A LOOK AT CyGNSS DEPENDENCE ON SEA SURFACE SALINITY AND SEA SURFACE TEMPERATURE

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Background on CyGNSS

- 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 (<u>up to 4 per sensor</u>) instead of the usual ‘swath based coverage’**
- Wind speed is inferred from the normalized bi-static radar cross section (NBRCS)

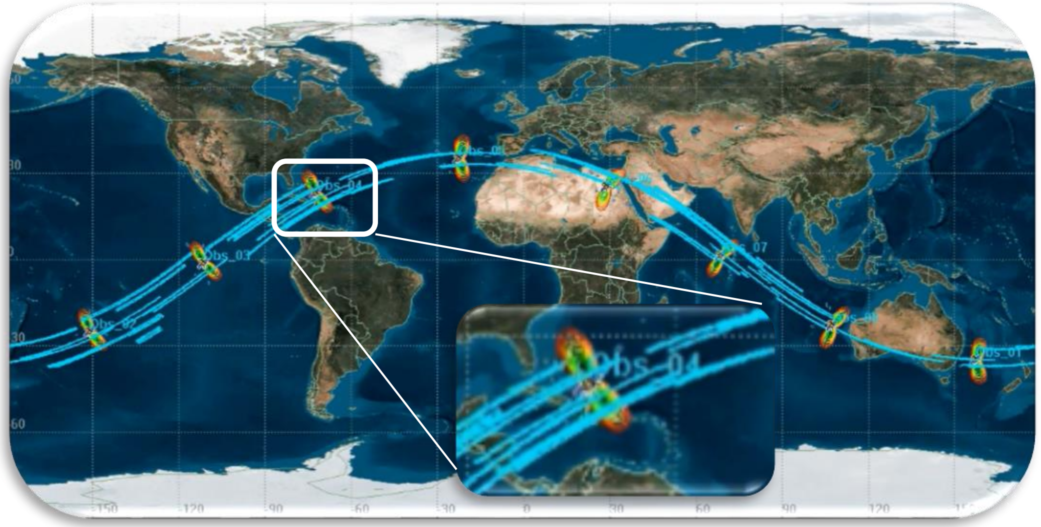
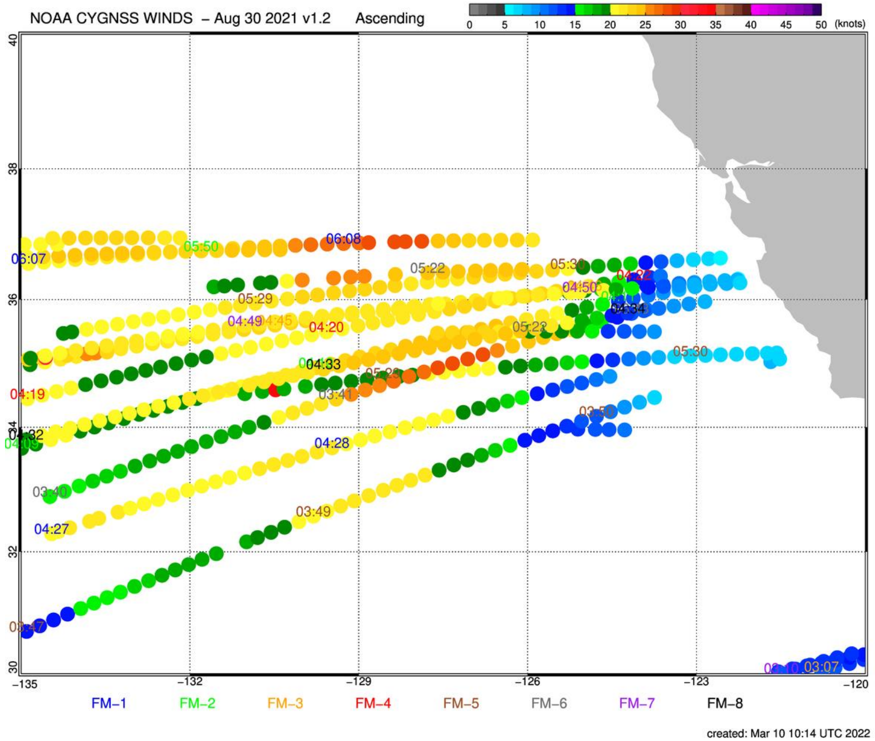
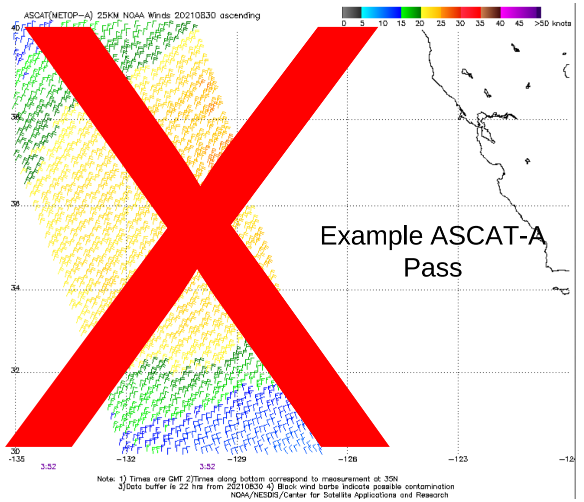


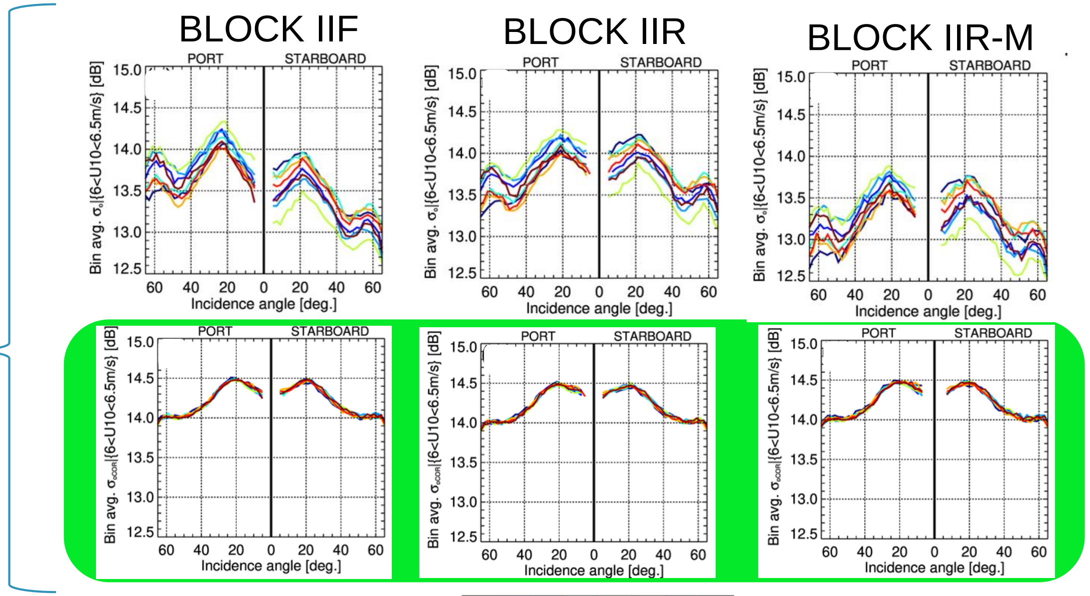
Image: NASA

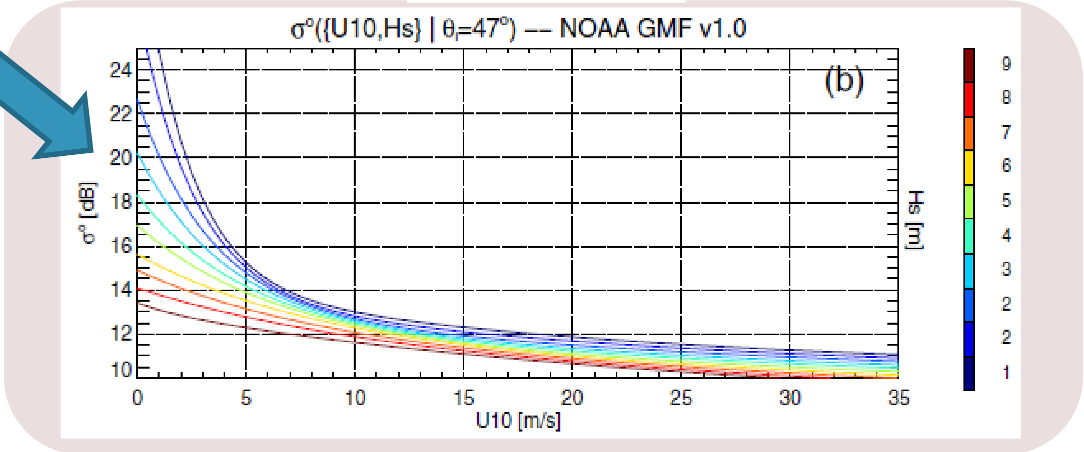




Background on CyGNSS: NOAA CyGNSS wind product

- Based on a ‘trackwise’ sigma0 bias correction algorithm
- Aimed to address
  - Intersatellite NBRCS calibration issues (recall that we are dealing with 8 sensors with 2 antennas per sensor)
  - NBRCS biases due to poor knowledge of GPS transmit power (30+ of them!)
- Uses a Geophysical Model Function relating CyGNSS NBRCS to the wind speed, incidence angle, and significant waveheight
- v1.2 is the latest 25km NOAA CyGNSS wind data product (based on v2.1 NBRCS) and is available on the PO.DAAC (https://podaac.jpl.nasa.gov/dataset/CYGNSS_NOAA_L2_SWSP_25KM_V1.2)
- Global wind images also available on the NOAA Manati site (https://manati.star.nesdis.noaa.gov/datasets/CYGNSSData.php)



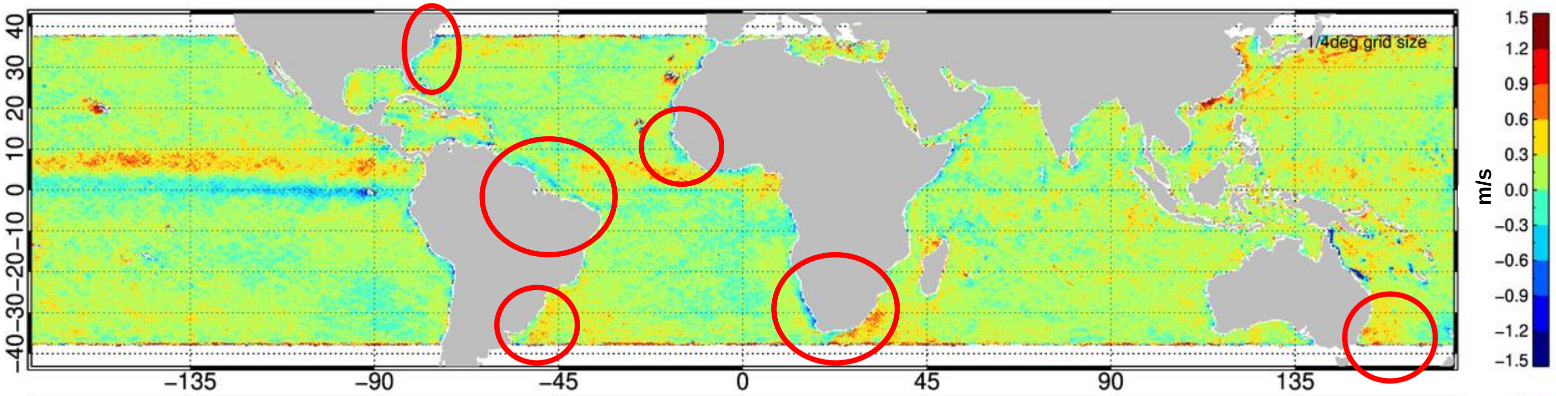


**Publication providing details on the NOAA Track-wise algorithm:

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

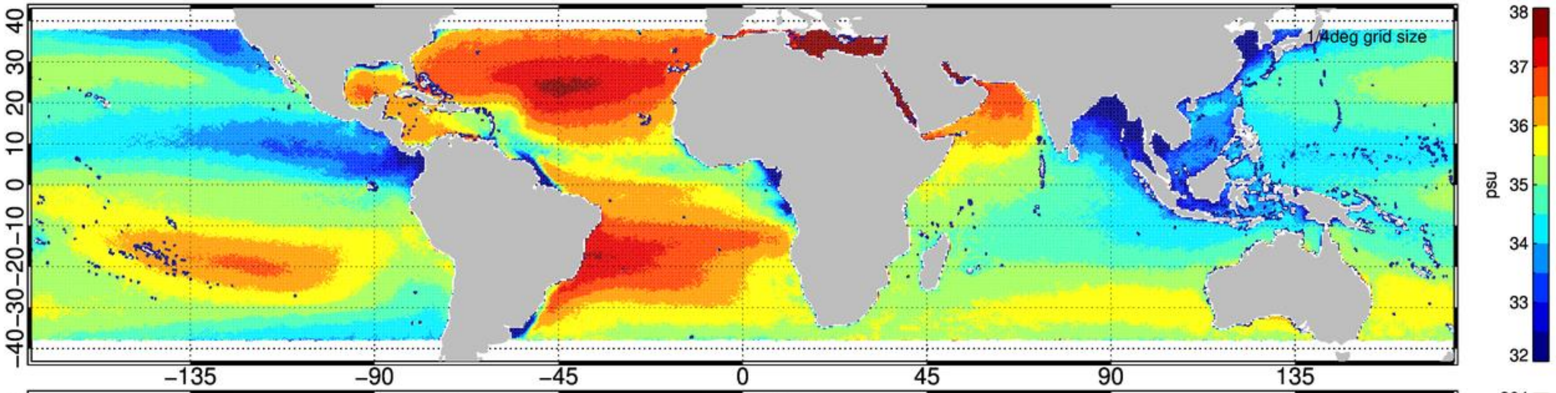
NOAA CyGNSS global wind retrieval performance (2017-2021)

CyGNSS wind speed bias map
(i.e. CyGNSS- ECMWF)

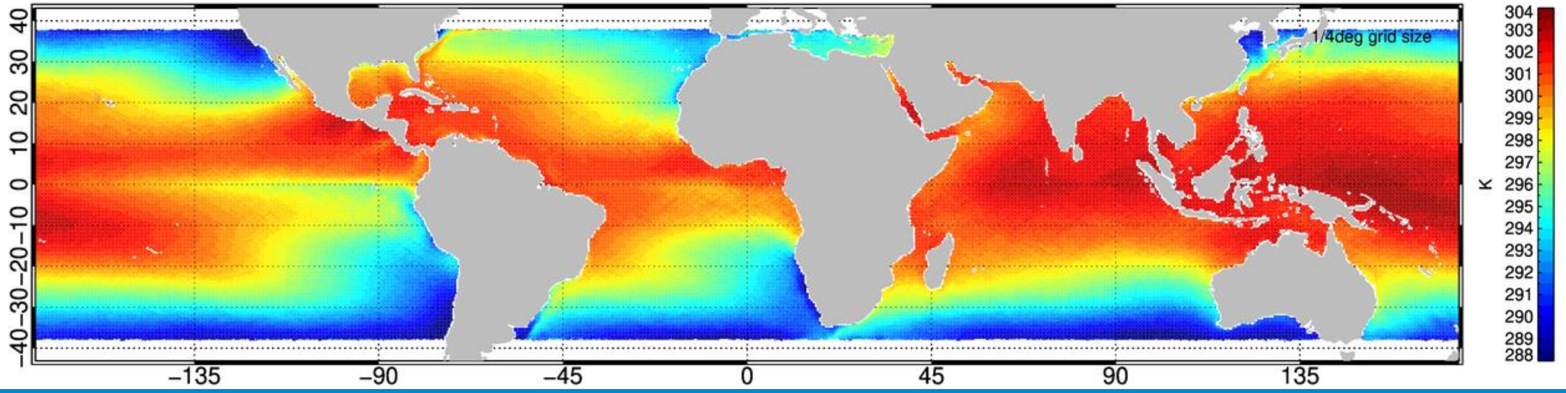


Note the presence of regional and persistent biases.
What is causing this?

Sea surface salinity map (SMAP)



Sea surface temperature map (NOAA)



Let's briefly check the physics…

In the case of CyGNSS (L band and LHCP), we can approximate $\sigma_0(\theta) = \frac{|\Re(\theta)|^2}{mss}$ (1)

Fresnel reflection coefficient: $\Re(\theta) = \frac{1}{2}\left[\frac{\epsilon \cos\theta - \sqrt{\epsilon - \sin^2\theta}}{\epsilon \cos\theta + \sqrt{\epsilon - \sin^2\theta}} - \frac{\cos\theta - \sqrt{\epsilon - \sin^2\theta}}{\cos\theta + \sqrt{\epsilon - \sin^2\theta}}\right]$ (1)

Relative permittivity of sea water: $\epsilon = \epsilon_\infty + \frac{(\epsilon_s - \epsilon_\infty)}{1 - i\omega\tau} - \frac{i\sigma}{\omega\epsilon_o}$ (2)

$$
\begin{aligned}
\text{Static dielectric constant:}\quad \epsilon_s &= (87.134 - 0.1949T - 0.01276T^2 + 0.0002491T^3) \\
&\quad (1 + 1.613 \times 10^{-5} TS - 0.003656S + 3.21 \times 10^{-5} S^2 - 4.232 \times 10^{-7} S^3) \\
\text{electrical permittivity at very high frequencies:}\quad \epsilon_\infty &= 4.9 \\
\text{relaxation time:}\quad 2\pi\tau &= (1.1109 \times 10^{-10} - 3.824 \times 10^{-12} T + 6.398 \times 10^{-14} T^2 - 5.096 \times 10^{-16} T^3) \\
&\quad (1. + 2.282 \times 10^{-5} TS - 7.638 \times 10^{-4} S - 7.760 \times 10^{-6} S^2 + 1.105 \times 10^{-8} S^3) \\
\text{ionic conductivity:}\quad \sigma &= S(0.18252 - 0.0014619S + 2.093 \times 10^{-5} S^2 - 1.282 \times 10^{-7} S^3) \\
&\quad \exp((T - 25)(0.02033 + 0.0001266(25 - T) + 2.464 \times 10^{-6}(25 - T)^2 \\
&\quad - S(1.849 \times 10^{-5} - 2.551 \times 10^{-7}(25 - T) + 2.551 \times 10^{-8}(25 - T)^2)))
\end{aligned}
$$
(2)

(1) See Eq 8.17 and Eq 8.18 from C. Ruf, P. Chang, M.P. Clarizia, S. Gleason, Z. Jelenak,J. Murray, M. Morris, S. Musko, D. Posselt, D. Provost,D. Starkenburg, and V. Zavorotny, **CYGNSS Handbook** Michigan Publishing, Ann Arbor, MI, April 2016, ISBN978-1-60785-380-0.

(2) Klein, L. A. and C. T. Swift, "**An improved model for the dielectric constant of sea water at microwave frequencies**," IEEE Trans. Ant. Prop., vol. AP-25, pp. 104–111, 1977

SST/SSS dependency investigation

Dataset used for analysis

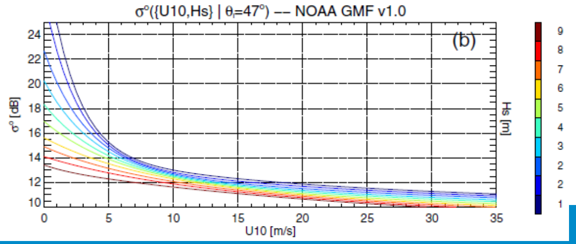
- 25km sea surface salinity (SSS) from NASA's Soil Moisture Active-Passive (SMAP) v5.0 dataset
- NOAA Optimum sea surface temperature (SST)
- Numerical weather prediction model winds from ECMWF
- Significant waveheight from Ifremer implementation of Wavewatch 3 model
- 25km v1.1 NOAA CyGNSS wind
- v2.1 CyGNSS NBRCS gridded on a 25km grid

Time period and collocation criteria

- May 2017 – March 2021
- CyGNSS wind/NBRCS collocated with SMAP SSS within +/-90 minutes and 25km
- Bilinear interpolation in space and time of both ECMWF and Hs to CyGNSS data

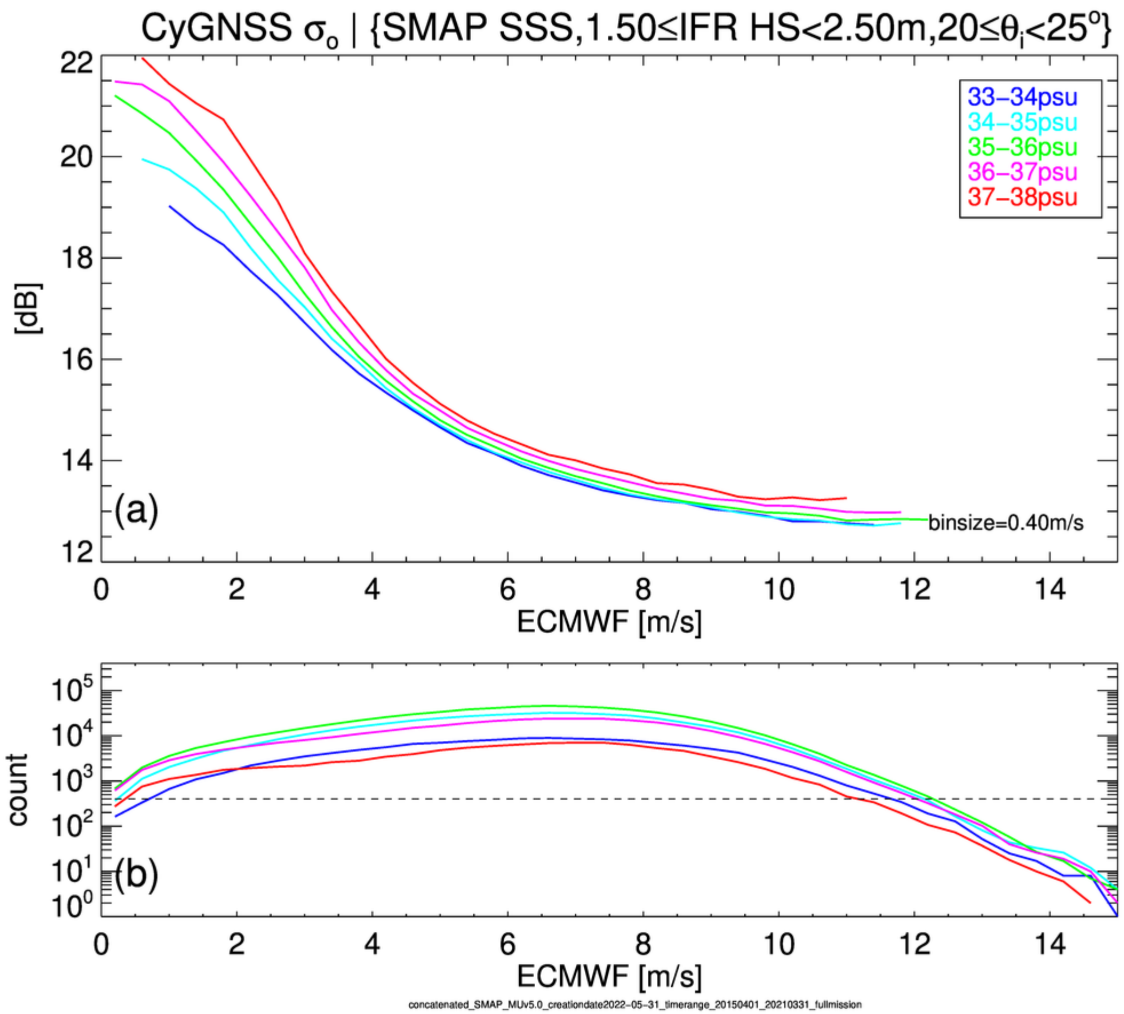
Additional conditions imposed on analysis

- Fixed significant waveheight range (1.5-2.5m -- where the most data lies)
- Fixed incidence angle range (20-25° -- same reason, including higher Rx gain region of antenna)



1. Sea surface salinity analysis

Bin averaged CyGNSS σ_o as a function of ECMWF wind, for various salinity bins

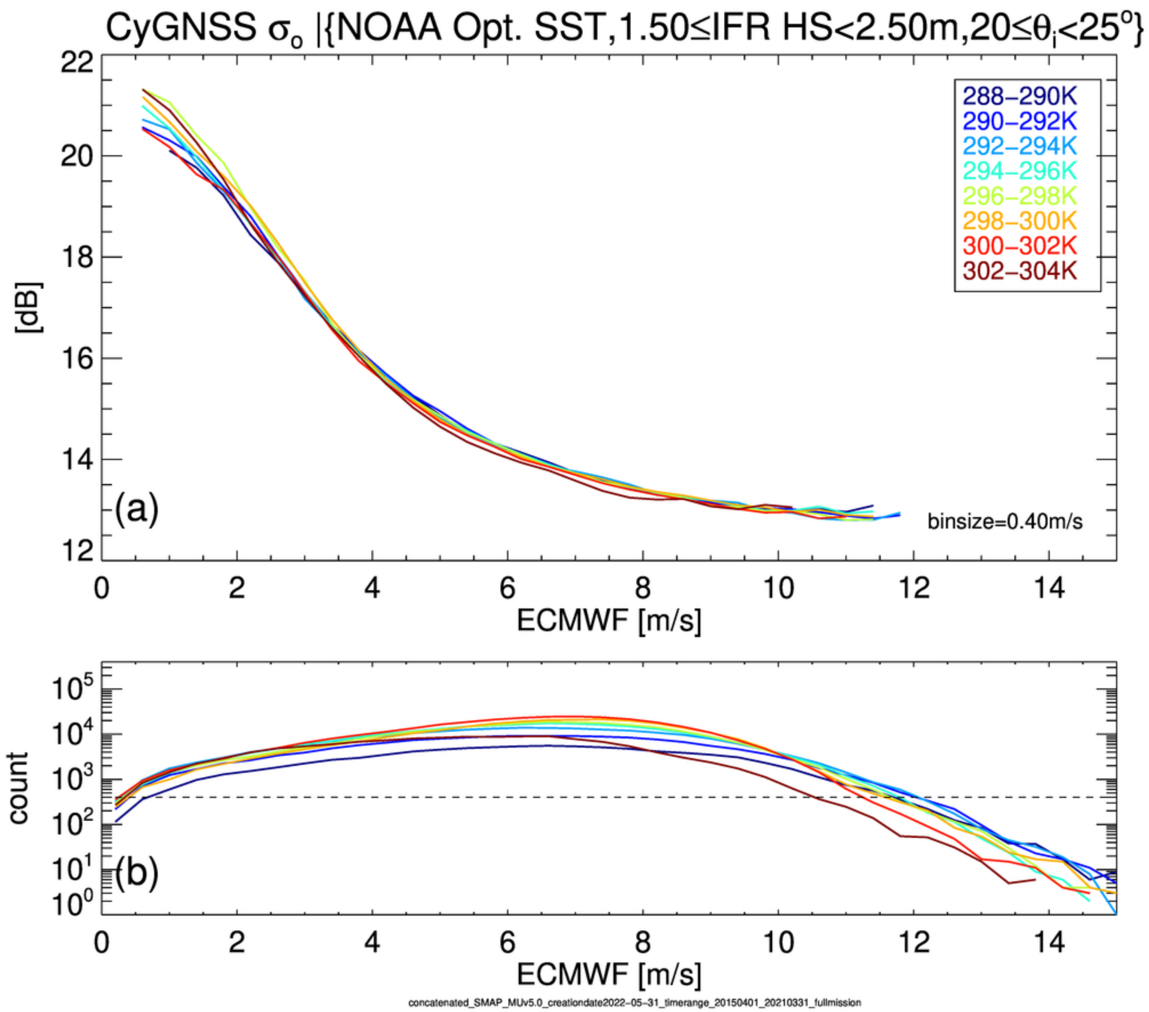


Observations:

- Noticeable CyGNSS NBRCS dependence on SSS
- For a given wind speed, CyGNSS NBRCS increases as the SSS increases
- This increase becomes more important as the wind speed decreases

2. Sea surface temperature analysis

Bin averaged CyGNSS σ_o as a function of ECMWF wind, for various sst bins

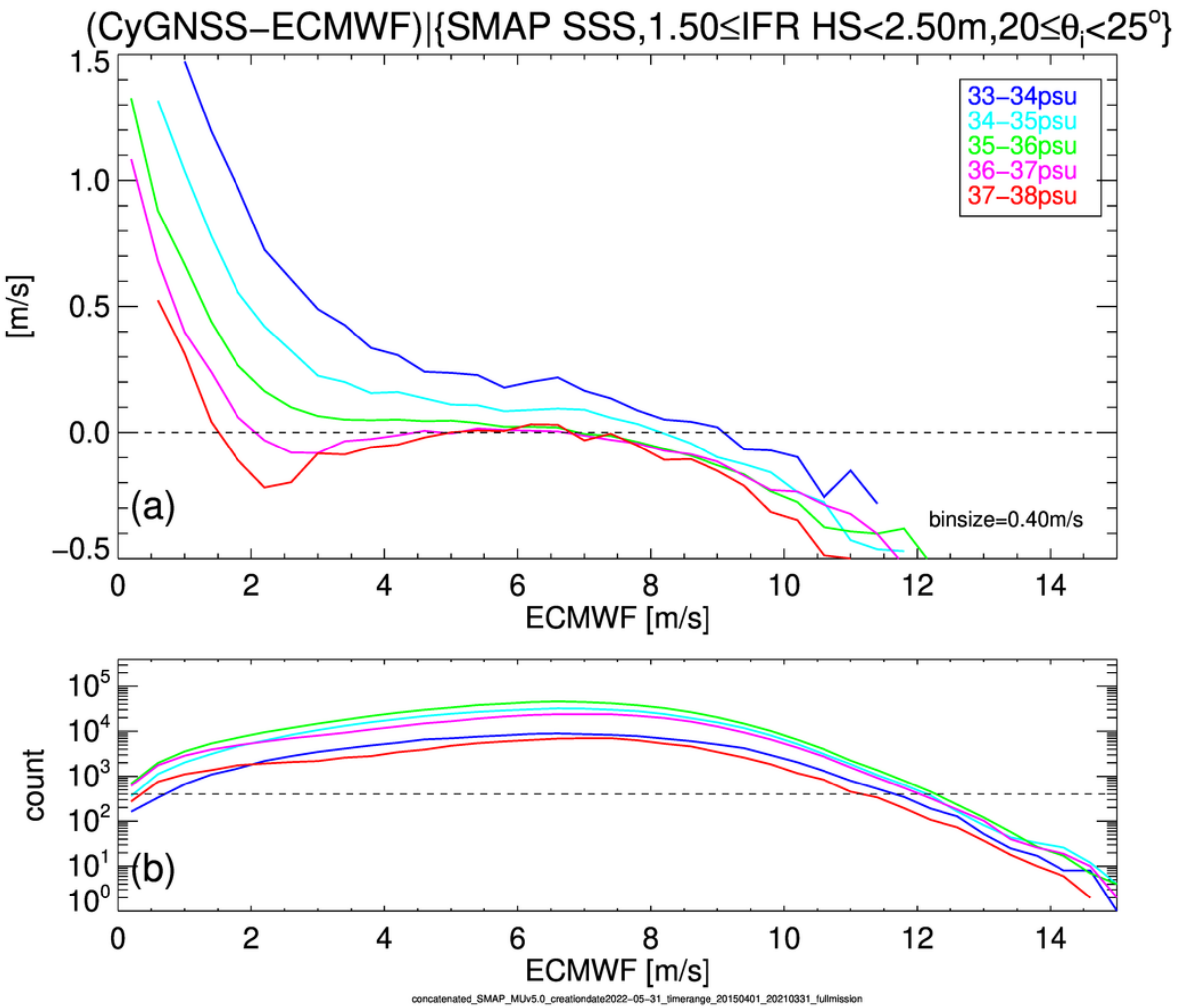


Observations:

- Weaker CyGNSS NBRCS dependence on SST compared to SSS
- Although it appears stronger at low winds, overall relationship is not clear

Impact on NOAA CyGNSS v1.1 wind speed product

Bin averaged wind speed bias as a function of ECMWF wind, for various sss bins

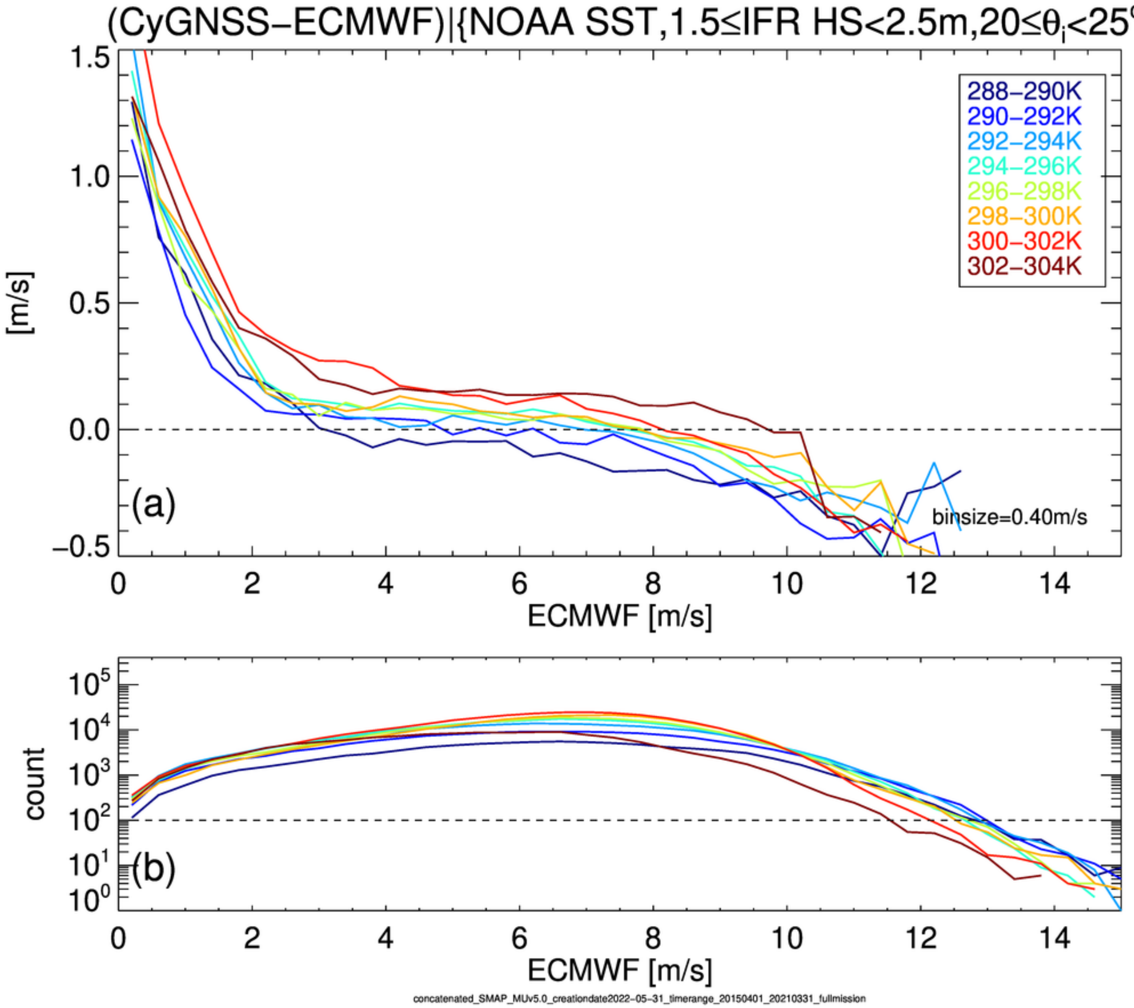


Observations:

- Error decreases as SSS increases
- Again, error is larger at lower wind speed
- Error remains constant between ~4-8 m/s

Impact on NOAA CyGNSS v1.1 wind speed product

Bin averaged wind speed bias as a function of ECMWF wind, for various sst bins



Observations:

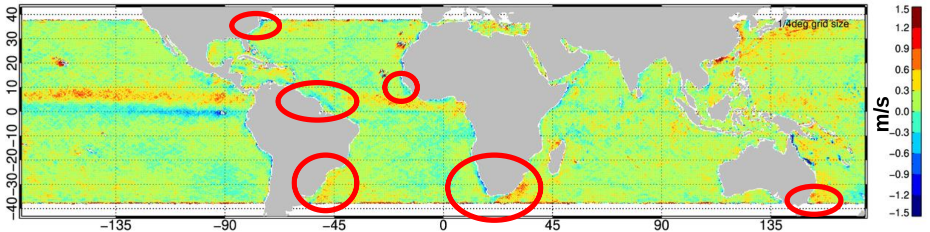
- although curves are a bit noisy, appears to show that error increases as SST increases
- as with SSS, error is larger at lower wind speed
- error remains fairly constant between ~3 and 8 m/s

Summary

- CyGNSS NBRCS dependence on SSS has been shown
  - For a fixed wind speed, CyGNSS NBRCS increases as the SSS increases
  - This increase becomes more important as the wind speed decreases
- CyGNSS NBRCS dependence on SST is much weaker with no clear relationship between the two
- NOAA CyGNSS wind dependence on SSS exists
  - Error decreases as SSS increases and is larger at lower wind speed
- Although CyGNSS NBRCS dependence on SST is much weaker than on SSS, NOAA CyGNSS winds are still showing a dependence on SST
  - error increases as SST increases
  - as with SSS, error is larger at lower wind speed

Future work

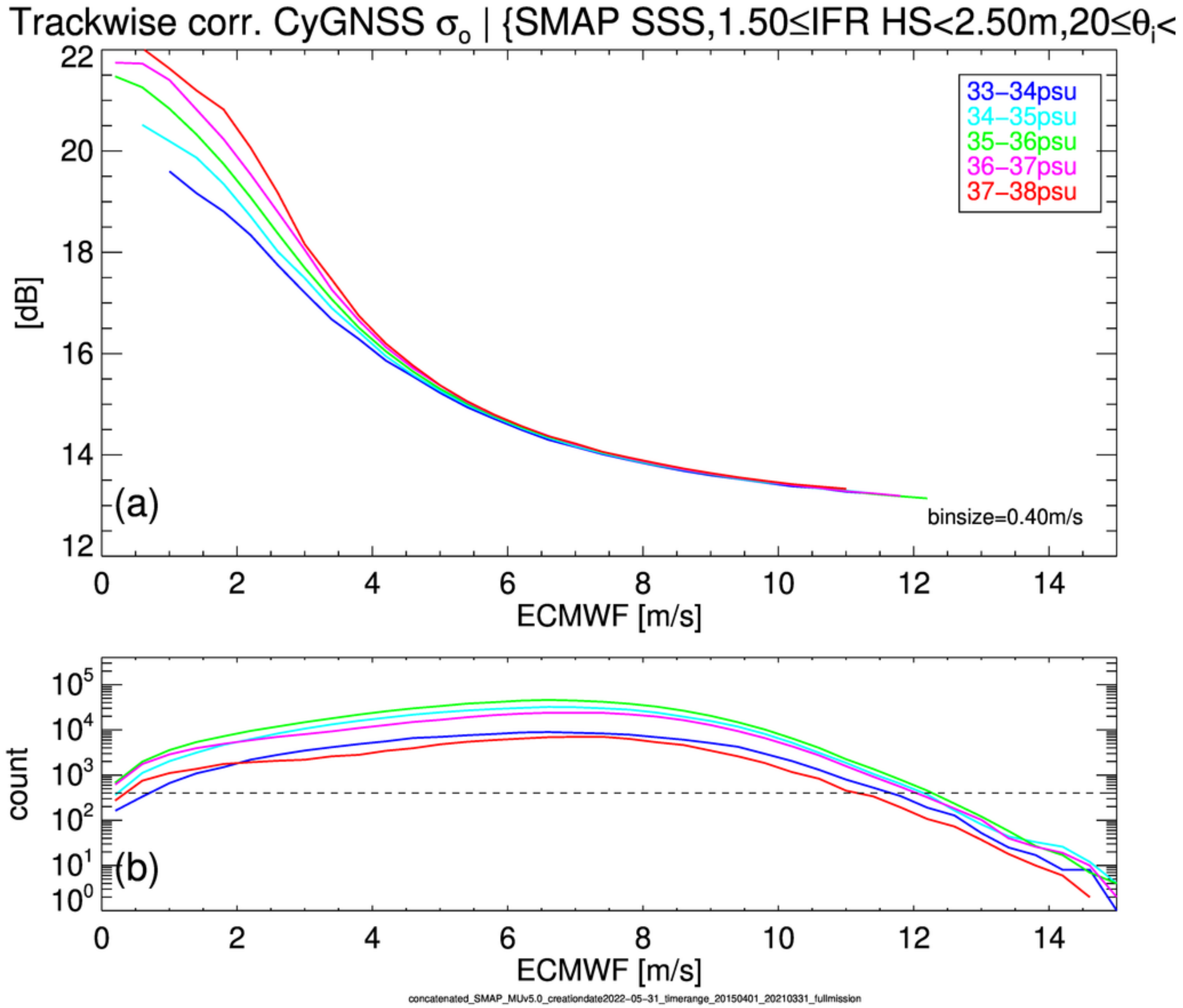
- next GMF version for CyGNSS will most likely take into account these SSS/SST dependences. These should not be neglected.



Extra slides

1. Sea surface salinity analysis

Bin averaged **Trackwise corrected** CyGNSS σ_o as a function of ECMWF wind, for various salinity bins



2. Sea surface temperature analysis

Bin averaged **Trackwise corrected** CyGNSS σ_o as a function of ECMWF wind, for various SST bins