High Resolution Vector Wind Retrieval from SeaWinds Scatterometer Data

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Abstract

The SeaWinds series of Ku-band wind scatterometer instruments were designed to measure near-surface winds over the ocean from space at a spatial resolution of 25 km. Scatterometers measure the normalized radar backscatter of the ocean's surface from which they infer the vector wind via a geophysical model function. The measurement geometry and sample characteristics of SeaWinds are well-suited for application reconstruction/resolution enhancement techniques to improve the effective resolution of the backscatter measurements. These can be used to retrieve the vector wind at much high spatial resolution. As can be expected there is a tradeoff: higher spatial resolution leads to higher noise; however, the high resolution winds can be very useful in near-coastal studies and in the study of severe weather, particularly in locating hurricane centers. The latter application is illustrated.

I. Introduction

The SeaWinds wind scatterometer has been operating aboard the QuikSCAT satellite since 1999. While originally a science mission, SeaWinds wind observations have proven to very useful for operational weather forecasting where it improves forecasting skill. SeaWinds was designed to measure the normalized radar backscatter (σ°) at 25 km resolution. With σ^o measurements spanning a diversity of azimuth angles, the vector wind (speed and direction) is inferred from the σ^o measurements with the aid a geophysical model function relating backscatter and vector wind. There is a monotonic relationship between wind speed and backscatter with a double cosine relationship between wind direction and backscatter. Conventional processing results in high accuracy 25 km resolution wind estimates. With its wide swath, SeaWinds provides nearly complete daily coverage of the oceans.

By applying reconstruction/resolution enhancement techniques to the σ^o measurements prior to wind retrieval, finer resolution wind estimates are possible. Here, a technique for retrieving enhanced resolution winds at ultra high resolution (UHR) with 2.5 km sample spacing from SeaWinds data is described. An experimental UHR wind product has been deployed at NOAA to support monitoring of severe weather events. Some sample results are described.

II. Scatterometer Imaging

Using a dual scanning pencil-beam antenna system, SeaWinds collects σ^o measurements over a 1800 km wide swath at two nominal incidence angles, 46° (h-pol) and 54.1° (v-pol). At each swath location, the scanning geometry provides multiple azimuth observations that are required for successful wind retrieval.

The nominal SeaWinds antenna illumination pattern at the surface is an ellipse. Using range/Doppler filtering, the antenna beam limited footprint is resolved into twelve individual elements termed 'slices' (Spencer et al. 2000). The slices are approximately 6×25 km. The summed slice measurements are known as 'egg' measurements which have an effective size of approximately 25×32 km and less noise (Ashcraft and Long 2003). Egg measurements are used in 25 km resolution wind retrieval reported in the JPL SeaWinds L2B and near-real time MGDR wind products.

The instrument measurement timing and antenna geometry provide a dense spatial sampling of the surface by the slices, with significant measurement response overlap. This dense 'over-sampling', along with the non-ideal roll-off of the spatial measurement response, is exploited by reconstruction and resolution enhancement algorithms to produce enhanced resolution images of the surface σ^o. The result of applying these algorithms are σ^o images with finer spatial resolution than the intrinsic resolution of a single slice measurement (Early and Long 2001). The σ^o product used in this paper is reported at a pixel resolution of 2.5 km/pixel. (Sample products are available from http://www.scp.byu.edu).

While the Scatterometer Image Reconstruction (SIR) can be used, due to reduced computational requirements the AVE algorithm is used. The AVE algorithm has more limited enhancement capability than SIR, but also tends to be less noisy (Long et al. 1993). Over most of the SeaWinds swath four separate σ^o values can be computed: h-pol fore and aft azimuth looks and v-pol fore and aft azimuth looks. Over the outer edges of the swath only v-pol measurements are available, resulting in only two looks per pixel compared to four looks per pixel elsewhere. The σ^o fields for each case are separately computed from the raw σ^o measurements using the individually varying spatial responses of the measurements (Ashcraft and Long

2003). Thus, four separate images are created. In computing the AVE σ^o image the azimuth and incidence angle at each pixel is also determined. These are used in wind retrieval. The enhanced resolution σ^o images are produced on a rectangular along-track/cross-track grid with a pixel size of 2.5 km. Pixels not covered by σ^o measurements are not used.

III. Operational Hurricane Monitoring

Even without wind retrieval, the enhanced resolution σ^o fields can be a useful tool in severe storm forecasting since the circulation center can be determined without regard to cloud cover or solar illumination. Since σ^o (in dB) is roughly proportional to wind speed, with modulation by wind direction, regions of high wind speeds can be identified as "bright" areas in the σ^o images.

It requires skill and practice to directly interpret ocean surface σ^o fields; however, the symmetry and low wind speed central eye of hurricanes make such features easy to identify and track (see Long 2001) and the higher spatial resolution of the σ^o images provides better precision than the 25 km wind fields. Incorporating eye locations derived from high resolution σ^o images can improve tracking accuracy. Currently, high resolution σ^o fields are being operationally used to support hurricane monitoring. High resolution σ^o images are produced in near-real-time for each SeaWinds orbit as well as for INVEST regions centered about storms. A set of sample high resolution σ^o fields for a recent hurricane are illustrated in Fig. 1. This particular example, Wilma, had an unusual eye structure at this point. The eye is visible as lower σ^o regions surrounded by higher backscatter values. The western side of the eyewall is over the Yucatan peninsula. Though this reproduction is poor quality, rain bands are evident in the image

IV. Wind Retrieval

While the enhanced resolution σ^o images can be used directly for hurricane and typhoon tracking (Long 2000), employing the high resolution σ^o measurements in wind retrieval results in further spatial enhancement and simplifies data interpretation (Long 2004). The additional refinement in resolution is due to diversity of the spatial response functions of the multiple looks combined in the wind retrieval.

For a given 2.5 km pixel location, the wind is retrieved using a standard SeaWinds wind retrieval algorithm using the 2-4 σ^o "looks". Here, we note that finer spatial resolution wind is not without cost: the noise level is increased compared to the averaged egg measurements employed in conventional 25 km retrieval since there is less averaging.

As in conventional retrieval, for each pixel location from one to four "ambiguities" having similar wind speeds, but differing directions, are retrieved. To select a single direction, an ambiguity selection algorithm is required. While improved algorithms are in development, currently the high resolution ambiguity closed to the nearest conventional resolution selected ambiguity field is chosen. For pixels with missing σ^o measurements, the wind speed can be estimated but the wind direction estimate is degraded and can be discarded.

Figure 2 illustrates the high resolution wind speed field corresponding to the enhanced resolution σ^o fields shown in Fig. 1. The high resolution wind speed field has greater detail than evident in the conventional resolution wind vectors, and enables more precise location of the center of circulation.

As in conventional wind retrieval, the accuracy of the wind estimate can be adversely affected by high rain, which is often associated with high winds (Draper and Long 2004). A separate paper addresses simultaneous wind/rain retrieval from high resolution scatterometer data.

V. Comparison of Conventional and High Resolution Winds

Since the high resolution σ^o values are noisier than the egg values normally used to retrieve the wind, the winds derived from the high resolution σ^o measurements tend to be noisier than conventional 25 km winds and can exhibit direction and speed biases, though biases can be minimized though an additional processing step. Recall, that SeaWinds was designed for 25 km resolution wind estimation and we are exceeding its original design specifications in computing high resolution winds. Nevertheless, the high resolution can be useful in many studies demanding high spatial resolution, including hurricane location and near-coastal studies.

Errors in wind ambiguity selection in scatterometer-derived wind fields can degrade the utility of the data. Evaluation and correction of ambiguity selection errors can be simplified in ultra high resolution wind estimates due to the spatial sampling. An illustrative example of how the high resolution wind speed field can assist in ambiguity selection is provided in Fig. 3. This example also illustrates how the high resolution speed field can be used to location hurricane centers. Here, the conventional 24 km wind field (shown as barbs), fails to identify the circulation center of Hurricane Ophelia. However, a classic high speed eyewall with a calm center is evident in the high resolution wind speed field. It is thus easy to accurately locate the circulation center, and correct the ambiguity selection of the conventional winds.

Conclusion

Although the SeaWinds scatterometer was originally designed to measure vector winds over the ocean at 25 km resolution, SeaWinds measurements can support wind retrieval at much higher resolution, albeit with higher noise levels. With caution, the high resolution winds can be applied in many applications needing higher spatial resolution or winds closer to the coast. The high resolution winds effective in severe weather monitoring. Additional examples and data samples are available from http://www.scp.byu.edu/data/Quikscat/Wind/HRwind.html

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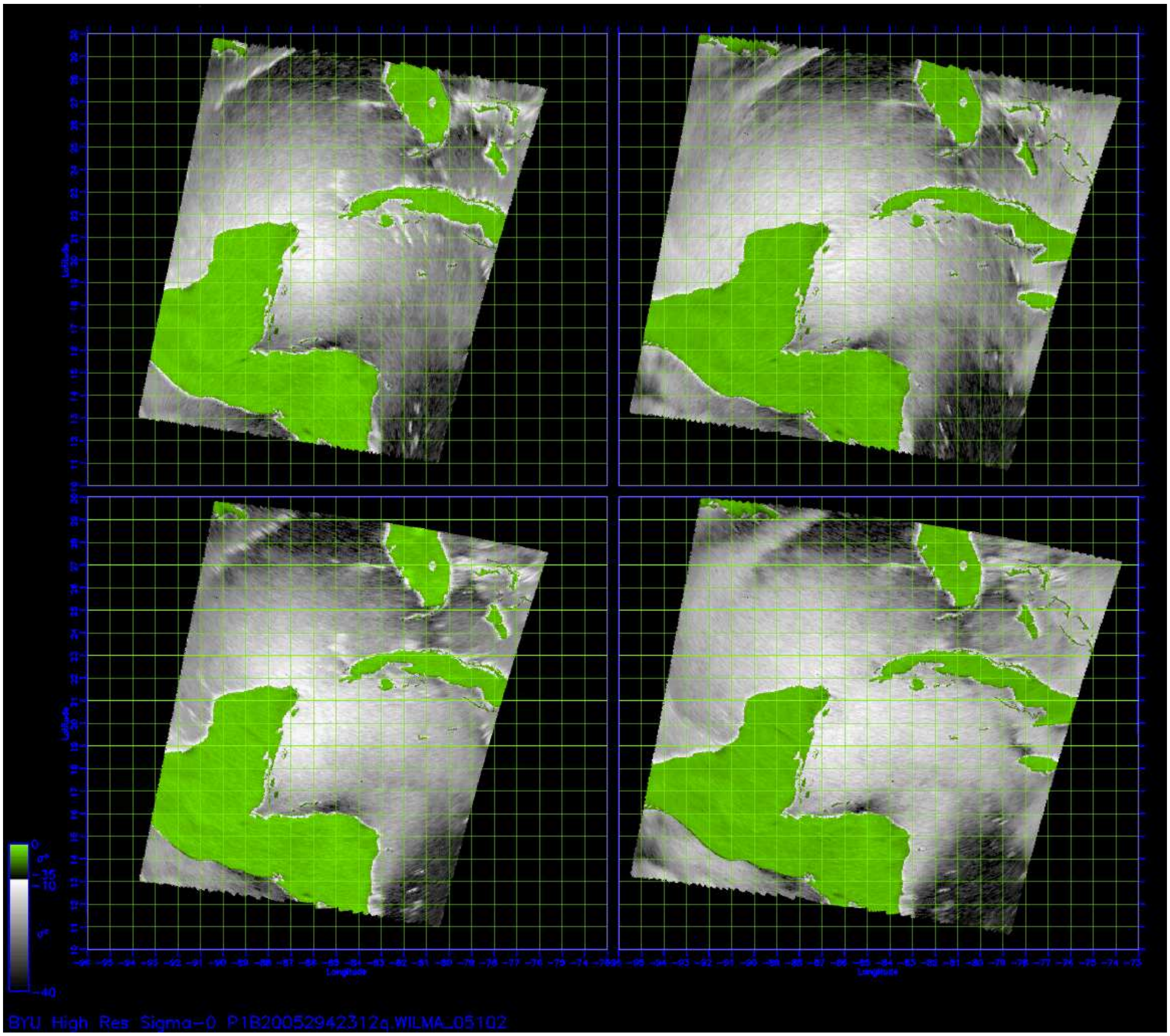

Fig. 1. Enhanced resolution backscatter images (in dB) of Hurricane Wilma on 22 Oct 2004, 23:12. Each panel represents a different "look", or combination of azimuth angle and polarization: (upper left) rear-facing inner beam [H-pol], (upper right) rear-facing outer beam [V-pol], (lower left) forward-facing inner beam [H-pol], (lower right) forward-facing outer beam [V-pol]. In general, higher σ^o over the ocean corresponds to higher wind speed. (compare Fig. 2)

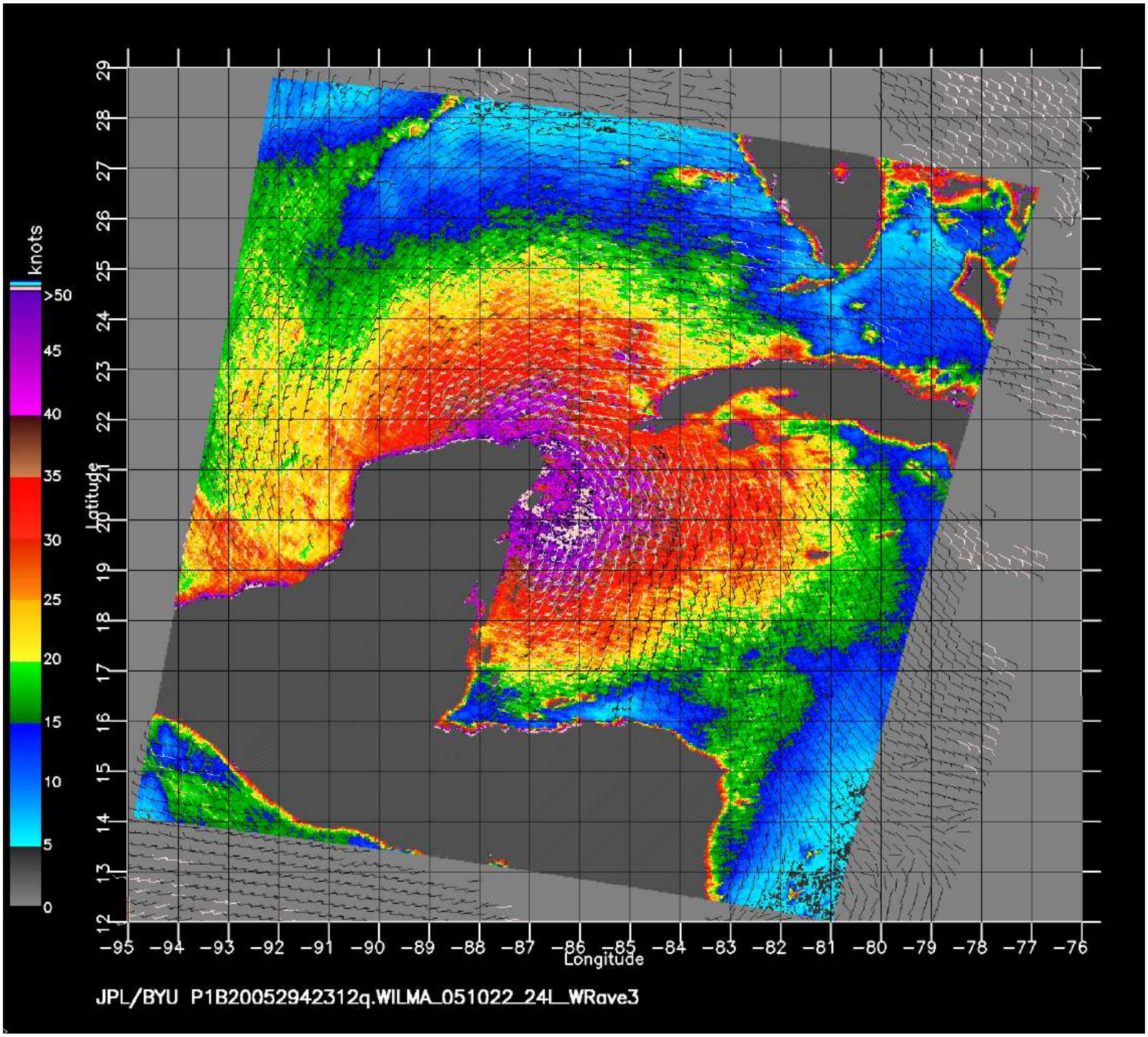

Fig. 2. Ultra high resolution wind speed image (colored background) with overlaid conventional 25 km resolution wind barbs of Hurricane Wilma on 22 Oct 2004, 23:12. Barbs are colored white if flagged as rain in conventional wind retrieval. High wind speeds with 15 km of coastlines result from land contamination of backscatter measurements.

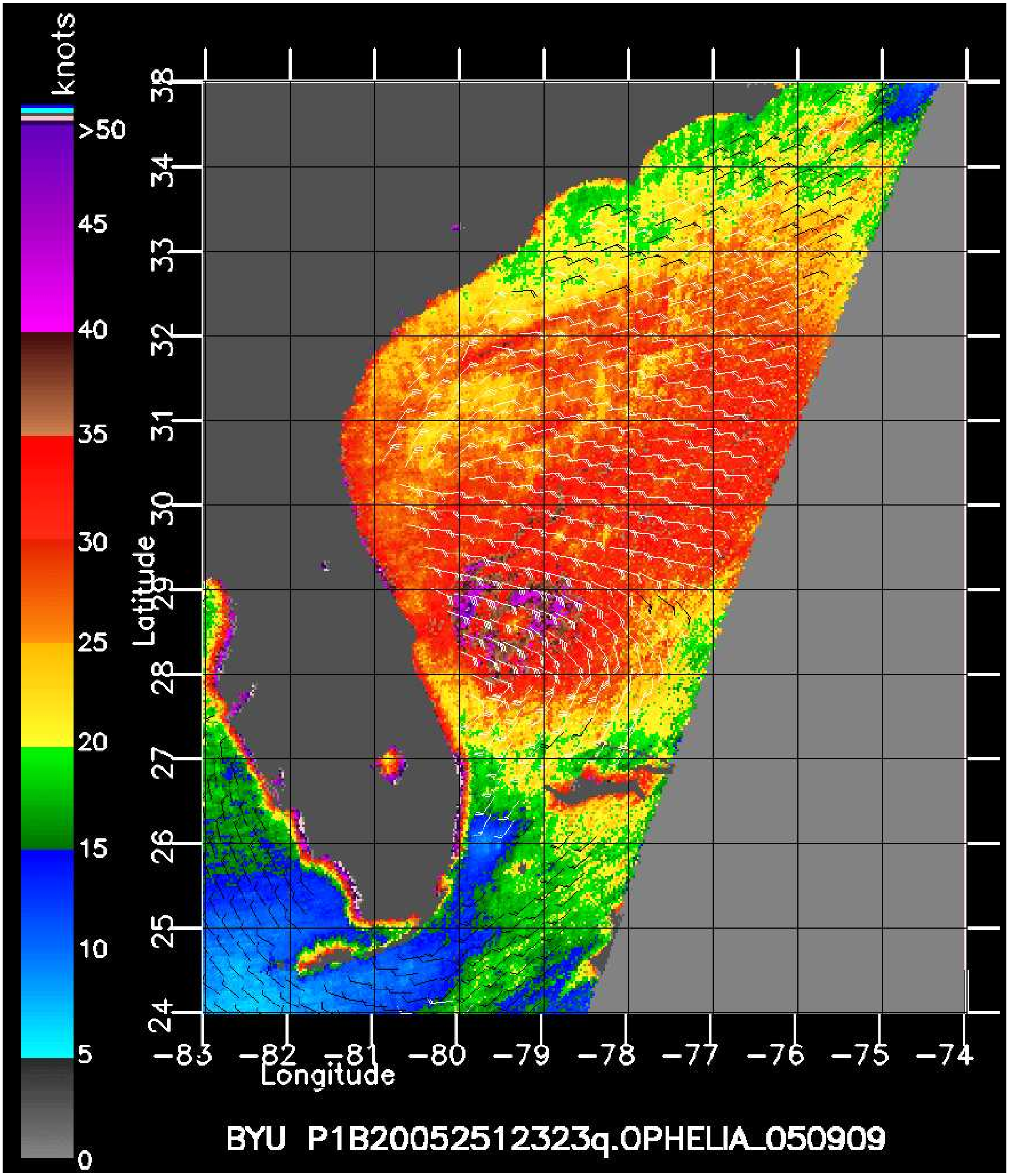

Fig. 3. Ultra high resolution wind speed image (colored background) with overlaid conventional 25 km resolution wind barbs of Hurricane Ophelia on 9 Aug 2005, 23:23 (see caption of Fig/ 2).