Application of WRF for Hurricane Prediction

Recent Results from Real-Time Hurricane Forecast Experiments

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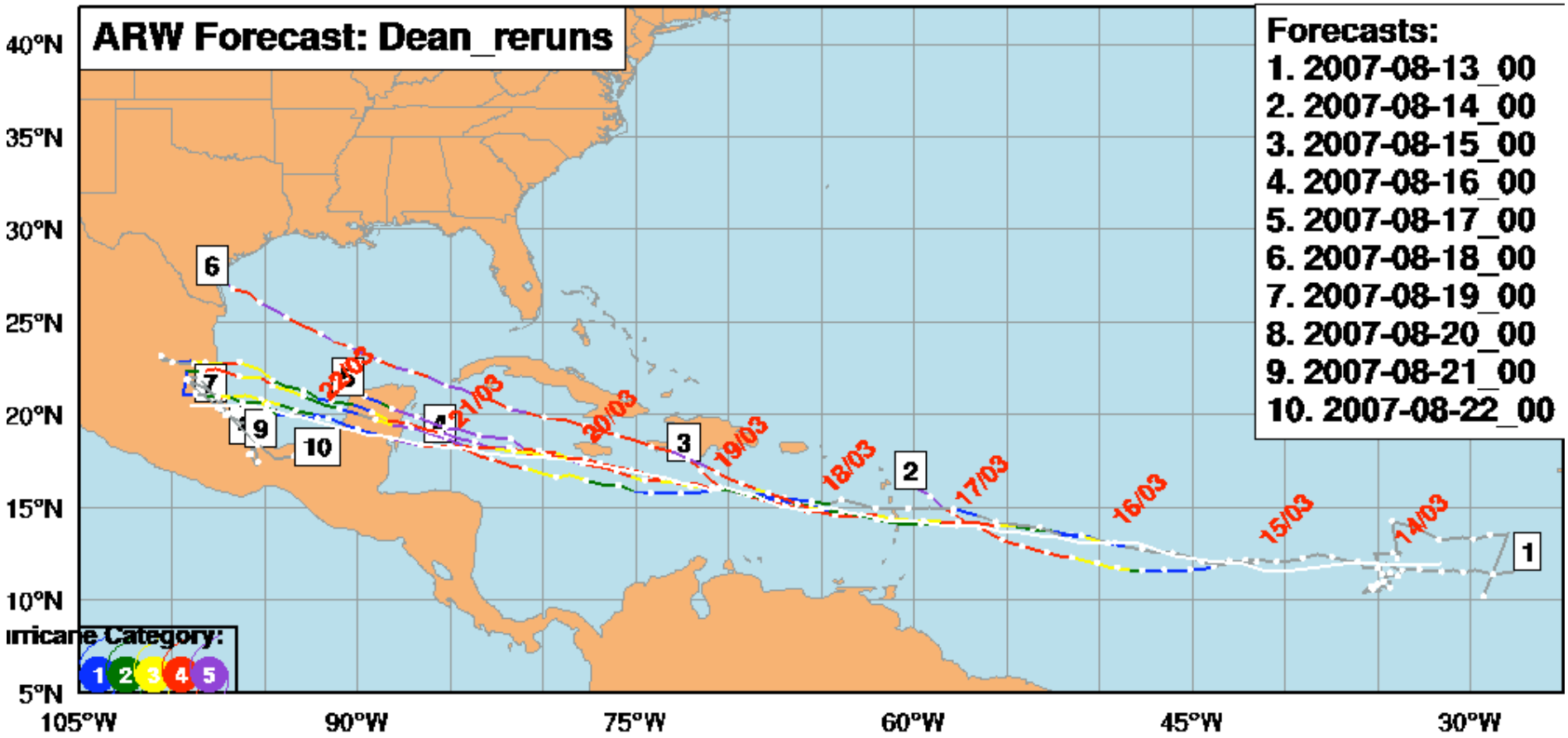
Background

- ARW WRF generally demonstrated good ability to forecast tropical storm and hurricanes in real-time environment (Davis et al. 2008).
  - Problem with initiailization stands out a prominent issue which directly affects the forecast especially in the first 12 - 36 hours.
- Recent work on using EnKF analyses for mesoscale analyses and forecasting [e.g. Meng and Zhang (2008)] demonstrates possibility and good performance.
- In this talk, we show some results from TC forecasts using EnKF analyses as initial conditions in a resolution comparison study and some examples of benefit and issues using EnKF analysis.

Another example: Dean forecast in 2007

(white line: best track)



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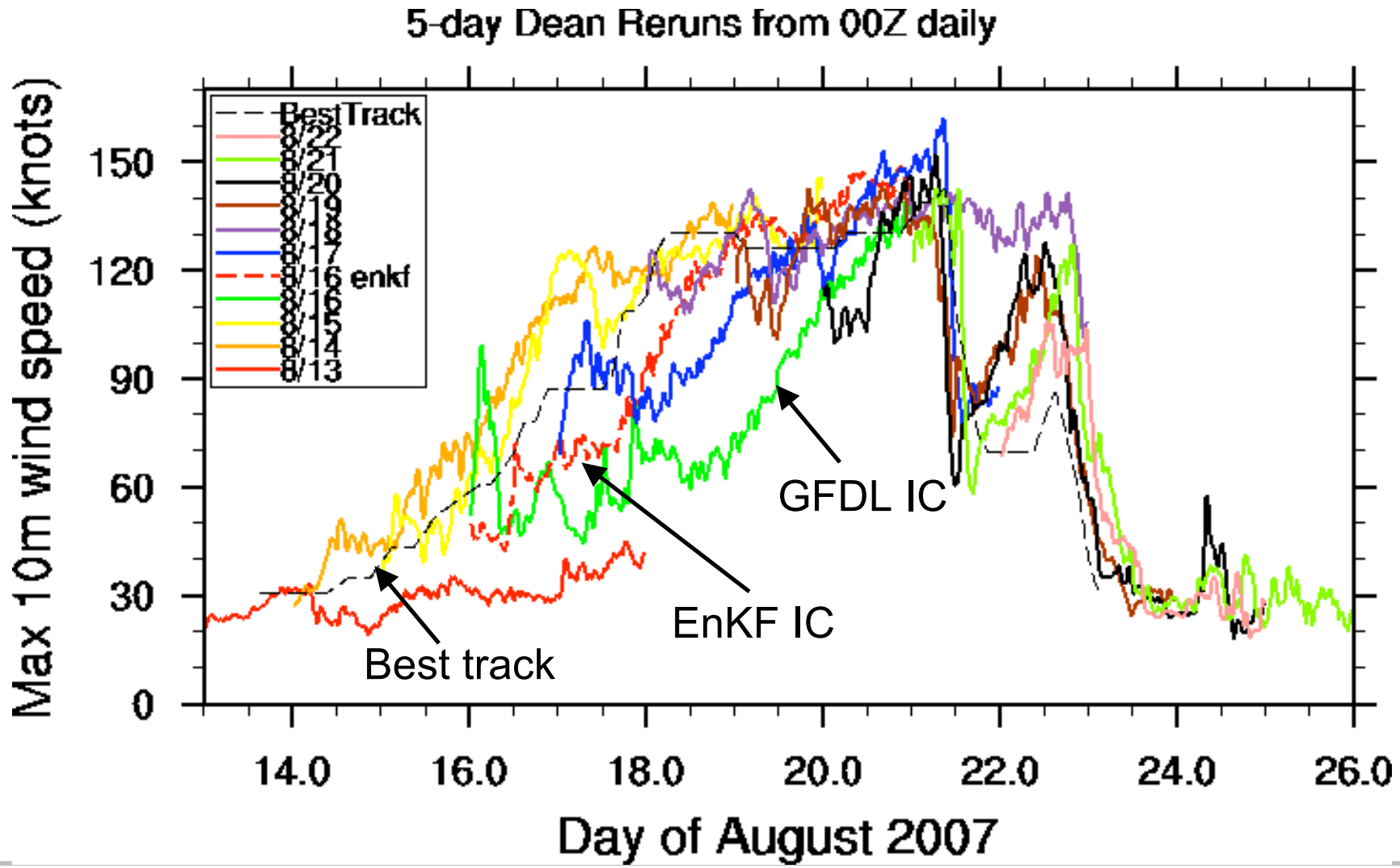
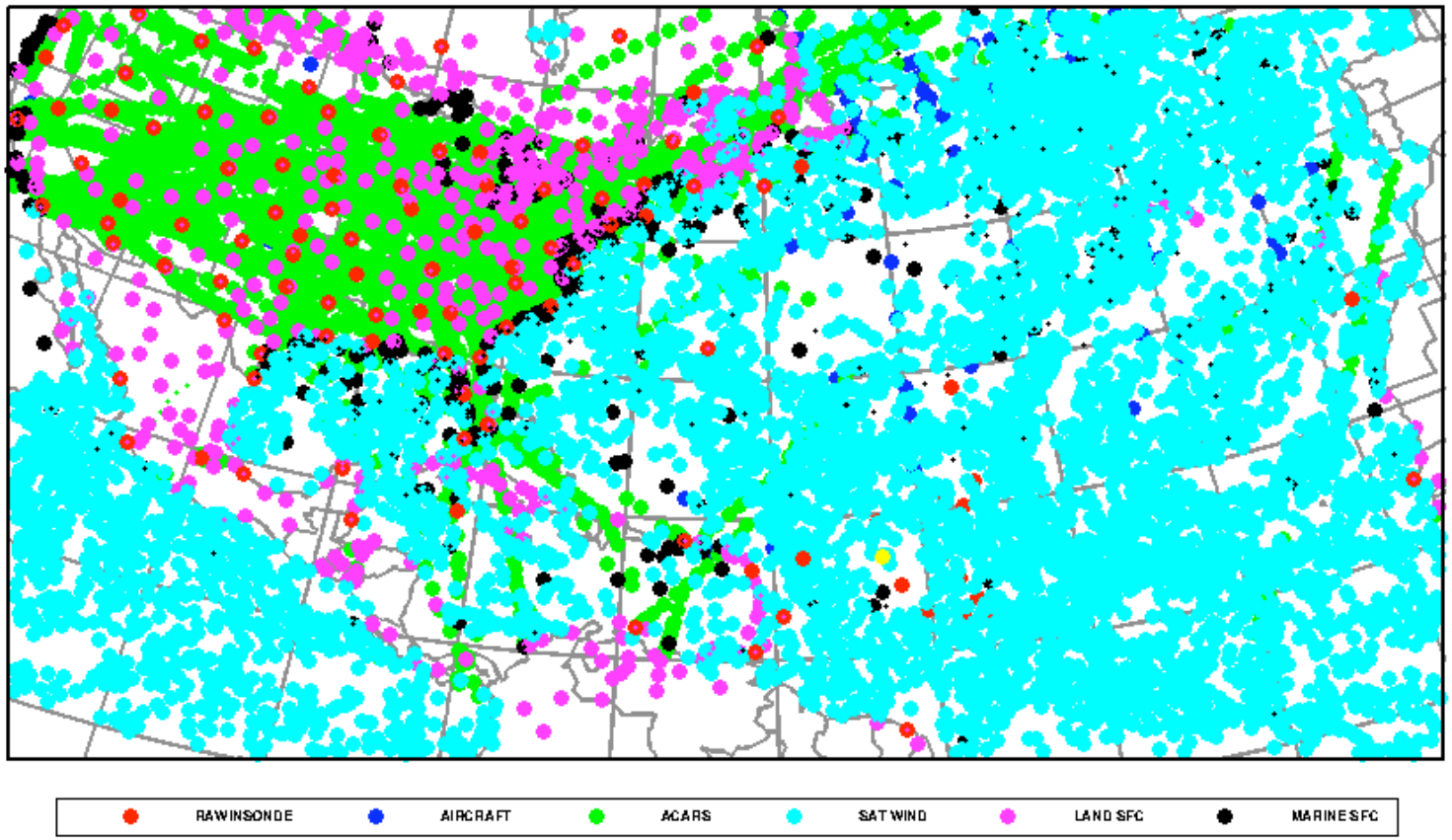


EnKF Analyses

- 96 ensemble members, 36 km horizontal resolution
- Observations assimilated each six hours using the Data Assimilation Research Testbed (DART) from 4 days prior to genesis to dissipation
- Surface pressure observations, rawinsondes, commercial aircraft, cloud motion vectors, synoptic dropsondes, TC position and minimum SLP (*no bogusing*)
- No inner-core observations due to coarse horizontal resolution

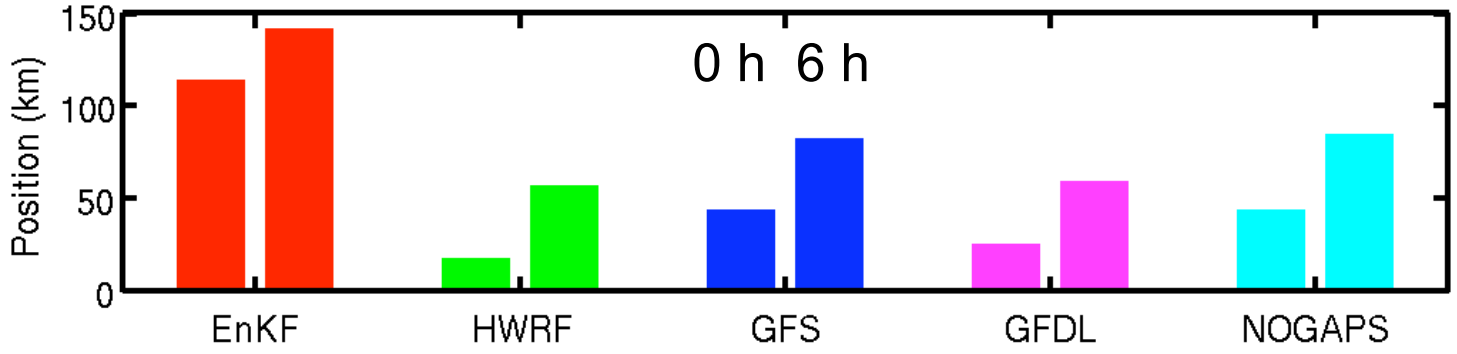
Example of Data Coverage

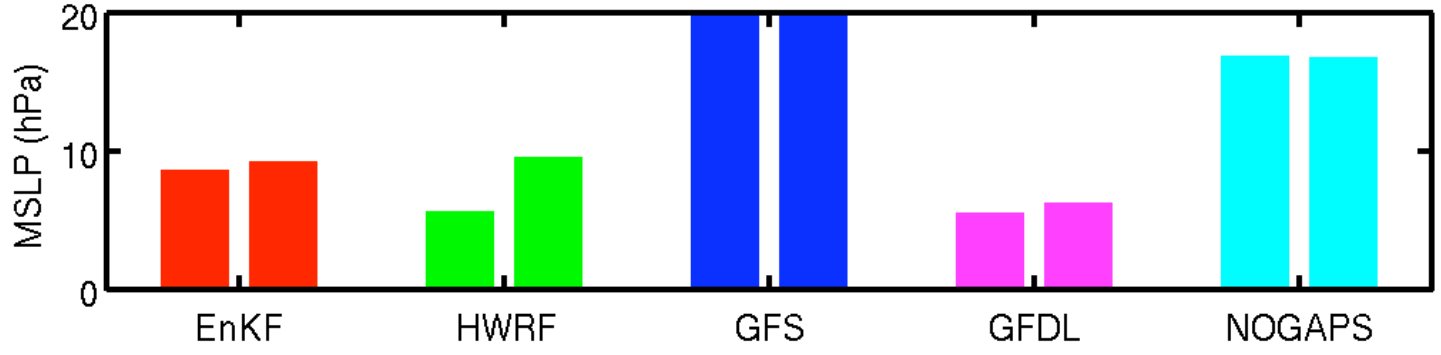


(from Torn)

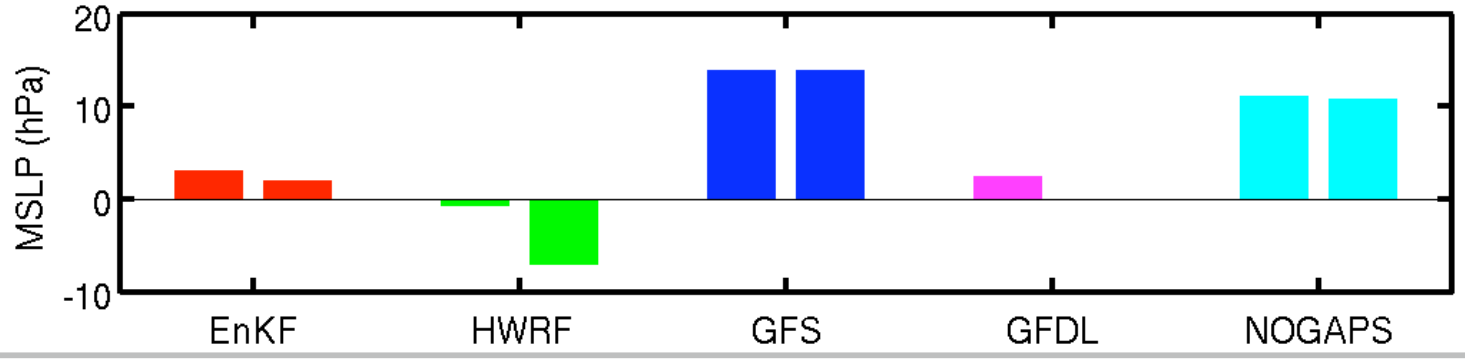
Cycling Errors for 2009 Season

RMS

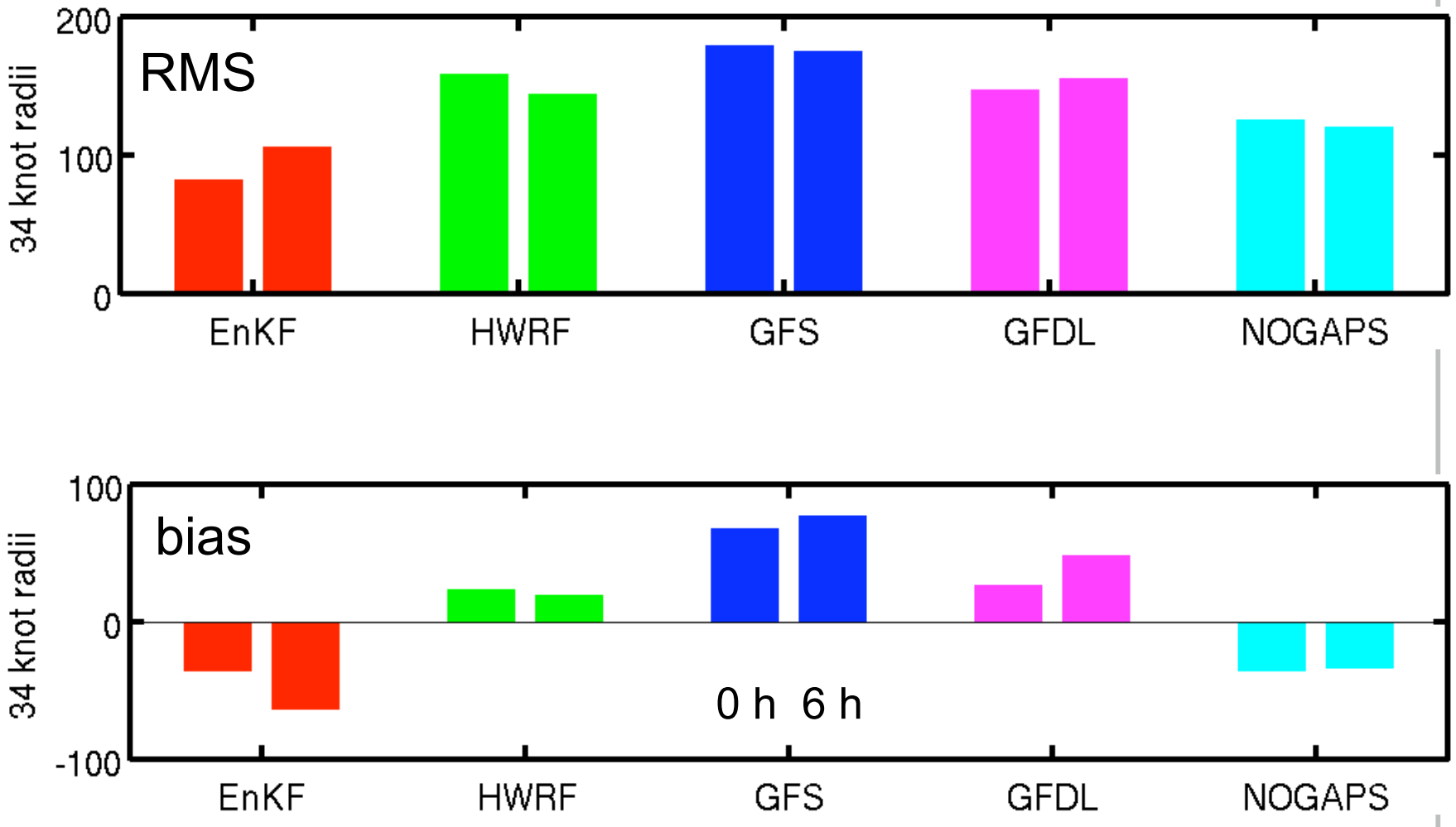




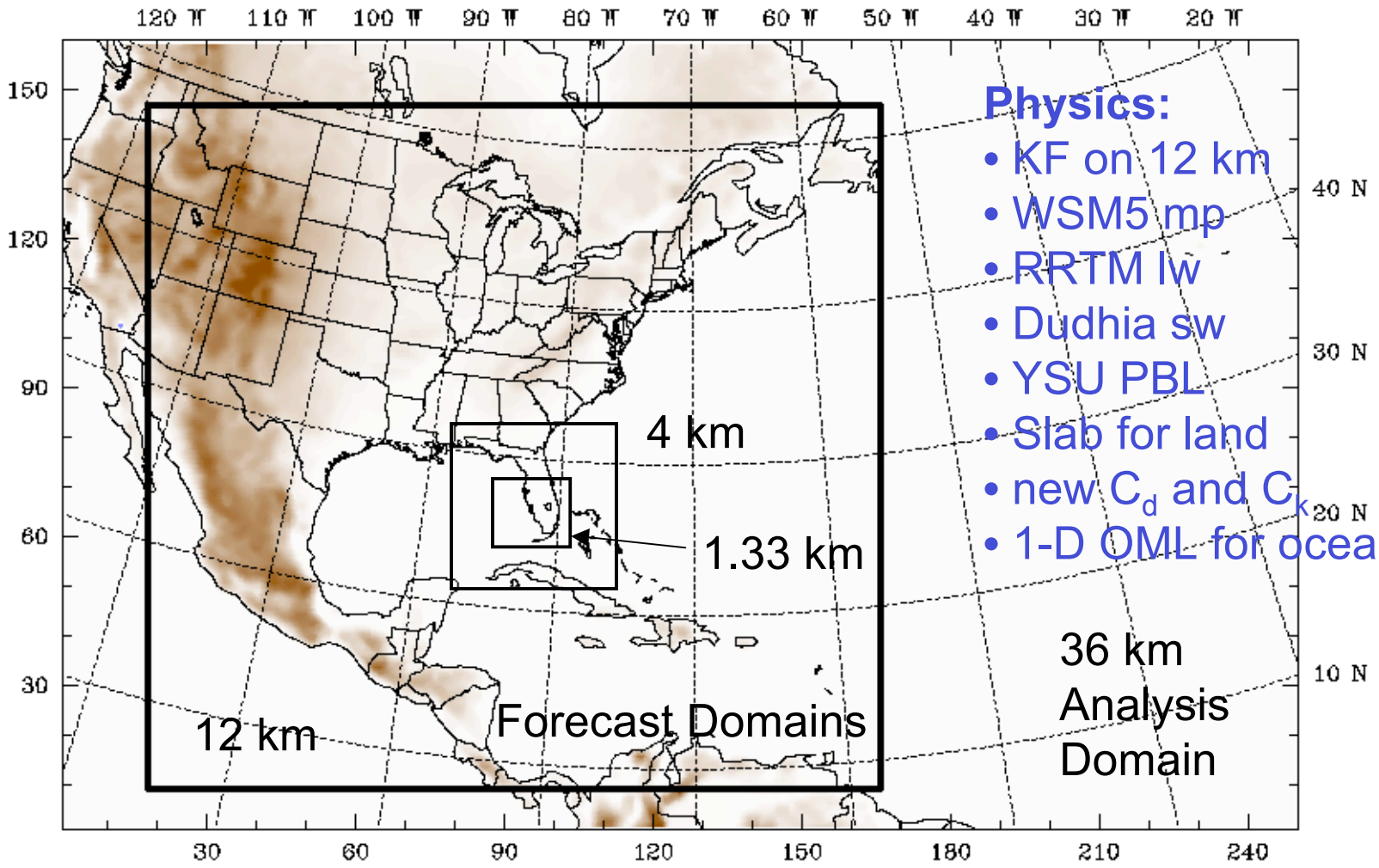
bias



Wind Radii Cycling Errors for 2009 Season



Model Configuration



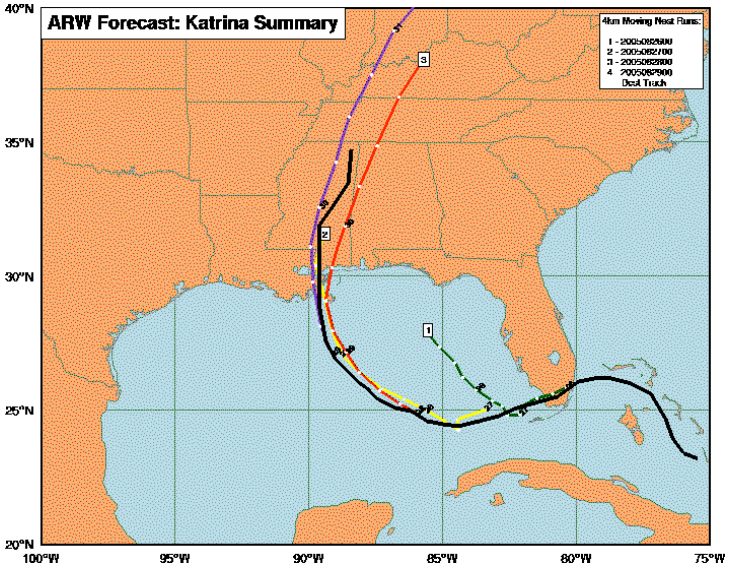
Physics:

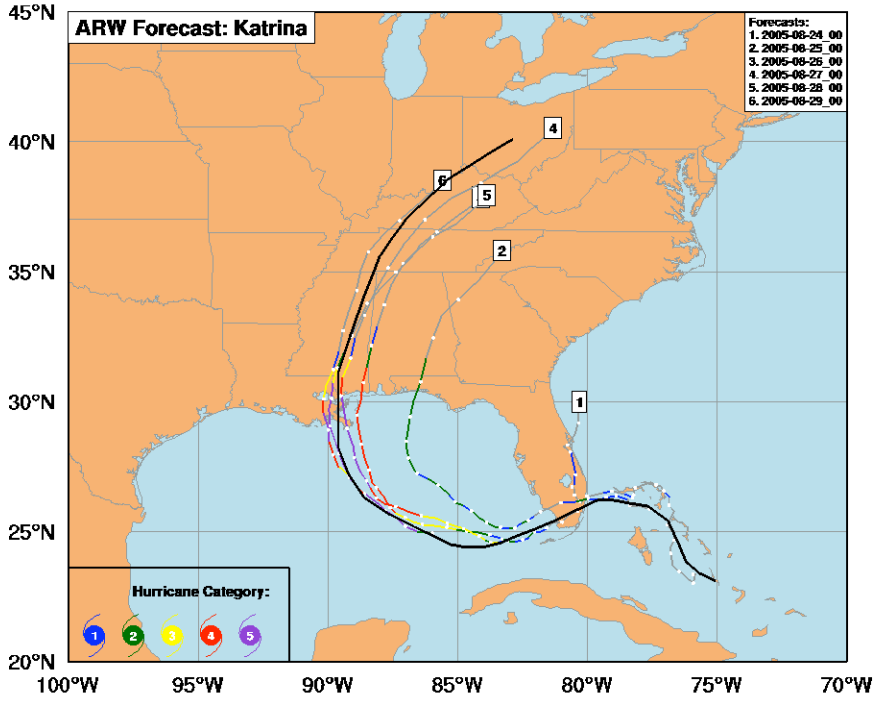
- KF on 12 km
- WSM5 mp
- RRTM lw
- Dudhia sw
- YSU PBL
- Slab for land
- new C_d and C_k
- 1-D OML for ocean

Experimental hurricane initialization using EnKF: Katrina daily track forecasts 8/24 - 8/29

Cycled EnKF Initial Condition

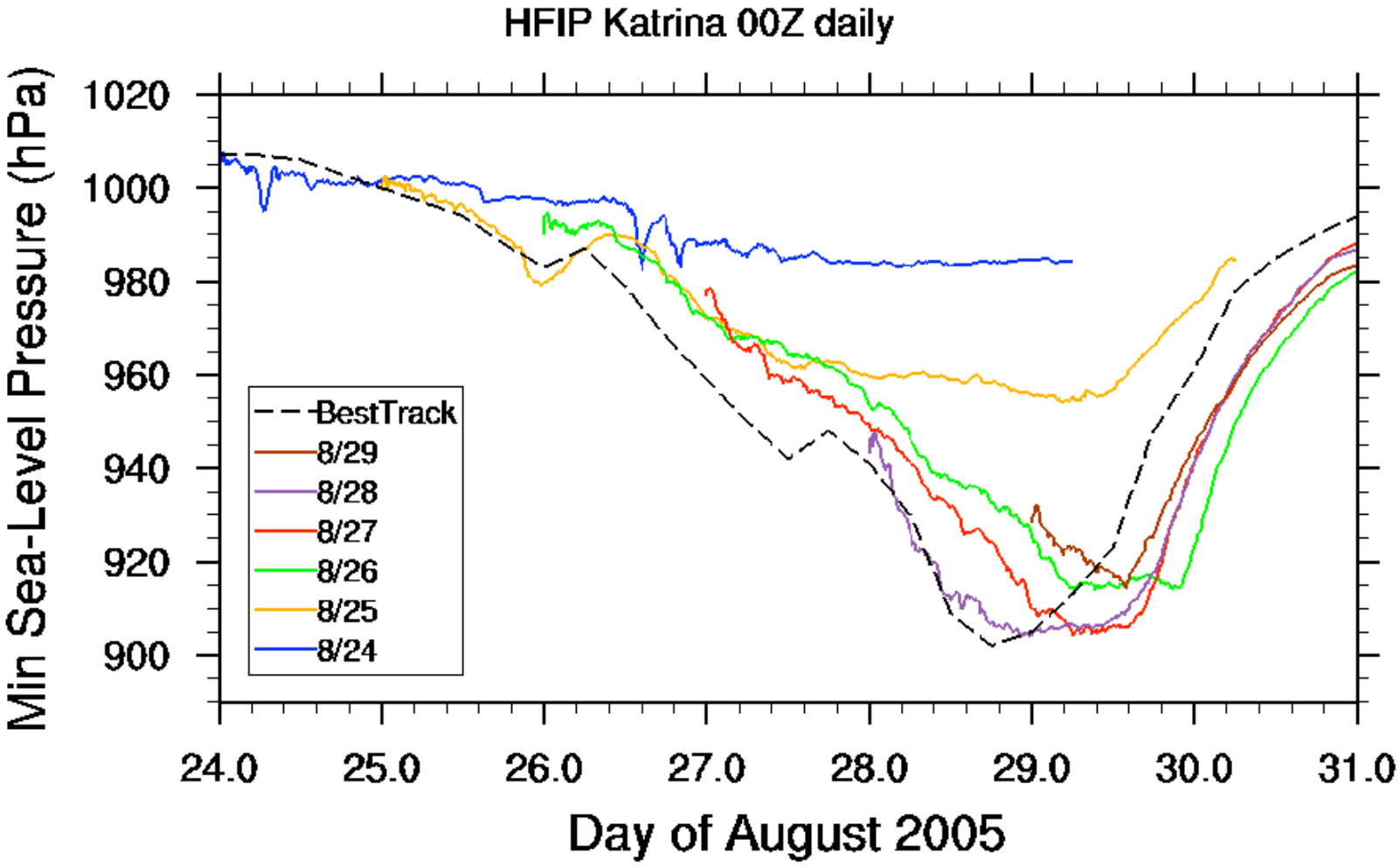
GFDL Initial Condition



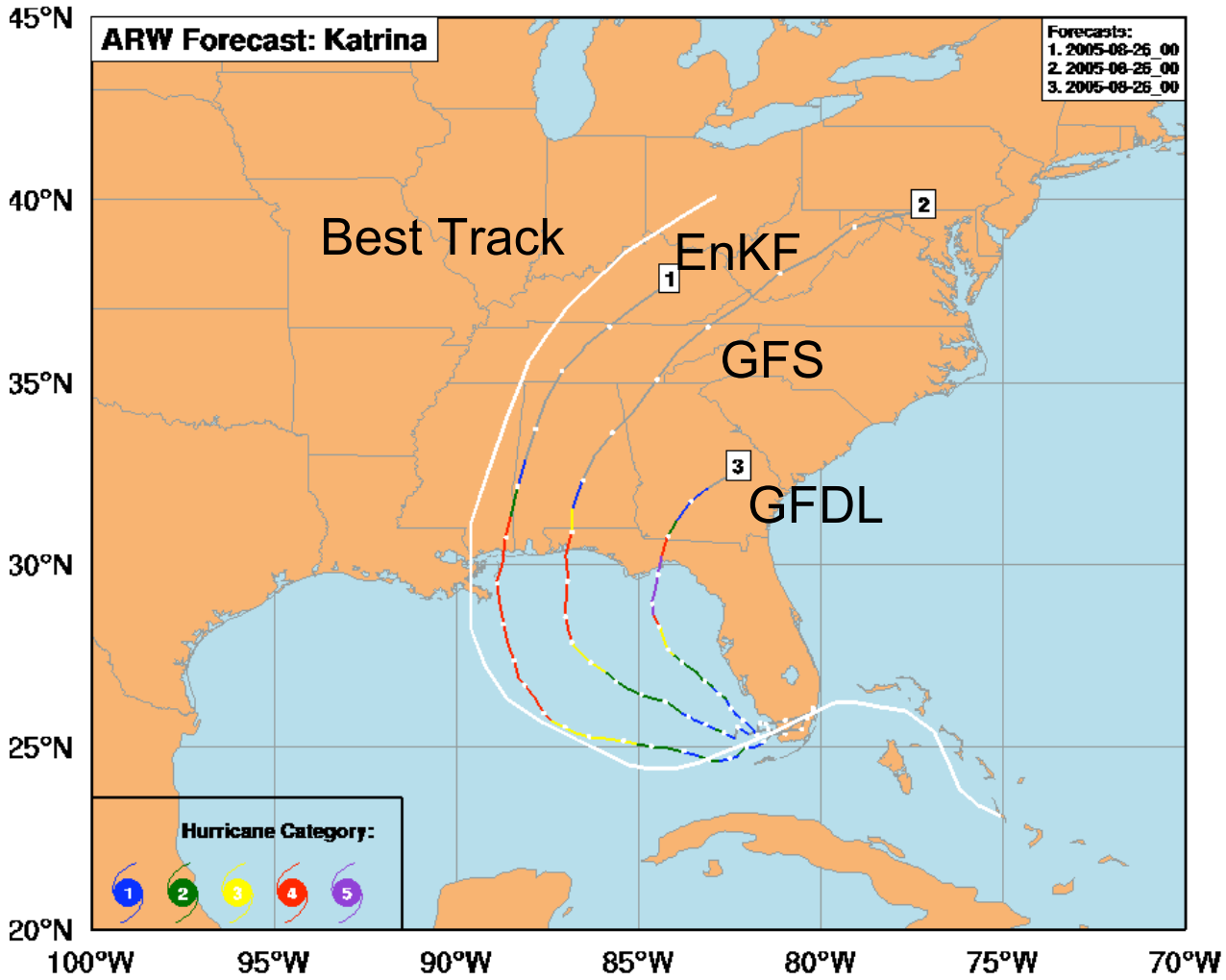


(best track: black)

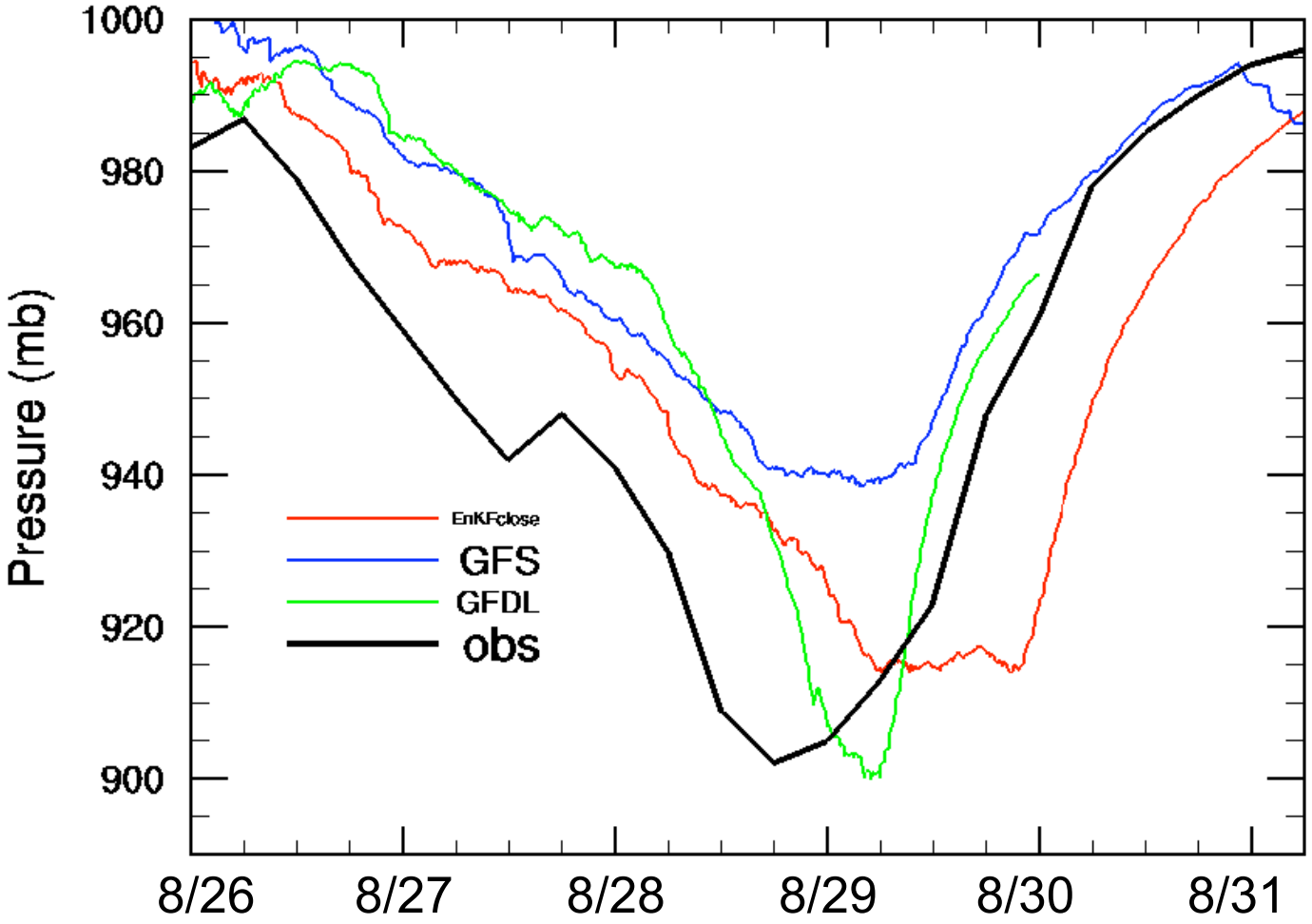
Experimental hurricane initialization using EnKF: Minimum SLP



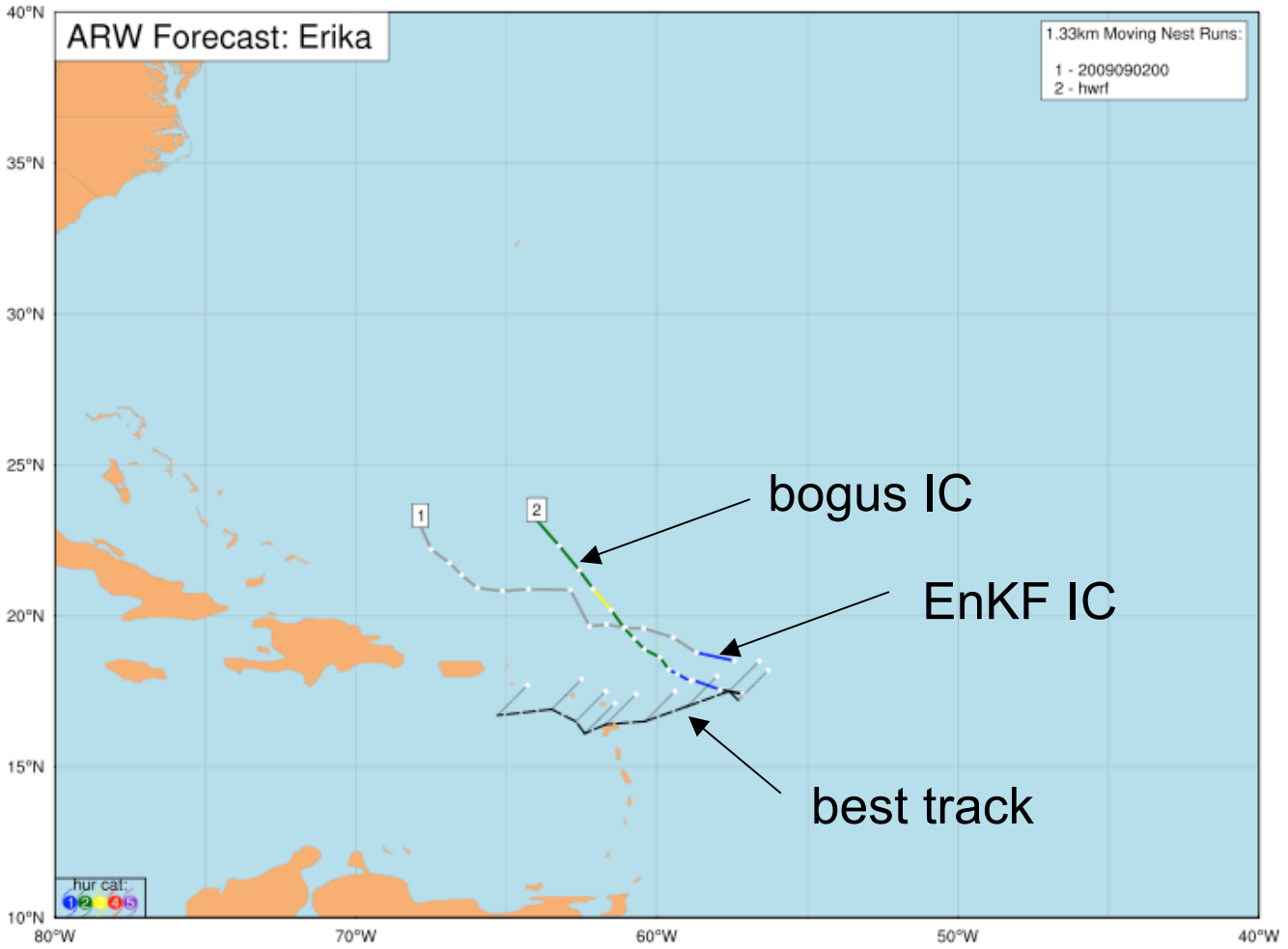
Track Forecasts from EnKF, GFS and GFDL IC, 8/26 Initialization



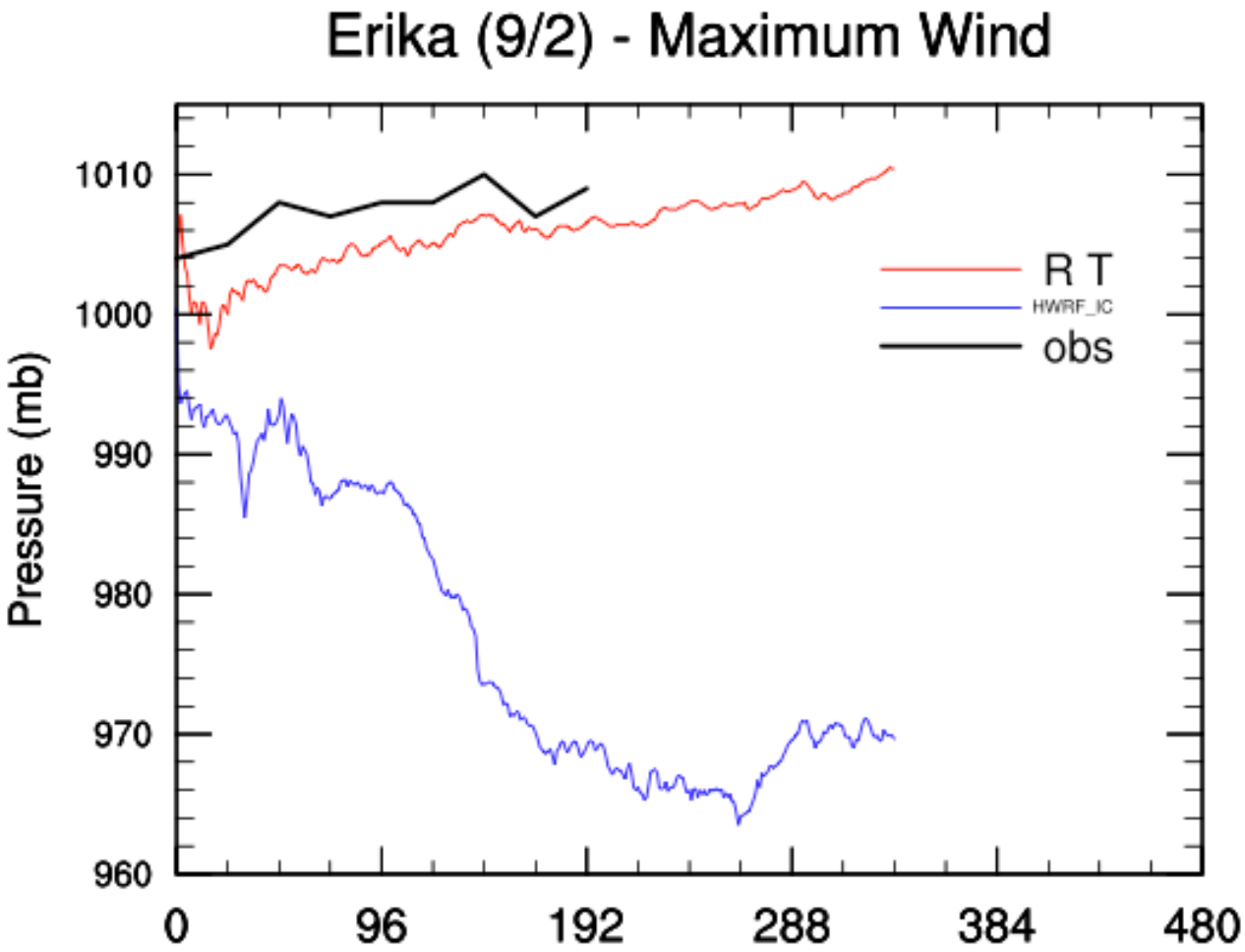
Min SLP Forecasts from EnKF, GFS and GFDL IC



Erika (2009) Track Forecasts using EnKF and bogus IC



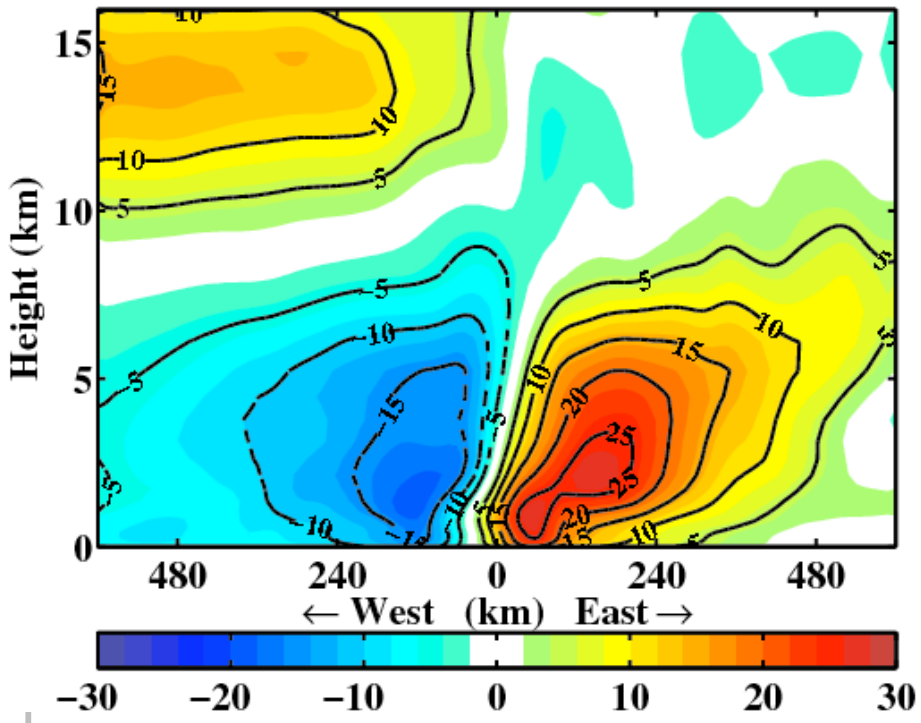
Erika Intensity Forecasts using EnKF and bogused IC

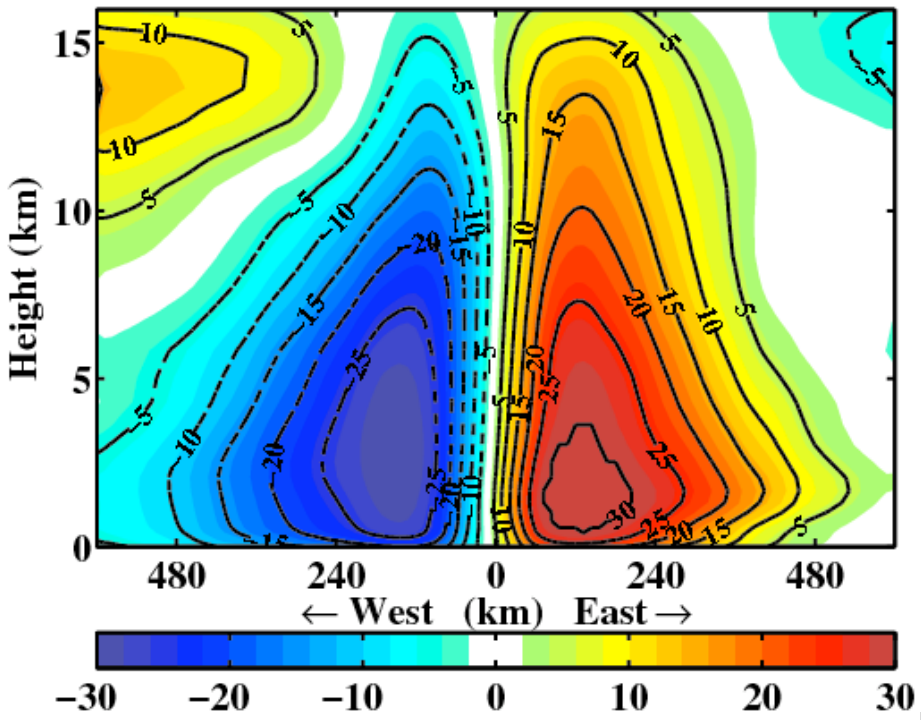


Erika Track Forecasts using EnKF

EnKF IC: shallow vortex, vertical tilt

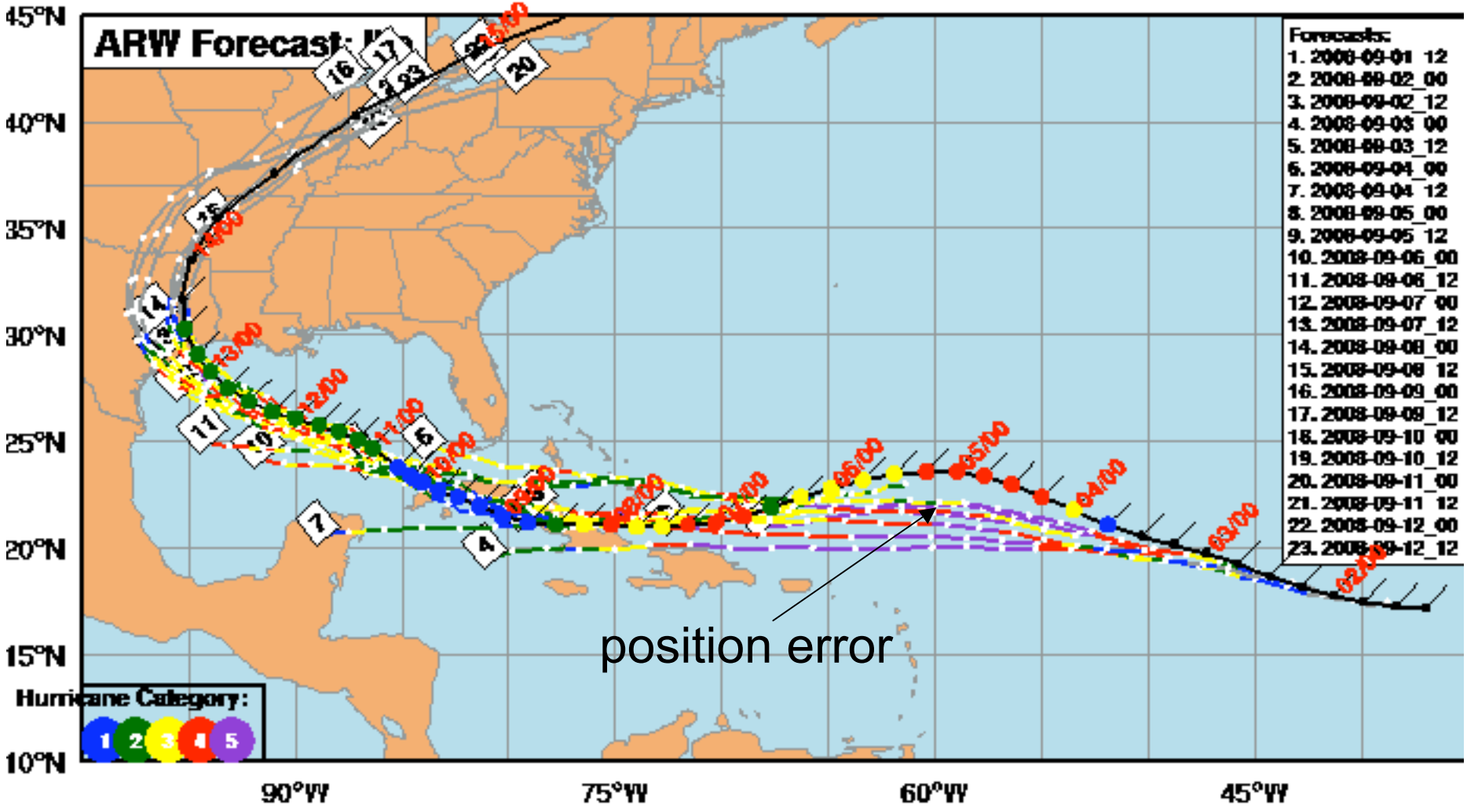
bogus IC: too symmetric, deep





Some Issue with EnKF Analysis

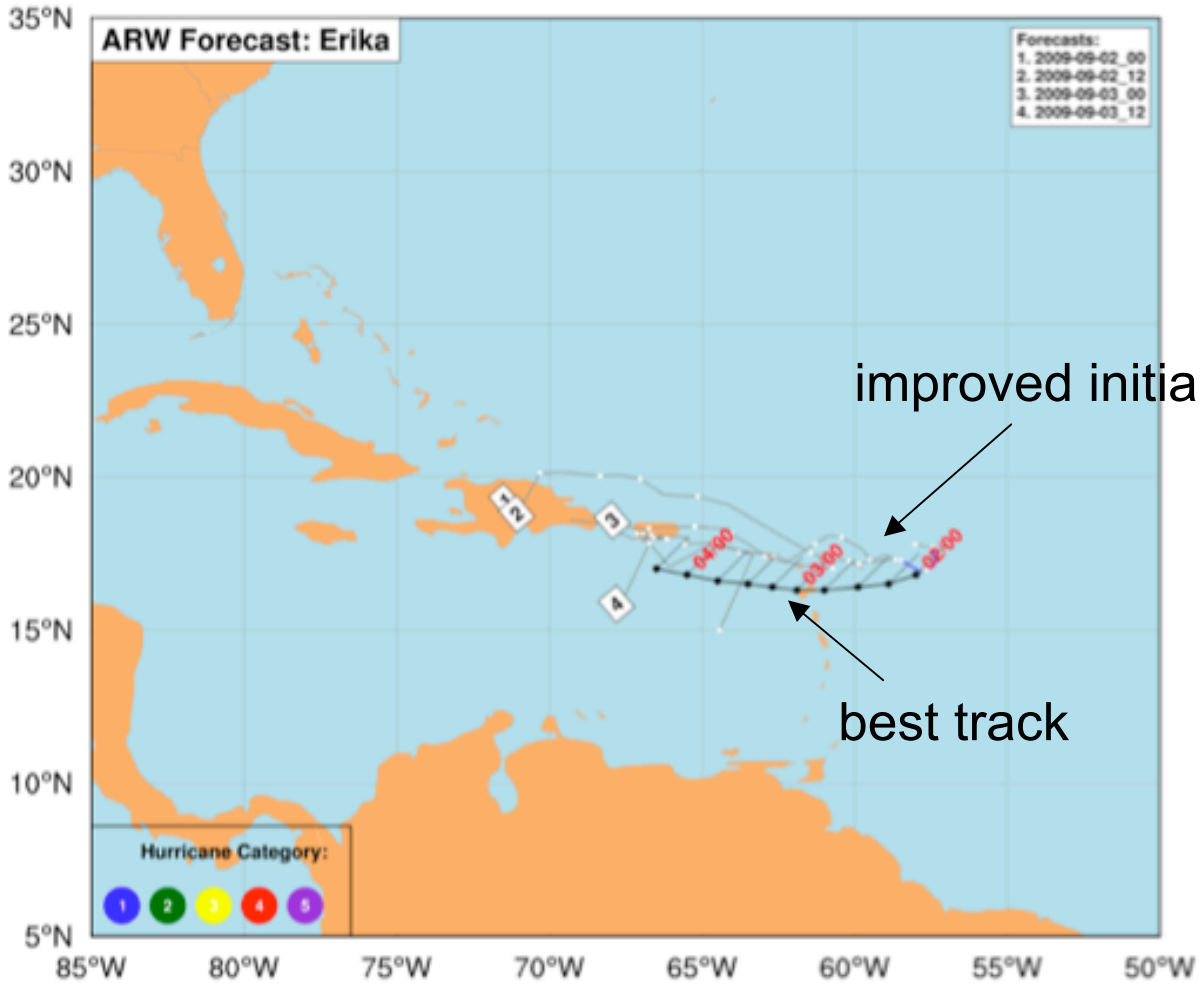
Hurricane Ike (2008)



Some Issues with EnKF Analysis

- Low intensity bias: shown in statistics
  - May be improved with high-resolution grid
- Position error:
  - Observation error used, exact position not enforced
  - Affect a number of cycles at a time - could be related to model error
  - May be improved by adjusting DA parameters

Erika (2009) Track Forecasts using EnKF and bogused IC



Resolution Tests

- Intensity forecast remains a challenging problem
- NOAA-funded 10-year Hurricane Forecast Improvement Project (HFIP) is aimed at addressing the problem
- Initial project to evaluate whether increased model resolution would have measurable improvement for intensity forecast - High Resolution Hurricane (HRH) test

Tests

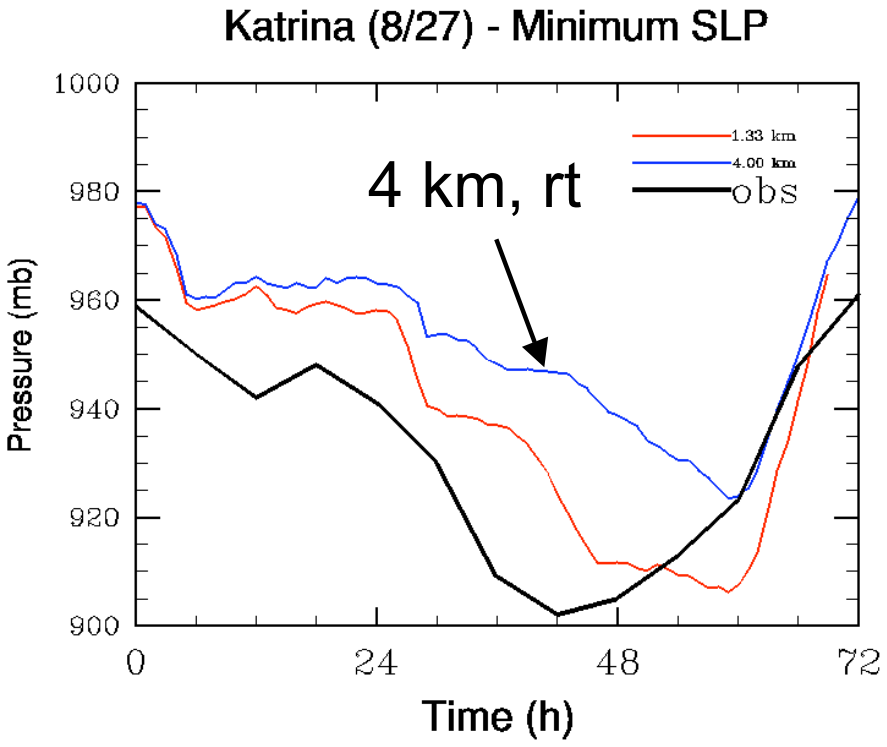
- Test of model at two grid configurations:
  - 12 km, single grid run, CPS
  - 12 / 4 / 1.33 km, two-way nested run
- Initial conditions:
  - cycled EnKF analysis at 36 km
- 69 pairs of forecasts from 10 storms in 2005 and 2007

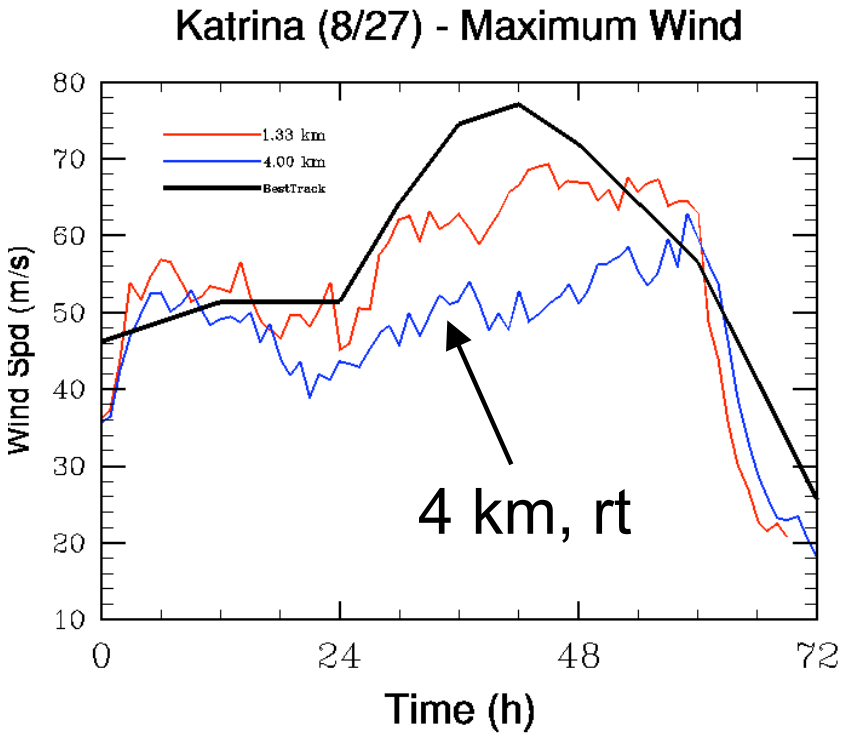
69 Pairs of HRH Forecasts

Storm	Category	# Forecasts	Initialization Times
Emily (2005)	5	10	00 UTC
Katrina (2005)	5	6	00 UTC
Philippe (2005)	1	6	12 UTC
Rita (2005)	5	7	00 UTC
Ophelia (2005)	1	11	12 UTC
Wilma (2005)	5	11	00 UTC (mostly)
Felix (2007)	5	8	6 hrly (mostly)
Humberto (2007)	1	2	Only 2 times
Ingrid (2007)	TS	4	12 UTC
Karen (2007)	1	4	00 UTC

4 km Time Series (blue curve)

Katrina, 0000 UTC 8/27 IC



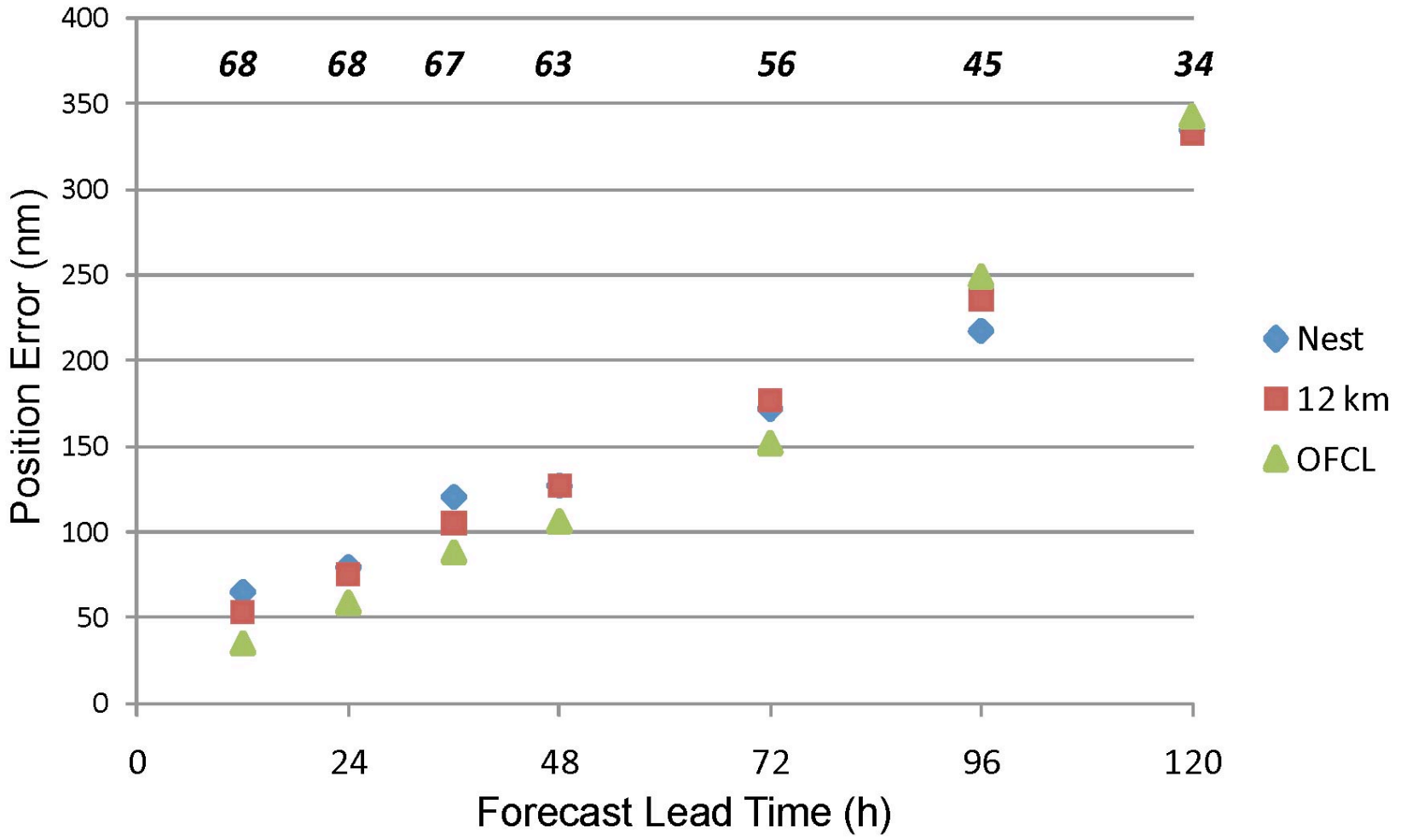


Best Track 1.33 km 4 km

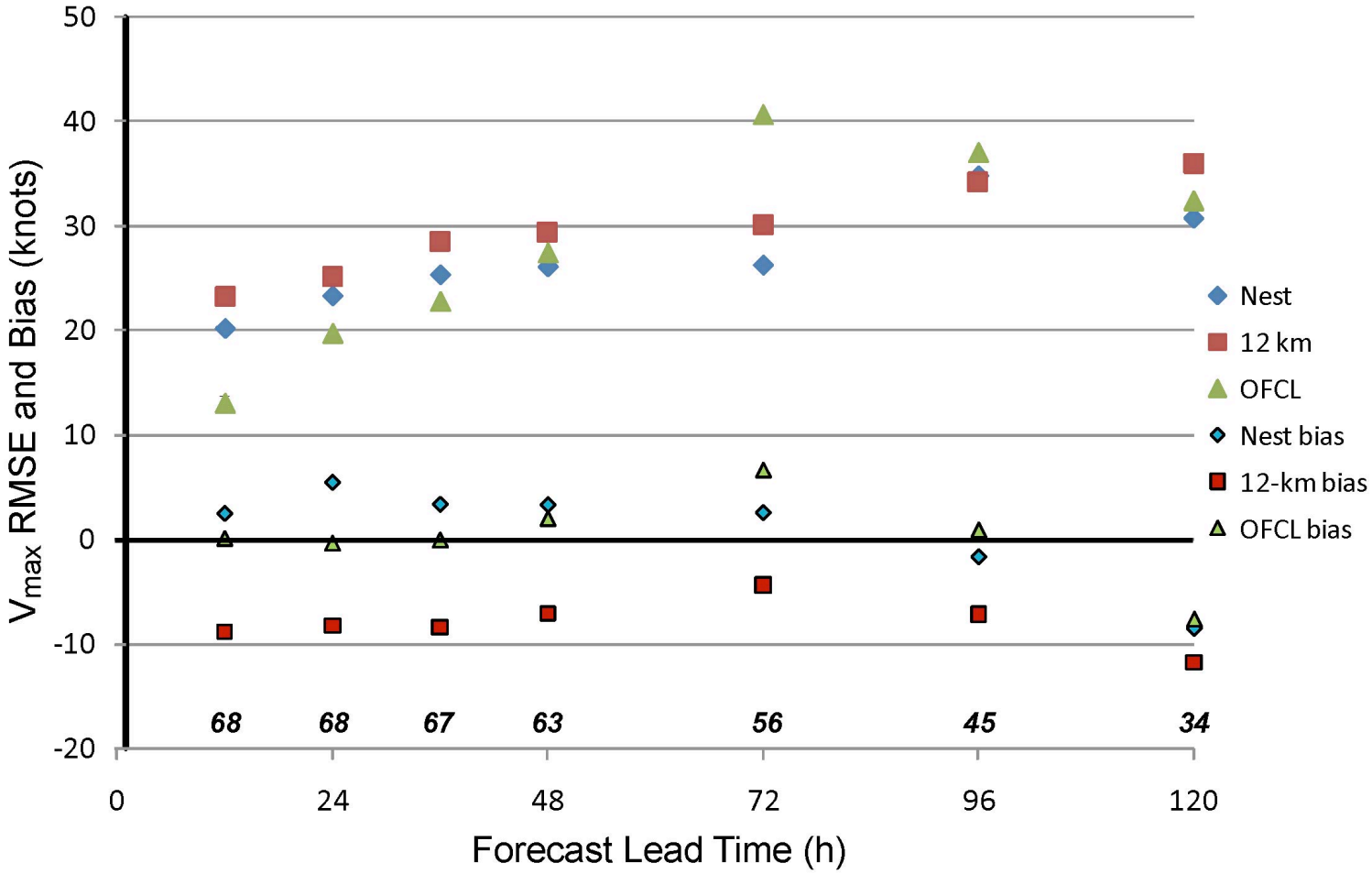
Verification

- Calculate forecast errors from both grids and compare with National Hurricane Center's (NHC) official forecasts
- Track forecast errors: bias and RMS
- Intensity forecasts (10 m maximum winds) is evaluated in a number of ways:
  - RMS and biases
  - Forecast radii of 34 kts and 64 kts winds
  - Rapid intensification
  - Asymmetry of wind radii

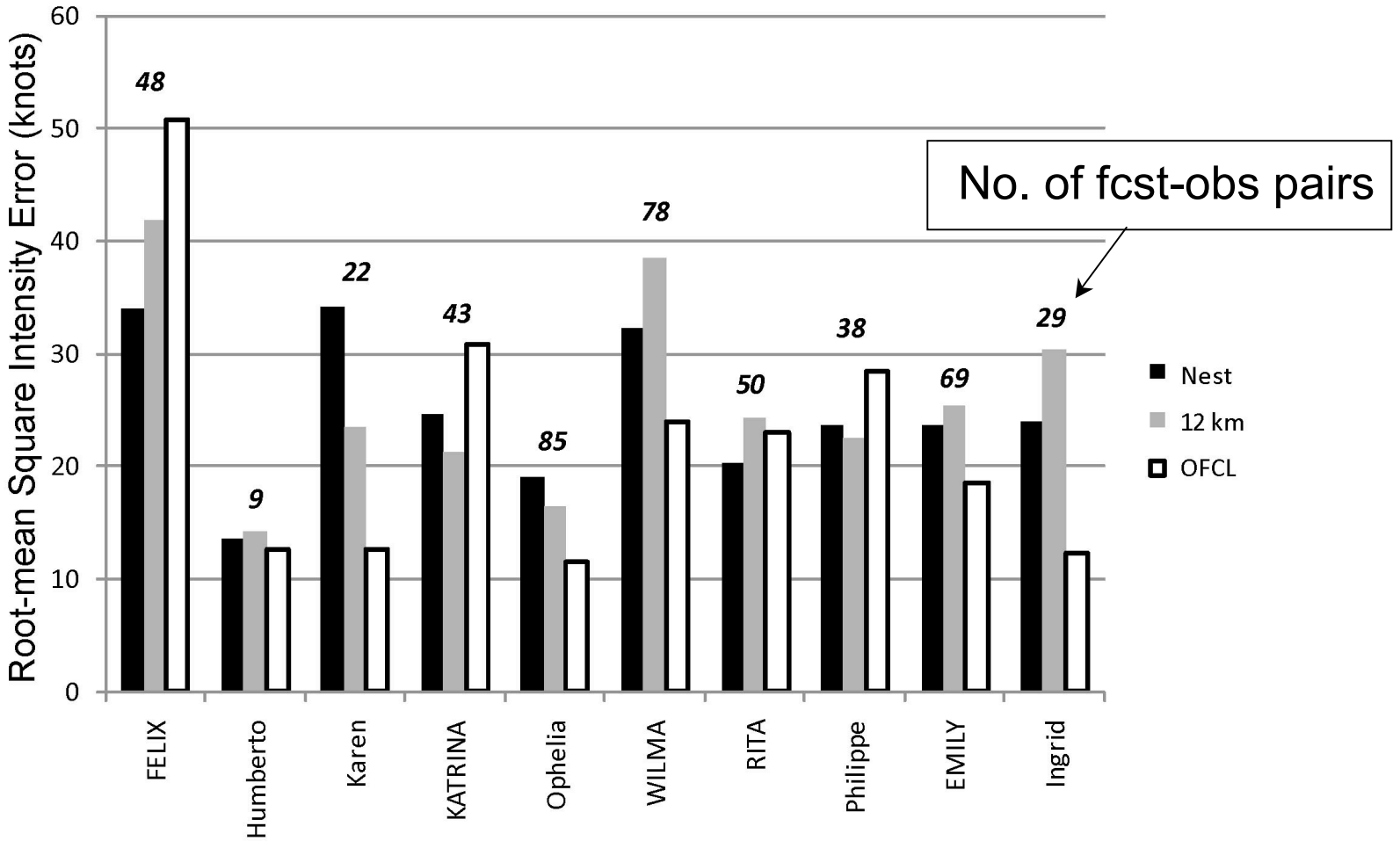
Position Errors in 12 km, 1.33 km and NHC Forecasts



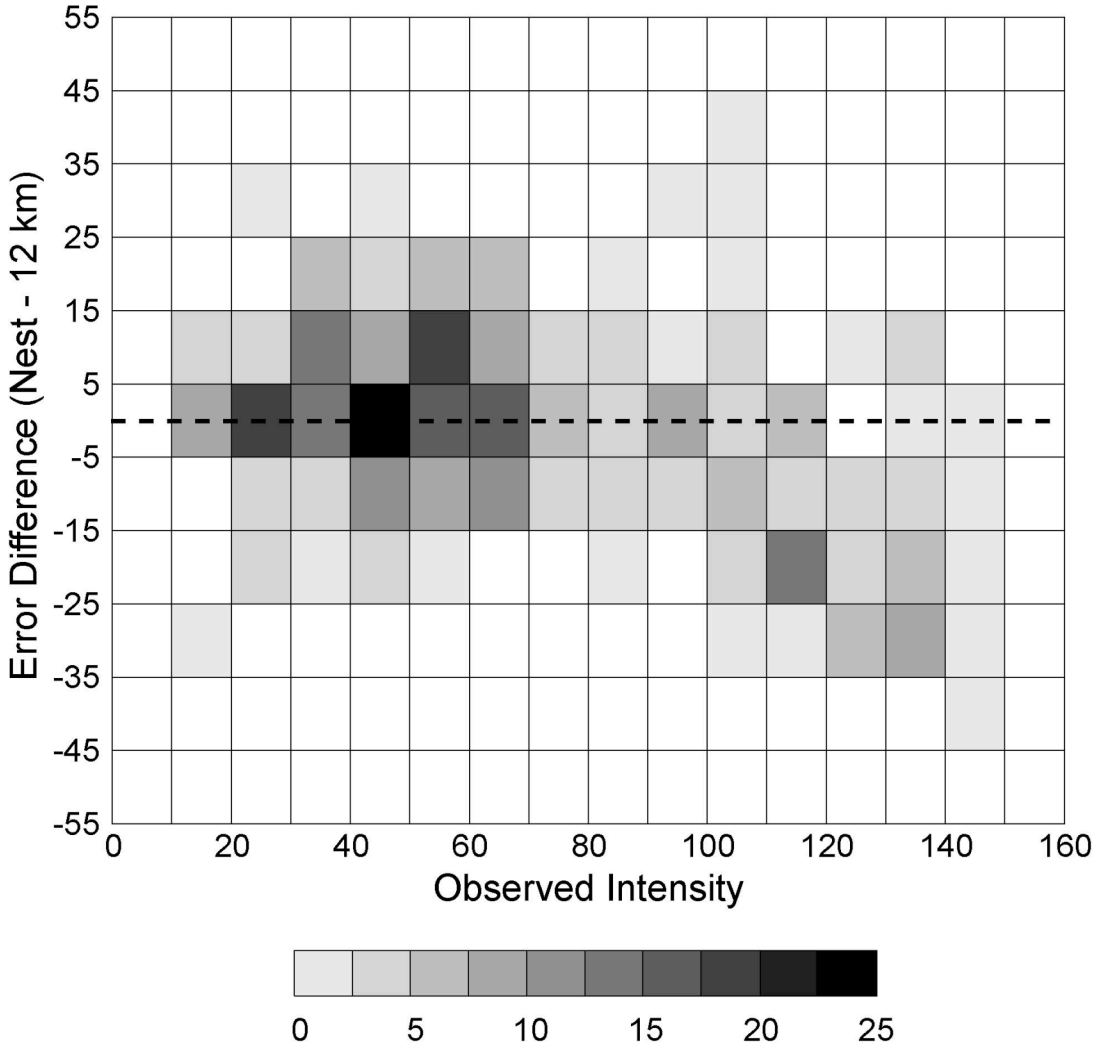
RMS Intensity Errors: 12-km, 1.33-km and NHC



RMS Intensity Errors by Storms



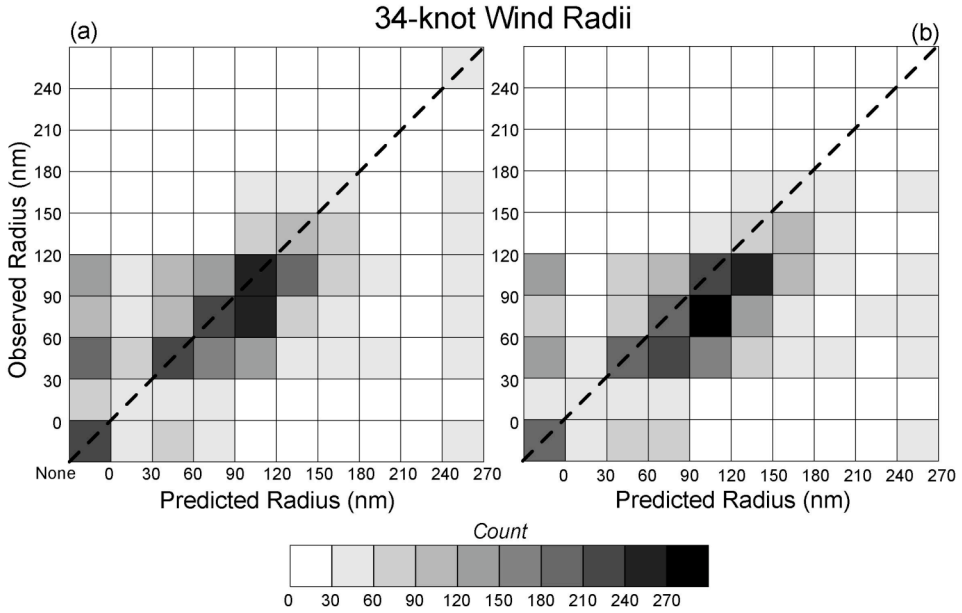
Errors As a Function of Intensity



larger error
in nest

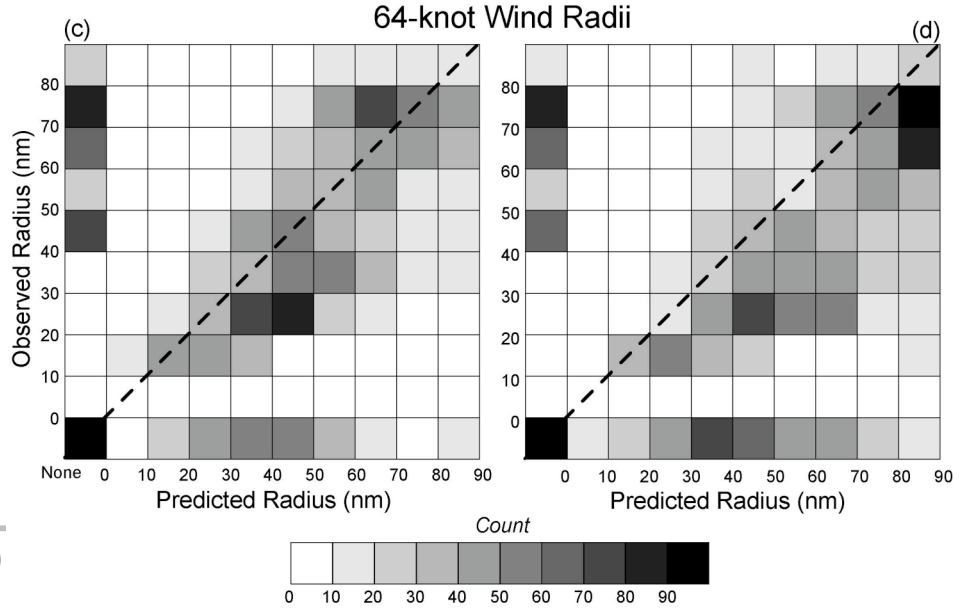
larger error
in 12 km domain

Wind Radii Errors



1.33 km

12 km



Rapid Intensification

Definition: 25 kts wind increase in 24 hours
Observed cases: 55

FCST	HITS	MISSES	FALSE ALARM	ETS
NHC	3	52	3	0.04
12 km	10	45	10	0.11
1.3 km	21	34	30	0.16

Summary (1)

- Our experiments demonstrate the possibility of using EnKF analyses as initial conditions for tropical storm and hurricane initialization.
- Using EnKF analyses as initial conditions for tropical storms show some improvements for track and sometimes intensity forecasts.
  - Smoother transition from EnKF analysis to high resolution forecast.
  - Better representation of some storm parameter (such as 34-knots wind radii).
  - Can distinguish sheared from upright storms.

Summary (2)

- The resolution comparison is the first study to use a relatively large sample forecasts (69 pair of runs for 10 storms).
- Though there is not significant difference in track errors between the two grid resolution, all measures of intensity show that the nest performs as well as or significantly better than the coarse grid counterparts.
  - What forecast parameter to use
  - High-resolution forecast can be panelized more if timing is wrong
  - No additional information in the high-resolution IC

Reference: Davis et al. 2010 (Wea. Forecasting)