Impacts of Physics Parameterization and Data Assimilation on Synoptic Feature Modeling in Severe Weather Outbreaks

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Introduction

The threat of a major severe weather outbreak can be anticipated multiple days in advance in ideal outbreak setups. However, the predominant mode of the outbreak is sometimes unclear to forecasters until hours prior to the event. The forecasts of numerical weather prediction (NWP) models contain inherent uncertainty. Given the greater risk to life and property posed by tornado outbreaks, it is useful to classify severe weather events as tornadic or nontornadic. Shafer and Doswell (2011) define a tornado outbreak as 6 or more tornado reports within a single synoptic-scale system over a 24 hour period (1200 UTC to 1200 UTC the following day). As such, 20 tornadic and 20 nontornadic outbreaks were selected for comparison in this study.

Mercer et al. (2012) determined that tornadic and nontornadic outbreaks exhibit distinct patterns of synoptic meteorological features. This research builds on their work, introducing NWP model variations into the analysis. The research question is to examine the effect that data assimilation and microphysics/planetary boundary layer (PBL) parameterizaton have on the modeling of synoptic-scale weather features in tornadic and nontornadic outbreaks.

Methodology

The selected 40 severe weather outbreaks were modeled in the WRF at 12 km spatial resolution on the North America Regional Reanalysis dataset. Variations were introduced to the model run for each case. Four variations were generated by varying the sources of data ingested into the model. Conventional meteorological data and infrared brightness temperatures from the HIRS-4 sounding unit were assimilated in the Gridpoint Statistical Interpolation (GSI) software at 6-hour intervals. Another set of variations was produced by varying microphysics and PBL physics parameterizations, though no additional data were assimilated. A summary of all model variations for each case is shown.

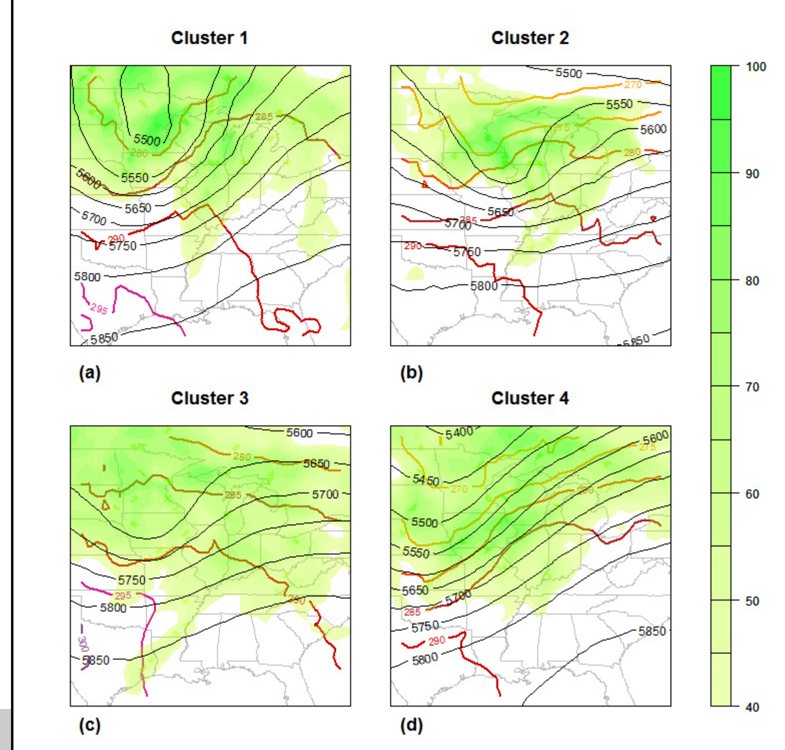
Assimilation Variants
Data assimilation control (no assimilation)
Conventional data assimilated
HIRS-4 data assimilated
Conventional and HIRS-4 assimilated

Parameterization Variants
Goddard microphysics
Morrison microphysics
Thompson microphysics
WRF Single Moment 6-class
WRF Double Moment 6-class
Asymmetric Convection Model PBL
Mellor-Yamada-Janjic PBL
Yonsei University PBL

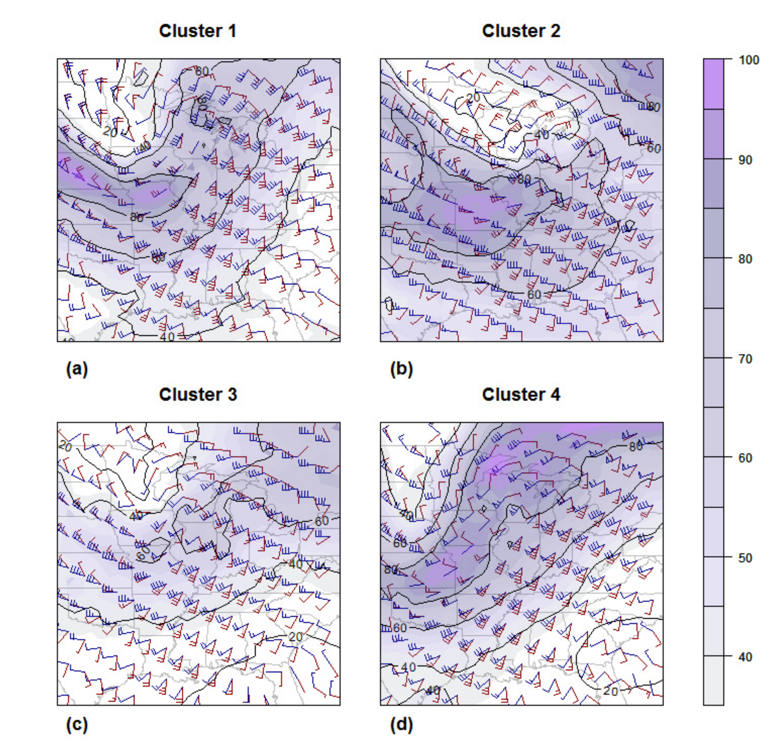
Since a variety of atmospheric setups can contribute to severe weather, and such differences would be averaged out, it was possible that synoptic composites could be produced that did not resemble the actual synoptic pattern of many of the tornadic or nontornadic cases. A statistical *k*-means cluster analysis was therefore employed on the tornadic and nontornadic outbreaks for each of the nineteen model variations. Standard synoptic variables averaged from the resulting clusters were then graphically depicted and visually examined to determine variations in the modeling introduced by data assimilation and physics parameterization.

Results & Discussion

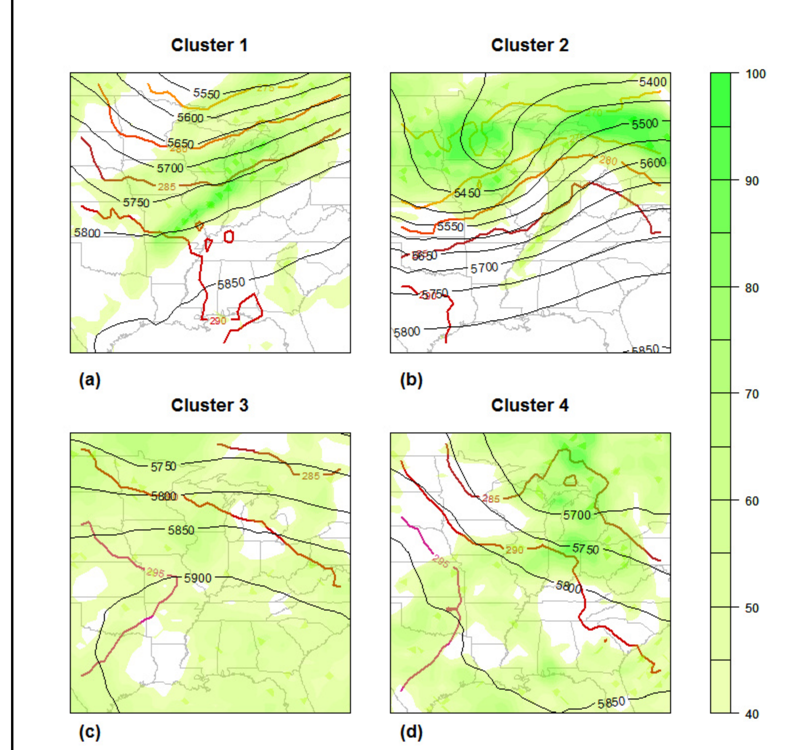
Differences existed among the model ensemble in terms of which tornado outbreaks were assigned to each cluster. The nontornadic outbreaks were all assigned to the same clusters irrespective of data assimilation or physics parameterization variations.



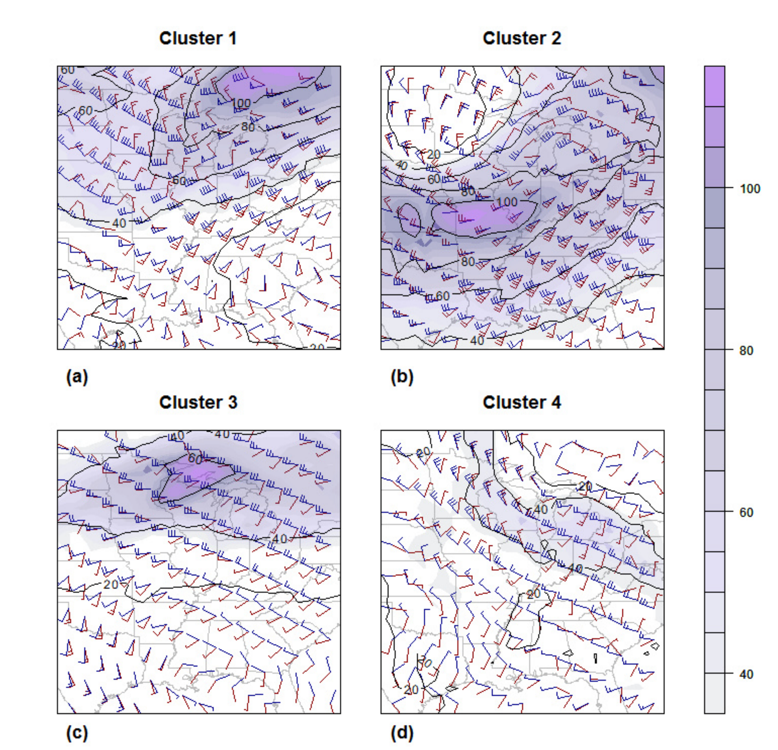
Composites of 500 mb height, 700 mb RH, and 850 mb temperature in tornado outbreak clusters.



Composites of 300 mb wind magnitude, 500 mb magnitude-direction, and 925 mb magnitude-direction in tornado outbreak clusters.



Composites of 500 mb height, 700 mb RH, and 850 mb temperature in nontornadic outbreak clusters.



Composites of 300 mb wind magnitude, 500 mb magnitude-direction, and 925 mb magnitude-direction in nontornadic outbreak clusters.

Assimilation Ensemble Synoptic Variations

Troughs were not as deep in the two runs containing conventional observations as they were in the control run and the HIRS-4 run. The troughs were also slightly more inverted in the control and HIRS-4 runs. The exception was tornadic cluster 2 in the HIRS-4/conventional run, in which the trough was slightly deeper than in any other assimilation run. Differences in the 700 mb moisture field were very small and followed no clear pattern. Warm 850 mb temperatures in cluster 2 extended farther north in the conventional and HIRS-4/conventional runs, but this pattern was not observed for the other clusters.

Far clearer differences existed among the wind fields. The conventional and HIRS-4/conventional runs modeled stronger 300 mb winds in all four tornadic clusters than the runs not containing conventional observations. HIRS-4 radiances alone also generated a larger area of high 300 mb winds in clusters 1 and 2 than the control run. The HIRS-4 run also produced higher winds at 500 mb in cluster 2 than any other assimilation run. The conventional run exhibited greater directional shear from 925-500 mb in cluster 3 than any other assimilation run.

Physics Parameterization Ensemble Synoptic Variations

Morrison and Thompson modeled the low pressure center in tornadic cluster 1 deeper than Goddard, especially with ACM2 PBL physics. WDM-6 and WSM-6 modeled this feature at a lower height still. The 290 K 850 mb isotherm in cluster 3 extended farther to the north with Morrison and Thompson than the other microphysics, especially with MYJ. With ACM2 PBL physics, Goddard modeled the jet streak in tornadic cluster 1 over a smaller region than any other microphysics. The temperature difference in cluster 3 did not translate into any visible differences in wind at 300 mb among the microphysics runs with MYJ PBL physics, but the 925-500 mb crossover shear for Morrison and Thompson microphysics is slightly greater over the region where the 290 K isotherm extends in these runs.

PBL physics parameterization produced significant differences for some clusters and variables in nontornadic outbreaks. In clusters 3 and 4, MYJ produced a much smaller area of high 850 mb temperatures than the other two PBL physics. This effect was observed very strongly for all microphysics options for these clusters. It was also apparent in clusters 1 and 2, though it was not observed as strongly. In clusters 3 and 4, Yonsei University produced a slightly larger area of 295 K temperatures than ACM2. In cluster 2, the low pressure core extended slightly farther west with MYJ than ACM2 or Yonsei. In clusters 1 and 3, the jet streak is smaller in size with MYJ than with the other two PBL physics. This feature could account for the more northerly extent of warm 850 mb temperature fields with Yonsei and ACM2. In cluster 3, 925 mb winds immediately due south of the jet streak on the north side of the ridge were west-northwesterly with ACM2 and Yonsei and west-southwesterly with MYJ.

Microphysics parameterization did not consistently influence the modeling of most features, comparably to the tornado outbreak clusters. In cluster 4, the 265 K isotherm at 850 mb extended farther northeast with Morrison and Thompson microphysics than Goddard, WDM-6, or WSM-6.

References

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