CYCLONE GLOBAL NAVIGATION SATELLITE SYSTEM (CYGNSS)

Algorithm Theoretical Basis Document Level 3 Merged Gridded Wind Speed		
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	Revision	Rev 9
	Date	16 Feb 2025
	Contract	NNL13AQ00C

Algorithm Theoretical Basis Documents (ATBDs) provide the physical and mathematical descriptions of the algorithms used in the generation of science data products. The ATBDs include a description of variance and uncertainty estimates and considerations of calibration and validation, exception control and diagnostics. Internal and external data flows are also described.

SPACE PHYSICS RESEARCH LABORATORY

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REVISION NOTICE

Document Revision History		
Revision	**Date**	**Changes**
Initial Release	11/12/2023	n/a
R2	12/19/2023	Updates made to Table 1 and Figure 5 caption.
R3	2/12/2024	Updates to Section 2.2
R4	2/15/2024	Updating the FDS re-gridding method and longitudinal range
R5	2/22/2024	Updating to include information about ‘time_offset’
R6	8/14/2024	Updates to Section 2.4
R7	8/29/2024	Updating merging and R34 algorithms
R8	10/21/2024	Adding section about Near Real-time modifications
R9	2/16/2025	Adding R50

Table of Contents

1. Summary

This document describes the algorithm and data processing implementation used to produce CYGNSS Level 3 Merged Storm (MRG) wind speed science data products. In contrast to the standard L3 gridded wind speed product, the L3 MRG windspeed product combines CYGNSS Storm-Centric Gridded (SCG) wind speed products (Mayers, 2021), which are derived from the L2 Young Seas Limited Fetch (YSLF) wind speeds for a region surrounding a given tropical cyclone, with Level 3 CYGNSS Fully Developed Seas (FDS) wind speeds far from the TC center (Ruf, 2021). The algorithm transitions from 100% L3 SCG wind speeds to 100% L3 FDS wind speeds, via a tapered weighted averaging scheme, over a radial distance defined by the storm's size. A 50/50 weighting between L3 SCG and FDS winds occurs at approximately the 34 knot wind radius (R_{34}). The algorithm produces global (+/- 40° latitude) windspeeds, averaged over a +/-6 hour window, and reported on a 0.1x0.1° grid. Gridded wind speeds are reported every 6 hours for each tropical cyclone, although some 6-hourly increments may be missing if there are an insufficient number of overpasses available during that time interval. The files are output on a storm-by-storm basis.

1.1 Introduction and Background

1.1.1 The CYGNSS mission

The CYGNSS constellation is comprised of 8 observatories (7 operational as of 27 Nov 2022), roughly evenly spaced about a common orbit plane at ~520 km altitude and 35° inclination angle. Each observatory contains a Delay Doppler Mapping Instrument (DDMI) which consists of a multi-channel GNSS-R receiver, a low gain zenith antenna for reception of the direct signals, and two high gain nadir antennas for reception of the surface scattered signals (Rose *et al.*, 2013). There are typically many specular reflections from the surface available at any given time due to the large number of GPS transmitting satellites. Each DDMI selects the four specular reflections located in the highest sensitivity region of its nadir antenna pattern and simultaneously computes DDMs centered on each of them. Individual DDM integration times last one second and wind speeds are derived from measurements over a 25x25 km^2 region centered on the specular point (Clarizia and Ruf, 2016). This results in a total of 32 wind measurements per second by the full constellation. CYGNSS spatial sampling consists of 32 simultaneous single pixel "swaths" that are 25 km wide and, typically, 100s of km long, as the specular points move across the surface due to orbital motion by CYGNSS and the GPS satellites. Temporal sampling occurs randomly due to the asynchronous nature of the CYGNSS and GPS satellite orbits. As a result, the CYGNSS revisit time is best described by its probability distribution. The distribution, shown in Fig 1, is derived empirically using a mission simulator to determine the time and location of each sample within the ±38° latitude coverage zone and then examining the time difference between samples at the same location.

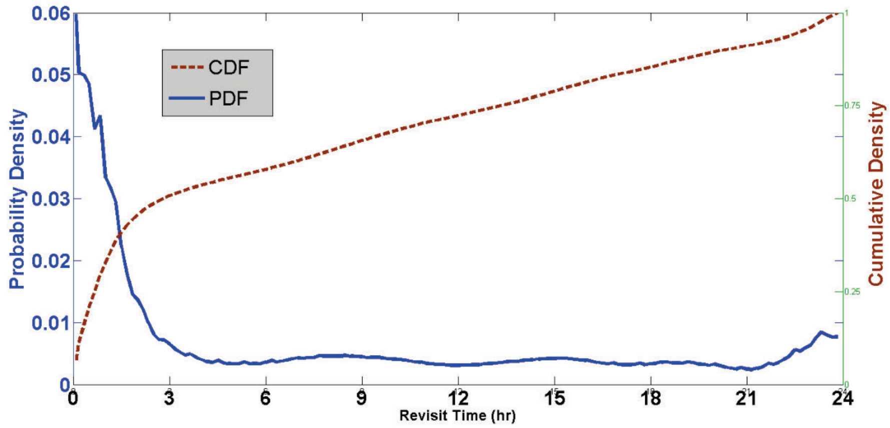

Fig. 1. Temporal sampling is characterized by the probability and cumulative density functions of revisit time. The median and mean revisit times are, respectively, 2.8 and 7.2 hours.

The empirical distribution features a high probability of very short revisit times (e.g. resulting from sequential samples by trailing satellites spaced tens of minutes apart) and a long, tapering "tail" at higher revisit times. Its median value is 2.8 hours and the mean revisit time is 7.2 hours.

CYGNSS combines the all-weather performance of GPS based bistatic scatterometry with the spatial and temporal sampling properties of a constellation of observatories. The GPS frequency of operation enables the instrument to make surface scattering observations through most precipitating conditions. This provides the ability to measure the ocean surface winds with high temporal resolution and spatial coverage under all precipitating conditions, up to and including those experienced in the hurricane eyewall. The 8 microsatellites were launched on a single Deployment Module that is attached to a NASA government furnished equipment Pegasus launch vehicle (Ruf *et al*., 2016).

1.1.2 Science Goals, Objectives and Requirements

The CYGNSS goal is to understand the coupling between ocean surface properties, moist atmospheric thermodynamics, radiation, and convective dynamics in the inner core of TCs. The goal of CYGNSS directly supports the NASA strategic objective to enable improved predictive capability for weather and extreme weather events. Near-surface winds are major contributors to and indicators of momentum and energy fluxes at the air/sea interface. Understanding the coupling between the surface winds and the moist atmosphere within the TC inner core is key to properly modeling and forecasting its genesis and intensification. Of particular interest is the lack of significant improvement in storm intensity forecasts over the past two decades, relative to forecasts of storm track. Advances in track forecast have resulted in large part from the improvements that have been made in observations and modeling of the mesoscale and synoptic environment surrounding a TC. The CYGNSS team hypothesizes that the lack of an accompanying improvement in intensity forecasting is largely due to a lack of observations and proper modeling of the TC inner core. The inadequacy in observations results from two causes:

- Much of the inner core ocean surface is obscured from conventional remote sensing instruments by intense precipitation in the eye wall and inner rain bands.

- The rapidly evolving genesis and intensification stages of the TC life cycle are poorly sampled by conventional polar-orbiting, wide-swath imagers.

The CYGNSS science goals are enabled by meeting the following mission objectives.

- Measure ocean surface wind speed in most naturally occurring precipitating conditions, including those experienced in the tropical cyclone eyewall.
- Measure ocean surface wind speed in the tropical cyclone inner core with sufficient frequency to resolve genesis and rapid intensification.

The CYGNSS baseline science requirements have been met (Ruf *et al.*, 2019) and are summarized here:

1) The baseline science mission shall provide estimates of ocean surface wind speed over a dynamic range of 3 to 70 m/s as determined by a spatially averaged wind field with resolution of 5x5 km.

2) The baseline science mission shall provide estimates of ocean surface wind speed during precipitation rates up through 100 millimeters per hour as determined by a spatially averaged rain field with resolution of 5x5 km.

3) The baseline science mission shall retrieve ocean surface wind speed with a retrieval uncertainty of 2 m/s or 10%, whichever is greater, with a spatial resolution of 25x25 km.

4) The baseline science mission shall collect space-based measurements of ocean surface wind speed at all times during the science mission with the following temporal and spatial sampling: 1) temporal sampling better than 12 hour mean revisit time; and 2) spatial sampling 70% of all storm tracks between 35 degrees north and 35 degrees south latitude to be sampled within 24 hours.

5) The CYGNSS project shall conduct a calibration and validation program to verify data delivered meets the requirements within individual wind speed bins above and below 20 m/s.

6) Support the operational hurricane forecast community assessment of CYGNSS data in retrospective studies of new data sources.

2. Algorithm Overview

2.1 Algorithm Objectives

The objective of this algorithm is to produce regular 6-hourly gridded wind speeds for TCs over both the inner core region of the storm and across the wider surrounding area. Inner core winds are drawn from the existing CYGNSS L3 Storm-Centric Gridded (SCG) wind speed product (Mayer, 2021). L3 SCG winds are derived from the CYGNSS L2 Young Seas Limited Fetch wind speed product, which is optimized for performance in high wind conditions and adds storm-centric regridding and improved quality control. Winds away from the storm are drawn from the CYGNSS L3 gridded Fully Developed Seas (FDS) product (Ruf, 2021). L3 FDS winds are optimized for performance globally assuming a fully developed sea state. The two products are merged over a transition zone between these two regions using a radially tapered averaging scheme over an annular region centered on the Best Track storm center and extending across the 25 m/s wind radius. This merged wind speed product (L3 MRG) provides improved spatial coverage compared to the L3 SCG wind speed, and improved retrieval performance in the storm's inner core compared to the L3 FDS gridded wind speed. The inclusion of L3 FDS winds allows for global coverage in place of the more limited 7.2x7.2° moving grid employed by the L3 SCG algorithm. In addition to the CYGNSS merged wind speeds, the L3 MRG product includes 34-knot and 50-knot wind radii (R34 and R50) estimated in each quadrant from the L3 MRG wind fields.

2.2 Input Data Description

The input data required by this algorithm are listed here.

1. Wind speed inputs are v3.2 L3 SCG and v3.2 L3 Gridded FDS winds.
2. Best Track storm center locations are from the Joint Typhoon Warning Center (JTWC 2024a, JTWC 2024b, JTWC 2024c) and the National Hurricane Center (Landsea & Franklin, 2013).

2.3 Merging Algorithm Description

The L3 FDS wind speed product is defined on a 0.2x0.2° grid, whereas the L3 SCG product uses a 0.1x0.1° grid. In order to merge the two windspeed products on a common grid, the L3 FDS product is bilinearly interpolated to a 0.1x0.1° grid. If the FDS wind speeds from all four surrounding points are not valid, only the valid ones will be utilized for the interpolation. L3 FDS products are generated at 1 hour intervals, whereas the L3 SCG product is generated every 6 hours. The L3 MRG product is also generated every 6 hours, so it uses the corresponding L3 SCG product directly. The L3 FDS wind field that is used in the merging algorithm is a composite of the L3 FDS products generated over a +/- 6 hour interval centered on each L3 MRG reporting time. L3 FDS samples are added to the composite grid beginning with the samples furthest in time from the center of the 12-hour time interval. If a sample is available at a closer time to the center of the 12 hour interval, it replaces any sample in the same grid cell from a more distant time relative to the reporting time. This composite approach is used: a) to provide a more fully populated L3 FDS grid for the L3 MRG algorithm; and b) have the reported winds be as close as possible to the center of the time interval. The offset in time of each L3 MRG sample derived from the L3 FDS product, relative to the center of the 12-hour time interval, is reported in the data file as the variable time_offset. For cases where there are FDS samples at the same time before and after the L3 MRG time, the FDS sample before the sample will be used. Time offsets for L3 MRG samples derived from the L3 SCG product are reported as zero.

The algorithm used to merge L3 SCG and FDS winds is defined with respect to three nested regions. The inner region corresponds to the inner core of the tropical cyclone. The outer region corresponds to distances far from the storm. A transition region lies in between the inner and outer regions. The borders of the three regions are defined by the radial distance from the storm center, as determined by the Best Track storm center location at the center time of the 12 hr time interval over which a particular L3 MRG product is generated. The radial distance from the storm center to the boundary of the inner core, R_{inner}, is given by

$$R_{inner} = \begin{Bmatrix} R25ms & if\ V_{max} \geq 25\ m/s \\ R_{max} - 50\ km & if\ V_{max} < 25\ m/s \end{Bmatrix} \tag{1}$$

where *R25ms* is the minimum radial distance from the storm center outside of which all L3 SCG wind speeds are less than 25 m/s, V_{max} is the maximum L3 SCG wind speed, and R_{max} is the minimum radial distance from the storm center to the boundary of the 7.2x7.2° L3 SCG domain.

The radial distance R_{outer} is defined as the maximum distance from Vmax in the L3 SCG grid, less 50 km:

$$R_{outer} = \max\left(\mathrm{R}(\mathrm{u_{SCG}})\right) - 50\mathrm{km} \tag{2}$$

The merging algorithm produces a merged wind speed, u_{MRG}, from the L3 SCG and FDS wind speeds, u_{SCG} and u_{FDS}, according to

$$u_{MRG} = \begin{Bmatrix} u_{SCG} & if\ r \leq R_{inner} \\ (1-a)u_{SCG} + a u_{FDS} & if\ R_{inner} < r < R_{outer} \\ u_{FDS} & if\ r \geq R_{outer} \end{Bmatrix} \tag{3}$$

where r is the radial distance from the storm center to the sample and $a = (r - R_{min})/(R_{max} - R_{min})$.

Each L3 MRG wind speed is accompanied by its corresponding uncertainty value, σ_{MRG}, as defined by

$$\sigma_{MRG} = \begin{Bmatrix} \sigma_{SCG} & if\ r \leq R_{inner} \\ \sqrt{(1-a)^2\sigma_{SCG}^2 + a^2\sigma_{FDS}^2} & if\ R_{inner} < r < R_{outer} \\ \sigma_{FDS} & if\ r \geq R_{outer} \end{Bmatrix} \tag{4}$$

where σ_{SCG} and σ_{FDS} are, respectively, the uncertainties of the SCG and FDS samples used.

2.4 Near Real-time Algorithm

Near Real-time (NRT) mode is used to produce low-latency data during the hurricane season. These runs are initiated every time new CYGNSS L0 data is received that intersects with the lifetime of any storm track file, including invest storms, posted on the NHC or JTWC websites. There may be cases where no CYGNSS data is available near a given storm, in which case an L3 MRG file will not be produced. Otherwise, an L3 MRG file will be produced for any active storm. When running in NRT mode, there are a few modifications that are made to the processing algorithm.

1. Instead of using a +/- 6-hour window for collecting winds, a +/- 3-hour window is used.

2. Only a single wind field, using the most recent data, is produced instead of a full storm record.
3. The reporting time of the single wind field is defined as 3 hours before the most recent L2 sample we have that is located within a +/- 5-degree latitude/longitude box around the interpolated storm center.
4. When constructing the FDS grid samples, if there are multiple L3 FDS samples at the same location, the most recent one in time will be selected instead of the one closest to the center of the time window.
5. An earliest and latest input sample time are output for the wind field. These times are determined as the earliest and latest times of all YSLF samples that passed through the SCG quality control and the global wind field of FDS winds in order to provide a time range of data over which the wind field is produced.

2.5 CYGNSS 34-Knot and 50-Knot Wind Radii Product Algorithm

Quadrant specific 34 kt (~17.5 m/s) and 50 kt (~25.7 m/s) wind radii (R34 and R50) are estimated directly from reported CYGNSS L3 MRG wind fields $u_{MRG}(\varphi, \theta)$ given an estimate of the storm center at latitudes φ_S (best_track_storm_center_lat) and longitudes θ_S (best_track_storm_center_lon). The estimation algorithm collects all wind speed samples within a given quadrant and orders them according to their radial distance from the storm center. The R34 wind radius is defined as the smallest radius above which no samples have wind speeds above 34 knots. Similar logic is used to estimate R50. An example is shown in Figure 2 of the two wind radii estimated for Hurricane Helene on 26 Sep 2024 at 1800 UTC.

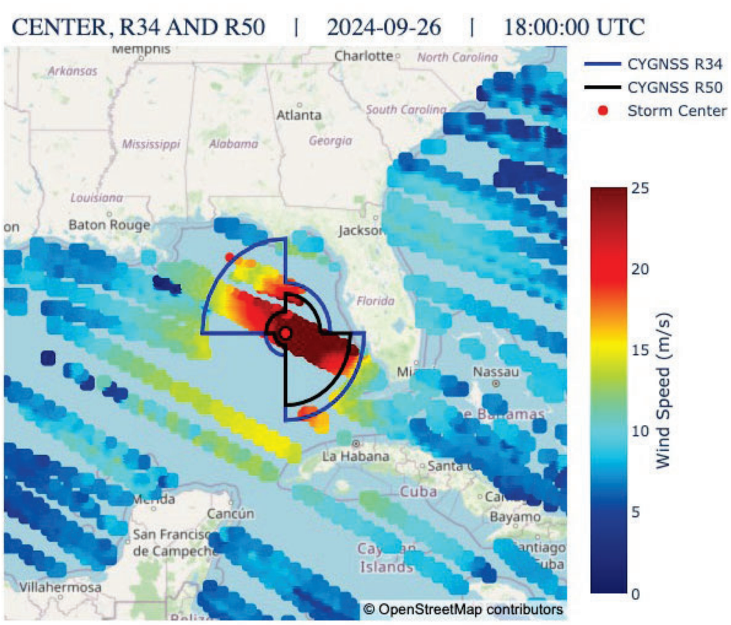

Fig. 2. Example CYGNSS L3 MRG wind field with R34(blue lines) and R50 (black lines) significant wind radii shown for Hurricane Helene on 26 Sep 2024 at 1800 UTC.

Several quality control filters are applied to the estimated wind radii. If all samples in a quadrant are below the threshold wind speed, its radius is reports as 0 km. If there are no samples whatsoever in a quadrant from the storm center to 1000 km radial distance, both R34 and R50 radii are reported as the netCDF filler value. If either radius is estimated to be greater than 800 km, its value is set to 800 km as a limit check.

The R34 and R50 estimates by CYGNSS were compared to those estimated from ASCAT wind fields for all coincident storms during 2018-2024. The results are shown in Figures 3 and 4 for the R34 and R50 comparisons, respectively. The CYGNSS retrieved wind radii contain considerable scatter compared to the ASCAT wind radii over all quadrants and storm categories, likely due to the sampling gaps in the L3 MRG wind fields and the lack of sensitivity to the highest wind speeds in the CYGNSS data.

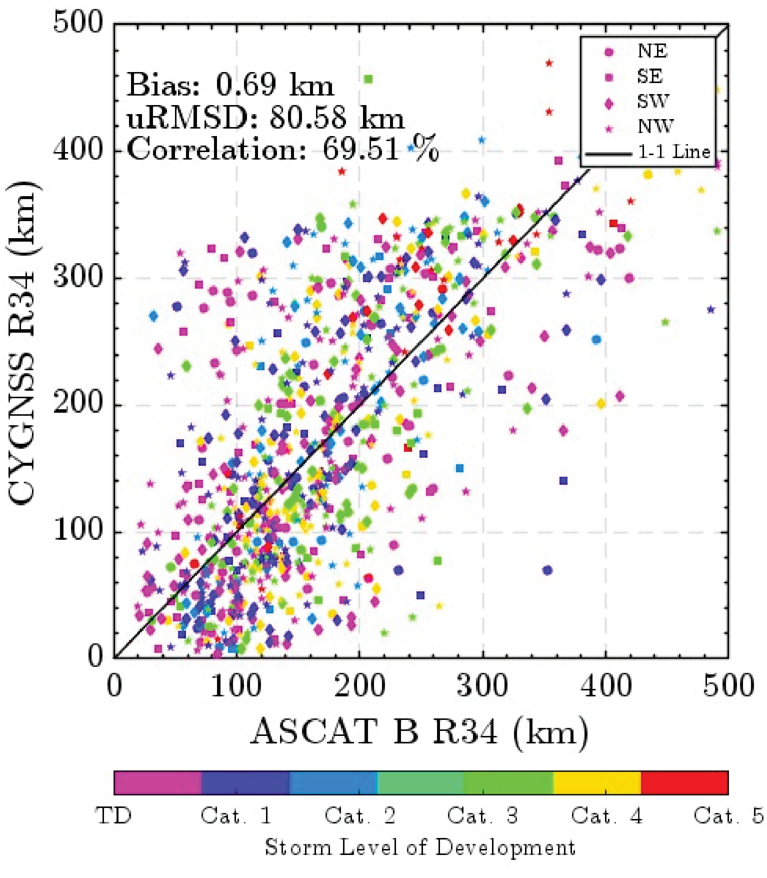

Fig. 3. R34 retrieval comparisons to ASCAT-B using a CYGNSS data record spanning all co-located storms over the period 2020-2024. Storm intensity indicated by color. Storm quadrant indicated by marker symbol. Correlation estimated to be 69.5%.

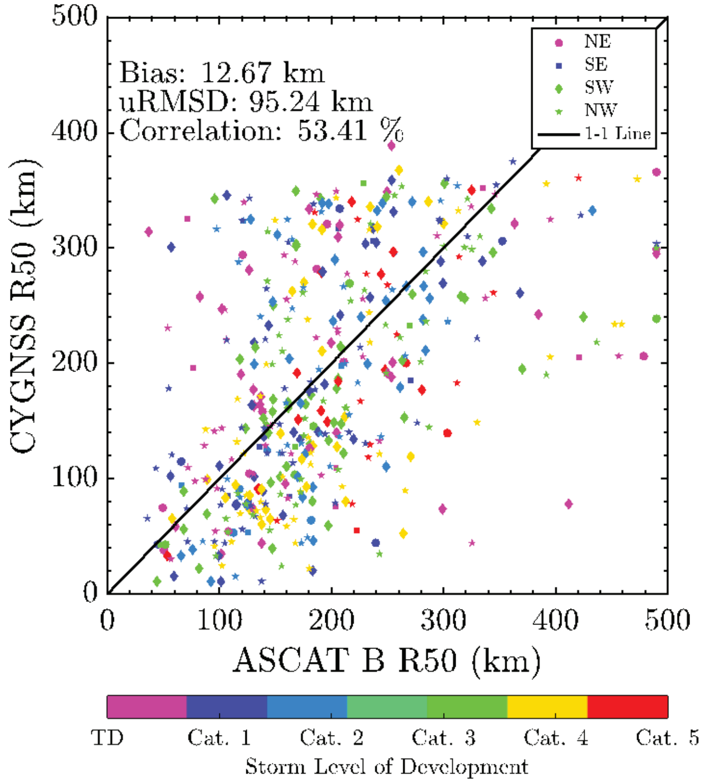

Fig. 4. R50 retrieval comparisons to ASCAT-B using a CYGNSS data record spanning all co-located storms over the period 2018-2024. Storm intensity indicated by color. Storm quadrant indicated by marker symbol. Correlation estimated to be 53.4%.

2.6 Dataset Examples

Examples of the L3 MRG data product wind fields are shown in Figures 5-7 for single times during Hurricane Calvin (2023), Typhoon Krathon (2024), and Hurricane Frederick (2023). Figure 5 demonstrates a case where coverage of the TC is sparse, but peak winds are captured. Figure 6 shows a wind field from Typhoon Krathon, around the time of its peak intensity. Figure 7 shows a wind field from Hurricane Franklin. Figure 8 shows the consecutive wind fields from Hurricane Milton, a short-lived but intense storm, showing intensification and weakening occurring over Oct 7-10.

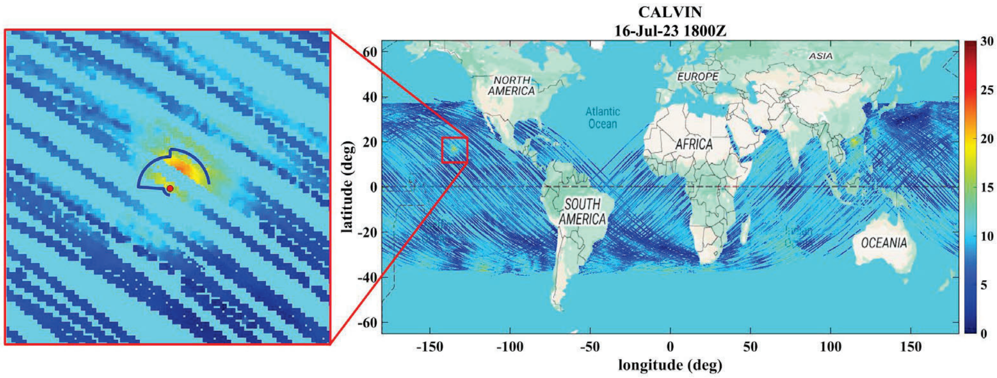

Fig. 5. Example L3 MRG wind field from Hurricane Calvin at reporting time July 16, 2023 1800Z. Left: Wind field in the vicinity of the of the TC (corresponding to red box on the right figure); right: full L3 MRG wind field.

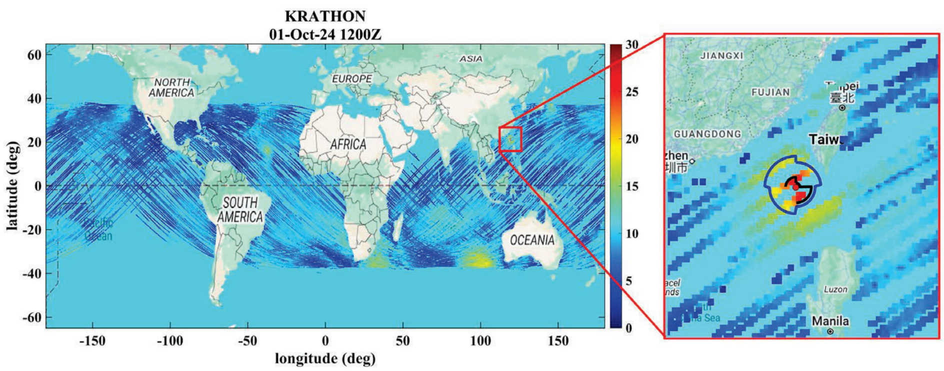

Fig. 6. Example L3 MRG wind field from Typhoon Krathon at reporting time Oct 01, 2024 1200Z. Left: Full L3 MRG wind field; right: Wind field in the vicinity of the of the TC (corresponding to red box on the right figure).

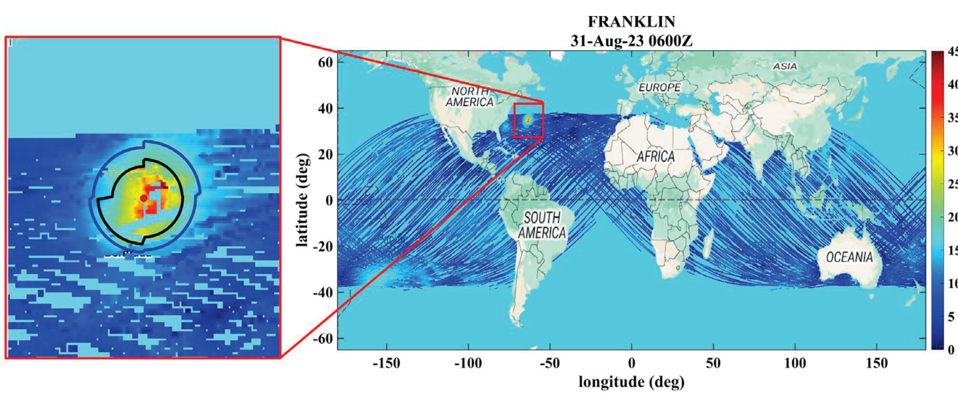

Fig. 7. Example L3 MRG wind field from Hurricane Franklin at reporting time Aug 30, 2023 0600Z. Left: full L3 MRG wind field; right: wind field in the vicinity of the of the TC (corresponding to red box on the left figure).

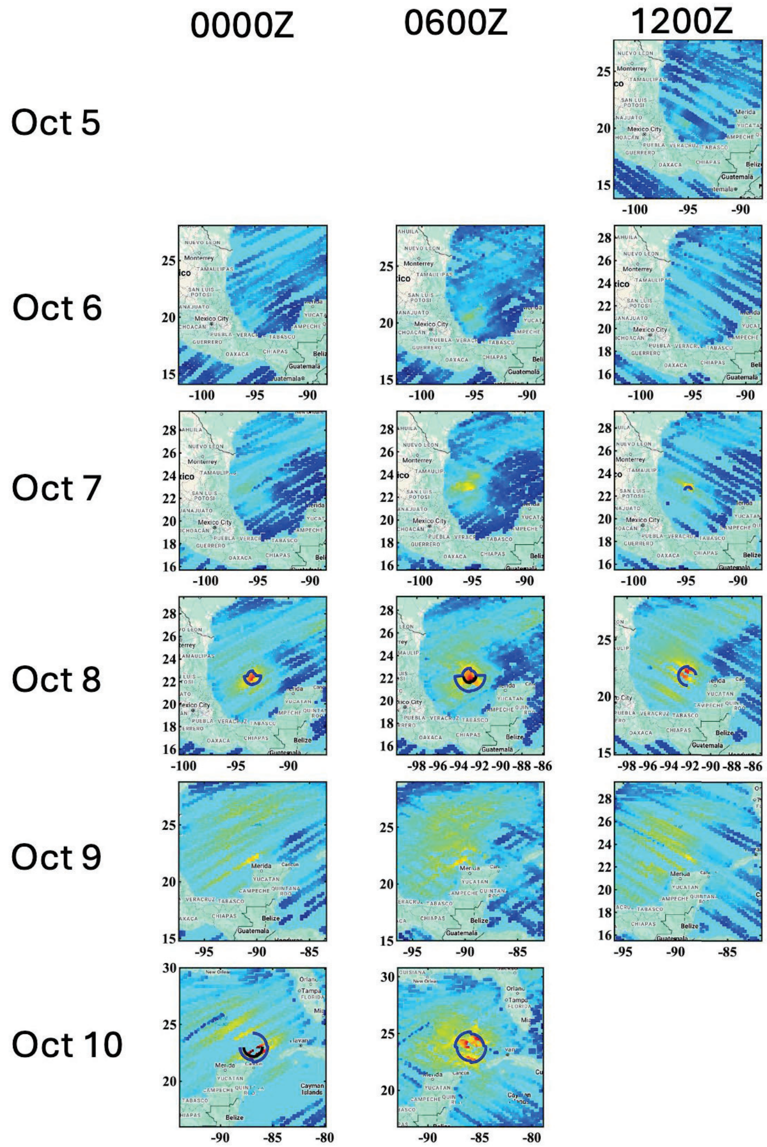

Fig. 8. L3 MRG wind fields and significant wind radii in the vicinity of Hurricane Milton.

2.7 Output Data Product Description

The L3 MRG wind speeds are calculated over 12-hour windows on a 0.1 x 0.1° resolution spatial grid. The timestamp coordinate is defined at the center of each 12-hour window and is incremented by 6 hours. Latitude and longitude coordinates are defined at the center of each 0.1 x 0.1° spatial bin. The latitude and longitude ranges of this L3 product are 39.9°N - 39.9°S and 0.0°E - 359.9°E degrees, respectively.

The key output data fields produced are:

u_{MRG}: The merged wind speed, as given by eqn. (3) (units of m/s)

σ_{MRG}: The uncertainty in u_{MRG} for a particular sample, as given by eqn. (4) (units of m/s)

$R34^{NE}$, $R34^{SE}$, $R34^{SW}$, $R34^{NW}$: CYGNSS 34-knot wind radii output for each storm quadrant

$R50^{NE}$, $R50^{SE}$, $R50^{SW}$, $R50^{NW}$: CYGNSS 50-knot wind radii output for each storm quadrant.

This product also contains ancillary storm-specific fields that are independent of the CYGNSS data, including the best track reported latitude and longitude, storm status, maximum sustained wind speed (V_{max}), 34-knot and 50-knot wind radii for each storm quadrant. These values are derived from the current season's best-track reports for the intermediate latency product version, and archival post-season analyzed best-track reports values for the archival version. For our applications, we have found limited differences between the final version of the current season's best-track report and the archival report. However, the archival product offers a single file for each storm unlike the intermediate latency product which is updated daily throughout the life of the storm.

In addition to a wind speed reported at each spatiotemporal bin over the lifetime of a TC, the L3 MRG algorithm outputs the latitude and longitude of the maximum wind speed in the L3 MRG wind field at each timestamp, the time offset in hours relative to the reporting time for each of the wind speed samples, and the associated quality flags at each timestep.

A full list of the data fields is provided in the Appendix.

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Appendix. L3 MRG Data Dictionary

Acronyms and Abbreviations
ISO: International Organization for Standardization
JTWC: Join Typhoon Warning Center
L2: Level 2
L3: Level 3
NHC: National Hurricane Center
NRT: Near Real-time
UTC: Coordinated Universal Time
YSLF: Young Seas, Limited Fetch

Name	**Long Name**	**netCDF Type**	**CF Conventions Units**	**netCDF Dimensions**	**Comment**
Global Attributes					
l3_merged_algorithm_version	<none>	file attribute, string	<none>	<none>	L3 merged processing algorithm version number.
source	<none>	file attribute, string	<none>	<none>	Level 3 netCDF source file names.
storm_name	<none>	file attribute, string	<none>	<none>	Name of storm
geospatial_min_lat	<none>	file attribute, string	<none>	<none>	Minimum latitude of the grid that bounds the whole storm's path.
geospatial_max_lat	<none>	file attribute, string	<none>	<none>	Maximum latitude of the grid that bounds the whole storm's path.
geospatial_min_lon	<none>	file attribute, string	<none>	<none>	Minimum longitude of the grid that bounds the whole storm's path.
geospatial_max_lon	<none>	file attribute, string	<none>	<none>	Maximum longitude of the grid that bounds the whole storm's path.

time_storm_track_access	<none>	file attribute, string	<none>	<none>	Date and time that the storm track file was accessed from the remote server in ISO-8601 form. Only available in the near real-time data product.
time_production	<none>	file attribute, string	<none>	<none>	Date and time that the file was produced in ISO-8601 form. Only available in the near real-time data product.
time_coverage_start	<none>	file attribute, string	<none>	<none>	sample_time of the first sample in the file in ISO-8601 form
time_coverage_end	<none>	file attribute, string	<none>	<none>	sample_time of the last sample in the file in ISO-8601 form
time_coverage_duration	<none>	file attribute, string	<none>	<none>	The time interval between test_coverage_start and test_coverage_end in ISO1806 form
time_coverage_resolution	<none>	file attribute, string	<none>	<none>	The nominal time interval between samples in ISO1806 form
Dimensions					
Time	Time	int	time	<none>	Timestamp coordinate at the center of the bin (12 hours for standard operations / 6 hours for NRT operations). The range length is unique to each storm in standard operations, and only one time is included in NRT operations.

epoch_time	Time Centering of Data Based on Epoch Reference	int	time	<none>	Timestamp coordinate is at the center of the HH hr bin referenced by the historical Epoch reference date/time. The Epoch reference date/time corresponds to the first observation time window in the CYGNSS data record after the automatic gain control was turned off. Total number of timestamps in a file corresponds to the length of the storm.
Lat	Latitude	float	degrees_north	<none>	Absolute latitude coordinate at the center of the bin, degrees_north, at 0.1 degree resolution. Range is geospatial_min_lat .. geospatial_max_lat.
Lon	Longitude	float	degrees_east	<none>	Absolute longitude coordinate at the center of the bin, degrees_east, at 0.1 degree resolution. Range is geospatial_min_lon .. geospatial_max_lon.
Per-Time Step Values					
best_track_storm_center_lat	Storm center latitude	float	degrees_north	time	Latitude coordinate of the storm center at the given time as reported by the (NHC/JTWC)'s Best Track data product.

best_track_storm_center_lon	Storm center longitude	float	degrees_east	time	Longitude coordinate of the storm center at the given time as reported by the (NHC/JTWC)'s Best Track data product.
best_track_storm_status	Storm status	byte	1	time	The level of storm development as reported by the (NHC/JTWC)'s Best Track data product: 0 = tropical depression 1 = tropical storm 2 = typhoon 3 = super typhoon 4 = tropical cyclone 5 = hurricane 6 = subtropical depression 7 = subtropical storm 8 = extratropical systems 9 = monsoon depression 10 = inland 11 = dissipating 12 = low 13 = tropical wave 14 = extrapolated 15 = unknown 16 = disturbance 17 = error
best_track_vmax	Maximum sustained wind speed	int	m s-1	time	Maximum sustained wind speed in meters per seconds as reported by the (NHC/JTWC)'s Best Track data product.

best_track_r34_ne	Radial extent of 34 knot winds in north east from Best Track	int	km	time	In the north east quadrant, how far from the storm center do 34 knot winds exist as reported by the (NHC/JTWC)'s Best Track data product.
best_track_r34_nw	Radial extent of 34 knot winds in north west from Best Track	int	km	time	In the north west quadrant, how far from the storm center do 34 knot winds exist as reported by the (NHC/JTWC)'s Best Track data product.
best_track_r34_sw	Radial extent of 34 knot winds in south west from Best Track	int	km	time	In the south west quadrant, how far from the storm center do 34 knot winds exist as reported by the (NHC/JTWC)'s Best Track data product.
best_track_r34_se	Radial extent of 34 knot winds in south east from Best Track	int	km	time	In the south east quadrant, how far from the storm center do 34 knot winds exist as reported by the (NHC/JTWC)'s Best Track data product.

best_track_r50_ne	Radial extent of 50 knot winds in north east from Best Track	int	km	time	In the north east quadrant, how far from the storm center do 50 knot winds exist as reported by the (NHC/JTWC)'s Best Track data product.
best_track_r50_nw	Radial extent of 50 knot winds in north west from Best Track	int	km	time	In the north west quadrant, how far from the storm center do 50 knot winds exist as reported by the (NHC/JTWC)'s Best Track data product.
best_track_r50_sw	Radial extent of 50 knot winds in south west from Best Track	int	km	time	In the south west quadrant, how far from the storm center do 50 knot winds exist as reported by the (NHC/JTWC)'s Best Track data product.
best_track_r50_se	Radial extent of 50 knot winds in south east from Best Track	int	km	time	In the south east quadrant, how far from the storm center do 50 knot winds exist as reported by the (NHC/JTWC)'s Best Track data product.
cygnss_vmax_lat	Storm V max latitude	float	degrees_north	time	Estimate of the latitude coordinate of the maximum storm velocity made from the CYGNSS wind speeds.

cygnss_vmax_lon	Storm V max longitude	float	degrees_east	time	Estimate of the longitude coordinate of the maximum storm velocity made from the CYGNSS wind speeds.
cygnss_r34_ne	Radial extent of 34 knot winds in north east from CYGNSS	int	km	time	CYGNSS derived 34 knot wind radii in the north east quadrant.
cygnss_r34_nw	Radial extent of 34 knot winds in north west from CYGNSS	int	km	time	CYGNSS derived 34 knot wind radii in the north west quadrant.
cygnss_r34_sw	Radial extent of 34 knot winds in south west from CYGNSS	int	km	time	CYGNSS derived 34 knot wind radii in the south west quadrant.
cygnss_r34_se	Radial extent of 34 knot winds in south east from CYGNSS	int	km	time	CYGNSS derived 34 knot wind radii in the south east quadrant.
cygnss_r50_ne	Radial extent of 50 knot winds in north east from CYGNSS	int	km	time	CYGNSS derived 50 knot wind radii in the north east quadrant.

cygnss_r50_nw	Radial extent of 50 knot winds in north west from CYGNSS	int	km	time	CYGNSS derived 50 knot wind radii in the north west quadrant.
cygnss_r50_sw	Radial extent of 50 knot winds in south west from CYGNSS	int	km	time	CYGNSS derived 50 knot wind radii in the south west quadrant.
cygnss_r50_se	Radial extent of 50 knot winds in south east from CYGNSS	int	km	time	CYGNSS derived 50 knot wind radii in the south east quadrant.
earliest_used_time	Time of earliest sample used	int	seconds since 'time'	time	The time of the earliest CYGNSS sample used for the creation of this wind field. If the earliest sample occurred before the center of the time window, this variable will contain a negative value. Only available in the NRT data product.
latest_used_time	Time of latest sample used	int	seconds since 'time'	time	The time of the latest CYGNSS sample used for the creation of this wind field. Only available in the NRT data product.
quality_flags	Per-time step quality flags	int	1	time	The per-time step quality flags. 1 indicates presence of condition. Flag bit masks:

					1/0x00000001 (Bit 01) = poor_overall_quality. This flag is allocated for potential future flags. There are currently no fatal flags. 2/0x00000002 (Bit 02) = low_quality_vmax: Set if there were not enough valid wind speeds to properly smooth the winds to locate the Vmax.
Gridded Variables					
wind_speed	Wind speed	float	m s-1	time, lat, lon	Merged CYGNSS L3 Storm Centric Gridded and CYGNSS L3 FDS gridded wind speed.
wind_speed_uncertainty	Wind speed uncertainty	float	m s-1	time, lat, lon	Standard deviation of the error in the wind speeds within the bin.
range_corr_gain	Range Corrected Gain	float	1e-27 dBi meter-4	time, lat, lon	Merged CYGNSS L3 Storm Centric Gridded and CYGNSS L3 FDS range corrected gains from their respective processings.
merge_method	Merge method	int	1	time, lat, lon	Method used for merging the FDS and SCG winds: 0 = Only FDS winds 1 = Only SCG winds 2 = No close SCG winds 3 = Blending FDS and SCG winds 4 = Using closest FDS winds

time_offset	Time offset of each sample from center time	float	hours	time, lat, lon	Time offset of individual samples in lat,lon grid from Timestamp coordinate at the center of the bin (12 hours for standard operations / 6 hours for NRT operations). A negative(positive) value indicates the sample was measured before(after) the center time.