Toward a consistent C- and Ku-band scatterometer ocean vector wind data record

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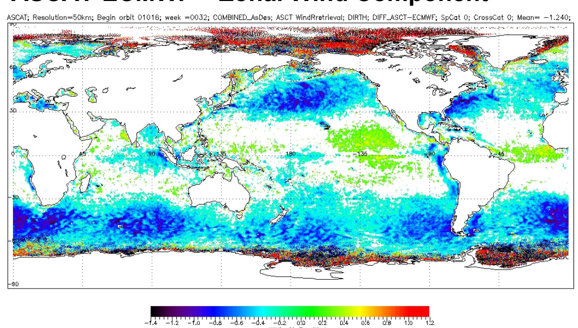
Are the existing ocean wind vector products consistent?

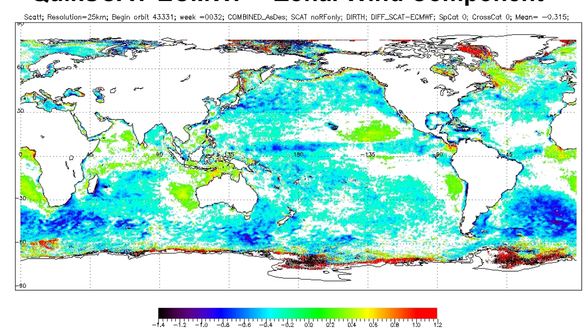
- Achieving consistency between the wind estimates from the different scatterometers has been a long-standing goal of the International Ocean Vector Wind Science Team (IOVWST).

- Significant effort has gone into instrument calibration, algorithm validation and cross-evaluation and significant progress has been made in this direction. Yet, some small but important inconsistencies still remain.
- These discrepancies have geographical patterns that suggest differences in the estimated large-scale atmospheric circulation and in the estimated forcing of the ocean.
- For more discussion of the scientific impact of inconsistencies between C- and K-band scatterometer winds see [Hristova-Veleva 2021].

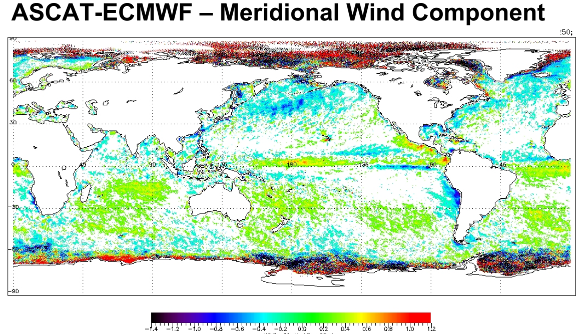
ASCAT-ECMWF – Zonal Wind Component



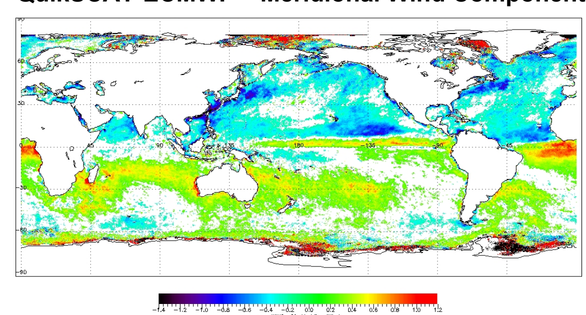
QuikSCAT-ECMWF – Zonal Wind Component



ASCAT-ECMWF – Meridional Wind Component



QuikSCAT-ECMWF – Meridional Wind Component



Why Not?

- **There are three main sources that contribute to differences between C-band and Ku-band ocean wind vector data products.**
  - ➢ Unlike C-band, Ku-band scatterometers are sensitive to SST.
  - ➢ Wind retrieval algorithms differ.
  - ➢ Geophysical model functions for the two sensors were validated with different ground truth data sets so that calibrations between backscatter and wind speeds may differ.
  - ➢ Ku-band scatterometers are much more sensitive to rain effects than C-band.

Does it matter?

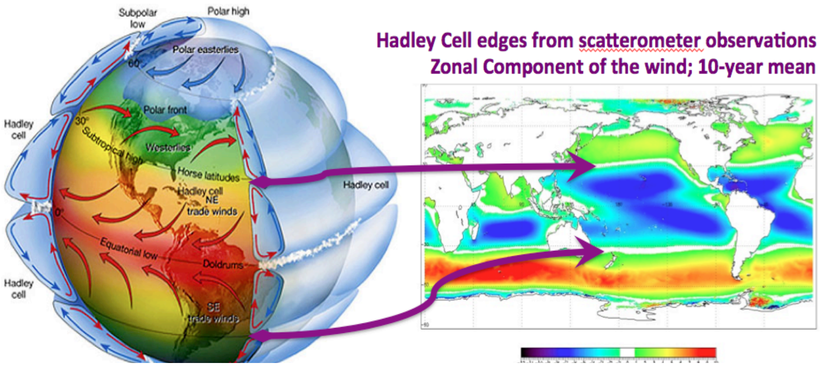


Fig. 1. Schematic of the large-scale circulation (left panel) and the zonal component of the surface wind as determined from QuikSCAT (right panel).

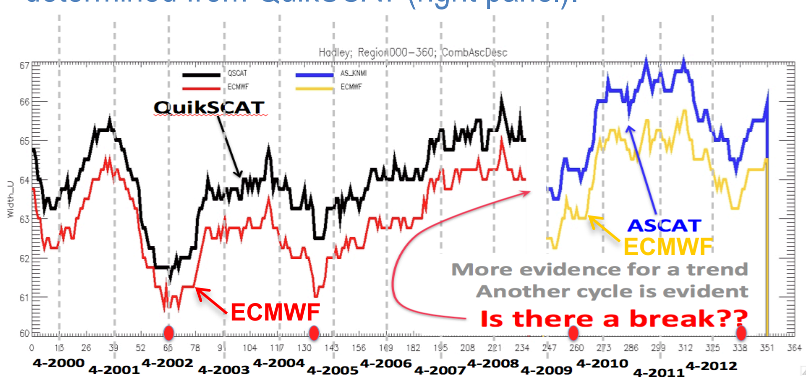


Fig. 2. Time evolution of the width of the combined Hadley cell as determined from the zero crossing of the mean zonal wind (from 1-year running averages)

Recent evidence suggests that the tropics have expanded over the last few decades by a very rough 1^{o} latitude per decade, considered to be an atmospheric response to the observed tropical ocean warming trend. If continued, the expansion of the tropics (the widening of the Hadley cell) could have a substantial impact on water resources and the ecology of the sub-tropics.

Until now, the understanding of the mechanisms that govern the changing width of the tropics has been confined to models and proxies because of the unavailability of systematic observations of the large-scale circulation.

Ocean surface vector winds, derived from scatterometer observations, provide for the first time an accurate depiction of the large-scale circulation and allow the study of the Hadley cell evolution through analysis of its surface branch.

In a 2015 study we determine the extent of the Hadley cell as defined by the subtropical zero-crossing of the zonally-averaged zonal wind component, determined from QuikSCAT observations (Fig. 1) - (Hristova-Veleva et al., 2015). We found:

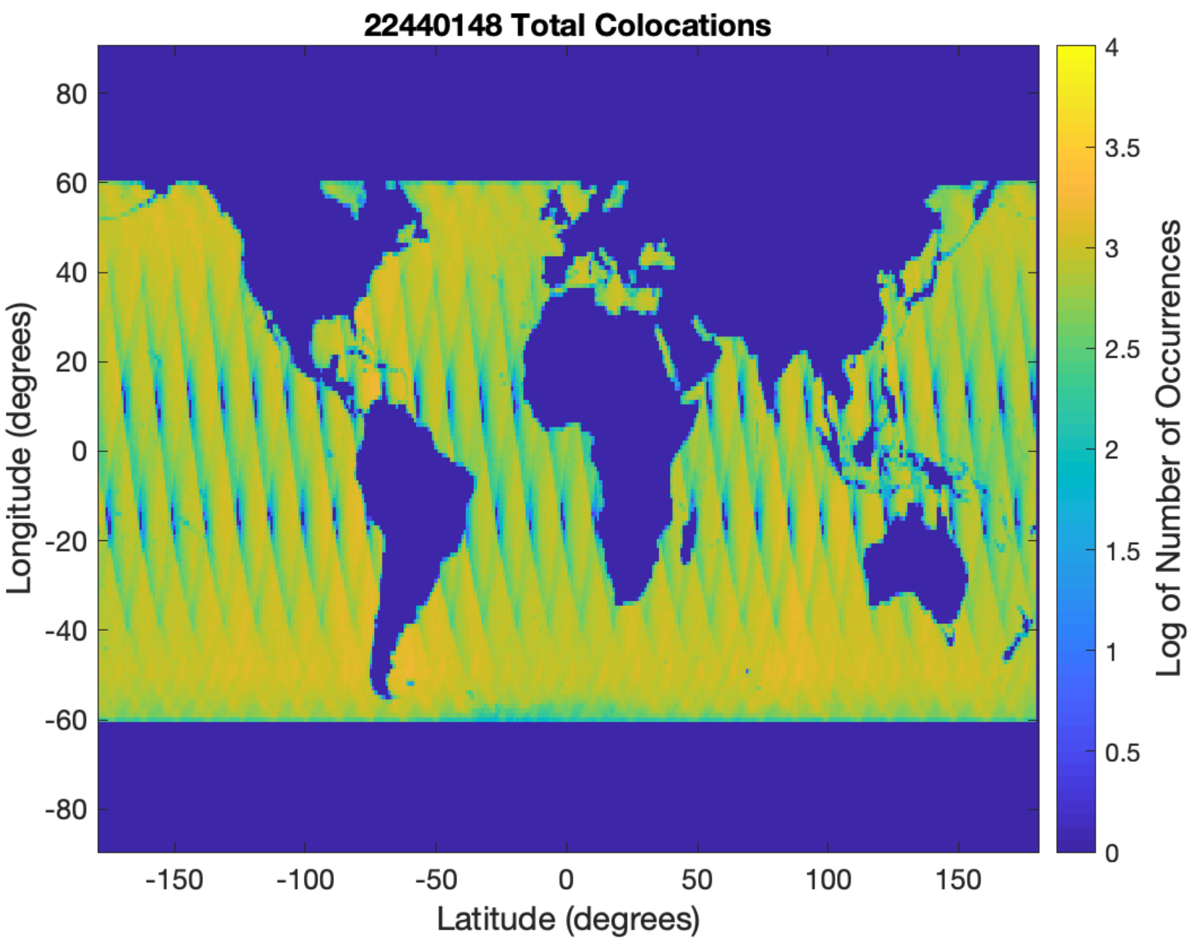
- The first half of the 10-year record shows two distinct cycles in the width of the Hadley cell while the latter part of the record shows a steady increase in the width, as has been shown by others (~1^{o}/decade, both south and north, for a total of about 2^{o} / decade);
- The two cycles in the 1999-2004 time period are likely a reflection of the modulation of the Hadley cell by the La Nina (1999) /El Nino (2002) events that dominated this period;

To investigate the consistency in the trends and variability when determined by different scatterometers, we performed similar analysis of the Hadley cell using the wind estimates from ASCAT. **We found an apparent discontinuity in the signal when the data source changes from one observing system to another (Fig. 2)!**

How do we make them consistent?

- The Ku-band ScatSAT scatterometer launched by the ISRO in Sept 26, 2016 has excellent overlap with ESA's intercalibrated C-Band ASCAT-A,B, and C scatterometers.
- Utilizing that overlap we deal with each source of inconsistency as follows:
  - Unlike C-band, Ku-band scatterometers are sensitive to SST.
    - **Fix: Utilize a SST-dependent GMF for Ku-band data to remove SST dependent errors in wind speed (see Ricciardulli and Wentz, 2017).**
  - Wind retrieval algorithms differ.
    - **Fix: retrieve data from all scatterometers using the same (or as similar as possible) wind retrieval algorithm that was used to produce the JPL version 4.1 QuikSCAT level 2B swath wind product.**
  - Geophysical model functions for the two sensors were validated with different ground truth data sets so that calibrations between backscatter and wind speeds may differ.
    - **Fix: Modify CMOD7 C-band geophysical model function so that line of maximal occurrence in the joint histogram between collocated ScatSAT and ASCAT wind speeds is along the one-to-one line.**
  - Ku-band scatterometers are much more sensitive to rain effects than C-band.
    - **Fix: After harmonizing the C-band and Ku-band GMFs, use the ASCAT wind retrievals to train a rain correction and flagging mechanism for Ku-band.**

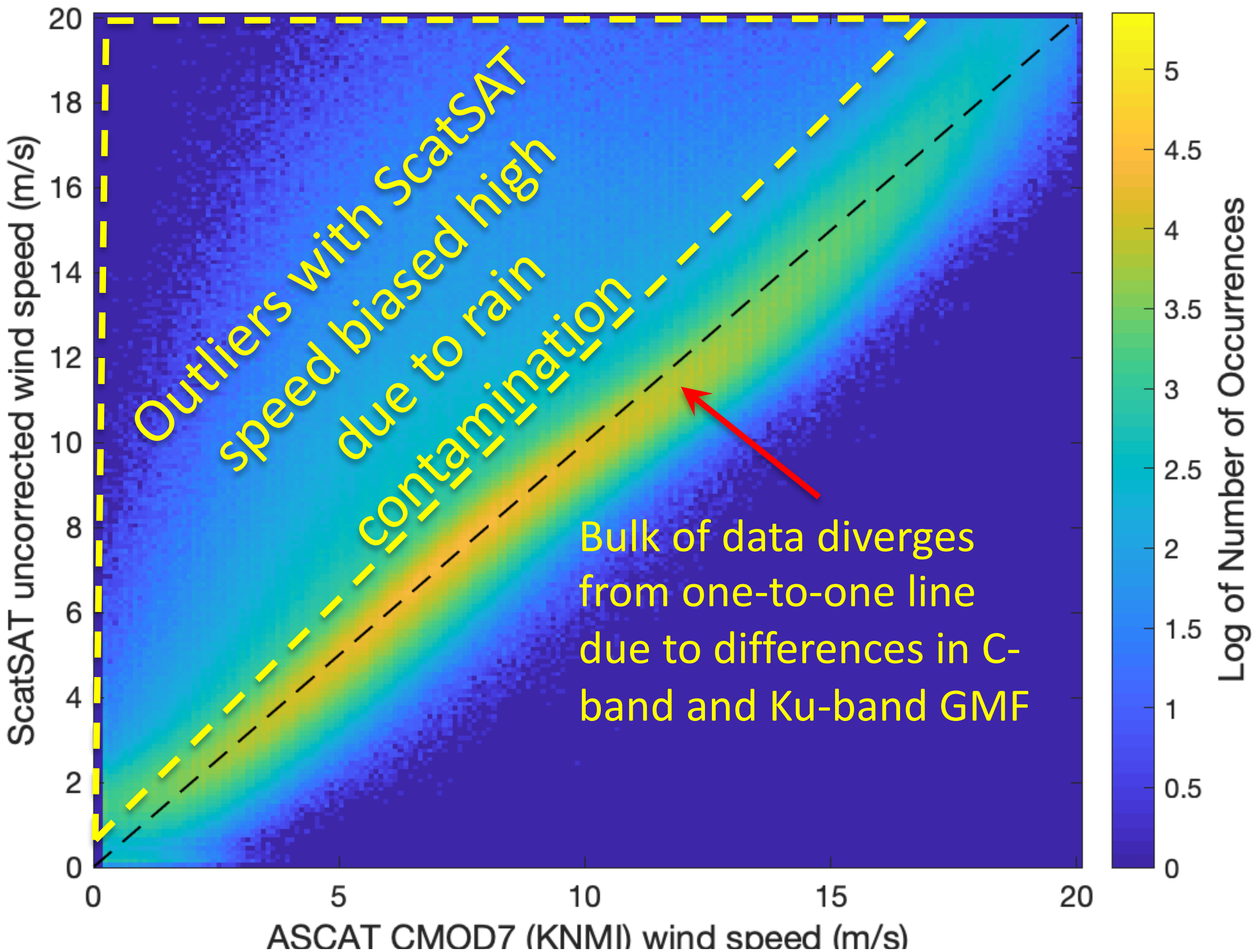
ASCAT/ScatSAT overlap is excellent



This map shows the location of ASCAT-B and ScatSAT matchups within 30 minutes that were used in this analysis.

- The color is the log of the number of occurrences per 1 degree by 1 degree grid cell. Typically over 1000 colocations are found in each grid cell.
- Latitudes north of 60 degrees and south of -60 degrees were excluded to avoid sea ice artifacts.
- The analysis data contains 22 million randomly selected 12.5 by 12.5 km wind vector cells during the time period April 1, 2018 to March 31, 2019. A random culling of the data set by a factor of 20 was done for computational efficiency.
- Periods in which ASCAT-A was better collocated than ASCAT-B are excluded as are wind vector cells that did not have all azimuth looks (e.g. the outer single beam part of the ScatSAT swath.)

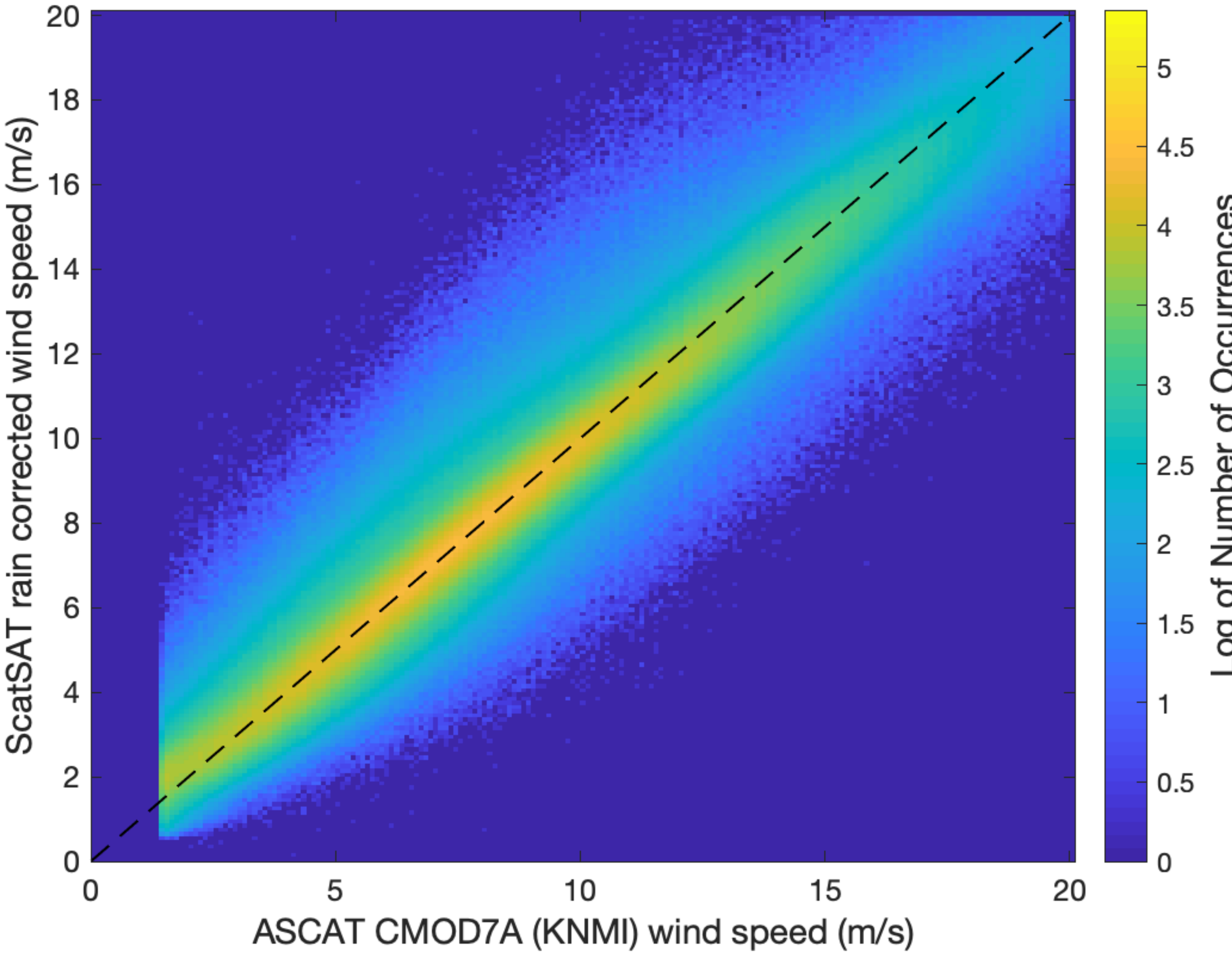
Using that Overlap we compare ScatSAT and ASCAT wind speeds



This figure is a 2-D dimensional histogram of the number of joint occurrences of each ASCAT KNMI and ScatSAT JPL wind speed retrieval.

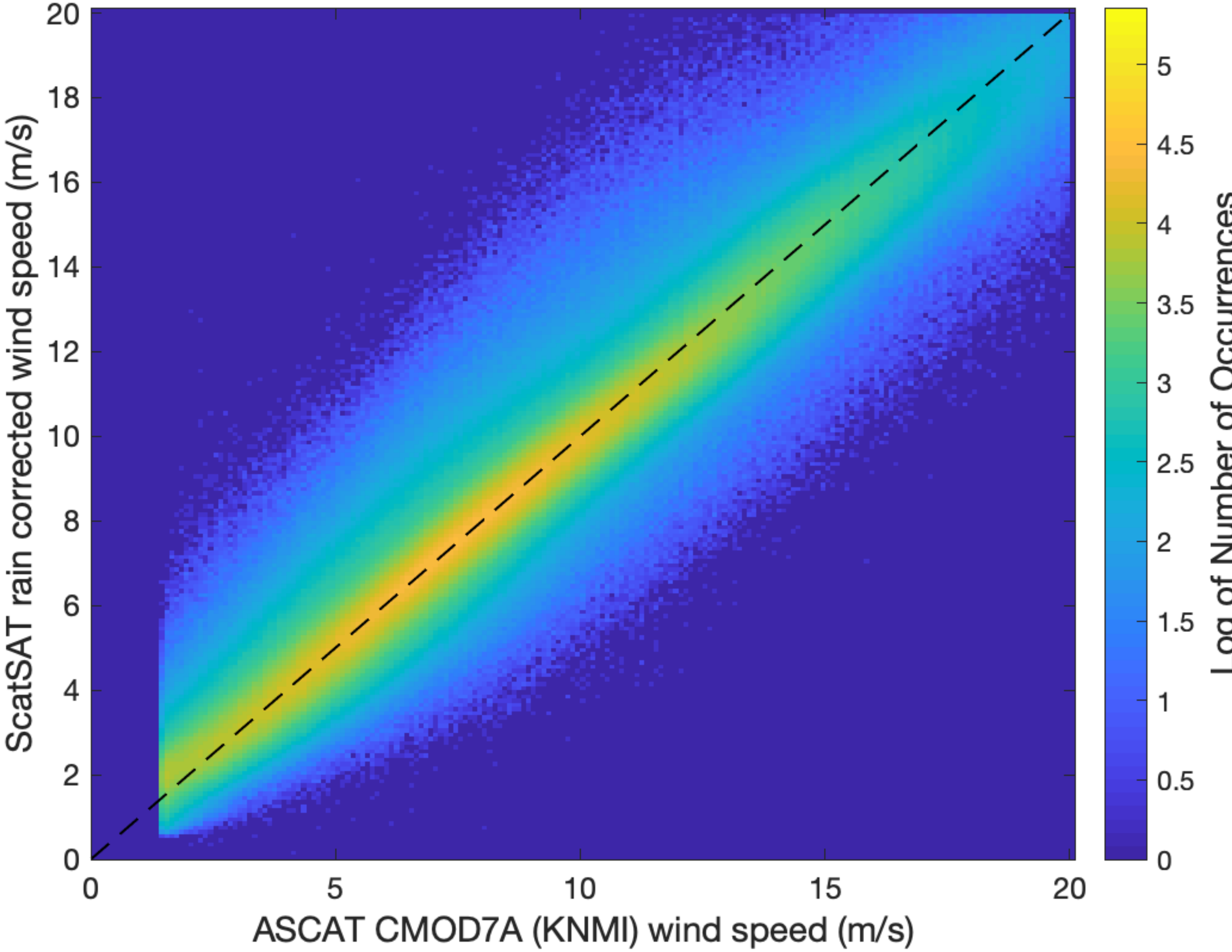
- ASCAT winds were retrieved using the CMOD7 GMF.
- ScatSAT winds were retrieved using the SST dependent Ku-Band GMF from [Ricciardulli and Wentz, 2017].
- The depicted JPL wind speeds were not corrected for rain.
- Histogram is log scaled to show outliers.

We align ScatSAT and ASCAT along the one-to one line using



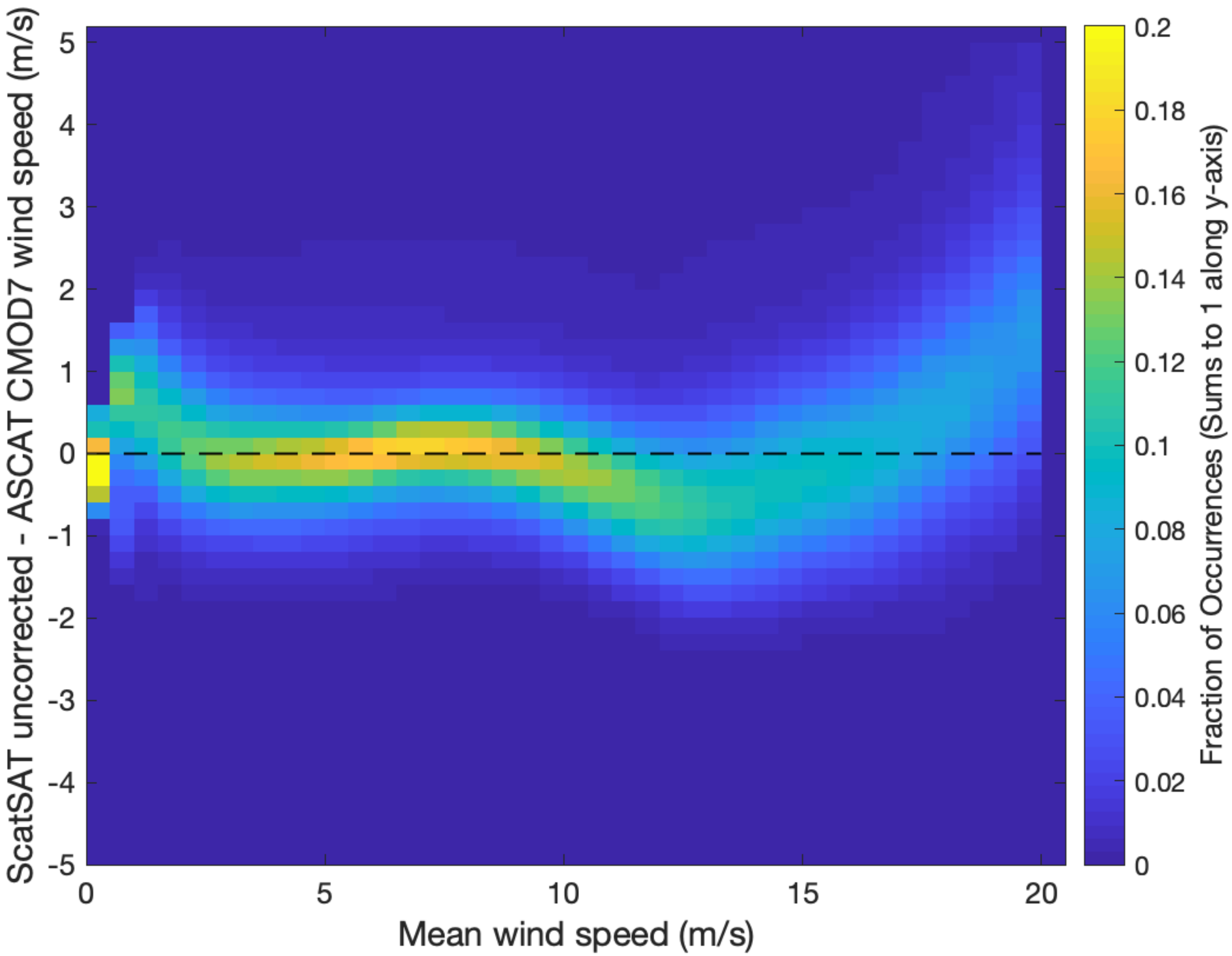
- ***A modified C-band GMF, CMOD7A,*** created by transforming the CMOD7 GMF to make the desired speed adjustment. For more details see [Fore et al, 2021].
- The CMOD7A ASCAT winds have a sharp cut-off at 2 m/s due to odd behavior of both C-band and Ku-band retrievals at very low winds. This artifact is removed when we go to CMOD7B (More on this later.)

We correct ScatSAT wind speeds for rain using…



- **A rain correction neural network** which is trained to use ScatSAT sigma-0s, brightness temperatures, and viewing geometry to estimate the bias between ScatSAT and ASCAT wind speeds due to rain.
- The bias estimated by the neural network is used to correct ScatSAT wind speeds.
- See [Stiles and Fore, 2019] for more details.

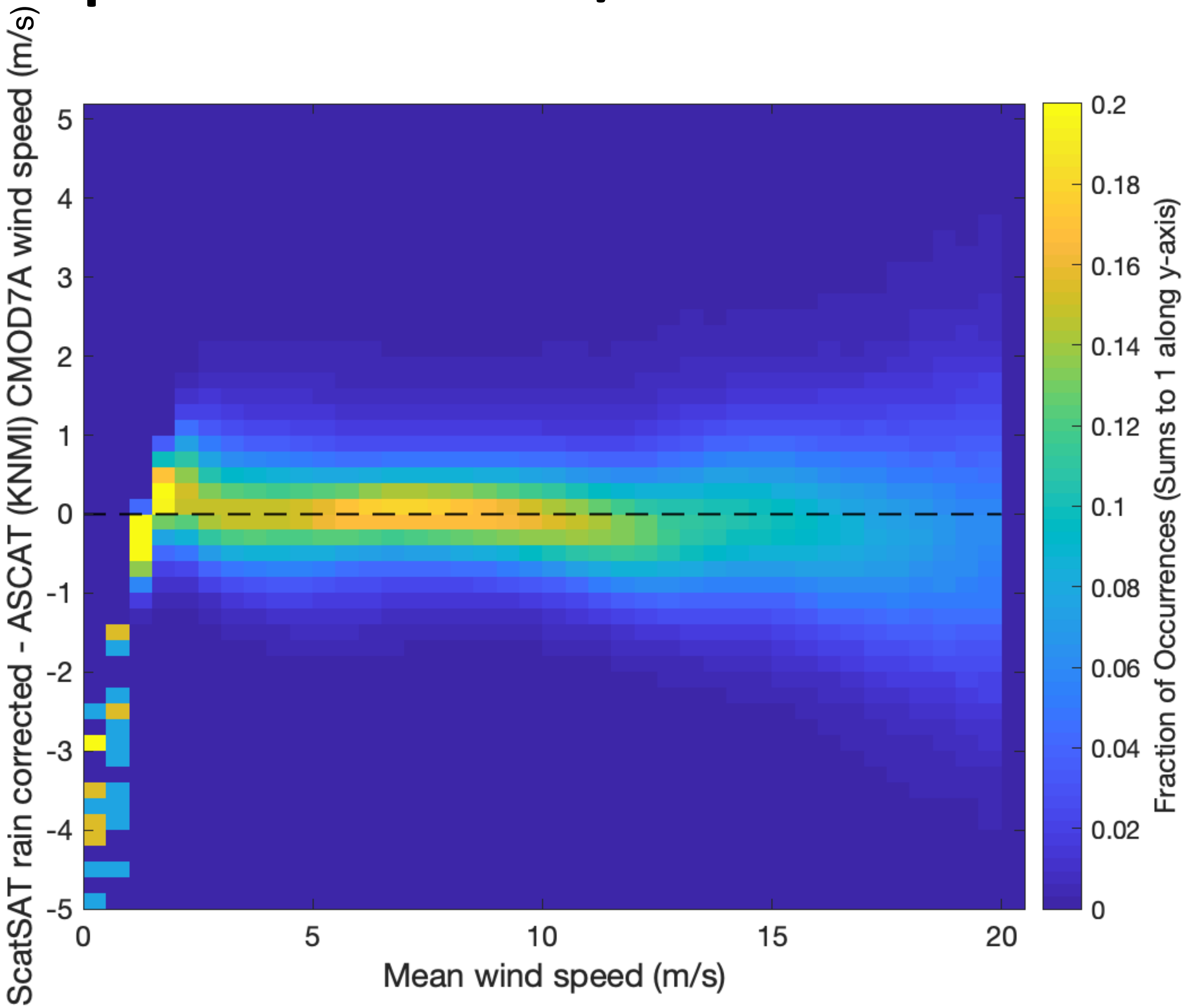
We better quantify the original divergence from the one-to-one line using a …



Bias vs. Mean 2-D histogram

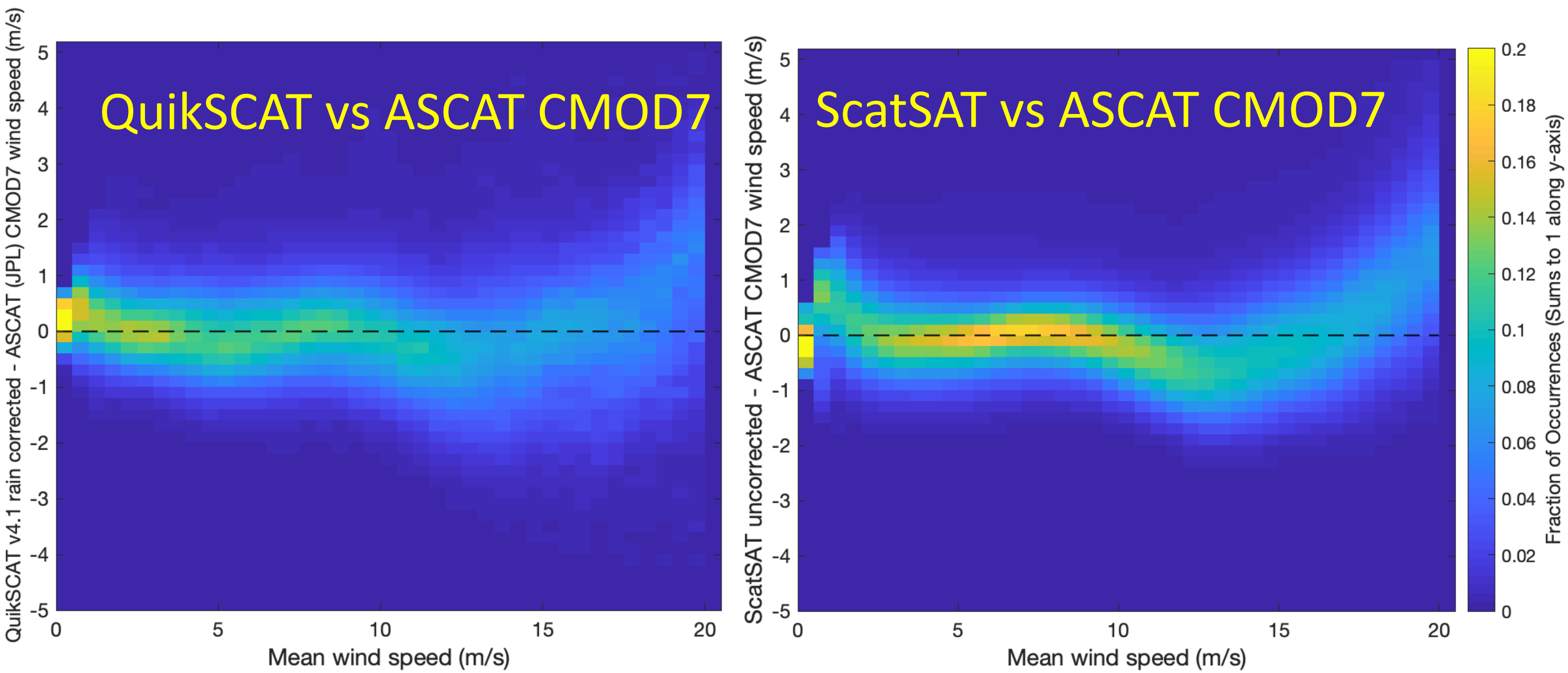
- The histogram is rotated so that the one-to-one line is along the x-axis
- Each column is normalized to sum to one.
- Y-axis is difference between ScatSAT and ASCAT.
- X-axis is the mean of the wind speeds from the two scatterometers.
- Color is the fraction of occurrence (i.e. probability of a given bias.)
- Discontinuity at < 1 m/s is due to a very small number of samples.

Data clusters around one-to-one line for speeds > 2 m/s when CMOD7A is used …



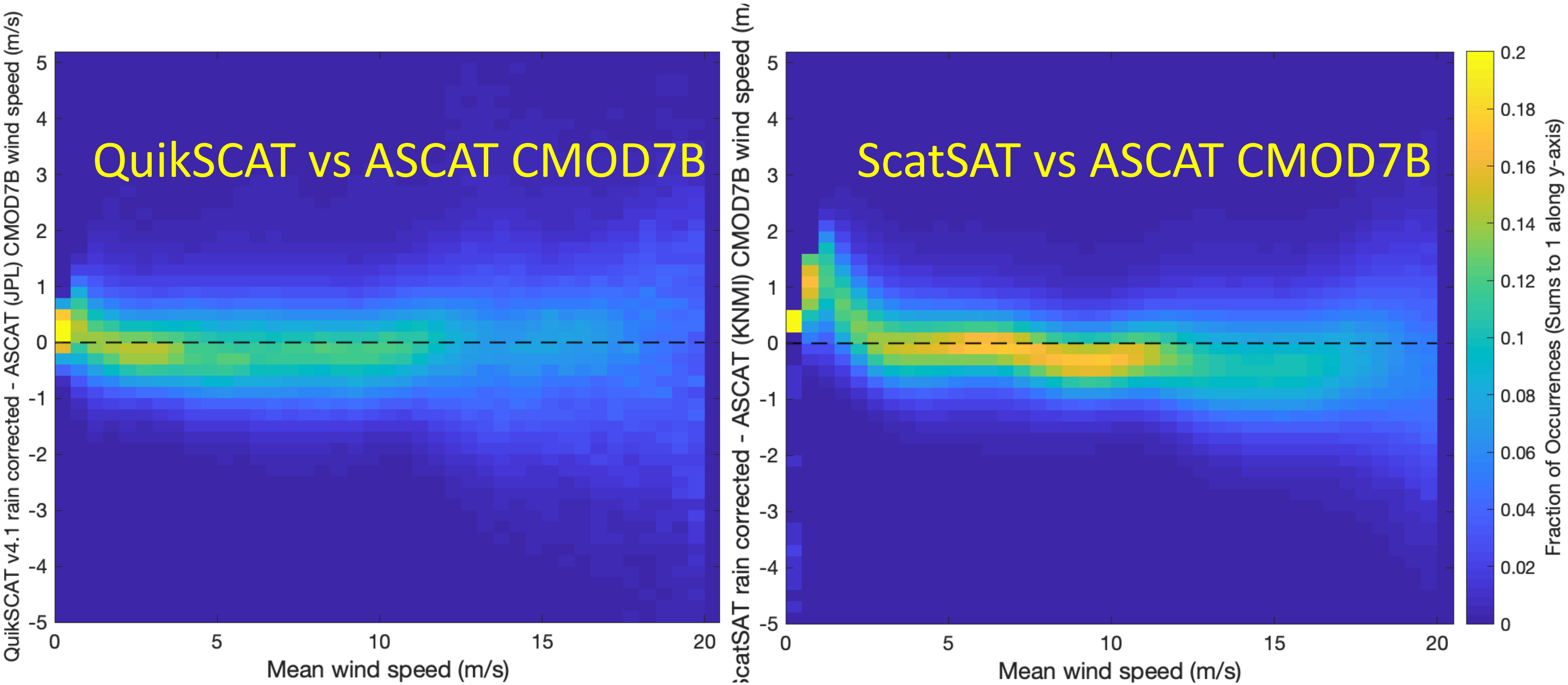
- The only exception is very low winds but as we shall see later this artifact is removed when we go to CMOD7B.
- KNMI appears to create an excess of low winds, while JPL has too few low winds.
- Histograms for both retrievals look non physical, but accurate validation data at winds below 2 m/s is hard to come by.
- There is also an important distinction between average speed and average vector wind over a wind cell that needs to be considered at very low winds.
- Zero average speeds are statistically unlikely but zero speeds for average vectors are not.

QuikSCAT/ASCAT-A comparisons are similar to ScatSAT/ASCAT-B, but …



They are not quite the same.

Here the CMOD7B GMF was created to match ASCAT to QuikSCAT and then compared to both Ku-back scatterometers.



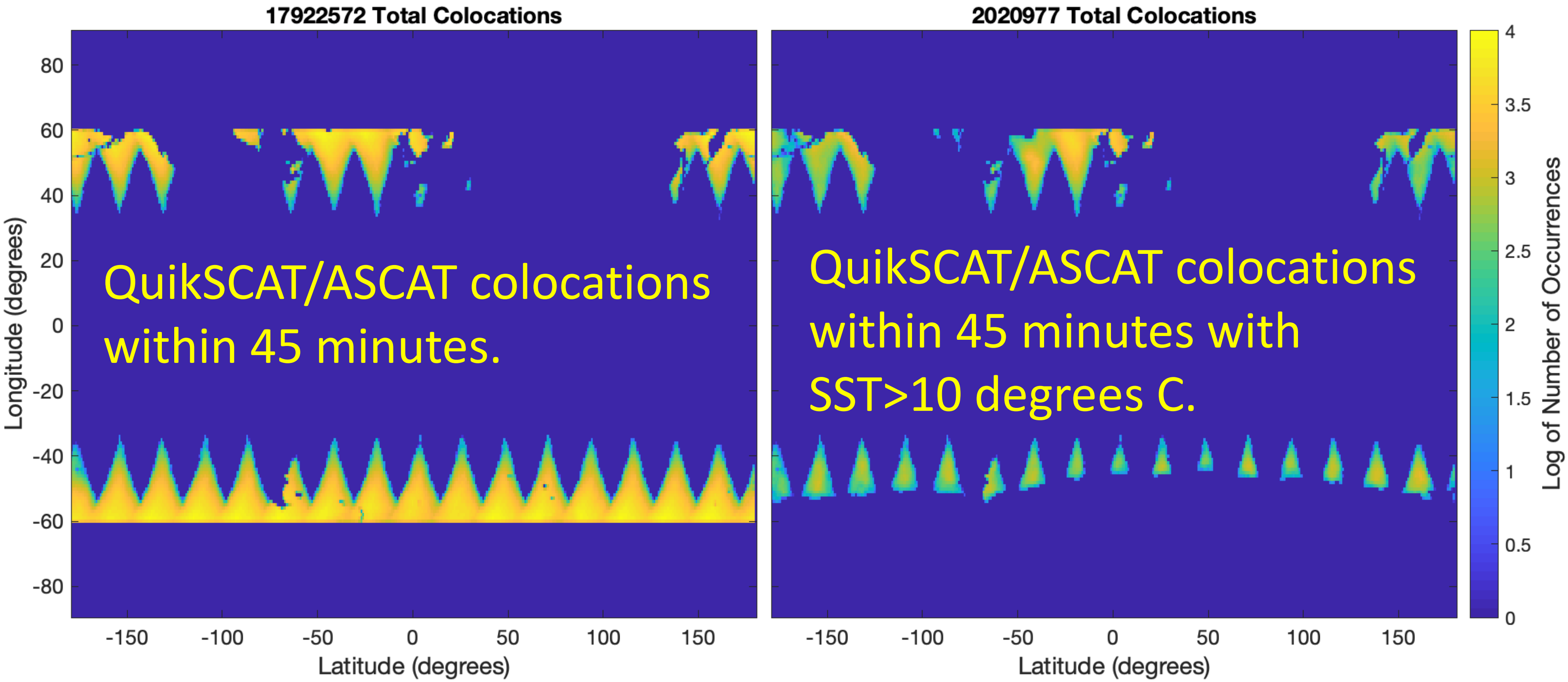
- ScatSAT speed biases are higher at low winds and lower at high winds than QuikSCAT.
- The QuikSCAT/ASCAT matchups were restricted by SST so that both data sets had the same mean SST.
- For consistency with ScatSAT, QuikSCAT/ASCAT matchups here are within 30 minutes, but more data with up to 90 minute time difference was used to estimate CMOD7B.
- The artifact that led to few speeds less than 2 m/s for CMOD7A was removed by matching JPL retrieved ASCAT-A data instead of KMNI retrievals.

Why do the ScatSAT and QuikSCAT comparisons differ?

- ScatSAT winds have been calibrated over all the QuikSCAT winds so they agree in the mean.
  - See [Fore et al, 2021]
- However when we compare with ASCAT, ScatSAT speed biases are higher at low winds and lower at high winds than QuikSCAT.
- The possibility of biases varying due to different average SSTs was examined and eliminated by utilizing data sets with similar mean SST– see following slides.
- Most likely remaining explanation is nonlinearity in backscatter calibration (e.g. unknown nonlinearity in radar receiver) for one or both Ku-band scatterometers.
- Such a nonlinearity would also explain why land and ocean calibrations between QuikSCAT and ScatSAT have been found to differ [Fore et al, 2021].

A quick note on QuikSCAT/ASCAT match-ups

Unlike ScatSAT they are not globally distributed.

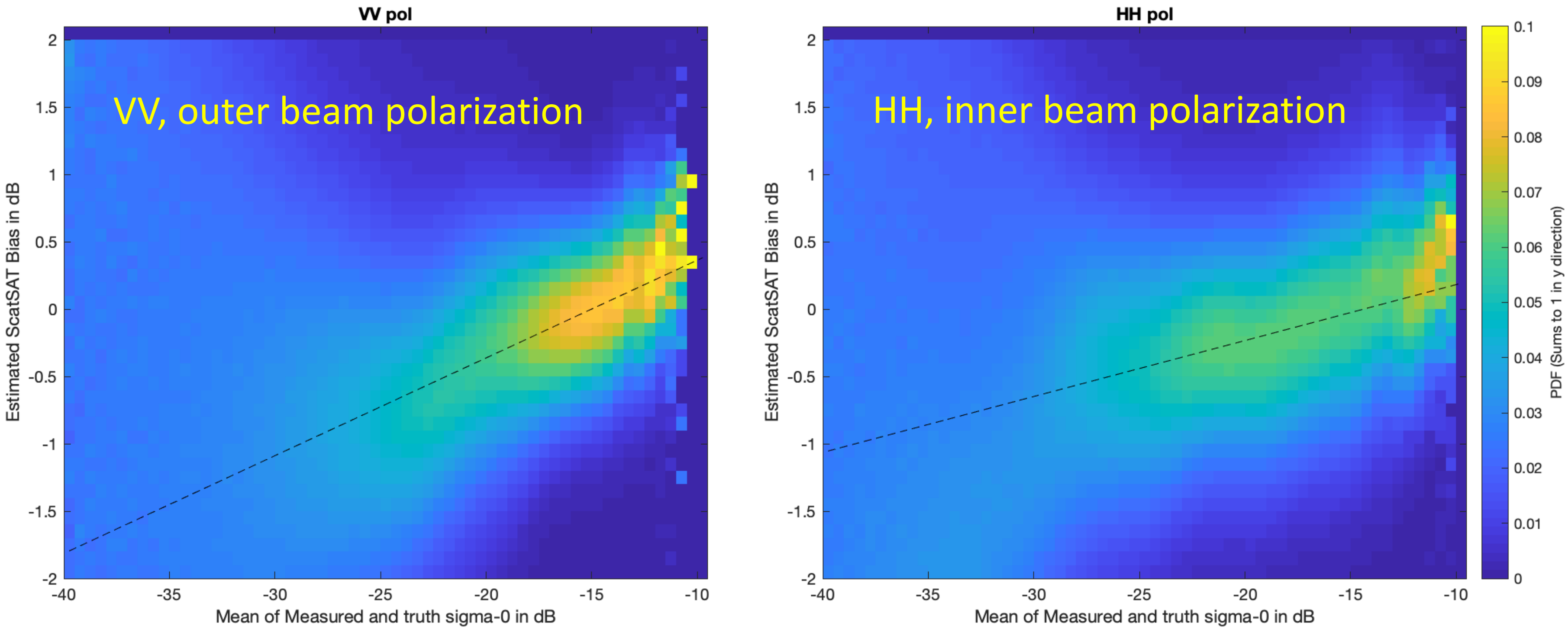


Because most ASCAT/QuikSCAT matchups are for far Southern or Northern latitudes with very low SST, it is necessary to use an SST-restricted data set like the one on the right to compare with global ScatSAT/ASCAT matchups and to develop CMOD7B.

We develop a new C-band GMF CMOD7B that harmonizes QuikSCAT and ASCAT

- First we adjust ASCAT-A speeds to match QuikSCAT
  - done with 90 minute colocation and using the SST limits [11.6 to 35 degrees] that provides a global mean of 16.1 deg C that matches the real global SST mean.
- Next we transform the CMOD7 GMF using the speed adjustment. See [Fore et al, 2021] for details.

We adjust ScatSAT backscatter to make QuikSCAT and ScatSAT winds match.



- Bias vs mean histograms are shown for ScatSAT - truth for both polarizations.
  - “Truth” sigma-0s are determined from the KuSST GMF using ASCAT-B winds retrieved with CMOD7B and thus are consistent with QuikSCAT sigma-0s.
- ScatSAT sigma-0s shows a linear bias trend in dB so that they are biased low w.r.t QuikSCAT for low sigma0s and high for high sigma0s.
- We plan to recalibrate ScatSAT sigma-0s to remove this trend, thereby removing the wind speed bias trend (right panel slide 13) between ScatSAT retrieved with the KuSST GMF and ASCAT-B winds retrieved with CMOD7B.

What is left to do?

- Recalibrate ScatSAT sigma-0s to remove trends in slide 17 and reprocess data to winds.
  - Removing a linear trend in dB will likely be sufficient for wind speeds greater than 4 m/s.
  - A different fit not performed in dB may be needed to appropriately handle very small sigma-0s to avoid introducing artifacts at low winds.
- Retrain the rain correction neural network for ScatSAT using
  - recalibrated ScatSAT sigma-0 data
  - ScatSAT wind speeds retrieved from recalibrated sigma-0s.
  - ASCAT-B wind speeds retrieved with JPL algorithms using CMOD7B
- Transform the rain correction neural network to apply it to QuikSCAT data using known differences in incidence angles and brightness temperature.

References

- Details of SST dependent GMF for Ku-band
  - Lucrezia Ricciardulli and Frank Wentz, "SST Impact on RapidScat and QuikSCAT Measurements," International Ocean Vector Wind Science Team meeting, May 2017, La Jolla CA, USA. https://mdc.coaps.fsu.edu/scatterometry/meeting/docs/2017/docs/Tuesday/afternoon/SecondSession/400_Ricciardulli_KuSST_ovwst_2017_posted.pdf
- Details of ScatSAT Rain correction method
  - Bryan W. Stiles and Alexander G. Fore, "Using ASCAT Overlaps to Develop Rain flagging and Corrections for ScatSAT Winds," International Ocean Vector Winds Science Team Meeting Portland, Maine May 29-31, 2019 https://mdc.coaps.fsu.edu/scatterometry/meeting/docs/2019/IOVWST_20190529-1625-Stiles.pdf
- Details of ScatSAT wind retrieval including transformation from CMOD7 GMF to CMOD7A and CMOD7B and calibration constants between QuikSCAT and ScatSAT.
  - Alexander G. Fore et al, "The JPL SCATSAT Climate Quality Data Product," International Ocean Vector Winds Science Team Meeting (Virtual) February-March 2021.
- Examples of scientific need for harmonization of C- and Ku-band scatterometers
  - Svetla M. Hristova-Veleva, "Strengths and weakness of using multi-instrument, multi-mission climate data records to understanding how the Earth System is changing," International Ocean Vector Winds Science Team Meeting (Virtual) February-March 2021.
  - Svetla M. Hristova-Veleva, E. Rodriguez, Z. Haddad, B. Stiles and F. J. Turk, "Hadley cell trends and variability as determined from scatterometer observations: How rapidscat will help establishing reliable long-term record," 2015 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Milan, 2015, pp. 1211-1214, doi: 10.1109/IGARSS.2015.7325990.