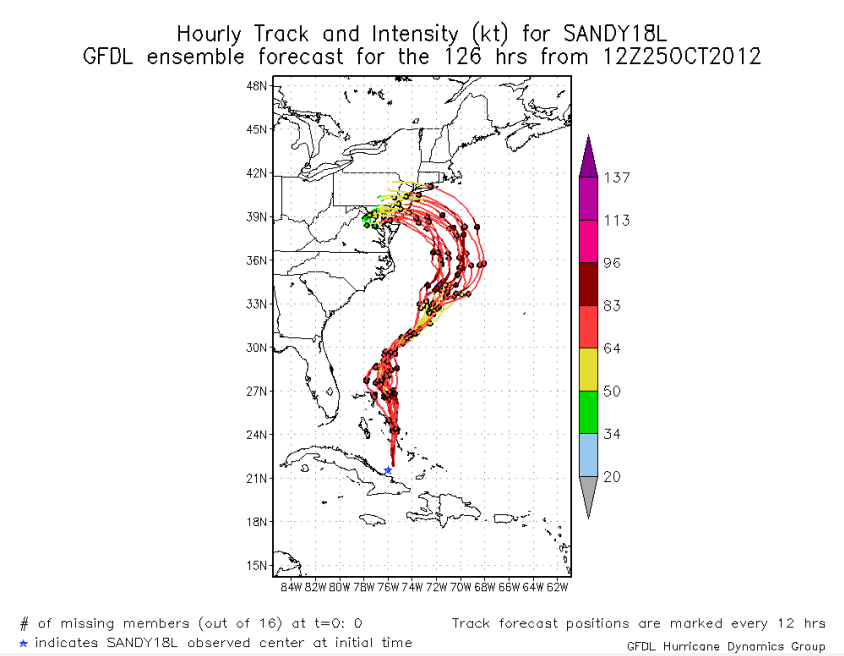
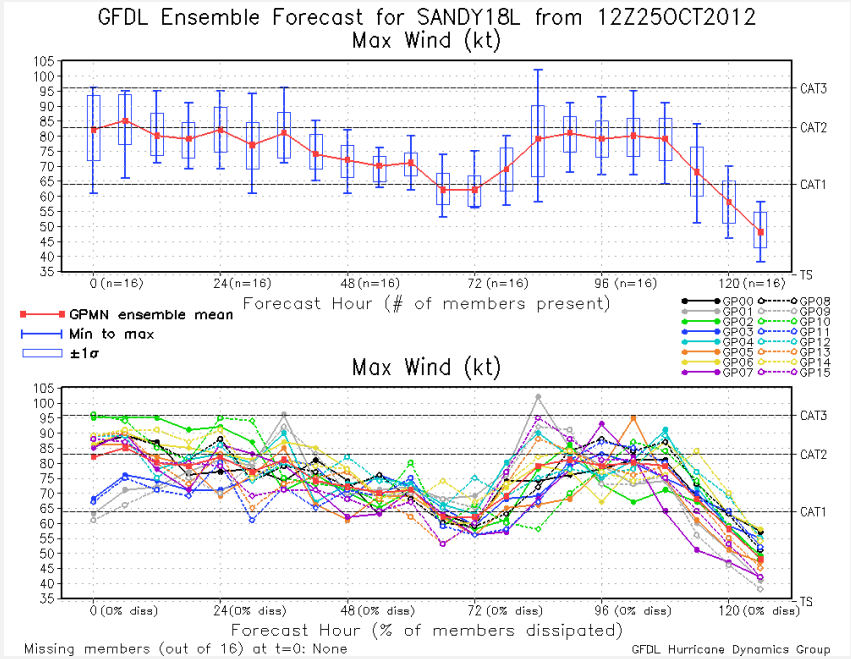
GFDL Hurricane Model Ensemble Performance During the 2012 Hurricane Season





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HFIP Team Telecon
12 December 2012

Acknowledgments:
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Outline

- GFDL ensemble overview & methods
- Results: 2012 Cases
- Results: Verifications
- Website and Real-Time Products
- Summary

GFDL Ensemble Overview

- **Model configuration:** Use same resolution as the operational GFDL model (3 nests with inner grid spacing of 1/12° (~9 km)).
- **Perturbations**: Modify observed TC parameters and model initial conditions to create spread in the model's 5-day forecasts and show realistic possibilities of storm track and intensity evolution
  - Vortex size & intensity
    - **Goal: Represent the typical uncertainty in the storm's reported observations**
  - Moisture fields; Sea-surface temperature
    - **Goal: Represent the typical uncertainty in the model's initial fields around the storm's core**
  - Global model (for initial fields and boundary conditions)
    - **Goal: Include some degree of diversity in the large-scale environmental fields and steering flow**

Hurricane Ensemble Membership

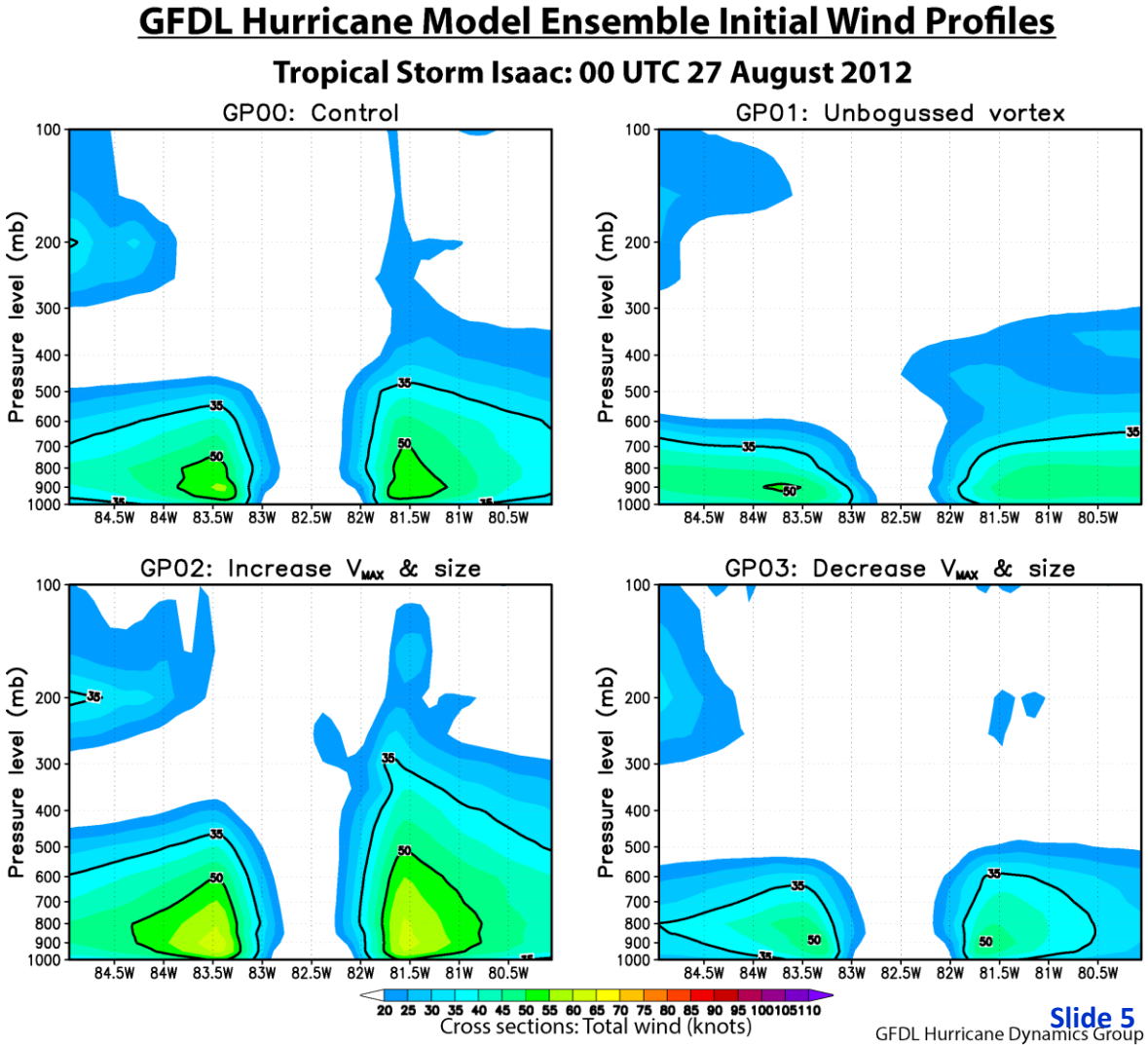
- **16 members (15 perturbations + 1 control)**
  - Members 08→15 have identical perturbations applied, but use GEFS Mean for initial and boundary conditions

ATCF ID	Description
GP00/GP08	Control forecast (same model as NCEP 2012 operational GFDL)
GP01/GP09	Unbogussed forecast using the 2012 GFDL control model
GP02/GP10	Increase NHC-observed V_{max} +10%, R34 +25%, R50 +40%, ROCI +25%
GP03/GP11	Decrease NHC-observed V_{max} -10%, R34 -25%, R50 -40%, ROCI -25%
GP04/GP12	Increase inner-core moisture by a max of +10%
GP05/GP13	Decrease inner-core moisture by a max of -10%
GP06/GP14	Increase SSTs by a max of +1°C within the initial extent of the TC
GP07/GP15	Decrease SSTs by a max of -2°C within the initial extent of the TC
GPMN	Ensemble mean computed at each lead time where the member availability is at least 6 members (40% threshold)

Example:
Vortex size & intensity perturbations

1000—100-mb Total Wind Magnitude (kt): Vertical cross-section through vortex center

NHC-reported surface V_{MAX} (from TC vitals) ≈ 55 knots



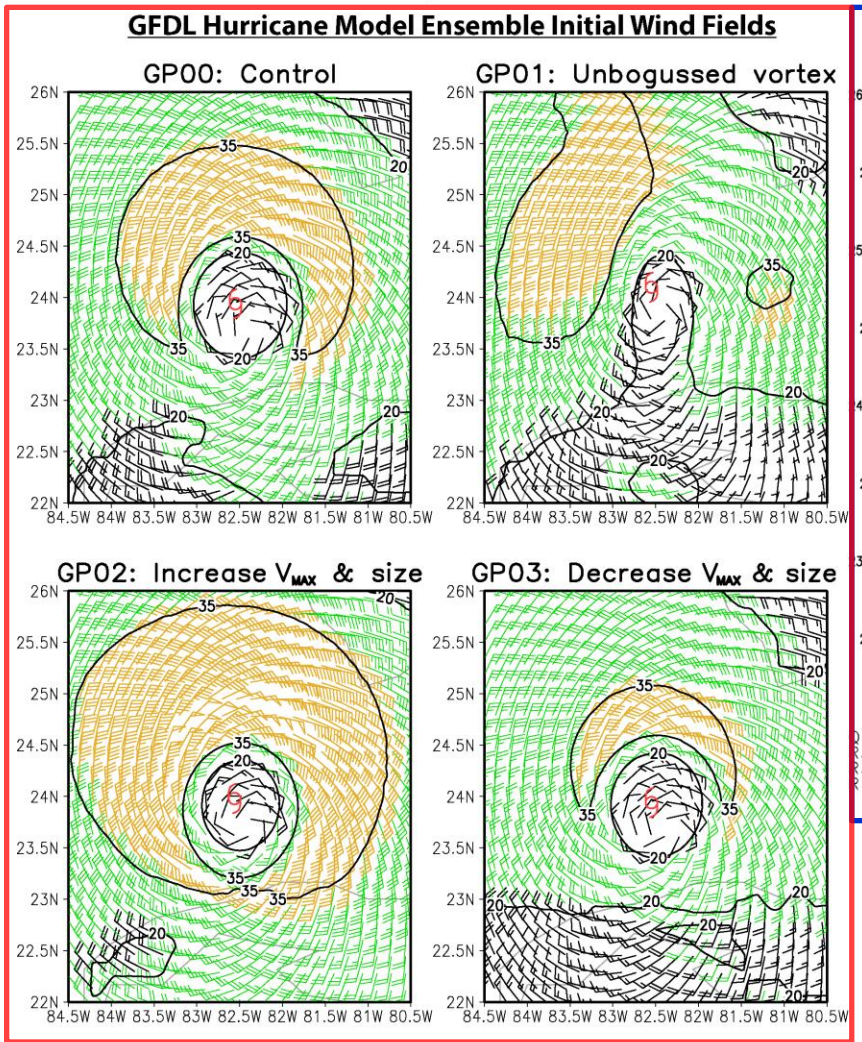
Example:
Vortex size & intensity perturbations

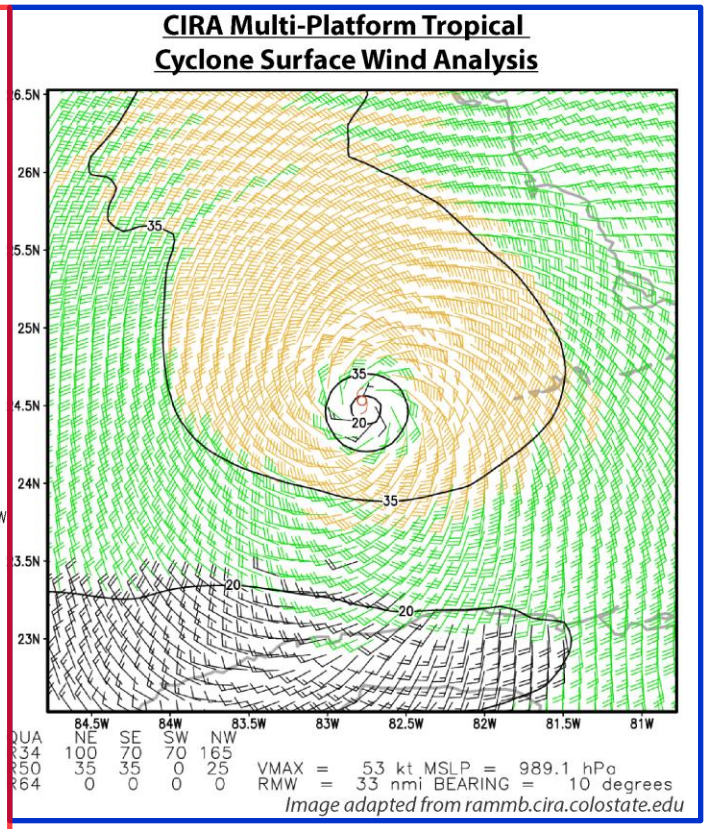
Plan view at 10 meters above ground level

NHC-reported surface V_{MAX} (from TC vitals) ≈ 55 knots

Tropical Storm Isaac 10-m Winds (knots)

Analysis based on model's initial conditions





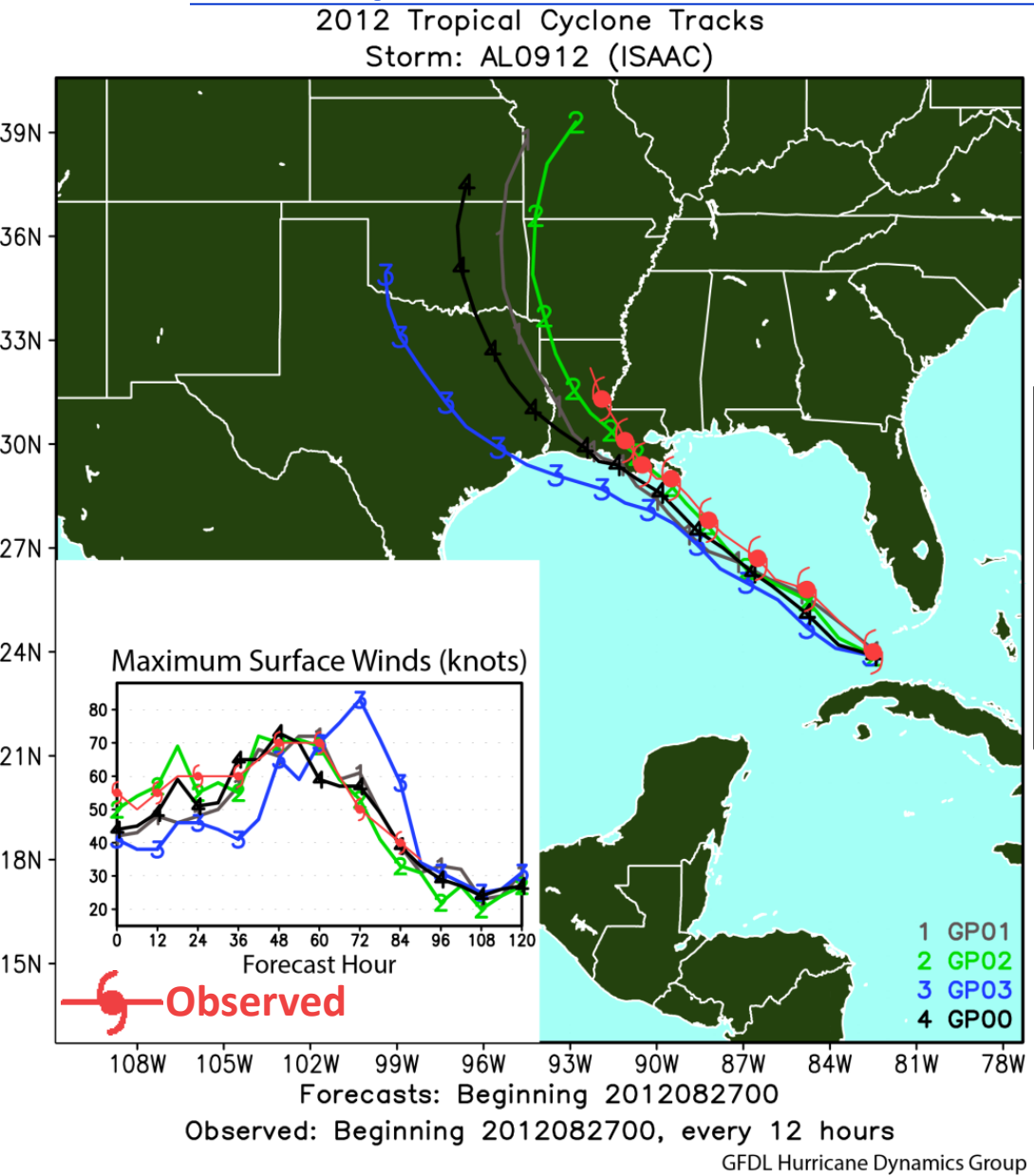
Analysis based on observations

00 UTC 27 August 2012

20 35 50 65

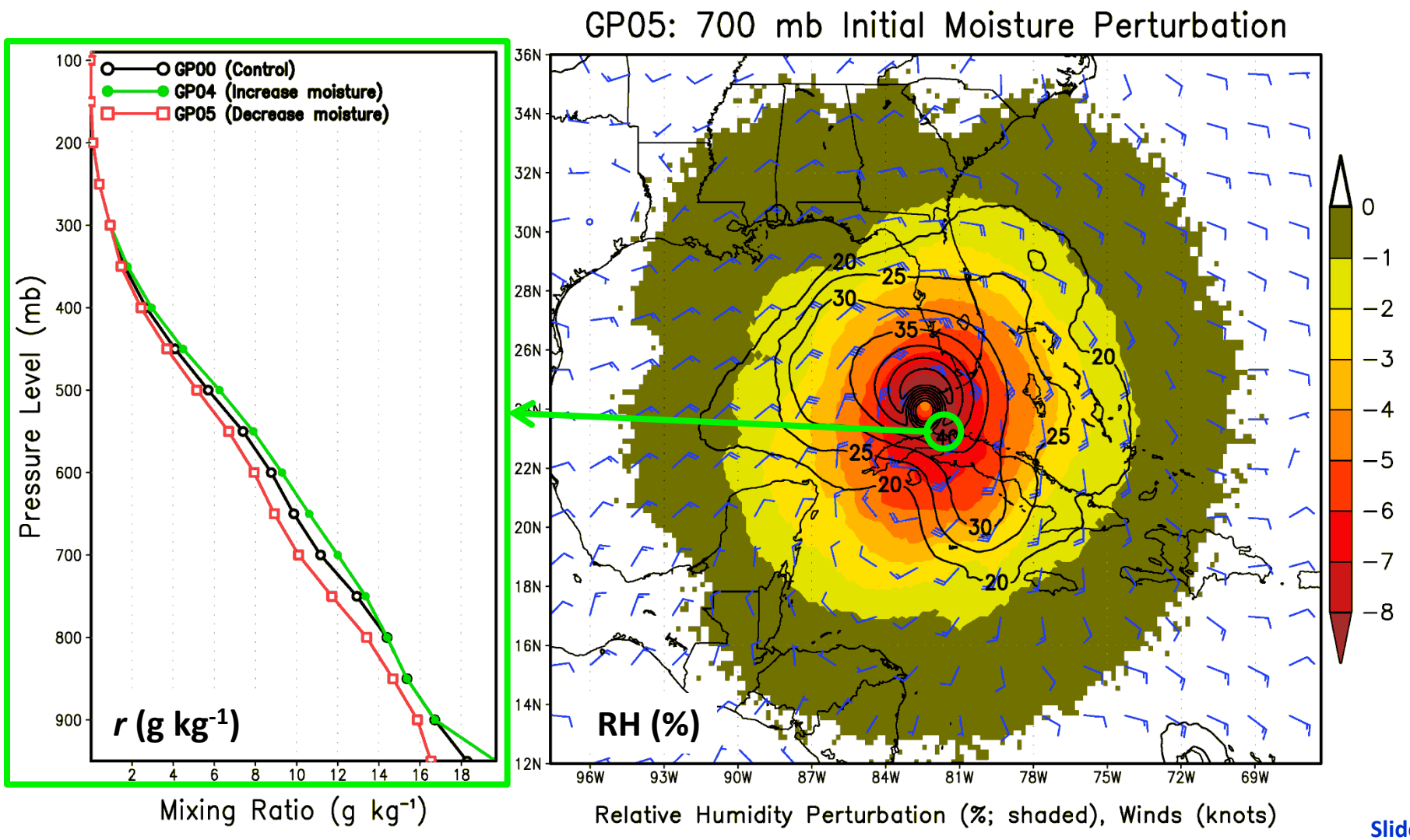
GFDL Hurricane Dynamics Group

Example: Impact of vortex size & intensity perturbations on TC forecasts

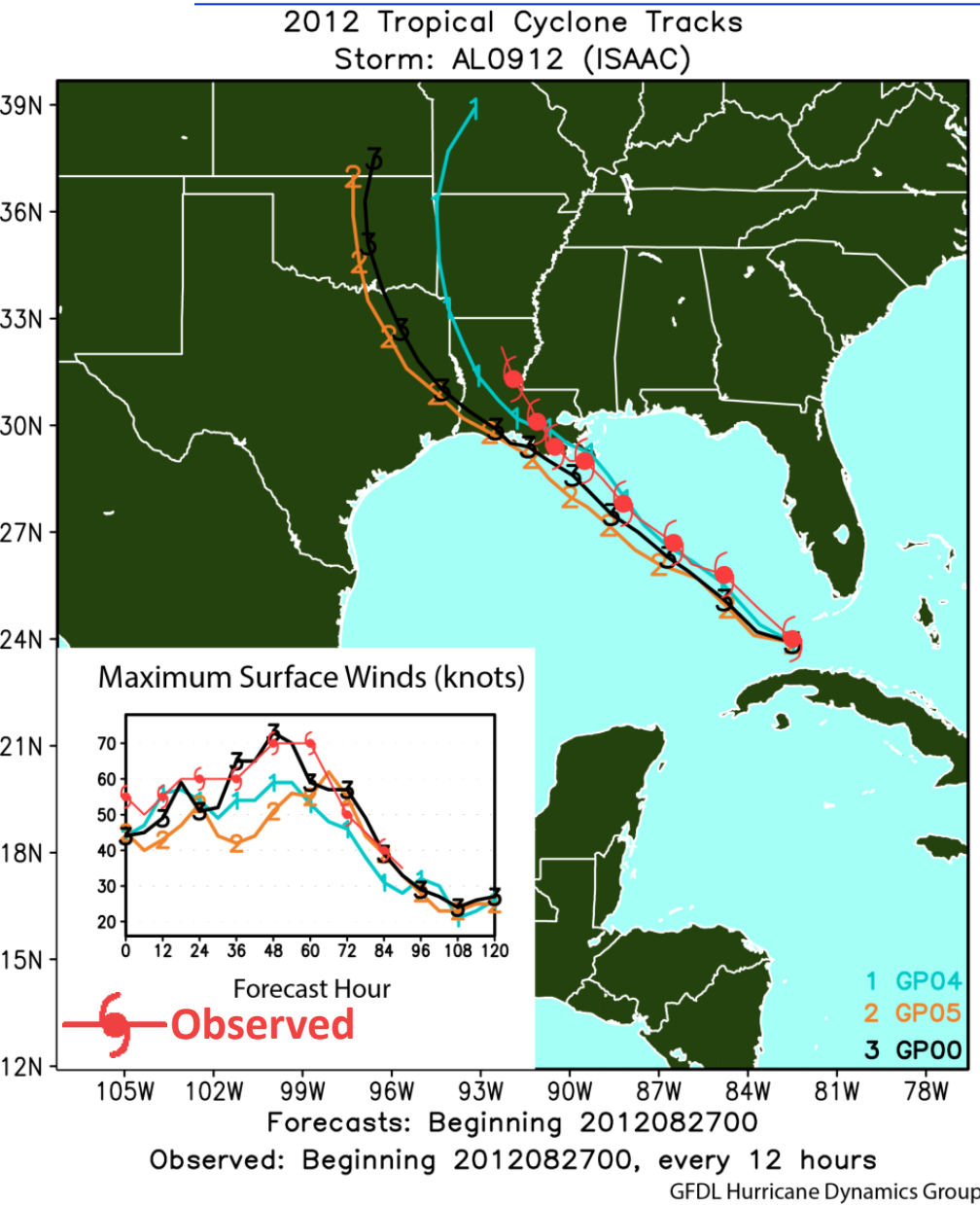


*In this particular case, bumping up the vortex's intensity and wind radii observations (**GP02**) resulted in a more accurate track and intensity forecast compared to its complement member (**GP03**), the Control (**GP00**), and the unbogussed member (GP01). However, this is not always the case.*

Example: Moisture perturbations



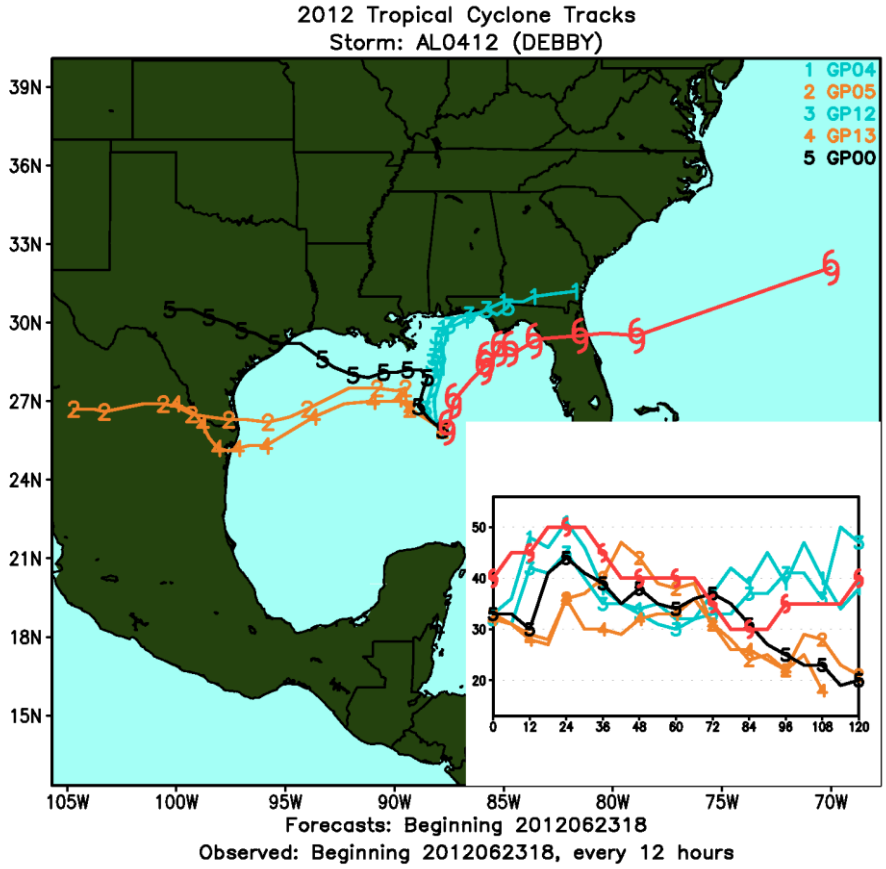
Example: Impact of moisture perturbations on TC forecasts



*In this particular case, bumping up the vortex's initial moisture profile (**GP04**) resulted in a more accurate track forecast compared to its complement member (**GP05**), while not perturbing the moisture (**GP00**) resulted in a more accurate intensity forecast.*

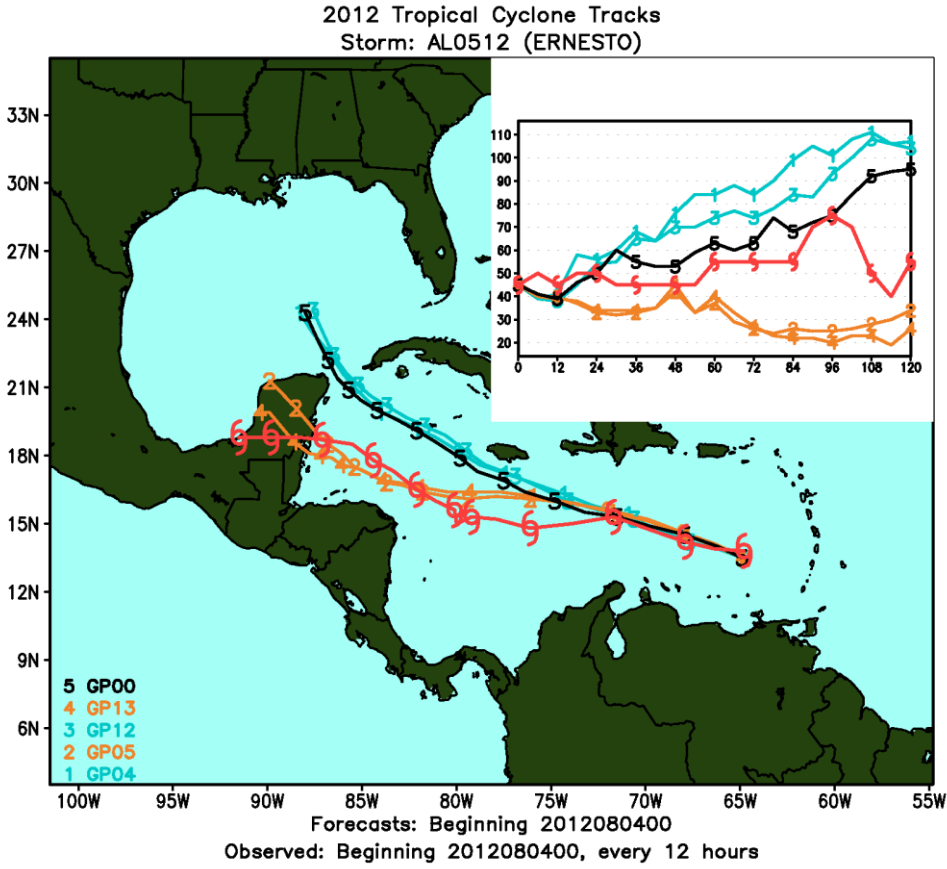
Track and Intensity Forecast Sensitivity to Initial Moisture Field Perturbations

Debby: 2012062318



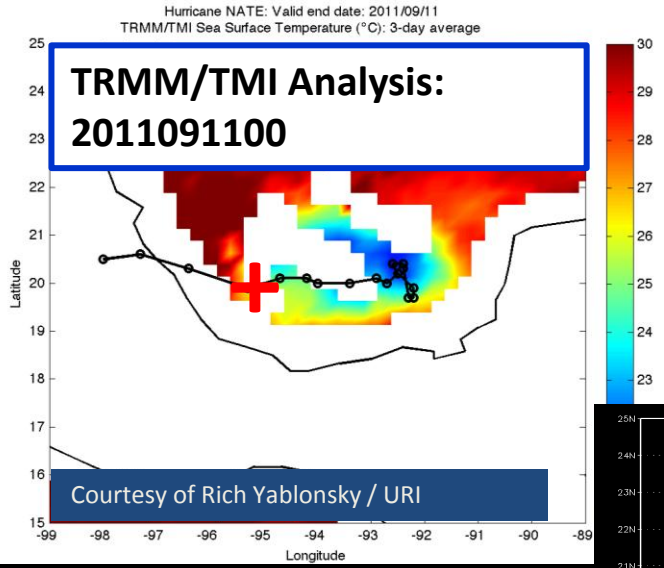
*In this case, the two members that <u>increased</u> moisture (**GP04**, **GP12**) resulted in more accurate track and intensity forecasts.*

Ernesto: 2012080400

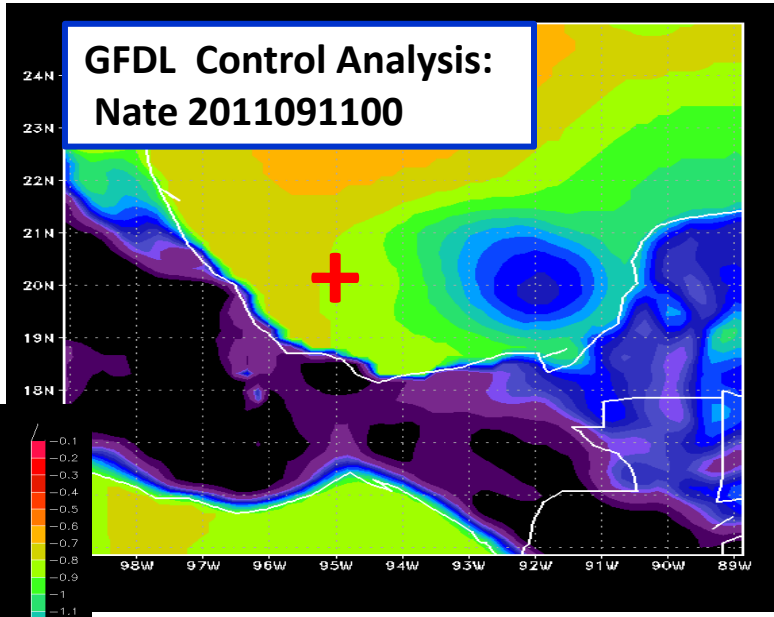


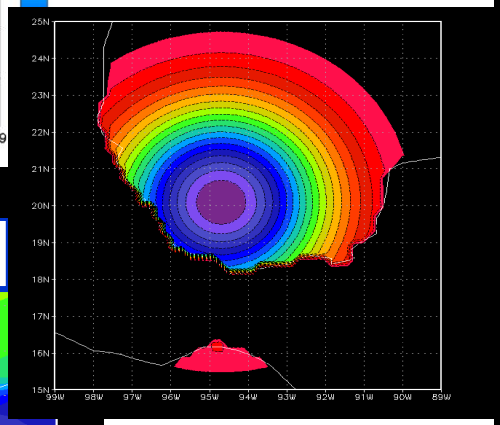
*In this case, the two members that <u>decreased</u> moisture (**GP05**, **GP13**) resulted in more accurate track forecasts.*

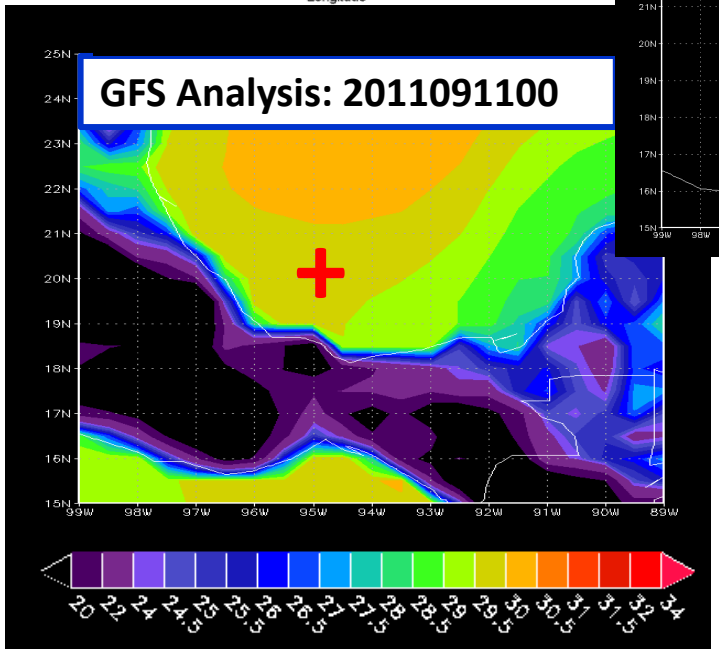
Motivation for SST perturbations

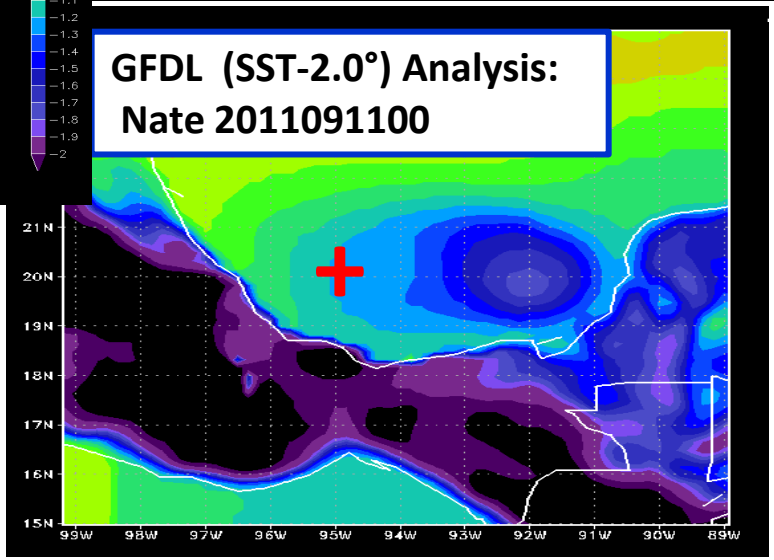


Nate (2011)

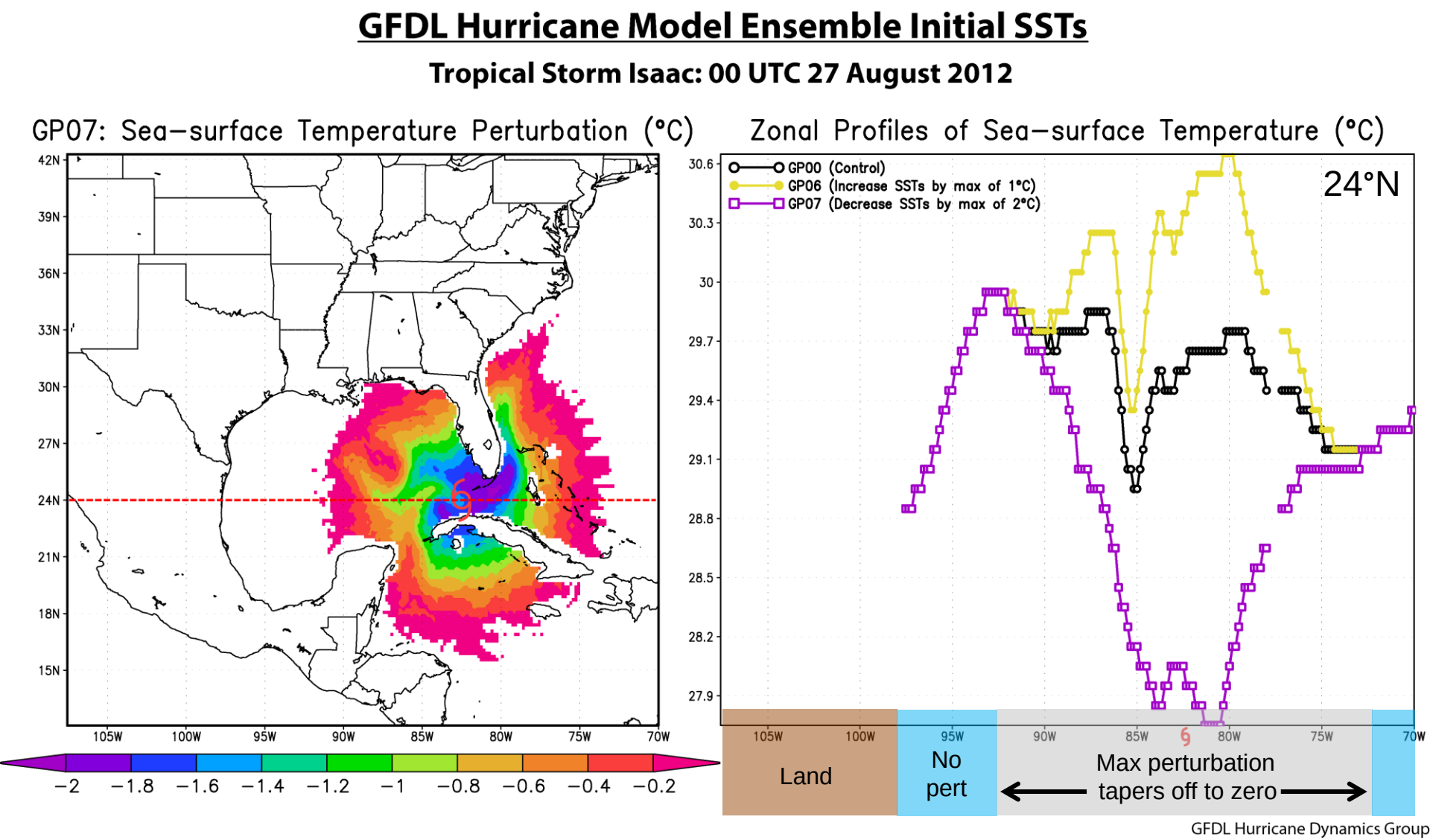




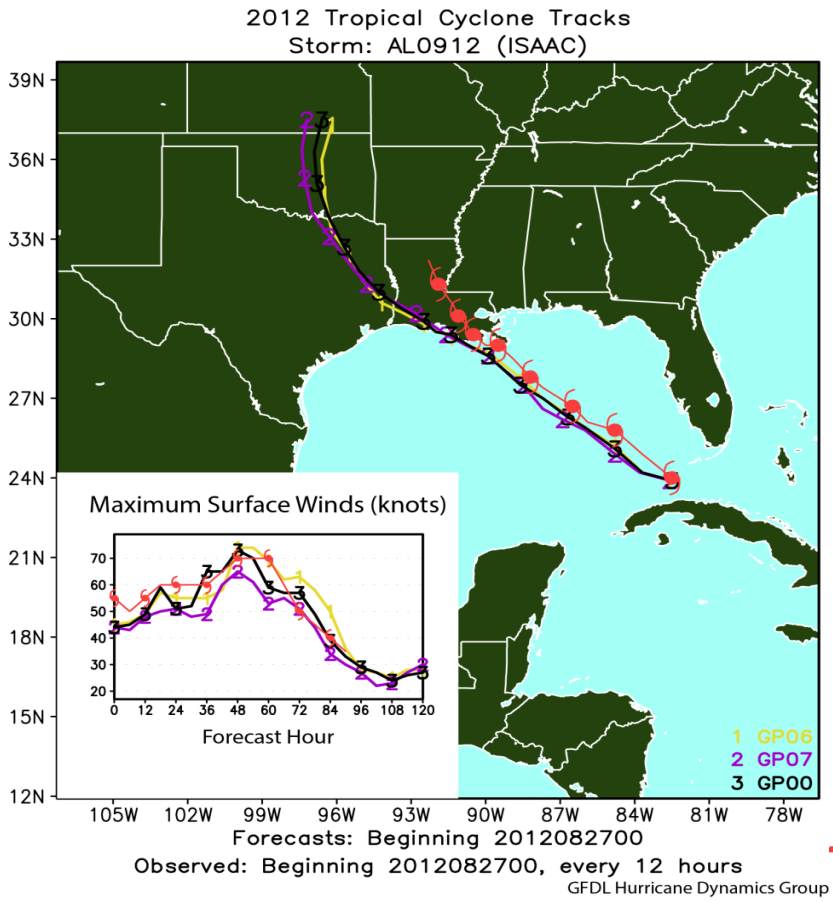


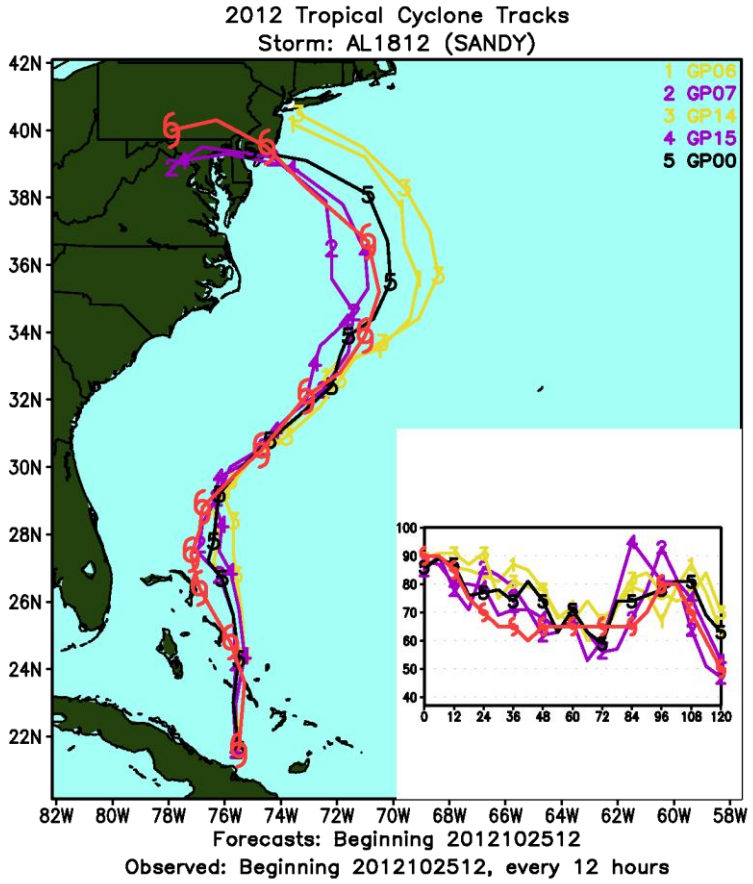


Example: SST perturbations



Example: Impact of SST perturbations





Observed

*In this case, perturbing the initial SST field around the vortex (↑**GP06**, ↓**GP07**) did not result in a more accurate track and intensity forecast compared to the Control (**GP00**).*

*In this case, the two members that <u>decreased</u> SST (↓**GP07**, ↓**GP15**) resulted in more accurate track forecasts than those which increased SST.*

Outline

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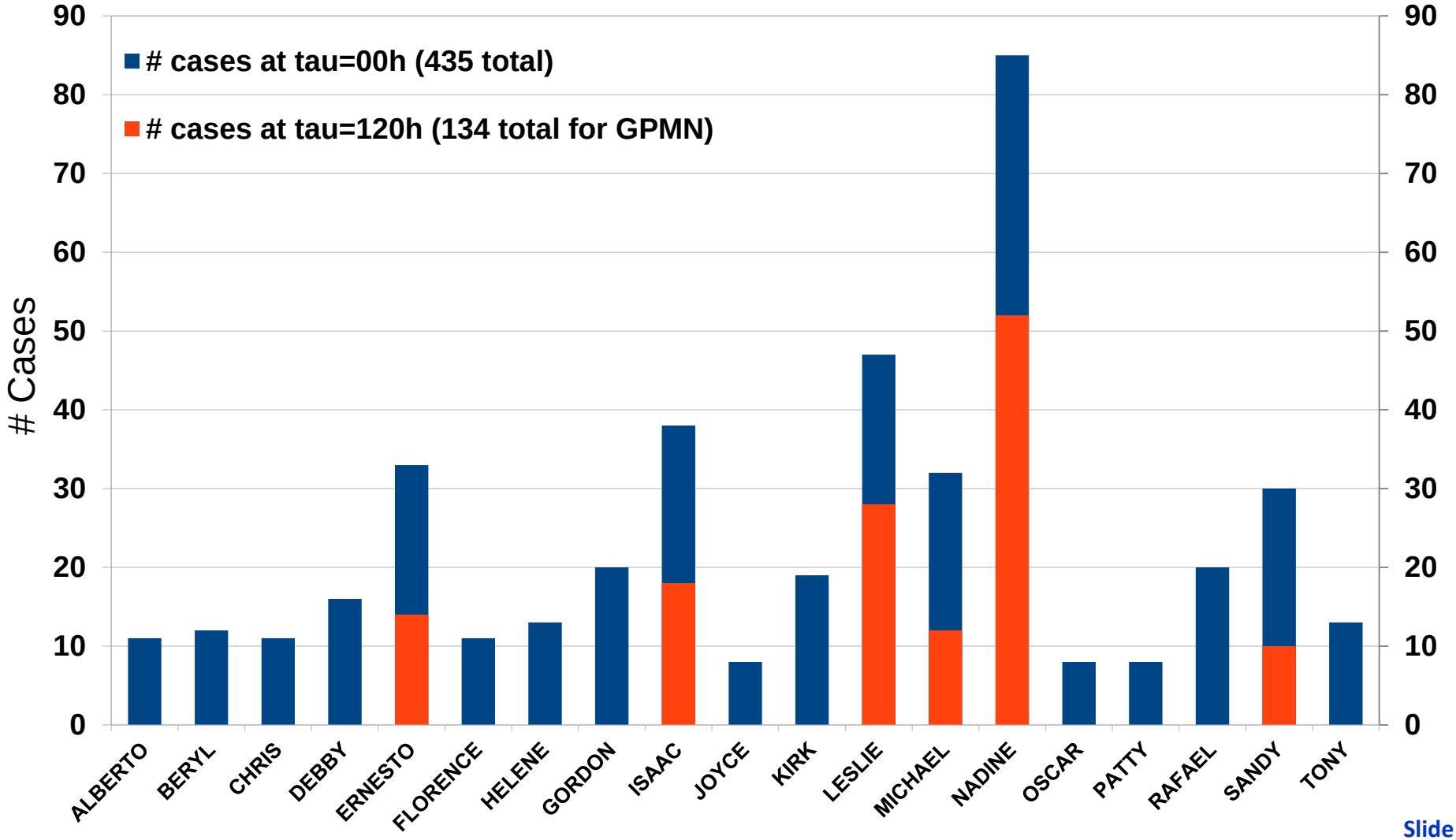
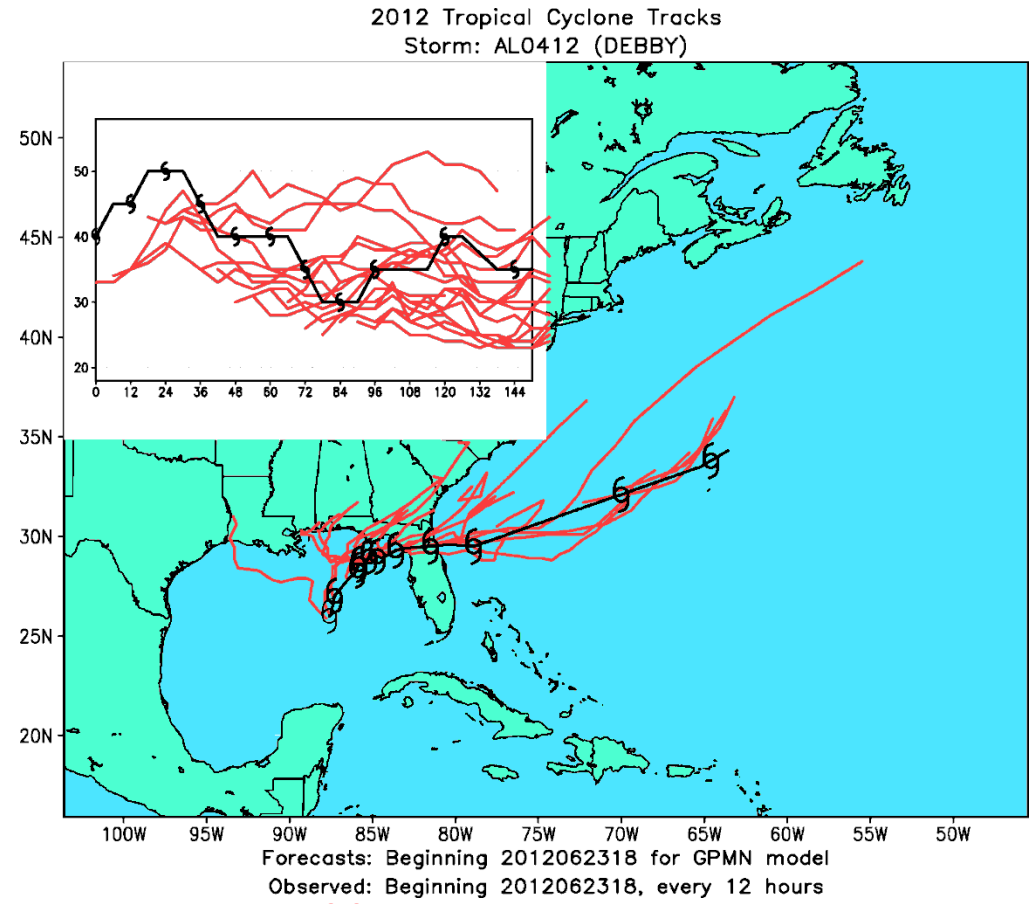
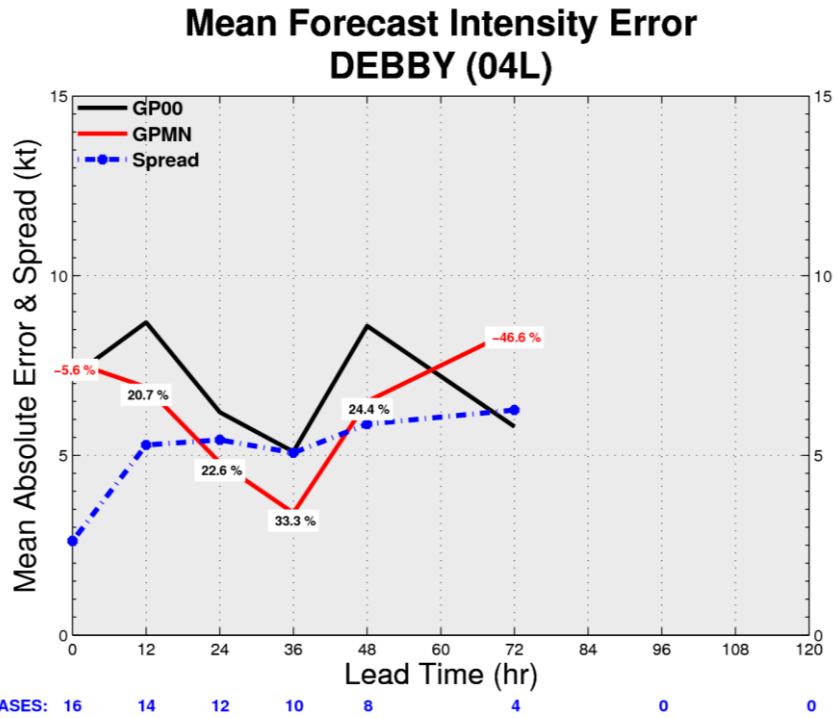
Verified Forecasts for GFDL Ensemble
2012 Atlantic Season



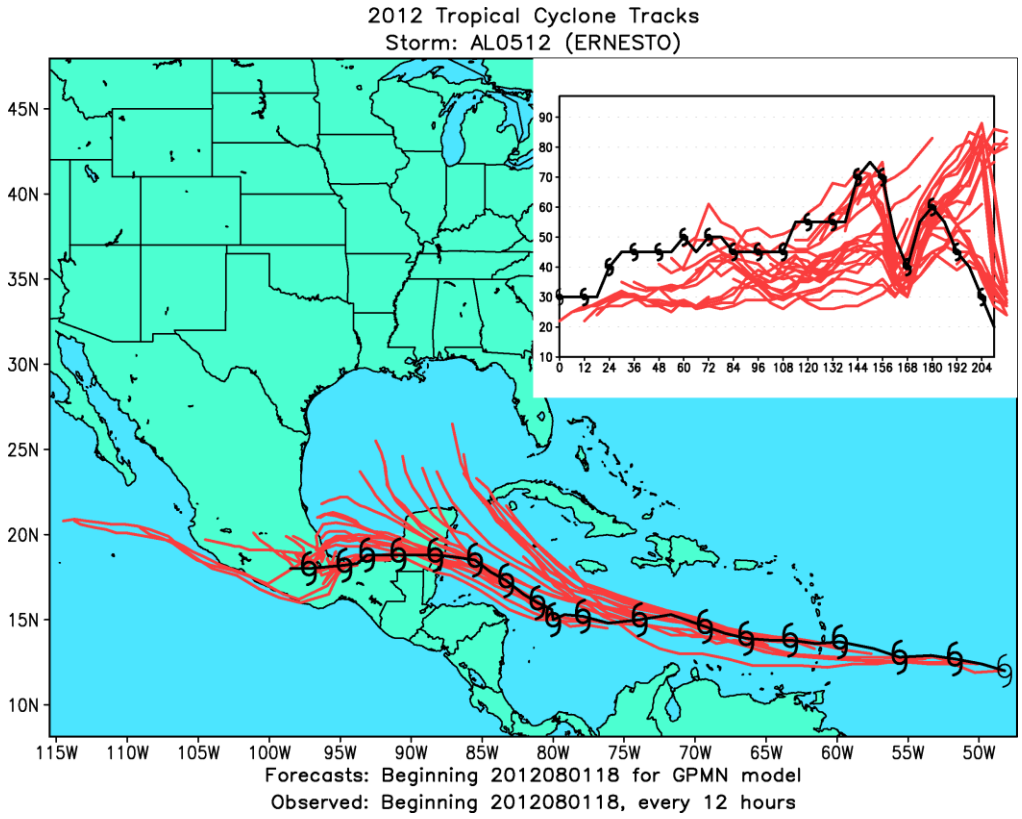
Tropical Storm Debby

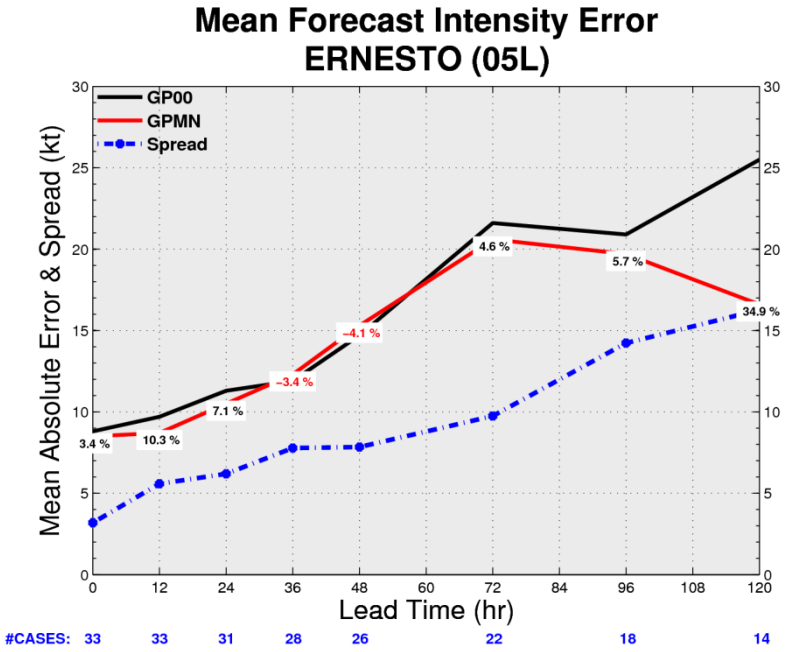




Ensemble mean (GPMN)

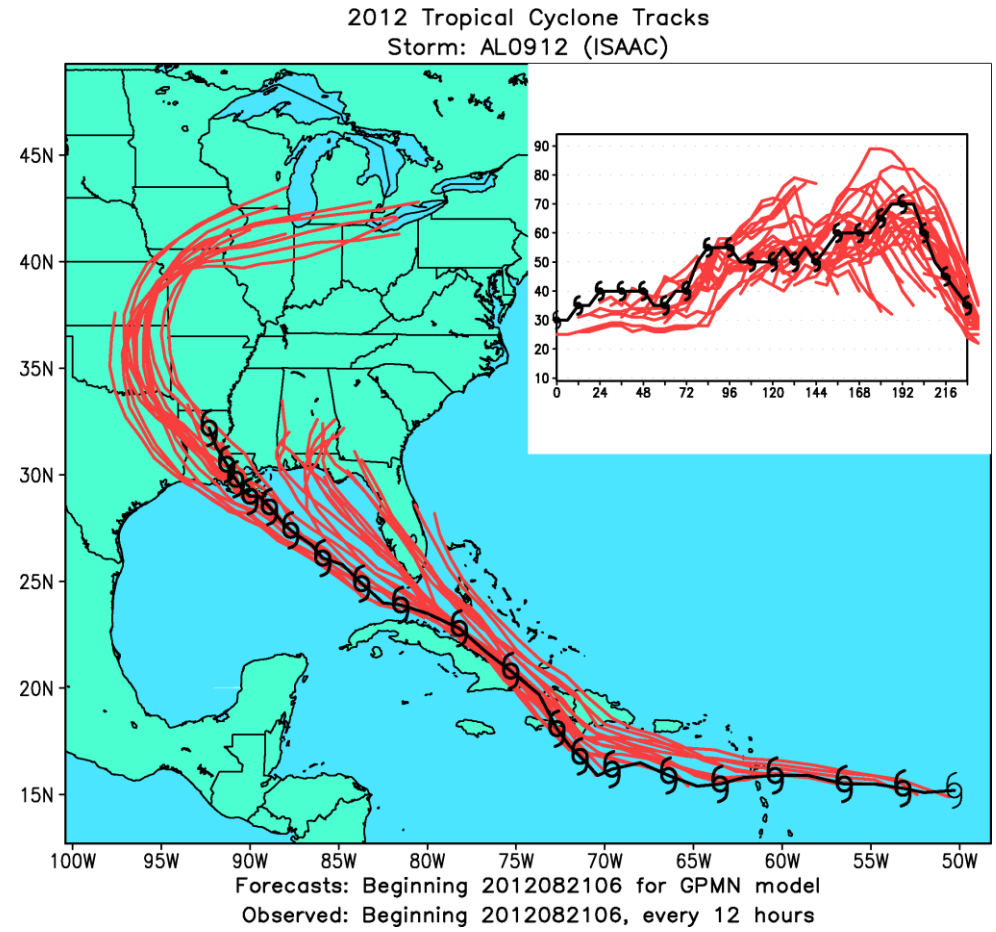
Hurricane Ernesto

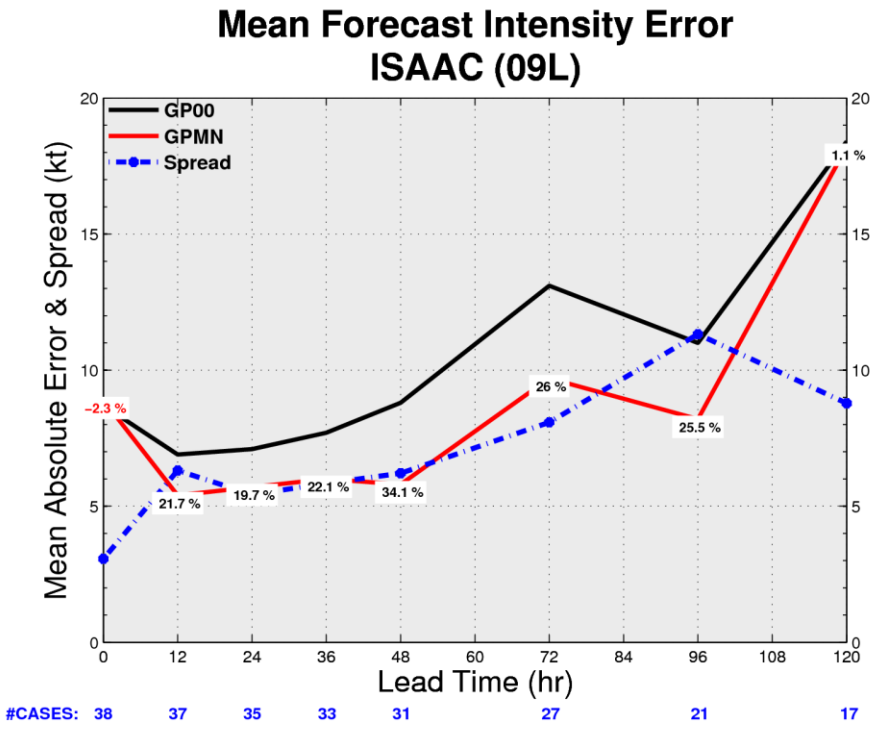




Ensemble mean (GPMN)

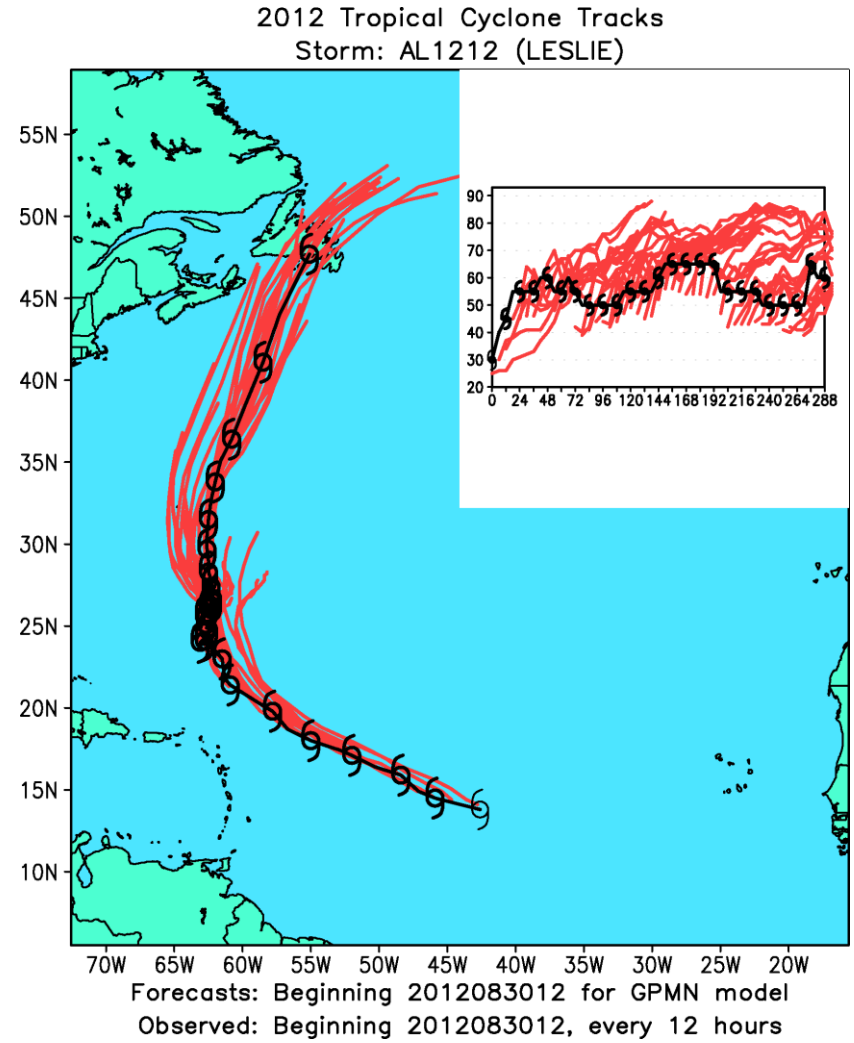
Hurricane Isaac

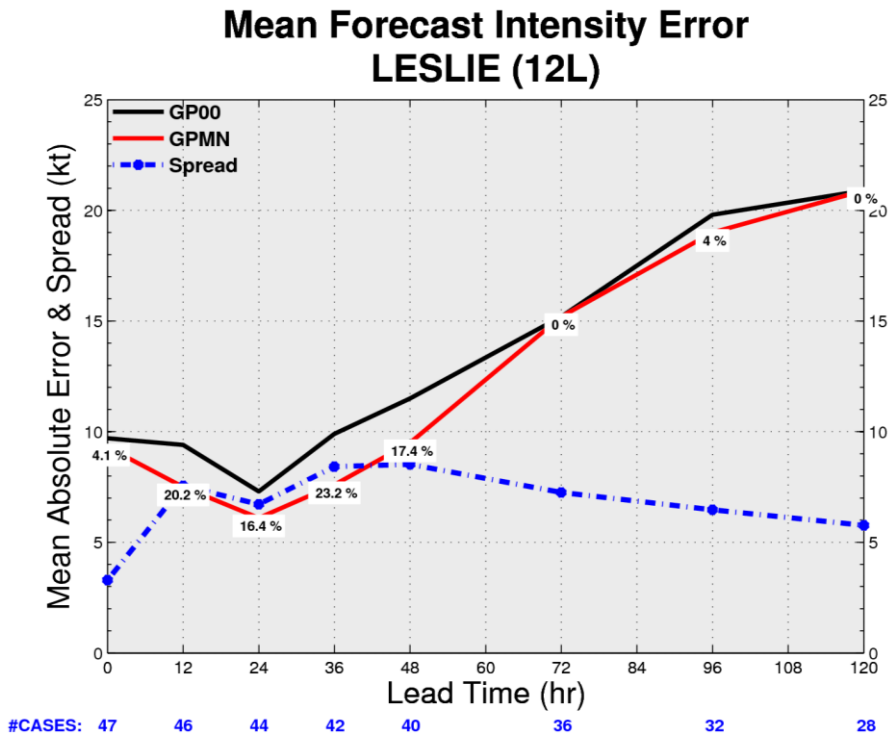




Ensemble mean (GPMN)

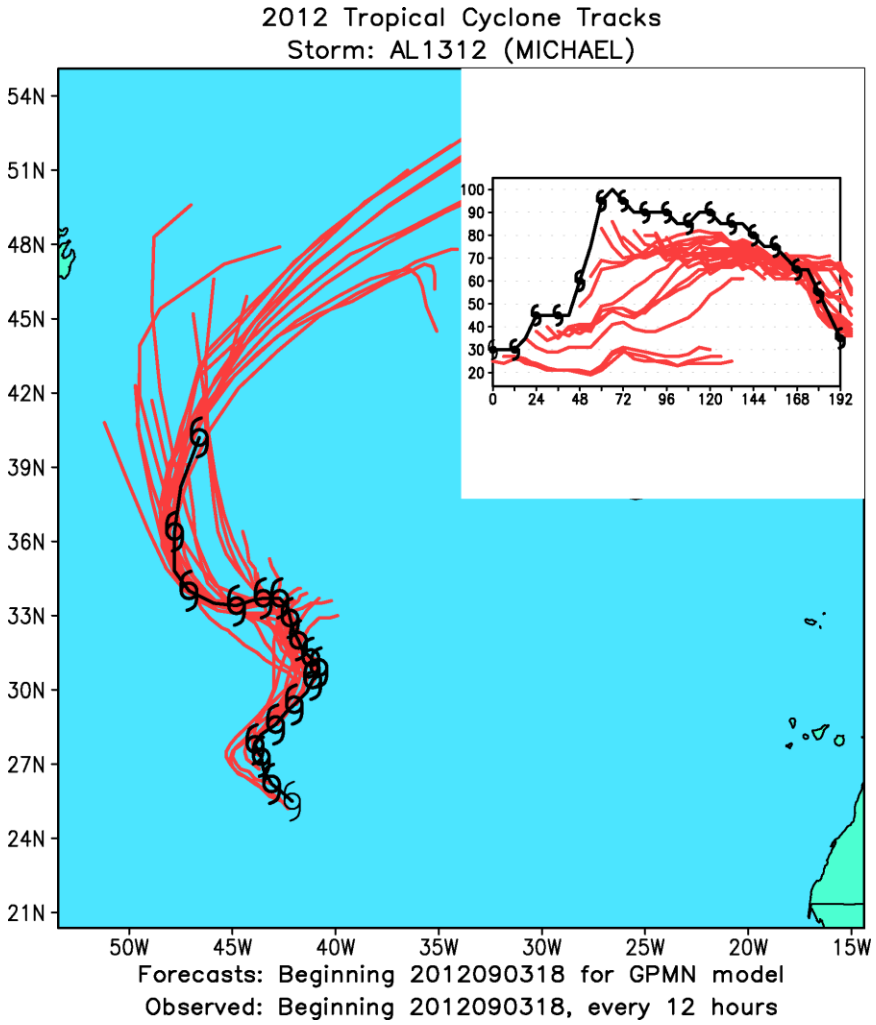
Hurricane Leslie

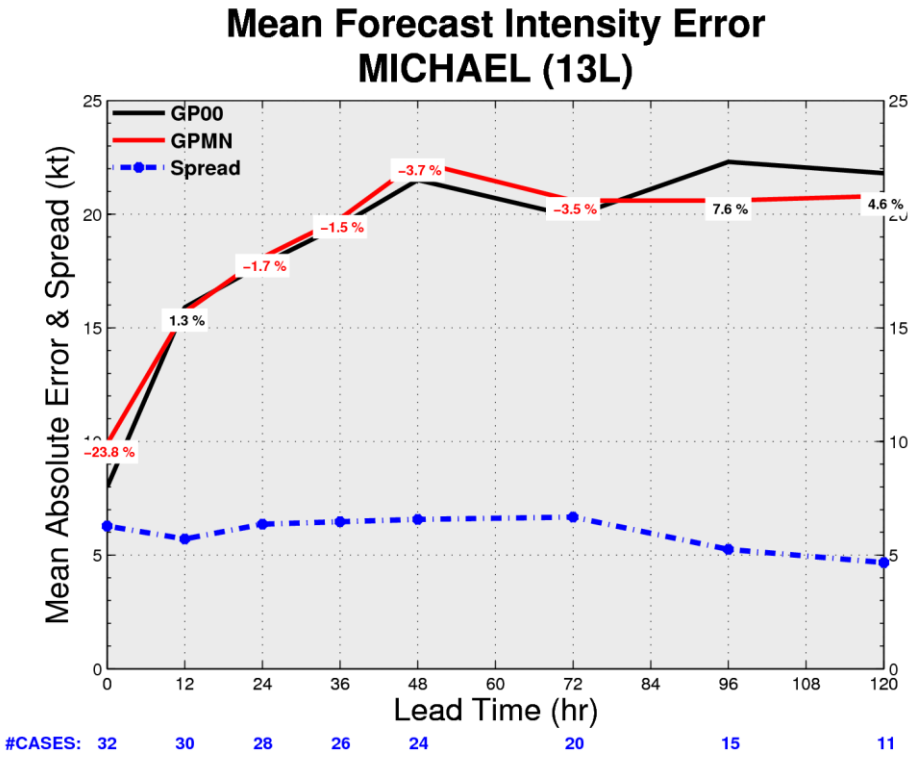




Ensemble mean (GPMN)

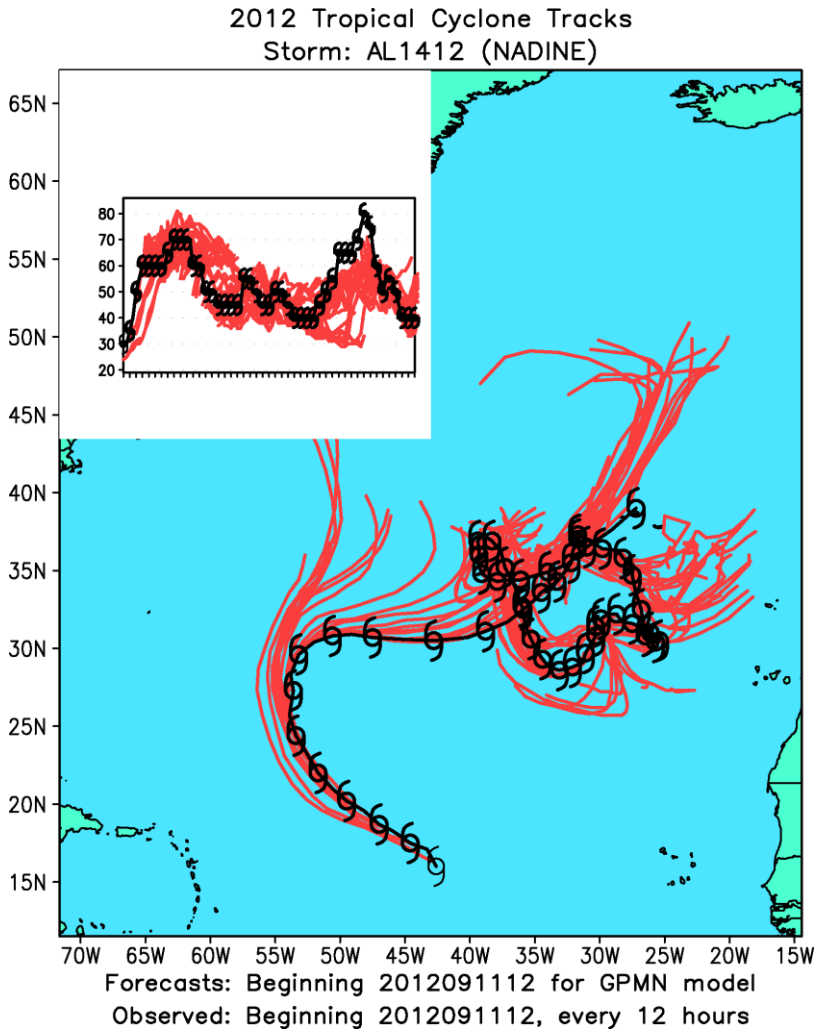
Hurricane Michael

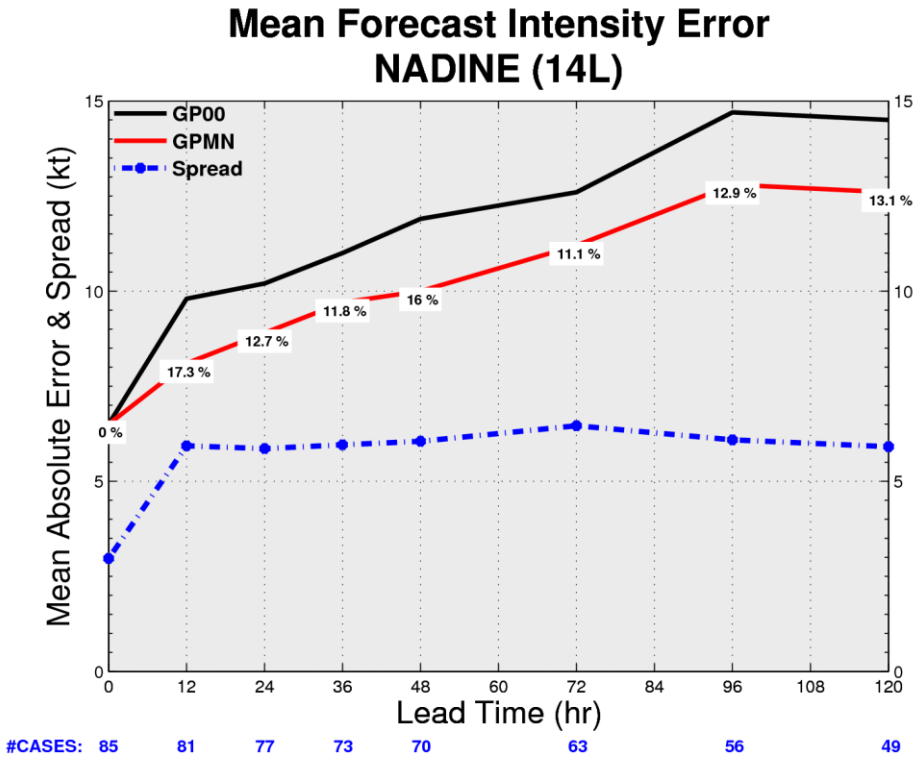




Ensemble mean (GPMN)

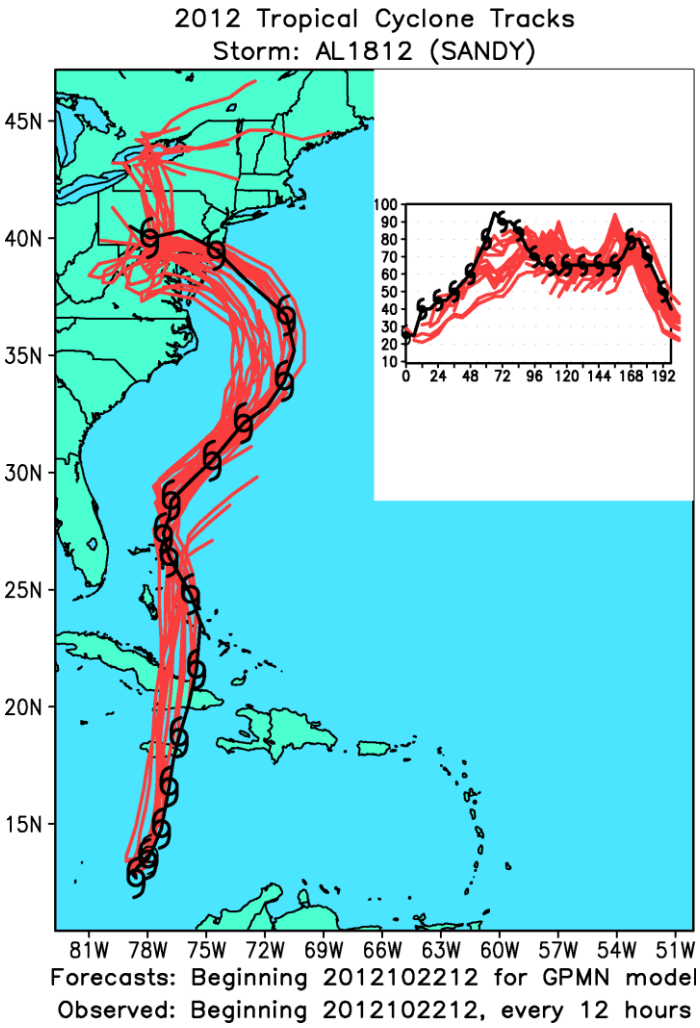
Hurricane Nadine

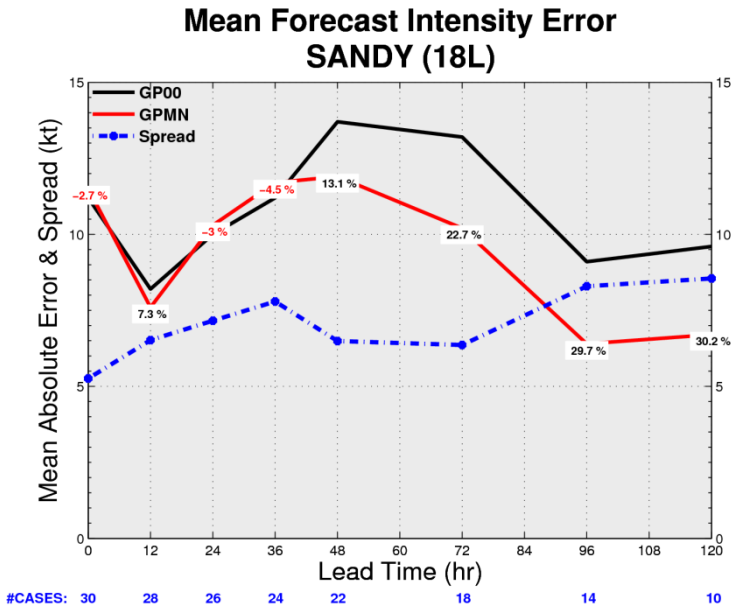


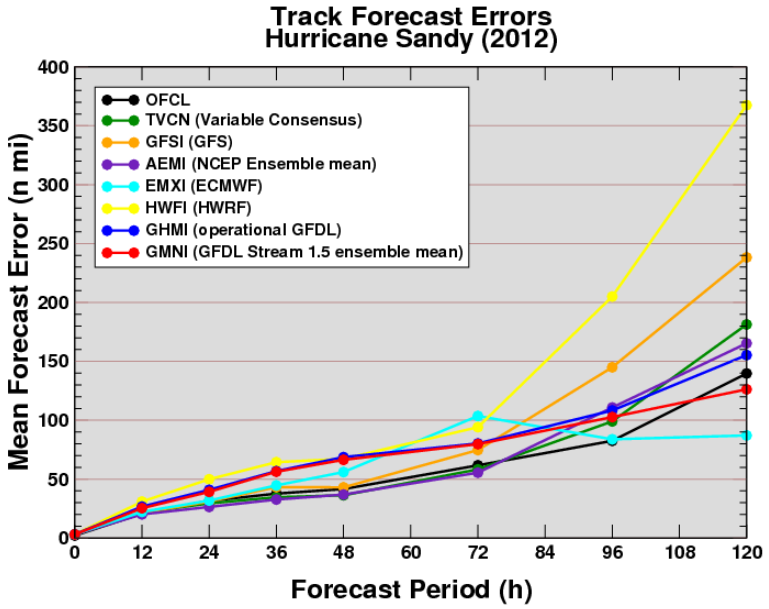


Ensemble mean (GPMN)

Hurricane Sandy







Ensemble mean (GPMN)

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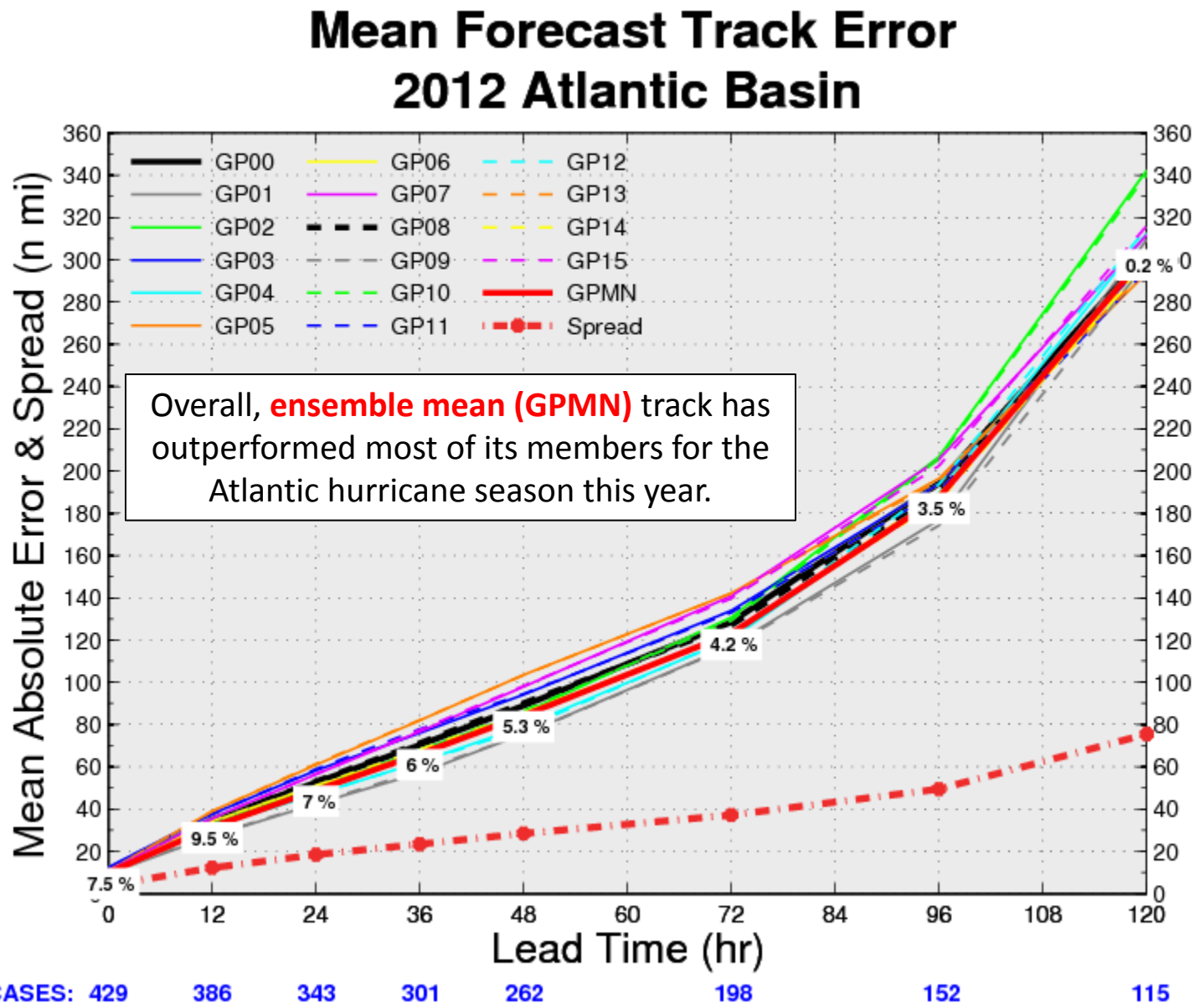
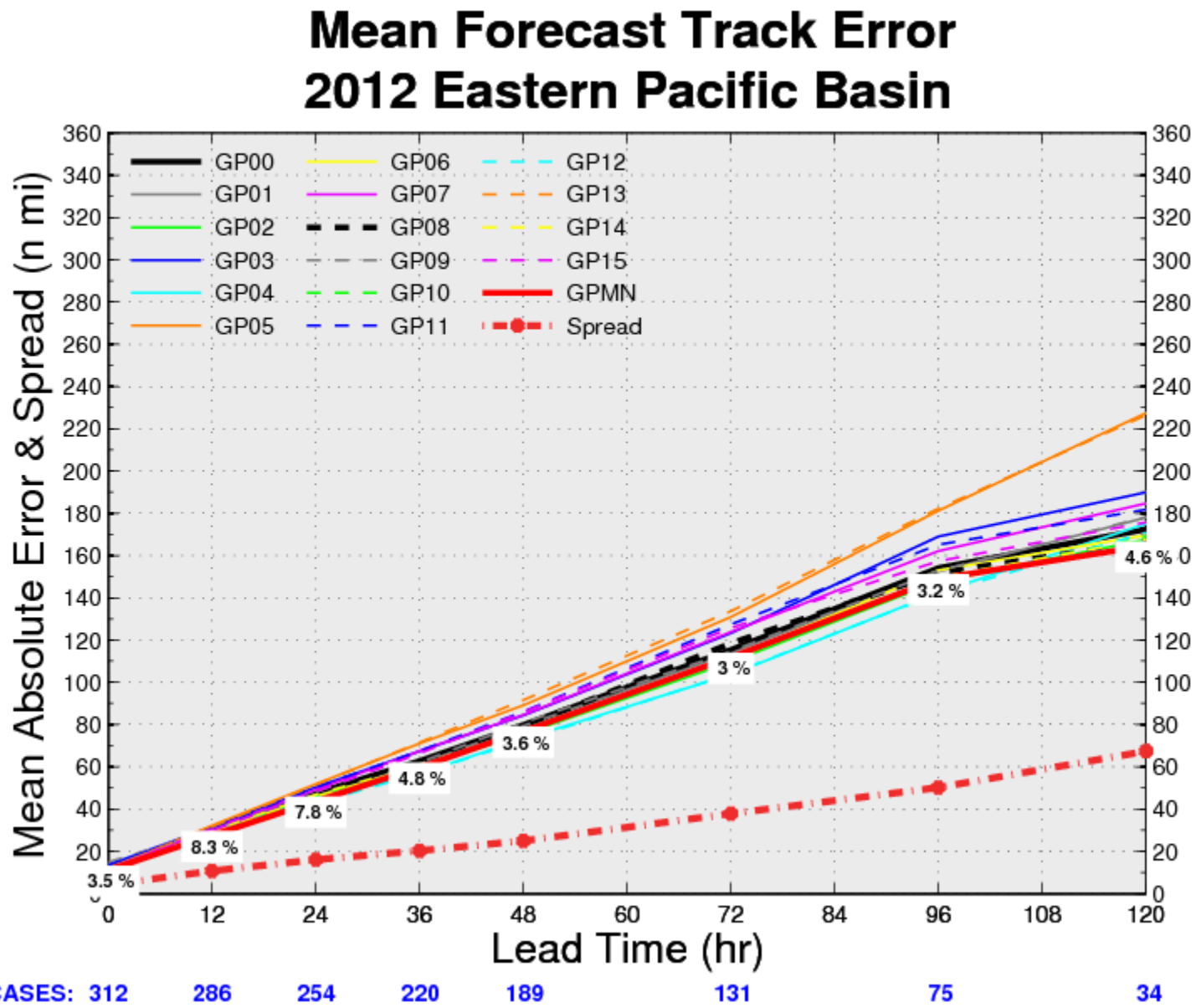
Results: Track Forecast Verifications (AL)



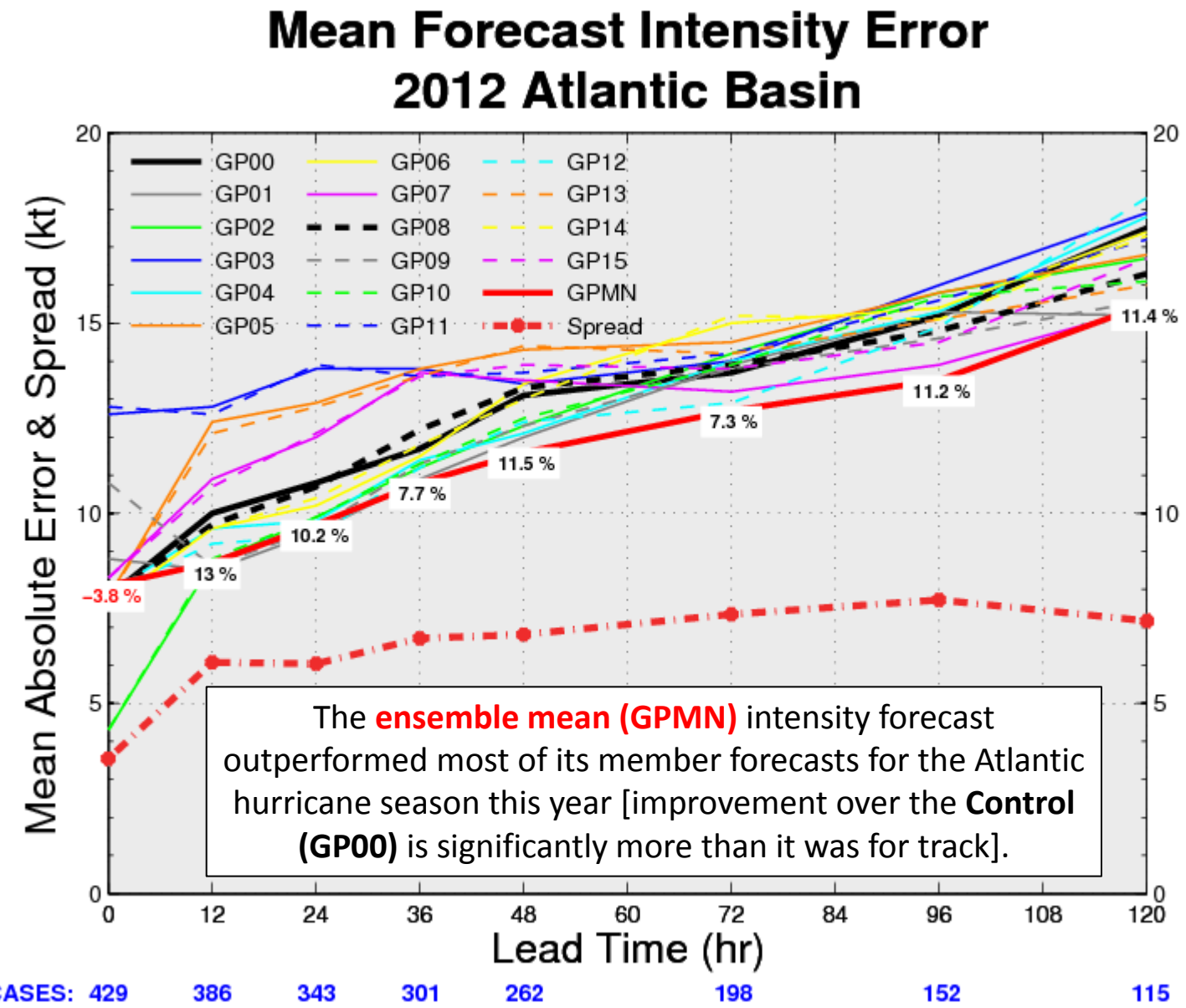
GPMN improvement (%) over the Control is noted in the white text boxes

Results: Track Forecast Verifications (EP)



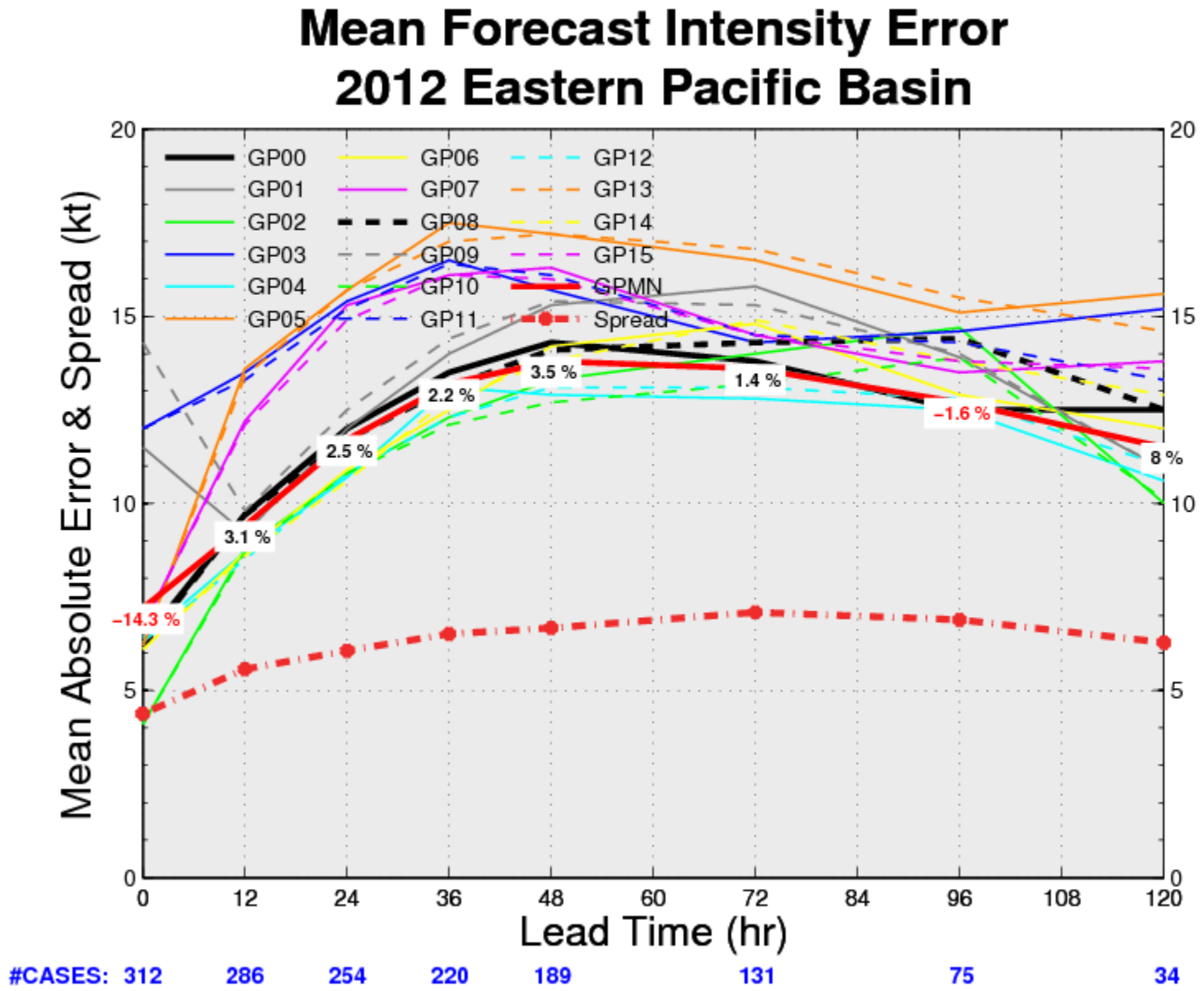
GPMN improvement (%) over the Control is noted in the white text boxes

Results: Intensity Forecast Verifications (AL)



GPMN improvement (%) over the Control is noted in the white text boxes

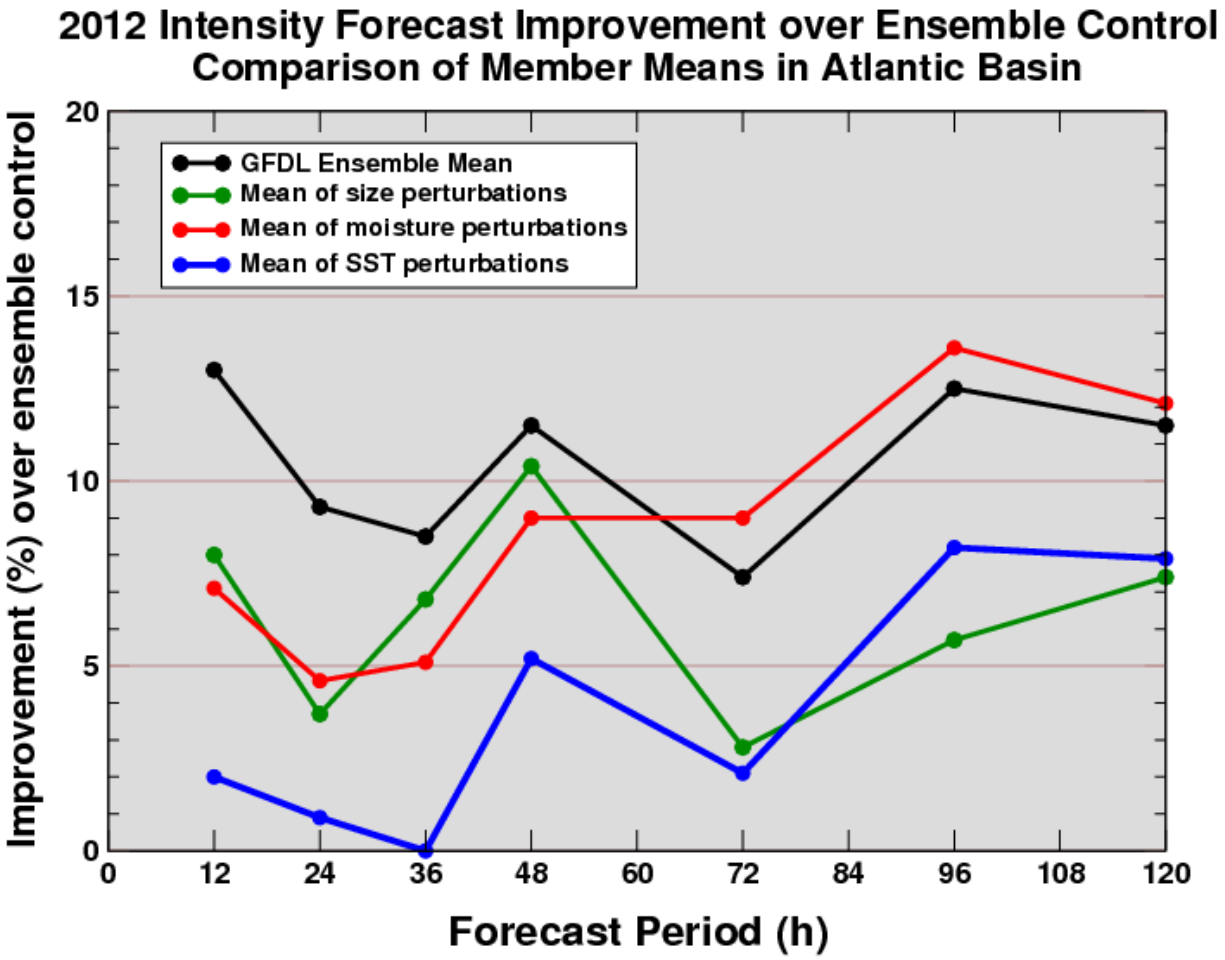
Results: Intensity Forecast Verifications (EP)



GPMN improvement (%) over the Control is noted in the white text boxes

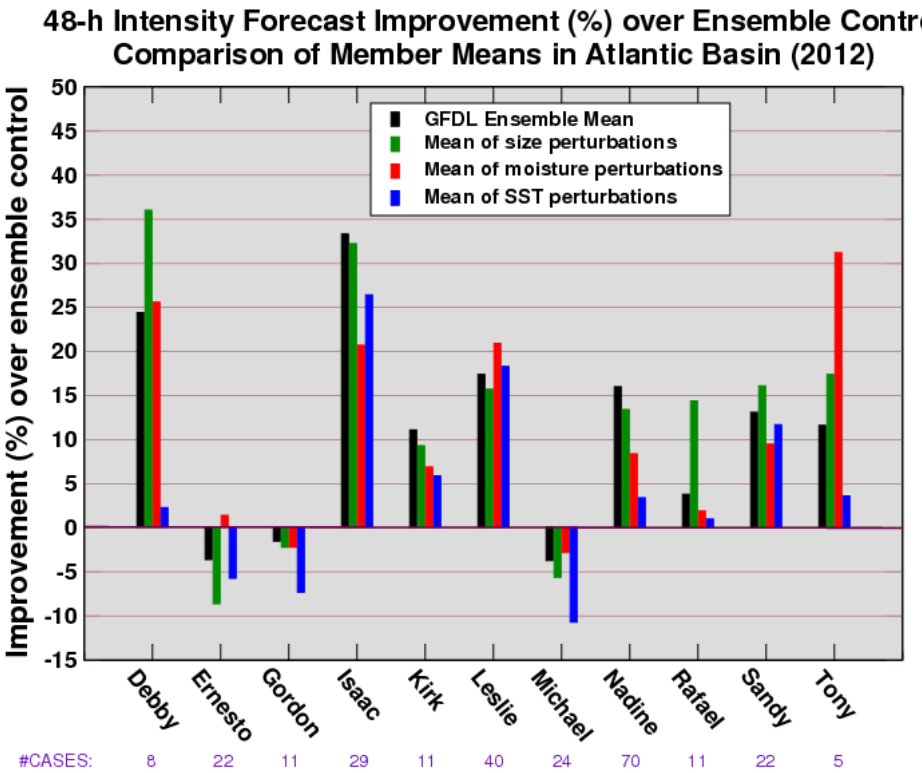
Intensity Forecast Performance by Member Means

Size and moisture perturbations provide the most improvement out to 48h. At later lead times, the moisture perturbations outperform the size and SST members

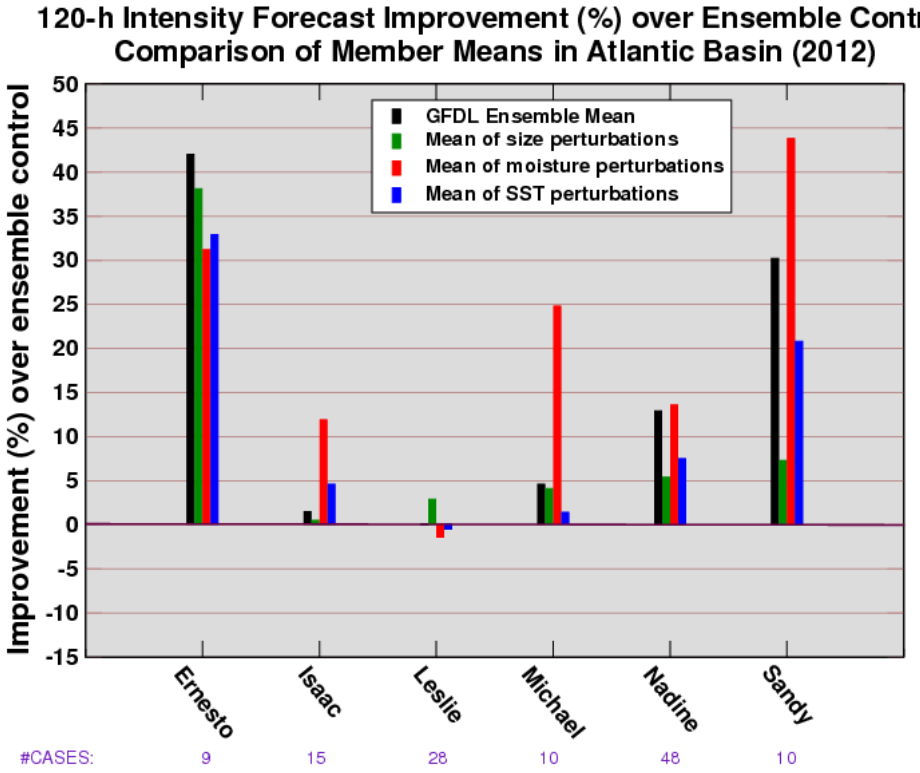


Intensity Forecast Performance by Storm

48h



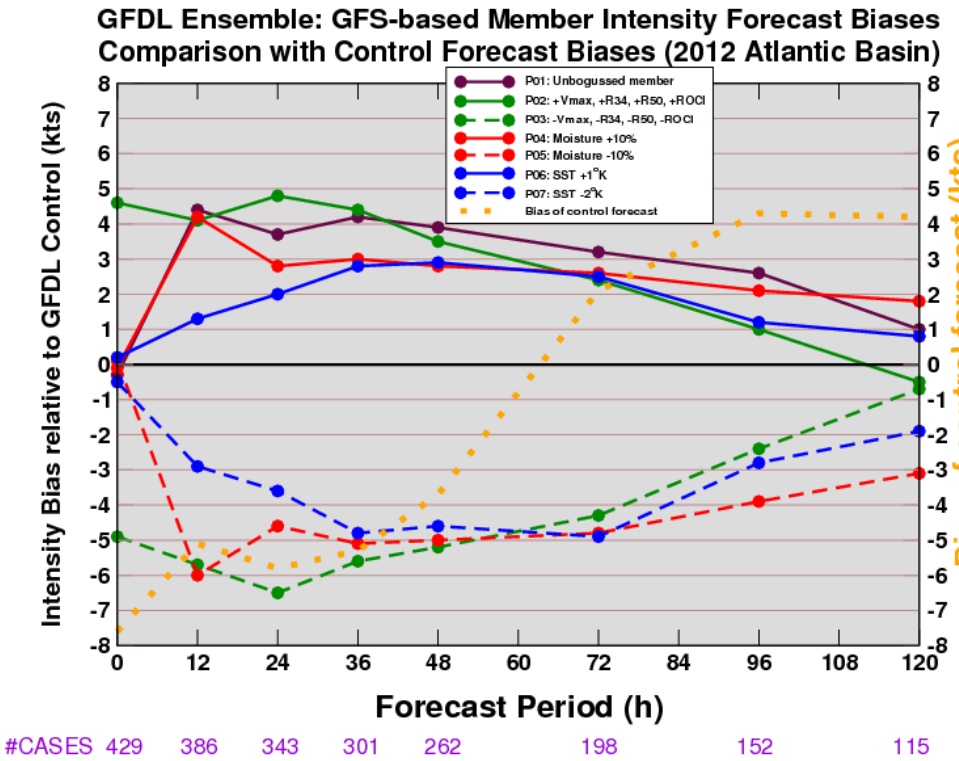
120h



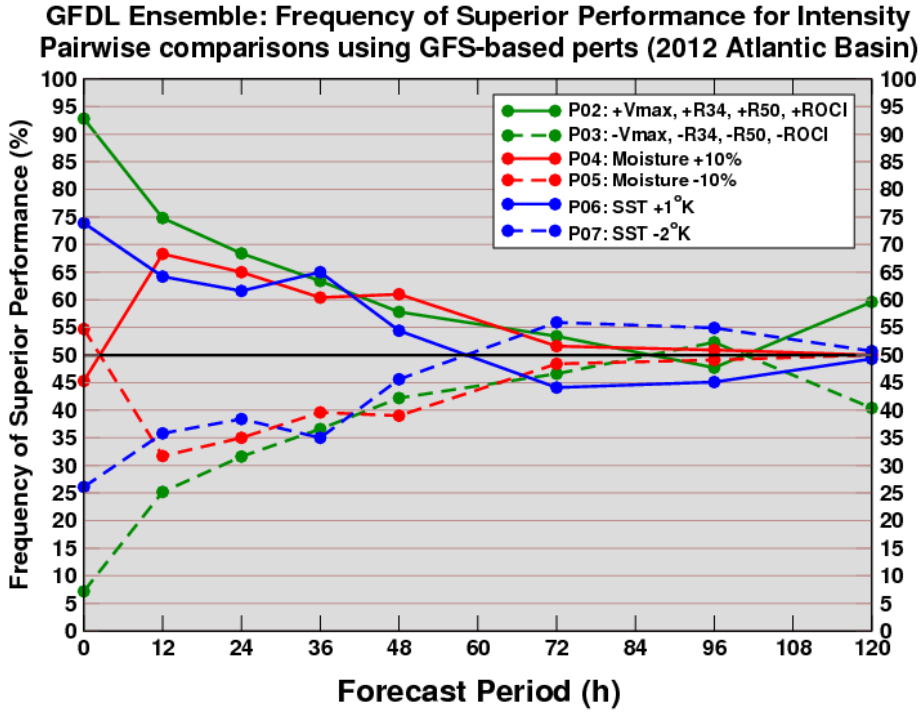
Magnitude of the improvement varied from storm to storm, but the sign of the improvement relative to the control was consistent among member means for a given storm.

Comparisons of forecast bias and FSP for Atlantic Basin intensity forecasts

Intensity bias of members relative to control forecast bias



Pairwise comparisons of FSP for Atlantic intensity forecasts

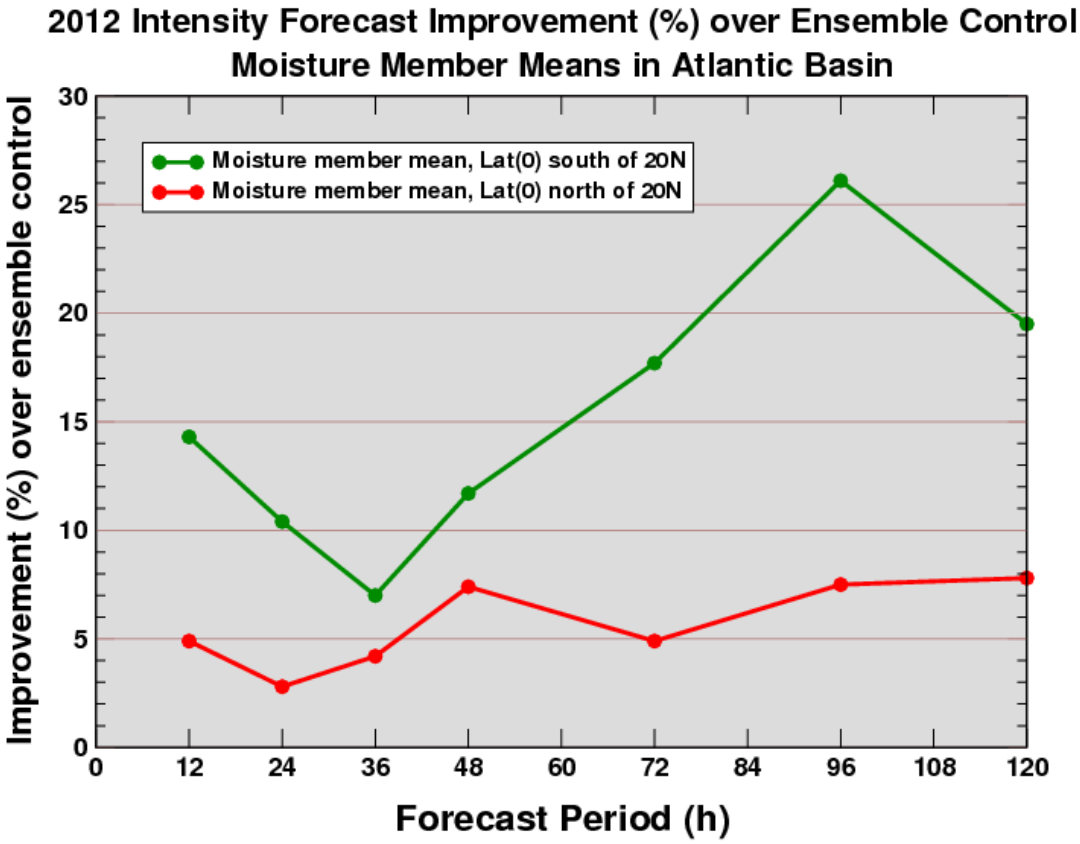


Perturbations to <u>reduce</u> intensity, size, moisture, etc, have a larger absolute impact on bias, likely due to control forecast's already strong initial negative intensity bias...

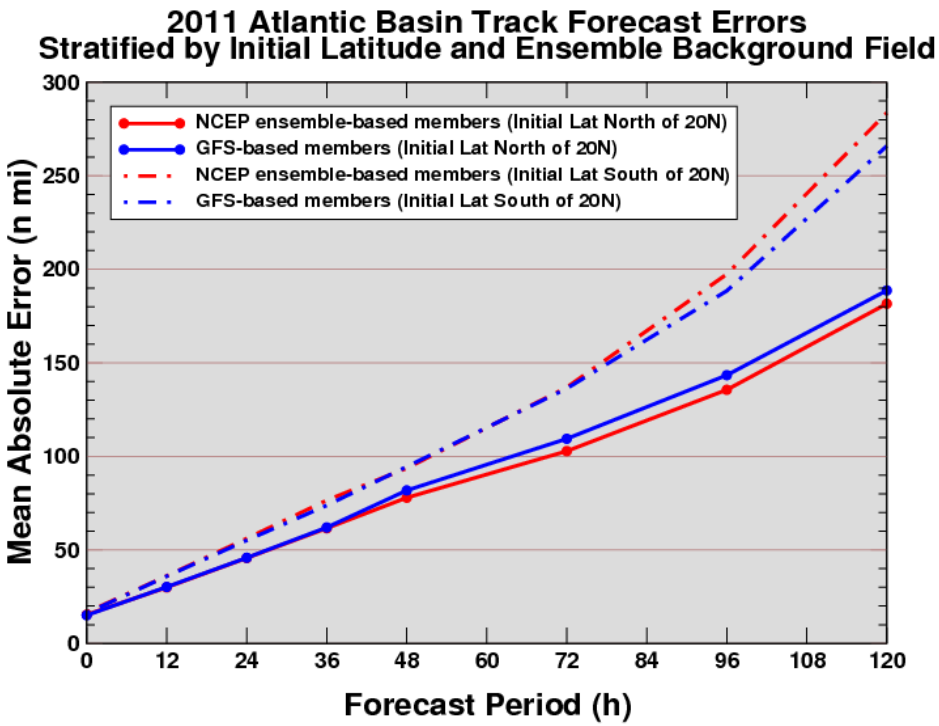
...which leads to a higher FSP at early lead times for perturbations that increase intensity & size.

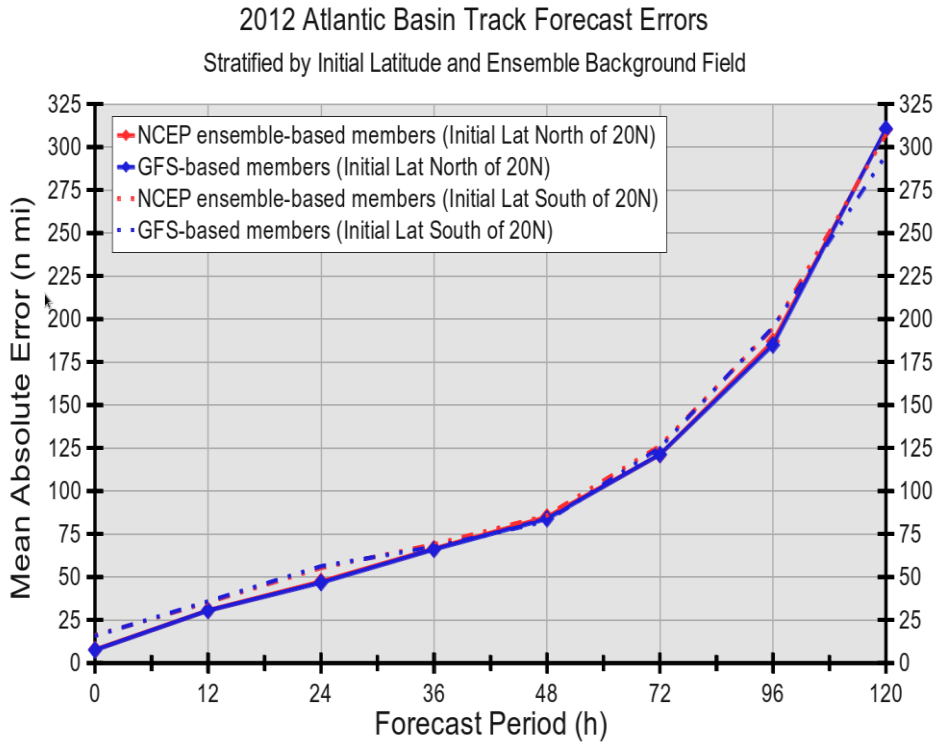
Impact on Intensity Forecasts of Moisture Perturbations North and South of 20°N

Beyond 48h, there is a significant increase in the improvement from the moisture members for forecasts initiated south of 20°N.



Atlantic Basin Track Forecast Errors Stratified by Initial Latitude and Ensemble Background Field





GFDL Ensemble Tier 1 Data Delivery

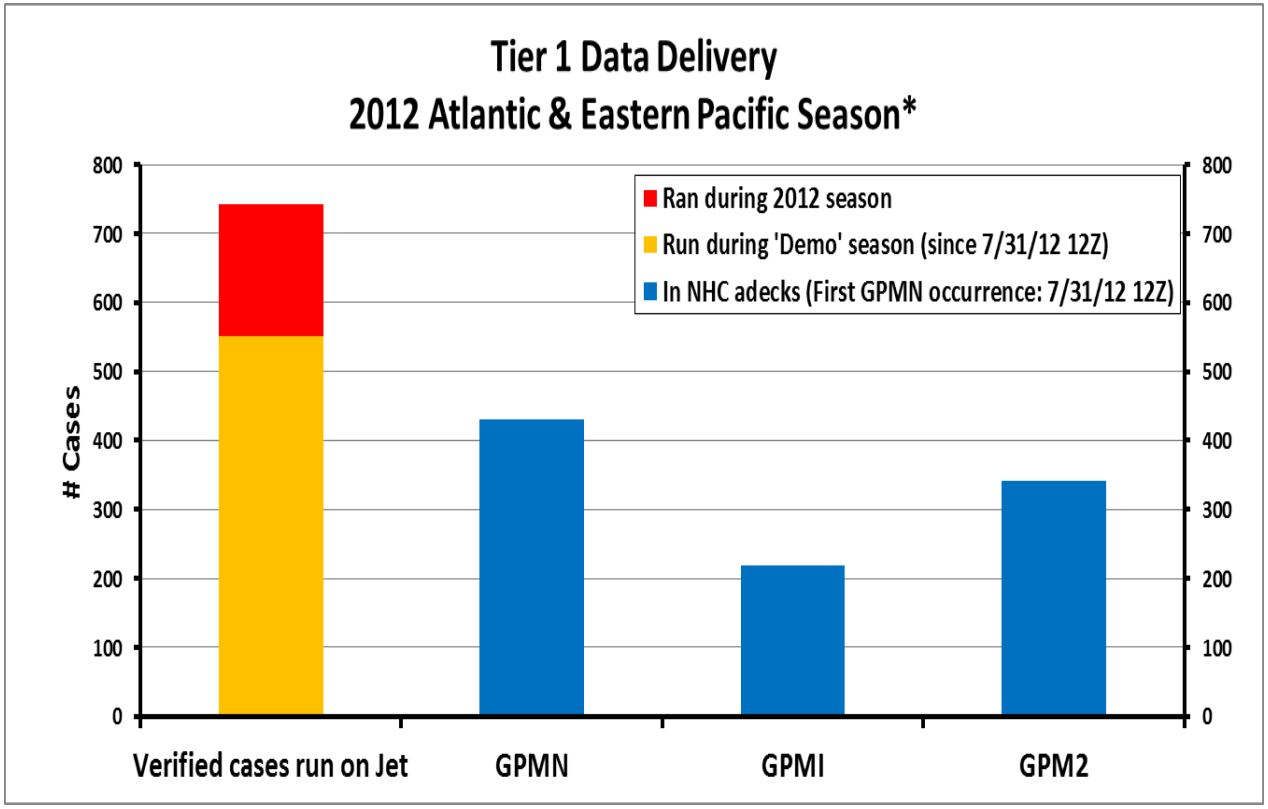
AL & EP forecast cases we ran during 2012= **742**

Forecast cases we ran since start of Stream 1.5 data flow (31 July) = **565**

Total GPMN cases during 2012 that did not get into NHC decks = **312**

GPMN cases during Demo that did not get into the operational decks = **121**

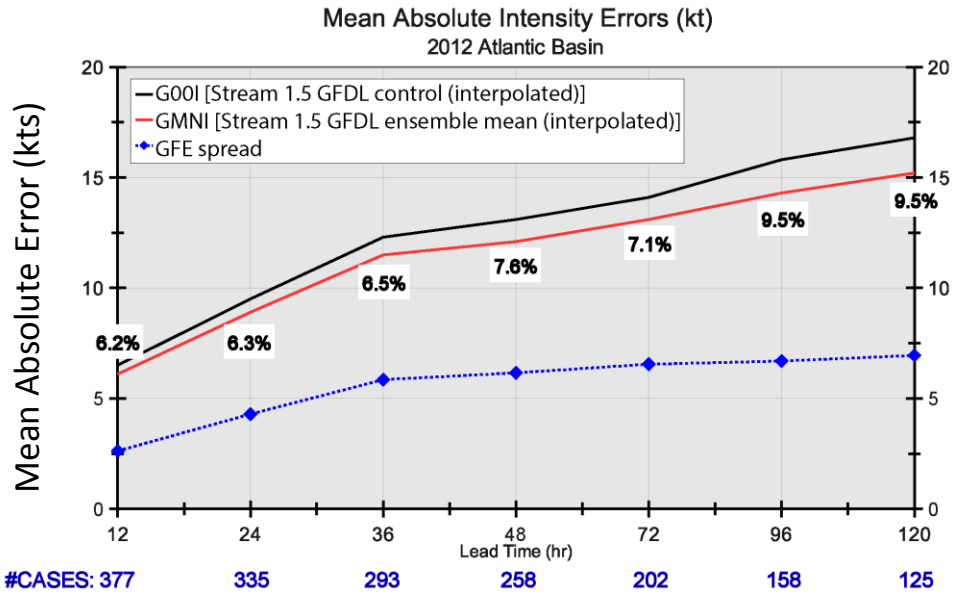
- Reasons include:
  (1) Only able to run 1 storm at a time
  (2) Forecast failures



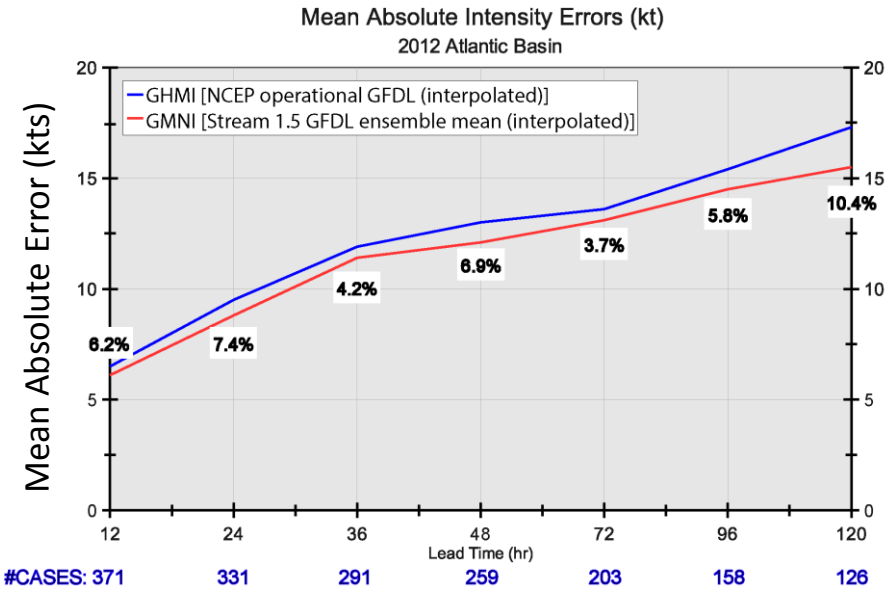
* Named storms only

Comparison of early intensity guidance

GFDL Ensemble Mean vs. Ensemble Control



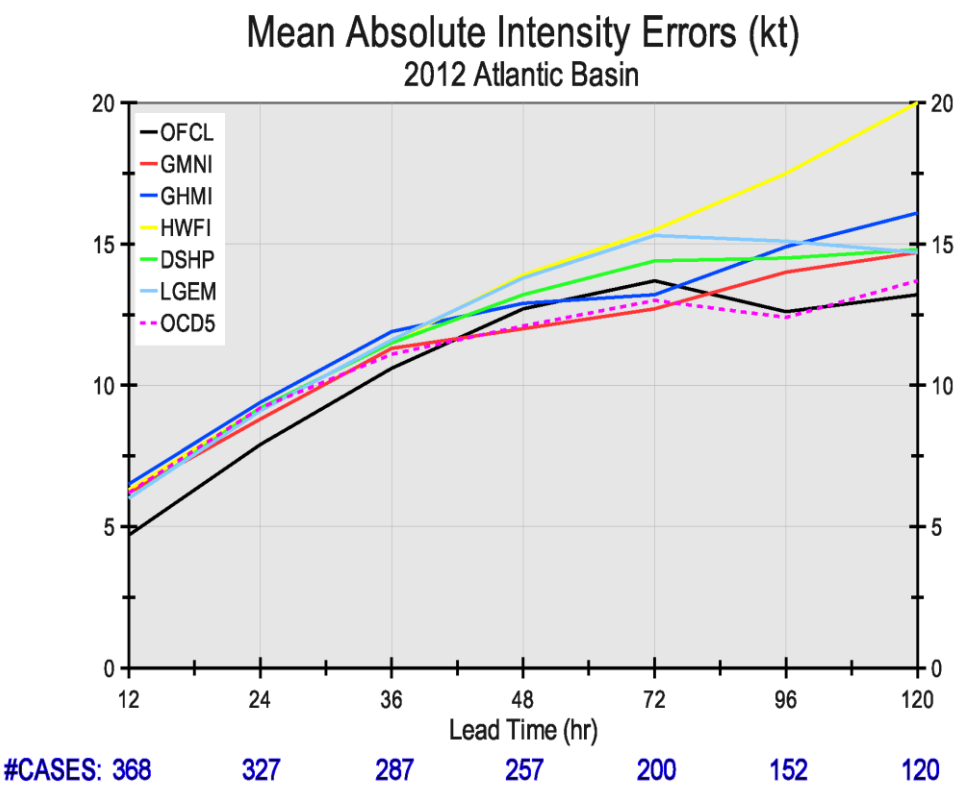
GFDL Ensemble Mean vs. Operational GFDL



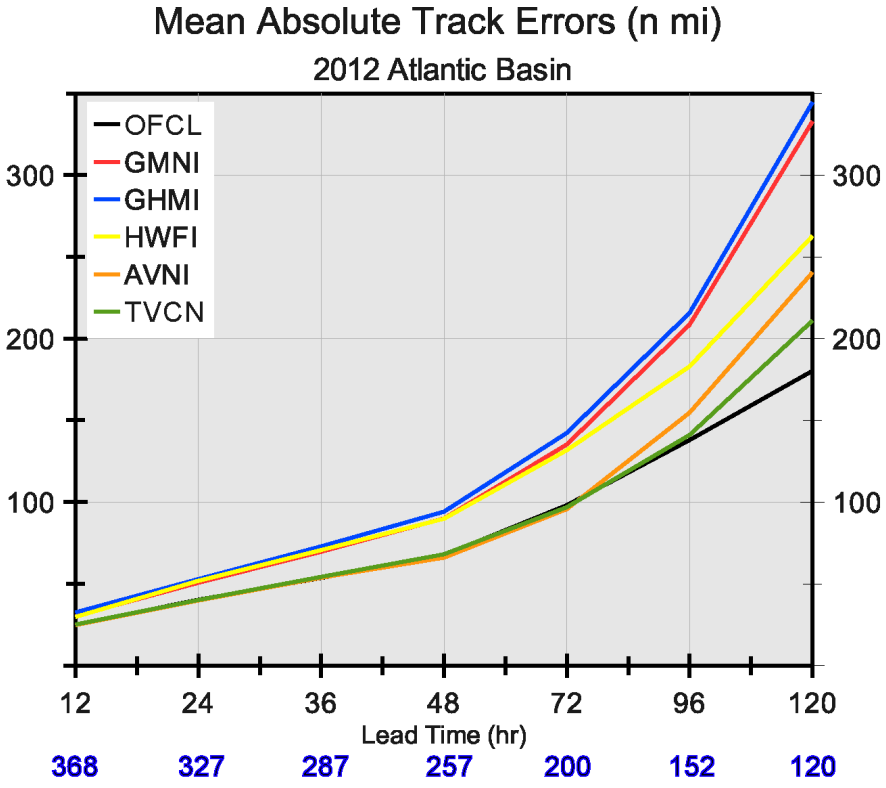
- *Statistically significant (95% level) improvements at every lead time.*
- *Moderate practical significance (>1kt) for lead times >36h compared to Control (left), and at tau=120h compared to operational GFDL (right).*

Comparisons with other operational guidance

Intensity



Track

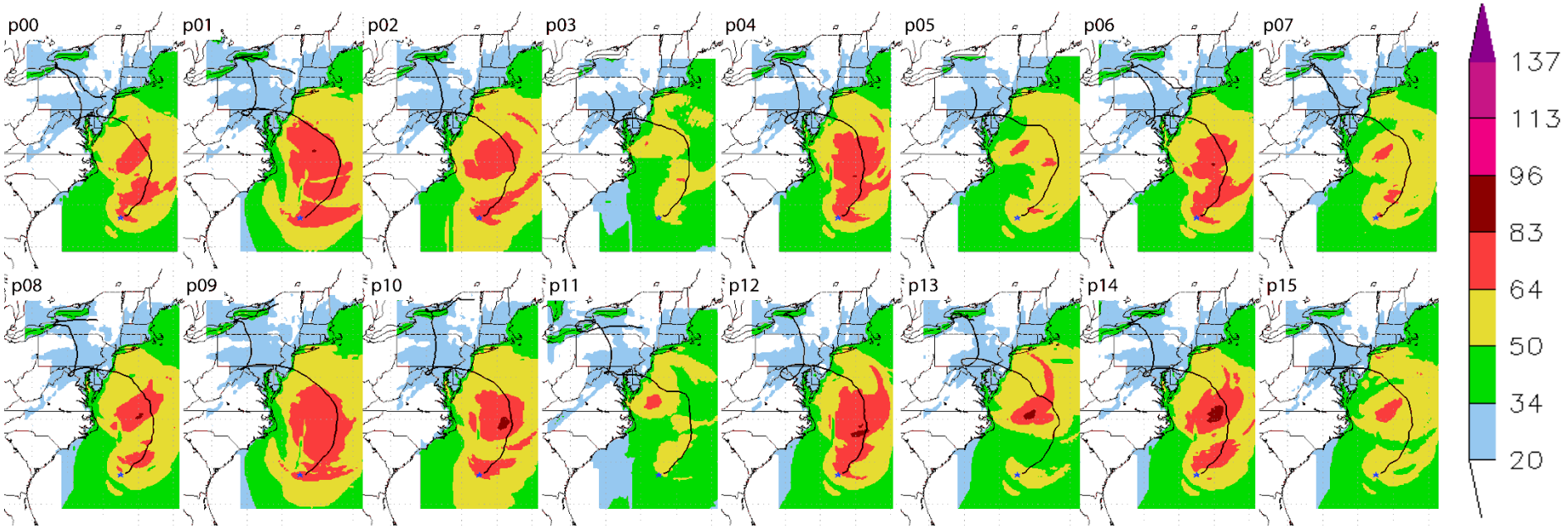


- *GFDL Ensemble mean (GMNI) was very competitive with top operational guidance for intensity forecasts (left), but with very little skill relative to Decay-Shifor (OCD5).*
- *GFDL Ensemble mean track forecasts (right) were slightly better than the operational GFDL, but not competitive with top operational guidance.*

Maximum Wind Swaths for Each Ensemble Member

Hurricane Sandy: 2012102812

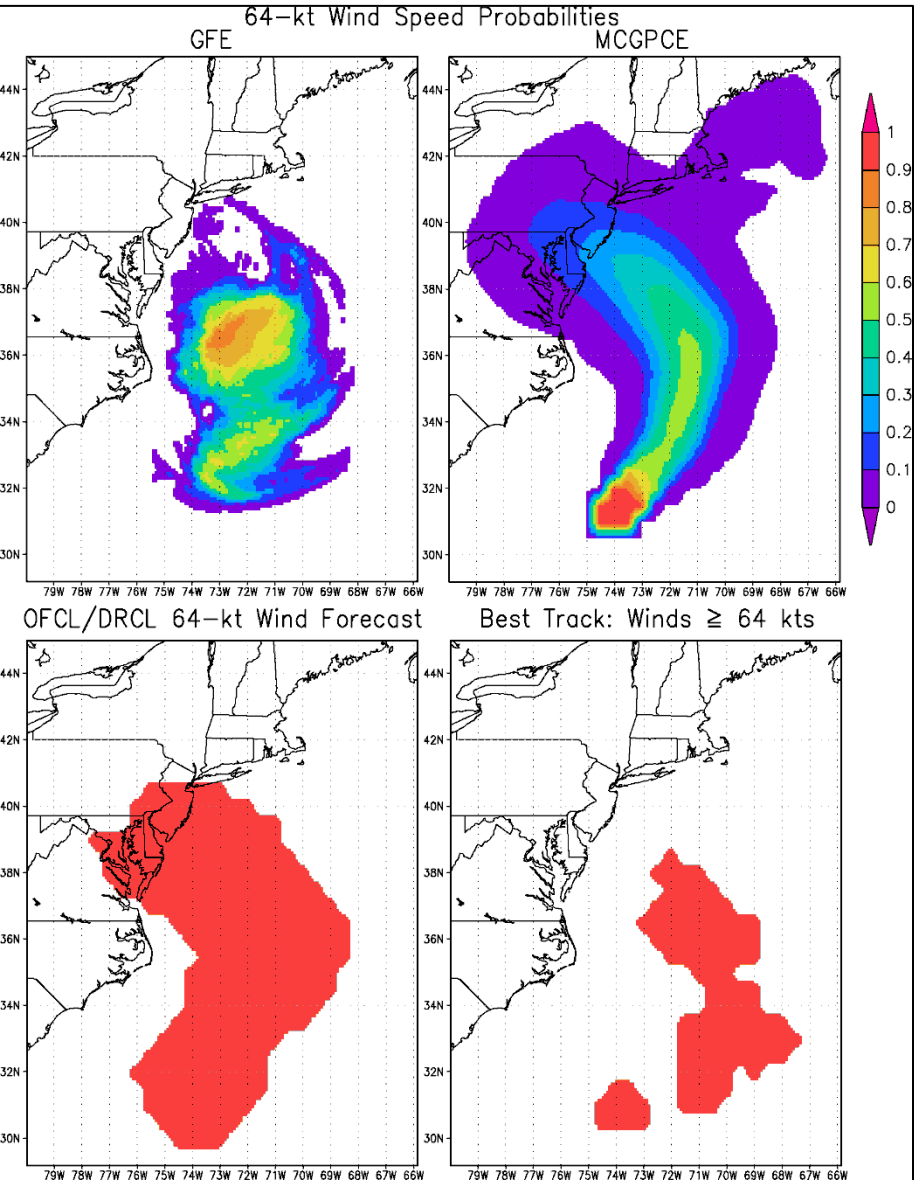
Maximum 10m winds (kt) for Sandy (18L)

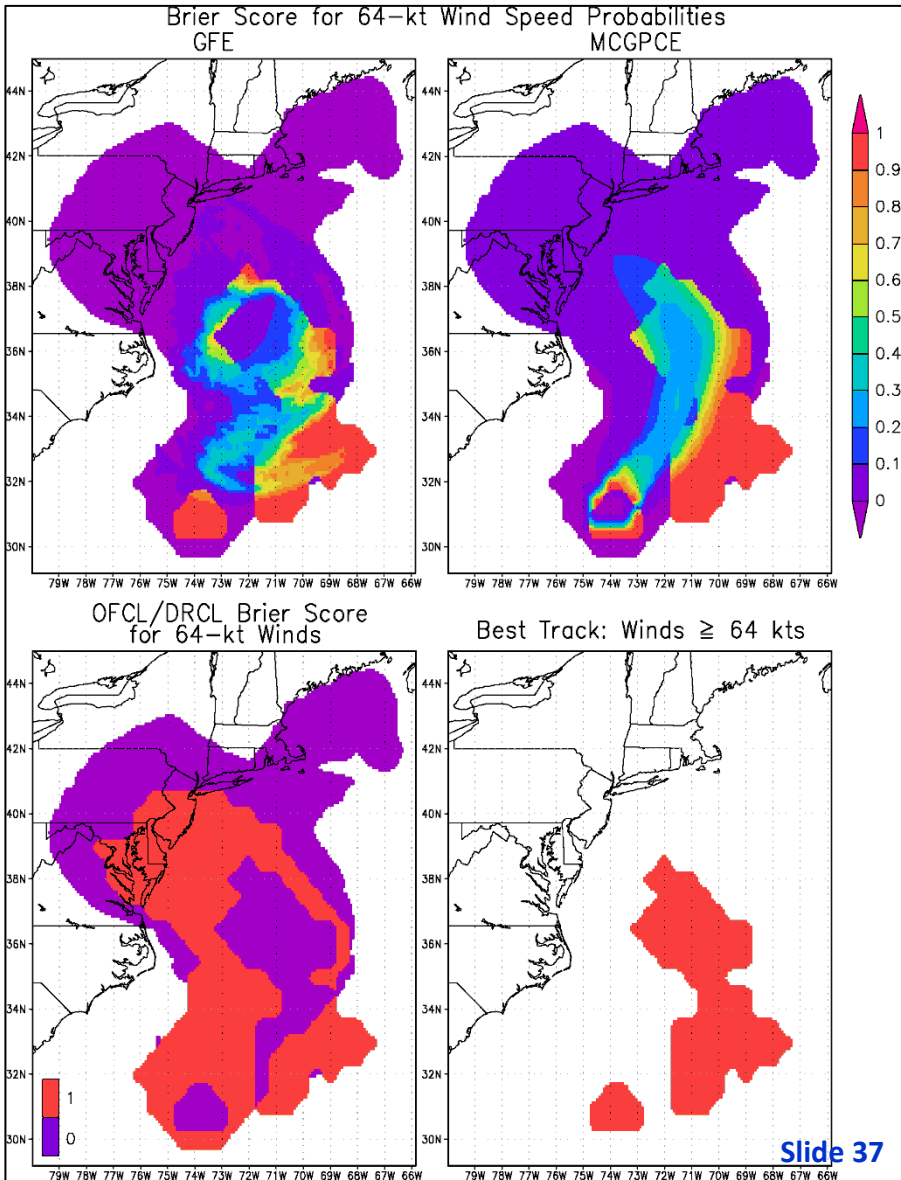


Forecast tracks shown by black trace in each plot

Ensemble Wind Speed Probability Verification

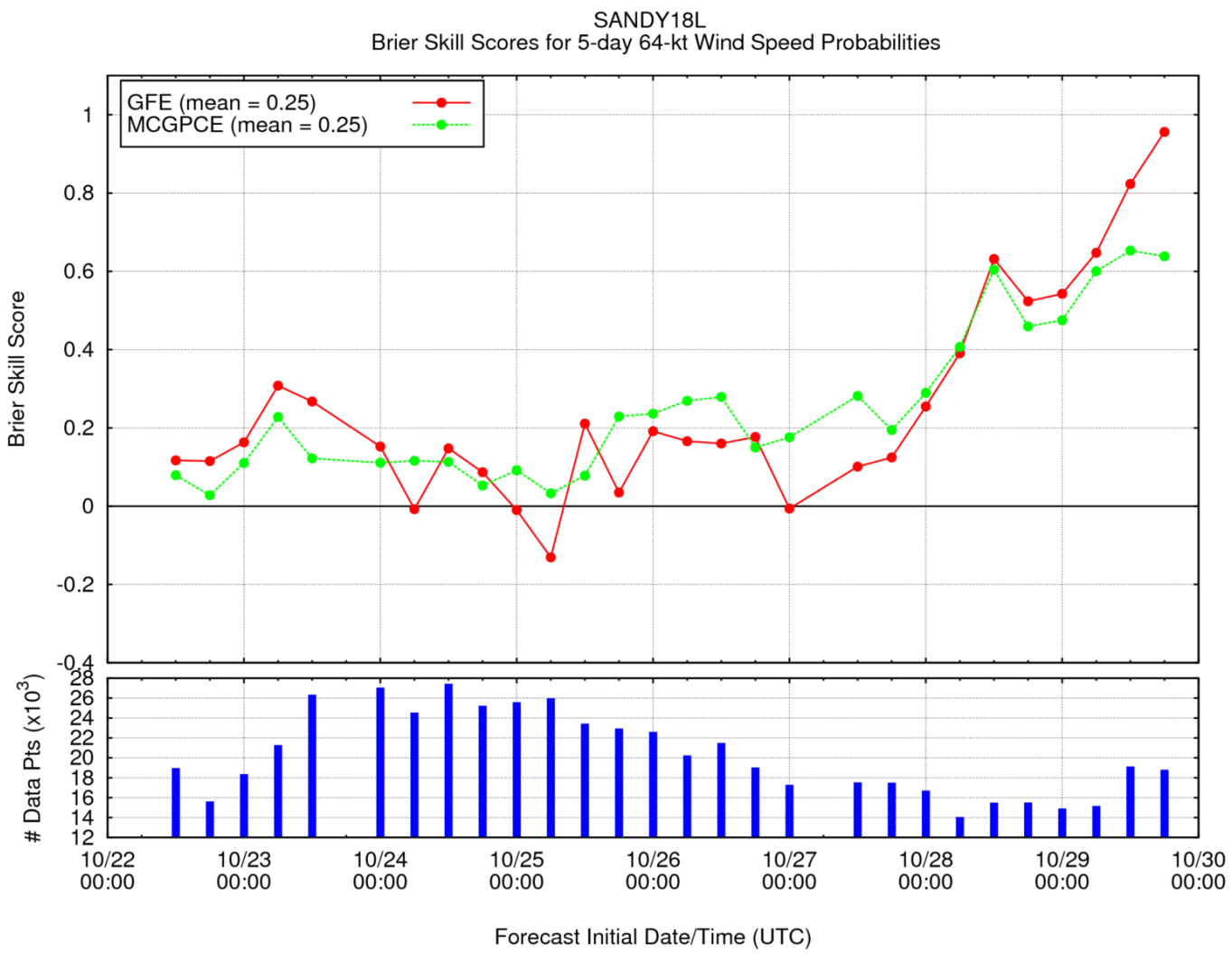
Sandy (18L) Init: 2012102812



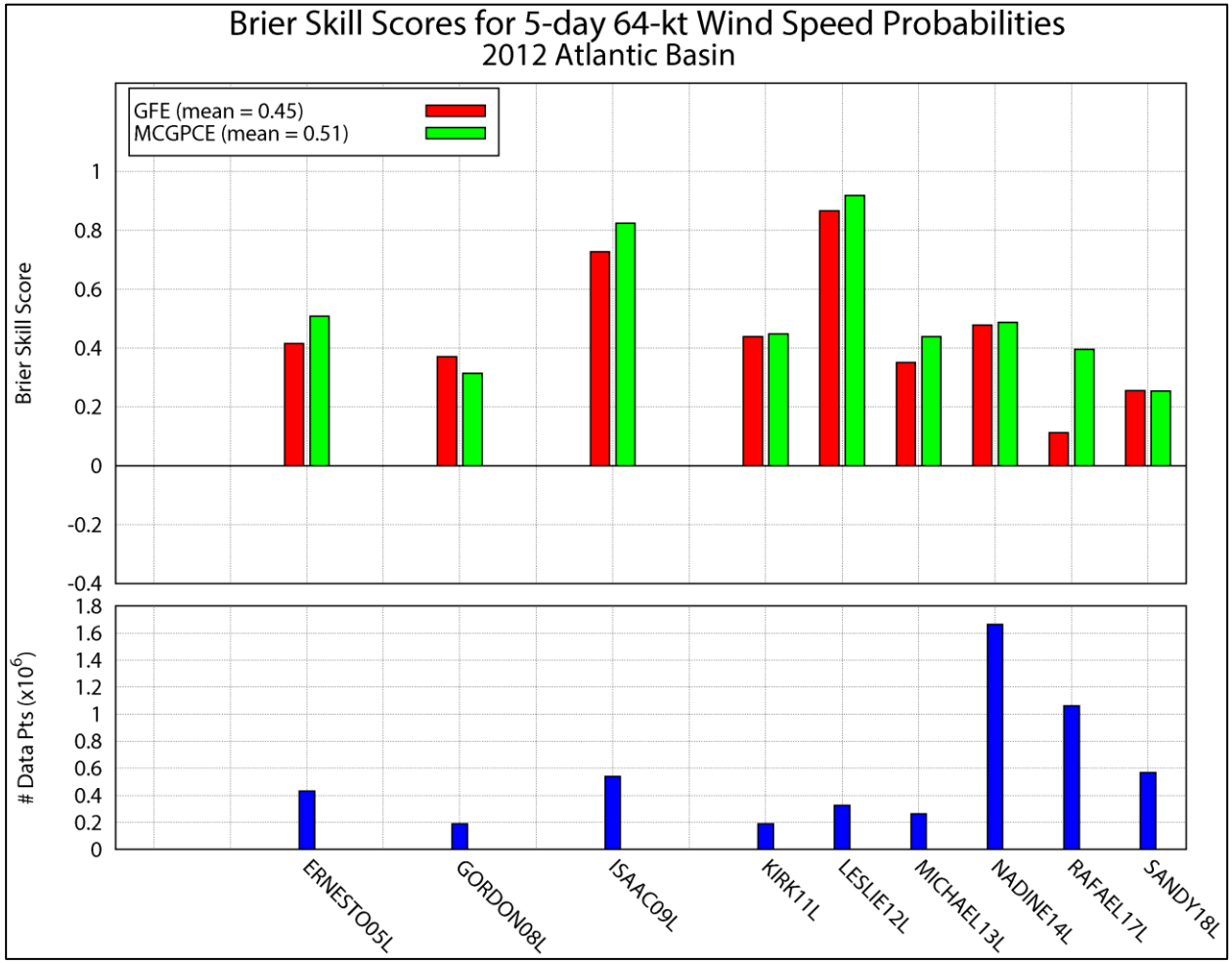


Ensemble Wind Speed Probability Verification

- For Sandy, Brier Skill Scores for 64-kt wind speed probabilities are comparable between the GFDL ensemble and the Monte Carlo model.



Ensemble Wind Speed Probability Verification



- For 2012, looking only at hurricanes, Brier Skill Scores for 64-kt wind speed probabilities are lower for the GFDL ensemble (0.45) than the Monte Carlo model (0.51), but they do show enough skill to encourage the utility of this type of wind speed probability product based on dynamical ensemble model output.

Outline

- GFDL ensemble overview & methods
- Results: 2012 Cases
- Results: Verifications
- Website and Real-Time Products
- Summary

data1.gfdl.noaa.gov/hurricane/gfdl_ensemble

GFDL Geophysical Fluid Dynamics Laboratory

ENSEMBLE PRODUCTS PAGE | ABOUT THE GFDL HURRICANE ENSEMBLE | HFIP HOME PAGE | ABOUT GFDL

GFDL Hurricane Model Ensemble

Products browser

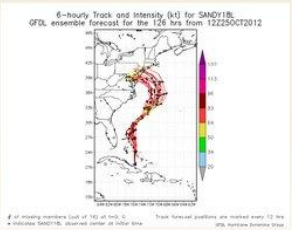
1.) Select a storm: SANDY18L

2.) Select a date: 2012102512_SANDY18L

3.) Select a product:

4.) Click: View products

Forecast preview



GFDL ensemble forecast for SANDY18L on 2012102512

Disclaimer: These are experimental research products and are not intended to replace the official forecasts issued by the National Hurricane Center and/or National Weather Service.

Click here for a printer-friendly display of all GFDL ensemble products for this forecast.

List of most recently added forecasts:

Use the 'Products browser' to load the graphics for a particular forecast

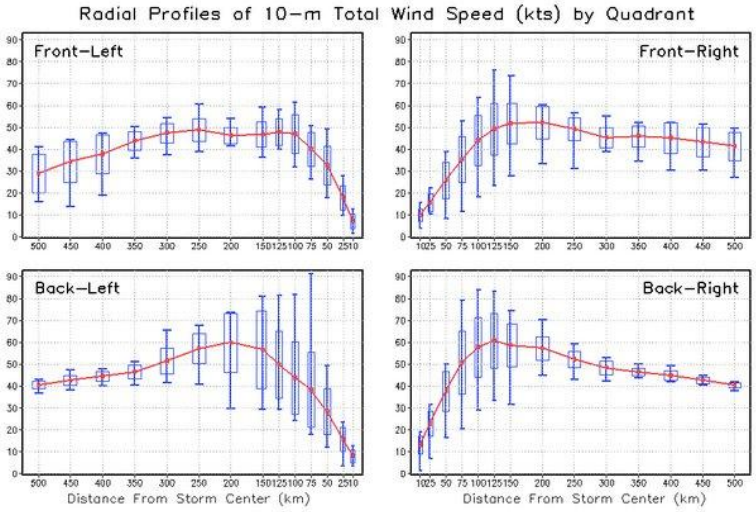
- INVEST90E_2012110406: Added on Sun Nov 04 08:24 EST 2012
- ROSA17E_2012110400: Added on Sun Nov 04 01:36 EST 2012
- ROSA17E_2012110318: Added on Sat Nov 03 20:21 EDT 2012
- ROSA17E_2012110312: Added on Sat Nov 03 14:33 EDT 2012
- ROSA17E_2012110306: Added on Sat Nov 03 08:27 EDT 2012
- ROSA17E_2012110300: Added on Sat Nov 03 02:39 EDT 2012

10-m wind structure

Click the tabs below to view each product

TC-relative total winds | Earth-relative total winds

0 hrs | 24 hrs | 48 hrs | 72 hrs | 96 hrs | 120 hrs



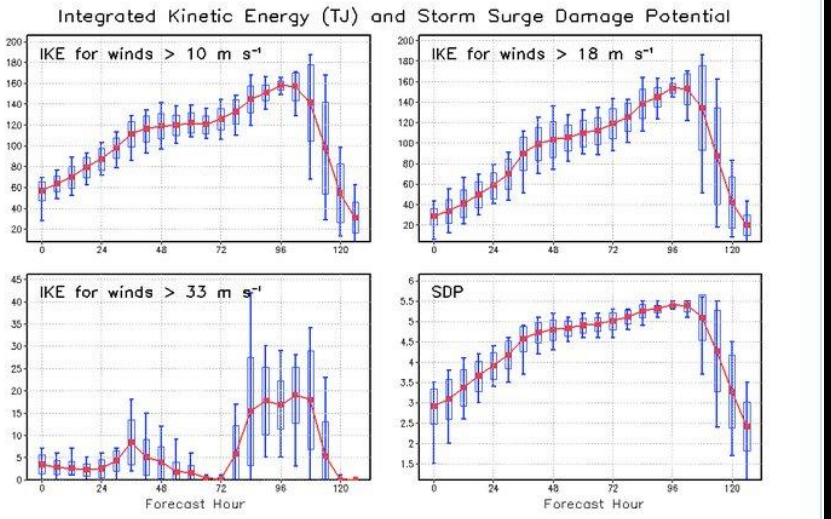
GFDL Ensemble Forecast for SANDY18L
Initial time: 12Z25OCT2012
Valid time: 12Z29OCT2012 (+96 hrs)
Missing members (out of 16) at t=0: None

Ensemble mean
Min to max
±1σ

Integrated kinetic energy and surge damage potential

Click the tabs below to view each product

IKE and SDP box plots | IKE and SDP spaghetti plots



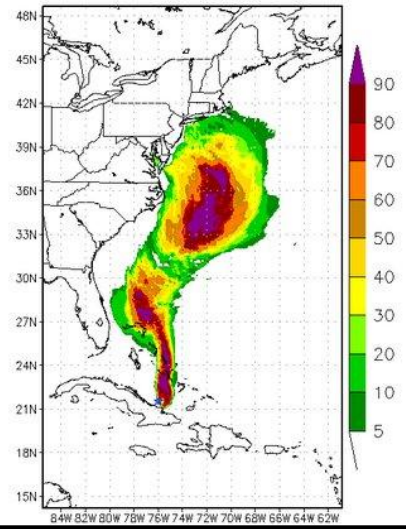
GFDL Ensemble Forecast for SANDY18L
Initial time: 12Z25OCT2012
R ≤ 400 km

Ensemble mean
Min to max
±1σ

Max wind speed swaths and probabilities

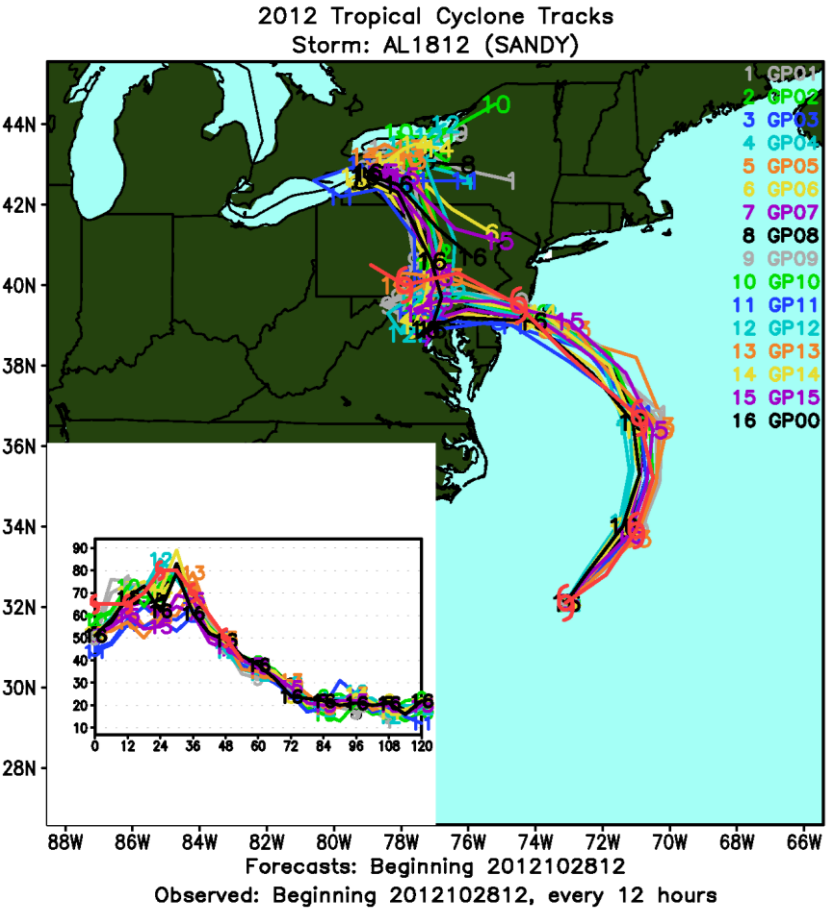
Click the tabs below to view each product

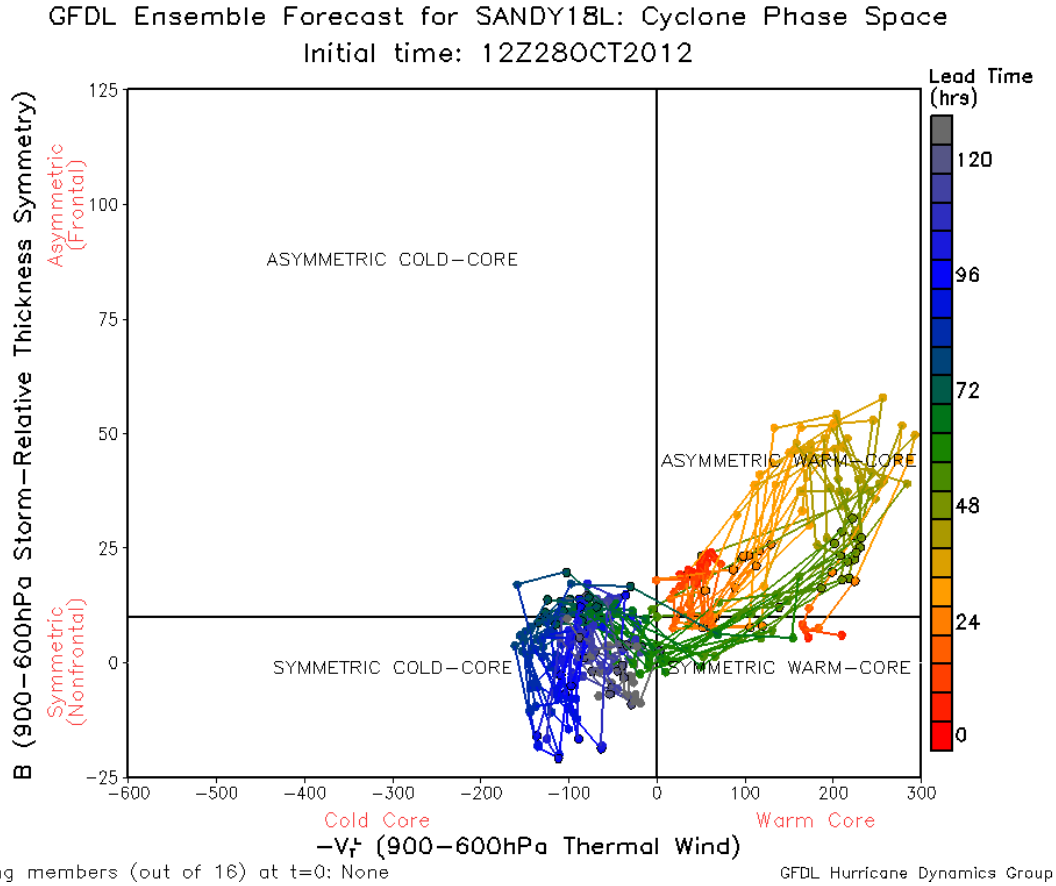
34-kt wind speed probability | 50-kt wind speed probability | 64-kt wind speed probability | Max 10-m winds swaths



Cyclone Phase Space computed for each member

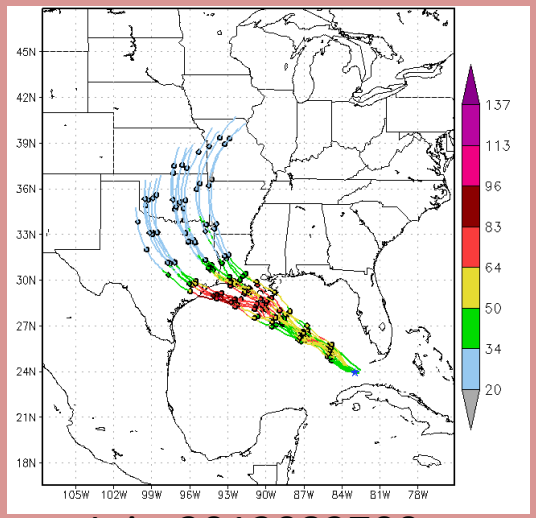
Hurricane Sandy: 2012102812





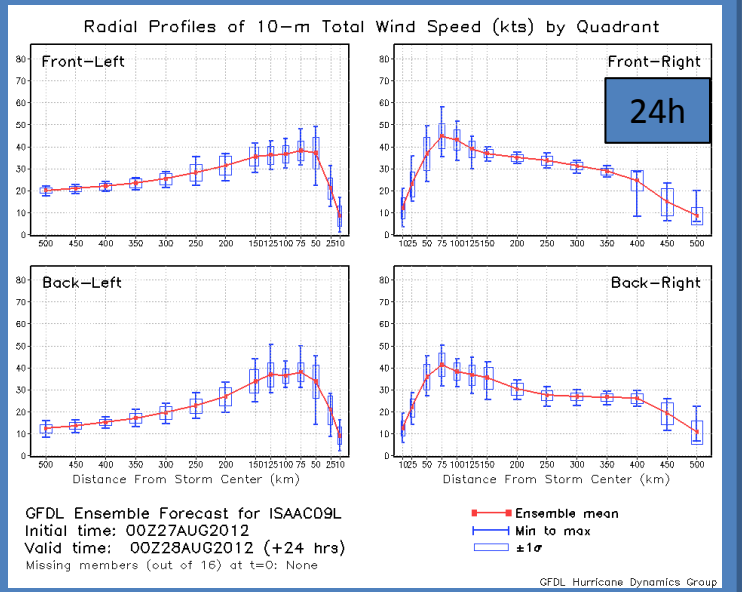
Product examples: Near-surface wind structure

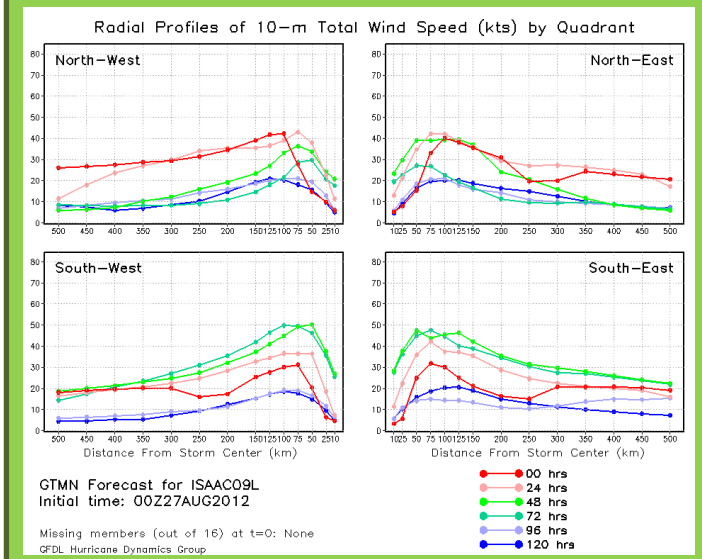
Hurricane Isaac



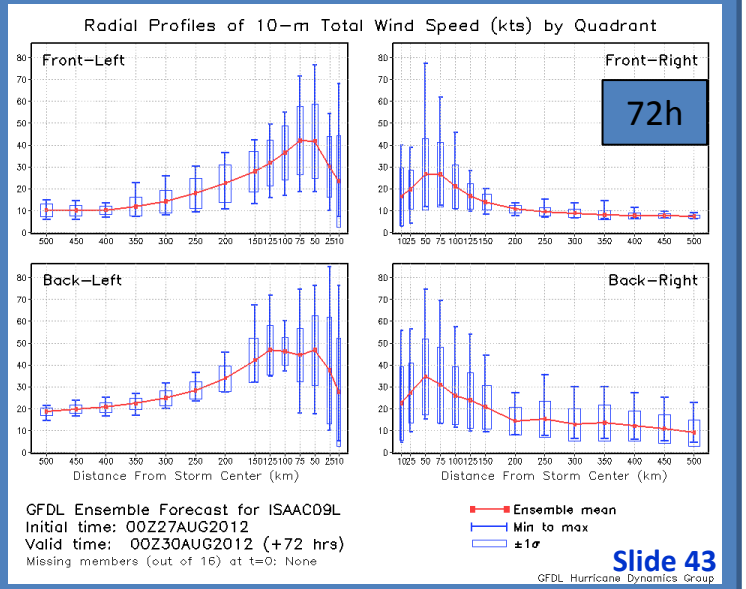
Init: 2012082700

Storm motion-relative box plots showing mean 10-m wind profiles at 24h and 72h.





Earth-relative plots of mean 10-m wind profiles, every 24h from 00 – 120h.



Summary

- Ensemble comprised of perturbations to the model vortex intensity and size, model moisture and SST fields, as well as background steering flow, was run for all Atlantic and eastern Pacific cases in 2012.
- *For intensity*, the ensemble mean forecasts in the Atlantic outperformed the control (G00I) and operational (GHMI) forecasts with statistically significant gains at all lead times, and with gains of moderate practical significance (>1 kt) over the control at lead times >36h, and over GHMI at 120h.
- *For track*, the ensemble mean forecasts in the Atlantic similarly outperformed G00I and GHMI with statistically significant gains at all lead times, but there were no gains that were considered to be of practical significance (>10 n mi).

Summary (*cont.*)

- *For intensity*, the member mean comprised of all +/- moisture members showed the most improvement over the control, especially at lead times >48h and for storms initialized south of 20N.
- Results for both track and intensity errors showed little difference between paired GFS- and GEFS-based members.
- Wind speed probability verification indicates potential for use of wind speed probability guidance from dynamical ensemble modeling systems.
- To be of more use in operations, work needs to be done to ensure forecasts complete in time for 6-h interpolation.

Questions?

Hurricane Sandy: Morning-after, neighborhood forecast verification:

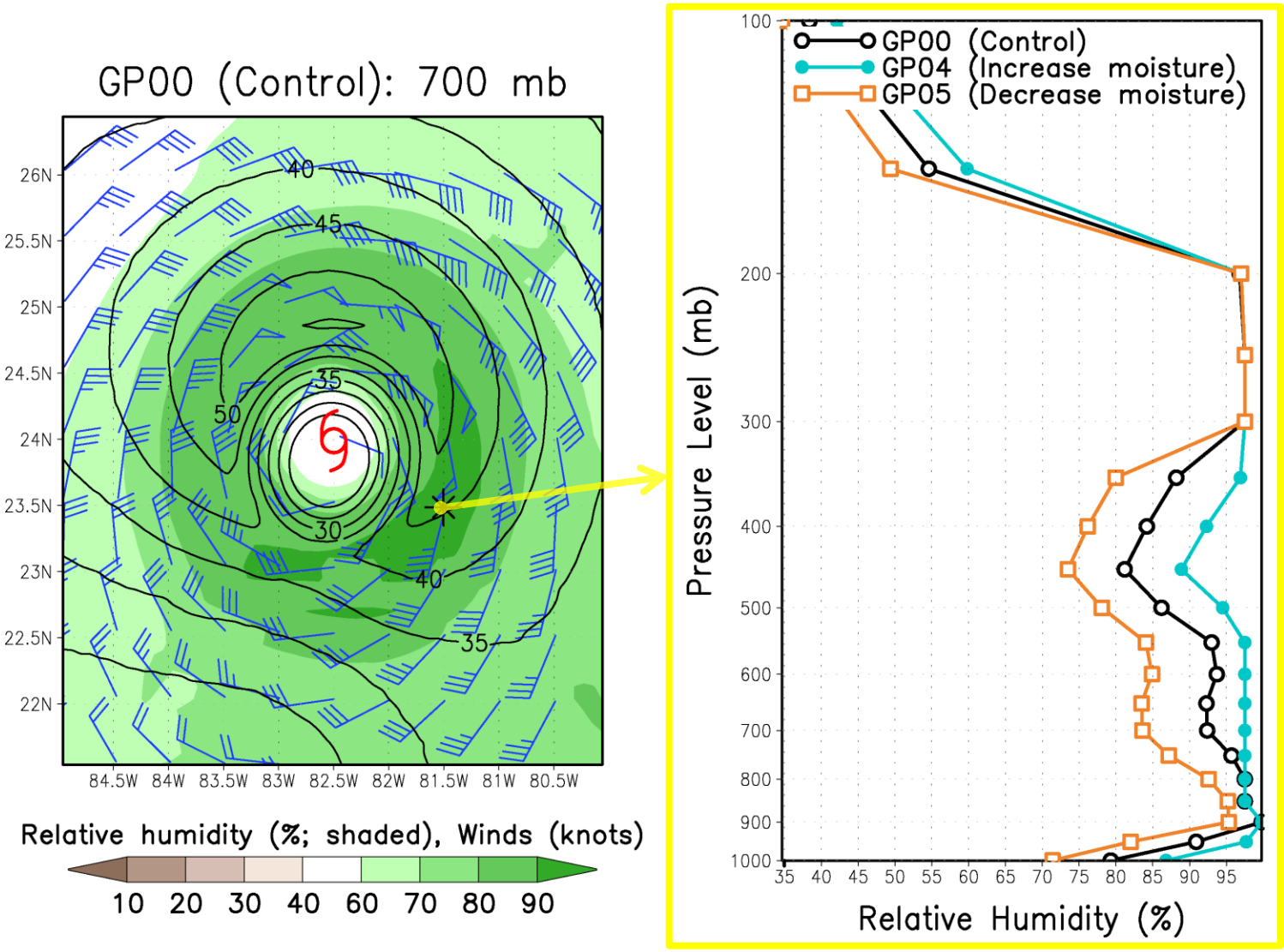
- *Strong winds predicted:* ✓
- *Strong winds observed:* ✓

Extra Slides

Example: Moisture perturbations

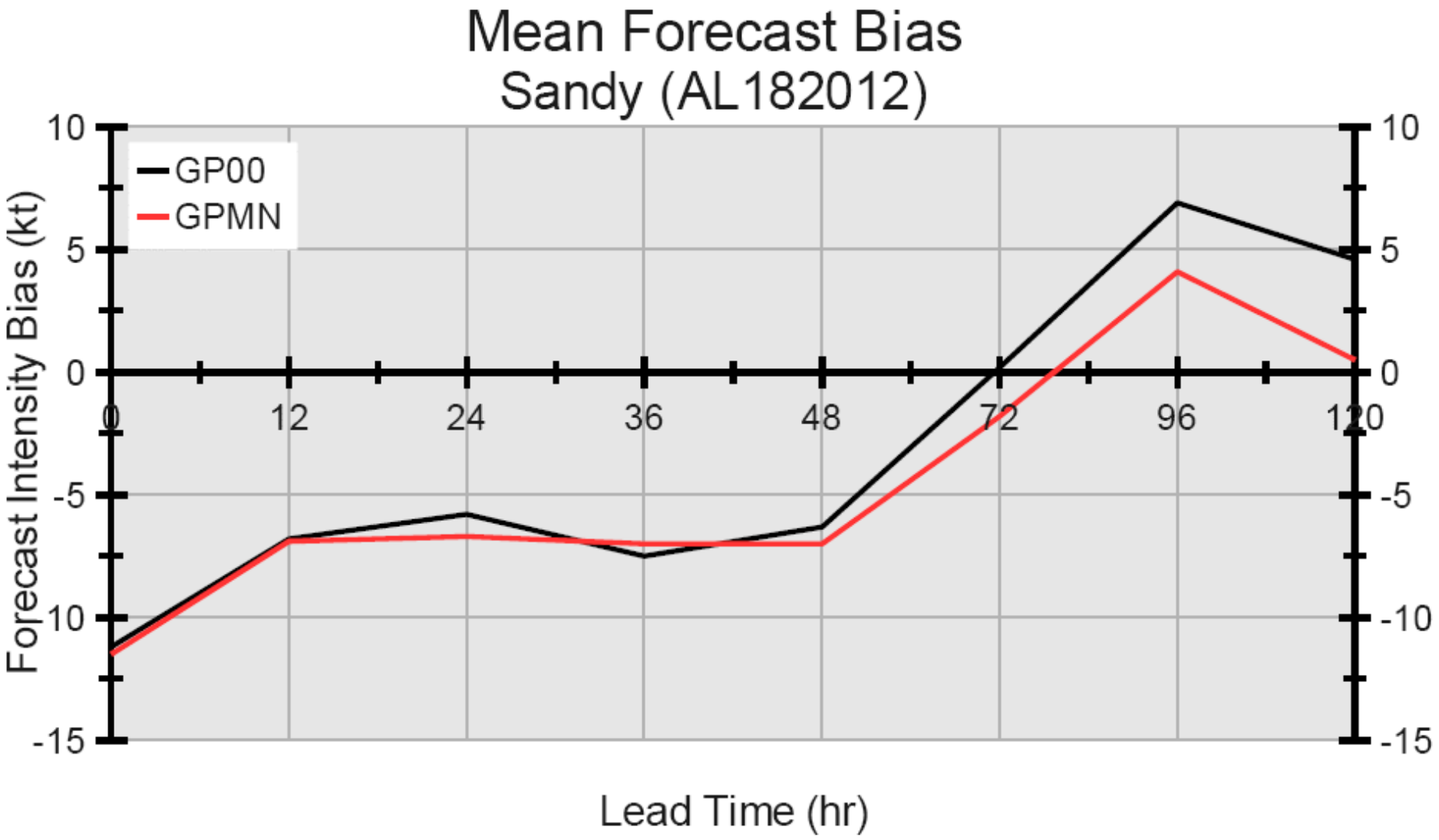
GFDL Hurricane Model Ensemble Initial Moisture Profiles

Tropical Storm Isaac: 00 UTC 27 August 2012

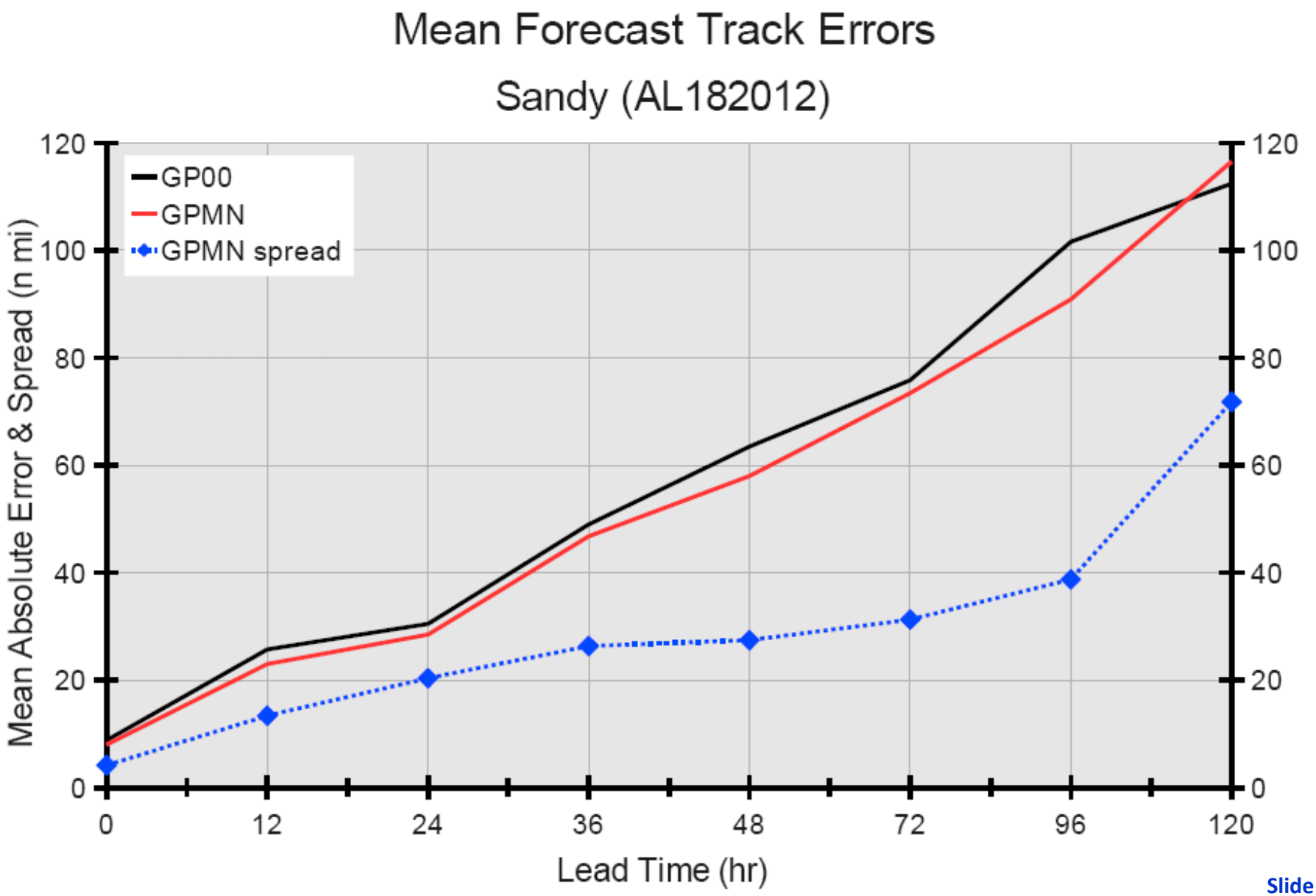


GFDL Hurricane Dynamics Group

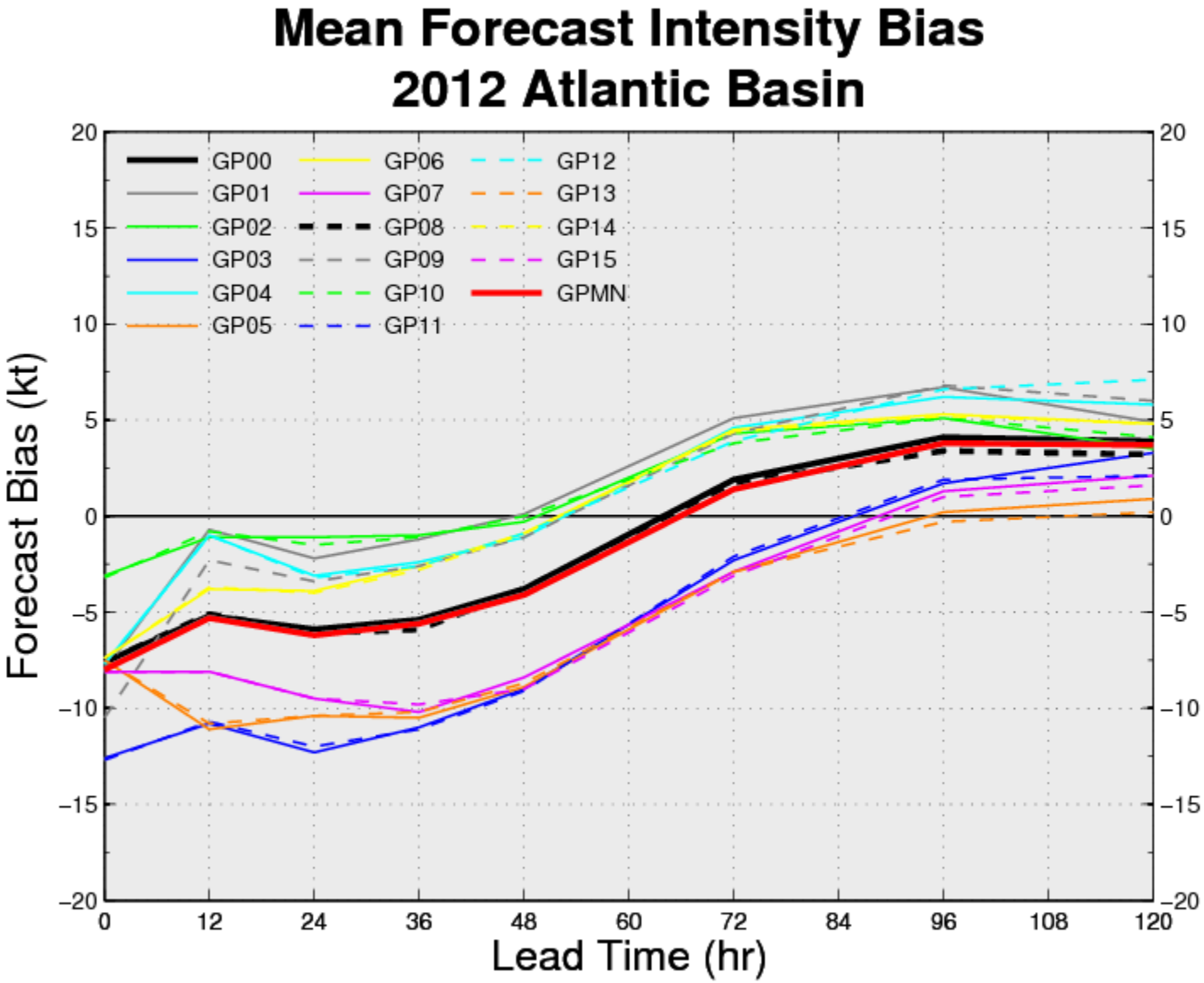
Intensity Forecast Bias for Sandy



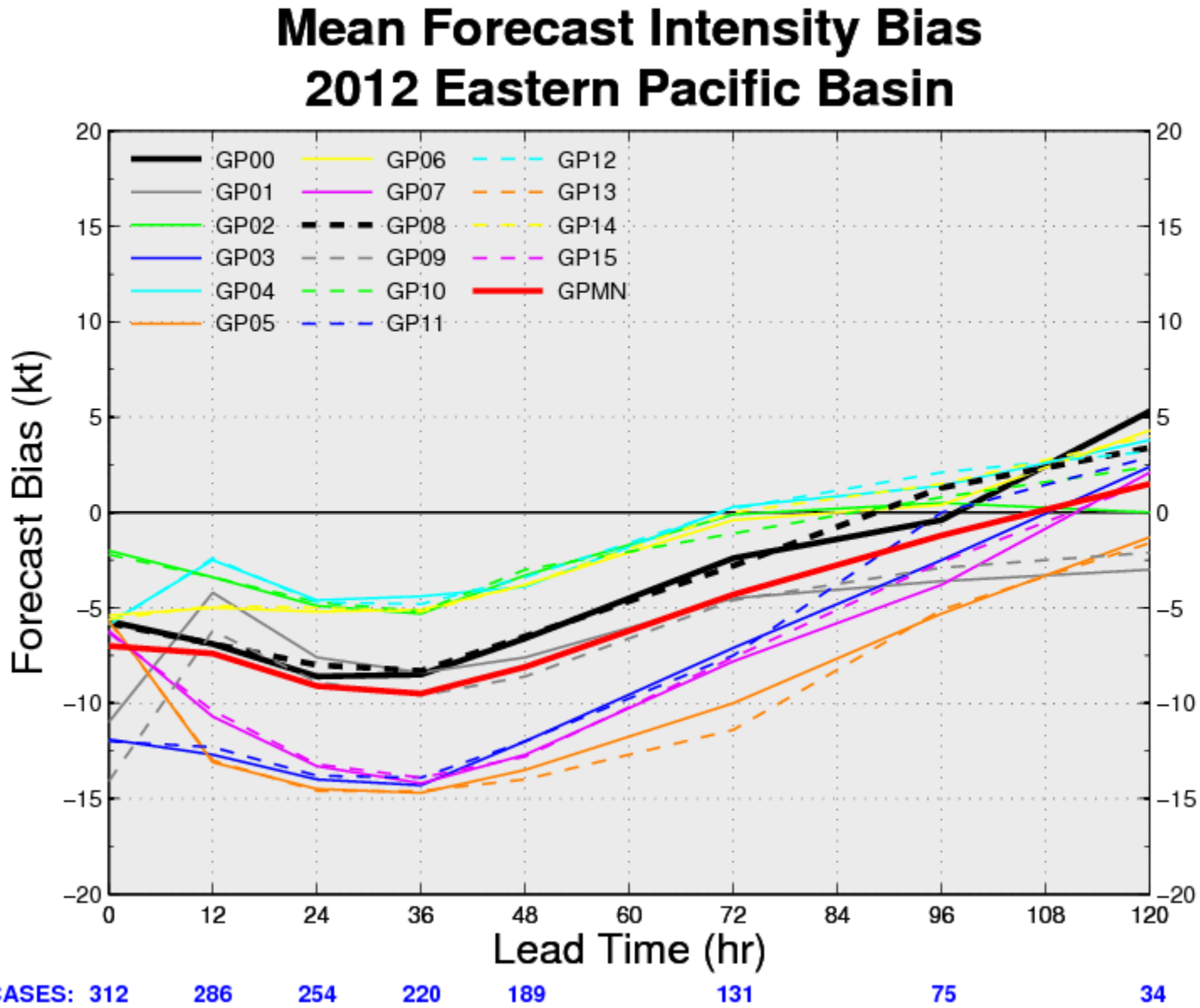
Track Forecast Errors for Sandy



Results: Intensity Forecast Verifications



Results: Intensity Forecast Verifications



Methods:
Vortex size & intensity perturbations

- Created by modifying certain components of the GFDL synthetic axisymmetric vortex
  - Perturbing certain "TC vitals" values from the NHC storm warning message
  - Percentages shown below represent the typical max uncertainty in observations of cyclone wind size and intensity (per NHC recommendations)

Tropical Storm Isaac "vitals" for 00 UTC 27 August 2012

NHC 09L ISAAC 120827 0000 240N 0825W 285 062
0992 1007 **0482** **28** 093 **0334 0222 0148 0334** D
0111 -999 -999 0111 72 307N 895W

Radius of outermost closed isobar (km)
Perturbation = ±25%

Max surface wind speed (m s^{-1})
Perturbation = ±10%

Radii of 34-knot winds in each quadrant (km)
Perturbation = ±25%

Radii of 50-knot winds in each quadrant (km)
Perturbation = ±40%

Differences between paired GFS/GEFS-based members were mostly not significant

PROBABILITIES FOR MODEL DIFFERENCES

2012 GFE DEMO

Intensity

Lead Time (hr)	GP00/GP08	GP01/GP09	GP02/GP10	GP03/GP11	GP04/GP12	GP05/GP13	GP06/GP14	GP07/GP15
0	0.622	1	0.579	0.97	0.5	0.575	0.585	0.5
12	0.96	0.747	0.745	0.904	0.968	0.969	0.58	0.918
24	0.69	0.727	0.54	0.642	0.908	0.7	0.744	0.809
36	0.965	0.961	0.516	0.8	0.783	0.78	0.824	0.62
48	0.774	0.778	0.667	0.731	0.745	0.68	0.842	0.914
72	0.762	0.556	0.635	0.744	0.984	0.785	0.705	0.875
96	0.73	0.974	0.566	0.661	0.676	0.864	0.668	0.895
120	0.964	0.823	0.631	0.832	0.865	0.882	0.729	0.963

Track

Lead Time (hr)	GP00/GP08	GP01/GP09	GP02/GP10	GP03/GP11	GP04/GP12	GP05/GP13	GP06/GP14	GP07/GP15
0	0.939	1	0.634	0.946	0.825	0.856	0.671	0.744
12	0.558	0.942	0.669	0.71	0.699	0.508	0.77	0.877
24	0.705	0.902	0.575	0.811	0.516	0.804	0.635	0.645
36	0.571	0.95	0.572	0.98	0.69	0.532	0.881	0.597
48	0.809	0.636	0.797	0.603	0.792	0.544	0.561	0.685
72	0.687	0.712	0.777	0.61	0.62	0.519	0.617	0.774
96	0.918	0.964	0.793	0.773	0.744	0.531	0.901	0.828
120	0.716	0.925	0.704	0.818	0.533	0.639	0.545	0.564