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Biogenic Aerosols—Effects on Clouds and Climate: Snowfall Experiment Field Campaign Report

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ARM CLIMATE RESEARCH FACILITY

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Executive Summary

The snowfall measurement campaign took place during deployment of the U.S. Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) Climate Research Facility second ARM Mobile Facility (AMF2) in Finland. The campaign focused on understanding snowfall microphysics and characterizing performance of surface-based snowfall measurement instruments. This was achieved by combining triple frequency (X, Ka, W-band) radar observations of vertical structure of the precipitation, microwave radiometer observations of liquid water path (LWP), and lidar measurements of supercooled water layers with surface-based observations of snowfall rate and particle size distributions. To facilitate accurate surface measurements of snowfall properties, a double-fence intercomparison reference wind protection for the weighing precipitation gauge and two-dimensional (2D)-video disdrometer was built on site. Due to the duplication of some instruments, namely the 2D-video disdrometer and the weighing gauge, we were able to characterize their measurement errors as a function of wind speed, thus aiming at providing a correction procedure for the other ARM sites.

Acronyms and Abbreviations

AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement Climate Research Facility
BAECC	Biogenic Aerosols—Effects on Clouds and Climate
BAECC SNEX	Biogenic Aerosols—Effects on Clouds and Climate: Snowfall Experiment
2D	two-dimensional
3D	three-dimensional
DFIR	Double-Fence Intercomparison Reference
DOE	U.S. Department of Energy
FMI	Finnish Meteorological Institute
GSFC	Goddard Space Flight Center
IOP	intensive operational period
KAZR	Ka-band ARM zenith radar
LWP	liquid water path
m	meter
MRR	Micro Rain Radar
MWACR	Marine W-band ARM Cloud Radar
MWR	Microwave Radiometer
NASA	National Aeronautics and Space Administration
PIP	Particle Imaging Package
PSD	particle size distribution
SACR	Scanning ARM Cloud Radar

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Figure 1. BAECC SNEX measurement setup.

1.0 Background

The snowfall measurement experiment (BAECC SNEX) is an intensive operational period (IOP) of the Biogenic Aerosols—Effects on Clouds and Climate (BAECC) campaign. The IOP is a collaborative effort between DOE's ARM Climate Research Facility, the University of Helsinki, the Finnish Meteorological Institute (FMI), the National Aeronautics and Space Administration (NASA), and Colorado State University. The IOP took place between February 1 and April 30 2014 and was dedicated to documenting snowfall microphysics through a combination of multi-frequency (C, X, Ka, W-band) radar, microwave radiometer, and lidar measurements supplemented by a comprehensive suite of surface-based precipitation observations. Multi-instrumental remote sensing and ground-based observations were used to give a detailed view of snow growth processes, i. e., condensation growth of ice crystals, snowflake growth by aggregation and, riming.

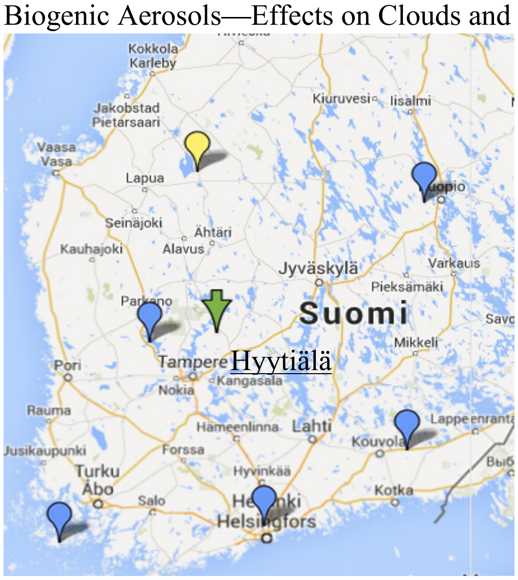

Figure 2. FMI weather radar network. Blue balloons denote locations of dual-pol C-band weather radars. The yellow balloon shows the location of a single pol weather radar. The green arrow indicates the AMF2 deployment site.

The standard AMF2 surface-based precipitation measurement instruments were supplemented by an array of sensors, see the list in Table 1. An operations schedule of the nearest FMI dual-polarization weather radar was changed to allow for one RHI scan over the location of AMF2.

To facilitate accurate surface measurements of snowfall properties. a double-fence intercomparison reference wind protection for the weighing precipitation gauge, optical disdrometer (OTT Parsivel), and 2D-video disdrometer was built on site, as shown in Fig. 1. Due to the duplication of some of instruments, namely disdrometers and weighing gauges, the data set can also be used to characterize their measurement errors as a function of wind speed. The wind measurements were done at the instrument heights inside and outside of the fence and at 10 meters (m) height.

Collaborative agencies: The main collaborating agencies of the IOP were the DOE ARM Climate Research Facility, the University of Helsinki, FMI, NASA, and Colorado State University.

The IOP principal investigators were Dmitri Moisseev (University of Helsinki), V. Chandrasekar (Colorado State University), and Walter Petersen (NASA Goddard Space Flight Center [GSFC]/Wallops Flight Facility).

The IOP team members were Annakaisa von Lerber (FMI), Matti Leskinen (University of Helsinki), Janne Levula (University of Helsinki), Antti Poikonen (FMI), Larry Bliven (NASA Wallops Flight Facility), and Jussi Tiira (University of Helsinki).

Table 1. List of BAECC SNEX instruments.

Instrument name	Inside DFIR	Outside DFIR	Measured quantities
Weighing gauge (OTT Pluvio^2)	x	x	Precipitation rate and accumulation
2D-video disdrometer	x	x	Particle size distribution (PSD), fall velocity and shape
Video disdrometer (OTT Parsivel)	x	x	PSD, fall velocity
Three-dimensional (3D) anemometer (METEK and GILL)	x	x	3D wind field
Total Precipitation Sensor (Yankee TPS-3100)	x	-	Precipitation rate and accumulation
Particle Imaging Package (NASA)	-	x	PSD, fall velocity, fall attitude, and shape of particles
Micro Rain Radar (METEK)	-	x	Radar reflectivity and Doppler velocity (from 60 m to 1000 m)
Snow Depth sensor (Jenoptik SHM-30)	-	x	Snow depth

2.0 Notable Events

In total, more than 20 precipitation events were recorded during the BAECC SNEX IOP. The list of events of interest is given in the Table 2.

A preliminary analysis of all of the events was carried out and tentative classification of the events is given in the Table 2. It was observed that in more than 80 % of the precipitation cases the ARM microwave radiometer has detected the presence of liquid water in the column above, as shown in Fig. 3, so in all those cases mixed-phase microphysics is of importance to precipitation formation.

Table 2. Notable events.

Table 1. List of notable events.

Starting time	Ending Time	Description	Temperature (C)
31 January 22 UTC	1 February 04 UTC	snow	-8.7- (-8.5)
1 February 10 UTC	1 February 16 UTC	snow (riming)	-7.6 - (-3.7)
2 February 14 UTC	2 February 15 UTC	snow/freezing rain	-4.3 - (-4.0)
2 February 16 UTC	2 February 22 UTC	snow	-5.0 -(-4.6)
7 February 22 UTC	8 February 05 UTC	snow/melting snow	-0.8 - 0.8
8 February 16 UTC	9 February 22 UTC	melting snow/rain	0.7 -2
10 February 21 UTC	11 February 05 UTC	snow/early state of melting	0.2-0.6
12 February 04 UTC	12 February 10 UTC	snow (aggregates)	-0.8- 0.14
13 February 00 UTC	13 February 06 UTC	snow/melting snow	0.3-0.6
15 February 21 UTC	16 February 02 UTC	snow (riming)	-1.8 - (-0.9)
18 February 17 UTC	18 February 22 UTC	snow	0.4-0.7
21 February 00 UTC	21 February 06 UTC	snow	-9.5 -(-5.7)
21 February 16 UTC	22 February 08 UTC	snow(riming)/melting snow	-2.4-0.9
22 February 10 UTC	22 February 11 UTC	melting snow/rain	1.4-1.8
22 February 22 UTC	23 February 10 UTC	melting snow/rain	0.9 - 2.9
26 February 12 UTC	27 February 11 UTC	PIP very light snow, larger particles 07 but very few particles	-1.1 - 0.3
28 February 22 UTC	1 March 06 UTC	PIP very light snow, higher velocities 02 but very few particles	-1.1 -(-0.6)
2 March 06 UTC	2 March 15 UTC	melting snow/rimed small particles	-1.8 - 0.4
3 March 02 UTC	3 March 16 UTC	melting snow / aggregation (07, 11 UTC)	-0.2 -0.8
7 March 12 UTC	7 March 18 UTC	light rain	3.1 - 5.1
7 March 22 UTC	8 March 08 UTC	rain/melting snow	0.6 - 2.8
13 March 21 UTC	13 March 22 UTC	rain	4.4 - 4.7
15 March 02 UTC	15 March 08 UTC	snow/ aggregation large particles	-1.2 - (0.1)
15 March 14 UTC	16 March 11 UTC	first melting, in the night snow aggregates, in the morning maybe riming	-3.4 -2.2
18 March 05 UTC	19 March 19 UTC	large aggregates/ riming (maybe 8 UTC and 21 UTC)	-8.5 - (-1.5)
20 March 13 UTC	21 March 00 UTC	snow/riming	-3.9 - (-3.0)
21 March 06 UTC	21 March 15 UTC	rain	4.2-7.6
23 March 11 UTC	23 March 16 UTC	rain/melting snow	2.0-3.7

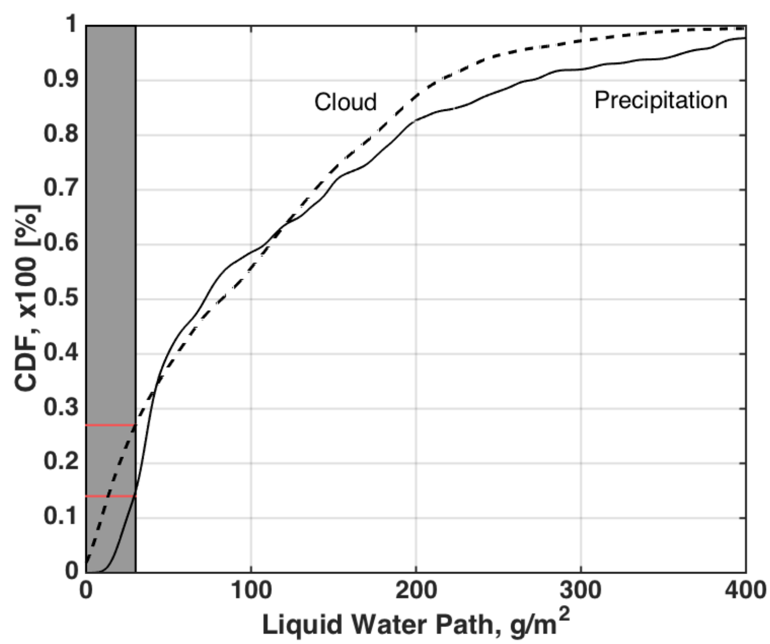

Figure 3. Cumulative distributions of observed LWP for the cases where either surface precipitation was detected or clouds were observed. In all cases the surface temperature is below 0 °C.

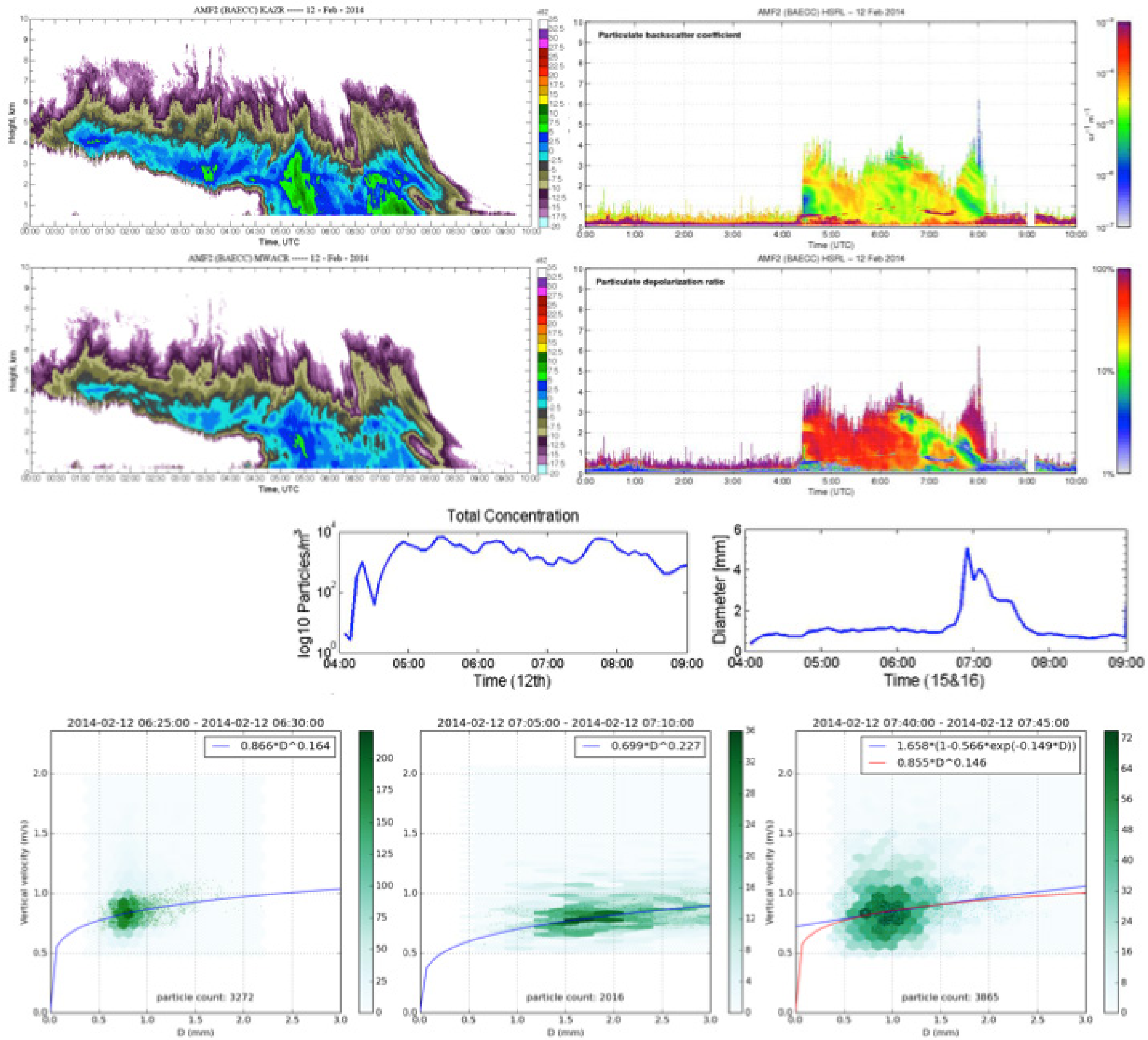

Figure 4. Example of joint analysis using radar, lidar, and PIP observations of snowfall.

During the IOP, all the instruments performed well. No major breaks in the observations took place. From mid-February the ARM 2D-video disdrometer was deployed. It has supplemented the University of Helsinki 2D-video disdrometer. To ensure that measurements from both 2D-video disdrometers were comparable, in June the university instrument was placed next to the ARM disdrometer on the measurement platform and remained there until the end of the campaign. In the beginning of BAECC and during the snowfall experiment, the university disdrometer was located inside the DFIR.

3.0 Lessons Learned

Overall, the campaign was highly successful. We did not have any major failures.

We found that duplication of instruments does provide an additional level of assurance on the quality of the observed variables. For snow measurements, monitoring of the wind field at the level of instrument sampling volume is very important. The dual-fence wind protection is also highly desirable.

Though, it does not come as a surprise, surface-based observations of snowfall microphysics are extreme useful for analysis and interpretation of cloud radar observations; see Fig. 4 for an example.

4.0 Results

The analysis of the campaign data is at an early stage. The main effort is towards deriving precipitation microphysical properties such as precipitation rate, precipitation type and phase, and particle size distribution. Furthermore, more detailed microphysical studies are also possible by analyzing fall velocity-dimensional relations and deriving bulk density and mass-dimensional relations. The bulk density is calculated by combining PSD and v-D observations with recorded precipitation accumulations. In moderate-to-heavy snowfall, those calculations can be carried out every 5 minutes. Following the procedure presented by Huang et al. (2015), mass-dimensional relations of falling snow can also be estimated. Given the duplication of most of the precipitation instruments and use of instruments with different measurement principles, consistency of the retrieved snow microphysical properties can be checked.

One of the early results of the experiment is a link between triple-frequency radar observations and snow microphysics. The result of this study is being prepared for a peer-reviewed publication.

5.0 Public Outreach

On February 12, 2014 a press event was organized at which reporters from local newspaper and national TV channel, YLE, visited the site. The interviews were aired on the next day's morning show segment by YLE and appeared in the newspapers.

6.0 BAECC SNEX publications

6.1 Journal Articles/Manuscripts

Several manuscripts are in preparation that are based on BAECC SNEX data.

6.2 Meeting Abstracts/Presentations/Posters

Moisseev, D, A von Lerber, M Leskinen, V Chandrasekar, L Bliven, and W Petersen. 2014. "Comprehensive snowfall experiment during DOE ARM AMF2 deployment in Finland." *European Conference on Radar in Meteorology and Hydrology,* Garmisch-Partenkirchen, Germany.

7.0 References

Huang, G-J, VN Bringi, D Moisseev, WA Petersen, L Bliven ,and D Hudak. 2015. "Use of 2D-video disdrometer to derive mean density-size and Z_e-SR relations: Four snow cases from the light precipitation validation experiment." *Atmospheric Research* 153: 34-48, doi:10.1016/j.atmosres.2014.07.013.

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