



# NOAA Updates on Science and Technology

*New Innovations from the National  
Hurricane Center*

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Workshop Session 146



# Outline

- **Overview of the Hurricane and Ocean Testbed (HOT)**
- **AI Weather Prediction (AIWP) activities at NHC**
- **Other AI-based Applications at NHC**
- **The Next Generation Wind Speed Probability Model**

# TC Risk Communication Value Chain

**Today's Focus:** Updates on tools used by NHC forecasters in the forecast process and new science and technology for products

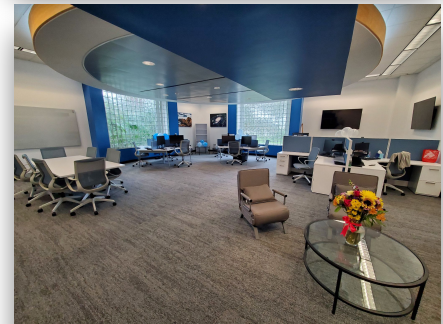


A background image showing a view of Earth from space, with the planet's surface and atmosphere visible against the dark void of space filled with stars. A semi-transparent blue rectangle is overlaid on the center of the image.

# **Overview of the Hurricane and Ocean Testbed (HOT)**

# The Hurricane and Ocean Testbed (HOT)

- The HOT is a framework for constantly improving the R2O process and NWS mission execution for tropical cyclone hazards
  - **Physical Space:** Lapenta Lab at NHC
  - **Technical Infrastructure:** cloud-based sandbox environments
  - **People:** Operations, Labs, Cooperative institutes, Academia, private sector
- Success is defined by constantly and measurably improving the toolkit for NHC forecasters
- Are we protecting life and property from TC hazards better today than we did yesterday?

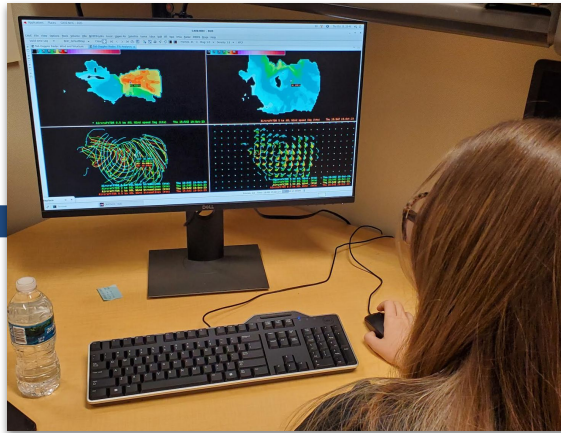


# R2O in a Nutshell – TDR Example

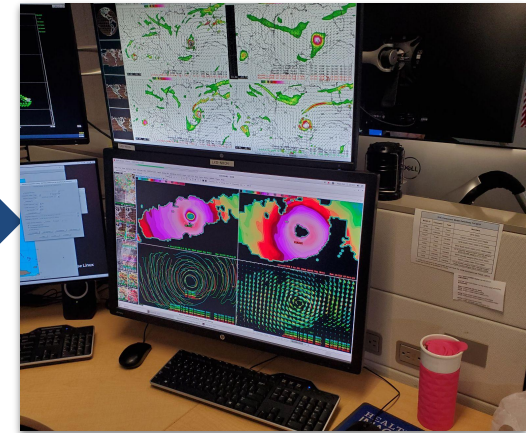
Hackathon / Prototyping



Development / Iteration

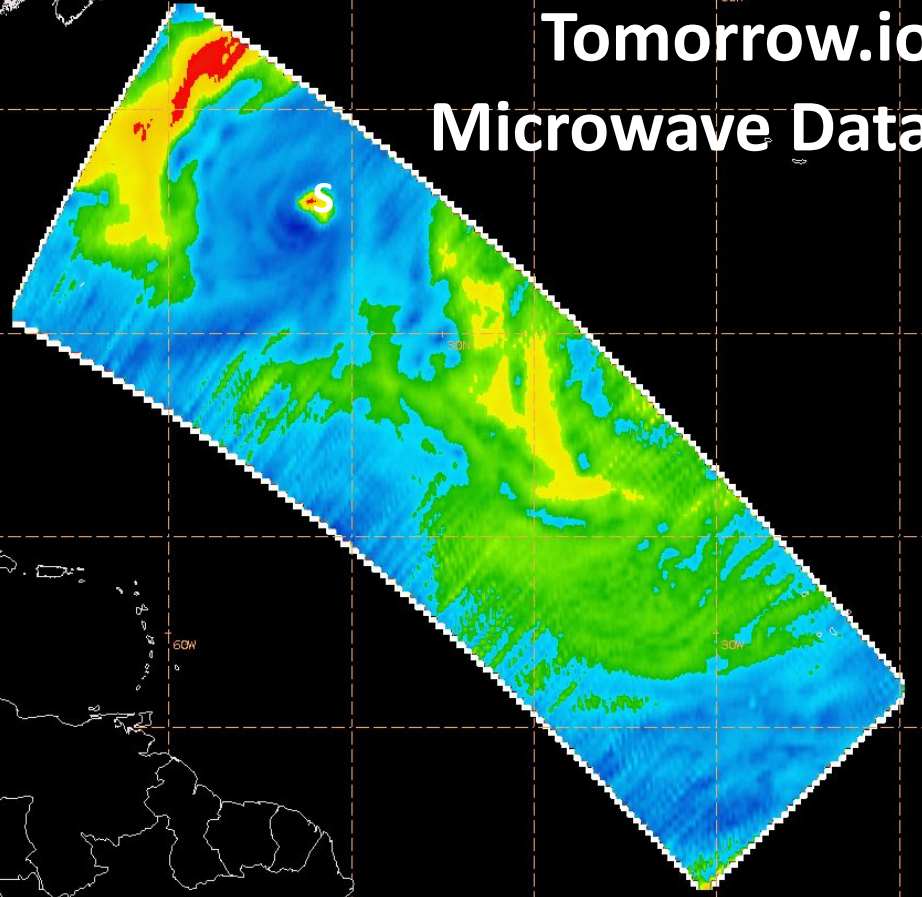
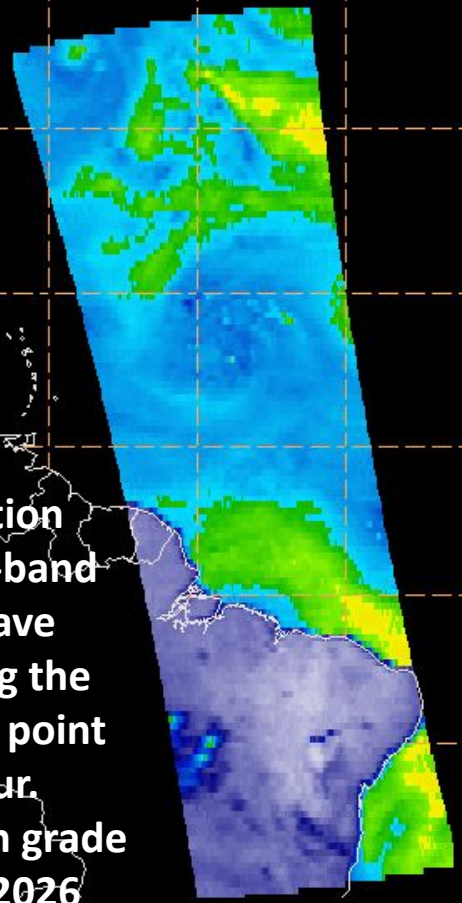


Operations



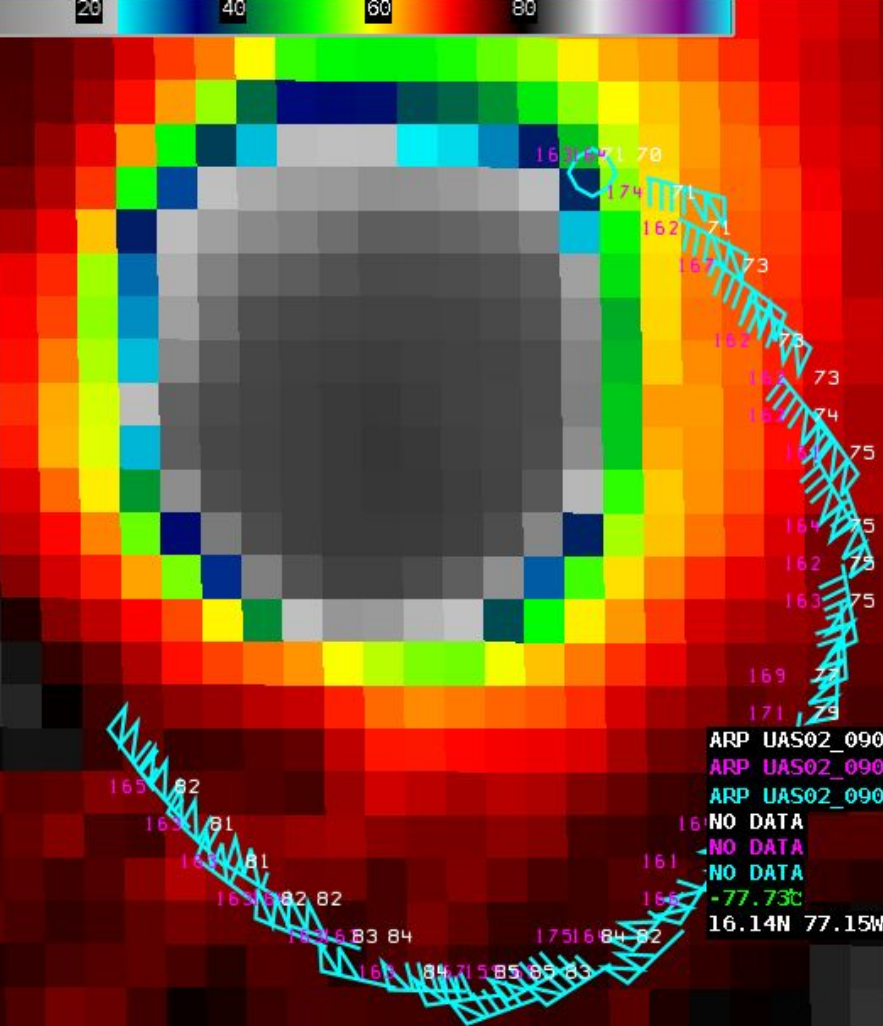
# Tomorrow.io Microwave Data

Satellite constellation equipped with Ka-band radar and microwave sounders achieving the ability to scan any point on Earth every hour. Deemed operation grade by NOAA in early 2026



Tomorrow-S05 TMS 91 GHz Brightness Temp (K)  
\* Tomorrow-S07 TMS 91 GHz Brightness Temp (K)

Tomorrow-S07 TMS 91 GHz Brightness Temp (K) Wed 07:08Z 24-Sep-25  
Tomorrow-S06 TMS 91 GHz Brightness Temp (K) Wed 07:09Z 24-Sep-25  
Tomorrow-S05 TMS 91 GHz Brightness Temp (K) Wed 07:07Z 24-Sep-25  
\* Tomorrow-S02 TMS 91 GHz Brightness Temp (K) Wed 07:04Z 24-Sep-25



# UAS Blackswift

Designed to be air-deployed from the NOAA P-3 Hurricane Hunter. These drones can fly into the low-level, high-wind environments of a tropical cyclone to capture critical real-time data on wind, temperature, and pressure.

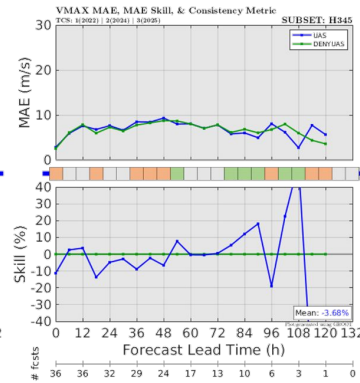
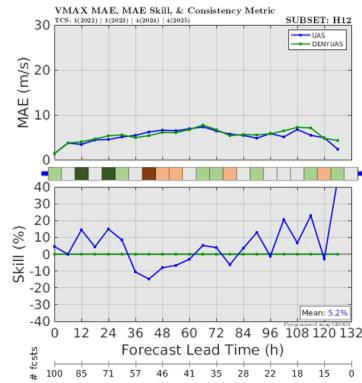
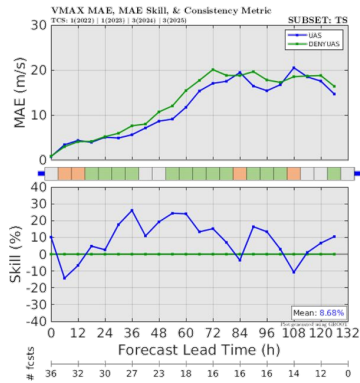
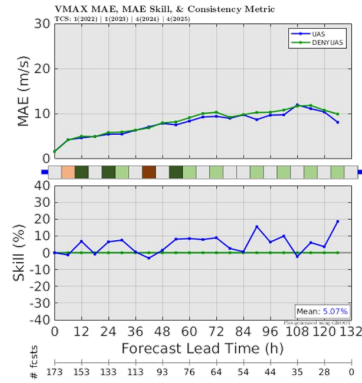
ARP UAS02\_090917 16.150N 77.150W 2343 F166 P81 227/99KT  
 ARP UAS02\_090917 16.150N 77.150W 2343 F166 P81 227/99KT  
 ARP UAS02\_090917 16.150N 77.150W 2343 Height:1660' 505m P81 227/99KT

16 NO DATA  
 16 NO DATA  
 16 NO DATA  
 16 -77.73C  
 16.14N 77.15W 0.00

UAS Recon	ExtPres	Mon 00:00Z	27-Oct-25
UAS Recon	SFMR	Mon 00:00Z	27-Oct-25
UAS Recon	Wind	Mon 00:00Z	27-Oct-25
NOAA Recon	ExtPres	Mon 00:00Z	27-Oct-25
NOAA Recon	SFMR	Mon 00:00Z	27-Oct-25
* NOAA Recon	Wind	Mon 00:00Z	27-Oct-25
GOES-19	EMES0-2	CH-14-11.20um	Sun 23:59Z 26-Oct-25



# UAS Impacts on HAFS - Preliminary

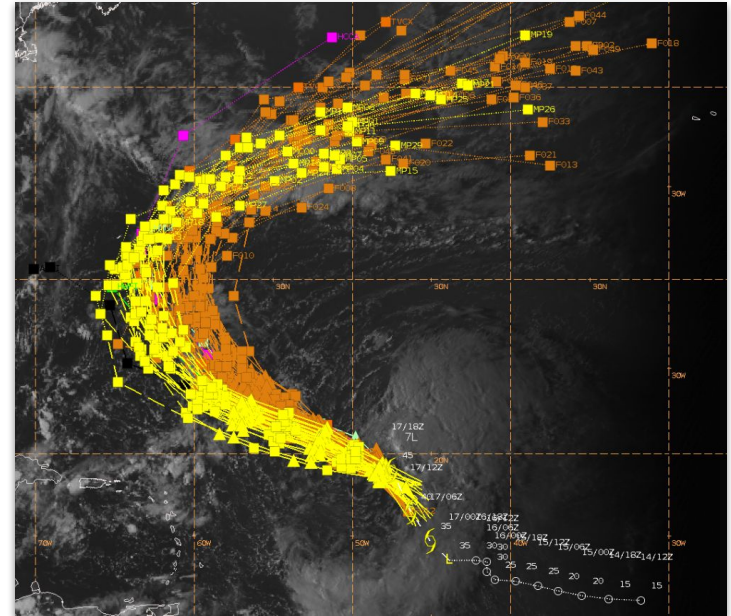


The background of the slide is a composite image. On the left, there is a view of Earth from space, showing the curvature of the planet and the atmosphere. The rest of the background is a dark blue space filled with numerous small, white stars of varying brightness. A large, semi-transparent blue rectangle is centered on the slide, containing the title text.

# **AI Weather Prediction (AIWP) at NHC**

# Accelerating AI Integration into Operations

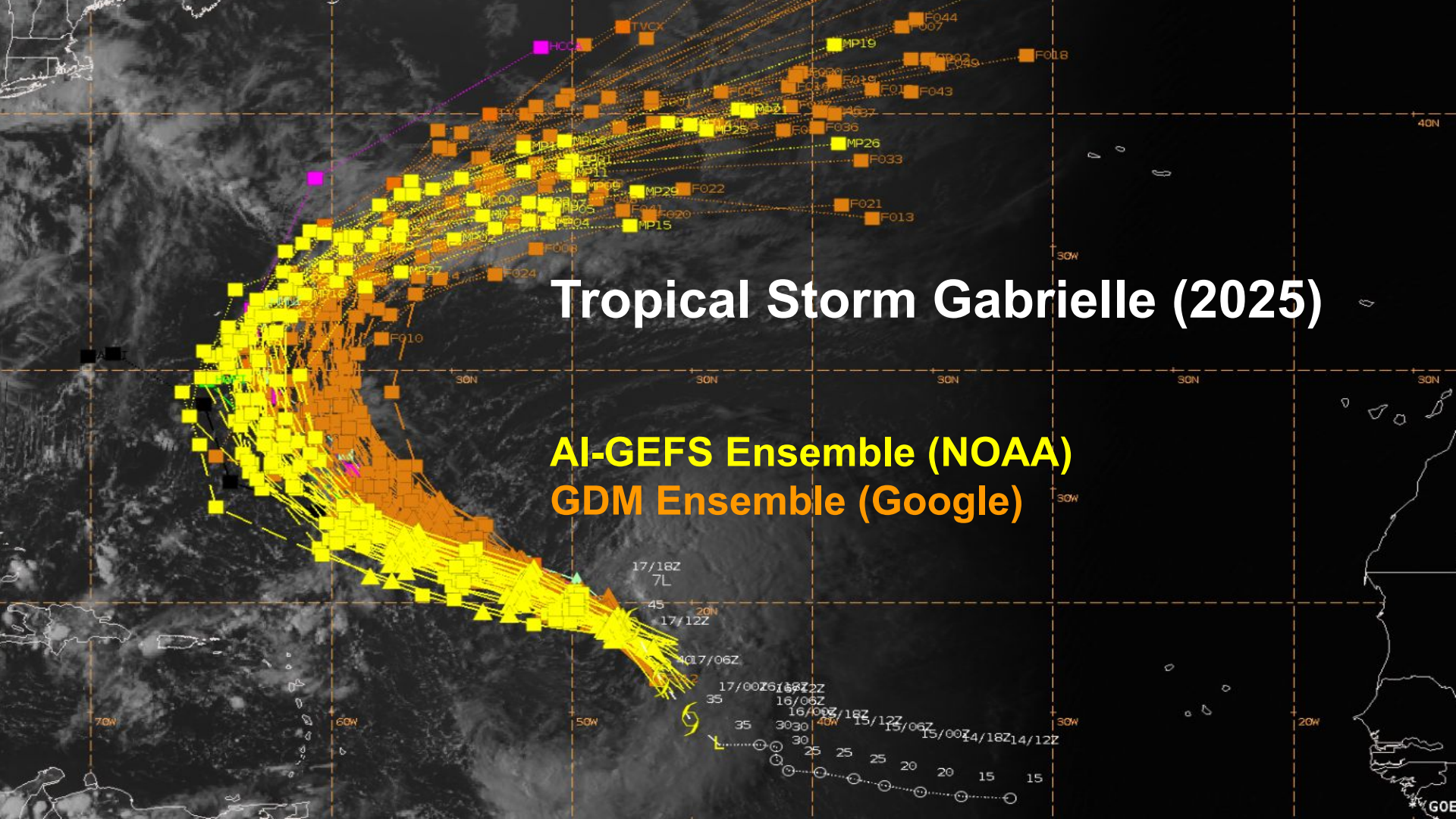
- NHC has been leveraging “simple” AI-based forecast guidance operationally for decades
- NHC is now accelerating efforts to evaluate and integrate new AIWP capabilities
- Private sector is playing an important role in model development and innovation, suggesting an increasing role for public-private engagement
- In 2025, NHC integrated AI weather prediction (AIWP) into operational workflows for the first time:
  - Google, NOAA, ECMWF models
  - AIWP-based tools developed by NHC staff



TS Gabrielle (2025): Google DeepMind and NOAA AI-GEFS Ensembles in cloud AWIPS

# Tropical Storm Gabrielle (2025)

AI-GEFS Ensemble (NOAA)  
GDM Ensemble (Google)



# AIWP Timeline at NHC

## R&D (2022-2024)

### Learning:

TC track skill demonstrated by ECMWF and private sector companies

NHC begins collaborations to leverage AI for TCs: CIRA, ECMWF, Google, NOAA EMC

## R2O (2024-2025)

### Begin Experimenting:

NHC begins collaborating with Google DeepMind

ECMWF and Google release first AIWP ensemble systems

NOAA announces Project EAGLE (AI-GFS, AI-GEFS, HGEFS)

NSF-funded project to design "AI-ready" Hurricane and Ocean Testbed (HOT)

## Operations (2025)

### Experimental Implementation:

Entered into CRADA with Google – close collaboration on data integration and validation

AIFS, Google, and AI-GEFS available for NHC forecasters:

1. Google DeepMind in ATCF
2. ECMWF AIFS fields in AWIPS
3. AI-GEFS Ensemble in ATCF

2025 NHC verification report will document AIWP model performance for the first time

## Future (2026+)

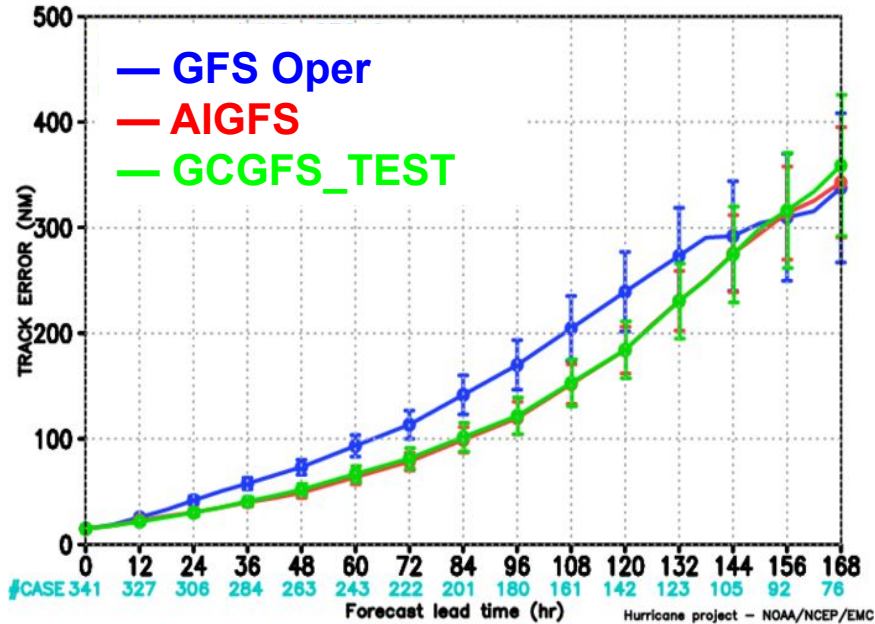
### Full Operational Integration:

Next steps include:

1. AIWP and hybrid consensus techniques for 2026
2. AI Ensemble post-processing
3. Continued close collaboration with GDM, CIRA, EMC and others

# AI-GFS Evaluation: Tropical cyclones

MODEL FORECAST – TRACK ERROR (NM) STATISTICS  
VERIFICATION FOR ATLANTIC BASIN 2021–2024



Track error in NATL

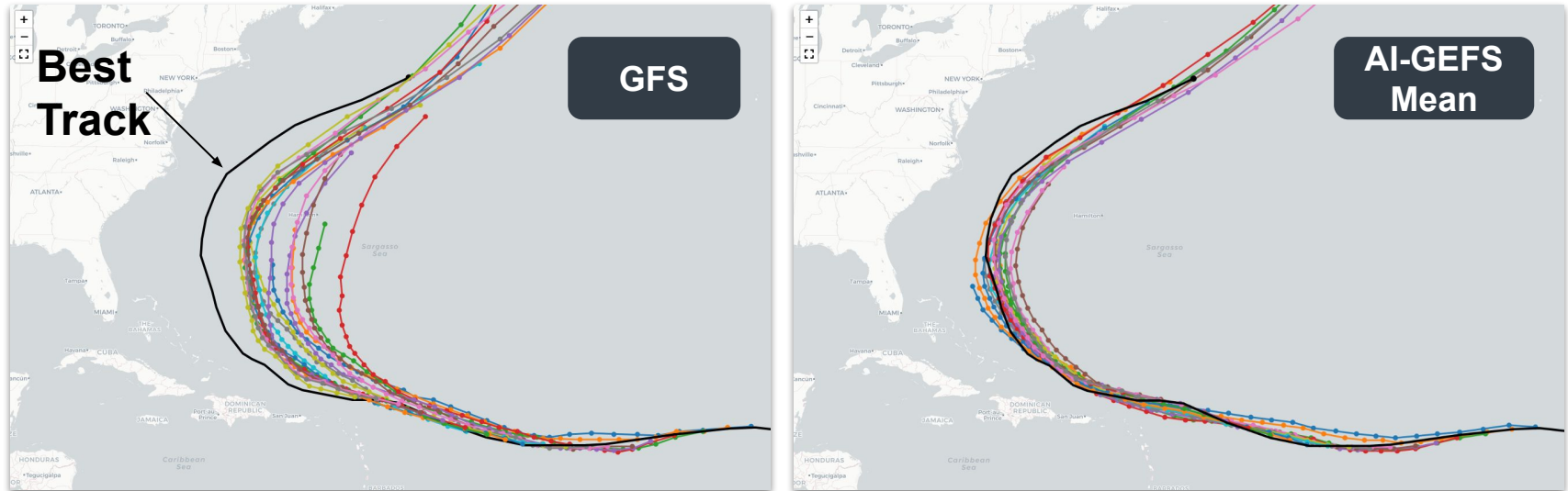
**AI-based GFS** model shows promise to improve track forecasts in the Atlantic Basin

NHC will continue evaluations during the 2026 season

Figure courtesy of NOAA/EMC

# Hurricane Erin: GFS & AI-GEFS

NOAA's AI-GEFS shows promise to improve track forecast guidance



Above: first 18 forecast cycles for Erin, out to 192h (Aug 12 00Z – Aug 16 06Z)

# NHC Partnership with Google

## Overview: NHC working directly with GDM

- Training Data
- Model verification
- Output formats
- Operational integration



**Joint Effort:** provide the best possible forecast guidance to support the NHC mission to protect life and property

***Hurricane Experts + AI Experts = rapid advances and impacts***

**NOAA and Google team up to advance the use of AI hurricane and tropical weather forecast models**

© Alexander Bukvich July 8, 2025 11:12 am

**The New York Times**

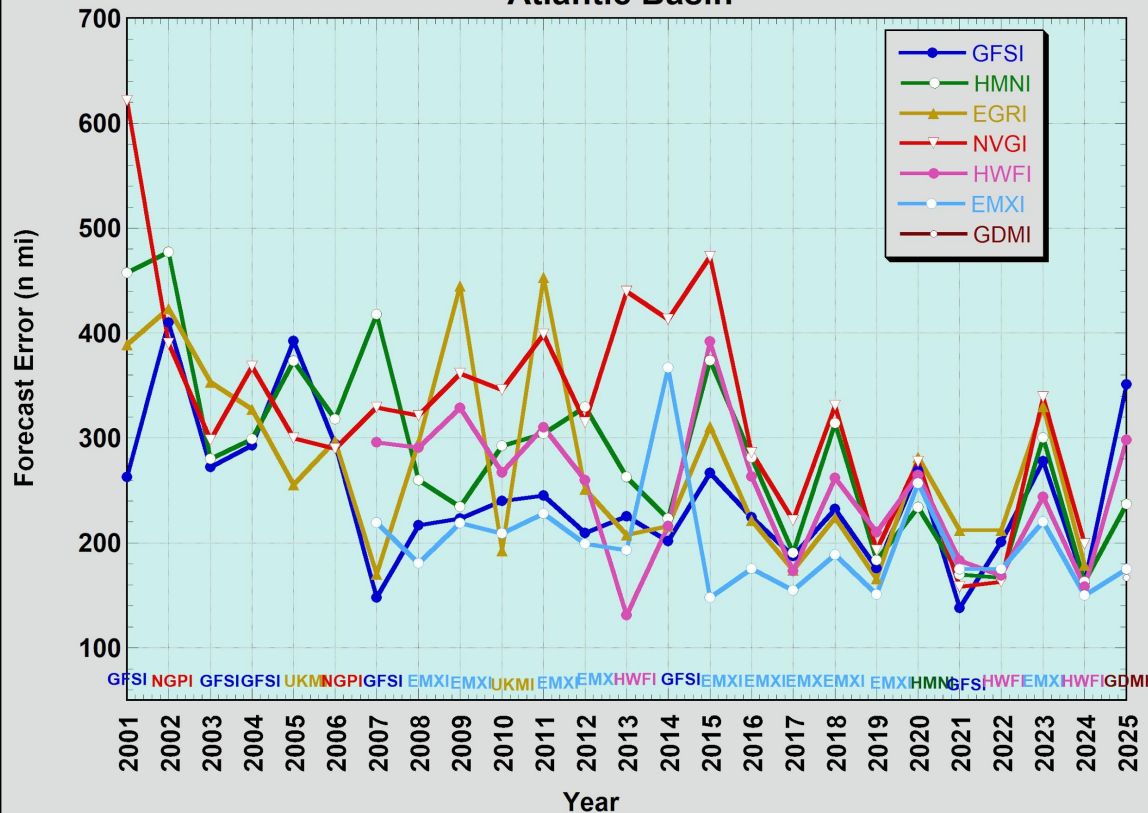
***Google and U.S. Experts Join on A.I. Hurricane Forecasts***

Google DeepMind

We're launching Weather Lab, featuring our experimental cyclone predictions, and we're partnering with the U.S. National Hurricane Center to support their forecasts and warnings this cyclone season.

# 5-day Annual Track Model Performance Trends

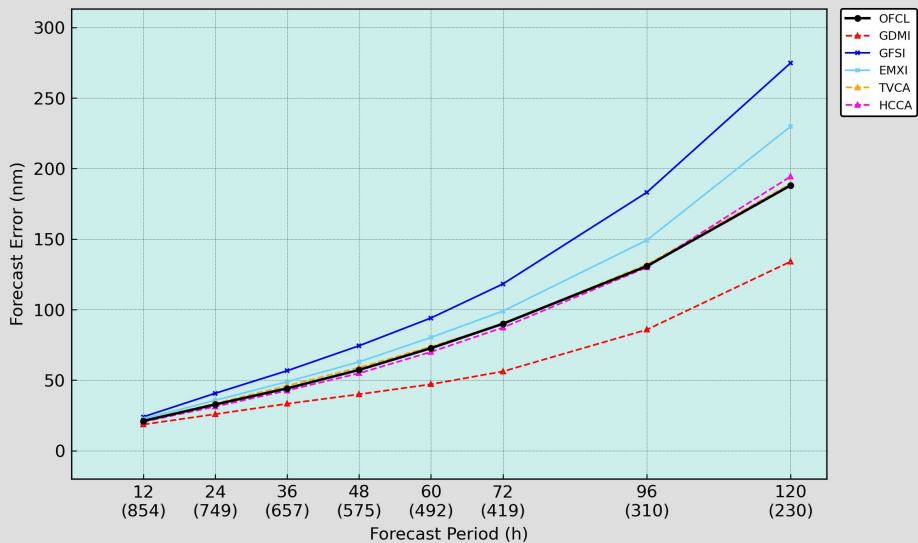
120-h Track Forecast Guidance Trends  
Atlantic Basin



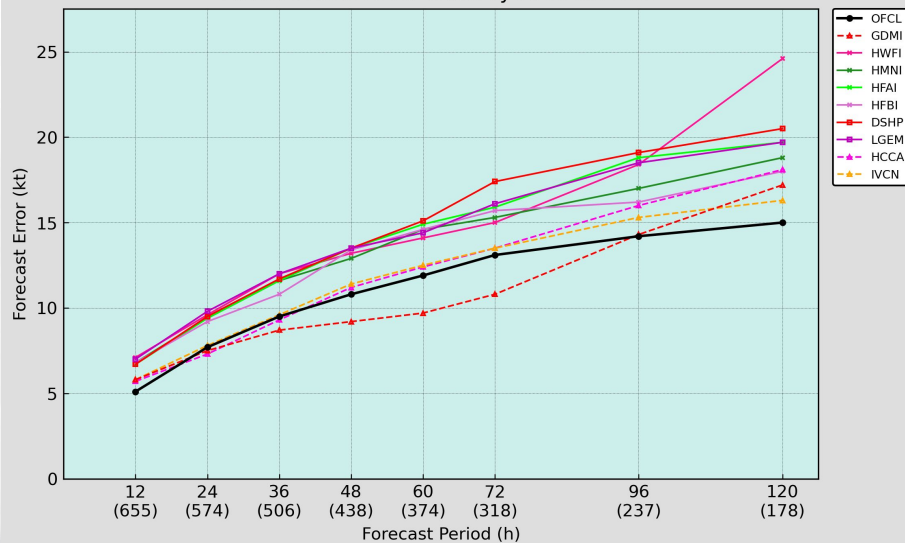
Due to model changes and other factors, the best performing model often varies from season to season

# 2022-25 Models Comparison - Track/Intensity Errors

Atlantic 2022-2025 Track Forecast Error

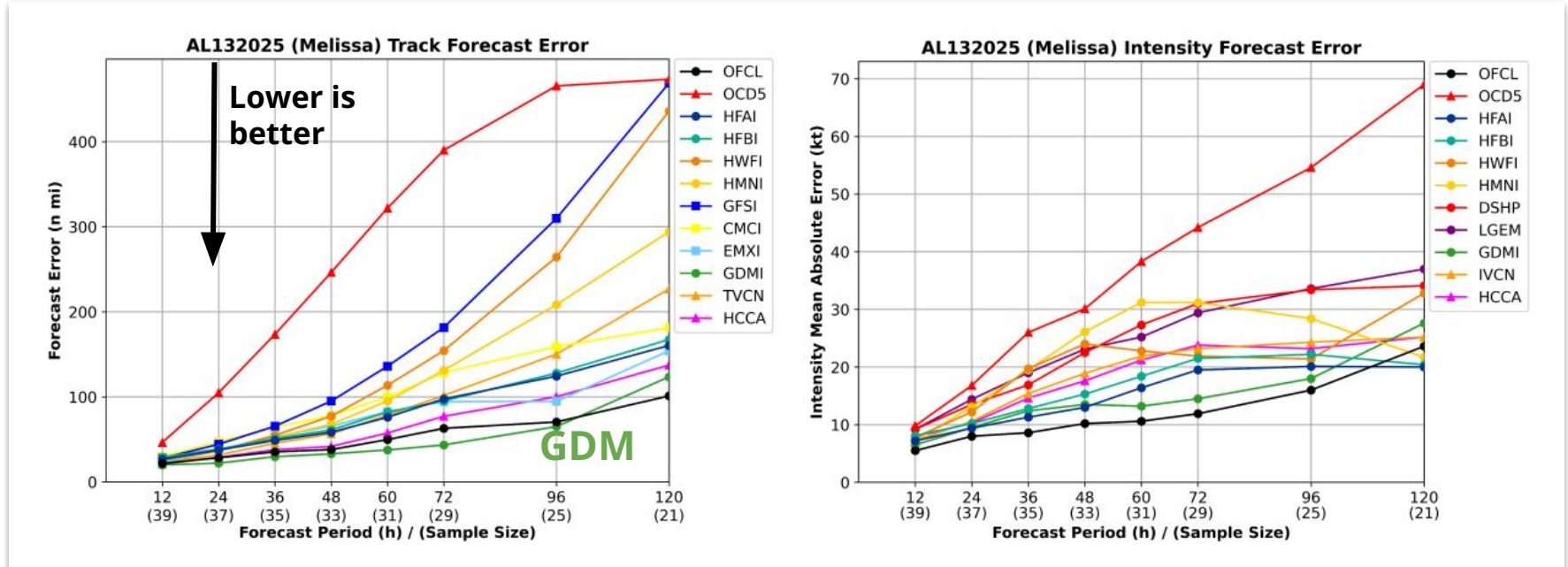


Atlantic 2022-2025 Intensity Forecast Error



# Model Performance – Melissa

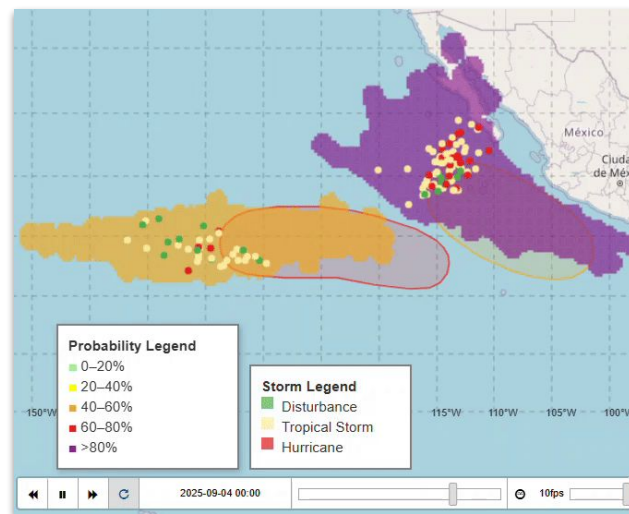
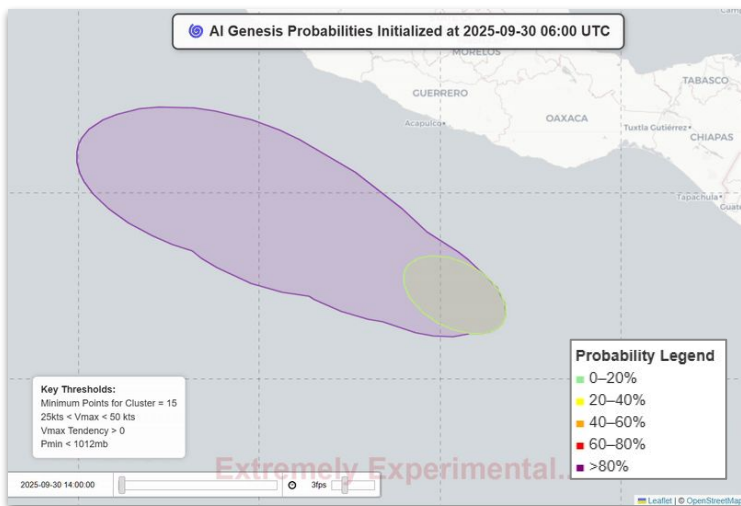
Among the individual models, **GDM** performed very well and helped forecasters effectively communicate risk to lives and property



Source: [NHC Verification Report Preview](#)

# AI-Based Genesis Guidance

NHC has developed experimental tools to distill up to thousands of individual AIWP ensemble members into guidance that can assist in TC genesis outlooks.



Above: Experimental ellipse-based (left) and neighborhood-based (right) probabilistic genesis guidance based on 100 AI forecasts (Google DeepMind)

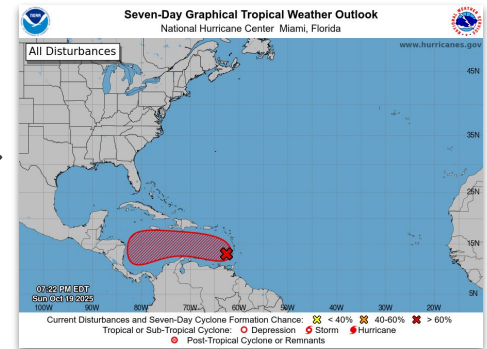
# AI-Based Genesis Guidance – Melissa

October 19 Guidance:  
**high chance of genesis**  
1000-member GDM AI ensemble



approximate  
genesis location

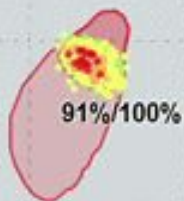
## NHC Tropical Weather Outlook (TWO)



GDM 1000-Member Initialized at 2026-03-30 12:00 UTC

## March 30th Example: Google-based Genesis Guidance

- Four discrete areas showing 2-day and 7-day prob>5%
- Intended as guidance for the Tropical Weather Outlook
- Verification TBD!



0%/17%

0%/83%

0%/80%

# AI Model Updates for 2026

- Further AI integration into NHC operations:
  - Google DeepMind collaboration will continue
    - New/updated models to test and evaluate
    - Improved timeliness so that it can be incorporated every forecast cycle
  - NOAA AI: AI-GFS and AI-GEFS
  - ECMWF AI: AIFS and AIFS-Ensemble
- We'll continue to leverage NWP Systems:
  - Operational GEFS, ECMWF, HAFS, etc
  - Experimental HAFS Ensemble

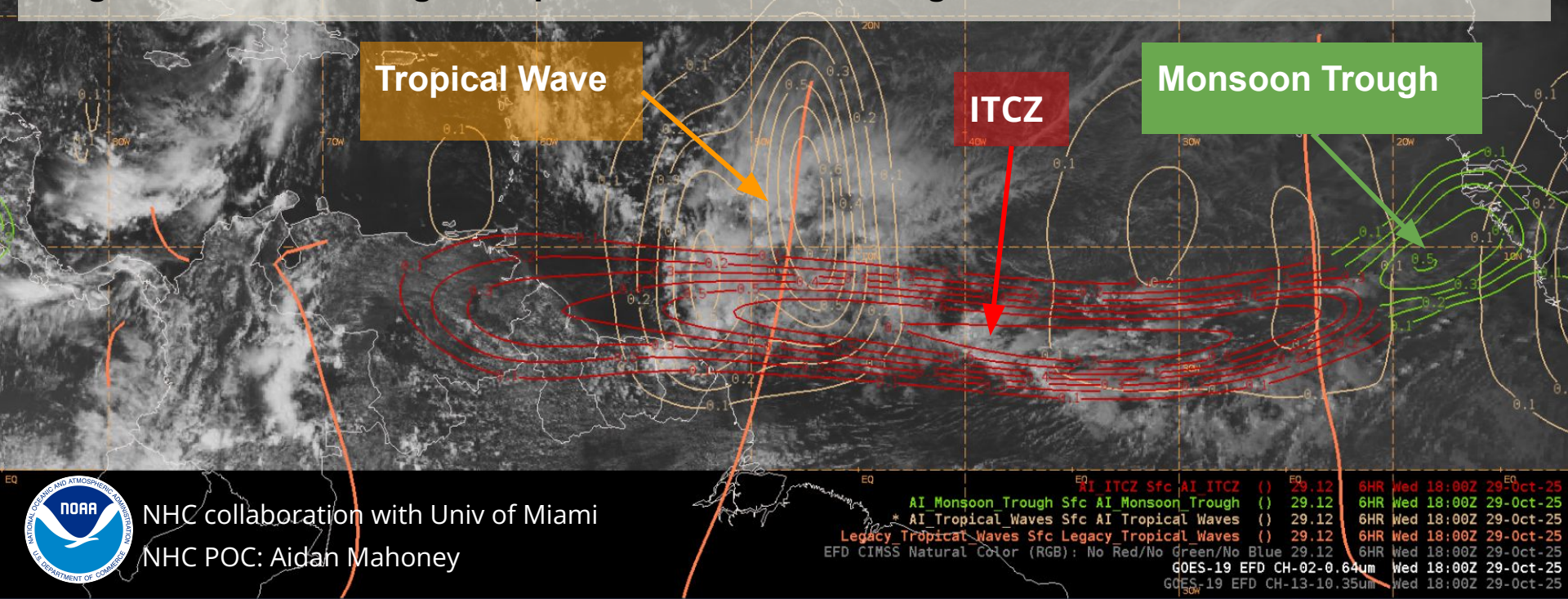
**Over 1000  
unique  
forecasts!**

A background image showing a view of Earth from space, with the planet's surface and atmosphere visible on the left side, and a dark starry sky on the right. A semi-transparent blue rectangle is overlaid in the center, containing the title text.

# **Other AI-Based Applications at NHC**

# AI Tropical Wave Tracking

- AI-based system trained on expert-produced surface maps and model forecast fields
- Outputs probabilities of features: ITCZ, Monsoon Trough, and Tropical Waves
- Significant time savings compared to manual tracking



NHC collaboration with Univ of Miami  
NHC POC: Aidan Mahoney

AI ITCZ Sfc	AI ITCZ	( )	29.12	6HR	Wed 18:00Z	29-Oct-25
AI Monsoon Trough Sfc	AI Monsoon Trough	( )	29.12	6HR	Wed 18:00Z	29-Oct-25
* AI Tropical Waves Sfc	AI Tropical Waves	( )	29.12	6HR	Wed 18:00Z	29-Oct-25
Legacy Tropical Waves Sfc	Legacy Tropical Waves	( )	29.12	6HR	Wed 18:00Z	29-Oct-25
EFD CIMSS Natural Color (RGB): No Red/No Green/No Blue			29.12	6HR	Wed 18:00Z	29-Oct-25
GOES-19 EFD CH-02-0.64um			29.12	6HR	Wed 18:00Z	29-Oct-25
GOES-19 EFD CH-13-10.35um			29.12	6HR	Wed 18:00Z	29-Oct-25

# Melissa (2025) Landfall:

In the future, can AI help us infer more information about the surface wind hazards?



ARP NOAA2\_013318 17.550N 78.017W 1351 F0 P34 275/173KT  
ARP NOAA2\_013318 17.550N 78.017W 1351 F0 P34 275/173KT  
ARP NOAA2\_013318 17.550N 78.017W 1351 F0 P34 275/173KT  
44.76%

Recon ExtPres Tue 14:00Z 28-Oct-25  
Recon SFMR Tue 14:00Z 28-Oct-25  
Recon Wind Tue 14:00Z 28-Oct-25  
GOES-19 EMES0-1 CH-02-0.64um Tue 14:00Z 28-Oct-25

# AI Surface Wind Field

Experimental AI-based surface wind analysis, developed by NCAR & CSU, was available for several storms in 2025, including Melissa

Leverages historical and real-time aircraft reconnaissance data to estimate the 2-D 10-m wind field

Early results show some promise to more precisely define the 10-m wind field – a critical input for NWP and messaging for public safety



165.46kts

The image shows a 2-D 10-m wind field visualization of a storm, likely Hurricane Melissa. The wind field is represented by a color gradient from purple (lower wind speeds) to red (higher wind speeds), with orange and yellow lines indicating wind direction and speed vectors. The center of the storm is marked with a black square and a green text label indicating a maximum wind speed of 165.46 kts.



Collaboration among NCAR/CSU/CIRA/NHC:

Thanks to Jen DeHart & Alan Brammer

CSU SWANN 10FHAG Wind (kts) Tue 13:46Z 28-Oct-25

\* CSU\_SWANN 10FHAG Wind speed Img (kts) Tue 13:46Z 28-Oct-25



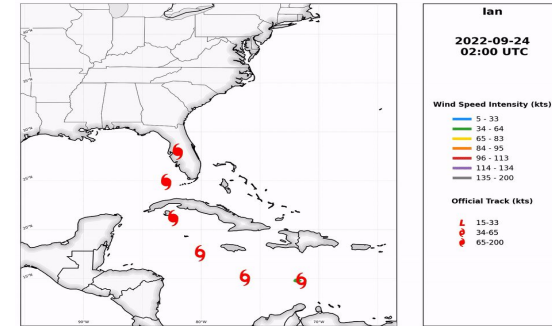
# **Next Generation Wind Speed Probability Model**



# NHC Legacy WSP Model (2006)



- Resolution: 0.5 Degrees
- Monte Carlo model - 1000 ensembles
- Track/intensity ensembles based on previous 5-year NHC/CPHC errors
- Wind radii perturbations - radii-CLIPER errors
- Uses initial Wind Radii and trends to climo by 36 hr
- Suite of text and graphical products
  - 34, 50, 64 kt wind probabilities 0-120 h
  - Time of arrival (TOA) of 34 kt winds



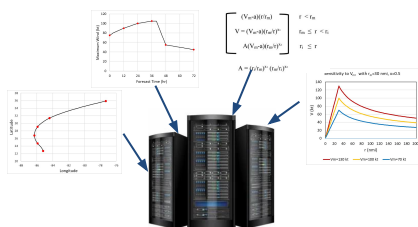
# The GTCM

NHC Forecast Points - Position/MaxW/Radii



15% radii reduction

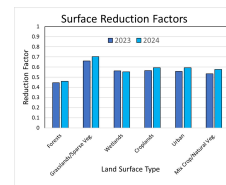
Modified Rankine vortex/2-D wind computed



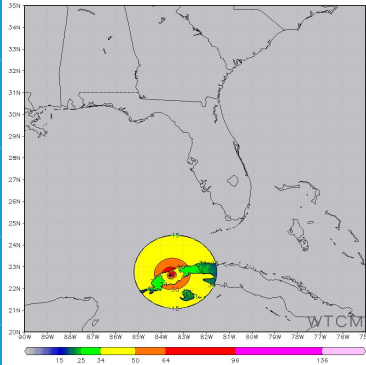
Surface roughness reduction applied



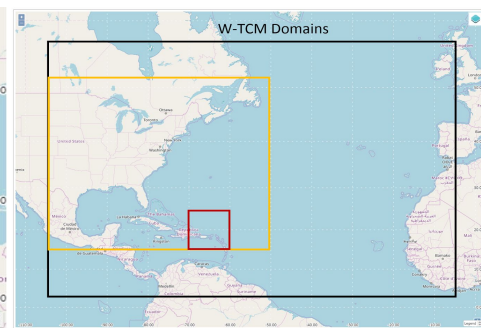
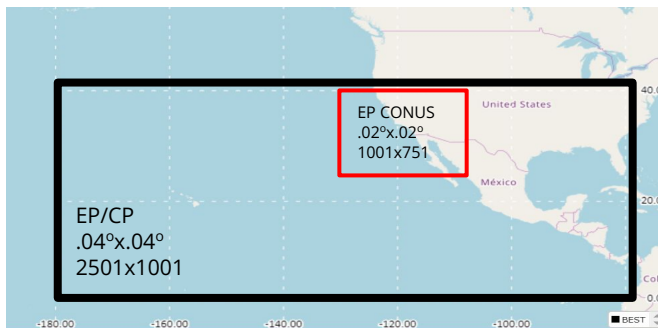
Sfc roughness tuned to give zero bias for training data



Ian AL092022 0927 12UTC fhr:0



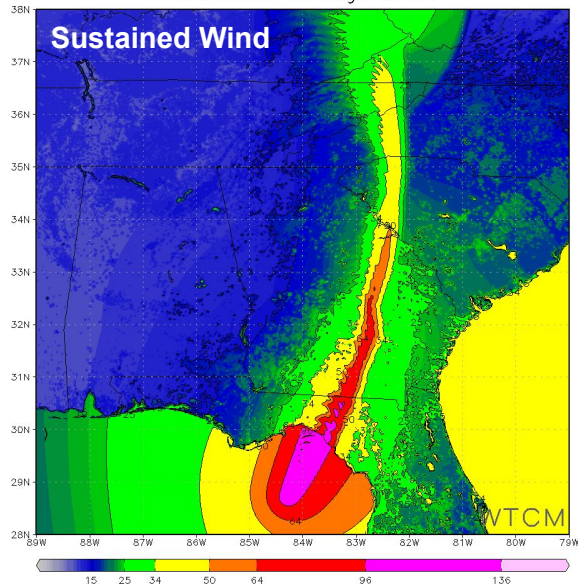
Post Processing



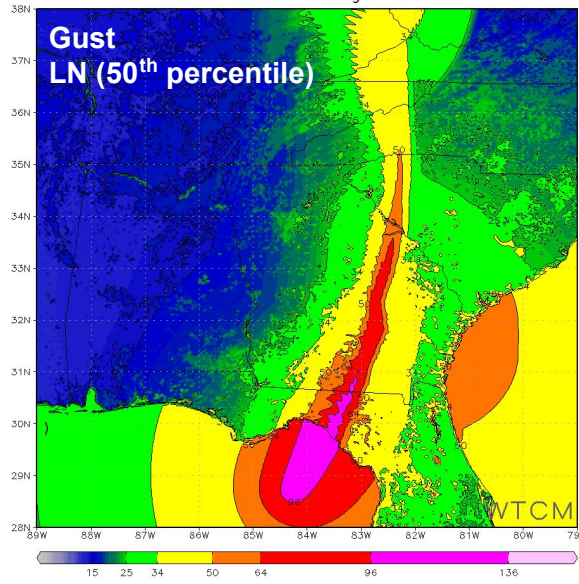
- Atlantic .09°x.09° 1101x601
- CONUS .02°x.02° 2101x1751
- Puerto Rico .01°x.01° 1001x1001

# GTCM Surface Winds and Gusts Best Track Input - Hurricane Helene

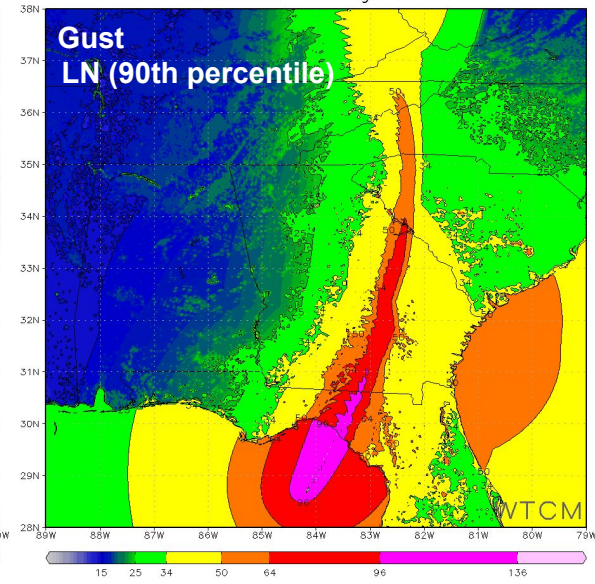
HELENE AL092024 0927 00UTC  
Wind Swath Through fhr:24



HELENE AL092024 0927 00UTC  
Wind Swath Through fhr:24



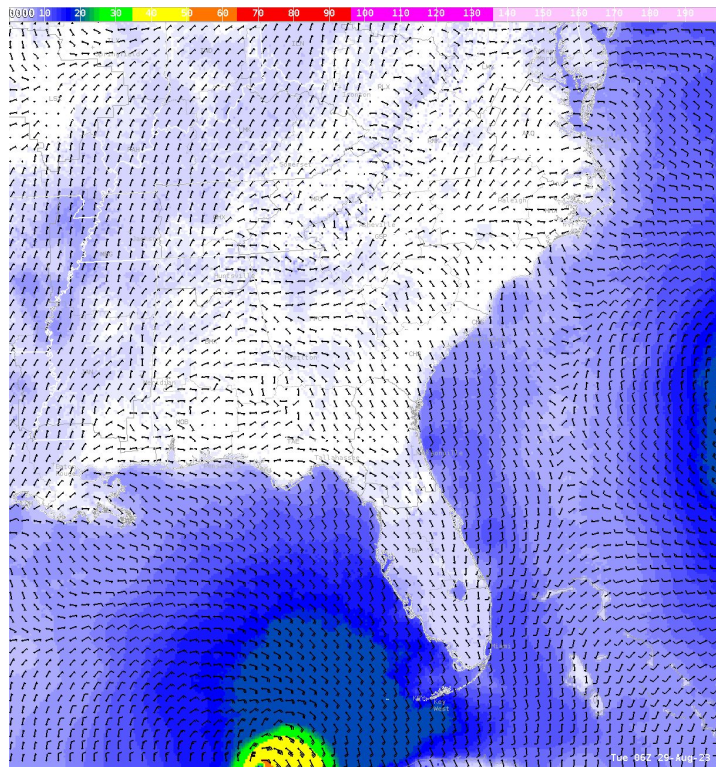
HELENE AL092024 0927 00UTC  
Wind Swath Through fhr:24



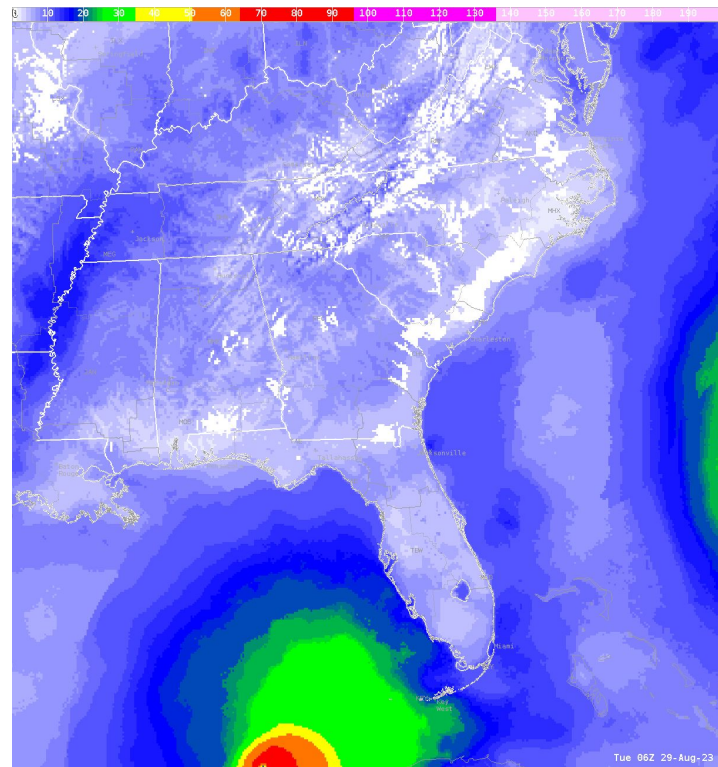


# GTCM Updates - AWIPS Examples

## 2023 Idalia - GTCM Winds



## 2023 Idalia - GTCM Gusts





# NHC Next Generation WSP

## In its End State, What is it? And Status?



- 1000 GTCM ensemble runs w/ complete surface wind fields
- 1000 members at 5 km versus 50 km resolution in legacy
- Smoother Tracks \*
- Zero Hour perturbations \*
- Forecast wind radii \*
- New track/intensity perturbations based on ensemble/AI models for situational dependence of error distributions



**\* These are being introduced in legacy WSP in 2026**





# NHC Next Generation WSP

## In its End State, What is it? And Status?



- In addition to legacy wind speed probabilities and TOA data:
  - Generate Probability of sustained winds > 96 kts
  - Cumulative sustained winds Exceedance data for the 5%, 10%, 25%, 50%, 75%, 90%, and 95% levels
  - **Generate Probabilities, Exceedance data, and TOA for Wind Gust as well**
- Also elevation adjustments to GTCM and hence WSP



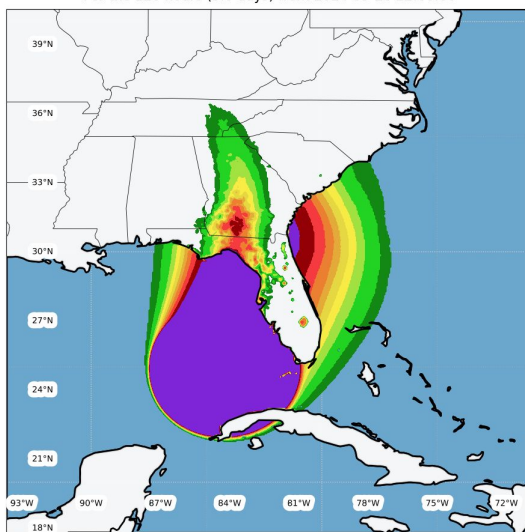


# NHC Next Generation WSP

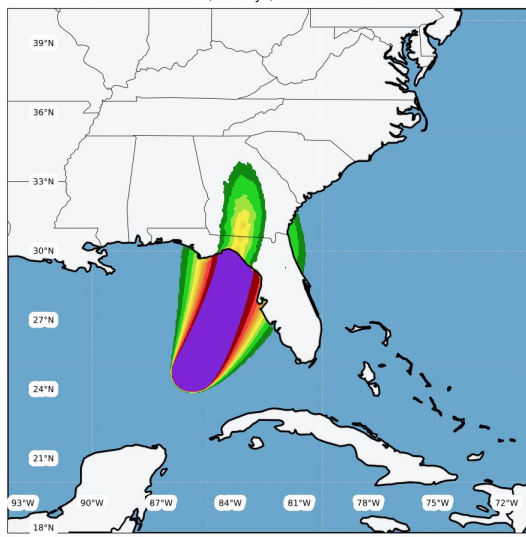
- **Sample Sustained Winds** using Hurricane Helene - 2024
- Point Probabilities



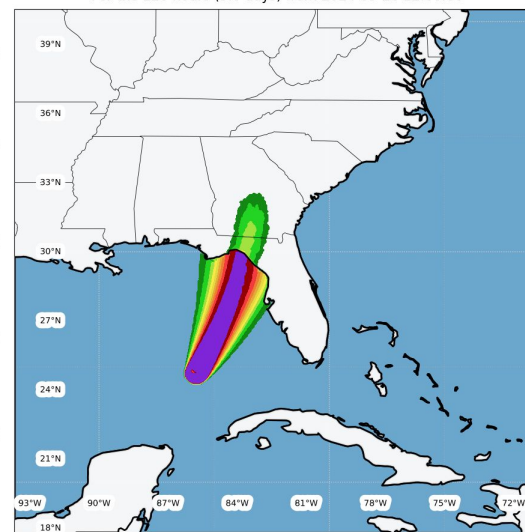
34 kt Wind Speed Probabilities  
For the 120 hours (5.0 days) from 2024-09-26 12:00:00



50 kt Wind Speed Probabilities  
For the 120 hours (5.0 days) from 2024-09-26 12:00:00



64 kt Wind Speed Probabilities  
For the 120 hours (5.0 days) from 2024-09-26 12:00:00



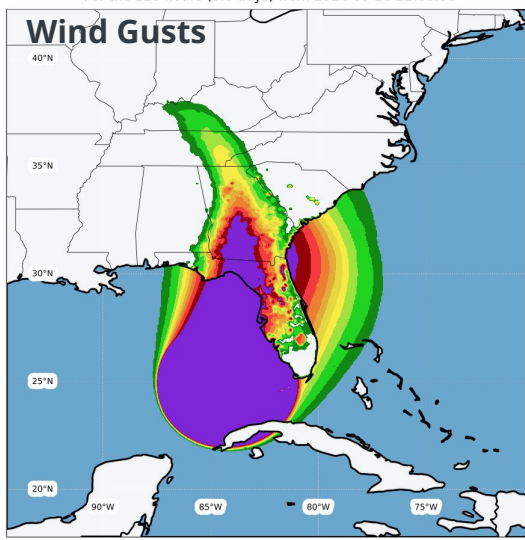


# NHC Next Generation WSP

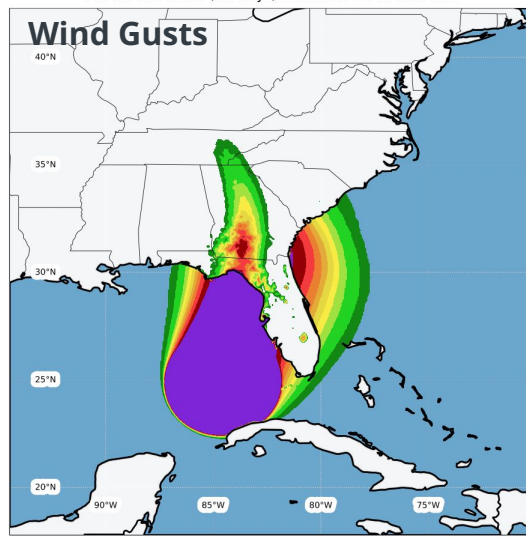
- **Sample New Wind Gusts** using Hurricane Helene - 2024
- Point Probabilities



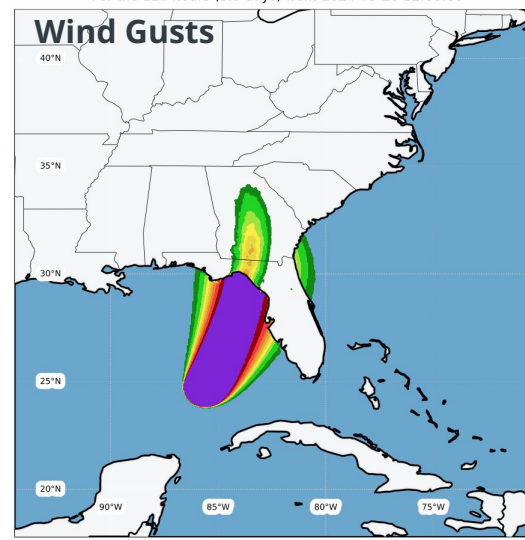
34 kt Wind Speed Probabilities  
For the 120 hours (5.0 days) from 2024-09-26 12:00:00



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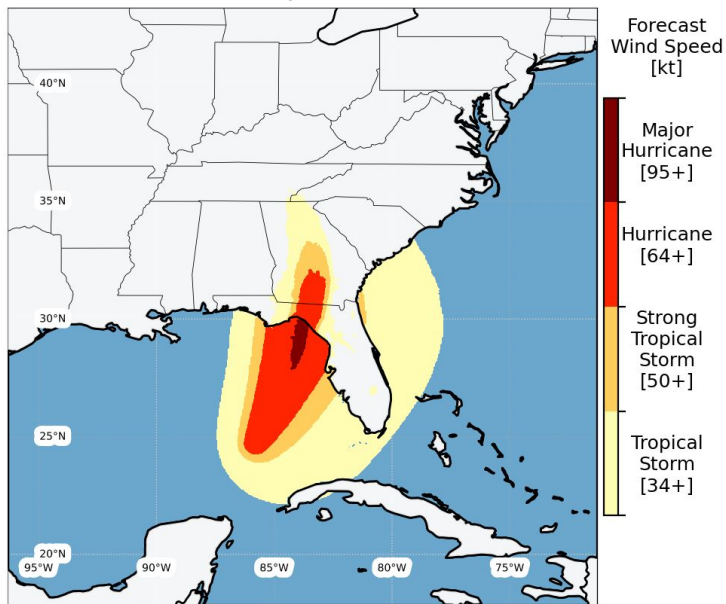


# NHC Next Generation WSP

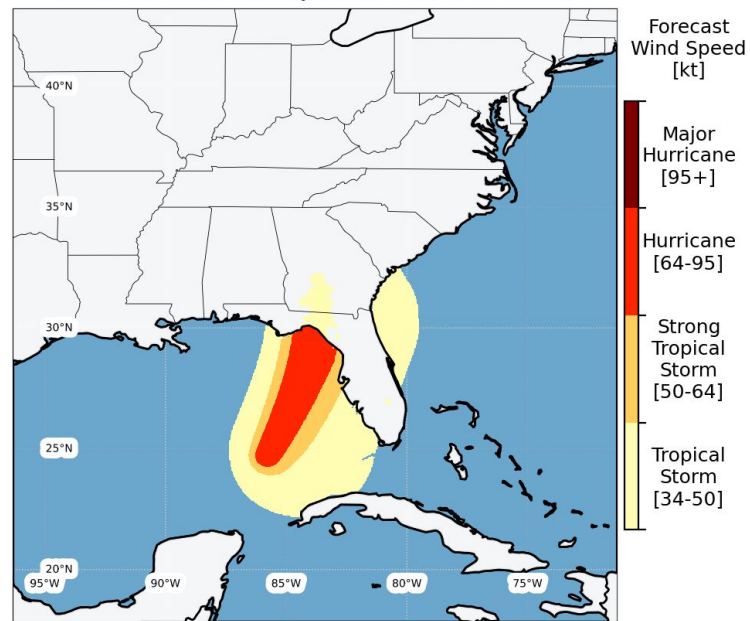


- **Sample Sustained Winds** using Hurricane Helene - 2024
- **Exceedances - Point Based**

High End Strength - 1 in 10 Chance (10%) of Stronger Windspeeds for the 120 hours (5.0 days) from 2024-09-26 12:00:00



50% Exceedance for the 120 hours (5.0 days) from 2024-09-26 12:00:00

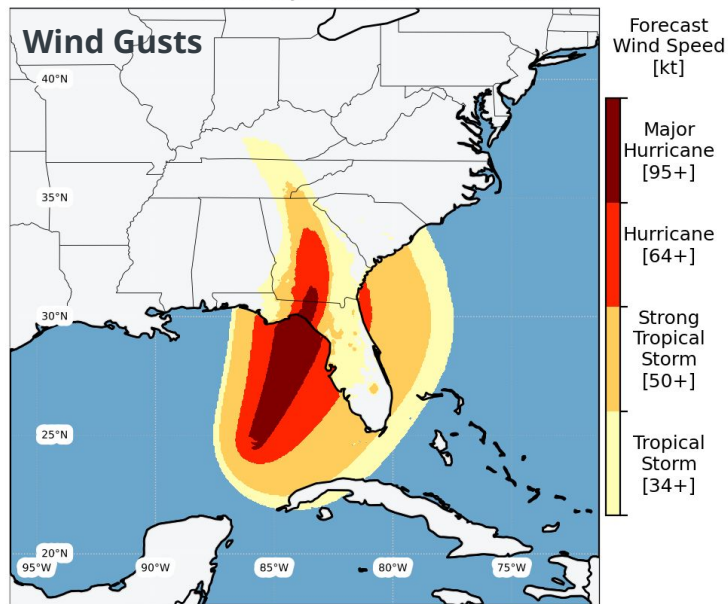




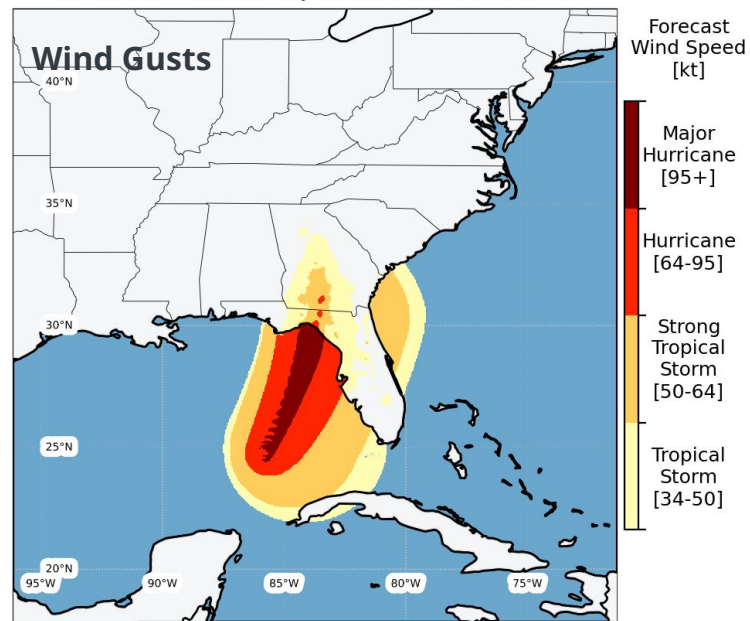
# NHC Next Generation WSP

- **Sample New Wind Gusts** using Hurricane Helene - 2024
- **Exceedances - Point Based**

High End Strength - 1 in 10 Chance (10%) of Stronger Windspeeds for the 120 hours (5.0 days) from 2024-09-26 12:00:00



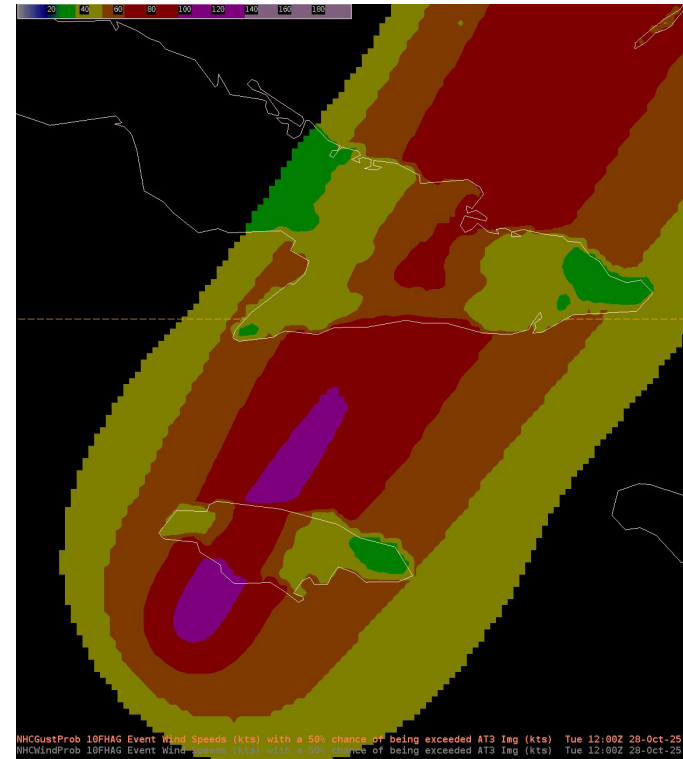
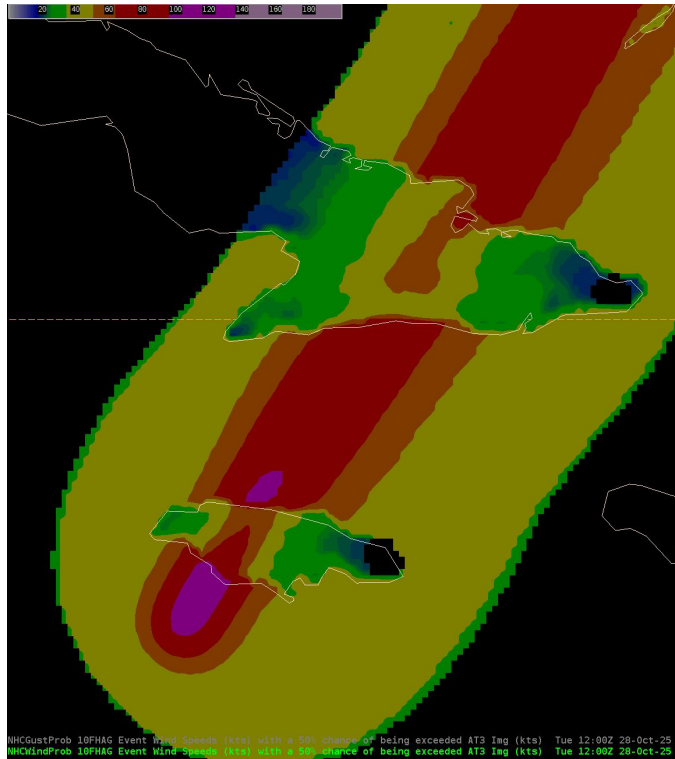
50% Exceedance for the 120 hours (5.0 days) from 2024-09-26 12:00:00





# NHC Next Generation WSP

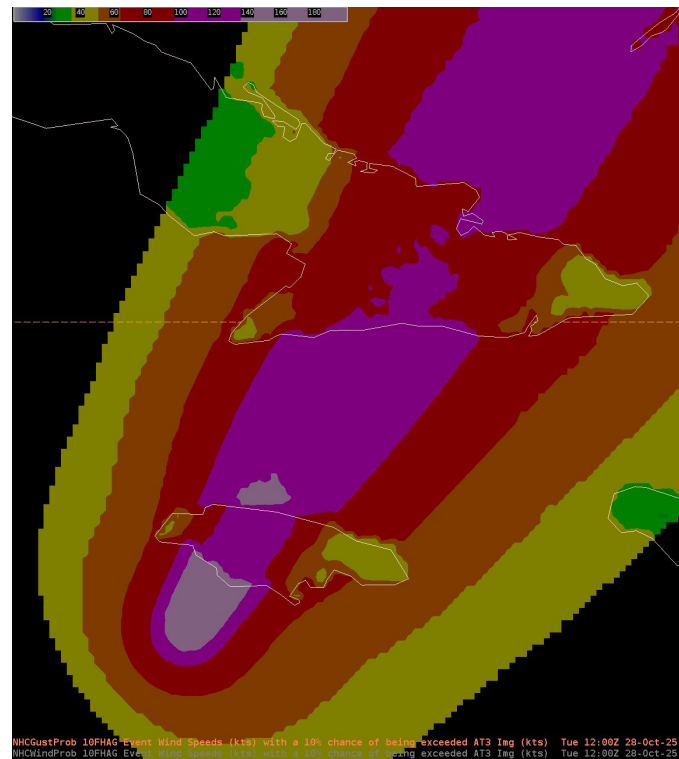
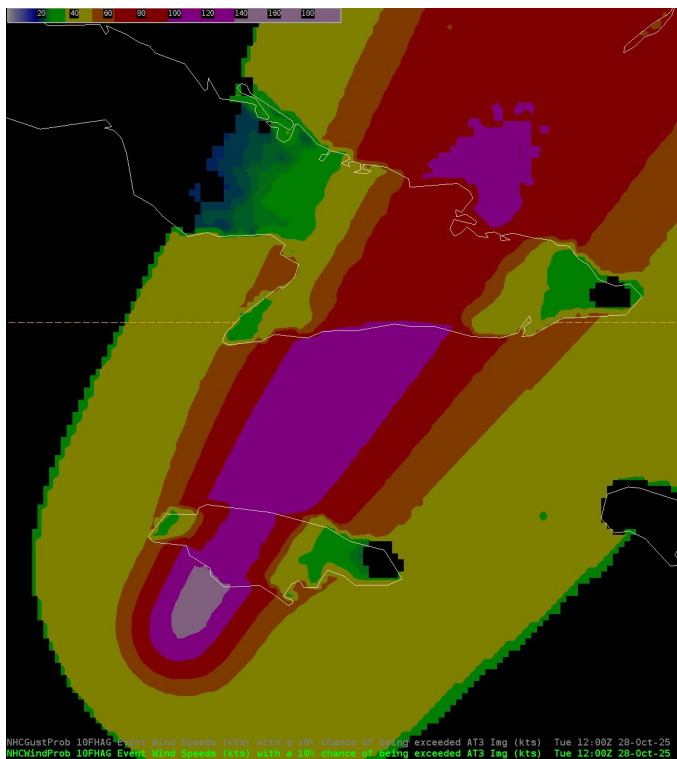
- Melissa 50% Exceedance Wind and WindGust





# NHC Next Generation WSP

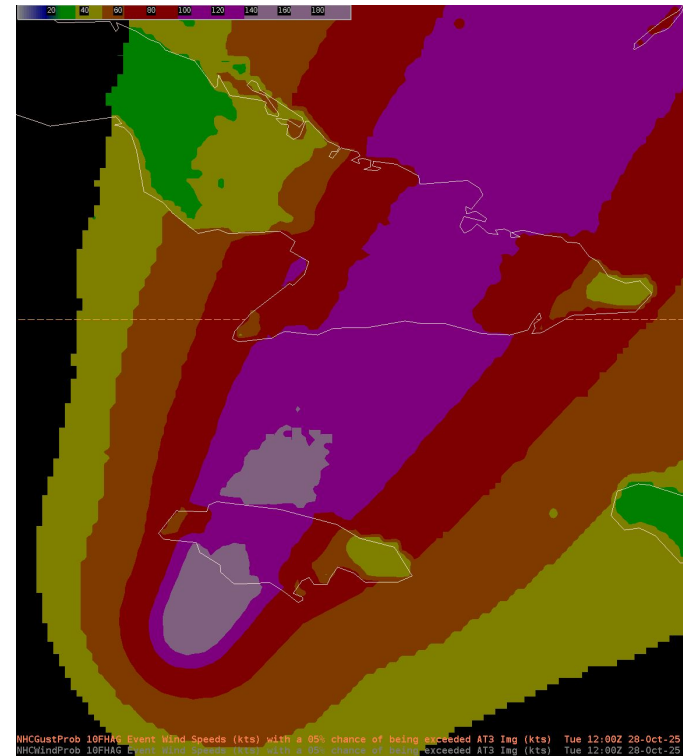
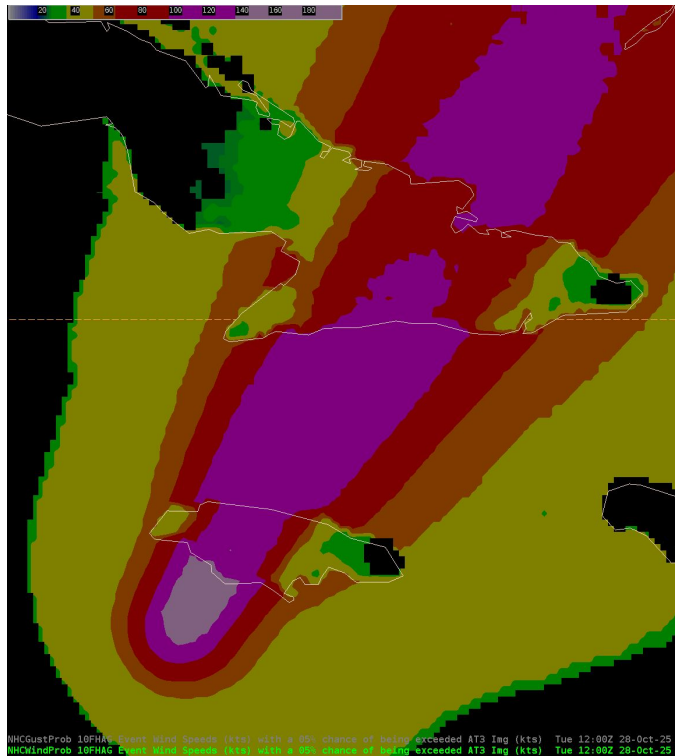
- Melissa 10% Exceedance Wind and WindGust





# NHC Next Generation WSP

- Melissa 5% Exceedance Wind and WindGust

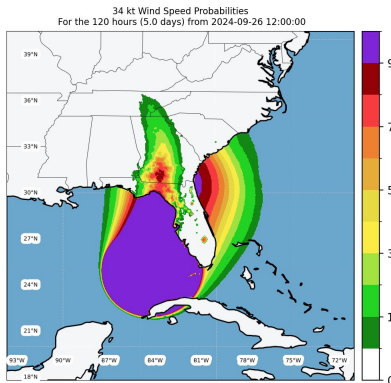


# WSP - Point (Top) Vs Neighborhood (Bottom) Based Probabilities

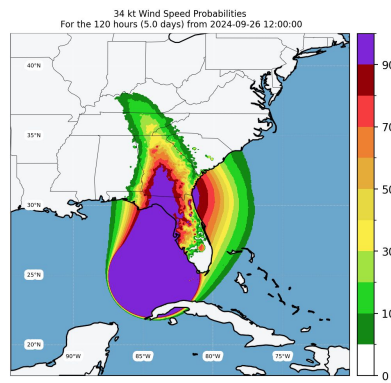
WSP Legacy - Sustained Winds



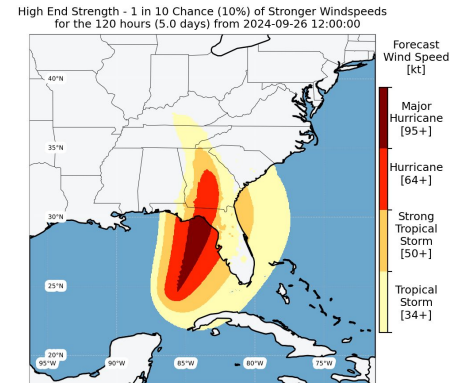
Next Gen WSP - Sustained Winds



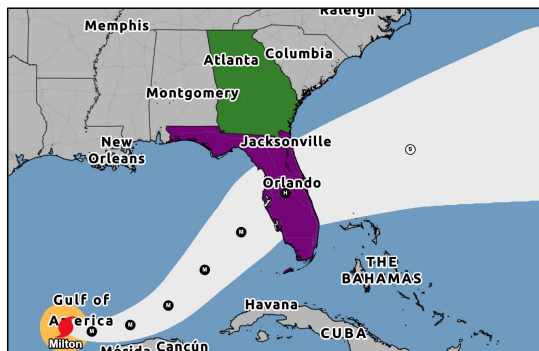
Next Gen WSP - Gust



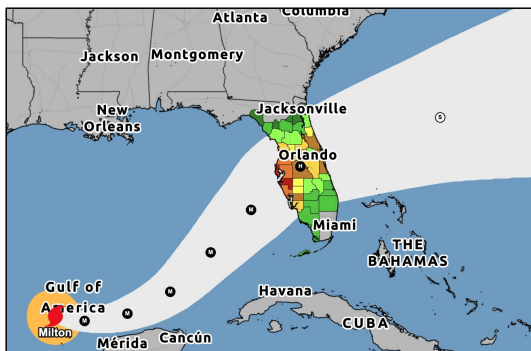
Next Gen WSP - Sustained Winds Exceedance Graphics



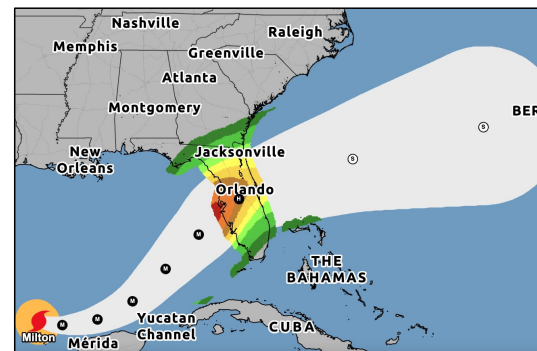
State-Based Probabilities



County-Based Probabilities



Neighborhood-Based Probabilities



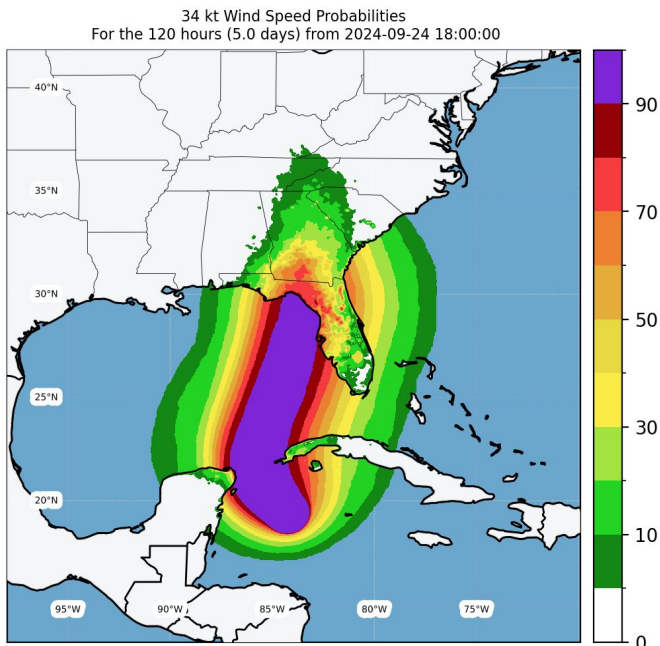


# NHC Next Gen WSP

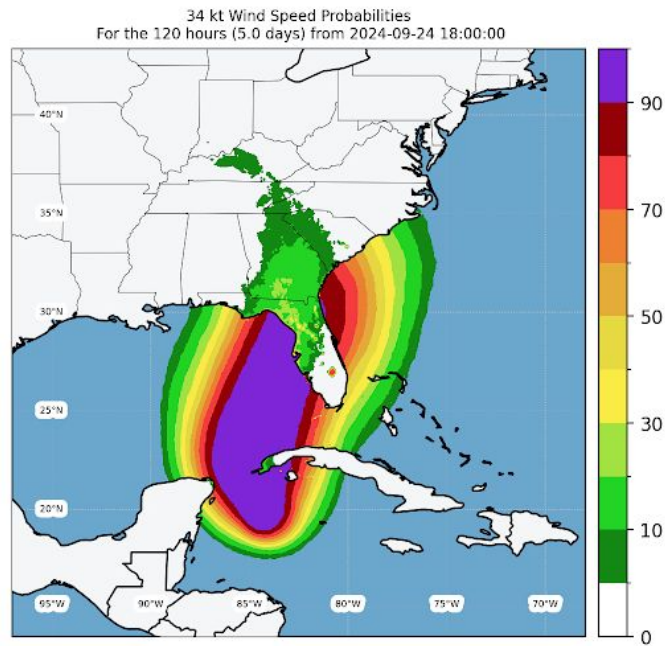


- Incorporating Situational Uncertainty - Helene

## Monte-Carlo Ensembles



## Dynamic Ensembles



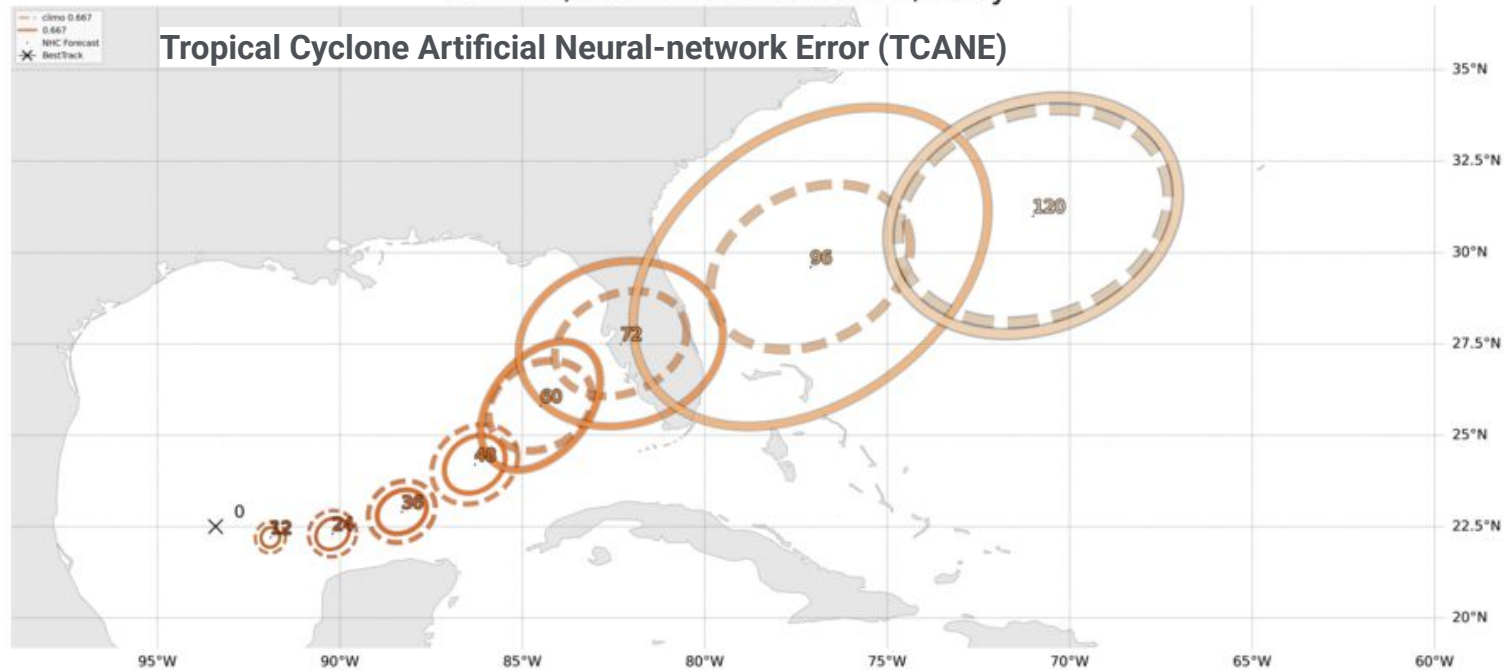


# NHC Next Gen WSP



- Incorporating Situational Uncertainty - Milton

MILTON, 2024-10-07 00:00:00, early





# NHC Generation WSP

## Transition to Ops



- 2026 Version - internal evaluation by NHC
  - Exploration of point versus neighborhood based products
  - Finalizing method to dynamically generate ensemble members
- 2027 Version - public experiment
  - Will include dynamic track/intensity perturbations and elevation adjustments
- 2028 Version - Operational implementation





# NHC Next Gen WSP



- Contacts

- Pablo Santos - Chief Technology and Science Branch
- Robbie Berg - Warning Coordination Meteorologist



# Summary

- Science and technology innovation that directly supports the NHC mission is moving extraordinarily quickly
  - The HOT and NHC, along with partners (e.g. EMC, CIRA and NOAA Labs), are working hard to make sure NHC remains near the leading edge without compromising the scientific rigor.
- AI is dramatically increasing the number of tools in the forecaster toolkit
  - The proliferation of data and tools further emphasizes the need for hurricane domain experts to distill and communicate risk to protect life and property
- Next Generation WSP will provide enhance risk communication capabilities
- Many opportunities and challenges are ahead; flexibility and constant learning will be a requirement!



**Questions?**