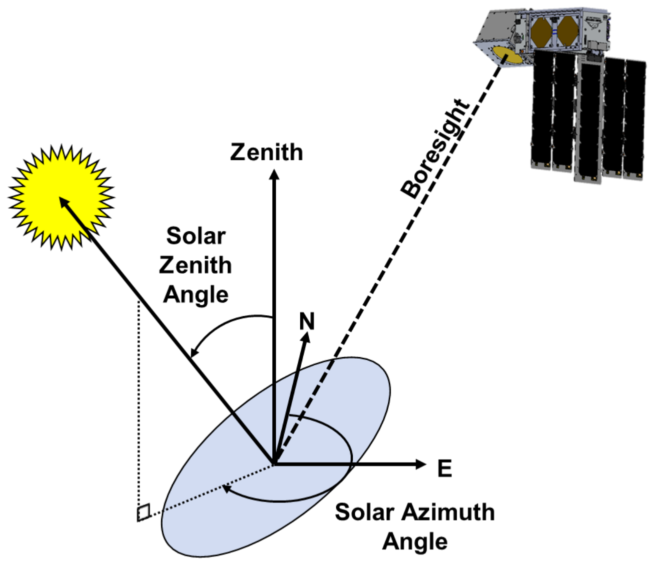

Figure 6 – Illustration of the Geometry of the Ephemeris Data. Blue ellipse is the projection of the antenna pattern onto the surface of the Earth with the boresight in the middle of the projection.

4.2.7 Quality Control

Radiance products have quality control with two objectives:

- Identify data product variables with questionable or substandard integrity to allow end users to vet measurements.
- Provide telemetry or circumstances to trend calibration biases and possibly adjust their bias.

The TROPICS calibration algorithm will remove biases, such as sidelobe contamination and diode drift, identified on first principles. For more details on bias removal, see the TROPICS L1 radiance ATBD.

There are three decoupled quality control mechanisms, applied in the following order:

1. Replacing unrealistic variable values, such as Earth antenna temperatures above 350 K, with fill values using simple threshold comparisons against principles of physics.
2. Calibration quality flags that identify subpar calibration conditions or metrics of the data, such as lunar intrusion in a calibration measurement.
3. Payload telemetry or circumstances that identify similar conditions, such as payload physical temperatures or ascending/descending orbits, to correlate with calibration bias.

These decoupled mechanisms allow the user to define their own threshold for quality control. An example of the meaning of decoupled is that a tripped calibration quality flag will not necessarily be replaced with a fill value if the value is realistic. The user can still use a degraded calibration identified by the quality flag if their application warrants it. Ultra-conservative users can vet the data to use only the highest quality (e.g., no calibration consistency flags were tripped).

Table 13 contains a list of the variables in the file that are compared against thresholds determined from physical limits. If the variable's algorithm or instrumentation reading produces values greater than the maximum limit or less than the minimum limit, the value is replaced with negative 999.

Table 13 – Table of the Variables Verified Against Thresholds

Data	Variable Name	Min. Limit	Max. Limit	Fill Value
Radiance	tempAntE_K tempBrightE_K	0 K	350 K	-999
Instr. Temp.	instrTemp_degC	-30°C	50C̊	-999
Latitude	losLat_deg	-90˚	-90˚	-999
Longitude	losLon_deg	-180˚	180˚	-999
Line-of-Sight scan angle	losScan_deg	0˚	180˚	-999
LOS zenith angle	losZen_deg	0˚	90˚	-999
LOS azimuth angle	losAzi_deg	0˚	360˚	-999
Lunar zenith angle	losLunZen_deg	0˚	180˚	-999
Lunar azimuth angle	losLunAzi_deg	0˚	360˚	-999
Solar zenith angle	losSolZen_deg	0˚	180˚	-999
Solar azimuth angle	losSolAzi_deg	0˚	360˚	-999

The next mechanism is the calibration quality flag. The flag is decoupled from the variable checks in Table 13, which means a fill value will not necessarily have a flag tripped in the calibration quality flag or vice versa. Table 14 contains the variables in a file related to calibration quality and trending (i.e., mechanism 2 and 3, respectively).

The calibration quality flag itself has both mechanisms of quality control. The dimension of the calibration quality flag provides an 8-bit flag for each spot, each scan, and each channel but some flags do not have that level of granularity (e.g., a spacecraft maneuver flag obviously applies to all spots, scans, and channels for the duration of the maneuver). The next section will explain the details of each bit (i.e., flag) of the calibration quality flag.

Table 14 – List of Variables Related to Quality Control

Long Name	Short Name	Dimensions	Data Type	Description	Units (Range)
Calibration Quality Flag	calQualityFlag	spots x scans x bands	uint8	See detailed descriptions in Quality Flag section. Bit 1: land/undefined Bit 2: Lunar/solar intrusion Bit 3: Active Maneuver Bit 4: Cold Cal. Consistency Bit 5: Hot Cal. Consistency Bit 6: Ascending/Descending Bit 7: Day/Night Bit 8: Payload forward/aft	0-255
Average instrument temperature	instrTemp_degC	sensors x scans	single	1st: The average of six temperature sensors placed throughout the payload. 2nd: average of WF-band receiver sensors (Ch. 1-8) 3rd: G-band receiver sensor (Ch. 9-12)	degrees Celsius (-30 to 50)
Land flag	LandFlag	spots x scans	uint8	Surface indicator where 0 is ocean, 1 is land or coastline, and 2 is bad geolocation or undefined (e.g., deep space measurement)	unitless (0, 1, or 2)
NEDT of cold calibration measurement	NEDT_DS	scans x channels	single	Estimated Noise Equivalent Delta Temperature (NEDT) using ten samples of deep space. Used the product of gain (K/DN), sample standard deviation (DN), and normal distribution bias correction (N=10)	kelvins (0.3 to 3)
NEDT of hot calibration measurement	NEDT_ND	scans x channels	single	Estimated Noise Equivalent Delta Temperature (NEDT) using ten samples with noise diode turned on viewing deep space. Used the product of gain (K/DN), sample standard deviation (DN), and normal distribution bias correction (N=10)	kelvins (0.3 to 3)
Standard Deviation of Ch. 12	stddev_ch12_l2a	spots x scans	singles	Standard deviation of channel 12 within the 118-GHz footprint (Backus-Gilbert weighted); Only found in L2a data product	kelvins (0-330)
Noise Reduction Factor	noise_reduction_l2a	spots x scans x channels	single	Backus-Gilbert G-band noise reduction parameter (Multiply sensor NEDT by this value to get reduced NEDT); Only found in L2a data product	unitless (>0)

The calibration quality flag is an unsigned single byte, which has eight bits. Bit 1 is the least significant position and bit 8 is the most significant. This will make the quality flag range from 0 (all zeros) to 255 (all ones). Here is a description of the bits:

1. <u>Bit 1 is a non-ocean flag</u> that can be useful for validation selection criteria. It is derived by comparing the spot's antenna pattern projected onto the surface of the Earth against a coastline map (Matlab coast dataset). If the spot's project contains land or does not intersect with the Earth, the flag is one. Zero is considered ocean. This is a simplified version of the LandFlag variable (see below for more details).
2. <u>Bit 2 is a Lunar/solar intrusion flag</u> that indicates that the calibration measurements in deep space could be corrupt based on spacecraft attitude, payload orientation, and ephemeris position. This bit will be set to 1 if the angle between any of the 20 cal. sector spots to the center of the moon/sun are less than the antenna pattern's beamwidth plus a 0.5 degree buffer. Note that this is extremely conservative because all ten calibration measurements spanning 15˚ of angular extent cannot be intruded at the same time. See cold calibration consistency flag below for the calibration measurement outlier check. 0 indicates no modelled intrusion.
3. <u>Bit 3 is a spacecraft maneuver flag</u> to inform the user that the CubeSat is actively undergoing a maneuver and the data is suspect. The maneuver is determined when the yaw, pitch, roll rates exceed thresholds. 1 means that the SV is actively in a maneuver and zero is no maneuver detected.
4. <u>Bit 4 is a cold calibration consistency flag</u> that rolls up these two conditions:
    a. Calibration used less than six out of ten deep space radiometric spots in this scan's cold calibration sector. Spots were identified and removed as outliers when they were significantly outside orbital median value from this file.
    b. Scan's cold calibration estimated NEDT is out-of-family when compared against a median-filtered NEDT vs time; outliers were identified when significantly outside orbital NEDT standard dev. See the NEDT variable description below for more details on deriving the per-scan NEDT.
5. <u>Bit 5 is a hot calibration consistency flag</u> that rolls up these three conditions:
    a. Calibration used less than six out of ten noise diode radiometric spots in hot calibration sector. Spots were identified and removed as outliers after they were significantly outside the orbital median value from this file.
    b. Scan's hot calibration estimated NEDT is out-of-family when compared against the median-filtered NEDT vs time; outliers were identified when significantly outside orbital NEDT standard dev. See the NEDT variable description below for more details on deriving the per-scan NEDT.
    c. Noise diode temperature is parameterized using other payload telemetry (e.g., receiver physical temperature). See L1 radiance ATBD for more information. The parameterization can produce unrealistic values (mainly due

to noise telemetry) and is therefore compared against a median-filtered noise diode temperature vs time to identify outliers. Outliers were identified when significantly outside the orbit estimated noise diode temperature standard deviation derived from the file's median-filtered noise diode temperature estimated values.

6. Bit 6 Ascending/Descending flag: 0 indicates that scan position in the orbit is ascending and 1 indicates it's in a descending part of the orbit. Flag uses the SV geodetic position on the ground by comparing the azimuthal direction of the next scan. Descending is defined as having azimuth greater than 90 and less than 270 degrees.
7. Bit 7 Day or night flag: 0 indicates the spot/footprint is illuminated by the sun and 1 indicates the spot is not illuminated by the sun. Flag uses the nadir solar zenith angle and angles greater than 85 degrees is considered night (90 deg. is horizon and zero is zenith).
8. Bit 8 Payload orientation in flight path: 0 indicates the payload is in front of the flight path and 1 indicates payload is in the rear or aft of flight path. Flag uses the SV body velocity vector.

For bias trending, the radiance data includes physical (i.e., kinetic) temperatures from temperature sensors inside the payload in the "average instrument temperature" variable. See the payload block diagram in the TROPICS L1 Radiance ATBD for more information. There are three values in the variable:

1. Average of all six temperature sensors in the TMS (i.e., payload).
2. A W- and F-band average temperature consisting of a sensor in the receiver front end and another one in the intermediate frequency processor. This value is best for channels 1 through 8.
3. A G-band temperature consisting of a single sensor in the direct-detect module. This value is best for channels 9 through 12.

Besides the non-ocean bit in the quality control flag, there is a land flag with more granularity. This variable has three indicators: 0 is ocean, 1 is land or coastline, and 2 is a bad geolocation. This gives more information for land versus ocean surface comparisons. Figure 7 has a sample of the non-ocean flag, which is essentially the land flag with the land/coastline and bad geolocation values combined. The algorithm blurs the mask so that land values also include coastlines, which can be seen in the figure.

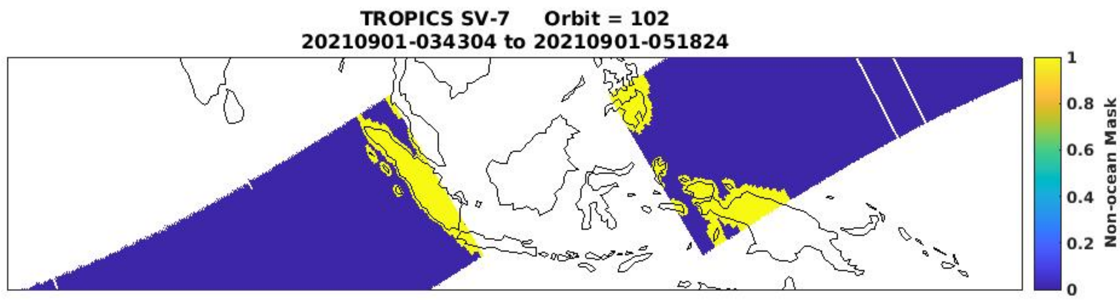

Figure 7 – Example of the non-ocean bit that is part of the calibration quality flag. Image shows the beginning and end of a granule (i.e., orbit) defined by ascending equatorial crossings. Note the additional margin around coastlines includes mixed land/sea spots.

An estimate of the NEDT is made for each scan using the two calibration sectors. Each scan has ten measurements in both the cold (i.e., deep space) calibration sector and in the hot (i.e., noise diode) calibration sector (see TROPICS L1 Radiance ATBD). The estimate uses that scan's gain estimate (kelvins per digital number) multiplied by the standard deviation metric of that scan's calibration sector digital numbers. Digital numbers are the analog-to-digital converter's output. The standard deviation metric is a noisy metric with only ten samples as can been seen in the example data in Figure 8. Furthermore, standard deviation metric is biased for such a sample set, and a standard deviation bias correction factor assuming a normal distribution with ten sample is applied, which is approximately a factor of 0.97. Since the input radiance is different in each sector, they are reported separately (i.e., NEDT is a function of the input radiance).

The estimated NEDT can be an indicator of that scan's quality. As mentioned in the calibration quality flag consistency bits, a threshold against the orbit's median NEDT estimate is applied to identify out-of-family scans (i.e., outliers). The threshold is a tunable multiplicative factor of the standard deviation of the estimated NEDT (i.e., the standard deviation of the NEDT estimator) for that channel and calibration sector.

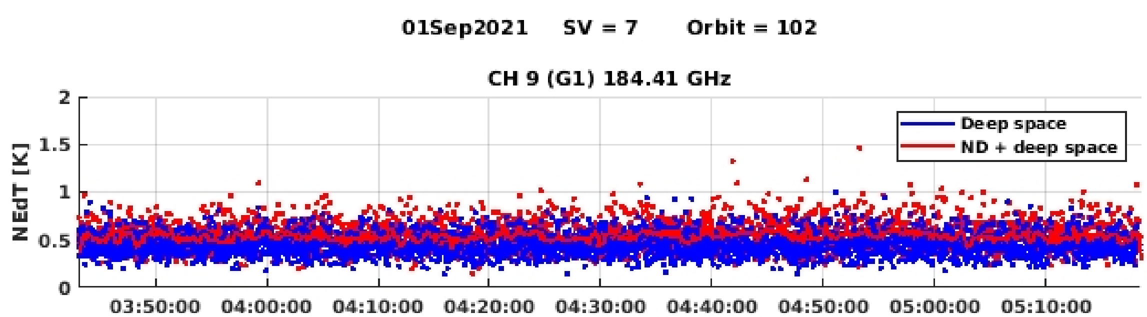

Figure 8 – Example of the estimated NEDT for each scan over a granule of pre-launch data.

4.3 Validation Plan

The TROPICS radiance validation plan is similar to validating operational passive microwave sounders.

4.3.1 Level-1 Radiance

Single Difference – compares TROPICS data with simulated data from a radiative transfer model

- GPSRO: best accuracy at altitudes between 8- 30 km and will use COSMIC-2/TGRS and MetOp/GRAS
- Radiosondes: GCOS Reference Upper Air Network (GRUAN) with 5 GRUAN stations matchup with TROPICS constellation latitudes (also Integrated Global Radiosonde Archive, IGRA)
- ECMWF ERA5 Re-analysis: 1 hour time resolution, 31-km spatial resolution with 5 days for initial output (final in 2-3 months)
- Radiative Transfer Model is the CRTM with individual sensor coefficients based on each TROPICS SV Spectral Response Functions.

Double Difference – compares TROPICS data to secondary sensors to capture data on noise diode drift

- Inter-sensor: between TROPICS and operational microwave sensors
- Intra-sensor: among the TROPICS constellation, expect about six matchups per day

Future Work: Solar/Lunar Intrusion – utilizing the solar and lunar intrusions found in TROPICS scan path to quantify noise diode drift

Table 15 L1 radiance validation techniques and sources

Type	Truth Source	Matchup frequency	Data Source	Criteria	Analysis Timeframe
Single Difference	NWP	~4k matchups/day	ECMWF ERA5	Clear sky, over ocean, < 50 km & < 1 hr	Daily
Single Difference	GPSRO	~ 40 matchups/SV/day	COSMIC-2 & MetOp	< 50 km & < 1 hr	To be determined
Single Difference	Radiosondes	4-6/month per SV	GRUAN	Near ocean, < 50 km, ± 1 hr	Monthly
Double Difference	Operational Sensors	~ 6 matchups/day per SV per sensor	ATMS, MWHS-2, GMI, MHS	Clear sky, over water, near nadir, <100 km, < 3 hrs	Weekly
Double Difference	TROPICS	~6 matchups/day per SV	TROPICS	Clear sky, over water, near nadir, <50 km, <1 hr	Weekly

4.3.2 Level-2a Radiance

Validated with the TROPICS data itself by cross-correlating different bands when spatial brightness temperature gradients are apparent (cross correlation between F and G should increase over the raw Level 1b cross correlation) and by studying brightness temperature gradients for coastal overpasses at least for the bands that are surface sensitive.

5.0 Geophysical Data Products

This section covers the retrieval of geophysical properties of the atmosphere or TC using the radiances described in Section 4.0. The TROPICS geophysical data products include atmospheric vertical temperature profile, atmospheric vertical moisture profile (also known as water vapor), integrated water vapor or Total Precipitable Water, instantaneous surface rain rate, and TC intensity using the metrics of maximum sustained wind speed and minimum sea-level pressure.

5.1 Algorithm Background

The geophysical retrievals are explained in three ATBDs: 1) Atmospheric Vertical Profiles, which includes AVTP, AVMP, and TPW, 2) Instantaneous Surface Rain Rate, and 3) TC Intensity. The AVTP, AVMP, and TPW algorithms were adapted from the NOAA Microwave Integrated Retrieval System (MIRS) algorithm. The ISRR algorithm used the NASA Goddard Precipitation Retrieval and Profiling Scheme (PRPS). TROPICS provides estimates of TC intensity from two algorithms: 1) Tropical Cyclone Intensity Estimate algorithm (TCIE) developed at the University of Wisconsin/CIMSS and 2) Hurricane Intensity and Structure Algorithm (HISA) developed at Colorado State University/CIRA.

5.2 Data Content

Each of the following sections describe the data contents of the individual geophysical data products.

5.2.1 File Attributes (Metadata)

The file global attributes are common to all geophysical output files.

Table 16 – List of Global Attributes for the geophysical data products

Global Attribute	Type	Description
Source	uint8	Spacecraft Identifier from TROPICS01 to TROPICS07
Filename	string	Filename of this file
_NCProperties	string	NetCDF versions
project	string	NASA Time-Resolved Observations of Precipitation structure and storm intensity with a Constellation of Smallsats (TROPIPCS) Mission
DatacenterID	string	UWI-MAD/SSEC/DPC

Global Attribute	Type	Description
ShortName	string	See Table 5 for list of TROPICS ShortNames
LongName or title	string	Longer, more descriptive name for data product
Orbit	string	00119 format
GranuleID	string	file name, e.g., TROPICS03.ANTT.L1A.Orbit00119.V01-00.ST20190408-204530.ET20190408-222035.CT20210301-183149.nc
ProductionDateTime	string	YYYY-MM-DD HH:MM:SS.SSSS format
RangeBeginningTime	string	HH:MM:SS.SSSSS format
RangeBeginningDate	string	YYYY-MM-DD format
RangeEndingTime	string	HH:MM:SS.SSSSS format
RangeEndingDate	string	YYYY-MM-DD format
license	string	http://science.nasa.gov/earth-science/earth-science-data/data-information-policy/
creator_name	string	TROPICS Data Processing Center (DPC)
creator_email	string	sips.support@ssec.wisc.edu
creator_url	string	https://sips.ssec.wisc.edu
publisher_name	string	GES DISC
publisher_email	string	gsfc-dl-help-disc@mail.nasa.gov
publisher_url	string	https://disc.gsfc.nasa.gov
publisher_institution	string	NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC)
dpc_software_delivery_id	string	Science Team algorithm delivery ID (e.g., 20210128-1)
dpc_version	string	DPC architecture version
BoundingBox_GPolygon	string	Latitude & longitude bounding box of the data
Collection Version	string	DAAC collection ID representing a collection of algorithm versions running at DPC
inputs	string	Geophysical's algorithm's input filename
ProcessingLevel	string	L2b

5.2.2 TROPICS MIRS Data Format

TROPICS channel set is not the same as many operational microwave sensors used in the NOAA MIRS algorithm. Due to the different channels sets, TROPICS is not able to produce all of the MIRS standard output data products. The TROPICS MIRS output file is similar in format as the typical MIRS output file, but the MIRS SND and IMG separate files are merged into a single TROPICS MIRS output with fewer variables. The main MIRS output variables are now temperature profile (K), moisture profile (g/kg), and Total Precipitable Water (mm). The contents of the TROPICS MIRS output file can be found in Table 17. Missing_value are -999 and notretrievedproduct_value is -888.

Table 17 – TROPICS MIRS Output File Contents

Parameter Name	Dimension	Data Type (Scale Factor)	Explanation
Atm_type	Scanline x Field_of_view	1*16	0-simple scene, 1-retrieved scene
ChiSqr	Scanline x Field_of_view	R*32	Convergence rate: <3-good,>10-bad
Freq	Channel	R*32	Central Frequency
LZ_angle	Scanline x Field_of_view	R*32	Local zenith angle: (-59,59) degree
Latitude	Scanline x Field_of_view	R*32	Latitude of the view (-90,90)
Longitude	Scanline x Field_of_view	R*32	Longitude of the view (-180,180)
Orb_mode	Scanline	1*16	0-ascending,1-descending
PTemp	Scanline x Field_of_view x P_Layer	R*32	Temperature profile in K via unified resolution
PVapor	Scanline x Field_of_view x P_Layer	R*32	Water vapor profile in g/kg via native resolution
Player	P_Layer	R*32	Pressure for each layer in mb
Plevel	P_Level	R*32	Pressure for each level in mb
Polo	Channel	1*16	Polarizations (Horizontal or Vertical)
Qc	Scanline x Field_of_view x Qc_dim	1*16	Qc(0): 0-good,1-usable with problem, 2-bad
RAzi_angle	Scanline x Field_of_view	R*32	Relative azimuth angle 0-360 degree
SZ_angle	Scanline x Field_of_view	R*32	Solar zenith angle (-90,90) degree
ScanTime_UTC	Scanline	R*64	Number of seconds since 00:00:00 UTC
ScanTime_dom	Scanline	1*16	Calendar day of the month 1-31
ScanTime_doy	Scanline	1*16	Julian day 1-366
ScanTime_hour	Scanline	1*16	hour of the day 0-23
ScanTime_minute	Scanline	1*16	minute of the hour 0-59
ScanTime_month	Scanline	1*16	Calendar month 1-12
ScanTime_second	Scanline	1*16	second of the minute 0-59
ScanTime_year	Scanline	1*16	Calendar Year 20XX
Sfc_type	Scanline x Field_of_view	1*16	Type of surface: 0-ocean,1-sea-ice,2-land,3-snow

Parameter Name	Dimension	Data Type (Scale Factor)	Explanation
BT	Scanline x Field_of_view x Channel	1*16	Channel Temperature (K)
ChanSel	Scanline x Field_of_view x Channel	1*16	Channels Selection Used in Retrieval
TPW	Scanline x Field_of_view	1*16	Total Precipitable Water (mm)
YM	Scanline x Field_of_view x Channel	1*16	Un-Corrected Channel Temperature (K)

5.2.3 ISRR Data Formats

The Instantaneous Surface Rain Rate data product content is described in Table 18. This output is very similar to the GMI PRPS algorithm output.

Table 18 ISRR data content (PRPS algorithm)

Parameter Name	Description	Units	Valid Range / Fill Value
Earth radiometric measurement time	TROPICS Epoch Time (TET) which is the number of atomic seconds elapsed since January 1, 2000 00:00:00.000 TAI.	Seconds	6.3172e+08–9.4742e+08
UTC year	UTC year of the nadir spot	Years	2015–2030
UTC month	UTC month of the year for the nadir spot	Months	1–12
UTC day	UTC day of month for the nadir spot	Days	1–31
UTC hour	UTC hour of day for the nadir spot	Hours	0–23
UTC minute	UTC minute of hour for the nadir spot	Minutes	0–59
UTC second	UTC second of minute for the nadir spot	Seconds	0–59
UTC millisecond	UTC millisecond of second for the nadir spot	Milliseconds	0–999
losLat	latitude A/B-scan (-90:90)	deg	–
losLon	longitude A/B-scan (-180:180)	deg	–
rain_rate	PRPS derived rain rates	mm/hr	999.f
rain_rmse	RMSE retrieved precipitation	–	999.f
tb_fit	fit of Tbs of the retrieved value to database Tbs	K	999.f
MLP_rate	Most Likely Precipitation	mm/hr	999.f
surface_type	retrieved surface type	–	999.f
Tb_fitMLP	fit of Tbs of the retrieved MLP to database Tbs	K	999.f
prps_flag	quality flag: zero=OK	–	999.f

5.2.4 TC Data Formats

TC TCIE Data Format

Table 19 TCIE TC Intensity Data Content

Entry	Units	Notes
Year – Day	YYYY – Julian Day	
Hurricane name	Name	
Time	HH:MM	UTC
Eye Latitude	degrees	-90 to 90 deg.
Eye Longitude	degrees	-180 to 180 deg.
Data used	Channel, FOV/spot, and SV	Storm position information
Estimated MSLP	hPa	
Estimated MSW	knots	
Channel 7 Tb Anomaly	kelvins	
Channel 6 Tb Anomaly	kelvins	
Eye diameter	km	
Environmental Pressure	hPa	

TC HISA Data Format

Table 20 HISA TC Intensity data content

Parameter Name	Description	Units	Valid Range	Fill/Missing Value
Height	Height	km	Z-axis, positive=up	
Radius	Radius	km	X-axis	
Air Pressure	Mean azimuthal pressure	hPa	0., 109000.	FillValue = -999.9 Missing_value=-999.9

Parameter Name	Description	Units	Valid Range	Fill/Missing Value
Air Density	Mean azimuthal density	kg m-3	0., 3.	FillValue = -999.9 Missing_value=-999.9
Air Temperature	Mean azimuthal temperature	K	0., 350.	FillValue = -999.9 Missing_value=-999.9
Wind Speed	Mean azimuthal gradient wind speed	m s-1	-125., 125.	FillValue = -999.9 Missing_value=-999.9

5.3 Validation Plan

5.3.1 Level-2b AVTP/AVMP

AVTP/AVMP/TPW will use the same truth sources as the L1 radiance validation, but without the radiative transfer model.

5.3.2 Level-2b ISRR

ISRR validation consists of these steps:

1. Descriptive statistics of retrievals: precipitation totals by region/latitude, precipitation occurrence, pdf of precipitation, maximum, means, conditional precipitation rates;
2. Comparison with IMERG (2.5x2.5 weekly – as per requirement);
3. Instantaneous matchups with surface reference data, e.g. MRMS over the US, Nimrod over UK/Europe, OPERA over Europe, and GPCC gauge data;
4. Inter-comparison with other satellite instantaneous precipitation products, including GPM Core Observatory.

5.3.3 Level-2b TC Intensity

TC intensity estimates using any available TC reconnaissance center-penetrating aircraft measurements, both from dropsondes for central MSLP and SFMR surface wind estimates. Also use the NHC 'recon-aided' Best Track to validate in situations when the overpass is close in time to a recon report (i.e. +/- 3 hrs). The recon are routine for most Atlantic TCs and some EPAC TCs. For areas outside of the reconnaissance domain, validation uses a best track derived from all available sensors including Dvorak and objective estimates from the Advanced Dvorak Technique (ADT) and other sounders.

6.0 Reference Documentation

W. J. Blackwell, et al., "An overview of the TROPICS NASA Earth Venture Mission," Quarterly J. of the Royal Meteorological Society, 144 (Suppl. 1): pp. 16-26, 2018

TROPICS L1 Radiance Algorithm Theoretical Basis Document hosted on GES DISC

TROPICS L2a Unified Resolution Radiometric Product Algorithm Theoretical Basis Document hosted on GES DISC

TROPICS L2b Atmospheric Vertical Profiles Algorithm Theoretical Basis Document hosted on GES DISC

TROPICS L2b Instantaneous Surface Rain Rate Algorithm Theoretical Basis Document hosted on GES DISC

TROPICS L2b Tropical Cyclone Intensity Algorithm Theoretical Basis Document hosted on GES DISC

7.0 Abbreviations, Acronyms, and Initialisms

ADCS	Attitude Determination & Control System
ATBD	Algorithm Theoretical Basis Document
ATMS	Advanced Technology Microwave Sounder
AVMP	Atmospheric Vertical Moisture Profile
AVTP	Atmospheric Vertical Temperature Profile
BCT	Blue Canyon Technologies
CDL	Common Data Language
CMA	China Meteorological Administration
CRTM	Community Radiative Transfer Model
DAAC	Distributed Active Archive Center
DPC	Data Processing Center
ESSP	Earth Science System Pathfinder
EVI	Earth Venture-Instrument (EVI-3) program
GES DISC	Goddard Earth Sciences Data and Information Services Center
GSN	Ground Station Network
HISA	Hurricane Intensity and Structure Algorithm
ISRR	Instantaneous Surface Rain Rate
JCSDA	Joint Center for Satellite Data Assimilation
LaRC	Langley Research Center
MIRS	Microwave Integrated Retrieval System (NOAA STAR)
MIT LL	MIT Lincoln Laboratory
MOC	Mission Operations Center
MSLP	Minimum Sea Level Pressure
MSW	Maximum Sustained Winds
MWHS-2	Microwave Humidity Sounder 2
NASA	National Aeronautics & Space Administration
PRPS	Precipitation Retrieval and Profiling Scheme (NASA Goddard)
RF	Radio Frequency
RTTOV	Radiative Transfer for TOV

SFMR	Stepped Frequency Microwave Radiometer
SMD	Science Mission Directorate
SPOC	Science & Payload Operations Center
SSEC	UW-M Space Science and Engineering Center
SV	Space Vehicle
TC	Tropical Cyclone
TCIE	Tropical Cyclone Intensity Estimate
TMS instrument	TROPICS Millimeter-wave Sounder instrument
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats
UW-M	University of Wisconsin - Madison

Appendix A: CDL File Definition for L1a

This section provides the CDL file definition format using the example file:

```
netcdf TROPICS01.ANTT.L1A.Orbit00163.V02-03.ST20200825-182245.ET20200825-
195749.CT20210621-211316 {
dimensions:
   scans = 2854 ;
   spots = 81 ;
   channels = 12 ;
   bands = 5 ;
   coord = 3 ;
   coord2 = 4 ;
   sensors = 3 ;
variables:
   ushort Year(scans) ;
         Year:Long\ Name = "UTC year" ;
         Year:Description = "UTC year of the nadir spot." ;
         Year:Units = "years" ;
         Year:Valid\ Range = "2015-2030" ;
   ubyte Month(scans) ;
         Month:Long\ Name = "UTC month" ;
         Month:Description = "UTC month of year for the nadir spot." ;
         Month:Units = "months" ;
         Month:Valid\ Range = "1-12" ;
   ubyte Day(scans) ;
         Day:Long\ Name = "UTC day" ;
         Day:Description = "UTC day of month for the nadir spot." ;
         Day:Units = "days" ;
         Day:Valid\ Range = "1-31" ;
   ubyte Hour(scans) ;
         Hour:Long\ Name = "UTC hour" ;
         Hour:Description = "UTC hour of day for the nadir spot." ;
         Hour:Units = "hours" ;
         Hour:Valid\ Range = "0-23" ;
   ubyte Minute(scans) ;
         Minute:Long\ Name = "UTC minute" ;
         Minute:Description = "UTC minute of hour for the nadir spot." ;
         Minute:Units = "minutes" ;
         Minute:Valid\ Range = "0-59" ;
   ubyte Second(scans) ;
         Second:Long\ Name = "UTC second" ;
         Second:Description = "UTC second of minute for the nadir spot." ;
         Second:Units = "seconds" ;
         Second:Valid\ Range = "0-59" ;
   ushort Millisecond(scans) ;
         Millisecond:Long\ Name = "UTC millisecond" ;
         Millisecond:Description = "UTC millisecond of second for the
nadir spot." ;
         Millisecond:Units = "milliseconds" ;
         Millisecond:Valid\ Range = "0-999" ;
   float tempAntE_K(channels, scans, spots) ;
         tempAntE_K:_FillValue = -999.f ;
         tempAntE_K:Long\ Name = "Earth radiometric antenna temperature" ;
```

```
        tempAntE_K:Description = "Planck blackbody equivalent antenna
temperatures" ;
        tempAntE_K:Units = "kelvins" ;
        tempAntE_K:Valid\ Range = "0-350" ;
   double timeE(scans, spots) ;
        timeE:Long\ Name = "Time of Earth radiometric measurements" ;
        timeE:Description = "TROPICS Epoch Time (TET) timestamp of the
Earth radiometric measurements." ;
        timeE:Units = "TET is the number of atomic seconds elapsed since
January 1, 2000 00:00:00.000 TAI" ;
        timeE:Valid\ Range = "6.7e+09" ;
   float losLat_deg(bands, scans, spots) ;
        losLat_deg:_FillValue = -999.f ;
        losLat_deg:Long\ Name = "Latitude: line-of-sight to Earth
intersection" ;
        losLat_deg:Description = "Geodetic latitude of the line-of-sight
intersection point with the Earth for each spot. Negative values are
South. These correspond to the middle of each spot integration period.
WGS84" ;
        losLat_deg:Units = "degrees" ;
        losLat_deg:Valid\ Range = "-90 to 90" ;
   float losLon_deg(bands, scans, spots) ;
        losLon_deg:_FillValue = -999.f ;
        losLon_deg:Long\ Name = "Longitude: line-of-sight to Earth
intersection" ;
        losLon_deg:Description = "Geodetic longitude of the line-of-sight
intersection point with the Earth for each spot. Negative values are West.
These correspond to the middle of each spots integration period. WGS84" ;
        losLon_deg:Units = "degrees" ;
        losLon_deg:Valid\ Range = "-180 to 180" ;
   float losScan_deg(bands, scans, spots) ;
        losScan_deg:_FillValue = -999.f ;
        losScan_deg:Long\ Name = "Line-of-sight scan angle" ;
        losScan_deg:Description = "The scan angle between the satellite
local nadir and the Line-Of-Sight (LOS) vector from radiometer aperture."
;
        losScan_deg:Units = "degrees" ;
        losScan_deg:Valid\ Range = "0-180" ;
   float losZen_deg(bands, scans, spots) ;
        losZen_deg:_FillValue = -999.f ;
        losZen_deg:Long\ Name = "Line-of-sight zenith angle" ;
        losZen_deg:Description = "The angle between the local zenith at
the LOS earth intersection point and the inverse LOS vector (a vector
pointing toward the satellite from earth)." ;
        losZen_deg:Units = "degrees" ;
        losZen_deg:Valid\ Range = "0-90" ;
   float losAzi_deg(bands, scans, spots) ;
        losAzi_deg:_FillValue = -999.f ;
        losAzi_deg:Long\ Name = "Line-of-sight azimuth angle" ;
        losAzi_deg:Description = "The angle between the local north
vector at the LOS earth intersection point and the inverse LOS vector (a
vector pointing toward the satellite from earth)." ;
        losAzi_deg:Units = "degrees" ;
        losAzi_deg:Valid\ Range = "0-360" ;
   ubyte calQualityFlag(channels, scans, spots) ;
        calQualityFlag:Long\ Name = "Calibration Quality Flag" ;
```

```
        calQualityFlag:Description = "See readme documents. Bit 1:
land/undefined Bit 2: Lunar/solar intrusion Bit 3: Active Maneuver Bit 4:
Cold Cal. Consistency Bit 5: Hot Cal. Consistency Bit 6:
Ascending/Descending Bit 7: Day/Night Bit 8: Payload forward/aft" ;
        calQualityFlag:Units = "unitless" ;
        calQualityFlag:Valid\ Range = "0 to 128" ;
   ubyte LandFlag(scans, spots) ;
        LandFlag:Long\ Name = "Land Flag" ;
        LandFlag:Description = "0 is ocean, 1 is land or coastline, and 2
is bad or undefined" ;
        LandFlag:Units = "unitless" ;
        LandFlag:Valid\ Range = "0 to 2" ;
   float losLunZen_deg(bands, scans, spots) ;
        losLunZen_deg:_FillValue = -999.f ;
        losLunZen_deg:Long\ Name = "Line-of-sight lunar zenith angle" ;
        losLunZen_deg:Description = "The angle between the local zenith
at the LOS\'s earth intersection point and a vector pointing at the center
of the Moon." ;
        losLunZen_deg:Units = "degrees" ;
        losLunZen_deg:Valid\ Range = "0 to 180" ;
   float losLunAzi_deg(bands, scans, spots) ;
        losLunAzi_deg:_FillValue = -999.f ;
        losLunAzi_deg:Long\ Name = "Line-of-sight lunar azimuth angle" ;
        losLunAzi_deg:Description = "The angle between the local north
vector at the LOS\'s earth intersection point and a vector pointing at the
center of the Moon." ;
        losLunAzi_deg:Units = "degrees" ;
        losLunAzi_deg:Valid\ Range = "0-360" ;
   float losSolZen_deg(bands, scans, spots) ;
        losSolZen_deg:_FillValue = -999.f ;
        losSolZen_deg:Long\ Name = "Line-of-sight solar zenith angle" ;
        losSolZen_deg:Description = "The angle between the local zenith
at the LOS\'s earth intersection point and a vector pointing at the center
of the Sun." ;
        losSolZen_deg:Units = "degrees" ;
        losSolZen_deg:Valid\ Range = "0 to 180" ;
   float losSolAzi_deg(bands, scans, spots) ;
        losSolAzi_deg:_FillValue = -999.f ;
        losSolAzi_deg:Long\ Name = "Line-of-sight solar azimuth angle" ;
        losSolAzi_deg:Description = "The angle between the local north
vector at the LOS\'s earth intersection point and a vector pointing at the
center of the Sun." ;
        losSolAzi_deg:Units = "degrees" ;
        losSolAzi_deg:Valid\ Range = "0-360" ;
   float scPosECEF_km(coord, scans) ;
        scPosECEF_km:_FillValue = -999.f ;
        scPosECEF_km:Long\ Name = "Spacecraft ECEF position" ;
        scPosECEF_km:Description = "The spacecraft position in ECEF
coordinate system.  The first dimension is [x,y,z]. WGS84 Use 41st spot of
variable timeE for timestamp." ;
        scPosECEF_km:Units = "km" ;
        scPosECEF_km:Valid\ Range = "-10,000 to 10,000" ;
   float scQuatECEF(coord2, scans) ;
        scQuatECEF:_FillValue = -999.f ;
        scQuatECEF:Long\ Name = "Spacecraft Body-to-ECEF quaternion" ;
        scQuatECEF:Description = "The unit length quaternion that rotates
from spacecraft body coordinate system to ECEF coordinate system.  The
```

```
second dimension is [i,j,k,r], where r is the scalar element of the
quaternion. WGS84 Use 41st spot of variable timeE for timestamp." ;
         scQuatECEF:Units = "norm one" ;
         scQuatECEF:Valid\ Range = "0 to 1" ;
   float instrTemp_degC(scans, sensors) ;
         instrTemp_degC:_FillValue = -999.f ;
         instrTemp_degC:Long\ Name = "Average instrument temperature" ;
         instrTemp_degC:Description = "1st: The average of six temperature
sensors placed throughout the payload. 2nd: average of WF-band IFP & RFE
sensors 3rd: G-band RFE sensor" ;
         instrTemp_degC:Units = "degrees Celsius" ;
         instrTemp_degC:Valid\ Range = "-30 to 50" ;
   float NEDT_DS_K(channels, scans) ;
         NEDT_DS_K:_FillValue = -999.f ;
         NEDT_DS_K:Long\ Name = "NEDT of cold cal. measurement" ;
         NEDT_DS_K:Description = "Estimated NEDT using ten samples of deep
space. Used the product of gain (K/DN), sample standard deviation (DN),
and normal distribution bias correction (N=10)" ;
         NEDT_DS_K:Units = "kelvins" ;
         NEDT_DS_K:Valid\ Range = "0.3-3" ;
   float NEDT_ND_K(channels, scans) ;
         NEDT_ND_K:_FillValue = -999.f ;
         NEDT_ND_K:Long\ Name = "NEDT of hot cal. measurement" ;
         NEDT_ND_K:Description = "Estimated NEDT using ten samples with
noise diode turned on viewing deep space. Used the product of gain (K/DN),
sample standard deviation (DN), and normal distribution bias correction
(N=10)" ;
         NEDT_ND_K:Units = "kelvins" ;
         NEDT_ND_K:Valid\ Range = "0.3-3" ;

// global attributes:
         :_NCProperties = "version=2,netcdf=4.7.3,hdf5=1.8.12," ;
         :SV_ID = 1UB ;
         :OrbitNumber = 163US ;
         :L1a_File_Creation_Date = "2021-Jun-21 21:13:16.421 UTC" ;
         :L0b_File_Creation_Date = "2021-Jun-09 00:07:48.860 UTC" ;
         :PayloadDriver_SW_Ver = 538510608U ;
         :L0b_SW_Ver = "2" ;
         :L1a_SW_Ver = "02.03.00" ;
         :BandsToChannel = "Band 1 = Ch. 1; Band 2 = Ch. 2-4; Band 3 = Ch.
5-8; Band 4 = Ch. 9-11; Band 5 = Ch. 12" ;
         :Filename = "TROPICS01.ANTT.L1A.Orbit00163.V02-03.ST20200825-
182245.ET20200825-195749.CT20210621-211316.nc" ;
         :ShortName = "TROPICS01ANTTL1A" ;
         :LongName = "TROPICS01 L1A Orbital Geolocated Native-Resolution
Antenna Temperatures" ;
         :Format = "NetCDF-4" ;
         :ProcessingLevel = "L1a" ;
         :Source = "TROPICS01" ;
         :title = "TROPICS01 L1A Orbital Geolocated Native-Resolution
Antenna Temperatures" ;
         :orbit = "00163" ;
         :GranuleID = "TROPICS01.ANTT.L1A.Orbit00163.V02-03.ST20200825-
182245.ET20200825-195749.CT20210621-211316.nc" ;
         :ProductionDateTime = "2021-06-21 21:13:16.000000" ;
         :RangeBeginningTime = "18:22:45.000000" ;
         :RangeBeginningDate = "2020-08-25" ;
```

```
        :RangeEndingTime = "19:57:49.000000" ;
        :RangeEndingDate = "2020-08-25" ;
        :license = "http://science.nasa.gov/earth-science/earth-science-
data/data-information-policy/" ;
        :dpc_software_delivery_id = "20210609-1" ;
        :dpc_version = "pathfinder_prelaunch" ;
        :inputs = "tropics_01_515_20200825_155043_20200825_203511.mat" ;
        :BoundingBox_GPolygon = "TBD" ;
        :IdentifierProductDOIAuthority = "https://dx.doi.org" ;
        :IdentifierProductDOI = "TBD" ;
        :Collection = "TBD" ;
        :DatacenterID = "UWI-MAD/SSEC/DPC" ;
        :project = "NASA Time-Resolved Observations of Precipitation
structure and storm intensity with a Constellation of Smallsats (TROPICS)"
;
        :creator_name = "TROPICS Data Processing Center" ;
        :creator_email = "sips.support@ssec.wisc.edu" ;
        :creator_url = "https://tropics.ssec.wisc.edu" ;
        :creator_institution = "Space Science & Engineering Center,
University of Wisconsin - Madison" ;
        :publisher_name = "GESDISC" ;
        :publisher_url = "https://disc.gsfc.nasa.gov/" ;
        :publisher_email = "gsfc-dl-help-disc@mail.nasa.gov" ;
        :publisher_institution = "NASA Goddard Earth Sciences (GES) Data
and Information Services Center (DISC)" ;
}
```

Appendix B: CDL File Definition for L1b

This section provides the CDL file definition format using the example file:

```
netcdf TROPICS01.BRTT.L1B.Orbit00163.V01-00.ST20200825-182245.ET20200825-
195749.CT20210622-205655 {
dimensions:
   scans = 2854 ;
   spots = 81 ;
   channels = 12 ;
   bands = 5 ;
   coord = 3 ;
   coord2 = 4 ;
   sensors = 3 ;
variables:
   ushort Year(scans) ;
         Year:Long\ Name = "UTC year" ;
         Year:Description = "UTC year of the nadir spot." ;
         Year:Units = "years" ;
         Year:Valid\ Range = "2015-2030" ;
   ubyte Month(scans) ;
         Month:Long\ Name = "UTC month" ;
         Month:Description = "UTC month of year for the nadir spot." ;
         Month:Units = "months" ;
         Month:Valid\ Range = "1-12" ;
   ubyte Day(scans) ;
         Day:Long\ Name = "UTC day" ;
         Day:Description = "UTC day of month for the nadir spot." ;
         Day:Units = "days" ;
         Day:Valid\ Range = "1-31" ;
   ubyte Hour(scans) ;
         Hour:Long\ Name = "UTC hour" ;
         Hour:Description = "UTC hour of day for the nadir spot." ;
         Hour:Units = "hours" ;
         Hour:Valid\ Range = "0-23" ;
   ubyte Minute(scans) ;
         Minute:Long\ Name = "UTC minute" ;
         Minute:Description = "UTC minute of hour for the nadir spot." ;
         Minute:Units = "minutes" ;
         Minute:Valid\ Range = "0-59" ;
   ubyte Second(scans) ;
         Second:Long\ Name = "UTC second" ;
         Second:Description = "UTC second of minute for the nadir spot." ;
         Second:Units = "seconds" ;
         Second:Valid\ Range = "0-59" ;
   ushort Millisecond(scans) ;
         Millisecond:Long\ Name = "UTC millisecond" ;
         Millisecond:Description = "UTC millisecond of second for the
nadir spot." ;
         Millisecond:Units = "milliseconds" ;
         Millisecond:Valid\ Range = "0-999" ;
   float tempBrightE_K(channels, scans, spots) ;
         tempBrightE_K:_FillValue = -999.f ;
         tempBrightE_K:Long\ Name = "Earth radiometric brightness
temperature" ;
```

```
        tempBrightE_K:Description = "Planck blackbody equivalent antenna
temperatures" ;
        tempBrightE_K:Units = "kelvins" ;
        tempBrightE_K:Valid\ Range = "0-350" ;
   double timeE(scans, spots) ;
        timeE:Long\ Name = "Time of Earth radiometric measurements" ;
        timeE:Description = "TROPICS Epoch Time (TET) timestamp of the
Earth radiometric measurements." ;
        timeE:Units = "TET is the number of atomic seconds elapsed since
January 1, 2000 00:00:00.000 TAI" ;
        timeE:Valid\ Range = "6.7e+09" ;
   float losLat_deg(bands, scans, spots) ;
        losLat_deg:_FillValue = -999.f ;
        losLat_deg:Long\ Name = "Line-of-sight earth intersection
latitude" ;
        losLat_deg:Description = "Geodetic latitude of the line-of-sight
intersection point with the Earth. Negative values are South. These
correspond to the middle of each spot\'s integration period. WGS84" ;
        losLat_deg:Units = "degrees" ;
        losLat_deg:Valid\ Range = "-90 to 90" ;
   float losLon_deg(bands, scans, spots) ;
        losLon_deg:_FillValue = -999.f ;
        losLon_deg:Long\ Name = "Line-of-sight earth intersection
longitude" ;
        losLon_deg:Description = "Geodetic longitude of the line-of-sight
intersection point with the Earth. Negative values are West. These
correspond to the middle of each spot\'s integration period. WGS84" ;
        losLon_deg:Units = "degrees" ;
        losLon_deg:Valid\ Range = "-180 to 180" ;
   float losScan_deg(bands, scans, spots) ;
        losScan_deg:_FillValue = -999.f ;
        losScan_deg:Long\ Name = "Line-of-sight scan angle" ;
        losScan_deg:Description = "The scan angle between the satellite
local nadir and the Line-Of-Sight (LOS) vector from radiometer
aperture." ;
        losScan_deg:Units = "degrees" ;
        losScan_deg:Valid\ Range = "0-180" ;
   float losZen_deg(bands, scans, spots) ;
        losZen_deg:_FillValue = -999.f ;
        losZen_deg:Long\ Name = "Line-of-sight zenith angle" ;
        losZen_deg:Description = "The angle between the local zenith at
the LOS earth intersection point and the inverse LOS vector (a vector
pointing toward the satellite from earth)." ;
        losZen_deg:Units = "degrees" ;
        losZen_deg:Valid\ Range = "0-90" ;
   float losAzi_deg(bands, scans, spots) ;
        losAzi_deg:_FillValue = -999.f ;
        losAzi_deg:Long\ Name = "Line-of-sight azimuth angle" ;
        losAzi_deg:Description = "The angle between the local north
vector at the LOS earth intersection point and the inverse LOS vector (a
vector pointing toward the satellite from earth)." ;
        losAzi_deg:Units = "degrees" ;
        losAzi_deg:Valid\ Range = "0-360" ;
   ubyte calQualityFlag(channels, scans, spots) ;
        calQualityFlag:Long\ Name = "Calibration Quality Flag" ;
        calQualityFlag:Description = "See TROPICS Data User\'s Guide. Bit
1: land/undefined Bit 2: Lunar/solar intrusion Bit 3: Active Maneuver Bit
```

```
4: Cold Cal. Consistency Bit 5: Hot Cal. Consistency Bit 6:
Ascending/Descending Bit 7: Day/Night Bit 8: Payload forward/aft" ;
         calQualityFlag:Units = "unitless" ;
         calQualityFlag:Valid\ Range = "0 to 128" ;
   ubyte LandFlag(scans, spots) ;
         LandFlag:Long\ Name = "Land Flag" ;
         LandFlag:Description = "0 is ocean, 1 is land or coastline, and 2
is bad or undefined" ;
         LandFlag:Units = "unitless" ;
         LandFlag:Valid\ Range = "0 to 3" ;
   float losLunZen_deg(bands, scans, spots) ;
         losLunZen_deg:_FillValue = -999.f ;
         losLunZen_deg:Long\ Name = "Line-of-sight lunar zenith angle" ;
         losLunZen_deg:Description = "The angle between the local zenith
at the LOS\'s earth intersection point and a vector pointing at the center
of the Moon." ;
         losLunZen_deg:Units = "degrees" ;
         losLunZen_deg:Valid\ Range = "0 to 180" ;
   float losLunAzi_deg(bands, scans, spots) ;
         losLunAzi_deg:_FillValue = -999.f ;
         losLunAzi_deg:Long\ Name = "Line-of-sight lunar azimuth angle" ;
         losLunAzi_deg:Description = "The angle between the local north
vector at the LOS\'s earth intersection point and a vector pointing at the
center of the Moon." ;
         losLunAzi_deg:Units = "degrees" ;
         losLunAzi_deg:Valid\ Range = "0-360" ;
   float losSolZen_deg(bands, scans, spots) ;
         losSolZen_deg:_FillValue = -999.f ;
         losSolZen_deg:Long\ Name = "Line-of-sight solar zenith angle" ;
         losSolZen_deg:Description = "The angle between the local zenith
at the LOS\'s earth intersection point and a vector pointing at the center
of the Sun." ;
         losSolZen_deg:Units = "degrees" ;
         losSolZen_deg:Valid\ Range = "0 to 180" ;
   float losSolAzi_deg(bands, scans, spots) ;
         losSolAzi_deg:_FillValue = -999.f ;
         losSolAzi_deg:Long\ Name = "Line-of-sight solar azimuth angle" ;
         losSolAzi_deg:Description = "The angle between the local north
vector at the LOS\'s earth intersection point and a vector pointing at the
center of the Sun." ;
         losSolAzi_deg:Units = "degrees" ;
         losSolAzi_deg:Valid\ Range = "0-360" ;
   float scPosECEF_km(coord, scans) ;
         scPosECEF_km:_FillValue = -999.f ;
         scPosECEF_km:Long\ Name = "Spacecraft ECEF position" ;
         scPosECEF_km:Description = "The spacecraft position in ECEF
coordinate system.  The first dimension is [x,y,z]. WGS84" ;
         scPosECEF_km:Units = "km" ;
         scPosECEF_km:Valid\ Range = "-10,000 to 10,000" ;
   float scQuatECEF(coord2, scans) ;
         scQuatECEF:_FillValue = -999.f ;
         scQuatECEF:Long\ Name = "Spacecraft Body-to-ECEF quaternion" ;
         scQuatECEF:Description = "The unit length quaternion that rotates
from spacecraft body coordinate system to ECEF coordinate system.  The
second dimension is [i,j,k,r], where r is the scalar element of the
quaternion. WGS84 Use 41st spot of variable timeE for timestamp." ;
         scQuatECEF:Units = "norm one" ;
```

```
            scQuatECEF:Valid\ Range = "0 to 1" ;
      float instrTemp_degC(scans, sensors) ;
            instrTemp_degC:_FillValue = -999.f ;
            instrTemp_degC:Long\ Name = "Average instrument temperature" ;
            instrTemp_degC:Description = "1st: The average of six temperature
sensors placed throughout the payload. 2nd: average of WF-band IFP & RFE
sensors 3rd: G-band RFE sensor" ;
            instrTemp_degC:Units = "degrees Celsius" ;
            instrTemp_degC:Valid\ Range = "-30 to 50" ;
      float NEDT_DS_K(channels, scans) ;
            NEDT_DS_K:_FillValue = -999.f ;
            NEDT_DS_K:Long\ Name = "NEDT of cold cal. measurement" ;
            NEDT_DS_K:Description = "Estimated NEDT using ten samples of deep
space. Used the product of gain (K/DN), sample standard deviation (DN),
and normal distribution bias correction (N=10)" ;
            NEDT_DS_K:Units = "kelvins" ;
            NEDT_DS_K:Valid\ Range = "0.3-3" ;
      float NEDT_ND_K(channels, scans) ;
            NEDT_ND_K:_FillValue = -999.f ;
            NEDT_ND_K:Long\ Name = "NEDT of hot cal. measurement" ;
            NEDT_ND_K:Description = "Estimated NEDT using ten samples with
noise diode turned on viewing deep space. Used the product of gain (K/DN),
sample standard deviation (DN), and normal distribution bias correction
(N=10)" ;
            NEDT_ND_K:Units = "kelvins" ;
            NEDT_ND_K:Valid\ Range = "0.3-3" ;

// global attributes:
            :_NCProperties = "version=2,netcdf=4.7.3,hdf5=1.8.12," ;
            :SV_ID = 1UB ;
            :OrbitNumber = 163US ;
            :L1b_File_Creation_Date = "2021-Jun-22 20:56:55.356 UTC" ;
            :L1a_File_Creation_Date = "2021-Jun-21 21:13:16.421 UTC" ;
            :L0b_File_Creation_Date = "2021-Jun-09 00:07:48.860 UTC" ;
            :PayloadDriver_SW_Ver = 538510608U ;
            :L0b_SW_Ver = "2" ;
            :L1a_SW_Ver = "02.03.00" ;
            :L1b_SW_Ver = "01.00.00" ;
            :Bands_to_Channel = "Band 1 = Ch. 1; Band 2 = Ch. 2-4; Band 3 =
Ch. 5-8; Band 4 = Ch. 9-11; Band 5 = Ch. 12" ;
            :Filename = "TROPICS01.BRTT.L1B.Orbit00163.V01-00.ST20200825-
182245.ET20200825-195749.CT20210622-205655.nc" ;
            :ShortName = "TROPICS01BRTTL1B" ;
            :LongName = "TROPICS01 L1B Orbital Geolocated Native-Resolution
Brightness Temperatures" ;
            :Format = "NetCDF-4" ;
            :ProcessingLevel = "L1b" ;
            :Source = "TROPICS01" ;
            :title = "TROPICS01 L1B Orbital Geolocated Native-Resolution
Brightness Temperatures" ;
            :orbit = "00163" ;
            :GranuleID = "TROPICS01.BRTT.L1B.Orbit00163.V01-00.ST20200825-
182245.ET20200825-195749.CT20210622-205655.nc" ;
            :ProductionDateTime = "2021-06-22 20:56:55.000000" ;
            :RangeBeginningTime = "18:22:45.000000" ;
            :RangeBeginningDate = "2020-08-25" ;
            :RangeEndingTime = "19:57:49.000000" ;
```

```
		:RangeEndingDate = "2020-08-25" ;
		:license = "http://science.nasa.gov/earth-science/earth-science-
data/data-information-policy/" ;
		:dpc_software_delivery_id = "20210616-1" ;
		:dpc_version = "pathfinder_prelaunch" ;
		:inputs = "TROPICS01.ANTT.L1A.Orbit00163.V02-03.ST20200825-
182245.ET20200825-195749.CT20210621-211316.mat" ;
		string :ancillary_inputs = "OR_ABI-L2-ACMF-
M6_G17_s20202381910321_e20202381919388_c20202381920100.nc", "OR_ABI-L2-
ACMF-M6_G17_s20202381900321_e20202381909388_c20202381910065.nc", "OR_ABI-
L2-ACMF-M6_G16_s20202381830209_e20202381839517_c20202381840303.nc",
"GEOS.fp.asm.inst3_2d_asm_Nx.20200825_1800.V01.nc4", "OR_ABI-L2-ACMF-
M6_G16_s20202381740209_e20202381749517_c20202381750264.nc",
"GEOS.fp.asm.inst3_2d_asm_Nx.20200826_0000.V01.nc4", "OR_ABI-L2-ACMF-
M6_G16_s20202381820209_e20202381829517_c20202381830232.nc", "OR_ABI-L2-
ACMF-M6_G16_s20202381950209_e20202381959517_c20202382000350.nc", "OR_ABI-
L2-ACMF-M6_G17_s20202381920321_e20202381929388_c20202381930047.nc",
"OR_ABI-L2-ACMF-
M6_G16_s20202381810209_e20202381819517_c20202381820275.nc", "OR_ABI-L2-
ACMF-M6_G16_s20202382000209_e20202382009517_c20202382010273.nc",
"GEOS.fp.asm.inst3_3d_asm_Np.20200826_0000.V01.nc4", "OR_ABI-L2-ACMF-
M6_G17_s20202381820321_e20202381829388_c20202381830051.nc", "OR_ABI-L2-
ACMF-M6_G17_s20202381950321_e20202381959388_c20202382000040.nc", "OR_ABI-
L2-ACMF-M6_G16_s20202381920209_e20202381929517_c20202381930280.nc",
"OR_ABI-L2-ACMF-
M6_G16_s20202381840209_e20202381849517_c20202381850239.nc", "OR_ABI-L2-
ACMF-M6_G17_s20202382020321_e20202382029388_c20202382030062.nc", "OR_ABI-
L2-ACMF-M6_G16_s20202381900209_e20202381909517_c20202381910309.nc",
"OR_ABI-L2-ACMF-
M6_G16_s20202381930209_e20202381939517_c20202381940292.nc", "OR_ABI-L2-
ACMF-M6_G17_s20202381750321_e20202381759388_c20202381800046.nc", "OR_ABI-
L2-ACMF-M6_G17_s20202381810321_e20202381819388_c20202381820092.nc",
"OR_ABI-L2-ACMF-
M6_G16_s20202381940209_e20202381949517_c20202381950285.nc", "OR_ABI-L2-
ACMF-M6_G17_s20202382010321_e20202382019388_c20202382020101.nc", "OR_ABI-
L2-ACMF-M6_G17_s20202381800321_e20202381809388_c20202381810078.nc",
"GEOS.fp.asm.inst3_2d_asm_Nx.20200825_2100.V01.nc4", "OR_ABI-L2-ACMF-
M6_G17_s20202381940321_e20202381949388_c20202381950039.nc", "OR_ABI-L2-
ACMF-M6_G16_s20202381750209_e20202381759517_c20202381800270.nc", "OR_ABI-
L2-ACMF-M6_G17_s20202381850321_e20202381859388_c20202381900049.nc",
"OR_ABI-L2-ACMF-
M6_G16_s20202381800209_e20202381809517_c20202381810289.nc", "OR_ABI-L2-
ACMF-M6_G17_s20202381830321_e20202381839388_c20202381840064.nc", "OR_ABI-
L2-ACMF-M6_G16_s20202382020209_e20202382029516_c20202382030290.nc",
"OR_ABI-L2-ACMF-
M6_G17_s20202381740321_e20202381749388_c20202381750048.nc", "OR_ABI-L2-
ACMF-M6_G16_s20202381910209_e20202381919517_c20202381920281.nc", "OR_ABI-
L2-ACMF-M6_G17_s20202381930321_e20202381939388_c20202381940072.nc",
"OR_ABI-L2-ACMF-
M6_G17_s20202382000321_e20202382009388_c20202382010073.nc", "OR_ABI-L2-
ACMF-M6_G16_s20202382010209_e20202382019516_c20202382020314.nc", "OR_ABI-
L2-ACMF-M6_G16_s20202382030208_e20202382039516_c20202382040286.nc",
"OR_ABI-L2-ACMF-
M6_G17_s20202382030321_e20202382039388_c20202382040065.nc",
"GEOS.fp.asm.inst3_3d_asm_Np.20200825_2100.V01.nc4",
"GEOS.fp.asm.inst3_3d_asm_Np.20200825_1800.V01.nc4", "OR_ABI-L2-ACMF-
```

```
M6_G17_s20202381840321_e20202381849388_c20202381850044.nc", "OR_ABI-L2-
ACMF-M6_G16_s20202381850209_e20202381859517_c20202381900275.nc" ;
         :BoundingBox_GPolygon = "TBD" ;
         :IdentifierProductDOIAuthority = "https://dx.doi.org" ;
         :IdentifierProductDOI = "TBD" ;
         :Collection = "TBD" ;
         :DatacenterID = "UWI-MAD/SSEC/DPC" ;
         :project = "NASA Time-Resolved Observations of Precipitation
structure and storm intensity with a Constellation of Smallsats
(TROPICS)" ;
         :creator_name = "TROPICS Data Processing Center" ;
         :creator_email = "sips.support@ssec.wisc.edu" ;
         :creator_url = "https://tropics.ssec.wisc.edu" ;
         :creator_institution = "Space Science & Engineering Center,
University of Wisconsin - Madison" ;
         :publisher_name = "GESDISC" ;
         :publisher_url = "https://disc.gsfc.nasa.gov/" ;
         :publisher_email = "gsfc-dl-help-disc@mail.nasa.gov" ;
         :publisher_institution = "NASA Goddard Earth Sciences (GES) Data
and Information Services Center (DISC)" ;
}
```

Appendix C: CDL File Definition for L2a

This section provides the CDL file definition format using the example file:

```
netcdf TROPICS01.URAD.L2A.Orbit00000.V01-21.ST20050804-105000.ET20050804-
105958.CT20210526-222254 {
dimensions:
   scalar = 1 ;
   spots = 81 ;
   scans = 300 ;
   channels = 12 ;
   bands = 5 ;
   coord = 3 ;
variables:
   double creTimeL1b(scalar) ;
         creTimeL1b:Long\ Name = "L1b file creation time" ;
         creTimeL1b:Description = "Elapsed GMT timestamp of the file\'s
creation time." ;
         creTimeL1b:Units = "Seconds since 1/1/2000 00:00.000." ;
         creTimeL1b:Valid\ Range = "1.5778e+09-1.8935e+09" ;
   float tempBrightE(channels, scans, spots) ;
         tempBrightE:_FillValue = -999.f ;
         tempBrightE:Long\ Name = "Earth radiometric brightness
temperature" ;
         tempBrightE:Description = "Planck blackbody equivalent antenna
temperatures" ;
         tempBrightE:Units = "kelvins" ;
         tempBrightE:Valid\ Range = "0-330" ;
   double timeE(scans, spots) ;
         timeE:Long\ Name = "Earth radiometric measurement time" ;
         timeE:Description = "Elapsed GMT timestamp of the Earth
radiometric measurements." ;
         timeE:Units = "Seconds since 1/1/2000 00:00.000;
         timeE:Valid\ Range = "1.5778e+09-1.8935e+09" ;
   float losLat(bands, scans, spots) ;
         losLat:_FillValue = 999.f ;
         losLat:Long\ Name = "Line-of-sight earth intersection latitude" ;
         losLat:Description = "Geodetic latitude of the line-of-sight
intersection point with the Earth. Negative values are South. These
correspond to the middle of each spot\'s integration period. WGS84" ;
         losLat:Units = "degrees" ;
         losLat:Valid\ Range = "-90 to 90" ;
   float losLon(bands, scans, spots) ;
         losLon:_FillValue = 999.f ;
         losLon:Long\ Name = "Line-of-sight earth intersection
longitude" ;
         losLon:Description = "Geodetic longitude of the line-of-sight
intersection point with the Earth. Negative values are West. These
correspond to the middle of each spot\'s integration period. WGS84" ;
         losLon:Units = "degrees" ;
         losLon:Valid\ Range = "-180 to 180" ;
   float losScan(bands, scans, spots) ;
         losScan:_FillValue = 999.f ;
         losScan:Long\ Name = "Line-of-sight scan angle" ;
```

```
        losScan:Description = "The scan angle between the satellite local
nadir and the Line-Of-Sight (LOS) vector from radiometer aperture." ;
        losScan:Units = "degrees" ;
        losScan:Valid\ Range = "0-180" ;
   float losZen(bands, scans, spots) ;
        losZen:_FillValue = 999.f ;
        losZen:Long\ Name = "Line-of-sight zenith angle" ;
        losZen:Description = "The angle between the local zenith at the
LOS earth intersection point and the inverse LOS vector (a vector pointing
toward the satellite from earth)." ;
        losZen:Units = "degrees" ;
        losZen:Valid\ Range = "0-90" ;
   float losAzi(bands, scans, spots) ;
        losAzi:_FillValue = 999.f ;
        losAzi:Long\ Name = "Line-of-sight azimuth angle" ;
        losAzi:Description = "The angle between the local north vector at
the LOS earth intersection point and the inverse LOS vector (a vector
pointing toward the satellite from earth)." ;
        losAzi:Units = "degrees" ;
        losAzi:Valid\ Range = "0-360" ;
   ubyte calQualityFlag(channels, scans, spots) ;
        calQualityFlag:Long\ Name = "Calibration Quality Flag" ;
        calQualityFlag:Description = "See TROPICS Data User\'s Guide.
Eight 1-bit flags." ;
        calQualityFlag:Units = "unitless" ;
        calQualityFlag:Valid\ Range = "0 to 63" ;
   float losLunZen(bands, scans, spots) ;
        losLunZen:_FillValue = 999.f ;
        losLunZen:Long\ Name = "Line-of-sight lunar zenith angle" ;
        losLunZen:Description = "The angle between the local zenith at
the LOS\'s earth intersection point and a vector pointing at the center of
the Moon." ;
        losLunZen:Units = "degrees" ;
        losLunZen:Valid\ Range = "-180 to 180" ;
   float losLunAzi(bands, scans, spots) ;
        losLunAzi:_FillValue = 999.f ;
        losLunAzi:Long\ Name = "Line-of-sight lunar azimuth angle" ;
        losLunAzi:Description = "The angle between the local north vector
at the LOS\'s earth intersection point and a vector pointing at the center
of the Moon." ;
        losLunAzi:Units = "degrees" ;
        losLunAzi:Valid\ Range = "0-360" ;
   float losSolZen(bands, scans, spots) ;
        losSolZen:_FillValue = 999.f ;
        losSolZen:Long\ Name = "Line-of-sight solar zenith angle" ;
        losSolZen:Description = "The angle between the local zenith at
the LOS\'s earth intersection point and a vector pointing at the center of
the Sun." ;
        losSolZen:Units = "degrees" ;
        losSolZen:Valid\ Range = "-180 to 180" ;
   float losSolAzi(bands, scans, spots) ;
        losSolAzi:_FillValue = 999.f ;
        losSolAzi:Long\ Name = "Line-of-sight solar azimuth angle" ;
        losSolAzi:Description = "The angle between the local north vector
at the LOS\'s earth intersection point and a vector pointing at the center
of the Sun." ;
        losSolAzi:Units = "degrees" ;
```

```
        losSolAzi:Valid\ Range = "0-360" ;
    float polG(scalar) ;
        polG:Long\ Name = "G-band polarization angle" ;
        polG:Description = "The measured G-band fixed polarization angle
for this spacecraft (see TROPICS Data User Guide)." ;
        polG:Units = "degrees" ;
        polG:Valid\ Range = "0-360" ;
    float polWF(scalar) ;
        polWF:Long\ Name = "W- & F-band polarization angle" ;
        polWF:Description = "The measured WF-band fixed polarization
angle for this spacecraft (see TROPICS Data User Guide)." ;
        polWF:Units = "degrees" ;
        polWF:Valid\ Range = "0-360" ;
    float scPosECEF(coord, scans, spots) ;
        scPosECEF:_FillValue = 999.f ;
        scPosECEF:Long\ Name = "Spacecraft ECEF position" ;
        scPosECEF:Description = "The spacecraft position every spot in
ECEF coordinate system.  The first dimension is [x,y,z]. WGS84" ;
        scPosECEF:Units = "km" ;
        scPosECEF:Valid\ Range = "-10,000 to 10,000" ;
    float tempBright_l2a(channels, scans, spots) ;
        tempBright_l2a:_FillValue = -999.f ;
        string tempBright_l2a:Long\ Name = "Level-2A Earth radiometric
brightness temperature at 118 GHz resolution" ;
        string tempBright_l2a:Description = "Planck blackbody equivalent
brightness temperatures" ;
        string tempBright_l2a:Units = "kelvins" ;
        string tempBright_l2a:Valid\ Range = "0-330" ;
    float stddev_ch12_l2a(scans, spots) ;
        stddev_ch12_l2a:_FillValue = -999.f ;
        string stddev_ch12_l2a:Long\ Name = "Standard deviation of Ch 12
within the 118 GHz footprint (Backus-Gilbert-weighted)" ;
        string stddev_ch12_l2a:Description = "Planck blackbody equivalent
brightness temperatures" ;
        string stddev_ch12_l2a:Units = "kelvins" ;
        string stddev_ch12_l2a:Valid\ Range = "0-330" ;
    float noise_reduction_l2a(channels, scans, spots) ;
        noise_reduction_l2a:_FillValue = -999.f ;
        string noise_reduction_l2a:Long\ Name = "Backus-Gilbert G-band
noise reduction parameter" ;
        string noise_reduction_l2a:Description = "Backus-Gilbert G-band
noise reduction parameter (Multiply sensor NEDT by this value to get
reduced NEDT" ;
        string noise_reduction_l2a:Units = "dimensionless" ;
        string noise_reduction_l2a:Valid\ Range = "larger than zero" ;

// global attributes:
        :Space_Vehicle_Identifier = 1. ;
        :Orbit_Number = 0. ;
        :Payload_Driver_SW_Version = 0. ;
        :L0b_SW_Version = 0. ;
        :L1a_SW_Version = 1. ;
        :L1b_SW_Version = 1. ;
        :Bands_to_Channel = "Band 1 = Ch. 1; Band 2 = Ch. 2-4; Band 3 =
Ch. 5-8; Band 4 = Ch. 9-11; Band 5 = Ch. 12" ;
        string :L2a_SW_Version = "1.2.1" ;
        :ShortName = "TROPICS01URAD" ;
```

```
          :LongName = "Unified Radiances" ;
          :Format = "NetCDF-4" ;
          :ProcessingLevel = "L2a" ;
          :Source = "TROPICS01" ;
          :title = "Unified Radiances" ;
          :orbit = "00000" ;
          :GranuleID = "TROPICS01.URAD.L2A.Orbit00000.V01-21.ST20050804-
105000.ET20050804-105958.CT20210526-222254.nc" ;
          :ProductionDateTime = "2021-05-26 22:22:54.000000" ;
          :RangeBeginningTime = "10:50:00.000000" ;
          :RangeBeginningDate = "2005-08-04" ;
          :RangeEndingTime = "10:59:58.000000" ;
          :RangeEndingDate = "2005-08-04" ;
          :license = "http://science.nasa.gov/earth-science/earth-science-
data/data-information-policy/" ;
          :dpc_software_delivery_id = "20210507-1" ;
          :dpc_version = "1.0dev4" ;
          :inputs = "TROPICS_L1b_SV01_Orbit00000_ST20050804-
105000_ET20050804-105958_CT20180429-112411.nc" ;
          :BoundingBox_GPolygon = "TBD" ;
          :DatacenterID = "UWI-MAD/SSEC/DPC" ;
          :project = "NASA Time-Resolved Observations of Precipitation
structure and storm intensity with a Constellation of Smallsats
(TROPICS)" ;
          :creator_name = "TROPICS Data Processing Center" ;
          :creator_email = "sips.support@ssec.wisc.edu" ;
          :creator_url = "https://tropics.ssec.wisc.edu" ;
          :creator_institution = "Space Science & Engineering Center,
University of Wisconsin - Madison" ;
          :publisher_name = "GESDISC" ;
          :publisher_url = "https://disc.gsfc.nasa.gov/" ;
          :publisher_email = "gsfc-dl-help-disc@mail.nasa.gov" ;
          :publisher_institution = "NASA Goddard Earth Sciences (GES) Data
and Information Services Center (DISC)" ;
}
```

Appendix D: CDL File Definition for L2b AVP

This section provides the CDL file definition format using the example file:

```
netcdf TROPICS01.MIRS.L2B.Orbit00000.ST20050804-1050000.ET20050804-
1059580.CT20210608-2017021 {
dimensions:
   Scanline = 300 ;
   Field_of_view = 81 ;
   Channel = 12 ;
   P_Layer = 100 ;
   P_Level = 101 ;
   Qc_dim = 4 ;
variables:
   short Atm_type(Scanline, Field_of_view) ;
         Atm_type:description = "0-simple scene, 1-retrieved scene" ;
         Atm_type:coordinates = "Longitude Latitude" ;
   float ChiSqr(Scanline, Field_of_view) ;
         ChiSqr:description = "Convergence rate: <3-good,>10-bad" ;
         ChiSqr:units = "1" ;
         ChiSqr:coordinates = "Longitude Latitude" ;
         ChiSqr:_FillValue = -999.f ;
         ChiSqr:valid_range = 0.f, 1000.f ;
   float Freq(Channel) ;
         Freq:long_name = "Central Frequency" ;
   float LZ_angle(Scanline, Field_of_view) ;
         LZ_angle:units = "degrees" ;
         LZ_angle:_FillValue = -999.f ;
         LZ_angle:valid_range = -70.f, 70.f ;
         LZ_angle:long_name = "Local zenith angle: (-59,59) degree" ;
         LZ_angle:coordinates = "Longitude Latitude" ;
   float Latitude(Scanline, Field_of_view) ;
         Latitude:long_name = "Latitude of the view (-90,90)" ;
         Latitude:units = "degrees" ;
         Latitude:_FillValue = -999.f ;
         Latitude:valid_range = -90.f, 90.f ;
   float Longitude(Scanline, Field_of_view) ;
         Longitude:long_name = "Longitude of the view (-180,180)" ;
         Longitude:units = "degrees" ;
         Longitude:_FillValue = -999.f ;
         Longitude:valid_range = -180.f, 180.f ;
   short Orb_mode(Scanline) ;
         Orb_mode:description = "0-ascending,1-descending" ;
         Orb_mode:units = "1" ;
         Orb_mode:_FillValue = -999s ;
         Orb_mode:valid_range = 0, 1 ;
   float PTemp(Scanline, Field_of_view, P_Layer) ;
         PTemp:units = "Kelvin" ;
         PTemp:coordinates = "Longitude Latitude Player" ;
         PTemp:_FillValue = -999.f ;
         PTemp:valid_range = 0.f, 1000.f ;
         PTemp:long_name = "Temperature profile in K via unified
resolution" ;
   float PVapor(Scanline, Field_of_view, P_Layer) ;
         PVapor:units = "g/kg" ;
```

```
            PVapor:coordinates = "Longitude Latitude Player" ;
            PVapor:_FillValue = -999.f ;
            PVapor:valid_range = 0.f, 100.f ;
            PVapor:long_name = "Water vapor profile in g/kg via native
   resolution" ;
      float Player(P_Layer) ;
            Player:description = "Pressure for each layer in mb" ;
            Player:units = "millibars" ;
            Player:_FillValue = -999.f ;
            Player:valid_range = 0.011f, 1085.458f ;
      float Plevel(P_Level) ;
            Plevel:description = "Pressure for each level in mb" ;
            Plevel:units = "millibars" ;
            Plevel:_FillValue = -999.f ;
            Plevel:valid_range = 0.005f, 1100.f ;
      short Polo(Channel) ;
            Polo:long_name = "Polarizations(Horizonal or Vertical)" ;
      short Qc(Scanline, Field_of_view, Qc_dim) ;
            Qc:description = "Qc(0): 0-good,1-usable with problem ,2-bad" ;
      float RAzi_angle(Scanline, Field_of_view) ;
            RAzi_angle:long_name = "Relative azimuth angle 0-360 degree" ;
            RAzi_angle:coordinates = "Longitude Latitude" ;
      float SZ_angle(Scanline, Field_of_view) ;
            SZ_angle:long_name = "Solar zenith angle (-90,90) degree" ;
            SZ_angle:coordinates = "Longitude Latitude" ;
      double ScanTime_UTC(Scanline) ;
            ScanTime_UTC:long_name = "Number of seconds since 00:00:00 UTC" ;
            ScanTime_UTC:units = "seconds" ;
            ScanTime_UTC:_FillValue = -999. ;
            ScanTime_UTC:valid_range = 0., 86400. ;
      short ScanTime_dom(Scanline) ;
            ScanTime_dom:long_name = "Calendar day of the month 1-31" ;
            ScanTime_dom:units = "days" ;
            ScanTime_dom:_FillValue = -999s ;
            ScanTime_dom:valid_range = 1, 31 ;
      short ScanTime_doy(Scanline) ;
            ScanTime_doy:long_name = "julian day 1-366" ;
            ScanTime_doy:units = "days" ;
            ScanTime_doy:_FillValue = -999s ;
            ScanTime_doy:valid_range = 1, 366 ;
      short ScanTime_hour(Scanline) ;
            ScanTime_hour:long_name = "hour of the day 0-23" ;
            ScanTime_hour:units = "hours" ;
            ScanTime_hour:_FillValue = -999s ;
            ScanTime_hour:valid_range = 0, 23 ;
      short ScanTime_minute(Scanline) ;
            ScanTime_minute:long_name = "minute of the hour 0-59" ;
            ScanTime_minute:units = "minutes" ;
            ScanTime_minute:_FillValue = -999s ;
            ScanTime_minute:valid_range = 0, 59 ;
      short ScanTime_month(Scanline) ;
            ScanTime_month:long_name = "Calendar month 1-12" ;
            ScanTime_month:units = "months" ;
            ScanTime_month:_FillValue = -999s ;
            ScanTime_month:valid_range = 1, 12 ;
      short ScanTime_second(Scanline) ;
            ScanTime_second:long_name = "second of the minute 0-59" ;
```

```
          ScanTime_second:units = "seconds" ;
          ScanTime_second:_FillValue = -999s ;
          ScanTime_second:valid_range = 0, 59 ;
    short ScanTime_year(Scanline) ;
          ScanTime_year:long_name = "Calendar Year 20XX" ;
          ScanTime_year:units = "years" ;
          ScanTime_year:_FillValue = -999s ;
          ScanTime_year:valid_range = 2011, 2050 ;
    short Sfc_type(Scanline, Field_of_view) ;
          Sfc_type:description = "type of surface:0-ocean,1-sea-ice,2-
land,3-snow" ;
          Sfc_type:units = "1" ;
          Sfc_type:coordinates = "Longitude Latitude" ;
          Sfc_type:_FillValue = -999s ;
          Sfc_type:valid_range = 0, 3 ;
    short BT(Scanline, Field_of_view, Channel) ;
          BT:_FillValue = -999s ;
          BT:long_name = "Channel Temperature (K)" ;
          BT:units = "Kelvin" ;
          BT:coordinates = "Longitude Latitude Freq" ;
          BT:scale_factor = 0.01 ;
          BT:valid_range = 0, 50000 ;
    short ChanSel(Scanline, Field_of_view, Channel) ;
          ChanSel:_FillValue = -999s ;
          ChanSel:long_name = "Channels Selection Used in Retrieval" ;
          ChanSel:units = "1" ;
          ChanSel:coordinates = "Longitude Latitude Freq" ;
          ChanSel:valid_range = 0, 1 ;
    short TPW(Scanline, Field_of_view) ;
          TPW:_FillValue = -999s ;
          TPW:long_name = "Total Precipitable Water (mm)" ;
          TPW:units = "mm" ;
          TPW:coordinates = "Longitude Latitude" ;
          TPW:scale_factor = 0.1 ;
          TPW:valid_range = 0, 2000 ;
    short YM(Scanline, Field_of_view, Channel) ;
          YM:_FillValue = -999s ;
          YM:long_name = "Un-Corrected Channel Temperature (K)" ;
          YM:units = "Kelvin" ;
          YM:coordinates = "Longitude Latitude Freq" ;
          YM:scale_factor = 0.01 ;
          YM:valid_range = 0, 50000 ;

// global attributes:
          :_NCProperties =
"version=1|netcdflibversion=4.4.1|hdf5libversion=1.8.17" ;
          :missing_value = -999 ;
          :notretrievedproduct_value = -888 ;
          :noretrieval_value = -99 ;
          :cdf_version = 4. ;
          :alg_version = 4141 ;
          :dap_version = "v11r4" ;
          :history = "Tue Jun  8 20:25:06 2021: ncks -x -v
PRain,PGraupel,PSnow,PIce,PClw,SurfP l1b/NPR-MIRS-
SND_v11r4_TRP1_s200508041050000_e200508041059580_c202106082017021.nc
l1b/NPR-MIRS-
```

```
SND_v11r4_TRP1_s200508041050000_e200508041059580_c202106082017021.tmp.nc"
;
		:NCO = "\"4.5.5\"" ;
		:ShortName = "TROPICS01MIRSL2B" ;
		:LongName = "Atmospheric Vertical Temperature & Moisture
Profiles" ;
		:Format = "NetCDF-4" ;
		:ProcessingLevel = "L2b" ;
		:Source = "TROPICS01" ;
		:title = "Atmospheric Vertical Temperature & Moisture Profiles" ;
		:orbit = "00000" ;
		:GranuleID = "NPR-MIRS-
SND_v11r4_TRP1_s200508041050000_e200508041059580_c202106082017021.nc" ;
		:ProductionDateTime = "2021-06-08 20:17:02.100000" ;
		:RangeBeginningTime = "10:50:00.000000" ;
		:RangeBeginningDate = "2005-08-04" ;
		:RangeEndingTime = "10:59:58.000000" ;
		:RangeEndingDate = "2005-08-04" ;
		:license = "http://science.nasa.gov/earth-science/earth-science-
data/data-information-policy/" ;
		:dpc_software_delivery_id = "20210310-1" ;
		:dpc_version = "1.0dev6" ;
		string :inputs = "TROPICS_L1b_SV01_Orbit00000_ST20050804-
105000_ET20050804-105958_CT20180429-112411.nc",
"TROPICS01.URAD.L2A.Orbit00000.V01-21.ST20050804-105000.ET20050804-
105958.CT20210526-222254.nc" ;
		:BoundingBox_GPolygon = "TBD" ;
		:DatacenterID = "UWI-MAD/SSEC/DPC" ;
		:project = "NASA Time-Resolved Observations of Precipitation
structure and storm intensity with a Constellation of Smallsats
(TROPICS)" ;
		:creator_name = "TROPICS Data Processing Center" ;
		:creator_email = "sips.support@ssec.wisc.edu" ;
		:creator_url = "https://tropics.ssec.wisc.edu" ;
		:creator_institution = "Space Science & Engineering Center,
University of Wisconsin - Madison" ;
		:publisher_name = "GESDISC" ;
		:publisher_url = "https://disc.gsfc.nasa.gov/" ;
		:publisher_email = "gsfc-dl-help-disc@mail.nasa.gov" ;
		:publisher_institution = "NASA Goddard Earth Sciences (GES) Data
and Information Services Center (DISC)" ;
}
```

Appendix E: CDL File Definition for L2b ISRR

This section provides the CDL file definition format using the example file:

```
netcdf TROPICS01.PRPS.L2B.Orbit00000.V01-01.ST20050731-044500.ET20050731-
044958.CT20210623-164911 {
dimensions:
   scans = 150 ;
   spots = 81 ;
variables:
   double timeE(scans, spots) ;
         timeE:Long\ Name = "Earth radiometric measurement time" ;
         timeE:Description = "TROPICS Epoch Time (TET) timestamp of the
Earth radiometric measurements." ;
         timeE:units = "Seconds since 1/1/2000 00:00.000." ;
         timeE:Valid\ Range = "1.5778e+09-1.8935e+09" ;
   ushort Year(scans) ;
         Year:long\ name = "UTC year" ;
         Year:description = "UTC year of the nadir spot." ;
         Year:units = "years" ;
         Year:valid\ range = "2015-2030" ;
   ubyte Month(scans) ;
         Month:long\ name = "UTC month" ;
         Month:description = "UTC month of year for the nadir spot." ;
         Month:units = "months" ;
         Month:valid\ range = "1-12" ;
   ubyte Day(scans) ;
         Day:long\ name = "UTC day" ;
         Day:description = "UTC day of month for the nadir spot." ;
         Day:units = "days" ;
         Day:valid\ range = "1-31" ;
   ubyte Hour(scans) ;
         Hour:long\ name = "UTC hour" ;
         Hour:description = "UTC hour of day for the nadir spot." ;
         Hour:units = "hours" ;
         Hour:valid\ range = "0-23" ;
   ubyte Minute(scans) ;
         Minute:long\ name = "UTC minute" ;
         Minute:description = "UTC minute of hour for the nadir spot." ;
         Minute:units = "minutes" ;
         Minute:valid\ range = "0-59" ;
   ubyte Second(scans) ;
         Second:long\ name = "UTC second" ;
         Second:description = "UTC second of minute for the nadir spot." ;
         Second:units = "seconds" ;
         Second:valid\ range = "0-59" ;
   ushort Millisecond(scans) ;
         Millisecond:long\ name = "UTC millisecond" ;
         Millisecond:description = "UTC millisecond of second for the
nadir spot." ;
         Millisecond:units = "milliseconds" ;
         Millisecond:valid\ range = "0-999" ;
   float losLat(scans, spots) ;
         losLat:description = " latitude A/B-scan (-90:90)" ;
         losLat:units = "[deg]" ;
```

```
    float losLon(scans, spots) ;
          losLon:description = " longitude A/B-scan (-180:180)" ;
          losLon:units = "[deg]" ;
    float rain_rate(scans, spots) ;
          rain_rate:description = "PRPS derived rain rates" ;
          rain_rate:units = "[mm/hr]" ;
          rain_rate:Fillvalue = "999.f" ;
    float rain_rmse(scans, spots) ;
          rain_rmse:description = "RMSE retrieved precipitation" ;
          rain_rmse:units = "[-]" ;
          rain_rmse:Fillvalue = "999.f" ;
    float tb_fit(scans, spots) ;
          tb_fit:description = " fit of Tbs of the retrieved value to
database Tbs" ;
          tb_fit:units = "[K]" ;
          tb_fit:Fillvalue = "999.f" ;
    float MLP_rate(scans, spots) ;
          MLP_rate:description = " Most Likely Precipitation" ;
          MLP_rate:units = "[mm/hr]" ;
          MLP_rate:Fillvalue = "999.f" ;
    float surface_type(scans, spots) ;
          surface_type:description = " retrieved surface type" ;
          surface_type:units = "none" ;
          surface_type:Fillvalue = "999.f" ;
    float Tb_fitMLP(scans, spots) ;
          Tb_fitMLP:description = " fit of Tbs of the retrieved MLP to
database Tbs" ;
          Tb_fitMLP:units = "[K]" ;
          Tb_fitMLP:Fillvalue = "999.f" ;
    int prps_flag(scans, spots) ;
          prps_flag:description = " quality flag: zero=OK" ;
          prps_flag:units = "[-]" ;
          prps_flag:Fillvalue = "999.f" ;

// global attributes:
          :_NCProperties =
"version=1|netcdflibversion=4.4.1|hdf5libversion=1.8.17" ;
          :ShortName = "TROPICS01PRPSL2B" ;
          :LongName = "Instantaneous Surface Rain Rate" ;
          :Format = "NetCDF-4" ;
          :ProcessingLevel = "L2b" ;
          :Source = "TROPICS01" ;
          :title = "Instantaneous Surface Rain Rate" ;
          :orbit = "00000" ;
          :GranuleID = "TROPICS01.PRPS.L2B.Orbit00000.V01-01.ST20050731-
044500.ET20050731-044958.CT20210623-164911.nc" ;
          :ProductionDateTime = "2021-06-23 16:49:11.000000" ;
          :RangeBeginningTime = "04:45:00.000000" ;
          :RangeBeginningDate = "2005-07-31" ;
          :RangeEndingTime = "04:49:58.000000" ;
          :RangeEndingDate = "2005-07-31" ;
          :license = "http://science.nasa.gov/earth-science/earth-science-
data/data-information-policy/" ;
          :dpc_software_delivery_id = "20210614-1" ;
          :dpc_version = "1.0" ;
          :inputs = "TROPICS01.BRTT.L1B.Orbit00000.V01-00.ST20050731-
044500.ET20050731-044958.CT20180713-122804.nc" ;
```

```
          :BoundingBox_GPolygon = "TBD" ;
          :DatacenterID = "UWI-MAD/SSEC/DPC" ;
          :project = "NASA Time-Resolved Observations of Precipitation
structure and storm intensity with a Constellation of Smallsats
(TROPICS)" ;
          :creator_name = "TROPICS Data Processing Center" ;
          :creator_email = "sips.support@ssec.wisc.edu" ;
          :creator_url = "https://tropics.ssec.wisc.edu" ;
          :creator_institution = "Space Science & Engineering Center,
University of Wisconsin - Madison" ;
          :publisher_name = "GESDISC" ;
          :publisher_url = "https://disc.gsfc.nasa.gov/" ;
          :publisher_email = "gsfc-dl-help-disc@mail.nasa.gov" ;
          :publisher_institution = "NASA Goddard Earth Sciences (GES) Data
and Information Services Center (DISC)" ;
}
```

Appendix F: CDL File Definition for L2b TCIE

This section provides the CDL file definition format using the example file:

```
tcie_200508050900_SV01.txt
CIMSS TROPICS TC Intensity Estimation:
 2005 D03
 Latitude: 22.724 Longitude: -58.145
 Storm position corresponds to TROPICS CH7 FOV 75 [1<--->81]
 ----------------- SAT is SV01 ------------------------------------------
-
 | Estimated MSLP:                        975.4 hPa
 | Estimated Maximum Sustained Wind:      71.1 kts
 Channel 7 Tb Anomaly: 4.1
 Channel 6 Tb Anomaly: 7.3
 EYE: 55.5 km
 Environmental Pressure:  1009
```

Appendix G: CDL File Definition for L2b HISA

This section provides the CDL file definition format using the example file:

```
netcdf TC-al112017-
RZA_v2r0_npp_s201709050600000_e201709051800000_c201709262358040 {
dimensions:
   height = 21 ;
   radius = 31 ;
variables:
   double height(height) ;
```

```
            height:standard_name = "height" ;
            height:long_name = "height" ;
            height:units = "km" ;
            height:axis = "Z" ;
            height:positive = "up" ;
      double radius(radius) ;
            radius:standard_name = "radius" ;
            radius:long_name = "radius" ;
            radius:units = "km" ;
            radius:axis = "X" ;
      double map(height, radius) ;
            map:_FillValue = -999.9 ;
            map:standard_name = "air_pressure" ;
            map:long_name = "mean azimuthal pressure" ;
            map:units = "hPa" ;
            map:missing_value = -999.9 ;
            map:valid_range = 0., 109000. ;
      double mad(height, radius) ;
            mad:_FillValue = -999.9 ;
            mad:standard_name = "air_density" ;
            mad:long_name = "mean azimuthal density" ;
            mad:units = "kg m-3" ;
            mad:missing_value = -999.9 ;
            mad:valid_range = 0., 3. ;
      double mat(height, radius) ;
            mat:_FillValue = -999.9 ;
            mat:standard_name = "air_temperature" ;
            mat:long_name = "mean azimuthal temperature" ;
            mat:units = "K" ;
            mat:missing_value = -999.9 ;
            mat:valid_range = 0., 350. ;
      double magw(height, radius) ;
            magw:_FillValue = -999.9 ;
            magw:standard_name = "wind_speed" ;
            magw:long_name = "mean azimuthal gradient wind speed" ;
            magw:units = "m s-1" ;
            magw:missing_value = -999.9 ;
            magw:valid_range = -125., 125. ;

   // global attributes:
            :_NCProperties =
   "version=1|netcdflibversion=4.4.1|hdf5libversion=1.8.17" ;
            :Metadata_Link = "TC-al112017-
   RZA_v2r0_npp_s201709050600000_e201709051800000_c201709262358040.nc" ;
            :date_created = "2017-09-26T23:58:10Z" ;
            :time_coverage_start = "2017-09-05T06:00:00Z" ;
            :time_coverage_end = "2017-09-05T18:00:00Z" ;
            :satellite_name = "npp" ;
            :instrument_name = "atms" ;
            :atcf_storm_id = "AL112017" ;
            :atcf_storm_basin = "AL" ;
            :atcf_storm_number = 11L ;
            :atcf_storm_name = "IRMA" ;
            :atcf_storm_date_time = "2017-09-05T18:00:00Z" ;
            :atcf_storm_latitude_degrees_north = 17. ;
            :atcf_storm_longitude_degrees_east = 301.1 ;
            :atcf_storm_speed_knots = 12L ;
```

```
		:atcf_storm_direction_degrees = 279L ;
		:atcf_storm_intensity_knots = 155L ;
		:atcf_storm_radius_of_maximum_winds_nautical_miles = 999L ;
		:swath_date_time = "2017-09-05T17:04:24Z" ;
		:swath_storm_extrapolated_latitude_degrees_north = 16.97 ;
		:swath_storm_extrapolated_longitude_degrees_east = 301.29 ;
		:missing_value = -999.9 ;
		:Conventions = "CF-1.5" ;
		:Metadata_Conventions = "CF-1.5, Unidata Dataset Discovery 1.0" ;
		:standard_name_vocabulary = "CF Standard Name Table (version 17,
24 March 2011)" ;
		:project = "S-NPP Data Exploitation" ;
		:institution = "DOC/NOAA/NESDIS/NDE > S-NPP Data Exploitation,
NESDIS, NOAA, U.S. Department of Commerce" ;
		:naming_authority = "gov.noaa.nesdis.nde" ;
		:title = "NPP_TC" ;
		:summary = "S-NPP ATMS tropical cyclone wind intensity and
surface wind radii thresholds" ;
		:history = "NPP_TC Version 1" ;
		:processing_level = "NOAA Level 3" ;
		:source = "MiRS-V9, ATCF, GFS" ;
		:id = "" ;
		:creator_name = "CSU/CIRA/RAMMB" ;
		:creator_email = "Andrea.Schumacher@colostate.edu,
Jack.Dostalek@colostate.edu, Scott.Longmore@colostate.edu" ;
		:creator_url = "http://rammb.cira.colostate.edu" ;
		:publisher_name = "DOC/NOAA/NESDIS/NDE > S-NPP Data Exploitation,
NESDIS, NOAA, U.S. Department of Commerce" ;
		:publisher_email = "espcoperations@noaa.gov" ;
		:cmd_data_type = "grid" ;
		:geospatial_radius_units = "km" ;
		:geospatial_height_units = "km" ;
		:geospatial_radius_min = 0. ;
		:geospatial_radius_max = 600. ;
		:geospatial_height_min = 0. ;
		:geospatial_height_max = 20. ;
data:

 height = 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17,
18,
    19, 20 ;

 radius = 0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260,
    280, 300, 320, 340, 360, 380, 400, 420, 440, 460, 480, 500, 520, 540,
    560, 580, 600 ;
}
```