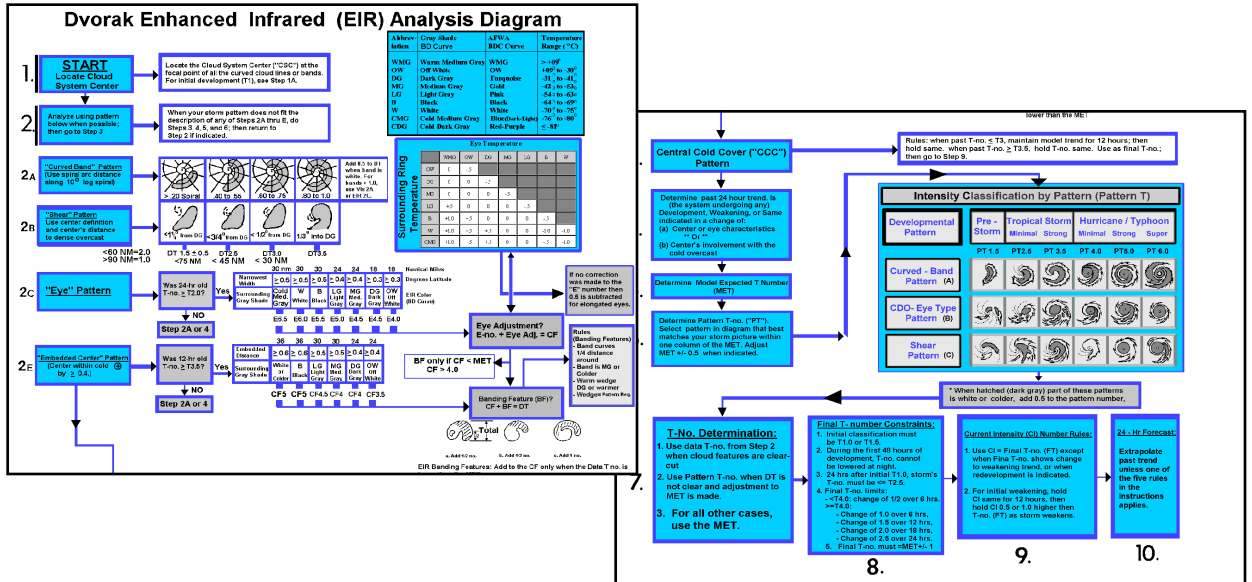
Advanced Dvorak Technique (ADT)

Overview

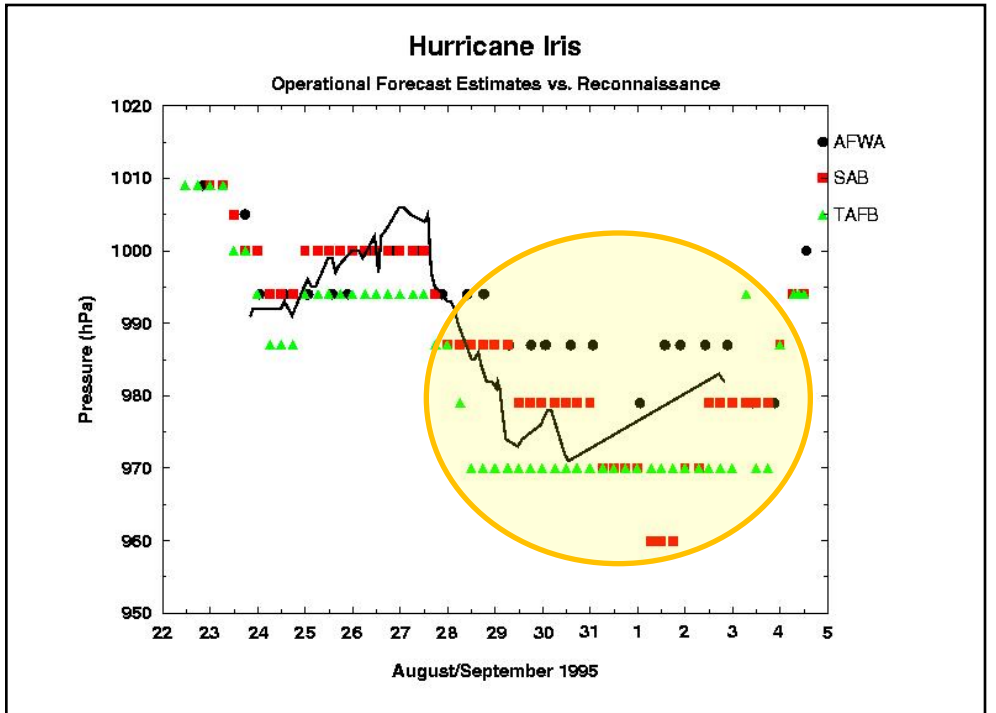
Background:

- The Advanced Dvorak Technique (ADT) is a mature, objective algorithm used by Operational Tropical Forecast Centers worldwide to estimate tropical cyclone intensity using geostationary infrared satellite imagery.
- The first version of the ADT was released in 1998 and has been used operationally since that time.



Motivation:

- Based on the Dvorak Technique (DT) but advanced beyond scope of original methodology.
- The ADT was developed to remove the inherent subjectivity of the DT due to user interpretation and experience.



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Overview

Highlights:

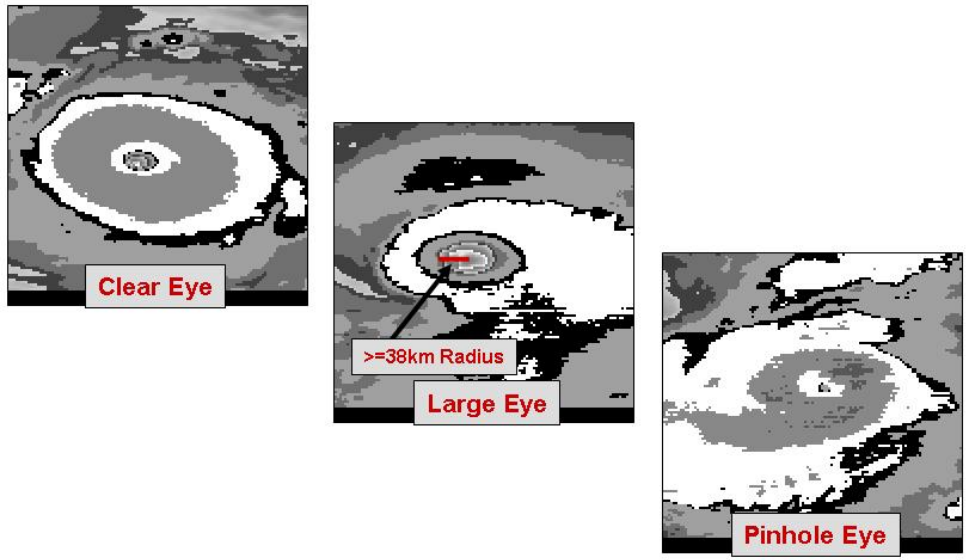
- **NHC, CPHC, and JTWC routinely cite the ADT in public products when determining the intensity of a current storm.**
- **NHC explicitly used ADT to increase the maximum wind speed for Hurricane Michael (2018) from 135 to 140kts, making it a Category 5 hurricane.**
- **ADT used operationally at NOAA/NESDIS since 2007. Other customers use real-time ADT estimates from CIMSS TC webpage.**
- **ADT used in several important climatological studies:**
  - **Kossin, Olander, and Knapp (2013):** Trend analysis with a new global record of tropical cyclone intensity, ***J. Climate,* 26**, 9960-9976
  - **Kossin, Knapp, Olander, and Velden (2020):** Global increase in major tropical cyclone exceedance probability over the past four decades, ***Proc. Nat. Acad. Sci.,* 117**, 11975-11980

Advanced Dvorak Technique (ADT)

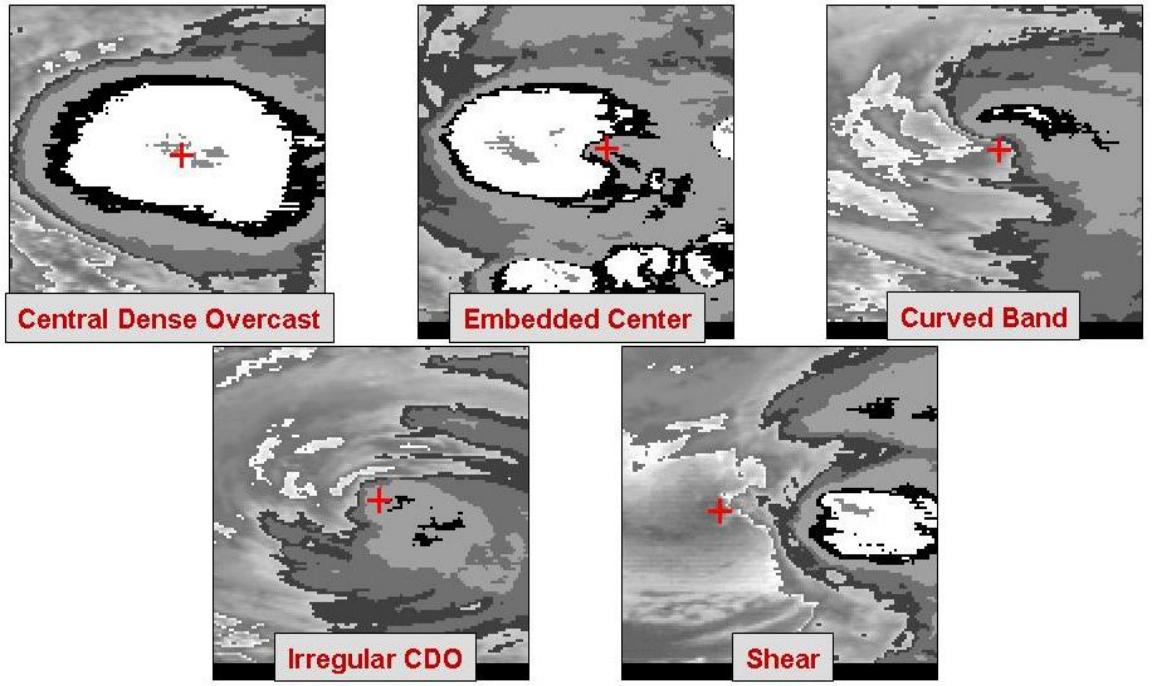
Processing Overview

- ADT will derive intensity estimate based on objectively determined scene type (Raw T#)
- Will apply DT constraint rules to limit strengthening/weakening over time (Final T#)
- Applies 3-hour time weighted averaging scheme to smooth out fluctuations
- Final DT weakening rules applied as storm weakens (CI#)

Examples of ADT Eye Region Scene Types

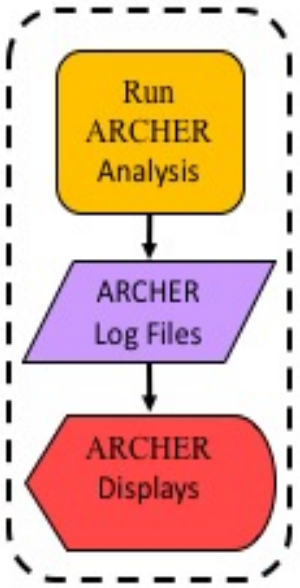


Examples of ADT Cloud Region Scene Types

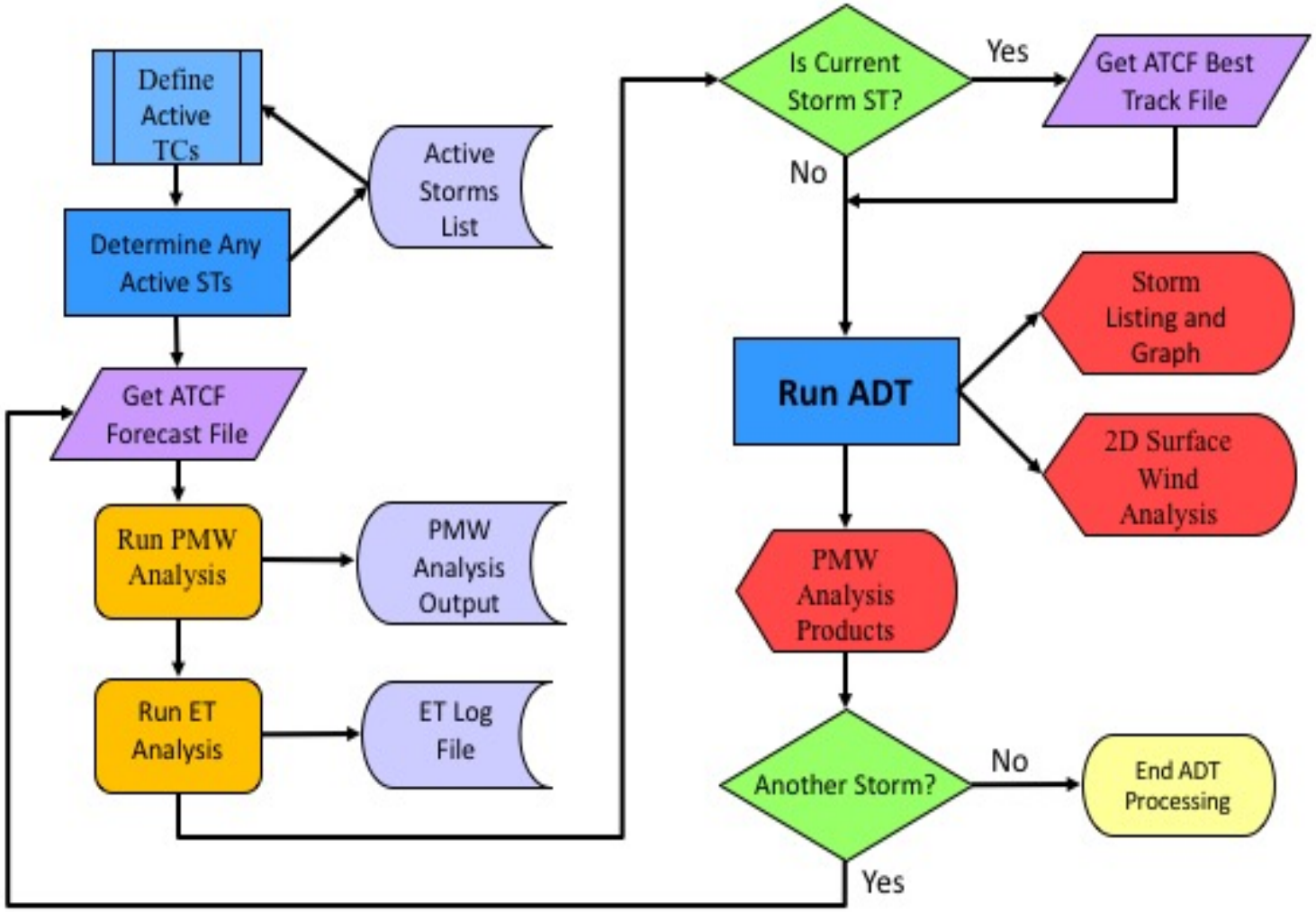


Advanced Dvorak Technique (ADT)

Processing Overview



ARCHER provides objectively determined TC center position to ADT algorithm based on IR, SWIR, Visible, and Microwave imagery



Advanced Dvorak Technique (ADT)

Latest Algorithm Upgrades

- **Primary ADT-V9.0 upgrades**
  - **Extratropical Transition intensity estimate adjustment**
  - **Analysis of Sub-Tropical systems with modifications to ADT logic**
  - **ARCHER (V2.8) objective algorithm for automated TC center position**
  - **SFC wind radii estimates** *(4 quadrants analysis, based on Knaff et al)*
  - **Extreme TC (CI=>7.0) intensity adjustments implemented**
  - **Modifications to allow for more frequent temporal image sampling**

Advanced Dvorak Technique (ADT)

2019 Performance Statistics

- **2019 ADT Basin-specific results** *(ADT within 30 minutes of Best Track)*
  - Atlantic – NHC Best Track within +/- 3 hours of aircraft reconnaissance
  - East/West Pacific – NHC/JTWC Best Track
  - +/- Bias equals Over/Underestimate of ADT versus Best Track

W Pacific – 573 total matches

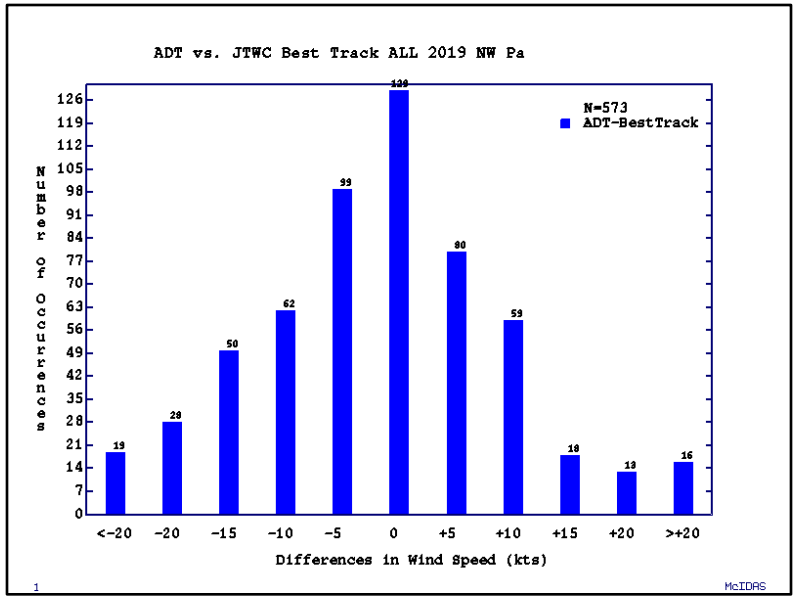
	bias	aae	stdv
CI#	-0.03	0.45	0.60
Wind(kts)	-1.38	8.52	11.09
MSLP(mb)	1.49	5.86	7.63

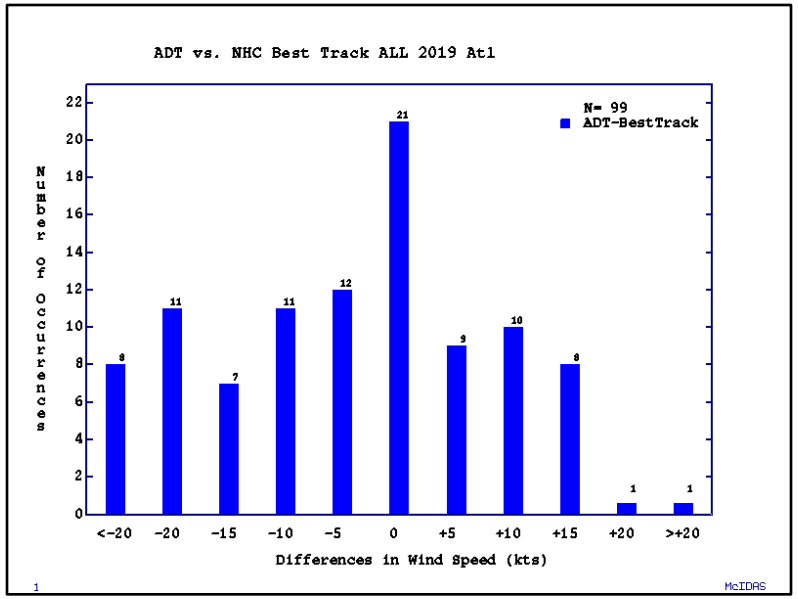
N Atlantic – 99 total matches

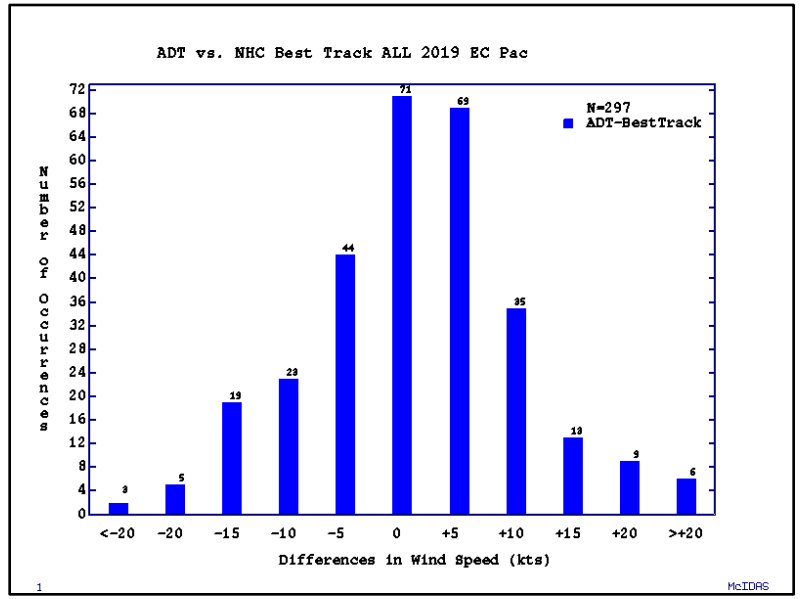
	bias	aae	stdv
CI#	-0.17	0.48	0.58
Wind(kts)	-3.91	10.94	13.53
MSLP(mb)	-1.22	8.85	8.77

E/C Pacific – 297 total matches

	bias	aae	stdv
CI#	0.10	0.40	0.50
Wind(kts)	2.32	7.39	9.74
MSLP(mb)	-2.75	5.68	7.36

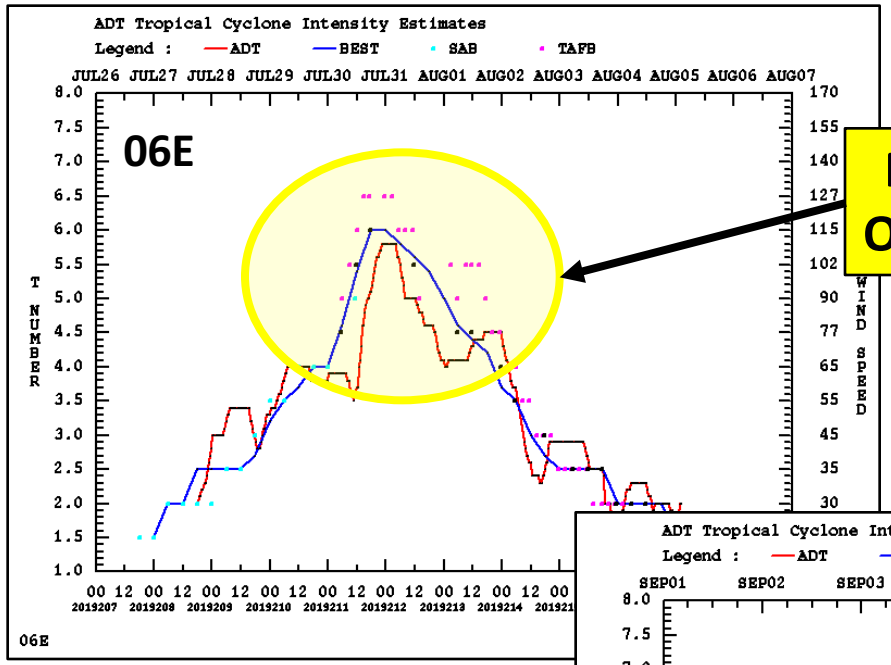


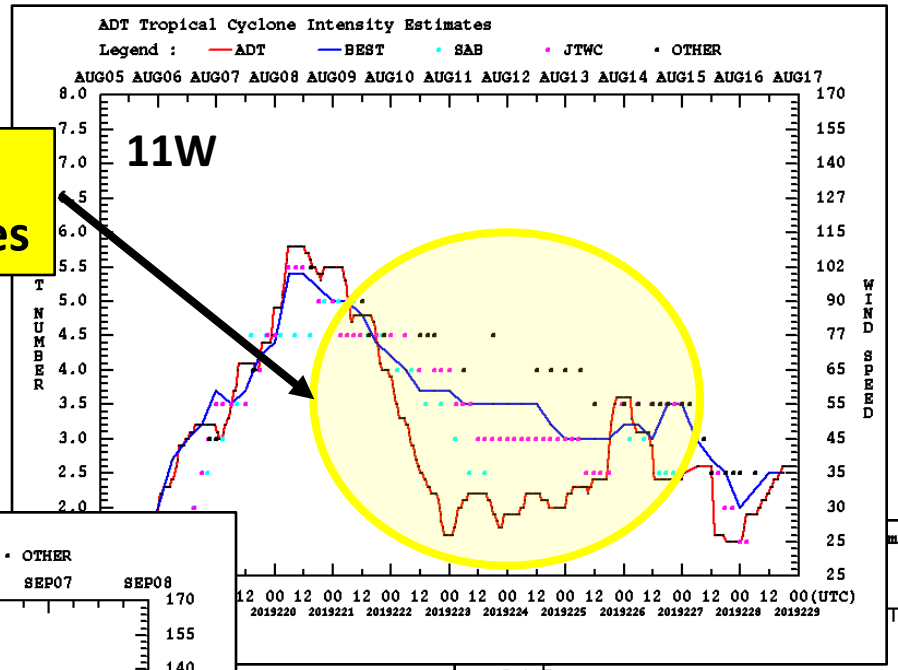




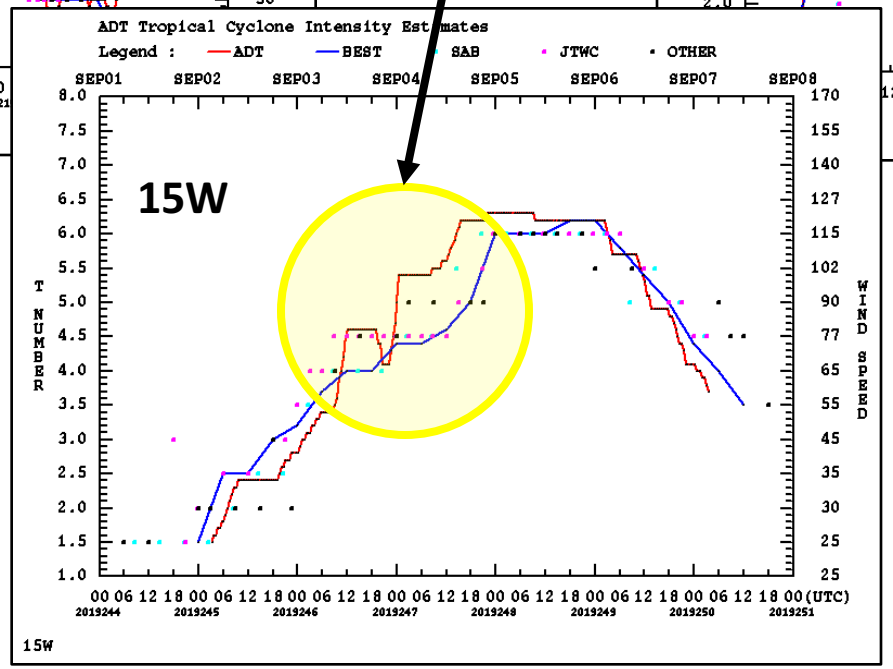
Advanced Dvorak Technique (ADT)

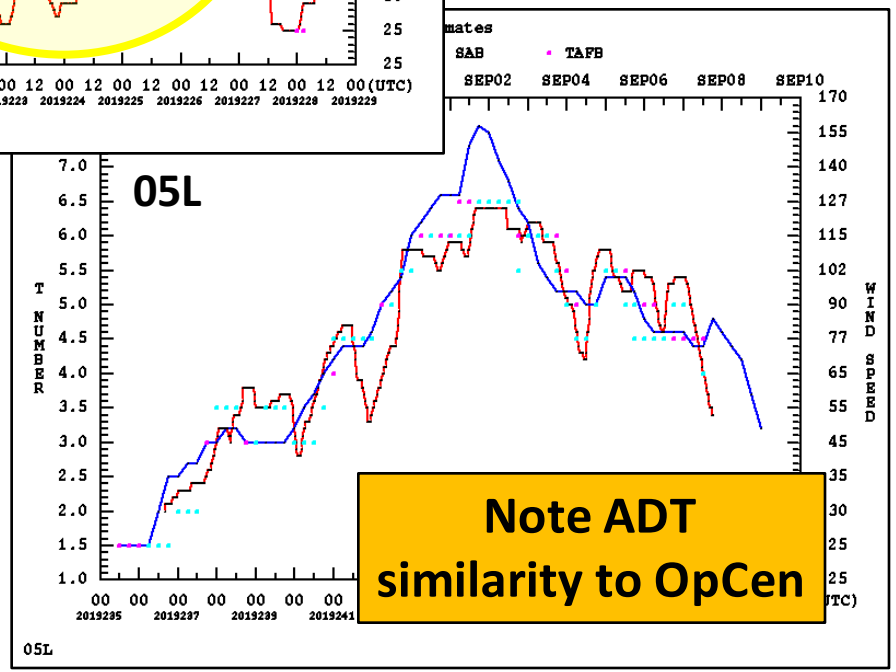
2019 Performance Examples





Note spread in OpCen estimates





Note ADT similarity to OpCen

- **ADT**
- **Official Best Track**
- **OpCen Dvorak**
  (symbols)

Advanced (AI-enhanced) Dvorak Technique (AiDT)

Overview

- **Current Deep Learning (DL) models being developed focus on directly interrogating satellite imagery and deriving objective maximum sustained wind (MSW) speed estimates**

- **These DL models can be time consuming and computationally expensive to derive**
  - Great care must be given to make sure the satellite data is homogeneous

- **The Advanced Dvorak Technique (ADT) already objectively interrogates satellite imagery and stores many environmental and analysis parameters in storm history files**
  - ADT accounts for satellite data and ocean basin differences through considerable research efforts developed over 20+ years of operational use

- **Can a DL model using ADT history file parameters be derived to improve the performance of the algorithm, especially to aid in situations were the ADT can struggle?**
  - Many different models could be investigated and would be computationally cheap to derive since we are only dealing with data values and not satellite imagery directly

Advanced (AI-enhanced) Dvorak Technique (AiDT)

Data Description

- **ADT history file parameters served as model "input" FEATURE DATA**
  - **ADT-Version 9.0** wind speed estimates for all global TCs from **2005-2018**
    - 30-minute temporal resolution; ocean estimates only
    - IR Window image (~10.7µm) from satellite with lowest viewing angle
    - Analysis for all storms with Best Track intensity >= 30 knots
    - **26 different ADT history file parameters utilized**
      - *Cloud and eye temperatures, storm position, scene type, regression values, etc.*

- **Final Best Track are used as model "ground truth" LABEL DATA**
  - **NHC/JTWC maximum wind speed** values are linearly interpolated to ADT analysis times

- **Models derived using combined global dataset but applied to storms in different basins**
  - Five ocean basins : North Atlantic, East/Central Pacific, Western North Pacific, North Indian Ocean, and South Pacific/Indian Ocean

Advanced (AI-enhanced) Dvorak Technique (AiDT)

Final AiDT Model

- **Final Model**
  - Fully-connected Deep Neural Network (DNN)
  - Regression-based loss function
  - 26 input ADT History File Features
  - One Hidden (Dense) layer with 32 neurons
  - One Output layer neuron representing a single continuous wind speed estimate value

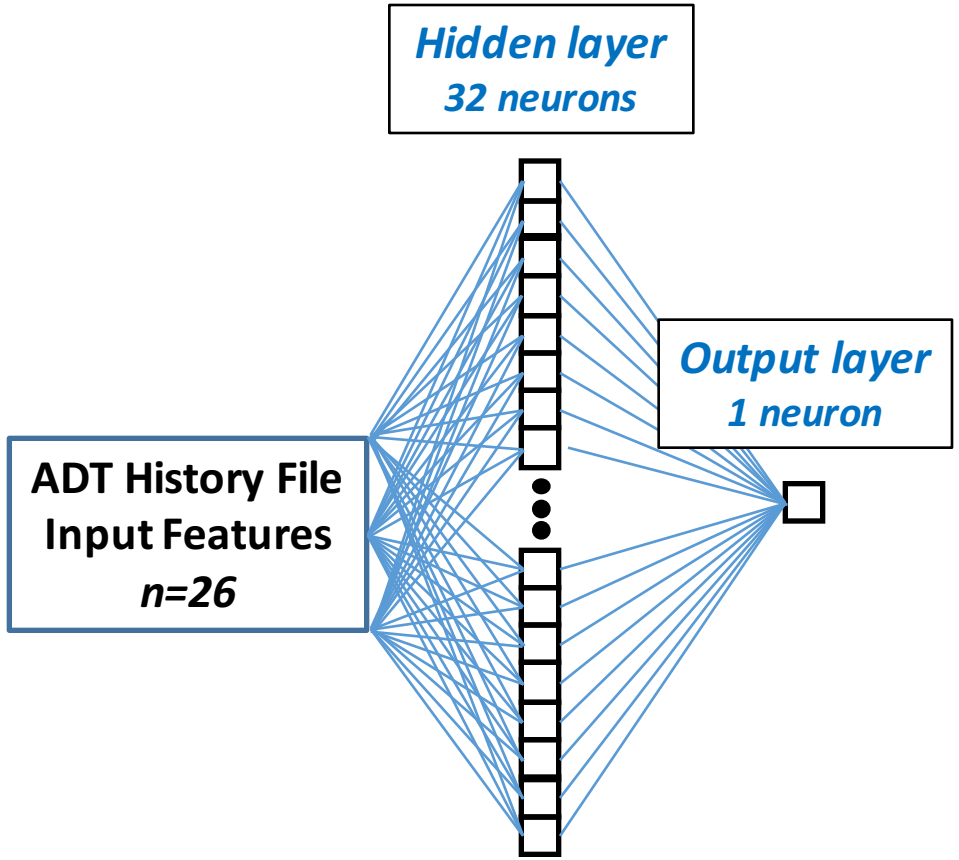
- **A 3-hour time weighted averaging scheme is implemented to dampen out small fluctuations between consecutive intensity estimates**
  - Time averaging reduces error by about 0.3kt

Trainable Parameters

L1: 26 X 32 + 32 = 864

L2: 32 X 1 + 1 = 33

897 Total



Advanced (AI-enhanced) Dvorak Technique (AiDT)

2017 Statistical Results

- **2017 Regression-base network Independent Test Data Set**
  - Table below shows statistical comparisons using global-derived model maximum sustained wind estimates (MSW) for each specific basin and combined global "All Basins" set
    - **ADT – Advanced Dvorak Technique – Version 9.0**
    - **AiDT-R – AiDT (unaveraged)**
    - **AiDT – AiDT (3-hour time-weighted average)**
    - *+/- Bias equals MSW over/underestimate versus Best Track values (knots)*

	Atlantic			**East Pacific**			**West Pacific**		
Network	Bias	MAE	RMSE	Bias	MAE	RMSE	Bias	MAE	RMSE
ADT	-0.91	9.50	**12.33**	-0.15	7.38	**9.44**	-1.87	8.47	**10.88**
AiDT-R	0.49	6.89	**8.76**	-0.13	5.50	**7.04**	-0.60	6.02	**7.56**
AiDT	0.33	6.59	**8.44**	-0.13	5.30	**6.77**	-0.86	5.89	**7.35**
# records	5188	5188	5188	3677	3677	3677	5475	5475	5475
	South Pacific			**North Indian**			**All Basins**		
Network	Bias	MAE	RMSE	Bias	MAE	RMSE	Bias	MAE	RMSE
ADT	2.71	8.43	**10.70**	5.03	7.51	**9.96**	-0.13	8.50	**10.98**
AiDT-R	0.80	6.52	**8.29**	1.50	5.90	**8.15**	-0.18	6.26	**7.98**
AiDT	-0.98	6.27	**7.99**	1.04	5.33	**7.49**	-0.35	6.03	**7.70**
# records	3766	3766	3766	566	566	566	18672	18672	18672

Advanced (AI-enhanced) Dvorak Technique (AiDT)

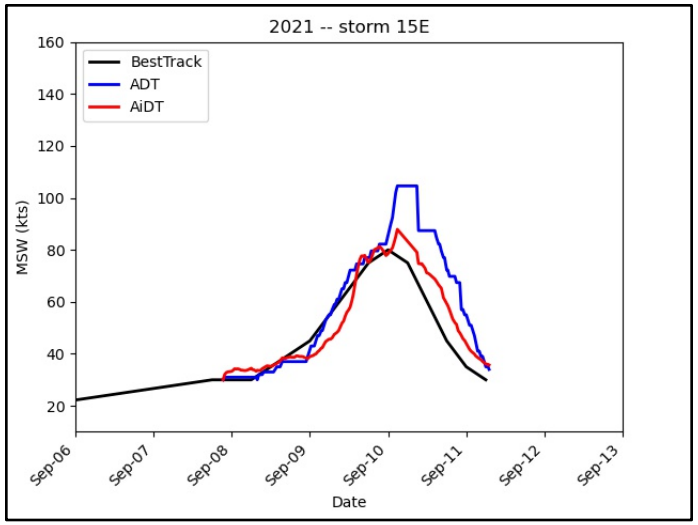
TC intensity Analysis

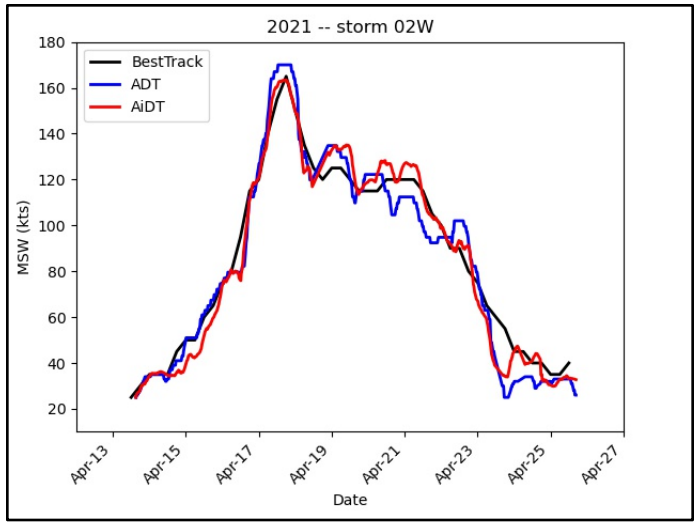
- **AiDT impacts on TC intensity categories**
  - 2017 Independent data set
  - Using AiDT Regression-based global model
  - **Largest AiDT impact on TS and H1 categories** (typically Curved Band and Shear scene types, along with CDO)
  - *+/- Bias equals MSW over/underestimate versus Best Track values (knots)*

Saffir-Simpson Intensity Category	Sample Size	ADT			AiDT		
		Bias	MAE	RMSE	Bias	MAE	RMSE
TD *<35.0 kt*	3519	5.34	6.58	9.27	5.96	6.28	7.83
TS *35.0-63.9kt*	9016	-0.37	8.54	**10.72**	-1.19	5.30	**6.79**
H1 *64.0-82.9kt*	3001	-3.99	9.90	**12.87**	-2.09	6.45	**8.15**
H2 *83.0-95.9kt*	1445	-2.03	10.02	12.43	-3.50	8.01	9.92
H3 *96.0-112.9kt*	845	2.44	8.35	10.22	-0.44	6.21	7.86
H4 *113.0-136.9kt*	607	-4.18	7.83	10.15	-4.14	6.35	8.24
H5 *>137.0kt*	239	-10.34	10.84	13.44	-10.02	11.00	12.82
H1-H2 *64.0-95.9kt*	4446	-3.35	9.94	**12.73**	-2.55	6.96	**8.77**
H3-H5 *>96.0kt*	1691	-2.95	8.52	10.71	-3.41	6.94	8.88

Advanced (AI-enhanced) Dvorak Technique (AiDT)

Examples





AiDT
ADT
Best Track