Likelihood of hail in Australia has changed substantially over the last four decades

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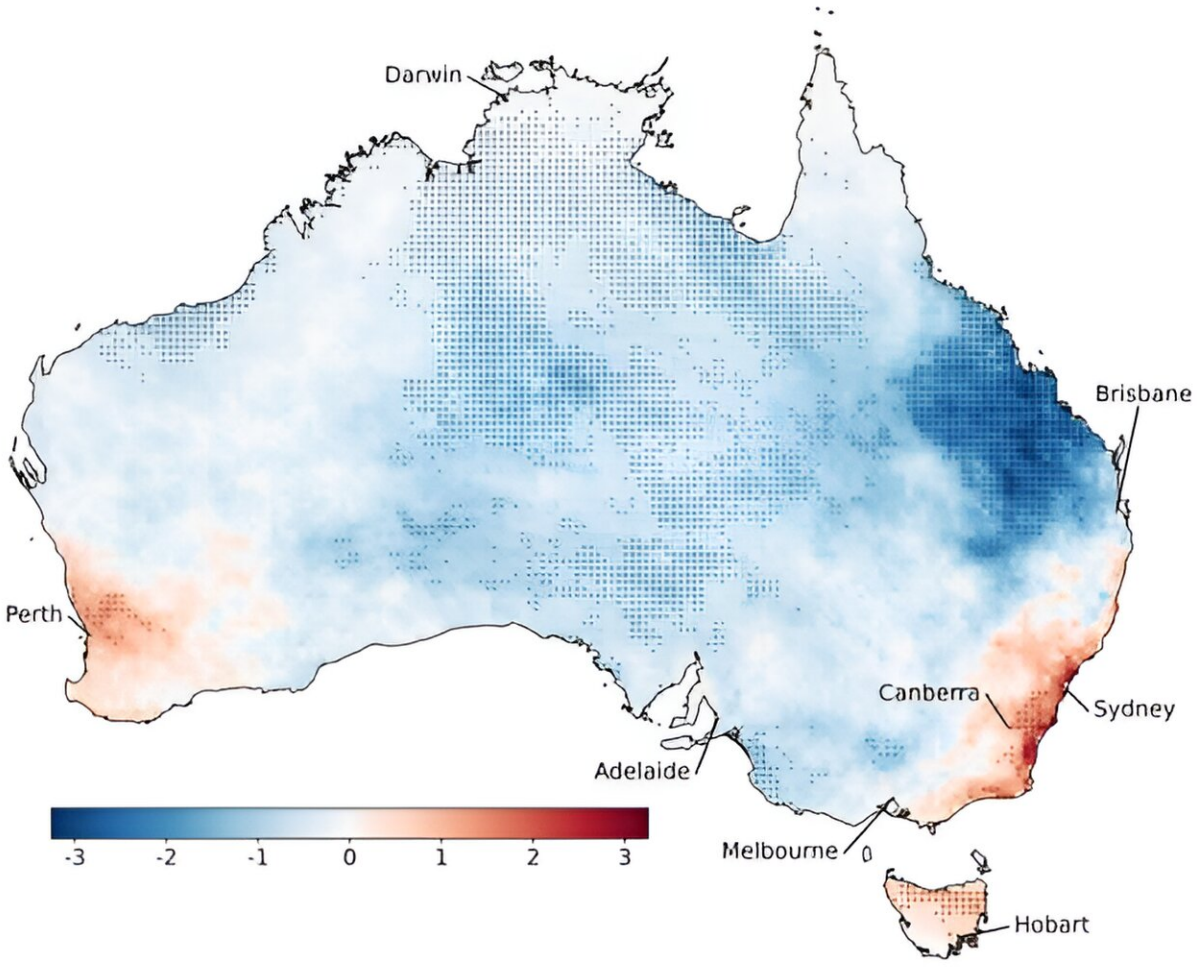

This map shows the changes in annual hail-prone days per decade. The black dots ("stippling") show where the trend was considered to be statistically significant. Credit: University of New South Wales

Understanding how hailstorm frequency has changed over time can help us build resilience against future hail events.

By studying atmospheric patterns across Australia over the last 40 years, scientists from UNSW Sydney and the Bureau of Meteorology have discovered that the number of "hail-prone" days have decreased across much of Australia, but have increased by up to approximately 40% in some heavily populated areas.

A "hail-prone" day is any given day when the atmosphere has all the required ingredients for a hailstorm to form.

"Hailstorms are really difficult to measure and model," says Dr. Tim Raupach, a researcher in atmospheric science at the UNSW Climate Change Research Center, who led the study. "Because of this, we don't really have a good idea of how they have changed over time, or how they are projected to change into the future."

To paint a clearer picture of how the frequency of hail events has changed, the researchers studied historical estimates of atmospheric conditions, with hail-prone conditions acting as a "proxy" for hail occurrence over the past four decades.

"We wanted to produce a continental map of how hail hazard frequency has changed across Australia, and to be able to look into what atmospheric changes are driving these patterns," says Dr. Raupach.

The latest study, published recently in the journal *npj Climate and Atmospheric Science*, provides the first continental-scale analysis of hail hazard frequency trends for Australia.

The team of researchers, which included scientists from the Bureau of Meteorology, hope that this research will help our understanding of hail

events, which is important to the insurance industry, as well as agricultural and city planning sectors.

How do hailstorms form?

Not just any thunderstorm can produce hail. Hailstorms require certain atmospheric "ingredients" to form. One of the important ingredients is that the atmosphere needs to be unstable.

"This means that there is a propensity for updrafts to form—updrafts occur when there's warm air near the ground and cooler air further up. And if a little bit of that warm air gets into the cool air, then it rises like a balloon and it draws air up into an updraft," says Dr. Raupach.

There also needs to be enough moisture in the updraft for there to be supercooled liquid water and ice all swirling around high in the storm.

"Another factor is that hail melts as it falls. And so even if you have hail forming up high, it has to be large enough to survive melting to actually reach the ground as a block of ice."

And finally, hail formation is enhanced by wind shear—the changing properties of the wind by height. "This is the wind changing direction or velocity as you get higher in the atmosphere," says Dr. Raupach. "If there's a lot of shear, then the storm tends to be more severe and more prone to forming hail."

When all of these factors are present, the atmospheric conditions become "hail-prone."

Producing a 'hail proxy'

The researchers combined the known ingredients required for a hailstorm to develop a "hail proxy," which they applied to 40 years of reanalysis data. Reanalysis products combine observations with numerical weather modeling techniques to obtain an estimate of the state of the atmosphere in the past.

The team then used the hail proxy to turn the reanalysis record of atmospheric conditions into an indication of whether each day was hail-prone or not. "This means that instead of looking for occurrences of hail at the surface, because our records there are so spotty, we used an estimate of the atmospheric conditions on a grid of points across Australia for the past four decades," Dr. Raupach says.

Using this statistical analysis on historic estimates, the researchers were able to produce a map of how the number of hail-prone days per year have changed across the whole continent, at a resolution of about 30 kilometers per pixel.

"The Bureau's long-term weather radar archive was used to compare radar observations with the reanalysis hail proxy," says the Bureau of Meteorology radar research scientist Dr. Joshua Soderholm.

Radars work by sending out pulses of electromagnetic radiation and looking for "echoes" of the pulses reflected off particles in the atmosphere. They can indicate there may be hail present when there are particularly strong echoes in the atmosphere.

"Data from 20 Bureau radar sites across the country was used in the comparison, with between 12 and 24 years of records at each site," says Dr. Soderholm.

"The radars cover a shorter time period and have limited spatial coverage, but they can pick up indicators of hail. Our radar results

helped to corroborate the pattern of results we saw," says Dr. Raupach.

Changes in hail-prone days

"We found that the number of days considered hail-prone have decreased over much of the country, but increased over the southwest and southeast where there are large population centers," says Dr. Raupach.

In particular, the annual number of hail-prone days increased by up to approximately 40% around Sydney and Perth. This relates to about a 10% increase per decade in the number of days that could cause a hailstorm.

"We found a decrease in hail-prone days across most of the country, particularly across Queensland, but also across the center and the north of the country. But we did see some increases in the southeast and the southwest. And that happens to coincide with large populations and exposed assets, including in Sydney, Canberra, and Perth."

As Dr. Raupach explains, a hail-prone day is far from guaranteed to produce hail. "Really what we're interested in is the changes in the data. It's all relative. So even though not every hail-prone day produces hail, we can say that if there are more hail-prone days, there is an increased chance of hail."

Building resilient cities

While we don't know exactly what is driving these significant changes in hail patterns, the research team have carefully considered the role climate change may be playing.

"This is not a climate attribution study, but we kept in mind a broad view of how we might expect hailstorms to behave in a warmer atmosphere," says Dr. Raupach. "The changes vary a surprising amount by region, and those differences highlight where we need more understanding."

The general expectation is that under climate change, surface hail may become less frequent due to increased melting, because the atmosphere is warmer and more hail melts away before it hits the ground. On the other hand, a warmer atmosphere would be expected to be more unstable, leading to generation of larger hailstones. Since large hail is more likely to survive increased melting, when hail does occur it may be larger and therefore more severe.

The research team discovered that the observed patterns in hail-prone day changes are primarily driven by changes in extreme atmospheric instability. "And those changes are incredibly complex," says Dr. Raupach. "They also depend a lot on the region. Where you have increased instability, then you might get more generation of hail and larger hailstones being generated in those regions that might survive more melting. But where you have decreases in instability, then you have kind of a dampening effect."

The links with climate change are multifaceted and more work needs to be done to understand how these hailstorm patterns will continue to change under warming conditions.

Importantly, these findings feed into our understanding of changes to the risk from hail. "This is essential information for the agricultural industry, because hailstorms can raze crops, the insurance industry, because of the damage hail can cause, and for city planning," says Dr. Raupach.

In fact, hail damage is a leading cause of insured losses in Australia. "Hail is really one of the driving factors in the year-to-year costs for the

insurance industry. The industry is interested in understanding how this hazard might change in the future."

Dr. Raupach and his team hope this information on trends can be incorporated into planning for how we build resilient infrastructure. "We need to think about resilient agriculture that can deal with potential increases in the hail hazards, if they were to continue into the future," says Dr. Raupach. "And likewise, how we can protect our densely populated areas from damage due to hailstorms."

This research has shown us how particular weather patterns have changed between 1979 to 2021, but Dr. Raupach is keen to extend his research to help predict future trends in hailstorms. "I am interested in moving from what we've observed in the past, to projections for the future. And that means using simulations and climate models to get the same kind of information for the future for Australia and globally."

More information: Timothy H. Raupach et al, Changes in hail hazard across Australia: 1979–2021, *npj Climate and Atmospheric Science* (2023). DOI: 10.1038/s41612-023-00454-8

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