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 enhancing the understanding of these violent weather phenomena increasingly important. This research project attempts to improve the understanding of tornadoes by making simulations used to study these destructive and dangerous weather events more physically realistic. For the first time, the impacts that centrifuging of precipitation has on the vorticity budgets of these numerically simulated tornadoes will be quantified. Preliminary findings so far have been consistent with radar observations of tornadoes by removing an unrealistic buildup of precipitation in the vortex center (widely seen in current tornado simulations) of simulated vortices and tornadoes. 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 air flow, 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 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. Addressing this challenge in improving the model's realism requires the efficient calculation of millions of trajectories during a simulation and a solution that is numerically stable with other components of the model physics. Creating a centrifuging code that can work consistently with many different microphysical parameterizations is one of the challenging goals of this project.

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 to improve forecasting, preparedness, and mitigation of their impacts. By including the centrifuging of precipitation into the model used to learn about tornadoes, simulations become more consistent with what is observed in nature. Research findings have shaped and will continue to shape forecasting methods and plans for preparedness and damage mitigation. Therefore, continued improvement in the understanding of tornadoes will provide results that can be used in operational settings, ultimately aiding those living in regions prone to tornadoes.

METHODS & CODES

The widely used Cloud Model 1, which 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, was used for this research. To quantify the impacts of centrifuging on tornado dynamics, simulations were first performed without centrifuging. Just prior to the formation of a tornado, a checkpoint was employed, allowing the model to be run both with and without centrifuging from that point to determine the impact of the centrifuging of precipitation on tornado dynamics. To determine the magnitude of the centrifuging occurring, a centrifuging algorithm based on [2] used trajectories released within the simulation to calculate the curvature of the flow and ultimately how quickly precipitation will be centrifuged 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

Idealized simulations and full-scale storm simulations (with a resulting tornado) have been completed with and without centrifuging. In simulations without centrifuging, an unrealistic maximum of precipitation developed within the vortex core. However, after adding centrifuging, the precipitation in the vortex center was removed and a physically realistic precipitation minimum formed 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 was completed within several minutes in both types of simulations.

Optimization of this centrifuging algorithm is in progress, with the goal of sharing the findings and eventually the centrifuging code to allow future research to benefit from the improved realism of tornado simulations. The work on the algorithm includes producing a centrifuging code that will work consistently with all microphysical parameterizations. 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.

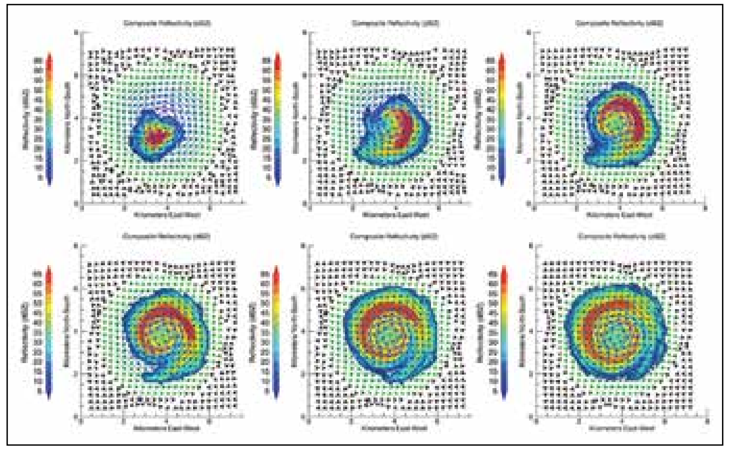

Figure 1: A time series of simulated reflectivity showing the centrifuging of precipitation away from an idealized vortex.

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. Data generated in a typical simulation are in the order of tens and sometimes even hundreds of gigabytes per node. The computing power of Blue Waters, along with the available storage for the data, was a perfect match for this project. In addition, the technical and visualization support available greatly facilitated the accomplishment of our research goals.

Ronald Stenz, a sixth-year doctoral candidate in atmospheric sciences at the University of North Dakota, works under the direction of Matthew Gilmore. He expects to receive his degree in 2020.