# Gargantuan Hail

## Documenting an Extreme Forecasting Challenge

**Adapted from** "Gargantuan Hail in Argentina," by **Matthew R. Kumjian** (The Pennsylvania State University), **Rachel Gutierrez, Joshua S. Soderholm, Stephen W. Nesbitt, Paula Maldonado, Lorena Medina Luna, James Marquis, Kevin A. Bowley, Milagros Alvarez Imaz**, and **Paola Salio**. Published online in *BAMS*, August 2020. For the full, citable article, see DOI:10.1175/BAMS-D-19-0012.1.

In the scientific literature, some studies have identified "giant" hail as those stones with maximum dimensions exceeding 10 cm or 4 in. We propose a new size class for hailstones with maximum dimensions exceeding 15 cm or 6 in. (referred to here as "gargantuan hail") to represent the upper extreme of hail sizes. As these are rare cases, only a few studies have specifically documented giant and gargantuan hail events, and most are individual case studies. One study of giant and gargantuan hailstones from the Aurora, Nebraska, storm of 2003 showed that every stone evaluated exhibited an outer (i.e., final) growth layer indicating wet growth, and in some cases this layer was of quite substantial thickness. Another study used social media reports to identify giant hail that ultimately became certified state records. It suggested that the occurrence of giant or gargantuan hail is significantly underreported. None of the aforementioned studies focused on observed


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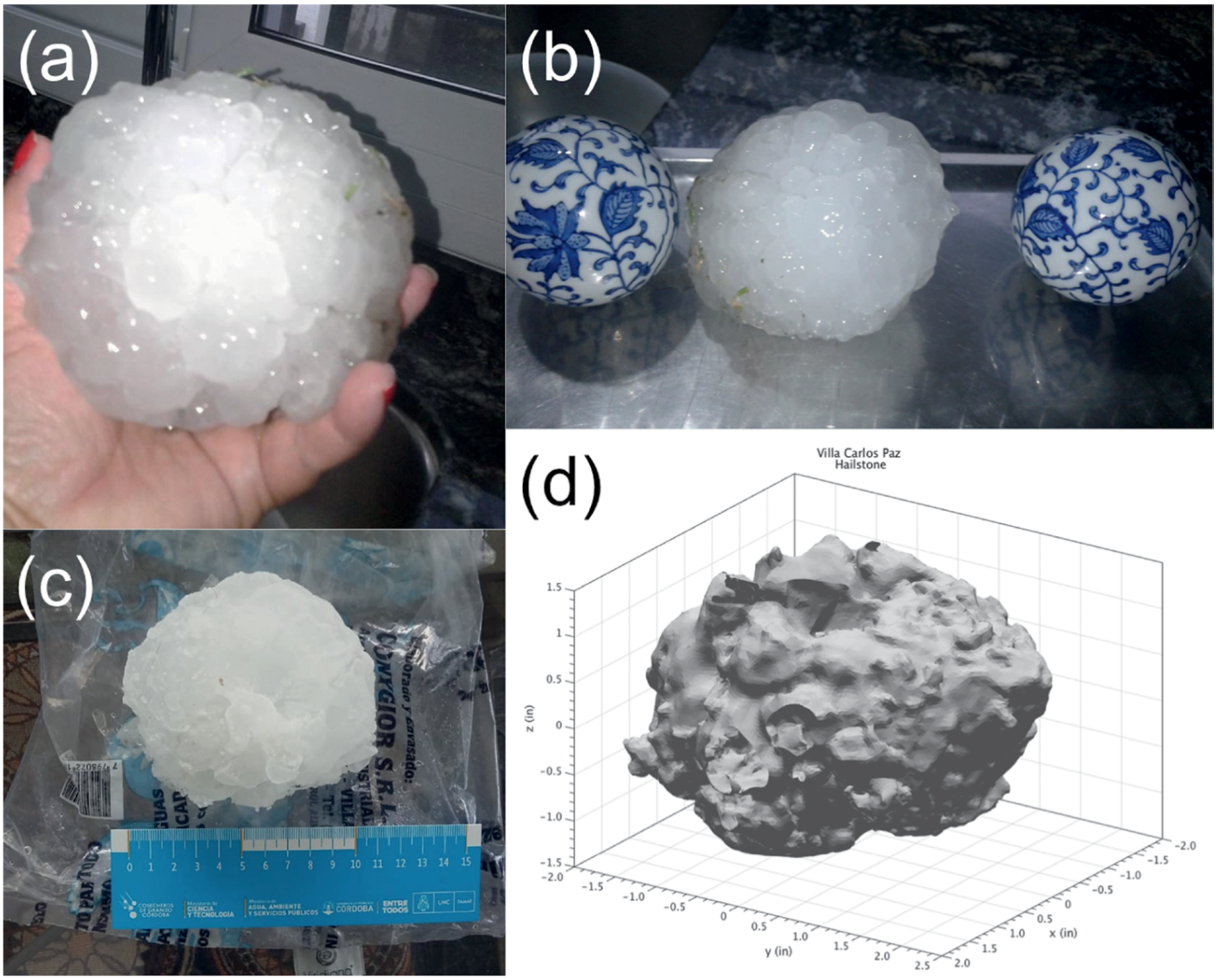


**(a) Photograph of Maria's hailstone shortly after it was retrieved from her front yard. (b) Photograph of the giant hailstone next to decorative balls, which measured 7.5 cm in diameter (as measured with digital calipers, not shown). Photos courtesy of Maria Navidad Garay, used with permission. (c) Photograph of preserved hailstone after being in the freezer for 9 months, with ruler for comparison. (d) 3D rendering of the laser-scanned hailstone.**

storm properties or environments. In contrast, a 2013 study documented the synoptic and mesoscale environment of the supercell that produced the Vivian, South Dakota, hailstone (which registers as the world record for maximum dimension of 20 cm or 8 in.). Analysis indicated that the environment was indeed supportive of severe convective storms, but not indicative of such large hail as was observed. Other studies focused on radar observations of storms producing giant or gargantuan hail; one compared equivalent radar reflectivity factor at horizontal polarization ($Z_H$) and radial velocity ($\upsilon_r$) signatures in giant-hail-producing storms to those in storms producing smaller hail. One conclususion was that giant hail was virtually always associated with supercells (>99% of cases), and that the best discriminators of hail sizes were strong midlevel azimuthal shear in $\upsilon_r$ associated with the mesocyclone and large values of storm-top divergence. An analysis of the 2013 El Reno, Oklahoma, storm revealed that large hailstones (including several ≥15 cm in maximum dimension) often fell outside the low-level maximum $Z_H$. Some of this hail occurred in regions of $Z_H$ < 50 dBZ, but within ~10 km of the updraft, consistent with findings of other


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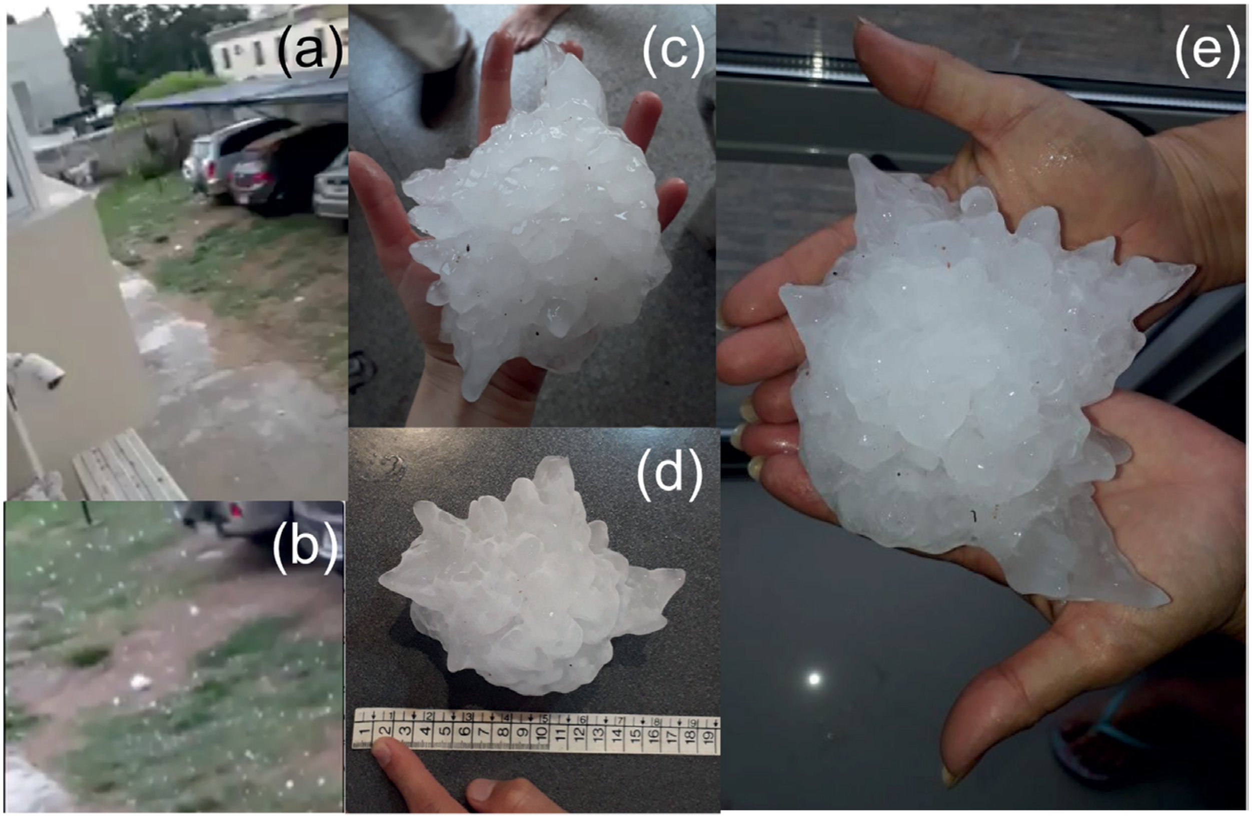


(a),(b) Screenshots of a Snapchat video of Victoria's hailstone shortly after it landed. (c) Photograph of the hailstone in hand just after retrieving it. (d) Official measurement, after noticeable sublimation and melting: 18 cm (7.1 in.) in maximum dimension, 422 g in mass. (e) Viral photo of her mother holding the stone, shortly after it was retrieved. Photogrammetry based on measurements of their hands suggests the maximum size after it was retrieved is close to 19 cm. All imagery provided courtesy of Victoria Druetta, used with permission.

studies. Additional research suggests that giant and gargantuan hail may have similar dual-polarization radar characteristics to hail of smaller sizes, complicating radar-based hail detection of such large hail.

Finally, features commonly used by operational meteorologists to forecast and monitor severe storms may only be subtly different for extreme-hail-producing storms, making anticipation and warning for such storms a substantial challenge. Documentation of extreme hailstorms is a necessary first step in unlocking clues leading to improved prediction and detection of such events.

Herein, we document a case from 8 February 2018 that, unlike the other cases described above, featured gargantuan hail in a densely populated urban region. The storm occurred in Villa Carlos Paz, in the Córdoba Province of Argentina, an area prone to hail, making it the first well-documented case of gargantuan hail outside the U.S. Great Plains, and the first in the Southern Hemisphere.

## Description of the environment

At 1200 UTC (0900 local time) on 8 February 2018, a broad upper-level trough was located off the west coast of Chile, which favored the presence of a warm, humid, conditionally unstable air mass conducive to severe convection over central Argentina. A radiosonde launched at SACO airport about 30 km east-northeast of Villa Carlos Paz at 1200 UTC revealed several elevated mixed layers above a low-level nocturnal inversion, although the most unstable parcel convective available potential energy (MUCAPE) was only about 300 J kg$^{-1}$ at this time. These broadscale features are consis-


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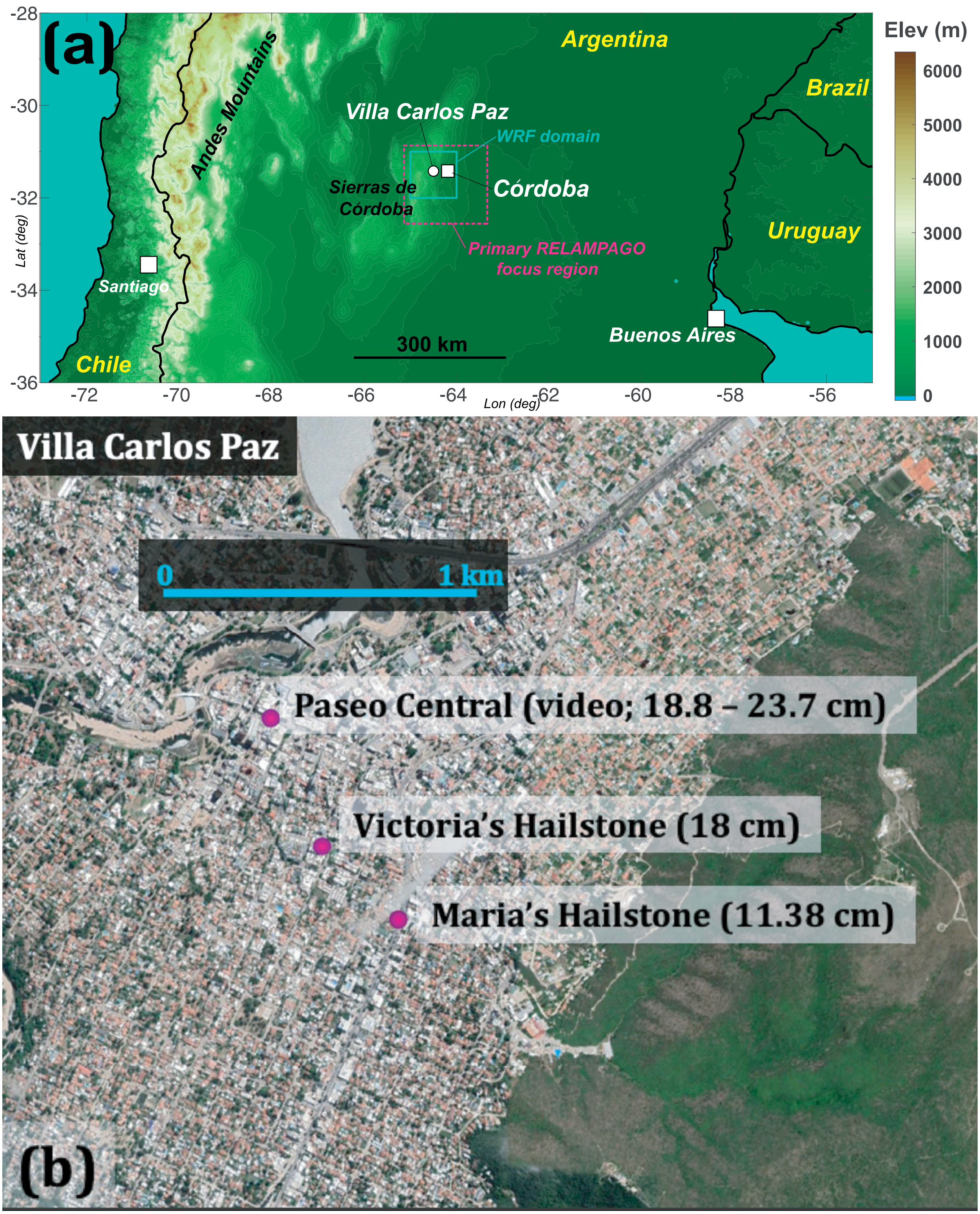


**(a) Map of the region of interest in South America, including WRF simulation innermost domain (cyan box) and the approximate Remote Sensing of Electrification, Lightning, and Mesoscale/Microscale Processes with Adaptive Ground Observations (RELAMPAGO) study region (light purple dashed box). The locations of Córdoba and Villa Carlos Paz are indicated as white square and circle markers, respectively. The map shows terrain elevation, shaded according to the outset scale on the right. Black solid lines are country boundaries. (b) A zoomed-in view of downtown Villa Carlos Paz, Argentina, and the location of three analyzed hailstones (with maximum dimensions indicated, in cm). Map imagery courtesy of Google.**



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tent with the composite pattern found for supercells in this region. Unsurprisingly, the environmental factors that promote hailstorms in the United States have also been identified as important in Argentina. To further examine the storm environment, we ran a doubly nested 3–1-km grid spacing Weather Research and Forecasting (WRF) Model v4.1 simulation using boundary conditions from the ERA5 hourly atmospheric reanalysis. Here, the simulation was primarily used to downscale the reanalysis boundary conditions with better-resolved topography and to examine the storm and the rapidly evolving environment leading up to it. The WRF simulation had 80 vertical levels and used the Thompson microphysics scheme. The simulation indicated an evolution toward an environment conducive to supercells at Villa Carlos Paz during the subsequent 8-h period. Instability increased through the development of a deep mixed layer, the boundary layer moistened, and a midlevel cap in the 625–500-hPa layer eroded. MUCAPE increased to 2,241 J $kg^{-1}$ at 2000 UTC, while most unstable convective inhibition (MUCIN) decreased in magnitude to just –10.4 J $kg^{-1}$. Especially rapid changes in the simulated environment occurred from 1930 to 2100 UTC, in part as a result of upslope flow along the east side of the Sierras de Córdoba. This anabatic flow transported in high-CAPE (>3,000 J $kg^{-1}$) over a ~1-h period prior to the storm arriving in Villa Carlos Paz, helping to erode the MUCIN and enhance low-level flow and storm-relative helicity. Thus, most indications pointed to a severe hail and wind threat for this event.

**Table 1. Proposed hail size naming convention, based on previous usage and operational terminology.**

| Size class | Maximum dimension threshold (cm) | Reference object |
|---|---|---|
| Small/sub-severe | ≤2.5 | ≤ U.S. quarter coin |
| Severe | ≥2.5 | ≥ U.S. quarter coin |
| Significantly severe | ≥5.0 | ≥ Hen egg |
| Giant | ≥10.0 | ≥ Softball |
| Gargantuan | ≥15.0 | ≥ Honeydew melon |

## Overview of the Villa Carlos Paz supercell storm

Despite partial radar beam blockage due to the Sierras Chicas mountains and tall city buildings, the storm's salient radar characteristics were still evident in low-level (<2° elevation angle) scans as observed with the operational C-band radar in Córdoba (RMA1). Throughout the analysis period (1819–2058 UTC), the storm displayed supercellular structure. By 1927 UTC, the heavy precipitation core passed south and east of Villa Carlos Paz. The main updraft moved directly over Villa Carlos Paz, as confirmed by the pronounced bounded weak echo region aloft. The gargantuan hail that was produced did not fall in the heaviest precipitation core of the storm, but rather beneath the updraft, consistent with conceptual models of hailstorms. Storm structure produced in our WRF simulation was qualitatively similar to the overall storm evolution observed with the RMA1 radar, albeit with inaccurate timing.

## Hail reports

There were numerous social media posts of photos and videos showing hail as it was falling, and/or retrieved after the storm. A giant (>10 cm) hailstone was retrieved shortly after it fell and preserved in a freezer by Maria Navidad Garay (hereafter "Maria's hailstone"). According to Maria, the hail fall lasted approximately 15 min. Photographs of the stone shortly after it was retrieved showed no preferred orientation direction in its final growth layer, presumably owing to random tumbling during its descent. There was damage to a carport roof and the hail net covering portions of her driveway. Thus, it is likely that some other large stones fell at her location, but perhaps melted, broke apart, or otherwise were not noticed.

The official measurements of Maria's hailstone showed that it weighed approximately 303 g. The maximum dimension measured from a 3D laser scan was 11.38 cm (4.48 in).

The most famous hailstone from the 8 February event was photographed by Victoria Druetta, a teenager living in Villa Carlos Paz. We believe that "Victoria's hailstone" has the largest maximum dimension documented in


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the Southern Hemisphere, measured at 18 cm (7.09 in.).

Finally, a high-resolution video posted on YouTube[1] features an extremely large hailstone falling in downtown Villa Carlos Paz. Frame-by-frame photogrammetric analysis suggests the hailstone might have been a world record for maximum dimension, with the highest-confidence estimates ranging from 18.8–23.7 cm (7.4–9.3 in.), but it was not officially measured.

## Discussion and conclusions

It is widely known that some supercells, such as the one affecting Villa Carlos Paz, are capable of producing large hail. Unfortunately, however, aside from being generally conducive for supercells and thus hail production, nothing in the environment of this storm indicated specific conditions favorable for such extreme hail production. Further, the storm's radar presentation as observed with the operational C-band RMA1 radar was not atypical of supercells. The 1-km grid spacing WRF simulation of this case, despite closely following the observed storm evolution, also did not indicate anything out of the ordinary for supercellular convection, though it did highlight the rapid environmental evolution leading up to the storm.

More broadly, the lack of indications of an extreme event in prestorm environments, numerical model forecasts, or radar imagery collectively demonstrate the challenges associated with forecasting or even detecting extreme hail events. Further research is needed to better understand the environmental conditions leading to storms capable of producing gargantuan hail, radar signatures of gargantuan hail, and the climatology of such events. We encourage local forecast offices, broadcast meteorologists, and emergency managers to interface with and educate the public during severe convective storm episodes to better document the occurrence of gargantuan hail, including accurate time and location of hail fall and accurate measurements of hailstone size, especially mass. Such documentation will facilitate an improved understanding of the storms capable of producing such hazardous hail.

[1] www.youtube.com/watch?v=3Oj0WRoAi0M; also available at https://sites.psu.edu/kumjian/files/2019/12/GargantuanHail_VillaCarlosPaz.mp4.

## METADATA

**BAMS:** What would you like readers to learn from this article?

***Matthew Kumjian (The Pennsylvania State University):*** *Extremely large hail can happen around the world. However, forecasting and even remote detection of this threat remains a formidable challenge. There is a strong need to better understand the environments supportive of, and in-storm processes conducive to, the production of such large and potentially damaging hail. A necessary first step is improved documentation and analysis of these events. In an effort to encourage further reporting and citizen-scientist participation in research, we have proposed a new category for the upper extreme of hail size: "gargantuan hail." Given newer scientific tools available for analysis and the emergence of social media, we hope that more cases are well-documented in the future.*

**BAMS:** How did you become interested in extremely large hail?

***MK:*** *Enormous chunks of ice falling from the sky is pretty noteworthy. The fact that currently we cannot anticipate such events points strongly to the need to better understand them.*

**BAMS:** What surprised you the most about the work you document in this article?

***MK:*** *The success in estimating hail size using photogrammetry from a YouTube video. It was serendipitous that we were stationed in Villa Carlos Paz for the RELAMPAGO field campaign, but I never thought I would be walking through the area captured in the video every day on my way to the operations center. Given such an opportunity, plus actually being able to measure objects in the frame and use the video for the analysis, was a pleasant surprise. I'm hopeful that similar efforts can be made for other cases, given the proliferation of social media photos and videos of extreme hail events in recent years.*

**BAMS:** What was the biggest challenge you encountered while doing this work?

***MK:*** *Tracking down and weaving together all the critical pieces of information: the eyewitnesses, observations, model simulation—this truly was a team effort, and I could not have even come close to putting together this article without the help of all of my coauthors. I am grateful to all of them for all that they did!*

**BAMS:** What's next? How will you follow up?

***MK:*** *We are using a variety of tools to better understand the environmental controls on hail size to start chipping away at the great uncertainty around that problem, as well as improvements to how we use remote-sensing platforms like radar to estimate hail size.*



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