Preliminary comparison of the various CyGNSS Wind Products available on the PO.DAAC
and
an overview of NOAA CyGNSS winds v1.1

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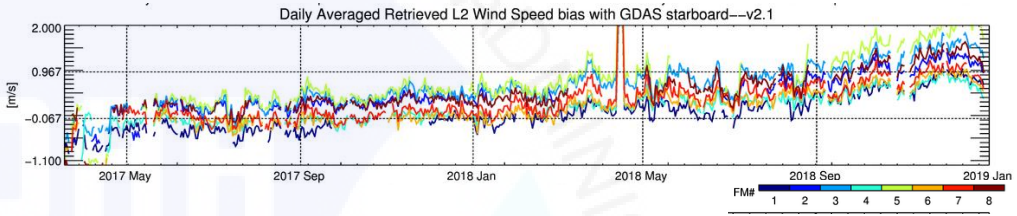
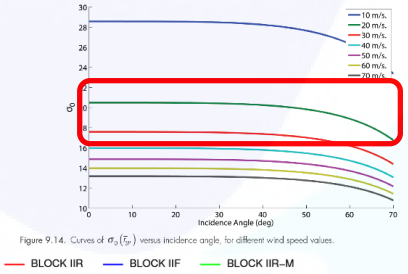
[2]Global Science & Technology, Inc.
[3]UCAR

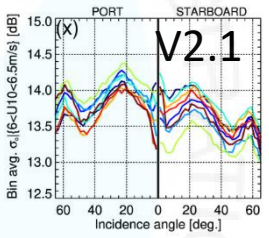
Why so many versions?

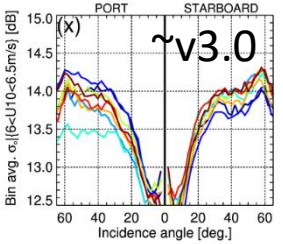
Cal/Val challenges:

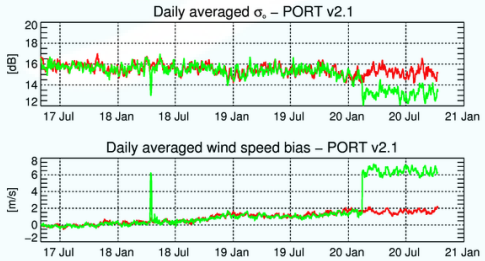
- 8 spacecraft, each with two receiving antennas
- No control and exact knowledge of the transmitted signals originating from **31** GPS satellites
- Received signal is quite sensitive to the transmit power and CyGNSS receiver antenna gain characteristics

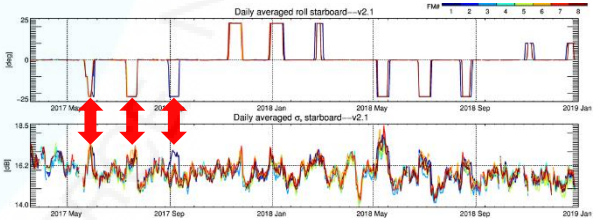












As a result, it is key to ensure

- the absence of inter-satellite sigma0 biases
- absence of sigma0 biases between receive antennas
- verify sigma0 dependence as a function of incidence angle
- absence of biases due to GPS block type
- no attitude variation impact to the sigma0
- no signal drift

Wind product must show consistency and reliability

CyGNSS L2 wind products (found on the PO.DAAC)

Product name	Level 1 source	Highlights
(UMICH) CyGNSS v2.1	v2.1	-uses their in-house 'minimum variance' retrieval technique -provides two different wind speed products ('fully-developed sea' --fds--and 'young sea limited fetch' --yslf--) -excludes IIF data -25km wind speed samples provided at each DDM location
(UMICH) CyGNSS CDR v1.0	v2.1	-performs a sigma0 correction on a track-by-track basis (inspired from NOAA[(1)]) -as such, requires the use of ancillary data (Merra2 winds) -similar retrieval method as UMICH v2.1 -also outputs two wind speed products -restores IIF data -lots of data being flagged -~2.5 months delay -25km wind speed samples provided at each DDM location
(UMICH) CyGNSS v3.0	v3.0	-same retrieval technique as v2.1 -also outputs two wind speed products -key difference is the use of a different Level 1 sigma0 data, which supposedly better accounts for the GPS transmit power while estimating sigma0 -25km wind speed samples provided at each DDM location
NOAA CyGNSS winds v1.1	v2.1	-performs a sigma0 correction on a track-by-track basis in order to remove unwanted intersatellite biases including 'inter-GPS block type' related biases -ancillary data used from ECMWF winds and IFREMER Wavewatch 3 significant waveheight -outputs a single wind speed product -25km 'along-track' gridded product **with no overlap between grid cells** -provided in 'near-real time'

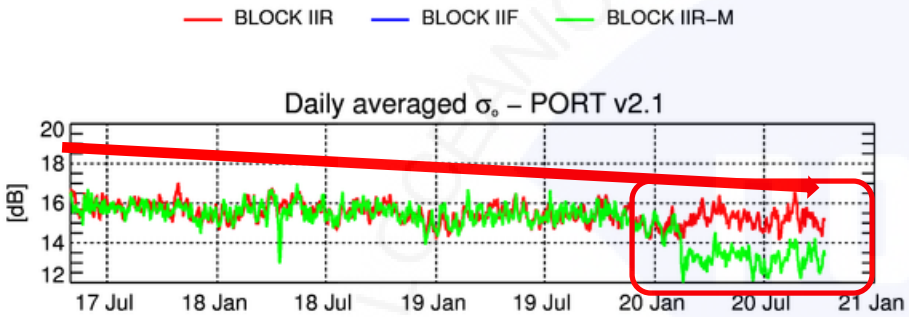
[(1)] Said, F., Jelenak, Z., Park, J., Soisuvarn, S., & Chang, P. S. (2019). *First Look at NOAA CyGNSS winds in the Tropical Cyclone Environment.* NOAA. Benevento: IEEE GNSS+R 2019. Retrieved from http://www.gnssr2019.org/files/gnssr_mtg_noaa_20190521_final[2454].pdf

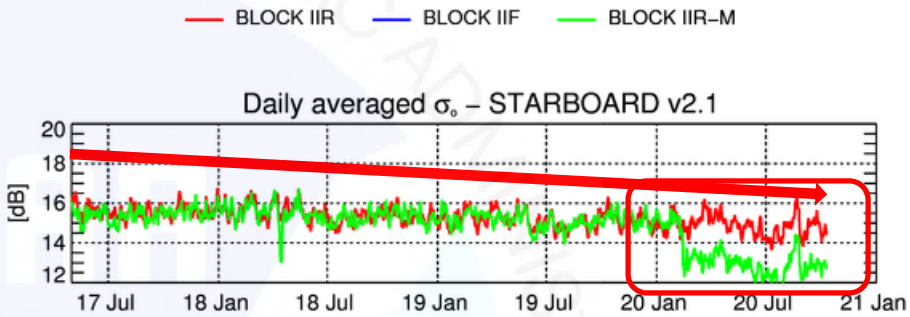
Said, F., Jelenak, Z., Chang, P. S., & Soisuvarn, S. (2019). An assessment of CyGNSS normalized radar cross section calibration. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 50-65

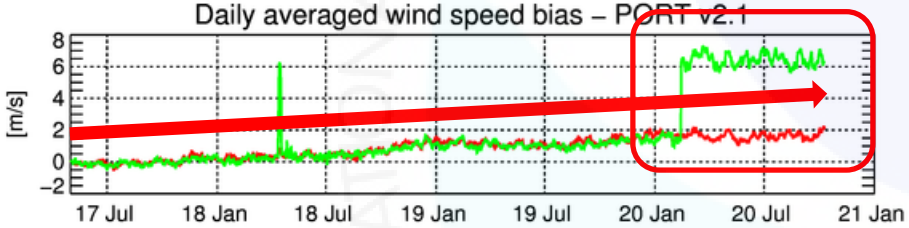
A closer look at the differences using timeseries

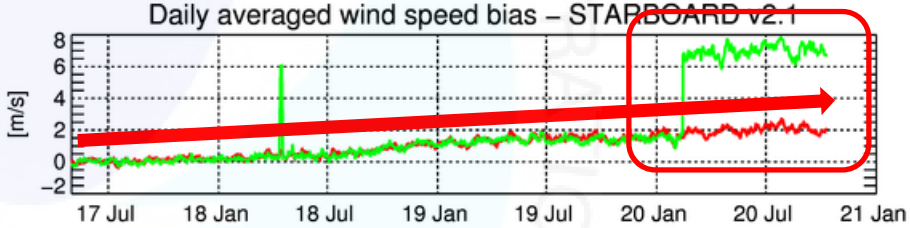
data separated by
GPS block types
and
CyGNSS antenna
(wind speed bias/std error with ECMWF)

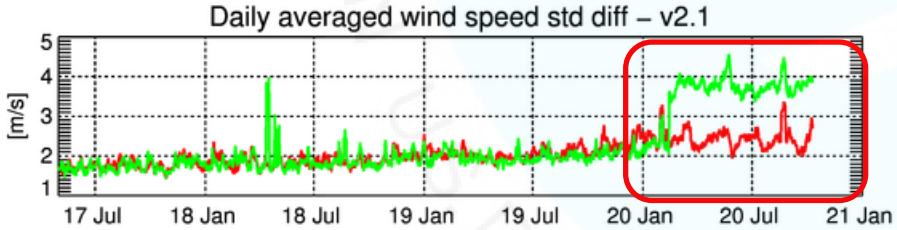
v2.1

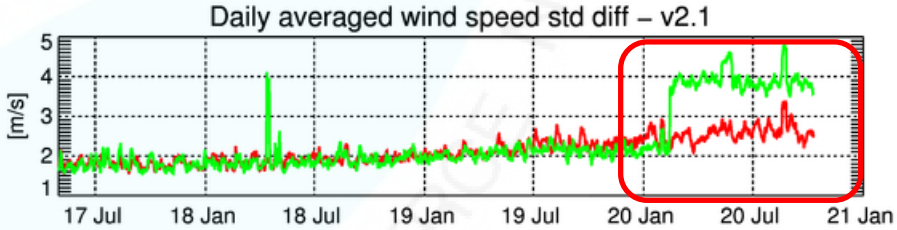

BLOCK IIR
BLOCK IIF
BLOCK IIR–M
Daily averaged σ₀ – PORT v2.1
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


BLOCK IIR
BLOCK IIF
BLOCK IIR–M
Daily averaged σ₀ – STARBOARD v2.1
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

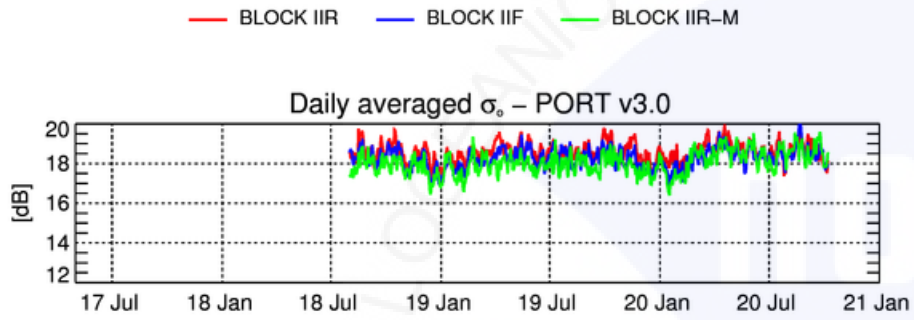

Daily averaged wind speed bias – PORT v2.1
[m/s]
8
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

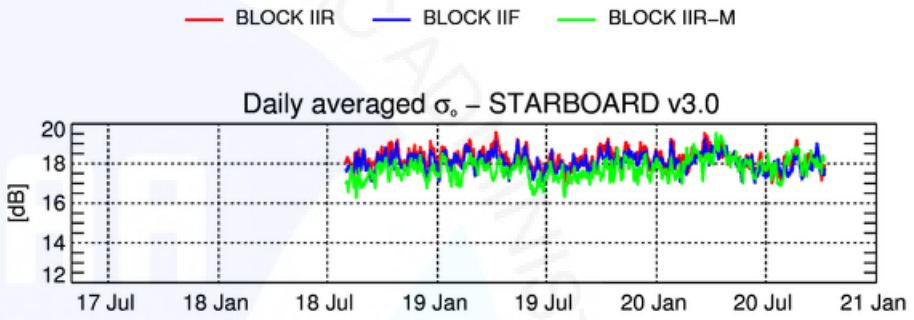

Daily averaged wind speed bias – STARBOARD v2.1
[m/s]
8
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

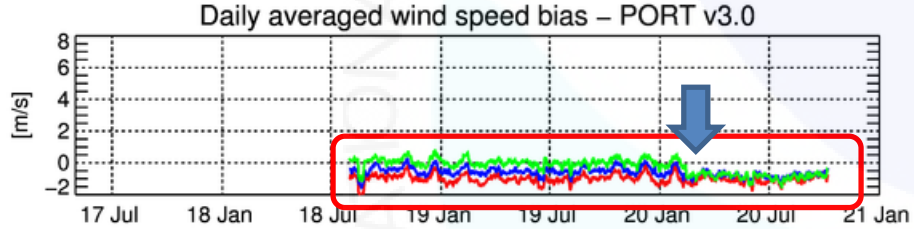

Daily averaged wind speed std diff – v2.1
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

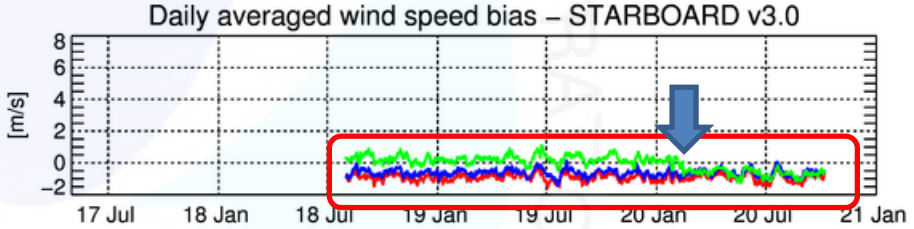

Daily averaged wind speed std diff – v2.1
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

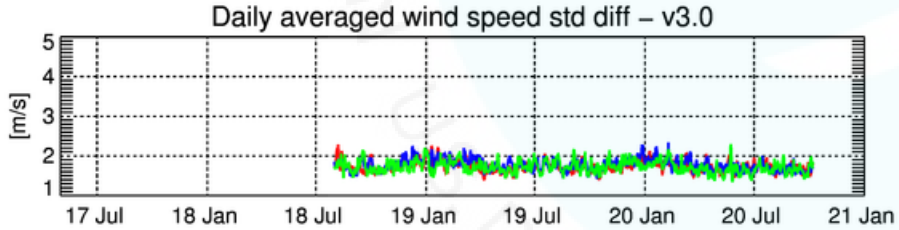
v3.0

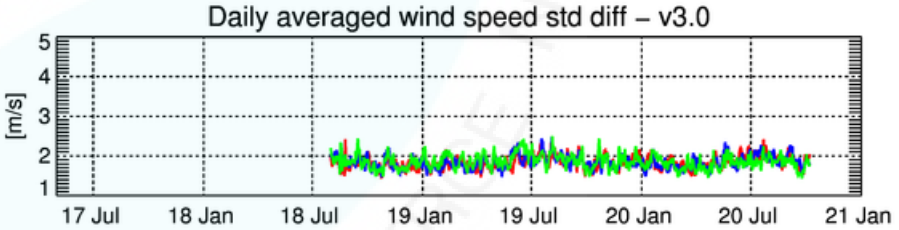

BLOCK IIR
BLOCK IIF
BLOCK IIR–M
Daily averaged σ₀ – PORT v3.0
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


BLOCK IIR
BLOCK IIF
BLOCK IIR–M
Daily averaged σ₀ – STARBOARD v3.0
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

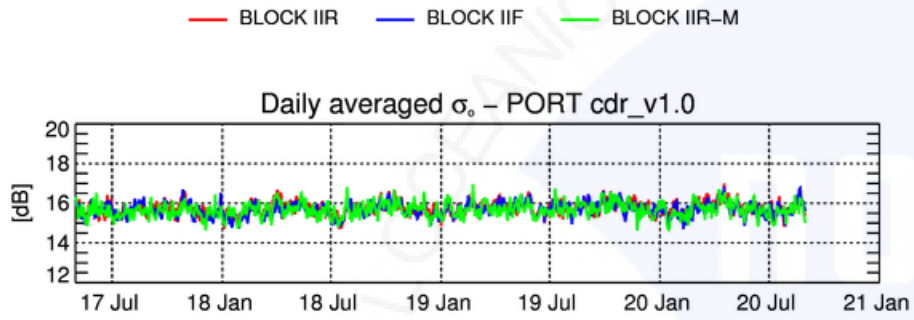

Daily averaged wind speed bias – PORT v3.0
[m/s]
8
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

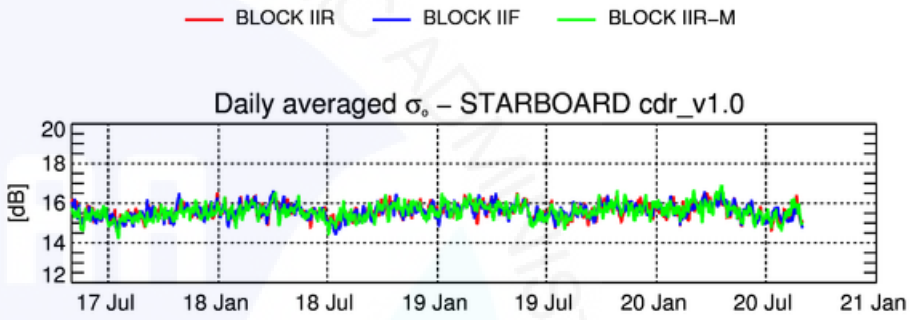

Daily averaged wind speed bias – STARBOARD v3.0
[m/s]
8
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

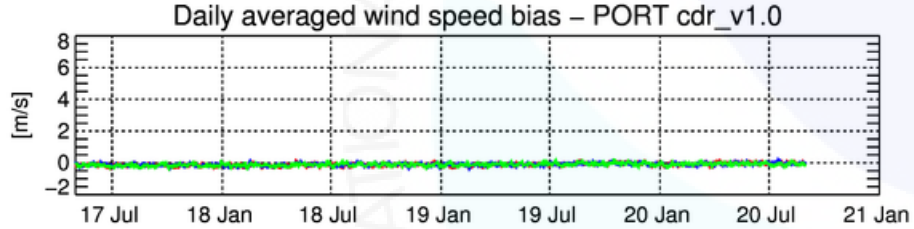

Daily averaged wind speed std diff – v3.0
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

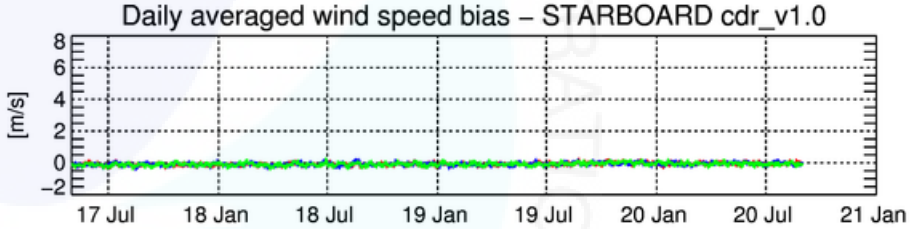

Daily averaged wind speed std diff – v3.0
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

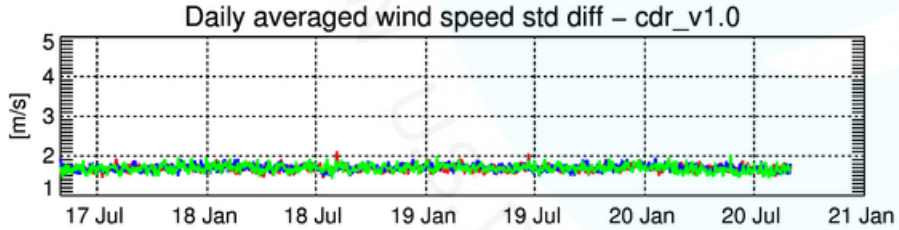
CDR v1.0

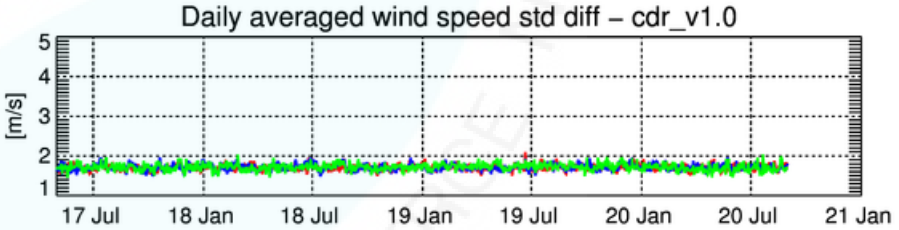

BLOCK IIR
BLOCK IIF
BLOCK IIR–M
Daily averaged σ₀ – PORT cdr_v1.0
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


BLOCK IIR
BLOCK IIF
BLOCK IIR–M
Daily averaged σ₀ – STARBOARD cdr_v1.0
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

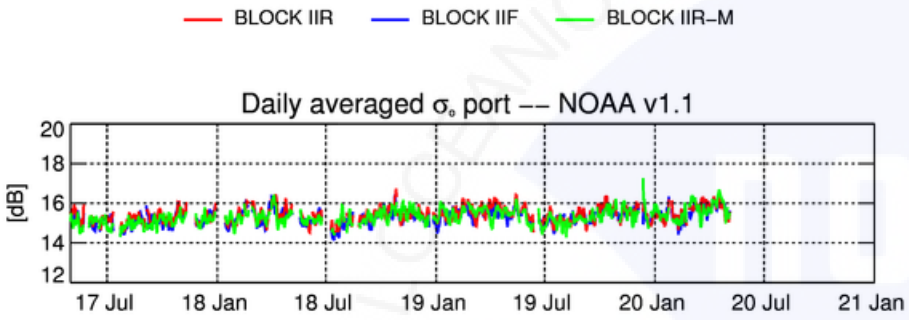

Daily averaged wind speed bias – PORT cdr_v1.0
[m/s]
8
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

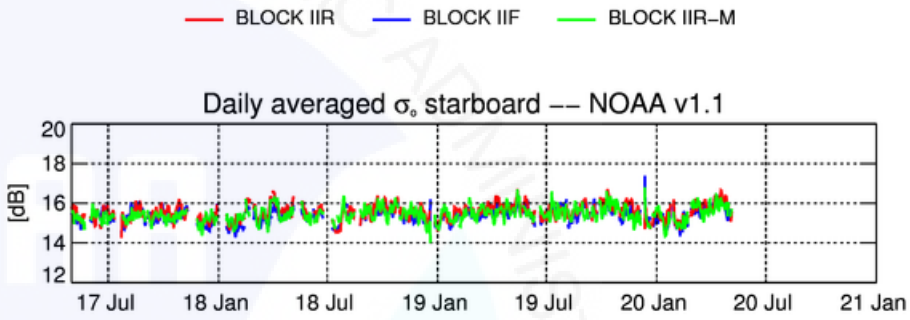

Daily averaged wind speed bias – STARBOARD cdr_v1.0
[m/s]
8
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

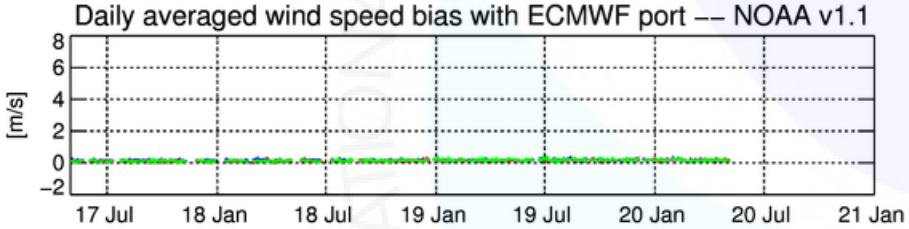

Daily averaged wind speed std diff – cdr_v1.0
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

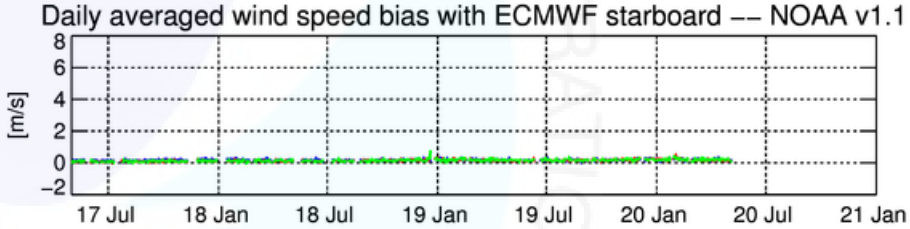

Daily averaged wind speed std diff – cdr_v1.0
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

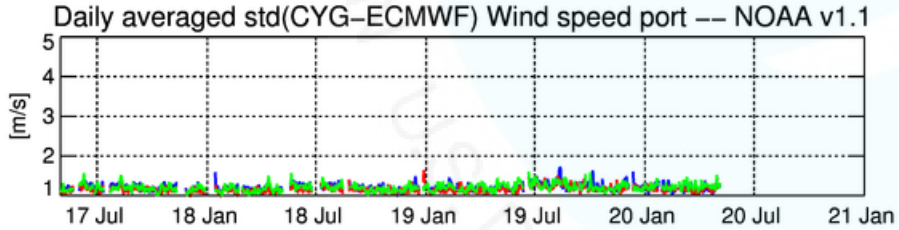
NOAA v1.1

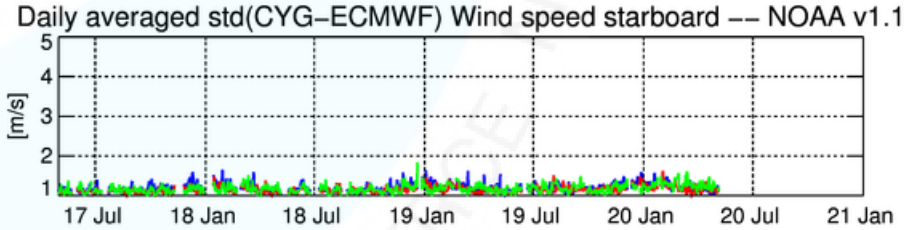

BLOCK IIR
BLOCK IIF
BLOCK IIR–M
Daily averaged σ₀ port –– NOAA v1.1
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


BLOCK IIR
BLOCK IIF
BLOCK IIR–M
Daily averaged σ₀ starboard –– NOAA v1.1
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged wind speed bias with ECMWF port –– NOAA v1.1
[m/s]
8
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

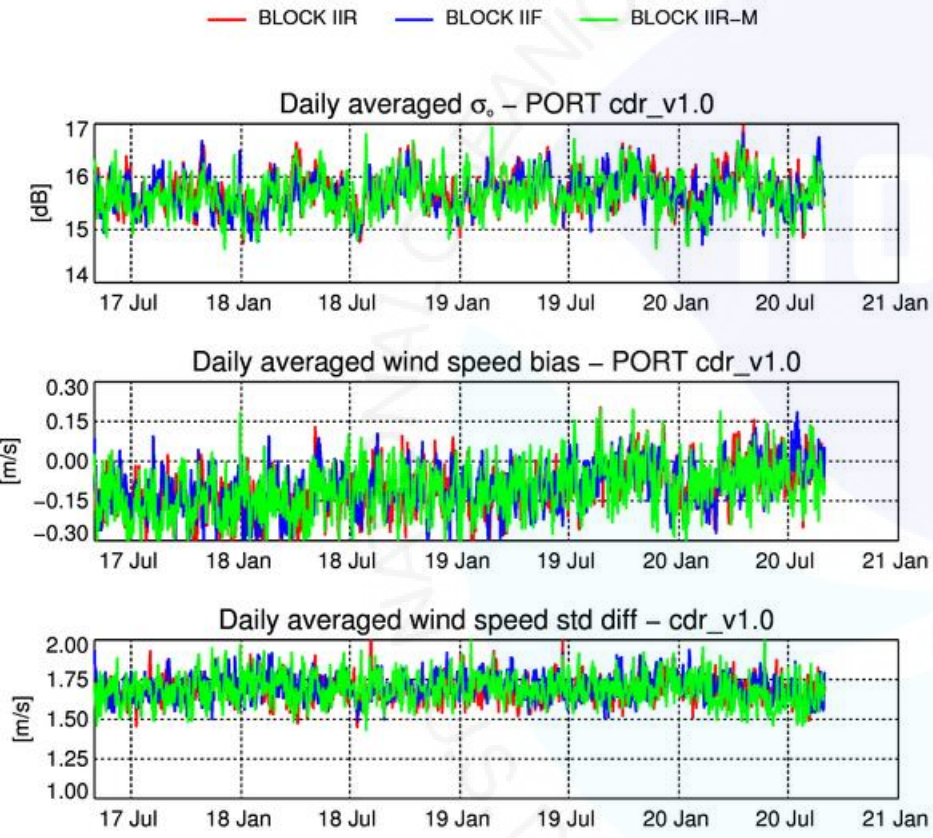

Daily averaged wind speed bias with ECMWF starboard –– NOAA v1.1
[m/s]
8
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

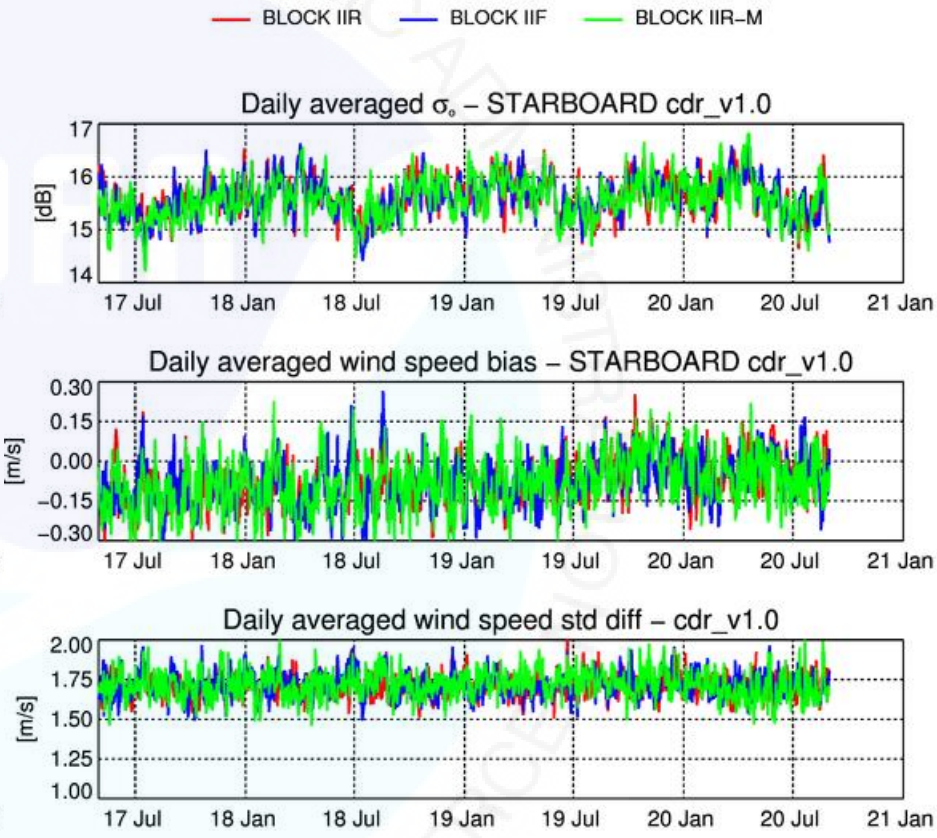

Daily averaged std(CYG–ECMWF) Wind speed port –– NOAA v1.1
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged std(CYG–ECMWF) Wind speed starboard –– NOAA v1.1
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

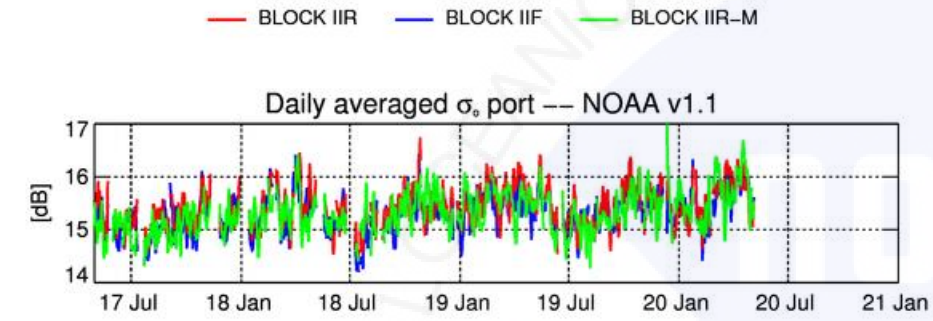
CDR v1.0 vs NOAA v1.1
(Y axes zoomed in)

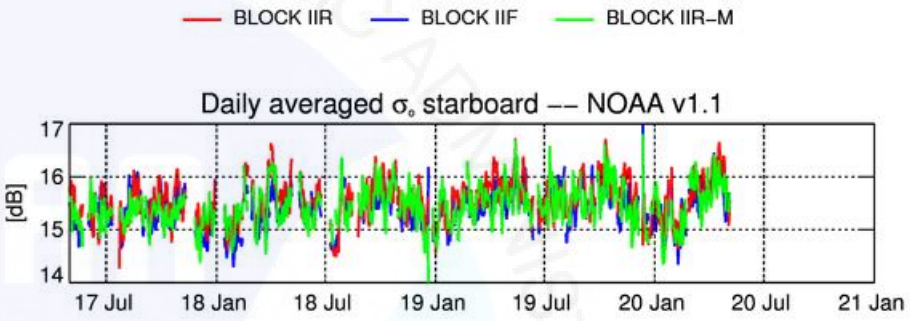
CDR v1.0

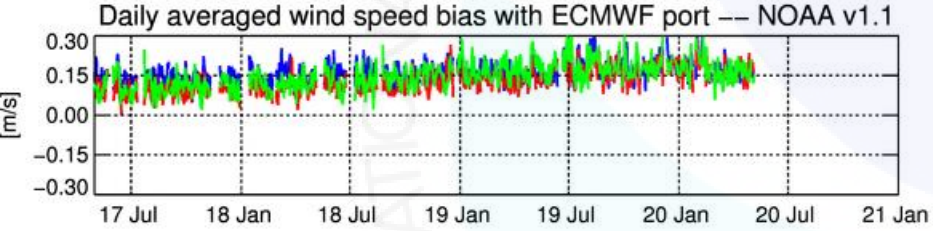

BLOCK IIR
BLOCK IIF
BLOCK IIR-M
Daily averaged σ₀ – PORT cdr_v1.0
[dB]
17
16
15
14
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan
Daily averaged wind speed bias – PORT cdr_v1.0
[m/s]
0.30
0.15
0.00
−0.15
−0.30
Daily averaged wind speed std diff – cdr_v1.0
[m/s]
2.00
1.75
1.50
1.25
1.00

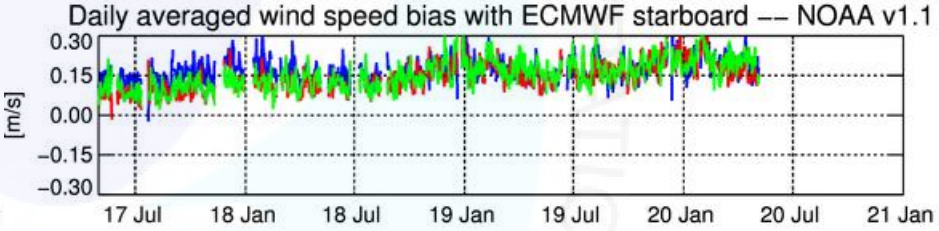

BLOCK IIR
BLOCK IIF
BLOCK IIR-M
Daily averaged σ₀ – STARBOARD cdr_v1.0
[dB]
17
16
15
14
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan
Daily averaged wind speed bias – STARBOARD cdr_v1.0
[m/s]
0.30
0.15
0.00
−0.15
−0.30
Daily averaged wind speed std diff – cdr_v1.0
[m/s]
2.00
1.75
1.50
1.25
1.00

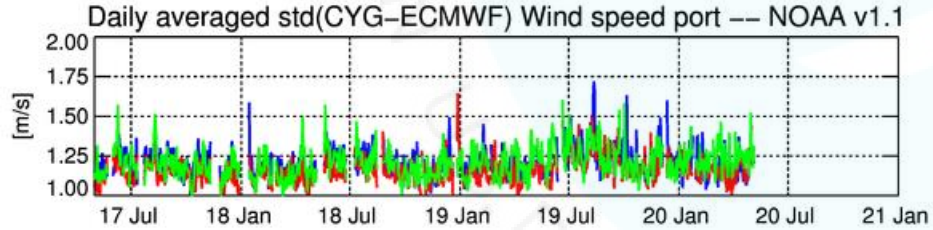
NOAA v1.1

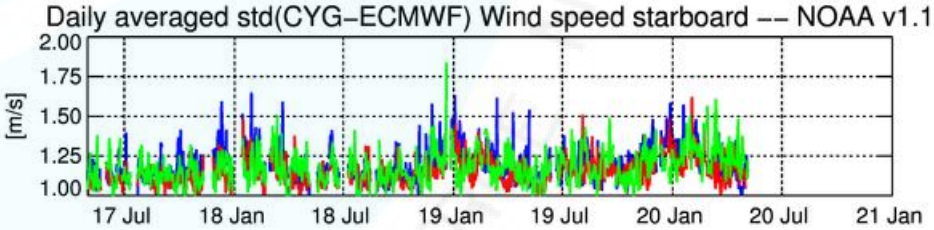

BLOCK IIR
BLOCK IIF
BLOCK IIR–M
Daily averaged σ₀ port –– NOAA v1.1
[dB]
17
16
15
14
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


BLOCK IIR
BLOCK IIF
BLOCK IIR–M
Daily averaged σ₀ starboard –– NOAA v1.1
[dB]
17
16
15
14
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged wind speed bias with ECMWF port –– NOAA v1.1
[m/s]
0.30
0.15
0.00
−0.15
−0.30
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

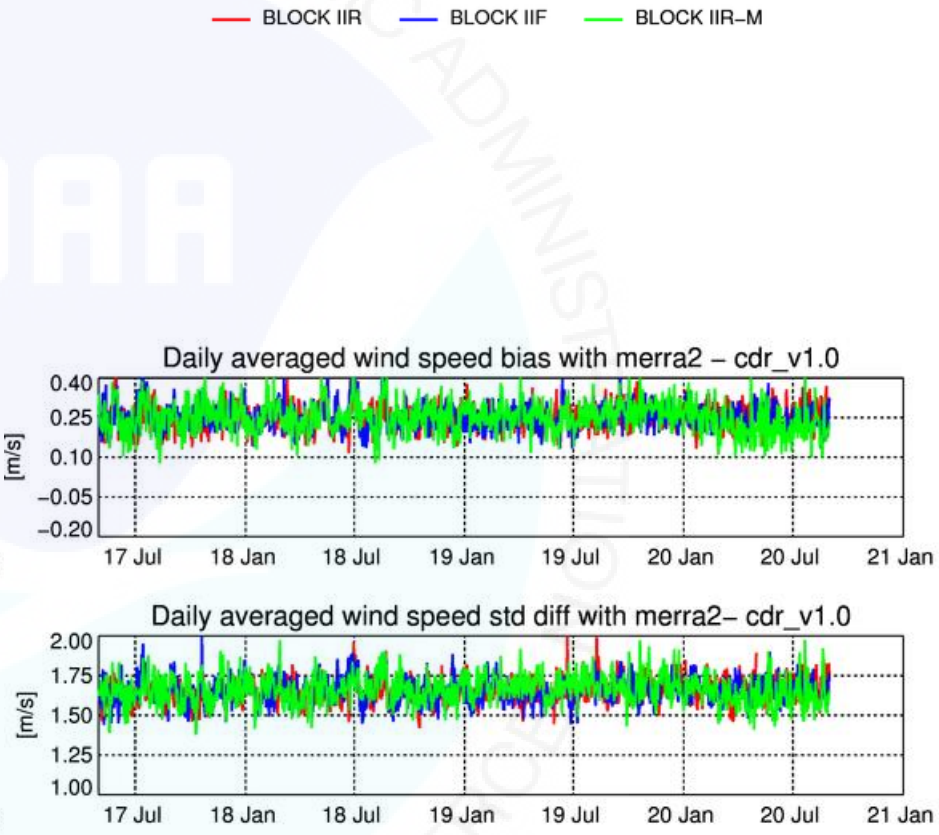

Daily averaged wind speed bias with ECMWF starboard –– NOAA v1.1
[m/s]
0.30
0.15
0.00
−0.15
−0.30
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged std(CYG–ECMWF) Wind speed port –– NOAA v1.1
[m/s]
2.00
1.75
1.50
1.25
1.00
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

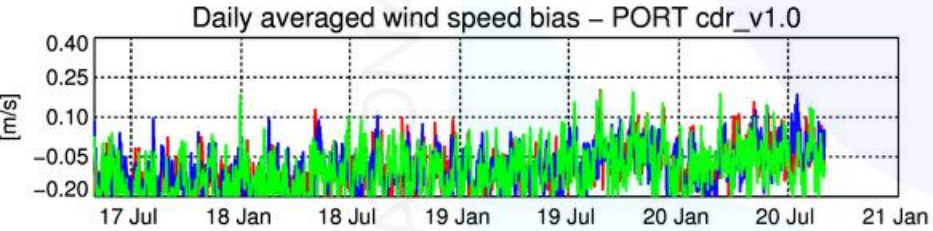

Daily averaged std(CYG–ECMWF) Wind speed starboard –– NOAA v1.1
[m/s]
2.00
1.75
1.50
1.25
1.00
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

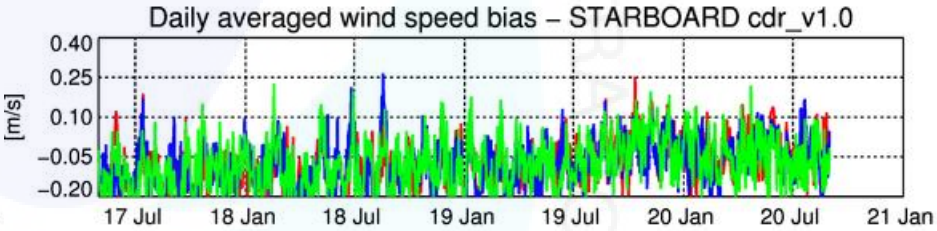
CDR v1.0
Compared to MERRA-2 winds and ECMWF

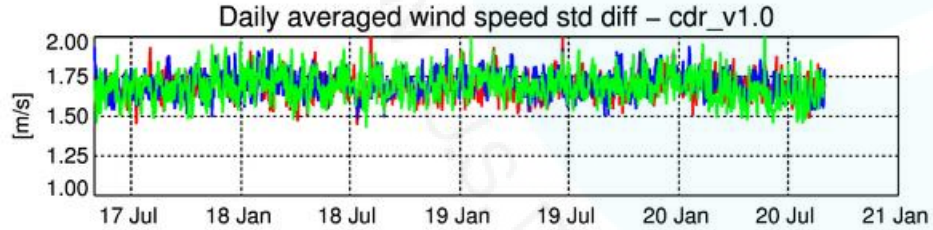
CDR v1.0 wind compared to Merra 2

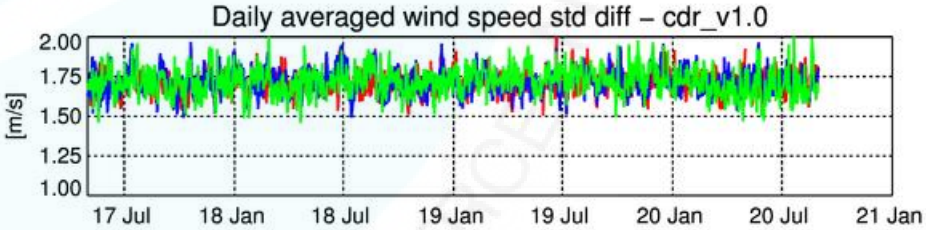


CDR v1.0 compared to ECMWF







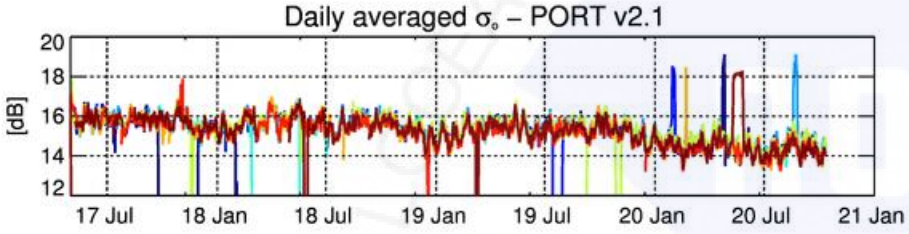


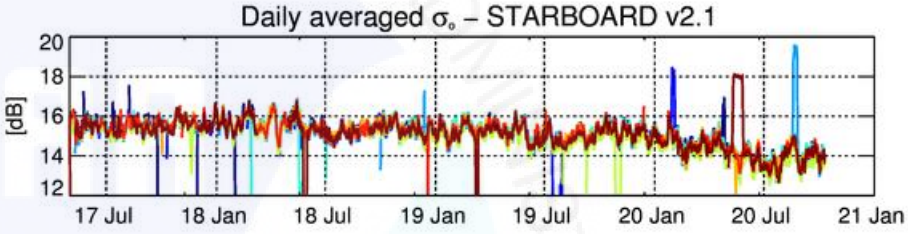
Data now separated by
CyGNSS observatory
and
CyGNSS antenna
(wind speed bias/std error with ECMWF)

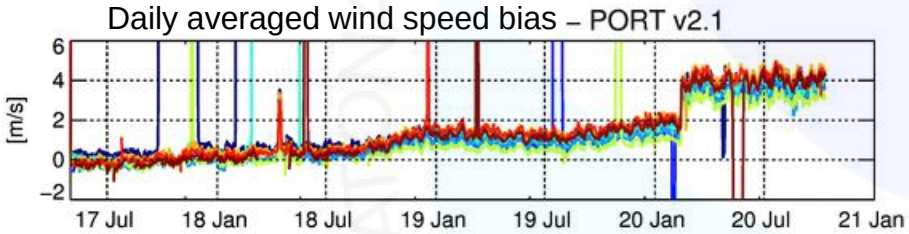
v2.1

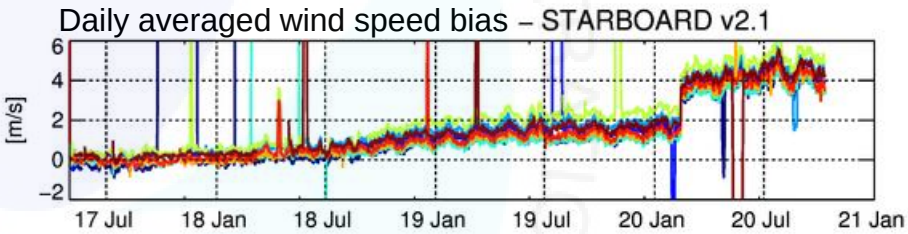
1 2 3 4 5 6 7 8

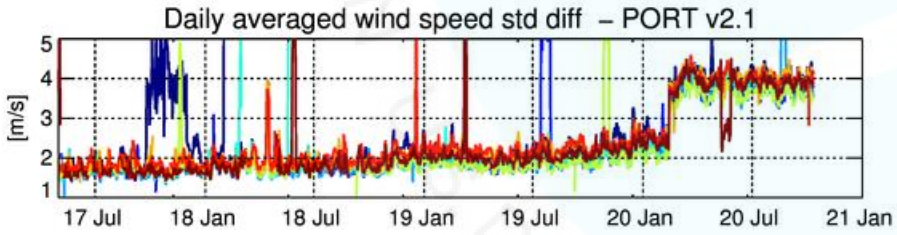
1 2 3 4 5 6 7 8

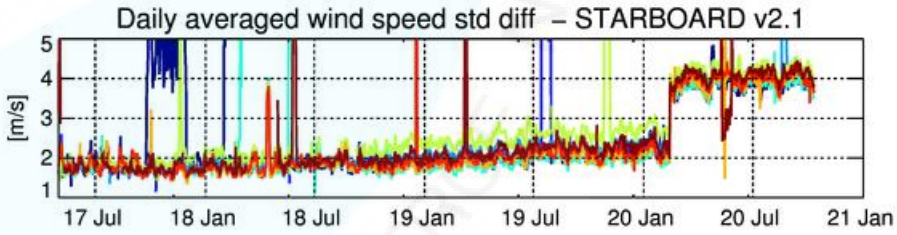

Daily averaged σ₀ – PORT v2.1
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged σ₀ – STARBOARD v2.1
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged wind speed bias – PORT v2.1
[m/s]
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged wind speed bias – STARBOARD v2.1
[m/s]
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

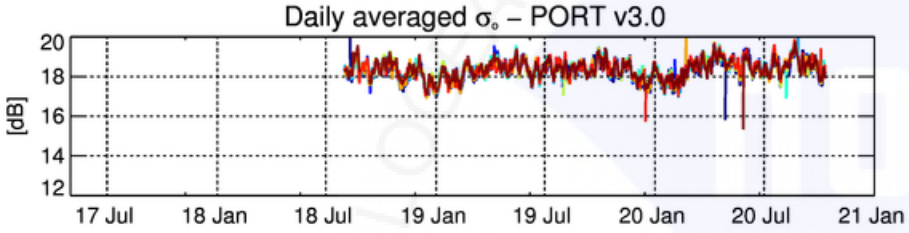

Daily averaged wind speed std diff – PORT v2.1
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

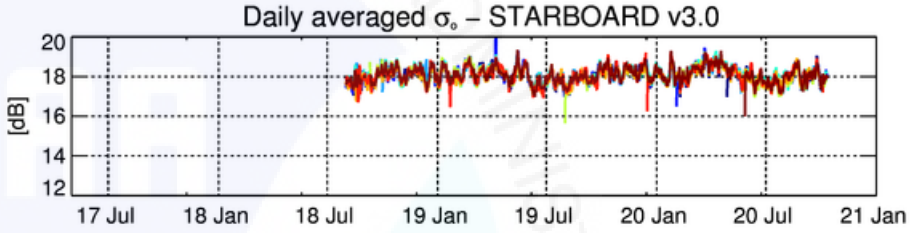

Daily averaged wind speed std diff – STARBOARD v2.1
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

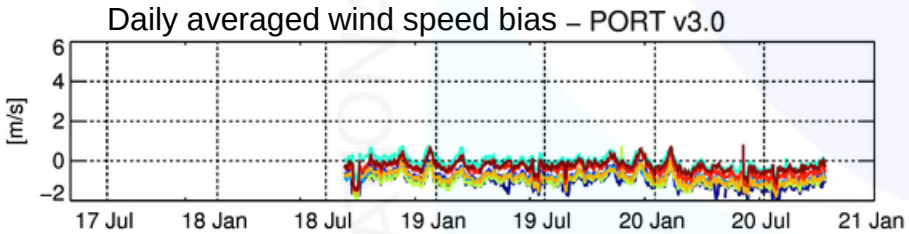
v3.0

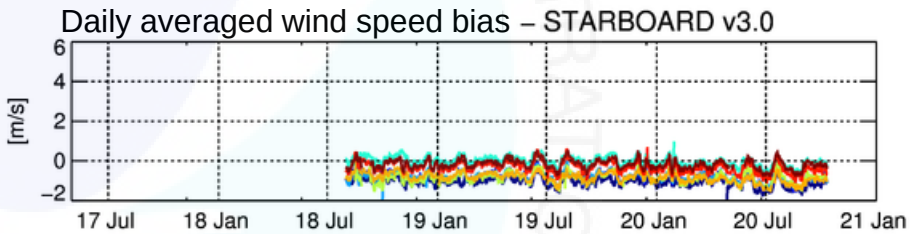
1 2 3 4 5 6 7 8

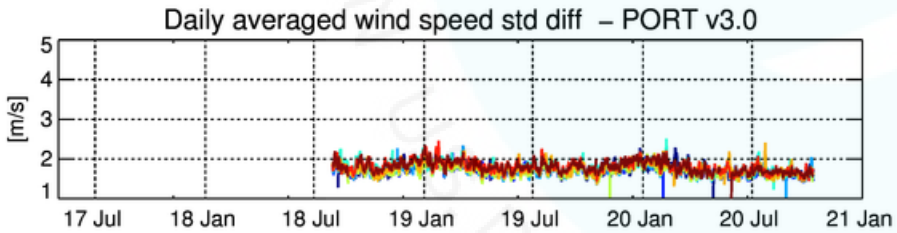
1 2 3 4 5 6 7 8

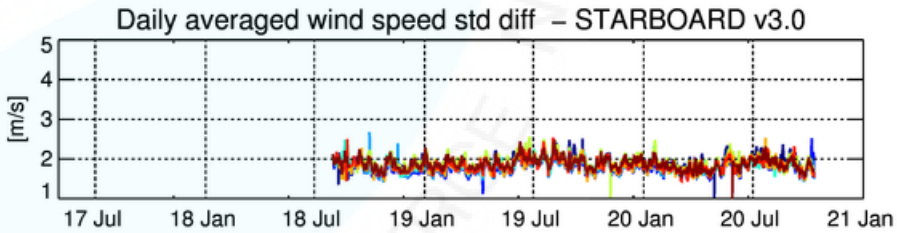

Daily averaged σ₀ – PORT v3.0
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged σ₀ – STARBOARD v3.0
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

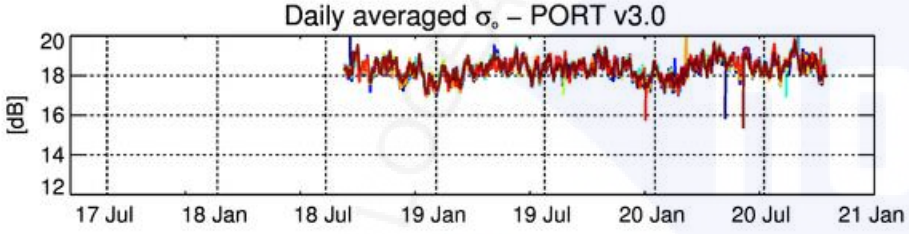

Daily averaged wind speed bias – PORT v3.0
[m/s]
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

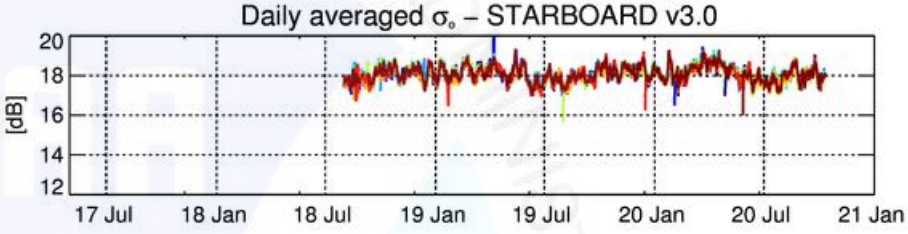

Daily averaged wind speed bias – STARBOARD v3.0
[m/s]
6
4
2
0
−2
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

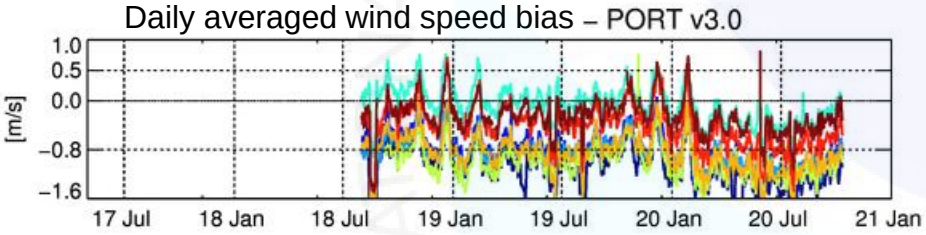

Daily averaged wind speed std diff – PORT v3.0
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

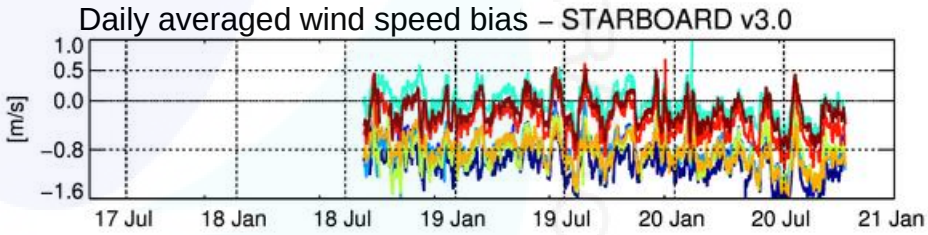

Daily averaged wind speed std diff – STARBOARD v3.0
[m/s]
5
4
3
2
1
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

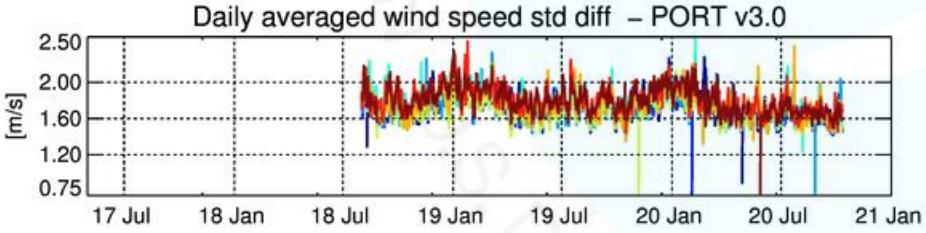
v3.0 (same plots but different wind speed axes)

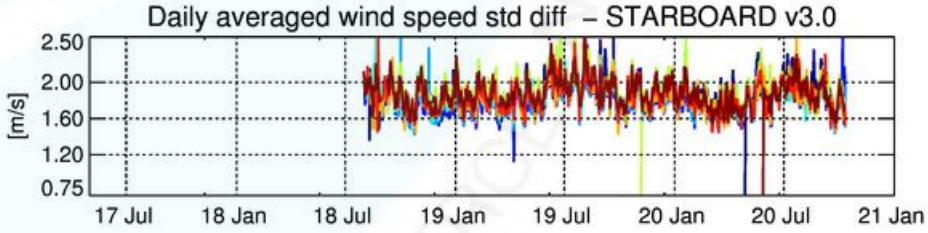








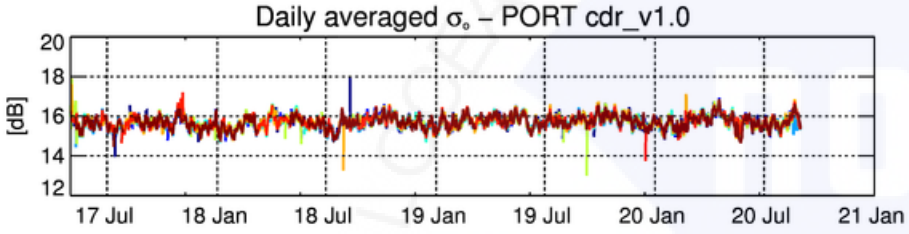


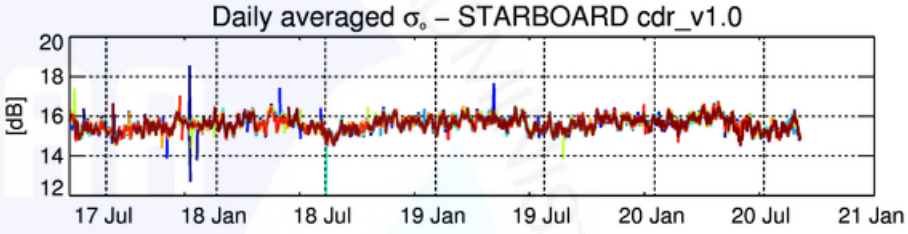


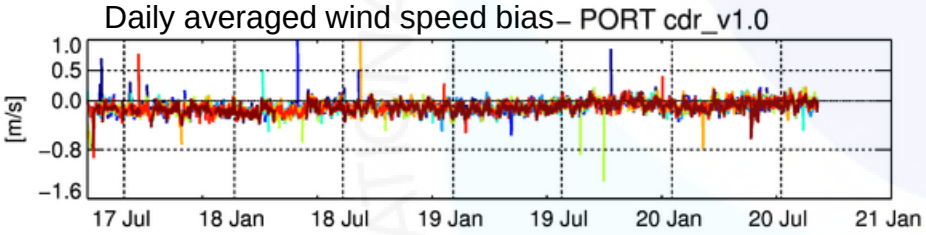
cdr v1.0

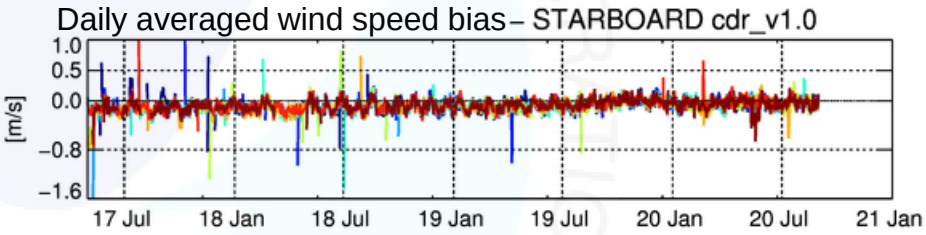
1 2 3 4 5 6 7 8

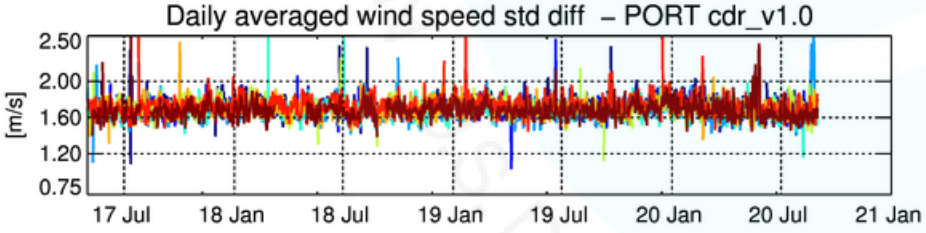
1 2 3 4 5 6 7 8

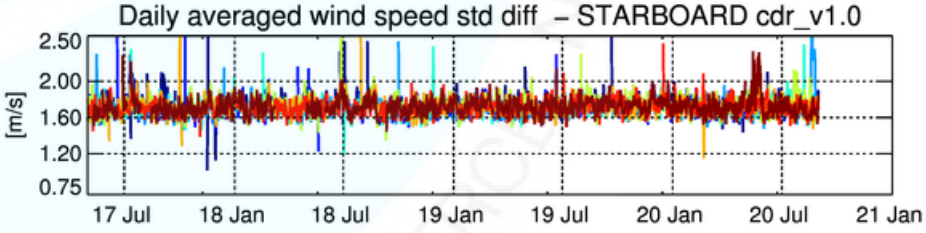

Daily averaged σ₀ – PORT cdr_v1.0
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged σ₀ – STARBOARD cdr_v1.0
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged wind speed bias– PORT cdr_v1.0
[m/s]
1.0
0.5
0.0
−0.8
−1.6
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged wind speed bias– STARBOARD cdr_v1.0
[m/s]
1.0
0.5
0.0
−0.8
−1.6
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

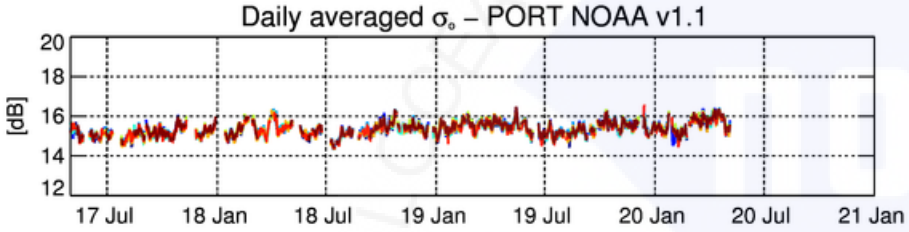

Daily averaged wind speed std diff – PORT cdr_v1.0
[m/s]
2.50
2.00
1.60
1.20
0.75
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

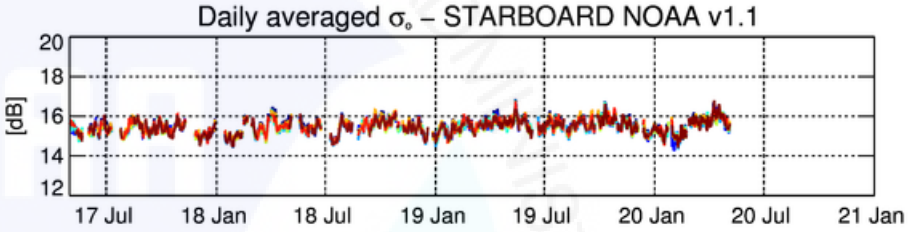

Daily averaged wind speed std diff – STARBOARD cdr_v1.0
[m/s]
2.50
2.00
1.60
1.20
0.75
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

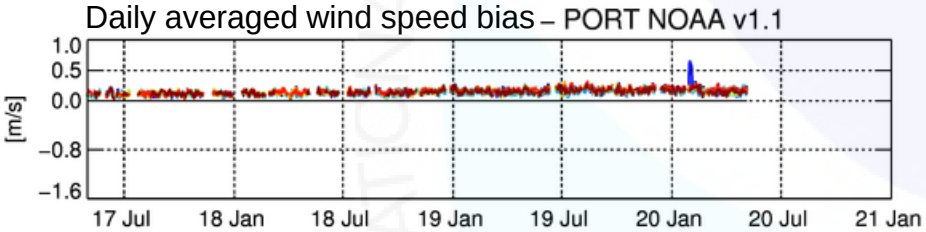
NOAA v1.1

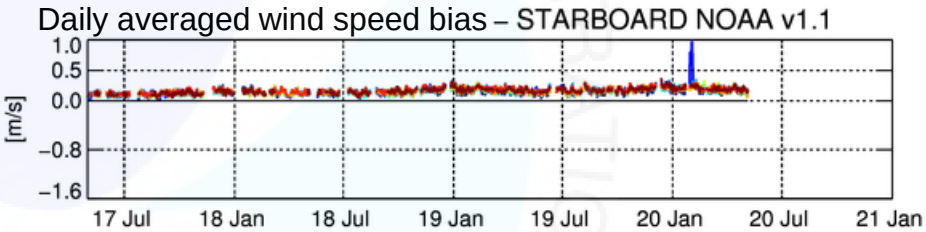
1 2 3 4 5 6 7 8

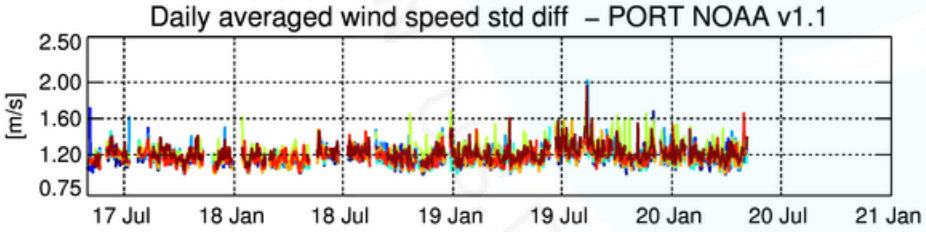
1 2 3 4 5 6 7 8

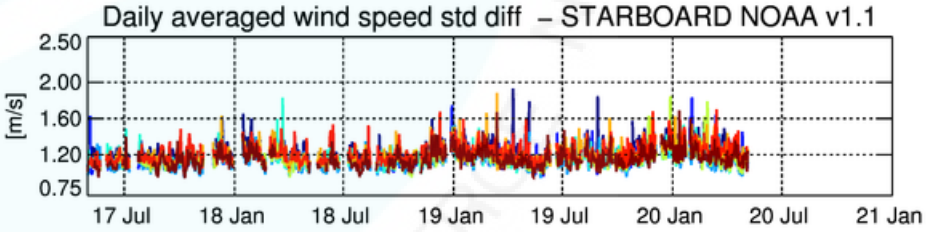

Daily averaged σ₀ – PORT NOAA v1.1
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged σ₀ – STARBOARD NOAA v1.1
[dB]
20
18
16
14
12
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged wind speed bias – PORT NOAA v1.1
[m/s]
1.0
0.5
0.0
−0.8
−1.6
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

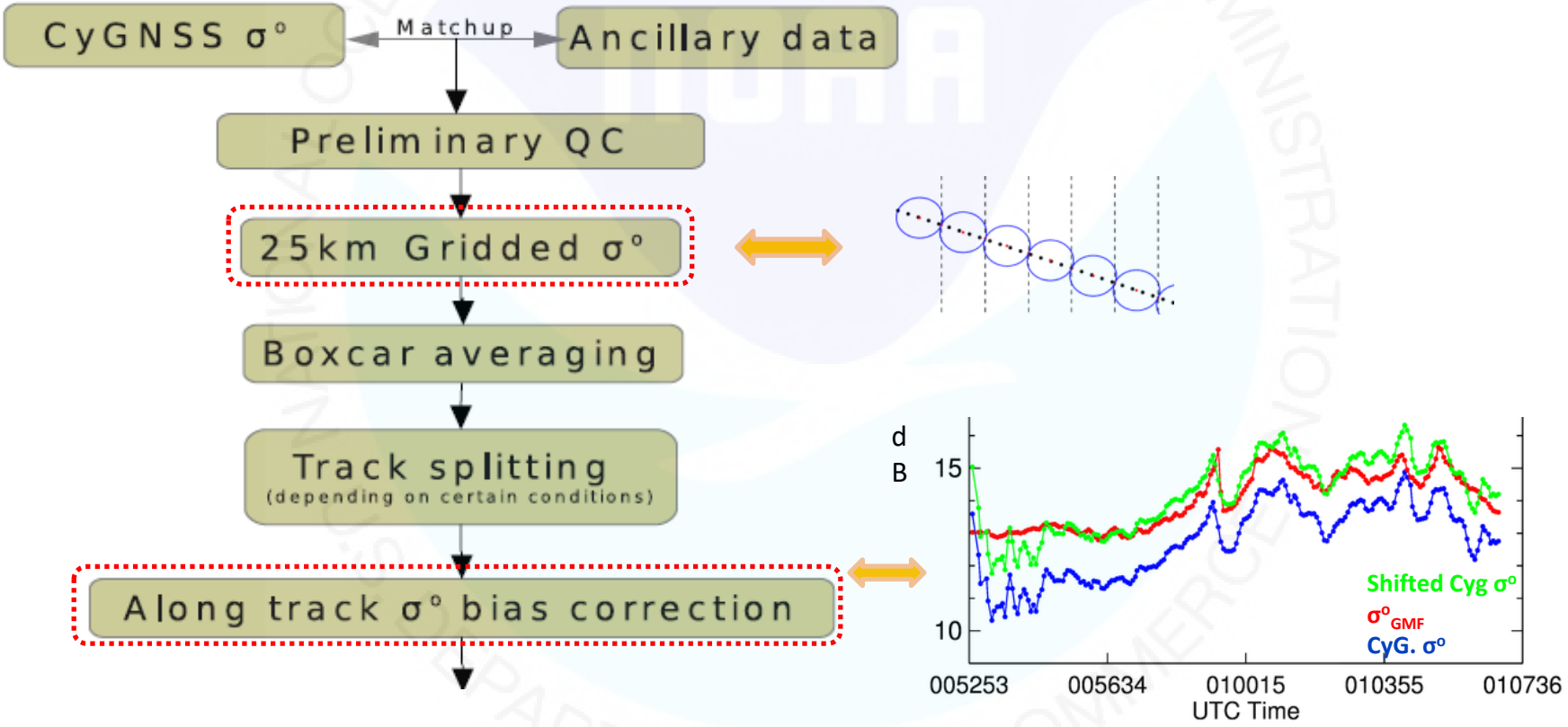

Daily averaged wind speed bias – STARBOARD NOAA v1.1
[m/s]
1.0
0.5
0.0
−0.8
−1.6
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged wind speed std diff – PORT NOAA v1.1
[m/s]
2.50
2.00
1.60
1.20
0.75
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan


Daily averaged wind speed std diff – STARBOARD NOAA v1.1
[m/s]
2.50
2.00
1.60
1.20
0.75
17 Jul
18 Jan
18 Jul
19 Jan
19 Jul
20 Jan
20 Jul
21 Jan

Overview of NOAA CyGNSS wind product Version 1.1

Data processing chain and product content description



Data processing chain and product content description

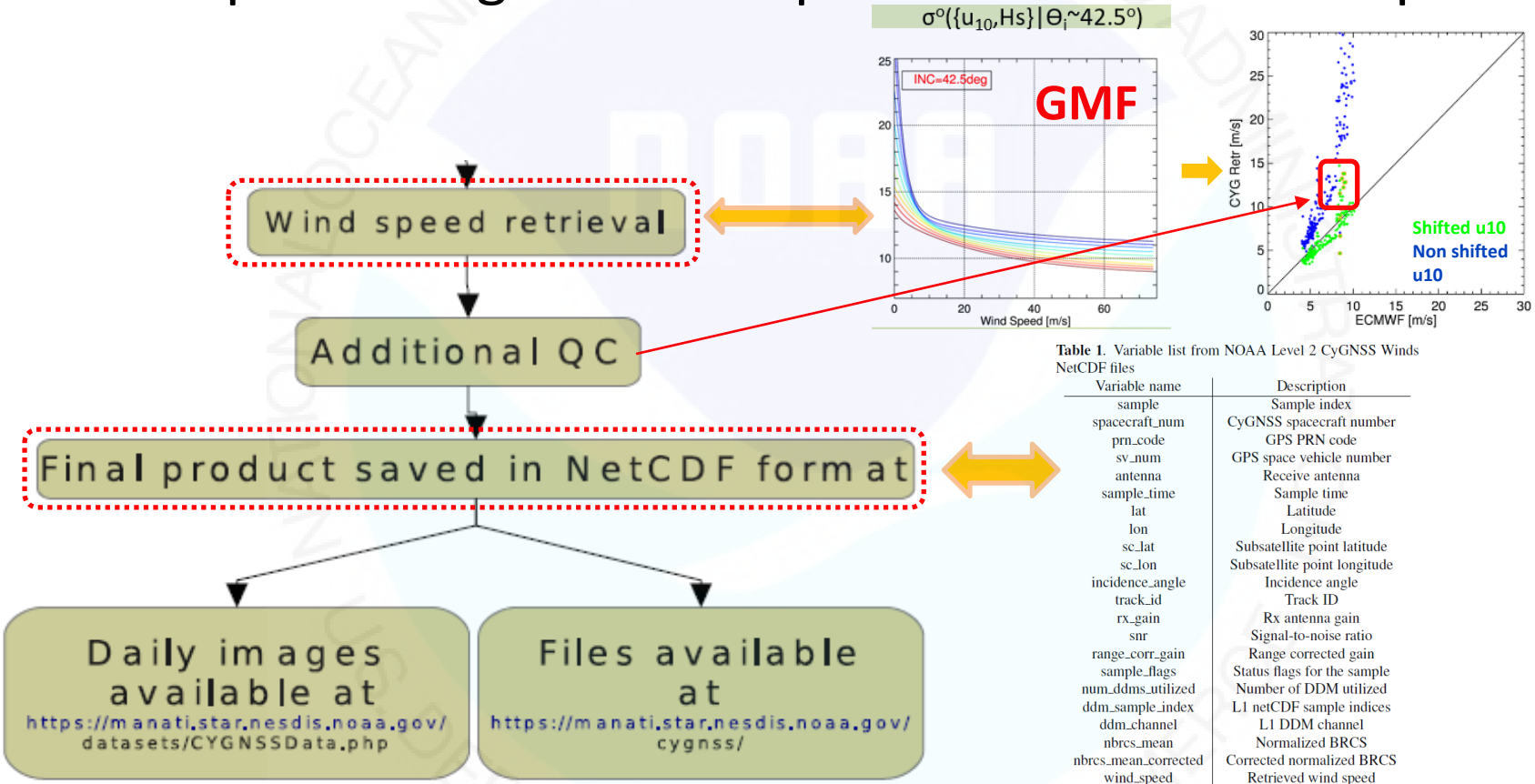
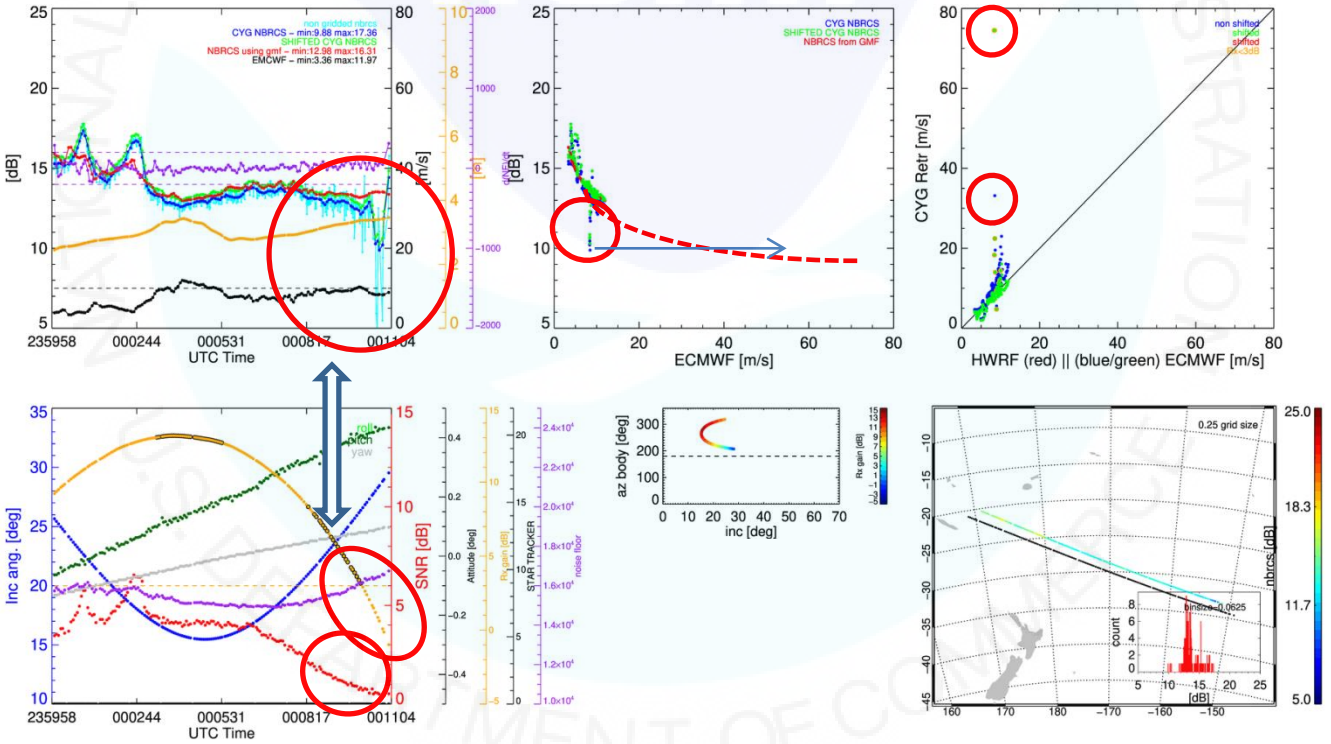


Table 1. Variable list from NOAA Level 2 CyGNSS Winds NetCDF files

Variable name	Description
sample	Sample index
spacecraft_num	CyGNSS spacecraft number
prn_code	GPS PRN code
sv_num	GPS space vehicle number
antenna	Receive antenna
sample_time	Sample time
lat	Latitude
lon	Longitude
sc_lat	Subsatellite point latitude
sc_lon	Subsatellite point longitude
incidence_angle	Incidence angle
track_id	Track ID
rx_gain	Rx antenna gain
snr	Signal-to-noise ratio
range_corr_gain	Range corrected gain
sample_flags	Status flags for the sample
num_ddms_utilized	Number of DDM utilized
ddm_sample_index	L1 netCDF sample indices
ddm_channel	L1 DDM channel
nbrcs_mean	Normalized BRCS
nbrcs_mean_corrected	Corrected normalized BRCS
wind_speed	Retrieved wind speed
azimuth_angle	Azimuth angle
sc_roll	Spacecraft attitude roll angle
sc_pitch	Spacecraft attitude pitch angle
sc_yaw	Spacecraft attitude yaw angle
sc_alt	Spacecraft altitude

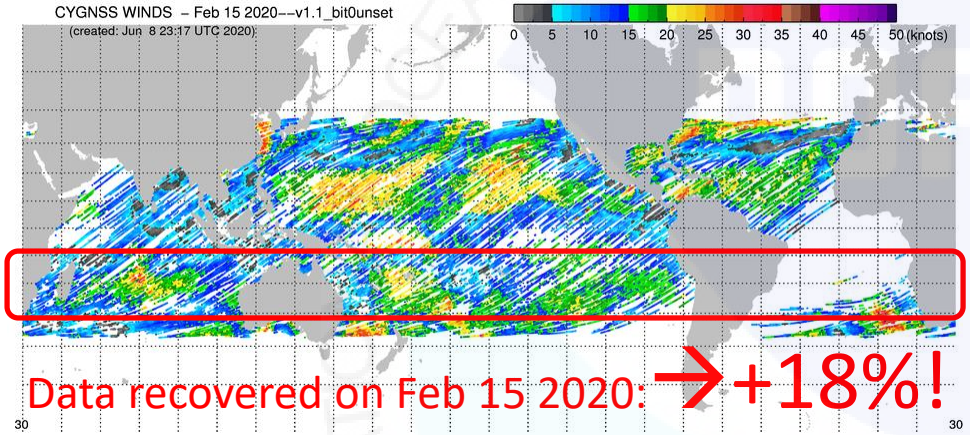
A word about quality control…

- Low Rx gain combined with Low SNR ranges mostly filtered out
- Algorithm implemented to detect block IIF tracks affected by power flex event
- Roll, Pitch, Yaw > 5 deg
- Track associated to Starboard antenna but showing on the Port side and vice versa

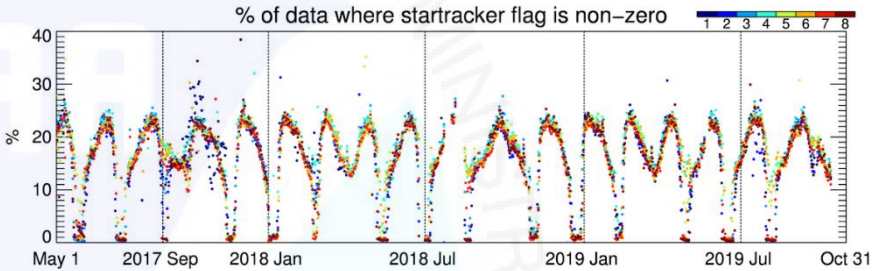


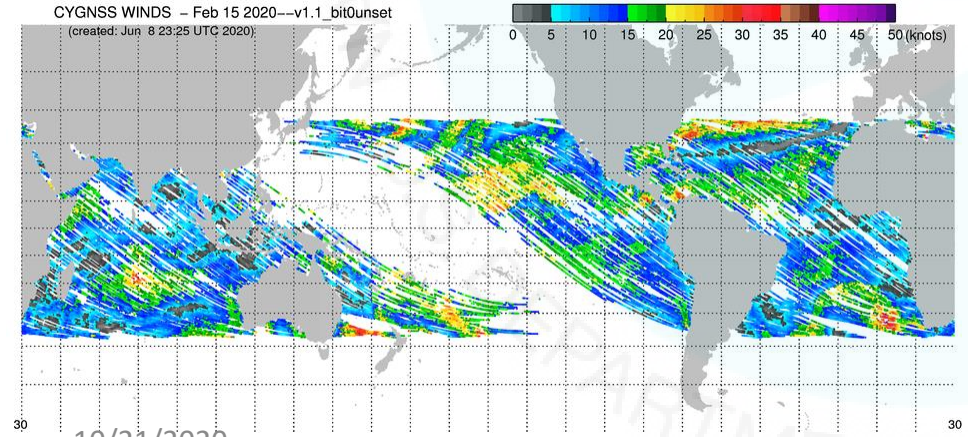
A word about quality control…

- Data with Star tracker flag set **now included** and partially flagged (bit 6 of quality flag)



Data recovered on Feb 15 2020: → +18%!





<u>Between May 1st 2017 until Oct 15th 2019:</u>

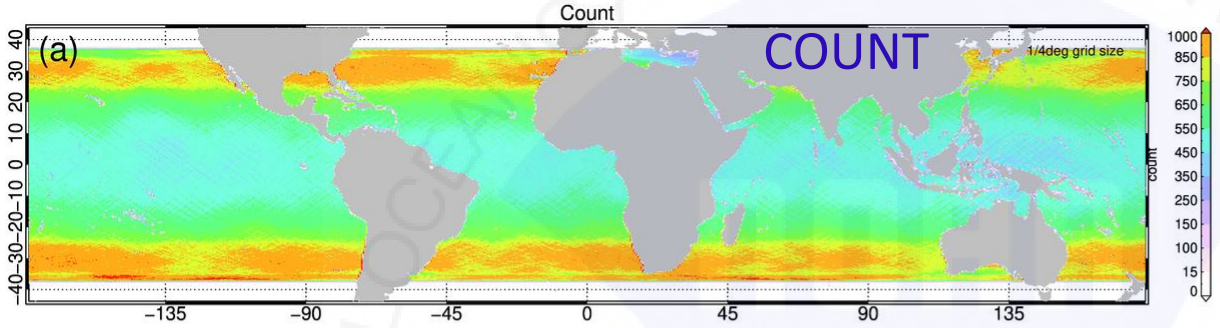
- % of full data set with star tracker flag set: ~17.85

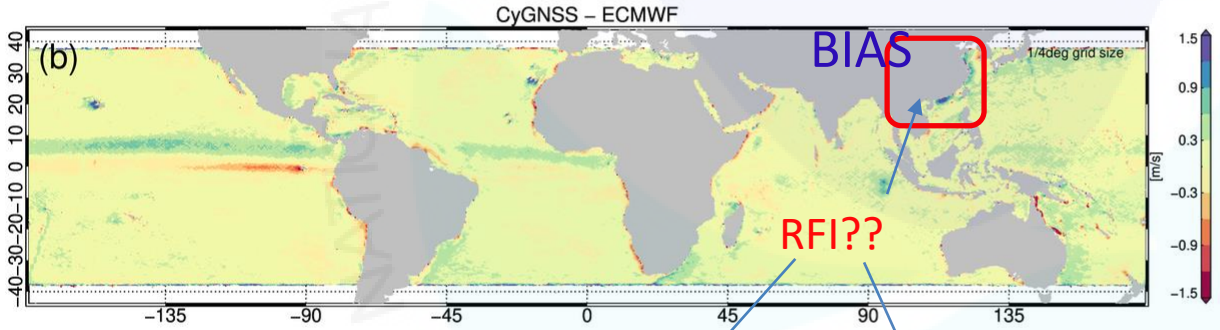
→ Now only flagging about 4.82% of the full data set

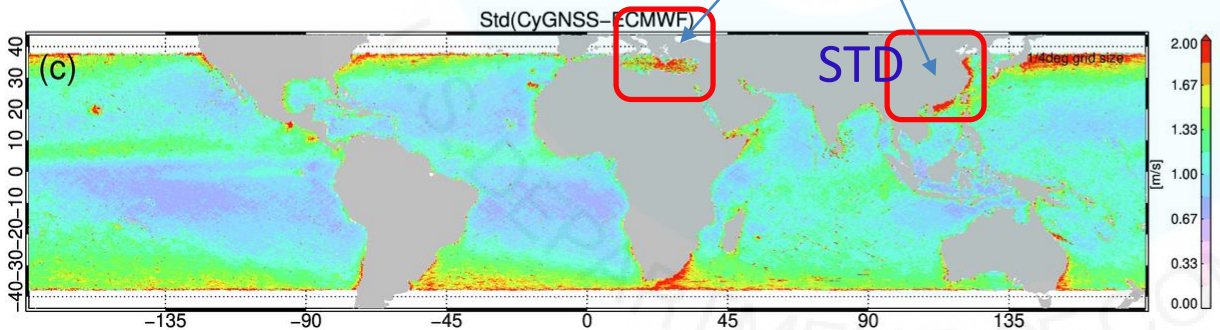
NOAA v1.1 overall performance

Overall performance against ECMWF – v1.1

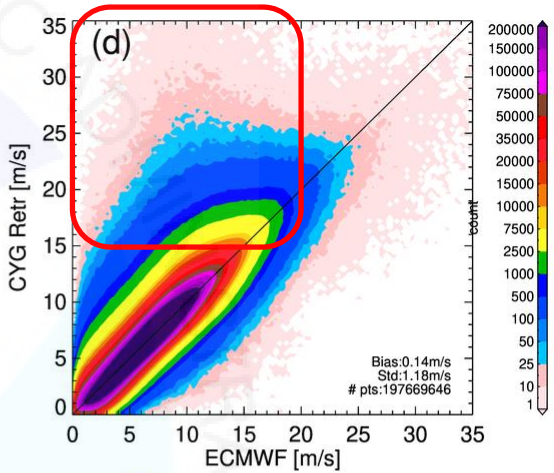
v1.1 | all FMs | All blocks | both_ant | | Time period: 2017 May 1st–2019 Oct 05th | NOAA L2 dataset | time window:N/A

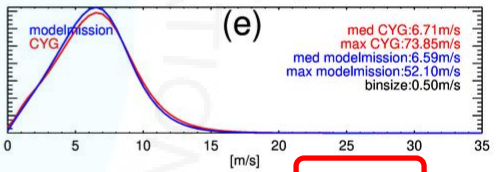


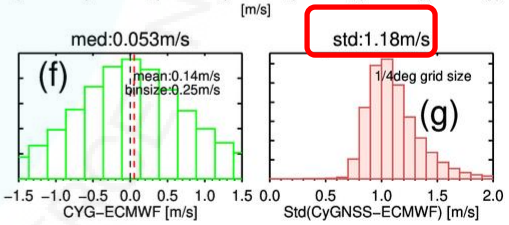


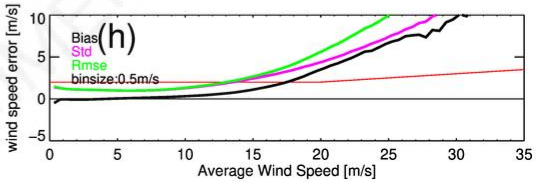


RFI??



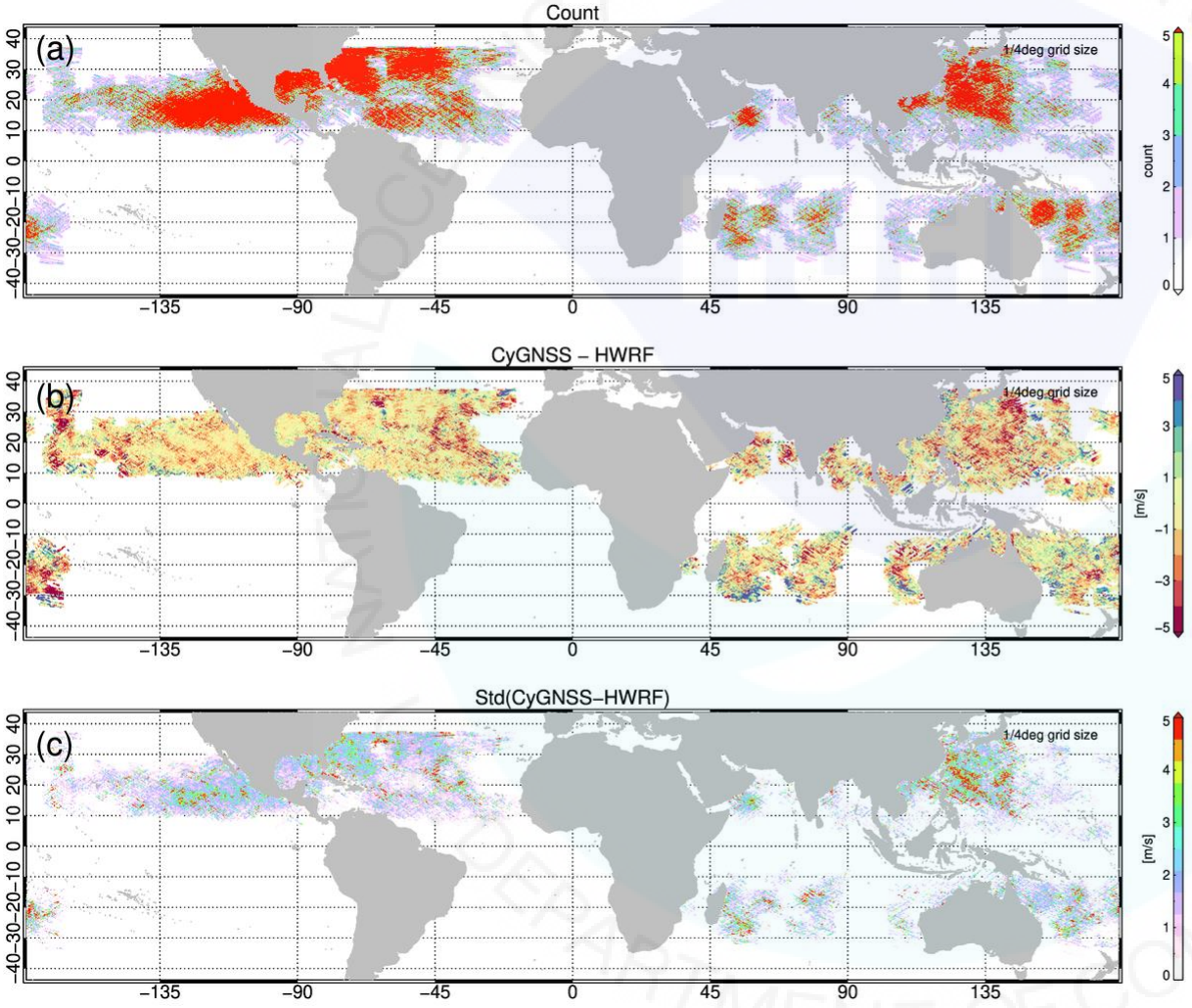


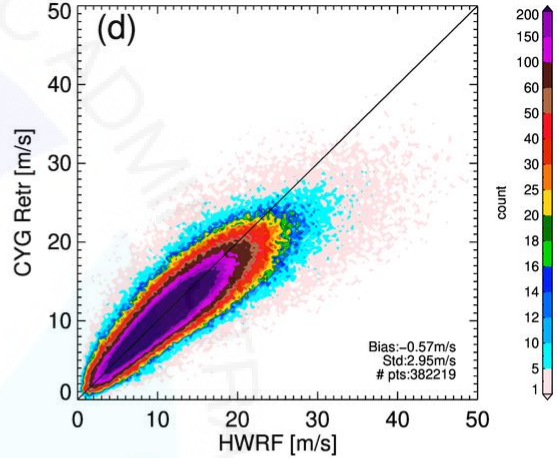


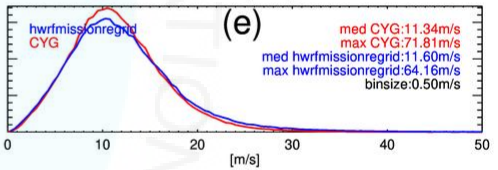


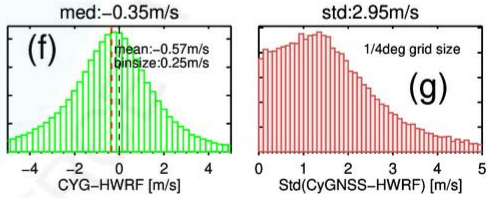
Overall performance against HWRF – v1.1

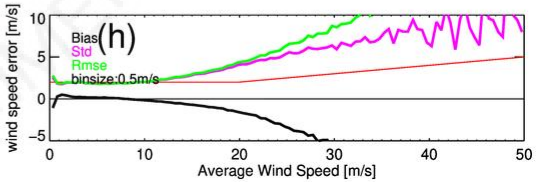
v1.1 | all FMs | All blocks | both_ant | | Time period: 2017 May 1st–2019 Oct 05th | NOAA L2 dataset | time window:N/A



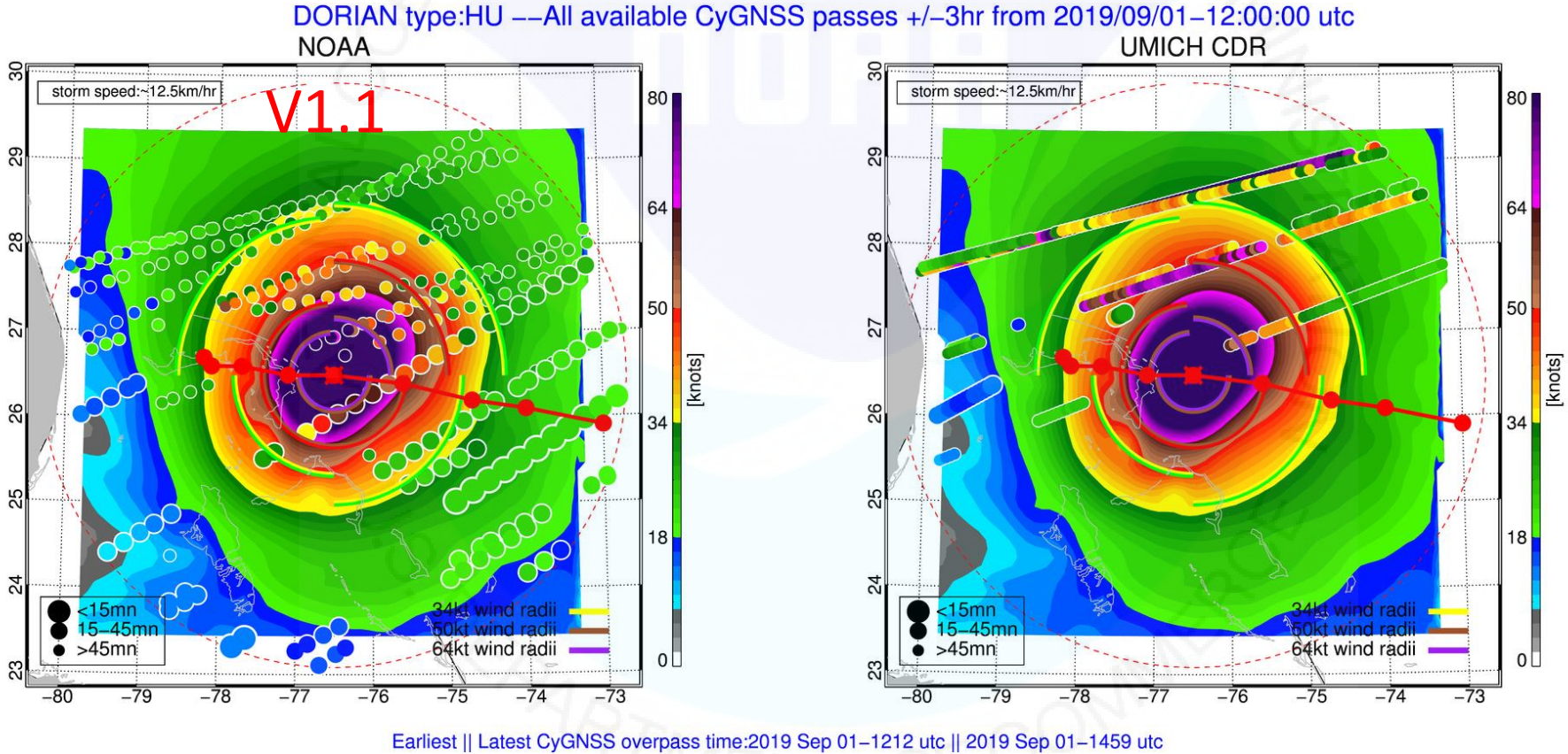




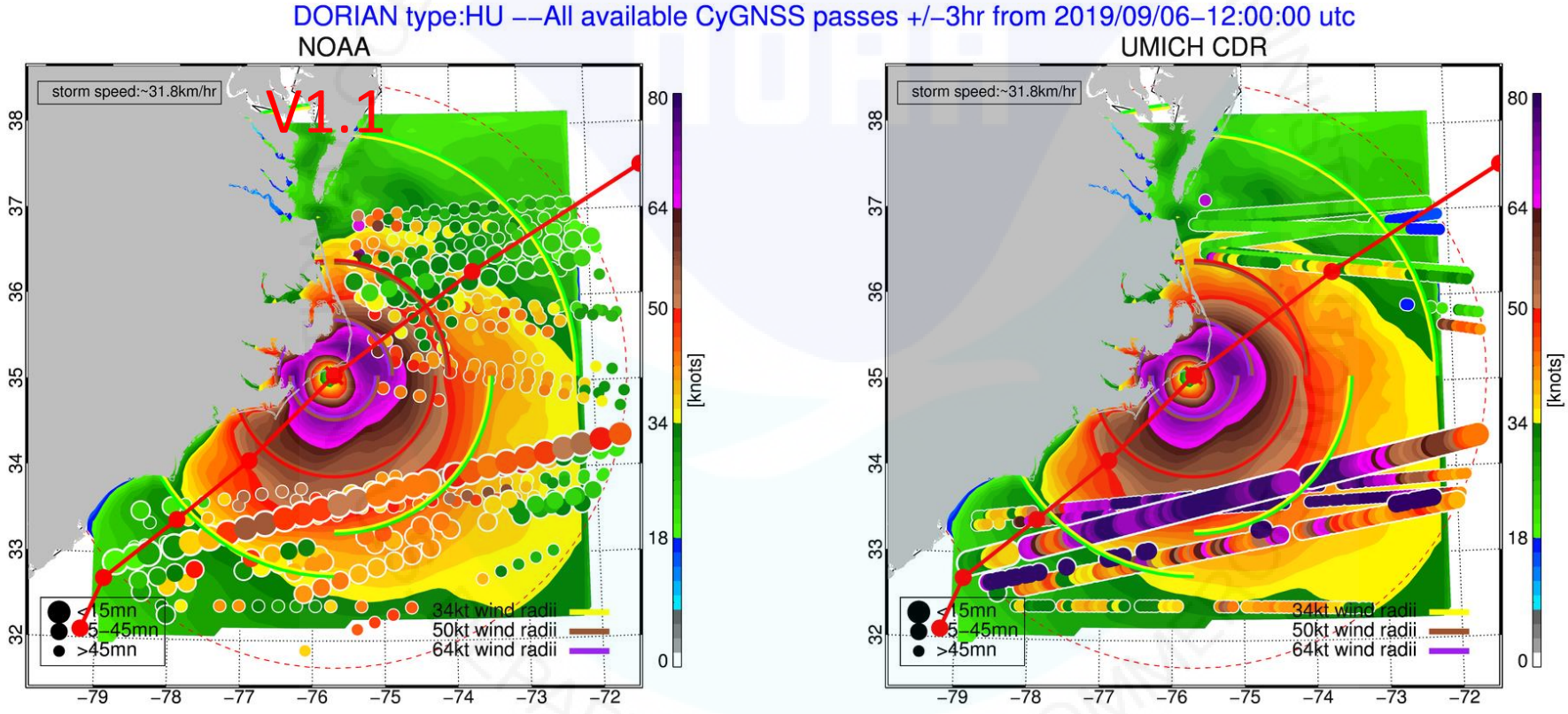




Example TC overpass

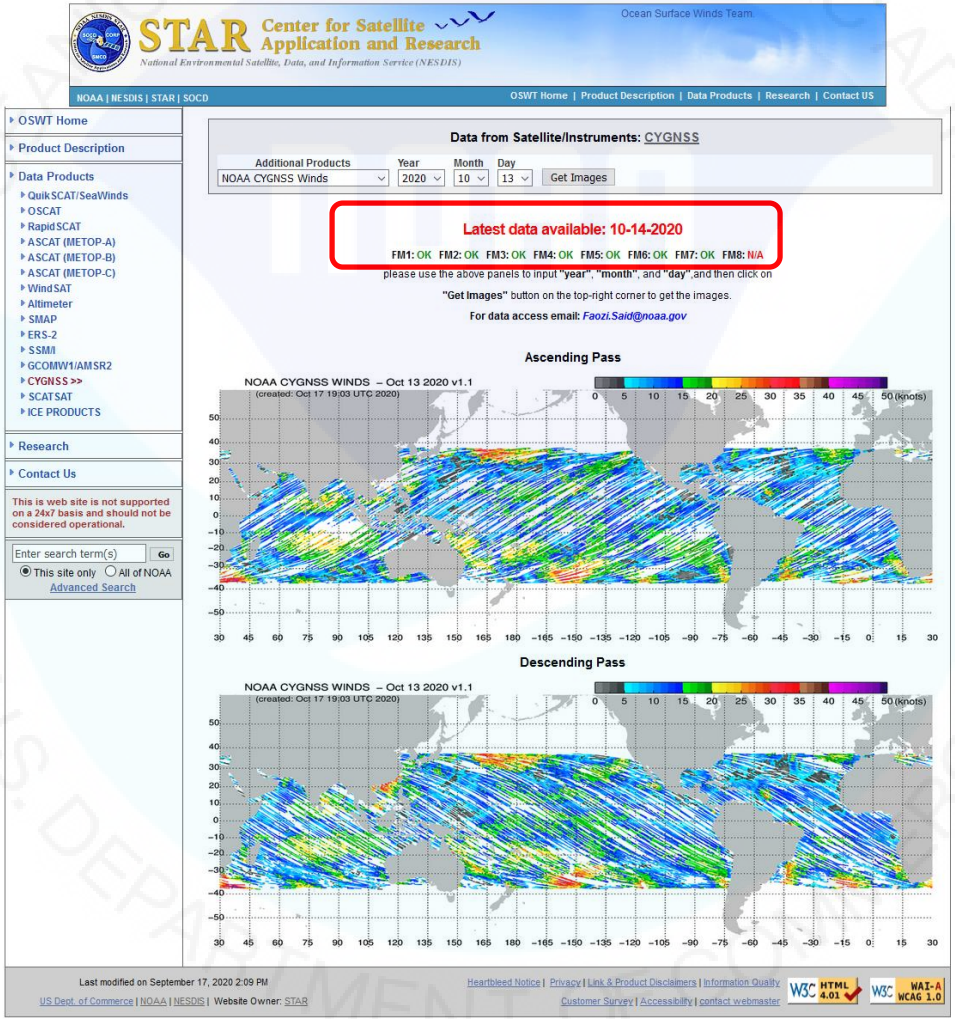


Example TC overpass



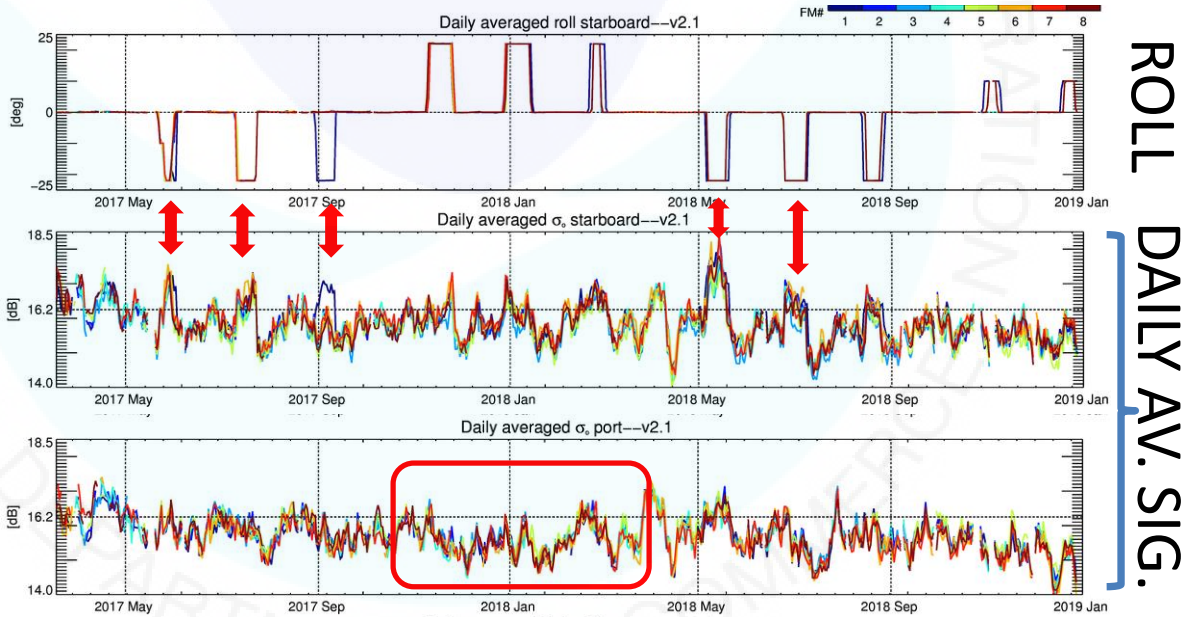
v1.1 images available on the ‘manati’ website

https://manati.star.nesdis.noaa.gov/datasets/CYGNSSData.php



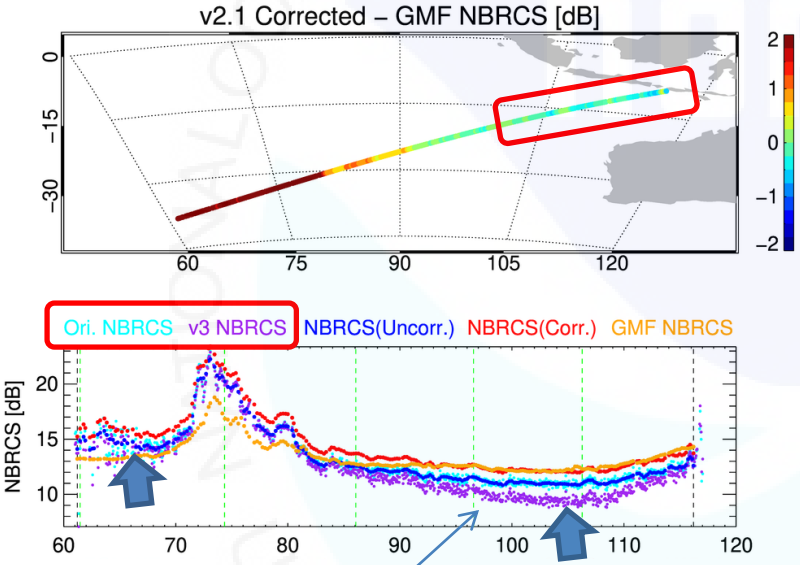
Future works

- Will begin assessing the possible impact of CYGNSS data on NOAA operations
- Recall that Roll, Pitch, Yaw > 5 deg data is currently flagged out. Plan is to figure out how much of the high roll angle data can be recovered



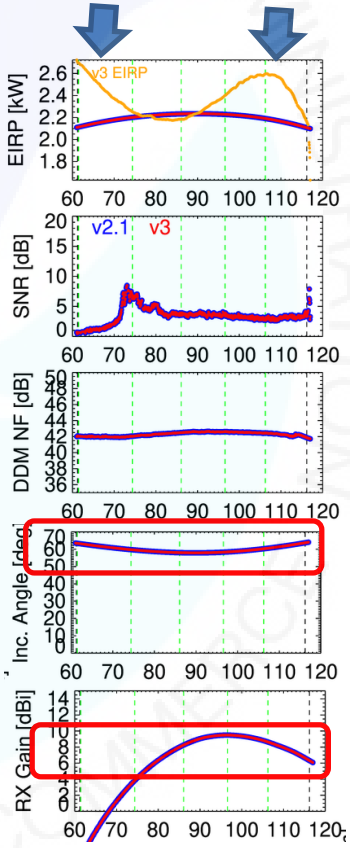
Future works

- Carefully inspect v3.0 sigma0 performance



What's going on here?

RFI?
Rx gain?
EIRP?
All of the above?



Originally noticed these sigma0 'drifts' in v2.1..

Lessons learned

When designing spacecraft, ensure

- absence of inter-satellite sigma0 biases
- absence of sigma0 biases between receive antennas
- verify sigma0 dependence as a function of incidence angle
- absence of biases due to GPS block type
- no attitude variation impact to the sigma0
- Resiliency to signal drift