6.3 PRELIMINARY OPERATIONAL EVALUATION OF WINDSAT OCEAN SURFACE VECTOR WINDS AT THE TROPICAL PREDICTION CENTER/NATIONAL HURRICANE CENTER

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1. INTRODUCTION

The mission of Tropical Prediction Center/National Hurricane Center (TPC/NHC) is to save lives, mitigate property loss, and improve economic efficiency by issuing the best watches, warnings, forecasts, and analyses of hazardous tropical weather, and by increasing the understanding of these hazards. One of the most significant challenges in accomplishing this mission is the scarcity of data over the oceans within the TPC/NHC area of responsibility. This area includes the North Atlantic basin (including the Gulf of Mexico and Caribbean Sea) and the eastern North Pacific basin (east of 140ºW) for tropical cyclones (TCs) and large portions of the tropical North Atlantic and eastern Pacific for marine analysis and forecasting (Fig. 1).

Since 2000, remotely-sensed ocean surface vector winds from the SeaWinds scatterometer onboard the NASA QuikSCAT satellite have been used available in near real time at TPC/NHC to help fill some of the gaps in surface wind data. These data have become very familiar to forecasters and, with careful interpretation, QuikSCAT can help them determine the location, intensity and outer wind radii of many TCs. More recently, new ocean surface vector wind data from the WindSat radiometer onboard the U.S. Navy/Air Force Coriolis satellite have been available in near real time at TPC/NHC for evaluation since June 2006. WindSat is a multi-frequency, polarized, passive microwave instrument designed to retrieve multiple environmental data records (EDRs), including near ocean surface wind speed and direction, sea-surface temperature (SST), cloud liquid water (CLW), rain rate (RR), and total precipitable water (TPW), in addition to more conventional passive microwave imagery (Gaiser et al. 2004). WindSat is the first radiometer to attempt full vector retrievals of the ocean surface wind; previous and existing passive microwave instruments (e.g., the Special Sensor Microwave Imager, SSMI) have provided only wind speed retrievals. Originally, WindSat was designed to be the risk-reduction mission for the now-canceled Conical Scanning Microwave Imager/Sounder (CMIS) instrument that was slated to be part of the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The eventual replacement for CMIS could still possess some of the capabilities of WindSat.

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The WindSat antenna footprint is an ellipse, the size of which varies with frequency from approximately 13 km for the 37.0 GHz channel to 40 x 60 km for the 6.8 GHz channel. The measured brightness temperatures for ocean EDRs are averaged over the footprint of 6.8-GHz channel and spaced in time for every fourth 37-GHz V and H polarized measurement along the scan and every scan along the track. This results in WindSat EDRs being sampled at approximately every 12.5 km, with an actual retrieval resolution of 50 km.

WindSat wind retrievals received at TPC/NHC are processed at the National Oceanic and Atmospheric Administration/National Environmental Satellite, Data, and Information Service (NOAA/NESDIS) using NOAA's WindSat Ocean EDR retrieval algorithm (Jelenak et al. 2004). The WindSat data swath for wind retrievals is 1000 km wide, and the typical daily coverage of the ascending pass of the instrument is shown in Figure 2.

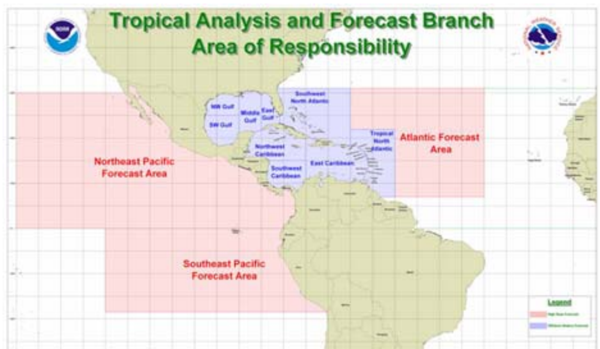

Figure 1. Map showing TPC/NHC's area of marine forecast responsibility.

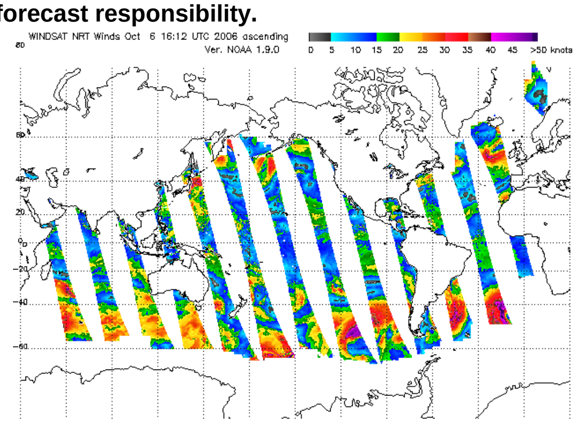

Figure 2. Typical daily coverage of ascending WindSat passes.

These wind data, along with gridded fields of CLW, RR, TPW, and SST are available for display in the NOAA/National Centers for Environmental Prediction (NCEP) Advanced Weather Interactive Processing System (N-AWIPS) workstations used by forecasters at TPC/NHC.

Wind retrievals from WindSat are being evaluated to determine their utility in operational applications at TPC/NHC. Wind vector retrievals in TCs are complicated by the presence of high cloud water and rain, and WindSat was not designed to provide accurate wind vector estimates in these conditions. Nevertheless, the first NOAA WindSat retrieval algorithm (Jelenak et al 2004) was applied in these conditions in an attempt to provide wind retrievals in TCs. An initial evaluation of these wind retrievals showed that the algorithm, originally developed for non-precipitating atmospheres and ocean surface winds below 20 m s^{-1}, is severely affected by high cloud water values and precipitation (Adams et al 2006). To improve the performance of the wind vector retrieval in these conditions, a separate high cloud water wind vector retrieval algorithm was developed at NOAA/NESDIS. This retrieval algorithm is used when cloud liquid water estimates reach or exceed 0.2 mm^2.

In particular, the WindSat retrievals are being compared to those from QuikSCAT, providing a baseline against which to judge the quality of WindSat retrievals. The quality of WindSat retrievals in estimating the intensity (i.e., maximum sustained surface wind) and center location/identification for tropical cyclones (TCs) will be evaluated here. In evaluating the WindSat wind retrievals, it is critical to also examine the other parameters retrieved by WindSat, particularly CLW and RR. This goal of this evaluation is to help determine if the quality of full wind vector retrievals in TCs using a passive approach will be comparable to those retrieved using scatterometry (i.e., QuikSCAT), which has a much longer history of operational application.

Additional evaluations of WindSat retrievals for other marine forecast and analysis applications, such as identifying and locating fronts, surface high and low centers, and areas of high winds outside of TCs will be the focus of future work this winter and spring.

2. EVALUATION OF WINDSAT IN TROPICAL CYCLONES

a.) Statistical summary

Through 9 October 2006, 40 WindSat passes were available during the 2006 hurricane season for intensity estimation over Atlantic and eastern North Pacific TCs. This number is rather small due to the narrow swath of the WindSat instrument and several WindSat data outages during the evaluation period. Five of the passes occurred over tropical depressions, 17 over tropical storms, and 18 over hurricanes. Among the passes over hurricanes, 14 occurred over category 1 storms, two over category 2 storms, and one pass each over both a category 3 and 4 hurricane.

Fig. 3 is a scatter plot comparing the maximum retrieved wind speed over each TC from WindSat data on a 0.25º x 0.25º grid with the NHC operational best track intensity at the time closest to the WindSat overpass. WindSat data were not considered in arriving at any of these best track intensities, so this limited set of cases provides an independent, preliminary assessment of any significant biases in WindSat intensity estimates. The WindSat estimates are clustered near the best track TC intensity in the 40–45 kt range, but WindSat consistently underestimated TC intensity once these storms reached an intensity of about 50 kt. WindSat was unable to retrieve wind speeds of hurricane force in this sample, as the highest retrieved wind speed was 63 kt. This results in a large underestimation of the intensity of most hurricanes in this sample.

The bias of WindSat intensity estimates was averaged for different tropical cyclone intensity categories and the result is shown in Fig. 4. In this sample, WindSat has a positive bias of 3.0 kt for tropical depressions. The bias becomes negative and increases in magnitude to –6.6 kt for tropical storms and increases markedly for hurricanes.

Among the 40 WindSat passes examined for intensity estimates, 29 occurred close enough to the time of a QuikSCAT pass over the same TC to compare the intensity estimates from both instruments. On average, the QuikSCAT passes had an average intensity bias (compared to the NHC operational best track) that was 6.6 kt less than for WindSat (10.3 kt for QuikSCAT compared to 16.9 kt for WindSat). When averaged within NHC best track intensity categories, QuikSCAT showed a smaller bias in all systems except tropical depressions (Fig. 5). While these results suggest that the WindSat wind vector solution from the current retrieval algorithm cannot be used for estimating the intensity of strong tropical storms and hurricanes, the relatively small intensity bias in tropical depressions suggests that WindSat might provide more reliable intensity estimates of these weaker systems compared to QuikSCAT.

The quality of the WindSat wind vector solution for TC center fixing was evaluated for 31 passes that depicted a well-defined TC center. Well-defined centers were not evident in almost 20% of the WindSat passes over active TCs. This center fixing evaluation is based only on the wind vector solution, and it does not take into account the utility of 37-GHz imagery from WindSat in TC center fixing, which has been already incorporated into the TPC/NHC analysis process.

The location of the TC center derived from the WindSat wind vector solution was compared to the linearly interpolated NHC operational best track position for the hour closest to the time of the WindSat pass. The average center location error from WindSat was 54.9

nm, and six passes had position errors exceeding 100 nm. The largest location errors occurred when the WindSat solution was biased to the southeast of the NHC best track position (Fig. 6).

Center fixes based on WindSat 37 GHz imagery for these 31 passes showed much smaller errors, averaging only 16.8 nm. The fixes from the 37 GHz imagery exhibit a much tighter clustering around the NHC best track location (Fig. 6), and on average they show about a 50% improvement over the center fix based on the wind vector solution. TPC/NHC forecasters are already utilizing WindSat 37-GHz imagery from the Naval Research Laboratory TC webpage (e.g., Hawkins et al. 2006) for operational TC center fixing and structural analysis.

It is useful to compare center fix errors from the WindSat wind vector solution to center fix errors from the QuikSCAT wind vector solution for a comparable number of cases. For example, the average error in center fixes from 55 QuikSCAT passes over Atlantic TCs during 2003 was 31.1 nm (in comparison with the NHC best track). This result suggests that the ability of the WindSat wind vector solution using the current retrieval algorithm in locating TC centers is less than that of QuikSCAT, and that the WindSat wind vector solution alone cannot be used for reliable, operational TC center fixing.

b.) Case examples

To assess the details of the WindSat wind vector solution in passes over TCs, we examined the relationship between the wind solution and other parameters retrieved by WindSat, and we compared the WindSat wind vector retrievals to those from QuikSCAT. Two examples from the 2006 season are described below.

First, a WindSat pass over Tropical Depression 3-E at 0116 UTC 11 July 2006 is shown in Fig. 7a. The WindSat solution suggests the center of the depression was near 12.0ºN 111.5ºW; however, this center was not well-defined, as WindSat shows no westerly wind component on the southwest side of the center. The interpolated NHC operational best track position for this time was 13.3ºN, 110.4ºW, or about 110 nm to the northeast of the WindSat center. In contrast, a QuikSCAT pass at 0145 UTC had a center fix error of only 21 nm (Fig. 7b) and suggests the presence of a better-defined circulation than that seen in WindSat.

Sharp wind direction shifts are seen in the WindSat retrieval. One occurs southwest of the depression center where the wind shifts from northwest to southeast and another is seen southeast of the center where the wind shifts from southeast to south. Both of these wind shifts occur along gradients in the retrieved CLW, suggesting that the directional retrieval is particularly sensitive to this parameter. This type of strong wind shift along cloud water gradients has been seen in several other WindSat passes (not shown).

The maximum wind retrieved by WindSat was 37 kt for this depression that had an intensity of 30 kt (Fig. 8a), representing a much smaller error than the 52-kt wind maximum in the QuikSCAT pass (Fig. 8b). The retrieved wind speeds from WindSat and QuikSCAT both appear to have been sensitive to precipitation south of the depression center, where WindSat retrieved 35 kt and QuikSCAT 52 kt. The WindSat CLW estimates in that region were greater than 4 kg m^{-2} (Fig. 8a), and the RR exceeded 36 mm hr^{-1} (Fig. 8b). A second maximum of 37 kt in the WindSat pass was located along the gradient in cloud water southeast of the depression center. QuikSCAT showed winds of 30–35 kt in this region, which was not rain contaminated according to the WindSat RR values, so QuikSCAT winds in the 30–35 kt range could be realistic there at that time.

Interestingly, WindSat shows a wind speed *minimum* in the CLW gradient southeast of the depression center, where retrieved wind speeds were only 20–25 kt (Fig. 9a). In contrast, QuikSCAT showed winds of at least 34 kt in this area (Fig. 8b). The reasons for this wind speed minimum in the WindSat retrieval appear to be associated with effects of CLW gradients and not actual wind speed gradients, but the retrieval algorithm in cases such as this needs to be better understood to improve forecaster interpretation of this type of feature.

In this pass the area of strongest winds in WindSat occurred in the region of highest CLW, also suggesting that the wind speed retrieval is sensitive to this parameter. The maximum wind from WindSat in this pass is more realistic than that from QuikSCAT when compared to the NHC operational best track intensity. However, the QuikSCAT directional solution shows a much more robust cyclonic circulation and appears more realistic for that of a tropical cyclone. Additionally, the CLW and RR retrievals from WindSat were useful in diagnosing rain contamination effects in the QuikSCAT pass.

The second example is a WindSat pass over Hurricane Hector in the eastern North Pacific at 0155 UTC 18 August 2006; Hector was a hurricane with an operationally-assessed intensity of 80 kt at that time. Fig. 10 shows isotachs and streamlines from the WindSat pass. The maximum WindSat speed of 63 kt was the highest wind retrieved by any WindSat pass in the sample for this study. The WindSat center location of 15.3ºN, 122.9ºW is close to the interpolated NHC operational best track position of 15.3ºN, 123.1ºW at this time, resulting in a WindSat position error of only about 12 nm.

The highest retrieved WindSat winds, an area of 50+ kt winds to the east of the center, were co-located with a large CLW maximum where values exceeded 3 kg m^{-2} (Fig. 11a). Rain rate values exceeded 45 mm hr^{-1} in this area as well (Fig. 11b), suggesting a relationship between high retrieved wind speeds and high CLW/precipitation. However, the retrieved wind speeds were 40 kt or less over the remaining portion of the circulation, and these values seem quite low for a hurricane with an intensity of 80 kt.

A QuikSCAT pass over Hector around 0200 UTC provided an opportunity to once again compare the wind retrievals from both instruments. In Fig. 12, isotachs of WindSat wind speed are plotted with the QuikSCAT wind barbs. The color scale is the same for both, so when the wind speeds from both instruments are in the same range, only the WindSat isotachs will be visible. The WindSat maximum wind of 63 kt is located relatively close to the 55-kt wind barb in the QuikSCAT solution (Fig. 12); however, WindSat shows a large area of winds greater than 60 kt where QuikSCAT has winds of only 40–50 kt. Elsewhere, the QuikSCAT winds are much higher near the center of Hector, with 60–65 kt north of the center where WindSat shows only 25–35 kt. Southeast of the center, WindSat shows winds of only 15–20 kt while QuikSCAT has 40–50 kt. The QuikSCAT values seem somewhat more reasonable, although still quite low-biased, for an 80-kt hurricane. As in the previous pass, the weaker WindSat winds were located in a region of relatively high CLW (> 1.5 kg m^{-2}).

Overall, this WindSat pass offers mixed results compared to QuikSCAT. The center location is quite good (especially compared to most other WindSat overpasses we examined), and the retrieval shows winds approaching hurricane force east of the center even though these wind speeds are co-located with high cloud water values. However, wind speed values in the rest of the retrieval seem low-biased. The relationship between the retrieved wind speed and CLW remains unclear, with the highest retrieved wind speeds again co-located with the CLW maximum, with lower wind speeds also seen in regions of high CLW.

3. CONCLUSIONS

Forty passes were examined to evaluate the ability of WindSat to estimate TC intensity. These preliminary results suggest that WindSat is unable to reliably retrieve wind speeds above tropical storm strength, leading to a large negative intensity bias for TCs exceeding an intensity of about 50 kt. This is a reduction in capability from what has been seen in QuikSCAT. However, WindSat appears to have some utility for estimating the intensities of weaker TCs, showing less of a high bias than QuikSCAT at the tropical depression stage. Ultimately, further evaluation is necessary to determine the ability of WindSat in estimating TC intensity, but preliminary indications are that it might be more useful than QuikSCAT only for weaker systems.

The inability of WindSat to retrieve winds of hurricane force or higher is likely due in part to its lower resolution (50 km for wind retrievals), as well as the impact of high CLW values typically found in regions of strong winds in TCs. An examination of individual passes further reinforces this relationship between retrieved wind speeds and CLW, since wind speed maxima are often found in regions of high CLW. However, wind speed minima are also seen in areas of high CLW. This issue needs further investigation before operational forecasters can be trained to interpret this data properly.

The quality of TC center fixes from the WindSat wind vector solution was also examined. Only 31 passes showed a well-defined center, and compared to NHC operational best track data, WindSat center fixes had an average error of over 50 nm. This average error was larger than the average center fix error for a similar number of QuikSCAT passes examined from 2003. This evaluation does not take into account the use of other products from the WindSat platform (e.g., 37-GHz imagery) for TC center fixing applications, which is already an established practice at TPC/NHC. However, these results strongly suggest that the wind vector solution from the current WindSat retrieval algorithm is not suitable for TC center fixing.

Other retrieved parameters from WindSat, such as cloud liquid water and rain rate, have potential uses in operational analysis of TC structure. Additionally, these parameters appear to be very useful in diagnosing the effects of rain on wind retrievals from the QuikSCAT scatterometer, which lacks a co-located measure of rain rate. Ultimately, it would seem that a future sensor combining the passive and active characteristics of WindSat and QuikSCAT could improve the quality of ocean vector wind retrievals in TC applications.

Evaluation of WindSat data at TPC will continue into the winter and spring, particularly in high wind events associated with fronts and gap wind events in the Gulf of Tehuantepec south of the Pacific coast of southeastern Mexico.

Forecaster training will be developed based on the results from this evaluation period, both in terms of the utility of the WindSat wind vector solution and the application of other retrieved parameters from WindSat such as cloud water and rain rate.

4. ACKNOWLEDGEMENTS

We thank Dr. Zorana Jelenek of NOAA/NESDIS/STAR for providing details and insight on the WindSat retrieval process.

5. REFERENCES

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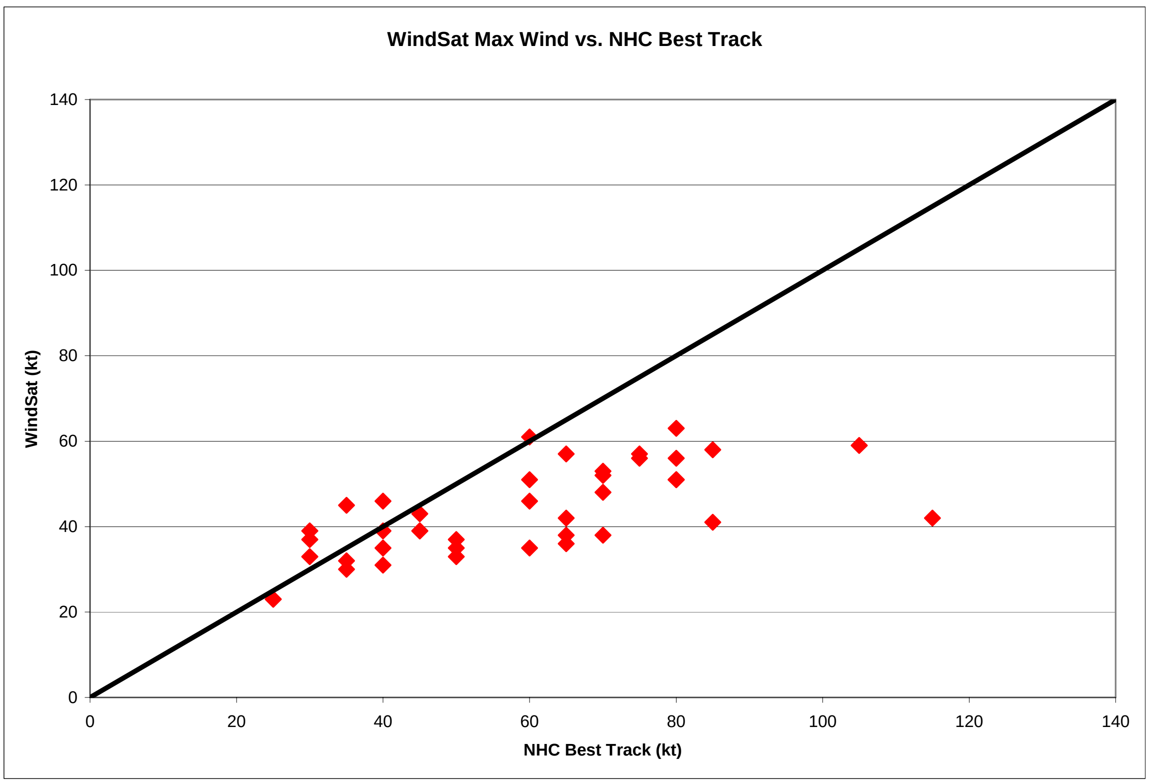

Figure 3. Scatter plot of WindSat maximum retrieved wind speed and NHC operational best track intensity (kt) in 40 passes over 2006 Atlantic and eastern North Pacific tropical cyclones. Solid black line depicts the perfect relationship between WindSat and NHC operational best track.

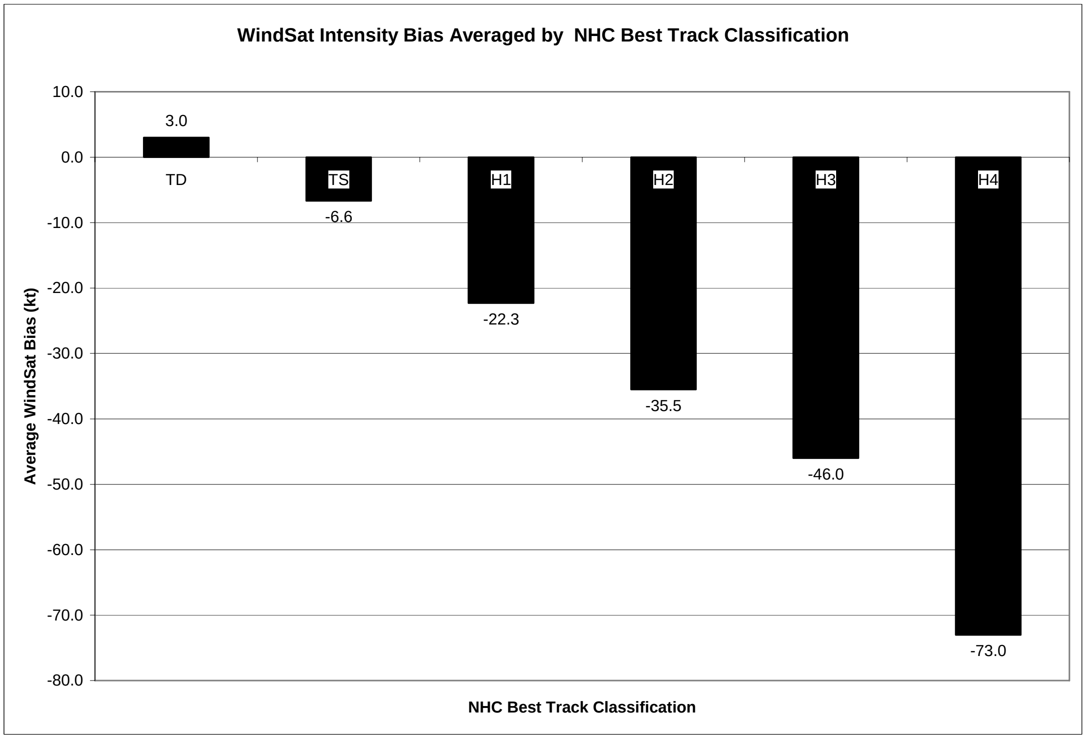

Figure 4. WindSat maximum wind speed bias compared to NHC operational best track intensity (kt) binned by TC intensity category (tropical depression, tropical storm, and hurricanes in each Saffir-Simpson Hurricane Scale category) for 40 passes over 2006 Atlantic and eastern North Pacific tropical cyclones.

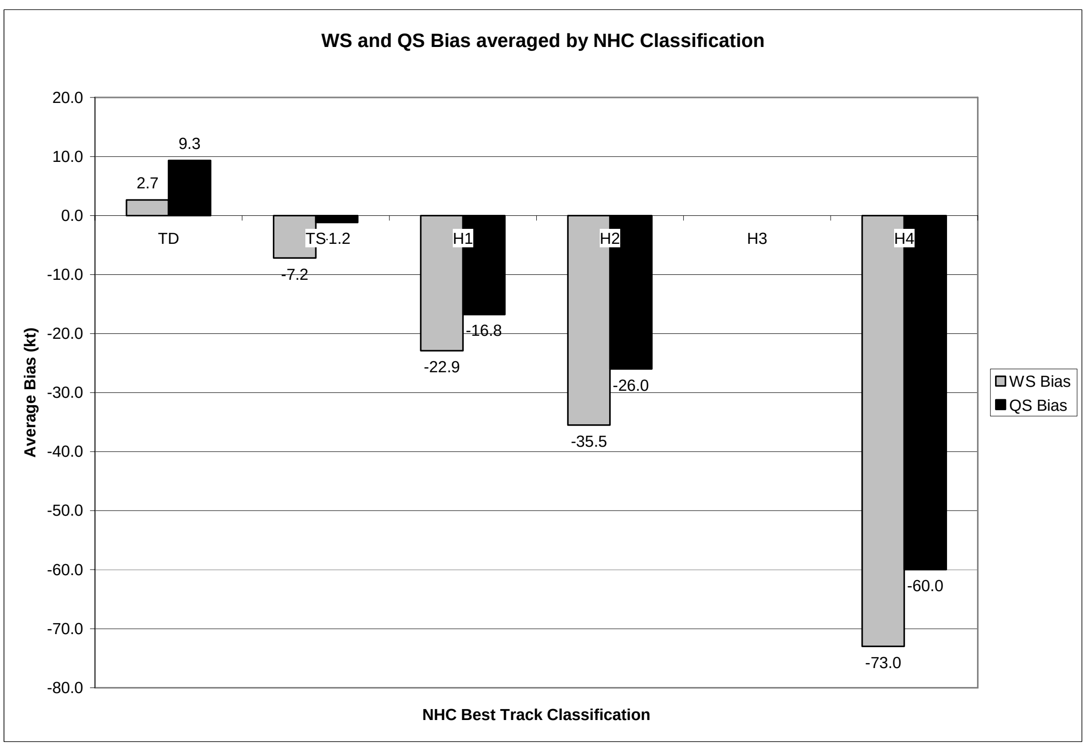

Figure 5. Comparison of the bias (kt) in WindSat and QuikSCAT intensity estimates binned by TC intensity category (tropical depression, tropical storm, and hurricanes in each Saffir-Simpson Hurricane Scale category) in 29 collocated passes over 2006 Atlantic and eastern North Pacific TCs.

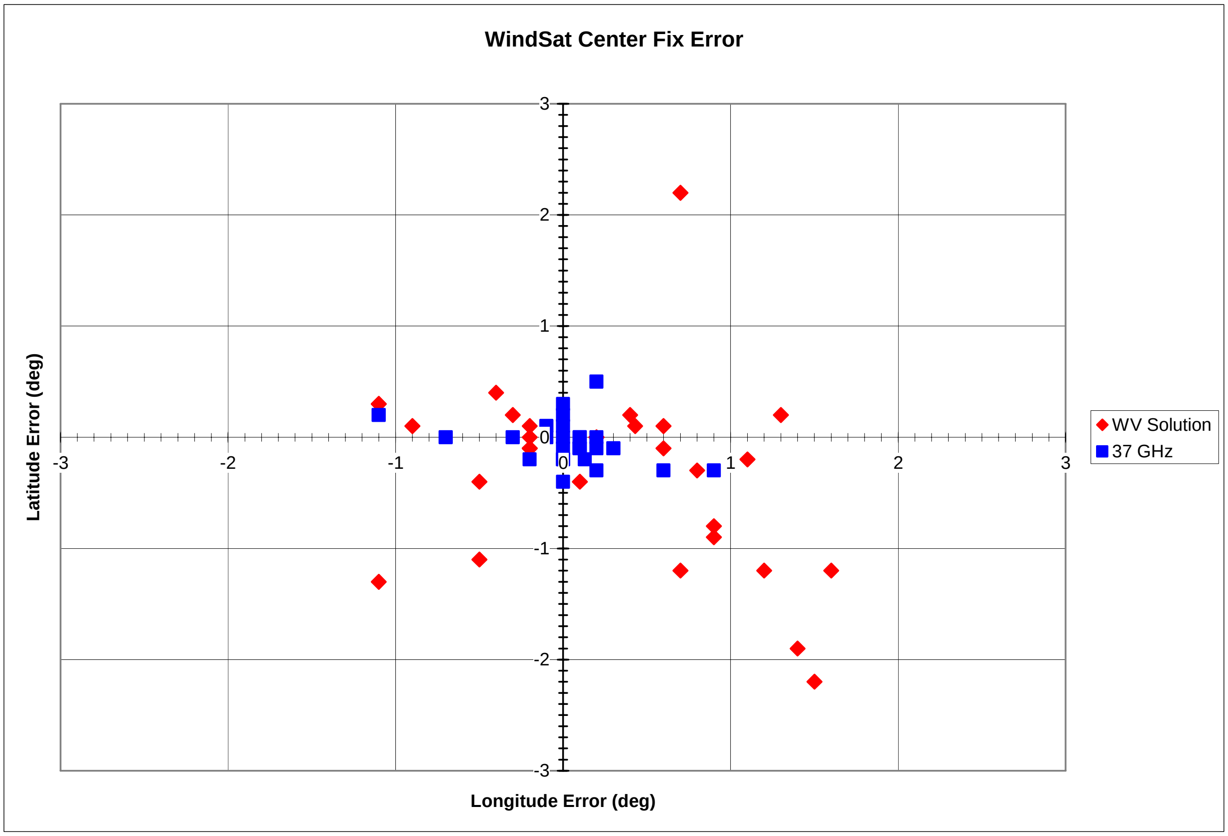

Figure 6. Plot of center fixing error from WindSat wind vector solution (red diamonds) and 37-GHz imagery (blue squares) in 31 passes over 2006 Atlantic and eastern North Pacific TCs. Location along the x-axis (y-axis) indicates the error in longitude (latitude) from the interpolated operational NHC best track position.

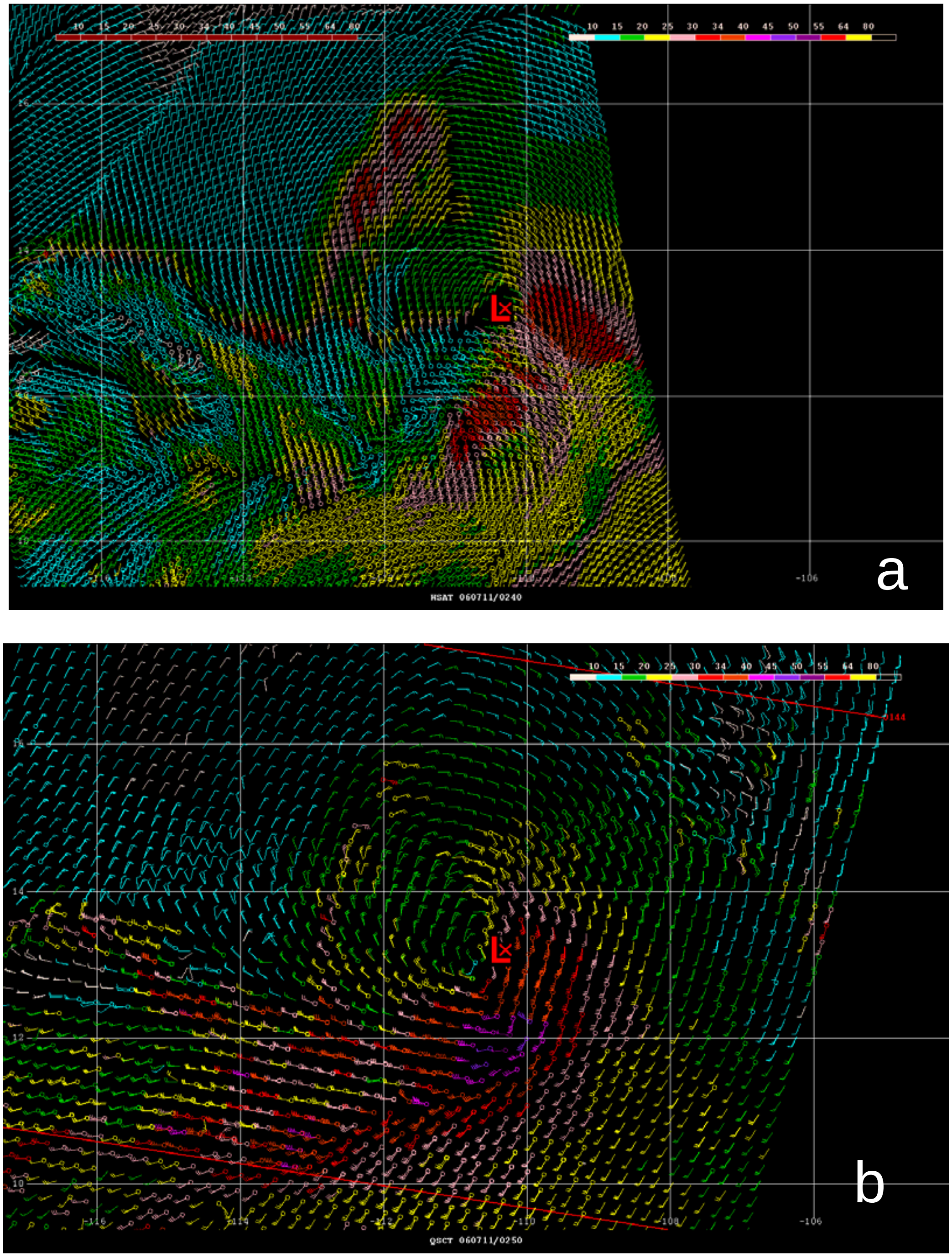

Figure 7. (a) Wind solution from a WindSat pass over Tropical Depression 03-E at 0116 UTC 11 July 2006. Retrieved wind speeds (kt) are indicated by the color bar at the top right. "L" represents the 0000 UTC operational best track position of the depression. (b) as in (a) except from QuikSCAT pass at 0146 UTC.

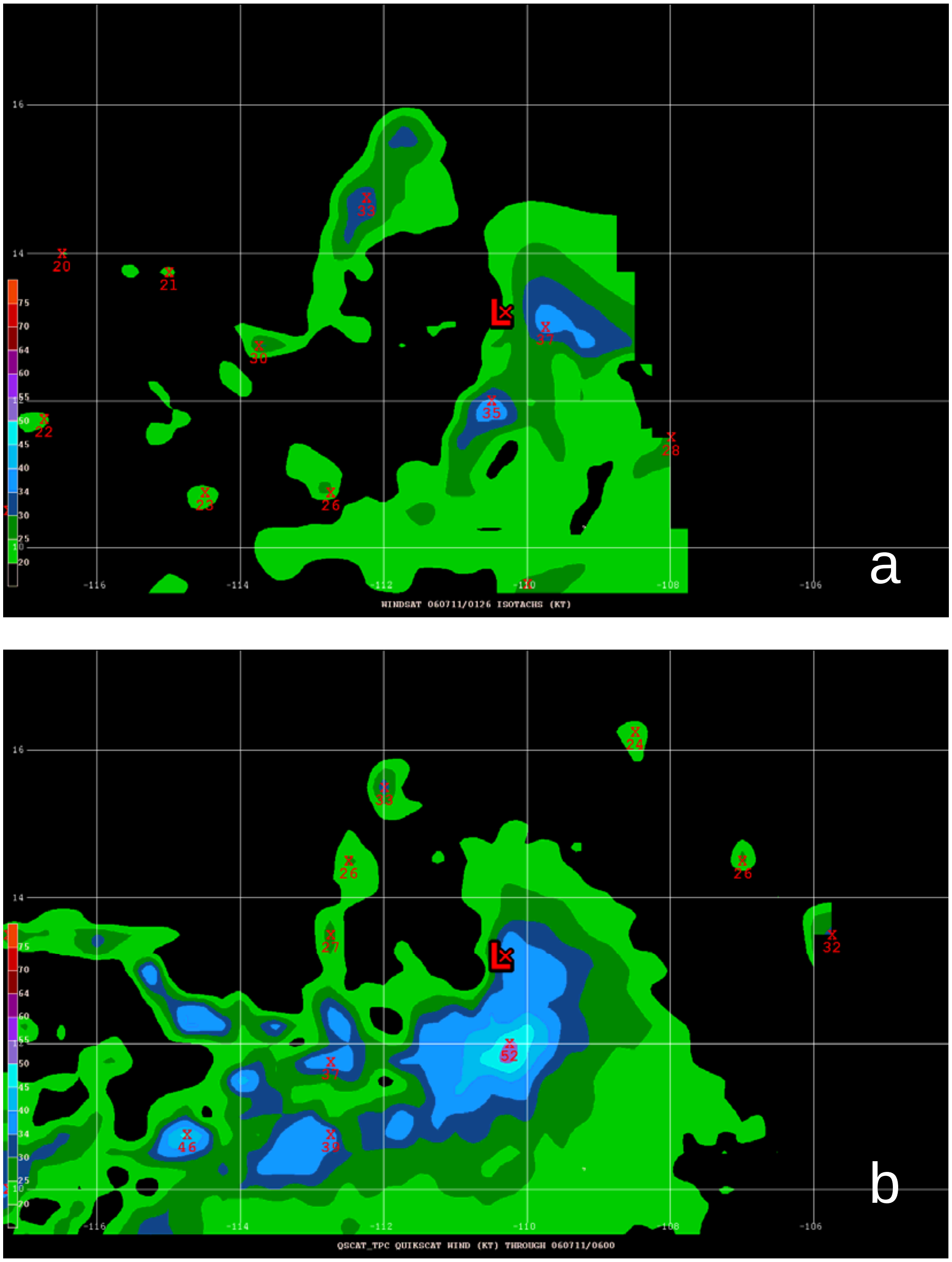

Figure 8. (a) Isotachs (color fill, kt) with grid point wind maxima (red numerals) from WindSat retrieval over Tropical Depression 03-E at 0116 UTC 11 July 2006. (b) as in (a), except from QuikSCAT retrieval at 0146 UTC. “L” represents the 0000 UTC operational NHC best track position of the depression.

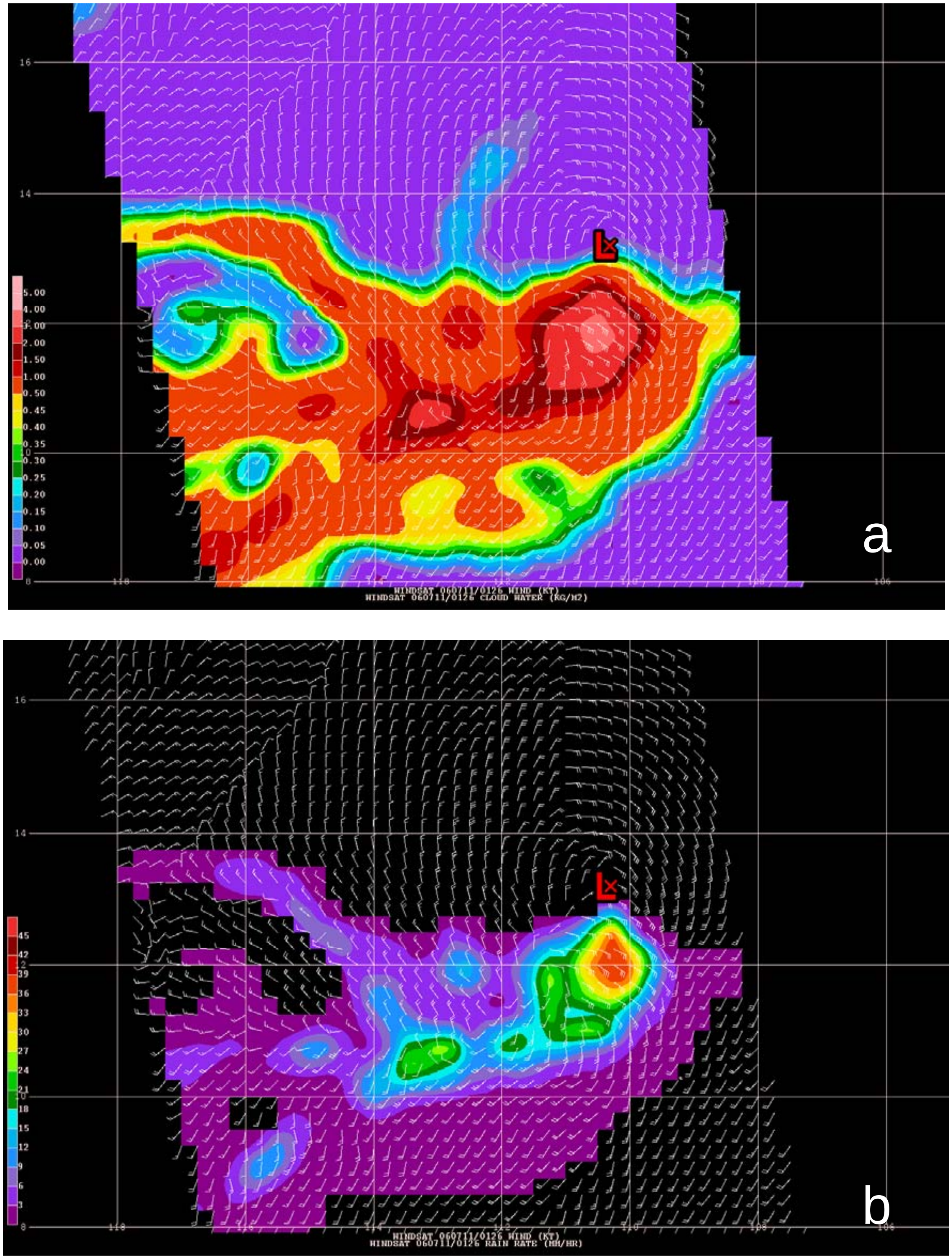

Figure 9. (a) WindSat cloud water retrieval (shaded, kg m^{-2}) and wind (barbs, kt) over Tropical Depression 03-E at 0116 UTC 11 July 2006, (b) as in (a), except rain rate (mm hr^{-1}). "L" represents the 0000 UTC operational NHC best track position of the depression.

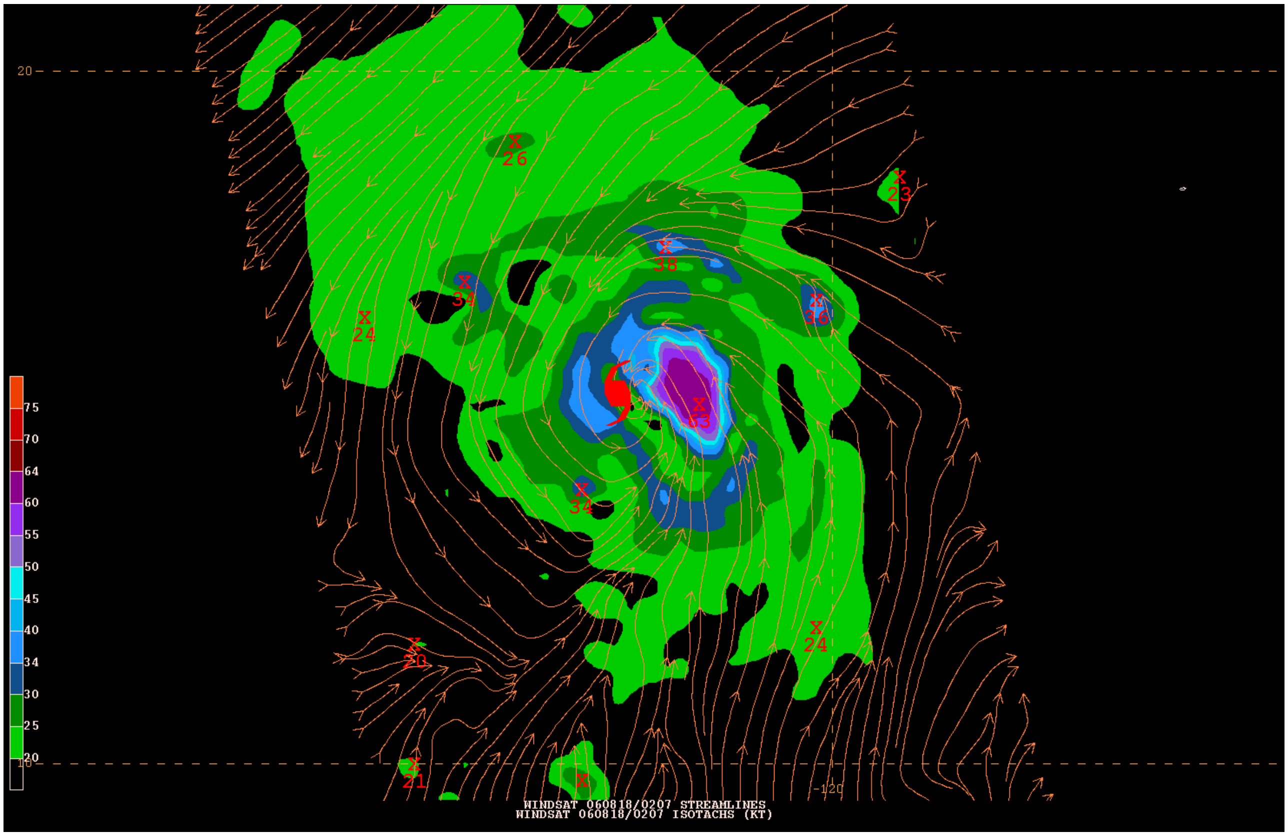

Figure 10. Isotachs (color fill, kt) and streamlines from WindSat pass over Hurricane Hector at 0155 UTC 18 August 2006. The hurricane symbol represents the 0000 UTC NHC best track position of the hurricane.

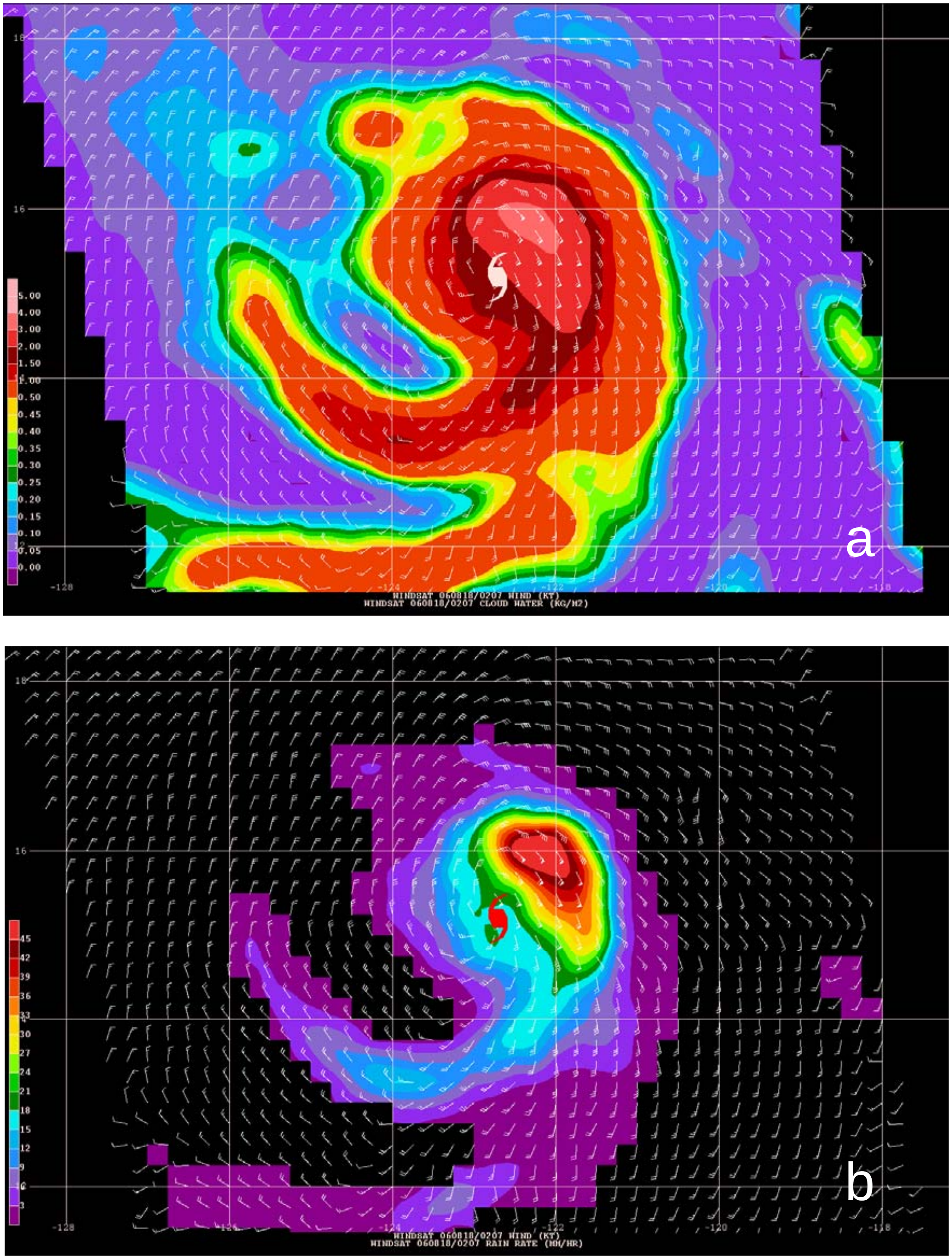

Figure 11. As in Fig. 9, except over Hurricane Hector at 0155 UTC 18 August 2006. The hurricane symbol represents the 0000 UTC operational NHC best track position of Hector.

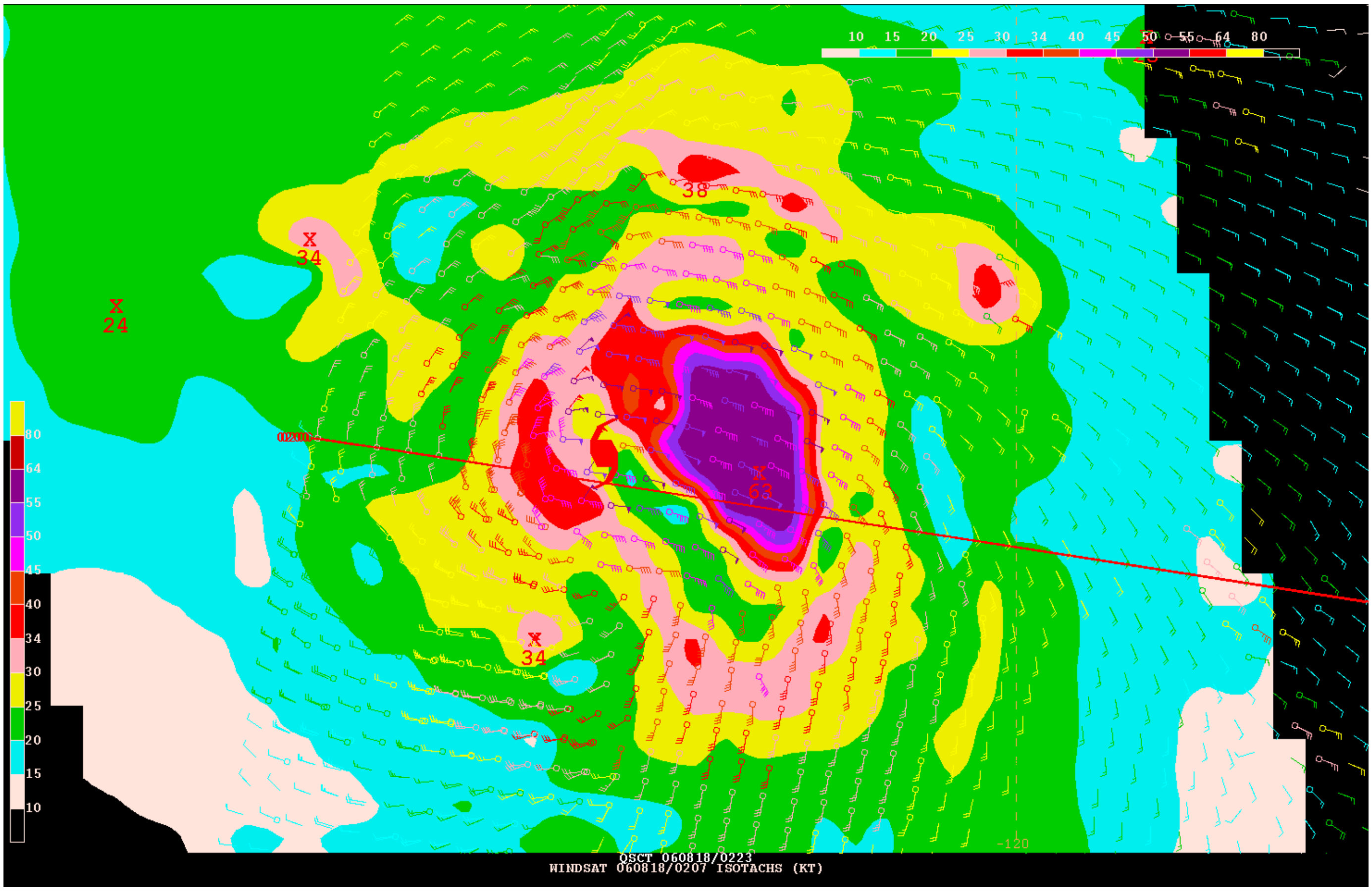

Figure 12. Isotachs (color fill, kt) from WindSat and wind barbs from QuikSCAT passes over Hurricane Hector near 0200 UTC 18 August 2006. Color shading for barbs and isotachs is identical, so that when QuikSCAT and WindSat retrieved wind speeds are in the same range, the QuikSCAT barbs become invisible. The hurricane symbol represents the 0000 UTC operational NHC best track position of Hector.