

*International Ocean Vector Wind Science Team Meeting
Salt Lake City, UT
29-31 May 2024*



CYGNSS Improved Wind Speed Product over Tropical Cyclones

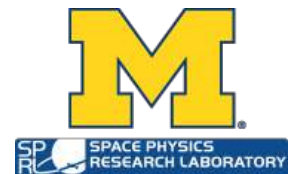
Chris Ruf¹, Mohammad Al-Khaldi², Raji Balasubramaniam¹,
Dani Pascual³, April Warnock⁴

(1) University of Michigan, Ann Arbor, MI USA

(2) Ohio State University, Columbus, OH USA

(3) Deimos Space UK Ltd., Harwell, Oxfordshire UK

(4) SRI International, Ann Arbor, MI USA





CYGNSS Mission Overview

- Flight Segment Design
 - Eight satellites in low earth orbit at 35° inclination
 - Bistatic radar receiver measures GPS signals scattered from the ocean surface
 - Retrieve ocean surface wind speed, similar to ocean scatterometer (only speed, not direction)
- Mission Timeline
 - Launch 15 Dec 2016
 - Science Phase E since Mar 2017
 - One of eight satellites lost Nov 2022
 - Currently in extended Phase E with 7 of 8 operating nominally



CYGNSS Ocean Data Products

(available at NASA PO.DAAC)

- Level 1 Engineering Data Products
 - Scattering Cross Section of the ocean and land for incoherent scattering from rough surfaces
 - Level 2 Science Data Products
 - Ocean surface wind speed (10 m ref height)
 - Fully Developed Seas (FDS), Young Seas/Limited Fetch (YSLF)
 - Ocean surface heat flux (latent and sensible)
 - Level 3 Science Data Products
 - Hourly 0.2 deg lat/lon gridded versions of L2 products
 - 6-hourly 0.1 deg lat/lon merged FDS+YSLF wind speed for tropical cyclone overpasses with storm-centric YSLF regridding
-

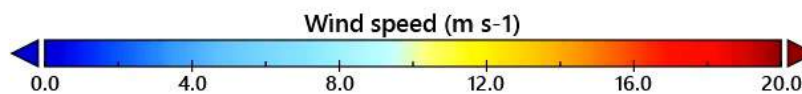
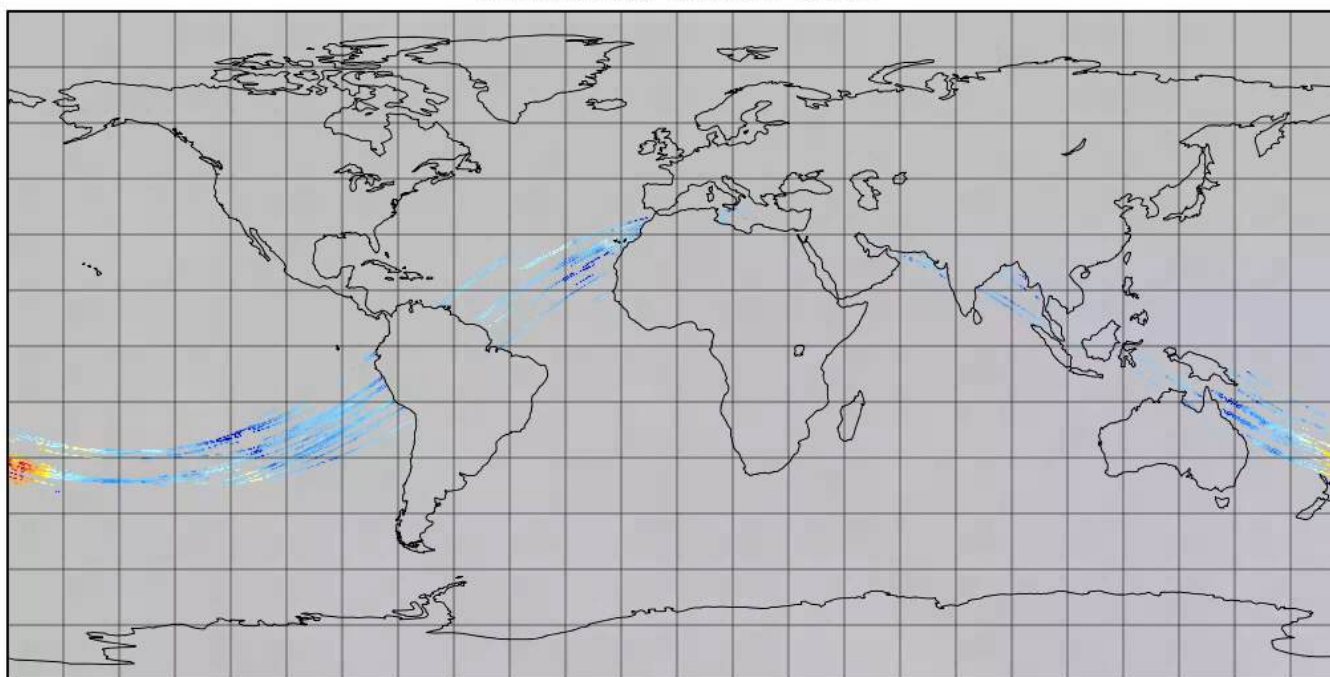


CYGNSS Global Wind Speed Product

Typical 24 hours of v3.1 L3 Winds

CYGNSS Level 3 FDS Wind speed (16 JAN 2022)

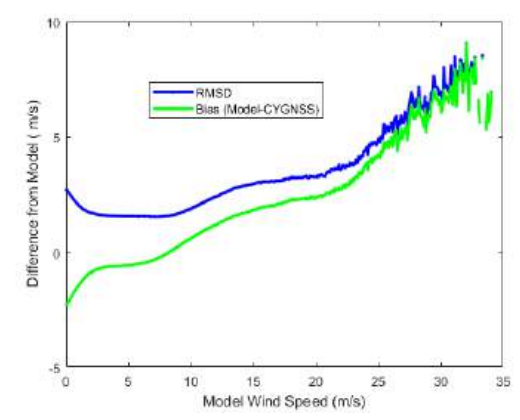
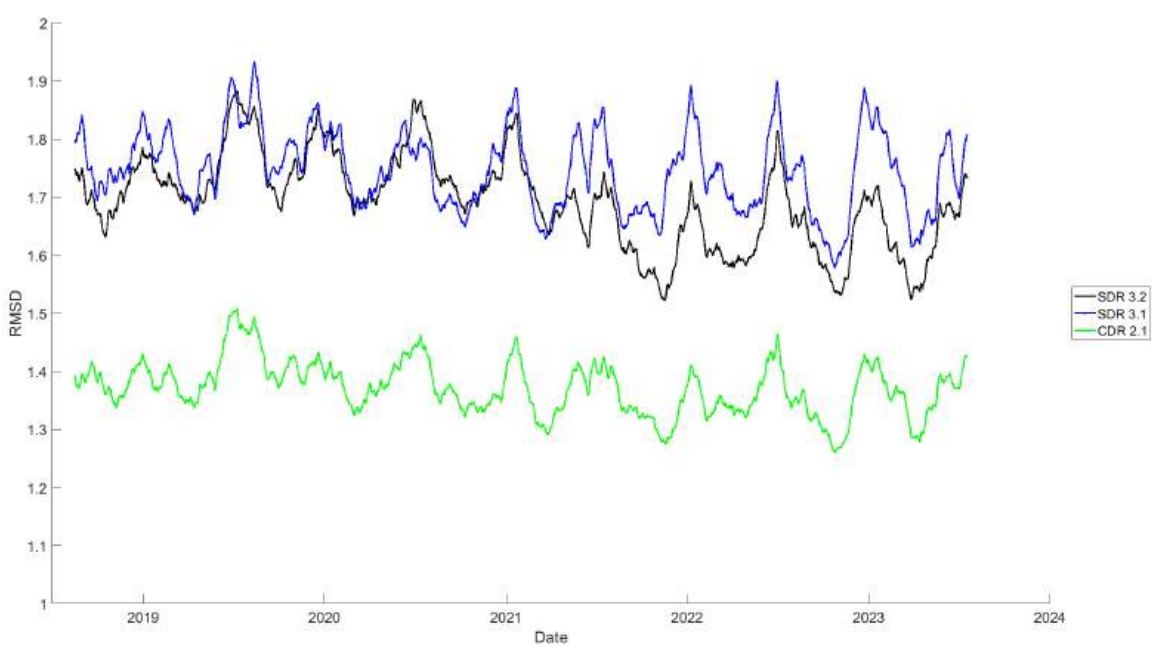
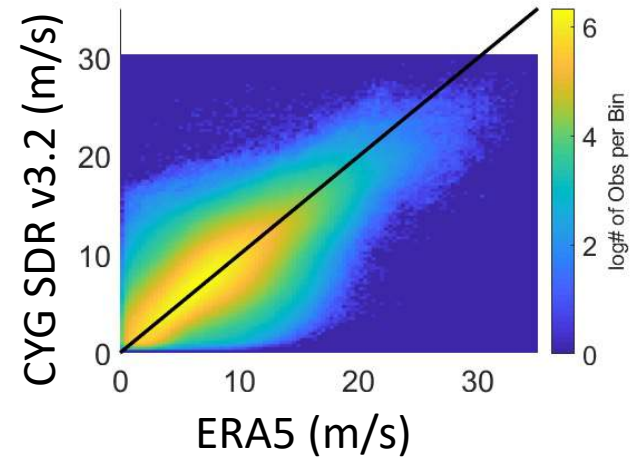
Reference time of file: 2022-01-16 00:30



Data Min = 0.2. Max = 19.8. Mean = 5.9



CYGNSS Global Wind Speed Performance w.r.t. ERA5





CYGNSS Global Wind Triple Collocation Performance Assessment

- Use triplets selected from 4 possible wind speed sources
 - CYGNSS (Project FDS v3.2 and NOAA v1.2)
 - ERA5 (u_{10} neutral stability)
 - ASCAT (scatterometer)
 - GMI (radiometer)

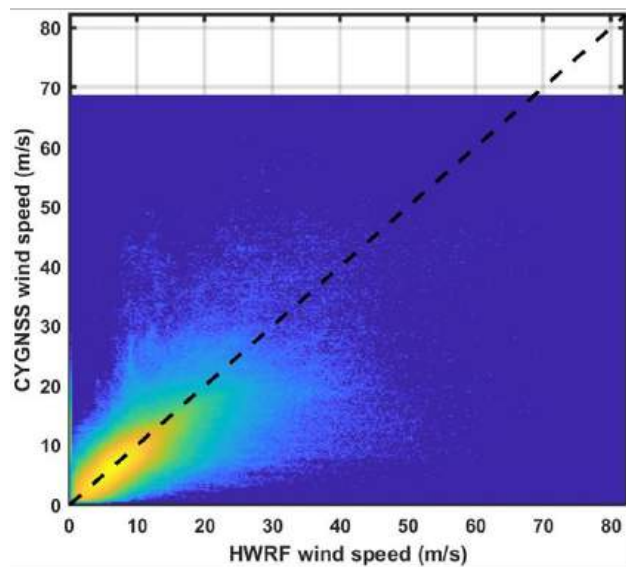
		RMSE [m/s]				
		FDS	NOAA	ERA5	ASCAT	GMI LF
Triplet used to estimate RMSE	FDS, ERA5, ASCAT	1.39	-	0.71	0.42	-
	FDS, ERA5, GMI LF	1.32	-	0.85	-	0.41
	FDS, ASCAT, GMI LF	1.34	-	-	0.57	0.31
	NOAA, ERA5, ASCAT	-	1.00	0.66	0.49	-
	NOAA, ERA5, GMI LF	-	0.93	0.74	-	0.59
	NOAA, ASCAT, GMI LF	-	1.02	-	0.46	0.45
	ERA5, ASCAT, GMI LF	-	-	0.76	0.31	0.57
Avg.		1.35	0.98	0.74	0.45	0.47



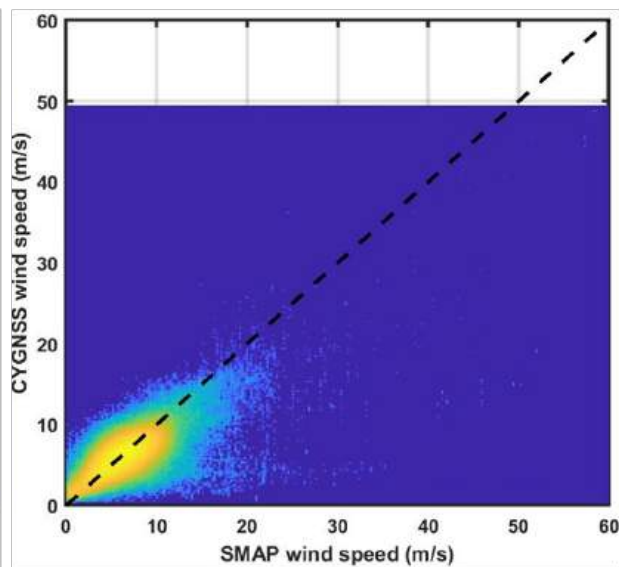
CYGNSS TC Wind Triple Collocation Performance Assessment

- Use triplets selected from 4 possible wind speed sources
 - Test System: CYGNSS (L Band reflectometer)
 - HWRF (Model re-analysis product)
 - SMAP (Spaceborne L Band radiometer)
 - SFMR (Airborne 4.6 -7.2 GHz radiometer)

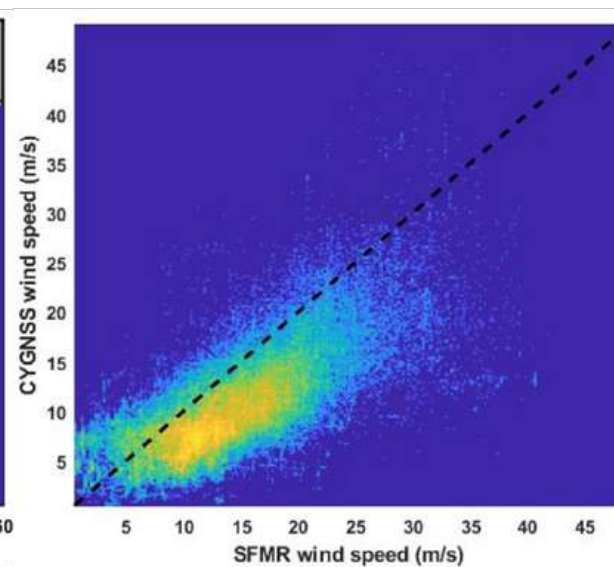
HWRF



SMAP



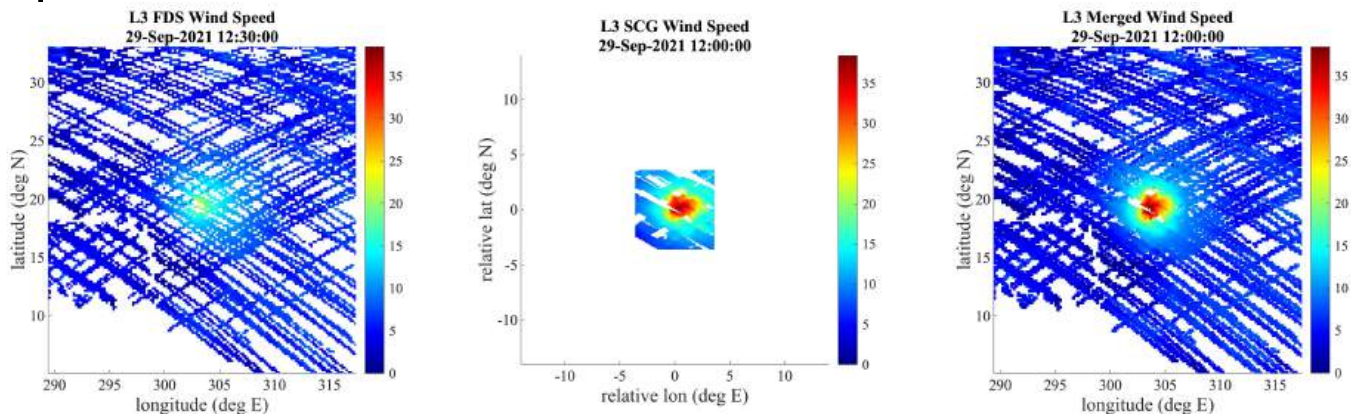
SFMR





CYGNSS L3 Merged Wind Speed

- L3 FDS winds
 - 0.2 x 0.2 deg grid; 1 hour averaging window
 - Global coverage
- L3 YSLF winds
 - 0.1 x 0.1 deg storm-centric grid; +/- 6 hour averaging window
 - Spatial coverage +/- 3.6 deg about storm center
- Tapered transition from YSLF to FDS at 34 knot wind radius

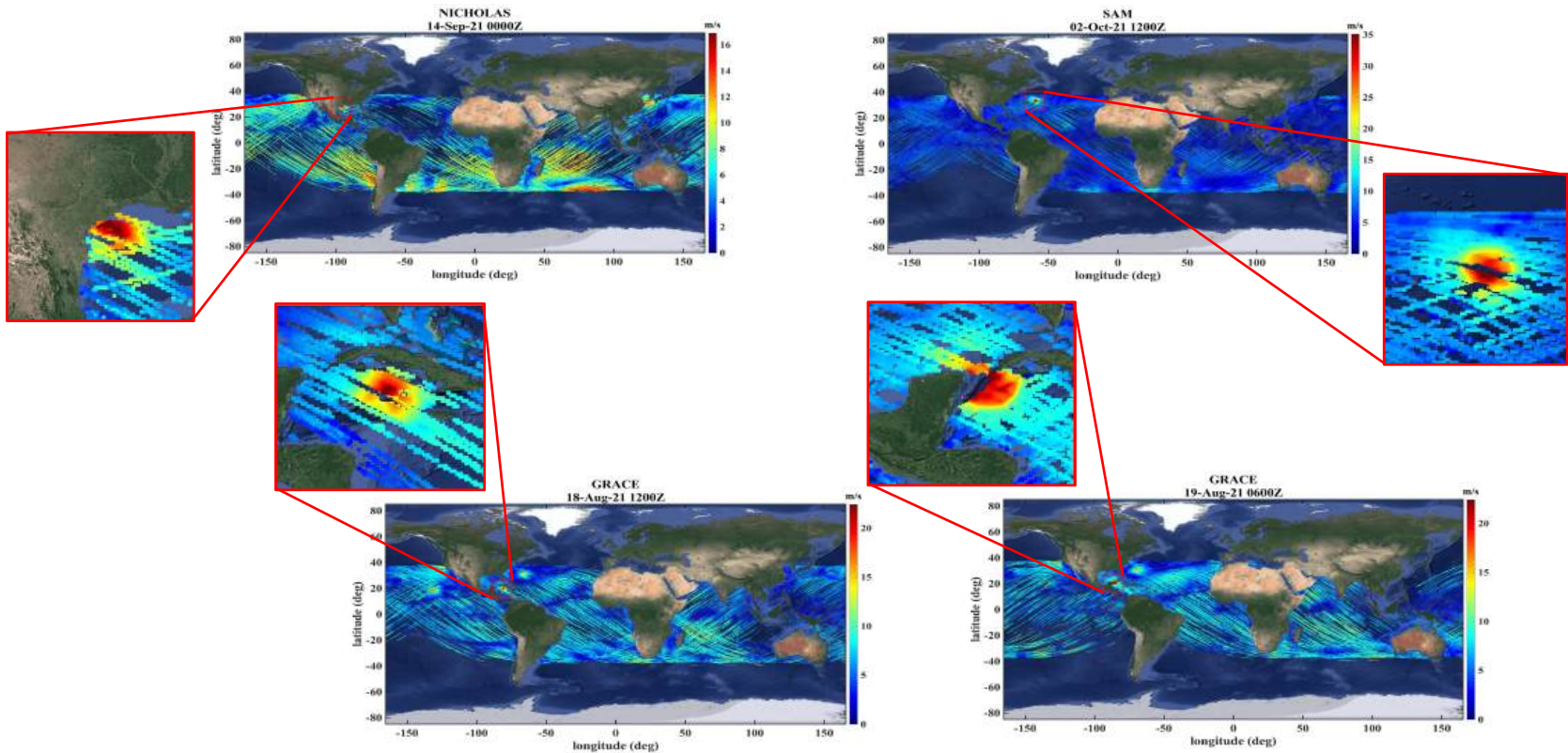


Warnock et al. (2024). CYGNSS Level 3 Merged Wind Speed Data Product for Storm Force and Surrounding Environmental Winds. *J. Selected Topics Appl. Earth Obs.*, doi: 10.1109/JSTARS.2024.3379934.



CYGNSS L3 Merged Wind Speed Global Coverage Examples

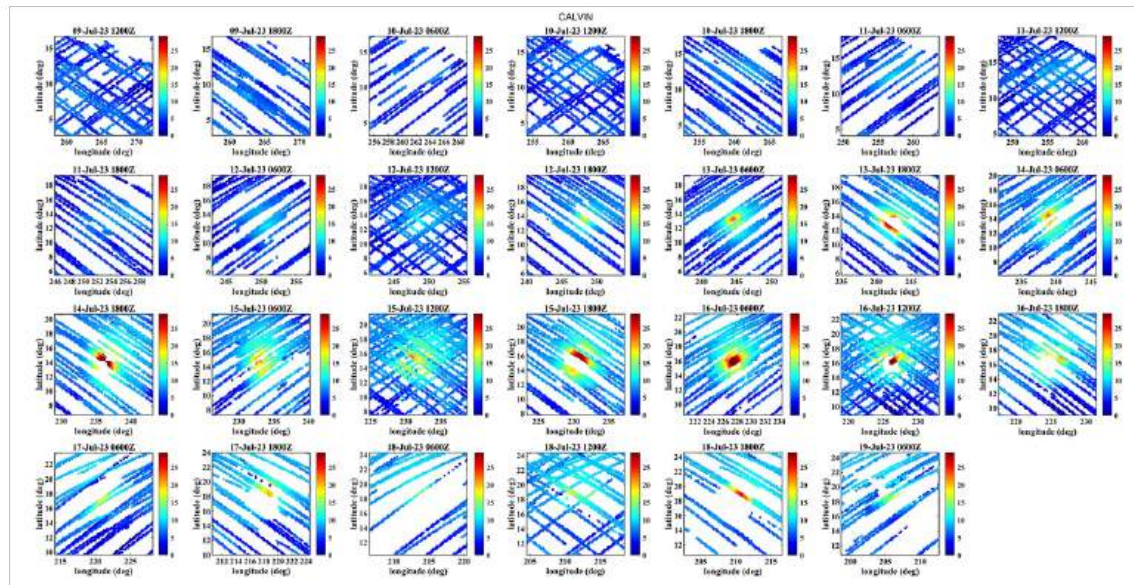
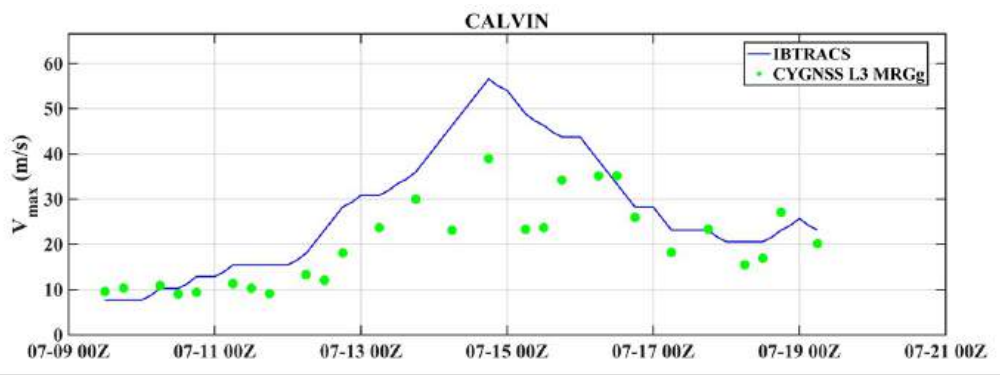
- TCs Nicholas, Sam and Grace





Time Series of L3 MRG and Vmax Hurricane Calvin, July 2023

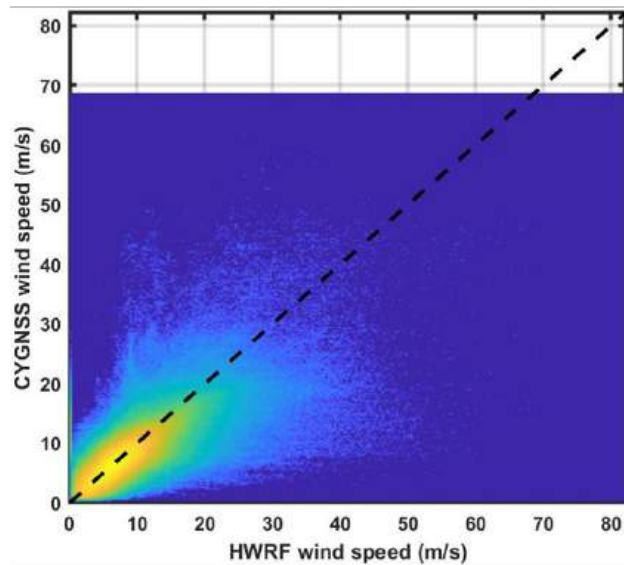
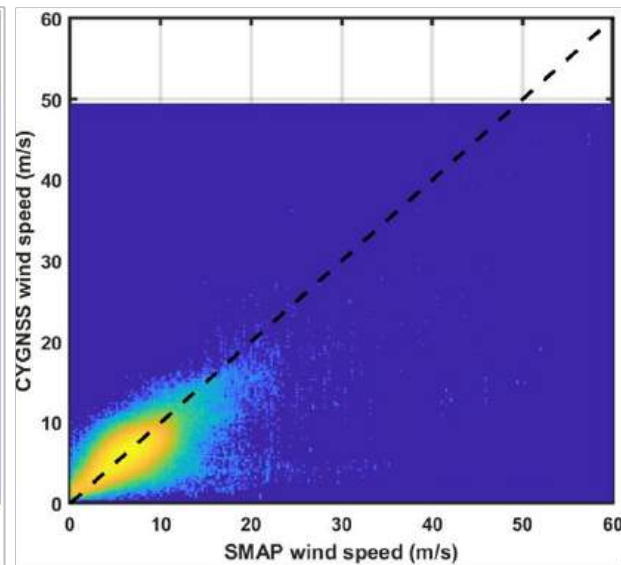
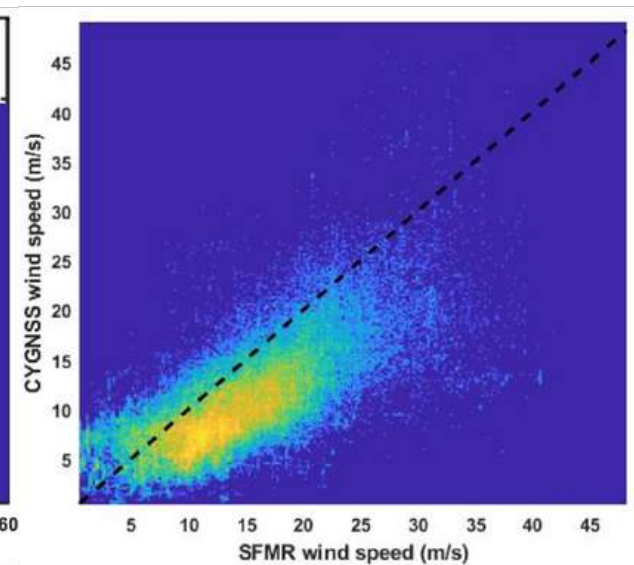
- *Frequent overpasses track day-to-day storm development*
- *Decrease in sensitivity at higher (>40 m/s) wind speeds*
- *Development of storm structure tracked*





CYGNSS TC Wind Triple Collocation Performance Assessment

- Use triplets selected from 4 possible wind speed sources
 - Test System: CYGNSS (L Band reflectometer)
 - HWRF (Model re-analysis product)
 - SMAP (Spaceborne L Band radiometer)
 - SFMR (Airborne 4.6 -7.2 GHz radiometer)

HWRF**SMAP****SFMR**



Triple Collocation Validation of TC Winds

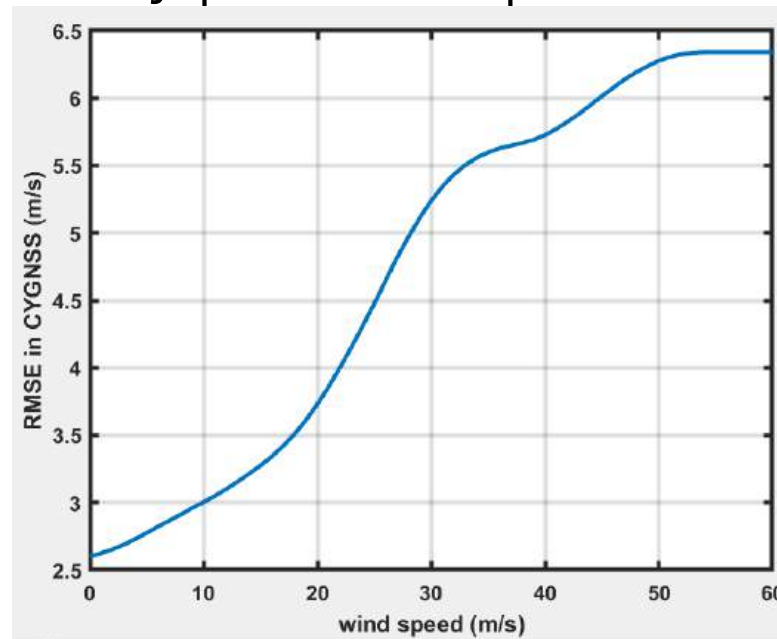
- 4 different triplets of matchups
 - A = [CYGNSS, SMAP, SFMR]
 - B = [CYGNSS, SMAP, HWRF]
 - C = [CYGNSS, SFMR, HWRF]
 - D = [SMAP, SFMR, HWRF]
- Data Set: All 2018-2022 TC Winds

Triplet	Individual RMS Errors (m/s)			
	CYGNSS	SMAP	SFMR	HWRF
A	5.1	5.9	3.5	
B	5.2	5.7		8.9
C	5.2		2.9	8.9
D		6.1	3.3	8.3



CYGNSS RMSE vs. Wind Speed

- CYGNSS 5.2 m/s RMSE includes all wind speeds in matchup dataset
- Partition storm matchup data into ± 5 m/s wind speed bins and repeatedly perform triple collocation analysis

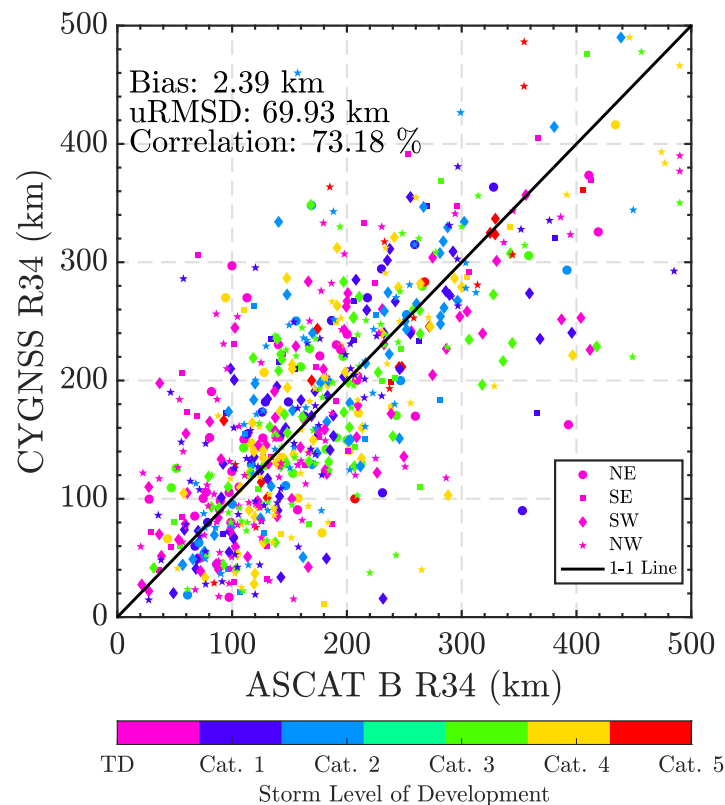
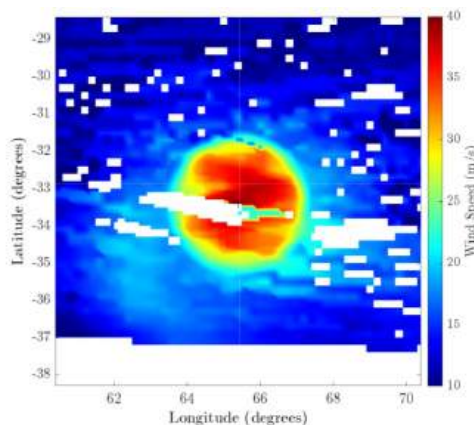




CYGNSS L3 MRG 34 knot Wind Radius

- *Start with a 6-hourly wind speed field*
- *Azimuthally average over each quadrant and select radius @ 34 knots (~17.5 m/s)*

TC Calvinia,
01Jan2020 0600Z





R34 Triple Collocation Performance Assessment

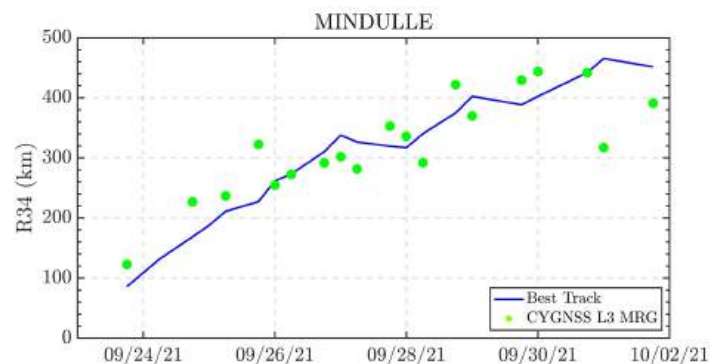
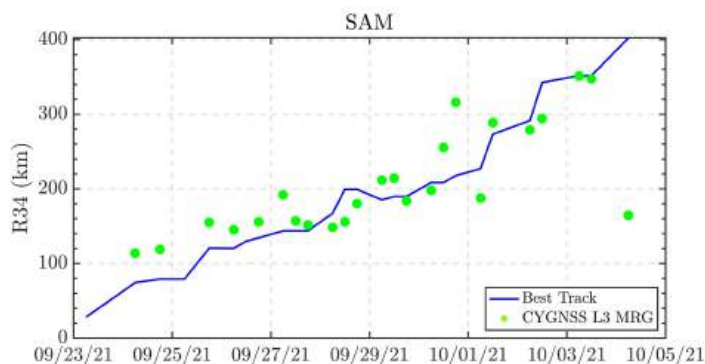
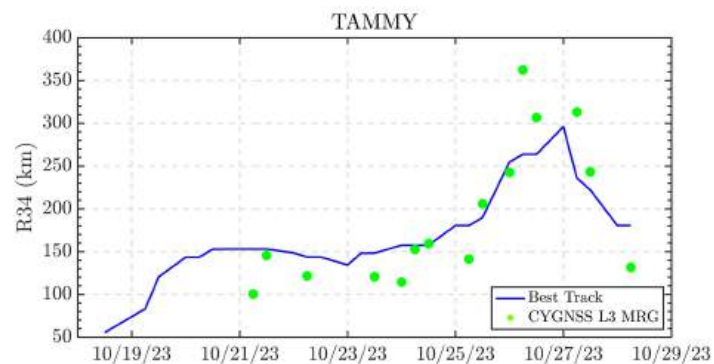
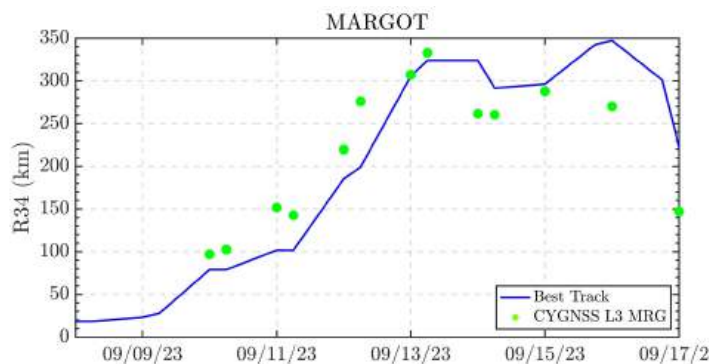
- 4 different triplets of R34 matchups selected from
 - CYGNSS
 - Best Track
 - ASCAT-B
 - SMAP

RMSE (km)	BT	ASCAT-B	CYGNSS	SMAP
Case 1	46.85	36.82	58.33	
Case 2	45.57		49.47	53.64
Case 3	40.05	43.32		43.48
Case 4		34.73	55.23	48.80
AVERAGE	44.2	38.3	54.3	48.6



Time series storm-by-storm comparison to Best Track

Average R34 over all reported quadrants





R34 Spatial & Temporal Sampling

Percent of wind fields where quadrant-specific 34-knot wind radii are available

	TD	TS	Ty/Hu
wind fields with no R34 values reported	89%	71%	31%
wind fields with any R34 values reported that report 1 quadrant	30%	17%	9%
wind fields with any R34 values reported that report 2 quadrants	32%	21%	11%
wind fields with any R34 values reported that report 3 quadrants	23%	24%	18%
wind fields with any R34 values reported that report 4 quadrants	15%	38%	62%

- Based on all storms from Aug 2018 through Nov 2023
- Generally better sampling with higher intensity storms



Summary

- CYGNSS ocean surface wind speed products provide 2-3 samples per day over +/- 38 deg latitude
- Negligible impact from precipitation at L-Band
 - Study diurnal patterns of tropical convection and precip
- RMSE performance 1.0-1.4 m/s over 0-20 m/s
- Performance degraded at higher winds, with RMSE approximately 10% of wind speed
- R34 wind radii by quadrant resolved at 6 hr intervals
 - 69% of all 6 hr intervals sampled through TC life cycles
 - 62% of cases sample all 4 quadrant, 18% (3 quadrants), 11% (2 quadrants), 9% (1 quadrant)