



CYGNSS Observations of Ocean Winds and Waves – NOAA Analysis

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Seubson Soisuvarn^{1,3}, Paul S. Chang¹

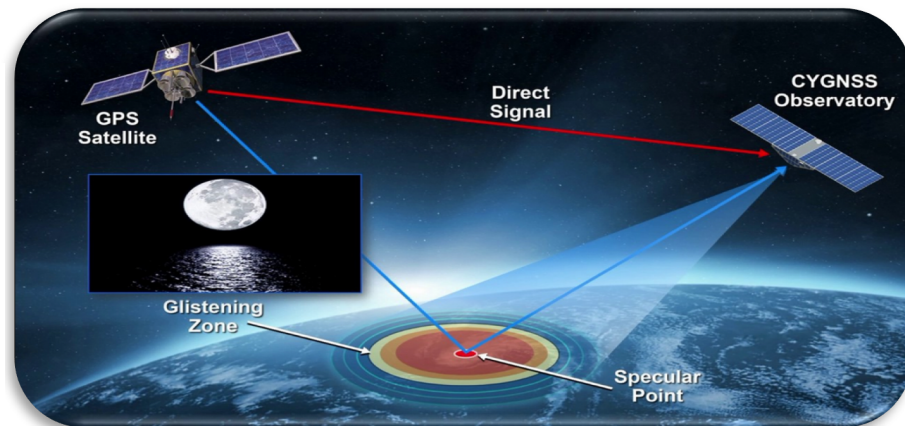
¹NOAA/NESDIS/STAR

²Global Science & Technology, Inc.

³UCAR

Unique CYGNSS Constellation and Challenges

- 2019 Conclusion
 - CYGNSS Calibration is work in progress...
 - NBRCS measurements inconsistencies found to be due to:
 - Specular point position
 - CYGNSS satellite
 - Knowledge of CYGNSS antennas patters
 - GPS block
 - Knowledge of GPS antenna patters
 - Change in transmitted power
 - Digital to analog conversion of the antenna Rx gain
 - New Version of L2 expected soon

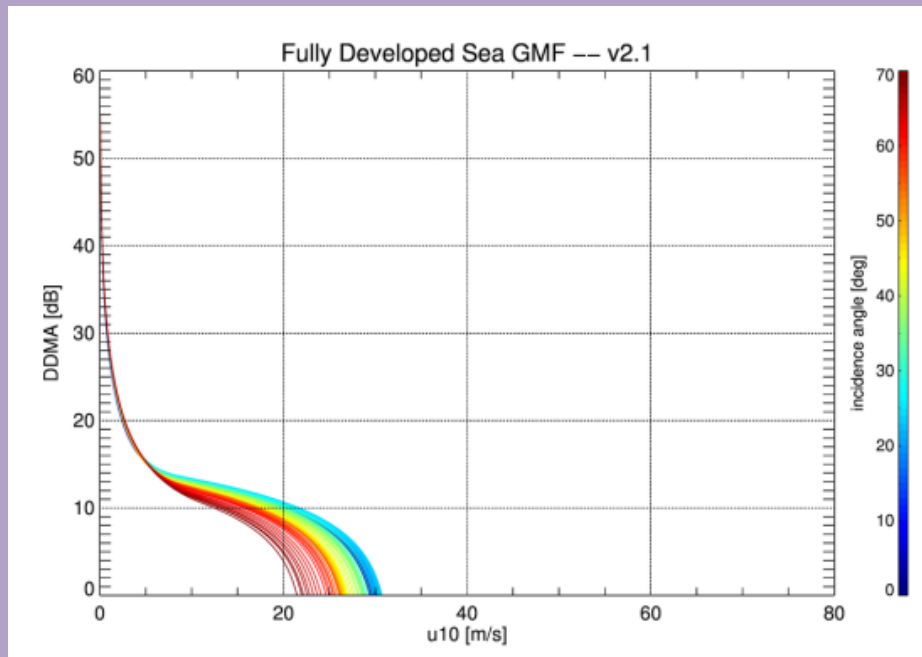


Two Official CYGNSS Wind Products:

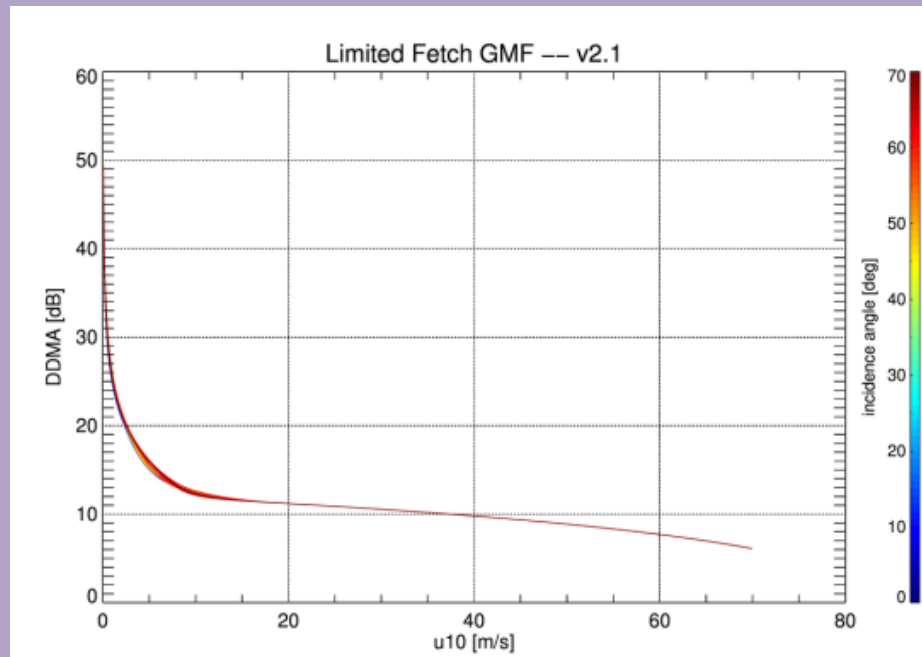
Fully Developed Seas

Young Seas Limited Fetch

UMICH FDS v2.1



UMICH YSLF v2.1



University of Michigan Developed CYGNSS GMF's – UMICH GMF

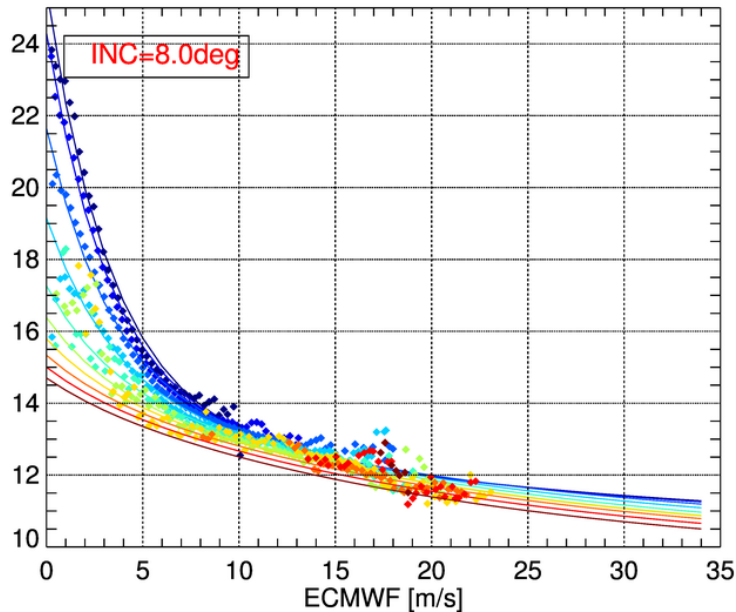
NOAA Wind and Wave Dependent CYGNSS GMF

Using Latest Release CYGNSS Data Version 2.1

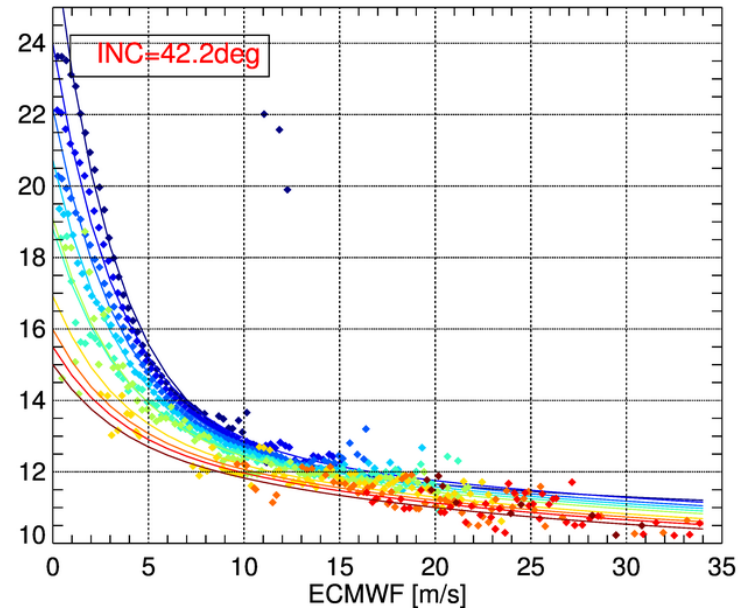
$$\sigma^0(u_{10}, H_s, \Theta_i)$$

0-75m/s | 0-10m | 0-70°

$$\sigma^0(\{u_{10}, H_s\} | \Theta_i \sim 8^\circ)$$

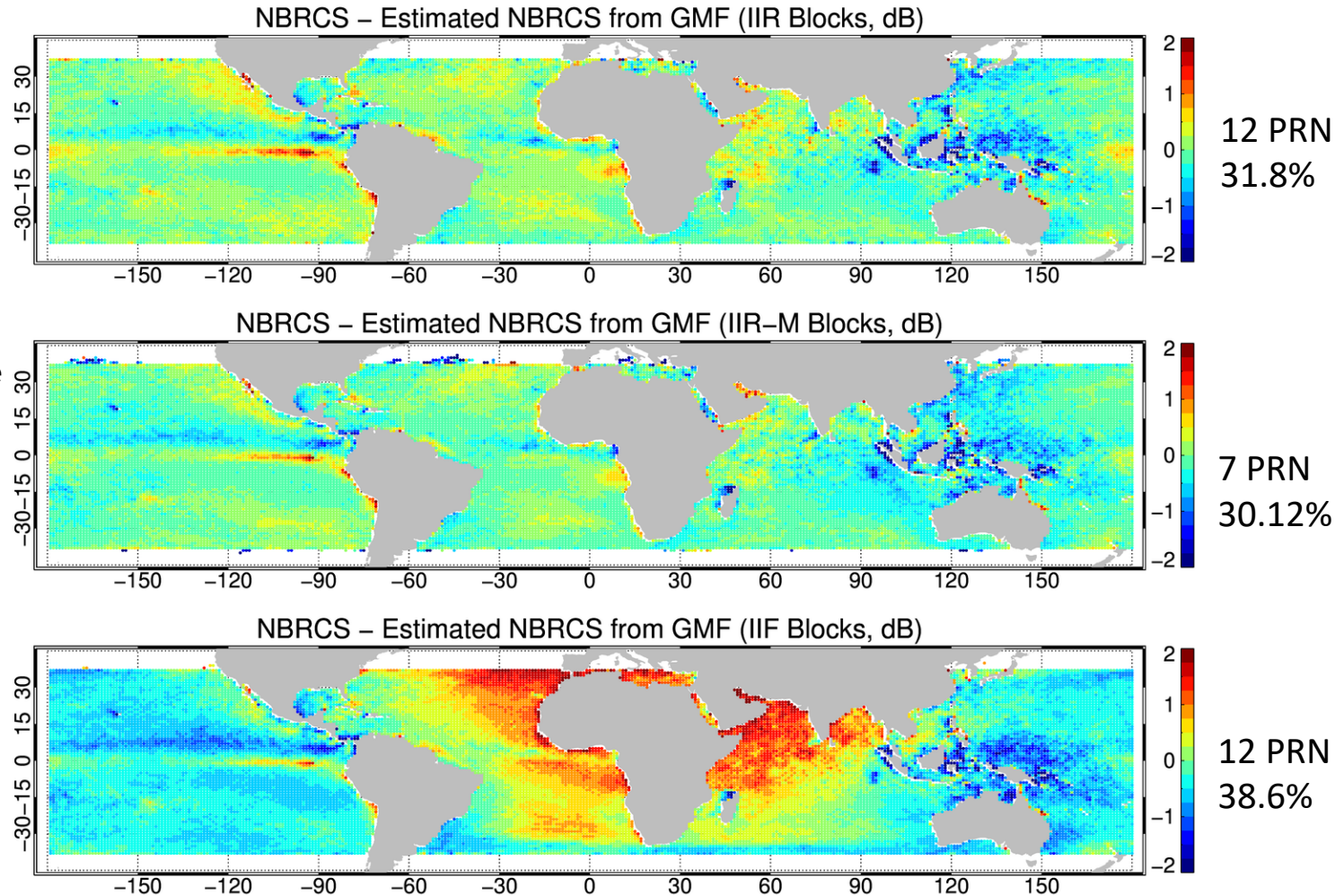


$$\sigma^0(\{u_{10}, H_s\} | \Theta_i \sim 42.2^\circ)$$



III GPS Blocks - NBRCS Bias - NOAA GMF

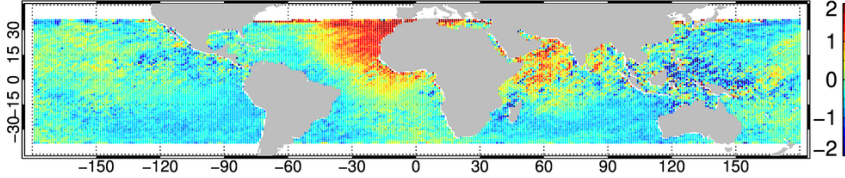
- 32 satellites on 6 orbital planes
- Built by 2 manufacturers
- Launched over the past 2 decades
- 3 block types of spacecraft design
 - IIR, IIR-M, IIF
- 2 types of antenna panel
 - Legacy and improved



Sat. ASC/DES and ANT (IIF) - Anomaly

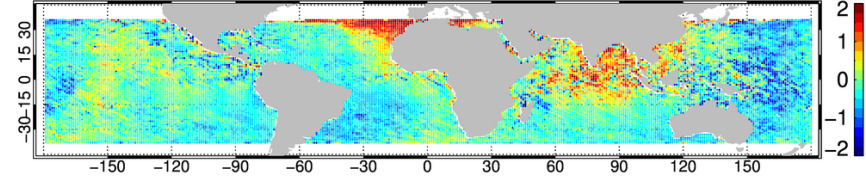
CYG ASC

IIF, GPS ASC and CYG ASC, STARBOARD



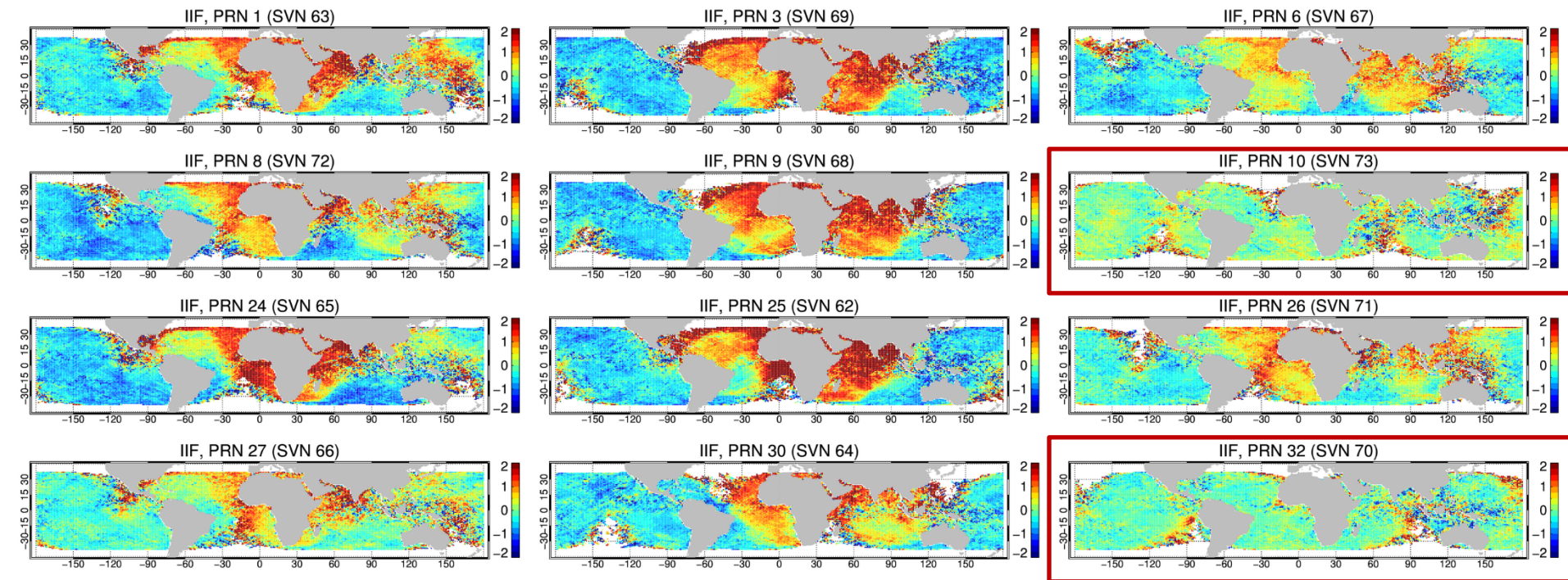
CYG DES

IIF, GPS ASC and CYG DES, STARBOARD



GPS ASC

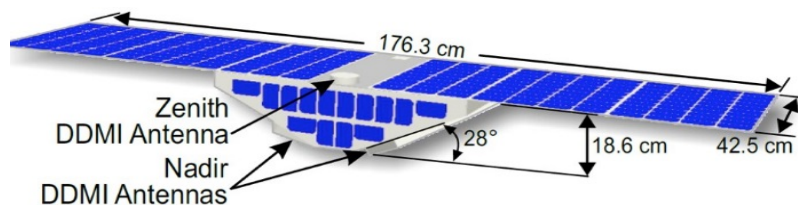
Each PRN Code (IIF) - Anomaly



All Blocks	IIR	IIR-M	IIF	
424333423	132726772	127815952	163790699	
			Flex On 136223077 (32.10%)	Flex Off 27567622 (6.50%)
100%	31.28%	30.12%	38.60%	

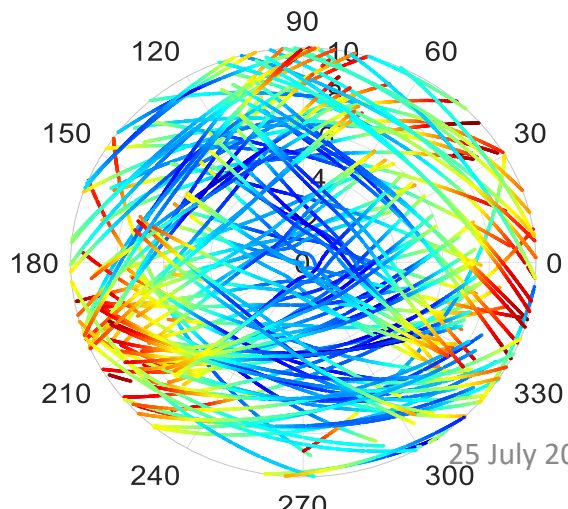
Direct GPS Signal Measured by CYGNSS Zenith Antenna Tialin Wang (IGARSS 2018)

- To characterize transmit power and antenna patterns of GPS constellations
- Unique advantage: much better coverage on the antenna pattern within a short period of time
- Retrieved antenna pattern has much higher resolution

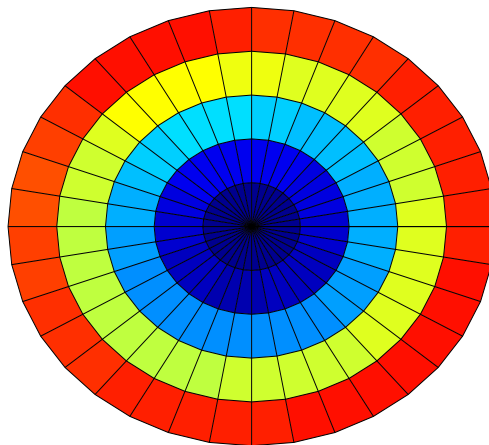


New data version hasn't been released yet

Retrieved antenna pattern (PRN 20)



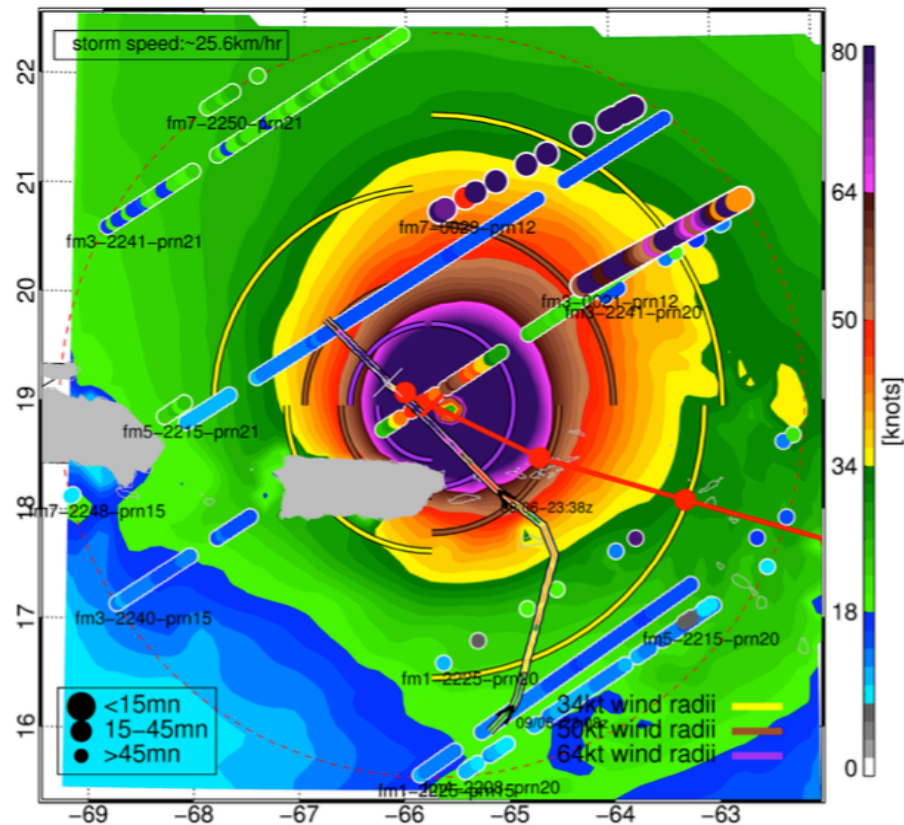
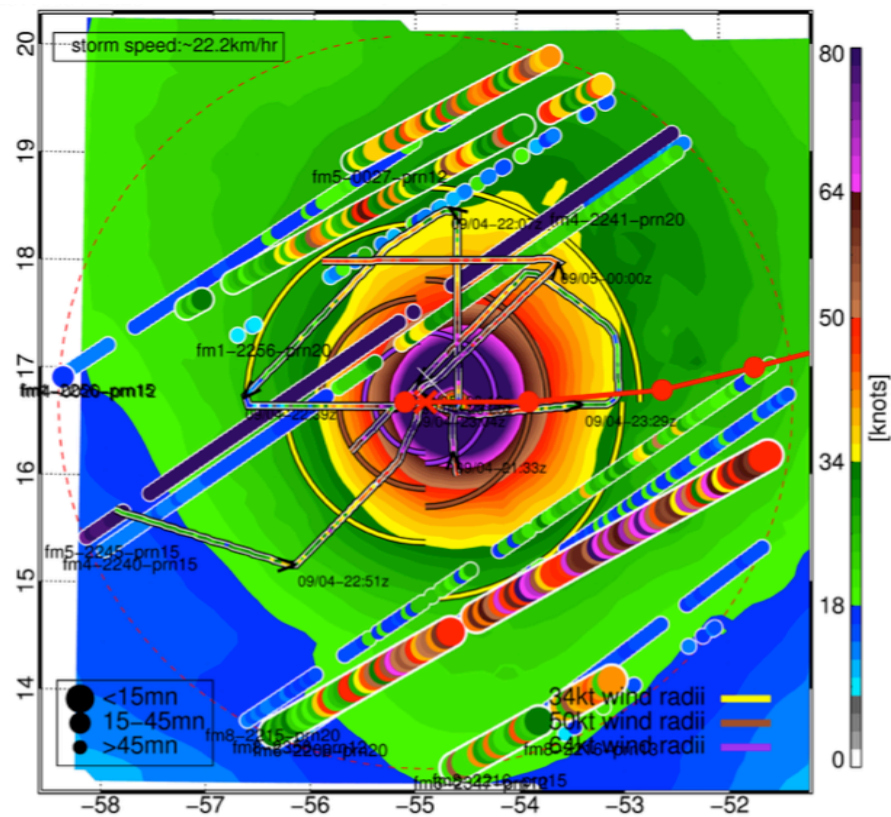
Published pattern of GPS PRN=20





Measurement Impact

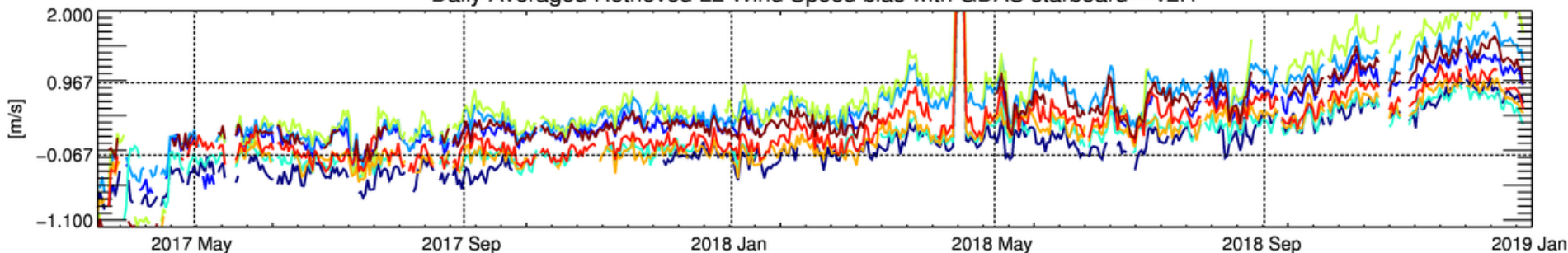
CYGNSS Observations of Hurricane Irma



CYGNSS Wind Bias Timeseries

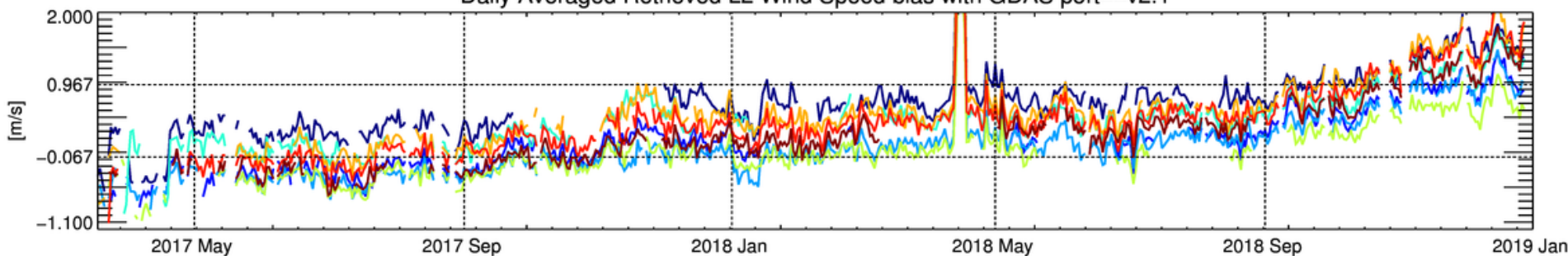
STARBOARD

Daily Averaged Retrieved L2 Wind Speed bias with GDAS starboard--v2.1



PORT

Daily Averaged Retrieved L2 Wind Speed bias with GDAS port--v2.1



Obs #



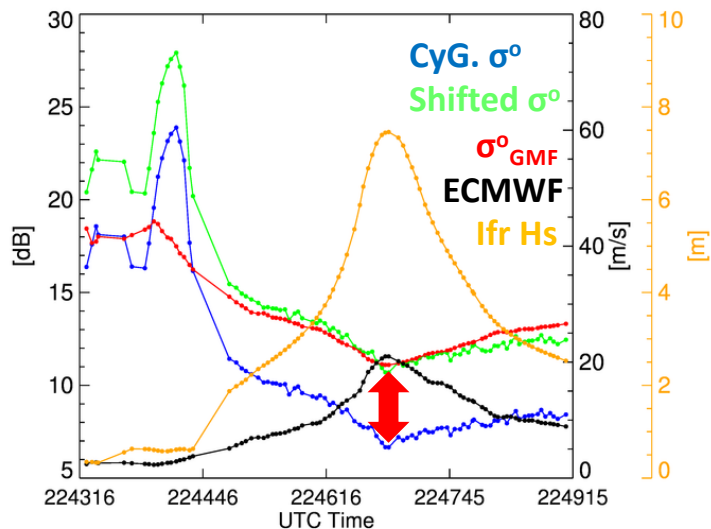
While Waiting for Promised Solution...

- To reduce measurement noise – create lower resolution NBRCS product ($0.25^{\circ} \times 0.25^{\circ}$)
- Implement track debiasing procedure
 - For a given track (i.e. where consecutive specular points are 'locked' to a particular GPS transmitter), generate σ° timeseries
 - Generate corresponding σ° timeseries using the GMF
 - Compute overall σ° bias between the two excluding 'poor quality' σ° (e.g. Rx gain < 5dB and poor attitude)
 - Apply this fixed bias correction to all measured σ° along the track

Track Debiasing

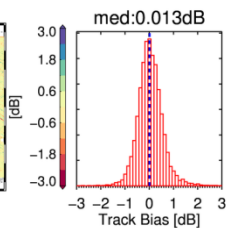
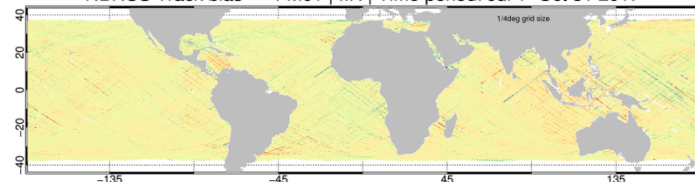
FM#5--2017 Sep 04—block IIR-M—trackID 893

σ^0 /u10/Hs timeseries along the track

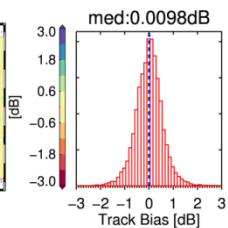
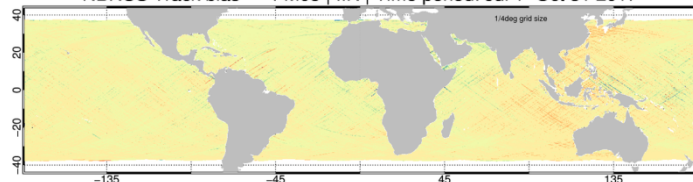


NBRCS Track Bias -- GPS Block IIR - Jul-Oct 2017

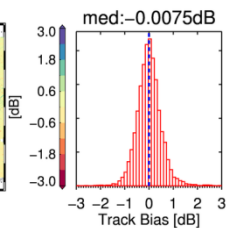
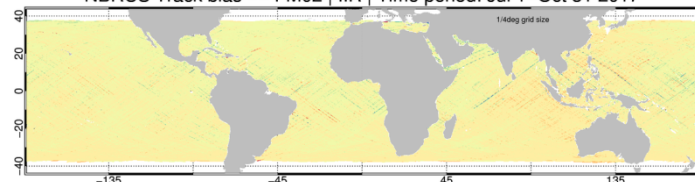
NBRCS Track bias -- FM01 | IIR | Time period: Jul 1–Oct 31 2017



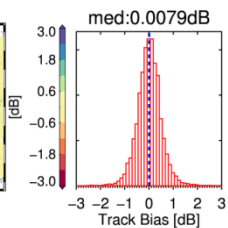
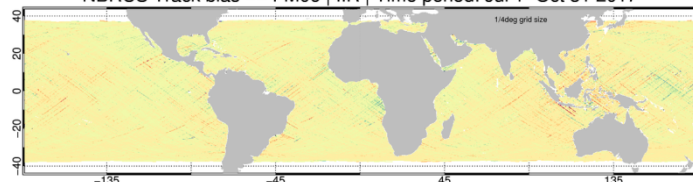
NBRCS Track bias -- FM05 | IIR | Time period: Jul 1–Oct 31 2017



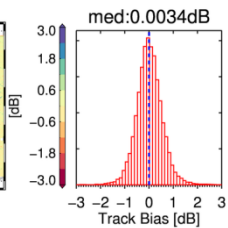
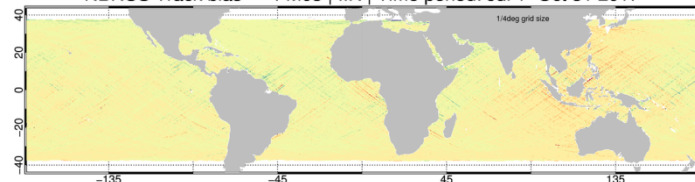
NBRCS Track bias -- FM02 | IIR | Time period: Jul 1–Oct 31 2017



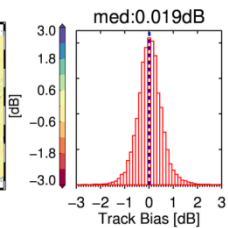
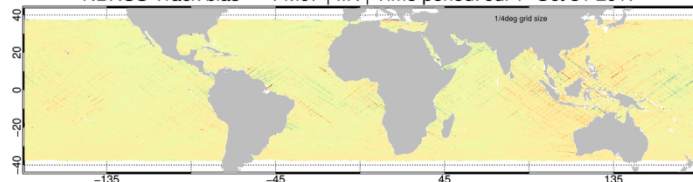
NBRCS Track bias -- FM06 | IIR | Time period: Jul 1–Oct 31 2017



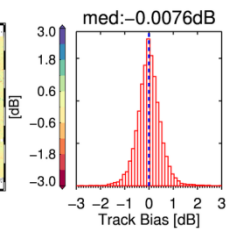
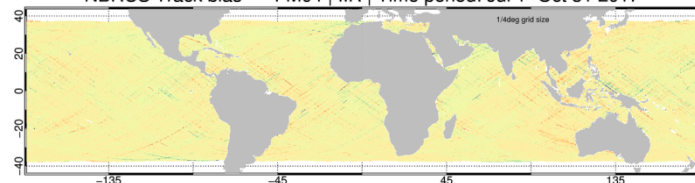
NBRCS Track bias -- FM03 | IIR | Time period: Jul 1–Oct 31 2017



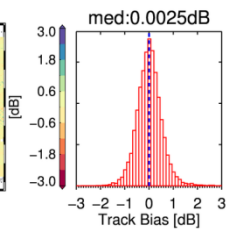
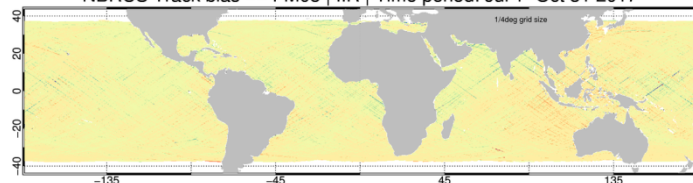
NBRCS Track bias -- FM07 | IIR | Time period: Jul 1–Oct 31 2017



NBRCS Track bias -- FM04 | IIR | Time period: Jul 1–Oct 31 2017

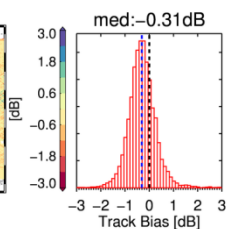
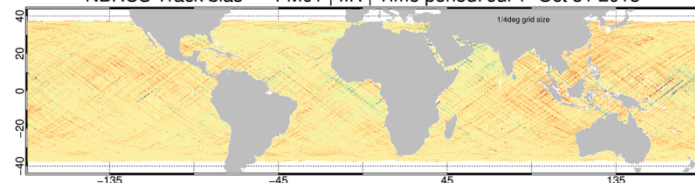


NBRCS Track bias -- FM08 | IIR | Time period: Jul 1–Oct 31 2017

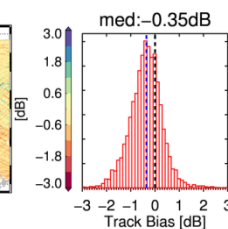
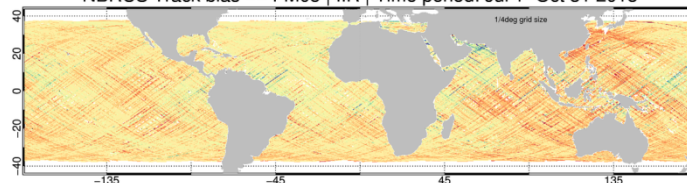


NBRCS Track Bias -- GPS Block IIR - Jul-Oct 2018

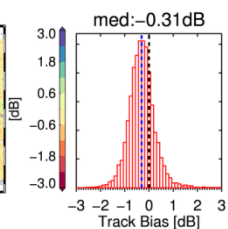
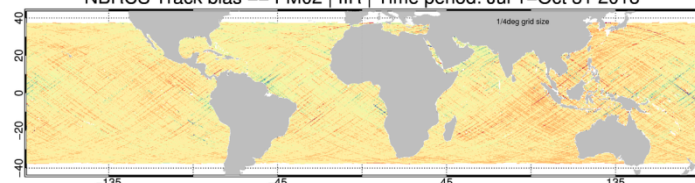
NBRCS Track bias -- FM01 | IIR | Time period: Jul 1–Oct 31 2018



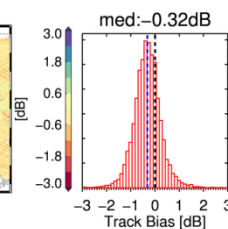
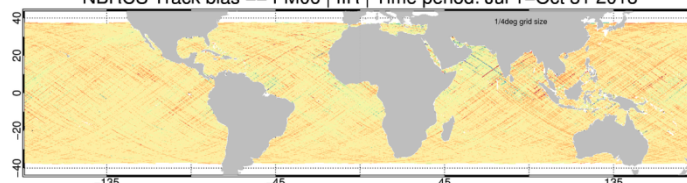
NBRCS Track bias -- FM05 | IIR | Time period: Jul 1–Oct 31 2018



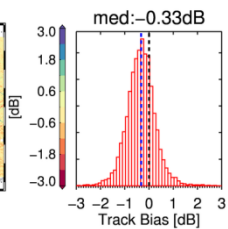
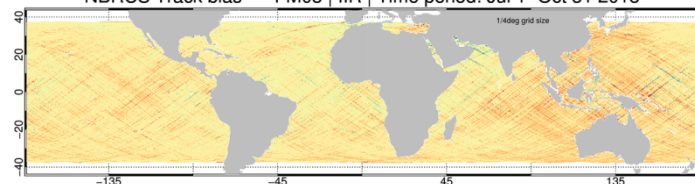
NBRCS Track bias -- FM02 | IIR | Time period: Jul 1–Oct 31 2018



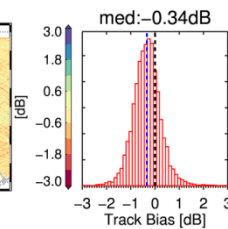
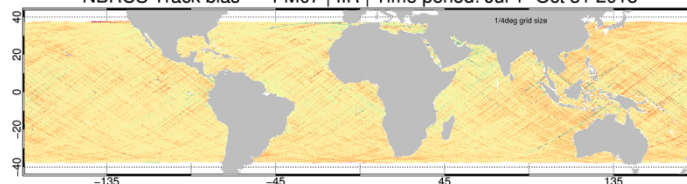
NBRCS Track bias -- FM06 | IIR | Time period: Jul 1–Oct 31 2018



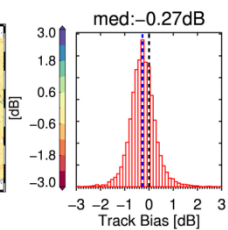
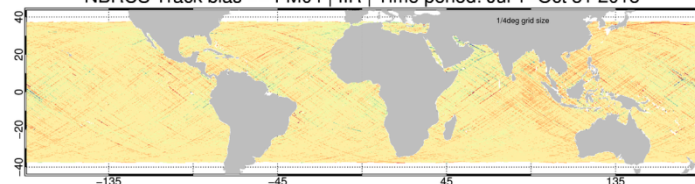
NBRCS Track bias -- FM03 | IIR | Time period: Jul 1–Oct 31 2018



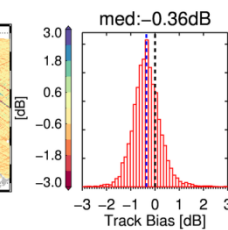
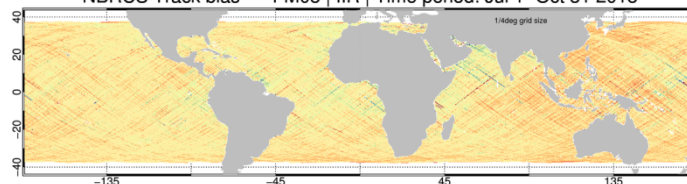
NBRCS Track bias -- FM07 | IIR | Time period: Jul 1–Oct 31 2018



NBRCS Track bias -- FM04 | IIR | Time period: Jul 1–Oct 31 2018

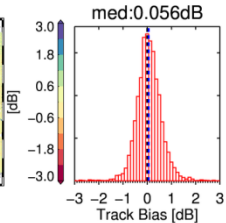
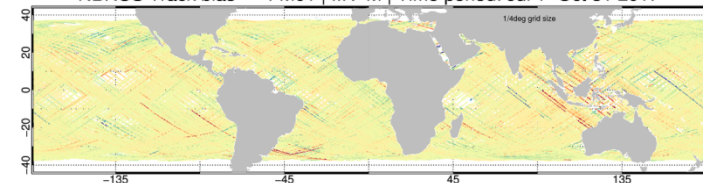


NBRCS Track bias -- FM08 | IIR | Time period: Jul 1–Oct 31 2018

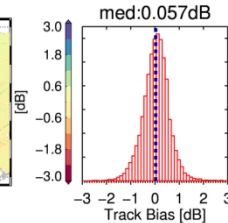
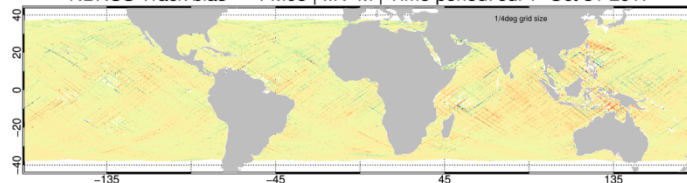


NBRCS Track Bias -- GPS Block IIR-M - Jul-Oct 2017

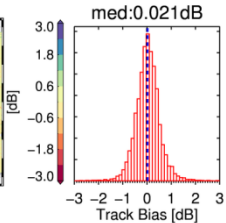
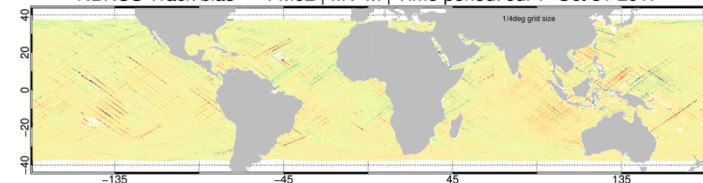
NBRCS Track bias -- FM01 | IIR-M | Time period: Jul 1-Oct 31 2017



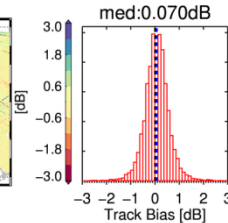
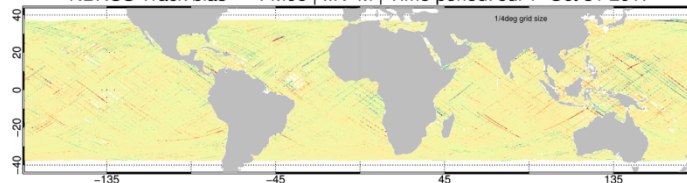
NBRCS Track bias -- FM05 | IIR-M | Time period: Jul 1-Oct 31 2017



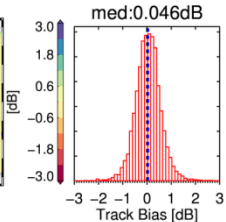
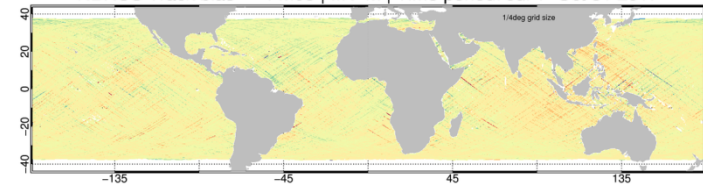
NBRCS Track bias -- FM02 | IIR-M | Time period: Jul 1-Oct 31 2017



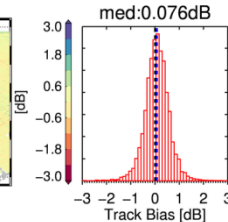
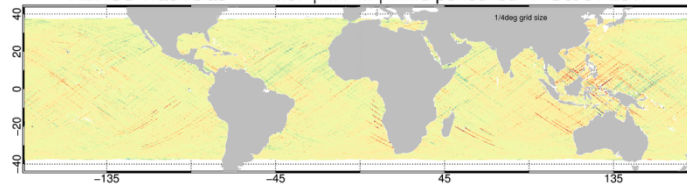
NBRCS Track bias -- FM06 | IIR-M | Time period: Jul 1-Oct 31 2017



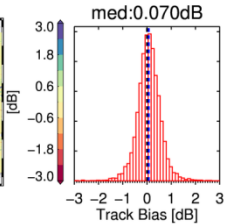
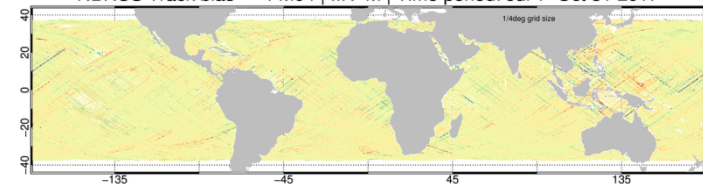
NBRCS Track bias -- FM03 | IIR-M | Time period: Jul 1-Oct 31 2017



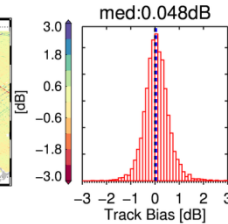
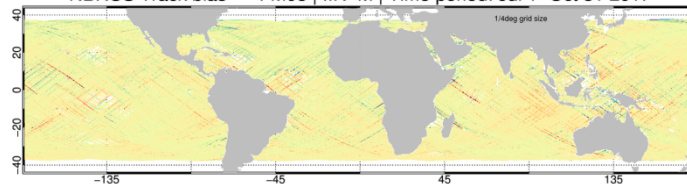
NBRCS Track bias -- FM07 | IIR-M | Time period: Jul 1-Oct 31 2017



NBRCS Track bias -- FM04 | IIR-M | Time period: Jul 1-Oct 31 2017

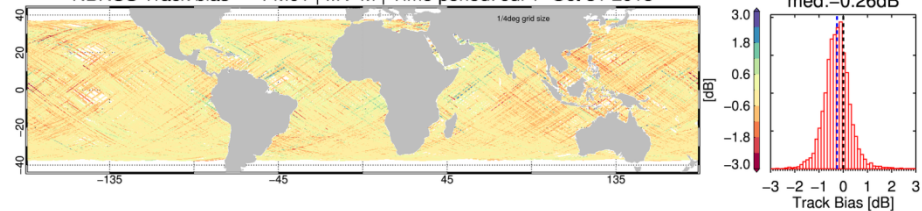


NBRCS Track bias -- FM08 | IIR-M | Time period: Jul 1-Oct 31 2017

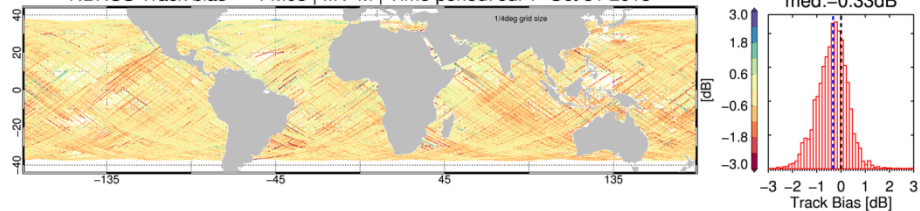


NBRCS Track Bias -- GPS Block IIR-M - Jul-Oct 2018

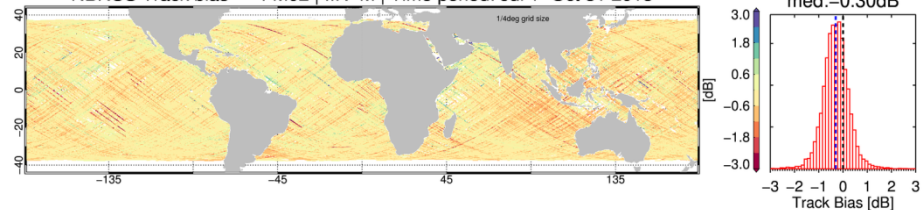
NBRCS Track bias -- FM01 | IIR-M | Time period: Jul 1-Oct 31 2018



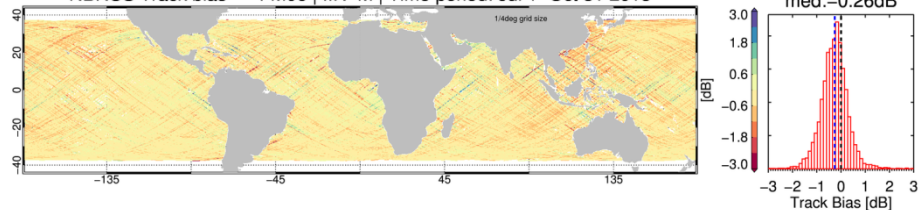
NBRCS Track bias -- FM05 | IIR-M | Time period: Jul 1-Oct 31 2018



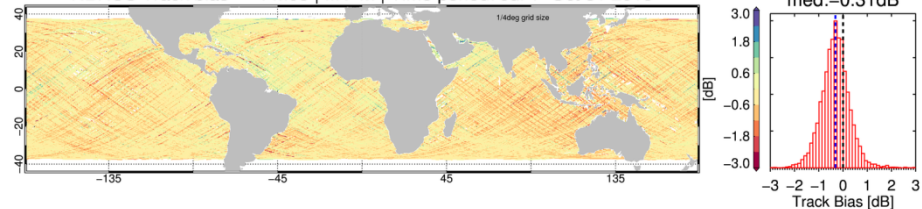
NBRCS Track bias -- FM02 | IIR-M | Time period: Jul 1-Oct 31 2018



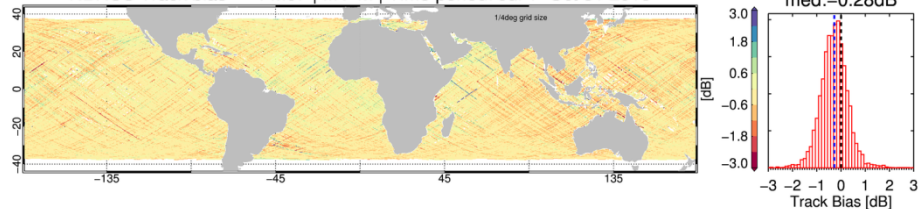
NBRCS Track bias -- FM06 | IIR-M | Time period: Jul 1-Oct 31 2018



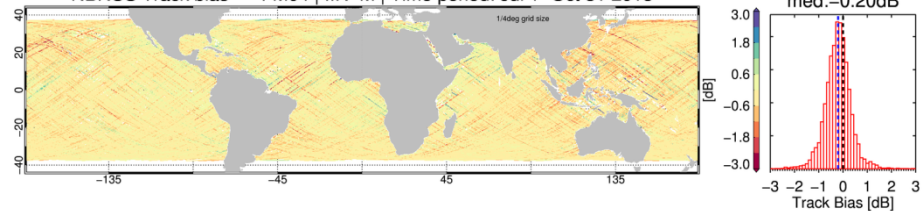
NBRCS Track bias -- FM03 | IIR-M | Time period: Jul 1-Oct 31 2018



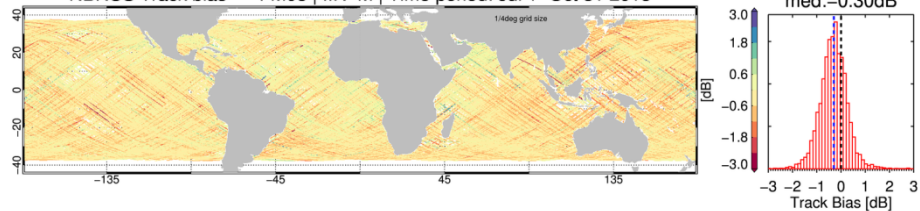
NBRCS Track bias -- FM07 | IIR-M | Time period: Jul 1-Oct 31 2018



NBRCS Track bias -- FM04 | IIR-M | Time period: Jul 1-Oct 31 2018

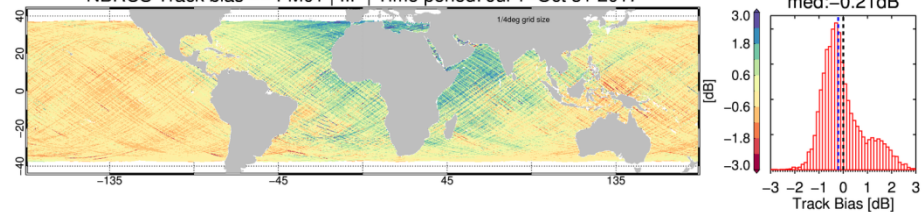


NBRCS Track bias -- FM08 | IIR-M | Time period: Jul 1-Oct 31 2018

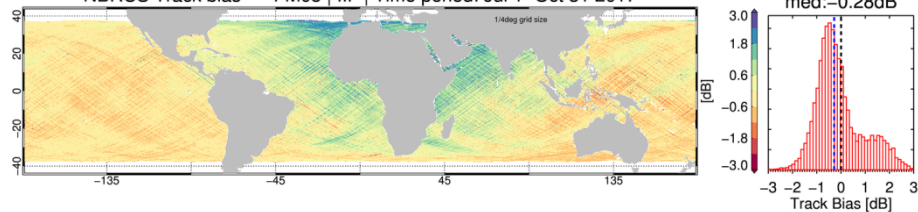


NBRCS Track Bias -- GPS Block IIF - Jul-Oct 2017

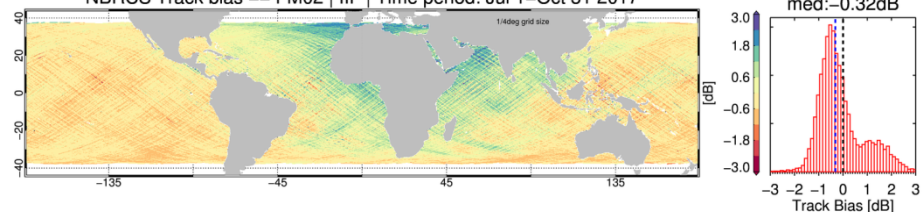
NBRCS Track bias -- FM01 | IIF | Time period: Jul 1–Oct 31 2017



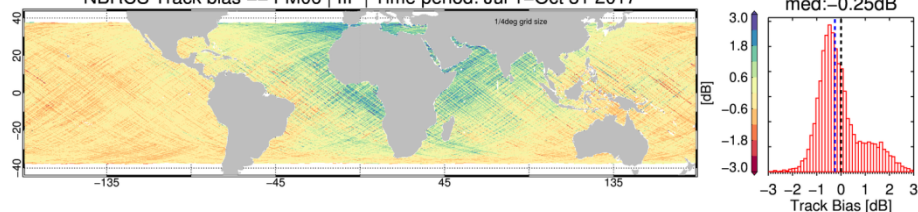
NBRCS Track bias -- FM05 | IIF | Time period: Jul 1–Oct 31 2017



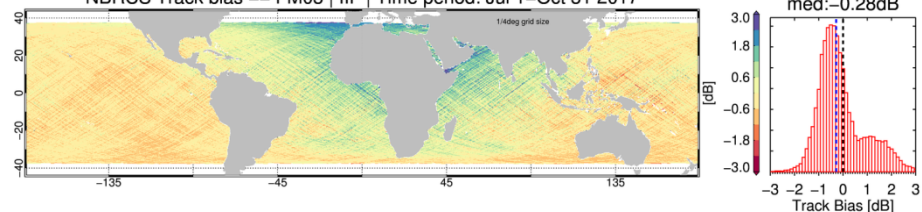
NBRCS Track bias -- FM02 | IIF | Time period: Jul 1–Oct 31 2017



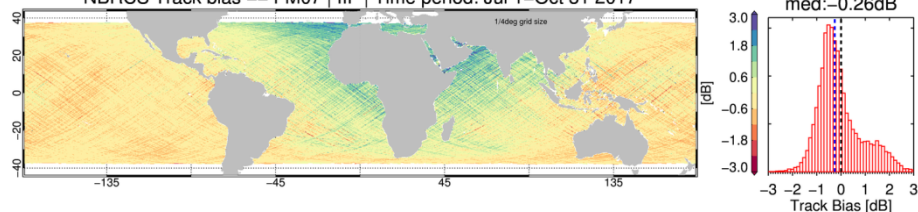
NBRCS Track bias -- FM06 | IIF | Time period: Jul 1–Oct 31 2017



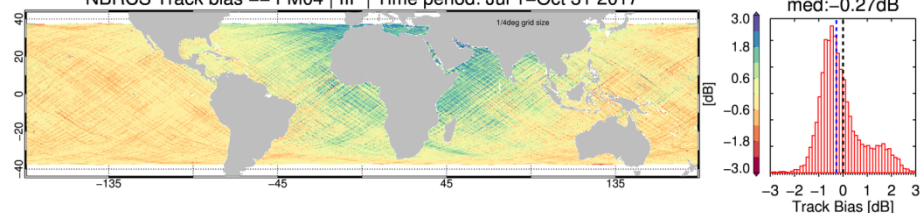
NBRCS Track bias -- FM03 | IIF | Time period: Jul 1–Oct 31 2017



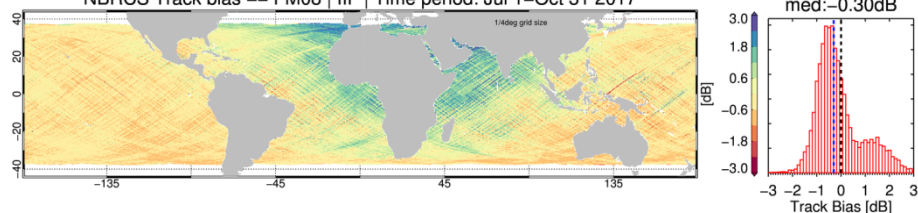
NBRCS Track bias -- FM07 | IIF | Time period: Jul 1–Oct 31 2017



NBRCS Track bias -- FM04 | IIF | Time period: Jul 1–Oct 31 2017

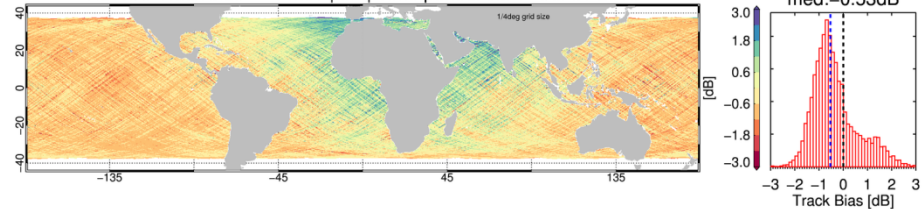


NBRCS Track bias -- FM08 | IIF | Time period: Jul 1–Oct 31 2017

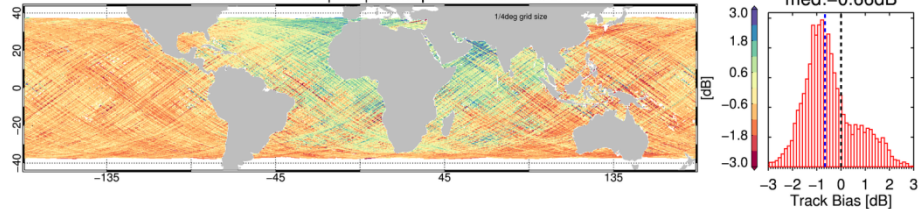


NBRCS Track Bias -- GPS Block IIF - Jul-Oct 2018

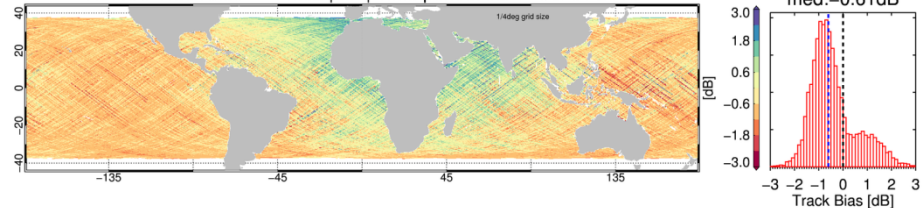
NBRCS Track bias -- FM01 | IIF | Time period: Jul 1–Oct 31 2018



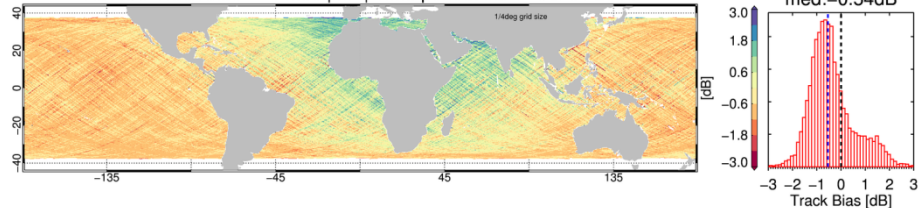
NBRCS Track bias -- FM05 | IIF | Time period: Jul 1–Oct 31 2018



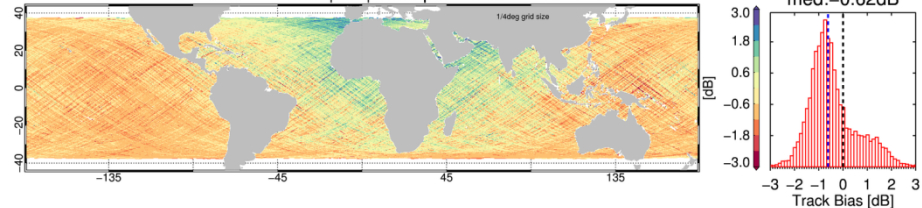
NBRCS Track bias -- FM02 | IIF | Time period: Jul 1–Oct 31 2018



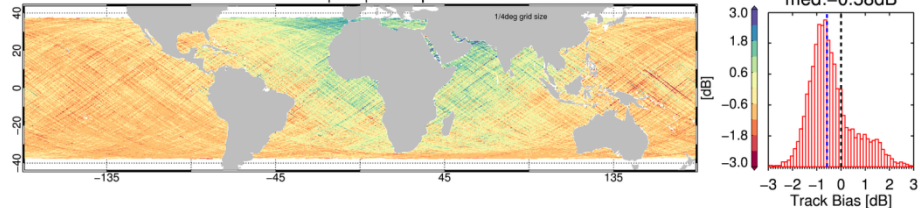
NBRCS Track bias -- FM06 | IIF | Time period: Jul 1–Oct 31 2018



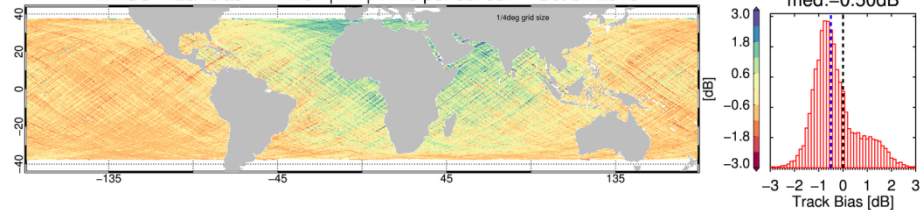
NBRCS Track bias -- FM03 | IIF | Time period: Jul 1–Oct 31 2018



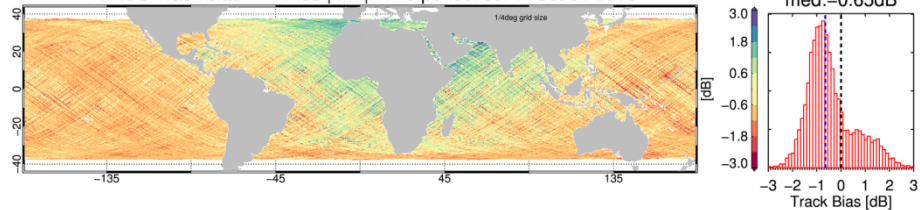
NBRCS Track bias -- FM07 | IIF | Time period: Jul 1–Oct 31 2018



NBRCS Track bias -- FM04 | IIF | Time period: Jul 1–Oct 31 2018



NBRCS Track bias -- FM08 | IIF | Time period: Jul 1–Oct 31 2018



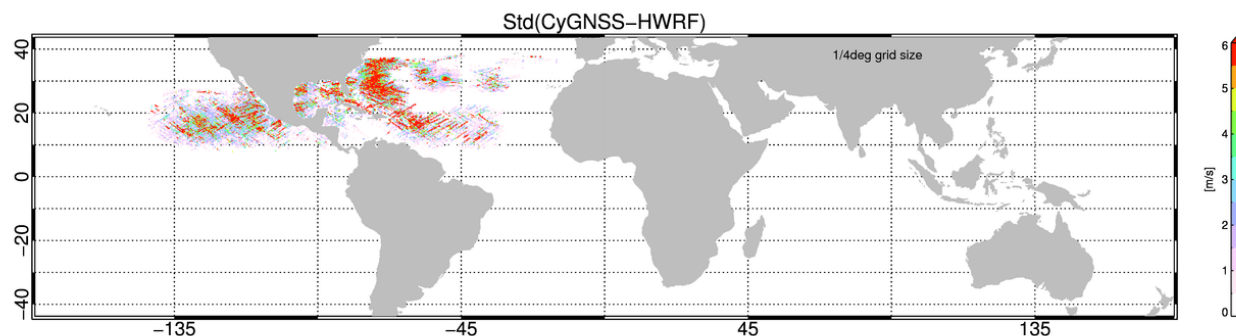
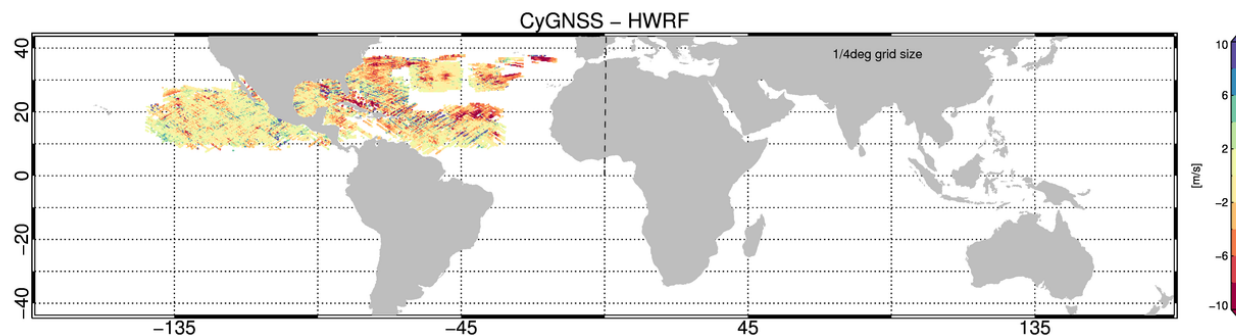
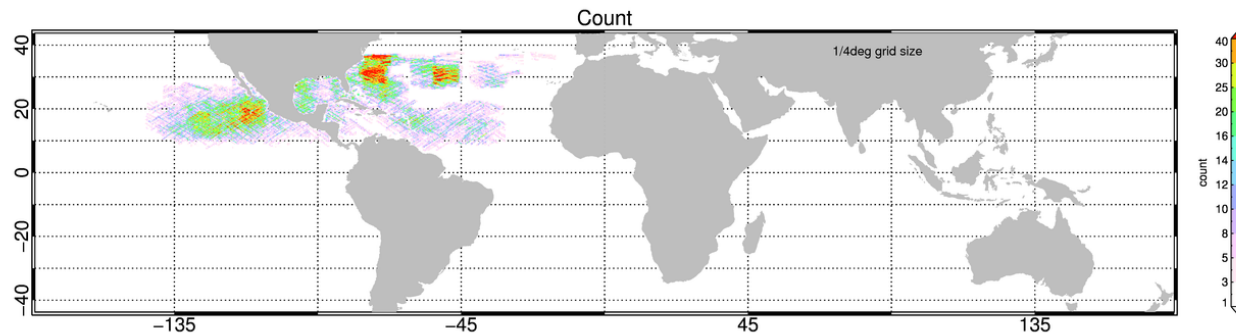


NOAA CYGNSS Wind Retrievals

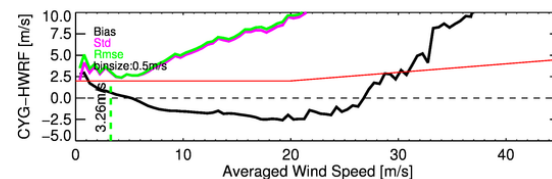
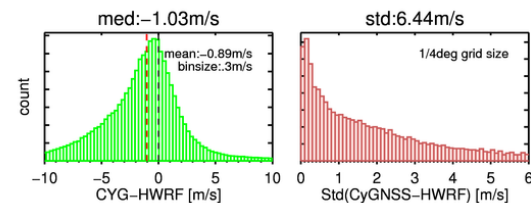
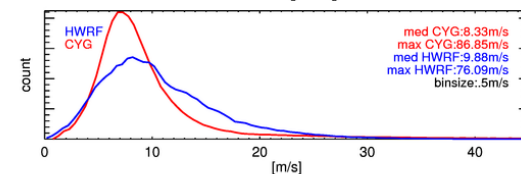
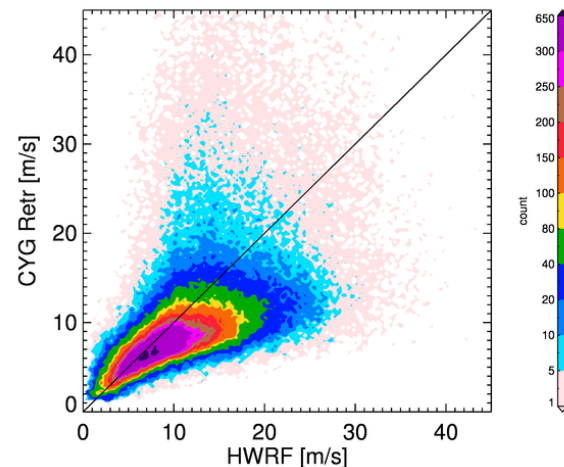
- Utilizing L2A gridded and track debiased NBRCS Measurements
- All PRNs included
- Comparison with HWRF and UMICH winds
 - AL/EP basins (2017)
 - All basins (2018)

UMICH 2017

all FMs | All blocks | Time period: Jul 1–Oct 31 2017 | UMICH L2 dataset

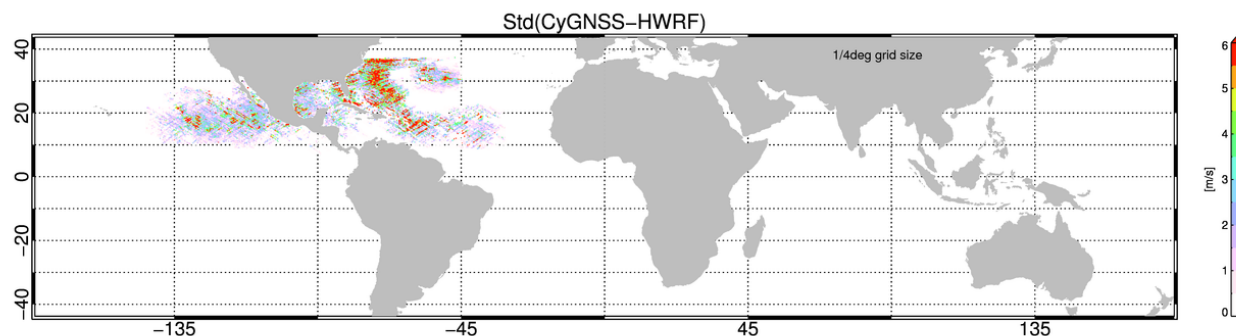
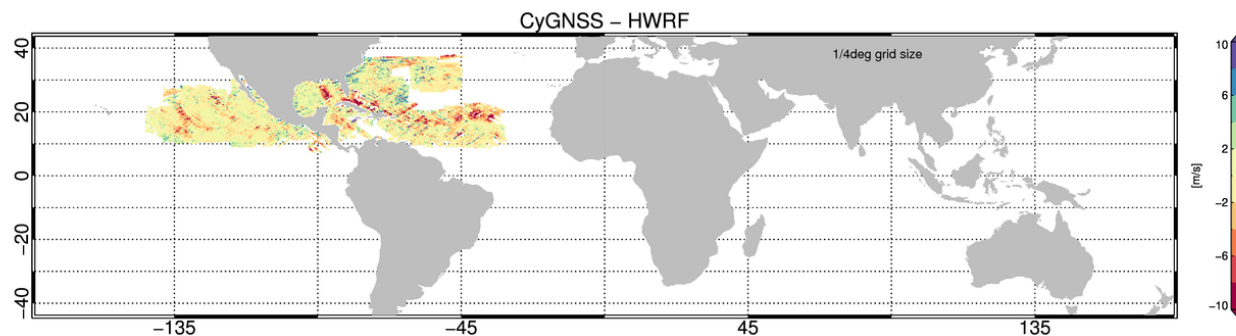
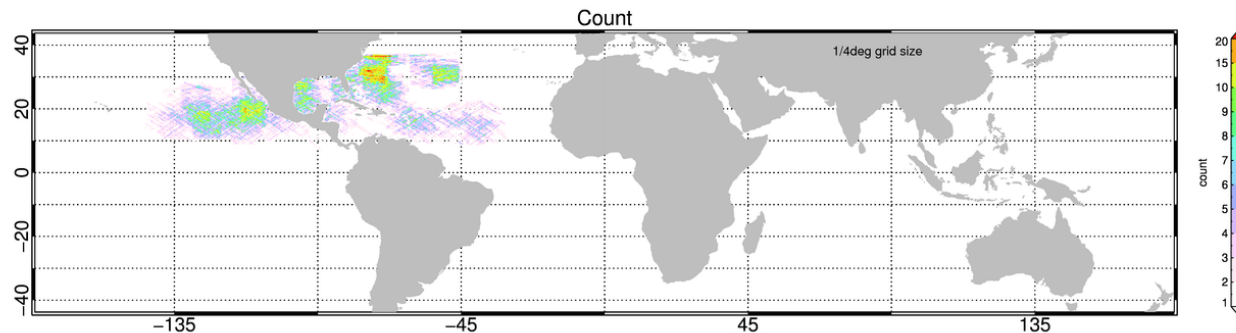


Applied flag:yslf_sample_flags bit 0 unset and range_corr_gain > 3

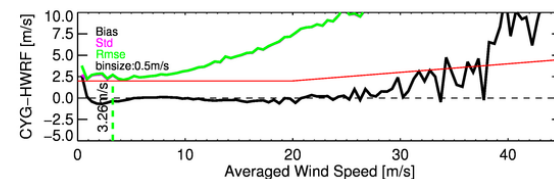
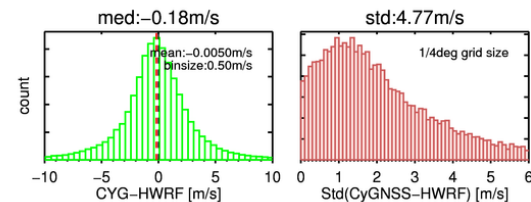
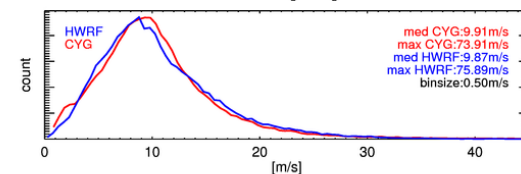
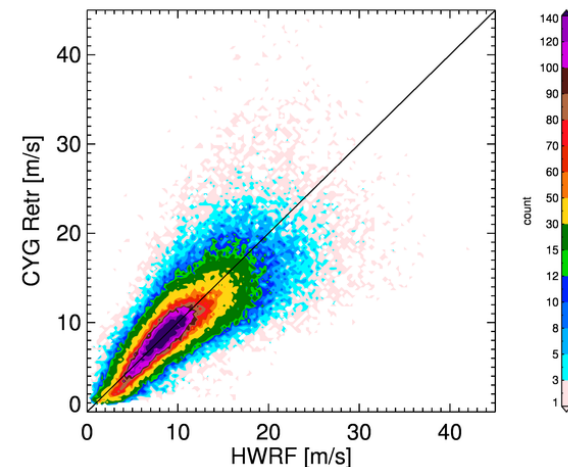


NOAA 2017

all FMs | All blocks | Time period: Jul 1–Oct 31 2017 | NOAA L2 dataset

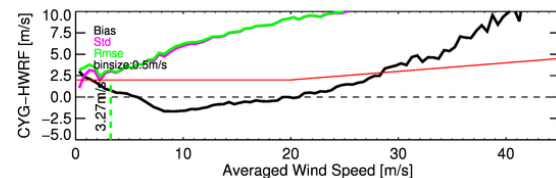
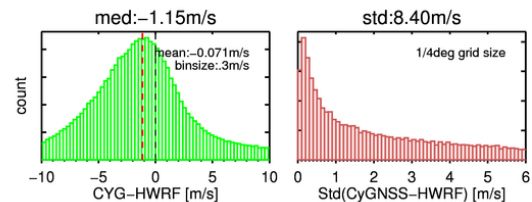
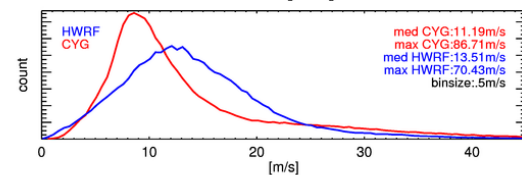
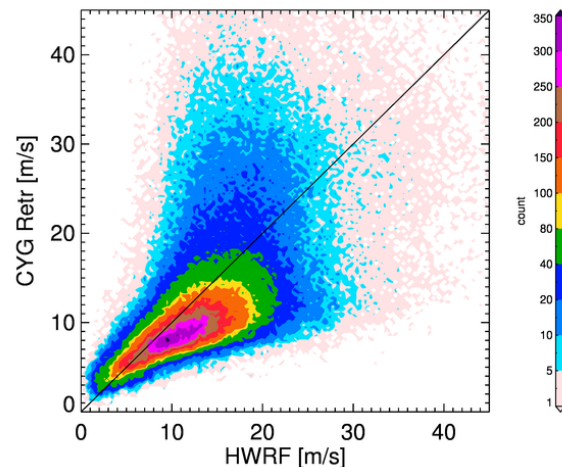
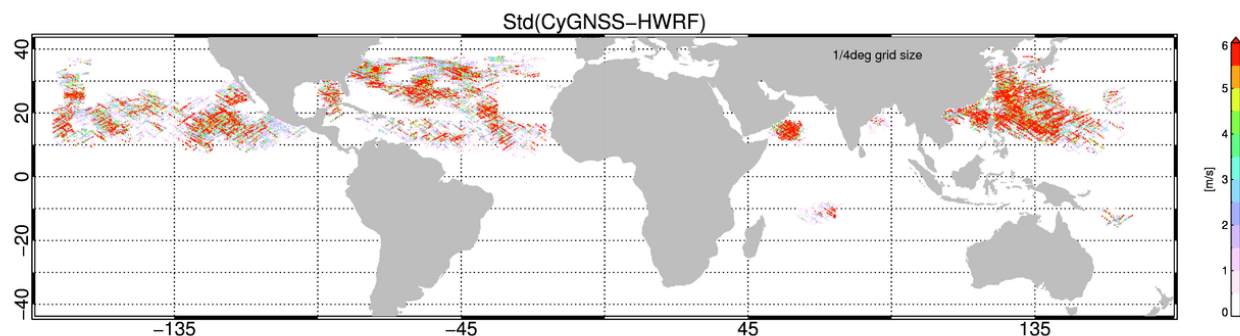
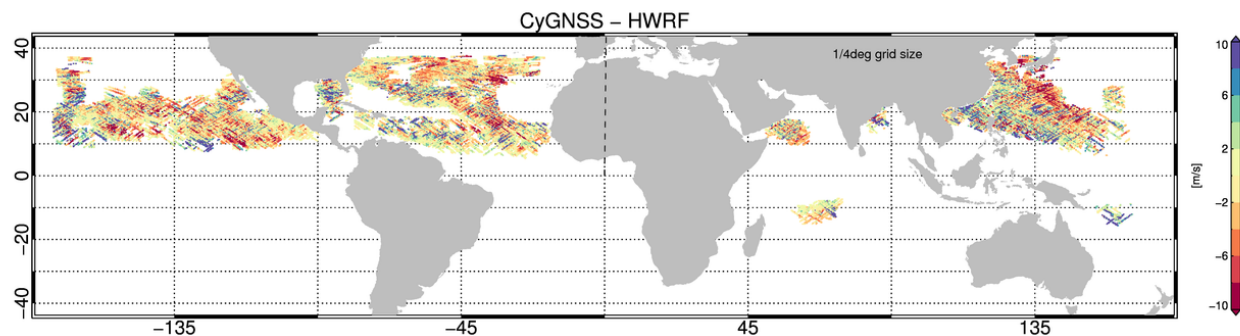
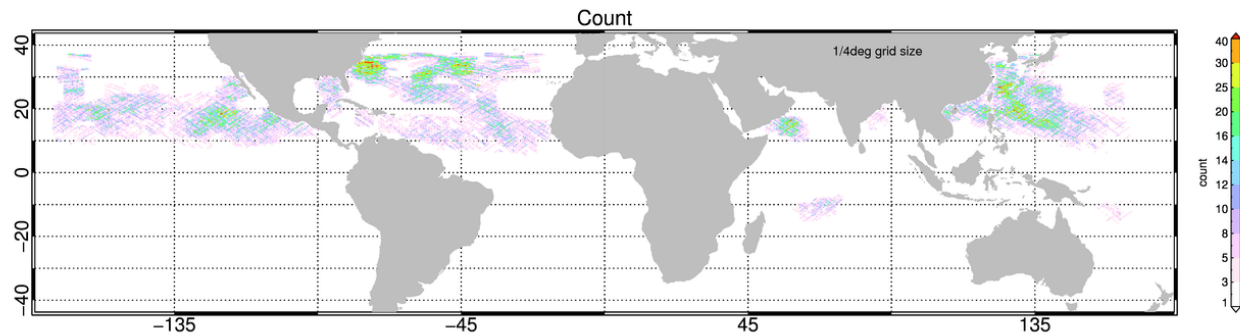


Applied flag: snr > 1 dB and -2<roll<2 deg



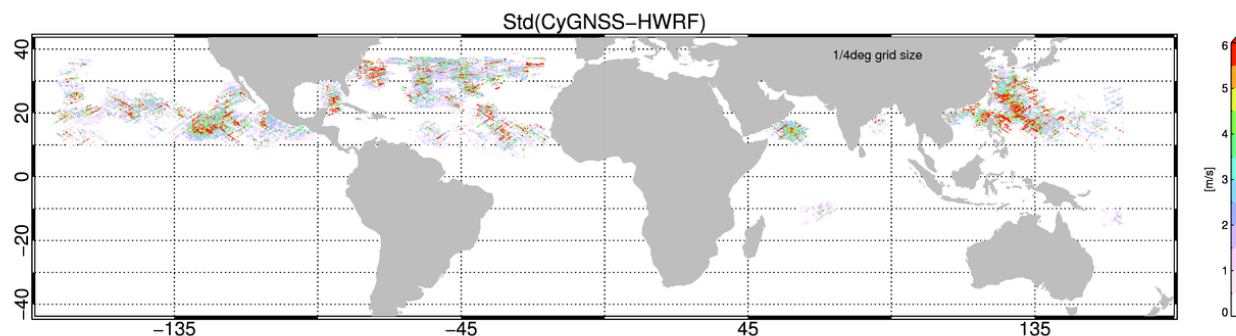
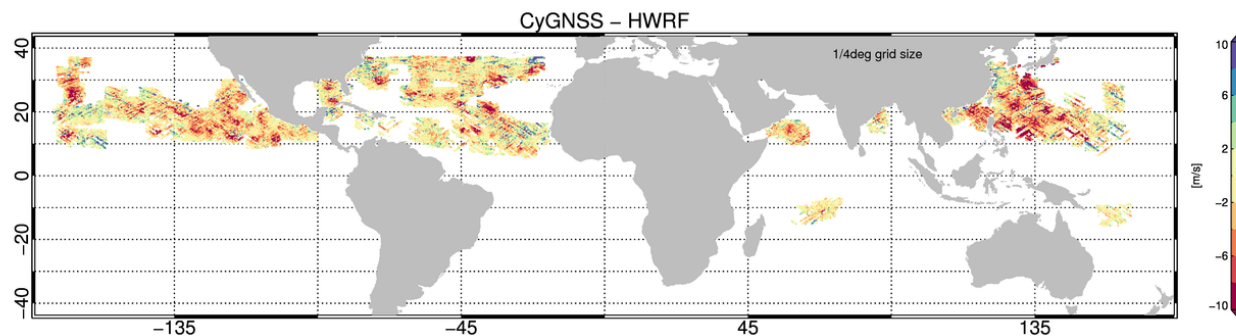
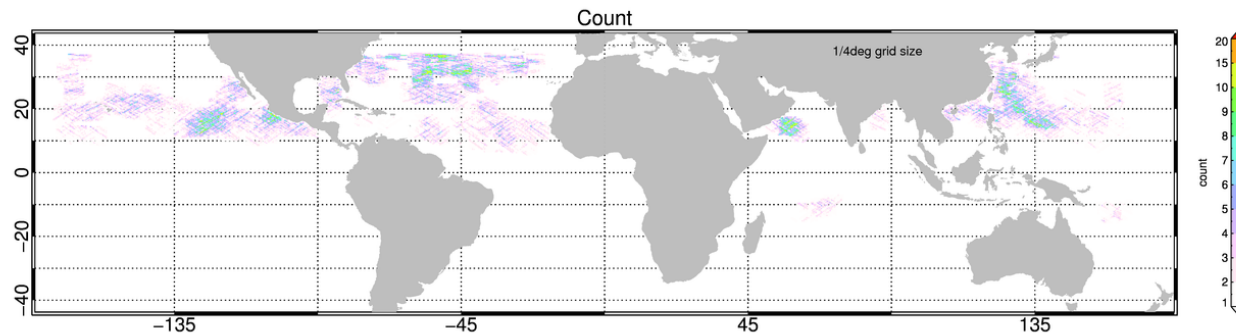
UMICH 2018

all FMs | All blocks | Time period: Jul 1–Oct 31 2018 | UMICH L2 dataset

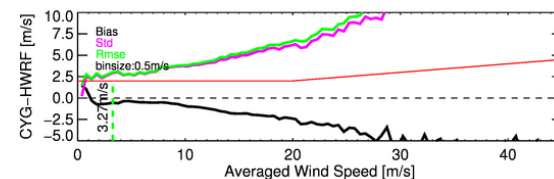
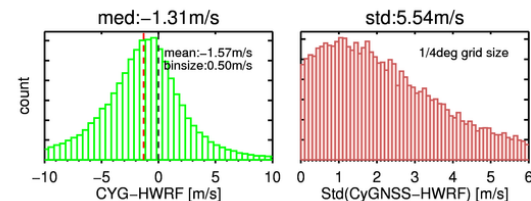
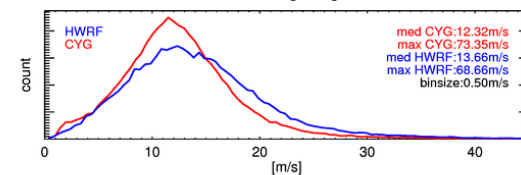
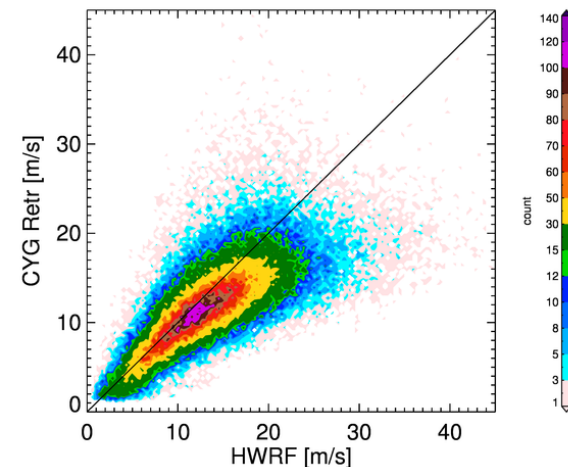


NOAA 2018

all FMs | All blocks | Time period: Jul 1–Oct 31 2018 | NOAA L2 dataset



Applied flag: snr > 1 dB and -2<roll<2 deg

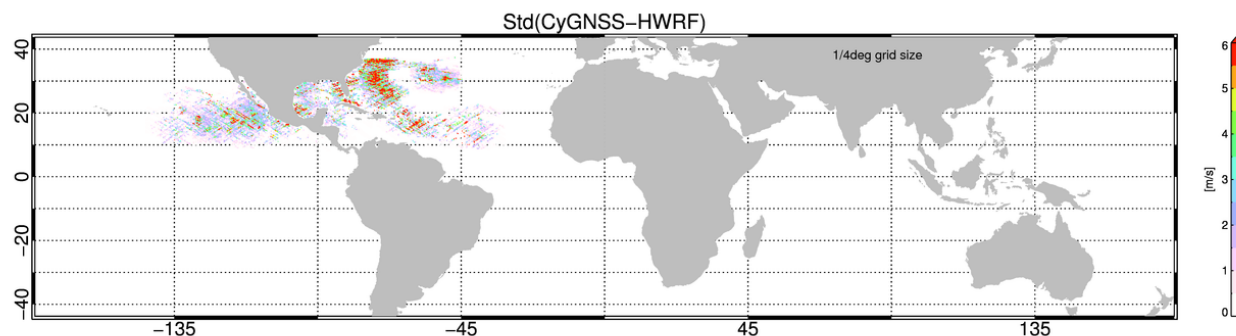
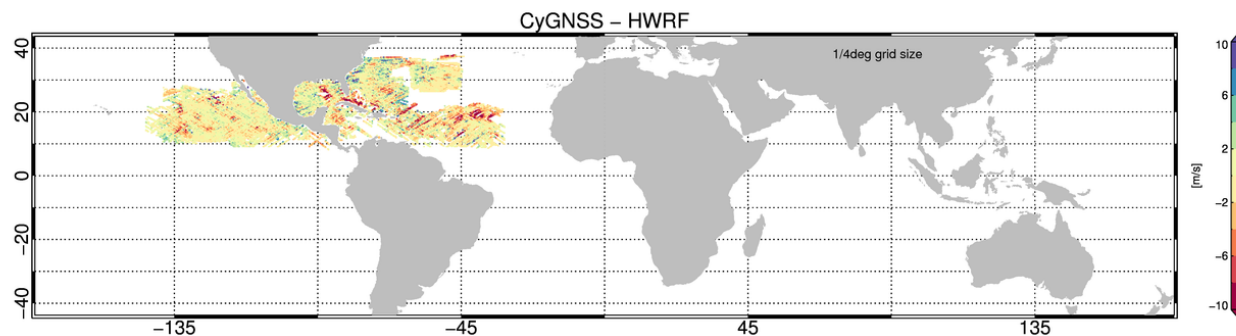
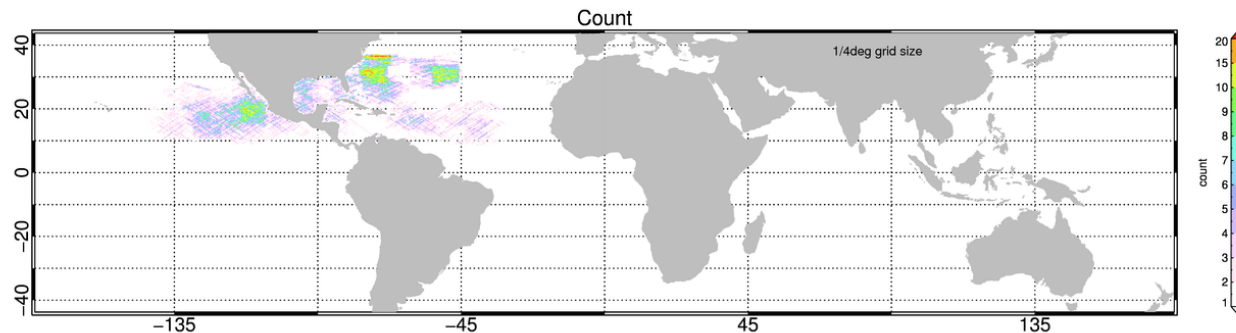




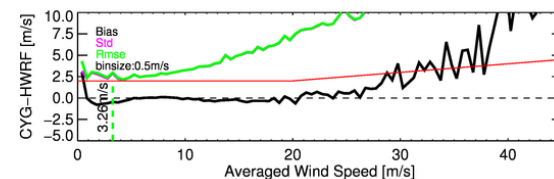
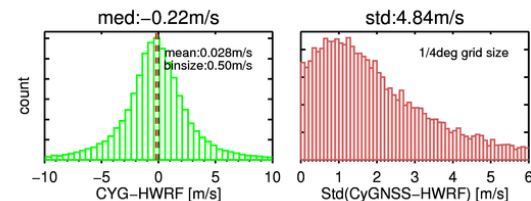
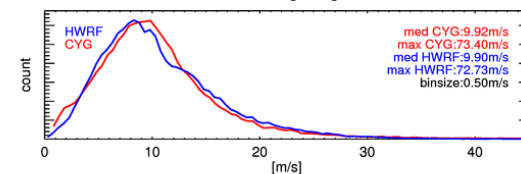
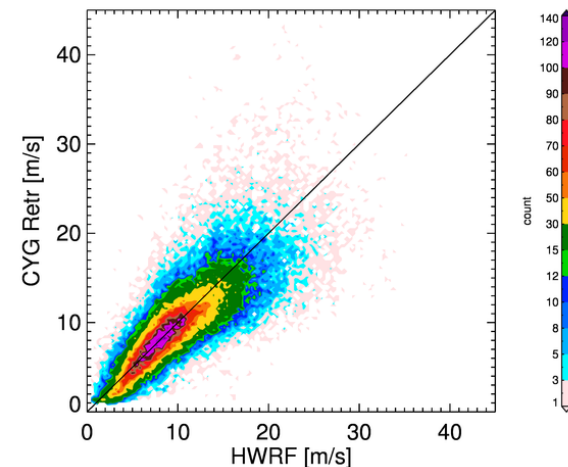
How about Retrievals from Block IIF?

NOAA 2017 – BLOCK IIF excluded

all FMs | IIF excluded | Time period: Jul 1–Oct 31 2017 | NOAA L2 dataset

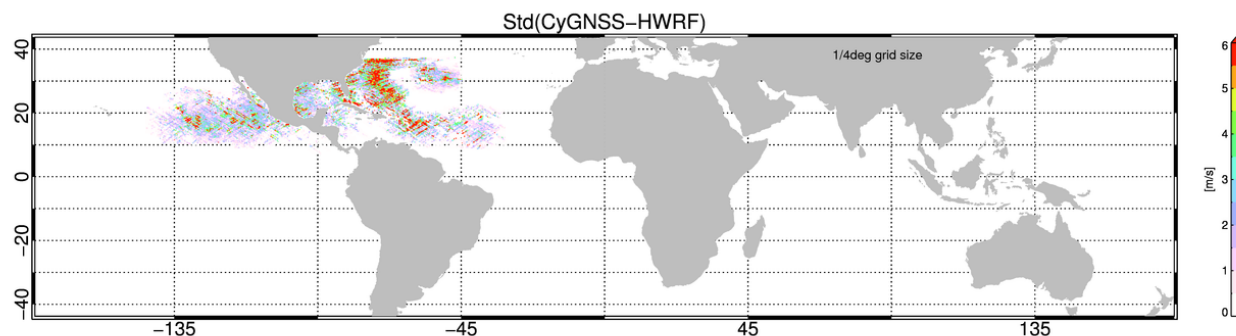
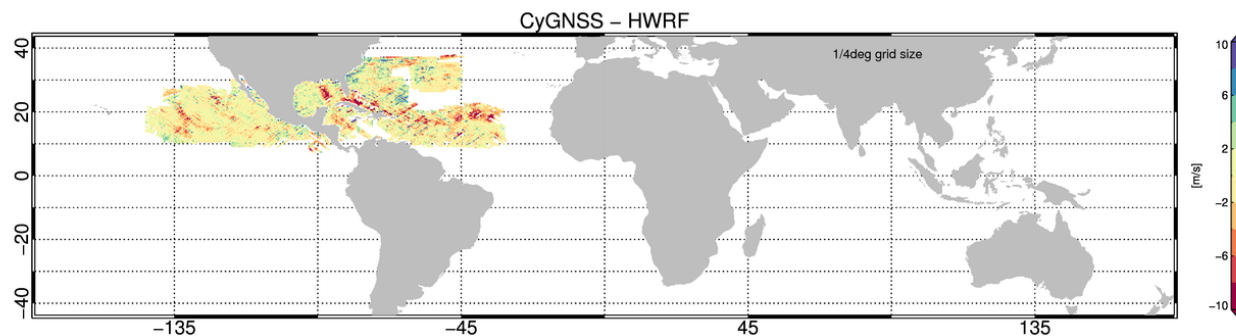
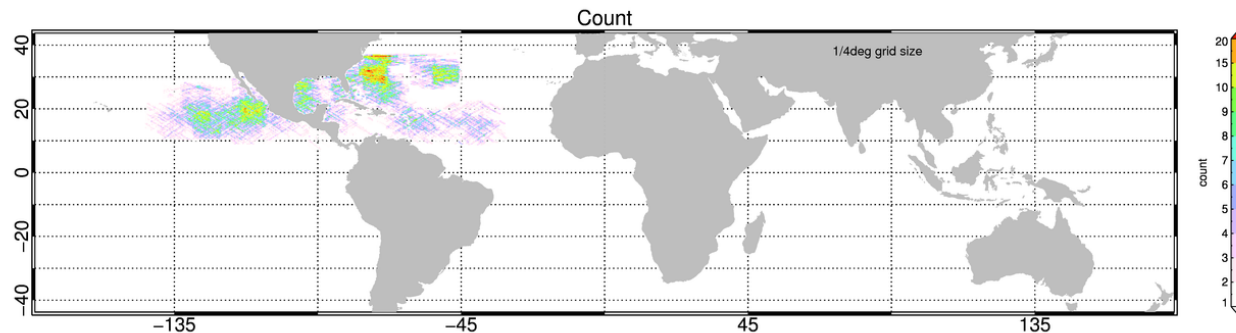


Applied flag: snr > 1 dB and -2<roll<2 deg

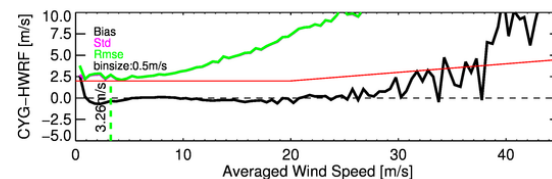
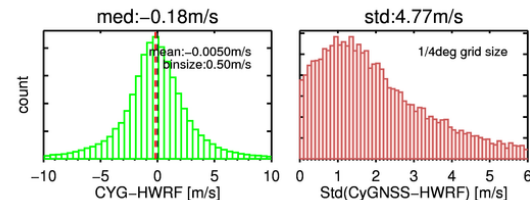
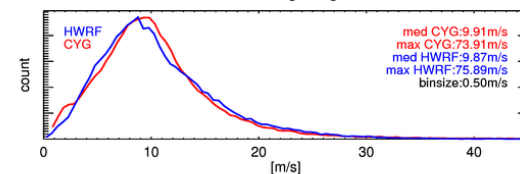
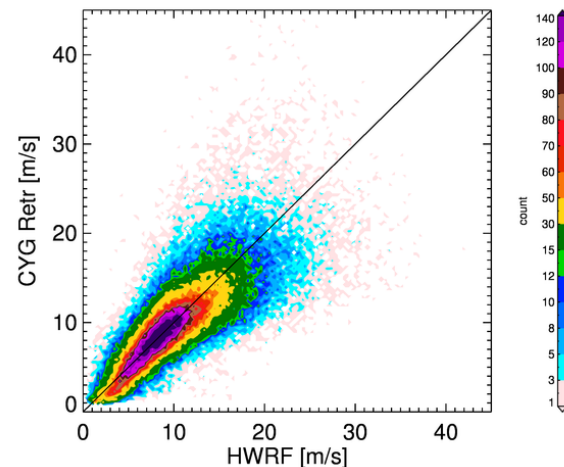


NOAA 2017 - ALL BLOCKS

all FMs | All blocks | Time period: Jul 1–Oct 31 2017 | NOAA L2 dataset

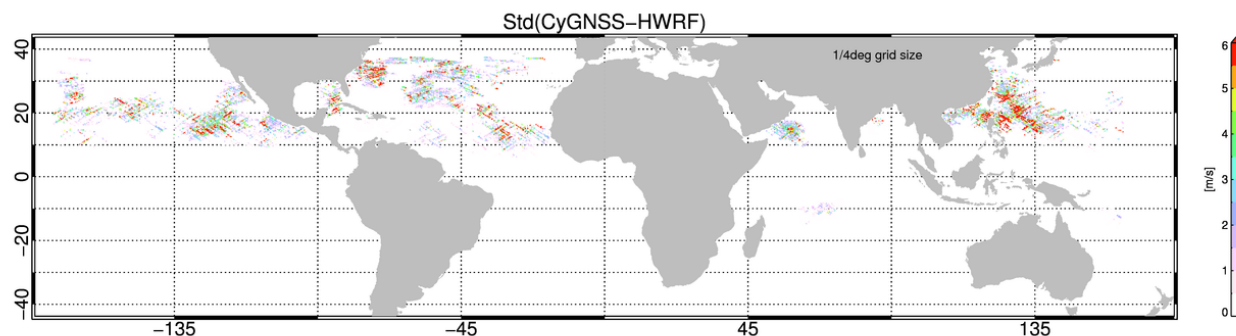
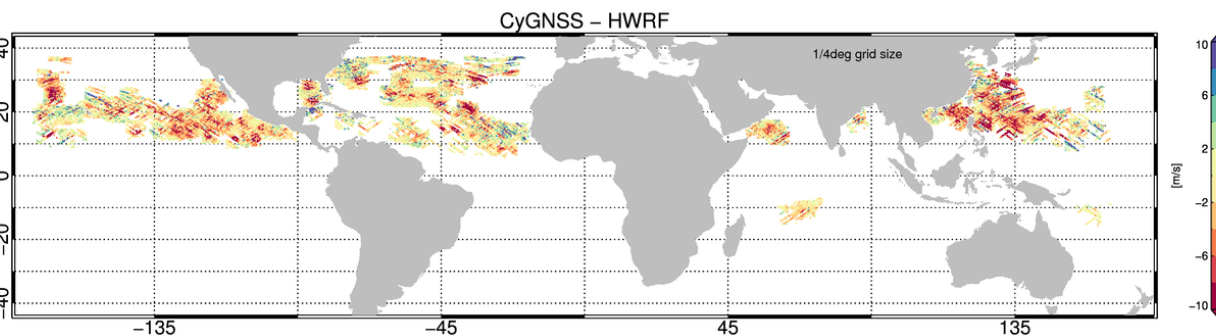
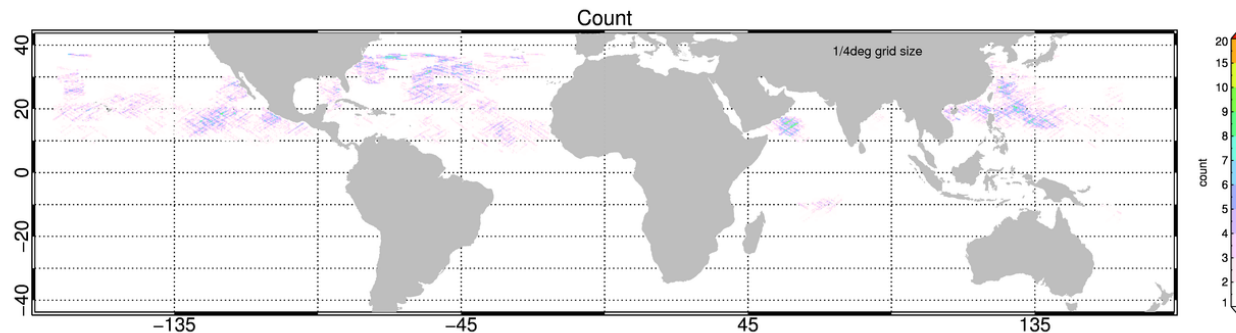


Applied flag: snr > 1 dB and -2<roll<2 deg

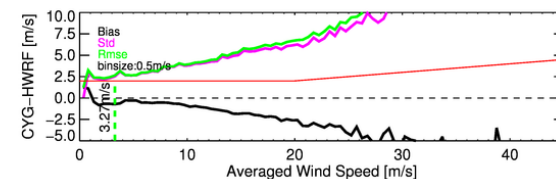
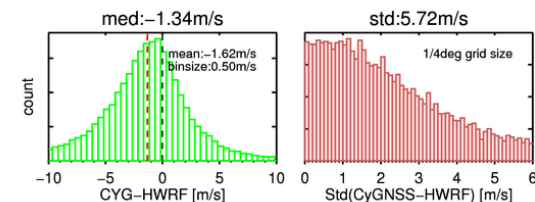
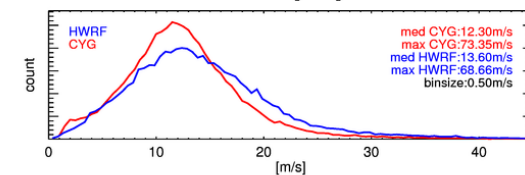
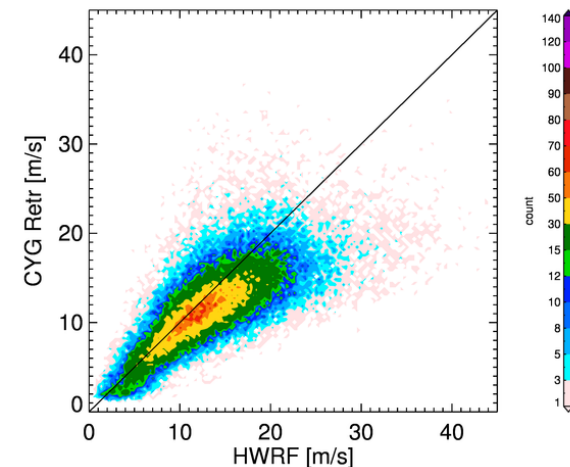


NOAA 2018 – BLOCK IIF excluded

all FMs | IIF excluded | Time period: Jul 1–Oct 31 2018 | NOAA L2 dataset

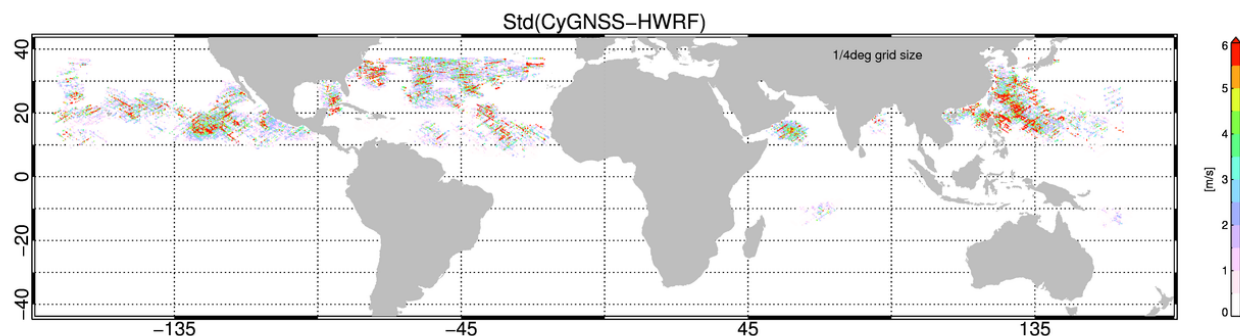
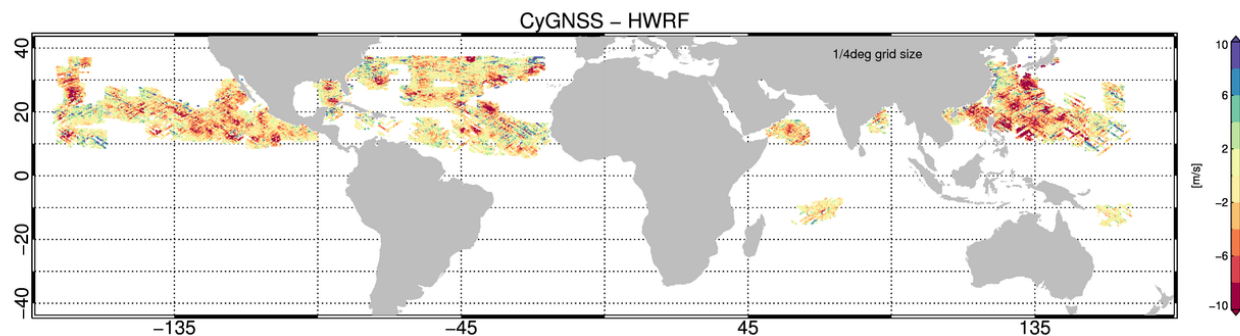
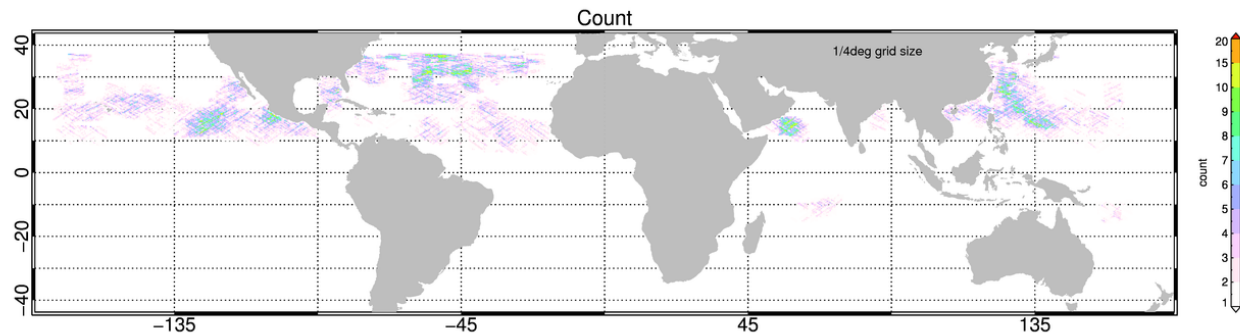


Applied flag: snr > 1 dB and -2<roll<2 deg

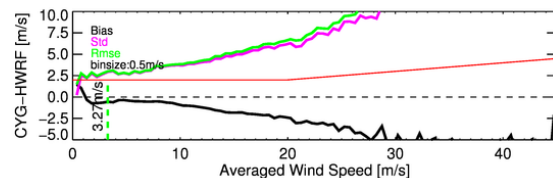
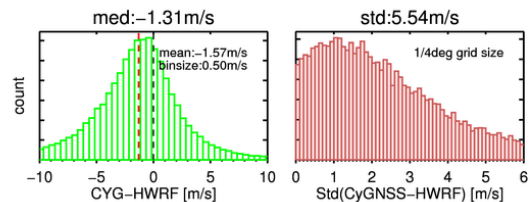
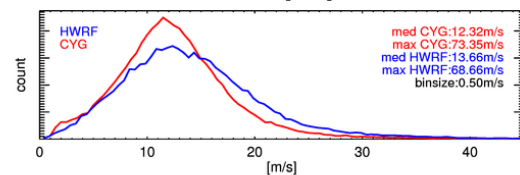
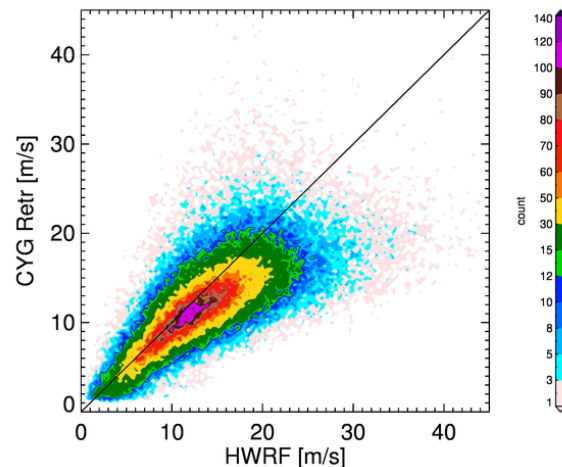


NOAA 2017 - ALL BLOCKS

all FMs | All blocks | Time period: Jul 1–Oct 31 2018 | NOAA L2 dataset



Applied flag: snr > 1 dB and -2<roll<2 deg





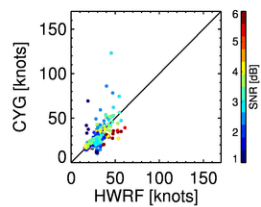
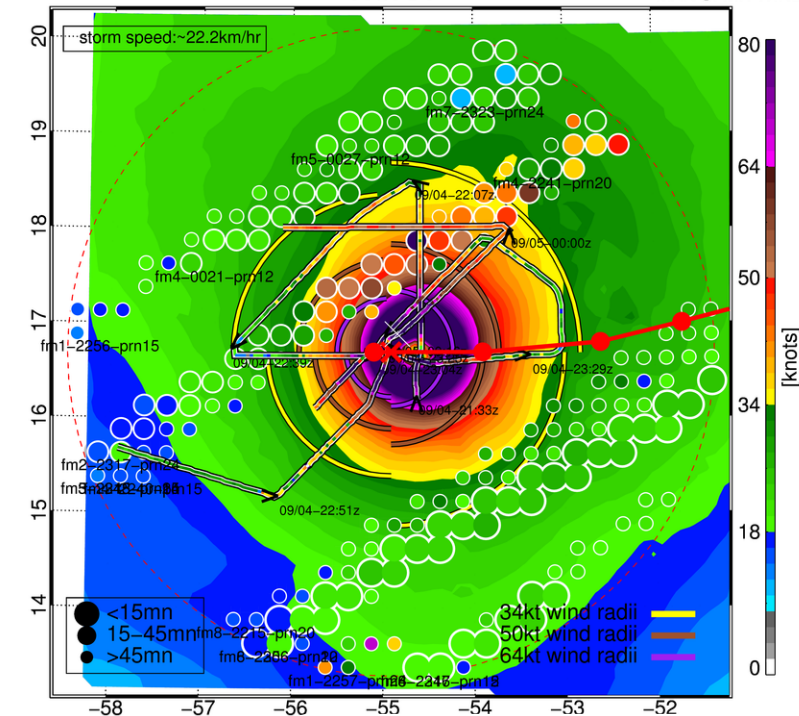
Selected Tropical Cyclone Case Studies

IRMA CASE 1

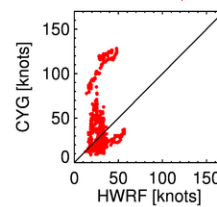
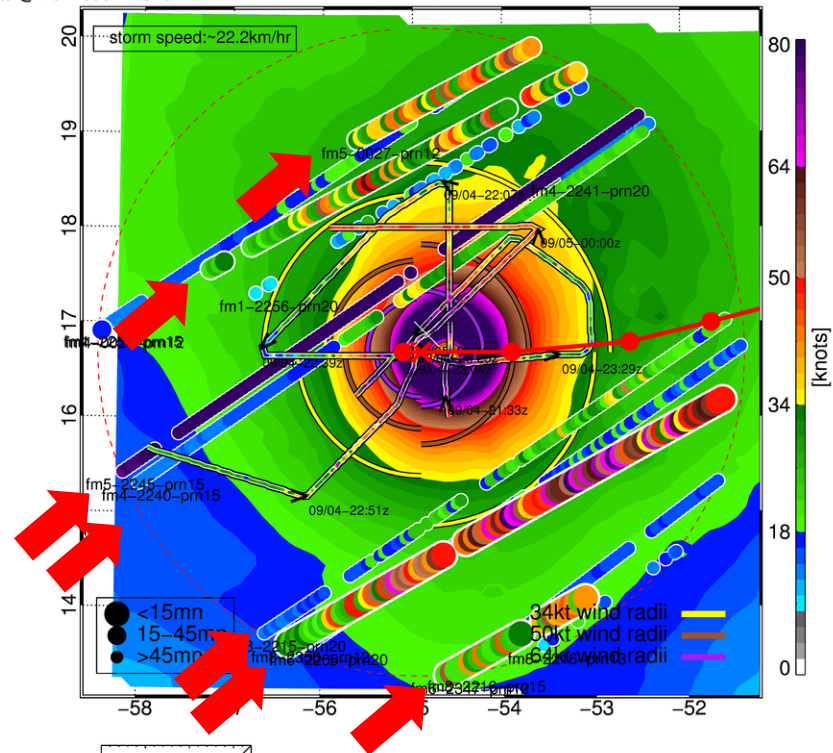
IRMA type:HU 2017/09/04-23:03:07 utc

MAX SFMR WIND:121.5knots @ 20170904-2328

NOAA



UMICH

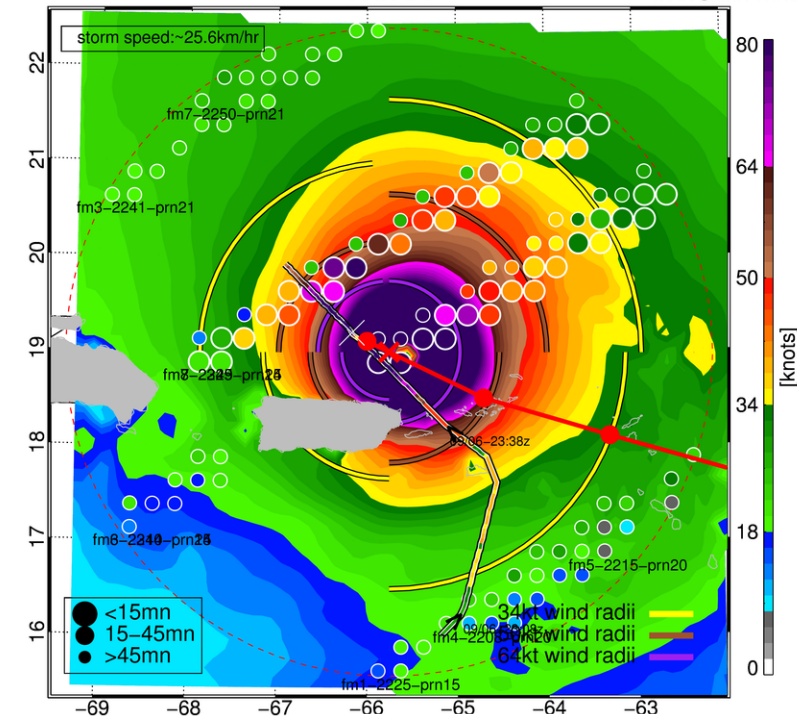


IRMA CASE 2

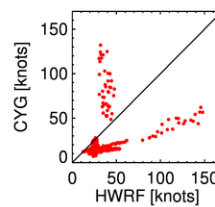
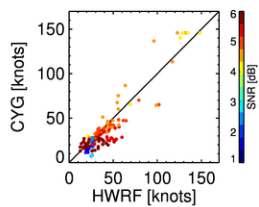
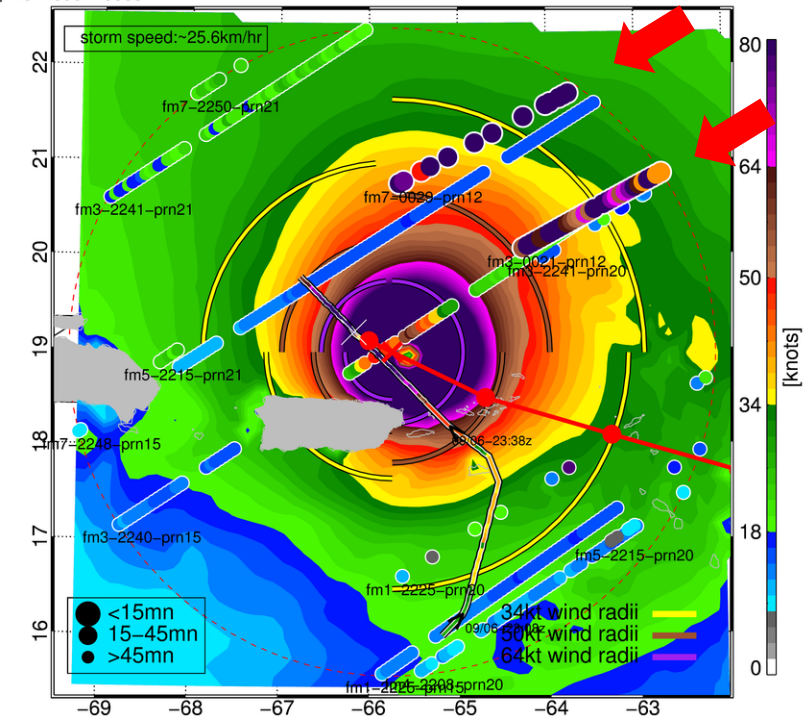
IRMA type:HU 2017/09/06-22:51:50 utc

MAX SFMR WIND:149.4knots @ 20170907-0003

NOAA



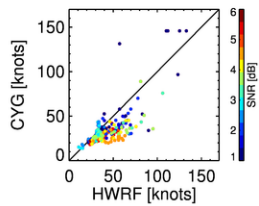
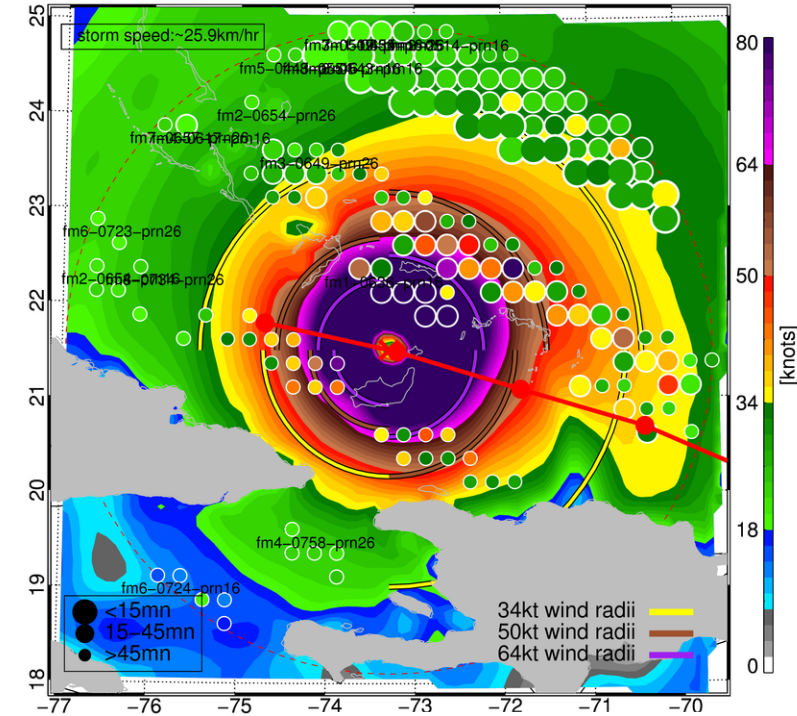
UMICH



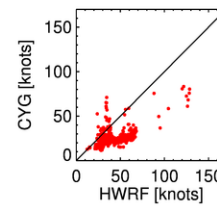
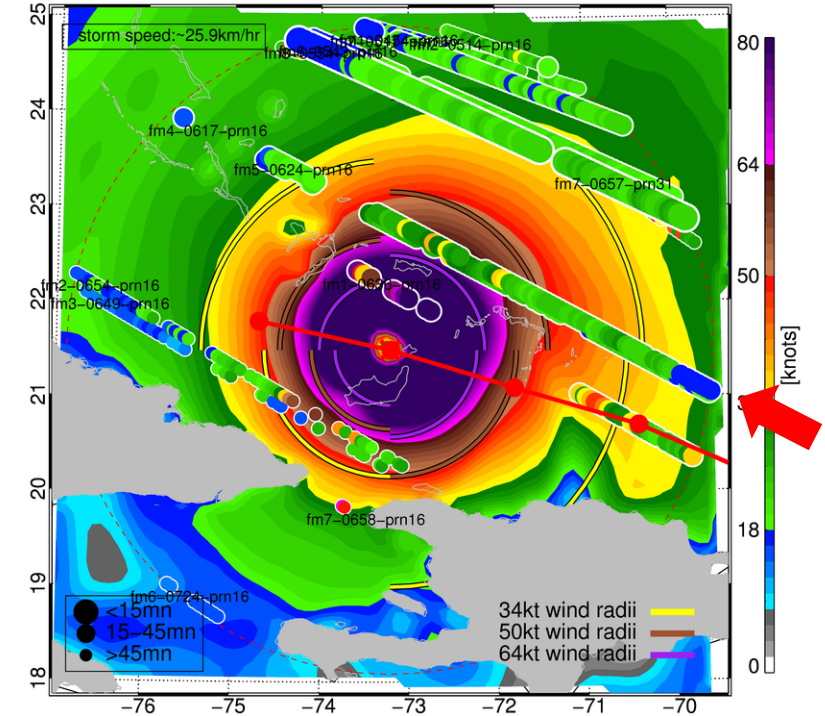
IRMA CASE 3

IRMA type:HU 2017/09/08-06:21:17 utc

NOAA



UMICH



Summary

- CYGNSS measurement drift observed starting mid November 2017
- There are still unresolved antenna pattern uncertainties for both CYGNSS and GPS antennas
- GPS Flex power mode significantly impacts CYGNSS measurement accuracy
- Specular Point position issue still unresolved
- NOAA CYGNSS wind retrieval algorithm:
 - implements a σ^0 bias removal on a track-by-track basis
 - makes use of a GMF dependent on incidence angle, wind speed and significant wave height
 - improves performance in Tropical Cyclone environment
 - Storm structure is more apparent on a case by case basis
 - Performance is similar regardless of GPS block