The AiDT – Development and Implementation of a Machine Learning Model Using Satellite-Derived Advanced Dvorak Technique (ADT)-Retrieved Features to Estimate Tropical Cyclone Intensity

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Motivation

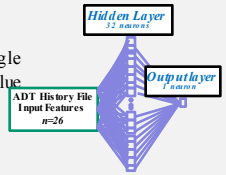
- **Machine Learning (ML) models** are rapidly becoming available for weather applications. While showing great promise, ML models can be time consuming and computationally expensive when **directly interrogating/analyzing big datasets such as satellite imagery,** i.e. great care must be given to make sure the satellite data is prepared and homogeneous.
- The **Advanced Dvorak Technique (ADT) objectively and efficiently interrogates geostationary satellite IR imagery** to derive intensity estimates (maximum sustained windspeed (MSW)) for targeted Tropical Cyclones (TC), globally, and accounts for satellite data and ocean basin differences through over two decades of algorithm development and refinement. The ADT:
  - Operates in real time and is familiar to operational TC analysts/forecasters
  - Uses IR Window imagery (~10.7 μm) at 30 minute resolution
  - Stores analysis parameters (features) in storm history files
- **Can a ML model be developed to interrogate already-analyzed ADT parameters to improve the performance, especially in situations where the ADT can struggle?** ***THE ANSWER IS YES!*** ***Introducing the AiDT***

The globally-defined AiDT Model

- Regression-based loss function
- 26 input ADT History File Features *(chart)*
- One Hidden (Dense) layer with 32 neurons
- One Output Layer neuron representing a single continuous TC intensity estimate (MSW) value

AiDT Features *(ADT history file parameters)*

RawT# (TC intensity metric)	Sin of Longitude	Cloud Symmetry
Adjusted Raw T#	Cos of Longitude	Curved Band Value
Final T#	Viewing Angle	Curved Band Amount
Current Intensity #	Eye FFT	CW Temp. Distance
Eye Temperature	Cloud FFT	PMW Eye Score
Cloud Temperature	Eye Scene ID value	Extratropical Flag
CW Temp. Diff.	Cloud Scene ID value	Subtropical Flag
Latitude	Eye StdDev	Eye Size (2/eye size)
	Shear Distance	CDO Size



CW – "Cold-as-Warmest-Below-TC-Core" PMW "Passive Microwave"
CDO – "Central Dense Overcast" FFT – "Fast Fourier Transform"

- ***Investigation of Machine Learning Using Satellite-Based Advanced Dvorak Technique Analysis Parameters to Estimate Tropical Cyclone Intensity 2021, Weather and Forecasting*** *https://doi.org/10.1175/WAF-D-20-0234.1*

AiDT performance comparisons with other algorithms/models

- **AiDT is on-par or superior to more complex and time-consuming satellite-based ML methods and techniques currently available to estimate TC intensity**

Technique	Method	Data Type	Inputs	Region	Dataset Years	MSW RMSE (kt)
Dvorak *(Dvorak, 1975, 1984)*	Empirical	Geo	IR, VIS	Global	1970s-80s	**10 - 15**
SATCON *(Velden and Hawkins, 2010)*	Statistical Ensemble	Geo Leo	Intensity estimates based on various other algorithms	Global	2006-2014	**9.0**
ADT *(Olander and Velden, 2019)*	Statistical Empirical	Geo Leo	IR (10.7 um) PMW (eye score)	Global	2017	**10.98**
DeepMicroNet *(Wimmers et al., 2019)*	CNN	Leo	PMW (37 GHz, 85-92 GHz)	Global	2007, 2012	**9.6 - 14.3**
CNN-TC *(Chen et al., 2019)*	CNN	Geo Leo	IR (10.7 um) WV (6.7 um) PMW (Rain Rate)	Global	2017	**8.39**
Pradhan model *(Pradhan et al., 2018)*	CNN	Geo	IR	Global	1999-2014	**10.18**
AiDT	ANN	Geo Leo	IR (10.7 um) features and PMW (eye score) analyzed by the ADT	Global	2017, 2018	**7.70 - 8.23**

CNN – Convolutional Neural Network; ANN – Artificial Neural Network

AiDT Model Performance

- A statistical analysis of AiDT intensity estimates on test cases independent from the development sample demonstrates a **notable reduction in the ADT MSW root mean squared error (RMSE).**
- Table below shows statistical comparisons between the AiDT model and parent ADT algorithm MSW estimates for each specific TC basin and combined global "All Basins" set for the independent validation test (TC cases in 2019-2021).
  - ***ADT – Advanced Dvorak Technique – Version 9.0***
  - ***AiDT– AiDT*** *(3-hour time-weighted average)*
  - *+/- Bias equals MSW over/underestimate vs. NHC/JTWC Best Track values (verifying dataset)*

	Atlantic			East Pacific			West Pacific		
MSW (kts)	Bias	MAE	RMSE	Bias	MAE	RMSE	Bias	MAE	RMSE
ADT	-2.79	9.03	**11.91**	-1.04	7.03	**9.20**	-1.73	7.93	**10.83**
AiDT	-1.63	7.65	**9.89**	-1.18	5.51	**7.22**	-1.48	6.57	**8.74**
# comparisons	13258	13258	13258	9774	9774	9774	16098	16098	16098

	South Pacific			North Indian			All Basins		
MSW (kts)	Bias	MAE	RMSE	Bias	MAE	RMSE	Bias	MAE	RMSE
ADT	-0.68	7.91	**10.29**	-1.22	8.18	**10.79**	-1.55	8.04	**10.69**
AiDT	-1.94	6.95	**8.91**	-1.11	7.37	**10.12**	-1.71	6.78	**8.90**
# comparisons	15744	15744	15744	2743	2743	2743	57617	57617	57617

- ***The AiDT results in a significant improvement of 14-22% in RMSE over the parent ADT in four of the five TC basins and 17% overall in the combined global data set***

AiDT impact by ADT Scene Type

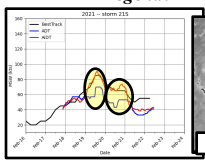
- As shown in the table below, the AiDT reduces the ADT MSW estimate errors most for ADT **Curved Band** and **Shear** scene types. *These scene types are most common in formation and dissipation stages of TC development and are the least studied and reliable scene types in the ADT algorithm.*
- *+/- Bias: AiDT/ADT MSW over/underestimate versus Best Track values (verification)*

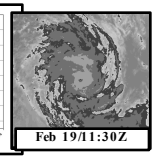
ADT TC Scene Type	Sample Size	ADT MSW (kts)			AiDT MSW (kts)		
		Bias	MAE	RMSE	Bias	MAE	RMSE
Eye	2590	0.10	8.66	**11.03**	-1.43	6.55	**8.30**
CDO	7246	2.20	8.92	**11.18**	-0.67	6.53	**8.30**
Curved Band	5670	-1.50	8.54	**11.17**	0.57	5.75	**7.27**
Shear	3166	-3.21	7.36	**10.12**	-0.41	4.95	**6.35**

Storm Examples

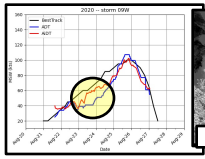
- Below are select TC time series MSW comparisons to illustrate AiDT impact
- **Note impact of AiDT during highlighted periods of storm history**

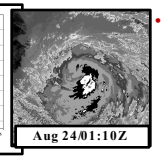
Legend: ***ADT*** ***AiDT*** ***NHC/JTWC Best Track***



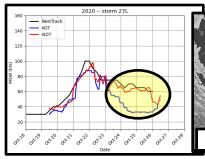


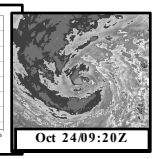
- **Eye Scenes**
  - ADT classified a brief Eye for three hours with CDO scene types afterwards. AiDT was able to better diagnose the eye/warm spot and increase the intensity.



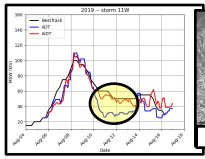


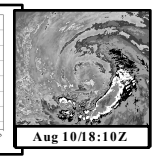
- **Convective Dense Overcast Scenes**
  - AiDT improved intensity estimates during ADT classified CDO scene type period during TC formation period prior to appearance of an eye





- **Curved Band Scenes**
  - During extended ADT Curved Band scene type period, AiDT drastically modified ADT intensity estimates during TC dissipation phase





- **Shear Scenes**
  - AiDT increased ADT intensity estimates during period of ADT mis-classified Shear scene types *(large displacement of convection from TC center interpreted as Shear by ADT)*

Summary

- **The ML element of the AiDT significantly improves ADT TC intensity estimates, especially in certain TC stages where the ADT can struggle.**
- **The AiDT is currently being run in a real-time demo mode at UW-CIMSS for TC forecast center evaluation and possible future operational transition.**
  https://tropic.ssec.wisc.edu/real-time/adt/AiDT/
- **Contact: Tim Olander <timo@ssec.wisc.edu>**