Aerosol Concentration Variability at Storm Peak Laboratory

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Abstract

A study was done at Storm Peak Laboratory (SPL) in Steamboat Springs, Colorado investigating the variability in aerosol concentration. A comparison was made with temperature, relative humidity, wind speed, and wind direction to find a relationship with the concentrations. The Scanning Mobility Particle Sizer (SMPS) was used between the days of March 29, 2010 and April 2, 2010 to retrieve the aerosol data while the SPL's online weather database was used to retrieve the weather information. It was found that while there were no obvious correlations between the aforementioned variables and aerosol concentration, there were other factors such as controlled fires and cloud cover that affected the concentrations.

Introduction

Aerosols are tiny solid and liquid particles that are suspended in the air that can range in size from a few nanometers to a thousand micrometers. They can be created naturally from dust storms, volcanoes, sea spray, and fire, or can be created anthropogenically by processes such as fossil fuel burning and deforestation (Fig. 1).

There are two methods for aerosols to be introduced into the atmosphere. Primary aerosols are directly injected by processes such as forest fires and dust storms. Secondary aerosols are produced by atmospheric gases reacting and condensing or by gas to particle conversion (Dorsey, 1999). The three general categories of aerosols are nucleation mode, accumulation mode, and coarse particle mode. Nucleation mode aerosols are smaller than 100 nanometers and are mostly created by gas to particle conversion. These size aerosols tend to last in the atmosphere much longer because they are so small that gravity cannot influence them as much. Accumulation mode aerosols are between 0.1 and 1 micrometer and are produced by the coagulation of smaller particles or by the heterogeneous condensation of gas vapor onto existing aerosol particles (NSDL, 2010). One important characteristic of accumulation mode aerosol is their tendency to become cloud condensation nuclei (CCN). CCN generally scavenge much of the aerosols between 0.1 and 1 micrometer. Coarse

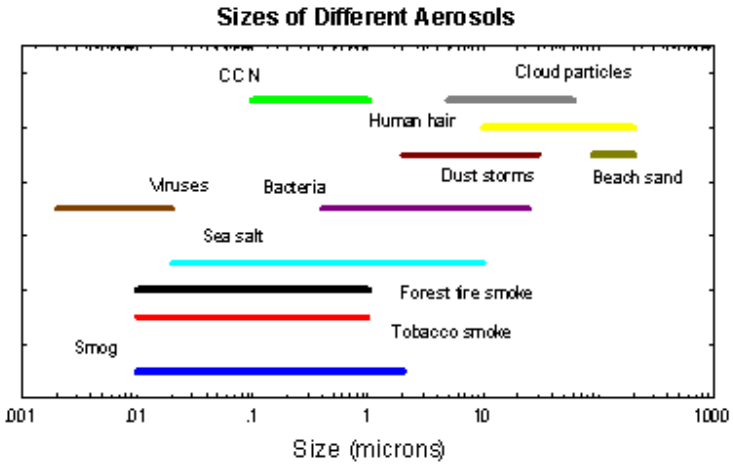


Figure 1: Plot showing sizes of aerosols from different sources (NSDL, 2010).

particle mode aerosols are greater than 1 micrometer and are either directly injected into the atmosphere or have grown from coagulation of smaller particles.

This experiment was conducted in order to find relationships between temperature, relative humidity, wind speed, and wind direction with aerosol concentration. A correlation between the variables and the different size ranges of aerosols was also looked for. There have been numerous studies investigating the relationship between aerosol sizes and their concentrations with different atmospheric variables at different locations around the world. It was found that over central Alaska, cold air masses contain relatively few, coarse aerosols while warm air masses' mean aerosol size is small (Shaw, 1988). When investigating aerosol variability with the Southeast Monsoon, it was found that the variation of aerosols during the winter season is in phase with relative humidity while it is out of phase with temperature (Singh, 2000).

While these and other studies have found fairly clear results correlating the aerosol concentrations with different atmospheric variables, there doesn't seem to be an obvious pattern between the different studies. It seems to be more dependent upon the location of the experiment site (eg. mountains vs. tropical) and the seasonality of when the data was collected. For these reasons, it was hypothesized that a relationship would be found that would be specific to the high elevation site of Storm Peak Lab.

Methods

The Scanning Mobility Particle Sizer (SMPS) uses a Differential Mobility Analyzer (DMA) (Fig. 2) to differentiate particle sizes according to their electrical mobility. The electrical mobility of a particle is a measure of a particle's ability to move through an electric field. This is because a particle in an electric field with an electrical charge experiences an electrical force causing it to move and reach a terminal velocity (TSI, 2003). The resulting drag force is then related to the electrical force to determine the electrical mobility of the particle with different sized particles having different electrical mobilities (TSI, 2003).

In the DMA, air with polydisperse aerosols enters one side while sheath flow, which is particle free, enters on the other side of the DMA. A central rod in the DMA is negatively charged while the outer wall of the DMA is grounded creating an electrical field (Longley, 2003). Positively charged particles in the polydisperse flow are attracted to the central rod at a rate determined by their electrical mobility. The sheath flow helps separate the particles that have the correct charge from the rest of the particles so that there is no mixing. Particles with a higher electrical mobility are attracted to the

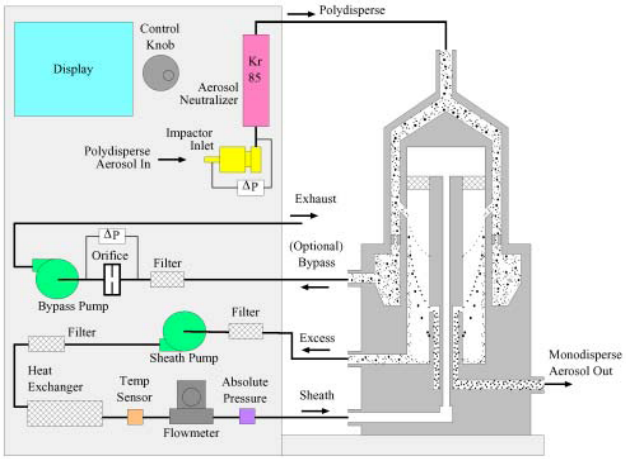


Figure 2: Schematic showing the inside of the DMA (TSI, 2003).

negative charge sooner and particles with a lower electrical mobility are attracted to the negative charge later while particles with the correct electrical mobility are attracted to the negative charge at the correct rate so that they enter a little slit. The monodisperse air that flows through the slit passes by a sensor that measures the concentration of that size particle while the remaining polydisperse flow exits via the exhaust.

This experiment took place at the Storm Peak Lab in Steamboat Springs, Colorado between 0748 UTC 29 March 2010 and 1016 UTC 2 April 2010. SPL is a unique atmospheric research lab because it is at 10,525 feet in elevation on the top of the mountain and is often in the cloud. The SMPS at SPL was set up to measure particle sizes between 8.66 nm and 339.7 nm. Because the limit of every finite particle's diameter concentration is zero, the particle sizes are divided into bins that encompass a certain range of particle sizes. The bins toward the smaller end of the spectrum have size ranges of only a few tenths of a nanometer while the bins toward the larger end of the spectrum have size ranges of a few tens of nanometers. The SMPS continually takes measurements as it cycles through its range of particle sizes and gets a distribution for all size particles every five minutes.

The total concentration of atmospheric aerosols was looked at in addition to the aerosol concentration of particles between 12 and 50.5 nanometers as a proxy for the nucleation mode and the concentration of particles between 148.55 and 305.1 nanometers as a proxy for the accumulation mode. To get this data, the bins containing the appropriate particle sizes were summed together. It is important to note that the values for these different groups of data cannot be compared against each other because they do not have the same units, but the trends between the same types of graphs of data can still be useful. Temperature, relative humidity, wind speed, and wind direction were also recorded during the same time period from SPL's website. The weather data that was taken takes measurement averages every five minutes making comparisons with the SMPS data an easy exercise. This data was taken from the website in local standard time but it was daylight savings time during the experimental period, so one hour should be added to the LST to get the actual local time.

Results

March 29, 2010 was a relatively mild day with fairly windy and clear conditions. The total concentration trend (Fig. 3a) shows a diurnal variation in aerosol concentration with the values being negligible throughout most of the day except between 1200 UTC and 1700 UTC 29 March 2010 (9am and 2pm MDT). The concentration quickly shoots up to its maximum value and stays relatively high throughout this time period. The nucleation mode concentration (Fig. 3b) shows an almost identical trend, which will become a pattern. The accumulation mode concentration (Fig. 3c) shows a peak during the same time, however, it is not substantially different from the concentration throughout the rest of the day as the total and nucleation mode concentrations were. There is also a second, smaller peak in the accumulation mode concentration around 0130 UTC 30 March 2010 (9:30 pm MDT March 29, 2010).

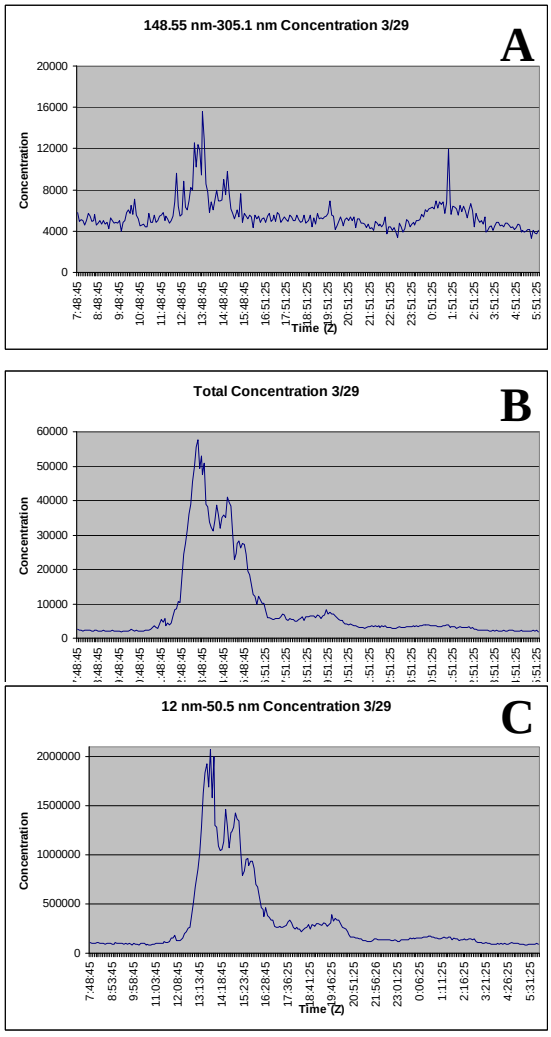


Figure 3: Aerosol concentration from 3/29/10. Figure 3a: Total concentration. Figure 3b: Nucleation mode concentration. Figure 3c: Accumulation mode concentration.

March 30, 2010 was characterized by high clouds and very warm temperatures that stayed above freezing all day. The wind speeds were also very strong with a maximum wind gust of 65 mph. Total (Fig. 4a) and nucleation mode (Fig. 4b) concentrations still peaked at about the same times as on the 29th but the magnitudes were

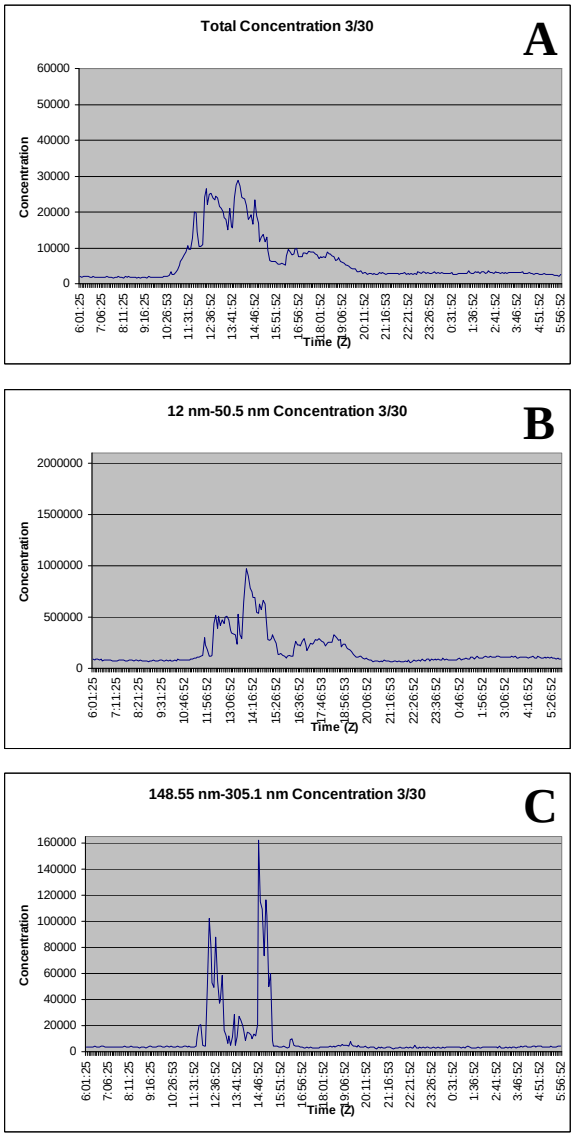


Figure 4: Aerosol concentration from 3/30/10. Figure 4a: Total concentration. Figure 4b: Nucleation mode concentration. Figure 4c: Accumulation mode concentration.

approximately cut in half. The accumulation mode concentration (Fig. 4c) graph for this day is very different than it is for the other days. The concentration values on the y-axis are a full magnitude of order greater on the 30th than they are on any other day. This is most likely due to a controlled burn that was near the lab affecting the concentrations. The wind direction (Fig. 5) changed from westerly to southerly around 4 am MDT, and starting at about 11 am MDT, began to slowly rebound back to westerly.

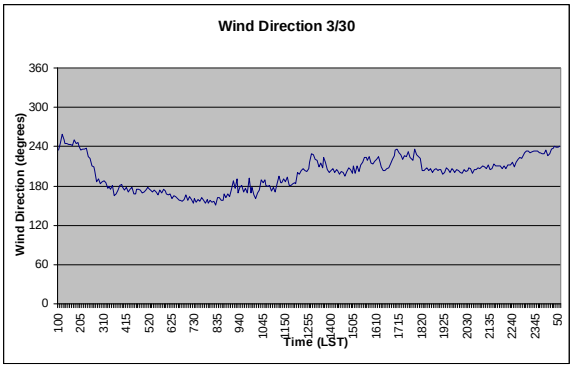


Figure 5: Wind direction in degrees from 3/30/10.

March 31, 2010 was another mild day with increasing moisture as cloud cover increased accompanied by snow showers. The winds also remained strong similar to the previous day. The trends in the data show a dramatic decrease in the total (Fig. 6a) and nucleation mode (Fig. 6b) concentrations. There are a couple very small peaks throughout the day, but in general the magnitudes of the concentrations are not that high. This is probably due to there being heavy cloud cover throughout most of the day. The accumulation mode concentrations (Fig. 6c) still have some variation in them but the most notable feature is when the concentrations go to zero around 0230 UTC 1 April 2010. This was the time when the lab was in cloud and the

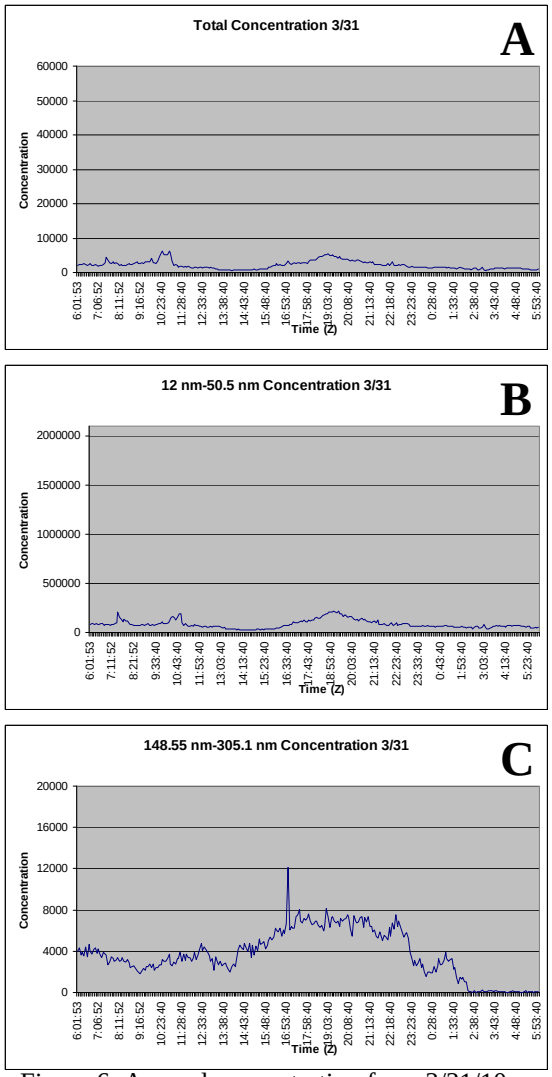


Figure 6: Aerosol concentration from 3/31/10. Figure 6a: Total concentration. Figure 6b: Nucleation mode concentration. Figure 6c: Accumulation mode concentration.

concentrations are zero because the aerosols in this size range are being scavenged out for cloud condensation nuclei. The relative humidity (Fig. 7) was greater on the 31st than it had been during the other days and around noon MDT it increased to about 80%. The relative humidity generally remained the same until about 10pm MDT when the instrument began reading relative humidities above 100%. The maximum relative humidity measured was 104% and while this is probably due to some

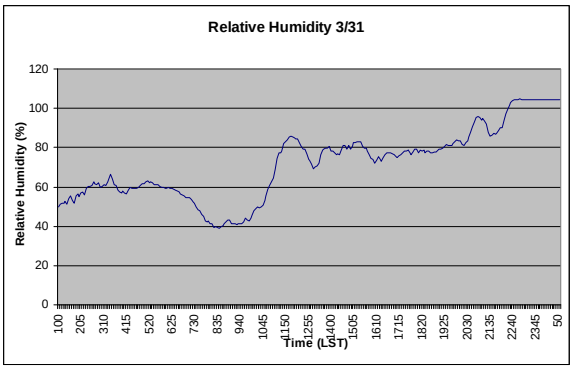


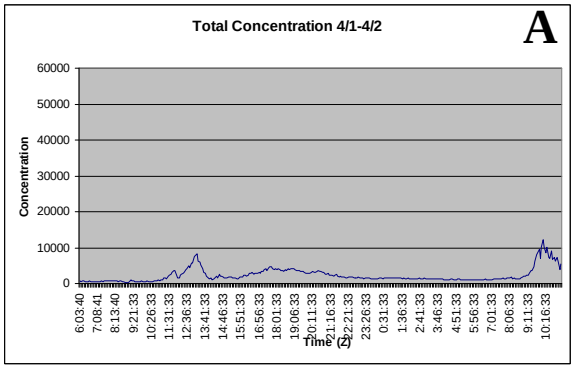
Figure 7: Relative humidity (%) from 3/31/10.

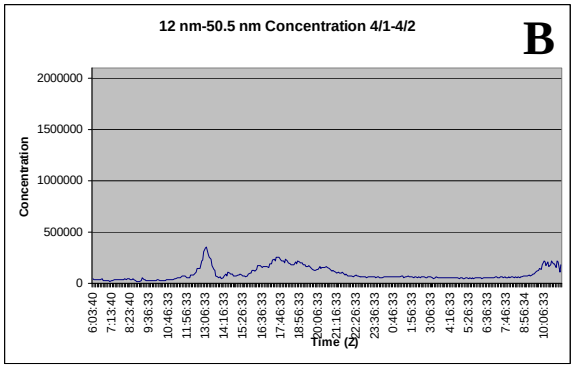
moisture getting on the device, the relative humidity being around 100% is most likely due to it being in cloud at that time.

April 1, 2010 was a colder day with snow showers and lighter winds compared to the rest of the week. The data still showed low magnitude total (Fig. 8a) and nucleation mode (Fig. 8b) concentrations similar to the previous day. The accumulation mode concentrations (Fig. 8c) began around zero in the morning when the lab was in cloud and increased throughout the day. Within the first couple hours of the day, the wind shifted from southerly to northwesterly (Fig. 9). Then, just a few hours later around 6am MDT, the wind shifted back to southerly for a couple hours, then back to northwesterly around 9:30am MDT and remained that way for the rest of the day and into the morning on the 2nd.

Discussion

This experiment did not seem to find many significant connections between the variability of aerosol concentration and the atmospheric variables, but some other interesting relationships were observed that impacted how the concentrations varied during the week.





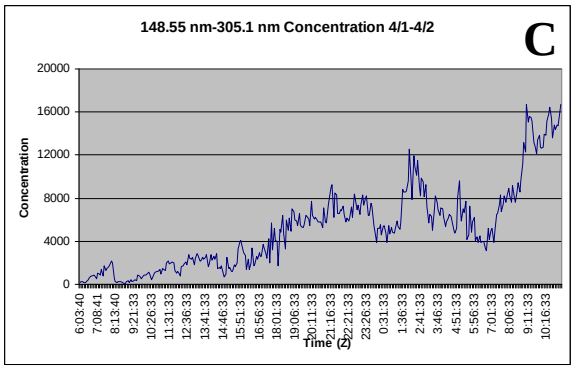


Figure 8: Aerosol concentration from 4/1/10-4/2/10. Figure 8a: Total concentration. Figure 8b: Nucleation mode concentration. Figure 8c: Accumulation mode concentration.

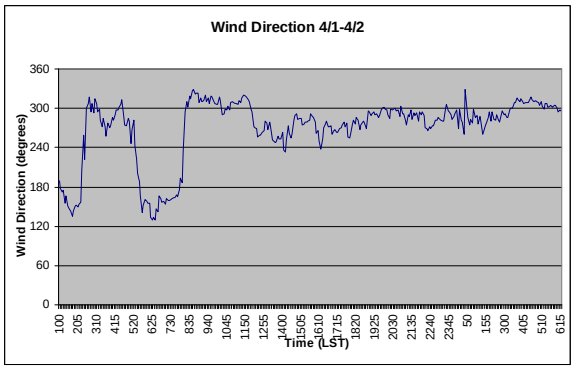


Figure 9: Wind direction in degrees from 4/1/10-4/2/10.

The first thing to notice when looking at the graphs of aerosol concentrations is that the nucleation mode concentration trends are almost identical to the total concentration trends. This is most likely due to the fact that the atmosphere up at the lab is highly dominated by these size particles. Another pattern that is easily noticeable is that on most days, the concentrations increase greatly during the late morning hours and peak shortly thereafter. This is because solar radiation is increasing rapidly during this time and the increased sunlight triggers the photochemical production of new particles from vegetation via homogeneous nucleation (Weingartner, et al., 1999). These new biogenic aerosols are in the nucleation mode which also helps to explain why the total concentration and nucleation mode concentration graphs are so similar and how the accumulation mode concentrations don't increase at the same rate since the biogenic aerosols created are smaller.

One of the more significant attributes in the graphs of aerosol concentrations is the entire order of magnitude difference between the accumulation mode concentration on the 30th compared to the other days of the week. This was due to controlled burns that were occurring a few miles to the south of the lab. The wind was out of the south during the peak in concentration which indicates that the extremely high values were due to the aerosols produced by the fires. The significantly lower concentrations on the 31st were likely due to the increasing cloud cover ahead of the snowstorm that occurred on the 1st and 2nd. The cloud cover didn't allow as much solar radiation to reach the surface to allow for the production of aerosols by vegetation.

The final feature to look at was when the accumulation mode concentrations went to zero the night of the 31st and morning of the 1st. This was most likely due to scavenging done because of CCN. CCN are generally 100 nanometers and larger which puts them in the accumulation mode of aerosols. These size aerosols are perfect for liquid water to coalesce on and make cloud droplets. So when the lab is in cloud, which it was for the night of the 31st and much of the day on the 1st, it is reasonable to assume that the larger aerosols in this experiment were being scavenged out for CCN.

Conclusion

While there may not have been a direct relationship between the atmospheric variables and the aerosol concentrations studied here, there were some other relationships noticed. The concentration tended to go down with increasing relative humidity, but this was more likely due to CCN scavenging than to a direct relationship between the two. There was no discernible correlation between temperature and aerosol concentration and this may be due to only having one week of data. With more time to collect information, some correlations could have been made. There was a fairly decent relationship between wind speed and aerosol concentration with concentrations decreasing with increasing wind speeds, although it is hard to say whether this is actually significant or just a coincidence. There was also some relationship between wind direction and aerosol concentration, with higher concentrations correlated with southerly

winds, but this was more likely due to the fires that were to the south of the lab than anything else.

The most significant correlations with aerosol concentrations had to do with the general atmospheric conditions in the area and other anomalies that occurred during the week. Cloudier skies tended to produce lower concentrations due to the less solar radiation reaching the surface. Local fires increased the concentrations while the usual diurnal variation of biogenic aerosols being created by vegetation from the increased solar radiation was probably the most significant factor in varying aerosol concentrations at Storm Peak Lab.

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