Corvallis Ozone and Aerosol Experiment (COAX)

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ABSTRACT

Air pollution can have serious implications for environmental health. High levels of particulate and gaseous matter in the lower atmosphere have been linked to the onset of respiratory distress, cardiovascular dysfunction, and ocular irritation in humans. Concentrations of these compounds are controlled by a variety of complex factors, including emission sources, transport and mixing, transformation, and removal (Ko, 1992). Using aerosol and ozone gas as indicator species, this study investigates the interplay of these factors at two sites in Corvallis, Oregon. It incorporates information about weather patterns, including data on temperature, relative humidity, surface and aloft winds, and mixing height to examine environmental controls on pollution. This project will increase understanding of how human exposure to contaminants can vary spatially and temporally on a local scale.

INTRODUCTION

Air pollution is composed of both particulate and gaseous matter. These particulates are known as aerosols, and represent a mix of primary emissions, such as those emerging from smoke stacks, and secondary products that result from chemical reactions of primary emissions in the atmosphere. These aerosols are not only significant contributors to environmental pollution, but many can also cause damage to the human respiratory system when inhaled (Seinfeld, 1989).

Of the gaseous components, ozone is one of the most closely monitored species, due to its role in the formation of photochemical smog (Dickerson et al, 1997). Notably, there are no anthropogenic emission sources of ozone gas in the troposphere, and concentrations are controlled by reactions of NO\textsubscript{x} with sunlight. Emission sources that involve combustion produce NO\textsubscript{x}, and the reaction of NO\textsubscript{x} with sunlight produces tropospheric ozone. Ozone and particulates are intrinsically linked or “chemically coupled,” because the same combustion sources that emit NO\textsubscript{x} also release aerosols into the atmosphere (Meng et al, 1997).

Concentrations of aerosols and gases in the atmosphere are controlled by a variety of complex factors, including emission sources, transport and mixing, transformation, and removal (Ko, 1992). As previously discussed, emission sources can include combustion, smelting, and natural processes. Transport and mixing are influenced by wind speed and direction, and the temperature profile of the atmosphere with height. Transformative
processes include chemical and physical reaction in situ, while removal occurs via wet and dry deposition.

This study will characterize regional air quality in Corvallis, Oregon, using concentrations of atmospheric aerosols and ozone gas as indicator species. By gathering data on the concentrations of particulate matter and ozone gas, and collecting information about the character of the wind and temperature profile, we can study emission sources and transport in the area. Using our knowledge of atmospheric chemical processes, and information about local weather patterns at a given time, we can investigate the role of transformation and removal. By examining these comprehensive data sets, we can draw conclusions about the relationships between the factors and the overall nature of local air quality.

METHODS

Study Area

The two experimental setups were located in the northeast and southeast regions of Corvallis, Oregon. The northeast site was located at 1820 NE Vine Avenue 97330 and the southeast site was located at 2115 SE Crystal Lake Drive 97333 (Appendix A, B). Both sampled air at a height of approximately 7 meters. The experimental setups at each site were analogous.

The Vine Avenue site was located several miles downwind of significant industrial activity in Albany, Oregon, including the Weyerhaeuser pulp mill and the Wah Chang chemical and metal manufacturing plant. The Crystal Lake Drive site is located less than a mile from Evanite Fiber Glass Corporation.

Data Collection

Data on total aerosol concentration in particles per cubic centimeter was gathered using two TSI Model 3010 Condensation Particle Counters (CPCs). The CPC measured concentrations every second and averaged the one second data to five minute data. Data on ozone concentrations in parts per billion was collected using a Dasibi Environmental Corp.
Model 1003-PC and a Dasibi Environmental Corp. Model 1008-AH. The ozone instruments measured concentrations every 20 seconds and averaged the 20 second data to five minute data. Two Campbell Scientific Model HMP45C-L probes measured temperature and relative humidity, while two R.M. Young Wind Monitor 05103-L anemometers measured wind speed and direction. The CPC data was recorded using a laptop equipped with Python software written by Ivar Vong and the remaining data was recorded using Campbell Scientific CR10 and CR10X loggers.

Oregon Climate Network Skew-T diagrams (soundings) were utilized to ascertain the ambient temperature profile with height and Unisys 850-millibar maps were used to monitor the prevailing winds of the upper atmosphere.

Data was collected at the Vine Avenue site from July 3rd through August 7th of 2008. Data was collected at the Crystal Lake Drive site from July 19th through August 7th of 2008.

Data Analysis

To correlate the outputs of the CPCs, simultaneous data was gathered from both machines at the same location. The time series produced by the instruments were plotted against each other in Microsoft Excel and a regression line was drawn to obtain the relationship between the two machines (Fig. 1). The same was done with the ozone instruments (Fig. 2).

To explore the spatial and temporal variations between the two sites, time series graphs of all of the data from July 19th through August 7th were constructed. The five-minute data from both sites (corrected using the regression line discussed earlier) was plotted against Julian date and time in a single figure (Fig. 3, 4). To further explore the temporal variations of aerosols and ozone, the diurnal hourly averages for the concentrations at each site were plotted versus time of day (Fig. 5, 6). The photochemical cycle of ozone was also illuminated in the graph of time versus ozone concentration (Fig. 7).

To learn more about the influence of the daily boundary layer break up on aerosols, average hourly particle concentrations and average mixing height were both plotted versus time of day. The information about the boundary layer breakup was ascertained by
comparing the temperature summary from the Vine Avenue site to data from 850mb maps. First, the change in potential temperature at 850mb was correlated with the same change in temperature at the surface at Vine Avenue. Then, the mixing height associated with the 850mb potential temperature change was extrapolated to the time at which the identical surface temperature change occurred. This was used to create an hourly profile of the relationship between time of day and mixing height (Fig. 8).

To study the relationship between aloft winds and air quality, four different classes of wind direction were established (Appendix C). Class 1 included southwesterly winds from approximately 155° - 270°, Class 2 included northeasterly winds from approximately 340° - 130° and Class 3 included northwesterly winds from 270° - 340°. Class 4 winds were declared “inconsistent,” meaning there was no prevailing direction. Next, the daily data sets from July 3rd through August 7th were each assigned to a class, based on their prevailing wind direction at 850mb. The “inconsistent” winds were those that mimicked the behavior of two different classes at 5:00am and 5:00pm on the same day. The influence of aloft winds was then explored by stratifying the data set according to wind class. Cumulative aerosol and ozone frequencies for the data falling into each of the four wind classes were calculated and contrasted.

RESULTS

Although the fluctuations appear to be in general agreement, the time series graph of total aerosol concentrations demonstrates significant, short-term spikes at Crystal Lake almost daily. Several of the peaks at Crystal Lake are at particle concentrations more than twice the simultaneous value at the Vine site (Fig. 3). The time series graph of ozone concentrations also displays general agreement between the two sites but does not contain the abrupt spikes evident in the aerosol series (Fig. 4).

The plots of hourly averages for both aerosols and ozone display clear diurnal patterns (Fig. 5, 6). The spatial variation between the two sites appears fairly minimal and both sites follow the same temporal pattern. There is, however, a significant spike in particle
concentrations at Crystal Lake Drive around 8:00am that is not mirrored at Vine Avenue (Fig. 5). When the hourly ozone averages are plotted alongside the hourly temperature averages, it is clear that they fluctuate in sync (Fig. 7).

The diurnal pattern of boundary layer breakup and mixing appears to be correlated with the daily rise in particle concentrations (Fig. 8). On average, at 8:00am, the atmosphere is mixed up to a height of approximately 170m and aerosol concentrations are 5000 particles per cubic centimeter. By 10:00am, the atmosphere is mixed to a height of approximately 500m, and aerosol concentrations are at 6000 particles per cubic centimeter. Both the average mixing height and average particle concentration increases throughout the morning and into the afternoon (Fig. 8).

The majority of the sampling days were classified as northeasterly winds. The next most prevalent aloft wind direction was southwesterly, followed by northwesterly (Fig. 9). At Vine Avenue, Class #1 (southwesterly) winds brought the cleanest air in terms of both aerosol and ozone concentrations. Class #2 (northeasterly) winds appear to be the dirtiest according to both aerosol and ozone measurements. Class #1 had the highest frequency of low particle concentrations (66% of occurrences under 5,000 particles per cubic centimeter), as well as the lowest frequency of high concentrations (0.2% of occurrences above 15,000 particles per cubic centimeter). In contrast, Class #2 had the lowest frequency of low particle concentrations (51% under 5,000 particles per cubic centimeter), and the highest frequency of high concentrations (3% above 15,000 particles per cubic centimeter) (Fig. 10). Class #1 also had the highest frequency of low ozone concentrations (82% under 30ppbv), while Class #2 had the lowest frequency of low values (52% under 30ppbv) (Fig. 11).

At Crystal Lake Drive, Class #3 (northwesterly) winds brought the cleanest air in terms of aerosol and ozone concentrations. Class #3 had the highest frequency of low particle concentrations (79% of occurrences less than 5,000 particles per cubic centimeter), and the lowest frequency of high concentrations (0.6% of occurrences greater than 15,000 particles per cubic centimeter) (Fig. 12). Class #3 also had the highest frequency of low ozone concentrations (93% less than 30ppbv) and the lowest frequency of high
concentrations (0% above 50ppbv) (Fig. 13). Class #2 was again the dirtiest in terms of ozone levels, but it was difficult to ascertain whether Class #1 or Class #2 winds were responsible for higher particle concentrations. Class #2 had the lowest frequency of low ozone concentrations (61% less than 30ppbv) and the highest frequency of high concentrations (6% above 50ppbv) (Fig. 13). Class #1 had the highest frequency of high particle concentrations (2% were greater than 30,000 particles per cubic centimeter) but Class #2 had the lowest frequency of low concentrations (only 55% below 5,000 particles per cubic centimeter) (Fig. 12).

DISCUSSION

The time series graphs of aerosol and ozone concentrations demonstrate a variable component both spatially and temporally (Fig. 3, 4). Both sites fluctuate in a similar pattern, but there are definite disparities, and both follow a predictable diurnal cycle. The slight spatial variation is to be expected; the two sites are located several miles apart, they have different environmental and anthropogenic emission sources located nearby, and the same weather patterns can affect them differently. The diurnal patterns were also expected and explored more thoroughly in the plots of time versus average hourly concentrations.

The spike in particle concentrations at Crystal Lake Drive around 8:00am can potentially be attributed to the presence of traffic (Fig. 5). The site is located less than a mile from Evanite Fiber Corp., and it is reasonable to assume that there is an influx of Evanite employees in cars around 8:00am. The site is also located adjacent to Highway 99, another significant source of particulate matter. This theory that traffic is responsible is supported by the fact that the phenomenon also occurs on a much smaller scale at Vine Avenue around the same time. Although Vine Avenue is not near a business complex and the forest canopy likely filters the material coming off of the highway, it is logical that the site would still register the high density of vehicles on the road at 8:00am.

The diurnal fluctuations of ozone with temperature are rational because temperature can serve as an indicator of sunlight availability. With no anthropogenic sources, the creation
of ozone depends upon the photochemical reaction of NO$_x$ in the presence of sunlight. Ozone levels drop significantly overnight when there is no sunlight available for the NO$_x$ to interact with and nighttime inversions (temperature increase with height) prevent the atmosphere from mixing thoroughly. Temperatures increase as the sun rises in the sky and heats the ground. The heating of the Earth’s surface causes the inversion to break up and begins the mixing process. Ozone concentrations begin to rise steadily as soon as sunlight and mixing opportunities increase when also influences particle concentrations. When an inversion forms it means that temperature is increasing with height above a certain point. The normal profile of the atmosphere is a steady decline in temperature with height (and a subsequent rise in density). Less dense warm air normally rises as it cools; however, the presence of an inversion acts as a “lid” on the atmosphere, preventing the upward movement and mixing of warm air. During an overnight inversion, emissions released in the lower atmosphere do not mix up and emissions with a source in the upper atmosphere are unable to mix down. Overnight concentrations may be higher at the surface if lower air emissions dominate. Concentrations may be lower at the surface overnight if upper air emissions are more significant. The heating of the Earth’s surface in the morning stimulates the breakup of the boundary layer and initiates the daily mixing process. Lower air emissions begin to mix up, while upper air emissions are now able to mix down.

At Vine Avenue, particle concentrations were low in the morning and began to rise steadily until noon with the breakup of the boundary layer (Fig. 8). The fact that concentrations started low and increased throughout the morning suggests that upper air emissions are more significant at that site than are lower air emissions. With most of Albany’s industrial activity directly to the northeast of Vine, it is logical that one of the biggest contributors to aerosols in the area would be tall smokestacks. If this were the case, the emissions released from an upper air smokestack would not be able to mix down until the boundary layer grows to reach the height of the stack.

In addition to the height of the boundary layer, this data shows that the nature of aloft winds also play a significant role. However, it is important to note that more data was
available from the Vine Avenue site, so all conclusions based on the aloft wind data are more compelling for the Vine site than for the Crystal Lake site. All data was normalized to minimize this bias. The graphs clearly demonstrate that different prevailing aloft wind directions can result in significantly different surface concentrations. They also show that different prevailing aloft wind directions can have significantly different effects over spatial scales.

It is logical that Class #1 (southwesterly) winds were significantly cleaner at Vine than any other wind class. Southwesterly winds likely originated over the ocean, and the air they brought to the site would lack a lot of the impurities present at other wind sources. It follows that Class #2 (northeasterly) winds were the dirtiest because the Albany industrial complex is directly to the northeast of the Vine site. Any northeasterly winds are likely to carry the particulates and gaseous components emitted from those industrial smokestacks several miles away.

The Crystal Lake Drive data is less straightforward; this can likely be attributed to the lack of available data at Crystal Lake as compared to Vine. Thus far, it is inexplicable why Class #1 (southwesterly, oceanic) winds were responsible for extremely high particle concentrations (reaching over 30,000 particles per cubic centimeter) and only average levels of ozone. It is also difficult to ascertain why Class #3 (northwesterly) winds were so much cleaner at Crystal Lake than at Vine Avenue, in terms of both particle and ozone levels. Based on the Crystal Lake data, it appears that the presence of southwesterly oceanic winds did not significantly improve the quality of the air. Again, this may be influenced by the lack of available data, and therefore more sampling would be necessary before conclusions can be drawn.

Based on the results of this study, it can be concluded that Corvallis, Oregon has air that is significantly cleaner than many other areas of the United States. The Environmental Protection Agency’s standard for 8-hour ozone averages is currently 75ppbv. Not a single instance of 75ppbv was detected at either site during our sampling period. It can also be concluded that no single emission source dominates in this region. Despite Crystal Lake’s
close proximity to Evanite Fiber Corp. and Vine’s relative distance from large emission sources, there was not particularly significant spatial variation between the two sites in terms of particle and ozone levels. Most of the temporal variation appears to be a result of environmental factors, including sunlight, mixing height, and aloft winds.
REFERENCES


Figure 1. Relationship between Condensation Particle Counters (CPCs).
Figure 2. Relationship between ozone instruments.
Figure 3. Spatial variation in particle concentration in Corvallis, Oregon, from July 19\textsuperscript{th} through August 7\textsuperscript{th} 2008.

Figure 4. Spatial variation in ozone concentration in Corvallis, Oregon, from July 19\textsuperscript{th} through August 7\textsuperscript{th} 2008.
Figure 5. Average diurnal cycle of particle concentration.

Figure 6. Average diurnal cycle of ozone concentration.
Figure 7. Average diurnal cycle of temperature and ozone concentration.

Figure 8. Average boundary layer growth and particle concentration at Vine Avenue.
Figure 9. Prevailing aloft winds at 850mb.

Figure 10. Cumulative particle frequencies for various wind sectors at Vine Avenue.
Figure 11. Cumulative ozone frequencies for various wind sectors at Vine Avenue.

Figure 12. Cumulative particle frequencies for various wind sectors at Crystal Lake Drive.
Figure 13. Cumulative ozone frequencies for various wind sectors at Crystal Lake Drive.
APPENDIX

Appendix A. A photograph of the two sampling sites (from left: Vine Avenue, Crystal Lake Drive).

Appendix B. A map of Corvallis, Oregon with sampling sites and prominent emission sources.