PROBABILISTIC THUNDERSTORM GUIDANCE FROM THE HIGH RESOLUTION RAPID REFRESH (HRRR) MODEL:

Evaluation and evolution of a prototype system

Eric James[1], Curtis Alexander[1], Steve Weygandt[2], Stan Benjamin[2], and Patrick Hofmann[1]

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

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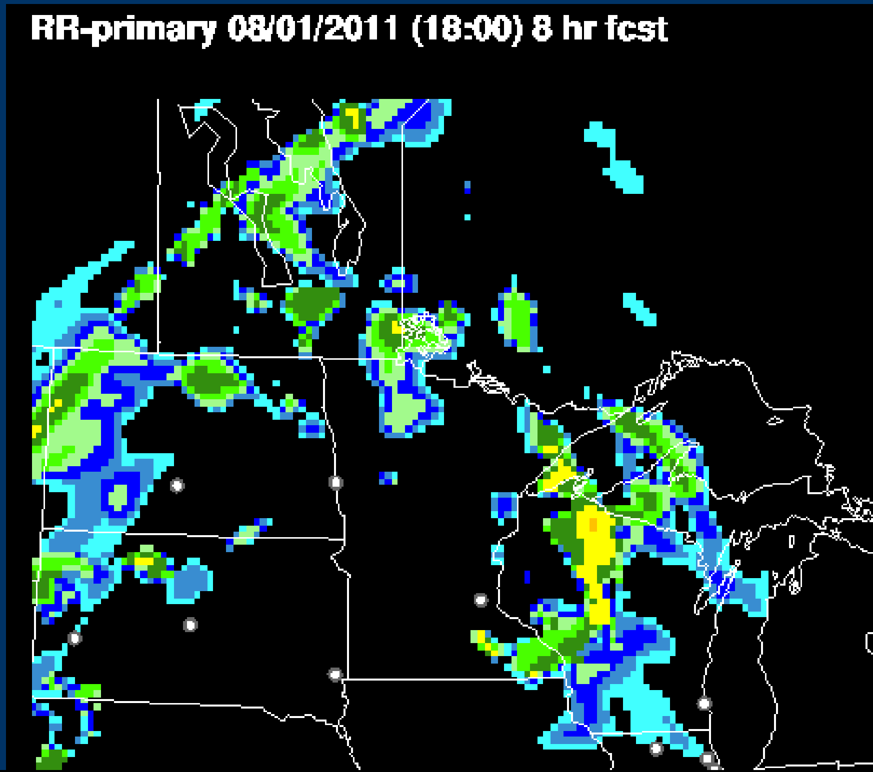
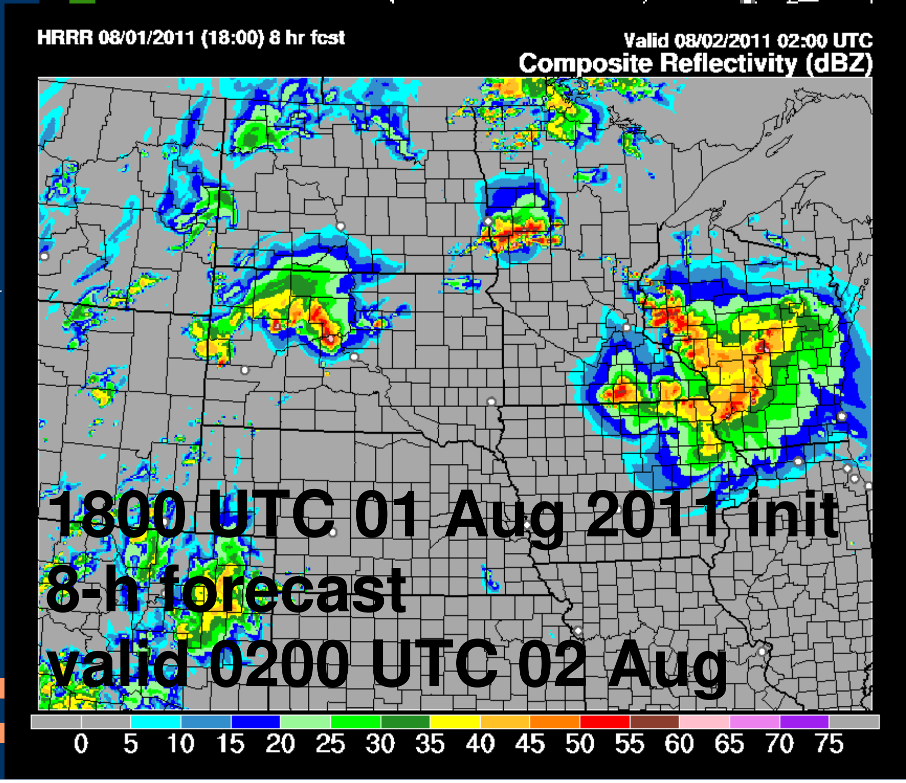
Motivation

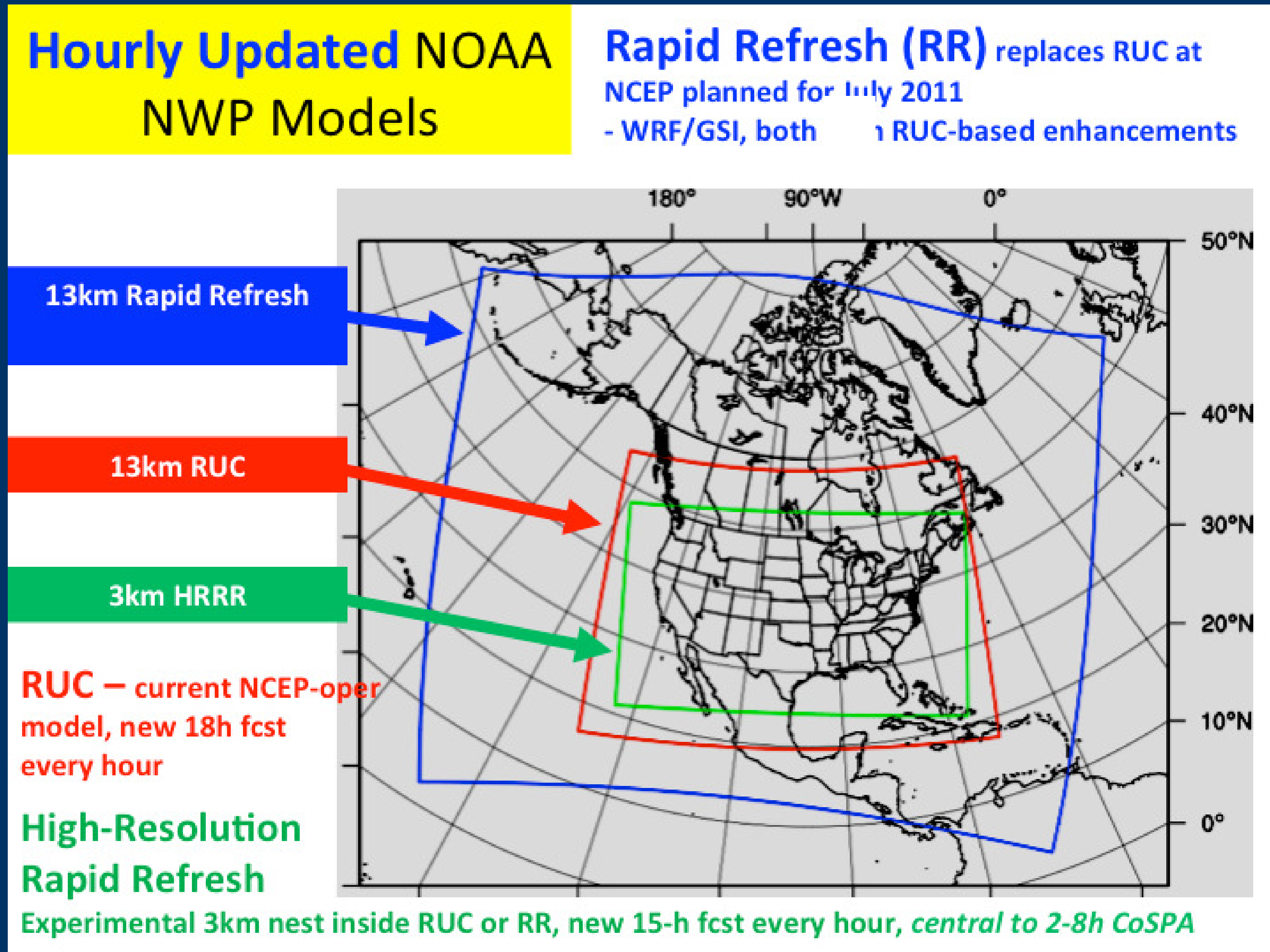
- Aviation impacts of deep, moist convection often occur on very small time and space scales
- Convective parameterizations in standard NWP models are not capable of producing convective cells with realistic structure and evolution
- High-resolution NWP guidance can better resolve convective cells, improving 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





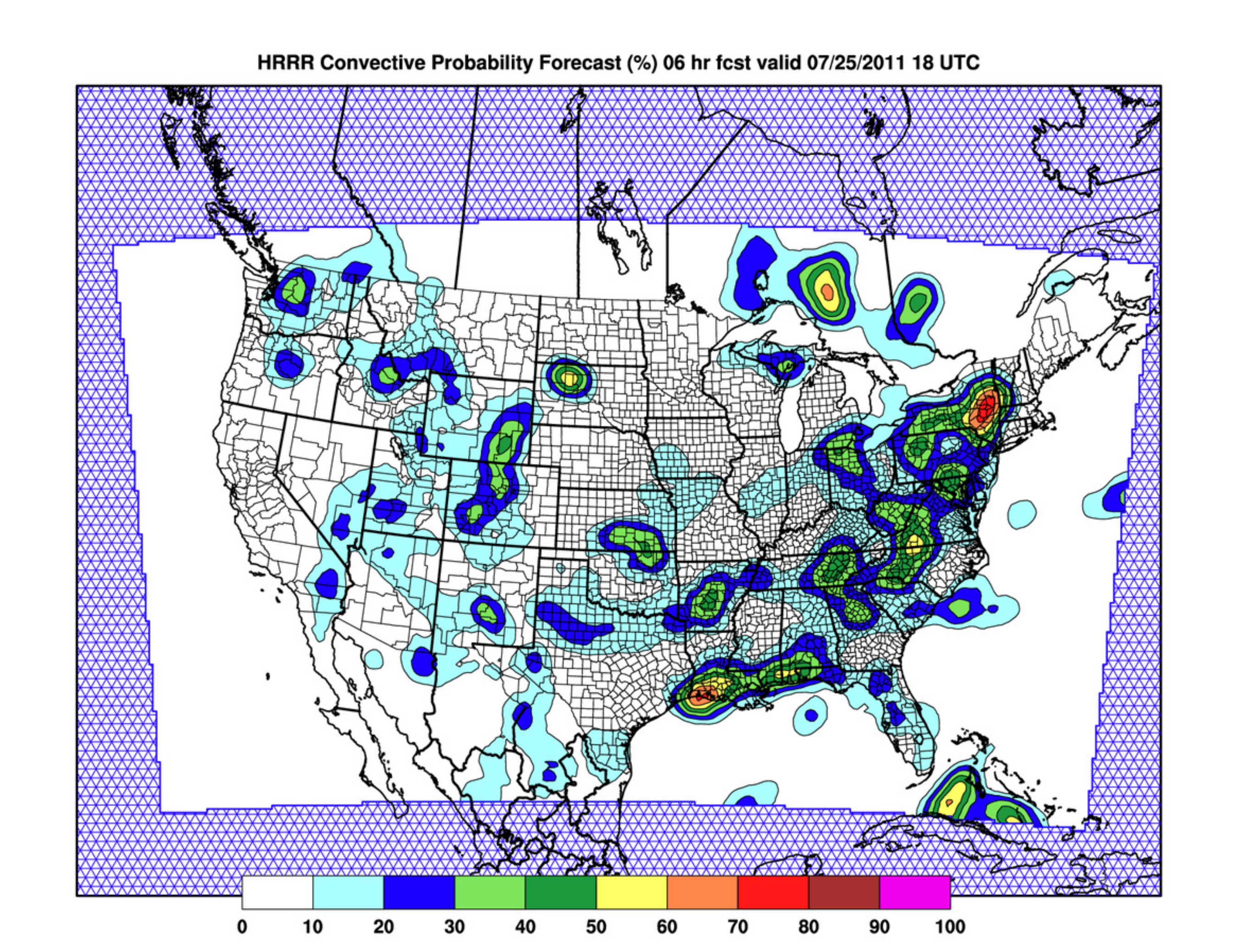
The High Resolution Rapid Refresh (HRRR)

- 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



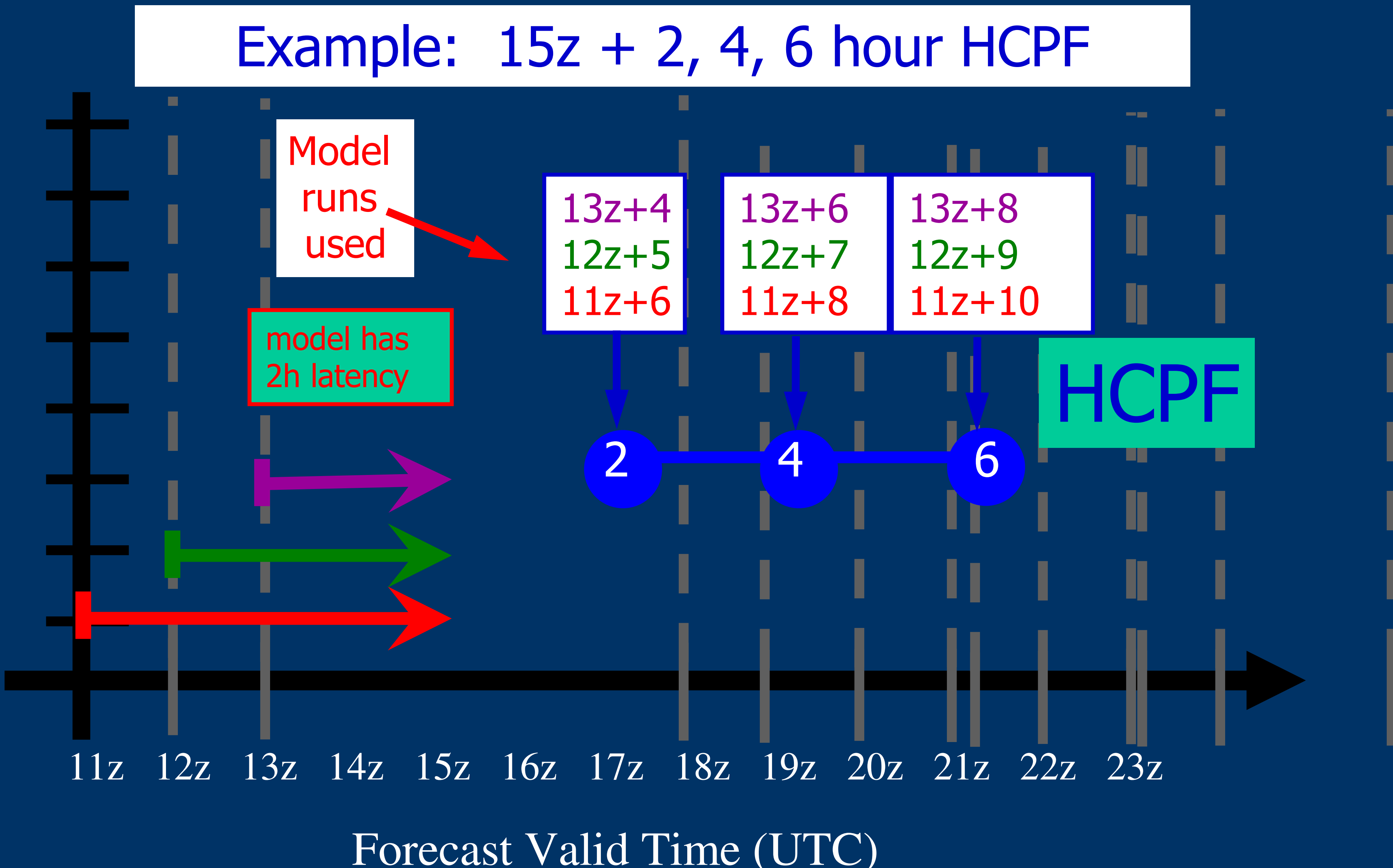
The HRRR Convective Probability Forecast (HCPF)

- 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

Time-lagged ensemble



Time-lagged spatial filter

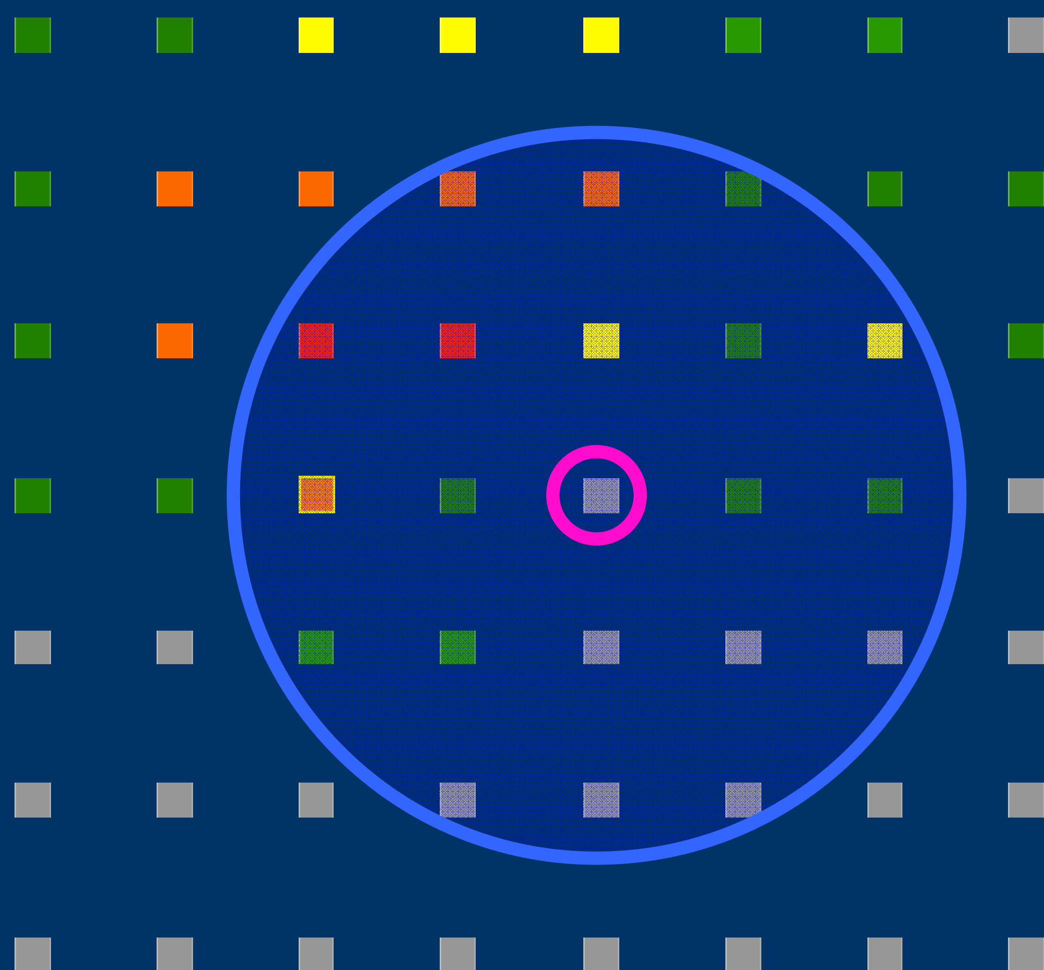
<u>Calculate probability:</u>

Find fraction of points within radius that exceed the threshold

<u>Example</u>

Threshold > 1.0 m s^{-1}

Probability = 7 / 21
= 33 %



Updraft (m s^{-1})

<0.5 | 0.5-1.0 | 1.0-2.0 | 2.0-3.0 | 3.0+

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

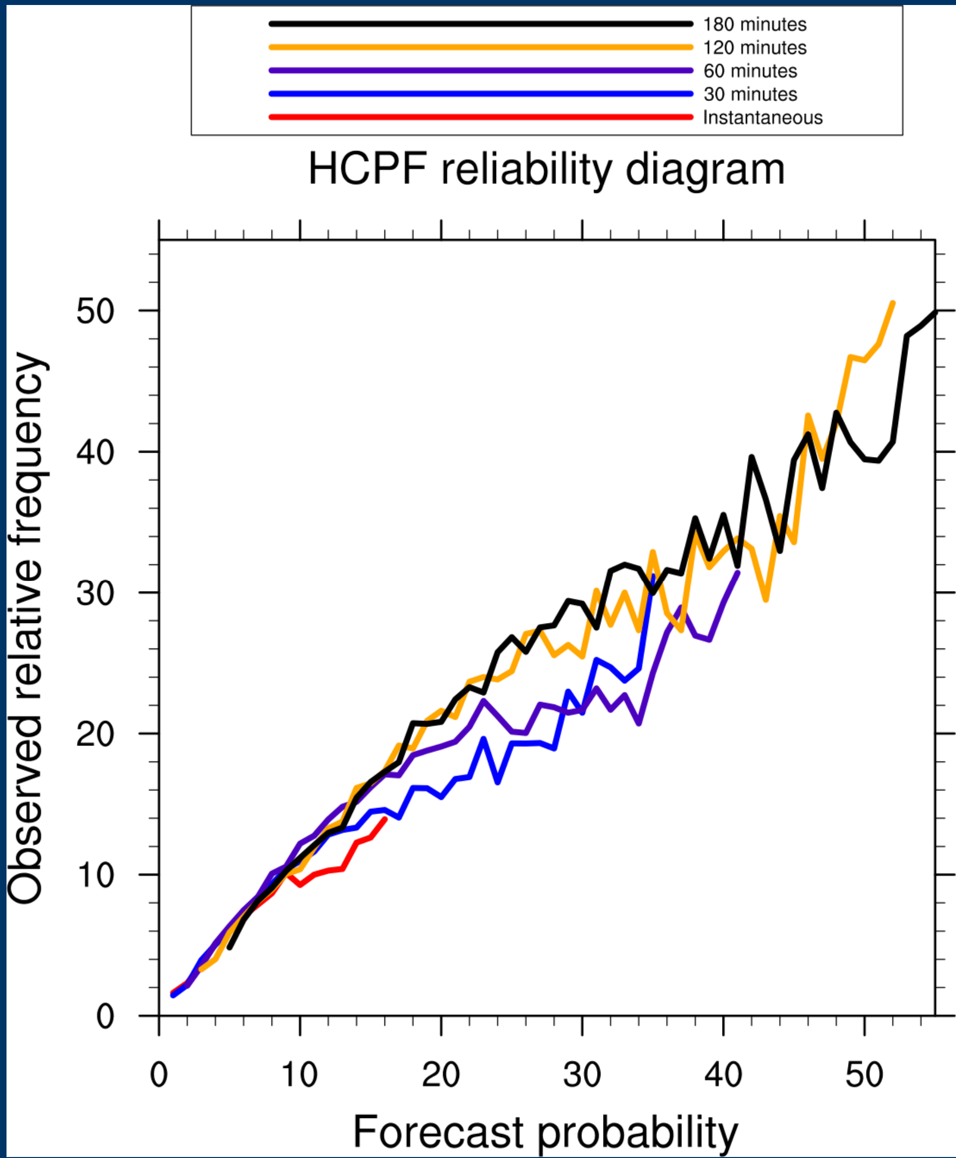
- The raw HCPF fields are not statistically reliable; statistical reliability can be improved through the use of a logistic regression to determine the weights of each member HRRR forecast

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

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

- $z = B_0 + B_1x_1 + B_2x_2 + B_3x_3$
  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)

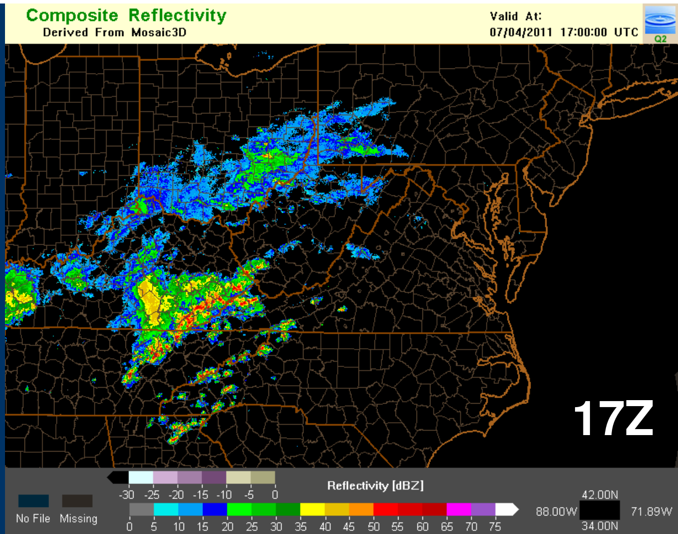
- The new version of the code incorporates flexibility in:
  - The specific variables used to identify convection
  - The exact values of the thresholds for these variables
  - The temporal search radius (time window)
  - The spatial search radius
  - The weights for each HRRR run member

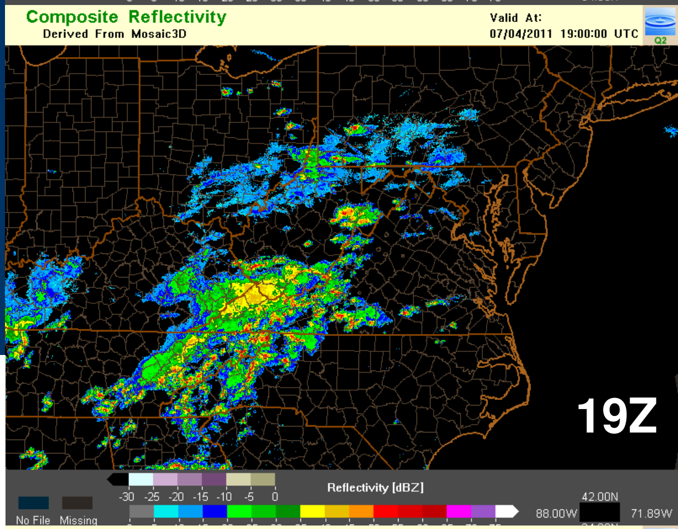
- The code also now allows thresholds to vary by time of day, lead time, and region

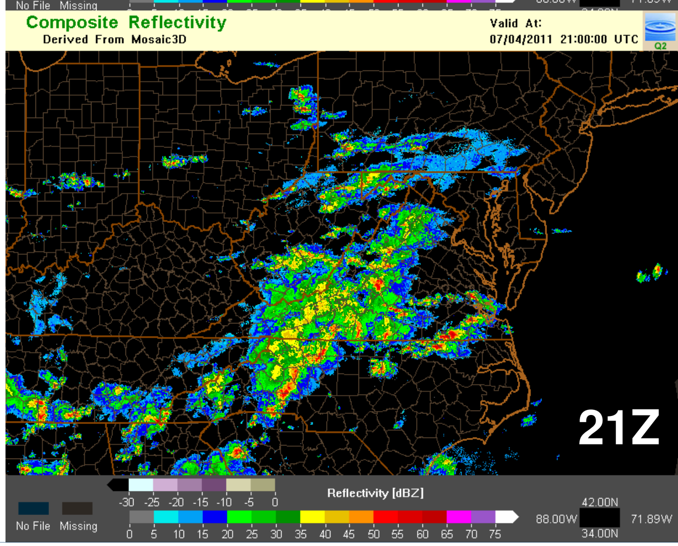
- HCPF input: two-dimensional hourly GRIB2 HRRR files from several previous hours' HRRR runs
- HCPF output: GRIB2 probability fields, which are then used to create graphics (GRIB2 output not yet implemented)

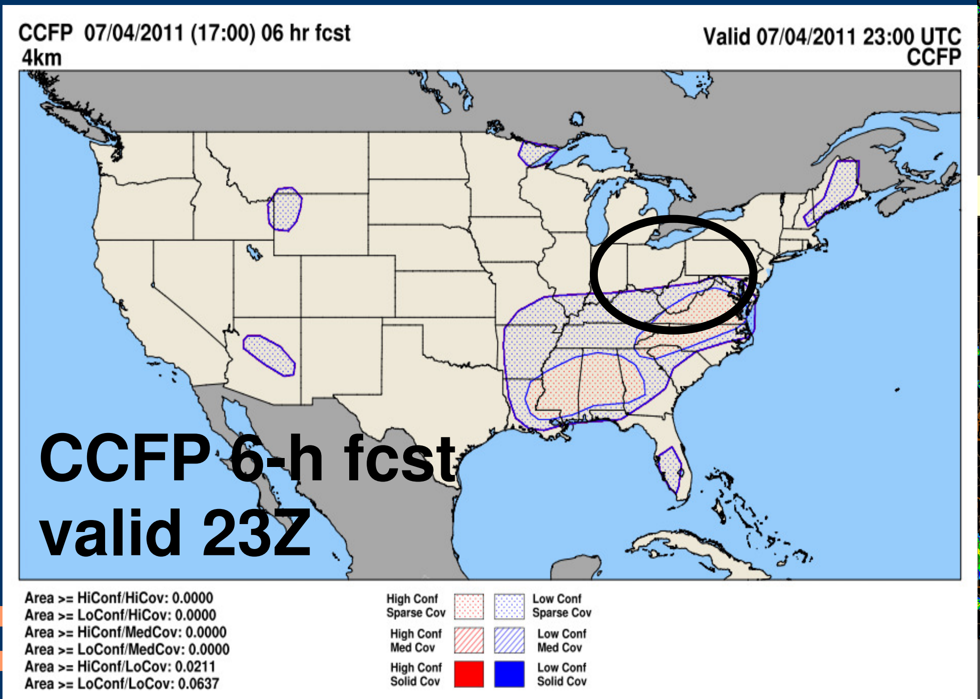
Example: 4 Jul 2011

- 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





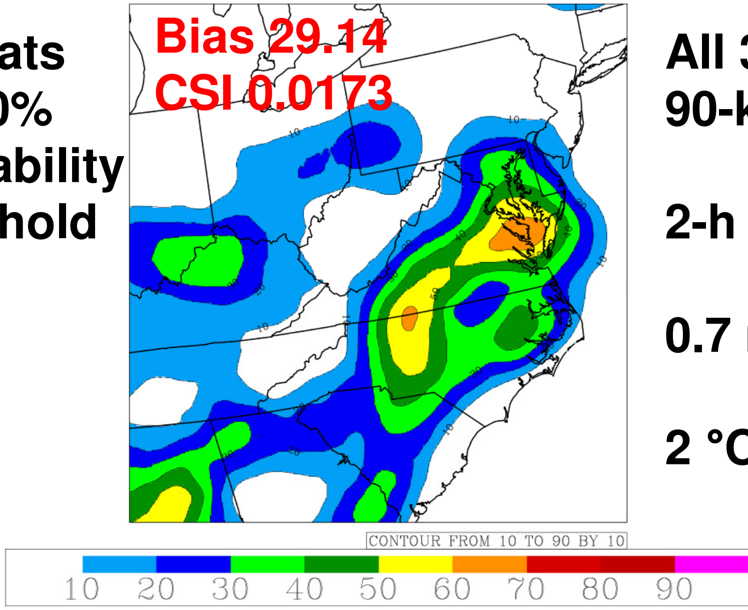




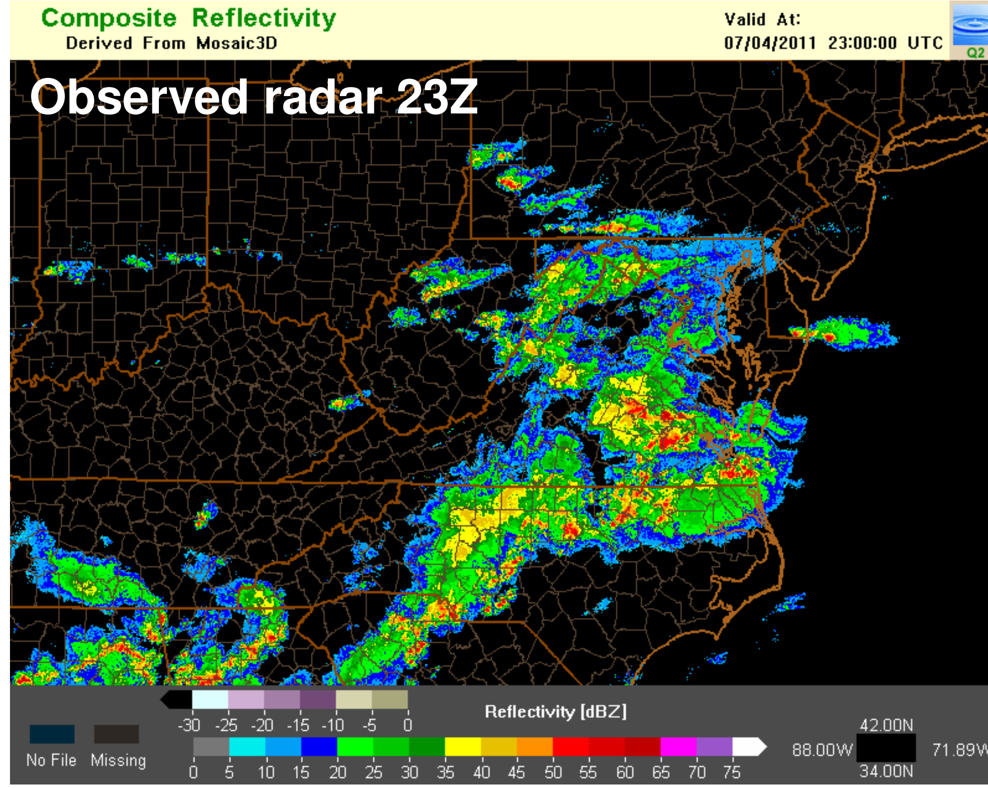
3 HRRR Run Members

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

All stats for 40% probability threshold

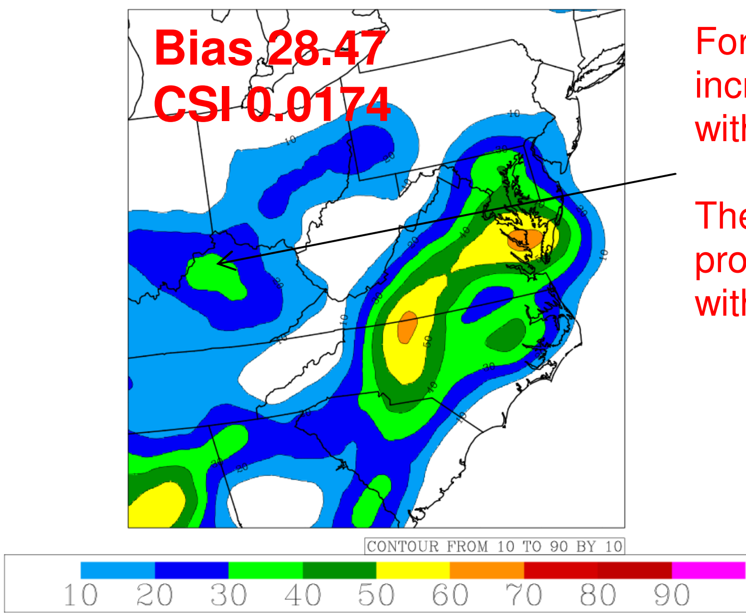


All 3 runs:
90-km search radius
2-h time window
0.7 m s^{-1} max updraft
2 °C lifted index



4 HRRR Run Members

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

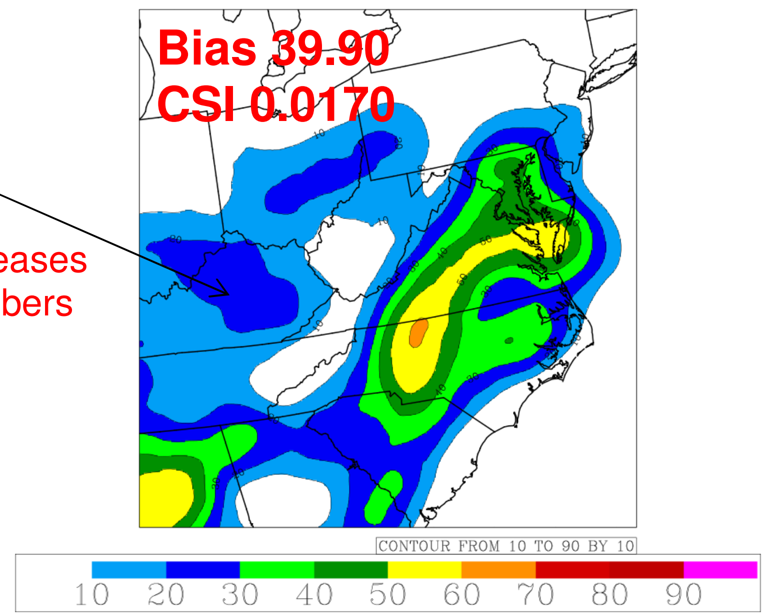


Forecast becomes increasingly smooth with more members

The amplitude of the probabilities also decreases with more HRRR members

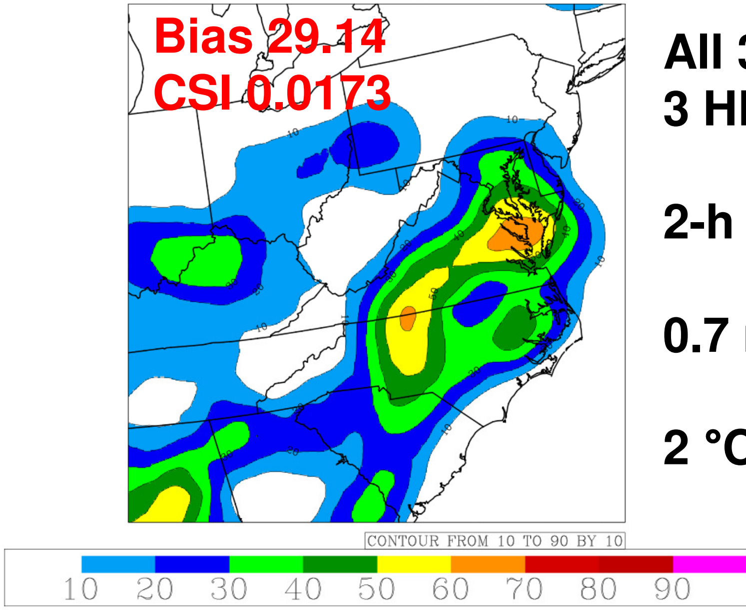
5 HRRR Run Members

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

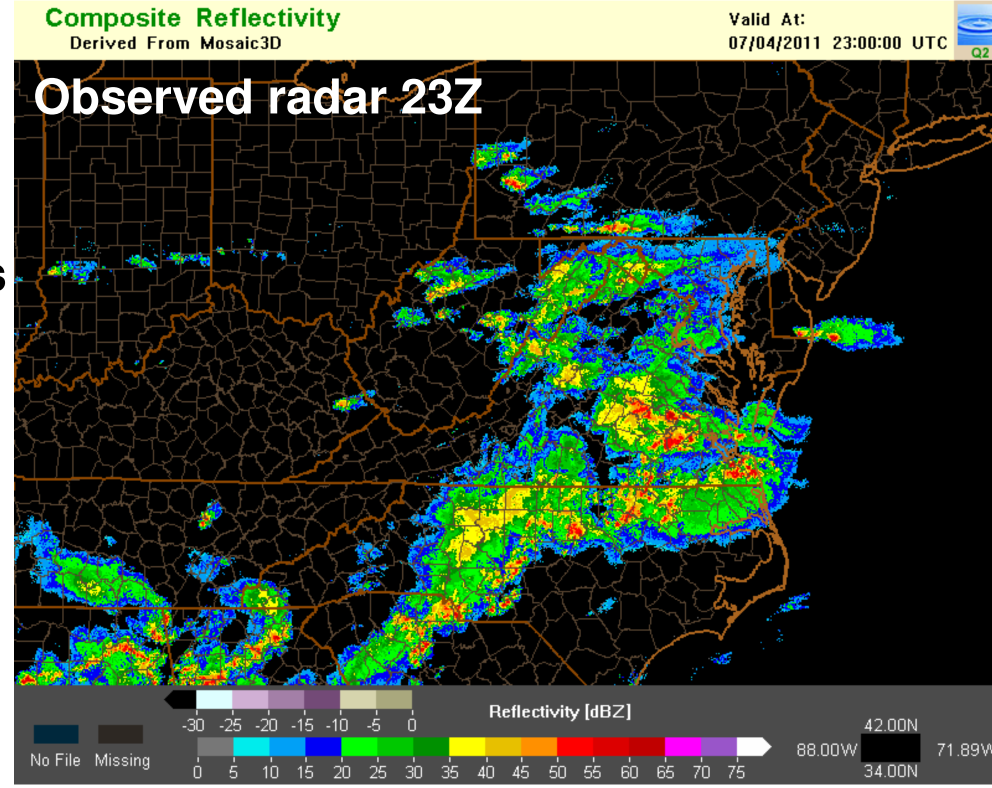


90-km Search Radius

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

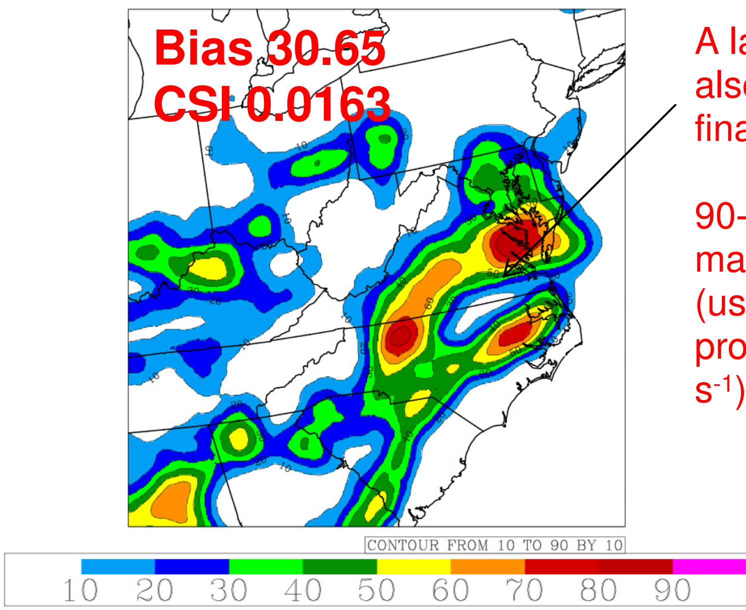


All 3 runs:
3 HRRR members
2-h time window
0.7 m s^{-1} max updraft
2 °C lifted index



45-km Search Radius

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

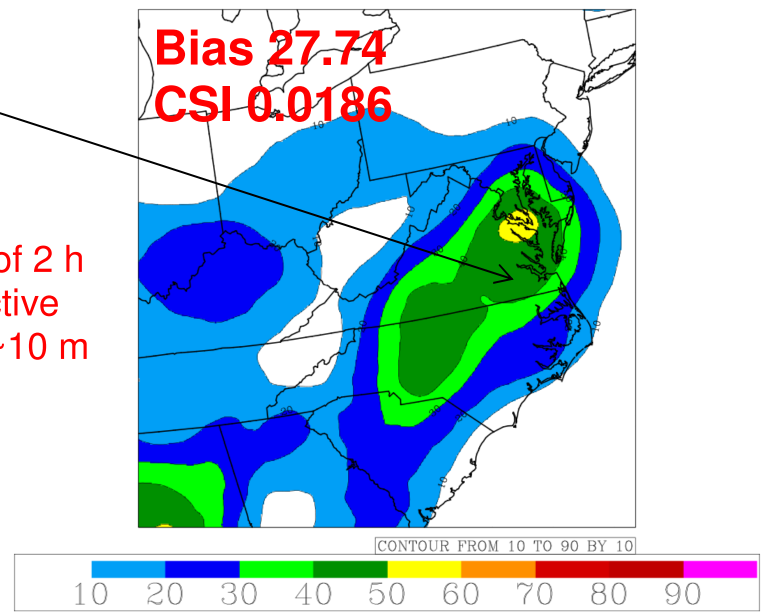


A larger search radius also smoothes the final probabilities

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

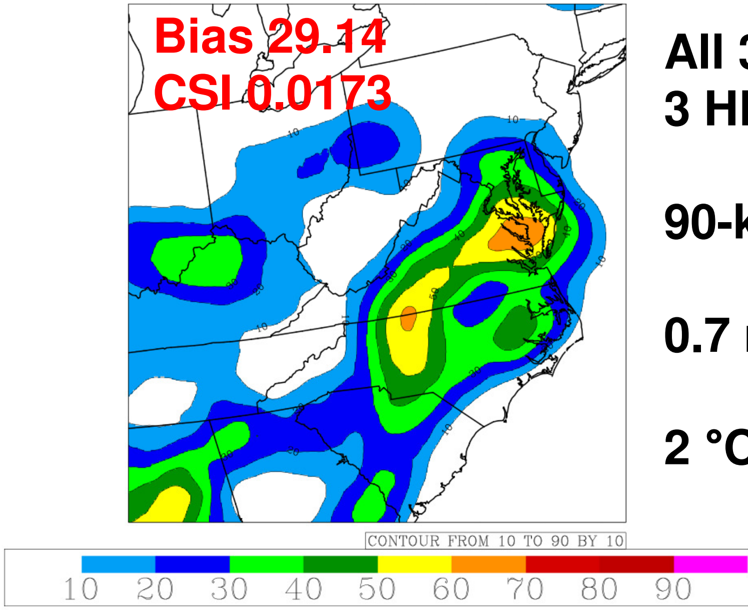
135-km Search Radius

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

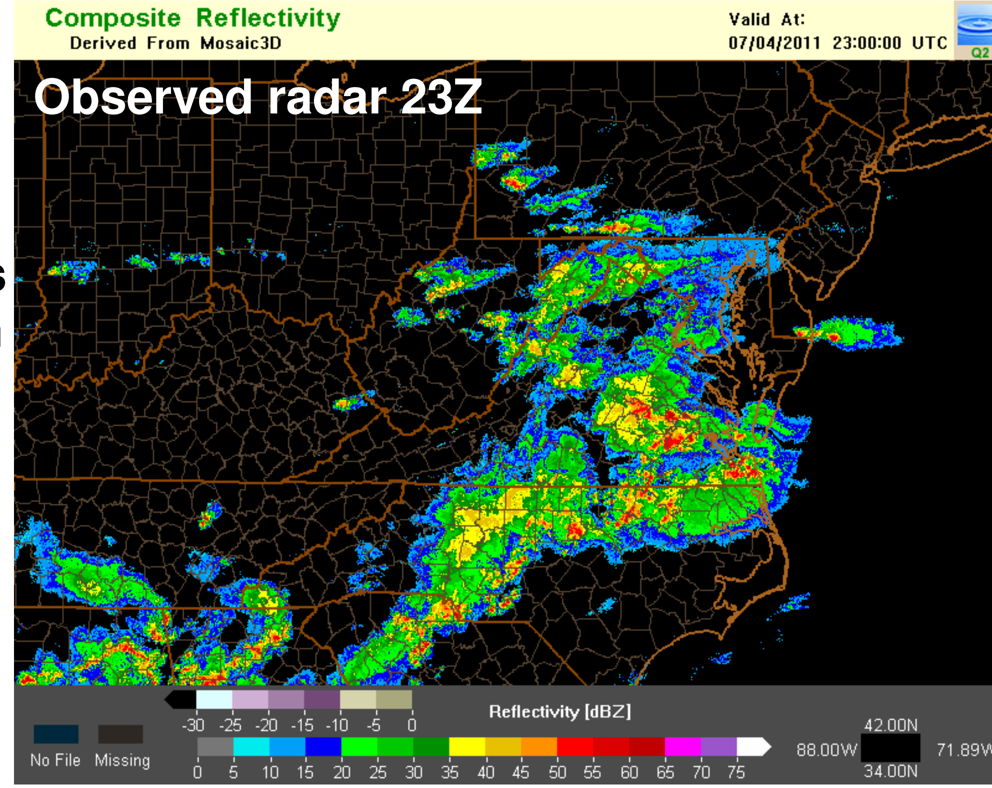


2-h Time Window

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

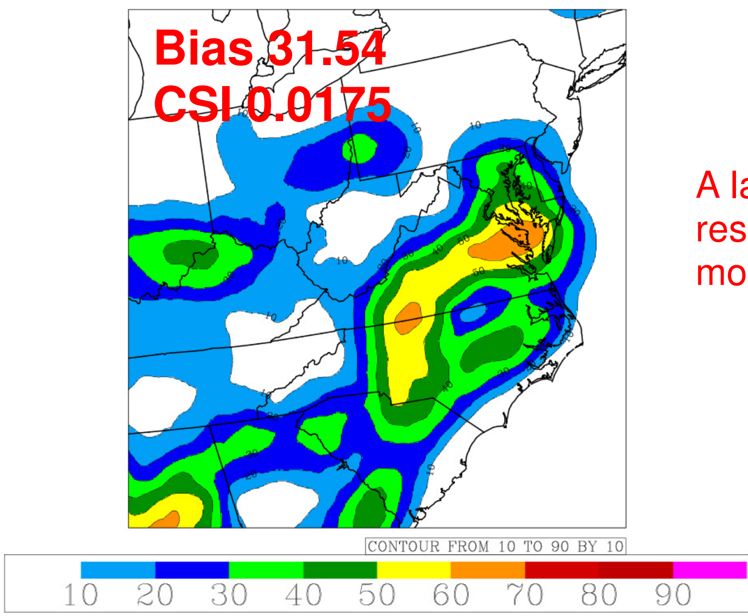


All 3 runs:
3 HRRR members
90-km search radius
0.7 m s^{-1} max updraft
2 °C lifted index



1-h Time Window

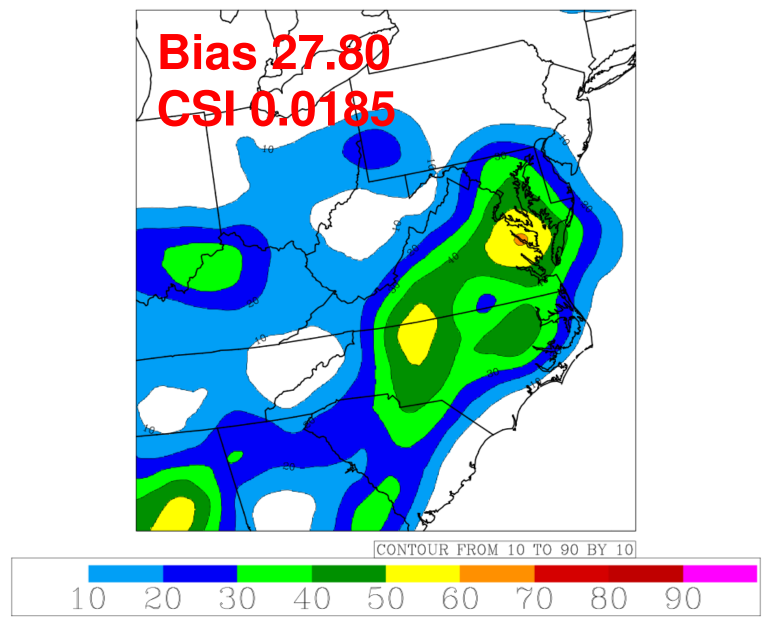
2300 UTC 04 Jul 2011 6-h Forecast of Convective Probability (%)



A larger time window results in a slightly more smoothed field

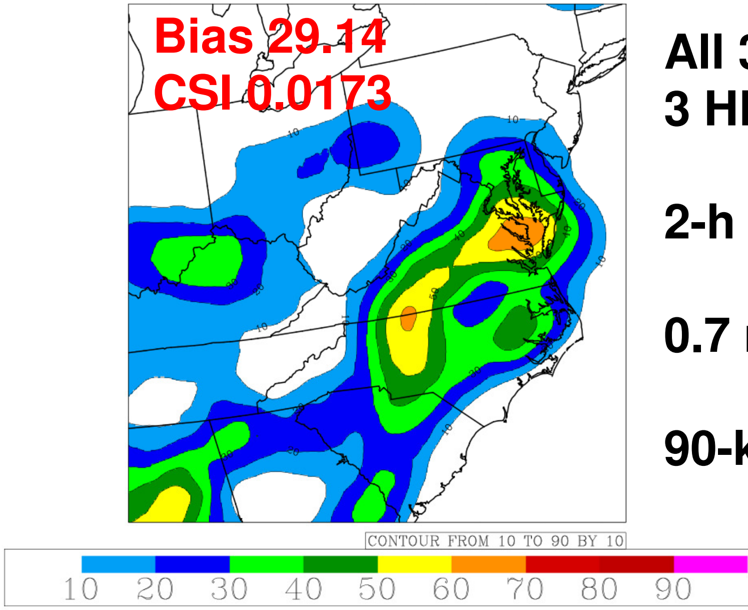
4-h Time Window

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

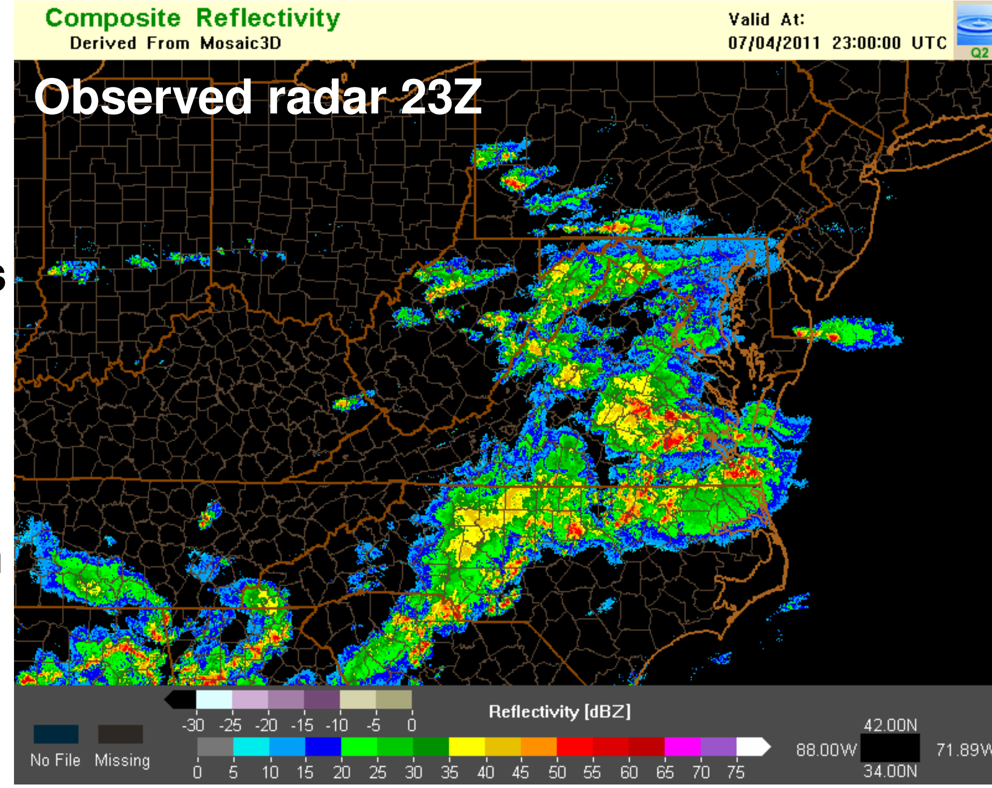


2 °C Lifted Index Instability Threshold

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

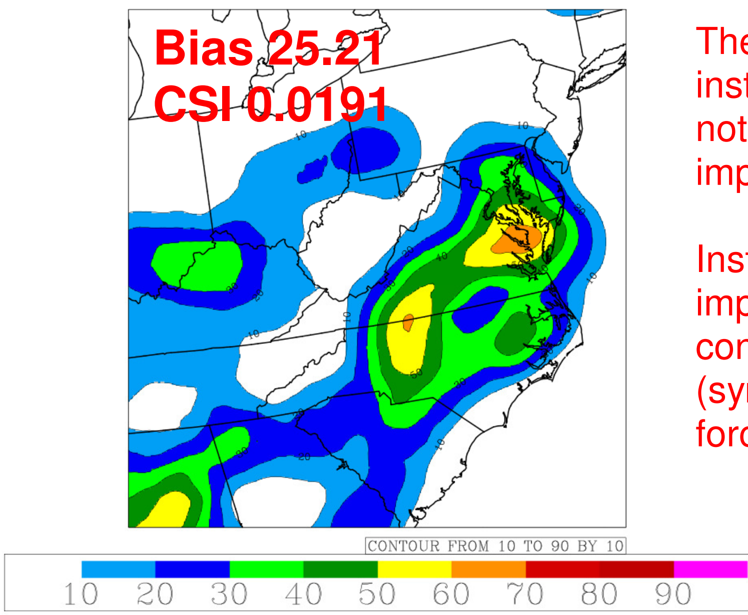


All 3 runs:
3 HRRR members
2-h time window
0.7 m s^{-1} max updraft
90-km search radius



1 °C Lifted Index Instability Threshold

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

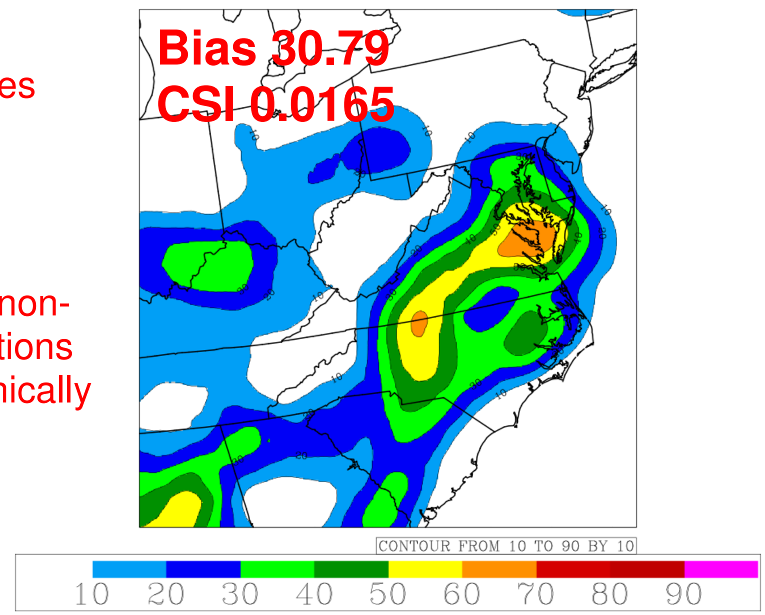


The exact value of the instability threshold does not have a significant impact on the HCPF

Instability threshold is important to mask out non-convective vertical motions (synoptic and orographically forced)

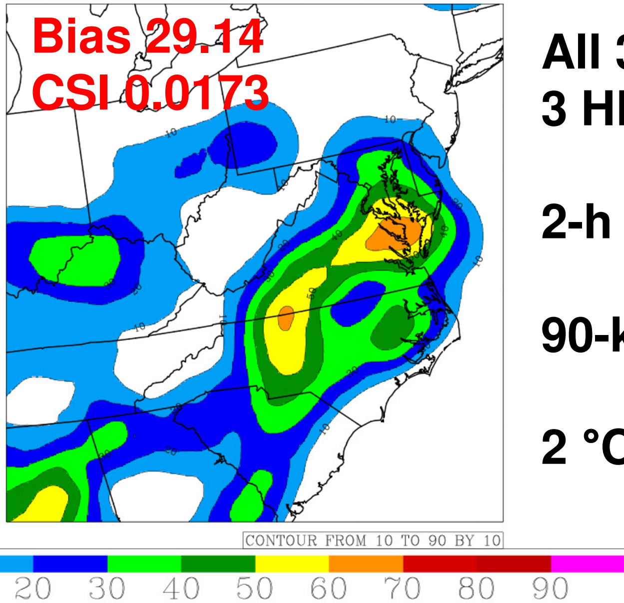
3 °C Lifted Index Instability Threshold

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

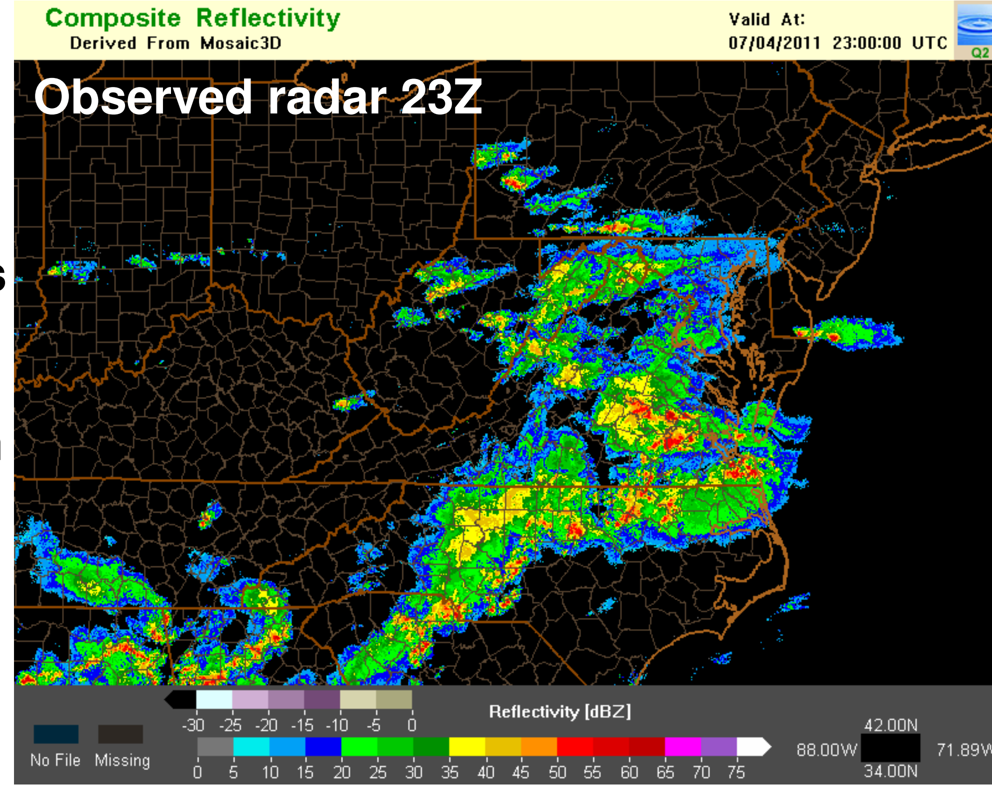


0.7 m s^{-1} Hourly Max Updraft Threshold

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

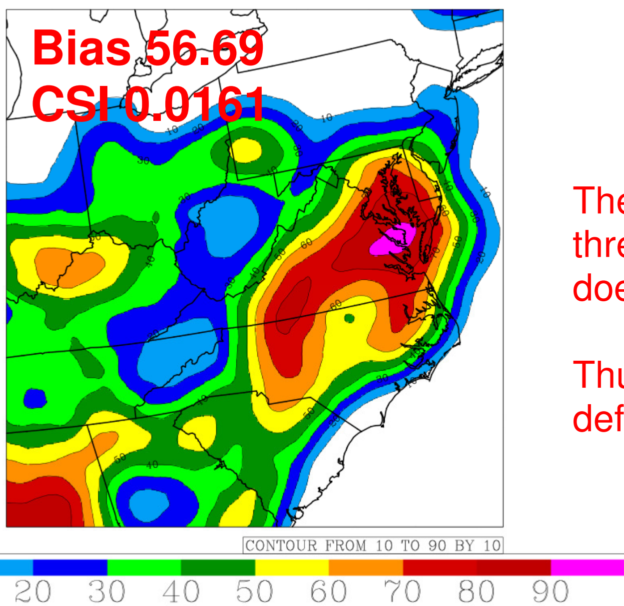


All 3 runs:
3 HRRR members
2-h time window
90-km search radius
2 °C lifted index



0.4 m s^{-1} Hourly Max Updraft Threshold

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

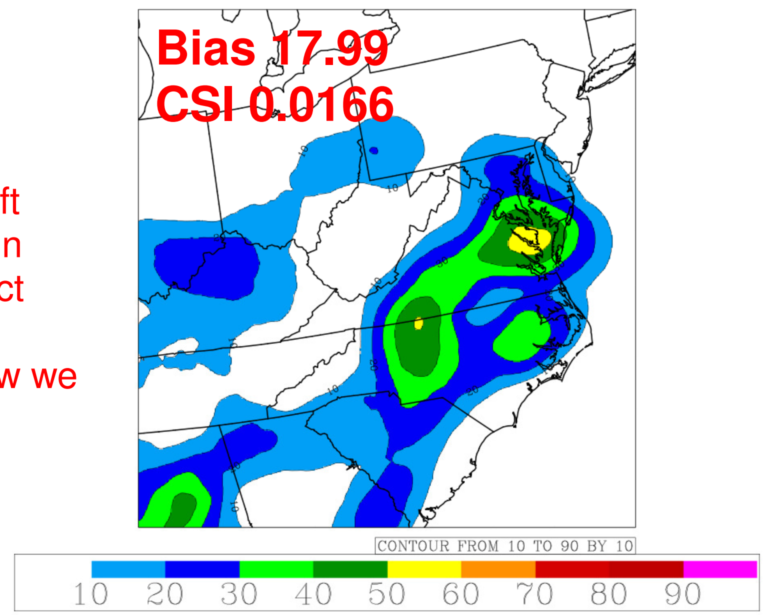


The value of the updraft threshold for convection does have a large effect

Thus it is important how we define convection

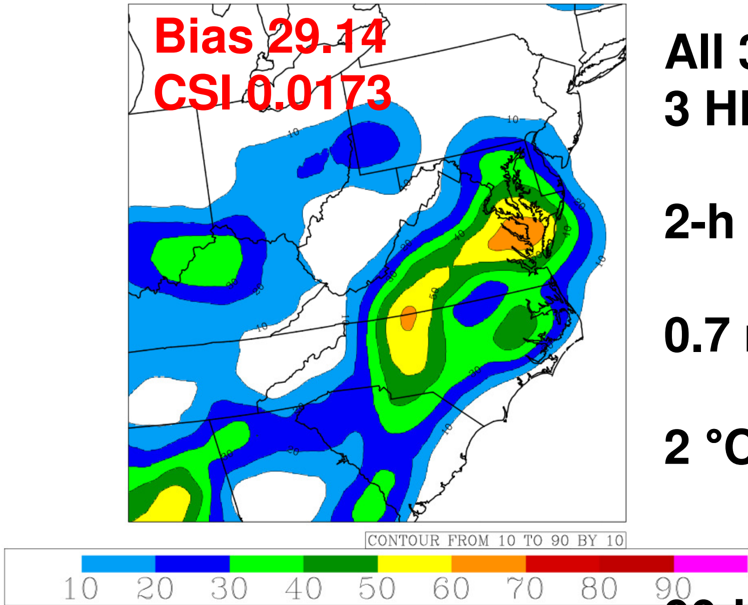
1.0 m s^{-1} Hourly Max Updraft Threshold

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

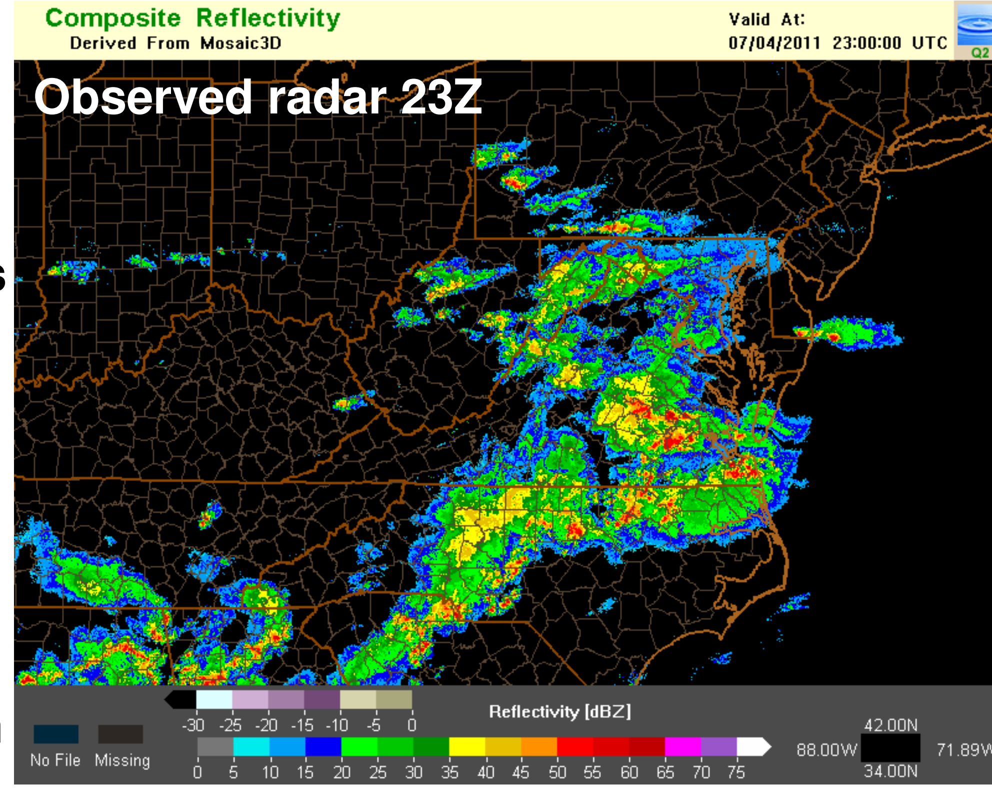


Equally Weighted HRRR Run Members

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

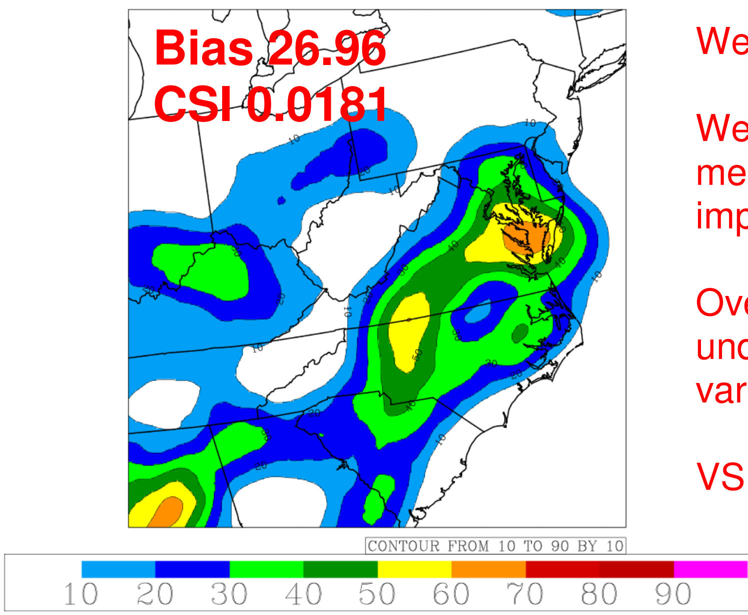


All 3 runs:
- 3 HRRR members
- 2-h time window
- 0.7 m s^{-1} max updraft
- 2 °C lifted Index
- 90-km search radius



Earlier HRRR Runs Weighted More

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



Weights: 50%, 33%, 17%

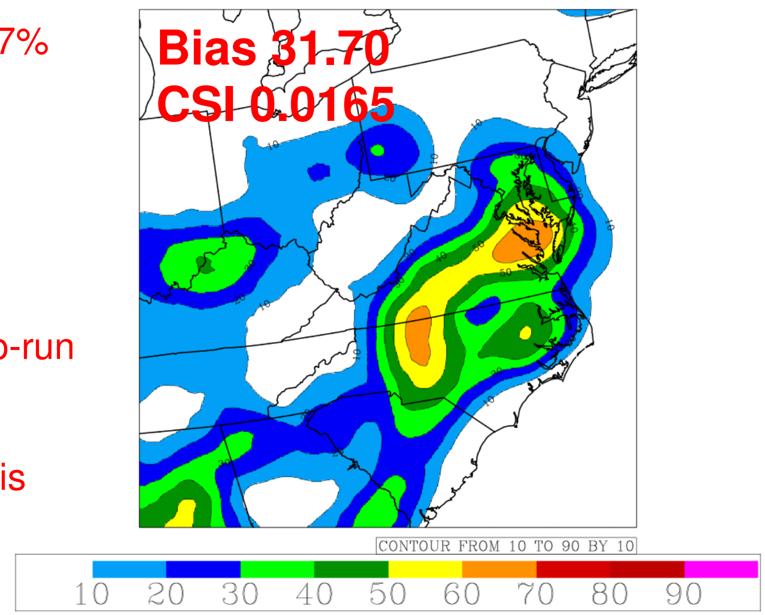
Weighting HRRR members has little impact

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

VSREF will address this

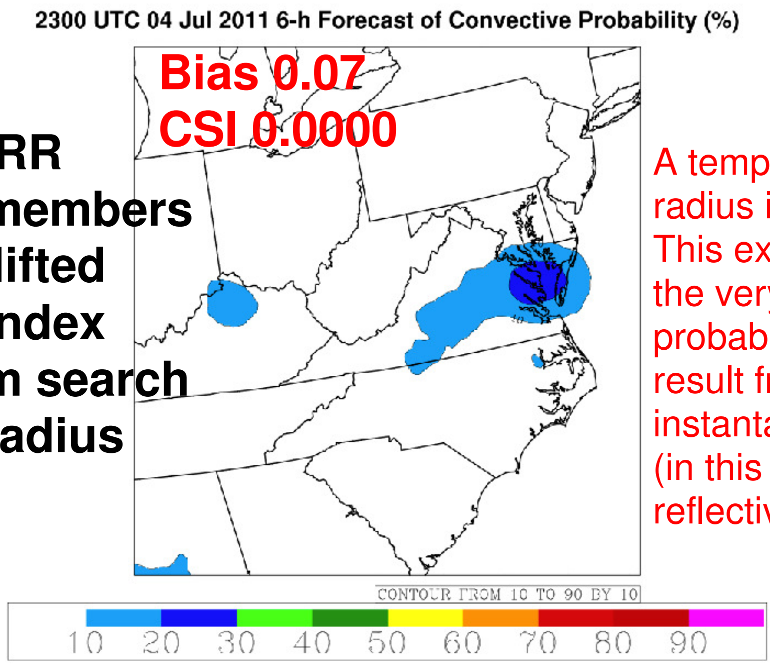
More Recent HRRR Runs Weighted More

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

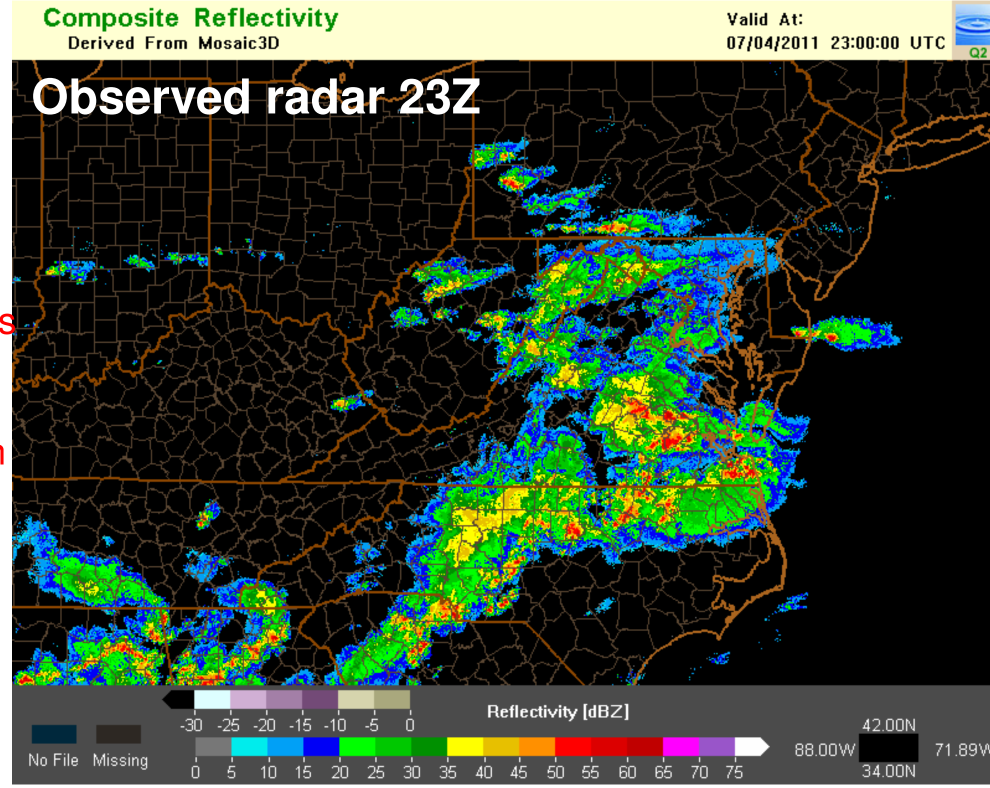


35 dBZ Threshold, No Time Window

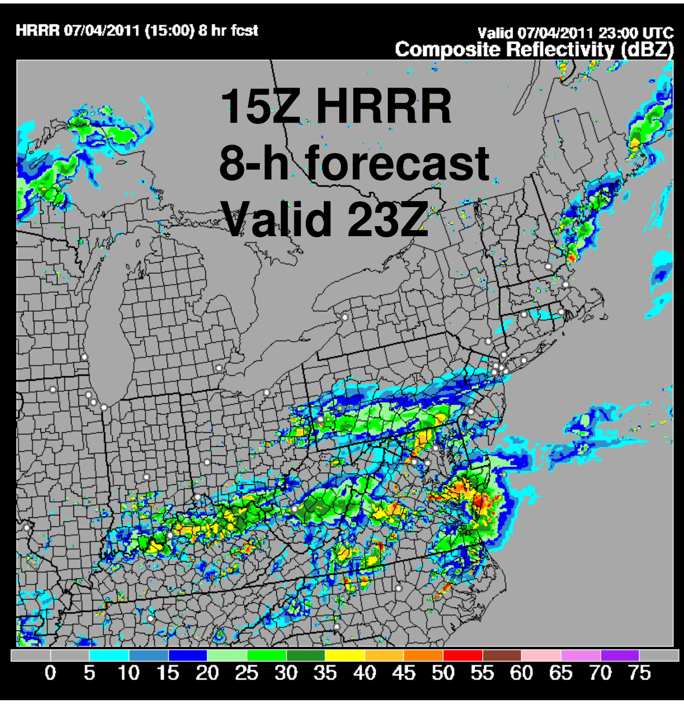
3 HRRR members
2 °C lifted Index
90-km search radius

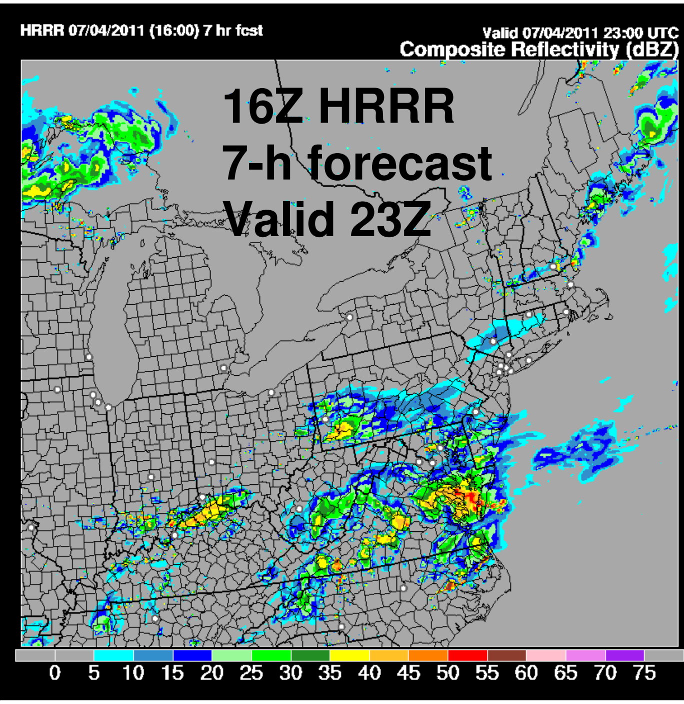


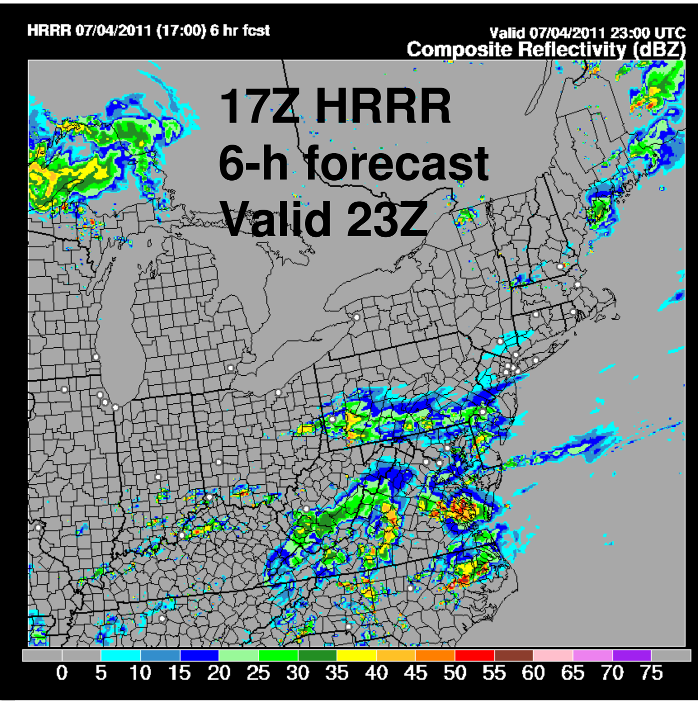
A temporal search radius is needed. This example shows the very low probabilities that result from using an instantaneous field (in this case comp. reflectivity)



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

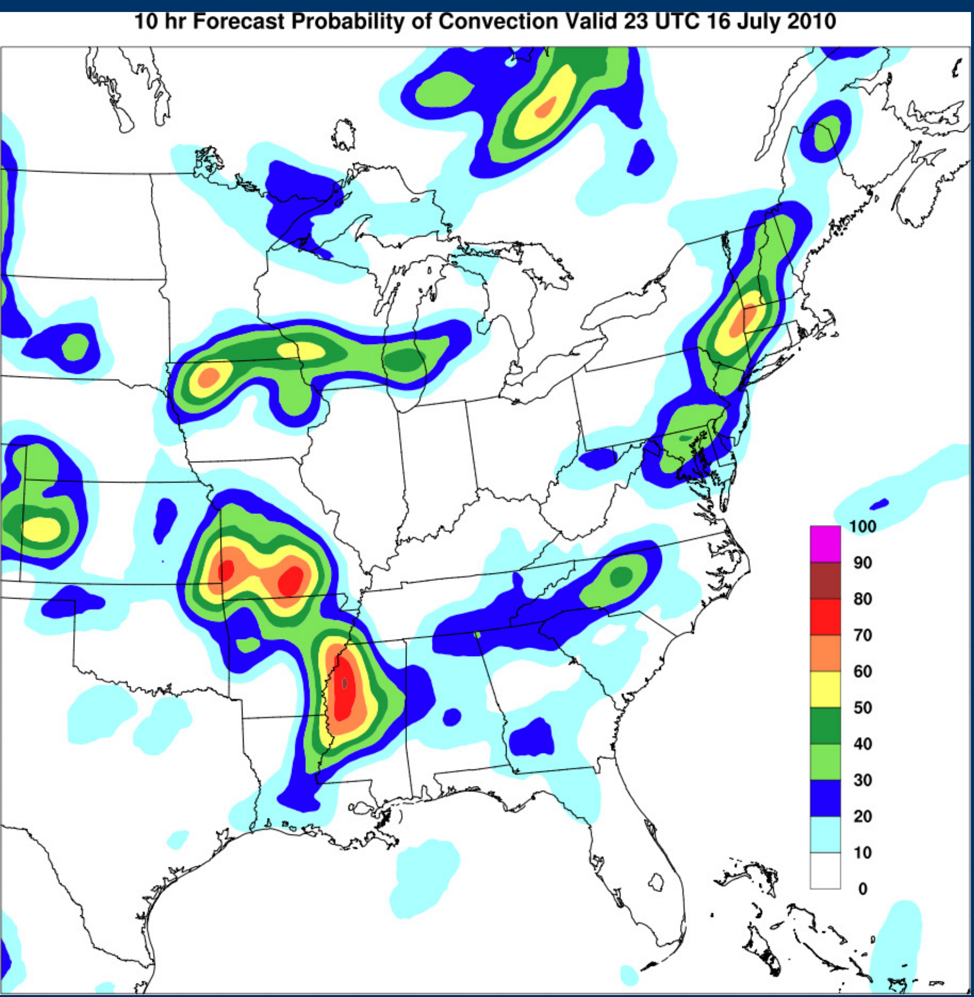


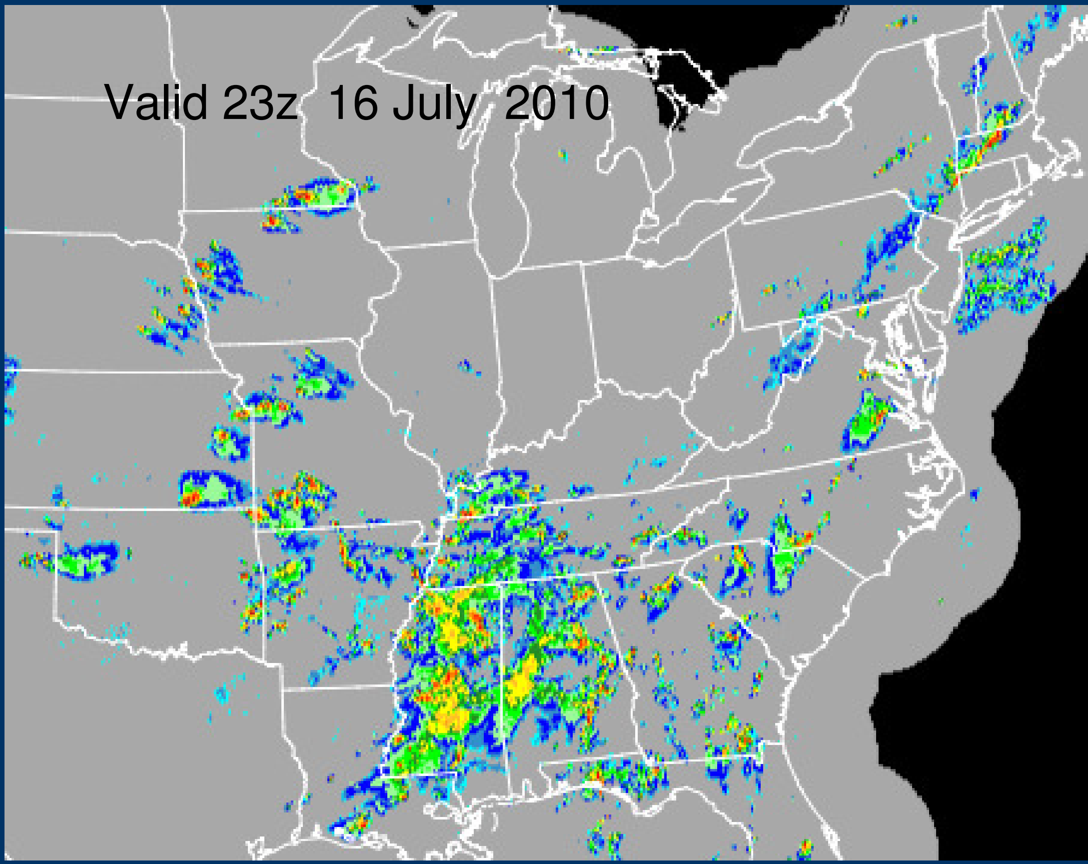




Visualization Concepts

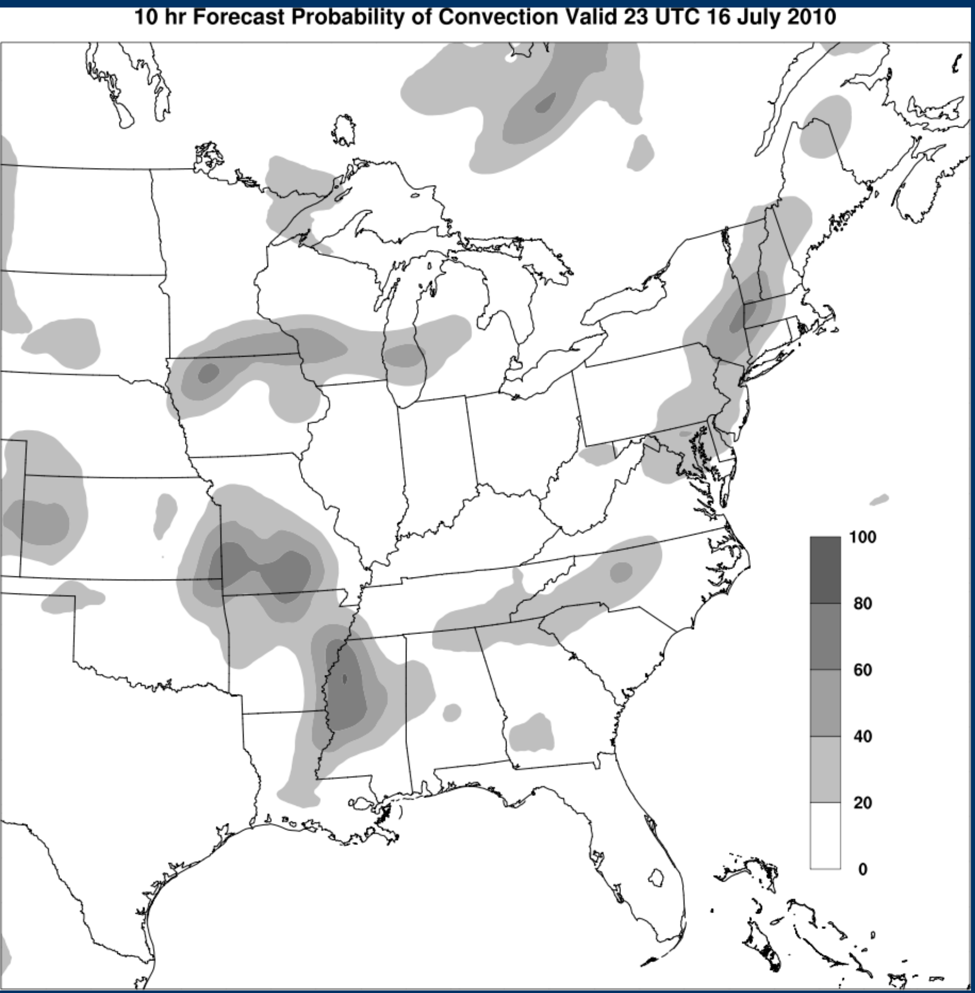
Confidence Probabilities Only

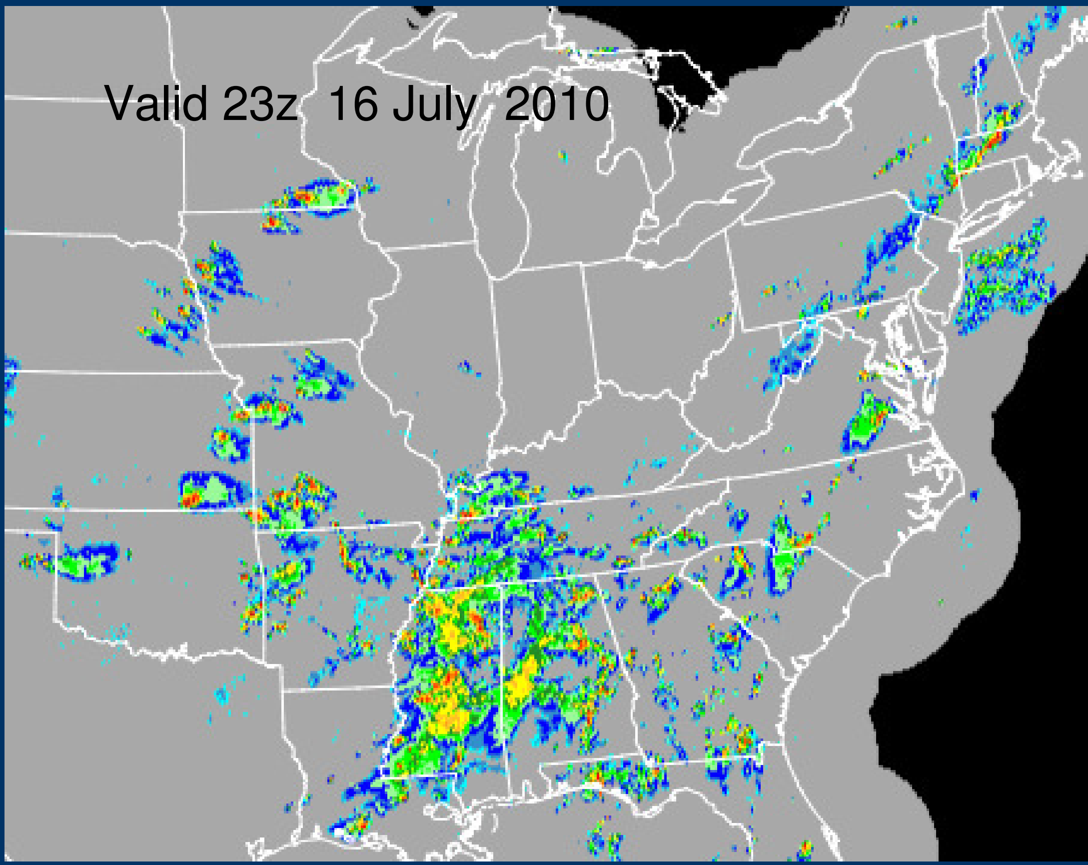




Visualization Concepts

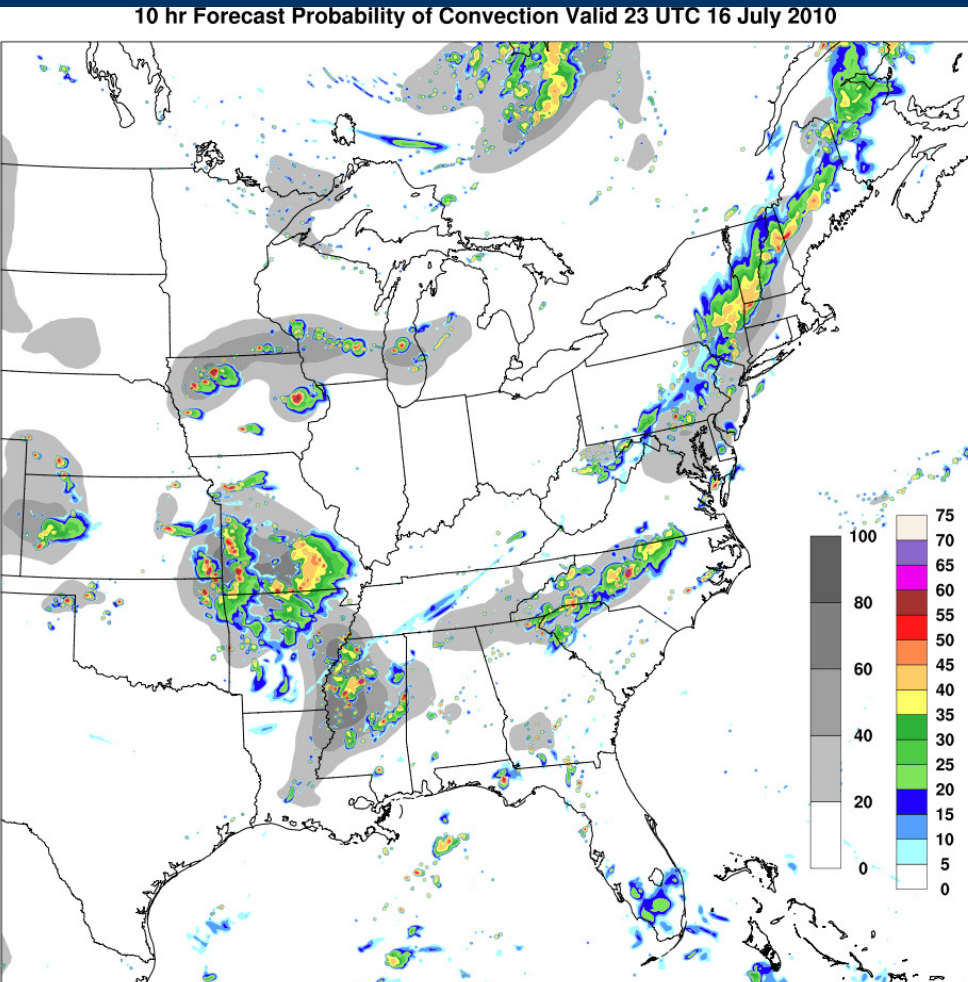
Confidence Probabilities Only

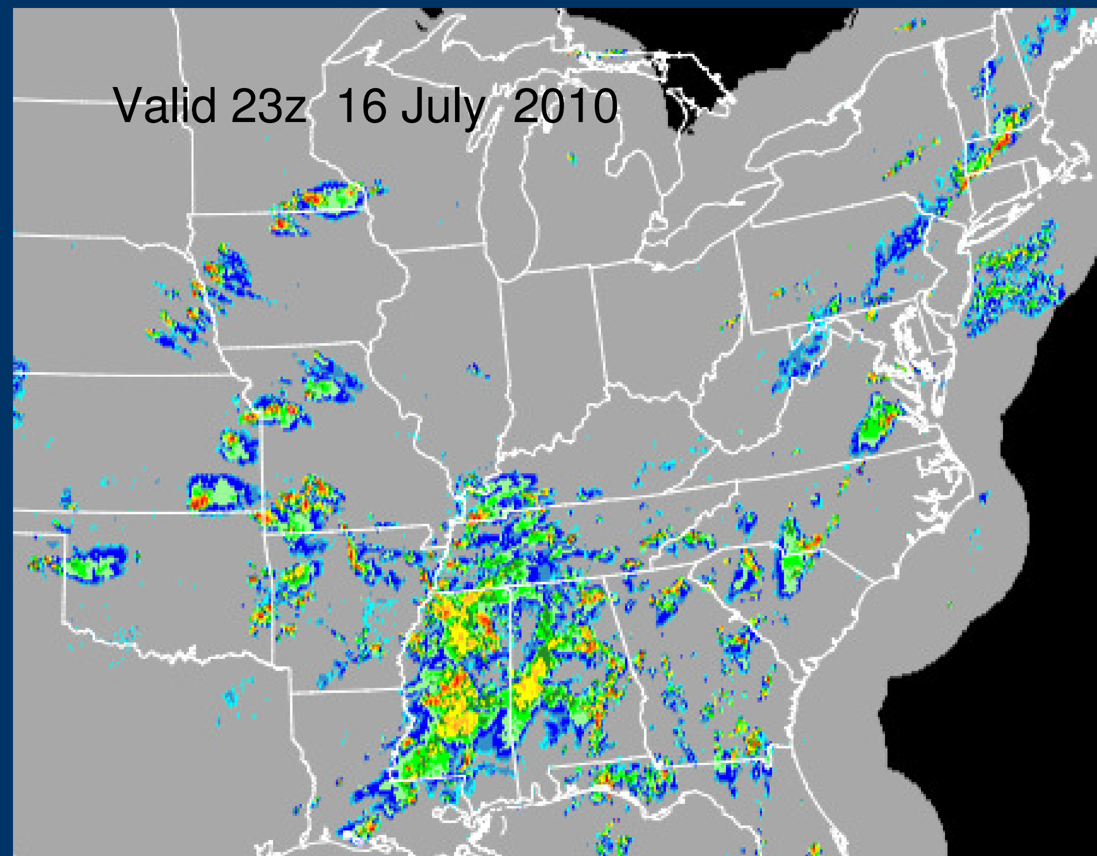




Visualization Concepts

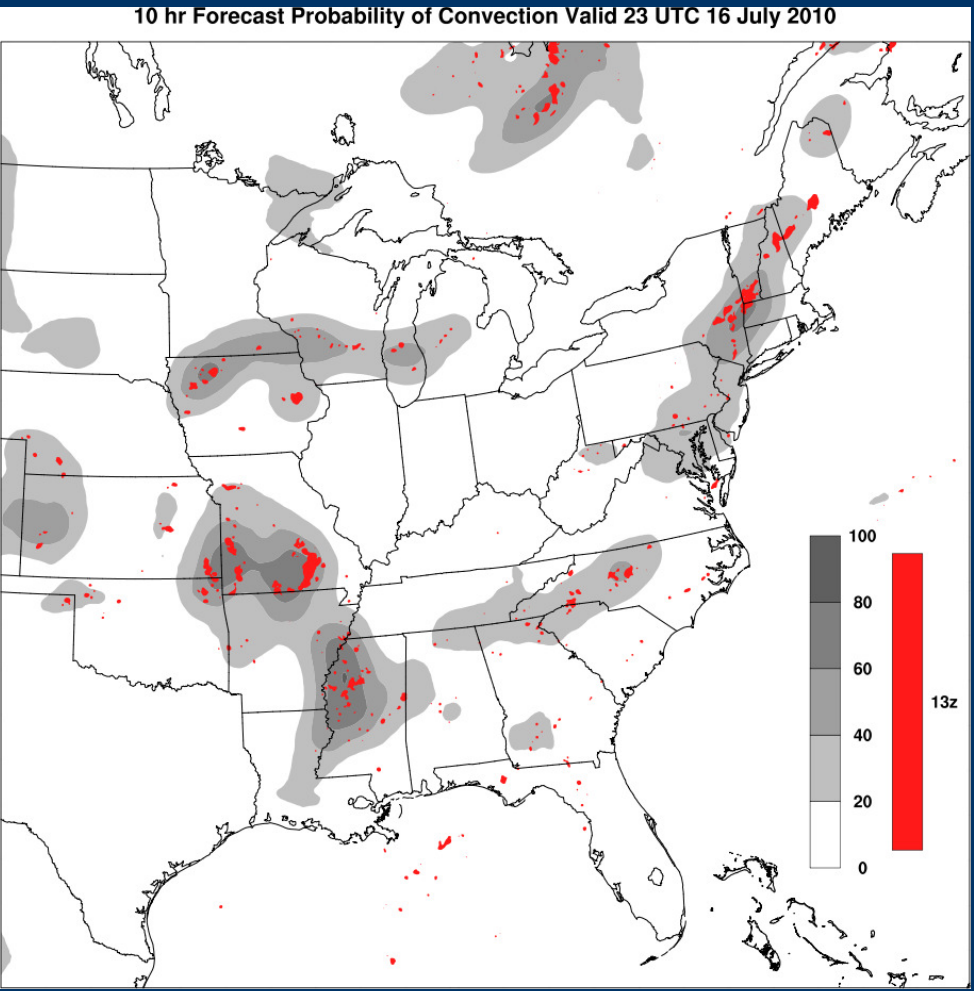
Confidence Probabilities and Deterministic

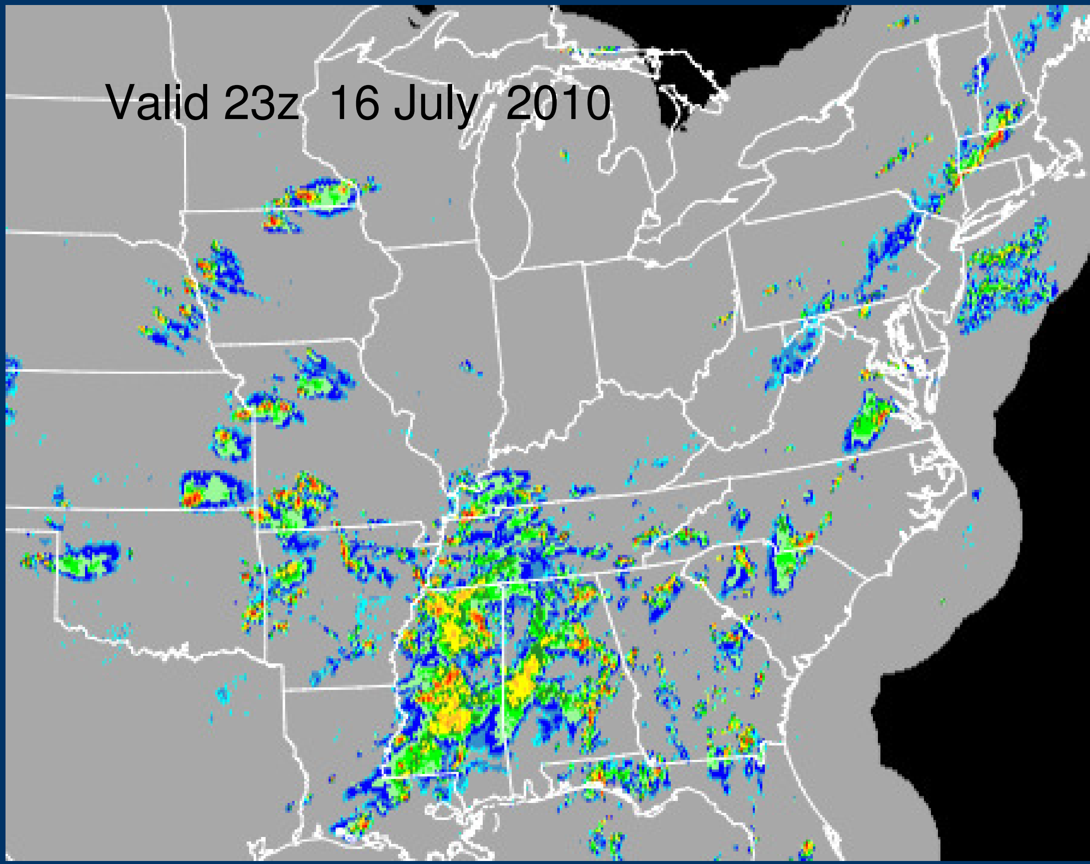




Visualization Concepts

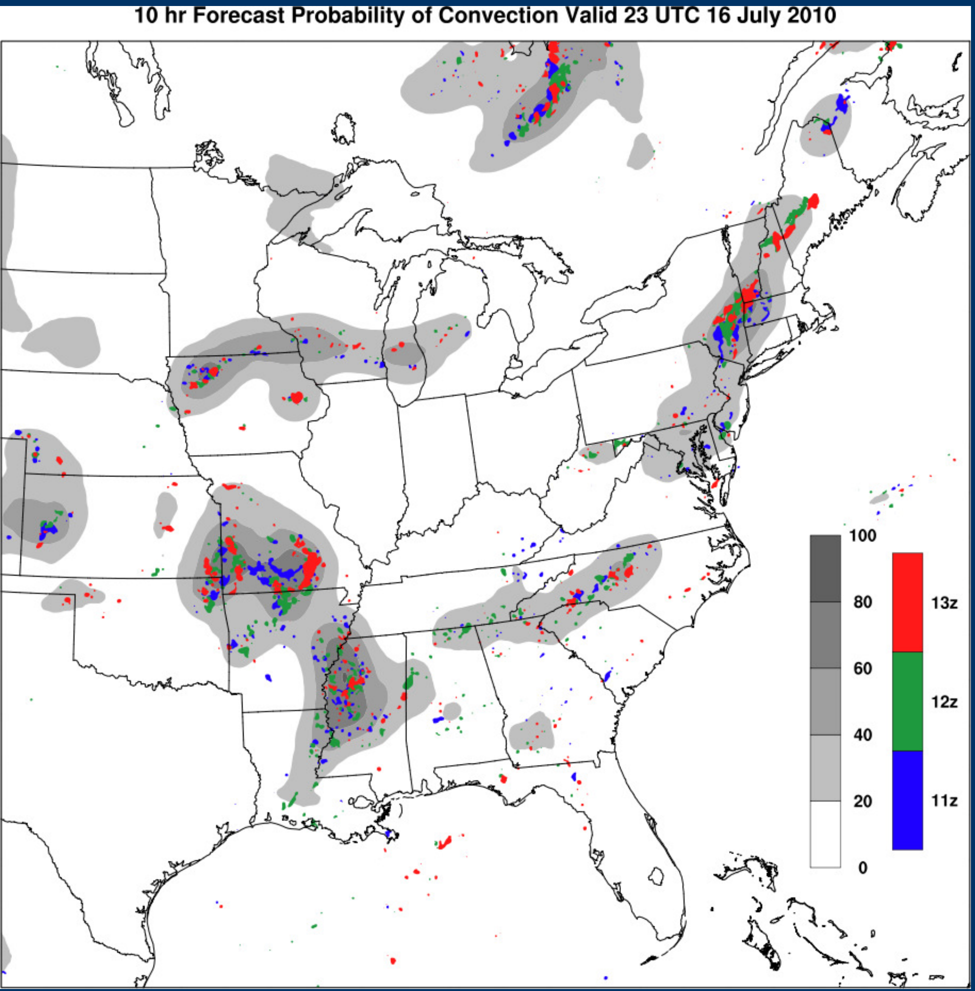
Confidence Probabilities and Deterministic

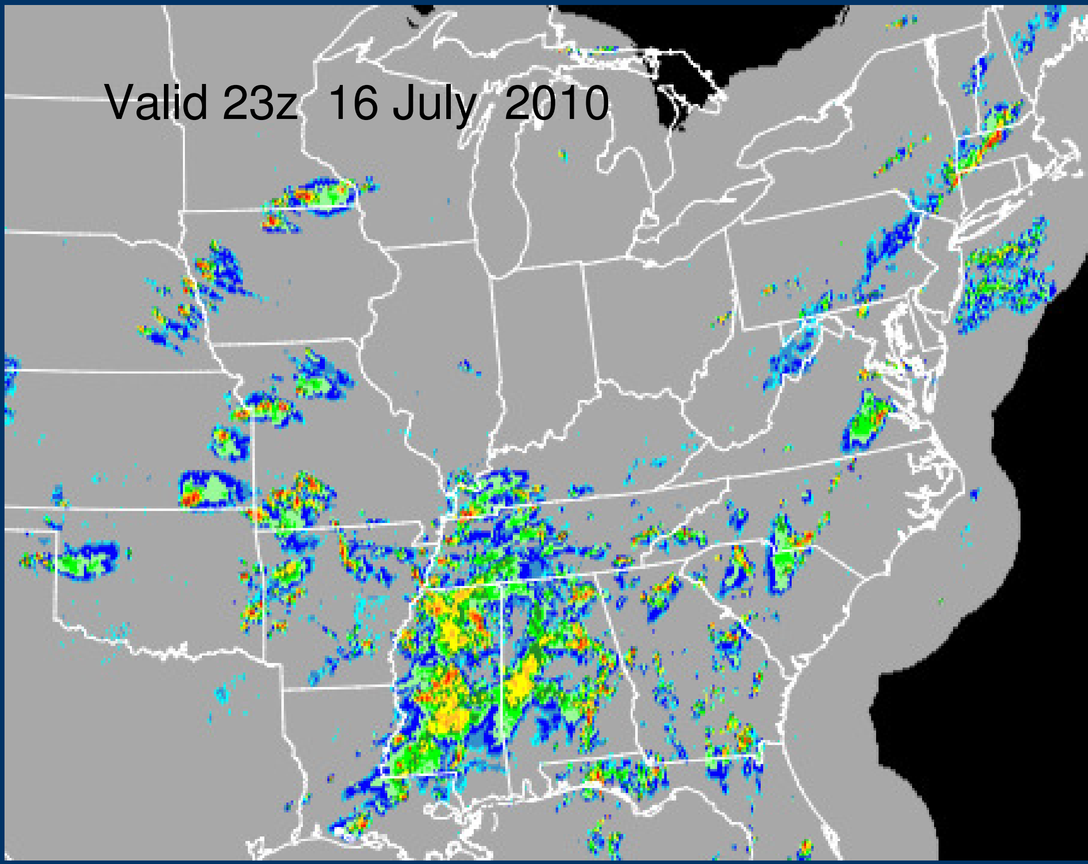




Visualization Concepts

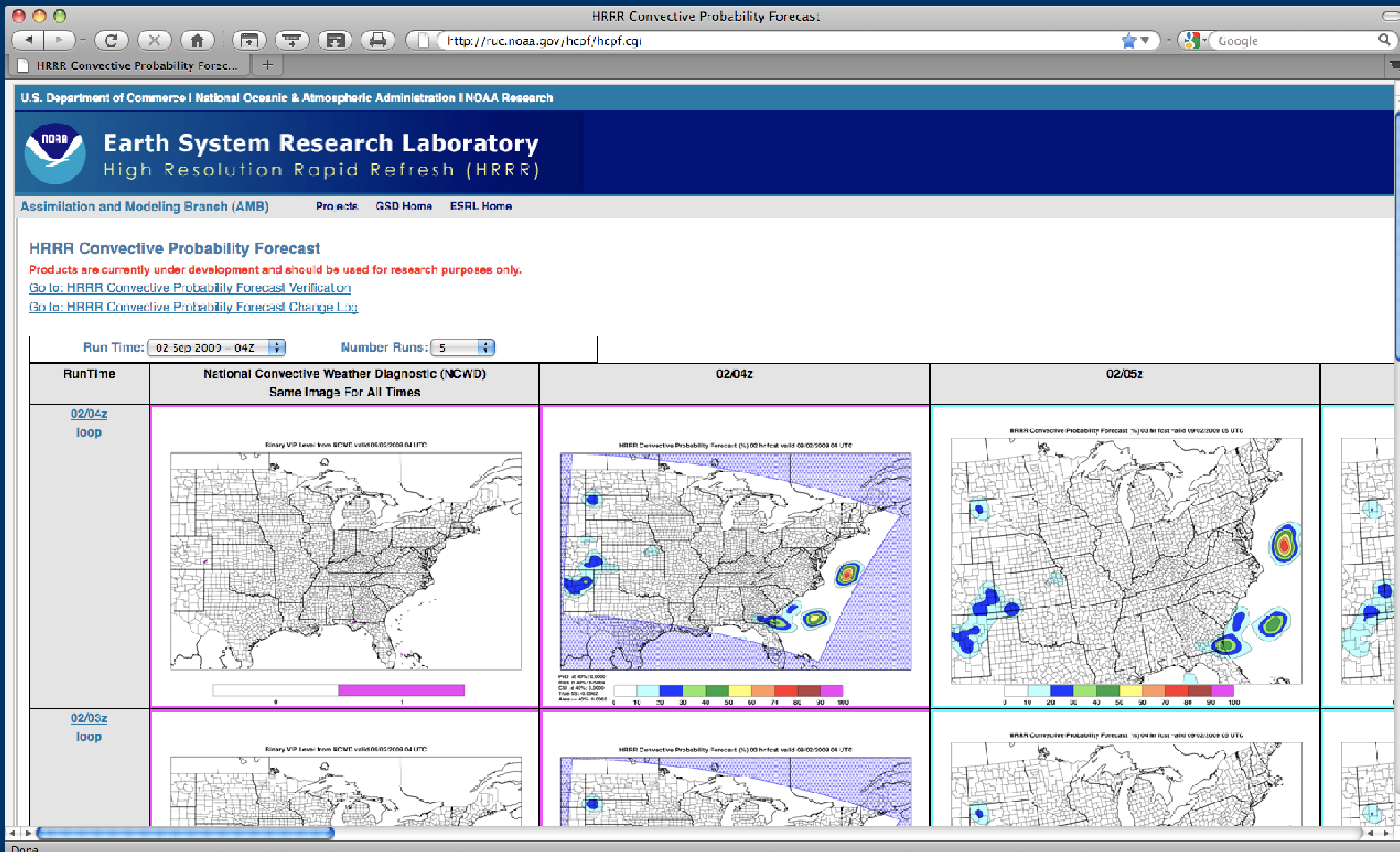
Confidence Probabilities and Deterministic





Real-time HCPF

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



HCPF generation time

Current verification

HCPF lead times

VSREF – Very Short Range Ensemble Forecast

VSREF members

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

VSREF

Hourly Updated Probabilistic Forecasts

Collaborative work EMC (Binbin Zhou), GSD

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