SeaWinds Scatterometer Wind Vector Retrievals Within Hurricanes Using AMSR and NEXRAD To Perform Corrections for Precipitation Effects: Comparison of AMSR and NEXRAD retrievals of rain

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Abstract - The opportunity provided by satellite scatterometers to measure ocean surface winds in strong storms and hurricanes is diminished by the errors in the received backscatter (SIGMA-0) caused by the attenuation, scattering and surface roughening produced by heavy rain. Providing a good rain correction is a very challenging problem, particularly at Ku band (13.4 GHz) where rain effects are strong. Corrections to the scatterometer measurements of ocean surface winds can be pursued with either of two different methods: empirical or physical modeling. The latter method is employed in this study because of the availability of near simultaneous and collocated measurements provided by the MIDORI-II suite of instruments. The AMSR was designed to measure atmospheric water-related parameters on a spatial scale comparable to the SeaWinds scatterometer. These quantities can be converted into volumetric attenuation and scattering at the Ku-band frequency of SeaWinds. Optimal estimates of the volume backscatter and attenuation require a knowledge of the three dimensional distribution of reflectivity on a scale comparable to that of the precipitation. Studies selected near the US coastline enable the much higher resolution NEXRAD reflectivity measurements evaluate the AMSR estimates. We are also conducting research into the effects of different beam geometries and nonuniform beamfilling of precipitation within the field-of-view of the AMSR and the scatterometer. Furthermore, both AMSR and NEXRAD estimates of atmospheric correction can be used to produce corrected SIGMA-0s, which are then input to the JPL wind retrieval algorithm

Introduction:

The MIDORI-II mission, during 2003, carried five earth-observing sensors including the SeaWinds scatterometer and the Advanced Microwave Scanning Radiometer (AMSR). The latter's six frequency brightness temperatures are collected to derive atmospheric water-related parameters and to measure the sea surface temperature. The AMSR's coverage was closely coincident and collocated with the scatterometer. It provided the opportunity to obtain the precipitation estimates necessary to evaluate the attenuation, volume backscatter and surface roughening caused by the raindrops within the scatterometer beam.

One event of interest is Hurricane Isabel, which crossed the U.S. coastline on September 18th near a part of the North Carolina coast which is being continuously monitored by the NWS Morehead City NEXRAD radar. The NWS NEXRAD network supports the acquisition and utilization, in real-time, of three-dimensional rain reflectivity data (S-band) with high spatial resolution. The archived Level-II data files are characterized by an approximate one-degree antenna beamwidth and 1-kilometer range resolution. The data is collected with 360° azimuth sweeps at fixed elevation angles (0.5,1.45,2.4,3.35, etc). The duration of each sweep is about 6 minutes. This permits coincident timing with the spacecraft to within 4 minutes or less. Taking into account the earth curvature, at a distance of 150 km from the station, the center of the lowest elevation beam (directed at 0.5° above the horizon) is about 2,500 meters above sea level. Special algorithms have been developed to work with the NEXRAD reflectivity files and to convert the native observations into a Cartesian grid volumes. Using well known methods of interpolation, resolutions of 5,10 or 25 km in the horizontal directions are straightforward. Vertical resolution for these grid cells is 2 km.

MIDORI-II encountered this same event within 4 minutes of the NEXRAD observations thereby providing an excellent opportunity to have the high resolution NEXRAD observe the atmospheric volume in which AMSR produces precipitation estimates. This is a vital factor since the typical rain spatial structure is on the order of a few kilometers, whereas the scatterometer and AMSR data are averages over 30 km sized areas. Our results shows how well the precipitation estimation techniques using the AMSR data perform in conditions where the NEXRAD observes appreciable variation of rain intensity (horizontal and vertical) within the much larger AMSR cell. Besides Hurricane Isabel, two other events, with different characteristics are being investigated. On August 20, near the Melborne, FL NEXRAD, a light wind but heavy rain condition had interesting effects on the SIGMA-0s. Hurricane Claudette, (July 15th 2003), crossed the Texas coast near the Louisiana border. The hurricane was simultaneously observed by MIDORI-II and the Houston NEXRAD radar. Claudette's winds were not as violent as Isabel's, but they covered a large area in the Gulf of Mexico away from the coastline and had intense rainfall. The scatterometer swath, during these hurricane overpasses, spans a substantial range of rain intensities, wind magnitudes and directions permitting performance examinations across this wide distribution.

In addition to comparing rain parameter estimates (rain rate and vertically integrated liquid water) obtained from AMSR to that obtained from NEXRAD, the two sensors can separately derive atmospheric corrections (volumetric attenuation and rain backscatter) to the satellite scatterometer SIGMA-0. There are several steps in the process of providing atmospheric correction to the scatterometer signal and the NEXRAD 3-D data allows the separate evaluation of most of these. In addition, NEXRAD's high-resolution sampling of the 3-D precipitation volume allows taking into account the unique incidence angles of each of the scatterometer two beams. The SIGMA-0's, corrected separately based on either AMSR or NEXRAD estimates, can then be used in a modified JPL wind retrieval algorithm, to produce two sets of corrected wind magnitudes and directions. Comparison between AMSR- and NEXRAD-corrected scatterometer winds will allow also evaluation of the impact of the observational geometry.

Scatterometer rain effects

The presence of rain during observations of the sea surface by orbiting Ku band (13.4 GHz) scatterometers, such as QuikSCAT and SeaWinds on MIDORI-II, usually results in the retrieval of winds that are erroneously oriented in a cross-track direction (at ~90 and ~270 degrees) and have higher speed than both buoy and global model winds suggest [1], [2]. The scatterometer signal that propagates through rain is impacted in three ways: the signal is attenuated by the rain, the cloud and the vapor in the atmosphere; the signal is augmented by the backscatter from the rain droplets; finally, the signal is augmented by the rain-induced roughening of the ocean surface ("splash"). Estimation of the near-surface wind velocity from scatterometer measurements is based on the assumption that variations in the measured power are solely due to variations in the backscattering cross-section (SIGMA-0) of the ocean surface that result from variations in the wind. It is, thus, very important to properly account for the three rain effects and to correct the SIGMA0 estimates before they are used to estimate the wind velocity.

AMSR corrections:

Passive microwave observations of the top of the atmosphere radiation have been proven to provide very valuable information about the sea surface temperature, the vapor and cloud amounts in the atmosphere, and the presence and the amounts of precipitating hydrometeors. We have developed a passive microwave precipitation retrieval algorithm for the purpose of providing atmospheric correction to be used by scatterometer wind retrieval algorithms for the SeaWinds instrument on board the short lived MIDORI-II satellite. This precipitation algorithm uses Advanced Microwave Scanning Radiometer (AMSR) observations that were closely collocated with the scatterometer observations. The algorithm addresses in a new way the issues of non-uniform beam filling and hydrometeor structure uncertainty. This involves the use of multiple retrieval databases, each representing a particular rain intensity and inhomogeneity regime. For each observational scene, the algorithm uses a specially developed Rain Indicator to determine the intensity and degree of rain homogeneity within the sensor's Field of View (FOV). With this information in hand, it selects the appropriate retrieval database to estimate a number of geophysical parameters: vertically integrated liquid water (or Liquid Water Path - LPW), vertically integrated water vapor, near-surface wind speed, and sea surface temperature. Once the retrieval of the geophysical parameters is accomplished, we proceed to derive the atmospheric correction to the scatteromter observations as a function of these parameters. In doing so, two approaches could be adopted: the "physical" approach and the "empirical" one. They differ in how the geophysical information is used. The "physical" approach uses statistical relationships to directly estimate each of the three components of the atmospheric correction in the following sequence: LWP – RainRate – Volumetric Attenuation, Volumetric Backscatter by the rain. The empirical approach determines the atmospheric correction by developing relationships, as functions of the geophysical retrievals, between the observed SIGMA-0 and the model-wind-equivalent one. Hence, both approaches use the geophysical retrievals but differ in how the corrections are computed.

The results:

Applying the AMSR-based atmospheric correction to the scatterometer observations has resulted in significant improvement of the scatterometer winds in rain [3], [4]. Our current success shows the high potential of our AMSR-based geophysical retrieval algorithm and validates our approach. However, there is need of improvement as our corrections appear to be somewhat noisy. A good correction requires good estimates of attenuation, precipitation backscatter and even estimates of the rain-induced roughening of the ocean surface. It is, thus, very sensitive to the accuracy of the rain rate estimates. This prompts us to evaluate the performance of the algorithms using other observations.

The remaining questions:

The question that our longer-term research will address is whether rain corrections to the scatterometer winds can be improved. We approach the issue from two different points: 1) How do the scatterometer winds change if the rain correction is inferred from high-resolution 3-D observations of precipitation provided by a ground-based radar versus when the rain correction is provided by a Top-of-the-Atmosphere (TOA) radiometer that is sensitive to the vertical integral of a number of geophysical parameters? 2) How good are the AMSR retrievals of precipitation parameters and can they be improved ? This second question involves improving our understanding about issues like: i) What is the representative spatial scale of the AMSR retrievals? ii) How important is the uncertainty that is associated with the unknown spatial variability of rain (the beam filling)? iii) How does the beam-filling impact differ for different types of precipitation (isolated storms; wide-spread convective precipitation; midlatitude frontal systems)?

Here we present results that address the second question, namely how good are the AMSR retrievals of precipitation parameters. In particular we look at how AMSR rain rate estimates compare to that produced from NEXRAD measurements. We reveal the existing uncertainties and propose ways to address the issues. The "Summary and future work" section outlines the direction our future research.

Approach:

We intend to use collocated NEXRAD /AMSR / SeaWinds observations to understand: i) the nature of the AMSR retrievals; ii) whether rain correction to the scatterometer winds can be improved.

The high spatial resolution of the NEXRAD data allows us to look at issues concerning the beam filling and the geometry of the observations. Each scatterometer beam has a footprint that is approximately 25 x 37 km. It is clear from the NEXRAD data in Figure1 that the spatial structure of rain is highly variable within this cell. Our technique represents the rain volume within each scatterometer footprint as being constituted of four 2km-layers of oblique angled parallelepipeds (with 5 km horizontal resolution used in [5]), directed along the scatterometer radar incident beam. Each of these volumes is characterized by its own rain rate, liquid water path, reflectivity and attenuation. We can then integrate along the scatterometer beam and average these volumes over larger footprint sizes to investigate the impact of precipitation inhomogeneity on the AMSR retrievals and on the scatterometer atmospheric corrections and wind estimates.

The underlying principle of providing atmospheric correction is the removal, from each scatterometer SIGMA-0 measurement, of the effect of the volume backscatter (based on the reflectivity factor, "Z", that the NEXRAD measures), the attenuation, and the rain-induced surface roughness within the FOV of the scatterometer beam. These volumetric radar parameters are needed at K_u-band, which can easily be inferred from the NEXRAD S-band reflectivity. The corrected SIGMA-0s can then be used to calculate the corrected wind vectors [5].

The success:

The first case that we investigated was a rain event observed by AMSR on August 20, near the Melborne, FL NEXRAD (see Fig. 1; 10 km resolution shown here).

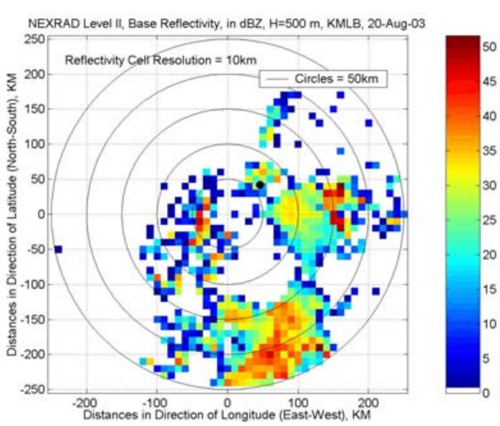

Figure 1: NEXRAD Reflectivity Observation, 20-Aug-03, Height=500 m

Figure 2 presents the comparison between NEXRAD and AMSR estimates of rain rate. To understand what the representative spatial scale of the AMSR retrievals is, the NEXRAD estimates were computed for two different footprint sizes. While both NEXRAD estimates compare very well to that from AMSR, it appears that the 25km (antenna-like averaged) NEXRAD estimate comes closer to the actual resolution of the AMSR retrievals. Indeed, this is what our expectations were since the precipitation retrievals were performed using brightness temperatures resampled to the19 GHz FOV (~25 km).

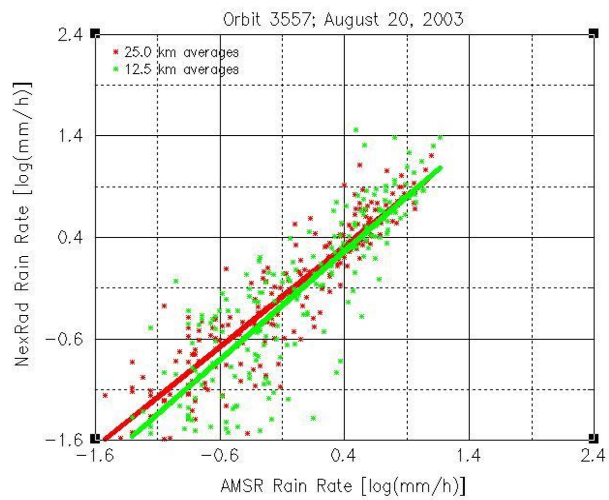

Figure 2. Shown is a scatter plot of the comparison between AMSR rain rate estimates (on the x axis) and the NEXRAD rain rate estimates (on the y_axis). The rain rates are plotted on the log scale. The results of two spatial averaging sizes for the NEXRAD data are shown (red is the averaging to a 25 km spatial resolution while the green is the averaging to a 12.5km spatial resolution). The lines of best fit are also shown.

The good comparison between AMSR and NEXRAD estimates of rain rates and volume backscatter (not shown) is very encouraging. Our next step is to compute and compare the volume attenuation by rain. Then we will substitute the NEXRAD atmospheric correction estimates in the wind retrievals and will compare the AMSR-corrected to the NEXRAD-corrected winds.

The challenges:

We next looked at rain rate comparison between AMSR and NEXRAD observations of Hurricane Isabel (September 18th 2003, near a part of the North Carolina coast). Figure 3 shows the two retrievals and compares them to that produced by the official AMSR product (AMSR-JAXA).

We see lower rain rate estimates from NEXRAD than from either AMSR-JPL or AMSR-JAXA. Before we decide that the satellite retrievals have a problem we want to exclude a possible problem with NEXRAD data (e. g. calibration) or uncertainties introduced by the DSD assumptions and the most representative spatial averaging. Figure 4 shows how NEXRAD estimates are impacted by assumed DSD assumptions (most-left uses a stratiform DSD while the central one uses a convective DSD) and spatial averaging window (central is a 25 km average while the most-right one is 35 km average).

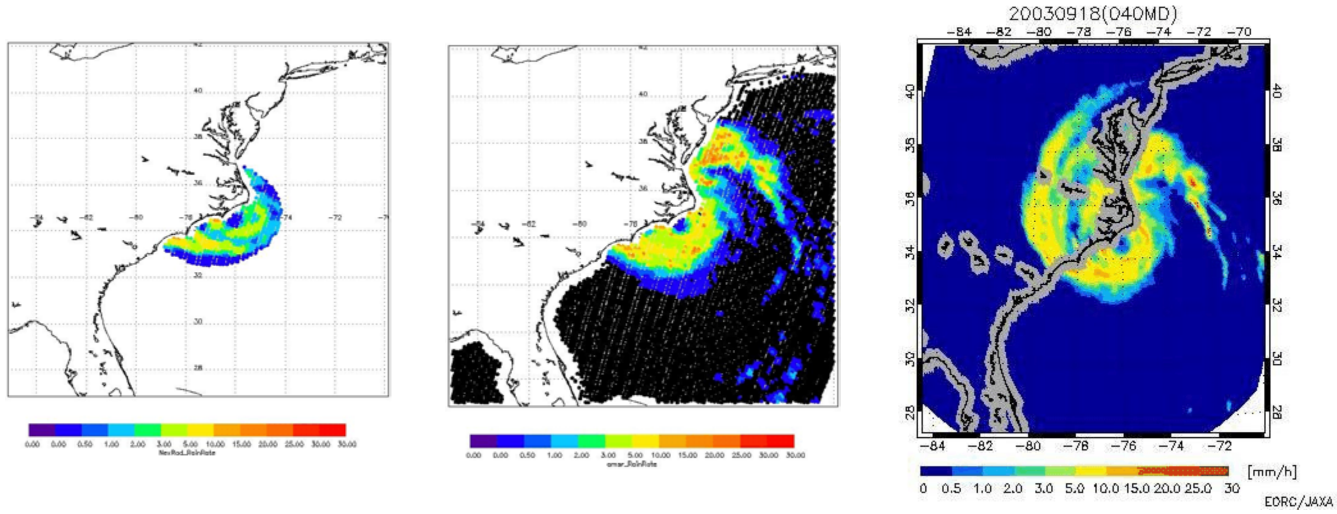

Figure 3. Shown are the rain rate estimates from NEXRAD (most-left panel), AMSR-JPL (central panel), and AMSR-JAXA(right panel).

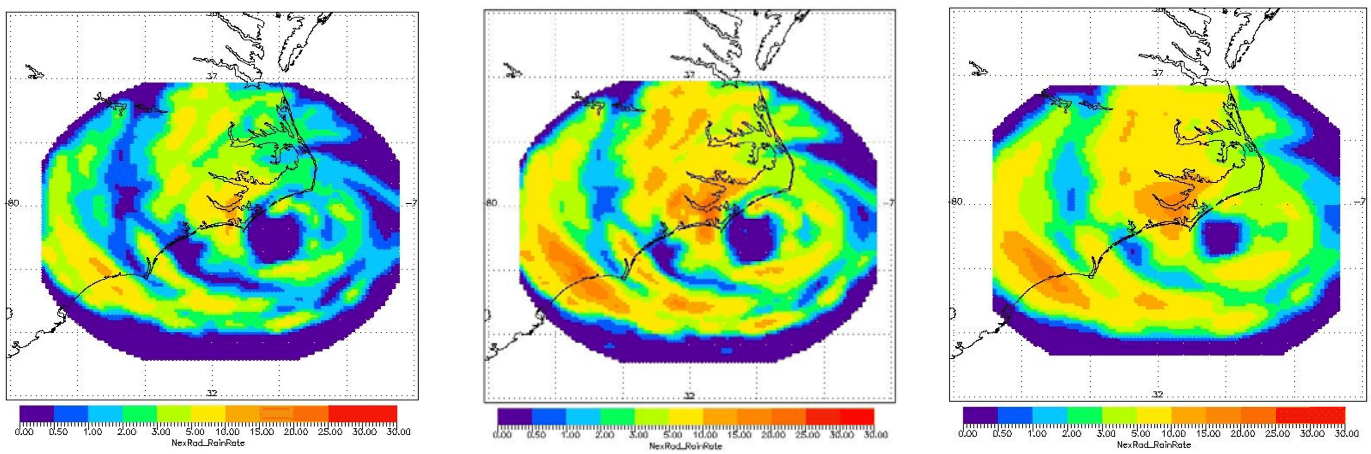

Figure 4. Shown is how NEXRAD estimates are impacted by assumed DSD assumptions (most-left uses a stratiform DSD while the central one uses a convective DSD) and spatial averaging window (central is a 25 km average while the most-right one is 35 km average).

We performed a similar comparison using AMSR observations of Claudette on July 15th when it was near the Houston radar. Figure 5 shows the results.

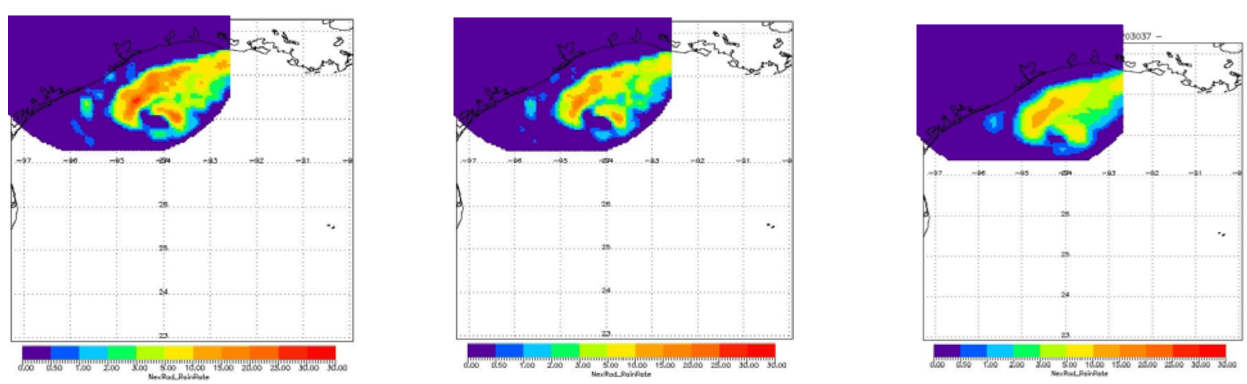

Figure 5. Shown are the NEXRAD rain rate estimates for different DSD assumptions and spatial averaging sizes: most-left panel shows rain rate estimates with convective DSD parameters and a 25 km spatial averaging; central panel shows retrievals with stratiform DSD parameters and a 25 km averaging; most-right panel shows retrievals with stratiform DSD parameters and a 35 km spatial averaging.

Figure 6 shows the AMSR-retrieved rain rate for the same time. In this case the AMSR estimates appear to be closer but slightly lower than the NEXRAD estimates that used a stratiform DSD parameters. Note that NEXRAD collects precipitation measurements only within ~200 km range from the radar. This, in addition to heavy precipitation along the radar beam, is a likely reason why NEXRAD does not see the multiple precipitation bands observed by AMSR.

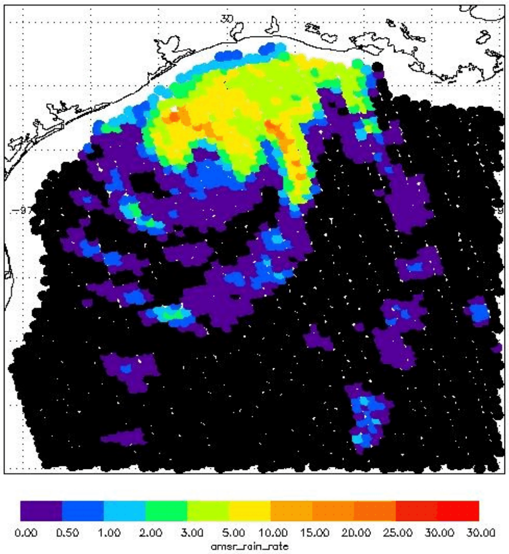

Figure 6. Shown are the AMSR estimates of rain rate.

These results indicate that before we proceed with a more quantitative comparison between AMSR and NEXRAD estimates we need to resolve the issues that are related to the DSD assumptions. Fortunately, NEXRAD observations carry information about the type of precipitation – convective versus stratiform. We need to use this information, on a point-by-point basis, to decide the DSD parameters that are most appropriate for each observation.

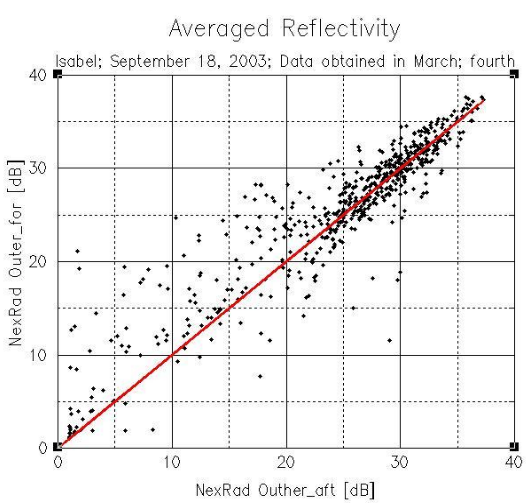

Figure 7. Shown is how volume-averaged reflectivity compares between the two NEXRAD-estimated looks of the scatterometer – the forward and the aft.

Finally, using the Isabel data, we also looked at the impact of AMSR geometry. Figure 7 shows how volume-averaged reflectivity compares between the two NEXRAD-estimated looks of the scatterometer – the forward and the aft. Obviously the geometry of the observations makes a difference in the estimates of the atmospheric corrections. Next, we will apply the corresponding to each beam SIGMA-0 correction to evaluate the impact on the winds.

Summary and future research

In this paper we focused our attention on evaluating AMSR estimates of rain rate as compared to those from NEXRAD's high-resolution observations of the 3-D reflectivity field within AMSR's much larger FOV. Our initial results show a very good agreement in the the spatial distribution and overall intensity of precipitation estimates. The August 20th 2003 case also revealed a very good agreement in the point-by-point comparison of rain rate estimates. However, the Hurricane Isabel comparison of rain rates showed lower NEXRAD estimates then either AMSR(JPL) or AMSR-JAXA retrievals. A sensitivity analysis revealed that NEXRAD rain rate estimates can be brought closer to the satellite retrievals if different DSD assumptions are made (convective versus the more often used stratiform ones). This highlights the importance of the long-standing DSD-related uncertainty of radar retrievals of rain rate. Fortunately, NEXRAD algorithms provide first-order information about the DSD parameters by allowing the broad classification of precipitation as either stratiform or convective. Our current results show that before proceeding with a more quantitative comparison of rain rates between AMSR and NEXRAD estimates we need to consider, point-by-point, the NEXRAD-produced precipitation classification in making the DSD assumptions.

We plan to address another source of NEXRAD rain rate uncertainty – possible radar calibration problems. Houston's and Melborne's NEXRAD radars are expected to be well calibrated since they are part of the "ground truth" network for the TRMM project. However, there is a possibility that other NEXRAD radars might have calibration issues. We plan to use TRMM / NEXRAD collocated observations to confirm the calibration for each NEXRAD radar that we use in our studies.

The next step in our studies will be to compare NEXRAD and AMSR estimates of volume backscatter and rain-related attenuation. The volume backscatter by NEXRAD is a direct measurement and its conversion to Ku band estimates (for comparison to AMSR estimates) involves minimal assumptions. However, the AMSR estimates of volume backscatter involve DSD assumptions. This is where the precipitation classification information that we can obtain from NEXRAD will help in the comparison.

The following step in our studies will be to incorporate NEXRAD estimates of attenuation, volume backscatter and rain-induced surface roughening into the JPL retrieval of rain-corrected ocean winds. Comparison between AMSR-corrected and NEXRAD-corrected winds will allow evaluation of the importance of beam-filling and beam geometry for the accuracy of the rain-corrected scatterometer winds.

In summary, our goals are: i) to use the high-resolution NEXRAD observations of 3-D precipitation to understand satellite passive microwave retrievals that use TOA brightness temperatures at low spatial resolution; ii) to use NEXRAD observations to understand how the geometry and spatial resolution of the satellite observations impact rain corrections to the scatterometer winds. The results from that might have impact on the design of future missions that will use combined active/passive observations of surface winds.

References

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