The 2012 High-Resolution Rapid Refresh (HRRR): WRF Enhancements and Challenges

NOAA/ESRL/GSD/AMB

Curtis Alexander, Steve Weygandt, Stan Benjamin, David Dowell, Tanya Smirnova, Ming Hu, John Brown, Patrick Hofmann, Eric James, and Haidao Lin

5 hr fcst valid 21z 29 May 2012

Observations 21z 29 May 2012
13km Rapid Refresh (RAP) (mesoscale)

Replaced RUC at NCEP 05/01/12

WRF, GSI, RUC features

13km RUC (mesoscale)

3km HRRR (storm-scale)

High-Resolution Rapid Refresh
Experimental 3km nest inside RAP, hourly 15-h fcst
Aviation Weather Center (AWC): 2-D grids
Federal Aviation Administration (FAA) Command Center
National Center for Atmospheric Research (NCAR): 2-D, 3-D, 15-min grids
  Operational evaluation in CoSPA
Storm Prediction Center (SPC): 2-D grids
  Operational severe weather forecasting and evaluation
National Severe Storms Laboratory (NSSL): 2-D, 3-D and 15-min grids
  Mesoscale analysis, Short-term precipitation forecasts
National Centers for Environmental Prediction (NCEP): 15-min grids
  Real Time Mesoscale Analysis (RTMA)
Department of Energy/NOAA Wind Forecast Improvement Project (WFIP)
  ~12 energy private sector companies via WFIP (WindLogics, 3Tier, AWS Truepower, Precision Wind, Weather Channel, etc.)
  Real-time forecasts of turbine-level wind and solar irradiance
Colorado State University (CSU/CIRA): 2-D grids
  Verification of solar irradiance forecasts at SURFRAD sites
Air Resources Laboratory (ARL): Tiled 3-D HRRR grids
  Dispersion forecasts, Local wind forecasts in complex terrain
National Weather Service (NWS): 2-D and 3-D grids
  Operational weather forecasting
United States Air Force (USAF): 2-D grids
  Operational weather forecasting
RAP: Data assimilation engine for HRRR

Hourly cycling model

Data Assimilation cycle

Observations

RAP

HRRR
Rapid Refresh
Hourly Update Cycle
Partial cycle atmospheric fields –
introduce GFS information 2x/day
Fully cycle all land-sfc fields

<table>
<thead>
<tr>
<th>Hourly Observations</th>
<th>RAP 2012 N. Amer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rawinsonde (T,V,RH)</td>
<td>120</td>
</tr>
<tr>
<td>Profiler – NOAA Network (V)</td>
<td>21</td>
</tr>
<tr>
<td>Profiler – 915 MHz (V, Tv)</td>
<td>25</td>
</tr>
<tr>
<td>Radar – VAD (V)</td>
<td>125</td>
</tr>
<tr>
<td>Radar reflectivity - CONUS</td>
<td>2km</td>
</tr>
<tr>
<td>Lightning (proxy reflectivity)</td>
<td>NLDN, GLD360</td>
</tr>
<tr>
<td>Aircraft (V,T)</td>
<td>2-15K</td>
</tr>
<tr>
<td>Aircraft - WVSS (RH)</td>
<td>0-800</td>
</tr>
<tr>
<td>Surface/METAR (T,Td,V,ps,cloud, vis, wx)</td>
<td>2200-2500</td>
</tr>
<tr>
<td>Buoys/ships (V, ps)</td>
<td>200-400</td>
</tr>
<tr>
<td>Mesonet (T, Td, V, ps)</td>
<td>flagged</td>
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<tr>
<td>GOES AMVs (V)</td>
<td>2000-4000</td>
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<tr>
<td>AMSU/HIRS/MHS radiances</td>
<td>Used</td>
</tr>
<tr>
<td>GOES cloud-top pressure/temp</td>
<td>13km</td>
</tr>
<tr>
<td>GPS – Precipitable water</td>
<td></td>
</tr>
<tr>
<td>WindSat scatterometer</td>
<td>2-10K</td>
</tr>
</tbody>
</table>
Rapid Refresh Specific Analysis Features

Cloud and hydrometeor analysis

Special treatments for surface observations

Digital filter-based reflectivity assimilation (DDFI)

Elevation correction

If abs[Psf_{obs-model}] < 70 hPa.

Extrapolate obs from Psfc_{obs} to Psfc_{model}

Use model 1h low-level lapse rate.

PBL-based pseudo-observations

RUC / RR HRRR model forecast

+ RUC/RR Convection suppression
Radar Reflectivity Assimilation

Convergence Cross-Section

RAP
HRRR
no radar

RAP
HRRR
RADAR

Rapid convective spin-up with radar data

00z init
00z 12 Aug 2011

RAP
HRRR
no radar

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Radar Reflectivity Assimilation

Convergence Cross-Section

Rapid convective spin-up with radar data

RAP HRRR no radar

RAP HRRR RADAR

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Model Configurations

ESRL/GSD/AMB

Retrospective

RAP Retro

HRRR Retro

Real-Time

RAP Dev2

RAP Dev1

RAP Primary

RAPv2 Primary

HRRR Dev1

HRRR Primary

NCEP

RAPv1 NCO

FAA-CoSPA

NWS-AWIPS

DOE-WFIP

AMB RAP/HRRR verification system

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HRRR Milestones

- Inception over northeastern US Sept 2007
- Integration into CoSPA: Aviation Users Spring 2008
- Domain expansion to eastern US Mar 2009
- HCPF time-lagged ensemble inception May 2009
- HRRR WRF-ARW updated to v3.1.1 Oct 2009
- Domain expansion to CONUS Oct 2009
- HRRR WRF-ARW updated to v3.2 Apr 2010
- Forecast period extended to 15 hrs Apr 2010
- Real-time multi-scale reflect. verification June 2010
- Parallel (shadow) retrospective system Sept 2010
- Attained ~95% reliability Jun 2010
# HRRR (and RAP) Milestones

- Reduced latency to ~2 hrs  
  **Dec 2010**
- Conversion of all output to GRIB2 format  
  **Apr 2011**
- Transition from RUC to RAP parent model  
  **Apr 2011**
- DOE-funded HRRR FTP site for energy industry  
  **May 2011**
- Update to WRF-ARW v3.3.1  
  **Feb 2012**
- Rapid Refresh operational at NCEP  
  **May 2012**
- 3-km data assimilation and cycling  
  **2012-2013**
- HRRR operational at NCEP  
  **2015?**
- Ensemble Rapid Refresh (NARRE) at NCEP  
  **2016?**
- Ensemble HRRR (HRRRE) at NCEP  
  **2017?**
## RAP/HRRR Changes for 2012

<table>
<thead>
<tr>
<th>RAP (13 km)</th>
<th>Model</th>
<th>Data Assimilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRFv3.3.1+</td>
<td>Physics changes (convection, microphysics, land-surface, PBL)</td>
<td>Soil adjustment, Temp-dep radar-hydrometeor building</td>
</tr>
<tr>
<td>Numerics changes (w-damp upper bound conditions, 5th-order vertical advection)</td>
<td>PW assim mods Cloud assim mods</td>
<td></td>
</tr>
<tr>
<td>MODIS land use, fractional</td>
<td>Tower/nacelle/sodar observations</td>
<td></td>
</tr>
<tr>
<td>30→10 min shortwave radiation</td>
<td>GLD360 lightning</td>
<td></td>
</tr>
<tr>
<td>New reflectivity diagnostic</td>
<td>GSI merge with trunk</td>
<td></td>
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<tr>
<td>Radial wind assim</td>
<td></td>
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<table>
<thead>
<tr>
<th>HRRR (3 km)</th>
<th>Model</th>
<th>Data Assimilation</th>
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<tbody>
<tr>
<td>WRFv3.3.1+</td>
<td>Physics changes (microphysics, land-surface, PBL)</td>
<td>3 km/15 min reflect assim</td>
</tr>
<tr>
<td>Numerics changes (w-damp upper bound conditions, 5th-order vertical advection)</td>
<td>3 km radial wind assim</td>
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</tr>
<tr>
<td>MODIS land use, fractional</td>
<td>3 km cloud cycling</td>
<td></td>
</tr>
<tr>
<td>30→05 min shortwave radiation</td>
<td>3 km land-surface cycling</td>
<td></td>
</tr>
<tr>
<td>New reflectivity diagnostic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td>Run at:</td>
<td>Domain</td>
</tr>
<tr>
<td>-------</td>
<td>---------</td>
<td>--------------</td>
</tr>
<tr>
<td>RAP</td>
<td>GSD, NCO</td>
<td>North America</td>
</tr>
<tr>
<td>HRRR</td>
<td>GSD</td>
<td>CONUS</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Version</th>
<th>Assimilation</th>
<th>Radar DFI</th>
<th>Radiation</th>
<th>Microphysics</th>
<th>Cum Param</th>
<th>PBL</th>
<th>LSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>WRF-ARW v3.2.1+</td>
<td>GSI-3DVAR</td>
<td>Yes</td>
<td>RRTM/Goddard</td>
<td>Thompson</td>
<td>G3 + Shallow</td>
<td>MYJ</td>
<td>RUC</td>
</tr>
<tr>
<td>HRRR</td>
<td>WRF-ARW v3.2.1+</td>
<td>None: RAP I.C.</td>
<td>No</td>
<td>RRTM/Goddard</td>
<td>Thompson</td>
<td>None</td>
<td>MYJ</td>
<td>RUC</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Horiz/Vert Advection</th>
<th>Scalar Advection</th>
<th>Upper-Level Damping</th>
<th>SW Radiation Update</th>
<th>Land Use</th>
<th>MP Tend Limit</th>
<th>Time-Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>5th/3rd</td>
<td>Monotonic</td>
<td>Diffusive 0.02</td>
<td>30 min</td>
<td>USGS</td>
<td>0.01 K/s</td>
<td>60 s</td>
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<tr>
<td>HRRR</td>
<td>5th/3rd</td>
<td>Monotonic</td>
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<td>30 min</td>
<td>USGS</td>
<td>0.10 K/s</td>
<td>18-23 s</td>
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</tbody>
</table>
### RAP and HRRR Config 2012

<table>
<thead>
<tr>
<th>Model</th>
<th>Run at:</th>
<th>Domain</th>
<th>Grid Points</th>
<th>Grid Spacing</th>
<th>Vertical Levels</th>
<th>Pressure Top</th>
<th>Boundary Conditions</th>
<th>Initialized</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>GSD,</td>
<td>North America</td>
<td>758 x 567</td>
<td>13 km</td>
<td>50</td>
<td>10 mb</td>
<td>GFS</td>
<td>Hourly (cycled)</td>
</tr>
<tr>
<td></td>
<td>NCO</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>HRRR</td>
<td>GSD</td>
<td>CONUS</td>
<td>1799 x 1059</td>
<td>3 km</td>
<td>50</td>
<td>20 mb</td>
<td>RAP</td>
<td>Hourly - RAP (no-cycle)</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Model</th>
<th>Version</th>
<th>Assimilation</th>
<th>Radar DFI</th>
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<th>Time-Step</th>
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<tbody>
<tr>
<td>RAP</td>
<td>5th/5th</td>
<td>Positive-Definite</td>
<td>w-Rayleigh 0.2</td>
<td>10 min</td>
<td>MODIS Fractional</td>
<td>0.01 K/s</td>
<td>60 s</td>
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<tr>
<td>HRRR</td>
<td>5th/5th</td>
<td>Positive-Definite</td>
<td>w-Rayleigh 0.2</td>
<td>5 min</td>
<td>MODIS Fractional</td>
<td>0.07 K/s</td>
<td>20-23 s</td>
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</tbody>
</table>

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Upper-Level Damping Upgrade

Diffusive Damping (HRRR 2011)

Vertical Velocity
18 July 2011 1800 UTC
(M m s⁻¹)
MAX 7.84
MIN -2.32
LEVEL 45

Vertical Velocity
at Level 45 (~15 km MSL)

- 2 hr fcst
Valid 18Z
18 July 2011

- 5 hr fcst
Valid 21Z
18 July 2011

w-Rayleigh Damping (HRRR 2012)

Vertical Velocity
18 July 2011 1800 UTC
(M m s⁻¹)
MAX 0.44
MIN -0.35
LEVEL 45

Reduced Noise Vertical Motion

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Upper-Level Damping Upgrade

**Diffusive Damping**  
(HRRR 2011)

Wind U-Component  
11 July 2011 0900 UTC

**Horizontal Wind Components at Level 45**  
(~15 km MSL)

**w-Rayleigh Damping**  
(HRRR 2012)

Wind U-Component  
11 July 2011 0900 UTC

**Smoother Horizontal Wind Field**

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Slightly higher ceiling in marine stratocumulus, Less eroding of clouds

3rd order vertical advection (HRRR 2011)

5th order vertical advection (HRRR 2012)

PODy 500 ft ceiling 12 hr fcsts

5th - 3rd

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Capability to use MODIS land use categories with RUC LSM
Mosaic approach to specify land use properties

24 USGS category (RAP/HRRR 2011)  
20 MODIS categories (RAP/HRRR 2012)

Improved Surface Fluxes, Roughness Lengths, Snow Physics
HRRR Water Vapor Histograms

CONUS
11-22 August 2011
0 hr Analysis on 3km grid

Moisture differences large enough to affect convective forecasts
HRRR Forecast Behavior

2011
(1) High bias in convection over eastern US
(2) False alarms
(3) Lead in convective initiation (early AM runs)
(4) Difficulty maintaining mesoscale convective systems
(5) Reflectivity biases in snow and convective storms

RAP/HRRR Model Development and Evaluation

2012 Targets
(1) Lower peak bias in convection over eastern US
(2) Fewer false alarms
(3) Improved timing of convective initiation
(4) More success maintaining mesoscale convective systems
(5) More realistic reflectivity biases

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Reflectivity ≥ 30 dBZ

03km Eastern US 160 cases 29 May – 12 June 2011

HRRR 2011 (real-time)
HRRR 2012 (retro)

Reduced high bias in first 6 hrs and improved CSI
HRRR June Retro Verification

Reflectivity ≥ 30 dBZ

40km Eastern US 160 cases 29 May – 12 June 2011

HRRR 2011 (real-time)
HRRR 2012 (retro)

Reduced high bias in first 6 hrs and improved CSI

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HRRR Retro Case Studies

HRRR 4hr fcst 2011 Real-Time

20z 01 June 2011 Observations

HRRR 4hr fcst 2012 Version

Large reduction in false alarm (excessive) convection
Improved structure to broken convective line
HRRR Retro Case Studies

HRRR 7hr fcst 2011 Real-Time
HRRR 7hr fcst 2012 Version
15z 07 June 2011 Observations

Composite Reflectivity (dBZ)

Improved mesoscale convective system (MCS) maintenance
HRRR Retro Case Studies

HRRR 10hr fcst 2011 Real-Time Observations HRRR 10hr fcst 2012 Version

Composite Reflectivity (dBZ)

Improved mesoscale convective system (MCS) maintenance
HRRR Retro Case Studies

HRRR 8hr fcst 2011 Real-Time
00z 31 May 2011 Observations
HRRR 8hr fcst 2012 Version

Composite Reflectivity (dBZ)

Reduction in false alarm convective initiation
Reflectivity Diagnostic Upgrade

HRRR 14-h forecast
initialized 1500 UTC 28 Feb 2012
WRF 3.2
old reflectivity diagnostic
Reflectivity Diagnostic Upgrade

HRRR 12-h forecast
initialized 1700 UTC 28 Feb 2012
WRF 3.3.1
new reflectivity diagnostic

Improved reflectivity structure:
Dry snow reflectivities lowered
Wet snow bright banding added
Smaller more intense precip cores
Echo Top Height Challenge

Observation
01z 21 June 2012

Current 2012

HRRR
4 hr fcst

18 dBZ Echo Tops > 30 kft Eastern US BIAS 03 km 10-28 June 2012

Current 2012 low bias in echo tops after reflectivity diagnostic made consistent with microphysics

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6th Order Diffusion Challenge

6 hr fcsts
Valid 21z
11 Aug 2011

No 6th OD

6th OD 0.12

6th OD 0.03
Water Vapor (and other fields)

Hourly Oscillations (Noise)

In Complex Terrain

Near Surface

Noise increases with higher 6th OD
Detected with values as low as 0.001
Convective System Challenge

HRRR – reflect, 2m Temp
2 Apr 2012 3z + 0h fcst
Valid 03z 2 April 2012
Convective System Challenge

HRRR – reflect, 2m Temp
2 Apr 2012 3z + 1h fcst
Valid 04z 2 April 2012
Convective System Challenge

HRRR -- reflect
2 Apr 2012 3z + 2h fcst
Valid 05z 2 April 2012
HRRR -- reflect
2 Apr 2012 3z + 3h fcst
Valid 06z 2 April 2012
Convective System Challenge

Cold Pool Too Weak?
Limitation In Assimilation Approach?
Model Error In Environment?

HRRR -- reflect
2 Apr 2012 3z + 9h fcst
Valid 12z 2 April 2012
# RAP and HRRR Resources

<table>
<thead>
<tr>
<th>Model</th>
<th>Version</th>
<th>Initialized</th>
<th>Forecast Length</th>
<th>Run Time</th>
<th># CPUs</th>
<th>Disk Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>WRFv3.3.1+</td>
<td>Hourly</td>
<td>18 hrs</td>
<td>~30 min</td>
<td>200</td>
<td>230 GB (per run)</td>
</tr>
<tr>
<td>HRRR</td>
<td>WRFv3.3.1+</td>
<td>Hourly</td>
<td>15 hrs</td>
<td>~50 min</td>
<td>1128</td>
<td>800 GB (per run)</td>
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<table>
<thead>
<tr>
<th>NOAA High-Performance Computer System</th>
<th>Number of Filesystems</th>
<th>Total Reserved Disk Space</th>
<th>CPU Type</th>
<th>Total Reserved CPUs</th>
<th>Performance Increase</th>
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<tbody>
<tr>
<td>Jet (current)</td>
<td>4</td>
<td>150 TB</td>
<td>Intel Nehalem</td>
<td>1736</td>
<td>-</td>
</tr>
<tr>
<td>Zeus (new)</td>
<td>2</td>
<td>230 TB</td>
<td>Intel Westmere</td>
<td>2000-4000</td>
<td>30%</td>
</tr>
</tbody>
</table>
HRRR 2013 Upgrade

Sub-hourly 3-km HRRR radar assimilation

Better short-range forecasts storm details

HRRR 3hr forecast WITH 3-km radar assimilation

HRRR 3hr forecast NO 3-km radar assimilation
HRRR Transition to NCEP

• Current – 1 computer running HRRR
  – NOAA/ESRL – Boulder
  – Current reliability: 97% for last 12h months (allowing up to 3h gaps)

• 2012-14 – 2 computers running HRRR – interim solution
  – Boulder – computer 1
  – Fairmont, WV – computer 2
  – Expected reliability to increase further to 98.5-99% via coordination of downtimes for Boulder vs. Fairmont computers

• 2015 – NCEP running HRRR
  – NOAA/NCEP computing budget – will allow no increase before 2015

• Conclusion: *Interim HRRR computing for 2012-14 on 2 sites to provide “research regular” HRRR from NOAA for NWS, FAA, DOE/energy users*
Summary and Plans

• Moist bias reduced in 2012 RAP and HRRR
  – Reduced false alarms, lower precipitation bias
  – GSI enhancements and WRF upgrade to v3.3.1
  – Reflectivity diagnostic consistent with microphysics

• Focus on cycled 3-km assimilation for 2013
  – 3-km variational analysis
  – 3-km non-variational cloud analysis
  – 3-km radar reflectivity data data assimilation

• Reduced latency for 2013 (currently 2-3 hrs)
  – Approximate 1-hr reduction in execution time
  – Faster post-processing with parallelization
  – Direct GRIB2 generation