PROBABILISTIC THUNDERSTORM GUIDANCE FROM THE HIGH RESOLUTION RAPID REFRESH (HRRR) MODEL: Evaluation and evolution of a prototype system

Eric James¹, Curtis Alexander¹, Steve Weygandt², Stan Benjamin², and Patrick Hofmann¹

¹CIRES/University of Colorado and NOAA/ESRL/GSD
²NOAA/ESRL/GSD

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Motivation

- Aviation impacts of deep, moist convection often occur on very small time and space scales.

- Convective parameterizations in standard NWP models are not capable of producing convective cells with realistic structure and evolution.

- High-resolution NWP guidance can better resolve convective cells, improving convective forecasts.

- However, the inherent lack of predictability of the exact timing and location of convection suggests that these forecasts should be complemented with a probabilistic framework.
The High Resolution Rapid Refresh (HRRR)

- WRF-ARW core
- 3-km resolution, 51 vertical levels
- Nested inside 13-km Rapid Refresh (RR)
- Run every hour out to 15 hours
- Diabatic digital filter initialization (DDFI) spins up model forecast from RR model radar assimilation

Hourly Updated NOAA NWP Models

Rapid Refresh (RR) replaces RUC at NCEP planned for July 2011
- WRF/GSI, both RUC-based enhancements

High-Resolution Rapid Refresh
Experimental 3km nest inside RUC or RR, new 15-h fcst every hour, central to 2-8h CoSPA
The **HRRR Convective Probability Forecast (HCPF)**

- The HCPF is constructed by using a time-lagged ensemble of several hours of HRRR runs.

- Thresholds in model fields are used to identify regions of active convection in each forecast hour of each HRRR run.

- Counts of convective gridpoints within a search radius and time window are used to calculate a probability.

- This probability is smoothed to create the final HCPF field.
Example: 15z + 2, 4, 6 hour HCPF

Model runs used

Model has 2h latency

Forecast Valid Time (UTC)
Time-lagged spatial filter

Calculate probability:

Find fraction of points within radius that exceed the threshold

Example

Threshold > 1.0 m s\(^{-1}\)

Probability = \(\frac{7}{21}\) = 33 %

<table>
<thead>
<tr>
<th>Updraft (m s(^{-1}))</th>
<th>&lt;0.5</th>
<th>0.5-1.0</th>
<th>1.0-2.0</th>
<th>2.0-3.0</th>
<th>3.0+</th>
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**HCPF Formulation**

- The HCPF uses a time-lagged ensemble to estimate likelihood of convection.
- Deep, moist convection is identified using thresholds in forecast fields:
  - Instability (lifted index < +2 °C)
  - Updraft intensity (updraft in model column > ~1 m s\(^{-1}\))
- Search conducted over:
  - Time (two hour search window centered on valid times)
  - Space (criteria evaluated within 30 gridpoints (radius ~90 km) of each gridpoint for each member)

- \( \text{HCPF} = \frac{\text{# of gridpoints matching criteria over all members}}{\text{total # of gridpoints searched over all members}} \)
Logistic Regression

- The raw HCPF fields are not statistically reliable; statistical reliability can be improved through the use of a logistic regression to determine the weights of each member HRRR forecast.

- Training period for logistic regression: 01-07 Jun 2010 (CONUS)

- \( P(\text{convection}) = \left[1 + \exp(-z)\right]^{-1} \)

- \( z = B_0 + B_1 x_1 + B_2 x_2 + B_3 x_3 \)

  where \( B_i \) are the regressed weights and \( x_i \) are the predictors (member HRRR forecasts).

- A new training period from 2011 will be used to recalculate the weights \( B_i \).
Recent HCPF Developments

- The HCPF code has been re-written in Fortran 90, a more flexible and efficient language (for this purpose) than the original NCAR Command Language (NCL).

- The new version of the code incorporates flexibility in:
  - The specific variables used to identify convection
  - The exact values of the thresholds for these variables
  - The temporal search radius (time window)
  - The spatial search radius
  - The weights for each HRRR run member

- The code also now allows thresholds to vary by time of day, lead time, and region

- HCPF input: two-dimensional hourly GRIB2 HRRR files from several previous hours’ HRRR runs
- HCPF output: GRIB2 probability fields, which are then used to create graphics (GRIB2 output not yet implemented)
Example: 4 Jul 2011

- Morning bands of thunderstorms over Tennessee and Kentucky moved eastward during the afternoon.

- CCFP had an area of high confidence, sparse coverage over North Carolina and Virginia, but the larger low confidence area did not extend northward into Pennsylvania.

- By mid-afternoon, convection crossed the Appalachians and was approaching major cities near the East Coast.

- Quantitative verification system for the HCPF is still in progress.
3 HRRR Run Members
2300 UTC 04 Jul 2011 6-h Forecast of Convective Probability (%)

All stats for 40% probability threshold

Bias 29.14
CSI 0.0173

Observed radar 23Z
All 3 runs: 90-km search radius
2-h time window
0.7 m s⁻¹ max updraft
2 °C lifted index

4 HRRR Run Members
2300 UTC 04 Jul 2011 6-h Forecast of Convective Probability (%)

Bias 28.47
CSI 0.0174

Forecast becomes increasingly smooth with more members

5 HRRR Run Members
2300 UTC 04 Jul 2011 6-h Forecast of Convective Probability (%)

Bias 39.90
CSI 0.0170

The amplitude of the probabilities also decreases with more HRRR members
90-km Search Radius
2300 UTC 04 Jul 2011 6-h Forecast of Convective Probability (%)

Bias 29.14
CSI 0.0173

All 3 runs:
3 HRRR members
2-h time window
0.7 m s\(^{-1}\) max updraft
2 °C lifted index

Composite Reflectivity
Derived From Meso3D

Observed radar 23Z

A larger search radius also smoothes the final probabilities

90-km search radius matches time window of 2 h (using a typical convective propagation speed of \(~10\) m s\(^{-1}\))

45-km Search Radius
2300 UTC 04 Jul 2011 6-h Forecast of Convective Probability (%)

Bias 30.65
CSI 0.0163

135-km Search Radius
2300 UTC 04 Jul 2011 6-h Forecast of Convective Probability (%)

Bias 27.74
CSI 0.0186
A larger time window results in a slightly more smoothed field.

Bias 29.14
CSI 0.0173

All 3 runs: 3 HRRR members
90-km search radius
0.7 m s⁻¹ max updraft
2 °C lifted index

Bias 31.54
CSI 0.0175

Bias 27.80
CSI 0.0185
The exact value of the instability threshold does not have a significant impact on the HCPF. Instability threshold is important to mask out non-convective vertical motions (synoptic and orographically forced).
The value of the updraft threshold for convection does have a large effect, thus it is important how we define convection.
Equally Weighted HRRR Run Members

Earlier HRRR Runs Weighted More

Weights: 50%, 33%, 17%

Weighting HRRR members has little impact

Overall, HCPF is underdispersive; run-to-run variability is too small

VSREF will address this

More Recent HRRR Runs Weighted More

Bias 29.14
CSI 0.0173

Bias 26.96
CSI 0.0181

Bias 31.70
CSI 0.0165

All 3 runs:
3 HRRR members
2-h time window
0.7 m s\(^{-1}\) max updraft
2 °C lifted Index

90-km search radius
35 dBZ Threshold, No Time Window

2300 UTC 04 Jul 2011 6-h Forecast of Convective Probability (%)

Bias 0.07
CSI 0.0000

3 HRRR members
2 °C lifted Index
90-km search radius

The HCPF ends up having bulls eyes in the vicinity of each HRRR member run’s convection

A temporal search radius is needed. This example shows the very low probabilities that result from using an instantaneous field (in this case comp. reflectivity)
Visualization Concepts

Confidence Probabilities Only
Visualization Concepts

Confidence Probabilities Only
Visualization Concepts

Confidence Probabilities and Deterministic

10 hr Forecast Probability of Convection Valid 23 UTC 16 July 2010

Valid 23z 16 July 2010
Visualization Concepts

Confidence Probabilities and Deterministic
Visualization Concepts

Confidence Probabilities and Deterministic
Real-time HCPF

http://ruc.noaa.gov/hcpf/hcpf.cgi

Current verification  HCPF lead times
Collaborative work EMC (Binbin Zhou), GSD

**VSREF – Very Short Range Ensemble Forecast**

- RR - hourly time-lagged ensemble members
- HRRR – hourly time-lagged ensemble members
- NAM
- NMM
- NMM-B (Nest)

**Updated Hourly Probabilistic Forecasts**
Conclusions and Future Improvements

- Recent developments with the HCPF code have greatly improved flexibility and allowed testing of all the component parameters; code is now compatible with VSREF software.

- Quantitative verification against other convective probability products, including CCFP, will demonstrate the value of the HCPF for operational aviation forecasting.

- In the future, HRRR sub-hourly diagnostic output will be used to produce the HCPF with sub-hourly temporal search radii.

- A new training period will be selected and used in a logistic regression to update the weights for the HCPF.

- Ultimately, the HCPF will be expanded to include probabilistic forecasts of other aviation-relevant variables (turbulence, echo top, etc.), and to include other models (such as the RUC and RR) in the ensemble; this will be an expansion of NCEP’s Very Short Range Ensemble Forecast (VSREF) system.