Tropical Cyclone Track Prediction

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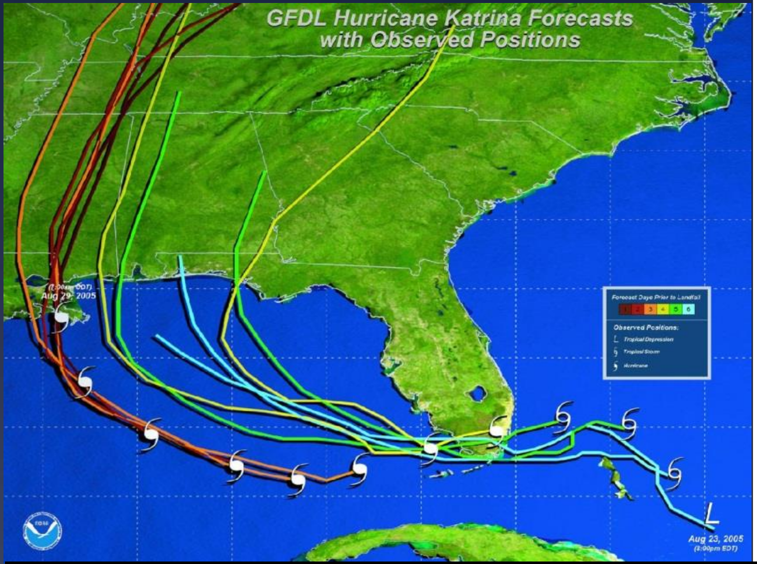
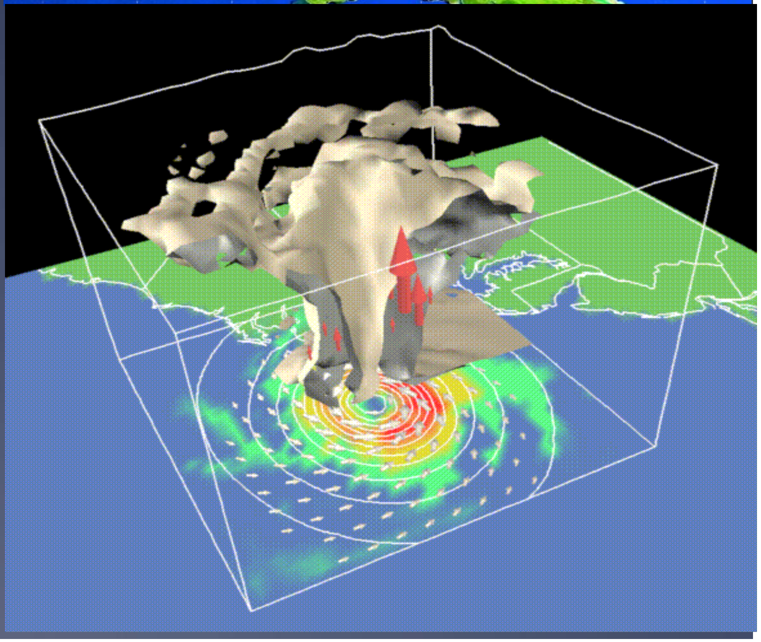
Outline

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





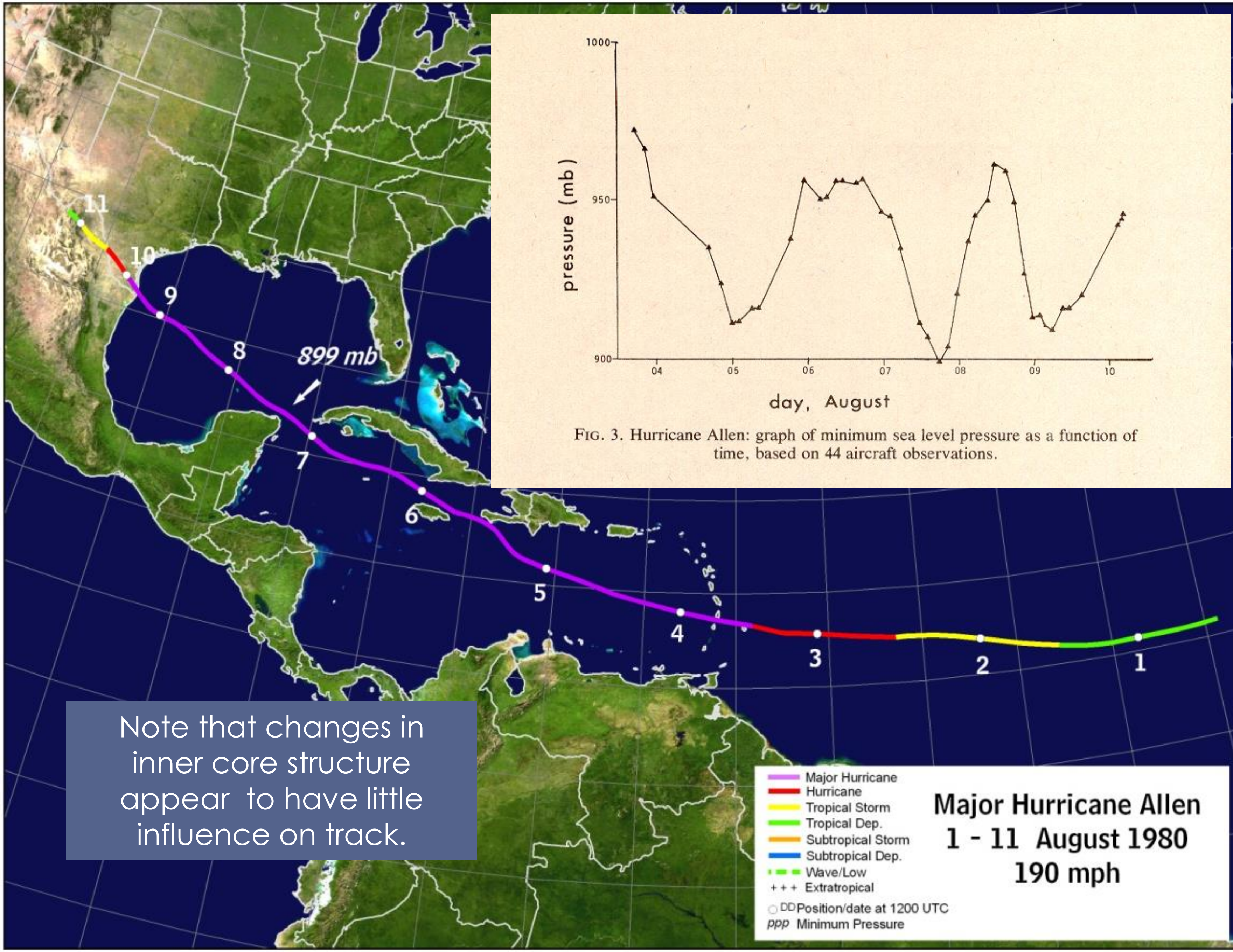


FIG. 3. Hurricane Allen: graph of minimum sea level pressure as a function of time, based on 44 aircraft observations.

Note that changes in inner core structure appear to have little influence on track.

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:

$L \sim 500 \quad km$

$Rotational \quad wind \quad V \sim 10 \quad m/s$

$Divergent \quad wind \quad U \sim 1 \quad m/s$

$\Delta P \sim 10^5 \quad Pa$

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

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

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

$\omega \sim \delta \Delta P \sim 0.2 \quad Pa/sec$

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

$\frac{\partial \zeta}{\partial t}$	$-V \cdot \nabla \zeta$	$-\omega \frac{\partial \zeta}{\partial P}$	$-\beta v$	$-(\zeta + f)\delta$	$-k \cdot \nabla \omega \times \frac{\partial V}{\partial P}$
(1)	(1)	(4)	(2)	(3)	(4)
4×10^{-10}	4×10^{-10}	4×10^{-11}	2×10^{-10}	1×10^{-10}	4×10^{-11}

Vorticity Equation

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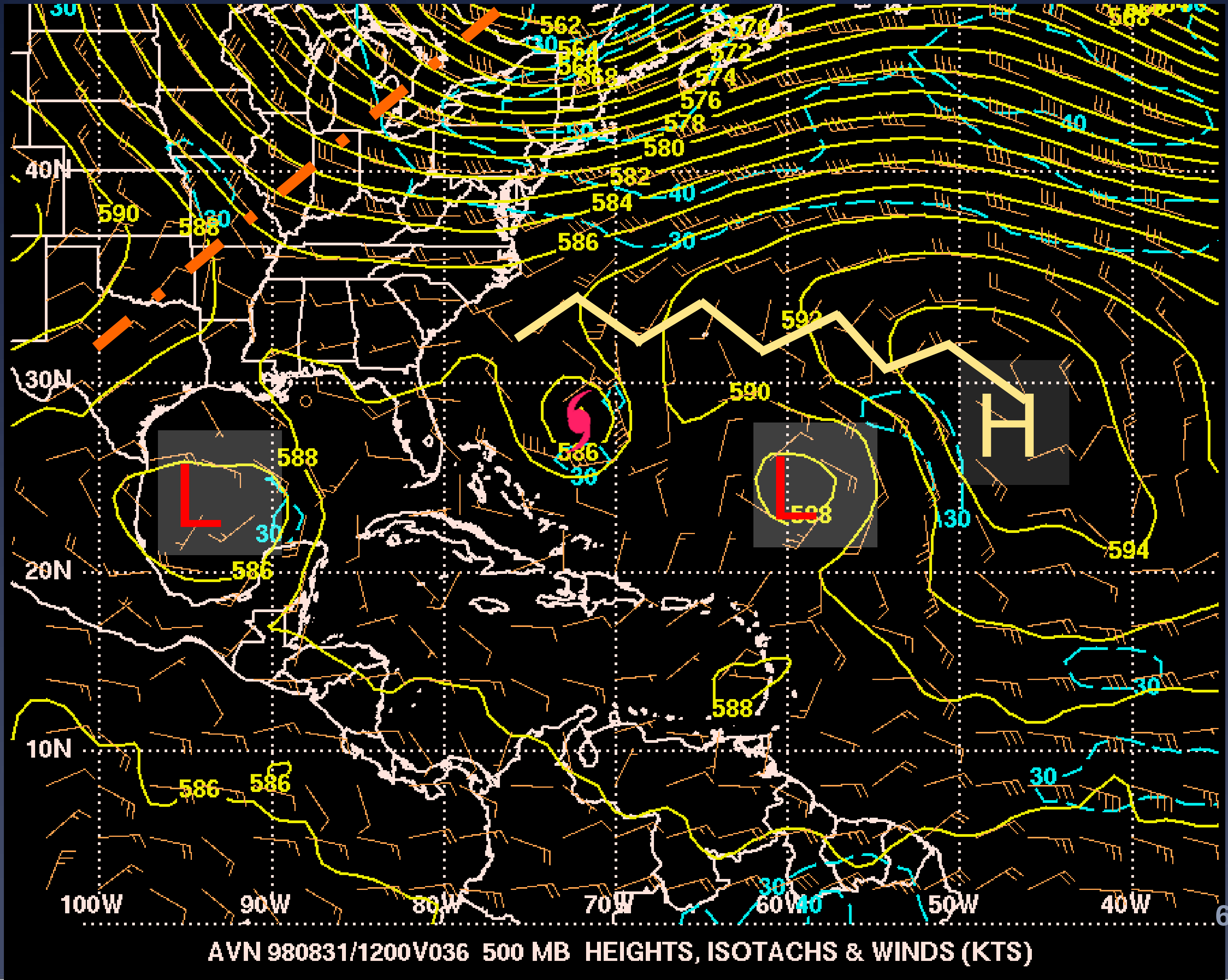
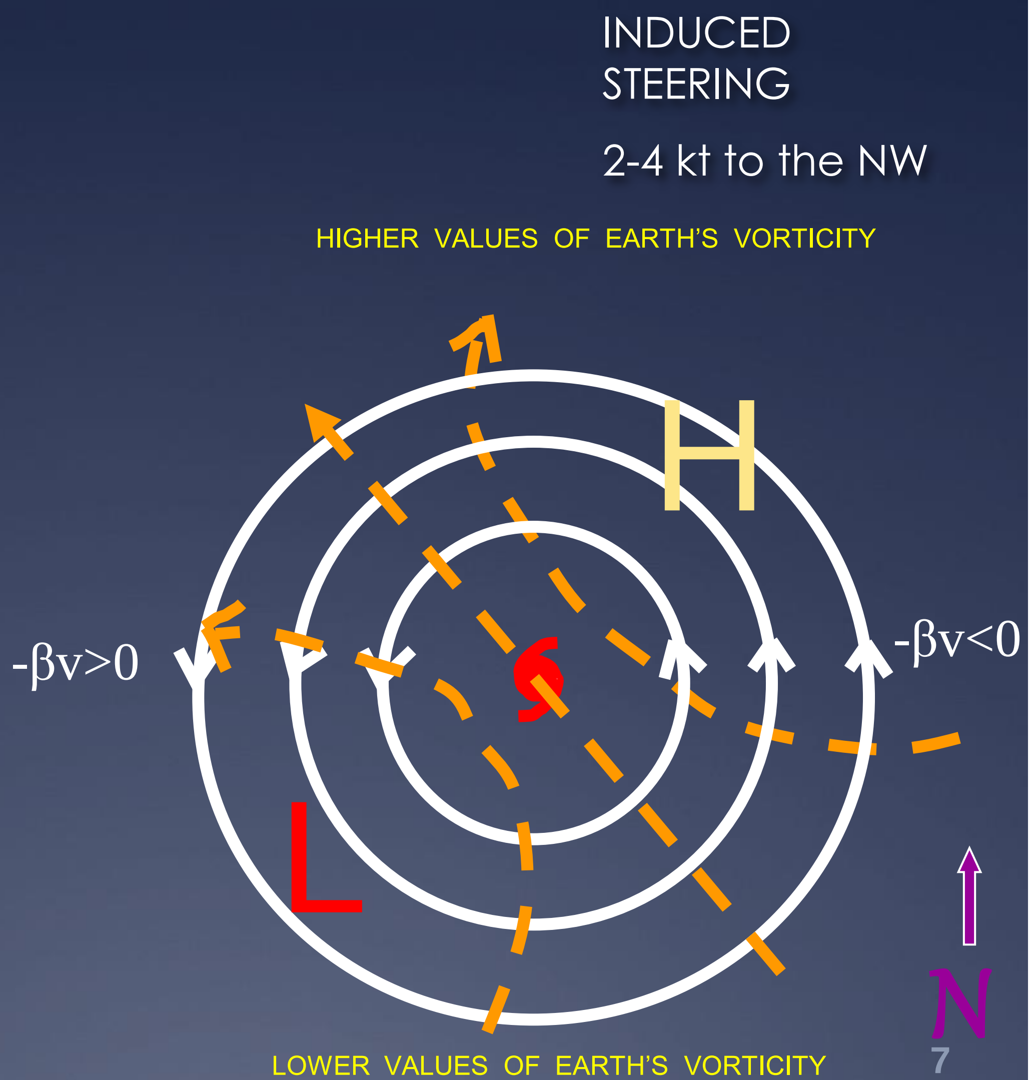
- To a first approximation, TC motion is governed by conservation of relative vorticity (vortex moves with the large-scale steering flow).
- Second order includes the Beta term (conservation of absolute vorticity).
- Divergence term (wavenumber 1 asymmetry in convection, interactions with orography,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

Large-Scale Steering



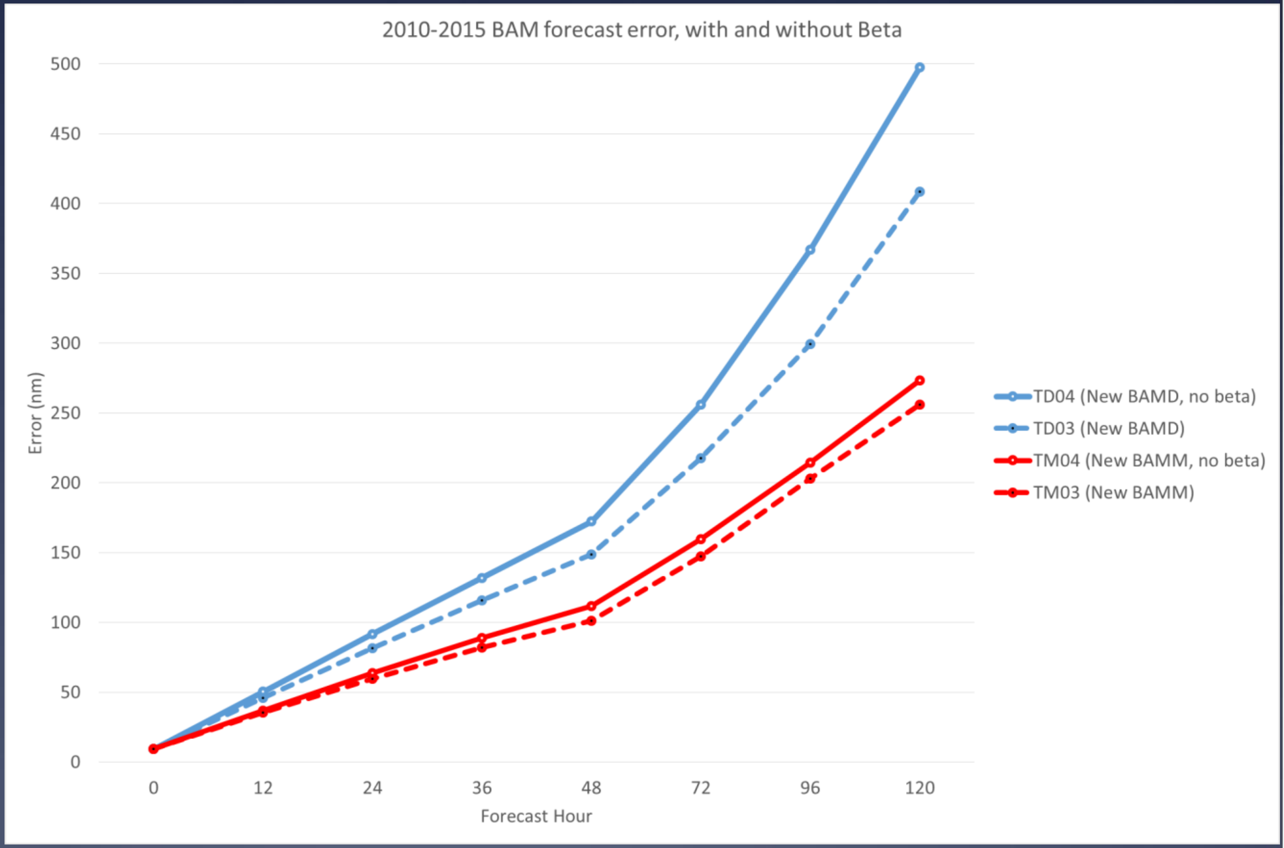
The Beta Effect

* 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.



Impact of Beta (Beta matters!)

* The inclusion of the Beta term in a simple trajectory track forecast model (BAMD), results in a track error reduction of as much as 21%



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:

$$\int_{100}^{1000} (\vec{V})\, dp \;\; / \int_{100}^{1000} dp$$

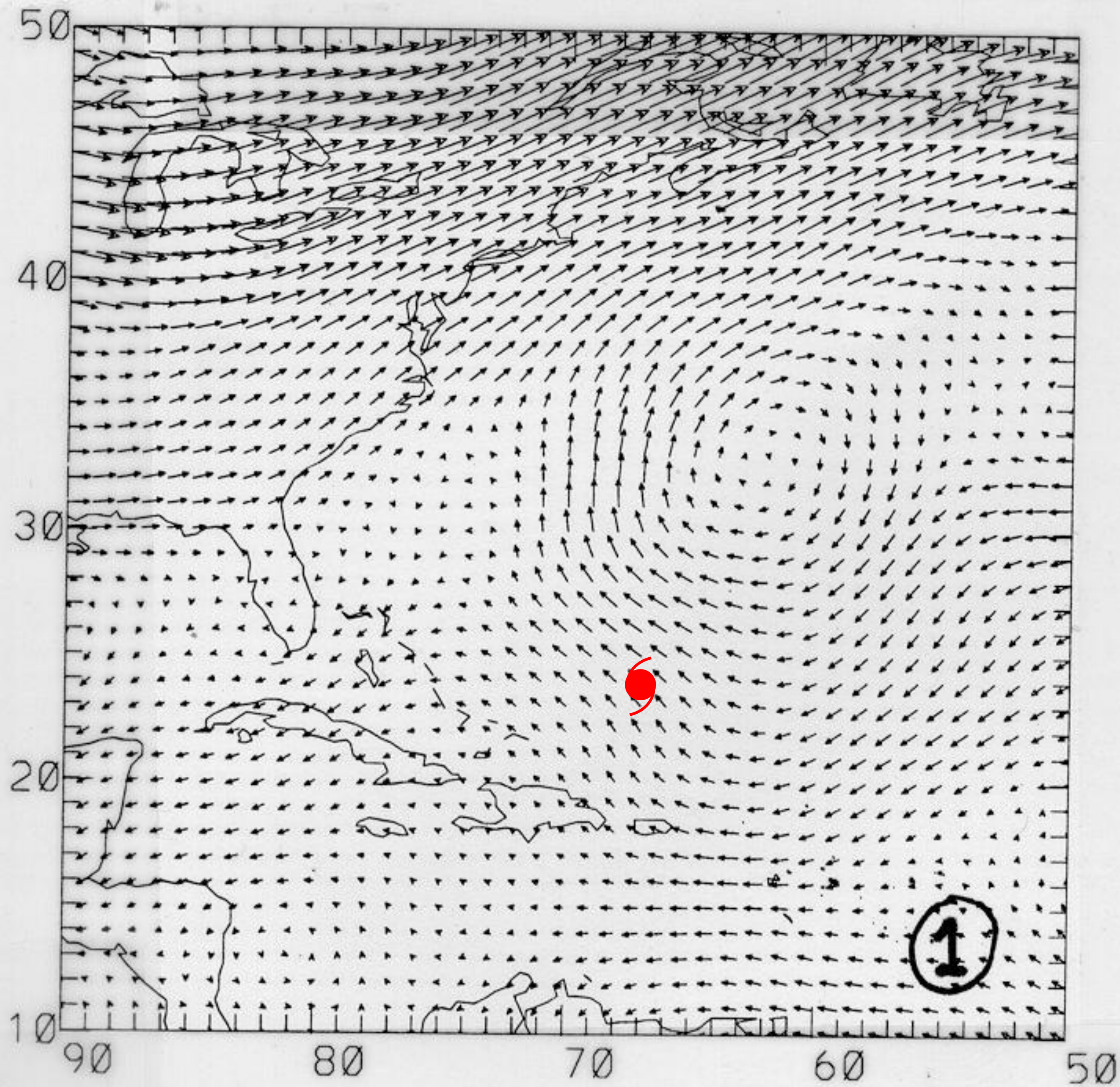
Exercise 1

- 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?



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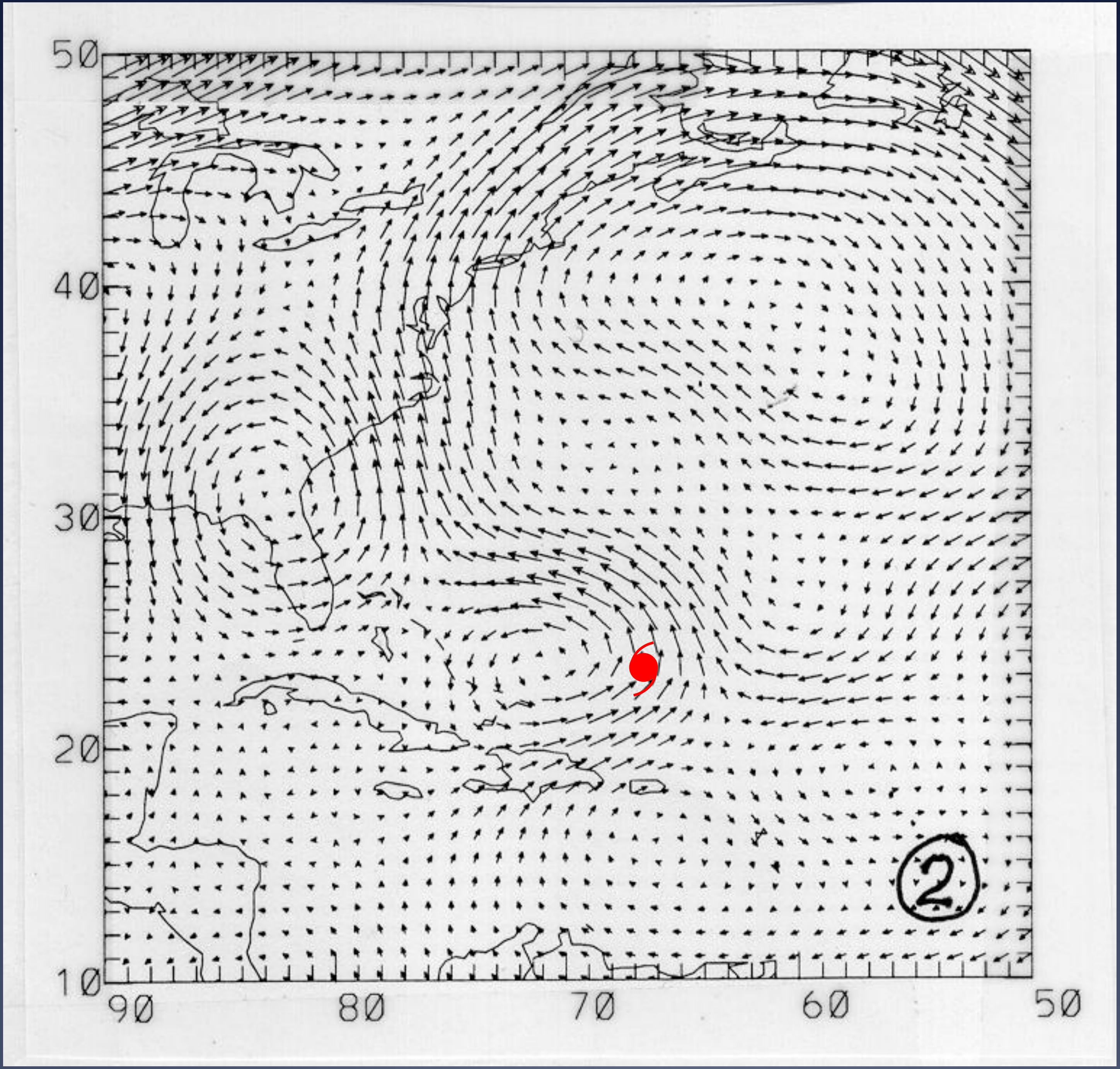

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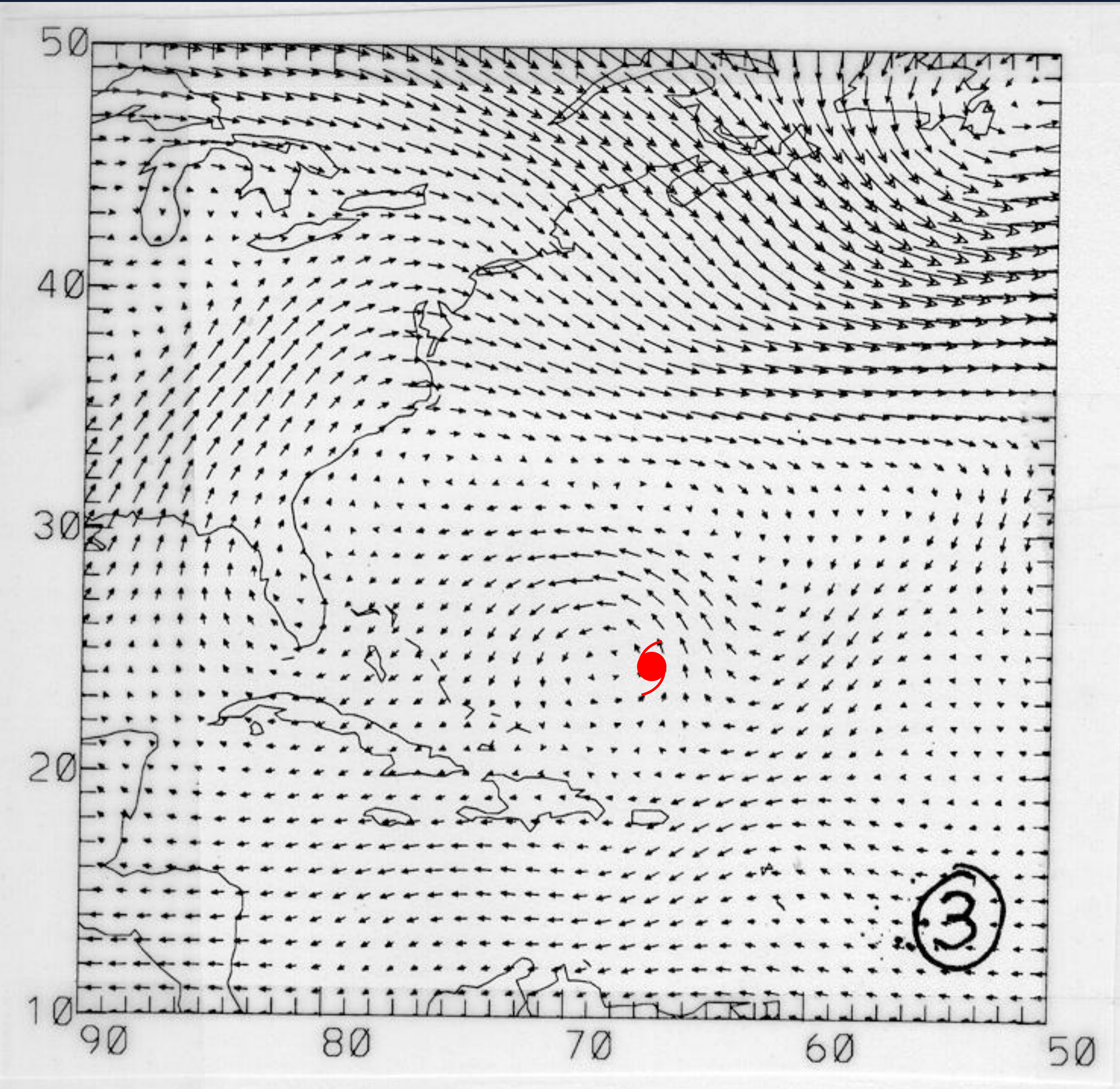

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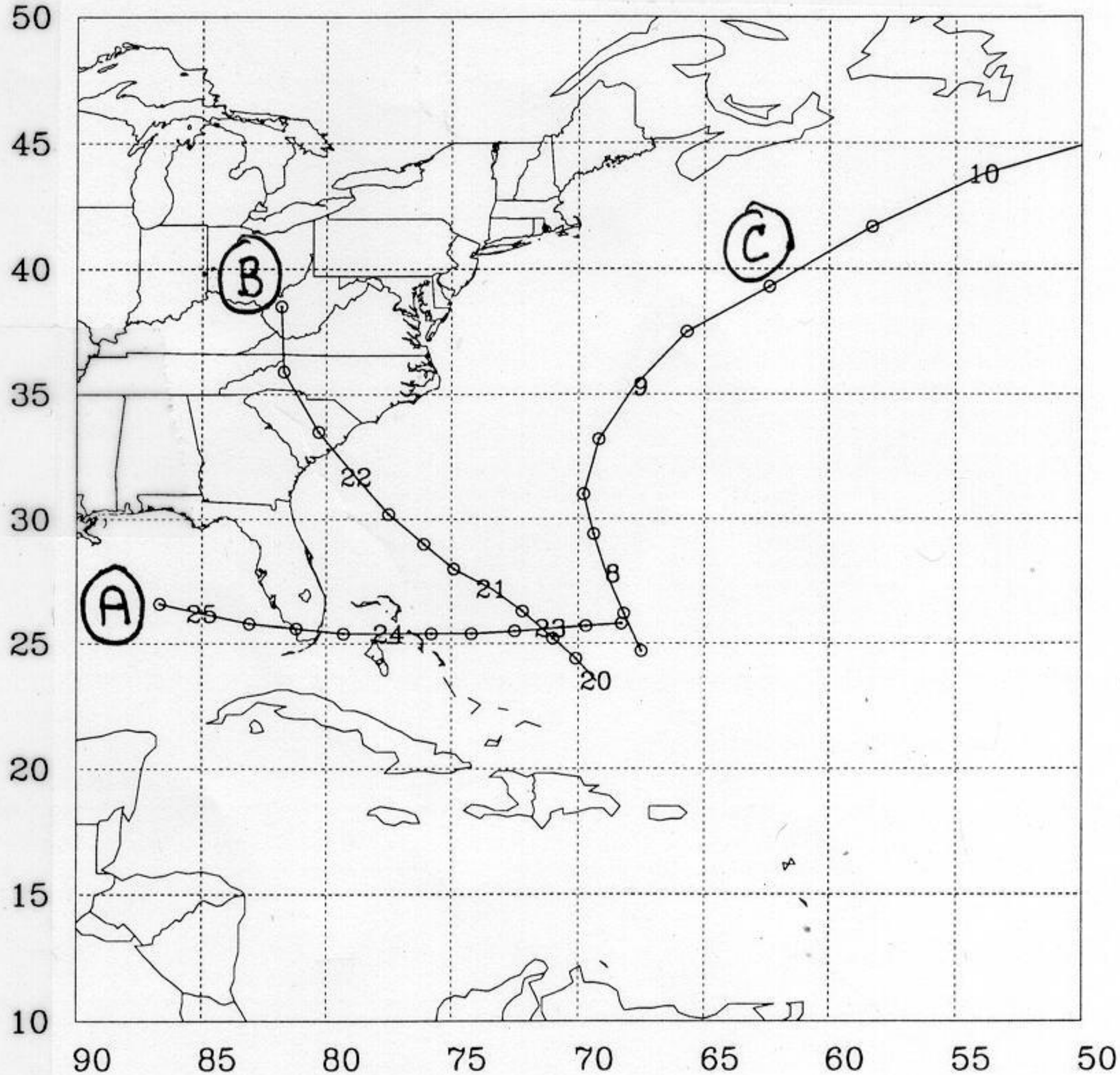
72 HR STORM TRACKS



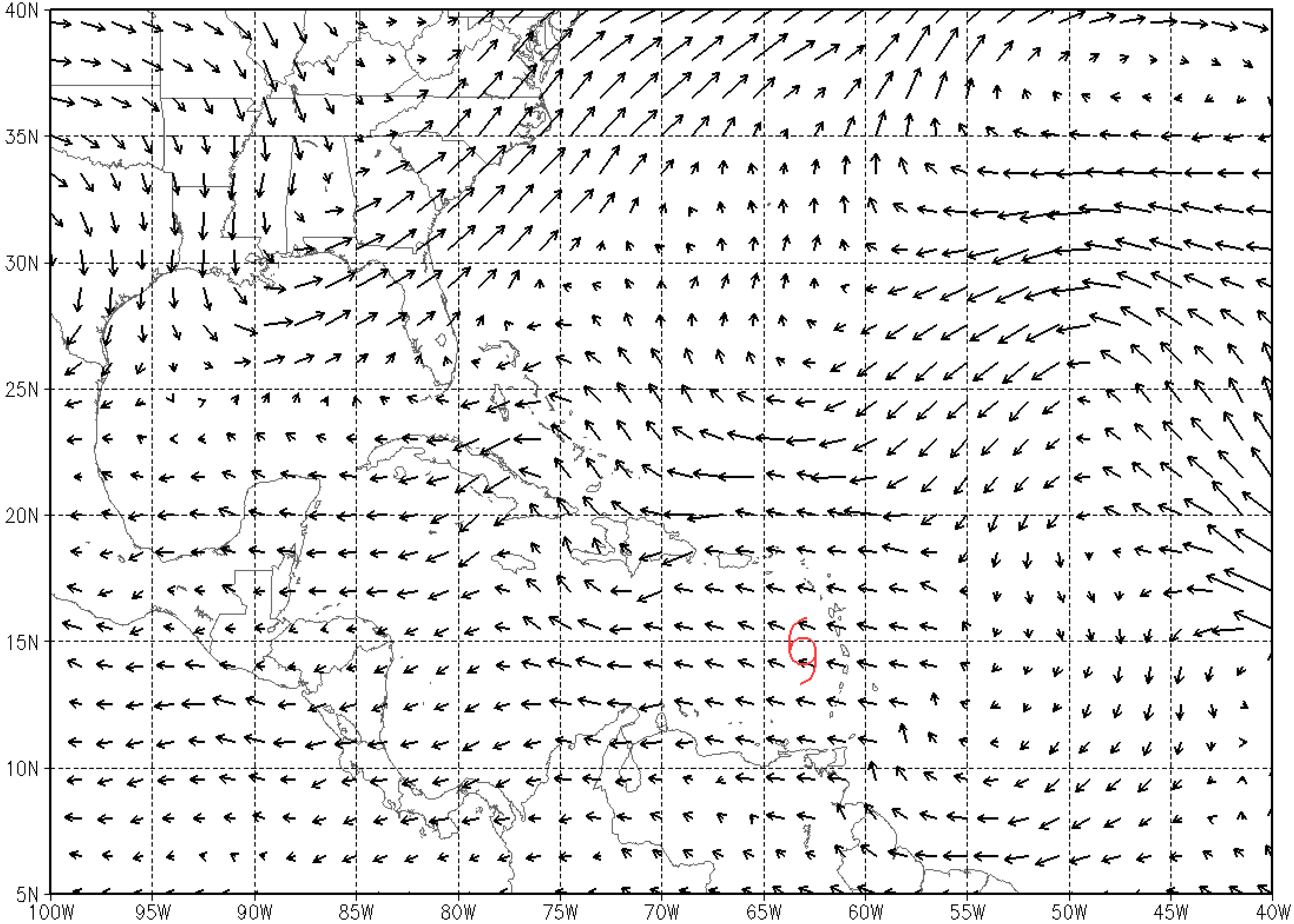
Exercise 2

- You are given deep-layer mean wind plots for 3 tropical cyclones (TCs) that were located in the vicinity of 15°N 63°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.

- What were the names/years of the 3 TCs?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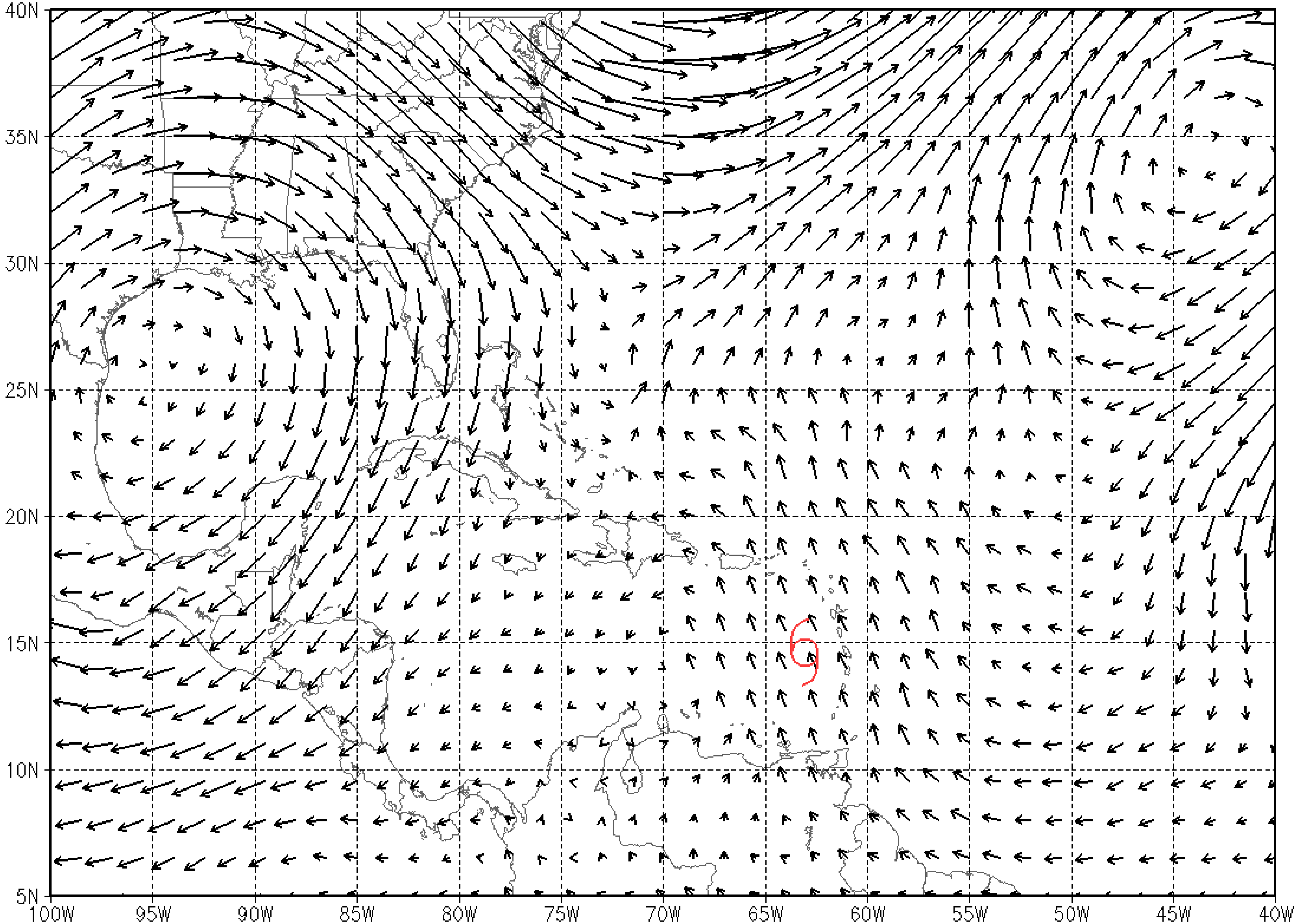
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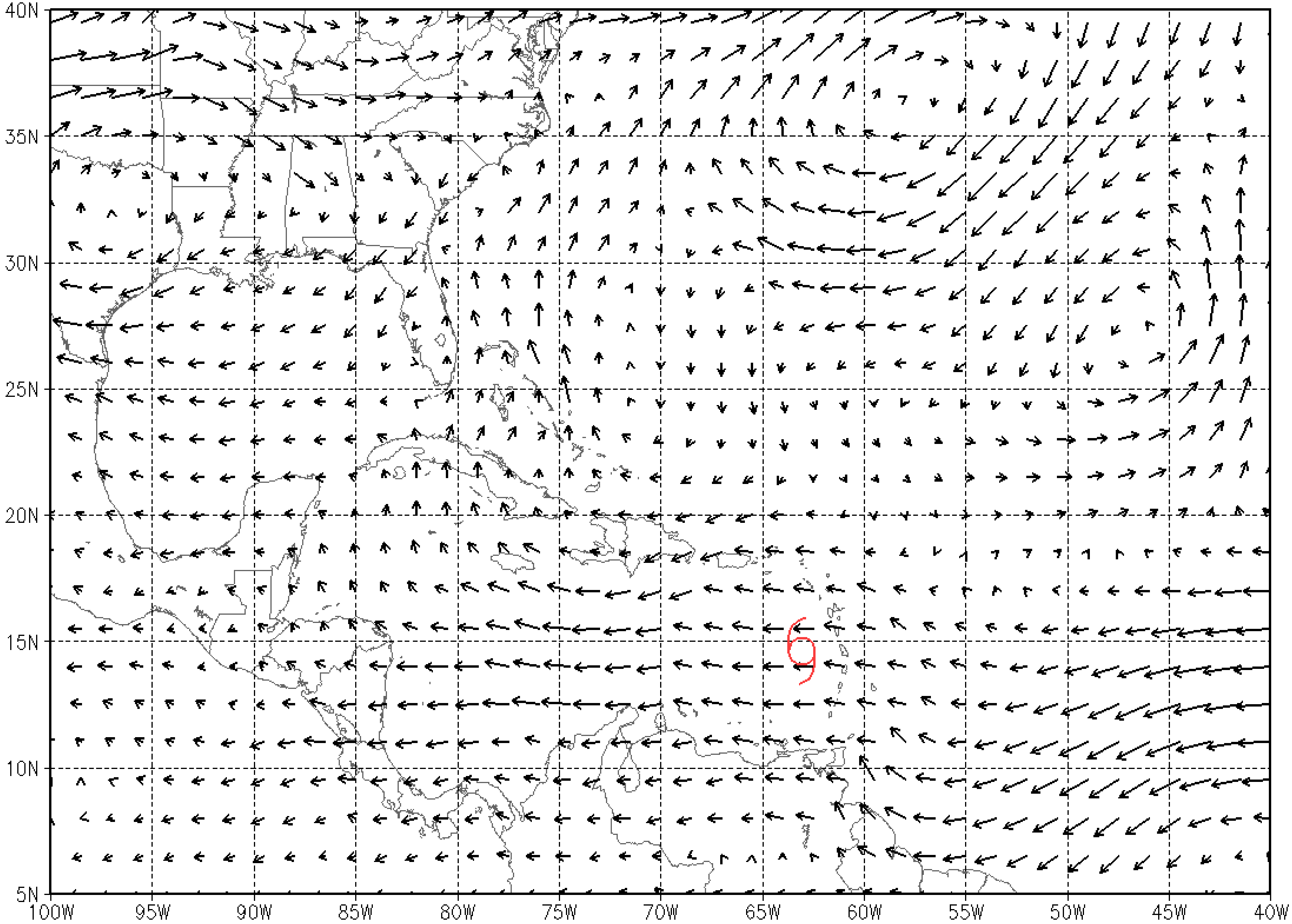
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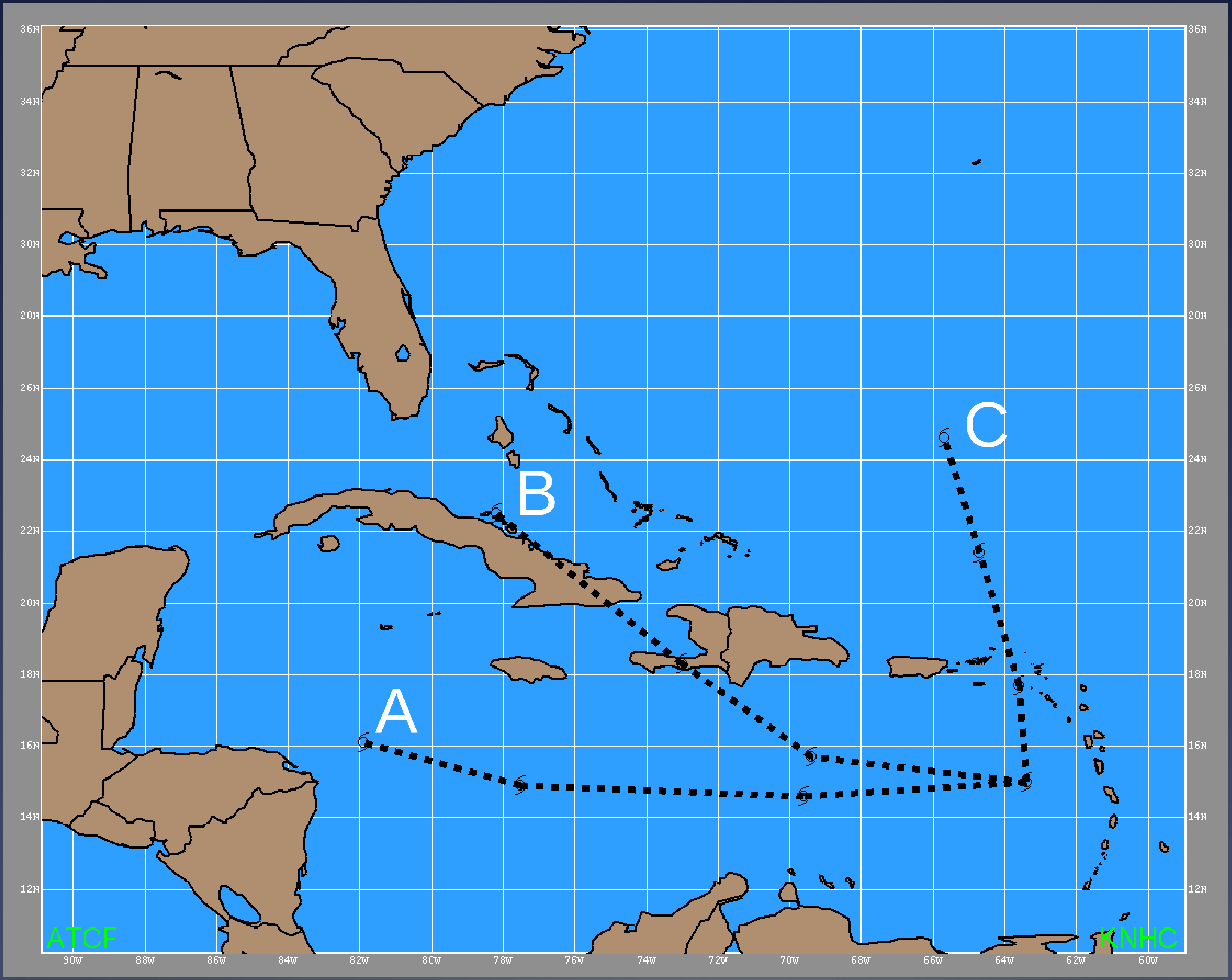
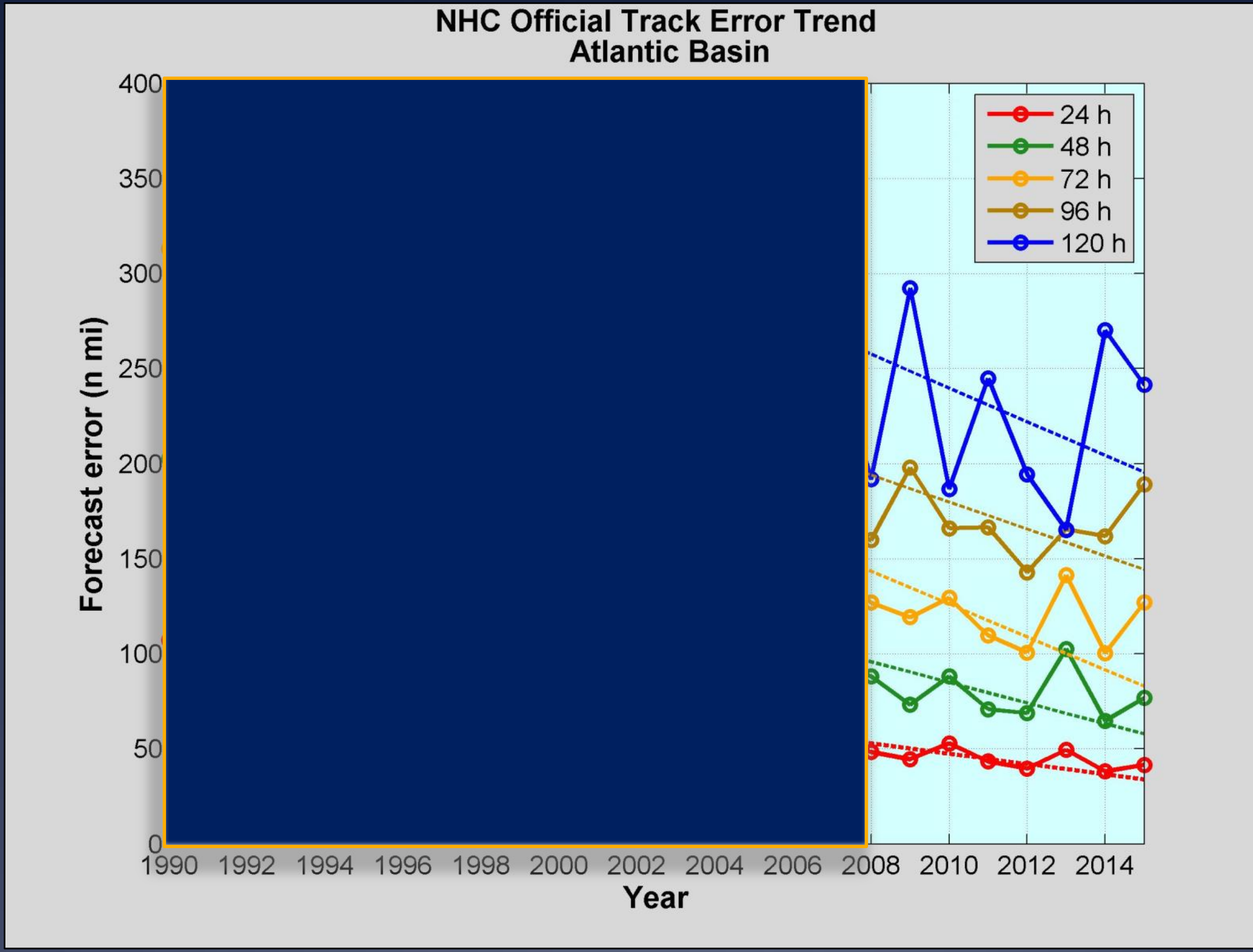
72-h Storm Tracks



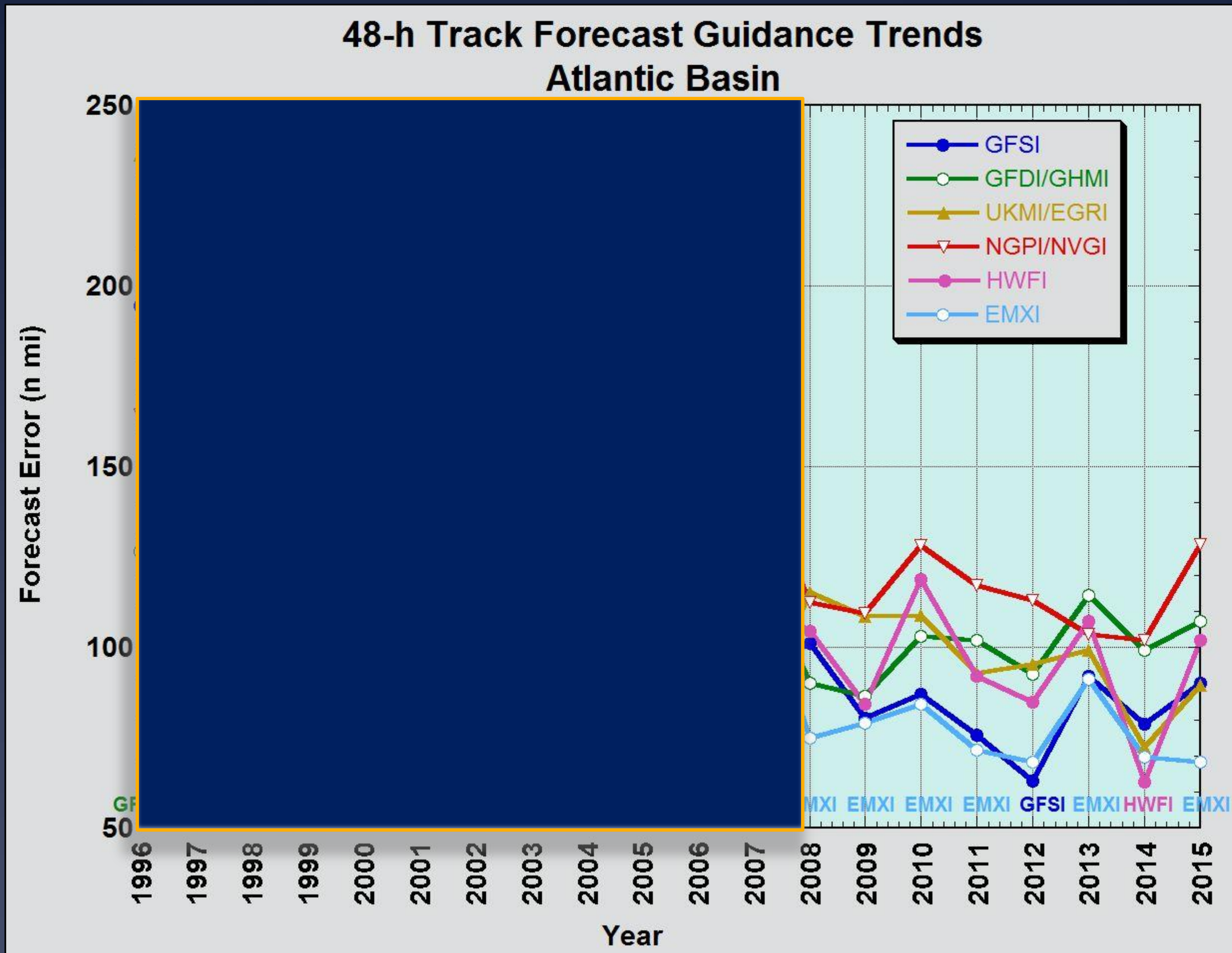
Numerical Weather Prediction Models for TC Track Prediction

Atlantic Track Error Trends



Track errors increased in 2015 compared to 2014 (except at 120 h), and the last five years have been basically flat.

Track Model Trends



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
  * LBAR: simple two-dimensional dynamical track prediction model that solves the shallow-water equations initialized with vertically averaged (850-200 mb) winds and heights from the GFS global model
  * BAMD, BAMM, BAMS: Forecasts based on simplified dynamic representation of interaction with vortex and prevailing flow (trajectory plus beta)
* Dynamical
  * GFDL, GFDN, GFS, NAVGEM, UKMET, ECMWF, HWRF: solve the three-dimensional physical equations of motion that govern the atmosphere.
* Consensus
  * TCON, TVCN, 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

* **Beta and Advection** (BAMS, BAMM, BAMD)
  * Two-dimensional "trajectory" model. Uses steering determined from layer-averaged winds from a global model (GFS), smoothed to T25 resolution.
  * Adds a correction to simulate the Beta effect.
  * Three versions, representing different depths. The spread of these is a useful indicator of environmental vertical shear:
    * BAMS (shallow): 850-700 mb
    * BAMM (medium): 850-400 mb
    * BAMD (deep): 850-200 mb
* **Limited-area Barotropic** (LBAR)
  * Barotropic dynamics: no temperature gradients or vertical shear
    * Shallow water equations on Mercator projection solved using sine transforms, using 850-200mb layer average winds and heights and boundary conditions from the GFS
    * Sum of idealized vortex and current motion vector added to the large-scale analysis
    * Lack of baroclinic forcing means the model cannot accurately depict the evolution of large-scale synoptic steering features. Consequently, the model has little or no skill beyond 1-2 days.

WHICH BAM TO USE?

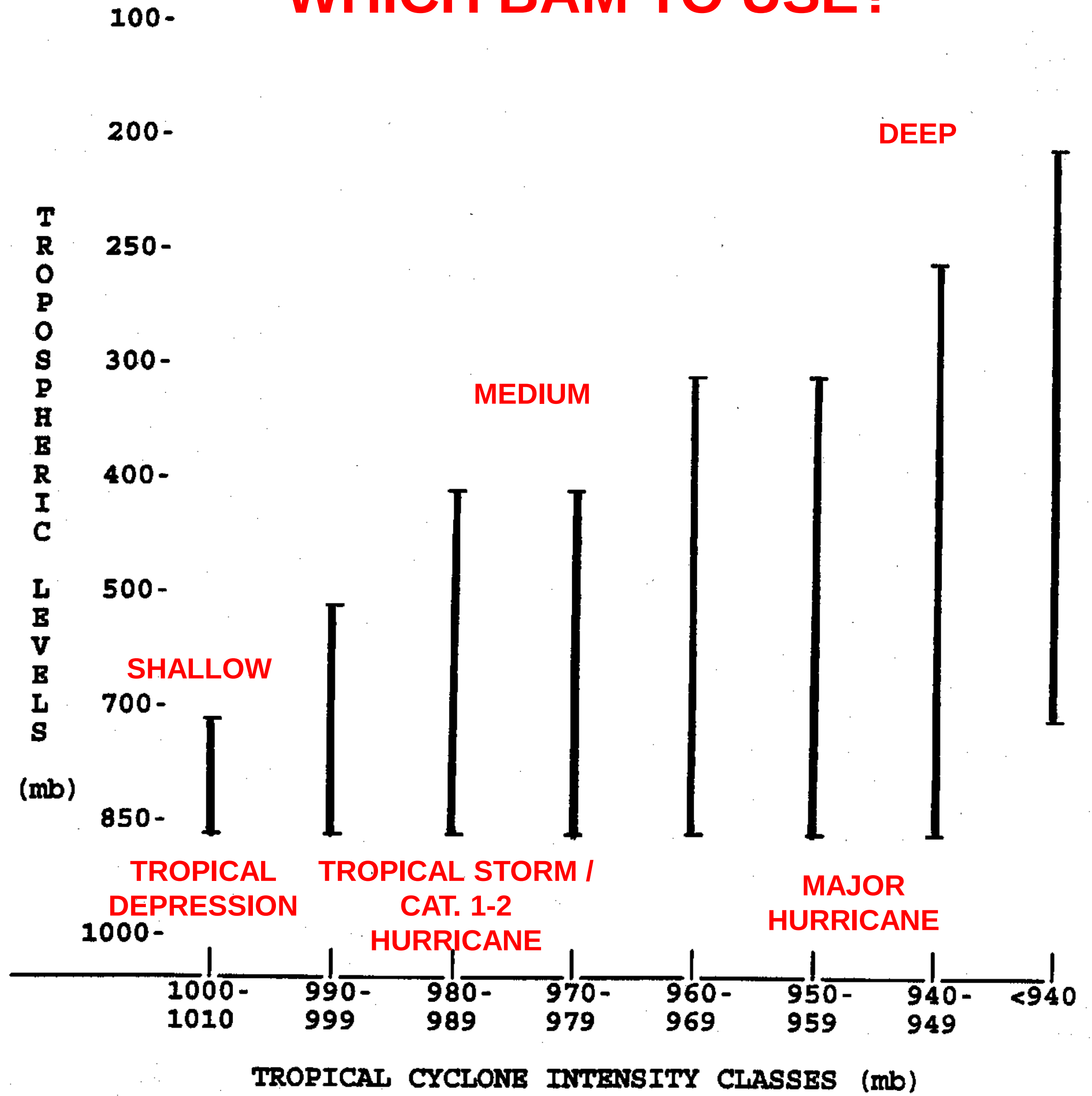


Figure 1. The relationship between tropospheric depth of the steering layer and intensity (mean sea level pressure at the center) for an Atlantic sample of tropical cyclones (based on 24h track forecast results). The black bars indicate the optimum steering layer for each intensity category.

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.

Model Name and ATCF ID	Global Forecast System (AVNO/AVNI)	ECMWF model (ECMO/EMXI/ EMX2)	U.K. Met Office Global Model (EGRR/UKMI)	Navy Global Environmental Model (NVGM/NVGI)	Canadian Global Deterministic Prediction System (CMC/CMCI)
Numerical Method and Resolution	Spectral (T1534L64) ~ 13 km horizontal (Semi-Lagrangian)	Spectral (TCo1279) ~ 9 km horizontal (upgraded today!)	Gridpoint Arakawa-C ~17 km horizontal	Spectral (T359L50) ~ 37 km horizontal	Gridpoint (1024X800 grid) ~ 25 km horizontal
Vertical Coordinates	64 Hybrid Sigma Levels	137 Hybrid Sigma Levels	70 Hybrid Sigma Levels	50 Hybrid Sigma Levels	80 Hybrid Sigma Levels
Cycling Frequency	6 hours, (to 180h) (00/06/12/18 UTC)	12 hours (to 240h) (00/12 UTC)	12 hours (to 144h) (00/12 UTC)	6 hours (to 144h) (00/06/12/18 UTC)	12 hours (to 240h) (00/12 UTC)
Data Assimilation	4-D EnVar Hybrid (Proposed 2016 upgrade)	4D-Variational	4D-Variational / Ensemble Hybrid	4D-Variational / Ensemble Hybrid	4D-Variational / Ensemble Hybrid
TC Bogus?	Yes (occasionally); always assimilates central pressure	No	Assimilation of central pressure	Yes	No
Convective Scheme	Simplified Arakawa-Schubert [Arakawa and Schubert (1974) / Pan and Wu (1994)]	Tiedke mass flux [Tiedke (1989)]	UKMET [Gregory and Rowntree (1990)]	Simplified Arakawa-Schubert	Kain -Fritsch [Kain and Fritsch (1990, 1993)]
Included in TVCN?	Yes	Yes	Yes	No	No
More info:	http://www.emc.ncep.noaa.gov/GFS	http://www.ecmwf.int/	http://www.metoffice.gov.uk/research/modelling-systems/unified-model	http://www.nrlmry.navy.mil/metoc/nogaps/	http://weather.gc.ca/grib/grib2_glb_25km_e.html

Data Assimilation and Model Initialization for Tropical Cyclones

- All operational dynamical models assimilates large quantities of remotely-sensed observations, including microwave data from polar-orbiting satellites, ASCAT vectors, cloud-drift winds, etc.
  - Generally, global models do not use any observations from the inner core
- Bogussing is used by some models to ensure that an appropriate representation of the vortex is present in the model initial condition. Examples include:
  - Creating artificial (synthetic) data points to the model's data assimilation process (NAVGEM, GFS).
  - Relocation of model-analyzed vortex to the correct location in first guess field (GFS), followed by real data assimilation.
  - Use the model itself to create (spin up) a cyclone vortex (GFDL).

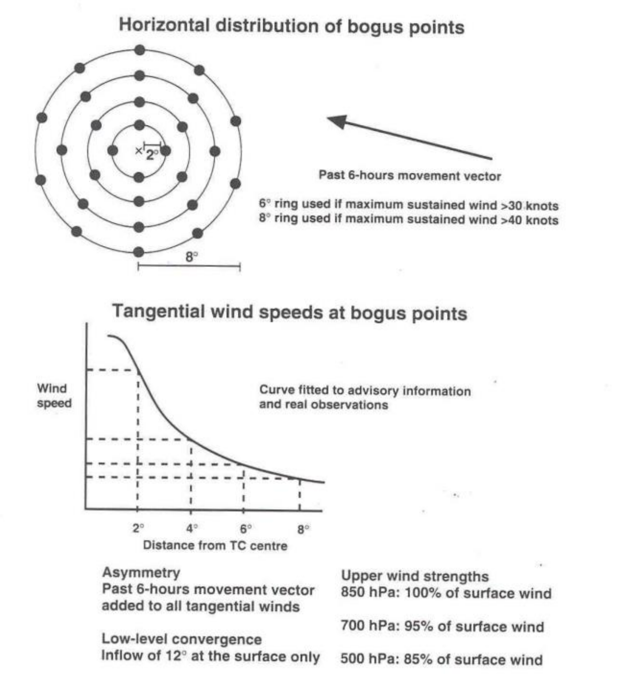
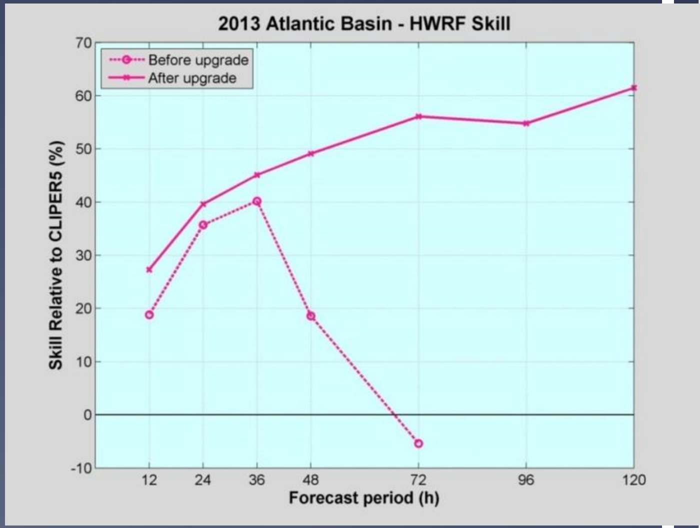


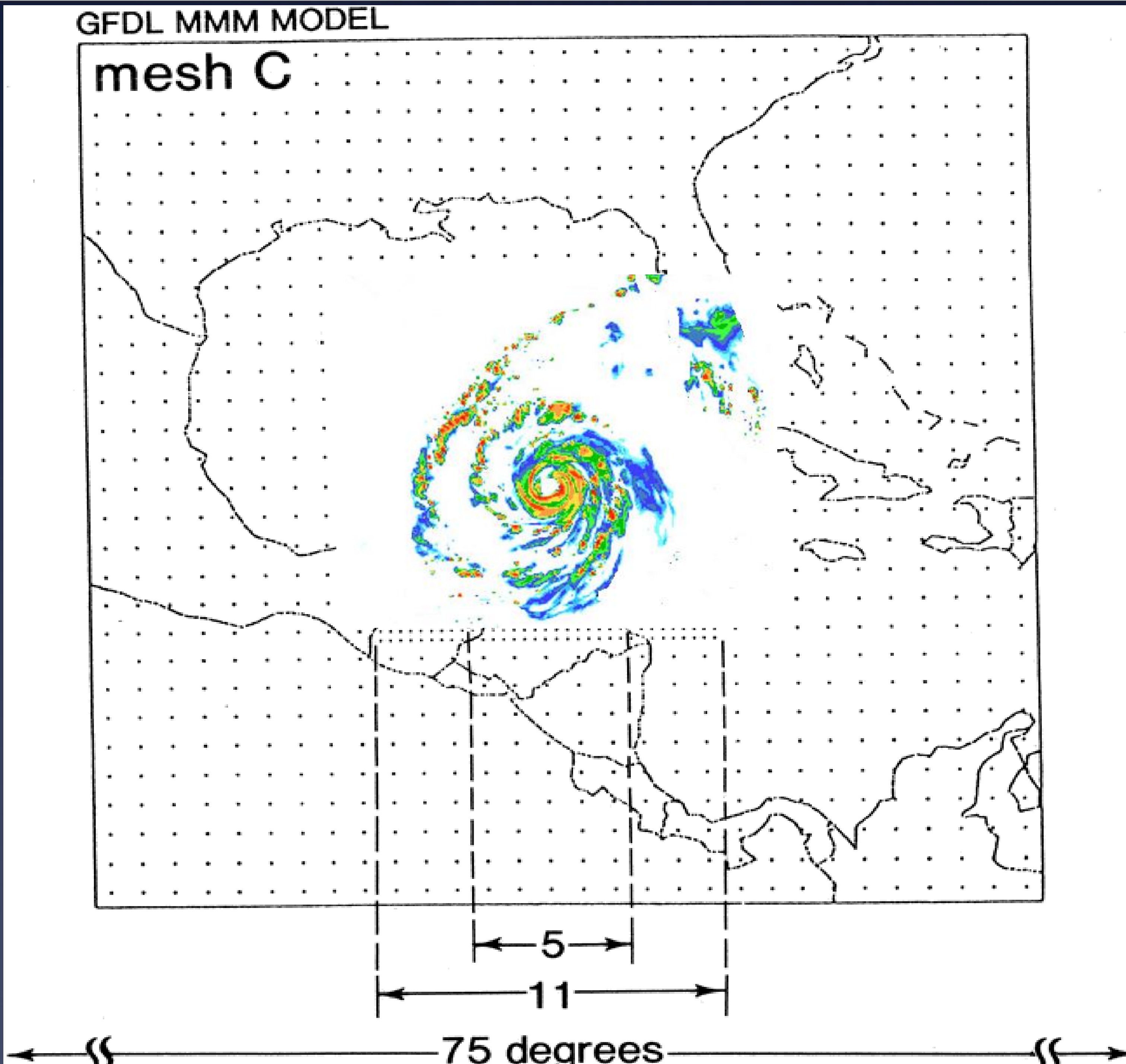
Figure 2. *Formulation of the new UKMO TC bogus scheme.*

Operational Regional Models for TC Track Forecasting

- **Geophysical Fluid Dynamics Laboratory Model** (GFDL)
  - Initialization spins up a vortex from a separate run of the model, which replaces GFS fields over the circulation of the TC.
- **Hurricane Weather Research and Forecasting Model** (HWRF)
  - 3D-Var-EnKF Hybrid data assimilation scheme independent of GFS. In 2013 the HWRF became the first operational system to assimilate inner core observations (Airborne Doppler Radar).
  - Initially modeled after the GFDL, and many of the physics packages remain closely related.



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.


GFDL MMM MODEL
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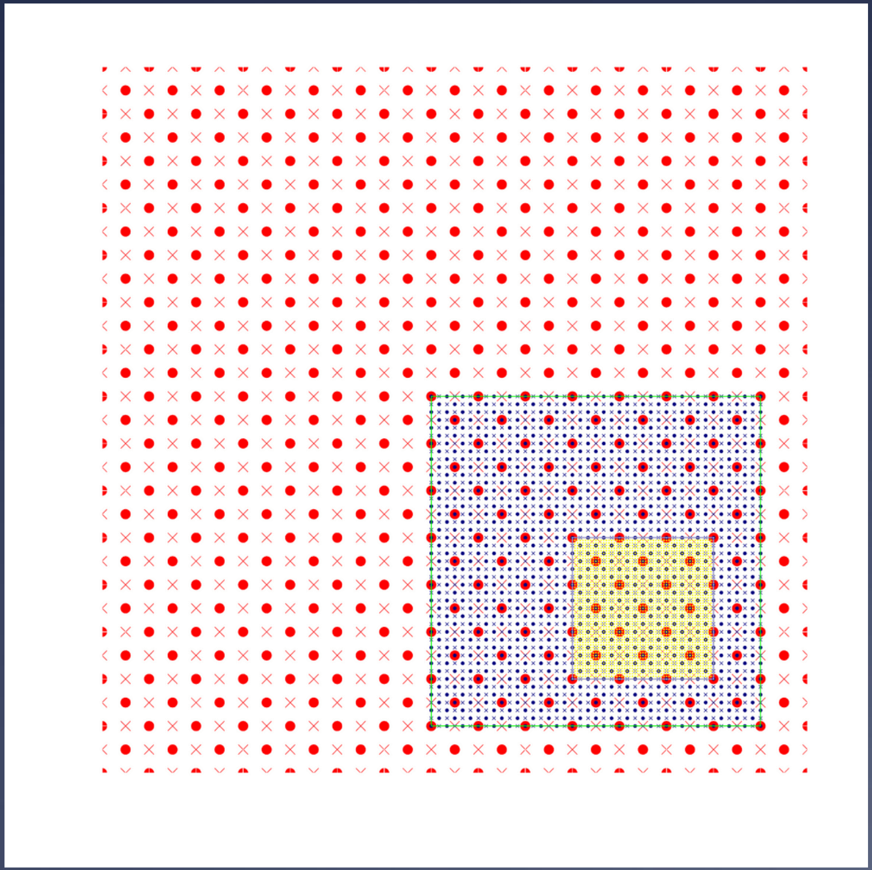
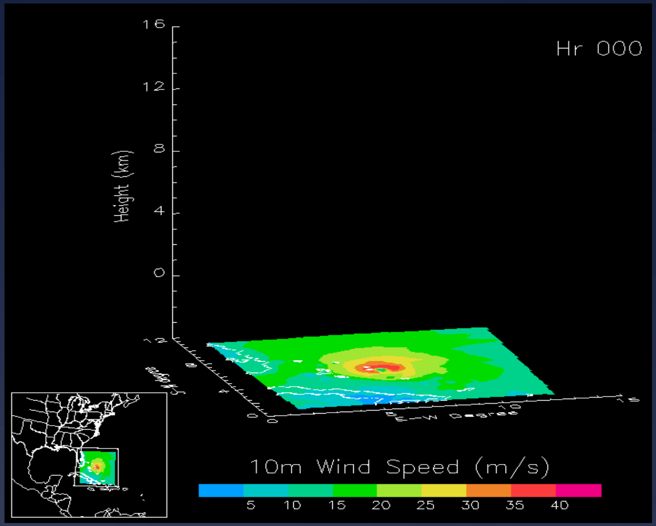
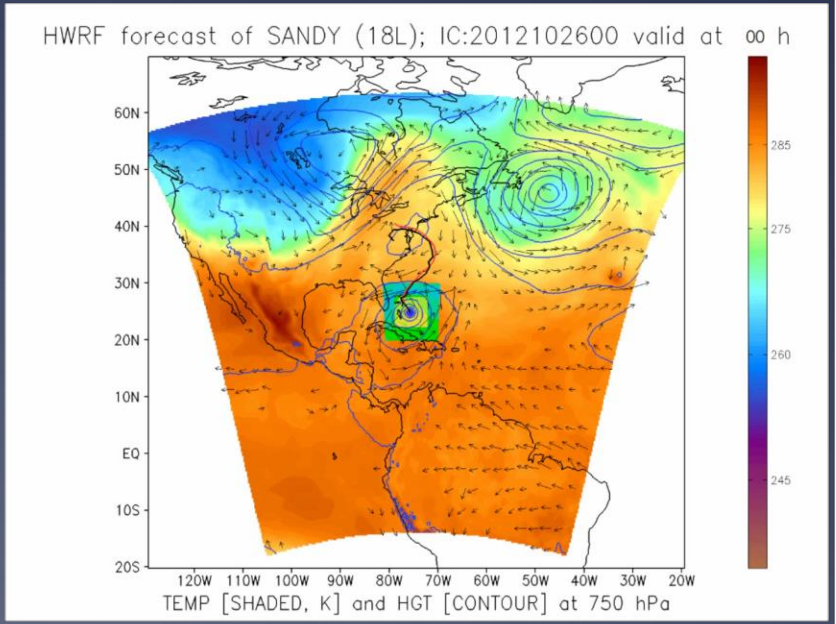
Regional Modeling: Nesting and Storm Structure





Three telescopic domains: 18km: 75x75º; 6km ~11x10º **2km inner-most nest 6x5.5º**



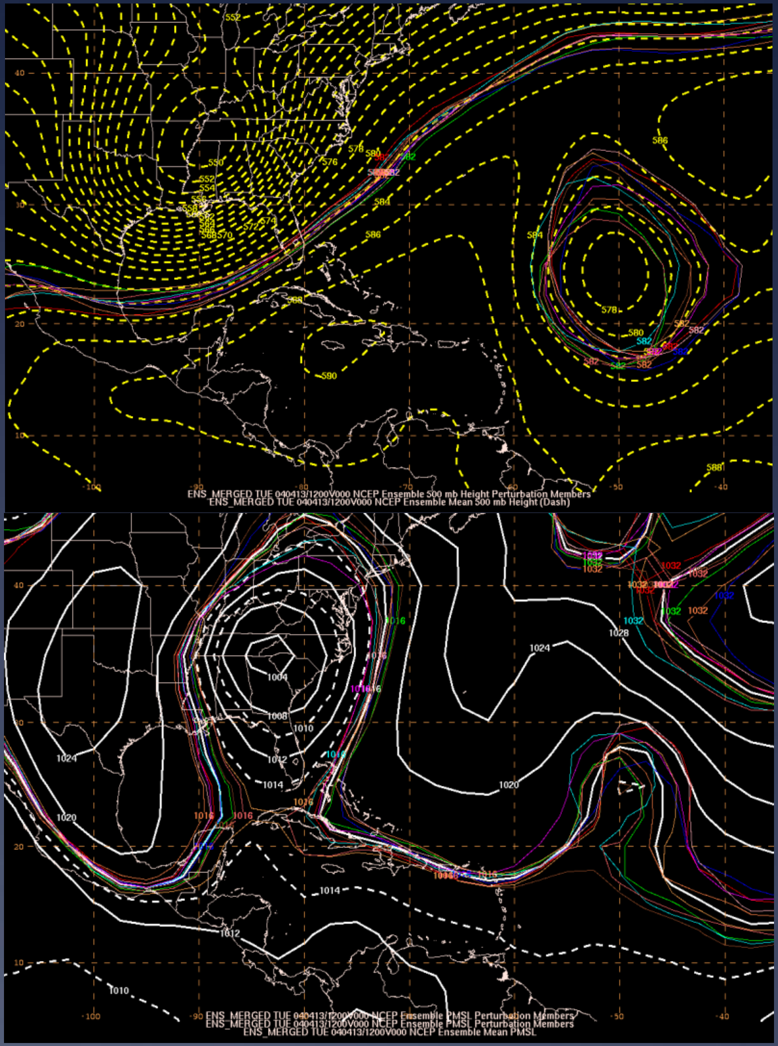
	HWRF	GFDL
Grid configuration	3-nests (coincident) (18 km – 6 km – 2km, upgrade for 2016)	3-nests(not coincident) (1/2° - 1/6° - 1/18°)
Nesting	Force-feedback (two-way interactive)	Interaction thru intra-nest fluxes
Vertical Levels	61 Hybrid Sigma	42 Sigma
Ocean coupling	MPIPOM (Trans-Atlantic and Eastern Pacific Basins)	MPIPOM (Trans-Atlantic and Eastern Pacific Basins)
Convective parameterization	SAS mom. mix. + GFS shallow convection (6km and 18km) 2km nest – none	SAS mom. mix. + GFS shallow convection
Microphysics	Ferrier-Aligo (upgrade for 2015)	Ferrier
Boundary layer	Modified GFS non-local	Modified GFS non-local
Surface layer	Modified GFDL	GFDL (Moon et. al.)
Land surface model	NOAH LSM (upgrade for 2015)	GFDL slab
Dissipative heating	Based on D-L Zhang	Based on M-Y tke 2.5
Radiation	RRTMG with partial cloudiness (upgrade for 2015)	GFDL

Ensembles and Consensus

* An ensemble is a collection of forecasts all valid at the same forecast time.

* Can be formed from a single model (e.g., the GFS) by making multiple runs of the model with slightly different (perturbed) initial conditions.

* 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.



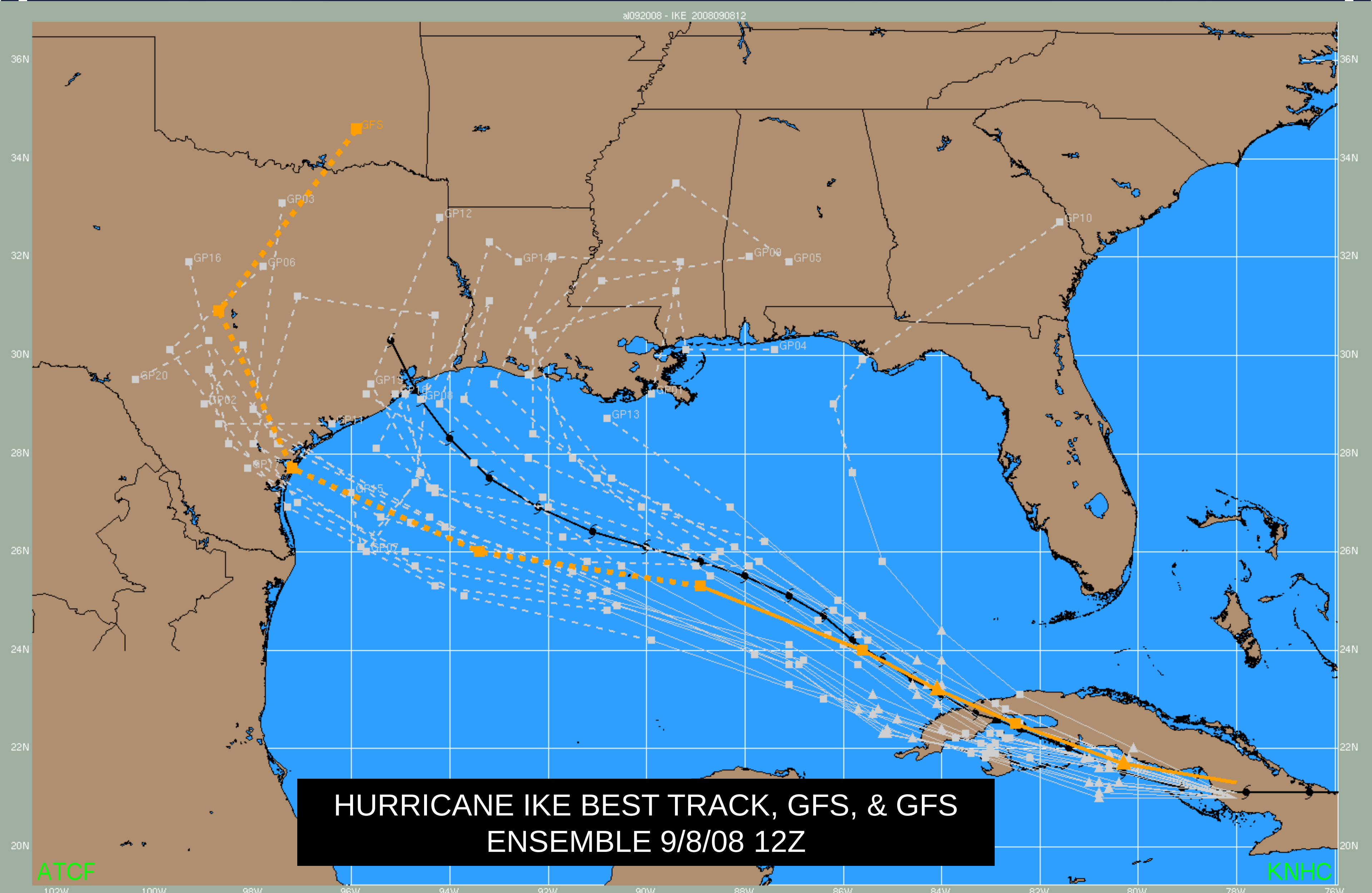
Ensembles and Consensus

* In the case of a single model ensemble, the perturbed initial conditions represent uncertainty in the initial analysis, but the model physics is the same for each ensemble member. In other words, the model is assumed to be perfect, with the only source of forecast error being initial analysis errors.
  * 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)

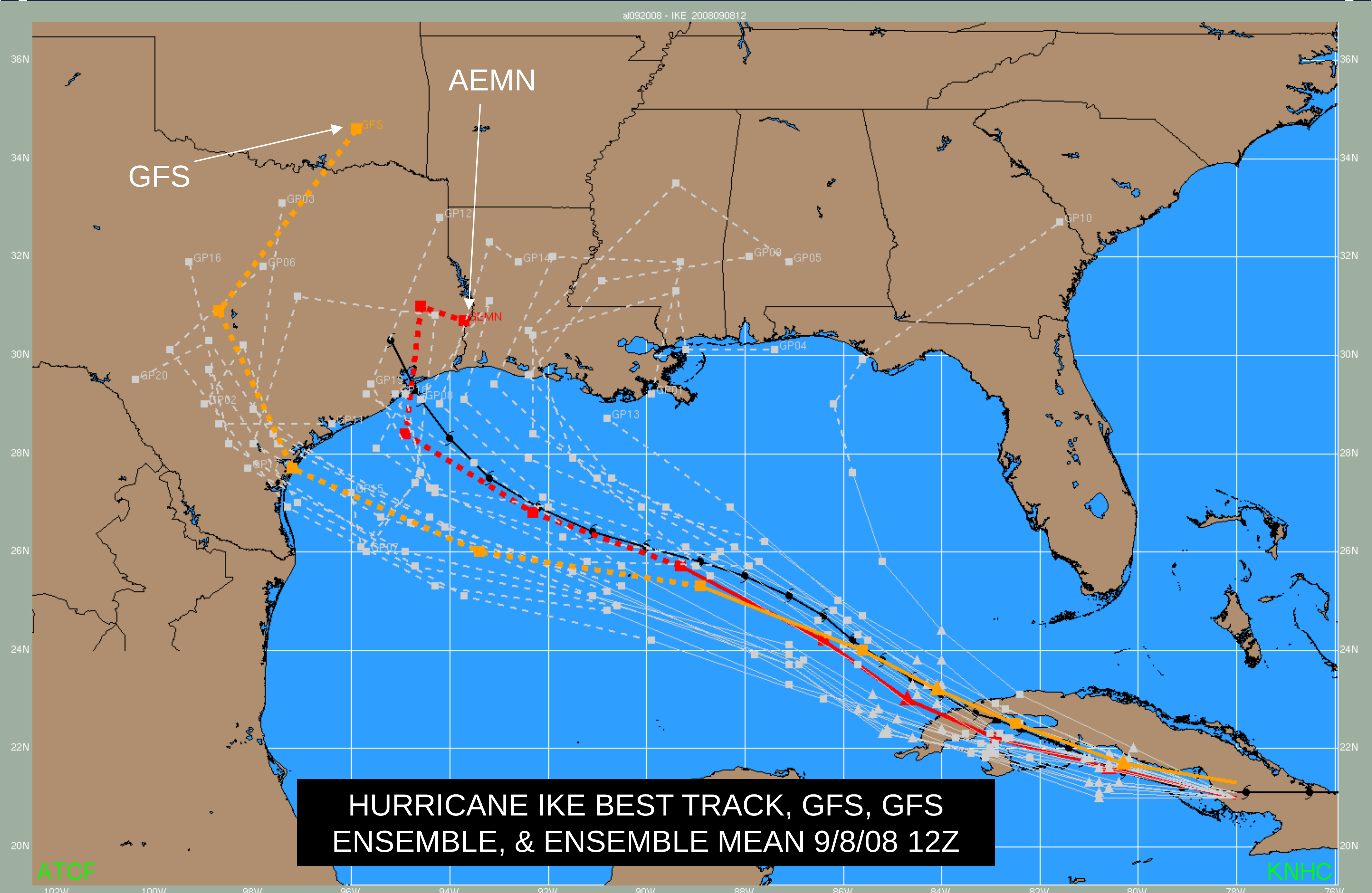
GFS Ensemble example

GFS Ensemble example

GFS Ensemble example



GFS Ensemble example

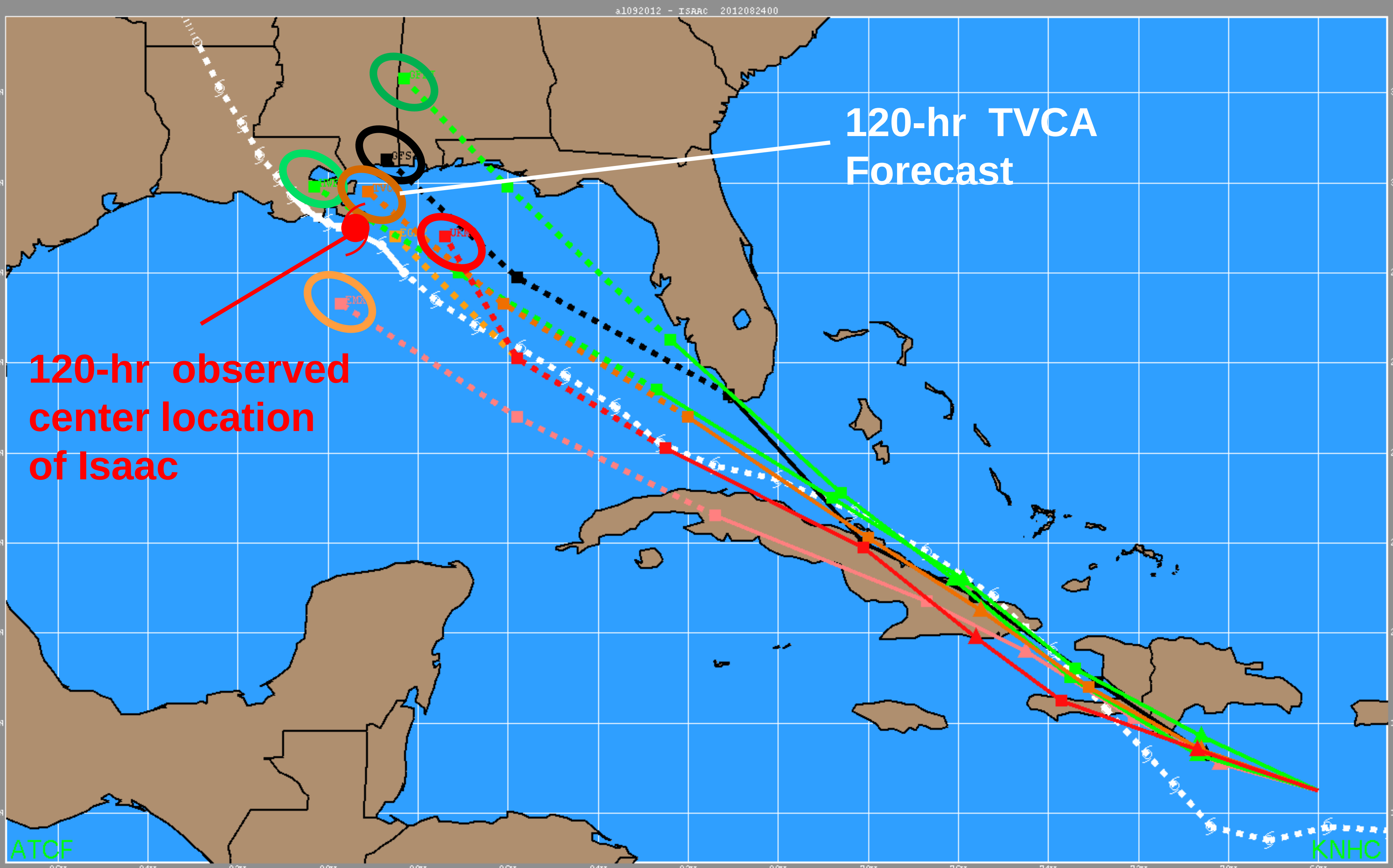


Ensembles and Consensus

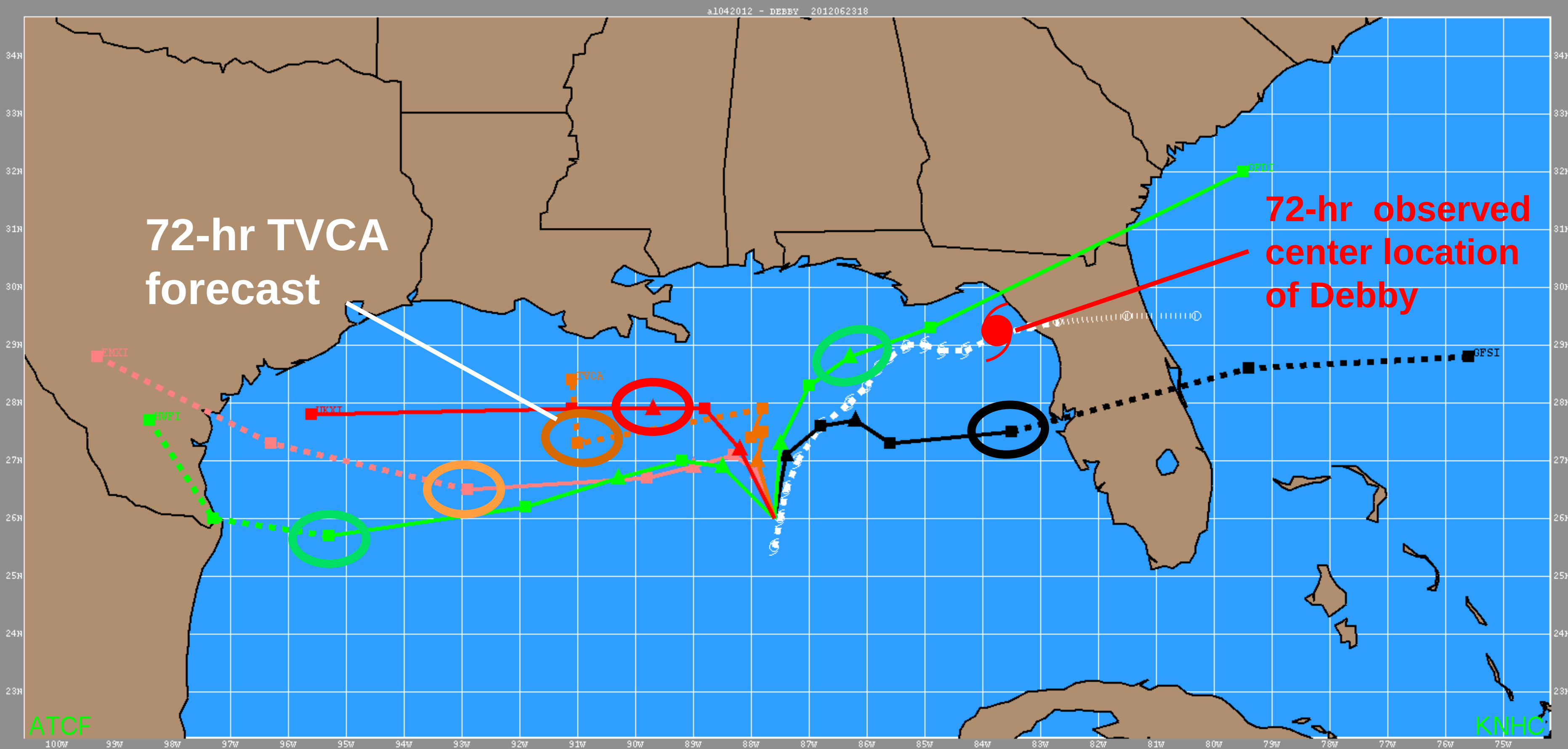
- Another way to form a consensus is to use an ensemble of <u>different</u> prediction models from the same initial time. This is called a multi-model ensemble.
- In a multi-model ensemble, the forecasts from the various member models differ due to differences in model initialization <u>and</u> model physics.
  - **TCON** is the consensus (average) of GHMI, EGRI, HWFI, and GFSI (formerly AVNI).
  - **TVCN** is the average of at least two of GFSI, EGRI, GHMI, HWFI, and EMXI.
  - **FSSE** is a weighted average of several models and the previous official forecast (OFCI). Includes bias correctors to account for model error tendencies.

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 better than the deterministic version of the same model, and nearly as well as the multi-model consensus.
* Single model ensembles are most useful around day 5 and beyond.



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!

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 (LBAR, BAMs, 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.

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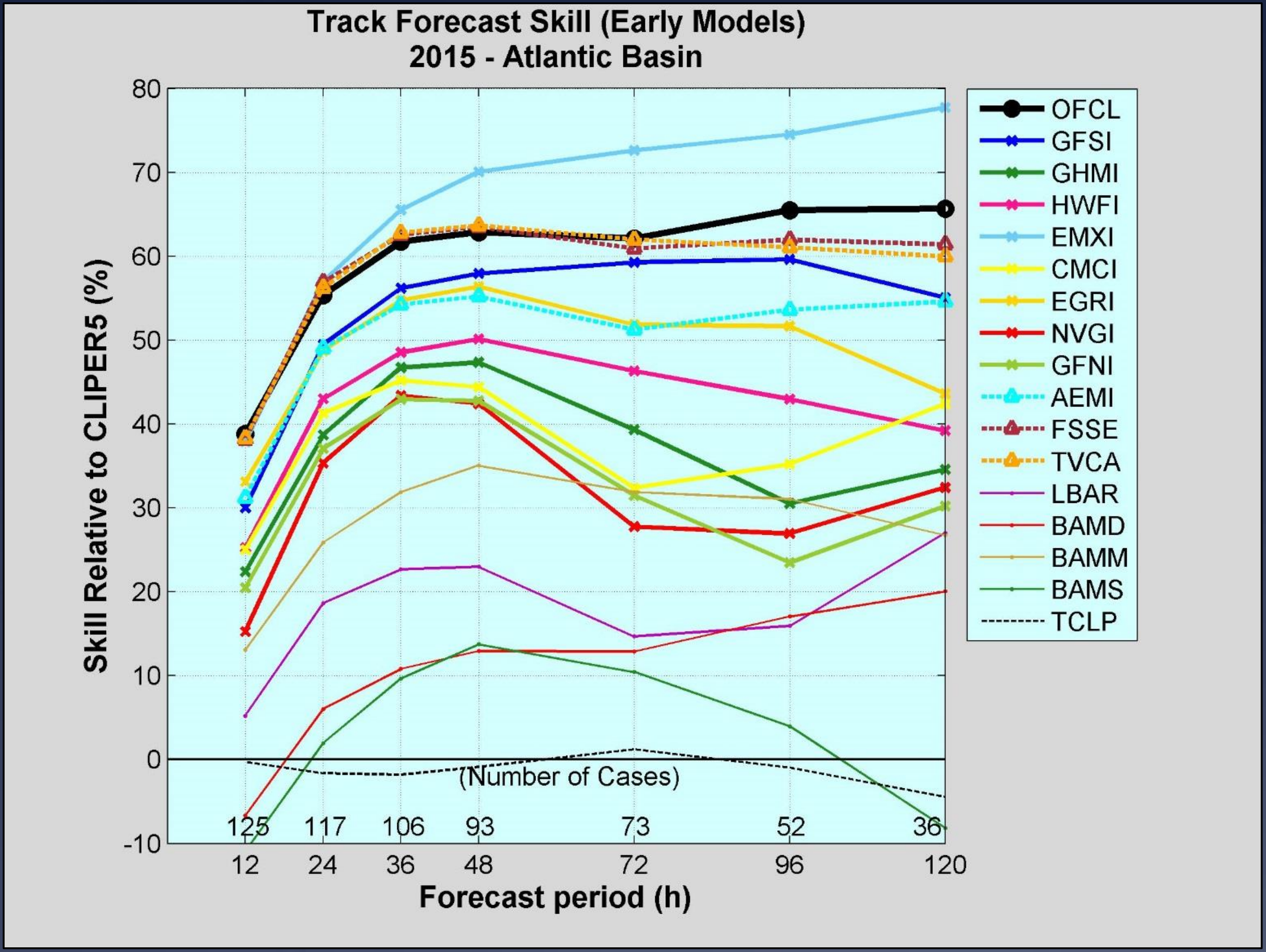
The "early" version of the model is what the forecasters actually have available to them when making a forecast

OFCL is verified against the early models

Early and Late Model IDs

Model	Late ID	Early ID
Dynamical Track Multimodel Consensus	(none)	TVCN
Corrected Multimodel Consensus	(none)	FSSE
GFS	AVNO/GFSO	AVNI/GFSI
GFS Ensemble	AEMN/GEMO	AEMI/GEMI
ECMWF global model	EMX/ECMO	EMXI/ECOI
UKMET global model	EGRR	UKXI/EGRI
Canadian GDP	CMC	CMCI/CMC2
U.S. Navy NAVGEM	NVGM	NVGI
HWRF	HWRF	HWFI
GFDL	GFDL	GHMI
Beta Advection Models	(none)	BAMS/BAMM/BAMD
Limited Area Barotropic	(none)	LBAR
Climatology and Persistence	(none)	CLP5/OCD5
NHC Previous Forecast	(none)	OFCI

2015 Track Guidance



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

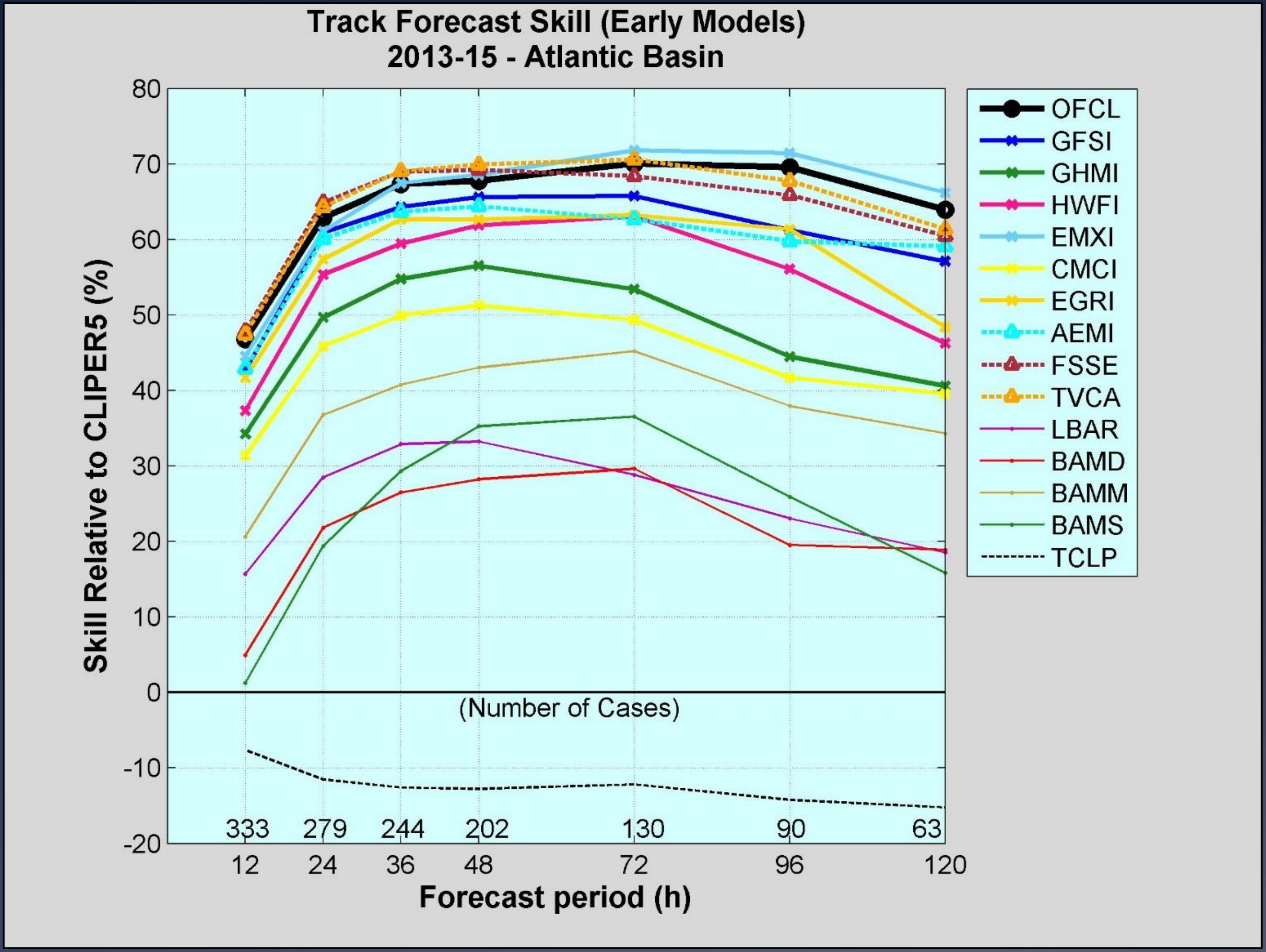
EMXI best model, and the only one that beat the official forecast at 36 h and beyond.

GFSI was a fair to good performer (second best individual model) with skill just below the official forecasts and the consensus models.

GFS ensemble mean (AEMI), HWFI, and EGRI next best models.

GHMI, CMCI, NVGI, GFNI trailed again in 2015.

2013-15 Track Guidance



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

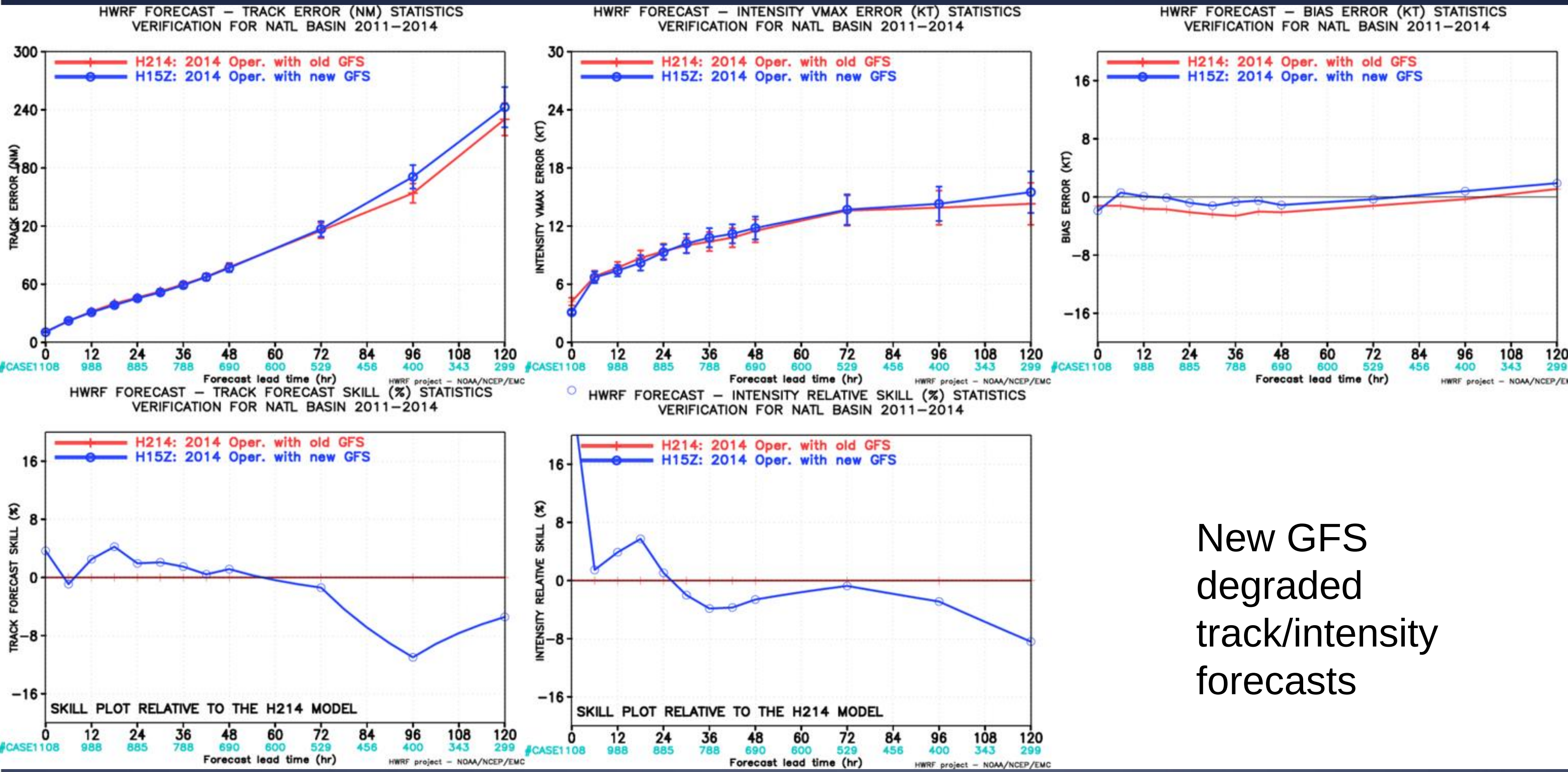
EMXI best individual model, and beat the official forecast at 48 h and beyond.

GFSI was good performer (second best individual model) with skill just below the official forecasts and the consensus models.

GFS ensemble mean (AEMI), HWFI, and EGRI next best models.

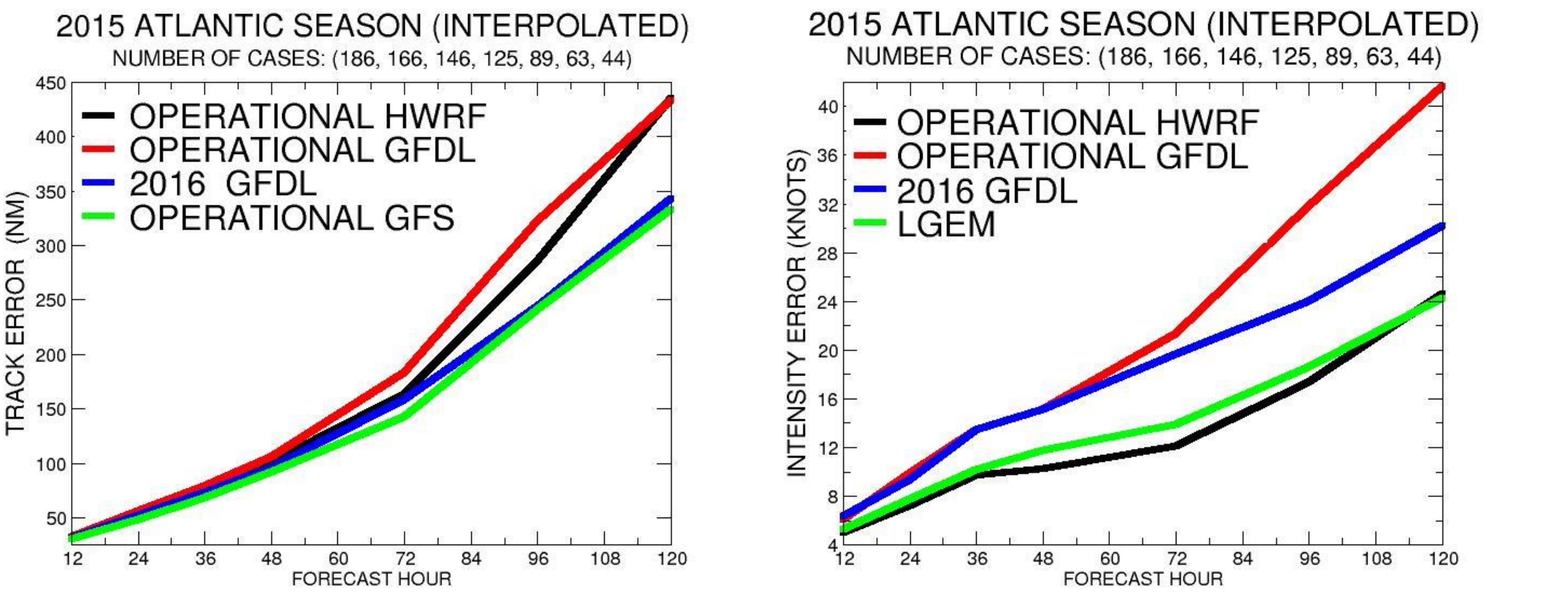
GHMI and CMCI trailed.

Impact of 2015 GFS on HWRF



New GFS degraded track/intensity forecasts

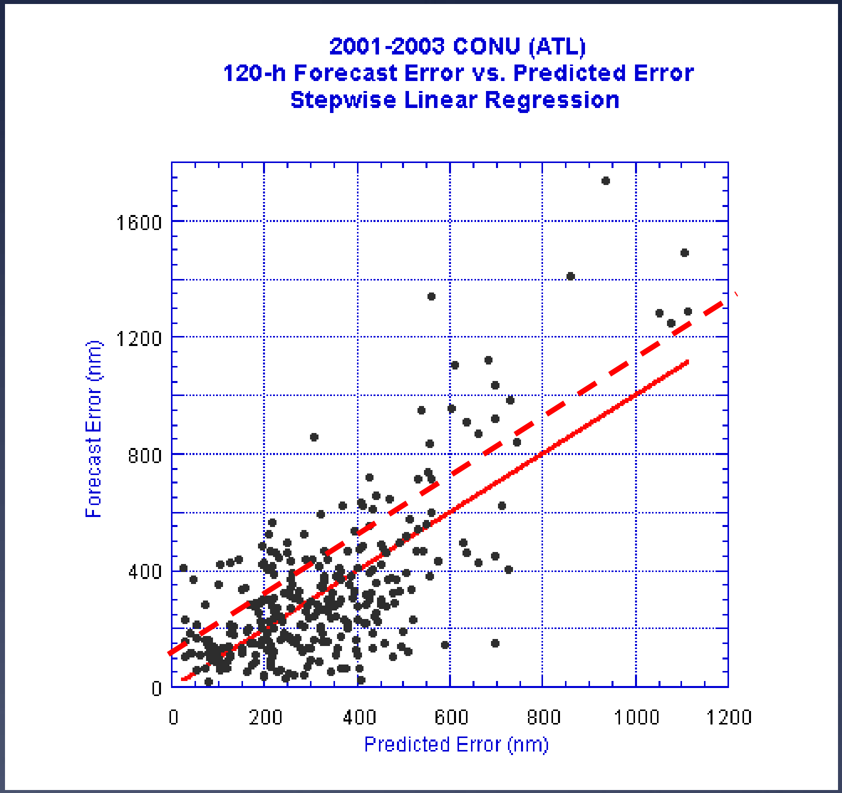
Expected Improvements to Regional Models in 2016: GFDL



Additional Tools and Considerations for TC Track Forecasting

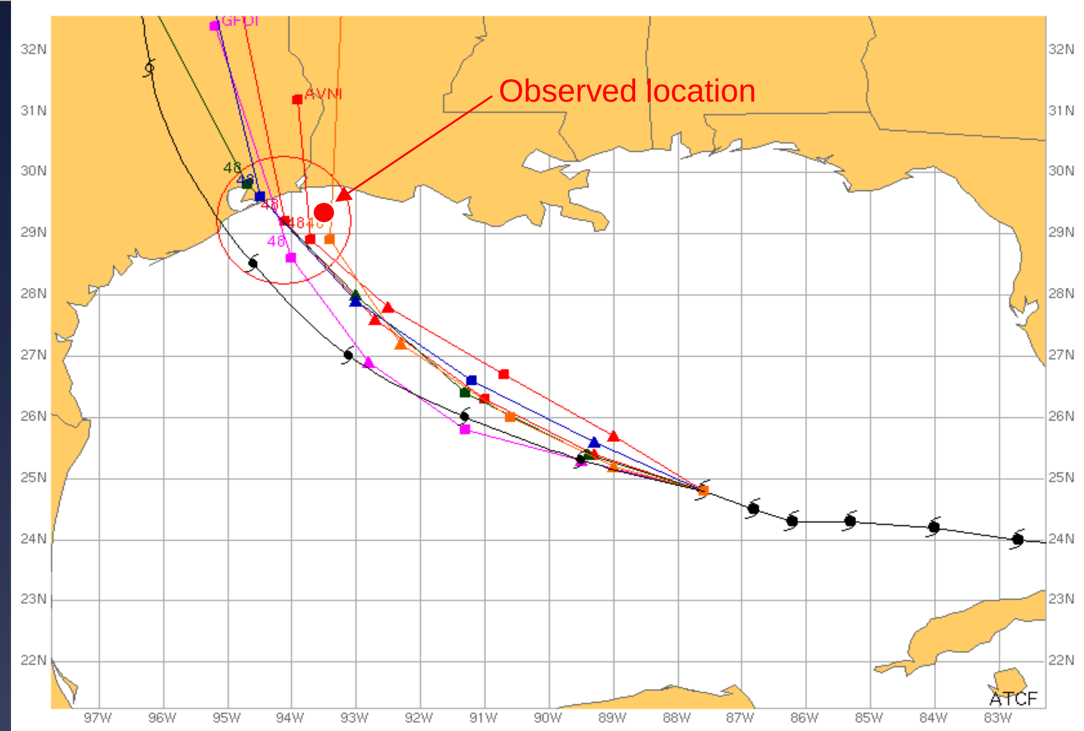
Goerss Prediction of Consensus Error (GPCE)

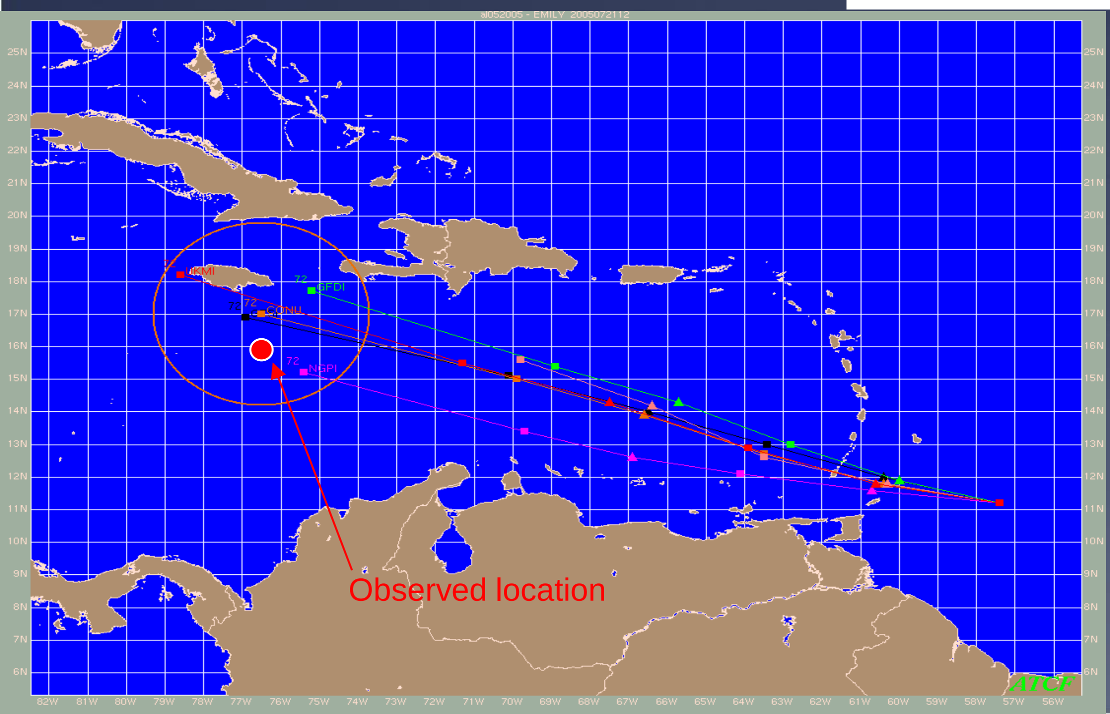
- The magnitude of the consensus (TVCN) error can be statistically predicted based on:
  - Model spread
  - Initial and forecast intensity
  - Forecast latitude and longitude displacements.
- Adjust the regression line upward so that 75% of the time the actual error is smaller than the predicted error.



- Adjusted regression gives you 75% "confidence circles" around TVCN.

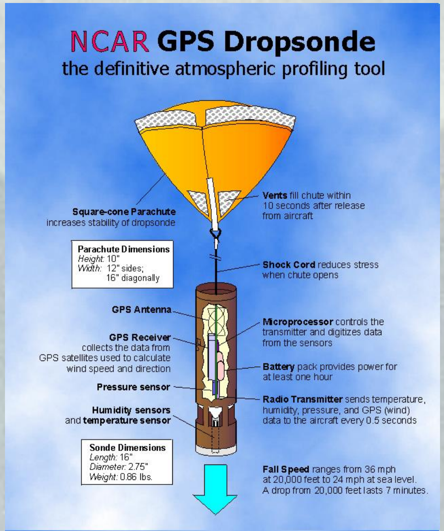
72 h 75% GPCE circle, Hurricane Emily
1200 UTC 13 July 2005



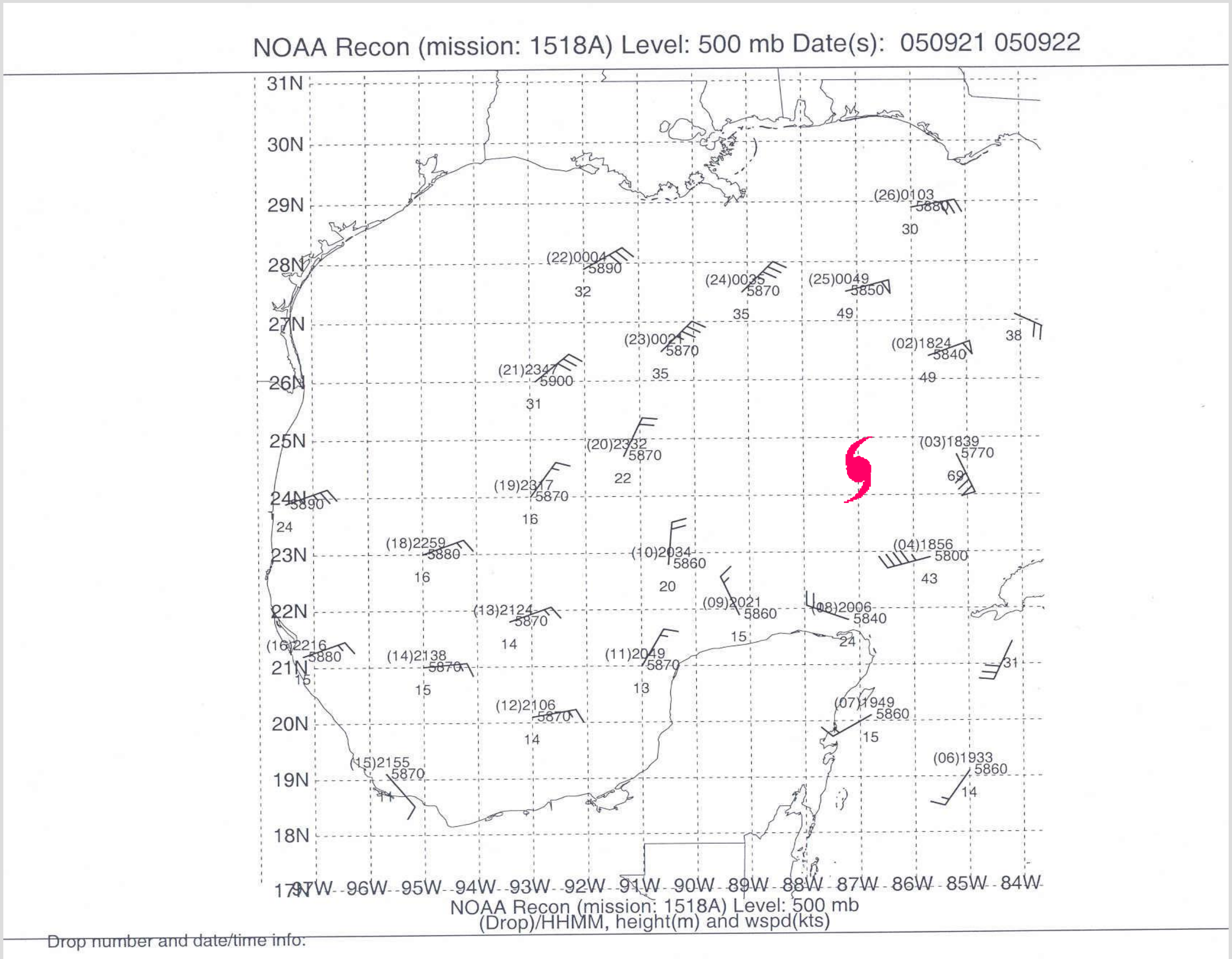


48 h 75% GPCE circle, Hurricane Rita
0600 UTC 22 September 2005

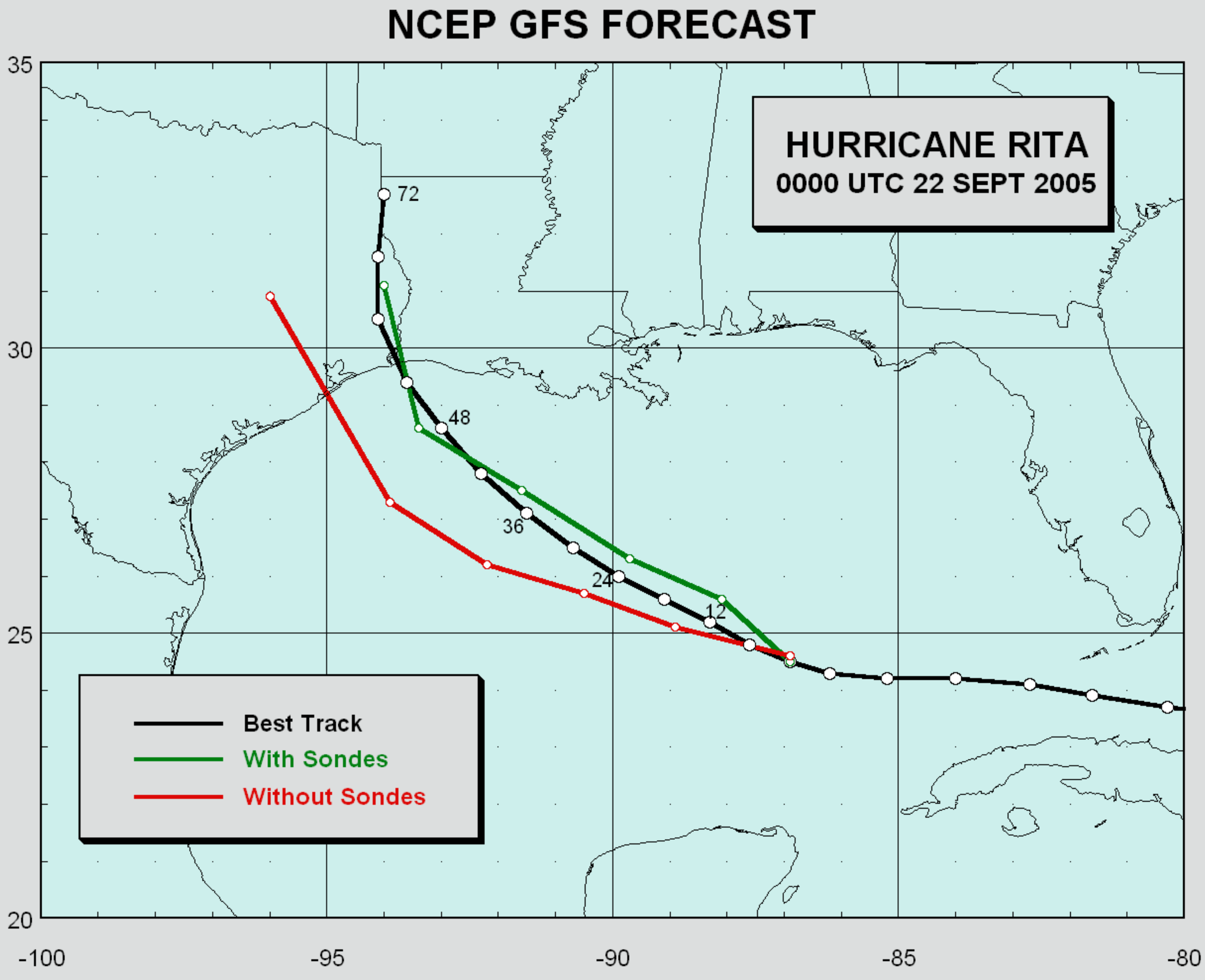
NOAA G-IV AIRCRAFT: A SYNOPTIC SURVEILLANCE PLATFORM



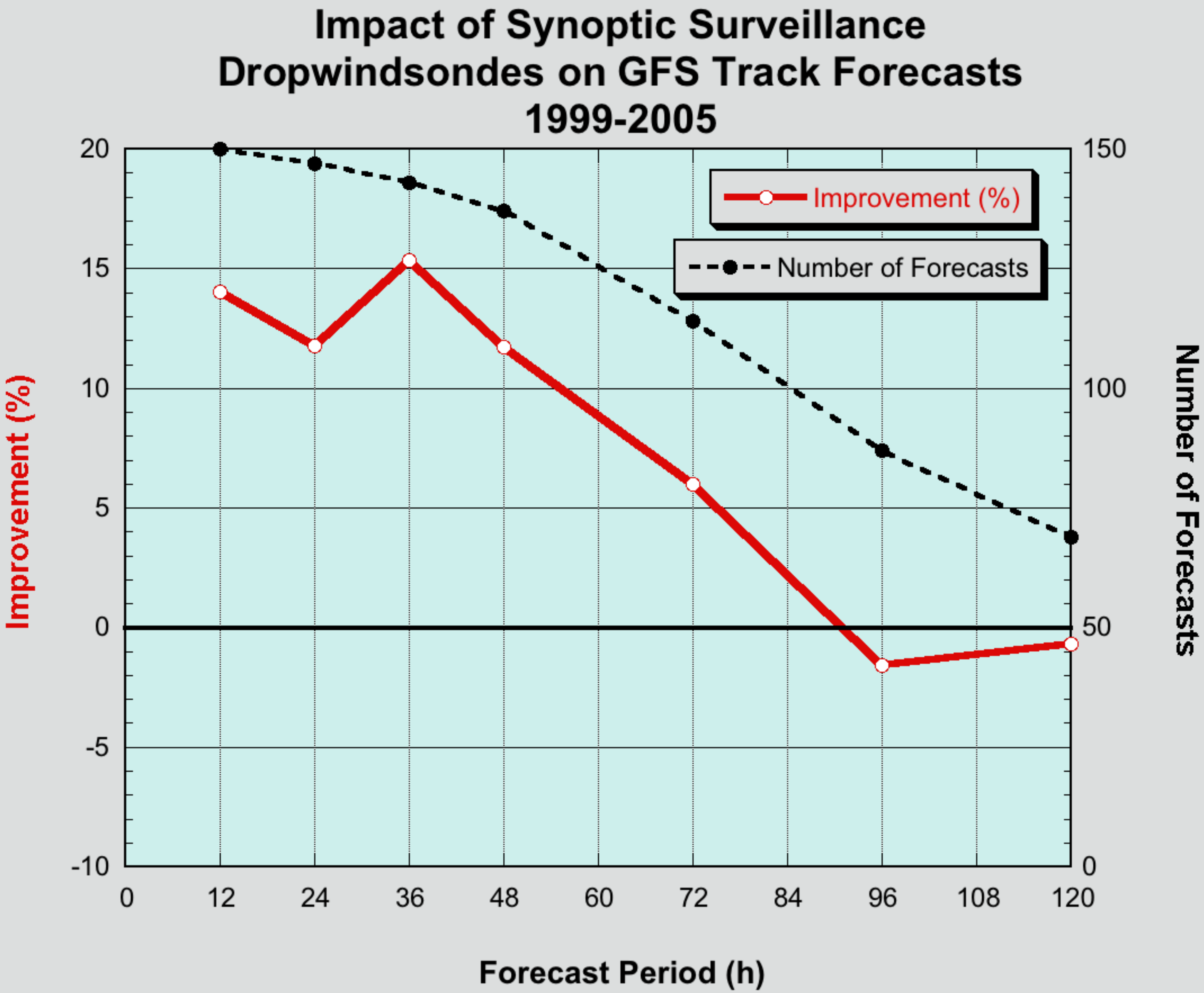
Rita: 500 mb Dropsonde Observations
1800 UTC 21 Sept – 0300 UTC 22 Sept 2005



Rita Dropsonde Impact Example

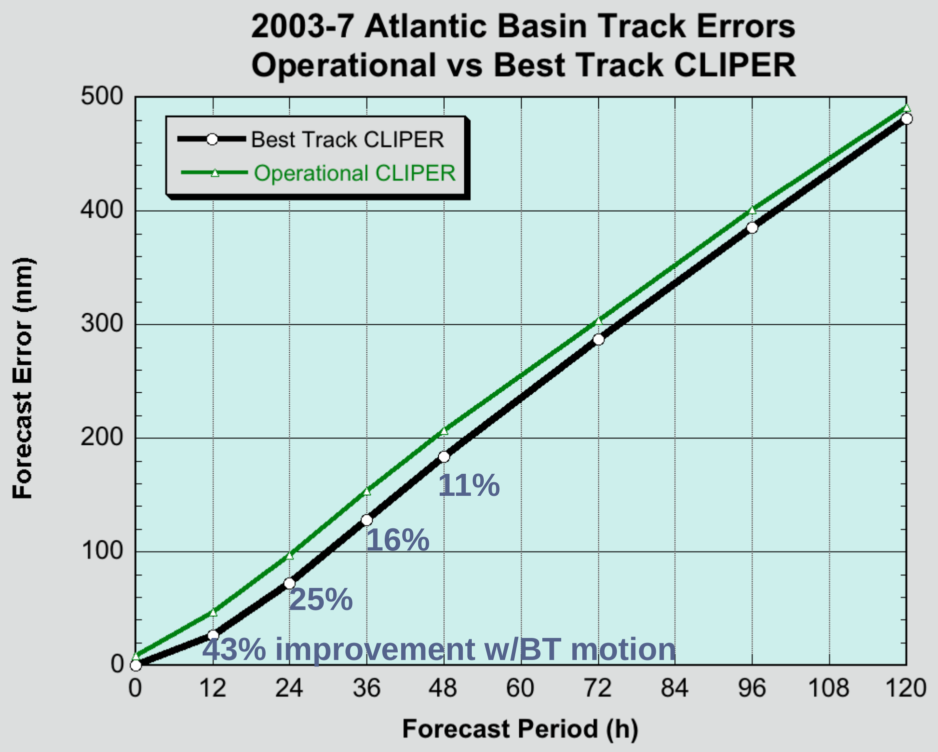


1999-2005 Dropsonde Impact



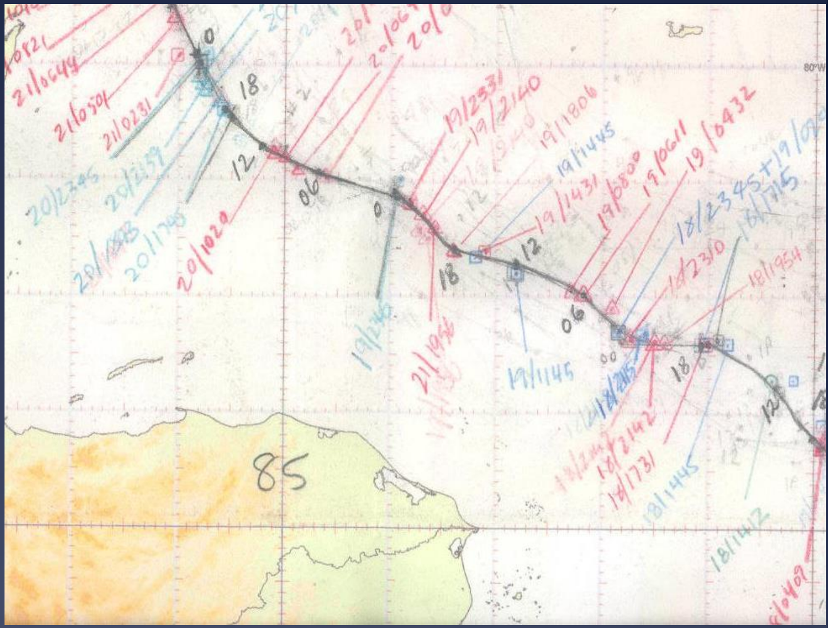
Track Forecasting at the NHC: Importance of Initial Motion

- 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.



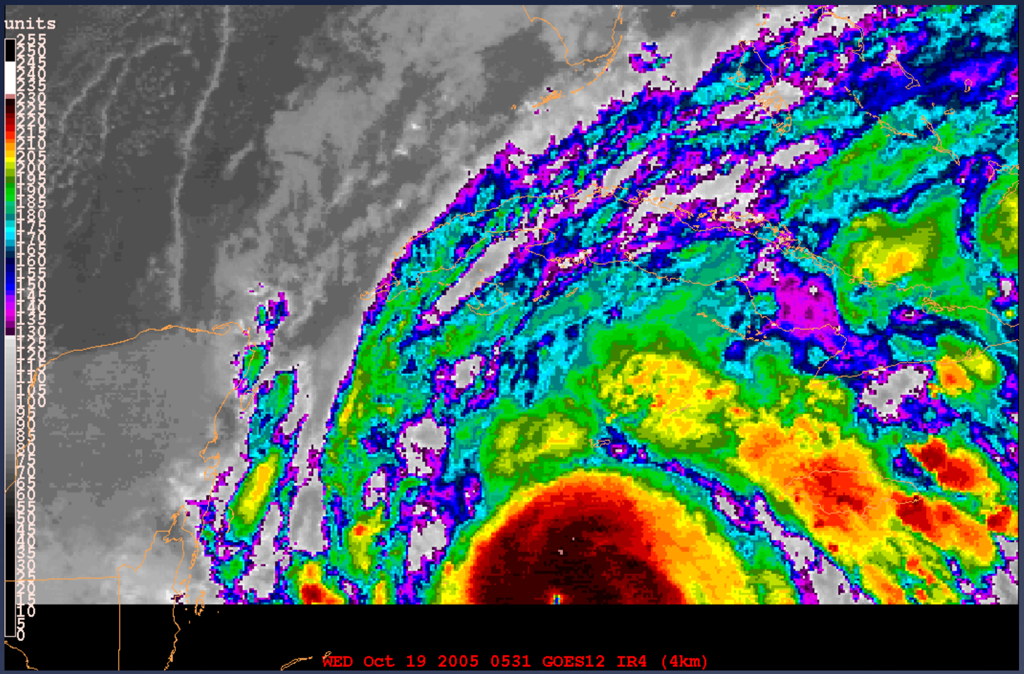
Track Forecasting at the NHC: Determination of Initial Motion

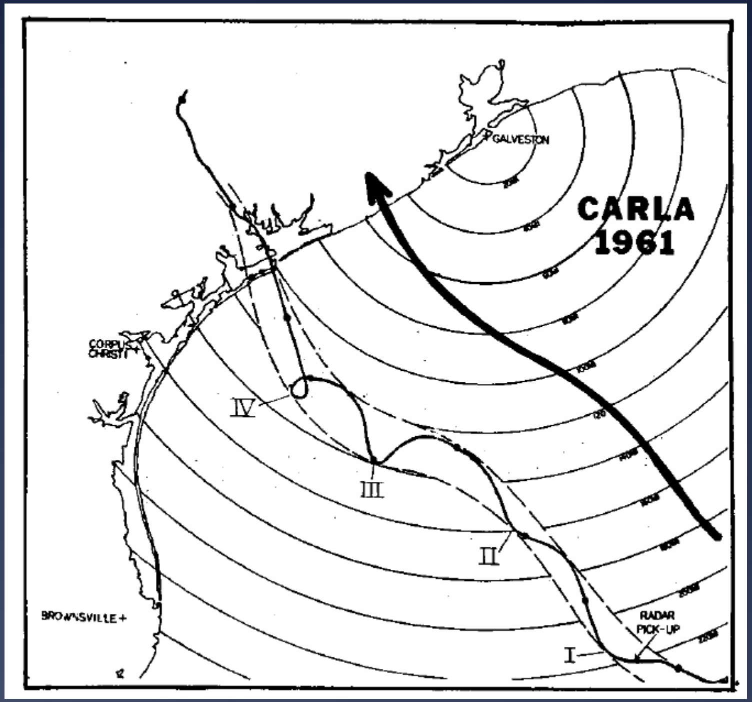
- Initial motion typically computed using the average motion over the previous 6, 12, or 18 h.
  - Shorter when known changes in track are occurring, longer when center location is uncertain.
  - Initial motion estimate should not reflect short-term track wobbles (e.g., trochoidal oscillations) that 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.

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!

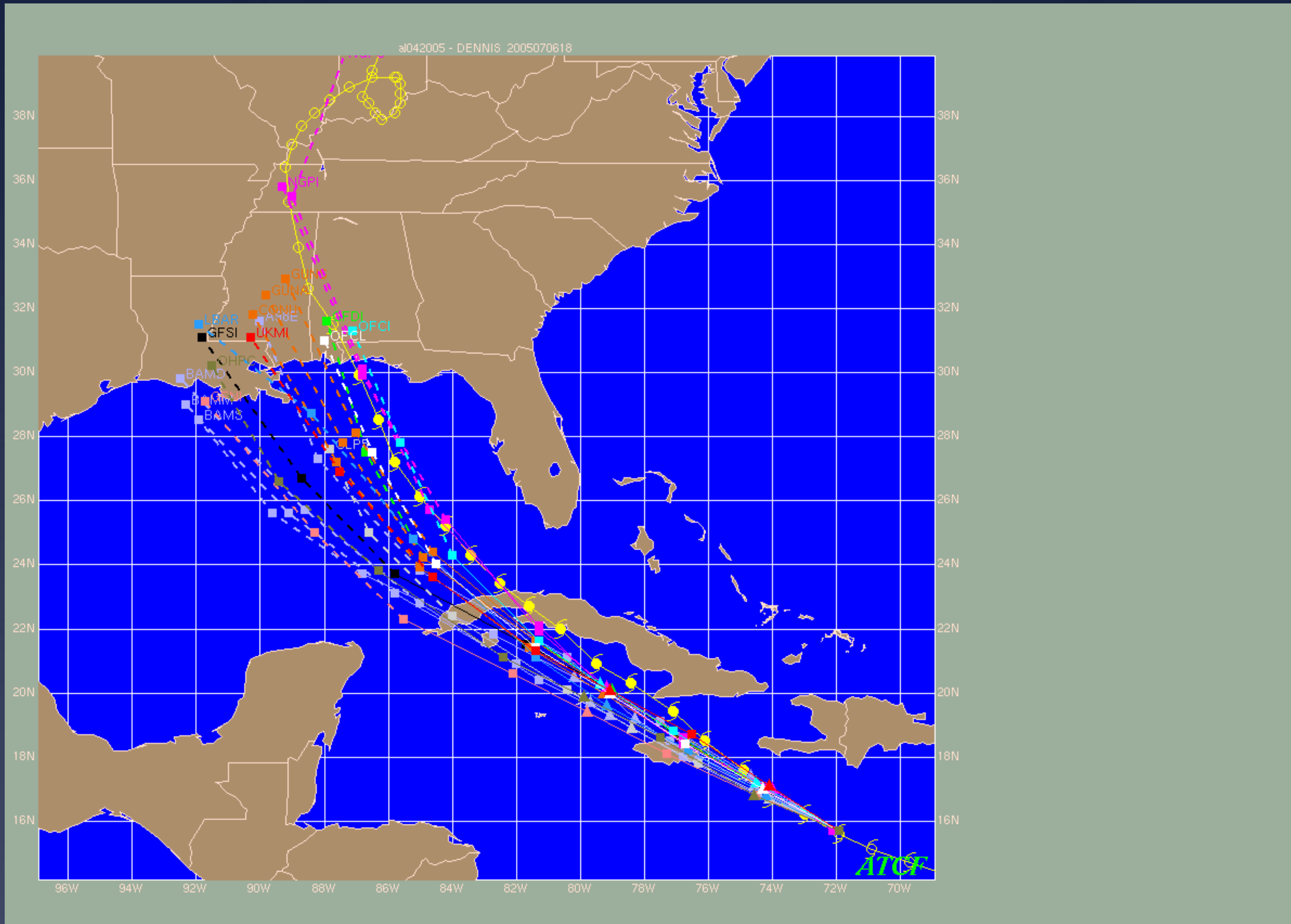
Track Forecasting at the NHC: Continuity

* 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

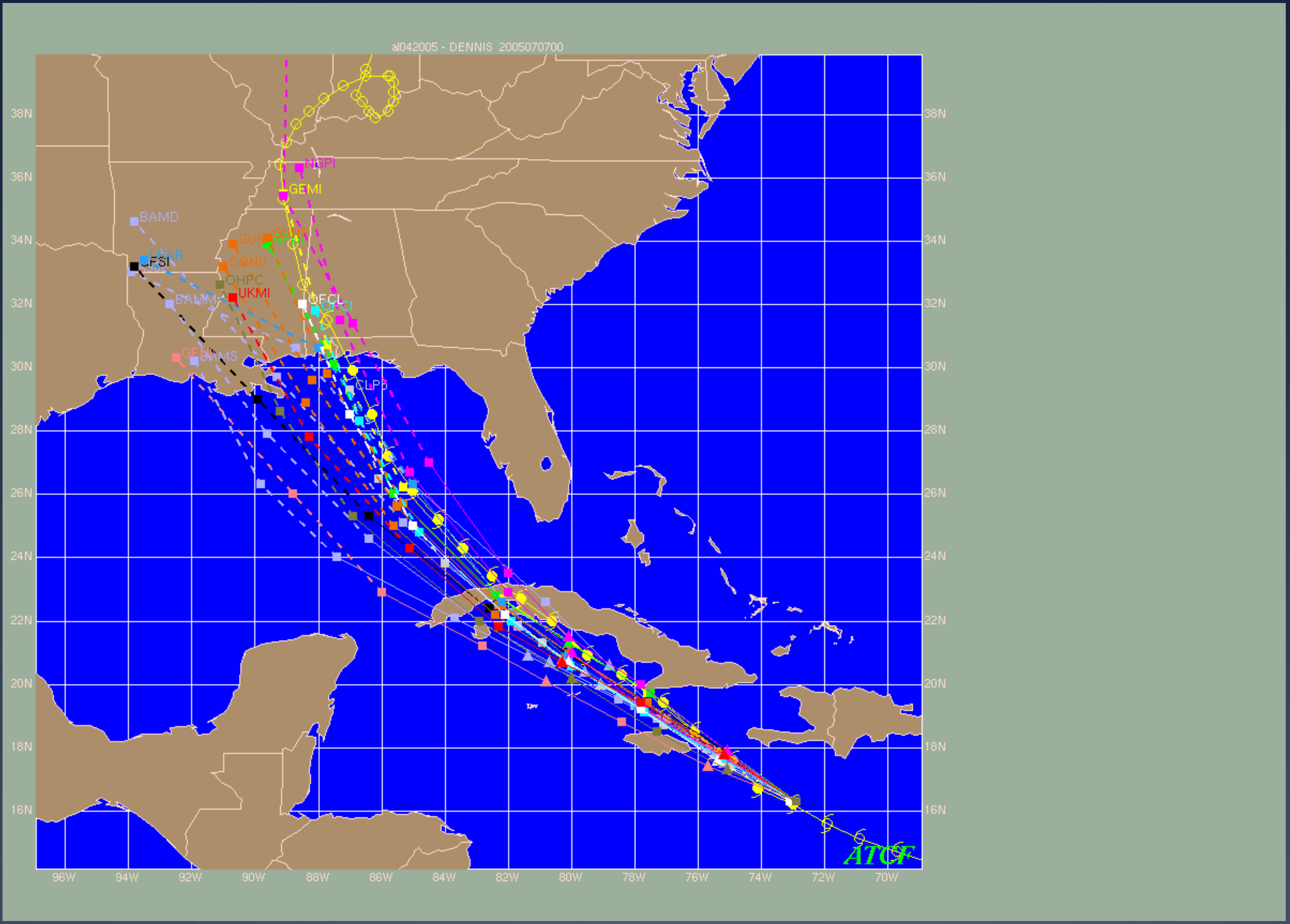
* Official forecast near model consensus in extreme western FL panhandle.

Dennis Guidance 6 July 1800 UTC



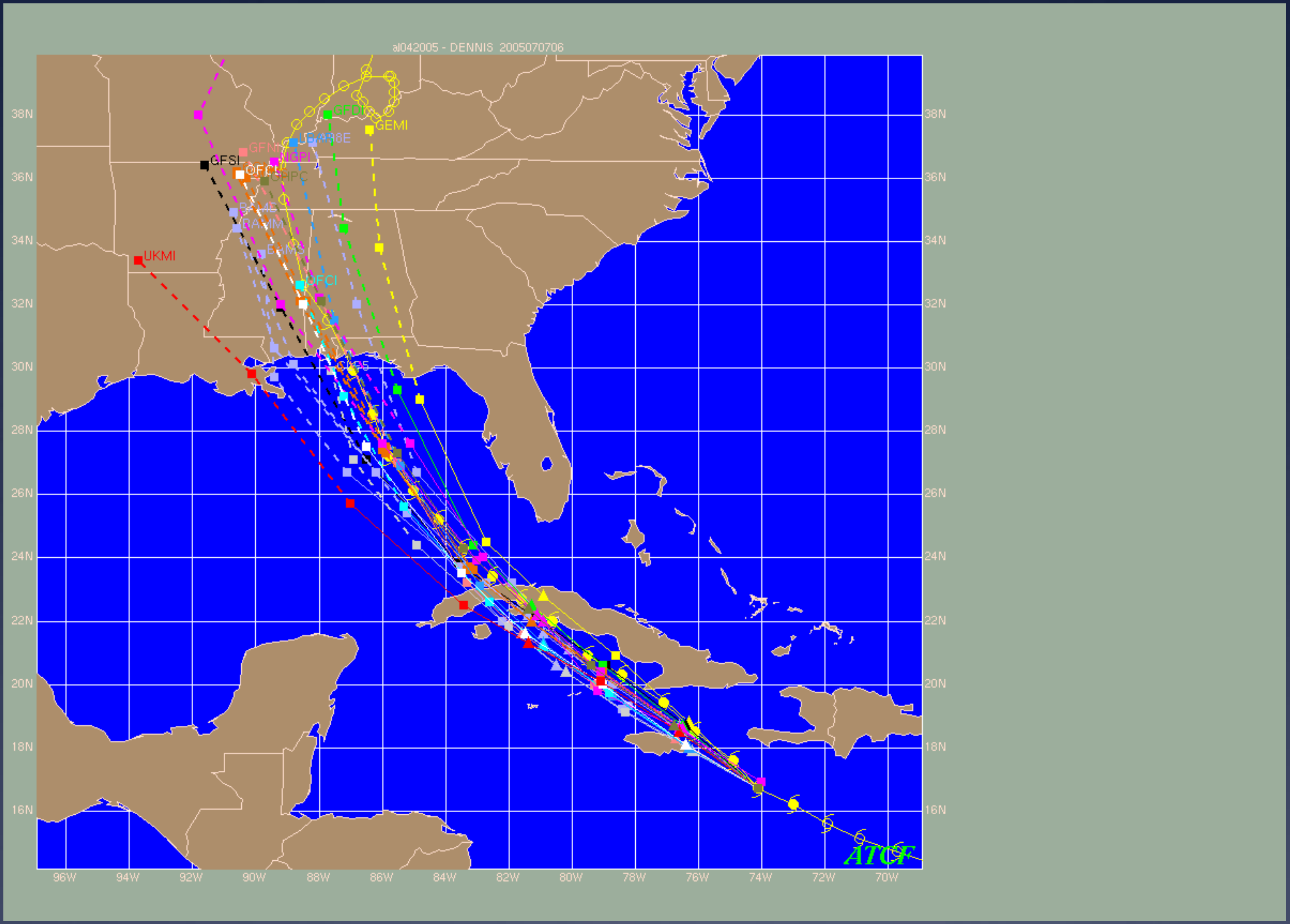
* Guidance shifts sharply westward toward New Orleans. Official forecast nudged westward into AL.

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.

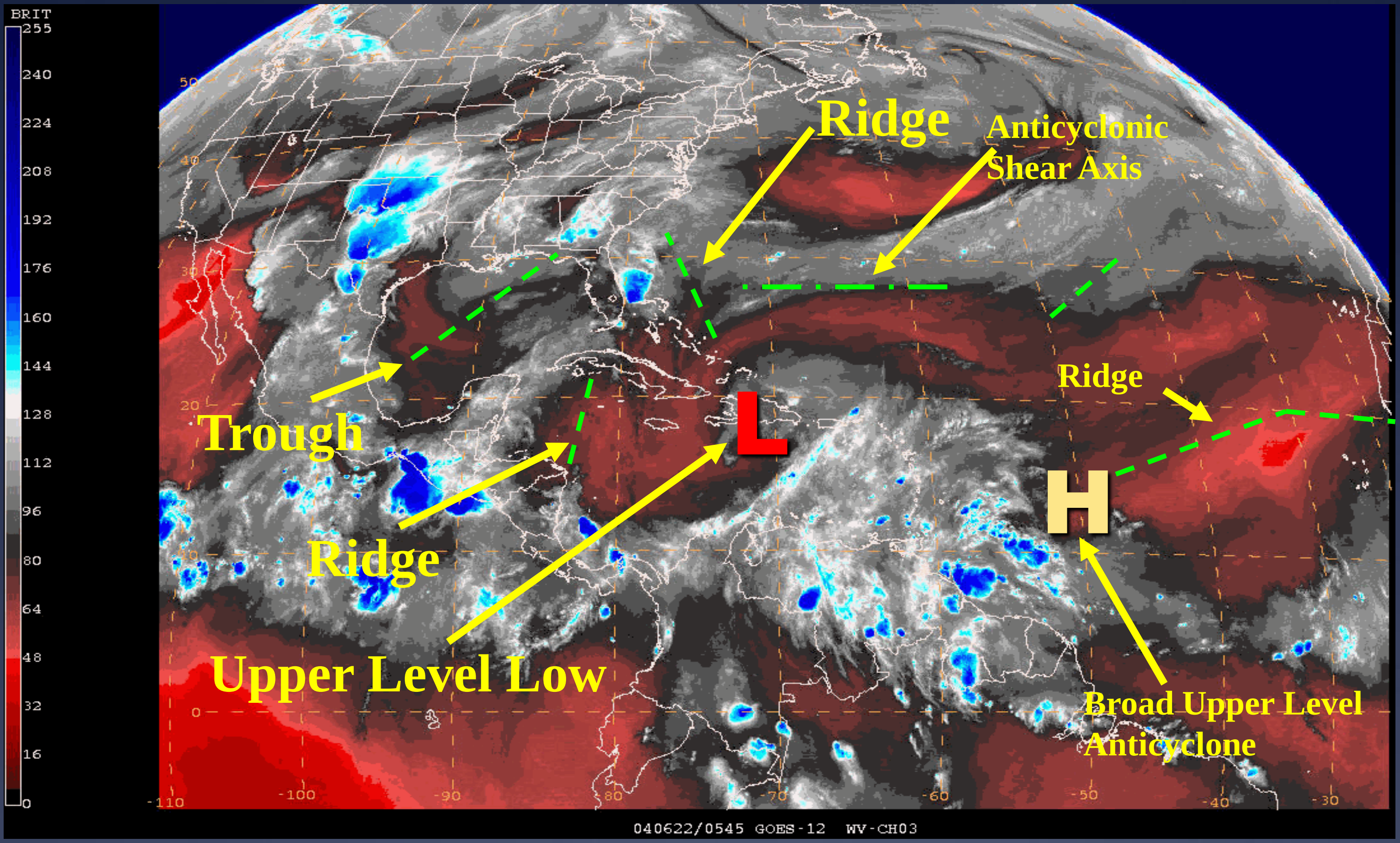
Track Forecasting at the NHC: Using Models

* 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

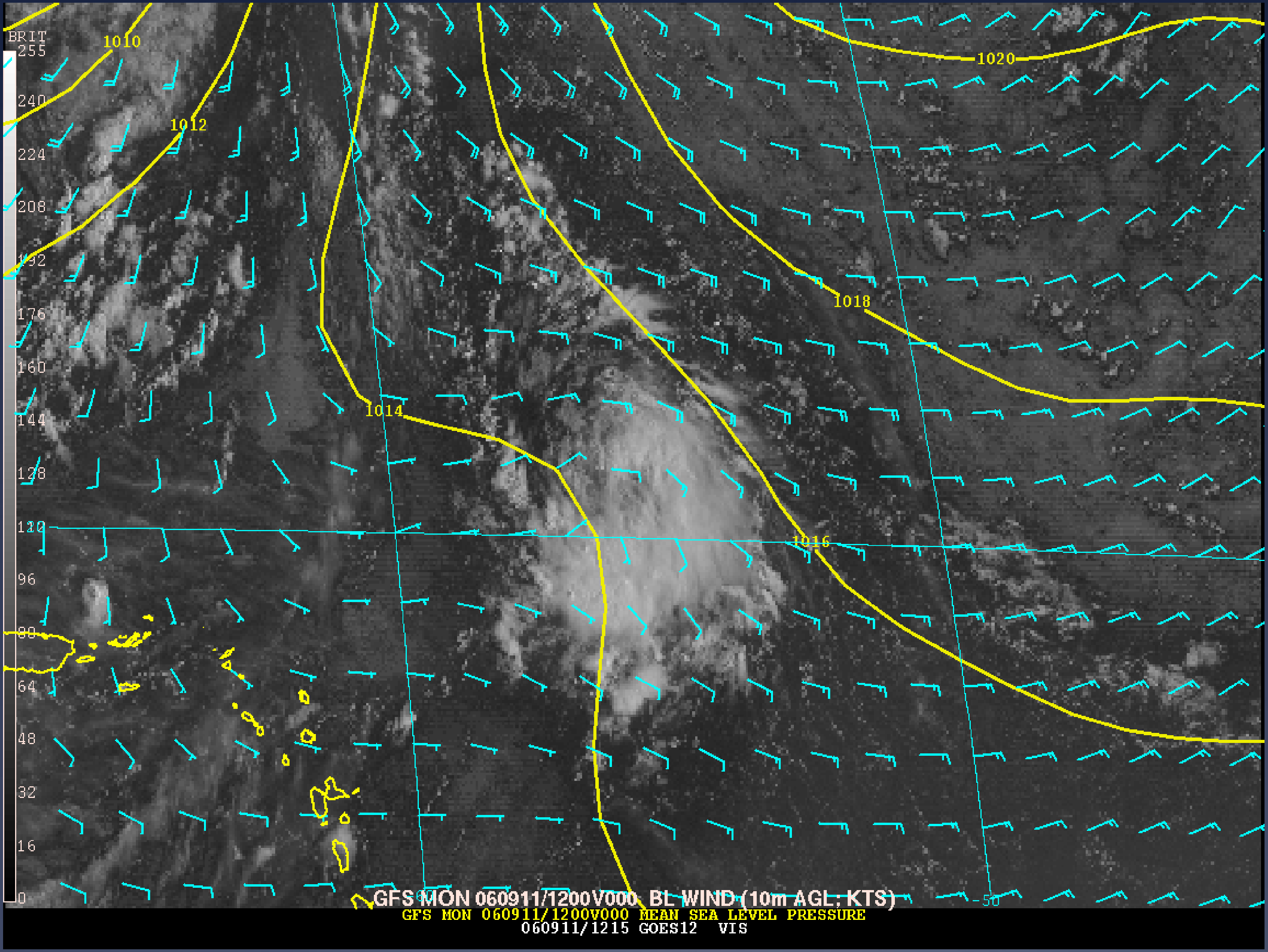
* Compare the models' forecast of the environmental features, not just the TC tracks.
  * Evaluate the initialization of the TC in the model fields. Unrealistic TC can affect the likelihood of a successful forecast.
  * Consider the recent performance of the various models, both in terms of accuracy and consistency.
  * Spread of models can dictate forecaster confidence.

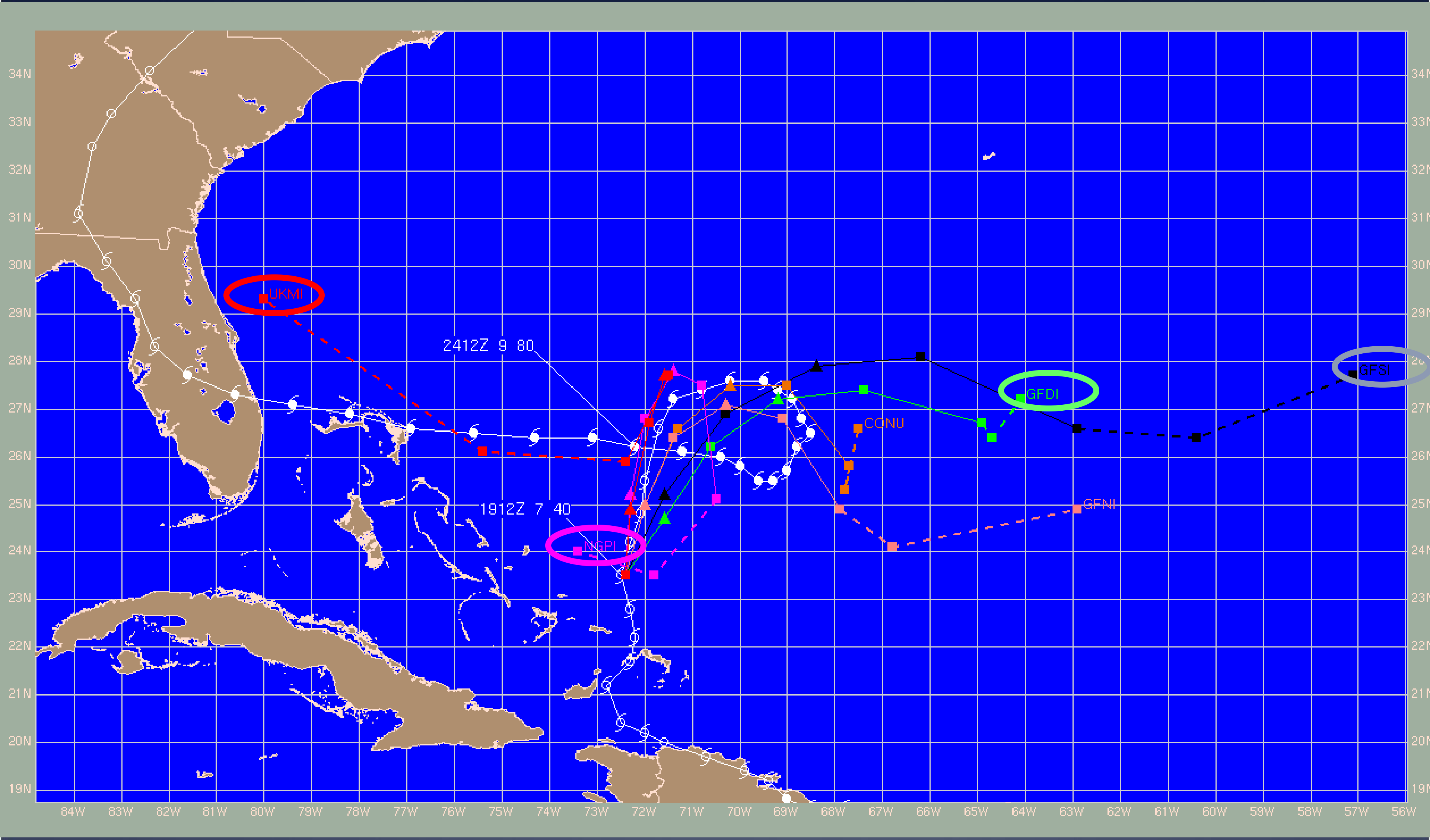
Large-Scale Steering Flow



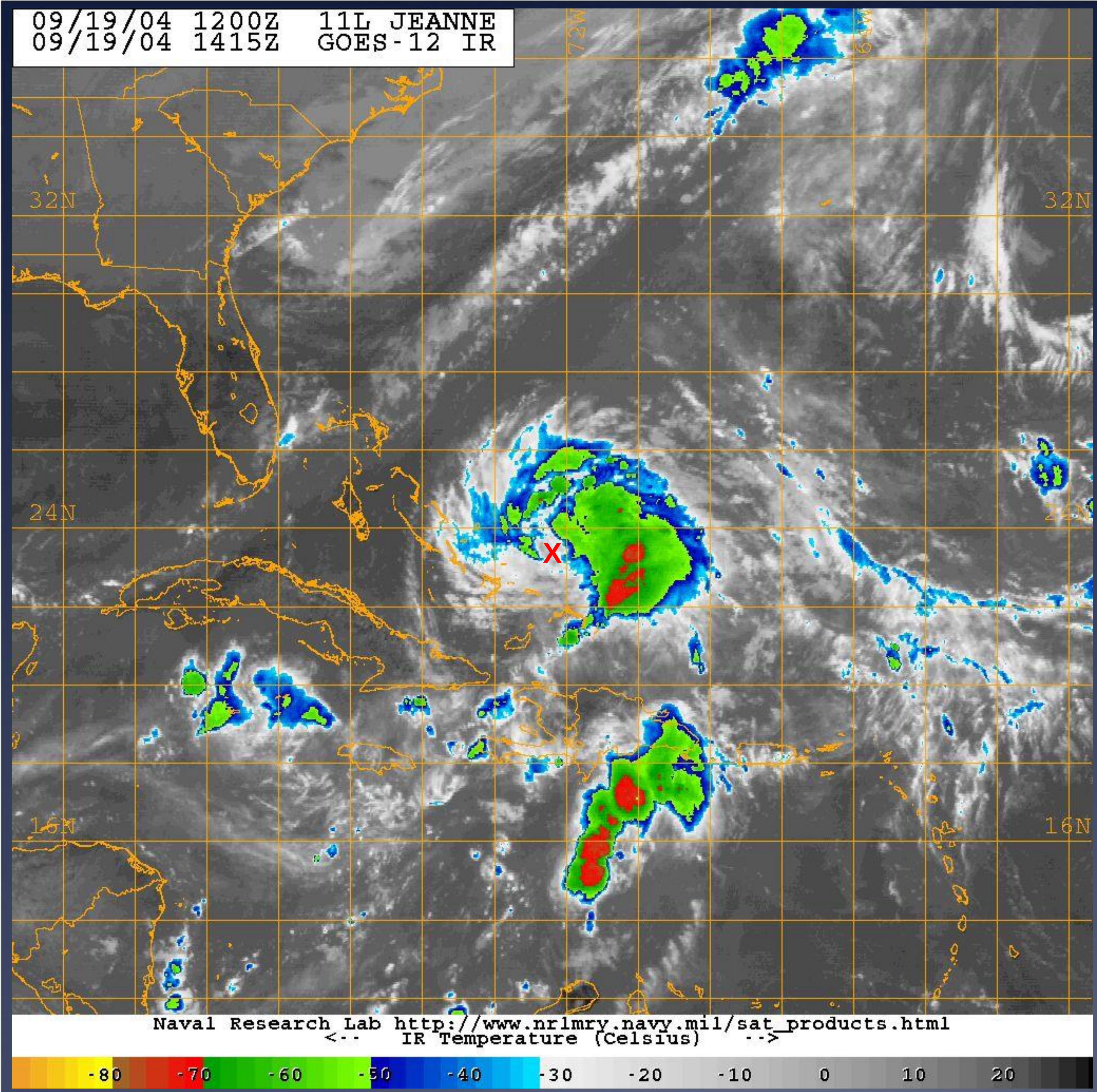
* Allow the forecaster to see features in the storm environment that could affect the future track and intensity of the cyclone.

Bad Initialization for Tropical Storm Gordon
1200 UTC 11 September 2006





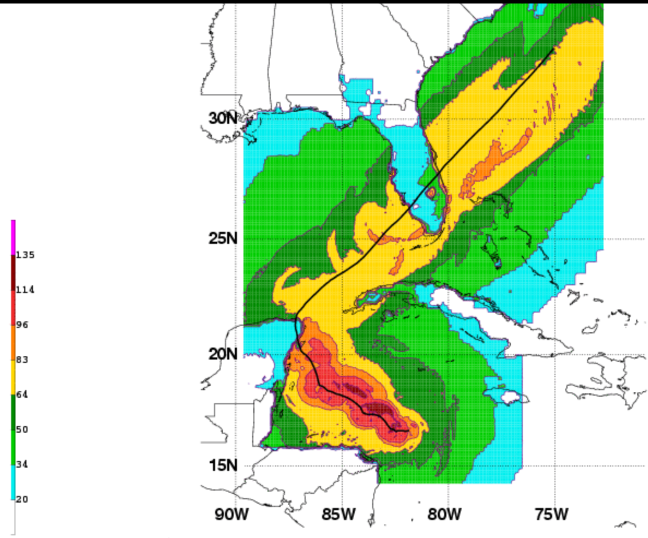
How to resolve the difference between guidance models?



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

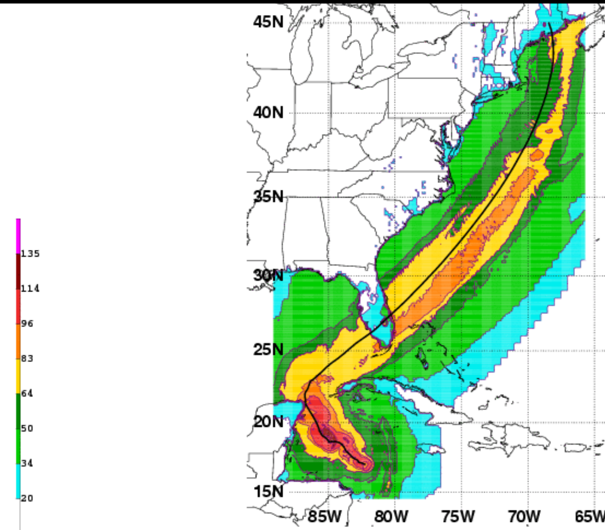
This reasoning allowed the forecasters to largely disregard the GFS and form a "selective consensus" of the remaining models.

Lack of consistency in GFDL forecasts for Wilma 19 October 2005



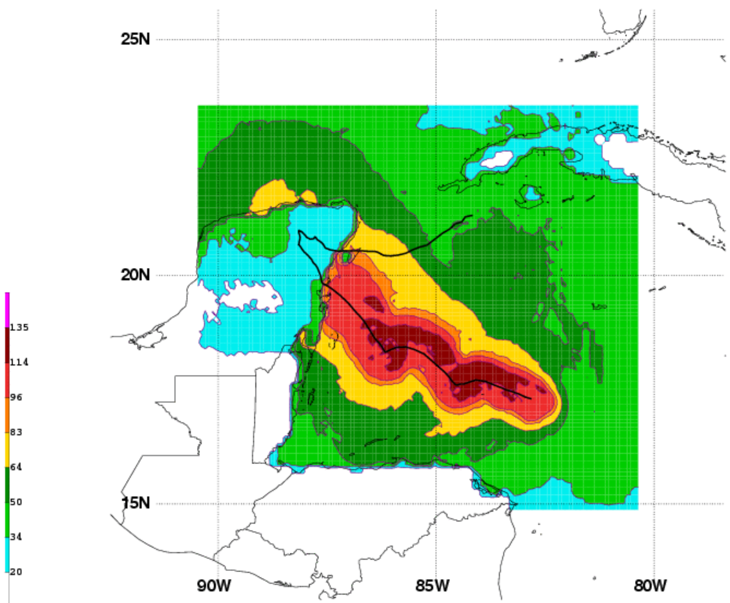
051019/0000 UTC Maximum Surface Wind Speed (knots) for wilma24l

00Z



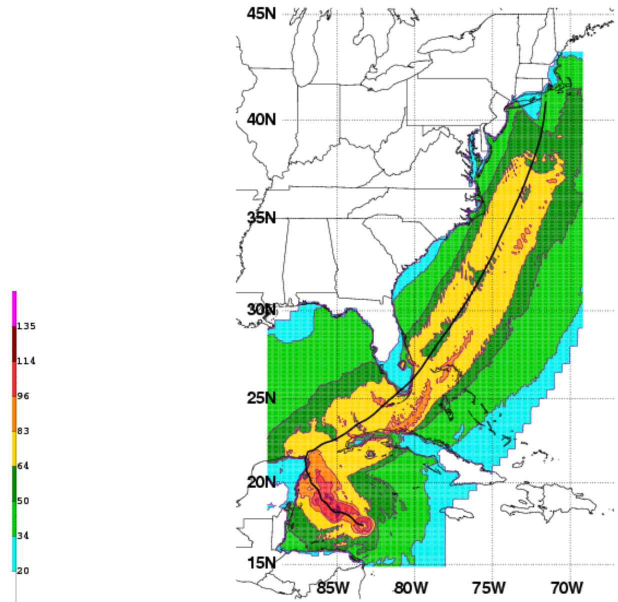
051019/0600 UTC Maximum Surface Wind Speed (knots) for wilma24l

06Z



051019/1200 UTC Maximum Surface Wind Speed (knots) for wilma24l

12Z



051019/1800 UTC Maximum Surface Wind Speed (knots) for wilma24l

18Z

HURRICANE WILMA DISCUSSION NUMBER 18
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL
5 PM EDT WED OCT 19 2005

AGREEMENT AMONG THE TRACK GUIDANCE MODELS...WHICH HAD BEEN VERY GOOD OVER THE PAST COUPLE OF DAYS...HAS COMPLETELY COLLAPSED TODAY. THE 06Z RUNS OF THE GFS...GFDL...AND NOGAPS MODELS ACCELERATED WILMA RAPIDLY TOWARD NEW ENGLAND UNDER THE INFLUENCE OF A LARGE LOW PRESSURE SYSTEM IN THE GREAT LAKES REGION. **ALL THREE OF THESE MODELS HAVE BACKED OFF OF THIS SOLUTION...WITH THE GFDL SHOWING AN EXTREME CHANGE...WITH ITS 5-DAY POSITION SHIFTING A MERE 1650 NMI FROM ITS PREVIOUS POSITION IN MAINE TO THE WESTERN TIP OF CUBA.** THERE IS ALMOST AS MUCH SPREAD IN THE 5-DAY POSITIONS OF THE 12Z GFS ENSEMBLE MEMBERS...WHICH RANGE FROM THE YUCATAN TO WELL EAST OF THE DELMARVA PENINSULA. WHAT THIS ILLUSTRATES IS THE EXTREME SENSITIVITY OF WILMA'S FUTURE TRACK TO ITS INTERACTION WITH THE GREAT LAKES LOW. OVER THE PAST COUPLE OF DAYS...WILMA HAS BEEN MOVING SLIGHTLY TO THE LEFT OR SOUTH OF THE MODEL GUIDANCE...AND THE LEFT-MOST OF THE GUIDANCE SOLUTIONS ARE NOW SHOWING WILMA DELAYING OR MISSING THE CONNECTION WITH THE LOW. I HAVE SLOWED THE OFFICIAL FORECAST JUST A LITTLE BIT AT THIS TIME...BUT IF WILMA CONTINUES TO MOVE MORE TO THE LEFT THAN EXPECTED...SUBSTANTIAL CHANGES TO THE OFFICIAL FORECAST MAY HAVE TO BE MADE DOWN THE LINE. NEEDLESS TO SAY...**CONFIDENCE IN THE FORECAST TRACK...ESPECIALLY THE TIMING...HAS DECREASED CONSIDERABLY.**

...DELETED DISCUSSION TEXT...

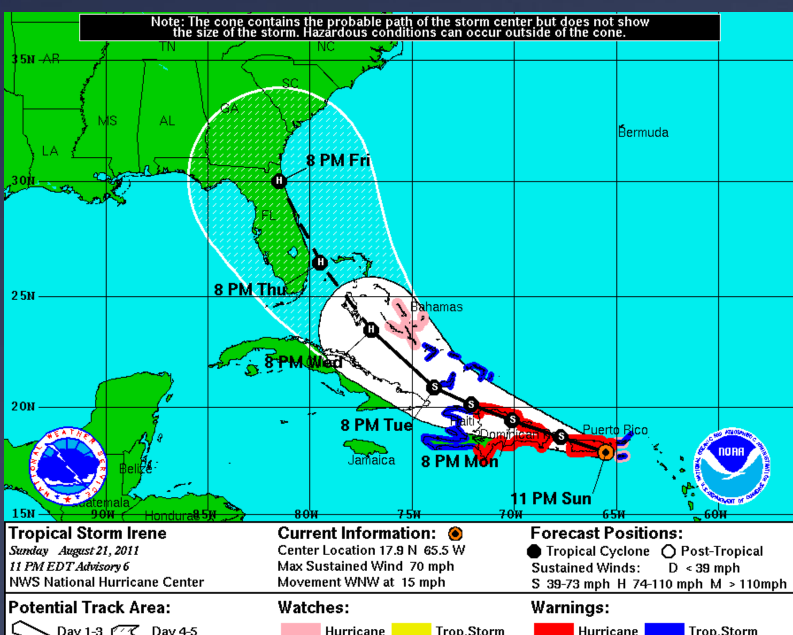
FORECASTER FRANKLIN

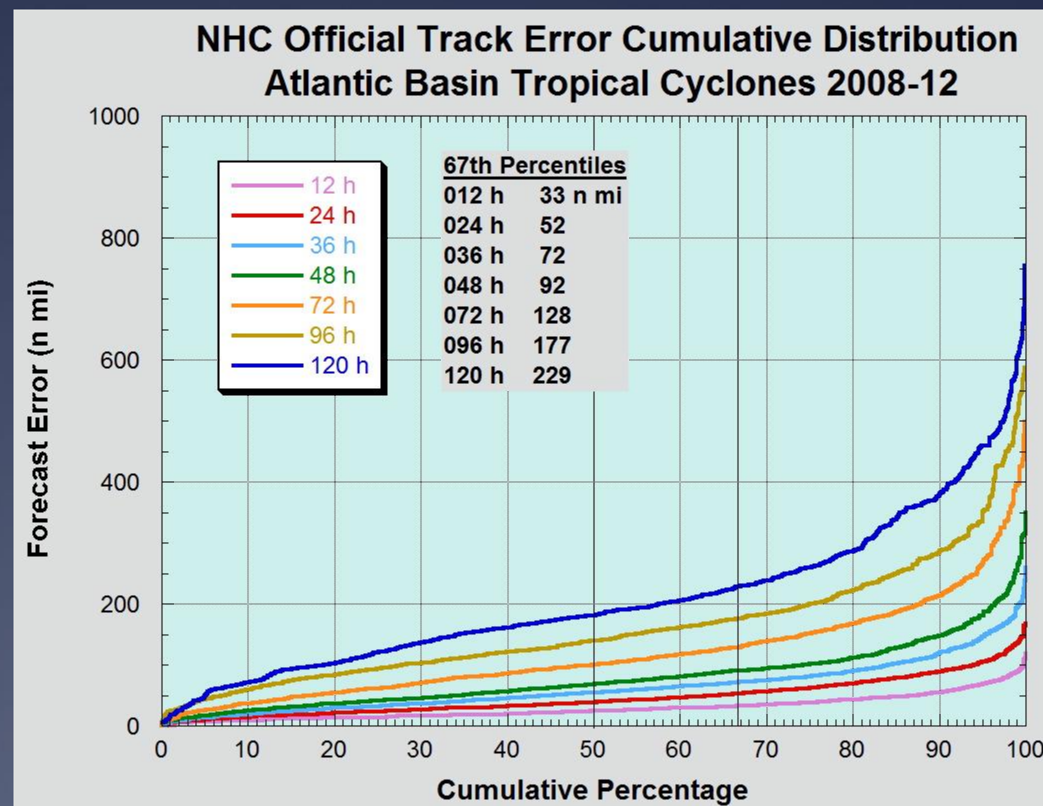
FORECAST POSITIONS AND MAX WINDS

INITIAL	19/2100Z	17.7N	83.7W	140 KT
12HR VT	20/0600Z	18.0N	84.6W	135 KT
24HR VT	20/1800Z	19.2N	85.6W	145 KT
36HR VT	21/0600Z	20.4N	86.2W	145 KT
48HR VT	21/1800Z	21.6N	86.3W	120 KT
72HR VT	22/1800Z	24.0N	84.5W	105 KT
96HR VT	23/1800Z	27.5N	79.0W	80 KT
120HR VT	24/1800Z	36.0N	70.0W	65 KT

Forecast Verification
OFCL Error Distributions and Cone Radii

The size of the NHC forecast uncertainty cone is now determined by the 67th 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 67th percentile. The circles are reevaluated each season, and they are tending to get smaller as years go by.





2016 Atlantic Cone

Forecast period (h)	Circle radii (n mi)	Percent change from 2015
12	30	- 6%
24	49	- 6%
36	66	- 7%
48	84	- 7%
72	115	- 6%
96	165	- 3%
120	237	+ 5%

The Atlantic cone will be a little smaller in 2016 through 96 h, and slightly larger at 120 h.

Concluding Remarks

* Multi-level dynamical models are the most skillful 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 (but not in 2015).

* Single-model ensembles appear to most useful for longer-range (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.