Simultaneous Wind/Rain OSCAT Geophysical Model Function

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Abstract

Ku-band scatterometers are designed to measure near surface vector winds (VW) over the ocean. Under non-raining conditions the wind-only (WO) Geophysical Model Function (GMF) accurately maps between near-surface VW and the normalized radar backscatter (σ^o) measured by space-bourne scatterometers. The presence of rain distorts the observed wind-induced σ^o (several surface alterations and interactions between the transmitted/reflected signal and the falling rain drops) causing the WO GMF estimated VW accuracy to decrease.

Simultaneous Wind/Rain (SWR) GMFs have been created in the past for other the C-band advanced Scatterometer (ASCAT) [1], and the Ku-band QuikSCAT [1,2]. The OceanSat-2 Scatterometer (OSCAT), though similar to QuikSCAT, operates at a different incidence angle and so needs a unique SWR GMF. OSCAT σ^o, Tropical Rain Measurement Mission (TRMM) Precipitation Radar rain rate, and European Center for Medium-Range Weather Forecast (ECMWF) near-surface wind numerical weather prediction product are combined into a triple collocated database called the OTED which is used to create the OSCAT SWR GMF.

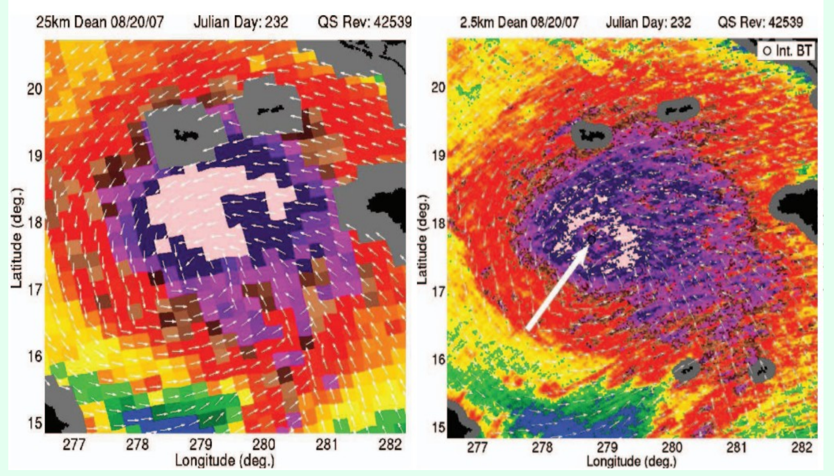
The SWR GMF uses a phenomenological model to capture the effect of rain on σ^o measurements, $\sigma^o = \alpha(R)M(s,d,f,p) + \sigma(R)$. Four methods for making the SWR GMF are highlighted: the Direct Parameterization method (DPM), Ratio Method (RM), Harmonic Decomposition Method (HDM), and Path Integrated Attenuation Method (PIAM). Estimated VW results show that PIAM is the most accurate SWR GMF creation method.

The key results are the SWR GMF improves the wind speed estimate accuracy in the presence of rain compared to WO estimates for all σ^o resolution size. Conversely the WO direction estimates outperform the SWR estimates. The estimate improvement for direction is not significantly improved. The UHR estimates for both direction and speed generally outperform other lower resolution estimates. These results are submitted in a journal paper that is under-review for IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing [3].

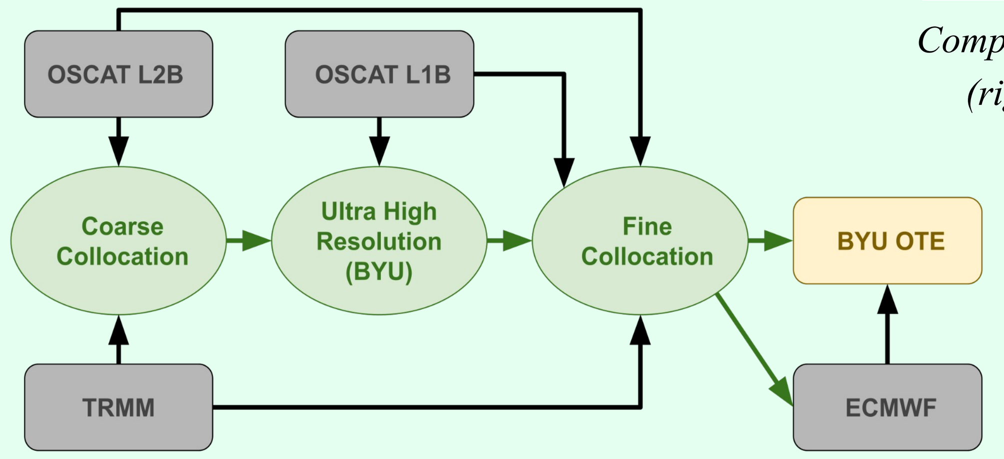
Collocations and the OTED

A triple collocated database is created between three sources: **OSCAT, TRMM, ECMWF** called the OTED. There are different resolution OSCAT data products. L1B raw σ^o have two resolutions, **slice** and **footprint** which have roughly 6 by 30 km and 20 by 68 km respectively. Ultra High Resolution (**UHR**) product uses the spatial response of OSCAT to produce σ^o on a rough 2.5 km grid. The difference resolution of UHR and conventional VW estimates is shown in the right. TRMM PR measured rain rate and reports the (1) near surface rain rate and (2) Path Integrated Attenuation (PIA). ECMWF is a numerical weather prediction product that calculates the near-surface wind vector ever 6 hours on a 1° grid.

The OTED is compiled by collocating the OSCAT, TRMM and ECMWF data in two steps: (1) **Coarse Collocations** between lower resolution conventional VW files and TRMM, and (2) **Fine Collocations** where specific UHR σ^o values are calculated, and OSCAT L1B, UHR, are collocated with TRMM PR. ECMWF wind product is interpolated for those locations and times. Collocations are within 5 km and 15 minutes.



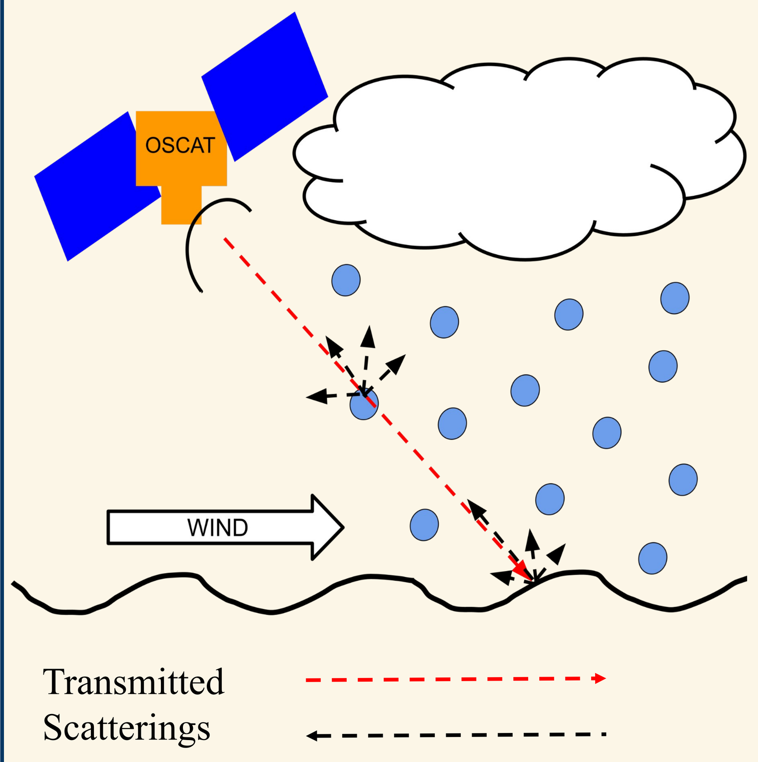
Comparison of VW field from conventional (left) UHR (right) for the same hurricane in 2006. Note the improved eye distinction



OSCAT and TRMM collocation steps.

Measurements Type	WVC Resolution
Footprint/Slice	25 km X 25 km
UHR	2.5 km X 2.5 km

The Phenomenological Model and SWR GMF Development Methods



Effects of rain on the transmitted scatterometer signal.

Rain alters the conventional WO relationship between the σ^o and the near surface VW. **Rain adds additional power to the wind-induced scattered signal via surface alterations and falling raindrop interactions.** The rain impacts on the ocean surface cause ripples and stalks which suppress the wind induced stress on the ocean surface. The raindrops attenuate the transmitted and scattered signals causing volume scattering to increase the non-wind-induced percentage of return power. Rain introduces other effects such as gust fronts and downdrafts that also alter the wind induced spectra on the ocean surface. A SWR GMF is needed to model these effects to increase the accuracy of VW estimates.

A phenomenological model is used to create the SWR GMF. The classic $\sigma^o = \alpha(R)\,M(s,d,f,p) + \sigma(R)$, where $\alpha(R)$ is the attenuation from the rain $M(s,d,f,p)$ is the WO GMF, and $\sigma(R)$ is the effective offset, is used.

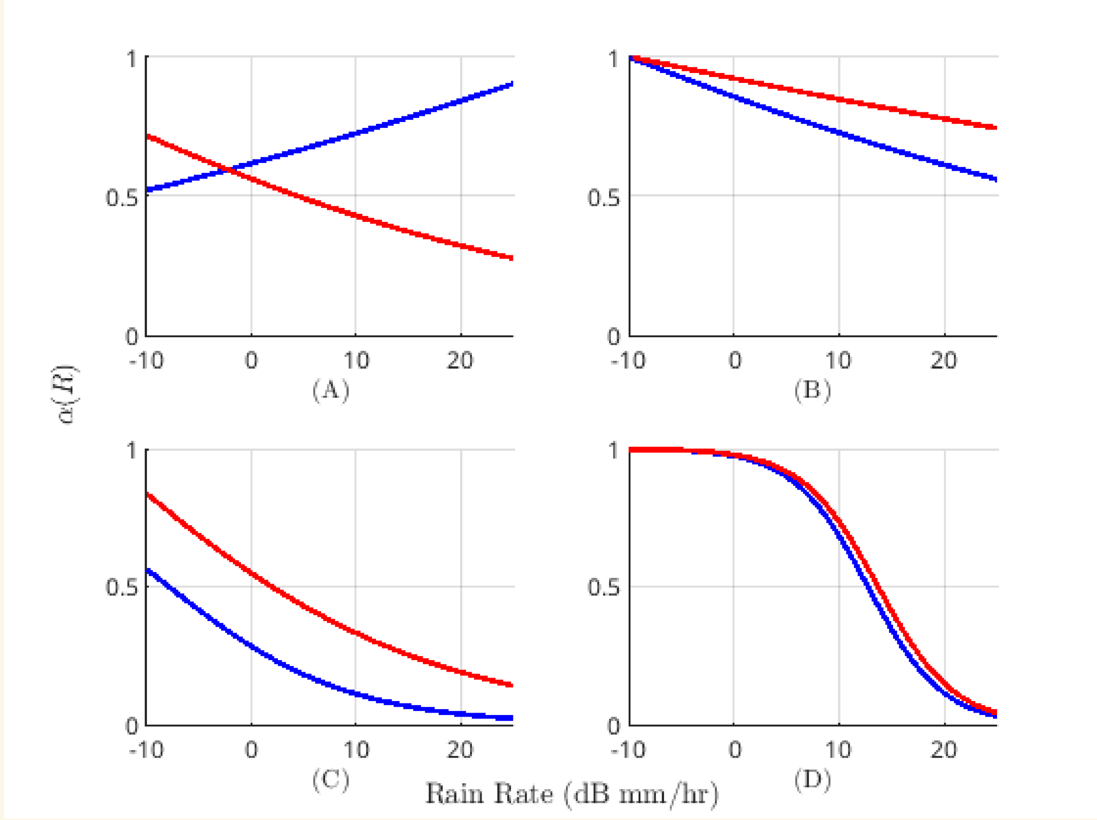
DPM: calculates $\alpha(R)$ and $\sigma(R)$ simultaneously using parametric equations (linear, logarithmic, exponential, and sigmoid). Through experimentation it is found that the most accurate parametric equations for $\alpha(R)$ and $\sigma(R)$ are both $x_1/(1-e^{(1+x_2R)})$ sigmoid equations (R in dB).

RM: calculates $\alpha(R)$ by binning σ^o measurements by R where the average ratio between each observed σ^o value and $M(s,d,f,p)$ calculated, i.e., $\alpha(R) = \langle\sigma^o/M(s,d,f,p)\rangle$.

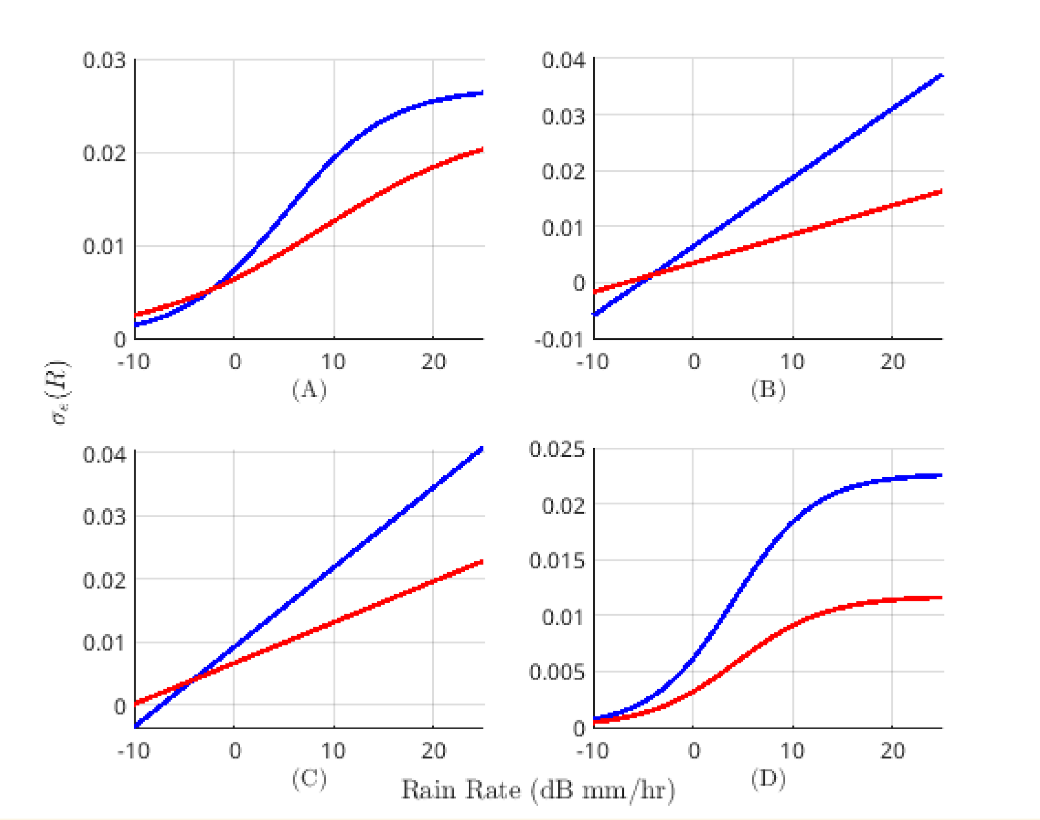
HDM: A harmonic decomposition is performed on σ^o data that has been binned by R and is calculated up to the 5th harmonic. The first coefficient in each ran bin ($A_0(R_b)$) is compared to the WO first coefficient ($A_0(0)$), $\alpha(R) = A_0(R_b)/A_0(0)$.

PIAM: calculates $\alpha(R)$ using the PIA from TRMM using $\alpha(R) = 10^{(PIA/10)}$. This is converted to OSCAT PIA using simple geometry.

Attenuation Term α(R)



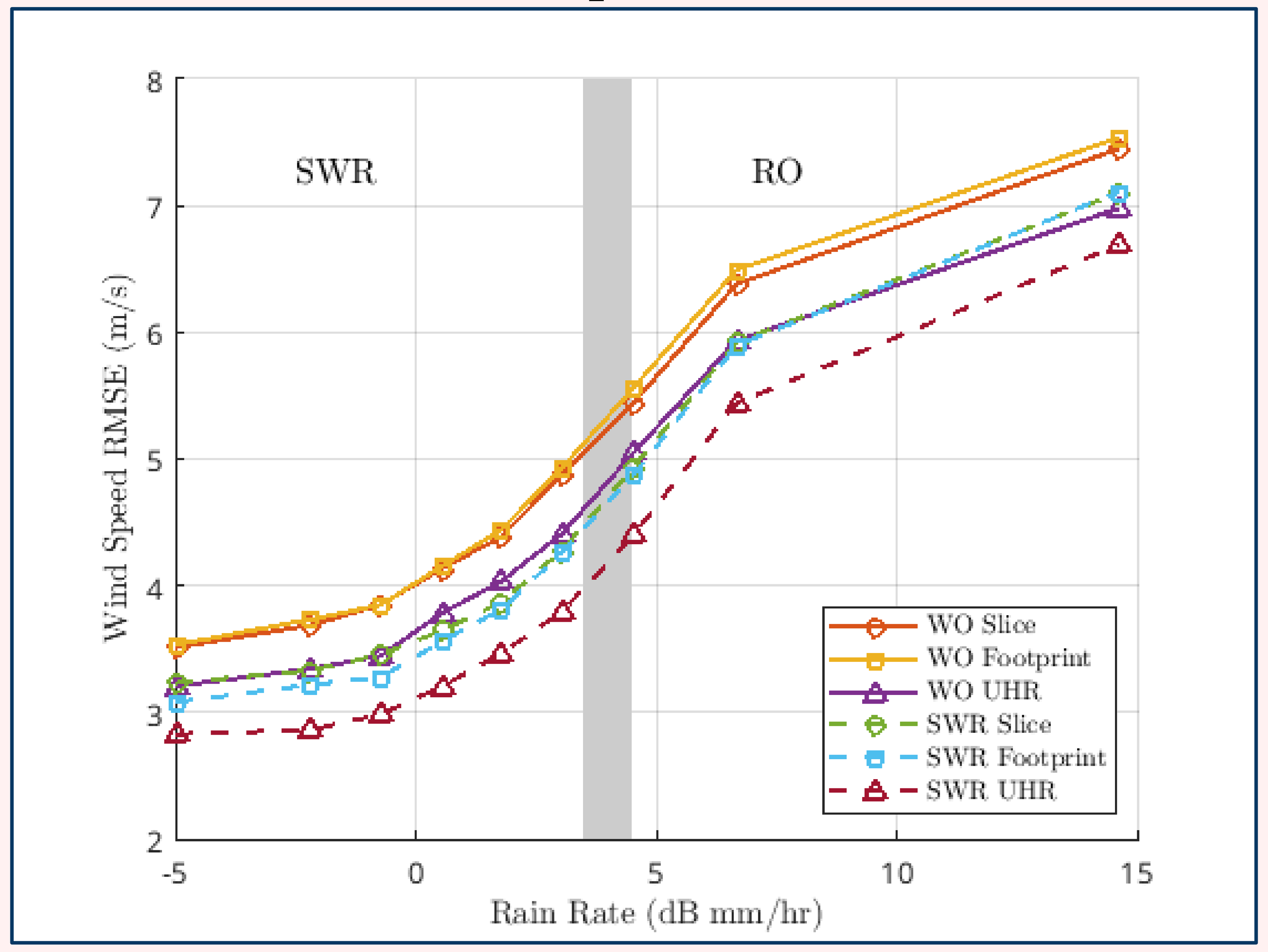
Effective Offset Term □(R)



Derived α(R) (left) and $\sigma_e(R)$ (right) as a function of rain rate parametric fits. (A) Direct Parametric Fit, (B) Rato Method, (C) Harmonic Decomposition Method, (D) Path Integrated Attenuation Method. Inner beam shown in blue and Outer beam shown in red.

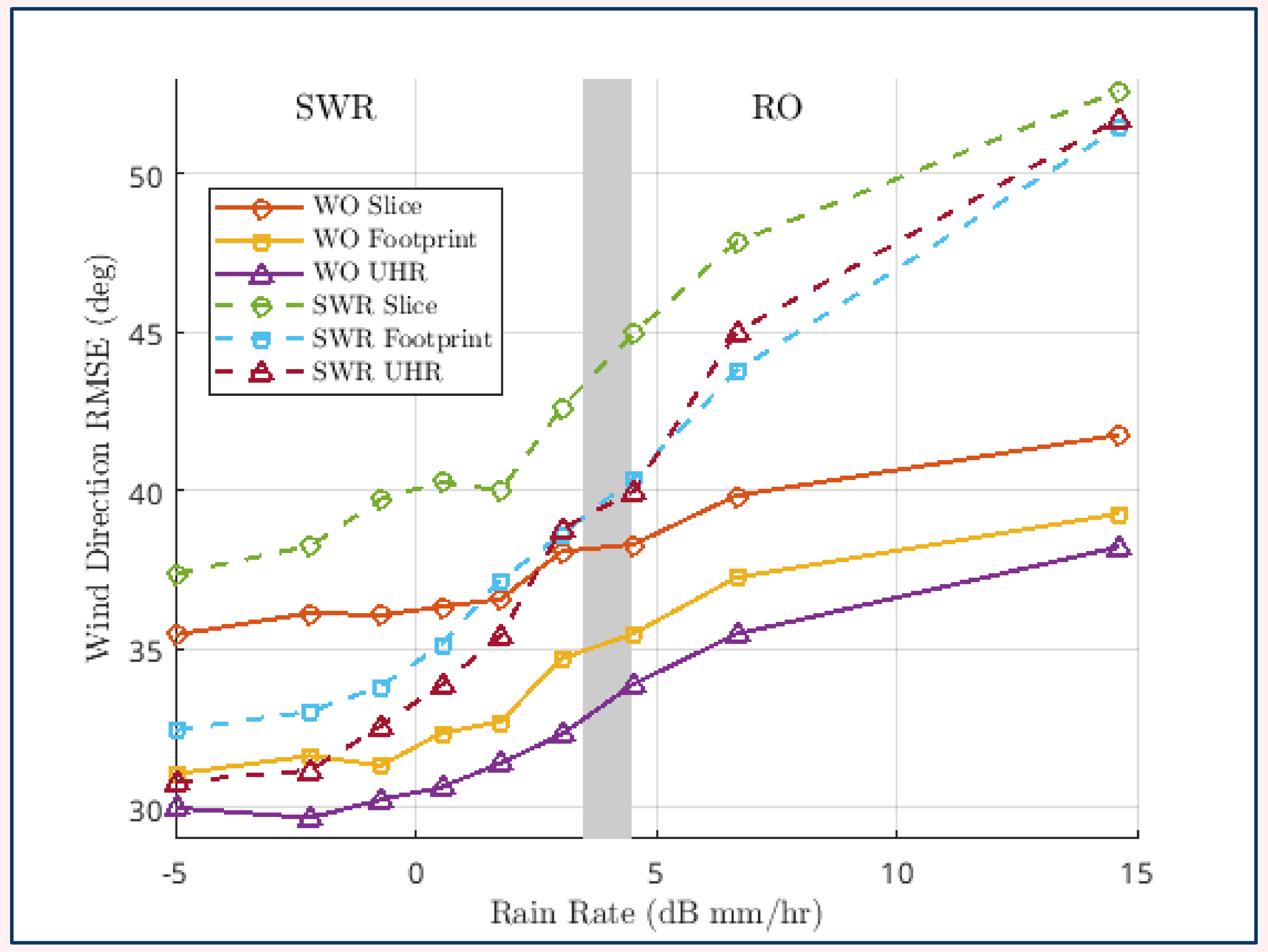
$\sigma(R)$ for RM, HDM and PIAM is found by rearranging the phenomenological equation. A parametric fit is calculated from each. All the $\alpha(R)$ and $\sigma(R)$ are shown above.

Wind Speed RMSE



(A)

Wind Direction RMSE



(B)

Rain-Present Retrieval Results

The accuracy of the SWR GMF is analyzed using OTED data. The results are shown for measurements where rain is present according to TRMM. The retrieved VW are compared with ECMWF using the root mean square error (RMSE) for both wind speed and direction.

The estimated wind speeds that are shown include the SWR UHR, WO UHR, SWR Footprint, WO Footprint, SWR Slice, and WO Slice. Two important comparisons need to be made. The first is between estimates using the same σ^o resolution data using the same retrieval algorithm. The second is between estimates using the same retrieval algorithm with different spatial resolution σ^o.

Figure (A) shows the RMSE between the estimated and ECMWF wind speeds. The first general trend is that the SWR algorithm outperforms the WO algorithm. This is true for all σ^o resolution estimates. The second general trend is that the UHR is the most accurate, while the footprint is the second most accurate, and the slice is the least accurate. This is true for both retrieval algorithms.

The most accurate wind speed accurate for all rain rates is the SWR UHR product. This product has the highest resolution and used the SWR GMF. It is roughly 0.25 m/s more accurate than the footprint resolution estimate that also uses the same SWR algorithm and it is roughly 0.5 m/s more accurate than the WO estimates with the same resolution σ^o values at low rain rates. The estimate accuracy increase with the increase in rain rate.

Figure (B) shows the RMSE between the estimated and ECMWF wind directions. The first general trend is that the slice estimates have the poorest performance. The second general trend is the WO outperforms SWR estimates except at lower rain rates where the both UHR and footprint SWR and WO have comparable estimate accuracy. The final trend is that as rain rate increases, the SWR estimate performance suffers more than WO estimates.

The most accurate direction estimate is the WO UHR estimate which has similar accuracy to the SWR UHR estimates at low rain rates but out performs it by roughly 10° at high rain rates. The WO UHR also has similar accuracy compared to the WO footprint estimates with only a about a 1° improvement across for all rain rates.

References and Contact

[1] M. P. Owen, "Scatterometer Contamination Mitigation," PhD. Dissertation, Brigham Young University, Provo, Utah, 2010.
[2] D. W. Draper and D. G. Long, "Simultaneous wind and rain retrieval using SeaWinds data," IEEE Transactions on Geoscience and Remote Sensing, vol. 42, no. 7, pp. 1411–1423, 2004.
[3] B. J. Fogg and D. G. Long, "An OSCAT Simultaneous Wind/Rain Geophysical Model Function," manuscript under review, 2025.

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