Review of GFS Forecast Skills in 2012

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Acknowledgments: All NCEP EMC Global Climate and Weather Modeling Branch members are acknowledged for their contributions to the development and application of the Global Forecast Systems.
Outline

1. Major GFS changes in 2012

2. Forecast skill scores
   – AC and RMSE
   – Hurricane Track and Intensity
   – Precipitation

3. Comparison with Surface and Rawinsonde Obs
Major GFS Changes

- 3/1999
  - AMSU-A and HIRS-3 data

- 2/2000
  - Resolution change: T126L28 → T170L42 (100 km → 70 km)
  - Next changes
    - 7/2000 (hurricane relocation)
    - 8/2000 (data cutoff for 06 and 18 UTC)
    - 10/2000 – package of minor changes
    - 2/2001 – radiance and moisture analysis changes

- 5/2001
  - Major physics upgrade (prognostic cloud water, cumulus momentum transport)
  - Improved QC for AMSU radiances
  - Next changes
    - 6/2001 – vegetation fraction
    - 7/2001 – SST satellite data
    - 8/2000 – sea ice mask, gravity wave drag adjustment, random cloud tops, land surface evaporation, cloud microphysics...
    - 10/2001 – snow depth from model background
    - 1/2002 – Quikscat included
Major GFS Changes (cont’d)

• 11/2002
  – Resolution change: T170L42 $\rightarrow$ T254L64 (70 km $\rightarrow$ 55 km)
  – Recomputed background error
  – Divergence tendency constraint in tropics turned off
  – Next changes
    • 3/2003 – NOAA-17 radiances, NOAA-16 AMSU restored, Quikscat 0.5 degree data
    • 8/2003 – RRTM longwave and trace gases
    • 10/2003 – NOAA-17 AMSU-A turned off
    • 11/2003 – Minor analysis changes
    • 2/2004 – mountain blocking added
    • 5/2004 – NOAA-16 HIRS turned off

• 5/2005
  – Resolution change: T254L64 $\rightarrow$ T382L64 (55 km $\rightarrow$ 38 km)
  – 2-L OSU LSM $\rightarrow$ 4-L NOHA LSM
  – Reduce background vertical diffusion
  – Retune mountain blocking
  – Next changes
    • 6/2005 – Increase vegetation canopy resistance
    • 7/2005 – Correct temperature error near top of model
Major GFS Changes (cont’d)

• 8/2006
  – Revised orography and land-sea mask
  – NRL ozone physics
  – Upgrade snow analysis

• 5/2007
  – SSI (Spectral Statistical Interpolation) → GSI (Gridpoint Statistical Interpolation).
  – Vertical coordinate changed from sigma to hybrid sigma-pressure
  – New observations (COSMIC, full resolution AIRS, METOP HIRS, AMSU-A and MHS)

• 12/2007
  – JMA high resolution winds and SBUV-8 ozone observations added

• 2/2009
  – Flow-dependent weighting of background error variances
  – Variational Quality Control
  – METOP IASI observations added
  – Updated Community Radiative Transfer Model coefficients

• 7/2010
  – Resolution Change: T382L64 → T574L64 (38 km → 23 km)
  – Major radiation package upgrade (RRTM2, aerosol, surface albedo etc)
  – New mass flux shallow convection scheme; revised deep convection and PBL scheme
  – Positive-definite tracer transport scheme to remove negative water vapor
Major GFS Changes (cont’d)

• 05/09/2011
  - **GSI**: Improved OMI QC; Retune SBUV/2 ozone ob errors; Relax AMSU-A Channel 5 QC; New version of CRTM 2.0.2; Inclusion of GPS RO data from SAC-C, C/NOFS and TerraSAR-X satellites; Inclusion of uniform (higher resolution) thinning for satellite radiances; Improved GSI code with optimization and additional options; Recomputed background errors; Inclusion of SBUV and MHS from NOAA-19 and removal of AMSU-A NOAA-15.
  - **GFS**: New Thermal Roughness Length -- Reduced land surface skin temperature cold bias and low level summer warm bias over arid land areas; Reduce background diffusion in the Stratosphere.

• 5/22/2012
  - **GSI Hybrid EnKF-3DVAR**: A hybrid variational ensemble assimilation system is employed. The background error used to project the information in the observations into the analysis is created by a combination of a static background error (as in the prior system) and a new background error produced from a lower resolution (T254) Ensemble Kalman Filter.
  - **Other GSI Changes**: Use GPS RO bending angle rather than refractivity; Include compressibility factors for atmosphere; Retune SBUV ob errors, fix bug at top; Update radiance usage flags; Add NPP ATMS satellite data, GOES-13/15 radiance data, and SEVERI CSBT radiance product; Include satellite monitoring statistics code in operations; Add new satellite wind data and quality control.

• 09/05/2012
  - **GFS**: A look-up table used in the land surface scheme to control Minimum Canopy Resistance and Root Depth Number was updated to reduce excessive evaporation. This update was aimed to mitigate GFS cold and moist biases found in the late afternoon over the central United States when drought conditions existed in summer of 2012.
Sample Results from GSI Hybrid EnKF-3DVAR Implementation

http://www.emc.ncep.noaa.gov/gmb/wd20rt/experiments/prd12q3s/vsdb/
Day at which forecast loses useful skill (500-hPa Height AC=0.6)

3D-Var Operational GFS vs Hybrid-Ensemble GFS Parallels

1. Summer (retrospective parallel prd12q3i): 27 August 2011 ~ 16 October 2011

<table>
<thead>
<tr>
<th></th>
<th>Operational</th>
<th>Parallel</th>
<th>parallel minus Operational</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Hemisphere</td>
<td>7.68</td>
<td>7.79</td>
<td>0.11 (2.6 hrs)</td>
</tr>
<tr>
<td>Southern Hemisphere</td>
<td>7.89</td>
<td>7.94</td>
<td>0.05 (1.2 hrs)</td>
</tr>
</tbody>
</table>

2. Winter and Spring (real-time parallel prd12q3s): 8 January 2012 ~ 21 May 2012

<table>
<thead>
<tr>
<th></th>
<th>Operational</th>
<th>Parallel</th>
<th>parallel minus Operational</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Hemisphere</td>
<td>8.43</td>
<td>8.65</td>
<td>0.22 (5.3 hrs)</td>
</tr>
<tr>
<td>Southern Hemisphere</td>
<td>7.62</td>
<td>7.73</td>
<td>0.11 (2.6 hrs)</td>
</tr>
</tbody>
</table>
Sample Results from 09/05/2012 GFS Soil Table Update

http://www.emc.ncep.noaa.gov/gmb/wx24fy/para/t2mbias/exp2012/
Outline

1. Major GFS changes in 2012

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   - Hurricane Track and Intensity
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3. Comparison with Surface and Rawinsonde Obs
Annual Mean 500-hPa HGT Day-5 Anomaly Correlation

GFS-NH
GFS-SH
CDAS-NH
CDAS-SH
CFSR-NH
CFSR-SH

CDAS is a legacy GFS (T64) used for NCEP/NCAR Reanalysis circa 1995
CFSR is the coupled GFS (T126) used for reanalysis circa 2006
Annual Mean 500-hPa HGT Day-5 Anomaly Correlation
GFS minus CDAS

NH: GFS-CDAS

SH: GFS-CDAS

Best Year,
For both NH and SH

Annual Mean 500-hPa HGT Day-5 Anomaly Correlation
GFS minus CFSR

Best Year,
For both NH and SH
• ECMWF, GFS and CMC were better in 2012 than in 2011. GFS has the largest gain.
• UKM and FNOMC were slightly worse in 2012 than 2011.
2012 was a difficult year to forecast, namely, both CFSR and CDAS scores dropped. Most models, except for GFS and CMC, had lower scores in 2012 than in 2011.
Die-off Curves of Annual Mean NH 500hPa HGT AC

Annual Mean HGT AC: NH 500hPa Wave 1–20

0.6 – useful forecast
For 2012
GFS: 8.0 day
ECMWF: 8.2 day
CDAS: 6.4 day

ECMWF’s useful forecast in 2012 was not as good as in 2010 and 2011. GFS had no change in past three years.
Die-off Curves of Annual Mean SH 500hPa HGT AC

0.6 – useful forecast
For 2012
GFS: 7.6 day
ECMWF: 8.2 day
CDAS: 6.5 day
Day at which forecast loses useful skill (AC=0.6)
N. Hemisphere 500hPa height calendar year means

![Bar chart showing the number of forecast days for 500hPa height at various calendar years (1989-2012) with NCEP/GFS data. The chart indicates a trend where the number of forecast days increases over time.]
Die-off Curves of 2012 Annual Mean Sea-Level Pressure AC

GFS lags behind ECMWF more in the SH than in the NH
Twenty bins were used to count for the frequency distribution, with the 1st bin centered at 0.025 and the last been centered at 0.975. The width of each bin is 0.05.

AC Frequency Distribution

- Jan 2000: T126L28 → T170L42
- May 2001: prognostic cloud
- Oct 2002: T170L42 → T254L64
- May 2005: T254L64 → T382L64; 2-L OSU LSM → 4-L NOHA LSM
- May 2007: SSI → GSI Analysis; Sigma → sigma-p hybrid coordinate
- July 2010: T382L64 → T574L64; Major Physics Upgrade
- May 2012: Hybrid-Ensemble 3D-VAR Data Assimilation
• Jan 2000: T126L28 → T170L42
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AC Frequency Distribution

ECMWF 00Z-Cycle Day-5 Fcst, 500hPa Height, NH

Frequency Distribution of Anomaly Correlation

ECMWF NH
AC Frequency Distribution

ECMWF SH

Frequency Distribution of Anomaly Correlation
• Jan 2000:  T126L28 → T170L42
• May 2001:  prognostic cloud
• Oct 2002:  T170L42 → T254L64
• May 2005:  T254L64 → T382L64; 2-L OSU LSM → 4-L NOHA LSM
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GFS 00Z Cycle Day-5 500hPa Height Anomaly Correlation

AC

0.6 0.65 0.7 0.75 0.8 0.85 0.9


Year

NH  SH

0.8 0.85 0.9
Percent Anomaly Correlations Greater Than 0.9
GFS 00Z Cycle Day-5 500hPa Height

- Jan 2000: T126L28 → T170L42
- May 2001: prognostic cloud
- Oct 2002: T170L42 → T254L64
- May 2005: T254L64 → T382L64; 2-L OSU LSM → 4-L NOHA LSM
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- May 2012: Hybrid-Ensemble 3D-VAR Data Assimilation
2012 is the first year for which GFS has no “BAD” forecast in the Northern Hemisphere

Percent Anomaly Correlations Smaller Than 0.7
GFS 00Z Cycle Day-5 500hPa Height

- Jan 2000: T126L28 → T170L42
- May 2001: prognostic cloud
- Oct 2002: T170L42 → T254L64
- May 2005: T254L64 → T382L64; 2-L OSU LSM → 4-L NOHA LSM
- May 2007: SSI → GSI Analysis; Sigma → sigma-p hybrid coordinate
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ECMWF 00Z Cycle Day-5 500hPa Height Anomaly Correlation

Year

AC


NH  SH
Percent Anomaly Correlations Greater Than 0.9
ECMWF 00Z Cycle Day-5 500hPa Height

Year

NH
SH
2012 Annual Mean Tropical [20S-20N] Wind RMSE
Tropical Wind RMSE, 200-hPa Day-3 Forecast

Tropic Vector Wind RMSE: 200hPa Day3. 3–Mon Mean

GFS matched UKM after Hybrid EnKF Implementation
Outline

1. Major GFS changes in 2012

2. Forecast skill scores
   – AC and RMSE
   – Hurricane Track and Intensity
   – Precipitation

3. Comparison with Surface and Rawinsonde Obs
2012 Atlantic Hurricanes

First storm formed: May 19, 2012
Last storm dissipated: October 29, 2012
Strongest storm: Sandy – 940 mbar (hPa) (27.77 inHg), 110 mph (175 km/h)
Total depressions: 19
Total storms: 19
Hurricanes: 10
Major hurricanes (Cat. 3+): 1
Total fatalities: 316 direct, 12 indirect
Total damage: At least $68.48 billion (2012 USD)

http://www.wikipedia.org
2012 Eastern Pacific Hurricanes

First storm formed  
May 14, 2012

Last storm dissipated  
November 3, 2012

Strongest storm  
Emilia – 945 mbar (hPa) (27.92 inHg), 140 mph (220 km/h)

Total depressions  
17

Total storms  
17

Hurricanes  
10

Major hurricanes (Cat. 3+)  
5

Total fatalities  
8 total

Total damage  
$123.2 million (2012 USD)

www.nhc.noaa.gov/
2012 Atlantic Hurricane Track and Intensity Errors

Hurricane Track Errors – Atlantic 2012
20120501_20121110_2cyc

Hurricane Intensity Errors – Atlantic 2012
20120501_20121110_2cyc

AVNO = GFS    EMX = ECMWF

00Z and 12Z cycles
2012 Eastern Pacific Hurricane Track and Intensity Errors

Hurricane Track Errors – East–Pacific 2012
20120501_20121110_2cyc

Hurricane Intensity Errors – East–Pacific 2012
20120501_20121110_2cyc

AVNO = GFS   EMX = ECMWF

00Z and 12Z cycles
Sandy Track Forecasts
Global Deterministic NWP Models

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Formed</td>
<td>October 22, 2012</td>
</tr>
<tr>
<td>Dissipated</td>
<td>October 31, 2012 (extratropical after October 29)</td>
</tr>
<tr>
<td>Highest winds</td>
<td>1-minute sustained: 110 mph (175 km/h)</td>
</tr>
<tr>
<td>Lowest pressure</td>
<td>940 mbar (hPa); 27.76 inHg</td>
</tr>
<tr>
<td>Fatalities</td>
<td>253 total</td>
</tr>
<tr>
<td>Damage</td>
<td>At least $65.6 billion (2012 USD) (Second-costliest hurricane in US history)</td>
</tr>
</tbody>
</table>

www.wikipedia.org

Hurricane Track Errors – Atlantic 2012
Sandy_20121022_20121030_2cyc

AVNO  -  EMX  -  UKM  -  NGX  -  CMC  -  OFCL

Average Track Error (nm)

#CASES (13) (12) (11) (10) (9) (7) (4) (2)
Tuesday, 20121023, 00Z and 12Z Cycles of Forecasts

6 days before landfall
Wednesday, 20121024, 00Z and 12Z Cycles of Forecasts

Forecasts: Beginning 2012102400

Observed: Beginning 2012102012, every 6 hours

5 days before landfall

2012 Tropical Cyclone Tracks
Storm: AL1812 (SANDY)
Thursday, 20121025, 00Z and 12Z Cycles of Forecasts

2012 Tropical Cyclone Tracks
Storm: AL1812 (SANDY)

Forecasts: Beginning 2012102500
Observed: Beginning 2012102012, every 6 hours

4 days before landfall
Saturday, 20121027, 00Z and 12Z Cycles of Forecasts

2 days before landfall
Sunday, 20121028, 00Z and 12Z Cycles of Forecasts

2012 Tropical Cyclone Tracks
Storm: AL1812 (SANDY)

Forecasts: Beginning 2012102800
Observed: Beginning 2012102012, every 6 hours

one day before landfall
Monday, 20121029, 00Z and 12Z Cycles of Forecasts

2012 Tropical Cyclone Tracks
Storm: AL1812 (SANDY)

Forecasts: Beginning 2012102900
Observed: Beginning 2012102012, every 6 hours

2012 Tropical Cyclone Tracks
Storm: AL1812 (SANDY)

Forecasts: Beginning 2012102912
Observed: Beginning 2012102012, every 6 hours
Tuesday, 20121030, 00Z Cycle of Forecast

2012 Tropical Cyclone Tracks
Storm: AL1812 (SANDY)

Forecasts: Beginning 2012103000
Observed: Beginning 2012102012, every 6 hours

NCEI
GFS and ECMWF Rainfall Forecasts for Sandy, 5 days before landfall

24-Hr Accumulated Precip (inch) Valid: 2012102912 − 2012103012
96hr to 120hr Forecast from Cycle 2012102512
GFS and ECMWF Rainfall Forecasts for Sandy, 3 days before landfall
Hurricane Track and Intensity Forecast Errors
NCEP GFS : 2001 ~ 2012
GFS Hurricane Track Errors -- Atlantic

Track Error (nm)

Fcst Hour
- 0
- 12
- 24
- 36
- 48
- 72
- 96
- 120

1. Major GFS changes in 2012

2. Forecast skill scores
   - AC and RMSE
   - Hurricane Track and Intensity
   - Precipitation

3. Comparison with Surface and Rawinsonde Obs
- ECMWF has the best ETS, but it tends to underestimate heavy rainfall events.
- GFS’s ETS score is only better than NAM; however, GFS has better BIAS score than most of the other models.
In the past three years (2010~2012), GFS annual mean ETS was improved; BIAS was reduced, especially for medium rainfall events.
In the past two years (2011~2012), GFS summer QPF scores were degraded for light rainfall events (lower ETS and larger BIAS).

This degradation was caused by excessive evaportranspiration in warm season. A soil table (Minimum Canopy Resistance and Root Depth Number) was changed in May-2011 Implementation.

This table has been reversed back to its older version since 09/05/2012. See slide 9 for the improvement of light rainfall QPF scores.
Outline

1. Major GFS changes in 2012

2. Forecast skill scores
   – AC and RMSE
   – Hurricane Track and Intensity
   – Precipitation

3. Comparison with Surface and Rawinsonde Obs
For 2012, ECMWF had almost perfect forecast of surface temperature in the afternoon, but was slightly too warm in the morning.

GFS had good T2m forecast in the morning, but was too cold in the afternoon in the warm season.
US T2m Verified against Surface Station Observations

- **Northwest**: GFS and ECMWF were similar in the west.
- **Northeast**: GFS is too cold in the east.
- **Southwest**: GFS and ECMWF were similar in the west.
- **Southeast**: GFS is too cold in the east.
Temperature Bias, Verified against Rawinsonde Observations, 2012 Annual Mean

Compared to RAOBS

1. GFS was too warm in the upper troposphere and too cold at the tropopause and lower stratosphere.

2. ECMF was too cold in the stratosphere.

3. ECMWF was better than the GFS in the troposphere but worse in the stratosphere.
1. It seems GFS cold bias near the tropopause was reduced after the May-2012 Hybrid EnKF implementation.

2. No seasonal variation in the upper troposphere.

3. ECMWF cold bias in the stratosphere was the worst in the first few months.
## Configuration of Major Global High-Res NWP Models (2012)

<table>
<thead>
<tr>
<th>System</th>
<th>Analysis</th>
<th>Forecast Model</th>
<th>Forecast Length and Cycles</th>
<th>upcoming</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NCEP GFS</strong></td>
<td>Hybrid 3DVAR (T382) + EnkF (T254)</td>
<td>Semi-implicit Spectral T574L64 (23km, 0.03 hPa)</td>
<td>4 cycles 16 days</td>
<td>semi-lag T1148</td>
</tr>
<tr>
<td><strong>ECMWF IFS</strong></td>
<td>4DVAR T1279L91 (T255 inner loops)</td>
<td>Semi-Lag Spectral T1279L91 (16km, 0.01 hPa)</td>
<td>2 cycles 10 days</td>
<td>T7999 (2.5km) convection permitting?</td>
</tr>
<tr>
<td><strong>UKMO Unified Model</strong></td>
<td>Hybrid 4DVAR with MOGREPS Ensemble</td>
<td>Gridded, 70L (25km; 0.01 hPa)</td>
<td>4 cycles 6 days</td>
<td></td>
</tr>
<tr>
<td><strong>CMC GEM</strong></td>
<td>3DVAR</td>
<td>Semi-lag Gridded (0.3x0.45 deg; 0.1 hPa)</td>
<td>2 cycles 10 days</td>
<td>Non-hydrostatic; 4DVAR</td>
</tr>
<tr>
<td><strong>JMA GSM</strong></td>
<td>4DVAR</td>
<td>Semi-lag spectral T959 L60 (0.1875 deg; 0.1 hPa)</td>
<td>4 cycles 9 days (12Z)</td>
<td></td>
</tr>
<tr>
<td><strong>NAVY NOGAPS</strong></td>
<td>NAVDAS-AR 4DVAR</td>
<td>Semi-implicit Spectral T319L42 (42km; 0.04hPa)</td>
<td>2 cycles 7.5 days</td>
<td>NAVGEM T359L50 semi-lag</td>
</tr>
</tbody>
</table>
Summary  -- Progress Made

- **Hybrid 3DVAR-EnKF implementation** improved GFS useful forecast (AC >0.6) by up to 5 hours.

- **Soil Table Update** reduced GFS warm season surface temperature cold bias and surface moisture wet bias over the central to western US.

- 2012 is a difficult year to forecast. CDAS and CFSR forecast scores (measured by 500hPa HGT AC) dropped in both hemispheres. Still, GFS performed better in 2012 than in 2011, having the largest gain among all major global NWP models.

- GFS useful forecast (measured by 500hPa HGT AC) reached to 8 days in the NH and 7.6 days in the SH. However, GFS still falls behind ECMWF by 0.2 days in the NH and 0.6 days in the SH.

- **GFS had no bad forecast (AC <0.7) in the NH in 2012.** This is unprecedented. GFS good forecasts (AC>0.9) reached 37% in the NH and 13% in the SH. However, ECMWF had 61% good forecast in the NH and 52% in the SH.

- GFS hurricane track forecast for the Atlantic in 2012 was the best among all major global NWP models, despite that ECMWF had better long-lead track forecast for Sandy than did the GFS.

- In the past ten years, GFS hurricane track and intensity forecast had been greatly improved in both the Atlantic and Pacific basins.

- GFS CONUS summer precipitation scores, especially for light rains, was degraded since the May 2011 model upgrade. A parameter table used in the soil model was found to be responsible for the degradation.
Summary -- A few things to consider

• The gap between GFS and ECMWF in the Southern Hemisphere is much larger than that in the Northern Hemisphere. How to reduce the gap?

• There are large surface temperature cold biases in summer in the US Northeast. Land model issue or could-radiation issue?

• Even though the GFS CONUS precipitation skill scores has been improved after the soil table update, it still falls behind ECMWF, UKM and CMC.

• Compared to RAOBS, GFS has large warm bias in the upper troposphere and large cold bias in the lower stratosphere. Does this imply the GFS tropopause is too low? Is it a dynamics problem, or physics problem related to deep convection, high cloud and radiation?