DOE/SC-ARM-23-046

Characterization of Orography-Influenced Riming and Secondary Ice Production and Their Effects on Precipitation Rates Using Radar Polarimetry and Doppler Spectra (CORSIPP-SAIL) Field Campaign Report

H Kalesse-Los
V Ettrichrätz
M Maahn
A Kötsche

December 2023

DISCLAIMER

DOE/SC-ARM-23-046

Characterization of Orography-Influenced Riming and Secondary Ice Production and Their Effects on Precipitation Rates Using Radar Polarimetry and Doppler Spectra (CORSIPP-SAIL) Field Campaign Report

H Kalesse-Los
M Maahn
Principal Investigators

V Ettrichrätz
A Kötsche
Co-Investigators

All at Leipziger Institute for Meteorology

December 2023

How to cite this document:

Kalesse-Los, H, M Maahn, V Ettrichrätz, and A Kötsche. 2023. Characterization of Orography-Influenced Riming and Secondary Ice Production and Their Effects on Precipitation Rates Using Radar Polarimetry and Doppler Spectra (CORSIPP-SAIL) Field Campaign Report. U.S. Department of Energy, Atmospheric Radiation Measurement user facility, Richland, Washington. DOE/SC-ARM-23-046.

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
CORSIPP	Characterization of Orography-Influenced Riming and Secondary Ice Production and Their Effects on Precipitation Rates Using Radar Polarimetry and Doppler Spectra
KAZR	Ka-band ARM Zenith Radar
KDP	specific differential phase
PAMTRA	passive and active microwave radiative transfer
PPI	plan position indicator
RHI	range height indicator
RHV	correlation coefficient
RMBL	Rocky Mountain Biological Laboratory
RPG	Radiometer Physics GmbH
SAIL	Surface Atmosphere Integrated Field Laboratory
STSR	simultaneous transmission simultaneous reception
VISS	video in situ snowfall sensor
ZDR	differential reflectivity

Contents

1.0 Summary

The Characterization of Orography-Influenced Riming and Secondary Ice Production and Their Effects on Precipitation Rates Using Radar Polarimetry and Doppler Spectra (CORSIPP) project was conducted to help improve the understanding of precipitation formation in orographically influenced terrain. Special focus is put on the two processes of riming and secondary ice production and their external drivers.

Two instruments, a polarimetric W-band simultaneous transmission *simultaneous* reception (STSR) Doppler cloud radar manufactured by Radiometer Physics GmbH (RPG, instrument type RPG-FMCW-94-DP), from now on named LIMRAD94, and the video in situ snowfall sensor (VISSS), were deployed at the U. S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility's Surface Atmosphere Integrated Field Laboratory (SAIL) site in Gothic, Colorado between November 2022 and June 2023 during the second SAIL winter. Note that the exact dates of data availability differ between the instruments. Both instruments arrived at Gothic on November 2, 2022 09:20 local time.

VISSS, described by Maahn et al. (2023), is equipped with two camera systems with telecentric lenses. The two cameras are at a 90° angle to each other. This configuration allows for size-independent measurements by capturing images of hydrometeors from two sides at a high frame rate of 250 Hz. With a minimum detection size of 200 µm, VISSS provides valuable insights into particle size, number, shape, complexity, and fall velocity. The VISSS was deployed on the grassland next to the ARM facility with the amazing help of the ARM employees on site. The setup started on November 2, 2022 and was finished on November 5, 2022 without major problems. VISSS measurements were started on November 6, 2022.

LIMRAD94 was installed on a scaffolding platform near Orehouse (Gothic) on November 9, 2022 with the great help of RMBL staff. LIMRAD94 was mounted on a cold temperature scanner prototype. After a short test of the setup on November 9, 2022, the digital control of the scanner elevation stopped working for (at that time) unknown reasons. All attempts to resolve the problem failed. This malfunction made it impossible to operate LIMRAD94 in scanning mode. The scanner was then manually moved to zenith pointing mode and between November 10 and November 15, 2022 vertical observations for polarimetric calibration were performed. On November 15, 2022, after the polarimetric calibration was applied, the scanner was manually moved to 40° elevation with azimuthal view towards the Ka-band ARM Zenith Radar (KAZR) and measurements were continued at constant elevation. Investigation of the scanner malfunction on February 6, 2023 by Benn Schmatz revealed a disengagement between the cogwheel of the elevation motor and the cogwheel moving the scanner in elevation. This mechanical issue was temporarily solved by re-engaging the cogwheels. This made the scanner operational again for about four weeks, until mechanical force disengaged the cogwheels again on March 15, 2023. This repeated scanner failure remained undetected for about three weeks until April 8, 2023; during this time the scanner was stuck at 72° elevation. However, the radar software continued to produce data files falsely indicating that the scanner was still operational. After the scanner failure was noticed, scanning was stopped again and we returned to constant elevation measurements. On May 15, 2023 the cogwheels of the elevation motor were secured with additional screws sent by the manufacturer. At some point in May, the cogwheels of the azimuth motor were also disengaged by mechanical force, which still allowed for range height indicator (RHI) but no plan position indicator (PPI) scans in the last weeks of the campaign.

The azimuth motor was repaired in Germany after the end of the campaign. Throughout the campaign, RMBL and ARM staff kept the radar and the VISSS free of snow.

2.0 Results

The data set shows a diverse range of snow particle shapes, including conical graupel, rosettes, dendrites, multi-particle aggregates, and chain-linked aggregates. A total of 883,874,476 snowflakes have been detected. Aggregates are the most common (35%) snow particle shape, followed by graupel (27%) and then dendrites (26%). Rosettes (4%), which are more typical of cirrus clouds than snow, were of great interest at the Clouds containing Ice Particles Workshop 2023. These numbers are based on an initial visual inspection of about 1,000 particles per day of snowfall. This assessment is subject to subjective errors.

We have also calculated the normalized rime mass using two methods described by Maherndl et al. (2023a). One method matches the observed reflectivity with a simulated reflectivity and derives the normalized rime mass. Passive and active microwave radiative transfer tool (PAMTRA) is used as a forward simulator to calculate the simulated reflectivity and the size distribution measured by VISSS is used as input data. The other method derives the riming mass via fit correlations between riming mass, complexity, and size (Maherndl et al. 2023 b).

To identify the different snowflake shapes, aggregate types, and degree of riming quickly, accurately, and reliably , we are currently working on different algorithms to sort the shapes automatically. We also want to compare the different automatic snowflake detection systems. One idea is based on Chandrasekar et al. (1990) and Moss and Johnson (1993). Furthermore, we want to compare different automatic snowflake detection systems.

We want to compare the distribution of snowflake types as a function of synoptic state. Particularly interesting can be cases where the snowfall is not associated with a frontal passage. The peculiarities of the snowfall process in the mountains could be further illustrated by a comparison between mountainous areas and similarly cold flat land, such as our measurements in Hyytiälä, Finland.

The LIMRAD94 data set contains common radar variables such as equivalent radar reflectivity factor, mean Doppler velocity, and Doppler spectrum width, as well as common polarimetric radar variables like differential phase shift (PhiDP), specific differential phase shift (KDP), correlation coefficient (RHV), and differential reflectivity (ZDR).

Profiles of ZDR and RHV measured by LIMRAD94 were used by Rizik et al. (2023) to generate realistic ZDR and RHV profiles in their simulations.

Combining VISSS and LIMRAD94 data has already provided great insights into the polarimetric signatures of specific snow particle types such as conical graupel. The common understanding of KDP as being strongly dependent on number concentration of small particles has been partially questioned by our data. We are currently investigating this question together with scientists from the University of Oklahoma, Ludwig Maximilian University in Munich, and RPG.

We also want to adapt the radar simulator PAMTRA (Mech et al. 2020) so that it can simulate the polarimetric radar variables for the different snow shapes. We will then compare the simulated values with our measured signals. The goal is to derive typical polarimetric values for certain shapes and size distributions.

3.0 Publications and References

Chandrasekar, V, Y Golestani, J Turk, and VN Bringi. 1990. “Fourier and Moment Methods Applied to Two-Dimensional Raindrop Images.” *Journal of Atmospheric and Oceanic Technology* 7(2): 197–205, https://doi.org/10.1175/1520-0426(1990)007<0197:FAMMAT>2.0.CO;2

Ettrichrätz, V, A Kötsche, N Maherndl, H Kalesse-Los, and M Maahn. 2023. “Complexity of snowflakes – A case study of the benefits of synergy between a snowfall camera VISSS, 94 GHz radar, and PAMTRA.” Presented at ISSW4 2023 in Leipzig, Germany.

Ettrichrätz, V, A Kötsche, N Maherndl, H Kalesse-Los, and M Maahn. 2023. “Complexity of snowflakes - A case study of the benefits of synergy between a snowfall camera VISSS, 94 GHz radar, and PAMTRA.” Poster presented at the workshop Clouds Containing Ice Particles in Mainz, Germany.

Kalesse-Los, H, M Maahn, A Kötsche, and I Steinke. 2022. “Studying orography-influenced riming and secondary ice production and their effects on precipitation rates using radar polarimetry and radar Doppler spectra.” Presented at ERAD 2022 in Locarno, Switzerland (Session ORO.P3).

Kötsche, A, V Ettrichrätz, H Kalesse-Los, and M Maahn. 2023. “First observations of a polarimetric W-band radar and the VISSS snowfall camera during the 2022/23 winter season in the Rocky Mountains.” Poster presented at ISSW4 2023 in Leipzig, Germany.

Maahn, M, D Moisseev, I Steinke, N Maherndl, and MD Shupe. 2023. “Introducing the Video In Situ Snowfall Sensor (VISSS).” *AMT/EGUsphere* (preprint), https://doi.org/10.5194/egusphere-2023-655

Maherndl, N, M Maahn, F Tridon, J Leinonen, D Ori, and S Kneifel. 2023. “A riming-dependent parameterization of scattering by snowflakes using the self-similar Rayleigh–Gans approximation.” *Quarterly Journal of the Royal Meteorological Society* 149(757): 3562–3581, https://doi.org/10.1002/qj.4573

Maherndl, N, M Moser, J Lucke, M Mech, N Risse, I Schirmacher, and M Maahn. 2023. “Quantifying riming from airborne data during HALO-(AC)3.” *EGUsphere* (preprint), https://doi.org/10.5194/egusphere-2023-1118

Mech, M, M Maahn, S Kneifel, D Ori, E Orlandi, P Kollias, V Schemann, and S Crewell. 2020. “PAMTRA 1.0: the Passive and Active Microwave radiative TRAnsfer tool for simulating radiometer and radar measurements of the cloudy atmosphere.” *Geoscientific Model Development* 13(9): 4229–4251, https://doi.org/10.5194/10.5194/gmd-13-4229-2020

Moss, SJ, and DW Johnson. 1994. “Aircraft measurements to validate and improve numerical model parameterisations of ice to water ratios in clouds.” *Atmospheric Research* 34(1-4): 1–25, https://doi.org/10.1016/0169-8095(94)90078-7