Supplement of Measurement report: Intercomparison of cloud spectrometers and a holographic probe during the ACTRIS sub-zero in-cloud Campaign at Sonnblick Observatory

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This Supplementary Material provides additional figures and supporting analysis for the instrument intercomparison presented in the main manuscript.

Inlet configurations tested during the campaign for the Fog Monitors.

Several alternative inlet configurations were tested during the campaign to mitigate ice accumulation and maintain continuous sampling under sub-zero conditions. These included modified polyethylene terephthalate (PET) bottle inlets with multiple openings, a bucket-type inlet attached to the standard horn inlet, and additional protective inlet designs used during periods of intense icing. These configurations were implemented to reduce riming, prevent blockage, and maintain sufficient airflow into the instruments. Visual documentation of the tested inlet configurations is provided below.

Figure S1. FM_CAS installation during the ECCINT-INT01 campaign, showing (left) swivel inlet, (middle) PET bottle inlet with four openings, and (right) bucket-type inlet.

Figure S2. Bucket-type inlet during operation with significant riming. Despite ice accumulation, airflow remained sufficient to allow continuous sampling.

Figure S3. Overview of alternative inlet configurations tested for the ETH FM-120 during the ECCINT-INT01 campaign.

These inlet modifications were implemented primarily to maintain continuous operation under icing conditions and were not specifically optimized for sampling efficiency. However, these configurations likely influenced sampling efficiency and should therefore be considered when interpreting the results.

Influence of wind speed and temperature on sampling efficiency of the Fog Monitors

To assess whether wind speed influenced sampling efficiency, the ratio of number concentration (N_c) measured by each instrument relative to ICEMET was examined as a function of wind speed. Across all instruments, no systematic dependence was observed during the campaign. The variability in N_c ratios remained consistent across the full range of wind speeds encountered during the campaign, indicating that wind speed was not a primary factor controlling sampling losses under the observed conditions.

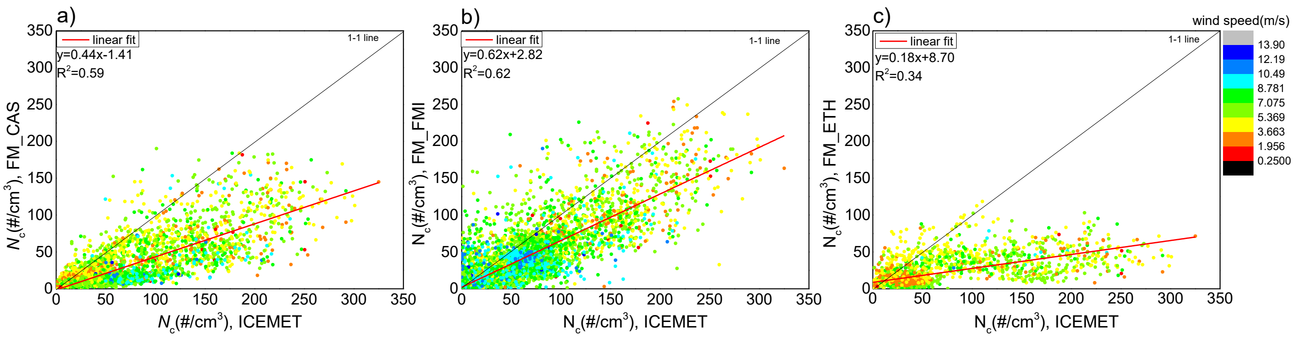

Figure S4. Comparison of 1-minute averaged number concentration (N_c) measured by (a) FM_CAS, (b) FM_FMI, (c) FM_ETH with respect to ICEMET over the whole campaign period. Data points are color-coded by wind speed (ms^{-1}). The black line indicates the 1:1 reference line, while the red line shows the linear regression fit.

The potential influence of ambient temperature on sampling efficiency was evaluated by comparing Nc ratios (instrument/ICEMET) across the observed temperature range. No clear relationship was identified between temperature and sampling efficiency. Sampling losses appeared largely independent of temperature within the range of −13 °C to −4 °C, suggesting that the observed discrepancies are primarily related to sampling configuration rather than thermodynamic conditions.

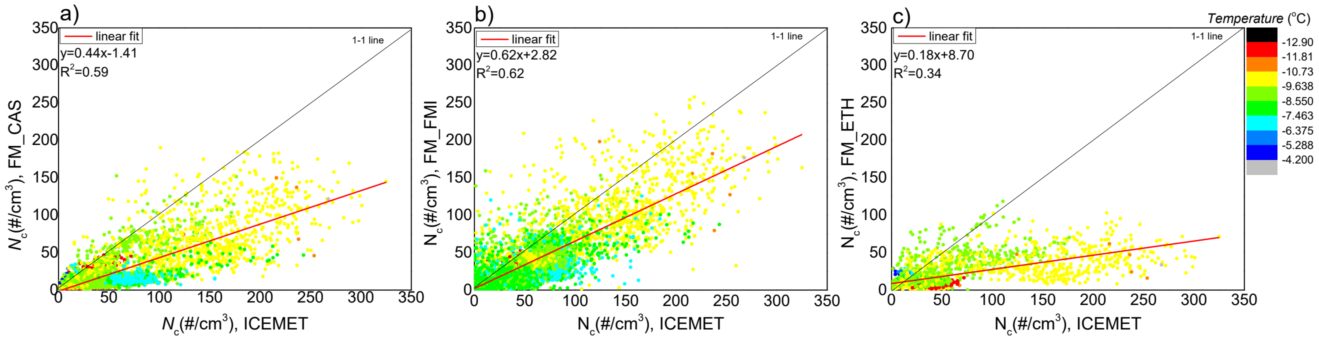

Figure S5. Comparison of 1-minute averaged number concentration (Nc) measured by (a) FM_CAS, (b) FM_FMI, (c) FM_ETH with respect to ICEMET over the whole campaign period. Data points are color-coded by temperature (°C). The black line indicates the 1:1 reference line, while the red line shows the linear regression fit.

Dependence of CDA performance on environmental conditions

To further evaluate the robustness of Cloud Droplet Analyzer (CDA) measurements, the dependence of derived parameters on wind speed and temperature was assessed. No systematic trends were observed for either parameter, confirming that sampling losses in CDAs are primarily governed by inlet geometry, sampling orientation, and droplet size rather than ambient environmental conditions.

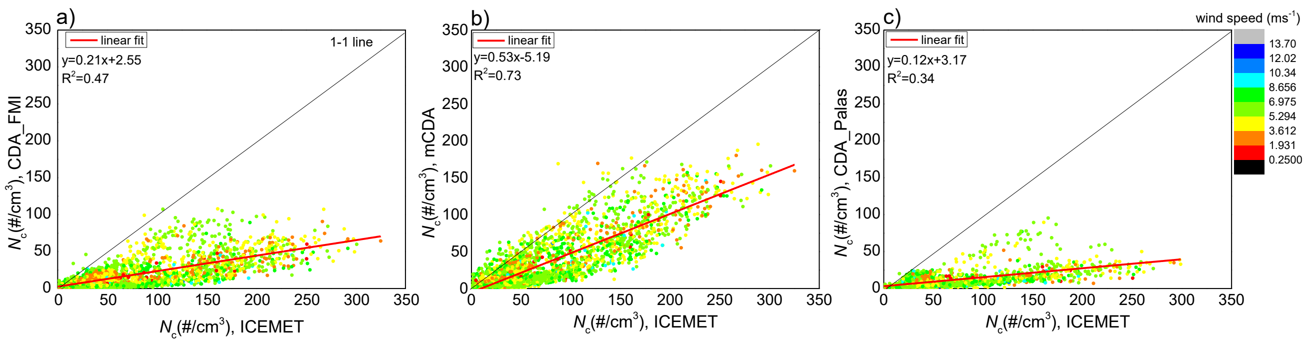

Figure S6. Comparison of number concentration (N_c) between ICEMET and (a) CDA_FMI, (b) mCDA, and (c) CDA_Palas. Points are color-coded by wind speed (ms^{-1}). The black line represents the 1:1 ratio; the red line shows the linear regression.

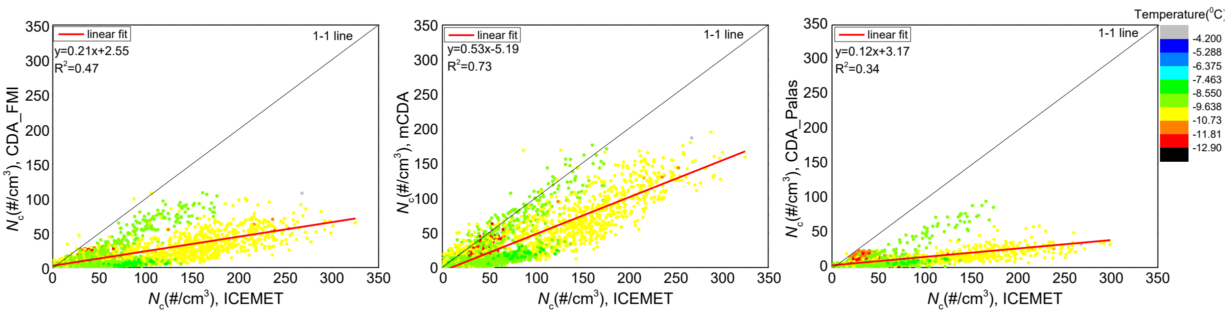

Figure S7. Comparison of number concentration (N_c) between ICEMET and (a) CDA_FMI, (b) mCDA, and (c) CDA_Palas. Points are color-coded by temperature (°C). The black line represents the 1:1 ratio; the red line shows the linear regression.

Effective diameter (ED) comparison

In addition to median volume diameter (MVD), the effective diameter (ED) was evaluated across all instruments. Similar to MVD, ED showed strong agreement between cloud spectrometers and ICEMET. The results confirm that derived sizing parameters remain robust despite sampling losses affecting number concentration.

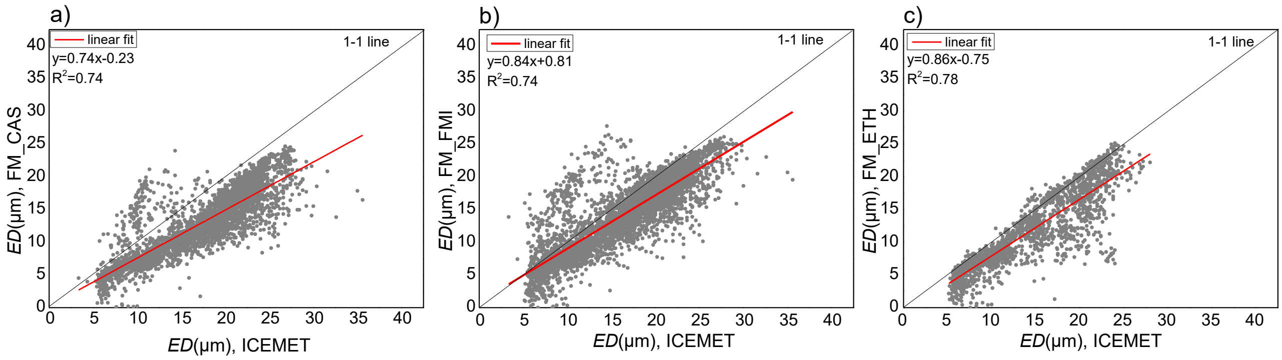

Figure S8. Comparison of 1-minute effective diameter (ED) measured by (a) FM_CAS, (b) FM_FMI, (c) FM_ETH with respect to ICEMET over the whole campaign period. The black line shows the 1:1 reference; the red line shows the linear regression fit.

Case study: Impact of horizontal inlet orientation.

As previously discussed, the optimal orientation of the fog monitor inlets is horizontal and facing the wind. As only FM_FMI follows this recommendation, a case study from 28 November 2022 is presented here to show the impact of horizontal inlet orientation under favourable conditions. During this event, the wind averaged 5.5 m/s and temperatures remained around –9.5 °C. Predominantly, the wind direction was westward during the sampling period, favouring the FM_FMI sampling from 220°. Under these conditions, FM_FMI had strong agreement with ICEMET across most parameters. MVD and ED showed strong agreement across all the instruments with a correlation coefficient near 0.9, confirming the robustness of sizing measurements. In contrast, N_c showed clear differences. Vertically sampling FM_CAS and FM_ETH recorded systematically lower concentrations, particularly during periods of larger droplet sizes. The concentration ratio between FM_CAS, FM_ETH, FM_FMI and ICEMET reached up to a factor of 5. Significant discrepancies were observed in LWC values, with FM_FMI showing closer alignment with ICEMET than the vertically sampling FMs. Between 22:00 and 22:30, FM_FMI and ICEMET track one another most closely in N_c and LWC, corresponding to a stable wind direction at about 240°. This case highlights that wind alignment is a key factor in improving fog monitor performance, particularly for N_c and LWC, and supports earlier findings that horizontal sampling reduces underestimation of larger droplets.

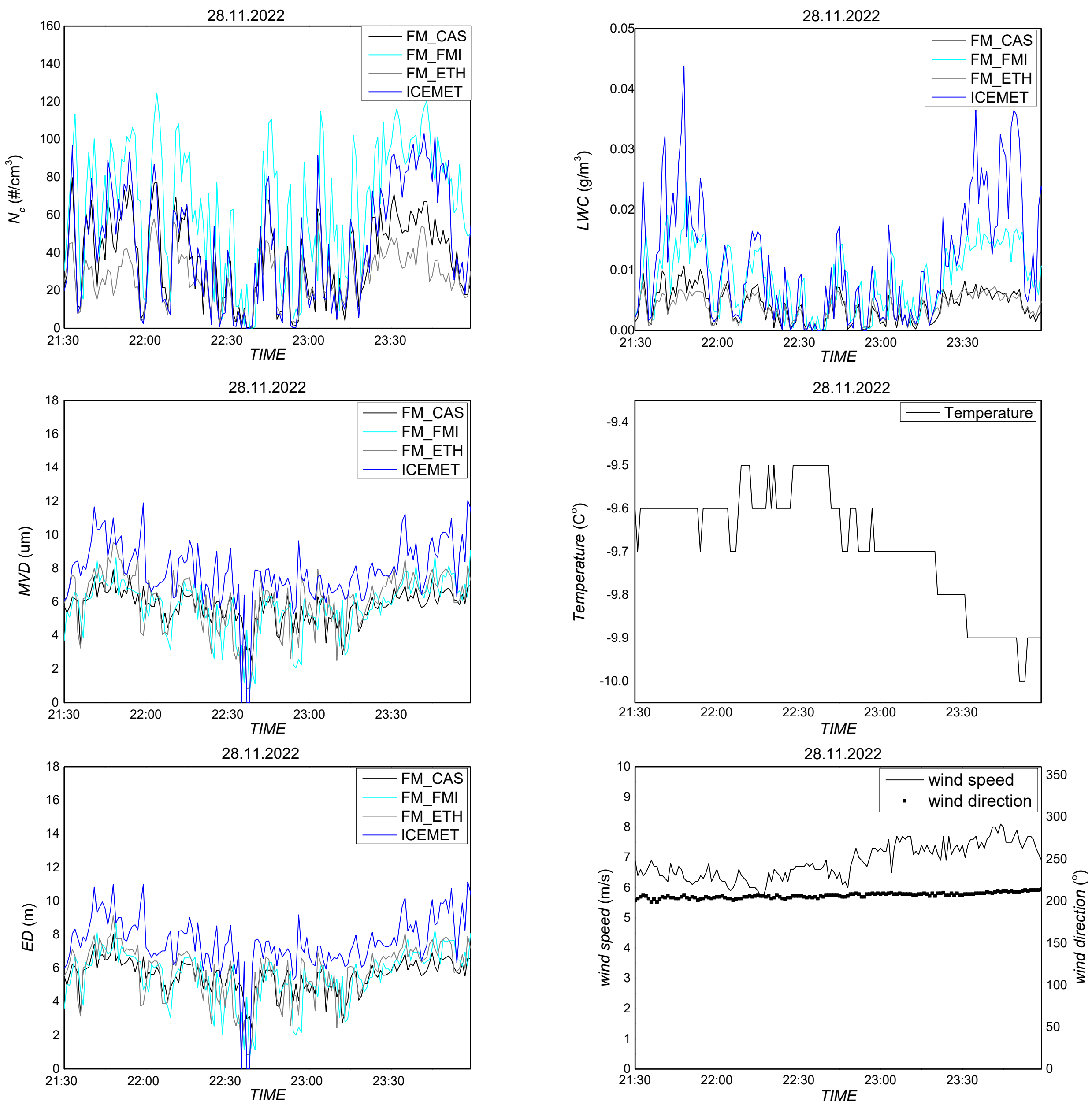

Figure S9. Time series of cloud microphysical parameters measured on 28 November 2022. Panels show (top left) number concentration (Nc), (top right) liquid water content (LWC), (middle left) median volume diameter (MVD), (bottom left) effective diameter (ED), (middle right) temperature, and (bottom right) wind speed and wind direction. FM_FMI (horizontal inlet) shows improved agreement with ICEMET compared to vertically sampling FM_CAS and FM_ETH, particularly for Nc and LWC.