SUMMER SNOWFALL WORKSHOP

Scattering Properties of Realistic Frozen Hydrometeors from Simulations and Observations, as well as Defining a New Standard for Scattering Databases

Stefan Kneifel, José Dias Neto, Davide Ori, Dmitri Moisseev, Jani Tyynelä, Ian S. Adams, Kwo-Sen Kuo, Ralf Bennartz, Alexis Berne, Eugene E. Clothiaux, Patrick Eriksson, Alan J. Geer, Ryan Honeyager, Jussi Leinonen, and Christopher D. Westbrook

The International Summer Snowfall Workshop (ISSW) is a new workshop format for the international scientific community working on ground- and space-based observations, retrievals, and radiative transfer related to snowfall. This new snowfall workshop was inspired by the successful series of International Workshops on Space-based Snowfall Measurements (IWSSM; Bennartz et al. 2011), the latest of which (IWSSM-5) was held concurrently with the International Precipitation Working Group (IPWG) meeting in Bologna, Italy, in 2016. The new biennial ISSW is not intended to replace the IWSSM but rather to provide a forum to discuss specific urgent research topics related to snowfall that have been identified at larger meetings.

The first ISSW was held at the University of Cologne, in Cologne, Germany during June 2017. The workshop was attended by about 50 scientists from various universities, research institutions, and weather services in the United States and Europe. The focus topic of this first workshop was the characterization of scattering properties of ice and snow particles at the recommendation of the last joint IWSSM–IPWG meeting in Bologna.

Almost 10 years ago, Liu (2008) presented in a *BAMS* article a freely available scattering database of realistically shaped ice particles; this database is still one of the most-used sources for scattering properties in the microwave region. Since then, not only has the number of datasets and particle habits grown greatly, thanks to increasingly available high-performance computing infrastructure and advances in modeling snowflake formation processes at the single-particle level, but so has their complexity (Fig. 1). There is a broad consensus in the remote sensing community that it is necessary to bring users and developers of scattering databases together to agree on standards and conventions on how to store the complex scattering datasets in a generalized format and according to well-defined quality standards. In addition to a discussion of the progress and current state of scattering computations, the workshop program also addressed topics such as how to better link in situ observations to the particle models used for scattering computations, how to achieve a close interaction between the users and developers of the databases, and how observational constraints can be developed to validate the scattering datasets.

FIRST INTERNATIONAL SUMMER SNOWFALL WORKSHOP

What: The workshop gathered almost 50 scientists from Europe and the United States to discuss the progress toward developing electromagnetic scattering databases for ice and snow particles in the microwave region, their applications, the physical approximations used to compute these scattering properties, and how remote sensing and in situ observations can be used to validate scattering datasets.

When: 28–30 June 2017

Where: Cologne, Germany

HIGHLIGHTS. There is an urgent need for better characterization of the scattering properties of various kinds of ice and snow particles. The applications range from ground-based, airborne, and space-based retrievals to active and passive forward simulators and the assimilation of all-sky microwave observations into numerical weather prediction models.

A review of published scattering computations for ice and snow particles in the microwave region (presentation available online at http://snowport.org/snow-scattering/scattering-databases/keynote_tyynela.pdf) illustrates the rapid development during the last 10 years in terms of scattering software and datasets (a visualization is provided in Fig. 1). Unfortunately, a large number of early calculations are no longer available, neither the single scattering computations nor the particle structures used for them. During the past few years, the number of scattering datasets, as well as the complexity of the included particles, has rapidly increased. More recent datasets include aggregates of various ice crystals, and some contain different degrees of riming and melting. Moreover, several also cover shorter wavelengths down to the submillimeter range.

An increasing number of studies have investigated how the internal structure of snow particles influences scattering properties and how much knowledge of the details of the snow particles is needed for deriving scattering behavior. New mathematical and numerical methods are currently being developed to lower the computational costs of scattering calculations and to derive new approximations of ensemble scattering properties. The realism and complexity of particle models, including deposition, aggregation, riming, and melting, have increased. Most of these models are not yet freely available and are often computationally expensive. Additionally, such models are limited by our imperfect knowledge of the detailed physical processes involved (e.g., the way ice crystals stick to one another or the way supercooled droplets impact and freeze on a rimer).

New campaign datasets allow an increasing number of closure studies to be performed using in situ observations and multifrequency radar and radiometer observations to validate not only the scattering but also the physical properties of model particles. The use of optimal estimation methods further allows quantification of the information content of different remote sensing techniques such as triple-frequency and polarimetric radar observations, which is also relevant for the design of future satellite instruments. Web-based discussion and information platforms related to snowfall (e.g., www.snowport.org) as well as web-based interface tools to access scattering data (e.g., https://storm.pps.eosdis.nasa.gov/storm/OpenSSP.jsp) have recently become available.

OUTCOMES AND RECOMMENDATIONS. One of the key workshop questions was how to store the various scattering datasets in a consistent way and which conventions should be used. General agreement emerged on storing the scattering data in netCDF4 files separated into different levels of processing and to use the Climate and Forecast (CF) convention for variable names. Although agreement was reached during the workshop for the general data-level file structures, discussions about the details of the structures are still ongoing. A group of dataset developers agreed to continue the discussions via a series of web-based conferences in order to produce example datasets with the new structures, which will then be tested for their applicability to existing application programming interfaces (APIs).

AFFILIATIONS: Kneifel, Dias Neto, and Ori—Institute for Geophysics and Meteorology, University of Cologne, Cologne, Germany; Moisseev—University of Helsinki and Finnish Meteorological Institute, Helsinki, Finland; Tyynelä—Finnish Meteorological Institute, Helsinki, Finland; Adams and Kuo—NASA Goddard Space Flight Center, Greenbelt, Maryland; Bennartz—Earth and Environmental Sciences, Vanderbilt University, Nashville, Tennessee, and Space Science and Engineering Center, University of Wisconsin–Madison, Madison, Wisconsin; Berne—Environmental Remote Sensing Laboratory, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland; Clothiaux—Department of Meteorology and Atmospheric Science, The Pennsylvania State University, University Park, Pennsylvania; Eriksson—Department of Space, Earth and Environment, Chalmers University of Technology, Gothenburg, Sweden; Geer—European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom; Honeyager—Department of Earth, Ocean and Atmospheric Science, The Florida State University, Tallahassee, Florida; Leinonen—Joint Institute for Earth System Science and Engineering, University of California, Los Angeles, Los Angeles, California, and Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California; Westbrook—Department of Meteorology, University of Reading, Reading, United Kingdom

CORRESPONDING AUTHOR: Stefan Kneifel, skneifel@meteo.uni-koeln.de

DOI:10.1175/BAMS-D-17-0208.1

In final form 3 August 2017

The scattering community should continue to work on APIs and best practices to produce higher-level data files (e.g., scattering cross sections and scattering properties integrated over size distributions) based on the basic scattering output contained in level-0 files. APIs should also allow users to extract information for their specific applications. To the extent possible, they should provide all of the functionality already present in established databases, such as that of Liu (2008).

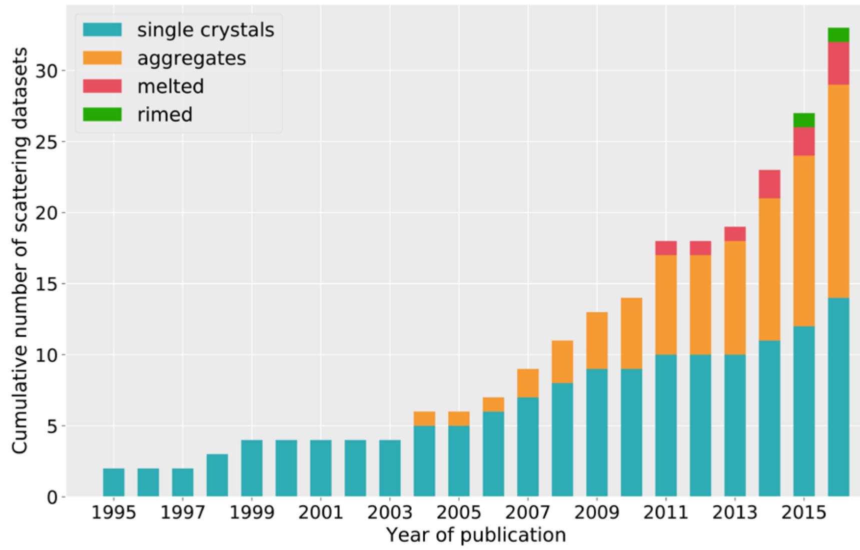

Fig. 1. Cumulative number of published scattering datasets from 1995 to 2016. The color indicates which particle classes are included in the datasets: single crystals, blue; snow aggregates, yellow; melted, red; and rimed particles, green. (This figure is based on the keynote presentation given by J. Tyynelä at the ISSW, Cologne, Germany, 2017.)

As the number and complexity of scattering datasets increase, studies assessing the physical assumptions used to generate them become ever more important. Furthermore, bulk scattering properties that can be applied globally, for example, to assimilate active and passive microwave observations into numerical weather predictions models, should be derived. Despite their known limitations, spheroidal approximations to ice particle shapes are still widely used, partly because the availability of bulk scattering properties covering a wide range of particle sizes, densities, temperatures, and frequencies is still limited. Moreover, given the limitations in our knowledge of snow microphysical properties, for some applications the errors associated with using less realistic spheroidal shapes are smaller than those caused by the uncertainties in snow microphysics.

In the past, scattering calculations were often specifically performed for a particular application (e.g., radar). Some of the outputs that would have been relevant for other applications (e.g., microwave radiometry) were not kept. In the future, scattering dataset developers should try to store as much of the output as possible in order to make the output valuable for a wider range of applications. All datasets should always contain the three-dimensional structures of the particles used as well as comprehensive metadata needed to reproduce the results or to extend them to other frequencies or temperatures.

Three-dimensional structures of the scattering particles will facilitate comparisons to in situ observations. Another recommendation was to develop in situ forward operators, converting three-dimensional particle models to simulated in situ observations (mostly in two dimensions), which would allow comparison of synthetic and real particles in observational space. Such forward operators would also be consistent in the definition of particle properties such as maximum diameter or aspect ratio, something that was heavily emphasized as important by users and scattering dataset developers alike.

Various observations, especially when polarimetric information is provided, indicate that the assumption of totally random orientation of snow particles is unrealistic. However, orientation and polarimetric variables have been widely neglected in earlier scattering databases because of their additional complexity. Accounting for this complexity in future datasets will be an important step to take. Although the rapidly growing variety and complexity of available datasets are appreciated, there are still particle classes missing from them, such as melting and oriented particles, rimed or accreted ice particles, particles representative for deep convection, or fragmented particles. It is still an open question as to what extent current snow particle models are representative of typical temperature and humidity conditions and of major cloud types. Users need databases to cover a range of temperatures, particle sizes, and frequencies (e.g., from 1 up to 880 GHz), but these ranges are not yet well defined. There may also eventually be a need to extend these databases into the infrared, particularly for cloud ice particles.

The physical and scattering properties contained in the scattering datasets need to be validated using ground-based and airborne in situ datasets. Collocated aircraft campaigns and ground-based datasets including comprehensive in situ observations as well as multifrequency and multi-instrument remote sensing measurements are suitable for closure studies in different climatic regions. In addition to field campaigns, laboratory experiments would help to refine models used to retrieve physical properties of ice particles from in situ observations (e.g., laboratory investigations of terminal velocity and orientation using snow analogs or detailed measurements of the internal structures of real snow particles). Assimilation of active and passive microwave observations in weather forecasting is emerging as an important activity; although there are problems such as systematic error in forecast models, there are benefits from examining global, long-term statistics.

MORE INFORMATION AND OUTLOOK. More information about the workshop and all presentations can be found on the new snowfall community web platform (www.snowport.org). In addition to a newsletter of ongoing activities, the platform provides for a discussion forum and easy ways to announce scattering datasets, snowfall-related field campaigns, or continuous snowfall measurement site observations to the community. The next snowfall workshop is planned for 2019 at the University of Helsinki in Finland.

ACKNOWLEDGMENTS. The workshop was financially and logistically supported by the German Research Foundation (DFG) via the Emmy-Noether Group OPTIMIce (Grant KN 1112/2-1), the Geoverbund ABC/J, Radiometer Physics GmbH, University of Cologne, and University of Bonn. We further acknowledge the IWSSM–IPWG for endorsing this new workshop format. The contribution of JL was carried out at the Jet Propulsion Laboratory, California Institute of Technology and was sponsored by the National Aeronautics and Space Administration.

REFERENCES

Bennartz, R., P. Joe, U. Löhnert, J. Koskinen, G. Skofronick-Jackson, and D. Vane, Eds., 2011: Report on the Third International Workshop on Space-Based Snowfall Measurement. International Precipitation Working Group, 30 pp., http://ipwg.isac.cnr.it/meetings/grainau-2011/iwssm_3_report_final.pdf.

Liu, G., 2008: A database of microwave single-scattering properties for nonspherical ice particles. *Bull. Amer. Meteor. Soc.*, **89**, 1563–1570, https://doi.org/10.1175/2008BAMS2486.1.