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Developing a Quantitative Measure of Convective Forcing to Evaluate High Resolution Rapid Refresh Ensemble (HRRRE) Variance

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Abstract

Hazardous weather events have the greatest impact when they are not accurately forecasted. The quest for advanced lead times of accurate forecasts has motivated the need for understanding the correlation between convective forcing and ensemble skill/variance of the High Resolution Rapid Refresh Ensemble (HRRRE) model. To analyze this relationship, this study developed the Reflectivity Convective Forcing Categorization (RCFC), a quantitative method to categorize convective forcing using Multi-Radar Multi-Sensor composite reflectivity observations. Both reflectivity coverage and rate of change of reflectivity were examined during May and June 2016 utilizing RCFC. Several events exemplifying strong and weak forcing regimes were qualitatively analyzed using Storm Prediction Center mesoscale/surface analyses and upper air maps, for RCFC verification. Findings included strongly forced days having a greater reflectivity rate of change and coverage than weakly forced days. Results enabled future examination of the correlation between convective forcing and HRRRE ensemble variance/skill, facilitating HRRRE improvements.

Considerable challenges remain in comprehending and predicting initiation and evolution of high impact convective weather events (Dowell et al., 2010). Hazardous thunderstorm events have the greatest impact when they are not accurately forecasted, yielding costly repairs and leaving people injured. Utilizing Numerical Weather Prediction (NWP) and ensemble forecasting is an important tool for issuing severe weather outlooks and warnings (Dowell et al., 2010).

Background

Today’s high-resolution models are essential to convective-scale forecast operations and provide information on future evolution of storms and their internal structure (Stensrud et al., 2009). The High Resolution Rapid Refresh Ensemble (HRRRE) is a cutting edge example of a convective allowing model (CAM), a high resolution weather predicting model independent of physical convective parameterization schemes, which was developed based on previous successful forecasting with the High Resolution Rapid Refresh (HRRR).

As part of the National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed (HWT) Experimental Forecast Program Spring Experiment 2016, high-resolution ensemble forecasts using the experimental HRRRE are being evaluated for improved prediction of high impact weather (Clark et al., 2012, NOAA, 2016). The goal of the HRRRE is to represent the true uncertainty of the forecast with ensemble variance, or spread. In order to examine the correlation between convective forcing and HRRRE ensemble variance, a quantitative measure of convective forcing is needed. This study describes how synoptic upward motion was quantitatively analyzed through the development of a forcing measure that stratified warm season events using case studies and an independent forcing measure.

Data

Composite reflectivity data were obtained from the Multi-Radar/Multi-Sensor (MRMS) product (NOAA, 2016). The MRMS composite reflectivity data were interpolated to the HRRR 3-km grid, and analyzed between 15 UTC and 6 UTC from May 1, 2016 through June 1, 2016. The data were examined and masked to match each of the five HRRRE domains in the contiguous United States.

Three main calculations were examined between 1500 UTC and 0600 UTC. First, the percentage of the total number of observations by MRMS radar over the total number of grid points was calculated for each hour. Then, the difference of the number of data point observations between each hour was calculated. Finally, the same difference rate of change calculation was repeated, but this time for every three hours. Thresholds were evaluated at 5 dBZ intervals between 15 dBZ and 45 dBZ. The 35 dBZ was deemed the most informative threshold, as it is a reasonable cutoff for strong storms and has been used as a convective storm threshold in previous studies (e.g. Dixon and Wiener 1993).

Methods

A Reflectivity Convective Forcing Categorization (RCFC) was developed to provide a quantitative measure of observed composite reflectivity. The max hourly percent of coverage was compared to the max hourly rate of change, and the max three hourly percent rate of change. Each of the three measures stratified convective events from strongly to weakly forced, yielding similar ranking. Given the similar rankings, a scatter plot was created to determine a correlation between the hourly reflectivity coverage and rate of change at 35 dBZ. A linear correlation exists between the coverage and rate of change. The rate of change of reflectivity was identified as the most effective measure to quantify convective forcing and is referred to as the RCFC method for the remainder of the study.

RCFC was qualitatively verified via Storm Prediction Center mesoscale/surface analyses, upper-air maps, and vertical wind shear. Key forcing mechanisms identified included fronts, shortwave troughs, deep layer shears, deepening surface lows, warm advection, and orographic lifting. The HRRR ensemble mean 500 mb height difference between 15 UTC and 18 UTC was calculated and 10 meter height falls were identified as large height falls for a given three hour period. Convective events were ranked from greatest to smallest height falls and compared to the RCFC values (strongest to weakest forcing) for quantitative verification.

Results

The RCFC method is a novel approach to measuring convective forcing that will be further explained in the discussion section. In order to determine the effectiveness of RCFC, six case studies were analyzed. For each case study, RCFC results were evaluated against atmospheric conditions using SPC map analyses. Three strongly forced cases and three weakly forced cases were evaluated. In summary of RCFC case studies, we found that strong RCFC values were associated with troughs and synoptic upward motion. However, the weakly ranked RCFC days occurred on days with ridges, little-to-no convection, or convection forced from the terrain or dryline (where a dry air mass meets a moist air mass). Therefore, the RCFC ranking system is an effective technique for classifying forcing.

Discussion

The concept of measuring forcing with reflectivity data was intended to be more reliable as opposed to a more traditional measure of synoptic forcing from Quasi-Geostrophic (QG) theory which requires analysis data. Use of analysis data would introduce additional errors and would necessitate more complex computations. On the other hand, reflectivity is an observed quantity free of model error. Therefore, the RCFC method would be the preferred way to measure forcing.

The second technique verified the RCFC method as it examined analyzed HRRRE height falls at 500 mb. A height falls analysis was chosen to represent a quantity related to QG forcing, which was a more elementary computation. One would expect heights to fall as a trough progresses or a ridge exits and rise as a trough exits or a ridge progresses.

More general limitations to the study included the removal of cases with missing MRMS time steps in May and June. Also, when comparing HRRRE height falls, there were two missing days due to HRRRE down days (18 May, 21 May 2016). This is especially unfortunate since 21 May was featured as a case study. Despite the limitations to the RCFC method, it will be a valuable tool for classifying forcing for convective events.

Conclusion

The initial hypothesis that atmospheric forcing can be quantitatively measured using the time rate of change and observed reflectivity coverage was proven successful. The RCFC method effectively classified strongly and weakly forced events. In developing RCFC, a linear correlation between hourly rate of change and coverage of reflectivity was discovered. Thus, the RCFC measure was quantified solely by the rate of change. The strongly and weakly forced case studies demonstrated consistent verification with SPC maps. RCFC compared well with HRRRE heights overall with the exception of a few cases. In particular, the RCFC method is biased by moisture availability. Future work will also extend the dataset to include days with missing reflectivity observations in May and June. Furthermore, the RCFC method will extend beyond the Spring Experiment study periods to incorporate data from all seasons and for multiple years.

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