16.1 PRELIMINARY FIELD REVIEW OF AUTOMATED INTENSITY ESTIMATES

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1. INTRODUCTION

The Joint Typhoon Warning Center (JTWC) Satellite Operations flight and U.S. Air Force Weather Agency Satellite Operations Branch (AFWA/XOGM) have been investigating automated TC intensity estimate skill for western Pacific TCs since 2004 using the Automated Objective Dvorak Technique (AODT) (Olander et al 2002) developed at the Cooperative Institute for Satellite Studies (CIMSS). To date, the AODT intensity estimates have not been used operationally or in real-time intensity estimation due to inconsistent performance of the algorithms at both agencies. An initial skill level of several automated intensity programs is assessed.

JTWC and AFWA/XOGM satellite analysts use the subjective Dvorak Technique (Dvorak 1975, 1984) to determine TC position and intensity from static and animated satellite imagery. TC position is determined by assessing satellite imagery for low-level cloud patterns spiraling toward the TC center. In the more subjective intensity determination process, the satellite analyst must compare current imagery to a pictoral database, assess a climatological intensification trend, evaluate a theoretical development pattern, and apply a complex series of rules outlined by Dvorak (1975, 1984). Since the late 1980s, researchers have been working to develop automated algorithms that utilize geostationary infrared satellite imagery to objectively assess tropical cyclone (TC) intensity (e.g., Zehr 1989, Velden et al 1998, and Olander et al 2002). These algorithms seek to automate the widely used intensity estimation process outlined by the Dvorak (1984), and decrease some of the technique's inherent subjectivity.

In his 1984 paper, Dvorak cites up to an 11-knot difference in intensity among analyses performed by skilled satellite analysts. While 11 knots may seem minimal, for military operations, it can represent the difference between evacuating personnel, aircraft, and ships or securing facilities and resources to ride out a TC in port or at home station, which can have significant monetary impact. Despite the known subjectivity of this process, it has not been updated to take advantage of improvements in satellite spatial resolution or the somewhat recent addition of microwave data.

2. DATA SOURCES & METHODS

JTWC has been evaluating AODT Version 6.3, called TeraScan Dvorak or JTWC AODT, developed by CIMSS and currently used on SeaSpace Corporation display terminals. The JTWC AODT is run independent of the JTWC six-hourly subjective Dvorak technique position and intensity estimate. JTWC satellite analysts modify the TC center position used to calculate the JTWC AODT intensity estimate to match the corresponding JTWC subjective satellite position estimate (or "fix"). The JTWC AODT estimates are included in the remarks section of satellite position estimate bulletins (WMO bulletin header TPPN10 PGTW) transmitted every six hours for tropical disturbances that are classified by JTWC as tropical cyclone formation alerts or meet the USCINCPACINST 3140.x criteria for the issuance of TC warnings. JTWC satellite fixes are archived in the Automated Tropical Cyclone Forecast (ATCF) system (Sampson & Schrader 2000).

AFWA/XOGM has been evaluating Version 6.2 of the AODT using the Satellite Image Display and Analysis System II (SIDAS), Version 6.1. The overall AODT process at AFWA/XOGM is similar to that of JTWC – the analyst manually enters the analyzed TC position into the automated program. The automated intensity estimates from AFWA/XOGM are included in the remarks section of WMO bulletin TPPN10 KGWC disseminated at six-hourly intervals. As with the TPPN10 PGTW bulletins, the TPPN10 KGWC bulletins are archived in the ATCF at JTWC.

607 AODT intensity estimates were collected for both JTWC AODT and AFWA/XOGM for 23 Western North Pacific TCs during the 2005 season. These estimates were further filtered for applicability, with those over land or identified as unavailable by the automated program regarded as non-applicable. Of the available JTWC AODT estimates 442 were determined applicable for comparison, while 547 AFWA/XOGM AODT fixes were applicable.

Also under evaluation at JTWC is the Advanced Dvorak Technique (ADT) (Olander & Velden 2005) developed by CIMSS. In the ADT, TC position and intensity are both determined objectively by the program. CIMSS posted the results of each ADT cycle online; JTWC retrieved and archived 607 ADT intensity estimates on 23 TCs. 478 estimates were identified as applicable for further assessment.

1,821 intensity estimates determined objectively and semi-objectively (manually entered TC position) by three computer algorithms and subjectively by the satellite analysts at JTWC are assessed in this study. The skill of these methods is assessed using a calculated accuracy percentage. Since JTWC and AFWA/XOGM report intensity in 0.5 Dvorak T-number increments, an automated intensity estimate was considered accurate if it fell within 0.5 Dvorak T-number of the JTWC subjective intensity estimate. The initial skill required for consideration in

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the operational intensity determination process at JTWC is 50%. Methods that meet this initial threshold are further examined for performance characteristics.

Data were initially examined by comparison with the coincident JTWC subjective Dvorak T-number, but to account for small sample sizes, were grouped based on TC intensity category, as listed in Table 1. An accuracy percentage representing the number of accurate cases compared to applicable cases was derived for each TC intensity category. Data were separately assessed for accuracy as a function of position confidence number (PCN) and satellite fix type.

3. RESULTS

Intensity estimates from each automated method were assessed and compared to coincident JTWC subjective Dvorak technique satellite intensity analyses. Data were assessed for accuracy within each sub-analysis. These calculated accuracy percentages are used to assess the skill compared to the JTWC subjective analysis.

CI	Max Wind (kt)	Category
≤ 1.0	25 G 35	Tropical Disturbance
1.5	25 G 35	Tropical Depression (TD)
2.0	30 G 40	
2.5	35 G 45	Tropical Storm (TS)
3.0	45 G 55	
3.5	55 G 70	
4.0	65 G 80	Typhoon (TY)
4.5	77 G 90	
5.0	90 G 110	
5.5	102 G 125	
6.0	115 G 140	
6.5	127 G 150	Super Typhoon (STY)
7.0	140 G 170	
7.5	155 G 190	
8.0	170 G 205	

Table 1. Dvorak Current Intensity (CI) chart, maximum sustained wind speed and gusts reported in knots (1-minute average), and intensity category as used by JTWC.

3.1. JTWC AODT

168 of 442 JTWC AODT intensity estimates fell within 0.5 T-number of the corresponding JTWC subjective estimate, for an overall accuracy rate of 38.0%. The standard deviation of all accurate estimates was 0.3 T-number, while the standard deviation of the remaining estimates was 1.4 T-number.

Data from the intensity category analysis of JTWC AODT are displayed in column A of Table 2. As expected, the accuracy rate increases with increasing intensity. While the overall accuracy percentage of this program based on TC intensity category was only 36.4%, the JTWC AODT exceeded the 50% threshold for TCs classified at typhoon (TY) intensity or greater.

Analysis of the JTWC AODT estimates as a function of PCN yielded 71.4%, 44.1%, and 23.3% for PCN 1, 3, and 5, respectively (bold numbers in column A of Table 3). This is consistent with the expectation that higher accuracy exists in conjunction with increased position confidence. Analysis of the data as a function of satellite fix type is also displayed in column A of Table 3. The highest accuracy percentages were calculated for large and irregular eye types (87.0% and 69.2%, respectively).

INTENSITY CATEGORY	A	B	C
	JTWC AODT	AFWA/XOGM AODT	ADT
TD	0	30.4	28.2
TS	16.7	19.6	50.5
TY	62.2	42.5	65.7
STY	66.7	80.8	69.7
Average	36.4	43.3	53.5

Table 2. Accuracy percentage based on TC intensity category for JTWC AODT (column A), AFWA/XOGM AODT (column B) and ADT (column C).

3.2. AFWA/XOGM AODT

191 of 547 AFWA/XOGM AODT intensity estimates fell within 0.5 T-number, for an overall accuracy rate of 34.9%. The standard deviation of all accurate estimates was 0.3 T-number, while the standard deviation of the remaining estimates was 1.4 T-number.

Data from the intensity category analysis of the AFWA/XOGM AODT are included in column B of Table 3. The lower accuracy rate for tropical storms (TS) compared to tropical depressions (TD) was unexpected. As a function of intensity category (column B of Table 3), AFWA/XOGM AODT achieved an overall accuracy percentage of 43.3%, but exceeded the 50% threshold only for TCs reaching super typhoon (STY) intensity.

Analysis of the AFWA/XOGM AODT accuracy as a function of PCN revealed 62.2%, 35.2%, and 27.3% PCN 1, 3 and 5, respectively (bold numbers in column B of Table 4), was again consistent with the expectation that higher accuracy is associated with lower PCN values. Analysis of accuracy as a function of fix type, also displayed in column B of Table 4, yielded the highest accuracy for small and large eye types (67% and 68%, respectively).

3.3. ADT

The ADT estimated 267 of 478 (55.9%) cases to within 0.5 T-number of the JTWC subjective estimate. As with the JTWC AODT and AFWA/XOGM AODT, the standard deviation of these 267 accurate estimates was 0.3 T-number. The standard deviation for the 211 remaining estimates

PCN	Satellite Fix Type	JTWC AODT	AFWA/XOGM AODT	ADT
1	**Eye**	**71.4**	**62.2**	**76.3**
	- small eye	60.6	66.7	68.8
3	**Well Defined**	**44.1**	**35.2**	**51.1**
	- embedded center	64.3	52.4	68.4
	- small or large CDO	57.0	20.0	37.5
	- tightly curved band or banding eye	48.3	27.7	53.3
	- ragged eye	45.7	47.3	52.8
	- fully exposed LLCC	22.2	35.7	40.0
5	**Poorly Defined**	**23.3**	**27.3**	**50.4**
	- CCC	100	0	100
	- large eye	87.0	67.7	86.2
	- irregular eye	69.2	45.2	82.8
	- spiral banding systems	23.5	34.8	51.4
	- partially exposed LLCC	15.7	17.6	44.3
	- animation or extrapolation	13.0	16.0	45.5

Table 3. Accuracy percentages based on position confidence number (bold values) and individual satellite fix types for JTWC AODT (column A), AFWA/XOGM AODT (column B), and ADT (column C). Analysis by PCN was conducted independently of the analysis by satellite fix type.

was 1.1 T-number, a small but marked improvement over both JTWC AODT and AFWA/XOGM AODT.

The data displayed in column C of Table 3 from the intensity category analysis of the ADT show that accuracy percentage improved with increasing intensity. Overall performance for this program was 53.5%, and the 50% skill level was exceeded for TCs classified as tropical storm (TS) or greater.

In the PCN analysis of ADT, lower PCN TCs were more accurately assessed than those with higher PCN values. Accuracy to within 0.5 Dvorak T-number for PCN 1 storms was 76.3%, 51.1% for PCN 3 storms, and 50.4% for PCN 5 storms (bold numbers in column C of Table 4). Overall, accuracy rates for the ADT, even for poorly defined TCs, were higher than those observed for JTWC AODT or AFWA/XOGM AODT. Accuracy measured as a function of satellite fix type, displayed in column C of Table 4, yielded the highest results for large eye (86%), irregular eye (83%) fix types.

4. SUMMARY & DISCUSSION

The overall performance of the automated intensity analyses as indicated by accuracy percentage shows consistent improvement from the AODT to the ADT. However, automated intensity analyses have yet to surpass the consistent performance of the subjective technique.

A breakdown of automated intensity estimates by intensity category (Table 2) revealed the most accurate percentages for the strongest TCs (averaging 72.4% for STY and 56.8% for TY). The lowest accuracy percentage was calculated for the weakest storms (19.5% on average for tropical depressions), which are also the most challenging to analyze using the subjective method. These results correspond well with the higher accuracy percentage observed in thus study for lower PCN, and lower accuracy for higher PCN.

Analysis of the automated position estimates showed the greatest overall accuracy for PCN 1 TCs (70% average), and decreasing accuracy with increasing PCN, as expected (Table 3). The accuracy percentage of the PCN 3 classification group averaged 43.5%. PCN 3 classification indicates a decrease in confidence associated with determining the LLCC in a more complex or less clear-cut cloud pattern. The lowest accuracy percentages were found within the PCN 5 classification (33.7% average). However, the ADT showed considerable improvement over the AODT programs for the satellite fix types associated with this PCN (Table 3), specifically spiral banding systems and partially exposed LLCCs. The lower confidence implied by this classification is warranted given the complex, diffuse, or poorly defined cloud patterns under consideration.

The size of the 2005 western North Pacific TC data set limited analysis opportunities in this study. Incorporation of additional data sets will improve analysis capability, and potentially yield valuable results regarding the performance characteristics of the automated position and intensity determination tools.

Position fixing cited in this study was accomplished by both subjective and objective means. While the objective means are considered to be less prone to error, subjective analysis can improve position accuracy in situations where automated tropical cyclone position analysis is shown to be less reliable, i.e., for weak and poorly defined TCs. Microwave-based intensity estimation techniques represent an independent and unconstrained assessment of intensity. While these data sources were not tested in this study, they have the potential to add value to the intensity determination process.

Based on the analysis above and previously established 50% skill level, the ADT is considered viable for consideration in the intensity determination process at JTWC. A single robust tool that functions independent of subjective methods and draws on the strengths of methods like the ADT is highly desirable for fusion into TC operations. Further investigation of intensity estimates for weak, poorly defined and sheared systems is encouraged. Incorporation of this research into a full-spectrum automated intensity determination tool and continued improvements in the accuracy of automated intensity estimates will further bolster the usage of such at product at JTWC.

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