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COMBLE ARM Mobile Facility (AMF) Measurements of Ice Nucleating Particles Field Campaign Report

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February 2021

ARM

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Both at Colorado State University

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Acronyms and Abbreviations

AGL	above ground level
AMF	ARM Mobile Facility
AOS	Aerosol Observing System
ARM	Atmospheric Radiation Measurement
ASL	above sea level
ASR	Atmospheric System Research
CAO	cold-air outbreak
COMBLE	Cold-Air Outbreaks in the Marine Boundary Layer Experiment
CSU	Colorado State University
DI	deionized
DOE	U.S. Department of Energy
INP	ice nucleating particle
IS	ice spectrometer
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
NIPR	National Institute of Polar Research
PCR	polymerase chain reaction
RH	relative humidity
sL	standard liter
UTC	Coordinated Universal Time
UV	ultraviolet

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1.0 Summary

During the Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE), a project with the overarching goal to shed light on the dynamics and microphysical properties of clouds and precipitation in the high-latitude marine boundary layer during cold-air outbreaks (CAOs), we were tasked with providing and assisting the collection of aerosol filter samples for measuring ice nucleating particle (INP) concentrations. Little is known about the properties of CAO cloud systems, how they vary with surface, environmental, and aerosol conditions, the role of cold-air outbreaks in the global atmospheric and ocean circulation, and the accuracy of the treatment of this atmospheric regime in climate models. Uncertainties in climate projections for the arctic and sub-arctic region are large, in part due to the lack of observational guidance to constrain the treatment of aerosol-cloud-precipitation linkages in climate models.

This report details these INP measurement efforts that were associated with deployment of the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility's first Mobile Facility (AMF-1). These measurements were specially focused around research needs for addressing COMBLE science questions regarding the sources and sinks of aerosol, including INPs, and the role of cloud-active aerosol on cloud processes and radiative fluxes during CAO conditions. As the primary means for first initiation of the ice phase in clouds, absent remnant ice particles from prior convection or overseeding from higher clouds (cirrus) where homogeneous freezing can occur, the abundance of INPs can play a vital role in the formation of precipitation. The INP data collected should ultimately find use in future investigations, especially in relational analyses to other AMF-1 measurements of aerosol properties, and can serve as the basis for developing and improving numerical model parameterizations of ice nucleation for use in simulations of CAO events. Some funding for additional analyses of COMBLE data in this regard, and collaboration with numerical modeling investigators, has been obtained by the authors of this report via the DOE Atmospheric System Research (ASR) program.

The AMF-1 INP measurements during COMBLE captured an extended seasonal cycle of INPs from the late fall to the late spring in the arctic Northern Hemisphere (1 December 2019 to 26 May 2020), representing populations that exist over vast expanses of the ocean north of Norway, and also characterizing other local and regional sources outside of CAO periods. The AMF-1 site was located at Nordmela Harbor on Andøya Island, Norway (69.141391°N, 15.684033°E). Within this region, it can be expected that marine sources dominate in the cold season, when there is snow cover. Other aerosol influences were expected to be encountered from local soil and plant emissions, especially the surrounding temperate forests, as well as long-range pollution from interior Eurasia.

This document describes the installation, collections, processing, and archiving of data from this effort. INP filters were sampled atop the Aerosol Observing System (AOS) trailer (Figure 1). Collections were made over periods of 6 to 74 hours (average 34 h and 42 m^3 filtered), with periods tailored to integrate CAO or flanking periods of non-CAO air. We used open-faced polycarbonate filters that were sampled at a height of 4 m AGL on the AOS trailer (6 m below its inlet), 6-8 m ASL and 30 m inland from the harbor wall, and near the other AMF measurements (Figure 1). Pre-cleaned and pre-sterilized 47-mm Nuclepore polycarbonate filters (0.2-μm pore size, backed by clean 0.45-μm pore size filters) were mounted in plastic holders that were open to the atmosphere. Single-use filter units were provided in sealed plastic by our research team (Figure 2), along with training materials for the group of ARM technicians assisting AMF-1 measurements. A total of 64 filters were collected over the COMBLE

deployment, plus 4 blanks (installed with no flow) at intervals throughout the project. Filters were stored temporarily in sealed petri dishes in a -20°C freezer prior to return to Colorado State University (CSU) at the end of the campaign with a dry nitrogen shipper.

Figure 1. AMF-1 site, looking just east of north from the site at Nordmela Harbor in the left panel, with the filter unit in place atop the AOS trailer (circled) at the start of the sampling period, placed as usual underneath a half-spherical rain hat. Positioning of the filter at 6 m below the AOS inlet intake is more clearly visible in the right figure. These images were at the installation time. Snow covered the site until late May.

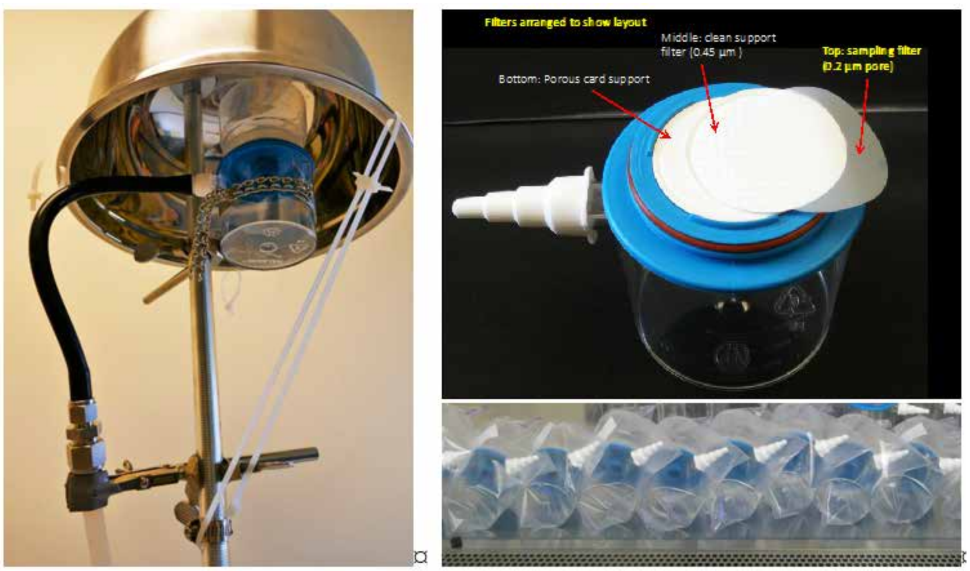

Figure 2. Filter sampler unit close up within rain hat (left), pre-cleaned and pre-sterilized filter configuration as arranged before shipping (upper right) and cleaned and bagged units as shipped to Norway prior to opening for sampling each day (bottom).

Initial processing to obtain spectra of INP number concentration active via the immersion freezing mechanism versus temperature was conducted using the CSU ice spectrometer (IS) instrument system (McCluskey et al. 2018). For processing, each filter was placed into a 50 mL Falcon polypropylene centrifuge tube with 7-8 mL of 0.1 µm-filtered deionized (DI) water, and shaken in a Roto-Torque rotator for 20 min to create a suspension. Thirty-two aliquots of 50 µL (i.e., 1.6 mL) of each sample, plus a series of dilutions, are then dispensed into polymerase chain reaction (PCR) plastic trays that are then fit into aluminum blocks in the IS. Samples are cooled at a rate of approximately 0.33°C min^{-1}. Freezing temperatures of wells were recorded using a camera and software system on each of three IS instrument systems. The lowest freezing temperature archived for each sample was defined by the temperature for which the number of sample wells frozen significantly exceeded those frozen in a 32-well, 0.1 µm-filtered DI water blank tested simultaneously in the same tray. This final temperature was typically -28°C for the COMBLE AMF-1 sample set. Cumulative INP concentrations were determined by first calculating the INPs per mL of suspension based on Vali (1971) and then converting to concentration per standard liter (sL) of air using the proportion of the total liquid sample dispensed and the air sample volumes. The number of INPs on the average of all blank filters that had been handled and processed identically, with exception of air flow, were subtracted from the calculated number of INPs on each sample filter before the conversion to number concentration per standard liter. The large sample volumes of filters led to numbers collected on filters that exceeded blank filter background numbers by significant amounts in most cases. Confidence intervals (95%) for binomial sampling were calculated based on Agresti and Coull (1998).

To gain insights in the biological proportion of INPs, a portion of a selected number of original suspensions was heated to 95°C for 20 min, prior to determining the immersion freezing temperature spectra. This thermal treatment should denature most heat-labile biological organics, such as proteins, and hence a reduction in concentrations reveals the proportion of all INPs that were likely of biological origin. Hydrogen peroxide (H_2O_2) digestions were also performed on a selected proportion of suspensions following methods detailed in McCluskey et al. (2018) and Suski et al. (2018). This was typically done for the same filter samples for which thermal treatments were done. Digestion in 10% H_2O_2 at 95°C under UV-B illumination was intended to remove all organic carbon INPs; the residual is presumed to be inorganic (likely mineral) INPs. Remnant suspensions have been physically archived frozen for future potential testing of INP source compositions and aerosol chemical and biological source attribution.

Synergy is expected to occur between COMBLE INP data and other measurements being conducted across the Arctic at the same time. The COMBLE measurements were complemented by the upstream INP measurements taken at Ny-Ålesund and coordinated by colleague Yutaka Tobo (National Institute of Polar Research [NIPR], Tokyo, Japan), and were also aligned in time with part of the record of INP data collected by our team (Dr. Jessie Creamean, Principal Investigator) during the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) campaign far north of the COMBLE measurement site (Figure 3), a connection being explored under new DOE ASR funding.

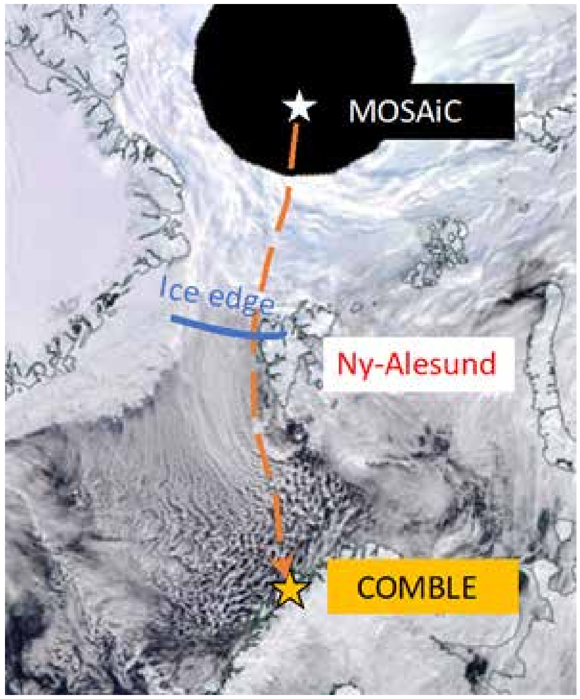

Figure 3. Spatial relation of simultaneous INP measurements during COMBLE, indicating northern locations of related sampling at **Ny-Ålesund** in Svalbard and the location of the MOSAiC sampling on the *Polarstern* mobile observatory.

For archival and completion of tasks under this ARM proposal, all 63 sample filters were processed for standard immersion freezing spectra (one filter was missing from its container) and 4 blanks were processed to define background corrections. Of 63 particle suspensions, 27 were tested for thermally removing microbial/proteinaceous contributions toward INPs and 24 of these were also tested for removal of all organic carbon. Selected metadata for processed filters is shown in Table 1. A very simple first attribution of events as CAO and non-CAO was made here, where CAO conditions are as defined in the report of Geerts et al. (2020), absent consideration of cloud conditions; instability as indicated by a positively valued potential temperature difference between the offshore sea surface temperature and the 850 mb air temperature, onshore winds exceeding >10 kts, and wind directions between 250 and 30 degrees deemed to persist during the filter period on the basis of United Kingdom Meteorological Office model forecasts provided by Dr. Paul Field. These attributions were needed at the time of processing in order to select appropriate filters for secondary treatments. All data have been added to the ARM Data Center (doi: 10.5439/1755091).

Table 1. Metadata for processed COMBLE filters. SL is standard liters of air collected. Tentative attribution of CAO/non-CAO conditions is indicated. These may not exactly follow those in Geerts et al. (2021), which should be strictly referenced in this regard.

Filter No.	Status	Date	Time (UTC)	CAO	Weather and Other Notes	Vol (SL)
1	Start	12/01/19	10:29	Y	Cloudy; temp = 1.5 C; Wind = 17.3 m/s 309 degrees; RH = 68%	
	Mid			Y		
	End	12/02/19	11:10	Y	Overcast temp = 1.7 C; Wind = 14.6 m/s 303 degrees; RH = 58.4%	33,766
2	Start	12/03/19	9:25	N	Overcast temp = 2.8 C; Wind = 5.3 m/s 162 degrees; RH = 74.5%	
	Mid	12/04/19	9:13	N	Raining temp = 7 C; Wind = 11 m/s 232 degrees; RH = 82.3%	
	End	12/05/19	9:20	N	Overcast temp = 2.6 C; Wind = 3.4 m/s 129 degrees; RH = 76.2%	47,595
3	Start	12/05/19	9:10	N	Overcast temp = 2.7 C; Wind = 3.4 m/s 129 degrees; RH = 76.2%	
	Mid					
	End	12/06/19	16:30	N	Overcast temp = 2.1 C; Wind = 4.6 m/s 100 degrees; RH = 71.1%	41,049
4	Start	12/07/19	10:10	N	Light snow temp = 0 C; Wind = 3.4 m/s 75degrees; RH = 88.8%	
	Mid			N		
	End	12/08/19	9:03	Y	Overcast temp = -0.3 C; Wind = 6.6 m/s 55 degrees; RH = 76.0%	30,004
5	Start	12/08/19	9:14	Y	Overcast Temp = -0.1 C; Wind = 7.7 m/s 47 degrees; RH = 72.8%	
	Mid	12/09/19	9:33	Y	Overcast Temp = -1.8 C; Wind = 7.6 m/s 196 degrees; RH = 54.3%	
	End	12/09/19	15:42	Y	Overcast Temp = -3.9 C; Wind = 1.1 m/s 121 degrees; RH = 66.3%	40,566
6	Start	12/10/19	9:10	N	Partly Cloudy Temp = -5.1; Wind = 3.7 m/s 177 degrees; RH = 78.55%	
	Mid	12/11/19	9:20	N	Light snow Temp = -1.5; Wind = 8.8 m/s 125 degrees; RH = 85.35%	
	Mid	12/12/19	11:12	N	Partially Cloudy Temp = 3.4; Wind = 4.4 m/s 122 degrees; RH = 46.8%	
	End	12/13/19	9:55	N	Mostly Cloudy Temp = 2.6; Wind = 4 m/s 1119 degrees; RH = 60.2%	89,797
7	Start	12/16/19	10:34	N	Partly Cloudy Temp = 1.2 C; Wind = 1.8 m/s 133 degrees; RH = 71.9%	
	Mid					
	End	12/18/19	12:26	N	Overcast Temp = 2.4 C; Wind = 3.1 m/s 232 degrees; RH = 83%	65,939
8	Start	12/18/19	12:43	Y	Overcast Temp = 2.4 C; Wind = 3.1 m/s 232 degrees; RH = 83%	
	Mid					
	End	12/19/19	9:52	Y	Mostly Cloudy Temp = -2.2 C; Wind = 2.3 m/s 165 degrees; RH = 79.5%	28,191

Filter No.	Status	Date	Time (UTC)	CAO	Weather and Other Notes	Vol (SL)
	Start	12/20/19	BLANK		Mostly cloudy Temp = -2.6 C; Wind = 1.9 m/s 168 degrees; RH = 60.2%	
	Mid					
	End					
9	Start	12/19/19	10:01	N	Mostly cloudy Temp = -1.9 C; Wind = 2.9 m/s 172 degrees; RH = 78.3%	
	Mid					
	End	12/20/19	18:00	N	Mostly cloudy Temp = -1.9 C; Wind = 3.3 m/s 143 degrees; RH = 65.3%	46,567
10	Start	12/23/19	12:10	N	Overcast Temp = -1.9 C; Wind = 2.2 m/s 148 degrees; RH = 79.6%	
	Mid					
	End	12/24/19	17:43	N	Raining Temp = 1.7 C; Wind = 1.4 m/s 179 degrees; RH = 88.4%	41,247
11	Start	12/27/19	12:00	N	Mostly Cloudy Temp = 0.7 C; Wind = 2.4 m/s 204 degrees; RH = 67.8%	Filter missing from bag
	Mid					
	End	12/29/19	14:30	N	Overcast Temp = 3.4 C; Wind = 2.7 m/s 169 degrees; RH = 83.3%	
12	Start	12/30/19	14:00	Y	Overcast Temp = 1.5 C; Wind = 8.7 m/s 30 degrees; RH = 67.1%	
	Mid					
	End	12/31/19	12:39	Y	Overcast Temp = 1.5 C; Wind = 14.7 m/s 300 degrees; RH = 67.1%	28,922
13	Start	01/02/20	10:00	N	Raining Temp = 2.2 C; Wind = 11.7 m/s 142 degrees; RH = 82.6%	
	Mid					
	End	01/03/20	16:10	N	Snowy Temp = -1.6 C; Wind = 5.6 m/s 189 degrees; RH = 88.4%	22,377
14	Start	01/03/20	16:30	Y	Snowy Temp = -1.6 C; Wind = 5.6 m/s 189 degrees; RH = 88.4%	
	Mid	01/04/20	11:35	Y	Mostly Cloudy Temp = -1 C; Wind = 14.3 m/s 1 degrees; RH = 66.1%	
	End	01/05/20	10:59	Y	Cloudy Temp = -0.7 C; Wind = 7.2 m/s 143 degrees; RH = 69.6%	39,730
15	Start	01/06/20	12:00	N	Mostly Cloudy Temp = 3 C; Wind = 4.4 m/s 195 degrees; RH = 78.3%	
	Mid	01/07/20	14:25	N	Mostly Cloudy Temp = 4.6 C; Wind = 5 m/s 175 degrees; RH = 64.2%	
	End	01/08/20	12:25	N	Clear Sky Temp = 4.2 C; Wind = 7.7 m/s 202 degrees; RH = 54.6%	55,075
16	Start	01/09/20	13:45	Y	Cloudy Temp = 3.3 C; Wind = 20.1 m/s 270 degrees; RH = 44.5%	
	Mid					
	End	01/10/20	16:54	Y	Hail Temp = 2.9 C; Wind = 6.6 m/s 261 degrees; RH = 70.9%	28,893

Filter No.	Status	Date	Time (UTC)	CAO	Weather and Other Notes	Vol (SL)
17	Start	01/12/20	10:50	N	Mostly Cloudy Temp = 3.4 C; Wind = 10.2 m/s 245 degrees; RH = 63.7%	
	Mid					
	End	01/13/20	16:00	N	Mostly Cloudy Temp = 3 C; Wind = 7.5 m/s 261 degrees; RH = 69.6%	38,511
18	Start	01/13/20	16:10	N	Raining Temp = 2.1 C; Wind = 13.6 m/s 274 degrees; RH = 77.3%	
	Mid	01/14/20	12:50	N	Mostly Cloudy Temp = 1.7 C; Wind = 8.1 m/s 103 degrees; RH = 61%	
	End	01/15/20	15:50	N	Cloudy Temp = 0.5 C; Wind = 4.0 m/s 124 degrees; RH = 90.3%	58,770
19	Start	01/17/20	10:07	N/Y*	Partially Cloudy Temp = -2.7 C; Wind = 6.7 m/s 85 degrees; RH = 69%	
	Mid					
	End	01/18/20	13:45	N	Partially Cloudy Temp = -1.1 C; Wind = 6.8 m/s 121 degrees; RH = 68.1%	39,418
	Start	01/18/20	BLANK		Partially Cloudy Temp = -1 C; Wind = 6.4 m/s 110 degrees; RH = 68.1%	
	Mid					
	End					
20	Start	01/19/20	11:55	N	Mostly Cloudy Temp = 3.2 C; Wind = 2.5 m/s 154 degrees; RH = 63.7%	
	Mid					
	End	01/20/20	15:56	N	Cloudy/Rain Temp = 3.8 C; Wind = 9.1 m/s 285 degrees; RH = 81.5%	30,174
21	Start	01/20/20	16:00	Y/N*	Cloudy/Rain Temp = 3.5 C; Wind = 7.8 m/s 294 degrees; RH = 82.3%	
	Mid	01/21/20	14:25	Y/N*	Mostly Cloudy Temp = 1.4 C; Wind = 9.9 m/s 270 degrees; RH = 59.9%	
	End	01/22/20	16:07	Y	Mostly Cloudy Temp = 1.4 C; Wind = 8.1 m/s 310 degrees; RH = 61.1%	47,570
22	Start	01/23/20	12:05	N	Cloudy/Rain Temp = 4.2 C; Wind = 7.8 m/s 259 degrees; RH = 85.1%	
	Mid	01/24/20	1:00	N		
	End	01/24/20	15:00	N	Cloudy/Snow Temp = -1.8 C; Wind = 2.6 m/s 138 degrees; RH = 90.1%	31,703
23	Start	01/26/20	10:35	N	Clear Sky Temp = -5 C; Wind = 9.2 m/s 85 degrees; RH = 61.8%	
	Mid					
	End	01/28/20	15:42	N	Partly Cloudy Temp = -2.7; Wind = 7.5 m/s 139 degrees; RH = 57.7%	70,769
24	Start	01/30/20	10:37	N	Partly Cloudy Temp = -0.5; Wind = 4.2 m/s 160 degrees; RH = 59.8%	
	Mid	01/31/20	11:23	N	Partly Cloudy Temp = -0.6; Wind = 12.0 m/s 136 degrees; RH = 53%	
	End	02/01/20	12:15	N	Cloudy Temp = 0.3; Wind = 10.3 m/s 119 degrees; RH = 71.7%	60,559

Filter No.	Status	Date	Time (UTC)	CAO	Weather and Other Notes	Vol (SL)
25	Start	02/02/20	12:40	Y	Mostly Cloudy; Temp = 2.2; Wind = 15.1 m/s 316degrees; RH = 55.6%	
	Mid	02/03/20	12:03	Y	Mostly Cloudy; Temp = -1.3; Wind = 10.7 m/s 288degrees; RH = 51.7%	
	Mid	02/04/20	10:44	Y	Snowing; Temp = -2.8; Wind = 6.4 m/s 157 degrees; RH = 67.5%	
	End	02/05/20	14:55	Y	Snowing; Temp = -3.7; Wind = 13 m/s 343 degrees; RH = 68.5%	73,807
26	Start	02/07/20	10:20	N	Overcast; Temp = 4.5; Wind = 5.7 m/s 251 degrees; RH = 86.2%	
	Mid					
	End	02/08/20	12:50	N	Overcast; Temp = 5.7; Wind = 4.1 m/s 204 degrees; RH = 65.9%	33,197
27	Start	02/11/20	10:38	N*	Overcast/Rain; Temp = 3; Wind = 7.3 m/s 281 degrees; RH = 77.5%	
	Mid	02/11/20	22:00	N		
	End	02/12/20	15:18	N	Overcast; Temp = 1.7; Wind = 3.5 m/s 316 degrees; RH = 71.8%	31,585
28	Start	02/15/20	10:16	N	Overcast; Temp = -2.6; Wind = 6.2 m/s 103 degrees; RH = 64.9%	
	Mid					
	End	02/16/20	14:40	N	Mostly Cloudy; Temp = 1.8; Wind = 13.7 m/s 133 degrees; RH = 59.3%	36,834
29	Start	02/19/20	14:02	N	Overcast; Temp = -4; Wind =3.4 m/s 160 degrees; RH = 86.7%	
	Mid					
	End	02/21/20	14:09	N	Overcast; Temp = 2.9; Wind = 8.3 m/s 170 degrees; RH = 67.2%	59,392
30	Start	02/23/20	13:00	Y	Overcast; Temp = -4; Wind =3.4 m/s 160 degrees; RH = 86.7%	
		02/24/20	13:00	Y		
	Mid	02/25/20		N	Filter was capped, pump turned off. Pump was restarted next morning.	
	End	02/26/20	10:15	N	Overcast; Temp = 2.4; Wind = 9m/s 217 degrees; RH = 71.3%	66,220
31	Start	02/28/20	12:00	Y/N	Rain; Temp =1.4; Wind =4.5 m/s 244 degrees; RH = 84.4%%	
	Mid			Y		
	End	03/01/20	16:23	Y/N	Overcast, Temp =-5.7; Wind =2m/s 83 degrees; RH = 83%	54,740
32	Start	03/02/20	9:00	Y	Partly cloudy; Temp =-2.4; Wind =4.7 m/s 78 degrees; RH = 63%	
	Mid	03/02/20	23:00	Y		
	Mid	03/03/20	9:00	Y*		
	End	03/03/20	14:48	Y*	Clear; Temp = -2.1; Wind = 10.2 m/s 103 degrees; RH = 63.7%	37,779

Filter No.	Status	Date	Time (UTC)	CAO	Weather and Other Notes	Vol (SL)
33	Start	03/04/20	9:14	N	Clear sky; Temp =-1.7C; Wind =9.9 m/s 141 degrees; RH = 48.3%	
	Mid					
	End	03/05/20	16:00	N	Overcast; Temp = -1.4; Wind = 3.6 m/s 144 degrees; RH = 71.7%	38,987
34	Start	03/08/20	9:35	N	Partly Cloudy; Temp = 1 C; Wind = 9.6 m/s 108 degrees; RH = 52.8%	
	Mid					
	End	03/09/20	15:00	N	Mostly Cloudy; Temp = 5.1 C; Wind = 5.7 m/s 192 degrees; RH = 67.9%	40,004
35	Start	03/09/20	15:05	N	Mostly Cloudy; Temp = 5.0 C; Wind = 5.9 m/s 194 degrees; RH = 68.2%	
	Mid	03/09/20	18:00	N		
	Mid	03/09/20	22:00	N		
	End	03/10/20	10:00	Y*	Overcast; Temp = -1.4 C; Wind = 8.2 m/s 43 degrees; RH = 57.6%	22,865
36	Start	03/11/20	9:40	N	Overcast; Temp = -0.7 C; Wind = 7.1 m/s 127 degrees; RH = 66.4%	
	Mid					
	End	03/11/20	15:50	N	Overcast; Temp = -1.0 C; Wind = 4.9 m/s 82 degrees; RH = 70.1%	8,729
37	Start	03/12/20	9:30	Y	Snowing; Temp = -1.9 C; Wind = 14.9 m/s 354 degrees; RH = 78.8%	
	Mid					
	End	03/14/20	8:50	Y	Partly Cloudy; Temp = -3.6 C; Wind = 3.4 m/s, 170 degrees; RH = 76.4%	52,375
38	Start	03/14/20	15:30	N	Overcast; Temp = -2.9 C; Wind = 12.3 m/s, 133 degrees; RH = 73.4%	
	Mid	03/15/20	15:00	Y		
	End	03/16/20	13:55	Y/N	Overcast; Temp = 1.0 C; Wind = 14.4 m/s, 302 degrees; RH = 70.6%	52,201
39	Start	03/17/20	10:00	N	Snowing; Temp = -0.7 C; Wind = 8.6 m/s, 133 degrees; RH = 88.7%	
	Mid					
	End	03/18/20	10:00	N	Mostly Cloudy; Temp = 2.8 C; Wind = 7.7 m/s, 219 degrees; RH = 63.0%	33,166
	Start					
	Mid	03/18/20	BLANK		Raining; Temp = 1.5 C; Wind = 4 m/s, 224 degrees; RH = 82.7%	
	End					
40	Start	03/18/20	13:00	Y	Raining; Temp = 1.6 C; Wind = 4.9 m/s, 209 degrees; RH = 80.7%	
	Mid					
	End	03/20/20	10:25	Y	Snowing; Temp = -3.7 C; Wind = 5.9 m/s, 196 degrees; RH = 76.0%	56,110

Filter No.	Status	Date	Time (UTC)	CAO	Weather and Other Notes	Vol (SL)
41	Start	03/23/20	10:00	N	Raining: Temp =4.5 C; Wind = 4.9 m/s, 207 degrees; RH = 80.4%	
	Mid					
	End	03/24/20	10:00	N	Raining; Temp = 3.0 C; Wind = 17.9 m/s, 214 degrees; RH = 74.6%	36,012
42	Start	03/25/20	15:50	Y	Raining; Temp = 3.0 C; Wind = 10.3 m/s, 289 degrees; RH = 68.2%	
	Mid					
	End	03/26/20	12:15	Y	Raining; Temp = 4.8 C; Wind = 8.4 m/s, 224 degrees; RH = 72.1%	27,583
43	Start	03/29/20	14:45	Y	Overcast; Temp = -3.0 C; Wind = 6.7 m/s, 19 degrees; RH = 69.2%	
	Mid					
	End	03/30/20	10:00	Y	Partly cloudy; Temp = -3.0 C; Wind = 5.5 m/s, 222 degrees; RH = 79.3%	25,996
44	Start	04/01/20	10:00	N	Sunny; Temp = -0.7 C; Wind = 1.4 m/s, 13 degrees; RH = 72.3%	
	Mid					
	End	04/02/20	15:10	N	Mostly Cloudy; Temp = -3.0 C; Wind = 5.1 m/s, 51 degrees; RH = 46.8%	41,459
45	Start	04/04/20	15:15	Y	Mostly Cloudy; Temp = -3.1 C; Wind = 4.7 m/s, 47 degrees; RH = 49.2%	
	Mid	04/05/20	10:00	Y		
	Mid	04/05/20	22:00	Y*		
	End	04/06/20	10:00	N*	Mostly Cloudy; Temp = -3.3 C; Wind = 2.4 m/s, 176 degrees; RH = 76.6%	56,684
46	Start	04/07/20	9:00	N	Partly Cloudy; Temp = 5.1 C; Wind = 5.4 m/s, 213 degrees; RH = 73.2%	
	Mid					
	End	04/08/20	16:20	N	Stormy; Temp = 1.3 C; Wind = 20.2 m/s, 249 degrees; RH = 89.9%	30,335
47	Start	04/08/20	16:20	Y	Stormy; Temp = 1.3 C; Wind = 20.2 m/s, 249 degrees; RH = 89.9%	
	Mid					
	End	04/11/20	10:00	Y	Mostly Cloudy; Temp = 0.1 C; Wind = 6.9 m/s, 230 degrees; RH = 92.7%	78,513
48	Start	04/12/20	14:00	Y	Overcast; Temp = 2.2 C; Wind = 5.0 m/s, 38 degrees; RH = 67.2%	
	Mid					
	End	04/13/20	13:00	Y	Partly cloudy; Temp = 1.7 C; Wind = 18.4 m/s, 0 degrees; RH = 65.2%	28,133
49	Start	04/14/20	10:00	N	Partly cloudy; Temp = 2.4 C; Wind = 3.3 m/s, 150 degrees; RH = 66.0%	
	Mid					
	End	04/14/20	16:00	N	Partly cloudy; Temp = 2.5 C; Wind = 3.2 m/s, 156 degrees; RH = 63.5%	7,839

Filter No.	Status	Date	Time (UTC)	CAO	Weather and Other Notes	Vol (SL)
50	Start	04/16/20	16:40	Y	Overcast; Temp = 2.4 C; Wind = 3.4 m/s, 207 degrees; RH = 79.6%	
	Mid					
	End	04/17/20	13:00	Y	Overcast; Temp = 3.2 C; Wind = 10.6 m/s, 299 degrees; RH = 72.8%	27,380
51	Start	04/18/20	11:00	N	Overcast; Temp = 4.4 C; Wind = 4.2 m/s, 209 degrees; RH = 81.8%	
	Mid					
	End	04/20/20	8:35	N	Mostly Cloudy; Temp = 4.9 C; Wind = 4.1 m/s, 241 degrees; RH = 75.7%	56,392
52	Start	04/22/20	9:40	N	Mostly Cloudy; Temp = 5.3 C; Wind = 4.5m/s, 242 degrees; RH = 73.9%	
	Mid					
	End	04/23/20	13:00	N	Mostly Cloudy; Temp = 16.1 C; Wind = 4.6m/s, 164.5 degrees; RH = 91.4%	36,531
53	Start	04/24/20	15:10	Y	Partly Cloudy; Temp = 2.6 C; Wind = 3.5 m/s, 350 degrees; RH = 54.5%	
	Mid	04/25/20	16:00	Y		
	End	04/26/20	13:00	Y	Overcast; Temp = 1.7 C; Wind = 7.1 m/s, 21 degrees; RH = 75.5%	55,642
54	Start	04/27/20	8:30	N	Overcast; Temp = 2.2 C; Wind = 5.4 m/s, 49 degrees; RH = 63.3%	
	Mid					
	End	04/28/20	15:00	N	Mostly Cloudy; Temp = 2.0 C; Wind = 5.4 m/s, 67 degrees; RH = 57.8%	43,176
55	Start	04/29/20	8:30	N	Clear Skies; Temp = 3.1 C; Wind = 7.8 m/s, 121 degrees; RH = 67.7%	
	Mid					
	End	04/30/20	15:00	N		45,044
56	Start	05/02/20	8:30	N	Partly cloudy; Temp = 6.4 C; Wind = 7.1 m/s, 115 degrees; RH = 54.1%	
	Mid					
	End	05/03/20	10:15	N	Overcast; Temp = 5.3 C; Wind = 2.5 m/s, 311.4 degrees; RH = 81.7%	37,742
57	Start	05/05/20	17:12	N	Overcast; Temp = 5.5 C; Wind = 10.1 m/s, 190 degrees; RH = 74.9%	
	Mid					
	End	05/06/20	17:00	N	Overcast; Temp = 4 C; Wind = 7.3m/s, 272 degrees; RH = 83%	26,534
58	Start	05/06/20	17:00	Y	Overcast; Temp = 4 C; Wind = 7.3m/s, 272 degrees; RH = 83%	
	Mid	05/07/20	17:00	Y		
	End	05/08/20	17:00	Y	Overcast; Temp = 1.5 C; Wind = 1.5 m/s, 189 degrees; RH 78.3%	50,908
59	Start	05/10/20	10:00	N	Overcast; Temp = 2.1 C; Wind 4.8 m/s, 193 degrees; Rh 61.7%	
	Mid					
	End	05/10/20	17:00	N	Overcast; Temp = 2.5 C; Wind 3.8 m/s, 271 degrees; RH 63.3%	9,383

Filter No.	Status	Date	Time (UTC)	CAO	Weather and Other Notes	Vol (SL)
60	Start	05/10/20	17:00	Y	Overcast; Temp = 2.5 C; Wind 3.8 m/s, 271 degrees; RH 63.3%	
	Mid					
	End	05/12/20	17:00	Y	Snowing; Temp=-0.3C; Wind 8.3 m/s, 306 degree; RH 82.1%	48,288
61	Start	05/14/20	8:00	N	Overcast; Temp = 2.9 C; Wind 0.7 m/s, 209 degrees; RH 51.8%	
	Mid			Y		
	End	05/15/20	8:00	Y	Overcast; Temp = 0.9 C; Wind 13.7 m/s, 288 degrees; RH 90.1%	30,927
62	Start	05/16/20	8:00	N	Mostly Cloudy; Temp = 4.8 C; Wind 8.1 m/s, 119 degrees; RH 47.4%	
	Mid					
	End	05/17/20	8:00	N	Mostly cloudy; Temp = 4.4 C; Wind 6.2 m/s, 20 degrees; RH 80.1%	33,974
63	Start	05/20/20	8:00	N	Partly Cloudy; Temp = 5.3 C; Wind 3.5 m/s, 281 degrees; RH 58.4%	
	Mid					
	End	05/21/20	9:30	N	Overcast; Temp = 4.9 C; Wind 3.5 m/s, 201 degrees; RH = 77.0%	36,864
BLANK					Flow meter suggests flow was drawn for this one	
64	Start	05/25/20	8:45	N	Cloudy; Temp = 11.9 C; Wind = 6.5 m/s, 204 degrees; RH = 60.8%	
	Mid					
	End	05/26/20	15:30	N	Cloudy; Temp = 12.1 C; Wind = 7.1 m/s, 155 degrees; RH = 51.4%	41,432

* These were partial CAOs during which there was a break or a wind deviation over land for short periods.

2.0 Results

Results are at an early stage of evaluation, as final processing was completed just prior to the drafting of this report. In Figure 4, the overall campaign INP temperature spectral results are represented for samples that were unamended or treated to indicate INP compositions. This represents one of the most comprehensive such databases accumulated for a coastal arctic site. Unamended results indicate significant temporal variations exceeding one order of magnitude. Treatment results reveal features of an apparent preponderant marine INP influence, with a source that is primarily organic as indicated by reductions of unamended samples following peroxide digestions. Attribution cannot be certain until additional analyses are performed, but these are likely marine organic INPs of the type discussed by McCluskey et al. (2018). Data also indicate occasional influences of biological INPs in two distinct temperature regimes; higher than -15°C and lower than -18°C, with a unique inflection between these points that is not seen for the more abundant biological INPs found over land regions (e.g., Hill et al. 2018, O'Sullivan et al. 2018). This inflection is due to an unusual population of organic INPs, as apparent in comparing thermal and peroxide treatments. The INP spectra of the inorganic populations of INPs, indicated by the INPs remaining after H_2O_2 treatments in Figure 4, are highly exponential versus temperature, with an approximate 1-order-of-magnitude increase in atmospheric concentrations for each 3-4°C of cooling.

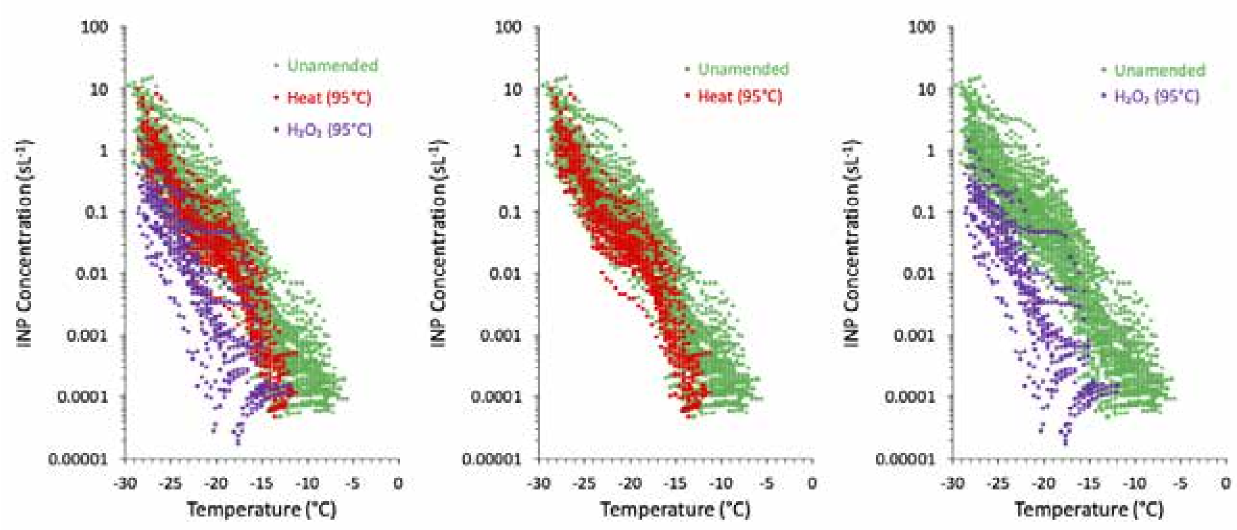

Figure 4. Ice nucleating particle number concentrations versus temperature for all multiply-processed samples from the AMF-1 (November 2018 to March2019). From left to right are all processes, unamended and thermally treated (95°C) only, and unamended and H_2O_2-treated only processes. Uncertainties are shown only for the middle panel. Results show the ubiquitous presence of organic and biological INPs in different temperature regimes, as discussed in the text.

Figure 5 shows all results obtained by month. These results demonstrate that similar results are reflected in every month, with inflection-type spectra especially prevalent during CAOs. CAOs also tended to have INP spectra with a relative absence of higher temperature, heat labile INPs except, interestingly, in the dark months of December and January. Plotting a timeline of INP concentrations at 5°C intervals, as in Figure 6, indicates no clear seasonal cycle to overall INP concentrations, except again a hint of the most high-temperature INPs present during the early COMBLE period in December and January.

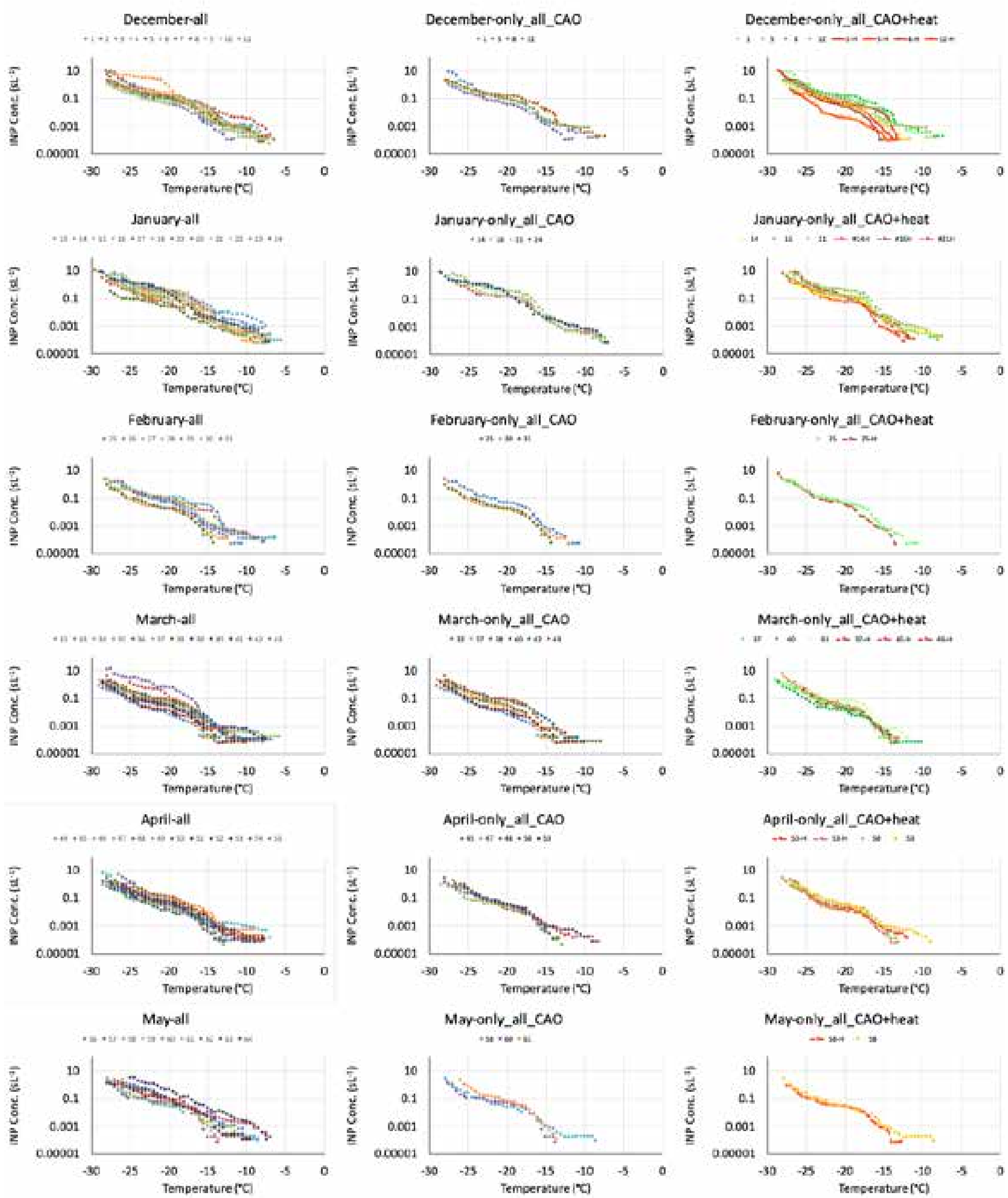

Figure 5. INP spectra by month during all times (left row) versus during CAOs (middle row), and comparison of unamended (no line) versus thermally treated samples (lines, darker points) in last row.

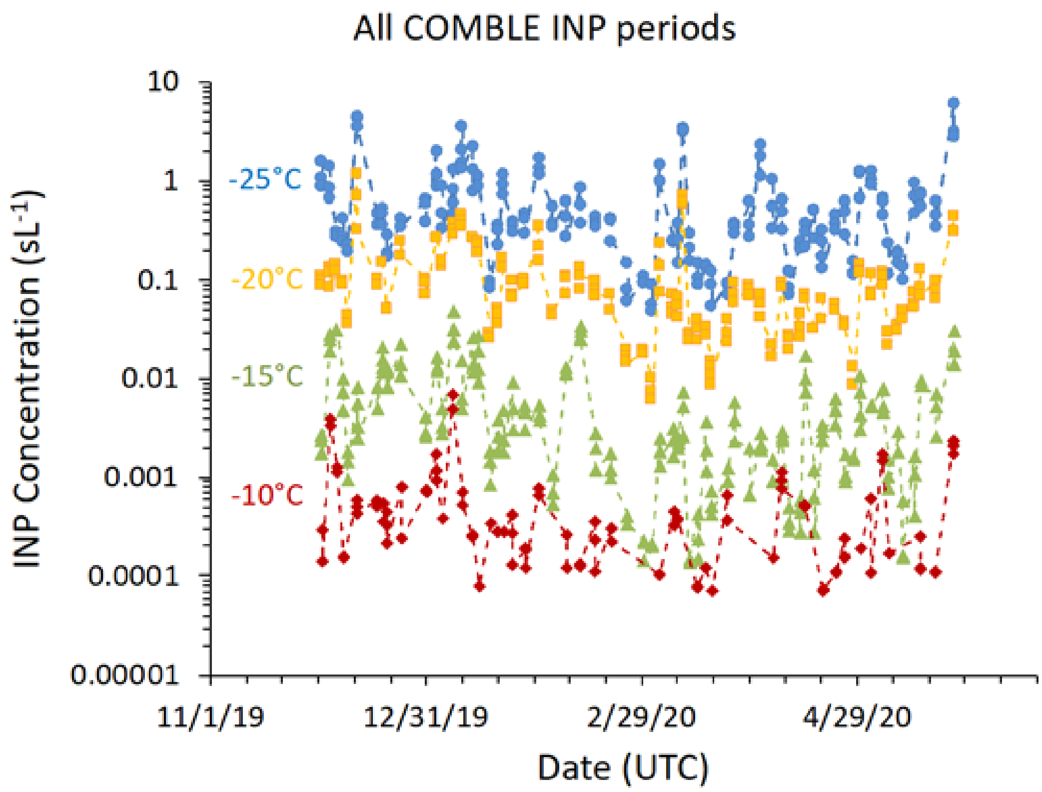

Figure 6. Timeline of INP concentrations at selected temperatures, indicating high variability at any temperature over time. All periods are shown, both CAOs and all other conditions.

3.0 Publications and References

3.1 Publications

No publications have been prepared at the time of this report. First presentation of results are planned to occur at the DOE ARM/ASR PI meeting in June 2021. Advanced analyses are underway under DOE ASR grant DE-SC0021116.

3.2 References

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