Shepherd T.J., Letson F., Barthelmie R.J. and Pryor S.C. How well are hazards associated with derechos reproduced in regional climate simulations? *Natural Hazards and Earth System Sciences Discussions (*nhess-2021-373)

Response to reviewer #2:

We thank the reviewer for their thoughtful and thought-provoking comments. Below we provide a complete list of their comments (in black) and our responses (in green). We further note in brief how this material will be included in the manuscript once we have received all reviews.

Review of nhess-2021-373: How well are hazards associated with derechos reproduced in regional climate simulations?
The authors used WRF as a convective-permitting regional climate model to produce 11 simulations of a severe derecho that affected the northeastern U.S. in 2012. The derecho had a major impact in terms of property damage and power outages over a large, populated region. This derecho was poorly forecast, yet we need to understand how climate change will impact such extreme mesoconvective systems. The authors examined the role of microphysical parametrization, nudging, and two different reanalysis products on 3km simulations of several days leading up to and including the derecho. The authors compared model output to surface and radar observations of precipitation, wind gust, hail, as well as variables describing the convective environment, such as vertical velocities and cold pool formation. The explanation of the methods of model assessment was particularly thoughtful.
Overall, the manuscript is well constructed with clear objectives, detailed methodology, and significant findings. I recommend that the manuscript be accepted following minor revisions.

Major comments

1. While most of the simulations poorly represented the derecho, this is not surprising given that this event was not well predicted. While I would not ask the authors to address in this manuscript, it would be intriguing to duplicate this work for a significant mesoconvective system that was well predicted.

Response: We appreciate the reviewer's comment. We do indeed plan to explore this work further, particularly in the context of pseudo global warming studies. As per minor comment 10, we have included references to such studies that are relevant to mesoscale convective systems in North America.

2. While the use of the different microphysical parameterizations in the model was well designed, it is unclear what is learned by the comparison of ERA5 and ERA-Interim. It is not clear to me that you can generalize that ERA-Interim is inherently better at producing boundary conditions for such simulations (l. 526-527), or whether the small differences in the pre-storm temperature and moisture fields in ERA-Interim (l. 413-415) fortuitously produced more realistic simulations.

Response: We thank the reviewer for presenting this concern. We do agree that the over-generalization of the initial condition results is not warranted. For this reason, we were particularly careful with the language used to not assert one dataset as being more accurate, but rather to explain why the simulations differed. We note the reviewer's concern, however, and have revised the manuscript text. The text at line 526-527 has been amended to (line 621 in the revised text): “Additional simulations using ERA5 and ERA-I are required before generalizable conclusions can be made about which dataset provides better boundary conditions.”

For lines 413-415, we note that we have already revised the manuscript text in response to reviewer 1 and their comments regarding the simulations. After additional research, the elevated mixed layer (EML) proved to be critical in this event. We note that there was a high degree of similarity between the two reanalysis products, but the key difference between the two initial conditions datasets is the coherency of the EML. This is one factor in the difference between simulations with ERA5 and ERA-I. The revised text reads (lines 480-492 in the revised manuscript):
“Evaluation of the initial conditions indicates a high degree of similarity between the two reanalysis products on 26 and 28 June for most properties (Figure 12). However, as described above, development of an intense elevated mixed layer (EML, 700-500 hPa) over the central US that subsequently propagated eastwards (Shourd and Kaplan, 2021) appears to have been a key ingredient in development of this Derecho. Earlier work (Banacos and Ekster, 2010) employed a definition of an EML as a layer of depth > 200 hPa with both a steep lapse rate (temperature declines of over 8°C per km) and an increase in the RH with height. Figure 12 shows the lapse rate in the four sets of IC and indicates that while both data sets correctly (relative to output from NOAA WRF-Rapid Refresh model presented in (Shourd and Kaplan, 2021)) indicate relatively low lapse rates at 0000Z 26 June (when the region with the EML was displaced further west), using the combined definition of a strong lapse rate and a strong gradient of RH (a 20% difference across the layer), the EML is, in both reanalysis products, displaced too far north at 0000Z 28 June relative to NOAA WRF-Rapid Refresh model simulations presented in (Shourd and Kaplan, 2021). The EML is, however, more consistent (across the two components) and more coherent in space in ERA-Interim. This may provide a partial explanation for why simulations with ERA-Interim initial and lateral boundary conditions exhibit higher fidelity with respect to aspects of the Derecho.”

References

Banacos, P. C. and Ekster, M. L.: The Association of the Elevated Mixed Layer with Significant Severe Weather Events in the Northeastern United States, Weather and Forecasting, 25, 1082-1102, 10.1175/2010waf2222363.1, 2010.

Shourd, K. N. and Kaplan, M. L.: The Multiscale Dynamics of the 29 June 2012 Super Derecho, Climate, 9, 155, 2021

3. I share the concern with the first reviewer that the abstract was not sufficiently specific, but I find the proposed new abstract in the authors’ response to be a significant improvement that addresses this concern.

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Response: We appreciate the reviewer's comment and thank them for reading the reply to reviewer 1 where we responded with the improved abstract.

4. I share the first reviewer's concern about the need for additional context on the convective environment for this storm in the background. The additions proposed by the authors appear to address this concern.

Response: Again, we thank the reviewer for reading the reply to reviewer 1 and we are pleased that the additions address these concerns.

Minor

1. 44: Is "atmospheric phenomena" another way of saying "weather"? Or is it intended to capture more.

Response: We are using this term in the AMS glossary sense; **atmospheric phenomenon**
As commonly used in weather observing practice, an observable occurrence of particular physical (as opposed to dynamic or synoptic) significance within the atmosphere.
Included are all hydrometeors (except clouds, which are usually considered separately), lithometeors, igneous meteors, and luminous meteors. From the viewpoint of weather observations, thunderstorms, tornadoes, waterspouts, and squalls are also included. The above usage excludes such "phenomena" as the local or large-scale characteristics of wind, pressure, and temperature; it also excludes clouds, although it includes many products of cloud development and composition. In aviation weather observation, atmospheric phenomena are divided into two categories: weather and obstructions to vision."
Which we believe is differentiable from 'weather', which again according to the AMS glossary has the following definition: **weather**
The state of the atmosphere, mainly with respect to its effects upon life and human activities.

As distinguished from climate, weather consists of the short-term (minutes to days) variations in the atmosphere. Popularly, weather is thought of in terms of temperature, humidity, precipitation, cloudiness, visibility, and wind.

1. As used in the taking of surface weather observations, a category of individual and combined atmospheric phenomena that must be drawn upon to describe the local atmospheric activity at the time of observation.
   Listed weather types include tornado, waterspout, funnel cloud, thunderstorm and severe storm, liquid precipitation(drizzle, rain, rain showers), freezing precipitation (freezing drizzle, freezing rain), and frozen precipitation (snow, snow pellets, snow grains, hail, ice pellets, ice crystals). These elements, with the exception of the first three, are denoted by a letter code in the observation. With the METAR code, reporting weather also includes an intensity qualifier (light, moderate, or heavy) or proximity qualifier. The weather used in synoptic weather observations and marine weather observations is reported in two categories, "present weather" and "past weather." The "present weather" table consists of 100 possible conditions, with 10 possibilities for "past weather"; both are encoded numerically. Another method, which has the advantage of

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being independent of language, is the recording of weather types using symbols. There are 100 symbols that identify with the numeric codes of the synoptic observation.

2. To undergo change due to exposure to the atmosphere.'

So, we perceive 'weather' as the totality of the atmospheric state and atmospheric phenomena as notable (perhaps even atypical) conditions that may derive from a singular event (e.g. downdrafts and lightning from MCS).

Nevertheless, given the reviewers concerns we have changed 'atmospheric phenomena' to 'weather events' (line 50 in the revised manuscript).

2. 54: focuses

Response: Thanks. Corrected.

3. 51: "function model configuration" – appears a word is missing

Response: Thanks. We have corrected the sentence to read "…as a function of model configuration…" (line 57 in the revised manuscript).

4. 56: Is "advected" the right word? Perhaps "propagated"?

Response: Thanks for this suggestion. We now use 'propagated' instead of 'advected' (line 63).

5. 66: run-on sentence

Response: Thanks for spotting this. The sentence now reads (line 72): "Over 20 deaths were reported during the 29-30 June 2012 derecho event. There was also widespread property damage and extensive power outages (Halverson, 2014)."

6. 88-89: it might be helpful to explain "scale-aware convective parameterizations". How are they "scale-aware"?

Response: Thanks for this suggestion. We have added a brief definition of what scale-aware convection schemes are, by changing the sentence to read (line 118): "Emerging research has shown that using scale-aware convective parameterizations (i.e. those schemes where numerical descriptions include a parameter that modulates convective processes as a function of horizontal resolution) throughout the model gray zone resolution…".

7. 93: "degree/manner in what the model parameterization interact" is unclear. What is this trying to say?

Response: Thanks for bringing this to our attention. We have amended this sentence to remove ambiguity. The revised text in the manuscript will read (line 122): "…model fidelity is a strong function of the precise cloud microphysics scheme applied, model grid spacing, lateral boundary conditions and the degree/manner in which the model parameterizations interact (for example, feedback between the cumulus parameterizations/cloud microphysics and the radiation scheme)…"

8. 306: Perhaps I'm missing something obvious, but why would s(w) be used as intensity for vertical motion rather than just w?

Response: We note that the text at line 308 states: "The height at which the maximum variability in vertical velocities occur is used to provide information regarding the vertical structure of convection." We have elaborated slightly to read: "The height at which the maximum standard deviation of vertical velocities ($\sigma(w)$) is used to infer the intensity and vertical structure of convection. Since updrafts and downdrafts are of relatively short duration, we use $\sigma(w)$ computed using vertical velocities output from the time of maximum cREF > 40 dBZ (i.e. from the 10-min time step WRF output file at that time) as a more descriptive as a metric rather than the mean velocity because the dispersion around the mean is reflective of the intensity of both downdrafts and updrafts in the column."

9. 322-323: This sentence (Rank correlation coefficients…") isn't clear. How does the rank correlation show which model property most greatly influences skill? The correlations show how well the model and observations agree, but the word "influences" suggests that you can determine a causal mechanism.

Response: We agree that this is ambiguous and could be misleading. We have amended the manuscript text to (line 368): "…to identify which model properties (wind speed, precipitation etc.) exhibit highest association with the diagnostic metrics used to examine model skill in simulating this event."

10. 501: The authors use the pseudo-global warming framework as a justification but don't provide references (perhaps I missed them) how this framework has been used to examine mesoconvective systems nor provide examples of how such a framework might be used.

Response: Thanks for raising this. There are indeed a few PGW studies related to MCSs, but not specifically to derecho events [e.g. Ikeda et al. (2010); Liu et al. (2017); Haberlie et al. (2019)]. We have added additional references to the manuscript text.

Thus, the previous text that read (line 521):
"Our finding has important implications for construction of hindcast simulations for use in Surrogate or Pseudo Global Warming (PGW) numerical experiments to quantify the potential of global warming on extreme weather events using regional models (Li et al., 2019). In such simulations an historically important extreme event is first simulated using contemporary LBC and then the simulation is repeated using LBC and IC perturbed to represent the change in, for example, air temperatures and water vapor availability. The difference in these two realizations

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is interpreted as the impact of global climate non-stationarity. Our work indicates use of ERA5 for IC and LBC may not always result in improved baseline simulations of the extreme event in the contemporary climate, and the simulation deficiencies may render evaluation of the PGW response highly uncertain."

Has been modified to read:
"Our finding has important implications for construction of hindcast simulations for use in Surrogate or Pseudo Global Warming (PGW) numerical experiments to quantify the potential of global warming on extreme weather events using regional models (Kröner et al. 2017; Li et al., 2019). In such simulations an historically important extreme event/period/season is first simulated using contemporary LBC and then the simulation is repeated using LBC and IC perturbed to represent the change in, for example, air temperatures and water vapor availability (Kroner et al. 2017). The difference in these two realizations is interpreted as the impact of global climate non-stationarity. A previous analysis over CONUS used ERA-Interim LBC and shifted the atmospheric profile by ± 5 °C. They found increases in both CAPE and convective inhibition, which implies shift the convective population (Rasmussen et al. 2020). Our work indicates use of either ERA-Interim or ERA5 for IC and LBC may not always result in high-fidelity baseline simulations of extreme convective events in the contemporary climate. These simulation deficiencies may render evaluation of the PGW response highly uncertain."

References:

Haberlie, A. M., & Ashley, W. S. (2019). Climatological representation of mesoscale convective systems in a dynamically downscaled climate simulation. International Journal of Climatology, 39(2), 1144-1153.

Ikeda, K., Rasmussen, R., Liu, C., Gochis, D., Yates, D., Chen, F., Tewari, M., Barlage, M., Dudhia, J., Miller, K., Arsenault, K., Grubišić, V., Thompson, G. and Guttman, E. (2010) Simulation of seasonal snowfall over Colorado. *Atmospheric Research*, **97**, 462–477.

Kröner, N., Kotlarski, S., Fischer, E., Lüthi, D., Zubler, E., & Schär, C. (2017). Separating climate change signals into thermodynamic, lapse-rate and circulation effects: theory and application to the European summer climate. *Climate Dynamics*, *48*(9), 3425-3440.

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