Supplementary

Measurement report: Role of Organic Coating and Chemical Composition on Ice Nucleation Potential of Atmospheric Particles in European Arctic

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S1. Micro-spectroscopy analysis

Individual particles were classified based on their elemental composition (as atomic %) obtained from SEM-EDX measurements (**Figure S2**). Particles containing both phosphorus and potassium ≥ 0.4 at.% were identified as **biogenic**. The remaining **non-biogenic** particles were categorized into dust-laden, Na-laden, non-dust, and other groups. **Dust-laden particles** were defined by elevated mineral content ([Al, Si, Fe, Ca] ≥ 4 at.% and > [Na]) and were subdivided into **dust** ([C, N, O] < 85 at.%) and **aged dust** ([C, N, O] ≥ 85 at.%), the latter further classified as **carbonaceous-coated dust** ([S] < 1 at.%) or **sulfate-rich dust** ([S] ≥ 1 at.%). **Na-laden particles** were defined by [Na] > 1 at.% and [Na] ≥ [Al, Si, Fe, Ca], and were classified as **Na-rich** when [Na] ≥ [S] or as **Na-rich sulfates** when [Na] < [S]. Among **non-dust particles** ([Al, Si, Fe, Ca] < 4 at.%), those dominated by [C, N, O, S] (> 99 at.%) with [S] ≥ 0.5 at.% were classified as **sulfates**, while those dominated by [C, N, O] (> 99 at.%) were classified as **carbonaceous**. Particles that did not meet any of the above criteria were grouped as **other**.

S2. Surface Type Influence and Free-Tropospheric Residence from FLEXPART Back-Trajectories

We used FLEXPART back-trajectory analysis to estimate the surface type influence and free-tropospheric (FT) residence time for ground-level aerosol samples (SA1–SA5) over a 168-hour period. The calculated percentages represent the time air masses spent over closed ice, open ice, open water, and land, as well as the duration spent in the FT, based on ERA5 reanalysis data and back-trajectory altitudes relative to the boundary layer (Table S3). Additionally, black carbon contributions were inferred from source apportionment using ERA5 sea ice edge data combined with back-trajectory analysis (Figure S3 and Table S4). These metrics provide critical context for understanding the origin, transport pathways, and potential ageing processes of sampled aerosols, which are important for interpreting their observed ice-nucleating properties.

Figure S1. Location of the Gruvebadet Observatory in Ny-Ålesund, Svalbard (red dot), situated in the European Arctic. The map highlights the surrounding regions, including Greenland, Iceland, and the Arctic Ocean, with a focus on the observatory's proximity to marine and polar environments. The white dashed box outlines the Svalbard archipelago. Scale bars represent distances in kilometers and miles. Map generated in MATLAB (R2024b using a KML file downloaded from © Google Earth (earth.google.com). The shaded-relief basemap is Esri World Imagery (© Esri, Maxar, Earthstar Geographics, and the GIS User Community).

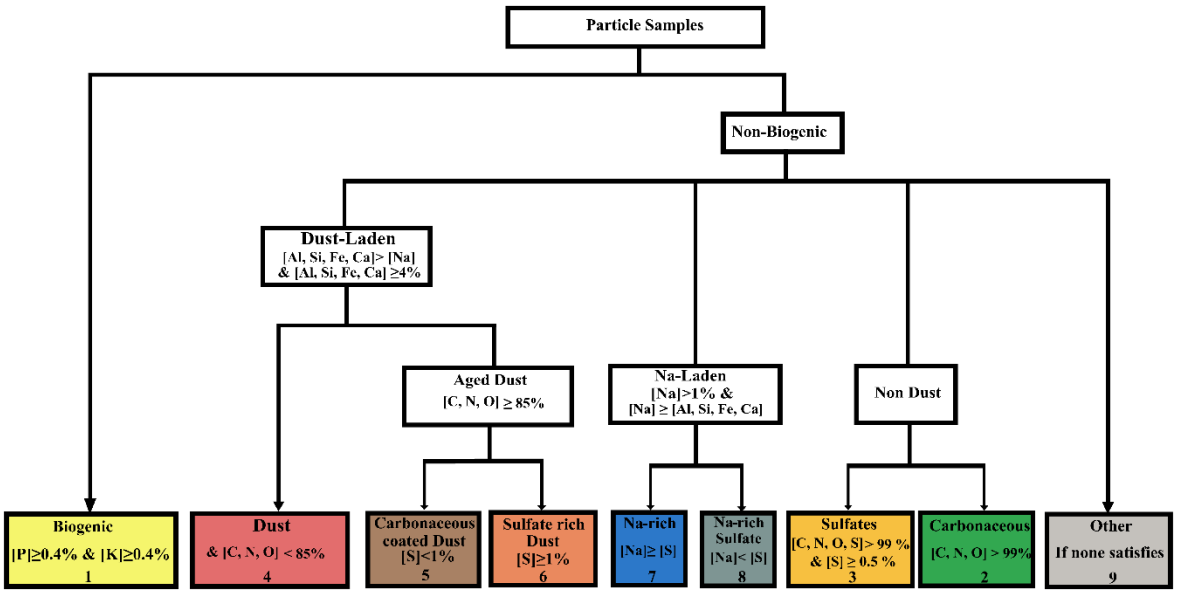

Figure S2. Particle classification scheme based on elemental composition from SEM-EDX analysis. Particles are first categorized as biogenic or non-biogenic. Non-biogenic particles are further classified into dust-laden, Na-laden, non-dust, and other types, with each main group subdivided based on dominant elemental composition and sulfur content.

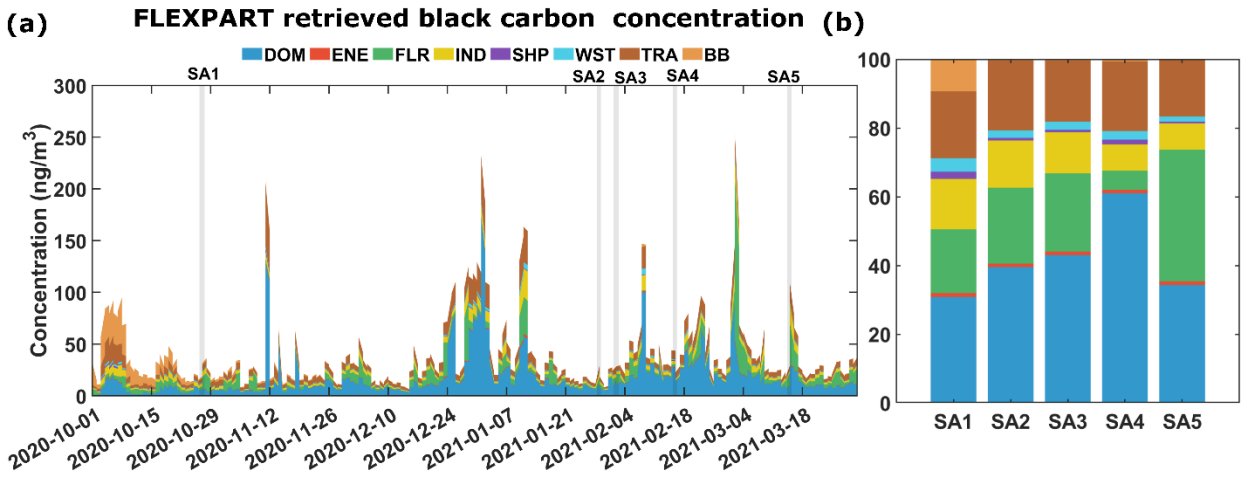

Figure S3. (a) Temporal variation of black carbon (BC) concentration (ng/m³) for ground-level aerosol samples (SA1–SA5) from October 2020 to March 2021. The BC source contributions are categorized as domestic emissions (**DOM**, blue), energy production (**ENE**, red), flaring (**FLR**, green), industrial activities (**IND**, yellow), shipping (**SHP**, purple), waste burning (**WST**, pink), transportation (**TRA**, brown), and biomass burning (**BB**, orange). Sampling events (SA1–SA5) are marked with grey bands.
(b) Relative contribution (%) of BC sources to total BC concentration for each sample (SA1–SA5), highlighting variability across different sampling periods.

Table S1. Summary of meteorological parameters during the sampling periods (SA1–SA5). Each value represents the mean ± standard deviation for air temperature (°C), relative humidity (%), wind speed (m/s) and precipitation (mm) within the specified intervals of sampling time.

Samples	Mean temperature (°C)	Mean RH (%)	Mean wind speed (m/s)	Mean precipitation (mm)
SA1	-4.1 ± 1.5	76.9 ± 9.3	0.9 ± 0.7	0.05 ± 0.19
SA2	-16.7 ± 0.9	56.7 ± 9.7	4.8 ± 2.9	0.00 ± 0.00
SA3	-8.6 ± 1.7	78.2 ± 6.5	5.8 ± 3.1	0.09 ± 0.20
SA4	-2.3 ± 2.2	79.3 ± 6.2	2.8 ± 1.5	0.00 ± 0.02
SA5	-19.4 ± 0.6	58.9 ± 8.0	3.0 ± 1.9	0.00 ± 0.00

Table S2. Summary of offline chemical analysis (CCSEM/EDX and STXM/NEXAFS) of the samples (SA1–SA5). Each value represents the number percentage ± standard deviation.

Offline chemical analysis	Type of analysis	Classes	SA1	SA2	SA3	SA4	SA5
CCSEM/EDX	Particle classes (# percentage)	Biogenic	3.9 ± 0.3	0.9 ± 0.1	0.0 ± 0.0	6.1 ± 0.6	12.8 ± 1.0
		Carbonaceous	11.2 ± 0.5	4.6 ± 0.3	18.7 ± 1.3	19.7 ± 1.0	13.3 ± 1.0
		Sulfate	5.3 ± 0.4	5.6 ± 0.3	32.1± 1.5	18.4 ± 0.9	1.7 ± 0.4
		Dust	0.8 ± 0.1	3.0 ± 0.3	1.2 ± 0.4	1.0 ± 0.2	1.7± 0.4
		Carbonaceous+Dust	0.2 ± 0.1	0.1 ± 0.0	0.3 ± 0.2	0.1 ± 0.1	0.0 ± 0.0
		Sulfate+Dust	0.1 ± 0.1	0.4± 0.1	0.4 ± 0.2	0.1 ± 0.1	0.0 ± 0.0
		Na-rich	70.3 ± 0.7	69.0 ± 0.7	22.9 ± 1.4	39.8 ± 1.2	66.2 ± 1.4
		Na-rich Sulfate	4.5 ± 0.3	8.3 ± 0.4	20.2 ± 1.3	5.2 ± 0.5	1.2 ± 0.3
		Other	3.8 ± 0.3	8.1 ± 0.4	4.2 ± 0.6	9.6 ± 0.7	3.1 ± 0.5
		In	2.2 ± 0.9	0.4 ± 0.4	3.3 ± 0.8	3.9 ± 0.9	0.0 ± 0.0
	Mixing state classes (# percentage)	OC	12.9 ± 2.0	16.1 ± 2.3	22.5 ± 1.8	12.0 ± 1.5	5.7 ± 1.1
		OCEC	4.1 ± 1.2	2.7 ± 1.0	4.8 ± 0.9	1.0 ± 0.5	0.7 ± 0.4
		OCIn	52.4 ± 3.0	73.6 ± 2.7	44.7 ± 2.2	77.1 ± 1.9	85.0 ± 1.7
		OCInEC	28.4 ± 2.7	7.3 ± 1.6	24.7 ± 1.9	6.0 ± 1.1	8.6 ± 1.4
		<20%	36.5 ± 2.9	8.4 ± 1.7	16.4 ± 1.6	33.2 ± 2.1	19.3 ± 1.9
		20-40%	17.0 ± 2.3	25.3 ± 2.7	43.0 ± 2.2	43.3 ± 2.2	31.4 ± 2.3
		40-60%	20.7 ± 2.5	30.7 ± 2.9	30.3 ± 2.0	18.1 ± 1.7	26.7 ± 2.2
		60-80%	12.5 ± 2.0	27.2 ± 2.8	9.2 ± 1.3	4.3 ± 0.9	16.2 ± 1.8
		80-100%	13.3 ± 2.1	8.4 ± 1.7	1.2 ± 0.5	1.0 ± 0.5	6.4 ± 1.2
STXM/NEXAFS	OVF classes (# percentage)	Overall OVF	0.4 ± 0.3	0.5 ± 0.2	0.4± 0.2	0.3 ± 0.2	0.4± 0.2

Table S3. Surface type influence and free tropospheric (FT) residence time for ground-level aerosol samples (SA1–SA5) over a 168-hour back-trajectory period obtained from Flexpart. Percentages represent the time spent over closed ice, open ice, open water, land, and within the free troposphere (FT), calculated using ERA5 reanalysis data and back-trajectory altitudes relative to the boundary layer.

Sample	Time over closed ice (168h)	Time over open ice (168h)	Time over open water (168h)	Time over land (168h)	Time in FT (168h)
	%	%	%	%	%
SA1	1.72	0.12	1.36	8.88	87.93
SA2	11.39	1.33	0.37	6.07	80.84
SA3	9.29	0.95	2.78	8.52	78.46
SA4	2.51	1.85	11.02	1.33	83.28
SA5	40.31	0.15	1.78	17.90	39.87

Table S4. Black carbon (BC) source contributions for ground-level aerosol samples (SA1–SA5). BC sources include domestic emissions (BC_DOM), energy production (BC_ENE), flaring (BC_FLR), industrial activities (BC_IND), shipping emissions (BC_SHP), waste burning (BC_WST), transportation (BC_TRA), and biomass burning (BC_BB). Percentages were derived using sea ice edge data from ERA5 reanalysis and back-trajectory altitude relative to the boundary layer.

Sample	BC_DOM	BC_ENE	BC_FLR	BC_IND	BC_SHP	BC_WST	BC_TRA	BC_BB
	%	%	%	%	%	%	%	%
SA1	30.86	1.10	18.56	14.66	2.09	3.95	19.44	9.34
SA2	39.54	1.00	22.08	13.74	0.78	2.17	20.36	0.33
SA3	43.03	1.03	22.78	11.92	0.71	2.41	17.77	0.36
SA4	61.02	0.99	5.58	7.64	1.39	2.51	20.24	0.63
SA5	34.26	1.12	38.35	7.67	0.51	1.44	16.50	0.14

Table S5. Ice nucleating particle (INP) concentrations for ground-level aerosol samples (SA1–SA5) under untreated and heat-treated conditions. INP concentrations (# of INP/L) were measured across temperatures ranging from –7.5°C to –25 °C to evaluate the effect of heat treatment n INP activity.

Temperature (°C)	SA1 (# of INP/L)	SA1_heat treated (# of INP/L)	SA2_ (# of INP/L)	SA2_heat treated (# of INP/L)	SA3 (# of INP/L)	SA3_heat treated (# of INP/L)	SA4 (# of INP/L)	SA4_heat treated (# of INP/L)	SA5 (# of INP/L)	SA5_heat treated (# of INP/L)
-7.500	-	-	-	-	0.001	-	-	-	-	-
-8.000	-	-	-	-	0.001	-	-	-	-	-
-8.500	-	-	-	-	0.001	-	-	-	-	-
-9.000	-	-	-	-	0.001	-	-	-	-	-
-9.500	-	-	-	-	0.001	-	-	-	-	-
-10.000	-	-	0.001	-	0.001	-	-	-	0.001	-
-10.500	-	-	0.001	-	0.001	-	-	-	0.001	-
-11.000	-	-	0.001	-	0.001	-	-	-	0.001	-
-11.500	-	-	0.001	-	0.002	-	-	-	0.001	-
-12.000	-	-	0.001	-	0.002	-	-	-	0.001	-
-12.500	-	-	0.001	-	0.002	-	-	-	0.001	-
-13.000	-	-	0.002	-	0.002	-	-	-	0.001	-
-13.500	0.001	0.001	0.002	-	0.002	-	-	-	0.002	-
-14.000	0.002	0.001	0.002	-	0.002	-	0.001	-	0.003	-
-14.500	0.002	0.001	0.002	-	0.003	-	0.001	-	0.003	-
-15.000	0.004	0.001	0.002	-	0.003	-	0.001	-	0.003	-
-15.500	0.004	0.001	0.002	-	0.003	-	0.001	-	0.003	-
-16.000	0.004	0.001	0.002	-	0.003	-	0.001	-	0.003	-
-16.500	0.005	0.001	0.003	-	0.003	-	0.001	-	0.003	-
-17.000	0.005	0.001	0.003	-	0.003	-	0.002	-	0.003	-
-17.500	0.006	0.001	0.005	-	0.003	-	0.002	-	0.003	-
-18.000	0.007	0.001	0.007	-	0.003	-	0.003	-	0.003	-
-18.500	0.008	0.001	0.007	-	0.006	-	0.003	-	0.005	-
-19.000	0.010	0.001	0.010	-	0.008	-	0.003	-	0.011	-
-19.500	0.011	0.002	0.011	0.001	0.011	0.001	0.003	-	0.013	0.001
-20.000	0.013	0.003	0.013	0.002	0.014	0.003	0.004	-	0.023	0.004
-20.500	0.017	0.003	0.018	0.005	0.017	0.005	0.004	-	0.034	0.012
-21.000	0.022	0.004	0.026	0.005	0.023	0.013	0.005	0.002	0.042	0.036
-21.500	0.029	0.006	0.039	0.010	0.031	0.021	0.010	0.003	0.052	0.080
-22.000	0.039	0.006	0.057	0.018	0.032	0.032	0.018	0.003	0.074	0.135
-22.500	0.048	0.012	0.077	0.023	0.039	0.059	0.029	0.004	0.087	0.183
-23.000	0.080	0.014	0.107	0.028	0.071	0.087	0.050	0.011	0.112	0.247
-23.500	0.117	0.019	0.151	0.036	0.094	0.107	0.091	0.014	0.135	0.247
-24.000	0.199	0.032	0.219	0.050	0.117	0.112	0.107	0.014	0.219	0.295
-24.500	0.295	0.042	0.295	0.098	0.171	0.142	0.129	0.021	0.247	-
-25.000	0.295	0.052	0.339	0.135	0.219	0.199	0.199	0.023	0.295	-