Global Weather & Climate Modeling

Mark Iredell and friends
NCEP Production Suite Review
December 12, 2007
GlobMoB review outline

• Recent Major Implementations
  – GFS (2007-05-01-12)
  – NCEP Post (2007-09-25-12)
  – NAEFS (2007-12-04-12)
  – CFS & GODAS (2008-01-??-??)

• Future Plans
  – GFS 2008
  – Collaboration Projects
  – NEMS
Recent Major Implementations
GFS Upgrade Implementation
May 1, 2007
Goals of this GFS implementation

- Unify the NCEP 3DVAR assimilation system under the GSI, improving some performance metrics without affecting others
- Change vertical coordinate to hybrid sigma-pressure, reducing some upper air model errors
- Add new observing systems
- Modernize the radiation package
- Increase output particularly for hydrology
GFS Implementation changes

- Observation changes
  - Full resolution AIRS
  - COSMIC GPSRO
- Analysis changes
  - GSI (Gridpoint Statistical Interpolation)
- Forcing changes
  - None
- Physics changes
  - Modularized radiation package
- Dynamics changes
  - Hybrid sigma-pressure vertical coordinate
- Infrastructure changes
  - None
- Resolution changes
  - None
- Post processing and product changes
  - Output hourly GDAS files
  - Change to internal model history file
  - More fields output in model flux file
Observation changes

• Full resolution AIRS
  – Every field of view form of AIRS data now used to locate least cloudy profile rather than using just center spot AIRS data
  – Data available starting September 2006

• COSMIC GPSRO
  – First implementation of global positioning system radio occultation technology
  – Data available starting November 2006
Analysis changes

• GSI (Gridpoint Statistical Interpolation)
  – Unifies NCEP’s 3DVAR with the operational mesoscale models, allowing more concentrated development
  – Enables future enhancements such as using non-isotropic background errors
  – Reduces analysis errors in the tropics where the global spectral background error assumptions were inappropriate
Physics changes

• Modularized radiation package
  – Overall restructuring of radiation related programs to help future development and upgrade.
  – In RRTM1-LW, minor upgrade of emissivity coefficient. Rare gas absorption effect turned on.
  – In aerosol calculation, vertical sigma based structure changed to pressure based structure
  – Minor bug correction in cloud related calculation
  – Performance of new radiation very close to operational model
Dynamics changes

- Hybrid sigma-pressure vertical coordinate
  - Model surface remain terrain-following in the lower troposphere but become pure pressure surfaces in the stratosphere
  - Reduces vertical advection errors and pressure-gradient calculation errors in the upper part of the model
  - Data assimilation and physics done on hybrid sigma-pressure coordinate as well
Vertical coordinate comparison across North America
Post processing and product changes

• Output hourly GDAS files
  – Supports hydrology and other needs
  – May be useful in data assimilation

• Change to internal model history file
  – Hybrid sigma-pressure vertical coordinate
  – Affects downstream codes

• More fields output in model flux file
  – Supports hydrology needs
  – No effect on downstream codes
Testing set

• Retrospective testing
  – 15 June 2005 to 5 November 2005
  – 31 July 2006 to 5 November 2006
  – 24 October 2006 to 5 February 2007
    http://wwwt.emc.ncep.noaa.gov/gmb/para/paralog.200607winter_retro_gsihybrid.html

• Real-time parallel
  – NCO started January 2007; in fairly final form about March 1, 2007 to present
    http://wwwt.emc.ncep.noaa.gov/gmb/para/paralog.gsихybrid.html
Overview of objective scores: Summer 2005 and 2006

500 hPa heights neutral in both Northern Hemisphere and Southern Hemisphere

rms vector wind error in pry at 200 and 850 hPa in tropics reduced

GSI hybrid precipitation over continental US less positive bias, more skill

compared to radiosondes, GSI hybrid temperatures warmer, temperature forecasts improved in lower troposphere in Southern Hemisphere and tropics, improved in upper troposphere tropics

forecast heights fit radiosondes significantly better

bias of 200 hPa winds over East Asia substantially reduced in GSI hybrid

GSI hybrid analysed moisture closer to radiosondes
### 500 hpa height anomaly correlations
*July 1-Nov. 5, 2005*

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<tr>
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<tr>
<td>NH day 5</td>
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<td>SH day 5</td>
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<td>.794</td>
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### Tropical rms vector wind error

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<tr>
<td>200 day 1</td>
<td>4.56</td>
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<td>Day 3</td>
<td>8.01</td>
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<td>850 day 1</td>
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<tr>
<td>Day 3</td>
<td>3.77</td>
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### 500 hpa height anomaly correlations

**Aug. 15-Nov. 6, 2006**

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<td>NH day 5</td>
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<tr>
<td>SH day 5</td>
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### Tropical rms vector wind error

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<td>4.47</td>
<td>4.36</td>
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<tr>
<td>Day 3</td>
<td>7.74</td>
<td>7.48</td>
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<tr>
<td>850 day 1</td>
<td>2.38</td>
<td>1.91</td>
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<tr>
<td>Day 3</td>
<td>3.71</td>
<td>3.30</td>
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</table>
2005-2006 Atlantic Season Average Track Error
Using The Current Operational and New GFS

GFDL

GFDL COMPARISON WITH CURRENT AND NEW HYBRID GFS
NUMBER OF CASES: (236, 236, 227, 215, 184, 112)

% SKILL RELATIVE TO CLIPER

FORECAST HOUR

LEAST SKILL

MOST SKILL

2006 GFDL WITH CURRENT GFS
2006 GFDL WITH NEW HYBRID GFS

GFS

COMPARISON OF CURRENT AND NEW HYBRID GFS
NUMBER OF CASES: (230, 221, 211, 195, 152, 112, 77)

% SKILL RELATIVE TO CLIPER

FORECAST HOUR

LEAST SKILL

MOST SKILL

CURRENT GFS
NEW HYBRID GFS

NEW GFDL

HYBRID GFS
2005-2006 Eastern Pacific Average Track Error

GF DL

GFDL COMPARISON WITH CURRENT AND NEW HYBRID GFS
NUMBER OF CASES: (148, 144, 133, 120, 92, 70, 50)

LEAST SKILL

% SKILL RELATIVE TO CLIPER

MOST SKILL

FORECAST HOUR

GFS

COMPARISON OF CURRENT GFS AND NEW HYBRID GFS
NUMBER OF CASES: (181, 147, 127, 106, 70, 38 )

LEAST SKILL

% SKILL RELATIVE TO CLIPER

MOST SKILL

FORECAST HOUR
Unified NCEP Post Implementation
September 25, 2007
Purpose of change

• Unify NAM post procedures into GFS
  – Create new master native and master post files, both in GRIB1 and on the native model grid, in both GDAS and GFS
  – GFS post processing now run as a separate job for each forecast hour, as in current NAM post processing
• Unify algorithms
  – GFS will use NAM precipitation type algorithm
  – NAM will use GFS tropopause algorithm (future)
• Unify product identifications (future)
• Unify development of post processing across NCEP (future)
• Support TIGGE
• Add new GOES look-alike fields
GFS Post differences and new fields

• Differences between operational and NCEP posts:
  – Precipitation type: Baldwin in operational versus dominant in NCEP post
  – Vorticity fields: spectral computation in operational versus grid space computation in NCEP post
  – Master Grib grid types: half degree in operational versus finer Gaussian grid in NCEP post
  – Week 2: replace double interpolation (model grid to 1 degree to 2.5 degree) with direct interpolation to 2.5 degree grid

• New fields to be generated by NCEP post:
  – GOES look alike
  – Helicity
Precipitation type comparison

Snow: blue, Rain: green, Freezing rain: magenta, Ice pellets: purple
Tropical storm Noel. Verified at 12 UTC November 2 2007

Water Vapor
channel

GOES 12 Ch 3

NAM 12 h forecast

GFS 12 h forecast
NAEFS Implementation
December 4, 2007
Planned Changes - Summary

- Bias corrected GFS forecast
  - Use the same algorithm as ensemble bias correction
  - Up to 180 hours

- Combine bias corrected GFS and ensemble forecast
  - Dual resolution ensemble approach for short lead time
  - GFS has higher weights at short lead time

- NAEFS new products
  - Combine NCEP/GEFS (20m) and CMC/GEFS (20m)
  - Produce Ensemble mean, spread, mode, 10% 50%(median) and 90% probability forecast at 1*1 degree resolution
    - Climate anomaly (percentile) forecasts also generated for ens. mean

- Statistical downscaling
  - Use RTMA as reference - NDGD resolution (5km), CONUS only
  - Generate mean, mode, 10%, 50%(median) and 90% probability forecasts
### NAEFS current configuration

*Updated: July 2007*

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<thead>
<tr>
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<th>NCEP</th>
<th>CMC</th>
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<tr>
<td><strong>Model</strong></td>
<td>GFS</td>
<td>GEM</td>
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<tr>
<td><strong>Initial uncertainty</strong></td>
<td>ETR</td>
<td>EnKF</td>
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<td><strong>Model uncertainty</strong></td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Stochastic physics</strong></td>
<td>None</td>
<td>Yes</td>
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<tr>
<td><strong>Tropical storm</strong></td>
<td>Relocation</td>
<td>None</td>
</tr>
<tr>
<td><strong>Daily frequency</strong></td>
<td>00,06,12 and 18UTC</td>
<td>00 and 12UTC</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>T126L28 (d0-d16) ~90km</td>
<td>(d0-d16) ~1.0degree</td>
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<tr>
<td><strong>Control</strong></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Ensemble members</strong></td>
<td>20 for each cycle</td>
<td>20 for each cycle</td>
</tr>
<tr>
<td><strong>Forecast length</strong></td>
<td>16 days (384 hours)</td>
<td>16 days (384 hours)</td>
</tr>
<tr>
<td><strong>Post-process</strong></td>
<td>Bias correction for ensemble mean</td>
<td>Bias correction for each member</td>
</tr>
<tr>
<td><strong>Last implementation</strong></td>
<td>March 27&lt;sup&gt;th&lt;/sup&gt; 2007</td>
<td>July 10&lt;sup&gt;th&lt;/sup&gt; 2007</td>
</tr>
</tbody>
</table>
New Products in CCS - Summary

- Bias corrected GFS forecast
  - Directory:/com/gens/para/gefs.yyyymmdd/cyc/pgrba_bc
  - Files: gegfs* (up to 180 hours)

- NAEFS new products: (early run: NCEP/GEFS only)
  - Probabilistic forecasts at 1*1 degree resolution (global)
    - Directory:/com/gens/para/gefs.yyyymmdd/cyc/pgrba_bc
    - Files: geavg*, gespr*, gemode*, ge10p*, ge50p*, ge90p* represent ensemble mean, spread, mode, 10%, 50% (median) and 90% probability forecast
  - Anomaly forecast for ensemble mean at 1*1 degree resolution (global)
    - Directory:/com/gens/para/gefs.yyyymmdd/cyc/pgrba_an
    - Files: geavg*
  - At 5km resolution (down-scaling for CONUS only)
    - Directory:/com/gens/para/gefs.yyyymmdd/cyc/ndgd
    - Files: geavg*, gemode*, ge10p*, ge50p* and ge90p*

- NAEFS new products: (later run: combine NCEP and CMC’s ensemble)
  - Probabilistic forecast at 1*1 degree resolution (global)
    - Directory:/com/gens/para/naefs.yyyymmdd/cyc/pgrba_bc
    - Files: geavg*, gespr*, gemode*, ge10p*, ge50p* and ge90p*
  - Anomaly forecast for ensemble mean at 1*1 degree resolution (global)
    - Directory:/com/gens/para/naefs.yyyymmdd/cyc/pgrba_an
    - Files: geavg*
  - At 5km resolution (down-scaling for CONUS only)
    - Directory:/com/gens/para/naefs.yyyymmdd/cyc/ndgd
    - Files: geavg*, gemode*, ge10p*, ge50p* and ge90p*
    - File: dvrtma.t00z.ndgd_conus (down-scaling vector)
GFS bias correction based on an accumulated bias by using decaying average weight (0.02) which is the same as GEFS used.

The absolute errors are reduced after bias correction for 2-meter temperature (The stats are accumulated from 0.02 decaying average)
Combined GFS and GEFS forecasts at first 180hr

GFS has more skill than ensemble control for short lead time

Combined GFS and GEFS Forecast has more skill (red) than GEFS only (black)

Jun Du first introduced dual-resolution to SREF, by using constant weight
Examples of NAEFS product
All these stats show the best values from probabilistic distribution of joined ensemble (NAEFS) for upper atmosphere and near surface. Green line is from NAEFS.
Statistical downscaling for NAEFS forecast

• Proxy for truth
  – RTMA at 5km resolution
  – Variables (surface pressure, 2-m temperature, and 10-meter wind)

• Downscaling vector
  – Interpolate GDAS analysis to 5km resolution
  – Compare difference between interpolated GDAS and RTMA
  – Apply decaying weight to accumulate this difference – downscaling vector

•Downscaled forecast
  – Interpolate bias corrected 1*1 degree NAEFS to 5km resolution
  – Add the downscaling vector to interpolated NAEFS forecast

• Application
  – Ensemble mean, mode, 10%, 50%(median) and 90% forecasts
Statistical Downscaling Verification
-Contributed by MDL

• 2-meter temperature only
• Period: July 20 – August 28 2007 (40 days)
• All verifications against RTMA
• NDFD: forecasts from 12UTC
• GMOS: forecasts from 00UTC
• GEFS: forecasts from 00UTC
  – Bias corrected NCEP GEFS ensemble mean only
  – Expect more improvement from:
    • Downscaling weight changes from 0.1(current) to 0.3(optimal)
    • Bias corrected GFS hybrid/multi-resolution (not applied in this verification)
    • Bias corrected CMC GEFS (NAEFS-joint ensemble)
For CONUS:
GEFS(3.07) : NDFD(3.60) GEFS (+17%)
GEFS(3.07) : GMOS(3.37) GEFS (+10%)
40 day average absolute errors of 2-meter temperature (NDFD has 12hr advantage)

CONUS only – verified against RTMA

2-m temp. forecast errors

<table>
<thead>
<tr>
<th>NDFD</th>
<th>GMOS</th>
<th>GEFS</th>
</tr>
</thead>
</table>

forecast hours

24 48 72 96 120 144 168
Summary

• This is a major implementation
• System delivery: September 11
• NCO Initial testing: September 17-October 12
• Parallel testing: October 16 – present
• Final version of system delivered: October 16
• NCO parallel evaluation period:
  – Request for participation - 10/16/07
  – Evaluation period is 10/24/07 through 11/23/07
  – Evaluations are due 11/26/07
• Implementation date: December 4th
• Full summary of this implementation:
• This package will be suitable for SREF, too.
Future Plan

• Correct NAEFS downscaling algorithm
  – Error in software implementation found on Nov. 15
    • Downscaling of Canadian ensemble data affected
      – Negatively affects primarily forecasts from 06, 12, 18Z cycles
      – Must implement correction operationally as soon as practical

• Apply statistical down-scaling method to other regions, Alaska, Hawaii, Puerto Rico and Guam, when RTMA is available
  – Streamline implementation process?

• Add new variables to NDFD grids, such as wind speed/direction, maximum/minimum temperature, 2-meter dew point temperature etc…

• Enhance products by
  – Improvements to RTMA
    • Bias correction of forecast first guess using recursive algorithm
CFS & GODAS upgrade
January, 2008
Purpose of change

• Deep water GODAS
  – Extend the GODAS assimilation to 2175 meters
  – Correct a temperature bias in the global intermediate waters

• CFS upgrade
  – Reduce the 8-day lag in the initial conditions to a 1-day lag for both ocean and atmosphere.
  – Introduce 2 new members (T62L64) out to 9 months. These 2 new members would initiate from perturbed initial conditions similar to the current 2 members.
  – Both these upgrades aim to improve upon the week 3-6 / monthly forecast leads
Standard vs. Deep assimilation

The standard assimilation extends down to 750 m.

Shallow assimilation can’t control temperature drift at 1200 m.

The deep assimilation extends down to 2200 m.

Deep assimilation eliminates drift in the Indian and Pacific Oceans and allows true positive trend in the Atlantic.
Future Plans
GFS 2008 Implementation
Proposed data assimilation changes

- FOTO (First-Order Time-extrapolation to Observations)
- Variational QC – tighter Gross checks
- Change in land/snow/ice skin temperature variance
- Situation dependent variances
- Changes to COSMIC QC
- Use of WINDSAT and ASCAT
FOTO

• (formerly called Simplified 4d-Var)

• At no additional cost includes:
  – Includes time extrapolation to observation using slow modes
  – Improves fit to obs
  – Some slowing of convergence
3D-VAR

Difference from Background Forecast

Updated Forecast

T - 3  →  Time  →  T = 0  →  T + 3

Obs - Background  Analysis

49
Difference from Background Forecast

Updated Forecast

FOTO

Obs - Background

Analysis
Situation dependent background variances

• Variances modified based on 9hr-3hr differences
  – Increased in rapidly changing locations
  – Decreased in others (global mean preserved)

• No additional cost
HPC Surface analysis (top) and $z=1$ Streamfunction (1e6) Background Error Standard Deviation for new flow-dependence algorithm (bottom) valid at 2007042412
Proposed forecast model changes

• Radiation parameterizations
  – RRTM1 longwave radiation
  – RRTM shortwave radiation
  – Maximum-random cloud overlap for shortwave
  – Hourly longwave radiation
  – Generalized aerosol treatment
  – Realistic CO2

• Other physical parameterizations
  – Retuned mountain blocking
  – Orographic gravity wave variance range limits
  – Shallow convection up to sigma 0.7

• Dynamical core
  – Enthalpy thermodynamic prognostic variable
Deferred forecast model changes

• Physical parameterizations
  – Microphysics from the NAM
  – Planetary Boundary Layer and Convection

• Dynamical core
  – Hybrid isentropic vertical coordinate
  – Semi-Lagrangian
Effect of new model (dotted line) on fits to sondes
Effect of new model (dotted line) on fits to sondes
Effect of new model (dotted line) on fits to sondes.
Effect of new model (dotted line) on fits to sondes
SH 500 mb Geopotential Height at day 5
for 00Z11JUL2005 – 00Z25OCT2005

operational
parallel
a partial list of Collaboration Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Organization</th>
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<td>Advanced Data Assimilation</td>
<td>NASA</td>
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<tr>
<td>Atmospheric Dynamics</td>
<td>ESRL, NASA, MesoMoB</td>
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<tr>
<td>Physical Parameterizations</td>
<td>MesoMoB</td>
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<td>NASA, EPA</td>
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<tr>
<td>Land Interaction</td>
<td>NASA</td>
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<tr>
<td>Ocean Interaction</td>
<td>GFDL, Navy</td>
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<td>Thermosphere and Ionosphere Interaction</td>
<td>SWPC</td>
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<tr>
<td><strong>NEMS</strong></td>
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</table>
NEMS – you will be assimilated

Application Driver

ESMF Superstructure (component definitions, “mpi” communications, etc)

Dynamics (1,2) <-> Physics (1,2,3)

Multi-component ensemble + Stochastic forcing

ESMF Utilities (clock, error handling, etc)

Post processor & Product Generator

Verification Resolution change

Analysis

Other Forecast Systems

* Earth System Modeling Framework (NCAR/CISL, NASA/GMAO, Navy (NRL), NCEP/EMC)

2, 3 etc: institutionally (non-NCEP) supported thru NUOPC or NOAA commitment
What is **NEMS**?

- **National Environmental Modeling System**
- A Tinkertoy™ model of NCEP systems.
- Uses ESMF to isolate model system into well-defined “components” and “couplers”.
- Each component can be developed by a different group and have multiple uses.
- As modeling systems gets more complex, component robustness gets more critical.
NEMS requirements

• Clear and complete interfaces
• Coding standards adherence
• Documentation and support
• Stand-alone driver
• Regression test set
• ESMF
NEMS prototype

• Components
  – NAM NMM-B dynamics working
  – NAM WRF physics working
  – GFS spectral dynamics working
  – GFS digital filter initialization working
  – Basic I/O component working
  – GFS physics under development
  – Flexible I/O component under development
  – ESMF 3.1 conversion under development
  – NCEP Post under development

• Schedule
  – Initial prototype with NAM and GFS working in 2008
  – Possible initial operational implementation in 2009
Questions