Automated High-Resolution Ensemble-Based Hazard Detection Guidance

20 April 2016

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NOAA/ESRL/GLOBAL SYSTEMS DIVISION
Moore, OK Tornado
20 May 2013
25 fatalities
1,150 homes destroyed

Yarnell, AZ Wildfire
30 June 2013
19 firefighter fatalities

Colorado Floods
9-15 September 2013
10,000 properties damaged or destroyed

Atlanta, GA Snowstorm
28 January 2014
$75 million in insurance claims

Research to Reduce Disasters and Enhance Resilience
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Ensemble-Based Hazard Detection Guidance
RAP/HRRR: Hourly-Updating Weather Forecast Models

13-km Rapid Refresh (RAP) – to 21h (June 2016)

3-km High-Resolution Rapid Refresh (HRRR) – to 18h (June 2016)

750-m HRRR nest Wind Forecast Improvement Project Experiment (ongoing)

Prototype 3-km storm-scale HRRR ensemble (HRRRE) (Spring 2016)

Expanded RAP to match NAM for SREF (June 2016)

3-km High-Resolution Rapid Refresh Alaska Testing (HRRR-AK) w/MRMS radar data (Spring 2016)

3-km High-Resolution Time Lagged Ensemble (HRRR-TLE)
Multiple runs from the HRRR can provide additional forecast insight and can be grouped into categories:

- **Run-to-run consistency (at least 3 consecutive runs)**
  - More common in strongly-forced events and can enhance forecast confidence
  - Solution, on limited occasions, could be erroneous, particularly in more weakly-forced events

- **Trend in guidance towards a particular solution (3 or more consecutive runs)**
  - Examples including increasing convective initiation/coverage
  - Forecasters should be judicious when extrapolating trends

- **Trend (at least 3 consecutive runs) then an abrupt change to a different solution/trend**
  - First run after convective initiation
  - First run assimilating new RAOB data (00/12 UTC)
  - Latest GFS cycle used (10/22 UTC)

- **No consistency and no trend with 3 or more consecutive runs with very different solutions**
HRRR Forecast Consistency Example

Radar Obs at 2200 UTC

11 May 2014
Storm Reports

Updraft Helicity
Time-Lagged Ensemble

HRRR Forecasts valid at 2200 UTC

15 UTC (7hr) 16 UTC (6hr) 17 UTC (5hr)
Project Overview

Challenge:
- About 5 trillion bits of data from a single 15-hr HRRR forecast
- How to extract most useful information for forecasters?

Goal:
- Automated monitoring of hourly-updating model forecasts
- Measure run-to-run consistency/trends in forecasted hazards
- Provide *accurate* measure of confidence (uncertainty) for hazards

How:
- Post-process model output (computationally inexpensive)
- Create multi-run ensemble of HRRR (and other) forecasts
- Identify forecasted hazards (heavy rainfall, snow bands, severe storms)
- Form probabilistic gridded guidance of the hazards and bias correct for statistical reliability
HRRR Time-Lagged Ensemble (HRRR-TLE)

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

Real-time

Member 1
Member 2
Member 3

Supercell probability past hour

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HRRR-TLE Severe Weather Example

Forecasts valid 22-23z

8 - 9 hr forecast

9- 10 hr forecast

10 - 11 hr forecast

HRRR 13z Init

HRRR 12z Init

HRRR 11z Init

Forecasts valid 23-00z

11 - 12 hr forecast

10- 11 hr forecast

11 - 12 hr forecast

Tornadic Storm Probability (%)

Neighborhood Search
Point Probability

Spatial radius 45 km
Time radius 1 hr
UH threshold 25 m²/s²

All six forecasts combined to form probabilities valid 22z 27 April 2011
11 Hour Forecast Valid 00z 23 May 2011

Tornadic Storm Probability (%)

22 May 2011
Storm Reports

Tornado = Red Dots

Joplin, MO

Observed Reflectivity
00z 23 May

HRRR-TLE Severe Weather Example
General convection problem (aviation application)
90 km search radius
\( \geq 1 \text{ m/s upward vertical motion in model column} \)
\( \leq 2\text{K} \) best lifted index
HRRR Convective Probability Forecast (HCPF) \( \rightarrow \) HRRR-TLE product
**HRRR-TLE Winter Weather Example**

Winter Weather Application
12 hr HRRR-TLE Forecast
27 Jan 2015 New England Blizzard

Three consecutive runs
45 km spatial radius
No time radius (1hr accumulation)

Probability of snowfall > 1”/hr
Probability of snowfall > 2”/hr

12-h HRRR time-lagged ensemble forecasts of heavier snow regions and sample feature extraction, valid 0900 UTC for Jan 27, 2015 New England blizzard.
HRRR component improvements to address warm/dry bias in RAPv3/HRRRv2

<table>
<thead>
<tr>
<th>Component</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSI Data Assimilation</td>
<td>Canopy water cycling</td>
</tr>
<tr>
<td></td>
<td>Temp pseudo-innovations thru model boundary layer</td>
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<td></td>
<td>More consistent use of surface temp/dewpoint data</td>
</tr>
<tr>
<td>GFO Convective Parameterization</td>
<td>Shallow cumulus radiation attenuation</td>
</tr>
<tr>
<td></td>
<td>Improved retention of stratification atop mixed layer</td>
</tr>
<tr>
<td>Thompson Microphysics</td>
<td>Aerosol awareness for resolved cloud production</td>
</tr>
<tr>
<td></td>
<td>Attenuation of shortwave radiation</td>
</tr>
<tr>
<td>MYNN Boundary Layer</td>
<td>Mixing length parameter changed</td>
</tr>
<tr>
<td></td>
<td>Thermal roughness in surface layer changed</td>
</tr>
<tr>
<td></td>
<td>Coupling boundary layer clouds to RRTMG radiation</td>
</tr>
<tr>
<td>RUC Land Surface Model</td>
<td>Reduced wilting point for more transpiration</td>
</tr>
<tr>
<td></td>
<td>Keep soil moisture in croplands above wilting point</td>
</tr>
</tbody>
</table>

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**Reduced warm / dry bias**

- **2m Temp**
  - Exper RAPv3 vs Oper RAPv2
  - Difference chart showing temperature variations over time (UTC).

- **2m Dewpt**
  - Exper RAPv3 vs Oper RAPv2
  - Difference chart showing dewpoint variations over time (UTC).
2013 Warm Season (June-August)

HRRR 0-6 hr precipitation forecast
Difference against Stage IV
2014 Warm Season (June-August)

HRRR 0-6 hr precipitation forecast
Difference against Stage IV

HRRR Model Improvements (HRRRv2)

HRRR 6h fcsts from 01JUN - 31AUG 2014

HRRR - StageIV Diff (Precipitation Total)

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2015 Warm Season (June-August)

HRRR 0-6 hr precipitation forecast difference against Stage IV

Reduction in high precipitation bias
Statistical Improvement in QPF skill
Reduction in bias from 2014 to 2015
Particularly at higher thresholds
HRRR-TLE Development: Bias Correction

PQPF Product Development

Bias Correction

Frequency Bias Correction Using “Quantile Mapping”

Adjust model forecast climatology to observation climatology for a particular threshold (1 in / 6 hrs)
Efficient, real-time bias correction is possible with a small training dataset

Want to limit sample size to single season or even weather regime
Membership Size

Maximize available forecast lengths (smaller ensemble)

Maximize spread/skill relationship (larger ensemble)

Three members (runs) appears sufficient but still underdispersive
Spatial Filter Size

Minimize forecast phase error penalty (larger filter)

Minimize forecast forcing variability in complex terrain and different weather regimes (smaller filter)

40-60 km appears sufficient
HRRR-TLE: Products

Real-Time Web Graphics
http://rapidrefresh.noaa.gov/hrrrtle

Current Experimental Probability Products:
- Based on 3 HRRRX runs (equal weight)
- Starting with forecast hour two
- 40 km neighborhood probabilities

1-hr, 3-hr, 6-hr QPFs
1-hr time filter (not on 3 or 6)
1-hr snowfall rates
+/- 1-hr ASNOW time filter
6-hr snowfall accumulations
Uses ASNOW (variable density/melt)

General Thunderstorm
UVV > 1 m/s, LI < -1C, > 0.01 precip

4-hr Wind
10 m max wind speed > 50 kts

4-hr Hail
VIG > 25 kg/m²

4-hr Tornado
UH > 100 m²/s², LCL < 1.5 km,
0-1 km shear > 10 m/s, SBCAPE > 75% max

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GRIB2 grids available on GSD LDM and FTP pull
Consecutive HRRR runs produced > 6” precip in ~12 hrs in/near Houston, TX.
HRRR-TLE forecasts > 60% probability of 6hr QPF exceeding 100 year average return interval (ARI) in Houston area based on ATLAS14
<table>
<thead>
<tr>
<th>Organization/Experiment</th>
<th>Hazards</th>
<th>Platform</th>
<th>Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPC WWE</td>
<td>PQPF, Snowfall, Snow Rate</td>
<td>NAWIPS and web site</td>
<td>January 2016</td>
</tr>
<tr>
<td>NSSL/SPC EFP/EWP</td>
<td>Tornadoes, Hail, Wind</td>
<td>NAWIPS and AWIPSII</td>
<td>May 2016</td>
</tr>
<tr>
<td>WPC FFaIR</td>
<td>Refined PQPF and FF guidance</td>
<td>NAWIPS</td>
<td>June 2016</td>
</tr>
<tr>
<td>AWC Summer Experiment</td>
<td>Initial aviation hazards: ceiling, visibility, convection</td>
<td>NAWIPS</td>
<td>August 2016</td>
</tr>
<tr>
<td>WPC WWE</td>
<td>Refined winter hazards and PQPF</td>
<td>NAWIPS</td>
<td>January 2017</td>
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<td>Refined aviation hazards</td>
<td>NAWIPS and AWIPSII</td>
<td>August 2017</td>
</tr>
<tr>
<td>Initiate NCO ‘on-boarding”</td>
<td>All</td>
<td>IDP</td>
<td>2018</td>
</tr>
</tbody>
</table>
# HRRR-TLE: Product Development Methodology

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Proxy</th>
<th>Truth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy rainfall</td>
<td>QPF</td>
<td>Stage-IV / MRMS</td>
</tr>
<tr>
<td>Snowfall rate</td>
<td>Microphysics-based</td>
<td>ASOS visibility</td>
</tr>
<tr>
<td>Precipitation type</td>
<td>Microphysics-based</td>
<td>ASOS type</td>
</tr>
<tr>
<td>Accum Snow</td>
<td>Explicit snow depth</td>
<td>Point observations</td>
</tr>
<tr>
<td>Severe wind</td>
<td>80-m hourly max wind or 10-m gust</td>
<td>METAR/mesonet observations</td>
</tr>
<tr>
<td>Large hail</td>
<td>Column graupel, updraft speed, ?</td>
<td>MESH</td>
</tr>
<tr>
<td>Tornado*</td>
<td>Updraft helicity</td>
<td>Post-processed MRMS rotation tracks</td>
</tr>
<tr>
<td>Visibility/Ceiling</td>
<td>Post-processed field in development</td>
<td>ASOS or future CIMSS technique</td>
</tr>
</tbody>
</table>
HRRRE

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

- Single core (ARW)
- Ensemble DA (EnKF) – RAPX 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 27 hr
- 03z - Three mem to 24 hr
- 12z - Six mem to 15 hr
- 15z - Eighteen mem to 12 hr
- 18z - Eighteen mem to 9 hr? (resources allowing)

Beginning development of formal 3-km data assimilation and forecast ensemble where these same post-processing techniques can be applied.

Prototype 3-km storm-scale HRRR ensemble domain 2016

More accurate storm-details from ensemble data assimilation

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HRRR-TLE: Summary

- Three-year USWRP-Funded HRRR Time-Lagged Ensemble Development
- Producing Probabilistic Hazard Prediction Guidance
- Ensuring Statistically Reliable Probabilities
- Engaging NCEP National Centers and Participating in Testbed Evaluations
- Transition to Operations Plan
- Experimental Real-Time GRIB2 LDM/FTP Feed Available
- Web Page Graphics Also Available
- An Evolutionary Step on the Path to Full 3-km Data Assimilation and Forecast Ensemble