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THE IMPACTS OF HYDROMETEOR CENTRIFUGING ON TORNADO DYNAMICS

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EXECUTIVE SUMMARY

Improving the understanding of tornadoes becomes more important as the population in regions prone to these violent weather phenomena increases. This research aims to advance our understanding of tornadoes by making the simulations used to study these destructive and dangerous storms more physically realistic. For the first time, we are quantifying the impacts that centrifuging of precipitation have on the vorticity budgets of these numerically simulated tornadoes. Preliminary findings have removed an unrealistic build-up of precipitation in the vortex center (widely seen in tornado simulations) for both idealized vortices and simulations of an entire storm and the tornado it produces. Ongoing work will examine a large number of tornado simulations to evaluate the significance of the inclusion of precipitation centrifuging in tornado dynamics, as well as to more generally study 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 air flow, which creates an unrealistic build-up of precipitation in the vortex center. This, 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, a better understanding of these destructive weather events is needed to improve forecasting, preparedness, and mitigation of their impacts. By including the centrifuging of precipitation into the model we use to learn about tornadoes, our simulations become more consistent with what is observed in nature, facilitating the improvement of our understanding. 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.

METHODS & CODES

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

RESULTS & IMPACT

Both idealized simulations and a simulation of a full-scale storm with a resulting tornado have been completed with and without centrifuging. In simulations without centrifuging, the unrealistic maximum of precipitation develops with 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. The removal of the unrealistic precipitation in the vortex center is completed within several minutes in both types of simulations. Work is underway to optimize and improve this centrifuging algorithm further. We will then share these findings and, eventually, the centrifuging code to allow future research to benefit from the improved realism of the tornado simulations. Findings from our study on both the importance of centrifuging, and also more general findings about how tornadoes work, have the potential to improve future forecasting and also to 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 available with Blue Waters greatly facilitated accomplishment of our research goals.

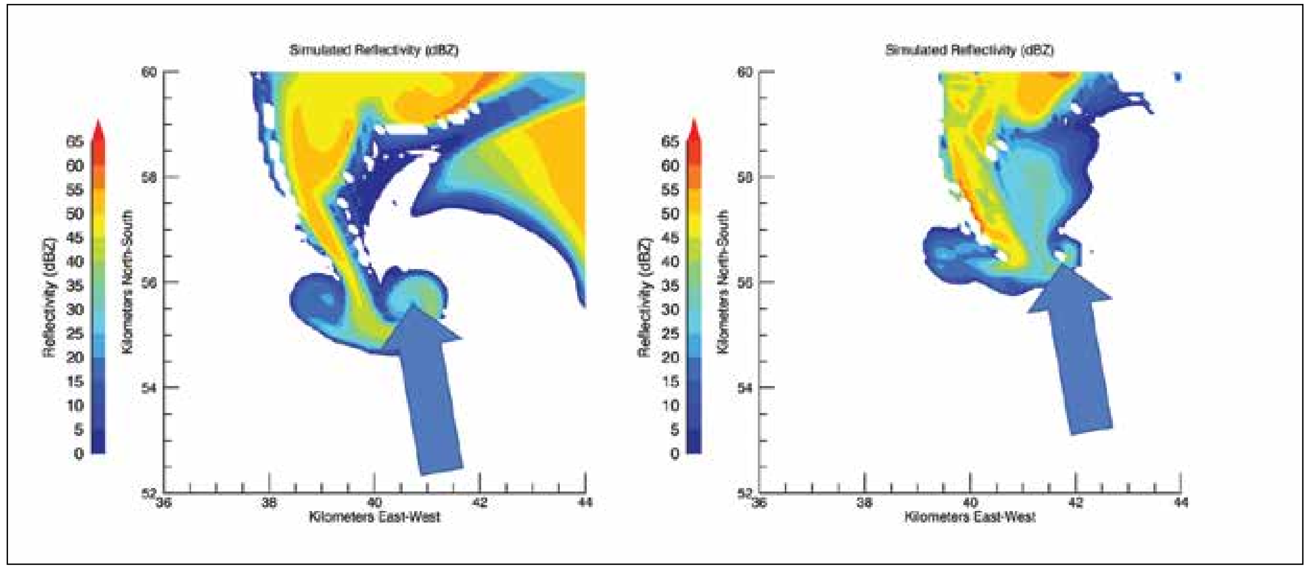

Figure 1: Rain is beginning to accumulate in the simulated tornado center (left). With centrifuging turned on (right), there is an eye-like feature in the simulated tornado center consistent with radar observations of actual tornadoes.

A fourth-year Ph.D. student in atmospheric sciences at the University of North Dakota, Ronald Stenz is working under the supervision of Matthew Gilmore. He expects to graduate in 2018.