An Evaluation of 3D and 4D Hybrid EnVar Sub-Hourly Data Assimilation in the High-Resolution Rapid Refresh (HRRR)

Jeff Beck*[1,4], Ming Hu[2,4], Hui Shao[3,4], and Chunhua Zhou[3,4]

[1]Cooperative Institute for Research in the Atmosphere (CIRA) at NOAA/ESRL/GSD
[2]Cooperative Institute for Research in Environmental Sciences (CIRES) at NOAA/ESRL/GSD
[3]National Center for Atmospheric Research (NCAR)
[4]Developmental Testbed Center (DTC)

*jeff.beck@noaa.gov

Introduction

The current operational configuration of the 3-km HRRR features an hourly update cycle based on a downscaled RAP initialization and a one-hour pre-forecast. Afterward, 3D hybrid EnVar data assimilation is conducted, followed by a free forecast. However, a wealth of observational data exists at sub-hour intervals, including aircraft and METAR observations, available every minute. To evaluate the advantage of assimilating these data, the HRRR was run for three days in a 15-minute DA update cycle during the one-hour pre-forecast, for 3D and 4D hybrid EnVar. Forecasts from these experiments were then compared to those produced with the hourly data assimilation configuration.

Employed Data Assimilation Methods

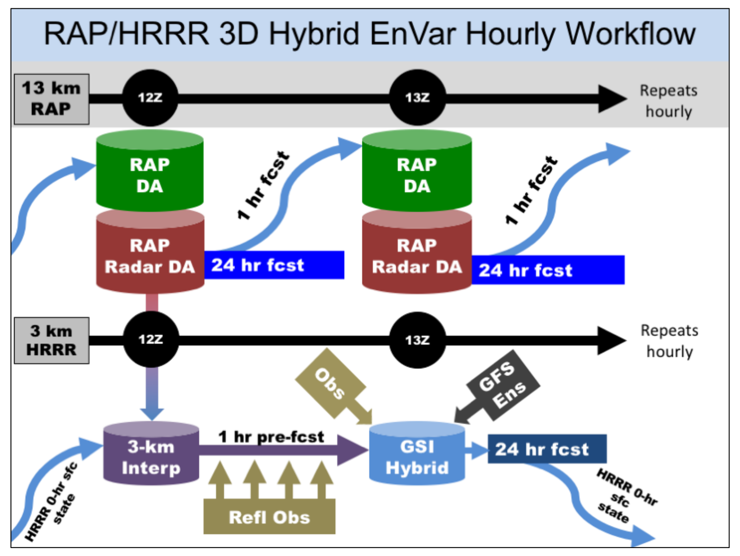
- **Hourly 3D Hybrid EnVar**: Data assimilation is conducted using an observation window of 30 minutes on either side of the hourly analysis period, with all observations considered to occur at one time. The covariance matrix is constructed in a hybrid manner, with 75% coming from one forecast of the 80-member GFS ensemble and 25% coming from static, isotropic background covariance based on model statistics.
- **Sub-Hourly 3D Hybrid EnVar**: Data assimilation is conducted using an observation window of 12 minutes on either side of each 15-minute analysis period, with all observations considered to occur at one time. The covariance matrix calculation is identical to that used in the hourly 3D hybrid EnVar.
- **Sub-Hourly 4D Hybrid EnVar**: Data assimilation is conducted by incorporating three time levels (separated by 15 minutes) with observation windows of 7.5 minutes on either side of each time level. Observations are considered to occur at one of these three times. The covariance matrix calculation is identical to that used in the hourly 3D hybrid EnVar, except that three matrices are computed from different forecasts of the 80-member GFS ensemble.

Experimental Design

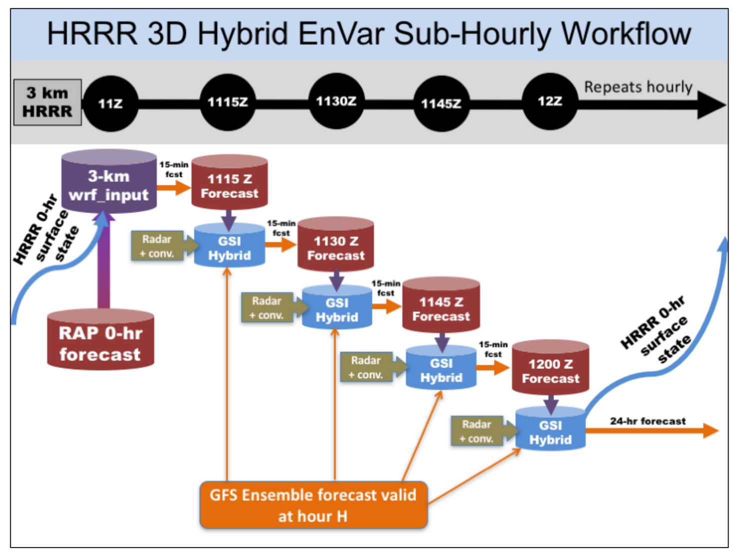
The goal of this study was to compare analysis and free forecast performance within the 3-km HRRR when using both hourly and sub-hourly 3D and 4D hybrid EnVar data assimilation techniques.

- **Configuration:**
  For this research, the operational HRRR set-up was used as an hourly data assimilation benchmark. The sub-hourly experiments were identical in design, except that they contained 15-minute cycling prior to the free forecast.

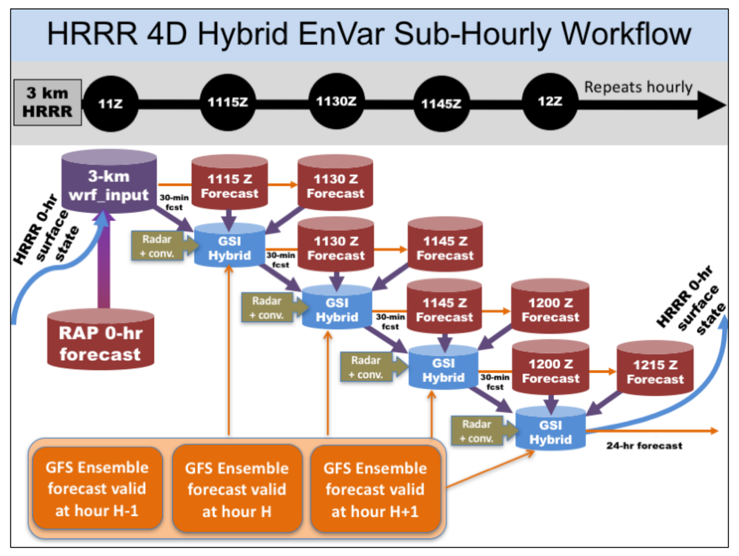
RAP/HRRR 3D Hybrid EnVar Hourly Workflow



HRRR 3D Hybrid EnVar Sub-Hourly Workflow



HRRR 4D Hybrid EnVar Sub-Hourly Workflow



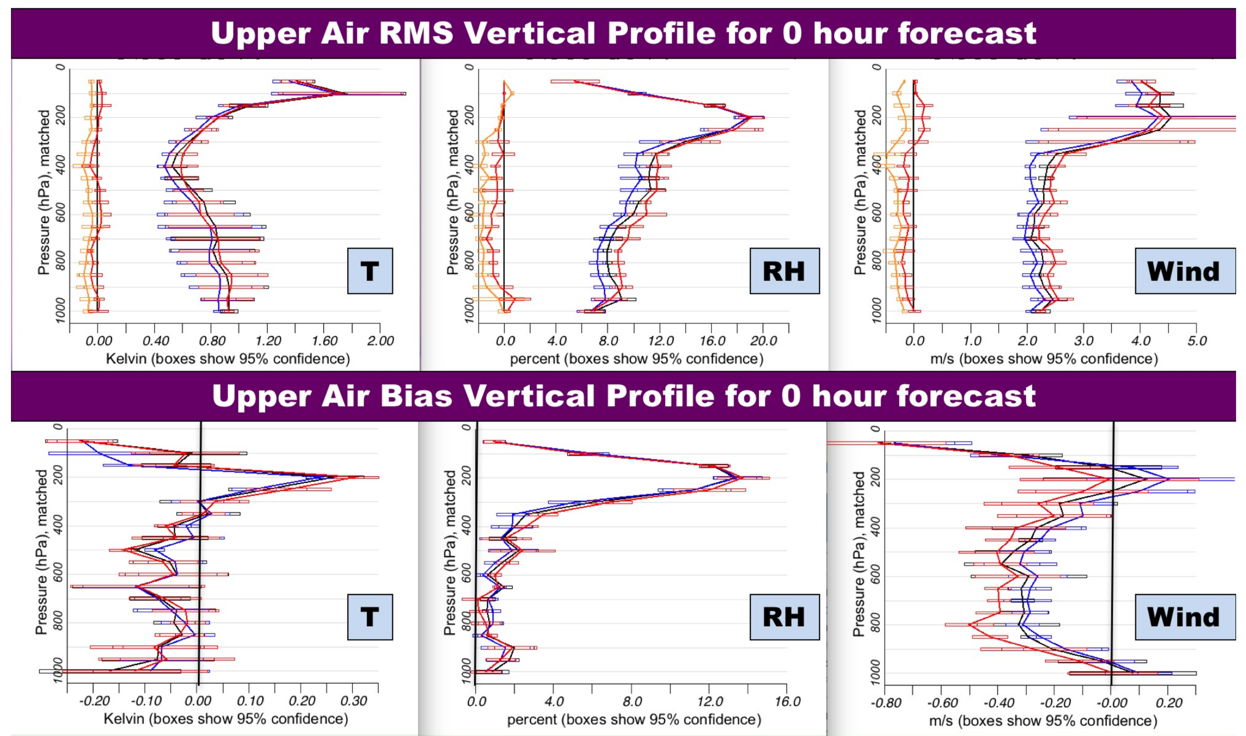
- **Workflows:**
  Shown above and to the right are the three different workflows for the hourly and sub-hourly 3D and 4D hybrid EnVar experiments. Each simulation begins with a RAP forecast issued at the top of the hour which is downscaled to the 3-km HRRR grid. Afterward, a one-hour pre-forecast is started. For the sub-hourly runs, subsequent DA cycles and forecasts are issued every 15 minutes. The sub-hourly 3D hybrid EnVar simulations use the same single GFS ensemble forecast as the hourly workflow, while the 4D hybrid EnVar simulations use three GFS ensemble forecasts. After the pre-forecast, a final 24-hr simulation is launched at the end of the hour.

- **Retrospective Forecasts:**
  Experiments were conducted for the period of 8-10 September, 2016. Simulations were cycled for the duration of this three-day period with free forecasts launched hourly.

- **Verification:**
  All three simulations were compared by verifying their free forecasts (analysis included) against each other. Verification metrics of RMSE and bias were calculated for temperature, relative humidity/dew point, and winds against radiosonde data for 0000 and 1200 UTC and at the surface using METAR stations at hourly intervals. Both time-series of surface data and vertical profiles for upper-air verification were produced. Error bars were also produced to help identify the statistical significance of the results. Time series of upper air verification (not shown) indicated that there was no significant change in RMSE/bias over the three-day period, suggesting a significant number of retrospective forecasts had been run to provide stable verification results. Finally, qualitative comparisons of radar reflectivity were conducted to assess storm-scale feature location and intensity.

Upper-Air Profile Verification: Analysis Time

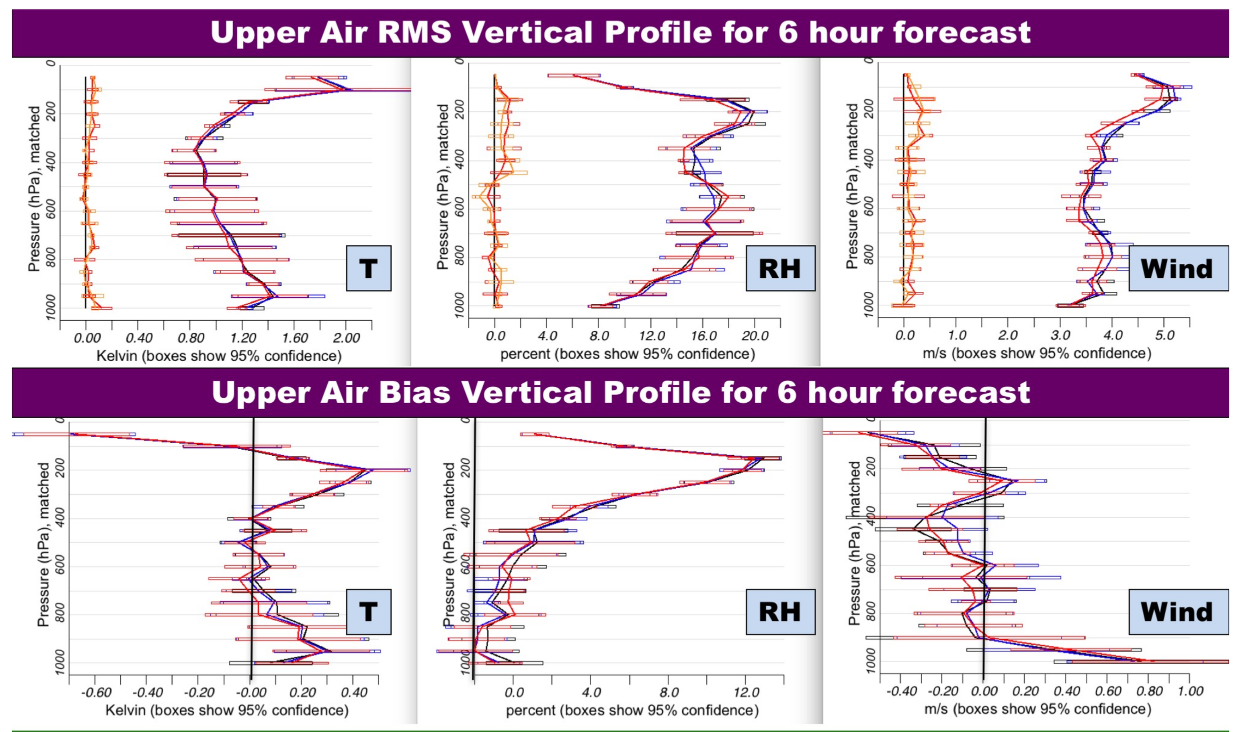
- Upper-air verification for analysis time indicates a closer fit to the observations for the sub-hourly experiments, particularly for 3D hybrid EnVar
- RMSE is better with statistical significance at multiple levels for all three variables in the sub-hourly experiments
- Bias shows improvements for sub-hourly, especially for winds



Red - HRRR operational (hourly); **Blue** - Sub-hourly 3DEnVar; **Black** - Sub-hourly 4DEnVar

Upper-Air Profile Verification: 6-hr Forecast

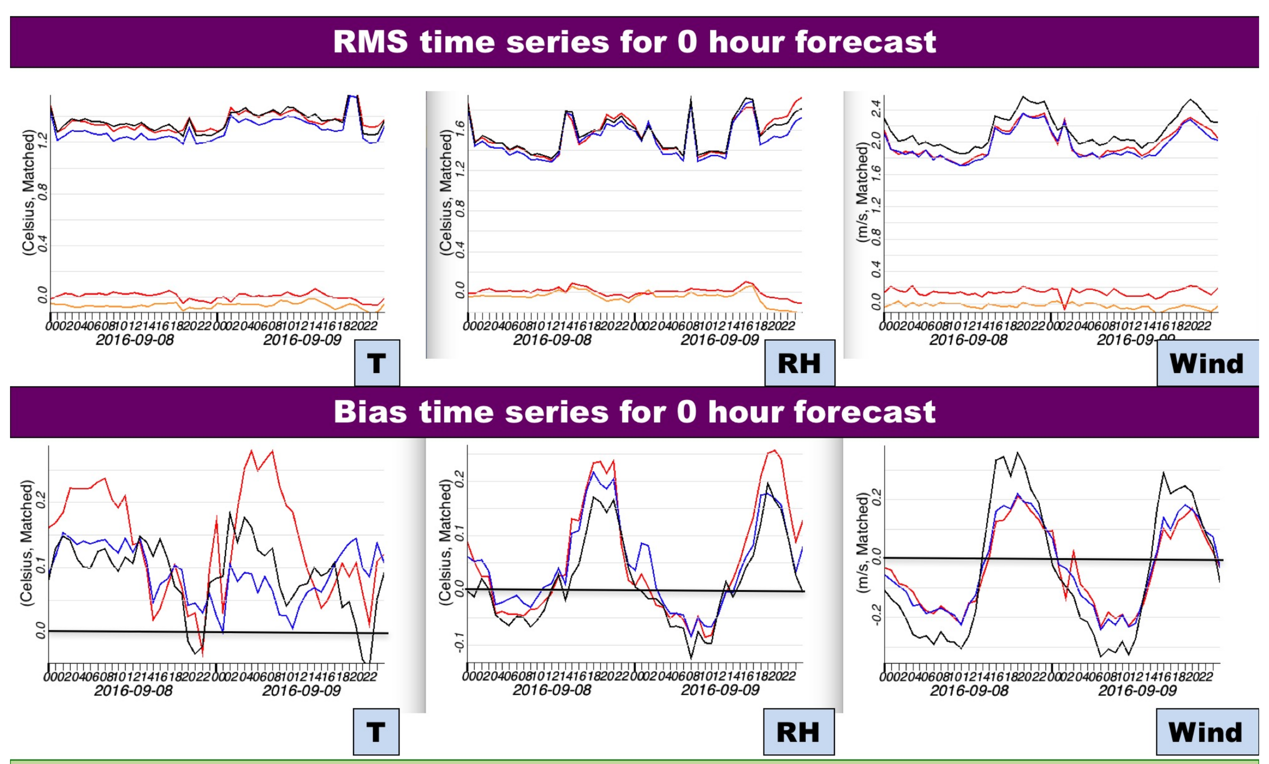
- RMSE for upper-air verification at 6-hr forecast time indicates mostly neutral to slightly negative impact of sub-hourly cycling, however most differences are not statistically significant
- Bias differences between the experiments are mixed, depending on variable and height



Red - HRRR operational (hourly); **Blue** - Sub-hourly 3DEnVar; **Black** - Sub-hourly 4DEnVar

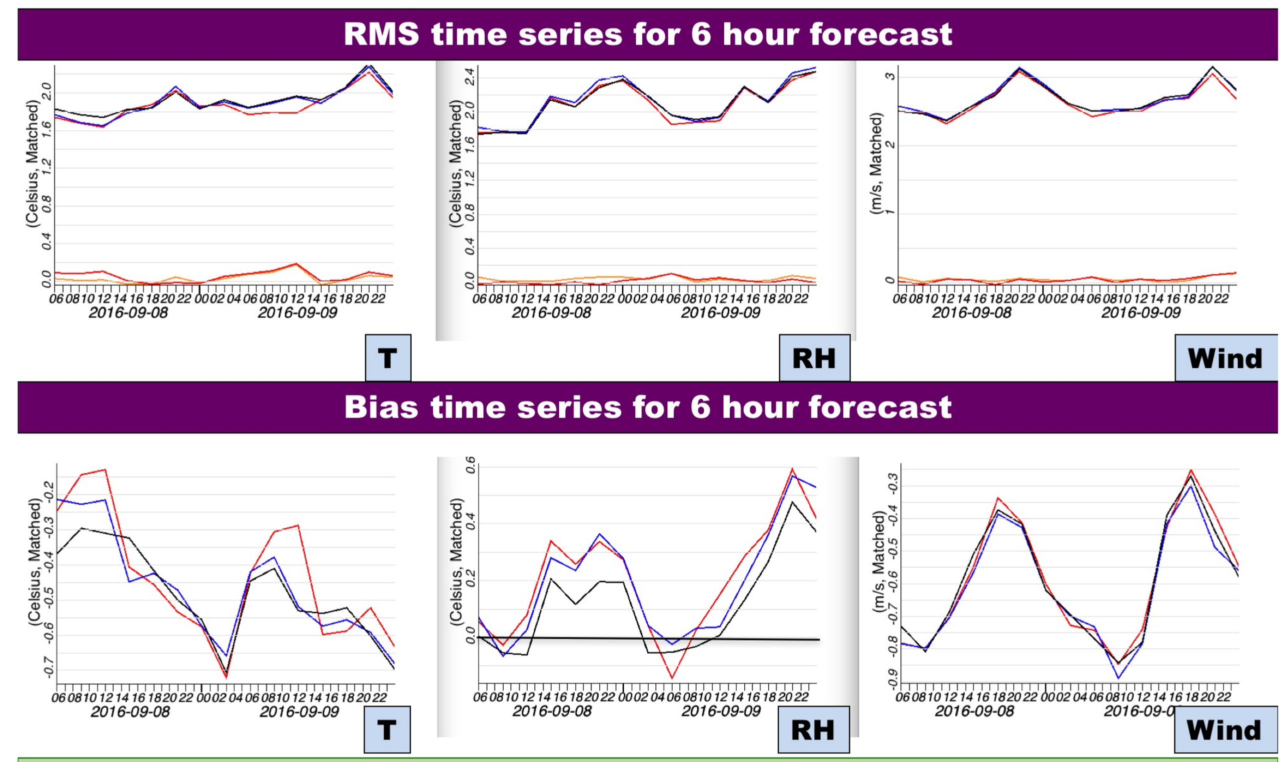
Surface Time-Series Verification: Analysis Time

- On average, sub-hourly 3D hybrid En Var provides lower RMSE than the other two experiments
- The 4D hybrid EnVar experiment does not fit to the observations as well, but this is to be expected given that DA is conducted with three time levels, but only verified against one
- Aside from wind, both sub-hourly experiments show lower bias than the hourly 3D hybrid EnVar



Red - HRRR operational (hourly); **Blue** - Sub-hourly 3DEnVar; **Black** - Sub-hourly 4DEnVar

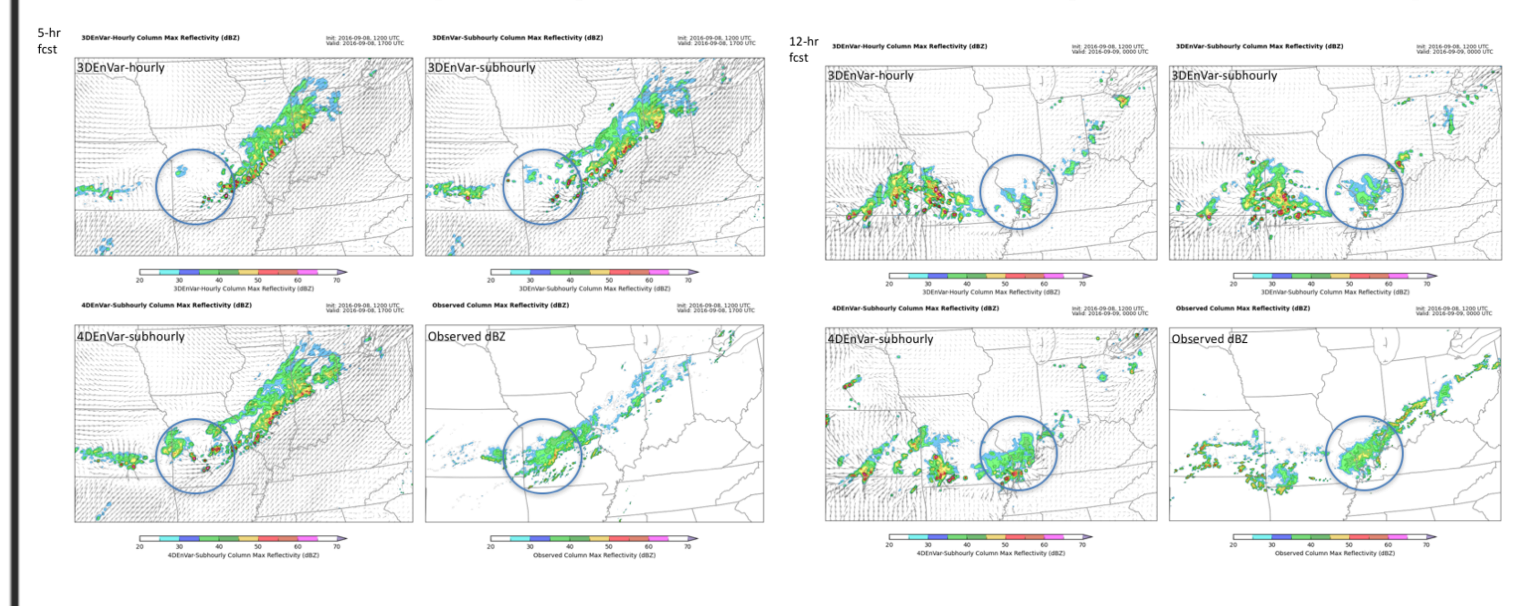
Surface Time-Series Verification: 6-hr Forecast



Red - HRRR operational (hourly); **Blue** - Sub-hourly 3DEnVar; **Black** - Sub-hourly 4DEnVar

- Mostly neutral to very slightly negative RMSE impact for the sub-hourly experiments compared to the operational hourly configuration
- Both sub-hourly experiments show lower bias, particularly for temperature and relative humidity

Radar Reflectivity Comparison: 1200 UTC 8 September 2016 Cycle



- Qualitatively improved location and intensity of storm-scale precipitation features (circled) for the sub-hourly experiments
- For this sample cycle, the 4D hybrid EnVar experiment appears to be qualitatively the best for 5- and 12-hr forecasts

Conclusions and Future Work

Initial results indicate that sub-hourly data assimilation within the HRRR is possible and is not detrimental to the synoptic features of the forecast, verified through upper-air profiles, and to a lesser extent, surface time series. In addition, benefits may be possible to storm-scale features that escape traditional verification metrics, including strength and placement of convection. While it may be difficult to implement such a system at the moment due to computational constraints, both sub-hourly cycling and data assimilation with 4D hybrid EnVar appear to be valid options for operational implementation in the future.

It is important to note that this system has not been tuned for sub-hourly time scales, and may benefit from modifications to observation error and/or the size of the data assimilation observation time window. Observation error tuning for data collected at sub-hourly intervals, particularly aircraft and METAR observations could greatly benefit the sub-hourly experiments. In addition, implementation of a regional ensemble, with 15-minute forecast intervals could improve the data assimilation, since currently only coarse, hourly GFS ensemble information is used.

Future work may include:

- Further radar reflectivity analysis of other convective events within the three-day retrospective period
- Verification of precipitation and ceiling forecasts
- Analysis of spatial/temporal sub-hourly differences for the three time levels in 4D hybrid EnVar
- Testing sub-hourly data assimilation in the HRRR with a regional ensemble

Acknowledgments

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