Development of the High-Resolution Rapid Refresh Ensemble (HRRRE)

11 January 2018

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NOAA/ESRL/GLOBAL SYSTEMS DIVISION
RAP/HRRR: Hourly-Updating Weather Forecast Suite

13-km Rapid Refresh (RAPv4) – to 39h (May 2018)

3-km High-Resolution Rapid Refresh (HRRRv3) – to 36h (May 2018)

750-m HRRR nest Scale-aware Physics Testing (ongoing)

3-km High-Resolution Time Lagged Ensemble (HRRR-TLE)

3-km Storm-Scale Ensemble Analysis and Forecast (HRRRE)
55% CONUS HRRR Experimental (ongoing)
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- **3-km HRRR-Smoke (VIIRS fire data)**
- **3-km High-Resolution Rapid Refresh Alaska, Hawaii and Puerto Rico Testing (HRRR-AK, HRRR-HI, HRRR-PR)** Experimental (ongoing)
- **3-km Storm-Scale Ensemble Analysis and Forecast (HRRRE)** 55% CONUS HRRR Experimental (ongoing)
### Upcoming RAPv4/HRRRv3

#### No Change in CONUS Domains

#### Newer Model Version
More Ensemble Weight
Advanced “Physics Suite”

#### Seasonal Vegetation Fraction/Leaf Area Index

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#### Table: RAPv4/HRRRv3 Summary of Changes

<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>Vertical Coordinate</th>
<th>Pressure Top</th>
<th>Boundary Conditions</th>
<th>Initialized</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>GSD, NCO</td>
<td>North America</td>
<td>953 x 834</td>
<td>13 km</td>
<td>50</td>
<td>Sigma-Isob Hybrid</td>
<td>10 mb</td>
<td>GFS</td>
<td>Hourly (cycled)</td>
</tr>
<tr>
<td>HRRR</td>
<td>GSD, NCO</td>
<td>CONUS</td>
<td>1799 x 1059</td>
<td>3 km</td>
<td>50</td>
<td>Sigma-Isob Hybrid</td>
<td>20 mb</td>
<td>RAP</td>
<td>Hourly (pre-forecast hour cycle)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Version</th>
<th>Assimilation</th>
<th>Radar DA</th>
<th>Radiation LW/SW</th>
<th>Microphysics</th>
<th>Cumulus Param</th>
<th>PBL</th>
<th>LSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>WRF-ARW v3.8.1+</td>
<td>GSI Hybrid Ensemble to 0.85</td>
<td>13-km DFI, ½ Strength</td>
<td>RRTMG/ RRTMG</td>
<td>Thompson Aerosol v3.8.1</td>
<td>GF + Shallow</td>
<td>MYNN v3.8.1</td>
<td>RUC v3.8.1</td>
</tr>
<tr>
<td>HRRR</td>
<td>WRF-ARW v3.8.1+</td>
<td>GSI Hybrid Ensemble to 0.85</td>
<td>3-km 15-min LH</td>
<td>RRTMG/ RRTMG</td>
<td>Thompson Aerosol v3.8.1</td>
<td>None</td>
<td>MYNN v3.8.1</td>
<td>RUC v3.8.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Horiz/Vert Advection</th>
<th>Scalar Advection</th>
<th>Upper-Level Damping</th>
<th>Diffusion Option</th>
<th>6th Order Diffusion</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/5th Positive</td>
<td>Positive</td>
<td>w-Rayleigh 0.2</td>
<td>Full (2)</td>
<td>Yes 0.12</td>
<td>20 min</td>
<td>MODIS Seasonal</td>
<td>0.01 K/s</td>
<td>60 s</td>
</tr>
<tr>
<td>HRRR</td>
<td>5th/5th Positive</td>
<td>Positive</td>
<td>w-Rayleigh 0.2</td>
<td>Full (2)</td>
<td>Yes 0.25</td>
<td>15 min with SW-dt</td>
<td>MODIS Seasonal</td>
<td>0.07 K/s</td>
<td>20 s</td>
</tr>
</tbody>
</table>

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**IOAS-AOLS**  
**RAPv4/HRRRv3**  
**11 Jan 2018**  
**3**
HRRR Ensemble Development/Testing

Deterministic HRRR:
- High-resolution forecast provides small-scale details
- Hourly-updating with fresh forecast always available

Time-Lagged Ensemble (HRRR-TLE):
- Leverage runs in ensemble of opportunity
- Form hazard likelihood probabilities
- Less small-scale detail
- Proxy for confidence/certainty
- Underdispersive

HRRR Ensemble (HRRRE):
- More expensive ensemble
- More spread/dispersive/skill
Complementary Systems: HRRRE and WoF

**HRRRE**

- 3-km CONUS
- Fixed domain
- Hourly updating
- 0-36 hr forecast (2-18 hr)
- “Watch-on-Forecast”
- Mesoscale uncertainty information
- Information supplied to WoF and FACETs
- Many types of “high-impact” weather (clouds, winter precip)

**WoF**

- < 1-km Sub-CONUS
- On-demand domain
- Sub-hourly updating
- 0-3 hr forecast (severe)/0-6 hr QPF
- “Warn-on-Forecast”
- Storm-scale uncertainty information
- Information supplied to FACETs
- Severe storms and heavy rain
Underdispersive:
Observations frequently fall outside range of ensemble forecasts

Overdispersive:
Ensemble frequently forecasts a very large range of solutions

IOAS-AOLS • Ensemble Spread

Ensemble Forecast Challenge: Spread vs Error

11 Jan 2018
Real-Time Web Graphics
http://rapidrefresh.noaa.gov/HRRRE

- Single core (ARW)
- Ensemble DA (GSI-EnKF)
- RAP mean + GDAS (GFS) perturbations
- Conventional observations only (no radar data)

**Assimilation**
- 20 members
- 1 hr cycling
- 21 fcsts / day
- Start 21z day zero
- End 18z day one

**Forecast**
- 00z - Three mem to 30 hr
- 03z - Three mem to 27 hr
- 12z - Six mem to 18 hr
- 15z - Eighteen mem to 15 hr
- 18z - Eighteen mem to 12 hr

Proof-of-concept
Real-time demonstration
With NSSL Experimental WoF System for ensembles “NEWS-e”
• Chased the weather across CONUS with movable on-demand domain
• Used 15-km outer domain for LBCs
HRRRE Case Study: 23 December 2015

Updraft Helicity (m²/s²) 3-7 h forecast

Reports for 12/23/15

- High Wind Report (65KT+)
- Large Hail Report (2" dia. +)

PRELIMINARY DATA ONLY

11 Jan 2018
HRRRE Case Study: 09 May 2016

Convective initiation along dryline

Rain-cooled Boundary

Tornadic supercell development near residual outflow boundary intersection

15z

20z

21z

22z

20z

RS

HRRRE

IOAS-AOLS

11 Jan 2018
1-hr Maximum Updraft Helicity Valid 22z
(colors > 25 m$^2$/s$^2$)

HRRRX 15z-17z initializations
Time-Lagged Ensemble

HRRRE 15z + 7hr fcst valid 22z
HRRRE Observation Space Diagnostics

Black = Observation Error
Red = Ens Bias (mean obs innovation)
Green = Total Spread (ensemble standard deviation + ob error)
Blue = Ens Forecast Error (innovation standard deviation)

Need accurate specification of observation error
Ensemble spread << Observation error → Not drawn towards obs
Based on initial results obs. errors reduced for some datasets

Want total spread to track with forecast errors of the day (green = blue)
Good spread-skill ratio during cycling for most ob types
Ensemble underdispersive in forecast

ACARS temperature (K)

1-h cycling

0-15 h forecast

11 Jan 2018
HRRRE 2017

Real-Time Web Graphics
https://rapidrefresh.noaa.gov/hrrr/HRRRE

- Single core (ARW)
- Hourly cycling ensemble DA (DART and GSI-EnKF)
- RAP mean + GDAS perturbations w/more inflation
- Conventional + Radar reflectivity observations
- Adaptive multiplicative posterior inflation
- Soil moisture + lateral boundary perturbations
- Stochastic LSM and PBL (time permitting)
- Cloud analysis + soil adjustments
- HRRR-TLE post-processing

Proof-of-concept
Real-time demonstration
With NSSL Experimental WoF System for ensembles “NEWS-e”

Assimilation
36 members
1 hr cycling
21 fcsts / day
Start 09z day one
End 00z day two

Forecast
12z – Nine members to 18 hrs
15z – Nine members to 18 hrs
18z – Nine members to 18 hrs
00z – Nine members to 36 hrs
HRRRE 2017 Design

DA Ens

RAP Mean

36 GDAS Members

3-km interp

36 HRRRE members

Ensemble Kalman Filter

10z

36 HRRRE Initial Conditions

Sat/Conv Obs

GSI Soil Adj + Cloud Anal

36 1-hr fcsts

11z

36 HRRRE Initial Conditions

Sat/Conv Obs

GSI Soil Adj + Cloud Anal

36 1-hr fcsts

12z

Ensemble Kalman Filter

36 HRRRE Initial Conditions

Sat/Conv Obs

GSI Soil Adj + Cloud Anal

36 1-hr fcsts

9 HRRRE 18-hr fcsts

Stochastic Parameter Perturbation (SPP) PBL - 00z Only

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14 April 2017 Severe Weather

Isolated Supercell
00z 15 April 2017

SPC Storm Reports for 04/14/17
near isolated STORM TRACK

30 dBz reflectivity CSI vs. forecast length

Increased short-range (0-6 hr) skill from ensemble system

Deterministic HRRR

HRRRE 04/14/2017 (18:00) 6h fcst - Experimental
Valid 04/15/2017 00:00 UTC

Composite reflectivity dB
16 May 2017 Severe Weather Outbreak
2017 Flash Flood and Intense Rainfall Experiment
June 19 - July 21, 2017 Weather Prediction Center College Park, MD
Findings and Results
Sarah Perfater - I.M. Systems Group, NOAA/NWS/WPC/HMT
Benjamin Albright - Systems Research Group, NOAA/NWS/WPC/HMT

Four week 00z initialization 18-24 hr forecast of blended (50% probability matched, 50% arithmetic) mean QPF

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**Figure 19.** Box plot of the subjective scores for the SSEFX, HRRRE, and HREFv2 6 hour blended mean QPF over the course of the experiment. Red plus symbols denote outliers.

**Figure 20.** ROCz Performance Diagram showing skill of the 6 hour blended mean forecast for 0.5 inch QPF from the HREFv2 (dark blue), SSEFX (magenta), and HRRRE (cyan).

**Figure 21.** ROCz Performance Diagram showing skill of the 6 hour blended mean forecast for 1 inch QPF from the HREFv2 (dark blue), SSEFX (magenta), and HRRRE (cyan).
26-28 Aug 2017 Harvey Extreme Rainfall

Experimental
HRRRE Forecast

Ensemble Maximum 36-h QPF (inches)
1200 UTC 26 Aug - 0000 UTC 28 Aug

MRMS Radar-Only Observations
48-h QPE (inches)
1200 UTC 26 Aug - 1200 UTC 28 Aug
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Initial & Lateral Boundary Conditions

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3-km High-Resolution Smoke (VIIRS fire data)

3-km High-Resolution Rapid Refresh Alaska, Hawaii and Puerto Rico Testing (HRRR-AK, HRRR-HI, HRRR-PR) Experimental (ongoing)

3-km Storm-Scale Ensemble Analysis and Forecast (HRRRE) 55% CONUS HRRR Experimental (ongoing)
Frequency Bias Correction Using “Quantile Mapping”

Model forecast climatology adjusted to observation climatology for a particular threshold (1 inch / 6 hrs)

Exploring modified gamma distribution for additional refinement in bias correction

99th %ile analysis climatology = 1.00”

99th %ile model climatology = 1.23”
HRRR-TLE Precipitation Products

Results: Probability of 0.5” Precipitation in 6 hours
May-Aug 2015

With relatively small sample size (~50 forecasts)

Produce statistically reliable probabilities
60% forecasts observed 60% of the time

Produce probabilities with sufficient resolution/sharpness
Large dynamic range to probabilities including extremes

Still fundamentally underdispersive (overconfident)
HRRR Time-Lagged Ensemble (HRRR-TLE)

Current Experimental Probability Products:
- Based on 3 HRRRX runs (equal weight)
- Starting with forecast hour two
- 40-km neighborhood probabilities
- 120-km spatial filter applied after identifying neighborhood hazard exceedance

Real-Time Web Graphics (and grids via LDM/FTP)
http://rapidrefresh.noaa.gov/hrrr/hrrrtle
HRRR-TLE forecasts > 60% probability of 6hr QPF exceeding 100 year average return interval (ARI) in Houston, TX area based on ATLAS14
HRRR-TLE Case Study: 12 UTC 23 June 2016

HRRR-TLE forecasts > 40% probability of 6hr QPF exceeding 100 year average return interval (ARI) in West Virginia area based on ATLAS14

6 hr QPE Valid 18z 23 June 2016

6 hr PQPF > 3”

3+” observed

24 hr QPE Valid 06z 24 June 2016

6 hr PQPF > 100 year ARI

10+” observed

HRRR-TLE 15 hr fcst valid 15z 23 June 2015
HRRRE vs HRRR


HRRRE skill > HRRRv3

to 10 hrs

HRRRv3 skill > HRRRE

beyond 10 hrs

Benefit of storm-scale ensemble DA

Need to improve meso-synoptic-scale DA
HRRRE 2018

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- Single core (ARW)
- Hourly cycling ensemble DA (GSI-EnKF only)
- RAP mean + 15-km RAP-like mesoscale perturbations
- Conventional + reflectivity + radial velocity + cloud base height
- Adaptive multiplicative posterior inflation, vertical localization
- Soil moisture + lateral boundary perturbations
- Stochastic parameters across entire physics package
- Cloud analysis + soil adjustments
- HRRR-TLE post-processing

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Producing all GRIB2 output on CONUS HRRR grid (missing data will be in regions when 55% CONUS executed)

Proof-of-concept
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RAP/HRRR Implementation Roadmap

ESRL/GSD – experimental version

- RAPv4 – GSD tested in 2016-17
  - Is initializing 2017 ESRL-HRRR(v3)
  - Improved PBL, LSM, cu-parm, DA
  - WRFv3.8.1 w/Thompson/NCAR aerosol-aware microphysics

- HRRRv3 – GSD tested in 2016-17
  - Initialized by 2017 RAP (v4)
  - Improved radar assimilation, hybrid vertical coordinate, PBL/cloud physics

- RAPv5 – GSD testing in 2018-19
  - Improved PBL, LSM, cu-parm, DA

- HRRRv4 – GSD testing in 2018-19
  - Improved 3km physics
  - Full 3-km hourly cycling
  - Storm-scale ensemble data assimilation and forecasts (HRRRE)?
  - Cycling of aerosols with fire/smoke/emissions

NWS-NCEP - operational

- Implement mid 2018

See R2O Session 1:30-3:00 pm Hilton Room 404
RAPv4/HRRRv3: 2:30-2:45 pm

IOAS-AOLS • Timeline

11 Jan 2018 • 27