Estimation of Medicane Intensity and Structure from Multispectral Satellite Imagery

Derrick Herndon
University of Wisconsin-Madison
Cooperative Institute for Meteorological Satellite Studies USA

Giulia Panegrossi and Leo Pio D'Adderio
National Research Council of Italy, Institute of Atmospheric Sciences and Climate (CNR-ISAC)

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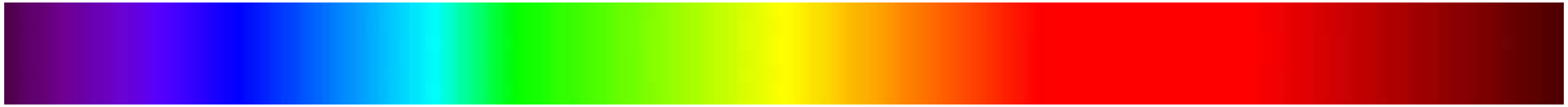
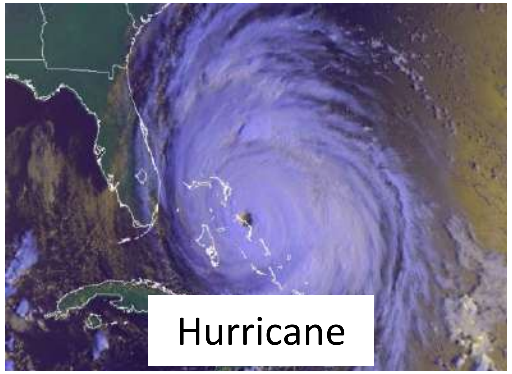
Approaches for Estimating Tropical Cyclone Intensity

What are Medicanes?

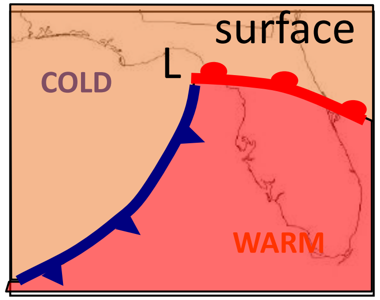
Medicanes exist within a spectrum of different types of low pressure systems.



Mid-Latitude Cyclone

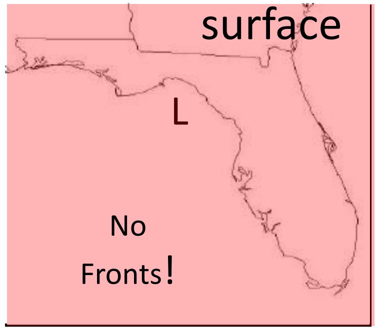


Hurricane



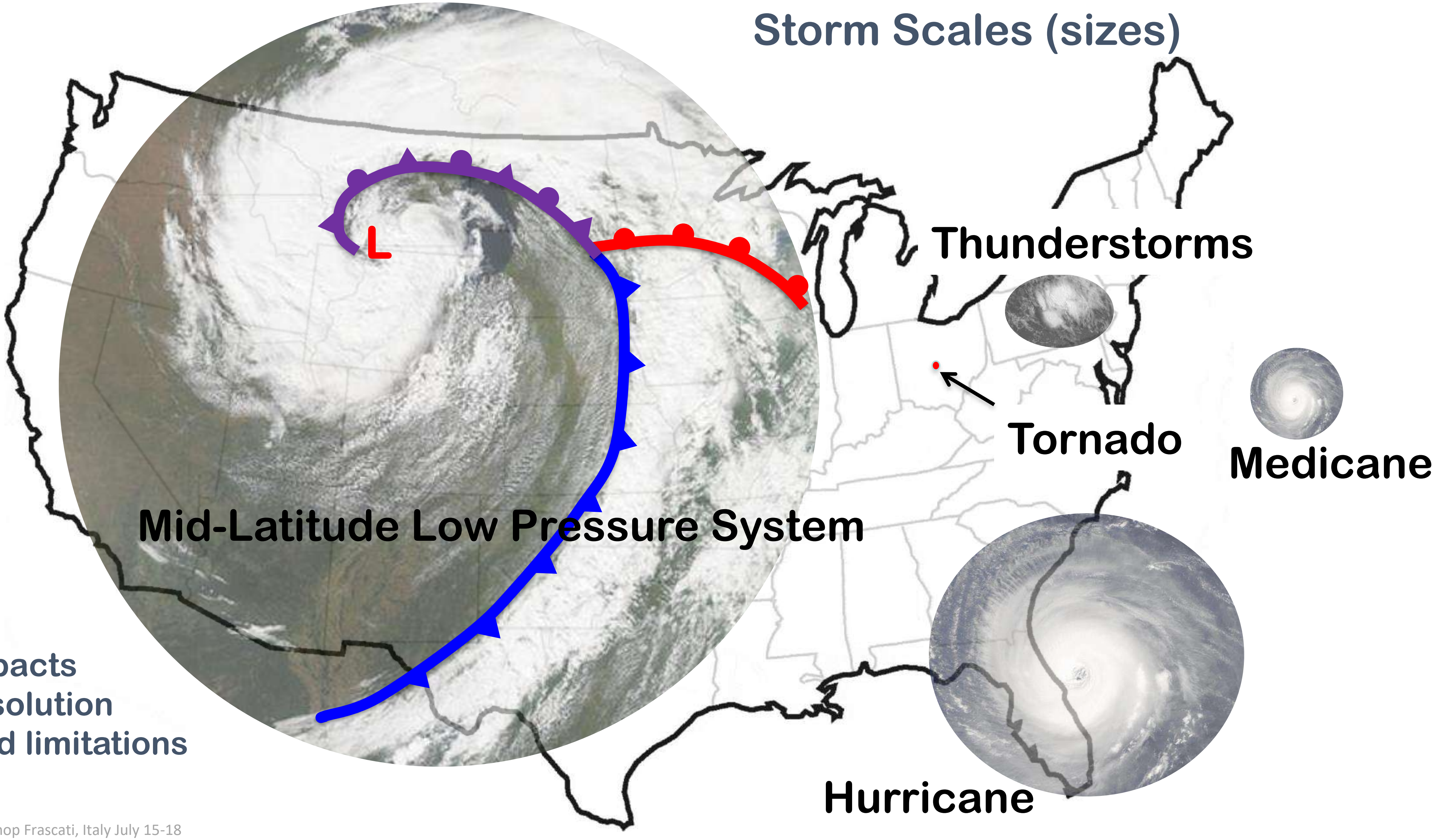
Hybrid Storm
Something in between

Often present a communication challenge !



And also an analysis challenge

Approaches for Estimating Tropical Cyclone Intensity

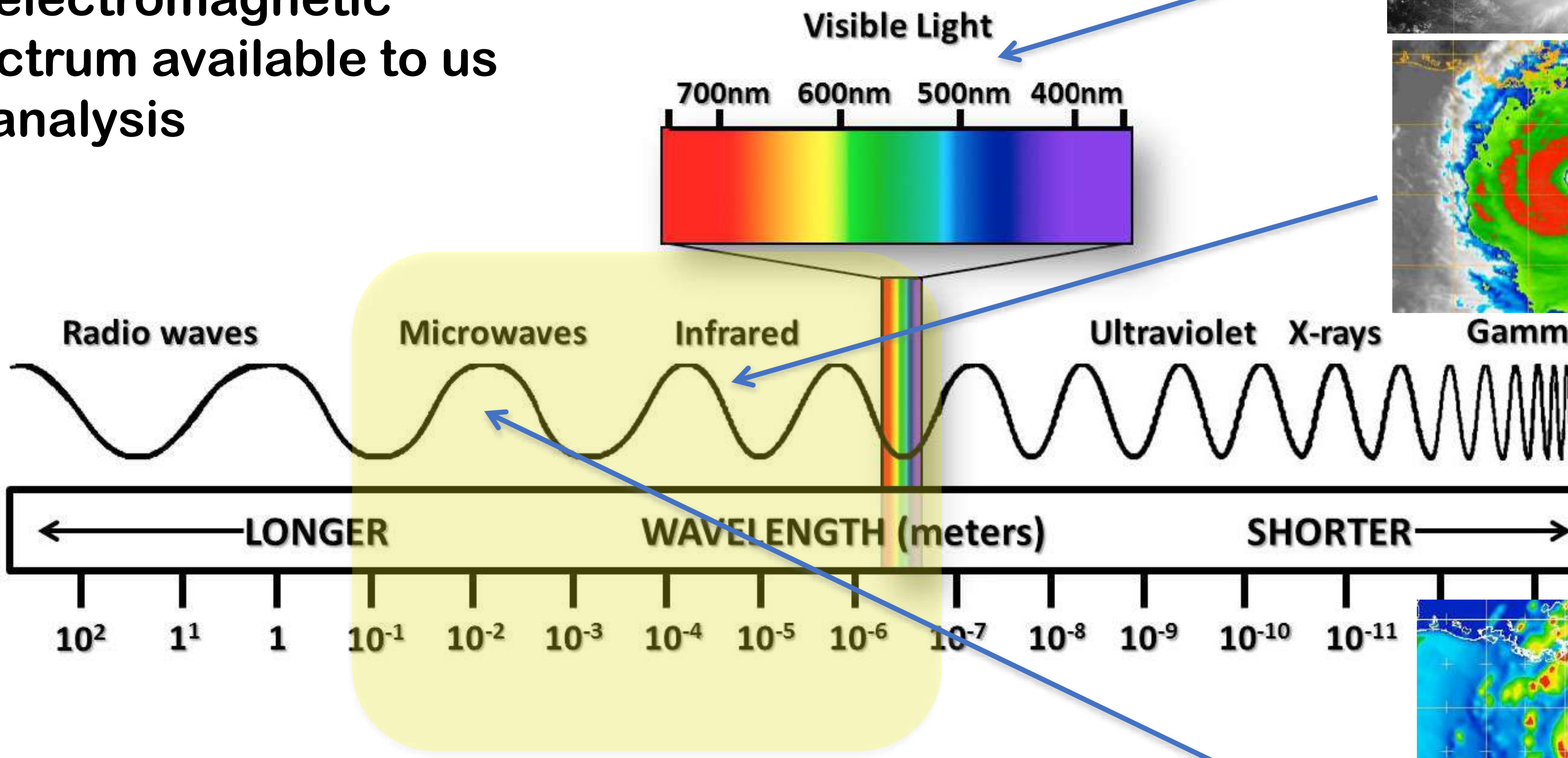


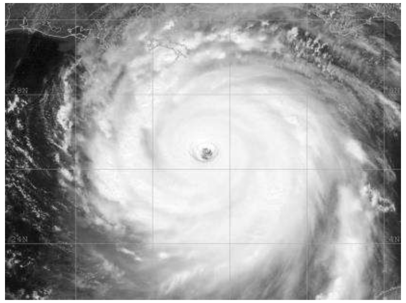
Storm size impacts
instrument resolution
and associated limitations

Approaches for Estimating Tropical Cyclone Intensity

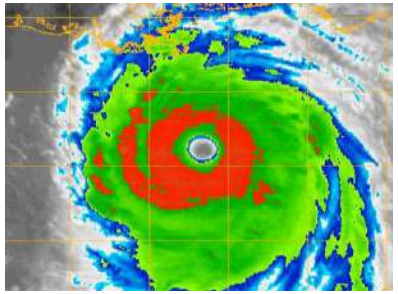
Satellite Analysis

Important to leverage the full electromagnetic spectrum available to us for analysis

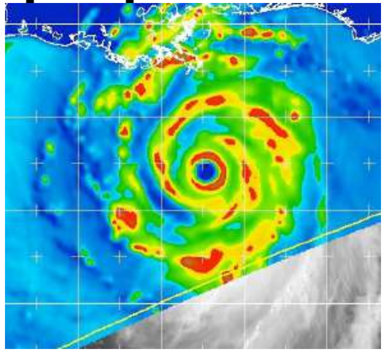




Geostationary Visible



Geostationary Infrared

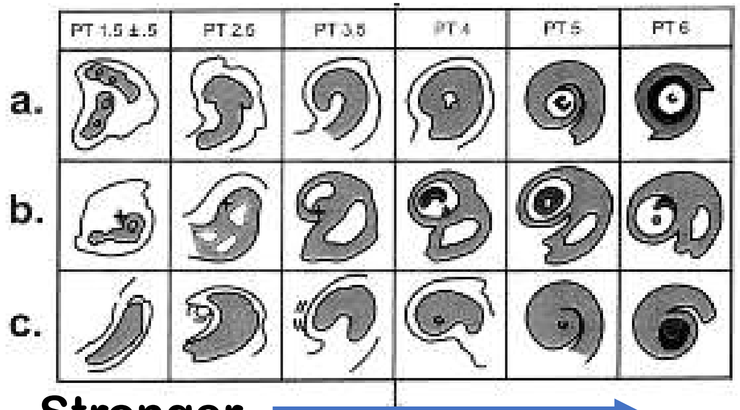


Passive and Active microwave (Polar orbiters)

Approaches for Estimating Tropical Cyclone Intensity

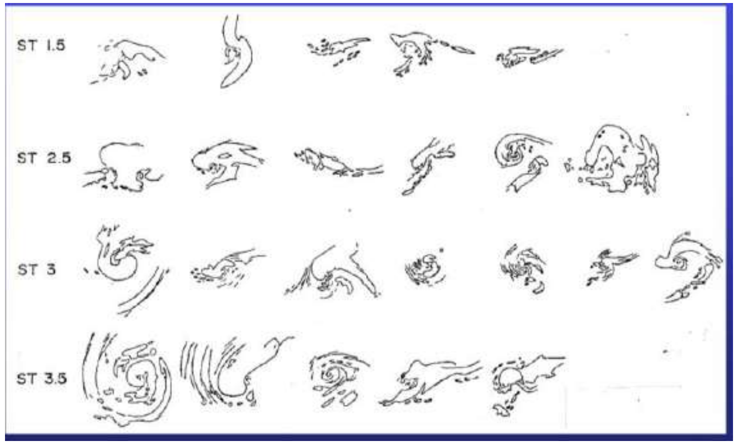
Morphological

Dvorak



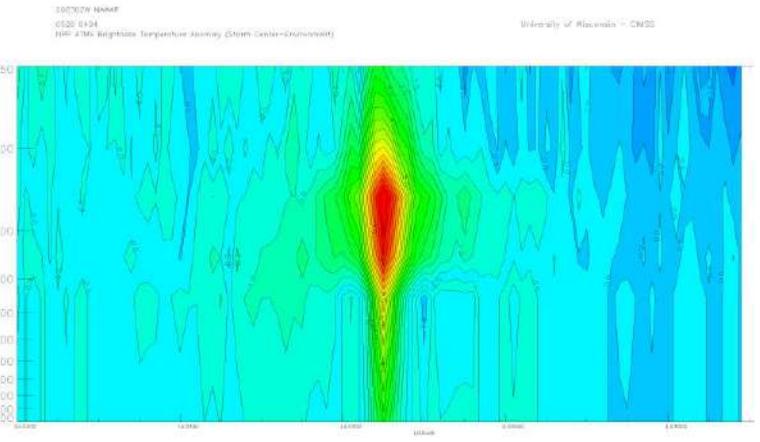
Stronger →

Hebert-Poteat

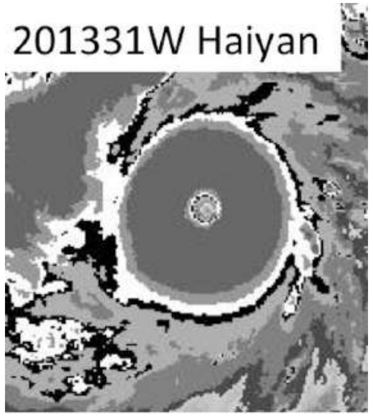


Thermodynamic

Microwave Sounder (warm core)



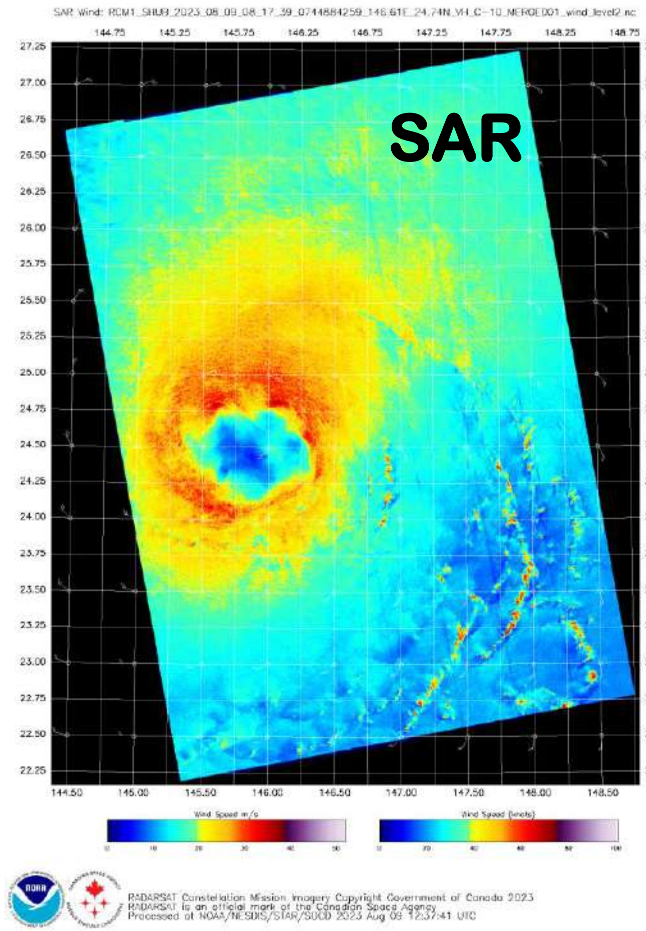
Infrared



Difference between eye temperature and surround cold ring

Kinematic

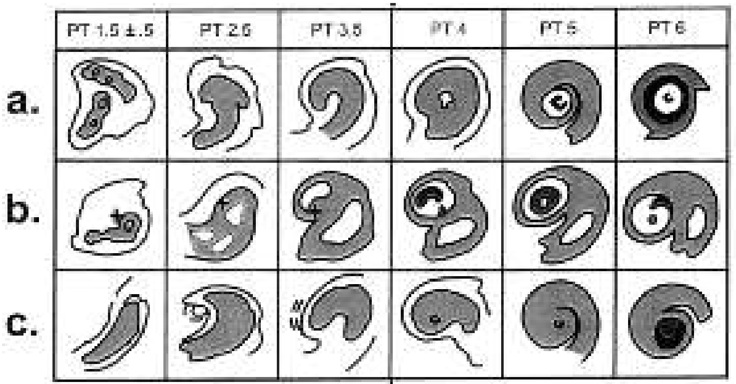
Remote sensing of winds (SAR, SMAP, ASCAT etc)



Approaches for Estimating Tropical Cyclone Intensity

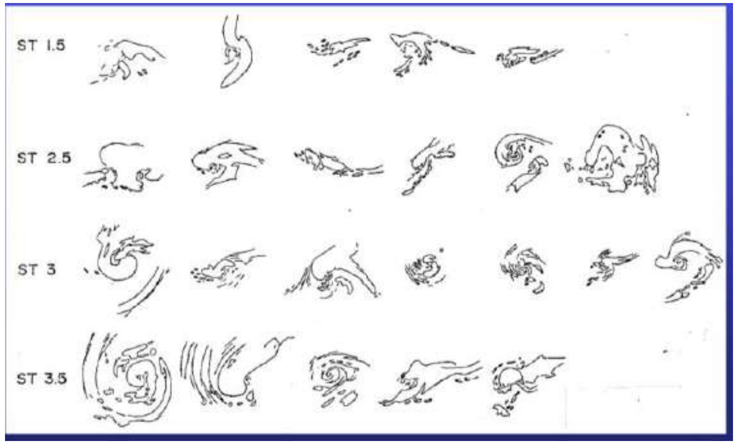
Morphological

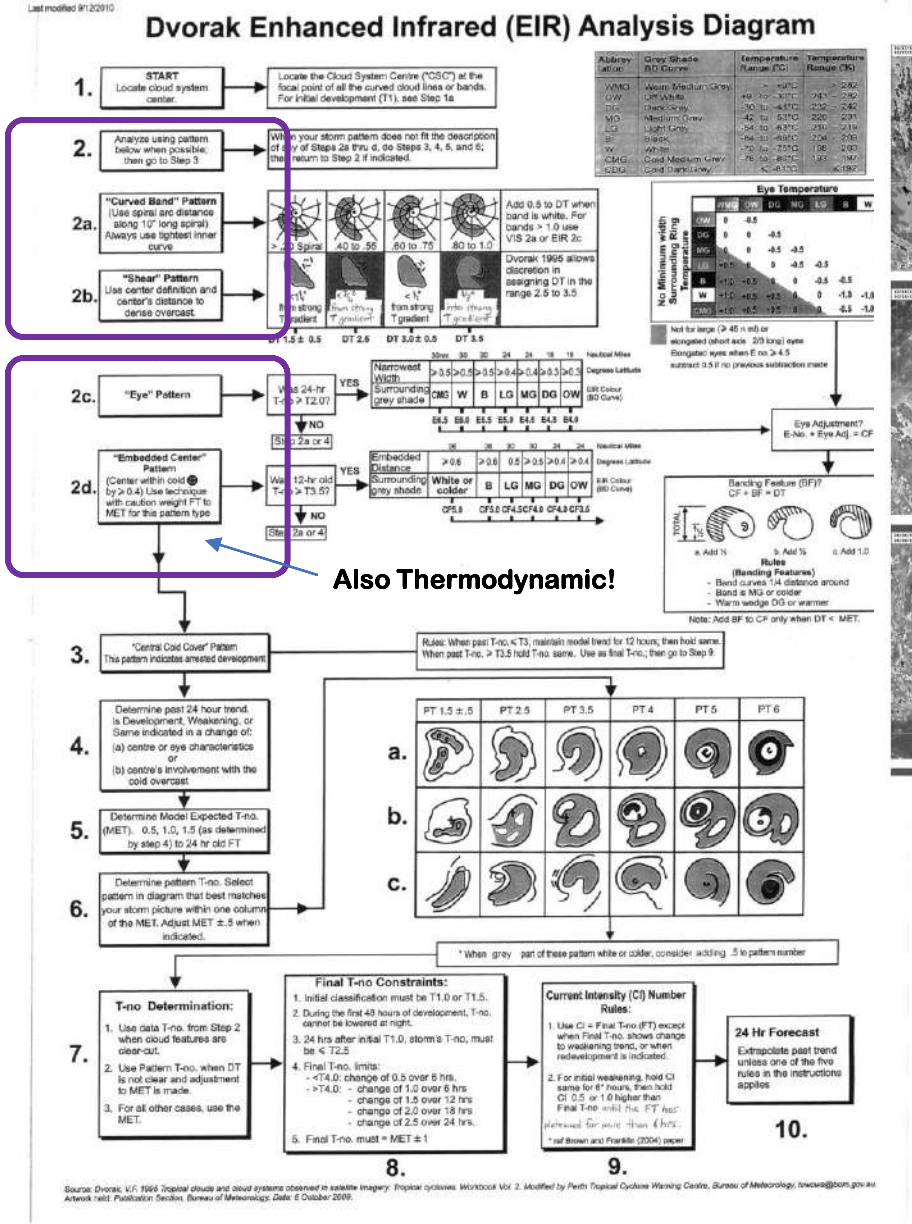
Dvorak



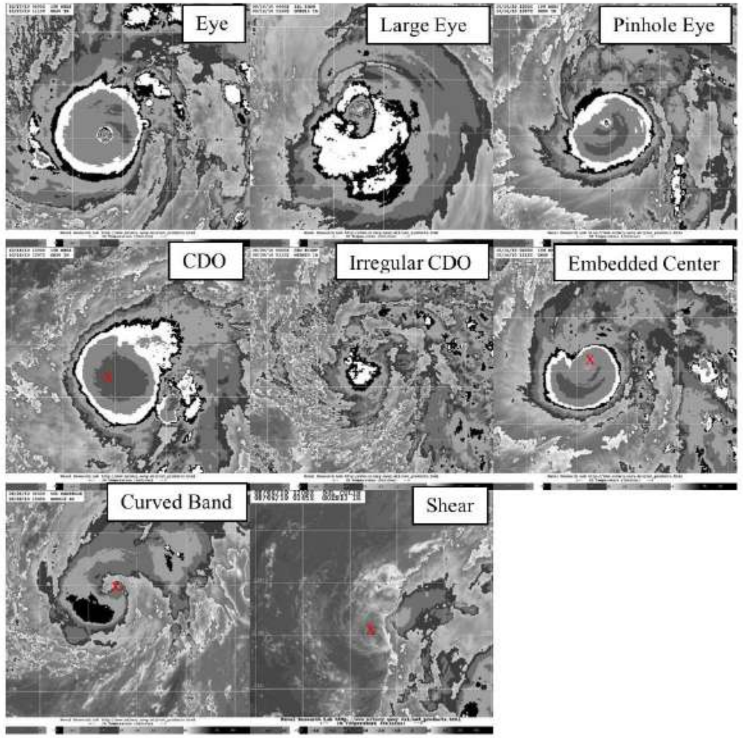
Stronger

Hebert-Poteat





Also Thermodynamic!



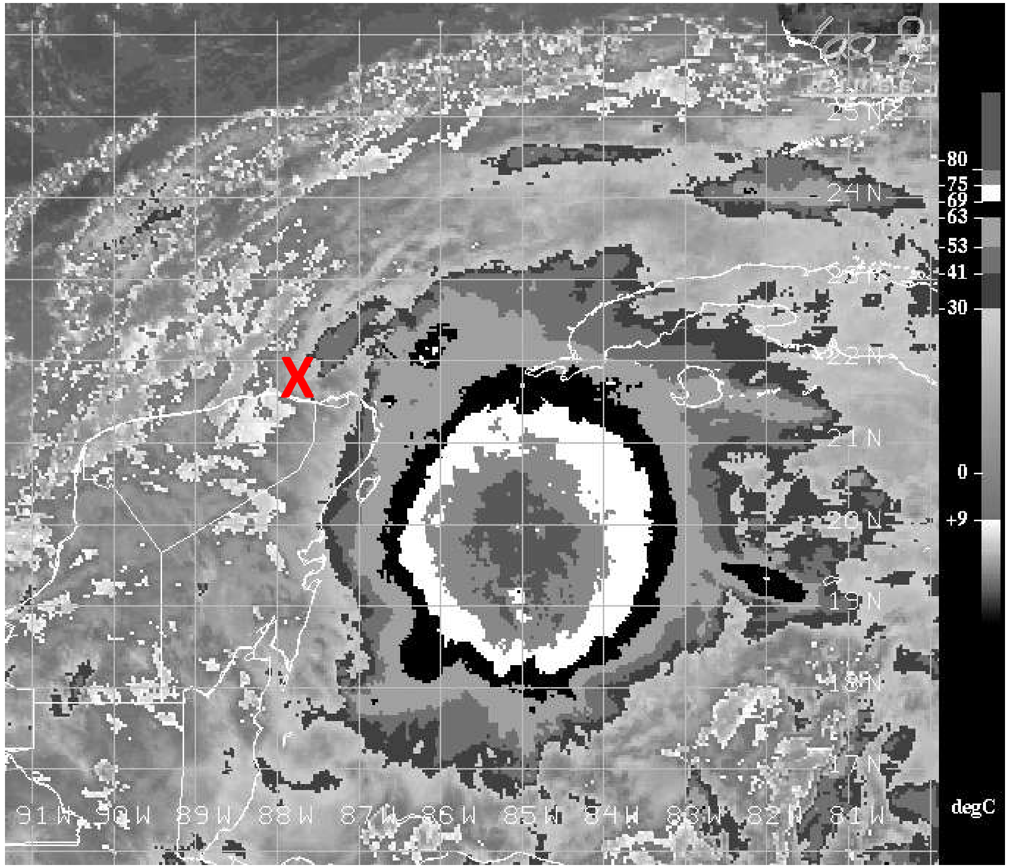
Dvorak is done manually every 6 hours at TC warning agencies worldwide

Technique was automated at CIMSS and CIRA in the 1990s

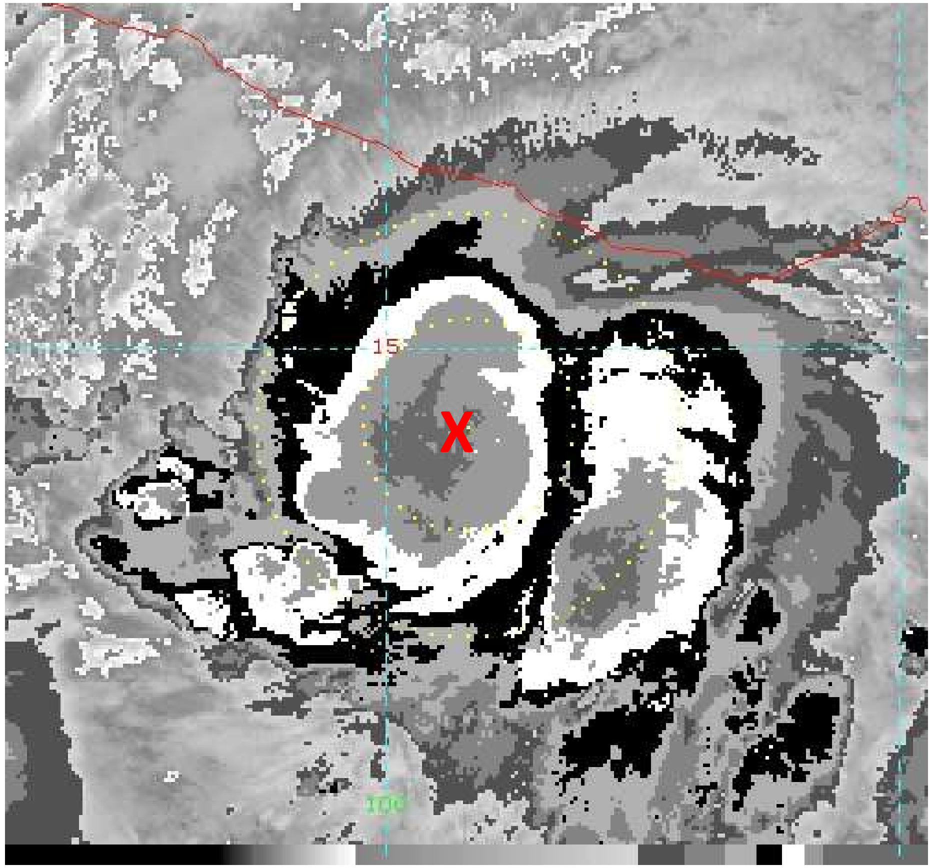
Approaches for Estimating Tropical Cyclone Intensity

Accurate storm location is critical for intensity analysis. Intensity estimation is sensitive to center proximity to convection

Let's play a game: Locate the center of these two cyclones



Pre-Alex (2022) 12 m/s

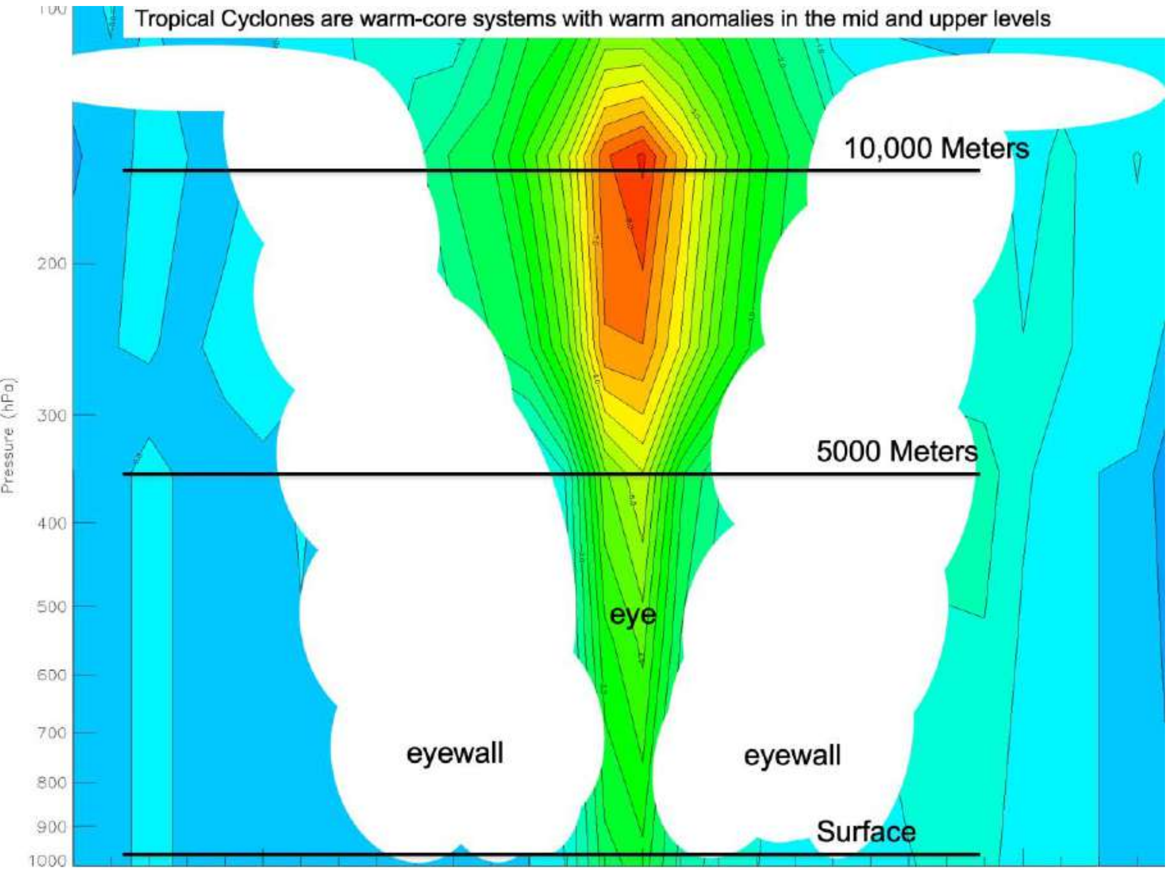


Hurricane Agatha (2022) 40 m/s

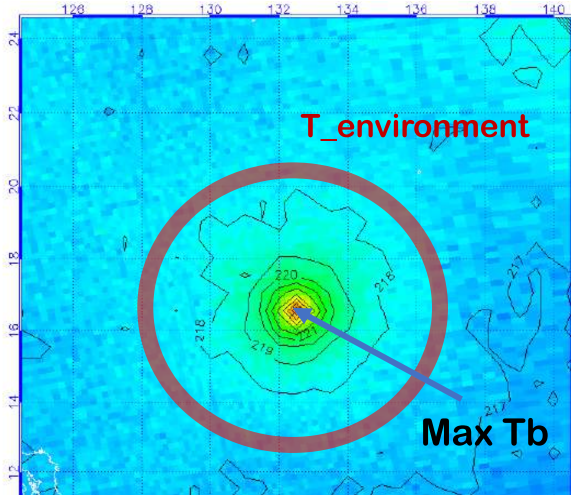
Approaches for Estimating Tropical Cyclone Intensity

Thermodynamic

Microwave Sounders: Temperature



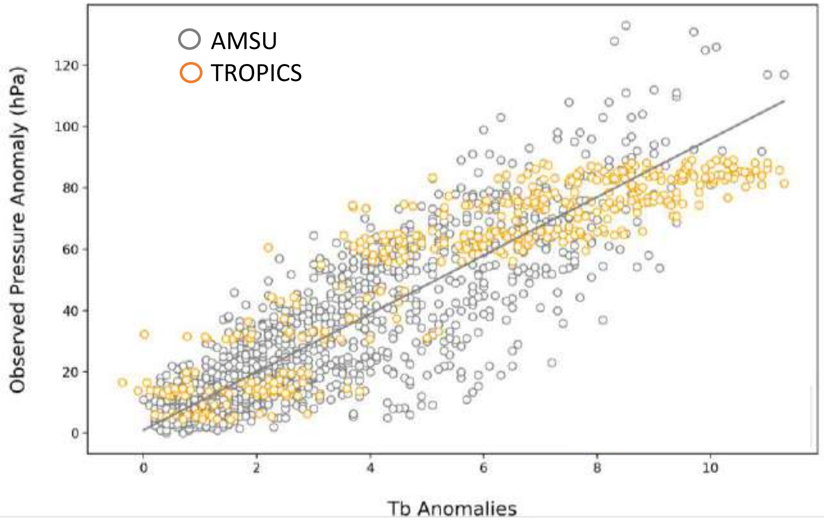
Calculate T anomaly



Tb Anomaly = 9 K

Match anomalies to TC intensity (Vmax or MSLP)

Apply corrections for under-sampling of the warm core:
- eye size
- attenuation effects
- position offsets



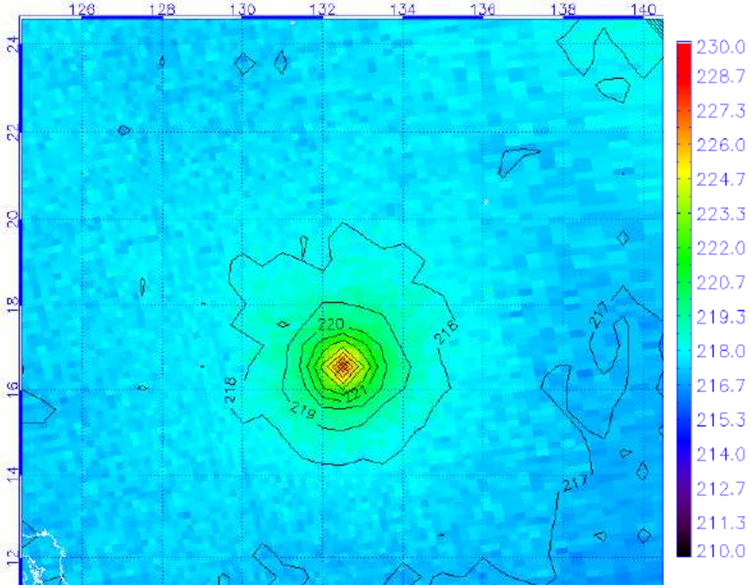
Has been used since launch of MSU in 1990's. Used to determine thermal structure (warm/cold core) and intensity

Approaches for Estimating Tropical Cyclone Intensity

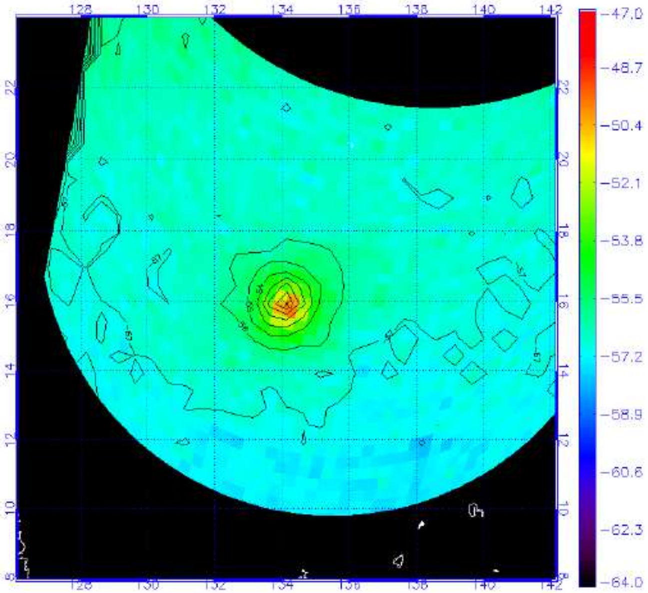
Thermodynamic

Microwave Sounders: Temperature (55 GHz and 118 GHz)

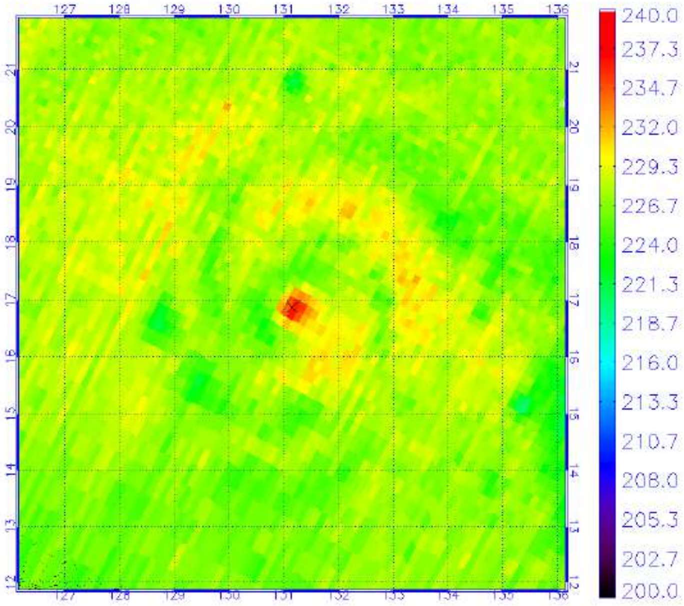
ATMS CH9



SSMIS CH5



TROPICS CH7



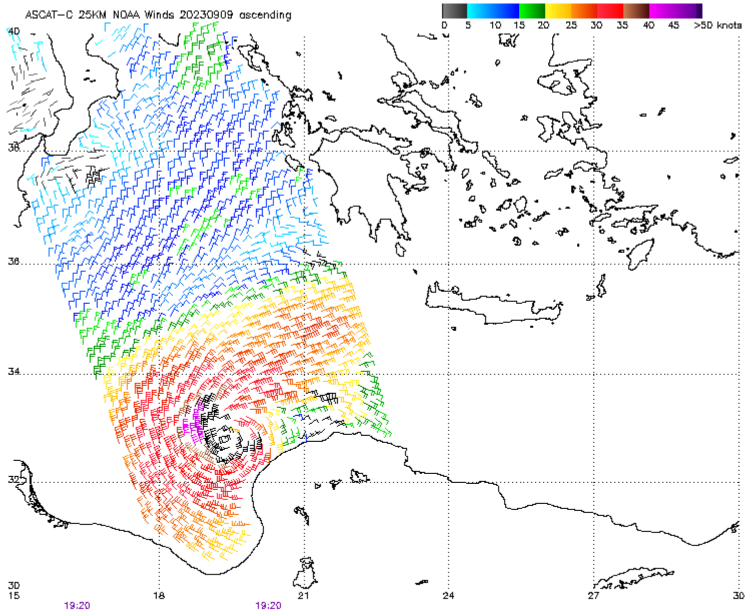
Super Typhoon Mawar 2023 near peak intensity from three difference microwave sounders

Also on China FY-series, Tomorrow.io and other upcoming cubesats/smallsats
118 GHz is more prone to attenuation from heavy convection and thus under-sampling of the warm core

Approaches for Estimating Tropical Cyclone Intensity

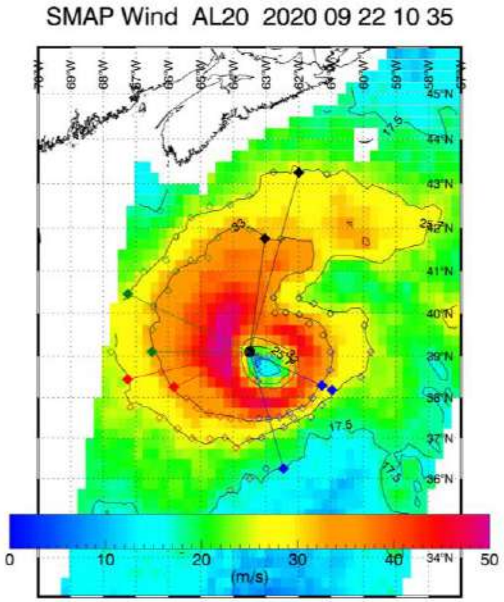
Kinematic

Scatterometer



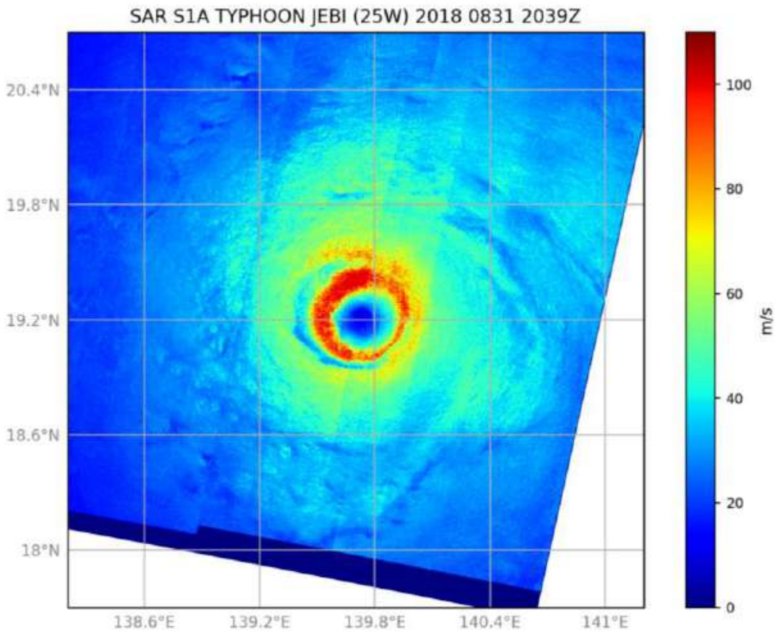
- C-Band 5.4 Ghz or Ku-Band ~ 5.4 GHz
- Signal can saturate at high intensities
- Resolution may under-sample winds
- Data gaps may miss the storm

SMAP/SMOS



- L-Band 1.4 GHz
- 40 km Resolution may under-sample winds
- Limited number of overpasses

SAR



- C-band (~5.4 GHz
- Data must requested in advance
- Limited number of overpasses (but getting better)
- Excellent detail of storm structure
- Can suffer from attenuation in heavy precipitation

Approaches for Estimating Tropical Cyclone Intensity

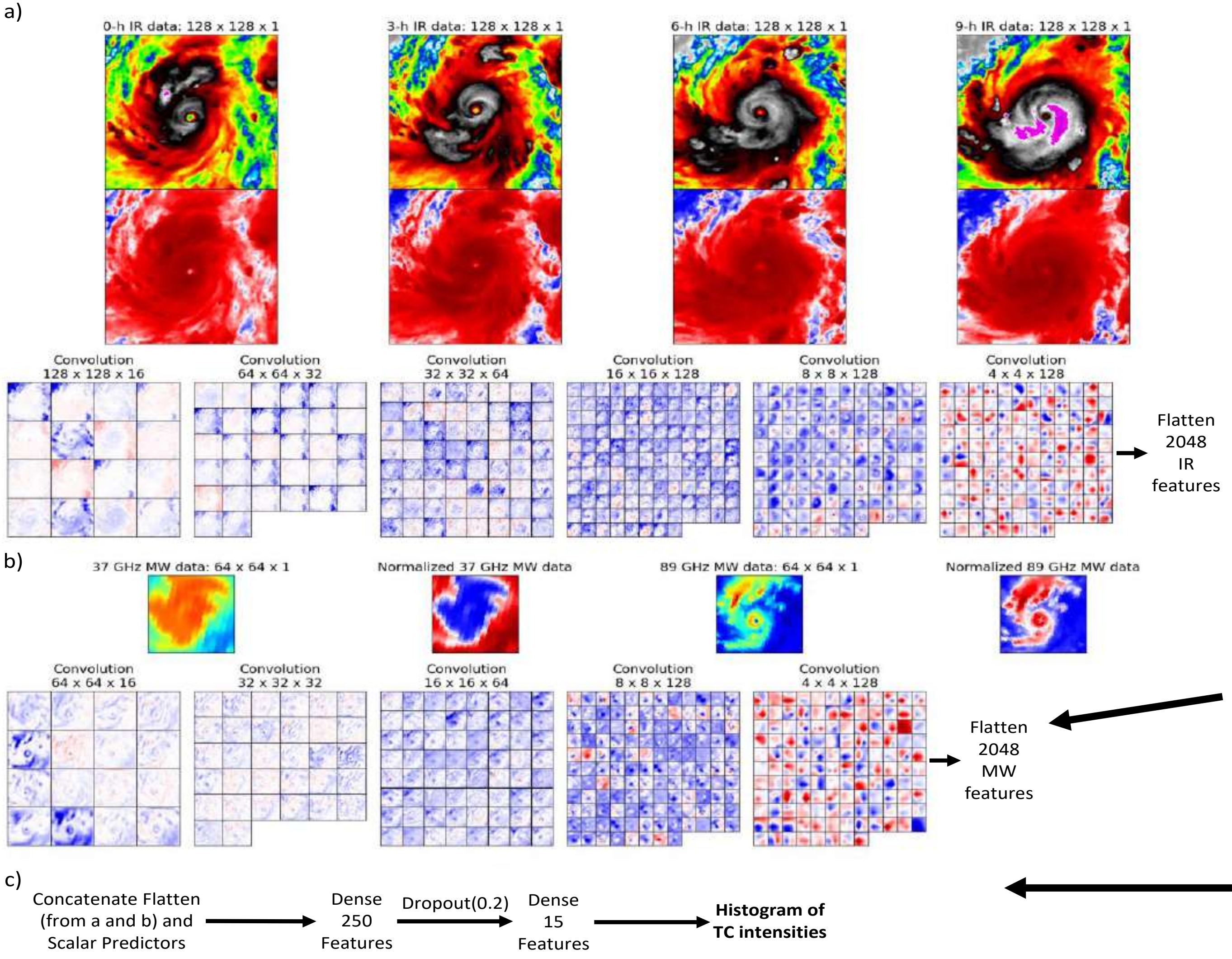
Morphological | **Thermodynamic** | **Kinematic**

AI Tools D-MINT and D-PRINT (CNNs)

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)

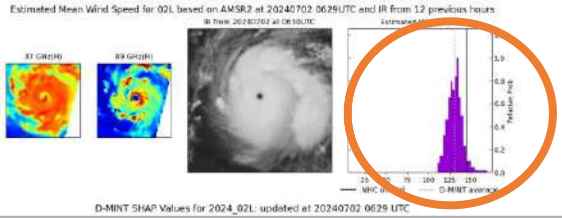
Output: 15 quantiles of TC intensity probabilities

Approaches for Estimating Tropical Cyclone Intensity

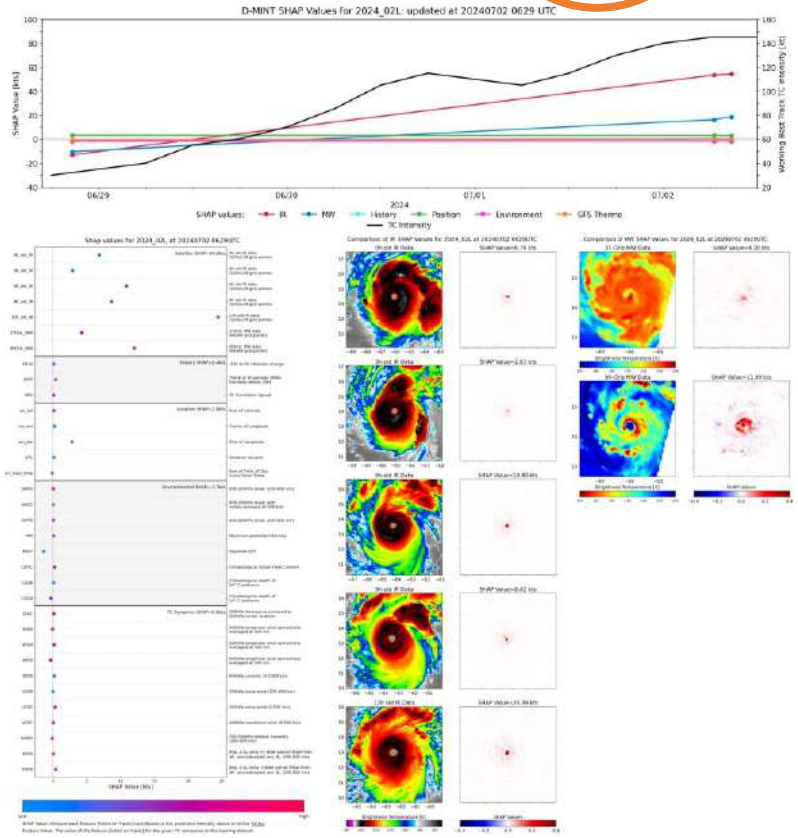
Morphological | **Thermodynamic** | **Kinematic**

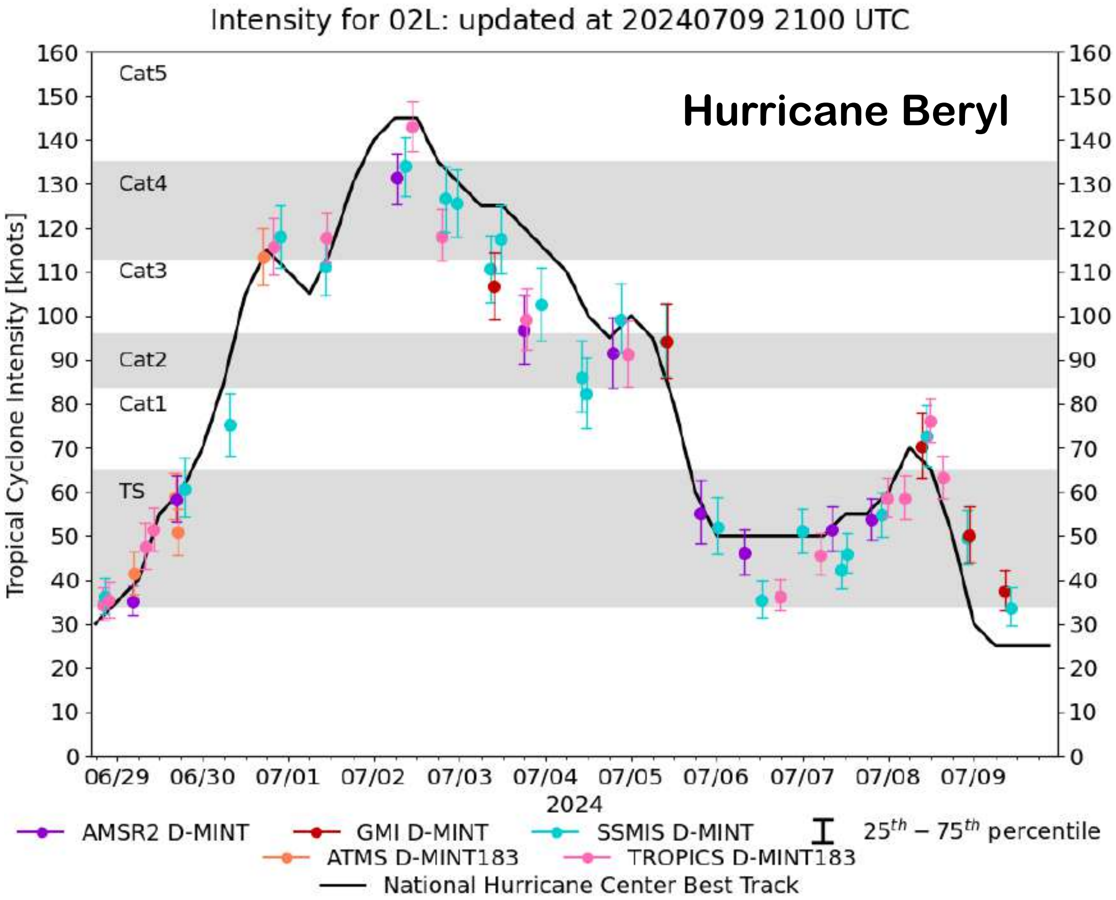
AI Tools: D-MINT and D-PRINT (CNNs)

Single D-MINT estimate for Hurricane Beryl

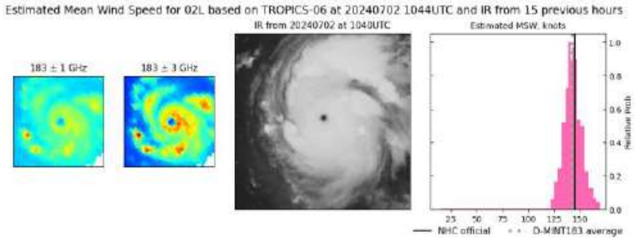


Intensity distribution





183 GHz added in 2024
ATMS/SSMIS/TROPICS



Approaches for Estimating Tropical Cyclone Intensity

Advanced (AI-enhanced) Dvorak Technique (AiDT)

Use output parameters from infrared-based ADT algorithm to develop new AI model
Improved performance in certain IR scenes

Trainable Parameters

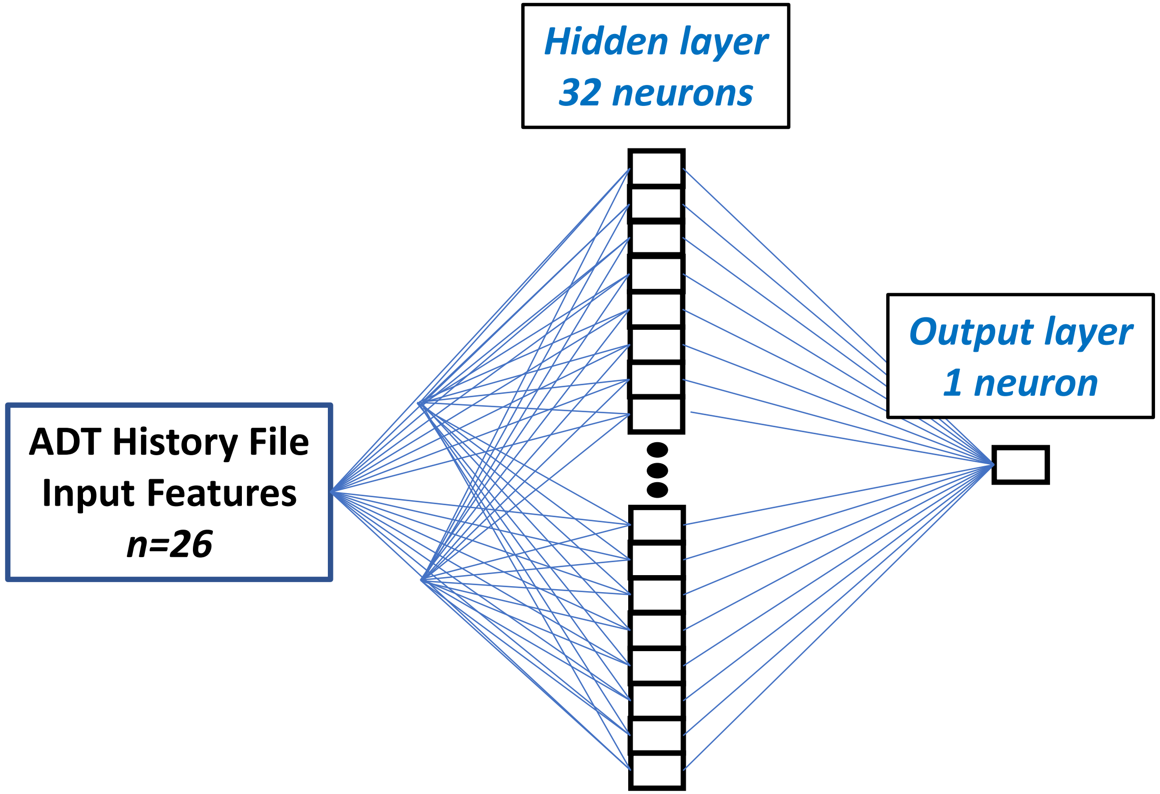
L1: 26 X 32 + 32 = 864

L2: 32 X 1 + 1 = 33

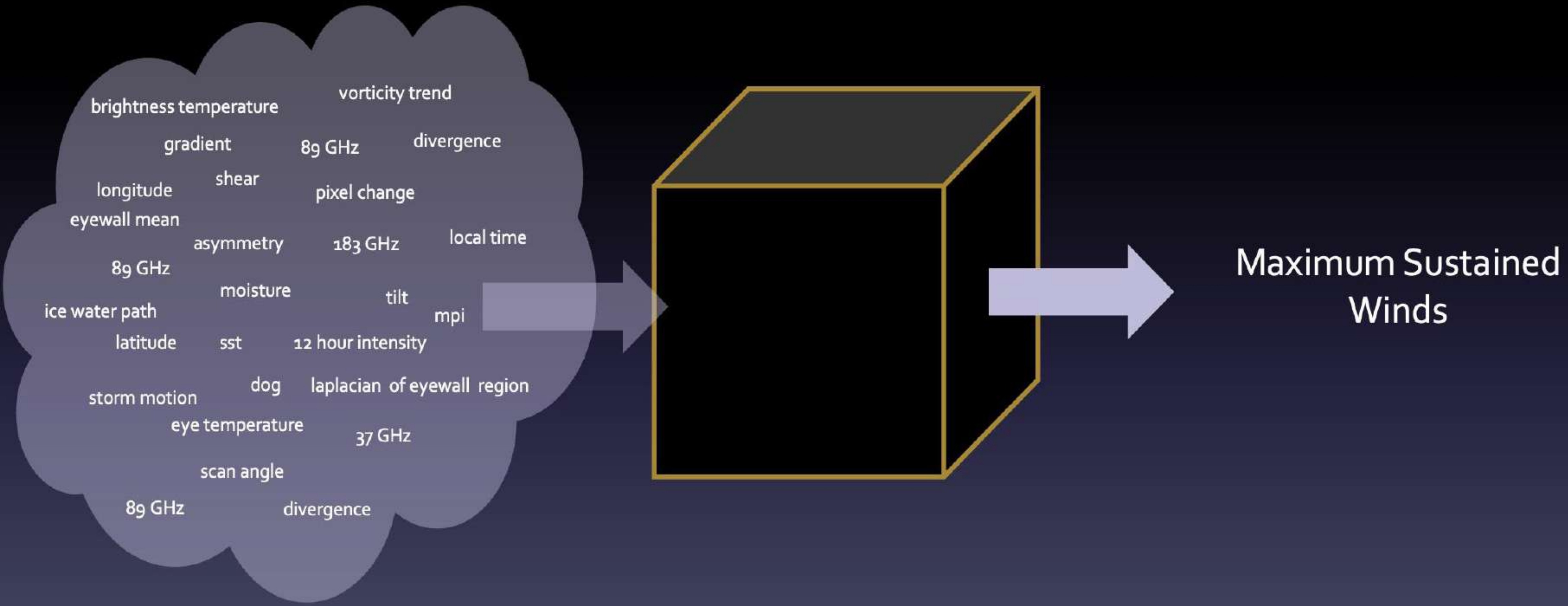
897 Total

- 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

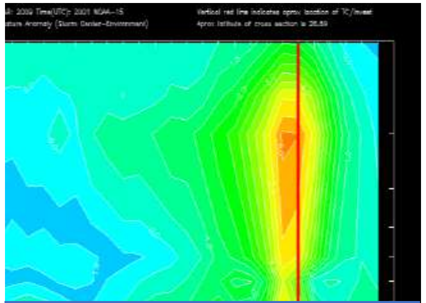


The Black Boxiness of AI Algorithms

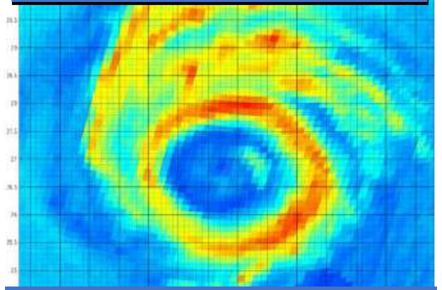


Approaches for Estimating Tropical Cyclone Intensity

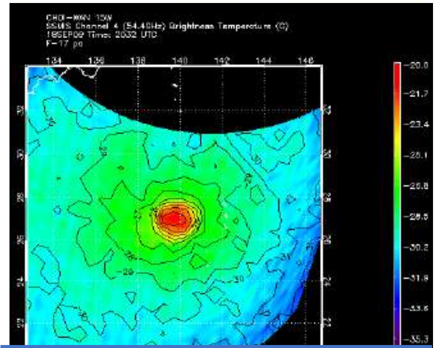
The more data sources the better! But which one to pick??


Advanced Microwave Sounding Unit (53-55 Ghz)

35 M/S

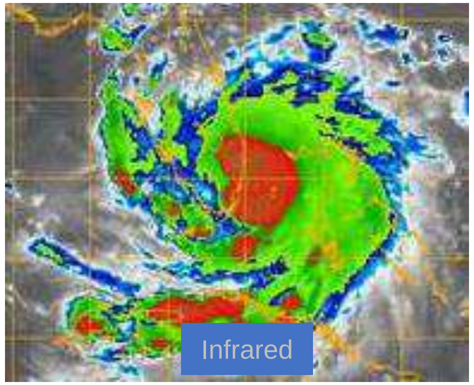

Special Sensor Microwave Imager (91 Ghz)

44 M/S

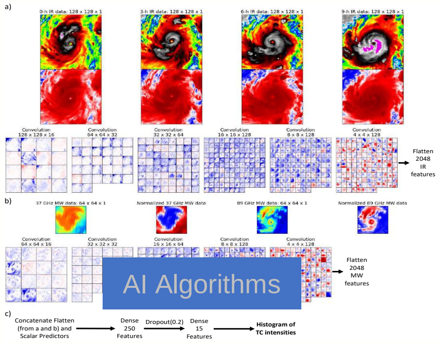

Special Sensor Microwave Sounder (54 Ghz)

48 M/S

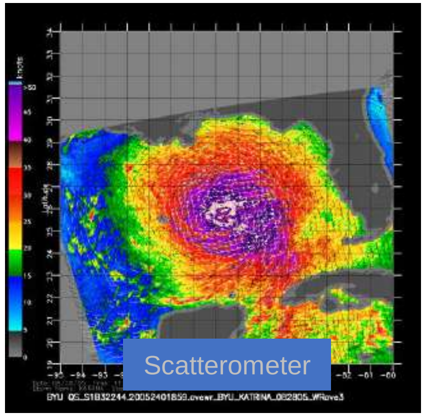
?


Infrared

31 M/S


AI Algorithms

40 M/S

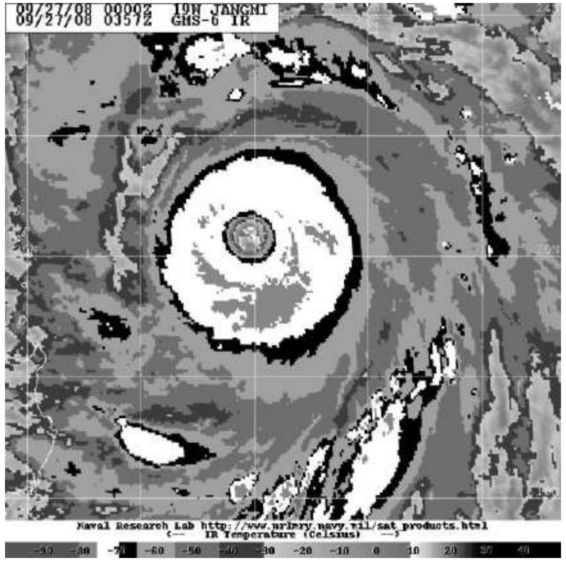

Scatterometer

28 M/S

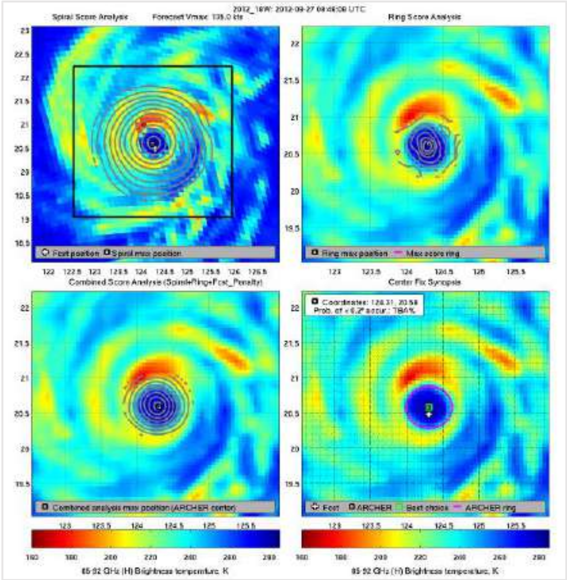
Approaches for Estimating Tropical Cyclone Intensity

SATellite CONsensus (SATCON)

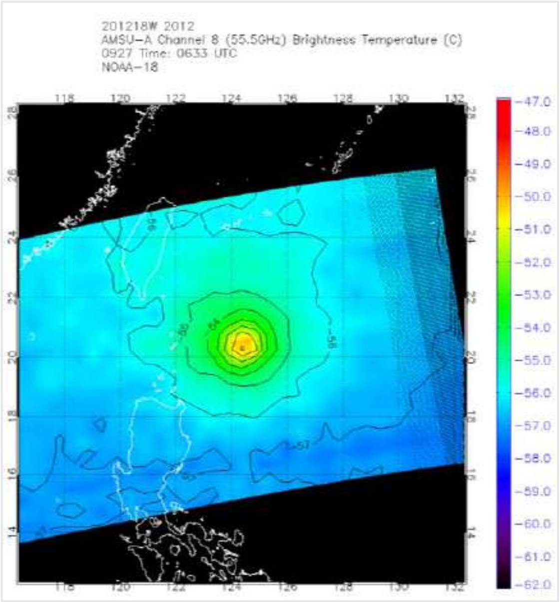
- In order to account for storms with different structures an “all the above” approach is needed.
- Multiple satellite scanning strategies (Geo/LEO)
- Multiple channels to measure the various TC features that are related to intensity. (subjective/objective)
- Used to assist forecasters at global warning agencies and inform changes to the best track



Geostationary
(G-16/G-18/H9)
- Intensity
- Position
- Structure



MW Imager
(AMSR2, GMI, SSMIS)
- Intensity
- Position
- Structure



MW Sounder
(AMSU, SSMIS, ATMS)
- Intensity
- Structure

Approaches for Estimating Tropical Cyclone Intensity

SATellite CONsensus (SATCON)

Current SATCON members

- LEO microwave sounder based
  - D-MINT (Passive mw AI member)
  - AMSU (Channels 6-8 and 16)
    NOAA-15,-16,-18,-19 (N16 AMSU-A failure 2014)
    Metop A-C (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)
    Used when eye > 40km
- GEO IR imager based
  - ADT/AIDT

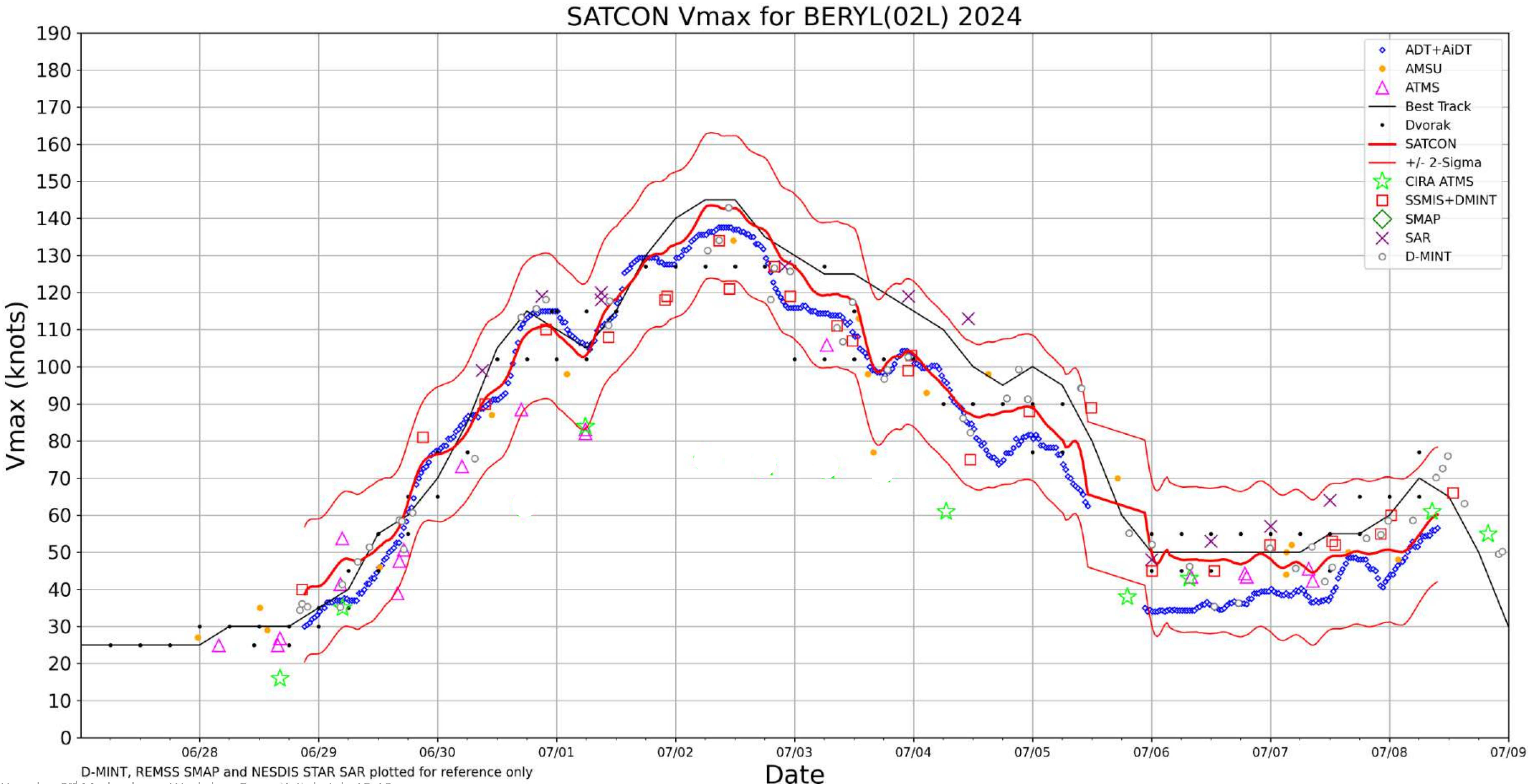
Also Displayed

- Warning agency BT
- SMAP
- SAR
- Dvorak Estimates

CIMSS ARCHER is not a member but contributes storm eye and structure information.

Approaches for Estimating Tropical Cyclone Intensity

SATellite CONsensus (SATCON)



Applications to Medicanes

Formal collaboration between UW-CIMSS and CNR-ISAC (Giulia Panegrossi) to improve analysis tools for Medicane analysis and forecasting established in 2023 through **COST Action Medcyclones CA19109**

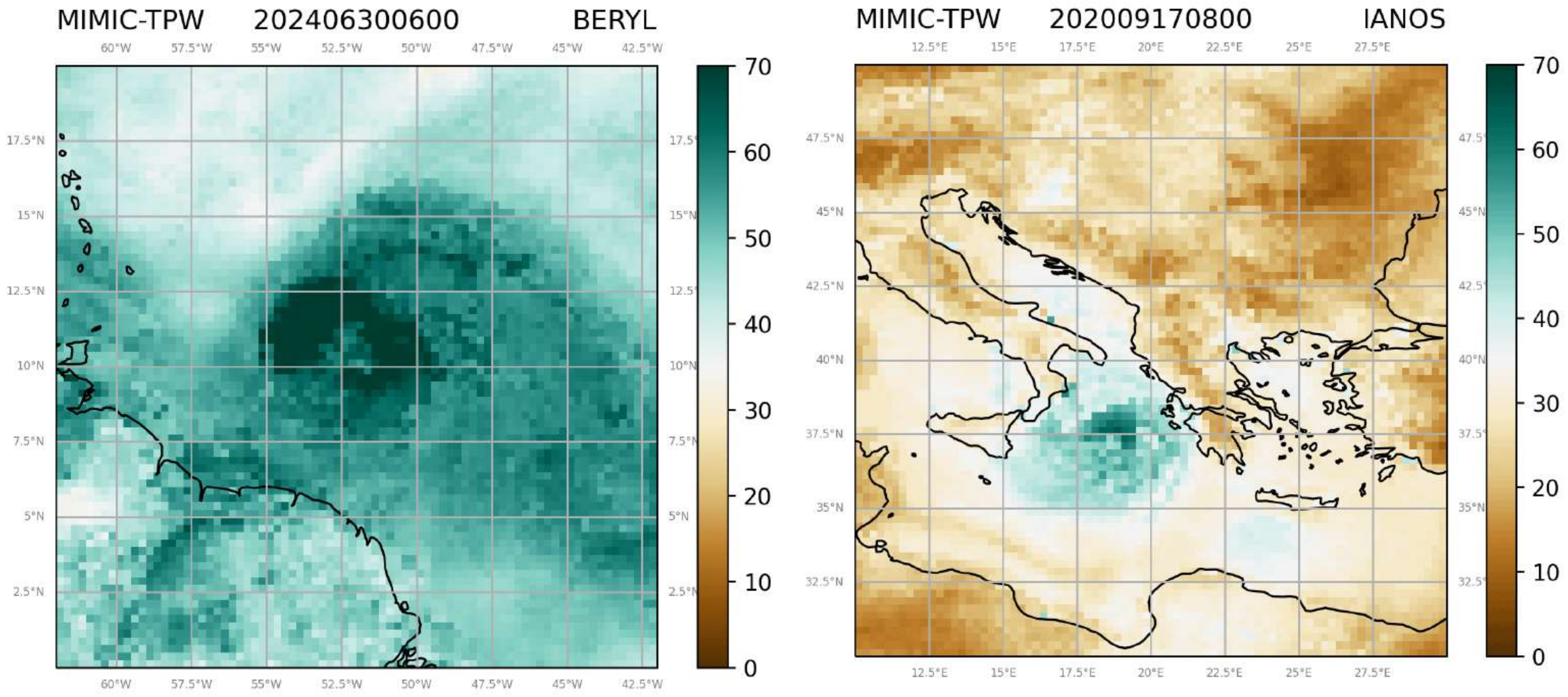
- Including sounder-based warm core observations in Medicanes
- Transition of ARCHER automated storm position
- CIMSS MIMIC-TPW
- AI-based tools

Challenges:

- Medicanes are on average smaller than TCs thus many of the under-sampling issues associated with passive microwaves can be aggravated
- Substantial data development process for analysis of Medicanes and non Medicane cases
- Algorithms were trained on TCs and may not always directly transfer to Medicanes
- Small number of Medicanes relative to non-Medicanes could make algorithms like Machine Learning binary classifier difficult

Applications to Medicanes

Comparison of Total Precipitable Water (TPW) environment for Hurricane Beryl and Medicane Ianos

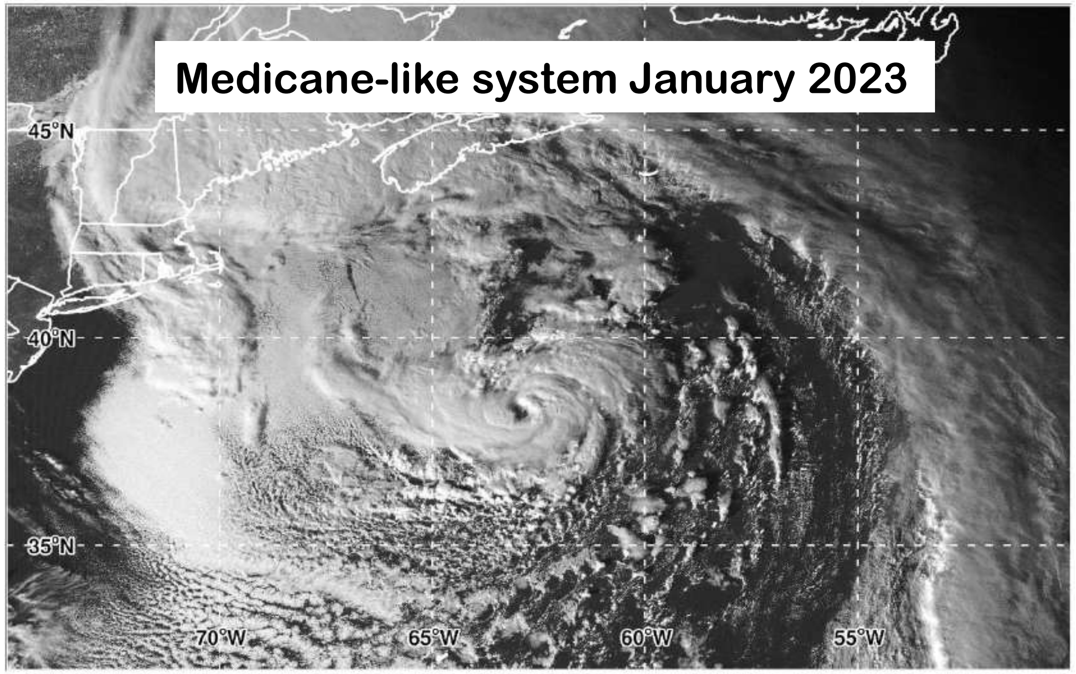


Applications to Medicanes

NATIONAL HURRICANE CENTER
TROPICAL CYCLONE REPORT

UNNAMED SUBTROPICAL STORM
(AL012023)
16–17 January 2023

Philippe P. Papin, John P. Cangialosi, and John L. Beven
National Hurricane Center
6 July 2023



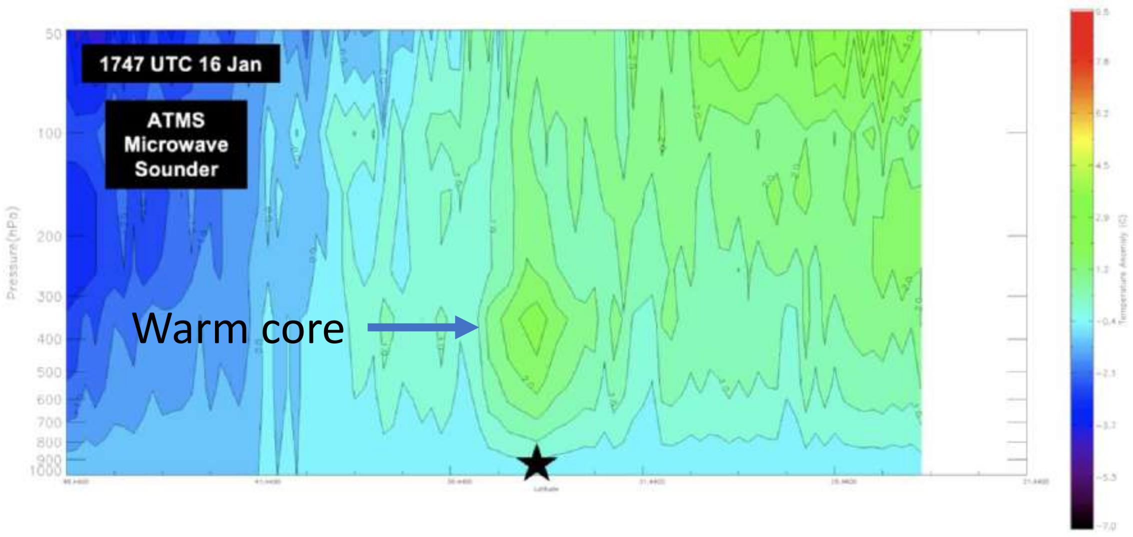
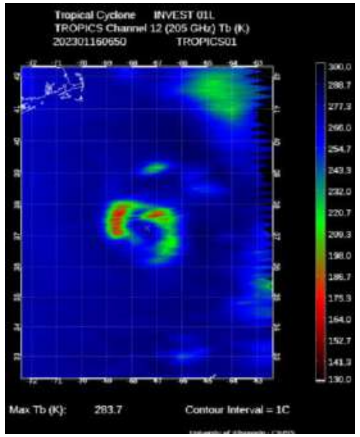
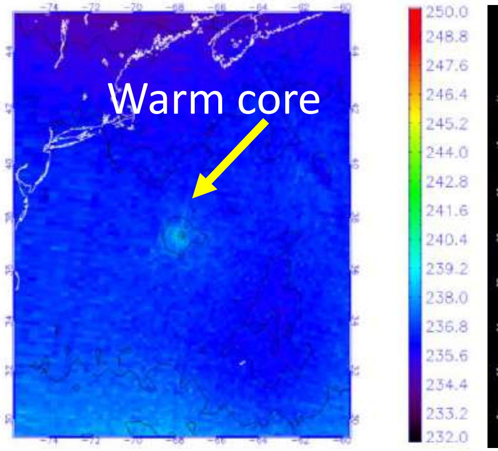


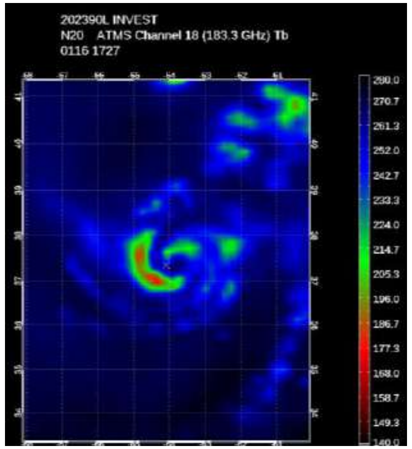
Figure 9. Advanced Microwave Sounder Unit temperature anomaly north (left) – south (right) cross section at 1747 UTC 16 January 2023. The black star denotes the center of the Unnamed Subtropical Storm at the time the cross-section was available. Adapted image courtesy of the Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin.



TROPICS Ch12 205 GHz

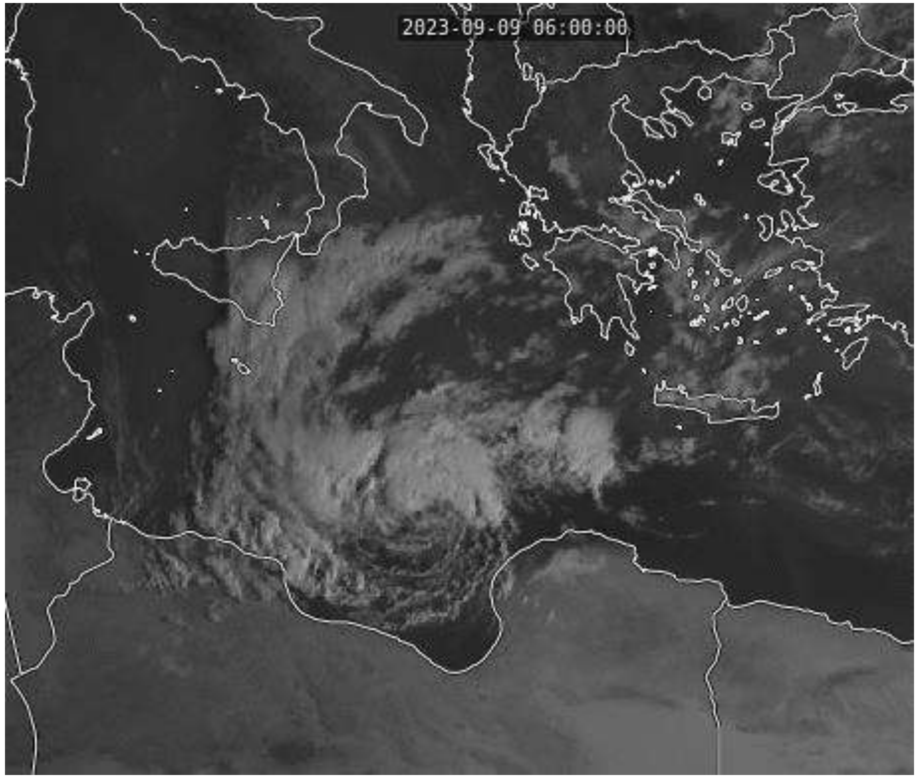


ATMS Channel 7



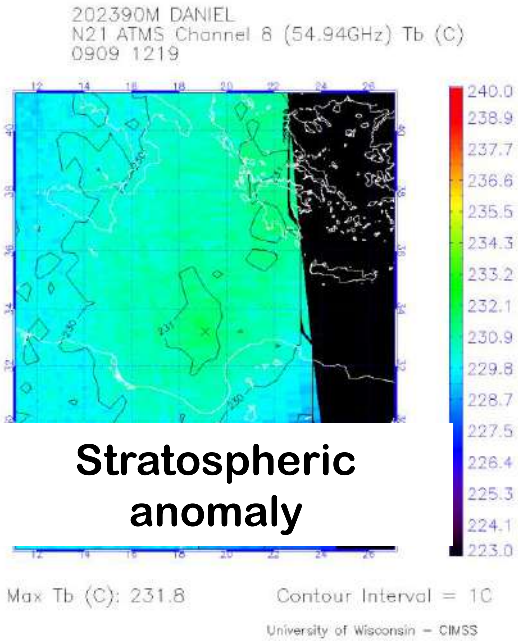
ATMS Channel 18

Applications to Medicanes

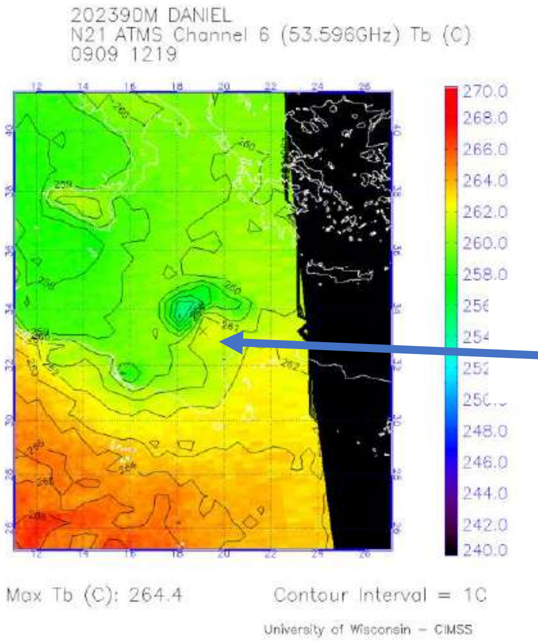


Medicane Daniel 2023
Deep convective banding suggests transition to more tropical ~ 45 knots

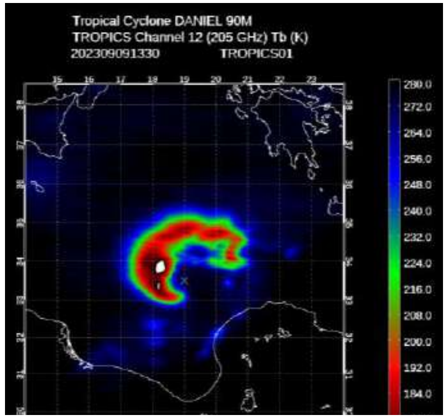
ATMS temperature CH8



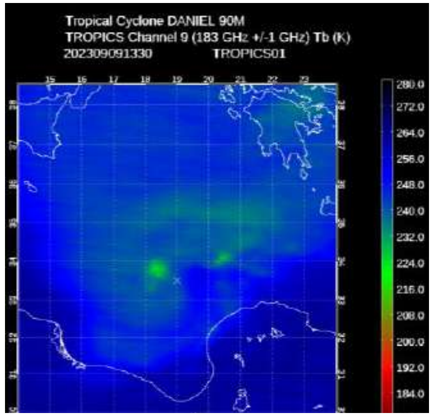
Stratospheric anomaly



Nascent warm core

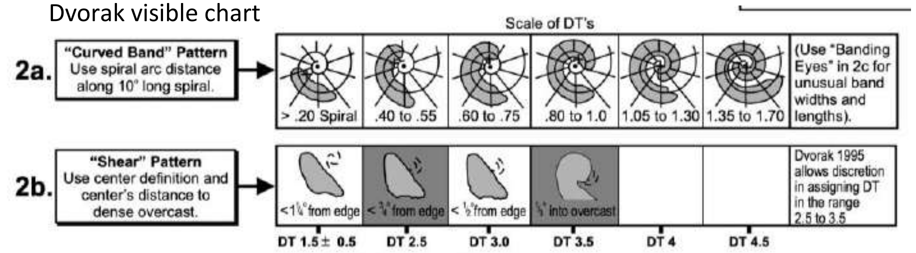


TROPICS Channel 12 ~ 2 km



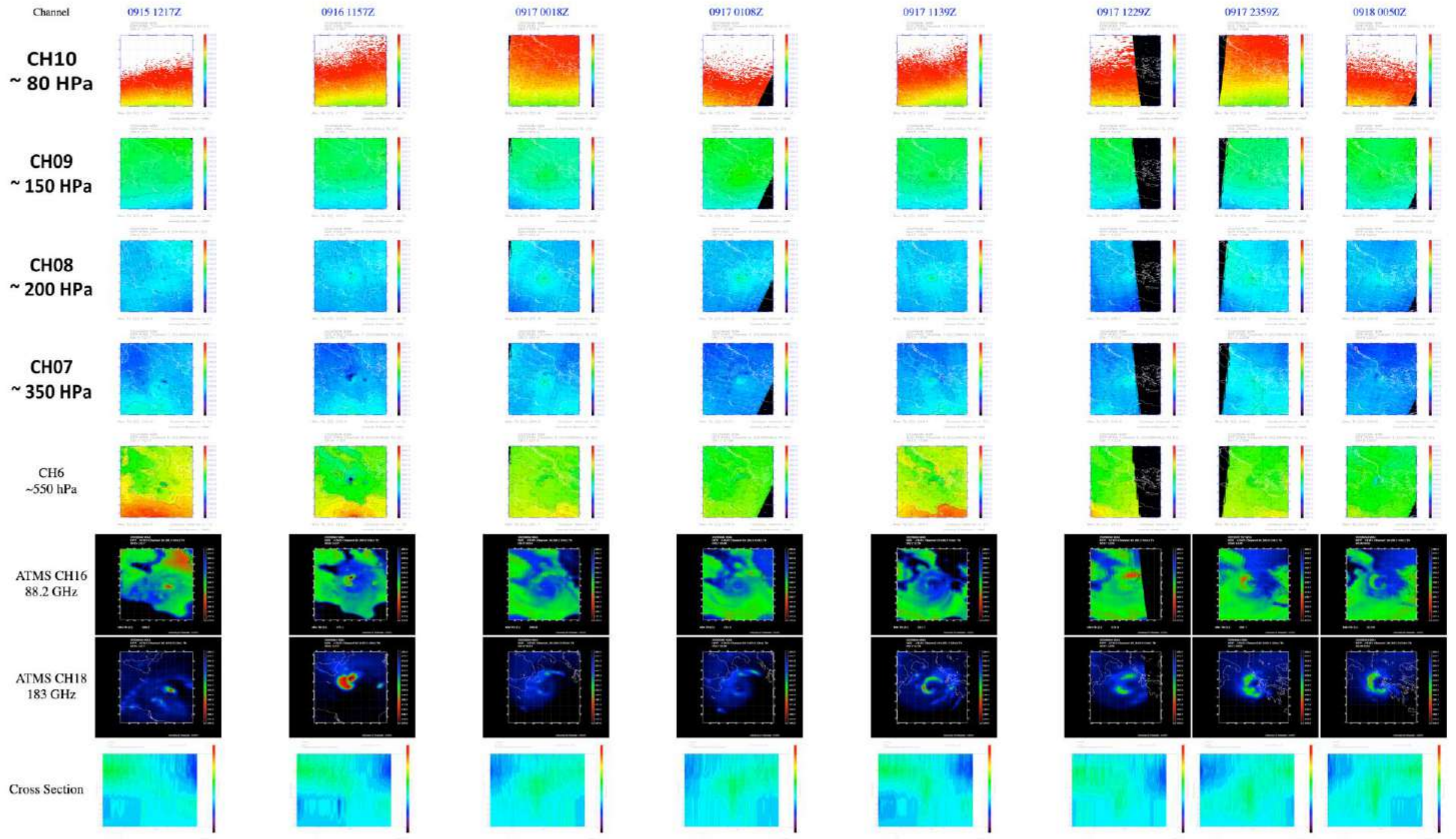
TROPICS Channel 9 ~ 8 km

Dvorak visible chart



Applications to Medicanes

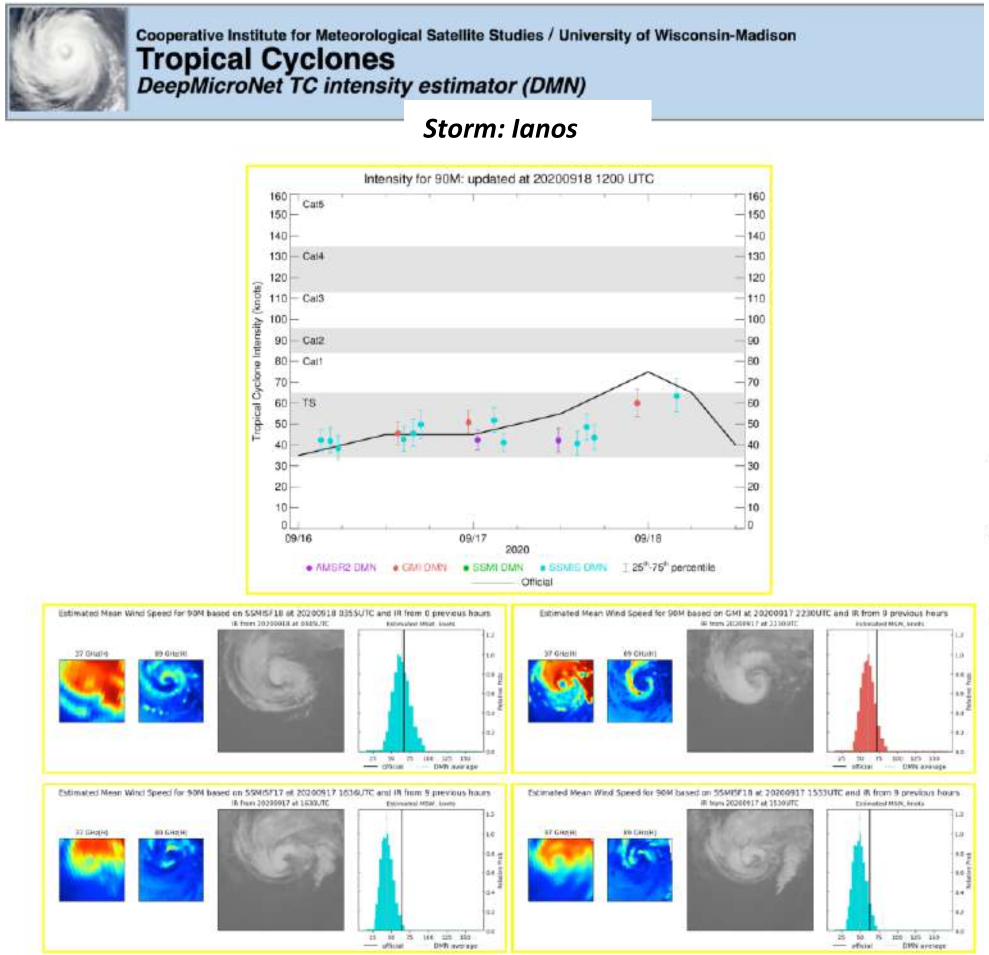
ATMS Imagery Matrix for Medicane Ianos



https://tropic.ssec.wisc.edu/real-time/amsu/amsu_medicanes.html

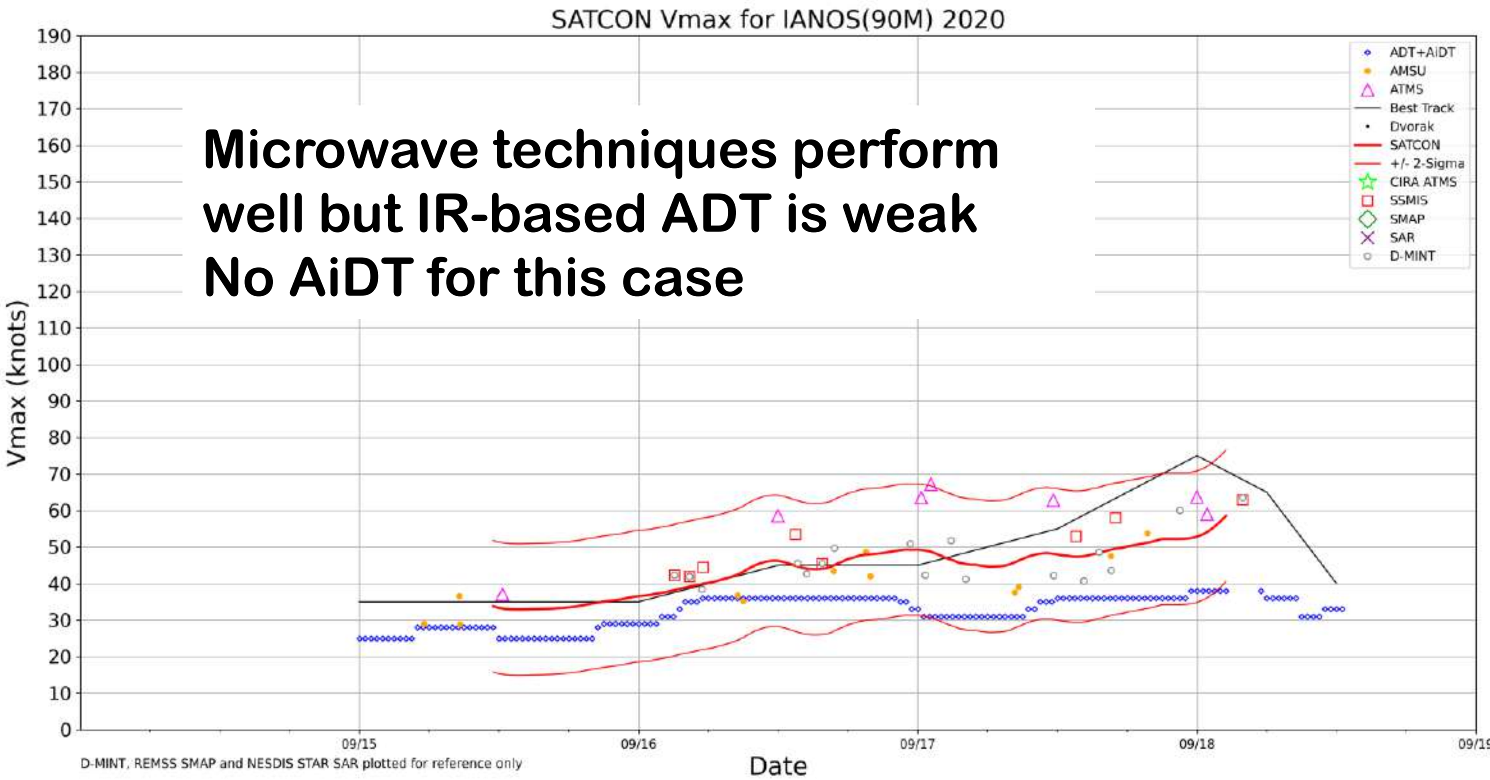
Applications to Medicanes

D-MINT Application of CNN for estimating intensity of Medicane Ianos



CIMSS-CNR SATellite CONsensus (SATCON) for Ianos

Microwave techniques perform well but IR-based ADT is weak
No AiDT for this case



Applications to Medicanes

CIMSS TROPICAL CYCLONE INTENSITY CONSENSUS FOR IANOS (90M) 2020

CURRENT ESTIMATE
Date (mmddhhmm): 09180050
SATCON: MSLP = 982 hPa   MSW = 58 knots
SATCON Member Consensus: 57.0 knots
Pressure -> Wind Using SATCON MSLP: 61 knots
Distance to Outer Closed Isobar Used is 170 nm
Eye Size Correction Used is -4.0 knots   Source: IR

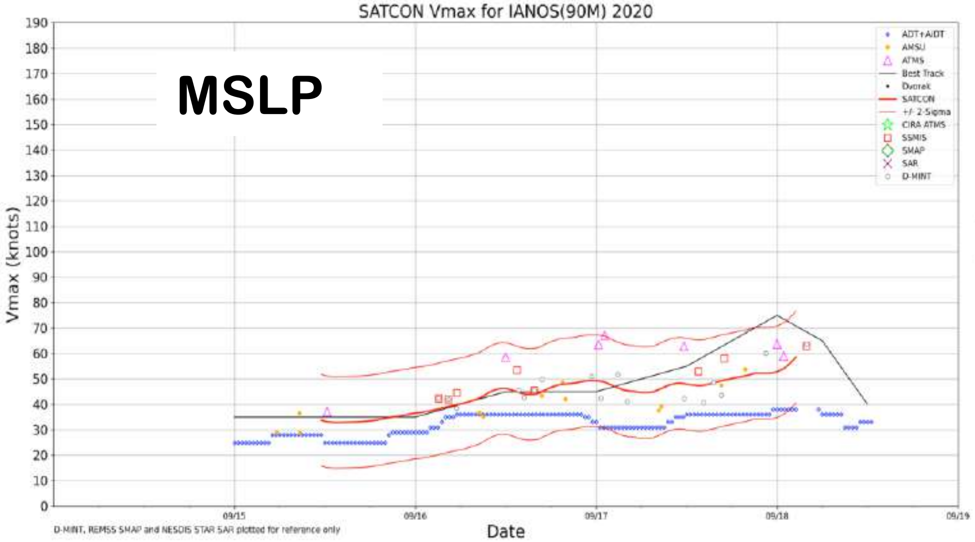
Current Intensity Estimate and member contributions

Member Estimates

ADT: 1004 hPa   38 knots   Scene: CDO   Date: SEP180230
CIMSS AMSU: 990.4 hPa   53.8 knots   Bias Corr: 0 (MW)   Date: 09171944
ATMS: 985.1 hPa   59.0 knots   Date: 09180050
SSMIS: 985.1 hPa   59.0 knots   Date: 09180050
CIRA ATMS: hPa   knots   Date:

SATCON HISTORY FILE for 2020 90M IANOS

SATCON MSW plot including pressure-wind contribution

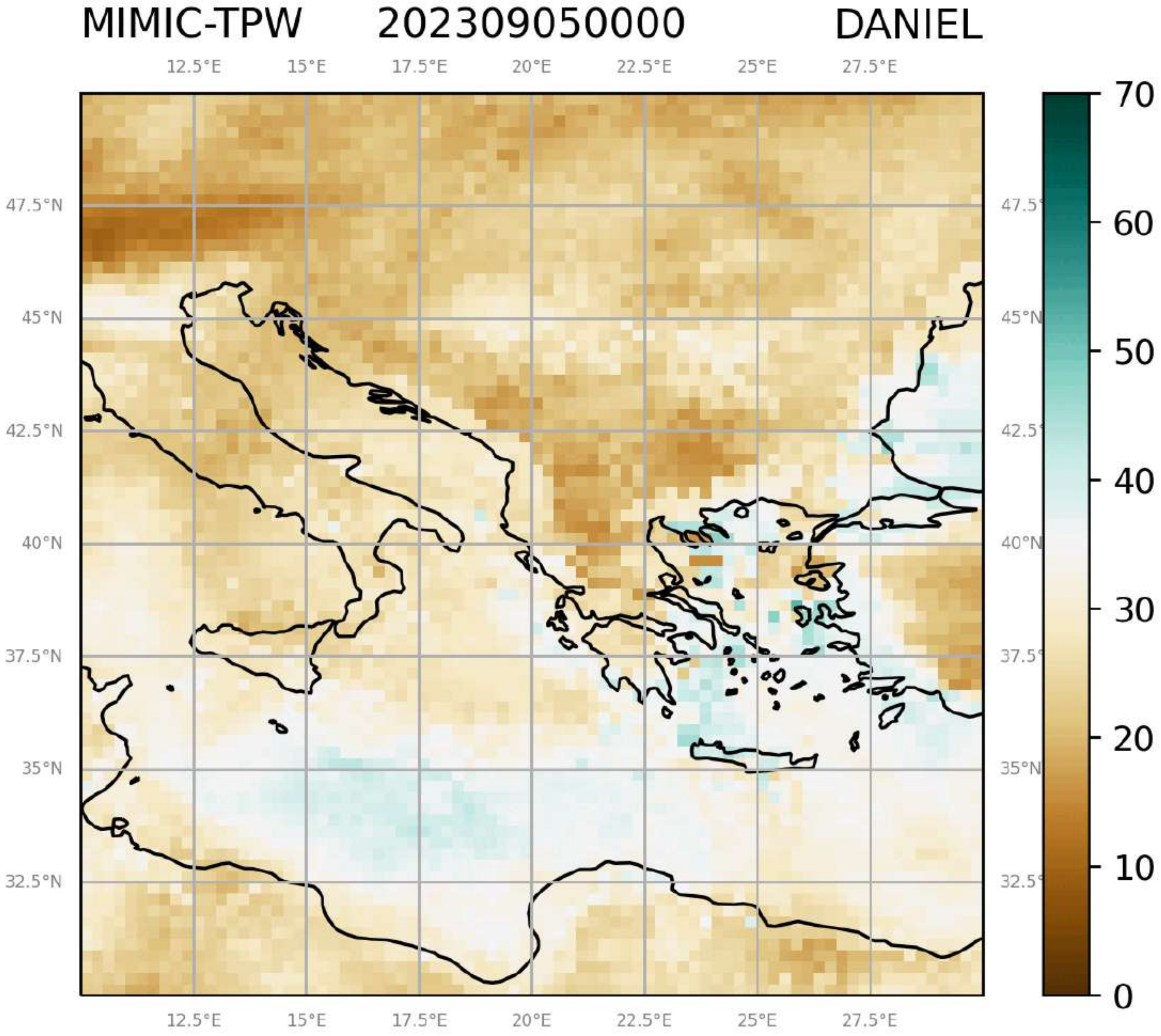


Return to SATCON Page

CIMSS AMSU Page
CIRA TC Page
ADT HISTORY for 90M

Thank You!

Applications to Medicanes



Medicane Daniel 2023
Total Precipitable Water evolution
Sep 5-10

References

Blackwell, William J.; Braun, S. A.; Bennartz, R.; Velden, C. S.; Greenwald, T.; Herndon, D. C.; DeMaria, M.; Chirokova, G.; Atlas, R.; Dunion, J. P.; Marks, F. D. Jr.; Rogers, R.; Annane, B. and Christophersen, H.. **Overview and performance simulations of the NASA TROPICS CubeSat constellation mission**. Boston, MA, American Meteorological Society, 2018, Abstract 11D.2

Herndon, Derrick. **Tropical cyclone warm core structures as observed by recent high-altitude aircraft and satellites**. Boston, MA, American Meteorological Society, 2016, Abstract 18A.1.

Herndon, Derrick and Velden, C. S.. **Upgrades to the UW-CIMSS AMSU-based tropical cyclone intensity algorithm**. Boston, MA, American Meteorological Society, 2006, Abstract 4B.5

Derrick C. Herndon, CIMSS, Madison, WI; and C. S. Velden, J. D. Hawkins, T. L. Olander, A. T. Wimmers, and S. Griffin. “From Vern's Vision to Computer Vision: The Evolution of Tropical Cyclone Intensity Estimation from Satellite Data” 104th AMS Annual Meeting January 28 - February 1 Baltimore, MD

Herndon, D and Langlade, S. Tenth International Workshop on Tropical Cyclones (IWTC-10). Topic 1 - Remote sensing for tropical cyclones analysis. 2022

Olander, Timothy; Wimmers, Anthony; Velden, Christopher and Kossin, James P. **Investigation of machine learning using satellite-based advanced Dvorak technique analysis parameters to estimate tropical cyclone intensity.** Weather and Forecasting, Volume 36, Issue 6, 2021, 2161�2186. Reprint # 8748

Julie Price, D. Herndon 2018: Satellite-Based Tropical Cyclone Intensity Estimation With a New Satellite Generation. JPSS Science Digests.

Velden, Christopher S. and Herndon, Derrick. **A consensus approach for estimating tropical cyclone intensity from meteorological satellites: SATCON**. *Weather and Forecasting*, Volume: 35, Issue: 4, 2020, pp.1645-1662. Reprint # 8611

Velden, Christopher S.; Olander, T. L.; Herndon, D. C. and Kossin, J. P.. **Reprocessing the 'top ten' most intense historical tropical cyclones in the satellite era using the Advanced Dvorak Technique**. Boston, MA, American Meteorological Society, 2016, Abstract 63

Wimmers, Anthony; Velden, Christopher and Cossuth, Joshua H. **Using deep learning to estimate tropical cyclone intensity from satellite passive microwave imagery.** Monthly Weather Review, Volume 147, Issue 6, 2019, pp.2261-2282. Reprint # 8393