OVERVIEW OF CURRENT TROPICAL CYCLONE FORECAST GUIDANCE AVAILABLE TO NWS

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TYPES OF GUIDANCE WE USE:

- **Purely statistical**
- **Statistical/dynamical**
- **Trajectory**
- **Limited-area dynamical deterministic**
- **Global dynamical deterministic**
- **Individual dynamical model ensemble**
- **Multi-model ensemble or consensus “models”**
- **Guidance on guidance**

Purely statistical guidance:

- CLIPER- CLImatology and PERsistence for track (used as a baseline for track forecast skill)
- SHIFOR- Statistical Hurricane Intensity FORecast, which is climatology and persistence for intensity (used as a baseline for intensity forecast skill)
- RII- Rapid Intensification Index, uses observed large-scale predictors with a linear discriminant analysis to give a probability of RI (intensity increase of 30 kt or more over the ensuing 24 h)

Statistical/dynamical guidance:

- SHIPS- Statistical Hurricane Intensity Prediction Scheme-predicts intensity change using large-scale (observed and dynamical model-predicted) and inner-core (satellite-observed) variables with a multiple-regression approach
- DSHIPS is the SHIPS model with inland decay
- LGEM- Logistic Growth Equation Model uses similar predictors as those for DSHIPS but is more sensitive to changes of these predictors over the 5-day forecast period (also more sensitive to track forecast errors)

Trajectory model guidance:

- Beta and Advection Model, BAM, uses trajectories from smoothed global dynamical model forecast with a correction added to simulate the beta drift
- BAM shallow, BAMS, uses 850-700 mb layer average
- BAM medium, BAMM, uses 850-400 mb layer average
- BAM deep, BAMD, uses 850-200 mb layer average
- BAM track forecasts can still be competitive with dynamical guidance

Limited-area dynamical guidance:

- Limited-area barotropic model, LBAR; generally the least skillful track forecast model
- Hurricane WRF model, HWRF; made operational a couple of years ago but still being developed
- GFDL hurricane model; generally our most reliable limited-area dynamical model for track at shorter time ranges
- Both HWRF and GFDL have nested grids with ~9 km resolution innermost mesh
- Both HWRF and GFDL are erratic for intensity prediction

Global dynamical guidance:

- NWS Global Forecast System, GFS, spectral model with ~35 km horizontal resolution and 64 levels (planned upgrade to ~27 km resolution this summer)
- Navy Operational Global Atmospheric Prediction System, NOGAPS, spectral model with ~55 km horizontal resolution and 60 levels (implemented 4D-VAR data assimilation late last September)
- United Kingdom Meteorological, UKMET, Office global model, grid-point with ~25 km horizontal resolution

Global dynamical guidance (cont.):

- European Centre for Medium-Range Weather Forecasts, ECMWF, global model, spectral with ~16 km horizontal resolution and 91 levels; as opposed to the other global models, the ECMWF model does no bogussing, relocation, or other adjustments to the initial conditions to account for existing TCs

Global dynamical guidance (cont.):

- GFS ensemble, GEFS, ~70 km control with 20 perturbed members; ensemble mean forecast is called AEMI
  - Member initial states perturbed using Ensemble Transform method; TC center relocation for each member
- ECMWF ensemble, EPS, ~30 km control with 50 perturbed members
  - Member initial states perturbed using Singular Vectors
- Other ensembles, such as NOGAPS or Canadian model ensemble have not been used much by NHC

“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 GFS, UKMET, GFDL, NOGAPS, ECMWF, etc., are not available until 16Z-19Z, well after forecast is made and released. Therefore, 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: GFSI, UKMI, GFDI, HWFI, NGPI, ECMI, etc.

Early vs. late models (cont.):

- 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.

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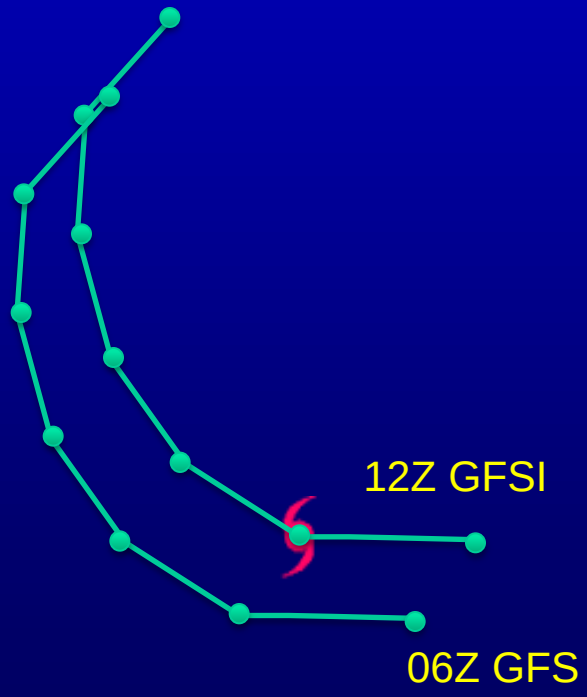
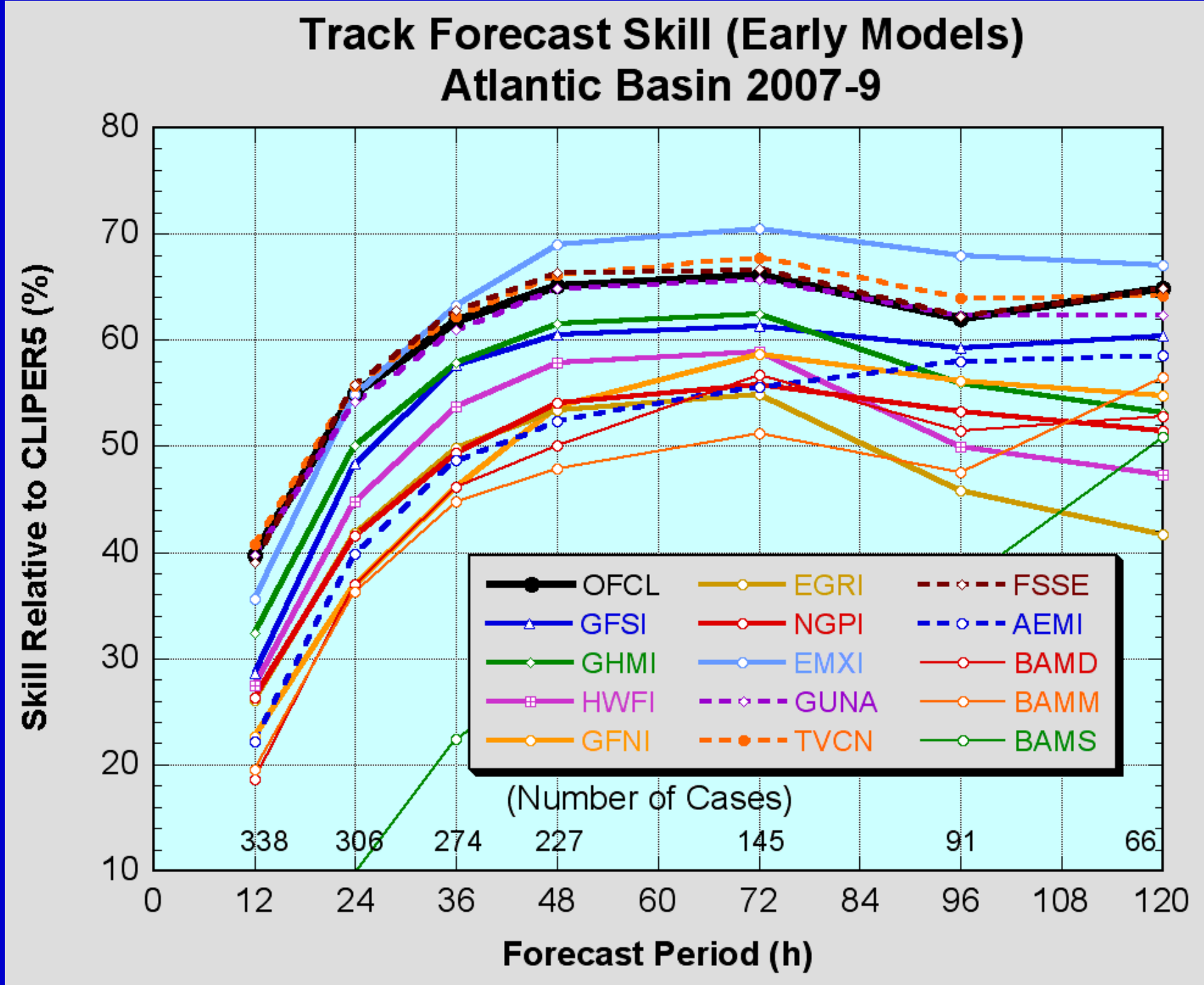


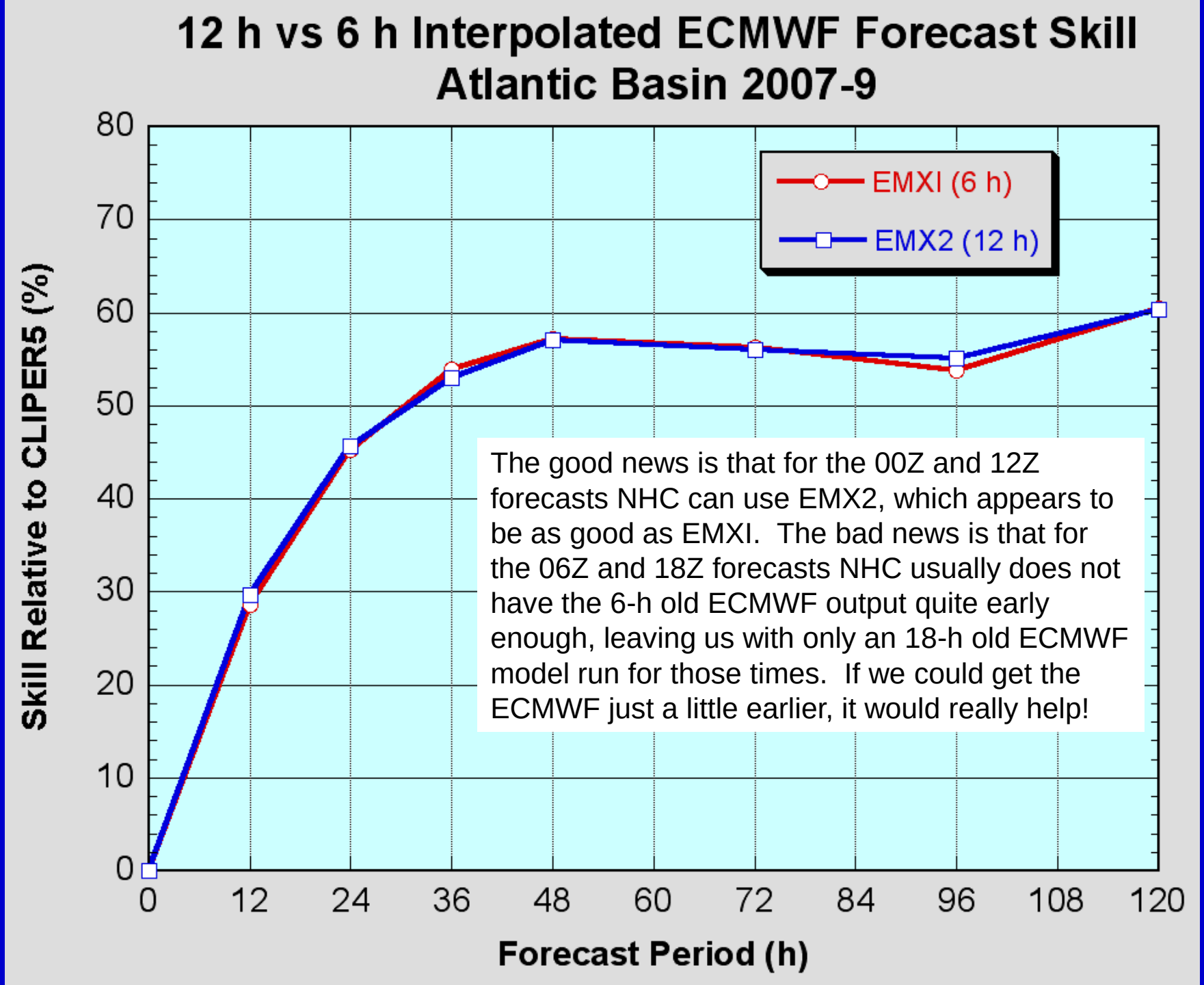
Simple consensus models for track and intensity (created by taking averages of position and intensity forecasts from the input models):

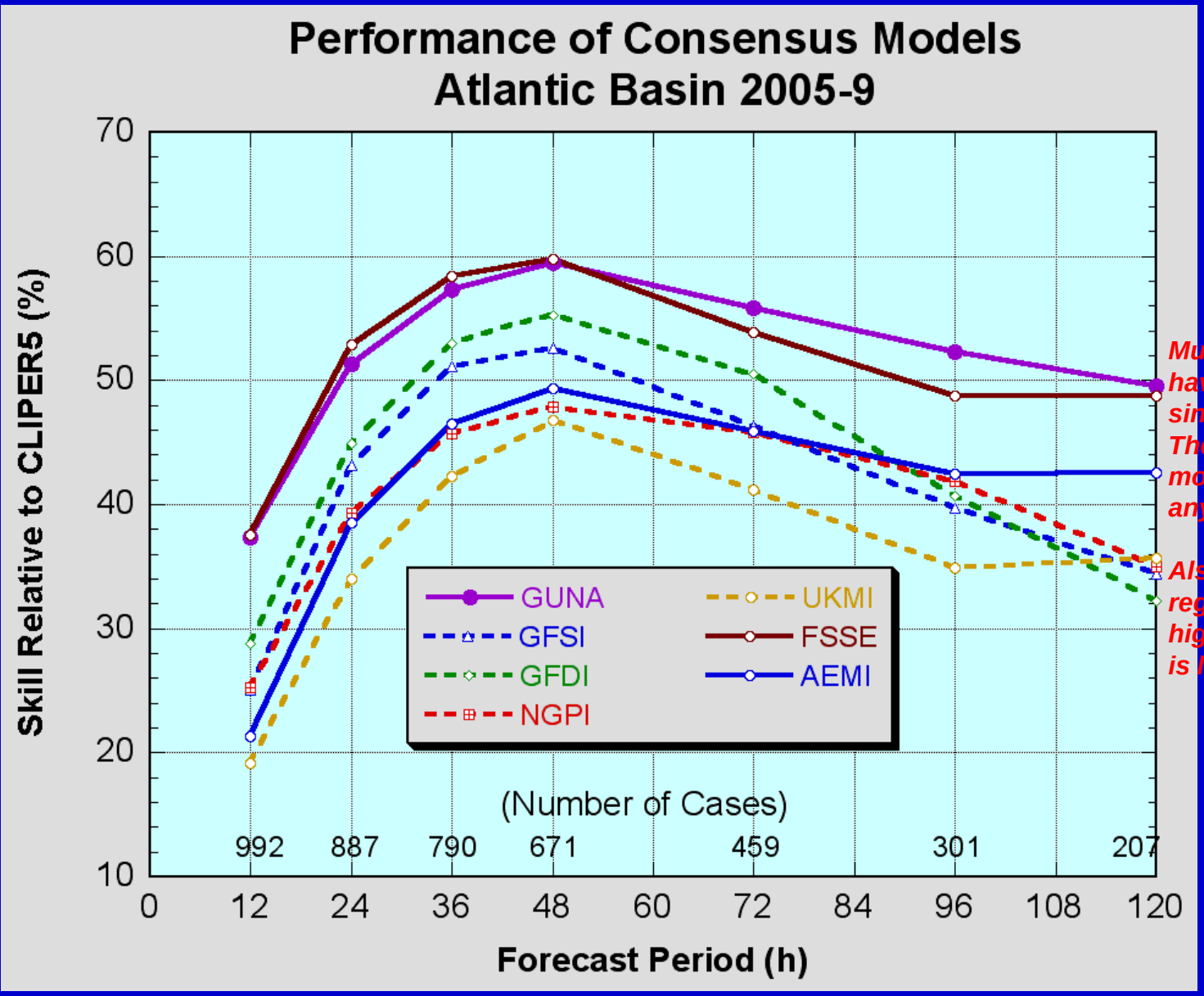
- Fixed consensus (require all present)
  - TCON: GFSI EGRI NGPI GHMI HWFI
  - GUNA: GHMI EGRI NGPI AVNI
  - ICON: DSHP LGEM GHMI HWFI
- Variable consensus (require 2 present)
  - TVCN: AVNI EGRI NGPI GHMI HWFI GFNI EMXI
  - IVCN: DSHP LGEM GHMI HWFI GFNI

“Smart” consensus models:

- Corrected consensus version of TCON, TCCN (track only) statistically based on initial storm parameters
- Corrected consensus version of TVCN, TVCC (track only) statistically based on initial storm parameters
- Corrected consensus version of GUNA, CGUN (track only) statistically based on initial storm parameters
- Florida State University Superensemble, FSSE, a weighted combination of dynamical guidance and the previous official forecast; attempts to correct for model biases (track and intensity)


Track Forecast Skill (Early Models)
Atlantic Basin 2007-9
Skill Relative to CLIPER5 (%)
80
70
60
50
40
30
20
10
0
12
24
36
48
60
72
84
96
108
120
Forecast Period (h)
OFCL
GFSI
GHMI
HWFI
GFNI
EGRI
NGPI
EMXI
GUNA
TVCN
FSSE
AEMI
BAMD
BAMM
BAMS
(Number of Cases)
338
306
274
227
145
91
66


12 h vs 6 h Interpolated ECMWF Forecast Skill
Atlantic Basin 2007-9
Skill Relative to CLIPER5 (%)
Forecast Period (h)
EMXI (6 h)
EMX2 (12 h)
0
10
20
30
40
50
60
70
80
0
12
24
36
48
60
72
84
96
108
120
The good news is that for the 00Z and 12Z forecasts NHC can use EMX2, which appears to be as good as EMXI. The bad news is that for the 06Z and 18Z forecasts NHC usually does not have the 6-h old ECMWF output quite early enough, leaving us with only an 18-h old ECMWF model run for those times. If we could get the ECMWF just a little earlier, it would really help!

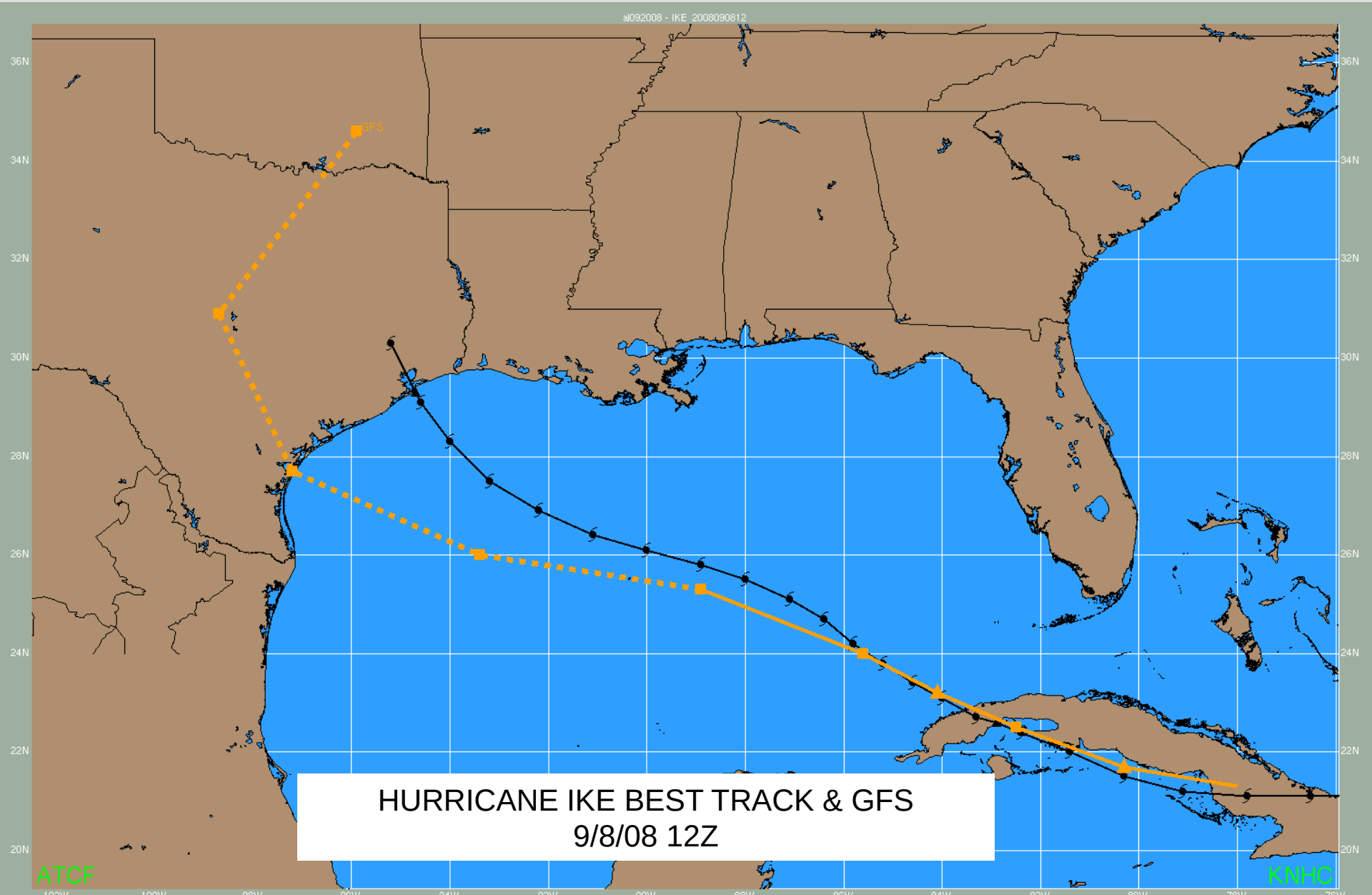


Multi-model consensus models have much greater skill than the single-model consensus AEMI. The multi-model consensus models are more skillful than any of the member models.

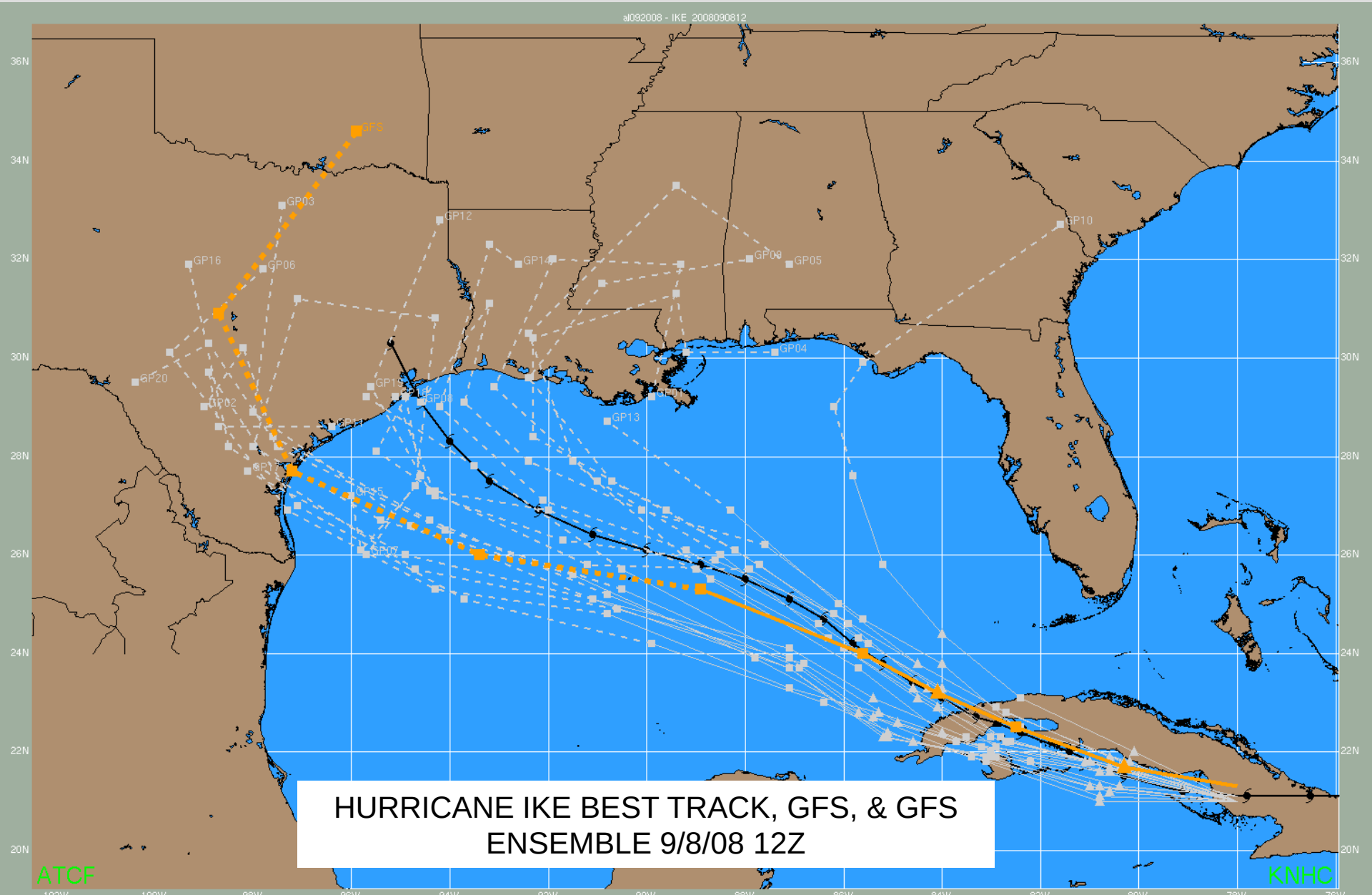
Also notice that GFDL (a regional model) has relatively high skill at the shorter leads bu is last by 120 h.

GFS Ensemble example

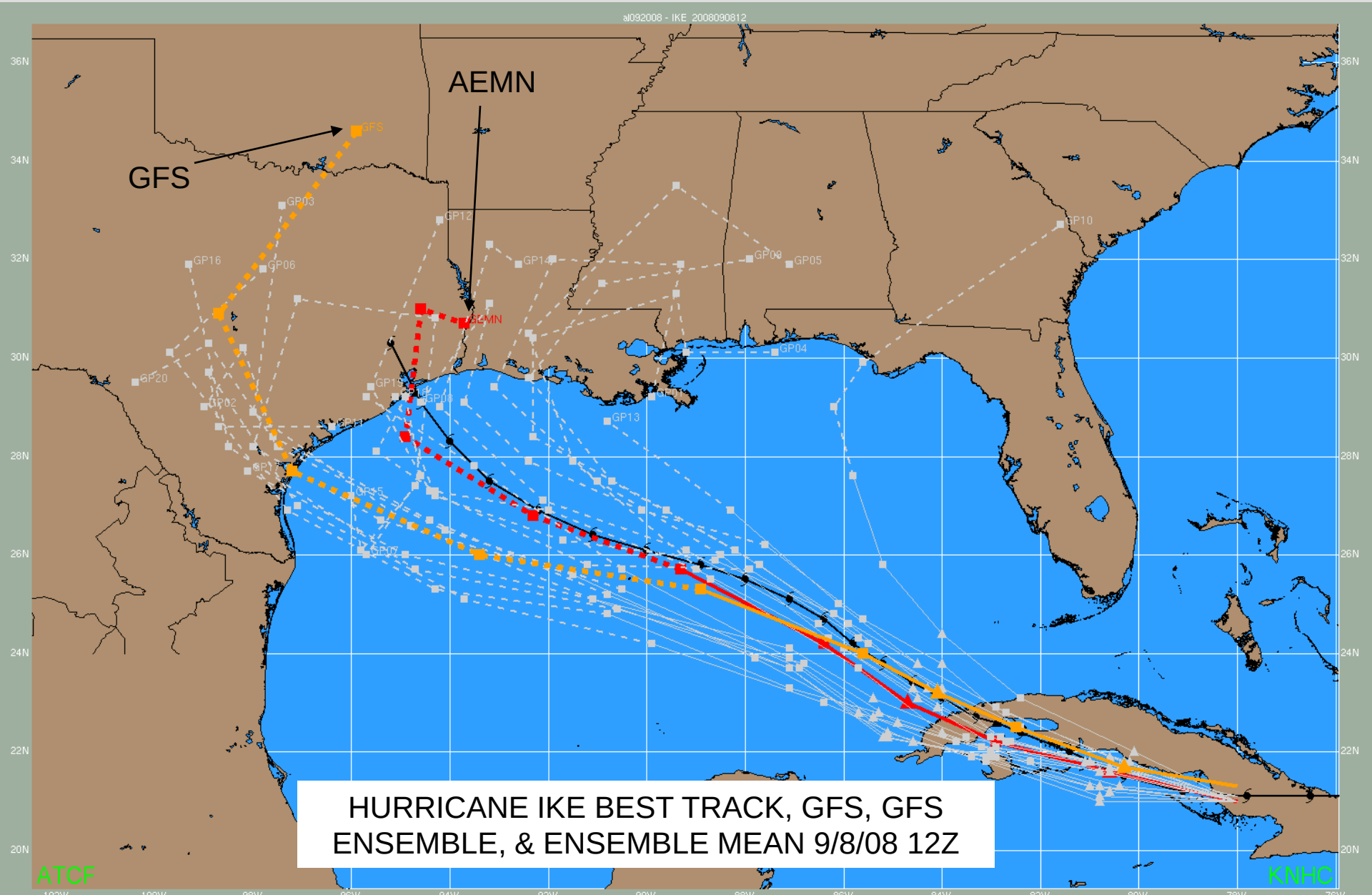
GFS Ensemble example



GFS Ensemble example

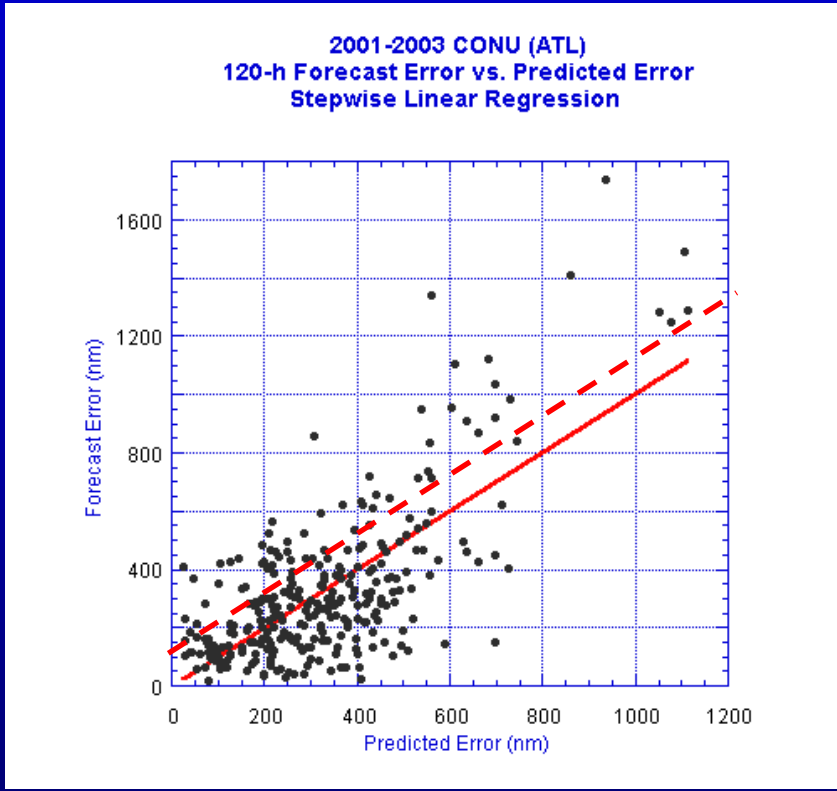


GFS Ensemble example



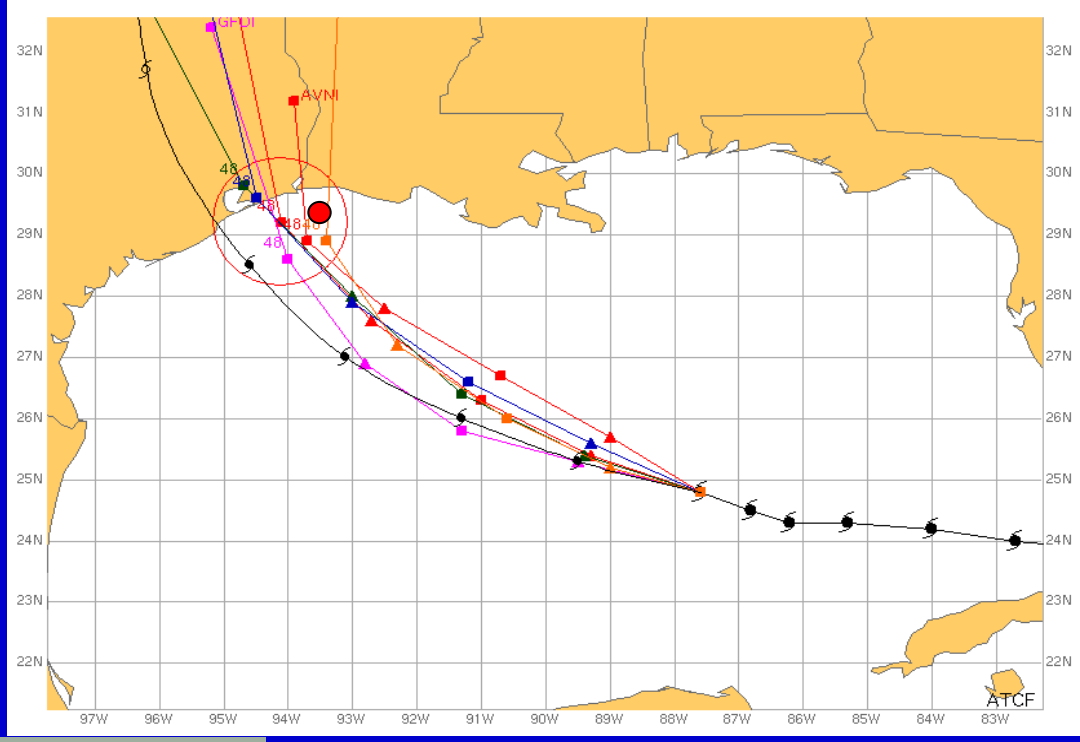
Guidance on guidance: Goerss Prediction of Consensus Error (GPCE)

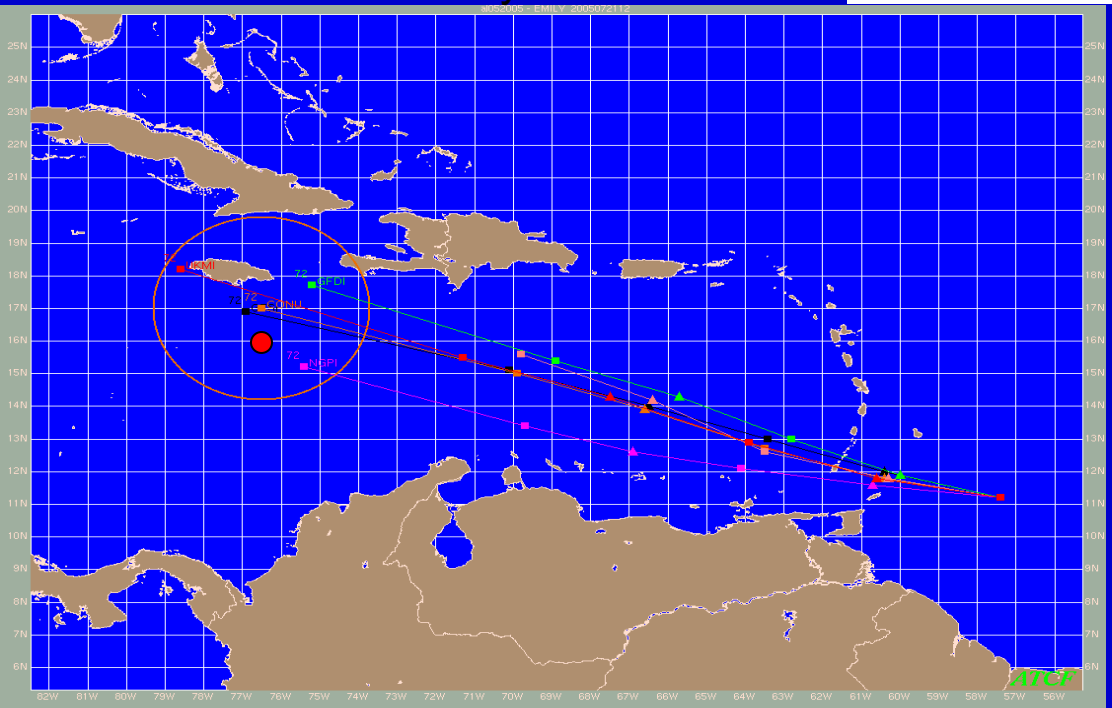
- TCON error assumed to depend on
  - Model spread
  - Initial and forecast intensity
  - Forecast latitude and longitude displacements.
- Adjust the regression line upward so that 75% of the time the actual error is smaller than the predicted error.



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

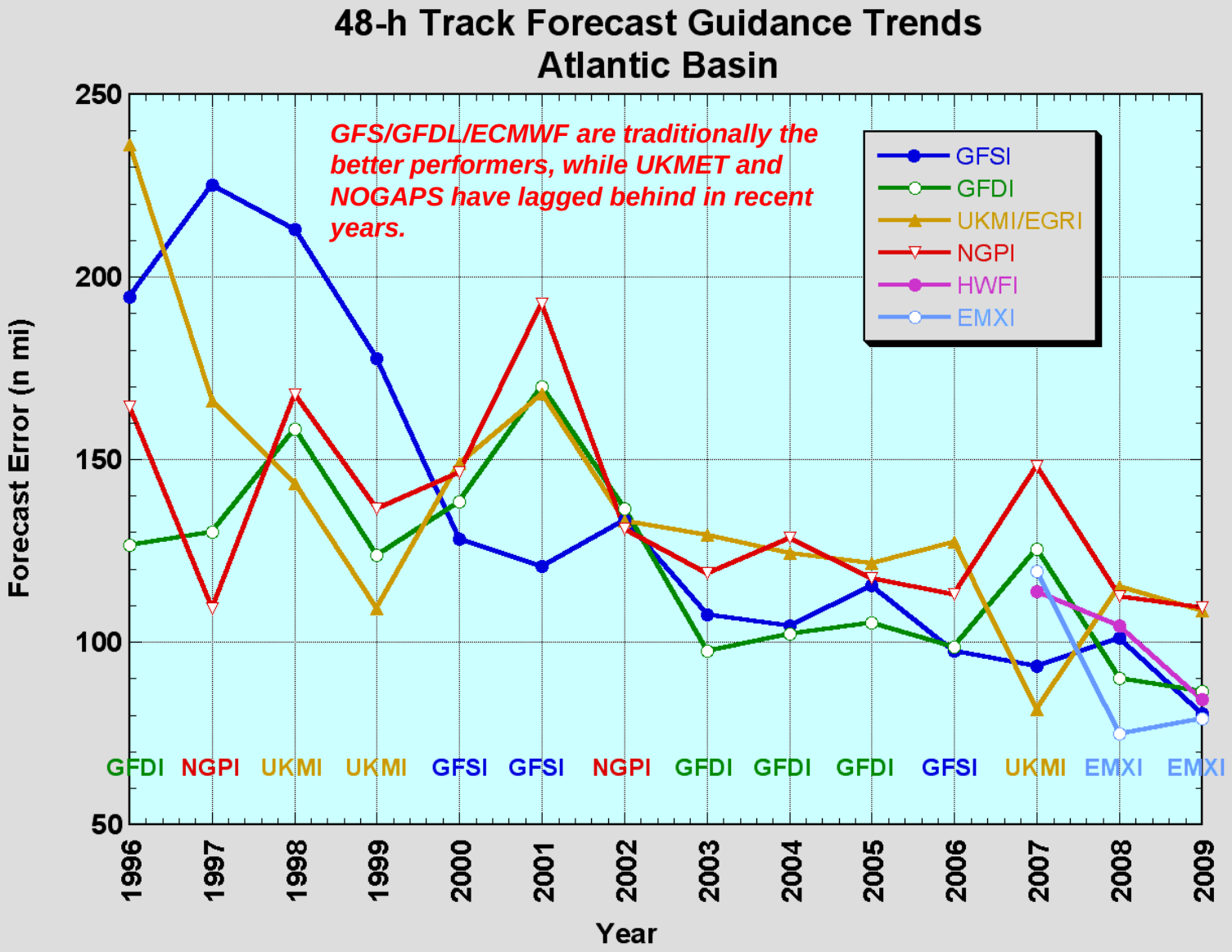
72 h 75% GPCE circle, Hurricane Emily
1200 UTC 13 July 2005



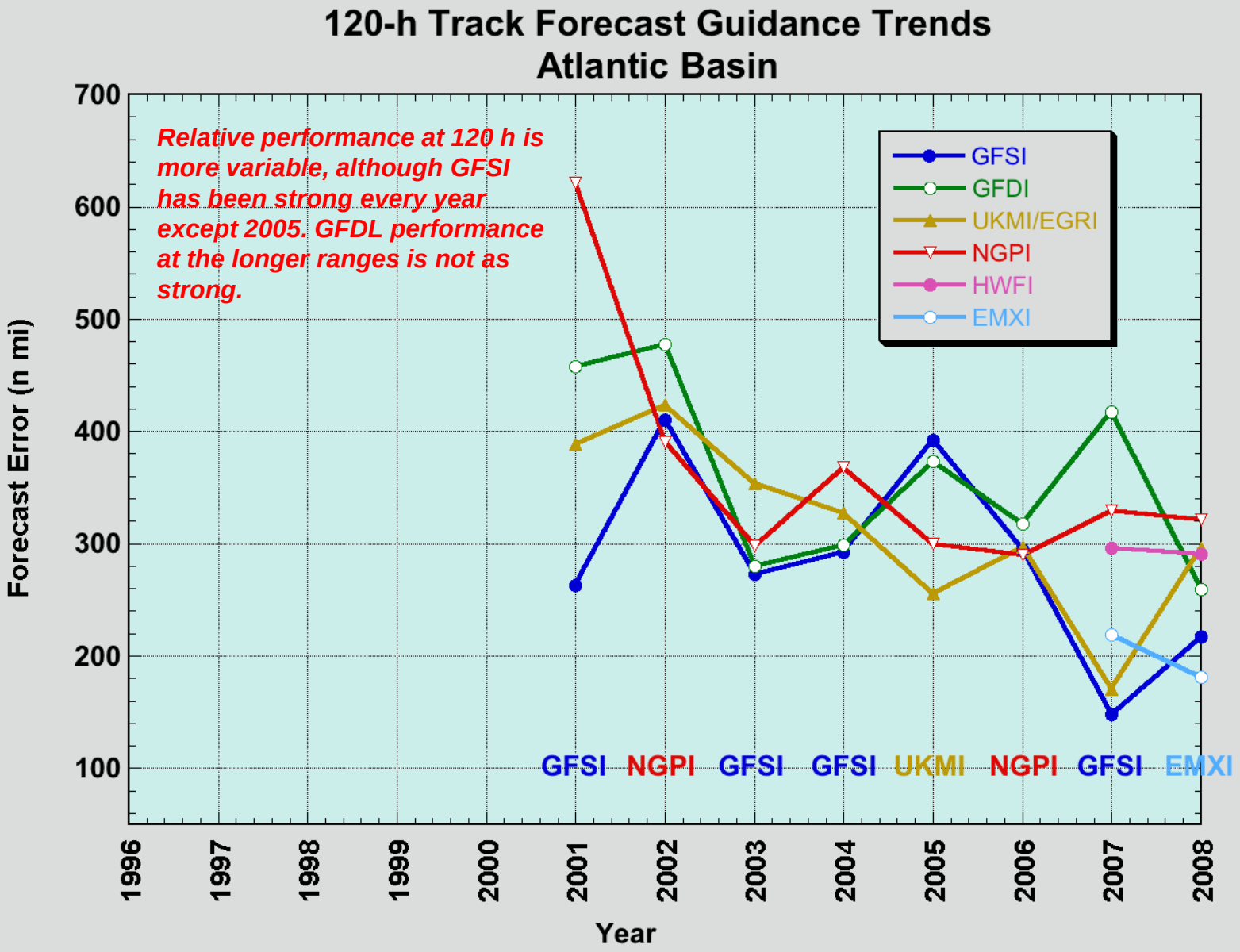


48 h 75% GPCE circle, Hurricane Rita
0600 UTC 22 September 2005

Guidance Trends



Guidance Trends

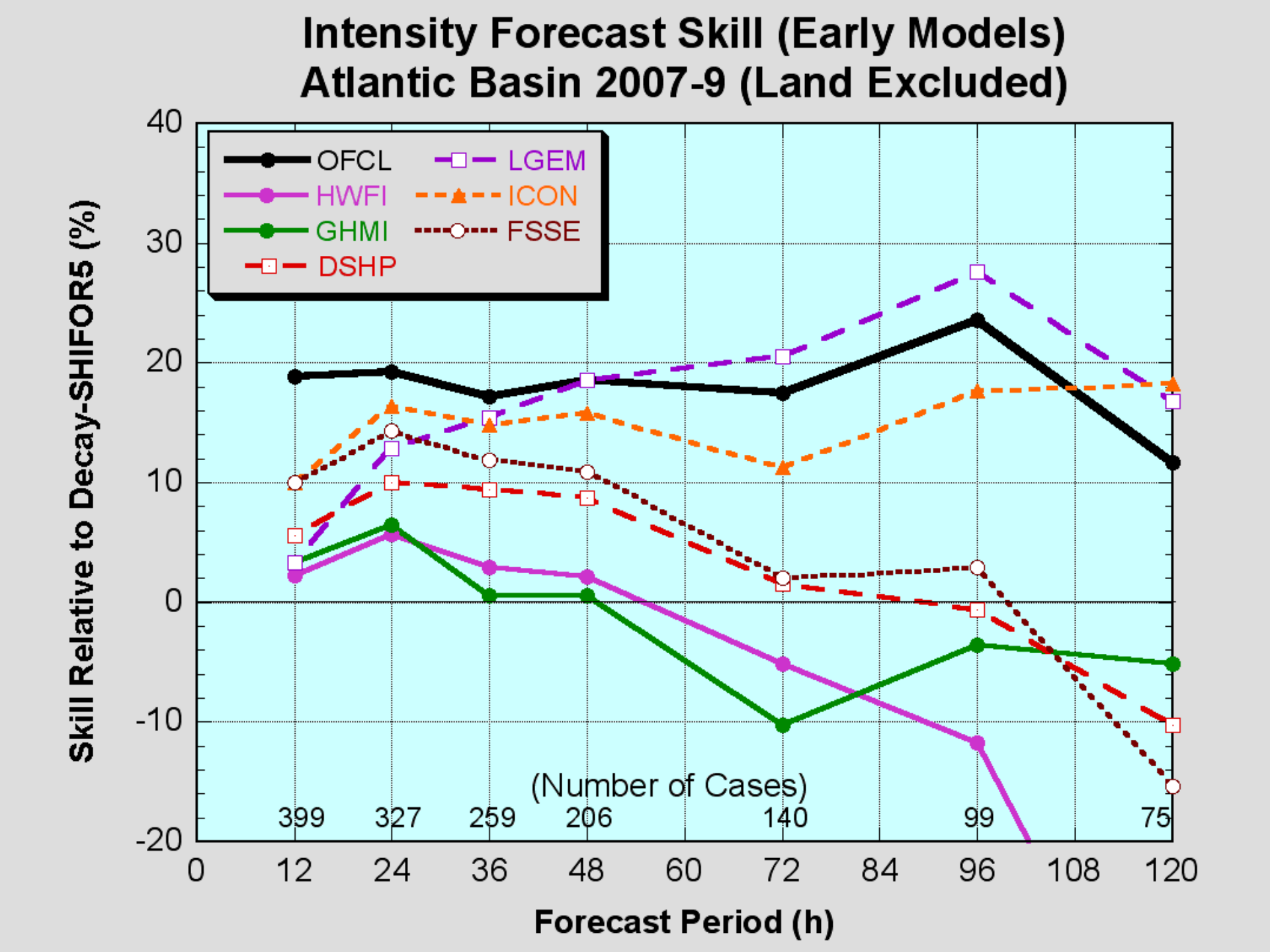


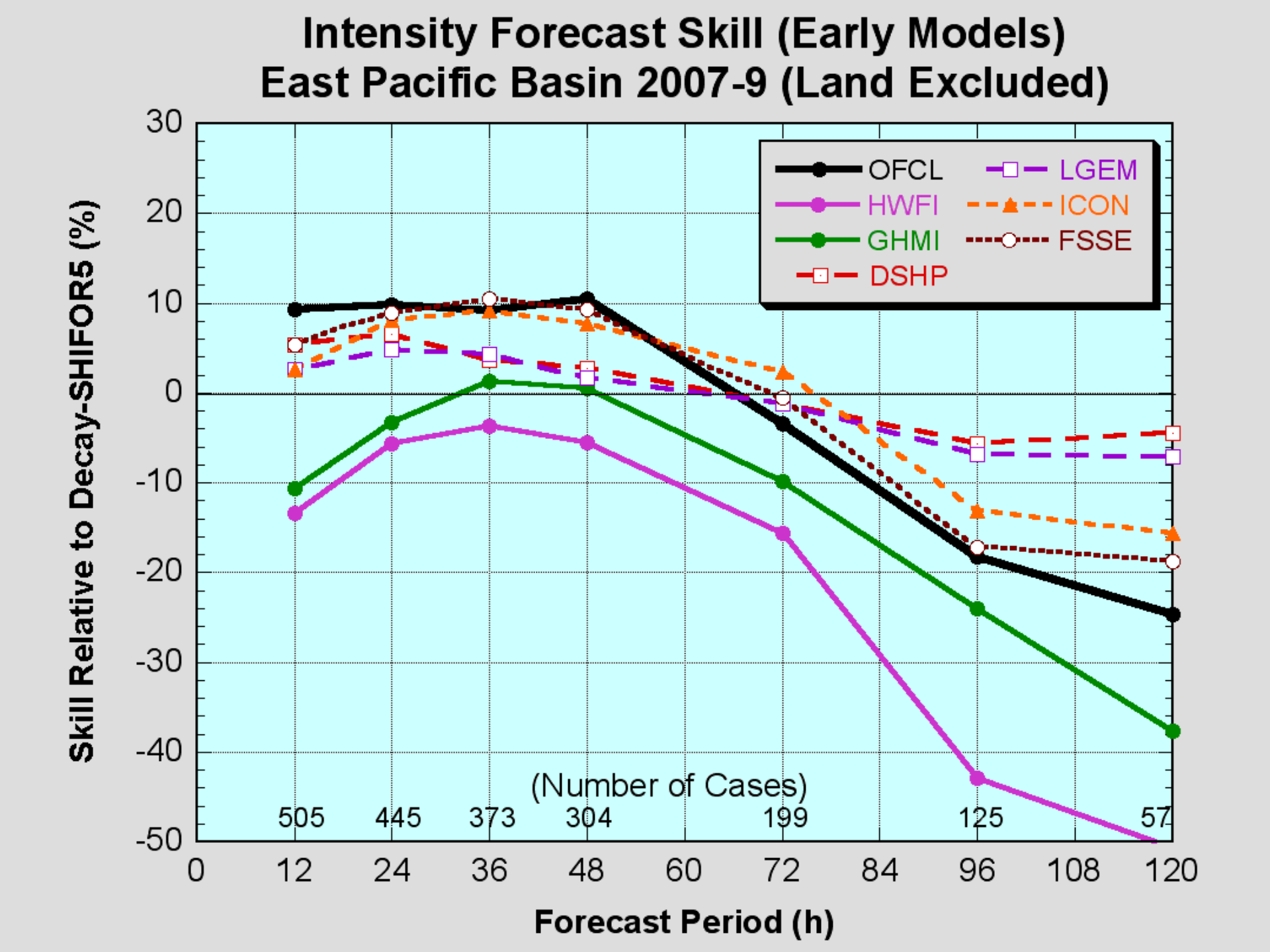
Overall assessment of track guidance:

- Global dynamical models and the GFDL model generally provide the best track guidance.
- The GFDL is generally the most reliable in the 1-3 day forecast range and the global models are better at days 4-5, although recently the ECMWF has had the lowest track errors at all forecast intervals.
- The ECMWF and GFS tend to outperform the UKMET and NOGAPS, although recent enhancements to the latter 2 models should improve their performance.
- A multi-model consensus tends to produce a more accurate forecast than any individual model except, over the last few years, the ECMWF!

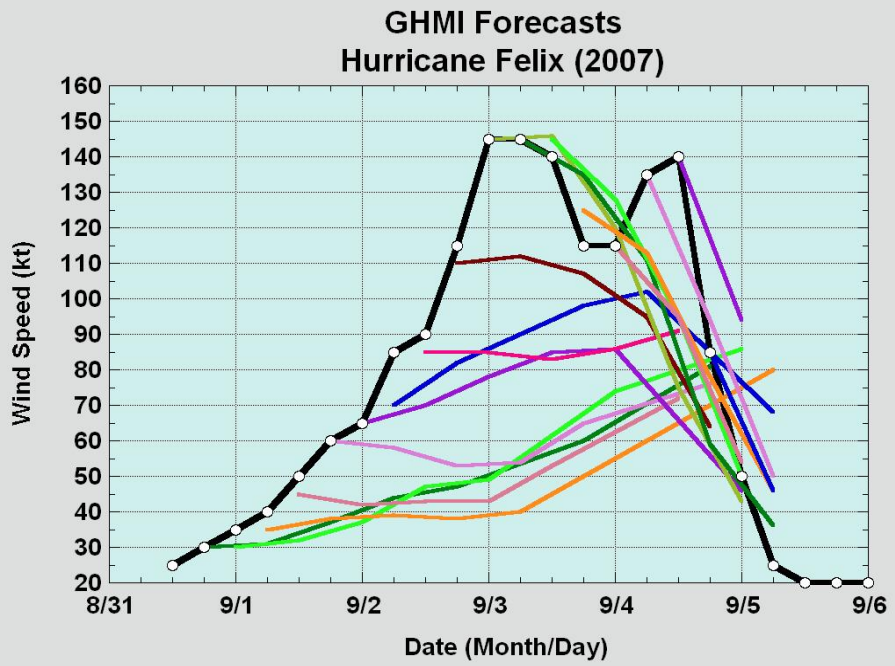
Overall assessment of track guidance (cont.):

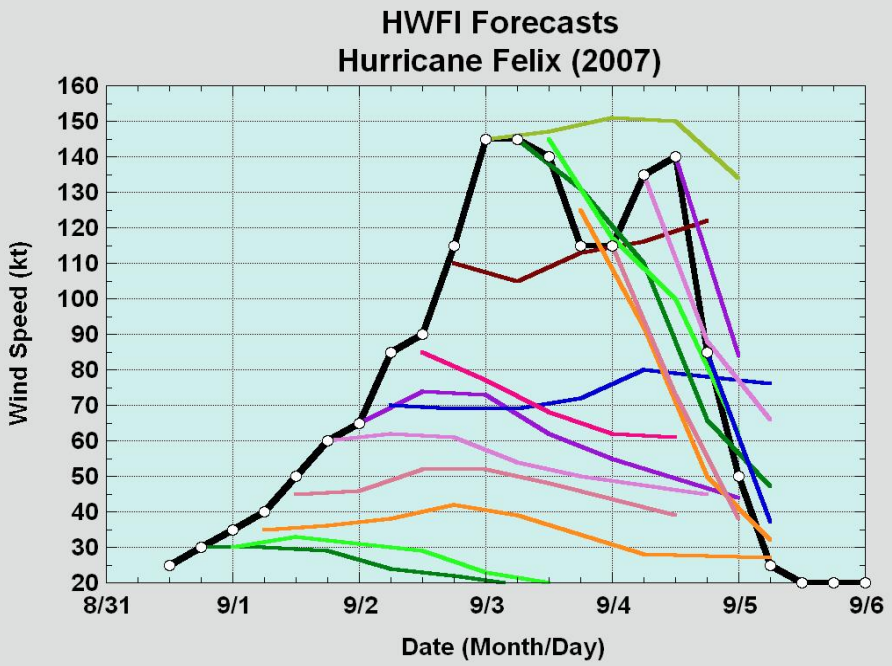
- A multi-model consensus such as GUNA or TCON is usually more accurate than an individual model ensemble mean but there are certainly exceptions such as the Ike example.
- Individual model ensemble means such as the GFS or ECMWF ensemble means are less accurate than the deterministic runs of those models (is lower resolution the main drawback?).
- Individual model ensembles are probably going to become more useful as we extend operational TC forecasts to 6 and 7 days in a few years.

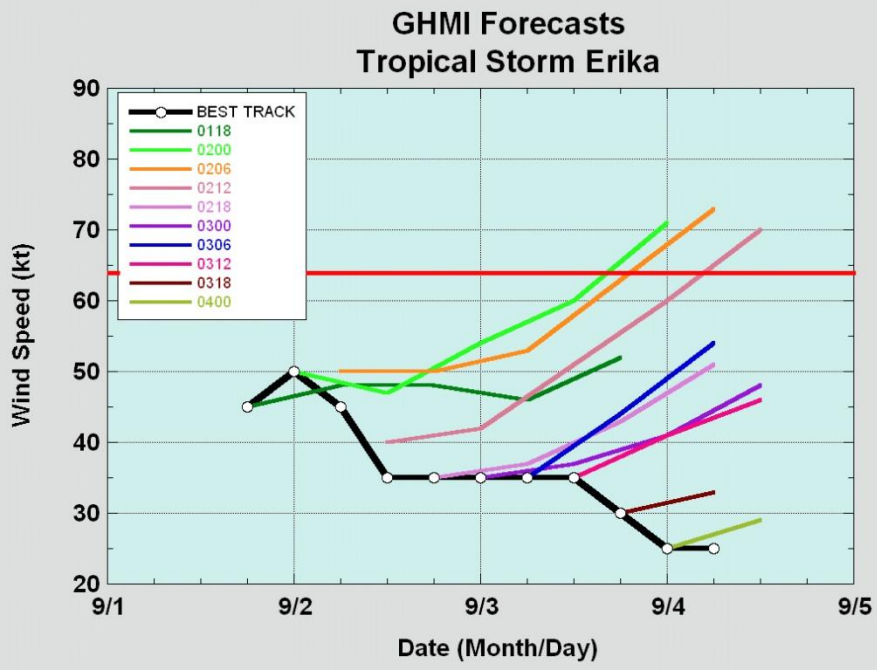

Intensity Forecast Skill (Early Models)
Atlantic Basin 2007-9 (Land Excluded)
OFCL
HWFI
GHMI
DSHP
LGEM
ICON
FSSE
Skill Relative to Decay-SHIFOR5 (%)
40
30
20
10
0
-10
-20
(Number of Cases)
399
327
259
206
140
99
75
0
12
24
36
48
60
72
84
96
108
120
Forecast Period (h)

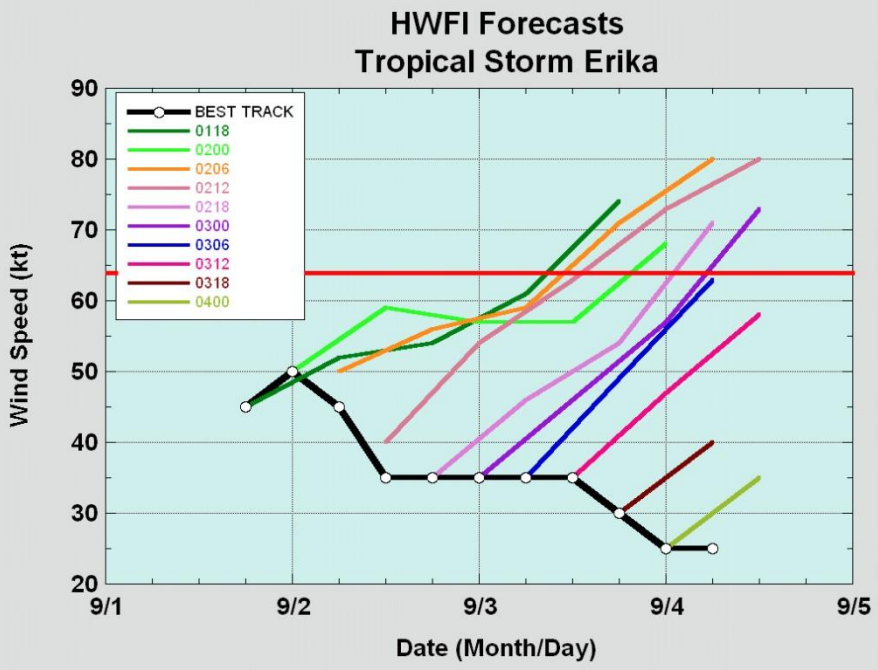

Intensity Forecast Skill (Early Models)
East Pacific Basin 2007-9 (Land Excluded)
Skill Relative to Decay-SHIFOR5 (%)
30
20
10
0
-10
-20
-30
-40
-50
OFCL
LGEM
HWFI
ICON
GHMI
FSSE
DSHP
(Number of Cases)
505
445
373
304
199
125
57
0
12
24
36
48
60
72
84
96
108
120
Forecast Period (h)

Lots of problems with dynamical guidance for predicting intensity change









SHIPS/LGEM guidance has problems with rapid intensification!

Hurricane Ike

Verified: 120 kt

* ATLANTIC SHIPS INTENSITY FORECAST *
* GOES/OHC INPUT INCLUDED *
* NINE AL092008 09/01/08 12 UTC *

TIME (HR)	0	6	12	18	24	36	48	60	72	84	96	108	120
V (KT) NO LAND	30	34	39	44	48	54	61	65	67	66	66	65	65
V (KT) LAND	30	34	39	44	48	54	61	65	67	66	66	65	65
V (KT) LGE mod	30	33	36	39	43	49	56	62	69	73	75	74	72
SHEAR (KTS)	3	3	7	8	11	7	8	6	16	19	26	25	21
SHEAR DIR	254	44	84	78	84	75	70	53	16	46	47	43	48
SST (C)	26.5	26.5	26.8	27.1	27.3	27.6	27.5	27.9	28.5	29.0	29.3	29.5	29.5
POT. INT. (KT)	121	120	124	127	129	133	132	138	146	153	158	162	162
ADJ. POT. INT.	118	116	119	122	124	128	127	133	140	144	148	150	151
200 MB T (C)	-53.7	-53.1	-53.1	-53.4	-53.5	-53.0	-53.4	-53.1	-53.1	-52.9	-52.9	-52.6	-52.7
TH_E DEV (C)	10	10	10	11	10	11	10	10	10	11	11	12	11
700-500 MB RH	54	53	52	51	50	48	50	47	48	43	44	45	49
GFS VTEX (KT)	10	10	12	12	12	10	11	9	8	7	6	6	5
850 MB ENV VOR	85	71	67	59	40	9	0	-38	-62	-70	-84	-87	-90
200 MB DIV	32	19	12	-3	2	-20	-4	-28	-16	-17	-4	-6	-13
LAND (KM)	2014	1952	1893	1830	1782	1723	1541	1245	927	732	620	563	452
LAT (DEG N)	17.4	17.9	18.3	18.7	19.1	19.9	20.7	21.6	22.5	23.3	23.8	24.0	23.8
LONG(DEG W)	38.8	40.3	41.7	43.2	44.7	47.6	50.9	54.3	58.0	61.1	64.1	67.0	70.0
STM SPEED (KT)	16	15	14	15	15	15	16	17	16	14	14	13	14
HEAT CONTENT	4	4	5	11	15	22	18	39	44	44	52	53	58

FORECAST TRACK FROM BAMM INITIAL HEADING/SPEED (DEG/KT):270/ 17 CX,CY: -16/ 0
T-12 MAX WIND: 25 PRESSURE OF STEERING LEVEL (MB): 619 (MEAN=625)
GOES IR BRIGHTNESS TEMP. STD DEV. 100-300 KM RAD: 25.0 (MEAN=20.0)
% GOES IR PIXELS WITH T < -20 C 50-200 KM RAD: 83.0 (MEAN=68.6)

RII guidance for Hurricane Rick (October 2009)

```
*   EAST PACIFIC SHIPS INTENSITY FORECAST   *
*      GOES DATA AVAILABLE                  *
*       OHC  DATA AVAILABLE                 *
*  RICK        EP202009  10/16/09  18 UTC   *
```

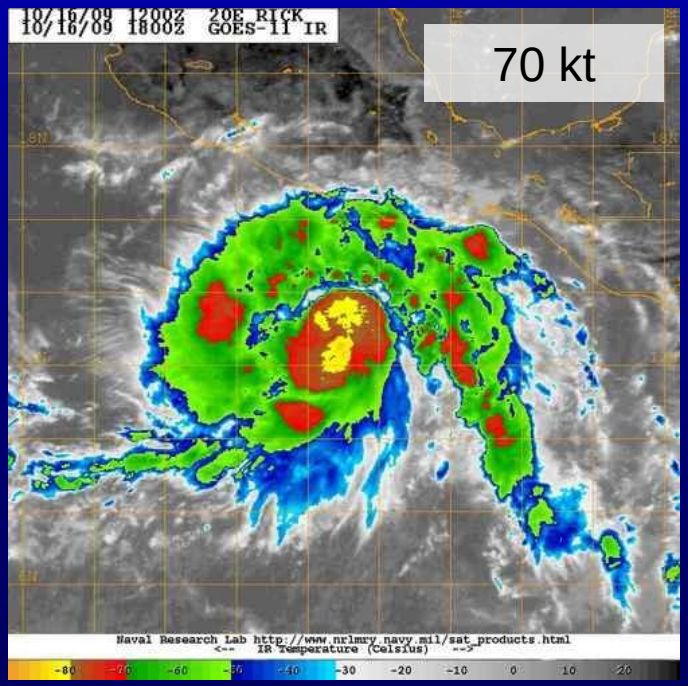
TIME (HR)	0	6	12	18	24	36	48	60	72	84	96	108	120
V (KT) NO LAND	70	79	86	92	97	104	108	111	111	107	107	101	93
V (KT) LAND	70	79	86	92	97	104	108	111	111	107	107	101	93
V (KT) LGE mod	70	79	86	92	96	99	95	91	87	85	83	80	76

```
** 2009 E. Pacific RI INDEX EP202009 RICK       10/16/09  18 UTC **
                ( 30 KT OR MORE MAX WIND INCREASE IN NEXT 24 HR)

      12 HR PERSISTENCE (KT):  20.0 Range:-20.0 to  35.0 Scaled/Wgted Val:  0.7/  1.6
      850-200 MB SHEAR (KT) :   6.0 Range: 15.2 to   1.6 Scaled/Wgted Val:  0.7/  0.8
      D200 (10**7s-1)       :  70.0 Range:-10.0 to 129.0 Scaled/Wgted Val:  0.6/  0.4
      POT = MPI-VMAX (KT)   :  96.7 Range: 46.6 to 134.3 Scaled/Wgted Val:  0.6/  0.6
      850-700 MB REL HUM (%):  79.4 Range: 64.0 to  88.0 Scaled/Wgted Val:  0.6/  0.2
      % area w/pixels <-30 C:  98.0 Range: 26.0 to 100.0 Scaled/Wgted Val:  1.0/  0.5
      STD DEV OF IR BR TEMP :   8.3 Range: 35.4 to   2.7 Scaled/Wgted Val:  0.8/  1.3
      Heat content (KJ/cm2) :  46.8 Range:  4.0 to  67.0 Scaled/Wgted Val:  0.7/  0.4

      Prob of RI for 25 kt RI threshold=    78% is    6.8 times the sample mean(11.5%)
      Prob of RI for 30 kt RI threshold=    71% is    9.3 times the sample mean( 7.7%)
      Prob of RI for 35 kt RI threshold=    66% is   12.6 times the sample mean( 5.2%)
```

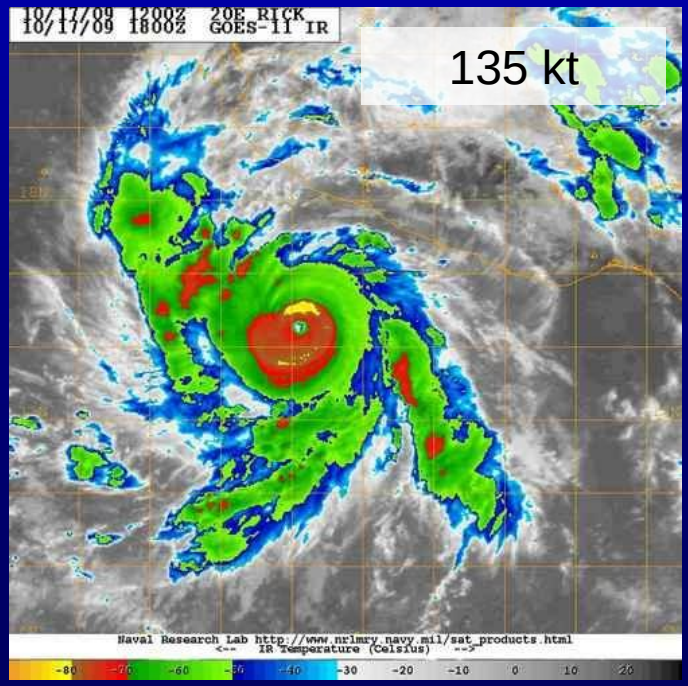
Rapid intensification of Hurricane Rick (October 2009)

FORECAST POSITIONS AND MAX WINDS

INITIAL	16/2100Z	13.0N	100.0W	75 KT
12HR VT	17/0600Z	13.2N	101.3W	90 KT
24HR VT	17/1800Z	13.7N	103.3W	105 KT
36HR VT	18/0600Z	14.3N	105.8W	115 KT
48HR VT	18/1800Z	15.0N	108.1W	125 KT
72HR VT	19/1800Z	16.5N	111.5W	120 KT
96HR VT	20/1800Z	18.5N	113.0W	105 KT
120HR VT	21/1800Z	20.5N	113.0W	85 KT



24 hrs



Overall assessment of intensity guidance:

- Global models can provide useful information for intensity forecasts (e.g. evolution of upper-level winds).
- The GFDL & HWRF models can predict rapid intensification, but *they do not do so reliably*; the HWRF has been especially notorious for over-intensifying TCs in strongly sheared environments.
- The RII is of some value for forecasting rapid intensification, and a modified version is being tested.
- LGEM provides the most accurate intensity forecasts at this time.

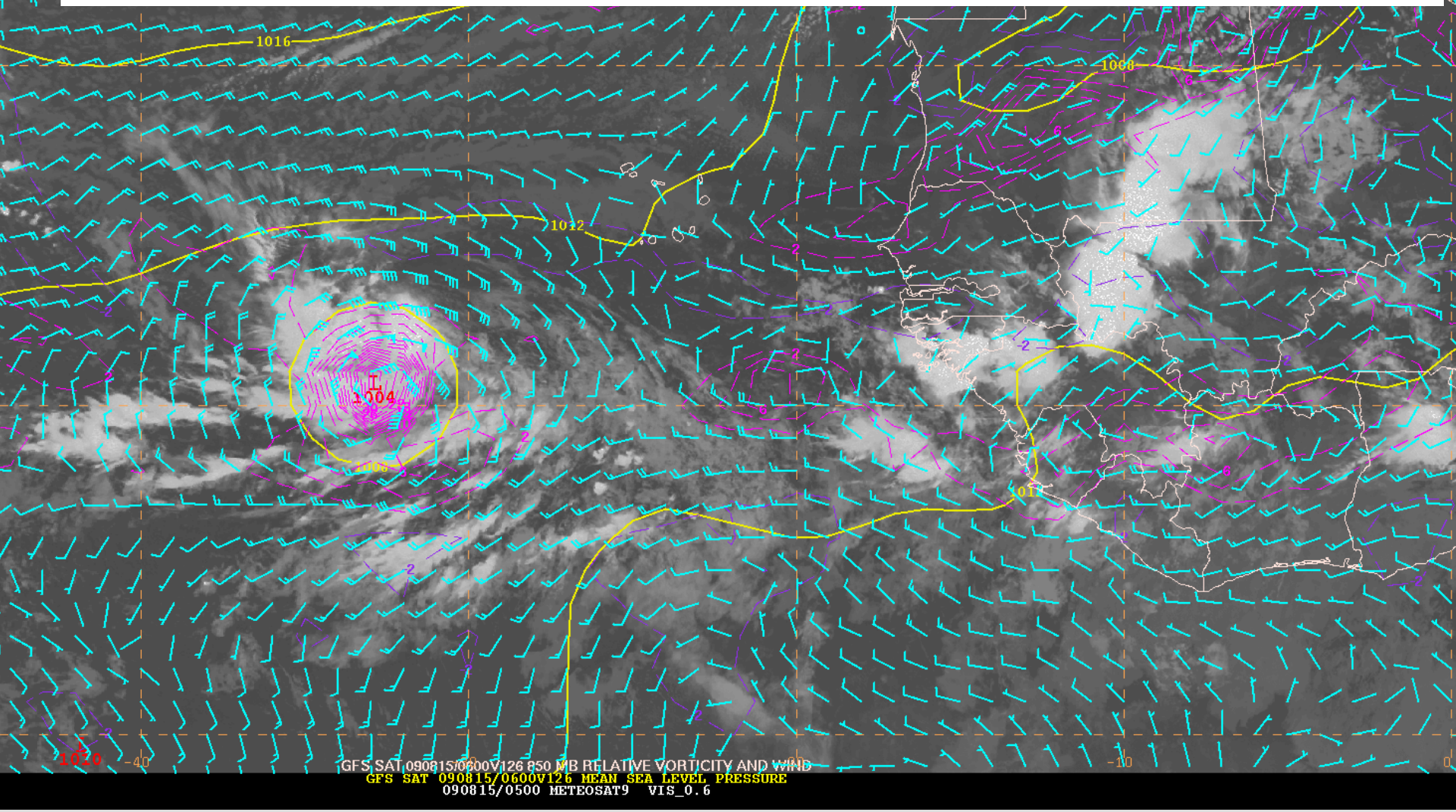
Overall assessment of intensity guidance (cont.):

- Our dynamical hurricane models, GFDL, GFDN, & HWRF require a more realistic initialization of the inner core and improved physics in order to produce better intensity forecasts; until this happens, our best intensity guidance will likely continue to be statistical/dynamical.

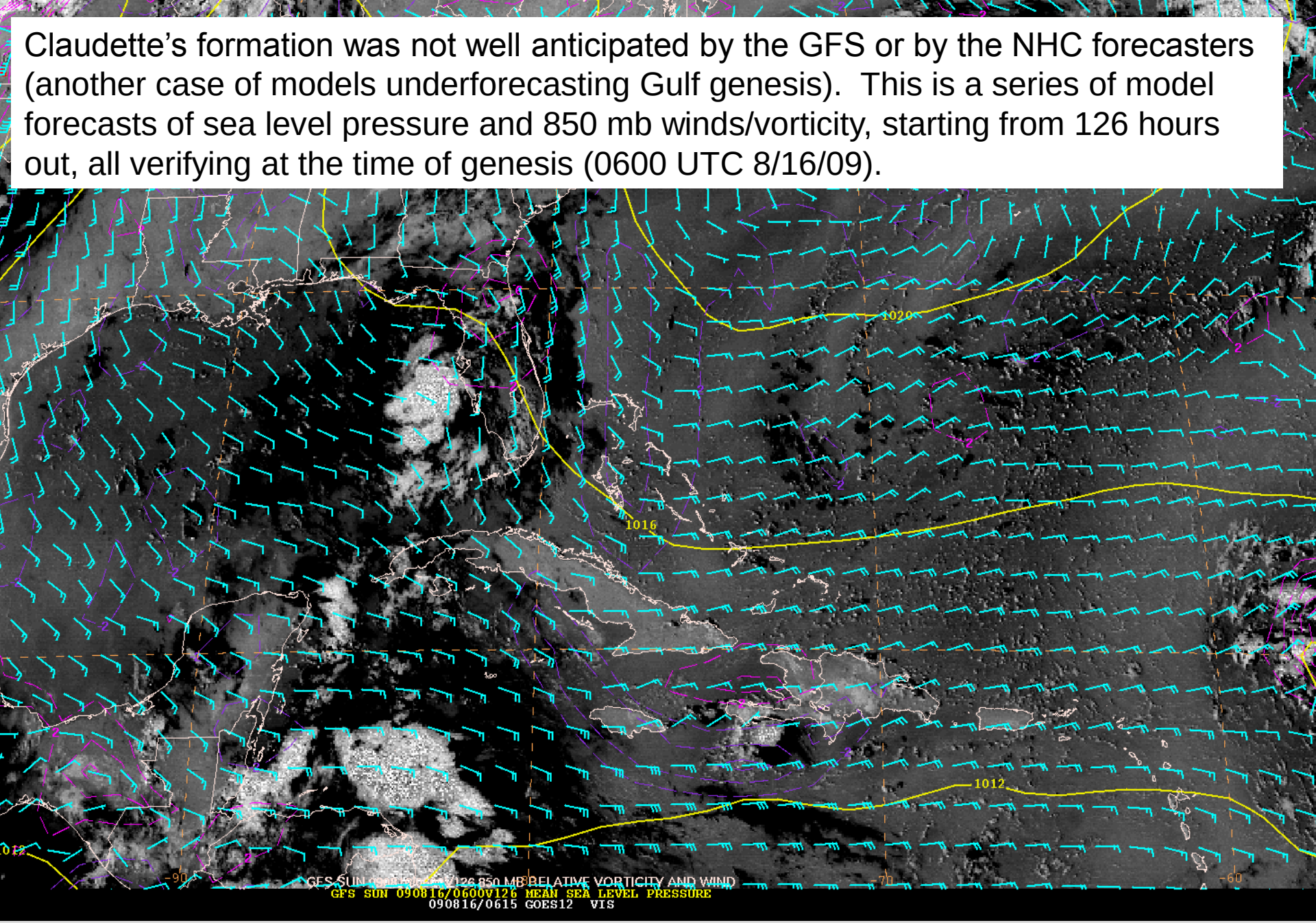
Guidance for predicting TC genesis

- Primary guidance for predicting TC formation comes from global models
- GFS has some success in forecasting genesis over the eastern Atlantic and eastern North Pacific
- All of the models seem to have difficulty predicting genesis over the Gulf of Mexico
- NOGAPS tends to underpredict genesis in general
- ECMWF has shown a lot of false alarms over the eastern North Pacific
- The new higher-resolution UKMET may have more success in forecasting genesis than its predecessor
- More systematic/objective verification of model forecast of TC genesis needs to be done

Genesis of Bill was well predicted by the GFS (another case of good GFS forecasts of eastern tropical Atlantic genesis). This is a series of model forecasts of sea level pressure and 850 mb winds/vorticity, starting from 126 hours out, all verifying at the time of genesis (0600 UTC 8/15/09).



Claudette's formation was not well anticipated by the GFS or by the NHC forecasters (another case of models underforecasting Gulf genesis). This is a series of model forecasts of sea level pressure and 850 mb winds/vorticity, starting from 126 hours out, all verifying at the time of genesis (0600 UTC 8/16/09).



CONCLUDING REMARKS:

- **Operational TC track forecasting has advanced substantially over the past couple of decades, mainly due to advances in dynamical guidance**
- **Generally, a multi-model consensus provides more skillful guidance for track prediction than an individual model ensemble, although the latter may become more useful at 6 & 7 days**
- **Operational TC intensity forecasting has shown little improvement and NHC's dynamical models for forecasting intensity change have not advanced much over the past several years**
- **Global models have some skill in predicting TC genesis and may provide the basis for extending operational genesis forecasts from 2 to 5 days**

THANKS TO:

JAMES FRANKLIN AND
MY OTHER COLLEAGUES AT NHC