An overview of
UW-CIMSS Tropical Cyclone Products

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Tim Olander, Derrick Herndon, Tony Wimmers, Chris Velden

University of Wisconsin-Madison
Cooperative Institute for Meteorological Satellite Studies

Overview

- Advanced Dvorak Technique (ADT) – Version 9.1
- Advanced (AI-enhanced) Dvorak Technique (AiDT)
- DeepMicroIRNet (D-MINT) and DeepIRNet (D-PRINT)
- Satellite Consensus Algorithm (SATCON)
- AI-RI
- ARCHER
- M-PERC

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ADT

The Advanced Dvorak Technique – Version 9.1

An objective algorithm advancing the Dvorak Technique

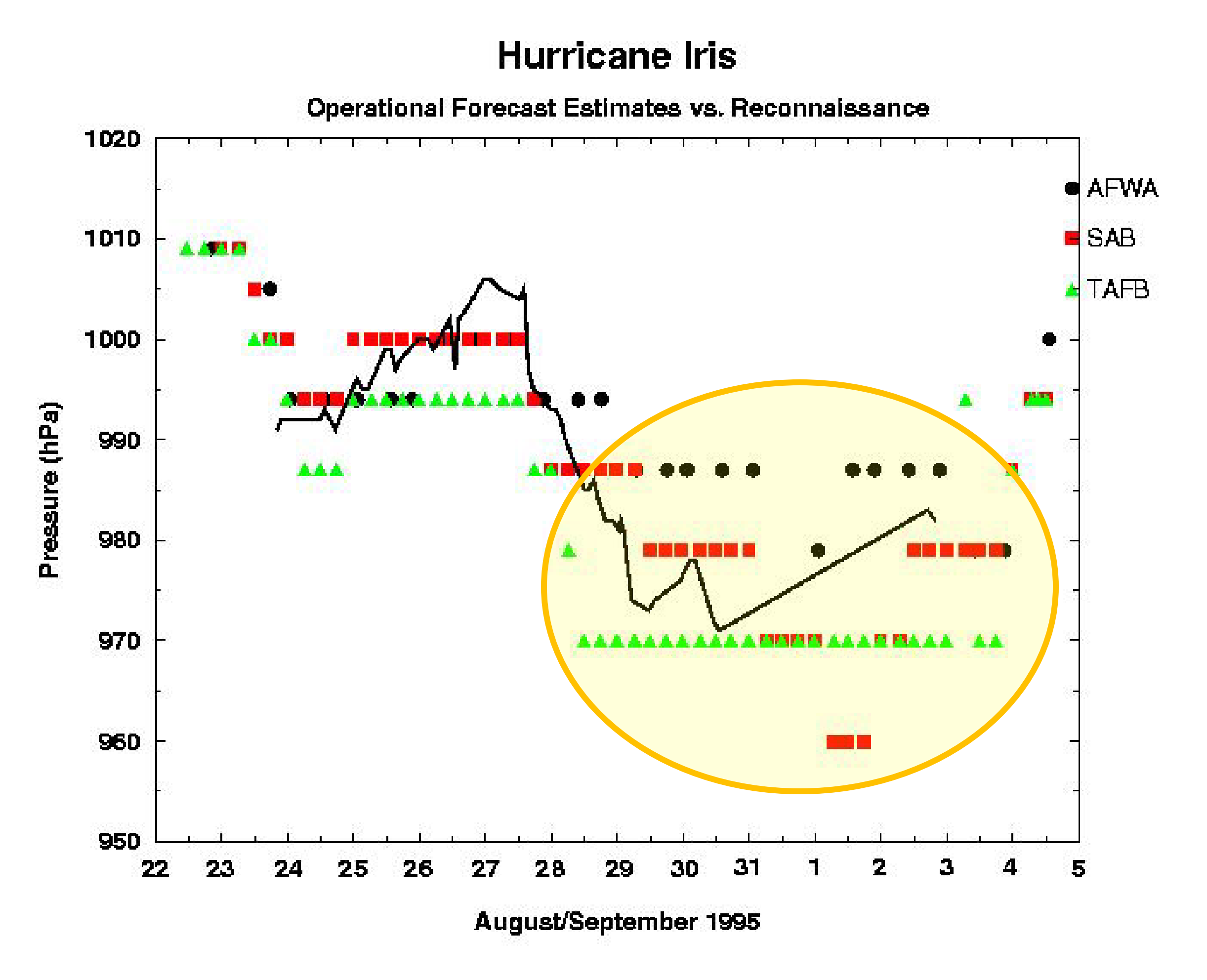
Tim Olander and Chris Velden

Advanced Dvorak Technique (ADT)

Overview

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.
- The first version of the ADT was released in 1998 and has been used operationally since that time.



Highlights:

- NHC routinely cites 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.
- Available in real-time from CIMSS TC webpage.

Advanced Dvorak Technique (ADT)

Latest Algorithm Upgrades

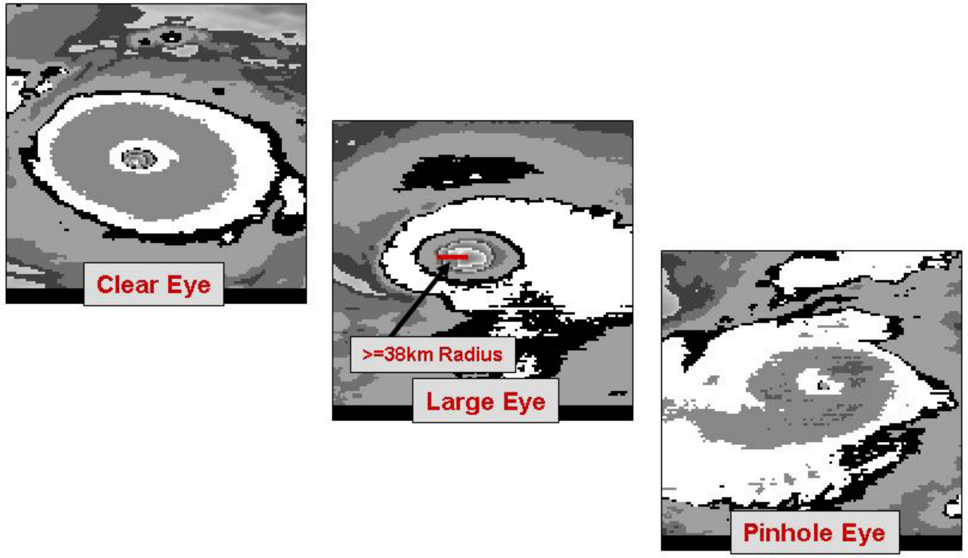
- **Primary ADT-V9.1 upgrades**
  - **Extratropical Transition intensity estimate adjustment**
  - **Analysis of Sub-Tropical systems with modifications to ADT logic**
  - **ARCHER (V2.8) objective algorithm for automated TC center position**
  - **SFC wind radii estimates** *(4 quadrants analysis, based 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)

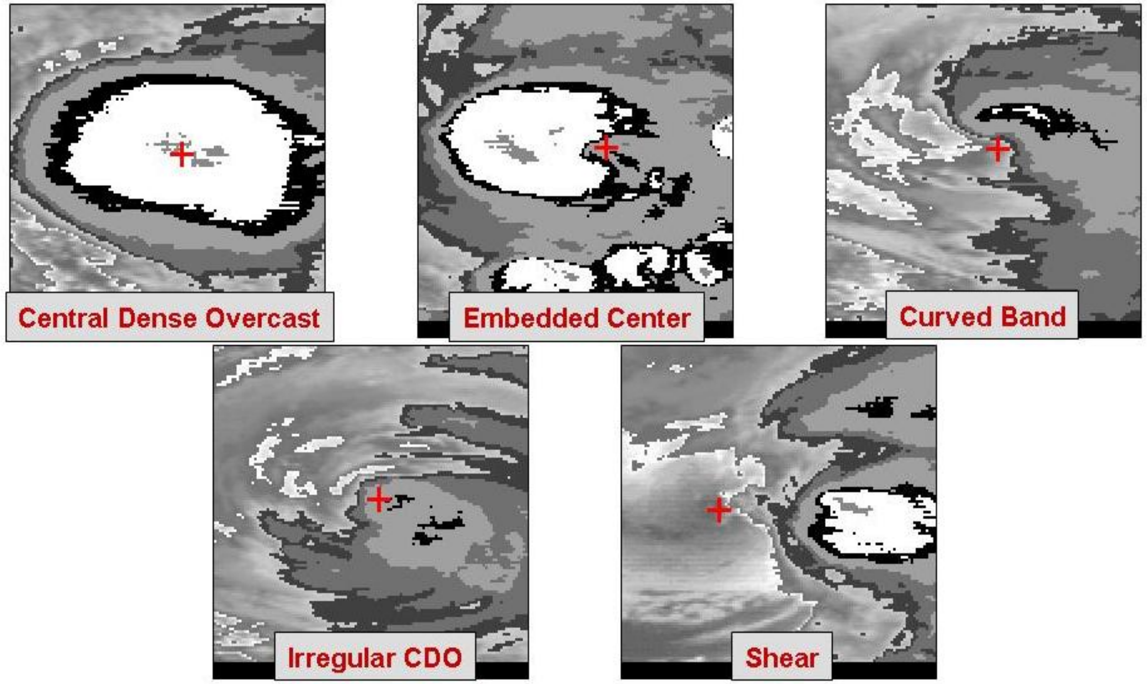
Processing Overview

- 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

- **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!***

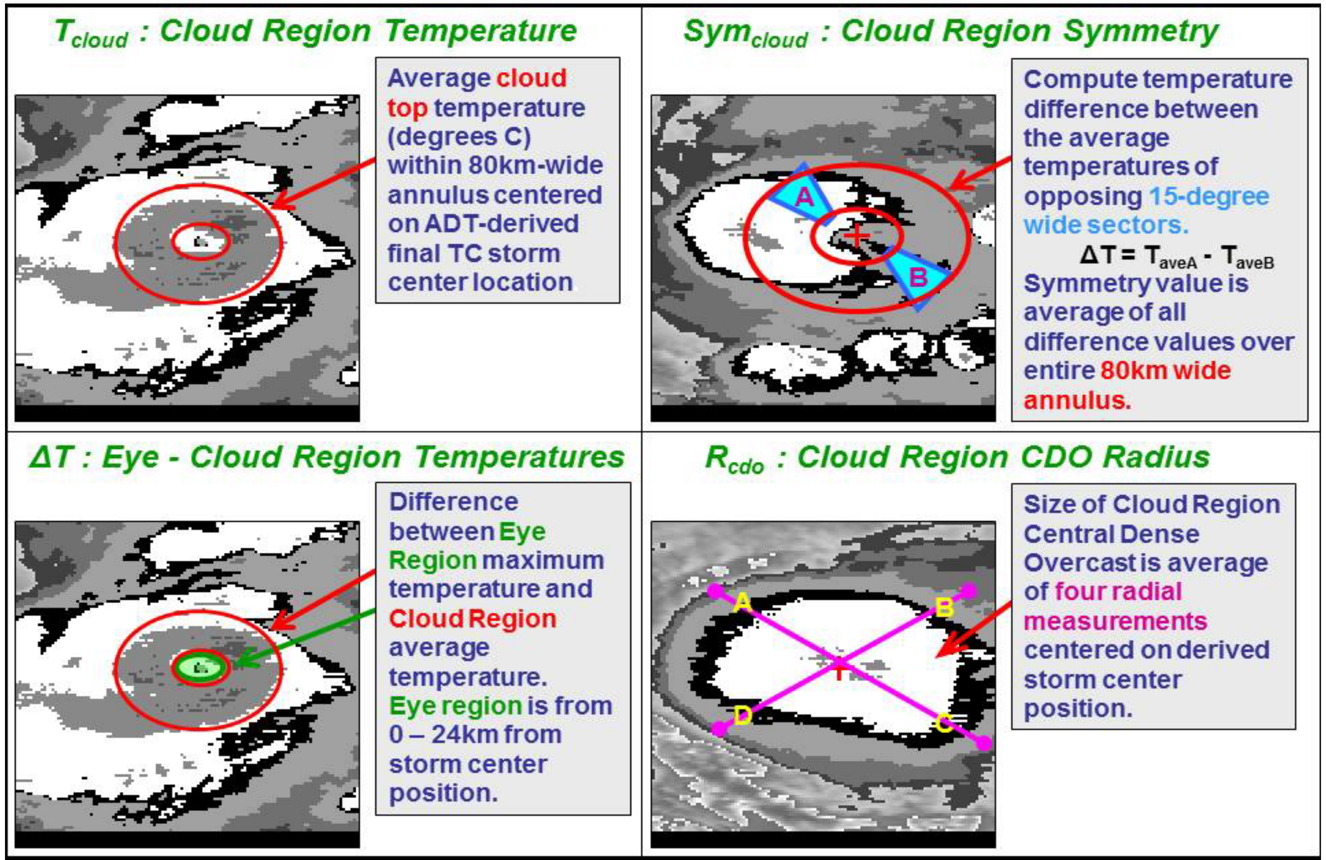
- **ADT still utilizes original DT estimate analysis methodology for Curved Band and Shear scene types.** ***These need to be investigated in the future!***

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 Performance Statistics

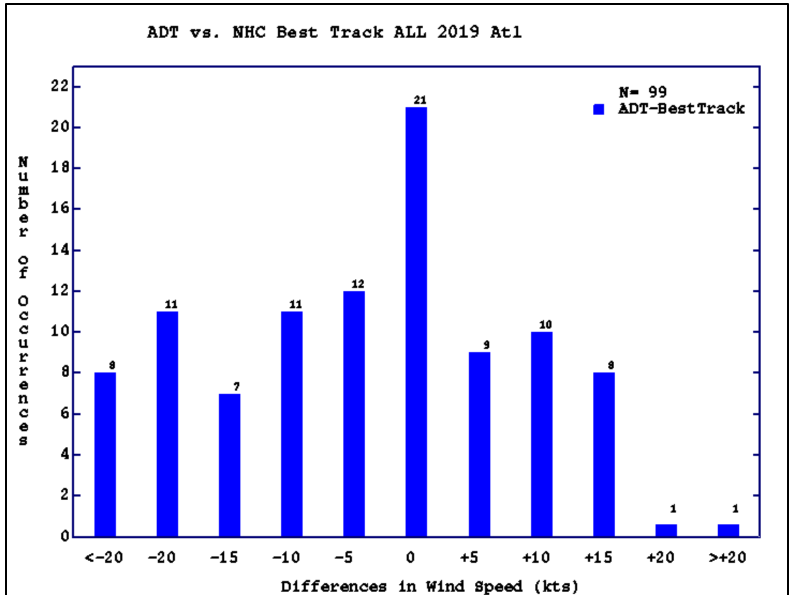
- **2019 Atlantic and E. Pacific results** *(ADT within 30 minutes of Best Track)*
  - Atlantic – NHC Best Track within +/- 3 hours of aircraft reconnaissance
  - +/- Bias equals Over/Underestimate of ADT versus Best Track

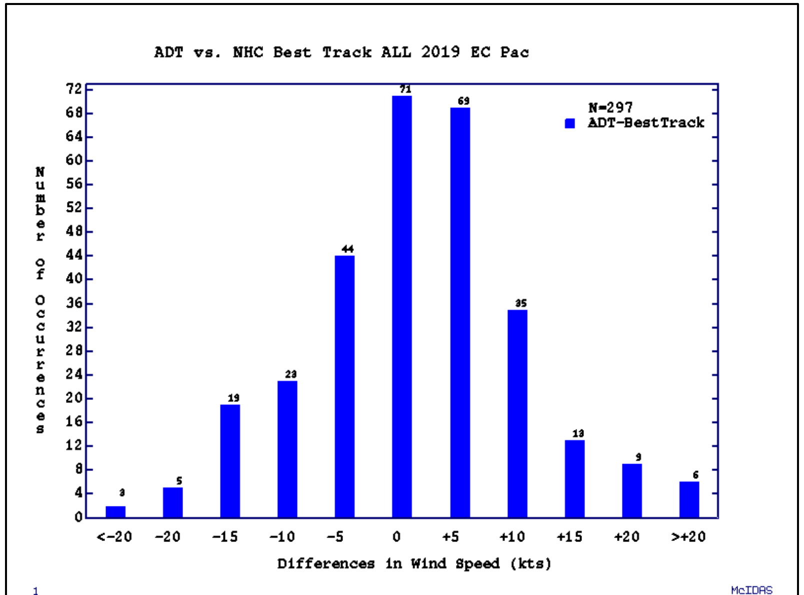
N Atlantic – 99 total matches

	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

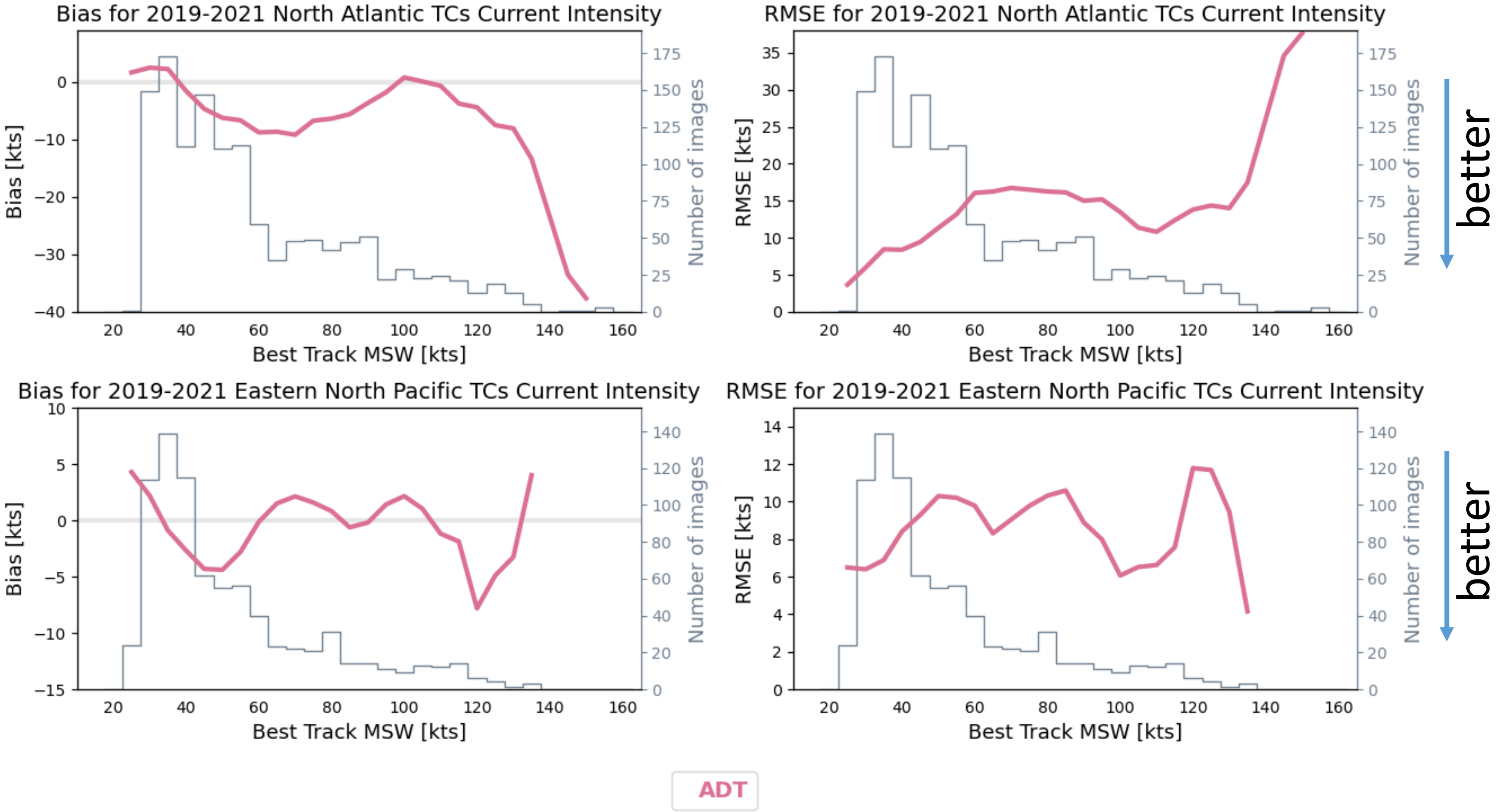




Advanced Dvorak Technique (ADT)

2019-2021 Performance Statistics

What TC intensity does the ADT underpredict the most?

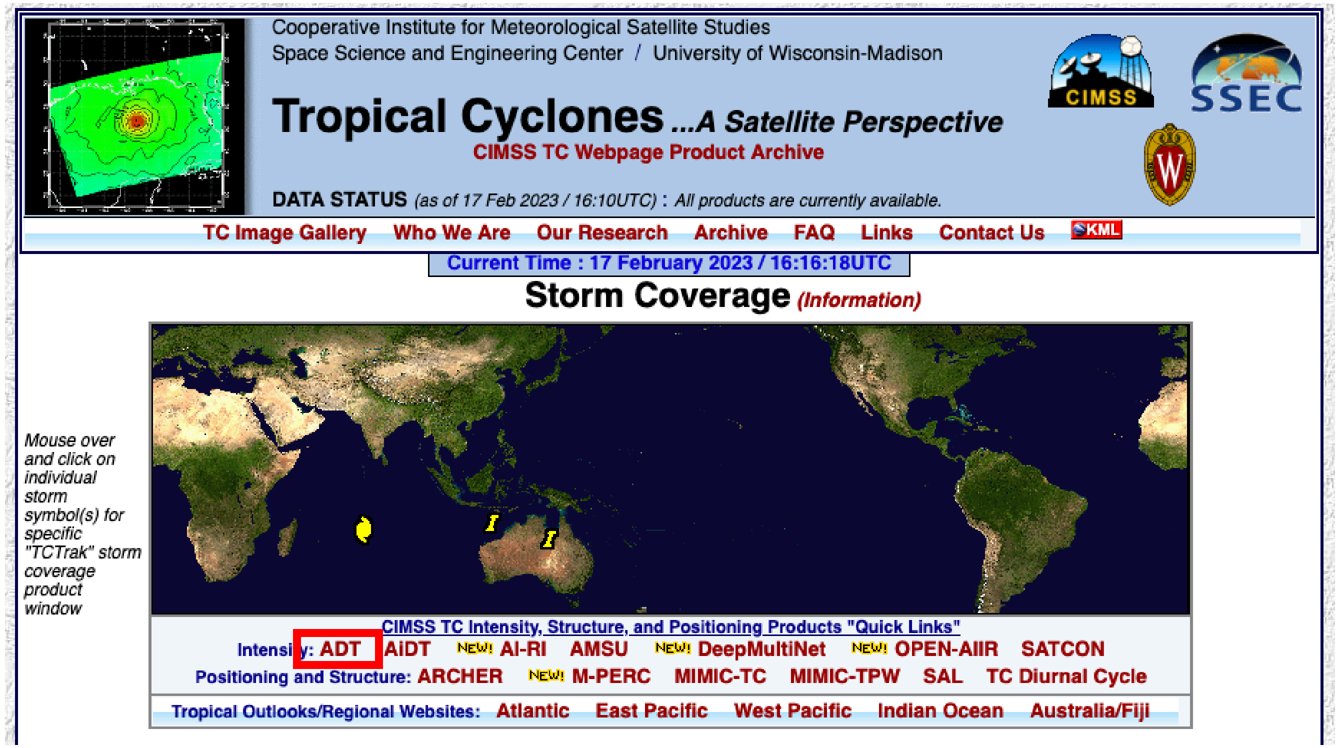


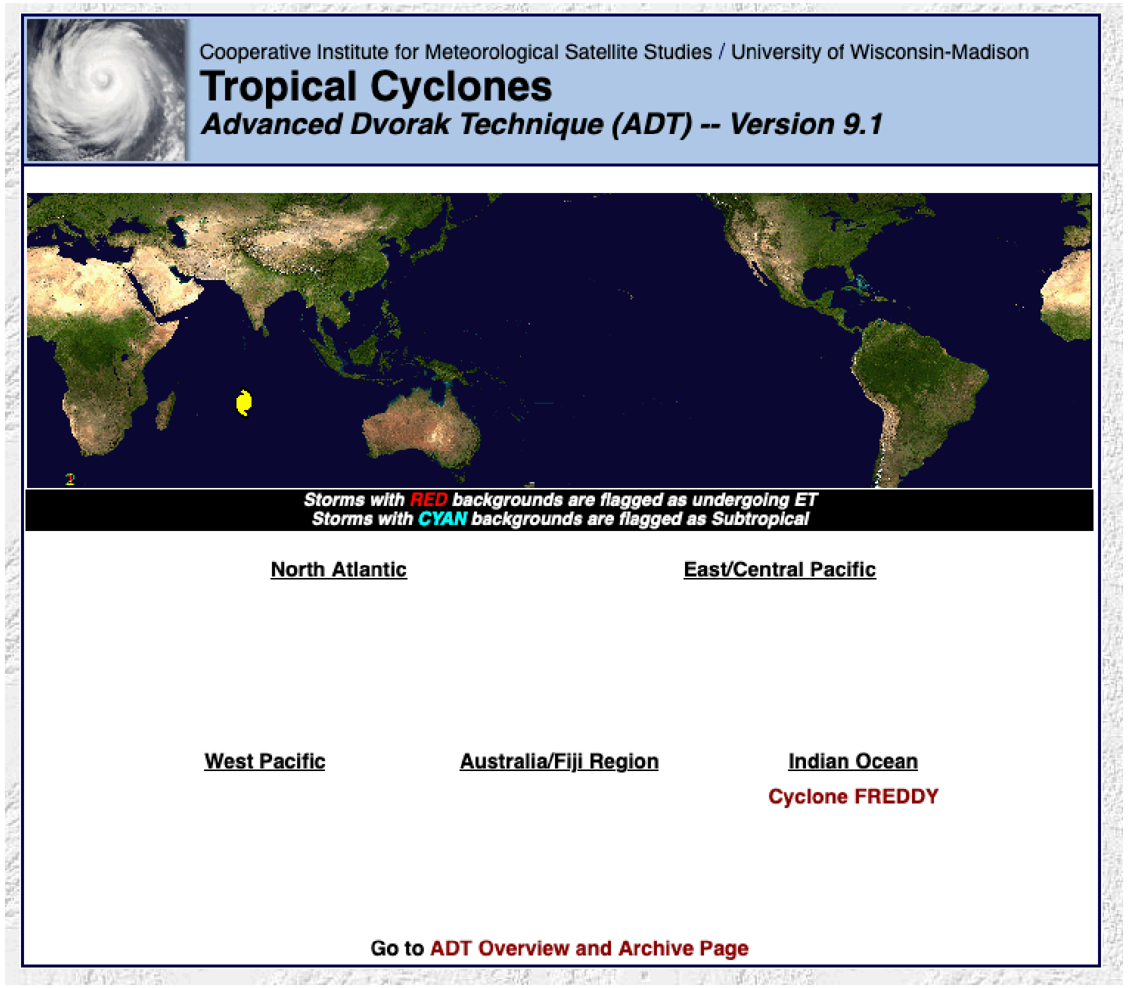
Category 5 TCs have the most negative Bias in the ADT. The ADT also generally underpredicts Category 1 and 2 TCs.

Advanced Dvorak Technique (ADT)

ADT Homepage

Where to find the ADT…





https://tropic.ssec.wisc.edu/real-time/adt

Advanced Dvorak Technique (ADT)

ADT Homepage

Current Intensity Analysis

```
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

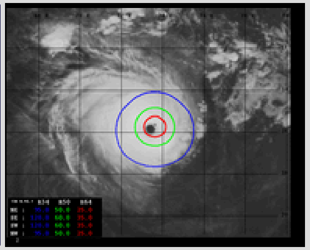
ARCHER Information

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)

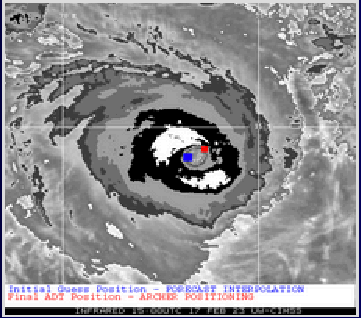
TC forward speed from Forecast Interpolation = 11.6 (kts)

TC heading from Forecast Interpolation = 262.3 (deg)

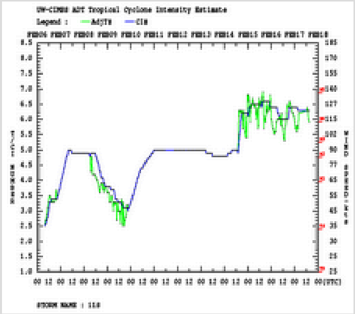
Historical listing of wind radii values

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

Satellite Imagery



Time Series



HTML5 Movie

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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)

Overview

- **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

ADT history file parameters served as model input

AiDT Features *(ADT history file parameters)*		
Raw T#	Sin of Longitude	Cloud Symmetry
Adjusted Raw T#	Cos of Longitude	Curved Band Value
Final T#	Viewing Angle	Curved Band Amount
CI#	Eye FFT	C/W Temperature Distance
Eye Temperature	Cloud FFT	PMW Eye Score
Cloud Temperature	Eye Scene ID value	Extratropical Flag
C/W Temperature	Cloud Scene ID value	Subtropical Flag
Latitude	Eye StdDev	Eye Size (2/eye size)
	Shear Distance	CDO Size

C/W: “Coldest-Warmest”
CDO : “Central Dense Overcast”
PMW: “Passive Microwave”
FFT: “Fast Fourier Transform”

Advanced (AI-enhanced) Dvorak Technique (AiDT)

Final AiDT Model

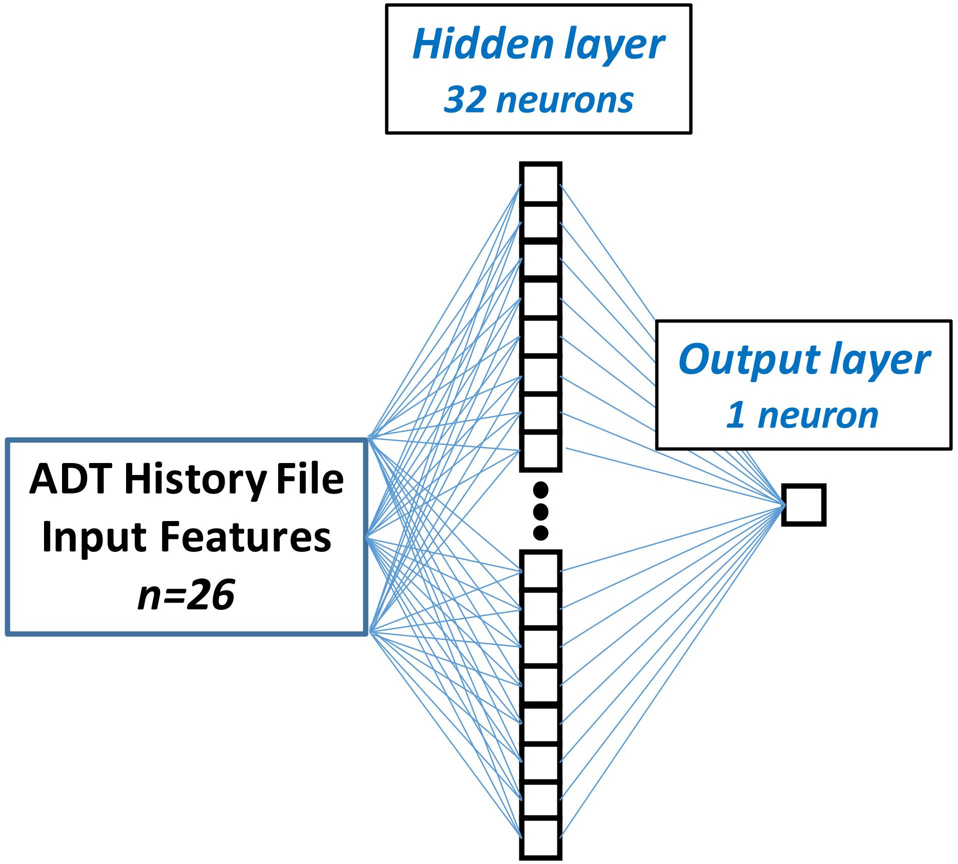
- **Final Model**
  - Fully-connected Deep Neural Network (DNN)
  - Regression-based loss function
  - 26 input ADT History File Features
  - One Hidden (Dense) layer with 32 neurons
  - One Output layer neuron representing a single continuous wind speed estimate value
- **A 3-hour time weighted averaging 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

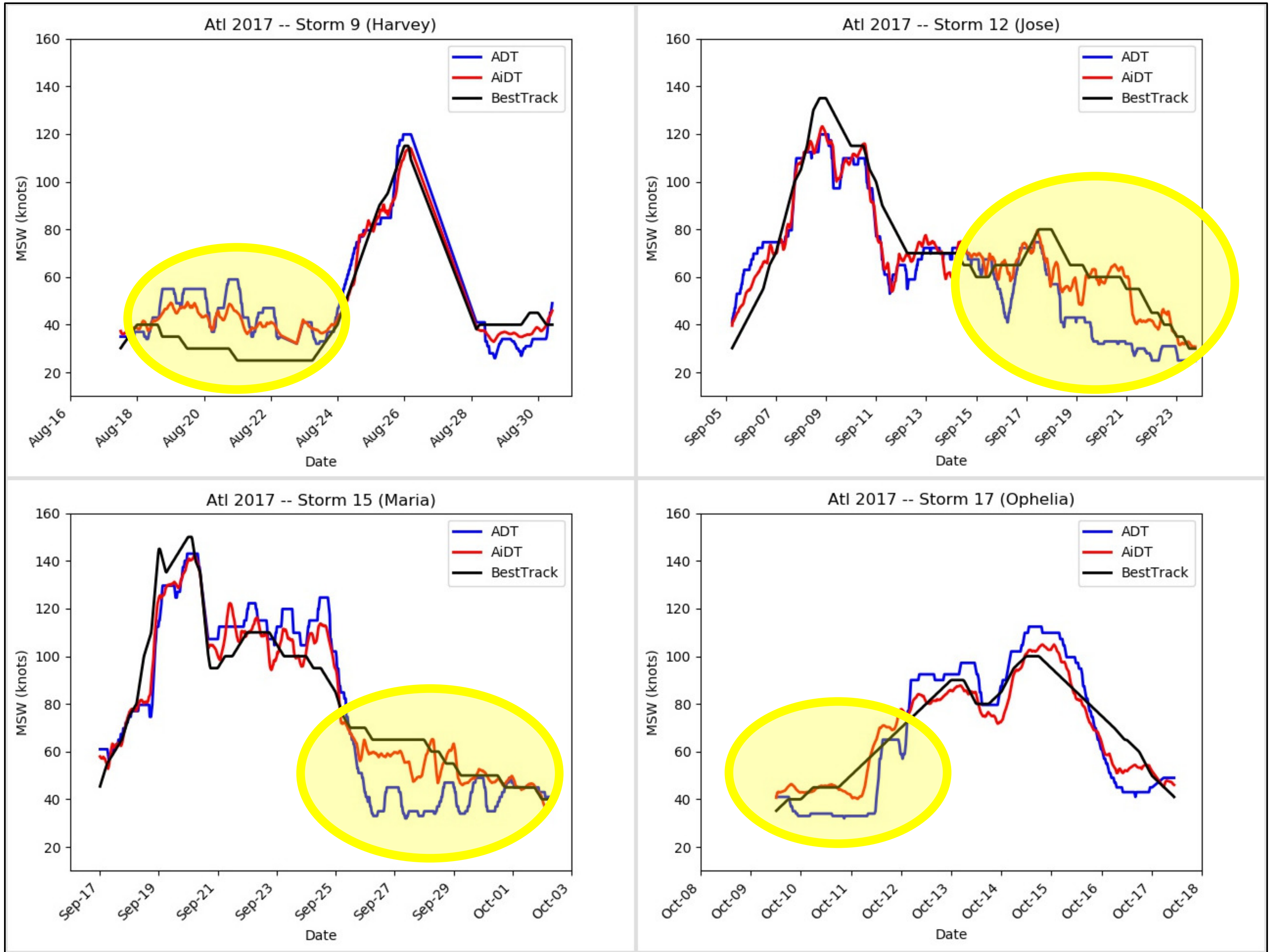
Advanced (AI-enhanced) Dvorak Technique (AiDT)

2017 Storm Examples

- **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**



• AiDT impacts on ADT performance by Scene Type

- 2017 Independent data set
- Using AiDT Regression-based global model

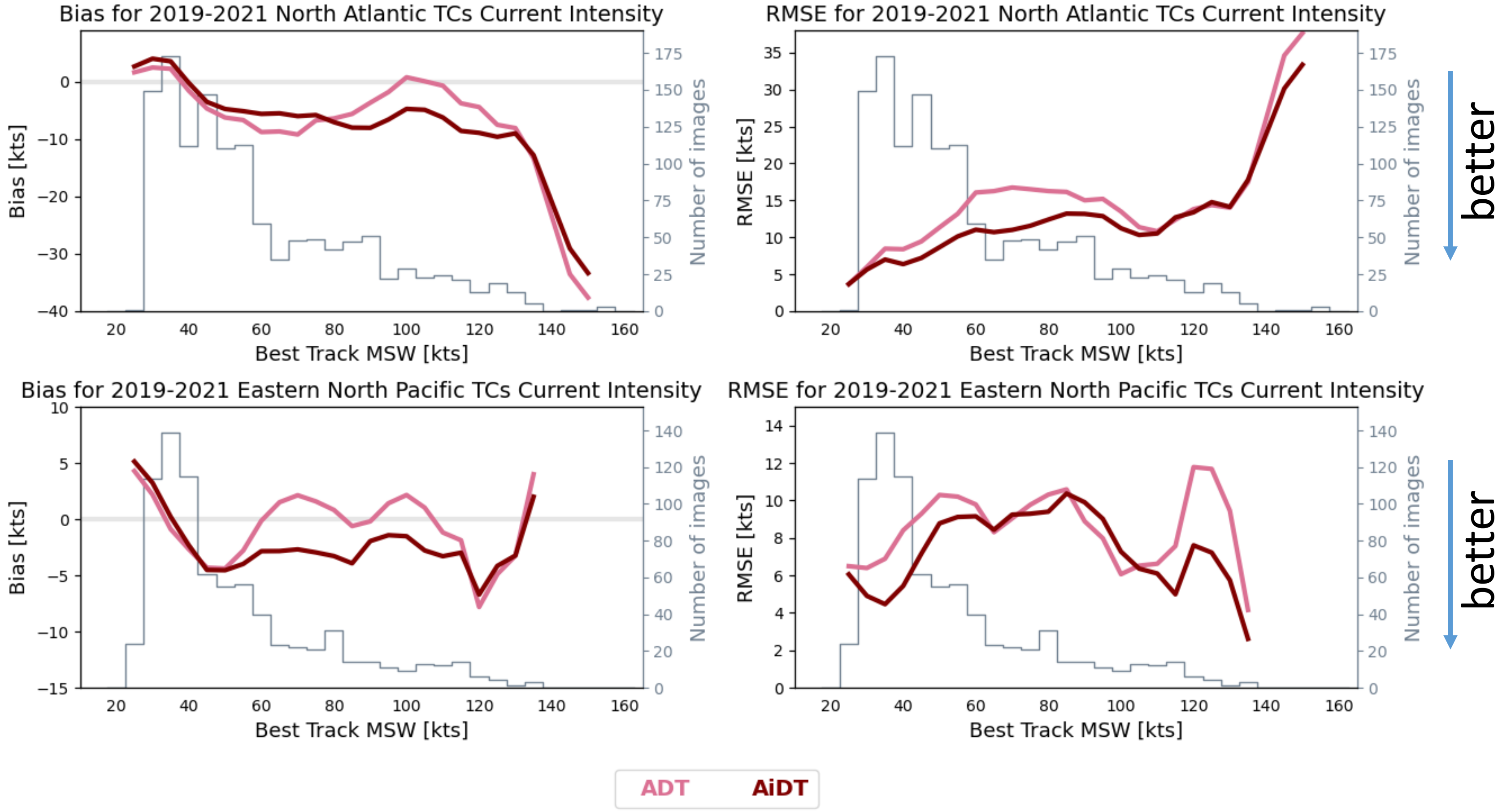
- AiDT reduces error most for ADT estimates using **Curved Band and Shear** scene types as well as also significantly reducing biases, especially for Shear estimates
- **Curved Band and Shear scenes are least studied scene types in ADT algorithm**
- *+/- Bias equals MSW over/underestimate versus Best 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 Dvorak Technique (ADT)

2019-2021 Performance Statistics

What TC intensity is AiDT more skillful than the ADT?

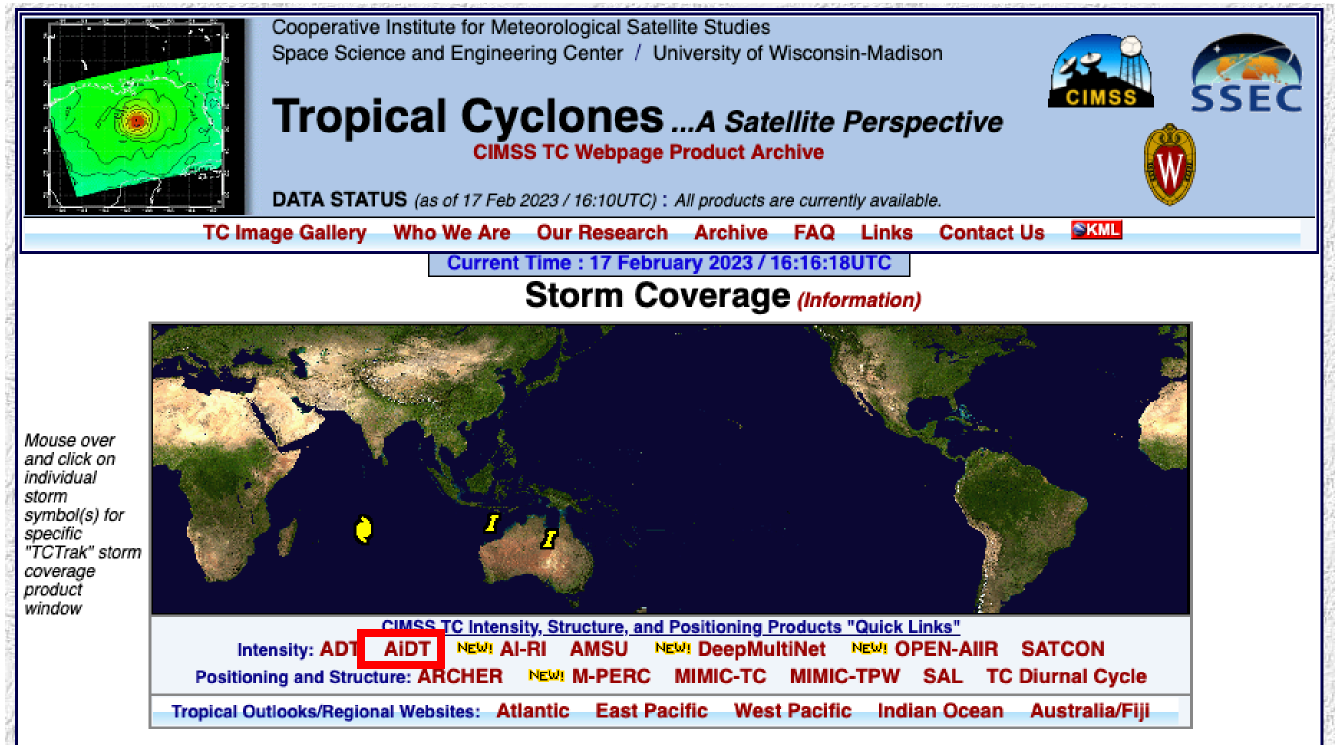


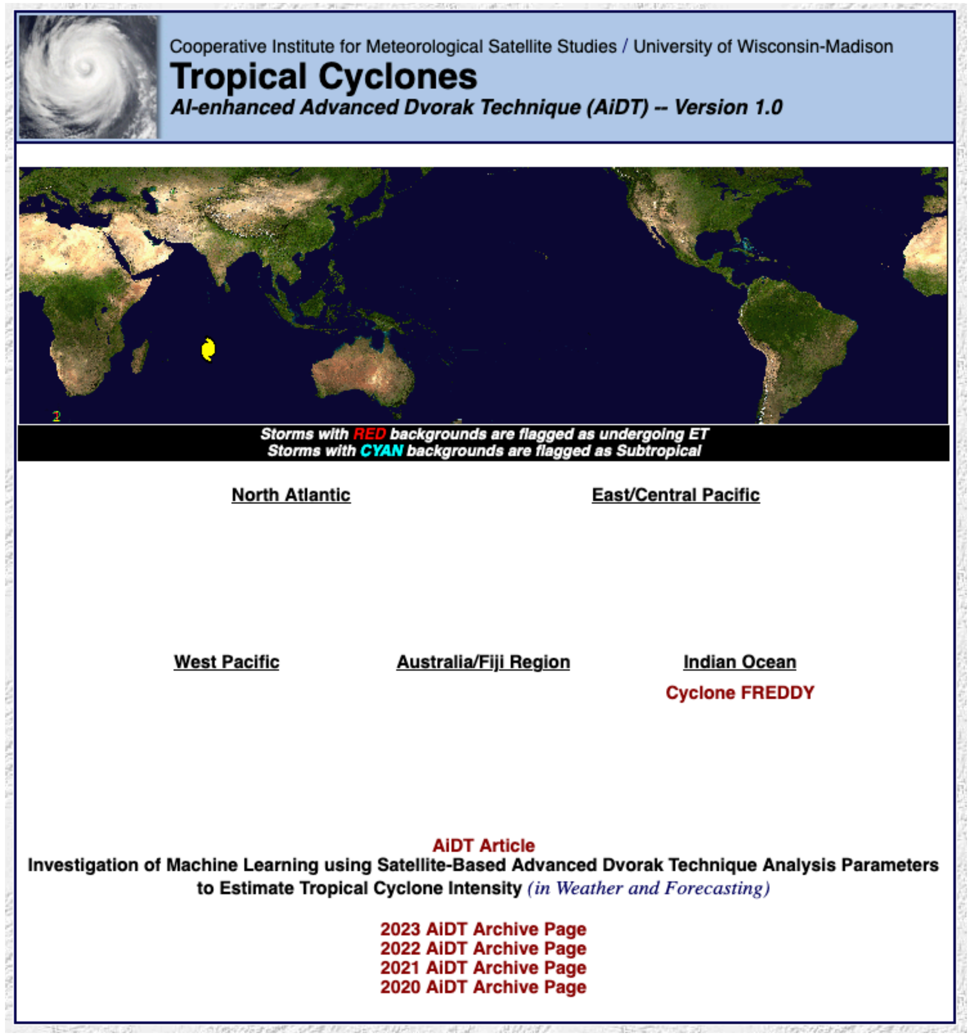
All of them. The RMSE for AiDT is lower or similar to the ADT for all TC intensities.

Advanced (AI-enhanced) Dvorak Technique (AiDT)

AiDT Homepage

Where to find the AiDT…





https://tropic.ssec.wisc.edu/real-time/adt/AiDT/aidt.html

Advanced (AI-enhanced) Dvorak Technique (AiDT)

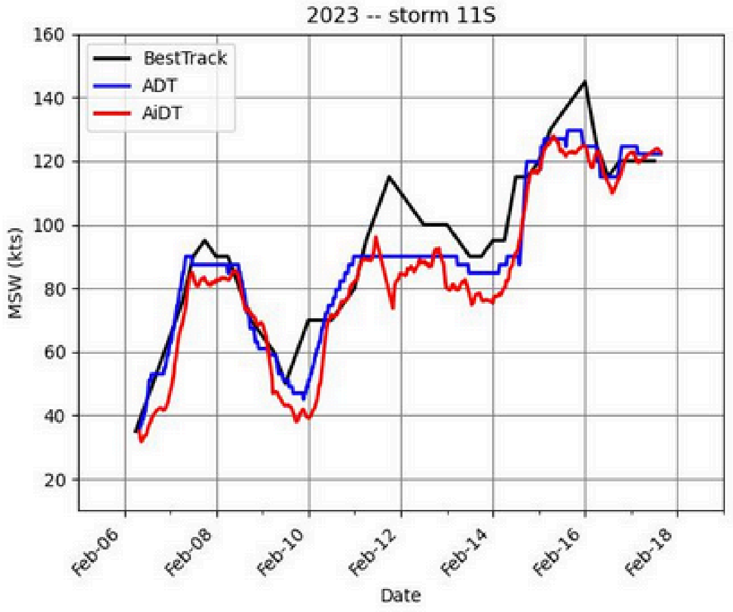
AiDT Homepage

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

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D-MINT and D-PRINT

DeepMicroIRNet and DeepIRNet TC intensity estimators

A convolutional neural network to estimate 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.

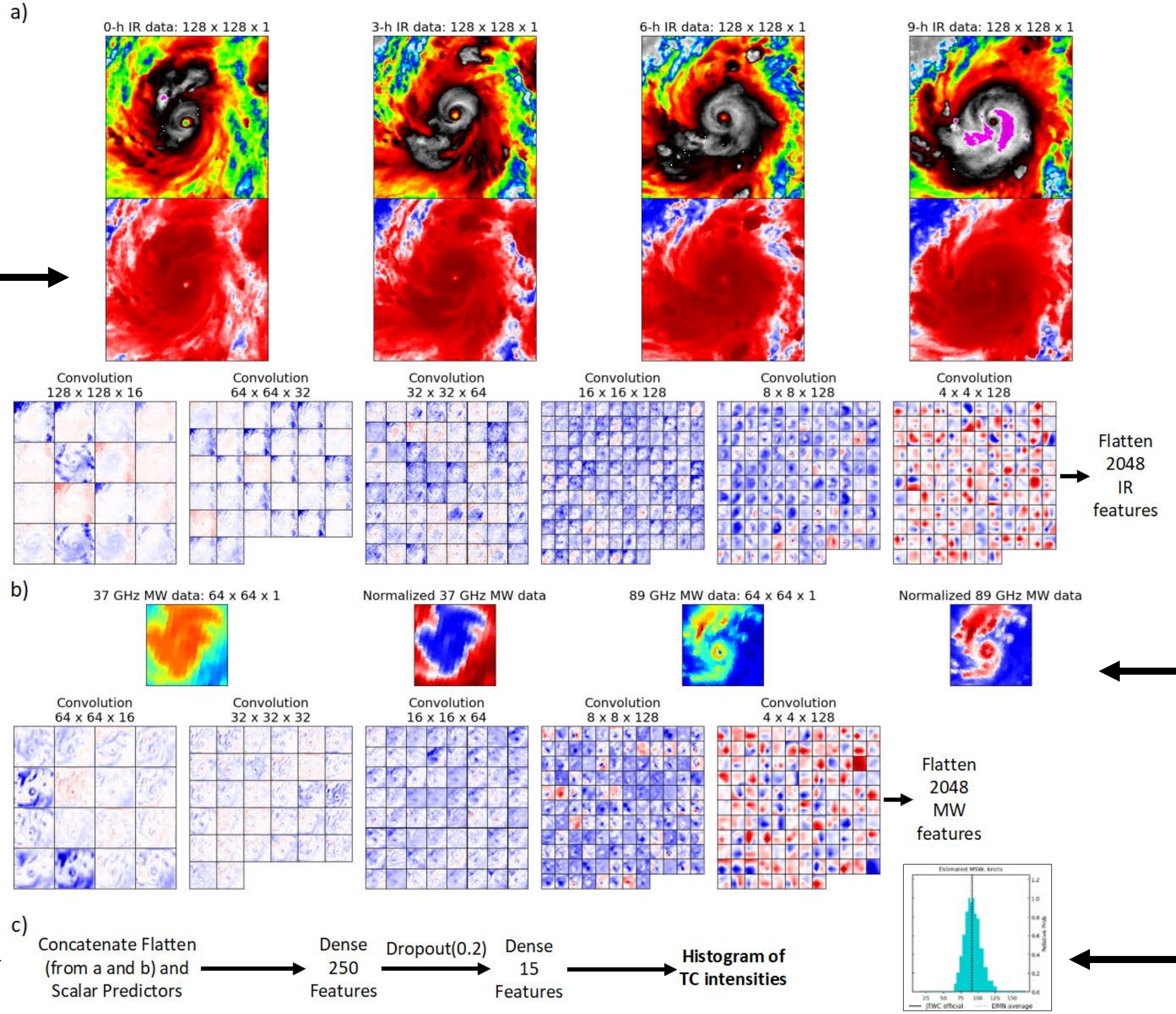
D-MINT and D-PRINT

Overview

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
Steps a), b) and c)

D-PRINT
Steps a) and c) only

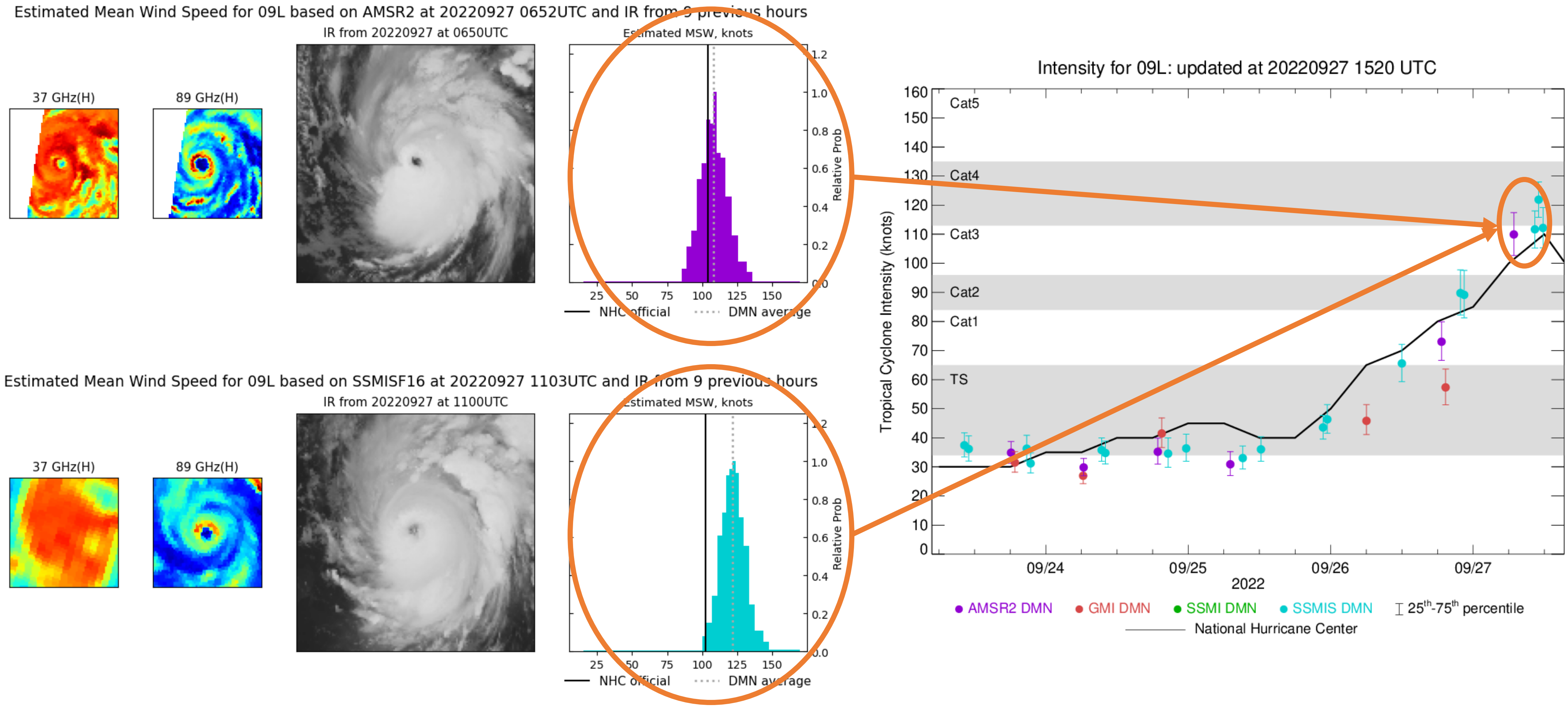
Input Features
MW data: 64 x 64 grid over ~3.2 X 3.2° area centered on TC, normalized.

5 convolution layers
(not included in D-PRINT)

Output: 15 quantiles of TC intensity probabilities

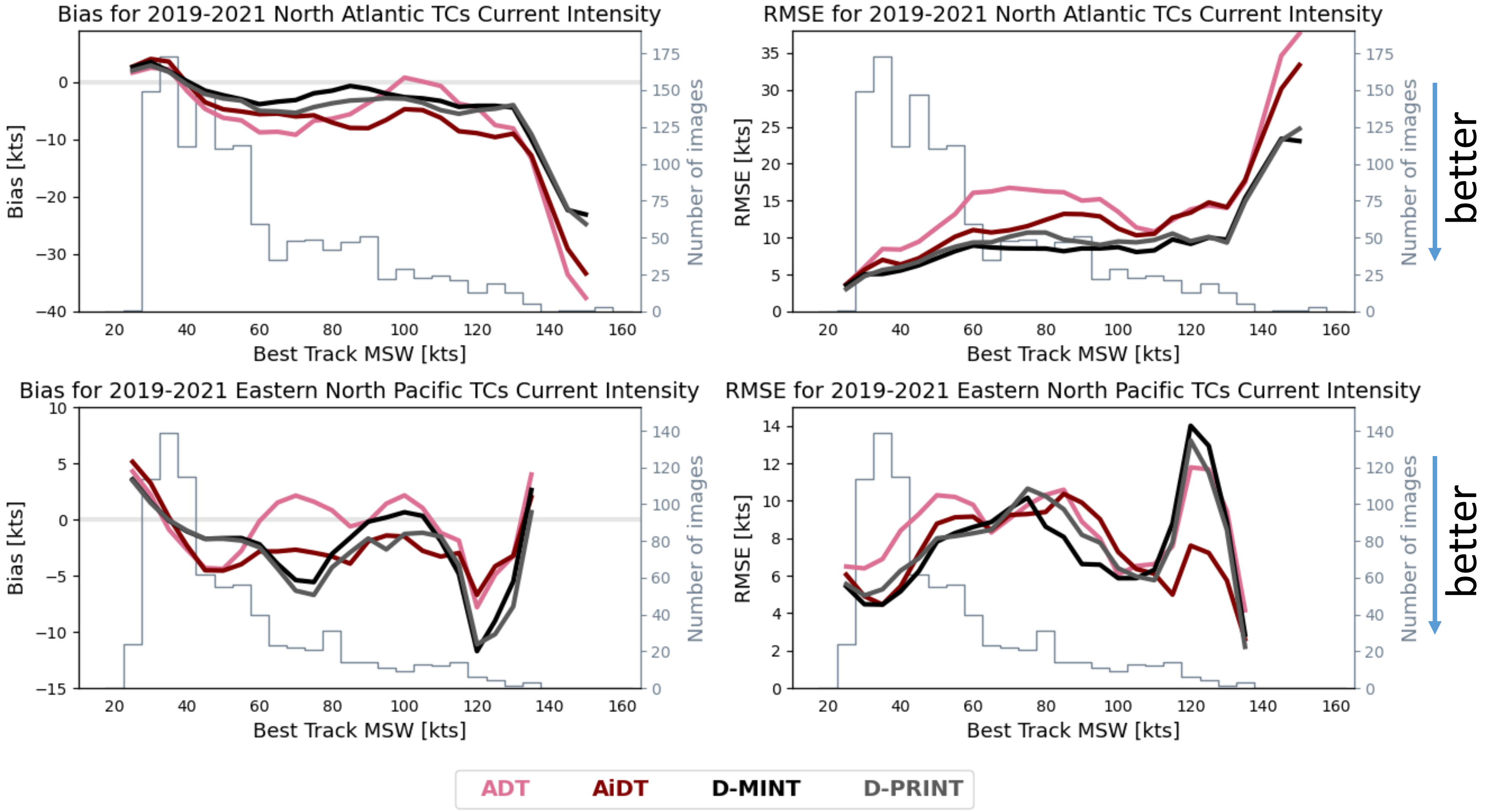
D-MINT and D-PRINT

Example



D-MINT and D-PRINT

2019-2021 Statistical Results



D-MINT is more skillful than D-PRINT, but has a lower temporal resolution.

D-MINT and D-PRINT are more skillful than ADT or AiDT.

They have a less negative bias and lower RMSE.

D-MINT and D-PRINT

Highlights

JTWC Discussion on TC 08S:
THE INITIAL INTENSITY MEANWHILE IS ASSESSED WITH LOW CONFIDENCE, BELOW THE MAJORITY OF THE OBJECTIVE AND SUBJECTIVE DVORAK CURRENT INTENSITY ESTIMATES, HEDGED TOWARDS RECENT D-PRINT AND D-MINT ESTIMATES WHICH SUBJECTIVELY APPEAR TO BE MORE REPRESENTATIVE.

JTWC Discussion on TC 11S:
THE INITIAL INTENSITY IS ASSESSED WITH HIGH CONFIDENCE BASED ON A BLEND OF SUBJECTIVE AND OBJECTIVE AGENCY DVORAK CURRENT INTENSITY ESTIMATES, HEDGED CLOSE TO THE CIMSS D-MINT AND D-PRINT INTENSITY ESTIMATES.

D-MINT and D-PRINT

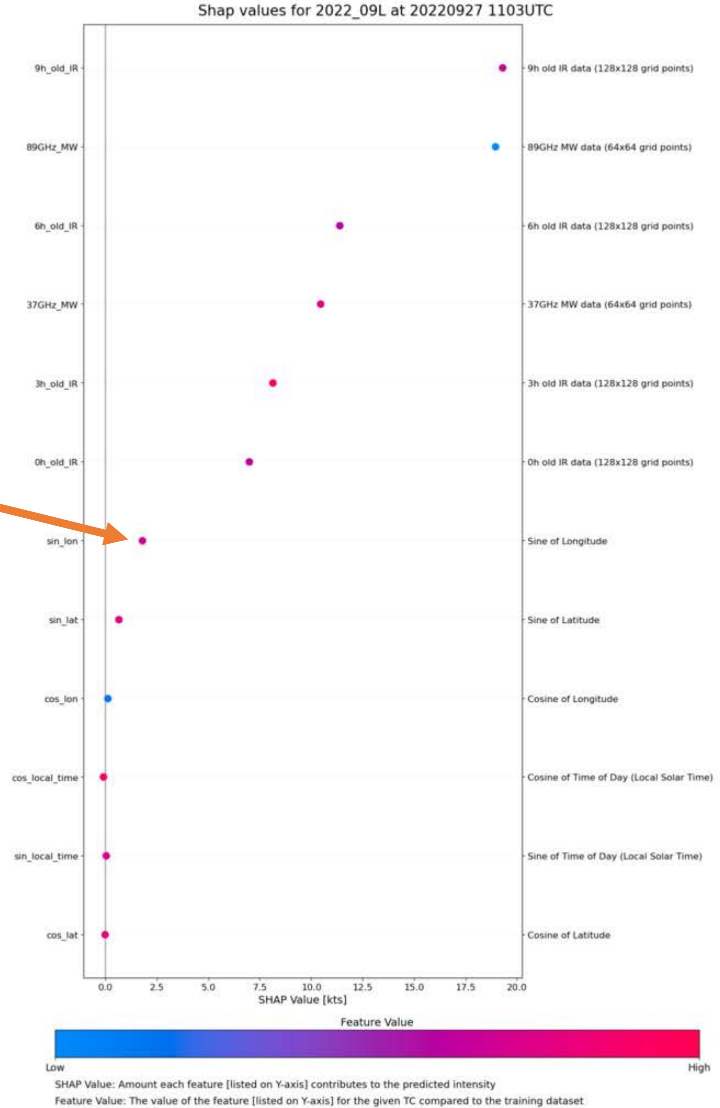
SHAP Values

What features in satellite imagery indicate a strong TC?

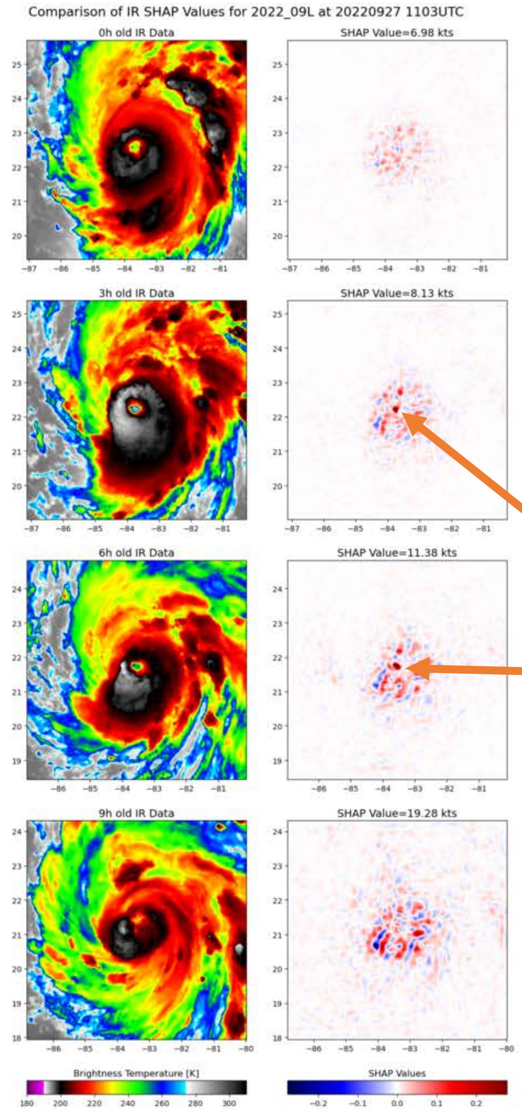
D-MINT and D-PRINT

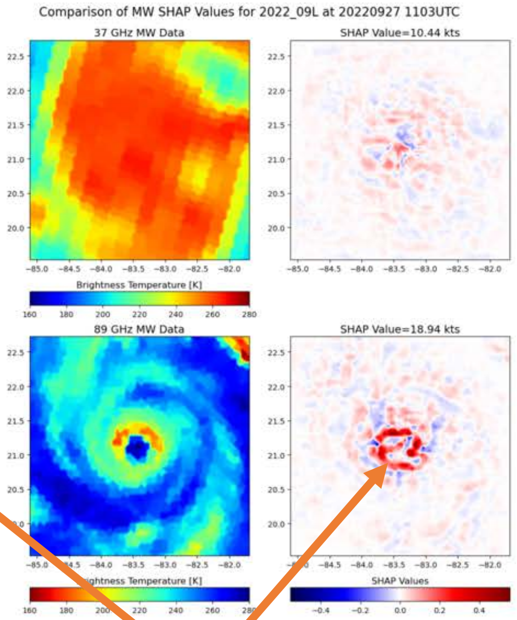
SHAP Values

What features in satellite imagery indicate a strong TC? SHAP values indicate what AI identifies.



Ian is in a good location to be more intense.

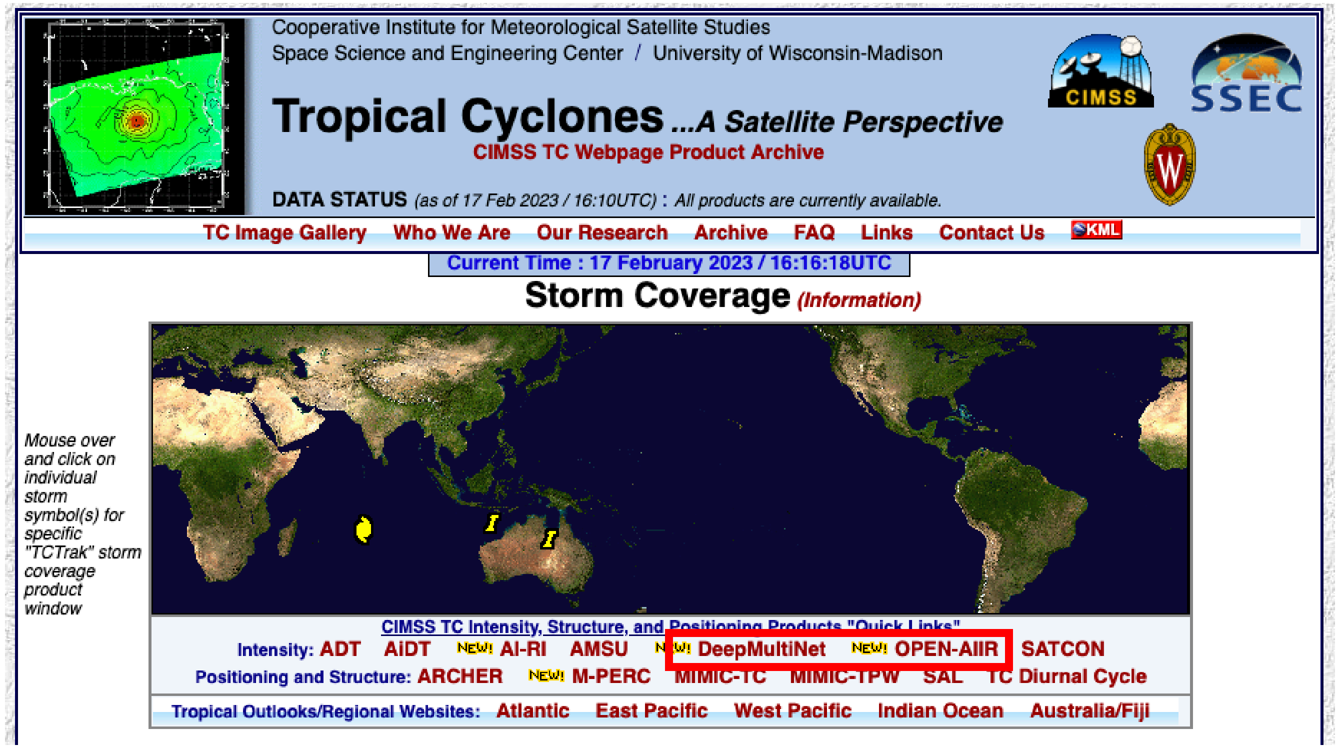


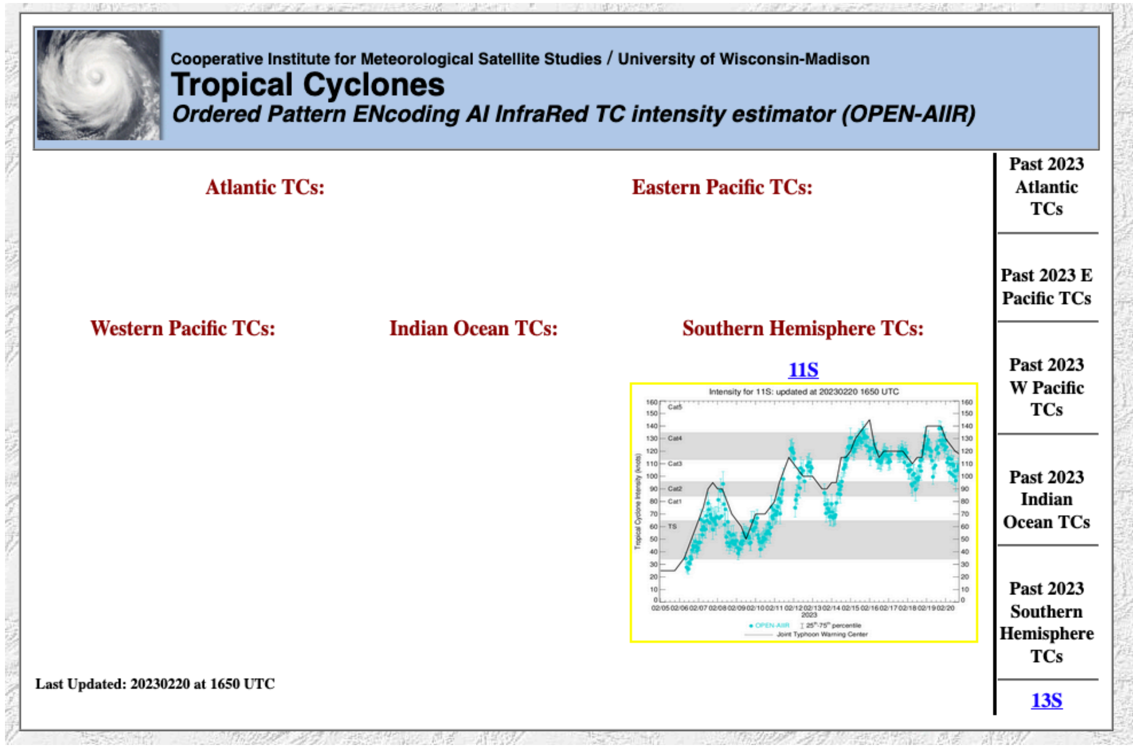


Eye and eyewall feature increasing estimated TC intensity.

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

Where to find D-MINT and D-PRINT…



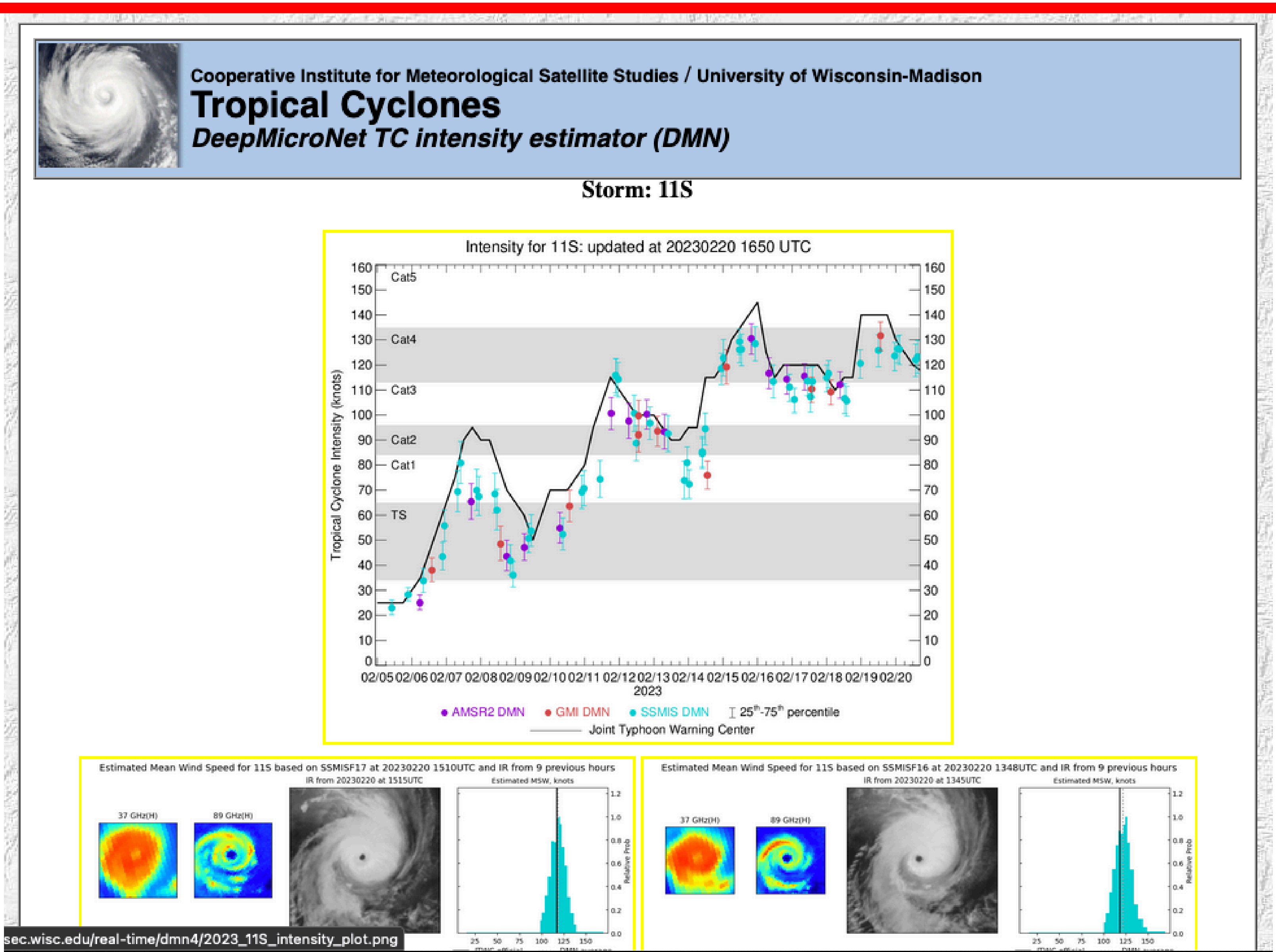


D-MINT: https://tropic.ssec.wisc.edu/real-time/dmn4/

D-PRINT: https://tropic.ssec.wisc.edu/real-time/open-aiir/

D-MINT and D-PRINT

Homepage



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SATCON

CIMSS SATellite CONsensus algorithm

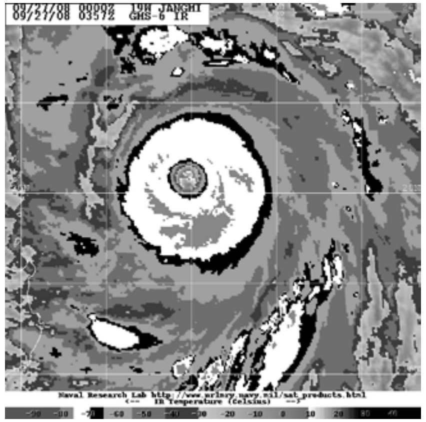
A consensus approach to estimating tropical cyclone intensity from meteorological satellites

Derrick Herndon and Chris Velden

SATellite CONsensus (SATCON)

Overview

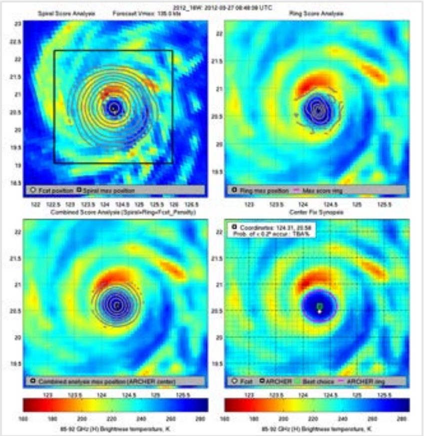
- **In order to account for storms with different structures an "all the above" approach is needed.**
- **Multiple satellite scanning strategies (Geo/LEO)**
- **Multiple channels to measure the various TC features that are related to intensity. (subjective/objective)**



Geostationary

(G-16/G-18/H9)

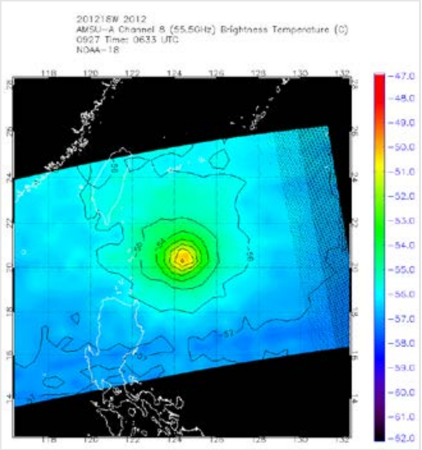
- **Intensity**
- Position
- Structure



MW Imager

(AMSR2, GMI, SSMIS)

- Position
- Structure



MW Sounder

(AMSU, SSMIS, ATMS)

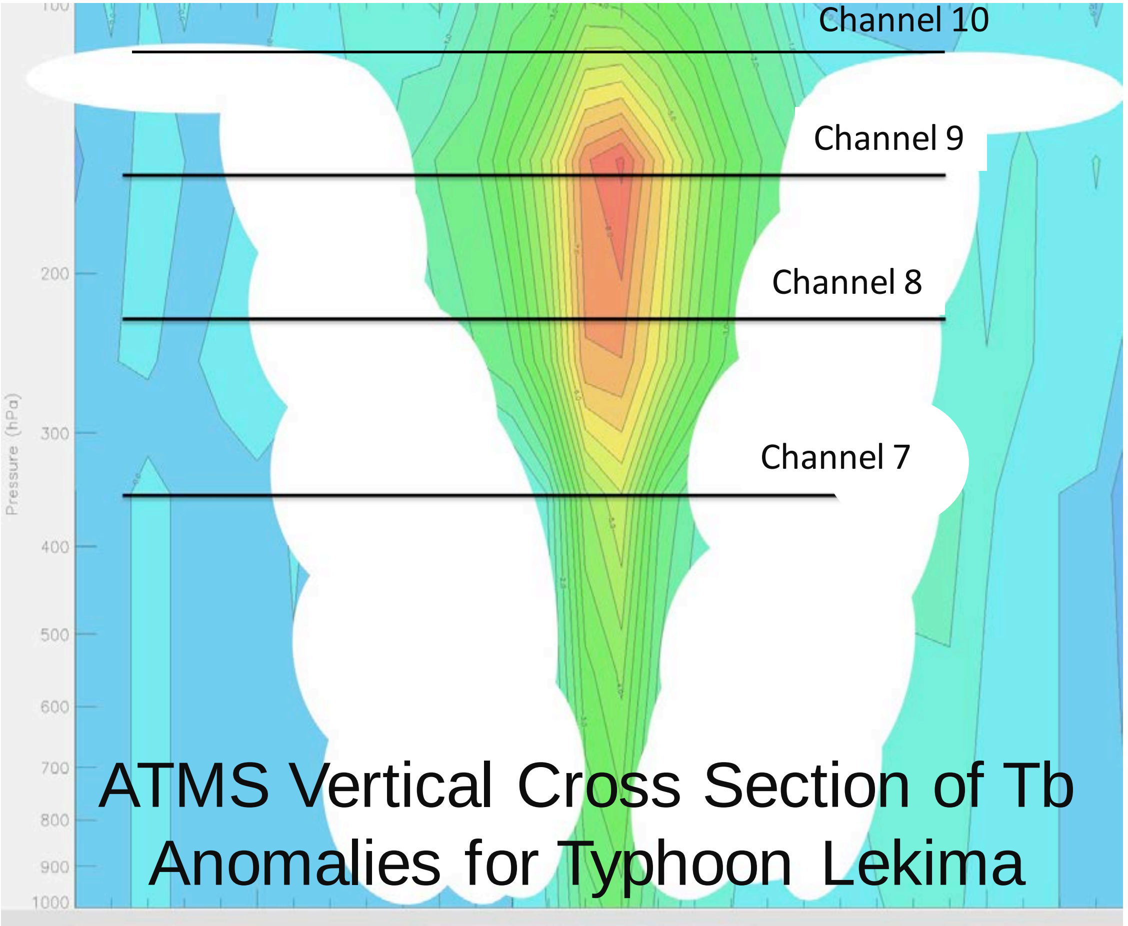
- **Intensity**
- Structure

SATellite CONsensus (SATCON)

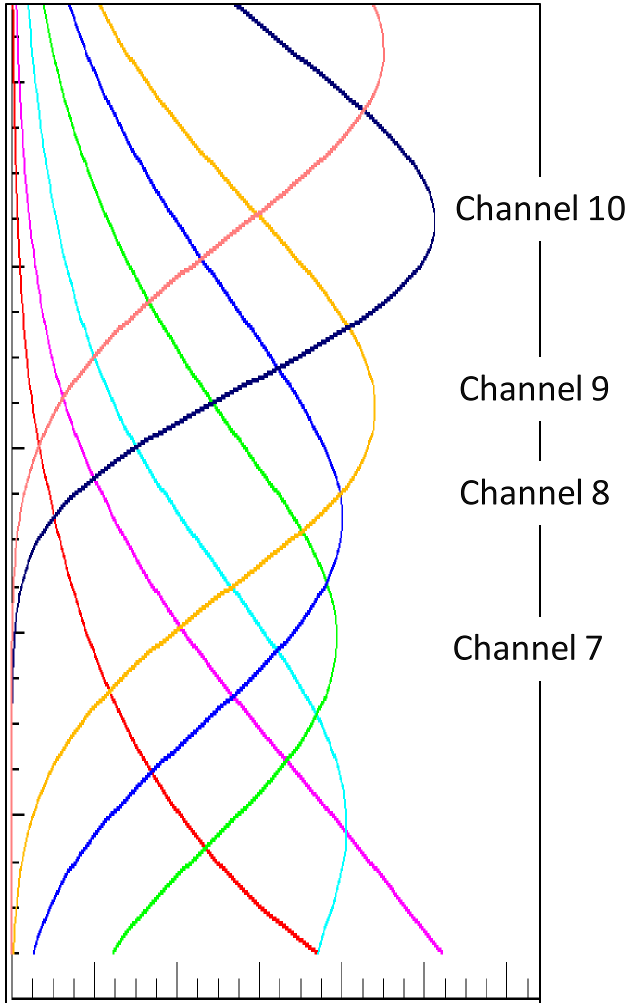
Overview

• Estimating TC Intensity from MW Sounders

- **Derive Tb anomalies from MW temperature sounders using multiple channels to view multiple levels within the TC**
- **Used since launch of AMSU in 1998**



ATMS Vertical Cross Section of Tb Anomalies for Typhoon Lekima



ATMS Weighting Functions for channels 3-11

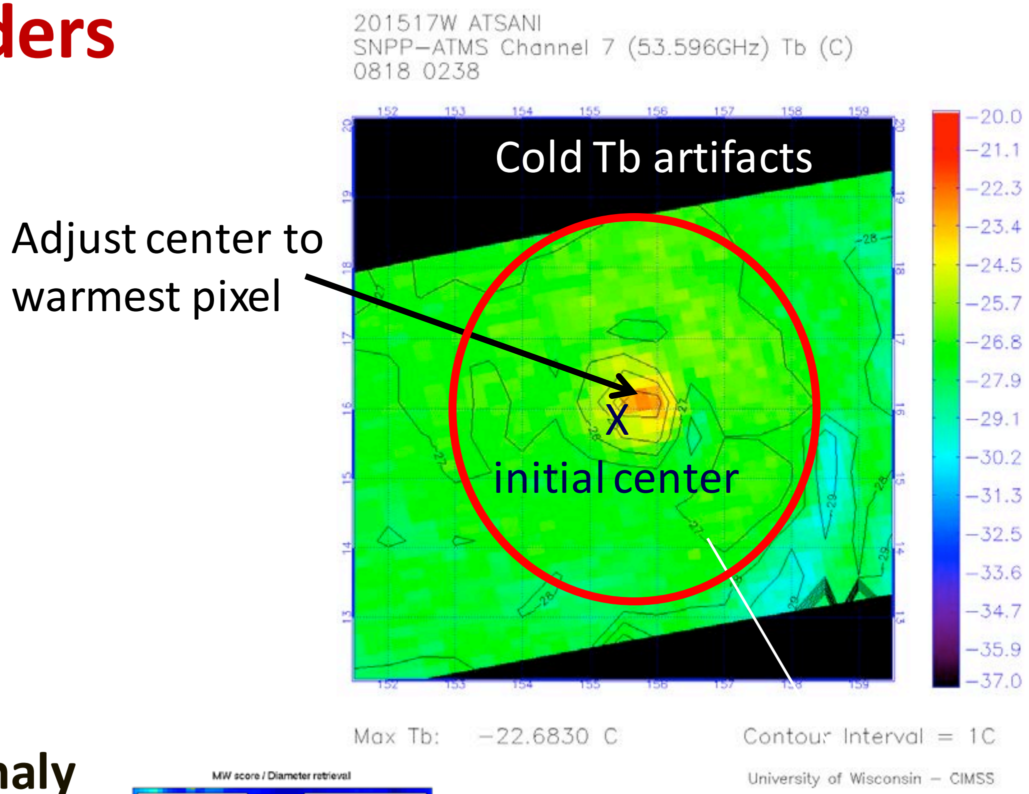
SATellite CONsensus (SATCON)

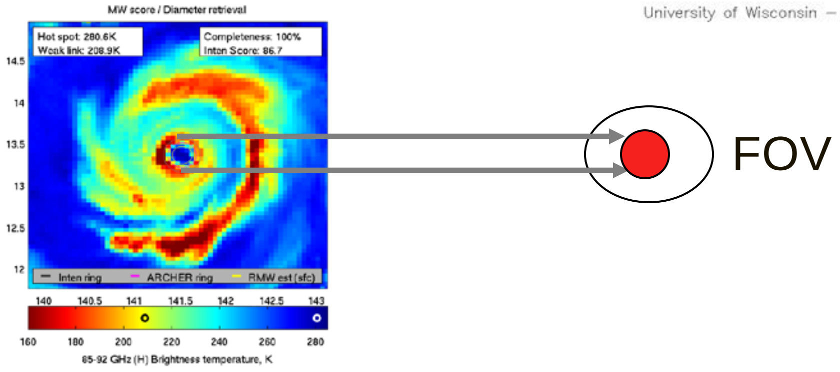
Overview

- ## Estimating TC Intensity from MW Sounders

  Algorithm General Approach

- **Initial estimate of TC center**
  - Warning agency forecast
  - ARCHER
- **Locate warmest pixel**
  - Estimate environmental temperature
  - Filter out unrepresentative temps
- **Calculate temperature anomaly**
- **Use regressions for each channel to estimate pressure anomaly**
- **Use estimate of eye size to correct initial pressure anomaly estimate**
- **Estimate Vmax using pressure anomaly, latitude, storm size, Tb gradient and motion**





SATellite CONsensus (SATCON)

Overview

- **Current SATCON members**
  - **LEO microwave sounder based**
    - **AMSU** *(Channels 6-8 and 16)*
      - **NOAA-15,-16,-18,-19** (N-16 AMSU-A failure 2014)
      - **Metop A-B-C** (Metop-A Channel 7 failure 2008)
    - **SSMIS** *(Channels 3-5 and 17)*
      - **F16-F17**
    - **CIMSS ATMS** *(Channels 7-9)*
      - **SNPP/N-20**
    - **CIRA ATMS** *(Channels 1-22)*
      - **Only used for eye >40km**
  - **GEO IR imager based**
    - **ADT**

SATellite CONsensus (SATCON)

Overview

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**

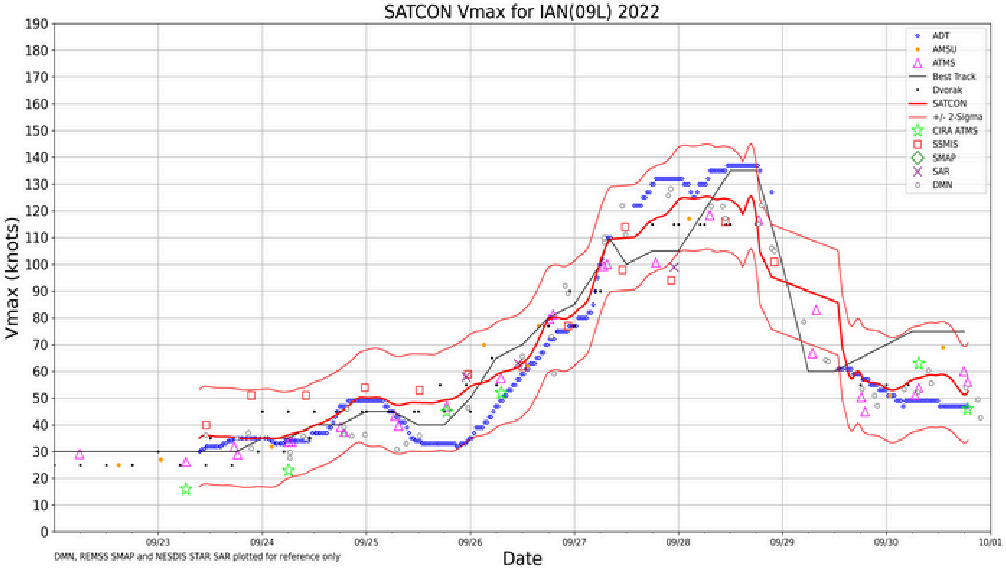
Member Estimates

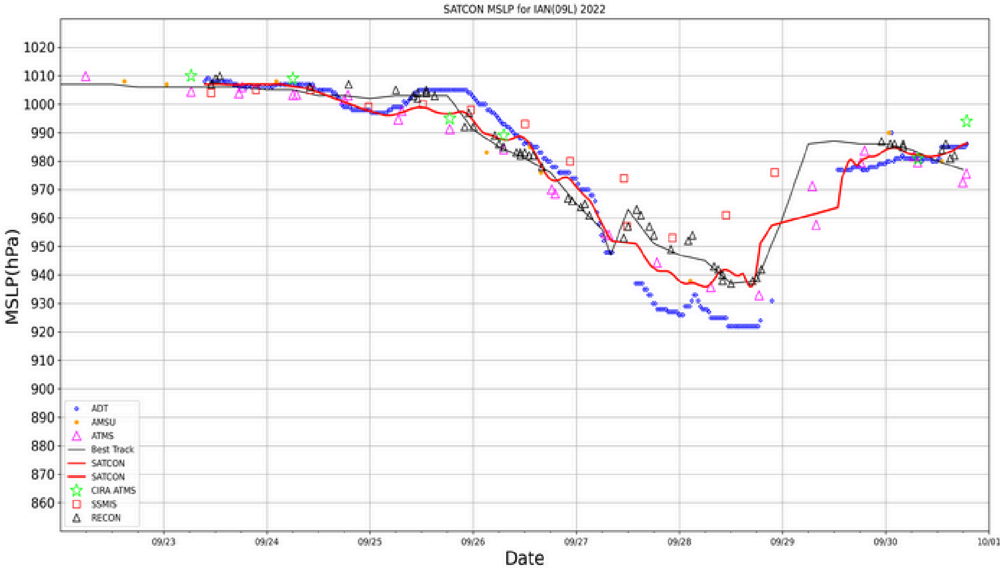
ADT: 985 hPa 62.32 knots Scene: CDO Date: SEP301550
CIMSS AMSU: 980 hPa 69 knots Bias Corr: 0 (MW) Date: 09301304
ATMS: 935.7 hPa 118.4 knots Date: 09280714
SSMIS: 935.7 hPa 118.4 knots Date: 09280714
CIRA ATMS: 994 hPa 46 knots Date:

← **Member estimates**

SATCON HISTORY FILE for 2022 09L IAN

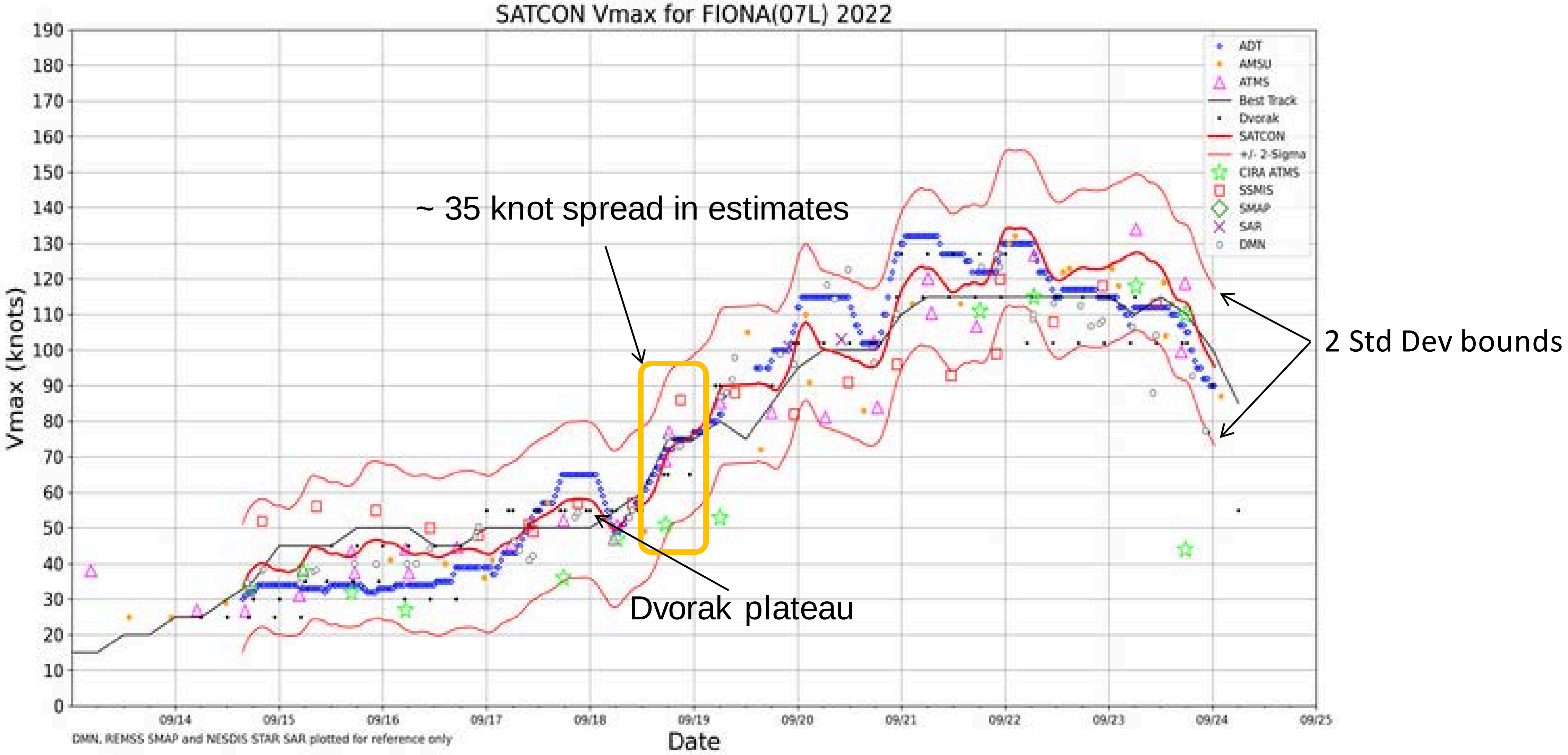
SATCON MSW plot including pressure-wind contribution





SATellite CONsensus (SATCON)

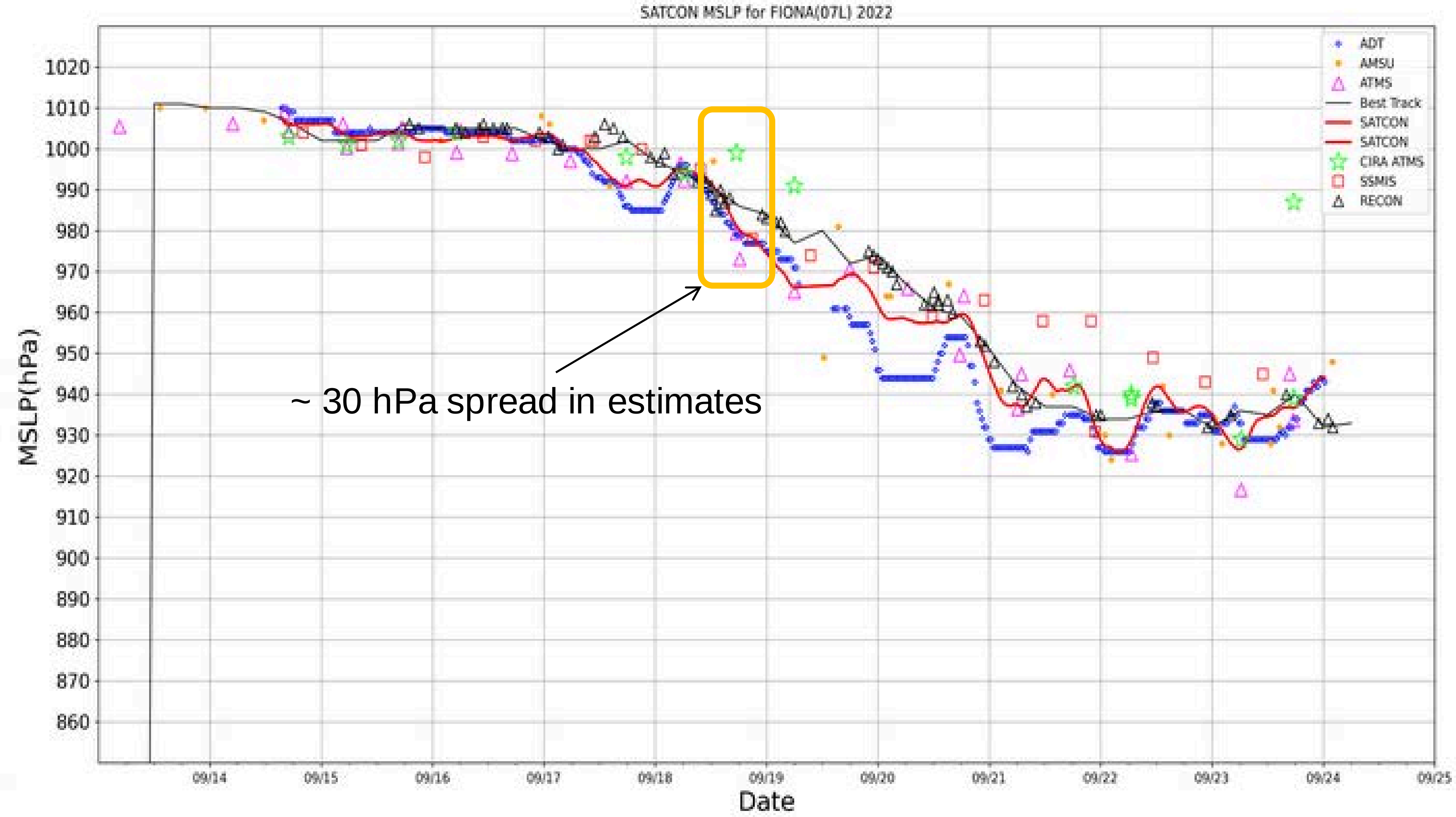
Example



SATCON example for Vmax – Hurricane Fiona (2022)

SATellite CONsensus (SATCON)

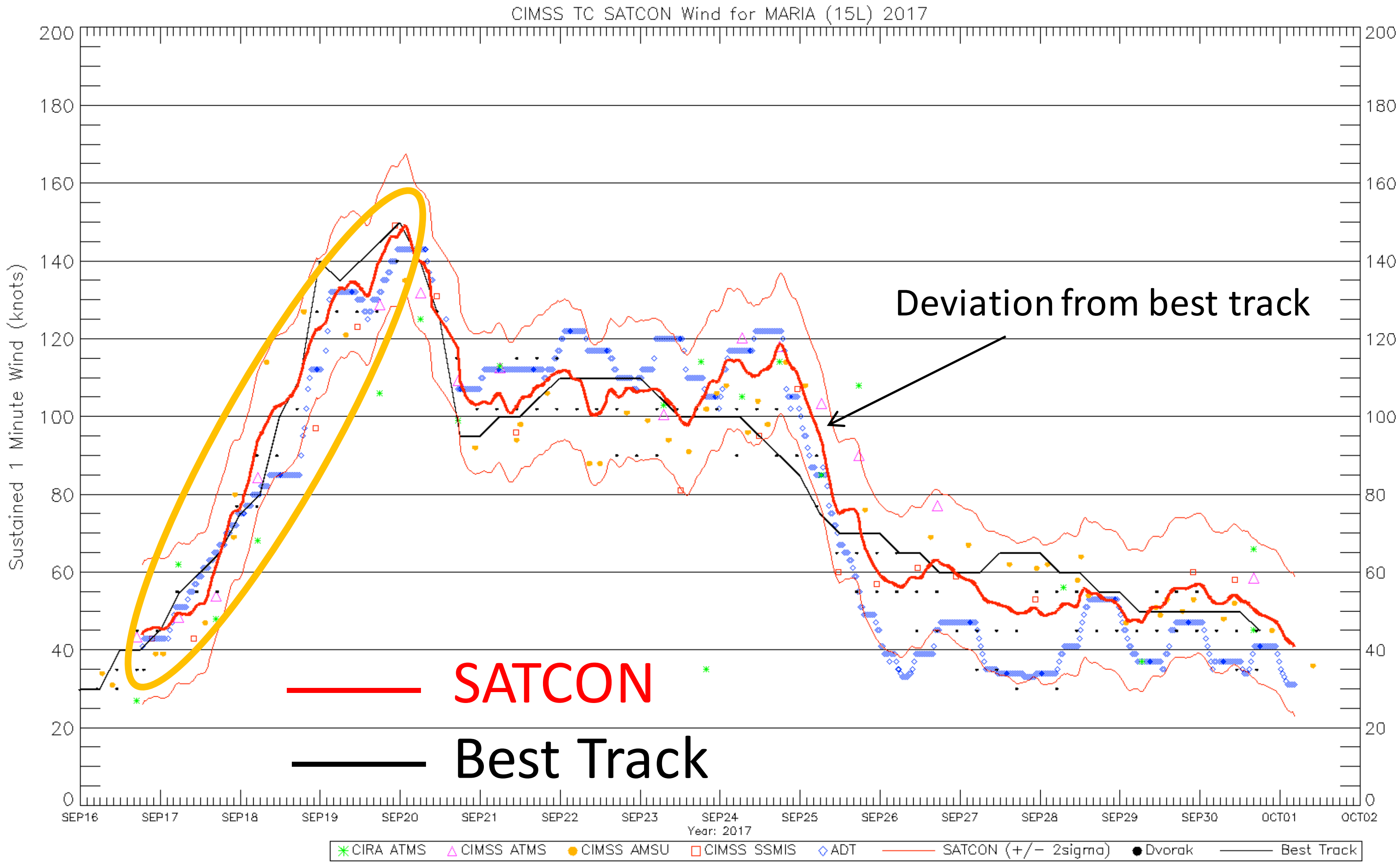
Example



SATCON example for MSLP – Hurricane Fiona (2022)

SATellite CONsensus (SATCON)

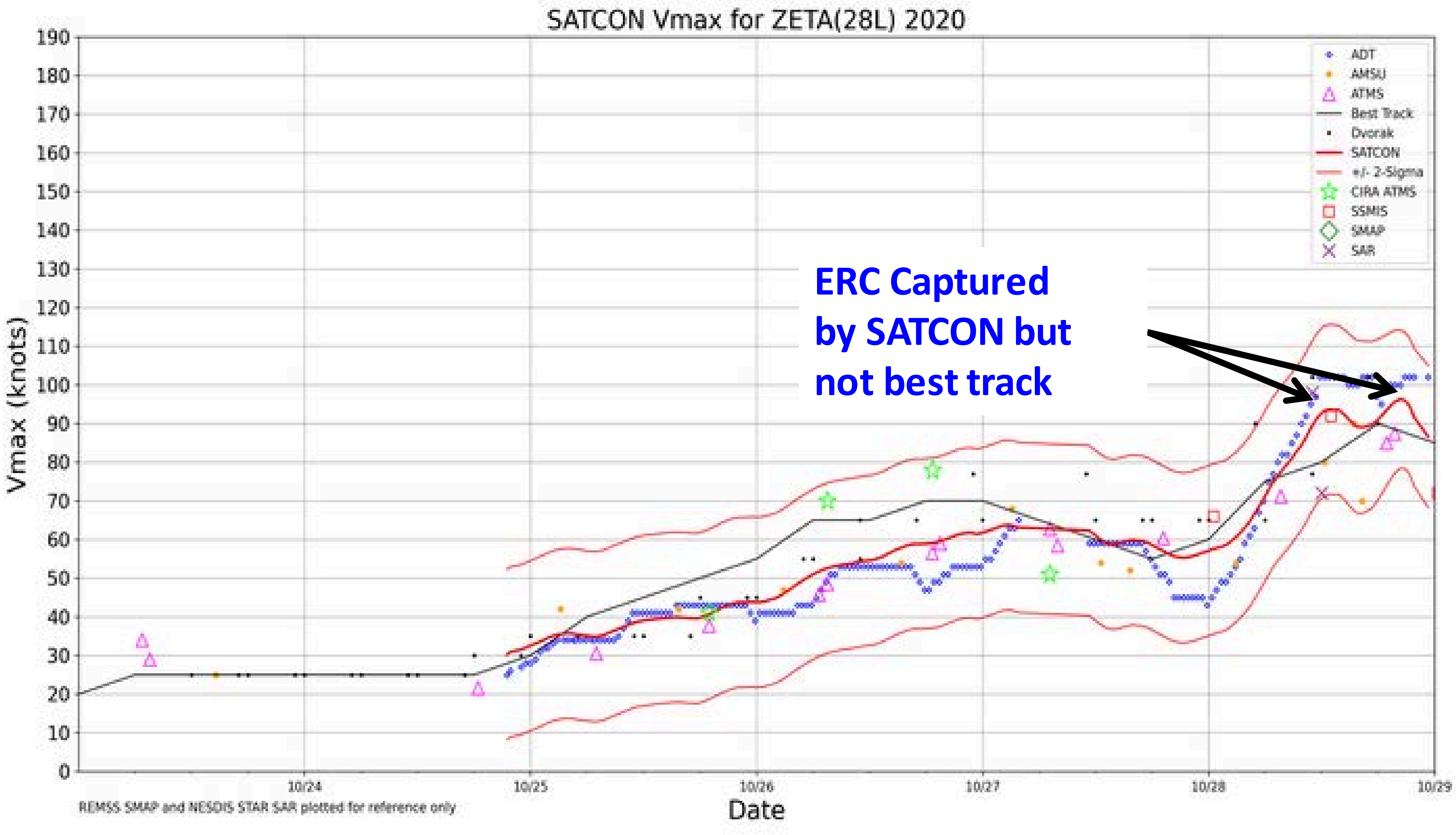
Example



Hurricane Maria 2017. SATCON performance during rapid intensification

SATellite CONsensus (SATCON)

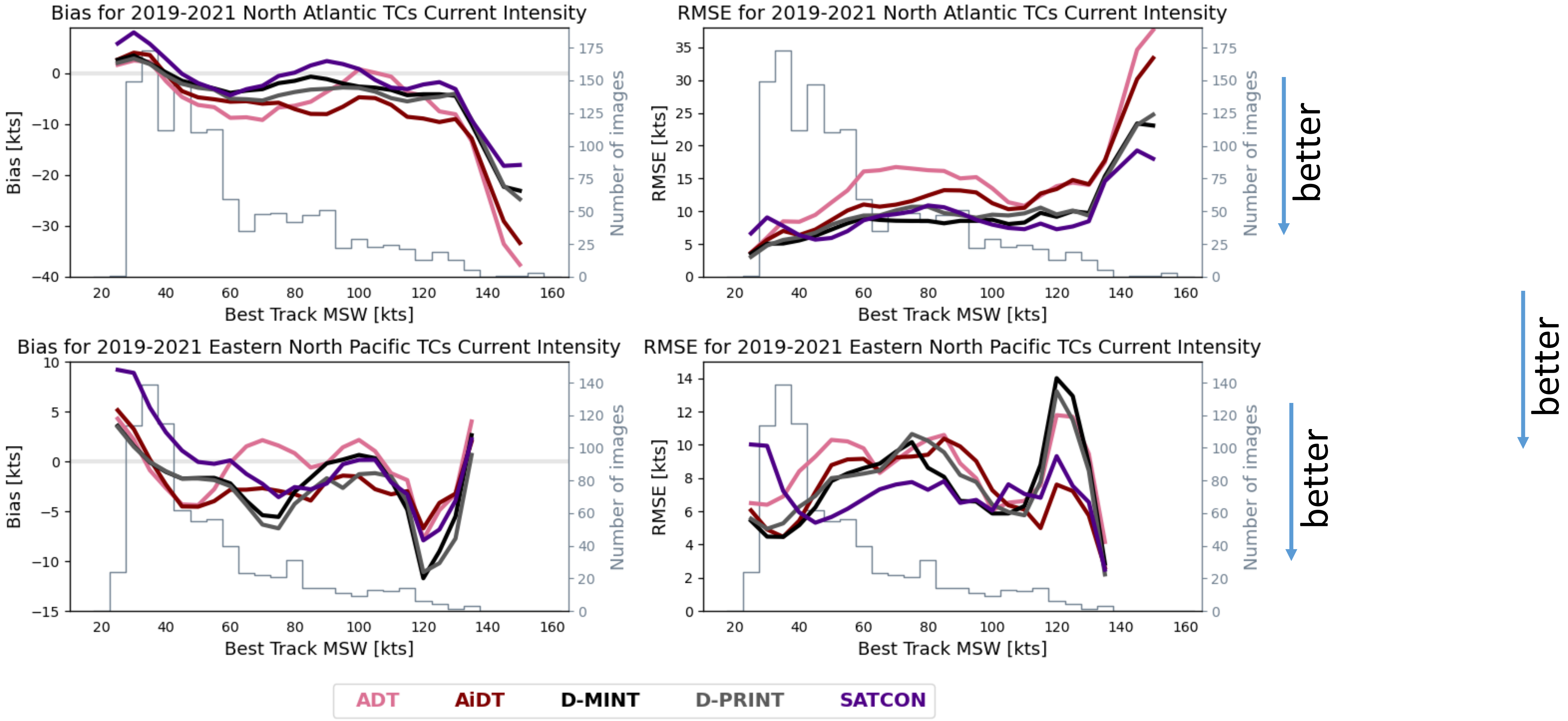
Example



CIMSS SATCON for Hurricane Zeta (2020)

SATellite CONsensus (SATCON)

2019-2021 Statistical Results



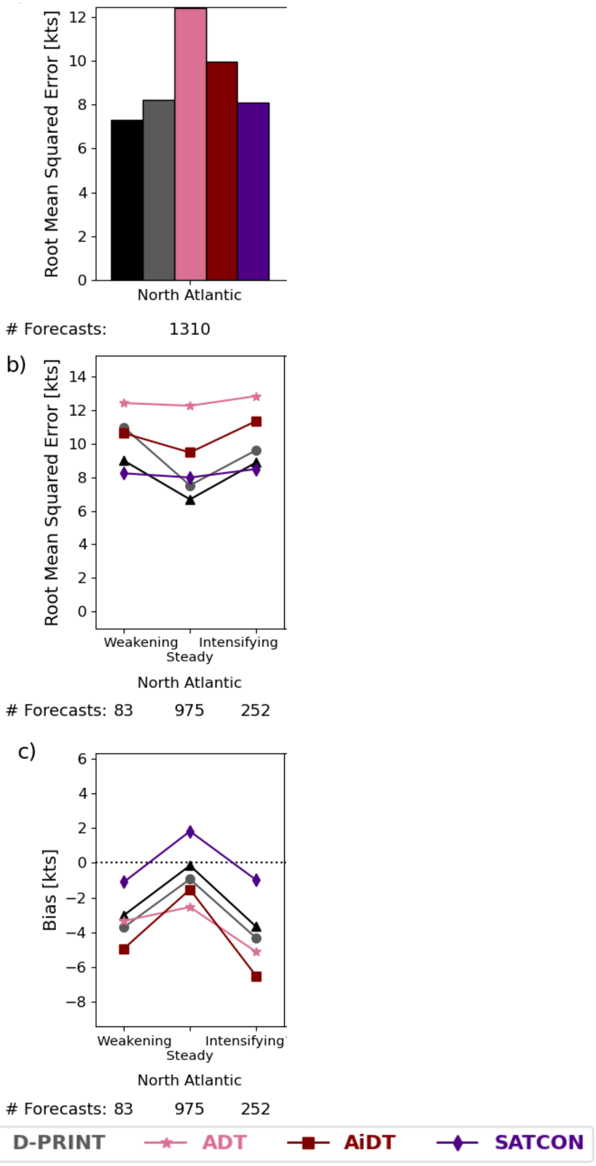
SATCON is the most skillful than for TC intensity > 95 kts. It underestimates strong TCs the least.

SATCON has the overestimates weak TCs (< 45 kts).

SATellite CONsensus (SATCON)

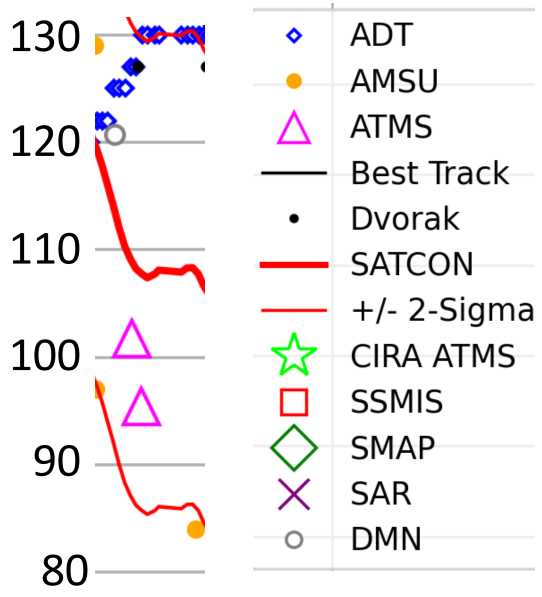
Future Directions

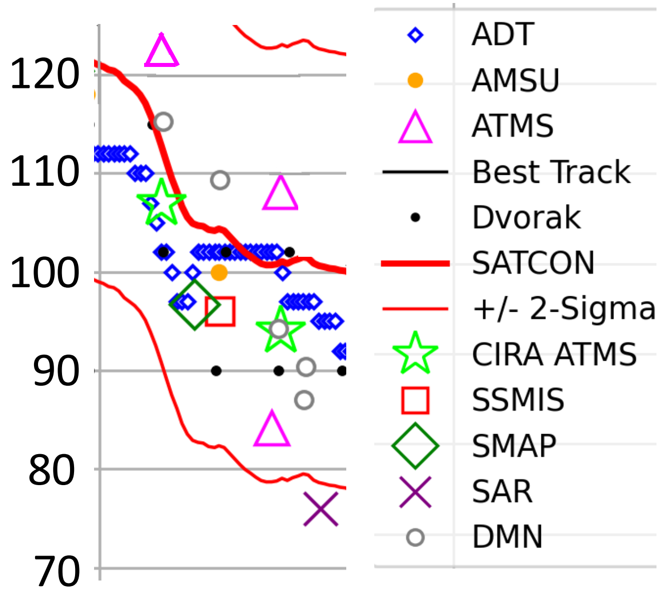
- **Possible future members of the CIMSS SATCON**
  - **New Members**
    - **"D-MINT" Deep Learning Model**
      - Lower RMSE overall
      - More Skillful for steady TCs (-10kt < 12h intensity change < 10 kts) but less skillful for weakening and intensifying TCs.
    - **CIMSS AiDT Deep Learning Model**
      - Could balance overestimation of steady TCs?



SATellite CONsensus (SATCON)

Exercise: TC Sam (2021)



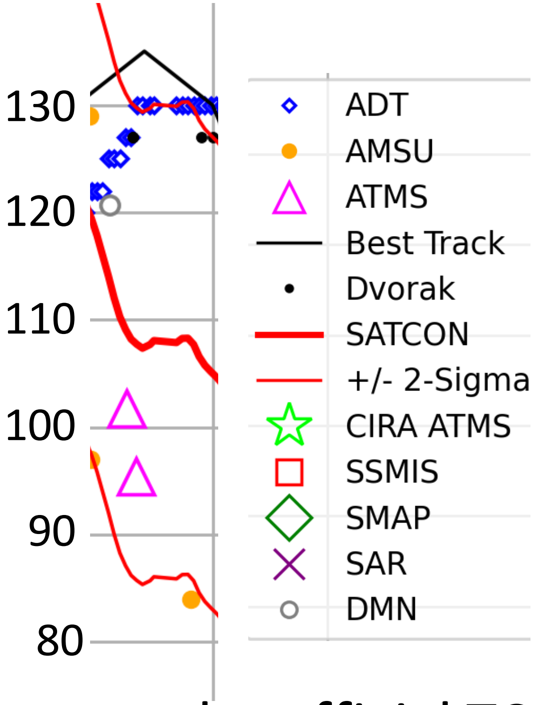


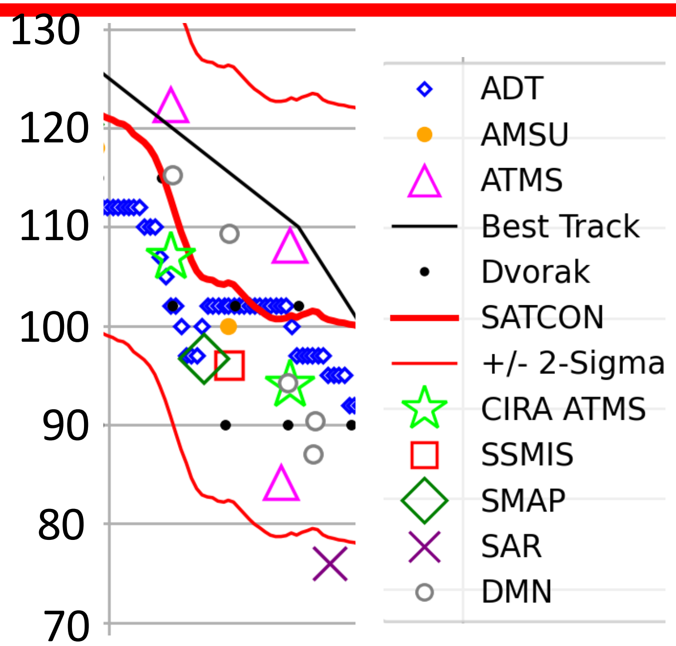
Do you expect the official TC intensity to be higher or lower than SATCON?

Do you expect the official TC intensity to be higher or lower than SATCON?

SATellite CONsensus (SATCON)

Exercise: TC Sam (2021)





Do you expect the official TC intensity to be higher or lower than SATCON?

Higher

Do you expect the official TC intensity to be higher or lower than SATCON?

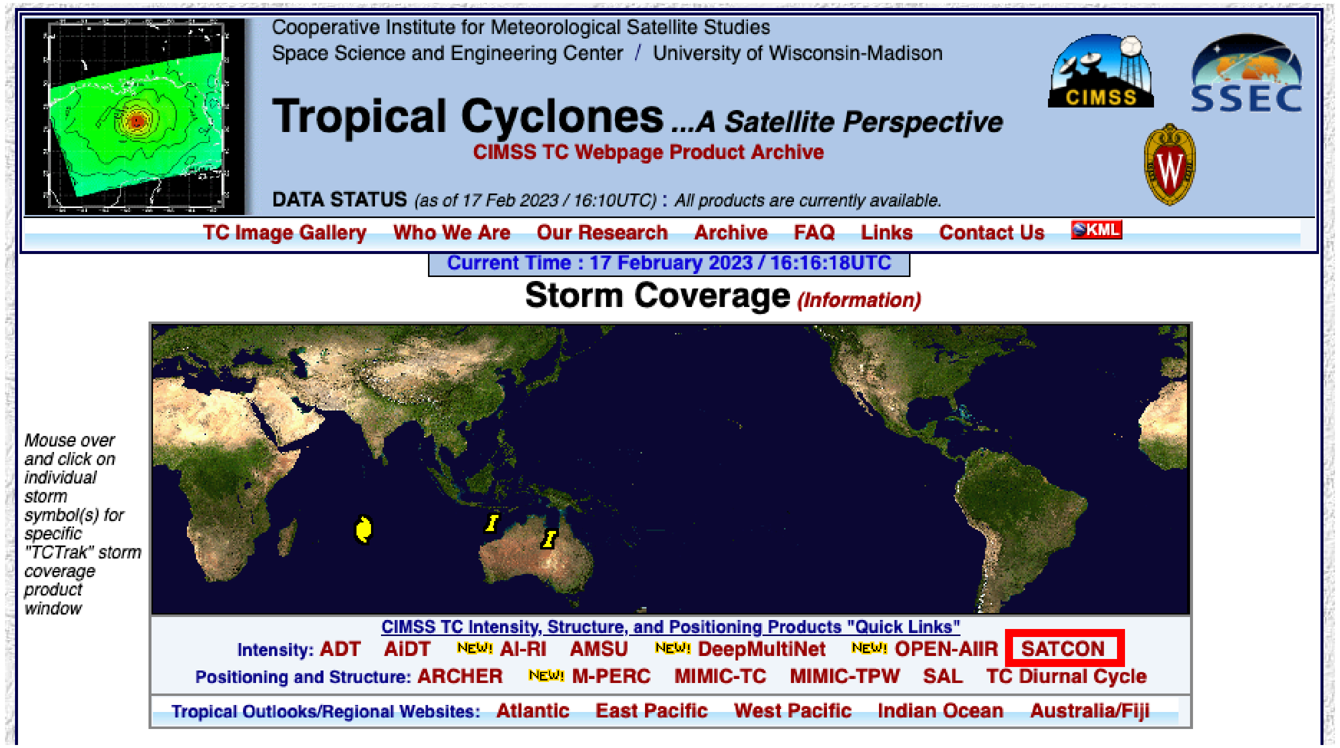
Higher

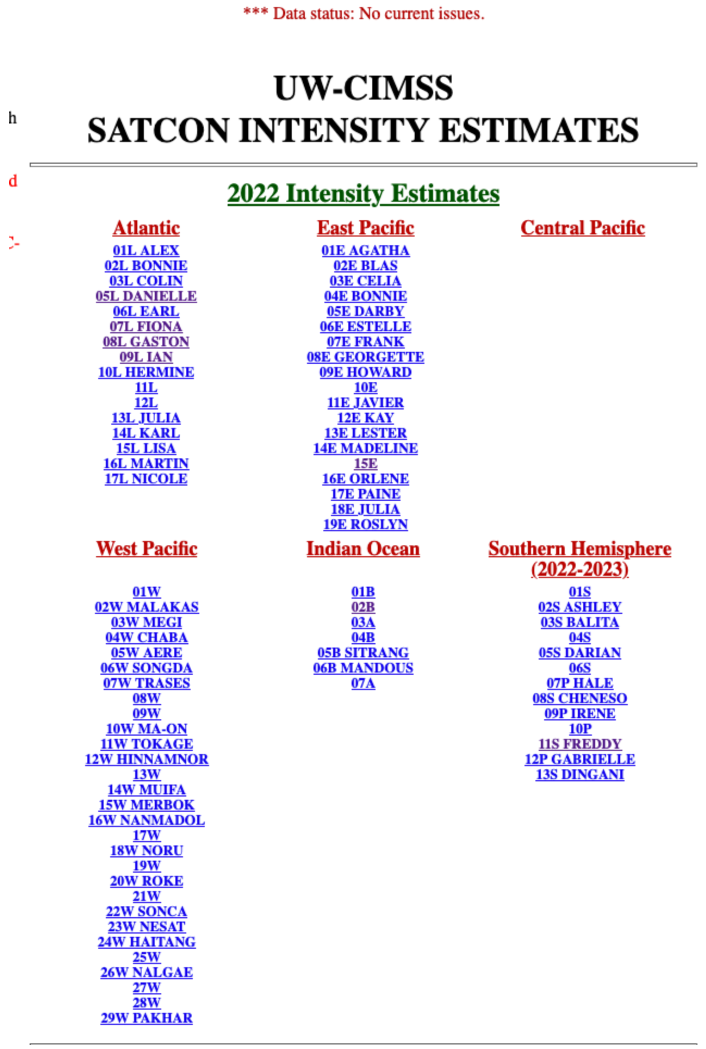
SATCON leaning towards ATMS in these 2 examples.
Hopefully adding D-MINT can provide additional balance to SATCON

SATellite CONsensus (SATCON)

Homepage

Where to find SATCON…





https://tropic.ssec.wisc.edu/real-time/satcon/

SATellite CONsensus (SATCON)

Homepage

CIMSS

THE UNIVERSITY of WISCONSIN MADISON

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

CURRENT ESTIMATE
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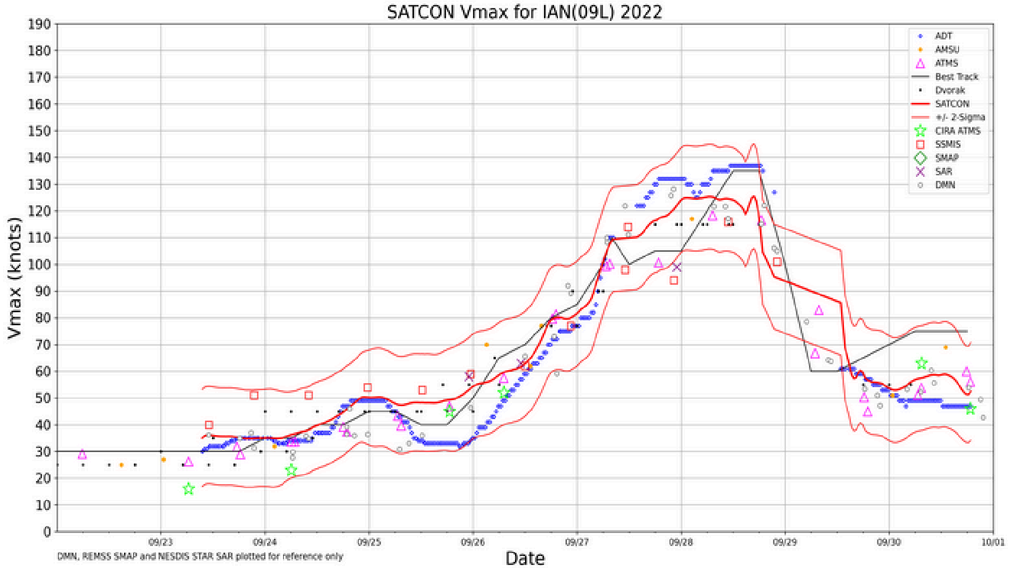
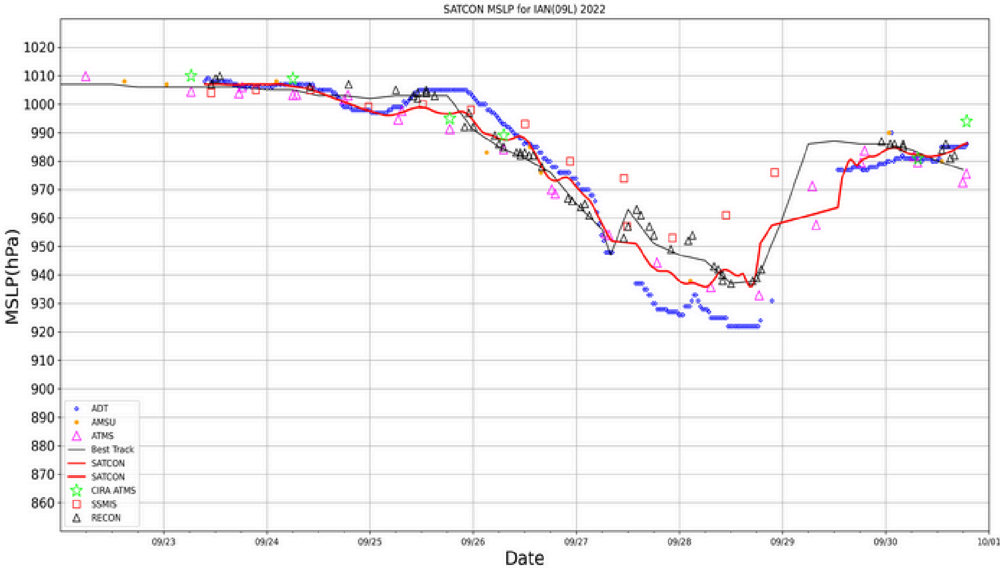
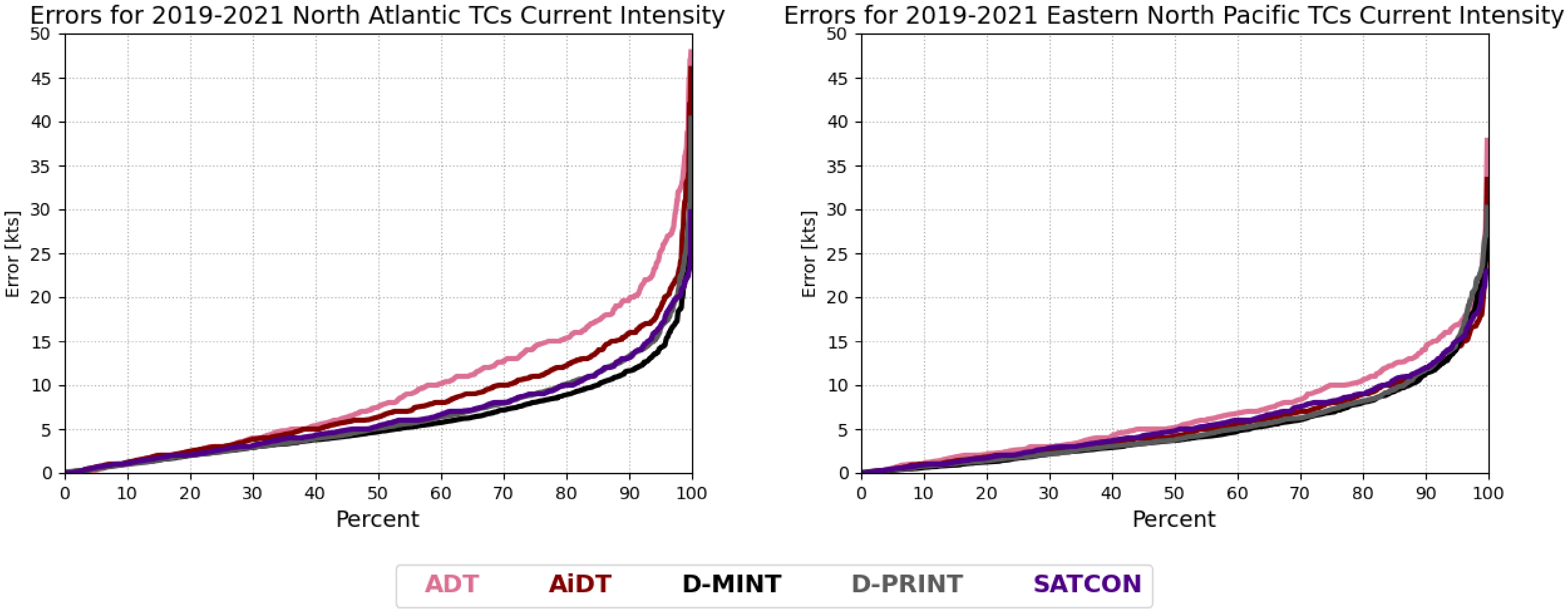
SATCON HISTORY FILE for 2022 09L IAN

SATCON MSW plot including pressure-wind contribution





Comparison of CIMSS Current Intensity Metrics



Overview

- Advanced Dvorak Technique (ADT) – Version 9.1
- Advanced (AI-enhanced) Dvorak Technique (AiDT)
- DeepMicroIRNet (D-MINT) and DeepIRNet (D-PRINT)
- Satellite Consensus Algorithm (SATCON)
- **AI-RI**
- ARCHER
- M-PERC

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

- Machine learning is the new “buzzword” and has been shown to be very skillful at estimating **current TC intensity**.

- Many studies have indicated **convection** is important to RI.
  - However, convection is hard to put into, say, a SHIPS parameter.

- Can we use a convolutional neural network to “see” RI precursors?

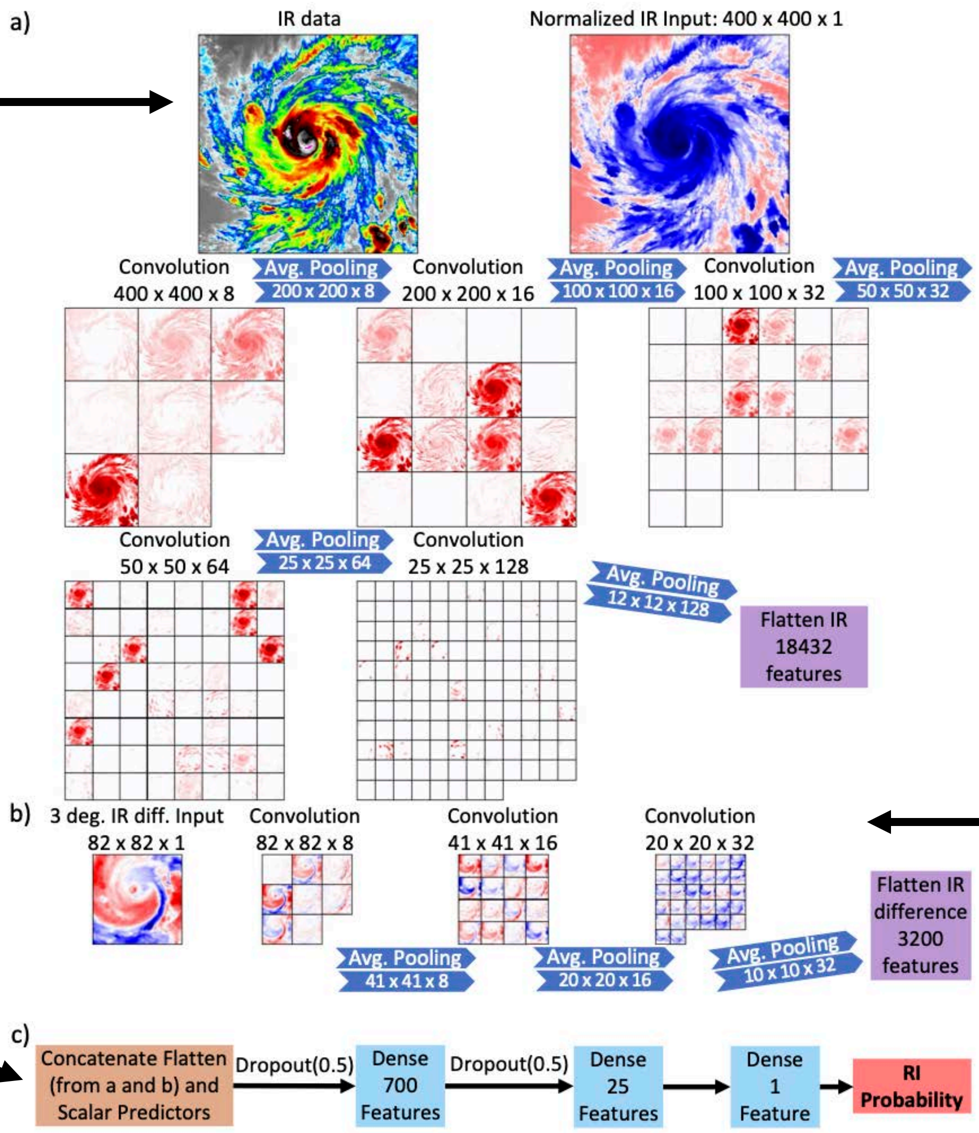
AI-RI

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.

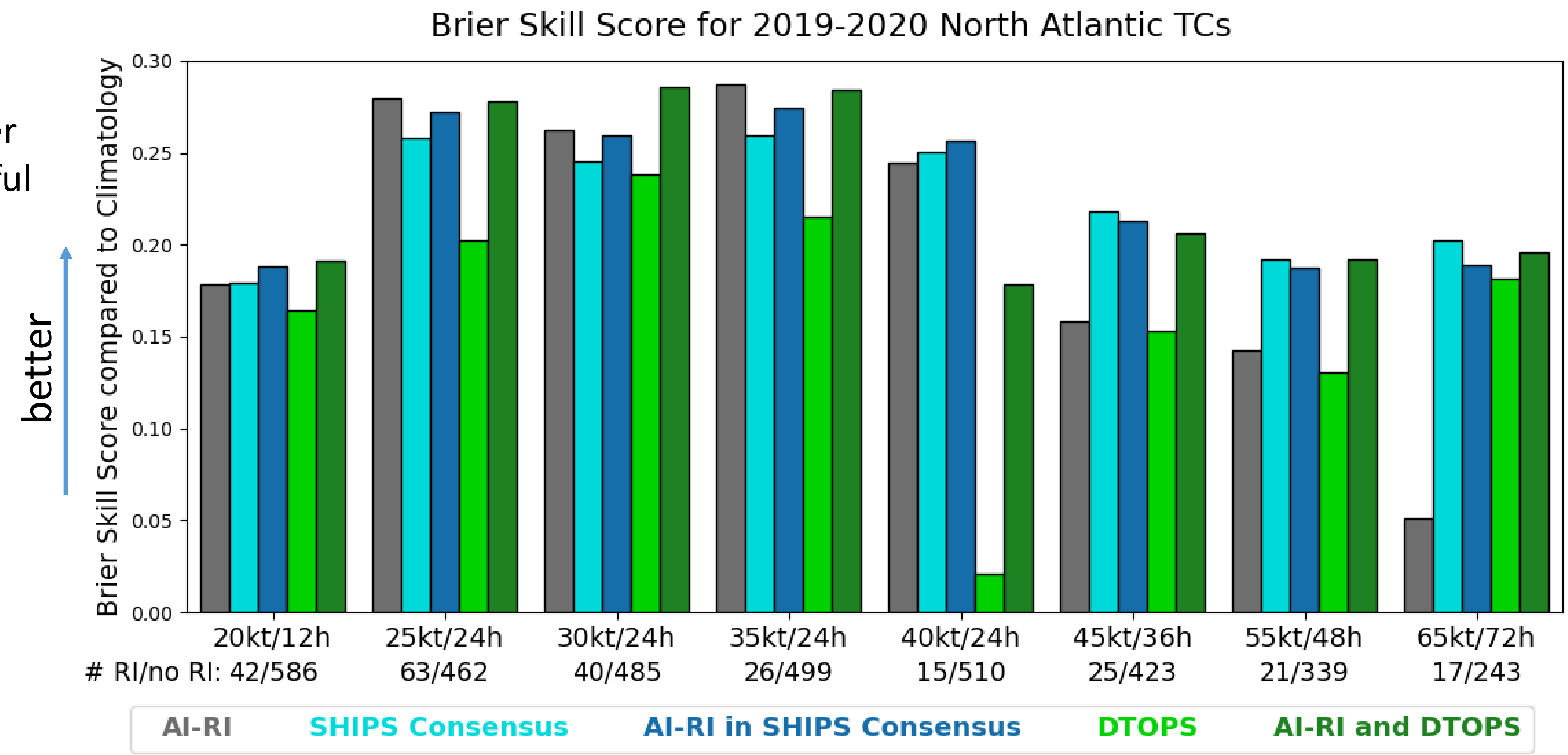
Add normalized scalar features from SHIPS lsdiag file.

Probability of RI from 0-1

AI-RI

2019-2020 Statistical Results

Brier Skill Score: higher = more skillful



AI-RI is more skillful than SHIPS Consensus for 25-, 30-, and 35-kt RI thresholds.

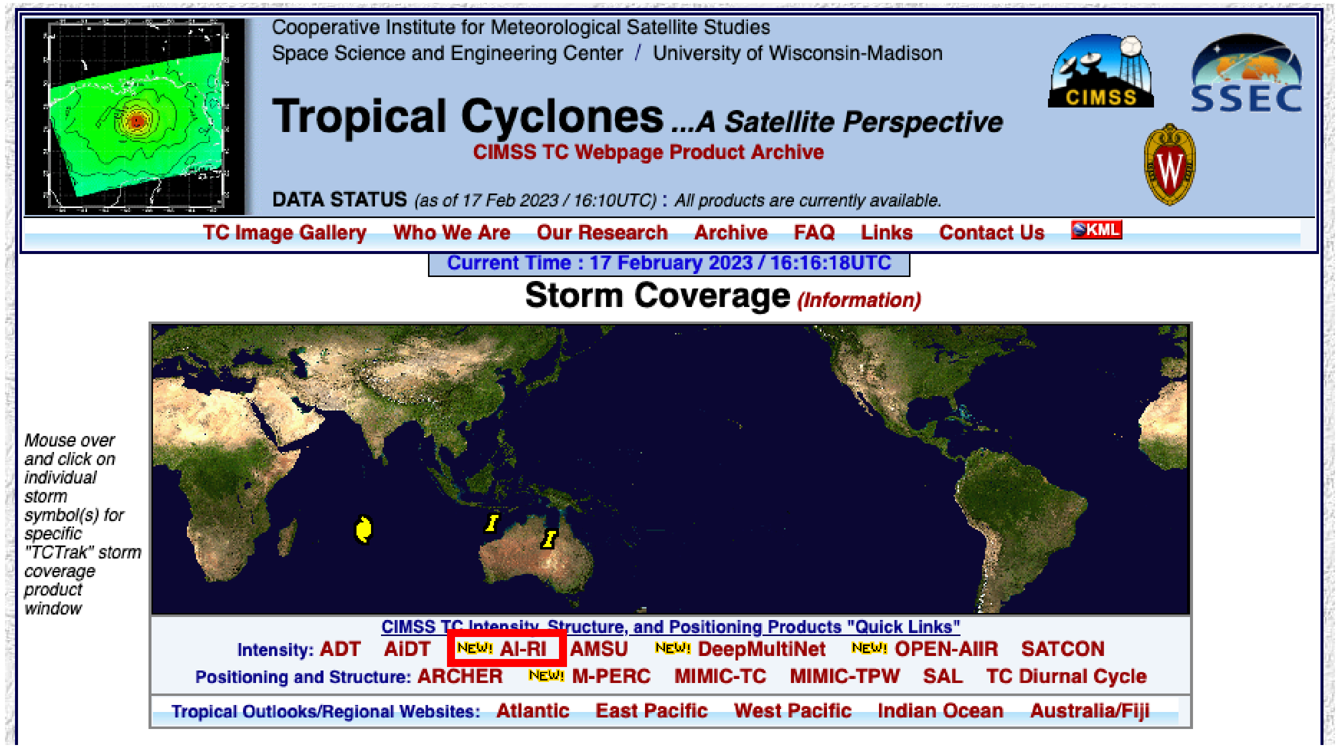
Including **AI-RI in the SHIPS Consensus average** is more skillful than SHIPS Consensus for all 12h and 24h RI.

AI-RI is more skillful than DTOPS for 7 RI thresholds.

AI-RI

Homepage

Where to find AI-RI…



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

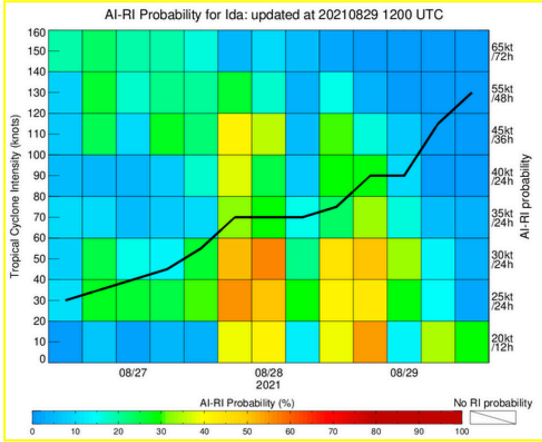
Ida History

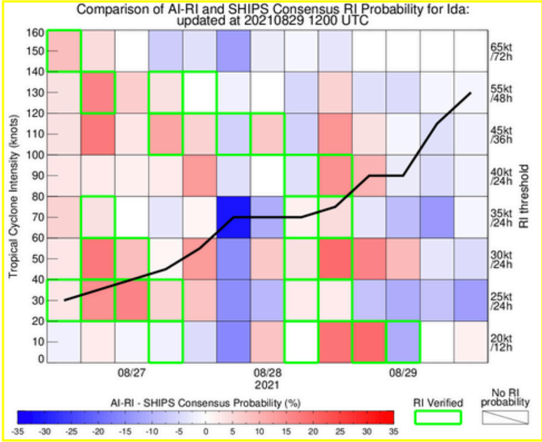
AI-RI Matrix of RI probabilities

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%

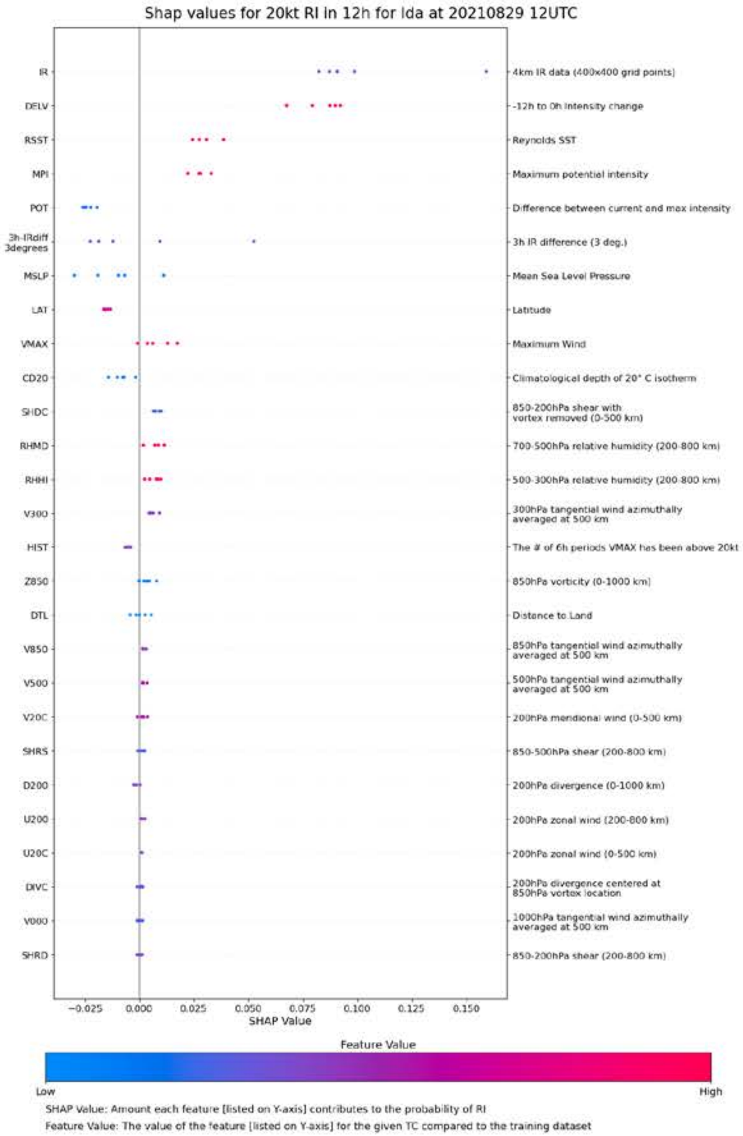


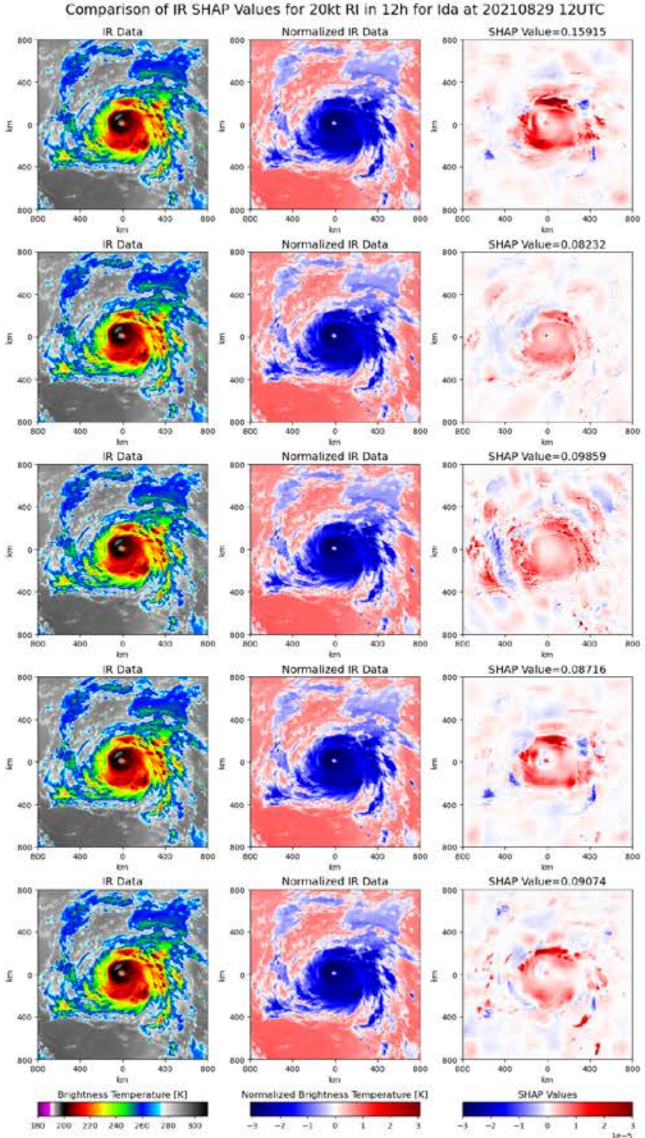


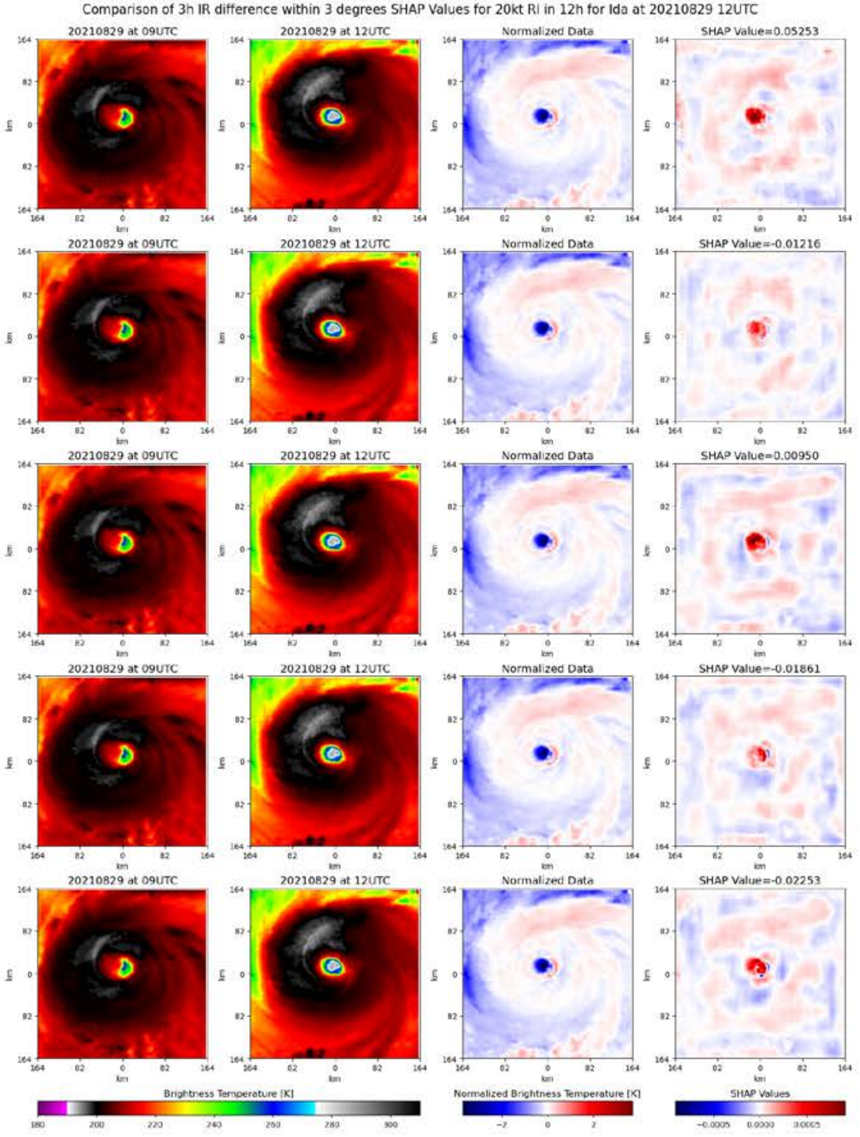
https://tropic.ssec.wisc.edu/real-time/ai-ri/

AI-RI

Homepage







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- **ARCHER**
- M-PERC

ARCHER

Automated Rotational Center Hurricane Eye Retrieval

A method for determining the center of tropical cyclones

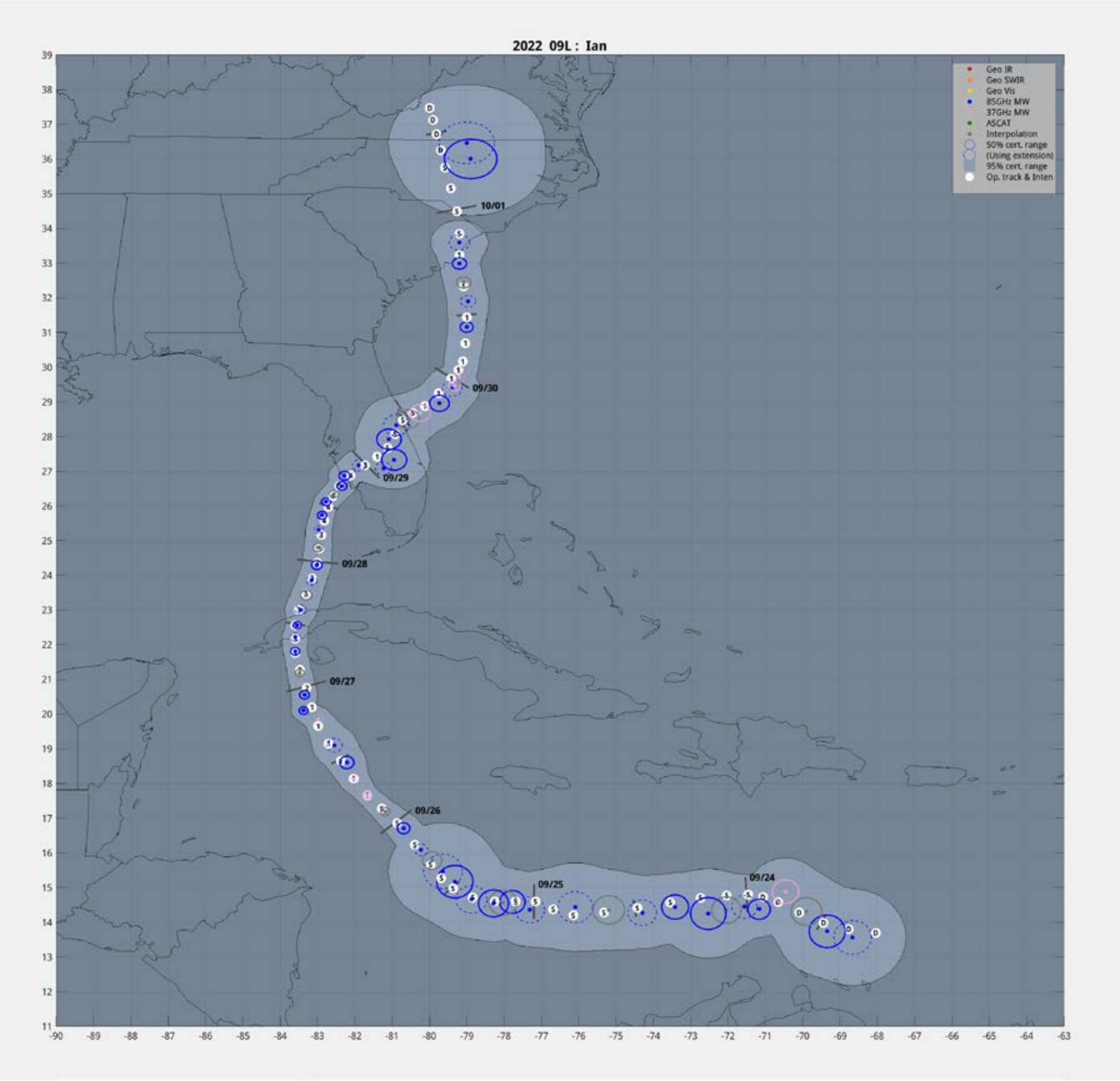
Tony Wimmers and Chris Velden

ARCHER

Overview

- Designed to aid TC forecasters to quickly and objectively arrive at key TC characteristics.

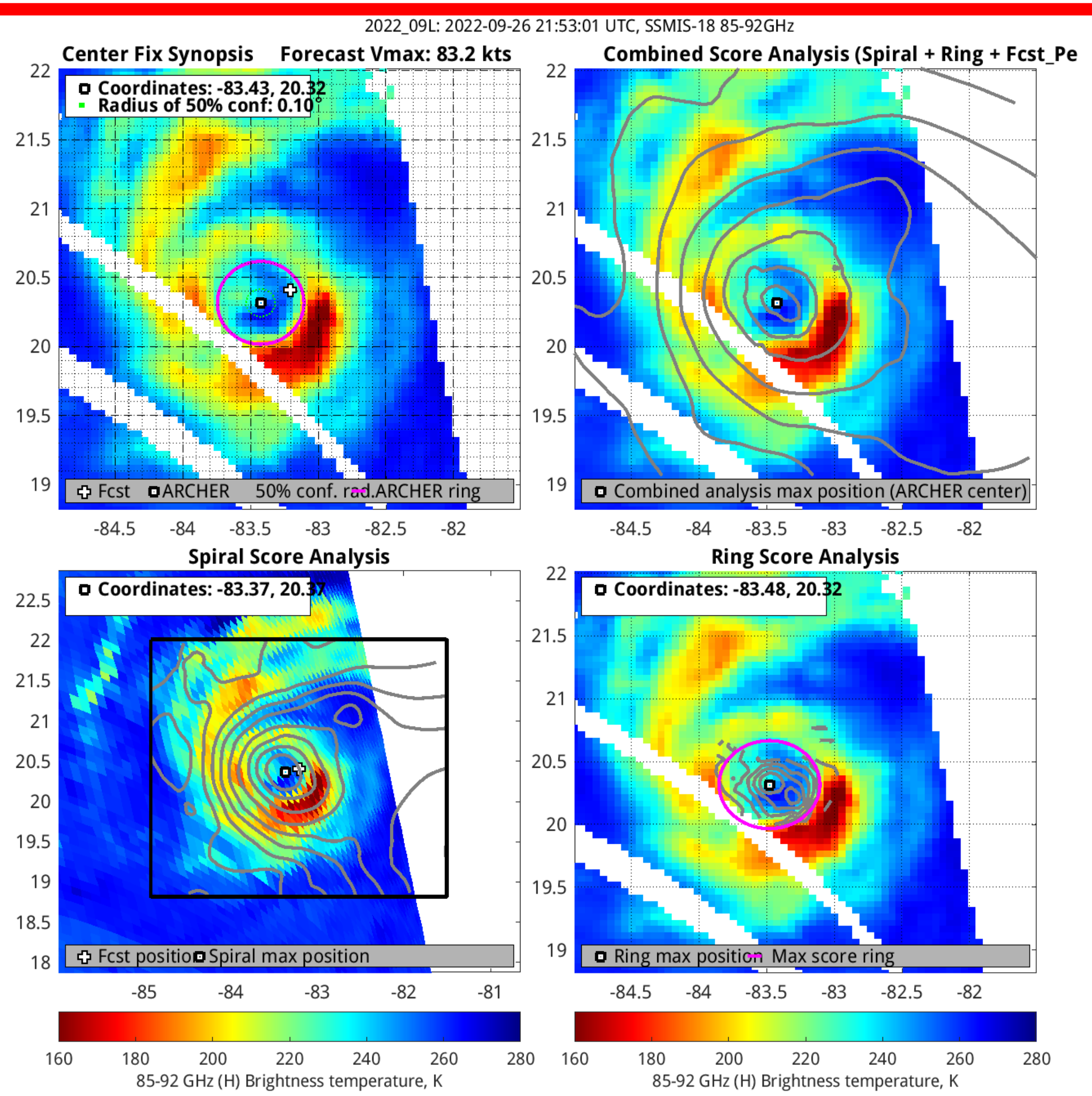
- **Current ARCHER members**
  - **LEO microwave sounder based**
    - **GMI** *(37 GHz and 85-92 GHz)*
    - **SSMIS** *(85-92 GHz)*
      - **F16-F18**
    - **AMSR2** *(37 GHz and 85-92 GHz)*
  - **Scatterometers**
    - **Metop-B** *(ASCAT)*



ARCHER

Processing

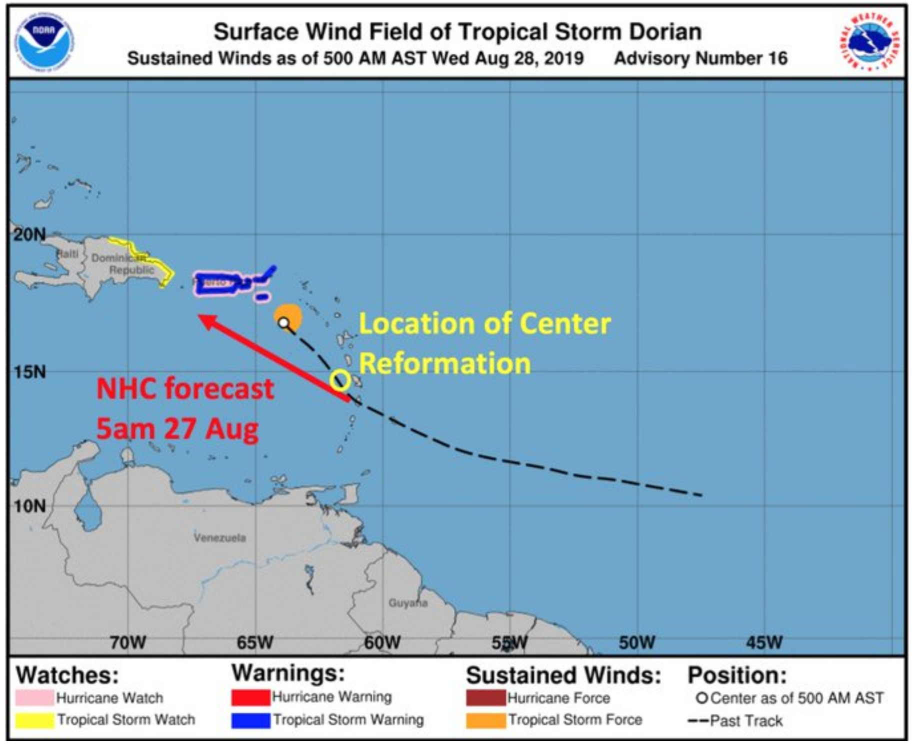
- **Spiral Score**
  - measure of how well the gradients in the image align with a spiral vector field.
- **Ring Score**
  - measures the best fit of the gradients of an inner eyewall (if exists) to a circular shape.
- **Distance Penalty**
  - very minor effect - prevents the maximum gridded score from gravitating toward the edges of the product domain.
- **Combined Score Grid**
  - weighted sum of the spiral score grid, ring score grid, and distance penalty grid. *The ARCHER center-fix is the the point on that grid with the maximum value.*



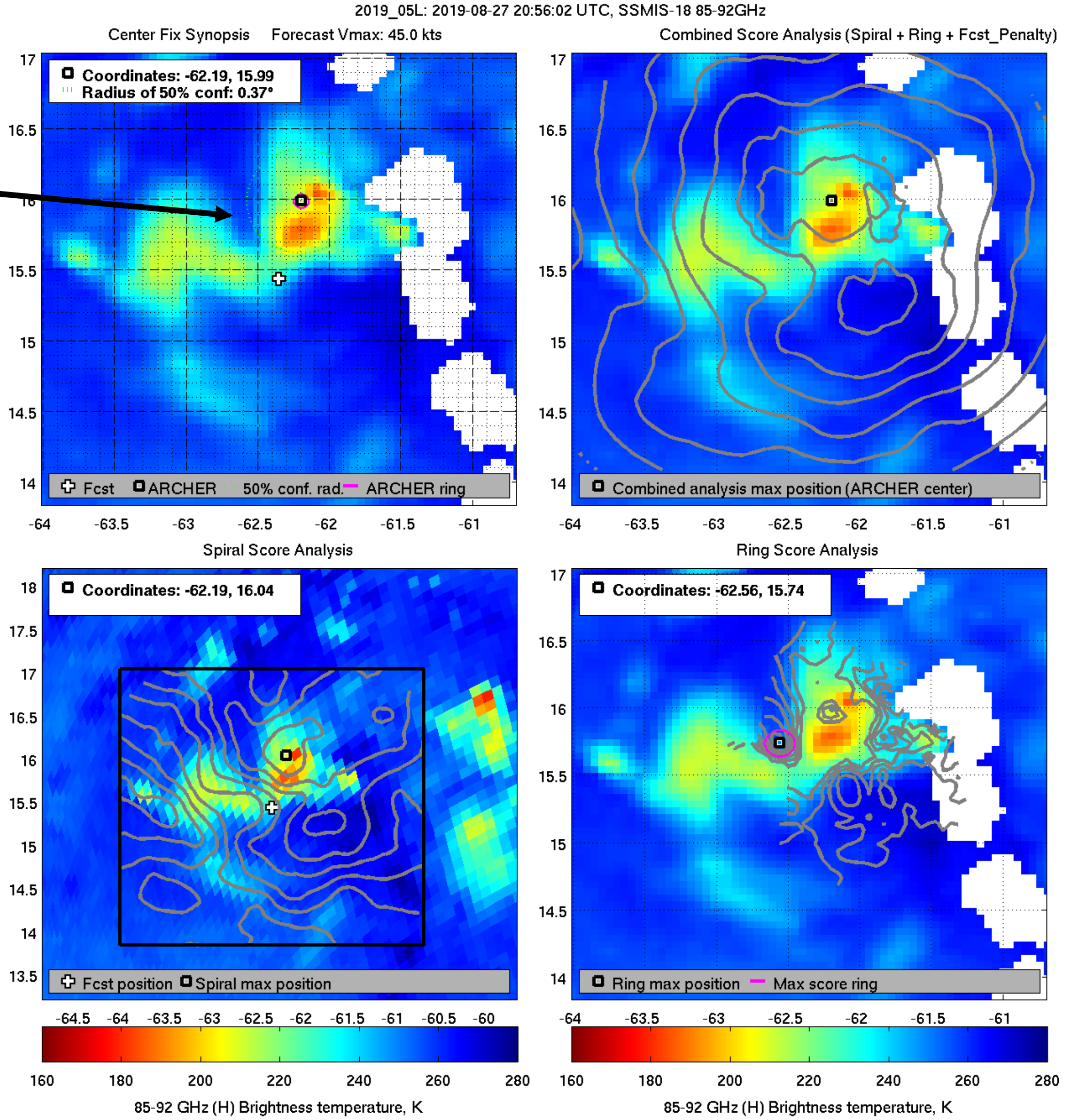
ARCHER

Examples

Hurricane Dorian (2019) center reformation. Notice the distance between the FCST center and ARCHER.

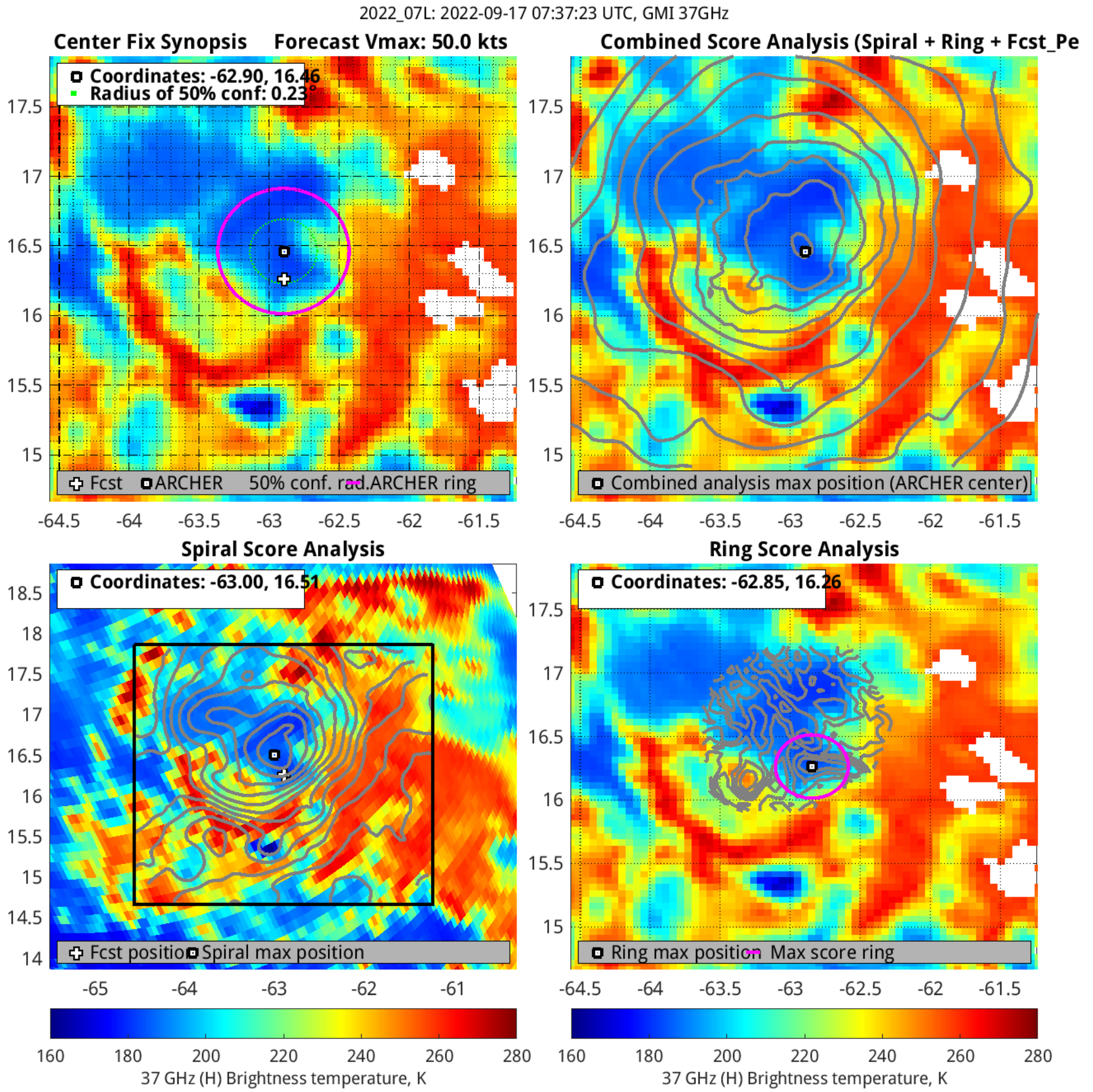


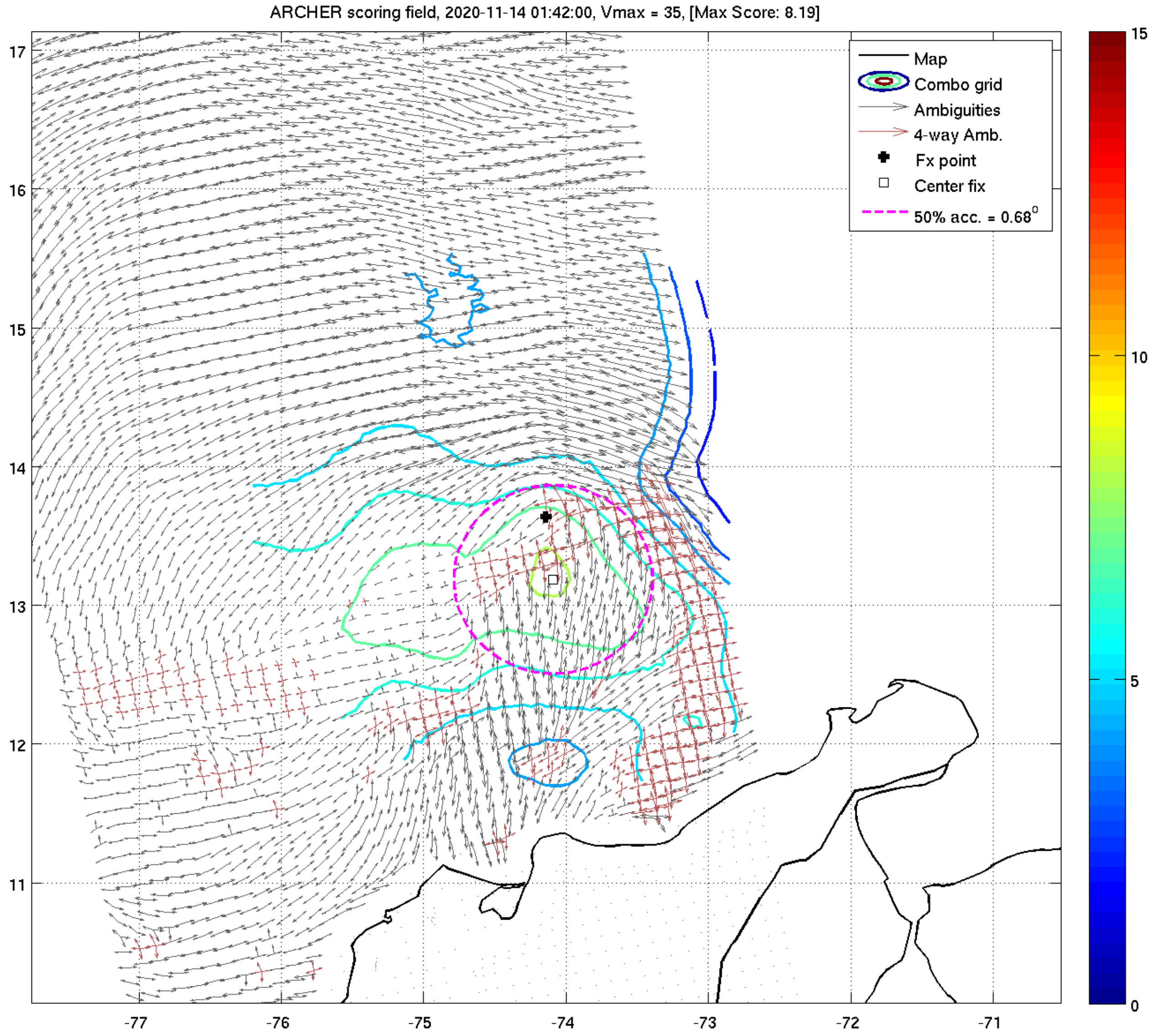
Credit: Phillippe Papin (Twitter)



ARCHER

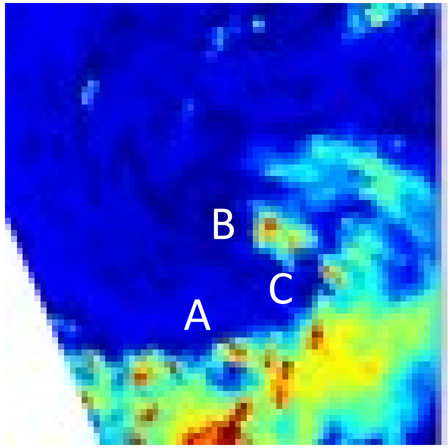
Examples





ARCHER

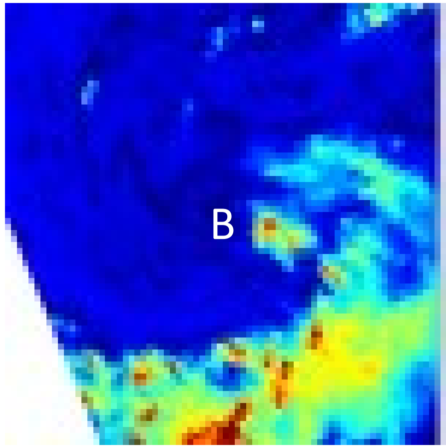
Examples



Where would you put the TC center?

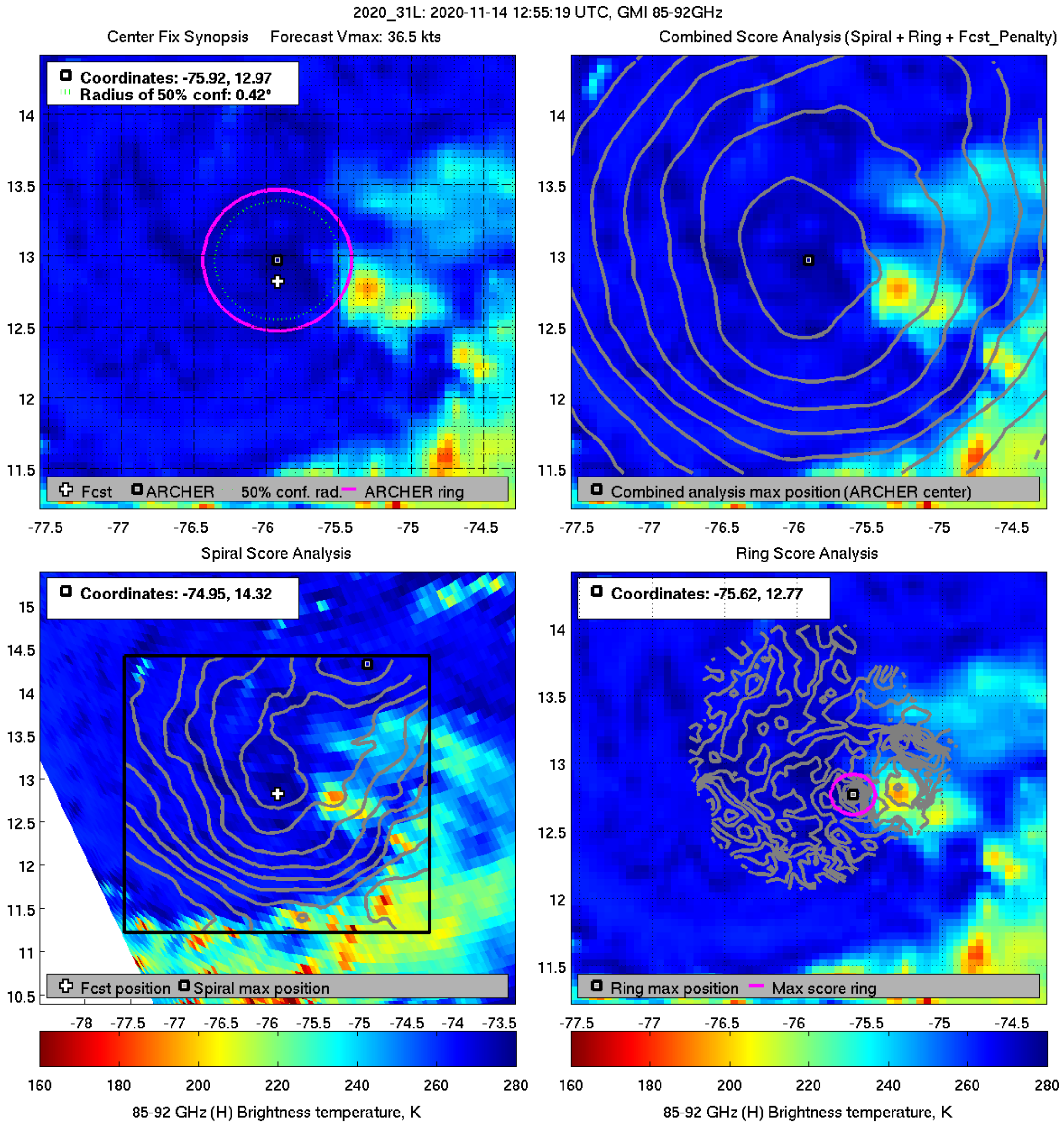
ARCHER

Examples



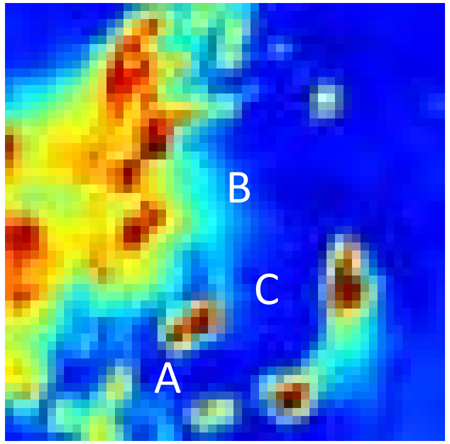
Where would you put the TC center?

B



ARCHER

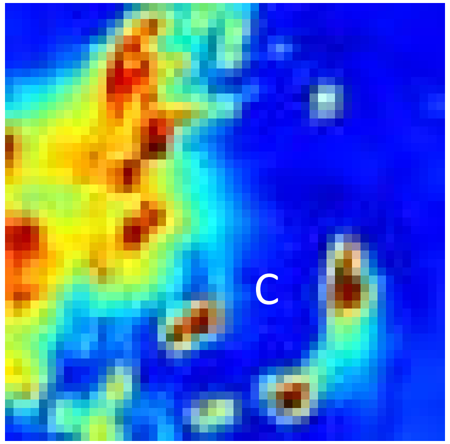
Examples



Where would you put the TC center?

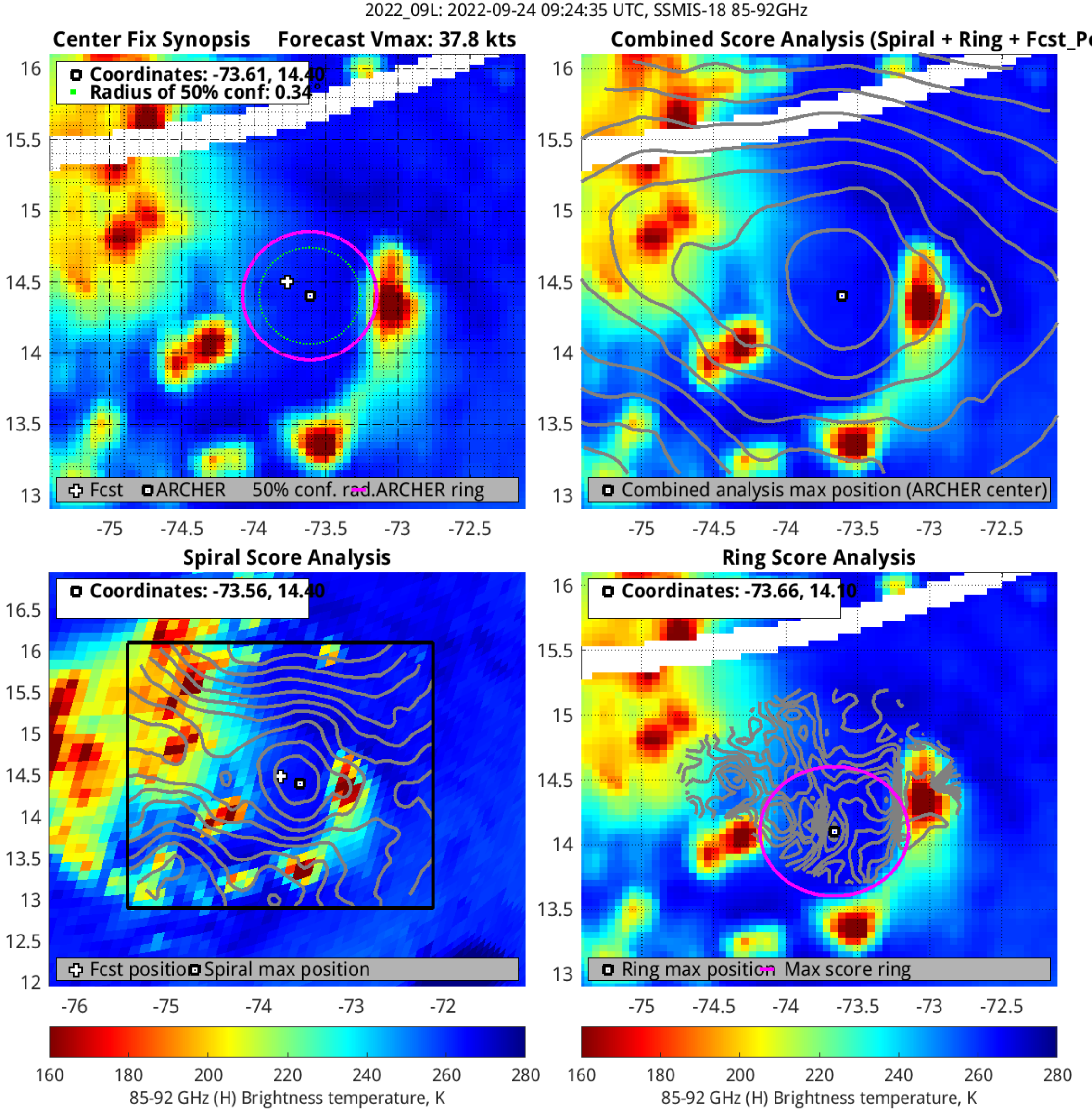
ARCHER

Examples



Where would you put the TC center?

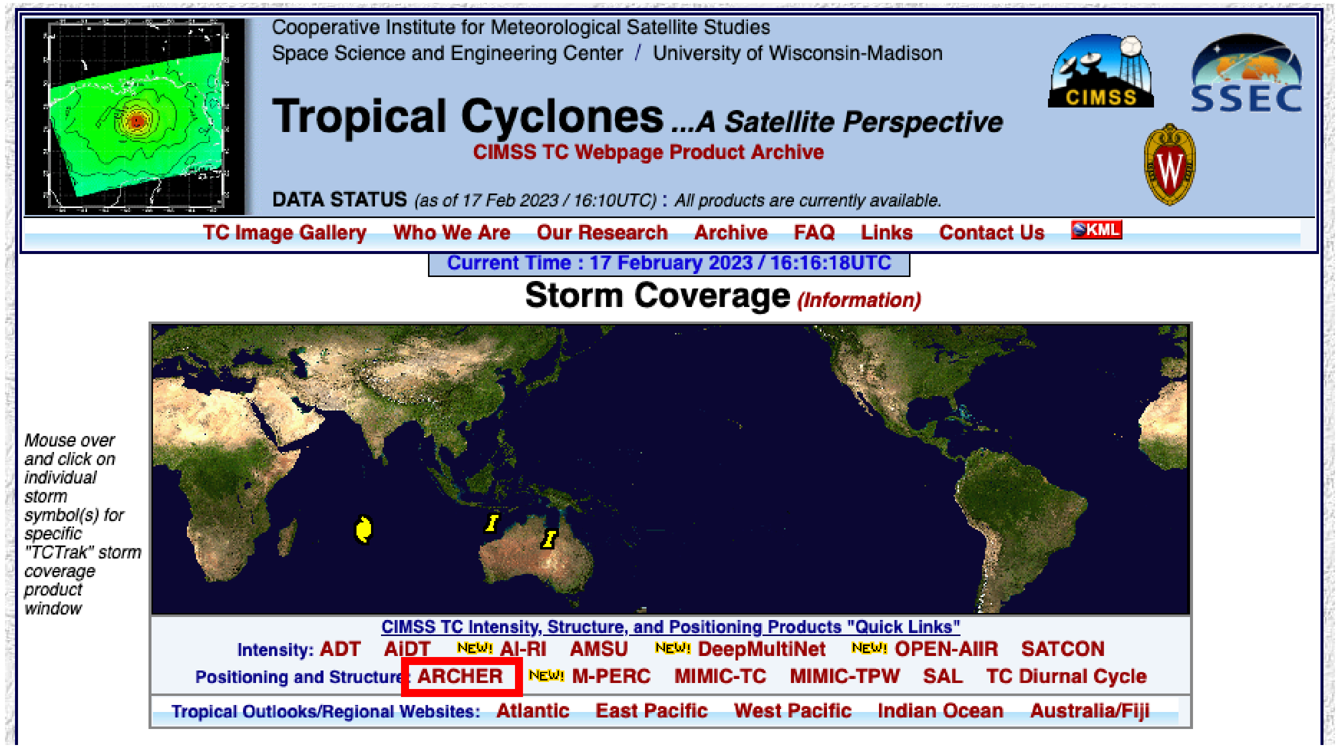
C



ARCHER

Homepage

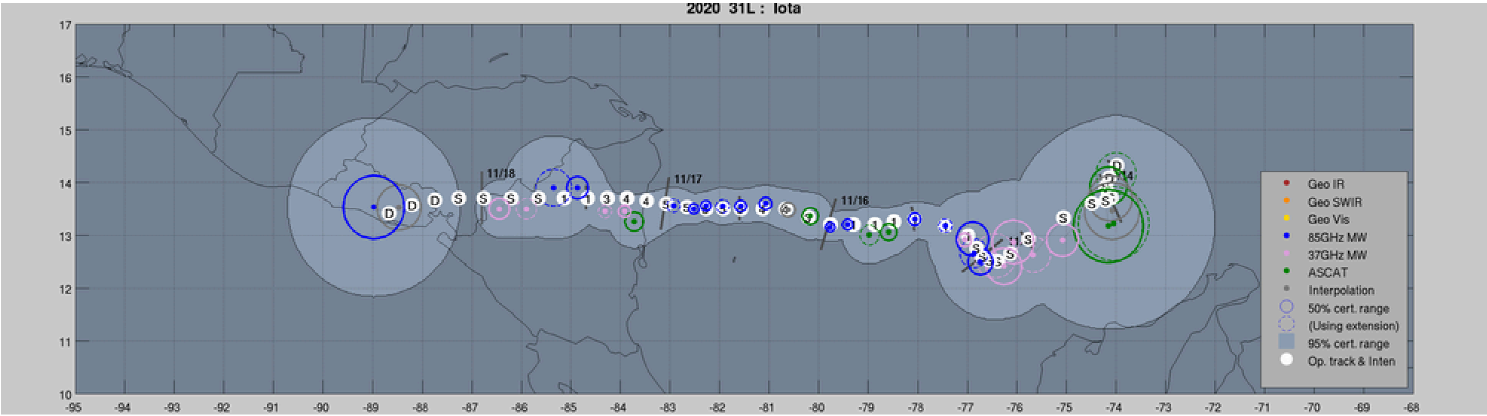
Where to find ARCHER…



https://tropic.ssec.wisc.edu/real-time/archerOnline/web/index.shtml

ARCHER

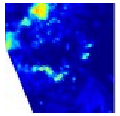
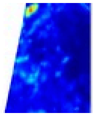
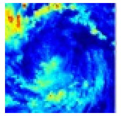
Homepage



ARCHER center locations every 3 hours compared to operational track.

Larger circle = less certain on center.

-- Link to M-PERC page --

Geo IR	85-92GHz	Date/Time (UTC)	Source	Sensor	Vmax(kts)	ARCHER Lat	Lon	Geo-ref Lat	Lon	50% cert. rad.	95% cert. rad.	Eye diam (deg)	% cert. of eye
		**20201118 12:35:18** *	**GMI**	**85-92GHz**	**25.0**	**13.48**	**-89.10**	**13.51**	**-88.97**	**0.59**	**1.67**	**0.90**	**0.3**
		20201118 12:35:18	GMI	37GHz	25.0	***	***	***	***	***	***	0.50	***
		20201118 09:49:25	SSMIS-16	85-92GHz	27.4	***	***	***	***	***	***	3.00	***
		20201118 07:30:46	AMSR2	85-92GHz	30.0	***	***	***	***	***	***	0.70	***
		20201118 07:30:46	AMSR2	37GHz	30.0	***	***	***	***	***	***	0.50	***
		20201117 19:16:35	AMSR2	85-92GHz	52.9	13.85	-85.71	13.85	-85.98	0.30	0.86	0.20	13.6
		20201117 19:16:35 *	**AMSR2**	**37GHz**	**52.9**	**13.50**	**-86.17**	**13.50**	**-86.44**	**0.18**	**0.52**	**1.00**	***
		20201117 14:51:00	Metop-A	ASCAT	65.5	***	***	***	***	***	***	***	***

Entries in the table are grouped in three-hour windows

Bolded: ARCHER track fix is taken for the three-hour window.

https://groups.ssec.wisc.edu/groups/archer/description-of-the-product-pages

Overview

- Advanced Dvorak Technique (ADT) – Version 9.1
- Advanced (AI-enhanced) Dvorak Technique (AiDT)
- DeepMicroIRNet (D-MINT) and DeepIRNet (D-PRINT)
- Satellite Consensus Algorithm (SATCON)
- AI-RI
- ARCHER
- **M-PERC**

M-PERC

Microwave-based Probability of Eyewall Replacement Cycle

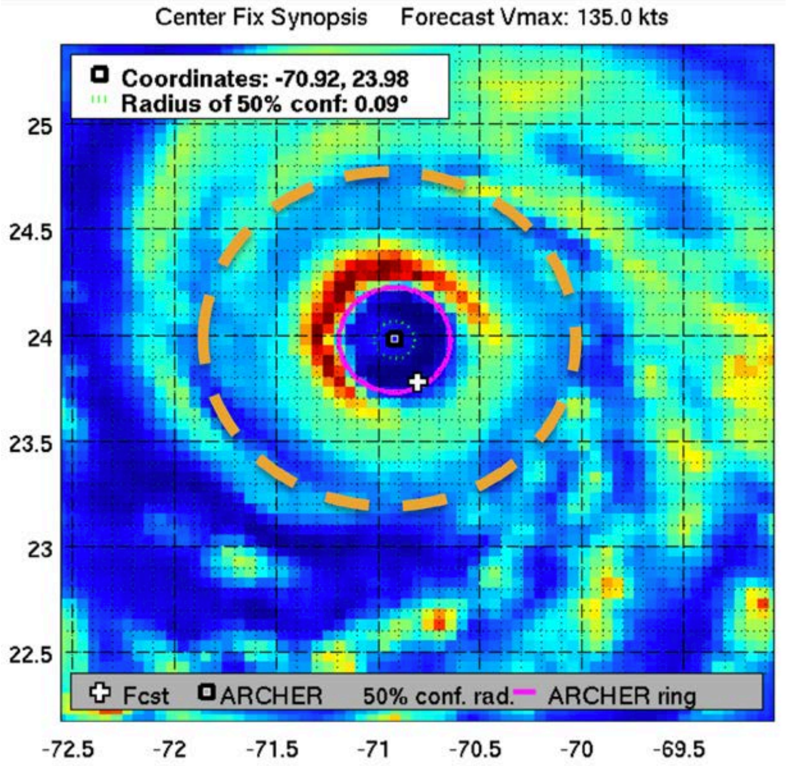
A method for determining the onset of ERCs

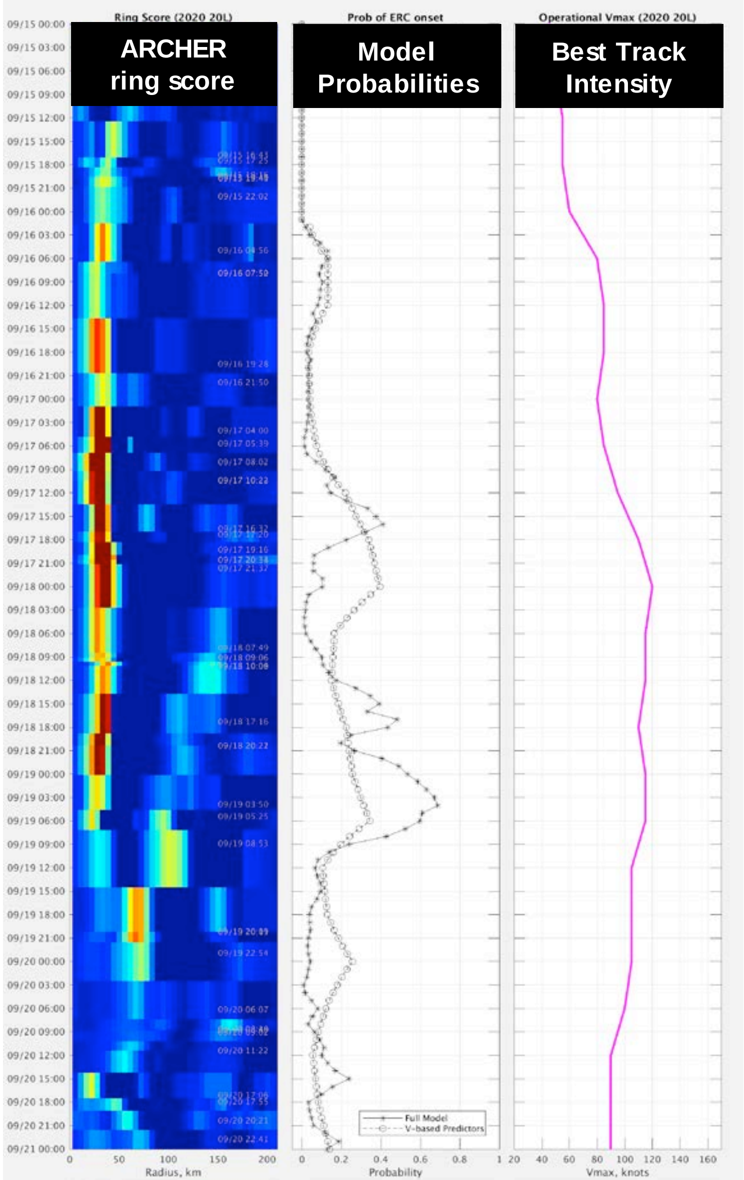
Derrick Herndon, Tony Wimmers and Chris Velden

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

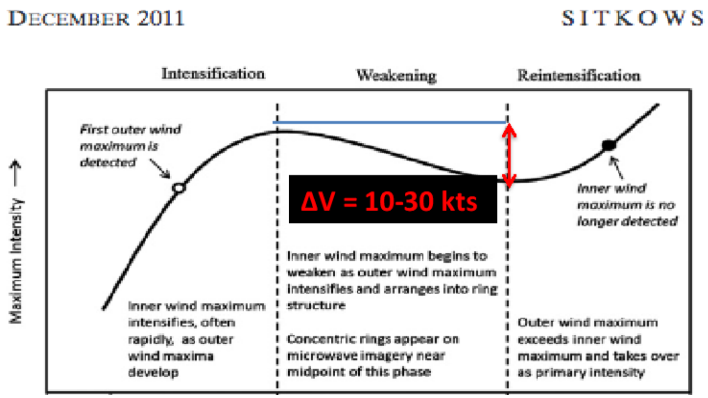
Overview

Guidance to forecasters:

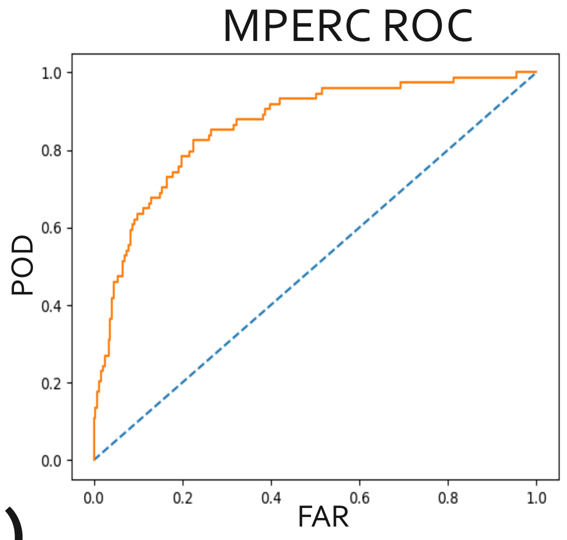
- Increase attention when probabilities exceed **25%.**
- Probabilities > **70%** likely will result in weakening
- Average lead time to change in intensity trend ~ 10 hours

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



Sitkowski, M., J. P. Kossin, and C. M. Rozoff, 2011: Intensity and structure changes during hurricane eyewall replacement cycles. *Mon. Wea. Rev.*, **139**, 3829-3847.



Compared to Climo probability of 13% (Kossin and Sitkowski 2009)

Brier Skill Score for Atl-trained model 0.40. (1 is perfect)

BSS for Epac/Cpac model 0.41 (using subset of Atl predictors)

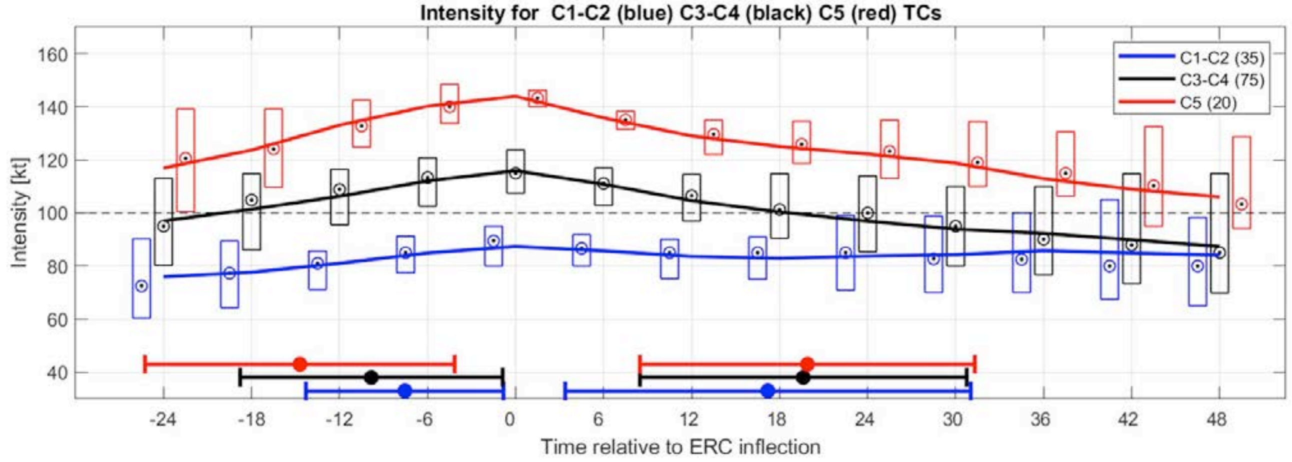
TC intensity change/ERC length for ERC events binned by intensity category- ATL

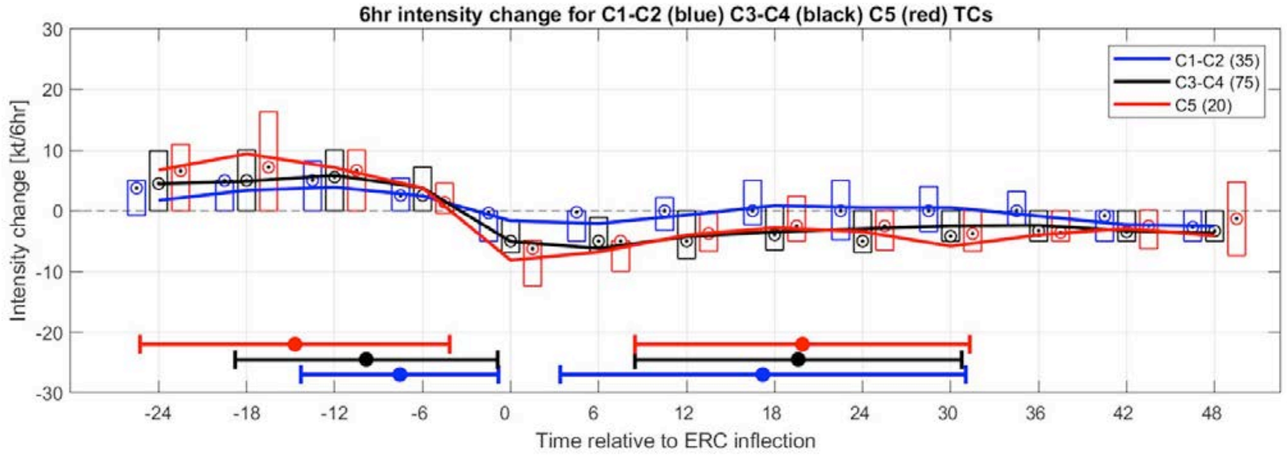
Moving beyond the ERC "weakening" paradigm

How can forecasters adjust intensity forecasts based on M-PERC?

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 (Lifetime Maximum Intensity occurs prior to ERC)

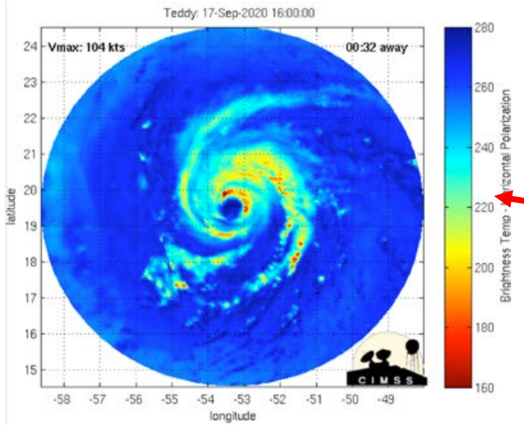




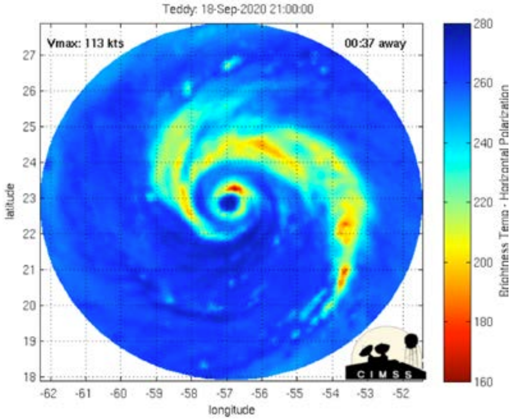
M-PERC
Overview

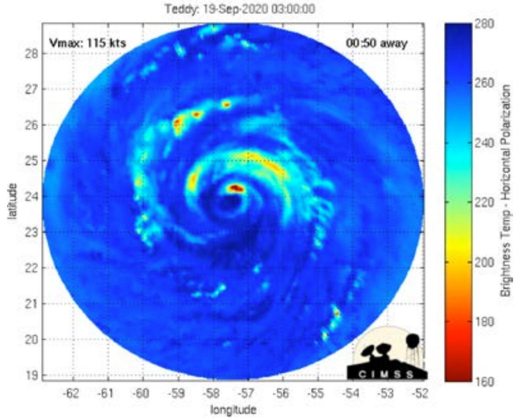
Types of ERC Events

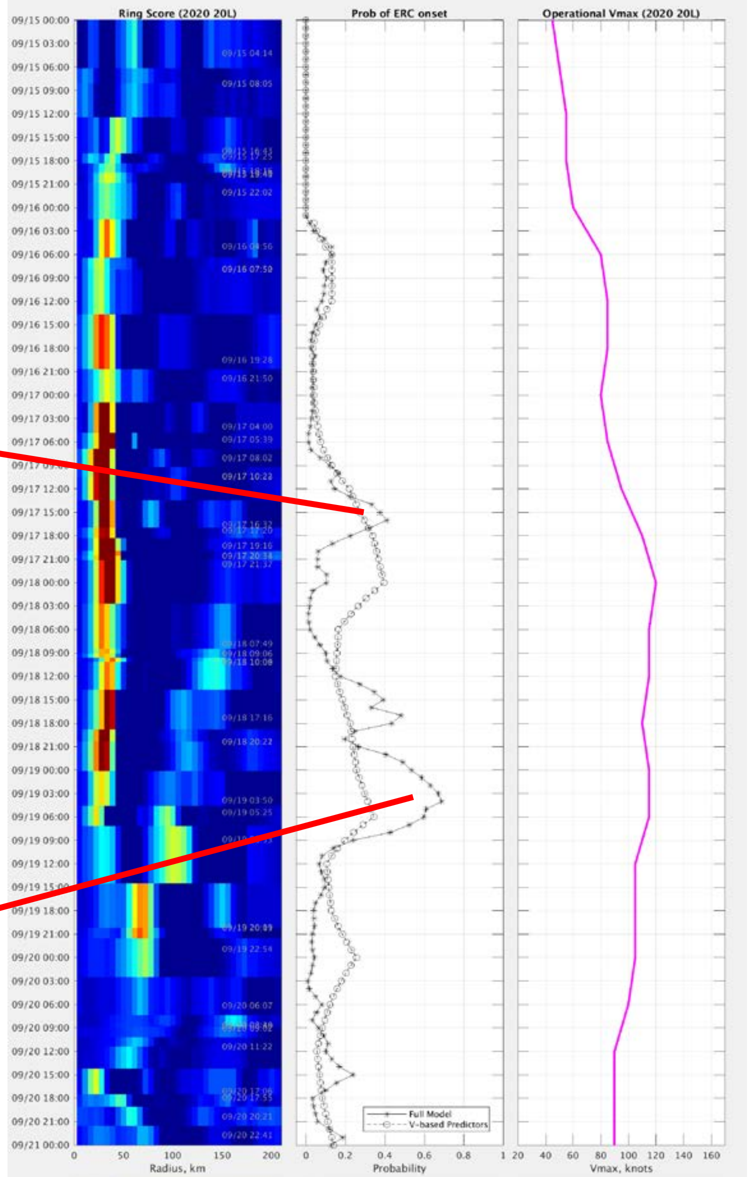
Fast Evolving: early events with lower probability that has less impact on Vmax.



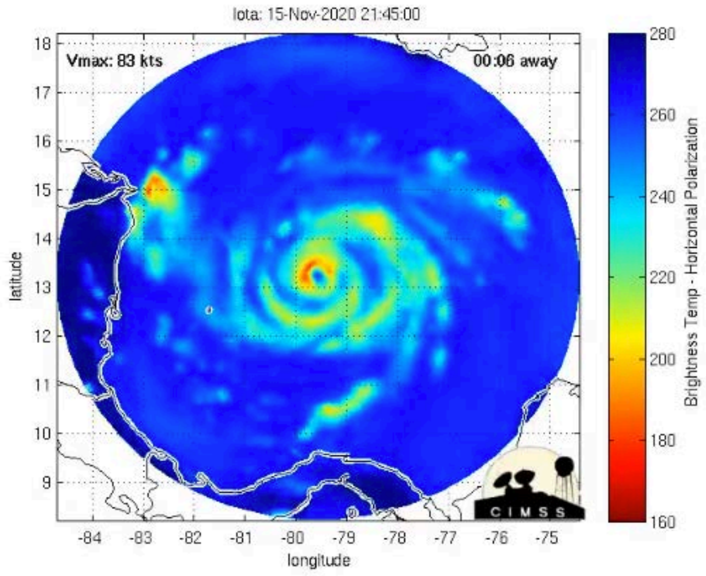
Higher Probability: Larger impact on Vmax. More likely to cause weakening.

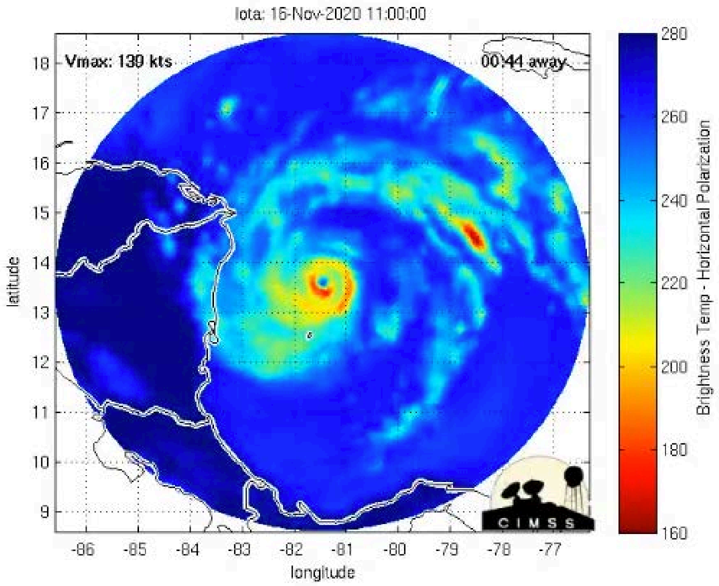






M-PERC
Exercise

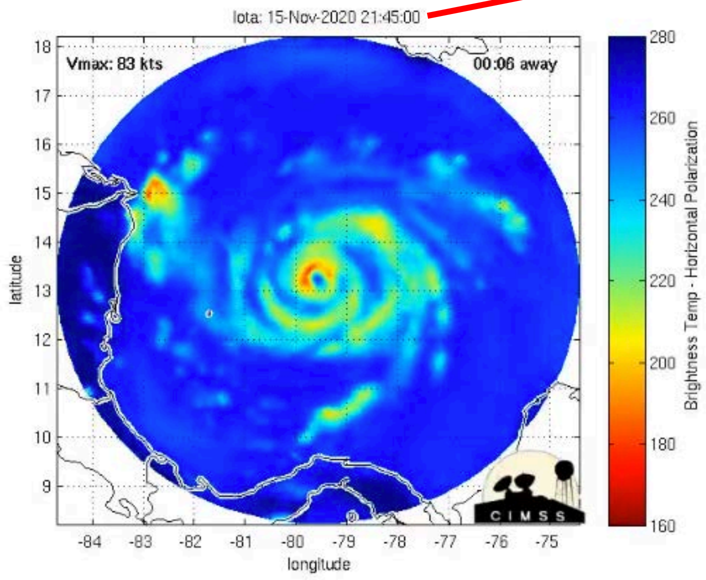


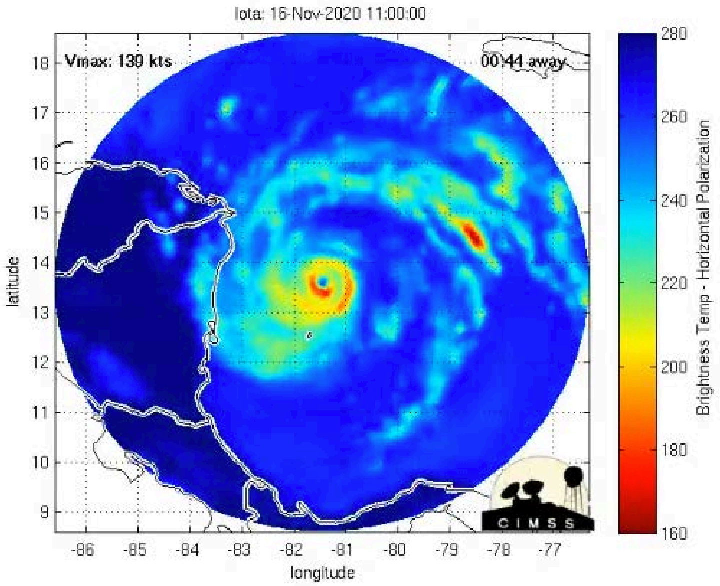


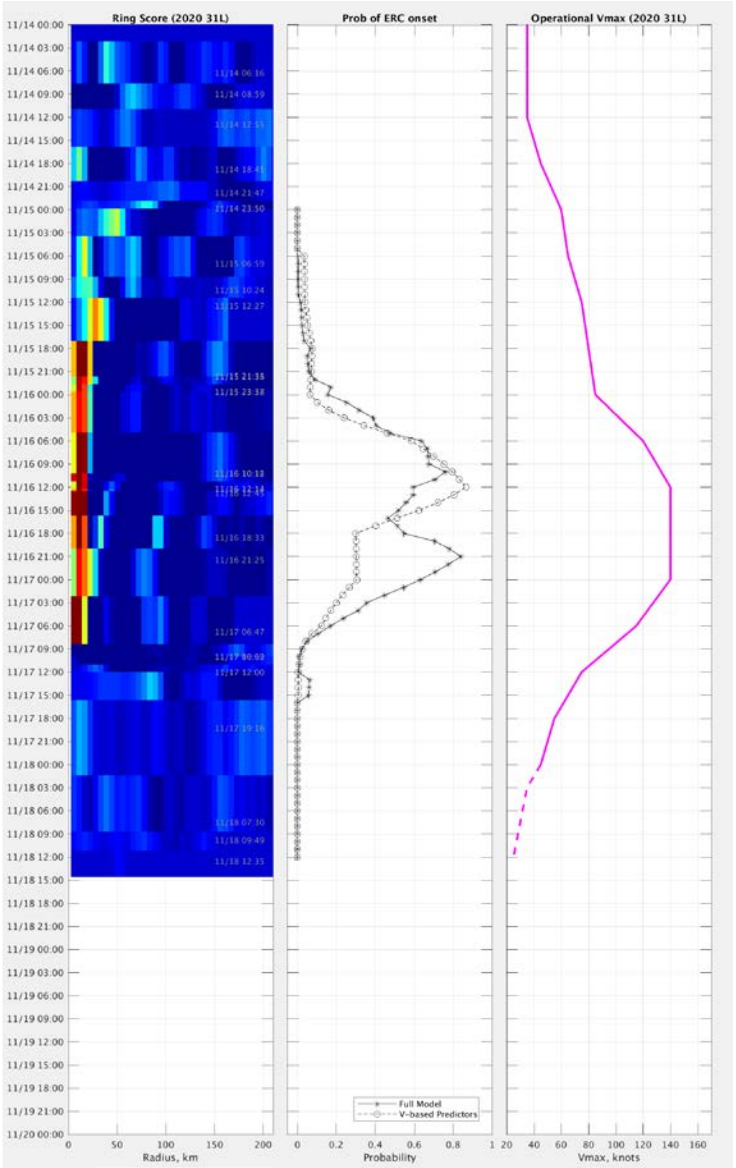
Would you predict an ERC is going to occur?

M-PERC

Exercise







Would you predict an ERC is going to occur?

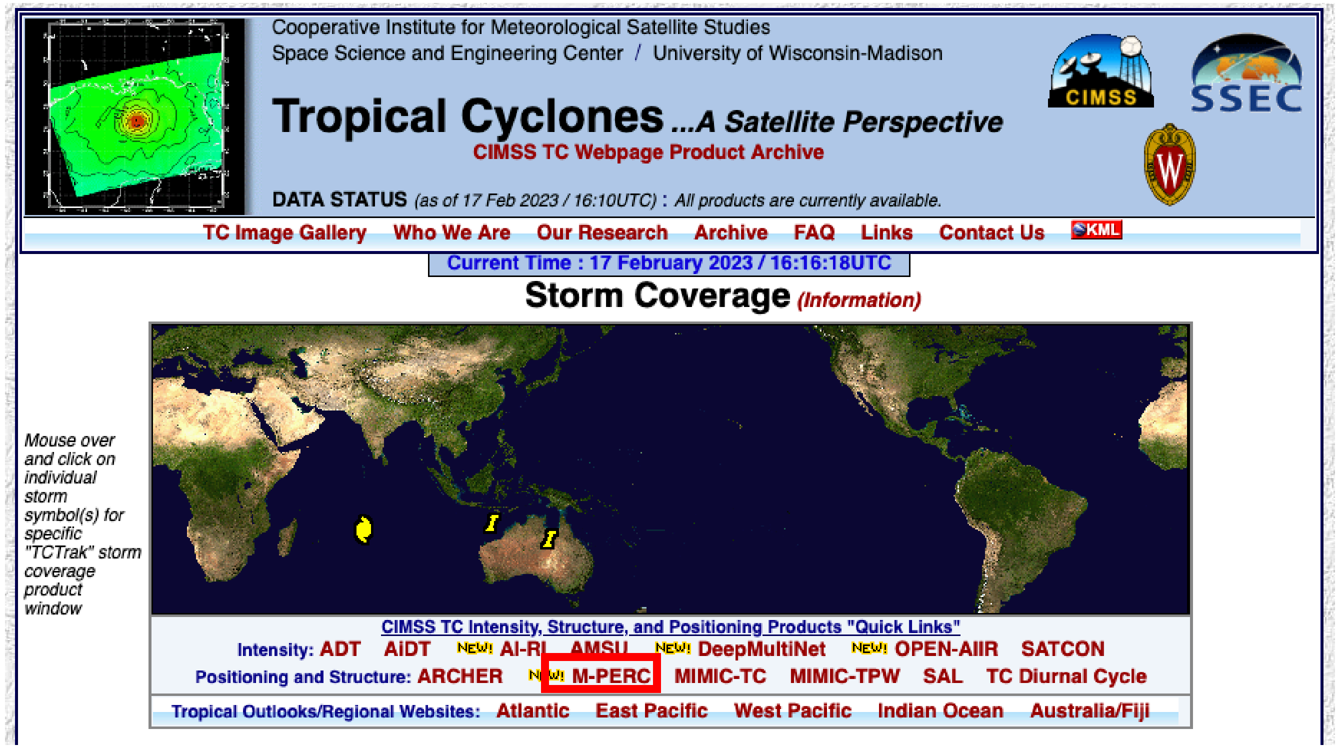
Yes.

Secondary eyewall in the first image.

Equal Magnitude Eyewall Rings in the second image.

M-PERC probabilities are high.

Where to find M-PERC…



https://tropic.ssec.wisc.edu/real-time/archerOnline/web/index.shtml