# High Resolution Rain Retrieval from SeaWinds Scatterometer Data

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## SUMMARY

Originally designed to measure near-surface winds over the ocean from space at 25 km resolution, the SeaWinds scatterometer directly measures the normalized backscatter from several azimuth angles. From these measurements, the wind speed and direction are estimated. While rain can adversely affect the accuracy of the retrieved wind, rain sensitivity can be exploited to enable SeaWinds to simultaneous estimate wind and rain. By applying resolution enhancement algorithms, the wind and rain can be estimated at significantly improved resolution, though with higher noise. Results are illustrated with hurricane examples.

## INTRODUCTION

The SeaWinds scatterometer is a Ku-band radar designed to measure near-surface winds from space (Spencer et al. 2000). It does this indirectly by measuring the normalized radar backscatter ($\sigma^{\circ}$) of the from multiple azimuth angles. The high precision $\sigma^o$ measurements are employed to retrieve the near-surface (10 m) equivalent neutral-stability wind speed and direction over the ocean with the aid of a geophysical model function (GMF) relating the vector wind and the surface backscatter. Data from SeaWinds on QuikSCAT has proven remarkably accurate (Chelton and Freilich 2005). The SeaWinds scatterometer has been operating aboard the QuikSCAT satellite since 1999. SeaWinds data is in operational use at various weather prediction agencies.

Unlike the precipitation radar (PR) onboard the Tropical Rain Measuring Mission (TRMM), SeaWinds is unable to separately resolve rain scattering above the surface. As a result, rain can adversely affect the accuracy of scatterometer wind estimates. Figure 1 schematically illustrates the influence of rain on the scatterometer signal: 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 on $\sigma^o$ 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 (Draper and Long, 2004a).

The sensitivity of $\sigma^o$ to rain can be exploited to estimate the rain rate from the $\sigma^o$ measurements by simultaneously retrieving the vector wind and the rain rate using a modified GMF which accounts for both wind and rain (Draper and Long 2004b). An example of the modified GMF is illustrated in Fig. 2. The modified GMF uses a conventional wind GMF, but includes attenuation effects and additive backscatter due to the rain and surface perturbation.

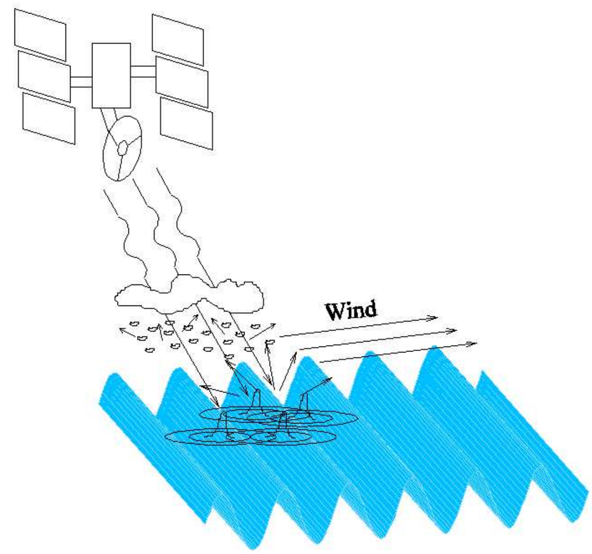


Fig. 1. Schematic diagram of rain effects on scatterometer wind/wave observations.

Rain rates derived from the SeaWinds scatterometer have been successfully validated against TRMM PR and TRMM microwave imager (TMI) data (Draper and Long 2004c) as well as against Next Generation Weather Radar (NEXRAD) data in hurricane conditions (Allen and Long 2005). Scatterometer-derived rains retrieved using simultaneous wind/rain retrieval exhibit greater variability than these other sensors, but are unbiased. Simultaneous wind/rain retrieval is particularly effective for flagging locations where rain contamination adversely affects conventionally-retrieved scatterometer winds.

## I. HIGH RESOLUTION

The relatively large (25 km by 35 km) footprint of "egg" SeaWinds observations is larger than typical rain cells and thus limits the spatial resolution of the SeaWinds rain rate observations in conventional 25 km retrieval. However, SeaWinds also collects somewhat finer resolution (6 km by 25 km) measurements known as "slices" using Doppler

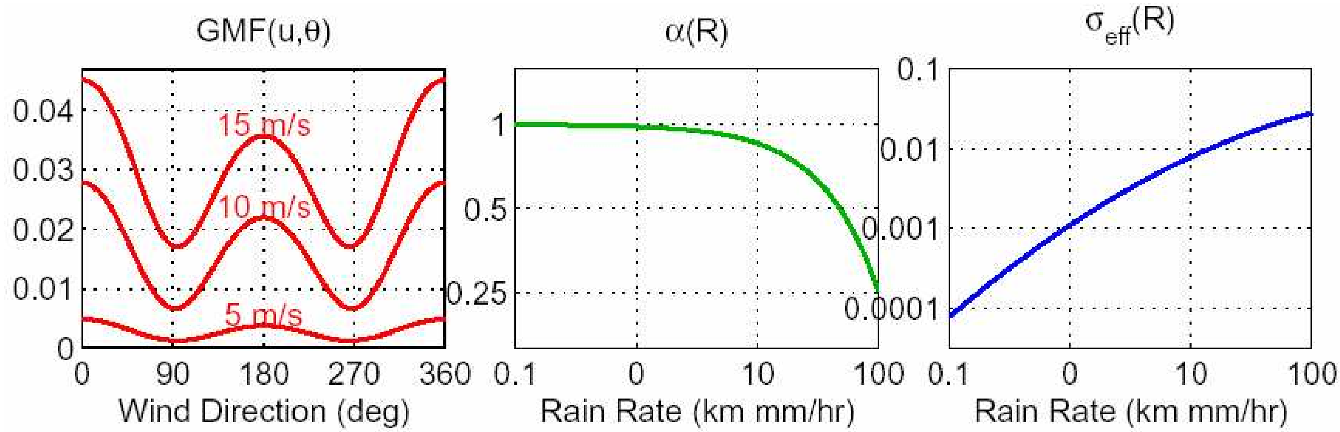


Fig. 2. Example plots from the Draper and Long (2004) simultaneous wind/rain model function for a particular radar look direction, polarization, and incidence angle. $\sigma^o$ as a function of wind speed ($u$), direction ($\theta$), and rain rate ($R$) is written as $\sigma^\circ(u,\theta,R) = \alpha(R)GMF(u,\theta) + \sigma_{\text{eff}}(R)$ where $GMF(u,\theta)$ is the conventional wind-only QMOD3 model function.

filtering (Spencer et al. 2000). The instrument measurement timing and antenna geometry provide a dense spatial sampling of the surface by the slices, with significant measurement response overlap. The sampling supports the application of reconstruction/resolution enhancement processing to generate backscatter estimates with significantly improved spatial resolution (Early and Long 2001). The result of applying a reconstruction algorithm is a set (one for each azimuth observation) of $\sigma^o$ images with finer spatial resolution ($\sim$ 2.5 km/pixel) than the intrinsic resolution of a single slice measurement (Early and Long 2001). While conventional processing results in 25 km resolution wind estimates, winds with very high spatial resolution can be estimated using the high resolution $\sigma^o$ estimates (Long 2001).

For a given 2.5 km pixel location, wind-only estimation of high resolution winds are obtained using the standard SeaWinds wind retrieval algorithm and the enhanced resolution $\sigma^o$ values. We note that finer spatial resolution wind 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 (Long 2004).

As in conventional 25 km wind retrieval, the accuracy of the high resolution winds can be adversely affected by rain. To address this problem we use simultaneous wind/rain (SWR) retrieval with the high resolution $\sigma^o$ values to simultaneously retrieve wind and rain at fine spatial resolution. The approach is identical to the Draper and Long (2004b) algorithm, but adapted for finer pixels. Wind and rain estimates are posted on a 2.5 km/pixel grid. Prefiltering the $\sigma^o$ values enables a tradeoff between spatial resolution and estimate accuracy. A 5 km spatial smoothing filter is applied to the individual $\sigma^o$ images prior to retrieval.

Sample results for Hurricane Floyd are illustrated in Fig. 3. In this figure conventional 25 km wind-only retrieval wind speeds are compared to winds from high resolution wind-only retrieval and from simultaneous wind/rain (SWR) retrieval. High resolution SWR retrieval reveals significantly more detail at the mesoscale than low resolution estimates. We note that the higher resolution SWR tends to report higher wind and rain values. The high rain values are associated with clearly defined 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 winds for these cases are corrected in the high resolution SWR images

As in conventional retrieval, for each pixel location from one to four wind/rain "ambiguities" having similar wind speeds, but differing directions, are retrieved. To select a single direction, an ambiguity selection algorithm is required. For SWR retrieval, the ambiguity selection algorithm must also consider rain ambiguities. Here for simplicity we have selected the ambiguity with wind closest to the selected, conventional 25 km wind estimate.

A second example for Hurricane Katrina is provided in Figs. 4 and 5. In this case, the conventional 25 km wind product (shown as barbs) does not correctly locate the center of circulation; however, the center can be easily determined from the circular eyewall seen near the center of the image. Large areas of extremely high rain rates are evident.

Although the rain rates estimated in SWR retrieval are

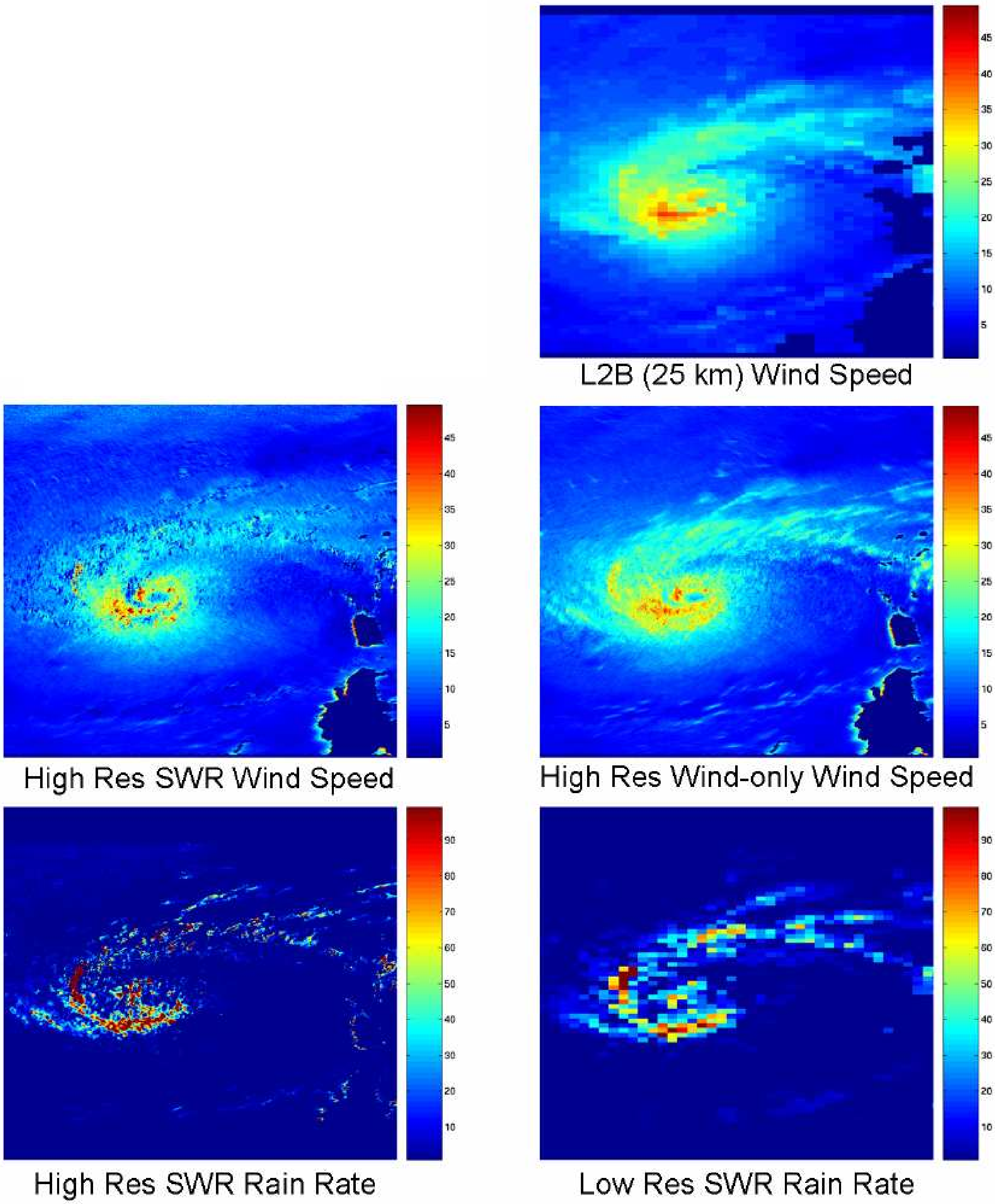


Fig. 3. Images illustrating wind and rain retrieval for Hurricane Floyd Sept. 11, 1999. (see text) The coordinate system used id the native SeaWinds along-track (left to right) / cross-track (top to bottom) swath. In these images north is approximately to the left. To the right are islands of Puerto Rico (center) and Hispanola (lower-right). Color scale is m/s or km-mm/hr as appropriate.

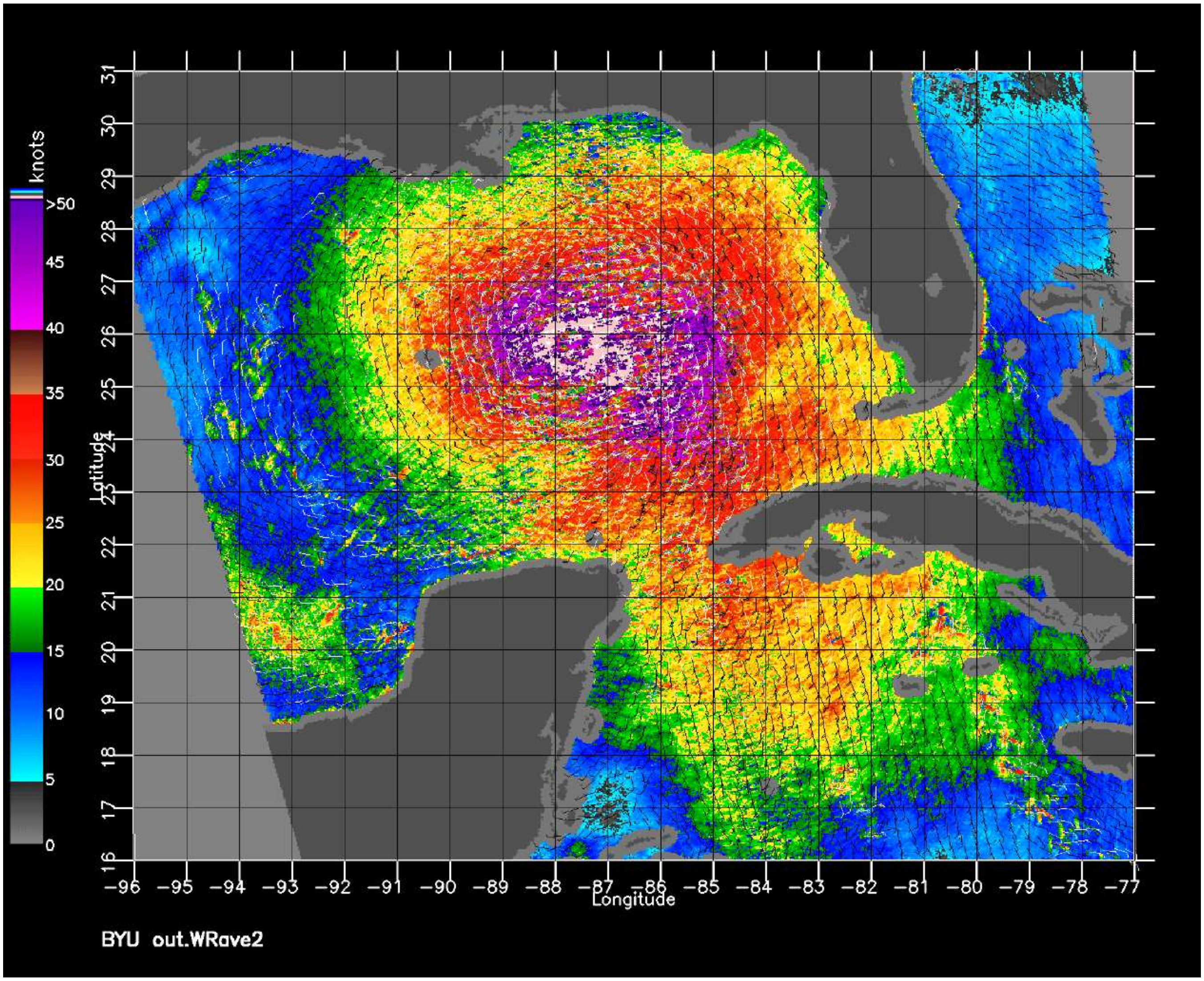


Fig. 4. Ultra high resolution wind speed derived from QuikSCAT data using simultaneous wind/rain retrieval for Hurricane Katrina Aug. 28, 2005 with overlaid conventional 25 km resolution wind barbs.

accurate for most conditions, rain retrieval can be ill-conditioned for certain wind directions and measurement geometries. This can produce spurious low rain rates. These can be eliminated by accepting only rain rates 2 km-mm/hr or higher (Allen and Long 2005).

## Conclusion

Although the SeaWinds scatterometer was originally designed to measure only winds at 25 km resolution, the measurements can be used to retrieve both wind and rain at higher resolution. The high resolution SeaWinds-derived rain fields reveal significant mesoscale features, including convective events associated with isolated, anomalous wind estimates occasionally seen in conventional wind-only retrieval. Still an experimental product in the validation stage, it is hoped that high resolution wind and rain estimates can be applied in applications needing high resolution, including monitoring hurricanes and tropical cyclones.

## References

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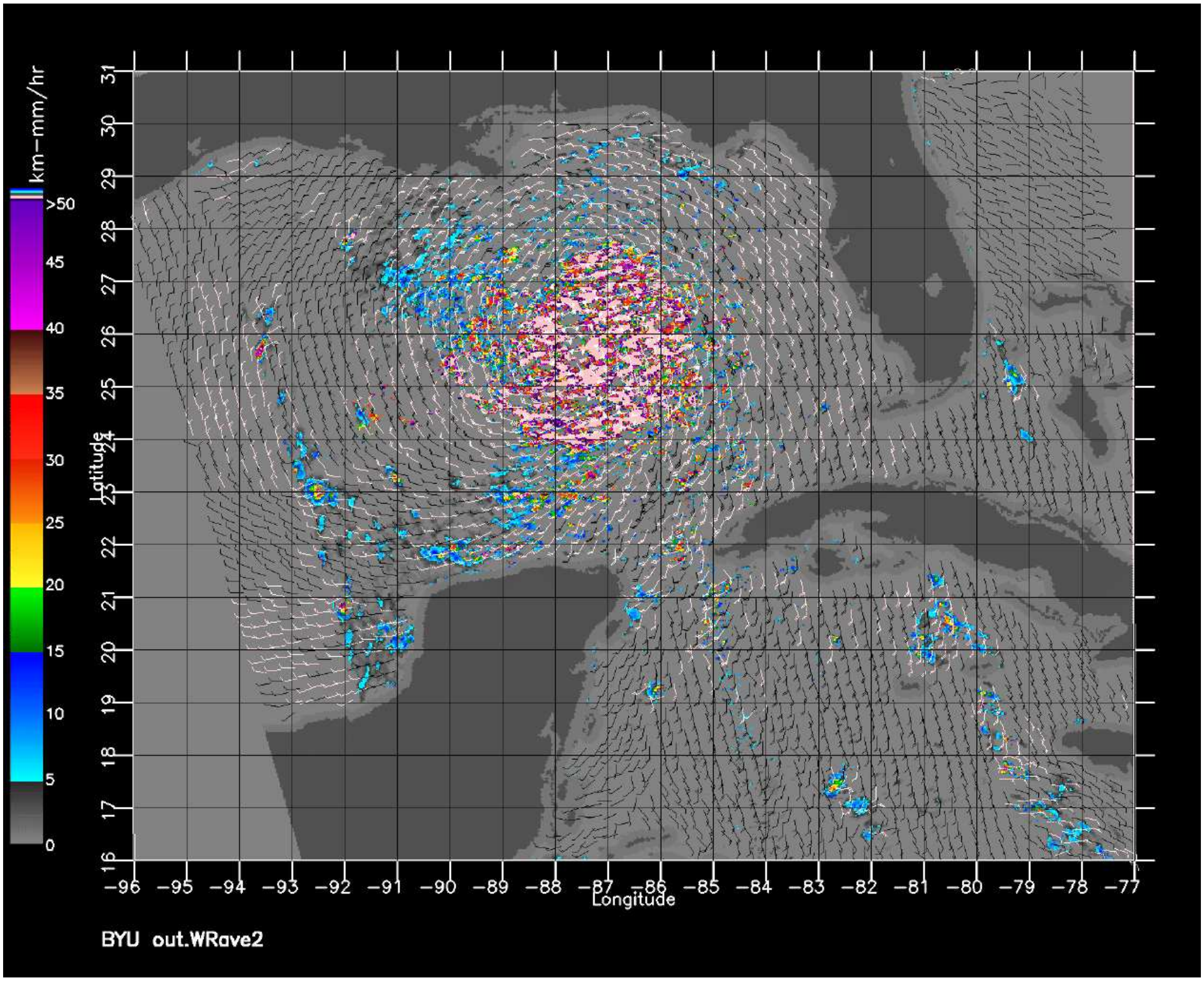


Fig. 5. Ultra high resolution rain rate derived from QuikSCAT data using simultaneous wind/rain retrieval for Hurricane Katrina Aug. 28, 2005 with overlaid conventional 25 km resolution wind barbs.

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