4D.1 UPGRADES TO THE UW-CIMSS AMSU-BASED TROPICAL CYCLONE INTENSITY ESTIMATION ALGORITHM

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1.0 INTRODUCTION

Since 1998, the Advanced Microwave Sounding Unit (AMSU) flown on board the NOAA KLM series of polar-orbiting satellites has been used to estimate Tropical Cyclone (TC) intensity. The AMSU-A (sounder) senses thermal information in the upper portion of the troposphere using channels in the ~55 GHz Oxygen absorption band. In TCs, warm upper-tropospheric temperature anomalies associated with subsidence in their core regions are directly related to the TC minimum sea level pressure (MSLP). An empirical algorithm developed by the UW-CIMSS TC team has been used since 2000 to estimate TC MSLP using a statistical regression of AMSU-derived brightness temperature anomalies. These estimates have been distributed in near real-time to TC forecast centers worldwide as a demonstration of the new technique. Improvements to the algorithm in 2002 and 2003 have lead to a significant increase in skill.

2.0 CIMSS TC INTENSITY ALGORITHM

AMSU-A channels 7 and 8 measure upper-tropospheric brightness temperatures (Tb) with peak energy emitting from altitudes equivalent to the climatological maximum temperature anomaly associated with TC core regions. The UW-CIMSS algorithm determines the Tb anomalies (core minus environment) for both channels 7 and 8, and then selects the channel that best represents the TC intensity based on linear regression statistics. The regression was developed using primarily reconnaissance observations of MSLP in the Atlantic basin, and ship, buoy and land station observations in other TC basins.

A hydrostatic integration of multiple AMSU tropospheric channel Tbs would be a more desirable way of determining MSLP in a TC core. However, the scattering of upwelling radiation by liquid hydrometeors in the TC eyewall region causes an attenuation of the thermal signal in the lower-tropospheric sensing AMSU channels (primarily channels 5 and 6). Attempts are being made to correct for this attenuation (Wacker, et al. this volume), and a physically-based, TC core temperature profile retrieval may soon be possible.

Due to the scanning geometry of the AMSU-A instrument, the horizontal resolution for each Field of View (FOV) varies from 48km at nadir to about 100 km at the limb. TCs of hurricane intensity or greater typically have eye diameters much less than 100 km. Because of this, many TC warm cores sampled by the AMSU-A instrument are a volumetrically-smoothed representation of the true warming present. In order to address this problem, it is assumed that the warm core is constrained by the eyewall convection, and the radius of maximum winds (RMW) can be used as a proxy for the TC warm core radius. In the development of corrective measures for the algorithm, RMW values for each AMSU estimate were determined using available data consisting of reconnaissance observations, SSM/I and TRMM 85/37 GHz imagery, AMSU-B 89GHz imagery and IR imagery. Storms considered to be sub-sampled, defined as those storms whose warm core diameters (2 x RMW) were smaller than the corresponding AMSU-A FOV resolution, were removed from the 1999-2002 developmental dataset. Brightness temperature anomalies for AMSU channels 7 and 8 for the remaining storms were then regressed against MSLP observations to baseline the approach. The resulting relationship yielded an R^2 of 0.82 for channel 7 and 0.92 for channel 8. TC MSLP estimates for the sub-sampled cases were then initially determined using the lower (deeper) of the two estimates from either channel 7 or 8. These estimates were compared to observed MSLP and the errors computed. A comparison of the errors and the RMW for each estimate showed that the warm core diameter (2 X RMW) relative to the FOV resolution explained 60% of the overall error. For storms that are designated as sub-sampled, the UW-CIMSS algorithm now produces a scan-corrected estimate based on FOV and TC size (RMW).

The developmental dataset used to derive the regression equations used by UW-CIMSS AMSU algorithm primarily consists of storms with average eye sizes. TCs with very large eyes contain few if any scattering hydrometeors within the sensor FOV, especially when the storm position falls near nadir. The TC warm anomalies in these cases are very well-resolved by the AMSU-A sensors. This results in MSLP estimates that are too deep when based on the developmental set of regression equations. To handle these situations, a separate regression equation was developed in 2003 using channel 8 and empirically-determined thresholds for FOV and eye size. This solution is chosen by the algorithm when the eye is large compared to the FOV resolution.

Another correction added in 2003 is an adjustment for Atlantic storms located in an environmental pressure field that is higher or lower than the climatological average. The average outermost closed isobar (OCI) for Atlantic hurricanes is ~1012 hPa. However, storms often

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form in environments significantly different from this value. Since the regression equations are based on absolute MSLP measurements, this offset is not taken into account. Atlantic OCI values from ATCF have now been added to the UW-CIMSS algorithm to adjust the MSLP intensity estimates accordingly. Adjustments for other TC basins are under study.

3.0 ALGORITHM PERFORMANCE

The new logic discussed above was evaluated during the 2003 hurricane season. The RMW parameter was obtained from the ATCF messages provided by the Tropical Prediction Center (TPC) in the Atlantic (ATL) and East Pacific (EPAC), and the Joint Typhoon Warning Center in the Northwest Pacific (NWPAC) and Indian Ocean (IO). Because the ATCF messages are only available every six hours, it was occasionally necessary for CIMSS personnel to manually adjust the RMW used by the algorithm in real-time. Table 1 shows the performance statistics for the upgraded UW-CIMSS TC intensity estimation algorithm in four TC basins. Because the IR-based Dvorak Technique (DT) is the standard by which remotely-sensed TC intensity methods are measured, the error statistics for coincident operational DT estimates are also provided. The DT estimates represent an average of the three US TC analysis/forecast centers providing estimates. As shown in Table 1, the UW-CIMSS AMSU algorithm performance is superior to the DT for this sample. Of the 119 UW-CIMSS AMSU-based estimates sent out in 2003 and validated, 84% had errors < 10 hPa.

Units in hPa	ATL and EPAC		NWPAC and IO	
	AMSU	DVK	AMSU	DVK
Bias	-0.60	0.33	-0.48	-6.02
Mean Error	4.77	6.66	4.99	8.26
RMSE	5.84	8.73	6.70	10.98
N	82	82	37	37

Table 1. Performance of the UW-CIMSS AMSU algorithm for estimates of TC intensity (MSLP). Recon aircraft and ground measurements of MSLP are used for validation. Coincident operational Dvorak estimates (DVK) are included for comparison.

A significant improvement in algorithm skill can be obtained by providing the algorithm with accurate and updated RMW input to account for changes in RMW that may occur between ATCF message times. RMW values for each individual AMSU pass from the 2002-2003 sample of cases were re-determined from available observations and multispectral satellite imagery. The algorithm was rerun using these values, with the results given in Table 2. The performance using ATCF RMW values, which represents the algorithm's skill running in a fully automated mode, is also shown. Improvements in skill are clearly evident when accurate RMW values using augmented information at the time of the AMSU pass are utilized.

Units in hPa	ATCF RMW	AUGMENTED RMW
Bias	-1.42	0.64
Mean Error	5.39	4.29
RMSE	6.95	5.38
N	240	240

Table 2. Comparison of skill for the UW-CIMSS AMSU-based TC intensity estimates (MSLP) using ATCF RMW, and RMW re-determined for each AMSU pass.

4.0 SUMMARY

Upgrades to the UW-CIMSS AMSU TC intensity algorithm over the past three hurricane seasons have lead to significant improvements in algorithm skill. The average absolute error has dropped from ~9 hPa in 2001 to a current value of ~5 hPa, with RMSE decreasing from 13 hPa to ~7 hPa. Precise RMW input is critical for providing the most accurate estimates. Work is needed to develop an objective RMW scheme, however, the RMW is not always well defined, especially in cases of multiple eyewalls. Other problem areas include situations with very small TC eyes of less than 10 km (not many cases for validation) and very large eyes, although recent corrective measures have helped alleviate some of the variance. There also continues to be estimate uncertainty that is not related to actual TC intensity changes but is a result of storm position relative to FOV center axes, variability in actual TC anomaly height, and precipitation contamination. Work is underway to improve the characterization of these situations and apply the necessary corrections. While the AMSU-A observations provide important TC structure/intensity information, they cannot completely describe the TC. An effort is underway at UW-CIMSS to integrate the AMSU with other satellite-based TC intensity methods in order to build upon the strengths of each technique (Velden et al., this volume).

In its present state, the UW-CIMSS AMSU-based TC intensity estimation algorithm outperforms the Dvorak method (on average) used by TC forecast centers. Because of this demonstrated level of skill, the algorithm is being implemented into NWS and military operations.

5.0 REFERENCES

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