

# Tropical Cyclone Track Prediction

A satellite image of a tropical cyclone, showing a well-defined eye and spiral cloud bands, set against a blue background with a grid overlay.

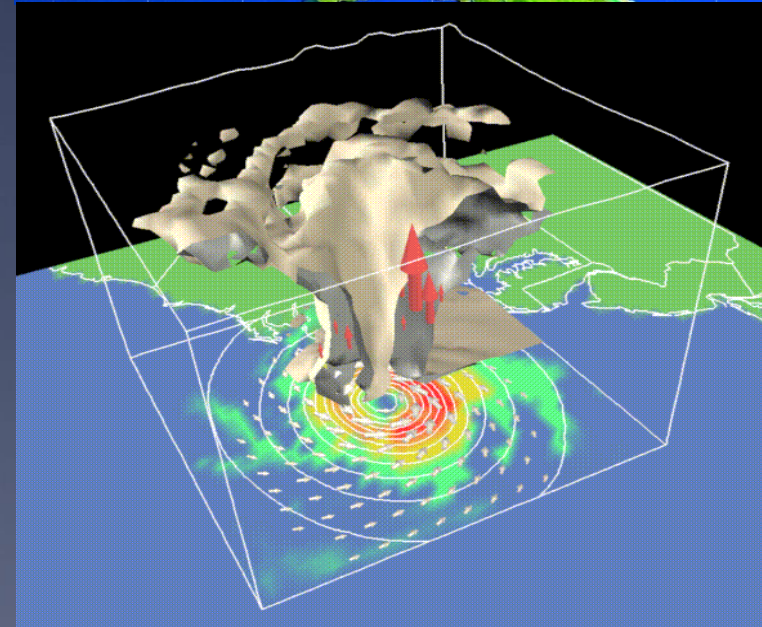
David A. Zelinsky and Richard J. Pasch  
National Hurricane Center

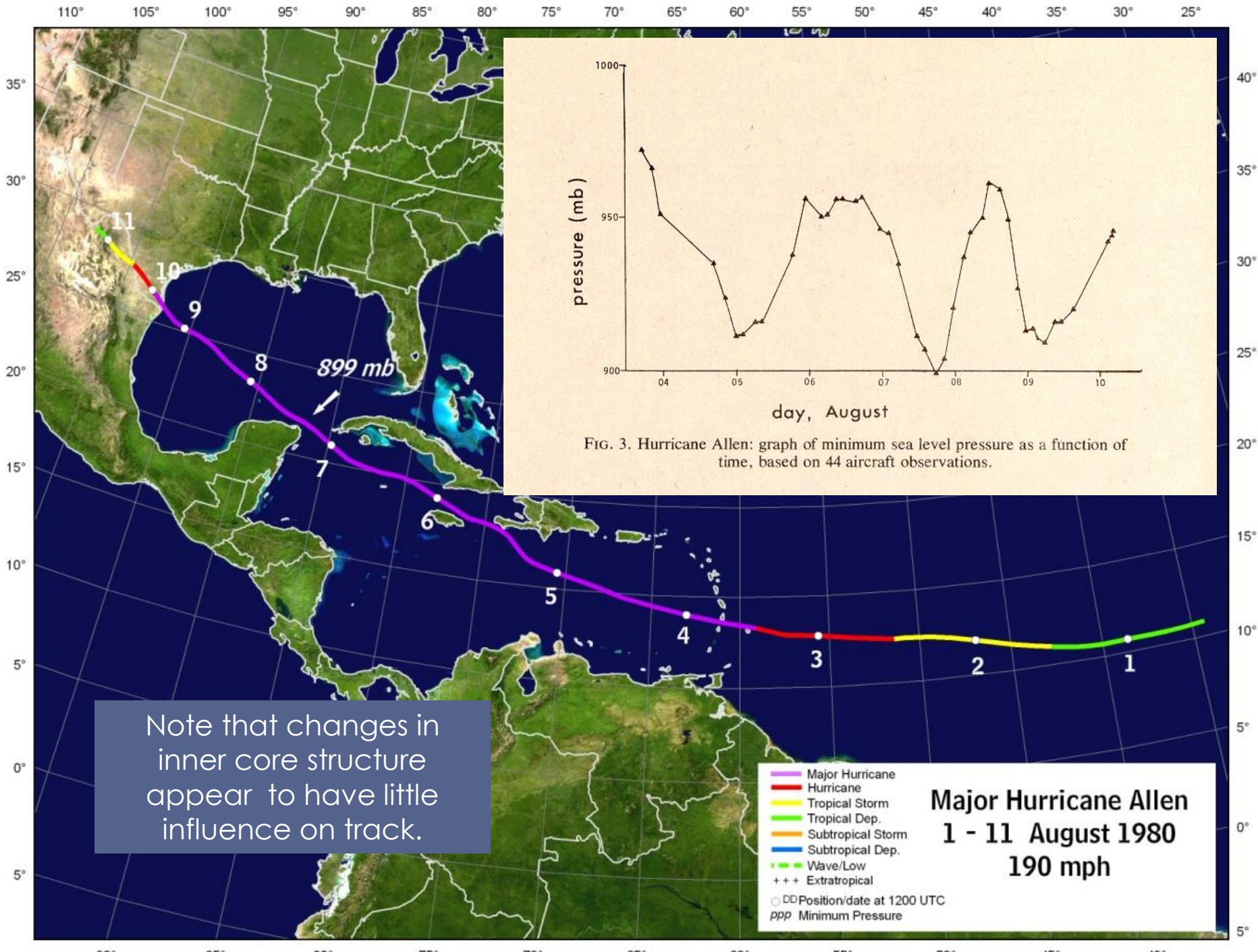
2019 RA-IV Workshop on Hurricane Forecasting and Warning

May 7, 2019

# Outline

- \* Basic Dynamics
- \* Guidance Models
  - \* Statistical models
  - \* Beta and Advection Models
  - \* Dynamical models
  - \* Ensembles and consensus
- \* Synoptic Surveillance
- \* Track Forecasting at NHC
  - \* Practical considerations
  - \* Verification





# Vorticity Equation

- \* Since inner-core variability does not have much influence on TC track, we can conclude that the dominant atmospheric motions are on the scale of the outer circulation of the TC.

## SCALE ANALYSIS OF THE VORTICITY EQUATION

Use scales for tropical cyclone outer wind:

$$L \sim 500 \text{ km}$$

$$\text{Rotational wind } V \sim 10 \text{ m/s}$$

$$\text{Divergent wind } U \sim 1 \text{ m/s}$$

$$\Delta P \sim 10^5 \text{ Pa}$$

$$T \sim \frac{L}{V} \sim 5 \times 10^4 \text{ sec}$$

$$\zeta \sim \frac{V}{L} \sim 2 \times 10^{-5} \text{ sec}^{-1}$$

$$\delta \sim \frac{U}{L} \sim 2 \times 10^{-6} \text{ sec}^{-1}$$

$$\omega \sim \delta \Delta P \sim 0.2 \text{ Pa/sec}$$

$$\underbrace{\frac{\partial \zeta}{\partial t}}_{(1)} = - \underbrace{V \cdot \nabla \zeta}_{(1)} - \underbrace{\omega \frac{\partial \zeta}{\partial P}}_{(4)} - \underbrace{\beta v}_{(2)} - \underbrace{(\zeta + f) \delta}_{(3)} - \underbrace{k \cdot \nabla \omega \times \frac{\partial V}{\partial P}}_{(4)}$$

$$4 \times 10^{-10} \quad 4 \times 10^{-10} \quad 4 \times 10^{-11} \quad 2 \times 10^{-10} \quad 1 \times 10^{-10} \quad 4 \times 10^{-11}$$

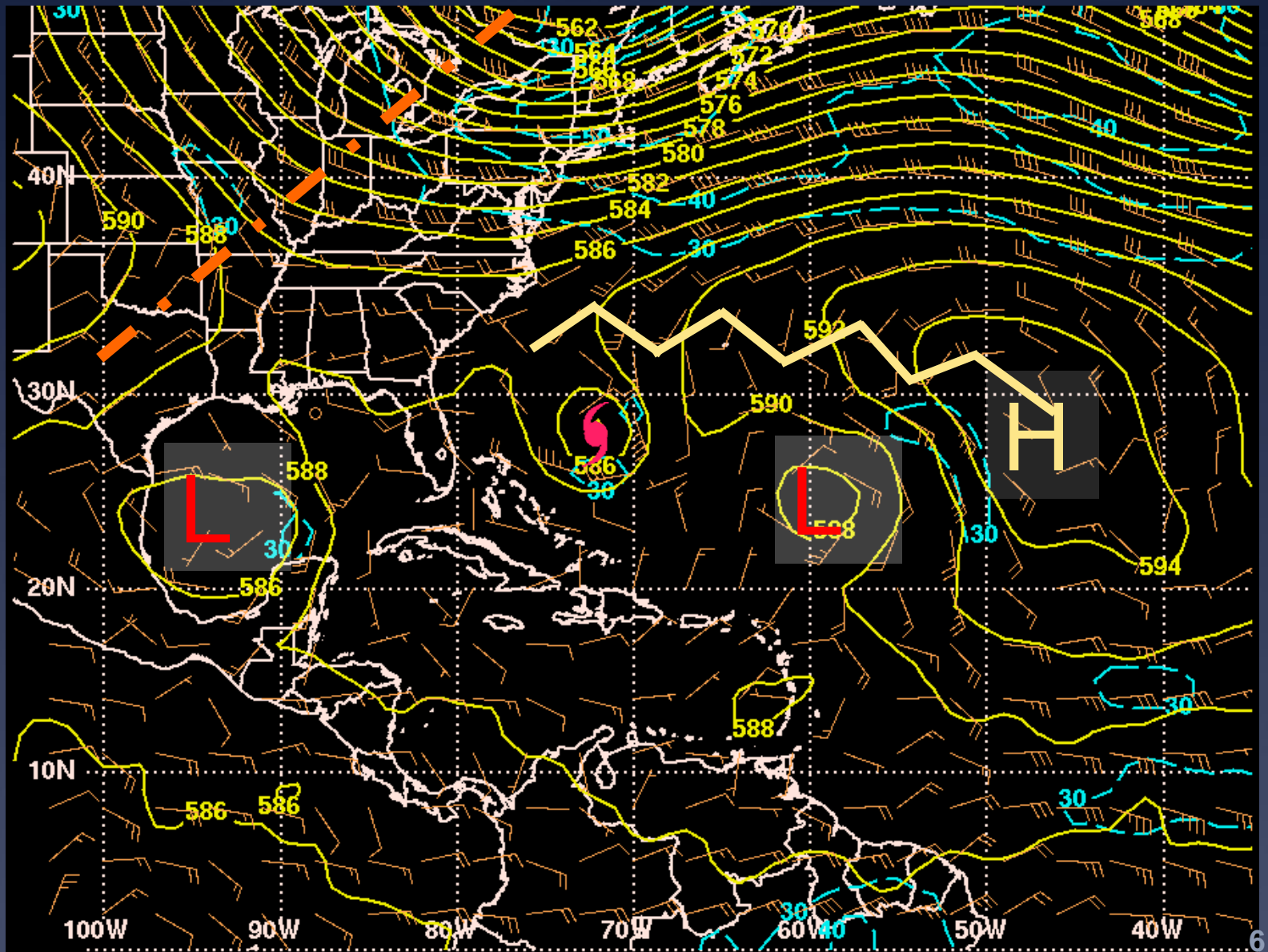
# Vorticity Equation

$$\frac{\partial \zeta}{\partial t} = -V \cdot \nabla \zeta - \omega \frac{\partial \zeta}{\partial P} - \beta v - (\zeta + f) \delta - k \cdot \nabla \omega \times \frac{\partial V}{\partial P}$$

<u>(1)</u>	<u>(1)</u>	(4)	(2)	(3)	(4)
$4 \times 10^{-10}$	$4 \times 10^{-10}$	$4 \times 10^{-11}$	$2 \times 10^{-10}$	$1 \times 10^{-10}$	$4 \times 10^{-11}$

- \* To a first approximation, TC motion is governed by conservation of relative vorticity (vortex moves with the large-scale steering flow).
- \* Second order includes the Beta term (conservation of absolute vorticity).
- \* Divergence term (e.g., wavenumber 1 asymmetry in convection, interactions with orography, friction)
- \* Vertical motions (e.g., twisting term) less important.
- \* 3-d dynamical model includes all of these terms.

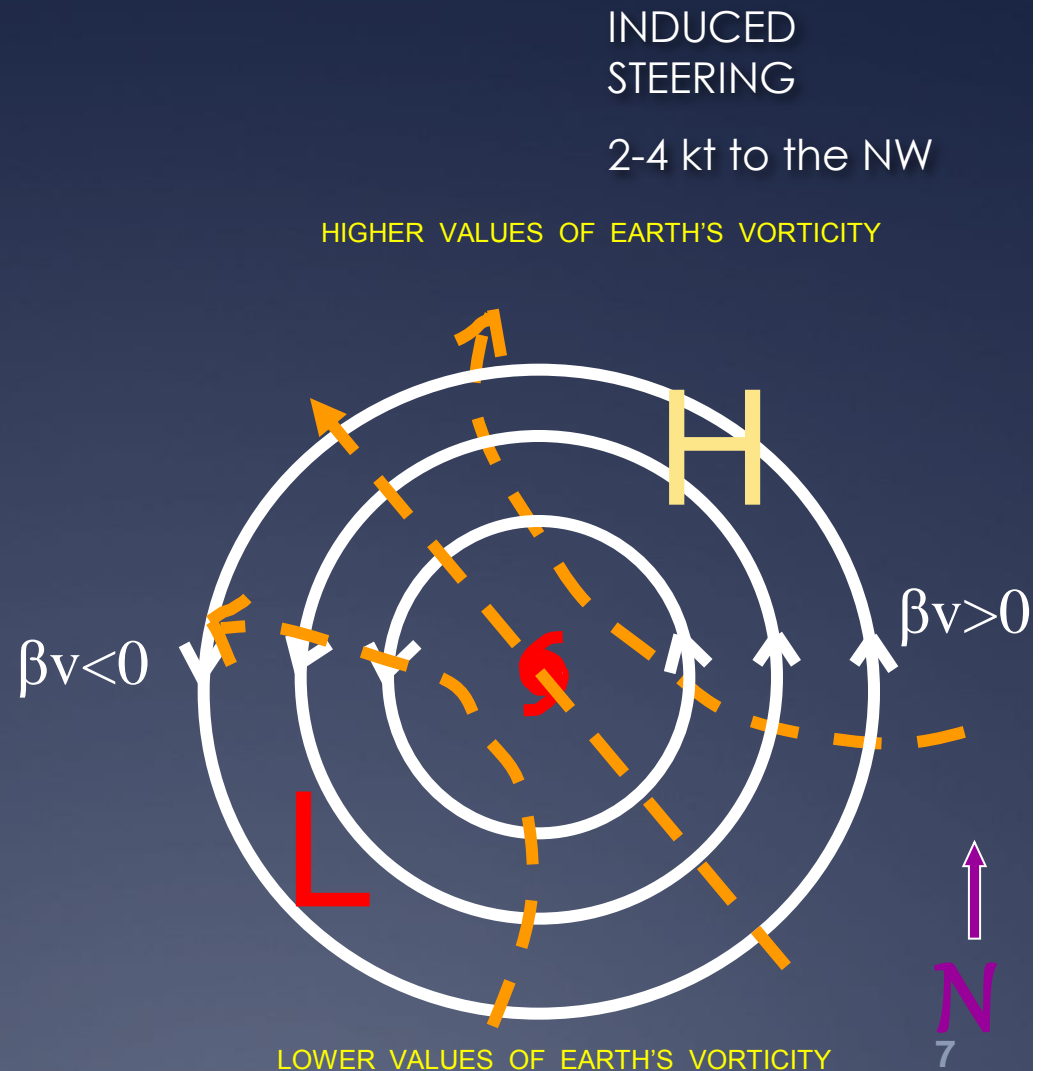
# Large-Scale Steering



AVN 980831/1200V036 500 MB HEIGHTS, ISOTACHS & WINDS (KTS)

# The Beta Effect

- \* The circulation of a TC, combined with the North-South variation of the Coriolis parameter, induces asymmetries known as Beta Gyres.
- \* Beta Gyres produce a net steering current across the TC, generally toward the NW at a few knots. This motion is known as the Beta Drift.



# Track Forecasting Exercise 1

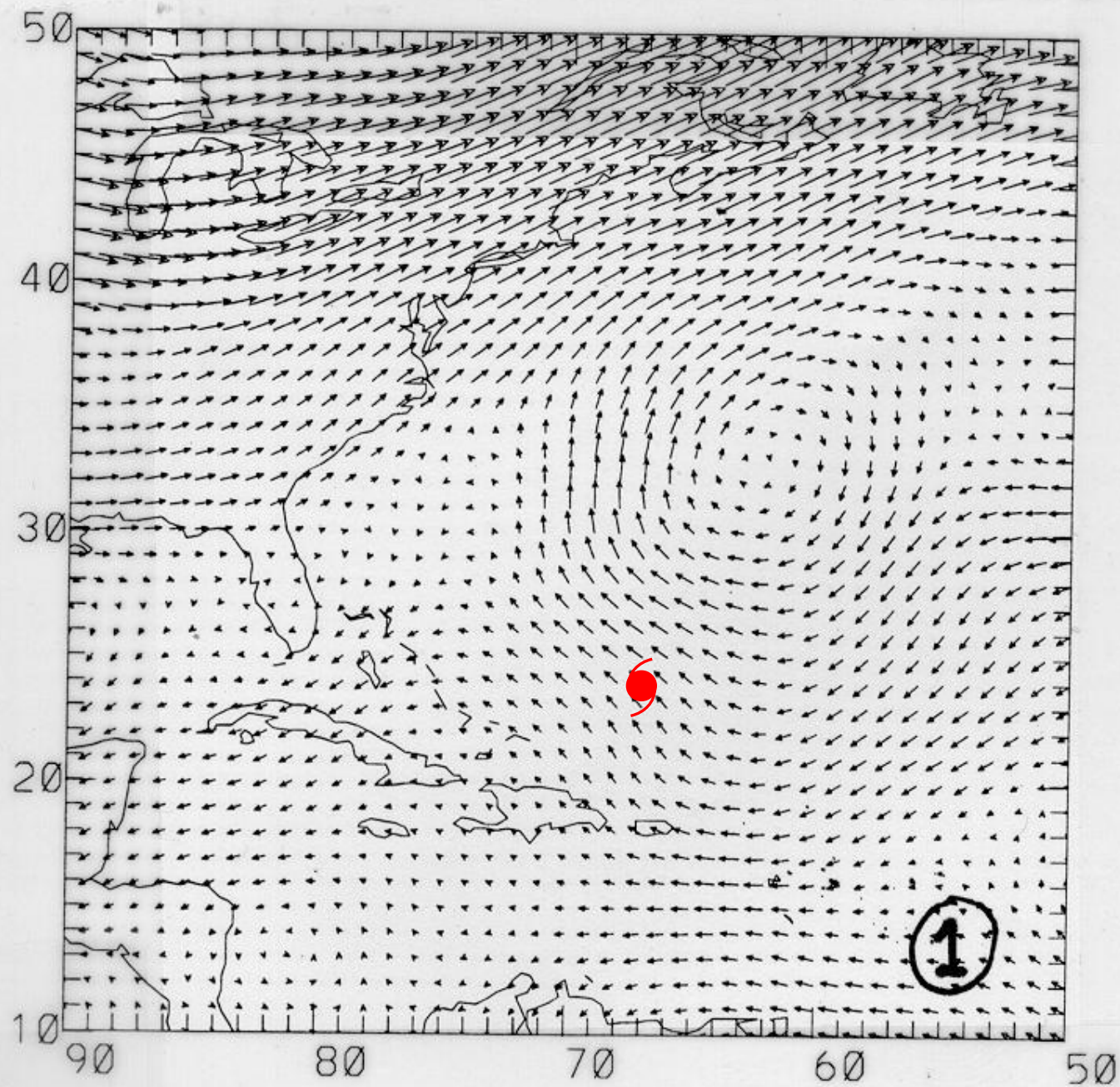
# Steering of Tropical Cyclones

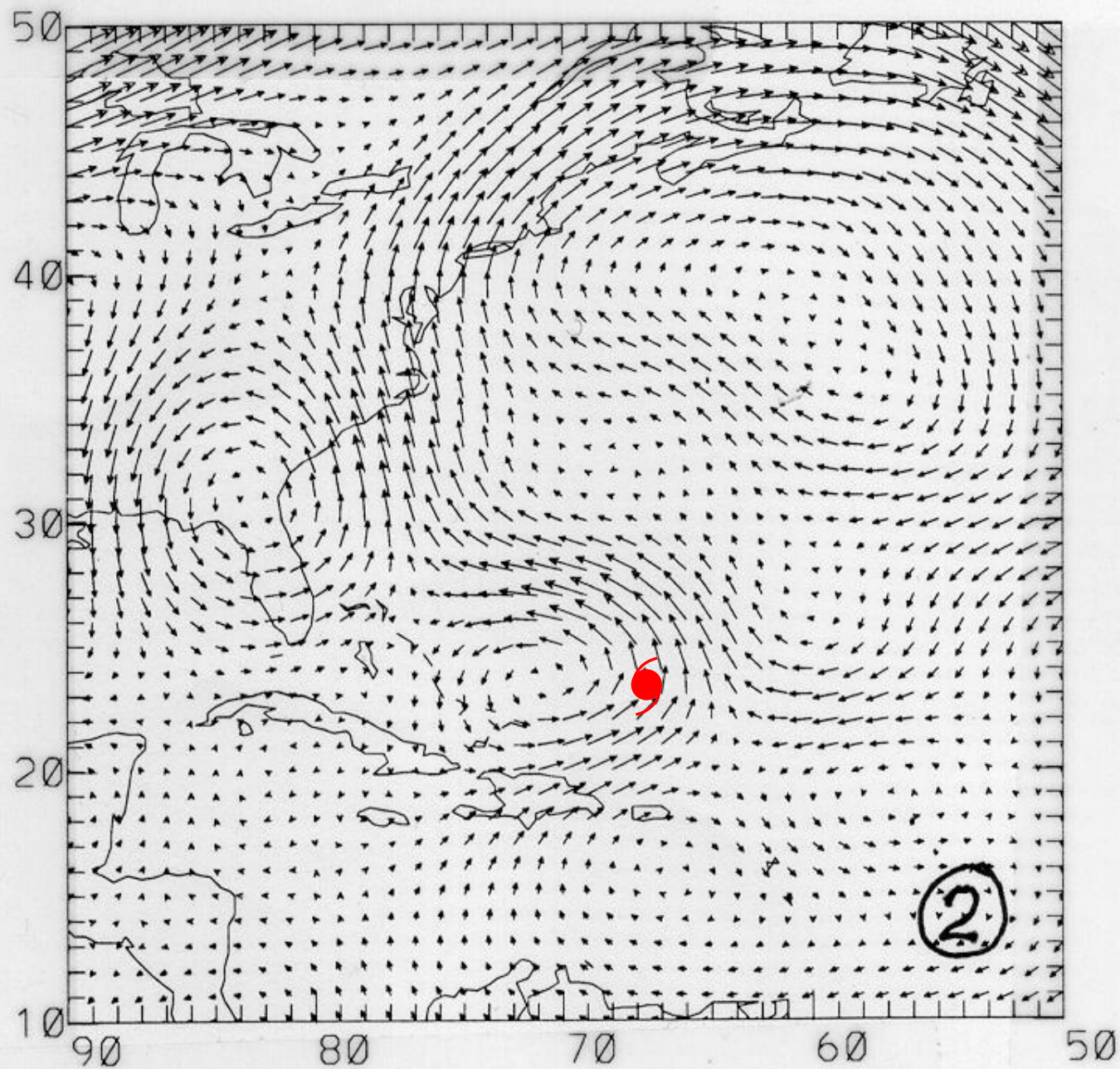
- \* The concept of “steering” of a TC by the environmental winds is still a very useful one.
- \* Which level(s) to use?
- \* The best single pressure level appears to be typically around 500mb.
- \* Even Better: A pressure-weighted deep-layer (100-1000mb) mean wind field:

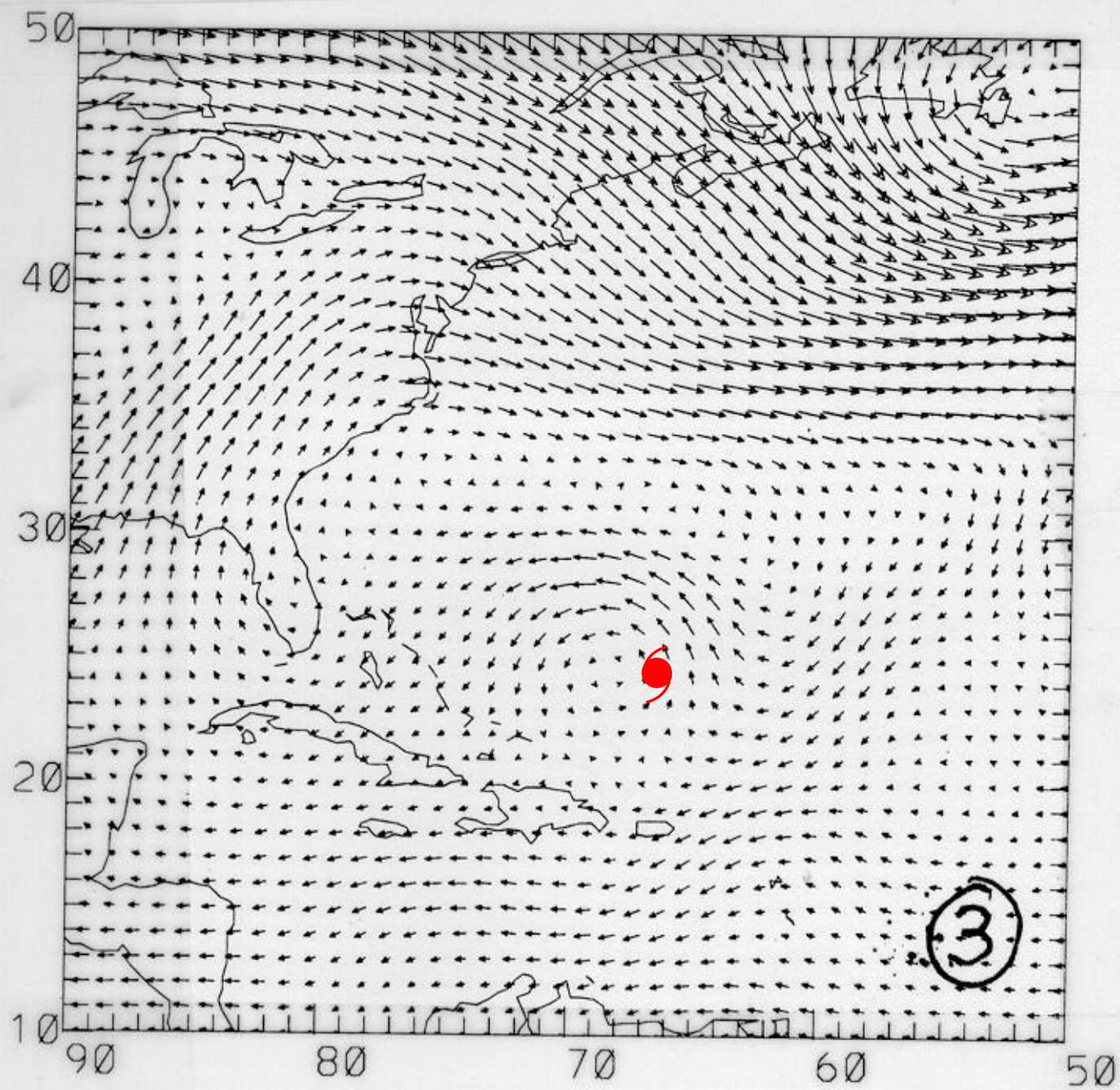
$$\frac{\int_{100}^{1000} (\vec{V}) dp}{\int_{100}^{1000} dp}$$

# Exercise 1

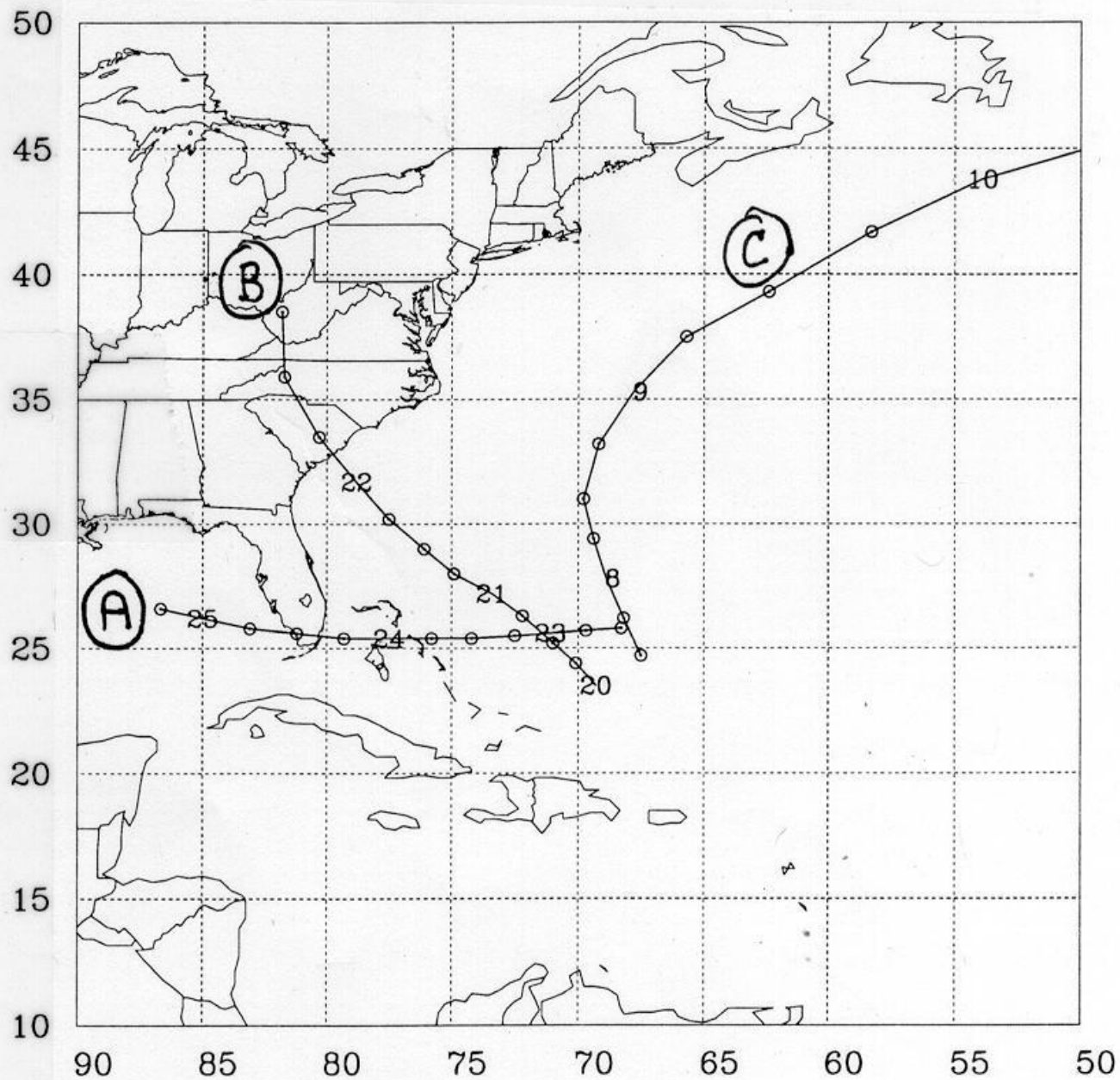
- You are given deep-layer mean wind plots for 3 tropical cyclones (TCs) that were located in the vicinity of 24-25°N 67-70°W.
- Also shown are the subsequent 72-h tracks taken by the 3 TCs.
- Match up each deep-layer flow chart with the correct track.
- Bonus: What were the names/years of the 3 TCs?





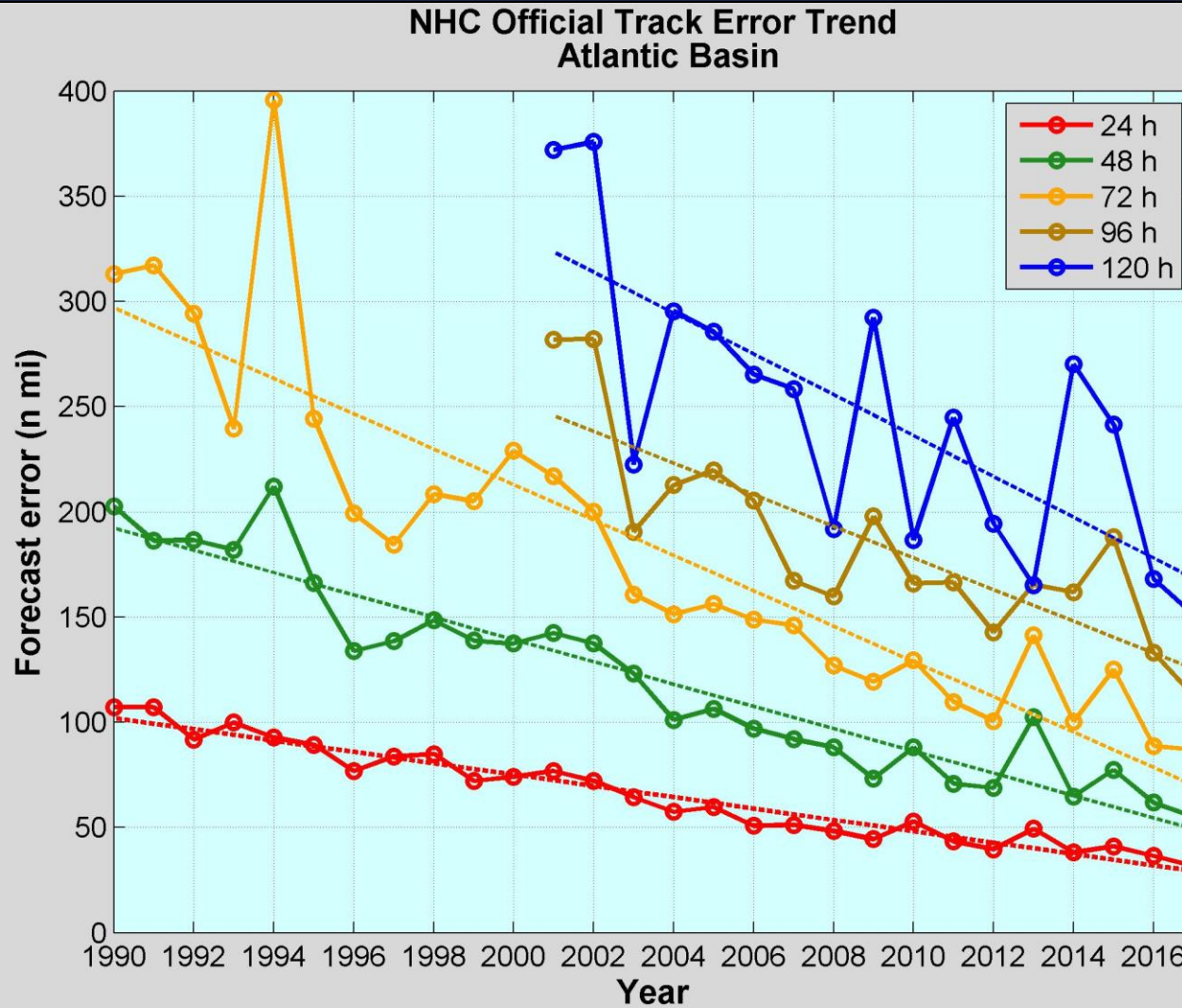


# 72 HR STORM TRACKS



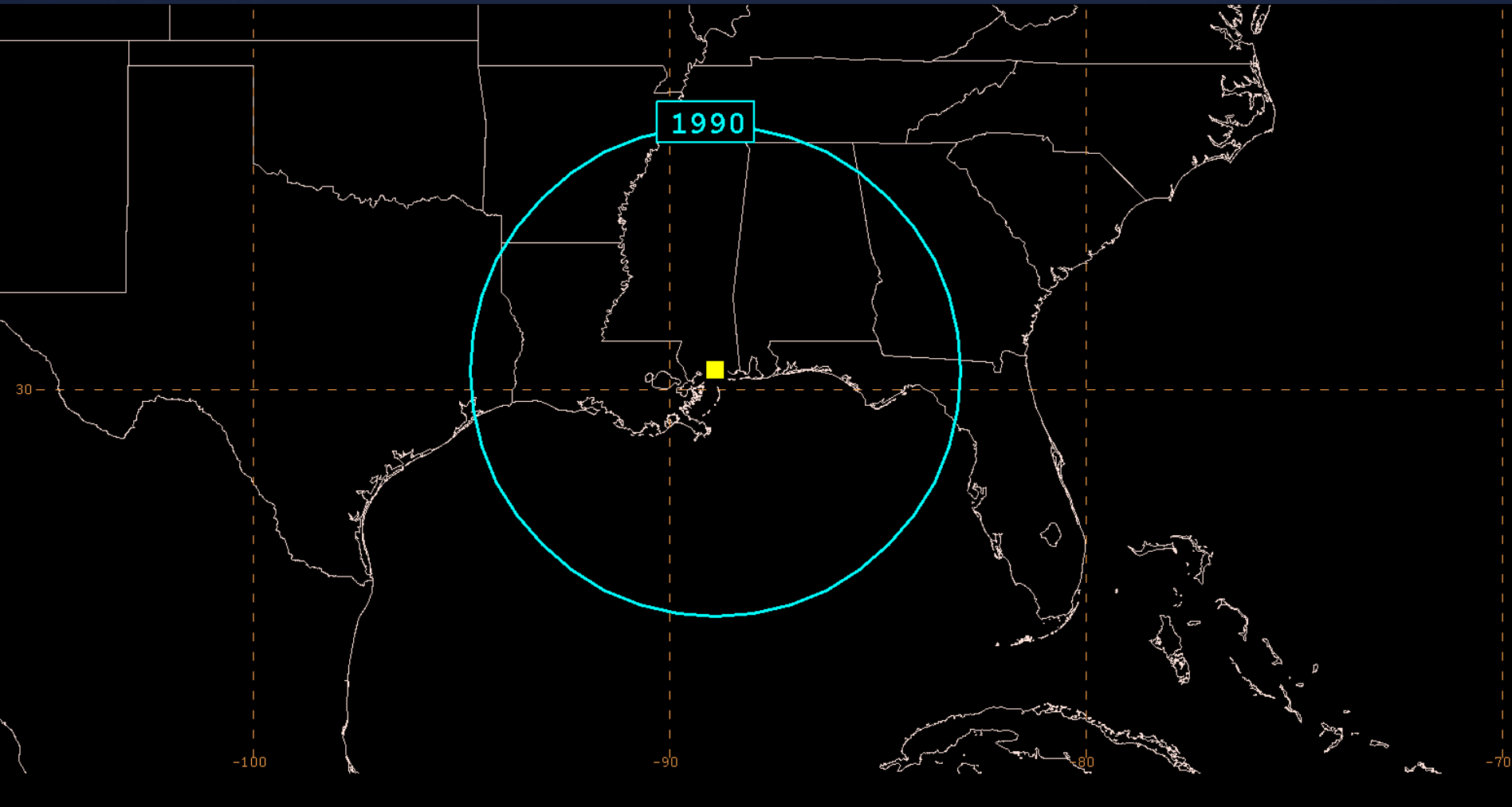


# Atlantic Track Error Trends



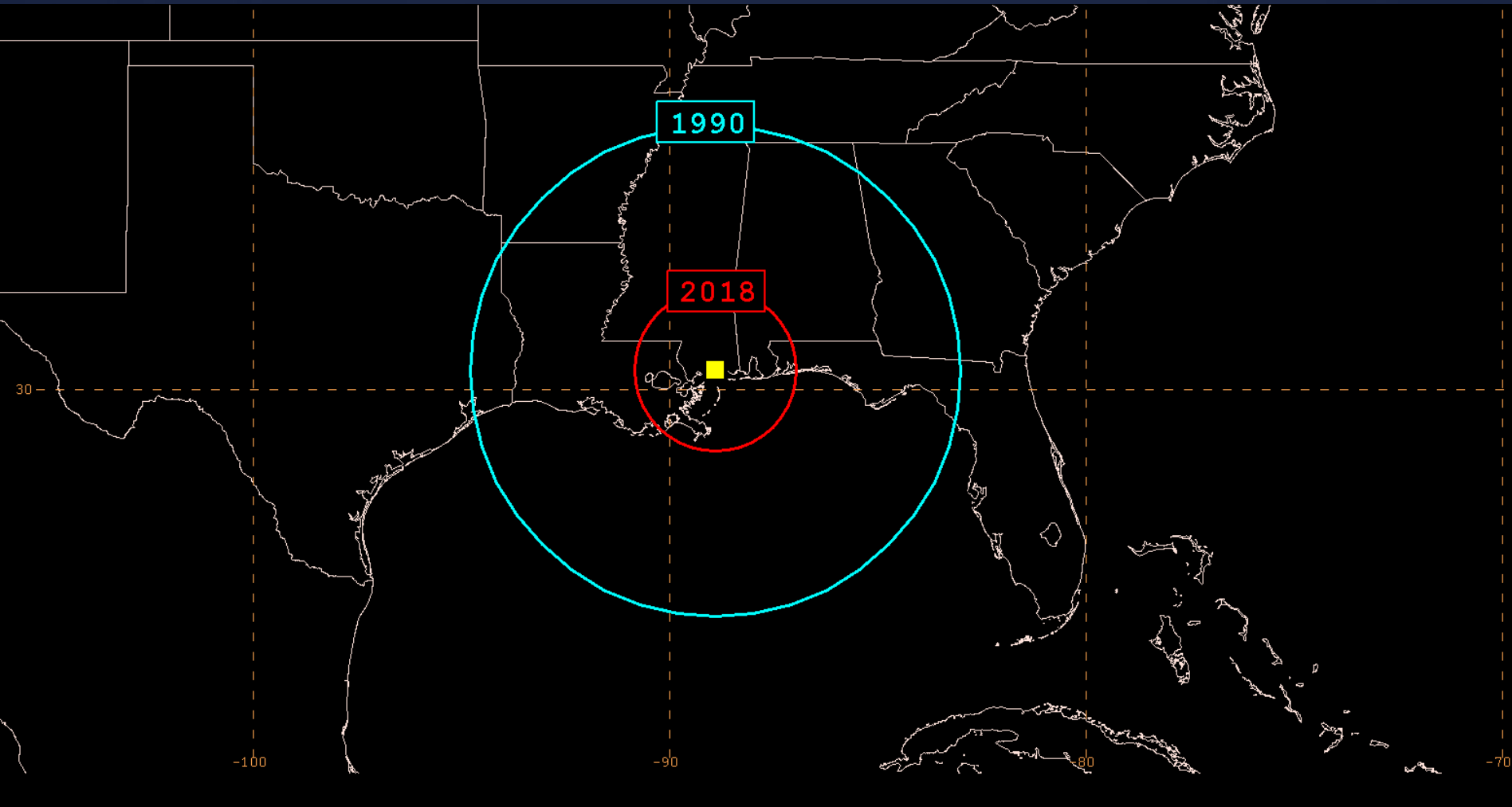


# 3-day NHC Average Track Error





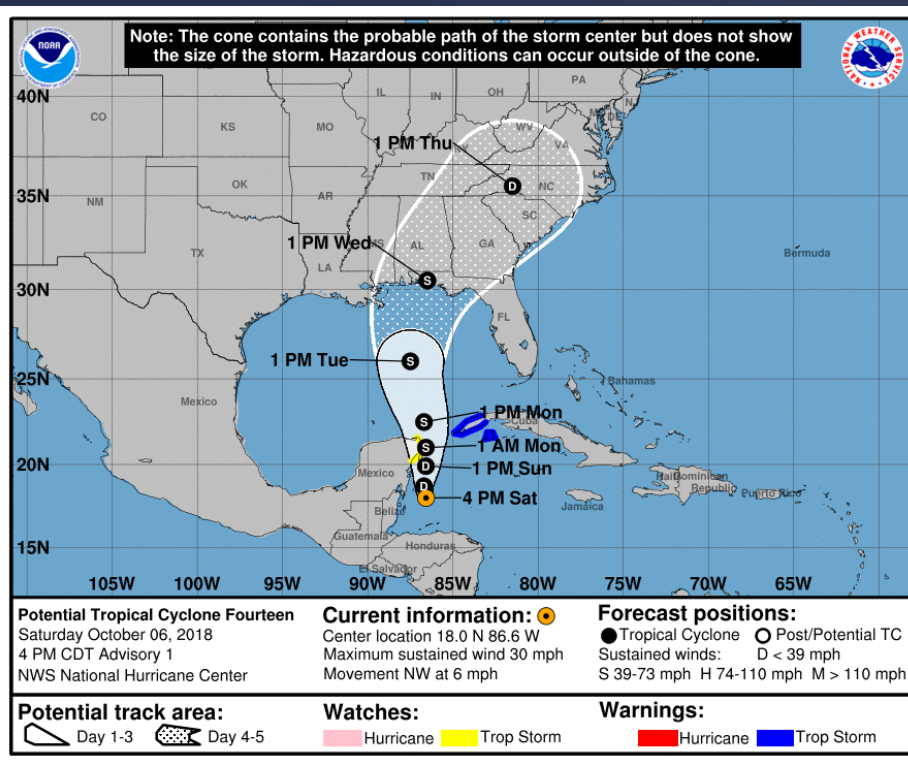
# 3-day NHC Average Track Error



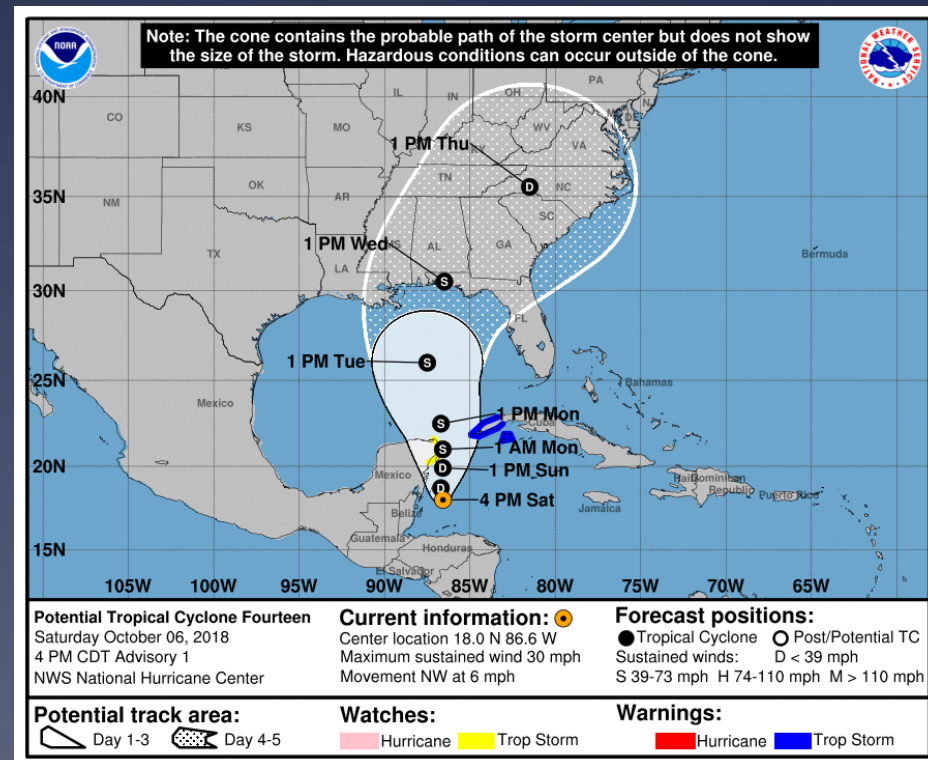
# Forecast Verification

## OFCL Error Distributions and Cone Radii

The size of the NHC forecast uncertainty cone is now determined by the 67<sup>th</sup> percentiles of the NHC official forecast errors over the previous 5 year period. The cone is formed by connecting circles at 12, 24, 36 h, etc., where the radius of each circle is given by the 67<sup>th</sup> percentile. The circles are reevaluated each season, and they are tending to get smaller as years go by.



2018 Cone



2008 Cone



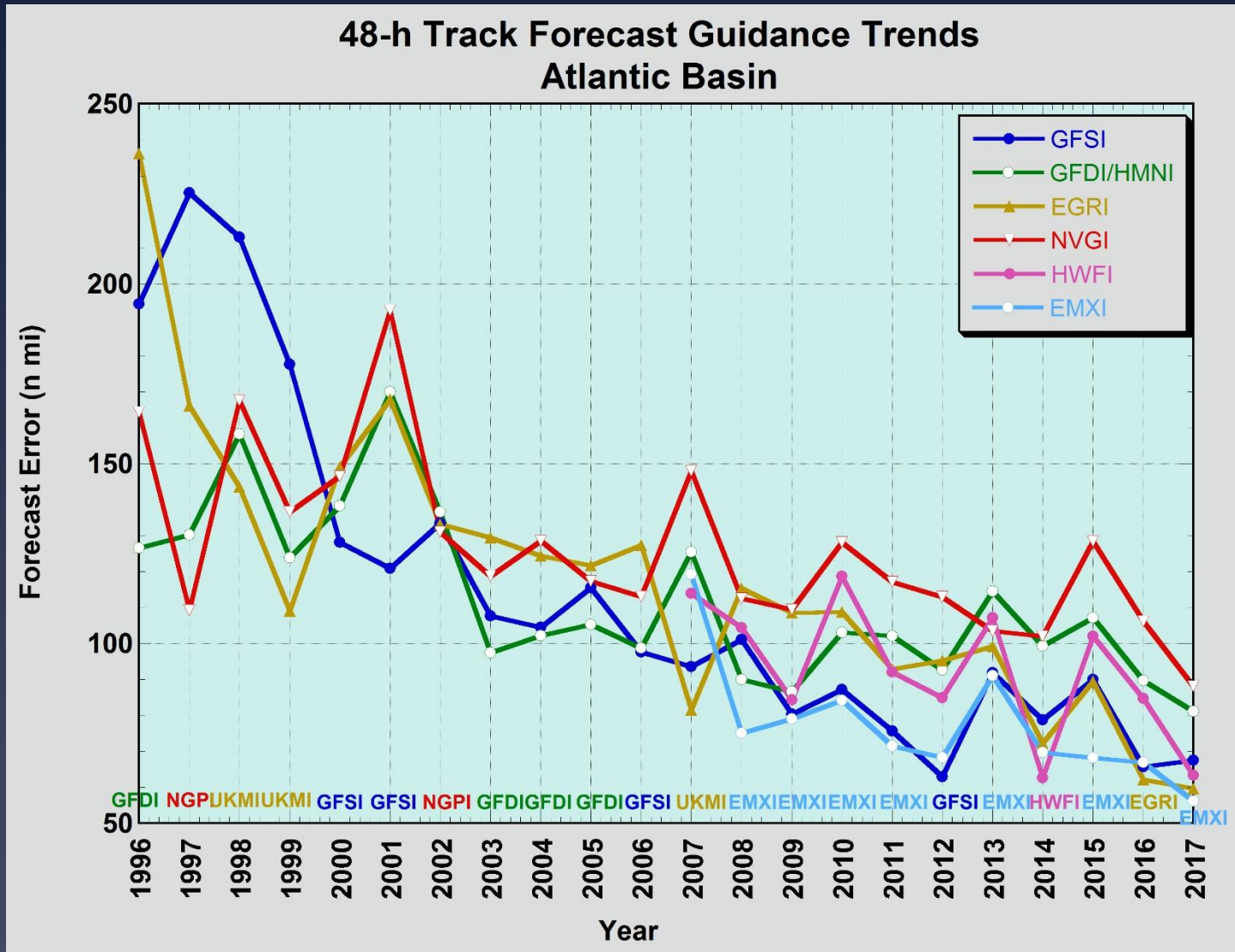
# 2019 Atlantic Cone (preliminary)



Forecast period (h)	Circle radii (n mi)	Percent change from 2018
12	26	0
24	41	-5
36	54	-4
48	68	-8
72	102	-1
96	151	0
120	198	0

**NHC is considering changing definition to increase the size of the cone.**

# Track Model Trends



*Advancements in technology and science are primarily responsible for these large improvements*

# Numerical Weather Prediction Models for TC Track Prediction

# Hierarchy of TC Track Models

- \* Statistical
  - \* CLIPER: Forecasts based on established relationships between storm-specific information (i.e., location and time of year) and the behavior of previous storms
- \* Simplified dynamical
  - \* TABS, TABM, TABD: Forecasts based on simplified dynamic representation of interaction with vortex and prevailing flow (trajectory)
- \* Dynamical
  - \* GFS, ECMWF, UKMET, CTCX, HWRF, HMON: solve the three-dimensional physical equations of motion that govern the atmosphere.
- \* Consensus
  - \* TVCN, HCCA, FSSE, AEMI: Based on multi-model or single-model ensembles

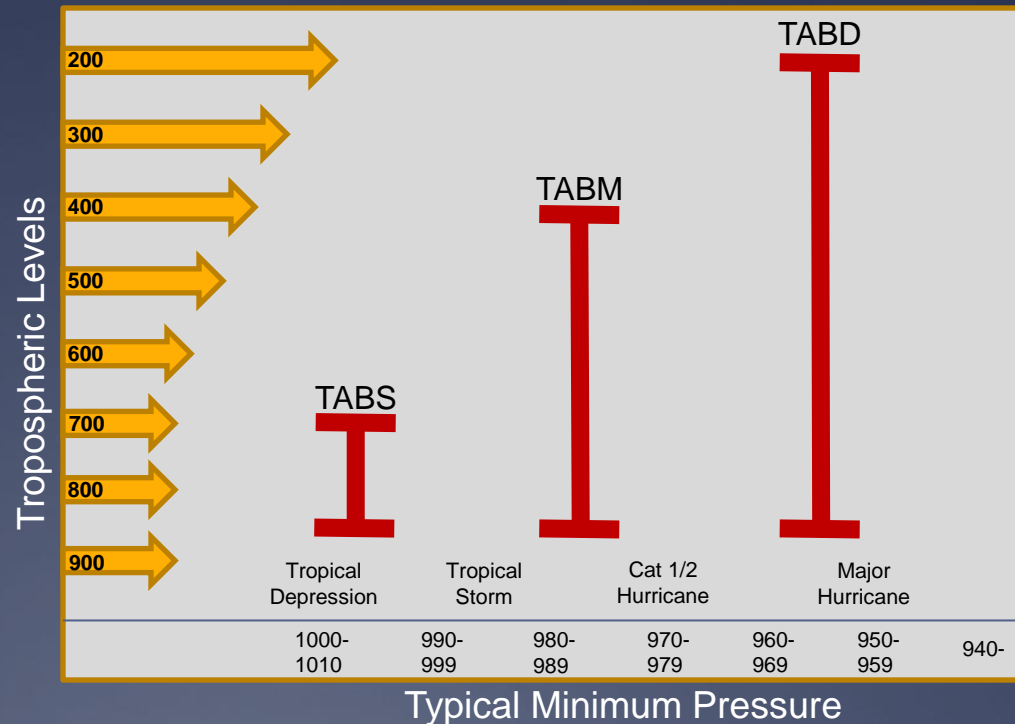
# Climatology and Persistence Model (CLIPER)

- \* Statistical model, developed in 1972, extended from 3 to 5 days in 1998, re-derived in 2005.
  - \* Developmental sample is 1931-2004 (ATL), 1949-2004 (EPAC).
- \* Required inputs:
  - \* Current and 12-h old speed and direction of motion
  - \* Current latitude and longitude
  - \* Julian day, maximum wind
- \* No longer provides useful operational guidance, but is used as a benchmark for other models and the official forecast. If a model has lower mean errors than CLIPER it is said to be “skillful”.
- \* New version has been developed that can be extended to 7 days (or beyond).

# Simplified Dynamical Models

## \* **Trajectory and Beta**(TABS, TABM, TABD)

- \* Two-dimensional “trajectory” model. Uses steering determined from a global model (GFS), averaged over a 400km radius circle around the storm location at a given time.
- \* Adds a correction to simulate the Beta effect (about 0.7 m/s)
- \* Includes a small component of persistence
- \* Three versions, representing different depths of steering flow. The spread of these is a useful indicator of environmental vertical shear:
  - \* TABS (shallow): 850-700 mb
  - \* TABM (medium): 850-400 mb
  - \* TABD (deep): 850-200 mb



# Three-Dimensional Dynamical Models

- \* Dynamical models
  - \* May be global or limited area.
  - \* May be grid point or spectral.
  - \* May employ a “bogussing” scheme to represent the TC vortex.
- \* Global models
  - \* Have inadequate resolution to define the TC inner core (eye and eyewall structure).
  - \* Are often useful for forecasting TC size and outer wind structure.
  - \* Have no lateral boundary conditions and therefore should have better performance at longer ranges than limited area models.
- \* Limited Area (Regional) models
  - \* Generally have higher horizontal resolution and are therefore more capable of representing core structure and intensity change.
  - \* Performance degrades at longer ranges.

# Operational Global Models for TC Track Forecasting

- \* National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS)
- \* United Kingdom Met Office Model (UKMET)
- \* Navy Global Environmental Model (NAVGEM)
- \* European Centre for Medium Range Weather Forecasting Model (ECMWF)
- \* Canadian Global Deterministic Prediction System (CMC)

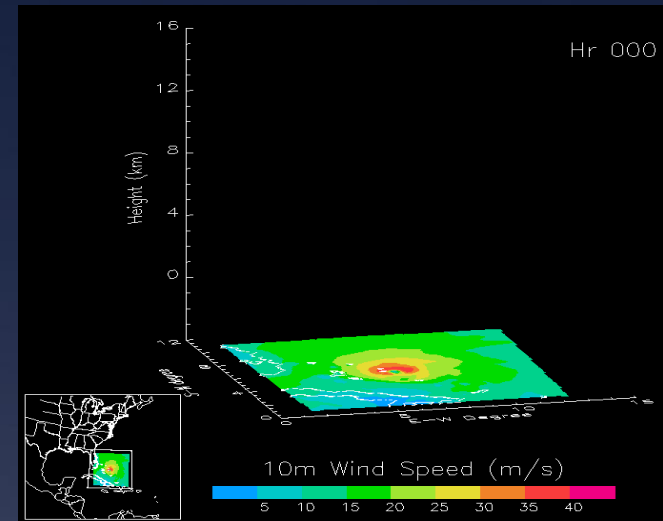
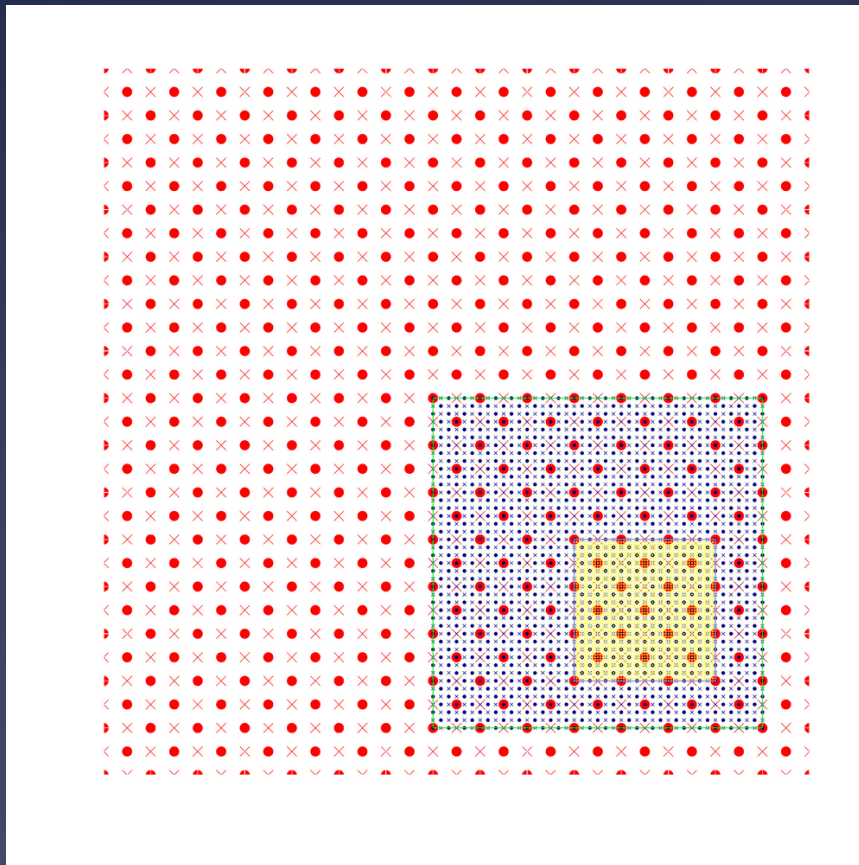
Each model consists of its own independent dynamical core, long- and short-wave radiation, cumulus convection, large-scale precipitation, surface fluxes, turbulent transports, and cloud microphysics.

SUMMARY OF NWP MODELS USED BY NHC FOR TC TRACK PREDICTION							
ATCF ID Tracker	Global/Regional Model Name	Horizontal Resolution	Vertical Levels and Coordinates	Data Assimilation	Convective Scheme	Cycle/Run Frequency	2018 TVCN INCLUSION
NVGM/NVGI	Navy Global Environmental Model	Spectral ~31km	60 Hybrid Sigma-pressure	NAVDAS-AR 4D-VAR	Simplified Arakawa-Schubert (SAS)	6 hr (144 hr) 00/06/12/18 UTC	NO
AVNO/AVNI	Global Forecast system	Spectral 13km	64 Hybrid Sigma-pressure	GSI/4D-VAR EnKF hybrid, including TC central pressure	Simplified Arakawa-Schubert [Arakawa and Schubert (1974) / Pan and Wu (1994)]	6 hr (240 hr) 00/06/12/18 UTC	YES
EMX/EMXI EMX2	European Centre for Medium-Range Weather Forecasts	Spectral ~9km	137 Hybrid Sigma-Pressure	4D-VAR	Tiedke mass flux [Tiedke (1989)]	12 hr (240 hr) 00/12 UTC	YES
EGRR/EGRI EGR2	U.K. Met Office Global Model	Grid Point ~10km	70 Hybrid Sigma-Pressure	4D-VAR Ensemble Hybrid	UKMET [Gregory and Rowntree (1990)]	12 hr (144 hr) 00/12 UTC	YES
CMC/CMCI	Canadian Deterministic Prediction System	Grid Point ~25km	80 Hybrid Sigma-Pressure	4D-VAR ensemble Hybrid	Kain -Fritsch [Kain and Fritsch (1990, 1993)]	12 hr (240 hr) 00/12 UTC	NO
HWRF/HWFI	Hurricane Weather Research and Forecast System	Grid Configuration 3 nests 13.5-4.5-1.5 km	75 Hybrid Sigma-Pressure	4D-VAR Hybrid GDAS GFS IC/BC	SAS mom. mix. + GFS shallow convection (6km and 18km) 2km nest – none	6 hr (126 hr) 00/06/12/18 UTC Runs commence on NHC/JTWC request	YES
HMON	Hurricane Multi-scale Ocean-coupled Non-hydrostatic model	Grid Configuration 3 nests 18-6-2 km	51	None for this season	SAS	6 hr (126 hr) 00/06/12/18 UTC Runs commence on NHC/JTWC request	NO
CTCX/CTCI	NRL COAMPS-TC (using GFS for IC and BC)	Grid Configuration 3 nests 45-15-5 km	40	3D-VAR (NAVDAS) EnKF DART	Kain-Fritsch Kain and Fritsch (1990, 1993)	6 hr (126 hr) 00/06/12/18 UTC Runs commence on 1 <sup>st</sup> NHC/JTWC advisory	YES

# Operational Regional Models for TC Track Forecasting

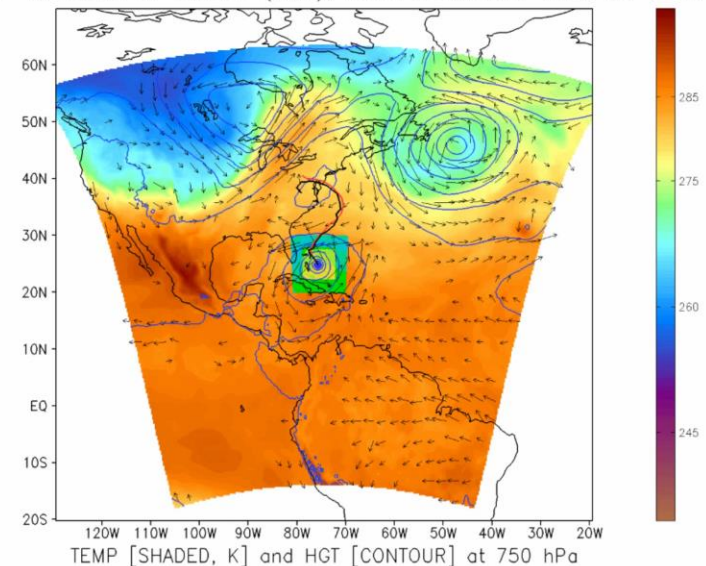
- \* **Hurricane Weather Research and Forecasting model (HWRF)**
  - \* HWRF is the only model that assimilates some inner-core or near-inner-core data, i.e. airborne Doppler velocities flight-level reconnaissance wind data
- \* **Hurricane Multi-scale Ocean-coupled Non-hydrostatic model (HMON)**
  - \* Replacement for GFDL model, first ran operationally in 2017
  - \* Shares many parameterization schemes with HWRF, but no data assimilation
- \* **Coupled Ocean-Atmosphere Mesoscale Prediction System for Tropical Cyclones (COAMPS-TC)**
  - \* 2 versions: one runs using initial and boundary conditions off of NAVGEM and the other off of GFS; the latter produces superior forecasts and is used by NHC

# Regional Modeling: Nesting and Storm Structure



**Three telescopic domains: 18km:  
75x75°; 6km ~11x10° 2km inner-most  
nest 6x5.5°**

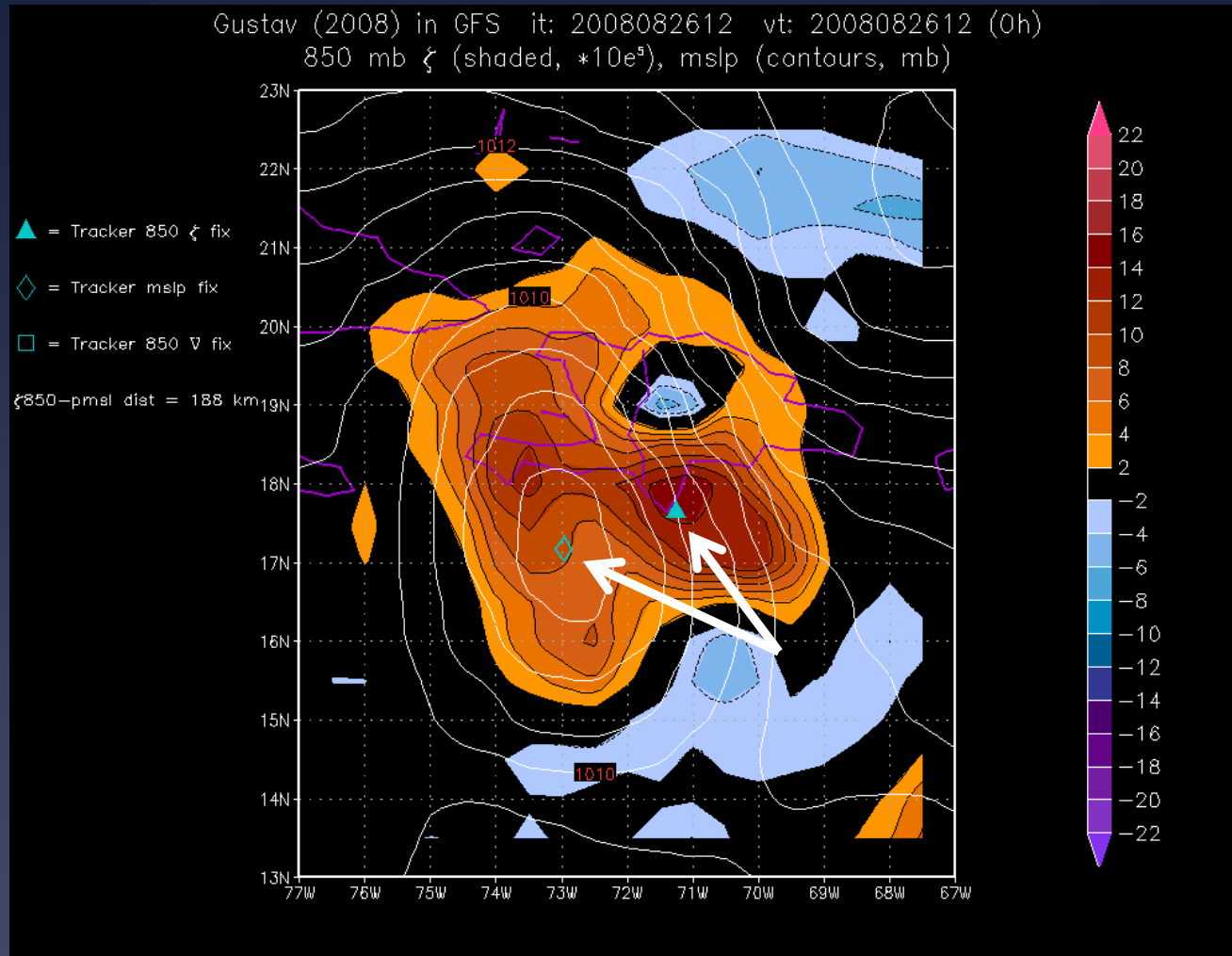
HWRf forecast of SANDY (18L); IC:2012102600 valid at 00 h



# Tracker Design

- \* Need to determine a point location of a storm in model output to use while making a track (or intensity) forecast
- \* An external tracker is applied to the model fields \*after\* the model run is complete
- \* A weighted average of the centroid positions of several low-level variables is used:
  - \* 850 mb vorticity
  - \* 700 mb vorticity
  - \* Surface/10m vorticity
  - \* 850 mb geopotential height
  - \* 700 mb geopotential height
  - \* Mean Sea Level Pressure
  - \* 3 secondary parameters (850 mb/700 mb/10m wind speed minimum)

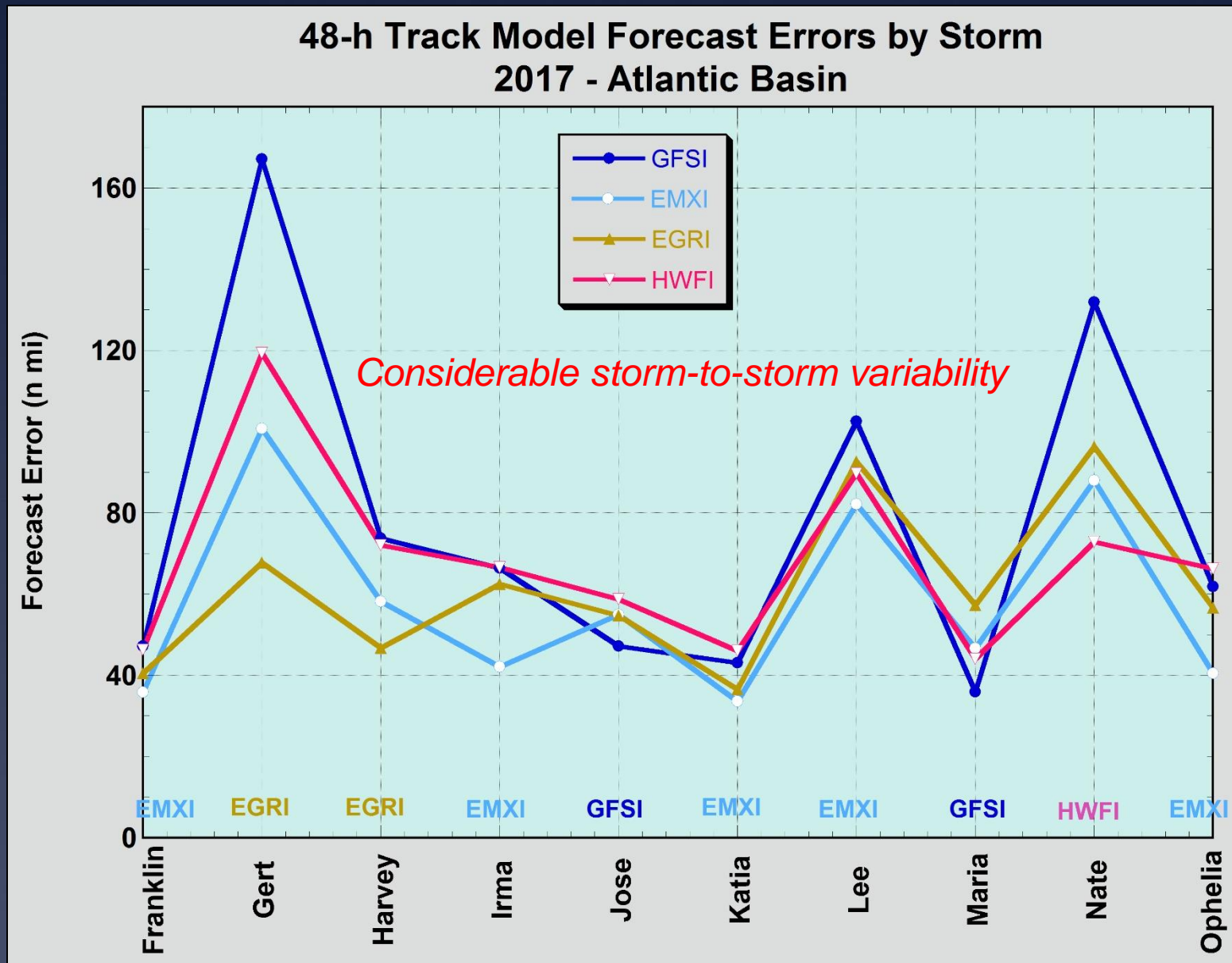
# Why the need for a multi-variate external tracker?



- Gustav in GFS: The SLP center was found 188 km from the vorticity center.

But which model should you use?

# 48-h Model Track Errors by Storm

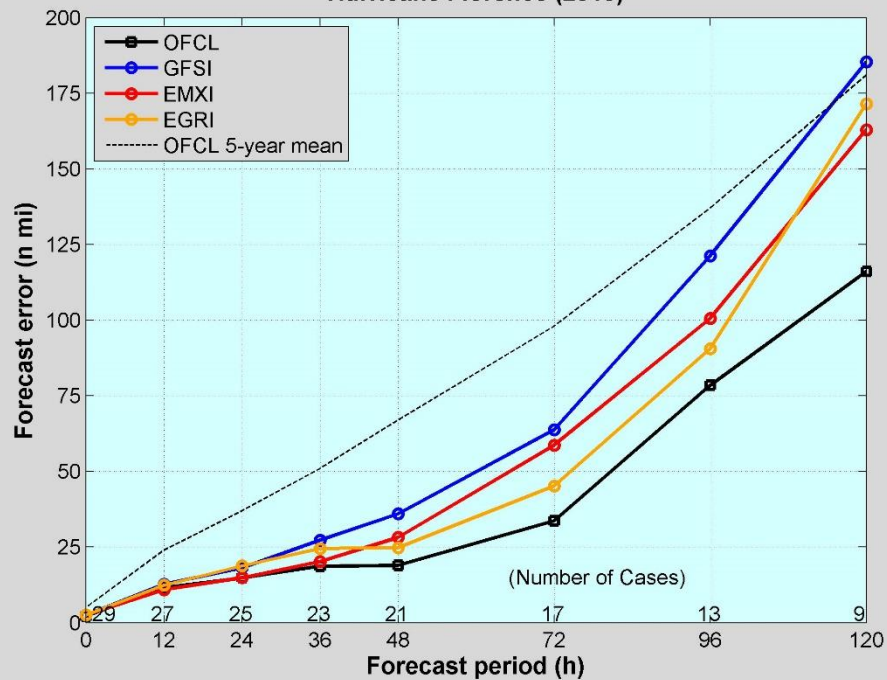




# Florence and Michael

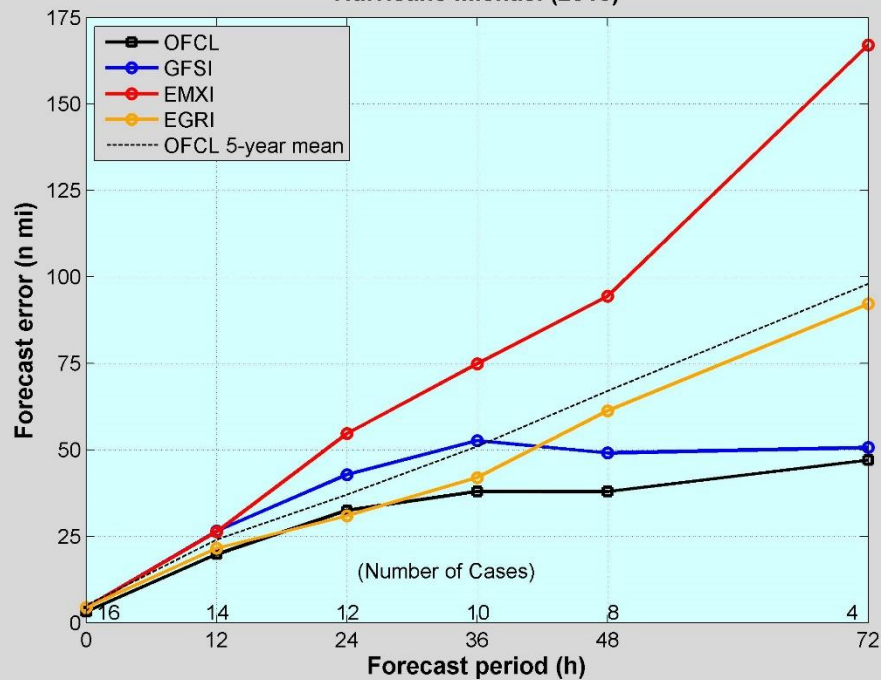
## Florence (W of 55W)

NHC and Model Track Errors  
Hurricane Florence (2018)



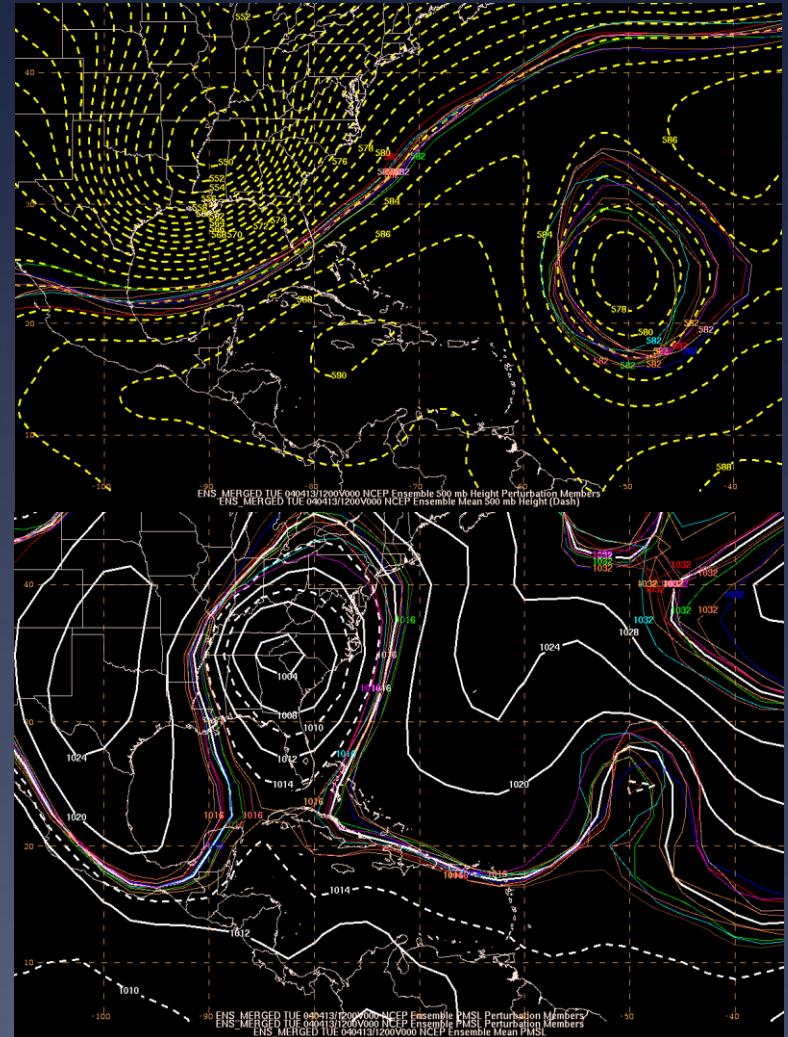
## Michael

NHC and Model Track Errors  
Hurricane Michael (2018)



# Ensembles and Consensus

- \* An **ensemble** is a collection of forecasts all valid at the same forecast time.
- \* Often formed by making multiple runs of a given model (e.g. the GFS) with slightly different initial conditions and/or randomly varying physics.
- \* At some forecast time, the average of all the ensemble member's forecasts is the **ensemble mean or consensus**. The average distance of each member's forecast from the ensemble mean is the **ensemble spread**.



# Ensembles and Consensus

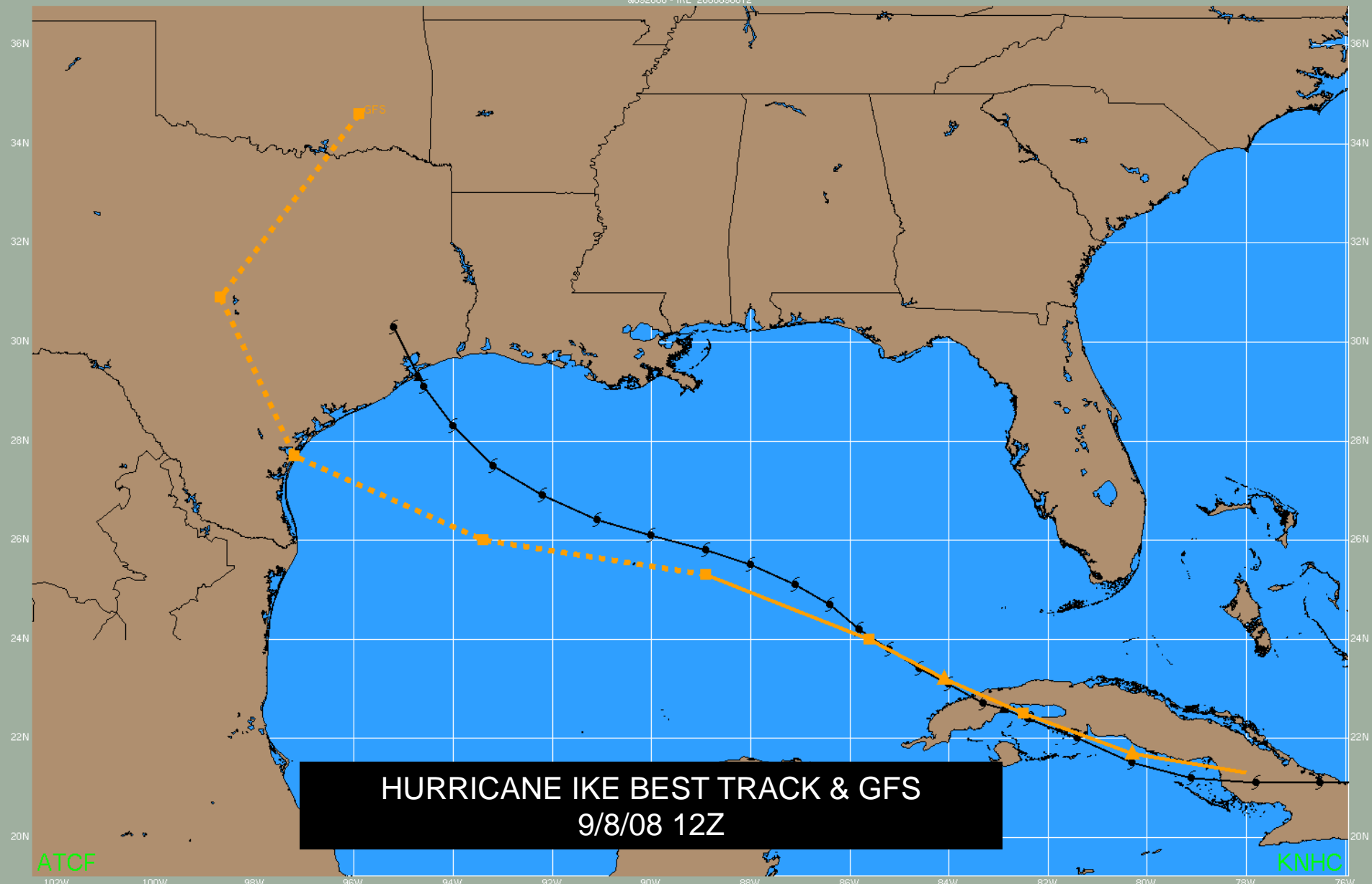
- \* In the case of a single model ensemble, the perturbed initial conditions represent uncertainty in the initial analysis. The model physics may also vary for each ensemble member.
- \* Single model ensembles are typically run with a lower resolution version of a model that is also used for the “deterministic” (regular) run
- \* **AEMN** is the average of the GFS ensemble members (**AEMI** is the interpolated version of the ensemble mean)

# GFS Ensemble example



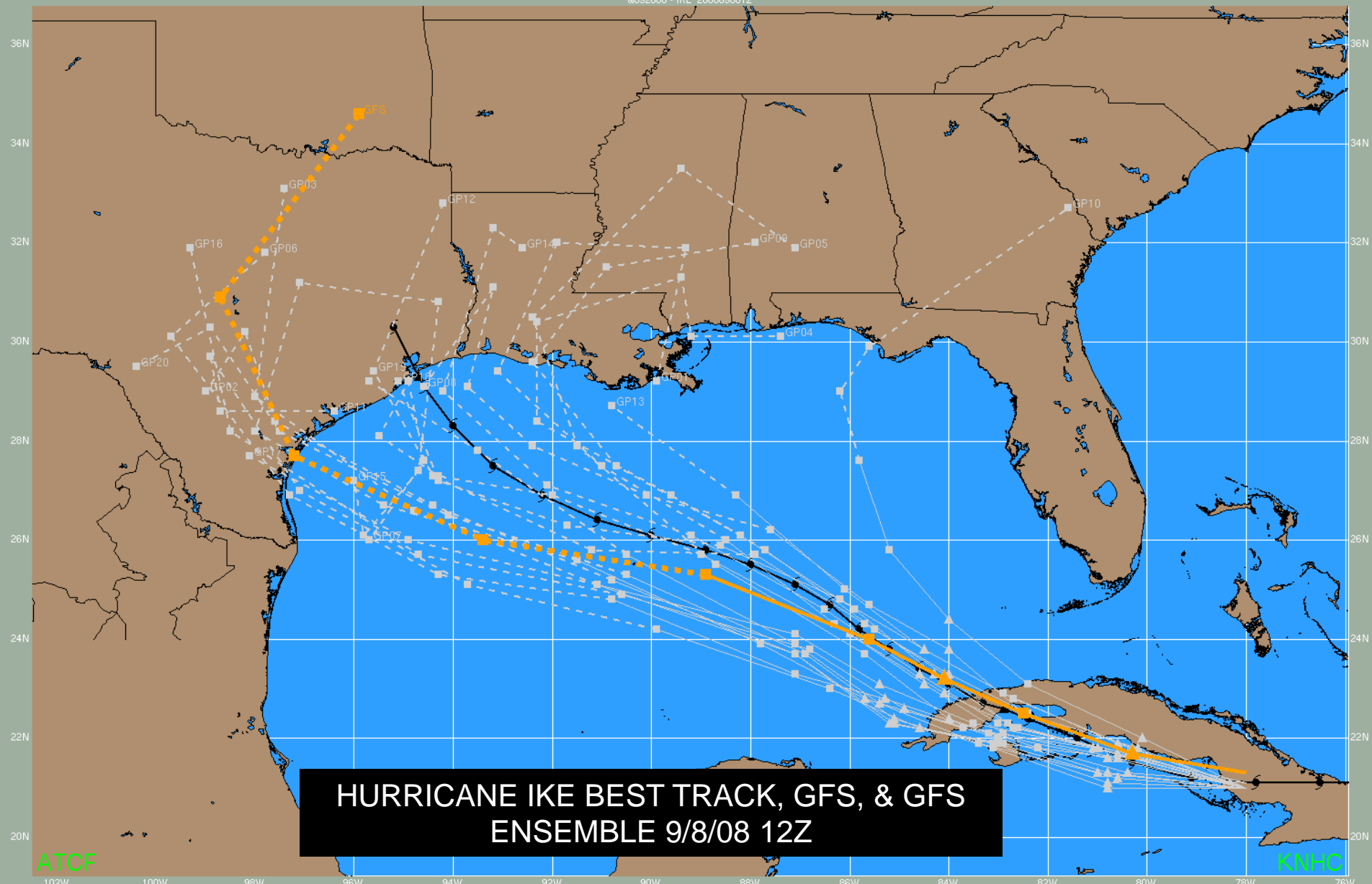
# GFS Ensemble example

092008 - IKE\_2008090812

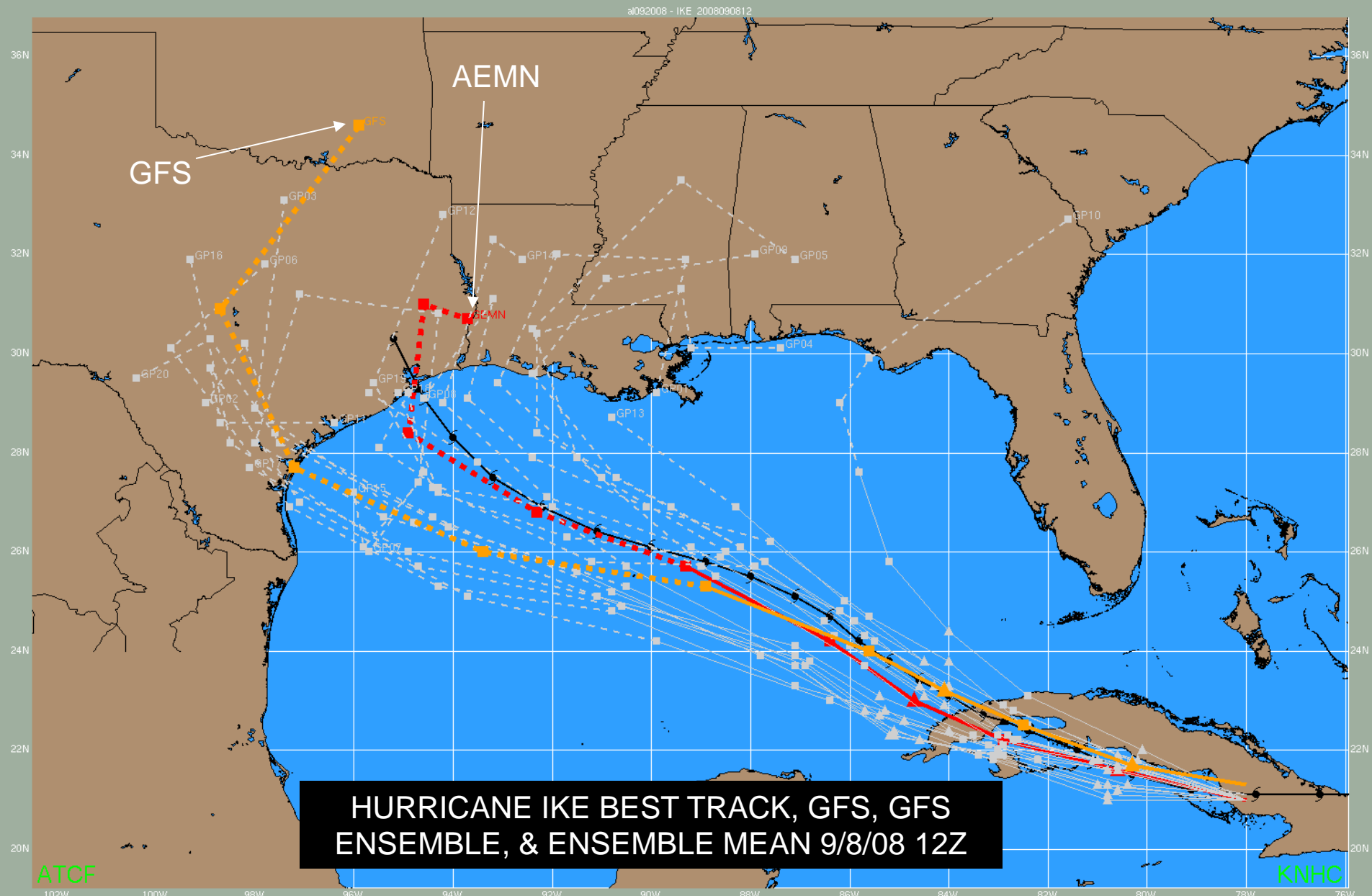


# GFS Ensemble example

092008 - IKE\_2008090812



# GFS Ensemble example

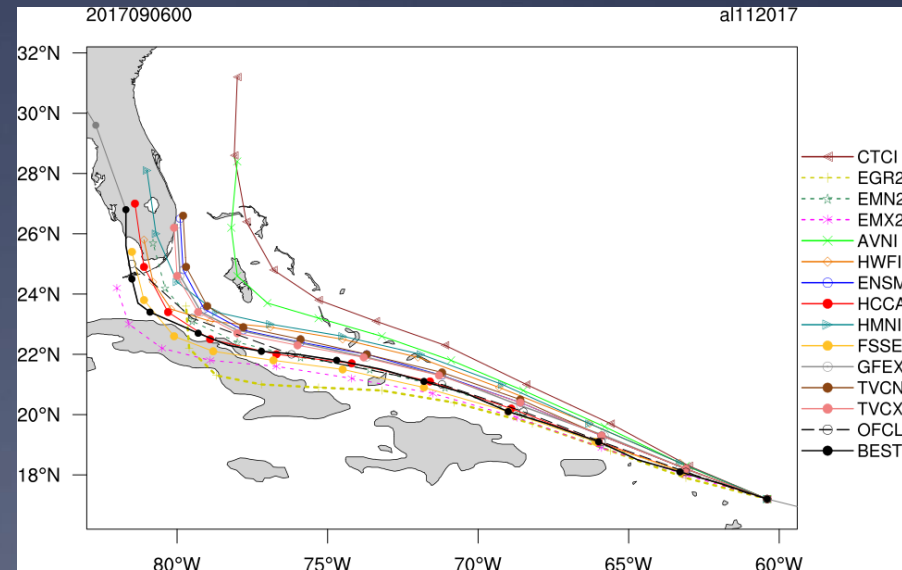
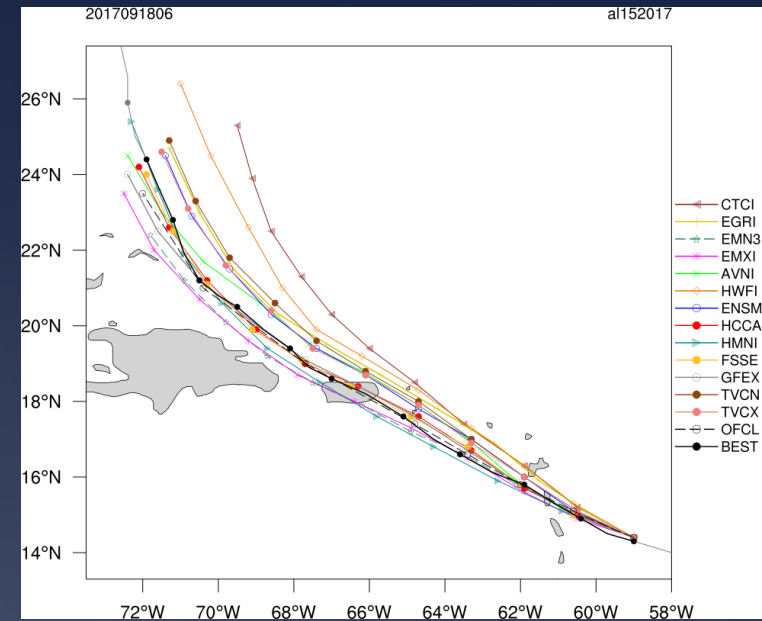


# Ensembles and Consensus

- \* Another way to form a consensus is to use an ensemble of different prediction models from the same initial time. This is called a **multi-model ensemble**.
- \* In a multi-model ensemble, the forecasts from the various member models differ due to differences in model initialization, dynamical cores, and model physics.
  - \* **TVCN** is the average of at least two of GFSI, EGRI, HWFI, CTCI, and EMXI (a “simple” average or consensus).
  - \* **FSSE and HCCA** are weighted averages of several models (and OFCI in FSSE). They include bias correctors to account for model error tendencies (a “smart” consensus).

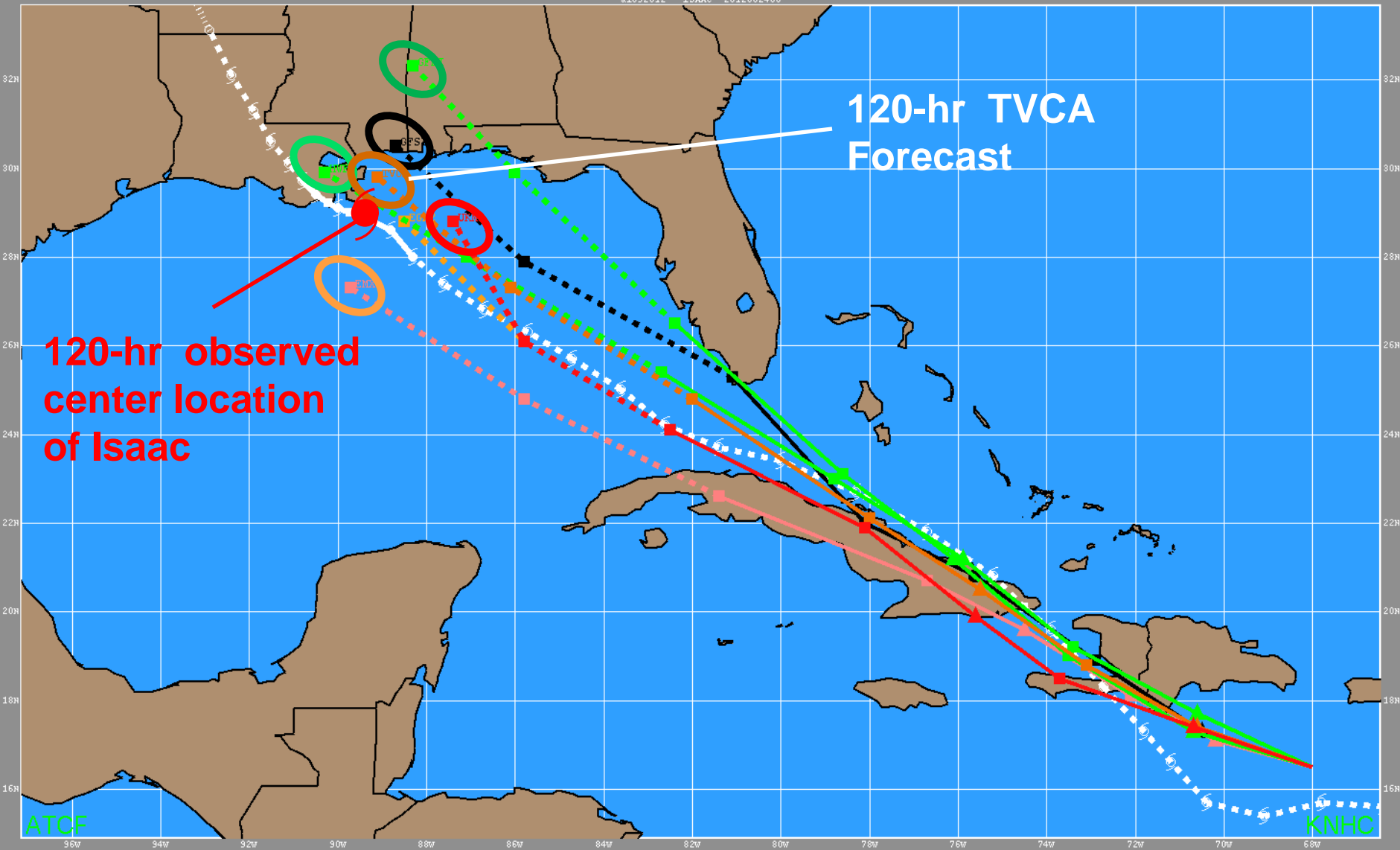
# HFIP Corrected Consensus Approach (HCCA) for Tropical Cyclone Track and Intensity Forecasts

- “in-house” unequally weighted consensus for TC track and intensity forecasts
- weighting coefficients chosen based on input model performance during a set of training forecasts
- 2017 input models for **track**: AVNI, CTCI, EGRI/2, EMN2/3, EMXI/2, HWFI
- 2017 input models for **intensity**:
  - **Atlantic**: AVNI, CTCI, DSHP, HWFI
  - **East Pacific**: AVNI, CTCI, DSHP, HWFI, LGEM

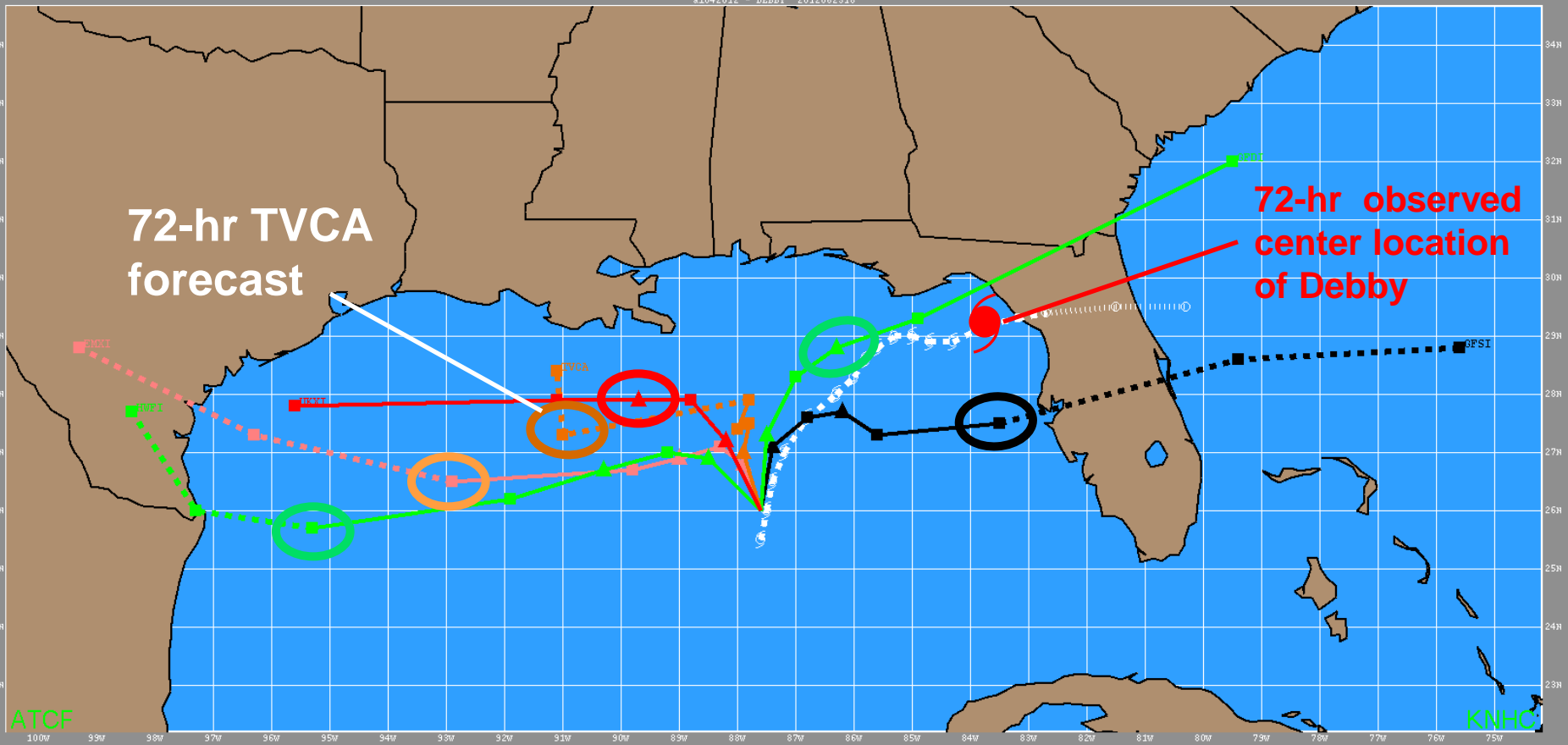


# Ensembles and Consensus

- \* Often, the most successful consensus models are those formed from an ensemble of good performing models with a high degree of independence.
- \* Recently, some single-model consensus models (especially the GFS ensemble) have performed as well as the deterministic version of the same model especially at longer ranges (day 5 and beyond).
- \* Inclusion of the single-model consensus mean into a multi-model corrected consensus (such as HCCA) may add more value than the inclusion of the corresponding deterministic model.



Excellent example of a TVCN consensus:  
Hurricane Isaac, 0000 UTC 24 Aug 2012



**Tropical Storm Debby 1800 UTC 23 June 2012**

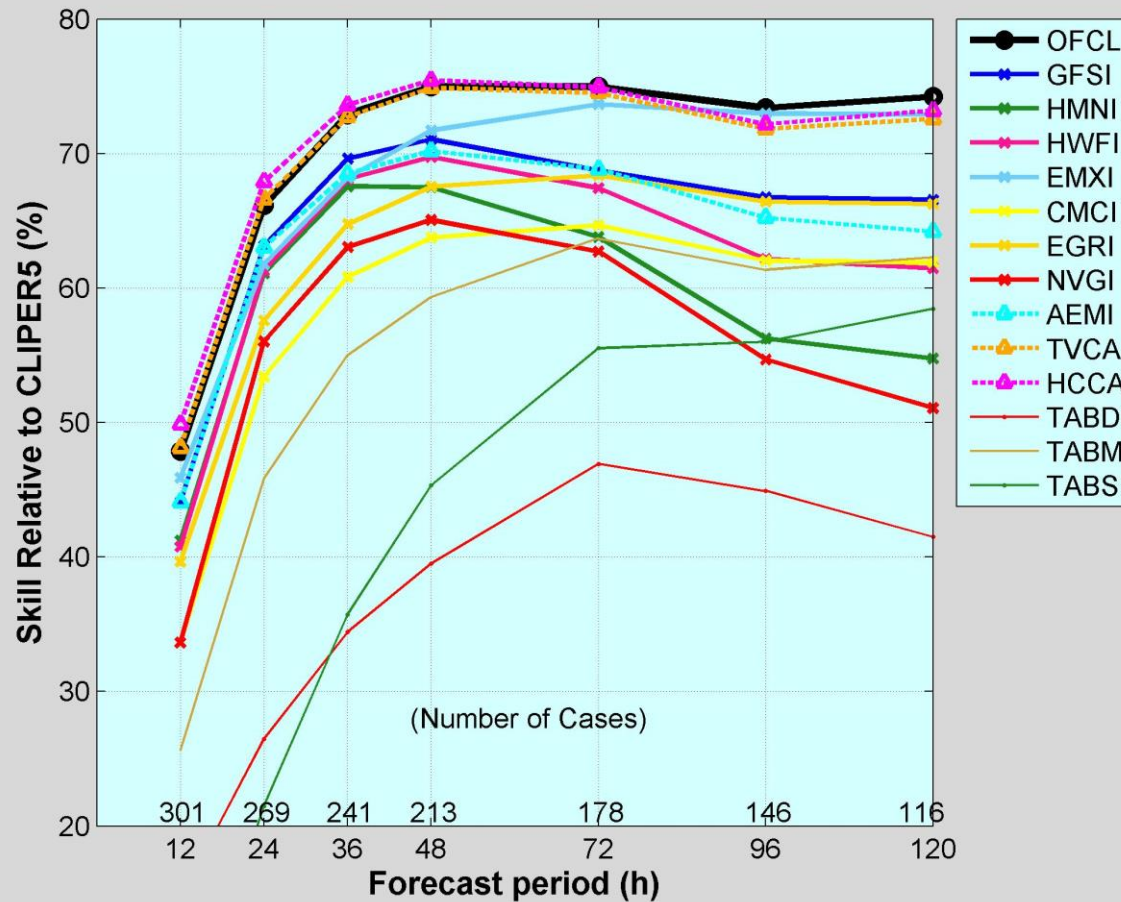
Of course, the consensus approach doesn't always work! Sometimes the forecaster might want to exclude certain models and form a "selective consensus", if the discrepancies among the models can be resolved.

Resolving these discrepancies is often more difficult than some may have you believe!



# 2018 Track Guidance

Track Forecast Skill (Early Models)  
2018 - Atlantic Basin



Official forecasts were very skillful and were near or better than the best performing models, the consensus aids (HCCA and TVCA).

EMXI best individual model at 48 h and beyond, and close to consensus aids at longer ranges.

GFSI best individual model at 24 and 36 h, but less skill than EMXI after that.

HWFI, AEMI, EGRI were fair performers (near the middle of the pack).

CMCI, NVGI, HMNI, and trailed in 2018.



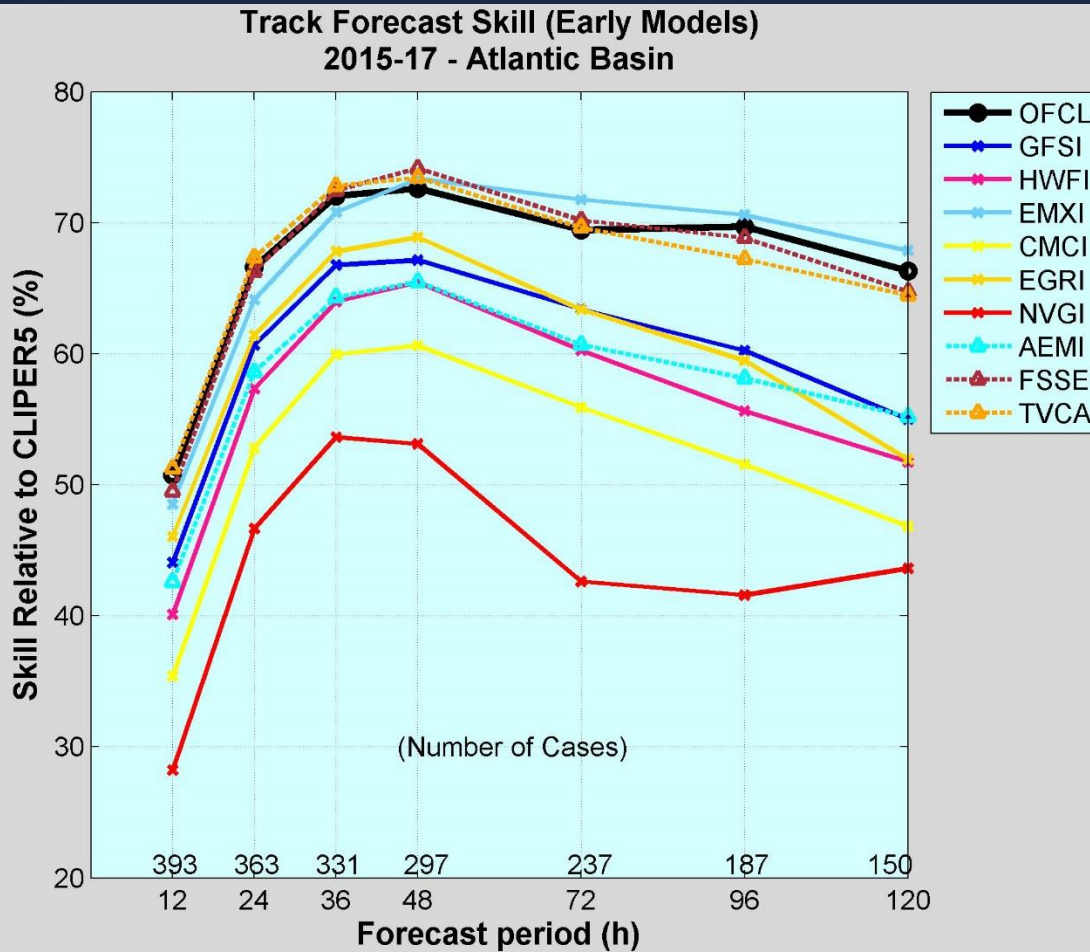
# 2015-17 Track Guidance

*Official forecasts were very skillful, near or better than the consensus aids.*

*EMXI best individual model, beating even the official forecast at 72h and beyond*

*GFSI, EGRI, AEMI, HWFI make up the middle tier of models.*

*NVGI and CMCI trailed.*



# Early vs. Late Models

- \* Forecast cycle begins at synoptic time (e.g., 12Z), and forecast is released at  $t+3$  h (15Z).
- \* The 12Z runs of the dynamical models (HWRF, GFS, etc.), are not available until 16Z-19Z, well after forecast is made and released.
  - \* These models are known as “late models”
- \* Forecasts that are available in time for forecast deadlines are called “early” models (TABs, CLIPER).
- \* For the 12Z forecast cycle, the latest available run of each model is taken (from the 06Z or even 00Z cycle), and adjusted to apply at 12Z. These modified forecasts are known as “interpolated” models (HWFI, GFSI, etc.).

# Early vs. Late Models

- \* Interpolated models are created by adjusting a smoothed version of the previous model run such that its 6 h forecast position exactly agrees with the current storm position. Then the rest of the forecast is adjusted by the same vector.



# Early vs. Late Models

- \* Interpolated models are created by adjusting the previous model run such that its 6 h forecast position exactly agrees with the current storm position. Then the rest of the forecast is adjusted by the same vector.



The “early” version of the model is what the forecasters actually have available to them when making a forecast

OFCL is verified against the early models

# Early and Late Model IDs

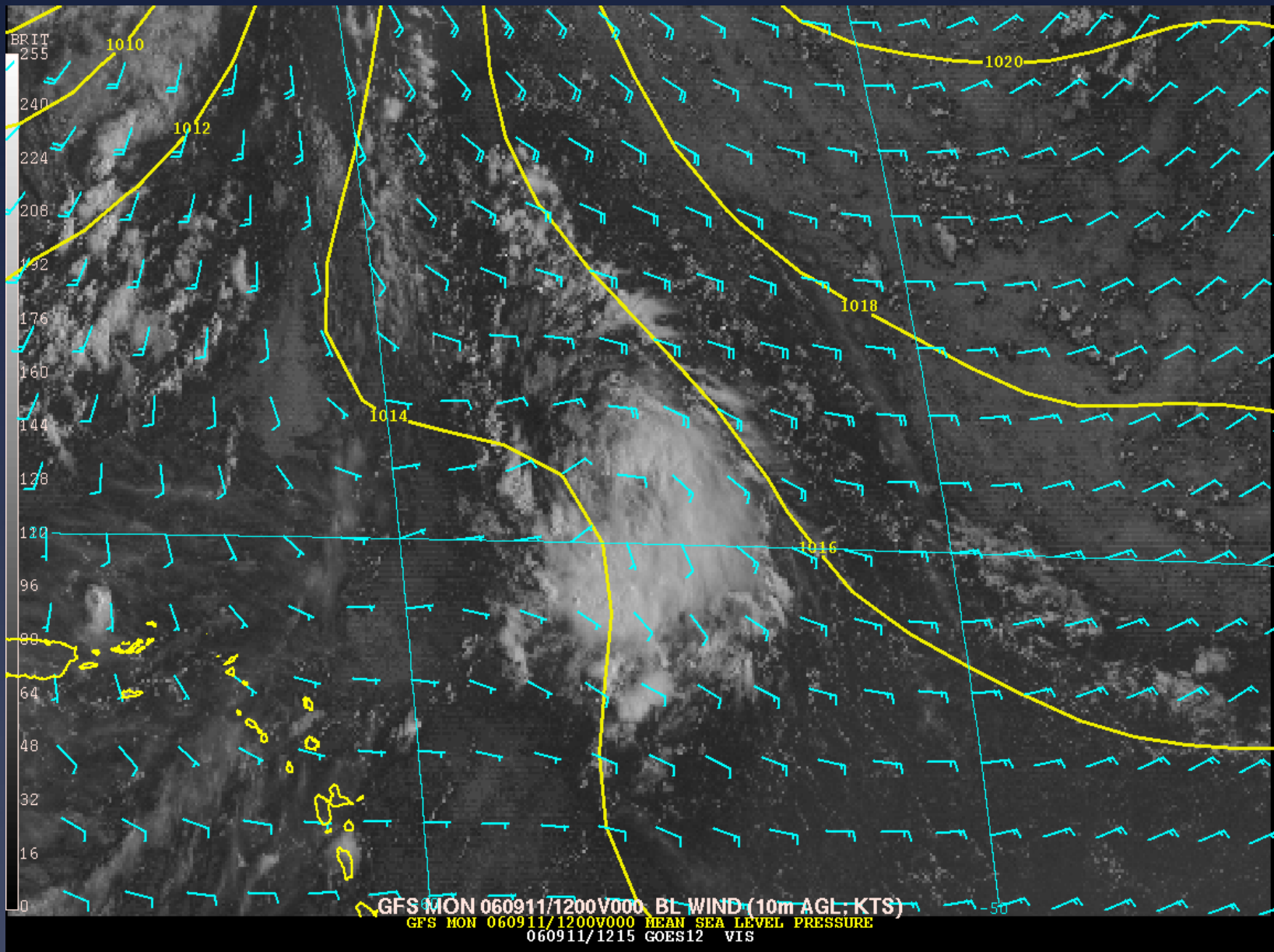
Model	Late ID	Early ID
Dynamical Track Multimodel Consensus	(none)	TVCN
HFIP Corrected Consensus	(none)	HCCA
FSU Superensemble	(none)	FSSE
GFS	AVNO/GFSO	AVNI/GFSI
GFS Ensemble	AEMN/GEMO	AEMI/GEMI
ECMWF global model	EMX/ECMO	EMXI/ECOI/EMX2
ECMWF Ensemble	ECMN	ECMI/ECM2/ECM3
UKMET global model	EGRR	EGRI/EGR2
Canadian GDPS	CMC	CMCI/CMC2
U.S. Navy NAVGEM	NVGM	NVGI
HWRF	HWRF	HWFI
HMON	HMON	HMNI
COAMPS-TC	CTCX	CTCI
Trajectory and Beta Models	(none)	TABS/TABM/TABD
Climatology and Persistence	(none)	CLP5/OCD5/TCLP
NHC Previous Forecast	(none)	OFCI

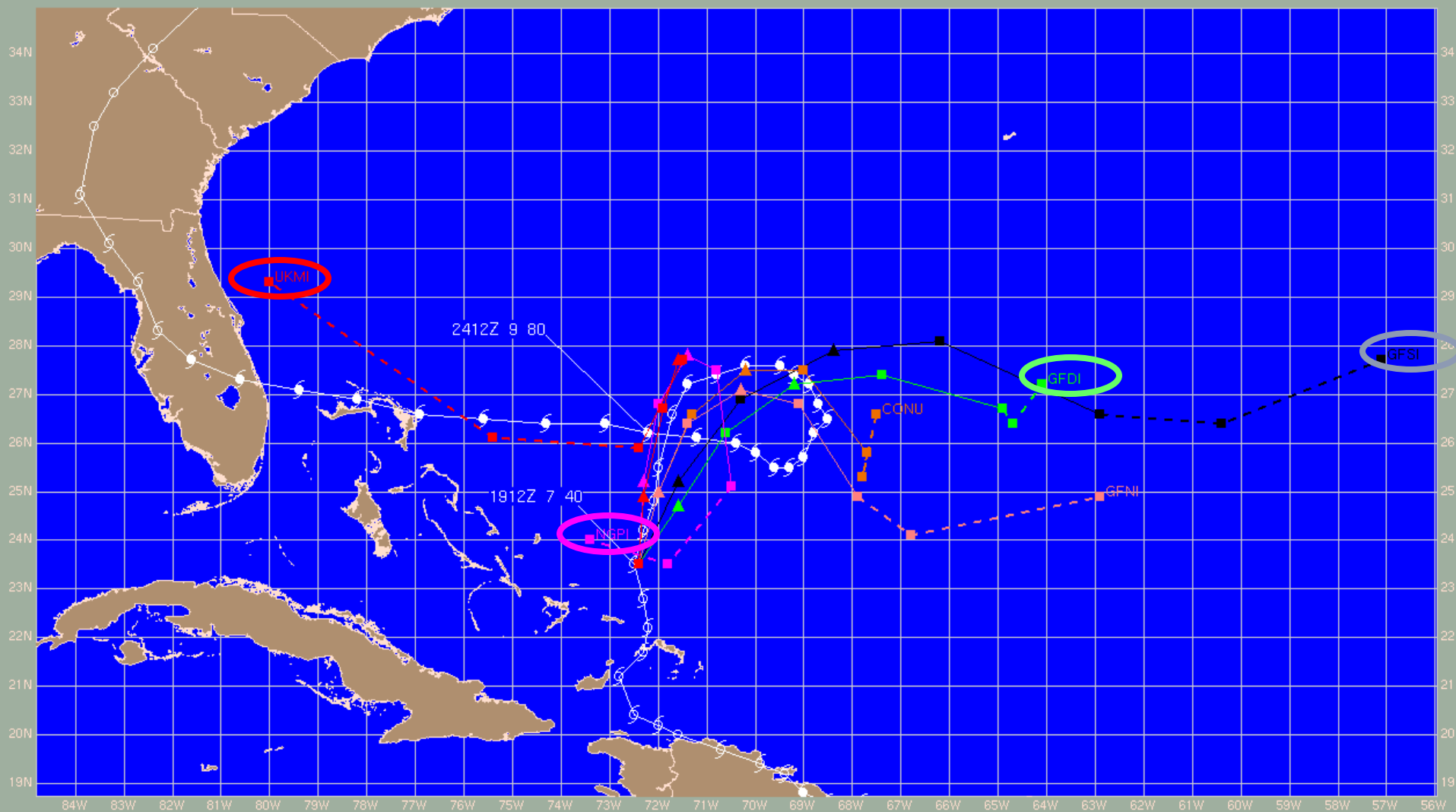
# Track Forecasting at the NHC: Using Models

- \* Dynamical model consensus is an excellent first guess for the forecast (and often a good final guess!). Continuity dictates that it must be considered in view of the previous official forecast.
- \* Evaluate the large-scale environment using conventional data and satellite imagery (e.g., water vapor)
  - \* Try to assess steering influences so that you understand and perhaps evaluate the model solutions
- \* Compare the models' forecast of the environmental features, not just the TC tracks.
  - \* Evaluate the initialization of the TC in the model fields. Unrealistic TC can affect the likelihood of a successful forecast.
  - \* Consider the recent performance of the various models, both in terms of accuracy and consistency.
  - \* Spread of models can dictate forecaster confidence.

# Bad Initialization for Tropical Storm Gordon

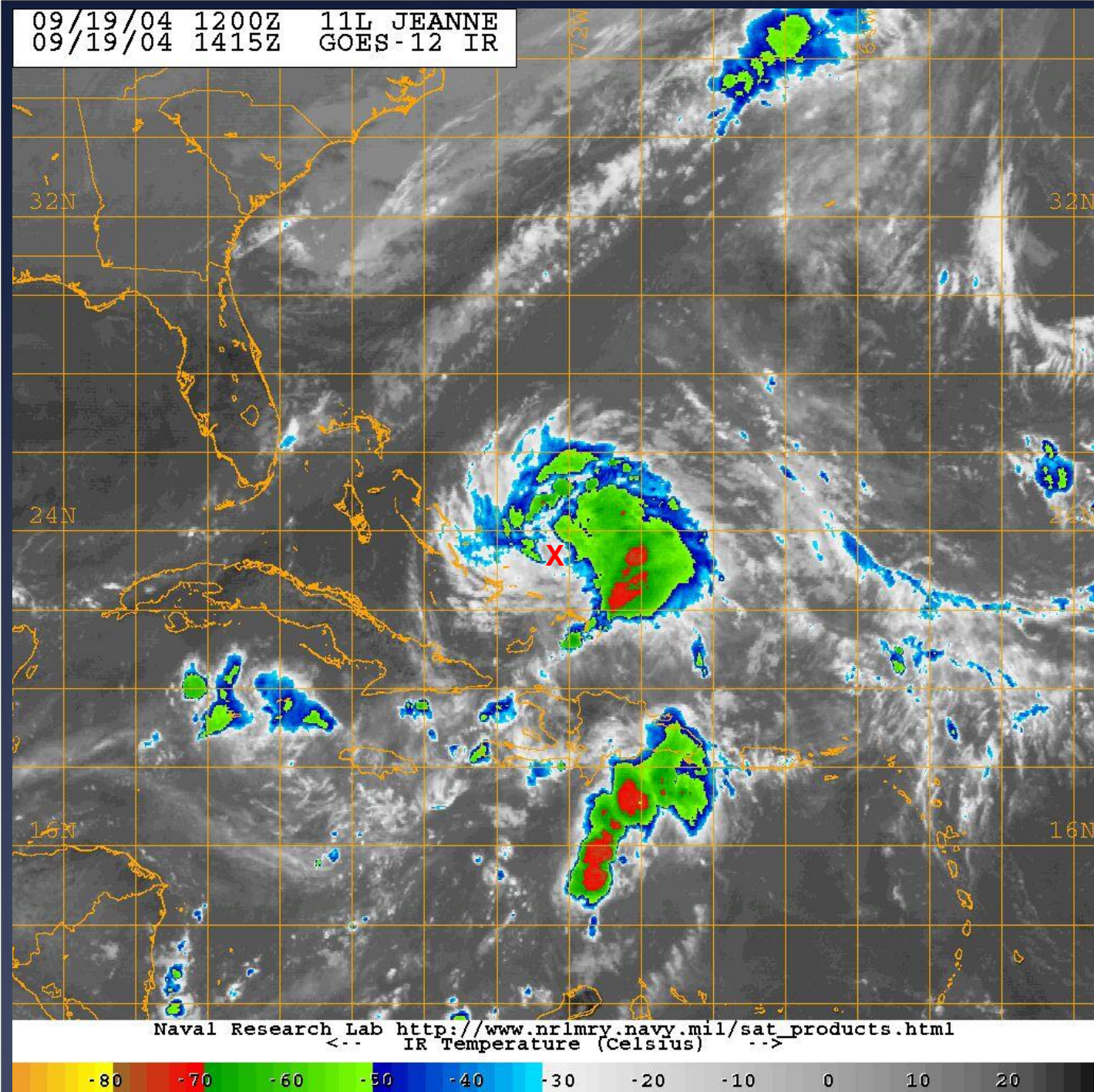
## 1200 UTC 11 September 2006





How to resolve the difference between guidance models?

09/19/04 1200Z 11L JEANNE  
09/19/04 1415Z GOES-12 IR



Poor organization (esp. lack of deep convection in the core) would argue against Jeanne being carried eastward by upper-level westerlies.

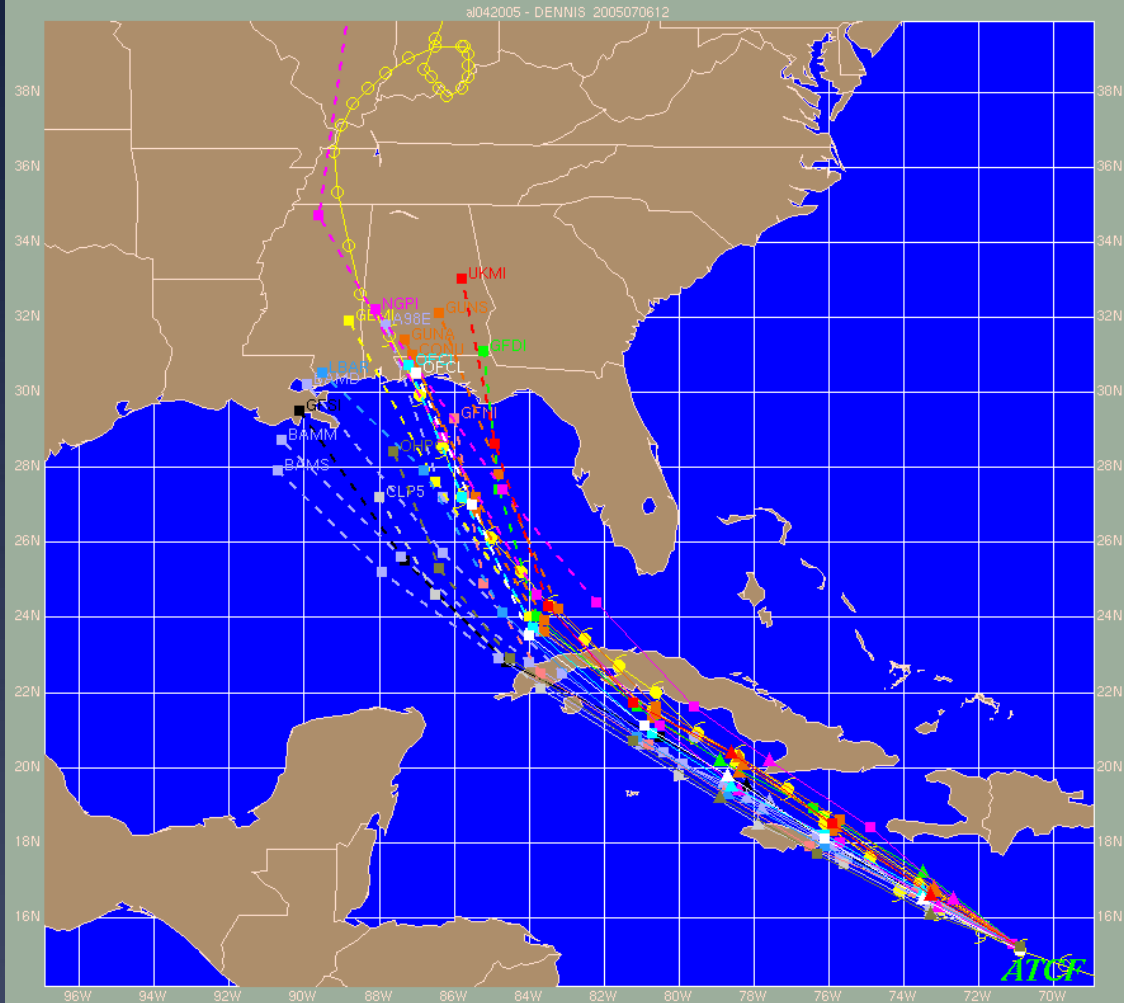
This reasoning allowed the forecasters to largely disregard the GFS and form a "selective consensus" of the remaining models.

# Additional Tools and Considerations for TC Track Forecasting

# Track Forecasting at the NHC: Continuity

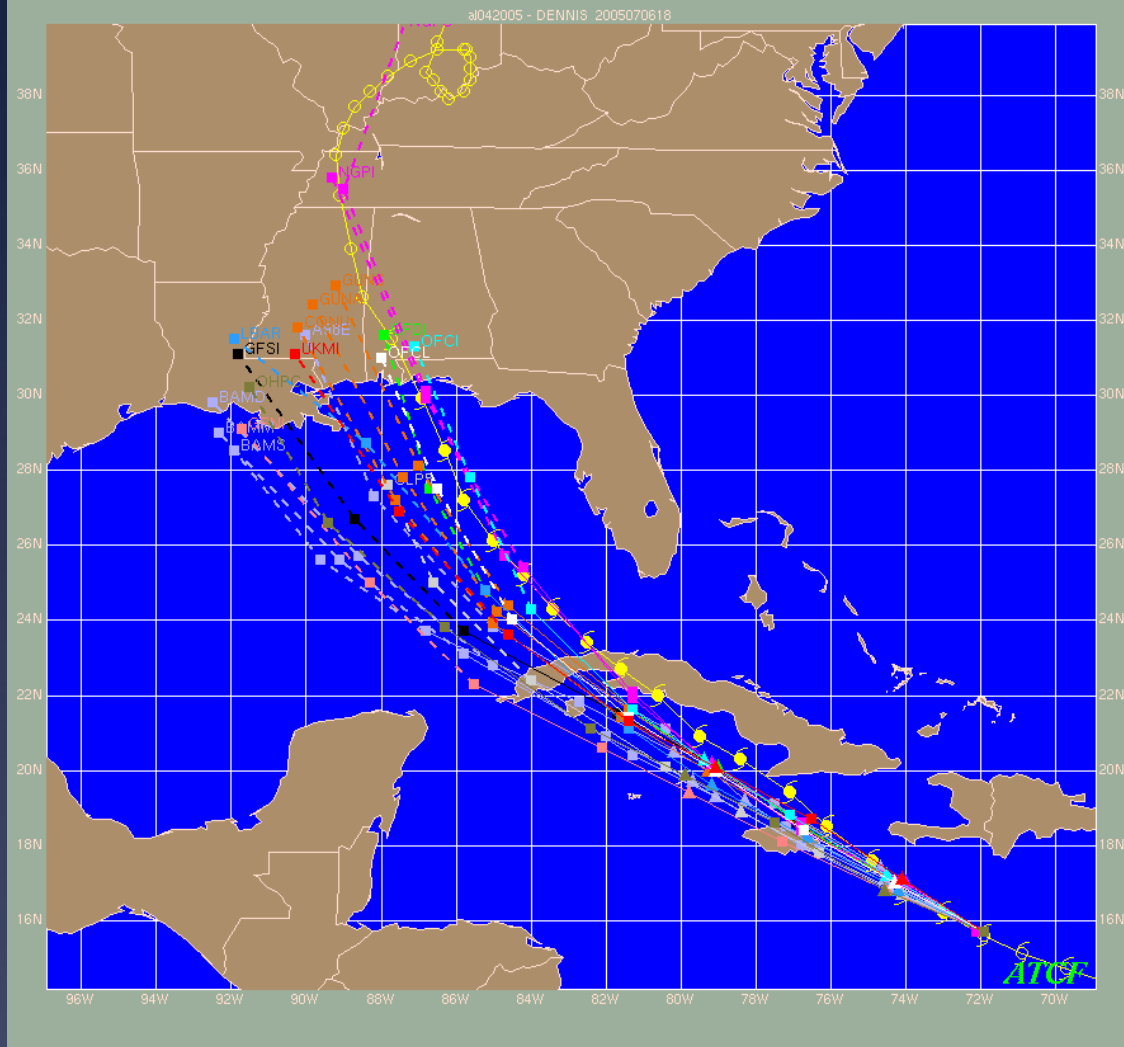
- \* Previous official forecast exerts a strong constraint on the current forecast.
- \* Credibility can be damaged by making big changes from one forecast to the next, and then having to go back to the original (flip-flop, windshield-wiper).
- \* Consequently, changes to the previous forecast are normally made in small increments.
- \* We strive for continuity within a given forecast (e.g., gradual changes in direction or speed from 12 to 24 to 36 h, etc).

# Dennis Guidance 6 July 1200 UTC



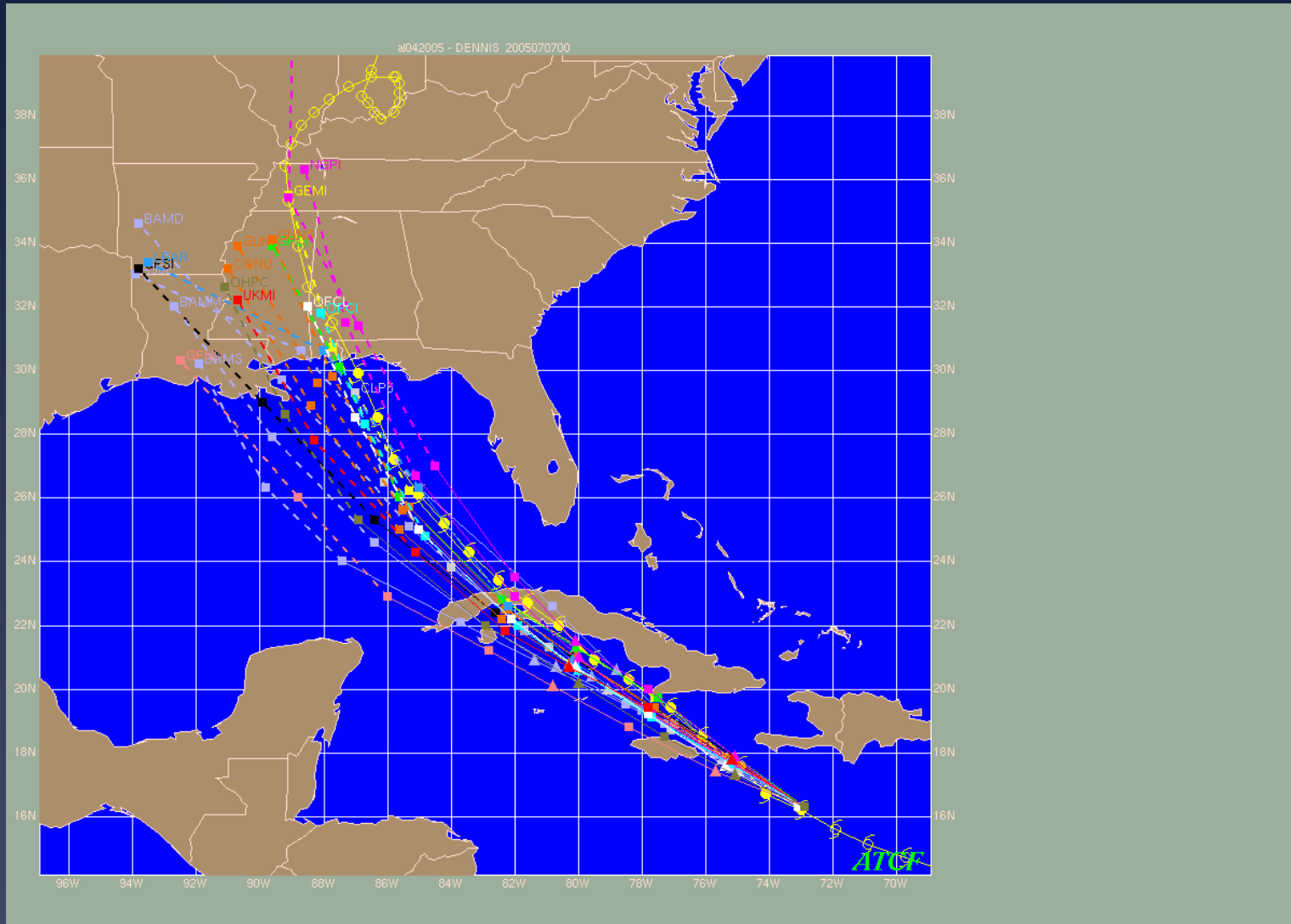
- \* Official forecast near model consensus in extreme western FL panhandle.

# Dennis Guidance 6 July 1800 UTC



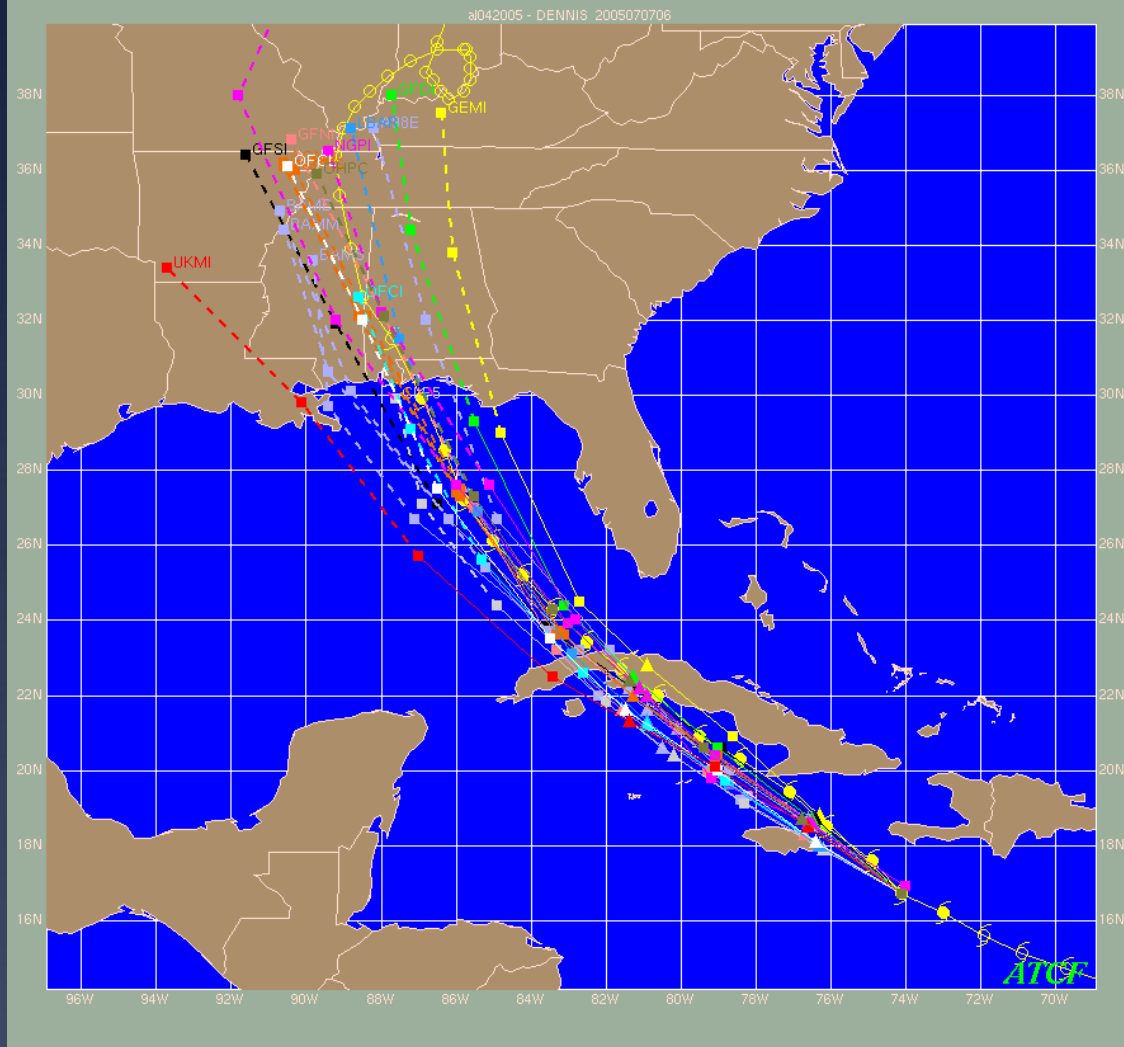
- \* Guidance shifts sharply westward toward New Orleans. Official forecast nudged westward into AL.

# Dennis Guidance 7 July 0000 UTC



- \* Little overall change to guidance, but NGPI shifts slightly eastward. Little change in official forecast.

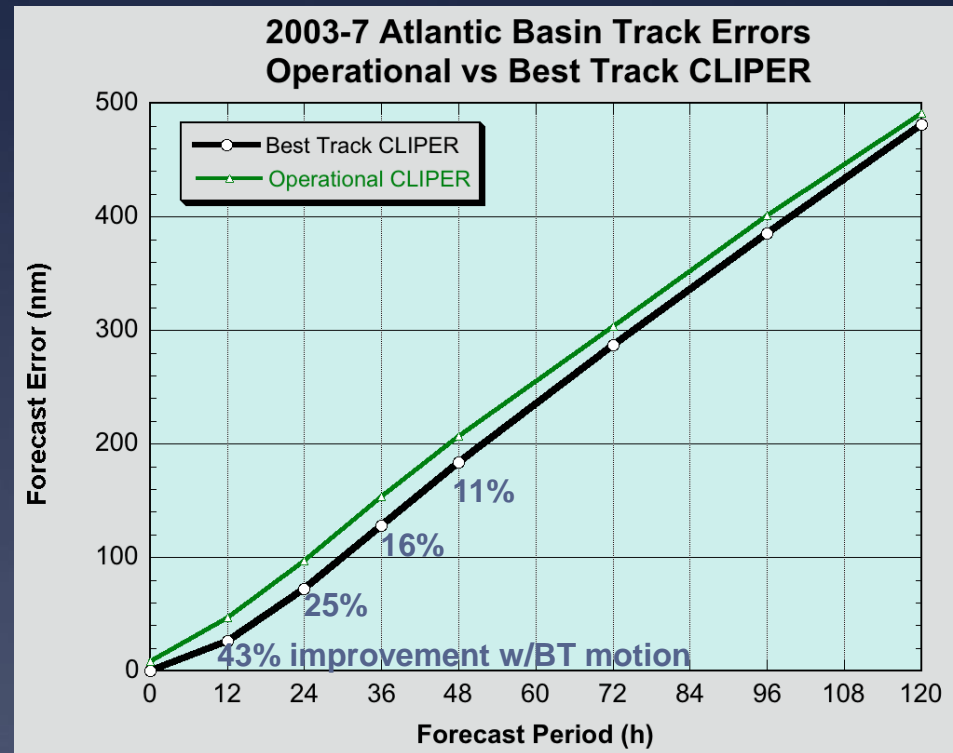
# Dennis Guidance 7 July 0600 UTC



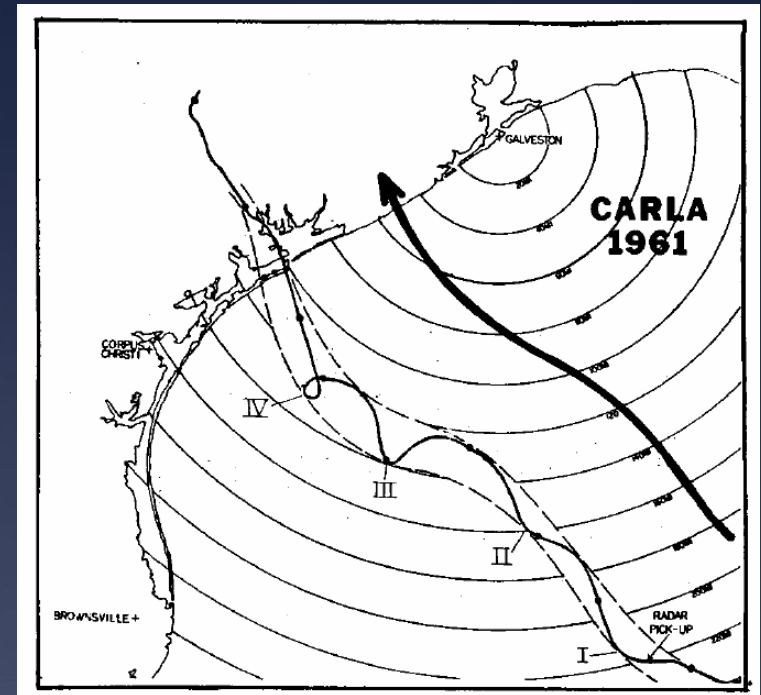
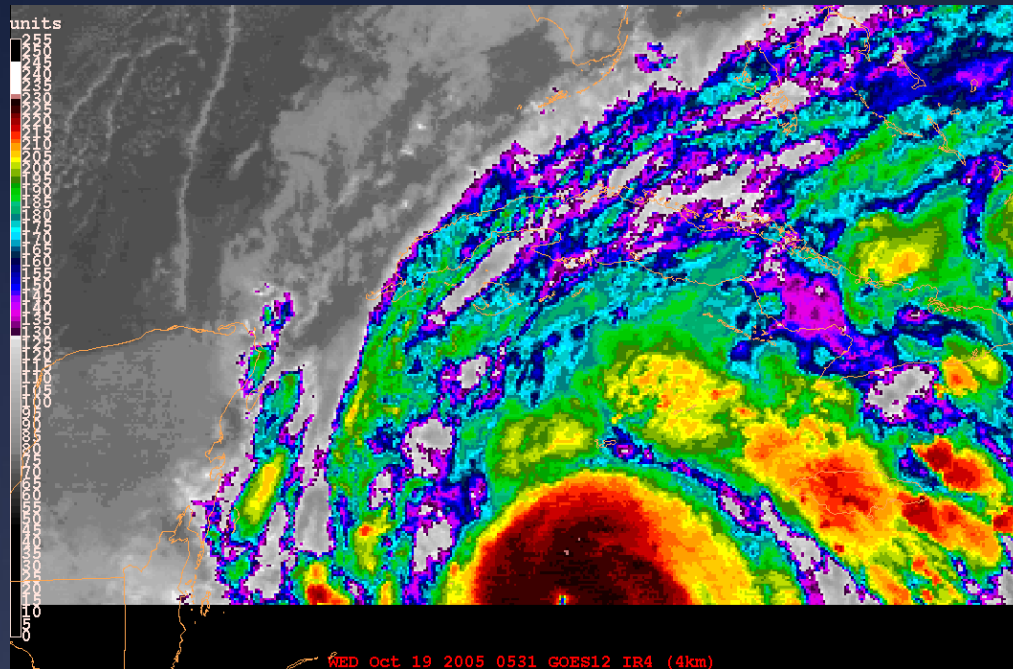
- \* Rest of the guidance shifts sharply eastward, leaving official forecast near the center of the guidance envelope (and very close to the actual track of Dennis).

# Track Forecasting at the NHC: Importance of Initial Motion

- \* Accurate estimate of initial motion is extremely important.
- \* Has dramatic impact on accuracy of the CLIPER model at shorter ranges.
- \* Initial motion vector is also used in some vortex bogussing schemes.
- \* 12-h NHC forecast is heavily weighted by the initial motion estimate.
- \* Not always easy to determine, particularly for systems with ill-defined centers.



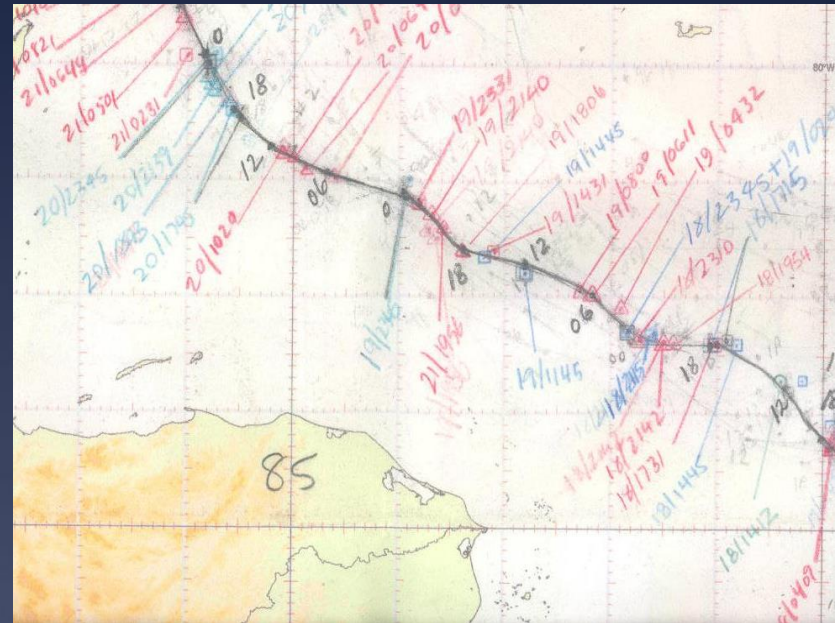
# Trochoidal Motion



- Substantial oscillation (wobble) of the center of a TC about its mean motion vector
- Primarily a side effect of convective asymmetries in the inner core
- Amplitude of motions varies but higher-frequency “wobbles” lost in ‘best track’ smoothing process
- Virtually impossible to forecast!

# Track Forecasting at the NHC: Determination of Initial Motion

- \* Initial motion typically computed using the average motion over the previous 6, 12, or 18 h.
  - \* Shorter when known changes in track are occurring, longer when center location is uncertain.
  - \* Initial motion estimate should not reflect short-term track wobbles (e.g., trochoidal oscillations) that will not persist.
- \* NHC philosophy is that it is better to lag events a little bit than to be going back and forth with analyses or forecasts. We will usually wait several hours before “calling” a change in track.



## Track Forecasting Review

What is the most important factor for tropical cyclone track?

- a) Large-scale steering flow
- b) Internal dynamics of the eyewall
- c) Beta effect
- d) Storm intensity

## Track Forecasting Review

Cuál es el factor más importante en la trayectoria de un ciclón tropical?

- a) Dirección del flujo a gran escala
- b) Dinámica interna en la pared del ojo
- c) Efecto Beta
- d) Intensidad del ciclón tropical

## Track Forecasting Review

Which of the following is typically the best type of model to use for track forecasting?

- a) Statistical-dynamical model  
(SHIPS/LGEM)
- b) High-resolution global model  
(ECMWF/GFS)
- c) Multi-model consensus (TVCN/HCCA)
- d) Regional hurricane model  
(HWRF/HMON)

## Track Forecasting Review

Cuál de los siguientes modelos es típicamente el mejor modelo para el pronóstico de trayectoria?

- a) Modelo estadístico-dinámico (SHIPS/LGEM)
- b) Modelo global de alta resolución (ECMWF/GFS)
- c) Consenso Multi-modelo (TVCN/HCCA)
- d) Modelo Regional de huracán (HWRF/HMON)

## Track Forecasting Review

What is the difference between AEMN and AEMI?

- a) AEMI is the 6-hour old version of AEMN, interpolated to match the current position of the storm.
- b) AEMI is the GFS ensemble control, and AEMN is the GFS ensemble mean.
- c) AEMN and AEMI are both GFS ensemble means, but only AEMI uses the NCEP tracker
- d) There is no difference

## Track Forecasting Review

Cuál es la diferencia entre AEMN and AEMI?

- a) AEMI es la versión de las pasadas 6-horas de AEMN, interpolada para coincidir con la posición actual del ciclón tropical.
- b) AEMI es el control del conjunto GFS, y AEMN es la media del conjunto GFS.
- c) AEMN y AEMI son ambos la media del conjunto GFS, pero sólo AEMI usa el rastreador de NCEP
- d) No hay diferencia

# Concluding Remarks

- \* Multi-level dynamical models are the most skillful individual models for TC track prediction. Among these models, the ECMWF and GFS have provided the best guidance overall in recent years, but performance does vary significantly from year to year (or storm to storm).
- \* A consensus formed from an ensemble of dynamical models is typically more skillful than the best dynamical model.
- \* Single-model ensembles appear to most useful for longer-range (4-5 days and beyond).
- \* NHC forecasters have philosophical constraints on the official forecast that results in a certain amount of response lag (and may contribute to our errors lagging the consensus).
- \* While it is possible to beat the models from time to time, model performance has improved significantly over the years, and they are very difficult to beat on a consistent basis.