ABSTRACT

Particulate matter, an EPA regulated pollutant, can have a severe impact on human health. Therefore, it is important to comprehensively understand particles as they enter the atmosphere, transform chemically and physically, and eventually deposit to the surface. Particle flux measurements, based on high frequency wind and particle concentration data, allow us to determine whether an area of interest is acting as a net source or sink of particulates. To calculate fluxes, we collect high frequency (10 Hz) data using a sonic anemometer and a condensation particle counter, which enables us to track changes in particle concentration within turbulent atmospheric eddies. Fluxes are calculated from these data using the eddy covariance method, which averages the covariance in the instantaneous fluctuations in the particle concentration and vertical wind speed. This fall, the Laboratory for Atmospheric Research (LAR) will be measuring the atmospheric conditions above Tianjin, the 6th most populous city in China, in order to characterize the pollutant emissions in a heavily industrialized urban area. The goal of this REU project was to assemble and test components of a particle flux measurement system that will be used in Tianjin. To ensure proper interpretation of the data provided by the condensation particle counter, we conducted laboratory experiments to measure the degree of mixing within the counter as well as the minimum response time for changes in particle concentration. We also conducted trial field observations at the WSU dairy to validate the overall system. The work done to characterize the system will allow the LAR researchers to obtain detailed measurements of particle fluxes over highly polluted cities, which in turn will allow for better emissions models and a better understanding of the most effective control strategies for urban aerosols.

INSTRUMENTS

- Condensation particle counter (CPC)
  - CPCs work by growing particles with a saturation of n-butanol to much larger sizes (from 4 nm to 1 µm), which are then counted by laser scattering.
  - First the aerosol is passed through a warm, butanol rich tube, then through a much colder tube. The butanol condenses onto the particles, increasing their size.
  - Sonic anemometer, capable of measuring the wind speed in three dimensions and temperature at 10 Hz.
  - By sending ultrasonic pulses back and forth between two transducers, the anemometer is able to measure the time required for a sound pulse to travel a known distance. Air moving between the transducers changes the transit time unevenly and the instrument calculates the speed of sound from this difference. There are three sets of transducers to measure the wind in three dimensions.
  - With transit time information, the sonic anemometer is also able to calculate the temperature of the air.
  - At the dairy, the sonic anemometer was mounted on a tower, 2.8 m above the ground.
  - A Labjack data acquisition module connected to a personal computer for stable 10 Hz data collection

RESPONSE CHARACTERIZATION

- Goal was to measure the time lag of the CPC as well as the shortest time for which the instrument could obtain valid data.
- Used a LabView code to cycle between pure air and particle laden air at various rates. For each valve timing period, the differences between several local maxima and minima were recorded. An exponential function of the form $y=A+Be^{-Ct}$ was fit to the differential data. The value A is the full response of the instrument. Minimum response time is calculated to be the time for which 80% response is seen.
- Using the same data set, the time delay between the opening of the valve and full response was calculated. The process was repeated with the addition of a copper tube between the valve and the CPC.
- Minimum response time of the CPC: 1.69 s
- Delay between signal and full response: 8.45 s

EDDY COVARIANCE

Since particle flux is the net movement of particles, it can be calculated by the average of the wind speed multiplied by the particle concentration.

$$ F = \frac{wC}{w} $$

Reynolds decomposition can be applied to equation (1), yielding

$$ F = \left( w + w' \right) \left( \frac{C + C'}{2} \right) $$

Because the average deviation from the average and the average vertical wind speed are both zero, the following manipulations can be applied.

$$ F = \left( \frac{wC + w'C + w'C'}{2} \right) $$

In the previous equations, $w$ is vertical wind speed (m/s), $C$ is particle concentration (particles/cm$^3$), and $F$ is the net particle flux. Overbars denote averages over a half hour period, and primes denote the instantaneous deviation from that average.

This calculation assumes that the instruments can measure quickly enough to measure the turbulent eddies. It is also an assumption that the average vertical wind speed is zero, but this assumption can be made true. (Martensson et al. 2006)

To make sure that the average vertical wind speed actually is zero, the coordinate system is rotated. The data is processed in other ways as well, such as smoothing and the Webb correction (Webb, Pearman, and Leuning, 1980).

CONCLUSIONS AND FUTURE WORK

- As mentioned before, the eddy covariance technique has several requirements. The most challenging is the high frequency nature of the measurements. The signal output by the CPC changes at 10 Hz, but as discussed before, there are several factors that degrade the quality of the data. Flow through the tube spreads out the sample. The CPC takes several seconds to register any change in particle concentration and more time to get to a full response. As we learned in the valve tests, if the sample is very brief, it will become mixed before being counted, so the difference in measured concentration is reduced.
- In the measurements taken at the dairy, negative (downward) net fluxes were detected. This makes sense because there should be relatively few processes generating particles in the area sampled by our instruments. Overall, the number of particles deposited dominates the number of particles generated.
- The system characterization and analysis routines developed during this REU project will be directly relevant to the particle flux measurements to be completed as part of LAR's research campaign in Tianjin in September.
- This summer's work will also inform and facilitate future particle flux measurements over a variety of environments, including forest, aquatic, and agricultural ecosystems.

REFERENCES:


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