

Editors' Vox

Perspectives on Earth and space science: A blog from AGU's journal editors

Ice from Above: Toward a Better Understanding of Hailstorms

Globally relevant and locally devastating, hailstorms produce significant societal impacts; despite this, our understanding of hailstorms and our ability to predict them is still limited.



A hailstone 2.5 inches in diameter, which came down southwest of Glendive, Montana.

Credit: John T. Allen

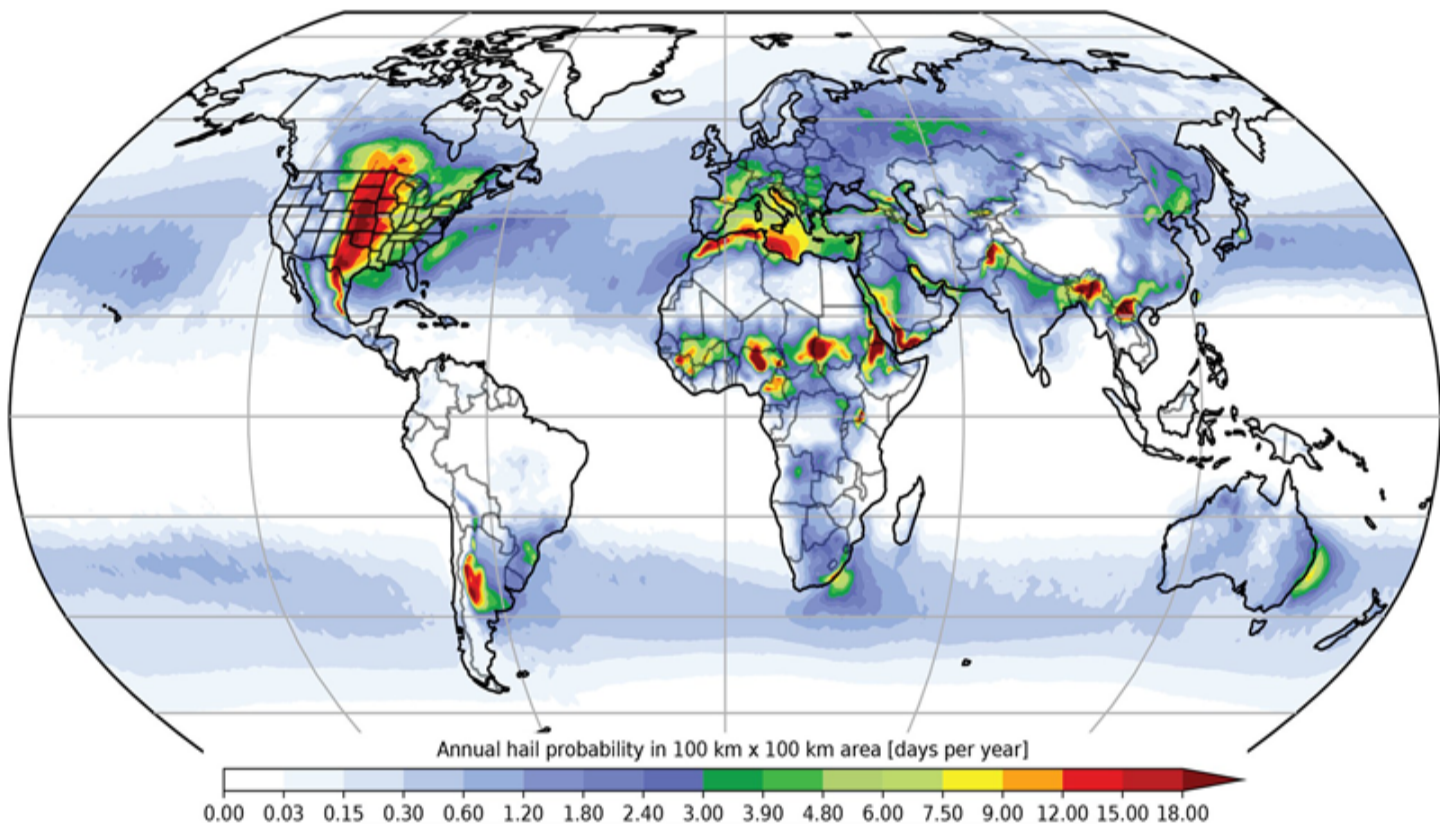
By [John T. Allen](#), [Ian M. Giammanco](#), [Matthew R. Kumjian](#), [Heinz Jürgen Punge](#), [Michael Kunz](#), [Qinghong Zhang](#), and [Pieter Groenemeijer](#) on 11 September 2020

Beginning life as small frozen embryos in a thunderstorm, hailstones can grow to 10 centimeters or more in just minutes, before falling to the ground where they can damage crops, property, and vehicles. A [recent paper](https://doi.org/10.1029/2019RG000665) (<https://doi.org/10.1029/2019RG000665>) in *Reviews of Geophysics* (<https://agupubs.onlinelibrary.wiley.com/journal/19449208>) describes the processes that lead to the development of hail, the observations available to characterize how frequently hail occurs, our limitations in forecasting these events, the response of hail to climate variability and change, and what is known about its effects on society. Here, the authors of the paper give an overview of our current understanding of hail and outline the research challenges and data necessary to improve our understanding.

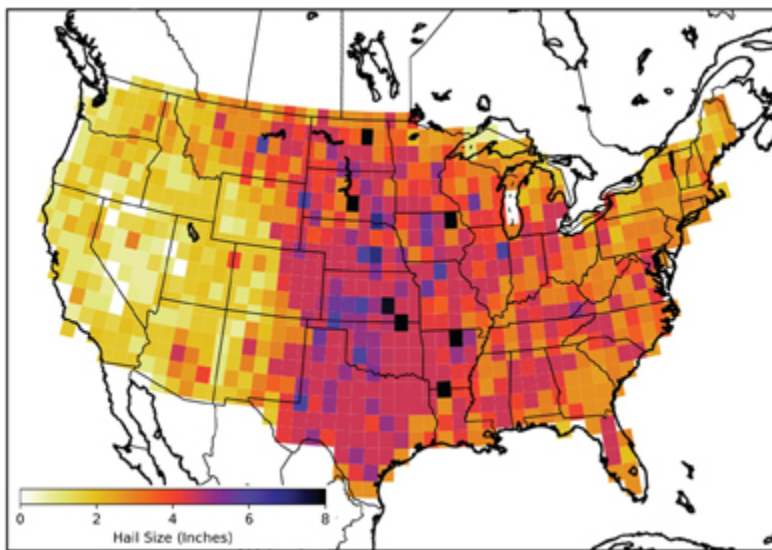
How widespread and frequent is the occurrence of hailstorms?

Hailstorms occur globally, with regular events on every continent except Antarctica.

Hailstorms are local weather phenomena that occur globally, with regular events on every continent except Antarctica. Recent research using indirect proxies has suggested that much of the mid-latitudes experience at least one hailstorm producing 2.5 cm (1 inch) stones per 100 km² each year.



Annual large hail probability from 1979 to 2015. Credit: [Prein and Holland \[2018\]](#) (<https://doi.org/10.1016/j.wace.2018.10.004>), Figure 11a, reproduced with permission of the authors



Maximum observed hail size in the continental United States for the period 1955 to 2013. Credit: [Allen et al. \[2020\]](#) (<https://doi.org/10.1029/2019RG000665>), Figure 9a

However, we really don't have a good handle on how often the largest hail sizes occur over different parts of the world. Hail in excess of 12-cm occurs regularly over the United States (<https://doi.org/10.1175/MWR-D-17-0119.1>) with the largest recorded being 20-cm. We've also seen 18-cm 'gargantuan' (<https://doi.org/10.1175/BAMS-D-19-0012.1>) hail over Argentina and 14-cm in Germany.

While historical records are incomplete, there is evidence that hail in this size range has been seen in Australia, China, South Africa, Bangladesh, and many other countries.

How damaging is hail in comparison to other atmospheric and climatic hazards?

Hail is the most impactful of the thunderstorm-related hazards, producing annual damage exceeding US\$13 bn over the USA and Europe.

Hail is the most impactful of the thunderstorm-related hazards, producing annual damage exceeding US\$13 billion over the United States and Europe. At the time of writing in summer 2020, more than US\$20 billion of the US\$27 billion (<https://www.artemis.bm/news/us-thunderstorms-dominate-27bn-h1-insured-disaster-losses-munich-re/>) in global insurance losses was caused by severe convective storms in the United States, with hail the largest contributor. In Europe, two hailstorms in July 2013 caused US\$4.3 billion of economic losses.

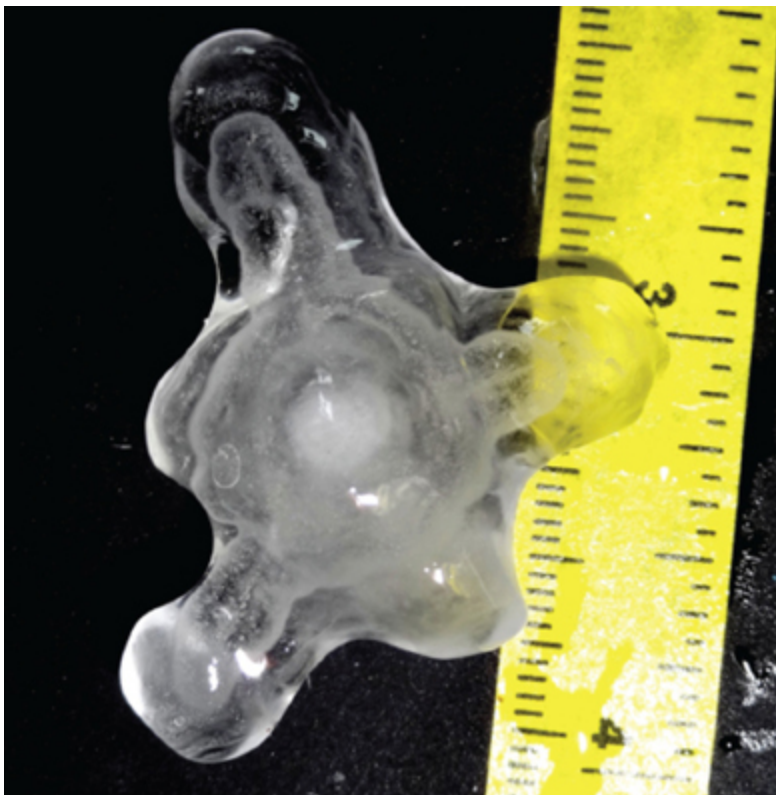
While this is relatively small compared to the losses associated with landfalling hurricanes, hail events occur every year, and can impact anything from a field of crops to a suburb and cause serious injury to people and animals. The impacts also vary depending on how much hail falls, and how big it gets. For agriculture, smaller hail and large volumes can strip trees and crops, while for property, generally hail above 30 mm (1.2 in.) is needed to damage roofs, cars, windows, and infrastructure.



This supercell thunderstorm near Kingfisher, Oklahoma, on 29 May 2012, produced hailstones between 4 and 5 inches in diameter. Credit: John T. Allen

What are some of the different methods for observing and measuring hailstorms?

There are many challenges in measuring and characterizing hail. One is that generally you need someone present to record whether a hailstone fell. Those observers don't necessarily have training for measuring hailstones, so size needs to be estimated, perhaps in comparison with a known object such as golf ball, or else measured using a ruler or calipers.



Hailstone showing prominent icicle lobes.

Credit: H. Pogorzelski, in [Allen et al, 2019](#)

(<https://doi.org/10.1029/2019RG000665>), Figure 2

Hail size and the number of hailstones falling can also vary considerably over the distance of a few hundred meters – to say nothing of the evidence melting! – making it all the more challenging to observe.

Of course, there are more scientific ways of measurement, for example deploying networks of impact sensors, using trained weather observers, or collecting data from hailpads, but these aren't typically deployed for large areas.

Remote sensing observations like radar and satellite can sometimes tell us when hail is present, but the information we receive lacks the precision needed for hail sizing.

What environmental factors influence hail occurrence, size, and magnitude?

The exact drivers of hail production are still poorly understood.

The exact drivers of hail production are poorly understood, partly due to our observational limitations. We know that strong, wide thunderstorm updrafts are needed in order to carry

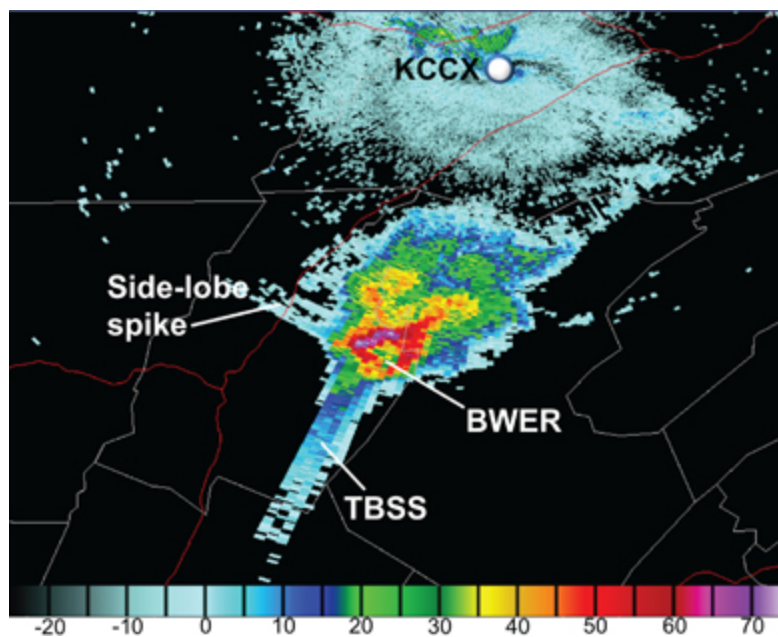
the small nuclei that form each hailstone. However, on its own this isn't enough to produce large hail.

Change in wind speed and direction with height is needed, which allows storms to organize, live longer, and most importantly, rotate. This mid-level updraft rotation appears to be extremely important to suspending hailstones at a near constant altitude, contrasting earlier misconceptions that hailstones repeatedly moved up and down in the storm's updraft.

Recent modeling (<https://doi.org/10.1175/JAS-D-20-0016.1>) suggests that 7.5 cm hail takes minutes to grow, and horizontal wind patterns in the updraft are important. While other factors such as details of the microphysical processes are also likely important, we don't have as good a handle on their relation to hail growth.

How accurately can the frequency, distribution, and severity of hail be forecasted?

Forecasting hail will likely always be a challenge. A day or two ahead we can use the conditions favorable to storms that produce hail to get a rough idea of where hail may be likely, but have little idea of size.



Radar image of a hailstorm over central Pennsylvania. TBSS = three-body scattering signature (TBSS); BWER = bounded weak echo

region (BWER). Credit: [Allen et al. \[2020\]](#)

(<https://doi.org/10.1029/2019RG000665>), Figure 15

On the day of the event, we can use [high-resolution models that can estimate hail growth and size](#) (<https://doi.org/10.1175/WAF-D-18-0024.1>), or new machine learning approaches to predict probabilistic [swaths of hail](#) (<https://doi.org/10.1175/WAF-D-17-0010.1>) and its size.

Once a storm has formed, attention then turns to radar products, and potentially satellite information, that can estimate where hail is likely. [Methods integrating these observations and conditions](#) (<https://doi.org/10.1175/WAF-D-19-0242.1>) promise improved skill over single sources.

Despite these recent advances, we still don't have a great capacity to predict hail occurrence and size with specificity, and there is much still to learn.

How might ongoing climate warming influence hail and its impact?

This is a challenge with our incomplete observations and limited understanding of how to forecast hail, but a growing number of studies are pointing toward a shift to larger hail in a warming world, though not uniformly.



Hail on the ground, southwest of Glendive,
Montana. Credit: John T. Allen

For example, we know that over [North America](#) (<https://doi.org/10.1175/JCLI-D-18-0740.1>)

smaller hail appears to decrease over the southeastern United States as it melts falling through a deeper, warmer layer, but larger hail frequency is expected to increase over the Northern Plains and Southern Canada.

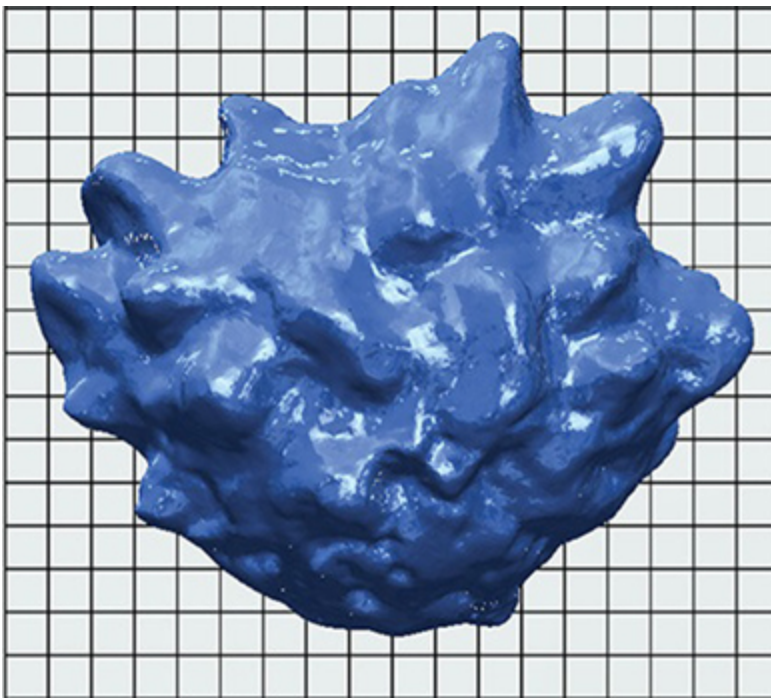
There is already at least some evidence of increases to the frequency of large hail over both North America (<https://www.nature.com/articles/s41612-019-0103-7>) and Europe, while over China (<https://www.nature.com/articles/s41598-017-11395-7>) large hail frequency seems to be decreasing.

These uncertainties are exacerbated by the lack of knowledge of what are the environmental controls on hail size as discussed above.

What are some of the unresolved questions where additional research, data or modeling is needed?

There are still a surprising number of things we don't know about these hail and hailstorms.

For all the impacts of hail, there are a surprising number of things we don't know about these storms. These range from the life cycle of both the storms and the hailstones themselves, to where the embryos come from that ultimately develop into damaging hailstones, to details of the microphysical processes occurring along their trajectories through the cloud.



Three-dimensional scan of a hailstone. Grid is 1 cm squares. Credit: [Allen et al. \[2020\]](#)

(<https://doi.org/10.1029/2019RG000665>), Figure 6, bottom right panel

Other uncertainties are found at the surface, where we need a better understanding of hailstone size distributions, the physical properties of hailstones, and to understand how they fall and what this means for its impact on our lives. Without aerial observations within and around storms, some of these questions will be hard to answer.

More broadly, we need a better understanding of how and where hail occurs globally in order to better understand this hazard, and better prepare structures, property and agriculture to mitigate its impacts in the present and future climate.

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