Calibration/Validation of the SeaWinds Radiometer Rain Rate Algorithm

Pet Laupattarakasem, W. Linwood Jones, and Khalil Ahmad
Central Florida Remote Sensing Laboratory
University of Central Florida
ECE Department
Orlando, FL 32816, USA
pe640141@pegasus.cc.ucf.edu

Svetla Veleva
Jet Propulsion Laboratory (JPL)
California Institute of Technology
Pasadena, CA 91109, USA

Abstract— **The SeaWinds scatterometer, which has been flown on both the QuikSCAT and ADEOS-II satellites, was designed to remotely sense ocean surface wind vectors. Because ocean wind retrievals are occasionally contaminated by rain in the tropics and because there is no independent rain measurement on QuikSCAT, a SeaWinds rain-estimation method was developed and implemented. This technique utilizes the SeaWinds receiver noise to measure ocean radiometric brightness temperature (T_b) and then applies a statistical regression algorithm to estimate the integrated rain rate. This rain algorithm was originally "trained" with QuikSCAT SeaWinds T_b and near-simultaneous rain rate measurements from the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI). In this study, the SeaWinds instrument on ADEOS-II and the Advanced Microwave Scanning Radiometer (AMSR), also onboard ADEOS-II, were used to refine the algorithm. This provided truly simultaneous and collocated measurements from the same platform and over the same swath, which was ideal for improving the SeaWinds rain algorithm. The improved algorithm can now be applied on QuikSCAT using the SeaWinds radiometric measurement.**

I. INTRODUCTION

The SeaWinds scatterometer and the Advanced Microwave Scanning Radiometer (AMSR) were launched onboard the Advanced Earth Observing Satellite-II (ADEOS-II) by Japanese Aerospace Exploration Agency (JAXA) in November, 2002. SeaWinds is the National Aeronautics and Space Administration (NASA) provided Ku-band radar scatterometer designed to remotely measure global ocean wind vector (speed and direction) over broad swath coverage with frequent temporal sampling. In the presence of rain, the measurement of ocean backscatter, σ^0, may be contaminated by rain volume backscattering and associated atmospheric attenuation of the surface echo. The AMSR provides independent estimates of rain rate that can be used to train the SeaWinds rain estimation algorithm developed for use on the QuikSCAT satellite [1, 2]. This paper describes the calibration of the rain rate algorithm using the SeaWinds instrument on ADEOS-II and AMSR. This research is particularly important for the QuikSCAT SeaWinds measurement of vector winds since there is no additional radiometer onboard for independent measurements of rain for σ^0 corrections.

AMSR rain rate measurement performance was independently verified by near simultaneous comparisons with the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), which has well-established rain measurement accuracy.

II. INSTRUMENTS DESCRIPTION

A. SeaWinds Scatterometer

SeaWinds is a 13.4 GHz scatterometer that uses a conically scanning parabolic reflector antenna with vertically (V-pol) and horizontally (H-pol) polarized beams that sample ocean backscatter over a full 360° scan (Fig. 1). The H-pol inner beam, at an incidence angle of 46°, produces a 1400 km swath and the V-pol outer beam produces an 1800 km swath at 54° incidence angle. The measurement geometry was designed to provide spatially overlapping measurements with an elliptical instantaneous field of view of approximately 30 x 40 km gridded into 25 km wind vector cells.

B. SeaWinds Radiometer (SRad)

Using ground signal processing, the SeaWinds system noise is used to calculate the ocean brightness temperature collected by the dual-beam antenna. The simplified radiometric block diagram for this measurement capability, also known as SeaWinds Radiometer (SRad), is shown in Fig. 2. The receiver is divided into a wide-band (1 MHz) noise channel and a narrow-band (250 KHz) echo channel. The noise-channel output signal includes both blackbody microwave emission from the ocean and the relatively narrow band radar echo signal. The echo-channel also contains narrow band ocean emission and the echo signal.

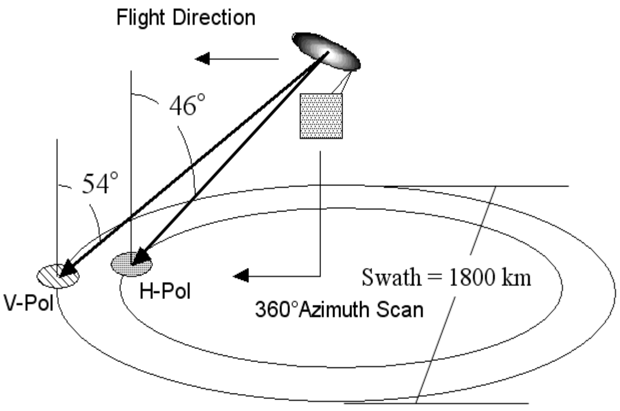

Fig. 1: SeaWinds measurement geometry.

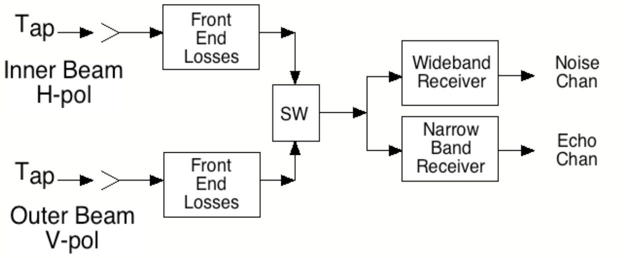

Fig. 2: SRad simplified block diagram.

When the echo-channel output is subtracted from the noise-channel output, with necessary corrections for differences in bandwidths and channel gain values, the excess noise energy of SRad (N_{ex}) is given as:

$$N_{ex} = kT_{sys}\left(B_n - B_{echo}\right)\times G_n\tau \,, \qquad (2.1)$$

where k is Boltzmann's constant, B_n and B_{echo} are noise bandwidth and echo bandwidth respectively, G_n is noise-channel gain, τ is the integration time and T_{sys} is the system noise temperature. The T_{sys} also depends on receiver front-end losses, which are determined by careful instrument characterization before launch and their physical temperatures measured on-orbit. Using the radiometer transfer function [3], the ocean brightness temperature is calculated from the excess noise energy.

Because SeaWinds was designed as a radar, SRad is not a high performance radiometer. Conventional microwave radiometers are designed with bandwidths of 100's MHz; consequently, the SRad radiometric precision, ΔT, equals 27 Kelvin/pulse and must be improved by spatial and temporal averaging.

C. Advanced Microwave Scanning Radiometer (AMSR)

AMSR is an absolute calibrated total power radiometer that also uses a conical scanning reflector antenna with multi-frequency bands of 6.9, 10.7, 18.7, 23.8, 36.5, 50.3, 52.8, and 89 GHz. This sensor detects blackbody microwave radiation from the ocean and atmosphere to infer a wide range of atmospheric geophysical parameters (e.g., water vapor, cloud liquid water and precipitation) and surface geophysical parameters (sea surface temperature and surface wind speed). The AMSR views the surface over approximately 1800 km swath symmetrical about the satellite flight direction.

III. SEAWINDS RAIN RATE ALGORITHM

This rain algorithm is an experimental algorithm developed for the SeaWinds Radiometer on QuikSCAT (QRad) [1, 2]. In the presence of rain, the observed brightness temperature is due to three components, namely; ocean/atmosphere background emission, ocean surface wind speed emission and rain emission. Therefore, rain intensity can be determined from the residual of the average measured QRad brightness temperature after subtracting the ocean background brightness temperature (non-raining atmosphere) and the brightness contributed from the ocean surface wind speed. This residue is known as the excess brightness temperature (T_{ex}) and is assumed to be only due to rain.

A. Excess Brightness Temperature (T_{ex}) & Rain Index (RI)

The ocean emission is polarization dependent and the emissivity varies with geophysical parameters, e.g., sea surface temperature (SST) and small scale wave roughness due to wind speed. Also rain contributes significantly to the measured brightness through absorption and emission. The excess brightness temperature, T_{ex}, is defined in terms of brightness temperatures as follows:

$$T_{ex} = T_b - T_{b,ocean} - T_{b,windspeed} \,, \qquad (3.1)$$

where T_b is the measured brightness temperature from the SeaWinds L2A data product provided by the Jet Propulsion Laboratory (JPL). The values of the brightness temperature due to ocean background, $T_{b,ocean}$, are from 7-year average global maps, by month, provided by Remote Sensing Systems analysis of SSMI climatology [4]. The values of $T_{b,windspeed}$ are from brightness temperatures calculated from wind speed on the SeaWinds L2B data product. The ocean background includes all relevant environmental parameters except wind speed and rain, which are transient in nature and have been removed. Also note that T_{ex} is polarization dependent and is computed separately for each polarization – H & V-pols.

Typically QRad observed T_b varies from approximately 100K (clear sky) to approximately 270 K (heavy rain) for H-pol, and over a 170 K – 270 K range for V-pol. Due to the large QRad radiometric precision of 27 K/pulse, a more statistically representative parameter, rain index (*RI*), was developed [5] as input to the SeaWinds rain retrieval algorithm. Rain index is a normalization of T_{ex} and is defined as,

$$RI = \frac{T_{ex}}{\Delta T} = \frac{T_{ex}}{\sigma/\sqrt{n}}, \tag{3.2}$$

where σ is the QRad standard deviation of the radiometric measurement per pulse (27 K), and n is the available number of QRad measurements averaged. The typical value $n = 6$ occurs for the wind vector cells spatial resolution of 25 km, which results in the improved radiometric precision, ΔT = 11 K. Note that the terms normalized T_{ex} and RI are used interchangeably.

B. Rain Index (RI)—Integrated Rain Rate (IRR) Relationship

The integrated rain rate, IRR, is the appropriate rain parameter because the total rain column affects the radiometer observations. Assuming that rain is uniform along the observation path length, IRR is the product of the rain rate (mm/hr) and the path length (km) in the rain. The path length is rain height freezing level multiplied by the secant of the incidence angle. In the propagation direction, the brightness temperature is directly proportional to the integrated rain rate [1, 2 & 5]. In order for QRad to infer rain rate, an empirical relationship between normalized brightness temperature, or rain index (RI), and AMSR integrated rain rate (IRR) was developed via statistical regression analysis. We developed this relationship using 9 days (125 revs) of collocated ADEOS-II, SRad brightness temperature and AMSR integrated rain rate data.

These data were bin averaged by AMSR IRR and then used to define the least squares 3rd order polynomial. The regression curve was required to pass through the origin since zero rain index is equivalent to no-rain. Third order polynomial coefficients were determined for both H & V-pols, and Fig. 3 illustrates the result for H-pol.

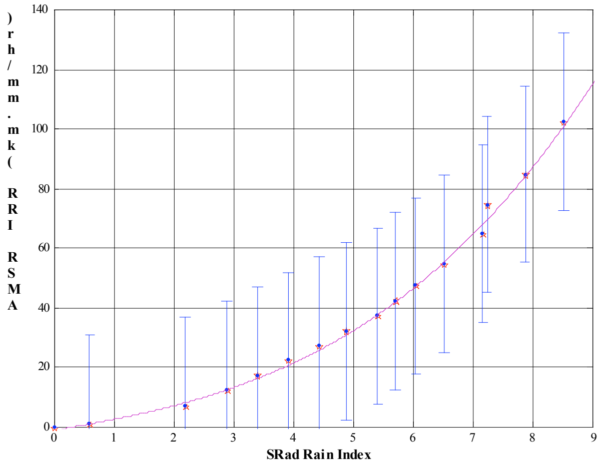

Fig. 3: The 3rd order polynomial regression fit between SRad rain index (RI) and AMSR integrated rain rate (IRR) H-pol.

IV. SRAD RAIN CHARACTERIZATIONS

Rain rates were calculated using this RI-IRR relationship in the QRad rain algorithm and verified with independent AMSR rain rate measurements as the surface truth. Fig. 4 shows a typical case of SRad and the AMSR rain rate comparison.

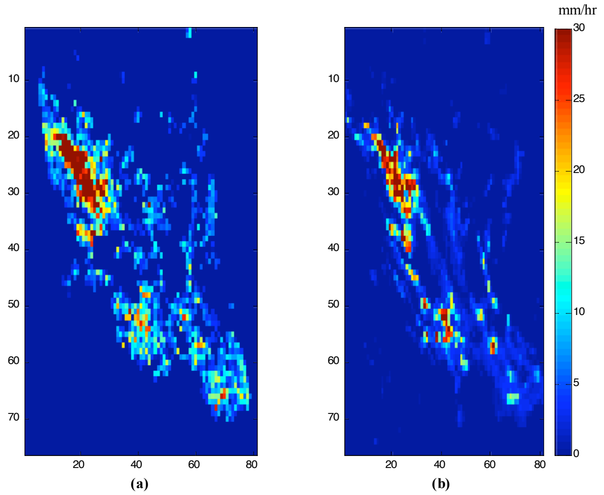

Fig. 4: (a) SRad rain rate, (b) AMSR rain rate. The ordinate is relative latitude index, and the abscissa is relative longitude index (0.25° steps).

To evaluate the QRad rain estimation for rain flagging purposes, binary rain maps were produced for rain > zero. Next, the weighted combination of these binary rain maps yielded four discrete levels: agreement-rain (*AR*), agreement-no-rain (*AN*), missed-rain (*MR*) and false-rain (*FR*). Using the AMSR binary rain map as the “truth” and the SRad binary rain map as the unknown: agreement-rain is defined as both SRad and AMSR indicate the presence of rain; agreement-no-rain is when both SRad and AMSR declare the pixel as no rain; missed-rain is when only AMSR identifies the pixel as raining; and false-rain is when only SRad specifies the pixel as raining. This evaluation case was selected so that rain covers approximately 25-30% of the area. Performances achieved in flagging rain are estimated from these maps using the following definitions:

Agreement- rain ratio: ARR = AR/(rain pixels)
Agreement-no-rain: ANR = AN/(no-rain pixels)
Missed-rain ratio: MRR = MR/(rain pixels)
False-rain ratio: FRR = FR/(no-rain pixels)

where *rain pixels = AR+MR* and *no-rain pixels = AN+FR*.

Results for this case are typical of numerous rain events examined. They show that errors due to missed-rain, which are mostly in the low rain rate areas, are more frequent than false-rain errors. The summary statistics presented in Table 1 are from the differential binary rain map in Fig. 5.

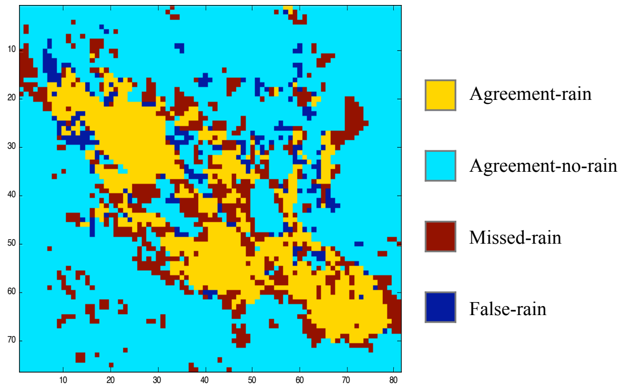

Fig. 5: Binary rain map. Agreement-rain is tan, agreement-no-rain is light blue, missed-rain is dark red, and false-rain is dark blue.

TABLE I
SRAD RAIN STATISTICS FOR FIG. 5

Agreement-rain ratio (*ARR*)	57.6%
Agreement-no-rain ratio (*ANR*)	94.2%
False-rain ratio (*FRR*)	5.8%
Missed-rain ratio (*MRR*)	42.4%
Rain fill fraction	30.1%

V. CONCLUSION

This paper presents calibration/validation results of the QRad rain rate algorithm using collocated and simultaneous SRad brightness temperature and AMSR rain rate measurements as the surface truth. Results from numerous rain events examined demonstrate excellent correlation in the spatial extent and rain intensity between SRad and AMSR and statistics are presented for 10 cases in Table 2. Thus this algorithm will be applied to the QuikSCAT Radiometer (QRad) to measure rain rate without using an external radiometer. These simultaneous and collocated rain measurements may be used to flag ocean wind retrievals that occur in the presence of rain.

TABLE II
SRAD RAIN STATISTICS FOR 10 RAIN EVENTS

Agreement-rain ratio (*ARR*)	45%
Agreement-no-rain ratio (*ANR*)	95%
False-rain ratio (*FRR*)	5%
Missed-rain ratio (*MRR*)	55%

VI. ACKNOWLEDGMENTS

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