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 \( R_b \)
• 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:

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

\[r_{\text{axi-sym vortex}}\] defined with respect to the Environmental moisture field
(Environent is determined by moisture field outside the filter radius)

Lead to Unrealistic drying in middle troposphere

\[(\text{Limited RL for weak, developing systems})\]

Revised Scheme:

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

\[r = r_{\text{gfs}} + r_{\text{vortex}}\]

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 ($R_b = 1.5 \times \text{RLCI}$)

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:  

$$(x = .4)$$ \quad \quad 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 radii 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

0000 UTC 23 September

1200 UTC 23 September

OLD Storm Size

New Storm Size

NEW Storm Size

Typhoon Pabuk

INITIAL TIME: (000 UTC 22 SEPTEMBER, 2013)
Performance Evaluation of Upgraded Model with Previous GFS
2014 Atlantic Season with 2014 GFS

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

INTENSITY PERFORMANCE MIXED
42 LEVEL IMPROVED EARLY TIME
60 LEVEL IMPROVED LATER TIME
Performance Evaluation With New GFS
New GFS Degrades GFDL degraded both track and intensity skill by 6% at days 1-2
Track (12%) and Intensity (10%) Skill Significantly degraded days 3-5

**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 than 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)

2014 EAST PACIFIC (NEW GFS)  
NUMBER OF CASES: (355, 317, 278, 247, 195, 145, 92)

GRAPH FOR TRACK ERROR (NM):
- Black: OPERATIONAL GFDL
- Red: 42 LEVEL UPGRADED GFDL
- Blue: 60 LEVEL UPGRADED GFDL

GRAPH FOR INTENSITY ERROR (KNOTS):
- Black: OPERATIONAL GFDL
- Red: 42 LEVEL UPGRADED GFDL
- Blue: 60 LEVEL UPGRADED GFDL

FORECAST HOUR vs TRACK ERROR (NM)
FORECAST HOUR vs INTENSITY ERROR (KNOTS)
Comparison of Intensity Bias with New GFS

Atlantic Bias (Knots)

NUMBER OF CASES: (638, 595, 552, 511, 472, 396, 326, 260)

Eastern Pacific Bias (Knots)

2014 EAST PACIFIC (NEW GFS)
NUMBER OF CASES: (397, 355, 316, 277, 248, 195, 145, 92)
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)

42 Level Model
Wind (knots)

Northeast eyewall
72 hours

60 Level Model
Wind (knots)

Northeast eyewall
72 hours

42 Level Model

60 Level Model
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)

INTENSITY ERROR (KNOTS)

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

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)**

NUMBER OF CASES: (596, 556, 518, 480, 410, 334, 267)

- OPERATIONAL GFDL (OLD GFS)
- 2015 GFDL (NEW GFS)

**INTENSITY ERROR (KNOTS)**

NUMBER OF CASES: (596, 556, 518, 480, 410, 334, 267)

- OPERATIONAL GFDL (OLD GFS)
- 2015 GFDL (NEW GFS)

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

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

**EASTERN PACIFIC (NEW GFS)**

NUMBER OF CASES: (538, 483, 428, 381, 297, 224, 154)

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

**INTENSITY ERROR (KNOTS)**

**EASTERN PACIFIC (NEW GFS)**

NUMBER OF CASES: (538, 483, 428, 380, 297, 224, 154)

5-10% Reduced Intensity Error Days 1-4
Summary of Intensity Bias with New GFS

Atlantic Bias (Knots)

NUMBER OF CASES: (642, 587, 537, 489, 405, 326, 259)

Temporal graph showing intensity bias for Atlantic seasons.

Eastern Pacific Bias (Knots)

EASTERN PACIFIC (NEW GFS)
NUMBER OF CASES: (538, 483, 428, 380, 297, 224, 154)

Temporal graph showing intensity bias for Eastern Pacific seasons.

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

Some Positive Bias Later Forecast Times
GFDL/HWRF Track Comparison

Atlantic

NUMBER OF CASES: (596, 544, 495, 450, 377, 305, 241)

- 2015 GFDL
- 2015 HWRF
- 2 Model Ensemble

East Pacific

2011, 2012, 2014 EAST PACIFIC SEASONS (EARLY)
NUMBER OF CASES: (555, 505, 448, 402, 315, 237, 162)

- 2015 GFDL
- 2015 HWRF
- 2 Model Ensemble

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

2-Model Ensemble errors average 11% less than HWRF days 1-5
GFDL/HWRF Intensity Comparison

Atlantic

NUMBER OF CASES: (596, 544, 495, 450, 377, 305, 241)

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

East Pacific

2011, 2012, 2014 EAST PACIFIC SEASONS (EARLY)
NUMBER OF CASES: (555, 505, 448, 401, 315, 237, 162)

2-Model Ensemble errors average 7% less than either HWRF or GFDL model
GFSDL/HWRF Intensity Bias Comparison

Atlantic
NUMBER OF CASES: (596, 544, 495, 450, 377, 305, 241)

- 2015 GFDL
- 2015 HWRF
- 2 MODEL ENSEMBLE

East Pacific
2011, 2012, 2014 EAST PACIFIC SEASONS (EARLY)
NUMBER OF CASES: (555, 505, 448, 402, 315, 237, 162)

- 2015 GFDL
- 2015 HWRF
- 2 MEMBER ENSEMBLE

2-Model Ensemble much less overall bias than either GFDL or HWRF
2014 vs 2015 Operational Guidance of Atlantic RI

Hurricane Edouard

1200 UTC 12 September

2014 HWRF
2015 HWRF
2014 GFDL
2015 GFDL

Hurricane Gonzalo

0600 UTC 13 October

2014 HWRF
2015 HWRF
2014 GFDL
2015 GFDL

2014 HWRF
2015 HWRF
2014 GFDL
2015 GFDL
2014 vs 2015 Operational Guidance of EPAC RI

Hurricane Odile
0600 UTC 12 September

Hurricane Marie
0000 UTC 22 August

Hurricane Vance
1200 UTC 3 August

2014 HWRF
2014 GFDL
2015 HWRF
2015 GFDL
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.
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