QuikSCAT Radiometer (QRad) Rain Rates for Wind Vector Quality Control

Khalil A. Ahmad , W. Linwood Jones and Takis Kasparis

Central Florida Remote Sensing Laboratory
Dept. of Electrical and Computer Engineering
University of Central Florida
Orlando, FL 32816-2450
kh393312@pegasus.cc.ucf.edu

Abstract - **The SeaWinds scatterometer onboard the QuikSCAT satellite measures the ocean normalized radar cross section to infer the surface wind vector. In addition, SeaWinds simultaneously measures the polarized microwave brightness temperature of the ocean/atmosphere, and this passive microwave measurement capability is known as the QuikSCAT Radiometer (QRad). QRad brightness temperatures are used to infer instantaneous rain rates over oceans using a statistical retrieval algorithm that has been developed using collocated QRad brightness temperatures with TRMM Microwave Imager (TMI) rain rate measurements. In this paper, QRad retrieved rain rate examples are presented and comparisons are made with independent near simultaneous rain observations including the TRMM 3B42RT data product. This near-real-time global precipitation data product combines all passive microwave with geostationary visible/infrared precipitation estimates in global 3-hour universal time windows. Results demonstrate that QRad rain measurements agree well with these independent microwave rain observations, which demonstrates the utility of using QRad rain retrievals as a "stand alone rain quality flag".**

I. INTRODUCTION

The QuikSCAT satellite was launched into space by the National Aeronautics and Space Administration (NASA) in mid 1999. QuikSCAT flies an ~800 km, near polar, sun synchronous orbit, and carries a single remote sensor, a Ku-band pencil beam scatterometer, known as SeaWinds. The primary mission objective of SeaWinds is to remotely sense the global near surface ocean wind vectors (speed and direction) via providing accurate measurements of the normalized radar backscattering cross section (σ^0) of the ocean surface.

In addition to measuring the ocean backscatter, SeaWinds has the capability to simultaneously collect the linearly polarized microwave emission from the surface and the intervening atmosphere. This radiometric measuring capability, which is known as the QuikSCAT Radiometer (QRad) was not originally envisioned, but it was implemented after launch through signal processing. Because the SeaWinds design was optimized as a radar, QRad is not a high performance radiometer. While typical radiometers have bandwidths of 100's MHz, QRad has a limited receiver bandwidth of about 750 KHz which results in a poor radiometric precision ΔT ~25 Kelvin per pulse. However, by averaging multiple pulses and employing some spatial filtering techniques, the effective radiometric sensitivity of the instrument is substantially improved.

While validation studies demonstrate that SeaWinds is very capable of providing accurate wind measurements under most weather conditions, unfortunately, the presence of rain can alter the wind induced radar backscatter signature, and even corrupt the wind retrieval process. Rain droplets striking the surface generate additional backscattering, moreover, rain in the atmosphere can scatter and attenuate the surface echo. This usually results in over estimates of the wind magnitude and meaningless wind directions. Thus, it is of vital importance to have an independent rain measurement capability for QuikSCAT to identify the possibly rain contaminated wind retrievals.

This paper describes the development of a rain retrieval algorithm using independent measurements from the QuikSCAT Radiometer (QRad). The dual polarized microwave brightness temperatures at 13.4 GHz are collected over the entire scan using a mechanically spun antenna, as shown in Fig. 1. The individual T_B's are averaged on a spacecraft wind vector cell measurement-grid of 25 km resolution, which results in mean polarized T_B's being perfectly collocated with the normalized ocean surface backscatter measurements. Those brightness temperature measurements are used to infer the instantaneous rainfall over the oceans.

II. QRad RAIN RATE ALGORITHM DESCRIPTION

The QRad rain rate algorithm [1] is a statistical retrieval algorithm that is based upon the correlation between the polarized brightness temperatures measured by QRad and rain rates observed by the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI). The algorithm is trained using more than 400 major rain events that have been observed within a collocation time difference restricted to ±30 minutes with the TRMM overpass. The importance of such simultaneous observation is driven by the fact that the spatial structure and intensity of a typical rain event can rapidly vary with time, thereby, a close collocation time difference is essential in order to have a valid observation of the precipitation conditions affecting the QuikSCAT measurement The collocated rain events are chosen from different seasons of the year 2000, having locations that span the full latitudinal range of the tropical rainfall region as shown in Fig.2.

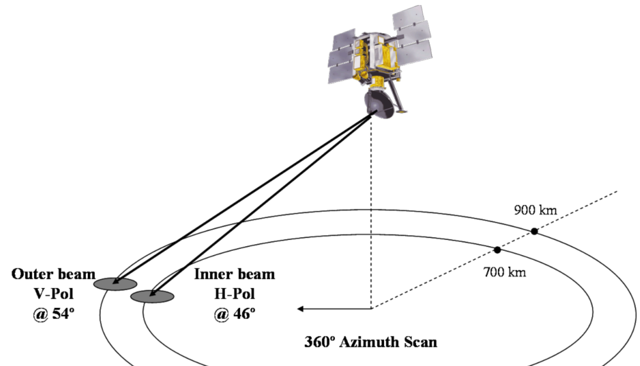

Fig.1. QuikSCAT measurement geometry.

To infer the oceanic rainfall, the QRad rain rate algorithm utilizes data from the collocated rain events to build an empirical brightness temperature – rain rate (T_b-R) relationship.

A. *Excess Brightness Temperature*

Because ocean surfaces have a low emissivity, they appear as cold backgrounds to passive microwave observations. The presence of rain in the atmosphere absorbs upwelling surface emission and re-emits precipitation radiation, thereby increasing the measured brightness temperatures. As a result, rain can be extracted from the differential (excess) part between raining and clear ocean brightness temperatures. To obtain an accurate estimate of the brightness contribution due to rain, it is necessary to correct for various atmospheric and ocean surface variables contributions to the measured T_b's. The usual remote sensing scenario is for the observing microwave radiometer to have the number of independent measurements greater than the number of unknown geophysical parameters. However, QRad is a single frequency dual polarized brightness measurement, thus most parameters (except transient rain and wind) are assumed to be known a priori using seven years of SSM/I brightness climatology. Fortunately, at the QRad Ku-band operating frequency of 13.4 GHz, the brightness temperature is a weak function of geophysical parameters included in this climatological data set, and the resulting background brightness varies slowly in space and time. We define the rain contribution to the measured brightness temperature as excess brightness (T_{ex}), which is equal to the residual of the average measured QRad T_b after subtracting the non-raining ocean background brightness, and brightness temperature due to ocean surface wind speed. Thus T_{ex} is defined as:

$$T_{ex} = T_{bQRad} - T_{bocean} - T_{bwspeed} \qquad (2.1)$$

where: T_{bQRad} is the average measured QRad T_b obtained

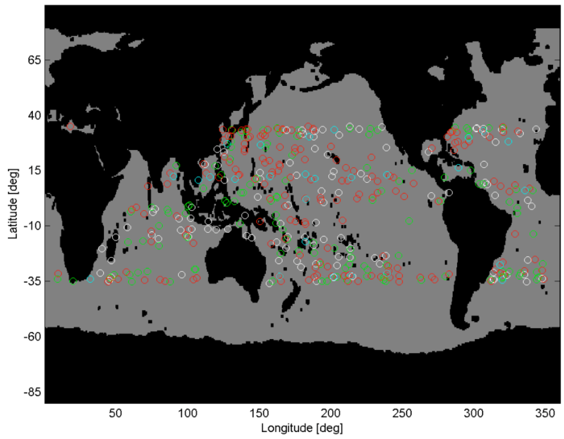

Fig.2. Locations of simultaneous collocated rain events for 420 QRad/TRMM training data set. Collocation time difference is restricted to ±30 minutes

from level 2A (L2A) data product provided by Jet Propulsion Laboratory (JPL). $T_{b\ wspeed}$ is the correction due to surface wind speed using the collocated QuikSCAT retrieved wind from L2B data product. $T_{b\ ocean}$ is the ocean background (monthly by latitude and longitude location) containing contributions from all relevant environmental parameters except transient effects of rain and wind speed.

B. *Excess Brightness – Integrated Rain Rate Relationship*

To infer the instantaneous oceanic rain, the QRad retrieval algorithm employs an empirical brightness temperature - rain rate (T_b-R) relationship. This relationship is derived using a QRad brightness temperature and TMI integrated rain rate data set of more that 400 significant rain events that are observed within ± 30 minutes. Because the total atmospheric absorption and emission of microwave energy is directly proportional to the rain path length along propagation direction; the observed QRad rain brightness temperature is proportional to the path integrated rain rate. Thus, the (T_b-R) relationship is calculated using a regression analysis of the QRad excess brightness (T_{ex}) with the corresponding collocated TMI integrated rain rate (IRR).

First, the QRad T_{ex} is produced on 0.25° grid, and smoothed using a 3x3 moving average spatial filter to reduce the unwanted random noise component of the measurement, thereby, improving the effective radiometric precision (ΔT). Next, the corresponding TMI 2A12 surface rain rates are converted to IRR. Because the TMI integrated rain rate value is not available in 2A12, the IRR is approximated to be the product of the TMI surface rain rate (mm/hr) and the rain path length (km) multiplied by the secant of the TMI incident angle. Finally, these data are binned by TMI IRR, averaged and then used in a least-squares curve fit procedure to determine an optimal 3rd order polynomial. This polynomial is forced to pass through the origin, which produces a T_b-R function with odd symmetry about zero T_{ex}. This odd function regression is adopted to cancel (in the mean) the effect of the QRad measurement noise (ΔT) that frequently causes the T_{ex} to be negative at low rain rates. Fig. 3 shows the resulting H-pol transfer function with error bars of ± one standard deviation for each bin.

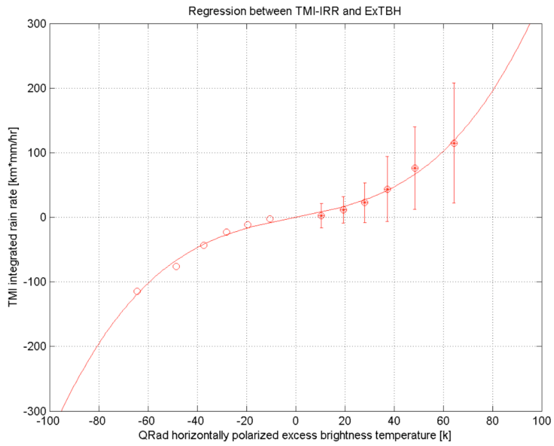

Fig.3. QRad (T_{ex}-R) 3rd order transfer function for H-Pol. Error bars denote ±one standard deviation.

Rain rates are calculated for the polarized excess brightness temperatures using the corresponding H- and V-pol (T_{ex}-R) transfer functions. The final QRad rain product is a weighted average of the polarized rain rates. The usual procedure is to weight measurements by their inverse variances; but for QRad, the variances for V- and H-pol are very similar. However, the H-pol (T_{ex}) has a wider dynamic range, thereby it is given a larger weight in the final result:

$$IRR_{QRad} = c_0 + c_1 \frac{(4 \cdot IRR_h + IRR_v)}{5} \qquad (2.2)$$

where: c_0 and c_1 are empirically derived parameters used to match the QRad integrated rain rates to the training data set TMI integrated rain. A quantitative comparison between TMI and the resulting QRad IRR's for the training rain events is presented as a scatter diagram in Fig.4. Although the derived QRad IRR's have a considerable scatter, which is mainly attributed to the coarse QRad (ΔT) measurement, the QRad IRR's are well behaved in the mean compared to TMI.

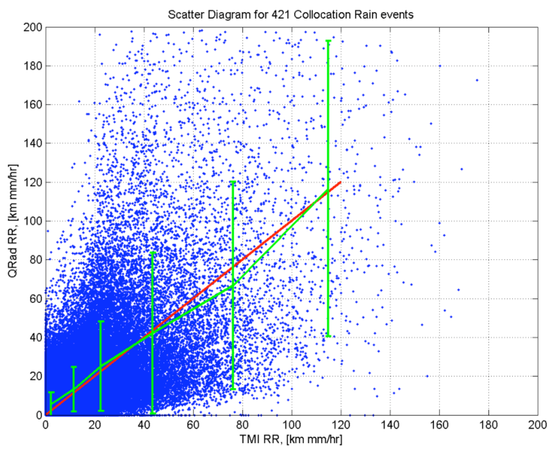

Fig.4. Instantaneous Integrated rain rate comparison for 420 collocated rain events. Error bars denote one standard deviation. Spatial resolution is 25 km (0.25^0)

III. ASSESSMENT OF QRad RAIN RETRIEVALS

The QRad rain algorithm performance is validated through near simultaneous comparisons with TRMM data products including the 3B42RT composite rain rates and the TMI 2A12 surface rain products, which have well-established rain measurement accuracy.

The TRMM 3B42RT is a near real time global precipitation data product that combines all available passive microwave with geostationary visible/infrared precipitation estimates in global 3-hour universal time windows. Those rain estimates are derived from all available high quality (HQ) microwave sources such as TMI and SSM/I instruments, merged with visible and infrared rain rate estimates (VAR) obtained from geostationary visible/infrared observations. The 3B42RT data product has a spatial resolution of 25 km. For each earth grid pixel the HQ rain estimate is used if available, otherwise the VAR value is used.

The first quantitative evaluation of the quality of QRad rain measurements is given in Fig.5 which presents a comparison of the rain probability density functions (pdf's) for one hundred and eight collocated rain events between QRad and 3B42RT HQ microwave rain estimates. While QRad slightly overestimates the lower rain rates, it does capture the behavior of the HQ pdf for rain rates > 1.5 mm/hr. An additional comparison between QRad and the HQ product is presented in terms of a typical instantaneous rain image as shown in Fig. 6. This rain event was observed on June 18 2003 during the 06 UTC time-window where the coincidence time difference is ~ 30 minutes. The HQ rain rates are shown on the upper panel, while QRad rain rates are shown on the lower. The color bar indicates the rain rate (mm/hr) values, and both images have identical color scales. It is evident that QRad well captures the shape and the relative intensity of the rain event.

In order to further investigate the rain detection and estimation capabilities of the QRad measurements, we examined numerous collocated rain events with the standard TRMM 2A12 surface rain product derived from TMI. Figure 7 depicts a representative example for a rain event that was observed within 10 minutes of the TRMM overpass. The top panel shows the TMI integrated rain rate, and the corresponding QRad rain estimate is given in the lower panel. The pixel resolution is 25 km, and color scales are identical for both images and proportional to the integrated rain rates in [km*mm/hr]. To reduce the possible occurrence of false rainy pixels resulting from the noisy QRad (ΔT), we applied a threshold of 4 km*mm/hr on the integrated rain values (equivalent to ~0.5 mm/hr). In all the cases that were examined, QRad rain retrievals were in very good agreement regarding the spatial distribution and the relative rain intensities compared to TMI.

Moreover, to quantify the performance of QRad measurements as a "stand alone" flag for identifying the rain contaminated wind vector cells, we produced differential binary maps that are quantized into four levels to classify the rain pattern for the different collocated rain events. An example is shown in the third panel of Fig. 7. Using the TMI binary rain image as the surface truth, we classify the differential binary rain image pixels into three categories: the first is agreement percentage, which is the percentage of pixels that are simultaneously identified by both sensors (QRad and TMI) as raining pixels or non-raining pixels. The second category is the false alarm percentage, which is the percentage of pixels classified as raining pixels by QRad, while identified as non-raining pixels by TMI. The third category defined, as miss-rain percentage is the percentage of pixels classified as raining pixels by TMI, while QRad identified those pixels as rain free.

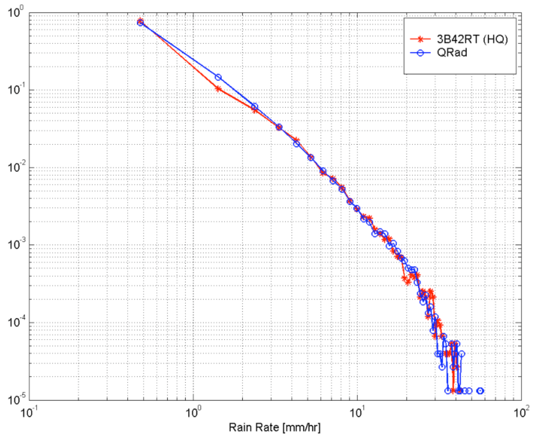

Fig.5. Rain rate probability density function for a hundred and eight collocated rain events near simultaneously observed by QRad and TRMM 3B42RT HQ (TMI and SSM/I) product.

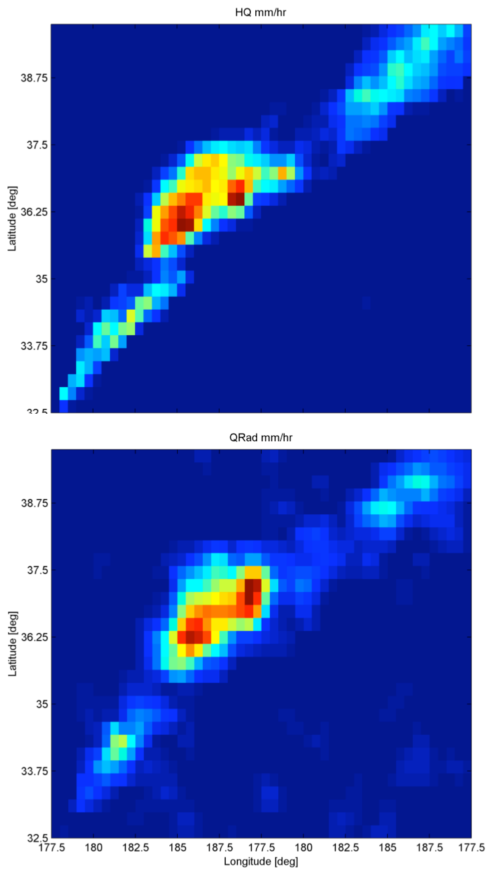

Fig.6. A typical example of rain event measured by TRMM HQ (TMI and SSM/I) product (top panel) and QRad (lower panel). Spatial resolution is 25 km. Coincidence time difference ~ 30 minutes.

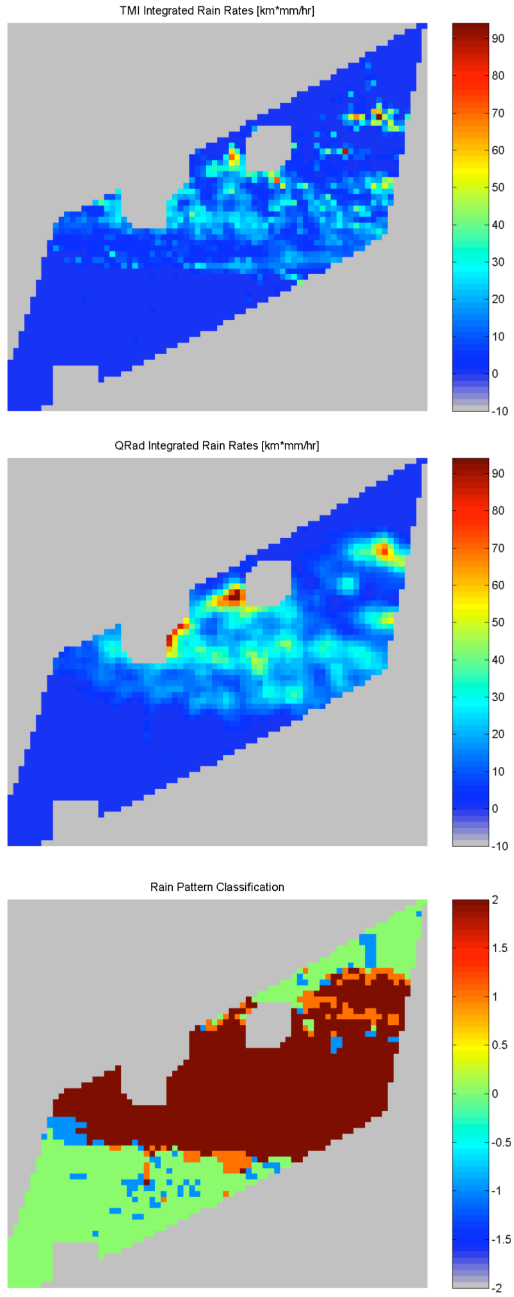

Fig.7. Example of instantaneous rain image produced by TMI (upper panel) and QRad (middle panel). Spatial resolution is 25 km. coincidence time difference is ~ 10 min. Lower panel shows rain pattern classification: agreement (color indices 0 no-rain & 2 rain), false alarm (color index 1) and miss rain (color index -1).

The different percentages of the rain pattern classification are calculated for the event under consideration, and found to be as follows: the agreement for rain and no-rain percentage = 89.52 %, false alarm percentage = 5.04 %, and miss-rain percentage = 5.44%. These values are very representative of QRad flagging capabilities, and emphasize the utility of QRad rain measurements for locating rain contaminated wind vector cells.

IV. CONCLUSIONS

This paper presents the QRad statistical rain retrieval algorithm developed for the QuikSCAT satellite. Comparisons between rain products produced by QRad, and various rain rate retrievals obtained from other independent rain measuring instruments demonstrate the fact that QRad rain measurements are in very good agreement with these independent microwave rain estimates. Thus, QRad rain measurements can be potentially used as a “stand alone” quality flag for identifying rain contaminated wind vector cells. Finally, these QRad rain estimates will be available in the planned data reprocessing (FY 2006) to users of QuikSCAT winds.

Acknowledgments

This research was sponsored under a grant from the QuikSCAT Project at the Jet Propulsion Lab, Pasadena, CA and the Tropical Rainfall Measuring Mission at NASA Goddard Space Flight Center, Greenbelt, MD.

REFERENCES

[1] K. A. Ahmad, W. L. Jones, T. Kasparis, S. W. Vergara, I. S. Adams, and J. D. Park (2005), Oceanic rain rate estimates from the QuikSCAT Radiometer: A Global Precipitation Mission pathfinder, J. Geophys. Res., 110, doi:10.1029/2004JD005560.