Dynamical Hurricane Guidance at NHC: Current Use and Future Challenges

Michael J. Brennan
Senior Hurricane Specialist
National Hurricane Center

WRF for Hurricanes Tutorial
Boulder, Colorado
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Outline

- Overview of NHC TC forecast parameters
- Current uses of dynamical guidance in NHC forecasts
  - TC Track
  - TC Intensity
  - TC Genesis
- Future challenges

What Does NHC Forecast?

- Track → center positions at 0, 12, 24, 36, 48, 72, 96, and 120 h
- Intensity → maximum sustained wind (and gusts) at 0, 12, 24, 36, 48, 72, 96, and 120 h
- Size/Structure → quadrant wind radii of 34-, 50-, and 64-kt winds at 0, 12, 24, 36, 48 and 72 h, and radii of 64-kt winds at 0, 12, 24, and 36 h
- Likelihood (probability to the nearest 10%) of TC formation within 48 h
- Storm surge (including inundation levels)
- Rainfall (HPC), Tornadoes (SPC)

Track Forecasting at NHC

- Determination and importance of initial motion
- Dynamical models
- Synoptic (subjective) analysis
- Continuity constraints

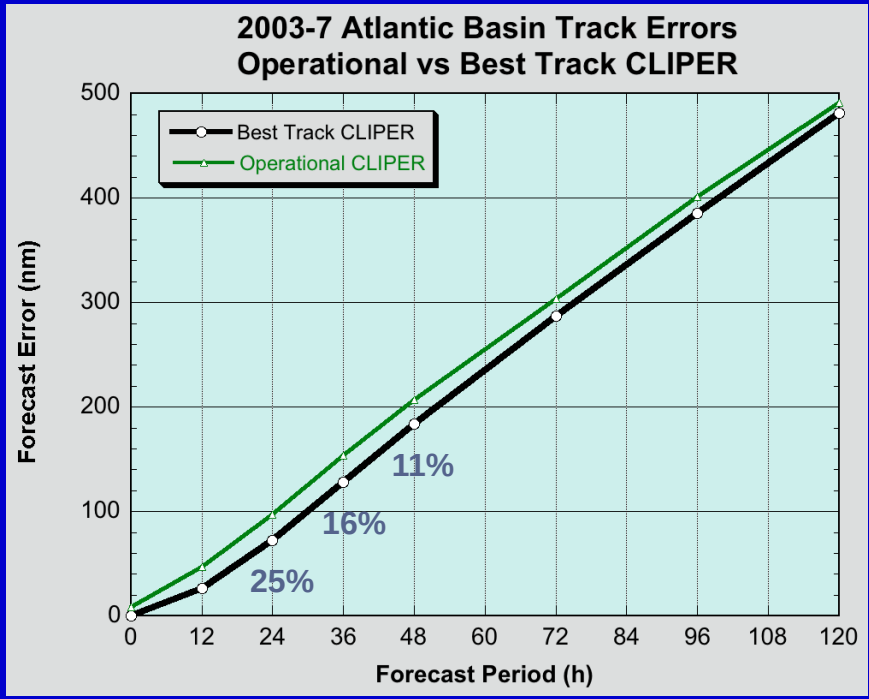
Guidance Models used by NHC for Track Forecasting

- Global Deterministic Models
  - GFS, UKMET, ECMWF, NOGAPS, CMC
- Ensemble Systems
  - GEFS, ECMWF, UKMET*
- Regional Hurricane Models
  - GFDL, GFDN, and HWRF
- Multi-Model Ensemble (Consensus Models)
  - GUNA, TCON, TVCN, TCCN, TVCC, FSSE - not actual models, but 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

Track Forecasting at 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, especially for weaker TCs with ill-defined centers

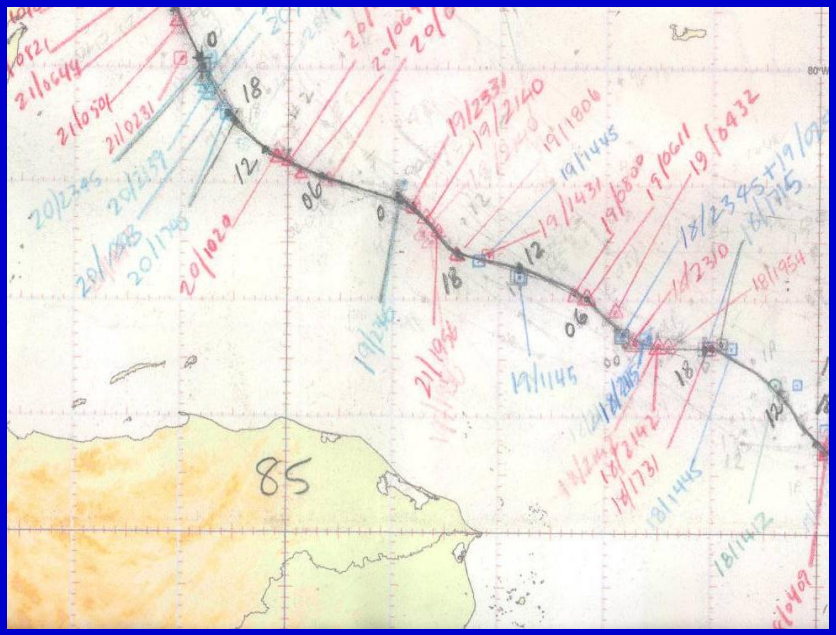


Substantial improvement out through 48 h when best track initial motion is used

Track Forecasting at NHC

Determination of Initial Motion

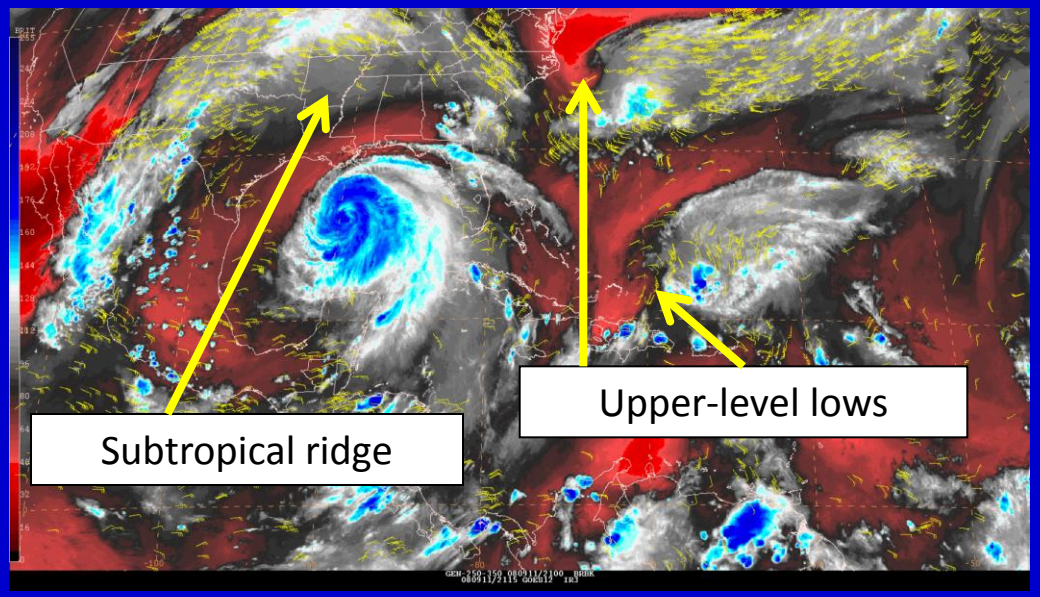
- Initial motion typically computed using average motion over the previous 6, 12, or 18 h
  - Shorter period used when known changes in track are occurring, longer period used when center location uncertain
  - Initial motion estimate should not reflect short-term track wobbles (e.g., trochoidal oscillations)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



Track Forecasting at NHC

Using Dynamical Models

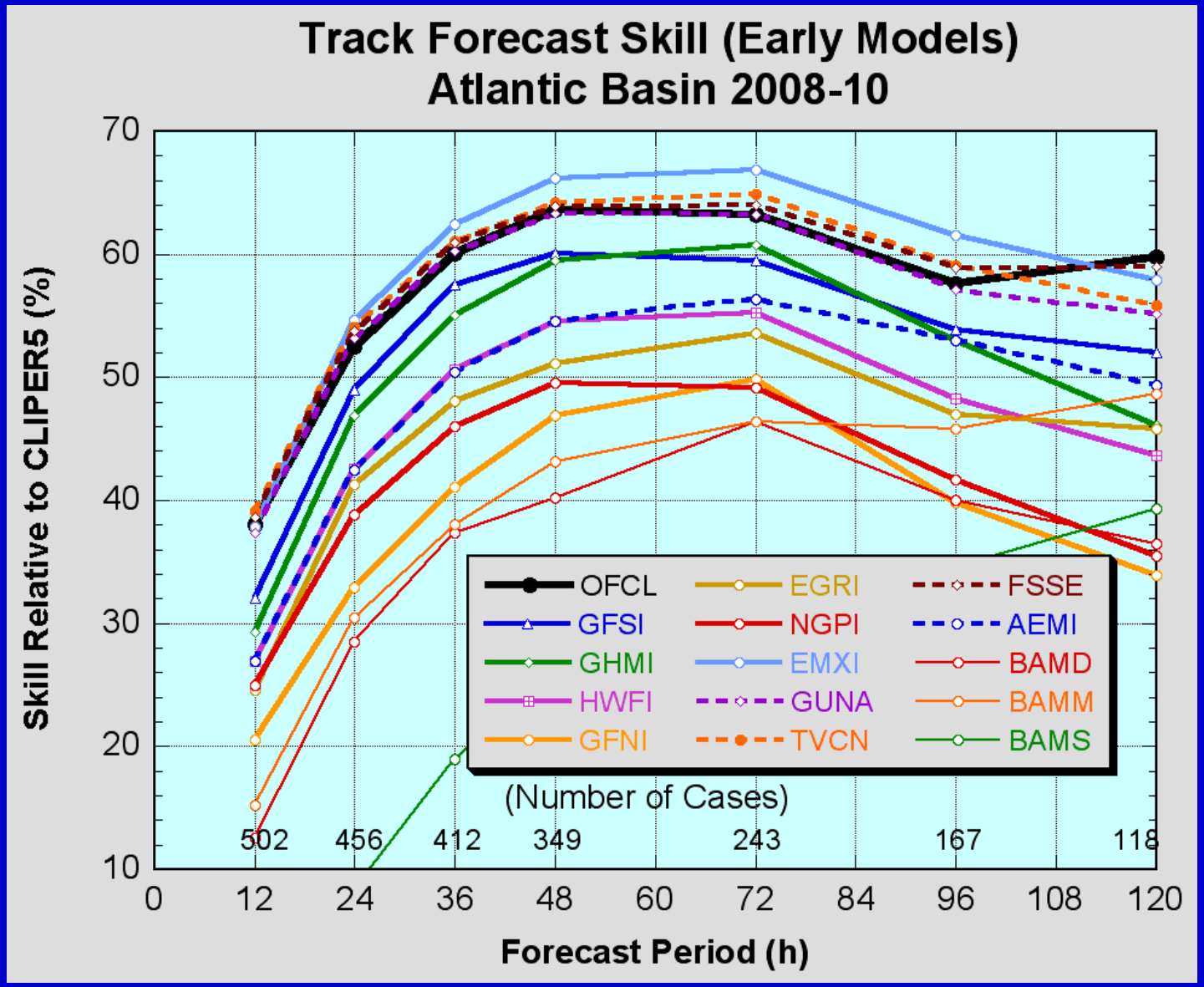
- Dynamical model consensus is an excellent first guess for the forecast (and often a good final guess!)
- However, continuity dictates that it must be considered in view of the previous official forecast
- Forecaster evaluates the large-scale environment using conventional data and satellite imagery (e.g., water vapor)
  - Try to assess steering influences to understand and evaluate model solutions



Track Forecasting at NHC
Using Dynamical Models (cont.)

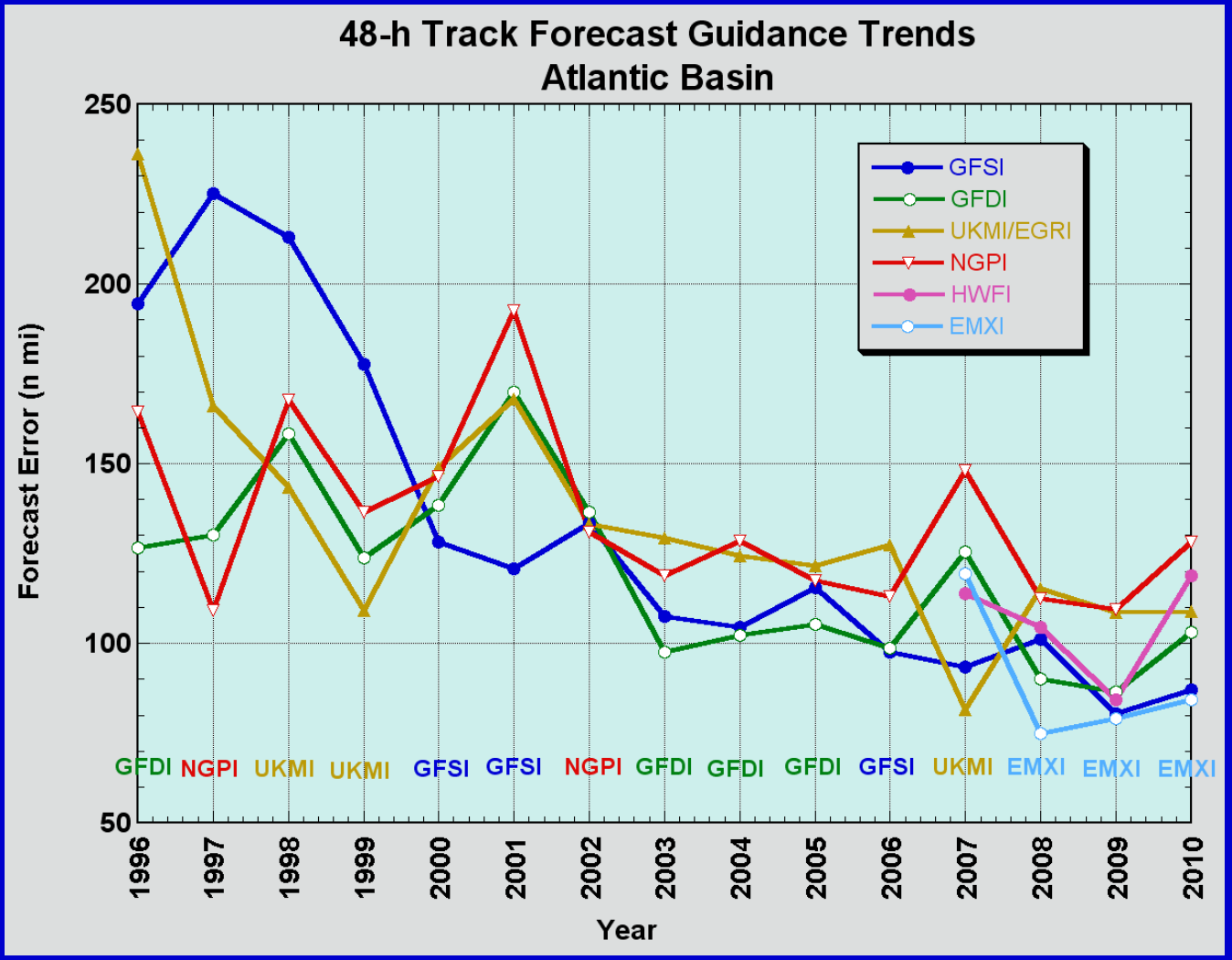
- Compare models' forecasts of environmental features, not just the TC tracks
- Evaluate initialization of the TC and the environment in model fields
  - Unrealistic initial TC structure can affect the likelihood of a successful forecast
- Consider recent performance of the models, both in terms of accuracy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

Performance of Consensus



- Multi-model consensus more skillful than member models, except for the EMCWF

Yearly Track Model Performance Trends



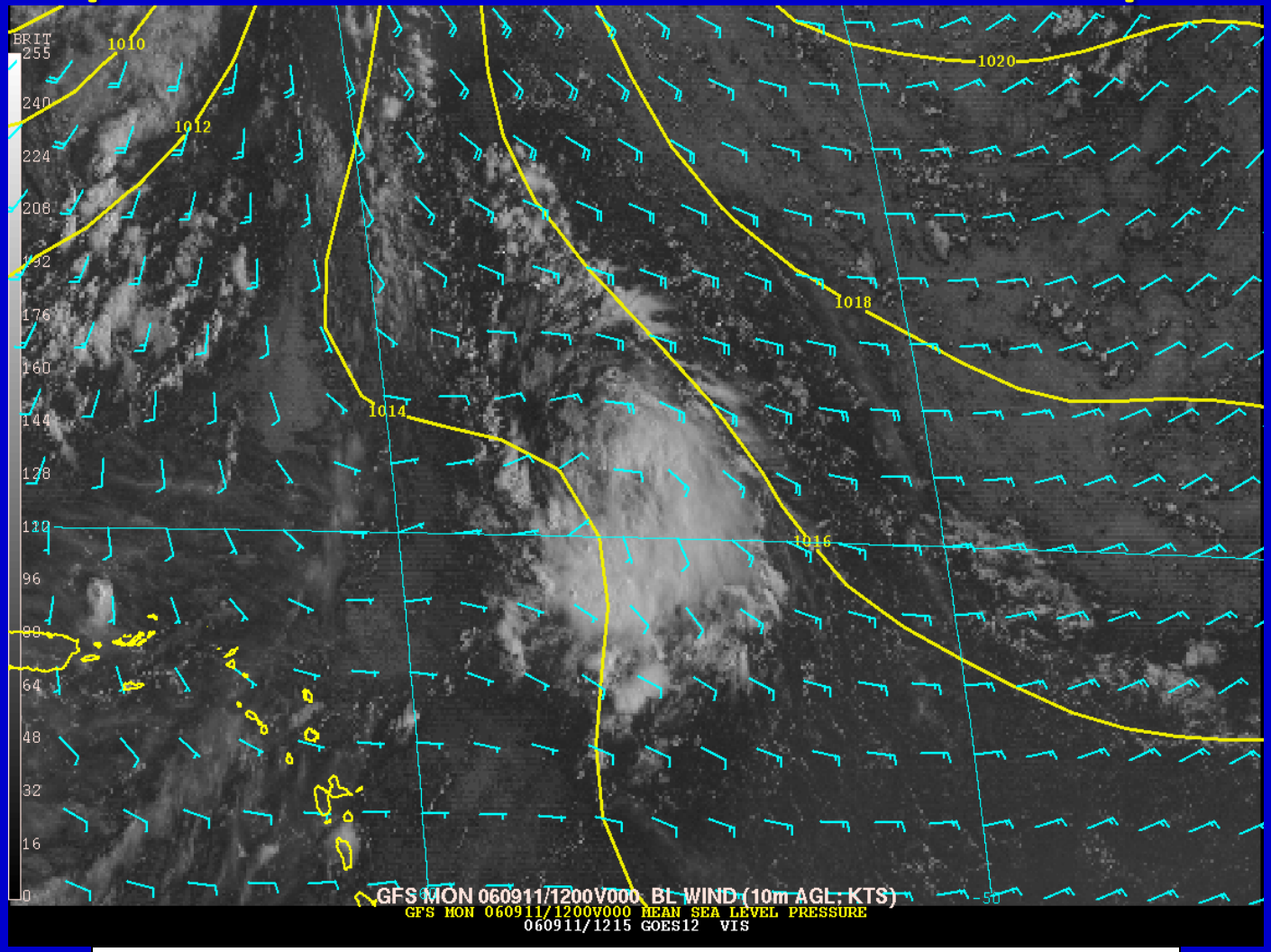
- Due to model changes and other factors, the best performing model often varies from season to season, although the ECMWF has been the best performer 3 years in a row

- Also, in the last three years the ECMWF, GFS, HWRF, and GFDL have outperformed the UKMET and NOGAPS by an increasing margin

Case Examples

Poor Initialization

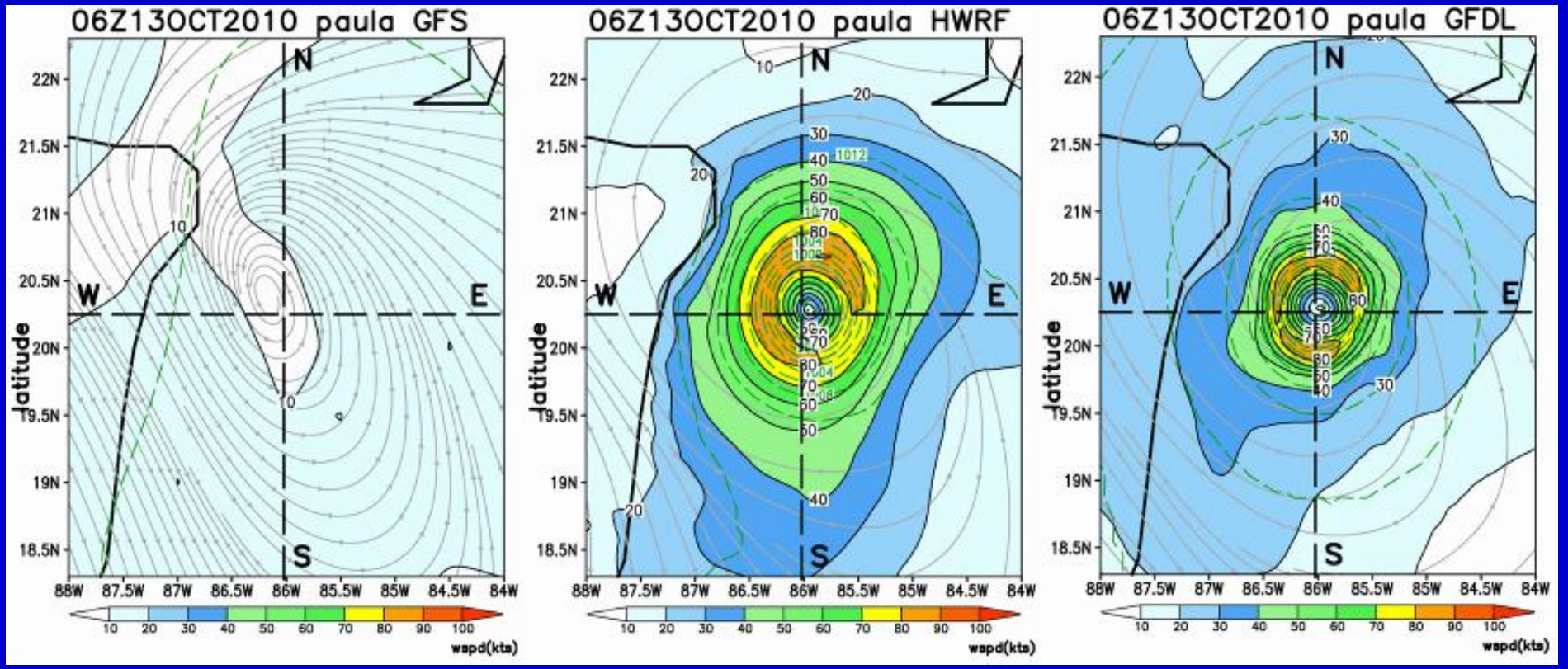
Tropical Storm Gordon – 1200 UTC 11 Sep 2006



GFS analysis of TS Gordon when the cyclone was a 35-kt tropical storm with a central pressure of 1008 mb

Poor Initialization

Hurricane Paula – 0600 UTC 13 October 2010



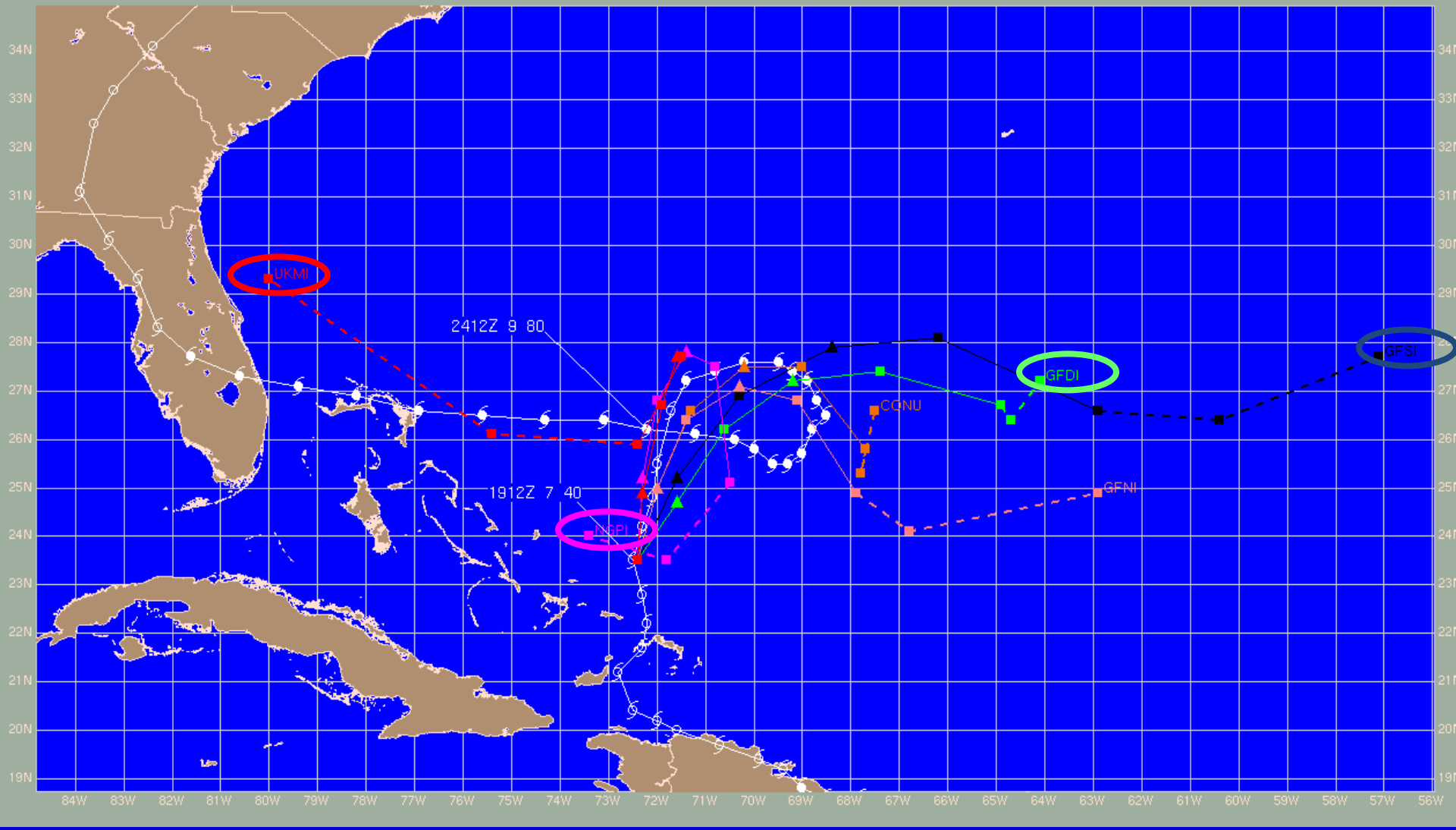
GFS central Pressure ~1009 mb

Estimated max winds were 85 kt with a central pressure of 984 mb

Scale issue with GFS analyzing such a small TC?

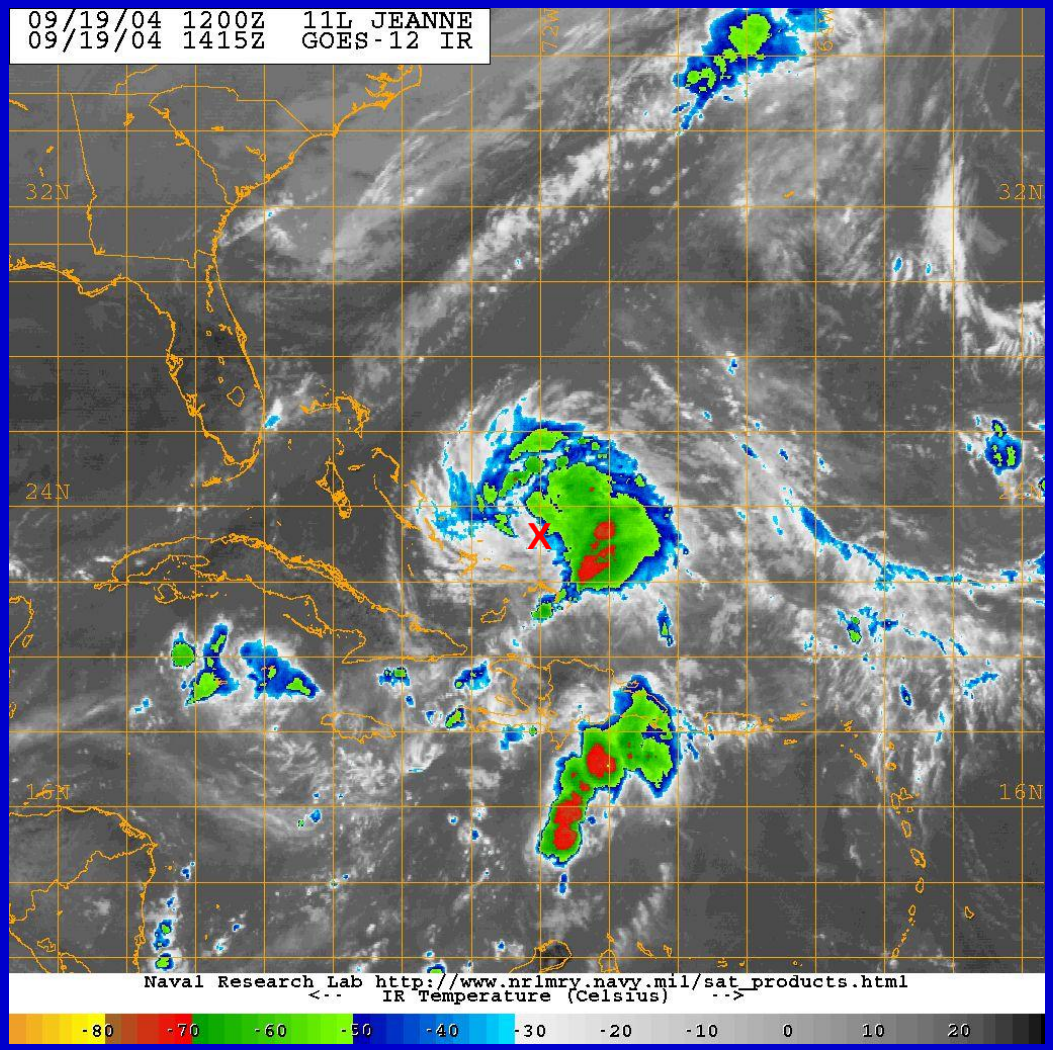
Hurricane Jeanne (2004)

How to Resolve Differences Between Guidance Models?



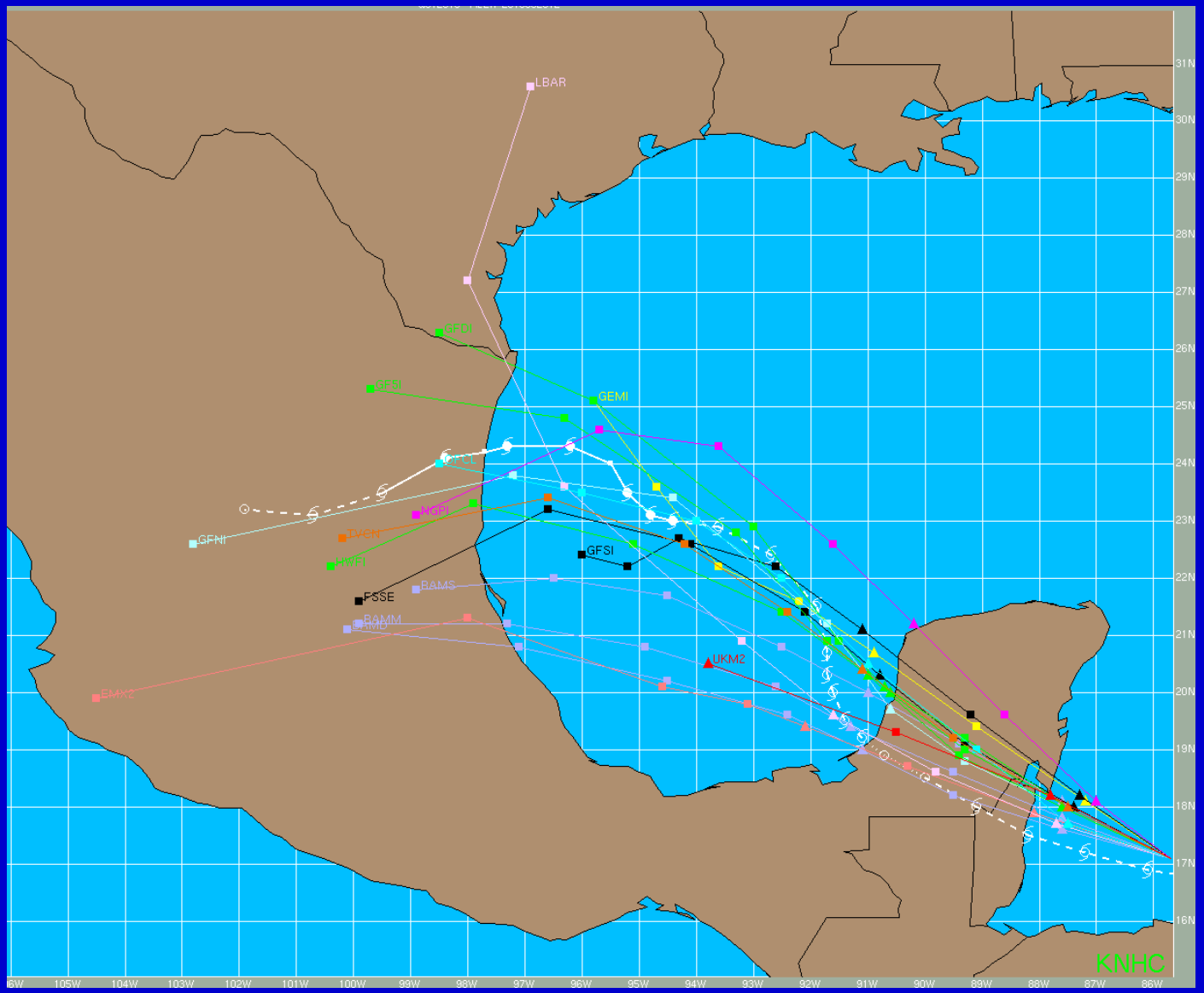
Hurricane Jeanne (2004)

How to Resolve Differences Between Guidance Models?

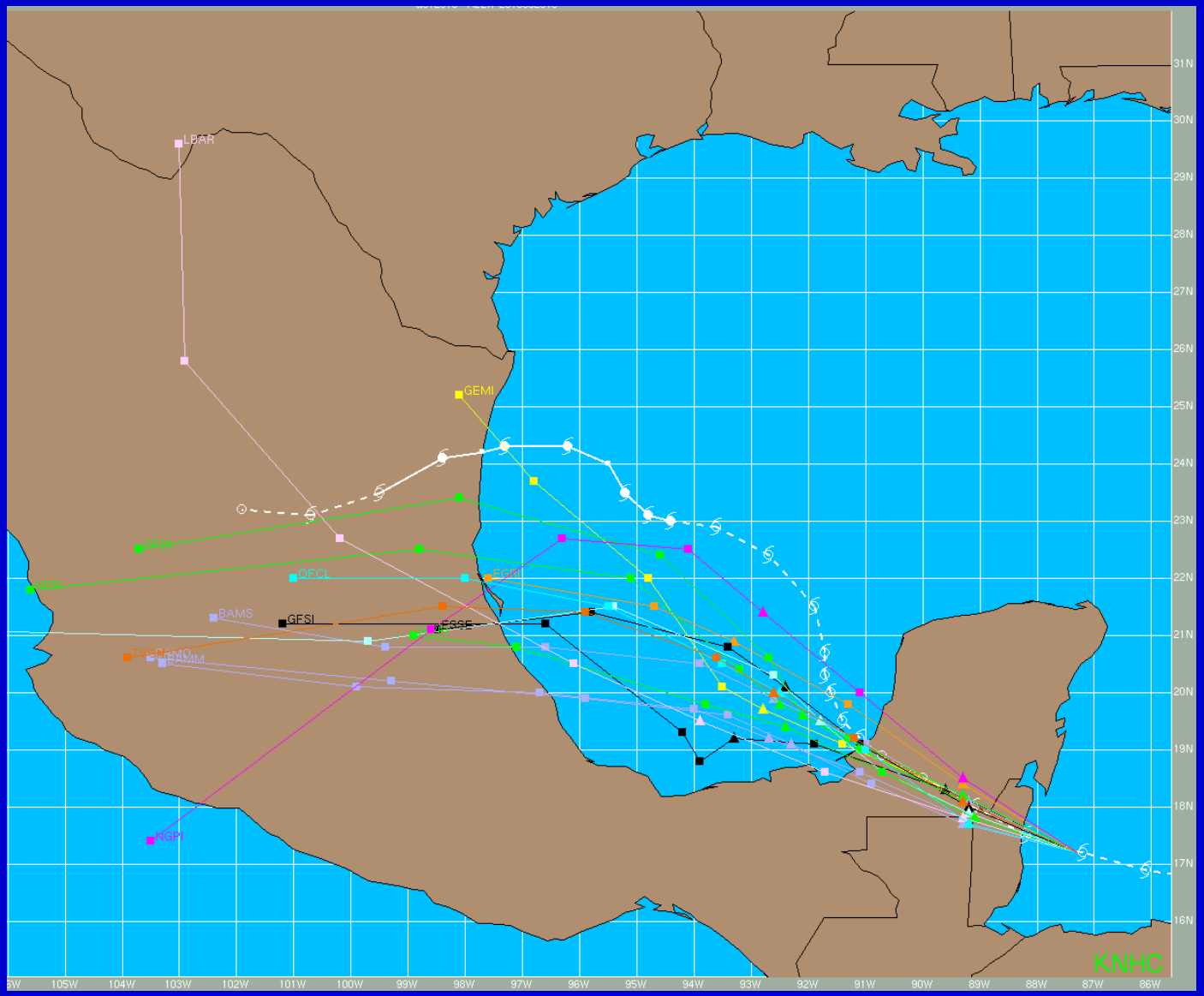


- Poor organization (especially a lack of deep convection in the core) would argue against Jeanne being carried eastward by upper-level westerlies
- This reasoning allowed forecasters to largely disregard the GFS and form a “selective consensus” of the remaining models
- Track forecast is therefore affected by the intensity forecast

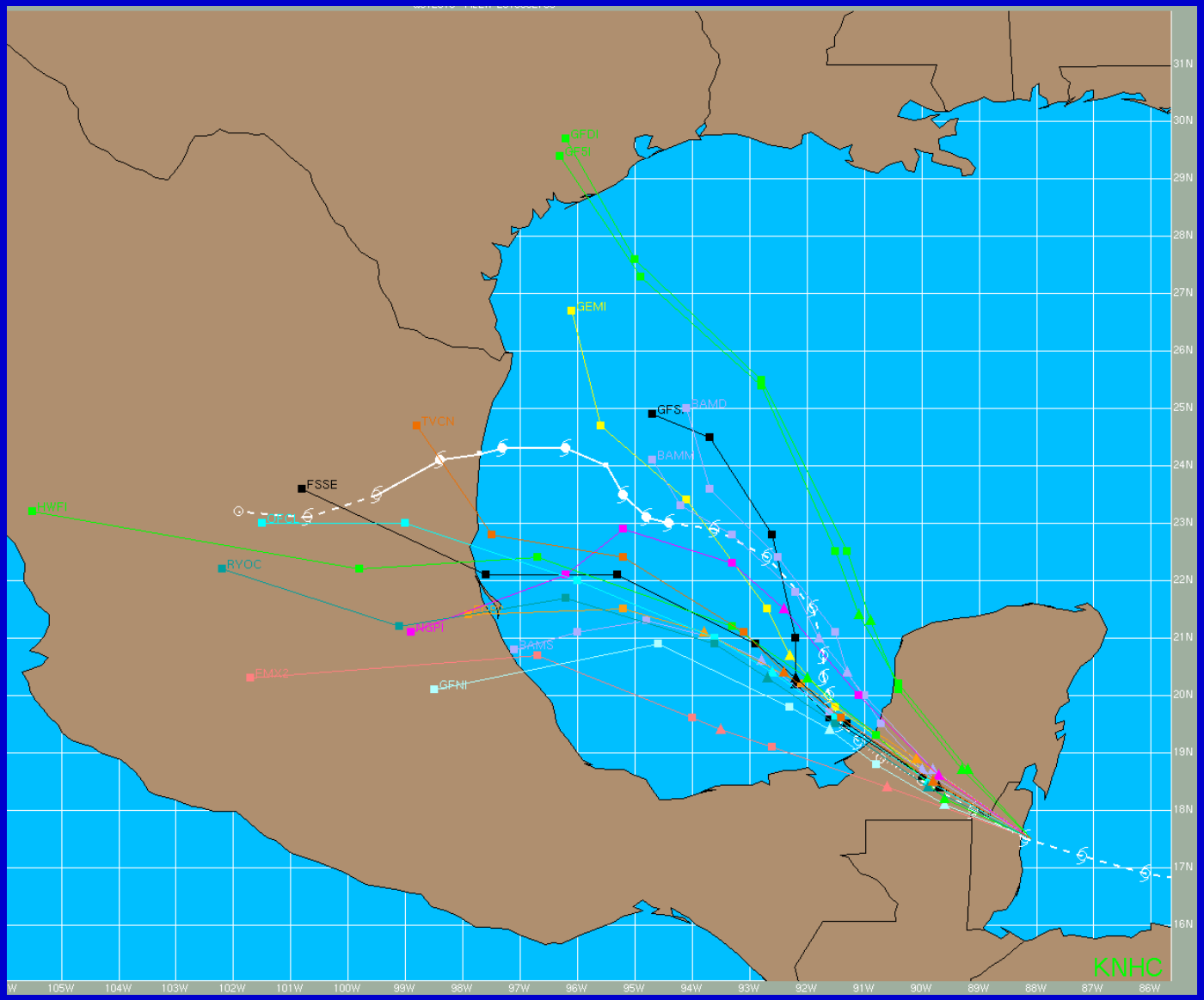
Alex Guidance – 1200 UTC 26 June 2010



Alex Guidance – 1800 UTC 26 June 2010

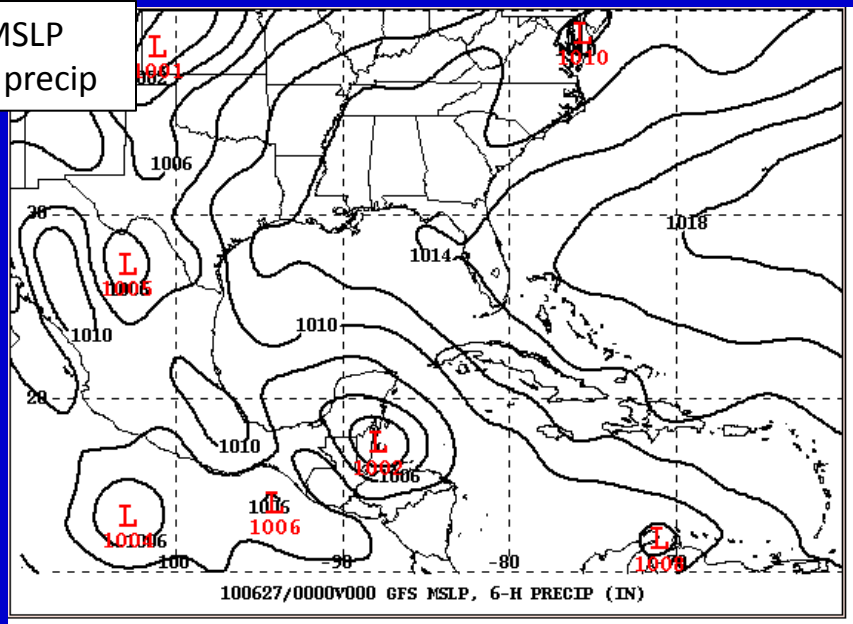


Alex Guidance – 0000 UTC 27 June 2010

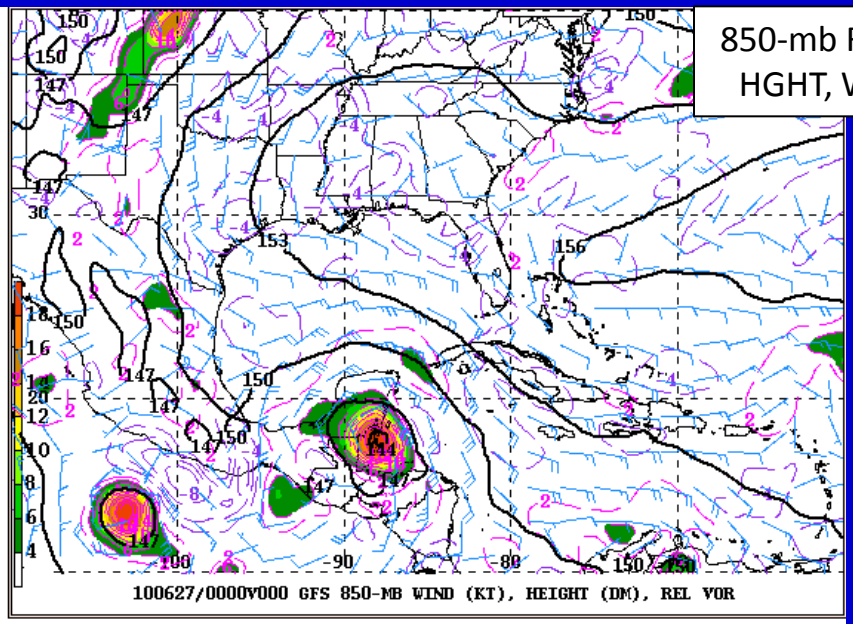


GFS – 0000 UTC 27 June 2010

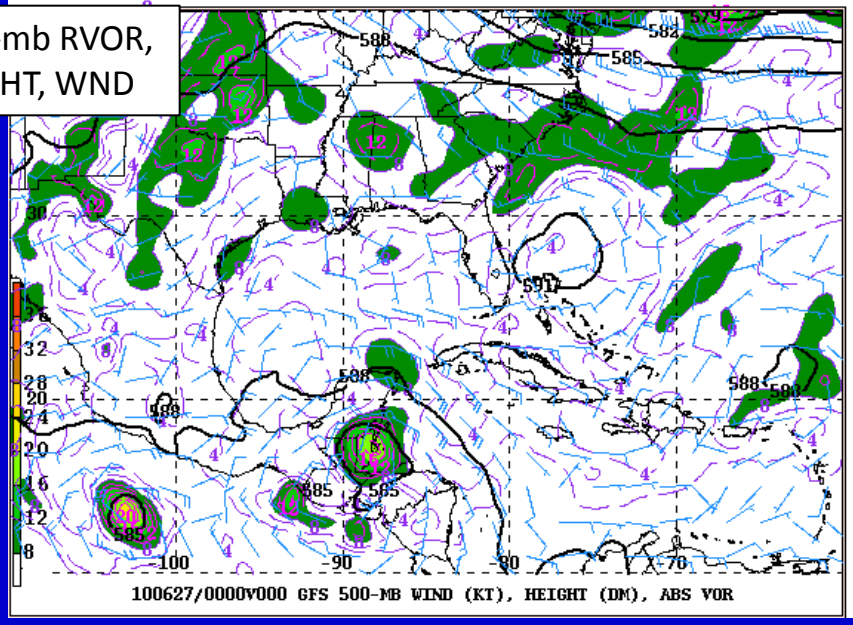
MSLP
6-h precip



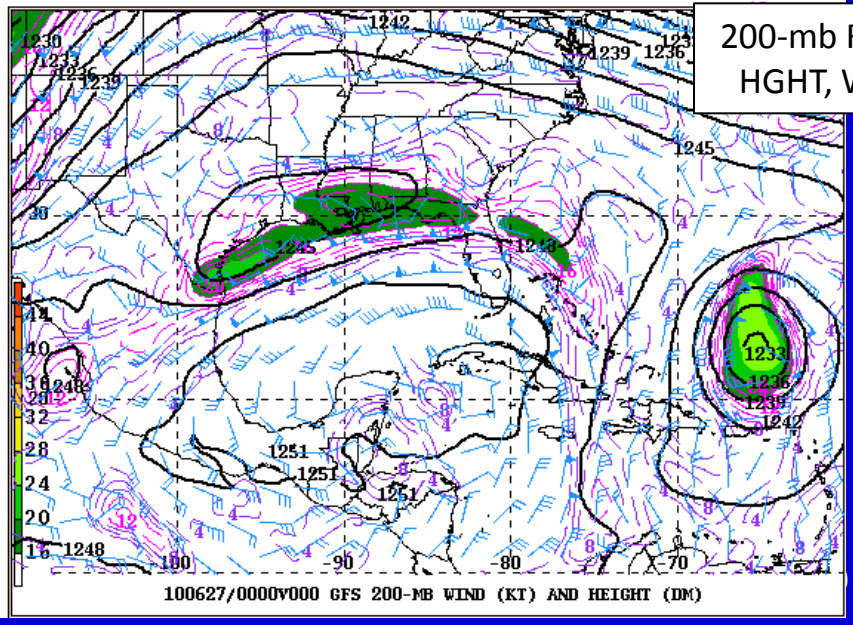
850-mb RVOR,
HGHT, WND



500-mb RVOR,
HGHT, WND



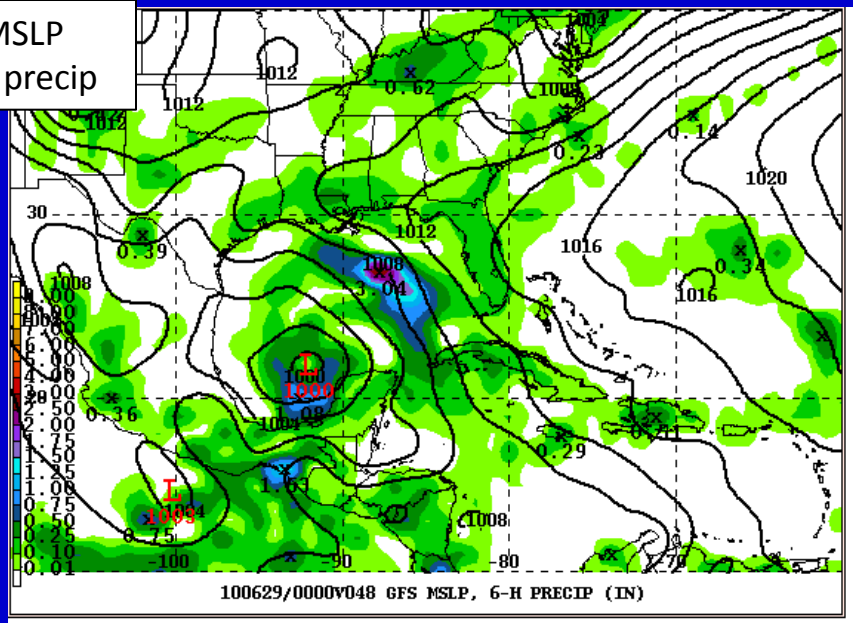
200-mb RVOR,
HGHT, WND



GFS – 0000 UTC 27 June 2010

48-h Forecast

MSLP
6-h precip



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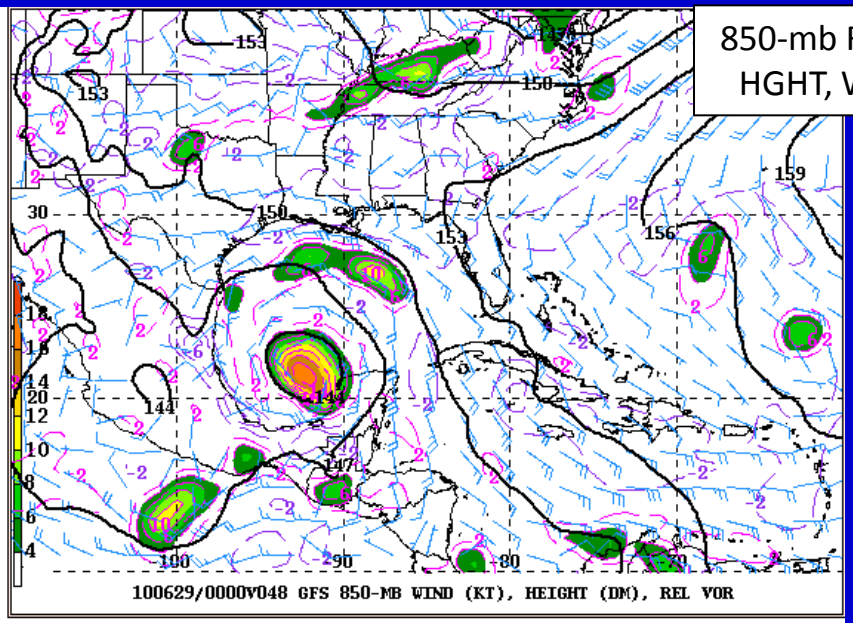
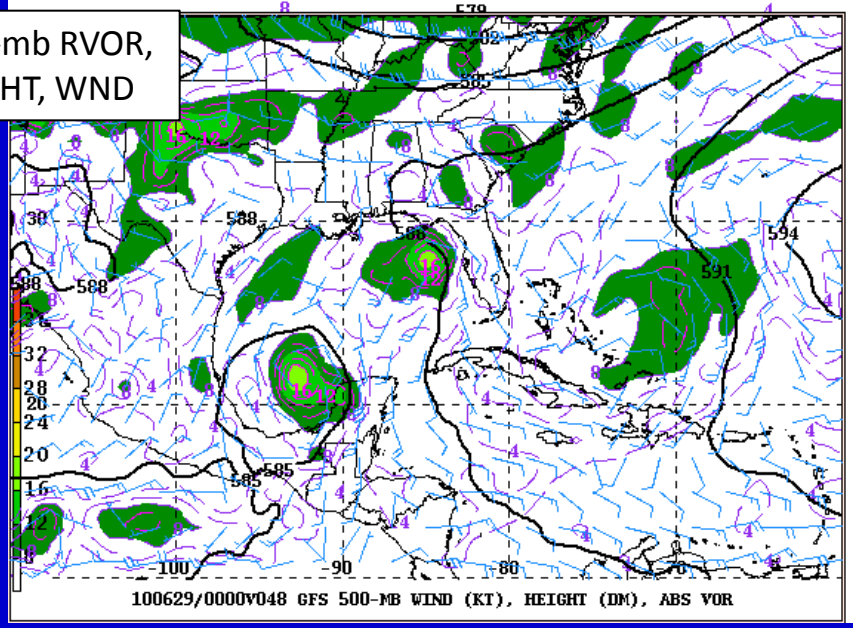
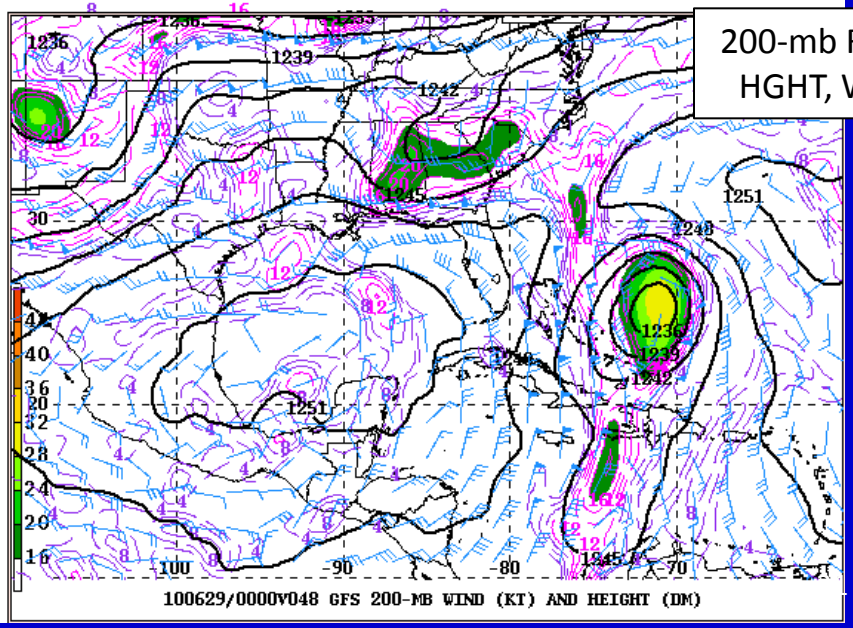


500-mb RVOR,
HGHT, WND



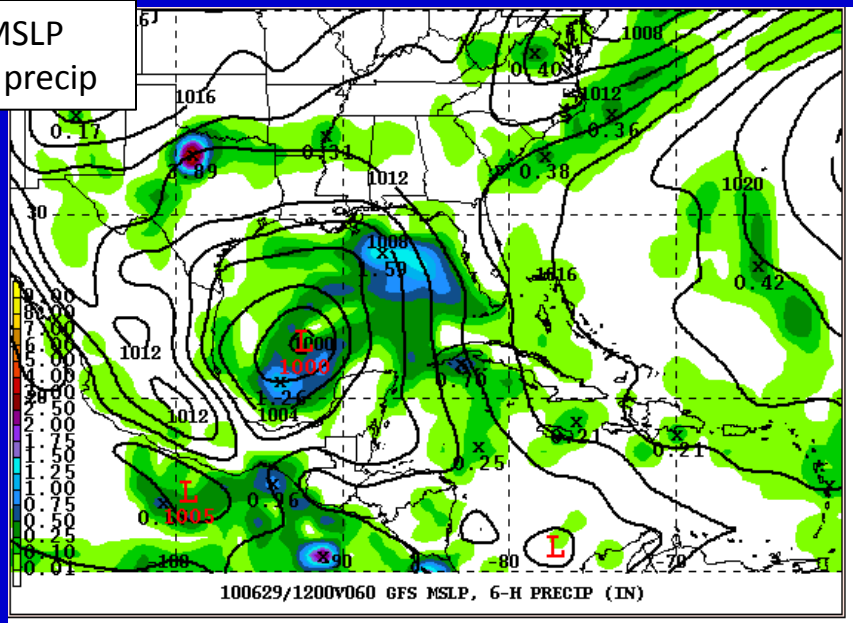
200-mb RVOR,
HGHT, WND



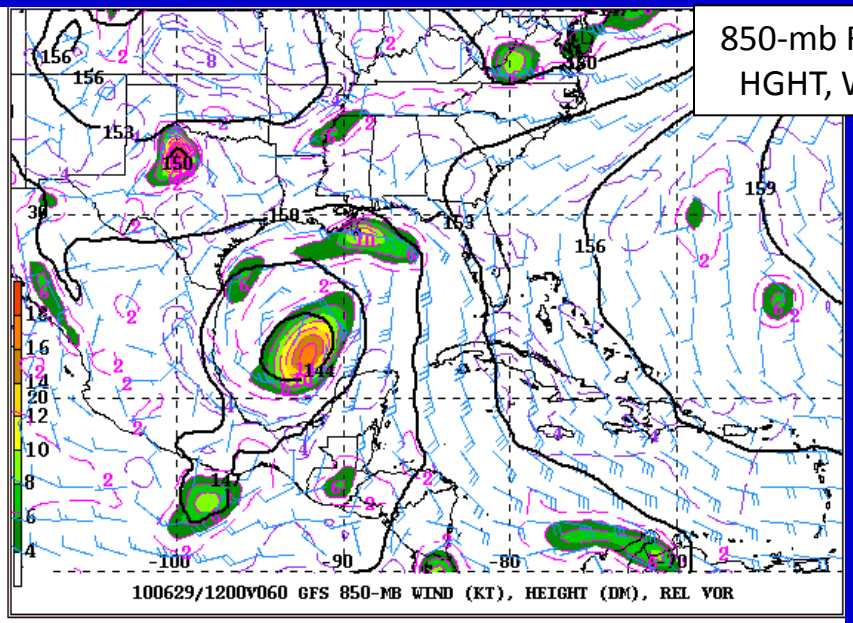
GFS – 0000 UTC 27 June 2010

60-h Forecast

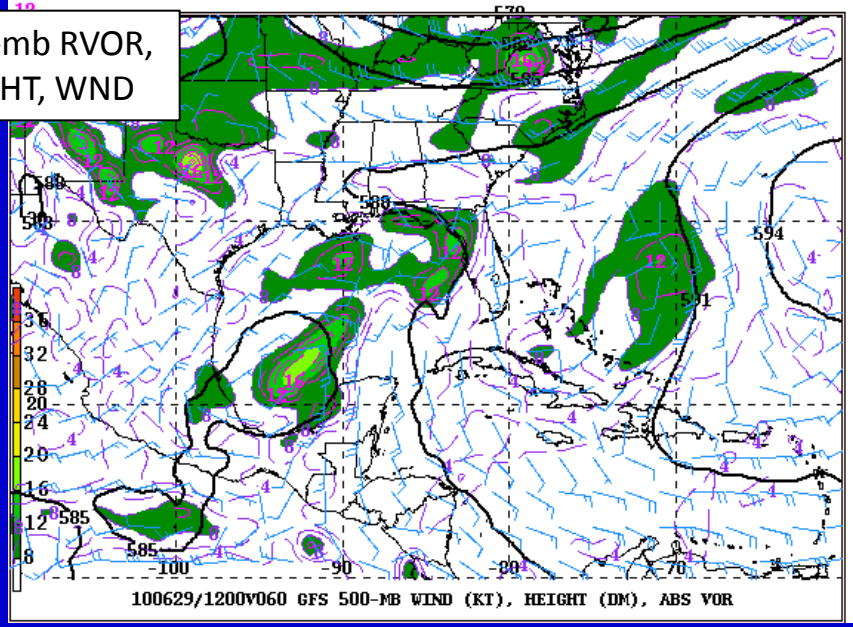
MSLP
6-h precip



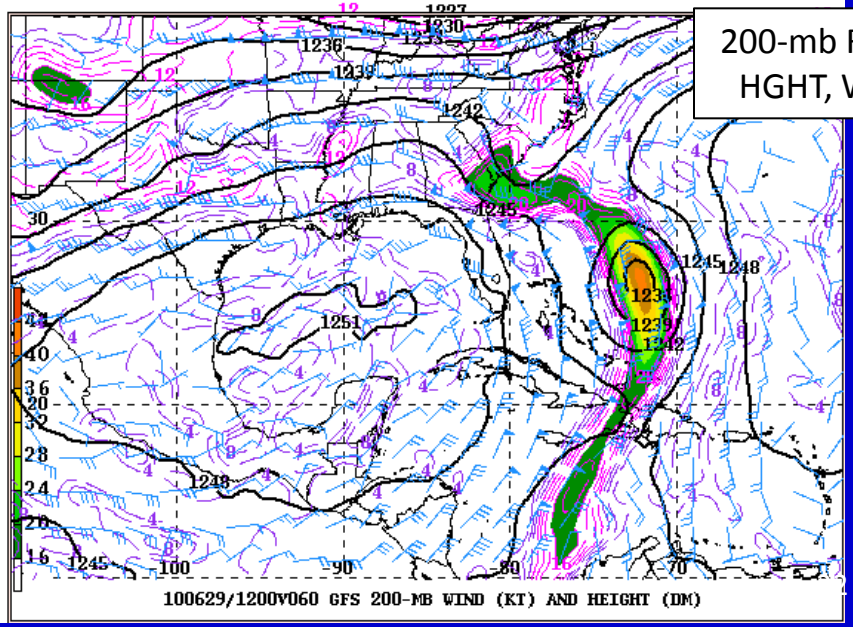
850-mb RVOR,
HGHT, WND



500-mb RVOR,
HGHT, WND



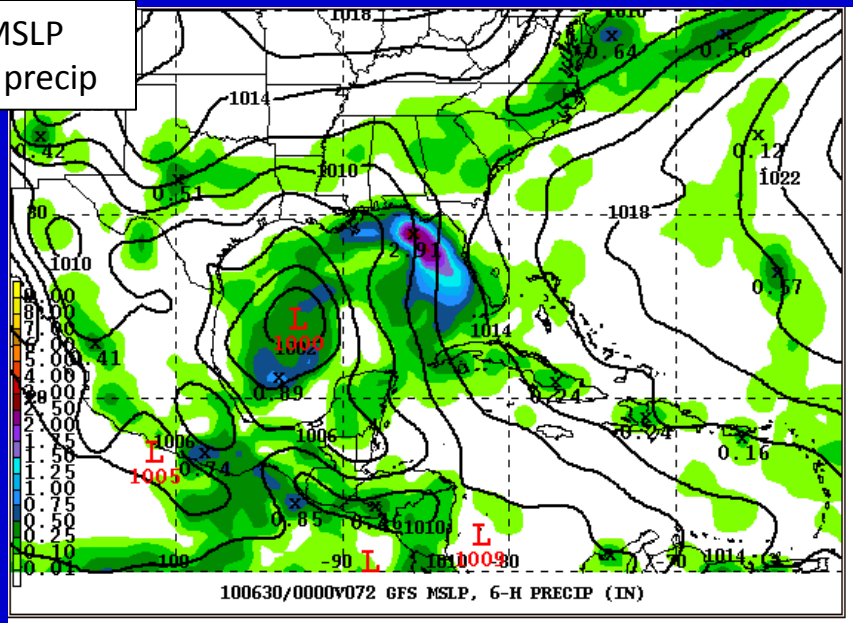
200-mb RVOR,
HGHT, WND



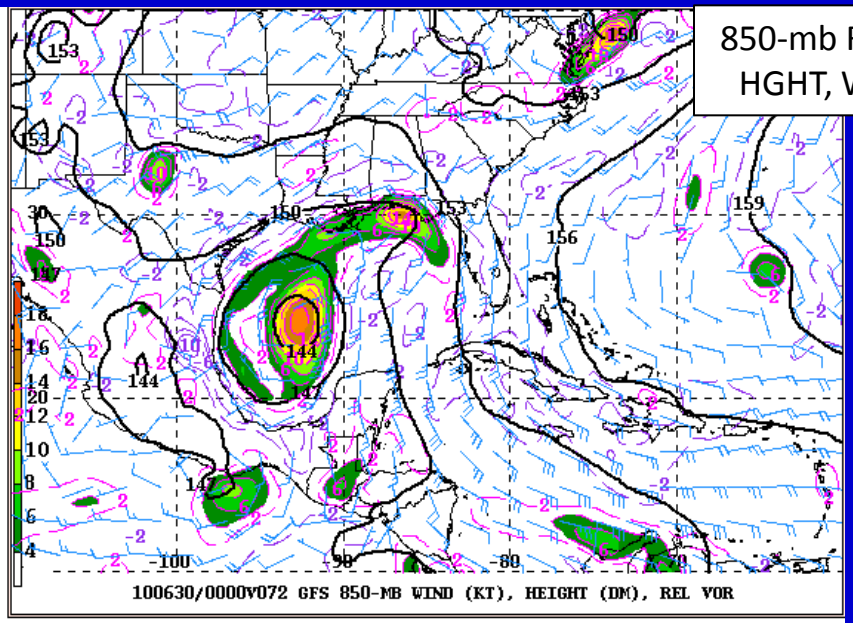
GFS – 0000 UTC 27 June 2010

72-h Forecast

MSLP
6-h precip



850-mb RVOR,
HGHT, WND



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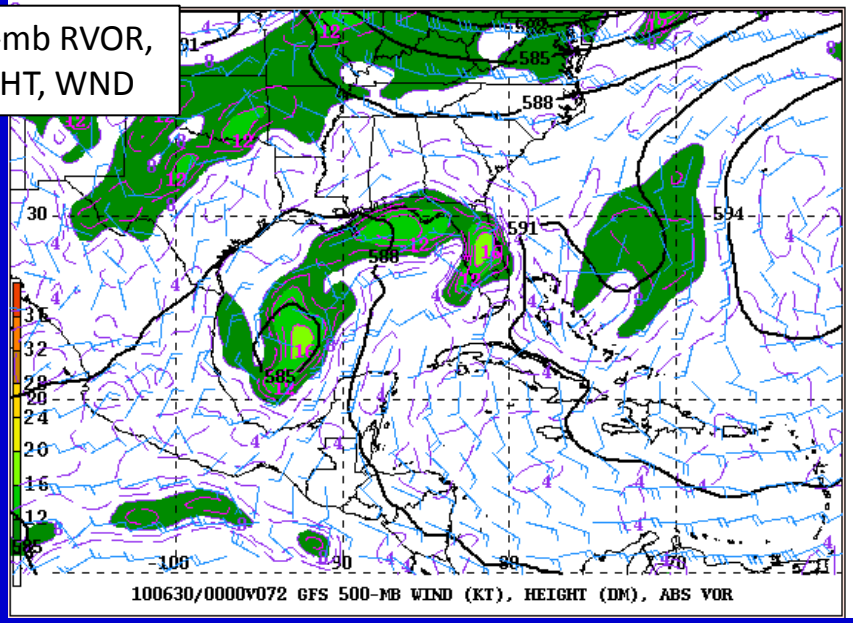

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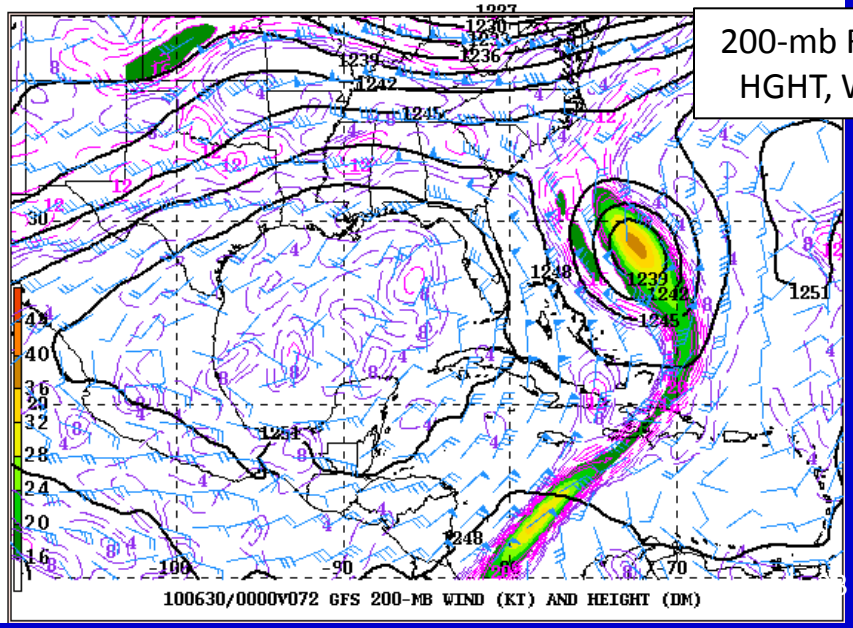

Forecaster Reasoning

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TROPICAL STORM ALEX DISCUSSION NUMBER   6
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL   AL012010
1000 PM CDT SAT JUN 26 2010

...DISCUSSION TEXT DELETED...

HOWEVER...THE LATEST RUNS OF THE GFDL AND GFS TAKE ALEX
FARTHER NORTH LATE IN THE PERIOD...BUT THIS APPEARS TO BE
DUE TO THE DEVELOPMENT OF SPURIOUS VORTICITY MAXIMA IN
BOTH MODELS THAT ERODE THE RIDGE NORTH OF ALEX. GIVEN
THEIR LACK OF CONTINUITY...THE GFS AND GFDL SOLUTIONS ARE
CONSIDERED OUTLIERS. THE NEW OFFICIAL FORECAST IS
ADJUSTED ONLY A LITTLE TO THE RIGHT OF THE PREVIOUS
PACKAGE DUE TO THE INITIAL POSITION AND MOTION...AND IS
IN GOOD AGREEMENT WITH A BLEND OF THE DYNAMICAL MODELS
EXCLUDING THE GFDL AND GFS.

FORECAST POSITIONS AND MAX WINDS

INITIAL      27/0300Z 17.7N  88.4W    50 KT
 12HR VT     27/1200Z 18.5N  89.9W    30 KT...INLAND
 24HR VT     28/0000Z 19.6N  91.5W    35 KT...OVER WATER
 36HR VT     28/1200Z 20.4N  92.6W    45 KT
 48HR VT     29/0000Z 21.0N  93.6W    55 KT
 72HR VT     30/0000Z 22.0N  96.0W    70 KT
 96HR VT     01/0000Z 23.0N  99.0W    55 KT...INLAND
120HR VT     02/0000Z 23.0N 101.5W    30 KT...INLAND

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FORECASTER BRENNAN
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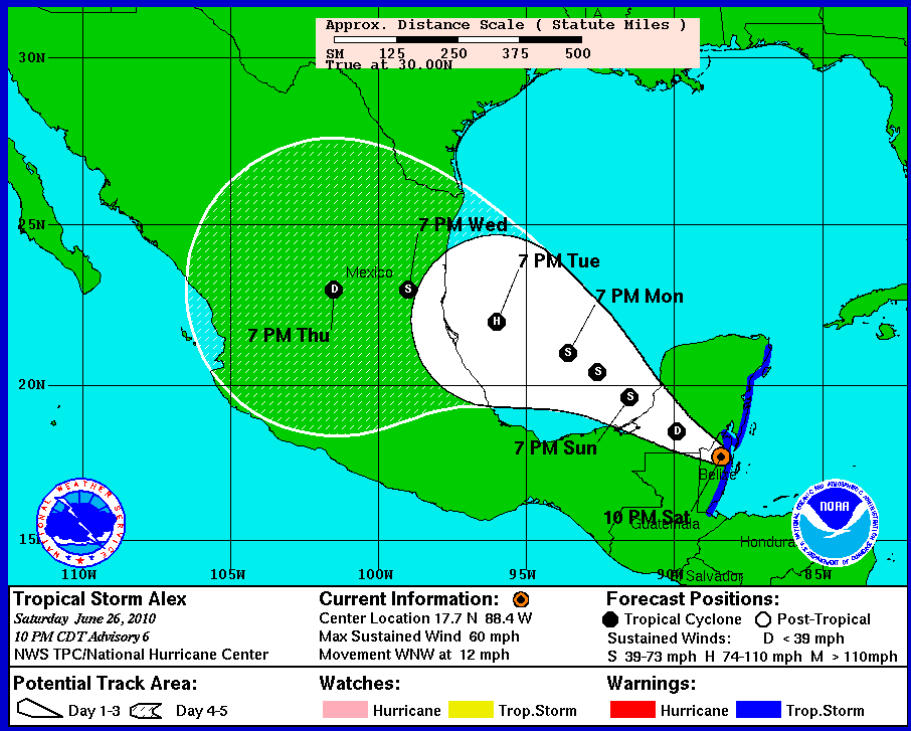
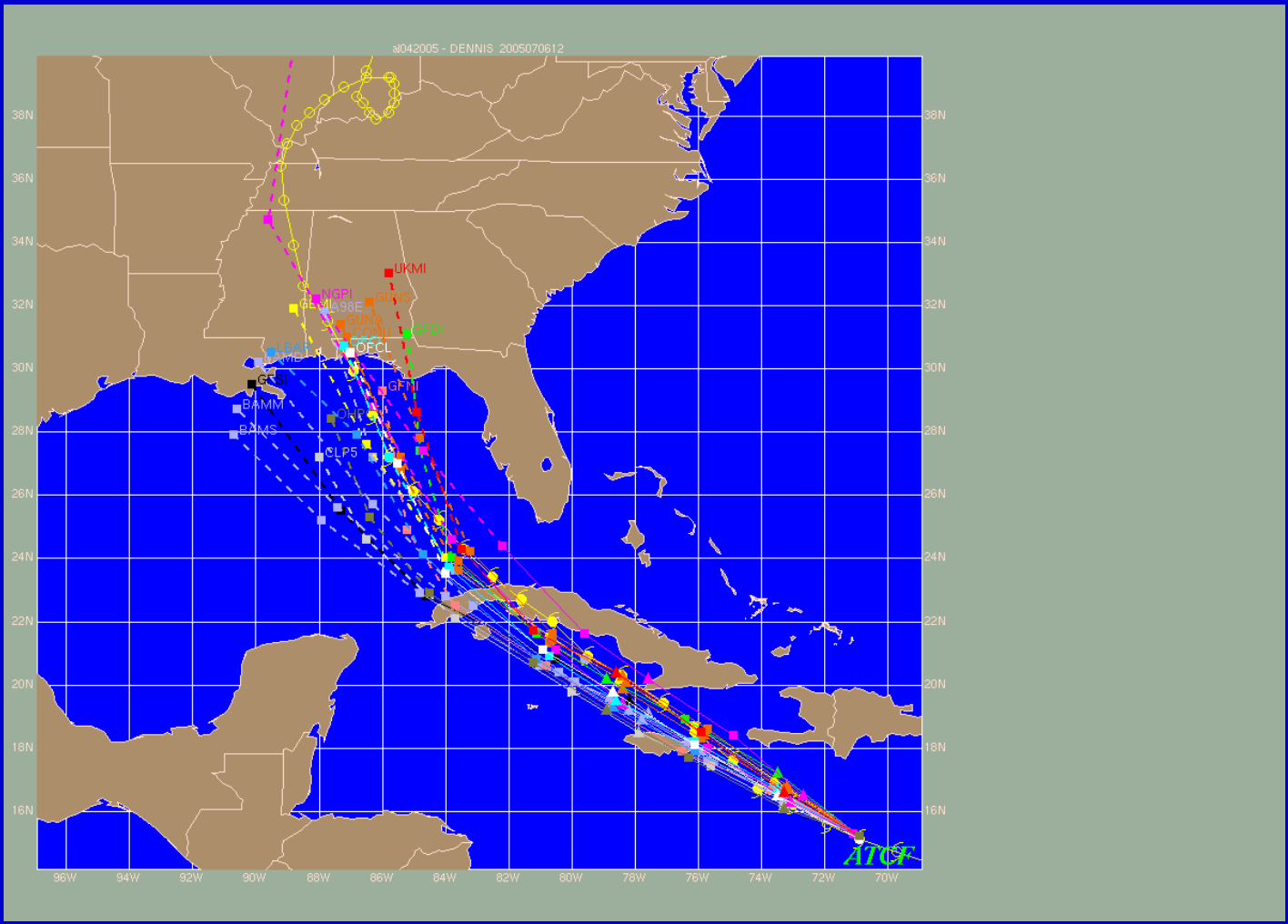


Track Forecasting at NHC
Continuity

- 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.)

Hurricane Dennis

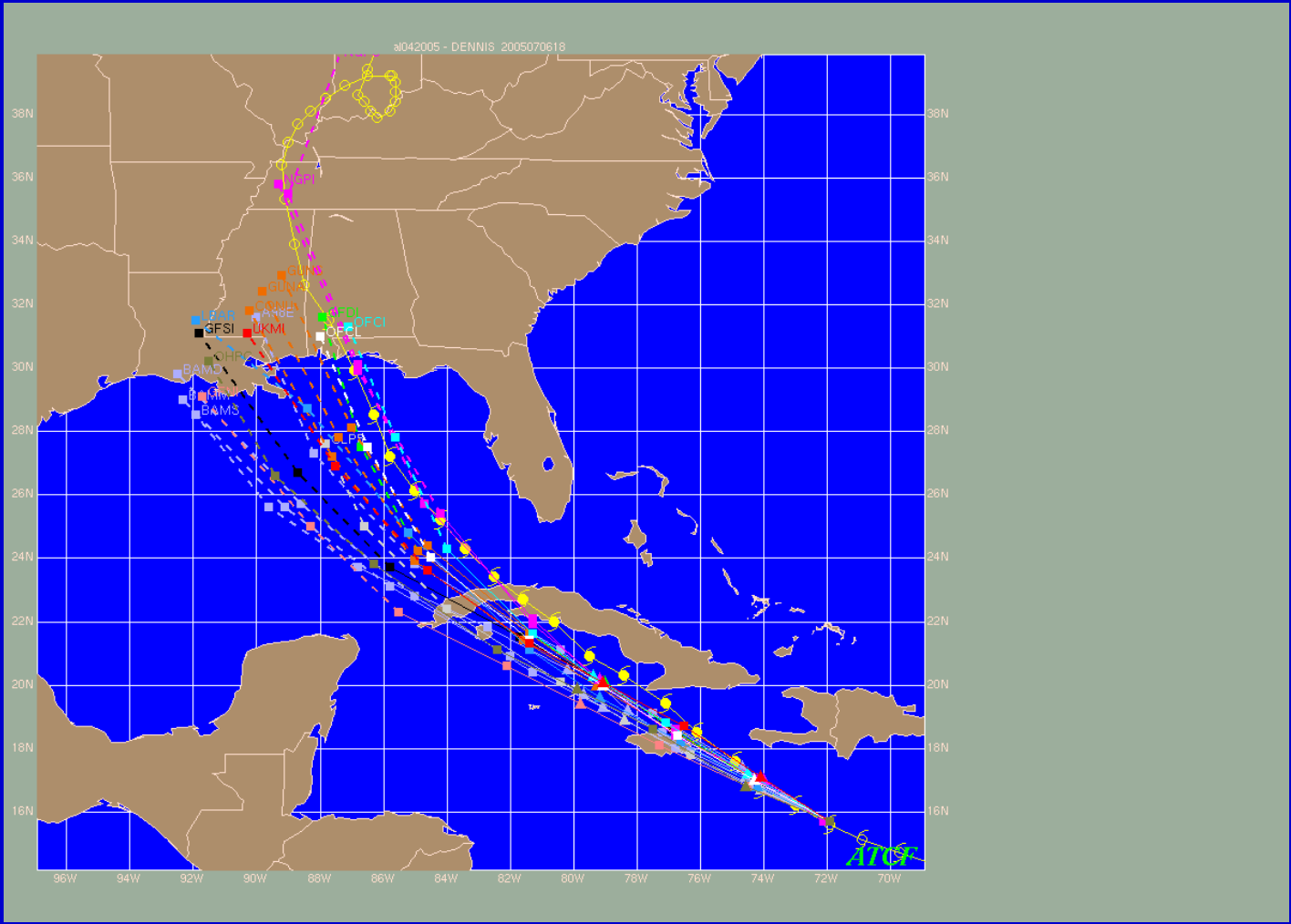
6 July 1200 UTC



Official forecast near model consensus in extreme western FL panhandle

Hurricane Dennis

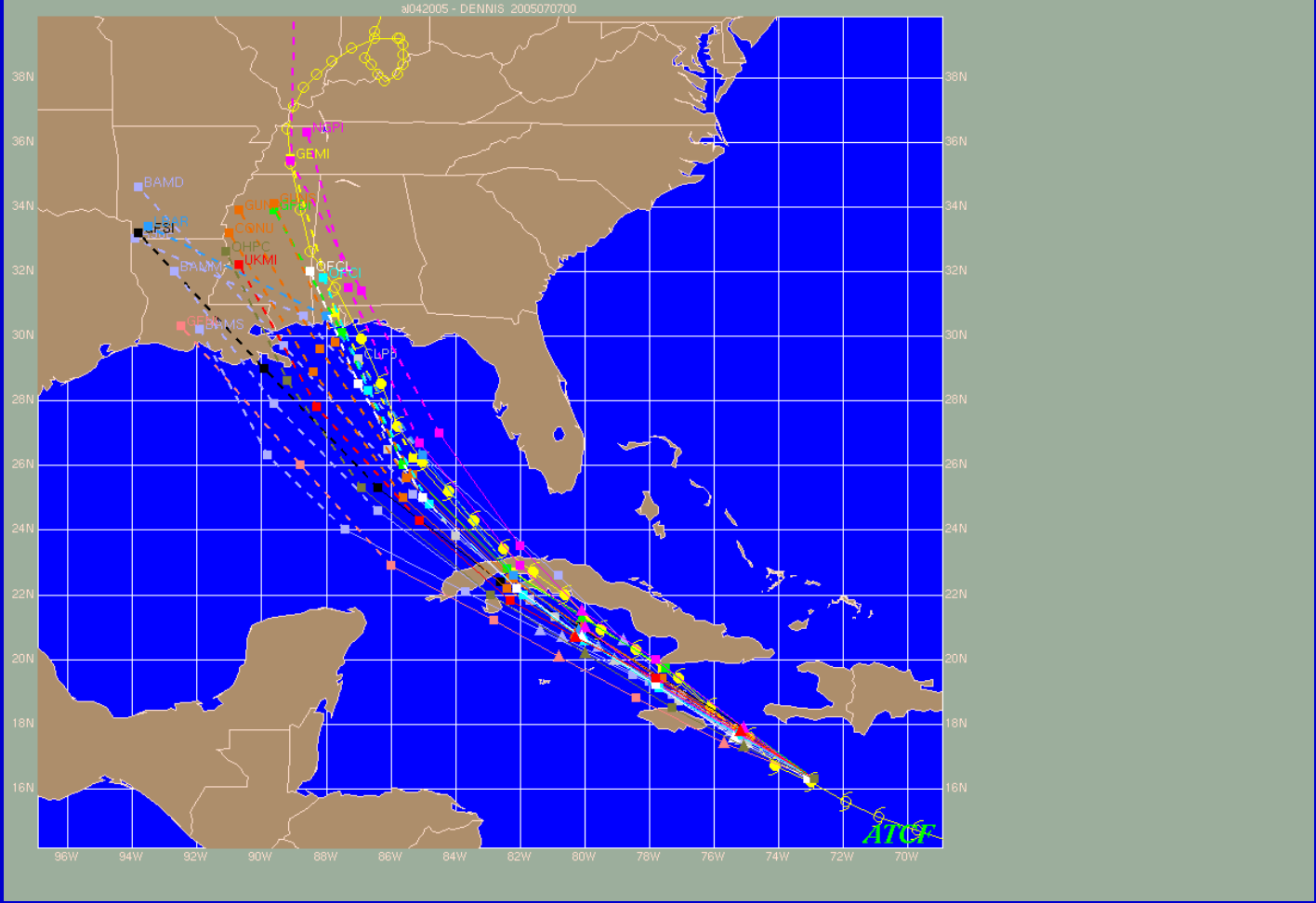
6 July 1800 UTC



Guidance shifts sharply westward toward New Orleans – official forecast nudged westward into AL

Hurricane Dennis

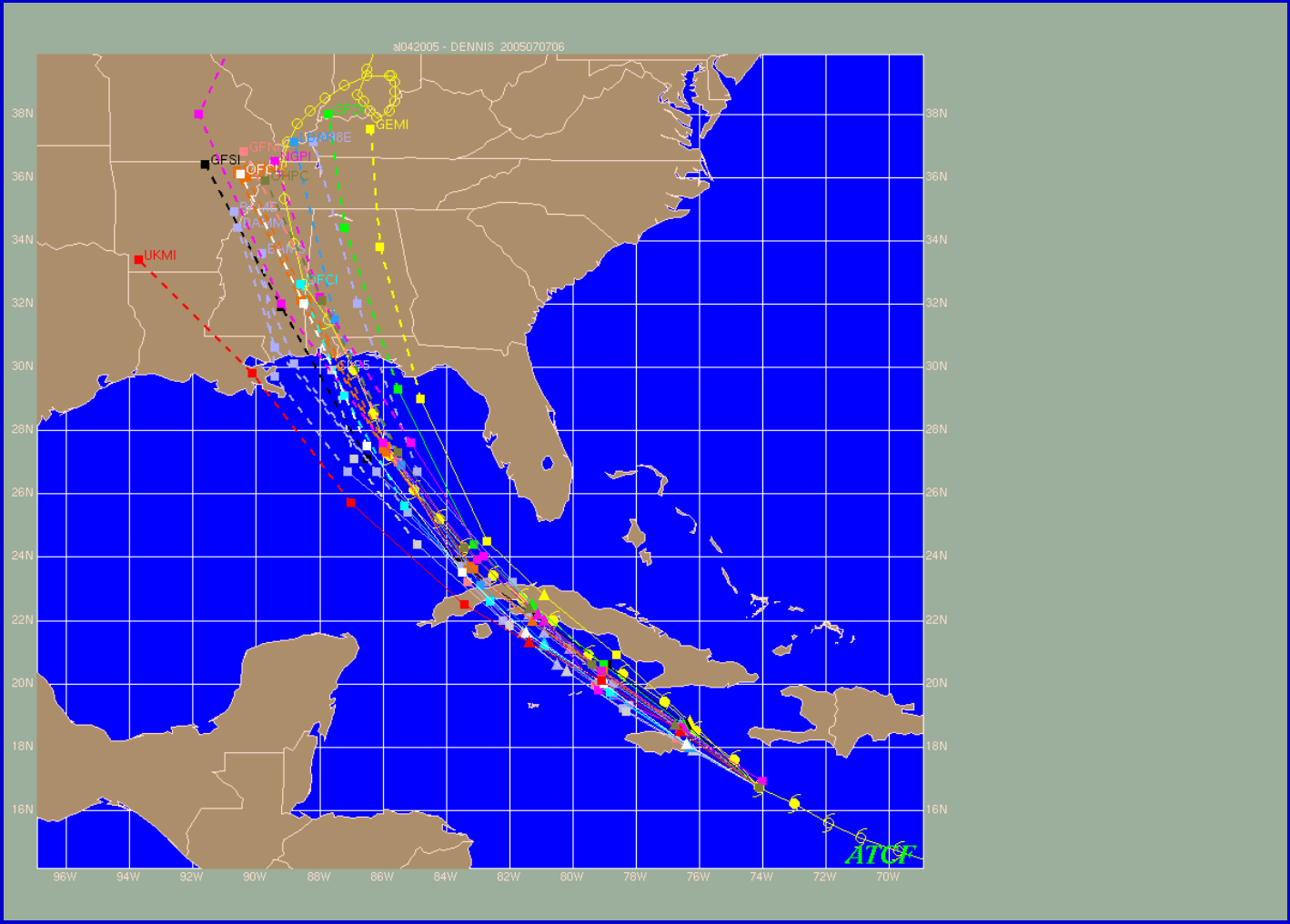
7 July 0000 UTC



Little overall change to guidance, but NGPI shifts slightly eastward – little change in official forecast

Hurricane Dennis

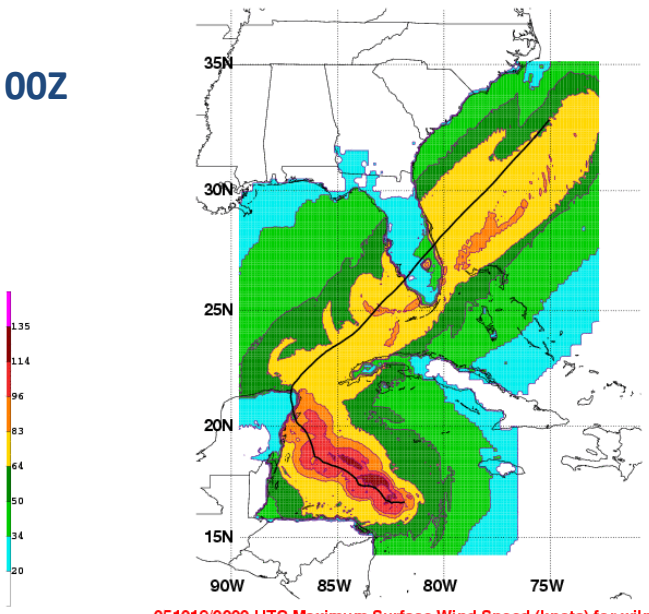
7 July 0600 UTC



Rest of the guidance shifts sharply eastward, leaving the official forecast near the center of the guidance envelope (and very close to the eventual track)

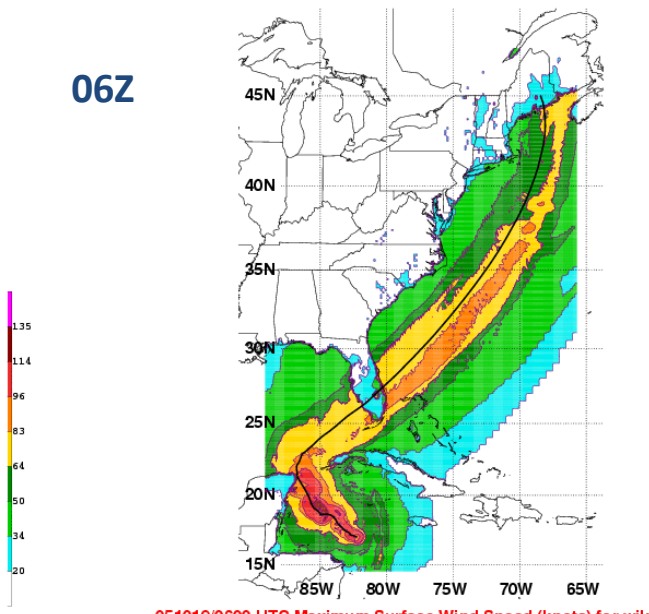
Hurricane Wilma GFDL Forecasts – 19 October 2005

00Z



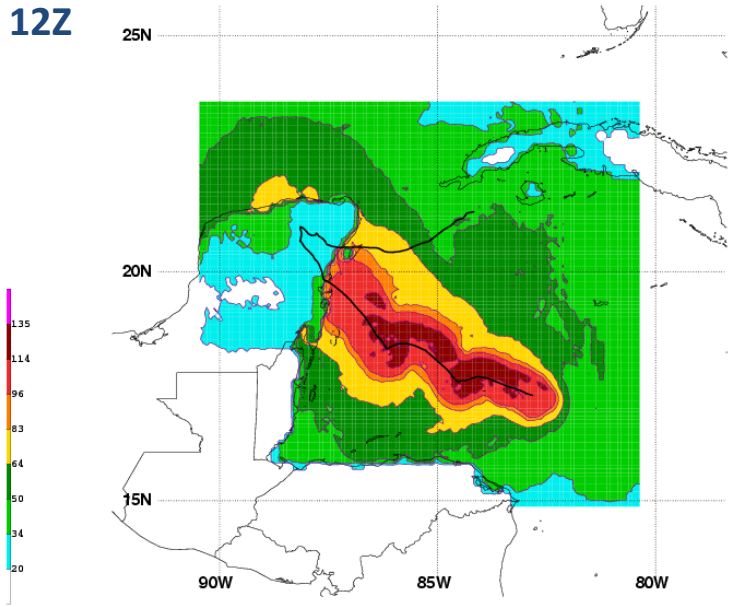
051019/0000 UTC Maximum Surface Wind Speed (knots) for wilma24l

06Z



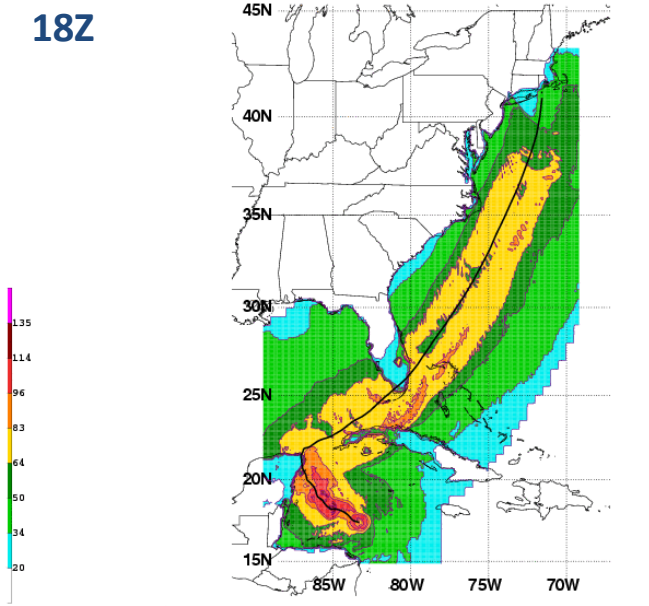
051019/0600 UTC Maximum Surface Wind Speed (knots) for wilma24l

12Z



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

18Z



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

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.**

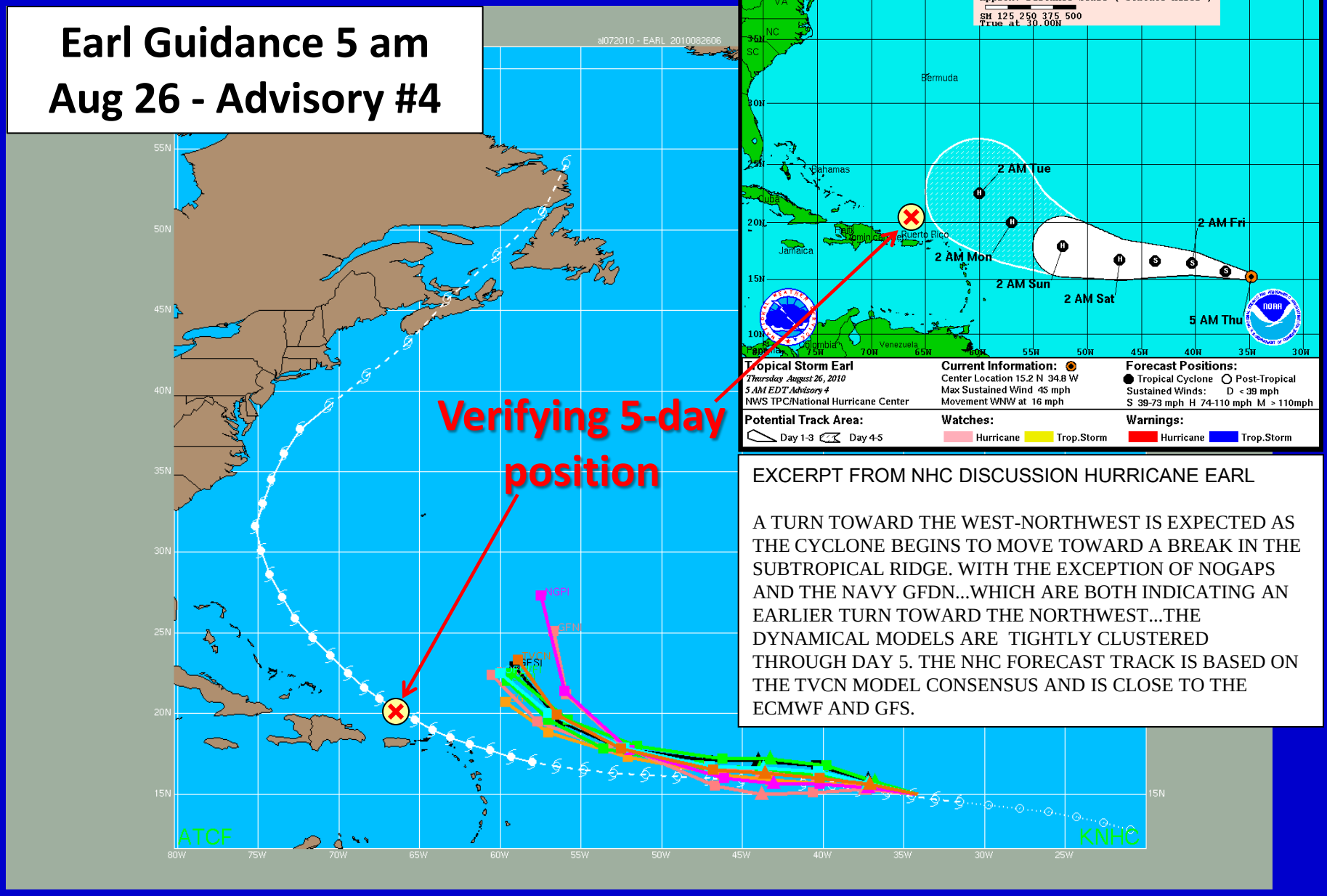
...DELTETED DISCUSSION TEXT...

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

Tightly Clustered Track Guidance Doesn't Guarantee Small Track Error

Earl Guidance 5 am Aug 26 - Advisory #4

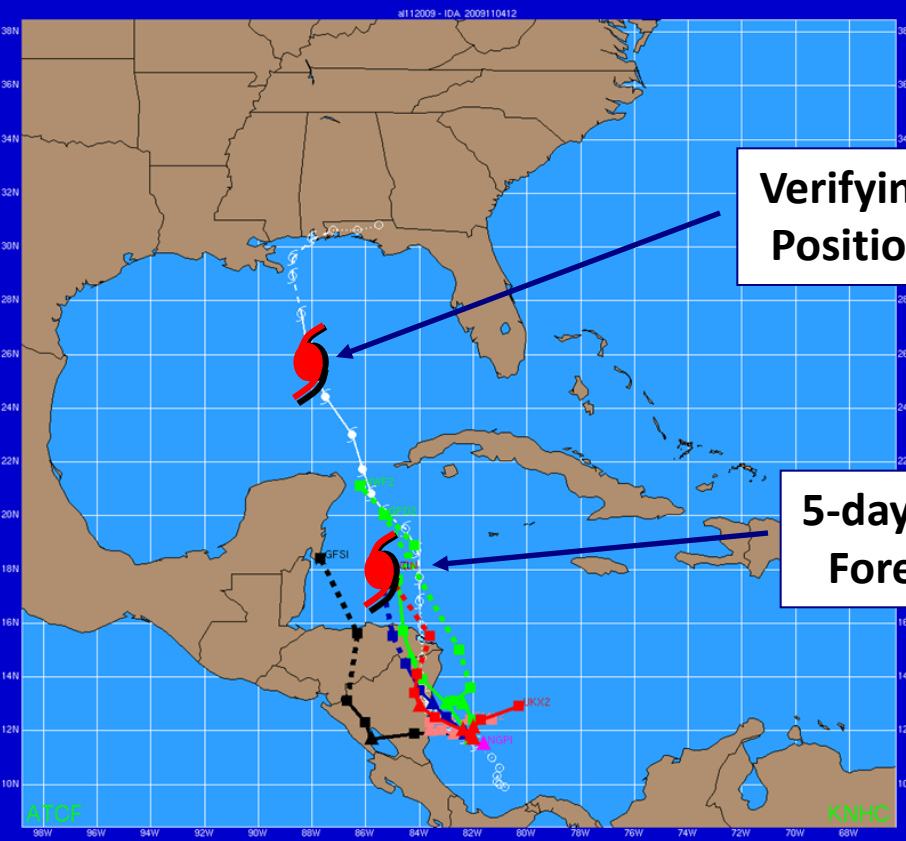


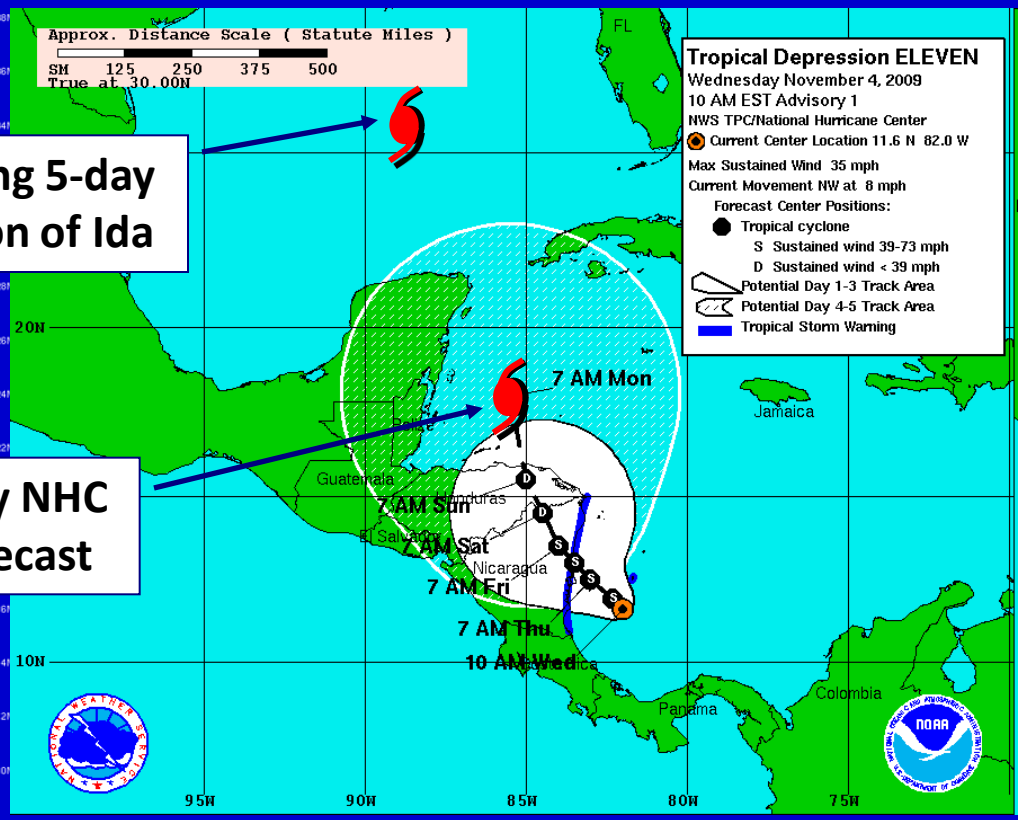
EXCERPT FROM NHC DISCUSSION HURRICANE EARL

A TURN TOWARD THE WEST-NORTHWEST IS EXPECTED AS THE CYCLONE BEGINS TO MOVE TOWARD A BREAK IN THE SUBTROPICAL RIDGE. WITH THE EXCEPTION OF NOGAPS AND THE NAVY GFDN...WHICH ARE BOTH INDICATING AN EARLIER TURN TOWARD THE NORTHWEST...THE DYNAMICAL MODELS ARE TIGHTLY CLUSTERED THROUGH DAY 5. THE NHC FORECAST TRACK IS BASED ON THE TVCN MODEL CONSENSUS AND IS CLOSE TO THE ECMWF AND GFS.

Timing (Along-Track Error) is Often an Issue

Ida (2009)





Track Model Guidance

NHC Forecast

Intensity Forecasting at NHC

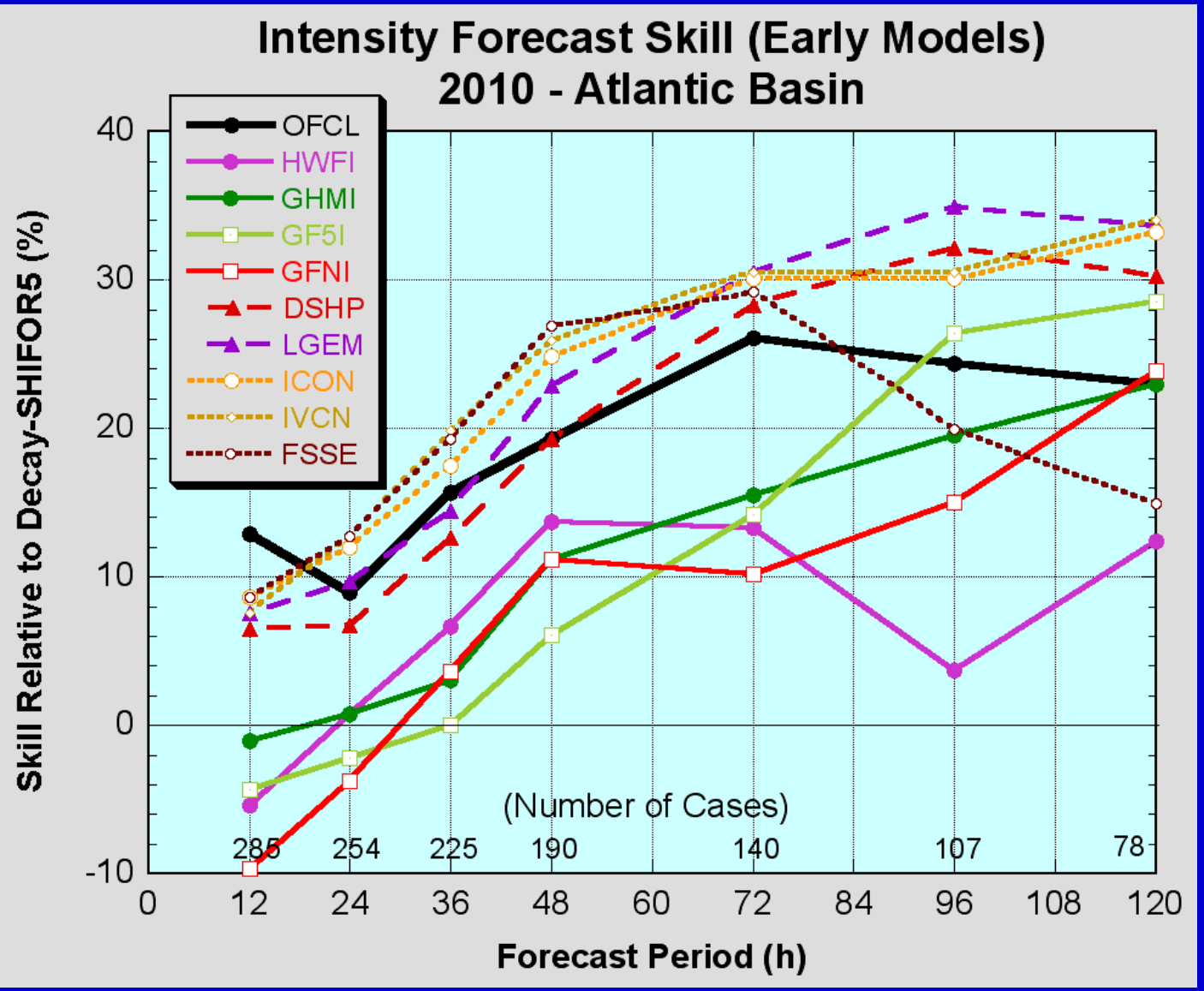
- Guidance models
- Synoptic (subjective) analysis
- General guidelines

Guidance Models used by NHC for Intensity Forecasting

- Decay-SHIPS & LGEM (Statistical-Dynamical)
- GFDL, GFDN, & HWRF (adjusted for biases in initial intensity) – these models are capable of predicting rapid changes in intensity, but they do not do it reliably
- Consensus of some or all of the above
- Global models (esp. for predicting environmental changes, e.g. changes in vertical shear, that could cause intensity change)
- SHIPS Rapid Intensification (RI) index gives probability of RI (30 kt or greater increase in 24 h)

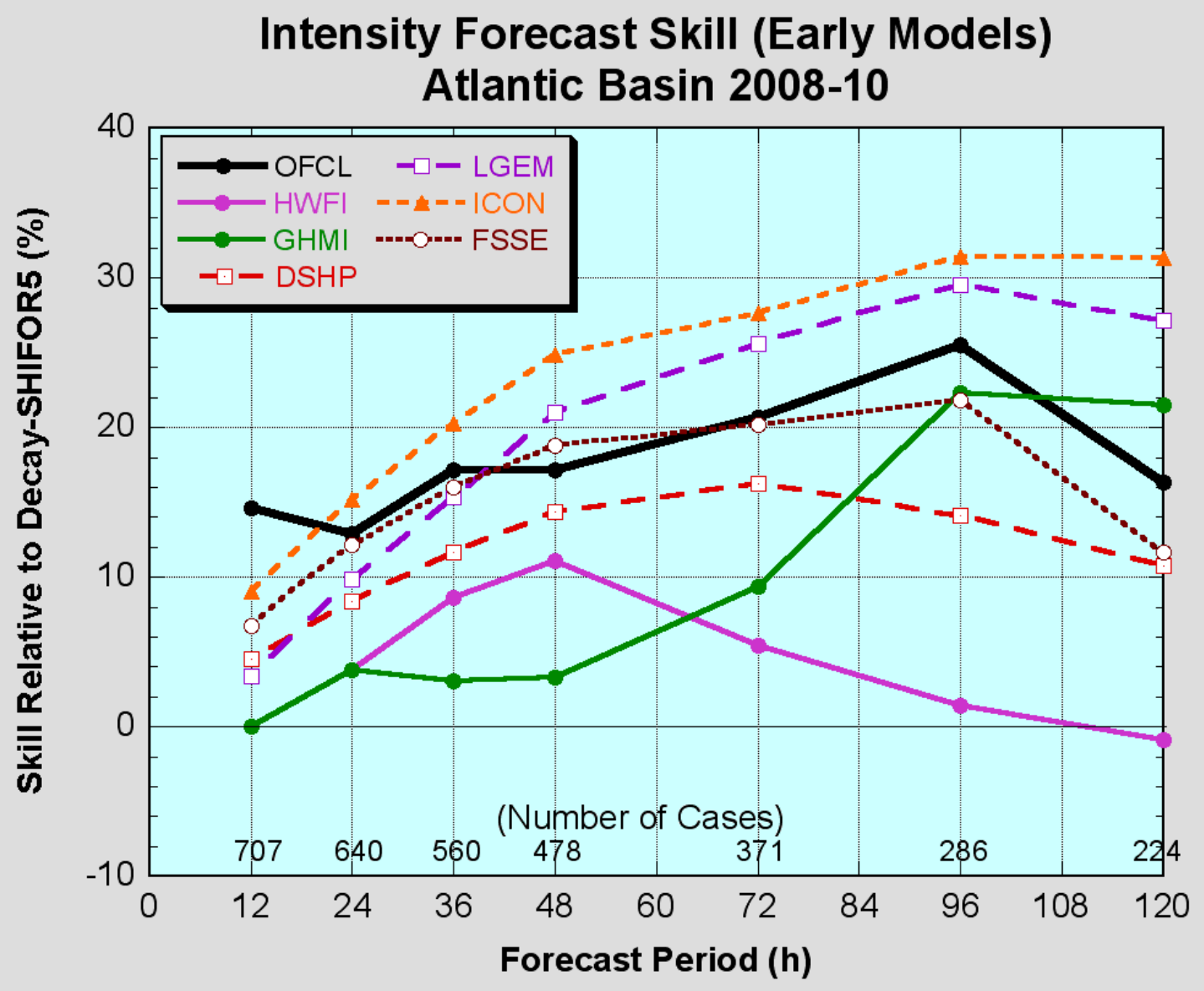
35

2010 Intensity Guidance

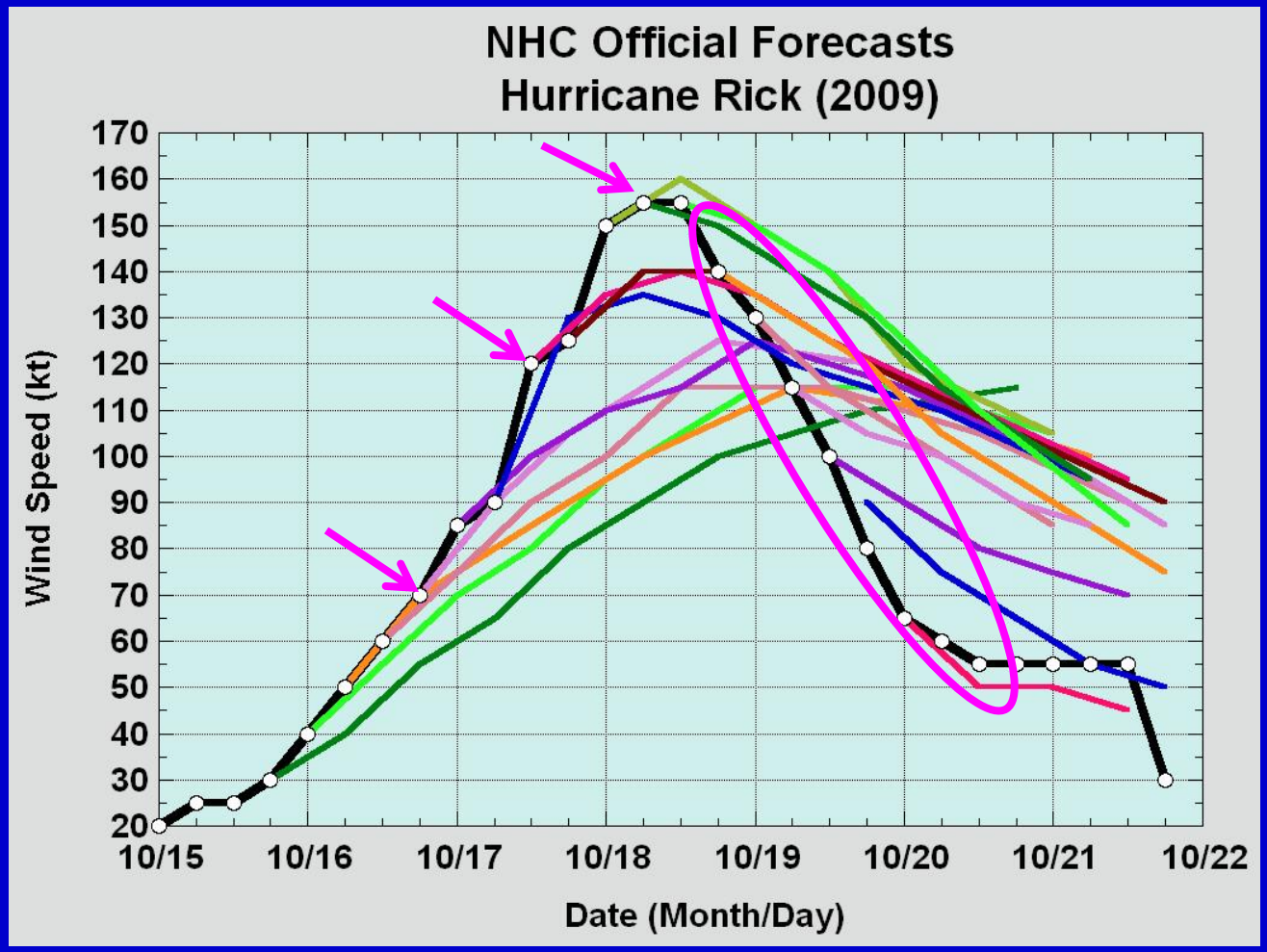


- Statistical and consensus models were competitive
- FSSE was the best model through 48 h, LGEM performed best beyond that
- Official forecasts paying too much attention to the dynamical guidance, especially late?

Atlantic Intensity Guidance

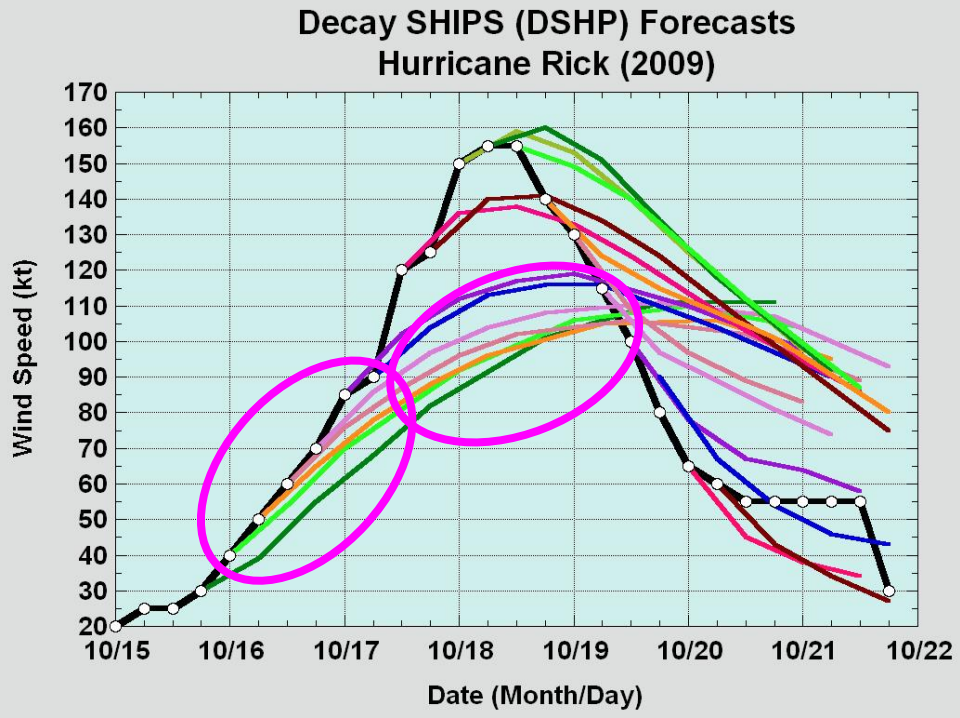


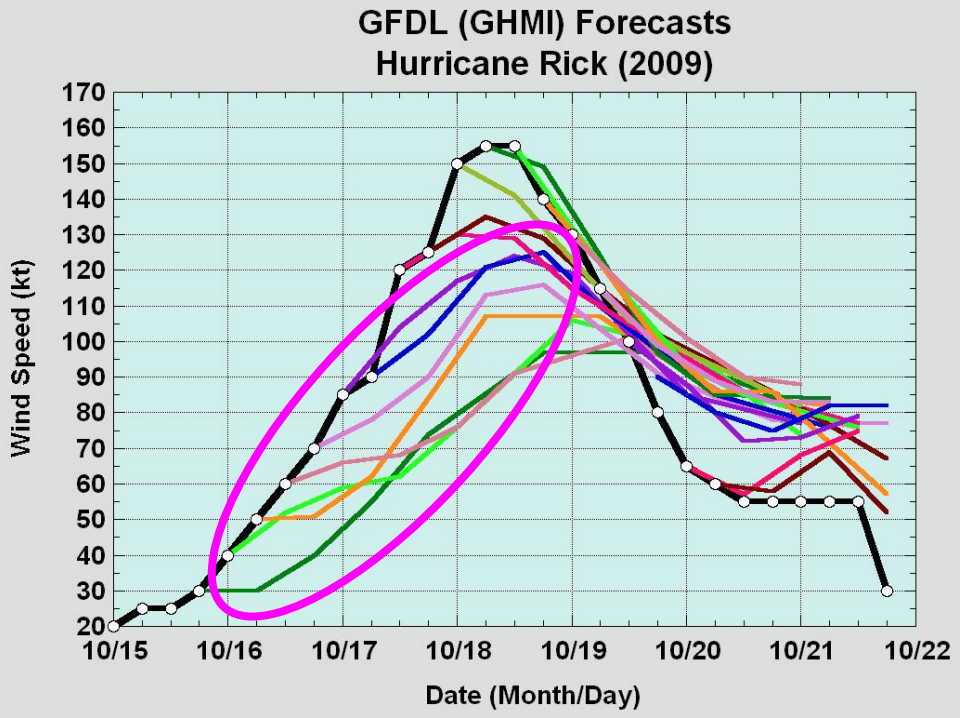
Difficulty with Rapid Intensity Change



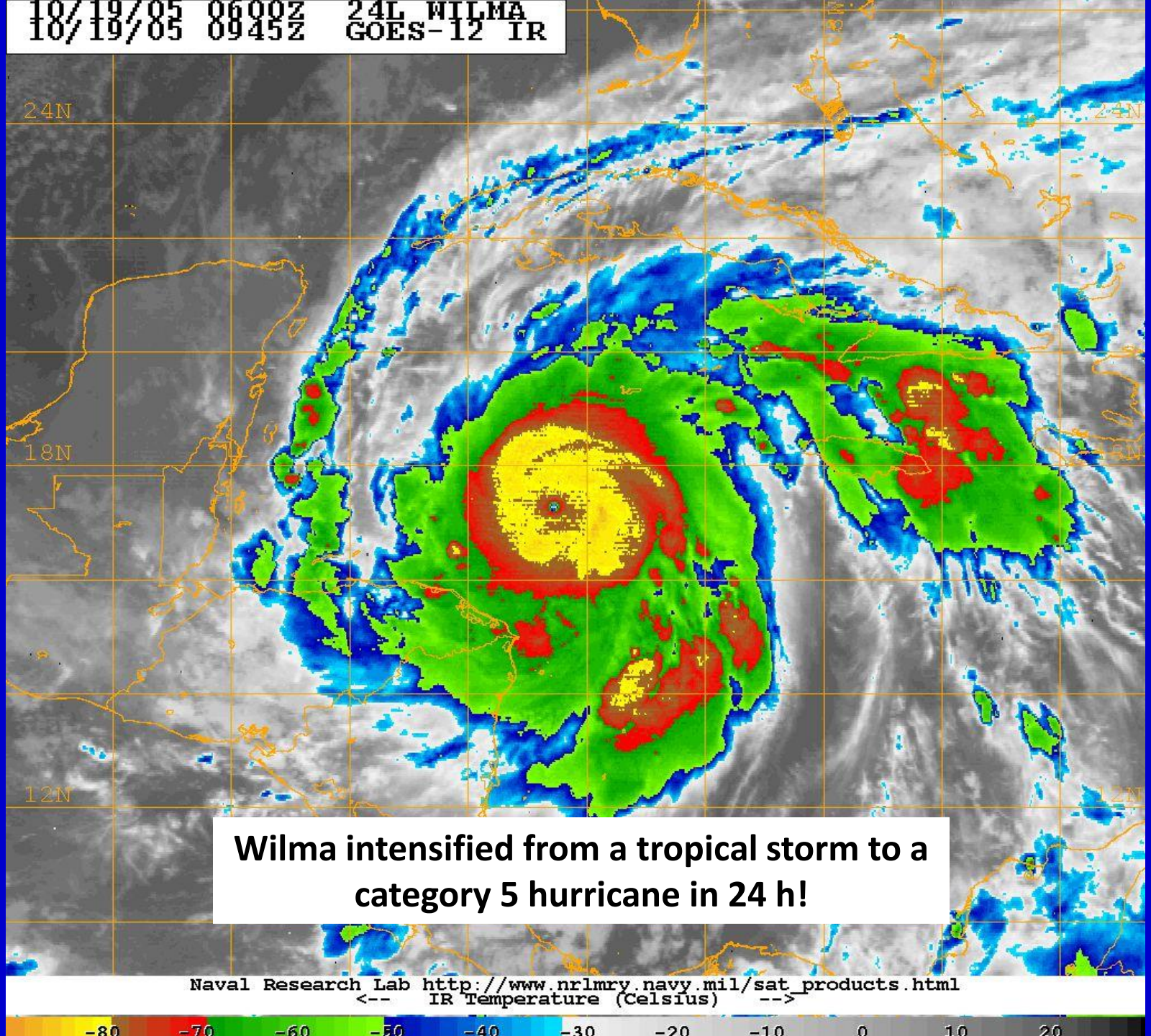
- First round of RI (intensification to Cat 1 hurricane) relatively well anticipated in official NHC forecasts
- Second more extreme instance of RI was not well forecast
- Rapid weakening after peak intensity not forecast well either

Difficulty with Rapid Intensity Change





- Decay-SHIPS showed some signal for first period of rapid intensification but badly under-forecast later intensification to cat 4/5
- GFDL can forecast more variability, but suffered from a low bias throughout Rick's life



Wilma intensified from a tropical storm to a category 5 hurricane in 24 h!

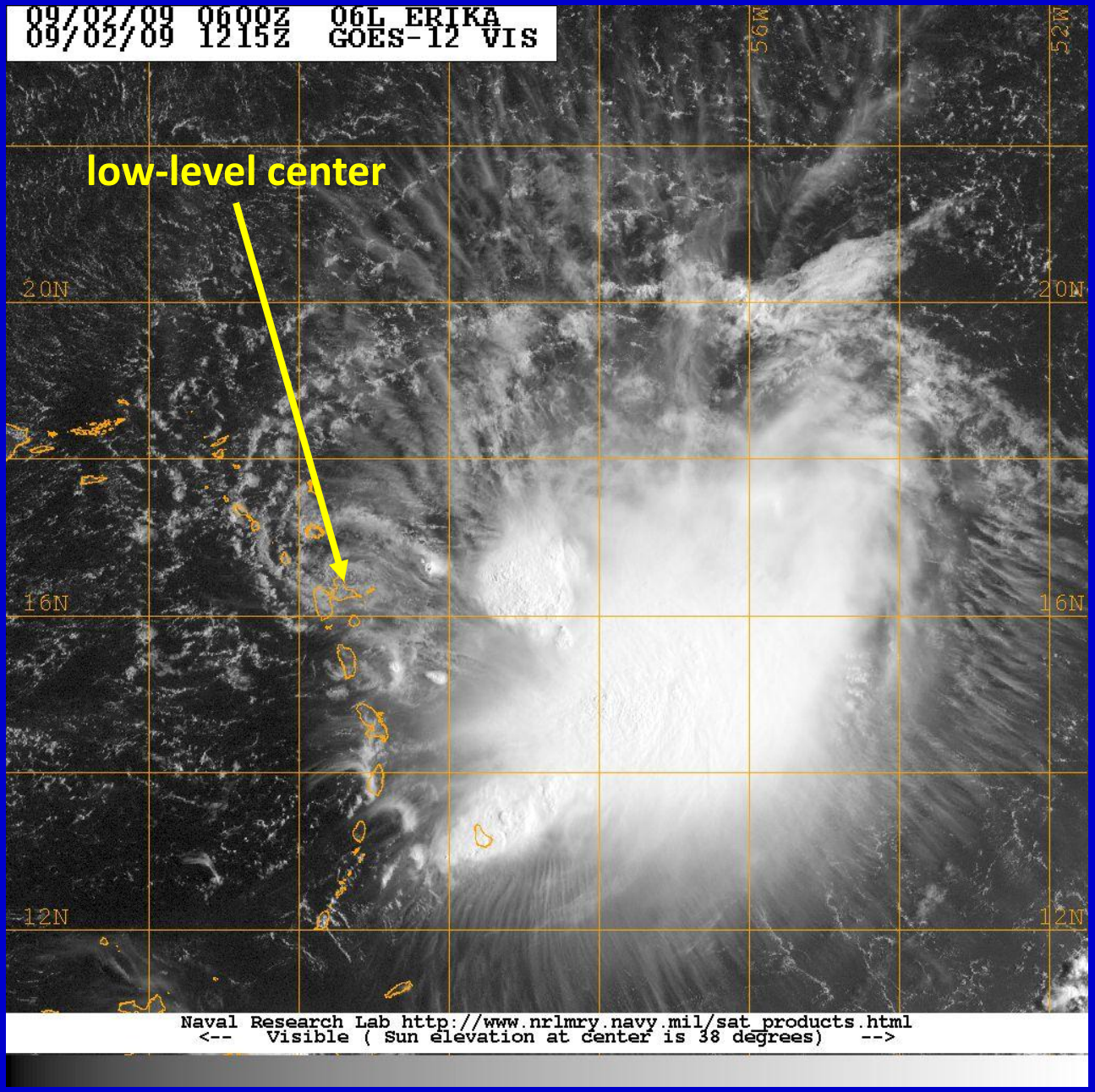
VERIFYING: 160 KNOTS

```
*    ATLANTIC SHIPS INTENSITY FORECAST        *
*         GOES/OHC INPUT INCLUDED             *

                    WILMA  10/18/05  18 UTC

TIME (HR)          0     6    12    18    24    36    48    60    72    84    96   108   120
V (KT) NO LAND    70    75    81    86    92   100   105   108   109   106   101    92    80
V (KT) LAND       70    75    81    86    92   100   105   108   109   106   101    67    61

          ** 2005 ATLANTIC RAPID INTENSITY INDEX **
        ( 25 KT OR MORE MAX WIND INCREASE IN NEXT 24 HR)

                    WILMA     10/18/05     18 UTC

12 HR PERSISTENCE (KT): Value:  10.0 Range: -20.0 to  25.0 Scaled value:  0.90
850-200 MB SHEAR (KT) : Value:   8.1 Range:  42.5 to   2.5 Scaled value:  0.86
SST (C)               : Value:  29.3 Range:  24.3 to  30.4 Scaled value:  0.82
POT = MPI-VMAX (KT)   : Value:  92.0 Range:  27.1 to 136.4 Scaled value:  0.59
850-700 MB REL HUM (%): Value:  81.6 Range:  57.0 to  88.0 Scaled value:  0.79
% area w/pixels <-30 C: Value:  98.0 Range:  17.0 to 100.0 Scaled value:  0.98
STD DEV OF IR BR TEMP : Value:  15.8 Range:  37.5 to   8.0 Scaled value:  0.74

Scaled RI index=  5.68 Prob of RI= 59.4% is   4.9 times the sample mean(12.1%)
```

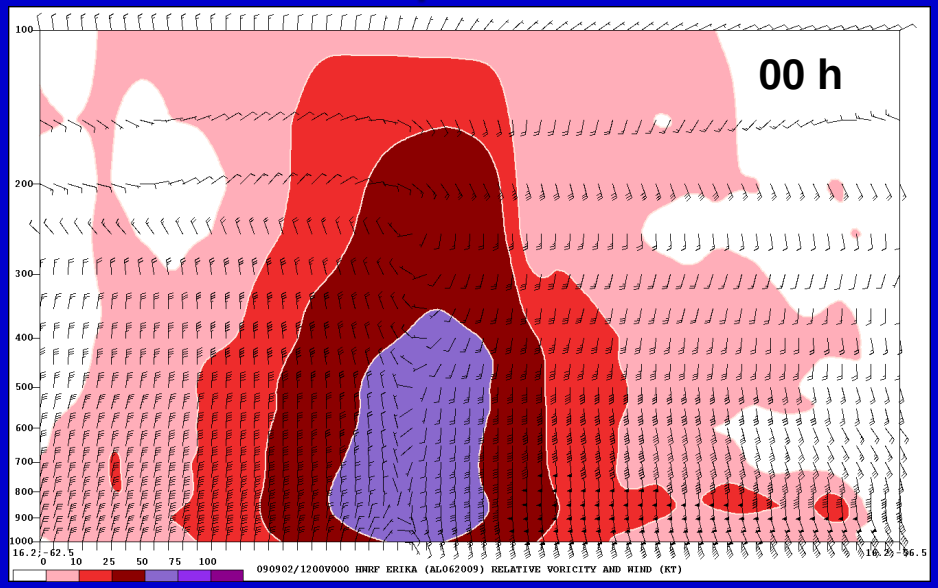
Official forecast called for 90-100 knots in 12-24 hours

```
INITIAL 18/2100Z 16.7N 81.5W 70 KT
12HR VT 19/0600Z 17.3N 82.3W 90 KT
24HR VT 19/1800Z 18.2N 83.5W 100 KT
36HR VT 20/0600Z 19.1N 84.5W 110 KT
48HR VT 20/1800Z 20.2N 85.2W 115 KT
72HR VT 21/1800Z 22.5N 85.5W 110 KT
96HR VT 22/1800Z 25.0N 82.5W 100 KT
120HRVT 23/1800Z 30.5N 75.5W 70 KT
```

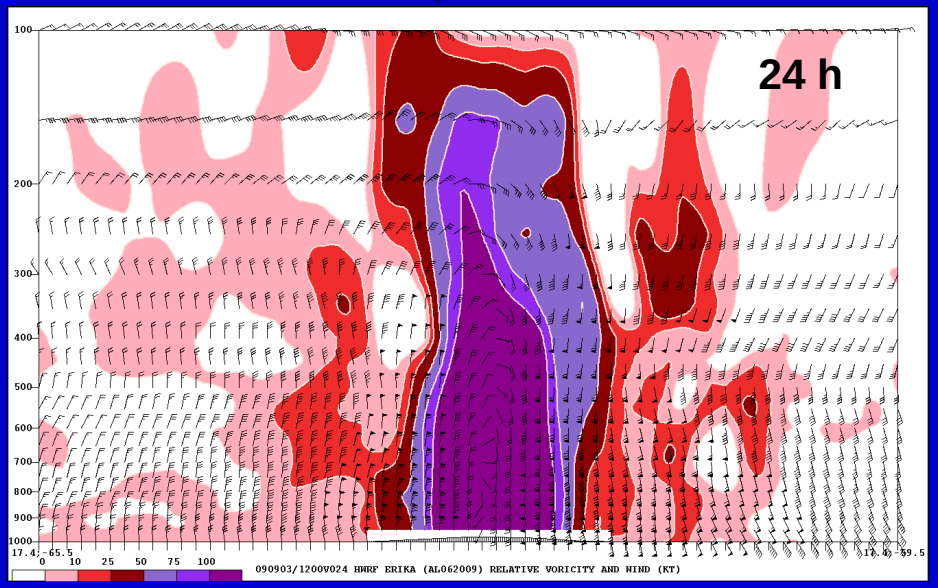
Tropical Storm Erika – 2 September 2009



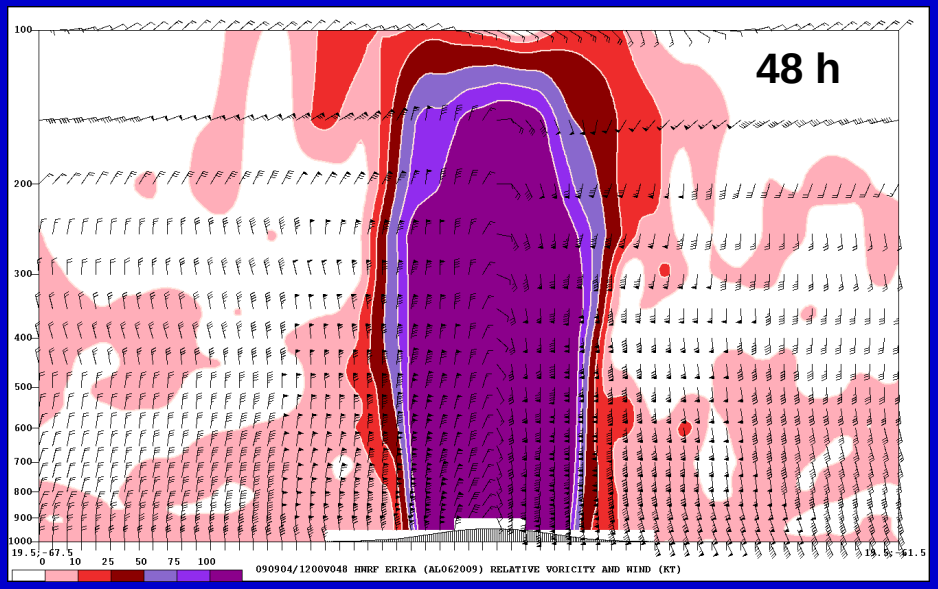
Zonal cross-section of wind and relative vorticity through HWRF forecast of Tropical Storm Erika initialized at 1200 UTC 2 Sep. 2009

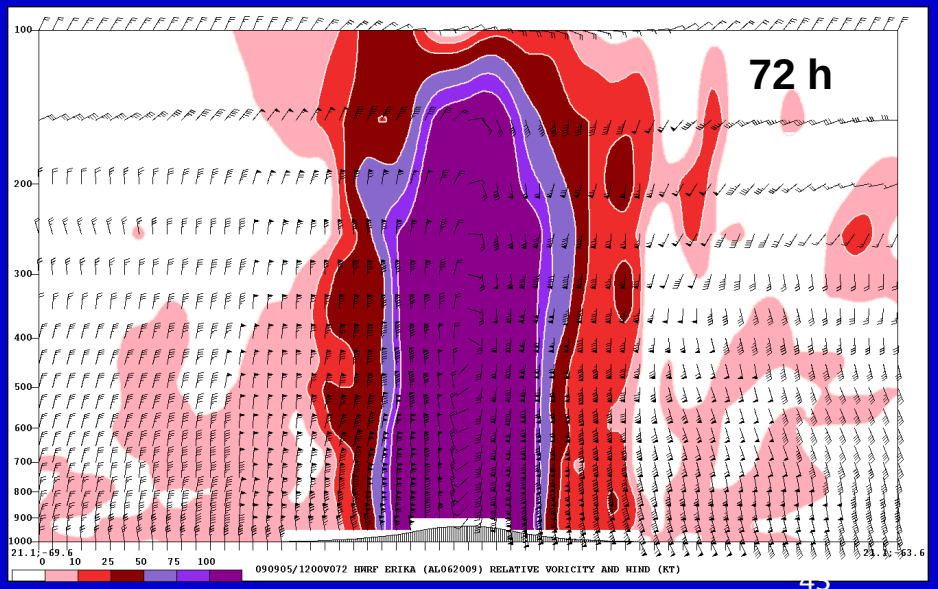


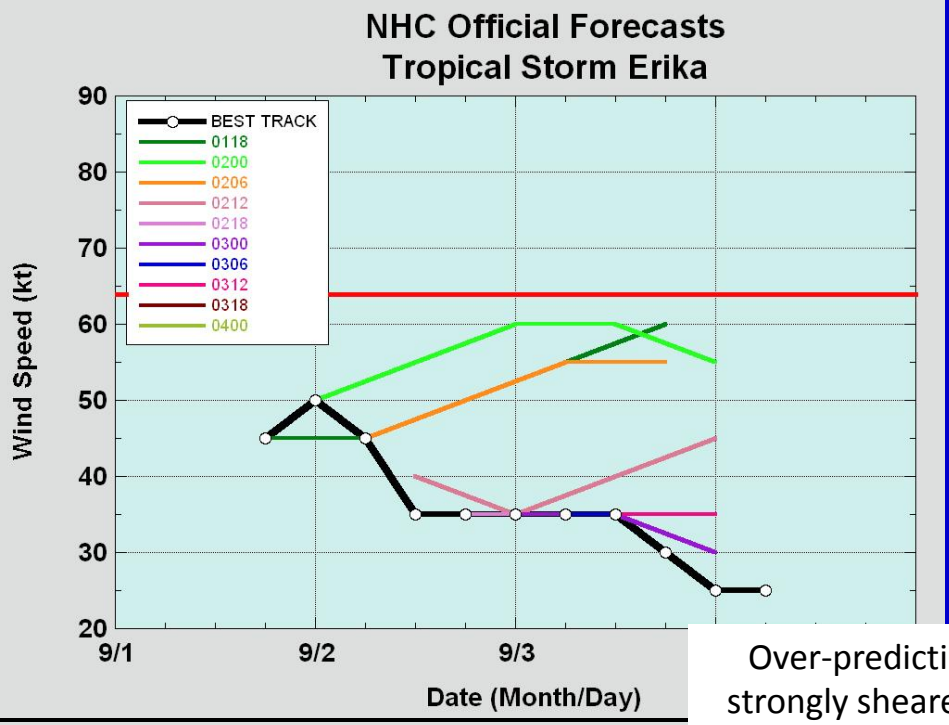
16.2°N
62.5°W

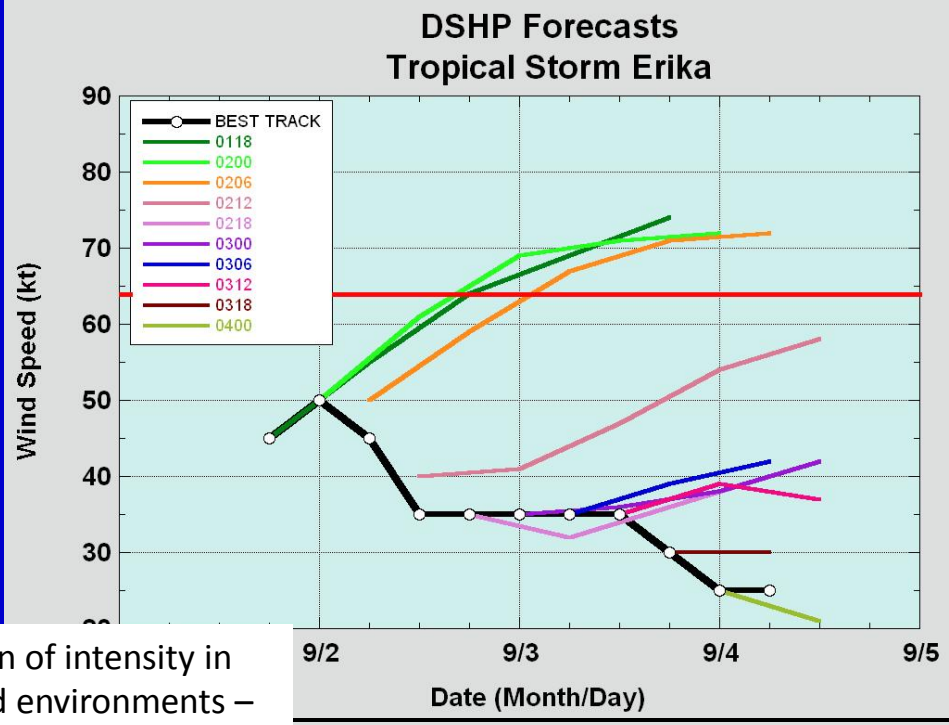


16.2°N
56.5°W

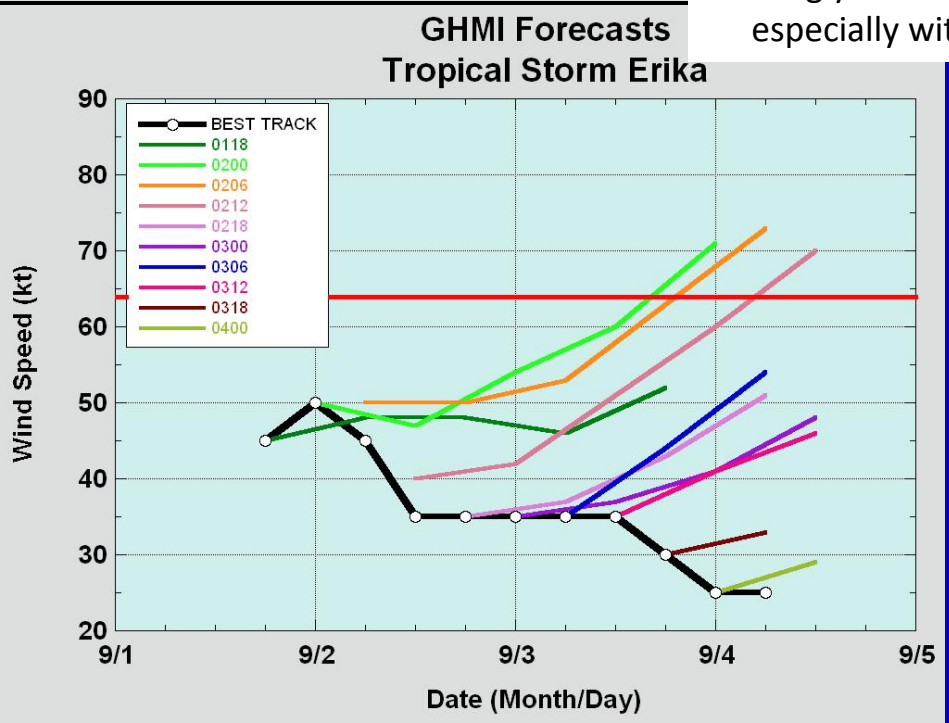


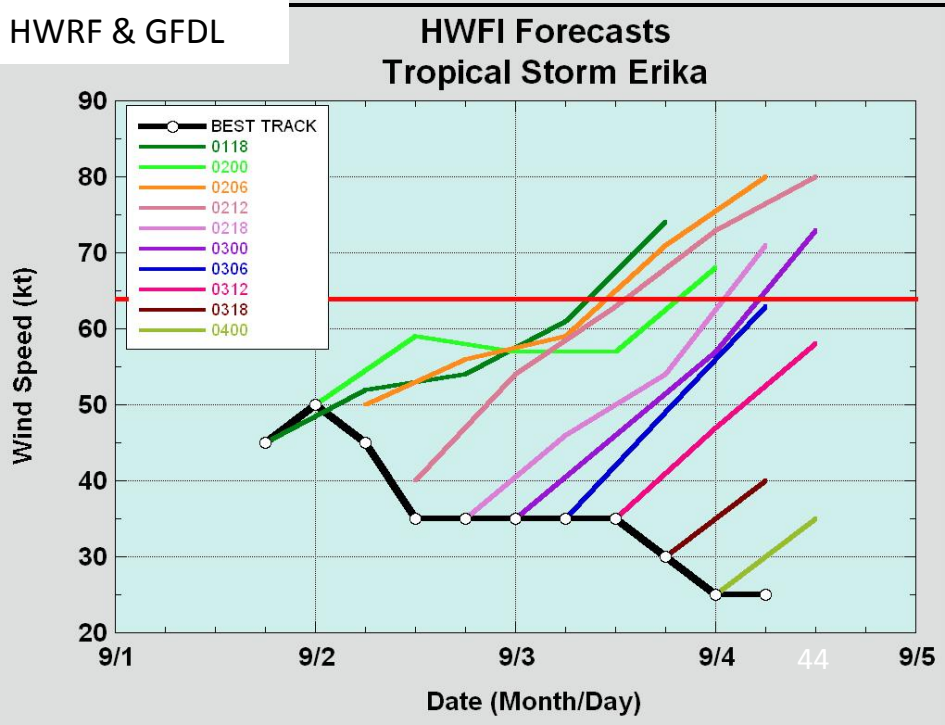


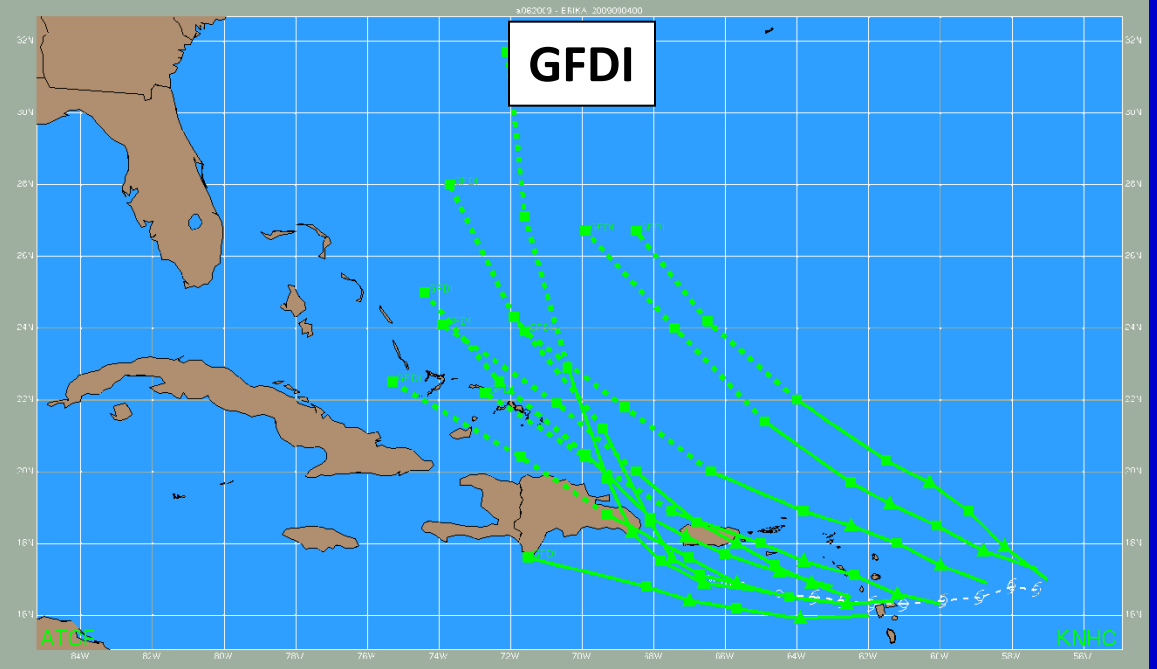


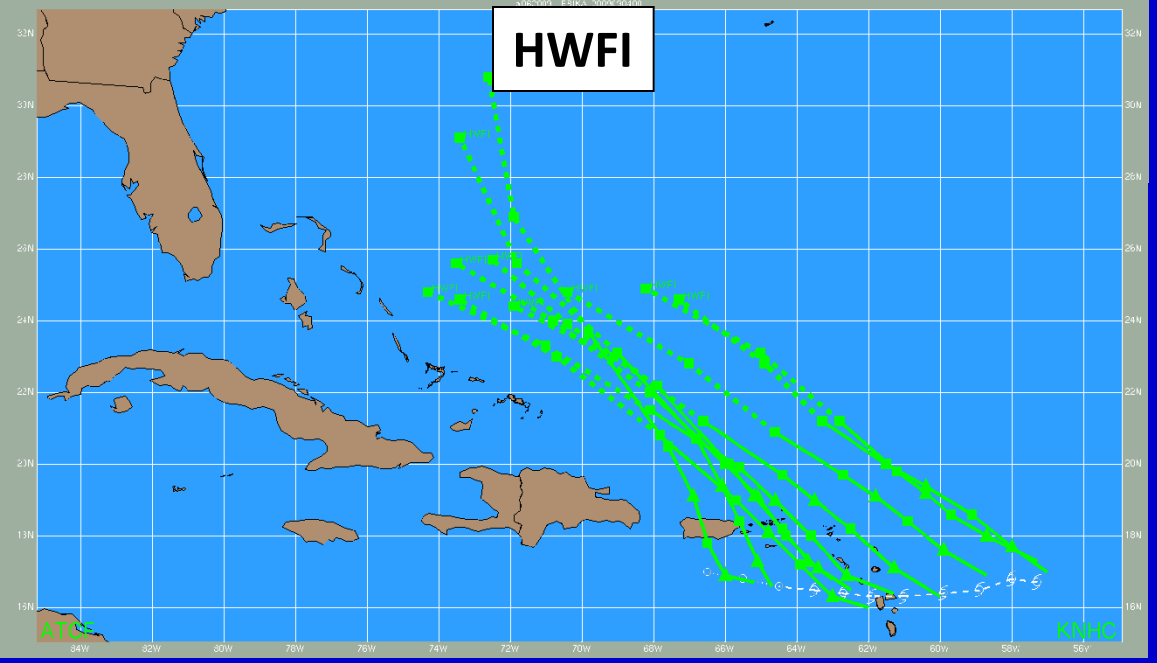


Over-prediction of intensity in strongly sheared environments – especially with HWRF & GFDL









Impact of bad model intensity forecast on track forecast; example of T.S. Erika (2009)

Significant northward bias in GFDL and HWRF (storm forecast to be too strong in these models)

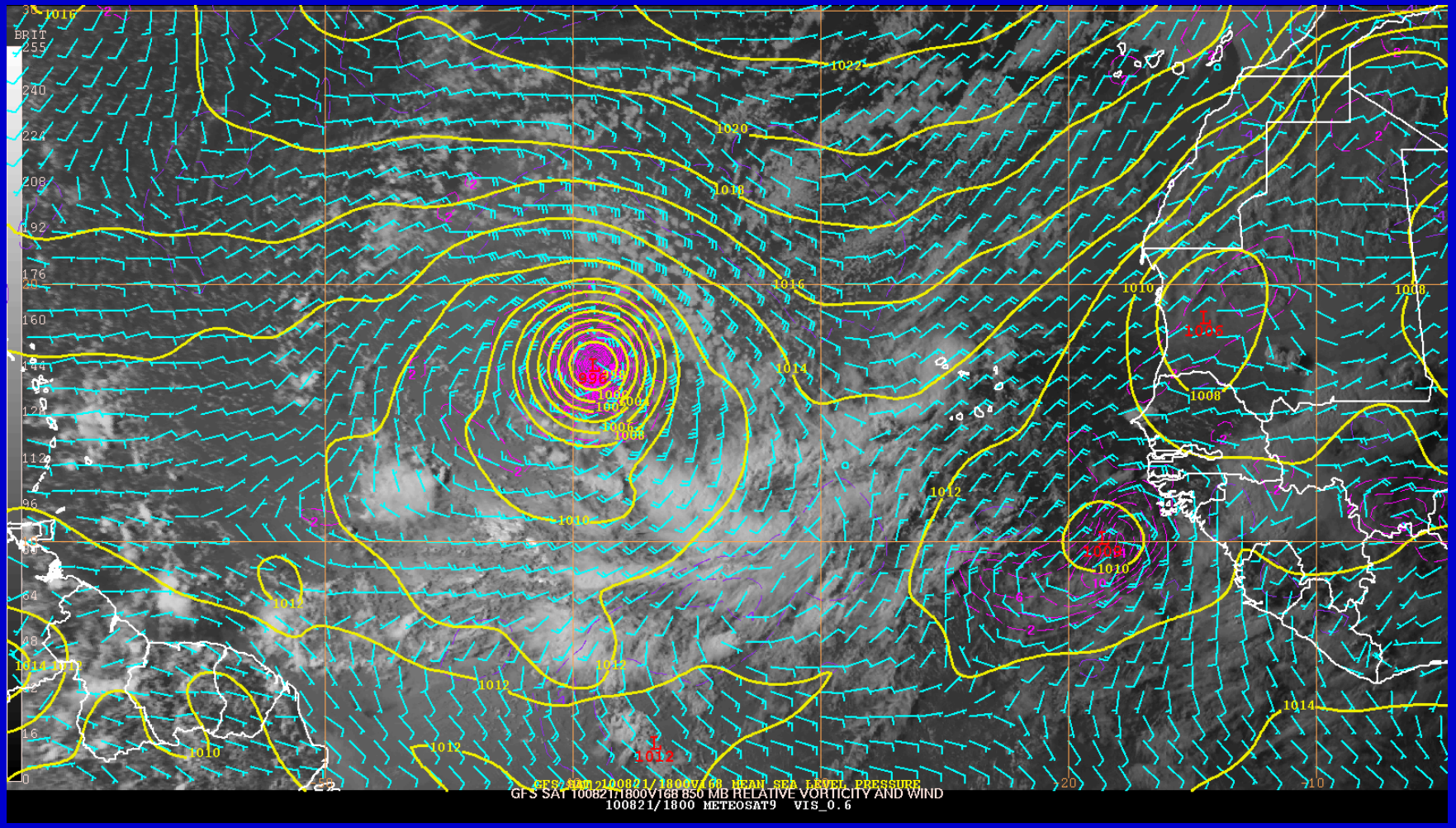
NHC Official Intensity Forecasts

- Based on guidance from SHIPS and LGEM, GFDL and HWRF and qualitative guidance from global models
  - Consensus technique combining SHIPS and LGEM with GFDL and HWRF holds some promise for modest improvements if dynamical models can improve
- Persistence is used quite a bit!
- Obvious signs in the environment, i.e. cooler waters, increasing upper-level winds, are taken into account
- Forecasts generally corresponds to what is *normal* for a storm in any particular situation (e.g., standard Dvorak development rate)
  - Forecast tends to be conservative; e*xtreme events rarely forecast*
- At 24 h and beyond, the average error is roughly 1 SSHS Category (15-20 knots)

TC Genesis Forecasting at NHC

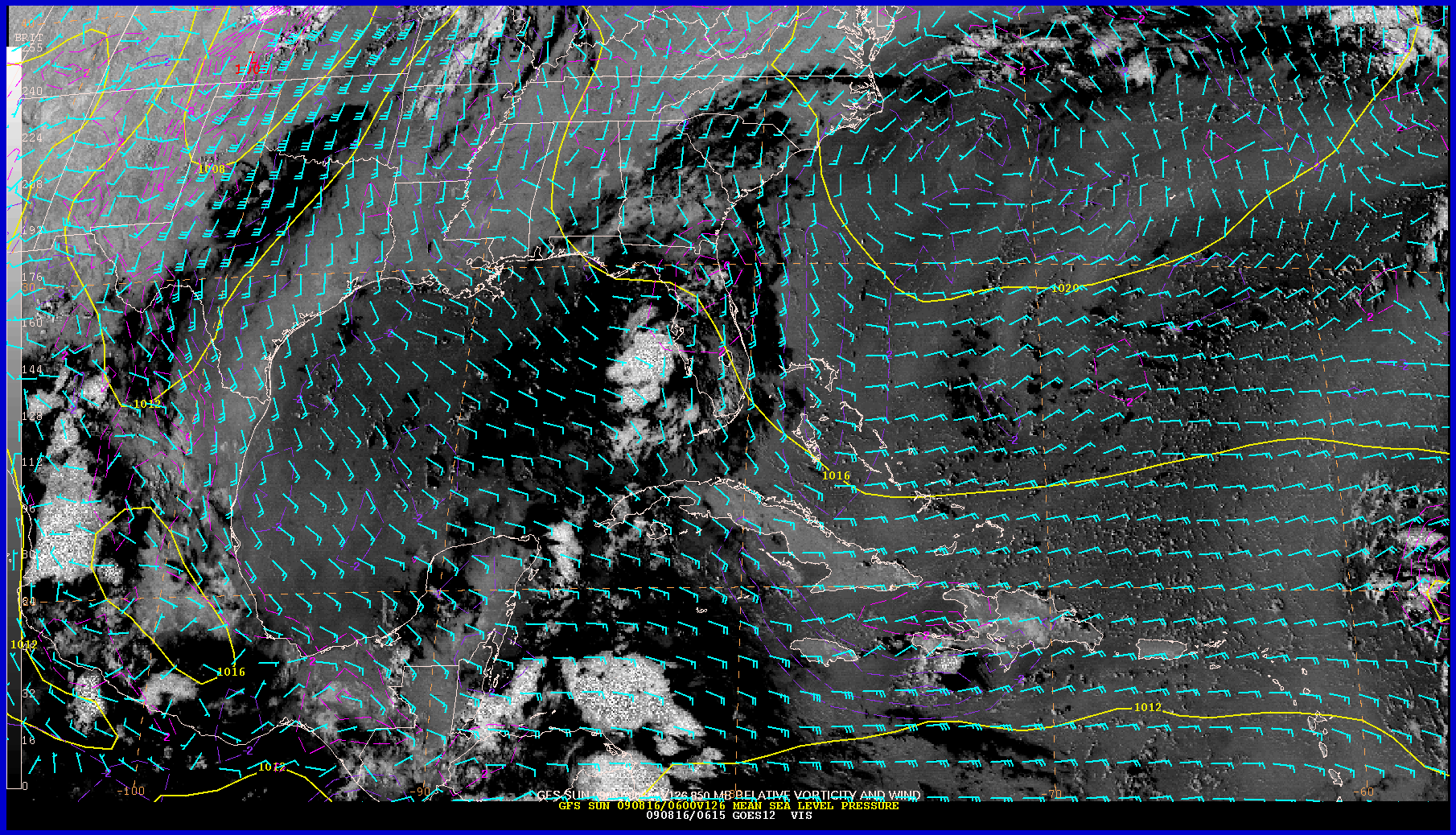
- Primary numerical guidance comes from global models
- GFS and ECMWF seem to have greatest skill, but more systematic verification is needed
- Considerable subjectivity involved in NHC genesis forecasts
- Models appear to have some geographical biases
  - Seem to do better when large-scale influences are the dominant mechanism (e.g., monsoonal flow near western Africa)
  - Models often fail to predict genesis over the Tropics between about 50°W and 70°W
  - Forecasts are also problematic in the Gulf of Mexico since models have difficulty depicting genesis there

Genesis of Hurricane Danielle (2010)



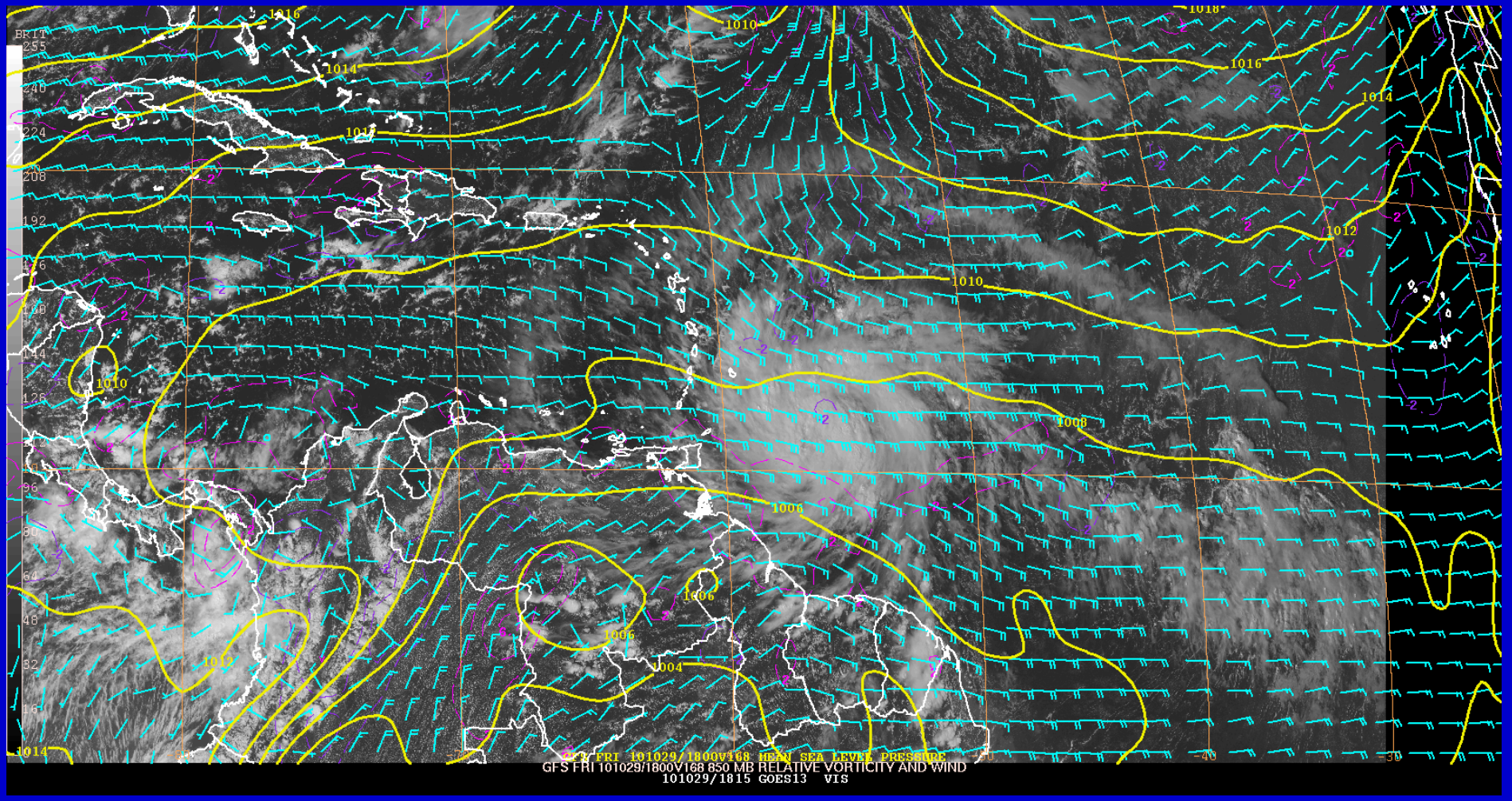
Series of GFS model forecasts of MSLP and 850-mb winds/vorticity, starting from 126 hours out, all verifying at the time of genesis (1800 UTC 8/21/10)

Genesis of T.S. Claudette (2009)



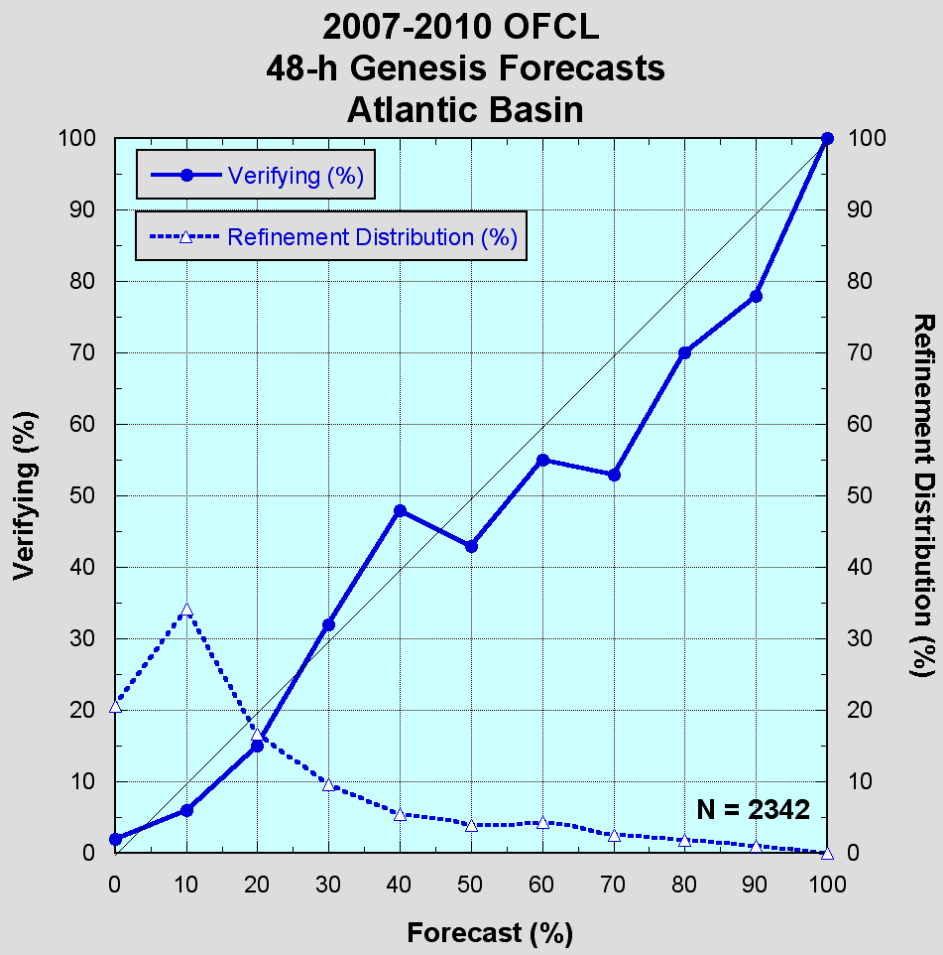
Series of GFS model forecasts of MSLP and 850-mb winds/vorticity, starting from 126 hours out, all verifying at the time of genesis (0600 UTC 8/16/09)

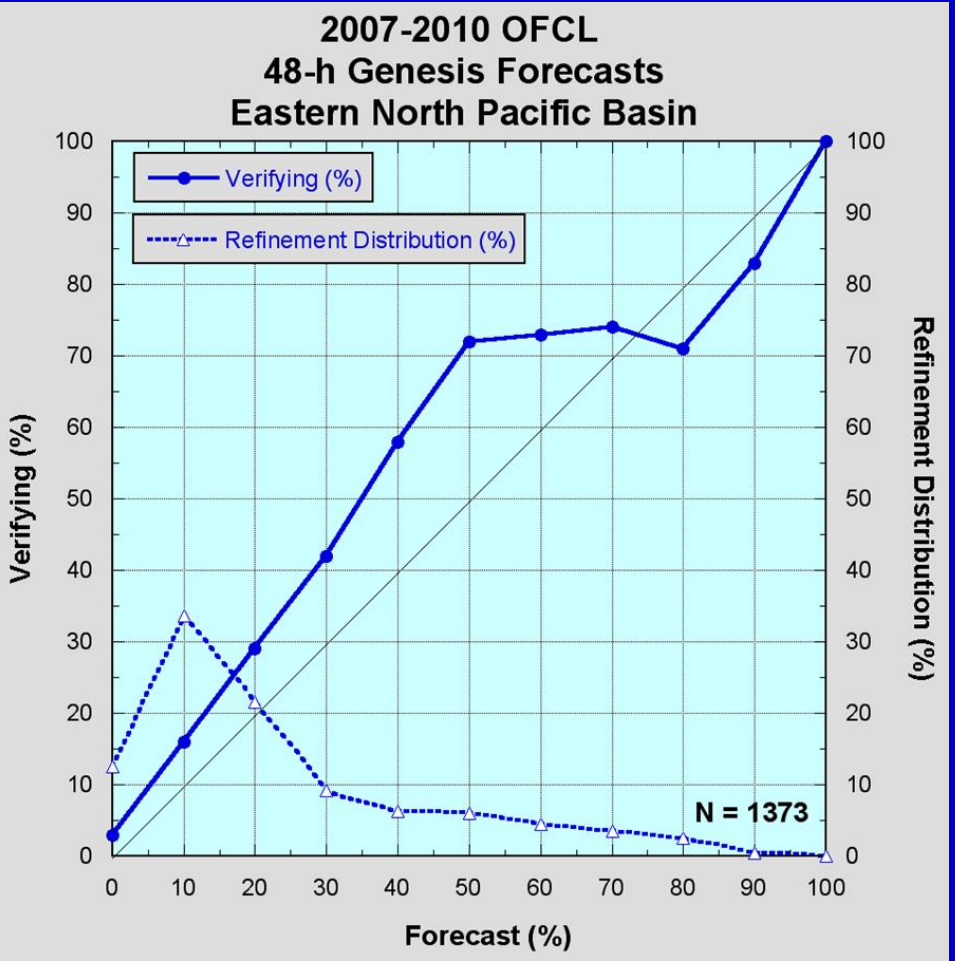
Genesis of Hurricane Tomas (2010)



Series of GFS model forecasts of MSLP and 850-mb winds/vorticity, starting from 126 hours out, all verifying at the time of genesis (1800 UTC 10/29/09)

Genesis Forecast Verification





Forecast probabilities verify pretty well in the Atlantic, although NHC tends to underpredict TC formation in the East Pacific

Future Challenges

- Track and intensity forecasts for days 6-7
- Size/Structure: additional quadrant radii of 34-, 50-, and 64-kt winds beyond 36 h? Full 2-d distribution of surface winds?
- Genesis forecasting through 120 h
- Track/intensity forecasts for TCs that have not yet formed
  - Pre-genesis watches and warnings?
- More detailed information on impacts:
  - Storm surge (including coastal waves)
  - Rainfall
  - Tornadoes

Thanks to Richard Pasch, James Franklin, Dan Brown and my other colleagues at NHC