Raindrops grow with turbulence in clouds: New findings could improve weather and climate models

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Scientists for decades have attempted to learn more about the complex and mysterious chain of events by which tiny droplets in clouds grow large enough to begin falling toward the ground. Better understanding this process, known as the "rain formation bottleneck," is fundamental to improving computer model simulations of weather and climate and ultimately generating better forecasts.

Now a research team led by scientists at the U.S. National Science Foundation National Center for Atmospheric Research (NSF NCAR) has found that the turbulent movements of air in clouds play a key role in the growth of droplets and the initiation of rain.

The researchers applied advanced computer modeling to detailed observations of droplets in cumulus clouds that were taken during a NASA field campaign. This enabled them to track the impacts of turbulence on embryonic droplets that eventually coalesce into raindrops.

"This research shows that turbulent effects on drop coalescence are critical for the evolution of droplet sizes and the initiation of rain," said NSF NCAR scientist Kamal Kant Chandrakar, the lead author. "Turbulence in cumulus clouds substantially speeds up rainfall and leads to far greater amounts of rain."

Chandrakar and his colleagues found that rain formed around 20 minutes earlier in computer simulations with turbulence than in computer simulations without turbulence. The mass of rainwater was more than seven times higher in simulations that included turbulence.

The study was published in the journal *Proceedings of the National Academy of Sciences.*

From small water droplets to rain

The process of rain begins when small water droplets in clouds condense around microscopic particles of dust, salt, or other materials, which are called cloud condensation nuclei (CCN). As millions of droplets collide with each other, they coalesce into larger droplets that eventually become heavy enough to fall out of the cloud.

The formation of raindrops can vary under different conditions, such as the distribution of different sizes of cloud droplets as well as other factors such as turbulent motions and the properties of particles in the cloud.

Representing this process correctly in computer models of weather events and the climate system is vital for improving the reliability of these models. The coalescence of water droplets is important not only for accurately predicting rainfall, but also for better understanding the evolution of clouds and the extent to which they reflect heat back into space, thereby affecting temperatures.

To tease out rainfall initiation, Chandrakar and his colleagues turned to observations of drop size distributions that were taken by research aircraft that flew into cumulus congestus clouds during a 2019 NASA field campaign, the Cloud, Aerosol and Monsoon Processes Philippines Experiment (CAMP2Ex).

Using a specialized computer model, the research team developed a series of high-resolution simulations to recreate the cloud conditions that were observed during the campaign and see how the droplets coalesced with different turbulent flows.

The simulations demonstrated the key role of turbulence in both the timing and extent of rainfall. They also indicated that the presence of large CCN, which has been the focus of some rain formation theories, could not account for the observed sizes and evolution of droplets. In the simulations with large CCN and little turbulence, droplet coalescence occurred more slowly and generated less rain.

"The development of rain is fundamental to clouds, weather, and the entire climate system," Chandrakar said. "Better understanding this process can point the way to significant improvements in our computer models and ultimately in weather forecasts and climate projections that help protect society."

More information: Kamal Kant Chandrakar et al, Are turbulence effects on droplet collision–coalescence a key to understanding observed rain formation in clouds?, *Proceedings of the National Academy of Sciences* (2024). DOI: 10.1073/pnas.2319664121

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