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QuikScat Brightness Temperatures and Their Impact on Rain Flagging

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Introduction

In this report we describe results we have obtained by adding brightness temperatures measured using the QuikScat receiver in radiometer mode to our rain flag algorithm. The algorithm for these brightness temperatures was developed by Linwood Jones and his team at Central Florida University, and were transcribed to Level 2B format by David Long at Brigham Young University. Since the QuikScat instrument was in no way designed to be a radiometer, the brightness temperatures are more than an order of magnitude more noisy than those obtained using an instrument optimized for radiometry. Still, we have found that the addition of the QuikScat Radiometer or "Qrad" brightness temperatures into our rain flagging algorithm has a profound and beneficial effect on its performance, especially at high wind speeds, where methods based on the M.L.E. or normalized beam balance have difficulty.

The presence of rain causes increased emissivity and scattering that increases the brightness temperature (T_b) of the scene above the background T_b that would be expected for non-rainy conditions. To develop a T_b-based rain detection algorithm, it is important to remove the background T_b as accurately as possible so that the T_b enhancements due to the presence of rain can be clearly seen. The most important geophysical contributions to the background T_b are due to water vapor, SST, surface wind, and the presence of cloud liquid water. Our approach is to calculate an estimate of the background T_b based on climatology and the retrieved QuikScat wind speed, and subtract that from the observed T_b to obtain an estimate of the excess T_b due to rain.

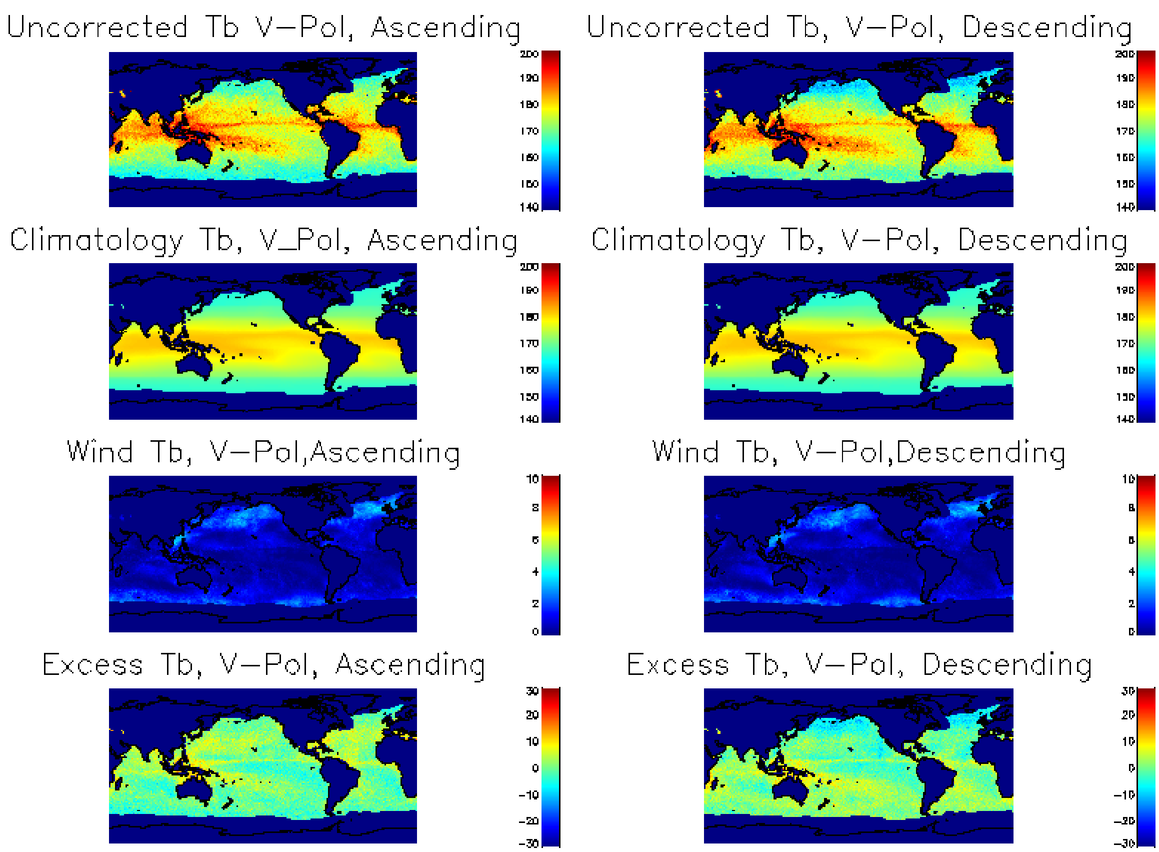

Figure 1. Global maps of brightness temperatures averaged over revs 2400-2699. The top row shows the measured T_b's, without any background subtraction. The next two rows show the climatological and wind-speed-based backgrounds to be subtracted. The bottom row shows the excess T_b's. Note that the geographical variation readily apparent in the measured T_b's has been much reduced in the background-subtracted excess T_b's.

Removing the Background from the QRad Brightness Temperatures

Climatology is used to determine the contribution to the background T_b due to water vapor, SST, and cloud water. Mean brightness temperature T_b maps were produced using eleven years (1988-1998) of monthly averaged SSM/I water vapor data and Reynold's monthly mean sea surface temperatures. The cloud liquid water was set to a constant value (0.05 mm), since we expect rain and cloud water to be highly correlated. The monthly-averaged SSM/I water vapor data input to the algorithm were calculated using all operating SSM/I instruments for any given month.

These values served as input to the SSM/I calibrated ocean algorithm[*Wentz*, 1997], which describes the relationship between ocean and atmospheric conditions and the observed brightness temperature. The SSM/I algorithm was adjusted to return the brightness temperatures expected at 46 and 54 degrees incidence for horizontal and vertical polarizations, respectively. These incidence angles and polarizations match those of QuikScat's two beams. The returned brightness temperature data were then mapped to monthly 1-degree global maps for each year. The eleven years of monthly maps were then averaged to produce a set of twelve climatological mean maps. A mean value for any given 1-degree cell was calculated only if there were more than 7 years of data available.

The estimate of the increased T_b due to surface wind was calculated using the simple, direction independent algorithm shown below where wind speed is the QuikScat retrieved wind using the selected ambiguity.

H-pol	T_b,wind = 1.0 * windspeed	(for all wind speeds)
V-Pol:	T_b,wind = 0.0	(for wind speed less than 7.0 m/s)
	T_b,wind = 1.0*(windspeed – 7.0m/s)	(for wind speed greater than 7.0 m/s)

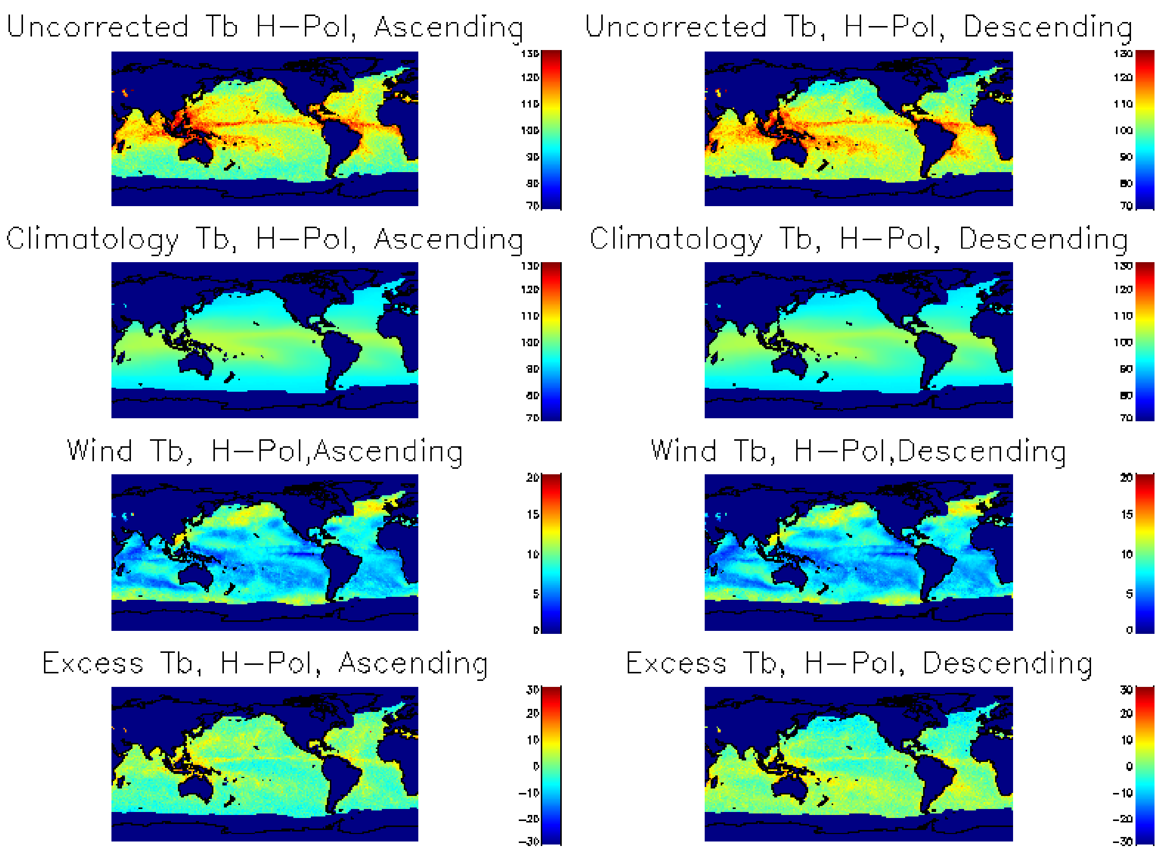

Figure 2. This figure is similar to Figure cm_1, except that this figure is for H-Pol. Because the brightness temperature of the ocean is significantly less for H-Pol, areas of rain are more clearly visible in the measured T_b's.

Since the wind speed correction is small compared to the rms noise of the T_b measurements, the first rank ambiguity could probably also be used without dramatically affecting the resulting excess T_b's.

In Figures 1 and 2, we show global maps of the raw Qrad T_b's, the background T_b due to climatology, the estimated background T_b due to wind, and the "excess" T_b's with the estimated background removed. Each map is an average over revs 2400-2699. In addition to the physically-based corrections described above, we have also removed an ad-hoc constant from the uncorrected and corrected T_b's to correct for an ascending/descending difference and to correct the overall mean values to the climatological estimates. We expect that later, more advanced versions of the algorithm that produce the T_b's will not require this correction, and may also remove a small north/south-ascending/descending bias apparent in the data.. Note that by removing the portion of the T_b's due to climatology and wind, we have significantly reduced the regional variation of T_b. Also note that expected rain features, such as that along the ITCZ, are clearly visible, especially in the H-Pol maps.

We have made the background removal algorithms described above and a dataset including several hundered revs of background-removed brightness temperatures available to the rest of the QuikScat cal-val team. It is our hope that these data will be incorporated into rain flag products developed by others, since the data should be more highly correlated with rain than the raw Qrad T_b's.

Development of a Simple, Combined ENOF-Brightness Temperature Rain Flag

We have constructed a simple, multiple threshold rain flag that uses both the value of our ENOF rain index[*Mears et al.*, 1999], and the excess T_b to decide whether it is raining in a given QuikScat cell. First, we combine the V-pol and H-Pol excess brightness temperatures into a single excess brightness temperature using a weighted average,

$$T_b\text{,excess} = 2/3 * T_{b,\text{excess}}(\text{H-Pol}) + 1/3 * T_{b,\text{excess}}(\text{V-Pol}).$$

The H-Pol T_b is weighted more heavily because the rain signal has a better signal to noise level. This is because the background T_b is much lower for H-Pol, leading to reduced error in the background-subtraction procedure. We then pick two upper thresholds, $T_{upper,ENOF}$, and $T_{upper,Tb}$. If either the ENOF index *or* the excess T_b is above their respective upper threshold, the rain flag is set. Two lower thresholds are also picked $T_{lower,ENOF}$, and $T_{lower,Tb}$. If *both* the ENOF index *and* the excess T_b are above their respective *lower* thresholds, then the rain flag is set. In this way, we require agreement between the ENOF- and T_b-based rain flags when they are near their threshold values. This appears to reduce flagging due to random noise, and improves the performance of the combined rain flag over that which can be achieved using the ENOF index or the excess T_b alone.

Figure 3. Rain Flag Performance Metrics for the ENOF flag alone, with the threshold set to flag 7.5% of the QuikScat cells as having rain. The horizontal lines are the false alarm rate.

Figure 4. Rain Flag Performance Metrics for the brightness temperature flag alone, with the threshold set to flag 7.5% of the QuikScat cells as having rain. The horizontal lines are the false alarm rate. Note the improved performance for winds greater than 14 m/s relative to the ENOF only flag

Figure 5. Rain Flag Performance Metrics for the combined rain flag with the thresholds set to flag 7.5% of the data. The horizontal lines are the false alarm rate. Note the improved performance relative to either of the previous flags

In Figures 3 – 5 we report performance for the ENOF-only, excess-T_b-only, and combined rain flags determined by a comparison with temporally and spatially collocated rain rates measured by SSM/I. For a collocation to be used, the center of the ¼ x ¼ degree SSM/I observation cell was required to lie within the QuikScat cell, and the SSM/I observation was required to be within 30 minutes of the QuikScat observation. We report two metrics. The first is the “False Alarm Rate”, which is the number of instances where our rain flag is set without any rain detected by SSM/I, normalized by the total number of rain-free SSM/I collocations. The second is the “misclassification rate”, which is the number of instances where our rain flag is not set and SSM/I reports a rain column above a certain threshold, normalized by the total number of SSM/I observations above the threshold. For perfect agreement with SSM/I, both metrics would be zero. This is unlikely to occur in practice, due to the movement, appearance and disappearance of rain cells within the collocation time, and the high sensitivity of the ENOF rain flag to rain events associated with low wind speed. Both metrics are plotted as a function of rain column, though only the misclassification rate is a function of rain column. The false alarm rate is simply a horizontal line, since it only depends on the thresholds used to determine the rain flag, not the SSM/I rain column threshold.

By itself, the ENOF flag performs well at low wind speeds and adequately at moderate wind speeds. For winds above 14 m/s, the ENOF flag misses most of the rain measured by SSM/I. The reasons for this poor performance have been discuss earlier[*Mears et al.*, 1999]. For these higher winds speeds, the brightness temperature flag does much better, but its performance, which is largely independent of wind speed, is significantly worse than the ENOF flag at low wind speeds. Using our combined flag, we can retain most of the high-wind performance of the T_b-only flag, and most of the low-wind performance of the ENOF only flag. In all cases, the flagging thresholds are chosen to flag about 7.5% of the total QuikScat wind vector cells as having rain. When choosing the 4 thresholds for the combined rain flag, we can trade off high wind speed performance for better performance at low wind speeds and vice-versa. The parameters for the flag used here were chosen to minimize the overall misclassification rate while flagging 7.5% of the data. A summary of the thresholds used and their performance at a rain column cutoff of 2.0 km*mm/hr is presented in the table below.

Flag Type		Thresholds		Misclassification	False Alarm
		ENOF	T_b (K)	Rate (%)	Rate (%)
ENOF only	Upper	45	-		
	Lower	-	-	34.8	4.7
T_b only	Upper	-	17.0		
	Lower	-	-	42.3	5.3
Combined	Upper	80	22.0		
	Lower	55	7.0	28.2	4.9

Summary

We have used water vapor and SST climatology, along with the wind retrieved by QuikScat, to estimate and remove the background T_b values from the QRad brightness temperatures. These excess T_b's should be a better indicator of rain than the raw QRad T_b's, and we encourage their use in any future rain flag that incorporates T_b information. We have constructed a simple rain flag based on the ENOF rain index and the excess T_b and have shown that it is superior in performance to flags based on ENOF or excess T_b alone.

References

Mears, C.A., D.K. Smith, and F.J. Wentz, Development of a Rain Flag for QuikScat, Remote Sensing Systems Technical Report 121999, 1999.

Wentz, F., A Well Calibrated Ocean Algorithm for SSM/I, *J. Geophysical Research*, *102*, 8703-8718, 1997.