Mesoscale Modeling Branch: Where We’ve Been and Where We’re Going

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Where the Nation’s climate and weather services begin
TOPICS

• Recent Changes in Operations
  – Observational & Modeling System
  – NMM Fire Weather / IMET Support – May+Oct
  – Eta Upgrade Package - July
  – SREF Upgrade – September

• Development & Other Highlights
  – Air Quality Forecast System - August
  – North American Regional Reanalysis – Jun-Sept

• Plans for the Future [most interspersed above]
  – Downscaling: Eta Extension and Analysis-of-Record
Observational Data Processing
Implementations affecting the Eta
[part of what Dennis Keyser does]

- 10/12/2002: CRISIS Restore the ingest of NOAA-14 HIRS-2 and MSU data after NESDIS’s switch NOAA-14
- 11/05/2002: CRISIS Correct error unpacking HIRS-3, AMSU-A and AMSU-B radiances when counts >32767
- 11/20/2002: Upgrade of aircraft duplicate checking in data dump job
- 05/06/2003: AIRS radiance data now ingested into the NCEP BUFR data base
- 06/24/2003: Data Restriction - Phase I to isolate WMO Resolution 40 SYNOP reports & other restricted obs
- 07/07/2003: Perform hourly dumps of GOES Single Field Of View cloud top data and Level III WSR-88D NEXRAD radial wind superobs for use in EDAS as part of Eta Spring Bundle
- 08/12/2003: Data Restriction - Phase II to strip off restricted data (i.e. Res 40 SYNOP, AMDAR and E-ADAS BUFR format ADSAR/ACARS, MDCRS ACARS & all Mesonet types), write resulting unrestricted files to /com directories for use by unregistered users
- 08/19/2003: Data Restriction - Phase III read permission on files w/ restricted obs ONLY for registered users
- 08/28/2003: CRISIS to correct error in calculation of RAOB balloon drift time when below ground mandatory level heights were reported - affected the sun angle calculation in the radiation correction step.
- 09/09/2003: CRISIS to correct error in the report date-time calculation to allow proper use of marine data subjective quality flags
- 11/04/2003: Unified BUFRLIB merges unique components from 3 versions (decoder, verification and ENDIAN-independent versions) into fully portable version for NCEP and for WRF. Adds DOCBLOCKS and more descriptive error messages as well as many other changes to existing routines and the addition of new routines. Necessary step for ultimate use in operational data assimilation of mesonet, GPS-IPW, RASS, CAP and boundary layer wind profiler, NEXRAD Level II.5 superobs and AIRS radiances (upcoming JIF package to be submitted December 2003).
Mesonet (non-AWS) Surface Ob Density
METAR Surface Ob Density
GPS IPW (Integrated Precipitable Water) Ob Density
Boundary Layer Profiler Ob Density
Modeling System Implementations affecting the Eta, NMM or RUC
[part of what Geoff Manikin & Eric Rogers do]

- 10/1/02: RUC Land sfc model modified to reduce cold bias over patchy snow cover; short wave radiative tendency error corrected; precip type left unsmoothed on 40 km output grid
- 11/12/02: Fix for Stage IV precip analysis to handle duplicate multi-sensor precip estimates from River Forecast Centers
- 11/22/02 CRISIS: Turn off NOAA-16 AMSU-A radiance channels 9-11
- 5/19/03: Implement Fire Weather run
- 7/8/03: Eta “SPRING” BUNDLE
- 7/22/03: Fix to code reading GOES cloud top
- 7/29/03: Eta product generator upgrade
- 9/8/03: Eta product changes including addition of Hawaiian aviation FD wind/temps levels at 305m, 457m, 610m, 4572m
- 9/10/03: Surface temps turned off in Eta 3DVAR
- 10/7/03: Mass conserving lateral boundary treatment implemented for NMM nests
- 10/29/03 CRISIS: Turn off NOAA-17 AMSU-A radiance channels due to degraded quality

- 1/7/03: Corrected error in list of Julian dates
- 5/27/03: 3DVAR data assimilation replaced OI
- 7/8/03: 00 hr bufr files fixed to use 'B' analysis
- 9/24/03: Analysis change to lower some QC thresholds for observations and to flag land stations located at model water grid points
- 10/6/03: Corrected errors in max wind level due to cubic spline computation sensitivity in situations where model levels are very close
- 10/10/03: Added check in boundary condition generation code in which Eta pressure level output is interpolated to RUC theta levels to prevent a denominator term from going to 0
- 10/7/03: Mass conserving lateral boundary treatment implemented for NMM nests
**HiRes Window Fixed-Domain Nested Runs**

- **Routine runs** made at the **same time every day**

  - 00Z : Alaska-10 & Hawaii-8
  - 06Z : Western-8 & Puerto Rico-8
  - 12Z : Central-8 & Hawaii-8
  - 18Z : Eastern-8 & Puerto Rico-8

- This gives everyone a **daily high resolution run** when <2 hurricane runs need to be made

http://www.emc.ncep.noaa.gov/mmb/mmbplll/nestpage/Alaska-10km soon to be slightly smaller 8km domain
Fire Weather / IMET Support
From NCEP: Selectable Runs of Nonhydrostatic Mesoscale Model

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Updated 28 November 2003
Where the Nation’s climate and weather services begin
Nonhydrostatic Mesoscale Model (NMM)

• See Janjic, Gerrity, and Nickovic, 2001 for model equations, solution techniques & other test results [MWR, Vol. 29, No. 5, 1164-1178]

• Highly refined version of nonhydrostatic option released in May 2000 upgrade to NCEP’s workstation Eta

• NMM retains full hydrostatic capability
  - Incorporate nonhydrostatic effects through $\varepsilon$ where $\varepsilon=(1/g) \frac{dw}{dt}$
  - Then split prognostic equations into:
    • hydrostatic parts plus
    • corrections due to vertical acceleration
  - Set $\varepsilon$ to zero to run in hydrostatic mode
## Nonhydrostatic Mesoscale Model
### Feature Comparison With Meso Eta

<table>
<thead>
<tr>
<th>Feature</th>
<th>Meso Eta Model</th>
<th>Nonhydrostatic Meso Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamics</td>
<td>Hydrostatic</td>
<td>Hydrostatic plus complete nonhydrostatic corrections</td>
</tr>
<tr>
<td>Horizontal grid spacing</td>
<td>12 km E-grid</td>
<td>8 km E-grid for FireWx/IMET&lt;br&gt;4 km E-grid for Homeland Security</td>
</tr>
<tr>
<td>Vertical coordinate</td>
<td>60 step-mountain eta levels</td>
<td>60 sigma-pressure hybrid levels</td>
</tr>
<tr>
<td>Terrain</td>
<td>Unsmoothed Silhouette with lateral boundary set to sea-level</td>
<td>Unsmoothed Grid-cell mean everywhere</td>
</tr>
</tbody>
</table>
Hybrid versus Step (Eta) Coordinates

Pressure domain

\( P_{\text{top}} = 0 \)

\( \text{ground} = 0 \)

Sigma domain

\( \text{ground} \)

\( P_{\text{top}} = 1 \)

\( \text{MSL} = 1 \)
NMM vertical domain compared to Eta

NMM 60 –Layer Distribution

18 pressure layers, model top still at 25-hPa

42 sigma layers between surface about 420 hPa

1st layer interface above 420 hPa is bottom of first fixed pressure layer

420 hPa

42 layers

18 layers

Eta Model 60 – Layer Distribution

25 hPa

250 hPa

500 hPa

700 hPa

850 hPa

1000 hPa

28 hPa

28

29

28

28

28

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3

2
## Nonhydrostatic Mesoscale Model Feature Comparison With Meso Eta

<table>
<thead>
<tr>
<th>Feature</th>
<th>Meso Eta Model</th>
<th>Nonhydrostatic Meso Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamics</td>
<td>Hydrostatic</td>
<td>Hydrostatic PLUS full set of nonhydrostatic corrections</td>
</tr>
<tr>
<td>Horizontal Advection spatial</td>
<td>Janjic conservative T, u, v, TKE; shape preserving for q and total condensate</td>
<td>Janjic conservative T, u, v; shape preserving for TKE, q, and total condensate</td>
</tr>
</tbody>
</table>
## Nonhydrostatic Mesoscale Model Feature Comparison With Meso Eta

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<tr>
<th>Feature</th>
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</thead>
<tbody>
<tr>
<td>Vertical Advection</td>
<td>Euler backward T, u, v, TKE; shape preserving conservative for q and condensate</td>
<td>Shape preserving conservative for all: T, u, v, TKE, q and condensate</td>
</tr>
<tr>
<td>Pressure gradient force</td>
<td>Forward backward</td>
<td>Forward backward with adjustment for sigma</td>
</tr>
<tr>
<td>Advevtive time scheme</td>
<td>Euler backward</td>
<td>Adams - Bashforth</td>
</tr>
</tbody>
</table>
## Nonhydrostatic Mesoscale Model

### Damping Features Comparison With Meso Eta

<table>
<thead>
<tr>
<th>Damping Features</th>
<th>Meso Eta Model</th>
<th>Nonhydrostatic Meso Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical advection</td>
<td>Euler backward is damping</td>
<td>Shape preserving scheme is not damping</td>
</tr>
<tr>
<td>Advective time-step</td>
<td>Euler backward is damping</td>
<td>Adams - Bashforth is not damping</td>
</tr>
<tr>
<td>Divergence damping</td>
<td>Coeff = 6.5</td>
<td>Coeff = 15</td>
</tr>
<tr>
<td></td>
<td>Grid-coupling=1.</td>
<td>Grid-coupling &lt; 0.5</td>
</tr>
<tr>
<td>Lateral diffusion</td>
<td>Coeff = .25 with no limit on deformation</td>
<td>Coeff = .10 with limit on deformation</td>
</tr>
</tbody>
</table>
## Nonhydrostatic Mesoscale Model

### Physics Features Comparison With Meso Eta

<table>
<thead>
<tr>
<th>Physics Feature</th>
<th>Meso Eta Model</th>
<th>Nonhydrostatic Meso Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbulent mixing</td>
<td>Mellor-Yamada Level 2.5 dry</td>
<td>Mellor-Yamada Level 2.5 including moist processes</td>
</tr>
<tr>
<td>Surface exchange</td>
<td>…+ Paulson functions</td>
<td>…+ Holtslag and de Bruin functions</td>
</tr>
<tr>
<td>Land-sfc</td>
<td>NOAA LSM</td>
<td>NOAA LSM</td>
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<tr>
<td>Gridscale</td>
<td>Ferrier</td>
<td>Ferrier</td>
</tr>
<tr>
<td>Convective</td>
<td>B-M-J</td>
<td>B-M-J’ (minor adjustments)</td>
</tr>
<tr>
<td>Radiation</td>
<td>GFDL</td>
<td>GFDL</td>
</tr>
</tbody>
</table>
Positive Aspects of HiResWindow/NMM for FireWx

• Higher resolution and use of sigma-pressure vertical coordinate should yield
  – Better low level winds (especially vs Eta)
  – Better low level temperatures
  – Better low level dew points

• Nonhydrostatic dynamics should yield
  – Better predictions in cases with strong vertical circulations / accelerations
12 km Meso Eta vs 8 km NMM Winds

30-h Forecast/Observed 10-m Winds at 12Z 23 Apr 2002

12km Meso

8km Western Nest
12 km Eta vs 8 km NMM Winds

42-H FCST/OBS 10-M WINDS AT 0000 UTC 06 FEB 2003

12KM ETA

8KM NMM WESTERN NEST
Alaska Case Eta-12 vs NMMM-4
17 March 2002

Eta-12

NMM-4
Negative Aspects of HiResWindow for FireWx

• One 48 hour run per day, BUT fire weather guidance to be used for strategic (1-2 day) planning not for tactical purposes

• Reliability - fire season nearly same as hurricane season so there will likely be conflict between NHC requests for runs of the GFDL hurricane model and need for HiResWindow to support fire weather

• Timeliness – HiResWindow runs after GFS
Vastly Improved Option Implemented
By NCEP in May 2003

- EMC gave up some growth potential for Eta and built a Fire Wx/IMET Support run designed to run over the top of the Eta at all four runtimes of 00z, 06z, 12z & 18z
- Better than using HiResWindow because it has no conflict with hurricanes
- Established reduced domain nests patterned after NCEP’s On-Call Emergency Response capability for Homeland Security
- Nests to run at 8 km resolution like the HiResWindow
- Only downside is smaller domain than HiResWindow
- Fixed lateral boundary problem in October which was causing height bias
Proposed NCEP Production Suite
Weather Forecast Systems
Version 1.2 January 15, 2003

Wx Production Suite Made Up of Four Uniform Cycles per Day

6 Hour Cycle

Hawaii
FIREWX
COFS
RUC
EDAS
Waves
GFSens
HUR/NWM
GFSfcst
GFSanal
ETAfcst
ETAanal
SREF
GDAS

Hurricane & Nested Window Model (HiResWindow) occupy same run slot
26 Selectable 8 km Domains For Fire Weather / IMET Support Identical To 4 km Homeland Security Domains
Fire Weather / IMET Support Run

• SDM receives request for run via coordination call with Boise, WR & SPC [et al?]
• Runs are made within 4 dedicated run slots at 0000z, 0600z, 1200z and 1800z running over the top of the Eta
• 8 km NMM run produces 3 hourly output grids
• Output grids (mapped to look just like HiResWindow) picked up by WR [et al?], clipped to relevant subregion and prepared for transmission to IMET laptops using same FX-NET procedure developed for Olympics.
• SPC gets their grids directly from NCEP
Fire Weather / IMET Run Output

The FireWx grids are available out to 48 hours on the TOC ftp server (tgftp.nws.noaa.gov) under the following format:

/SL.us008001/ST.opnl/MT.nmm_CY.{CC}/RD.{YYYYYMMDD}/PT.grid_DF.gr1_AR.nest{xx}  where

\[ \text{CC} = 00, 06, 12, \text{ or } 18 \]

\[ \text{YYYYYMMDD} = \text{the current date} \]

\[ xx = 01 - 26 \text{ (geographic location)} \]

Filenames follow the convention:

\( fh.\{hhhh\}_tl.press_gr.awpreg \)  where

\[ hhhh = 0000, 0003, 0006, \ldots, 0048 \]

File on TOC with gif of region
Fire Weather / IMET Support Run

• Unfortunately, to view these runs required an upgrade to FX-NET which was deemed too risky in middle of Fire Weather season - so these runs were not used by IMETs in 2003
• These runs were used by SPC in making their Fire Weather Outlooks
• These runs are being used by NCEP’s HPC and OPC [et al?] during 2003-2004 Winter Weather Experiment
• We would like to increase resolution of these runs but not if that requires another upgrade to FX-NET – working with WR & Boise
July Upgrade Package for Eta-12 (Rogers)

• Gridscale cloud & precipitation (Ferrier)
  – Begin proper cycling of total condensate & ice/water rain/snow ratios
  – Upgrade microphysics and improve cloud - radiation interaction

• 3DVAR analysis (Parrish)
  – Add direct analysis of WSR-88D radial velocity from NWS Multicast
  – Upgrade radiance processing – begin use of NOAA-17 – 20x more

• Precipitation assimilation (Ying Lin)
  – Assimilation of GOES cloud top pressures
  – Assimilate Stage IV instead of Stage II hourly precip

• Increased output frequency and content (Manikin +)

http://wwwt.emc.ncep.noaa.gov/mmb/tpb.spring03/tpb.htm
http://wwwt.emc.ncep.noaa.gov/mmb/mmbpll/etapllsup12.etax/
Surface Temperature Response: Reduced Daytime Hot Bias

Mean 2-M Temp vs. sfc obs (12Z cycle) over the Western US for ctrl Bta-12 and parallel Bta-12 (with mod old physics, assim of NEXRAD winds and GOES cloud)
forecast from 200302201200 to 200302221200

- Observed mean
- Control Bta-12
- Parallel Bta-12

True for East and West and for both 00z and 12z runs.
Impact of Use of Cloud-Top on 24 hr QPF Scores

24 hour forecasts

Blue: cloud top assim; Red: Control

ETS

BIAS

24+36+48+60 hour forecasts

ETS

BIAS
Bundle Verification Results Upper-Air

**T**

- RMS temperature error vs. raobs over the CONUS for control Sta-12 (solid) and parallel Sta-12 (with winter 2003 bundle) 12-h forecast from 200301051200 to 200301051200
- 12-H Control Sta-12
- 12-H Parallel Sta-12

24 hr

**Z**

- RMS height error vs. raobs over the CONUS for control Sta-12 (solid) and parallel Sta-12 (with winter 2003 bundle) 12-h forecast from 200301051200 to 200301051200
- 12-H Control Sta-12
- 12-H Parallel Sta-12

**RH**

- RMS relative humidity error vs. raobs over the CONUS for control Sta-12 (solid) and parallel Sta-12 (with winter 2003 bundle) 12-h forecast from 200301051200 to 200301051200
- 12-H Control Sta-12
- 12-H Parallel Sta-12

**V**

- RMS vector wind error vs. raobs over the CONUS for control Sta-12 (solid) and parallel Sta-12 (with winter 2003 bundle) 12-h forecast from 200301051200 to 200301051200
- 12-H Control Sta-12
- 12-H Parallel Sta-12
Example of Total Condensate Field From Upgraded Eta Model Post
Example of Hydrometeor Fields from Eta

Cloud Water

Cloud Ice

Rain

Snow
Baldwin Diagnostic Precip Type vs Model Direct Percent Frozen

Baldwin Diagnosed Precip Type  Percent Frozen Direct from Model's Gridscale Scheme
Manikin’s Precip Type Meteogram Page
http://wwwt.emc.ncep.noaa.gov/mmb/precip_type/
Manikin’s Convective Forecasting Page

http://wwwt.emc.ncep.noaa.gov/mmb/svrfcst/index.html

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**NCEP ETA CONVective FORECASTING PAGE**

The current forecast cycle is **00Z 06 Dec** with graphics finished at 23:54:36 EST Fri Dec 5 2003

This page displays 00/12Z Eta model forecasts of convective parameters from the operational 12-km Eta model. Some of the newer fields such as 0-1km storm-relative helicity and **mixed-layer CAPE** are not widely available to the field, so this site offers a chance to examine more model output. Check out a complete documentation of the output from the [Eta Post Processor](http://wwwt.emc.ncep.noaa.gov/mmb/svrfcst/index.html).

**NOTE:** All displayed winds are in knots. Precipitation values are in inches.

GRIB files from the operational Eta-12 forecast can be found on the [NCEP ftp server](http://wwwt.emc.ncep.noaa.gov/mmb/svrfcst/index.html) or at the [NWS Gateway server](http://wwwt.emc.ncep.noaa.gov/mmb/svrfcst/index.html). Descriptions of some of these output files can be found at the [EMC Eta Grid Domains](http://wwwt.emc.ncep.noaa.gov/mmb/svrfcst/index.html) page.

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**CHECK OUT THESE OTHER EMC WEB PAGES WITH CONVective FORECASTING INFO**

- [Eta Meteograms](http://wwwt.emc.ncep.noaa.gov/mmb/svrfcst/index.html)
- [RUC Meteograms](http://wwwt.emc.ncep.noaa.gov/mmb/svrfcst/index.html)
- [Eta Forecast Soundings](http://wwwt.emc.ncep.noaa.gov/mmb/svrfcst/index.html)

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**Get the forecasts for the previous 7 days here (link opens a new window):**

```
<table>
<thead>
<tr>
<th>SUNDAY</th>
<th>MONDAY</th>
<th>TUESDAY</th>
<th>WEDNESDAY</th>
<th>THURSDAY</th>
<th>FRIDAY</th>
<th>SATURDAY</th>
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</thead>
<tbody>
<tr>
<td>12z</td>
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</table>
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**EMC DISCLAIMER:** This web page is not "operational" and therefore not subject to 24-h monitoring by NCEP’s Central Operations staff.

**NWS Disclaimer**
September Upgrade to Short Range Ensemble Forecast (SREF) System

- Added 5 members based on Eta using Kain-Fritsch
- Additional GRIB output:
  - Requested by AWC, SPC, HPC Service Centers
  - Eta: Additional cloud and convective products
  - RSM: Additional convective fields and vertical levels
- Create BUFR Sounding File
  - BUFR Soundings for all 10 Eta ensemble members
  - Requested and used by SPC, HPC and AWC
September SREF Upgrade
July 2003 Correlation Coefficients

850 mb Temperature

850 mb U-wind
September SREF Upgrade

July 2003 Spread (Std. Deviation)

850 mb Temperature

850 mb U-wind
General Weather Forecasting (site A, animation & zooming)

General Weather Forecasting (site B, static, same products as A)

Specific Applications (Aviation, Hydrology, Energy and Fire Weather)

Project Description  References  R&D Site  New Site
Case Study  SREF Training  Verification  Other Links

PLEASE READ THE DISCLAIMER ON INFORMATION INCLUDED IN THESE WEB DOCUMENTS!

Environmental Modeling Center (EMC)
SREF Aviation webpage
Displays 65 products
For 2 cycles per day (4 in FY04)
At 22 output times (00-63 hr)
Individually or animated loops
5 member combined or
5 member subsets of 3 model configurations:
  - Eta (using BMJ like opnl)
  - Regional Spectral Model
  - Eta using Kain-Fritsch
5 member subsets composed of
Control run and two pairs
Pairs initialized with +/- bred-mode perturbations

<table>
<thead>
<tr>
<th>Field</th>
<th>COM 15members</th>
<th>ETA 5members</th>
<th>RSM 5members</th>
<th>KFETA 5members</th>
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</thead>
<tbody>
<tr>
<td>Jet Stream threshold (Knots)</td>
<td>34Kft</td>
<td>18Kft</td>
<td>4.5Kft</td>
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</tr>
<tr>
<td>Icing (T &amp; Rh algo)</td>
<td>FL240</td>
<td>FL180</td>
<td>FL150</td>
<td>FL120</td>
</tr>
<tr>
<td>Tropopause (no RSM)</td>
<td>Height</td>
<td>Temp</td>
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<tr>
<td>Frz-level (no RSM)</td>
<td>Height</td>
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<td></td>
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<tr>
<td>Cloud total Cloud prob Mean &amp; spr</td>
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<td>Cloud prob</td>
<td>Clear</td>
<td>Max</td>
<td>Min</td>
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<td>Cloud prob</td>
<td>Scattered</td>
<td>Broken</td>
<td>Overcast</td>
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<td>C &amp; V and Fog (no RSM)</td>
<td>LIFR</td>
<td>IFR</td>
<td>MVFR</td>
<td>VFR</td>
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<td>Visibility</td>
<td>Ceiling</td>
<td>Cloud top</td>
<td>Fog</td>
<td></td>
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<tr>
<td>Convection</td>
<td>Cloud no RSM</td>
<td>Speed &amp; dir</td>
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<tr>
<td>Turbulence in the Layer (Ellrod algo)</td>
<td>FL420-FL390</td>
<td>FL390-FL360</td>
<td>FL360-FL330</td>
<td>FL330-FL300</td>
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<tr>
<td>Intensity threshold</td>
<td>LGT</td>
<td>MDT</td>
<td>SVR</td>
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<td>Vertical Wind shear</td>
<td>1000-950mb</td>
<td>950-900mb</td>
<td>900-850mb</td>
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<tr>
<td>Max wind</td>
<td>Speed</td>
<td>Hght no RSM</td>
<td></td>
<td></td>
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</tbody>
</table>
Short Range Ensemble Forecast (SREF) System
For January 2004 Implementation

- Combines value of initial condition breeding, physics diversity and improved horizontal resolution
- 3 Meso Eta Model (BMJ) members
- 3 Regional Spectral Model (SAS – new GFS & MPI)
- 2 Meso Eta with Kain-Fritsch members
- 2 Meso Eta with Relaxed Arakawa-Schubert (RAS)
- 2 Regional Spectral Model with RAS
- 2 Meso Eta with Kain-Fritsch Full Detrainment
- 1 Meso Eta with Ferrier Modified Shallow Convection
- BUFR soundings from RSM members as well as Eta
- Domain is full North American continent
- Resolution is 32/35 km versus 48 km
Air Quality Prediction at NCEP
Jeff McQueen, Pius Lee, Marina Tsildilko, with Geoff DiMego, Hui-Ya Chuang and Eric Rogers

CONGRESSIONAL EARMARK
Paula Davidson – NWS/HQ/OST Program Manager

Vision
National Air Quality Forecast System which provides the US with ozone, particulate matter and other pollutant forecasts with enough accuracy and advance notice to take action to prevent or reduce adverse effects

Strategy
Work with EPA, State and Local Air Quality agencies and private sector to develop end-to-end air quality forecast capability for the Nation
National Air Quality Forecasting

**Planned Capabilities**

• **Initial (1-5 years started FY2003):**
  – 1-day forecasts of surface ozone ($O_3$) concentration
  – Develop and validate in Northeastern US in 2 years
  – Deploy Nationwide within 5 years

• **Intermediate (5-7 years):**
  – Develop and test capability to forecast particulate matter (PM) concentration
    * Particulate size ≤ 2.5 microns

• **Longer range (within 10 years):**
  – Extend air quality forecast range to 48-72 hours
  – Include broader range of significant pollutants

• **Program has purchased additional computer power to perform AQF and promised this increment for perpetuity**
National Air Quality Forecasting

Initial Operational System

Linked numerical prediction system

NCEP Eta-12 mesoscale model for meteorology & its evolution
EPA community multi-scale air quality model (CMAQ) for ozone & eventually PM
Consistent model structures for interaction of urban thru continental scales

AQ Observational Input:

1999 EPA emissions inventory
Meteor. Dependent biogenic emissions
Climatological averaged mobile sources

Gridded forecast guidance products

NCEP delivers ozone grids to NWS TOC / Communications Gateway
EPA picks up and passes to State agencies
State agencies issue official forecast

Verification basis

EPA ground-level ozone observations

Customer outreach/feedback

State and Local AQ forecasters coordinated with EPA
Public and Private Sector AQ constituents
Air Quality Prediction System

Components

- Eta-CMAQ Post:
  - Interpolate from eta to 22 CMAQ sigma levels
  - Additional fields for AQ (pbl height, canopy cond., etc)
- Eta Product Generator: Interpolate to CMAQ C grid
- PREMAQ: Process static & met dependent emissions

Volatile Organic Compounds (VOCs)
- Biogenic (>50% of emissions): Strong met. dependence (T, PAR)
- Mobile (~25% of inventory) Large diurnal & day-of-week variations
- Evaporative Emission ~ temperature
- Other anthropogenic - assume no diurnal met influence

Nitric oxides (Nox)
- Major fossil-fuel power plants (~35%) t dep & maint sched
- Mobile (~30%) temp & wind dependence
- Soil (~10%) temp & soil moisture dependence
- Other anthropogenic (25%) – Lightning - not modeled

- CMAQ: Community Multi-scale Air Quality Model
- CMAQ Product Generator: Output sfc ozone in Grib
AQF Specifications

• Development Test & Evaluation was run in 2003
• Operational Test & Evaluation to be run in 2004
• IOC Northeastern US Domain:
  • 166x142 Lambert-Conformal Arakawa C grid
  • 12 km grid spacing
  • 22 sigma-P levels to 100 mb
  • 35 minutes for a 48 hour forecast (33 tasks)
• Initial Conditions: CMAQ forecast with new Eta forecast every 6 hours
• Boundary Conditions: Constant
• Data Assimilation: None
CMAQ Capabilities

- **Chemical Transport Mechanism**
  - Advection: Piecewise Parabolic method (PPM)
  - Vertical Diffusion: Asymmetric Convective Model (ACM)
  - Horizontal Diffusion: Eddy-diffusivity with Kh grid size dependent

- **Cloud processes:** Aqueous chemistry & sub-grid clouds from RADM: **OFF**

- **Plume-in-Grid:** Subgrid Lagrangian plume effects: **OFF**

- **Dry Deposition:** M3dry: deposition velocities computed from the Pliem-Xu LSM

- **Gas-Phase Chemistry Mechanisms:**
  - Smaller Carbon Bond 4 (CB4), limited species - Use Chemical steady states

- **Gas-phase Chemistry Solver:** Fast Henkel solver

- **Aerosols:**
  - Inorganic, 2nd anthropogenic & Speciated primary emissions (Carbon, sulfate, nitrates) **OFF**

- **Particulates, Visibility, Acid Deposition & Air Toxics** **OFF**
Retrospective Test Results: Predicted Surface Ozone Concentrations

September 20, 2002 – 14:00 EDT

September 20, 2002 – 16:00 EDT

September 20, 2002 – 18:00 EDT

September 20, 2002 – 20:00 EDT

September 21, 2002 – 00:00 EDT
DT&E Spatial Evaluation vs Obs

Hourly O$_3$

Root Mean Square Error

Mean = 29.0
CMAQ (green), Obs (blue), Bias (red) after land-use correction
NCEP Regional Reanalysis
http://wwwt.emc.ncep.noaa.gov/mmb/rreanl/index.html

Fedor Mesinger\textsuperscript{1}, Geoff DiMego\textsuperscript{2}, Eugenia Kalnay\textsuperscript{3}, Perry Shafran\textsuperscript{4}, Dusan Jovic\textsuperscript{4}, Wesley Ebisuzaki\textsuperscript{5}, Jack Woollen\textsuperscript{4}, Yun Fan\textsuperscript{6}, Robert Grumbine\textsuperscript{2}, Wayne Higgins\textsuperscript{5}, Hong Li\textsuperscript{3}, Ying Lin\textsuperscript{2}, Kenneth Mitchell\textsuperscript{2}, David Parrish\textsuperscript{2}, Eric Rogers\textsuperscript{2}, Wei Shi\textsuperscript{6}, and Diane Stokes\textsuperscript{2}

\textsuperscript{1}NCEP/EMC and UCAR, \textsuperscript{2}NCEP/EMC, \textsuperscript{3}Univ. of MD, \textsuperscript{4}NCEP/EMC and SAIC/GSO, \textsuperscript{5}NCEP/CPC, \textsuperscript{6}NCEP/CPC and RSIS
Motivation for Regional Reanalysis

• Create long-term set of consistent climate data on a regional scale on North American domain

• Superior to NCEP/NCAR Global Reanalysis (GR) due to:
  – use of higher resolution regional model (the Eta model)
  – Advances in modeling and data assimilation since 1995, especially:
    • Precipitation assimilation
    • Direct assimilation of radiances
    • Land-surface model updates
Regional Reanalysis System Design

- Fully cycled 3-hr EDAS
- Lateral boundary conditions supplied by Global Reanalysis 2 (GR2)
- Free forecasts made out to 72 hr every 2.5 days, using GR2 forecast boundary conditions
- Pilot Test resolution 80-km, 38 layers
- Production resolution: 32-km, 45 layers
- Domain covers North American continent
- RR time period: 1979-2003 (continued later in near-real time, as in CDAS)
## Data Used in Global Reanalysis and Regional Reanalysis

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Details</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiosondes</td>
<td>Temperature, winds, moisture</td>
<td>NCEP/NCAR Global Reanalysis (GR)</td>
</tr>
<tr>
<td>Dropsondes</td>
<td>Same as above</td>
<td>GR</td>
</tr>
<tr>
<td>Pibals</td>
<td>Wind</td>
<td>GR</td>
</tr>
<tr>
<td>Aircraft</td>
<td>Temp. and wind</td>
<td>GR</td>
</tr>
<tr>
<td>Surface</td>
<td>Pressure</td>
<td>GR</td>
</tr>
<tr>
<td>Cloud drift winds</td>
<td>Geostationary satellite</td>
<td>GR</td>
</tr>
</tbody>
</table>
## Data Added or Improved Upon for Regional Reanalysis

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Details</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>CONUS (with PRISM), Mexico, Canada, CMAP over oceans</td>
<td>NCEP/CPC</td>
</tr>
<tr>
<td>TOVS-1B radiances</td>
<td>Winds, precipitable water over oceans</td>
<td>NESDIS</td>
</tr>
<tr>
<td>Surface</td>
<td>Temperature, wind, moisture</td>
<td>GR</td>
</tr>
<tr>
<td>TDL Surface</td>
<td>Pres, temp, wind, moisture</td>
<td>NCAR</td>
</tr>
<tr>
<td>COADS</td>
<td>Ship and buoy data</td>
<td>NCEP/EMC</td>
</tr>
<tr>
<td>Air Force Snow</td>
<td>Snow depth</td>
<td>COLA and NCEP/EMC</td>
</tr>
<tr>
<td>SST</td>
<td>1-degree Reynolds, with Great Lakes SSTs</td>
<td>NCEP/EMC, GLERL</td>
</tr>
<tr>
<td>Sea and lake ice</td>
<td>Contains data on Canadian lakes, Great Lakes</td>
<td>NCEP/EMC, GLERL, Canadian Ice Center</td>
</tr>
<tr>
<td>Tropical cyclones</td>
<td>Locations used for blocking of CMAP Precipitation</td>
<td>Lawrence Livermore National Laboratory</td>
</tr>
</tbody>
</table>
Surface Data Assimilation

- Reduction of time-window for sfc obs in 3DVAR
  - Reduces noise, improves analysis and 3-hr first guess
- Exclude 2-m land surface station air temperatures:
  - Harm the analysis so that first guess is worse
  - Increases upper-air errors: T at 850- and 700-mb, winds at mid- and upper troposphere (!)
  - Removal from analysis decreases errors
- Led to turning off these same data in operational Eta 3DVAR 10 September 2003
January 1997 Precipitation Results
Unique RR Achievement

• Completed 24 years of RR production in just over 3 months, running 4 simultaneous streams, on old NCEP Production half of IBM Class-VIII
Work in Progress

• Getting data subsets to distribution centers
  – National Climatic Data Center
  – National Centers for Atmospheric Research
  – San Diego Supercomputing Center
  – University of Maryland

• Preparing DVD for AMS Bulletin article

• Preparing R-CDAS for perpetual running of RR system by NCEP’s CPC
NCEP Proposal for: Downscaling Model Grids for NDFD Out To 8 Days

Geoff DiMego
21 October 2003

where the nation’s climate and weather services begin
OUTLINE

- Purpose of Downscaling
- Chronology
- Relevance to NDFD
- Extension to Day 8
  - Background
  - Feasibility
  - Proposal
- Product Generation & Distribution
- Exit Strategy
- Steps for Implementation
- NCEP Concerns
Purpose of Downscaling

• Extend the information content of coarse model prediction fields to finer scales that reflect the influence of detailed local effects such as terrain and or land-surface
• Initialization of NDFD especially at day 8
• Analysis of Record needed to verify NDFD
CHRONOLOGY

• Request from Glahn & Livesey for Analysis of Record to verify NDFD (unofficial & unfunded)

• Request from Jack Hayes/Brad Colman for 1-page proposals for downscaling approaches:
  – 25 year 2 km climo of sensible wx by downscaling 25 year 32 km NARR used as observed basis for MOS/Neural Net development to downscale NARR & GR forecasts to 2 km
  – Local model with nudging
  – Anomaly techniques (Lord & Toth)

• First approach (preferred) had long timeline (2+ yrs)

• Brad Colman came to EMC based on strong desire for something to help forecasters with NDFD in the short term -- led to idea to downscale GFS guidance using reduced domain Eta extension to 8 days
Relevance to NDFD

• Immediate need of the NWS Field is for high res grids to initialize GFE/IFPS/NDFD especially at day 8:
• High resolution grids of at least 5 km with a preference for 2.5 km
• Grids with uniform content out to day 8 at least once per day (currently using MRF grids which will be replaced by 4/day GFS so demand may be for more than just once per day)
• NDFD parameters (sensible weather) but preferably full 3-D grids to populate GFE / IFPS in anticipation of improving SMART TOOLS
Extension to 8 Days: Background

• Original discussion with Brad called for a single 24 hour Eta-12 forecast cold-started from 6.5 or 7 day GFS forecast (would have major spin-up problems)

• EMC countered with extension from 60 hr for small (1/6th) domain and run instead of 06z extension

• NCEP Director pushback eliminated option to run instead of 06z extension

• EMC adjusted plan to push current 60 hr primary run from 60 hr to 84 hr with computer upgrade

• Colman pushback eliminated option to wait until after computer upgrade (06/04)
Extension to 8 Days: Feasibility

- Eta extension will produce the desired effect of downscaling the GFS solution because the GFS synoptic scale forecast will dominate the Eta solution in the interior through the effects of the lateral boundary conditions especially for this small a domain and for this long of a prediction.

- EMC/CPC have run Eta for extended periods before with no ill effects (but on larger domain)
  - 10+ days with MRF forecast lateral boundaries
  - 90+ days with Global Reanalysis lateral boundaries
Extension to 8 Days: Proposal

• Currently run Eta-12 in 2 pieces:
  – Large block of machine to make 0-60 hr fcst
  – Small block of machine to make 60-84 hr extension

• Proposal is to:
  – Make first block bigger to make 84 hr fcst in same time window as 60 hr is taking now (NCO has verified availability of sufficient processors to do this)
  – Use small block (no change in cpu resource) to run 4.5 day (84-192 hr) extension for small domain (1/4.5=2/9th)

• Initially, can run CONUS domain (2/9th) at 06z & 18z
• Subsequently, might also run OCONUS domains for AK (1/7th), HI (1/25th) & PR (1/25th) at 00z & 12z
Wx Production Suite Made Up of Four Uniform Cycles per Day

Proposed NCEP Production Suite
Weather Forecast Systems
Version 1.2 January 15, 2003

Percent Used

Unused cpu’s

6 Hour Cycle
Large block Eta 0-60hr
Small block Eta 60-84hr
GFS analysis
Reduced Eta Domains Which Would Allow \textbf{5} or \textbf{6} Day Extension in Same Slot as Current \textbf{1} Day Extension on Full Domain

Domain could be slightly larger since we only need to extend 4.5 days so we only need to reduce domain to 2/9th
Product Generation/Distribution

• Regional subsets of 12 km Eta grids made available to Regional Offices from TOC server via WAN or dark fiber
• *Regions download, convert to NeTCDF and distribute to their WFO’s using LAN’s & LDM
• *WFO Downscales 12 km Eta grids using national form of SMART INIT (Tim Barker)
• Eventually, downscale 12 km Eta grids centrally
  – Take advantage of full 3-D Eta-12 grids available centrally
  – Produce much smaller volume of 5 km NDFD parameter grids (GRIB2) which are 2-D sensible weather fields

*Can’t be decided by NCEP – must be worked from NWS/HQ & CIO & Regions
NCO is concerned about overloading comm’s & TOC processing capability
NCEP is concerned about getting locked into doing this extension forever
Steps to Implementation

• NCO to validate strategy in general and verify availability of processors in particular - done
• Precise definition of products (almost done)
• Precise definition of product form (GRIB or GRIB2)
• Resolve exact distribution / comm’s path all the way into AWIPA/GFE/IFPS so NDFD benefits
• Assurance that MIC’s in all regions embrace this strategy and the field forecasters can use the resulting guidance grids
Analysis of Record (AoR)

• Forecasters want one (in near real-time)
• NWS/HQ wants one to verify NDFD
• Glahn & Livesey expressed desire for a centrally generated AoR in October 2002 but said there were no resources available
• This and other possible uses / requirements (e.g. Surface Transportation and Local Modeling etc) were enough justification to start thinking
EMC’s AoR Concept

- Can’t just apply simple 2-d analysis to surface data - even though we have tens of thousands of mesonet obs, we have millions of grid-points
- Need a 3-d forecast model to obtain proper solution dictated among observed data, terrain & lower boundary forcing and synoptic forcing
- Propose to apply tried & true NCEP 4-dimensional data assimilation technique of forecast-analysis cycle at high resolution (2 km) with cost cutting measures to make feasible in production
EMC’s AoR Concept

- NCEP’s 4DDA (EDAS) uses full complexity of NOAH Land-Surface Model and assimilation of precipitation data to ensure lower-boundary states are optimal.
- Use WRF-NMM as assimilating model to include nonhydrostatic effects in terrain following coordinate.
- Nudge prediction in free atmosphere to existing solution provided by operational Eta-12 (NAM-WRF)
  - Allows focus of 3DVAR on surface where we have majority of truly mesoscale observations
  - Allows use of coarser resolution in vertical (20 vs 60 levels)
- 3DVAR can be (is being) tuned to be primarily 2-dimensional with anisotropic covariance structures that follow the terrain and depend on atmospheric flow.
EMC’s Downscaling Concept

- Apply EMC’s AoR concept to 25-year North American Regional Reanalysis (2-2.5 FTE+CPU)
- Produce 25 years of 2 km sensible weather grids
- Use with NARR & GR free forecasts to produce MOS/NN coefficients for use with NCEP model guidance to produce downscaled results for every gridpoint at every WFO (? FTE – primarily MDL)
  - Produce just NDFD variables (sensible weather)
  - Produce 3-d variables for high res input to SMART INIT to allow forecaster to add value via GFE and IFPS in producing the actual NDFD fields
Where (or Whether) to Downscale NARR and Perform AoR

- Need substantial computer power to produce 2 km downscaled NARR even if done just every 3 hours – might have to settle for 5 km
- Near real-time AoR would take ~15% of current machine 24 hours a day to do hourly AoR at 2 km with 6 hour delay (to get precip)
- EMC needs direction and resources if either of these are to pursued. Regions might want to push through their RDs.
Eta Upgrade Package Targeted for January 2004 Implementation

• Parallel testing with both 32-km and 12-km EDAS/Eta parallel systems is ongoing
• Upgrades being tested include:
  – Upgrade of NOAH Land-Surface Model from version 2.3.2 to version 2.7
  – Adjustment of biases in the multi-sensor precipitation analyses using daily gauge data
  – Upgrades to the Eta 3DVAR analysis
    • Include use of GOES-12 radiances
    • Better code with vastly improved memory use
Noah LSM Changes: Version 2.7 versus Ops Eta 2.3.2

1 – Reduce cool season daytime cool bias, especially over snow
- remove vegetation effect in snow albedo formulation
- change patchy snow cover parameters
- when fractional snow cover present, separate the calculation of surface evaporation over snow-covered and non-snow covered patches

2 – Reduce warm season daytime warm bias
- reduce vegetation-dependent soil moisture threshold
- decrease thermal-roughness length coefficient (CZIL)
- diurnal surface albedo function of solar zenith angle

3 – Reduce nighttime cool bias
- increase ground heat flux at night by
  -- increase thermal heat capacity of soil medium
  -- increase depth of lower boundary condition on soil temperature

4 – Improve snowfall (precip-type) diagnosis in land-sfc physics
- pass fraction of frozen precip from Eta microphysics to land-sfc module

5 -- Miscellaneous
- move soil heat flux calculation to end of SFLX
- small bug fix to calculation of thermal diffusivity of the soil medium
- increase sea-ice albedo from 0.60 to 0.65.
“THE PHYSICS WHEEL OF PAIN”

Compliments of Dr. Jaiyu Zhou (NOAA/OST)

1. - Hydrometeor type (phase)
   - Cloud optical properties
   - Cloud overlap (merging Cu, grid-scale cloudiness)
   - Cloud fractions

5. - Precipitation

6. - Sfc energy fluxes

4. - Convection, PBL evolution, precipitation
Improving Precipitation Assimilation

Hourly multi-sensor (radar+gauges) precip analysis used as input for Eta/EDAS precipitation assimilation tends to have a low bias, leading to drier soil:

July 2003 Total Rainfall

In EDAS

From Daily Gauge analysis
Bias Adjustment of Hourly Analyses for EDAS

1. Each day, compare 24h EDAS precip (12Z-12Z) to daily gauge analysis

2. Add the difference to a precipitation budget history file

3. Use the **budget history file** to adjust hourly precip input. Goal: to ‘pay off the debt’ in 1 day. Limit of adjustment: +/- 20% of pre-adjustment total
Impact in 32km Parallels, 20031006-20031204

EDAS precip scores
w/adjustment; control

Eq. Threat

Bias
Eta Upgrade Package Targeted for Later 2004 Implementation

- Next [Spring->Summer->Fall] Bundle
  - Replace GFDL radiation with GFS radiation
  - Improve shallow convection
  - Upgrade NOAH Land-Surface Model
  - Start using high resolution land use etc fields
  - Return 3DVAR analysis to using sfc temps over land
  - Begin use of mesonet surface obs, GPS IPW, boundary layer & RASS profiler data, Level 2.5 88D radial velocities
  - Begin assimilation of AIRS radiance data
  - Expand domain by 15%
  - Move model top to 2 mb during data assimilation
Planned 15% Expansion in 2005

SOLID = PROPOSED EXPANDED ETA-12 DOMAIN ; DASHED = OPS ETA-12
Proposed SREF Upgrades Later in FY04

• Improve lateral boundary conditions from medium range ensembles
• Improve breeding scaling factor
• Implement SREF at 0300 and 1500 UTC
• Improve resolution and/or increase number of members (WRF-NMM)
• Implement ensemble mean BUFR files
• Implement WRF post for RSM output
• Improved and new products