**P4.8** UTILIZATION OF SATELLITE SCATTEROMETER WIND MEASUREMENTS AND NEXRAD PRECIPITATION DATA TO IMPROVE REGIONAL OCEAN FORECASTS

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## 1. INTRODUCTION

Data from the SeaWinds scatterometer on the QuikSCAT polar orbiting satellite (Graf et al. 1998) provide valuable near real-time measurements of a variety of derived meteorological fields over the open ocean. The scatterometer's 2.2 cm wavelength (13.4 GHz) and high incidence angle result in primary backscatterer by centimeter-sized ripples (capillary waves) on the ocean surface that are highly responsive to changes in wind speed. This allows for wind and surface pressure data to be derived from reflectivity measured by the scatterometer. These data sets are now available for the operational meteorological community on various web sites. One of the known limitations of scatterometer data set is precipitation falling within the radar cross-section. Unfortunately, these areas are often in the vicinity of cyclones where meteorological fields are important to analysis and modeling efforts, not to mention operational issues such as warnings and advisories.

In a unique collaborative effort, a team has formed through the support of the Cooperative program for Operational Meteorology Education and Training (COMET). Through COMET's funding, the team has examined the potential to correct scatterometer reflectivity data for rainfall through comparison with land based radar and in-situ buoy data. While doing this investigation, the team has found that the differential reflectivity is valuable for discerning where rainfall has affected the data and can also be used to actively sense rainfall rate.

Lastly, the collaborative team has facilitated the utilization of scatterometer derived meteorological fields in an operational environment. This has allowed operational meteorologists to integrate the satterometer data with other more conventional datasets within the Advanced Weather Interactive Processing System (AWIPS).

## 2. BUOY AND NEXRAD COMPARISONS TO SCATTEROMETER MEASUREMENTS

The SeaWinds scatterometer data has a resolution of 25 km. Comparisons to National Data Buoy Center (NDBC) operated data buoys along the East Coast with scatterometer derived winds showed high correlations. For example, in Fig 1, a scatter plot of NDBC data and co-located scatterometer collocations shows that 80% of scatterometer derived wind speeds were within 50% of the buoy measured wind speeds. Additionally, Fig 1. demonstrates the tendency for some scatterometer derived wind speeds to greatly exceed those measured by the buoy. The cause is precipitation.

Precipitation in the scatterometer's radar cross-section results in an over estimate of the sea surface wind speed. The rain causes

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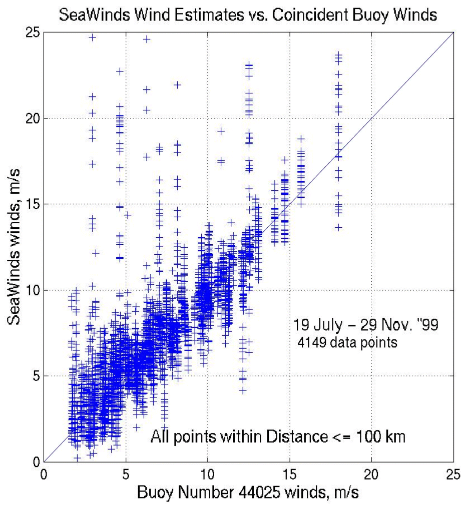


FIG 1. NDBC buoy 44025 wind speeds ($ms^{-1}$) versus co-located scatterometer derived wind speeds for July 19 to Nov. 29, 1999.

attenuation, increased ocean surface roughness as well as direct reflectivity from raindrops themselves. To investigate this phenomena, land based weather radars were used.

The network of Weather Surveillance Radar – 1988 Doppler (WSR-88D) (referred to as NEXRAD) provides a routine product data set (Klazura and Imy, 1993) that extends over portions of the open ocean that are also monitored by the sparse NDBC data buoys. Combining these data with those derived from the scatterometer has allowed for both a validation of the scatterometer derived wind fields and insight into the affect of precipitation on the scatterometer data.

The S band (~10.7 cm wavelength) NEXRAD provides fine-resolution reflectivity, radial velocity and spectrum width atmospheric slice data that are processed and archived. While NEXRAD archive level II data is commonly used for research, this study chose to use the more plentiful and easier to access archived level III data set. Of the many products within the archive level III data set, two were chosen. The base reflectivity from the 0.5$^o$ radar elevation angle archived in polar coordinates, with 16 levels of reflectivity in steps of 5 dBZ, and composite reflectivity which is a volume product that provides the maximum reflectivity observed at a particular location, regardless of the elevation. These products were converted into a rectangular grid for analysis and converted to rain-rate using a Z-R relation of $Z=300R^{1.4}$ [Hunter 1996].

In Fig 2., composite reflectivity is converted rain-rate from the Upton, NY (OKX) WSR-88D and overlaid with coincident centers of scatterometer 25 km resolution cells as well as the location of NDBC buoy 44025. The coincident buoy wind speed was 4.6 $ms^{-1}$ in this near homogeneous environment as determined through meteorological analysis.

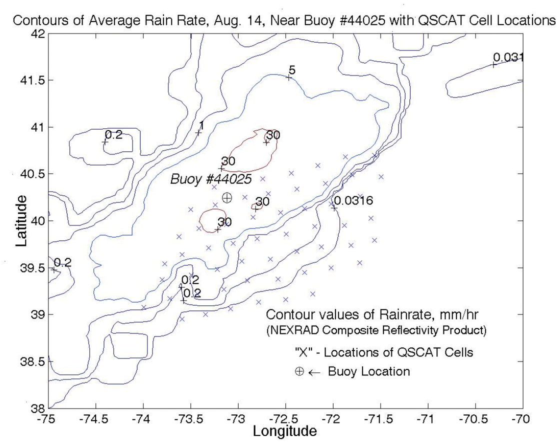


FIG 2. Rain-rate contoured to 0.03, 0.2, 1.0, 5.0, and 30.0 $mmhr^{-1}$ overlaid with locations of center of scatterometer data cross-section points (x) and NDBC buoy 44025 ( ¿) at 1002 UTC on Aug. 14, 1999.

When the scatterometer derived winds speeds are plotted verses NEXRAD determined rate-rate, the relationship of rain-rate to scatterometer derived wind speed becomes evident. At the buoy-observed wind speed of 4.6 $ms^{-1}$, rain-rates in excess of 1 $mmhr^{-1}$ (Fig. 3) begin to affect the scatterometer data with significance (that resulting in derived winds speed at least double that of the buoy) occurring with rain-rates of 5 $mmhr^{-1}$ or higher.

The ability to compare co-located NEXRAD rain measurements with scatterometer derived wind speeds and buoy observations is an

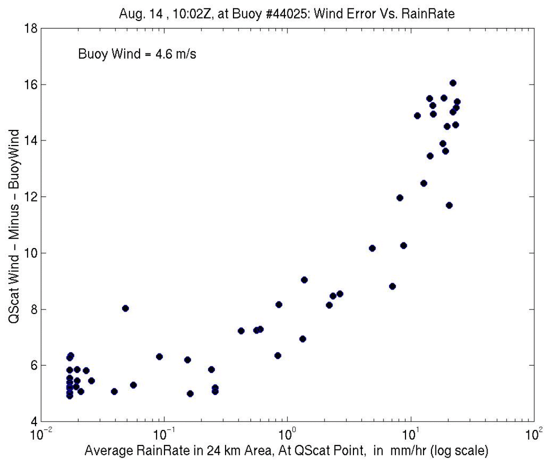


FIG 3. Rain-rate (mmhr$^{-1)}$ logarithmic scale as determined from WSR-88D at Upton, NY verses collocated scatterometer derived wind speed ms$^{-1}$ at 1002 UTC on Aug. 14, 1999.

important advance in the quantitative determination of the effect of rainfall on scatterometer wind estimates. The NEXRAD data products consist of radar scans taken only 6 minutes apart, so that the time coincidences with the scatterometer observations are sufficiently close to be viewed as effectively instantaneous.

## 3. SURFACE PRESSURE FIELDS

Surface pressure calculated using scatterometer observations through various techniques (Harlan and O'Brien 1986; Brown and Zeng 1994; Foster et al. 1999; Zierden et al. 2000) is another meteorological field that proves valuable to operational forecasts. Several of these techniques (Harlan and O'Brien 1986; Zierden et al. 2000) smoothly mesh the scatterometer derived pressure fields (in and near areas with scatterometer observations) with first guess (analysis or forecast) pressure fields in areas away from scatterometer observations. In other words, the pressure field is improved in and near the swath of vector wind observations. These methods have demonstrated the ability to correctly reposition cyclones that had ~50% scatterometer coverage. Pressure fields derived from scatterometer observations have also been shown to have the mesoscale features associated with fronts (Zierden et al. 2000).

Near real-time images of scatterometer derived winds and mean sea level pressure (MSLP) are available from http://www.coaps.fsu.edu/~zierden/qscat/ for the Gulf of Mexico and northeastern U.S. An example from this site is seen in Fig 4.

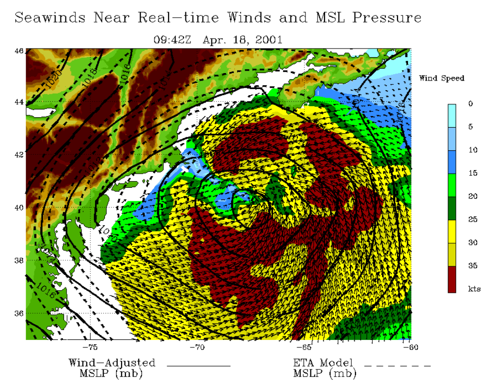


FIG 4. Example of scatterometer derived winds (kts) and MSLP (mb) from http://www.coaps.fsu.edu/~zierden/qscat/ at 0942 (UTC) on Apr. 15, 2001. The wind speeds are color coded and binned to 5-knot increments to highlight standard winds speed levels used for advisories and warnings. The MSLP from the eta model is also overlaid.

## 4. RAIN-RATE

When the rain-rate exceeds a threshold level that is dependent on the wind speed, the scatterometer-derived winds can be identified as rain affect or "flagged" using techniques described by Mears et al. (2000). Studies intended to better understand the affect of rain in scatterometer derived wind data and has led to the discovery that rain-rate can be estimated directly from the SeaWinds scatterometer radar cross section (RCS) measurements. Analysis of the SeaWinds RCS data performed with coincident and collocated NEXRAD measurements of rain-rate within each scatterometer cell showed encouraging results such as those in Fig 5 where both the reflectivity from the horizontally polarized (H-pol) and vertically polarized (V-pol) RCS's are displayed.

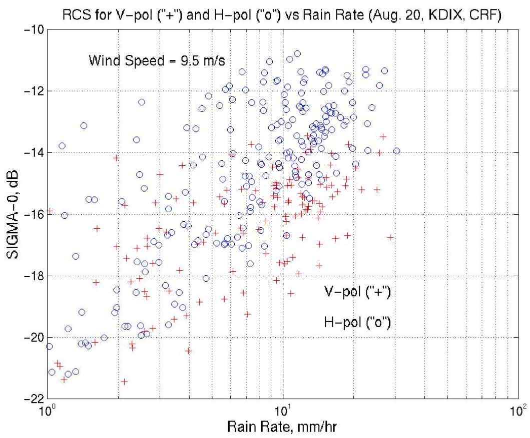


FIG 5. Scatterometer RCS reflectivity ($\sigma^{o}$) (dB) verses NEXRAD derived rain-rate (mmhr$^{-1}$) for Aug. 20, 2000. H-pol cells are designated "o" and V-pol "+". Coincident NDBC Buoy 44025 indicated 9.5 ms$^{-1}$.

In Fig 5, relatively high resolution rain estimates are used to determine the dependence of both the H-pol and V-pol RCS values on rain-rate. Both are observed to increase steadily with rain-rate, and reach levels well in excess of the RCS associated with the wind-roughened surface. At the higher rain-rates, the measured reflectivity ($\sigma^{o}$) is consistent with scattering from the rain volume, with attenuation playing a secondary role. Especially interesting is the difference in the rate of increase, whereby H-pol increases more rapidly than V-pol.

The physical basis for the difference between H-pol and V-pol is the evolution of the oblate raindrop volume and shape as rain-rate increases. This effect is well documented in the literature of radar meteorology, and applications are based on the ratio of the H-pol to V-pol RCS. This ratio is defined as the differential reflectivity, which can be expressed as a function of the rain parameter statistics.

Our studies of the scatterometer RCS data and calculations of the differential reflectivity indicate a clear functional form that lends itself to rain-rate estimation wherever scatterometer measurements are made – see Fig. 6. However, this is subject to threshold levels that depend on the surface wind speed. For example our initial studies (with a very limited data set) suggest that, at wind speeds near 5 m/s, rain-rates at 2 mm/hr and above are detectable. With the larger surface backscatter at winds of 10 m/s, rain-rates above 3 mm/hr can be discerned. This study is in a very early stage and the quantitative results will evolve as more data is analyzed. However, we view our data analysis and physical understanding to be self consistent, and look forward to developing a major new application for SeaWinds and subsequent scatterometers.

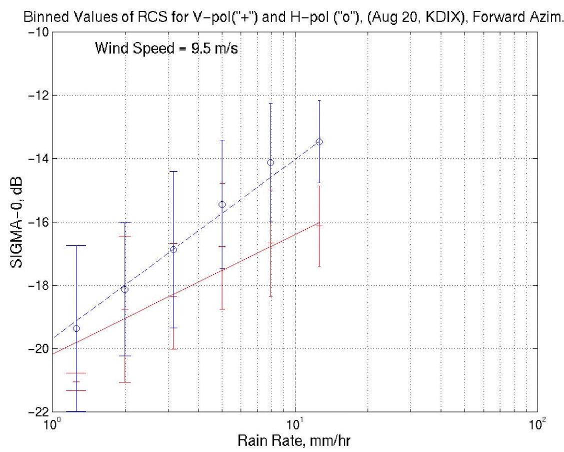


FIG 6. As in Fig. 5, except regression lines for H-pol (dashed line) and V-pol (solid line are displayed) with binned values (mean & STD).

## 5. INTEGRATION INTO AWIPS

The integration of these data sets into AWIPS for use by the National Weather Service (NWS) field offices and NWS National Centers has and will be a critical part of this work. Ingestion of this data into AWIPS will allow for additional new discoveries and utilization for this potentially global database.

NetCDF scatterometer data is being ingested by two local NWS forecast offices – Upton, NY and Tallahassee, FL. Initially, plots of scatterometer-derived winds were ingested into AWIPS. The next step is to ingest U and V components of the derived winds along with MSLP in ¼ degree latitude spaced grids. These data will allow operational forecasters interact with the data using the calculative abilities within AWIPS.

## 6. CONCLUSIONS

Scatterometer derived surface winds and MSLP provide valuable information in near real-time over the data sparse ocean. Through use of NDBC buoy and NEXRAD data, it has been shown that the reflectivity in the RCS is significantly affected in the presence of rainfall.

The use of differential reflectivity has been shown to provide a method to detect rainfall. Differential reflectivity from the QuikSCAT scatterometer, through additional study, can be used to determine rain-rate and correct for rainfall affected wind calculations.

Lastly, the integration of scatterometer data into AWIPS is an important advance in the evolutionary utilization of this data set.

## 7. ACKNOWLEDGEMENTS

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