An overview of

UW-CIMSS Tropical Cyclone Products

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University of Wisconsin-Madison

Cooperative Institute for Meteorological Satellite Studies

Overview

Storm Coverage *(Information)*

Active Storm Product Summary Pages:

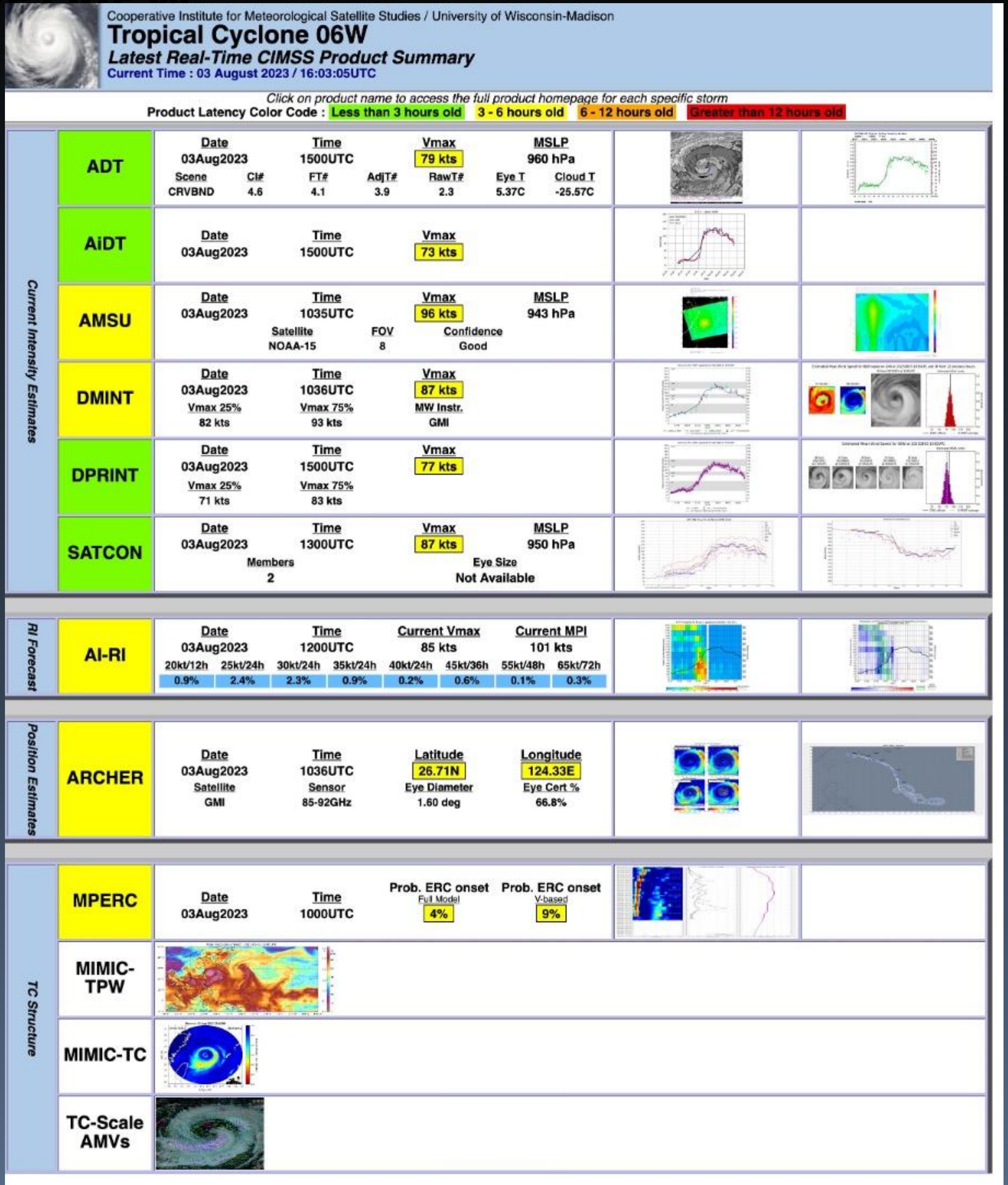
CIMSS TC Intensity, Structure, and Positioning Products "Quick Links"

Intensity: ADT AiDT AI-RI AMSU D-MINT D-PRINT SATCON

Positioning/Structure: ARCHER Meso-AMV M-PERC MIMIC-TC MIMIC-TPW SAL TC Diurnal Cycle

Tropical Outlooks/Regional Websites: Atlantic East Pacific West Pacific Indian Ocean Australia/Fiji

CIMSS Summary page



Quick glance of all of the CIMSS products.

- Color indicates the age of the product
- Each product name is a hyperlink to the product page
- Images will pop-out on mouseover.

Overview

- Advanced Dvorak Technique (ADT)
- Advanced (AI-enhanced) Dvorak Technique (AiDT)
- Deep Multi INTensity (D-MINT) and DeeP IR INTensity (D-PRINT)
- Satellite Consensus Algorithm (SATCON)
- AI-RI
- Microwave Probability of Eyewall Replacement Cycle (M-PERC)

ADT

The Advanced Dvorak Technique – Version 9.1

An objective algorithm advancing the Dvorak Technique

Tim Olander and Chris Velden

Advanced Dvorak Technique (ADT)

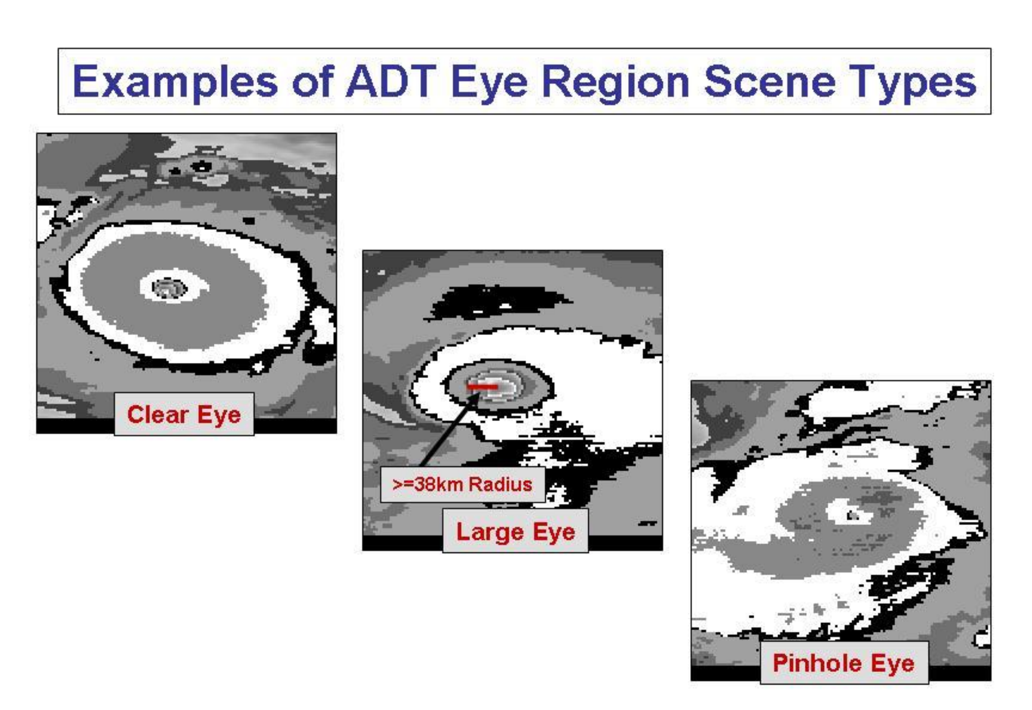
Processing Overview

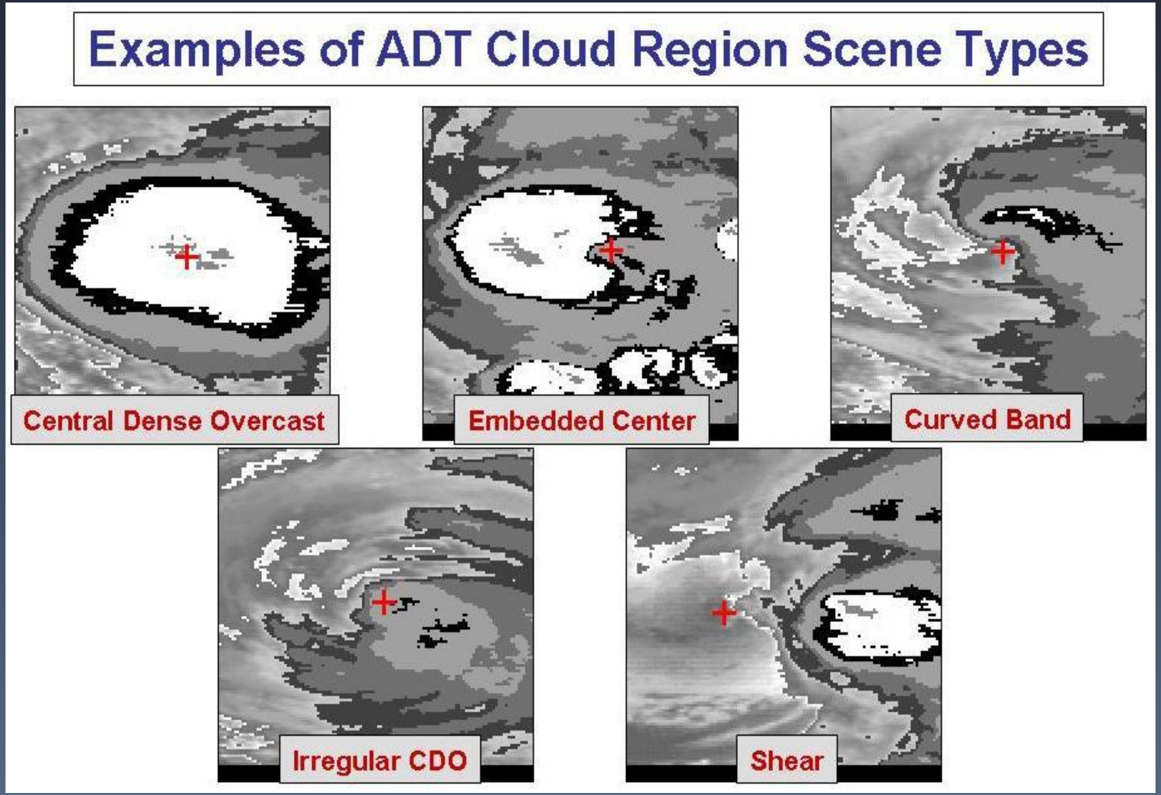
Raw T# : Intensity estimate based on objectively determined scene type

Final T#: Intensity after applying DT constraint rules to limit strengthening/weakening over time

Apply 3-hour time weighted averaging scheme to smooth out fluctuations

CI#: Apply final DT weakening rules applied as storm weakens





Advanced Dvorak Technique (ADT)

Processing Overview

- **ADT uses regression equations** ***(shown to right)*** **to derive intensity for EYE and Cloud/CDO scene types.** ***This is a significant departure from original DT!***

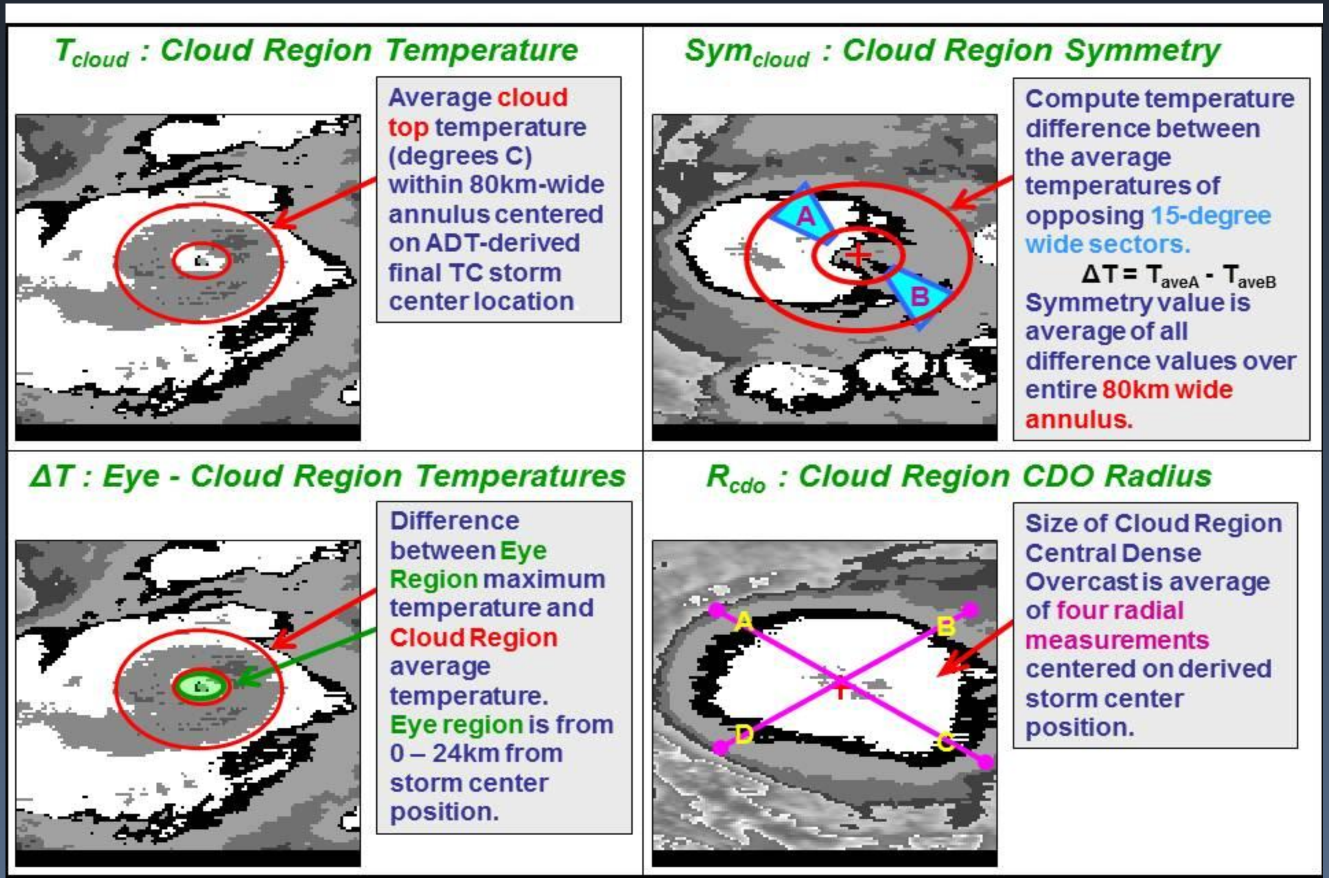
- **ADT still utilizes original DT estimate analysis methodology for Curved Band and Shear scene types.** ***These need to be investigated in the future!***

Eye Scenes

Atlantic : Intensity = $1.10 - 0.070 * T_{cloud} + 0.011 * \Delta T - 0.015 * Sym_{cloud}$

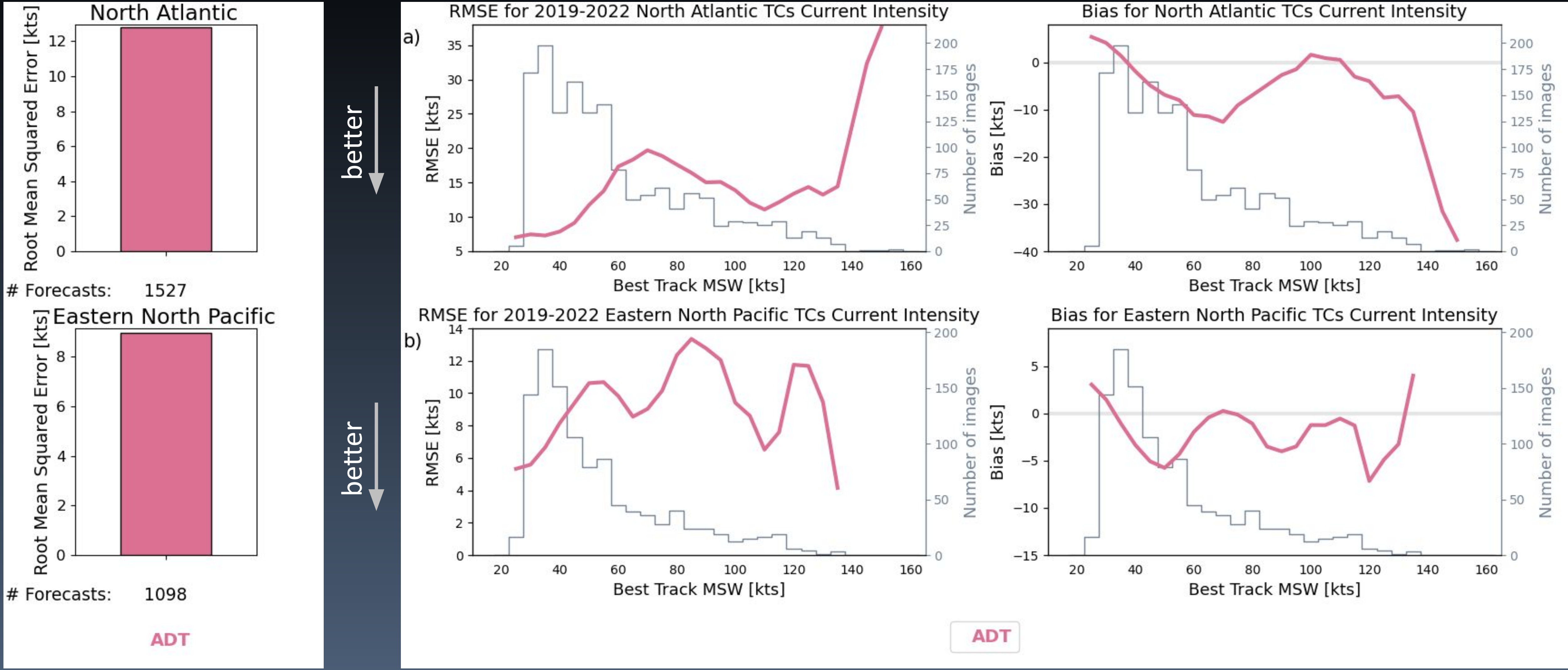
Cloud/CDO Scenes *(excluding shear and curved band)*

Atlantic : Intensity = $2.60 - 0.020 * T_{cloud} + 0.002 * R_{cdo} - 0.030 * Sym_{cloud}$



Advanced Dvorak Technique (ADT)

2019-2022 Statistical Results



ADT struggles with the strongest TCs, especially in the North Atlantic.

This could possibly be related to issues with SFMR estimates being too high.

Advanced Dvorak Technique (ADT)

ADT Homepage

Current Intensity Analysis

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UW - CIMSS
ADVANCED DVORAK TECHNIQUE
ADT-Version 9.1
Tropical Cyclone Intensity Algorithm

----- Current Analysis -----
Date :  17 FEB 2023    Time :    150000 UTC
Lat :   15:38:59 S      Lon :    73:37:12 E

CI# /Pressure/ Vmax
6.3 / 940.3mb/122.2kt

Final T#  Adj T#  Raw T#
   6.1     5.9     5.9

Estimated radius of max. wind based on IR :N/A km

Center Temp : +17.6C    Cloud Region Temp : -64.7C

Scene Type : EYE

Subtropical Adjustment : OFF

Extratropical Adjustment : OFF

Positioning Method : ARCHER POSITIONING

Ocean Basin : INDIAN
Dvorak CI > MSLP Conversion Used : CKZ Method

Tno/CI Rules : Constraint Limits : NO LIMIT
                  Weakening Flag : ON
          Rapid Dissipation Flag : FLAG

C/K/Z MSLP Estimate Inputs :
 - Average 34 knot radii :    77nmi
 - Environmental MSLP     : 1008mb

Satellite Name :     MSG2
Satellite Viewing Angle : 37.0 degrees

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History File Listing

Threshold

All Basins = 12.0

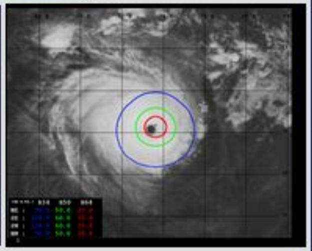
ARCHER Information

PMW Information

Wind Radii Estimates

(based on Knaff et al. 2016)

(naut.mi.)	R34	R50	R64
NE	95.0	50.0	25.0
SE	120.0	60.0	35.0
SW	120.0	60.0	35.0
NW	95.0	50.0	25.0



Parameters Used

RMW derived from Climatology

TC current intensity from ADT = 122.2 (kts)

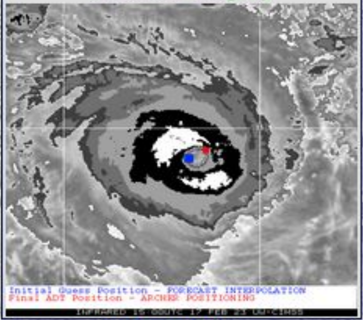
TC forward speed from Forecast Interpolation = 11.6 (kts)

TC heading from Forecast Interpolation = 262.3 (deg)

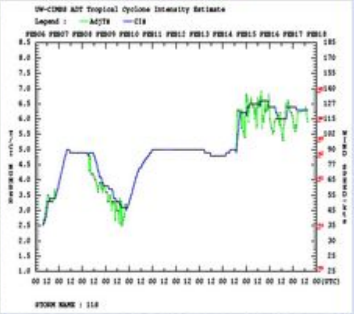
Historical listing of wind radii values

Timeline plots of Wind Radii : 34kt 50kt 64kt

Satellite Imagery



Time Series



HTML5 Movie

AiDT

The Advanced (AI-enhanced) Dvorak Technique

Improving the ADT using Machine Learning

Tim Olander, Tony Wimmers and Chris Velden

Advanced (AI-enhanced) Dvorak Technique (AiDT)

Final AiDT Model

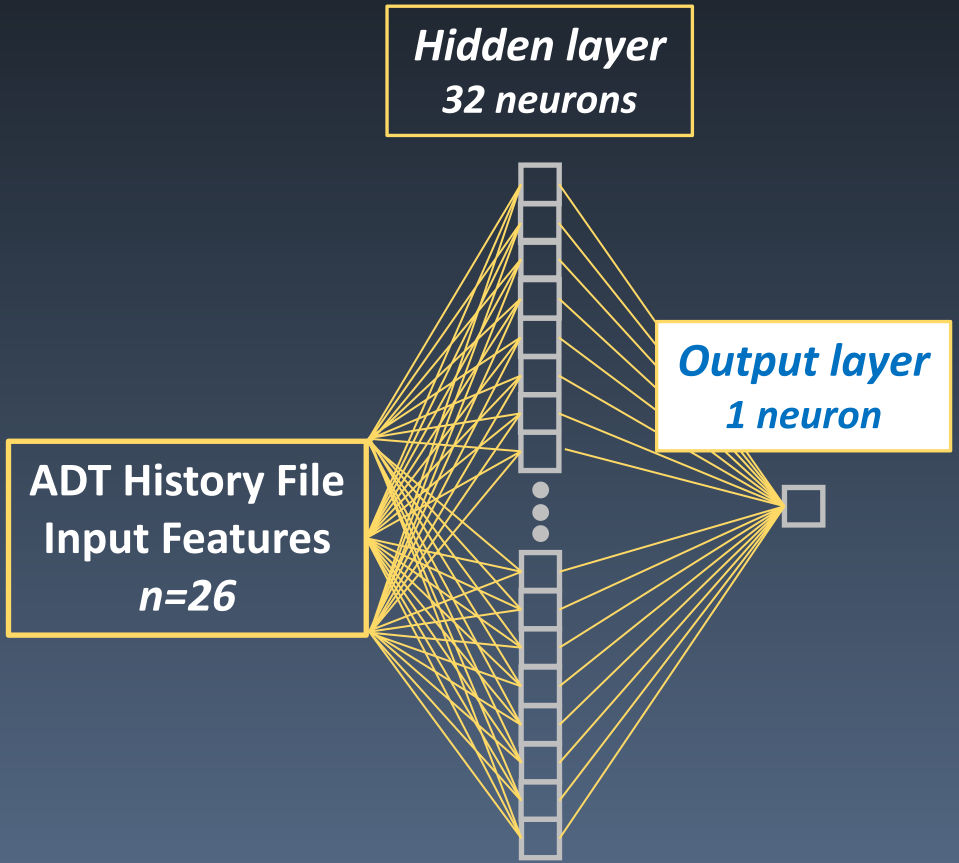
- **Final Model**
  - Fully-connected Deep Neural Network (DNN)
  - Regression-based loss function
  - 26 input ADT History File Features
  - One Hidden (Dense) layer with 32 neurons
  - One Output layer neuron representing a single continuous wind speed estimate value
- **A 3-hour time weighted averaging scheme is implemented to dampen out small fluctuations between consecutive intensity estimates**
  - Time averaging reduces error by about 0.3kt

<u>**Trainable Parameters**</u>

L1: 26 X 32 + 32 = 864

L2: 32 X 1 + 1 = 33

897 Total



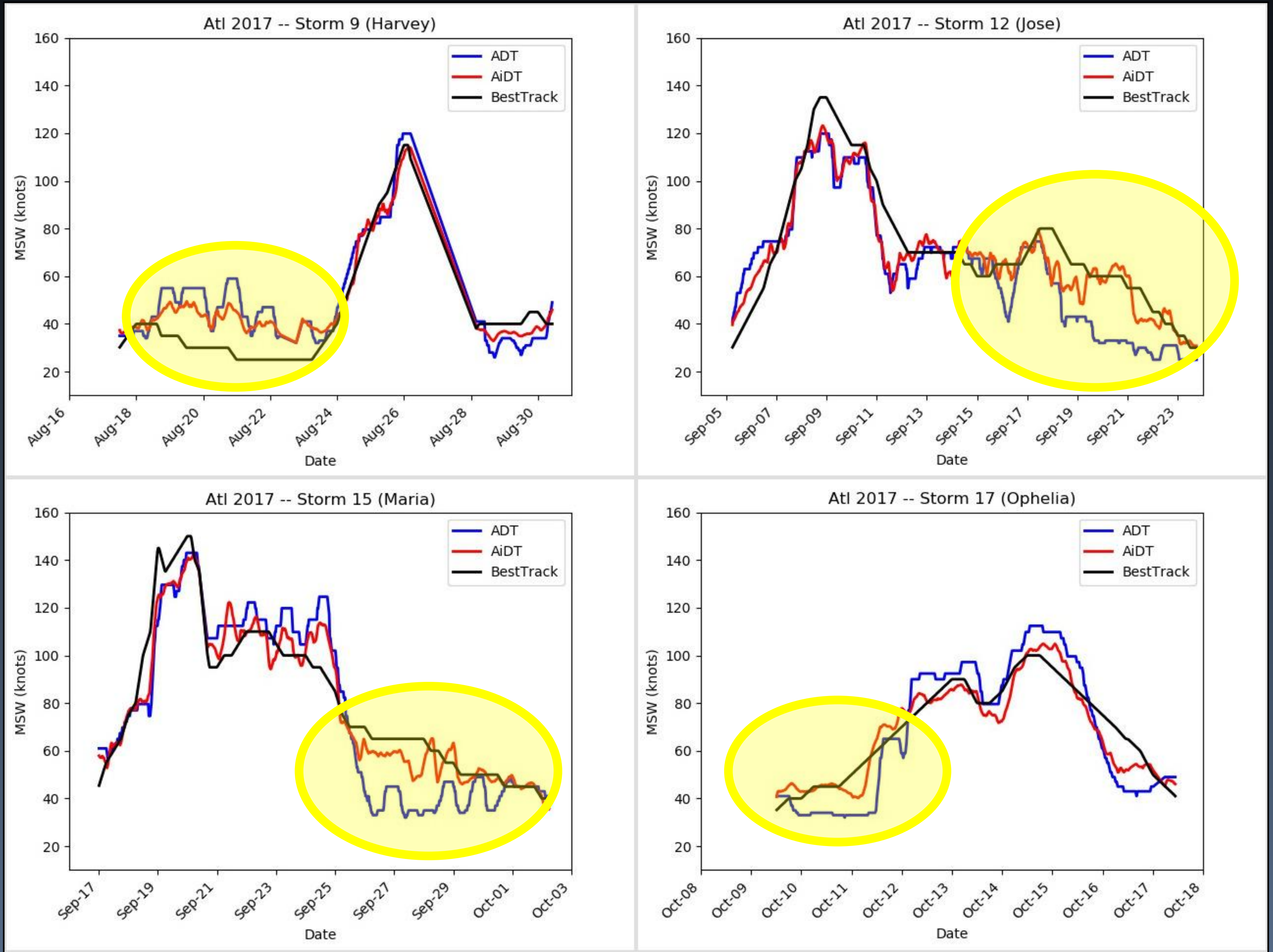
Advanced (AI-enhanced) Dvorak Technique (AiDT)

ADT Scene Type Analysis: 2017 Global Results

- **2017 North Atlantic**
  - *09L (Harvey)*
  - *12L (Jose)*
  - *15L (Maria)*
  - *17L (Ophelia)*

  - *Note impact of AiDT during formation and dissipation stages*

BLUE – ADT
RED – AiDT
BLACK – NHC Best Track



Advanced (AI-enhanced) Dvorak Technique (AiDT)

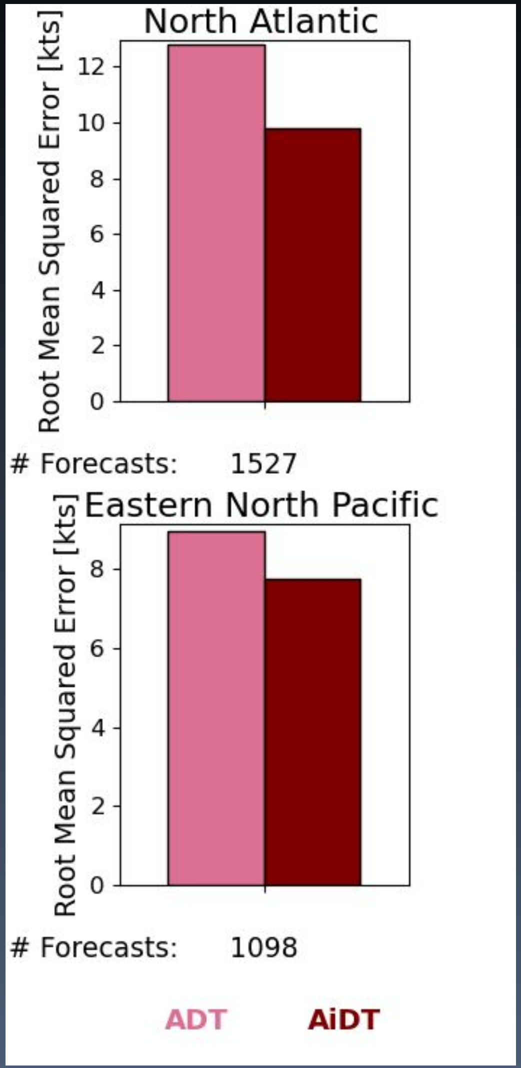
ADT Scene Type Analysis: 2017 Global Results

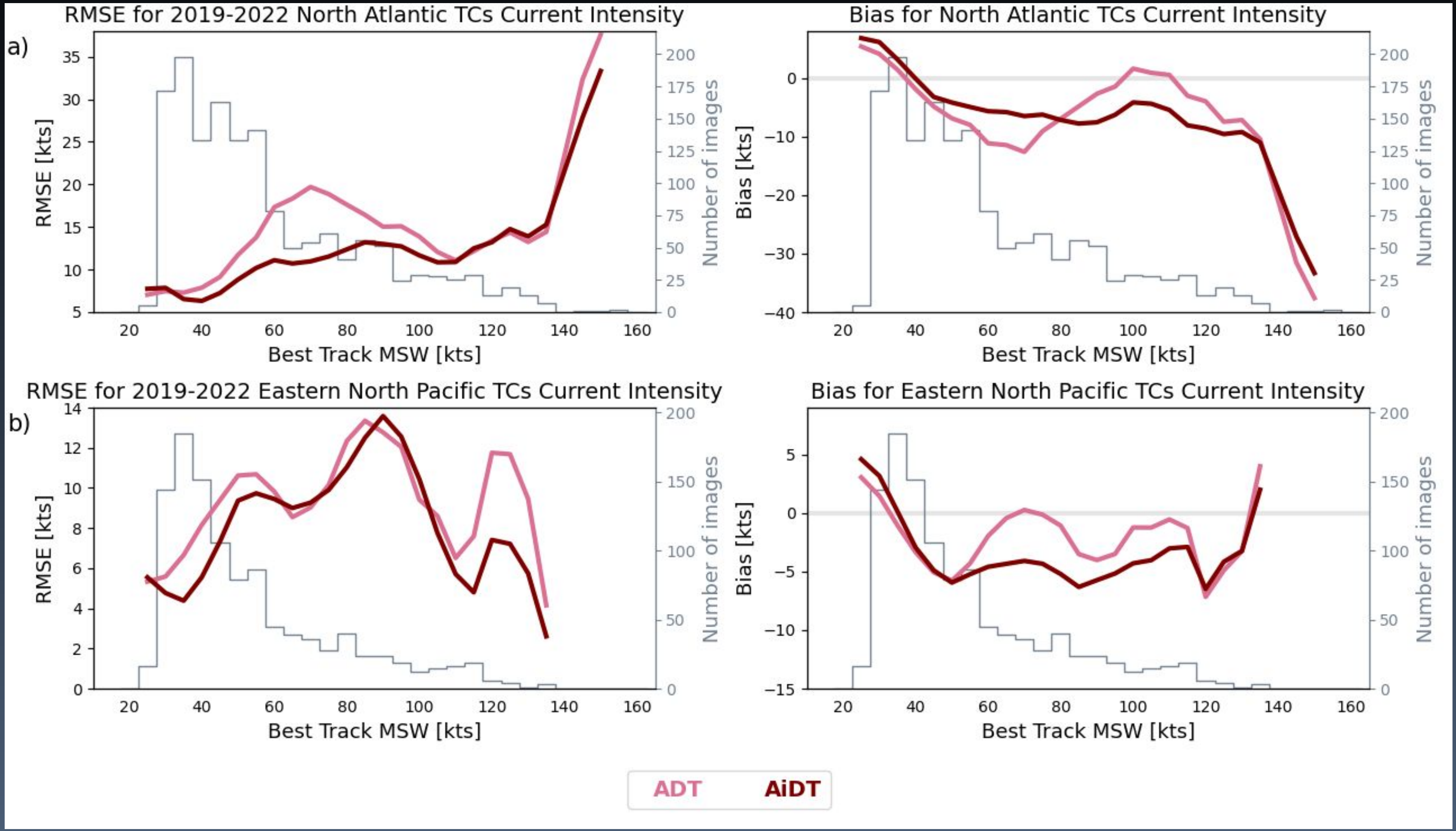
- **AiDT impacts on ADT performance by Scene Type**
  - Using AiDT Regression-based global model
  - AiDT reduces error most for ADT estimates using **Curved Band and Shear** scene types as well as also significantly reducing biases, especially for Shear estimates
  - **Curved Band and Shear scenes are least studied scene types in ADT algorithm**
  - *+/- Bias equals MSW over/underestimate versus Best Track values (knots)*

ADT Scene Type	Sample Size	ADT			AiDT		
		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**

Advanced (AI-enhanced) Dvorak Technique (AiDT)

2019-2022 Statistical Results





AiDT is more skillful than **ADT** in both the North Atlantic and eastern North Pacific for almost all intensities.

Advanced (AI-enhanced) Dvorak Technique (AiDT)

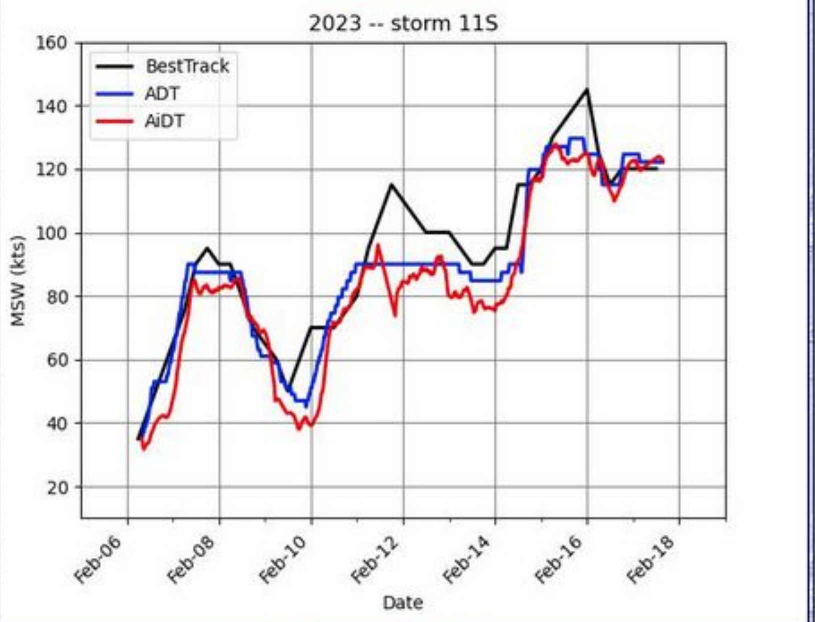
AiDT Homepage

UW-CIMSS
AI-enhanced Advanced Dvorak Technique (AiDT)
Version 1.0

Current Intensity Analysis

Date	Time	ADT Vmax *(kts)*	AiDT Vmax *(kts)*
2023/02/17	153000Z	122	123

Time Series



History File Listing

D-MINT and D-PRINT

Deep Multi INTensity and Deep IR INTensity estimators

A convolutional neural network to predict future TC intensity

Sarah Griffin, Tony Wimmers, and Chris Velden

D-MINT and D-PRINT

Overview

- **Can we use another method of machine learning, called convolutional neural networks, to estimate current TC intensity?**

- **Why 2 models?**
  - D-MINT which uses MW imagery in addition to IR imagery
    - MW imagery is not always available
    - MW imagery has a lag, it can take 1-3 hours for it to be available.

  - D-PRINT is constantly available since it only uses IR imagery and only has a 30 minute lag.

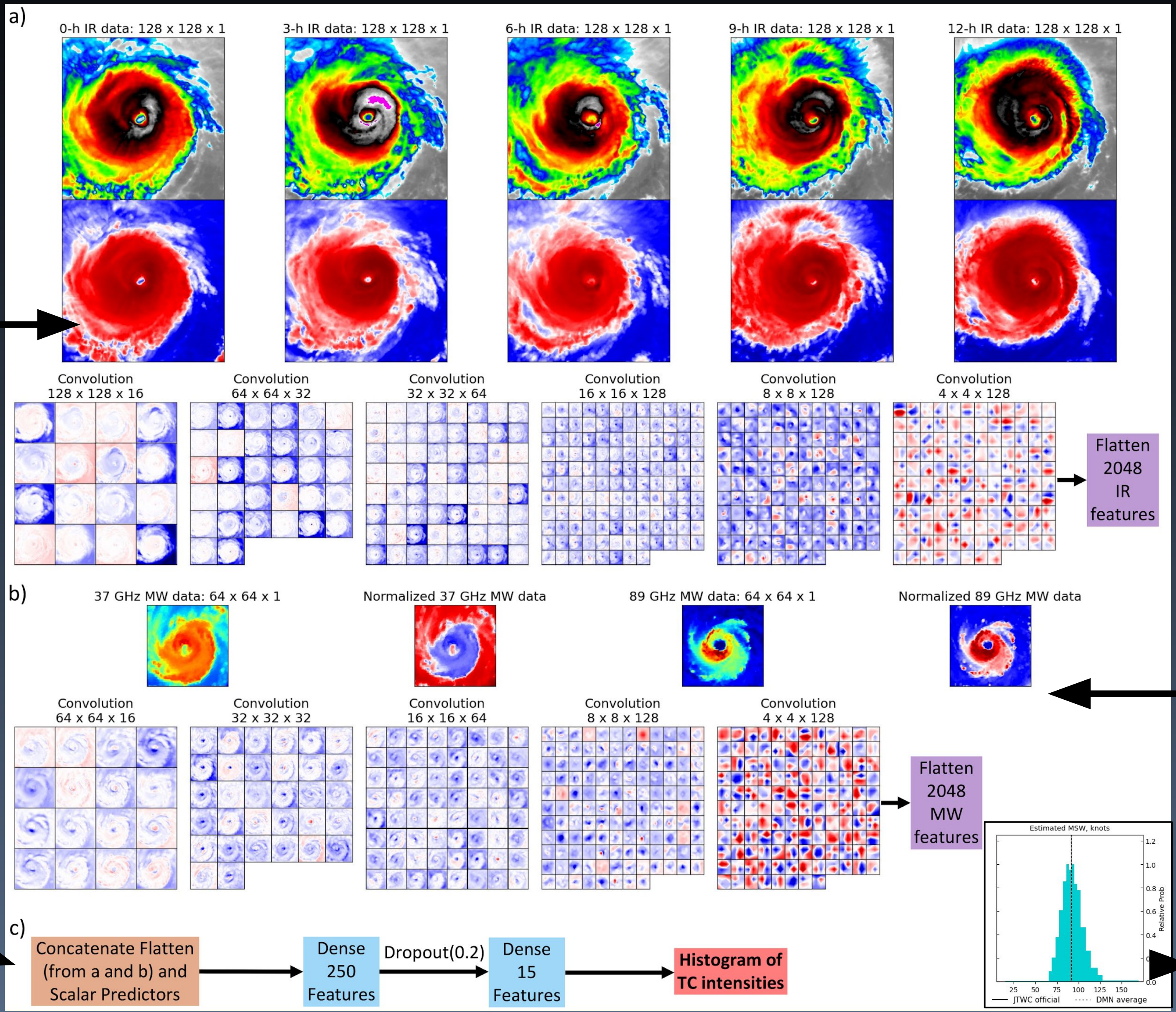
D-MINT and D-PRINT

Model Diagram

Input Features:
IR data: 128x128 grid over ~6 X 6° area centered on TC, normalized.

6 convolution layers where the scale gradually increases and more feature maps are added.

Input Features:
Add normalized scalar location and time features.



D-MINT
- Uses MW data
- Steps a), b) and c)
- Not always available and has a lag.

D-PRINT
- Always available since only uses IR imagery

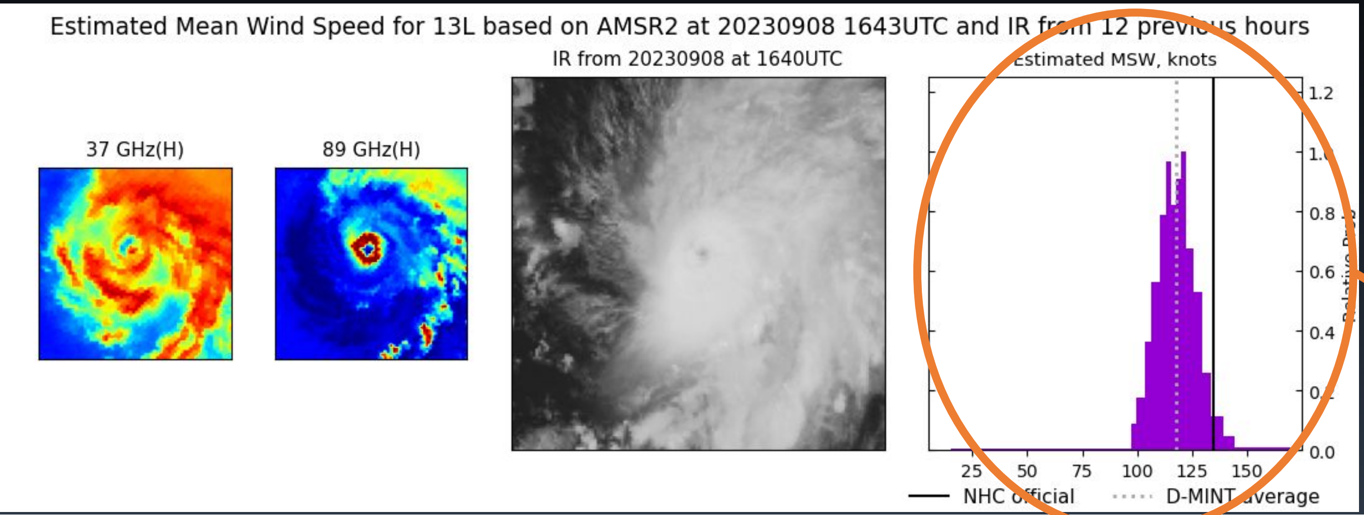
Input Features
MW data: 64 x 64 grid over ~3.2 X 3.2° area centered on TC, normalized.

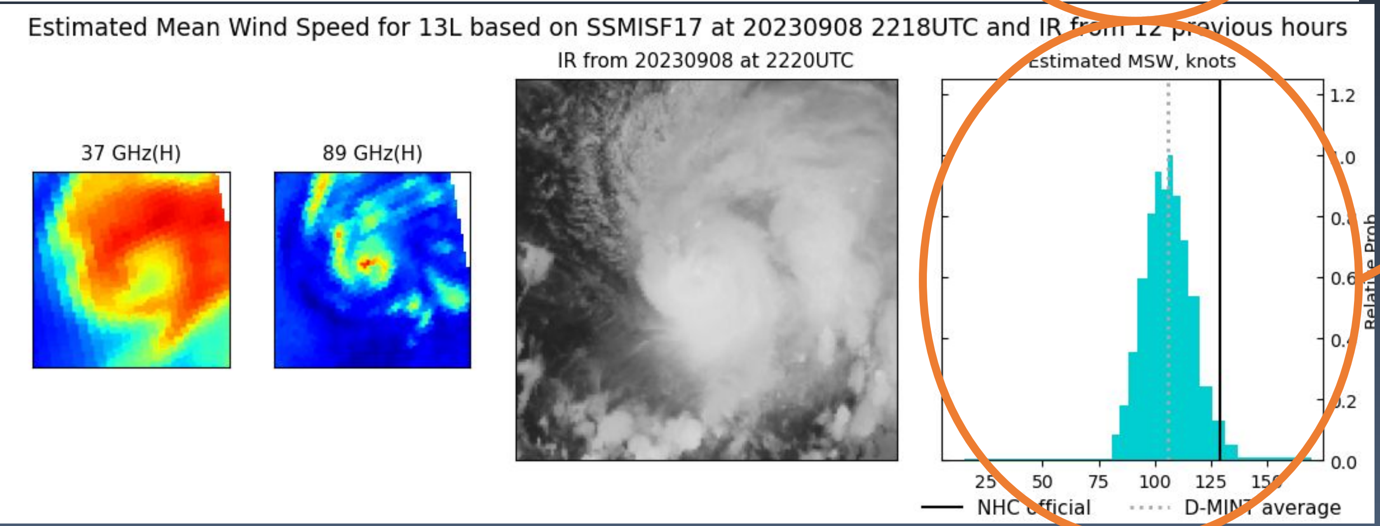
5 convolution layers
(not included in D-PRINT)

Output:
15 quantiles of TC intensity probabilities

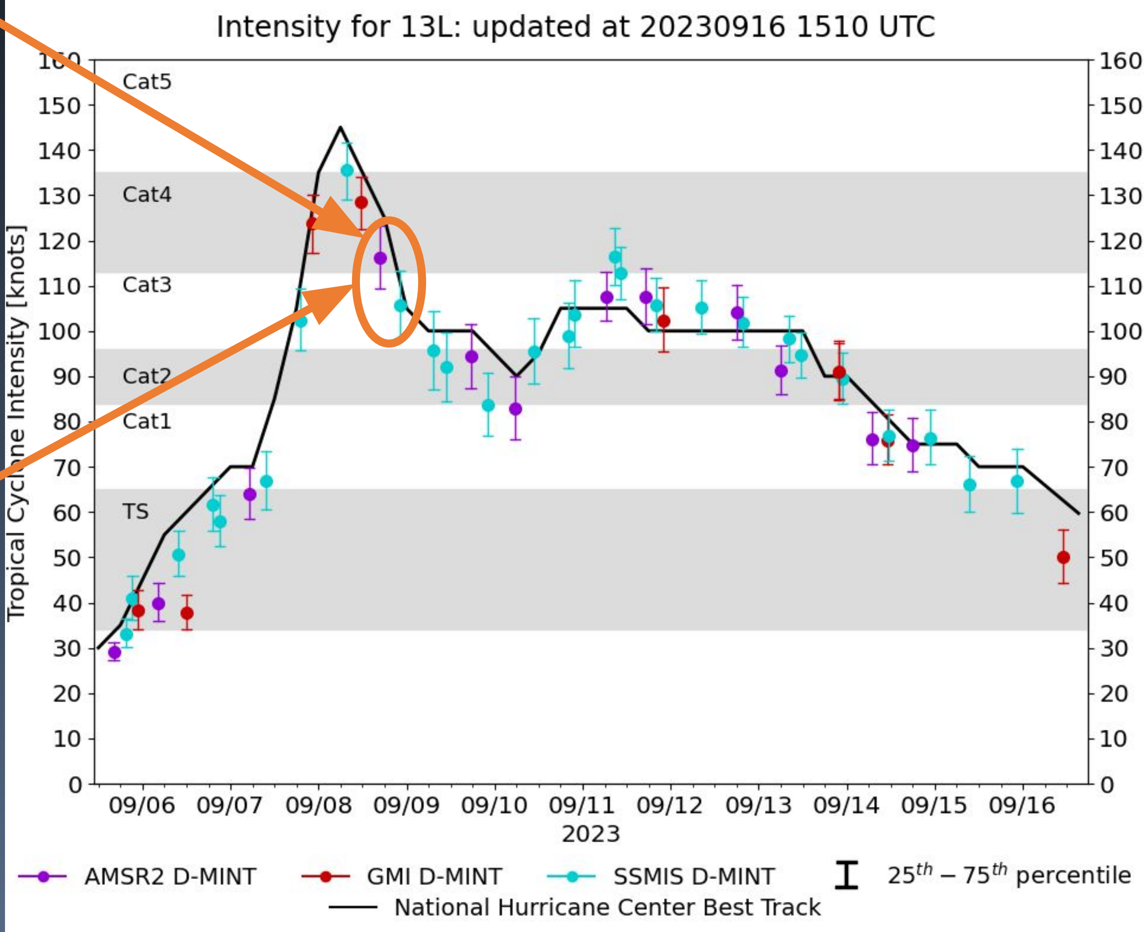
D-MINT and D-PRINT

Example



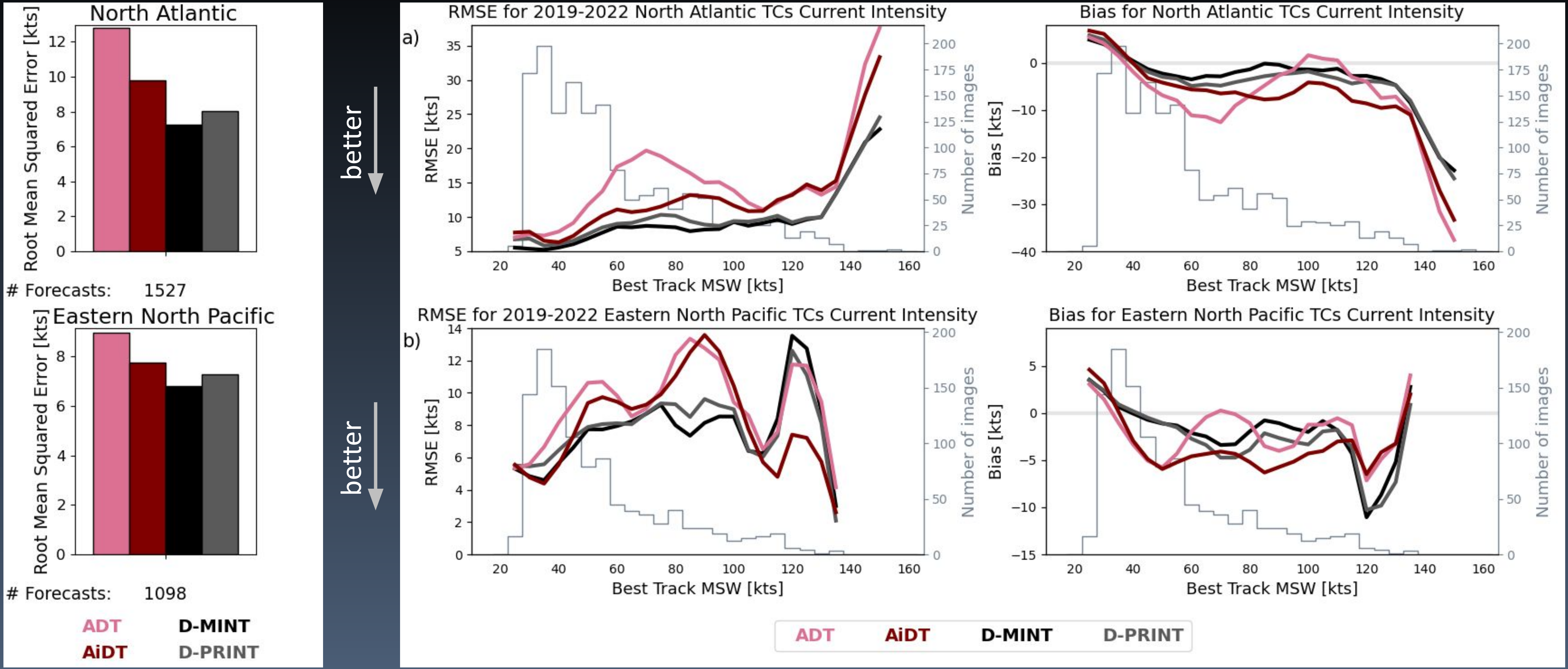


D-MINT and D-PRINT intensity are the average of the 30th to 70th percentile



D-MINT and D-PRINT

2019-2022 Statistical Results



D-MINT and **D-PRINT** are is more skillful than **AiDT** in the North Atlantic for almost all intensities, but are less skillful for the highest intensities compared to **AiDT** in the eastern North Pacific.

D-MINT and D-PRINT

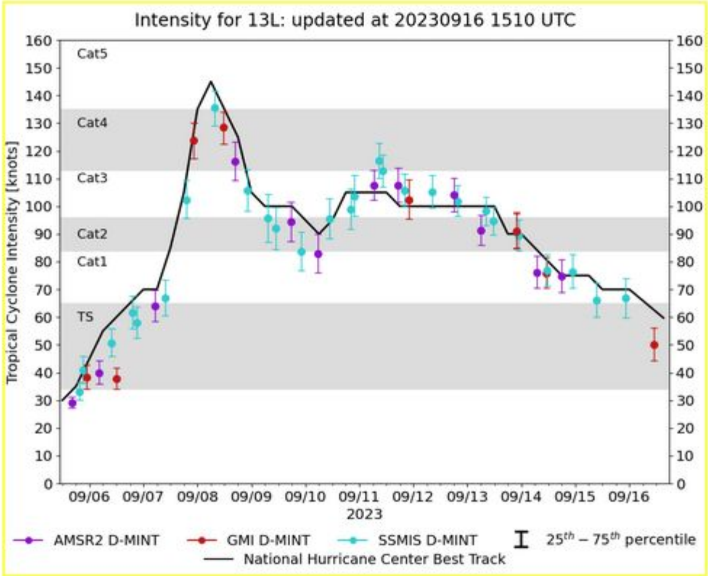
Homepage

Cooperative Institute for Meteorological Satellite Studies / University of Wisconsin-Madison

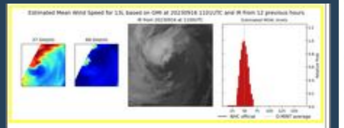
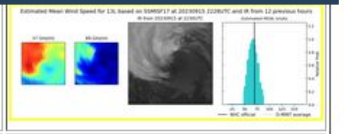
Tropical Cyclones

Deep Multispectral INtensity of TCs estimator (D-MINT, formerly DMN)

Storm: 13L



[D-MINT HISTORY FILE for 2023_13L]

Date	Time	MW Sensor	MSLP	Vmax (30th-70th percentile average)	Vmax 25th percentile	Vmax 75th percentile	Image
20230916	1101 UTC	GMI	987 hPa	50 kts	44 kts	56 kts	
20230915	2228 UTC	SSMISF17	974 hPa	67 kts	60 kts	74 kts	

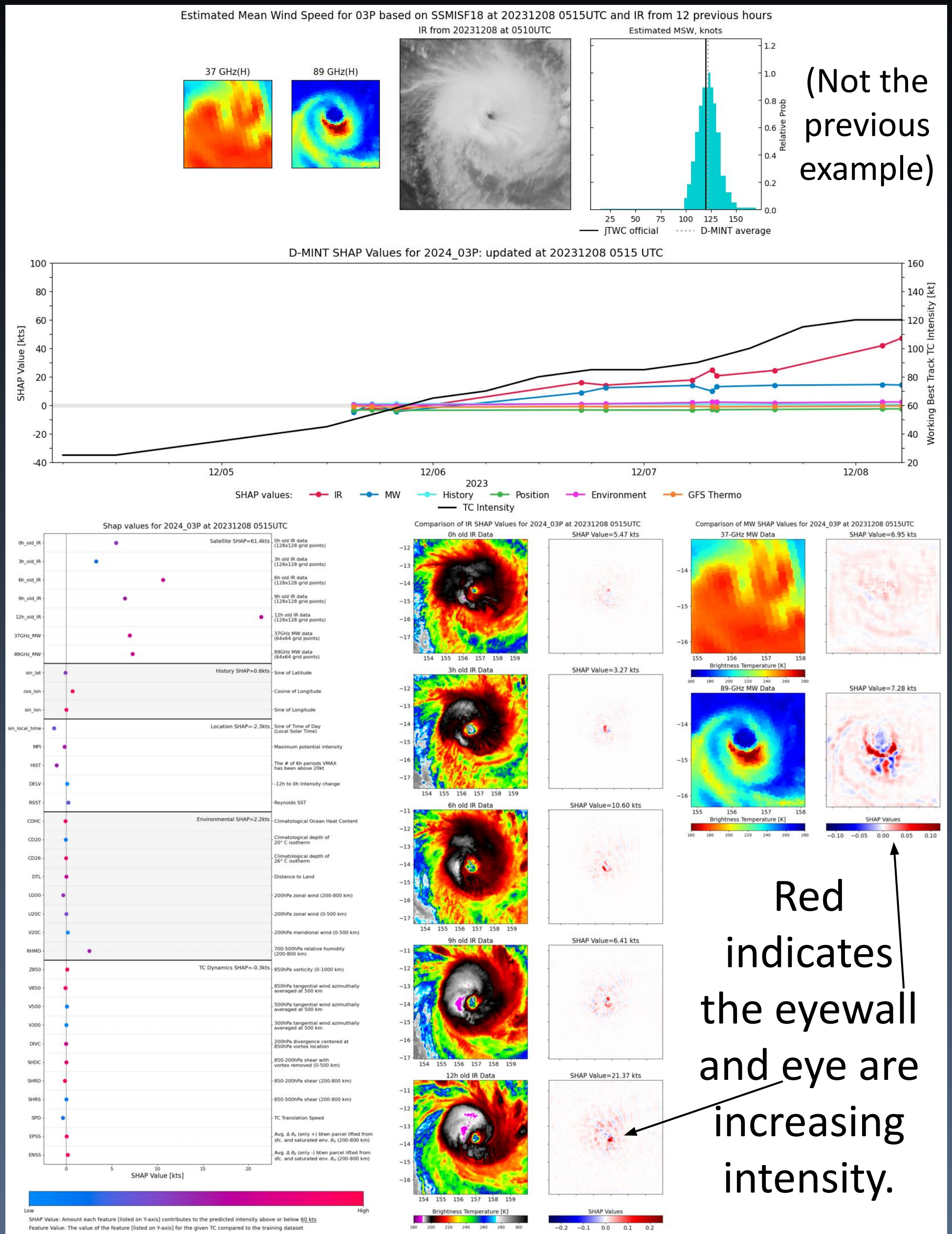
D-MINT and D-PRINT

SHAP values

SHAP values indicate which part of the TC image or scalar predictors are contributing to the estimated intensity.

D-MINT and D-PRINT can compare current and older imagery, which is why older image has more impact on TC intensity.

SHAP values categorized and total impact added.



(Not the previous example)

Timeline of SHAP values categories.

Red indicates the eyewall and eye are increasing intensity.

D-MINT and D-PRINT

Future updates

We've been developing a version of D-MINT which uses 183 GHz imagery instead of 37- and 89-GHz imagery.

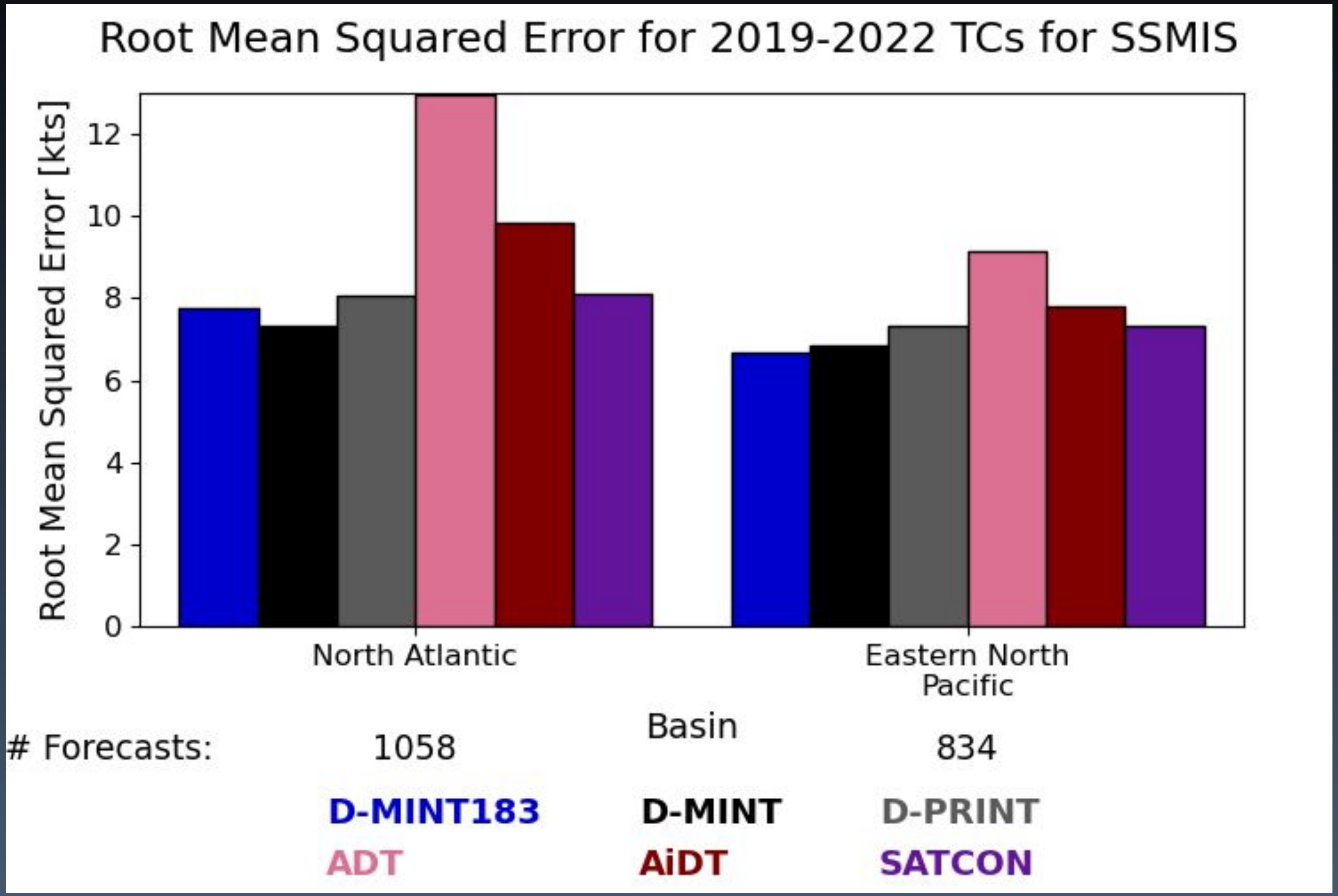
D-MINT and D-PRINT

Future updates

We've been developing a version of D-MINT which uses 183 GHz imagery instead of 37- and 89-GHz imagery.

It's similar skill to D-MINT based on a comparison with SSMIS data.

- Bit worse in the North Atlantic
- Better in the Eastern North Pacific



D-MINT and D-PRINT

Future updates

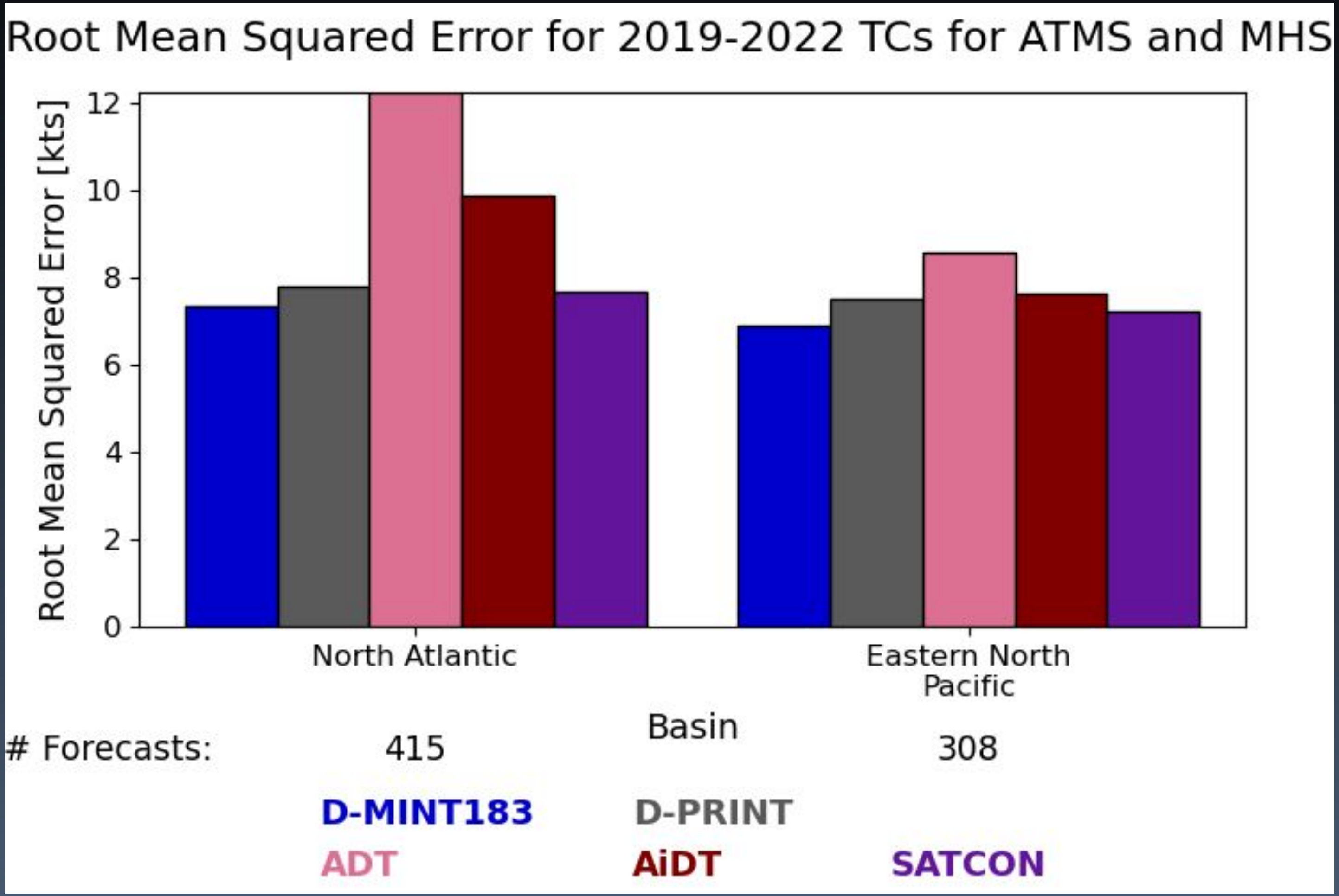
We've been developing a version of D-MINT which uses 183 GHz imagery instead of 37- and 89-GHz imagery.

It's similar skill to D-MINT based on a comparison with SSMIS data.

- Bit worse in the North Atlantic
- Better in the Eastern North Pacific

Now we can run D-MINT183 on ATMS and MHS imagery

- Most skillful for 2019-2022 TCs.
- Will be adding to the website in May
- Hoping to add D-MINT183 estimates from TROPICS as well



SATCON

CIMSS SATellite CONsensus algorithm

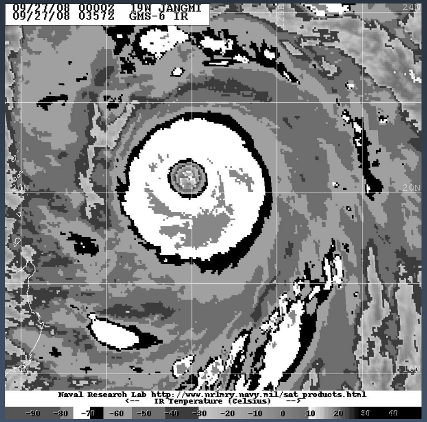
A consensus approach to estimating tropical cyclone intensity from meteorological satellites

Derrick Herndon and Chris Velden

SATCON

Overview

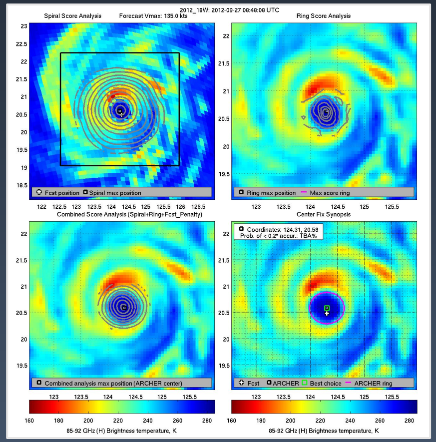
- In order to account for storms with different structures an “all the above” approach is needed.
- Multiple satellite scanning strategies (Geo/LEO)
- Multiple channels to measure the various TC features that are related to intensity. (subjective/objective)



Geostationary

(G-16/G-18/H9)

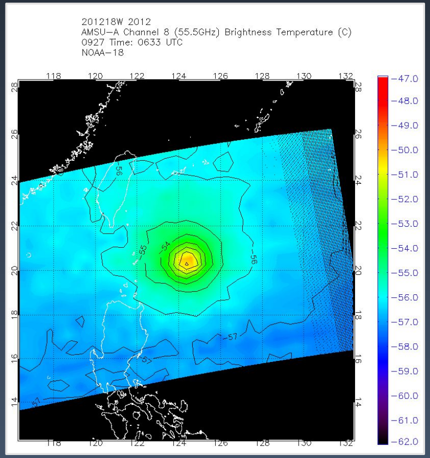
- Intensity
- Position
- Structure



MW Imager

(AMSR2, GMI, SSMIS)

- Position
- Structure



MW Sounder

(AMSU, SSMIS, ATMS)

- Intensity
- Structure

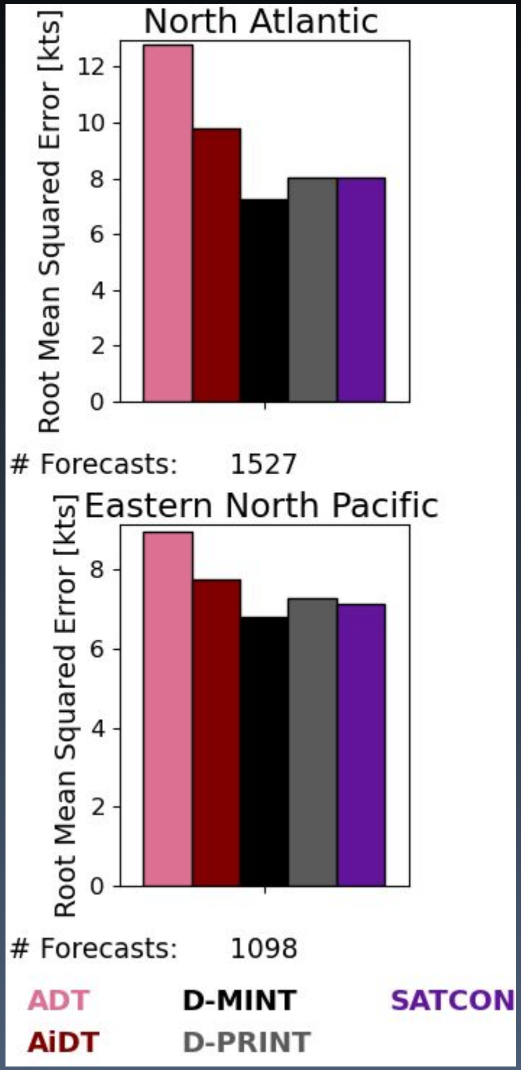
SATCON
Overview

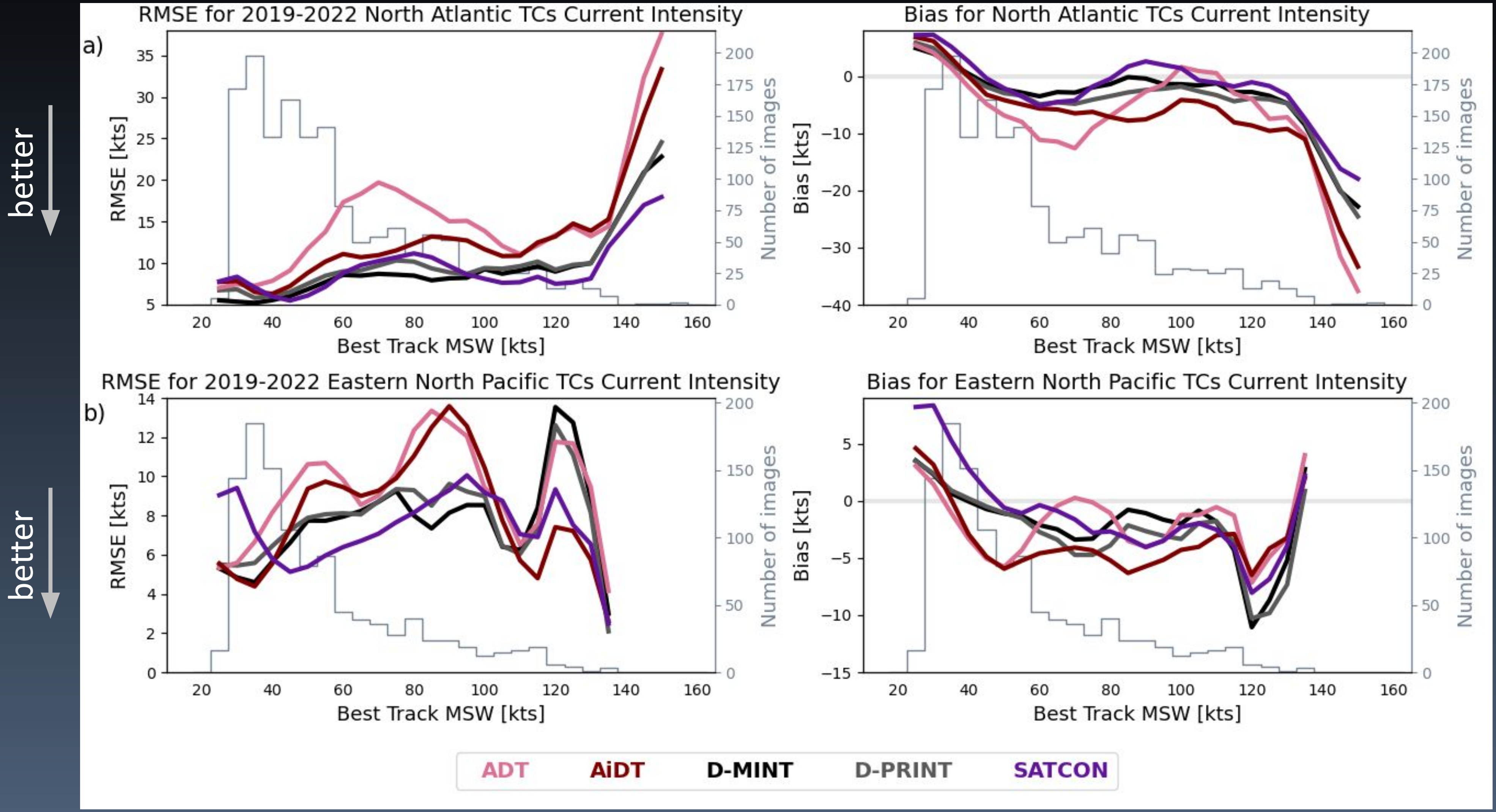
- **Current SATCON members THROUGH 2023**
  - **LEO microwave sounder based**
    - **AMSU** *(Channels 6-8 and 16)*
      - **NOAA-15,-16,-18,-19** (N-16 AMSU-A failure 2014)
      - **Metop A-B** (Metop-A Channel 7 failure 2008)
    - **SSMIS** *(Channels 3-5 and 17)*
      - **F16-F19** (F18 failure 2015, F19 failure 2016)
    - **CIMSS ATMS** *(Channels 7-9)*
      - **SNPP/N-20**
    - **CIRA ATMS** *(Channels 1-22)*
      - **Only used for eye >40km**
  - **GEO IR imager based**
    - **ADT**

Also Displayed
- Warning agency BT
- SMAP
- SAR
- D-MINT
- Dvorak Estimates

SATCON

2019-2022 Statistical Results





SATCON has more skill than **D-MINT** and **D-PRINT** for TCs > 90 kts in the North Atlantic.

SATCON has the highest RMSE for TCs > 35 kts in the eastern North Pacific.

SATCON

Homepage

CIMSS TROPICAL CYCLONE INTENSITY CONSENSUS FOR IAN (09L) 2022

CURRENT ESTIMATE
Date (mmddhhmm): 09301304
SATCON: MSLP = 983 hPa   MSW = 64 knots
SATCON Member Consensus: 65.0 knots
Pressure -> Wind Using SATCON MSLP: 60 knots
Distance to Outer Closed Isobar Used is 210 nm
Eye Size Correction Used is 0 knots   Source: NA

← **Current SATCON estimate**

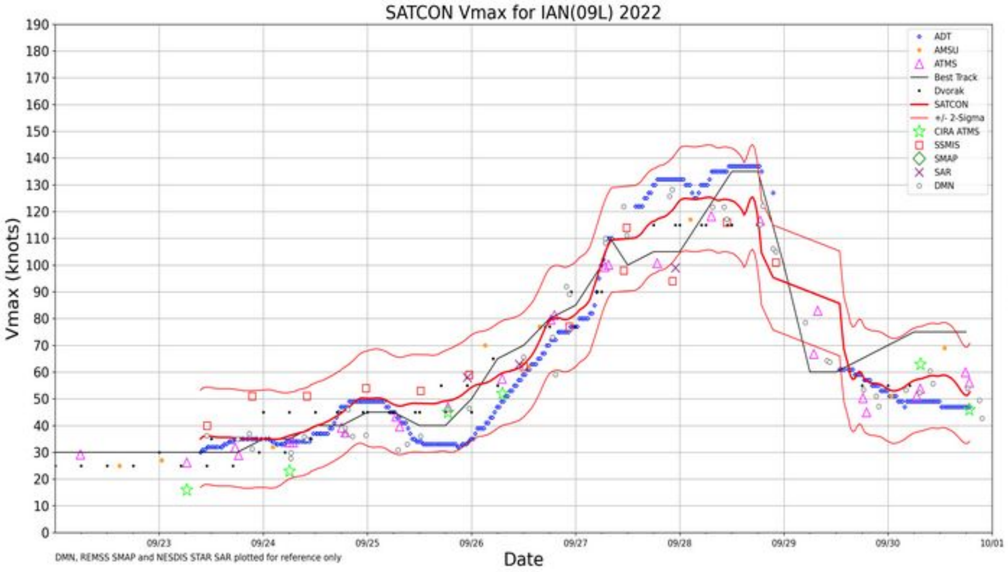
Member Estimates

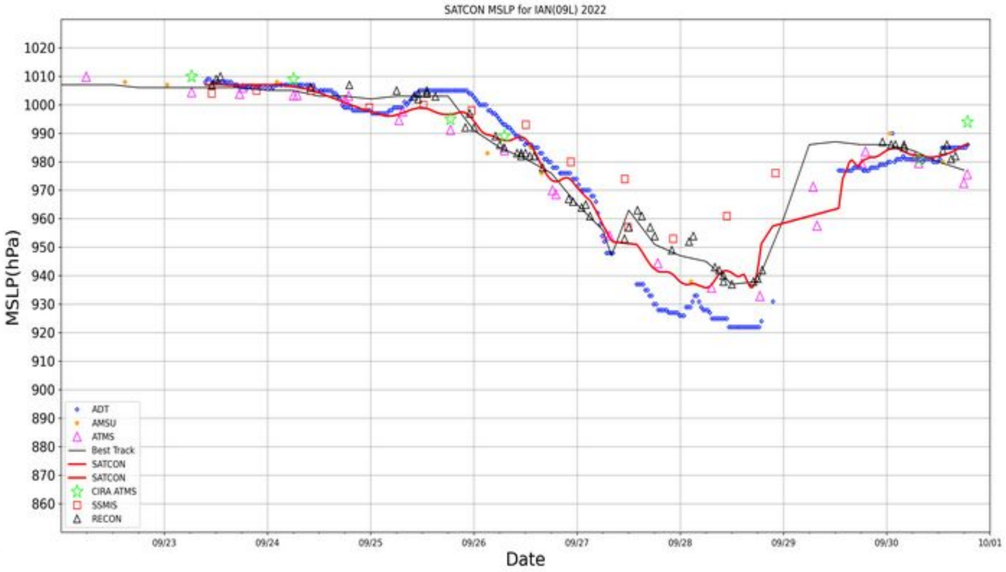
ADT: 985 hPa   62.32 knots   Scene: CDO   Date: SEP301550
CIMSS AMSU: 980 hPa   69 knots   Bias Corr: 0 (MW)   Date: 09301304
ATMS: 935.7 hPa   118.4 knots   Date: 09280714
SSMIS: 935.7 hPa   118.4 knots   Date: 09280714
CIRA ATMS: 994 hPa   46 knots   Date:

← **Member estimates**

SATCON HISTORY FILE for 2022 09L IAN

SATCON MSW plot including pressure-wind contribution



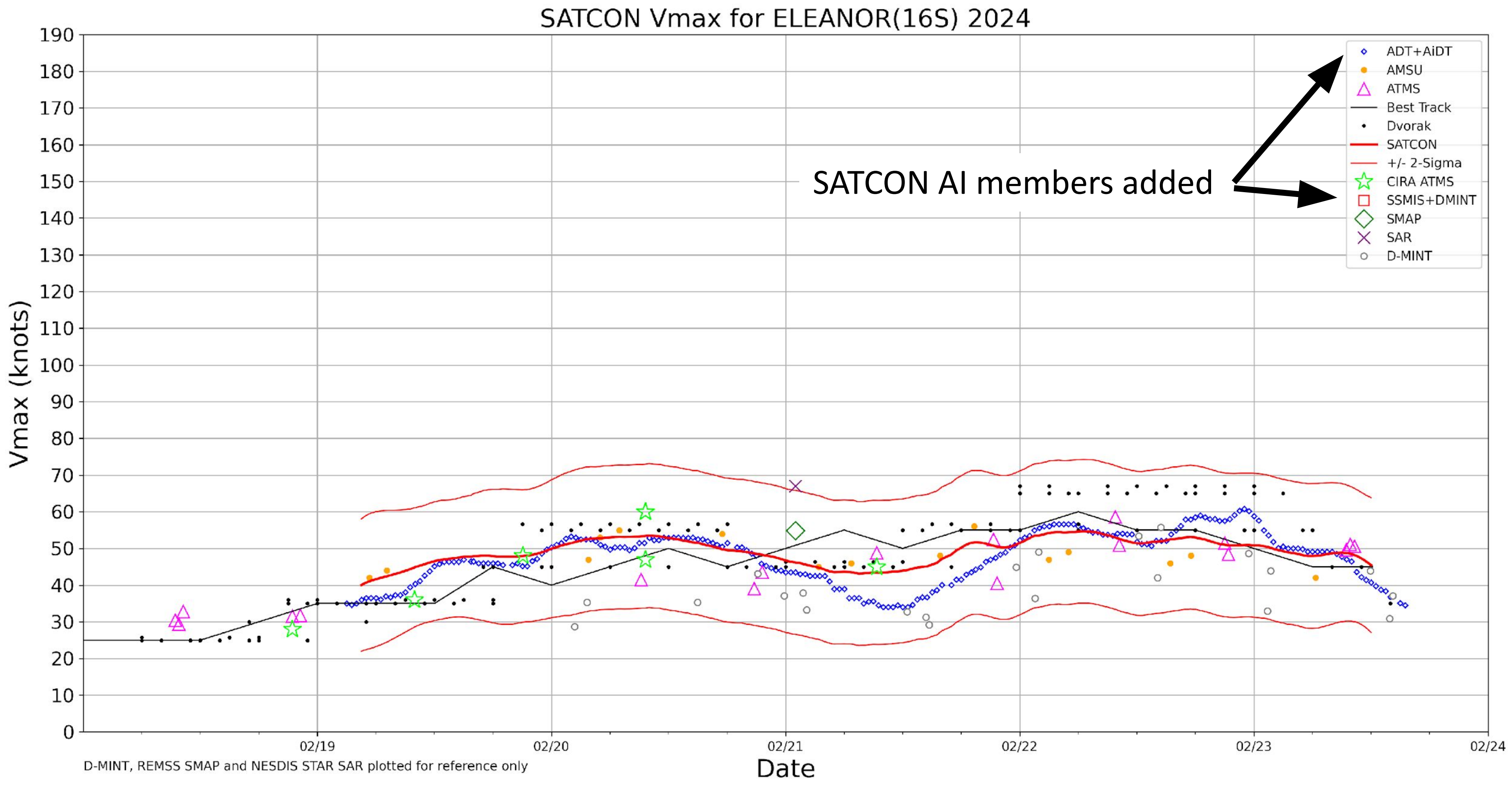


SATCON

Future Directions

SATCON added new members starting in 2024!

- **D-MINT**
  - added as a first cut by creating a D-MINT/SSMIS sounder intensity consensus.
- **CIMSS AiDT**
  - added as a member via an ADT-AiDT consensus.



Future additions:

D-PRINT

AI-RI

AI-Rapid Intensification

A convolutional neutral network to calculate the probability of TC rapid intensification

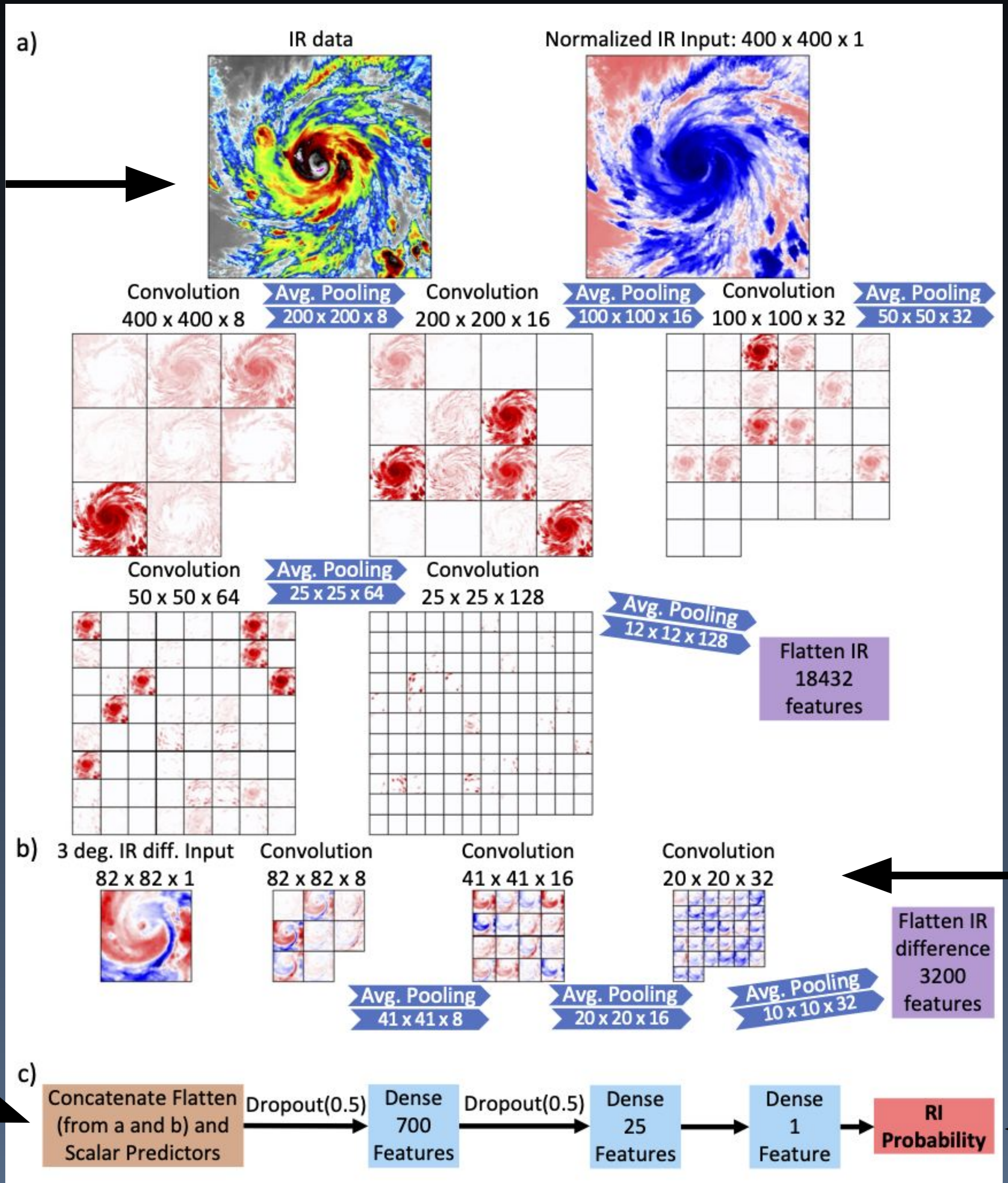
Sarah Griffin, Tony Wimmers and Chris Velden

AI-RI

Overview

IR data: 400x400 grid at 4km resolution, normalized.

5 convolution and pooling layers where the scale gradually increases and more feature maps are added.



AI-RI is an ensemble of output from 5 different CNNs with the same configuration

IR differencing data: 82 x 82 grid at 4km resolution, normalized.

3 convolution and pooling layers.

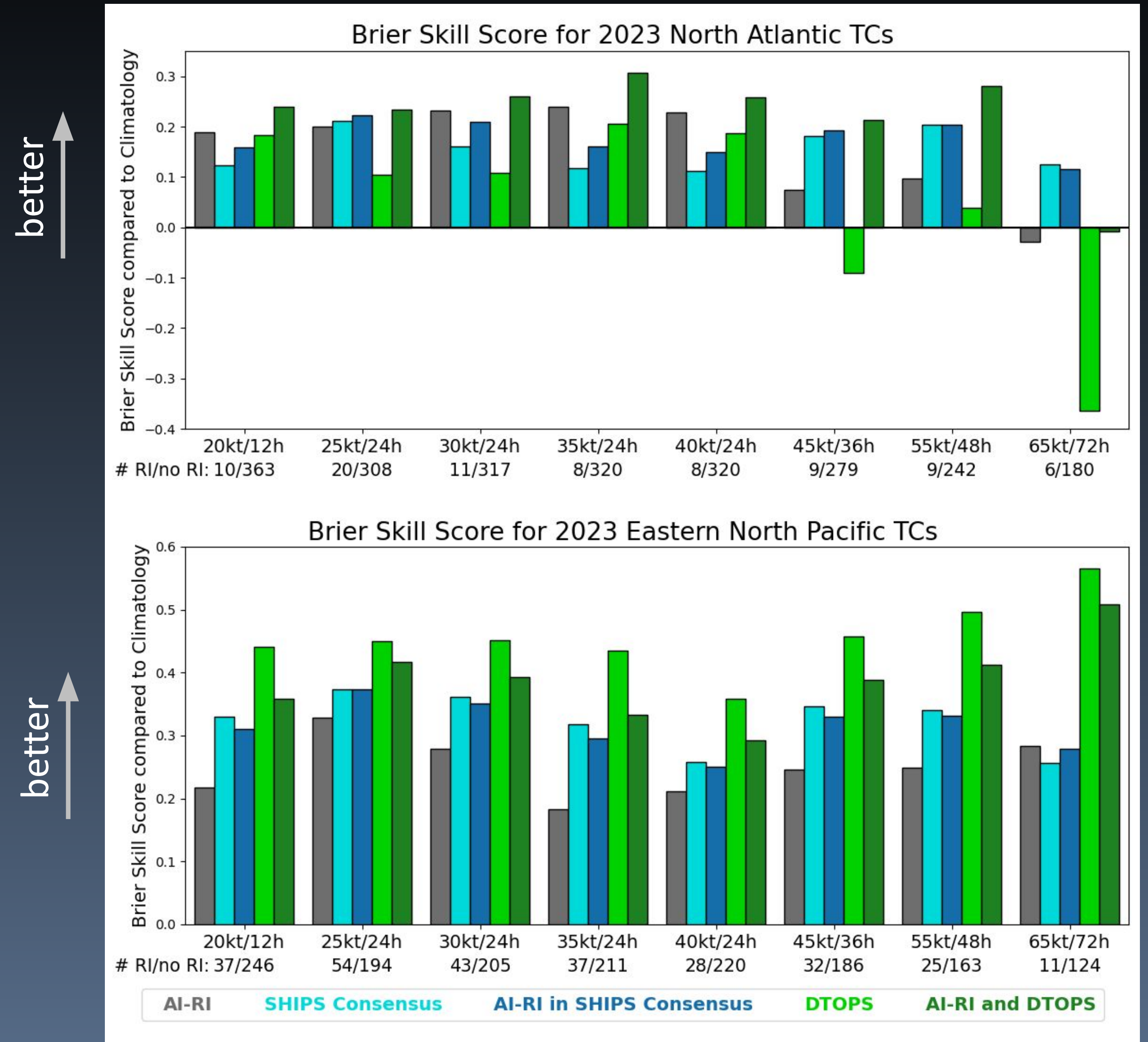
Add normalized scalar features from SHIPS lsdiag file.

Probability of RI from 0-1

AI-RI

2023 Real-time results

- AI-RI was more skillful than SHIPS Consensus and DTOPS for 4 RI thresholds in the North Atlantic in 2023
  - 20/12, 30/24, 35/24, and 40/24.
  - Taking the **average of the AI-RI probability and DTOPS probability** is the more skill for 7 RI thresholds (not 65/72).
- Least skillful in eastern North Pacific than SHIPS Consensus and DTOPS, and averaging did not improve skill



AI-RI

Homepage

Ida at 08/29/21 12 UTC. Intensity = 130 kts, MPI = 166 kts

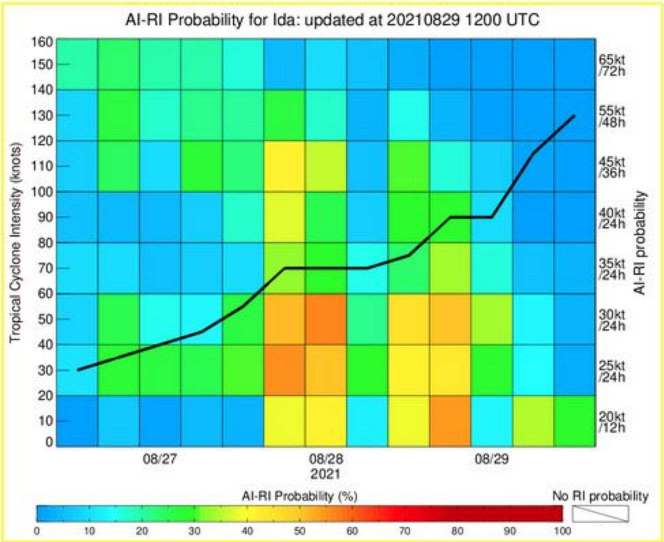
Ida History

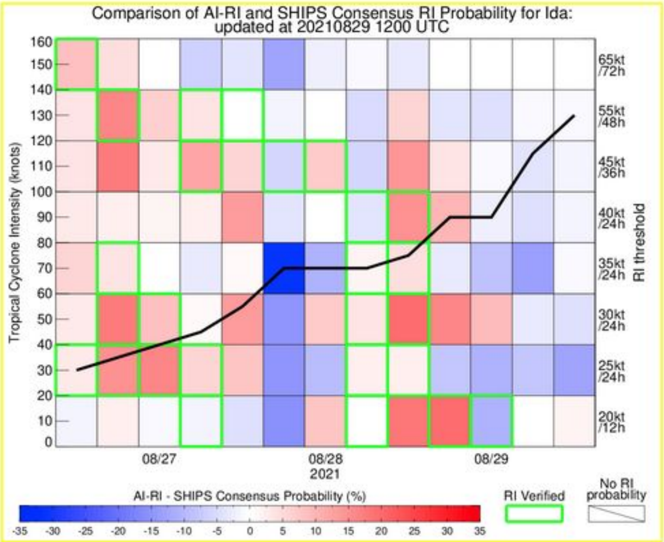
AI-RI Matrix of RI probabilities

RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
AI-RI	29.3%	2.8%	3.1%	3.6%	0.1%	0.2%	0.0%	0.0%
AI-RI in SHIPS Consensus	27.9%	12.5%	6.5%	4.5%	1.3%	1.3%	0.7%	0.0%
AI-RI and DTOPS	14.6%	1.5%	1.6%	1.8%	0.0%	0.1%	0.0%	0.0%

SHIPS Matrix of RI probabilities

RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
SHIPS Consensus	27.4%	15.8%	7.6%	4.9%	1.7%	1.7%	1.0%	0.0%
SHIPS-RII	39.4%	17.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Logistic Regression	33.4%	29.3%	22.6%	14.0%	4.9%	5.1%	3.0%	0.0%
Bayesian	9.5%	0.5%	0.3%	0.6%	0.2%	0.0%	0.0%	0.0%
DTOPS	0.0%	25.0%	22.0%	16.0%	0.0%	0.0%	0.0%	0.0%





M-PERC

Microwave-based Probability of Eyewall Replacement Cycle

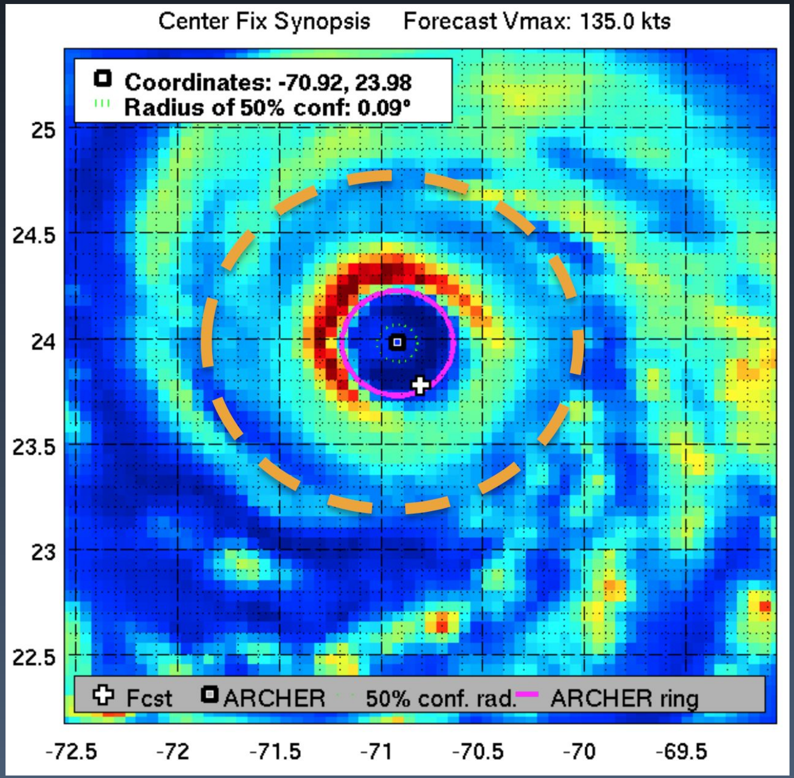
A method for determining the onset of ERCs

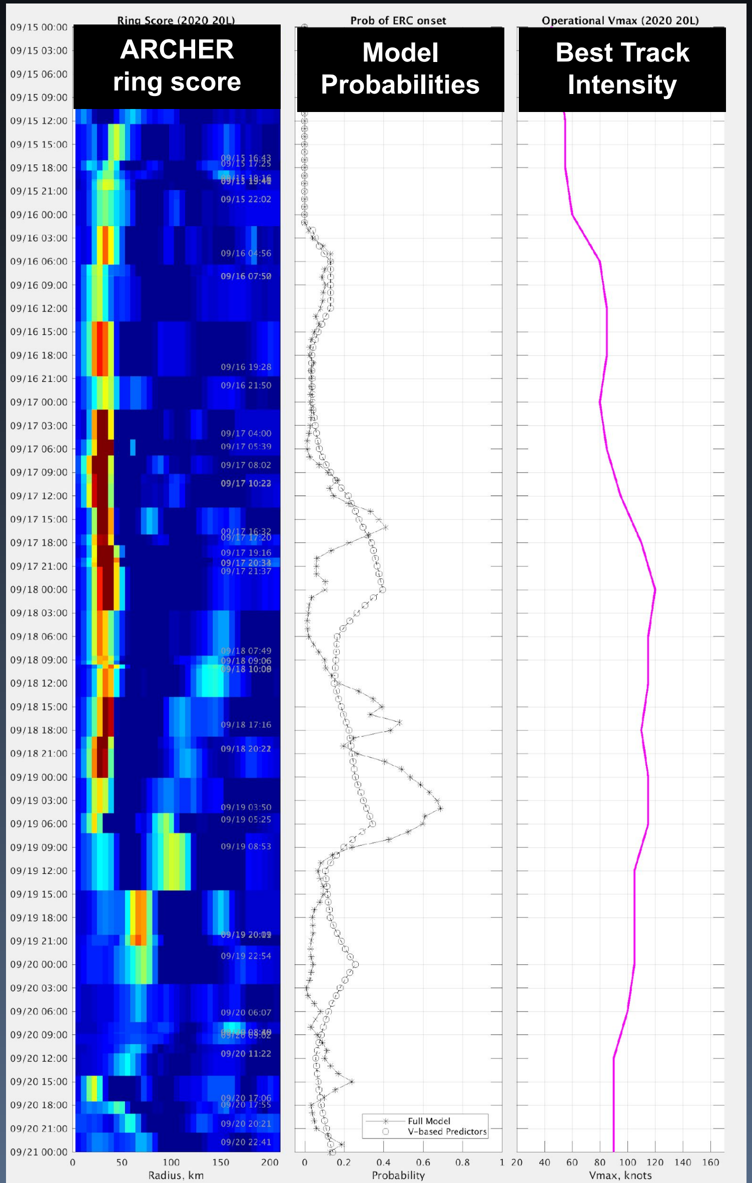
Derrick Herndon, Tony Wimmers and Chris Velden

M-PERC

Overview

- Uses 89GHz ring score from ARCHER plotted in Hovmöller diagram to show evolution of features.





- ARCHER ring score plotted versus time shows a branching/merging patter during ERCs.

M-PERC

Motivation

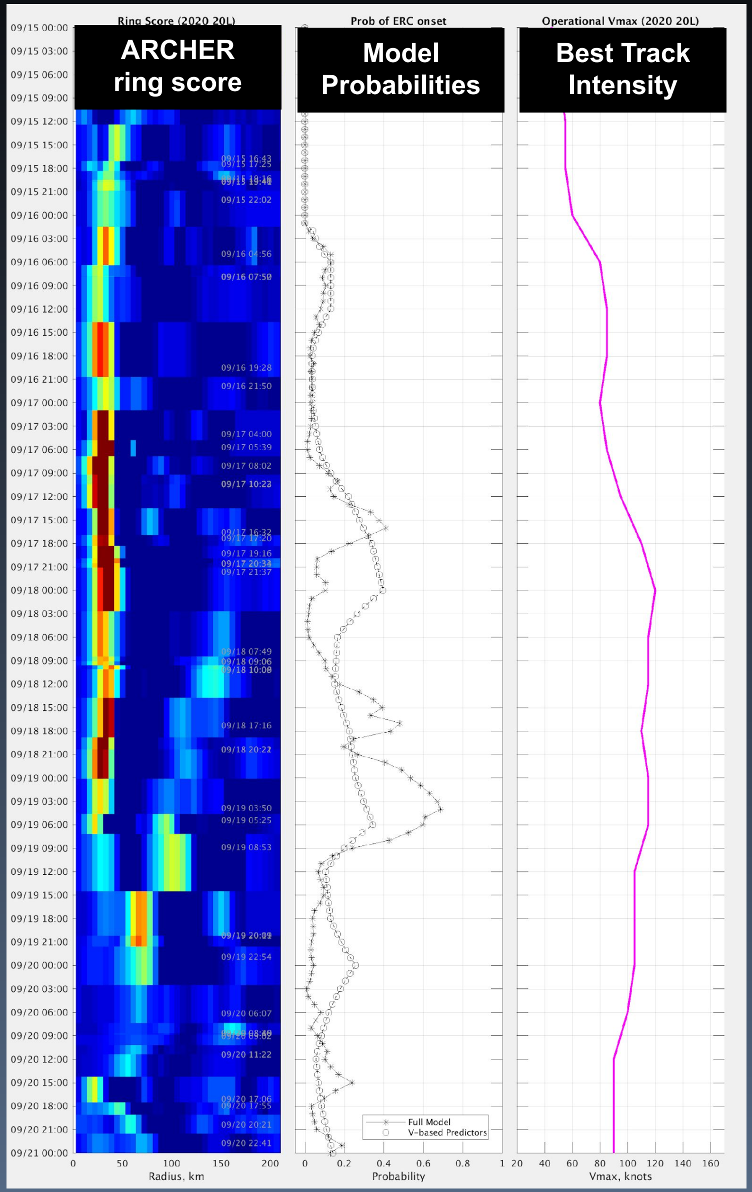
Guidance to forecasters:

- Increase attention when probabilities exceed **25%.**
- Probabilities > **70%** likely will result in weakening
- Average lead time to change in intensity trend ~ 10h

- Cat 1-2 ERCs are faster and result in less weakening or none at all (a pause in RI)
- Cat 4-5 ERCs take longer and result in more weakening. TCs may not return to previous intensity.

Model is sensitive to Vmax.

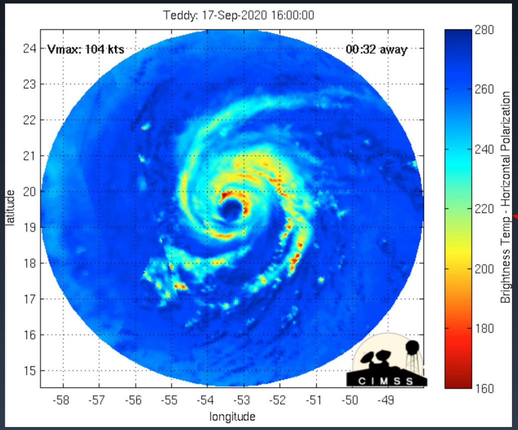
- Probabilities only output for Vmax > 65 knots.
- Uncertainty of 10 knots in Vmax results in ~ 10% change in M-PERC



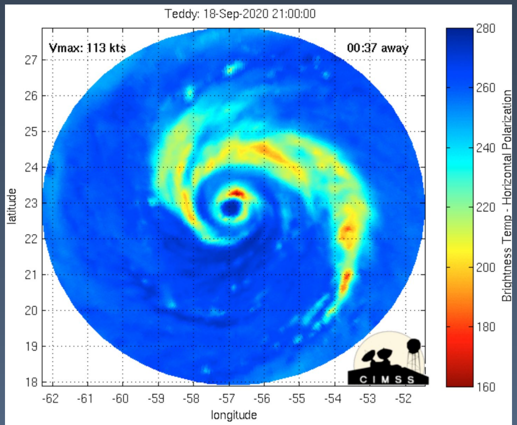
M-PERC

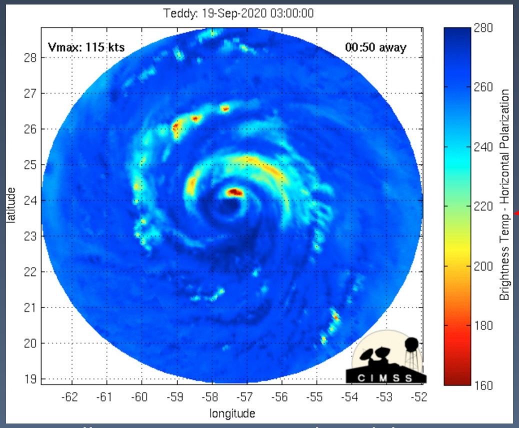
Types of ERC Events

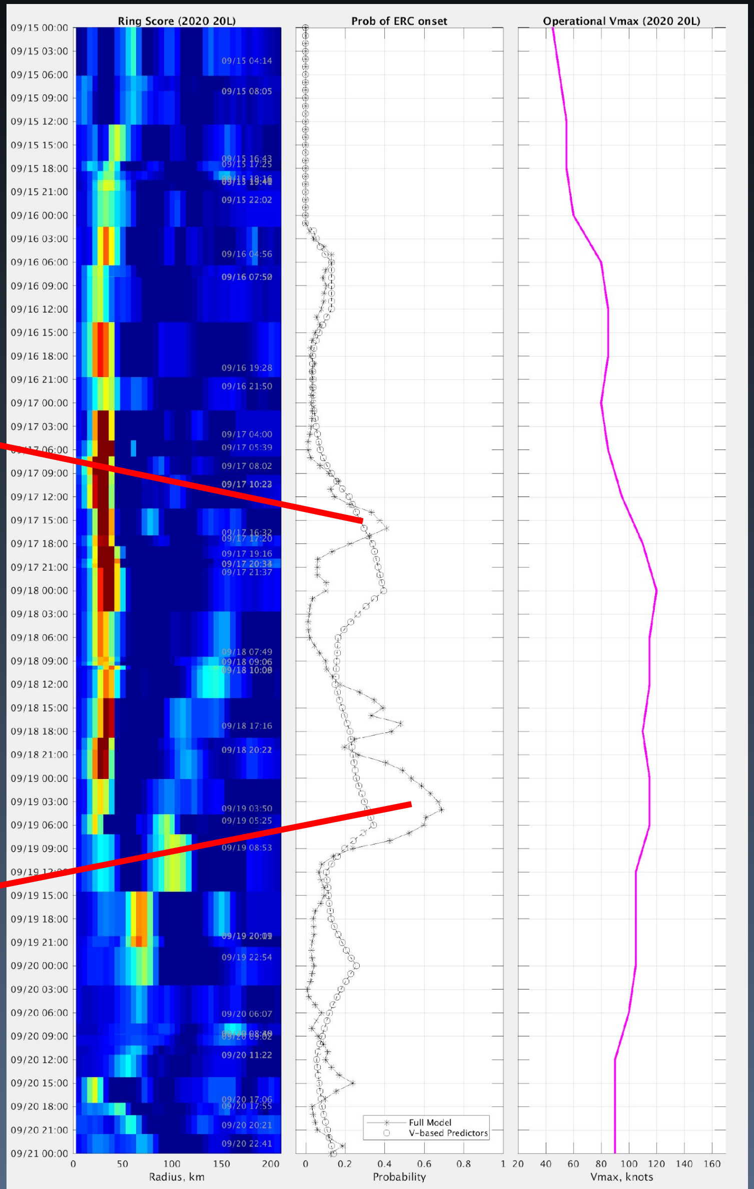
Fast Evolving: early events with lower probability that has less impact on Vmax.



Higher Probability: Larger impact on Vmax. More likely to cause weakening.





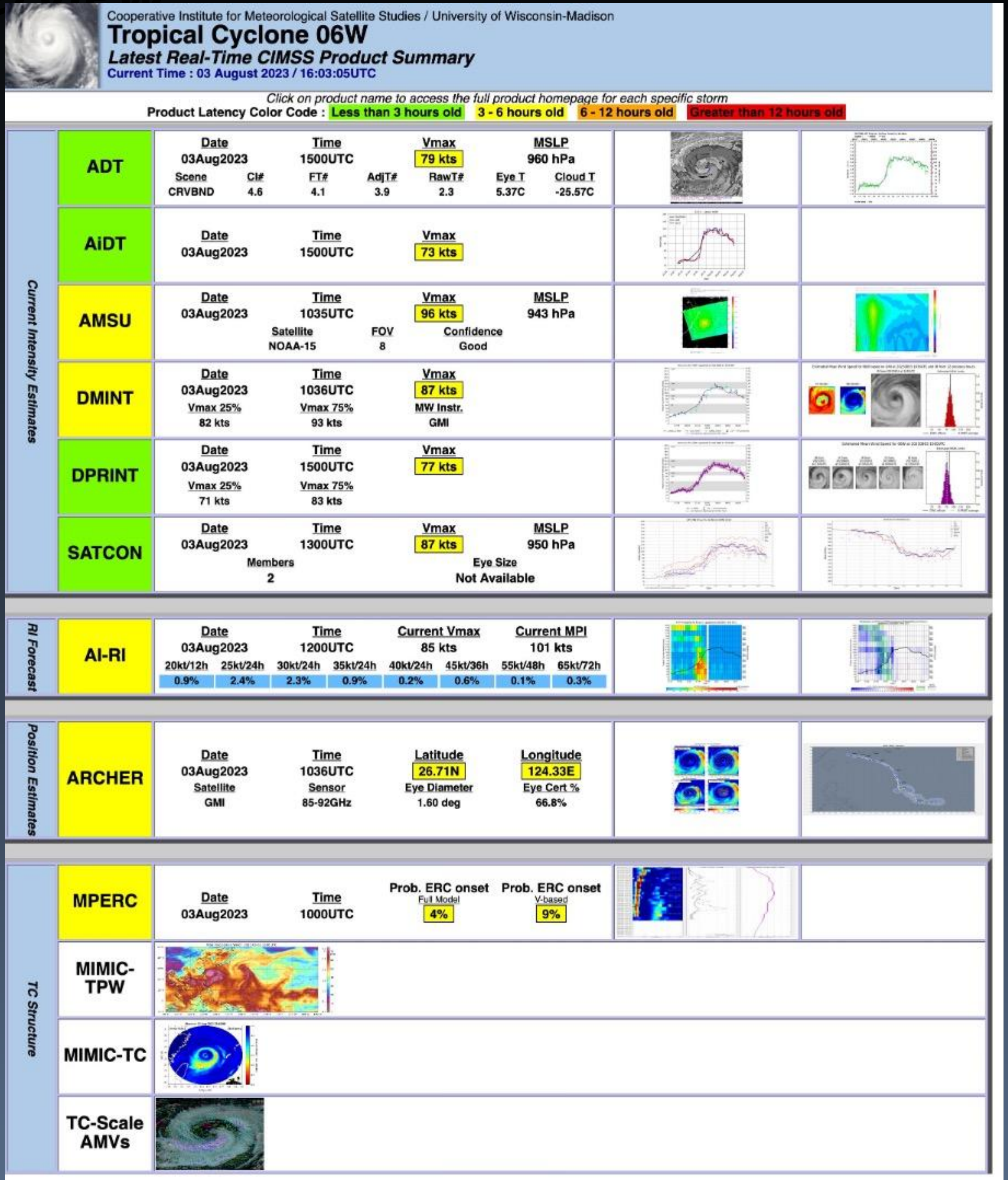


Kossin, J. P., D. C. Herndon, A. J. Wimmers, X. Guo, and E. S. Blake, 2023: M-PERC: A New Satellite Microwave-Based Model to Diagnose the Onset of Tropical Cyclone Eyewall Replacement Cycles. *Wea. Forecasting*, **38**, 1405–1411.

Conclusions

Ways to view our products:

1. CIMSS website
   a) Everything I've dicussed: ADT, AiDT, D-MINT and D-PRINT, SATCON, AI-RI, M-PERC and more!
   b) Either view the product pages or the CIMSS summary page
2. Operational partners
   a) ADT is run by NESDIS
   b) AiDT and SATCON are transitioning to operations at NOAA


Cooperative Institute for Meteorological Satellite Studies / University of Wisconsin-Madison

Tropical Cyclone 06W

Latest Real-Time CIMSS Product Summary

Current Time : 03 August 2023 / 16:03:05UTC

Click on product name to access the full product homepage for each specific storm

Product Latency Color Code : Less than 3 hours old | 3 - 6 hours old | 6 - 12 hours old | Greater than 12 hours old

Current Intensity Estimates	ADT	Date 03Aug2023; Time 1500UTC; Vmax 79 kts; MSLP 960 hPa; Scene CRVBND; CI# 4.6; FT# 4.1; AdjT# 3.9; RawT# 2.3; Eye T 5.37C; Cloud T -25.57C
	AiDT	Date 03Aug2023; Time 1500UTC; Vmax 73 kts
	AMSU	Date 03Aug2023; Time 1035UTC; Vmax 96 kts; MSLP 943 hPa; Satellite NOAA-15; FOV 8; Confidence Good
	DMINT	Date 03Aug2023; Time 1036UTC; Vmax 87 kts; Vmax 25% 82 kts; Vmax 75% 93 kts; MW Instr. GMI
	DPRINT	Date 03Aug2023; Time 1500UTC; Vmax 77 kts; Vmax 25% 71 kts; Vmax 75% 83 kts
	SATCON	Date 03Aug2023; Time 1300UTC; Vmax 87 kts; MSLP 950 hPa; Members 2; Eye Size Not Available
RI Forecast	AI-RI	Date 03Aug2023; Time 1200UTC; Current Vmax 85 kts; Current MPI 101 kts; 20kt/12h 0.9%; 25kt/24h 2.4%; 30kt/24h 2.3%; 35kt/24h 0.9%; 40kt/24h 0.2%; 45kt/36h 0.6%; 55kt/48h 0.1%; 65kt/72h 0.3%
Position Estimates	ARCHER	Date 03Aug2023; Time 1036UTC; Latitude 26.71N; Longitude 124.33E; Satellite GMI; Sensor 85-92GHz; Eye Diameter 1.60 deg; Eye Cert % 66.8%
TC Structure	MPERC	Date 03Aug2023; Time 1000UTC; Prob. ERC onset Full Model 4%; Prob. ERC onset V-based 9%
	MIMIC-TPW	
	MIMIC-TC	
	TC-Scale AMVs	