Ultra High Resolution Rain Retrieval from QuikSCAT Data

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***Abstract*— Originally designed only to measure near-surface winds over the ocean at 25 km resolution, backscatter measurements made by the QuikSCAT scatterometer can be used to simultaneously estimate wind and rain. By applying resolution enhancement algorithms, the wind and rain can be estimated at significantly improved resolution, though with higher noise. Initial results for inferring wind and rain at ultra high resolution are presented.**

I. INTRODUCTION

The Ku-band QuikSCAT scatterometer retrieves the near-surface (10 m) wind over the ocean from measurements of the normalized radar backscatter (σ°) of the surface [1]. Multiple σ^o measurements from several different azimuth angles are employed to estimate the equivalent neutral-stability wind speed and direction with the aid of a geophysical model function (GMF) relating the vector wind and the surface backscatter. Winds from QuikSCAT have proven remarkably accurate [2]. Unfortunately, rain can adversely affect the accuracy of wind estimates: rain attenuates the radar signal passing through to the surface, adds backscatter from droplets and perturbs the surface due to droplet impact and rain-induced wind drafts. The precise effects of rain on σ^o are dependent on radar frequency, surface wind and wave conditions, and the rain rate. Rain can lead to biases in the estimated wind speed and direction [3].

The sensitivity of σ^o to rain can be exploited to estimate the rain rate from the σ^o measurements by simultaneously retrieving the vector wind and the rain rate using a modified GMF which accounts for both wind and rain [3]. The modified GMF uses a conventional wind GMF, but includes attenuation effects and additive backscatter due to the rain. Simultaneous wind/rain retrieval (SWR) has been demonstrated using 25 km resolution backscatter measurements [4] and rain rates derived from QuikSCAT have been validated against Tropical Rain Mapping Mission (TRMM) Precipitation Radar (PR) TRMM Microwave Imager (TMI) data [5] and against Next Generation Weather Radar (NEXRAD) data under hurricane conditions [6]. SWR-derived rains exhibit greater variability than TRMM PR, TMI, and NEXRAD, but are nearly unbiased. SWR-derived winds also have reduced bias, but tend to be noisier than conventional estimates. SWR is particularly effective for flagging locations where rain contamination adversely affects conventionally-retrieved scatterometer winds [6].

It has been demonstrated that QuikSCAT σ^o measurements can support ultra high resolution wind retrieval [7], [9]. While designed for 25 km retrievals, reconstruction techniques can be employed to enhanced the effective resolution of the σ^o observations. This is be done separately for each azimuth/polarization look direction, producing multi-azimuth backscatter estimates posted on a 2.5 km resolution grid. From these, ultra high resolution scatterometer winds can be estimated. The high resolution winds tend to be noisier than conventionally-retrieved winds but reveal mesoscale features not evident in 25 km wind fields and can be retrieved closer to the coast than 25 km winds. High resolution wind retrieval is also affected by rain, and mesoscale rain-related features, e.g. convective rain effects, are evident in the data.

Given the success of rain retrieval from QuikSCAT σ^o measurements, can rain be retrieved at high resolution? In this paper we apply SWR to the enhanced resolution QuikSCAT σ^o values to simultaneously retrieve wind and rain at very fine spatial resolution, with vector winds and rain estimates posted on a 2.5 km/pixel grid. The fundamental technique is briefly described and sample results for actual data are provided. Some of the strengths and limitations of the technique are described.

II. HIGH RESOLUTION

QuikSCAT employs a dual scanning pencil-beam antenna system to make σ^o measurements over a 1800 km wide swath at two nominal incidence angles, 46° (h-pol) and 54.1° (v-pol). Using range/Doppler filtering, the antenna footprint is resolved into 6×25 km 'slices'. The summed slice measurements, termed 'eggs' have an effective size of approximately 25×32 km [1]. Egg measurements are used in conventional 25 km resolution wind retrieval reported in the L2B wind product. Summing slices reduces the noise level of the egg measurements. For wind retrieval over the inner swath, σ^o measurements at four azimuth angle/polarization combinations are used. In the outer swath, only two azimuth angles are available.

The relatively large footprint of QuikSCAT egg observations is larger than typical rain cells and thus limits the spatial resolution of the SWR rain rate observations in conventional 25 km retrieval. Slices, too, have larger foot prints than typical rain cells. However, the pulse timing and measurement geometry results in dense spatial sampling, with significant overlap, by the slice σ^o measurements. The over-sampling is exploited by the reconstruction algorithm to produce enhanced resolution images of the surface σ^o. Each beam and look direction (forward or aft) each processed separately. This results in four σ^o images with finer effective resolution than the intrinsic resolution of a single slice measurement. As can be expected, the noise level of the enhanced resolution σ^o measurements have increased noise levels compared to the eggs [10]. The σ^o images are produced on a rectangular along-track/cross-track grid with a pixel size of 2.5 km using the AVE algorithm [7]. In the AVE algorithm each of the slice σ^o measurements which overlap a given pixel are averaged, weighted by the spatial response function evaluated at the pixel center [8]. The effective resolution of the σ^o images varies over the swath.

For a given 2.5 km pixel location, wind-only estimation of high resolution winds are obtained using the standard QuikSCAT wind retrieval algorithm and the enhanced resolution σ^o values. The effective resolution of the resulting winds is approximately 5-10 km. We note that finer spatial resolution wind estimates comes at the cost of higher noise levels in the wind estimates, i.e. there is a tradeoff between resolution and noise. Nevertheless, these high resolution wind estimates find application in near-coastal studies and in monitoring severe weather events [9]. The high resolution reveals mesoscale features of the wind field.

As in conventional 25 km wind retrieval, the accuracy of the high resolution winds can be adversely affected by rain. Rain suppresses high wind speeds, enhances low wind speeds and changes the apparent wind direction. At high rain rates, the conventionally-retrieved wind appears to blow cross-track. To address the problem of rain contamination of the winds and to provide rain estimates, we use simultaneous wind/rain (SWR) retrieval based on the high resolution σ^o values to simultaneously retrieve wind and rain at fine spatial resolution. The approach is identical to the maximum-likelihood Draper and Long SWR algorithm [4], but adapted for finer resolution pixels. Wind and rain estimates are computed for each 2.5 km pixel and posted on a 2.5 km/pixel grid.

Due to the high noise levels in the measurements the SWR-estimated wind and rain tend to be very noisy. To ameliorate this, spatial filtering of the enhanced resolution σ^o values is employed prior to retrieval. This reduces the noise level, but also degrades the resolution. There is thus a tradeoff between spatial resolution and rain estimate accuracy. Here, a 5 km spatial smoothing filter is applied to the individual σ^o images prior to SWR. We note that four azimuth-diverse σ^o measurements are required for SWR. Thus, SWR can not be used for the outer swath where only σ^o measurements for the outer V-pol beam are available.

As in conventional retrieval, for each pixel location from one to four wind/rain "ambiguities" having similar wind speeds, but differing directions, result from the maximum likelihood wind retrieval. To select a single direction, an ambiguity selection algorithm is required. Ultra high resolution SWR is computationally very intensive and is complicated by the need for an ambiguity selection algorithm that considers both wind and rain ambiguities. Convective rain events modify the local wind direction, further complicating the ambiguity selection process. In this paper for simplicity we have selected the ambiguity with wind closest to the selected, conventional 25 km wind estimate. Improved performance can be expected with better ambiguity selection algorithms.

Although the rain rates estimated in SWR retrieval are accurate for a wide range of wind and rain conditions, rain retrieval can be ill-conditioned for certain wind directions and measurement geometries, resulting in biases in the wind and rain estimates [4]. Rain and wind estimates are less accurate near the nadir track and for winds blowing directly cross-track.

III. Results

Two identical SeaWinds scatterometers have flown: one on QuikSCAT and the other on ADEOS-II. ADEOS-II also carried an AMSR radiometer, which provides simultaneous spatially co-located radiometric observations. AMSR rain estimates are useful for validating SeaWinds-derived winds. An example from SeaWinds-on-ADEOS-II is provided below.

Sample ultra high resolution wind and rain results for Hurricane Isabel are illustrated in Fig. 1. Figure 2 presents 25 km SWR-retrieved wind and rains for comparison. In these figures conventional 25 km wind-only retrieval wind speeds are compared to winds derived from enhanced resolution σ^o fields using conventional wind-only retrieval and to winds retrieved using SWR retrieval. As previously noted, for both low resolution and high resolution SWR, rain is not retrieved in the outer swath region on the left. High resolution wind retrieval reveals significantly more detail at the mesoscale than low resolution estimates. In both wind-only and SWR high resolution wind retrieval the location of the hurricane eye is plainly visible. High resolution SWR more clearly resolves rain features of rain bands than. The high rain values are associated with rain bands. We also note that a number of isolated spots with anomalously high wind speeds in the bottom of the image in the wind-only retrieval are associated with raining, convective events. The excessively high winds for these cases are corrected in the high resolution SWR images. We note that high resolution SWR has a higher dynamic range for wind and rain values than 25 km SWR. This is attributed to the higher resolution.

Figure 3 shows AMSR-retrieved rain rate for comparison. We note that the majority of the rainfall occurs in the upper right quadrant of the storm. The general rainfall patterns are similar in the rain estimates in Figs. 1-3 but the high resolution SWR provides finer detail. We note that the SWR rain model function is calibrated against TRMM PR and thus reports rain in km-mm/hr while AMSR reports rain rate in mm/hr. To aid in comparison the color bar shown in Fig. 3 was arbitrarily scaled. As expected, SWR rain estimates exhibit higher scatter than AMSR measurements (see [5] for discussion).

Both low resolution SWR retrieval ultra high resolution rain retrievals are a particularly useful rain impact flag as they can indicate when wind-only retrieval is adversely effected by rain. When the retrieved rain is over 2 km-mm/hr, rain-induced errors in wind-only retrieval are significant [6]; however, SWR-retrieved are unbiased so long as wind continues to dominate the total backscatter. For sufficiently high rain rates,

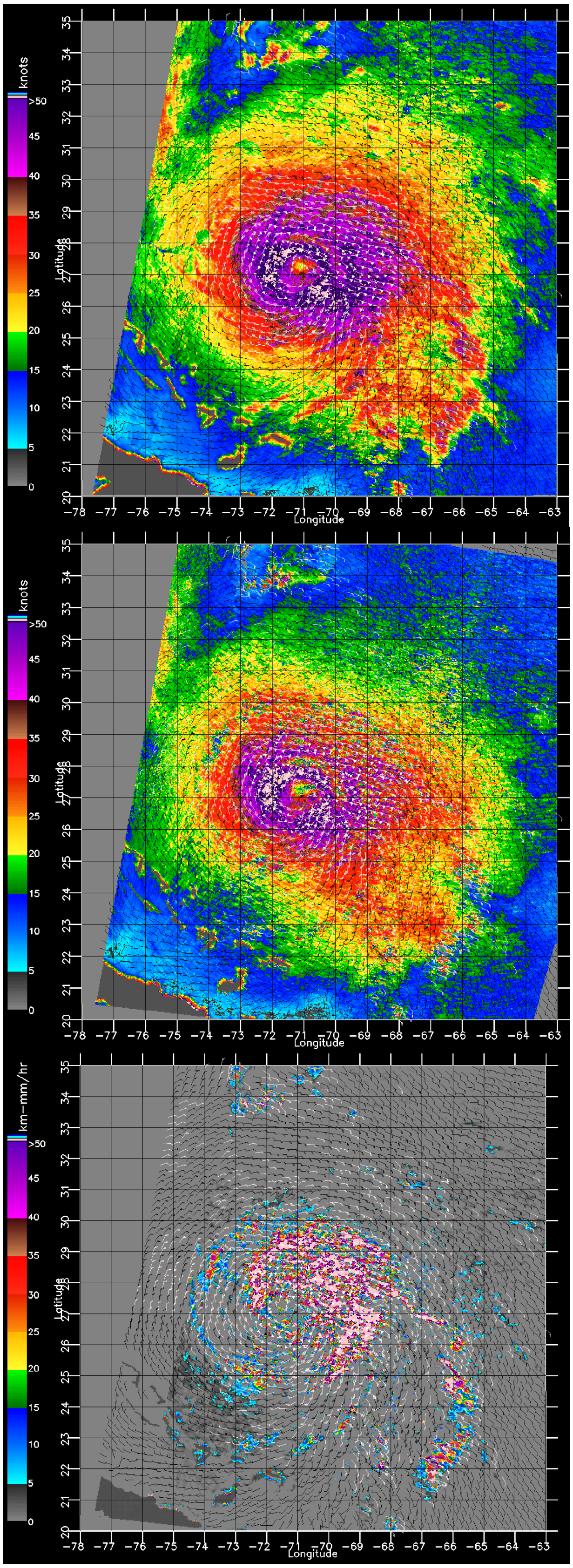

Fig. 1. Ultra high resolution fields with 25 km wind barb overlay for Hurricane Isabel Sept. 16, 1999. (top) Wind-only retrieval speed. (center) SWR-retrieved speed. (lower) SWR-retrieved rain. Land is dark gray.

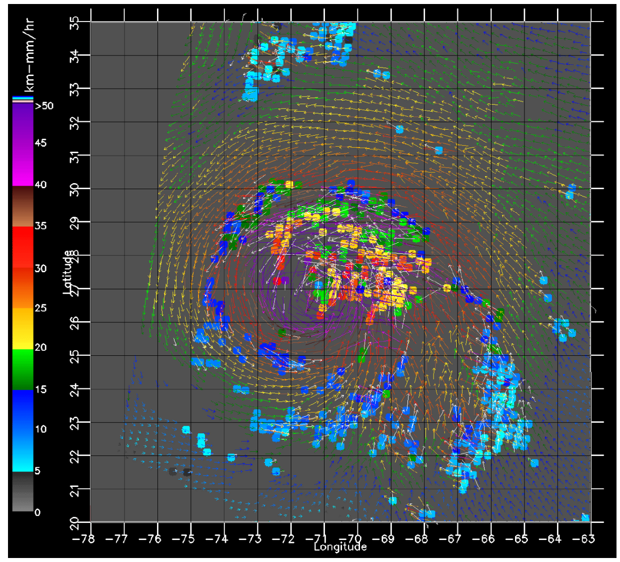

Fig. 2. SWR-derived winds and rain derived from 25 km egg σ^o measurements for Hurricane Isabel Sept. 16, 1999.

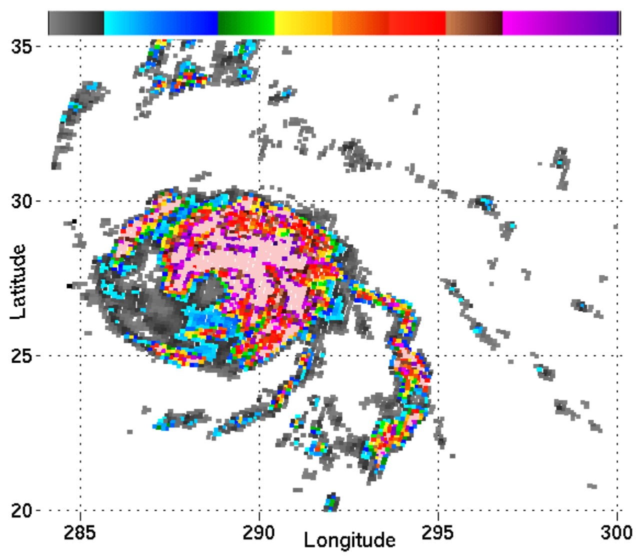

Fig. 3. ADEOS-II AMSR-derived rain rate for Hurricane Isabel Sept. 16, 1999. Scaling is arbitrary, see text.

rain dominates the backscatter signature and winds cannot be accurately retrieved [4].

IV. Conclusion

Although QuikSCAT was originally designed to measure only wind at 25 km resolution, QuikSCAT σ^o measurements can be used to retrieve both wind and rain at higher resolution using reconstruction and simultaneous wind/rain retrieval techniques. Scatterometer-derived rain and wind fields reveal significant mesoscale features, including convective events. Although an experimental product, it is hoped that high resolution wind and rain estimates can be applied in applications requiring high resolution, including near coastal studies and tracking tropical storms.

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