Tropical Cyclone Track Prediction

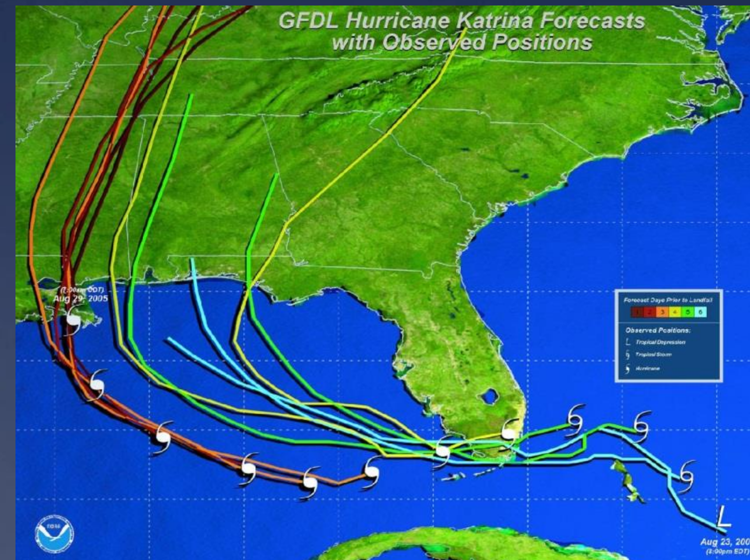
Richard J. Pasch and David A. Zelinsky
National Hurricane Center

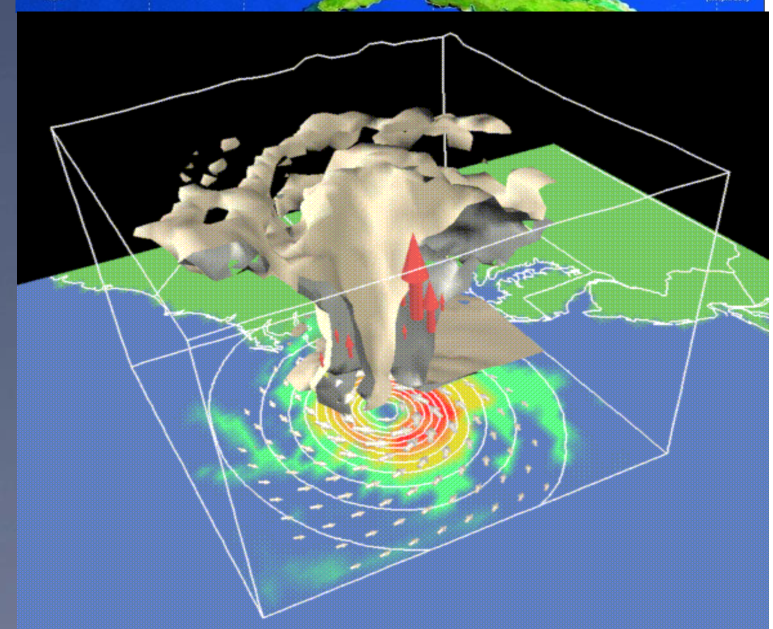
2017 RA-IV Workshop on Hurricane Forecasting and Warning

March 7, 2017

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





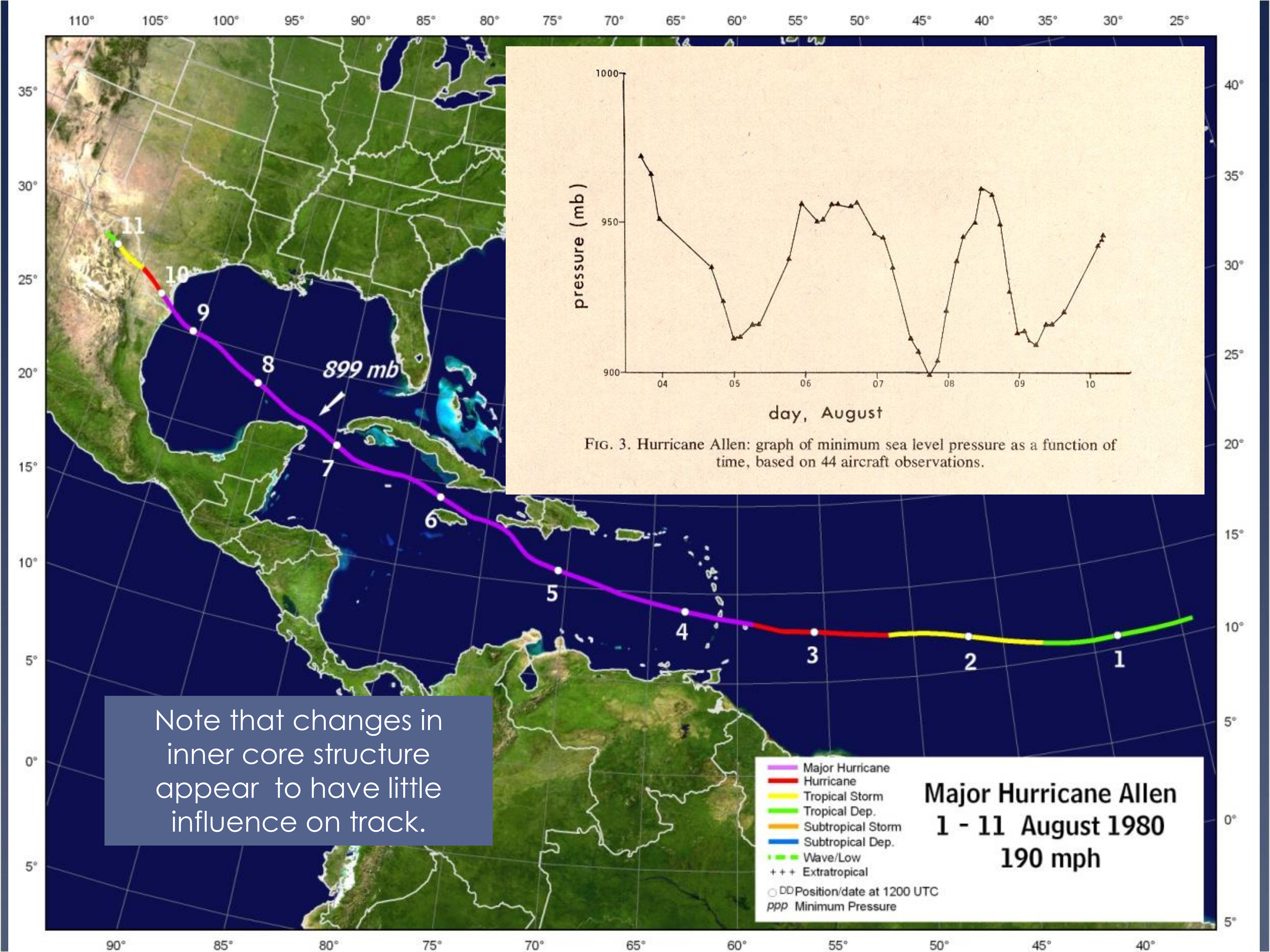


FIG. 3. Hurricane Allen: graph of minimum sea level pressure as a function of time, based on 44 aircraft observations.

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:

$L \sim 500 \quad km$

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

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

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

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

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

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

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

$$\underbrace{\frac{\partial \zeta}{\partial t}}_{\substack{(1)\\ 4\times10^{-10}}} = \underbrace{-V \cdot \nabla \zeta}_{\substack{(1)\\ 4\times10^{-10}}} \underbrace{- \omega \frac{\partial \zeta}{\partial P}}_{\substack{(4)\\ 4\times10^{-11}}} \underbrace{- \beta v}_{\substack{(2)\\ 2\times10^{-10}}} \underbrace{- (\zeta + f)\delta}_{\substack{(3)\\ 1\times10^{-10}}} \underbrace{- k \cdot \nabla \omega \times \frac{\partial V}{\partial P}}_{\substack{(4)\\ 4\times10^{-11}}}$$

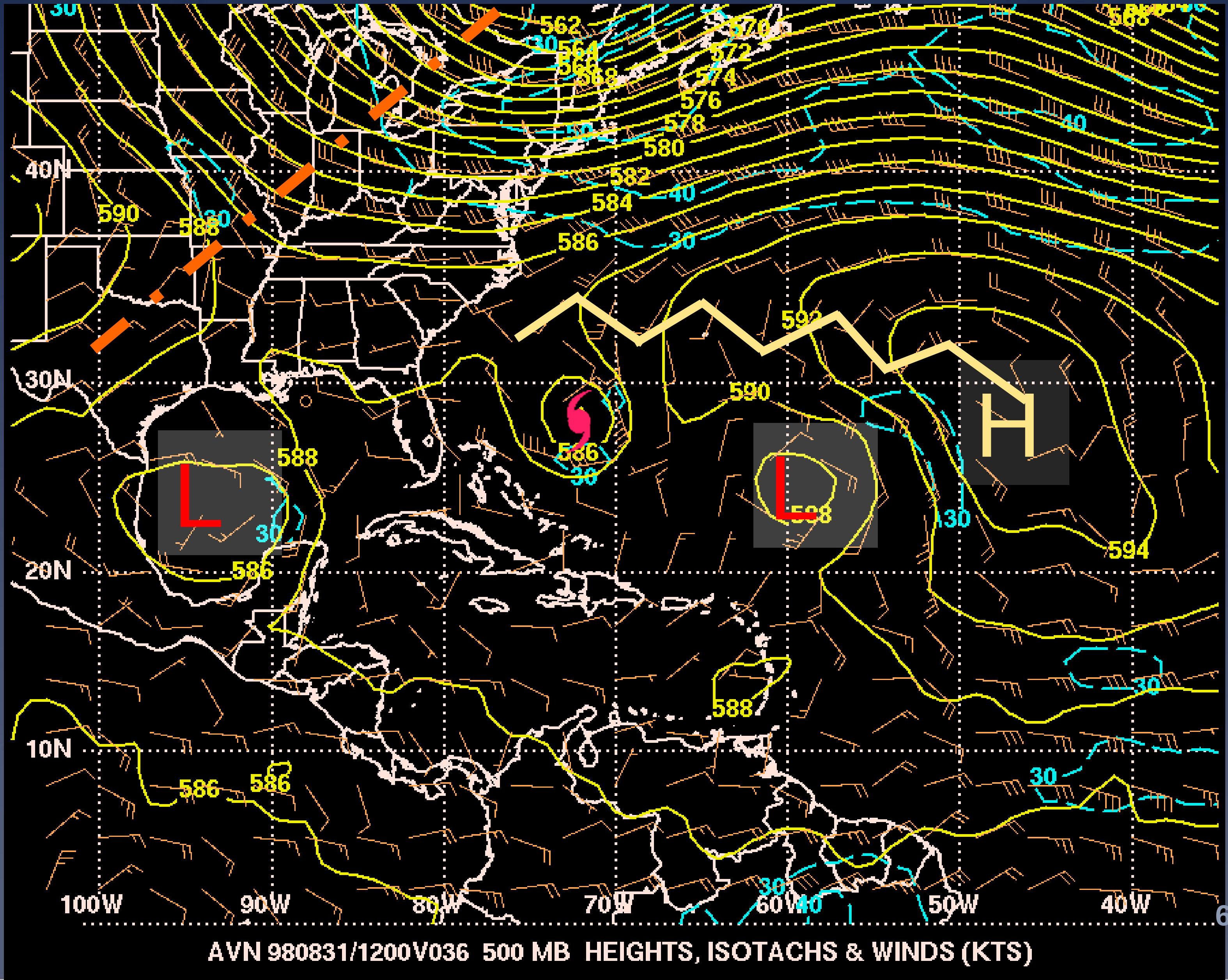
Vorticity Equation

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

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

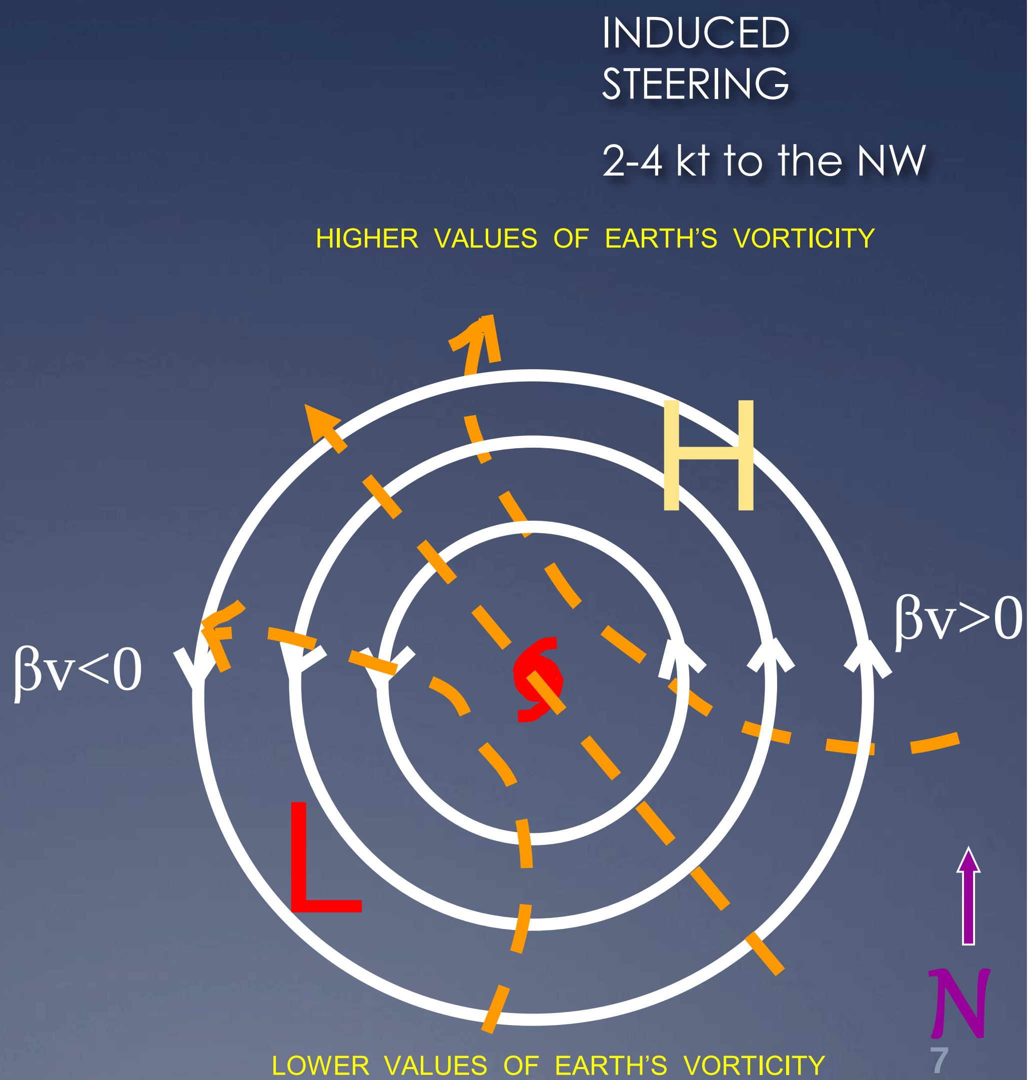
- To a first approximation, TC motion is governed by conservation of relative vorticity (vortex moves with the large-scale steering flow).
- Second order includes the Beta term (conservation of absolute vorticity).
- Divergence term (e.g., wavenumber 1 asymmetry in convection, interactions with orography,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

Large-Scale Steering



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:

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

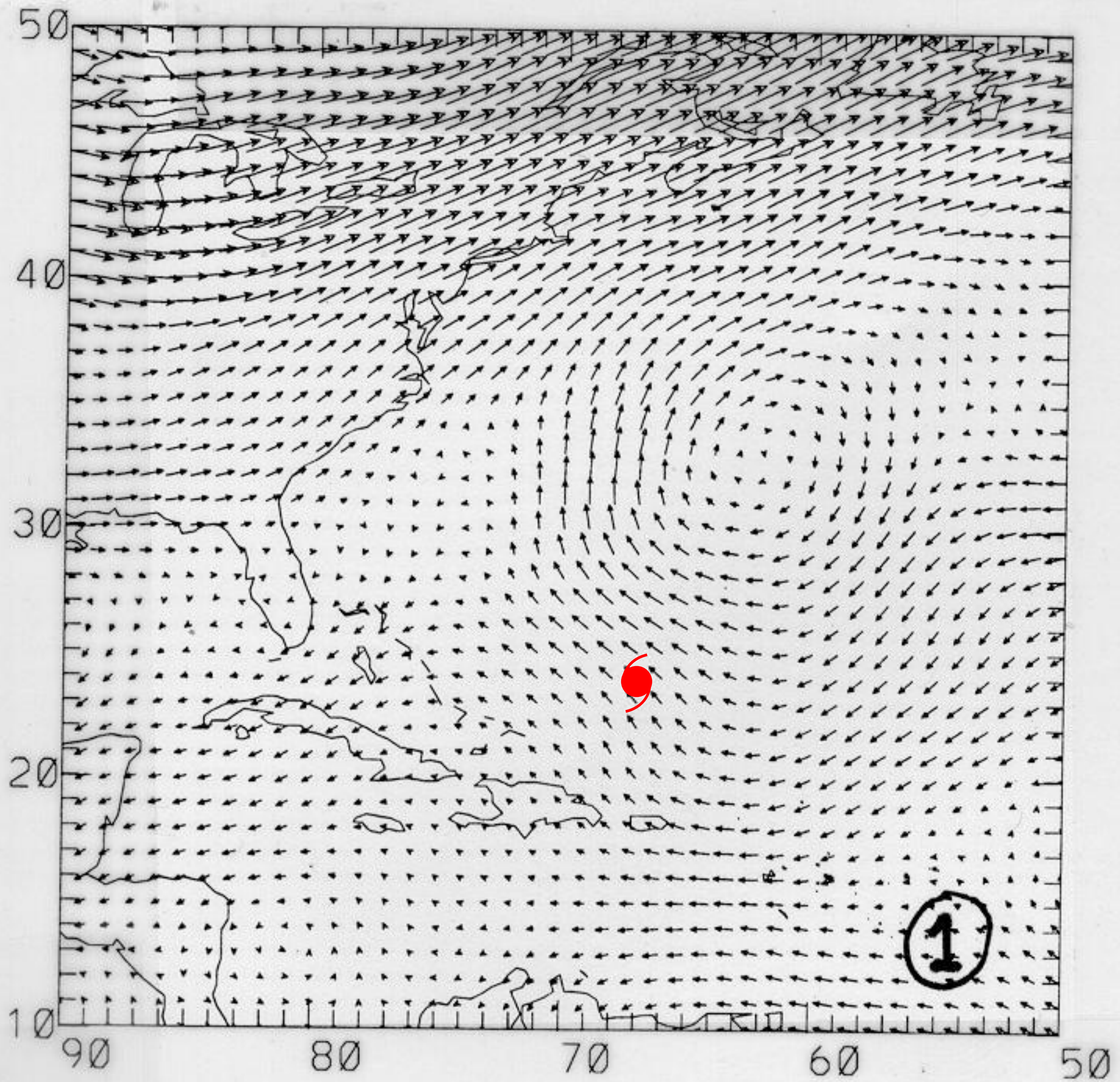
Exercise 1

- 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.

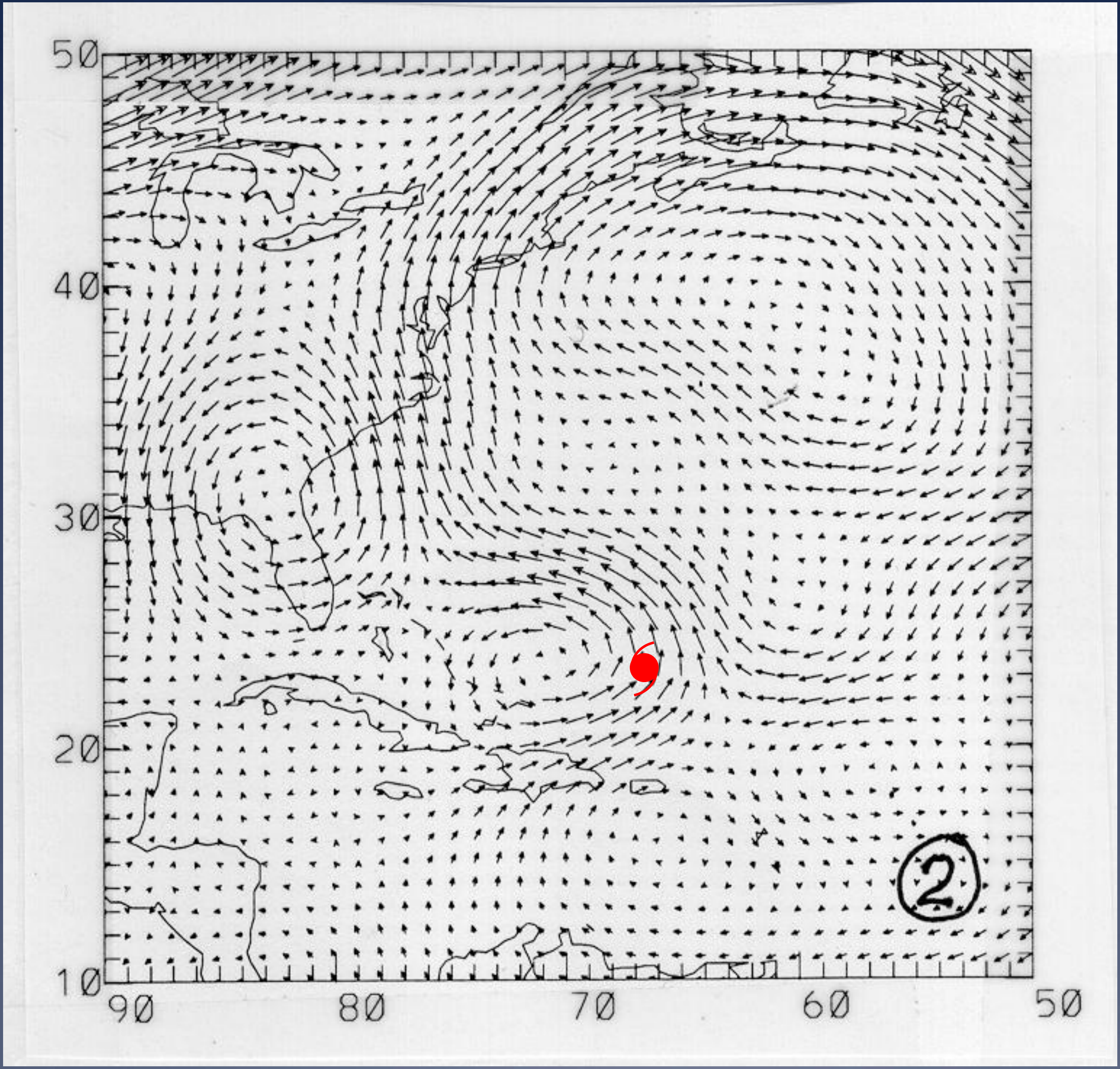
- Also shown are the subsequent 72-h tracks taken by the 3 TCs.

- Match up each deep-layer flow chart with the correct track.

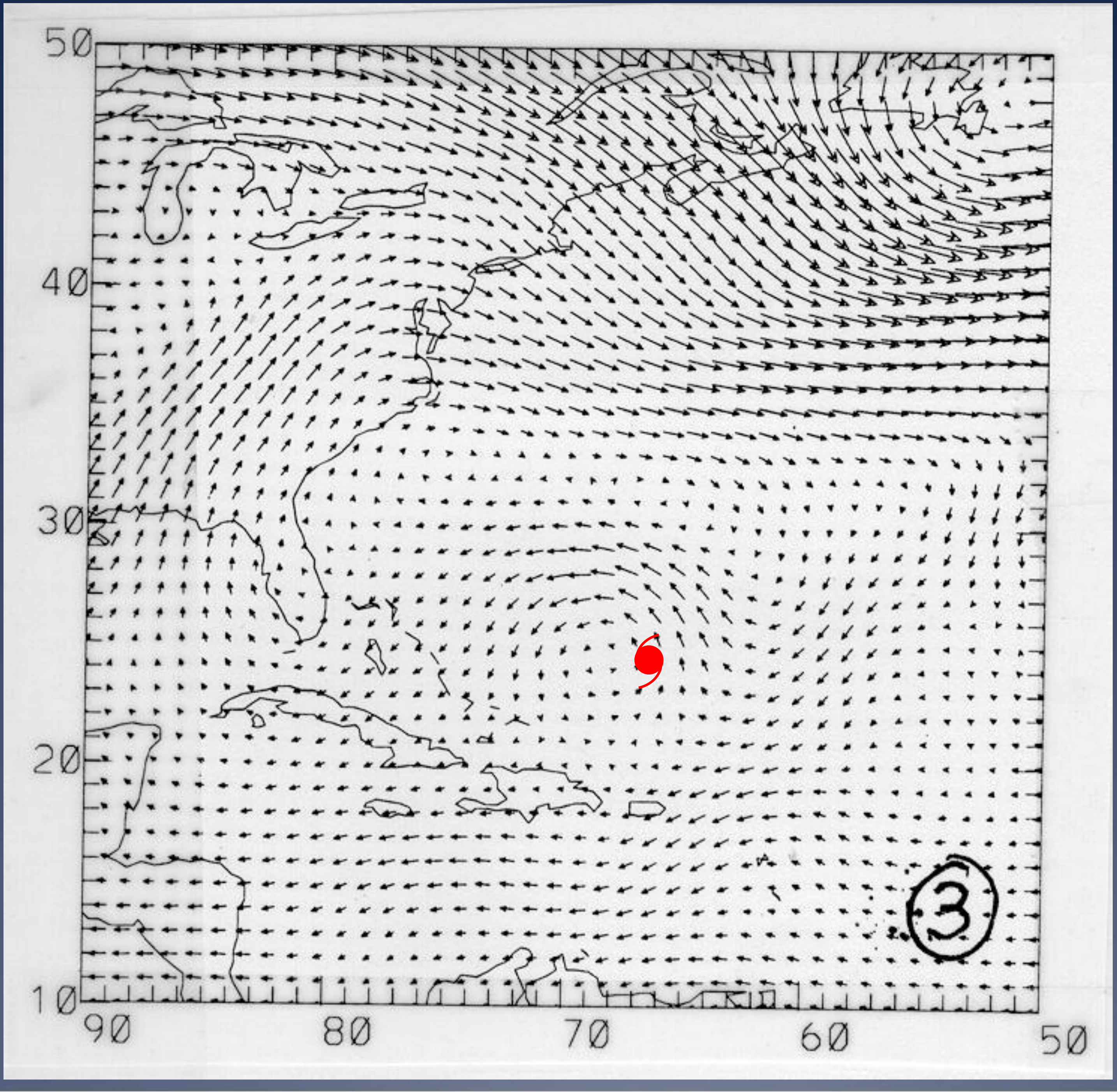
- Bonus: What were the names/years of the 3 TCs?



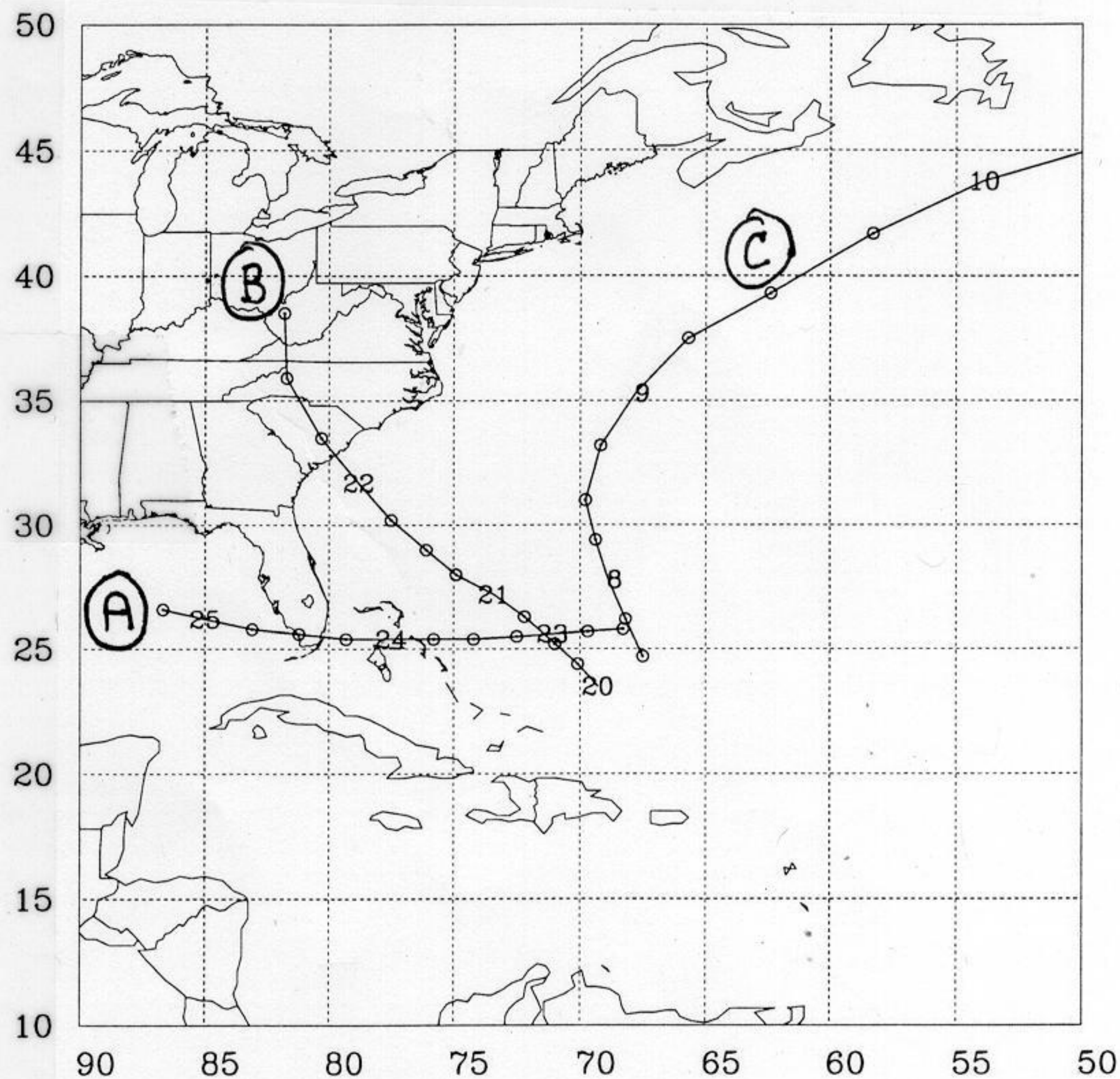
50
40
30
20
10
90
80
70
60
50
1



50
40
30
20
10
90
80
70
60
50
2


50
40
30
20
10
90
80
70
60
50
3

72 HR STORM TRACKS



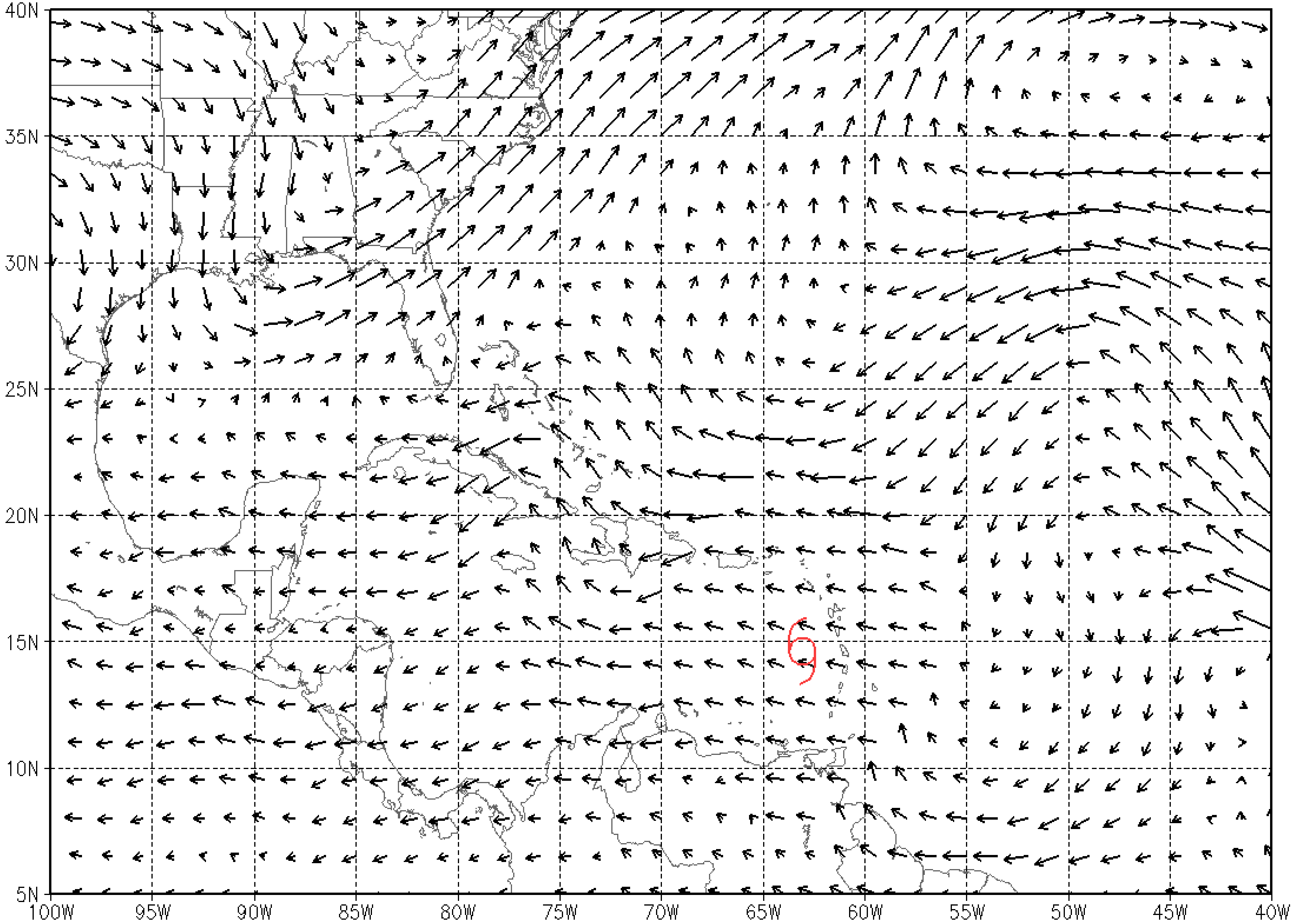
Exercise 2

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

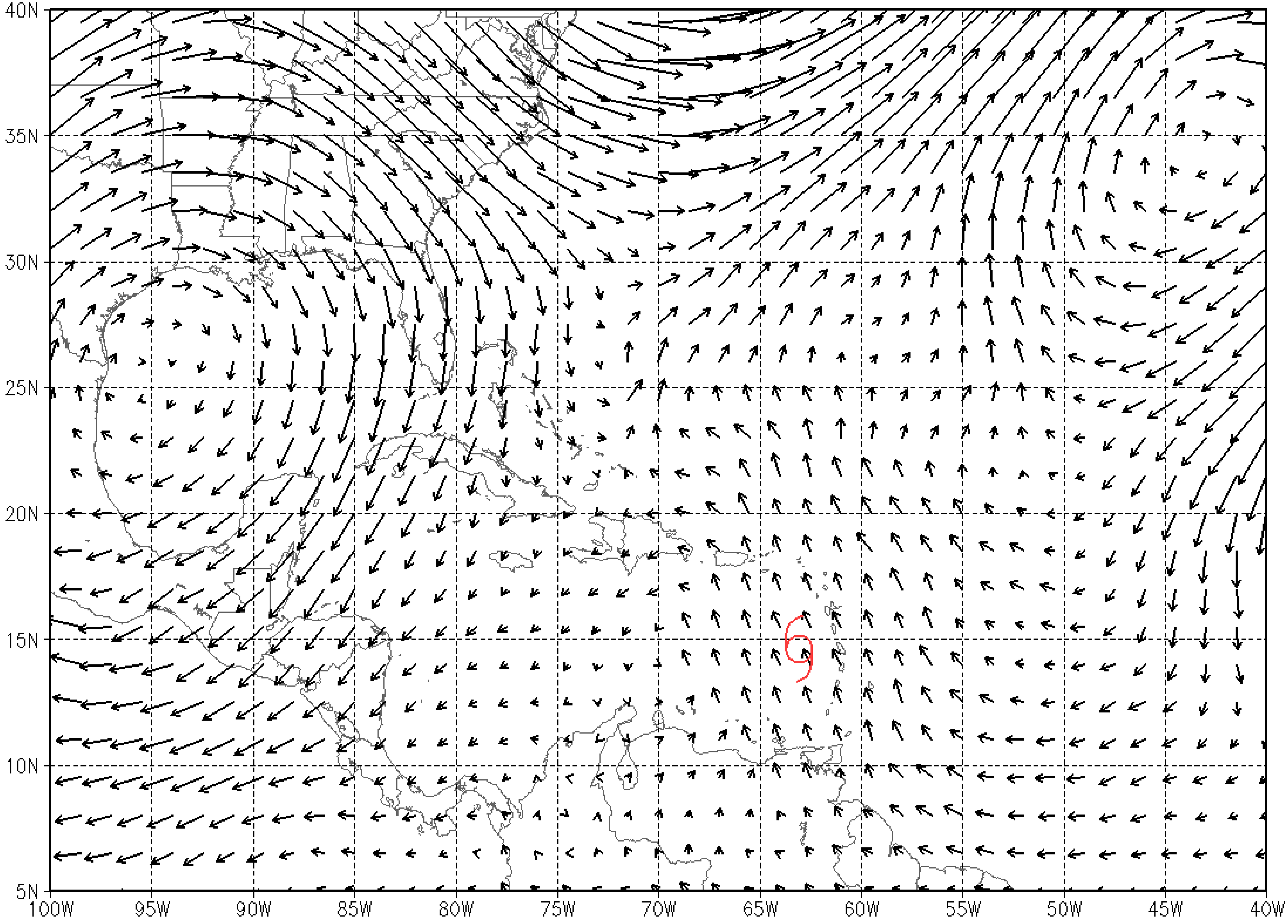
- Also shown are the subsequent 72-h tracks taken by the 3 TCs.

- Match up each deep-layer flow chart with the correct track.

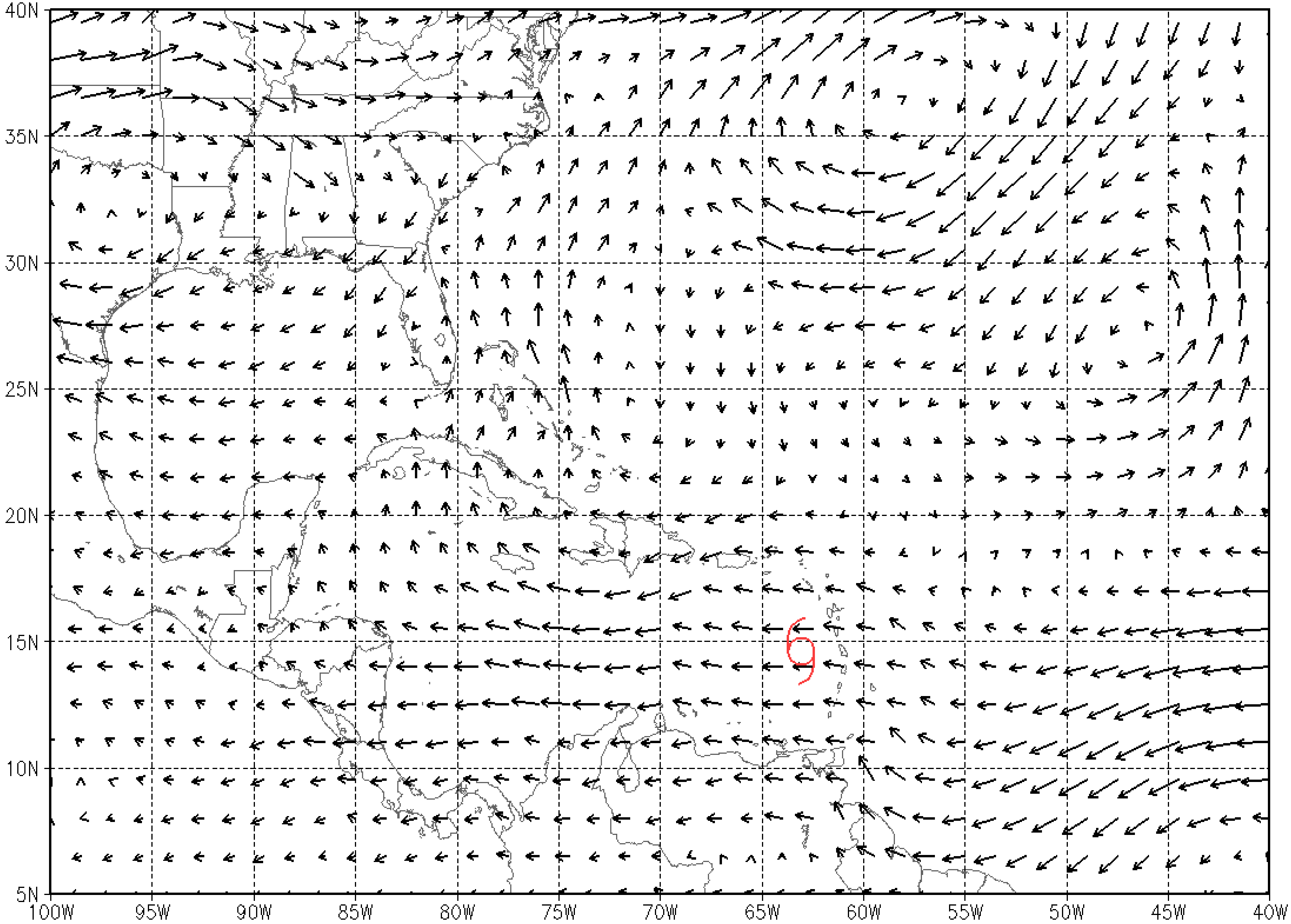
- What were the names/years of the 3 TCs?


40N
35N
30N
25N
20N
15N
10N
5N
100W
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
6

1

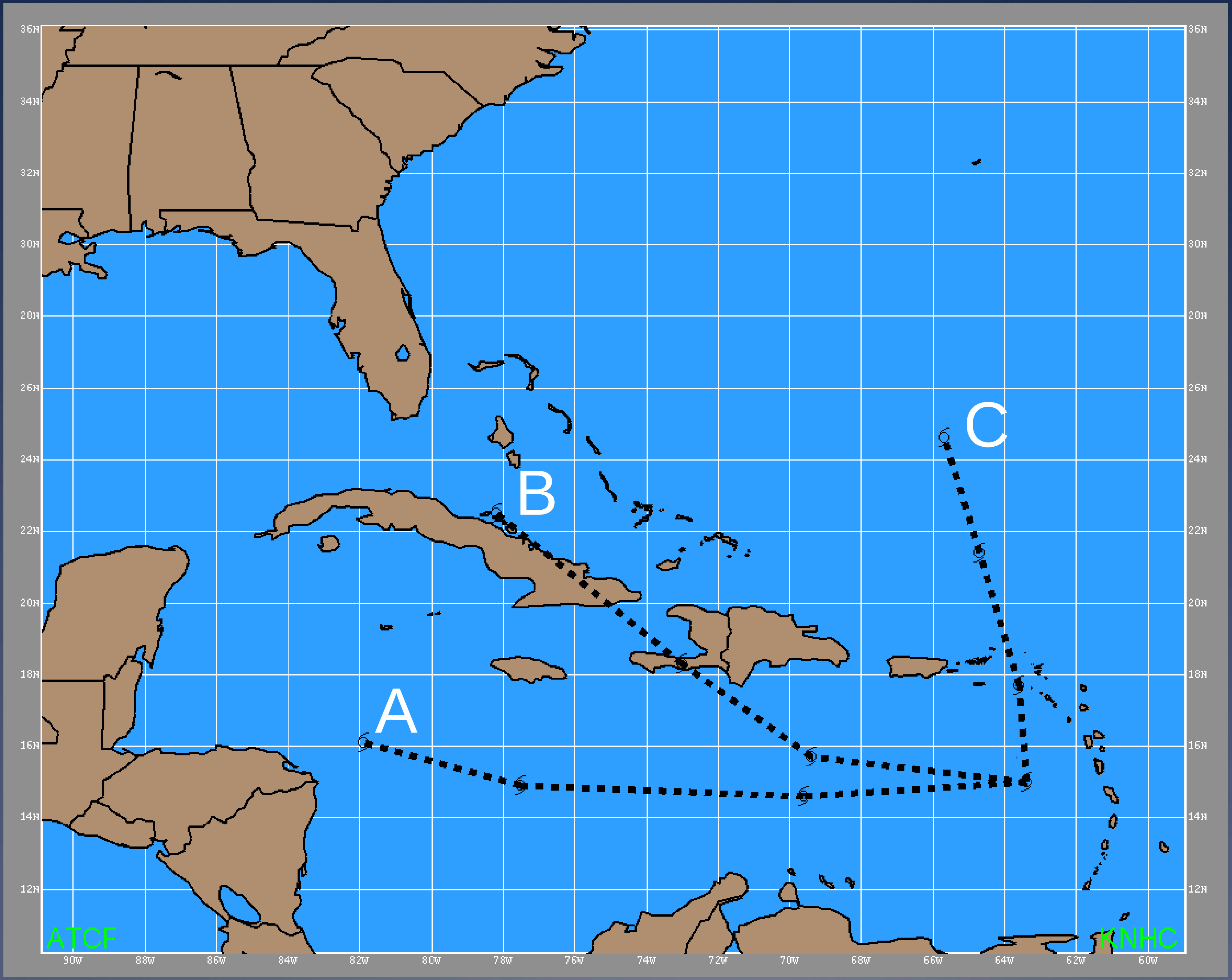

40N
35N
30N
25N
20N
15N
10N
5N
100W
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
9

2


40N
35N
30N
25N
20N
15N
10N
5N
100W
95W
90W
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
6
9

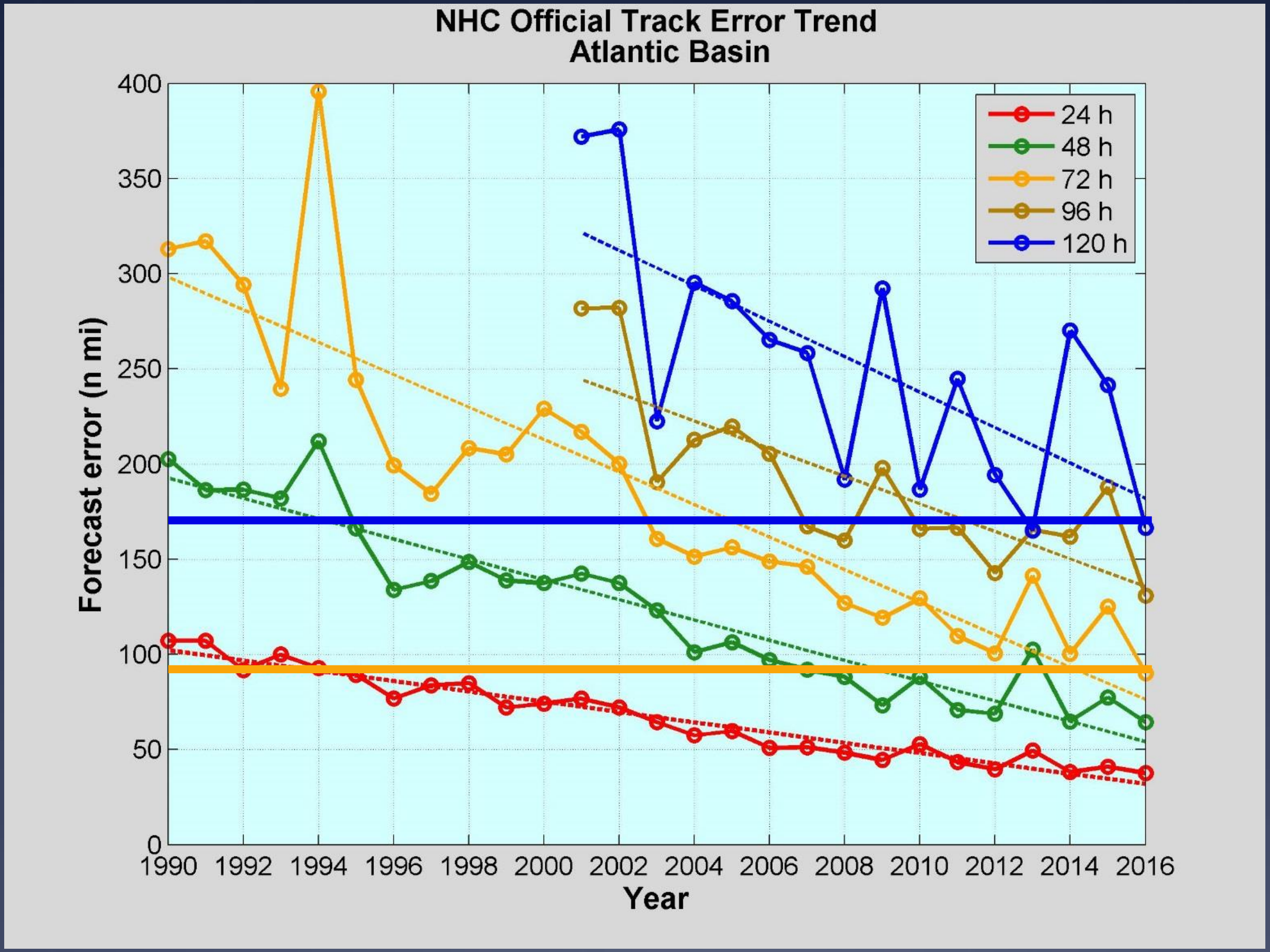
3

72-h Storm Tracks

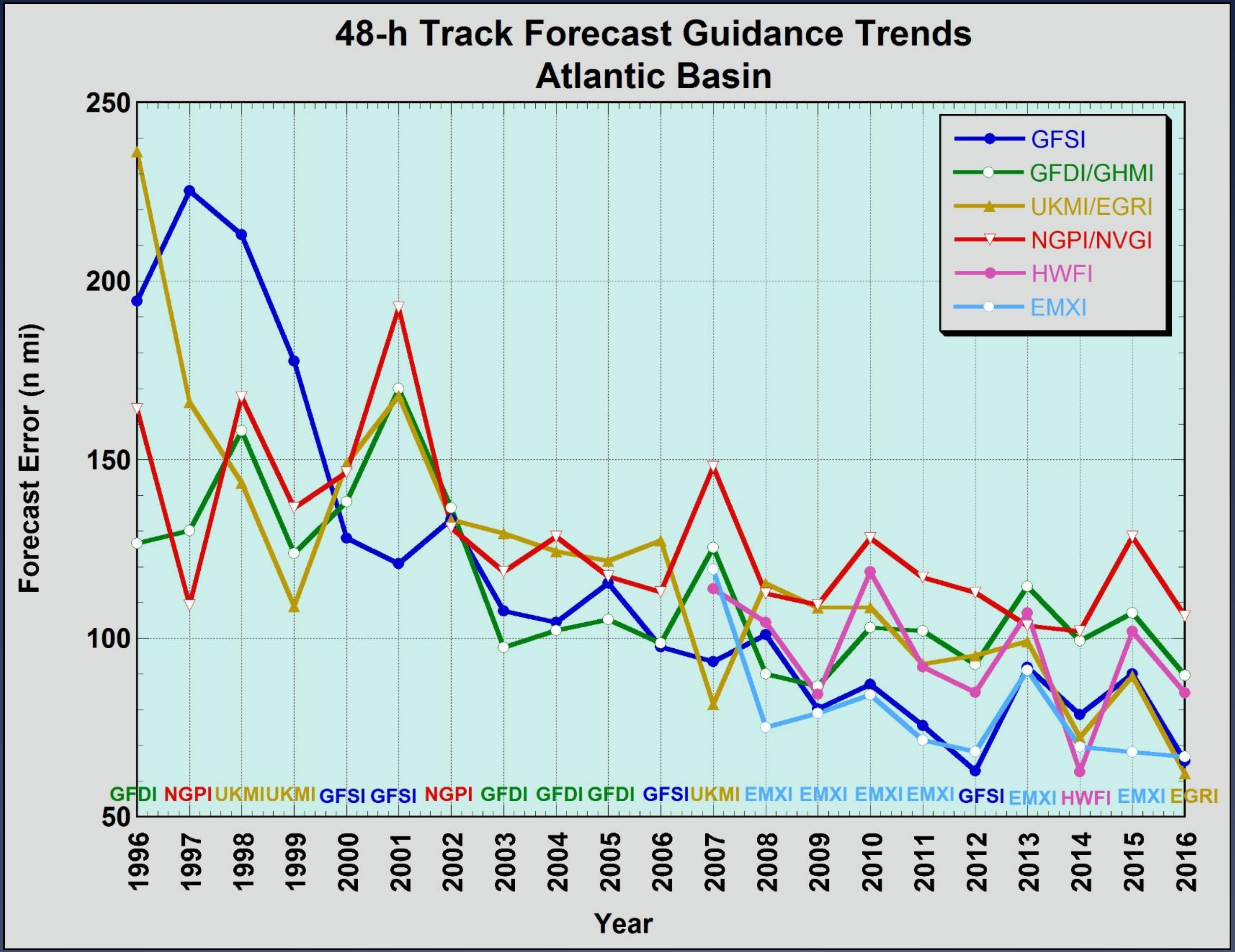


Numerical Weather Prediction Models for TC Track Prediction

Atlantic Track Error Trends



Track Model Trends



Hierarchy of TC Track Models

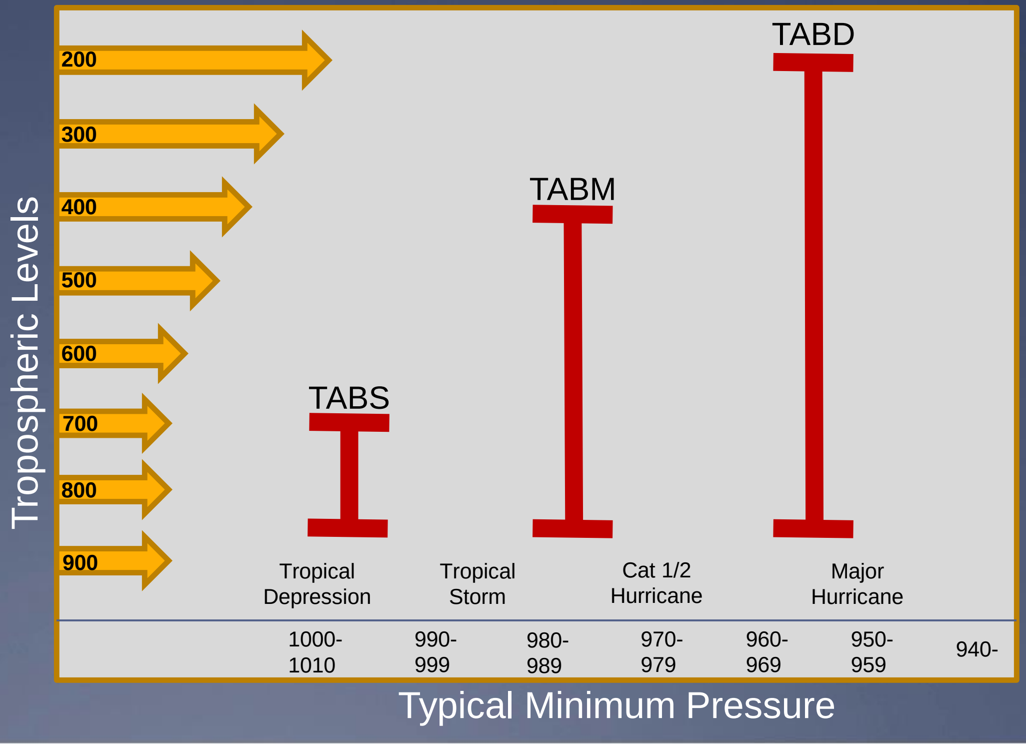
* Statistical
  * CLIPER: Forecasts based on established relationships between storm-specific information (i.e., location and time of year) and the behavior of previous storms
* Simplified dynamical
  * TABS,TABM,TABD: Forecasts based on simplified dynamic representation of interaction with vortex and 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 in 2016)
  * 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	2016 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 (180 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 ~17km	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 18-6-2 km	61 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	42	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 1st NHC/JTWC advisory	YES

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.

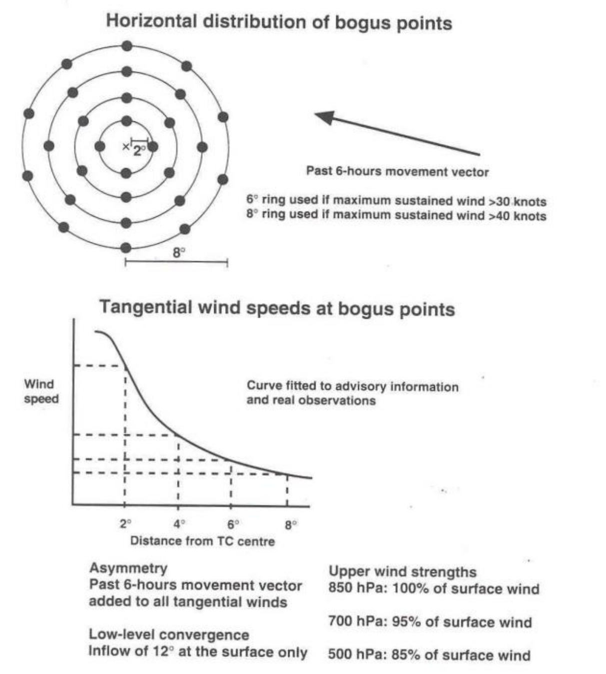
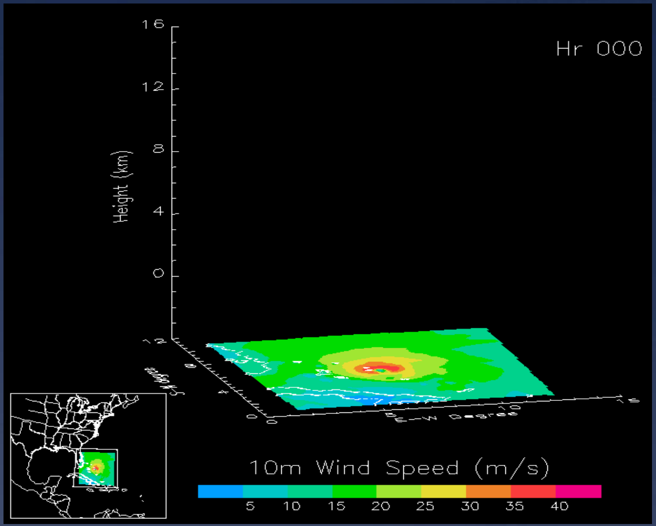


Figure 2. *Formulation of the new UKMO TC bogus scheme.*

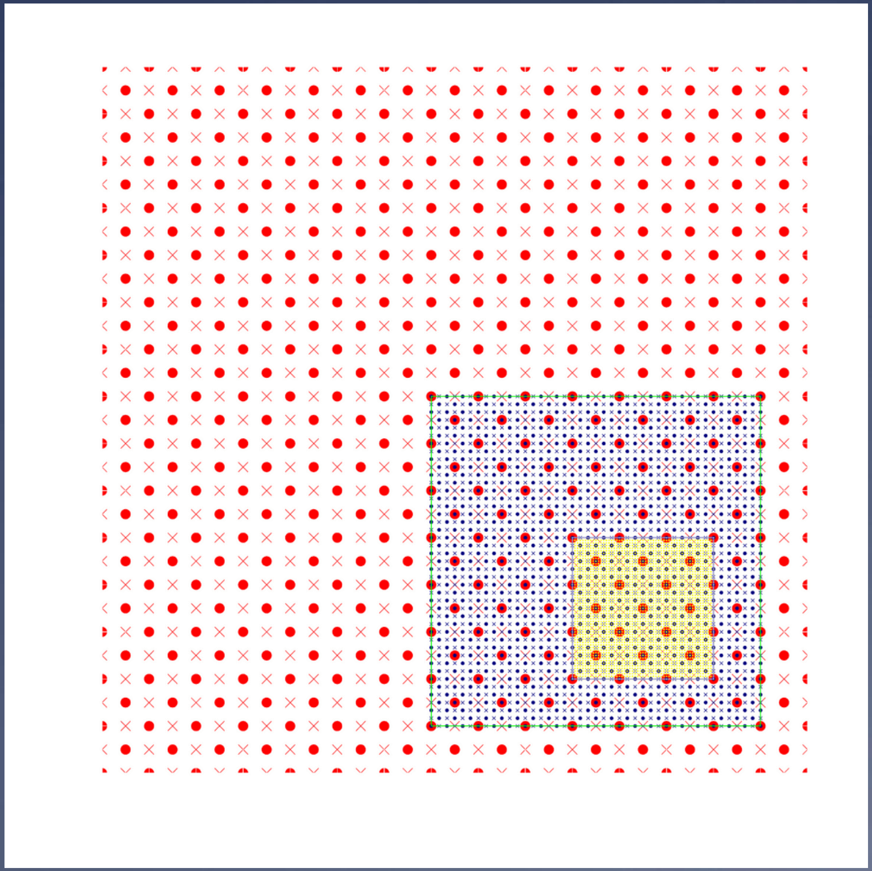
Operational Regional Models for TC Track Forecasting

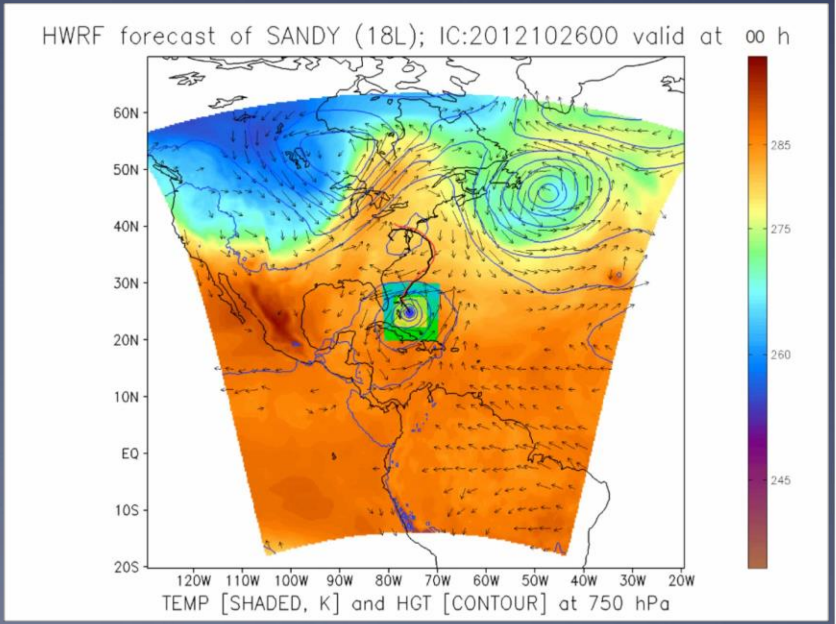
- **Hurricane Weather Research and Forecasting model** (HWRF)
  - HWRF is the only model that assimilates some inner-core or near-inner-core data, i.e. airborne Doppler velocities and (hopefully this year) flight-level reconnaissance wind data
- **Hurricane Multi-scale Ocean-coupled Non-hydrostatic model** (HMON)
  - Will run in operations for the first time this year, but with no data assimilation; some similarities to HWRF
- **GFDL Hurricane model being retired this year; HMON is its replacement**
- **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: 75x75º; 6km ~11x10º** 2km inner-most nest 6x5.5º

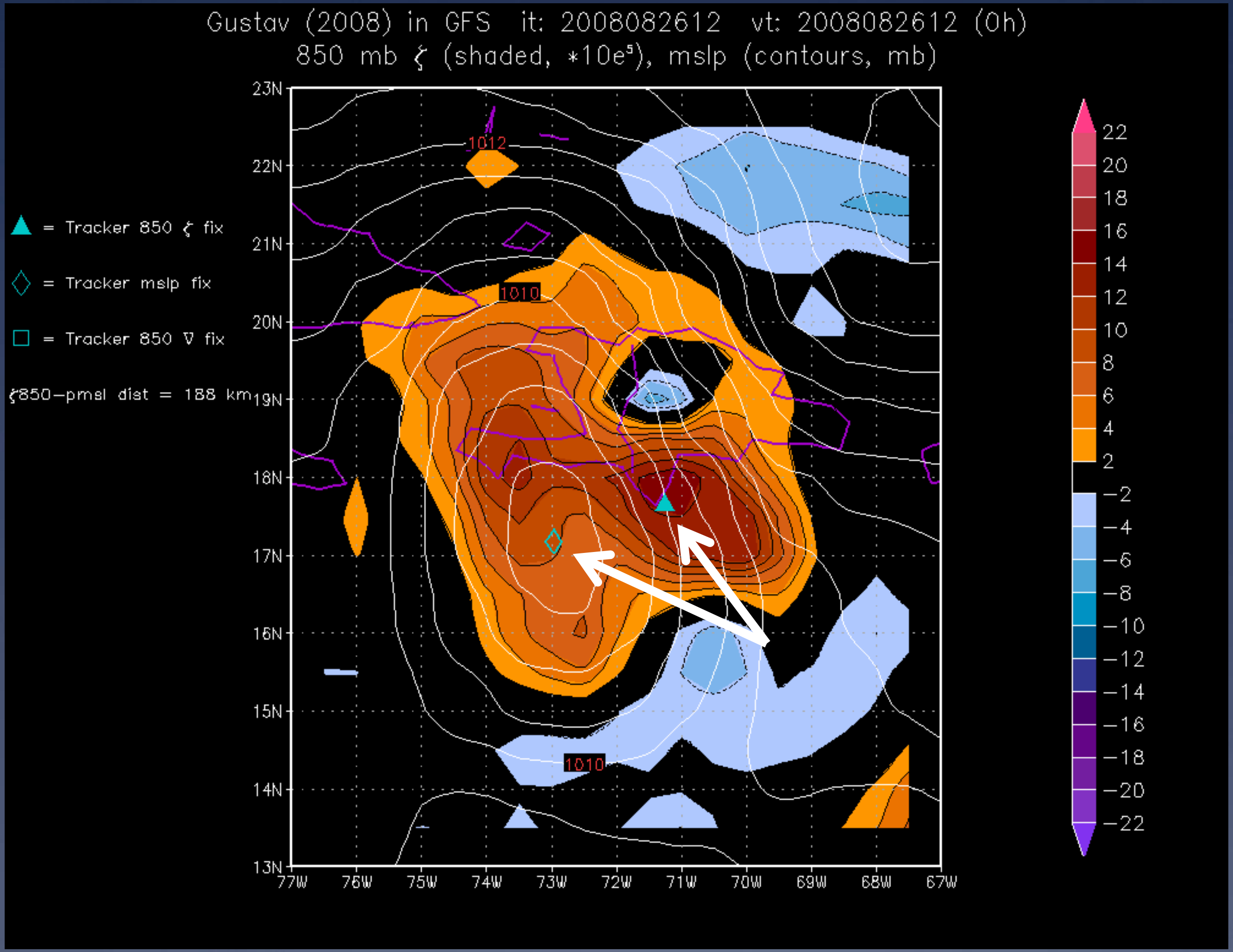




Tracker Design

* 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)

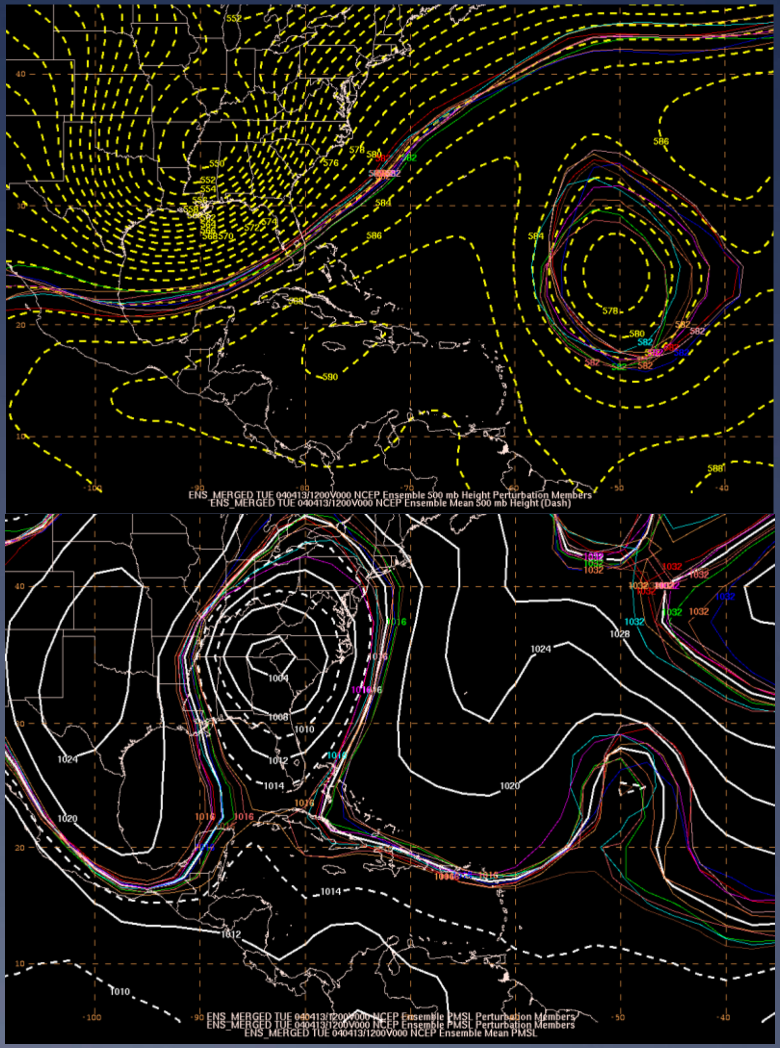
Why the need for an external tracker?



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

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.



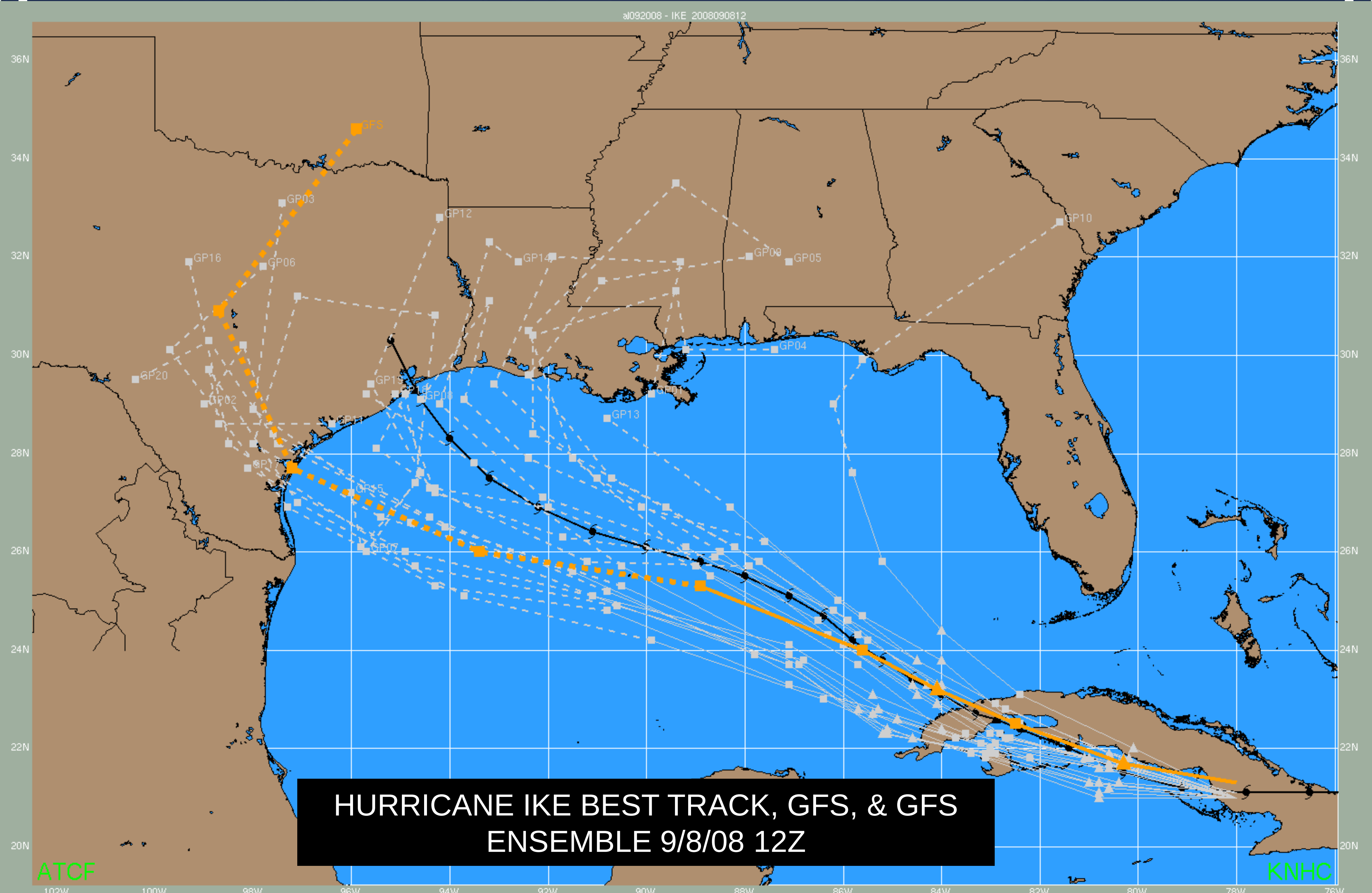
Ensembles and Consensus

* 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)

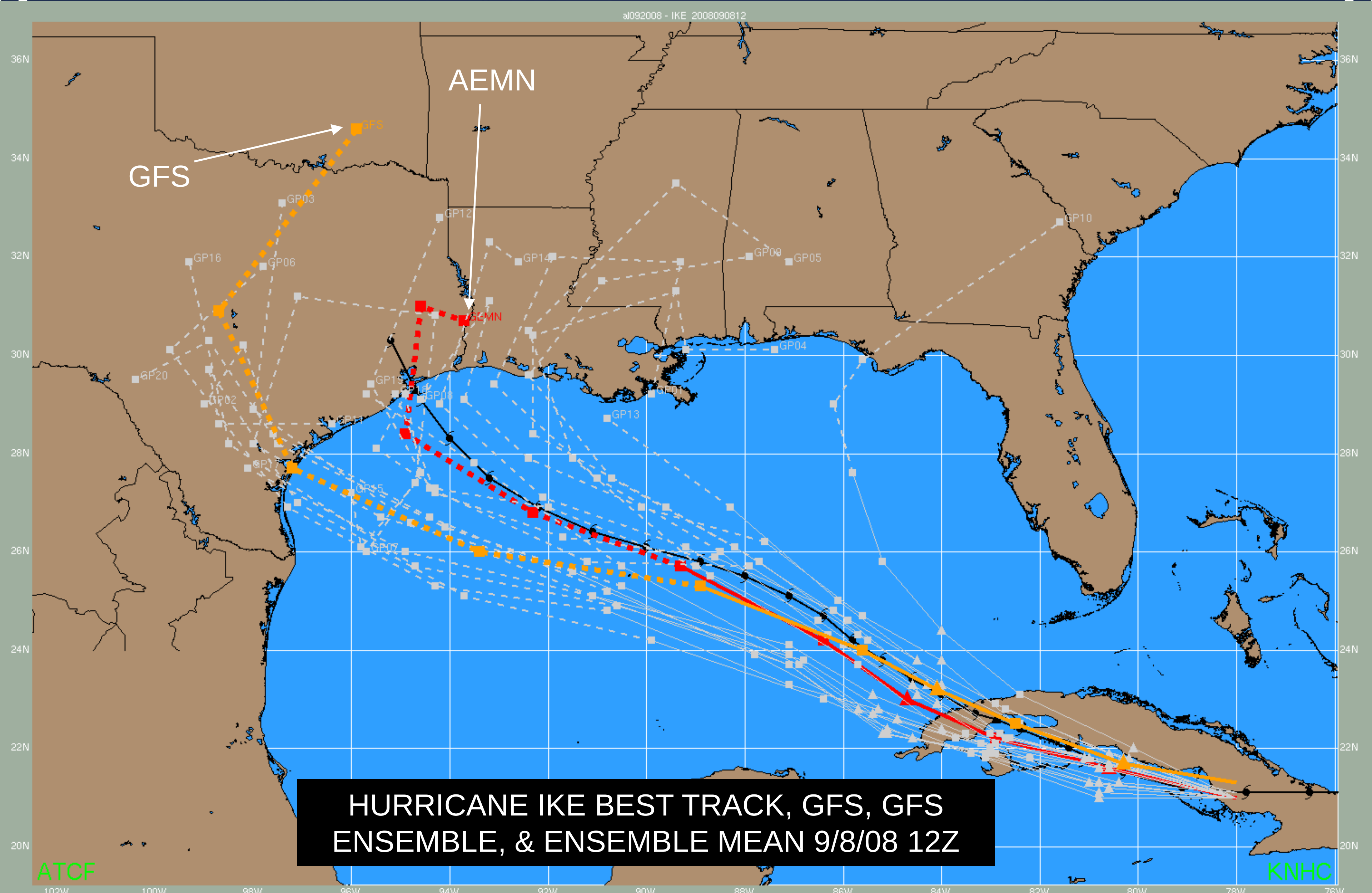
GFS Ensemble example

GFS Ensemble example

GFS Ensemble example



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).

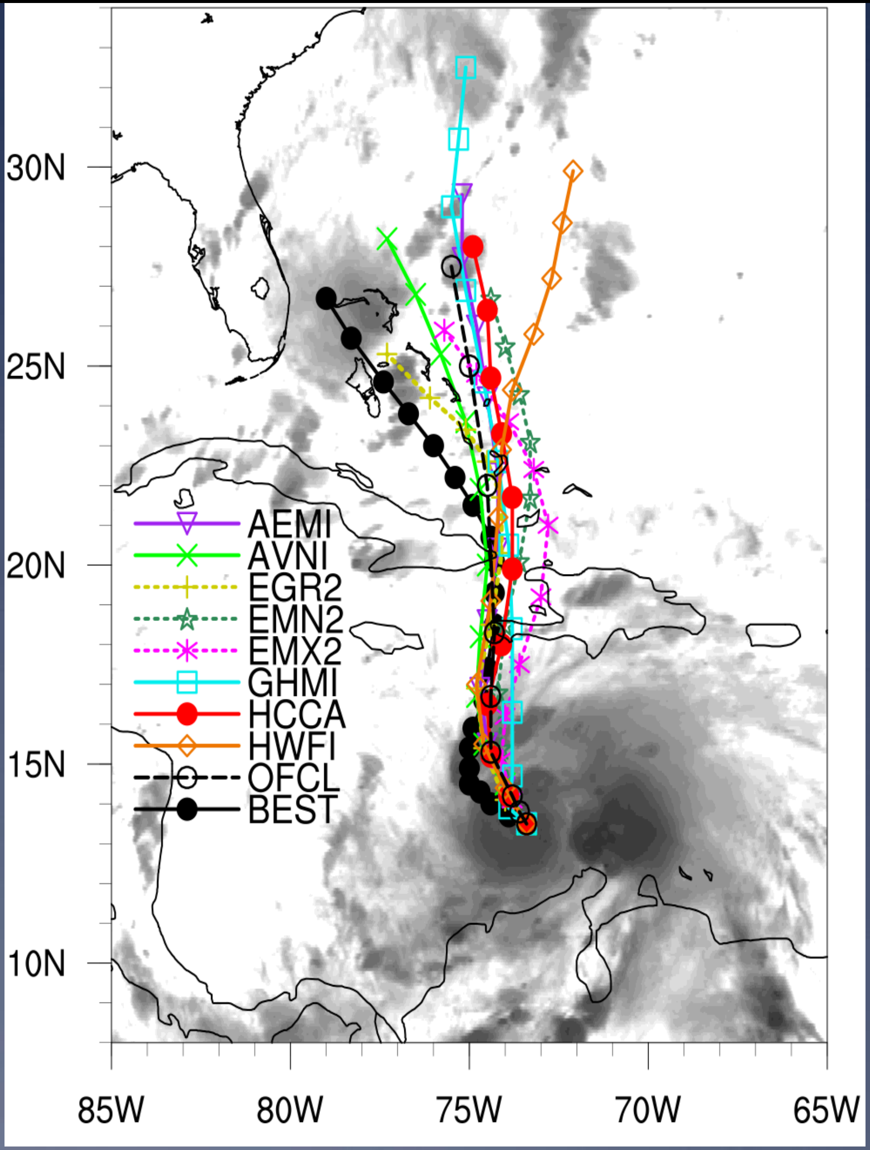
HFIP Corrected Consensus Approach (HCCA) for Tropical Cyclone Track and Intensity Forecasts

- "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

- 2016 input models for **track**: AEMI, AVNI, EGRI, EMNI, EMXI, GHMI, HWFI

- 2016 input models for **intensity**: AVNI, CTCI, DSHP, GHMI, HWFI, LGEM

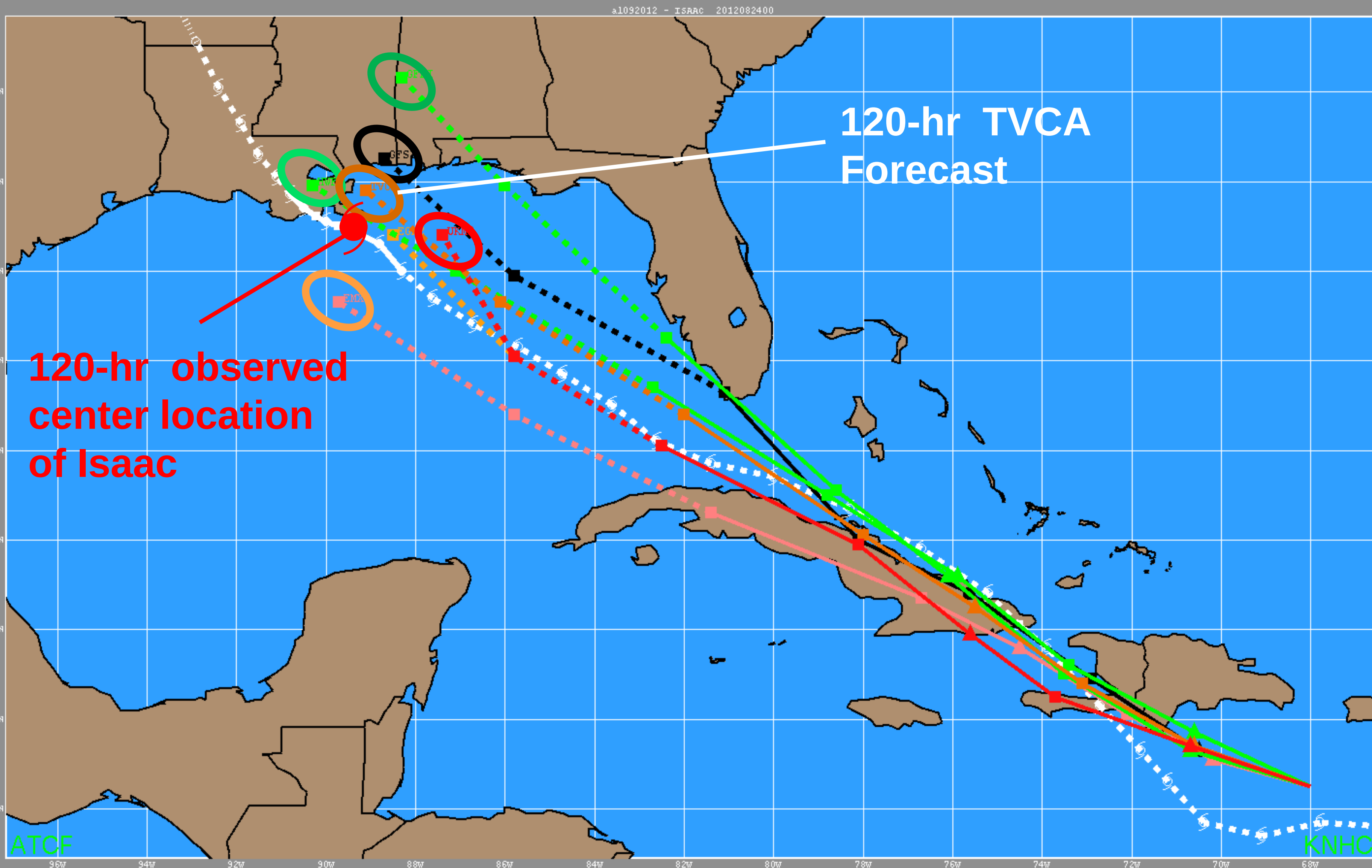


Ensembles and Consensus

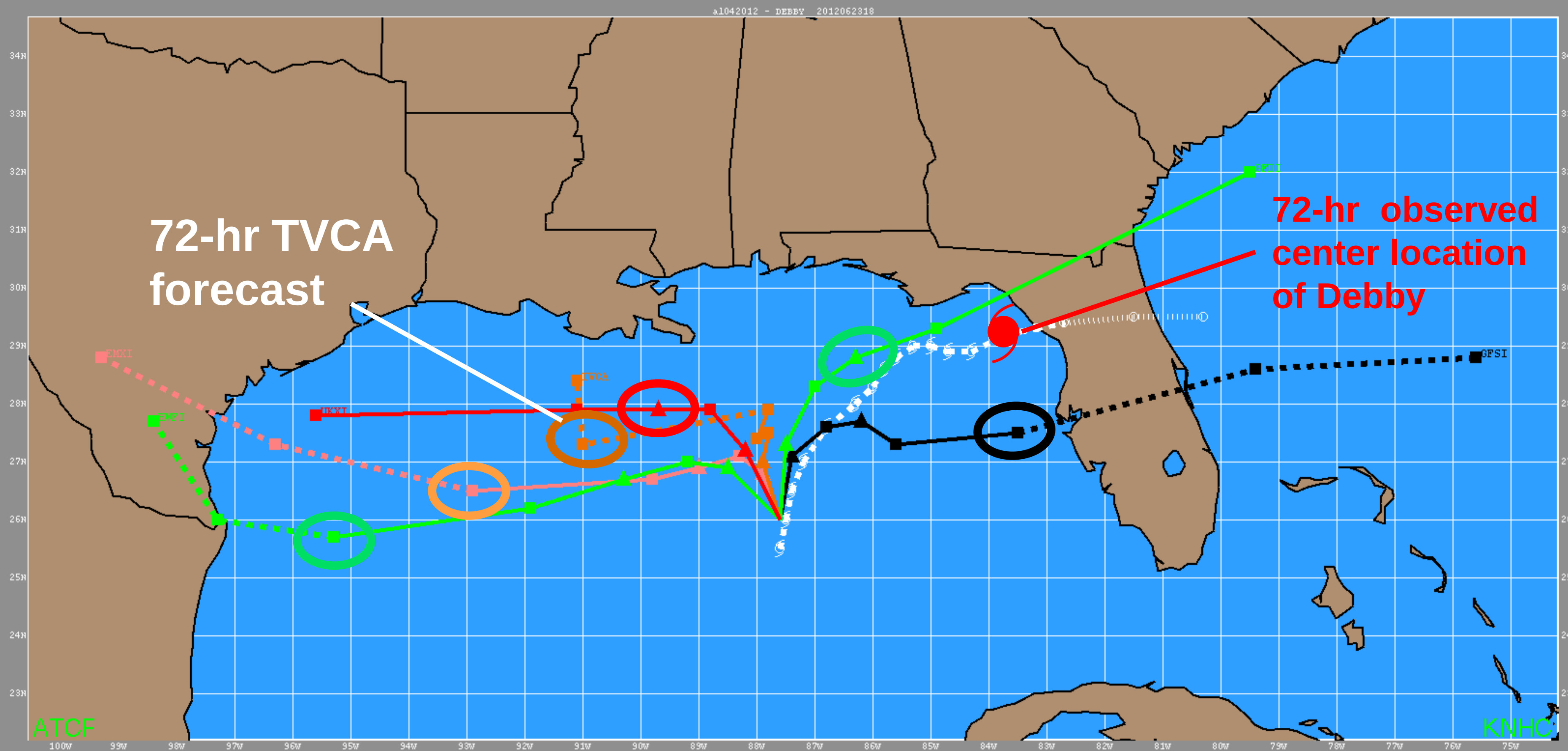
* Often, the most successful consensus models are those formed from an ensemble of good performing models with a high degree of independence.

* 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!

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.

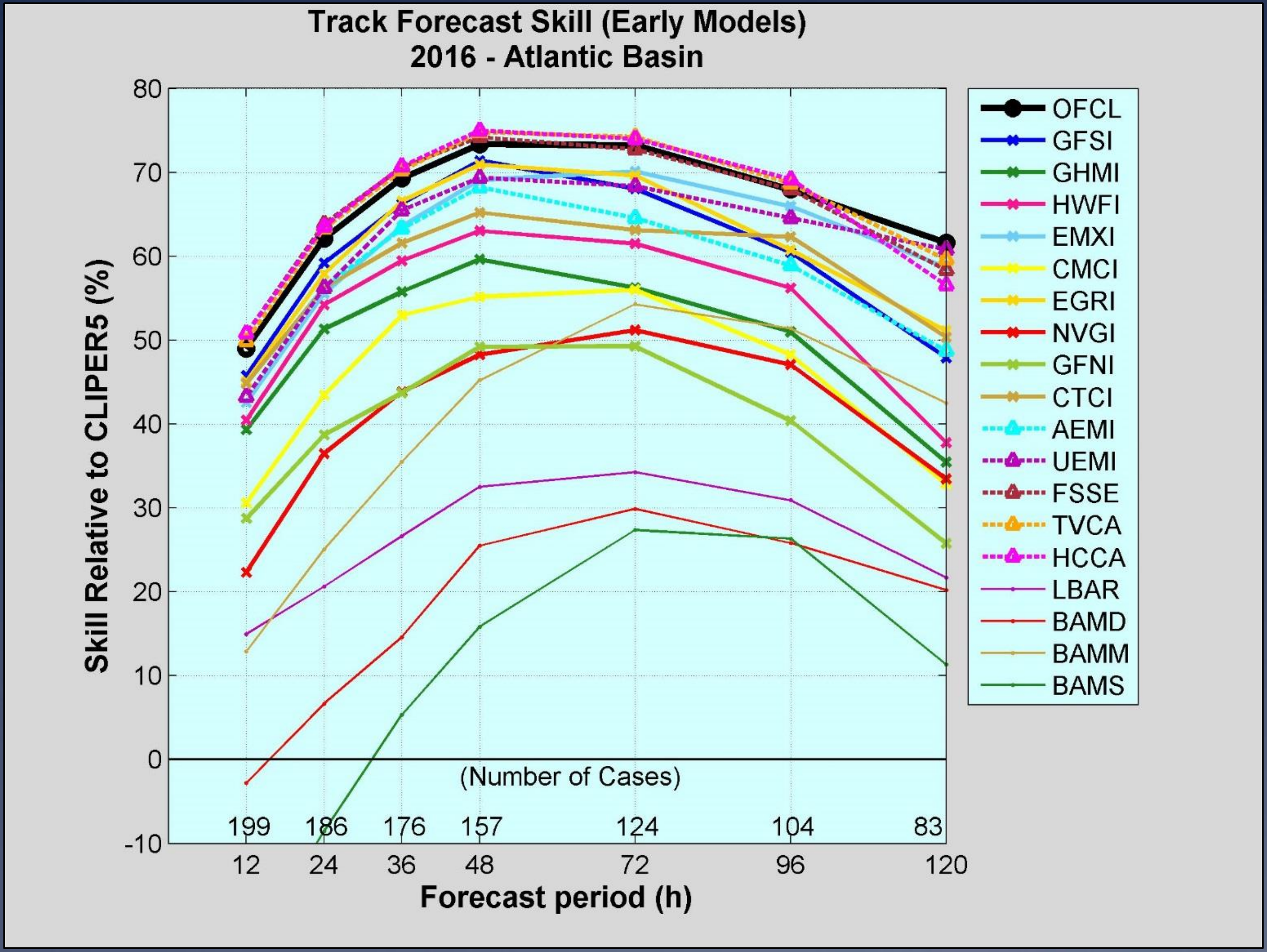
The "early" version of the model is what the forecasters actually have available to them when making a forecast

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
UKMET global model	EGRR	EGRI
Canadian GDPS	CMC	CMCI
U.S. Navy NAVGEM	NVGM	NVGI
HWRF	HWRF	HWFI
HMON	HMON	HMNI
Trajectory and Beta Models	(none)	TABS/TABM/TABD
Climatology and Persistence	(none)	CLP5/OCD5/TCLP
NHC Previous Forecast	(none)	OFCI

2016 Track Guidance



Official forecasts were very skillful, near the best-performing models (consensus aids).

Among the consensus aids, HCCA, TVCA, and FSSE were very close to one another.

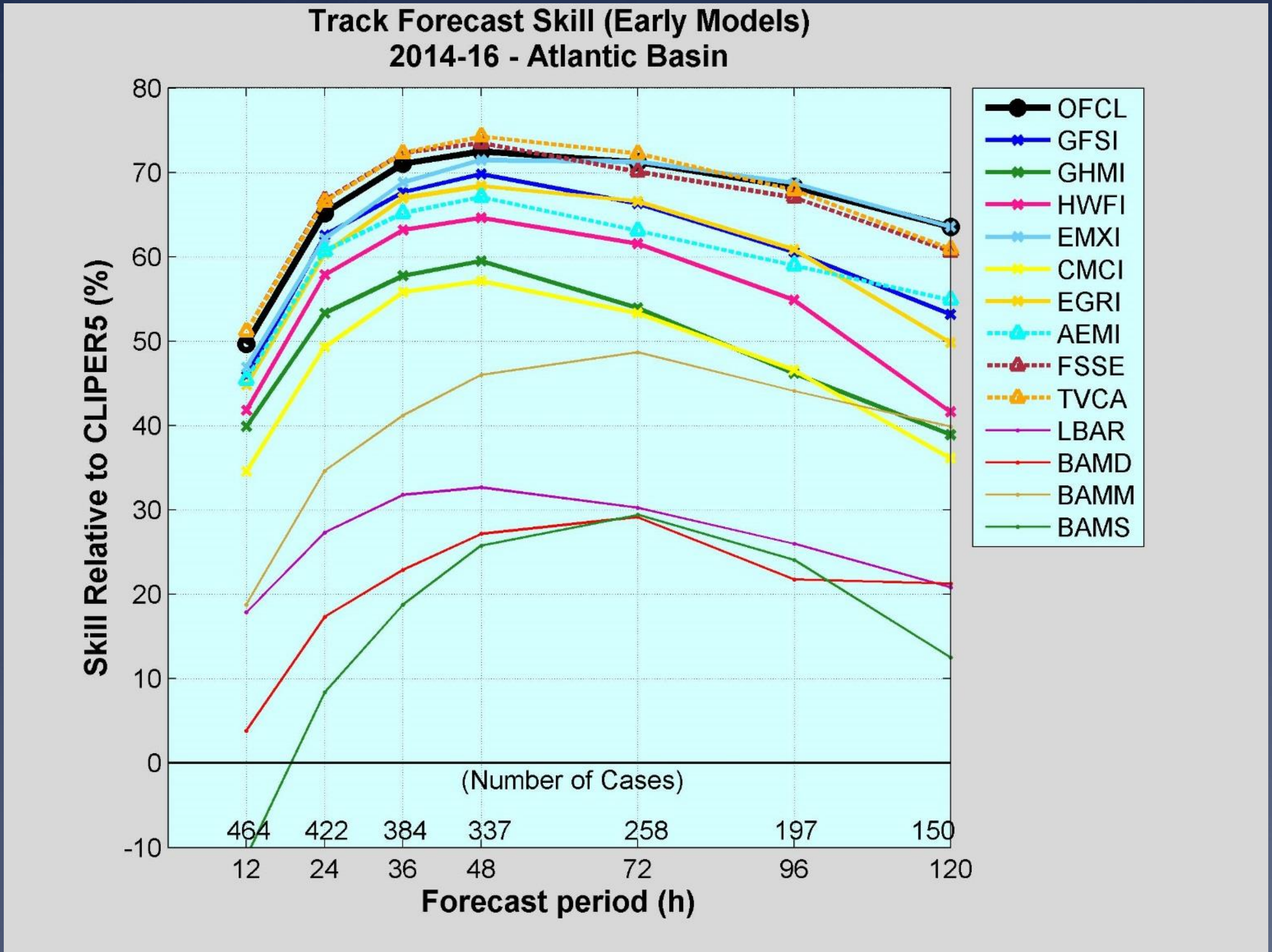
GFSI and EGRI were the best individual models in the short range, EMXI best at longer leads.

UK Met ensemble mean (UEMI) was very skillful and as good as or better than GFSI, EMXI, and EGRI.

AEMI, CTCI, and HWFI were the next best models.

GHMI, CMCI, NVGI, GFNI trailed again in 2016.

2014-16 Track Guidance



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

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

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

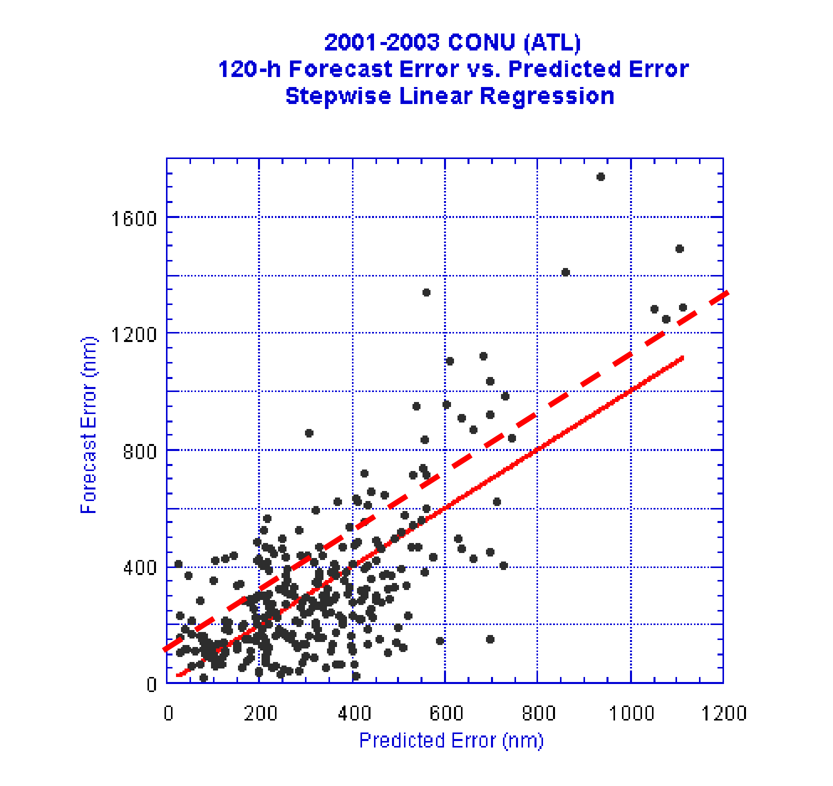
GFS ensemble mean (AEMI), HWFI, and EGRI next best models.

GHMI and CMCI trailed.

Additional Tools and Considerations for TC Track Forecasting

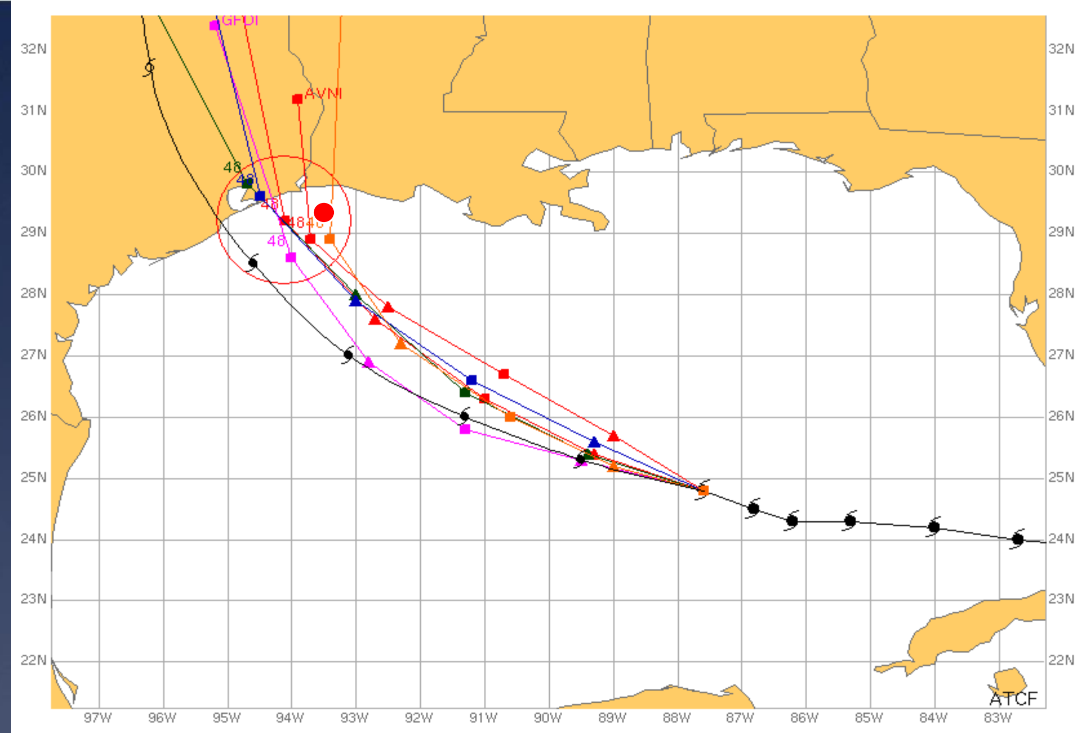
Goerss Prediction of Consensus Error (GPCE)

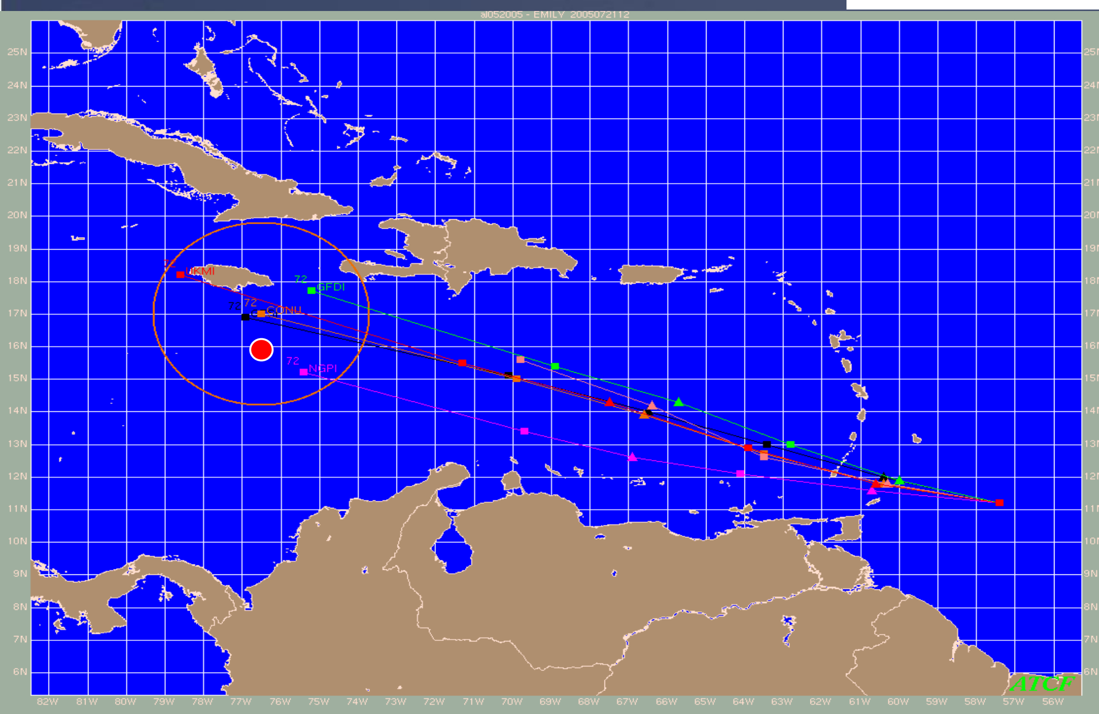
- The magnitude of the consensus (TVCN) error can be statistically predicted based on:
  - Model spread
  - Initial and forecast intensity
  - Forecast latitude and longitude displacements.
- Adjust the regression line upward so that 75% of the time the actual error is smaller than the predicted error.



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

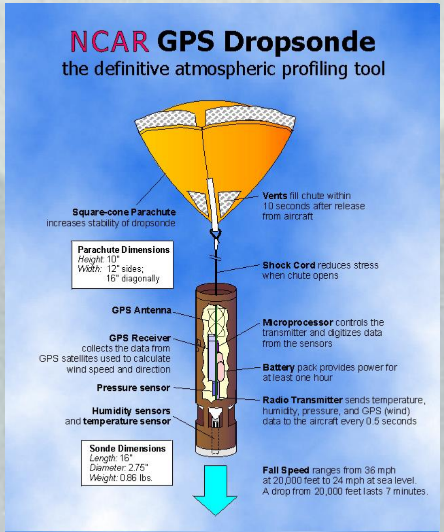
72 h 75% GPCE circle, Hurricane Emily
1200 UTC 13 July 2005



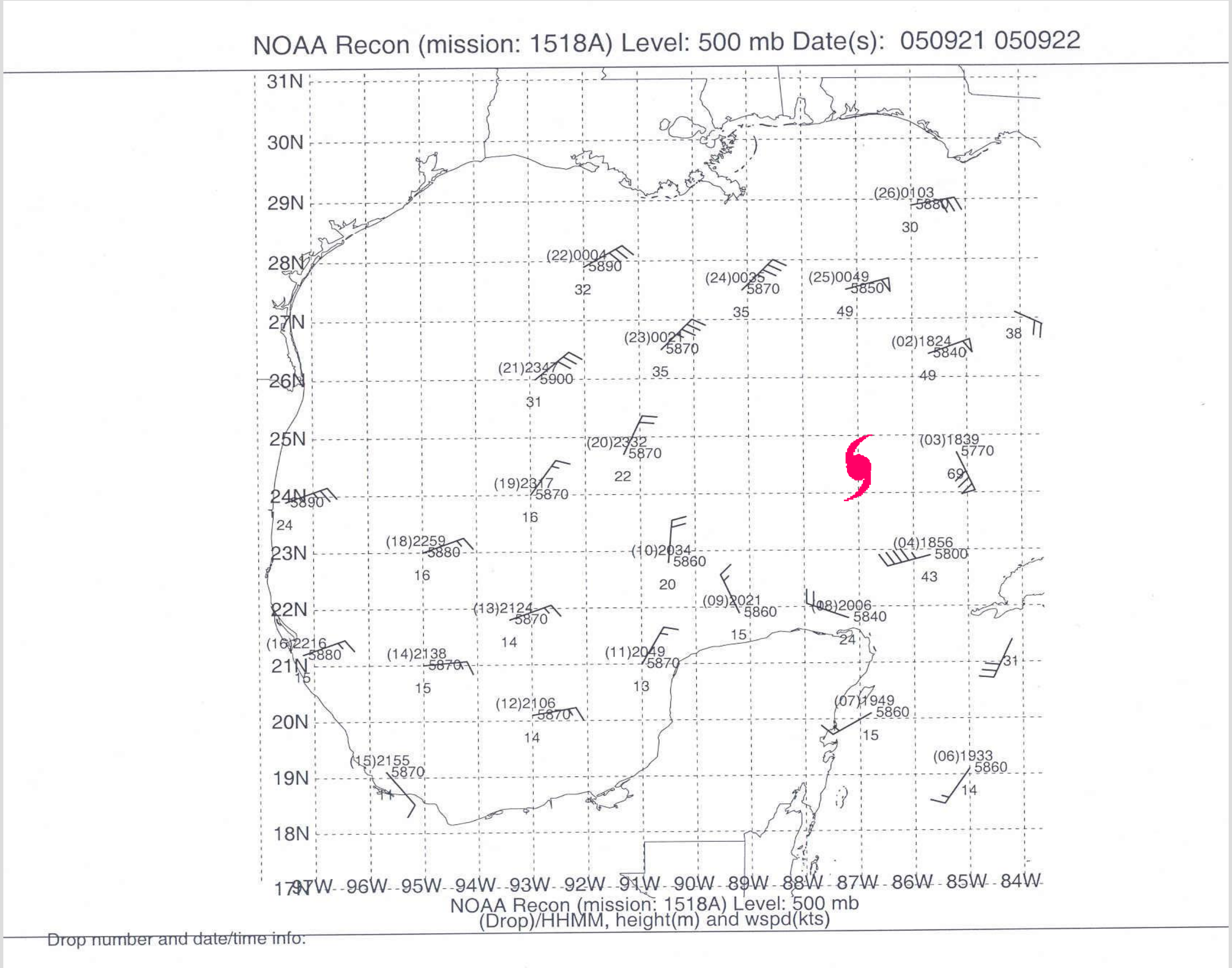


48 h 75% GPCE circle, Hurricane Rita
0600 UTC 22 September 2005

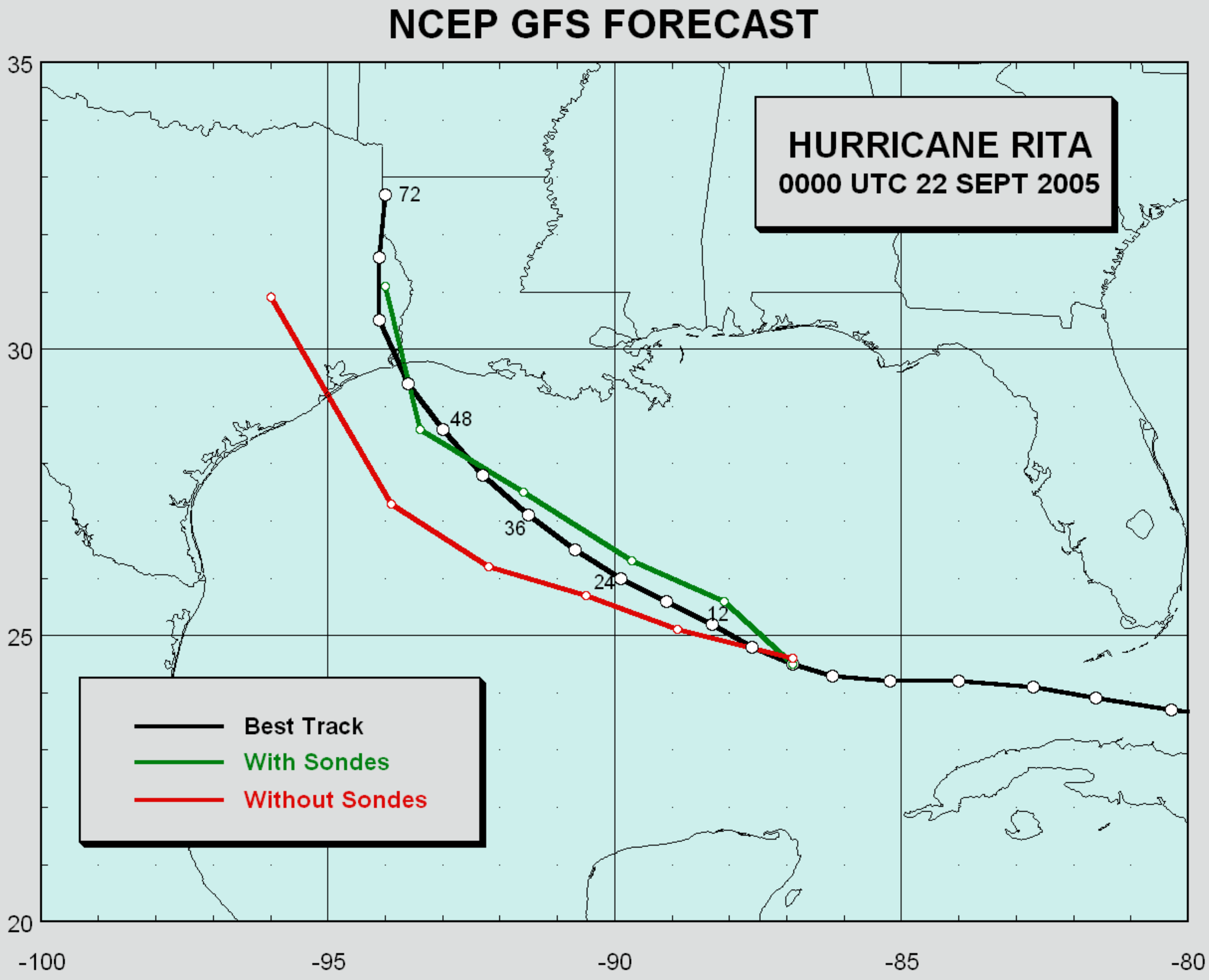
NOAA G-IV AIRCRAFT: A SYNOPTIC SURVEILLANCE PLATFORM



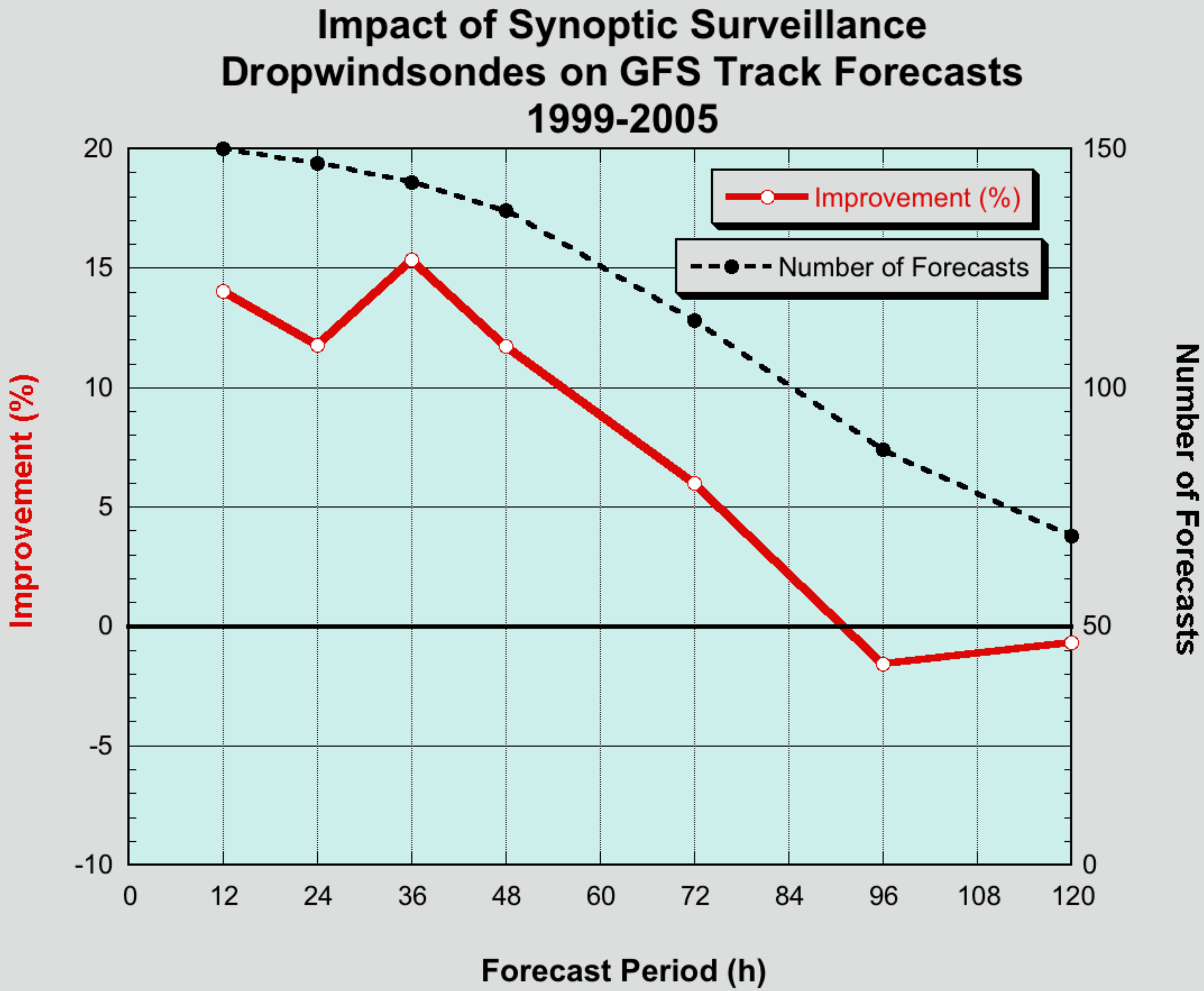
Rita: 500 mb Dropsonde Observations
1800 UTC 21 Sept – 0300 UTC 22 Sept 2005



Rita Dropsonde Impact Example

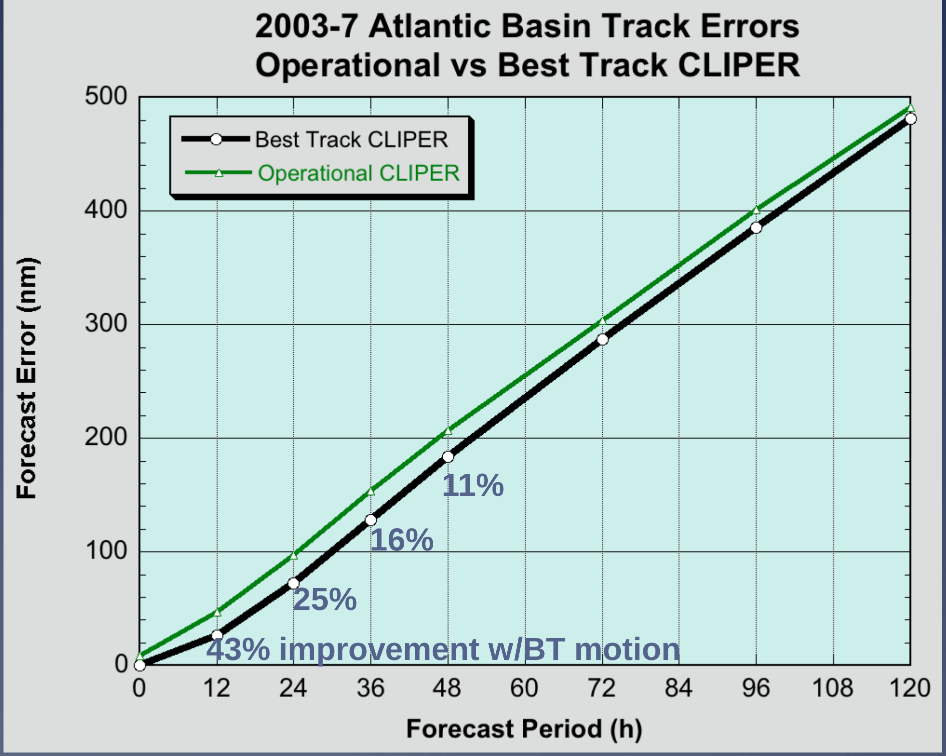


1999-2005 Dropsonde Impact



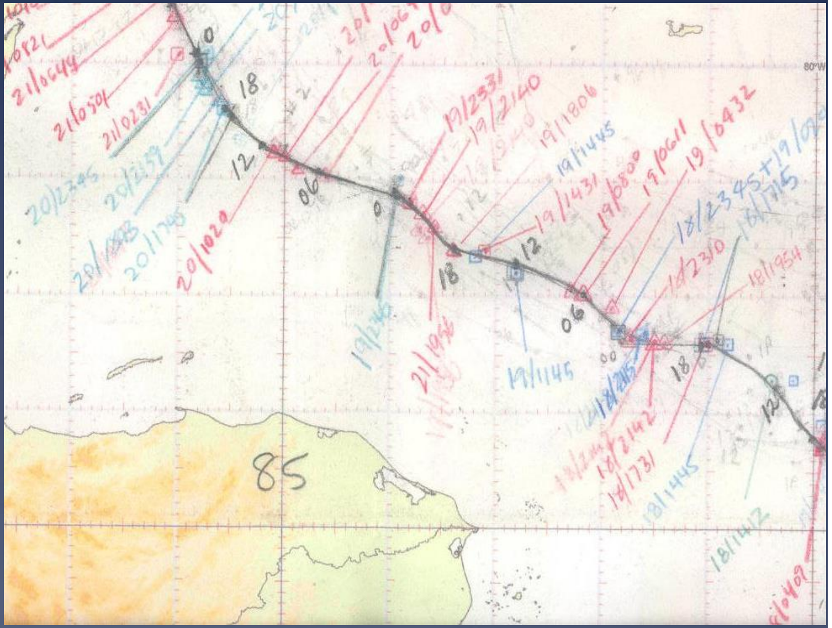
Track Forecasting at the NHC: Importance of Initial Motion

- 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.



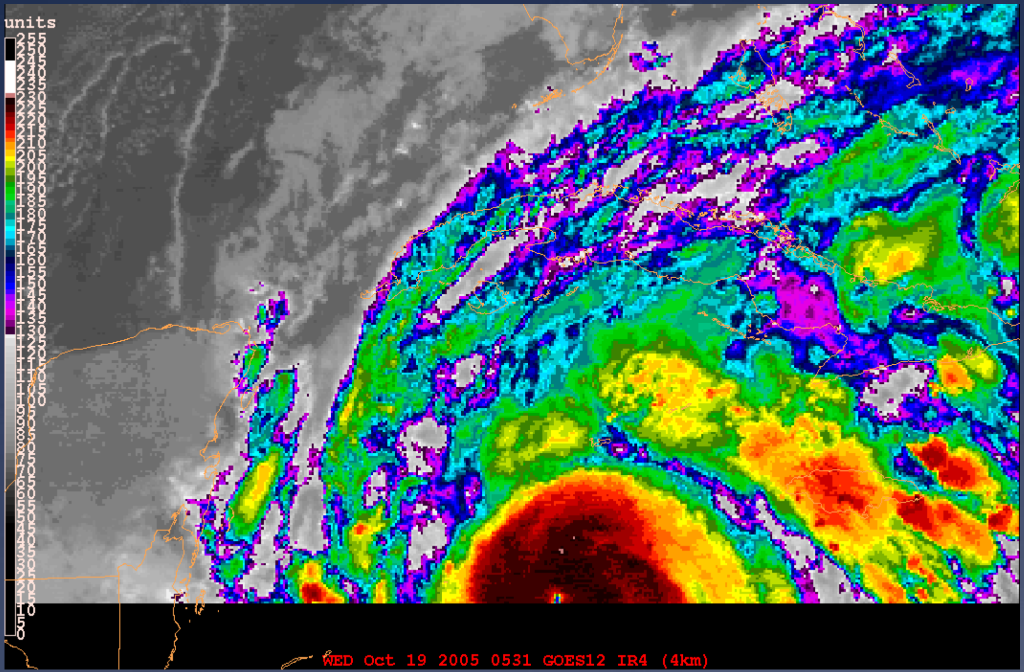
Track Forecasting at the NHC: Determination of Initial Motion

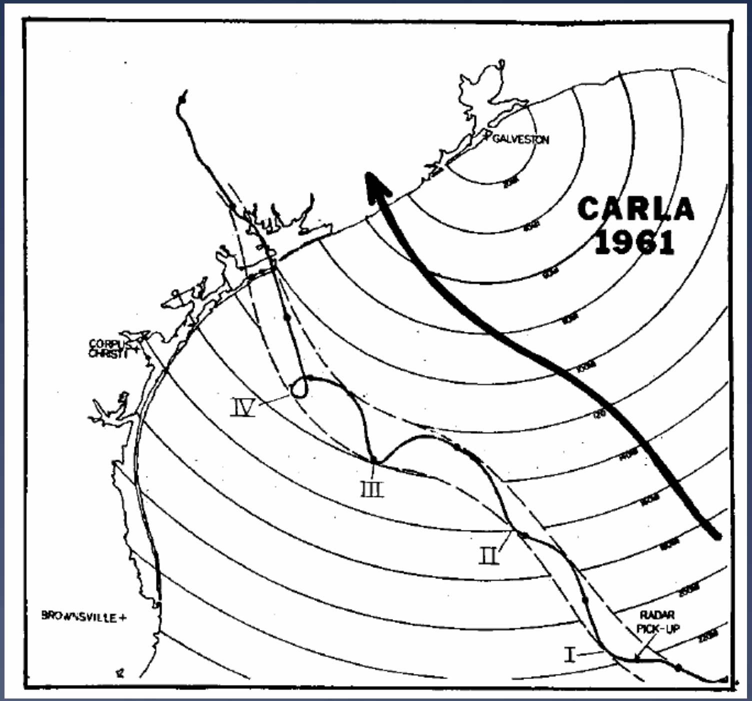
- Initial motion typically computed using the average motion over the previous 6, 12, or 18 h.
  - Shorter when known changes in track are occurring, longer when center location is uncertain.
  - Initial motion estimate should not reflect short-term track wobbles (e.g., trochoidal oscillations) that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



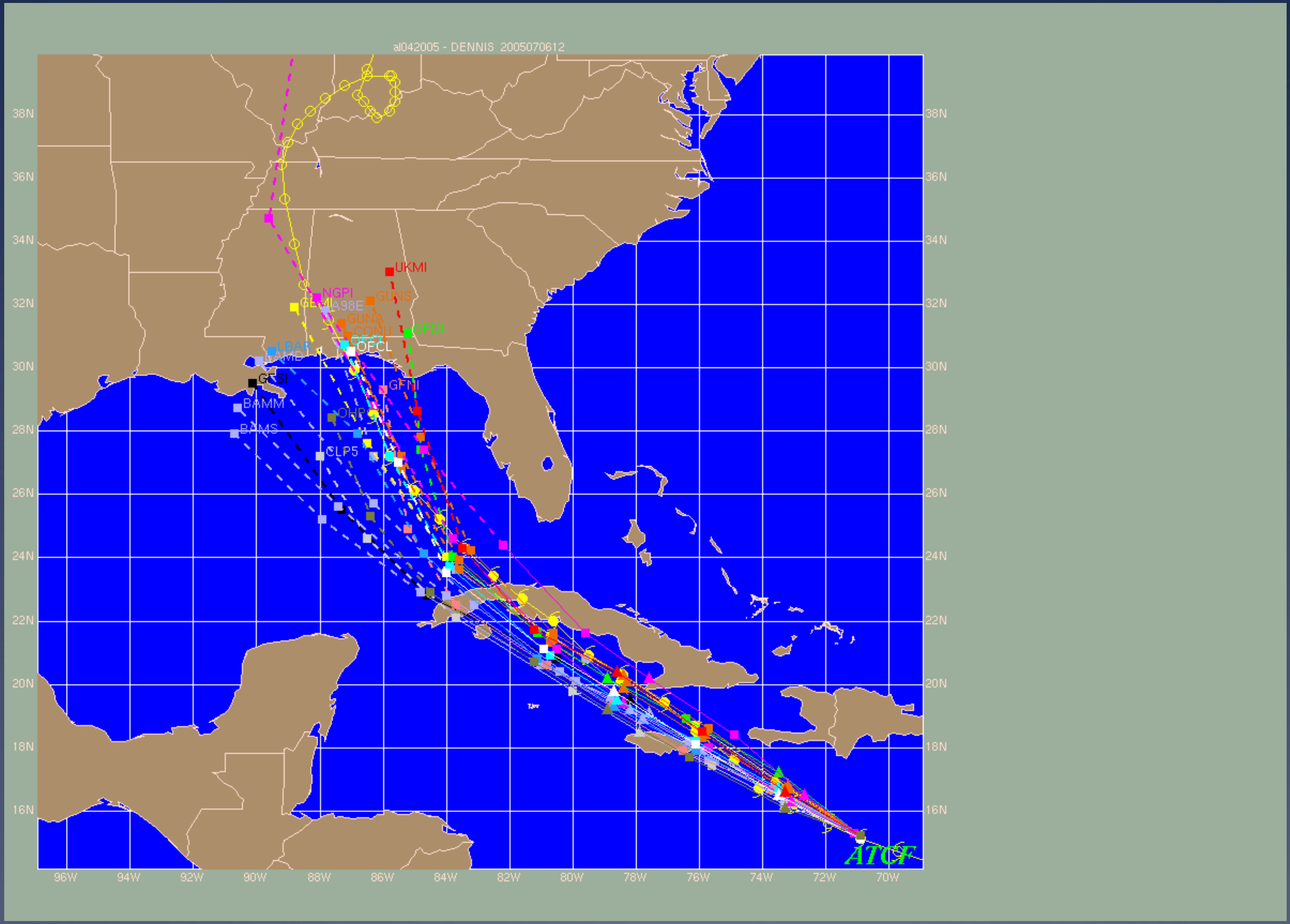


- Substantial oscillation (wobble) of the center of a TC about its mean motion vector
- Primarily a side effect of convective asymmetries in the inner core
- Amplitude of motions varies but higher-frequency "wobbles" lost in 'best track' smoothing process
- Virtually impossible to forecast!

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

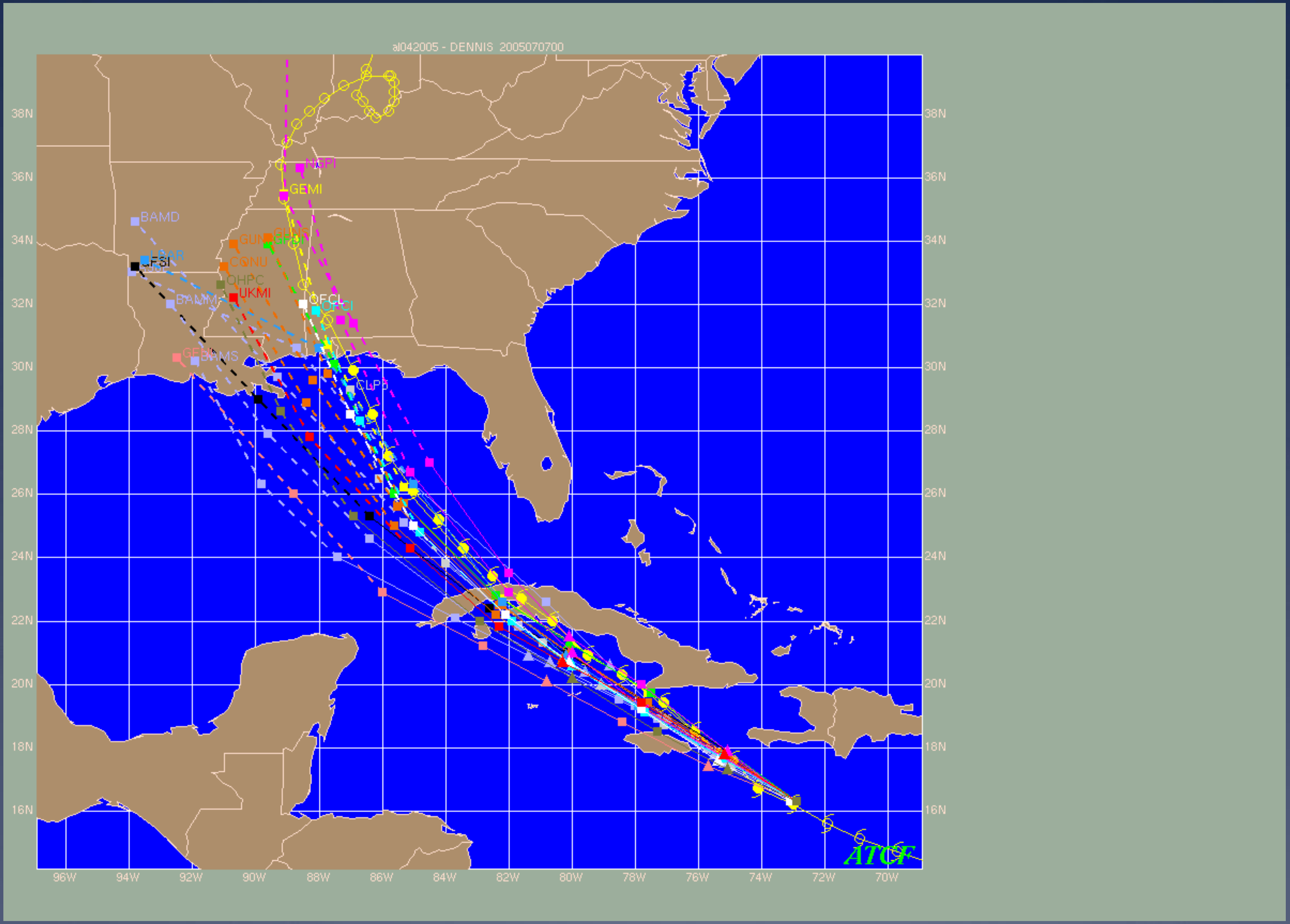


* Official forecast near model consensus in extreme western FL panhandle.

Dennis Guidance 6 July 1800 UTC

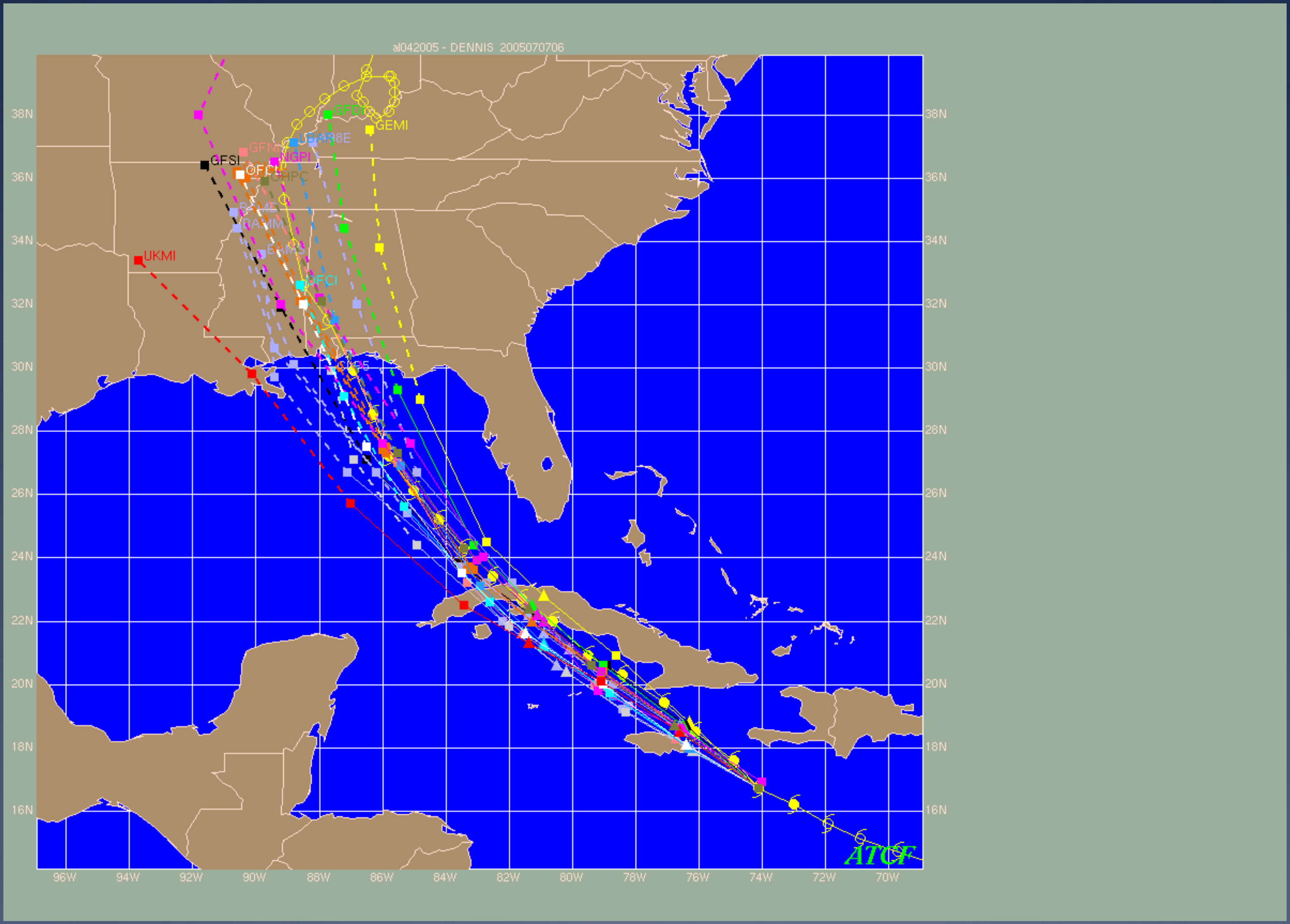
- Guidance shifts sharply westward toward New Orleans. Official forecast nudged westward into AL.

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

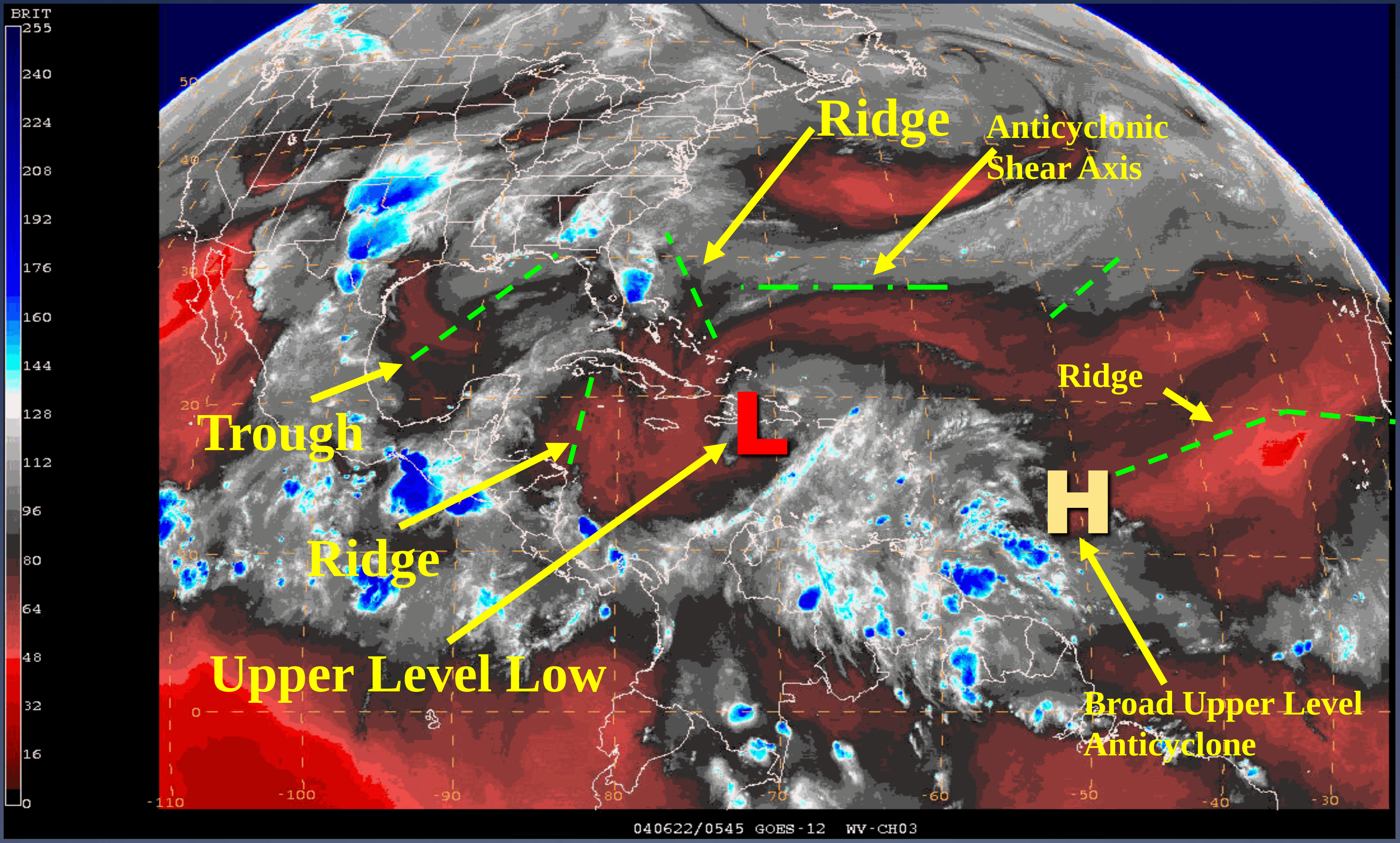


* Rest of the guidance shifts sharply eastward, leaving official forecast near the center of the guidance envelope (and very close to the actual track of Dennis.

Track Forecasting at the NHC: Using Models

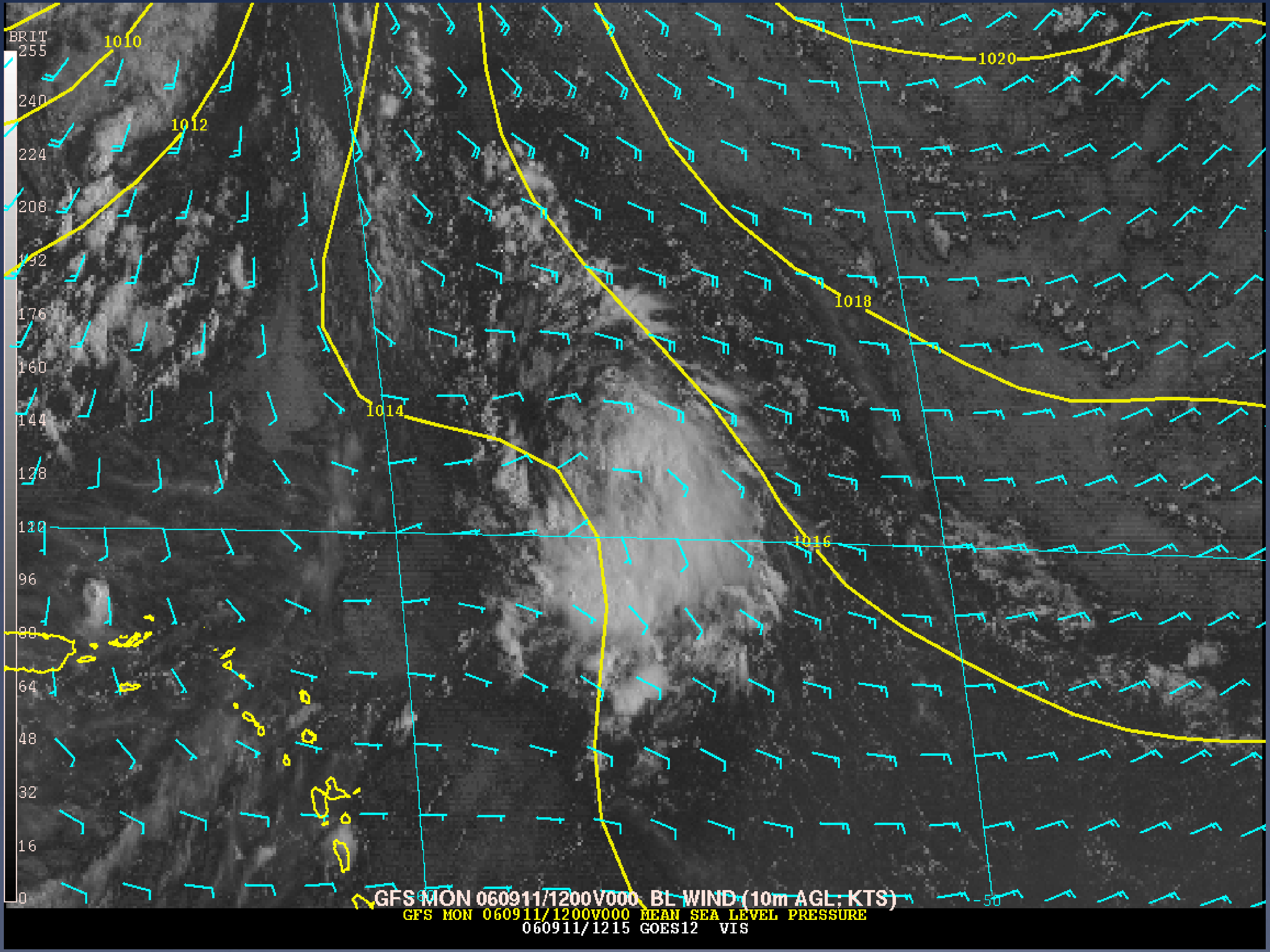
* Dynamical model consensus is an excellent first guess for the forecast (and often a good final guess!). Continuity dictates that it must be considered in view of the previous official forecast.
* Evaluate the large-scale environment using conventional data and satellite imagery (e.g., water vapor)
  * 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.

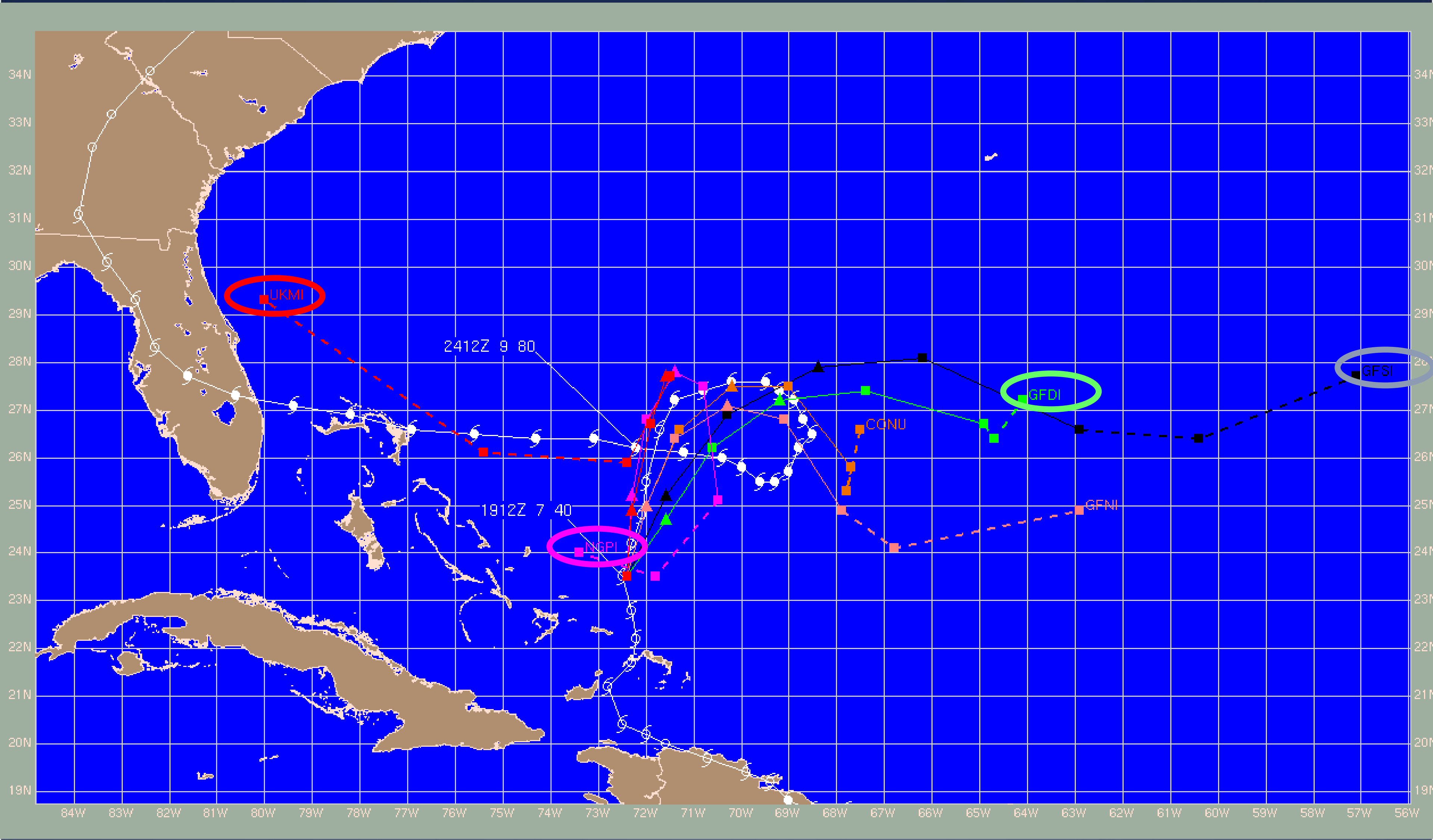
Large-Scale Steering Flow



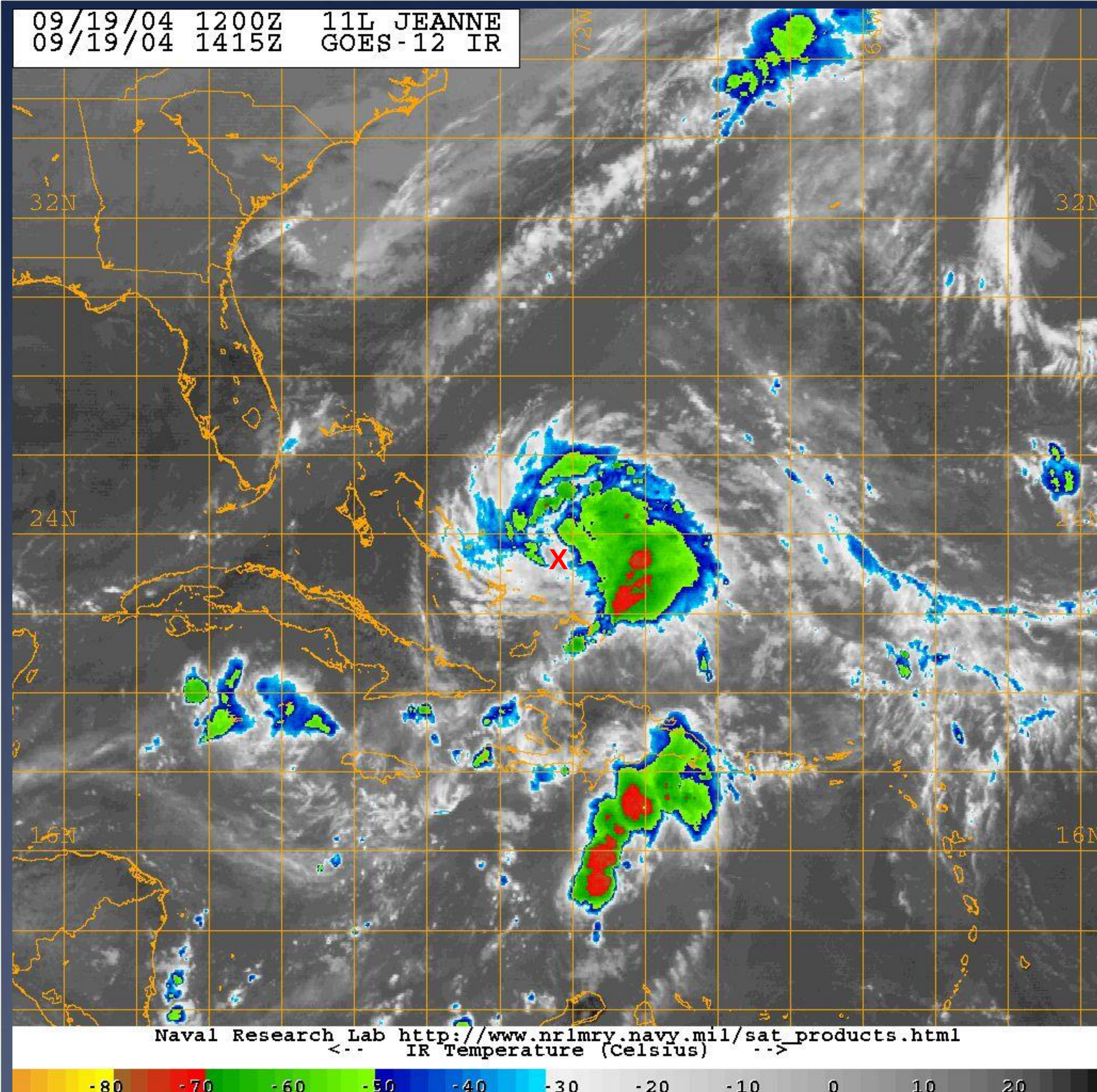
* Allow the forecaster to see features in the storm environment that could affect the future track and intensity of the cyclone.

Bad Initialization for Tropical Storm Gordon
1200 UTC 11 September 2006





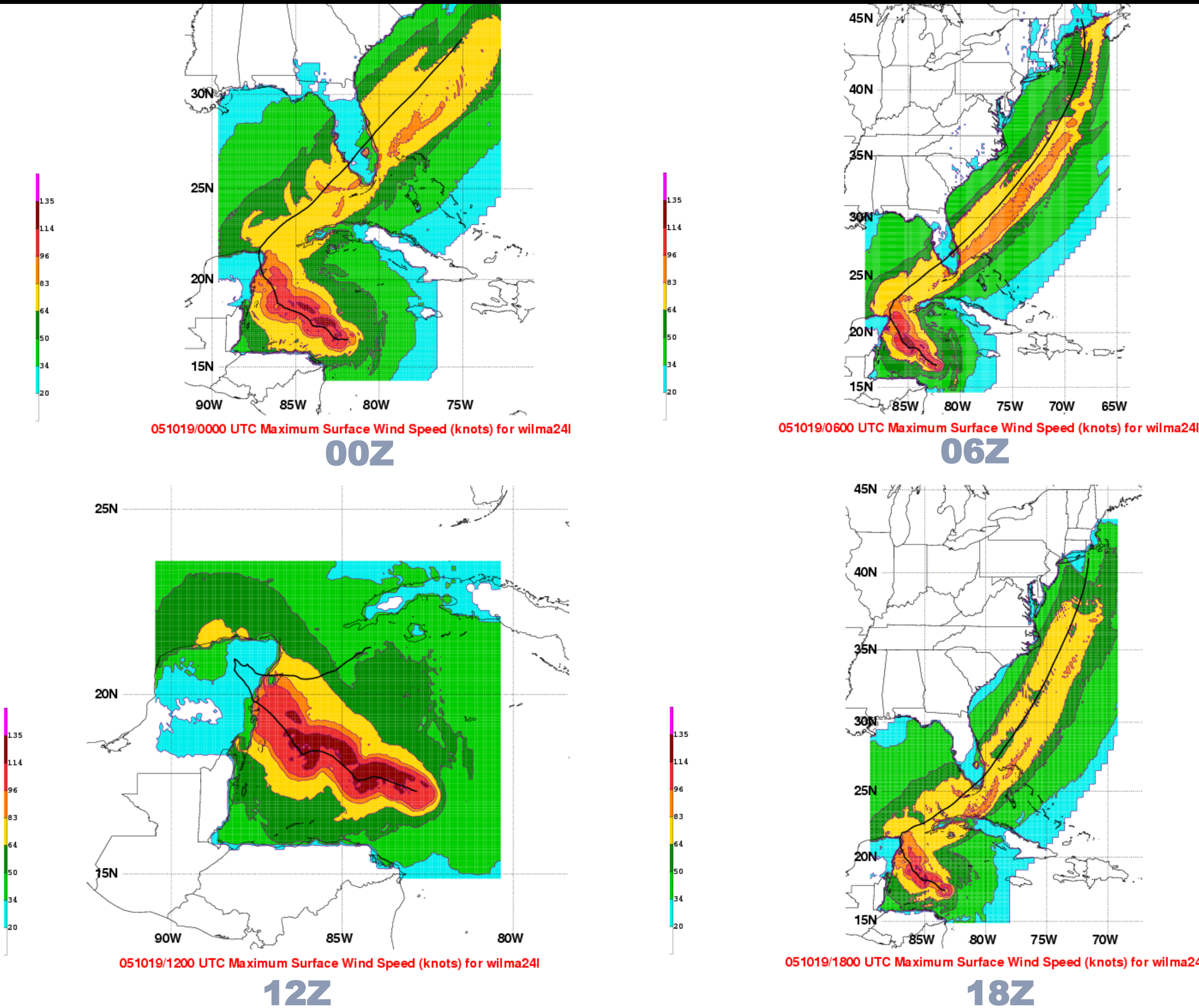
How to resolve the difference between guidance models?



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



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...

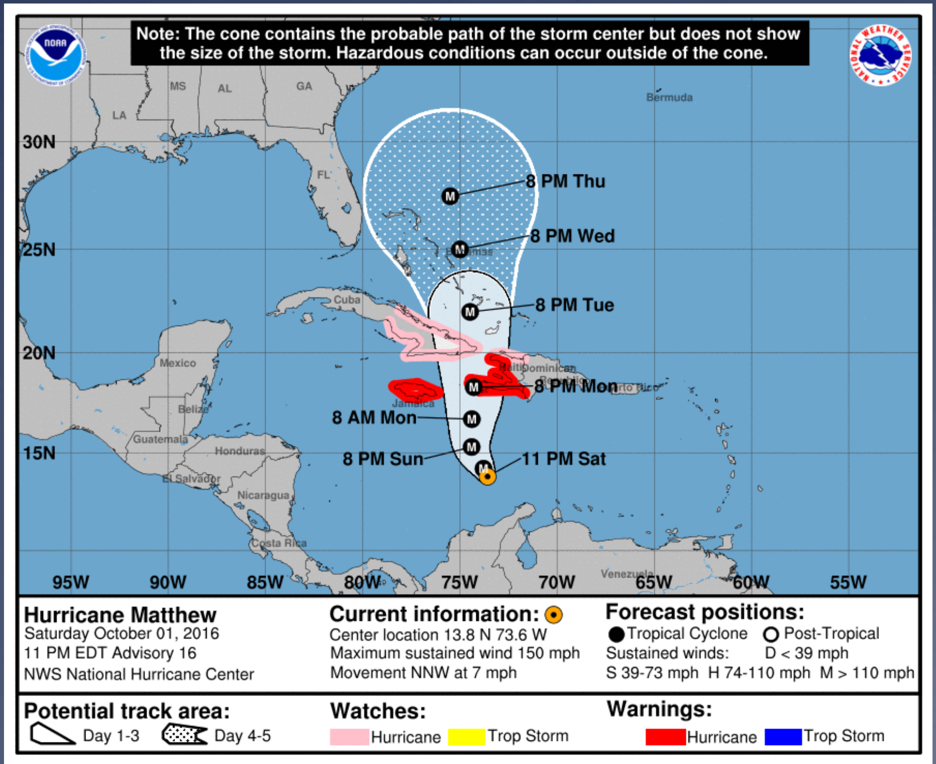
FORECASTER FRANKLIN

FORECAST POSITIONS AND MAX WINDS

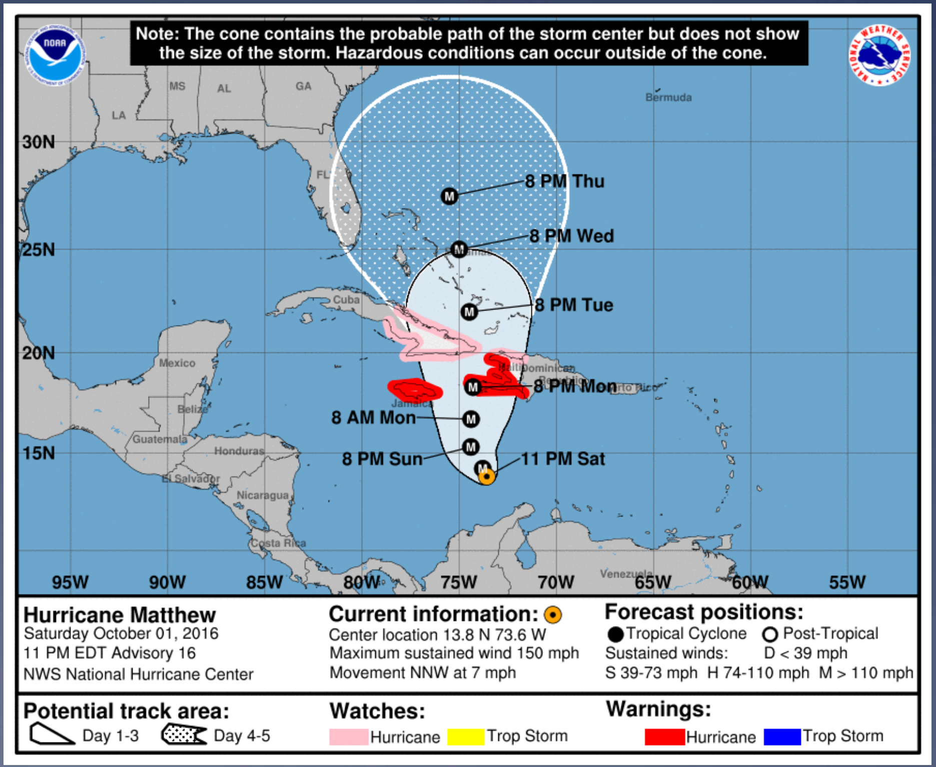
INITIAL	19/2100Z	17.7N	83.7W	140 KT
12HR VT	20/0600Z	18.0N	84.6W	135 KT
24HR VT	20/1800Z	19.2N	85.6W	145 KT
36HR VT	21/0600Z	20.4N	86.2W	145 KT
48HR VT	21/1800Z	21.6N	86.3W	120 KT
72HR VT	22/1800Z	24.0N	84.5W	105 KT
96HR VT	23/1800Z	27.5N	79.0W	80 KT
120HR VT	24/1800Z	36.0N	70.0W	65 KT

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 Cone



2007 Cone

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%

It is anticipated that the cone in 2017 will be slightly smaller, but the 2016 verification is not yet complete.

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

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

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

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.