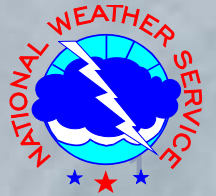


The Use of Track Forecasting Models at the National Hurricane Center

James L. Franklin
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National Hurricane Center

2010 Florida Governor's Hurricane Conference



Two Basic Model Types

* Statistical

- * Models based on historical relationships between storm-specific information (i.e., storm location, time of year, current motion, intensity, environment) and the behavior of previous storms. **Statistical models tell you what normally occurs in similar situations.**

* Dynamical

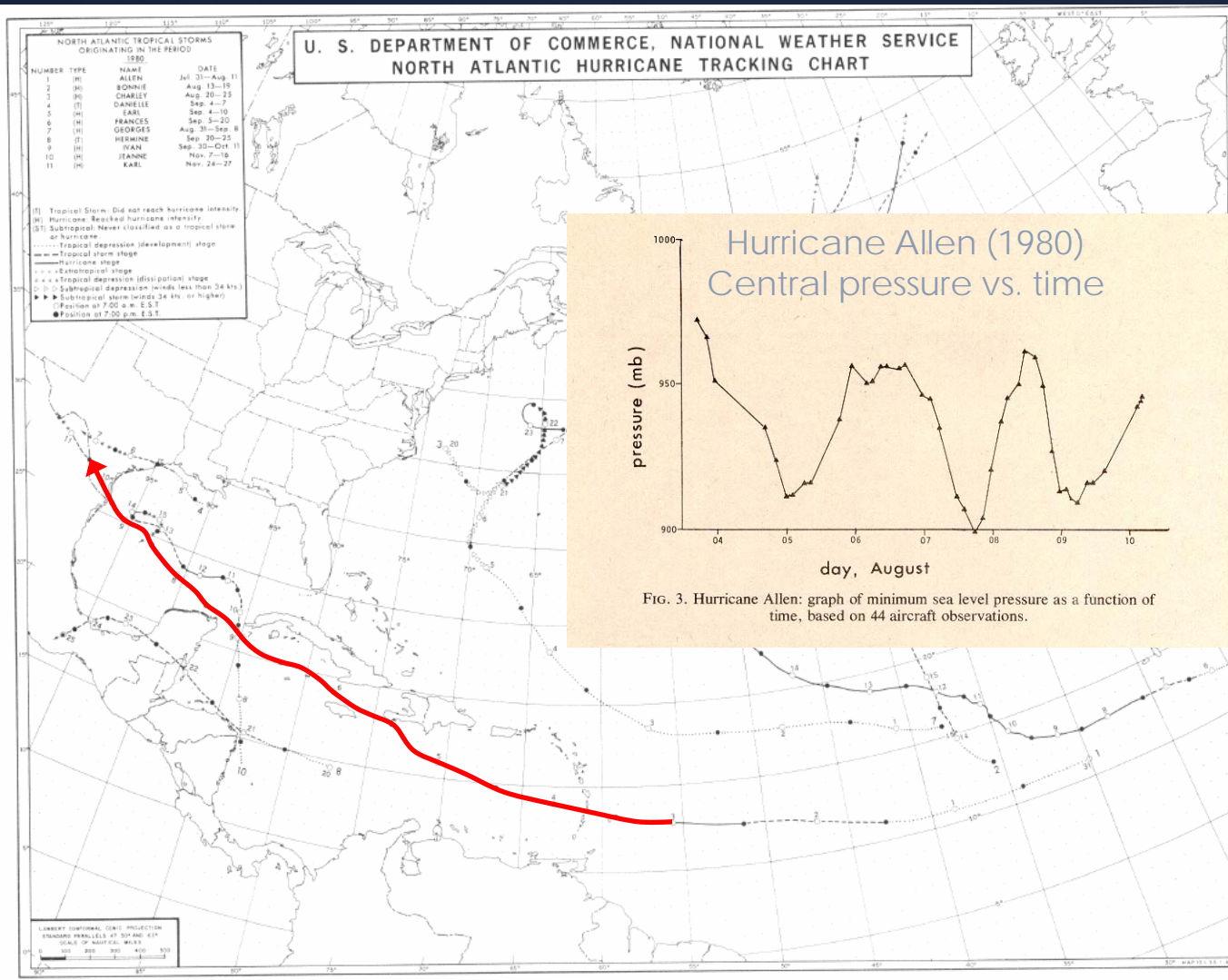
- * Models that solve fundamental physical laws that govern motion in the atmosphere. They begin with an analysis of the current state of the atmosphere and then apply the physical laws to project (integrate) into the future. **Dynamical models attempt to predict what will happen in this specific situation.**

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

Tropical Cyclone Motion

- * Track forecasting is a relatively simple dynamical problem with well-understood physics.
 - * Motion mostly caused by a “steering” of the cyclone by the layer-averaged winds in its environment (cork in the stream).
 - * A small portion (~10%-20%) is due to interaction between the storm and the environment (presence of the cork modifies the flow in the stream).
 - * Occasionally, structure of storm itself can lead to motion (or apparent motion) distinct from the environmental steering.
- * Important atmospheric features are relatively large and easy to measure.
- * Dynamical models do very well at forecasting tropical cyclone tracks and are constantly improving. They long ago surpassed statistical models in accuracy.

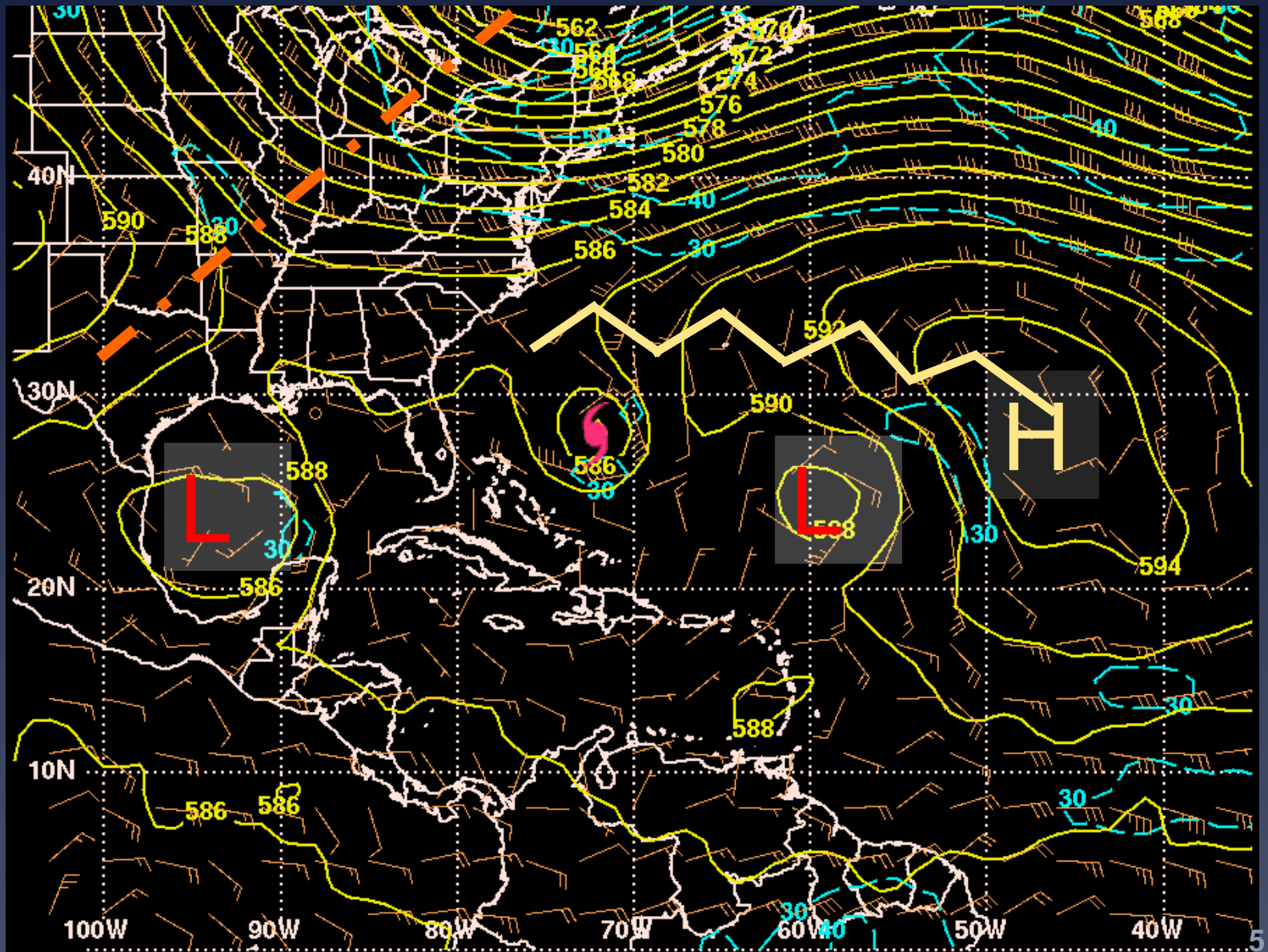
Intensity and Motion



With the exception of very weak cyclones with little thunderstorm activity, changes in intensity generally have little direct influence on track.

Because of this, highly successful track forecasts can be obtained by focusing on the evolution of the storm environment, rather than on the storm itself.

Large-Scale Steering



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

Hierarchy of TC Track Models

- * **Statistical**

- * **CLIPER (Climatology-Persistence)**

- * Knows NOTHING about the current state of the atmosphere. Tells you what is a typical track for storms in this location at this time of year that start off moving in a similar direction. Can be used to evaluate more complex models (skill baseline) but should NEVER be taken as a serious forecast.

- * **Simplified Dynamical (Trajectory)**

- * **BAMD, BAMM, BAMS**

- * Follow the cork in stream analogy, where the hurricane is not allowed to have any impact on the stream. Forecast of the stream (the environment) is taken from a more complex model but greatly smoothed and simplified (two-dimensional). Can be effective when environmental flows are very simple, such as in the deep tropics. Need to know which one (deep, medium, or shallow) is appropriate.

Hierarchy of TC Track Models

* Dynamical models – General characteristics

- * The most complex models available.
- * Solve the fundamental physical equations that govern the atmosphere. Include a wide range of physical processes.
- * Three dimensional (25-90 layers in the vertical).
- * Come in two flavors: Global and Regional

* Primary dynamical models used at NHC

- * National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS)
- * United Kingdom Met Office Model (UKMET)
- * Navy Operational Global Atmospheric Prediction System (NOGAPS)
- * European Centre for Medium Range Weather Forecasts Model (ECMWF)
- * Geophysical Fluid Dynamics Laboratory Model (GFDL, GFDN)
- * Hurricane Weather and Research Forecasting Model (HWRF)

Hierarchy of TC Track Models

- * **Dynamical (Global)**

- * **ECMWF, GFS, UKMET, NOGAPS**

- * Developed for general weather prediction, not specifically for tropical cyclones.
 - * Horizontal resolutions of 15-35 miles (too large to depict the core).
 - * Because they handle environmental large-scale features well, they tend to do an excellent job with tropical cyclone track prediction, especially at the longer lead times.

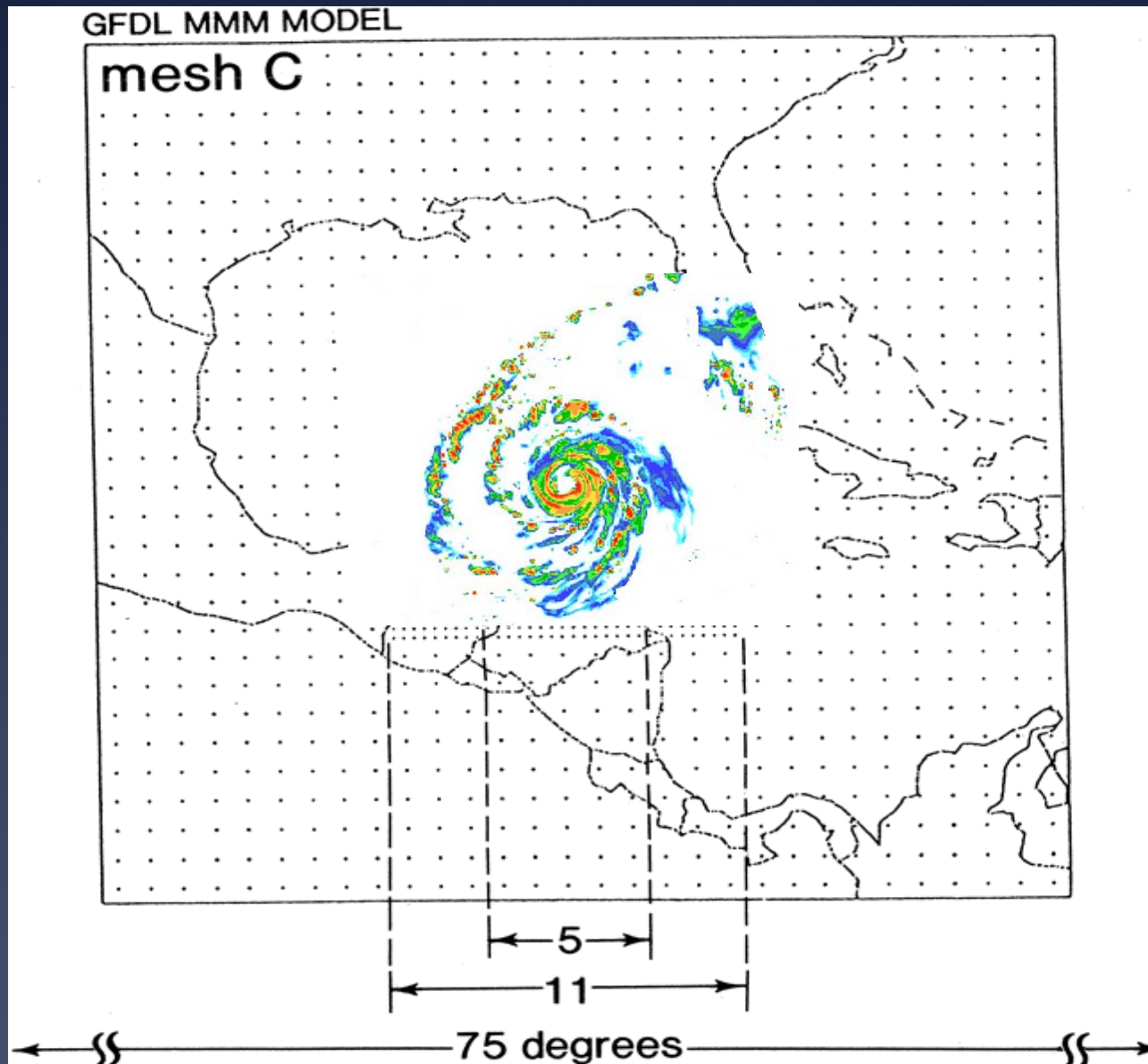
Hierarchy of TC Track Models

- * Dynamical (Regional)

- * GFDL, GFDN, HWRF

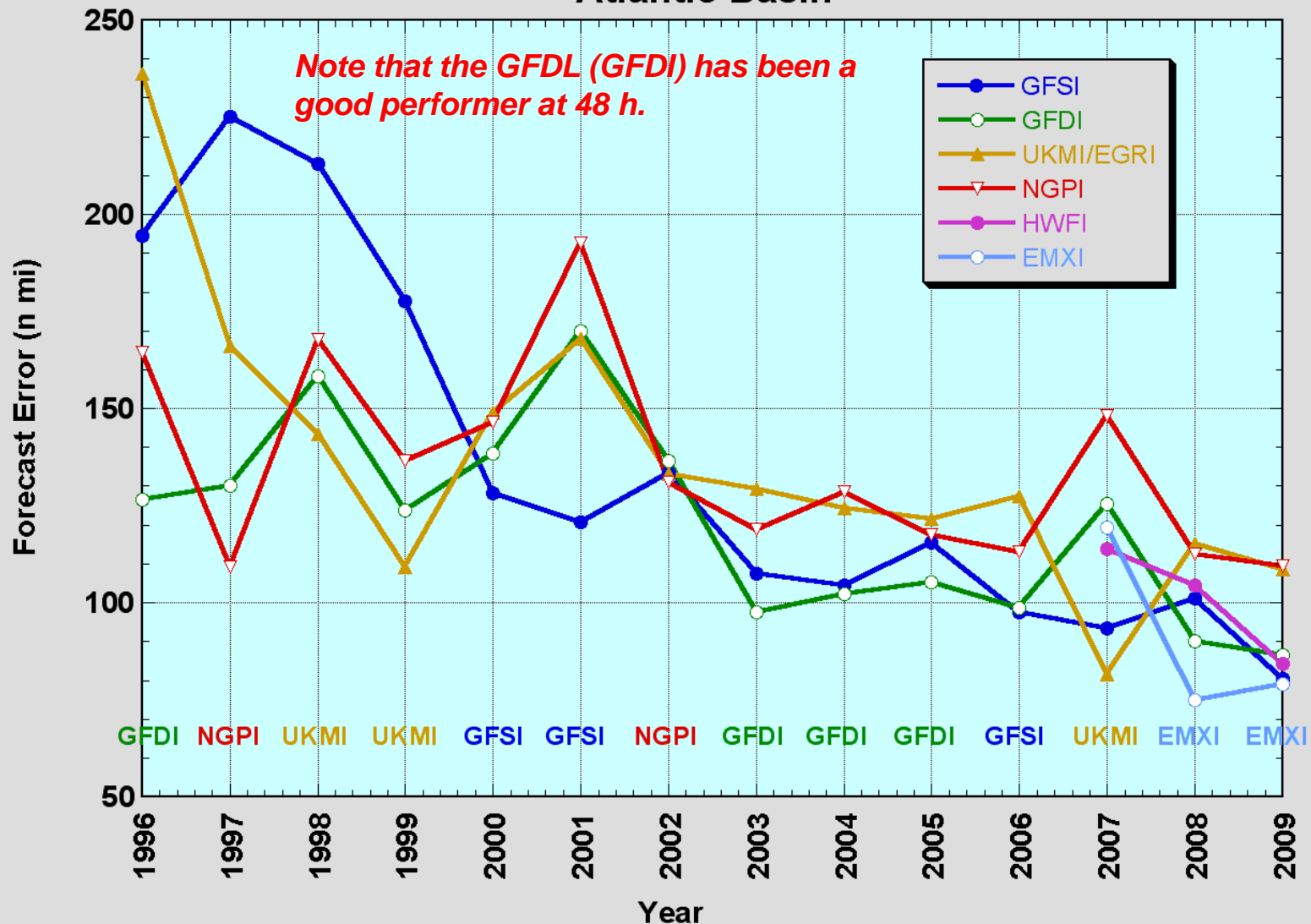
- * Developed specifically for tropical cyclones.
 - * Limited areal coverage means they can have higher resolution. GFDL/HWRF have inner nest resolution of 6 miles. This is small enough to simulate a semi-realistic eyewall.
 - * More explicit representation of the storm means they can potentially do a better job of handling interactions between the tropical cyclone and the environment. This can result in better track and intensity forecasts.
 - * Downside of limited coverage is that features far away from the storm are not handled as well, and this can degrade the longer-range forecasts.

GFDL Mesh Configuration

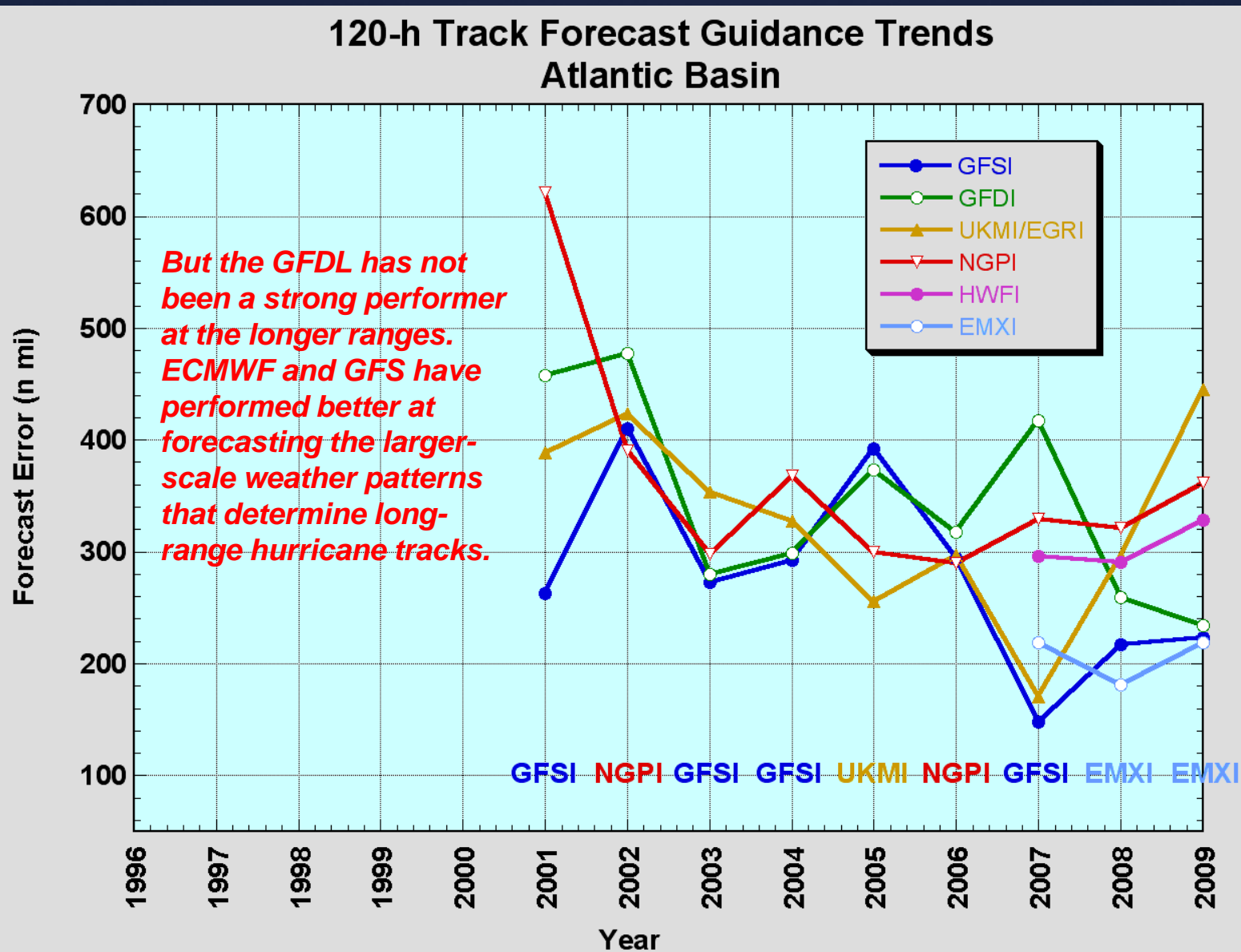


And the winner is...

48-h Track Forecast Guidance Trends Atlantic Basin



And the winner is...



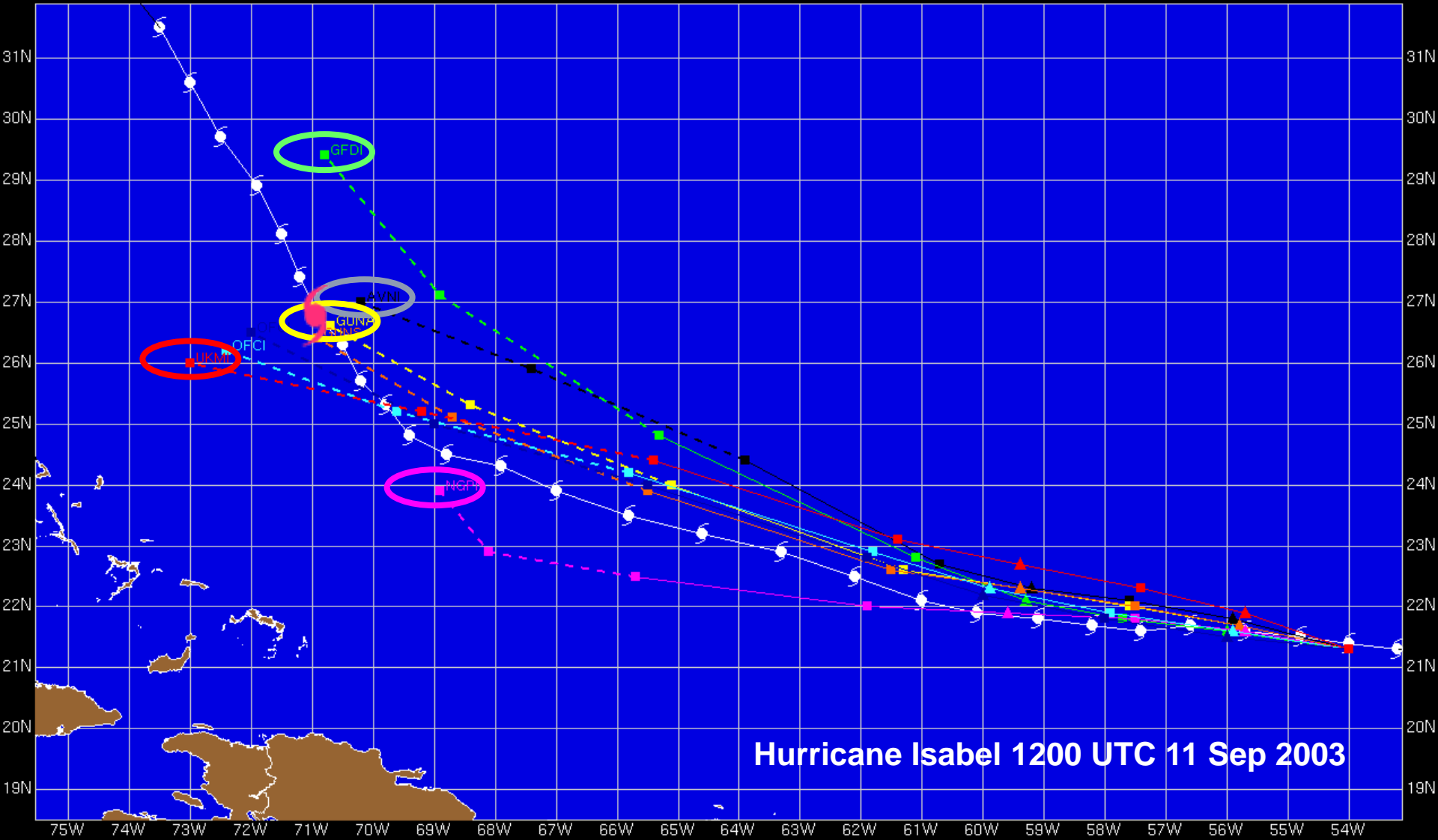
Hierarchy of TC Track Models

* Consensus

* GUNA, TCON, TVCN, TCCN, TVCC, FSSE, AEMI

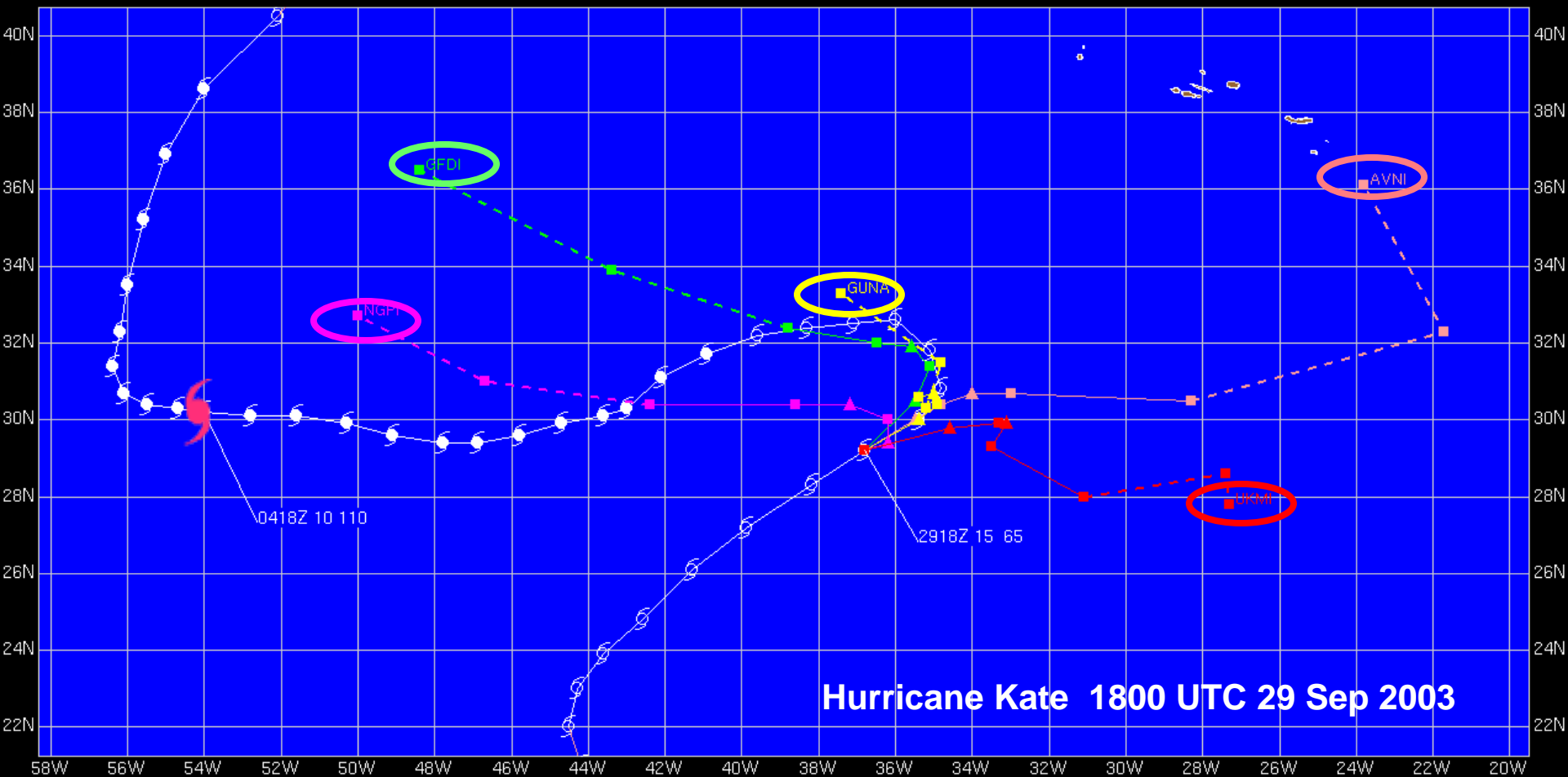
- * Not really models, per se, but merely combinations of other models. Consensus models generally outperform the individual models that make them up. The more independent the individual models are, the better the consensus does.
- * Can be a simple average (e.g., GUNA is a simple average of GFDL, UKMET, NOGAPS, and GFS).
- * Can be more complicated, where past performance is used to try to come up with an optimal combination and/or to correct model biases ("corrected consensus").
- * It is also possible to run the same model repeatedly using different initial conditions, but a "single-model consensus" is not as effective as a multi-model consensus.

Consensus Example



Model errors are often random (e.g., small variations on a common theme). In this case, the consensus frequently cancels out these random errors, resulting in a better forecast.

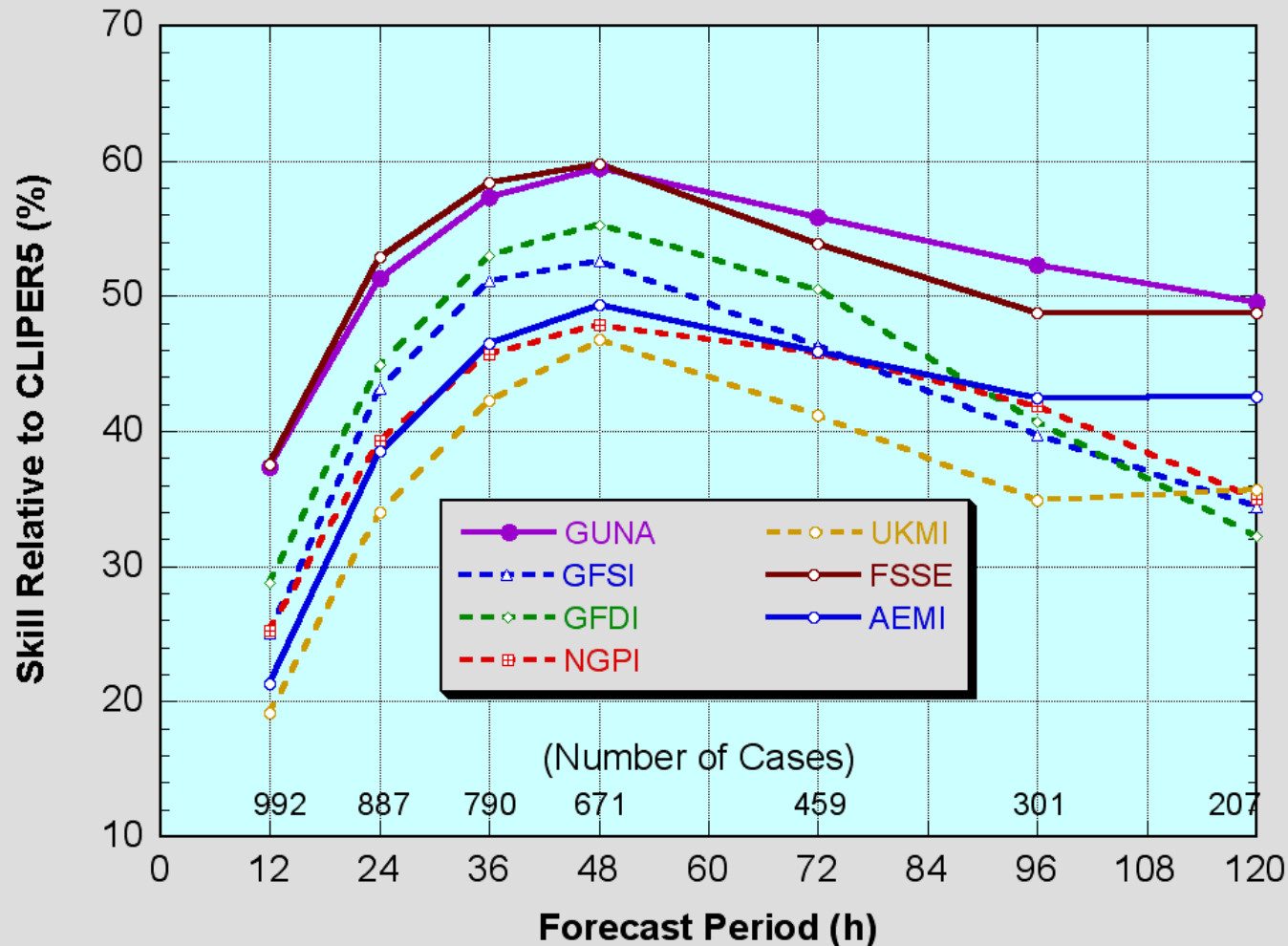
Consensus Example



Of course, the consensus approach doesn't always work, particularly if the model scenarios are completely different. 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 VERY DIFFICULT.

Performance of Consensus

**Performance of Consensus Models
Atlantic Basin 2005-9**

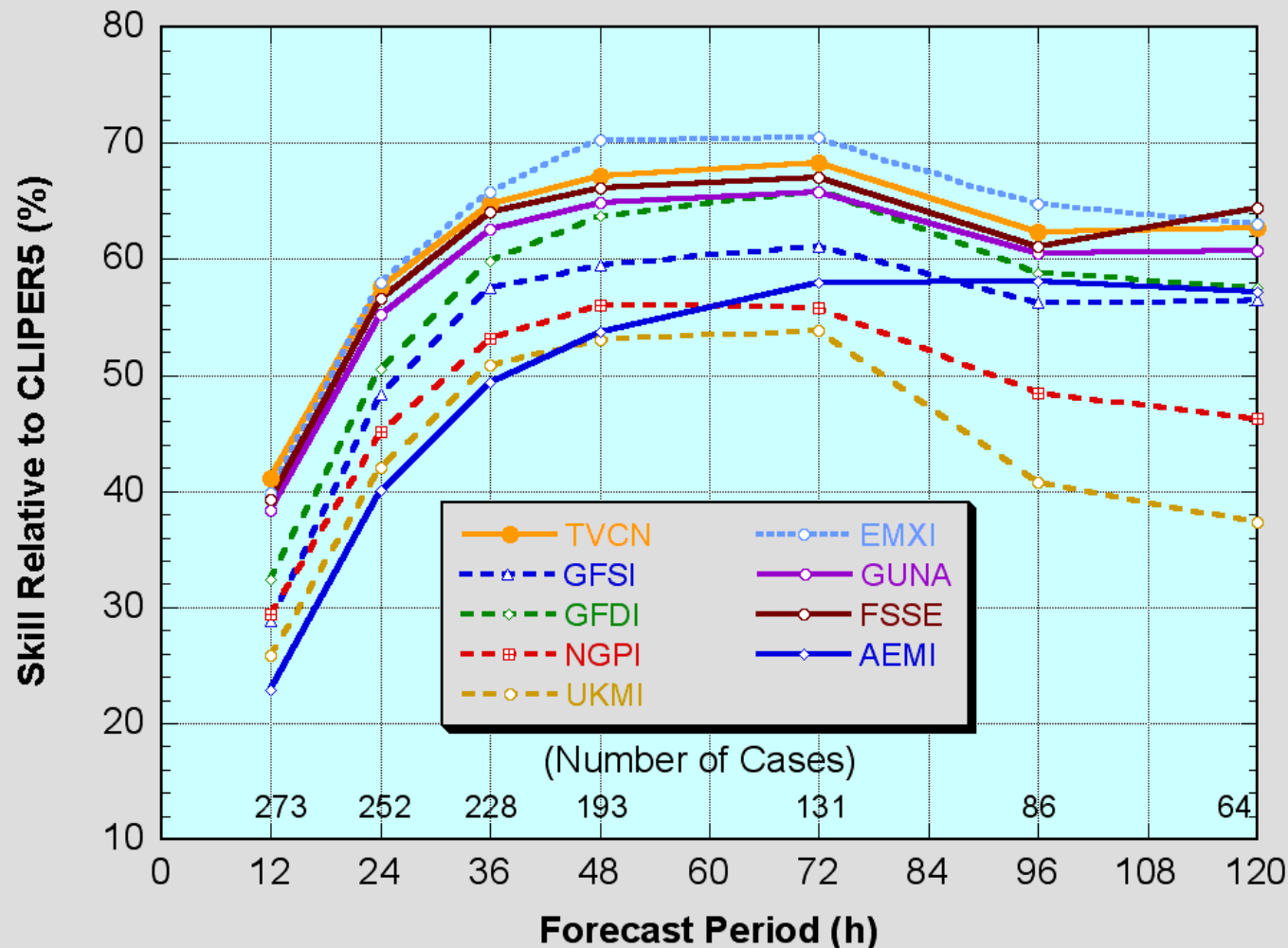


The two multi-model consensus models have much greater skill than the single-model consensus AEMI. The multi-model consensus models are more skillful than any of the member models.

Not much difference in performance between simple and corrected consensus models.

Performance of Consensus

**Performance of Consensus Models
Atlantic Basin 2008-9**



Over the past two seasons, ECMWF has outperformed the consensus models in the Atlantic (although not in the eastern North Pacific). Unclear whether this result will hold up in a larger sample.

Interpreting Model Guidance (or Why Good Models Go Bad)

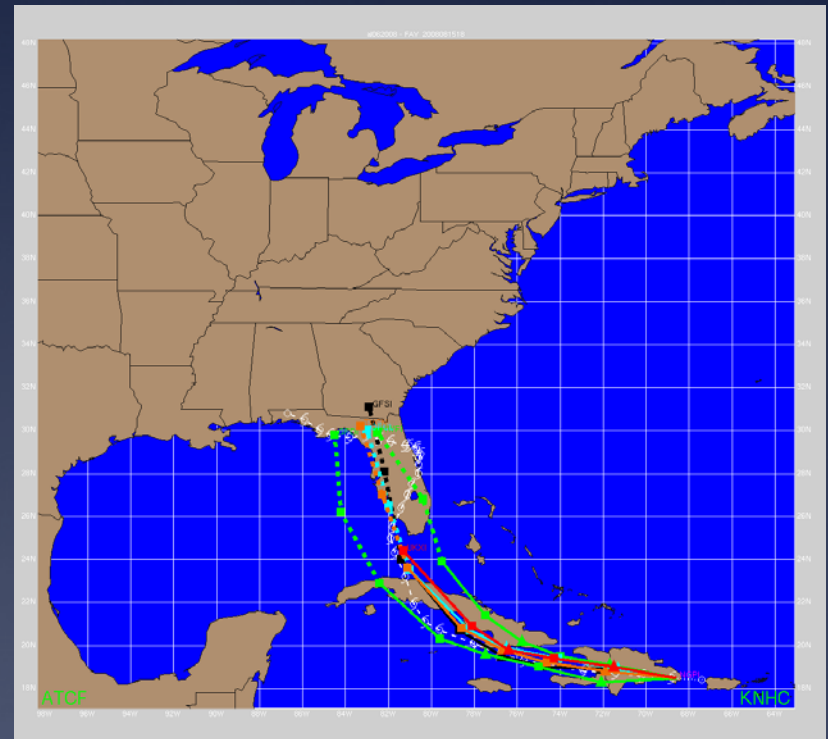
- * **All models contain assumptions about how the atmosphere works.**
 - * Some are reasonable, some are reasonable in certain circumstances, and some are completely unreasonable (XTRP).
 - * All represent some kind of compromise (e.g., lack of computing resources, lack of understanding).
- * **The atmosphere is a “chaotic” system.**
 - * Initial state of atmosphere (the “analysis”) is never perfect, and when you try to model a chaotic system small errors grow with time.
 - * Not enough data to provide a perfect initial condition.
 - * Each model starts off with a different initial condition.

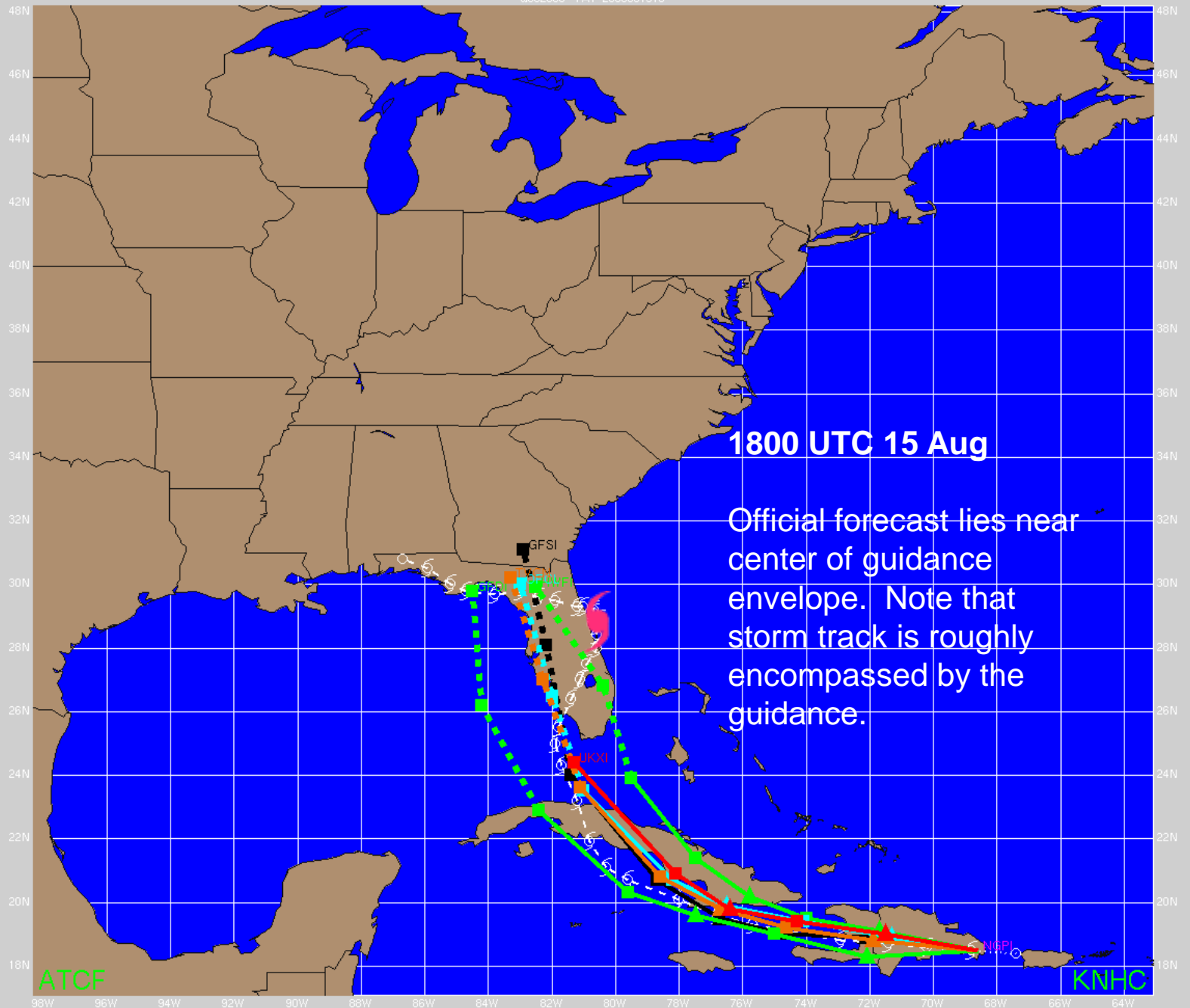
Track Forecasting at the NHC: Continuity

- * 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).

Sequence of Model Guidance Plots for Tropical Storm Fay (2008)

- * OFCL —————
- * UKMET —————
- * GFS —————
- * NOGAPS —————
- * GFDL/HWRF —————
- * GFDN —————
- * ECMWF —————
- * CONSENSUS —————
- * BEST TRACK - - - - -



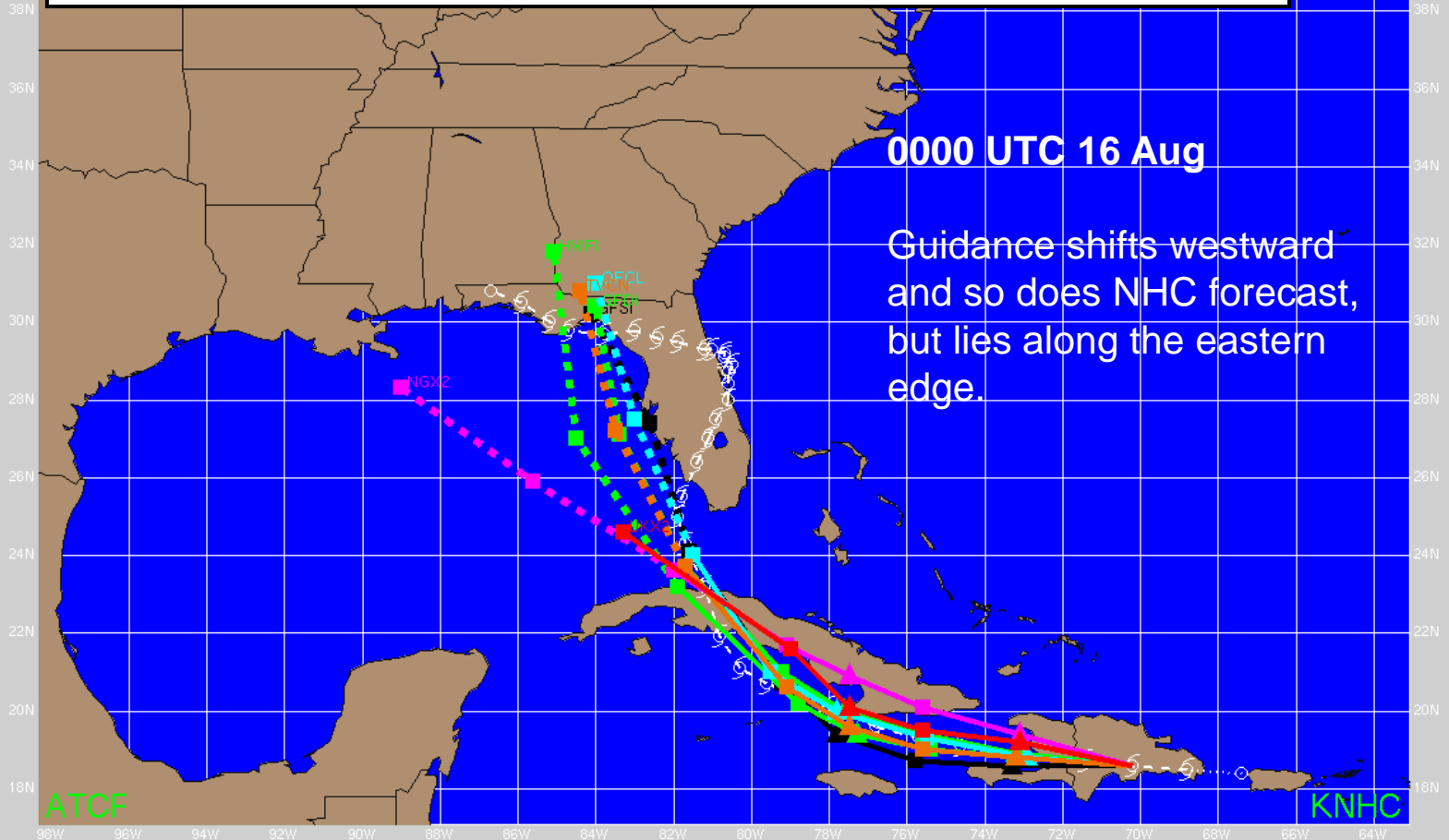


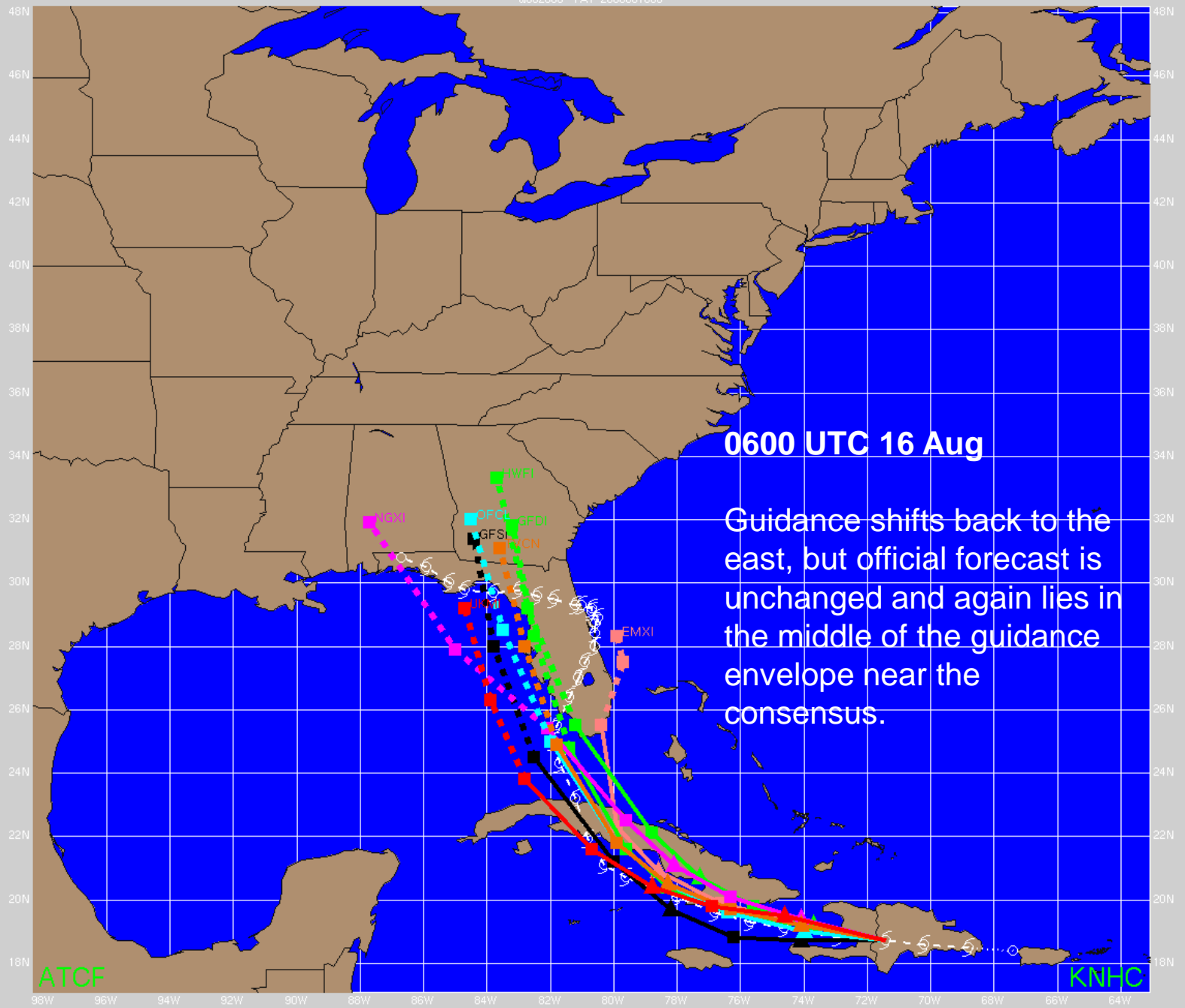
Excerpt from Tropical Cyclone Discussion

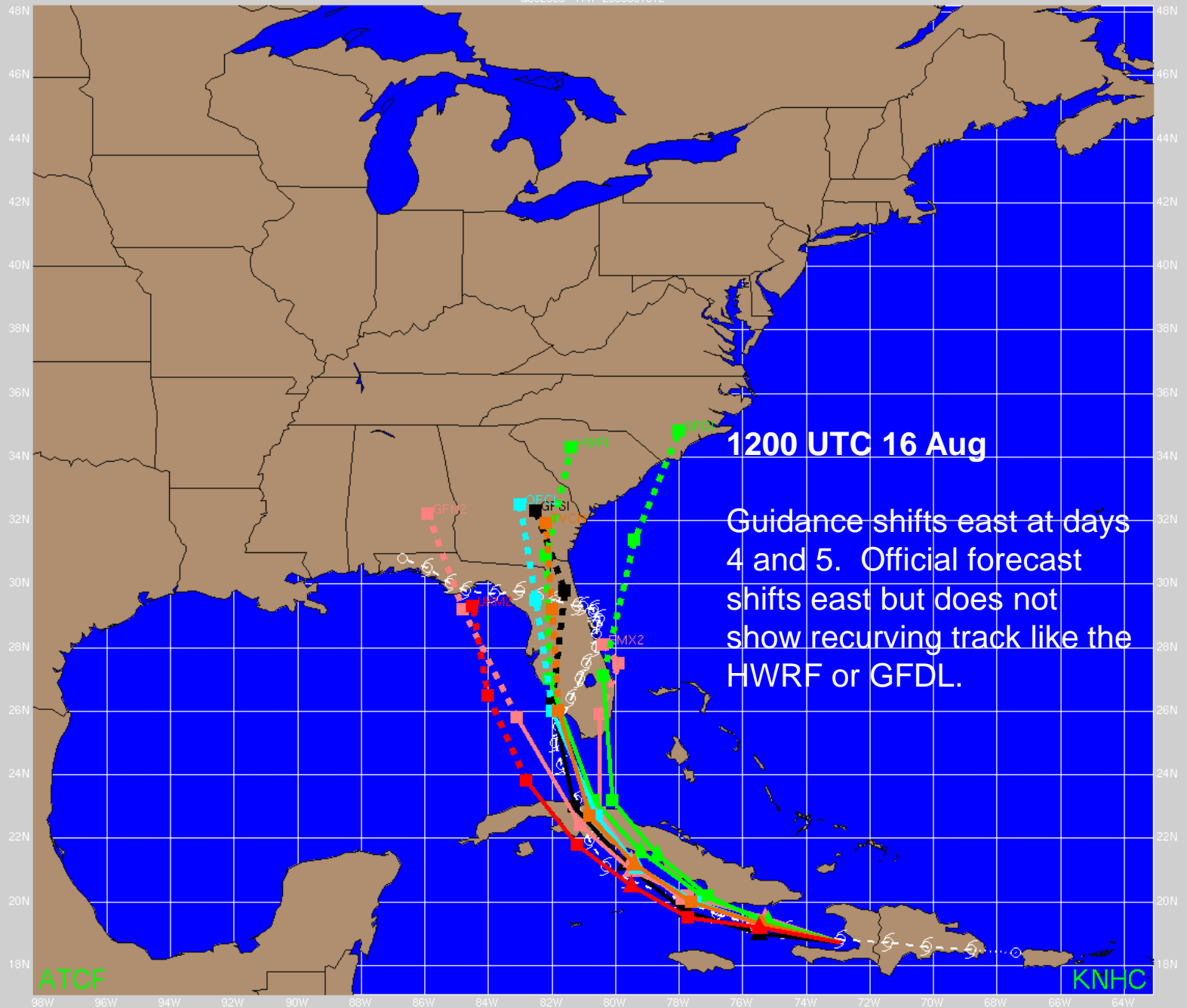
NORTH-NORTHWESTERLY TRACK ACROSS CENTRAL CUBA AND THE EXTREME EASTERN GULF OF MEXICO. ONE SHOULD MENTION HERE THAT IN GENERAL...MOST OF THE GUIDANCE HAS SHIFTED WESTWARD AND THE OFFICIAL FORECAST IS ON THE EASTERN EDGE OF THE ENVELOPE. BEFORE I AM COMMITTED TO SHIFT THE TRACK FARTHER WEST...I WOULD RATHER WAIT TO SEE IF GUIDANCE BECOMES MORE STABLE FROM ONE RUN TO THE NEXT.

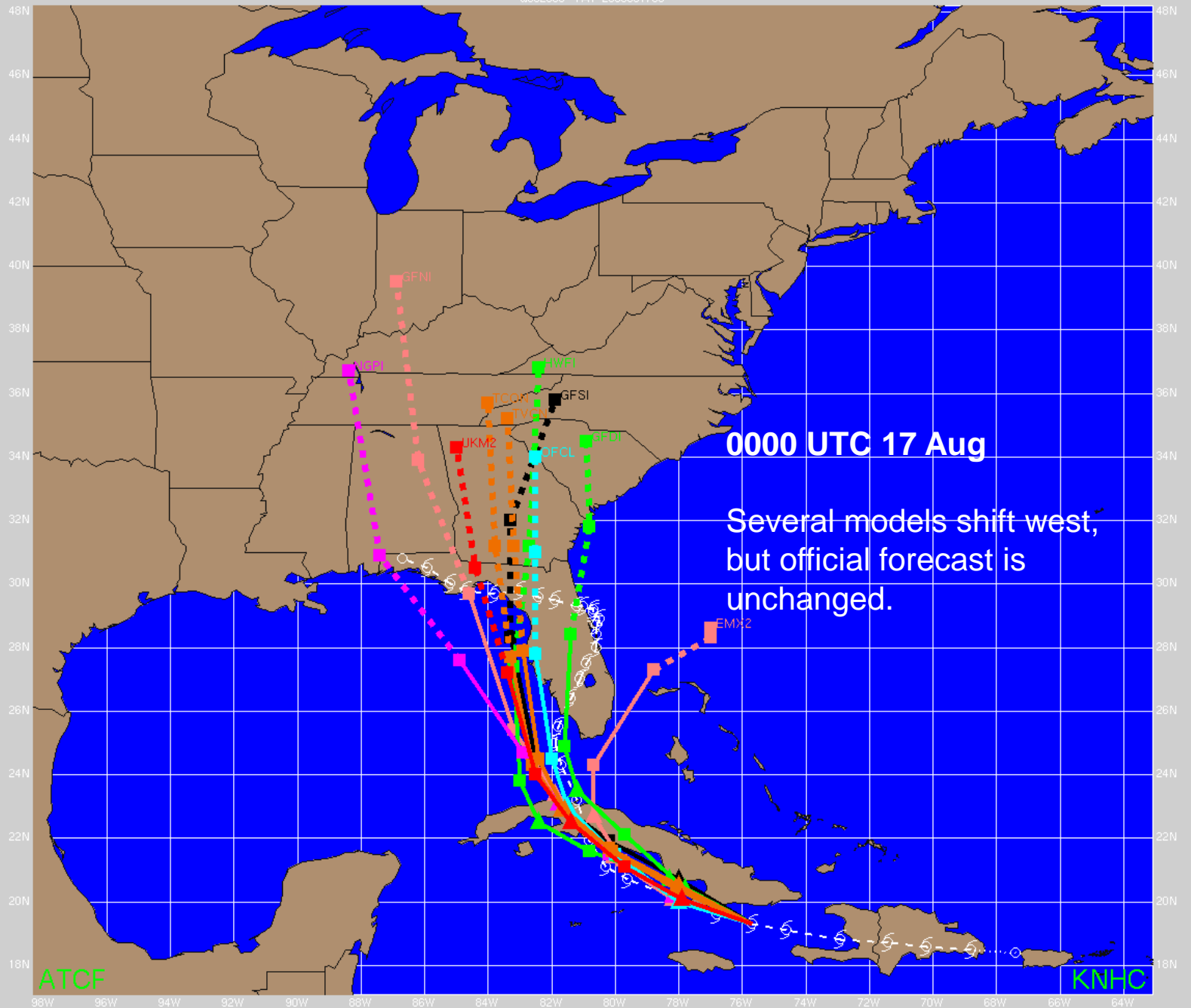
0000 UTC 16 Aug

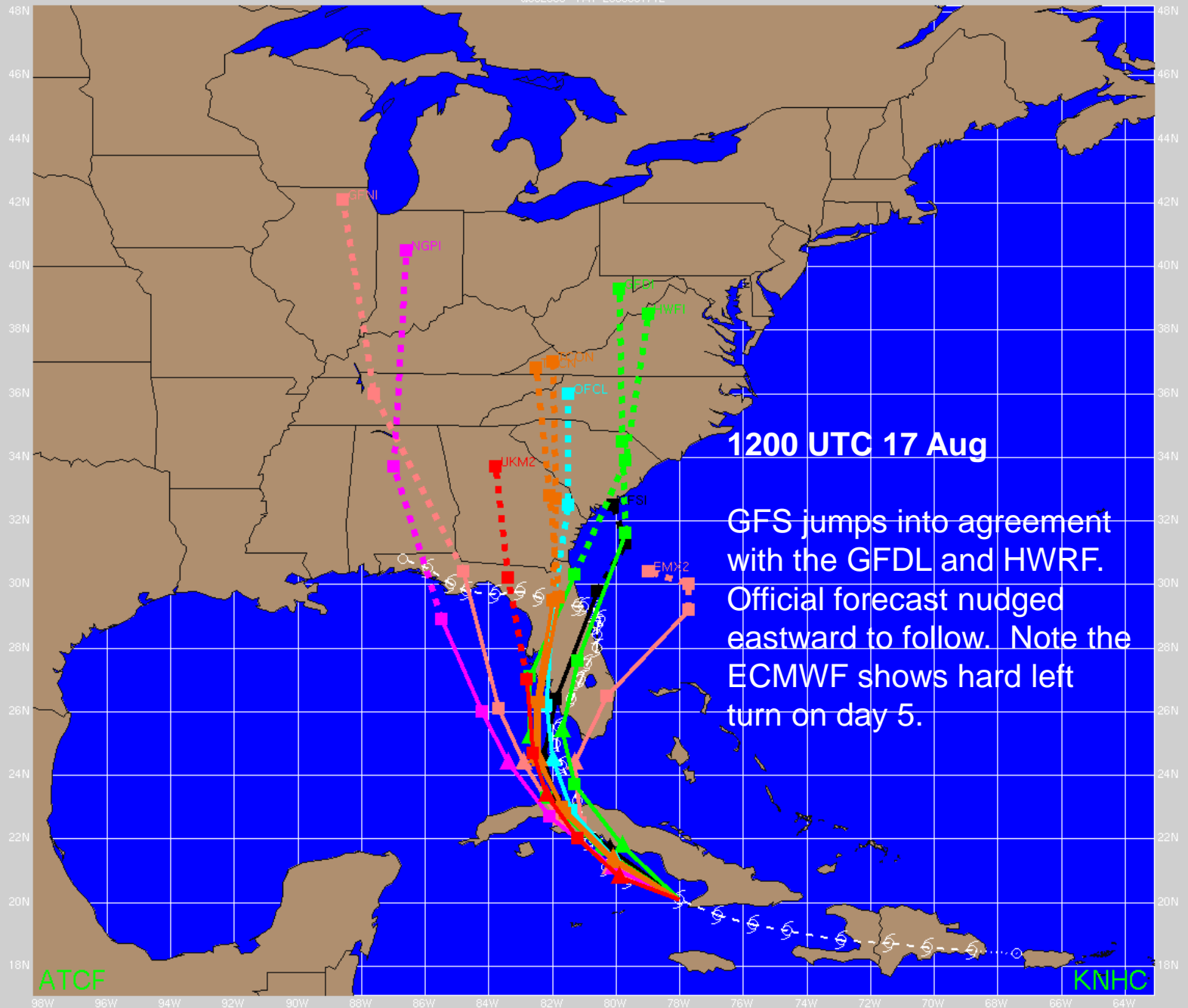
Guidance shifts westward and so does NHC forecast, but lies along the eastern edge.



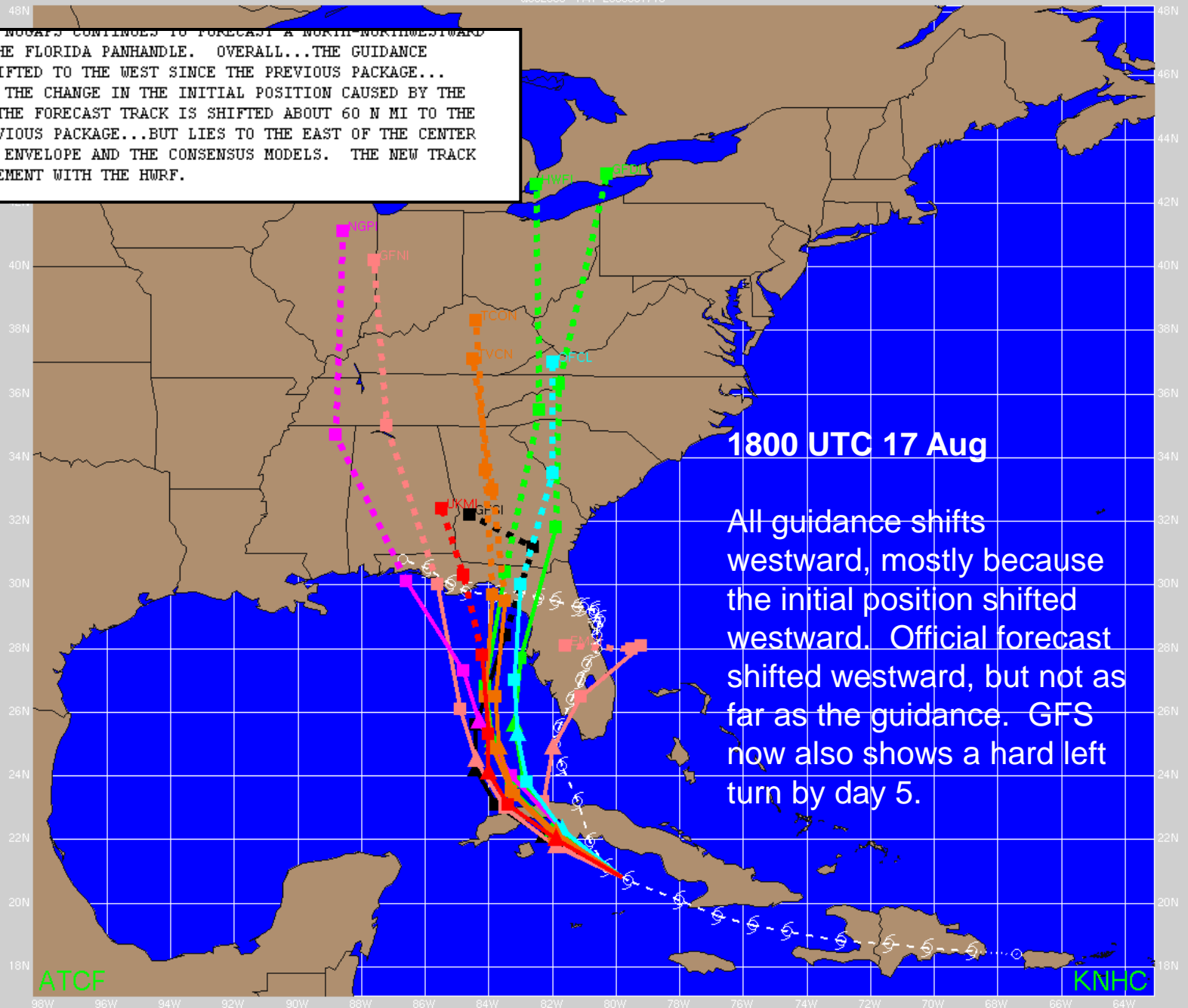


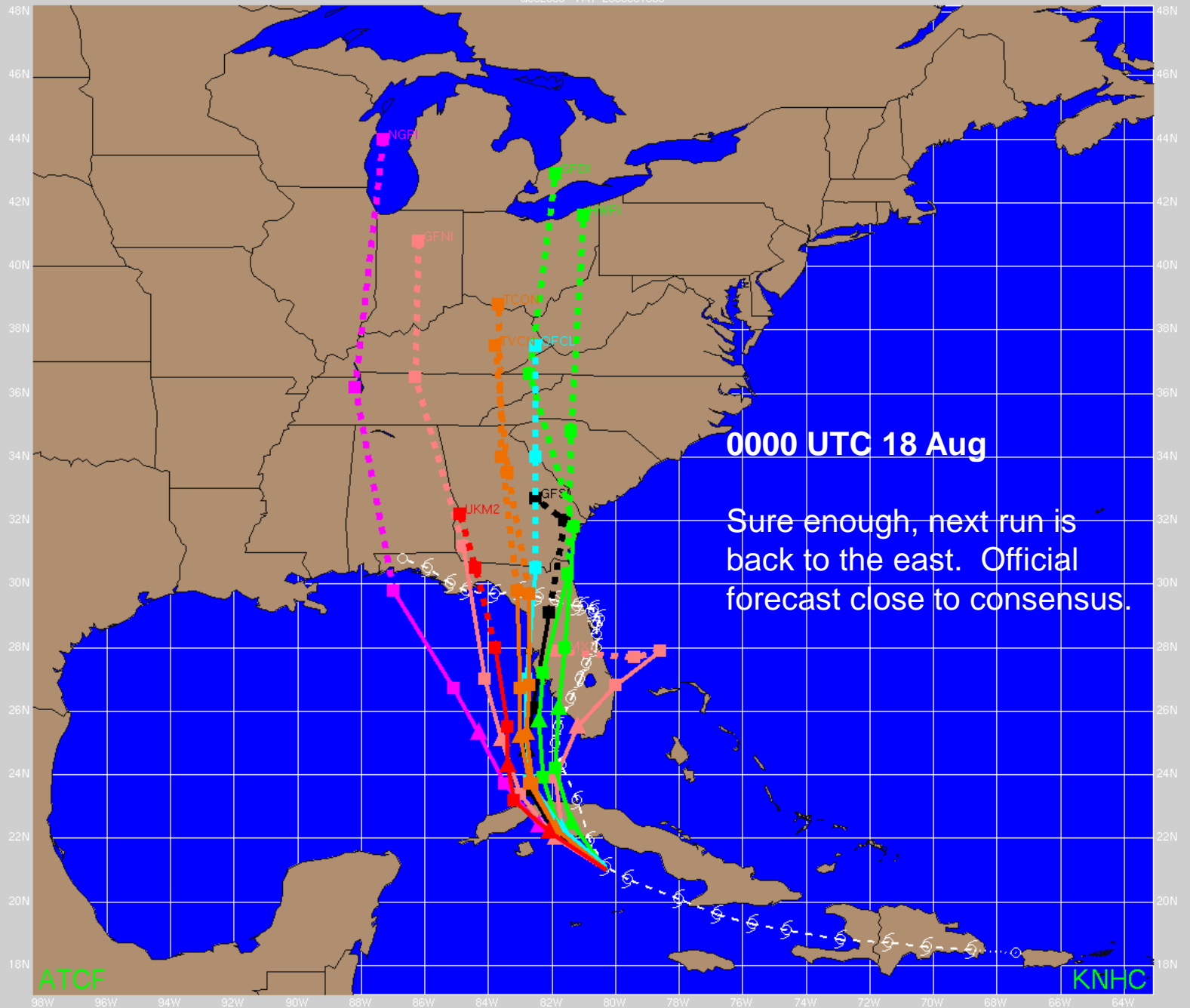


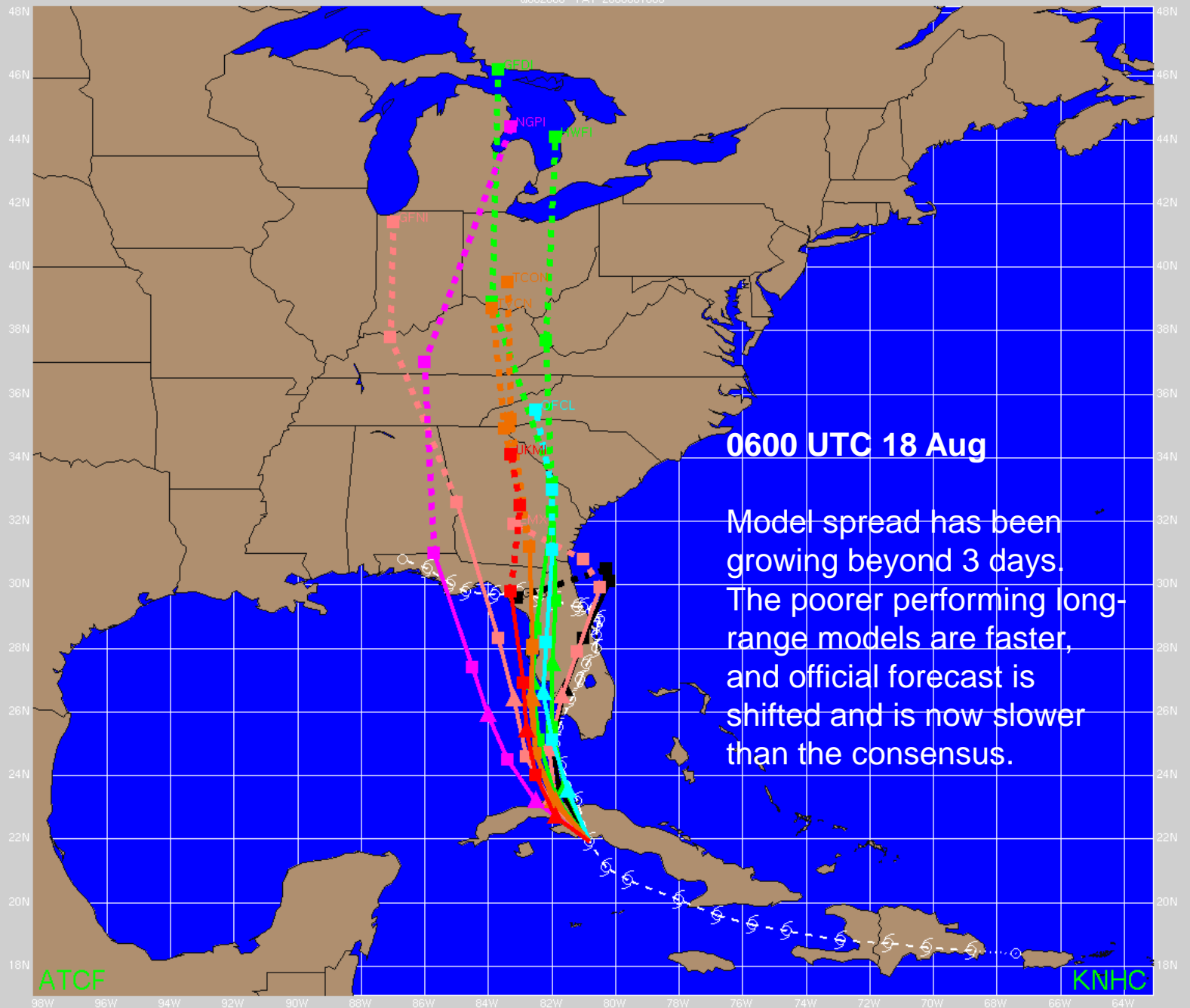


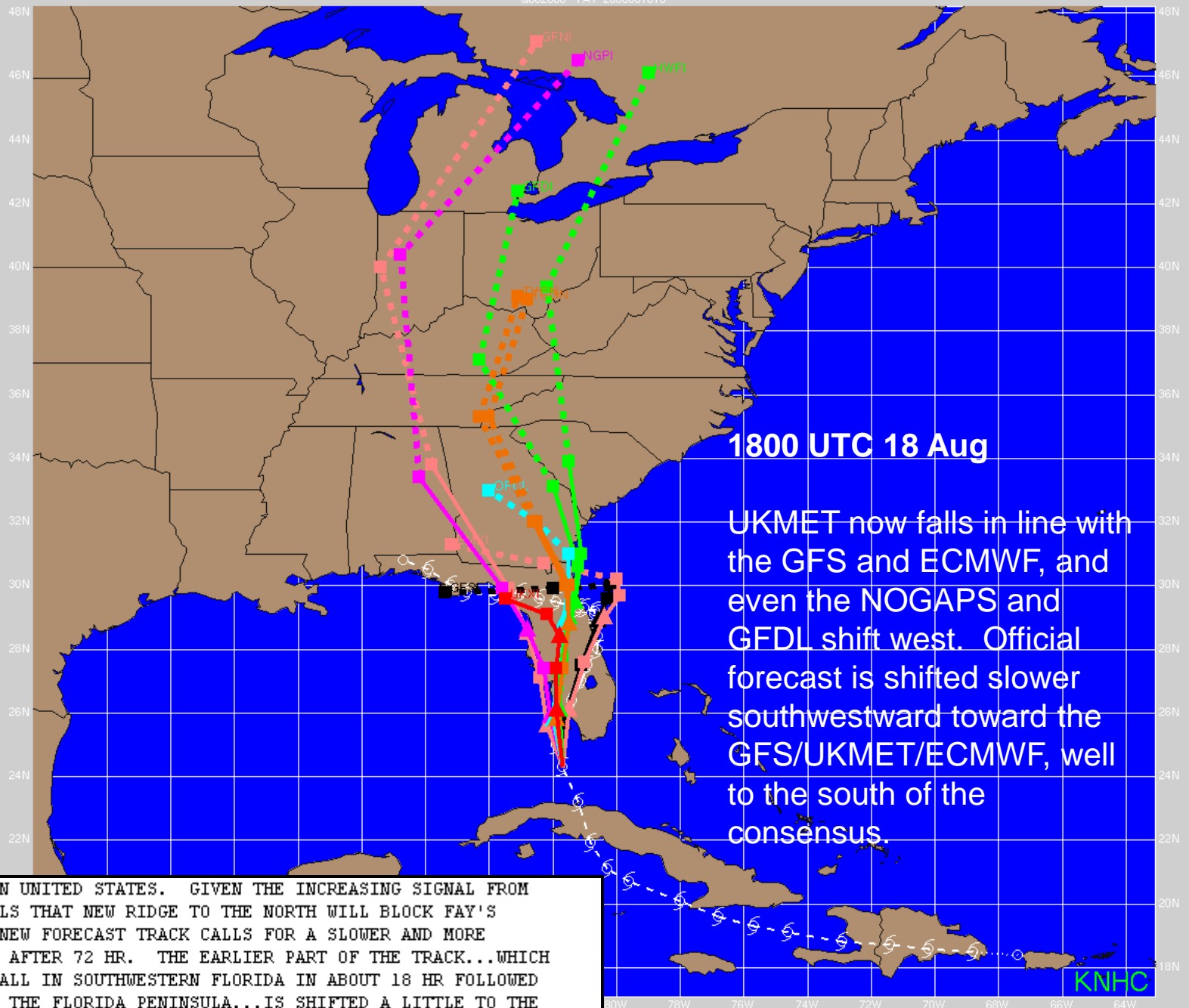


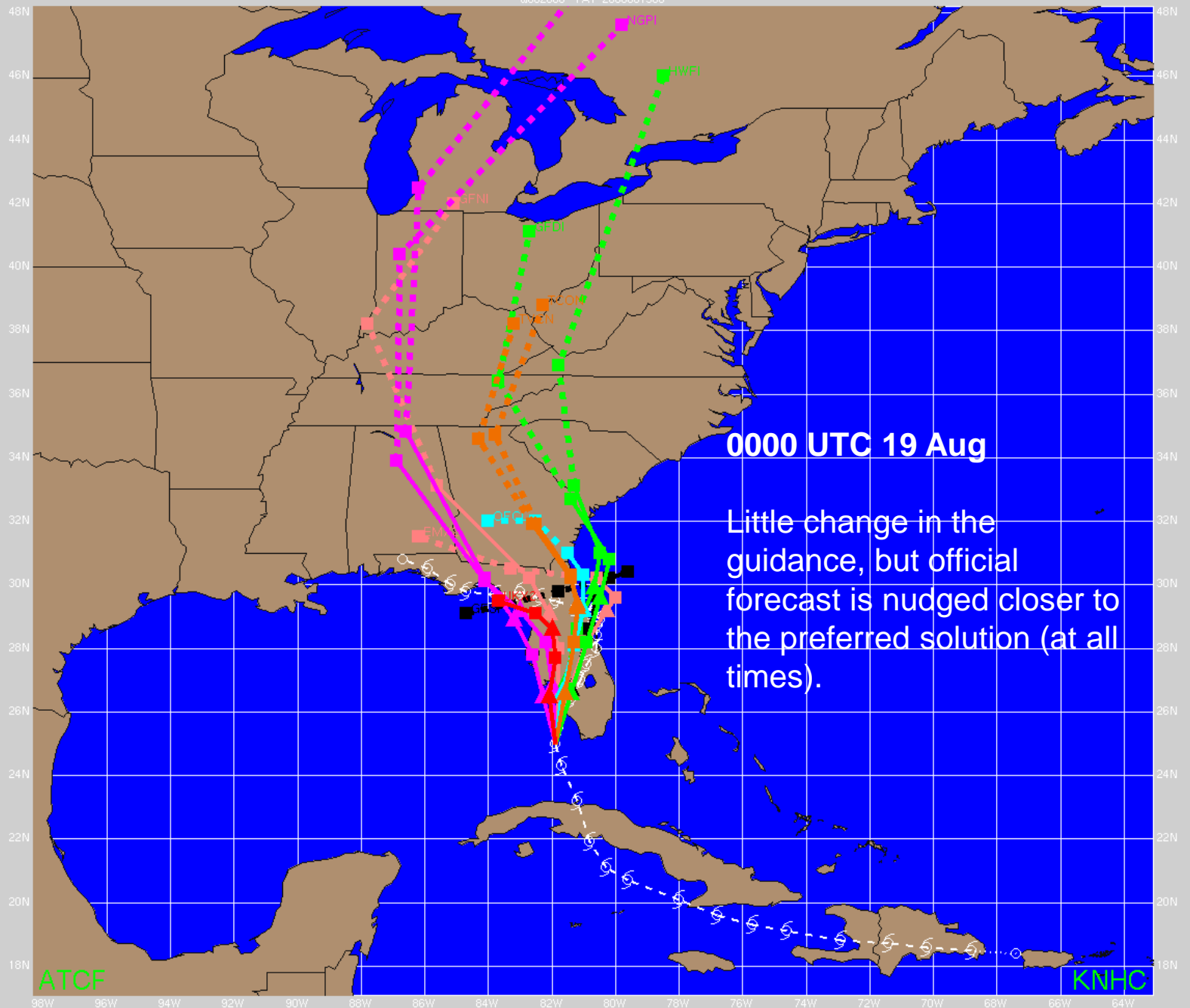
PENINSULA. THE NUGAPS CONTINUES TO FORECAST A NORTH-NORTHWESTWARD MOTION TOWARD THE FLORIDA PANHANDLE. OVERALL...THE GUIDANCE ENVELOPE HAS SHIFTED TO THE WEST SINCE THE PREVIOUS PACKAGE... POSSIBLY DUE TO THE CHANGE IN THE INITIAL POSITION CAUSED BY THE MOTION SURGE. THE FORECAST TRACK IS SHIFTED ABOUT 60 N MI TO THE WEST OF THE PREVIOUS PACKAGE...BUT LIES TO THE EAST OF THE CENTER OF THE GUIDANCE ENVELOPE AND THE CONSENSUS MODELS. THE NEW TRACK IS IN BEST AGREEMENT WITH THE HWRF.

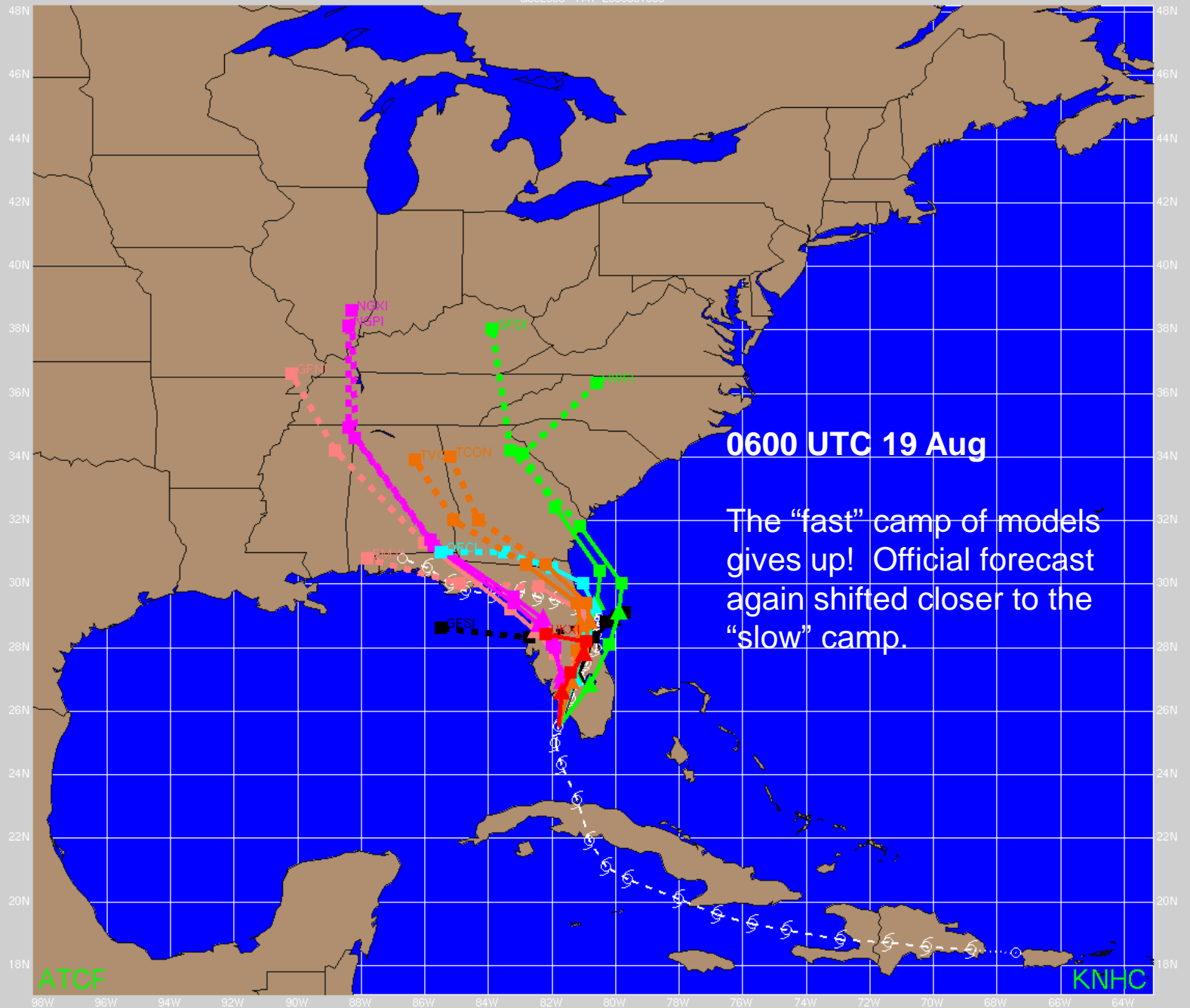


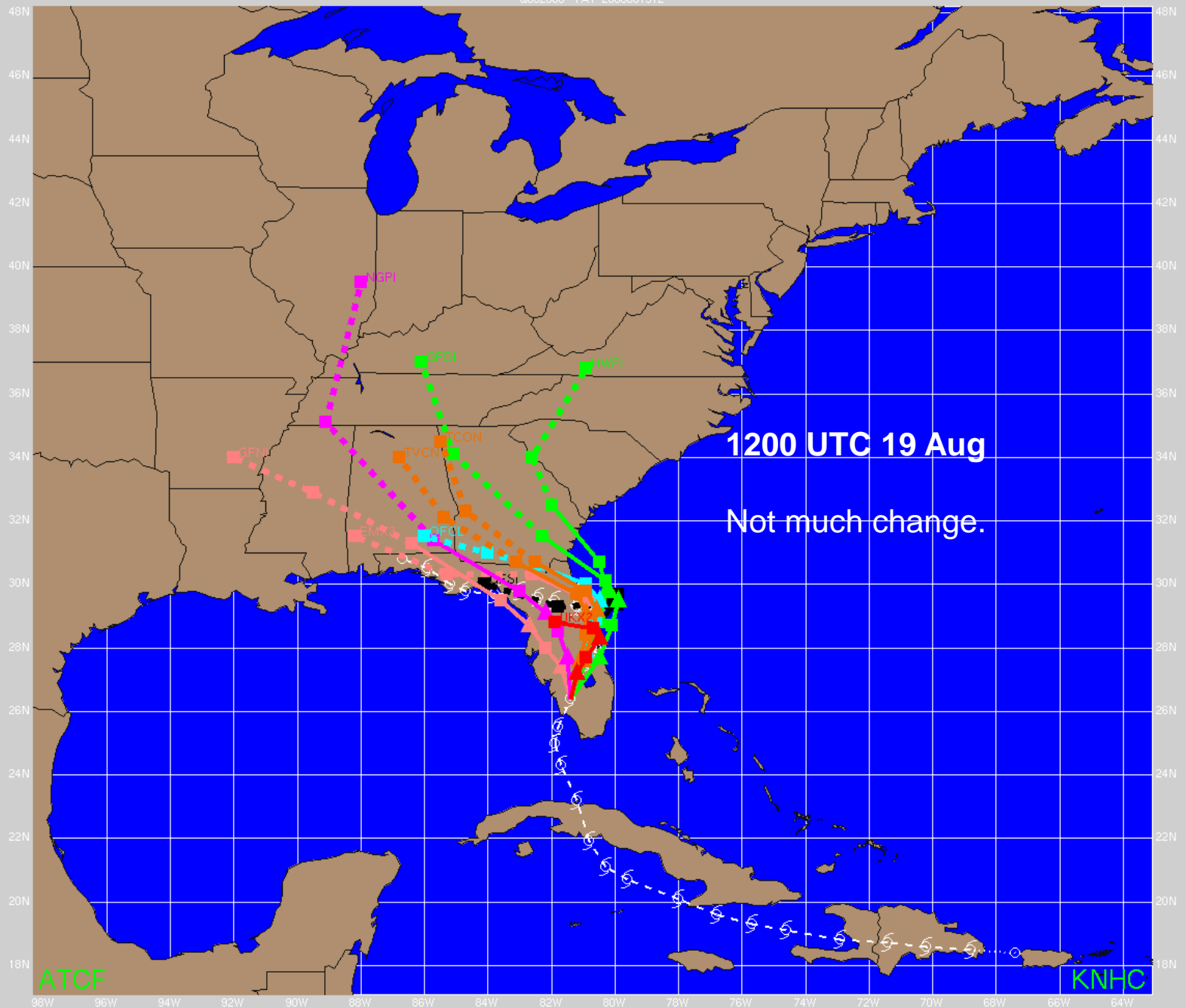


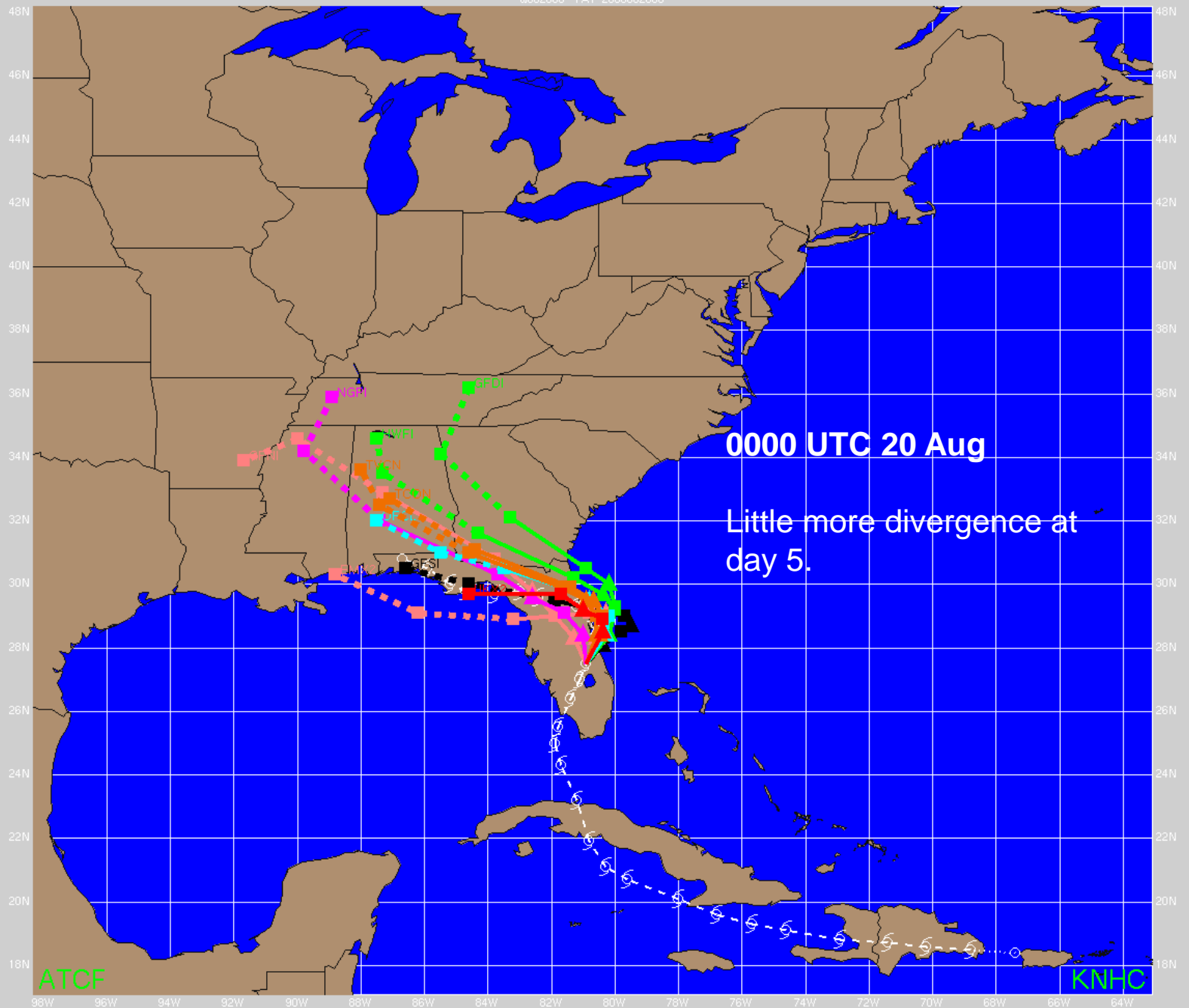


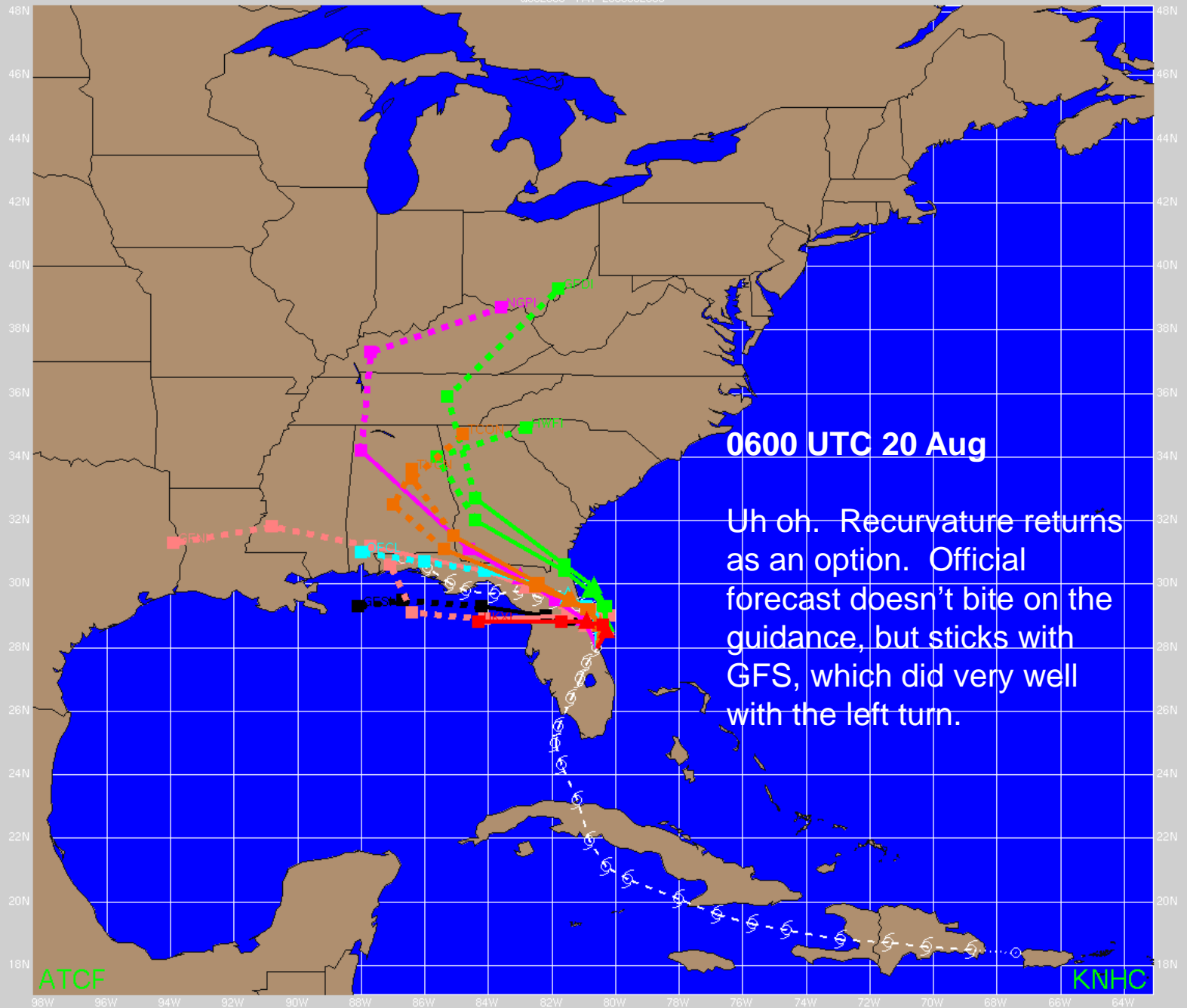






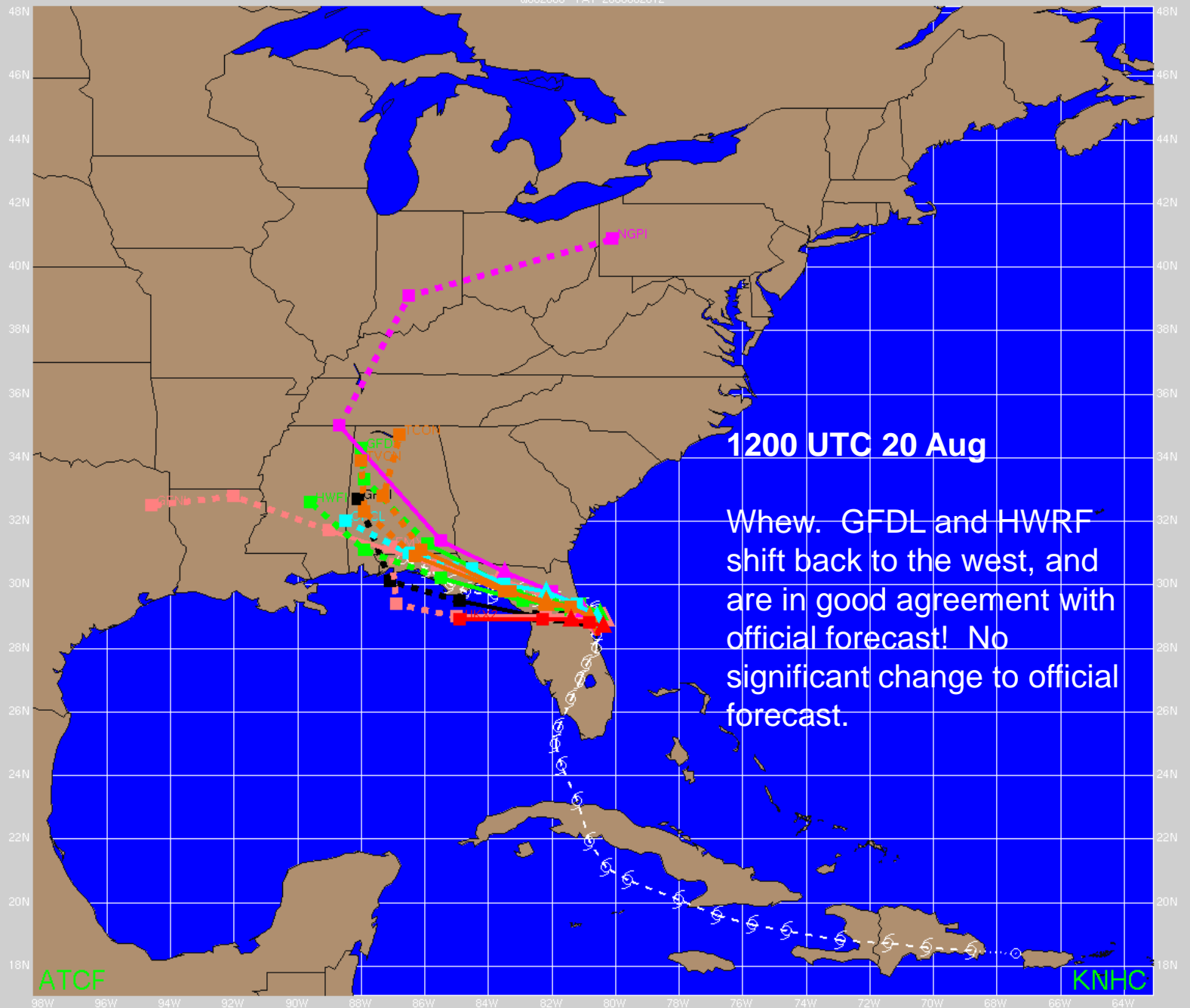


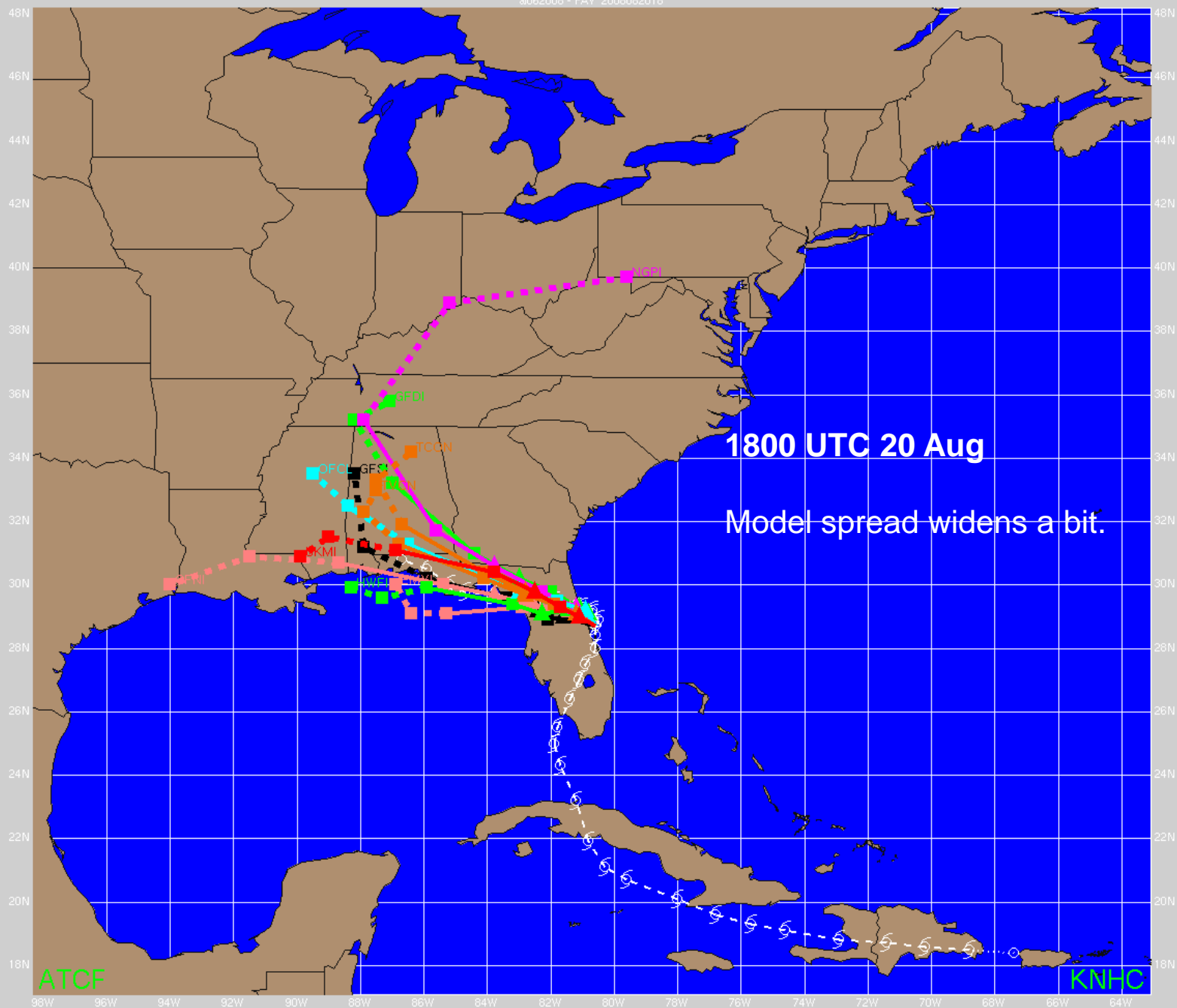


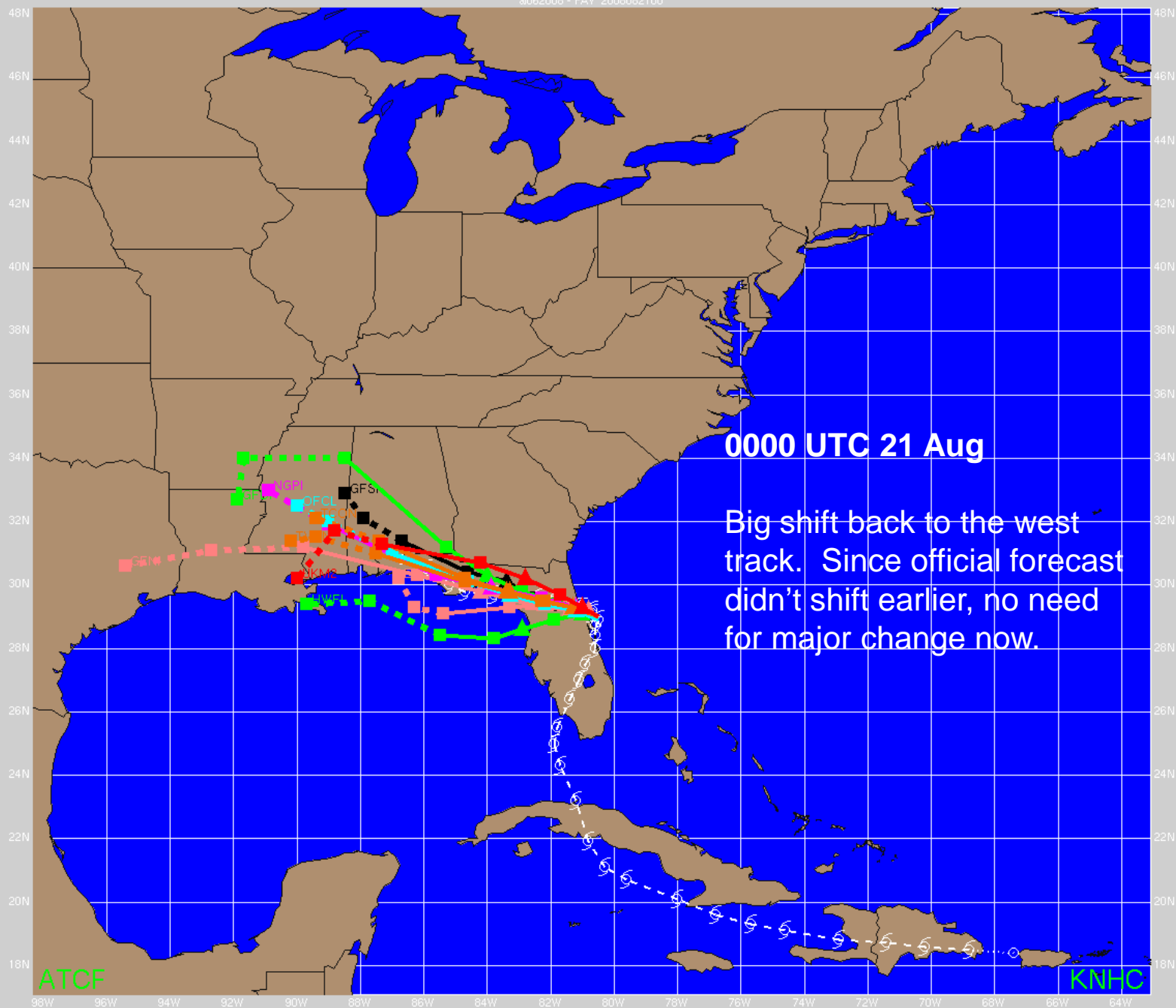


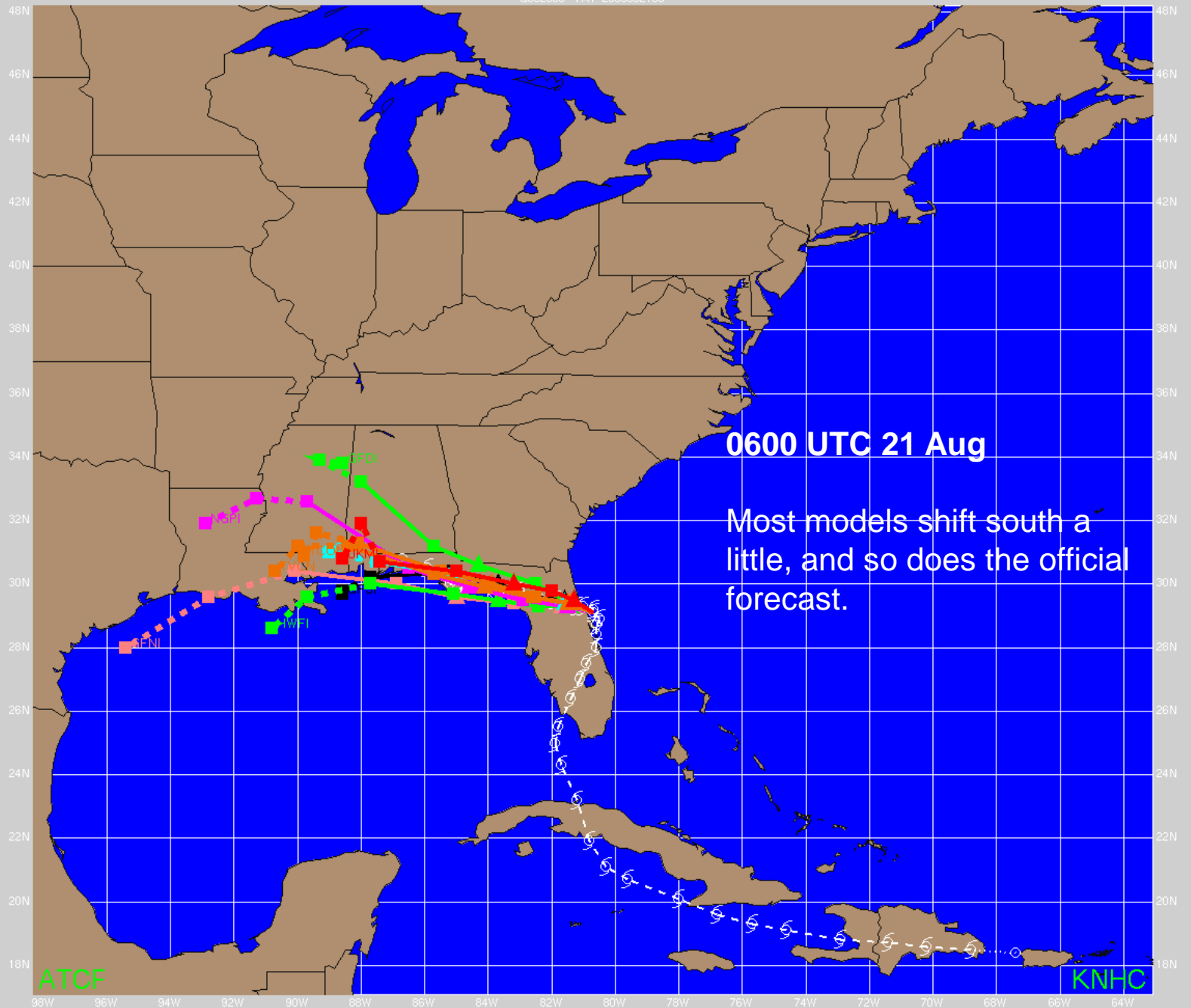
0600 UTC 20 Aug

Uh oh. Recurvature returns as an option. Official forecast doesn't bite on the guidance, but sticks with GFS, which did very well with the left turn.





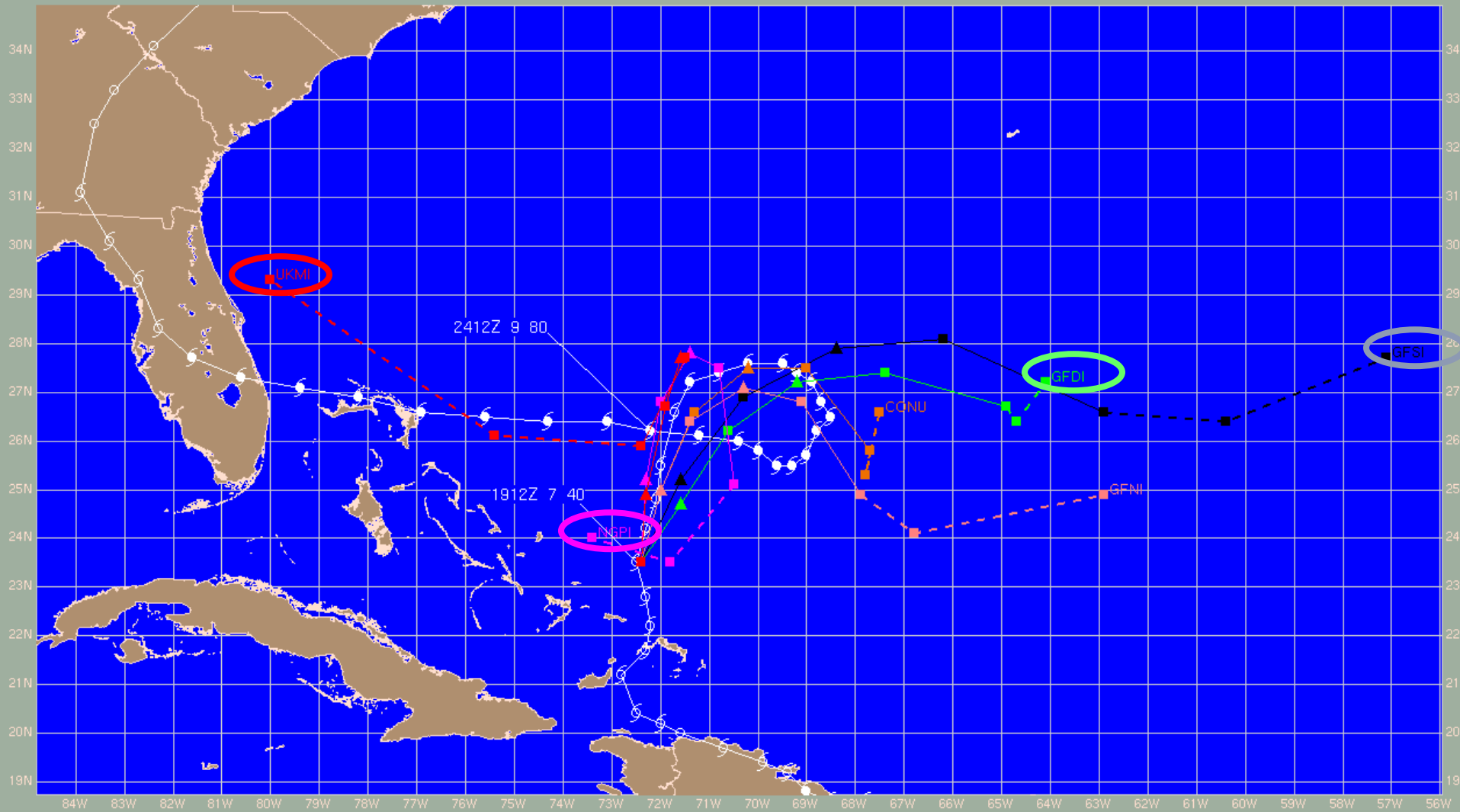




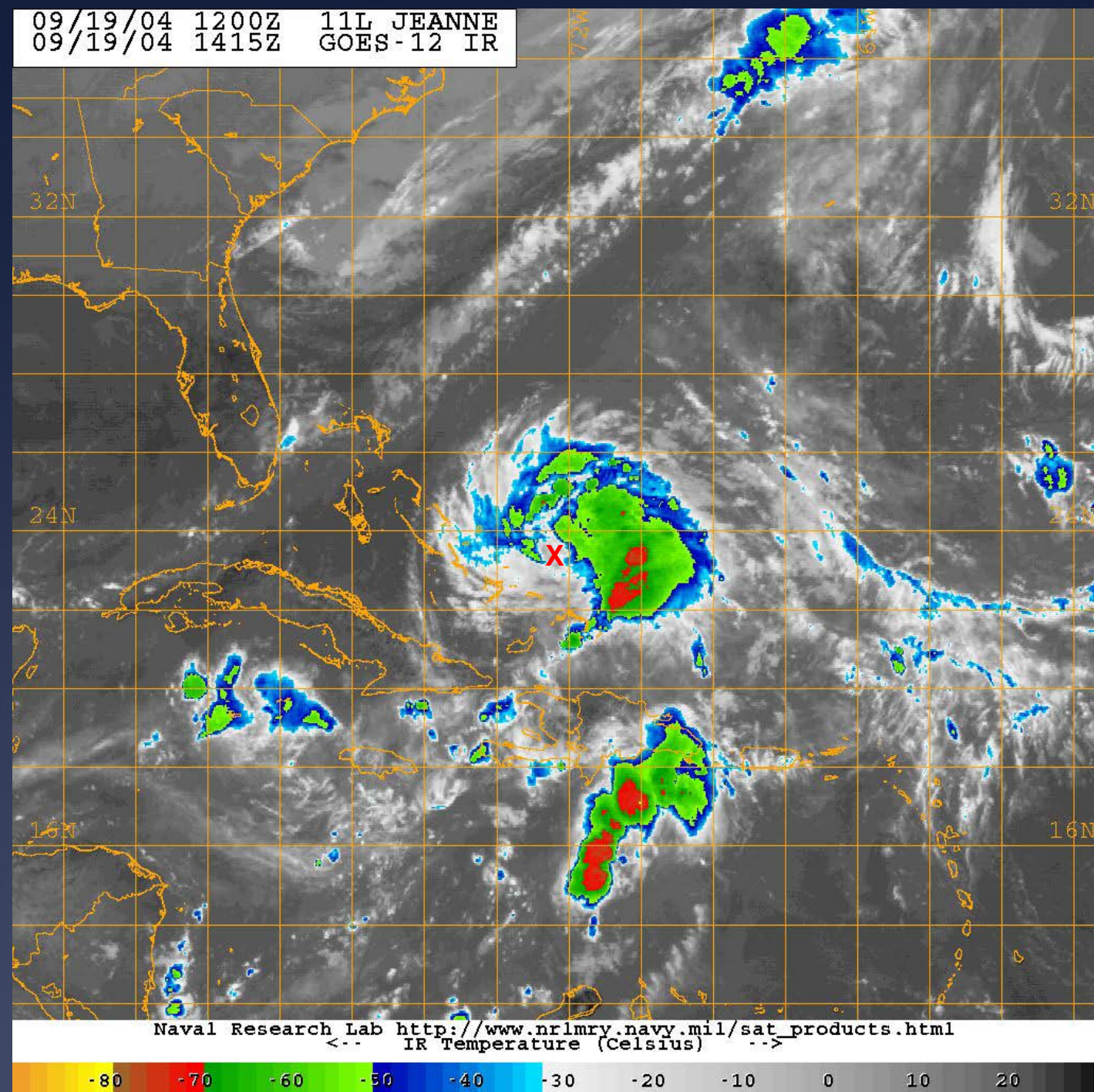
Track Forecasting at the NHC: Using Models

- * **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.

Resolving Differences Between Guidance Models



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

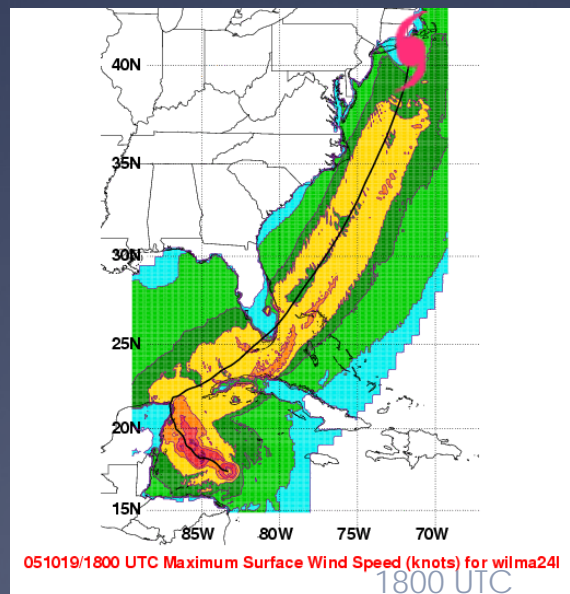
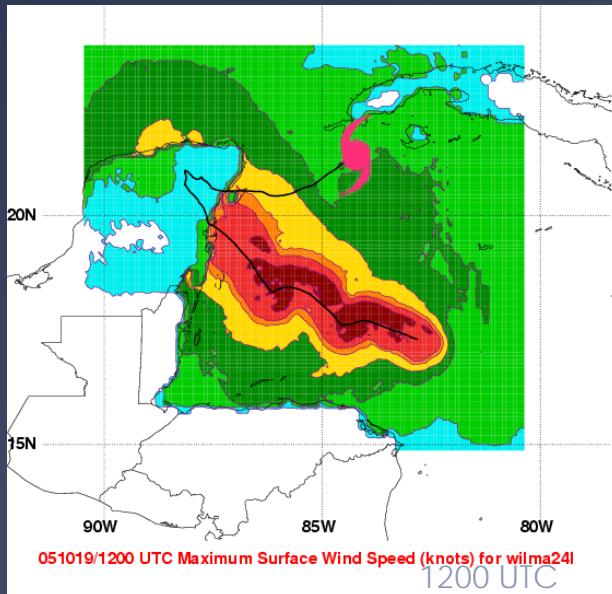
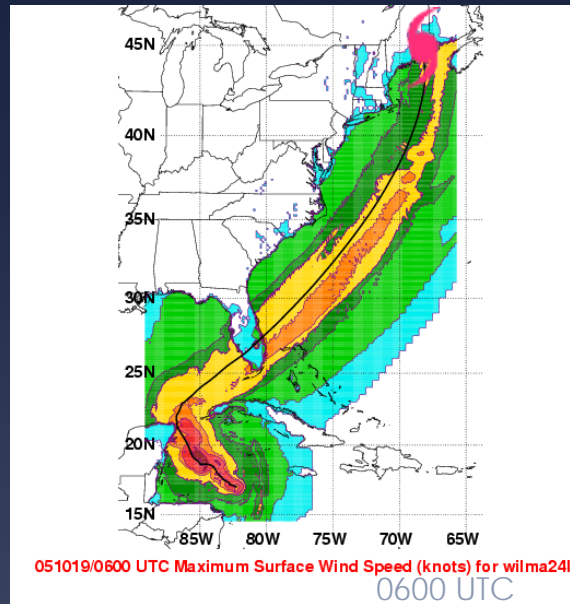
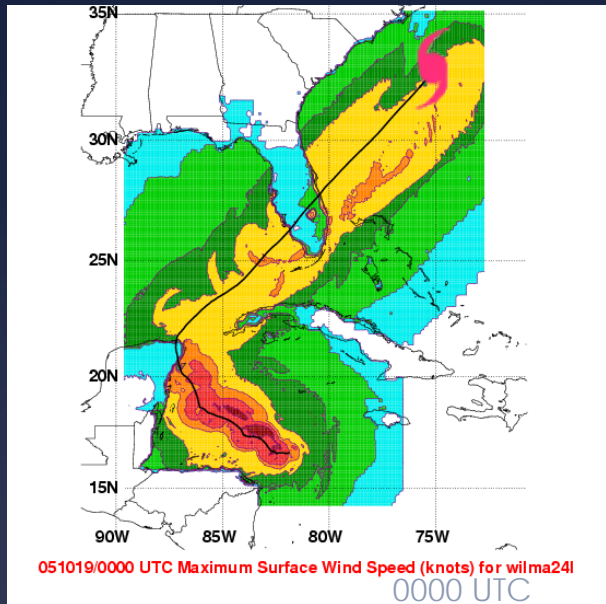


Poor organization (esp. lack of deep convection in the core) would argue against Jeanne being carried eastward by upper-level westerlies.

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

Track forecast is therefore affected by the intensity forecast.

Model Consistency



Four consecutive runs of the GFDL model for Wilma on 19 October 2005, showing tremendous variability in forward speed, with 5-day forecast points ranging from off the Carolinas (0000 UTC), northern New England (0600 UTC), northwestern Caribbean (1200 UTC), and southern New England (1800 UTC).

Wilma Discussion

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

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 even more skillful than the best dynamical model, and in general beats the NHC official track forecast.
- * NHC forecasters have philosophical constraints on the official forecast that results in a certain amount of response lag (and may contribute to forecast biases and slightly poorer performance than 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.