CYGNSS Coverage Statistics of Tropical Cyclones

Brian McNoldy[1], **Sharanya Majumdar**[1]
Lisa Bucci[2], Wallace Hogsett[2]

[1] University of Miami
[2] National Hurricane Center

ROSENSTIEL SCHOOL of MARINE, ATMOSPHERIC & EARTH SCIENCE
MIAMI

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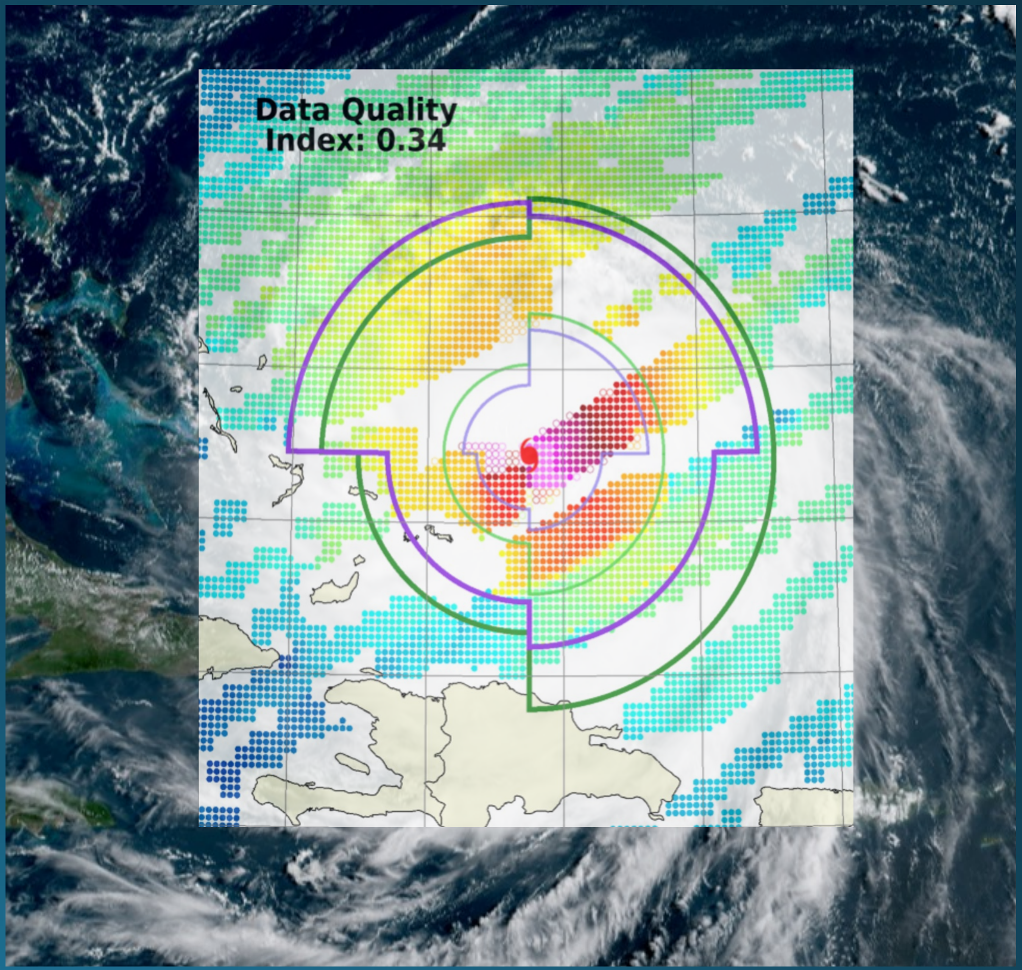
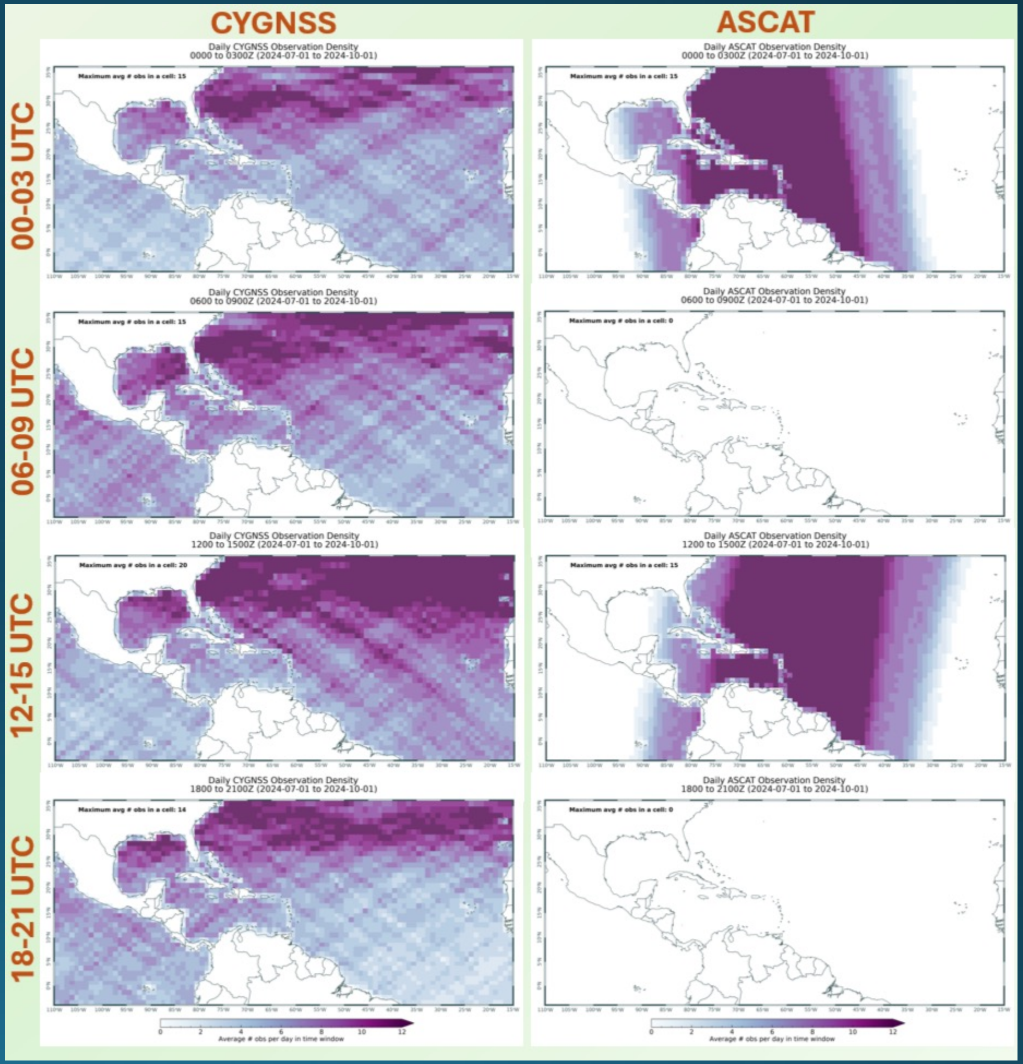
Motivation

- CYGNSS can provide quality data coverage of TCs and the large-scale ocean
  - Low-inclination orbit (± 35°) means superior temporal coverage in tropics and subtropics compared to polar orbit
  - Long-wavelength (19 cm) GNSS signals are not attenuated by precipitation
- Demonstrate easy-to-use graphics and indices that National Hurricane Center (NHC) specialists could use
- CYGNSS has been in orbit since December 2016, but these techniques could apply to any future CYGNSS-like mission



CYGNSS versus ASCAT

- Although it does not provide wind direction, CYGNSS provides ocean surface wind speed data when ASCAT data are unavailable or between ASCAT swaths and provides additional information when ASCAT data are present
  - McNoldy and Majumdar (2024)
  - Majumdar et al. (2025)



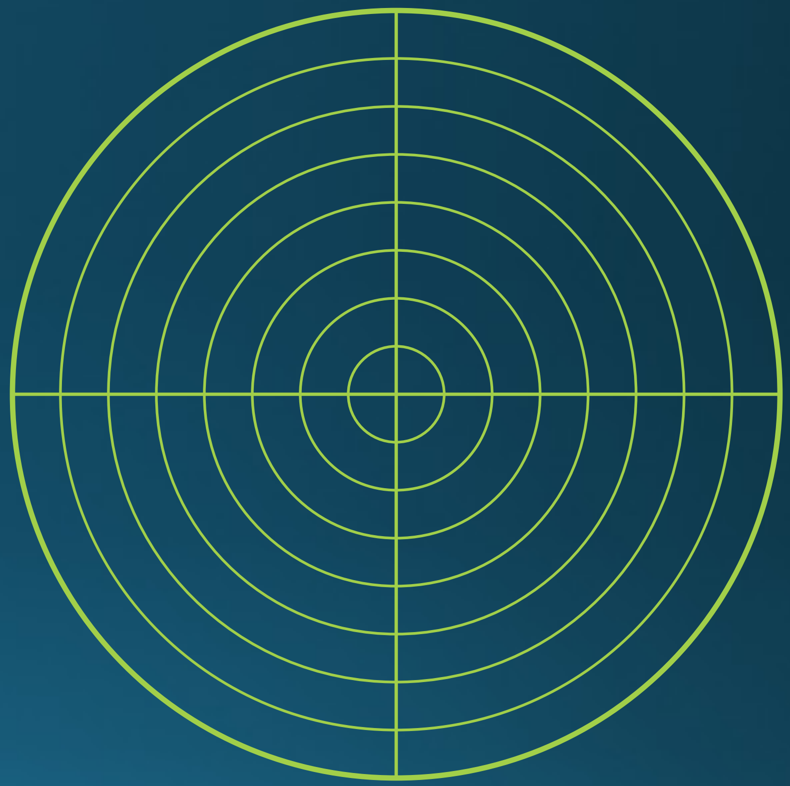
Observation density in 3-hour time windows leading up to NHC advisory times, averaged over Jul-Aug-Sep 2024.

Data

- CYGNSS Level 3 “MRG” product (v 3.2.3)
- Mayers et al. (2023) introduced a storm-centric gridded (SCG) ocean surface wind speed product using the CYGNSS “Young Seas / Limited Fetch” (YSLF) data around tropical cyclones (TCs)
- **Warnock et al. (2024) introduced a merged product (MRG) that builds upon the SCG product by blending the TC area with global coverage of wind speeds provided by the CYGNSS “Fully Developed Seas” (FDS) data**
- MRG product is nominally available every six hours (data are pooled ±6 hr from synoptic times) for every global TC, though availability depends on data coverage
- Data provided on a 0.1° grid and includes CYGNSS-derived estimates of R34 and R50 in four quadrants
- Statistics will be provided for 2024-2025 Atlantic hurricane seasons

Spatial Coverage Index

- Evaluate statistics within 400 km of storm center (~2x average R34 in Atlantic, Knaff et al. (2007))
- Break 0-400 km circle around storm center into 4 quadrants (NE, SE, SW, NW) and 8 radial bins (0-50, 50-100, …, 350-400 km)
- Calculate percentage of possible grid points that have wind speed data
- Combine into 0-400 km quadrant values
- Average for total "spatial coverage index"



Normalized Uncertainty

- Each CYGNSS wind speed data point has an associated "uncertainty", related to the standard deviation of the error in the wind speed retrieval for that point
- Values are nominally 0-10 m/s, though values over ~ 3 m/s start to appear noisier compared to neighbors
- Set all uncertainty values > 3 m/s to 3 m/s
- **Normalized uncertainty = 1 – (uncertainty/3)**
  - Range is 0-1, where 0 is very noisy and 1 is perfect

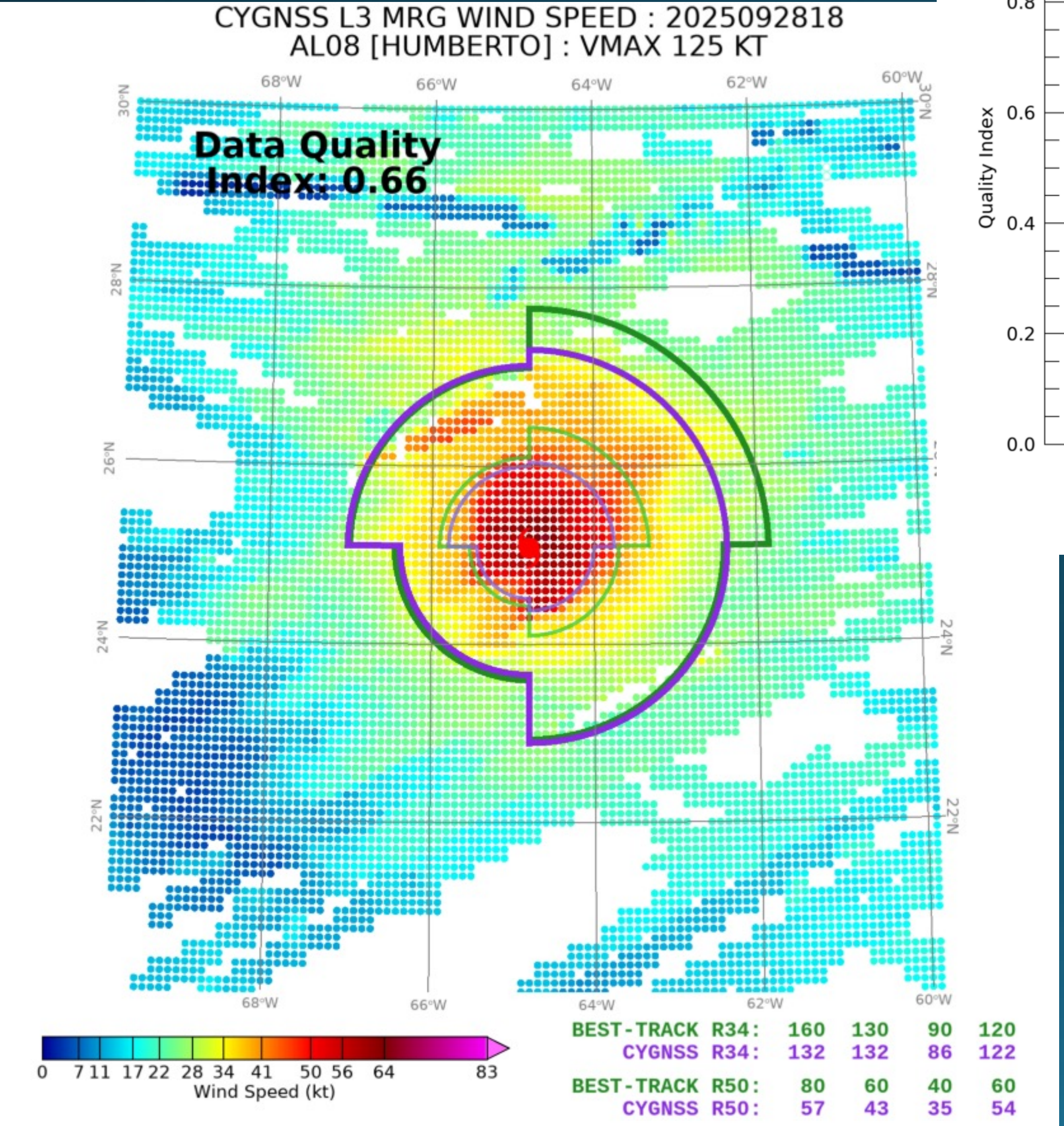
Data Quality Index

- **DQI = Spatial Coverage Index * Normalized Uncertainty**
- Range is 0-1
  - 0 is very poor quality and/or coverage, 1 is perfect quality and coverage
  - 2024-2025 Atlantic Hurricane season mean uncertainty is ~ 0.68
  - 2024-2025 Atlantic Hurricane season mean spatial coverage is ~0.57
  - 2024-2025 Atlantic Hurricane season mean DQI is ~0.39
    - For context, a DQI > ~0.7 at a specific time is exceptionally good

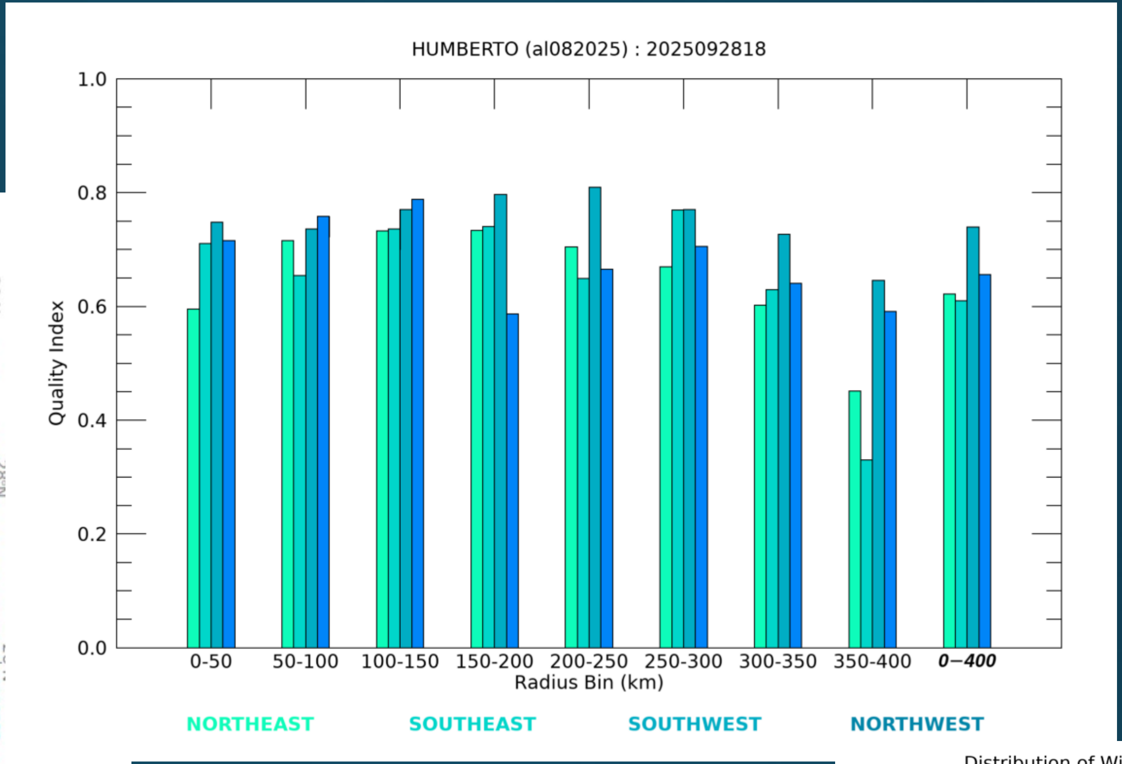
Critical Wind Radii

- NHC's best-track estimates of R34 and R50 have historically ***not*** been informed by CYGNSS data
- CYGNSS could provide an additional data source when creating best-track estimates of R34 and R50
  - Like any other data source, the specialist would need to use discretion about what CYGNSS data look reliable or not

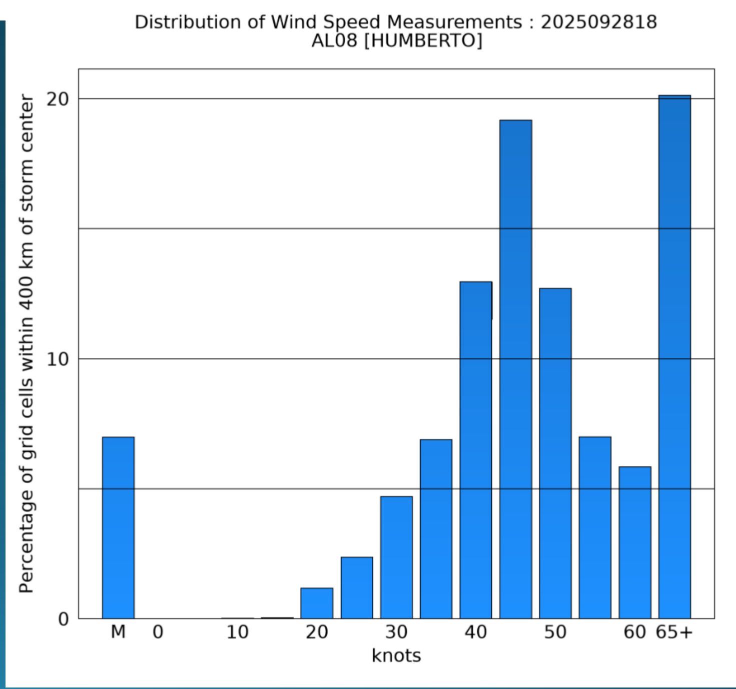
Examples



CYGNSS L3 MRG WIND SPEED : 2025092818
AL08 [HUMBERTO] : VMAX 125 KT
Data Quality Index: 0.66
68°W
66°W
64°W
62°W
60°W
30°N
28°N
26°N
24°N
22°N
0 7 11 17 22 28 34 41 50 56 64 83
Wind Speed (kt)
BEST-TRACK R34: 160 130 90 120
CYGNSS R34: 132 132 86 122
BEST-TRACK R50: 80 60 40 60
CYGNSS R50: 57 43 35 54

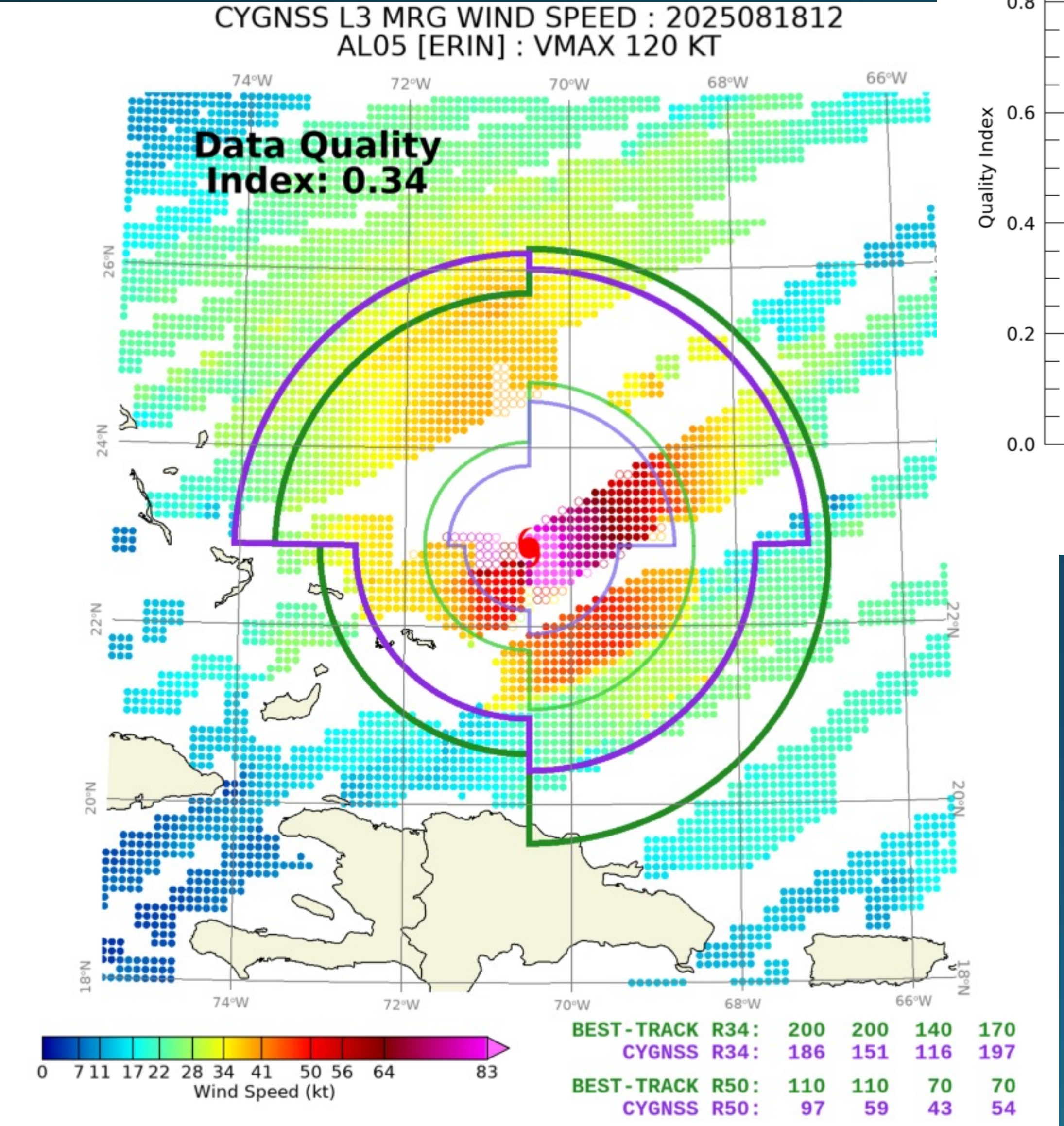


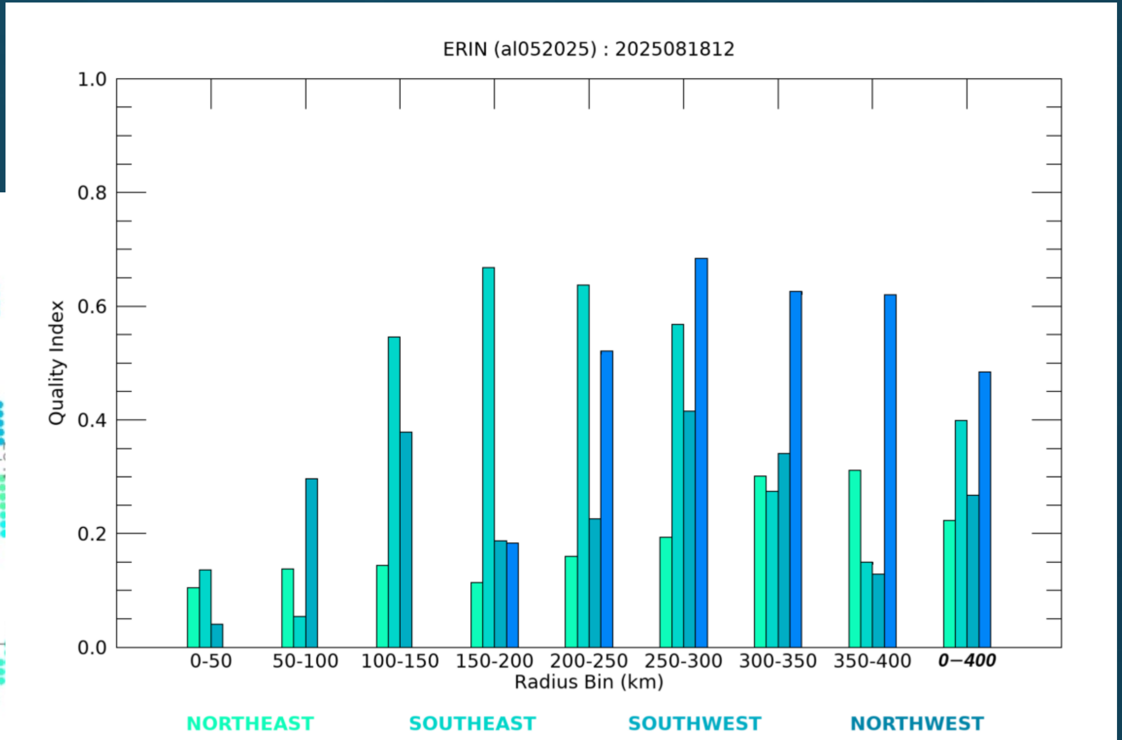
HUMBERTO (al082025) : 2025092818
Quality Index
0.0
0.2
0.4
0.6
0.8
1.0
0-50
50-100
100-150
150-200
200-250
250-300
300-350
350-400
0–400
Radius Bin (km)
NORTHEAST
SOUTHEAST
SOUTHWEST
NORTHWEST

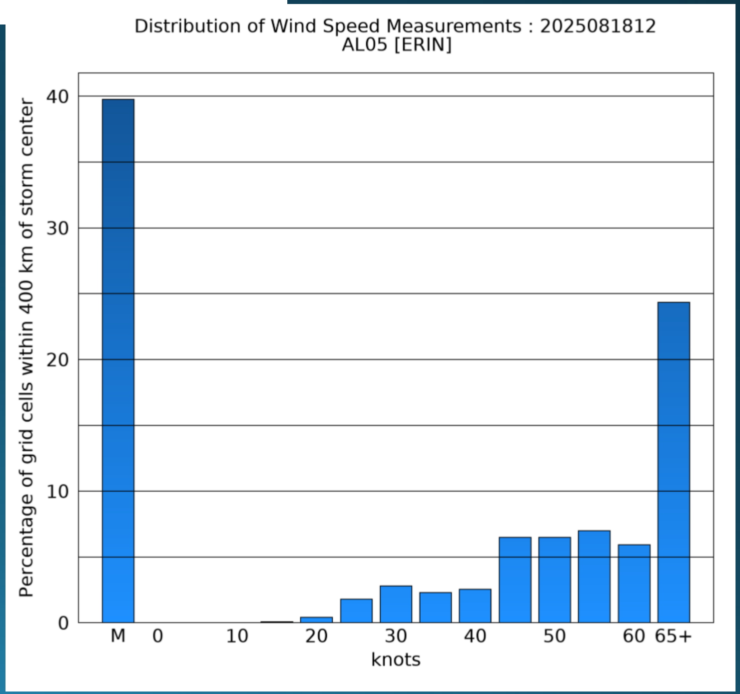


Distribution of Wind Speed Measurements : 2025092818
AL08 [HUMBERTO]
Percentage of grid cells within 400 km of storm center
0
10
20
M
0
10
20
30
40
50
60
65+
knots

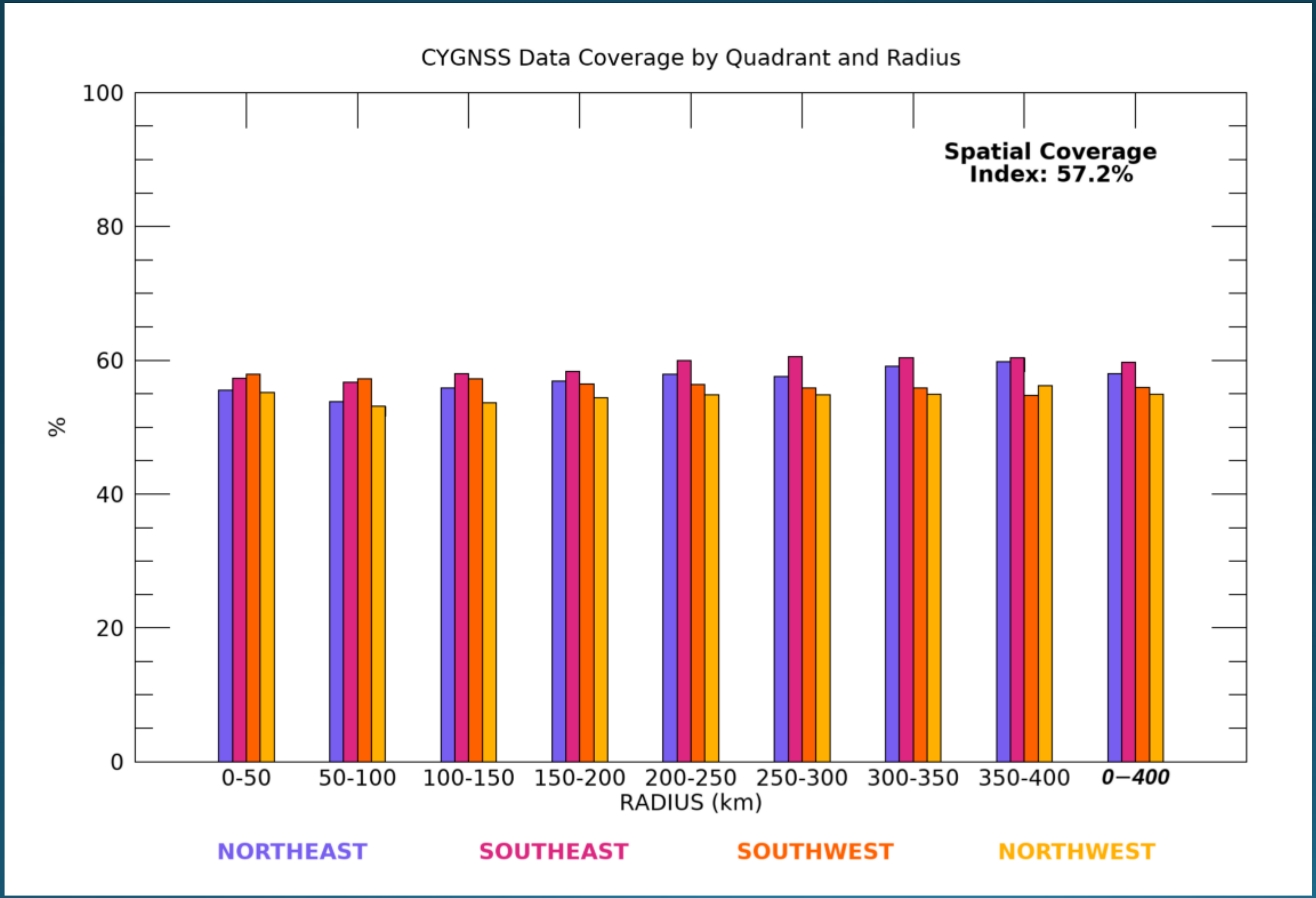
Examples


CYGNSS L3 MRG WIND SPEED : 2025081812
AL05 [ERIN] : VMAX 120 KT
Data Quality Index: 0.34
74°W
72°W
70°W
68°W
66°W
26°N
24°N
22°N
20°N
18°N
0 7 11 17 22 28 34 41 50 56 64 83
Wind Speed (kt)
BEST-TRACK R34: 200 200 140 170
CYGNSS R34: 186 151 116 197
BEST-TRACK R50: 110 110 70 70
CYGNSS R50: 97 59 43 54

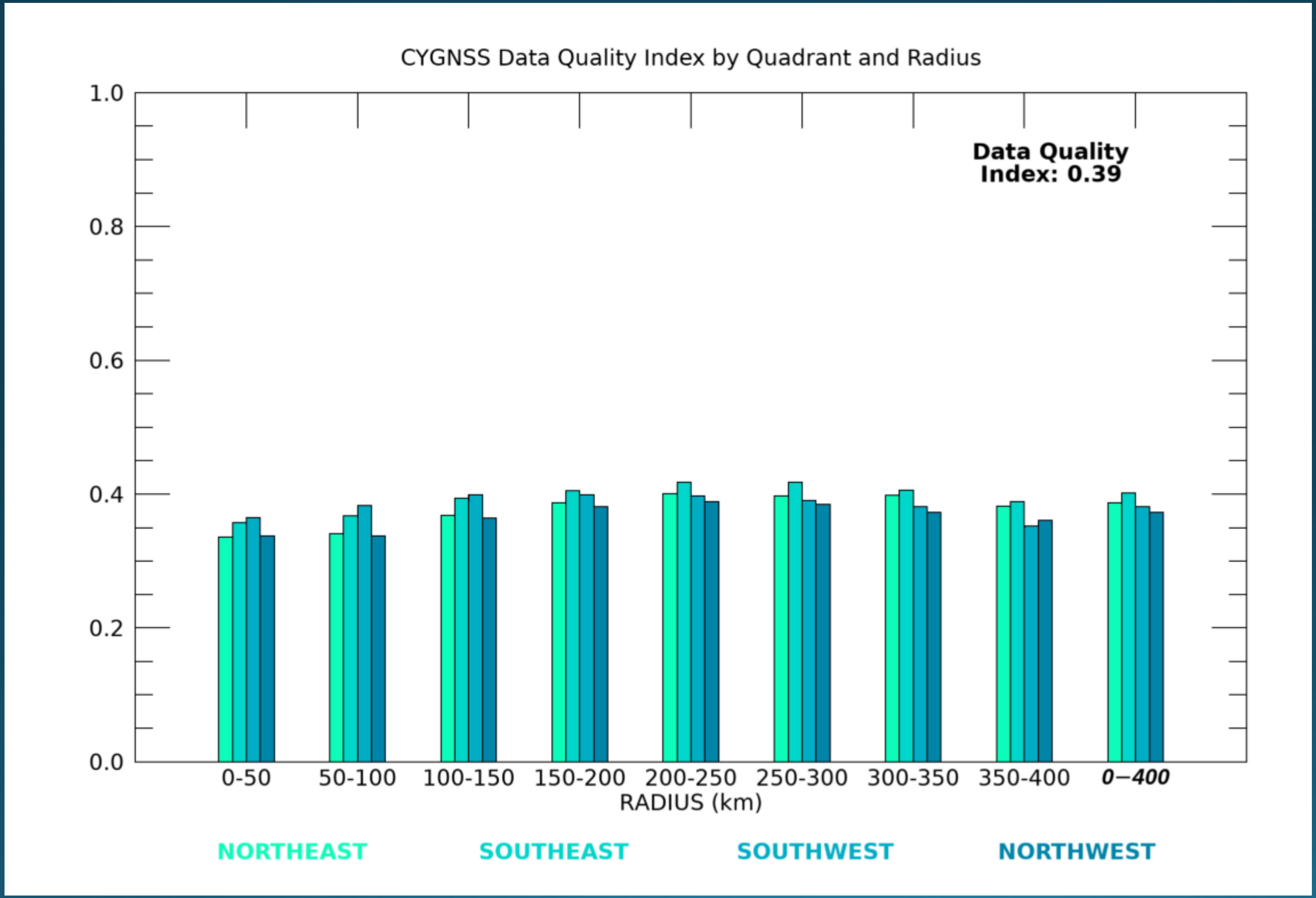

ERIN (al052025) : 2025081812
Quality Index
1.0
0.8
0.6
0.4
0.2
0.0
0-50
50-100
100-150
150-200
200-250
250-300
300-350
350-400
0–400
Radius Bin (km)
NORTHEAST
SOUTHEAST
SOUTHWEST
NORTHWEST


Distribution of Wind Speed Measurements : 2025081812
AL05 [ERIN]
Percentage of grid cells within 400 km of storm center
0
10
20
30
40
M
0
10
20
30
40
50
60
65+
knots

Multi-season Statistics: Spatial

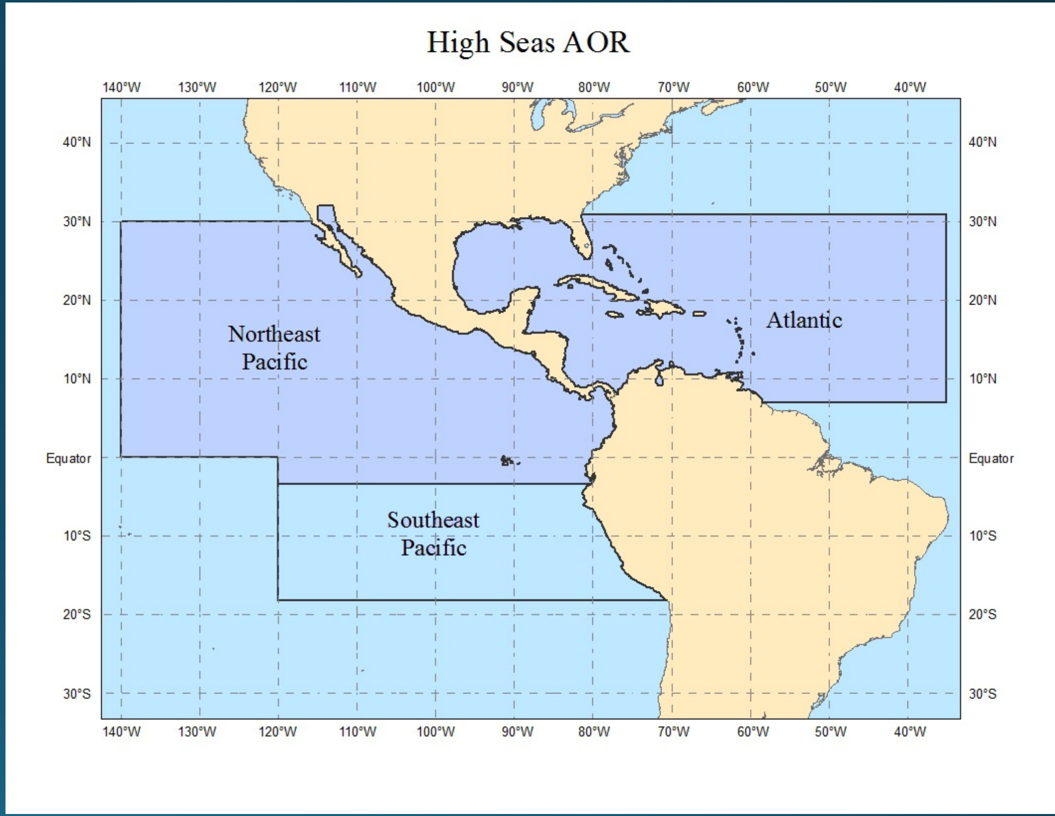


Multi-season Statistics: Data Quality



Large-scale Ocean Analysis

- NHC's Tropical Analysis and Forecast Branch (TAFB) issues six-hourly high seas forecasts
  - issued at 0430, 1030, 1630, 2230 UTC
- Northeast Pacific and Atlantic Oceans
- 20 kt threshold (also 34 and 50 kt)



CYGNSS Level 2 Data

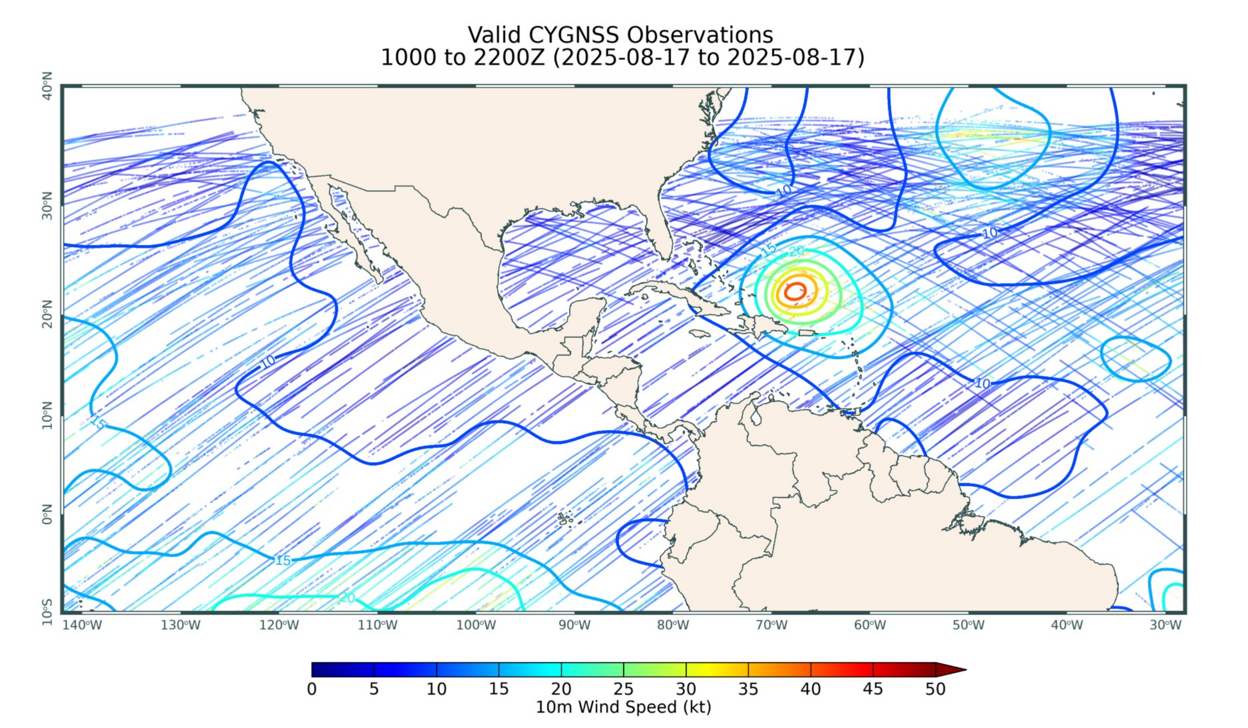
- Irregularly-spaced and sometimes noisy
- Goal: create meteorologically-coherent maps that highlight key wind speed thresholds every six hours by the advisory times
- Temporal: exponential decay weighting from analysis time
  - Use previous 12 hours of data to increase spatial coverage
  - 4 hour decay rate (61% at -2h, 37% at -4h, 22% at -6h, …, 5% at -12h)
- Spatial: exponential decay weighting from each observation point
  - Use 2-pass Barnes analysis to grid and smooth data
  - 200 km decay rate (79% at 100km, 37% at 200km, …, 2% at 400km)
- Omit data where "uncertainty" >3 m/s

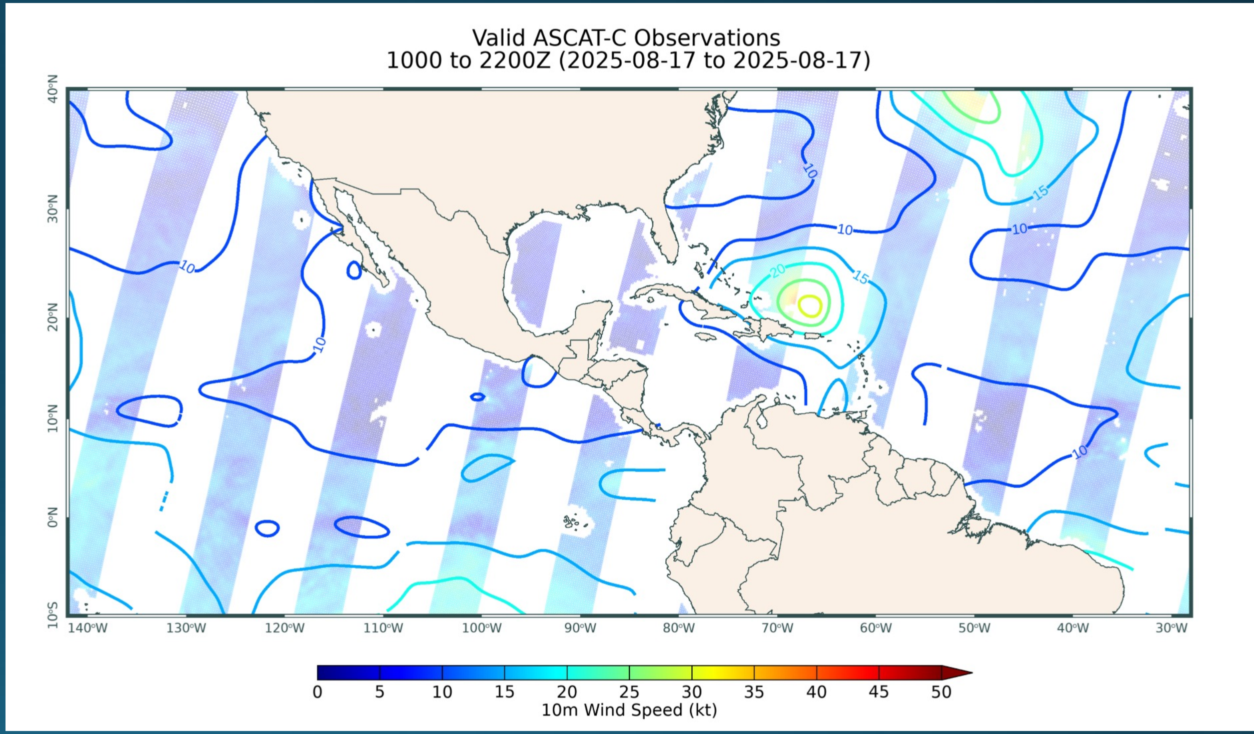
ASCAT Level 2 Data

- Regularly-spaced within a swath then ~600 km gaps between swaths in tropics, fairly smooth retrieved wind field, prone to rain contamination
- Goal: create meteorologically-coherent maps that highlight key wind speed thresholds every six hours by the advisory times
- Temporal: exponential decay weighting from analysis time
  - Use previous 12 hours of data to increase spatial coverage
  - 4 hour decay rate (61% at -2h, 37% at -4h, 22% at -6h, ..., 5% at -12h)
- Spatial: exponential decay weighting from each observation point
  - Use 2-pass Barnes analysis to grid and smooth data
  - 150 km decay rate (64% at 100km, 37% at 150km, ..., 2% at 300km)
- Omit data with rain flag and QC-fail flag

CYGNSS

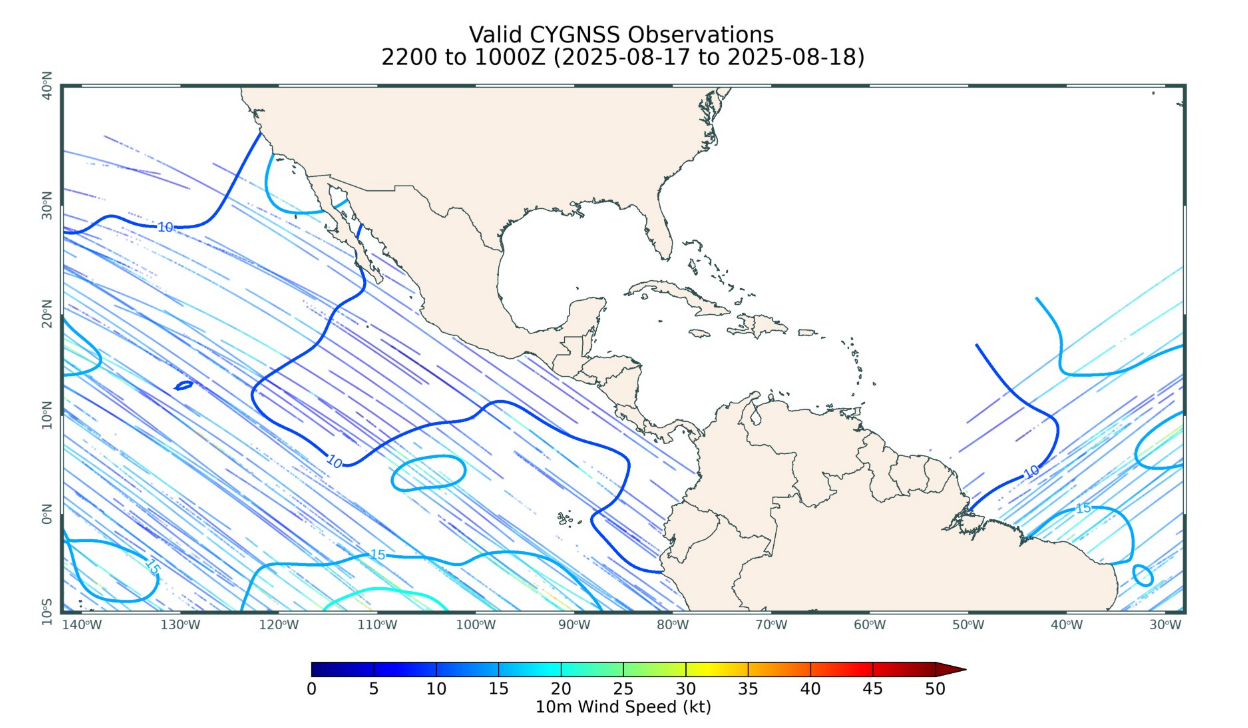
ASCAT

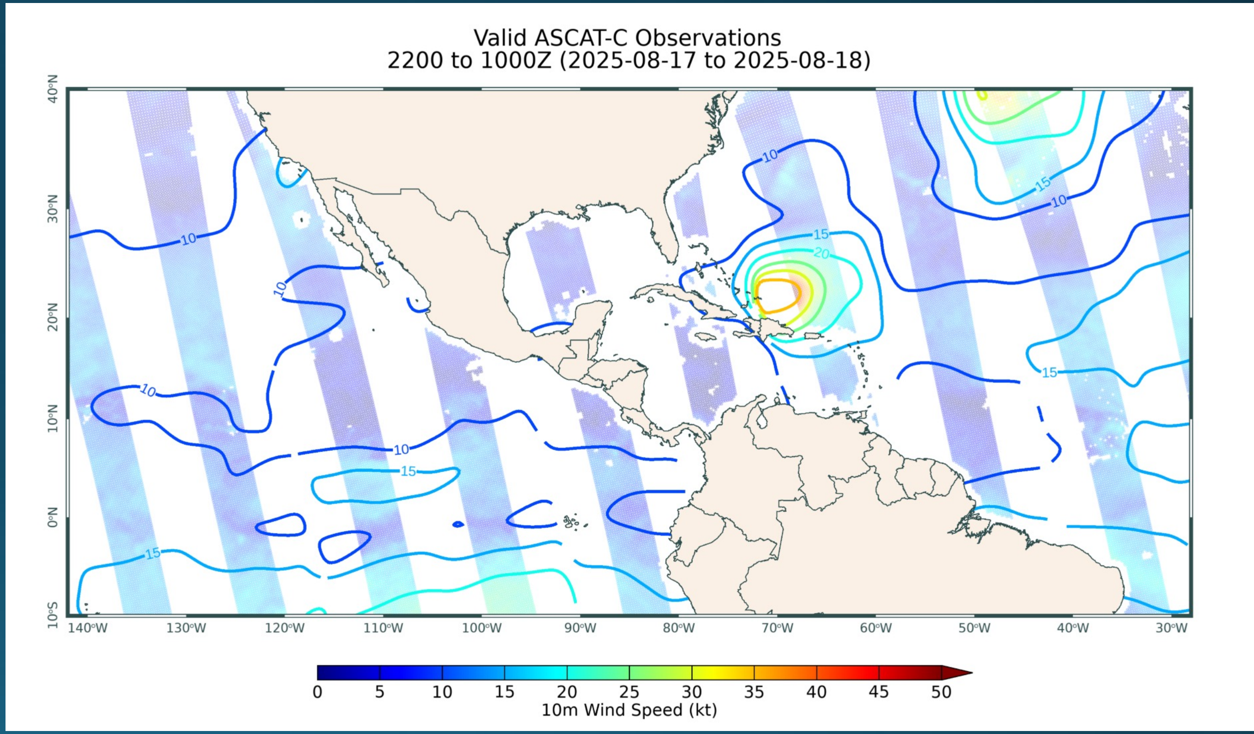




CYGNSS

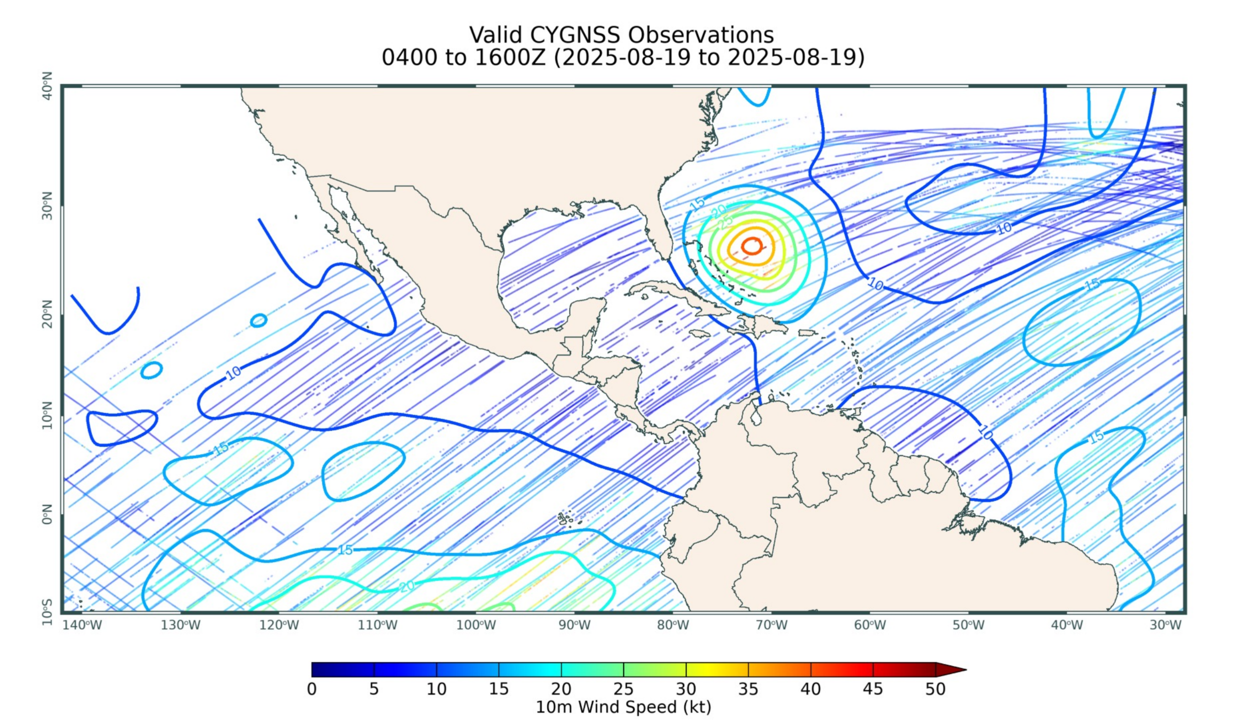
ASCAT

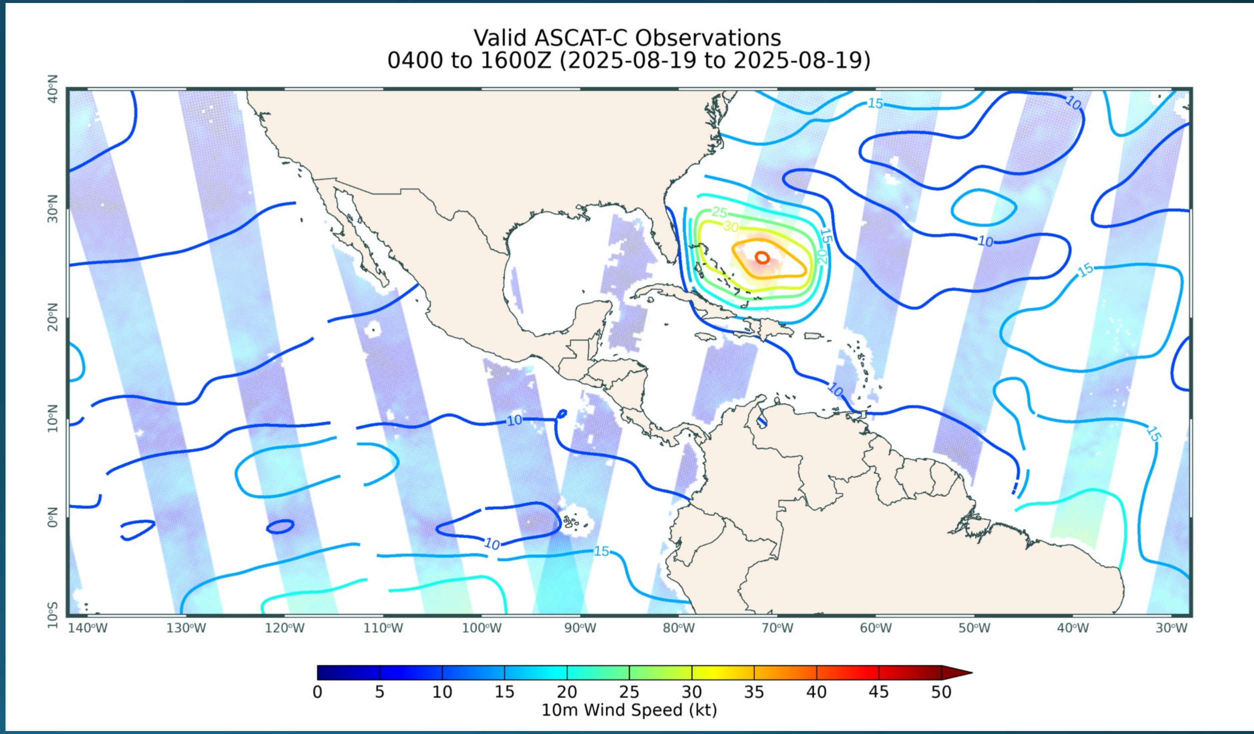




CYGNSS

ASCAT





Summary

- CYGNSS ocean surface wind speed data can provide valuable input to estimates of critical wind radii in TCs and other large-scale wind speed thresholds
- CYGNSS data can complement available scatterometer data, but also have availability when scatterometer data are not present
- The "MRG" product facilitates 6-hourly storm-centric analyses of all global TCs
- Data coverage and quality vary by time and storm, but easy-to-use graphics and indices help to quickly identify the most reliable data

Thank you

Contact: BMCNOLDY@miami.edu
S.MAJUMDAR@miami.edu

Resource:

Website with daily maps of global and TC-specific CYGNSS data
https://bmcnoldy.earth.miami.edu/cygnss/

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