WMO RA-IV Workshop on Hurricane Forecasting and Warning 2022

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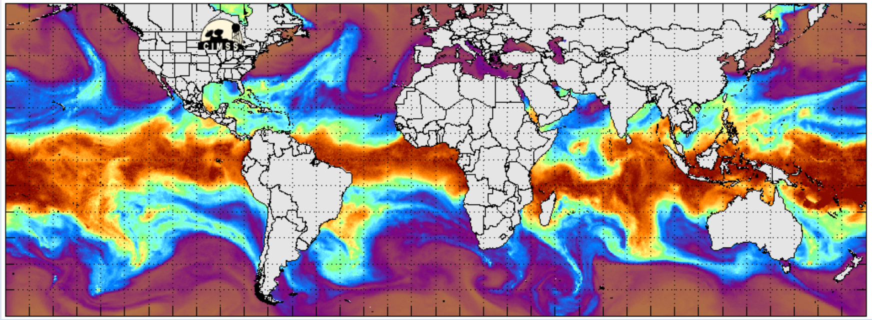
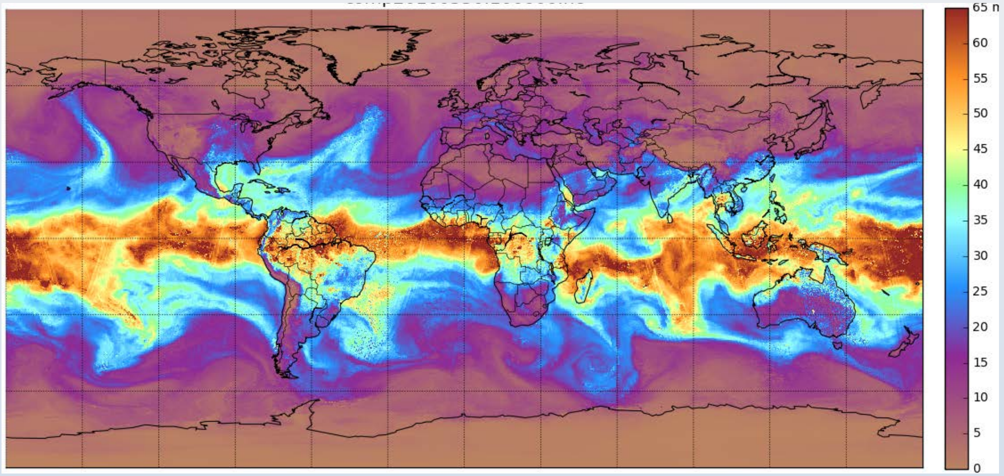
Real-time products

MIMIC-TPW



Version 1: 2008-2018

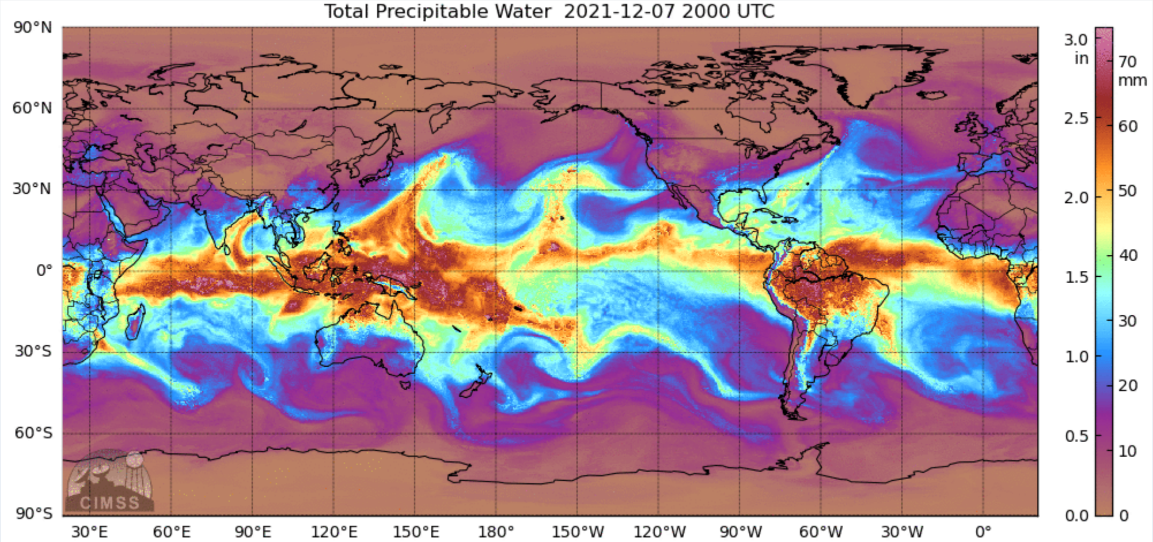


Version 2: 2016-present

- MIMIC-TPW: Morphed, Integrated Microwave Imagery at CIMSS – Total Precipitable Water
- Optimal sampling for morphing: TPW is a long-lived tracer (~12 hours), observed by polar-orbiting satellites every ~6 hours
- Built from MiRS retrievals of water vapor, using NOAA-19, -20, Suomi NPP, Metop-A, -B.

Benefits of using MIRS

Version 2: Uses MIRS



4

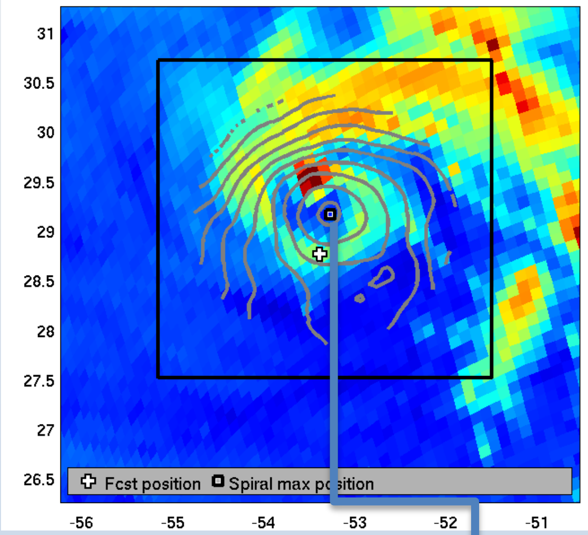
- *Full global coverage* (versus over-water only)
- *Continuity*: We can be sure that this will continue after the DMSP program is over
- *Accuracy*: MIRS is well-validated and actively maintained
- *Big surprise benefit*: Morphed data also works well over land
- Collaboration with CIRA (Colorado State University) to produce a NOAA-operational multi-layer morphed precipitable water product

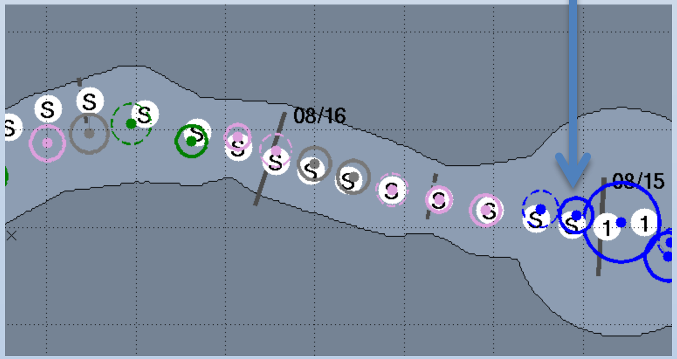
ARCHER Version 4

- Three main components:

1. **Image analysis**
   - Parallax adjustment
   - Determination of **center-fix**
   - Determination of **center-fix confidence (expected error)**
   - Additional metrics (**e.g. eye size)**
2. **Integration into storm track**
   - Track-ready layout of fix history
3. **Eyewall trends**
   - Hovmoller-type radial info vs. time to evaluate eyewall replacement cycles

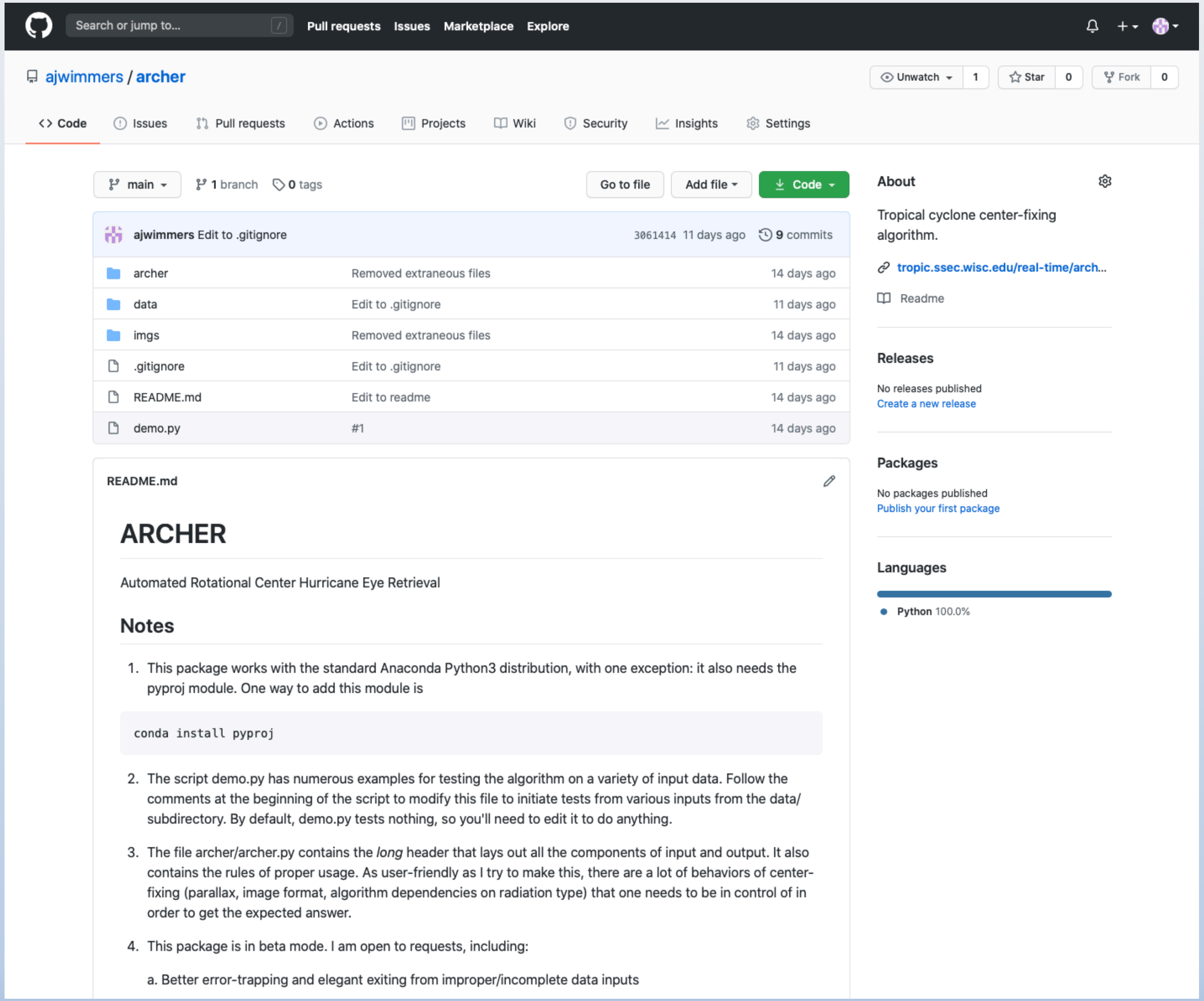
   M-PERC





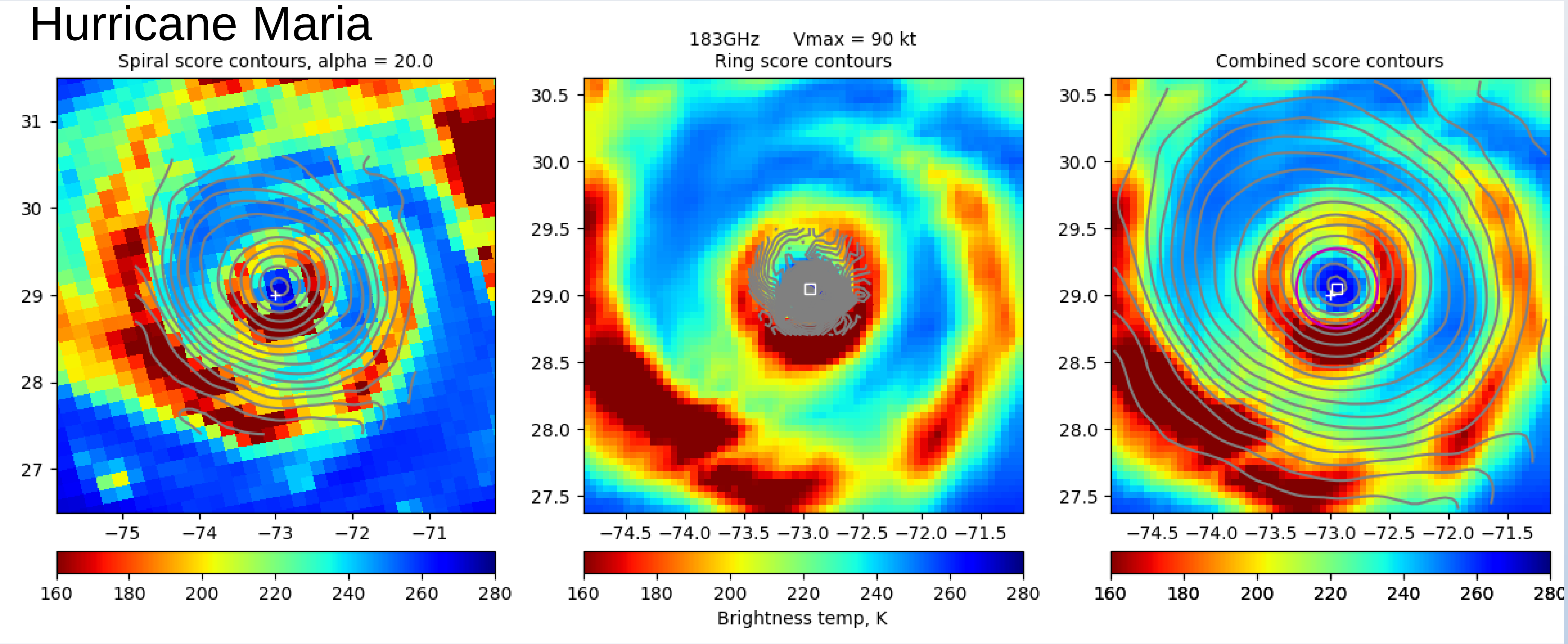
ARCHER Status Update

- We have recoded ARCHER into Python and are now sharing it publicly on GitHub
- This is serving as a pathfinder for integrating CIMSS and other research algorithms into the GeoIPS platform for future, extensive real-time analysis of TC imagery.



ARCHER Status Update

Adapting ARCHER to JPSS: **ATMS 183 GHz (H)** (cross-track sounders)

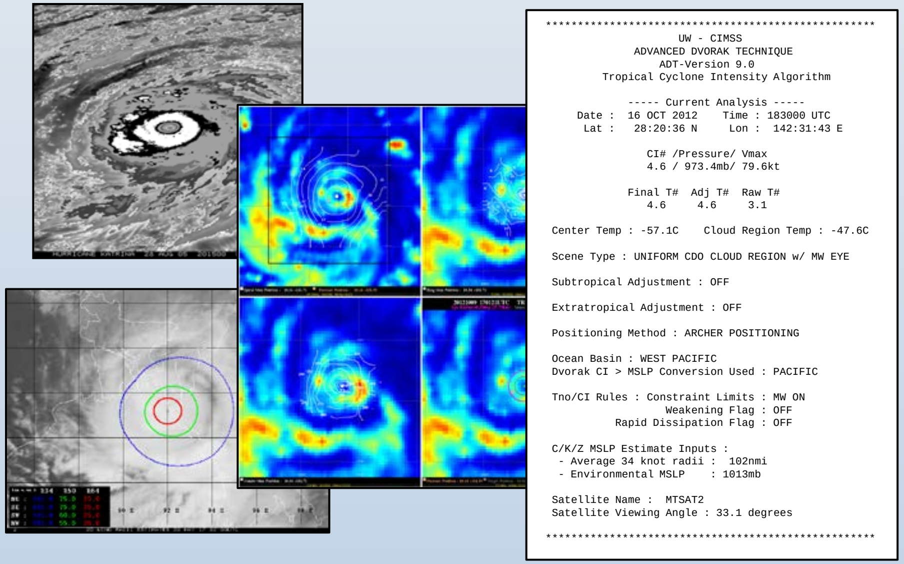


Eye size and structure inputs from ATMS 183 GHz to sounder intensity algorithms

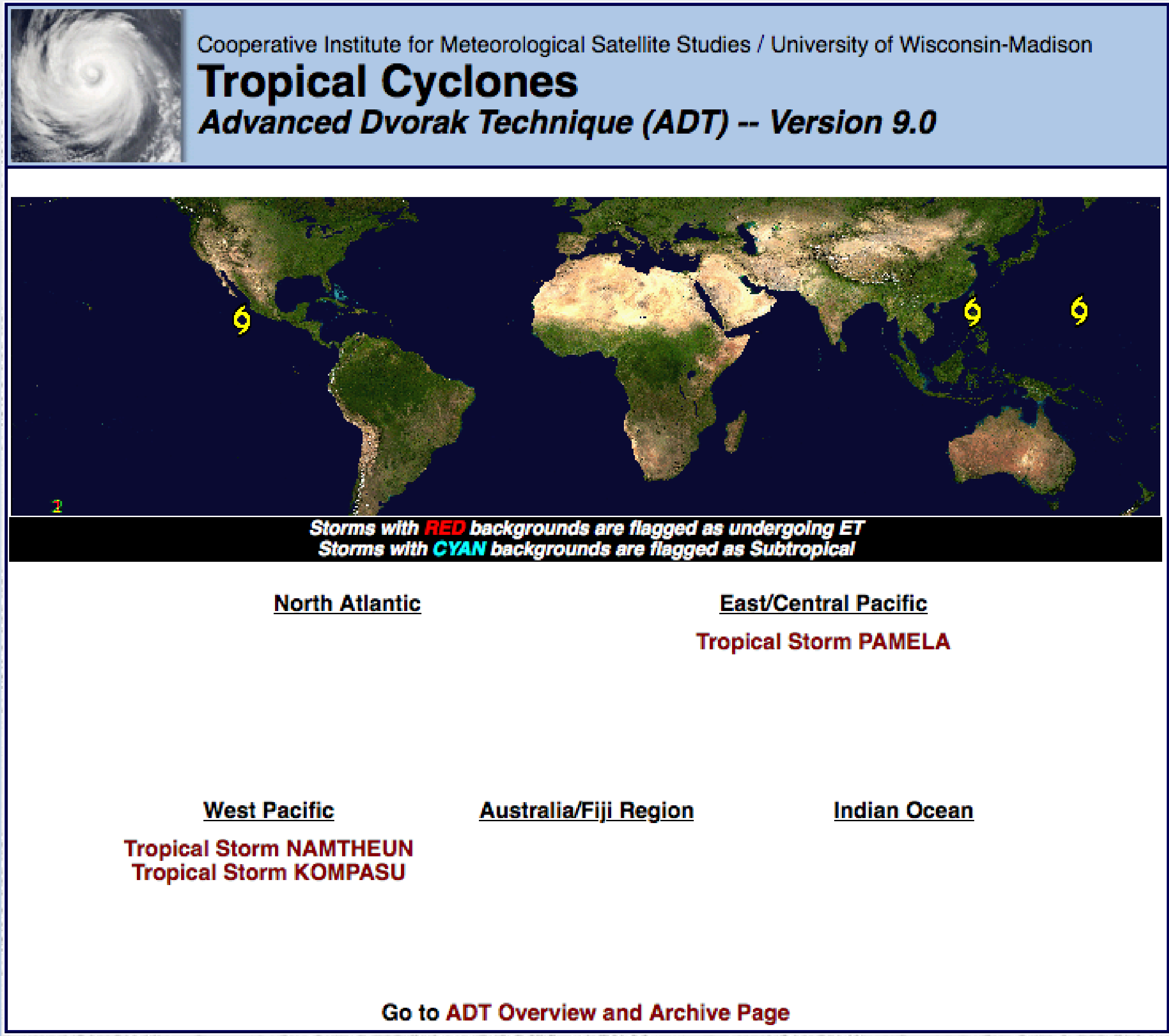
Advanced Dvorak Technique (ADT)

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

- **Real-time, global tropical cyclone intensity estimation using geostationary IR satellite imagery**



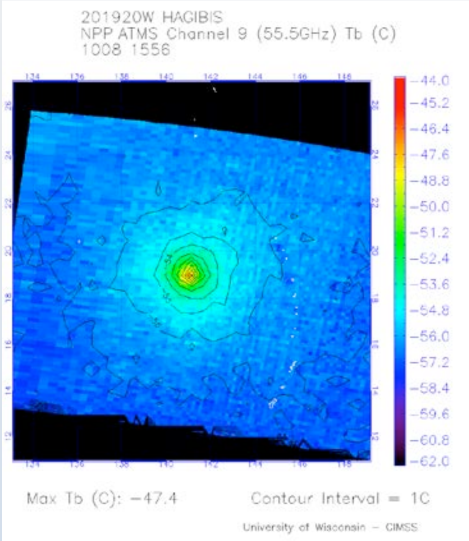
- **Olander, T. and C. Velden, 2019:** The Advanced Dvorak Technique (ADT) for Estimating Tropical Cyclone Intensity: Update and New Capabilities, ***Wea. Forecasting*, 34, 905-922.**

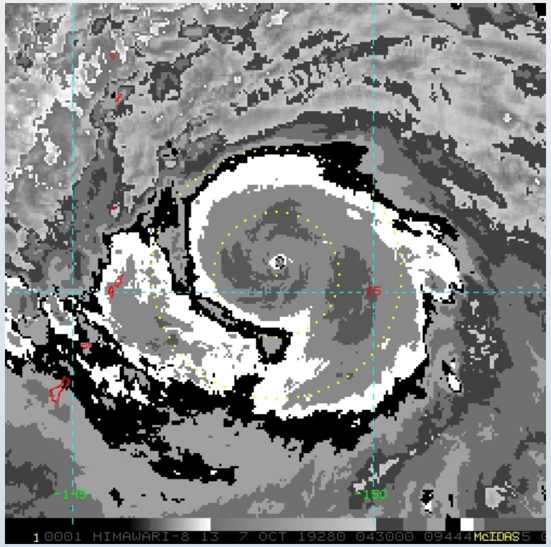


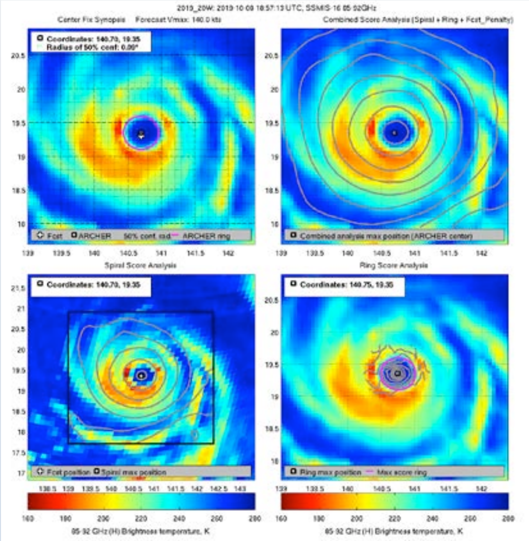
Advanced Dvorak Technique (ADT)

- **Primary ADT-V9.0 upgrades**
  - **Extratropical Transition intensity estimate adjustment**
  - **Analysis of Sub-Tropical systems with modifications to ADT logic**
  - **ARCHER 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**

Estimating TC Current Intensity: SATCON







MW Sounders **ADT** **ARCHER**

Note

ARCHER primarily provides location, eyewall convective vigor, and eye size information to SATCON for intensity adjustments

- **Make use of known bias information for each estimate to produce a weighted consensus**
- **SATellite CONsensus (SATCON)**

AUGUST 2020 VELDEN AND HERNDON 1645

A Consensus Approach for Estimating Tropical Cyclone Intensity from Meteorological Satellites: SATCON

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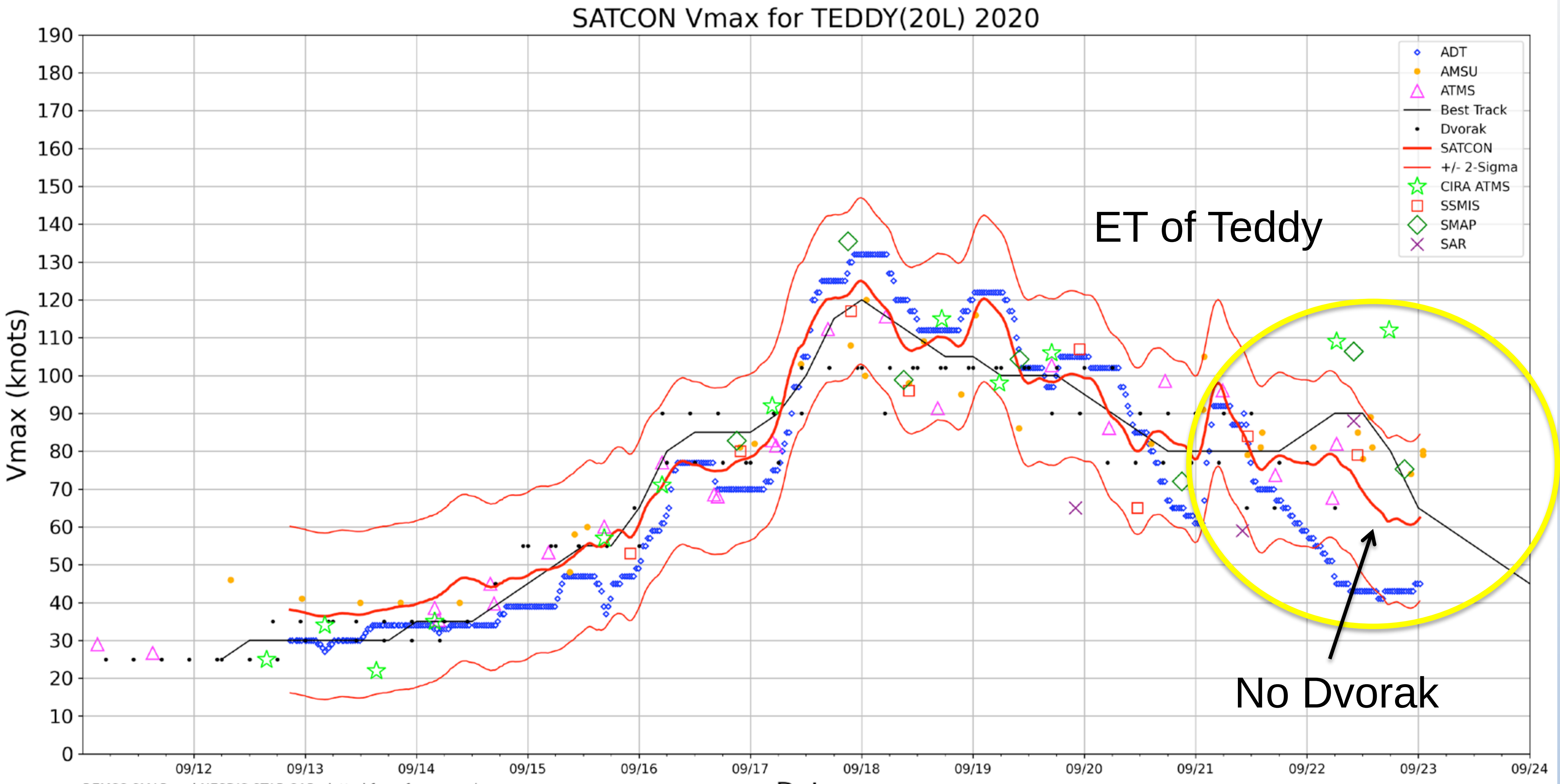
(Manuscript received 27 January 2020, in final form 11 May 2020)

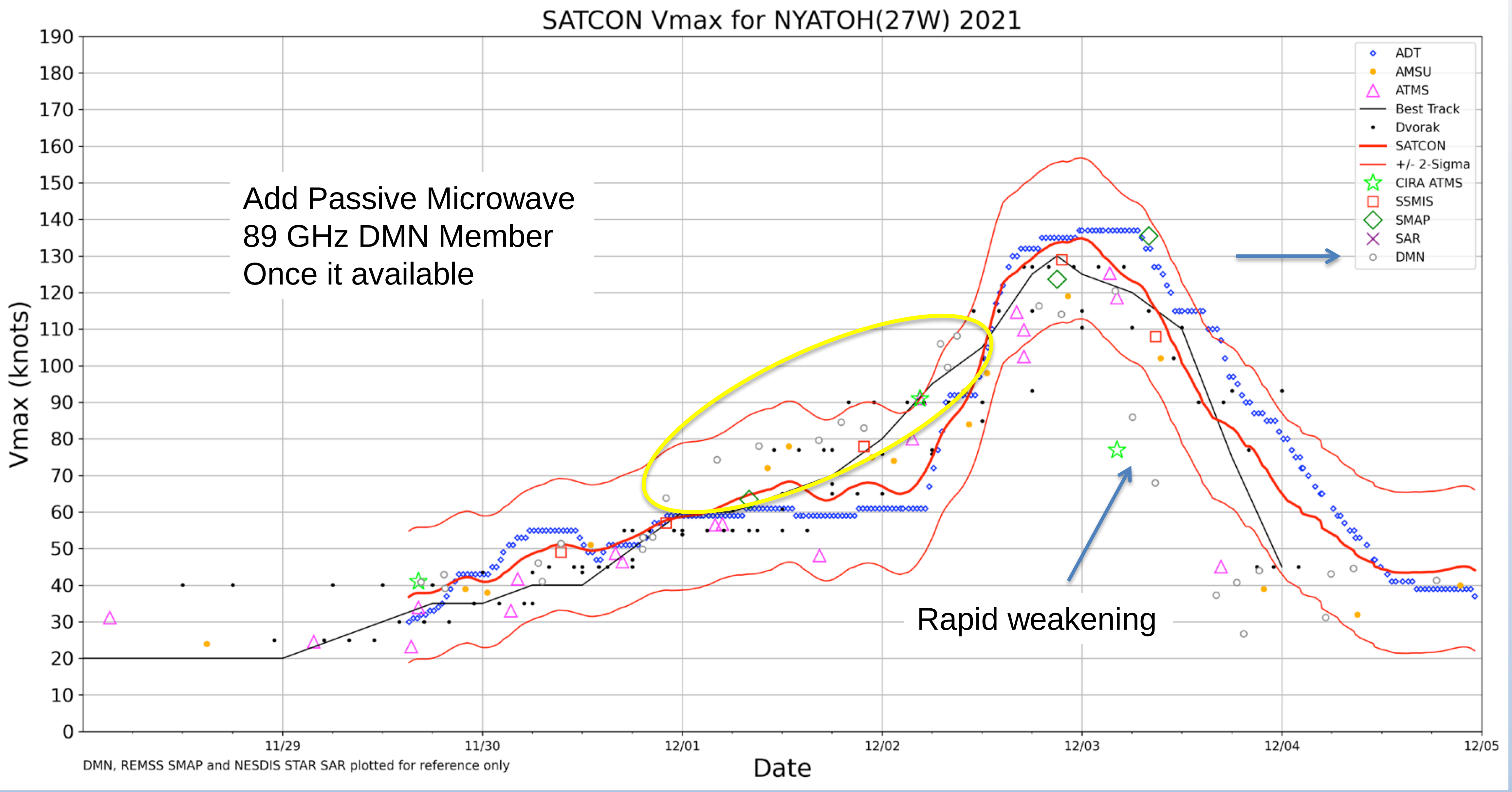
https://doi.org/10.1175/WAF-D-20-0015.1

Estimating TC Current Intensity: SATCON

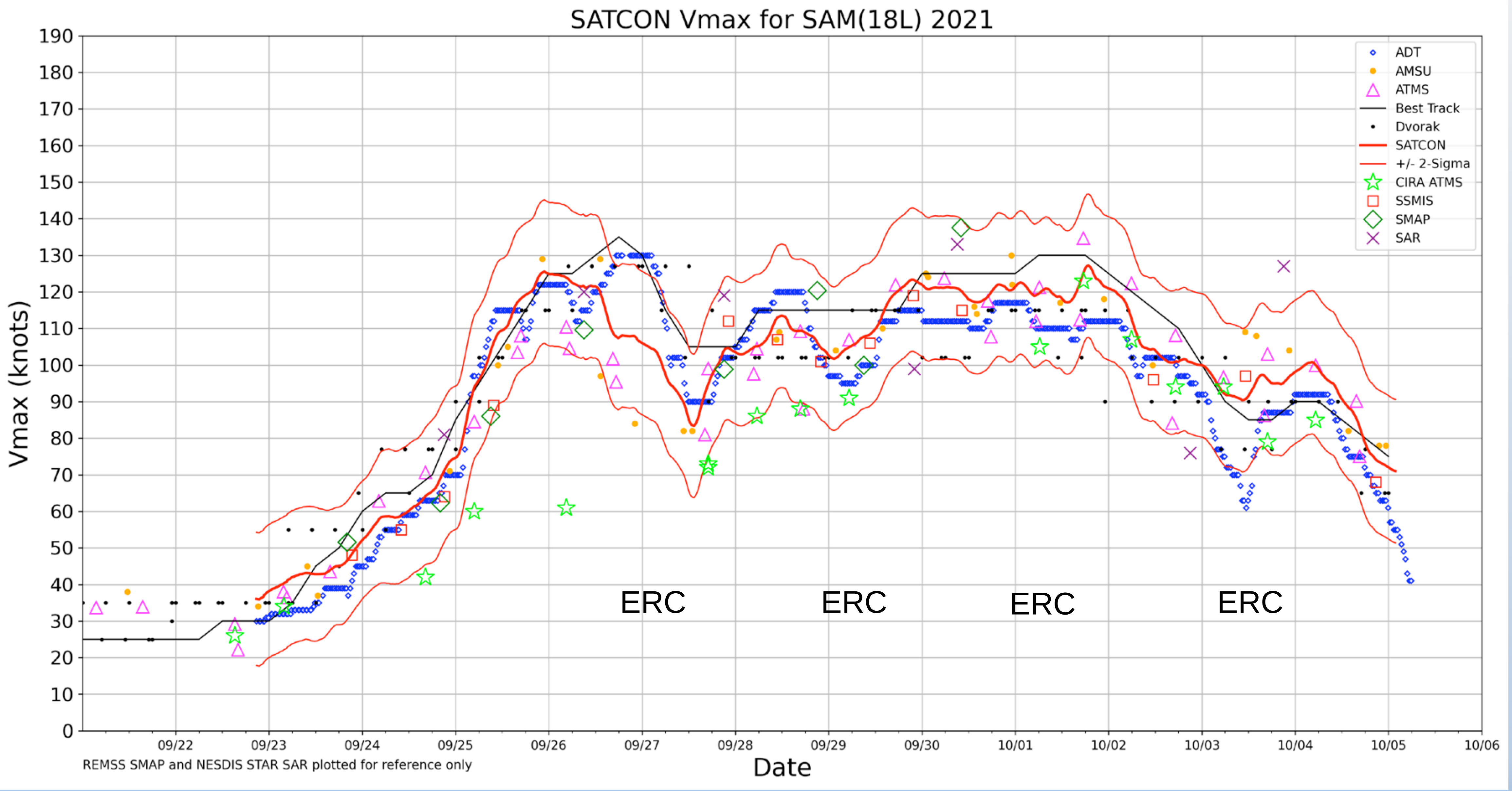


REMSS SMAP and NESDIS STAR SAR plotted for reference only

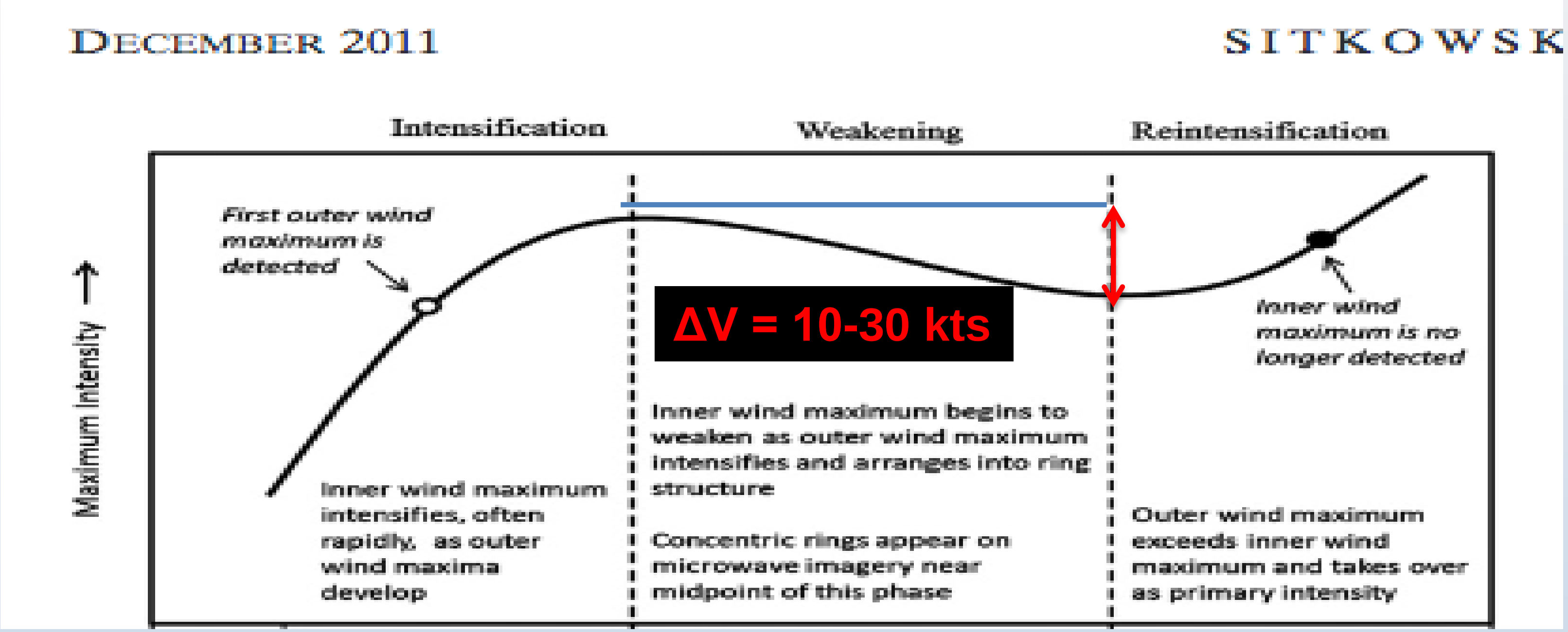
Estimating TC Current Intensity: SATCON



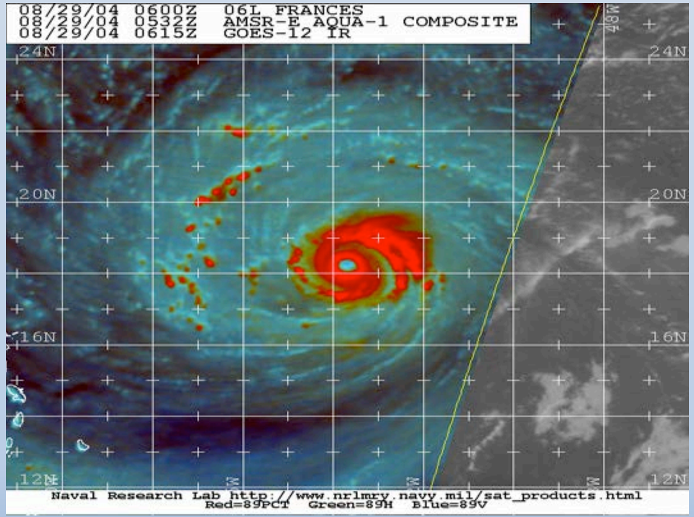
Estimating TC Current Intensity: SATCON

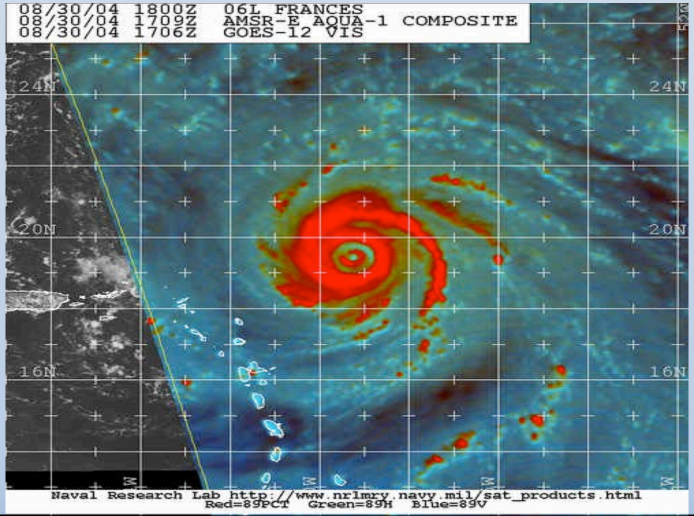


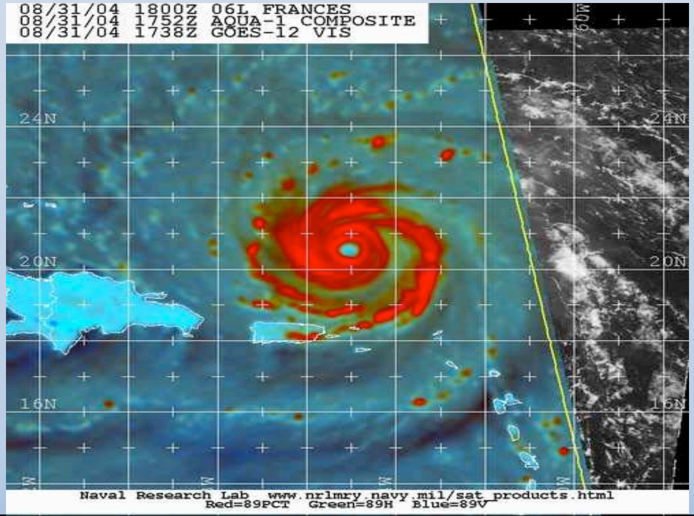
ERC Onset Guidance: M-PERC



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.

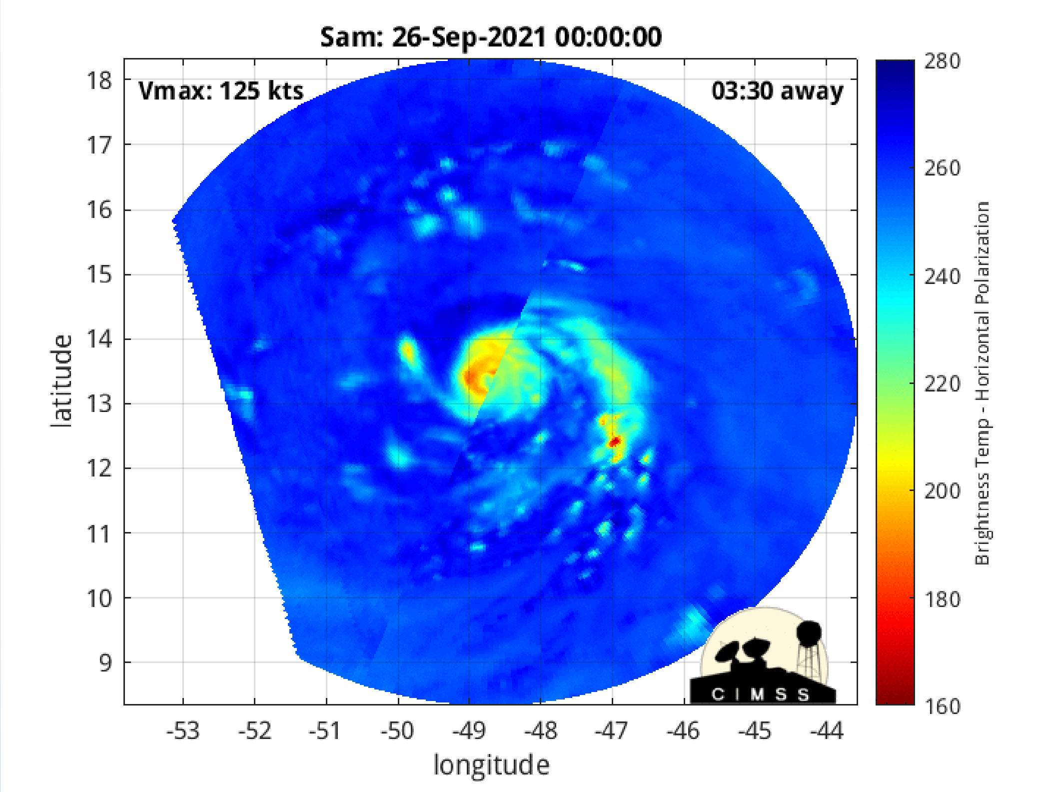






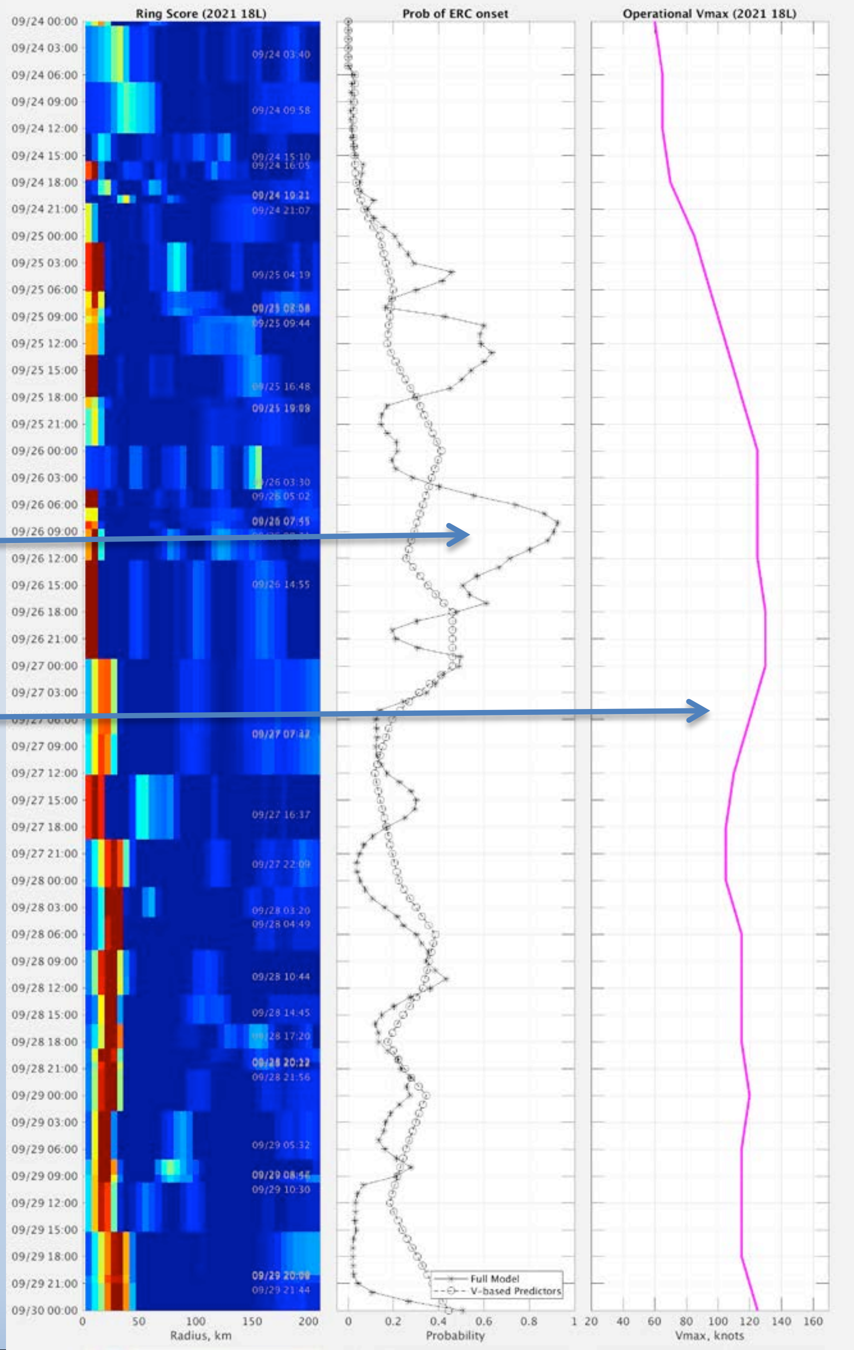
TC Structure and Intensity Change: M-PERC

Hurricane Sam 2021



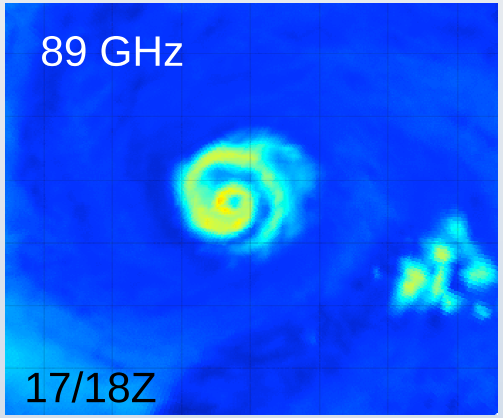
M-PERC peak at 90%

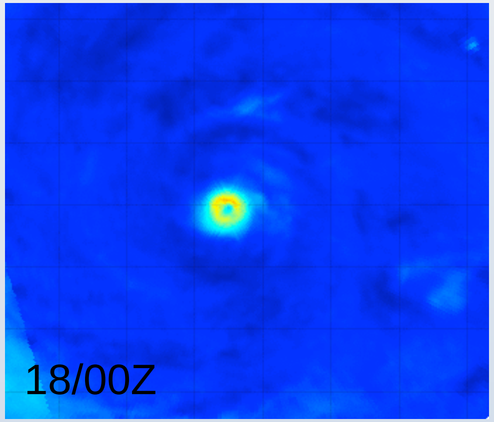
30 Knots of weakening

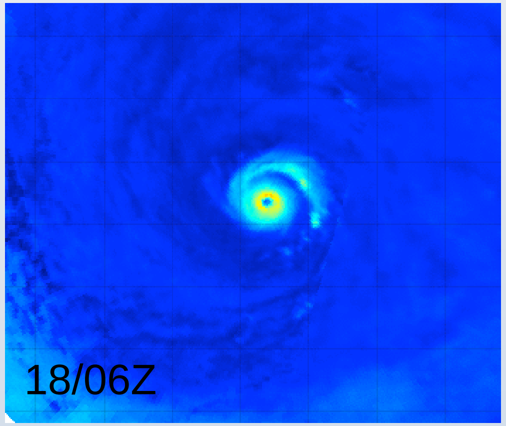


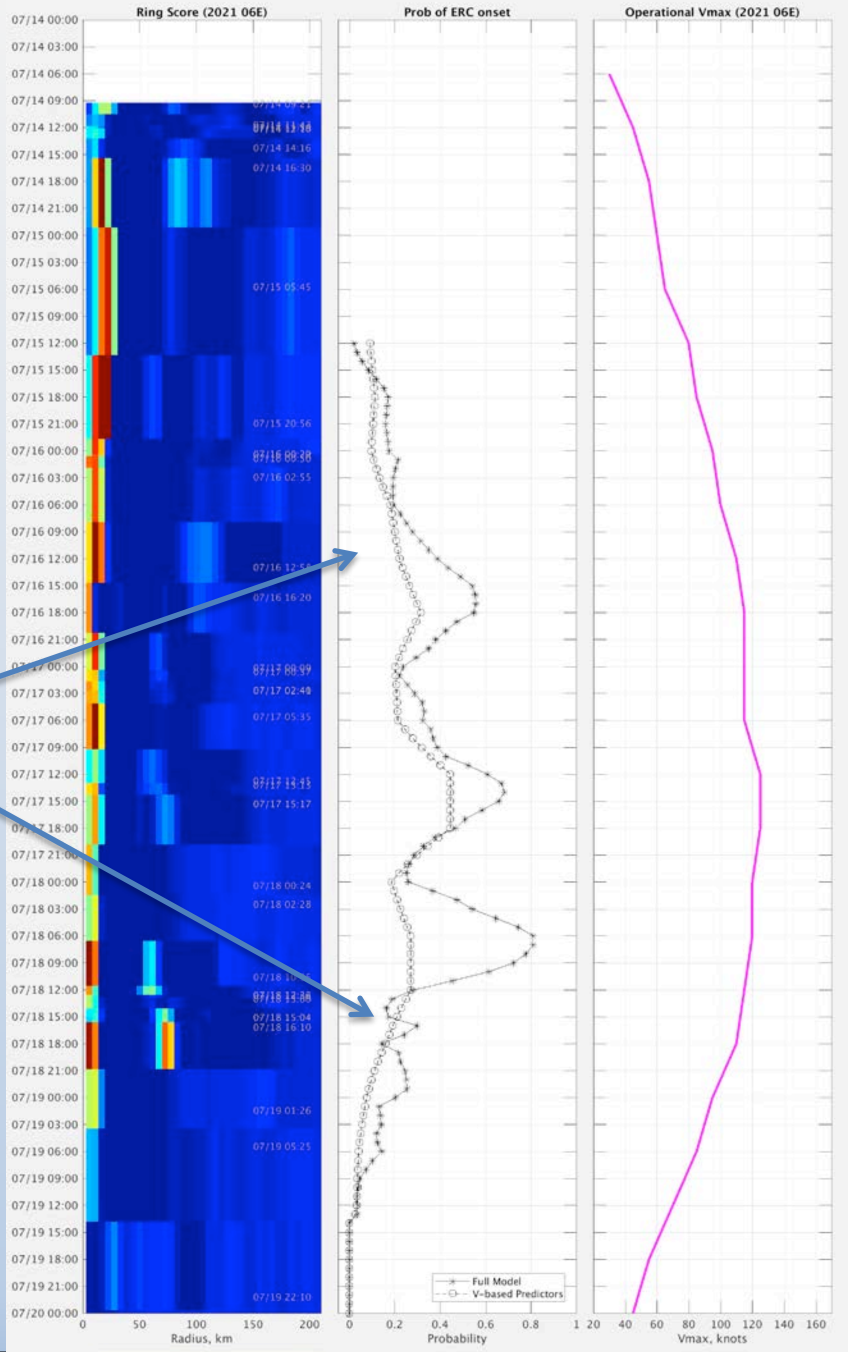
TC Structure and Intensity Change: M-PERC

Hurricane Felicia 2021









Fluctuation between banding and annular.

Development of M-PERC version for Epac to account for smaller storm size.

Develop PERC for SHIPS in Epac

AiDT - “AI-enhanced” ADT

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

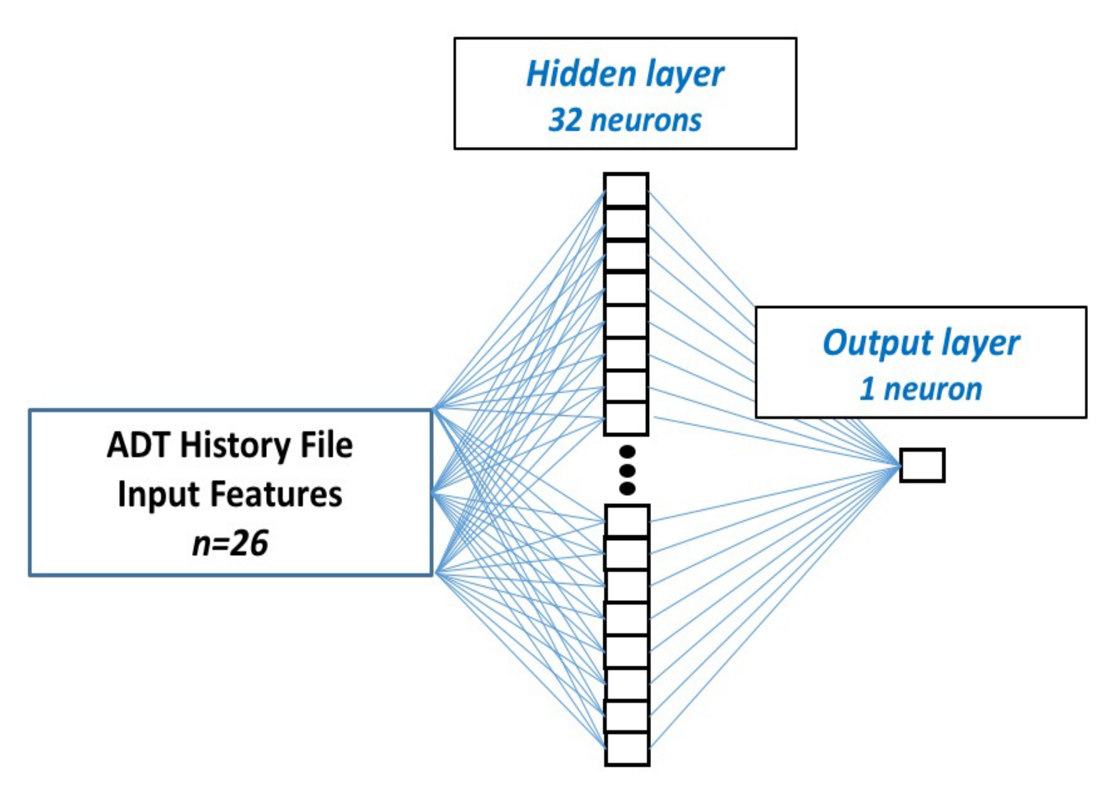
- **These DL models can be time consuming and computationally expensive to derive**
  - Great care must be given to make sure the satellite data is homogeneous

- **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

AiDT - “AI-enhanced” ADT

- **ADT-Version 9.0** wind speed estimates for all global TCs from **2005-2016**
    - 30-minute temporal resolution; ocean estimates only
    - **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**
    - **NHC/JTWC maximum wind speed** values
- **Final Model**
    - Fully-connected Multi-Layer Perceptron Model
    - 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

AiDT - "AI-enhanced" ADT

- **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

AiDT - "AI-enhanced" ADT

- **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)*

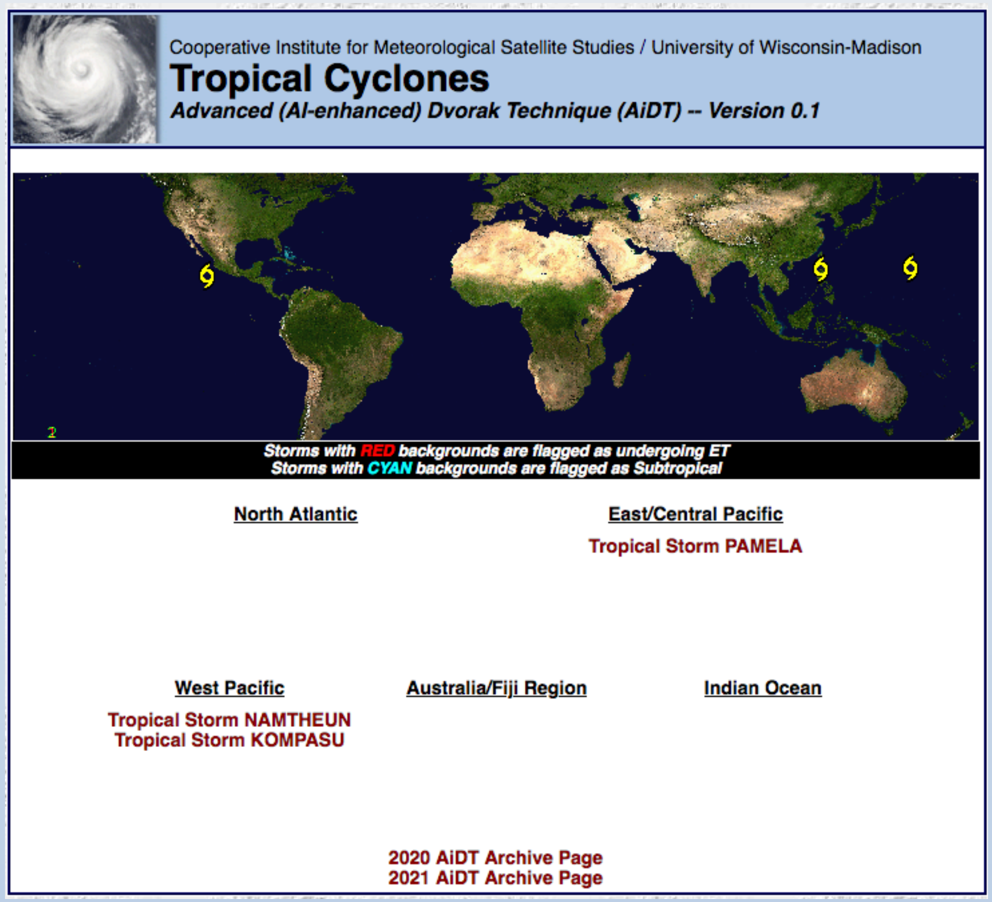
Saffir-Simpson Intensity Category	Sample Size	ADT			AiDT		
		Bias	MAE	RMSE	Bias	MAE	RMSE
TD *<35.0 kt*	3519	5.34	6.58	9.27	5.96	6.28	7.83
TS *35.0-63.9kt*	9016	-0.37	8.54	**10.72**	-1.19	5.30	**6.79**
H1 *64.0-82.9kt*	3001	-3.99	9.90	**12.87**	-2.09	6.45	**8.15**
H2 *83.0-95.9kt*	1445	-2.03	10.02	12.43	-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

AiDT - “AI-enhanced” ADT

- **The AiDT improves ADT estimates overall, especially in certain TC stages where the ADT has historically struggled or not been fully investigated**

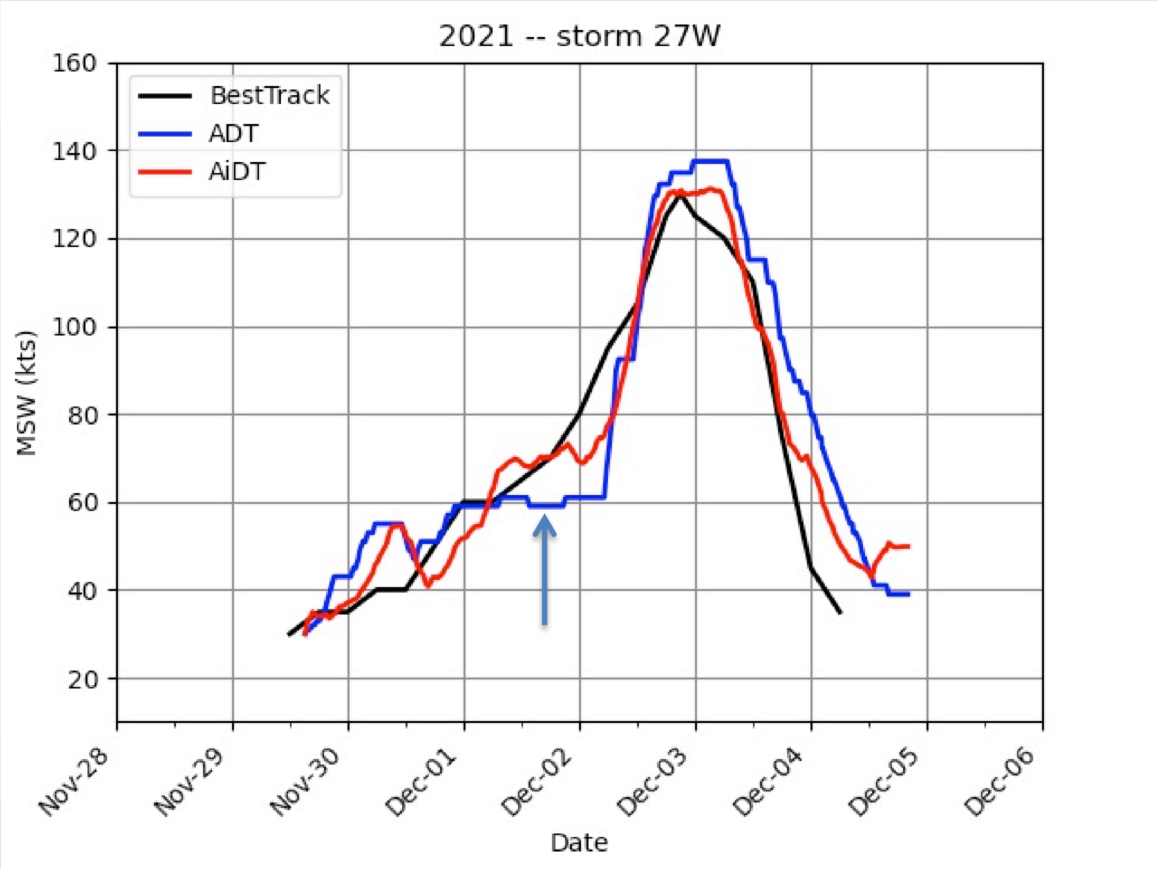
- **We are running the AiDT in real-time at UW-CIMSS in parallel with our real-time ADT processing**
    - The AiDT analysis will be made public shortly

- **Integration of the AiDT estimates within the UW-CIMSS SATellite CONsensus (SATCON) algorithm is planned**

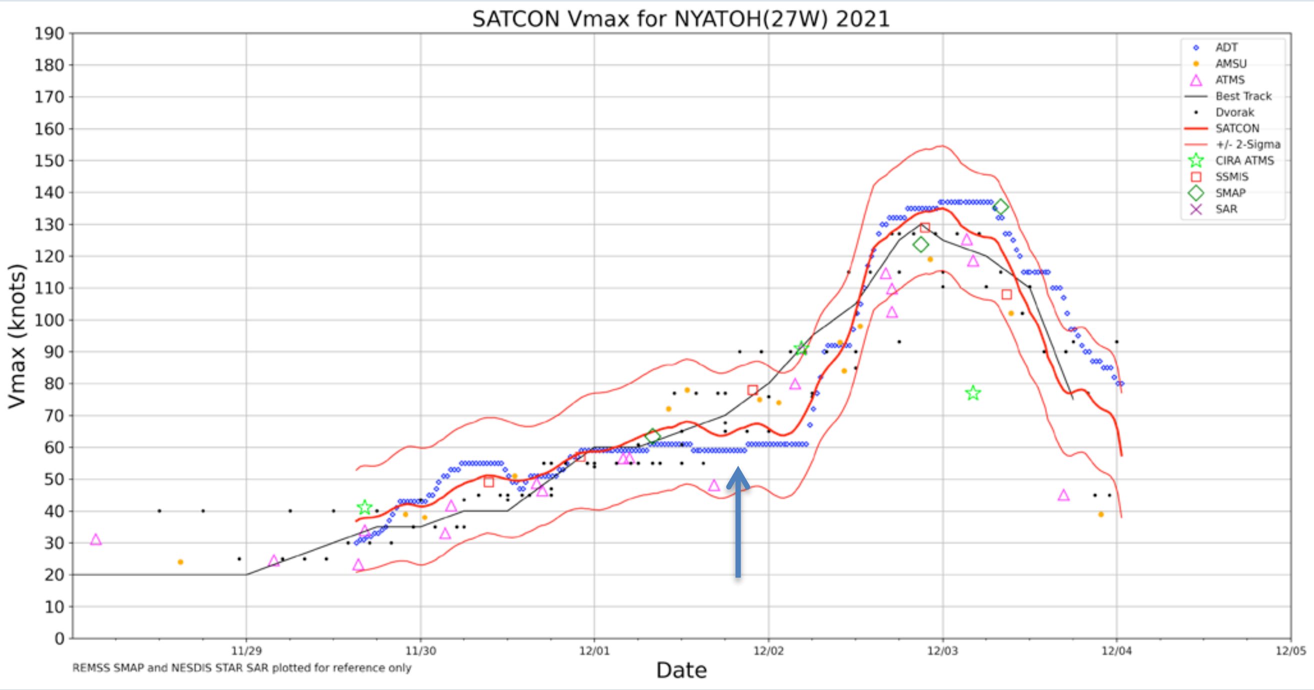


AiDT - “AI-enhanced” ADT

Recent example for TC 27W Nyato – significant improvement during the “plateau” period



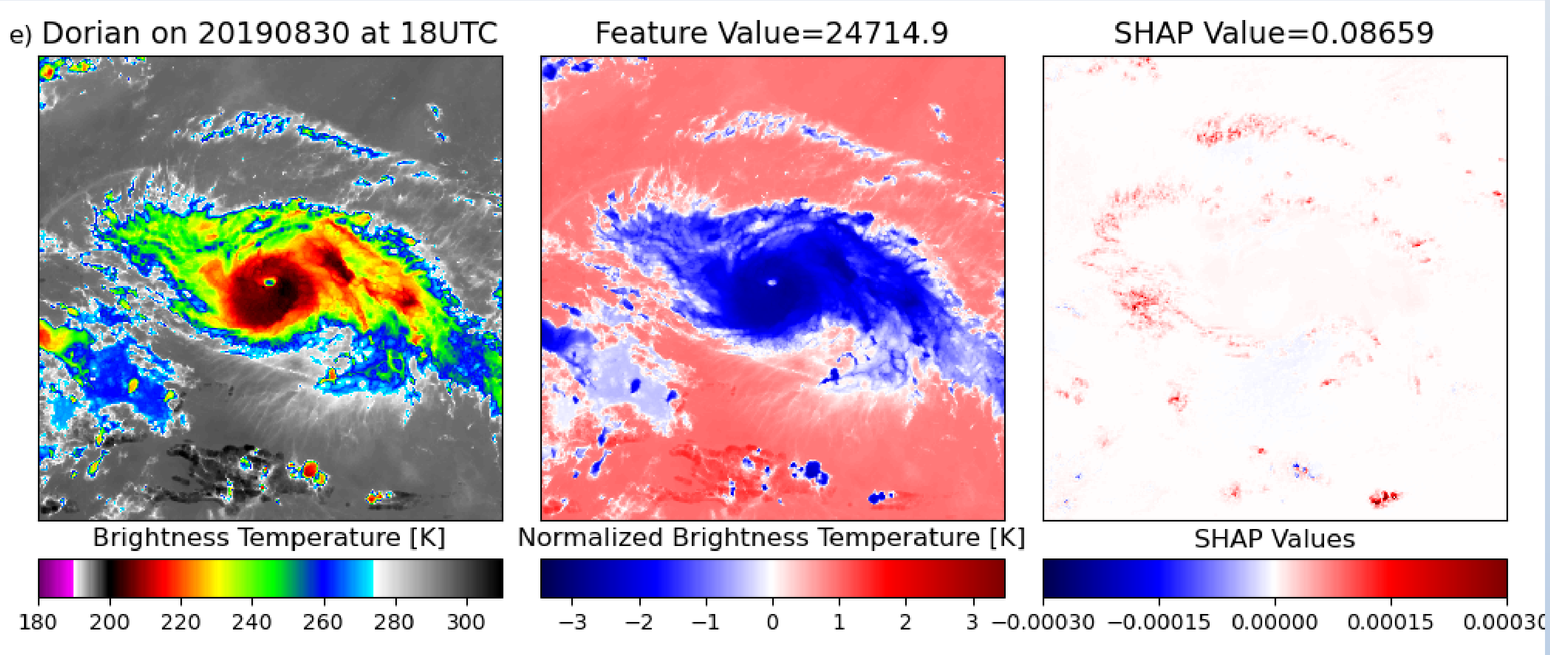
CIMSS SATCON along with Dvorak fixes for 27W



Research work and future products

Objective

To use deep learning and large TC datasets to find new nonlinear, highly multivariate predictors of future TC intensity



1) Using satellite imagery and environmental variables to predict RI

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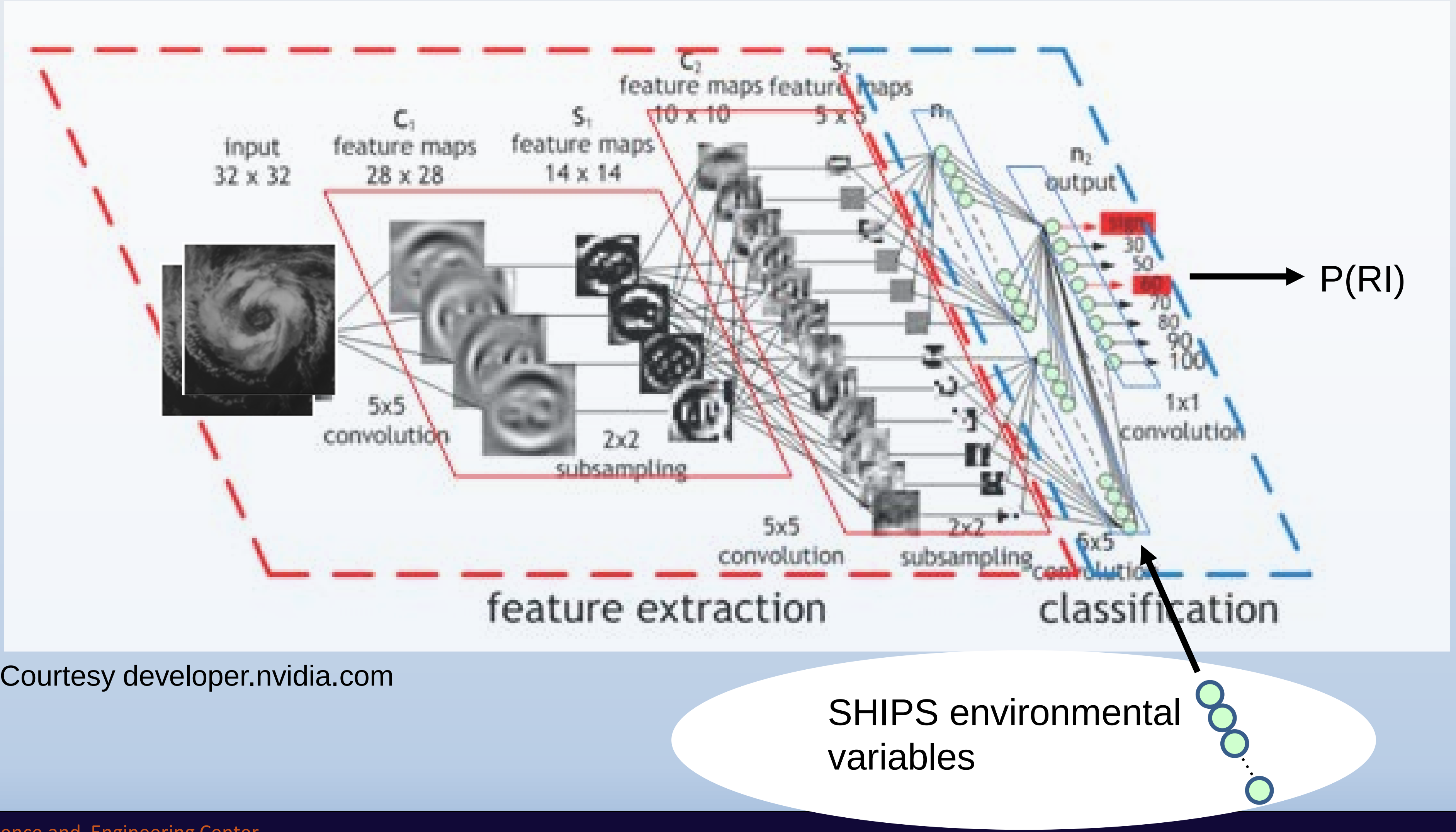
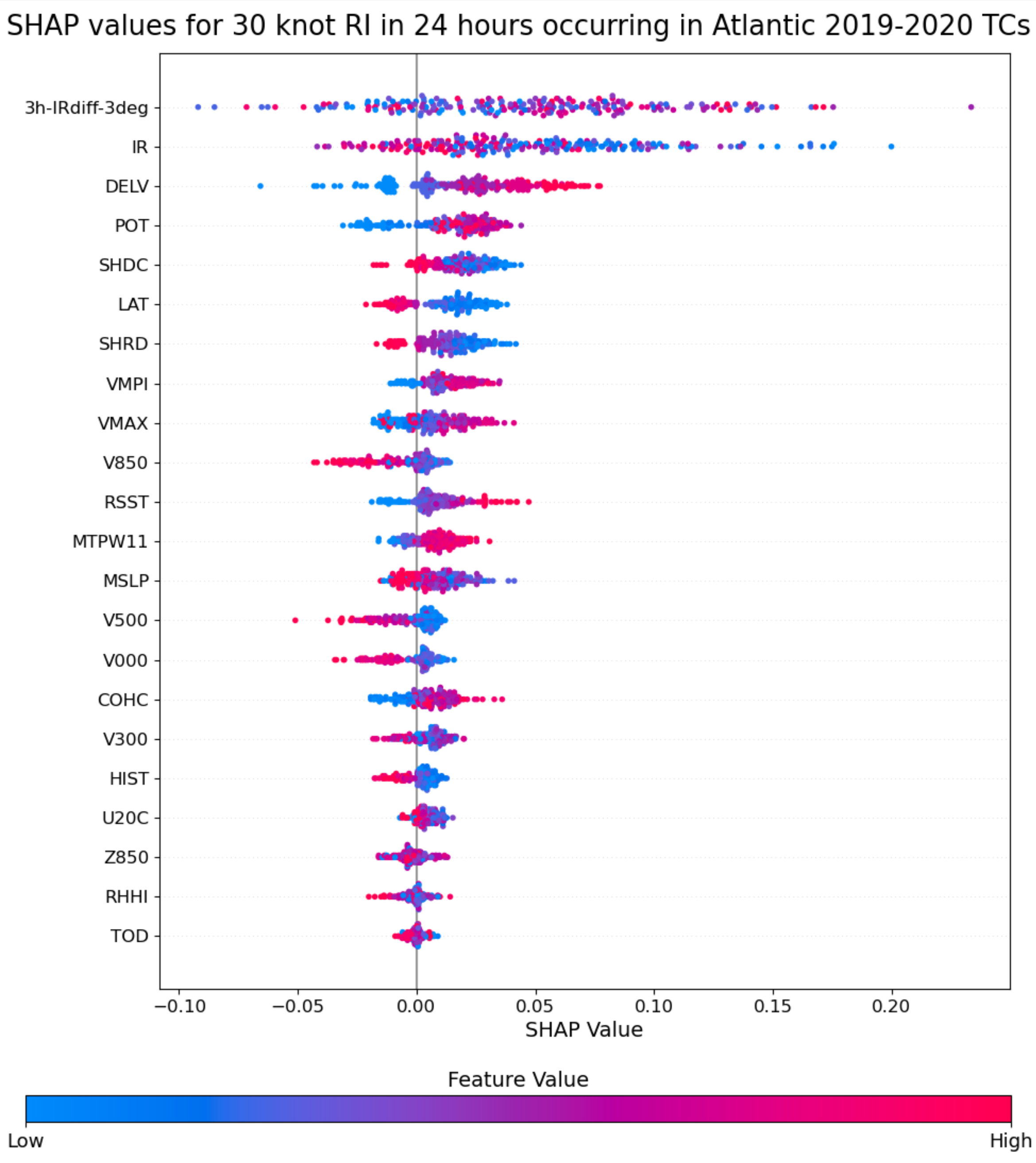


Courtesy developer.nvidia.com

1) Using satellite imagery and environmental variables to predict RI

- IR (t=0) and IR (t=-3hr) are the most important predictors
- They play a more complicated role than any SHIPS variables (shouldn't be approximated linearly)
- The third most important factor in intensification is DELV (-12hr to 0hr intensity change). This shows clear potential for improvement if/when we start using more details of the inner core.



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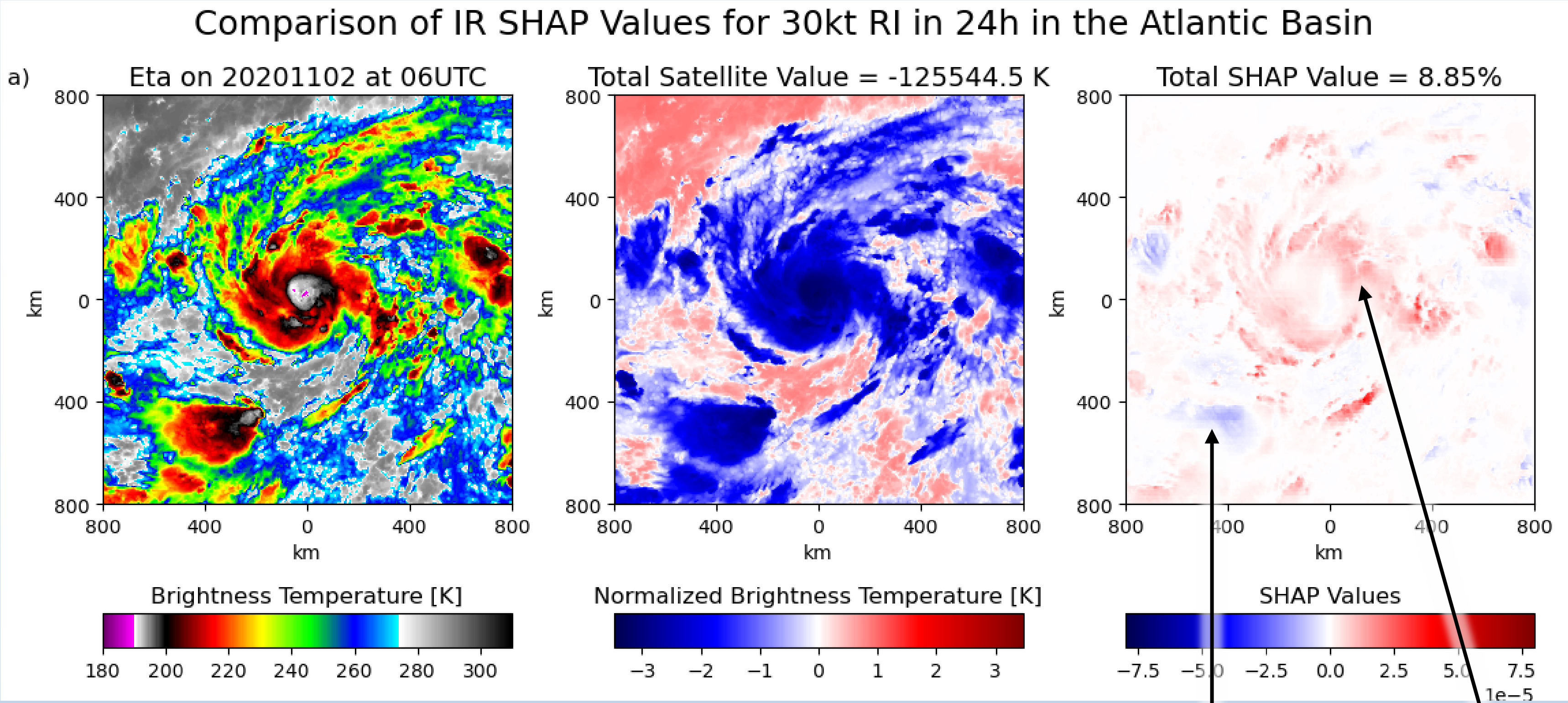
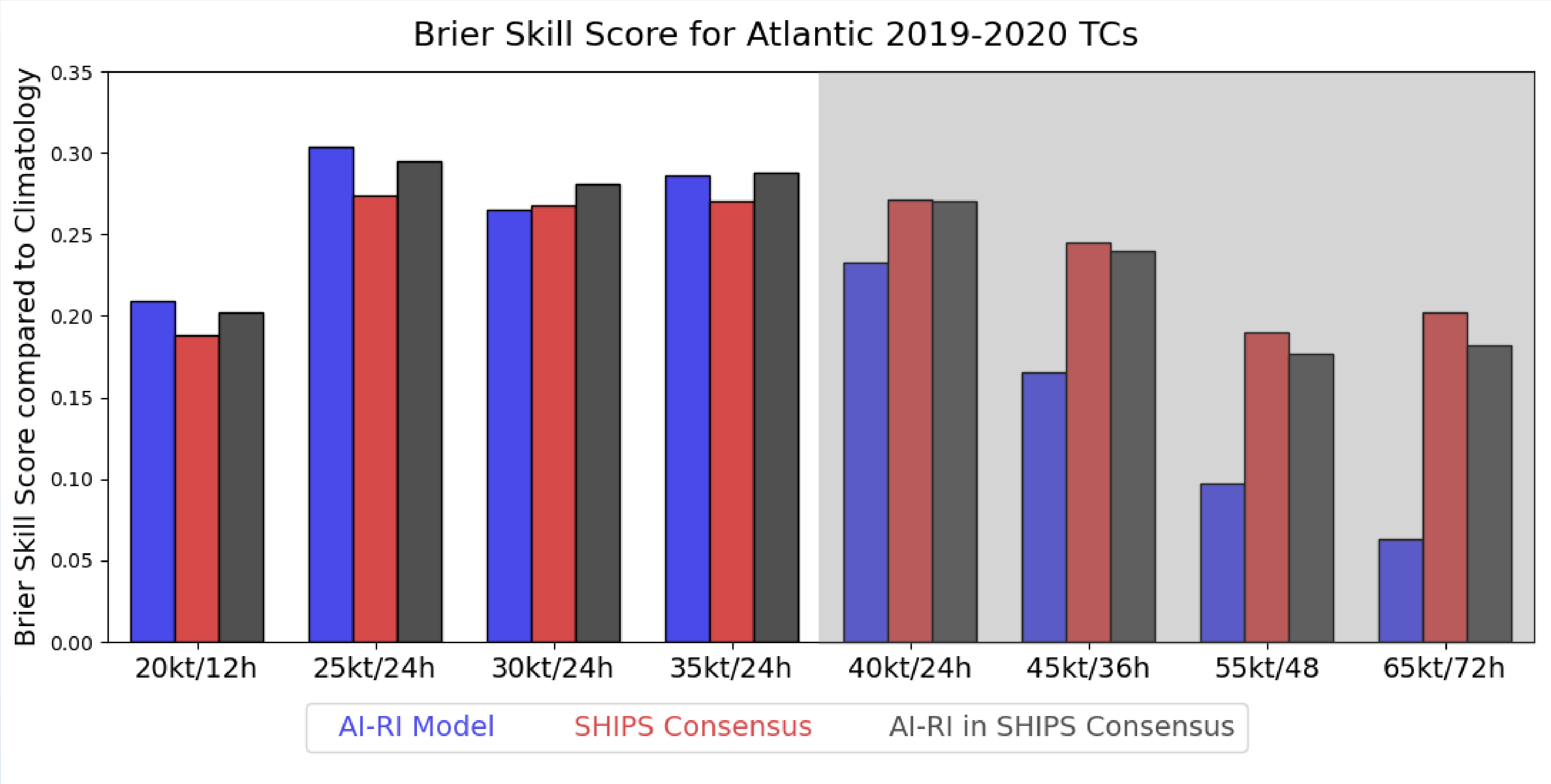


Blue areas contribute negatively to rapid intensification

Red areas contribute positively to rapid intensification

1) Using satellite imagery and environmental variables to predict RI



2) Determining the best satellite inputs for TC intensity estimation

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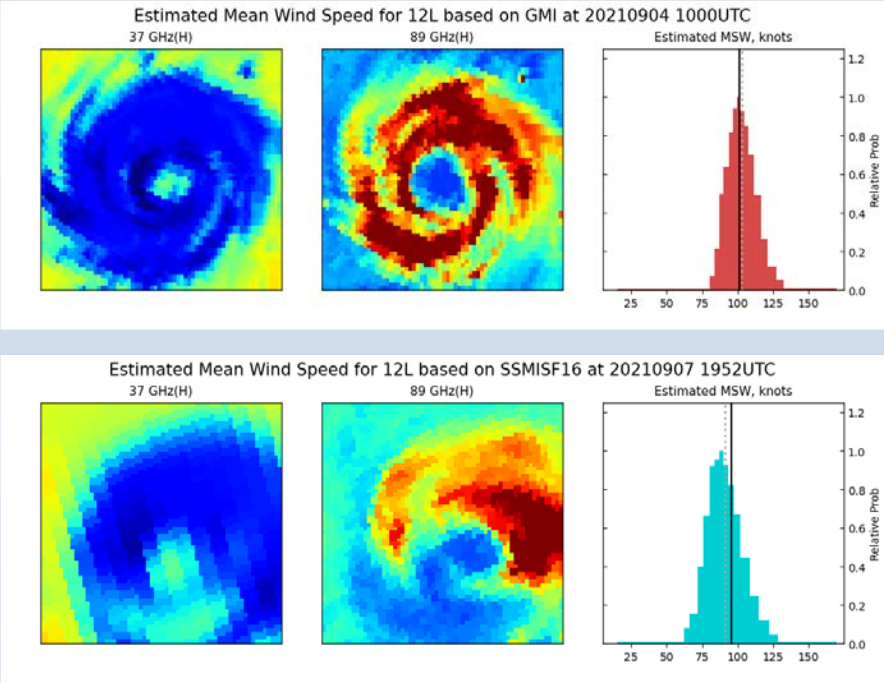
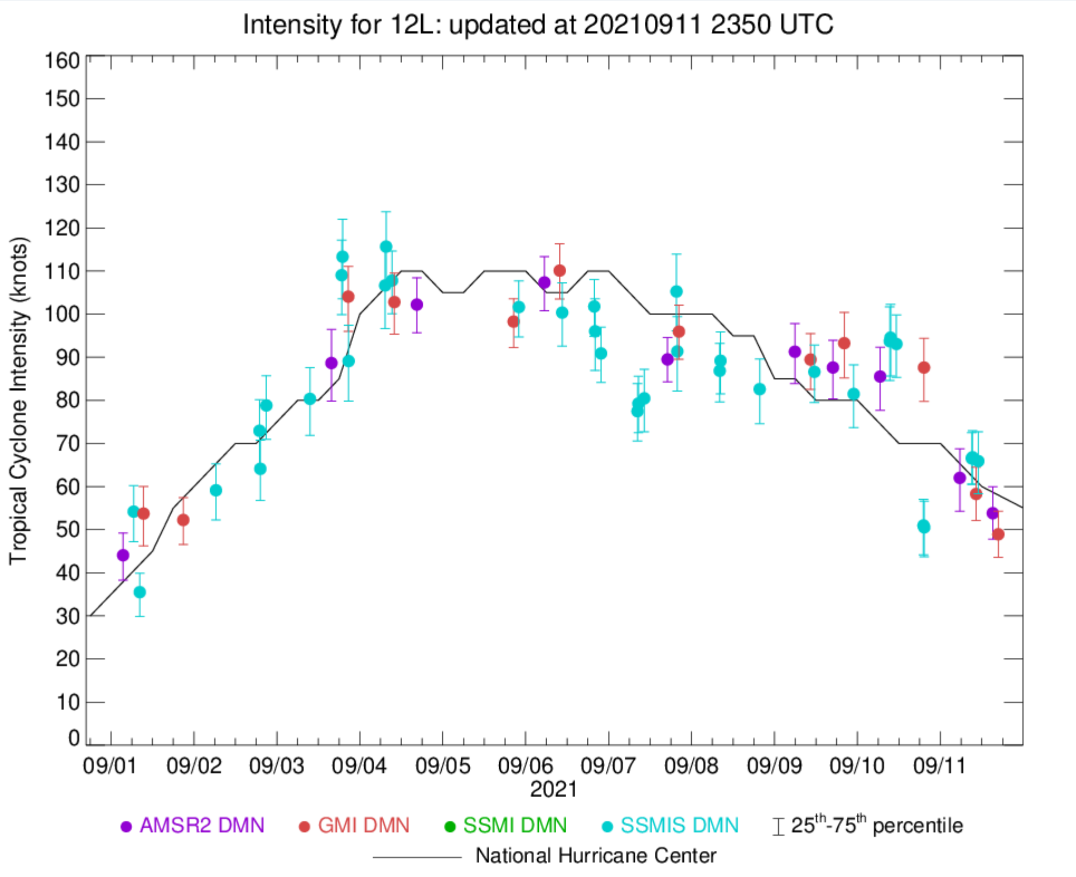
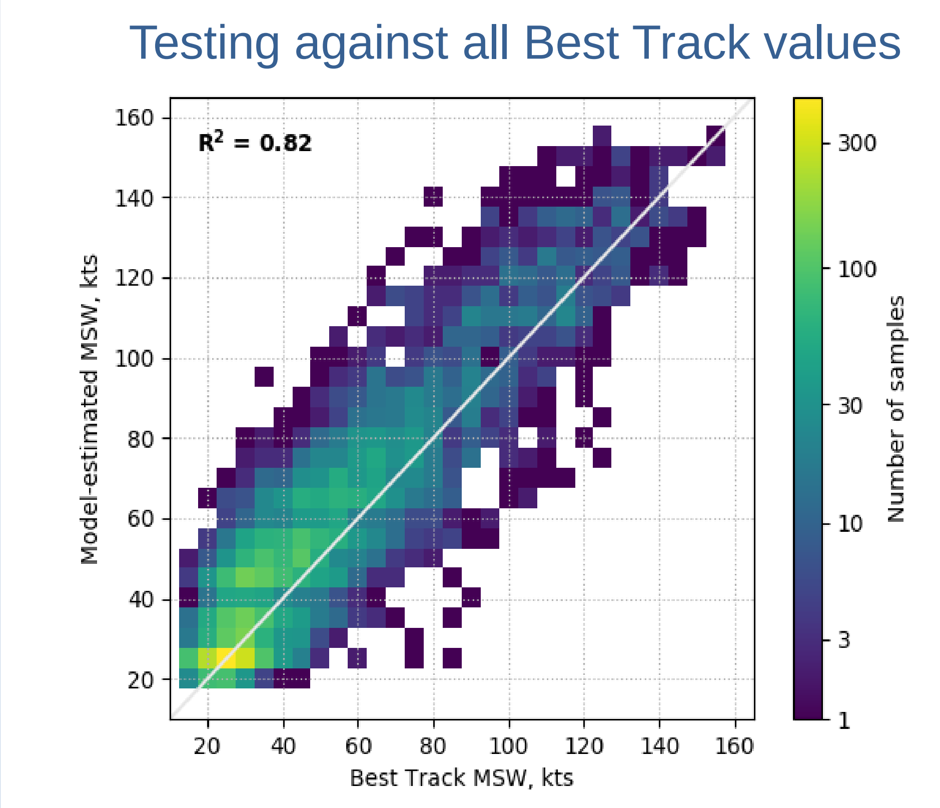


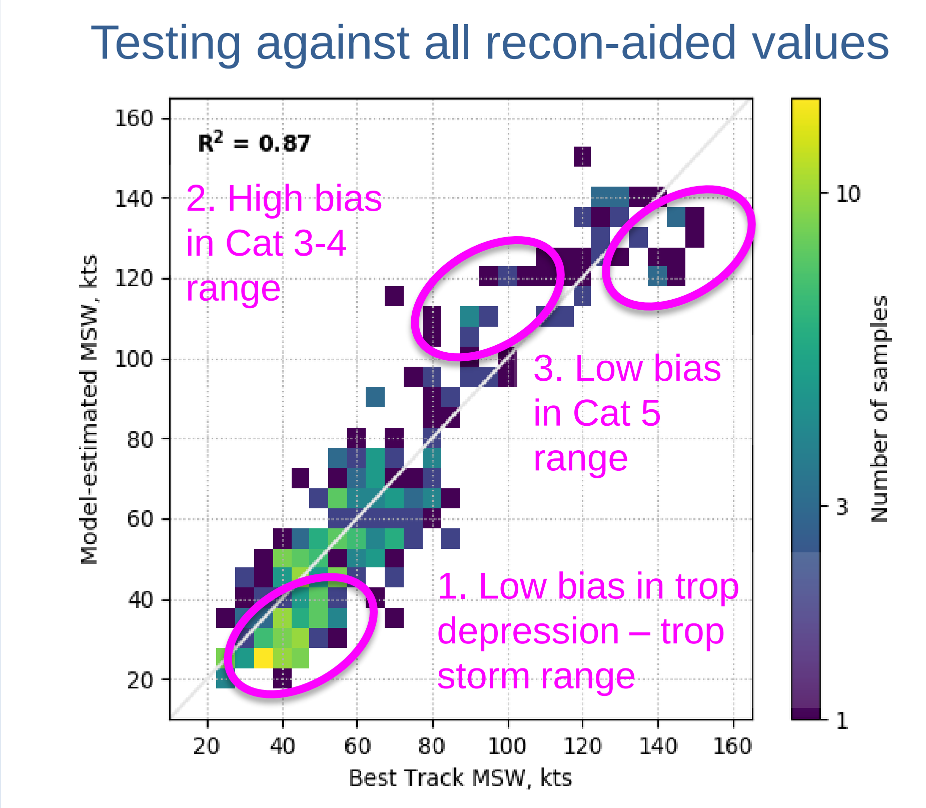


- TC intensity estimates using 37 GHz and 89 GHz
- Published in 2019, tested in real time in 2021

2) Determining the best satellite inputs for TC intensity estimation

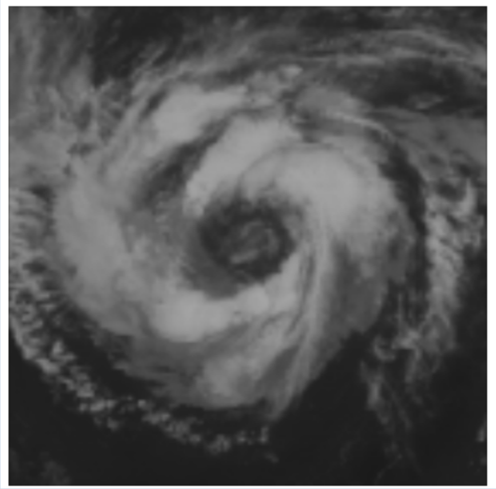


RMSE = 14.6 kt



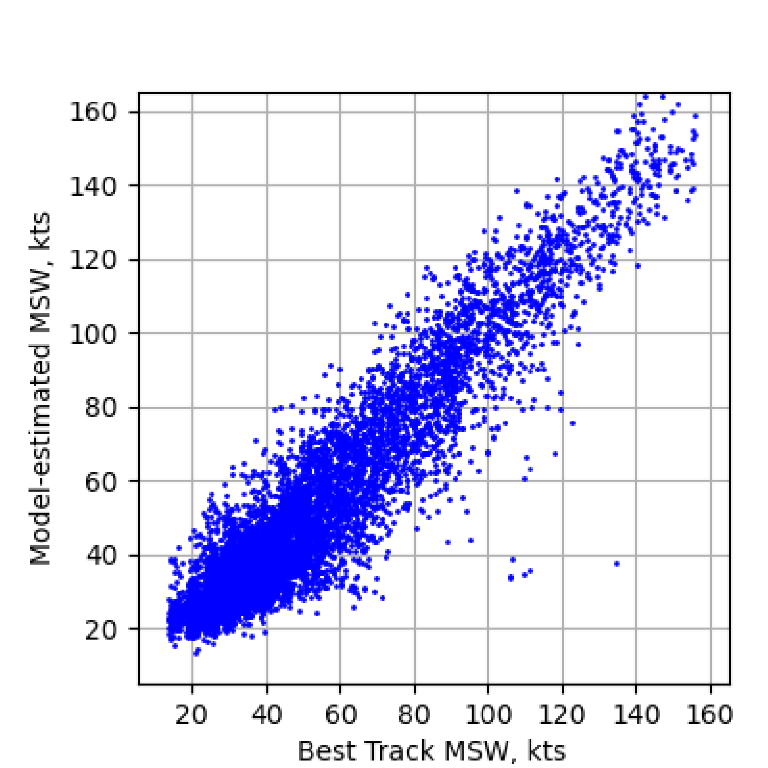
RMSE = 10.3 kt

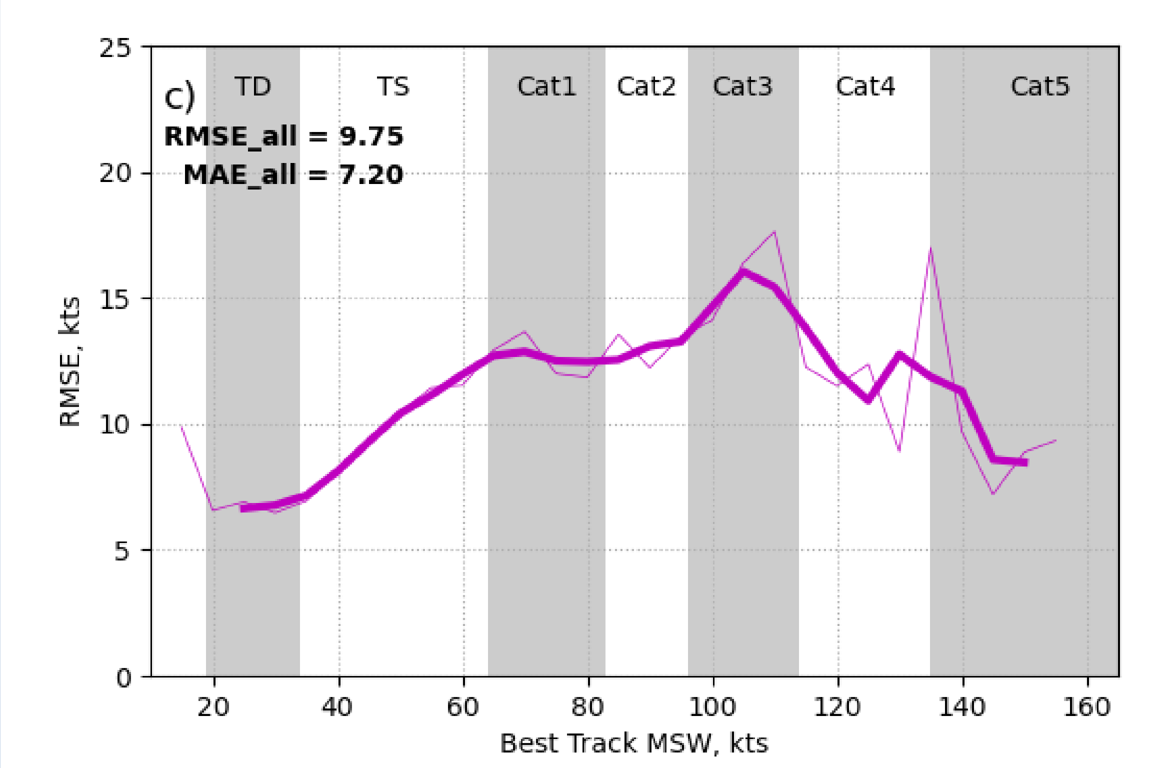
2) Determining the best satellite inputs for TC intensity estimation



?

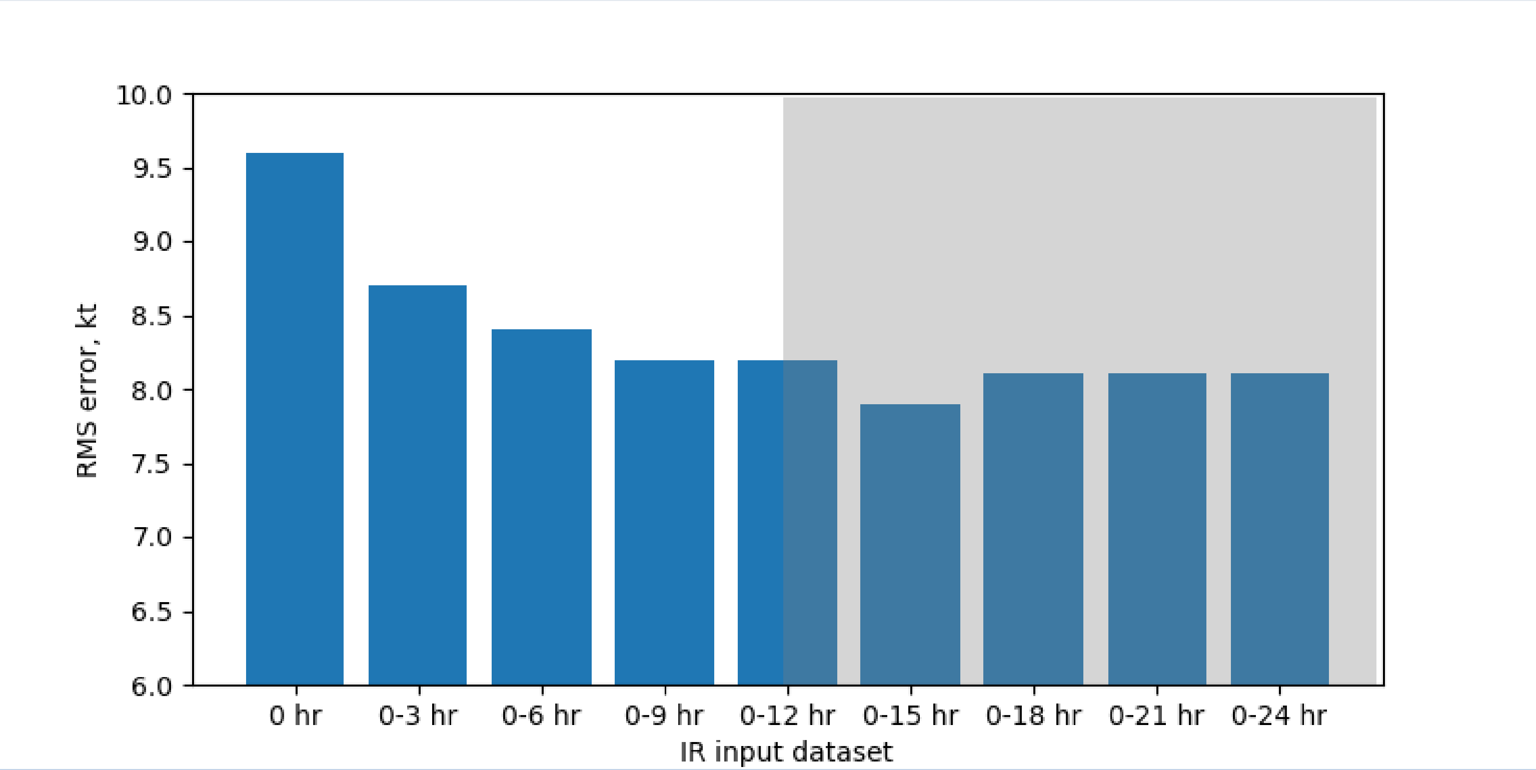
2) Determining the best satellite inputs for TC intensity estimation

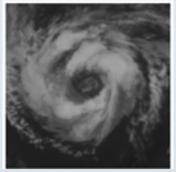


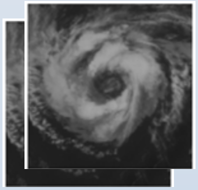


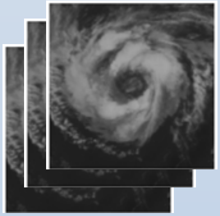
- Using IR imagery to estimate global Best Track intensity: RMSE = 9.7 kt
- (Compare to last year's estimate of global Best Track with microwave imagery: RMSE = 13 kt)

2) Determining the best satellite inputs for TC intensity estimation







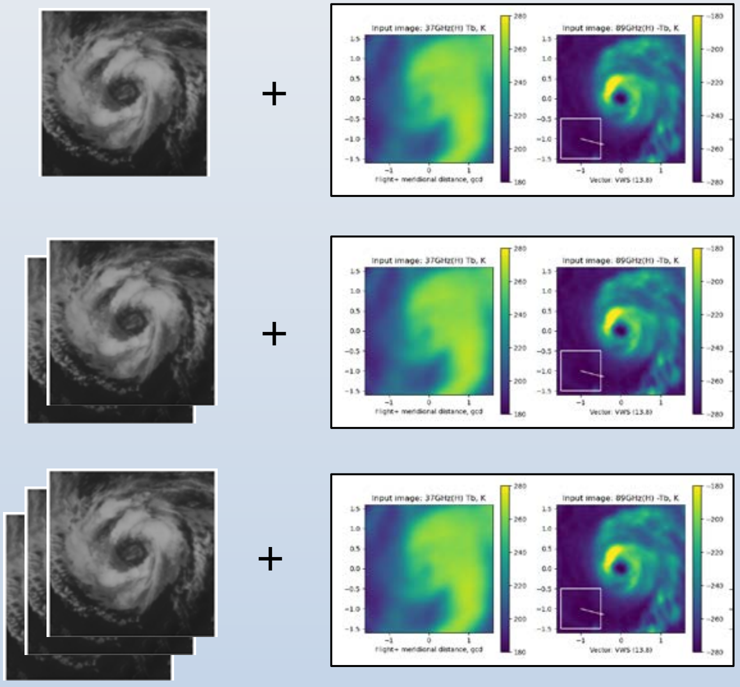


… etc

- Prior imagery back to 9 or 12 hr is relevant to knowing the current TC state

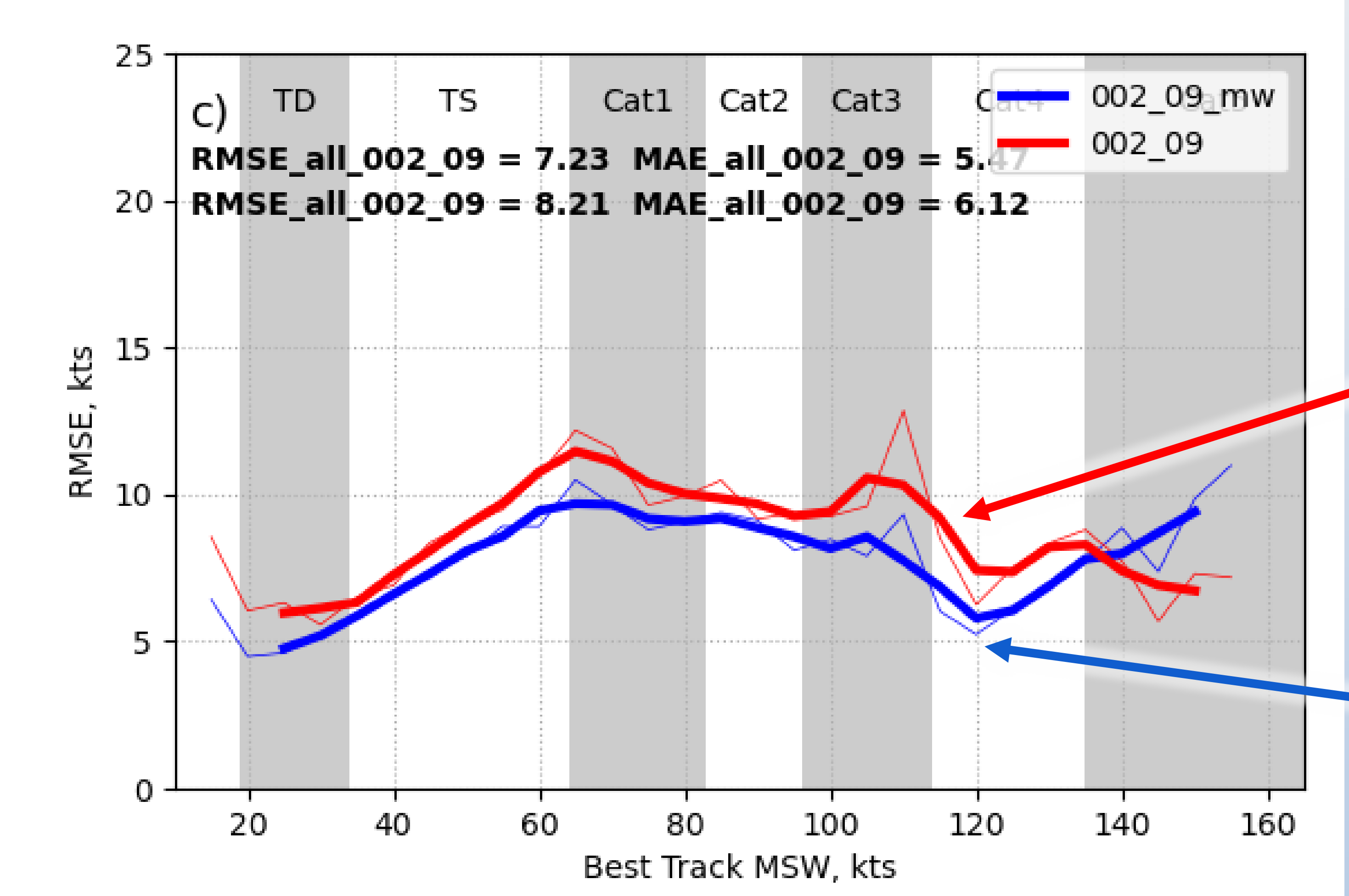
2) Determining the best satellite inputs for TC intensity estimation

- How about IR *plus* Microwave?



… etc

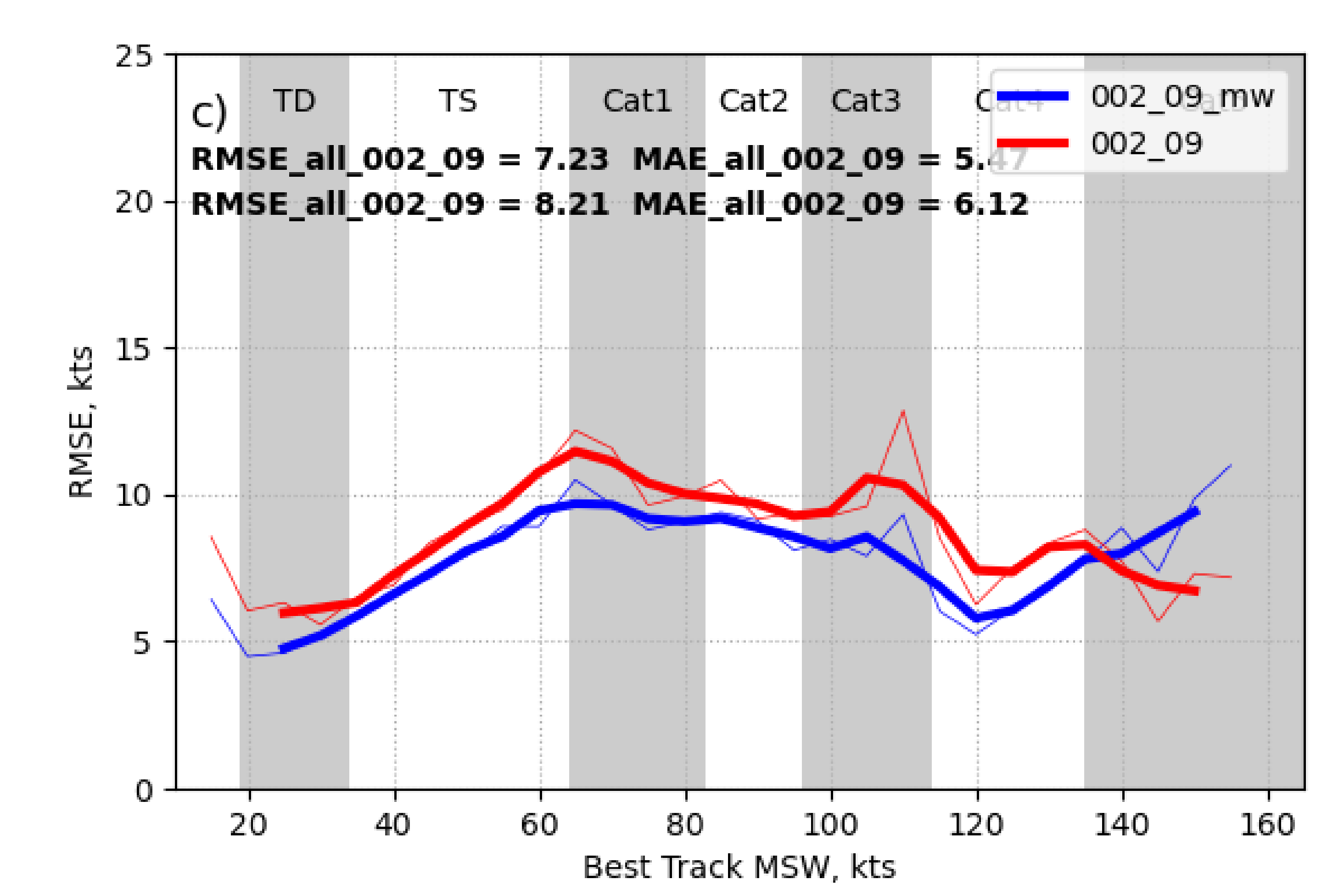
2) Determining the best satellite inputs for TC intensity estimation

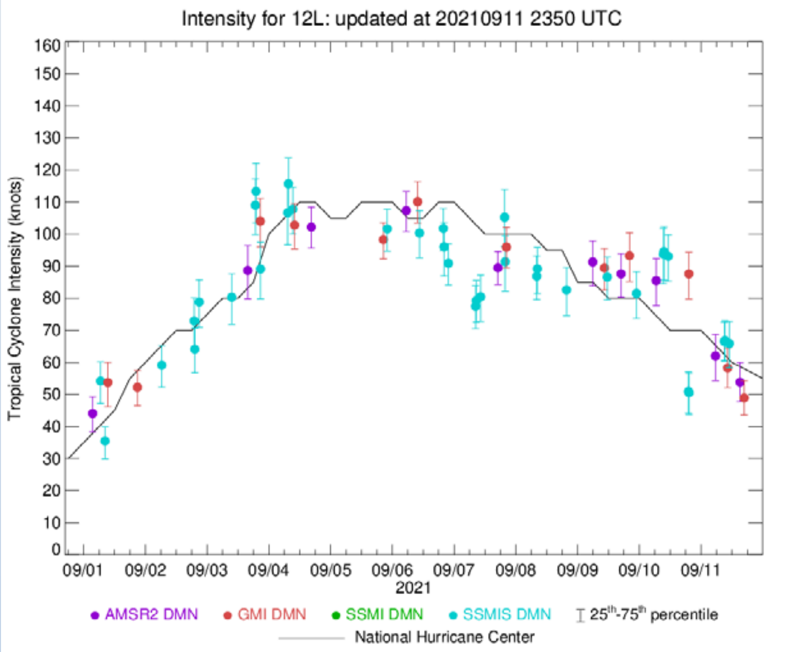


0-9 hr IR model
RMSE: 8.21 kt

0-9 hr IR + MW model
RMSE: 7.23 kt

2) Determining the best satellite inputs for TC intensity estimation



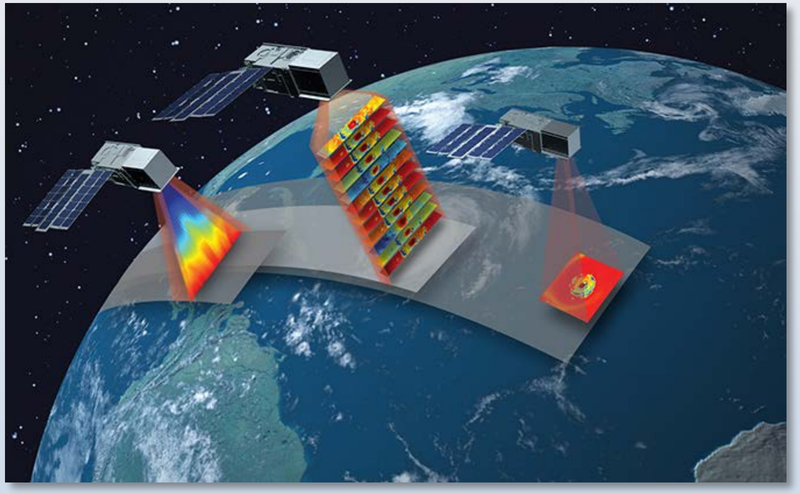


Steps toward real-time, public application

- Run IR+MW model in a private check-out mode in early 2022.
- Release IR+MW model publicly in July 2022
- Release AI-Rapid Intensification model in July 2022

TROPICS: Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

- NASA Earth Venture Program led by MIT Lincoln Lab
  - Principal Investigator: Dr. William J. Blackwell
  - Project Scientist: Dr. Scott A. Braun (NASA GSFC)
- Innovative solution to provide temperature, moisture, and precipitation data for tropical cyclone studies
  - Observations in 12 channels spanning 90/118/183/205 GHz
- Constellation of six 3U cubesats
  - 2U spacecraft bus from Blue Canyon Technologies
  - 1U microwave radiometer payload from MIT Lincoln Lab
- Pathfinder (qualification unit) launched on 6/30/2021
  - Contact established on first day, cal/val in progress
- Astra to provide three launches in first half of 2022



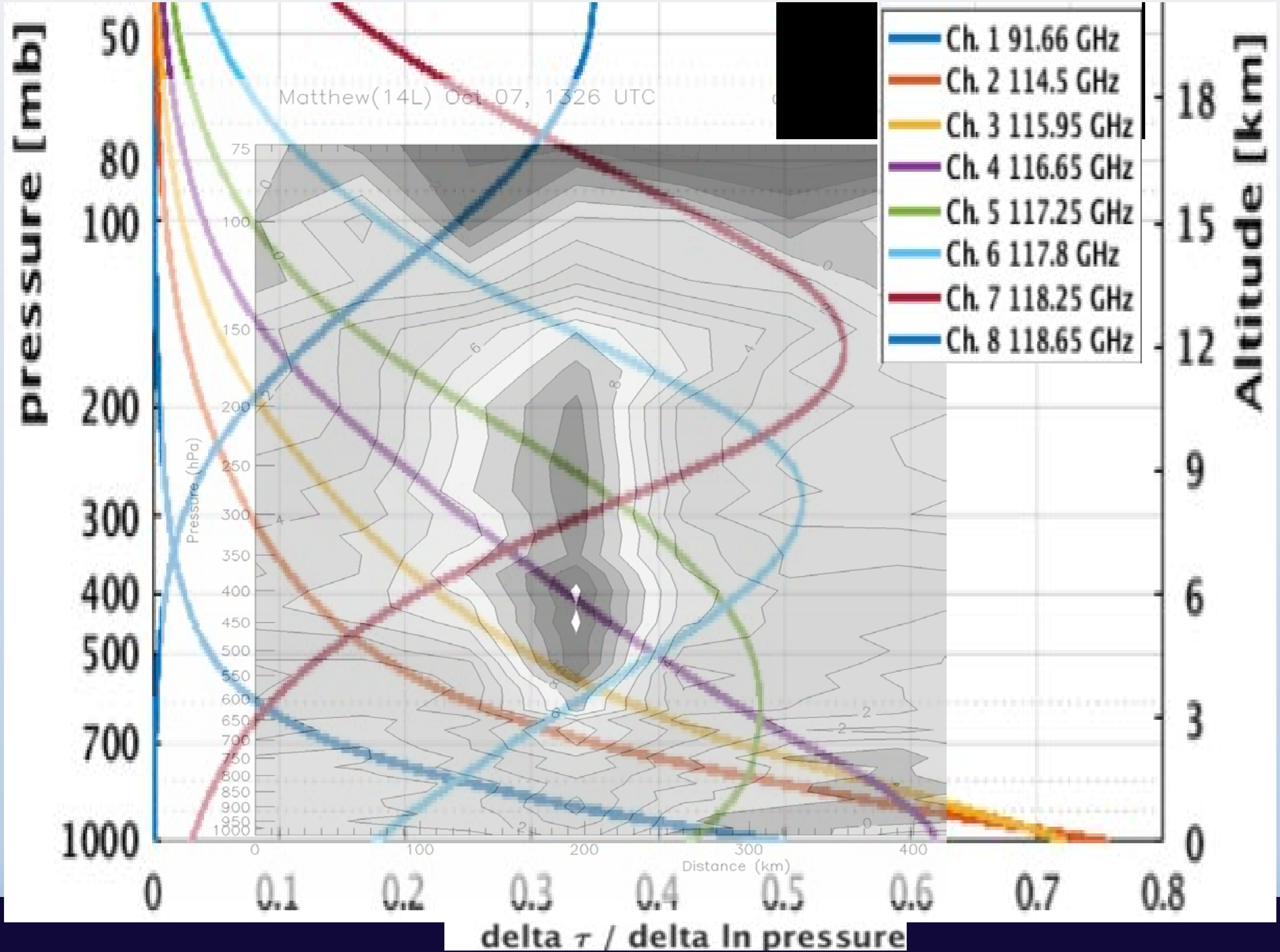
TROPICS Suitability for Measuring TC Intensity

TROPICS channels and weighting functions

Hurricane Matthew warm anomaly from Global Hawk dropsondes (in grey shades)

Channels 5-7 observe the TC warm anomaly

Fewer channels than AMSU/ATMS however channel location favorable for warm core monitoring



TROPICS Suitability for Measuring TC Intensity

Current microwave sounders used for TC intensity estimation

	Temperature Sounder Resolution (km)	Moisture Sounder /Imager Resolution (km)	Swath Width (km)	# of Sats	Scan Type
AMSU	48 (nadir) 79 x 149 (limb)	16 (nadir) 27 x 52 (limb)	2340	6*	Cross-track
SSMIS	37.5	12	1700	1+	Conical
ATMS	32 (nadir) 70 x 137 (limb)	16 (nadir) 30 x 68 (limb)	2500	2	Cross-track
TROPICS	24 km 55x177 (limb	16 km 34x126 (limb)	2000	6+1	Cross-track

* NOAA-15 & 18 AMSU-B failed, NOAA-19 Ch8 noise, Metop-A Ch7 failure

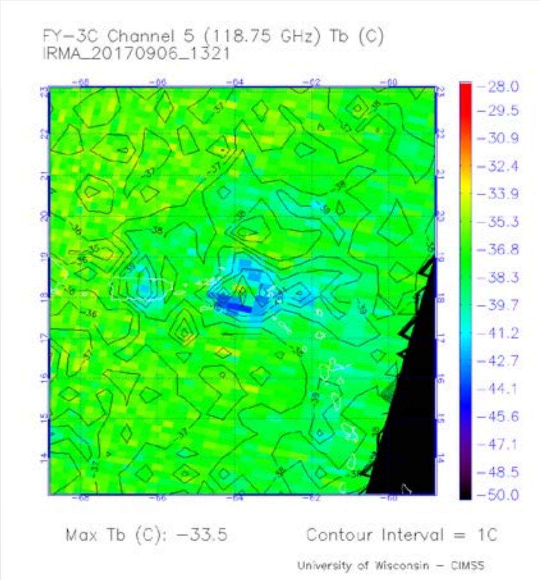
+ F-17 SSMIS Ch4 noise

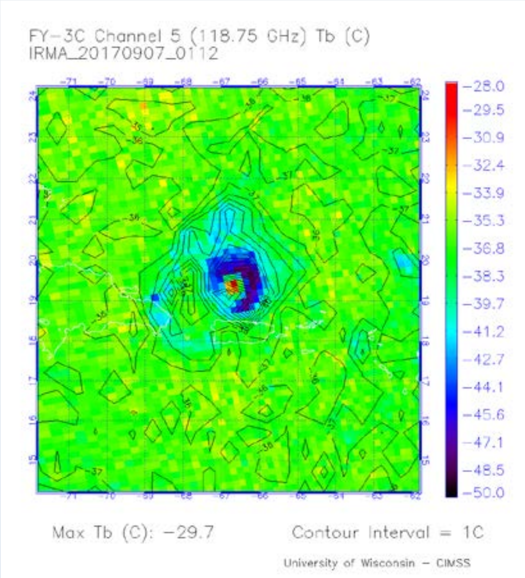
TROPICS Suitability for Measuring TC Intensity

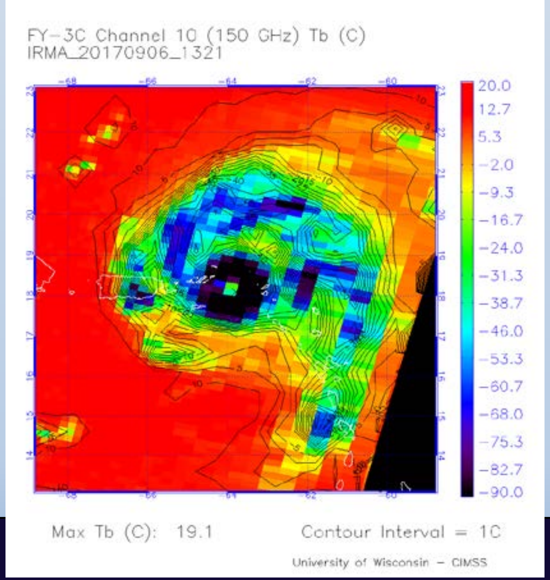
- Attenuation of the sensed Tb due to the presence of scattering hydrometeors TROPICS 118 GHz will be more impacted than ATMS/AMSU

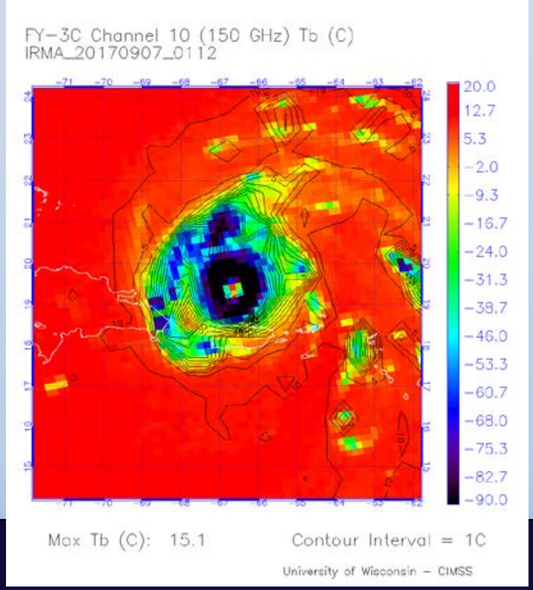
FY-3c Channel 5 Tb (similar to TROPICS Ch 6)
FY-3C Channel 10 depicting TC structure

Images 12 hours apart but significantly reduced warm anomaly for left image. Irma is near the edge of the scan so both resolution and scattering are impacting sensed Tb.









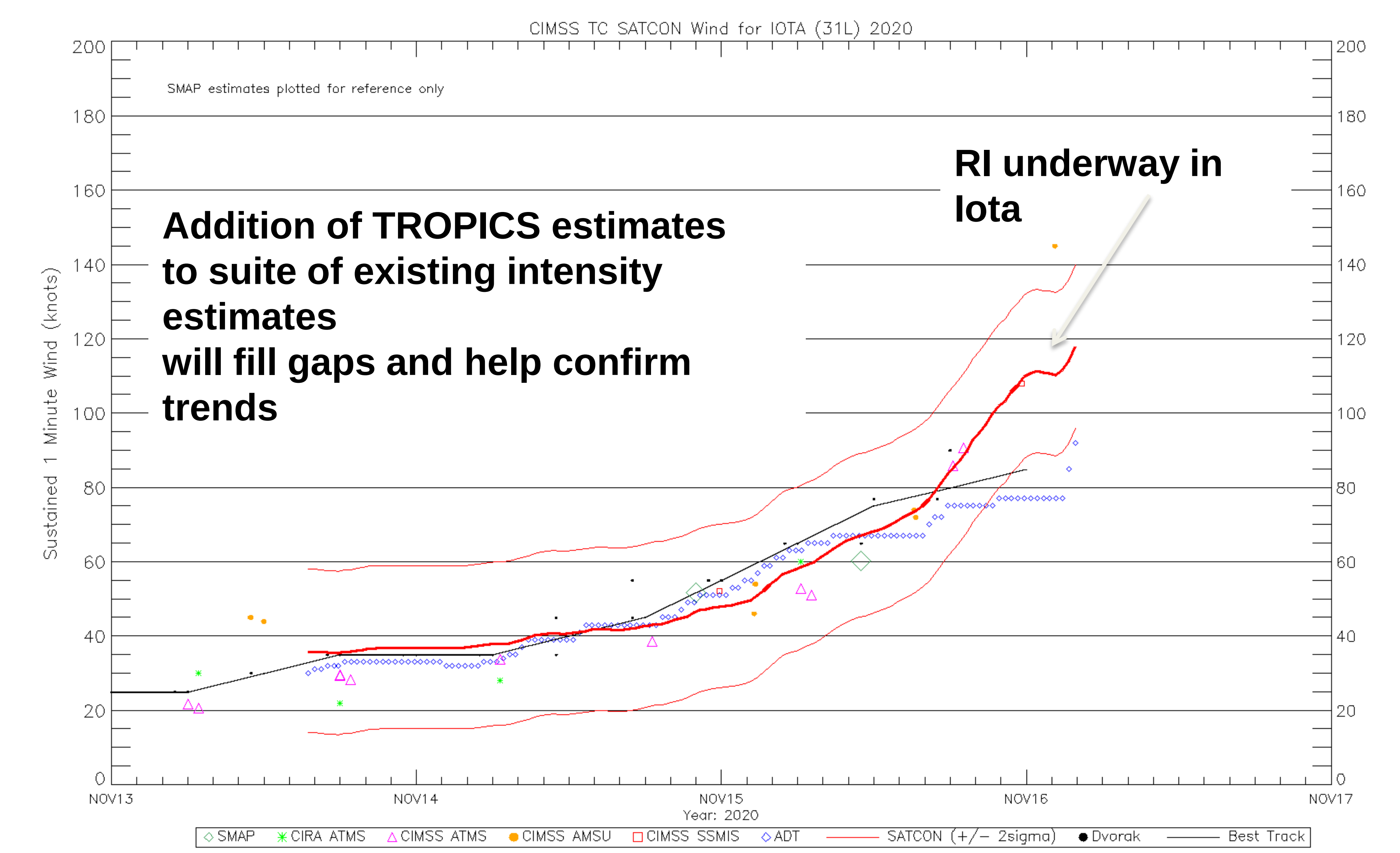
TROPICS Tropical Cyclone Intensity Estimates

Two parallel approaches based on legacy microwave sounder work from CIMSS and CIRA

- CIMSS approach uses Tb anomalies from select channels that capture the bulk of the TC warm anomaly

- CIRA approach is to use temperature and moisture retrievals from the data

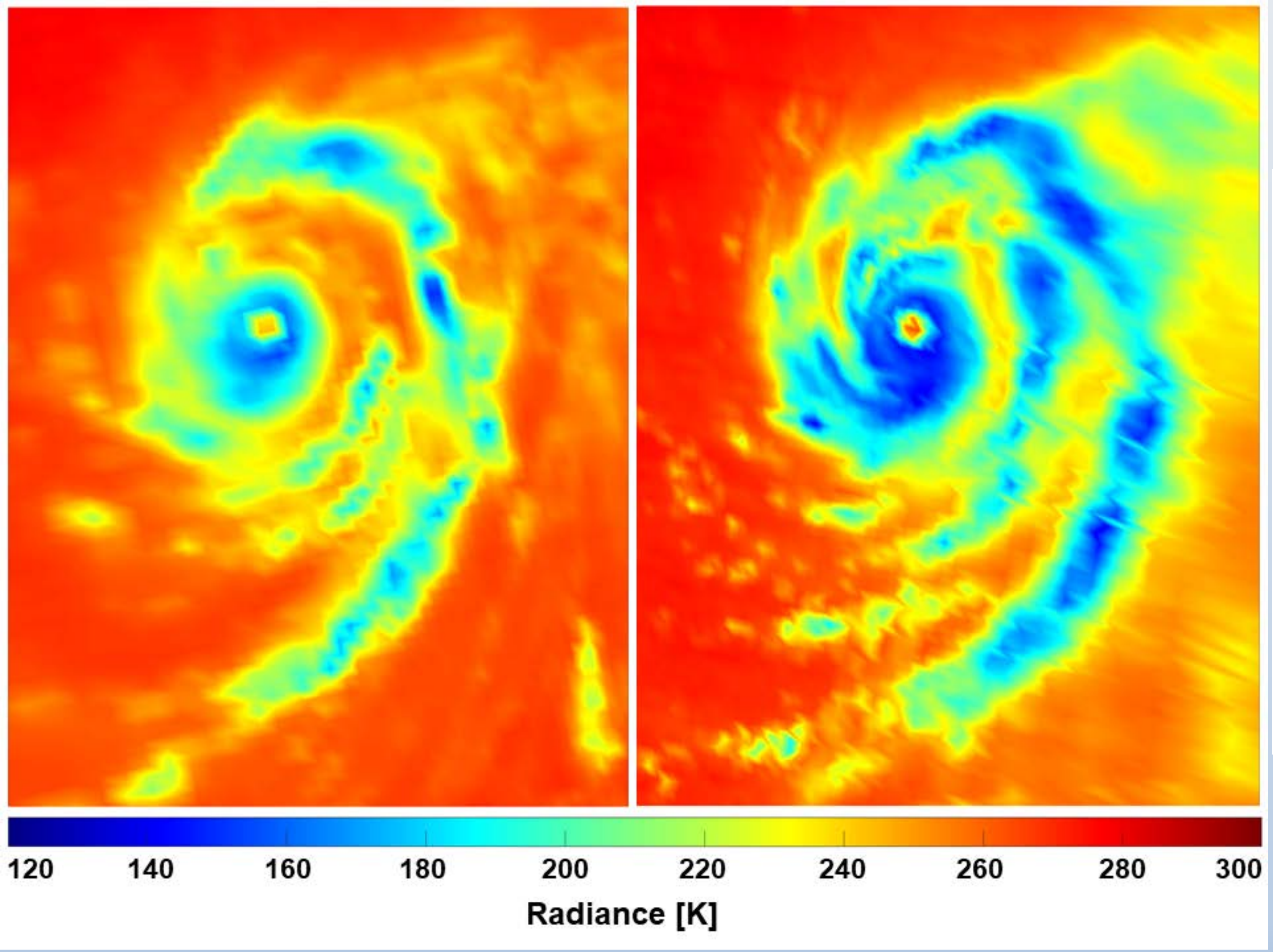
TROPICS TC Intensity Algorithms



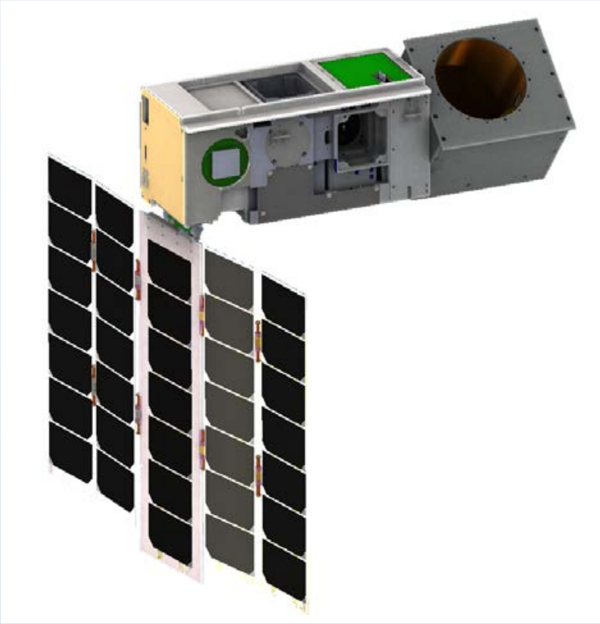
TROPICS Pathfinder Launched June 30, 2021

Super Typhoon Mindulle (Sep 26, 2021)
Observed near 183 GHz

JPSS (NOAA-20) Satellite
>2000 kg



TROPICS Pathfinder Satellite
5.4 kg

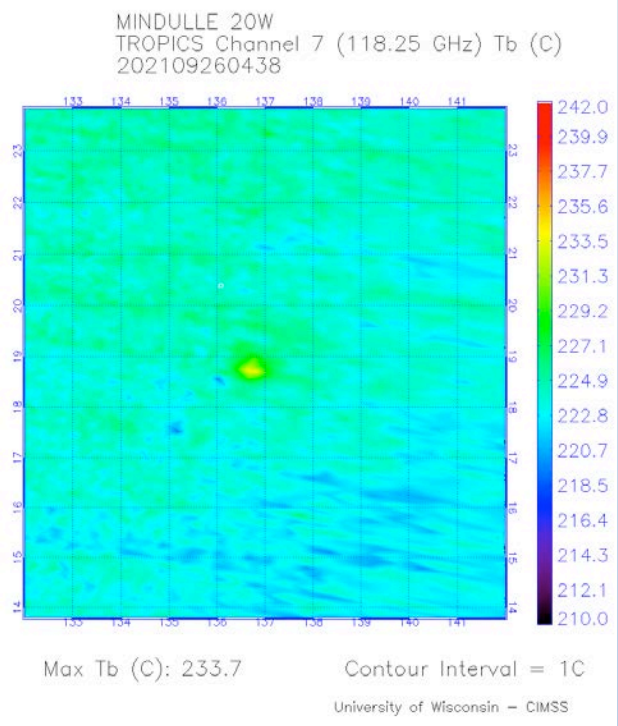


90-day initial data record (Aug 8, 2021 – Nov 6, 2021) to be released this month

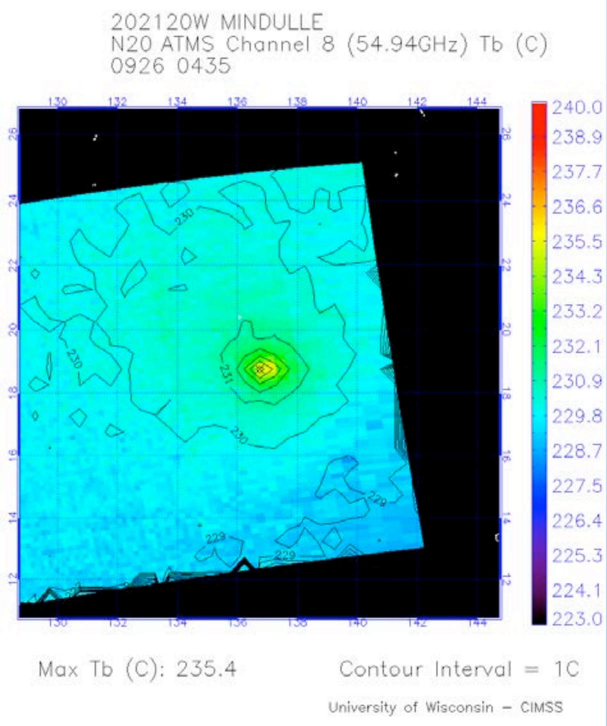
TROPICS Pathfinder Launched June 30, 2021

Super Typhoon Mindulle (Sep 26, 2021) Warm Core

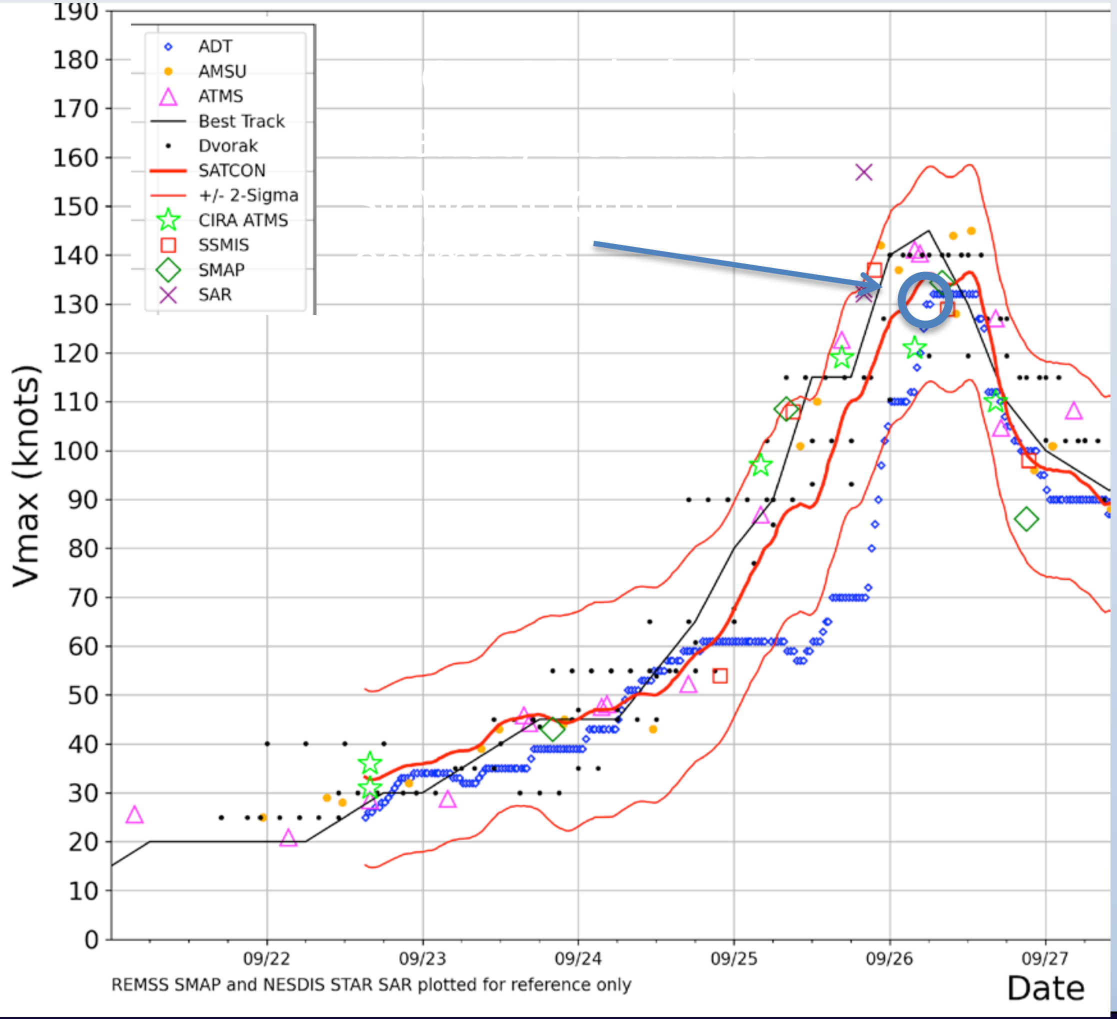
TROPICS 118 GHz Ch7
9.9 K



ATMS 54 GHz Ch8
7.0 K



CIMSS SATCON for Mindulle



TROPICS: What's Next

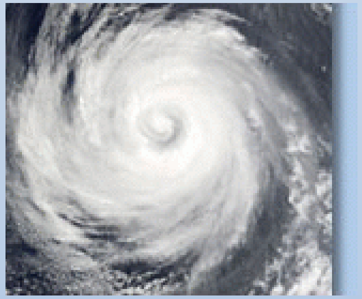
Astra Rocket 3.3 launches Nov. 19, 2021

- Extended mission operations for TROPICS Pathfinder
  - Funded by NASA and NOAA
  - Low-latency demonstration planned for early 2022
    - 1-2 hour latency objective
- Three constellation launches (Mar/Apr/May 2022)
  - Six CubeSats (two per launch) yield <60 minute revisit
  - Astra Space selected by NASA as launch provider
  - Plan to commission the constellation in time for 2022 Atlantic Hurricane season

CIMSS Products Update

Derrick Herndon, Chris Velden, Tony Wimmers, Tim Olander, Sarah Griffin, Dave Stettner

Thank for all your support and feedback!



WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

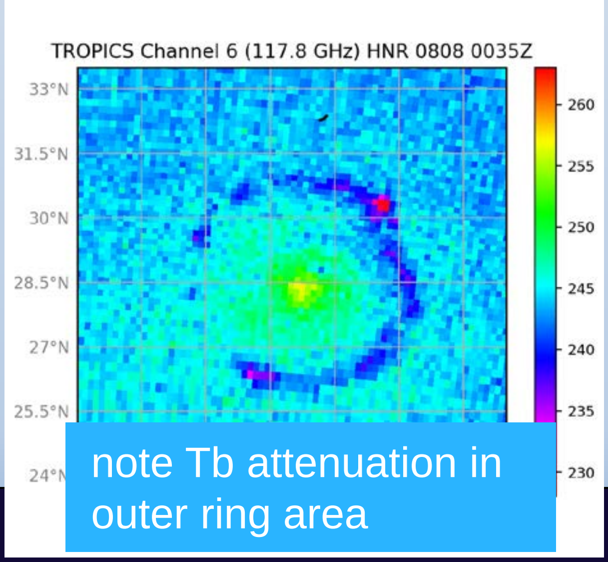
SSEC

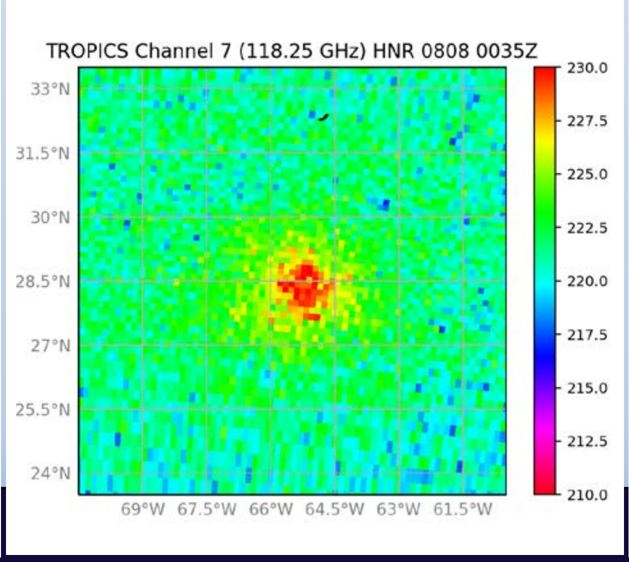
TROPICS Suitability for Measuring TC Intensity

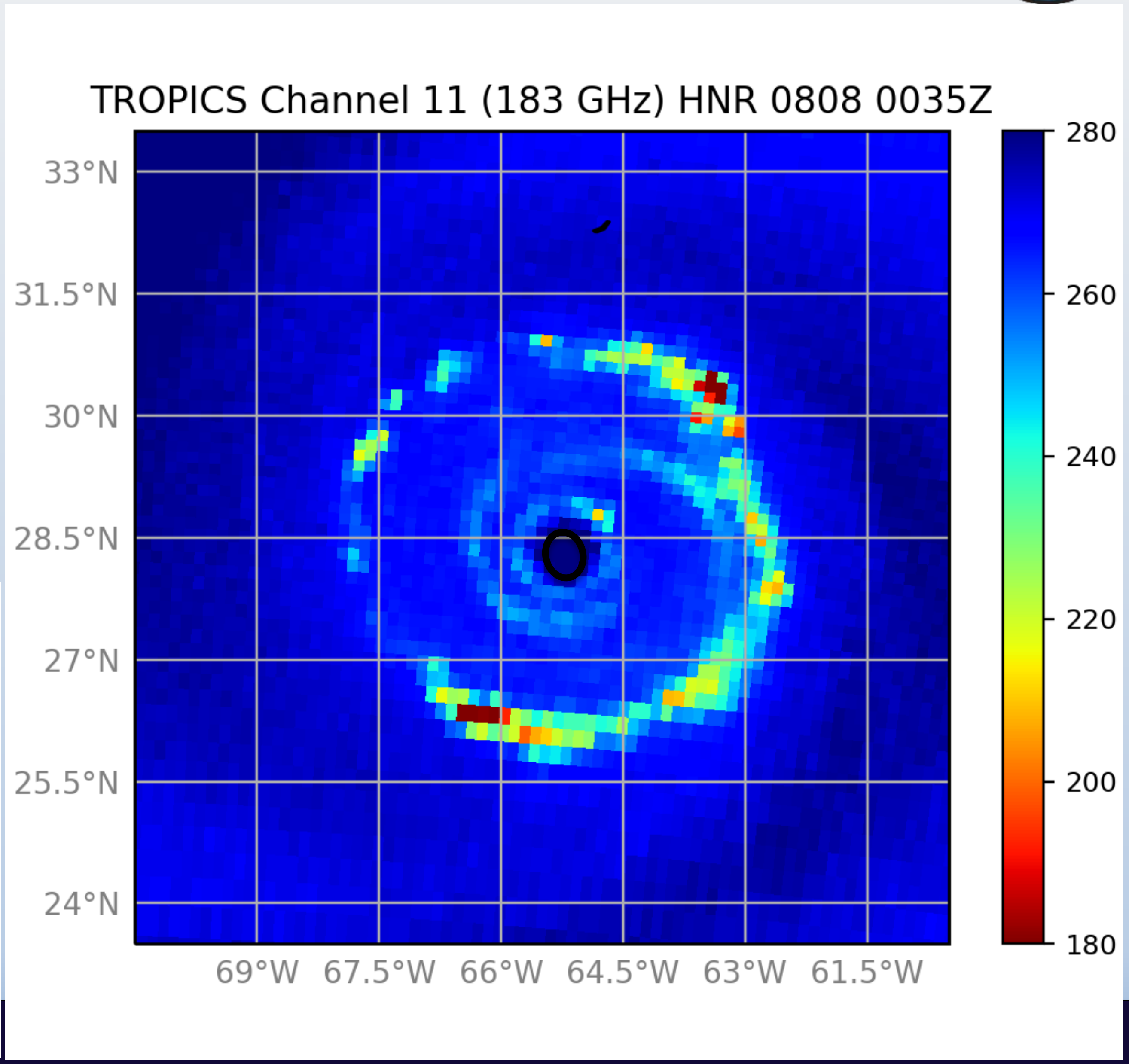
HNR TROPICS Ch6 and Ch7 clearly depict TC warm anomaly for this storm case.

However the simulated HNR storm has an eye that is fairly large which allows TROPICS to resolve much of the warm anomaly

Nature will not be so kind so …





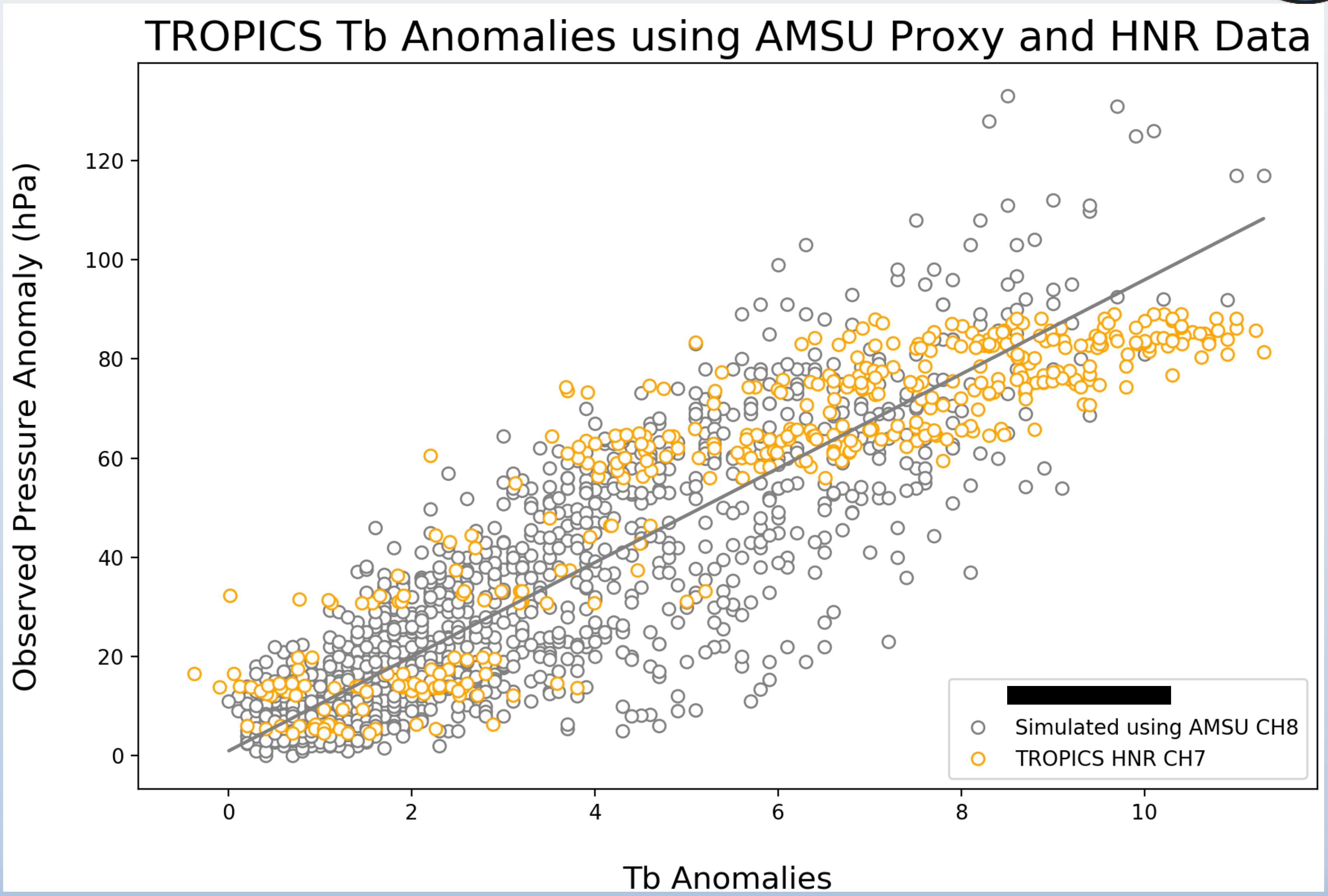


TROPICS Proxy Data Comparisons

Proxies and HNR simulated data
AMSU 1998-2016
TROPICS HNR Tbs
HNR data convolved to 75 km

Point of this plot is ..
Do HNR TROPICS estimates fall within the envelope of values predicted by AMSU?

Does convolution result in a more realistic distribution?



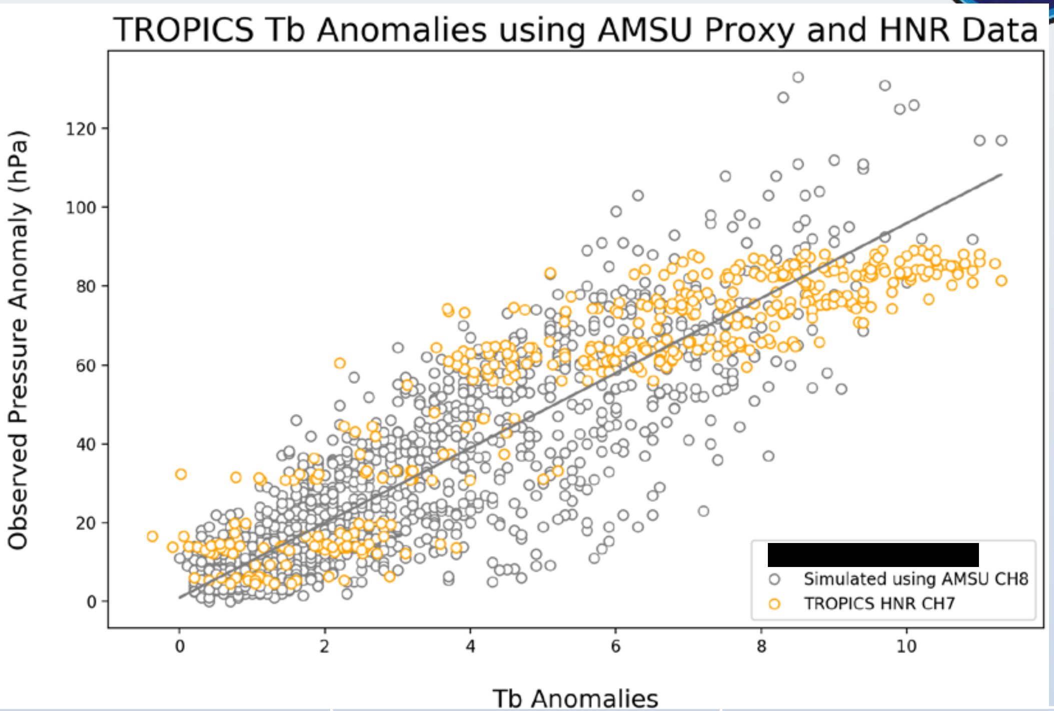
TROPICS Tropical Cyclone Intensity Estimation (TCIE)

Based on approach of CIMSS AMSU, ATMS and SSMIS algorithms that are part of the SATetellite CONsenus (SATCON)

TCIE

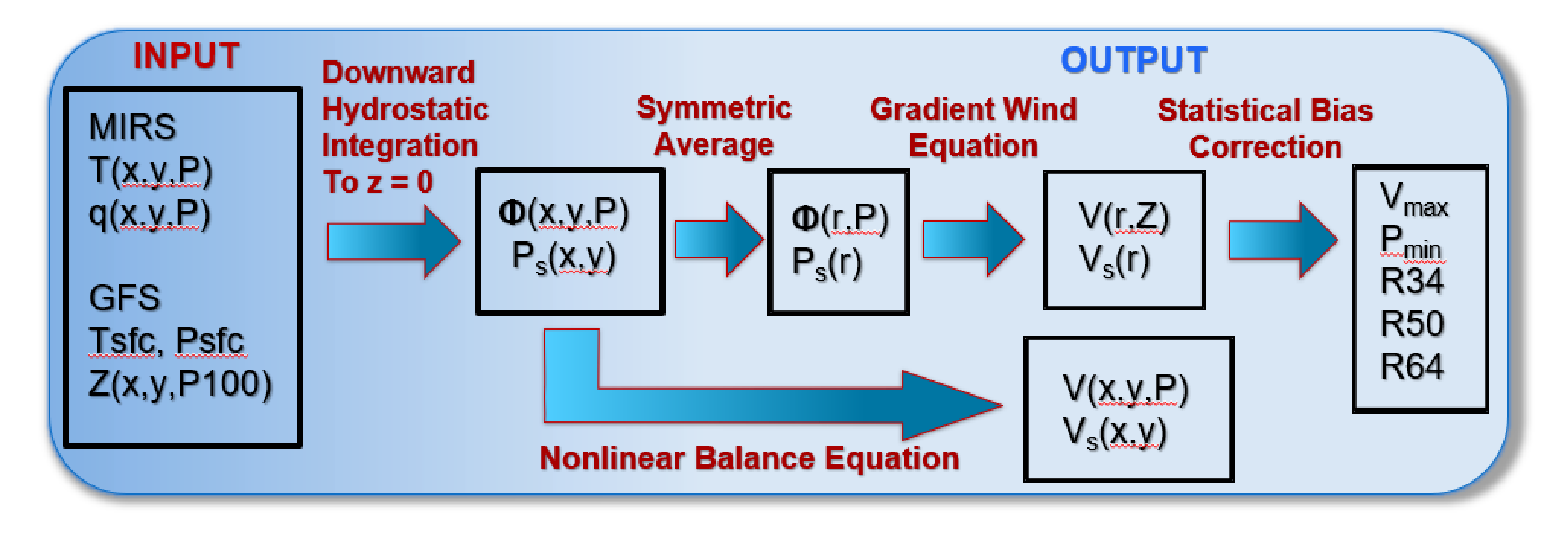
Linear regression of derived Tb anomalies from TROPICS channels 6 and 7.

- Correct for TC eye diameter under-sampling
- Storm position offset (use 183 GHz vs 89 GHz used in AMSU/ATMS)
- Estimates of Vmax and MSLP
- Adjust Vmax for latitude, storm size and convective vigor of eyewall (ARCHER)



TROPICS N=286	MSLP (hPa)	Vmax (knots)
Bias	0.3	1.7
Abs Error	7.7	7.1
RMSE	9.7	8.9

Hurricane Intensity and Structure Algorithm (HISA)



Input: ATMS-/AMSU-MiRS temperature profiles, CLW (correction for hydrometeors); and GFS boundary conditions

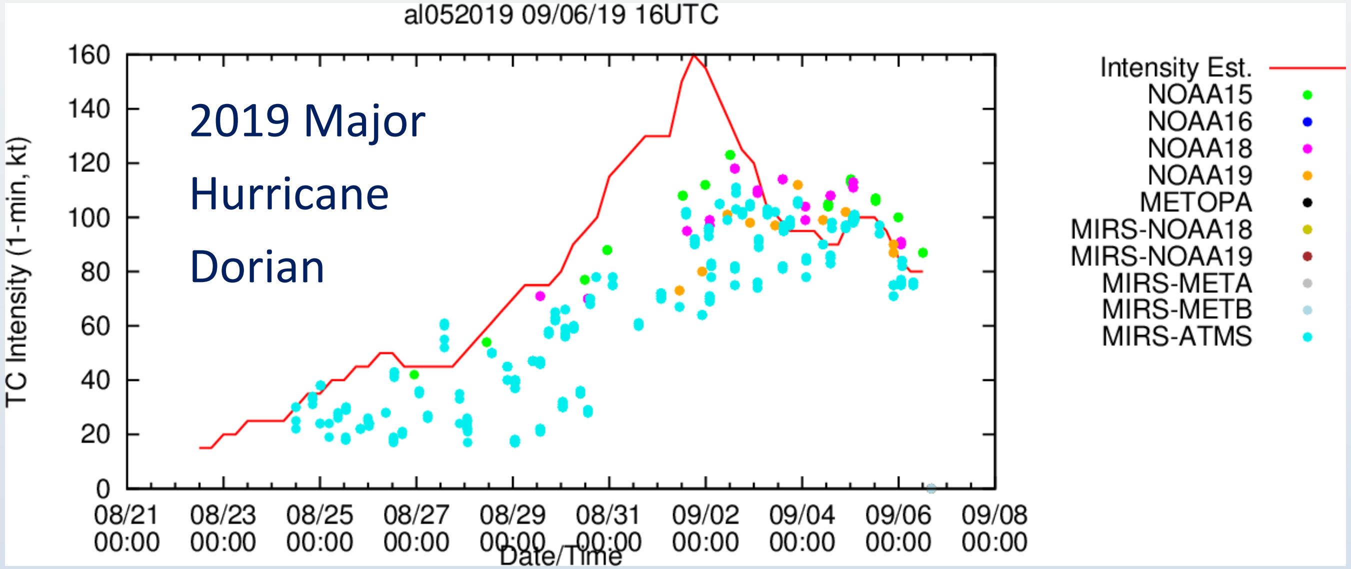
Output:

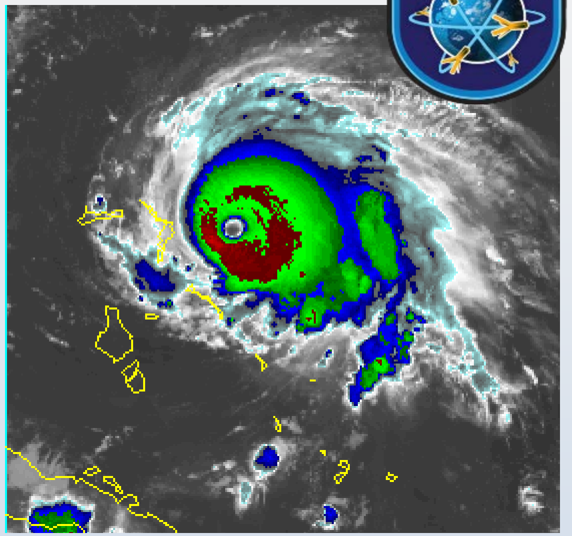
- Vmax, Pmin, wind radii in ATCF f-deck format
- Azimuthally-averaged gradient winds as a function of geopotential height and distance from TC center
- 2-d nonlinear balanced winds

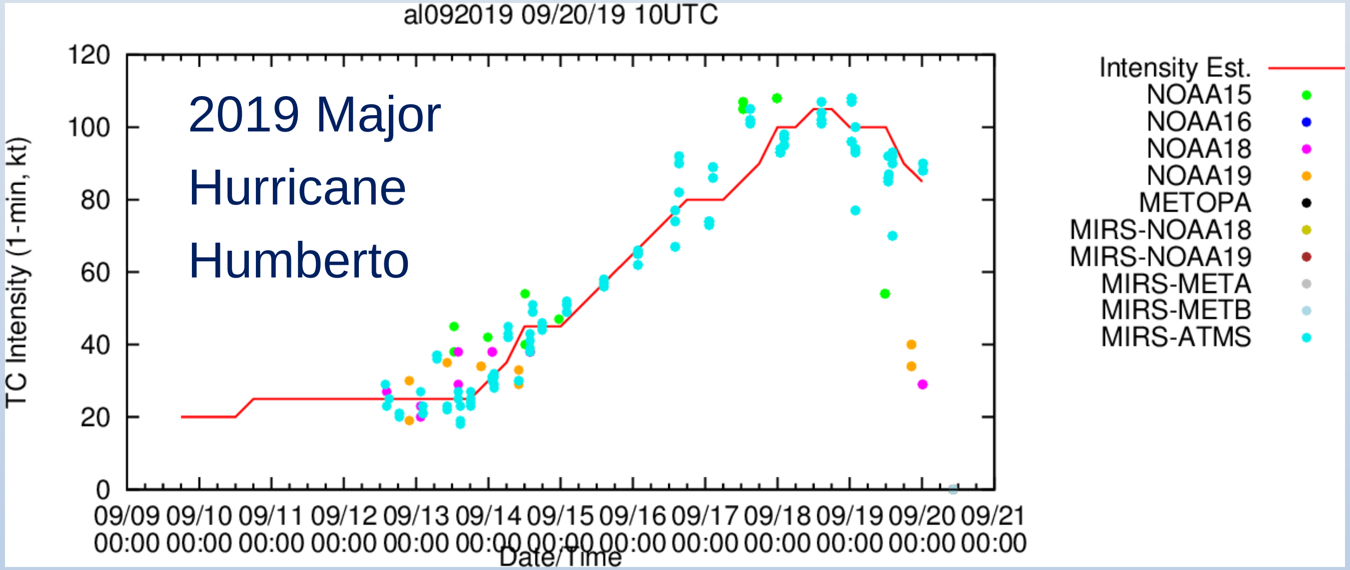
HISA Output: Intensity

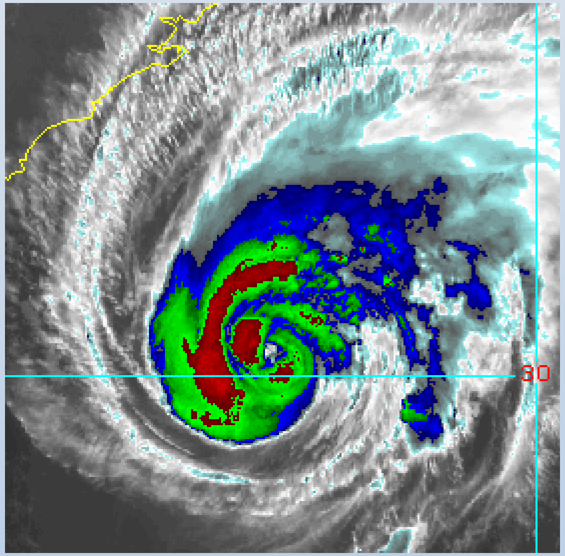
Degraded performance for small storms:

- Higher spatial resolution of TROPICS temperature channels might help
- TROPICS – 24 km
- ATMS – 32 km









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```

TROPICS TC Intensity Algorithms

Challenges

- Temperature channels: 118 GHz (TROPICS) instead of ~ 55 GHz (ATMS/AMSU)
- Scattering will be a challenge for TCs with small eyes
- A bit higher noise values than AMSU

Both TCIE and HISA are being implemented to process TROPICS Pathfinder data

- Intensity estimates will be produced as soon as data is received (high latency possible)
- Pathfinder will provide information on algorithm performance including proxy-based assumptions of suitability and importantly the scattering impacts.
- Apply lessons learned to improve performance for follow-on launch of TROPICS in 2022

GeoIPS Overview

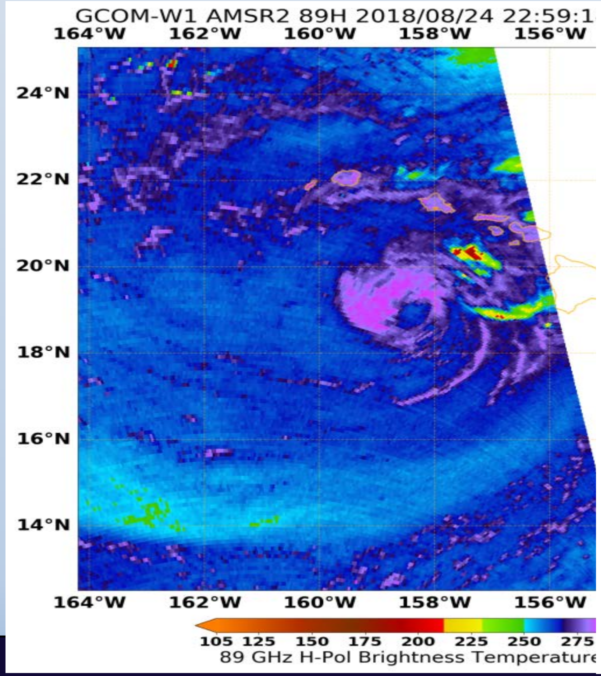
Josh Cossuth, Chris Selman, Tony Wimmers, Melinda Surratt, Derrick Herndon

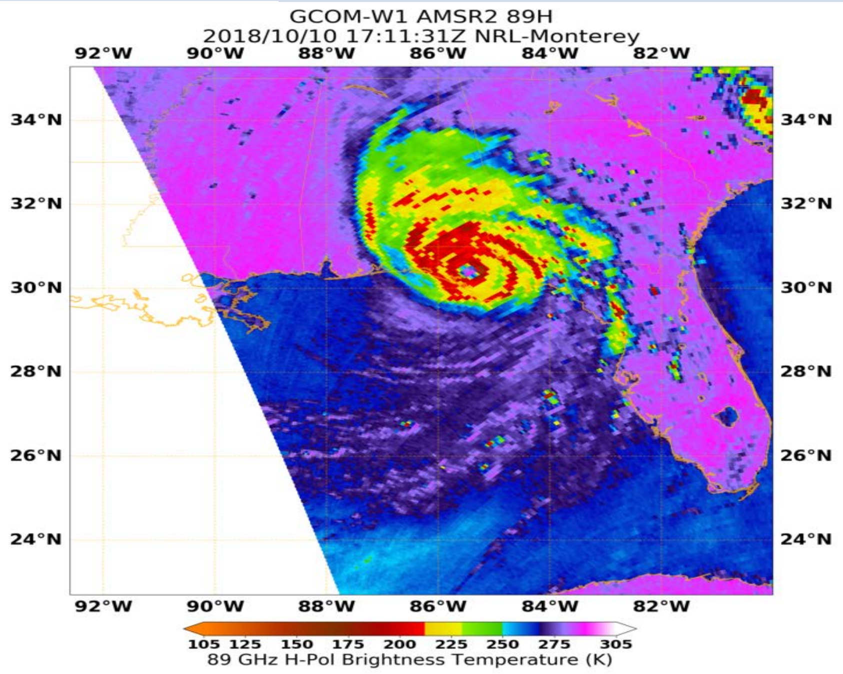
Real-time acquisition, processing, analysis, and operational integration of TC-centric polar orbiting data.

Part I: Implementation of a data ingest, standardization, and output system.

BLUF: Distribute NRL TC Web functionality at NOAA, CIMSS, and CIRA via GeoIPS® to better collaborate on polar orbiting (especially microwave-based) data processing capabilities for both research and operations.

- Leverage previous NOAA JHT project to update NRL TC web processing (see right)
- Work with research partners on development to build upon each others resources
- Release work as open source to allow community development





GeoIPS® Motivation

Multiple data formats ingested into one processing system

Source	Platform	Data type
ABI	GOES-16	netCDF4
AHI	Himawari-8	HSD Binary
AMSR2	GCOM-W1	netCDF4
AMSU-A/B	M2A	
ASCAT	METOP-A/B	
GVAR	GOES-13/14	TDF
GMI	GPM	HDF5
SEVIRI	METEOSAT-8/11	HRIT
MODIS	Aqua/Terra	HDF-EOS
NAVGEM	Model	GRIB2
OSCAT	ScatSat-1	netCDF3
SAPHIR	Meghatropiques	HDF5
TPW	CIRA	HDF4
TPW-MIMIC	CIMSS	GIF
VIIRS	NPP-1/JPSS-1	netCDF4

Takeaway…

- ***Users need varied data types in a standard delivery.***
- ***GeoIPS processes satellite data in a common infrastructure.***

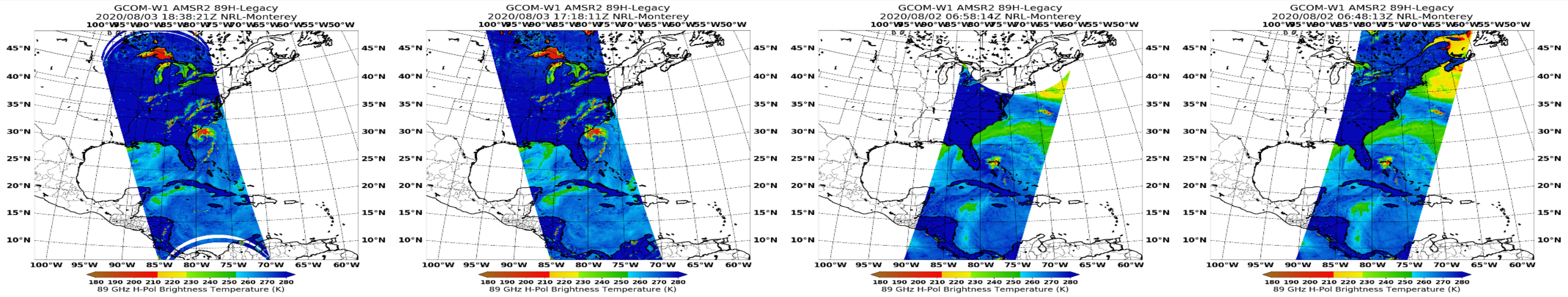
GeoIPS® Defined

What is GeoIPS® and What is GeoIPS® designed to do?

- ***GeoIPS® is an establishment of longterm, flexible data ingest and processing capability framework for both research and operations.***
  - NRL developed software package (python-based architecture) for next generation METOC data ingest, processing, and output.
    - Function: Download, read, and process native-format geospatial data sets and standardized them for research and operational use.
    - Output products: Qualitative and quantitative imagery and data products.
    - Algorithm and functionality developments are done modularly for stable and efficient upgrades/modifications.

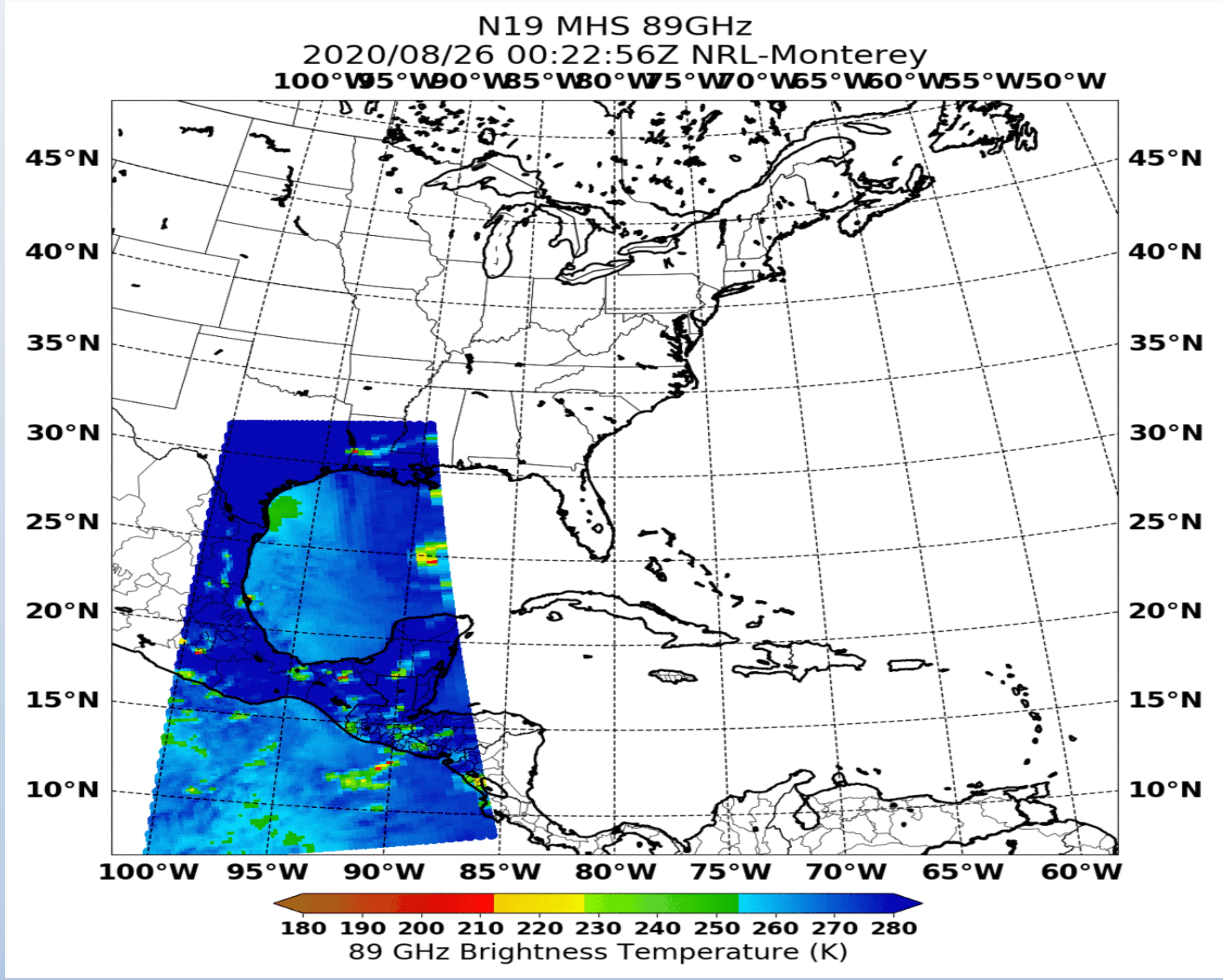
Takeaway: *GeoIPS® is an open source environmental data processing system replacing legacy proprietary software.*

Direct Broadcast (DB) Comparison



	NESDIS PDA System	Direct Broadcast	Difference	
Point Scan to retrieval [Mean] (Ascending Orbit/Morning Scan)	36.39	13.47	22.92	minutes
Point Scan to retrieval [Std. Dev.] (Ascending Orbit/Morning Scan)	3.31	2.05	1.26	minutes
Point Scan to retrieval [Mean] (Descending Orbit/Afternoon Scan)	101.41	15.1	86.31	minutes
Point Scan to retrieval [Std. Dev.] (Descending Orbit/Afternoon Scan)	2.14	0.74	1.4	minutes
GeoIPS Processing Time [Mean]	21.84	17.87	3.97	seconds
GeoIPS Processing Time [Std. Dev.]	1.83	1.13	0.7	seconds

JPSS Family of Satellites from DB



- Animation shows approach of Hurricane Laura to Louisiana coast in late August 2020
- All data processed from GeoIPS at the National Hurricane Center using direct broadcast (DB) data from the JPSS Miami (AOML) antenna
- Large variety of resolutions, scan coverages, and overpass times