AMERICAN
METEOROLOGICAL
SOCIETY

Bulletin of the American Meteorological Society

The DOI for this manuscript is doi: 10.1175/BAMS-D-17-0207.1

The final published version of this manuscript will replace the preliminary version at the above DOI once it is available.

If you would like to cite this EOR in a separate work, please use the following full citation:

Martius, O., A. Hering, M. Kunz, A. Manzato, S. Mohr, L. Nisi, and S. Trefalt, 2017: Challenges and recent Advances in Hail Research - A report from the 2nd European Hail Workshop. Bull. Amer. Meteor. Soc. doi:10.1175/BAMS-D-17-0207.1, in press.

Challenges and recent Advances in Hail Research – A report from the 2nd European Hail Workshop

Olivia Martius[1], A.Hering, M. Kunz, A.Manzato, S. Mohr, L.Nisi., S.Trefalt

[1] Corresponding author

Institute of Geography

Hallerstrasse 12

3012 Bern

Switzerland

+41316313337

Olivia.martius@giub.unibe.ch

Infobox

2nd European Hail Workshop

What: Severe hailstorms pose a significant threat to buildings, crops, and vehicles. At the same time, these storms are difficult to predict, model, and observe. About 130 representatives from the academic community, operational weather services, and the insurance industry met in Bern (Switzerland) for three days to discuss the current state of hail research and to identify key research gaps and future challenges.

When: 19 – 21 April 2017

Where: Bern (Switzerland)

Introduction

In several regions around the world, severe hailstorms frequently cause considerable damage to buildings, agriculture, and vehicles, resulting in large economic and insured losses. Estimating local-scale hail frequency, which is required e.g. for insurance risk models, or assessing long-term trends in light of climate change are challenging tasks – particularly because direct, homogeneous, long-term hail observations are mostly missing. At present, numerical weather prediction (NWP) and nowcasting models often still fail to reliably predict hailstorms, even at lead times of minutes to hours. This is due mainly to the microphysical processes involved that are yet to be better understood, as well as to a lack of appropriate atmospheric observations assimilated into these models. Alternative methods have been developed that relate hail occurrence to proxies such as remote sensing observations from radar, satellite, and lightning sensors or less conventional monitoring systems such as hail reports from crowd-sourcing.

The scope of hail research presented at the 2nd European Hail Workshop spanned from basic research on the dynamics and microphysics of hailstorms or past and future changes of hail probability, to more applied research on hail forecasting, hail warnings, and hail loss modeling. About 130 representatives from 27 countries from research institutions, operational weather services, and insurance companies attended the workshop. The main objectives of the workshop were to identify and discuss topics relevant for both basic and applied researchers, to facilitate communication and data exchange among these groups, to foster new collaborations, and to strengthen the international hail research community.

Key topics and results

The three-day workshop featured 37 talks (9 key note talks) and 20 poster presentations. Podcasts of the presentations and PDF documents of the posters are available from the workshop website

(http://www.oeschger.unibe.ch/services/events/conferences/past_conferences/2nd_european_hail_workshop/presentations/index_eng.html).

The workshop was organized in five thematic sessions:

1) Local probabilities and long-term statistics of hail
2) Convection and hail in a changing climate
3) Hail damage and hail damage prevention
4) Microphysics and dynamics of hailstorms: observations and modeling
5) Nowcasting and forecasting of hail

Local probabilities and long-term statistics of hail

The contributors to this session presented local-, regional-, and continental-scale hail frequency estimates and analyses of hail-conducive atmospheric environments. Hail occurrence statistics are based mainly on radar- or satellite-derived hail proxies (see Punge et al. 2016 for an overview) and few Hailpad networks.

Radar-based statistics have a good accuracy thanks to the high spatio-temporal resolution of radar measurements. The generation of composites encompassing large regions is difficult because of the different characteristics of existing (mostly national) radar networks (S-, C-, and X-band, single or dual-polarization). The presented statistics reveal a large spatial variability of hail probability governed by both large-scale atmospheric conditions and local-scale orography, the latter through its role in triggering convection. Satellite-based hail proxies (overshooting cloud tops, OT) are particularly promising when focusing on continental scales. For some regions, however, uncertainties are very large mainly because of the sometimes weak relation between hail on the ground and OT events. Furthermore, the OT approach misses or underestimates hail in thunderstorms with comparatively low and warm cloud tops. Global analyses reveal that hail occurs worldwide, both in the subtropics and extratropics, and single very large hailstones (above 10 cm) have been reported from many locations around the world. Such global overviews of hail occurrence allow the classification of the intensity and rarity of individual hailstorms in a global perspective.

A further approach to derive hail statistics is based on hail-favoring environments, i.e. atmospheric parameters statistically associated to hailstorm formation (e.g., atmospheric instability and low-level moisture content) in reanalysis data or atmospheric soundings. This method is simple to implement, generally robust given the long-term availability of data series, and has the potential to provide new insights into the drivers of the temporal variability of severe convection. Discussed limitations of this approach are i) the omitted information about the occurrence of thunderstorm triggers, as the method only allows an estimation of the atmospheric hail potential and not the true hail occurrence; ii) a strong dependence on the specific reanalysis product used (e.g., resolution, data assimilation); and (iii) the missing information on potentially small-scale spatial and short-term temporal variability of the atmospheric hail proxies.

To identify the most skillful environmental hail proxies and to calibrate radar- and satellite-based hail-identification algorithms, plausible ground observations are required. If no direct hail observations are available (e.g., Hailpad networks, automatic hail sensors), insurance loss data or crowd-sourced data, such as that collected within by the European Severe Weather Database (Dotzek et al., 2009), are extremely valuable.

Convection and hail in a changing climate

Potential changes in hail frequency, intensity, and hailstone size distribution in a warmer climate are complex to assess. This is due to uncertainties regarding, e.g., the effect of increased freezing level heights or potentially stronger thunderstorm updrafts on hail size, but it is also due to uncertainties concerning the mean prevailing dynamical and thermodynamical conditions and the evolution of cloud microphysical processes with compounding effects of increasing/decreasing aerosol concentrations in the future.

Furthermore, analyses of hail frequency and/or intensity changes during recent decades also show large uncertainties, mainly because of the scarce availability of homogeneous long-term observations. In the limited areas with high-density Hailpad networks, such as parts of France, Northern Spain, Eastern Italy or China, the trends may be opposite: For example, decreasing trends were found in China and increasing trends in Spain. The differing trends are related to physical, microphysical, and dynamical effects such as changes in instability, changes in moisture advection, level of freezing, or changing aerosol concentrations. In addition, there have been changes in observation practice and changes in vulnerability and exposure of the insured objects, in case of insurance loss data.

Where no observations are available, environmental proxies from reanalyses or climate model simulations are often used to investigate temporal changes and variability of hail occurrence. While this approach does not consider storm triggers, it still enables a spatially quasi-homogenous long-term view. According to proxies extracted from an ensemble of EURO-CORDEX models, an increase of hail frequency is expected for future decades for parts of Europe.

A novel method to estimate the impact of climate change on convection is the so-called “pseudo-global-warming” approach, where present-day hail events are simulated with a high-resolution local area model both in current and future atmospheric environments. Results based on this approach point to a higher frequency of large hail in the future over Switzerland and the U.S., while at the same time hailstorms are shorter-lived and spatially less widespread.

Microphysics and dynamics of hailstorms: observations and modeling

One of the open questions – relevant for both the present and a changing climate – pertains to the effect of aerosols on ice secondary multiplication and hail formation. Model simulations show contradicting results, and theory provides plausible explanations for both an increase and decrease of hail with increasing aerosol concentrations. Large model sensitivities to the integration time-step, lead time, and the microphysics schemes used are furthermore found. For impact modeling and impact studies, the terminal velocity of hailstones (proportional to the kinetic energy) and the hail size are relevant. The terminal velocity is very difficult to estimate because it non-linearly depends on the density and shape of the hailstones, and especially large hailstones are not spherical.

Hail size and related kinetic energy estimates are currently provided by specific hail models such as the 1D HAILCAST cloud model. Simulations with the Weather Research and Forecasting (WRF) model with HAILCAST module show promising results even in complex topography. In the discussion of this session it was pointed out that the small number of direct observations and laboratory experiments limits the development of sophisticated hail parametrizations and hail models.

Hail damage and hail damage prevention

The development of catastrophe (CAT) models of insurance companies requires information on hail hazard (i.e., hail probability and severity), vulnerability (i.e., damage of insured objects as a function of hail size), and exposure (i.e., insured objects at a given location). Typically, insurance companies estimate the hazard part by stochastically modeling thousands of synthetic hailstreaks based on data from remote sensing instruments (satellite, radar, lightning), or use data from regional climate models or reanalysis, or a combination thereof. A large source of uncertainty is the lacking information about hailstone size distributions. For some insurance applications, near real-time hail estimates of affected areas and intensities, e.g. by radar-based hail nowcasting, is of high practical value.

Nowcasting and forecasting of hail

An optimal nowcasting system should combine information from all observing systems to extend the forecasting lead time and to increase the accuracy. Accordingly, several efforts are underway to improve nowcasting of hail using the real-time characteristics of thunderstorms recorded by radar, satellite, and lightning. Satellite-based thunderstorm detection algorithms typically capture thunderstorms several tens of minutes before the first radar observations, but lack the level of detail provided by the latter, in particular if with dual-polarization capabilities. During the lifecycle of hailstorms, lightning activity increases substantially, a phenomenon referred to as ‘lightning jump’. Results, however, disagreed regarding the exact timing of those features related to the onset of hail. These indicated either a nowcasting relevant lead time for the first hail at the ground or for the maximum hail intensity. In principle, nowcasting of hail is possible by combining lightning jump information and the approximation of the future hailtrack. However, cell displacement estimate methods are yet to become more precise to produce less uncertain results. Characteristic life-cycle information of hailstorms (e.g., for how long they typically persist after hail first reaches the ground) may add valuable information and should be incorporated into the nowcasting systems. With increasing implementation and coverage of dual-polarimetric radar networks that have the capability to identify hail through complex hydrometeor classifications, new hail detection methods become available.

Conclusions and next steps

A recurring issue discussed in all sessions of the workshop and relevant for a broad range of applications is the lack of reliable, high-quality, long-term observational data as well as laboratory experimental data of hail. Furthermore, the comparability of observing systems even within the same category (e.g., differently calibrated radar networks) represents an unresolved problem. Ground-truth observations through crowd-sourcing mobile applications (European Weather OBserver App, EWOB, Groenemeijer et al., 2017; MeteoSwiss App, Social Media) or drone-observations to detect the spatial pattern of areas affected by hail are valuable and low-cost. Such methods, however, also need to be complemented by standardized direct ground observations such as those from automatic hail sensors. Additionally, observations of properties such as drag coefficients of falling hailstones or freezing processes in laboratory experiments are needed to improve theoretical knowledge. Only this will allow further improving microphysical parametrizations of hail in NWP models.

Results presented from high frequency, high resolution radar assimilation into an ensemble numerical weather prediction system gave a glimpse of the enormous potential of this method for nowcasting applications.

Concerning the frequently asked question about the relation between hailstorm frequency/ intensity and climate change, additional knowledge is necessary to better understand the link between large-scale natural climate variability and local-scale convection, including the drivers behind these links such as teleconnection patterns. First model analyses and (sparse) observations, with large uncertainty and variability, generally point to more intense hail storms in a warming climate, but also to enhanced melting of small hailstones.

Acknowledgements:

The Hail Workshop was supported by the Swiss Science Foundation and the Mobiliar Lab for Natural Risks.

References

Dotzek, N., Groenemeijer, P., Feuerstein, B. and Holzer A.M. Overview of ESSL's severe convective storms research using the European Severe Weather Database ESWD. *Atmos. Res.*, 2009, 93, 575–586, doi:10.1016/j.atmosres.2008.10.020.

Groenemeijer, P., Púčik, T., Holzer A.M., Antonescu, B., Riemann-Campe, K., Schultz D.M., Kühne, T., Feuerstein, B., Brooks, H.E., Doswell III, C.A., Koppert, H.-J. and Sausen, R. Severe convective storms in Europe: Ten years of research at the European Severe Storms Laboratory. *Bull. Am. Meteorol. Soc.*, 2017, doi:10.1175/BAMS-D-16-0067.1.

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