

# Acidity of Cloud Droplets as a Function of Droplet Size

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## ABSTRACT

Research was conducted at Storm Peak Laboratory in Steamboat Springs, Colorado on 1 April 2010 investigating the relationship between cloud droplet size distribution and sulfate aerosols. Three cloud sieves with differing grid spacing and cylindrical diameter of material were used to capture super cooled water droplets. Further data was taken with the Droplet Measurement Technologies (DMT) Scattering Spectrometer Probe (SSP)-100 to measure cloud properties such as liquid water content and the density of cloud droplets. This was compared with measurements of the pH from each rime sample. The results were largely inconclusive. There was a direct correlation between collection time and the density of the cloud. Extended collection time increased the probability that on average, each sieve collected a similar size range of droplets explaining why no real trend in pH values can be seen when comparing the three sieves. Using only the data from the DMT SSP-100 a trend of more acidic pH values corresponding to smaller mean volume diameters could be seen in the experiments that had low average liquid water content. No definite trends could be seen in the experiments with high average liquid water contents.

## Introduction

Aerosols from anthropogenic sources are known to have adverse effect on human health, interfere with the radiation budget of the Earth, and suppress precipitation in shallow clouds with warmer cloud tops. The indirect aerosol effect revolves around the premise that small pollution aerosols can act as cloud condensation nuclei (CCN). More CCN means smaller cloud droplets which in turn play a role in the lifetime of the cloud and the possibility of it forming precipitation. This is enhanced in shallow orographic clouds. A study by Borys (2003) found that the addition of  $1\mu\text{g m}^{-3}$  of anthropogenic sulfate aerosols can reduce orographic snow fall rates in the Rocky Mountains by as much as 50% (Givati 2004).

Exploration of the relationship between cloud droplet size distribution and

aerosol presence as CCN in orographic clouds was motivation for this research. According to Hindman et al. (1992) size-segregated collection of cloud droplets is necessary because the chemical composition of droplets can vary as a function of droplet size. It was found by Munger et al (1989) that the larger aerosol particles, such as  $\text{Na}^+$ ,  $\text{Ca}_2^+$  and  $\text{Mg}_2^+$ , had higher concentrations in larger droplets. Smaller aerosols, such as  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$  and  $\text{NH}_4^+$ , had higher concentrations in smaller droplets (Hindman 1992). There are currently 33-coal fired power plants in operation in Colorado. Even with laws regulating the amount of sulfate emissions by these coal plants, much of the fine air mass over Steamboat Springs contains significant presence of sulfate aerosols (Goldberg 2010).

This research was focused on capturing super cooled water droplets as a function of size by collecting rime using three different sized cloud sieves. Measurements of the pH of each sample were also taken for comparison. It was hypothesized that because the aerosols act as cloud condensation nuclei the concentration of sulfate would remain constant for each droplet and become more diluted, thus making the droplet less acidic, as the droplet size increased.

## Methods

The research for this paper was conducted on 1 April 2010 at Storm Peak Laboratory in Steamboat Springs, Colorado. From 31 March 2010 to 1 April 2010 there was fairly steady northwesterly wind flow regime which is favorable for snow in the Park Range Mountains. Storm Peak Lab was

in and out of cloud for the entire day on 1 April 2010. When in cloud, the cloud sieves were placed on the roof. When the smallest sieve seemed to be too rimed to collect any more super cooled cloud droplets, all sieves were taken down. 7 experiments were conducted throughout the course of the day.

Cloud sieves can be used to capture super cooled cloud droplets. Cloud droplets are collected on sieves through the principle of inertial impaction (Hindman 1992). Instead of capturing droplets by allowing them to become wedged in the mesh of the cloud sieve, the cloud droplets freeze on the mesh upon impaction. The cylinder diameter of the material used to make the grid ultimately determines the sizes of the cloud droplets that will be collected. With smaller cylinder diameters, smaller particles can be collected through impaction. As the cylinder diameter is increased the smaller droplets

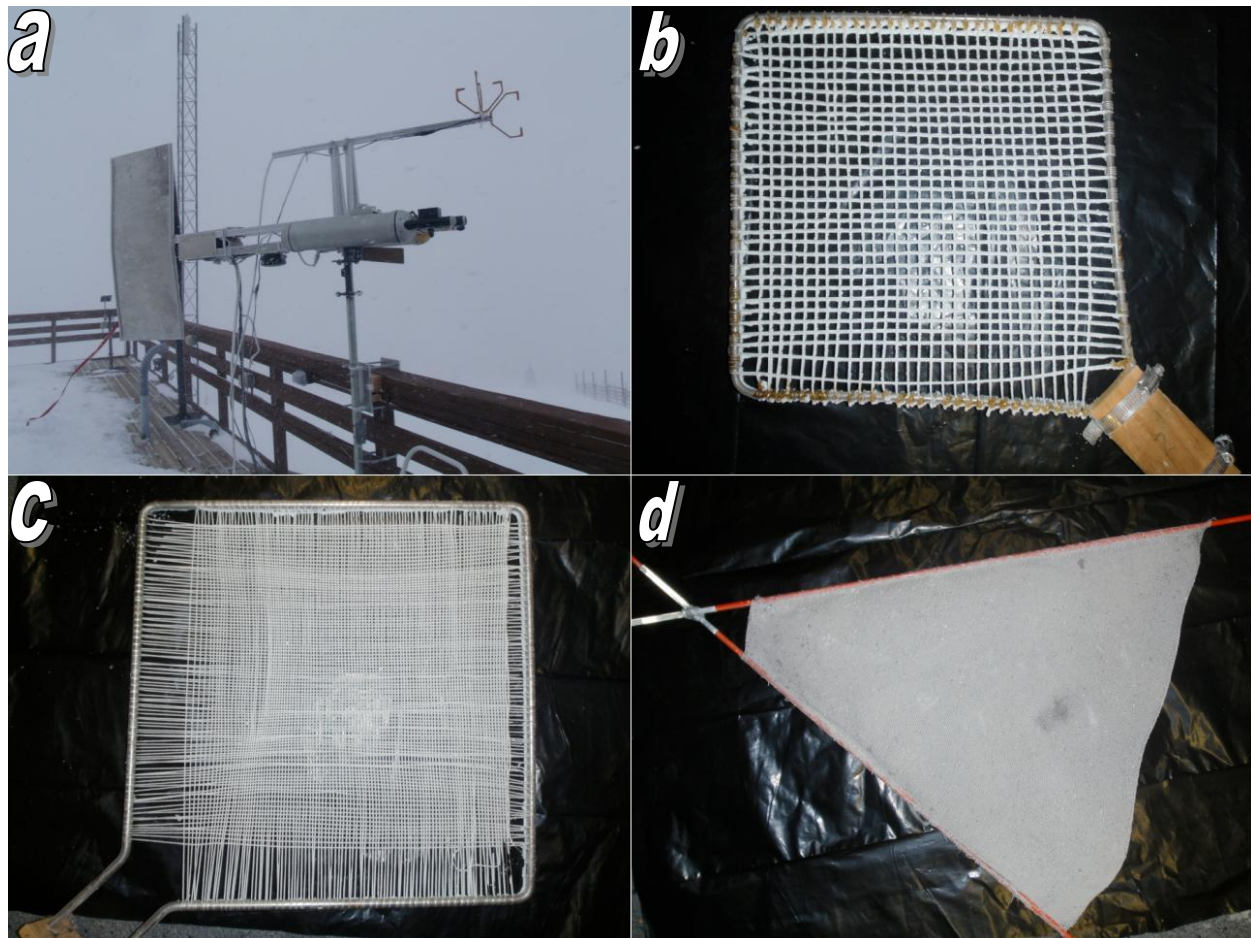


Figure 1 – a. Picture of the DMT SSP-100. b. Picture of the cloud sieve with large grid spacing. c. Picture of the medium cloud sieve used in experiments. d. Picture of the small cloud sieve that was specifically designed for this experiment.

flow around the mesh instead of freezing on the mesh. Three separate sieves were used for the collection of super cooled cloud droplets in this experiment. For each sieve the grid spacing and the thickness of the material differed. Figure 1 shows images of the three sieves. The first two, Figures 1B and 1C, are both made out of nylon and the third, Figure 1D, was made out of anodized aluminum. The first sieve, Figure 1B, had the largest grid spacing and the largest cylindrical diameter. According to Hindman et al. (1992) for a 3.84 mm cylindrical diameter, the smallest droplets that can be collected with 50% efficiency would be 10  $\mu\text{m}$  in size. There were not instruments at the lab precise enough to measure cylindrical diameter but by estimation, the large sieve had a diameter of a few millimeters. The second sieve, shown in Figure 1C, had smaller grid spacing and was made out of a finer material

and the last sieve had the smallest grid spacing and was made out of a slightly finer material than the medium sieve. The medium and small sieve should be able to capture smaller droplets than 10  $\mu\text{m}$  with 50% efficiency or greater.

Data was also collected using the Droplet Measurement Technologies (DMT) Scattering Spectrometer Probe (SSP)-100. This instrument measures droplet sizes on the range of 3-57  $\mu\text{m}$ . The instrument is shown in Figure 1A. Data was used to get a better idea of the properties of the cloud, including when the lab was in and out of cloud, the liquid water content of the cloud, and average size of the droplets. Data is continuously recorded while in cloud. Measurements from the cloud sieves were compared to the pH value from each sample and the data collected with the DTM SSP-100.

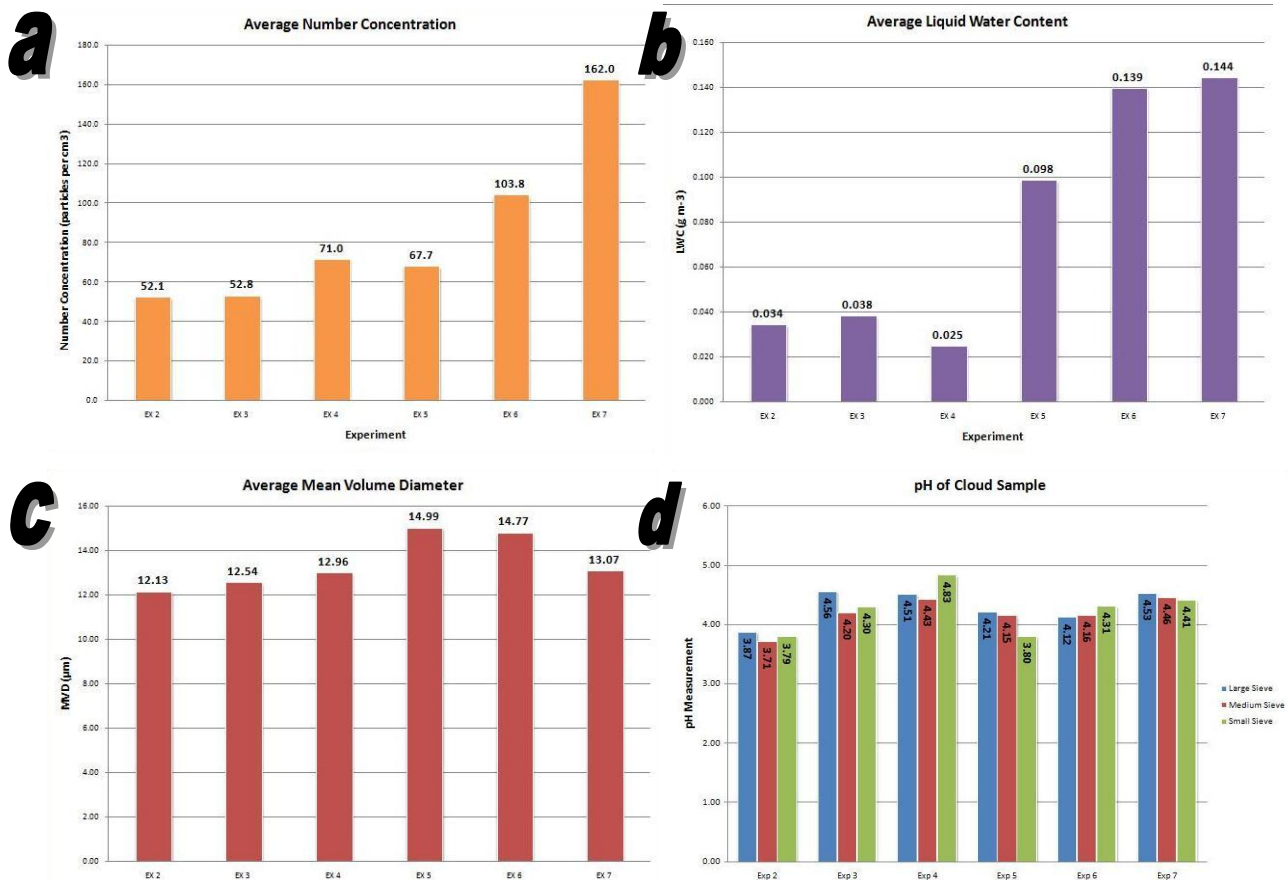


Figure 2 – a. Graph of the average number concentration of particles in the cloud during each experiment. b. Graph of the average liquid water content in the cloud during each experiment. c. Graph of average mean volume diameter for each experiment. d. Graph comparing the pH values measured from rime collected by each sieve in each experiment. Blue shows the small cloud sieve, red shows the medium sieve and green shows the measurements from the large sieve.

## Results

A series of 7 experiments were conducted on 1 April 2010. Data from Experiment 1 was not analyzed for this paper due to the loss of data from the DTM SSP-100. Figure 2A shows a graph of the average number concentration of cloud particles per  $\text{cm}^2$  for each experiment. This gives a proxy for the thickness of the cloud, as well as the average liquid water content (LWC) which is shown in Figure 2B. It can be seen from these two graphs that the density of the cloud increased throughout the day. Much less time was needed for the sieves to rime when the cloud was denser with a higher LWC. Figure 2C shows the average mean volume diameter (MVD) of the cloud droplets. The range of droplet sizes should have been favorable for catching different sized droplets for each cloud sieve seeing that the MVD is not too much over  $10\ \mu\text{m}$ , which is the estimated size of droplets that the large sieve should be able to capture with 50% efficiency. The values of MVD also do not vary significantly throughout the course of the day. Figure 2D shows the measurements of pH taken for each experiment. The medium and large sieve did not need any extra calibration seeing that nylon is a non-conductive and non-reactive material. The measurements of samples taken from the small sieve were calibrated by subtracting the average difference between averaged

measurements from each material. Figure 3A shows the amount of time the sieves were on the roof for each experiment. The capture time decreased significantly as the density of the cloud increased. The flux of rime for each sieve was calculated and is shown in Figure 3B. The amount of liquid collected was measured in grams. This value was divided by the collection area and the capture time. The flux of rime in Figure 3B is given in units of  $\text{g cm}^{-2} \text{min}^{-1}$ . There is a definite trend that can be seen in the Experiments 2 through 6. The smaller sieve collected much less rime on average than the medium and large sized sieves. The seventh experiment seems to be highly anomalous at a first glance because this trend is reversed.

## Discussion

The results from this experiment are fairly inconclusive. There was a direct correlation that can be seen between the density of the cloud and the time that it took for the cloud sieves to completely rime up. Figure 3B also showed that the flux of rime was much greater when the density of the cloud was greater. The medium and large cloud sieve had very similar fluxes of rime for all experiments, as also seen in Figure 3B. The results from Experiment 7 are anomalous in comparison to the prior five experiments.

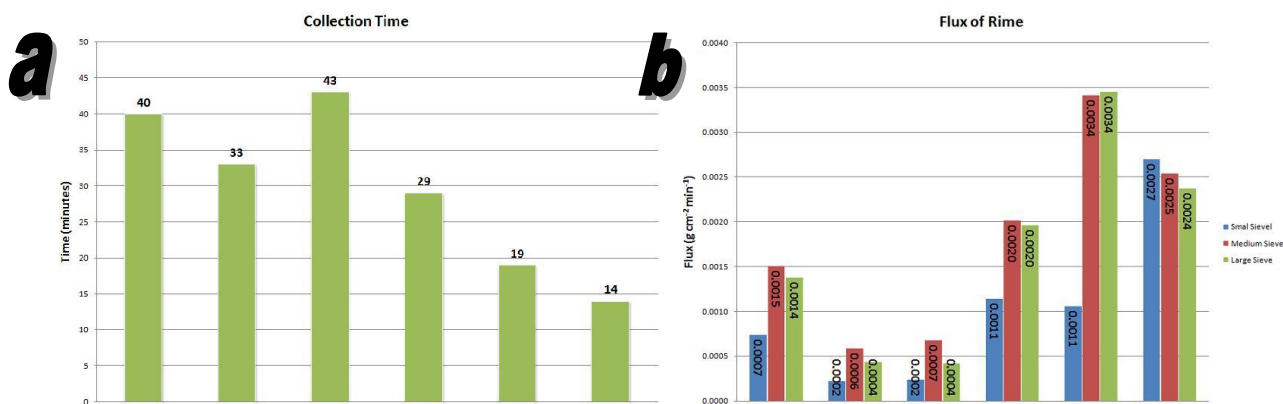


Figure 3 – a. Graph of the collection time for each experiment. b. Flux of rime through each cloud sieve for each experiment. Blue shows measurements from the small cloud sieve, red shows the medium sieve and green shows the measurements from the large sieve.

When comparing this to the collection time from Figure 3A, it seems that the collection time may have interfered with the results of this experiment. The cylindrical diameter of the material used to make the cloud sieves determines the particle sizes that are collected. As droplets rime onto the strands of the cloud sieve, the cylindrical diameter increases altering the droplet sizes that are able to be collected. The cloud sieves were left on the roof for significant periods of time to ensure that there would be enough liquid water collected to test the pH. By doing this, it is possible that on average, each sieve collected a similar size range of droplets explaining why no real trend in pH values can be seen when comparing the three sieves. It was hypothesized that the pH from the small cloud sieve would be more acidic as a result of smaller droplets being collected.

It can also be seen in Figure 3B that the flux of rime through the medium and large sieves was much greater than the small sieve for all experiments besides Experiment 7. It is hypothesized that the reasoning for this is a result of the grid spacing. With greater grid spacing, the cylindrical diameters of the material plus the rime were able to grow much larger and the flow of particles through the mesh was still not inhibited. With the smaller grid spacing, the strands seemed to rime initially and as the grid became more filled with rime, the air was not able to flow through the grid as well and droplets most likely started to become wedged in the mesh. Seeing that the grid spacing was much smaller and there were more strands of the material, thus more area for the droplets to impact on, it likely should have had a higher flux of rime despite the tendency for smaller droplets to be able to impact on it. This held true for the last experiment when the time that the sieves were left on the roof was reduced.

When investigating the initial hypothesis considering only data collected from the DTM SSP-100, some basic correlations can be made. The overall pH in the cloud droplets collected seems to be a function of both the MVD, which gives a reference for average droplet size, and the total liquid water content in the cloud. Figure 2B shows that the average liquid water content for Experiments 2-4 was low; whereas, for Experiments 5-7 it was much higher. When comparing the values in Figure 2C with those in Figure 2D it can be seen that for the experiments with a low average liquid water content the pH values seemed to increase as a function of MVD, as expected. A trend of smaller MVDs corresponding to more acidic pH values can be seen in Experiments 2-4. This does not hold true for the three Experiments with higher liquid water contents. The liquid water content in the cloud seems to have an influence on the cloud acidity on the same order of magnitude as the average mean volume diameter of the droplets. There were not enough experiments in total to make any strong correlations and overall the results seem to be inconclusive.

## Conclusion

It was hypothesized that because the aerosols act as cloud condensation nuclei the concentration of sulfate would remain constant for each droplet and become more diluted, thus making the droplet less acidic, as the droplet size increased. Three cloud sieves with different grid spacings and varying cylindrical diameters were used to collect different sized cloud droplets. The pH value of every sample of rime was then taken for comparison. Correlations were seen between the density of the cloud and the time it took for each sieve to become completely rimed. The cloud sieves were left on the roof for significant periods of time to ensure that there would be enough liquid

water collected to test the pH. As droplets rimed onto the strands of the cloud sieve, the cylindrical diameter of the strands increased altering the droplet sizes that were collected. By doing this, it is possible that on average each sieve collected a similar size range of droplets explaining why no real trend in pH values could be seen when comparing the data from the three sieves.

When investigating the initial hypothesis considering only data collected from the DTM SSP-100 a trend of more acidic pH values corresponding to smaller mean volume diameters could be seen in the experiments that had low average liquid water content. No definite trends could be seen in the experiments with high average liquid water contents. Overall, the results of the experiment were largely inconclusive. There was only one day that conditions were good enough to collect data and therefore there was only a small pool of data to analyze. Better results would likely be found if the capture time allowed for each sieve were to be drastically reduced and a higher variability and quantity of samples would be taken to be analyzed.

### Acknowledgements

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### References

Borys, R. D., Lowenthal, D. H., Cohn, S. A., and Brown, W. O. J., 2003: Mountaintop and radar measurements of anthropogenic aerosol effects on snow growth and snowfall rate, *Geophys. Res. Lett.* (retrieved from scholar.google.com).

Goldberg, J., 2010: Acid Concentration of Cloud Mass in Relation to Size Distribution and Origin in Steamboat Springs, Colorado

Givati, A., and D. Rosenfeld, 2004: Quantifying precipitation suppression due to air pollution. *J. Appl. Meteor.*, **43**, 1038–1056.

Hindman, E.E., Carter, E.J., Borys, R.D. and Mitchell, D.L., 1992. Collecting supercooled droplets as a function of droplet size. *Journal of Atmospheric and Oceanic Technology* **9**, pp. 337–353.

Kaufman, Y. J., D. Tanre, and O. Boucher, A satellite view of aerosols in the climate system, *Nature*, 419, 215– 223, 2002.