Measurements of the Effect of Rain-induced Sea Surface Roughness on the Satellite Scatterometer Radar Cross Section

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Abstract

Radar measurements of the sea surface, with Ku-band satellite scatterometers, are affected by the presence of rain through modification of the sea surface roughness by rain impacts. Surface-based studies have shown the increase in the total NRCS depends on radar frequency, incidence angle, polarization and wind speed. Herein is a case study of the increase of the total radar cross section, averaged across surface illuminated areas of the scatterometer, caused by rain. The results are applicable to questions regarding the interpretation of wind vector estimates in the presence of rain of varying intensity, to air-sea momentum exhange and gas transfer.

1. Introduction

On a global scale, recent studies [Freilich, 2005] have indicated that about 7% of the SeaWinds scatterometer wind observations are affected by rain events. This study seeks to contribute methods for obtaining more accurate Scatterometer measurements in rain-affected regions. This investigation uses the NWS NEXRAD stations to provide quantitative estimates of precipitation distribution and intensity. Normalized radar cross section (NRCS) data from SWS and wind vector data products (available from JPL PO.DAAC) can be examined in the vicinity of the U.S. coastline (Gulf of Mexico, and from Florida up to New England) wherein NOAA and other buoys and numerous NEXRAD [Doviak and Zrnic, 1993, Klazura and Imy, 1993] stations can provide near-simultaneous, collocated surface and near surface observations for actual winds and rain.

A unique method has been developed to utilize the volumetric scans of the S-Band NEXRAD radar (which has high spatial resolution; 1 km in range and 1° azimuth) to model the 3-dimensional K_u-band reflectivity of the volume of precipitation that the scatterometer beam passes through as it samples the sea surface. This enables the correction to the measured NRCS for the effects of rain attenuation and rain volume backscatter. The removal of these effects leaves the total contribution of the sea surface; both the wind driven and rain-impact roughness terms. This study is providing knowledge about the relative influences and contributions of these three mechanisms to the satellite measured NRCS at different wind speeds, rain rates and polarizations.

Natural rain events have the property that they are strongly inhomogeneous beyond distances of a few kilometers. The fact that rain cells typically have uniform intensities across horizontal dimensions of 2 -to- 2.5 km (covering only a few percent of the Scatterometer NRCS footprint) means that innovative approaches need to be developed that can model the effect of these small rain cells on the 25-by-37 km NRCS spatial measurement [Durden, et al, 1998; Goldhirsh and Musani, 1986]. By reconstructing a 3-D model of the precipitation and rain K_u-band reflectivity within a scatterometer beam, techniques were developed for removing this electromagnetic contribution to each NRCS measurement. The initial phase of this project produced techniques for modeling the volume backscatter and attenuation. These results are used (see Appendix) to estimate the influence of the remaining electromagnetic process that affects the scatterometer NRCS measurement; the rain impact “splash” roughness and its relative NRCS as a function of wind speed, rainrate, polarization
and relative azimuth angle.

2. Approach

The initial work created effective methods for using NEXRAD measurements at S-band to model the K_u-band volume reflectivity and attenuation for each scatterometer radar beam. The next step is to

develop a model function for the rain-impact NRCS relative to the wind-only NRCS. This model function will depend on wind speed and rainrate. For this study, it was necessary to create collocated and coincident observations of the QuikSCAT NRCS, that spans a wide swath of precipitation with high resolution NEXRAD measurements of the three-dimensional reflectivity within the scatterometer beam. The significant difference between this measurement configuration and the surface based techniques is that all these measurements are virtually coincident, and yet span a wide variation of rain intensity conditions across hundreds of kilometers.

3. Description of Observations

The region in the Gulf of Mexico just south of Houston is an attractive area for our comparisons because of the presence of two NEXRAD stations, KHGX (Houston) and KCRP (Corpus Christi) both close to the. On May 30, 2005 a broad and intense rain event covered the Texas Gulf coast from Corpus Christy to across the Louisiana border. Figure 1 shows the S-band reflectivity from KCRP NEXRAD at the time of the QuikSCAT overpass, about t=12:00Z. Its interesting features show it contained large areas of intense rain (> 35 dBZ) and gradients of varying intensity towards each of the NEXRAD's. The swath of SWS on QuikSCAT illuminated a region large enough to include all areas of interest. In an attempt to create spatial regions in which as many of the radar parameters as possible are relatively constant, two adjacent rectangular areas (about 1° in size) were defined as "BOX 1" and "BOX 2". Surface wind measurements (nearly simultaneous with the QuikSCAT overpass; see Figure 1) indicated that the mean wind speeds were different in each of these. In BOX 1, the mean wind is estimated to be 7 m/s in the direction of 190°. A lower wind of 5.3 m/s, with a 129° direction, was measured by buoy #42020 in BOX 2, in its northwest section. The QuikSCAT observations in each box can be segregated into just two azimuth look directions (having variations within a 30° range).

4. Surface NRCS and Relative Rain-Impact Roughness

One such region, BOX 1, ranges from Lon=263.5^o to 264.5^o and Lat= 27° to 28.25^o. The wind speed here is in the 6-to-8 m/s range. There are 164 scatterometer NRCS observation cells, extracted from the PO.DAAC Level 2A data product [JPL, 2006], which lie in this region; 93 are H-pol and 71 are V-pol. These are then separated into two groups, by azimuth angle look direction. The measured values are either σ_{av} or σ_{ah} at each respective polarization, and at that specific azimuth angle. In Figure 2 (upper plot) the measured H-pol NRCS, at one cluster of azimuth angles, is plotted versus the corresponding rainrates, using the "+" symbols. All NRCS data plotted herein using the "+" symbol will represent original measurements from the L2A data files, with no alteration. The azimuth angle is arbitrarily labeled as #1, and they span a 10° range centered about 175°. The NRCS values observed in cells where the mean rainrate is less than 0.1 mm/hr (a higher threshold of 0.3 mm/hr was used for the V-pol groups) are averaged and serve as a reference in which the "no-rain" and wind only value can be estimated.

The effect of rain volume backscatter and atmospheric attenuation for each scatterometer measurement, is removed using the NEXRAD data and the Ku-band models. By removing the atmospheric volume reflectivity part of the NRCS and correcting for the two-way attenuation, the "corrected" NRCS is plotted as the colored square symbols versus rainrate. This now only represents the wind driven plus the rain roughened surface impact NRCS; and this is referred to as the "corrected NRCS" at the surface. At 2 mm/hr and below, there is negligible difference between the measured and corrected values. Above this level, clear differences indicate that the corrected value can be smaller or larger than the measured value, depending on whether the volume correction or two-way attenuation is dominant. As discussed above the results here are very sensitive to the parameter in the DSD that determines a convective or stratiform rain model. Our choice was "convective" which was partially influenced by our consideration of the stratiform model, which led to problematic results.

The NRCS values in the very light rain areas (< 0.1 mm/hr) give us a mean value of about -19 dB to normalize all the corrected NRCS. The plotted points in the lower-half of this figure are the ratio (in dB) of the wind-plus-rain impact NRCS to the "no-rain" NRCS at the same conditions of wind speed, polarization and azimuth angle look. The wind magnitude in this area is estimated to be in the range of 6-8 m/s. The results show a steady increase in the impact NRCS, with a nominal value of 7 dB at a rainrate of

10 mm/hr. It is hoped that further studies will better define these roughness-enhancement functions under similar and higher wind conditions.

5. Summary and Discussion

This research program seeks to collect information equivalent to a model function that quantifies the relative change of the surface NRCS caused by rain, at any wind speed for each of the polarizations of QuikSCAT. One of many difficulties in this endeavor results from the relatively small scale of spatial inhomogeneity of the rain within the nominal 30 km-sized scatterometer footprint size. The unique contribution of this work is to create a configuration in which the three-dimensional structure of atmospheric rain within the radar beam can be measured using the ground based NEXRAD radar virtually simultaneously with the satellite observations. The resolution of this S-band instrument is excellent, but it does have limitations in its vertical dimension. When observations are coordinated to be over ocean regions that contain nearby, multiple NDBC buoys to provide simultaneous surface winds, this assembly of resources constitutes conditions analogous to a “laboratory” even though individual observations cannot be repeated. Considering the very extensive QuikSCAT and NEXRAD data archives, a specific region can studied with many repetitions. The approach presented in this paper uses a single weather event to illustrate this technique, the relevant data sets and the quality of the results. In order to develop useful models for satellite applications this program will continue to study rain-induced modifications as a function of wind speed, rainrate (drop size distribution) and azimuth angle. With this information, it should be possible to improve estimates of scatterometer-derived wind speed and related air-sea interactions.

6. Acknowledgment

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7. References

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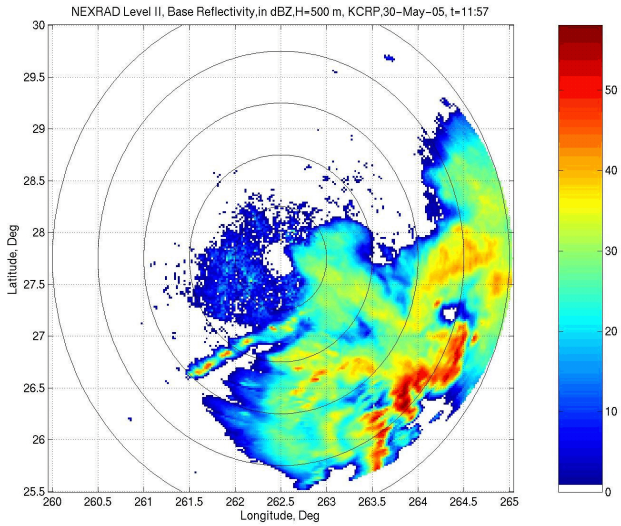

Figure 1. Interpolated S-band reflectivity at altitude of 500 meters elevation, in dBZ (40 dBZ equivalent to 20 mm/hr rainfall), within a range limit of 250 km from the KCRP NEXRAD station.

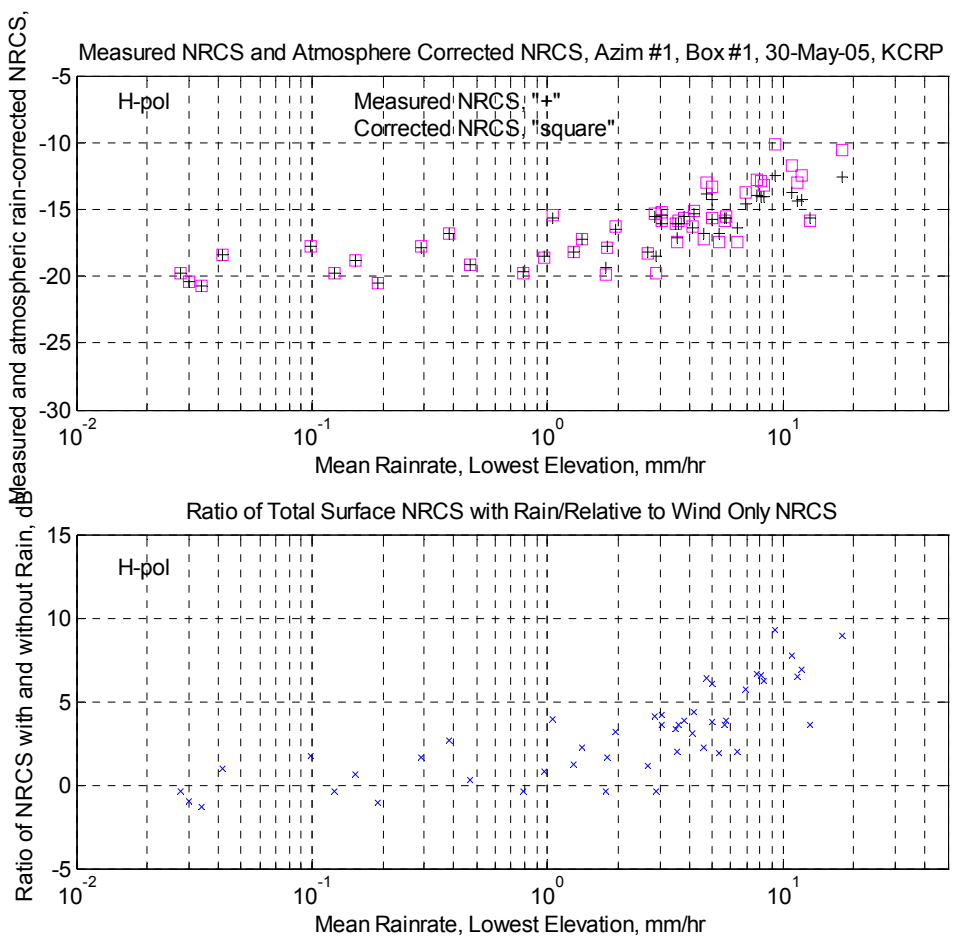

Figure 2.: H-pol data and calculations for Box # 1, Azimuth Angle #1 (Mean of 175°), Upper plot: Uncorrected and corrected (for atmospheric rain) H-pol NRCS versus mean rainrate at each QSCAT cell. Lower Plot: Ratio of total surface NRCS to wind-driven NRCS vs. rainrate. Mean wind is 7 m/s, towards 190°.