Gauging CyGNSS wind reliability and consistency within the tropical cyclone environment

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National Environmental Satellite, Data, and Information Service

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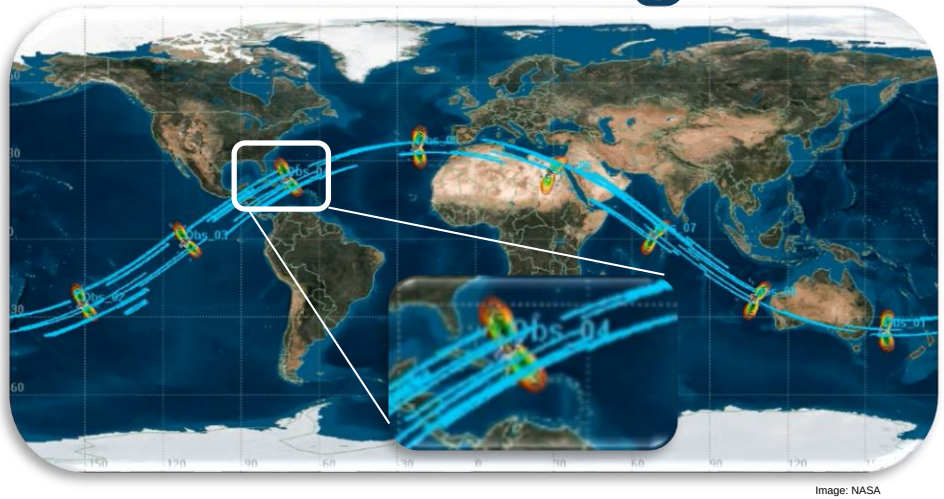
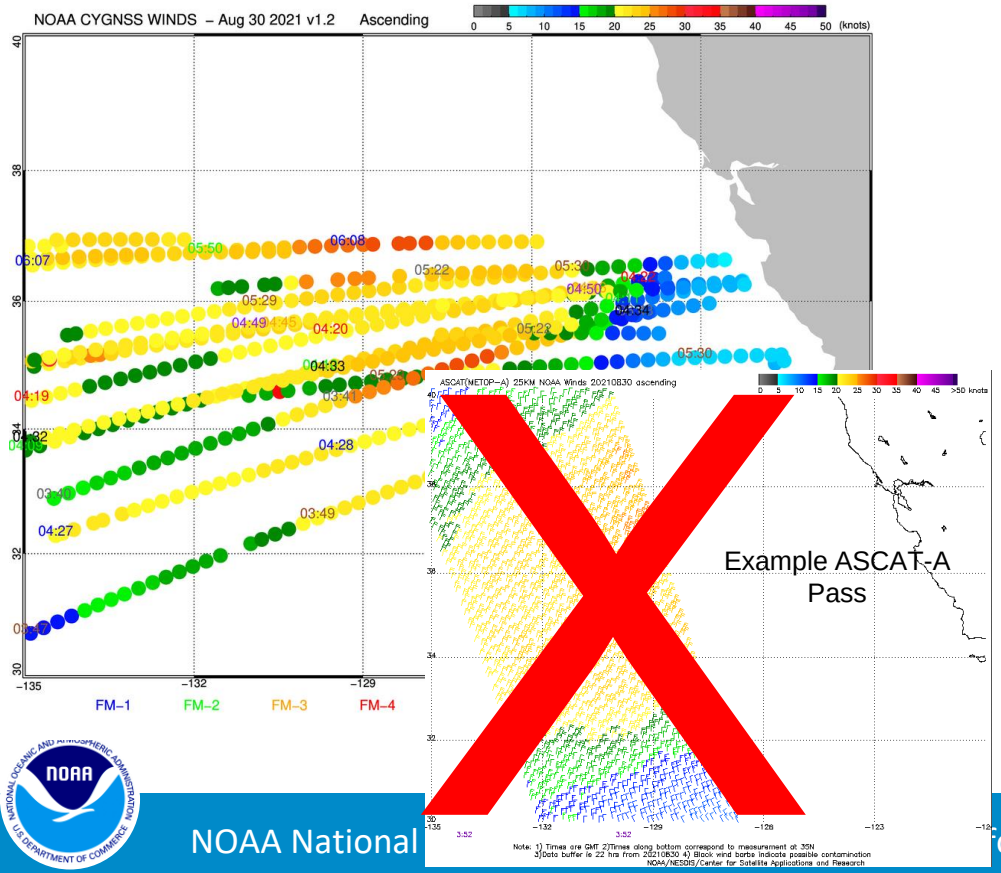
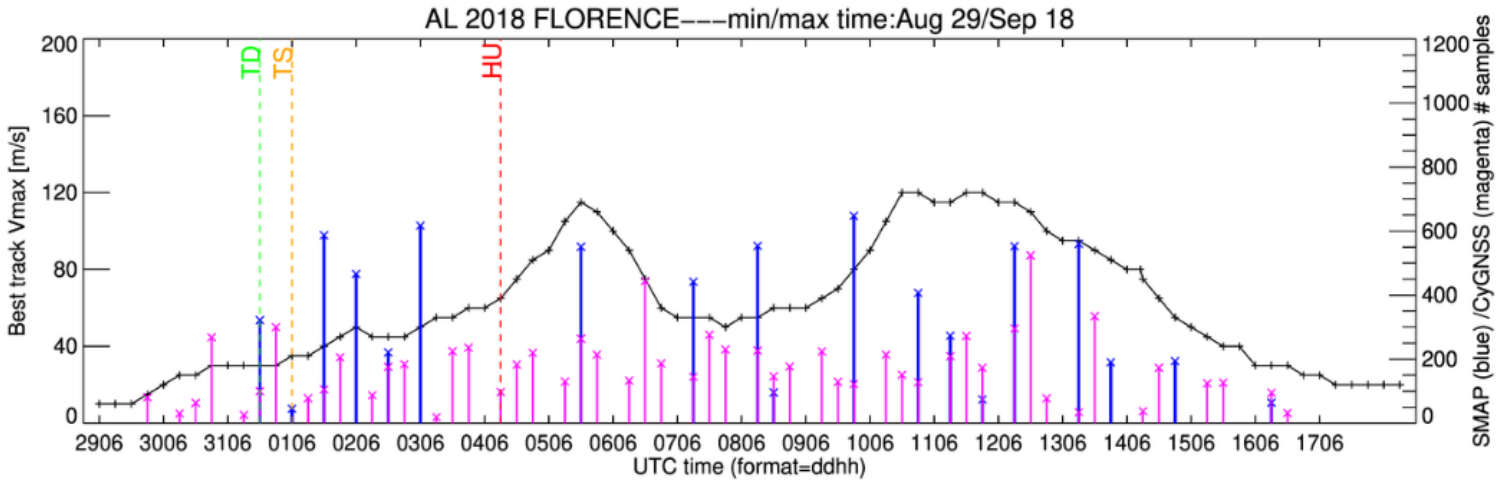
Background on CyGNSS: sensor and coverage

- Constellation of 8 (low cost) micro-satellites launched on December 15 2016
- Operating at 1.57 GHz L1-band radio frequency (minimal rain impact)
- Each sensor processes specular reflections from Global Positioning System (GPS) satellites **resulting in a set of tracks (up to 4 per sensor) instead of the usual 'swath based coverage'**
- Wind speed is inferred from the normalized bi-static radar cross section (NBRCS)





CyGNSS storm revisit and coverage example (compared to SMAP)

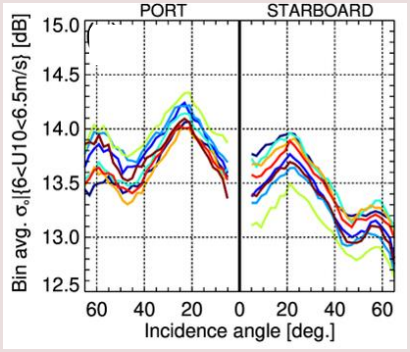


Background on CyGNSS: ongoing challenges

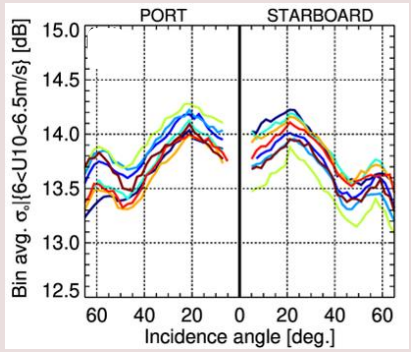
1. Intersatellite NBRCS calibration

Recall → dealing with a total of 8 sensors with 2 antennas per sensor

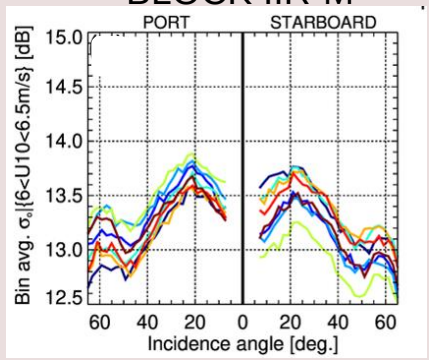
BLOCK IIF



BLOCK IIR

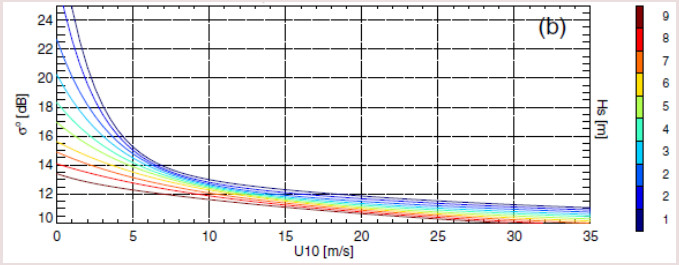


BLOCK IIR-M

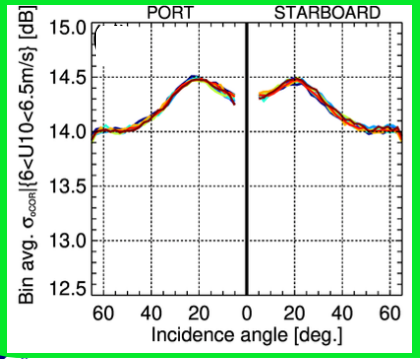


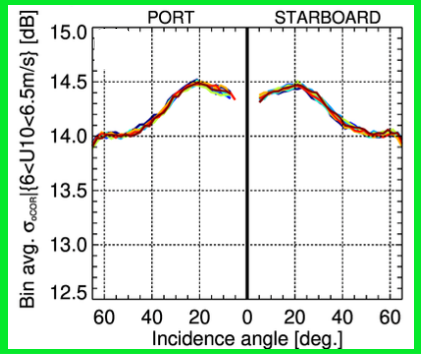
2. No exact knowledge of GPS transmit power (30+ of them!)

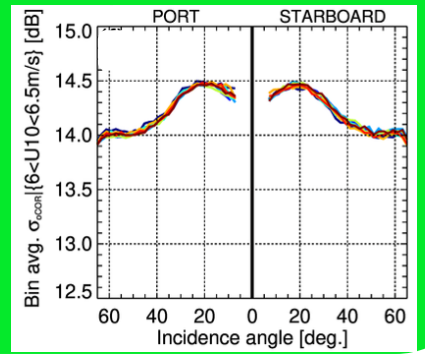
3. Signal sensitivity decreases as the wind speed increases



These issues are currently addressed using the NOAA 'trackwise'** sigma0 bias correction algorithm







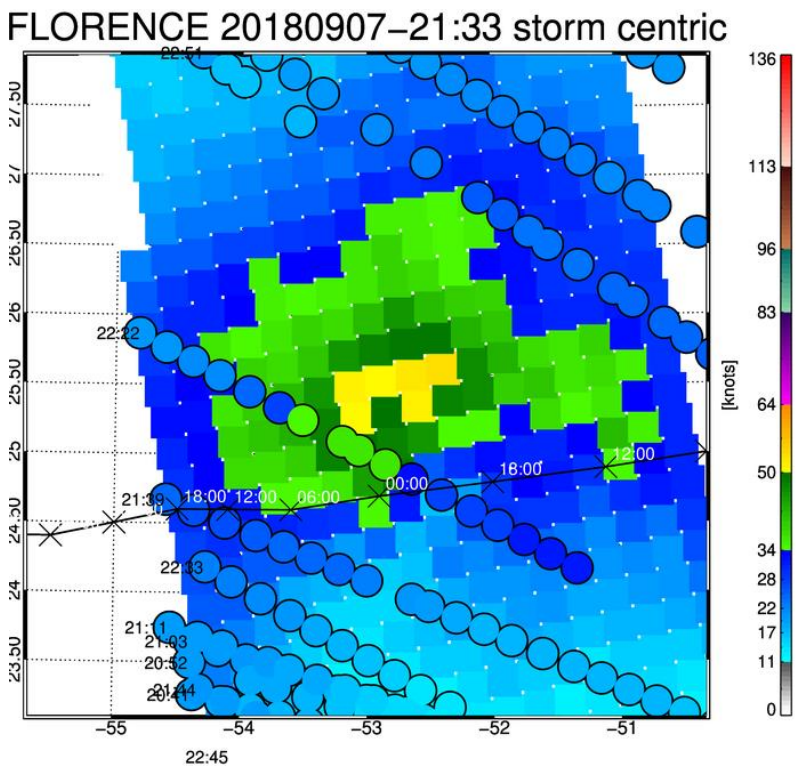
- v1.2 is the latest NOAA CyGNSS wind data product (based on v2.1 NBRCS) soon to be available on the PO.DAAC
- Global wind images already available on the NOAA Manati site (https://manati.star.nesdis.noaa.gov/datasets/CYGNSSData.php)

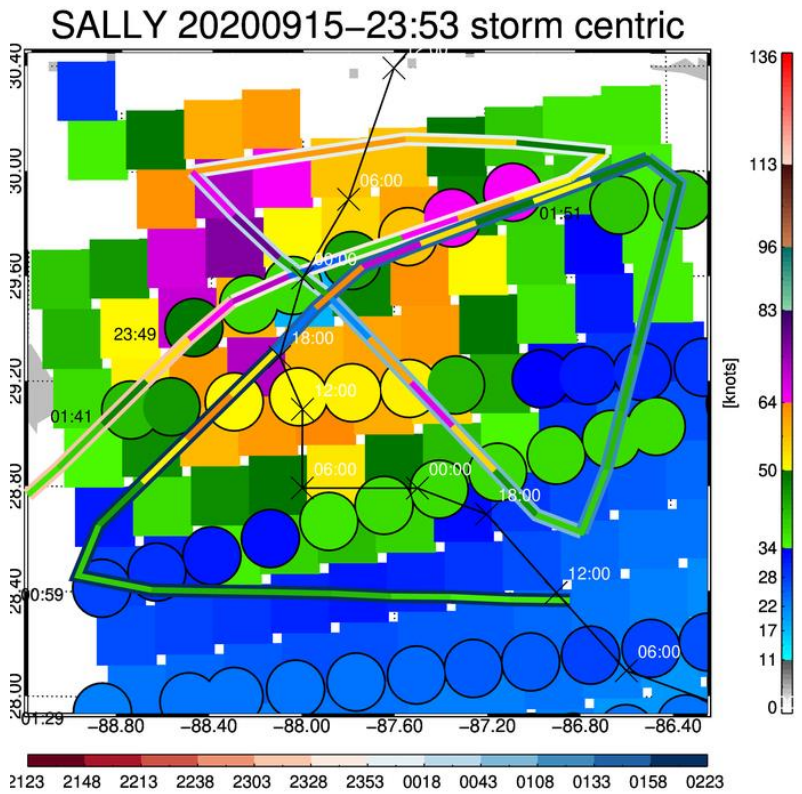
**Publication providing details on the NOAA Track-wise algorithm:

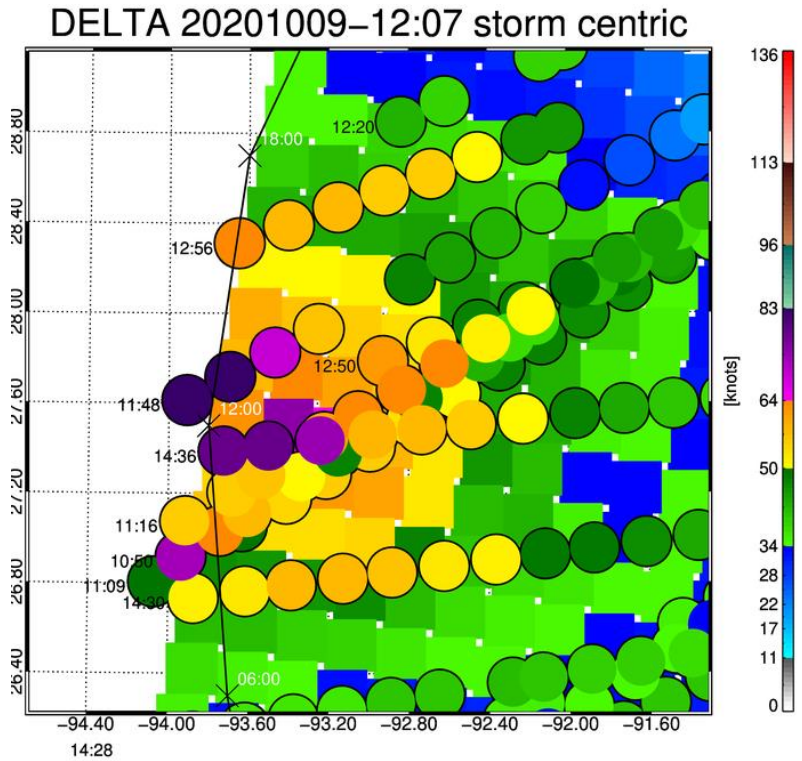
F. Said, Z. Jelenak, J. Park, P. S. Chang, "The NOAA track-wise wind retrieval algorithm and product assessment for CyGNSS", Geoscience and Remote Sensing, IEEE Transaction on, July 2021, DOI: 10.1109/TGRS.2021.3087426

Background on CyGNSS: TC overpass examples

Background wind field from Sentinel 1a/1b regridded at 25km







Outline for the rest of the presentation:

1. Use storm composite imagery to assess CyGNSS performance against other sensors and HWRF
2. Overall statistical performance within the TC environment compared against HRWF, SFMR and other sensors (e.g. SMAP-RSS, Sentinel, and CyGNSS product from UMICH)

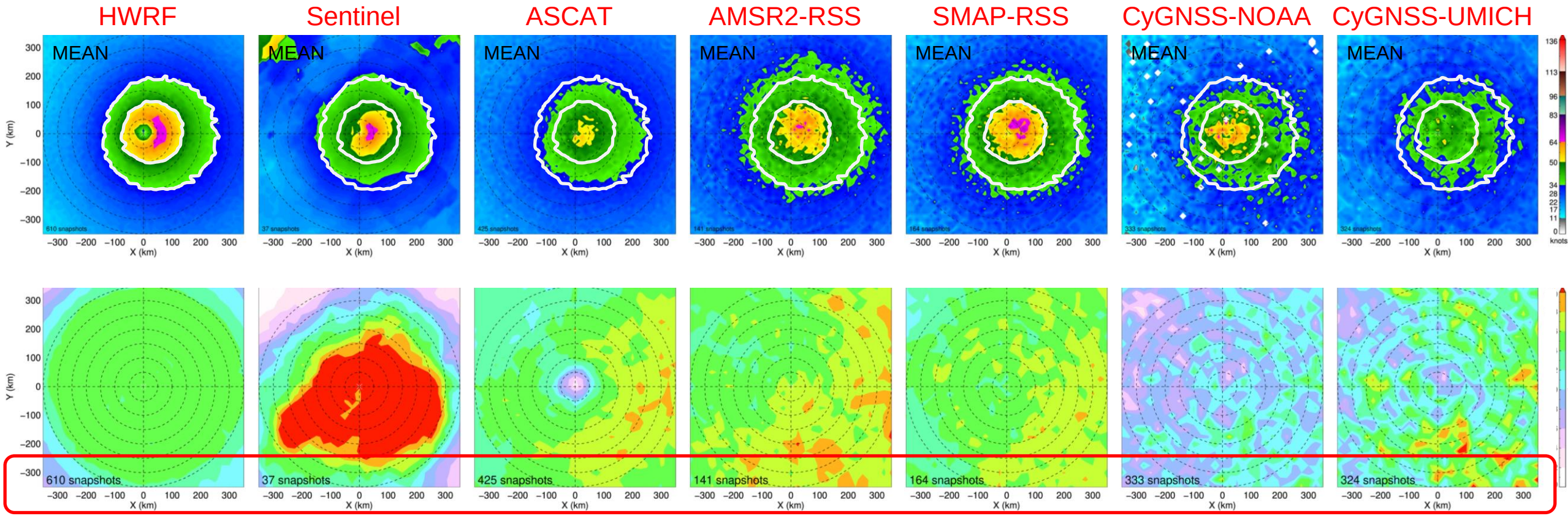
Composite Storm Analysis Methodology

- Collocate sensor/model data within a preset radius (e.g. 750km) centered around storm center
- Collocated data is gridded and set on a **kilometer grid**
- Storm rotation is taken into consideration (i.e. 'North' of each snapshot corresponds to storm direction)
- Once all snapshots are generated, a storm composite (of average/max wind speed, wind speed bias, etc..) image can be created
- For this presentation, *hurricane category* snapshots are exclusively used

Selected dataset

- Selected sensors/models:
  - v1.2 NOAA and latest UMICH CyGNSS winds (sand310 a.k.a v3.2)
  - 0.25° HWRF (i.e. 1-3km HWRF regridded to 0.25°)
  - 25km NOAA ASCAT, AMSR-2-RSS, SMAP-RSS, Sentinel 25km,
- Selected hurricane seasons and basin: 2019-2021 || Atlantic basin

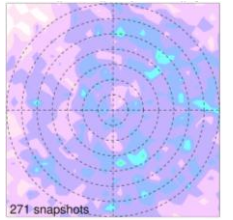
Atlantic Basin 2019-2021 -- hurricane cat. overpasses only



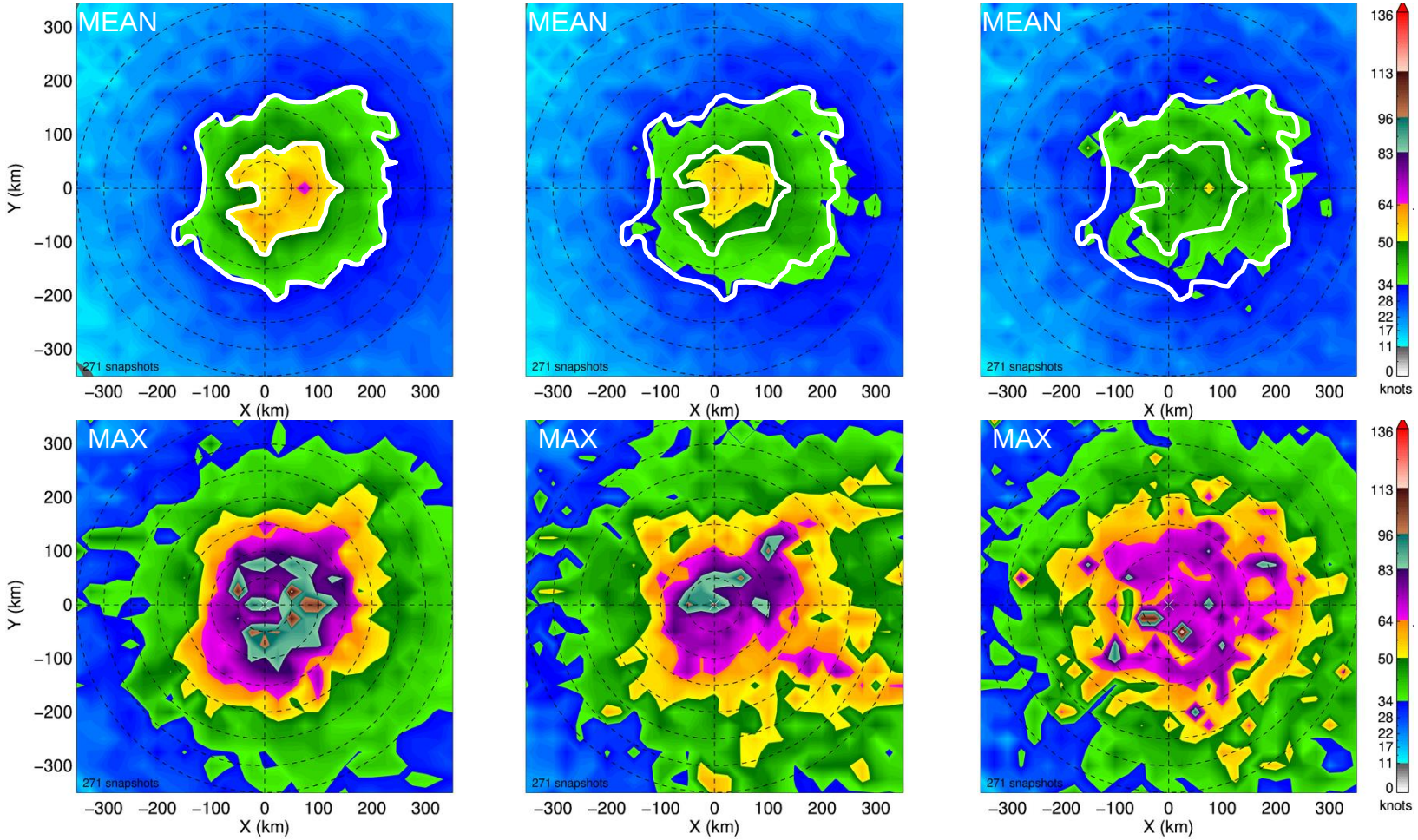
Not exactly apple to apple comparison!

Atlantic Basin 2019-2021 -- hurricane cat. overpasses only

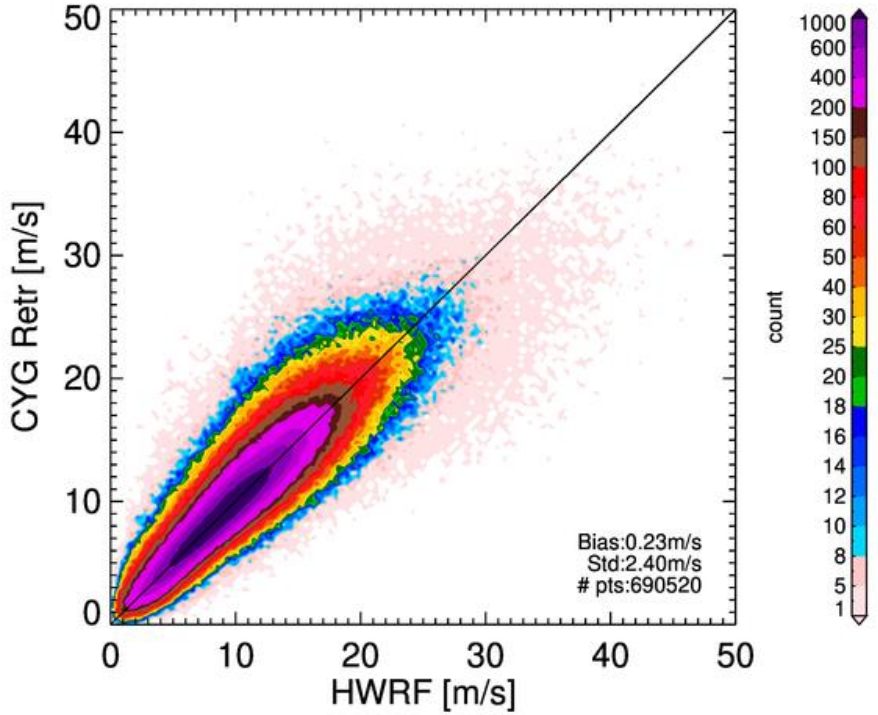
collocated HWRF/CyGNSS

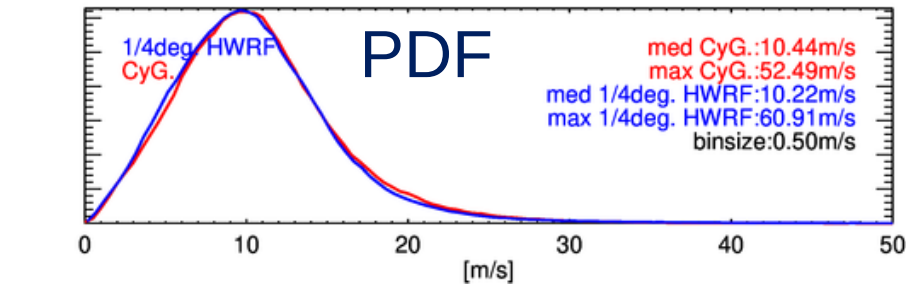


HWRF | CyGNSS-NOAA | CyGNSS-UMICH

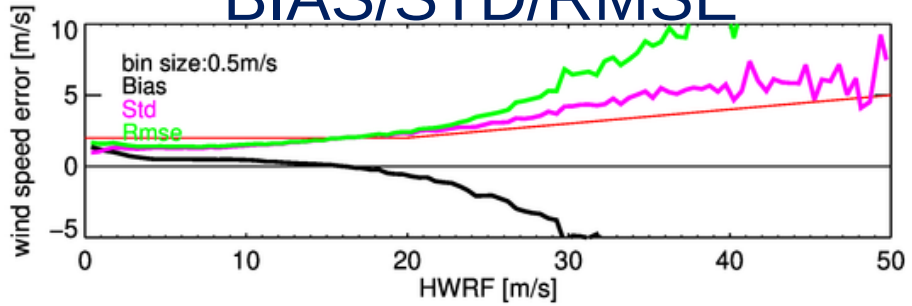


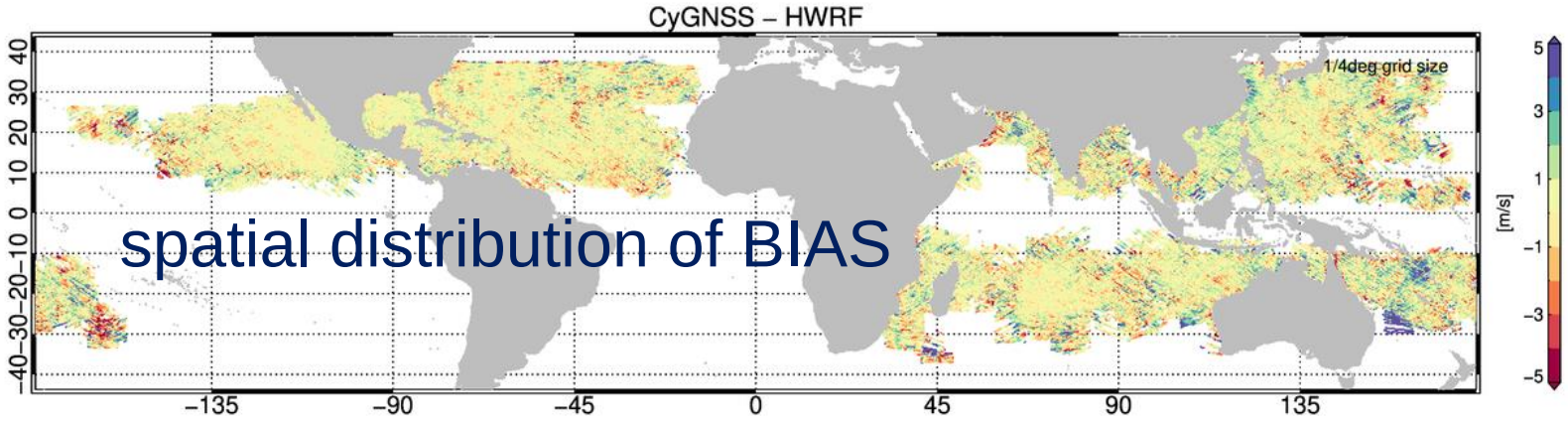
2019-2021 overall statistical performance: CyG NOAA vs. HWRF





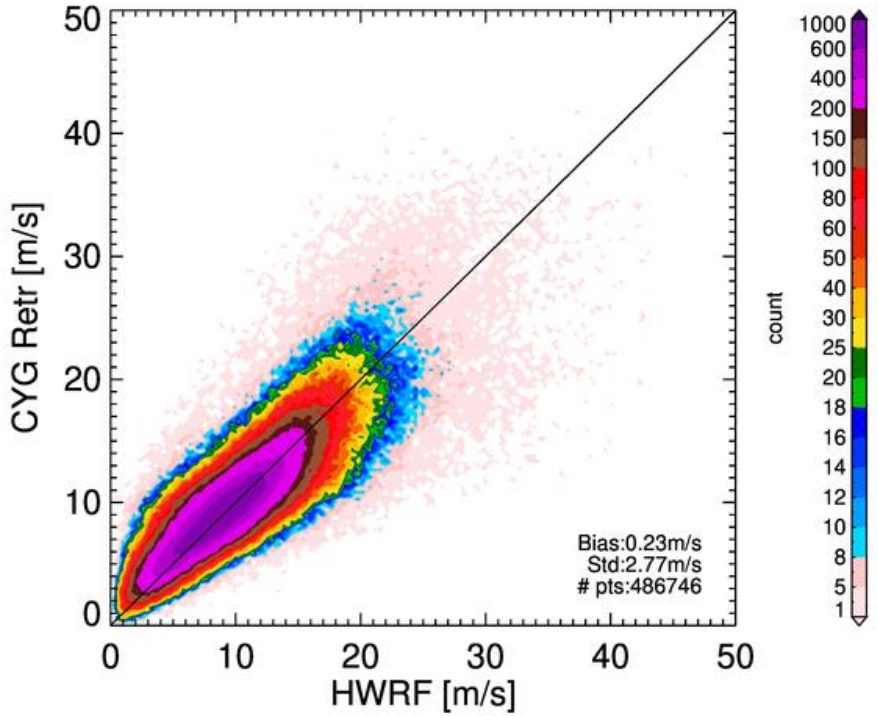
BIAS/STD/RMSE

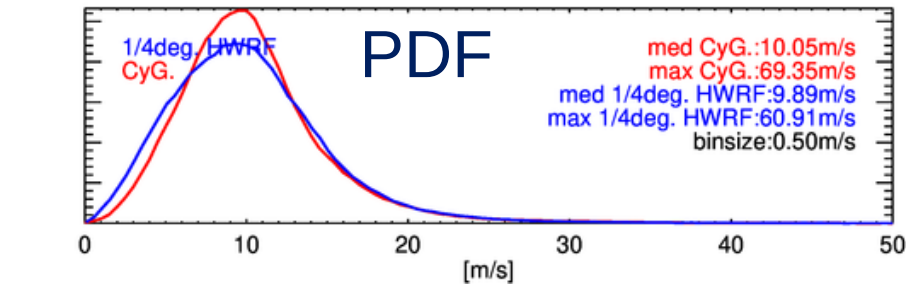


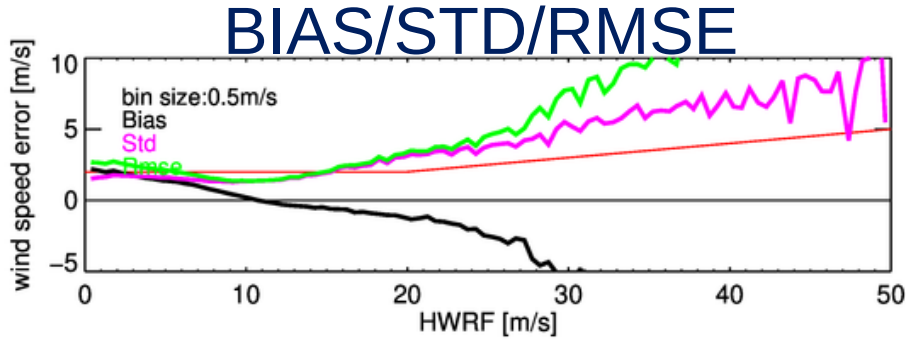


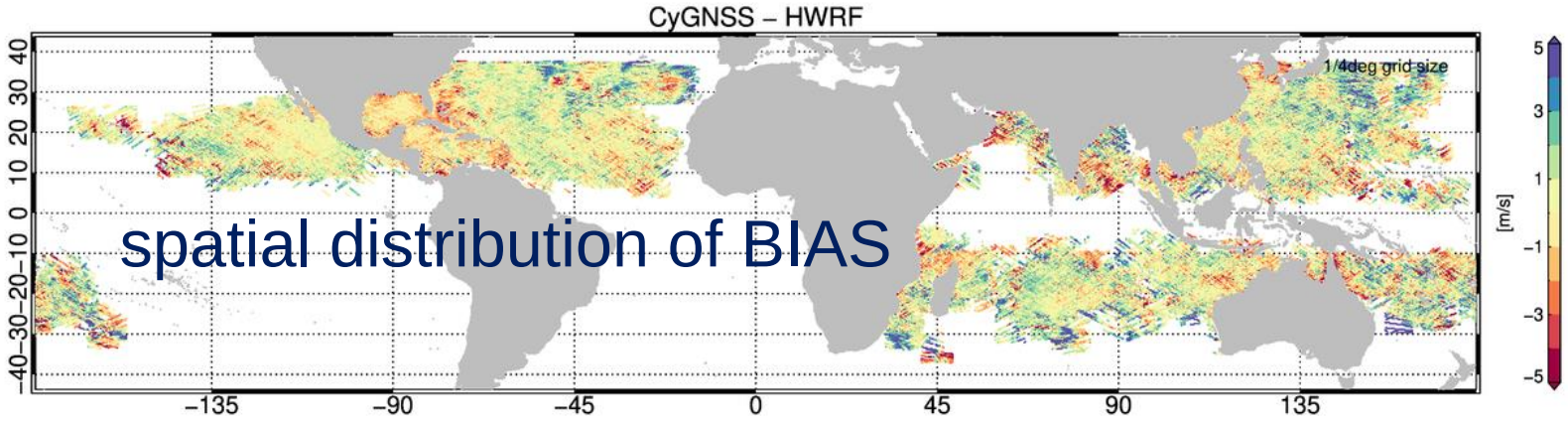
spatial distribution of BIAS

2019-2021 overall statistical performance: CyG UMICH vs. HWRF



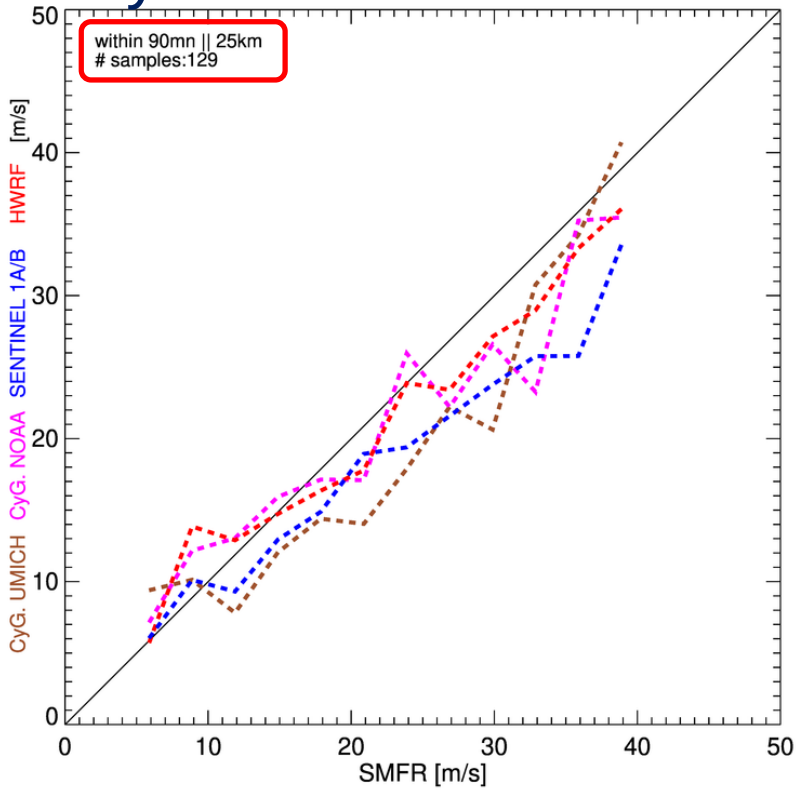






Performance against SFMR (2019-2021 AL basin)

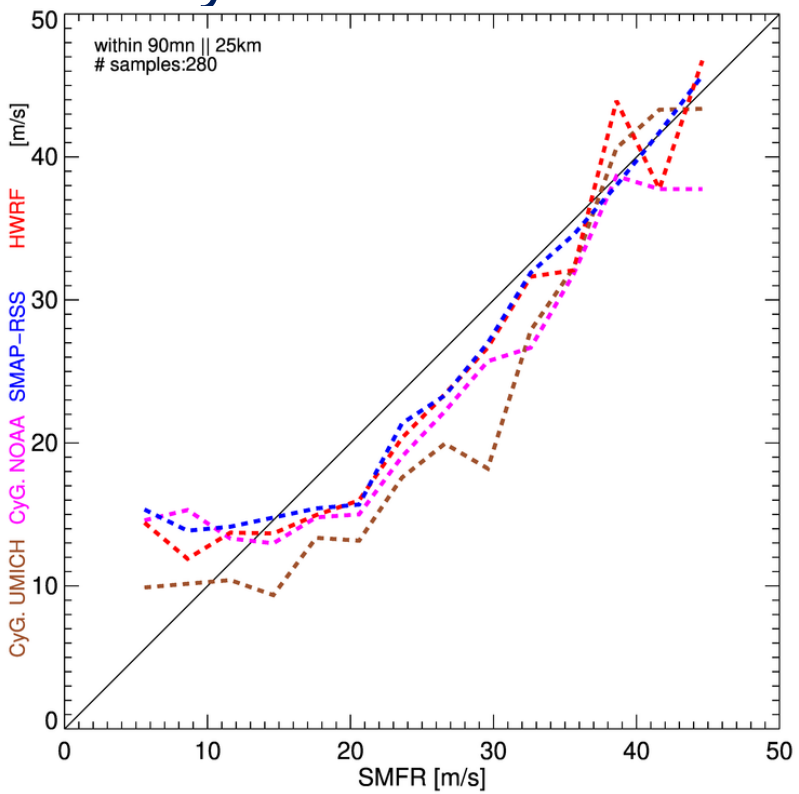
CyG/SENTINEL/HWRF



STATS with SFMR winds > 15 m/s:

HWRF/SFMR	Bias:–3.23m/s	Std:5.36m/s	Max:43.12m/s
Sent./SFMR	Bias:–5.36m/s	Std:5.48m/s	Max:36.33m/s
CyGNOAA/SFMR	Bias:–3.21m/s	Std:6.01m/s	Max:40.50m/s
CyGUMICH/SFMR	Bias:–5.00m/s	Std:6.68m/s	Max:46.56m/s

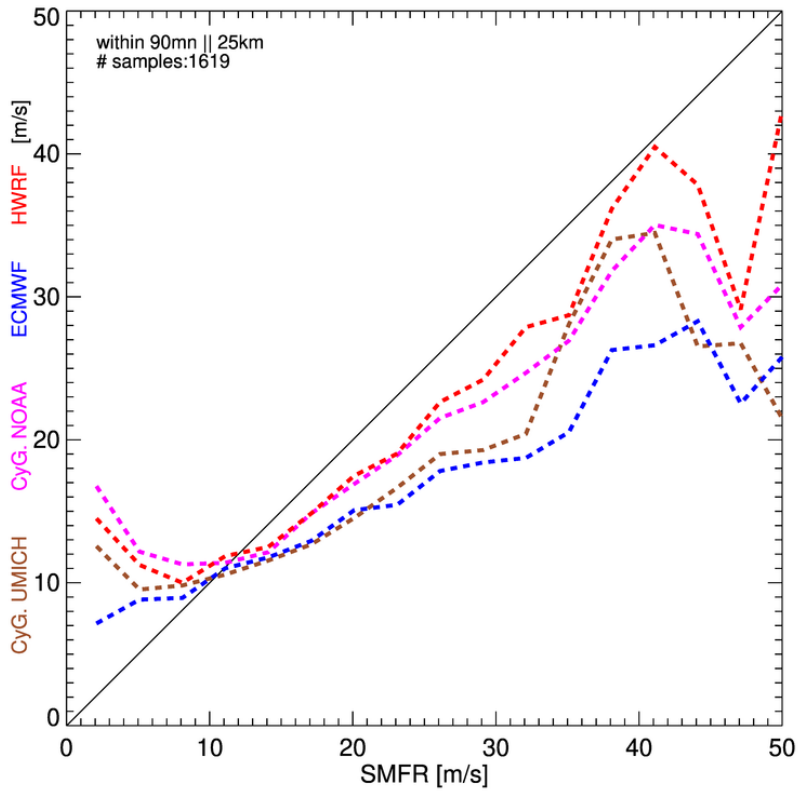
CyG/SMAP/HWRF



STATS with SFMR winds > 15 m/s:

HWRF/SFMR	Bias:–3.96m/s	Std:4.91m/s	Max:46.73m/s
SMAP–RSS/SFMR	Bias:–3.43m/s	Std:4.62m/s	Max:45.69m/s
CyGNOAA/SFMR	Bias:–4.80m/s	Std:5.04m/s	Max:38.85m/s
CyGUMICH/SFMR	Bias:–6.32m/s	Std:5.34m/s	Max:46.56m/s

CyGNSS/ECMWF/HWRF



STATS with SFMR winds > 15 m/s:

HWRF/SFMR	Bias:–3.48m/s	Std:5.16m/s	Max:58.46m/s
ECMWF/SFMR	Bias:–7.88m/s	Std:5.34m/s	Max:33.04m/s
CyGNOAA/SFMR	Bias:–4.46m/s	Std:5.38m/s	Max:47.55m/s
CyGUMICH/SFMR	Bias:–6.29m/s	Std:5.56m/s	Max:57.26m/s

Summary

-CyGNSS provides unique storm coverage (e.g. storm revisit rate / tracks vs 'swath')

-CyGNSS storm composite imagery analysis is promising. Wind field similar to HWRF

-Respectable performance against HWRF overall within the TC environment

→0.23 m/s bias and 2.40 m/s stde within AL 2019-2021

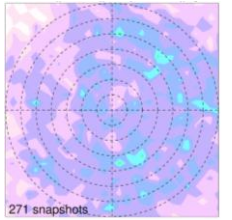
-Triple collocation results between CyGNSS, HWRF, and SFMR are encouraging as well, despite CyGNSS trailing behind HWRF in terms of statistical performance (-3.48 vs. -4.46 m/s bias and 5.16 vs. 5.38 m/s stde)

→So, is CyGNSS getting there in terms of consistency and reliability? Yes, getting close!

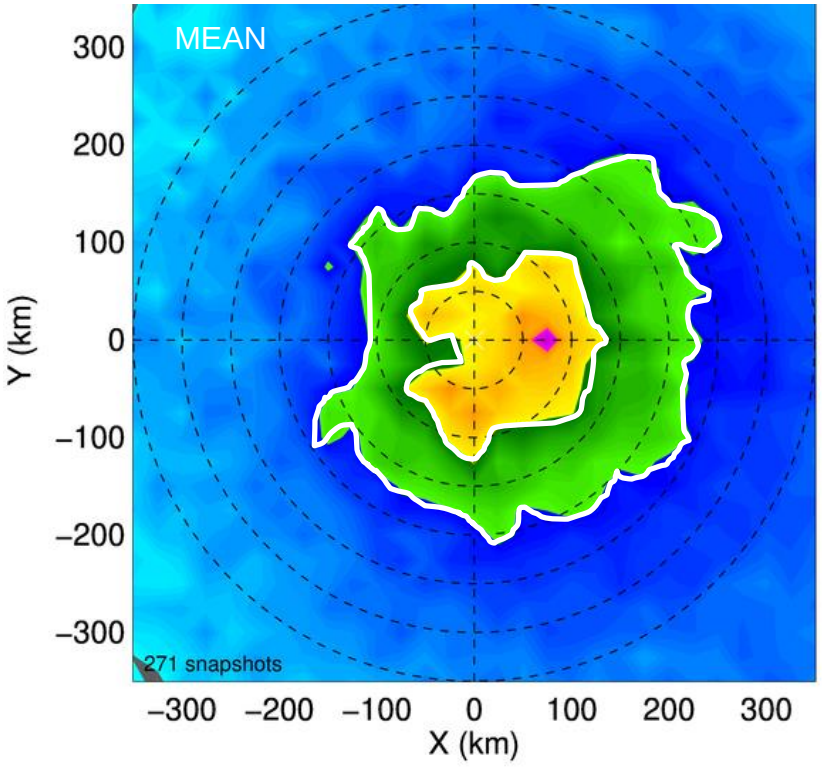
Extra slides

Atlantic Basin 2019-2021 -- hurricane cat. overpasses only

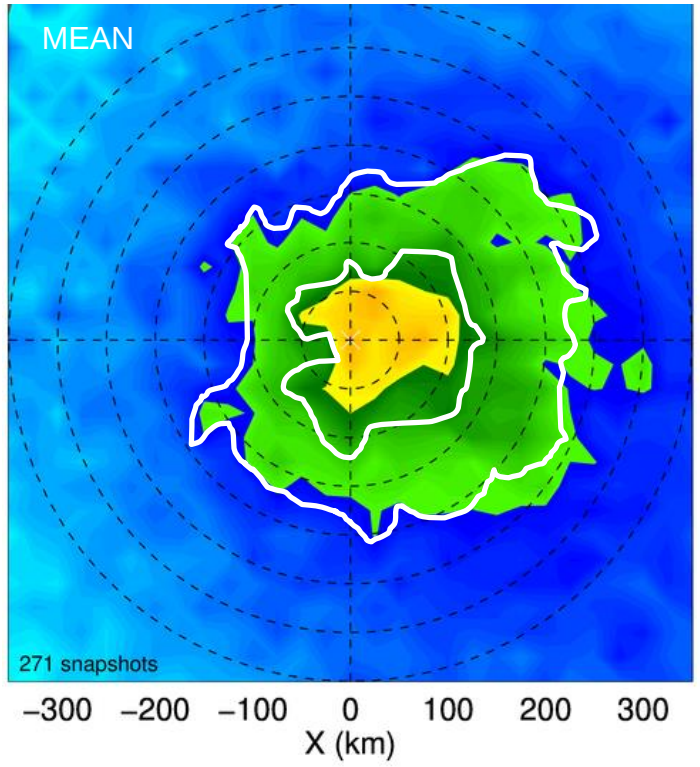
collocated HWRF/CyGNSS



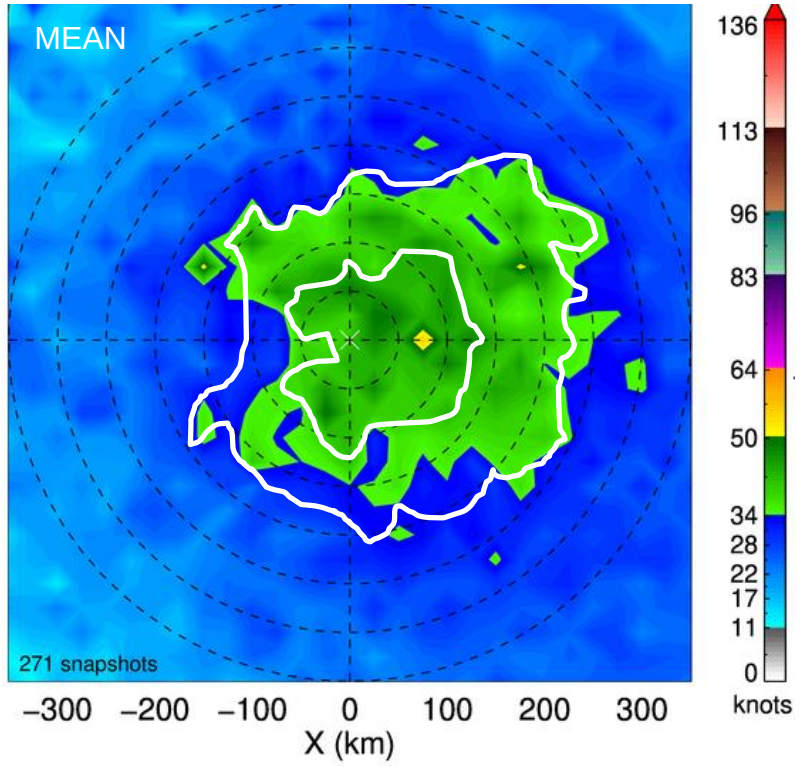
HWRF



CyGNSS-NOAA

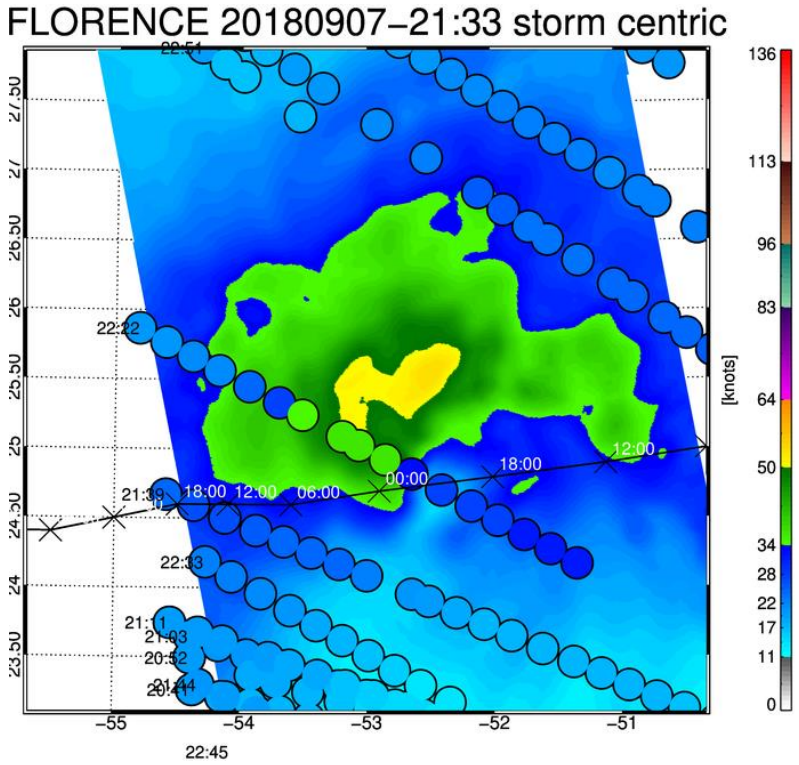


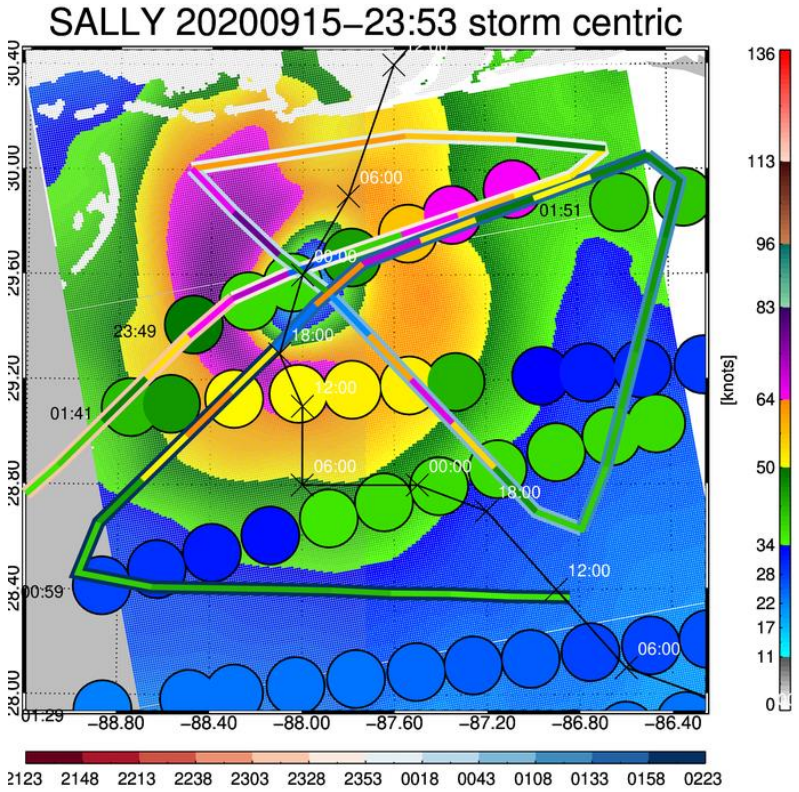
CyGNSS-UMICH

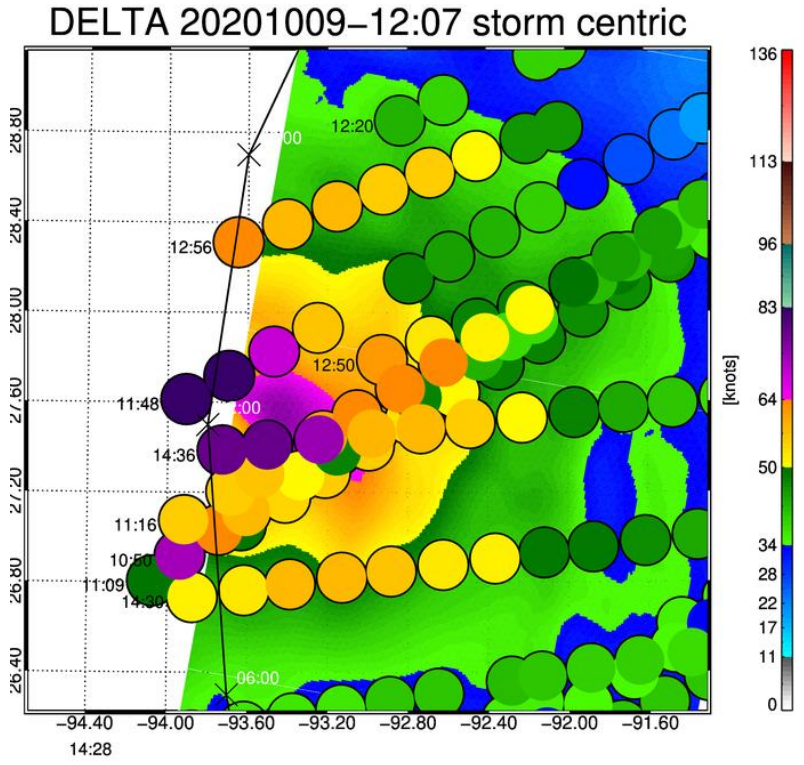


Background on CyGNSS: TC overpass examples

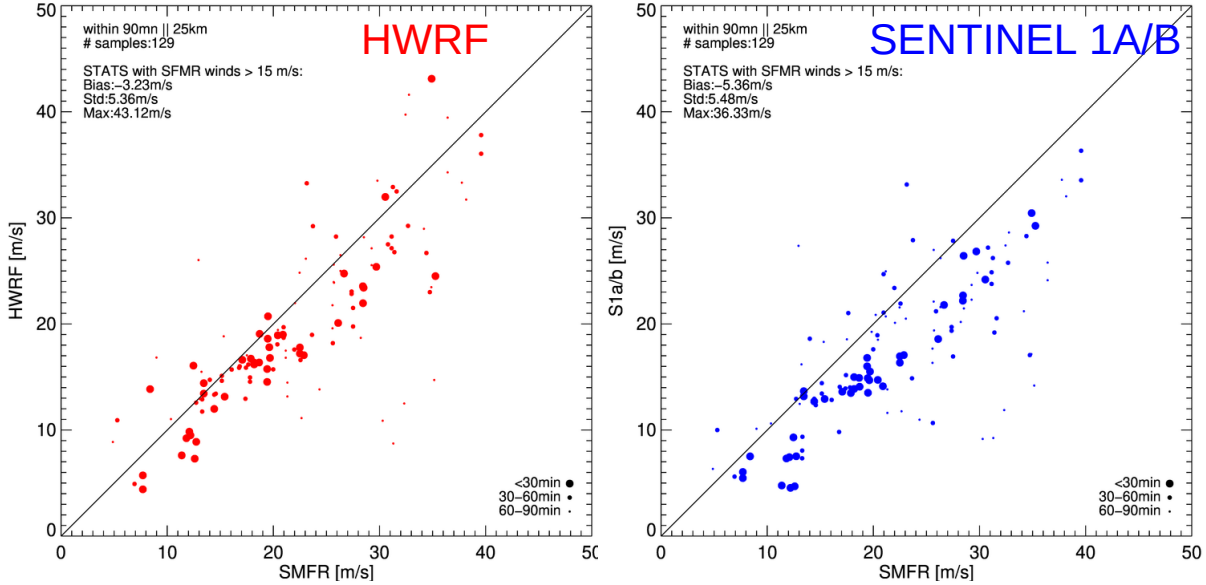
Background wind field from Sentinel 1a/1b regridded at 25km

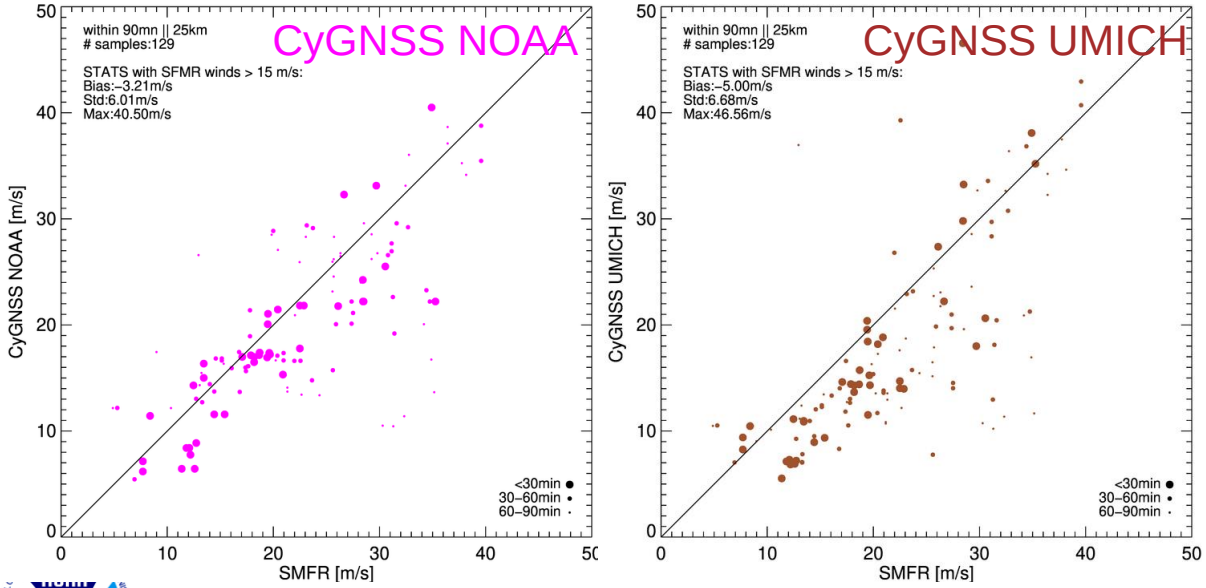


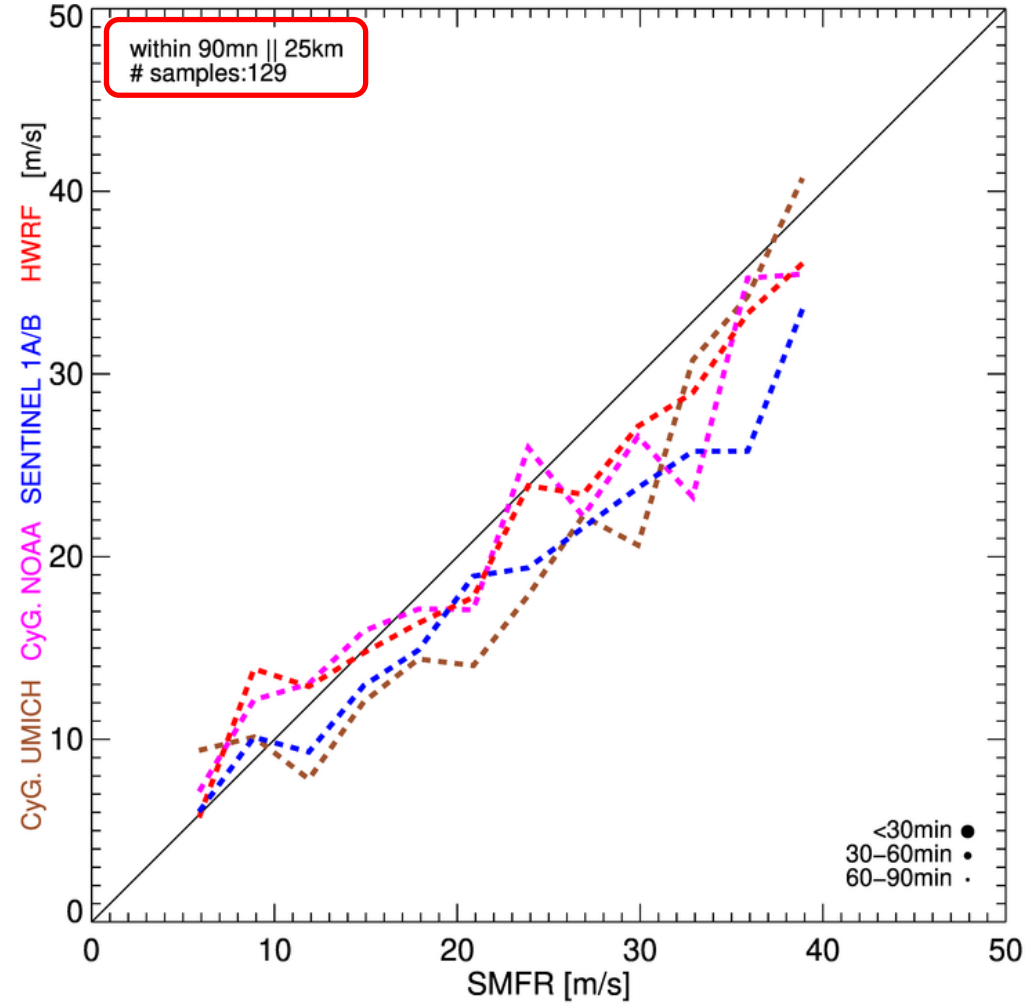




2019-2021collocated HWRF/Sentinel 1a/b/CyGNSS vs. SFMR







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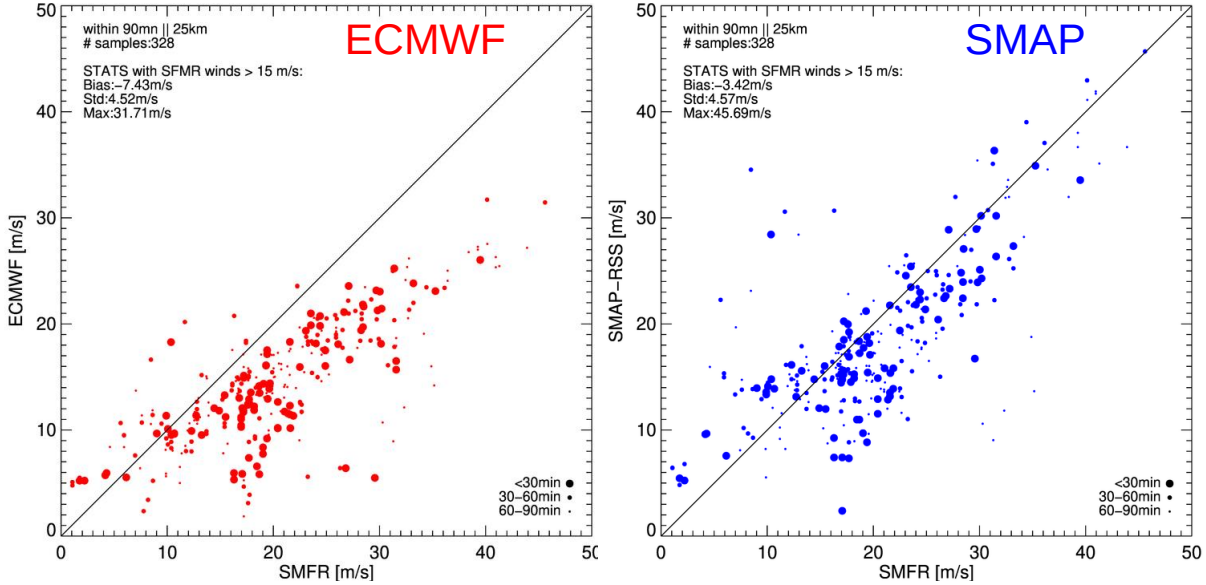
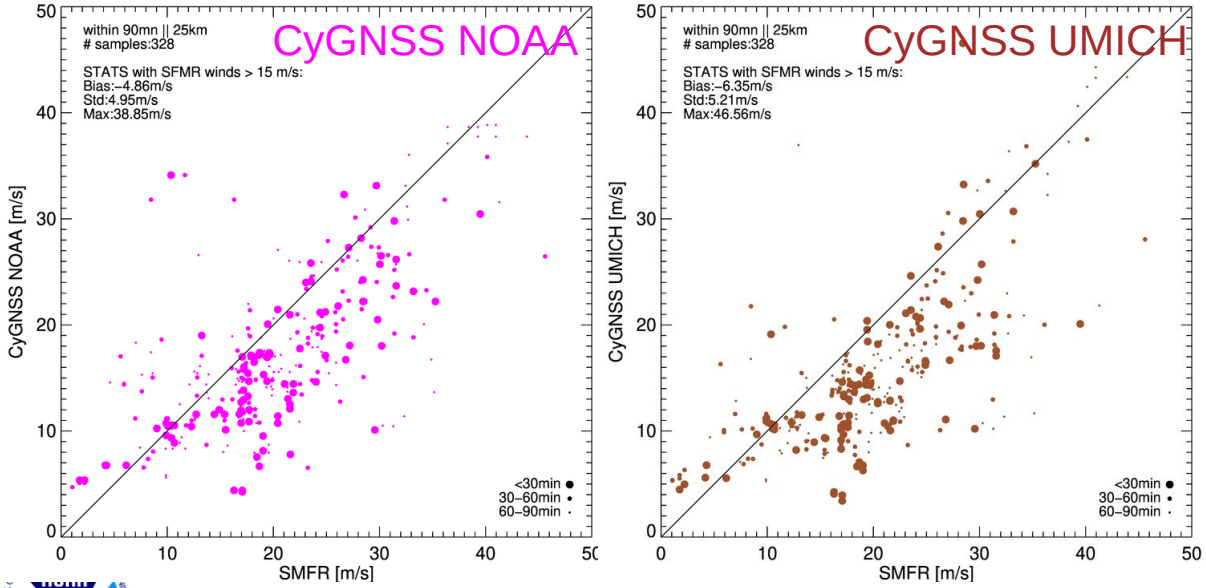
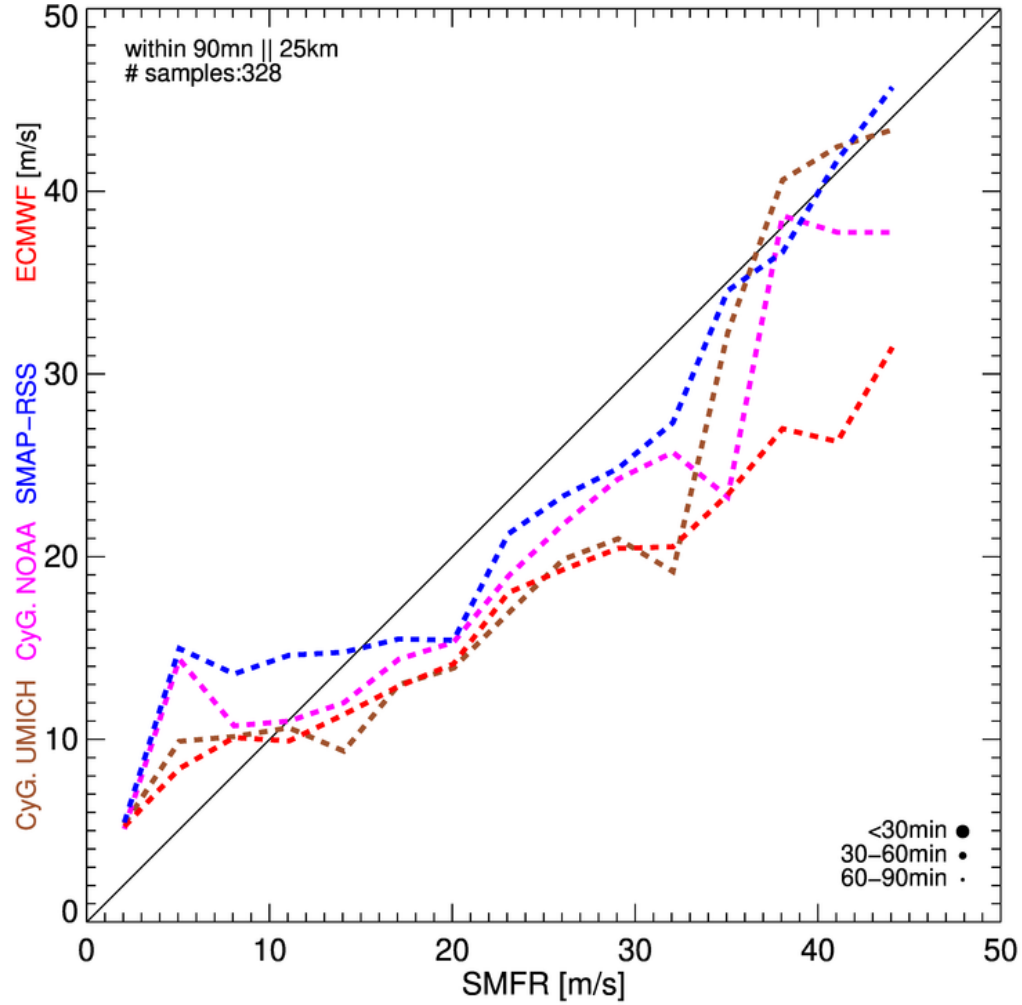
2019-2021collocated ECMWF/SMAP-RSS/CyGNSS vs. SFMR







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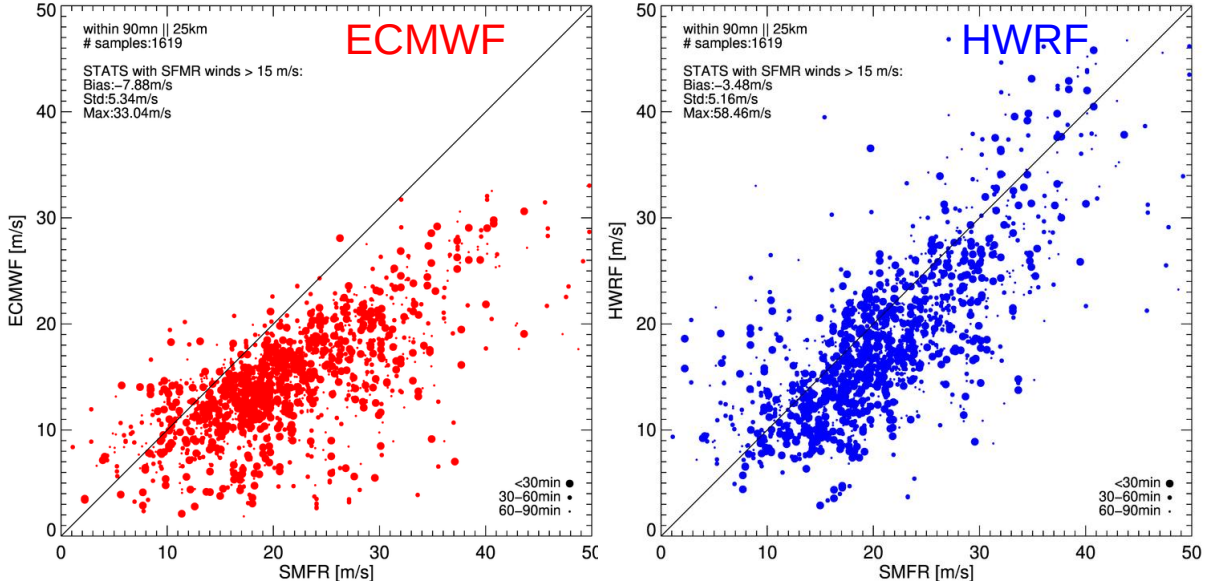

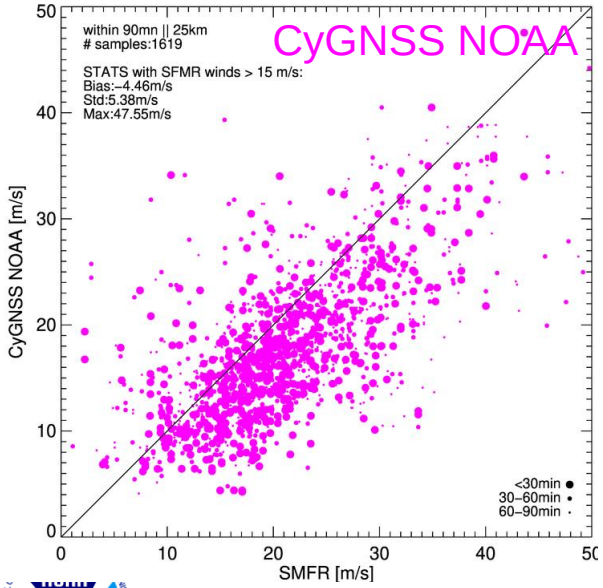

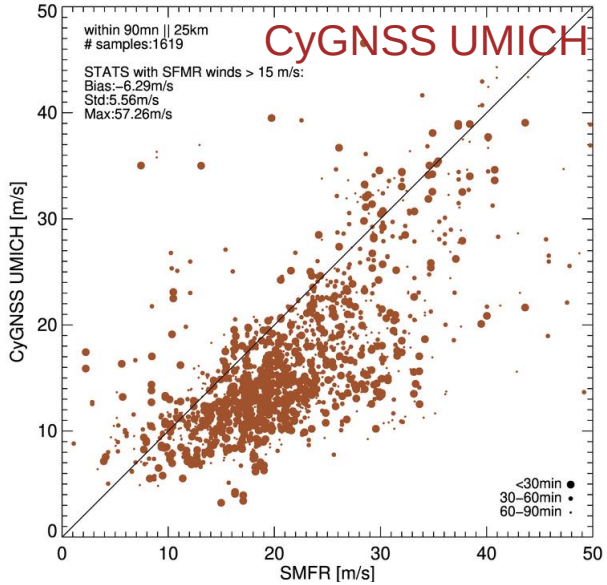

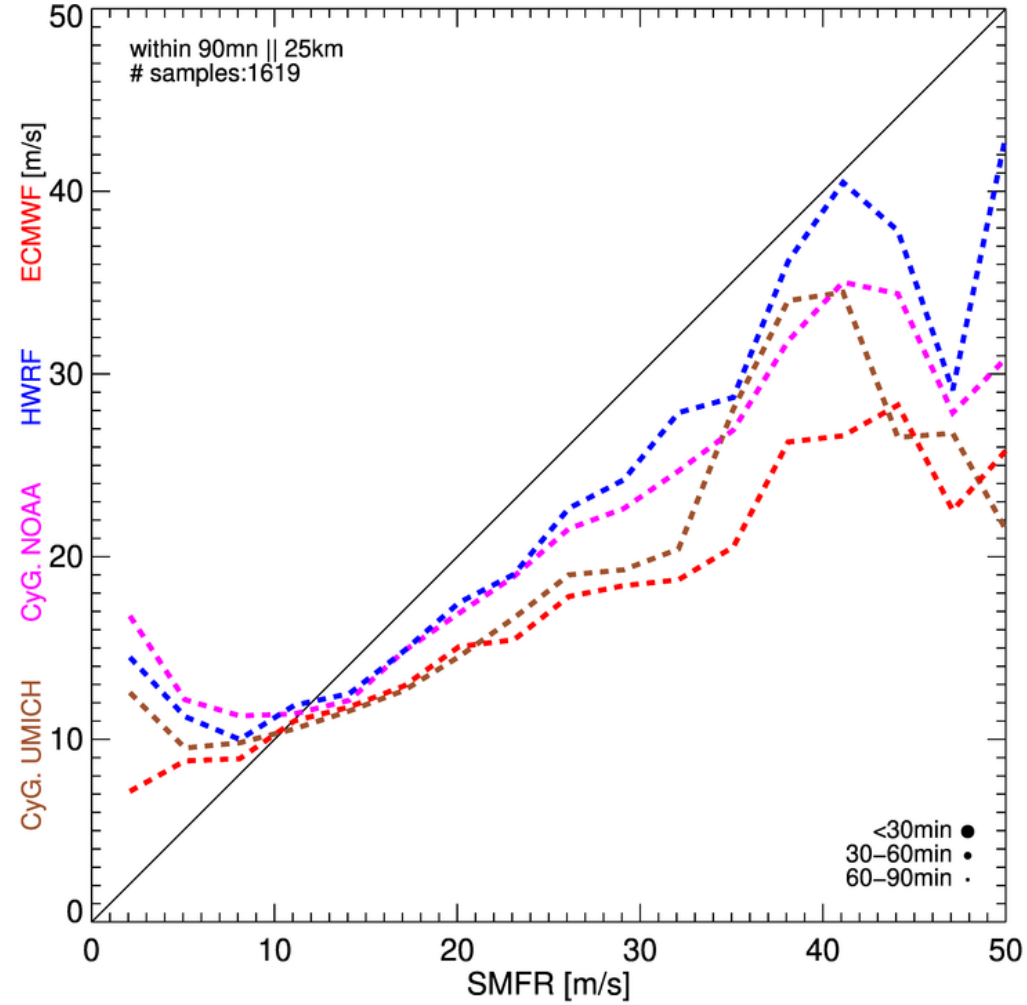

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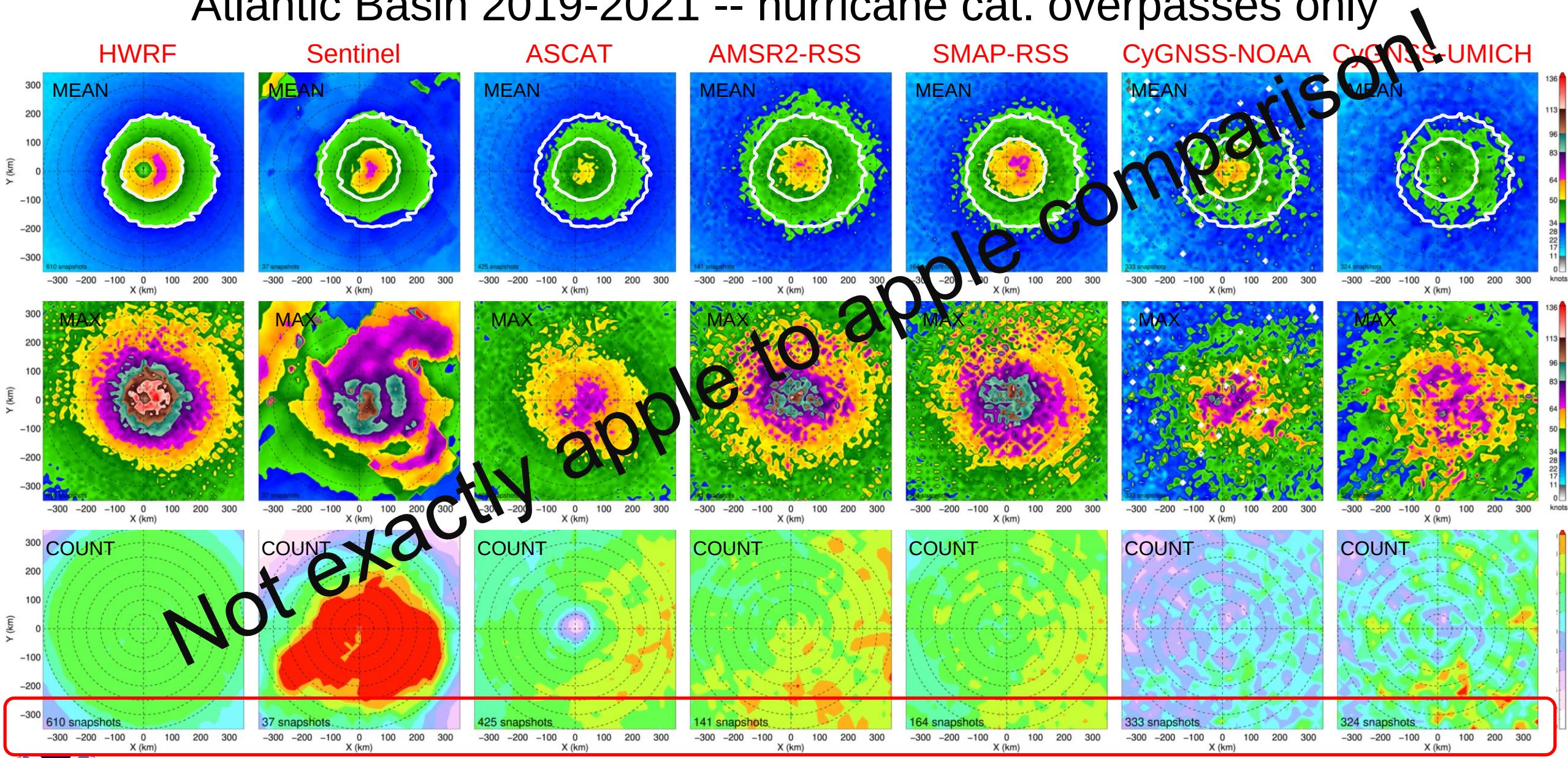
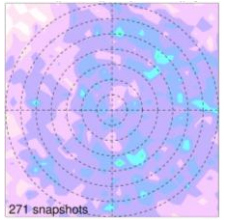
Atlantic Basin 2019-2021 -- hurricane cat. overpasses only



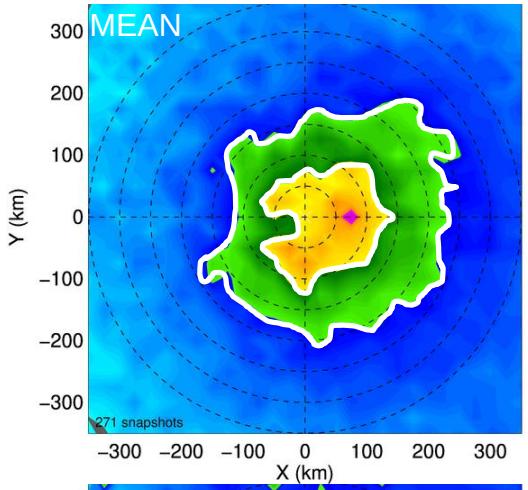
Not exactly apple to apple comparison!

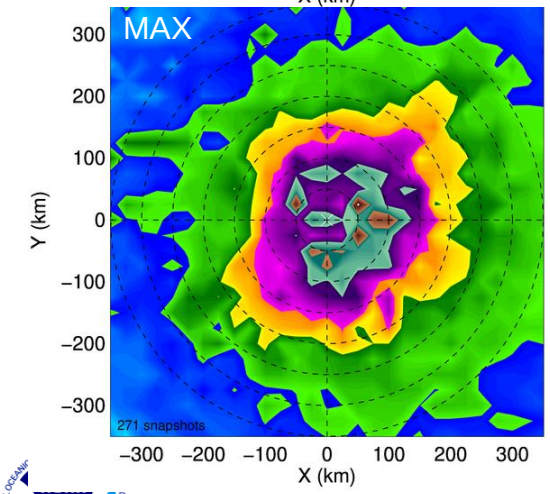
Atlantic Basin 2019-2021 -- hurricane cat. overpasses only

collocated HWRF/ECMWF/CyGNSS

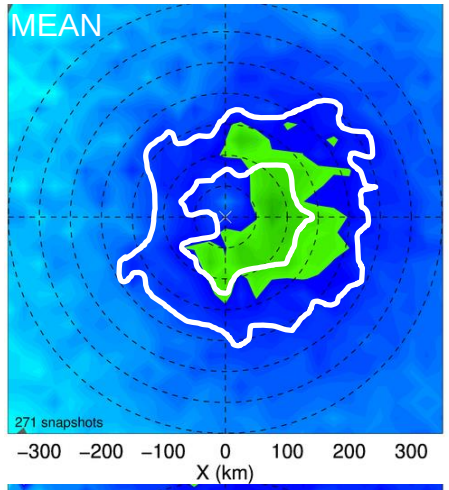


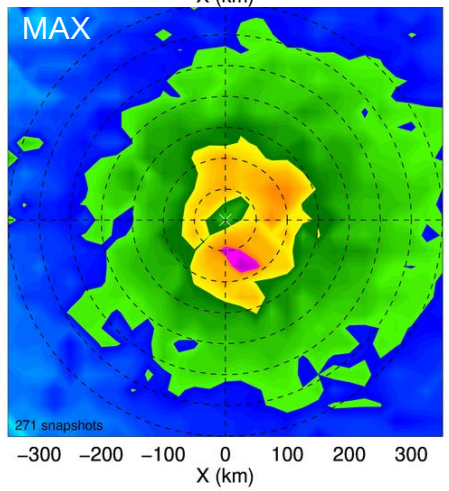
HWRF



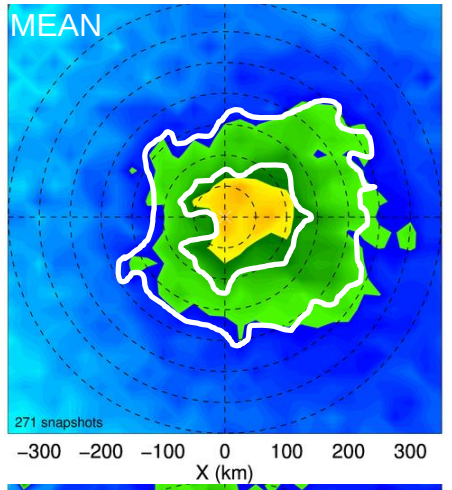


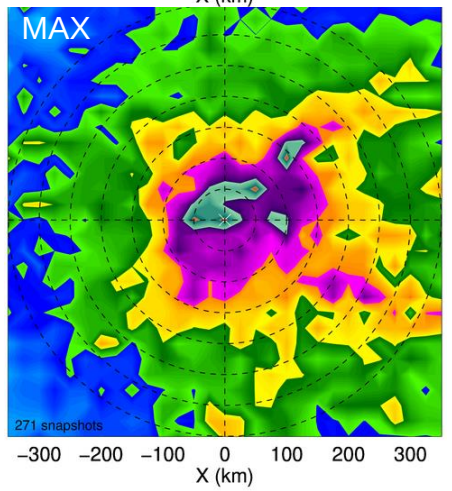
ECMWF



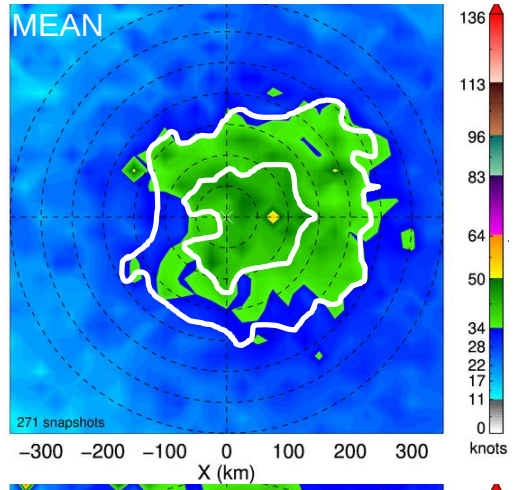


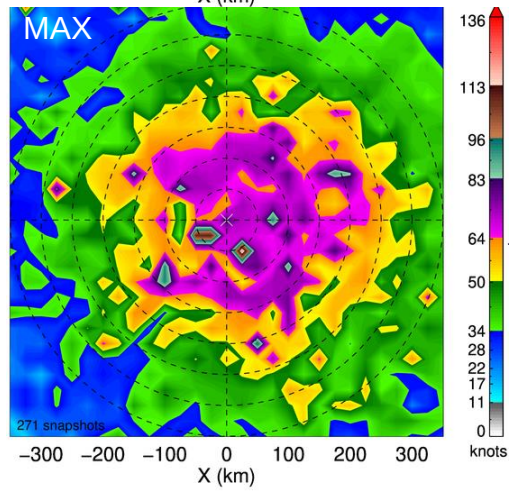
CyGNSS-NOAA





CyGNSS-UMICH

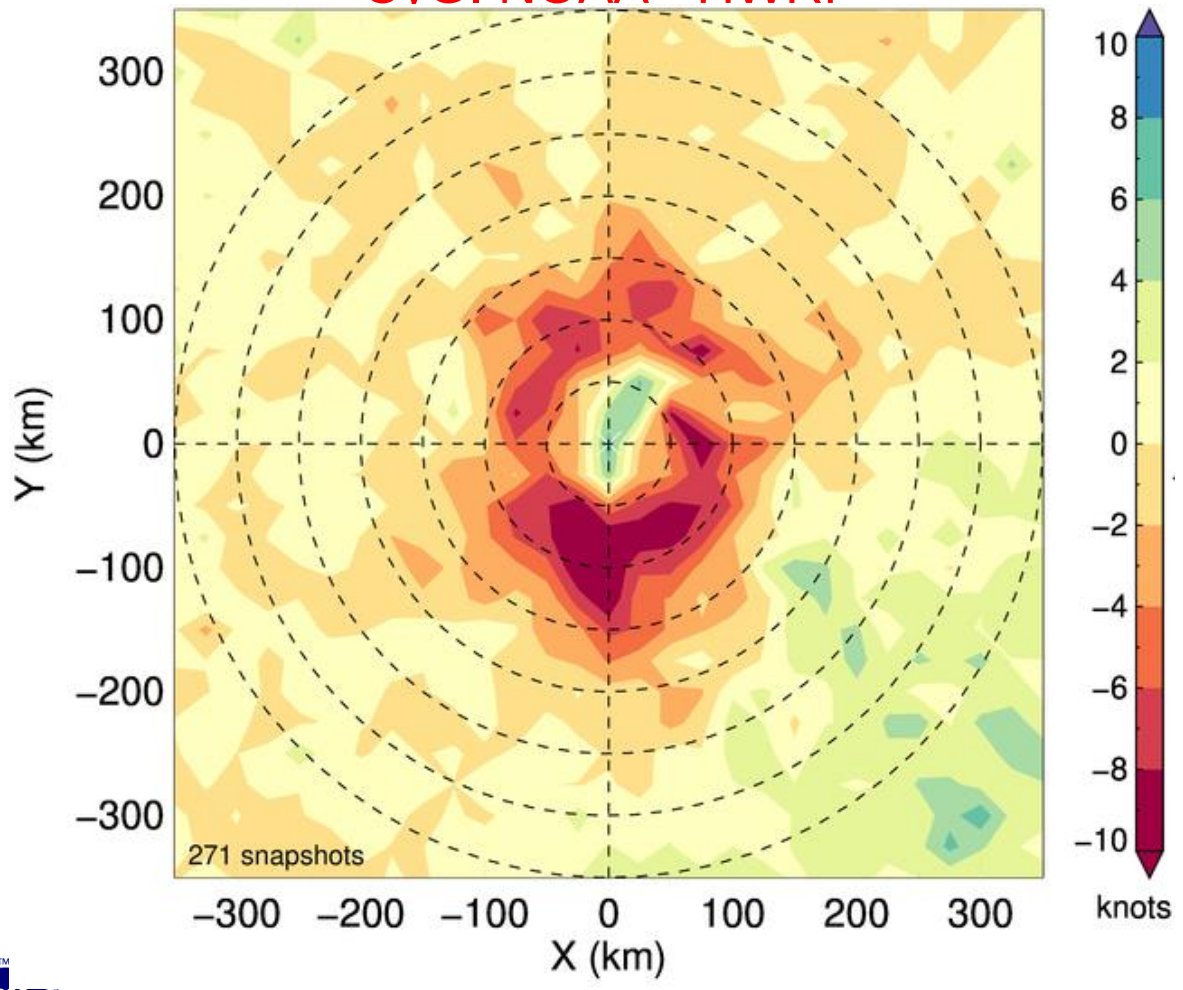




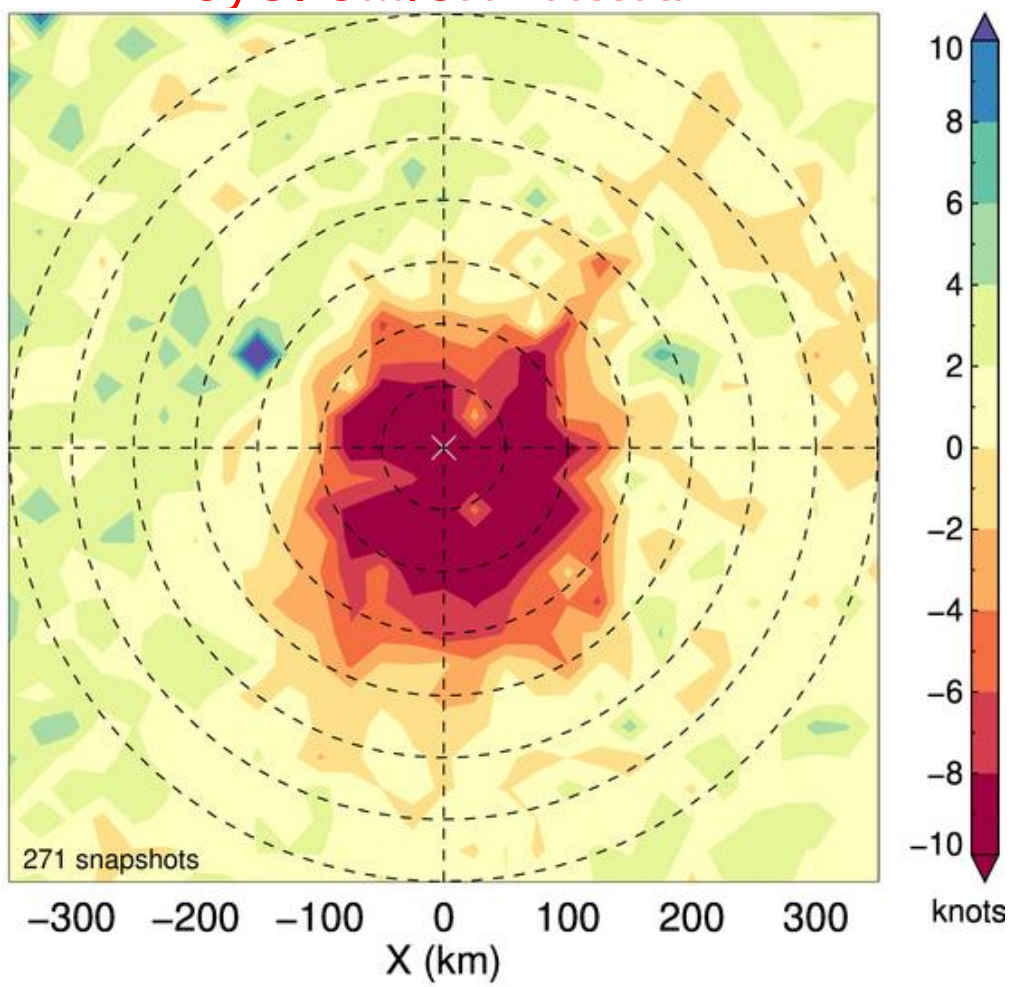
Atlantic Basin 2019-2021 -- hurricane cat. overpasses only

collocated HWRF/CyGNSS

CvG. NOAA - HWRF



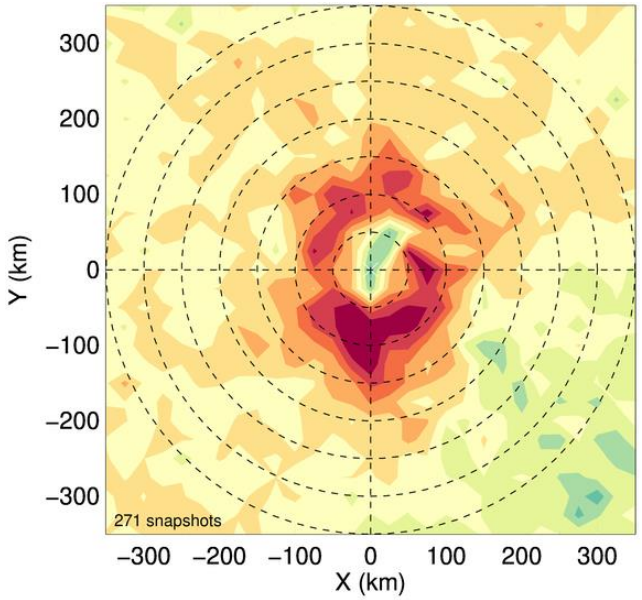
CyG. UMICH - HWRF



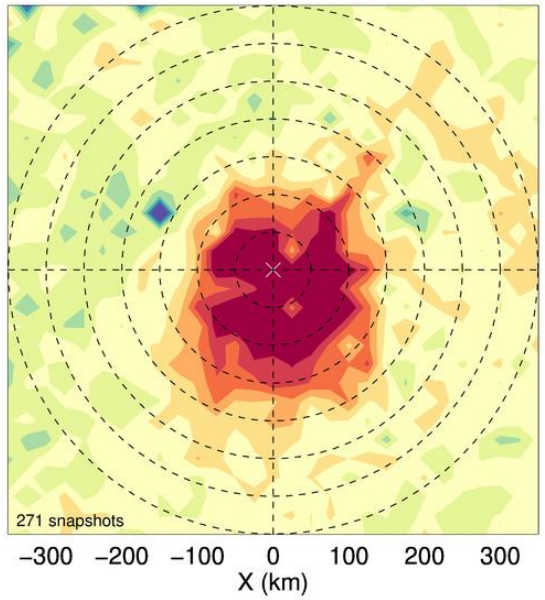
Atlantic Basin 2019-2021 -- hurricane cat. overpasses only

collocated HWRF/ECMWF/CyGNSS

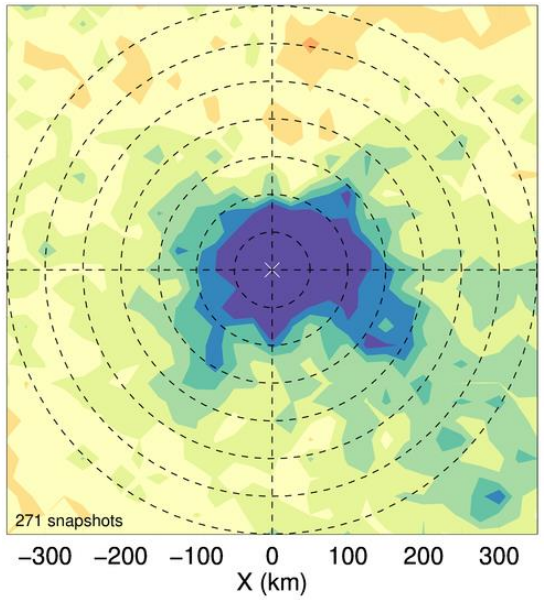
CyG. NOAA - HWRF



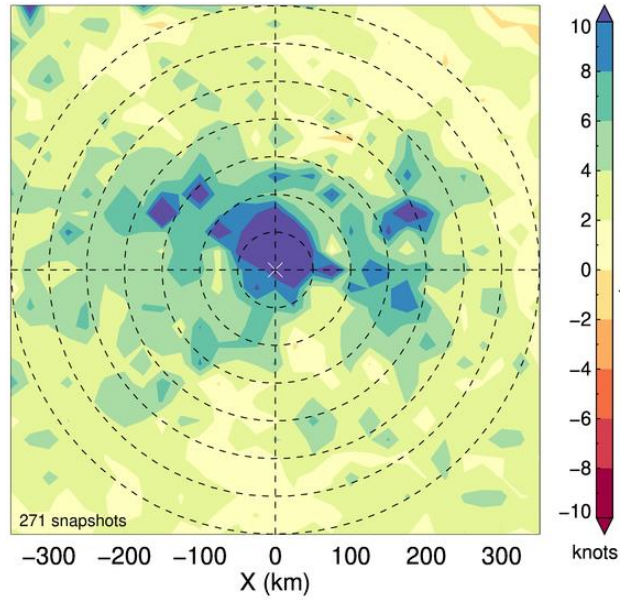
CyG. UMICH - HWRF



CyG. NOAA - ECMWF



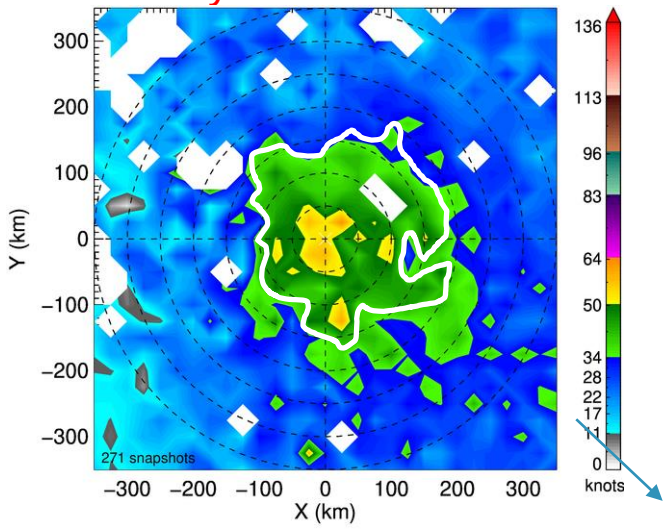
CyG. UMICH - ECMWF



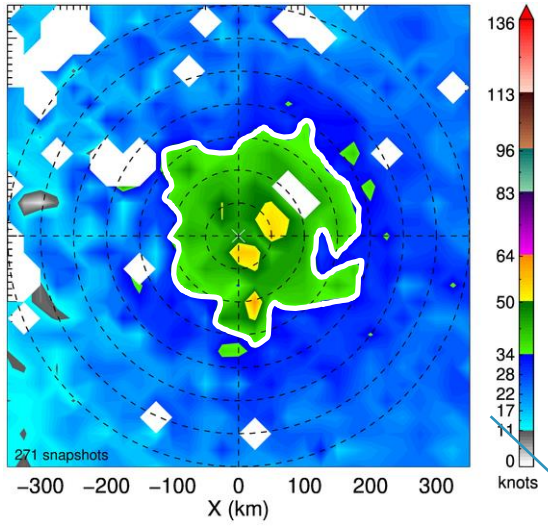
Atlantic Basin 2019-2021 -- hurricane cat. overpasses only

collocated ASCAT/CyGNSS

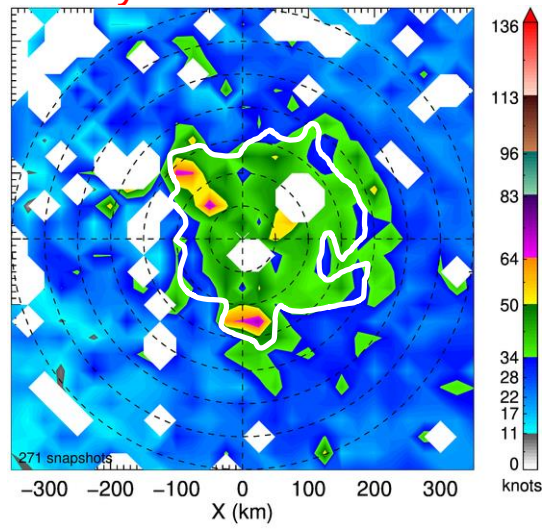
CyGNSS NOAA



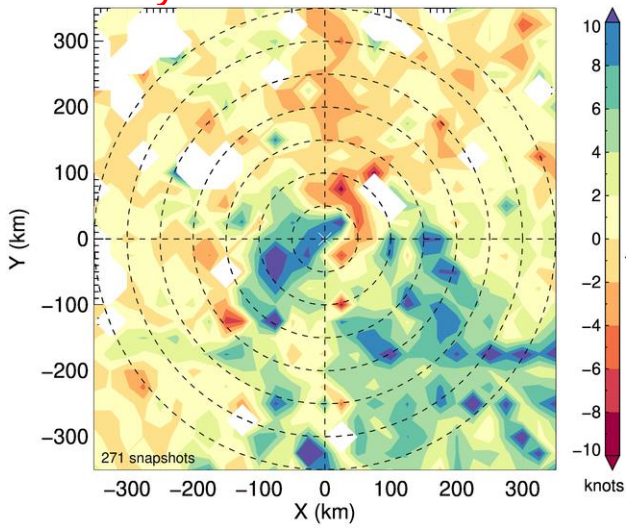
ASCAT



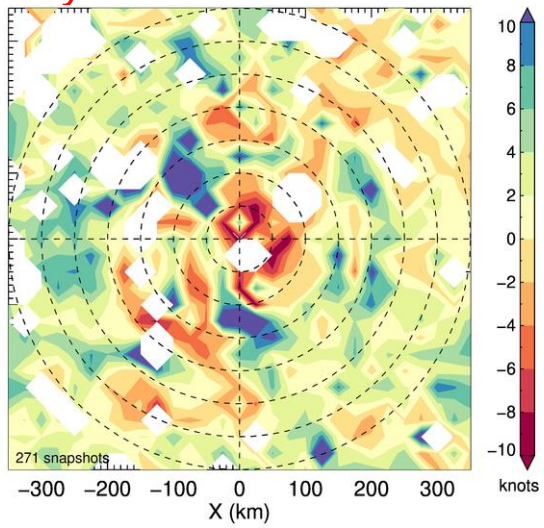
CyGNSS UMICH

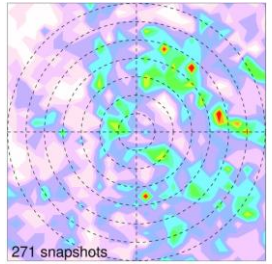


CyG. NOAA - ASCAT

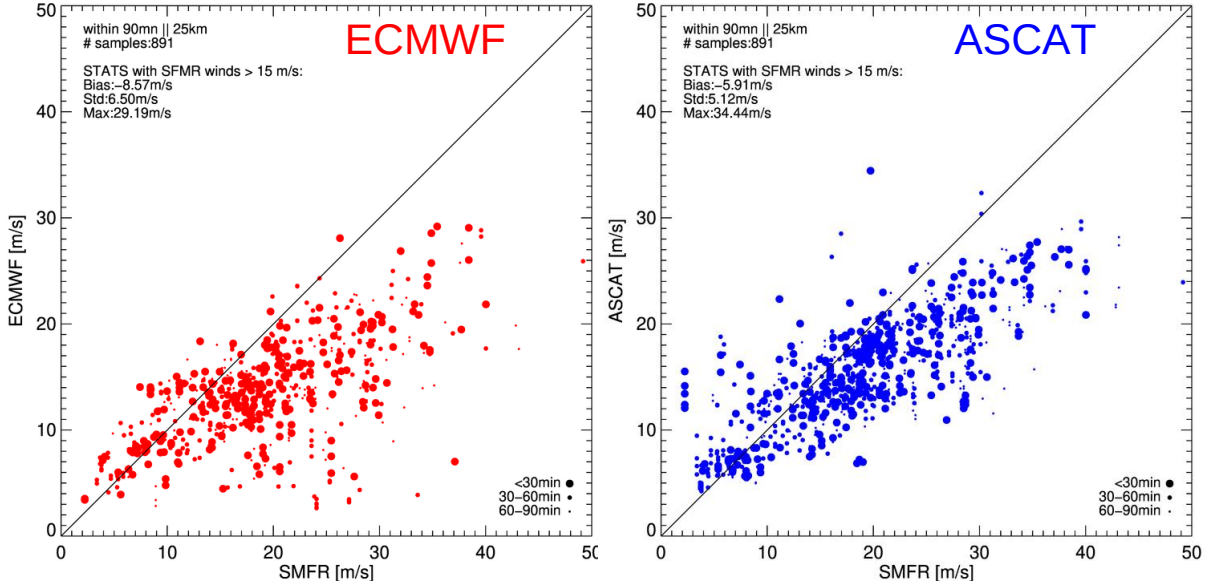


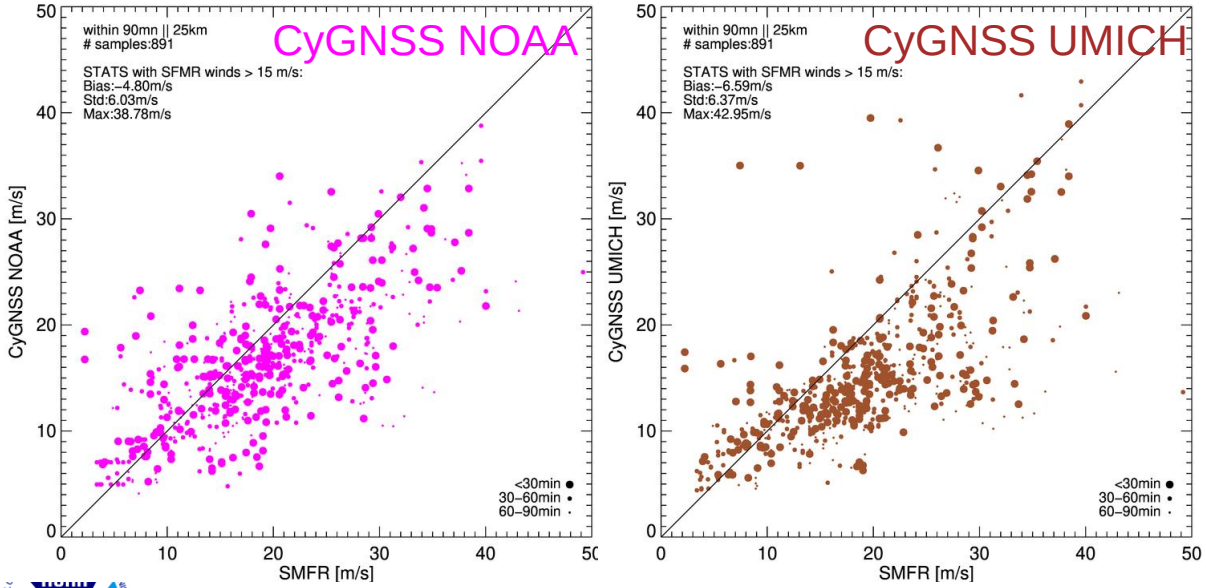
CyG. UMICH - ASCAT

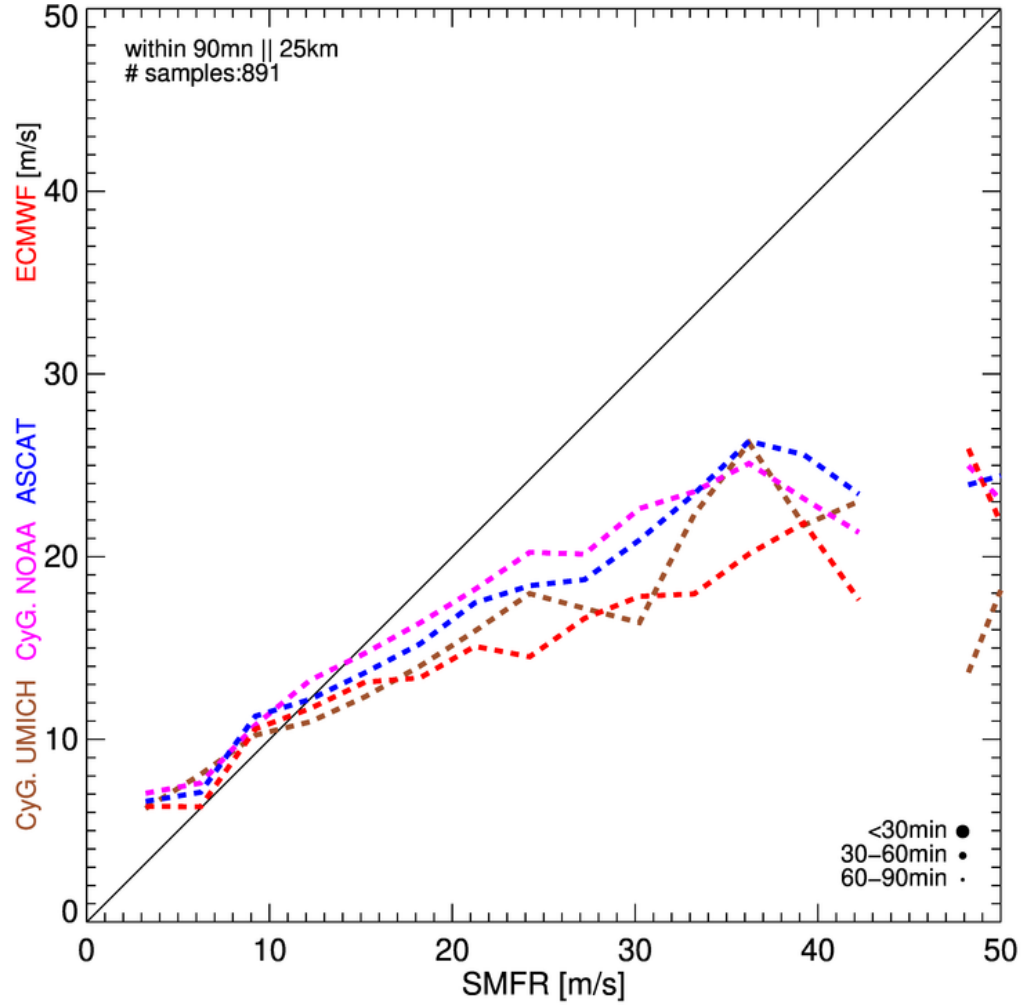




2019-2021collocated ECMWF/ASCAT/CyGNSS vs. SFMR

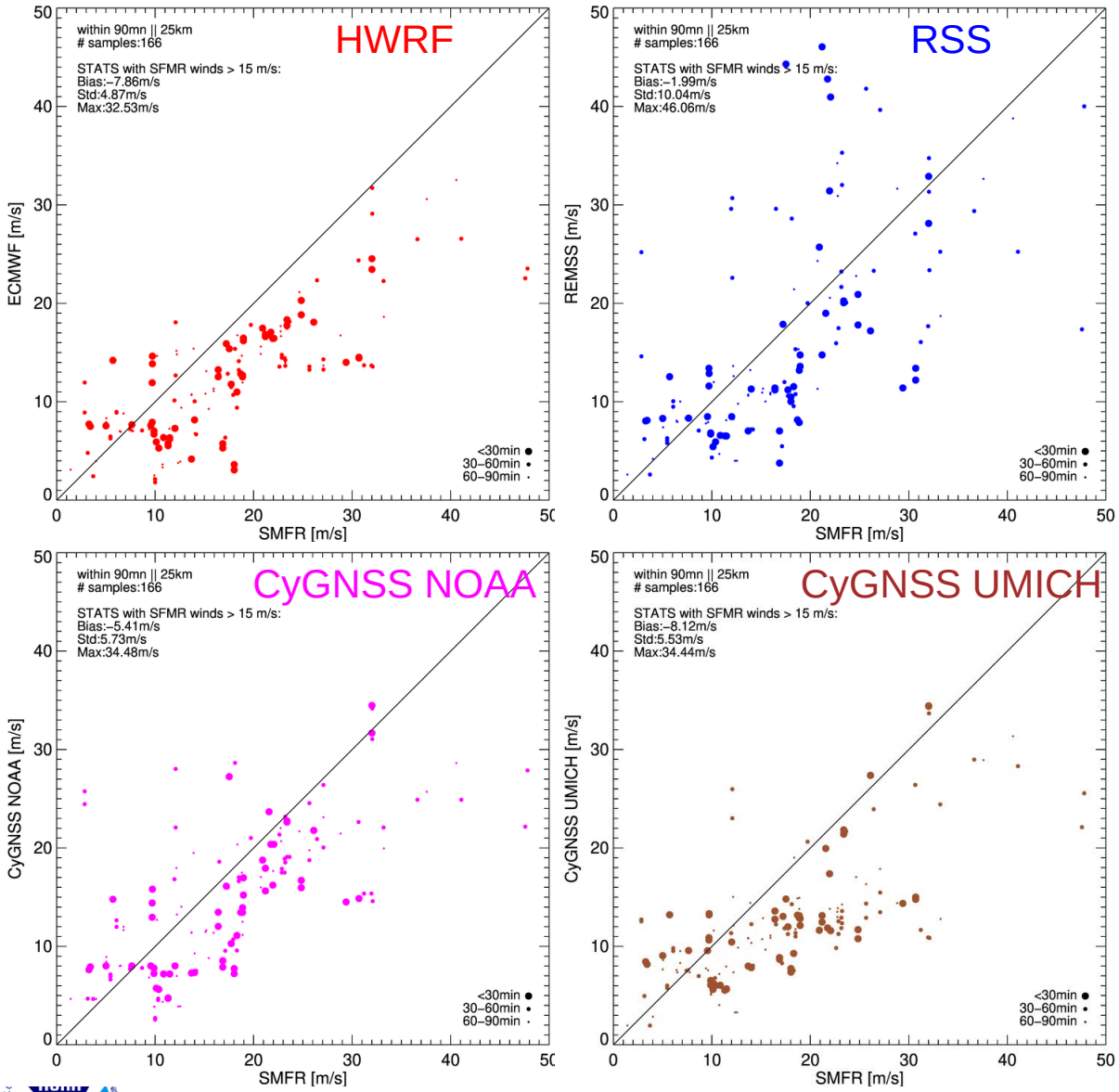


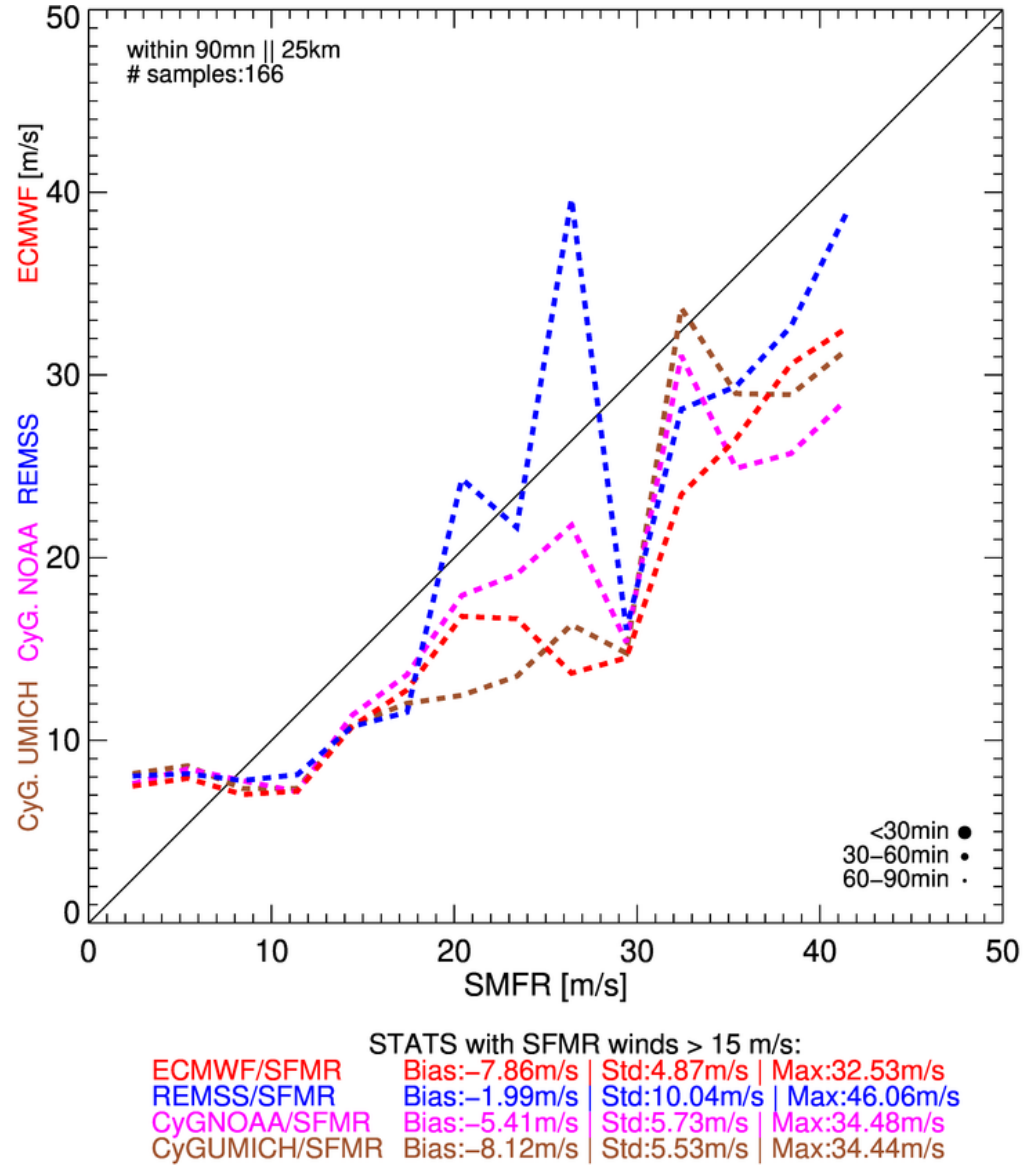


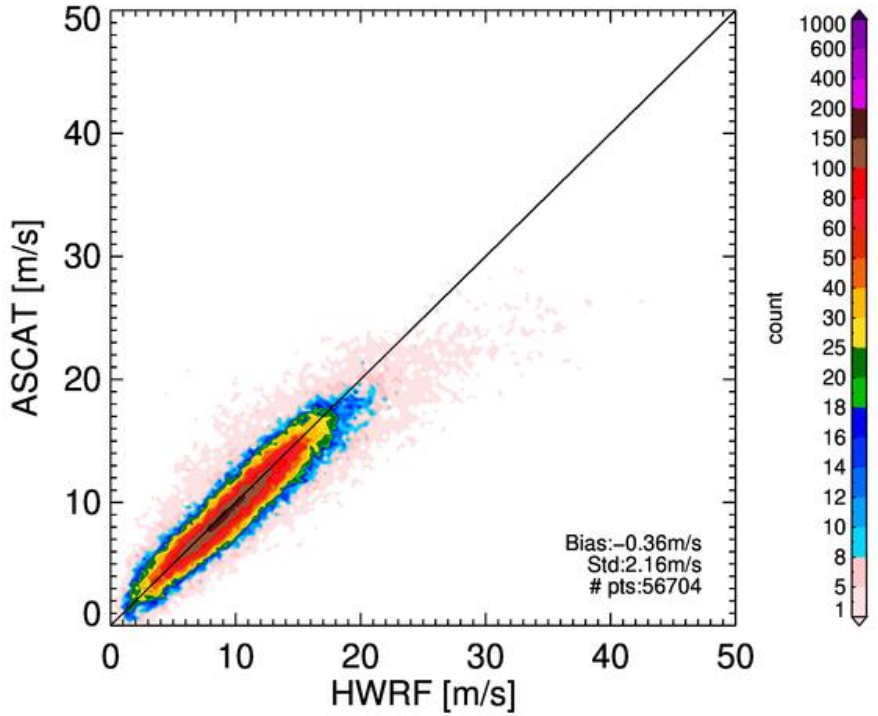


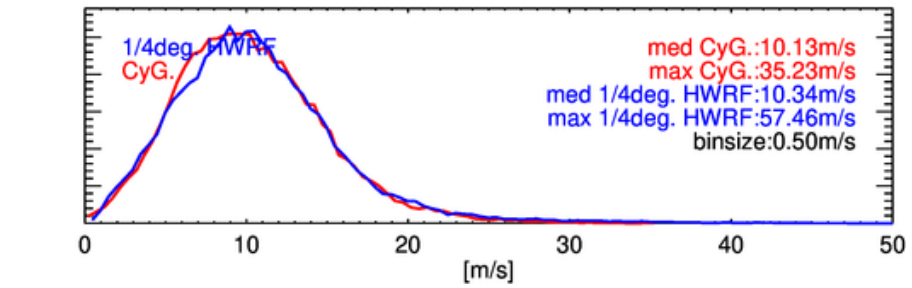
STATS with SFMR winds > 15 m/s:

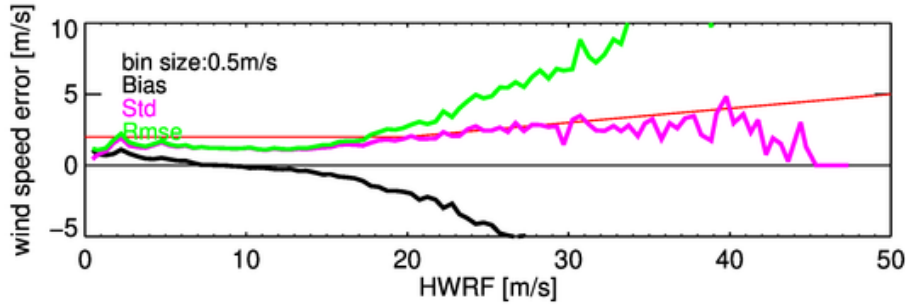
ECMWF/SFMR	Bias:–8.57m/s	Std:6.50m/s	Max:29.19m/s
ASCAT/SFMR	Bias:–5.91m/s	Std:5.12m/s	Max:34.44m/s
CyGNOAA/SFMR	Bias:–4.80m/s	Std:6.03m/s	Max:38.78m/s
CyGUMICH/SFMR	Bias:–6.59m/s	Std:6.37m/s	Max:42.95m/s

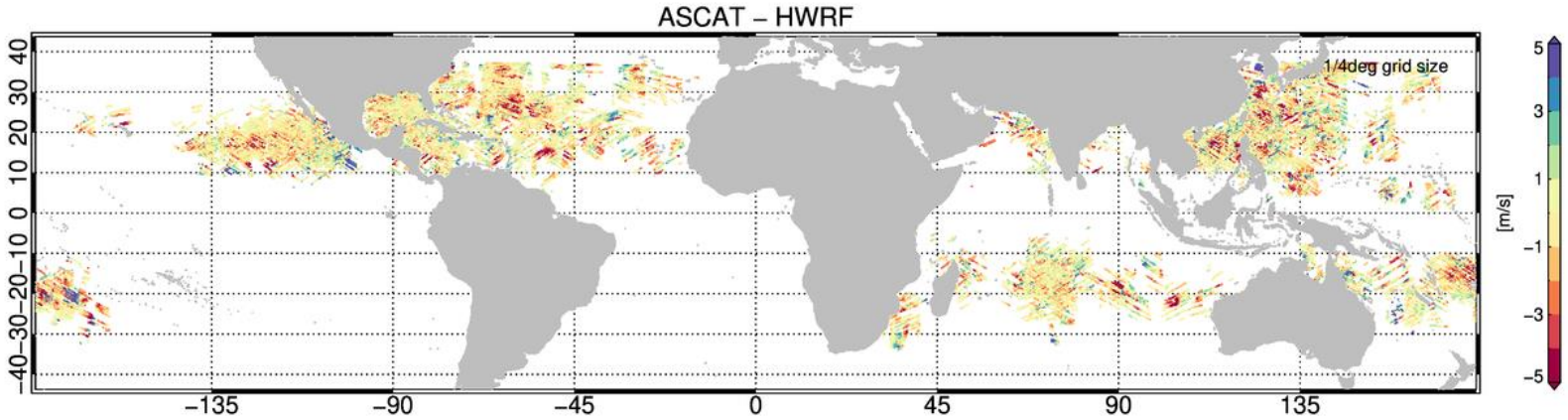

HWRF
within 90mn || 25km
samples:166
STATS with SFMR winds > 15 m/s:
Bias:–7.86m/s
Std:4.87m/s
Max:32.53m/s
ECMWF [m/s]
SMFR [m/s]
<30min
30–60min
60–90min
RSS
within 90mn || 25km
samples:166
STATS with SFMR winds > 15 m/s:
Bias:–1.99m/s
Std:10.04m/s
Max:46.06m/s
REMSS [m/s]
SMFR [m/s]
<30min
30–60min
60–90min
CyGNSS NOAA
within 90mn || 25km
samples:166
STATS with SFMR winds > 15 m/s:
Bias:–5.41m/s
Std:5.73m/s
Max:34.48m/s
CyGNSS NOAA [m/s]
SMFR [m/s]
<30min
30–60min
60–90min
CyGNSS UMICH
within 90mn || 25km
samples:166
STATS with SFMR winds > 15 m/s:
Bias:–8.12m/s
Std:5.53m/s
Max:34.44m/s
CyGNSS UMICH [m/s]
SMFR [m/s]
<30min
30–60min
60–90min

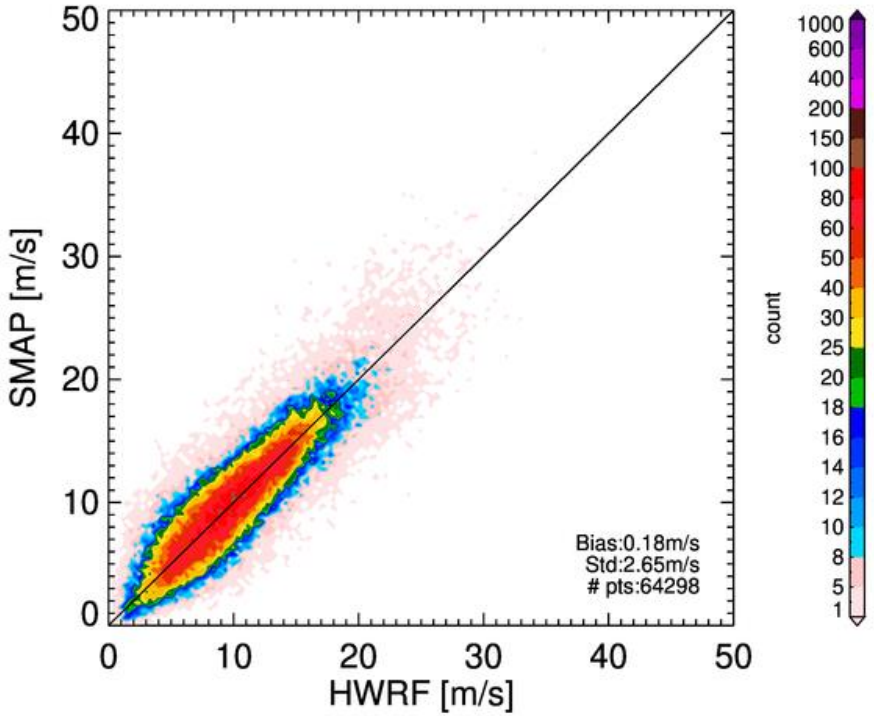

within 90mn || 25km
samples:166
ECMWF [m/s]
REMSS
CyG. NOAA
CyG. UMICH
SMFR [m/s]
<30min
30–60min
60–90min
STATS with SFMR winds > 15 m/s:
ECMWF/SFMR Bias:–7.86m/s | Std:4.87m/s | Max:32.53m/s
REMSS/SFMR Bias:–1.99m/s | Std:10.04m/s | Max:46.06m/s
CyGNOAA/SFMR Bias:–5.41m/s | Std:5.73m/s | Max:34.48m/s
CyGUMICH/SFMR Bias:–8.12m/s | Std:5.53m/s | Max:34.44m/s

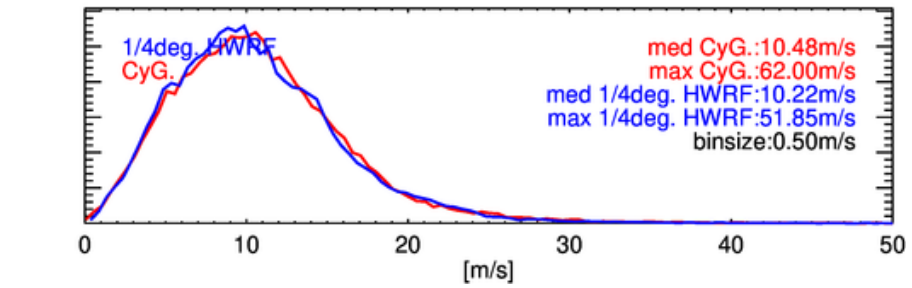

ASCAT [m/s]
HWRF [m/s]
Bias:−0.36m/s
Std:2.16m/s
pts:56704
count
1000
600
400
200
150
100
80
60
50
40
30
25
20
18
16
14
12
10
8
5
1

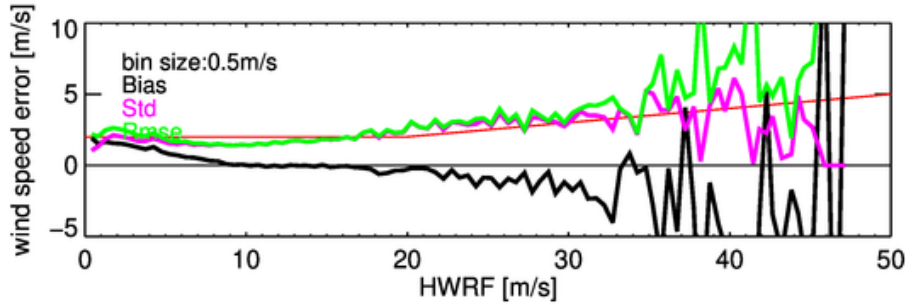

1/4deg. HWRF
CyG.
med CyG.:10.13m/s
max CyG.:35.23m/s
med 1/4deg. HWRF:10.34m/s
max 1/4deg. HWRF:57.46m/s
binsize:0.50m/s
[m/s]

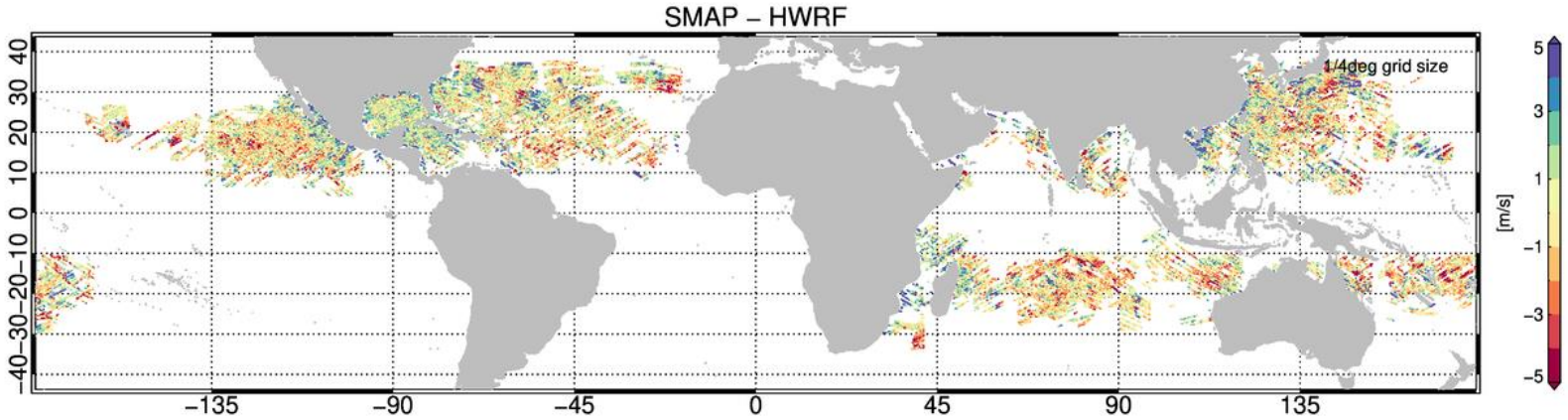

wind speed error [m/s]
bin size:0.5m/s
Bias
Std
Rmse
HWRF [m/s]


ASCAT – HWRF
1/4deg grid size
[m/s]


SMAP [m/s]
HWRF [m/s]
count
Bias:0.18m/s
Std:2.65m/s
pts:64298


1/4deg. HWRF
CyG.
med CyG.:10.48m/s
max CyG.:62.00m/s
med 1/4deg. HWRF:10.22m/s
max 1/4deg. HWRF:51.85m/s
binsize:0.50m/s
[m/s]


wind speed error [m/s]
bin size:0.5m/s
Bias
Std
Rmse
HWRF [m/s]


SMAP – HWRF
1/4deg grid size
[m/s]