7C.1/P1.19 CURRENT STATUS OF THE UW-CIMSS ADVANCED DVORAK TECHNIQUE (ADT)

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1. INTRODUCTION

The Advanced Dvorak Technique (ADT) is a mature algorithm developed at the University of Wisconsin-Madison, Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS) to objectively determine tropical cyclone (TC) intensity utilizing geostationary infrared satellite data (Olander and Velden, 2007). This algorithm was originally founded upon the original subjective Dvorak Technique (DT) (Dvorak, 1984) for determination of the TC current intensity estimate, but has continued to undergo significant modification to advance the algorithm beyond the scope of the original objective technique. Additional research avenues are currently being explored and are planned for the future to integrate new satellite data information and data analysis techniques into the ADT to further improve the accuracy of the algorithm for use in the TC forecasting community.

2. BACKGROUND

The ADT algorithm is currently utilized by several operational TC forecasting centers around the world. It has proven to be an important tool for TC forecasters, especially in regions where in-situ aircraft intensity measurements are not available. It will also be the official hurricane intensity estimation algorithm for the GOES-R program, further demonstrating how the ADT has become engrained in the normal routine for TC intensity analysis.

The algorithm was first developed in the mid-1990's to provide TC forecasters with an objective tool to augment their subjective DT analysis. The first version of the code, the Objective Dvorak Technique (ODT) (Velden et al, 1998), was limited to use with only strong tropical storms and hurricanes and required manual selection of the TC storm position to initiate the intensity estimation process. The next version, the Advanced Objective Dvorak Technique (AODT) (Olander et al, 2002) expanded the algorithm for use over the entire TC lifecycle and implemented an initial, objective storm center determination scheme, which allowed for the algorithm to be completely automated.

The current version, the ADT, still utilizes several aspects of the original DT in the intensity estimation process, however new image interrogation methods and statistical analysis routines have augmented and/or replaced methodologies defined in the DT. In addition, advanced storm center determination methods have been implemented to drastically improve this aspect of the procedure. Continued research avenues to explore to improve the ADT have been identified by the developers as well as ADT users, including several analysis techniques based on the original DT still utilized in the ADT. Additional improvements will also be needed to optimize the code as satellite technologies continue to advance.

3. CURRENT EFFORTS

3.1 Passive Microwave (PMW) information

A well-known limitation of the ADT, and also in the DT, occurs during the strong tropical storm and/or weaker hurricane stage prior to the appearance of an eye feature in the IR imagery. During this period of the storm lifecycle a cirrus shield, known as the Central Dense Overcast (CDO), typically obscures the forming eye feature. The ADT and DT have difficulty determining the intensity of the TC during this period due to the limited amount of information available in the IR imagery (the CDO typically possesses a uniform temperature field which, at best, correlates marginally with actual storm intensity). Thus during this CDO period the ADT intensity estimates typically plateau until the eye feature appears and the ADT intensity estimates increase. Initial efforts to improve the ADT estimates during the CDO period using IR imagery alone have resulted in slight accuracy improvements.

In order to remedy this limitation in the ADT algorithm, an externally-derived TC "eyewall organization score" (EOS) value is derived from 85 Ghz passive microwave imagery and passed into the ADT. The EOS value measures the amount of eyewall convective uniformity, organization, and strength. The EOS value is then correlated to one of two intensity estimate values, 73 or 90 knots, within the ADT. Additional algorithm logic merges the EOS-based intensity estimates into the storm's intensity historic timeline to eliminate unnatural intensity jumps at the onset of use or during transition from one intensity level to another. Once an eye feature appears in the IR imagery, use of the PMW EOS information ceases and the ADT intensity estimates are once again derived from the IR imagery information alone.

Figure 1 illustrates the statistical impact of the PMW EOS information on the ADT. A significant reduction in the bias and absolute error is realized the strong tropical storm/weak hurricane intensity range, as expected, with an especially large impact noted in the 86-105 knot range. Within this wind-speed range the ADT, without the PMW EOS information, will typically plateau in intensity and fall significantly behind the observed TC intensity curve prior to the forthcoming appearance of an eye feature. Once the eye appears in

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the IR imagery, the ADT estimates quickly intensify and catch up to the actual TC intensities. Utilization of the PMW EOS information reduces/eliminates the false intensity plateau and decreases the spread between the ADT estimates and the observed TC intensity at the onset of the eye feature appearance in the IR imagery.

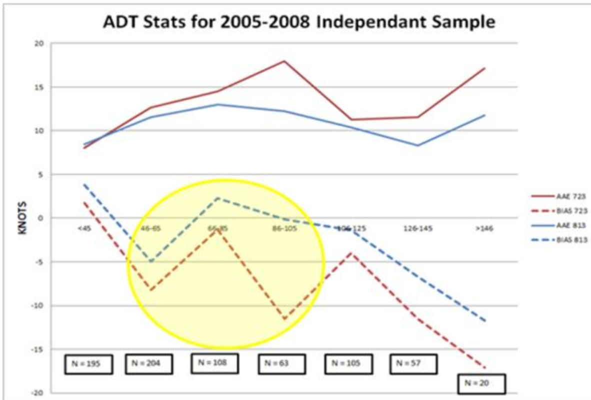

Figure 1: Impact of PMW eye-wall organization score (EOS) values on ADT wind speed intensity estimates versus NHC Best Track wind speed estimates of TC intensity for storms in the North Atlantic between 2005 and 2008.. ADT Version 7.2.3 (red lines) do not include the EOS values while ADT Version 8.1.3 (blue lines) utilize the externally-derived EOS values during CDO situations. Area highlighted in yellow shading indicates TC intensities most strongly affected by EOS utilization. Bias (dashed) and absolute error (solid) are shown. Units are in knots.

3.2 Multi-channel differencing

One of the current areas being investigated for the ADT is the inclusion of a multi-channel differencing product (Olander and Velden, 2009) which attempts to identify and quantify convective vigor around the storm center (within 136km radius from the storm center). This process subtracts the brightness temperature (BT) values from IR and water vapor (WV) imagery to identify regions where the WV BT values are warmer than the corresponding IR BT values. Typically, in clear sky conditions, the WV will be colder than the corresponding IR considering the spectral response functions possessed by the different channels. In opaque cloud regions, where active convection has penetrated the tropopause, the channel differencing relationship can become reversed, due to readmitted absorbed radiation from the upper tropospheric-lower-stratospheric (UTLS) water vapor (Schmetz et al, 1999). Several observational field studies and model simulations have confirmed the existence of UTLS water vapor associated with this convective process in the tropics.

A preliminary assessment of how the utilization of the IR-WV differencing could improve correlations between current ADT intensity estimates and observed TC intensities was presented in Olander and Velden (2009). More recent research is showing an even stronger correlation between IR-WV information and RI at time periods 18-24 prior to the onset of such events. Further research is needed to fine tune the IR-WV signals for integration into the ADT rules schemes, but the initial results are encouraging.

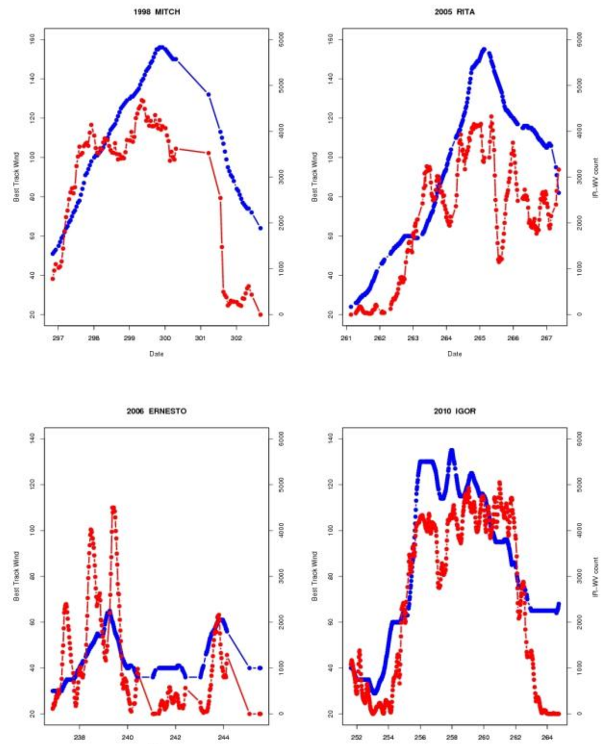

Figure 2: IR-WV pixel count values less than zero (Y-axis/right side; red lines/dots) versus NHC Best Track wind speed (units in knots) estimates (Y-axis/left side; blue lines/dots) for four storms in rapid intensification (RI) study sample. Hurricanes Mitch, Rita and Igor all exceeded the NHC criteria for RI and were correctly identified by the IR-WV RI identification scheme prior to the onset of RI in the NHC Best Track. Hurricane Ernesto (bottom left) was falsely identified as a potential RI storm with the IR-WV methodology, but did not meet the NHC criteria during its lifecycle possibly due to land interaction after reaching its maximum intensity of 65 knots on August 29 (Julian day 239).

Figure 2 presents the IR-WV counts versus the NHC Best Track intensity for four individual storms. It must be noted that several of the storms which were labeled false alarms may have actually been very close to reaching the official wind speed criteria (e.g. Bonnie in 1998) or may have been hindered from reaching RI due to environmental factors such as the TC moving over land, interaction with other TCs, or encountering significant atmospheric shear. Such cases may be inflating the false alarm rate misleadingly since the storm may have undergone an RI event if not for the extenuating circumstance. Further research is needed to closely examine all cases and continue to modify the RI identification criteria; however initial results are quite promising.

3.3 Independent Statistical Verification

Prior to operational implementation of the ADT at the NOAA Satellite Analysis Branch (SAB) in Washington, DC, a year-long, global, independent statistical analysis of the ADT performance was performed comparing ADT objective intensity estimates versus SAB manual DT intensity estimates during the 2010 TC season. In the North Atlantic (21 storms) and East/Central Pacific (12 storms) domains ADT and SAB estimates were compared to NHC Best Track (ADT and SAB estimates within 30 minutes of each other; Best Track estimates only used in North Atlantic if co-located with aircraft reconnaissance within +/-2 hours). Comparisons in the West Pacific, South Pacific, and Indian Ocean (48 storms combined) constituted only a simple difference between the two estimates.

106 cases	Bias	AbsErr	StdDev
SAB	-1.40	7.77	10.23
ADT	2.59	8.22	10.47

Table 2: Statistical comparisons between SAB DT and ADT wind speed intensity estimates versus NHC Best Track wind speed (with corresponding aircraft reconnaissance w/in +/- 2 hours) for the 2010 North Atlantic tropical cyclone season (21 storms total). AbsErr is absolute error and StdDev is standard deviation. Units are in knots.

126 cases	Bias	AbsErr	StdDev
SAB	0.48	5.91	8.56
ADT	-0.38	5.94	7.73

Table 3: Statistical comparisons between SAB DT and ADT wind speed intensity estimates versus NHC Best Track wind speed for the 2010 East/Central Pacific tropical cyclone season (12 storms total). AbsErr is absolute error and StdDev is standard deviation. Units are in knots.

Statistical verifications are presented in Tables 2 and 3 for the Atlantic and East/Central Pacific regions, respectively, and clearly show that the objective ADT estimates are on par with those obtained with the subjective SAB DT estimates. It must be noted that the Atlantic results represent a “worse case” scenario for the ADT since SAB analysts may have access to real-time aircraft reconnaissance reports, which may bias their estimates. Conversely, the East Pacific results are a “best case” scenario for the ADT comparisons since NHC may utilize the real-time ADT estimates when determining the Best Track intensities.

4. FUTURE PLANS

4.1 Pre-depression/depression intensity estimation

The ADT currently relies upon the wind speed obtained from the official TC forecast product to initialize the intensity of the storm at the beginning of the storm’s analysis lifetime. This can quickly lead to inaccuracies in the storm intensity due to the implementation of various DT-based intensity change constraints used within the ADT, especially if the storm is intensifying rapidly. Related to this, the methodologies used within the ADT to derive intensity estimates for weaker systems were based upon the DT methods and need to be re-examined and potentially improved.

In addition, it would be a tremendous aid to TC forecasters if the ADT could help provide objective intensity estimate information on forming TC systems to assist in determining when a system has become a tropical depression and when to issue the first official forecast products for the system in question.

A method has been developed by scientists at the University of North Carolina-Asheville which objectively identifies and tracks tropical convective systems that could develop into tropical depressions (Hennon et al, 2011). Identification and tracking of such systems would not only help TC forecasters with these somewhat tedious tasks, but could greatly aid in the improvement of the “Curved Band” and “Shear” DT-based intensity estimation methods currently employed in the ADT by providing objectively-determined case study samples on which to base research efforts.

The process of importing and implementing the cloud tracking routine within the ADT is currently underway. Testing of the algorithm will occur during the 2012 North Atlantic tropical cyclone season.

4.2 Extratropical transition

On the opposite end of the storm lifecycle spectrum, the transition of a storm from tropical to extratropical has always been an issue with the ADT and DT. No objective methodology exists for determining the intensity of an extratropical system. These systems may not be as intense or destructive as mature TCs, but they can still pose a significant threat to those in its path, so proper objective determination of the intensity of these systems is vital.

Initial studies to assess and quantify the intensity errors obtained by the ADT and DT on such systems have been performed. Avila (1998) examined Hurricane Bonnie and noted the estimates from the DT to be 5-10kt and 10hPa weaker than available observations. Schott et al. (2012) examined a sample of eighteen cases in the North Atlantic between 2005 and 2011 and found the ADT estimates to be on order of one-half Saffer-Simpson Hurricane Wind Scale category too weak for ET storms. It is clear that both the DT and ADT need to be improved for ET TCs. Research and testing of possible ET analysis methods to improve the ADT will potentially begin in the near future.

4.3 McIDAS-V

The ADT currently operates within the Man-computer Interactive Data Analysis System (McIDAS) platform, a software package designed and maintained at the Space Science and Engineering Center (SSEC) in Madison, WI. McIDAS allows for easy display and interrogation for current and historical satellite imagery as well as other meteorological data. The Unix-based version of McIDAS, called McIDAS-X, requires a license with SSEC to download the software package, which has limited the availability of the ADT algorithm to potential users. Special arrangements have been made to port the ADT into non-McIDAS-X satellite display systems, but this route is not always feasible, especially for research scientists and non-US government TC forecasting centers.

In order to make the ADT more easily accessible and globally available, a strategy is in place to integrate the ADT into the next version of McIDAS called McIDAS-V. This version is a freely available, open source software package which operates on any platform which supports JAVA and JAVA 3D, including Linux, Mac OS X, and Windows machines. Initial work to integrate the ADT into McIDAS-V has already begun, with continued efforts to fully integrate the latest version of the ADT into McIDAS-V planned for the near future. This would allow users previously denied access to the ADT to easily obtain and utilize it for their TC research and analysis needs.

5. SUMMARY

The Advanced Dvorak Technique is a mature and widely utilized satellite analysis algorithm for determining the current intensity of global TCs. Much work has been done during the past decade to advance the ADT beyond the scope of the original subjective DT, upon which it was initially based. New research efforts are either being conducted or are planned to make use of new satellite image and platform data information as well as expand the ability of the ADT to derive intensity estimates for tropical systems not currently defined within the scope of the algorithm. Continued improvement beyond the facets listed in this paper will also be explored as new methods and techniques are identified, either through individual or collaborative efforts. The ADT may be a mature algorithm, but it is definitely not static.

6. ACKNOWLEDGMENTS

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7. REFERENCES

Avila, L.A., 1998: Hurricane Bonnie preliminary report. [Available online at http://www.nhc.noaa.gov/1998bonnie.html]

Dvorak, V., 1984: Tropical cyclone intensity analysis using satellite data. NOAA Tech. Rep. NESDIS11, 47pp. [Available from NOAA/NESDIS, 5200 Auth Rd., Washington, DC 20233.]

Hennon, C.C., C.N. Helms, K.R. Knapp, and A.R. Bowen, 2011: An objective algorithm for detecting and tracking tropical cloud clusters: Implications for tropical cyclogenesis prediction, *J. Atmos. Oceanic Technol*., **28**, 1007-1018.

Olander, T.L., C.S. Velden, and M.A. Turk: Development of the Advanced Objective Dvorak Technique (AODT) – Current progress and future directions. Preprints, *25th Conf. on Hurricanes and Tropical Meteorology*, San Diego, CA, Amer. Meteor. Soc., 585-586.

Olander, T.L. and C.S. Velden, 2007: The Advanced Dvorak Technique: Continued development of an objective scheme to estimate tropical cyclone intensity using geostationary infrared satellite imagery. *Wea. Forecasting*, **22**, 287-298.

Olander, T.L. and C.S. Velden, 2009: Tropical cyclone convection and intensity analysis using differenced infrared and water vapor imagery. *Wea. Forecasting*, **24**, 1558-1572.

Schmetz, J., S.A. Tjemkes, M. Gube, and L. van de Berg, 1997: Monitoring deep convection and convective overshooting with METEOSAT, *Adv. Space Res*., **19**, 433-441.

Schott, T., and coauthors, 2012: The Saffir-Simpson hurricane wind scale. [Available online at http://www.nhc.noaa.gov/pdf/sshws.pdf].

Velden, C.S., T.L. Olander, and R.M. Zehr, 1998: Development of an objective scheme to estimate tropical cyclone intensity from digital geostationary satellite infrared imagery. *Wea. Forecasting*, **13**, 172-186.