2015 Upgrades to the GFDL Hurricane Model

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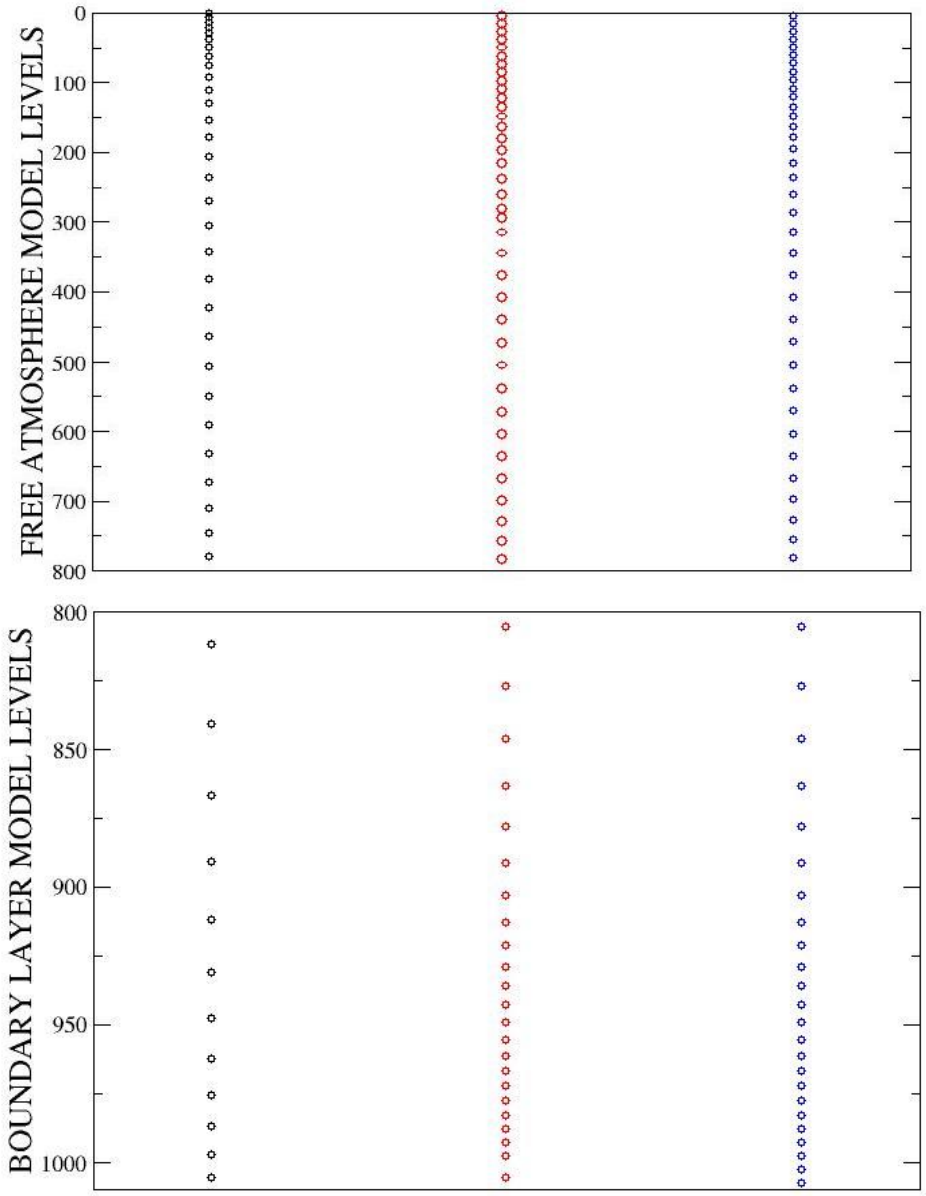
EMC/NCP CCB Review
Wednesday, April 15th, 2015

Summary of Proposed Upgrades

- **Upgraded version of GFS**
- **Increase of vertical sigma levels from 42 to 60**
  Similar Configuration to HWRF levels
- **Improved Initialization of Moisture Field (r)**
- **Using improved moisture specification: reintroduction of Vortex Specification for all storms (e.g. TD, and weak TS) except Nameless systems**
- **New Specification of Storm size (Rb)**
- **Modified filter depth in vortex specification**
  (Tested, but rejected due to unfavorable impact)
- **Correct Specification of Ocean Currents in Surface flux computation**
- **Bug Fix in GFDL coupler**

VERTICAL LEVEL CONFIGURATION

42 Level GFDL 60 Level GFDL 60 Level HWRF



Improved Moisture Initialization

Current Scheme :

$(U, V, T, r, p^*) = (U, V, T, r, p^*)_{Envr} + (U, V, T, r, p^*)_{axi\text{-}sym\ vortex}$

$r_{axi\text{-}sym\ vortex}$ defined with respect to the Environmental moisture field

(Environment is determined by moisture field outside the filter radius)

Lead to Unrealistic drying in middle troposphere

(Limited RI for weak, developing systems)

Revised Scheme :

$(U, V, T, p^*) = (U, V, T, p^*)_{Envr} + (U, V, T, p^*)_{axi\text{-}sym\ vortex}$

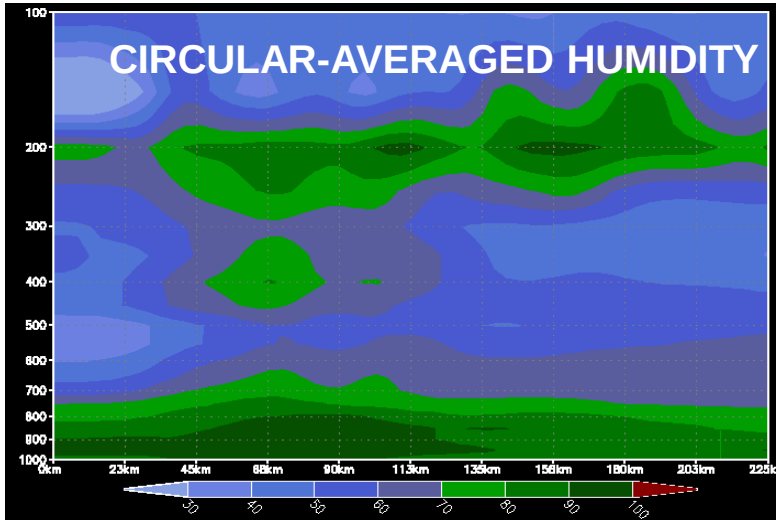
$r = r_{gfs} + r_{vortex}$

More realistic Initial Moisture lead to significantly Improved Intensification in RI situations

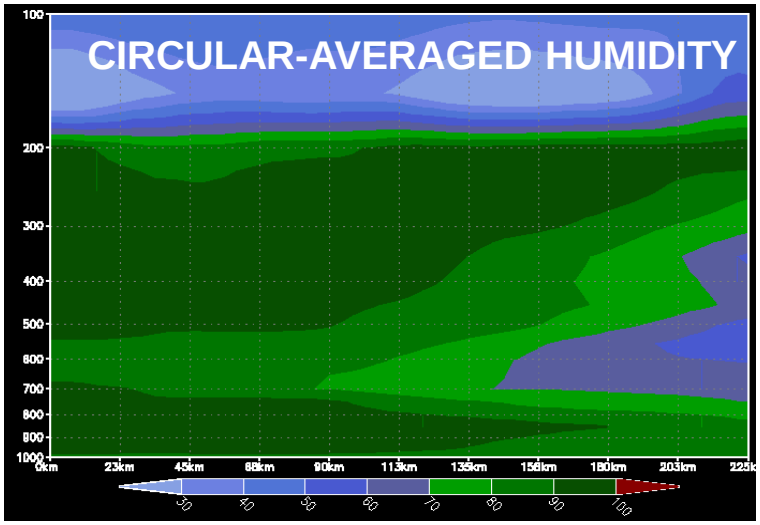
Impact of Improved Moisture Initialization

Hurricane Earl (Initial time: 0000 UTC 27 August, 2010)

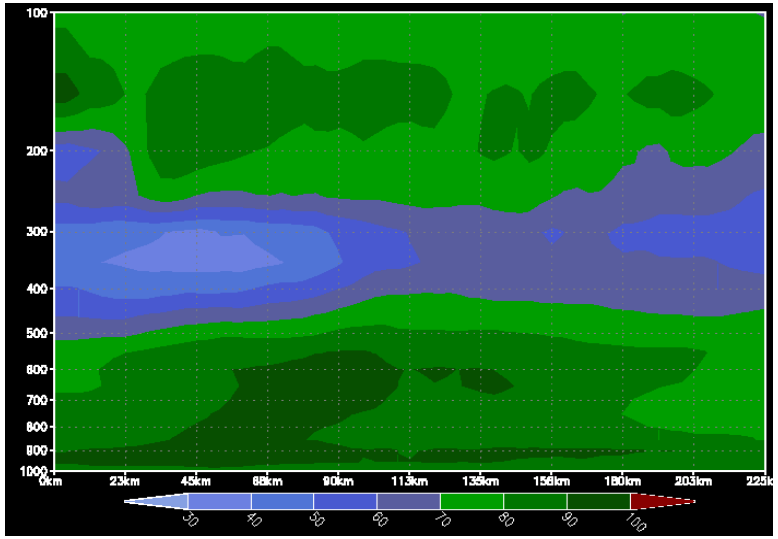
OLD MOISTURE INITIALIZATION



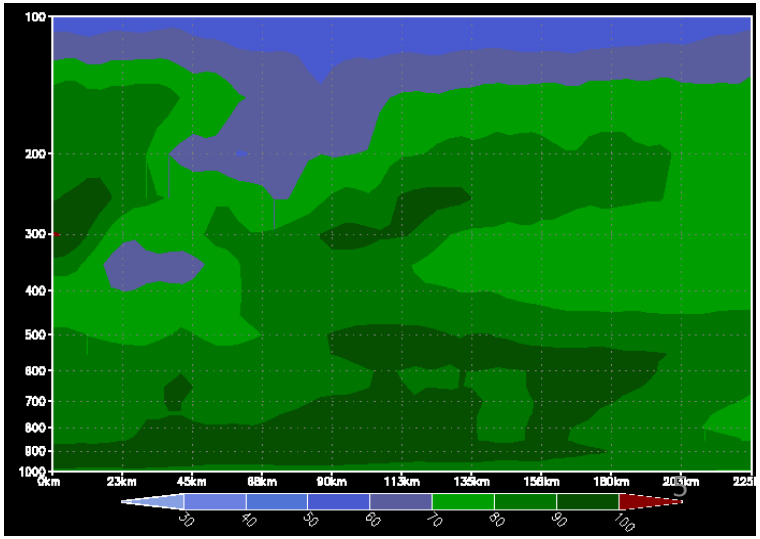
NEW MOISTURE INITIALIZATION



HOUR 0

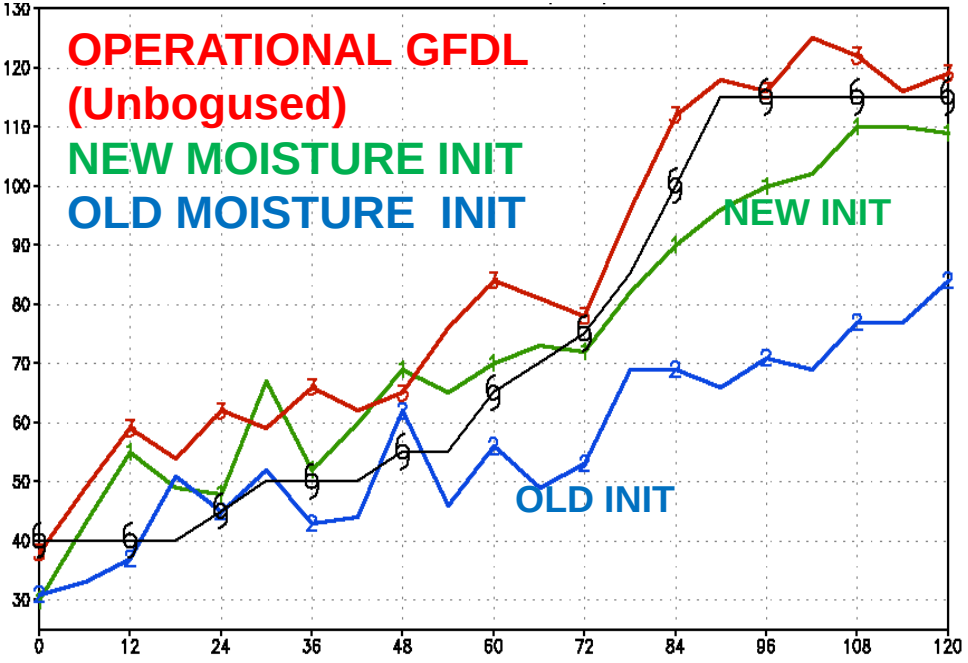


FORECAST HOUR 42

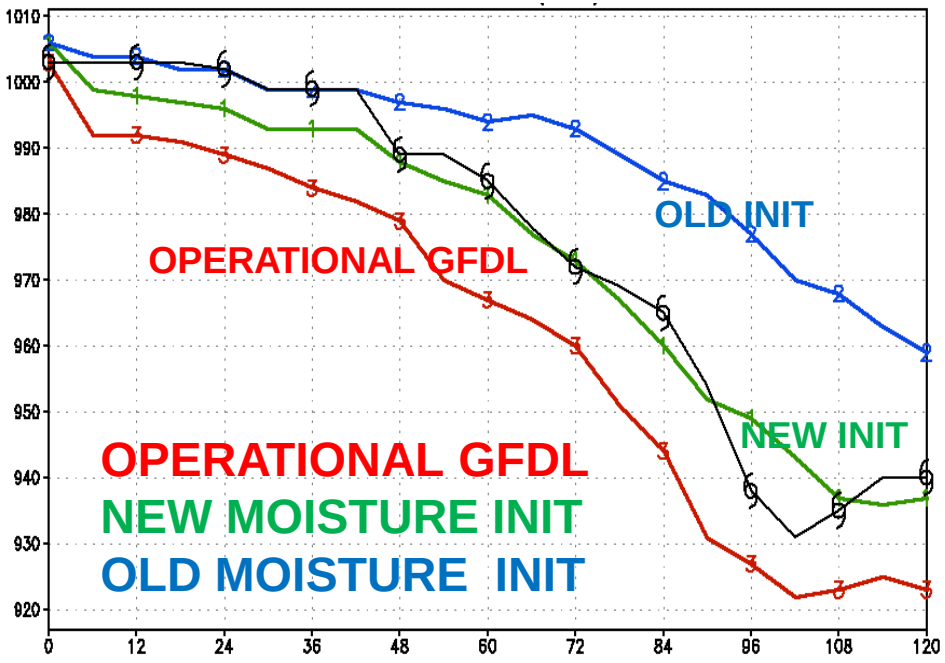


Impact of Improved Moisture Initialization

MAXIMUM SURFACE WINDS (KTS)



CENTRAL PRESSURE (hPa)



HURRICANE EARL (INITIAL TIME: 000 UTC 27 AUGUST, 2010)

Formulation of New Storm Size (R_b)

(radius where the tangential wind of specified vortex goes to 0)

In current vortex initialization we assume R_b is a simple function of the Radius of the Last closed Isobar (RLCI) from the tcvitals file (R_b = 1.5 * RLCI)

Assume the Absolute Angular Momentum M(r)

$M(r) = rv + \frac{1}{2}$ f r^2 *is roughly conserved for*

A parcel of air moving radially inwardly toward the storm center

$$V(r)_{tan} = \frac{M(p)}{r^x} - \frac{1}{2} f r$$ *Carr and Elsberry, MWR (1997)*

Where: **(x = .4)** $M(p) = M(r)/r^{(1-x)}$

$$M(p) = \frac{1}{2} f (R_b)^{(1+x)}$$ **Assuming R_b = Radius where tangential wind vanishes**

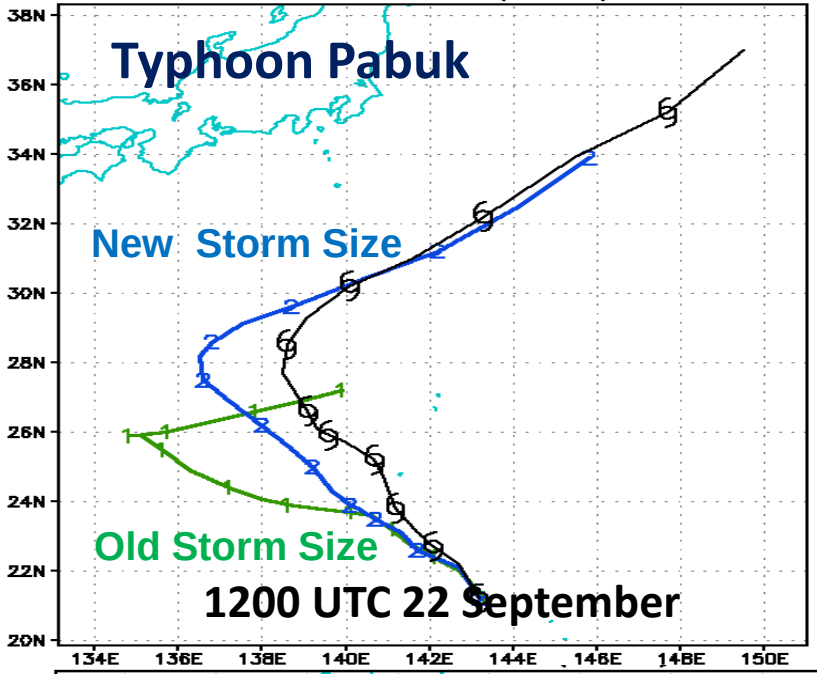
The Absolute Angular Momentum (M_{gale}) at the radius of Gale winds can be determined from the tcvitals :

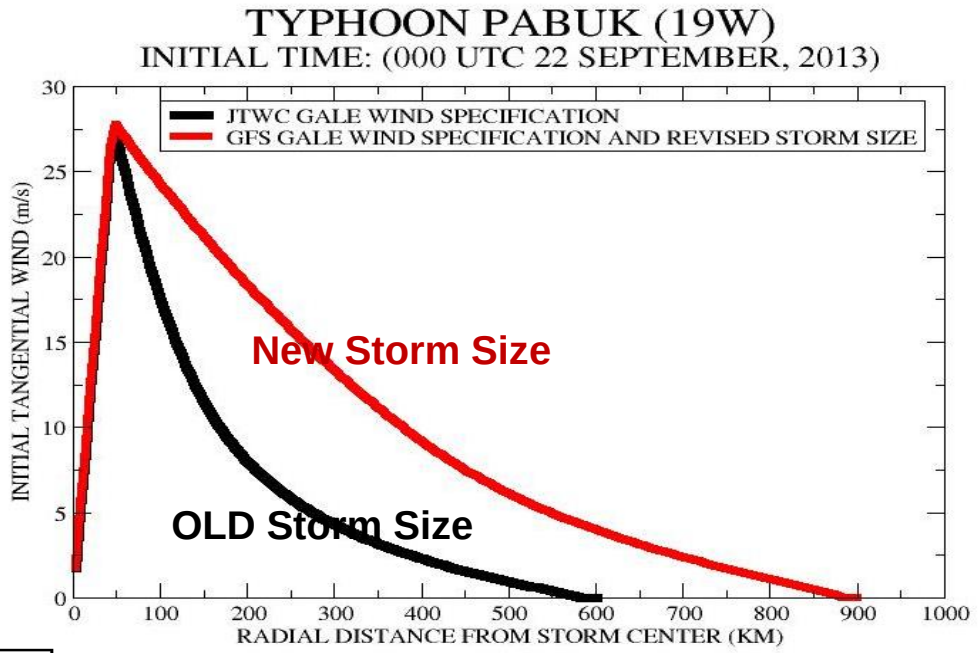
$$M(r)_{gale} = r_{gale} v_{gale} + \frac{1}{2} f r_{gale}^2$$

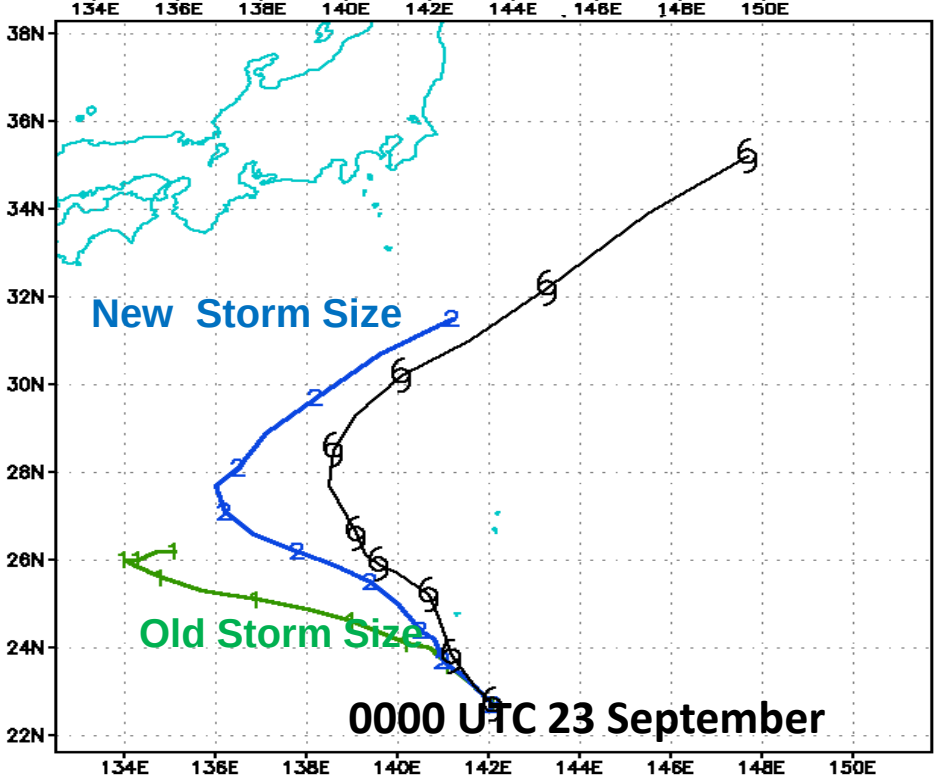
r_{gale} *averaged sum of* radli of gale winds v_{gale} at each of the 4 storm quadrants

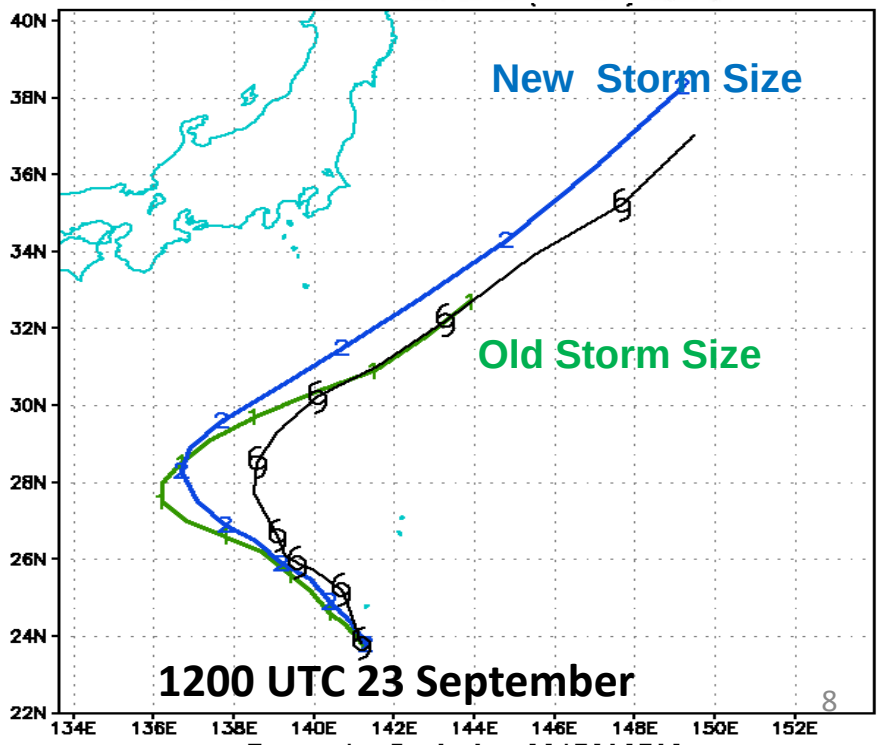
$$MLG = log\,(2(M(r))_{gale}/f\, r_{gale}^{(1-x)}$$

New Estimate for R_b : $(R_b) = e^{(MLG/(1+x))}$

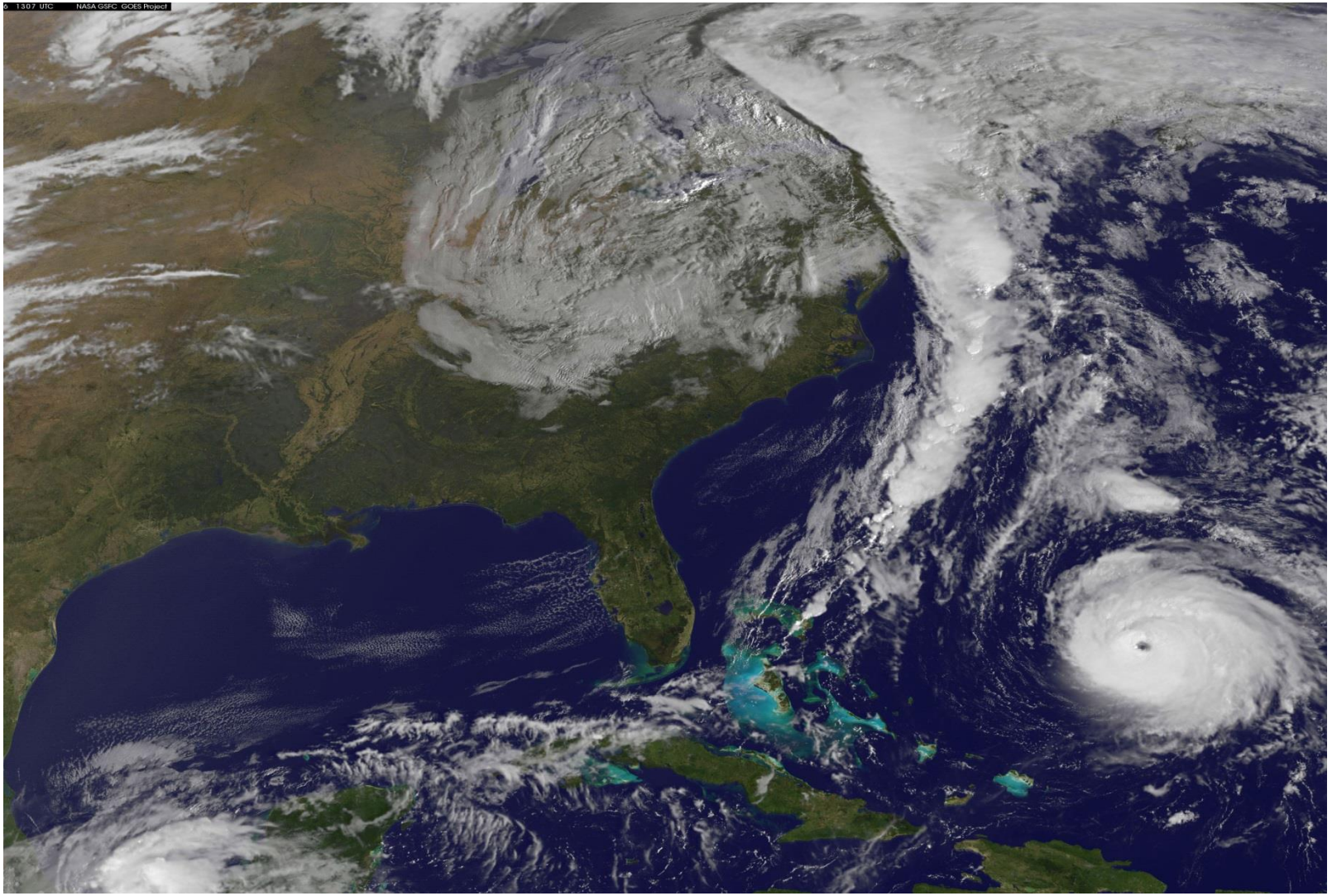

Typhoon Pabuk
New Storm Size
Old Storm Size
1200 UTC 22 September


TYPHOON PABUK (19W)
INITIAL TIME: (000 UTC 22 SEPTEMBER, 2013)
JTWC GALE WIND SPECIFICATION
GFS GALE WIND SPECIFICATION AND REVISED STORM SIZE
New Storm Size
OLD Storm Size
INITIAL TANGENTIAL WIND (m/s)
RADIAL DISTANCE FROM STORM CENTER (KM)


New Storm Size
Old Storm Size
0000 UTC 23 September

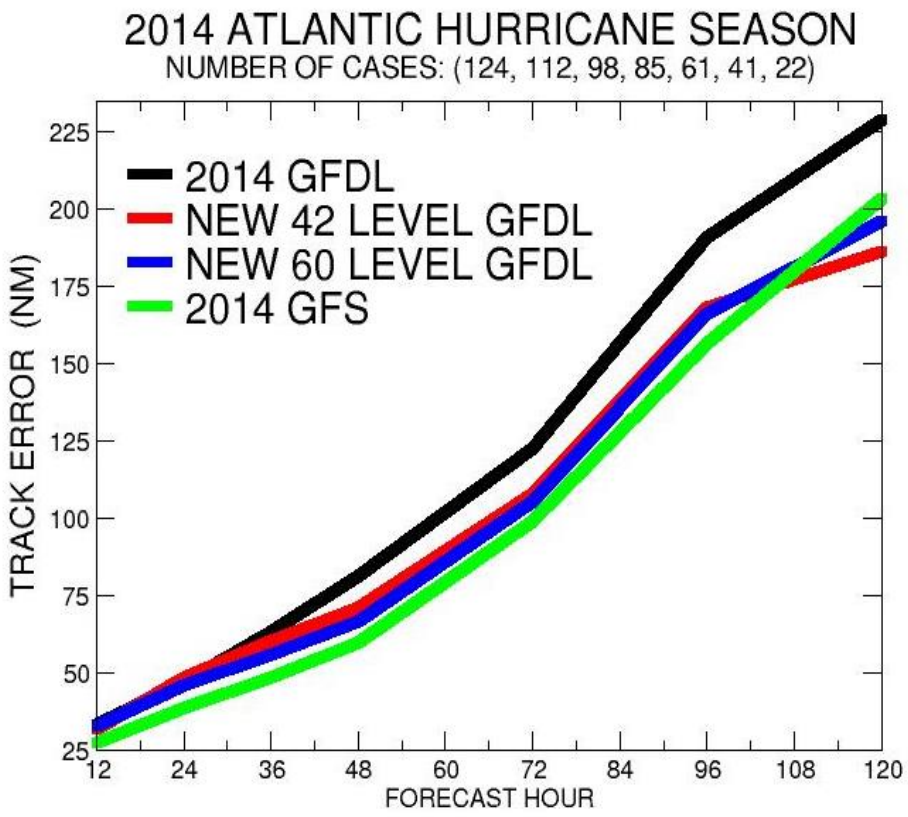

New Storm Size
Old Storm Size
1200 UTC 23 September

Performance Evaluation of Upgraded Model with Previous GFS



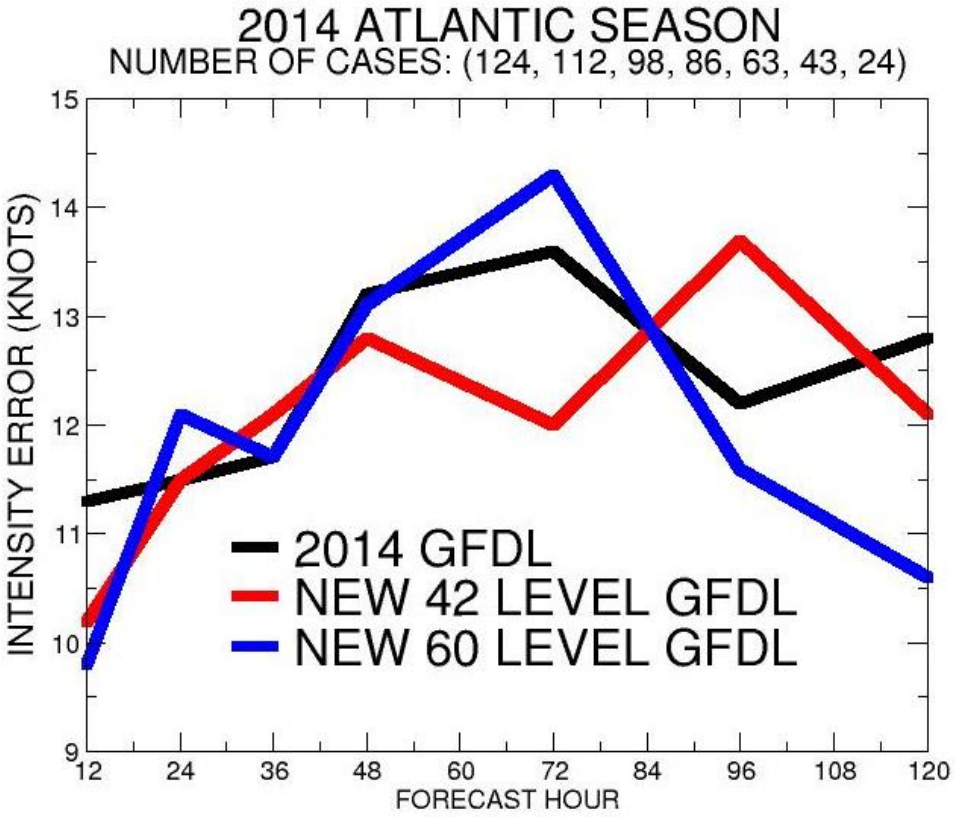
2014 Atlantic Season with 2014 GFS

TRACK ERROR (NM)



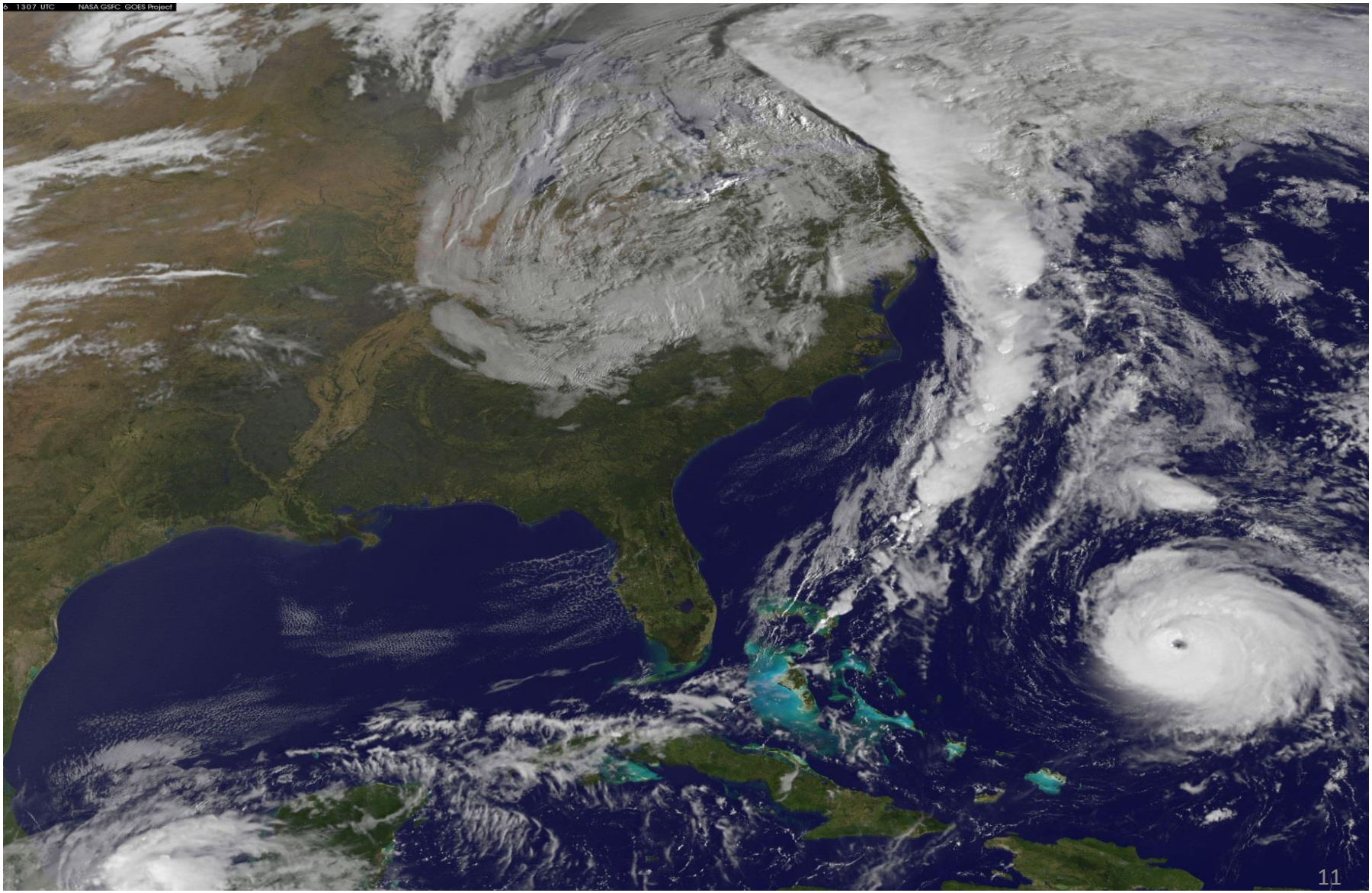
16-18% Reduced Track Error for 2-5 Days for Both Upgraded Models New Models Comparable to GFS

INTENSITY ERROR (KNOTS)



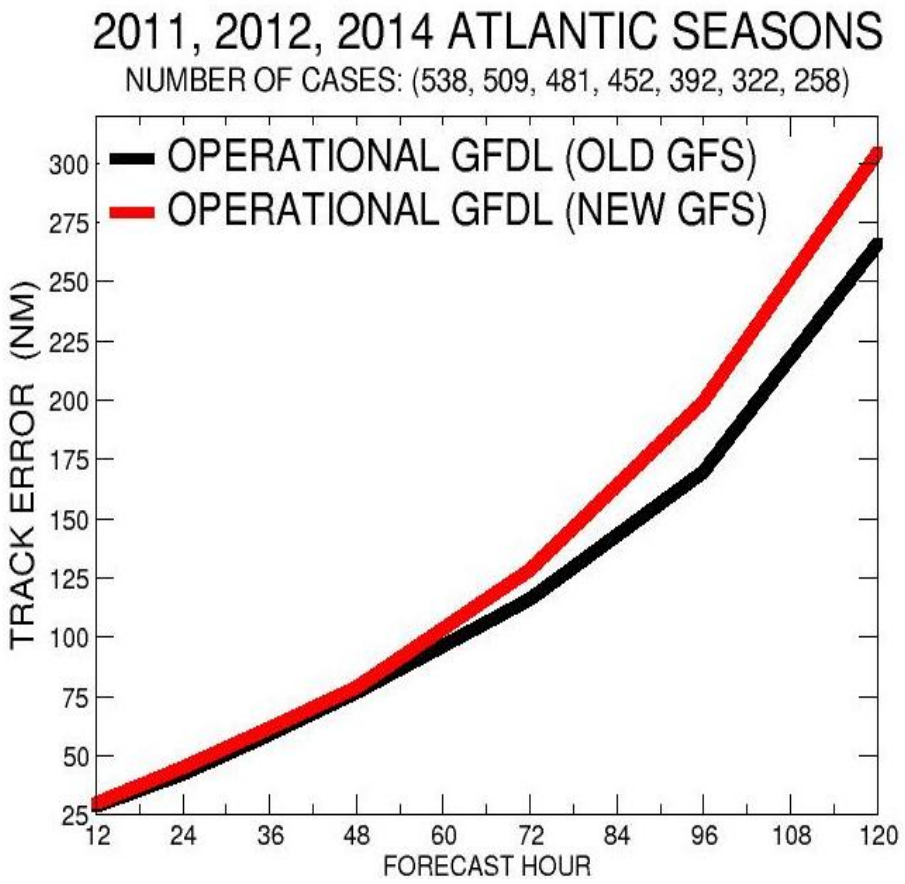
INTENSITY PERFORMANCE MIXED
42 LEVEL IMPROVED EARLY TIME
60 LEVEL IMPROVED LATER TIME

Performance Evaluation With New GFS

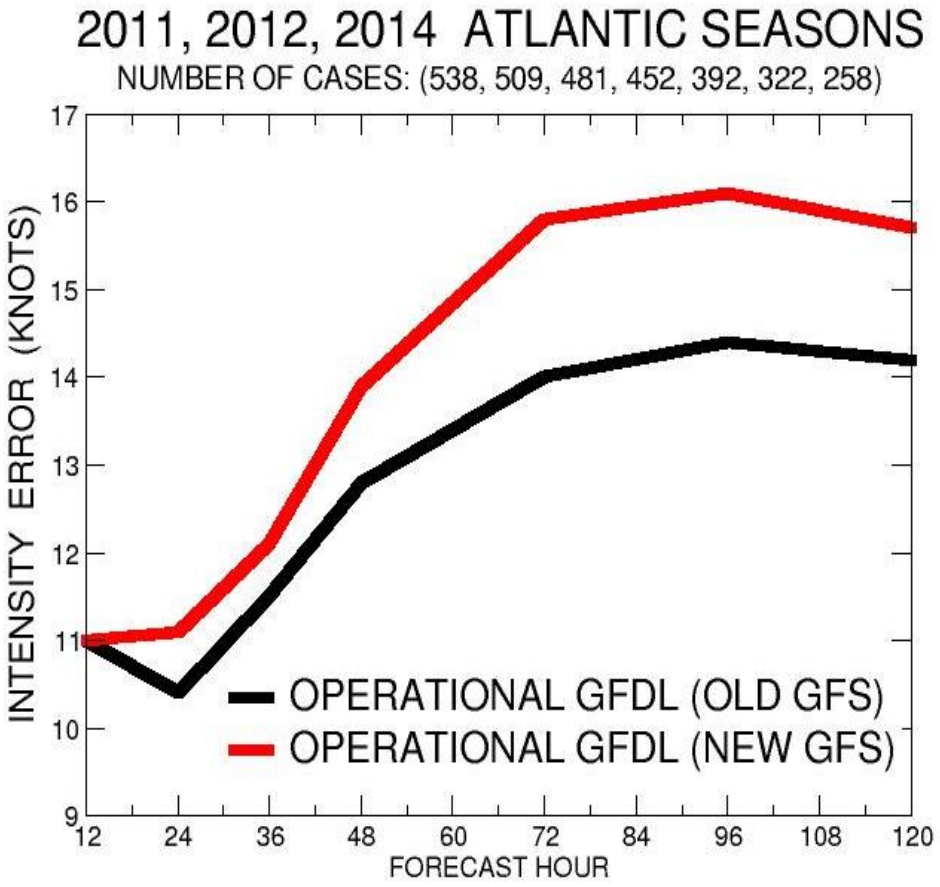


Impact Only of GFS Upgrade in Atlantic

TRACK ERROR (NM)



INTENSITY ERROR (KNOTS)

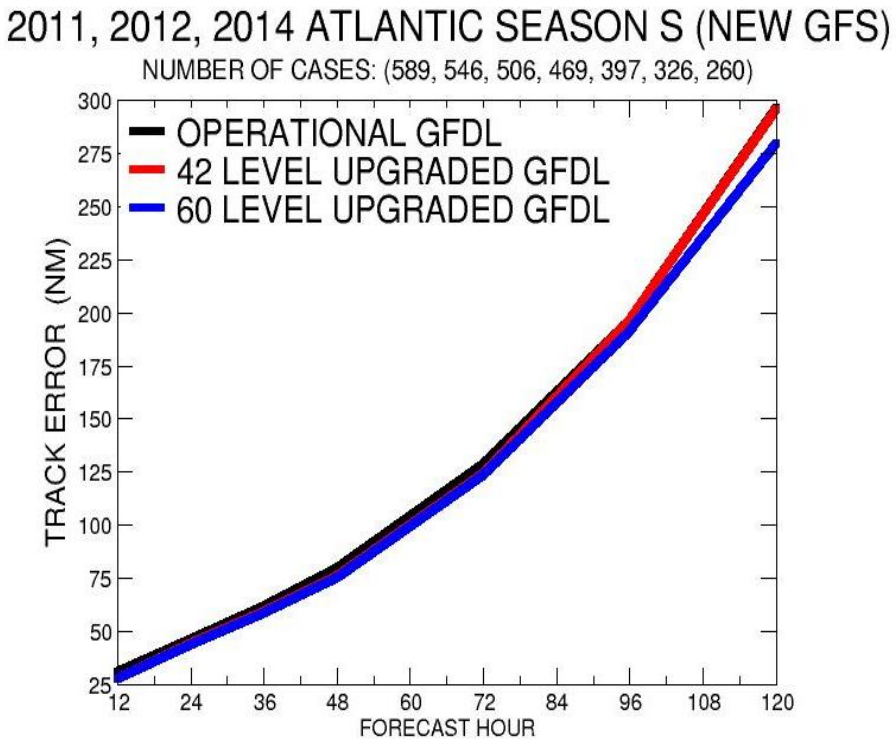


New GFS Degrades GFDL degraded both track and intensity skill by 6% at days 1-2

Track (12%) and Intensity (10%) Skill <u>Significantly</u> degraded days 3-5

2011, 2012, 2014 Atlantic Seasons with New GFS

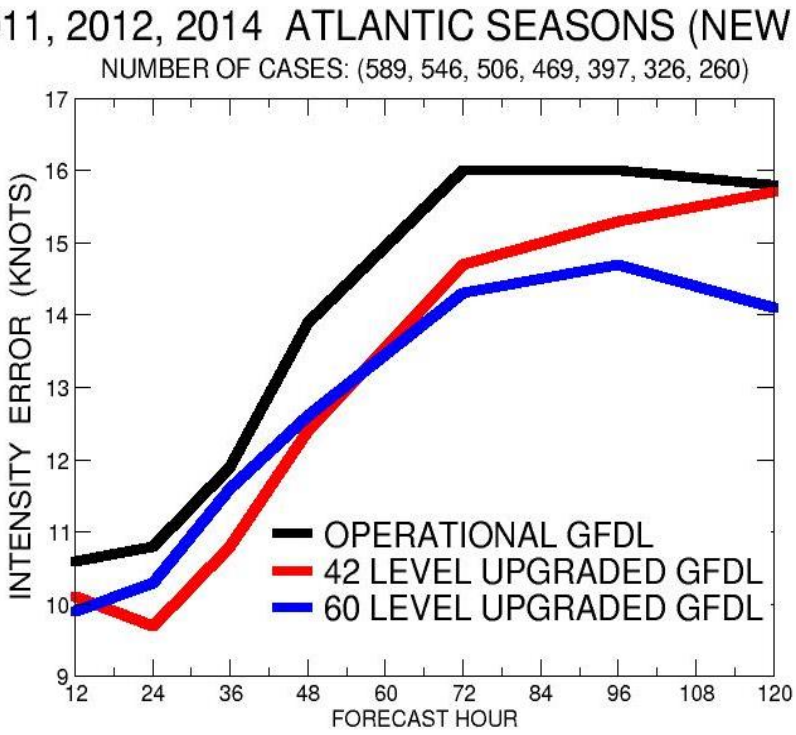
TRACK ERROR (NM)



60 Level Model performed slightly better at days 4-5

42 and 60 level models had 5 % and 6% reduced track error through day 3, compared to Current GFDL model

INTENSITY ERROR (KNOTS)



42 Level Model performed better then 60 Level Model through 48 hours.

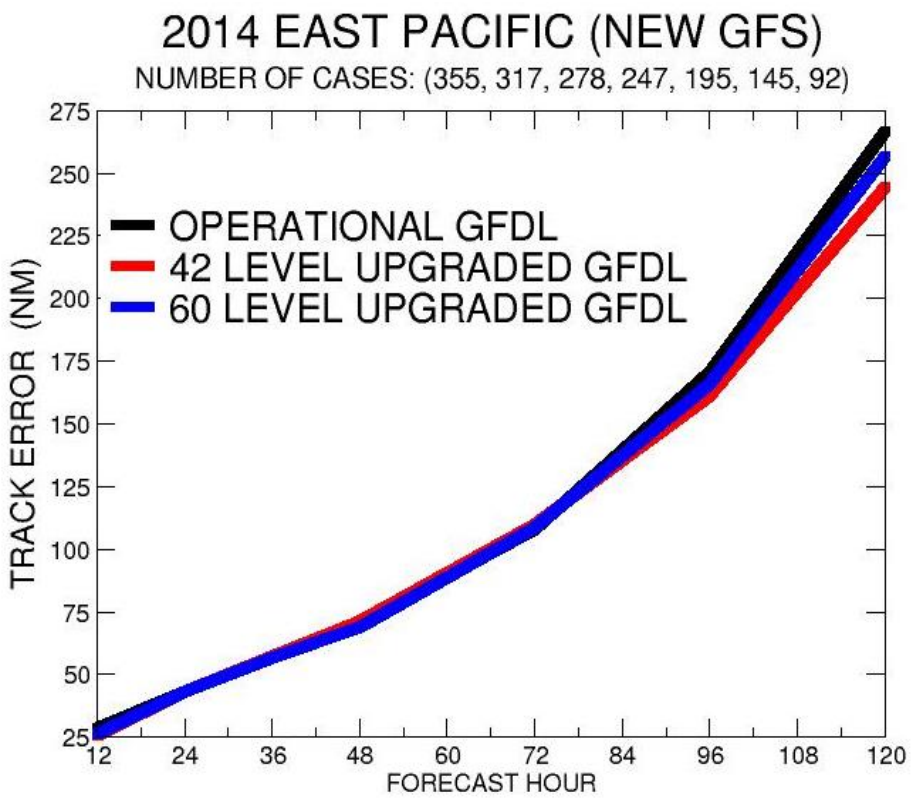
(10% reduced intensity error compared to current model)

60 Level Model performed best for 4-5 Days

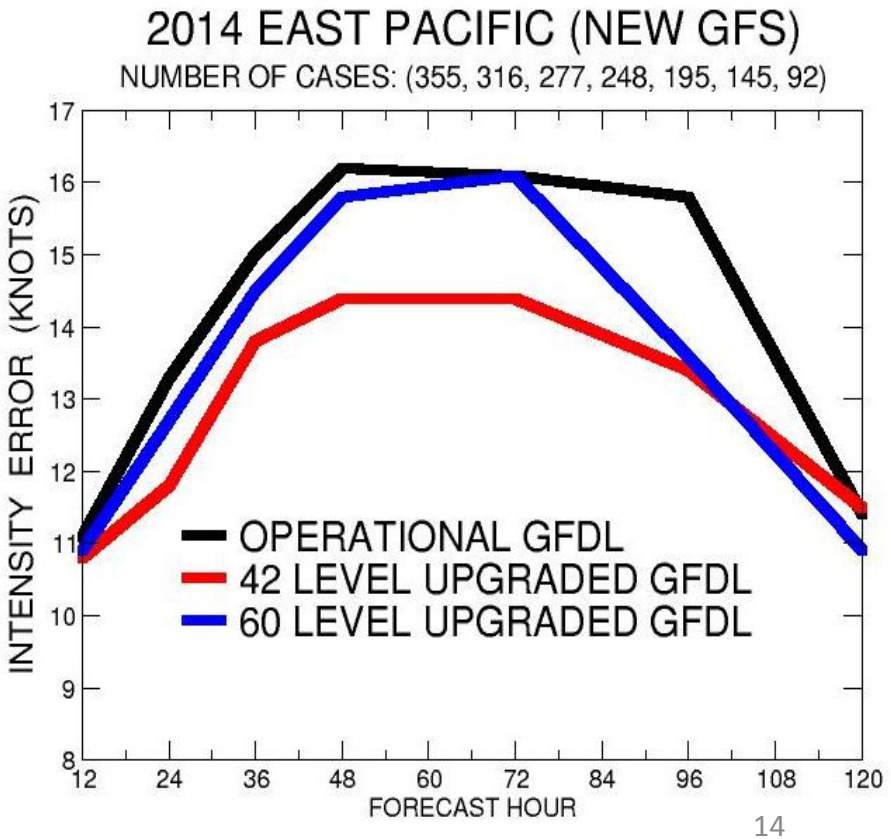
(11% reduced intensity error)

2014 EAST PACIFIC SEASON

TRACK ERROR (NM)

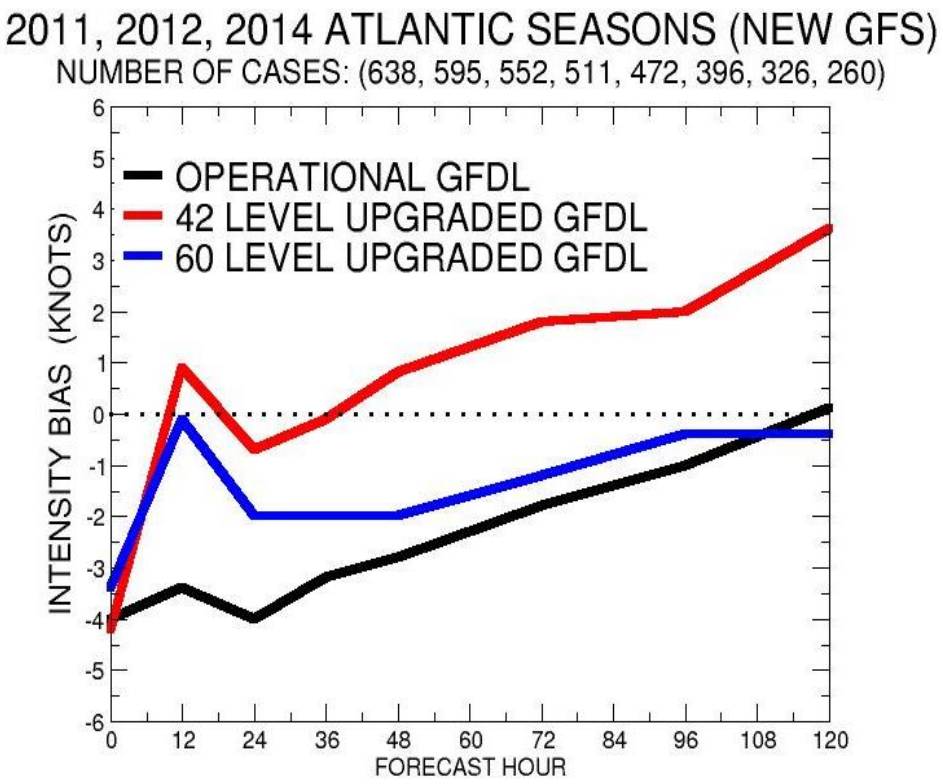


INTENSITY ERROR (KNOTS)

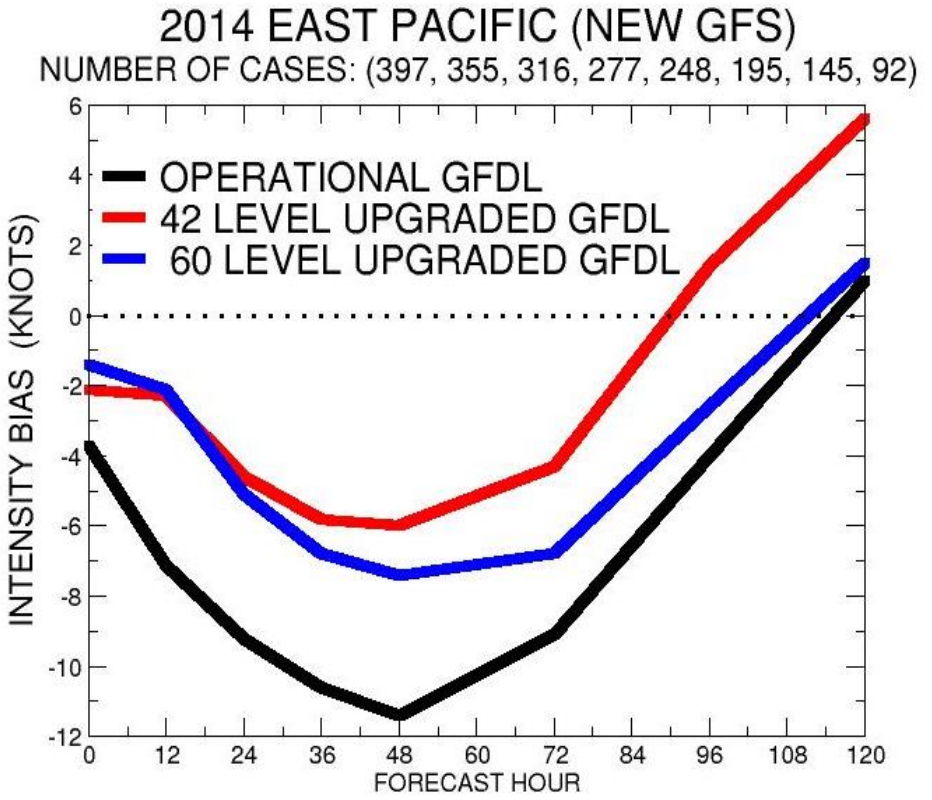


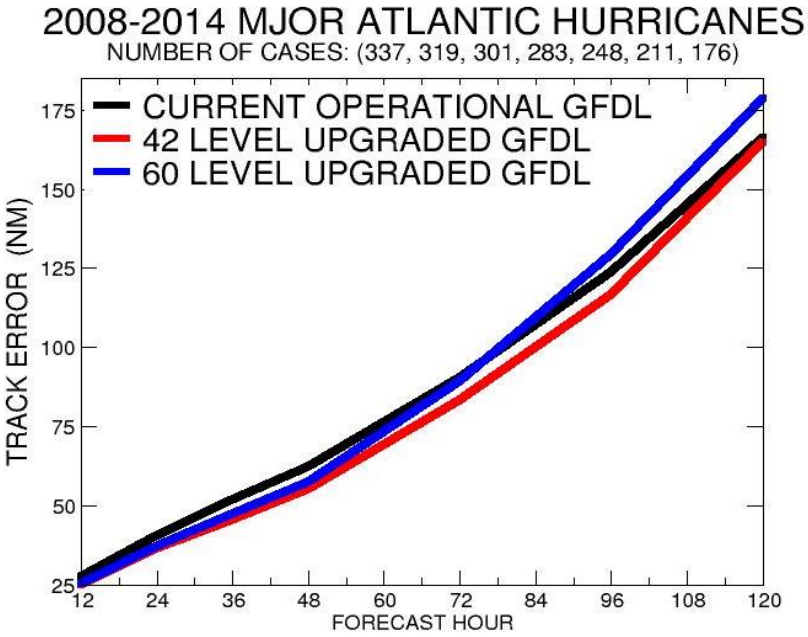
Comparison of Intensity Bias with New GFS

Atlantic Bias (Knots)



Eastern Pacific Bias (Knots)





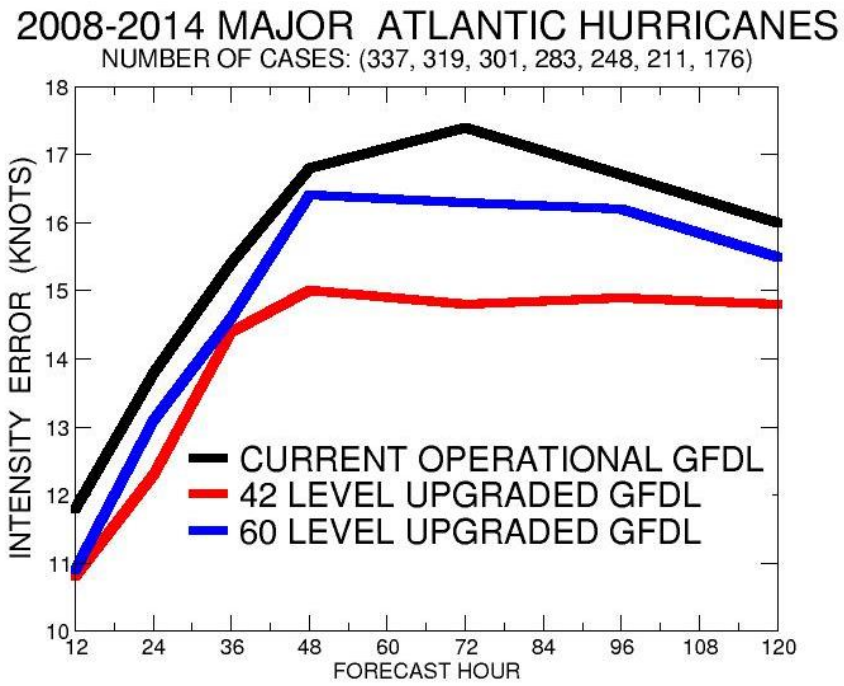
2008 and 2010 Storms Run With Old GFS

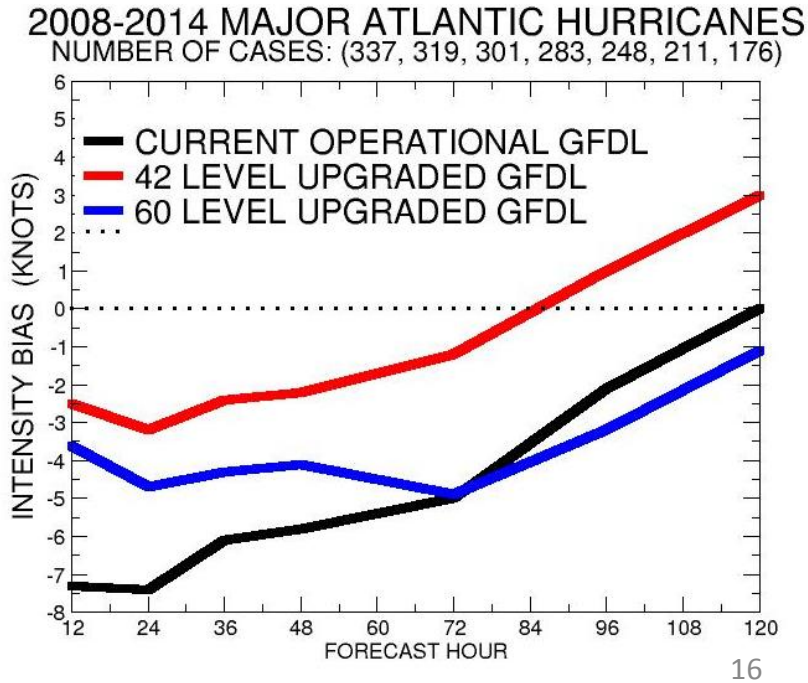
(Ike, Danielle, Earl, Igor, Julia)

2011 and 2014 used new GFS

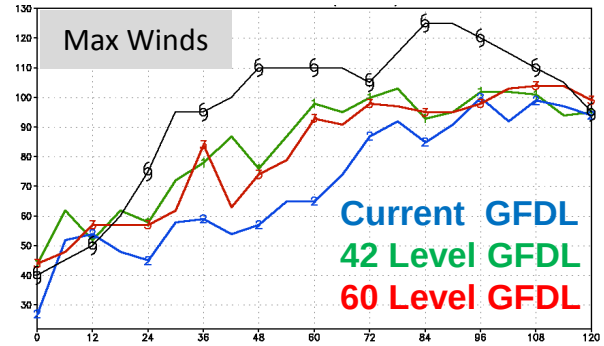
(Irene, Katia, Edouard, Gonzalo)

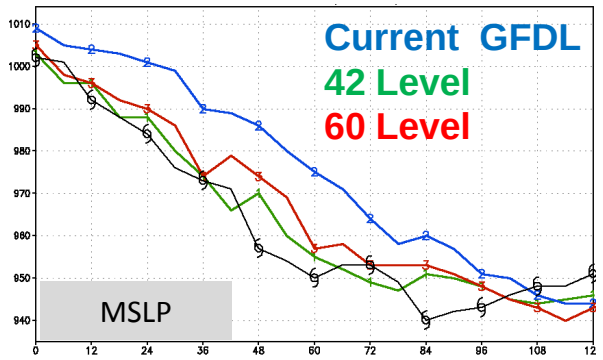
Results Suggest 60 Level Model has Excessive Negative Bias for Intense Hurricanes

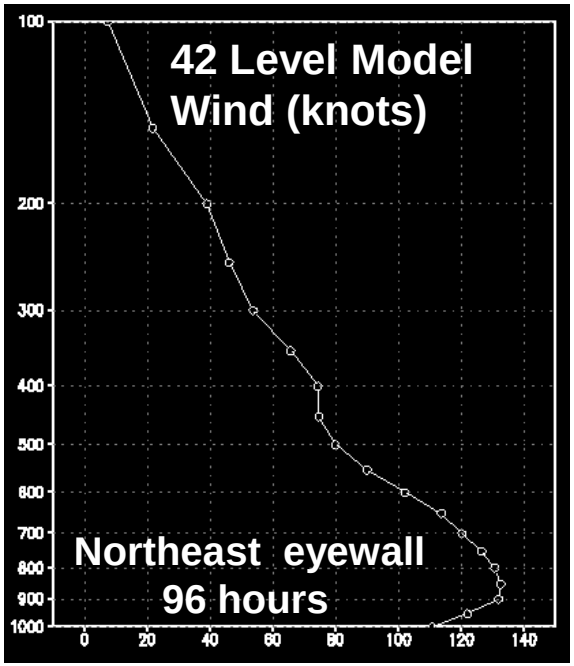


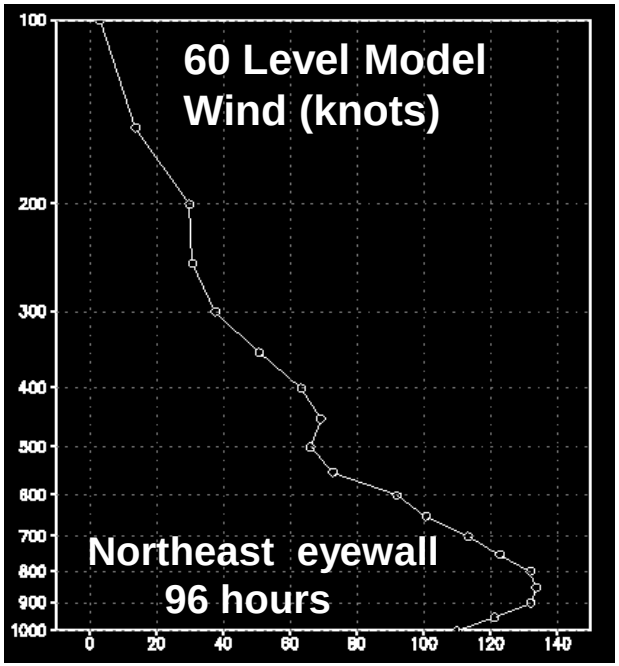


Hurricane Gonzalo (0000 UTC 13 October)



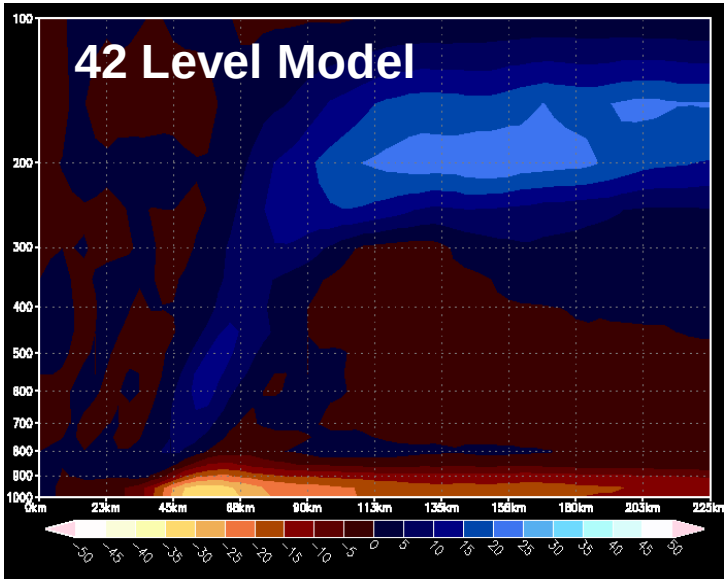


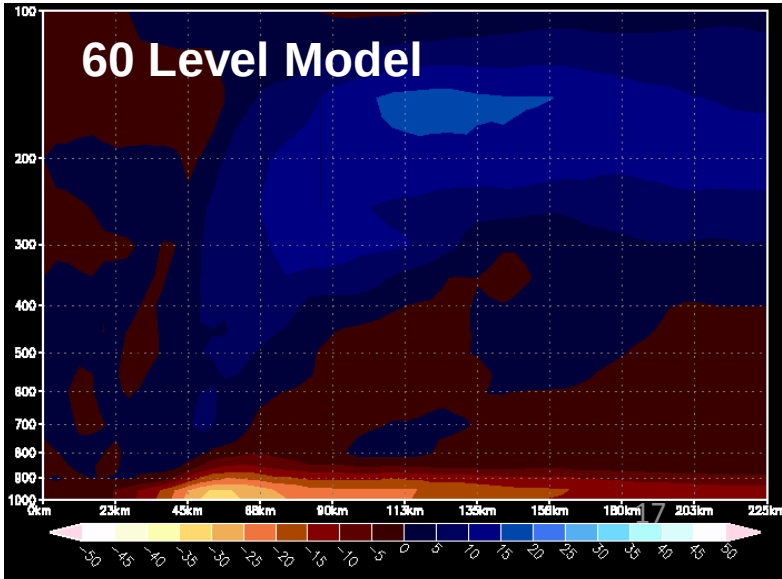




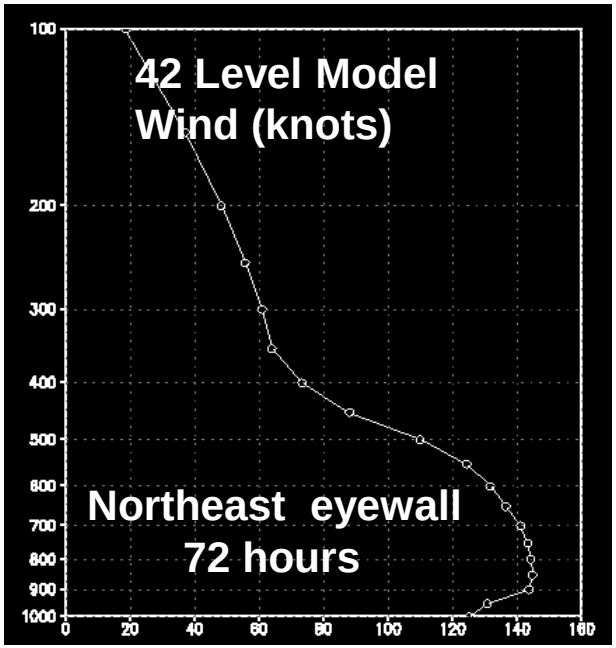
Circular Averaged Radial Wind (96 hours)

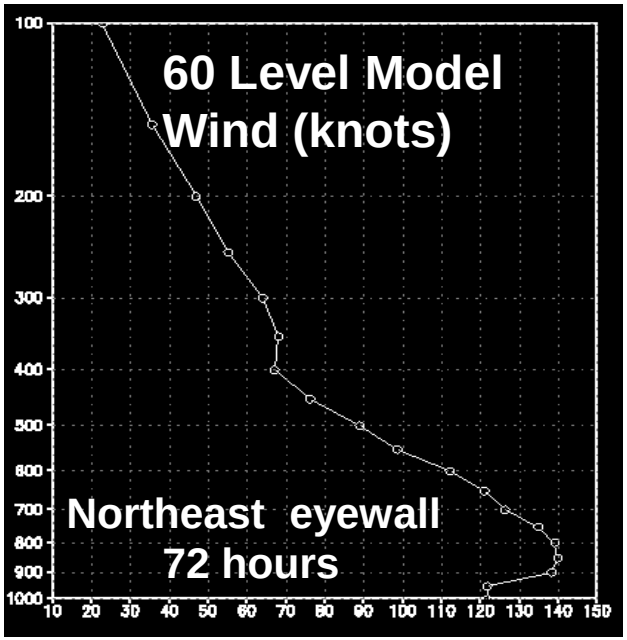
42 level model enhanced secondary circulation

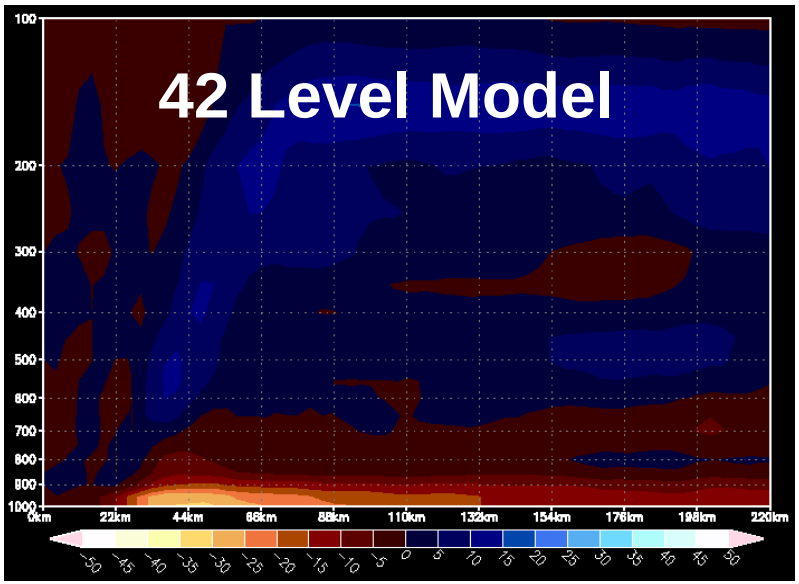


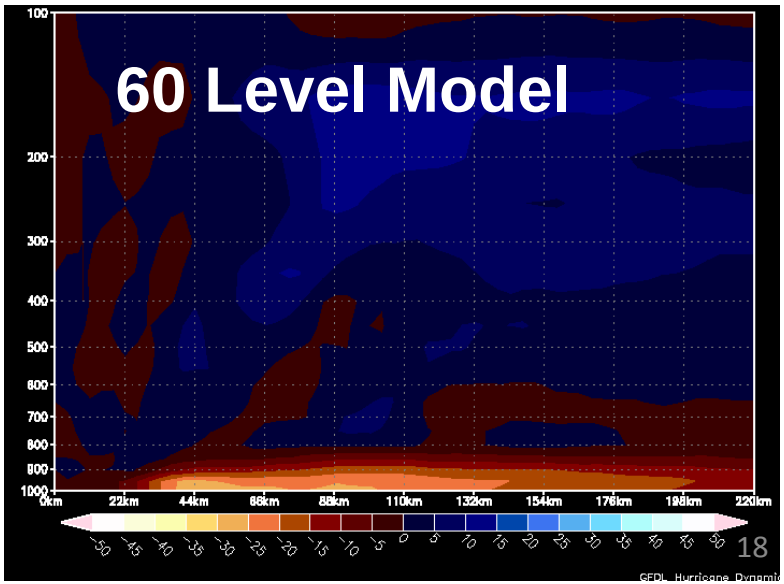


Hurricane Earl (0000 UTC 29 August, 2010)

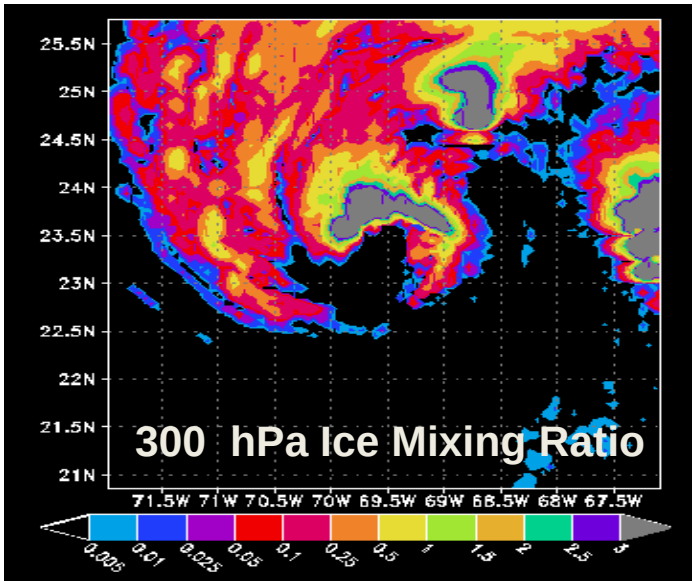






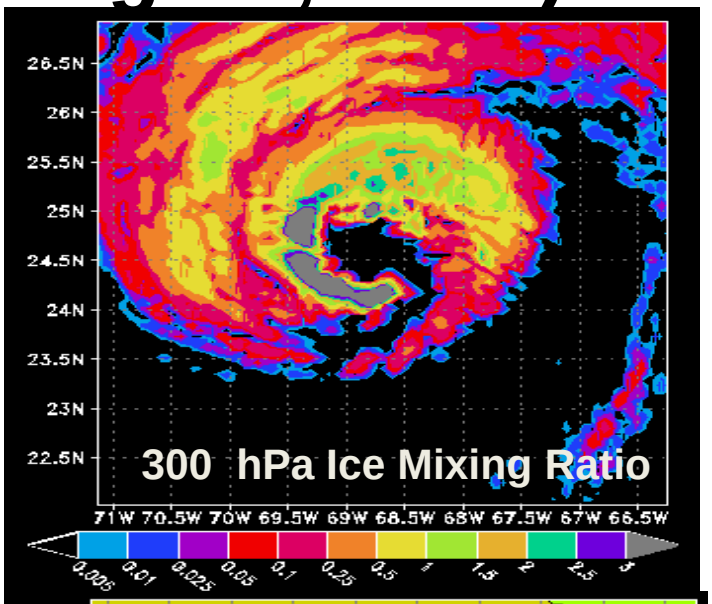


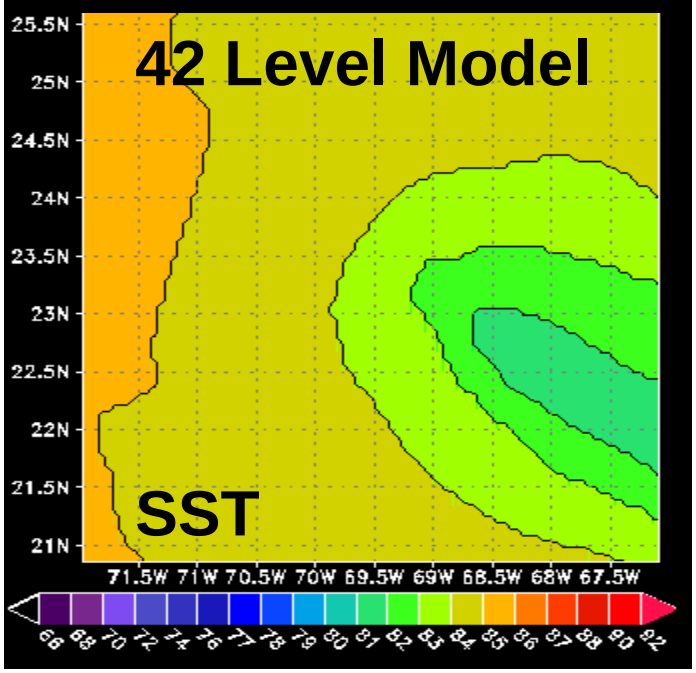
Hurricane Earl (0000 29 August, 2010)



78 Hours

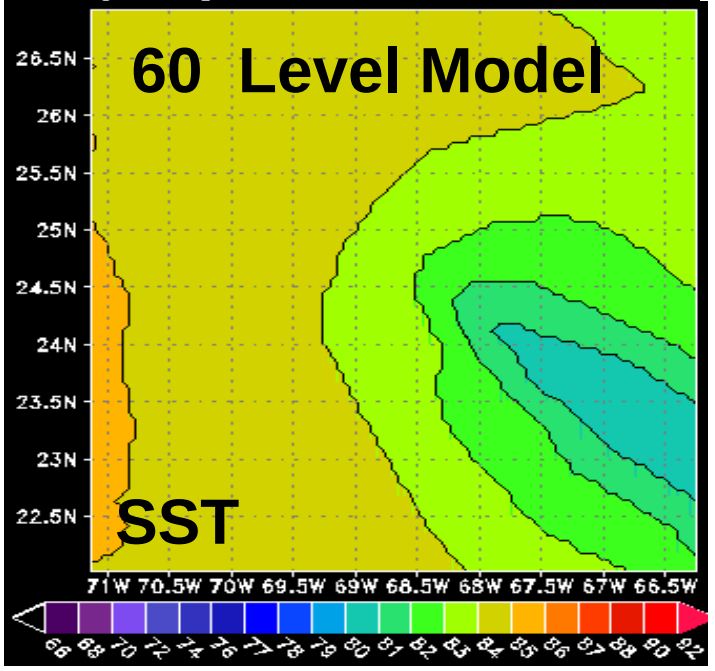
Larger ice concentration in 60 level model at upper levels





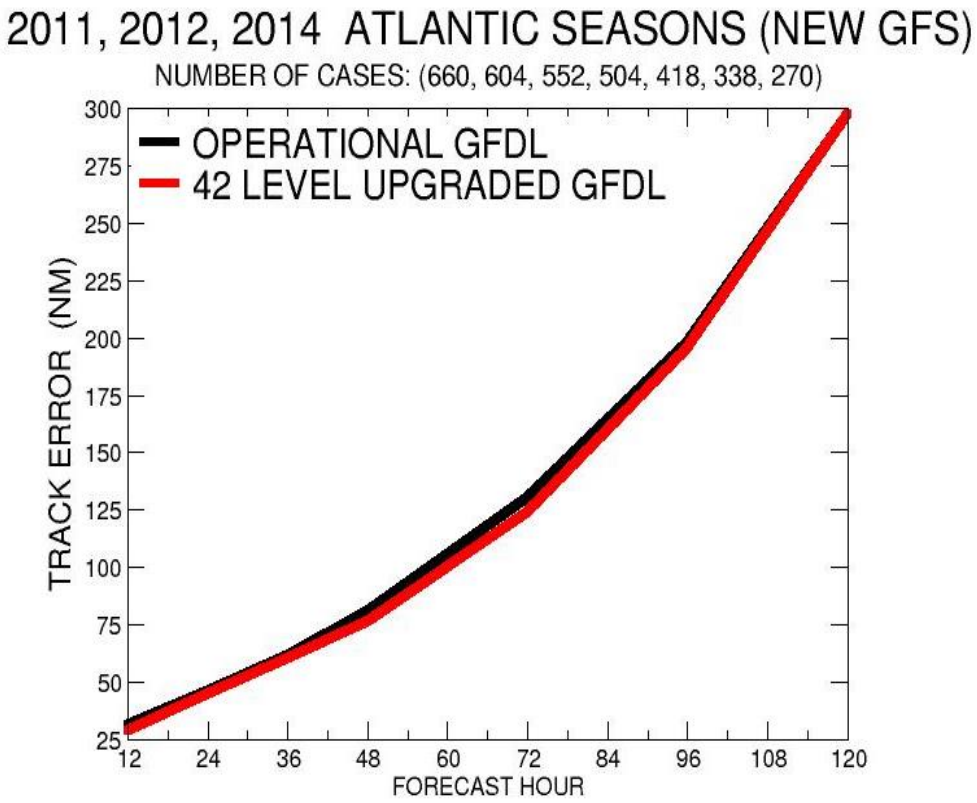
78 Hours

Reduced Solar radiation Lead to more ocean cooling



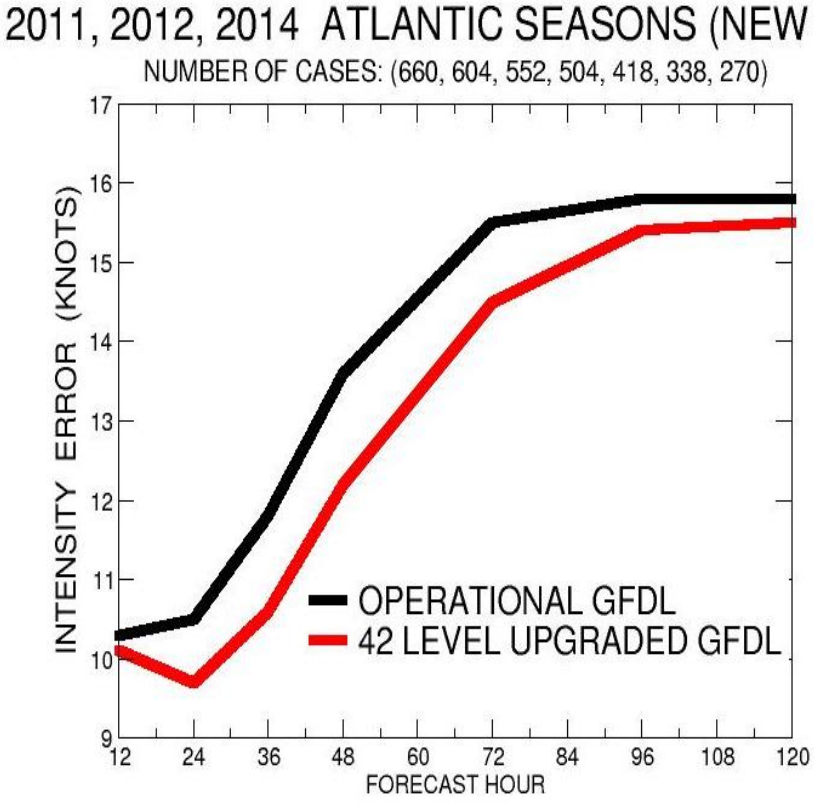
Complete 2011, 2012 and 2014 Atlantic Seasons with New GFS for Late Guidance

TRACK ERROR (NM)



5% Reduced Track Error for 42 level model Days 1-3

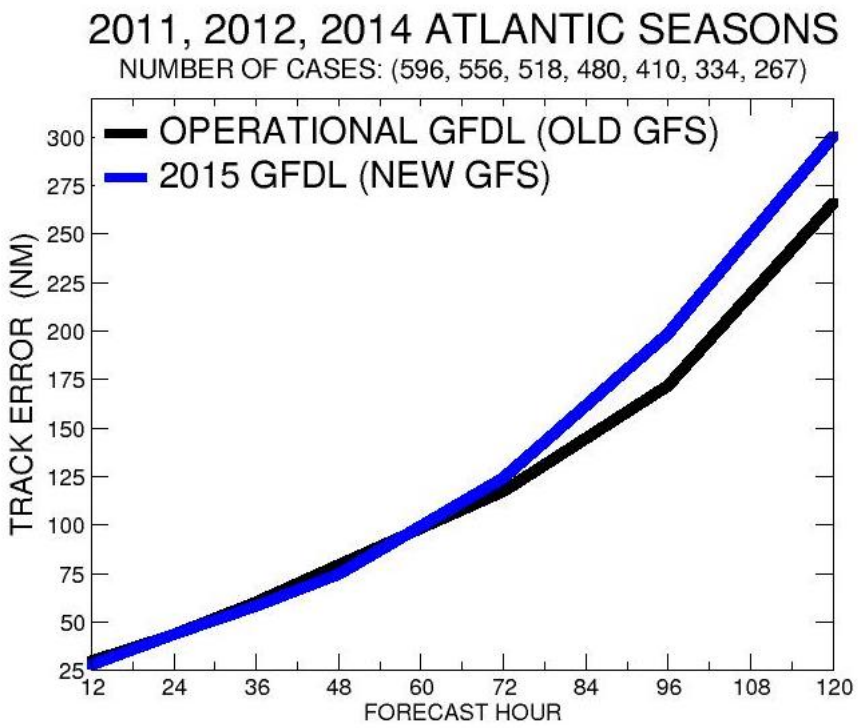
INTENSITY ERROR (KNOTS)



10% Reduced Intensity Error for 42 level model at Days 1-3

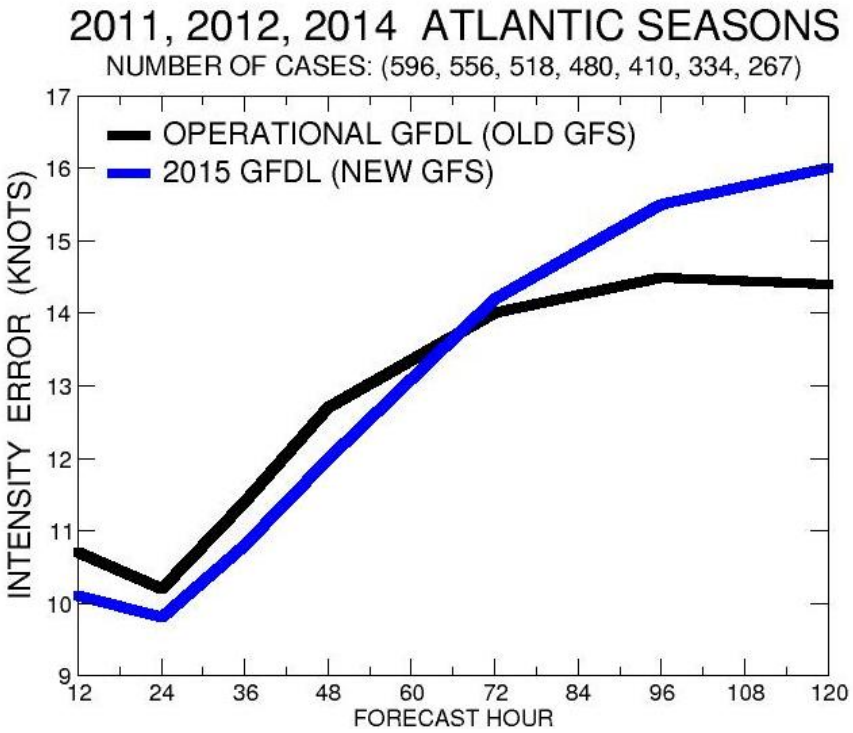
Comparison of Previous Operational System with new GFDL and GFS upgraded System

TRACK ERROR (NM)



Improved Guidance through 48h (4%)
Neutral day 3
Degraded Guidance (11%) Days 4-5

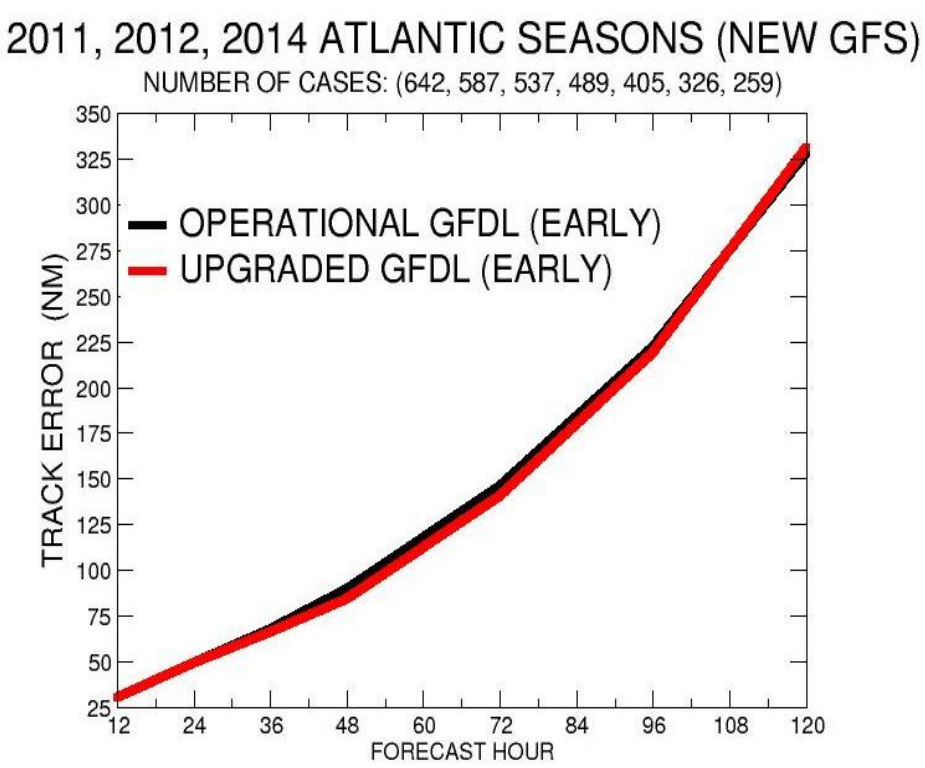
INTENSITY ERROR (KNOTS)



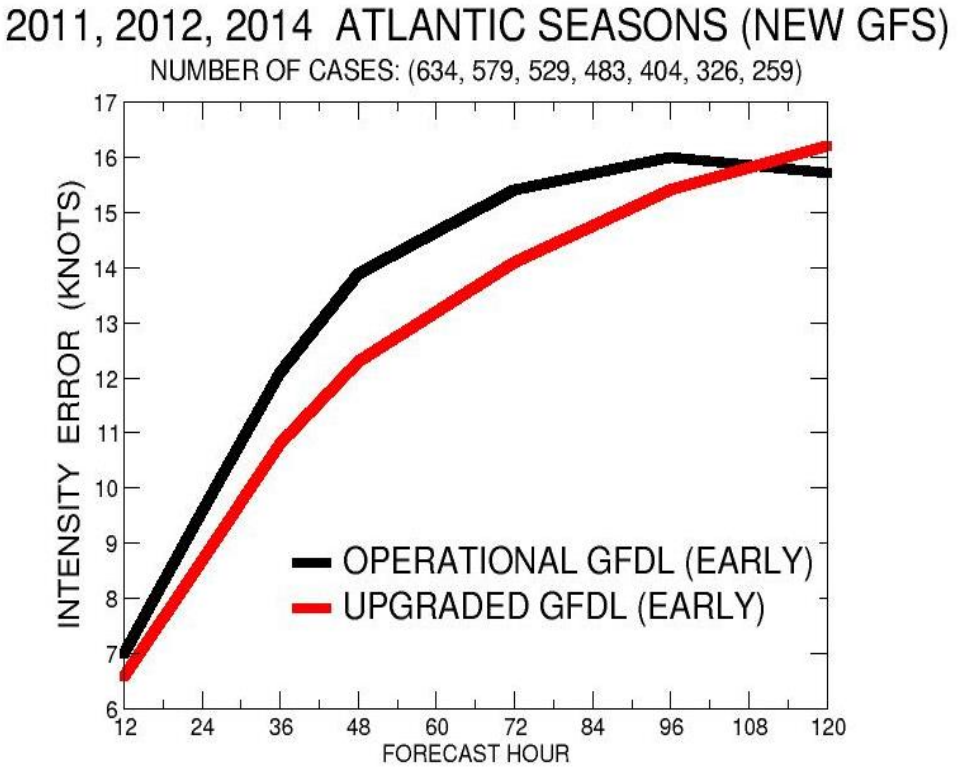
Improved Guidance through 48h (5%)
Neutral day 3
Degraded Guidance (9%) Days 4-5

Complete 2011, 2012 and 2014 Atlantic Seasons (Early Guidance)

TRACK ERROR (NM)



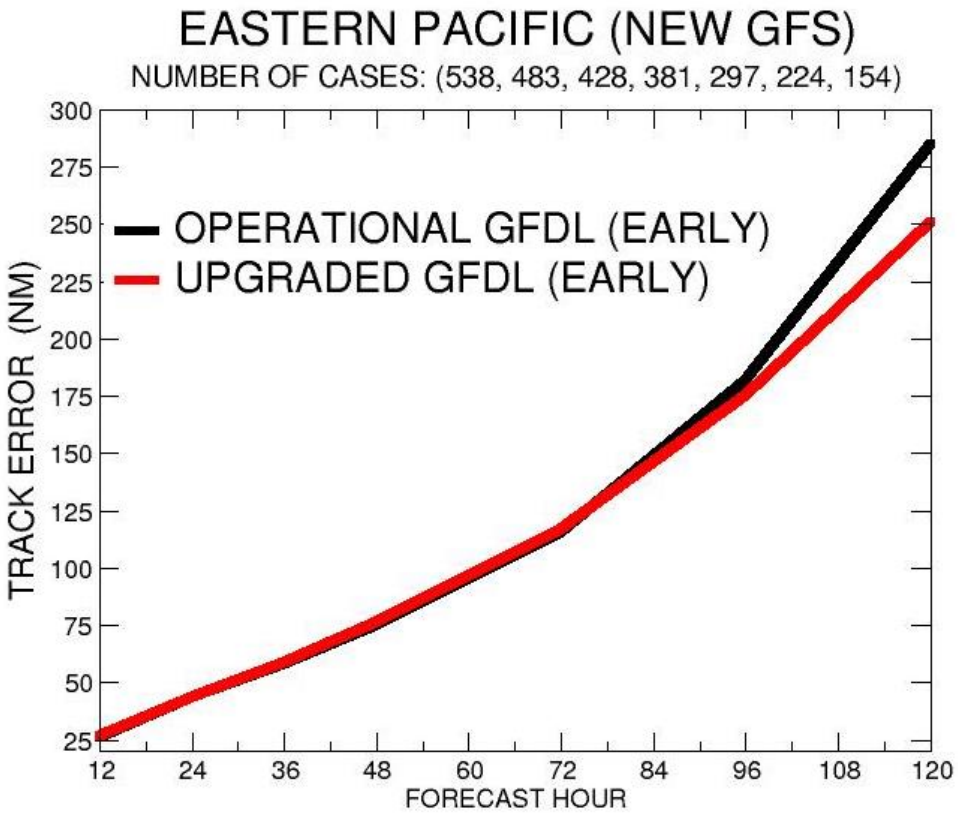
INTENSITY ERROR (KNOTS)



Early Guidance Improvements are similar to Late Guidance
Comparing Upgraded GFDL with Current Model using New GFS

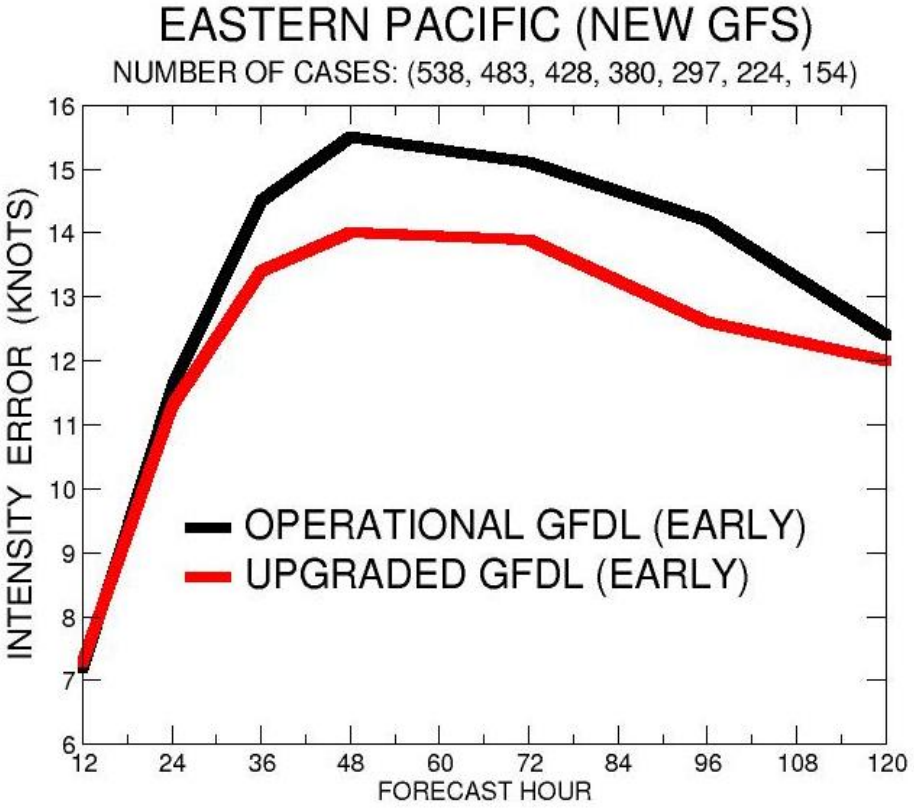
Eastern Pacific with Early Guidance

TRACK ERROR (NM)



10% Reduced Track Error Days 4-5
60% forecasts improved for days 3-5

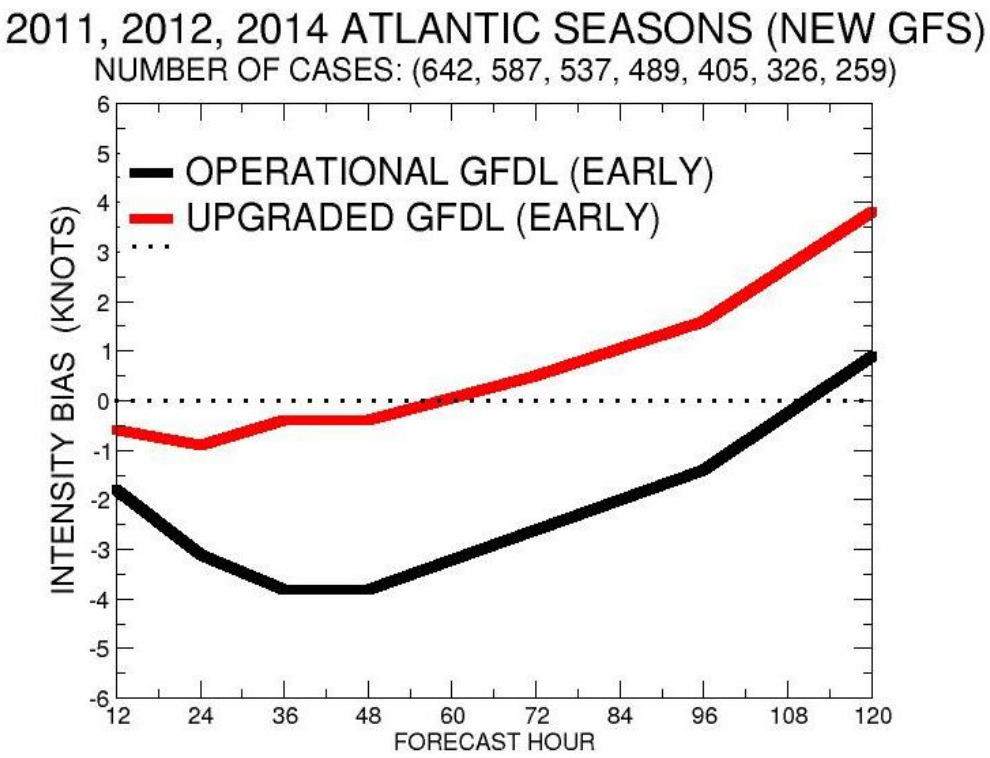
INTENSITY ERROR (KNOTS)



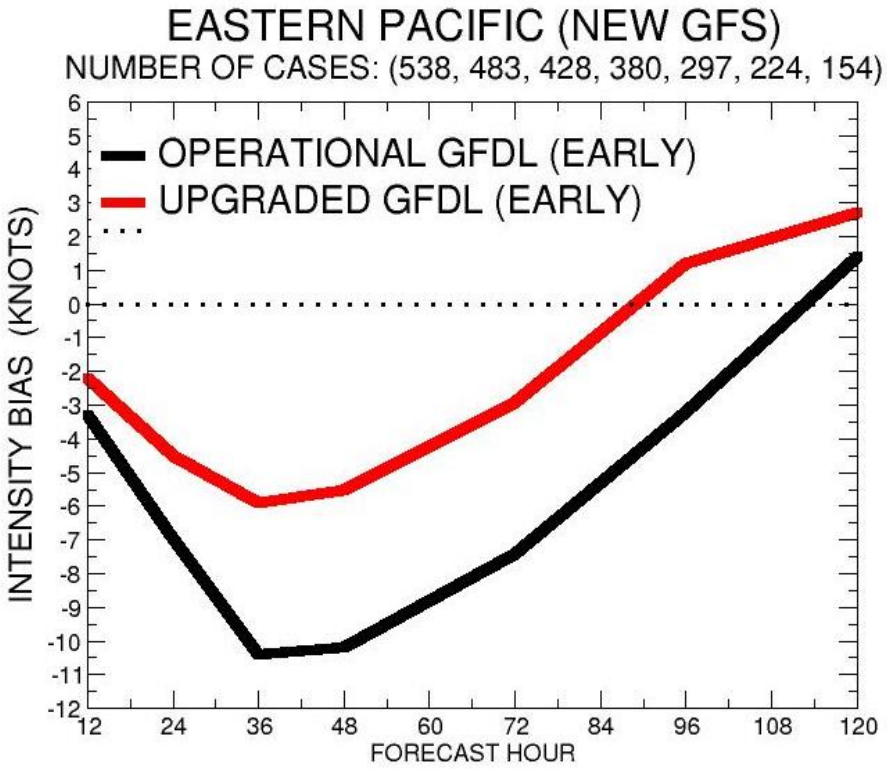
5-10% Reduced Intensity Error Days 1-4

Summary of Intensity Bias with New GFS

Atlantic Bias (Knots)



Eastern Pacific Bias (Knots)

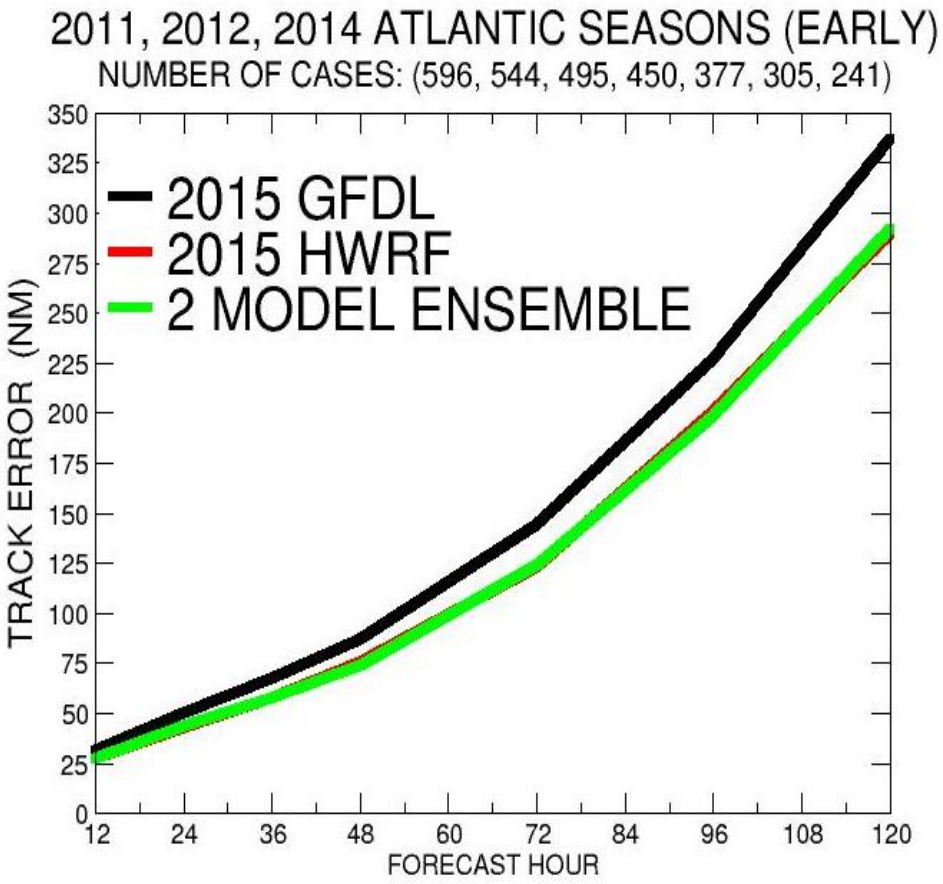


Reduced negative bias in both ocean basins at 1-3 Days Lead Times

Some Positive Bias Later Forecast Times

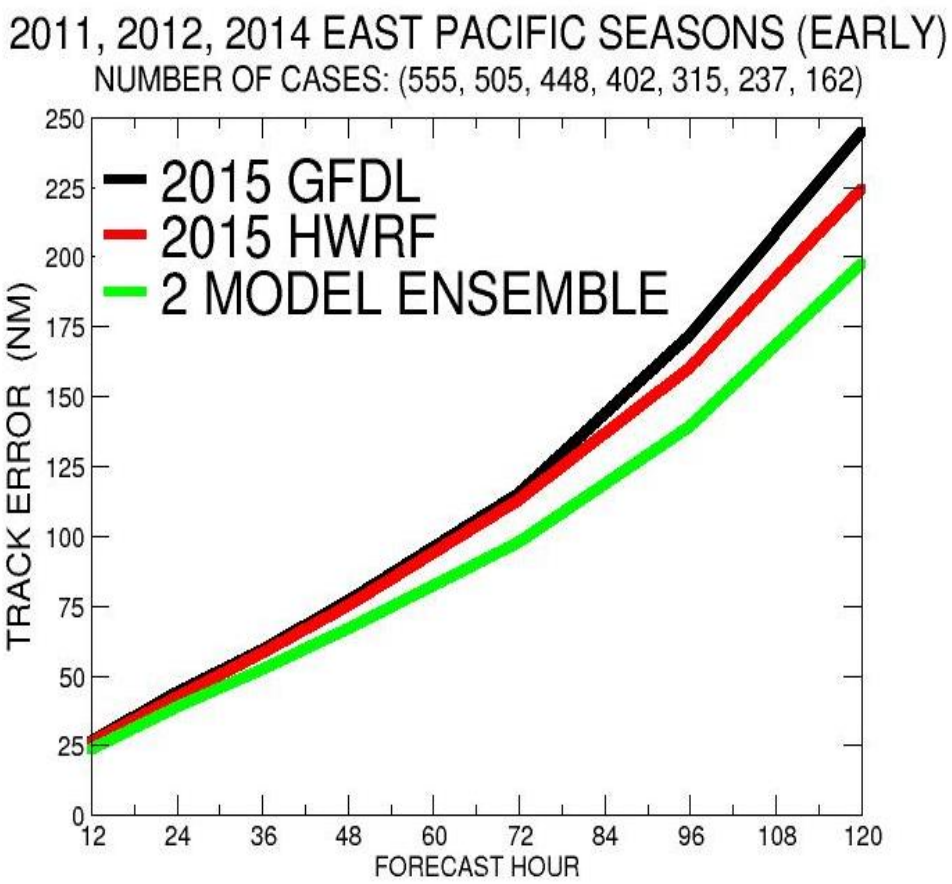
GFDL/HWRF Track Comparison

Atlantic



2-Model Ensemble errors very comparable to HWRF all forecast times

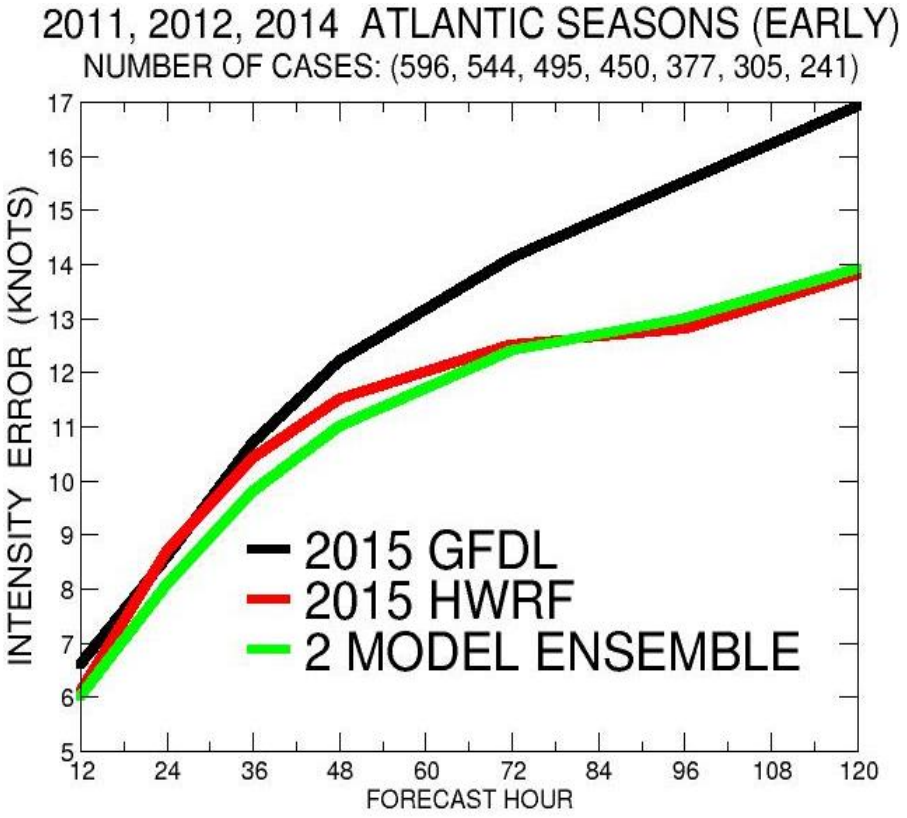
East Pacific



2-Model Ensemble errors average 11% less then HWRF days 1-5

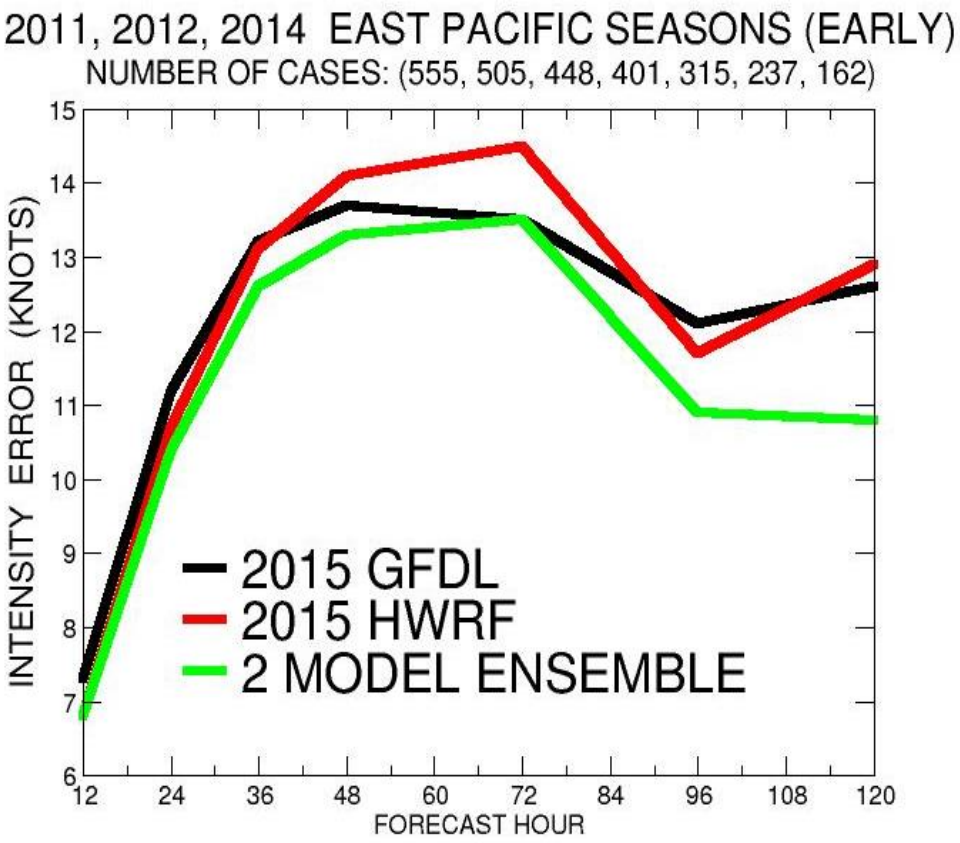
GFDL/HWRF Intensity Comparison

Atlantic



2-Model Ensemble errors 5% less then HWRF days 1-2.
Comparable to HWRF days 3-5

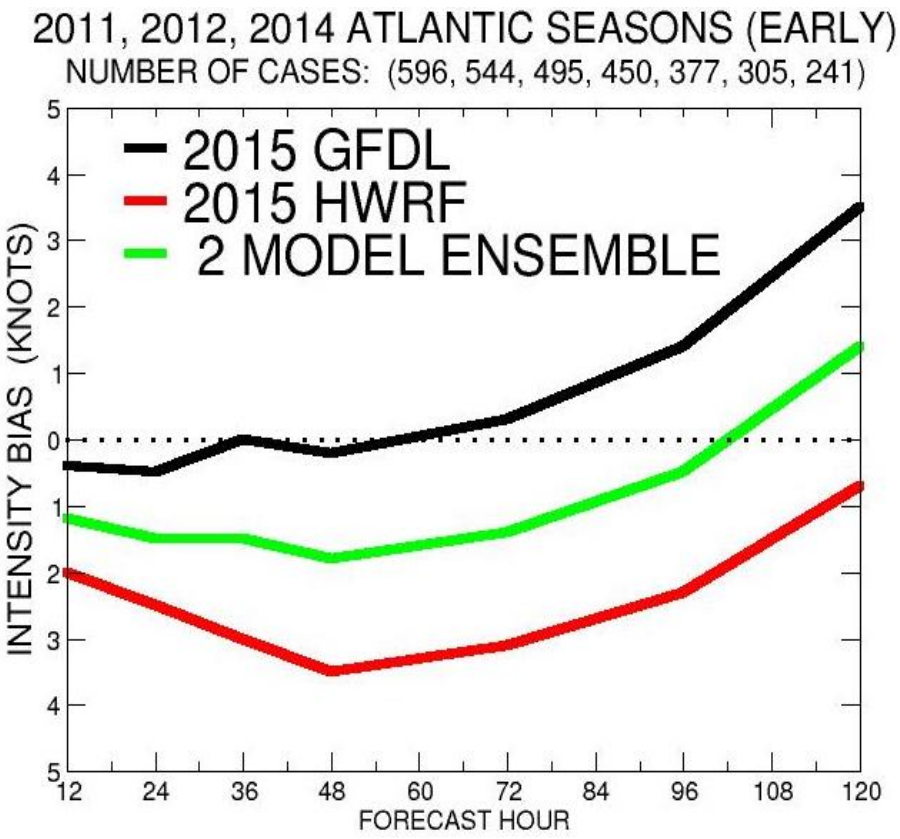
East Pacific



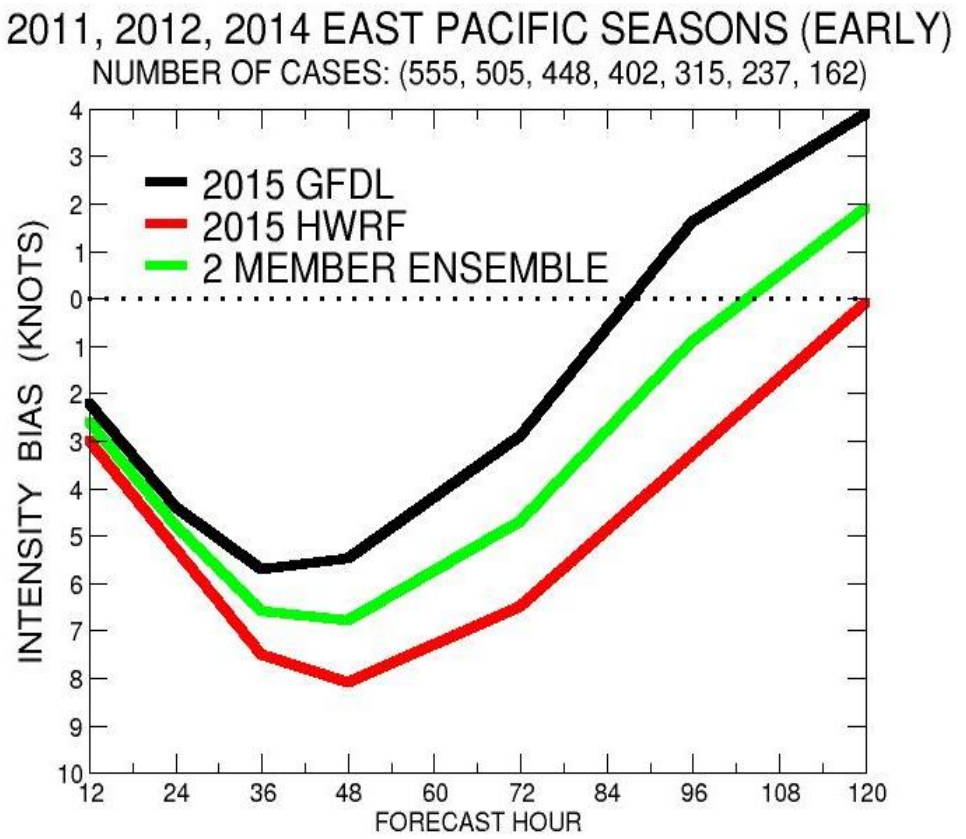
2-Model Ensemble errors average 7% less then either HWRF or GFDL model

GFDL/HWRF Intensity Bias Comparison

Atlantic

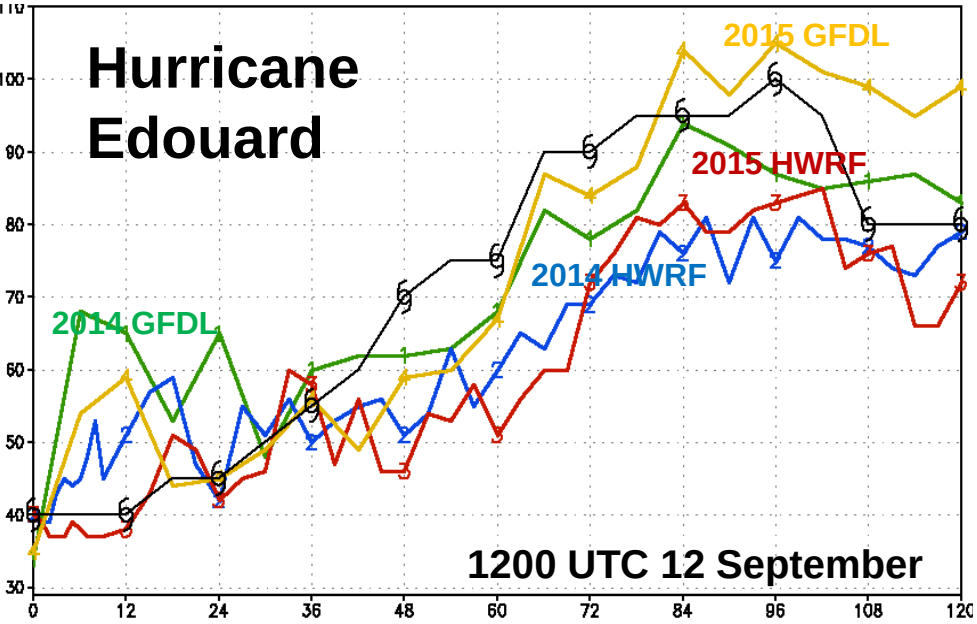


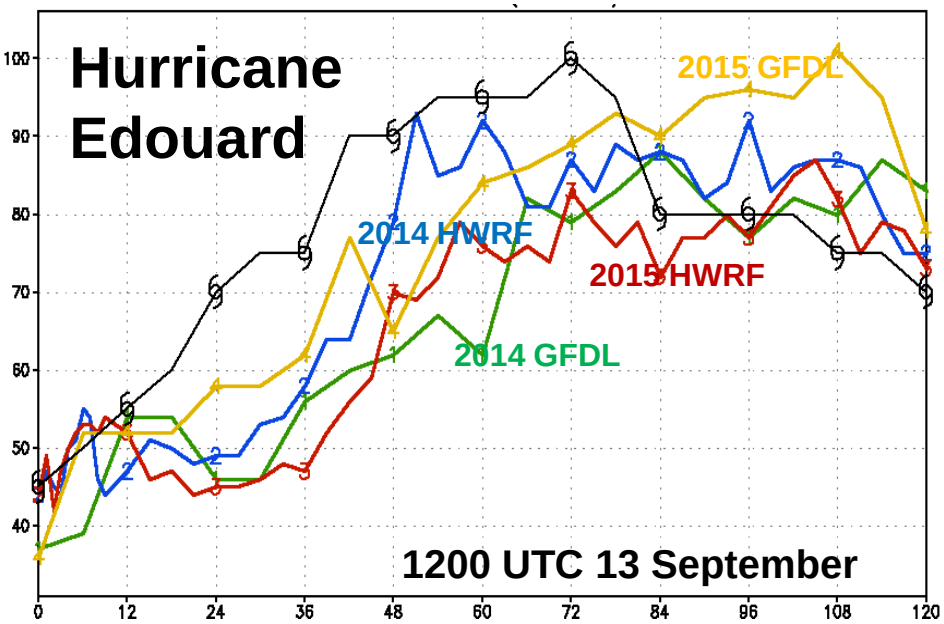
East Pacific

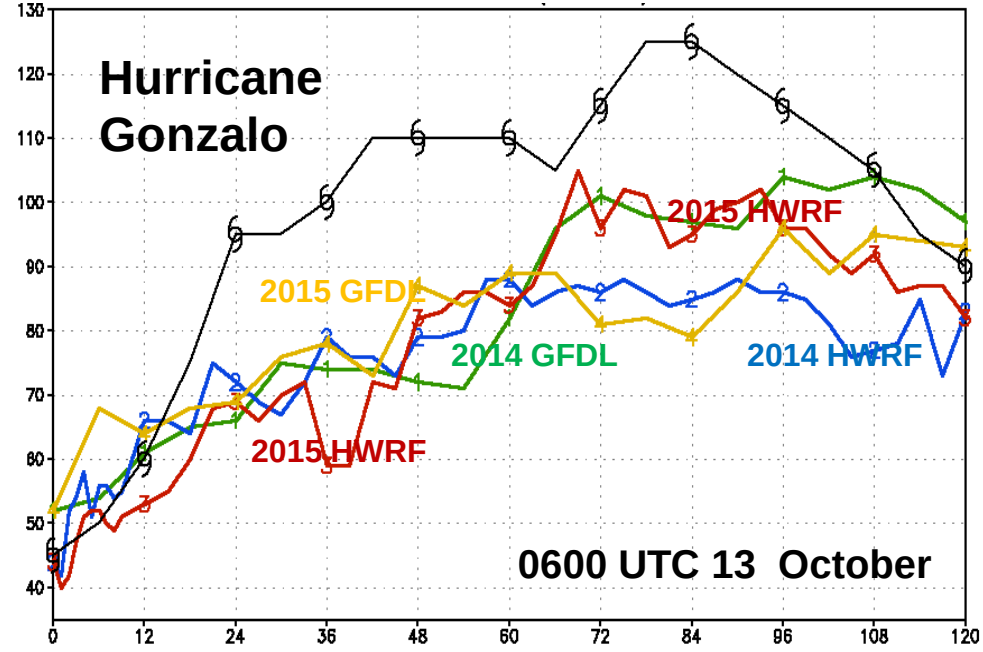


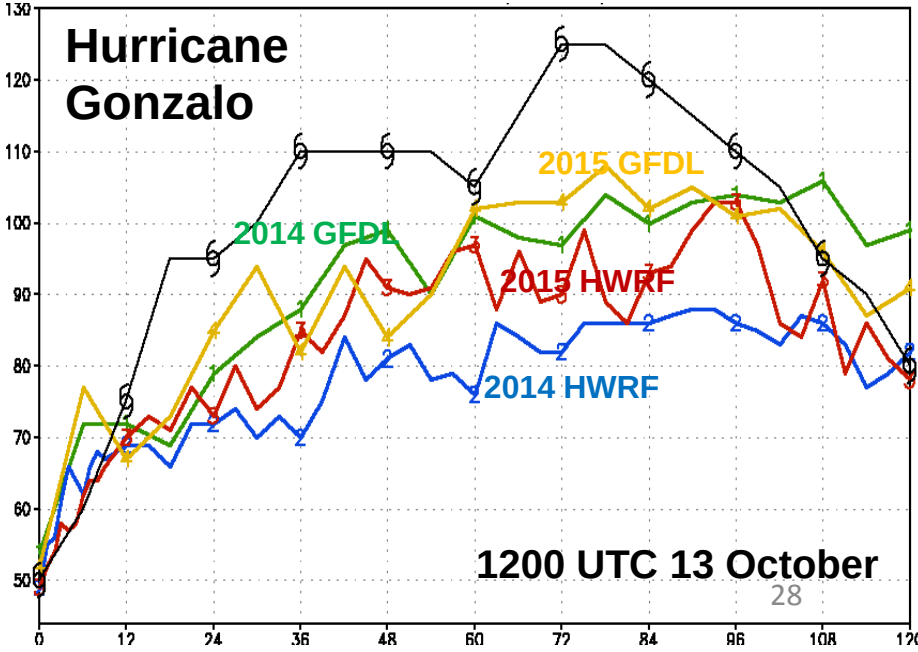
2-Model Ensemble much less overall bias then either GFDL or HWRF

2014 vs 2015 Operational Guidance of Atlantic RI

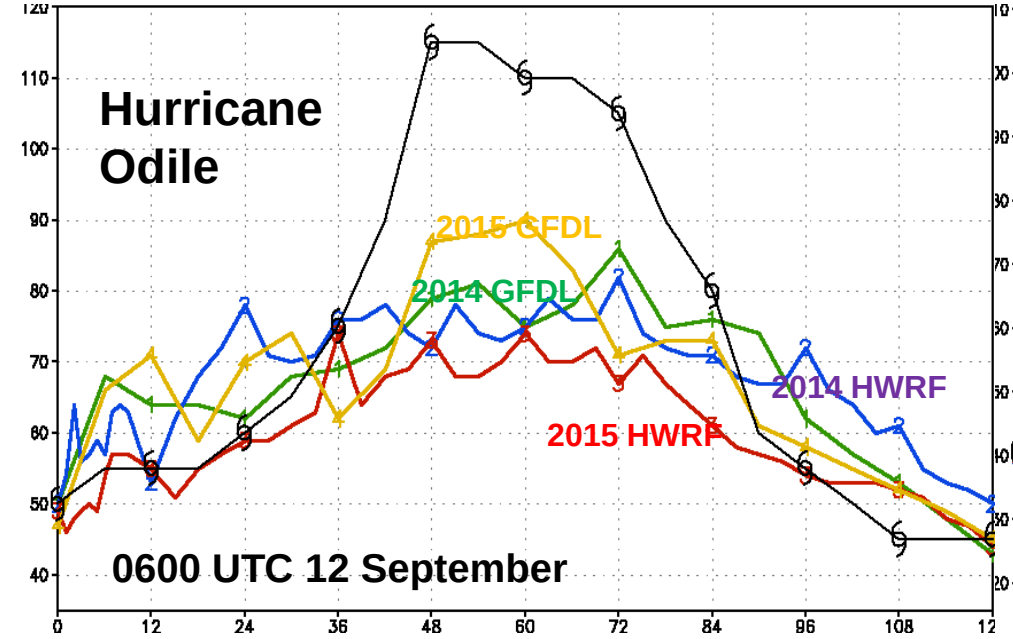


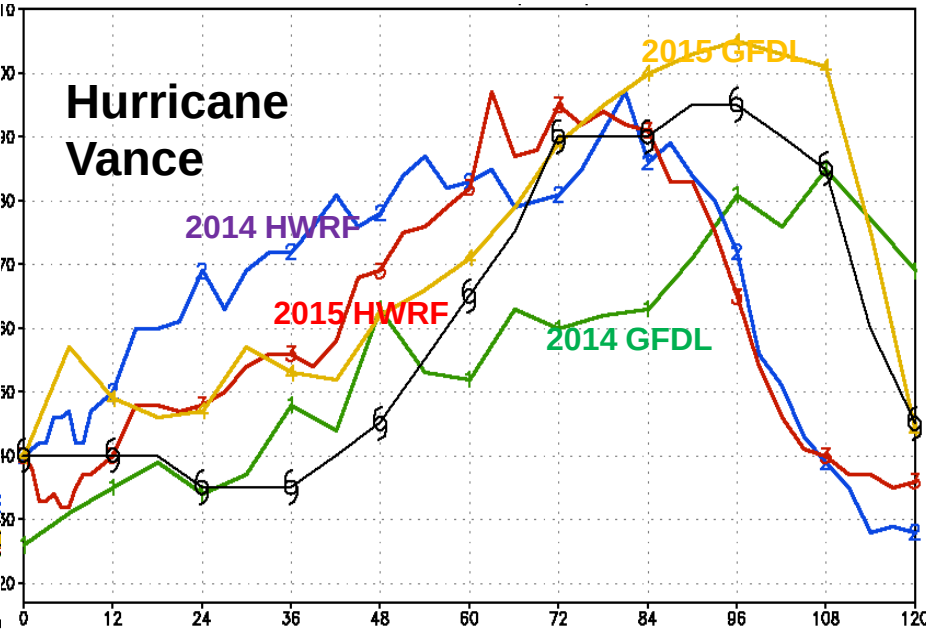


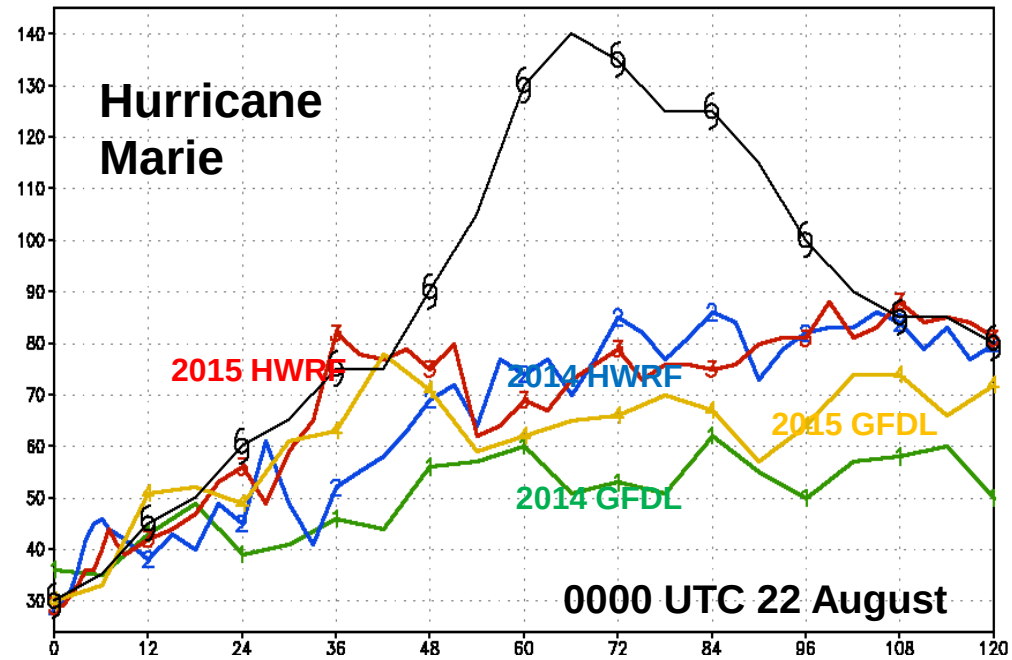


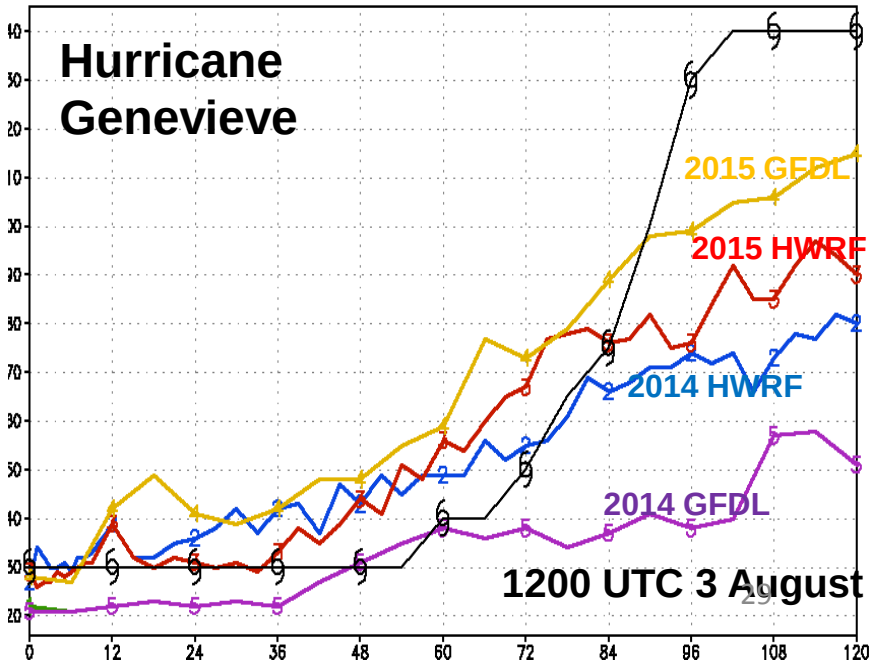


2014 vs 2015 Operational Guidance of EPAC RI









Future Plans

- **Address Negative Bias in 60 level GFDL model for intense hurricanes, by:**
- **1. Evaluating impact of GFS enhanced PBL turbulence mixing in stratocumulus regions**
- **2. Evaluating different distributions of vertical levels (e.g., reduced number in outflow and more in mid-levels)**
- **Study could have benefit of reducing negative bias in 60 level HWRF in RI and intense hurricanes**

Summary of GFDL upgrades

- **GFDL model upgrade demonstrates improved track and intensity guidance with both old and upgraded version of GFS for Atlantic and Eastern Pacific Hurricane Seasons for both the 42 and 60 level models.**
- **Upgraded version with increased vertical resolution (60 vertical levels) performed well in multi-year Atlantic sample dominated with weaker storms.**
- **For Major hurricanes 60 level version had large negative bias and degraded tracks at later times.**
- **42 Level Upgraded Model is being recommended for 2015 implementation while a more optimal distribution of increased vertical levels is being evaluated for future upgrades and potentially as part of 2015 GFDL ensemble system.**

ENDOSEMENT FROM THE NATIONAL HURRICANE CENTER

The National Hurricane Center (NHC) endorses the proposed implementation of the GFDL Hurricane Model for 2015. Retrospective runs of this model for a large number of cases from the 2011, 2012, and 2014 hurricane seasons showed a significant reduction, in comparison to the current operational version of the model, in the intensity forecast error of 10-11 % in the Atlantic basin. Also, there was a considerable reduction of a negative bias of intensity forecasts in both the Atlantic and eastern North Pacific. In this regard the intensity bias was reduced to nearly zero in the critical 1-3 day time range in the Atlantic.
The impact on track forecasts was largely neutral to slightly positive, except at days 4-5 for the east Pacific where the improvements were more substantial - and on the order of 12%.

The NHC looks forward to having these improvements to our numerical guidance for TC prediction for the upcoming hurricane season.

Sincerely,
Dr. Richard J. Pasch
Senior Hurricane Specialist
National Hurricane Center/NOAA