frontiers in Environmental Science

TYPE Editorial
PUBLISHED 14 July 2026
DOI 10.3389/fenvs.2026.1925143

OPEN ACCESS

EDITED AND REVIEWED BY
Hong Liao,
Nanjing University of Information Science and Technology, China

*CORRESPONDENCE
Michael Kunz,
michael.kunz@kit.edu

RECEIVED 01 July 2026
ACCEPTED 06 July 2026
PUBLISHED 14 July 2026

CITATION
Kunz M, Mohr S, Martius O, Hering A and Schröer K (2026) Editorial: Outcome of the 4th European hail workshop 2024: opening the discussion.
Front. Environ. Sci. 14:1925143.
doi: 10.3389/fenvs.2026.1925143

Editorial: Outcome of the 4th European hail workshop 2024: opening the discussion

Michael Kunz[1,2]*, Susanna Mohr[1,2], Olivia Martius[3], Alessandro Hering[4] and Katharina Schröer[5]

[1]Institute of Meteorology and Climate Research Troposphere Research (IMKTRO), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany, [2]Center for Disaster Management and Risk Reduction Technology (CEDIM), KIT, Karlsruhe, Germany, [3]Institute of Geography, Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland, [4]Federal Office of Meteorology and Climatology MeteoSwiss, Locarno-Monti, Switzerland, [5]Institute of Environmental Social Sciences and Geography, University of Freiburg, Freiburg, Germany

KEYWORDS
aerosol-cloud interactions, AI/ML driven air interface, hail climatology, hail structure, hail-size spectrum, severe hailstorm, sub-severe hail, trends

Editorial on the Research Topic
Outcome of the 4th European hail workshop 2024: opening the discussion

1 Introduction

Every year, severe convective storms (SCS) accompanied by large hail cause extensive damage to buildings, infrastructure, agriculture, and vehicles, resulting in billions of euros in losses worldwide. Owing to the marked increases in losses observed in recent years, hail is now among the most damaging weather-related hazards (Swiss Re, 2026). Despite its socioeconomic relevance, however, hail remains one of the least understood atmospheric hazards (Punge and Kunz, 2016; Groenemeijer et al., 2017; Allen et al., 2020).

Recent years have seen substantial advances in hail research through improved remote sensing, enhanced microphysical parameterizations in numerical weather prediction (NWP) models, systematic hailstone Research Topic, dedicated field campaigns, and the increasing application of machine learning (ML) techniques. Nevertheless, major uncertainties remain regarding hailstorm initiation and evolution, hail growth processes, regional hail occurrence under present and future climate conditions, and the resulting socioeconomic risks.

The 4^{th} European Hail Workshop, held in Karlsruhe, Germany, in March 2024, brought together researchers, forecasters, engineers, and industry experts to exchange findings and chart directions for future hail research. The contributions collected in this Research Topic highlight both the progress achieved and the challenges that remain.

2 Overview of contributing articles

Two studies investigate hailstorm climatology using multi-decadal radar archives. Schulte-Fischedick et al. analyze approximately 60,000 radar-based hailstorm tracks between 2002 and 2021 in the Swiss radar domain. Their results suggest a shift towards fewer but larger, longer-lived, and more organized hailstorms in the western Alpine region, implying an increased damage potential. For Germany, Mohr et al. leveraged a homogeneous 20-year radar dataset to identify over 15,500 potential hail tracks between 2005 and 2024. Their analysis reveals pronounced spatial gradients, with the highest hail occurrence in southern Germany. While national hail frequencies remained nearly unchanged, hail activity has substantially increased in southern Germany. Meanwhile, there has been a tendency towards a decrease in northern and central regions. Together, these studies demonstrate both the value and limitations of long-term radar archives for assessing hail climatology and changes in storm characteristics.

Two papers focus on the analysis of large hailstones using innovative laboratory and imaging techniques. Manzato et al. examined the exceptional Azzano Decimo hailstorm on 1 August 2021 in northeastern Italy, which produced hailstones up to 9 cm in diameter. Dual-polarization radar observations confirmed intense updrafts consistent with the extreme convective instability recorded by a nearby radiosonde. Detailed analyses of nine collected hailstones, including thin-section photography and stable isotope measurements, revealed that primary growth occurred between 8 and 10 km altitude. Isotopic variability across growth layers indicates complex recirculation and wet-growth processes. Likewise, Farnell Barqué et al. investigate giant hailstones up to 12 cm produced by a catastrophic Catalonia hailstorm on 30 August 2022. Their study introduces computed tomography (CT) scanning as an innovative, non-destructive technique for analyzing hailstone interiors. Results show that embryo nuclei may be located far from the geometric center even in externally spherical hailstones, offering new insights into hail growth processes.

Addressing observational gaps, Portmann et al. evaluate drone-based photogrammetry coupled with ML techniques for estimating hail size distributions on the ground. Their experiments demonstrate high detection accuracy and reliable size retrievals across large sampling areas. Because drones can comprehensively survey parts of a hail swath, this method provides representative areal hail size distributions that can complement radar estimates or hail reports and be utilized for post-event damage assessments and risk quantification.

Understanding hail impacts and vulnerability is essential for effective risk management. Meisenzahl et al. investigate the cumulative effects of sub-severe hail on asphalt shingle roofs in North America. Laboratory experiments show that repeated impacts from relatively small hailstones can progressively weaken roofing materials and increase their susceptibility to subsequent severe hail events. The study suggests that current vulnerability assessments and durability standards may underestimate the contribution of frequent, lower-intensity hailstorms to overall losses.

The representation of hail-related processes in numerical weather prediction (NWP) models remains a major challenge. Tonn et al. explore the interaction between aerosols, wind shear, and convective precipitation using high-resolution ICON simulations with a two-moment microphysics scheme. Simulations of three severe convective days reveal complex dependencies between environmental conditions and cloud microphysics, highlighting that conclusions drawn from idealized simulations cannot always be transferred to real events. These findings underscore the need for continued efforts to improve the representation of multiscale processes governing severe convective storms and hail formation.

Finally, Kunz et al. summarizes key outcomes of the 4^{th} European Hail Workshop. The authors review recent advances in hail detection, forecasting, climatology, impact assessment, field observations, and ML applications, while identifying critical knowledge gaps that limit progress. Their synthesis emphasizes the importance of interdisciplinary collaboration and integrated approaches that link observations, modeling, forecasting, and risk analysis.

3 Synthesis and outlook

To conclude, the papers in this Research Topic illustrate both the substantial progress achieved in hail research in recent years and the substantial challenges that remain. Advances in observational technologies, long-term radar archives, numerical modeling, and innovative analytical methods are transforming our ability to investigate hailstorms across a wide range of spatial and temporal scales.

Further progress will depend on extending and harmonizing observational networks across national borders that integrate automated hail sensors, radar archives, crowd-sourced observations, drone surveys, and targeted field campaigns. Such datasets are essential for reducing uncertainties in hail forecasting by improved NWP and new AI models and climatological analyses. At the same time, advances in observational capability must be matched by improved understanding of hail microphysics. Emerging techniques such as CT scanning and stable isotope analysis demonstrate the potential of laboratory studies and dedicated field observations to provide new insights into hail growth and internal structure. Finally, ML techniques are paving the way for increasingly integrated and innovative methodologies in hail research.

By bringing together contributions from multiple disciplines, this Research Topic reflects the collaborative spirit of the European Hail Workshop and aims to stimulate further discussion and cooperation within the international hail research community. We hope that the studies presented here will contribute to improved understanding, forecasting, and management of hail hazard and risk in a changing climate.

Author contributions

MK: Writing – original draft, Writing – review and editing. SM: Writing – review and editing. OM: Writing – review and editing. AH: Writing – review and editing. KS: Writing – review and editing.

Funding

The author(s) declared that financial support was received for this work and/or its publication. MK and SM are supported by the Helmholtz Association (Research Program "Changing Earth – Sustaining our Future"). OM acknowledges support by the Swiss National Science Foundation Grant Number CRSII5_201792.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was used in the creation of this manuscript. OpenAI ChatGPT (GPT-5) and Claude.ai were used for the article's grammar, spelling, and stylistic check, and used to shorten and arrange the manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

References

Allen, J. T., Giammanco, I. M., Kumjian, M. R., Punge, H. J., Zhang, Q., Groenemeijer, P., et al. (2020). Understanding hail in the Earth system. *Rev. Geophys.* 58, e2019RG000665. doi: 10.1029/2019RG000665

Groenemeijer, P., Púčik, T., Holzer, A. M., Antonescu, B., Riemann-Campe, K., Schultz, D. M., et al. (2017). Severe convective storms in Europe: ten years of research and education at the European severe storms laboratory. *Bull. Am. Meteorol. Soc.* 98, 2641–2651. doi: 10.1175/BAMS-D-16-0067.1

Punge, H., and Kunz, M. (2016). Hail observations and hailstorm characteristics in Europe: a review. *Atmos. Res.* 176–177, 159–184. doi: 10.1016/j.atmosres.2016.02.012

Swiss Re (2026). *Sigma – Natural Catastrophes in 2025: The Persistent Rise of Wildfire and Storm Risk, No. 1/2026*. Zurich, Switzerland: Swiss Re Institute. Available online at: https://www.swissre.com/dam/jcr:4b5669a3-b7e2-4682-bf96-a597085958a6/sigma-1-2026-natural-catastrophes-report.pdf (Accessed May 6, 2026).