Global Hydrology Resource Center

# Data User Guide

# *Tropical Cyclone Intensity (TCI) Hurricane Imaging Radiometer (HIRAD)*

## Introduction

The Tropical Cyclone Intensity (TCI) Hurricane Imaging Radiometer (HIRAD) dataset was created for the TCI field campaign from August 30, 2015 through October 23, 2015. The goal of the TCI field campaign was to improve the prediction of tropical cyclone (TC) intensity and structure change. The specific focus was to have an improved understanding of TC upper-level outflow layer processes and dynamics. These Hurricane Imaging Radiometer (HIRAD) data were obtained from the instrument onboard the NASA WB-57 aircraft flow on specific dates during the campaign. The data files include brightness temperature, rain rate, wind speed, and sea surface temperature estimates in netCDF-3 format, with corresponding browse imagery in PNG format.

## Citation

Cecil, Daniel J.. 2018. Tropical Cyclone Intensity (TCI) Hurricane Imaging Radiometer (HIRAD) [indicate subset used]. Dataset available online from the NASA EOSDIS Global Hydrology Resource Center Distributed Active Archive Center, Huntsville, Alabama, U.S.A. doi: http://dx.doi.org/10.5067/GHRC/HIRAD/DATA101

## Keywords:

*NASA, GHRC, TCI, hurricanes, tropical cyclones, Atlantic Ocean, HIRAD, radiometers, brightness temperature, rain rate, wind speed, sea surface temperature, WB-57 aircraft*

## Campaign

The Tropical Cyclone Intensity (TCI) field campaign is an Office of Naval Research Direct Research Initiative collaborative experiment combining efforts from scientists at the Naval Research Laboratory, industry, and universities. This field campaign operated in an “on demand” fashion, mobilizing the aircraft and personnel when a promising opportunity to observe a Tropical Cyclone (TC) was identified by the mission science team. This concept of operations was facilitated by the flexibility in base locations for the NASA WB-57 aircraft.

The aircraft was based out of Ellington Field in Houston, Texas, which was well-positioned for a flight over a TC in the Gulf of Mexico, and moved over to Warner Robbins, Georgia, which was well-positioned for a flight over a TC in the Atlantic Ocean.

The goal of TCI was to improve the prediction of TC intensity and structure change. The specific focus was to have an improved understanding of TC upper-level outflow layer processes and dynamics. This was investigated in a comprehensive manner using the observations obtained during the TCI field phase in 2015 and high-resolution TC models. Another goal of the TCI initiative was to improve the prediction of TC intensity change, especially Rapid Intensification (RI) and Rapid Decay (RD), as well as TC structural changes that are hypothesized to occur through synergistic interactions with storm outflow. More information about the TCI field campaign can be found in Doyle et al., 2017 and the TCI Experiment webpage.

## Instrument Description

The Hurricane Imaging Radiometer (HIRAD) instrument is a passive microwave sensor onboard the NASA WB-57 high-altitude aircraft that operated using 4 channels in the C-band frequencies (4, 5, 6, and 6.6 GHz) to measure strong winds and rain over the ocean surface. Using a synthetic aperture technique with no moving parts, the instrument provided both along-track and cross-track measurements at a 1-2 km resolution at nadir and closer to 5 km as it moves out towards the swath edges with a swath width of approximately 60 km when flown on a the WB-57 high-altitude aircraft. The broad spectral coverage and signal processing algorithm enables the simultaneous retrieval of both hurricane surface wind speeds and rain rates. HIRAD added the capability for cross-track wind retrievals by using a synthetic thinned array planar antenna.

Wind speed retrievals from HIRAD are possible due to the fact that the C-band emissivity of the ocean surface increases with increasing surface wind speed due to increased foam coverage. The 4 HIRAD C-band channels also have varying sensitivity to rain, so both rain and wind speed can be retrieved simultaneously. Figure 1 shows the HIRAD system being mounted on the WB-57 aircraft. More information about the HIRAD instrument can be found in Doyle et al., 2017, Biswas and Cecil, 2017, Cecil and Biswas, 2017, Rue et al., 2007, and HURRICANE IMAGING RADIOMETER (HIRAD) PI Document.

Figure 1: HIRAD system being mounted on the bottom of the WB-57 aircraft (Image Source: Doyle et al., 2017)

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## Data Characteristics

The TCI HIRAD dataset contains netCDF-3 data files with corresponding PNG browse imagery from August 30, 2015 through October 23, 2015. These data are at a Level 2 processing level. More information about the NASA data processing levels are available on the NASA Data Processing Level website. Table 1 lists the characteristics of this dataset.

Table 1: Data Characteristics

| Characteristic | Description |
|---|---|
| Platform | NASA WB-57 aircraft |
| Instrument | Hurricane Imaging Radiometer (HIRAD) |
| Projection | Equirectangular |
| Spatial Coverage | N: 37.875, S: 12.828, E: -63.035, W: -109.283 (Atlantic Ocean) |
| Spatial Resolution | 1-5 km |
| Temporal Coverage | August 30, 2015 - October 23, 2015 |

| | |
|---|---|
| Temporal Resolution | minute-<hour |
| Sampling Frequency | 1 second |
| Parameter | Brightness temperature, rain rate, wind speed, sea surface temperature |
| Version | 2.1 |
| Processing Level | 2 |

## File Naming Convention

The TCI HIRAD dataset has the file naming convention shown below. These data are available in netCDF-3 format with corresponding PNG browse imagery.

**Data files:** HIRAD_<start time>_<end time>_leg##.nc
**Browse files:** HIRAD_<start time>_<end time>_leg##.png

Table 2: File naming convention variables

| Variable | Description |
|---|---|
| <start time> | Date and time of when data collection started with format YYYYMMDDThhmmss where,<br>YYYY: four-digit year<br>MM: two-digit month<br>DD: two-digit day<br>hh: two-digit hour in UTC<br>mm: two-digit minute in UTC<br>ss: two-digit second in UTC |
| <end time> | Date and time of when data collection ended in YYYYMMDDThhmmss format |
| leg## | Data file number during flight |
| .nc | netCDF-3 format |
| .png | Portable Network Graphics (PNG) format |

## Data Format and Parameters

The Tropical Cyclone Intensity (TCI) Hurricane Imaging Radiometer (HIRAD) data files are organized by storm name that was observed and are available in netCDF-3 format with corresponding PNG browse imagery. The data and browse files show brightness temperatures, rain rates, wind speeds, sea surface temperature measurements from the HIRAD instrument, as well as estimates from satellite observations. Aircraft navigation data are also included (AC* variables).

Table 3: Data Fields

| Field Name | Description | Data Type | Unit |
|---|---|---|---|
| ACALT | Aircraft altitude | float | m |
| ACGS | Aircraft ground speed | float | m/s |
| ACLAT | Aircraft latitude | float | Degrees North |

| | | | |
|---|---|---|---|
| ACLON | Aircraft longitude | float | Degrees East |
| EXTB4 | Excess brightness temperature at 4.0 GHz* | float | K |
| EXTB5 | Excess brightness temperature at 5.0 GHz* | float | K |
| EXTB6 | Excess brightness temperature at 6.0 GHz* | float | K |
| EXTB7 | Excess brightness temperature at 6.6 GHz* | float | K |
| flag4 | Validity flag for 4.0 GHz observations | int | - |
| flag5 | Validity flag for 5.0 GHz observations | int | - |
| flag6 | Validity flag for 6.0 GHz observations | int | - |
| flag7 | Validity flag for 6.6 GHz observations | int | - |
| flagHRR | Validity flag for HIRAD rain rate | int | - |
| flagHWS | Validity flag for HIRAD wind speed | int | - |
| HRR | HIRAD Rain Rate | float | mm/hr |
| HWS | HIRAD Wind speed | float | m/s |
| JSST | JPL MUR Sea Surface Temperature | float | C |
| MWS | MERRA Wind Speed | float | m/s |
| PANG | Aircraft pitch angle | float | degree |
| PAZ | View angle of each antenna beam relative to the sensor (+ve is starboard side) | float | degree |
| PEIA | Pixel Earth incidence angle | float | degree |
| PLAT | Pixel latitude | float | Degrees North |
| PLON | Pixel longitude | float | Degrees East |
| RANG | Aircraft roll angle | float | degree |
| TB4 | Brightness temperature at 4.0 GHz | float | K |
| TB5 | Brightness temperature at 5.0 GHz | float | K |
| TB6 | Brightness temperature at 6.0 GHz | float | K |
| TB7 | Brightness temperature at 6.6 GHz | float | K |
| THDG | Aircraft true heading (clockwise from North) | float | degree |
| TIME | Time in UTC | double | Seconds since 2001-01-01 00:00:00 |

*Excess brightness temperature is the mean hypothetical background value for a zero-wind, zero-rain ocean surface.

## Algorithm

The data retrieval approach for this dataset was to minimize the difference between a vector of measured brightness temperatures at HIRAD's four frequencies, and a vector of modeled brightness temperatures from an ensemble of possible wind-rain combinations. The complication of varying rain along the instrument's slant path is not accounted for, but it may be incorporated with future algorithm improvements. Simultaneous Maximum Likelihood Estimates (MLE) of surface wind speed and column-averaged rain rate were constructed.

The "Excess Brightness Temperature" data field is derived by subtracting the modeled top of the atmosphere brightness temperature (at 0 surface wind speed) from the observed brightness temperatures. This method intends to compensate for the incidence angle dependence of the observed H-pol brightness temperatures. A fixed atmospheric profile (Temperature, Pressure, Humidity) is assumed and JPL MUR sea surface temperature data (see included JSST variable) is used for the computation. More information about the algorithms used can be found in Cecil and Biswas, 2017 and HURRICANE IMAGING RADIOMETER (HIRAD) PI Document.

## Quality Assessment

Ice particles are neglected in the radiative transfer model used, as emission is negligible at HIRAD's four frequencies and scattering should be negligible in all but the rarest of cases. If ice scattering does occur, it would preferentially reduce brightness temperatures in the higher-frequency channels, which would be misinterpreted as a reduction in rain rate.

Also, the HIRAD instrument would cause image streaks. To remove these streaks, the construction of the images were improved by excluding measurements from antennas 1, 6, 8, 9, and 10 before computing the average brightness temperature. Furthermore, there are 45 possible cross correlations between the 10 antenna elements, but these only correspond to 36 unique baselines; therefore, there are several redundant baseline measurements which can be used judicially to improve the brightness temperature image quality. To quantitatively measure this improvement, the wind speed estimates from the new brightness temperature measurements were compared with 636 coincident dropsonde measurements during TCI flights. The wind retrievals exhibits 4.7 m/s root mean square error which is considered to be a promising performance result.

This HIRAD dataset includes validity flags at each frequency for excess brightness temperature, rain rate, and wind speed estimates. Table 4 describes each validity flag value.

Table 4: Validity Flags

| Value | Description |
|---|---|
| 0 | Valid data |
| 1 | Questionable data |
| 2 | Invalid data |

More information about the quality of these data can be found in Cecil and Biswas, 2017 and Biswas and Cecil, 2017.

## Software

These data are available in netCDF-3 format, so no software is required to view them; however, Panoply can be used to easily plot the data.

## Known Issues or Missing Data

No issues or missing data are known for this dataset.

## References

Biswas, Sayak K. and Daniel J. Cecil (2017). Recent improvements in Hurricane Imaging Radiometer's brightness temperature image reconstruction, *El Sevier*, 7, 4349-4351. doi: https://doi.org/10.1016/j.rinp.2017.11.006

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## Related Data

All data within the 'Hurricane Sciences' collection in HyDRO 2.0 are considered to be related data.

Also, HIRAD data from other field campaigns can be considered to be related data:

Hurricane Severe Storm Sentinel (HS3) Hurricane Imaging Radiometer (HIRAD): http://dx.doi.org/10.5067/HS3/HIRAD/DATA201

GRIP Hurricane Imaging Radiometer (HIRAD) V1: http://dx.doi.org/10.5067/GRIP/HIRAD/DATA202

## Contact Information

To order these data or for further information, please contact:

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