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# THE IMPACTS OF HYDROMETEOR CENTRIFUGING ON TORNADO DYNAMICS: IMPROVING THE REALISM OF TORNADO SIMULATIONS

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## EXECUTIVE SUMMARY

Continued population growth in regions prone to tornadoes makes improving the understanding of these violent weather phenomena increasingly important. This research project attempts to improve our understanding of tornadoes by making the simulations used to study these destructive and dangerous weather events more physically realistic. For the first time, we have quantified the impacts that centrifuging of precipitation has on the vorticity budgets of these numerically simulated tornadoes. Preliminary findings have been consistent with radar observations of tornadoes, removing an unrealistic buildup of precipitation in the vortex center of simulated vortices and tornadoes, which has been widely seen in current tornado simulations. Ongoing work uses numerous tornado simulations to evaluate the significance of the inclusion of precipitation centrifuging in tornado dynamics, as well as more generally studying how a tornado acquires its vorticity, or spin, in different environmental conditions.

## RESEARCH CHALLENGE

The primary research challenge being addressed is the lack of precipitation centrifuging in numerical simulations of tornadoes. In current simulations, precipitation follows the airflow, creating an unrealistic buildup of precipitation in the vortex center, which in turn creates a source of negative buoyancy that potentially limits the stretching of vorticity in these simulated tornadoes. In nature, as precipitation moves around a circulation such as a tornado, there is no force strong enough to keep the precipitation from moving outward, or being centrifuged, away from the circulation center. Observed tornadoes have a minimum of precipitation in the vortex center, while simulated tornadoes often have a relative maximum of precipitation in the vortex center.

With millions and sometimes billions of dollars of damage caused by tornadoes every year, along with the risk of fatalities or serious injuries from each tornado, a better understanding of these destructive weather events is needed in order to improve forecasting, preparedness, and mitigation of their impacts. By including the centrifuging of precipitation in the model we use to learn about tornadoes, our simulations are more consistent with what is observed in nature, facilitating the improvement of our understanding of tornadoes. Research findings have and continue to shape forecasting methods and plans for preparedness and damage mitigation; therefore, continued improvement of our understanding of tornadoes will provide results that can be used in operational settings, ultimately aiding those living in regions prone to tornadoes.

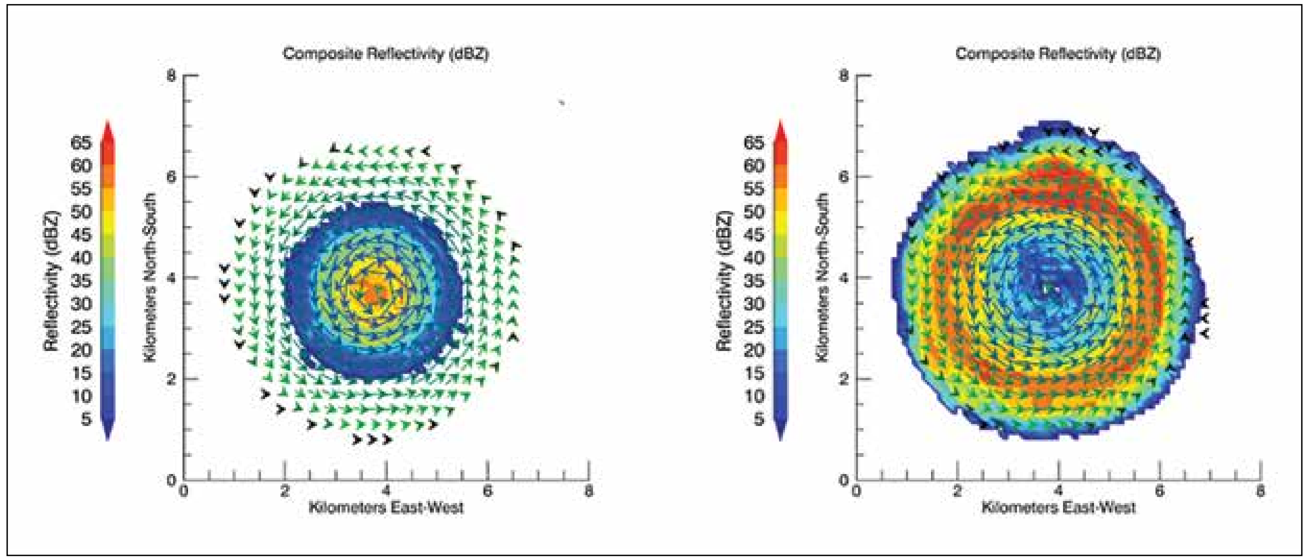


Figure 1: An idealized vortex simulation (left) where an unrealistic buildup of precipitation occurs in the vortex center. The same idealized vortex simulation (right) with centrifuging applied and a physically realistic minimum of precipitation in the vortex center.

## METHODS & CODES

We employed the widely used CM1 (Cloud Model 1) code for our simulations. CM1 was designed for studying small-scale atmospheric phenomena such as thunderstorms [1] and has also been designed to run efficiently on supercomputers such as Blue Waters. To quantify the impacts that the inclusion of centrifuging has on tornado dynamics, we first ran simulations without centrifuging. Just prior to the formation of a tornado, a checkpoint is saved, allowing the model to be run both with and without centrifuging from this point forward to determine how the centrifuging of precipitation influences the tornado dynamics. To define the magnitude of the centrifuging, an algorithm based on [2] uses trajectories released within the simulation to calculate the curvature of the flow and ultimately determine how quickly precipitation will be centrifuged, or moved outward, from the tornadic circulation. To quantify these impacts over a large sample size, we used atmospheric profiles of temperature, moisture, and wind from atmospheric soundings that were in close proximity to observed supercells [3] as the environmental conditions for our simulations of storms and their resulting tornadoes. A subset of these environments, which have been known to produce simulated tornadoes in previous research, was used for this study.

## RESULTS & IMPACT

We completed idealized simulations and full-scale storm simulations (with a resulting tornado) with and without centrifuging. In simulations without centrifuging, an unrealistic maximum of precipitation develops within the vortex core; however, after turning centrifuging on the precipitation in the vortex center is removed and a physically realistic precipitation minimum forms in the vortex center for both the idealized and full-scale tornado simulations. Similar to radar observations of tornadoes, the removal of precipitation from the vortex center is completed within several minutes in both types of simulations. Continued optimization and improvement to this centrifuging algorithm is in progress, with the goal of sharing these findings and eventually the centrifuging code to allow future research to benefit from the improved realism of the tornado simulations. Potential findings from this study on both the importance of centrifuging and also more general findings about how tornadoes work have the potential to improve future forecasting of tornadoes and also facilitate further research into understanding these deadly and destructive storms.

## WHY BLUE WATERS

Blue Waters was critical to this project because tornado simulations require thousands of computing cores and produce large amounts of data that must be stored and analyzed. The computing power of Blue Waters, along with the available storage for our data, was a perfect match for our project. Additionally, the technical and visualization support provided by the Blue Waters team greatly facilitated accomplishing our research goals.

Ronald Stenz is a fifth-year PhD student in atmospheric sciences at the University of North Dakota. He is working under the supervision of Dr. Matthew Gilmore and hopes to graduate in 2019.