WRF-ARW in NCEP operations: Rapid Refresh

NOAA/ESRL/GSD/
Assimilation and Modeling Branch
RAP development scientists

Stan Benjamin
Steve Weygandt

Ming Hu Tanya Smirnova
Curtis Alexander John M. Brown
David Dowell Joe Olson
Bill Moninger Haidao Lin
Georg Grell Patrick Hofmann
Eric James Tracy Smith
Susan Sahm

NCEP – EMC/NCO

Geoff Manikin, Geoff DiMego,
Dennis Keyser, Julia Zhu,
Xiaoxue Wang, Thomas Pepe,
Becky Cosgrove, Chris Magee

Major topics:
- Overview
- WRF-ARW model configuration at NCEP
- RAPv2 changes
- Case examples

http://rapidrefresh.noaa.gov

Transition from RUC to Rapid Refresh

Provides hourly cycled guidance to all North America

Community-based model and analysis

- **WRF-ARW**: better numerics than RUC, non-hydrostatic
- **GSI**: advanced satellite data assimilation

<table>
<thead>
<tr>
<th>Model</th>
<th>Domain</th>
<th>Grid Points</th>
<th>Grid Spacing</th>
<th>Vertical Levels</th>
<th>Vertical Coordinate</th>
<th>Pressure Top</th>
<th>Boundary Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RUC</strong></td>
<td>CONUS</td>
<td>451 x 337</td>
<td>13 km</td>
<td>50</td>
<td>Sigma/Isentropic</td>
<td>~50 mb</td>
<td>NAM</td>
</tr>
<tr>
<td><strong>RAP</strong></td>
<td>North America</td>
<td>758 x 567</td>
<td>13 km</td>
<td>50</td>
<td>Sigma</td>
<td>10 mb</td>
<td>GFS</td>
</tr>
</tbody>
</table>
Hourly Updated NOAA NWP Models

Rapid Refresh (RAP) replaces RUC at NCEP
WRF, GSI with RUC features

13km Rapid Refresh

13km RUC

3km HRRR

HRRR talk by Curtis Alexander 0830 tomorrow
# Rapid Refresh GSI-based Hourly Assimilation Cycle

**Cycle hydrometeor, soil temp/moisture/snow**

## Data Type

<table>
<thead>
<tr>
<th><strong>Data Type</strong></th>
<th>~Number/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rawinsonde (12h)</td>
<td>120</td>
</tr>
<tr>
<td>NOAA profilers</td>
<td>21</td>
</tr>
<tr>
<td>VAD winds</td>
<td>~125</td>
</tr>
<tr>
<td>PBL – profiler/RASS</td>
<td>~25</td>
</tr>
<tr>
<td>Aircraft (V, temp)</td>
<td>2K-15K(avg 7K)</td>
</tr>
<tr>
<td>WVSS (RH)</td>
<td>0-800(avg 520)</td>
</tr>
<tr>
<td>Surface/METAR</td>
<td>~2500</td>
</tr>
<tr>
<td>Buoy/ship</td>
<td>200-400</td>
</tr>
<tr>
<td>GOES cloud winds</td>
<td>4000-8000</td>
</tr>
<tr>
<td>GOES cloud-top pres</td>
<td>10 km res</td>
</tr>
<tr>
<td>GPS precip water</td>
<td>~260</td>
</tr>
<tr>
<td>Mesonet (temp, dpt)</td>
<td>~8000 (RAPv2)</td>
</tr>
<tr>
<td>Mesonet (wind)</td>
<td>~4000 (RAPv2)</td>
</tr>
<tr>
<td>METAR-cloud-vis-wx</td>
<td>~2000</td>
</tr>
<tr>
<td>AMSU-A/B/HIRS/etc. radiances</td>
<td></td>
</tr>
<tr>
<td><strong>GOES radiances</strong></td>
<td>- testing – RAPv2</td>
</tr>
<tr>
<td>Radar reflectivity</td>
<td>1km</td>
</tr>
<tr>
<td>Lightning (proxy refl)</td>
<td>– ready for RAPv2</td>
</tr>
<tr>
<td>Radar radial wind</td>
<td>– ready for RAPv2</td>
</tr>
<tr>
<td>Nacelle/tower/sodar</td>
<td>– ready for RAPv2</td>
</tr>
</tbody>
</table>
WRF model enhancements for Rapid Refresh

- WRF - ARW - v3.2.1+ for initial RAP
  - WRF v3.3 issued too late in April 2011 – NCEP code freeze
- Benefited from ongoing community improvements to WRF
- GSD contributions –
  - Digital filter initialization (DFI - allows quiet 1h forecasts) (with NCAR)
  - DFI-radar
  - Grell 3-d cumulus
  - RUC LSM (snow LSM cycling on sea ice and modifications to snow melt--v3.3.1+ version)
- Use of rotated lat-lon grid - GSD was first to make extensive use of ARW with RLL
Hydrostatic v non-hydrostatic option

- Changed to non_hydrostatic = .false. spring 2011 in attempt to cure some balance issues with RAP use of DFI
- (later cured by changes to dfi.F, discussed June 2011)
- June 2011 workshop: hydrostatic option reported
- During NCEP field test late December last year: crashes
- Traced to CFL violations with Greenland Tip Jet
- Tried non-hydrostatic option with damp_opt = 3 (Rayleigh damping, only available with non_hydrostatic = .true.)
- No such crashes on rerun and since ...
- Not surprising: very little difference in any of our non_hydrostatic .false. / .true. comparisons at dx = 13km
ncview plots for Greenland tip jet
NE corner RAP domain

non-hydrostatic = .false.
damp_opt = 1
damp_coeff = 0.02
zdamp = 5000

non-hydrostatic = .true.
damp_opt = 3
damp_coeff = 0.2
zdamp = 5000

Terrain
The Rapid Refresh is able to use recent obs to improve forecast skill down to 1-h projection.
**RAP vs. RUC**

**Precipitation Verification**

**13-km CONUS Comparison**

2 X 12 hr fcst vs. CPC 24-h analysis

1 May – 15 July 2011

Matched

**SPRING/SUMMER**
RAP vs. RUC
24-h precip. verif.

2 x 12h fcst ending 12z
21 June 2011

Interpolated to 20-km grid

Thrs  CSI  Bias
1.00  .31  0.69
2.00  .21  0.58

Thrs  CSI  Bias
1.00  .45  1.22
2.00  .29  1.95
Snow cover and daytime temperature 21 Feb 2012

Better daytime temperature forecast in RAP with faster snowmelt (Virginia USA) (enhancements to RUC LSM).
Faster snow melt in RAP than RUC (new version of RUC LSM). More realistic 2m temp over snow in RAP. Tues 21 Feb 2012 case
Faster snow melt in RAP than RUC
More realistic 2m temp over snow in RAP
Tues 21 Feb 2012 case
Faster snow melt in RAP than RUC
More realistic 2m temp over snow in RAP
Tues 21 Feb 2012 case
RAPv2 modifications driven in part by overzealous HRRR convection forecasts in summer 2011

New observations: level II radial wind, lightning, wind energy obs

Significant improvement over RAPv1 esp. for improved precipitation and convective environment (less false alarms for thunderstorms), improved data assimilation (surface, radar, cloud)

Replace GSI and WRF versions with updates to trunk

NOAA Earth System Research Laboratory, Boulder, CO
Main differences RAPv1 vs. RAPv2 - assimilation

- Updated already to much more recent community repositories
  - GSI - r9374 (2010-09-23) to r16882 (2012-01-05)
- Better use of surface observations
  - Pseudo-PBL obs for moisture (in RUC, not in RAPv1)
  - Soil adjustment (in RUC, not in RAPv1)
- Cloud assimilation
  - Building from GOES restored (in RUC (large moist bias), not in RAPv1)
  - Forcing subsaturation in clearing, conserve $q_v$
  - Allow partial cloudiness in METAR assimilation
- New observations
  - Radial wind (level 2, following NAM)
  - Lightning (proxy for radar reflectivity)
  - Wind energy obs available
    - Tower, nacelle, special sodar, profiler obs
- Change to radar reflectivity assimilation
  - Hydrometeor addition largely removed in RAPv2 (avoids moist bias)
- PW obs (GPS primarily) – elevation correction, innovation limitation
Main differences RAPv1 vs. RAPv2 - model

• WRF – v3.2 (from summer 2010) to v3.3.1+ (summer 2011)

• MODIS land use instead of USGS land-use
  • Updated land-use information
  • Following NAM change in October 2011

• Updated Thompson microphysics
  • Reflectivity now calculated consistently inside WRF
  • RAPv1 – inconsistent reflectivity calculation in Unipost, exaggerates
    snow reflectivity

• Higher-order (5th vs. 3rd) vertical advection
  • Improved cloud forecasts, better retention of stable layers and
    inversions
Improved cloud analysis: assume virtual potential temperature is conserved

**RAP v1**

Before DA

After DA

**NOT** conserving $\theta_v$

**RAP v2**

Before DA

After DA

conserving $\theta_v$
Precipitation verification in RAP:

**Bias**

- Bias for RR_rad_radar_ctrl_13km, EUS rgn, 2 12h fcst totals, valid 12z, 2010-11
- Bias for RR_rad_radar_ctrl_13km, EUS rgn, 8 3hr fcst totals, valid 12z, 2010-11
- Bias for RR_rad_radar_ctrl_13km, EUS rgn, 2 12h fcst totals, valid 12z, 2010-11

**Critical Success Index (CSI)**

- Critical Success Index (CSI) for RR_rad_radar_ctrl_13km, EUS rgn, 2 12h fcst totals, valid 12z, 2010-11
- Critical Success Index (CSI) for RR_rad_radar_ctrl_13km, EUS rgn, 8 3hr fcst totals, valid 12z, 2010-11

---

*Eastern US, 2x12hr Forecasts vs. 24h CPC*

11-21 August 2011

**RAP V2 = 2012 ESRL RAP**
20z 13 June 2012
analysis
NCEP-RAP ←
ESRL-RAP →

19z 13 June 2012 Obs
SPC NCD #1152

20z 13 June 2012 1hr fcst
NCEP-RAP ←
ESRL-RAP →
20z 13 June 2012
analysis
←NCEP-RAP
ESRL-RAP →
20z 13 June 2012 Obs

21z 13 June 2012 Obs

20z 13 June 2012 1hr fcst
←NCEP-RAP
ESRL-RAP →
Case study – NCEP (RAPv1) vs. ESRL (RAPv2) versions
1h forecasts init 20z 2 Mar 2012

2 March 2012 severe weather outbreak- 160 tornadoes, 29 fatalities
Problem: RAP(v1) had too low dewpoint in 1-6h forecast in Ohio Valley.
Much lower Td/CAPE in Ohio Valley/KY/TN in NCEP RAPv1 than in ESRL RAPv2 (and RUC).

Higher Td/CAPE in KY/TN in RAPv2 attributable, in this case, to PBL-based pseudo-moisture obs to retain sfc TD obs.
Future plans for advanced hourly NWP/DA

- 2013 – RapidRefresh v2 –
  - cloud/surface/soil assimilation ➔ much lower moist bias (better convective fcsts), GOES, sodar/tower/nacelle winds, updated GSI
  - model – MODIS, cloud/PBL/numerical improvements, updated WRF
- 2013-14 – application of hybrid/EnKF assimilation to RAP in real-time testing
- 2012-14 – HRRR @ESRL improves, add Fairmont/zeus HRRR to reach 99%
- 2015 – High-Resolution Rapid Refresh operational at NCEP for CONUS

N. American Rapid Refresh Ensemble
- NEMS-based NMMB, ARW cores
- Hourly updating with GSI-hybrid EnKF
- Initially 2 members, 1 each core, later 6, physics diversity (RAP, NAM, other suites)
- Forecasts to 24-h
- NMM to 84-h 4x per day

- 2015 – Ensemble Rapid Refresh – NARRE w/ hybrid assim
- 2016 – Add operational Alaska HRRR
- 2017 – CONUS Ensemble HRRR – HRRRE

Other improvements in init testing
- RAP with inline chem, chem DA
- 15-min radar assimilation
- Storm-scale radar assimilation
NCEP Unipost options for output added for Rapid Refresh application

- **Ceiling** - includes NCAR code for effect of falling snow
- **Visibility** - includes RH component and updated coefficients from NCAR
- **MAPS SLP reduction** – more coherent SLP pattern over elevated terrain, matches RUC output SLP
- **Precip-type** – based on explicit qi/qc/qr/qs/qg (bug in RUC for mixed snow/rain fixed with RAP)
- **Heights** for ARW input
- Switch to virtual temp for CAPE/CIN/LI
- All commits into NCEP Unipost repository
Other post-processing, NARRE-TL

- **BUFR soundings**
- replace RUC files for HYSPLIT background with RAP
- **Downscaling for CONUS RTMA background**
  - RAP replacing RUC
- **GEMPAK grids**
  - for SPC, AWC, HPC
- **Hourly updated regional ensemble** with RAP and NAM time-lagged ensemble members
  - Formerly known as VSREF (very short range)
  - Official name – **NARRE-TL** – *N. American Rapid Refresh Ensemble – Time-lagged*
# Model physics comparison

<table>
<thead>
<tr>
<th>model</th>
<th>Shortwave Radiation</th>
<th>Cloud physics (# hydrometeor prog vars)</th>
<th>Cumulus parm</th>
<th>Boundary layer (PBL)</th>
<th>Shallow cumulus</th>
<th>Land-surface model</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFS</td>
<td>RRTM</td>
<td>Zhao-Carr (1)</td>
<td>Simplified Arakawa-Schubert</td>
<td>MRF – Troen-Mahrt</td>
<td>J Han &amp; H-L Pan (2011)</td>
<td>Noah</td>
</tr>
<tr>
<td>NAM</td>
<td>GFDL</td>
<td>Ferrier (1)</td>
<td>Betts-Miller-Janjic</td>
<td>Mellor-Yamada-Janjic</td>
<td>BMJ</td>
<td>Noah</td>
</tr>
<tr>
<td>RAP</td>
<td>Goddard</td>
<td>Thompson - 2010 – 2-moment rain (7)</td>
<td>Grell-3D</td>
<td>Mellor-Yamada-Janjic</td>
<td>Grell</td>
<td>RUC – from WRFv3.3</td>
</tr>
</tbody>
</table>
Rapid Refresh layer-interface sigma values (50 layers)

1.0000, 0.9980, 0.9940, 0.9870, 0.9750, 0.9590, 0.9390, 0.9160, 0.8920, 0.8650, 0.8350, 0.8020, 0.7660, 0.7270, 0.6850, 0.6400, 0.5920, 0.5420, 0.4970, 0.4565, 0.4205, 0.3877, 0.3582, 0.3317, 0.3078, 0.2863, 0.2670, 0.2496, 0.2329, 0.2188, 0.2047, 0.1906, 0.1765, 0.1624, 0.1483, 0.1342, 0.1201, 0.1060, 0.0919, 0.0778, 0.0657, 0.0568, 0.0486, 0.0409, 0.0337, 0.0271, 0.0209, 0.0151, 0.0097, 0.0047, 0.0000,

Consistent with RUC in having high resolution close to ground and in vicinity of the tropopause
Rapid Refresh – specific analysis features

Cloud and hydrometeor analysis

Digital filter-based reflectivity assimilation

Special treatments for surface observations

Elevation correction

If \( \text{abs}[\text{Psfc}_{\text{obs}} - \text{Psfc}_{\text{model}}] < 70 \text{ hPa} \),

- Extrapolate obs from \( \text{Psfc}_{\text{obs}} \) to \( \text{Psfc}_{\text{model}} \)
- Use model 1h low-level lapse rate.

PBL-based pseudo-observations

- RUC / RR HRRR model forecast
- + RUC/RR Convection suppression

PBL-based sfc. assim. better retention of sfc. obs in model
Rapid Refresh Partial Cycling

- Hourly cycling of land surface model fields
- 6 hour spin-up cycle for hydrometeors, surface fields
Radar reflectivity assimilation

Digital filter-based reflectivity assimilation initializes ongoing precipitation regions

-20 min  -10 min  Initial  +10 min  + 20 min

Backwards integration, no physics

Forward integration, full physics with radar-based latent heating

Initial fields with improved balance, storm-scale circulation

RUC / RAP HRRR model forecast

+ RUC/RAP Convection suppression
**Member Weighting** = 1.0 minus forecast duration (hr)/30:

e.g., 1 for current fcst and 0 for 30hr-old fcst

(NAM always older than RAP → gives more weight to RAP members)

Last 6 RAP hourly forecasts, last 4 NAM forecasts are used for time-lagged components

Example for 06Z cycle’s NARRE-TL:
RAP grid distribution from NCEP will include:

- 130 (13 km CONUS): pressure level output, native level output
- 252 (20 km CONUS): pressure, native
- 236 (40 km CONUS): pressure levels only
- 242 (11 km Alaska): one file with all needed parameters
- 221 (32 km nearly full domain): one file with all needed parameters
- 200 (16 km Puerto Rico): one file with all needed parameters

(Note: Full NAM grid is also on 221 grid)

Additional grid not to be distributed initially due to bandwidth limitation:

- 83 (13km full Rapid Refresh domain on rotated lat/lon grid)