THE COMBINED EFFECT OF SURFACE RAIN AND WIND ON SCATTEROMETER OBSERVATIONS OF SURFACE ROUGHNESS

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Changes in the sea surface roughness from the combined effects of wind and rain, on scales of tens of kilometers, are being studied using the QuikSCAT scatterometer and simultaneous NEXRAD three-dimensional measurements of rain. Buoys and related data provide the additional wind information. From the remote sensing perspective, these results will show the dependence of the sea surface radar cross section, at Ku-band, as a function of the rainrate, wind speed and relative direction, and polarization. The studies of air-sea interaction, related to surface fluxes (e.g., momentum, sensible heat, and latent heat), require extended investigations because heavy rain in the boundary layer changes the surface stress and stratification, both of which alter the surface stress and turbulent heat fluxes. A new finding is that certain combinations of wind speed and rainrate can result in reduced surface roughness; implying reduced surface stress and a reduced drag coefficient. This finding naturally leads to the question ‘do such conditions occur in tropical cyclones?’ The methodology described below is used to address this question.

This question is particularly relevant to tropical cyclones, particularly those of hurricane strength, because of both observational and theoretical studies that indicate the rate at which surface stress increases with increasing wind speed is diminished for wind speeds greater than 25 or 30m/s. These finding suggest that traditional algorithms for calculating remotely sensed wind speed or stress for wind speeds less 20m/s can not be usefully extrapolated beyond 30m/s. However, the physical mechanism or mechanisms responsible for this change in functionality have not been identified. It is more than interesting to note that some scatterometer (active radar) observations in hurricane force winds show similar behavior when no rain is present [1]. Also notable are the differences between V-pol and H-pol. Scatterometry responds to characteristics of surface roughness that are very closely related to surface stress for wind speeds <20m/s. This suggests that scatterometry could plausibly be used to investigate at least one of the mechanisms responsible for the reduced drag at high wind speeds. In particular, we investigate the influences of rain on surface roughness. The influences of rain are traditionally ignored in in-situ observational studies because most instruments are not accurate in substantial rain.

The unique aspect of this method is that it combines satellite based Ku-band data with high-resolution 3-D volumetric rain measurements, from simultaneous collocated

NEXRAD data [2]. The volumetric scans of this high resolution S-Band radar are used to model the 3-dimensional Ku-band reflectivity of the volume of precipitation that the scatterometer beam passes through as it samples the sea surface. Consideration was also given to the choice of rain drop-size-distribution and the associated Z-R relation used for the NEXRAD application. The choice of a convective rain model had an appreciable effect on the correction to each measured QuikSCAT NRCS cell for 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

Of particular interest are the conditions within Hurricanes Isabel, Claudette and Dennis. These results show the dependence of the sea surface radar cross section, at Ku-band, as a function of the rainrate, wind speed and relative direction, and polarization. The higher wind conditions lead to large and distinctly different changes in roughness and backscatter for the two polarizations. Of particular interest is the change in surface roughness induced by rain, relative to what would be expected from purely wind forcing.

Comparisons between the new high wind results with those at lower wind speeds show that when the speed approaches and exceeds the terminal velocity of raindrops in low wind conditions (about 8 m/s for the larger drops) the surface roughness features are distorted from the symmetric properties that exist in still-air. This is probably due to an increase in the speed and direction with which the larger raindrops impact the sea interface. This leads to substantial differences in the H-pol versus V-pol NRCS response to increasing rainrates. In most cases, the V-pol increase is much less than H-pol. This also suggests that the air-sea interaction and momentum transfer will depend on the rainrate.

A reduced V-pol backscatter strongly suggests a reduced surface turbulent stress. Reduction in stress due to sea spray and spume have been hypothesized and modeled; however, rain impacts have not been considered in such studies. An alternative mechanism for reducing the stress for hurricane winds is related to wave breaking. Our results indicate that for very large rain rates and strong enough winds, rain is responsible for a reduction in stress. Extrapolations of stress from lower wind speed and rain free conditions result in much too large a surface stress in idealized models of hurricane strength. Our finding is particularly interesting not only because it is another mechanism for reducing surface stress in hurricanes, but because the changes in surface stress would be localized to the eye wall and the rain bands. Such a pattern in surface stress will result in bands of surface convergence and divergence, adding additional structure to vertical motion about the rain bands.

[1] D.E. Fernandez, J.R. Carswell, S. Frasier. P.S. Chang, P.G. Black and F.D. Marks, “Dual-polarized C- and Ku-band ocean backscatter response to hurricane force winds”, J. Geophys. Res., Vol. 111, C08013, 2006

[2] D.E. Weissman and M.A. Bourassa, “Measurements of the effect of rain-induced sea surface roughness on the QuikSCAT scatterometer radar cross section”, IEEE Trans. Geosci. Remote Sens., Vol. 46, No. 10, October, 2008, pp 2882-2894