



Supplement of

A long-term study of cloud residuals from low-level Arctic clouds

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Figure S1. Wind conditions during cloud sampling at Zeppelin Observatory. a–b show monthly averages (upper panels) and histograms (lower panels) of horizontal wind speed and updraft, respectively. For the upper panels in **a–b**, solid and dotted lines show median and mean values, respectively, and shaded areas indicate the 25th to 75th percentile ranges. **c** shows a histogram of the wind direction. In all panels, data are only from cloud sampling periods.



Figure S2. Comparison of particle number size distributions from DMPS 1 and DMPS 2a–b during non-cloud periods. a Particle number size distributions measured with DMPS 1 (blue) and DMPS 2a–b (orange) when measuring on the same inlet. **b** Absolute difference between hourly average particle number size distributions (DMPS 1 minus DMPS 2a–b). For panels **a–b**, solid and dotted lines show median and mean values, respectively, and shaded areas indicate the 25th to 75th percentile ranges. Panels **c–d** show scatter plots of hourly average integrated particle number concentrations (integrated above 10 nm and 15 nm particle diameter, respectively) from the DMPS systems, colour coded by month of the year. Red lines show orthogonal distance linear regressions, and black dashed lines indicate the 1:1 relation.



Figure S3. Comparison of different numbers of clusters in *k*-means. Normalised (left) and non-normalised (right) cloud residual number size distributions resulting from *k*-means clustering using a-b 2 clusters, c-d 3 clusters, e-f 4 clusters, g-h 5 clusters, i-j 6 clusters. Solid and dotted lines show median and mean values, respectively, and shaded areas indicate the 25^{th} to 75^{th} percentile ranges.



Figure S4. Transmission efficiency of the GCVI inlet and cloud particle size distributions. Left y-axis: The squares show the experimentally determined transmission efficiency of the GCVI from Shingler *et al.* (2012) (for the tubing prior to the expansion segment). The grey curve shows the transmission efficiency extrapolated to cover the fog monitor particle size range. Right y-axis: Cloud particle number size distribution (CPSD) during the sampling period shown in red. Solid and dotted lines show median and mean values, respectively, and the shaded area indicates the 25th to 75th percentile range (inter-quartile range, IQR). The grey shaded region covers the part of the size distribution that is smaller than the GCVI cut size, and hence is not measured by the instrument.



Figure S5. Comparison of measured and calculated visibility. a 2D histogram of visibility as measured by the GCVI visibility sensor (y-axis) versus visibility calculated from the cloud particle size distributions measured by the FM-120 fog monitor (x-axis). **b** Same as a, but colourcoded by temperature instead of data point density. Visibility was calculated assuming spherical particles, a refractive index of 1.33, and a wavelength of 880 nm of the visibility sensor.



Figure S6. Heatmaps of wind parameters for different cloud residual and cloud particle concentrations. The figure shows heatmaps where cloud residual and cloud particle number concentrations have been cross tabulated with **a** wind speed **b** updraft and **c** wind direction (rounded to the nearest 10 degrees). Note that the pixels do not contain the same number of data points, please refer to Figure 2b in the main manuscript for the corresponding density plot.



Figure S7. Comparison of cloud residual number concentrations and cloud particle concentrations for different wind directions. Density scatter plots of cloud residual versus cloud particle number concentrations, including an orthogonal distance linear regression with coefficient of determination (grey line), for different wind directions, δ . a southerly winds (90° < $\delta \le 270°$), b northerly winds(-90° < $\delta \le 90°$) The black dashed line represents the 1:1 line and the dotted lines represent 10:1 and 1:10 lines. The transmission efficiency of the GCVI inlet (Shingler et al., 2012) has been included in the calculation of the cloud particle number concentration in all panels.



Figure S8. $D_{50\%}$ dependence on updraft. a Ratio of mean size distributions, i.e. cloud residual concentrations divided by total particle concentrations. The coloured ratio curves have been normalised to 1 at 200 nm. The grey dotted curves represent the position of the non-normalised ratio curves (Fig. 5 in main manuscript). b Interpolated $D_{50\%}$ for each updraft interval (i.e. the diameter at which the ratio in **a** is 0.5). The "error bars" represent the width of the diameter bin within which each interpolated value falls.



Figure S9. Monthly average cloud residual number size distributions. Data have been segregated based on temperature, T. The columns show data for **a** all T, **b** $T > -4^{\circ}$ C, **c** $T \leq -4^{\circ}$ C. Solid and dotted lines show median and mean values, respectively, and shaded areas indicate the 25th to 75th percentile ranges. The numbers in the upper right corner of each panel indicates the 25th to 75th percentile ranges of the integrated cloud residual number concentrations (and cloud particle number concentrations in parentheses). The grey numbers below indicate the number of data points we have per month.



Figure S10. Comparison of cloud residual number concentrations and cloud particle concentrations for the clusters in Fig. 2 in the main manuscript. Density scatter plots of cloud residual versus cloud particle number concentrations, including an orthogonal distance linear regression with coefficient of determination (grey line), for each cluster. The black dashed line represents the 1:1 line and the dotted lines represent 10:1 and 1:10 lines. The text in the lower right corner indicates the percentage of data where the two concentrations are within a factor of 2, 5, and 10 from each other (i.e. the amount of data between, e.g., the 10:1 and 1:10 lines etc.). Panels **a–e** show the data for clusters 1–5, respectively. The transmission efficiency of the GCVI inlet (Shingler et al., 2012) has been included in the calculation of the cloud particle number concentration in all panels.



Figure S11. Cloud radar target classification for the clusters from Figure 8 in the main manuscript. Relative frequency of occurrence of different Cloudnet airmass classes (0–10, see legend). Panels **a–e** show the classifications for clusters 1–5, respectively.



Figure S12. Dependence of activated fraction on ambient air temperature. The activated fraction is here defined as the ratio of cloud residual and total particle concentrations integrated above 100 nm diameter (as in Fig. 7 in Verheggen et al., 2007). The ratios are based on 30 min average concentrations. Solid and dotted lines show median and mean values, respectively, and shaded areas indicate the 25th to 75th percentile ranges.



Figure S13. Results of *k*-means clustering of cloud residual number size distributions (data with concentrations within a factor of **10 from cloud particle concentrations**) using 6 clusters. a Normalised cloud residual number size distributions for each cluster (left), and normalised number size distributions for the corresponding cloud particle population (right). Solid and dotted lines show median and mean values, respectively, and shaded areas indicate the 25th to 75th percentile ranges. **b** Monthly frequency of occurrence of each cluster. The cluster analysis in this figure uses only the data where the cloud residual and cloud particle concentrations are within a factor of 10 from each other (i.e. between dotted lines in Fig. 2 in main manuscript).

Table S1. Hours of concurrent data from different instruments. Table showing the amount of simultaneous data, rounded to the nearest hour, for different combinations of instruments. The data are divided into cloudy (i.e. GCVI on and visibility < 1 km) and clear (i.e. GCVI off and visibility > 1 km). Data combinations that are not available or not used within our analysis are marked with dashes.

	cloudy (h)	clear (h)	Relevant for
DMPS 1	1 729	_	_
DMPS 2a–b	1 339	8 000	_
DMPS 1 & FM-120	1 700	-	Figs. 2a-b,8,9c-d,Fig. S3,S4, S5,S10,S13*
DMPS 1 & uSonic & FM-120	1 603	-	Figs. 2c,3,9a-b+f,S1,S6,S7,S9
DMPS 1 & FM-120 & Cloudnet	490	-	Figs. 10, S11
DMPS 1 & DMPS 2a-b	1 1 3 6	3 684	Figs. S2
DMPS 1 & DMPS 2b & uSonic	1 086	-	Figs. 4
DMPS 1 & DMPS 2b & FM-120 & uSonic	1 086	-	Figs. 7,S12
DMPS 1 & DMPS 2a-b & FM-120	1111	-	Figs. 9e,11
DMPS 1 & DMPS 2a-b & FM-120 & uSonic	1 029	_	Figs. 5,6,S8

References

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