1.15 REMOTE QUANTIFICATION OF PLUME AEROSOL CONCENTRATIONS OVER AGRICULTURAL AND FOREST CANOPIES

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1. INTRODUCTION

Boundary layer aerosol plumes are generated from a variety of sources. More common agricultural sources include aerial spraying and field preparation. To date, knowledge of dynamic concentrations, fluxes and transport distances of such aerosols is limited (Holmén et al., 1998). Information about concentration is most often predicted by a model such as AgDrift (Teske et al., 2002), or measured via samplers (Clausnitzer and Singer, 1996; Hoffmann and Kirk, 2005; Miller et al., 2003; Miller et al., 2000; Teske et al., 2002). Samplers, however, are only useful for small areas or very spatially regular plumes, and are not reliable for many of the meteorological conditions encountered by plumes.

In an effort to overcome these limitations, remote elastic backscatter lidar measurements are used to quantify the mass aloft in two types of boundary layer aerosol plumes. Independent measurements of the source's strength and particle size distributions are used together with the lidar backscatter to calculate the dynamics and spatial distributions of the mass concentrations of material aloft in the plume. Examples are presented from a stable boundary layer smoke plume above a forest canopy and a stable boundary layer aerial spray plume for vector control.

2. METHODS

2.1 *Lidar Measurements*

The unique aspect of this research is the ability to remotely capture entire cross sectional images of plumes for a period of time after they are generated. This is achieved through the use of the University of Connecticut miniature elastic backscatter lidar. The lidar is capable of scanning either horizontally or vertically as plume movement conditions dictate. The lidar returns a measurement of relative backscatter through the plume. Lidar slices can also be analyzed to provide a measurement of plume area, volume and spread using the methods of Hiscox et al.(2006).

2.2 *Quantification Techniques*

The first step in quantifying aerosol plumes is having information about the size range of the particles in the plume. This means an independent measurement of the source must be made. Each type of source has different requirements for such a measurement. Controlled releases from spray equipment or smoke generators can be measured using a wind tunnel and particle sizer.

For a continuous source, the drop size distribution and mass estimate are constant during the measurement period, so it is only necessary to estimate mass from the measured volume distribution. For a single release source, such as aerial spray, it is necessary to determine how the drop size distribution and mass aloft change over time. To estimate the change in mass aloft over time, it is necessary to calculate changes in the distribution. This is done following the techniques of Flesch and Aylor (2000) and Wang et al. (1995). Assuming a hard core model to determine final droplet sizes, evaporation is modeled as:

$$\frac{dD}{dt} = \frac{4\eta m_w}{\rho_w R D_0}\left(\frac{e_w}{T_a} - \frac{e_{sw}}{T_a}\right) \qquad (1)$$

after (Baron and Willeke, 2001), where D is the droplet diameter (μm), η is the atmospheric diffusivity, m_w is the molecular weight of water (kg), ρ_w is the density of water (kg m^{-3}), R is the gas constant (8.3144 m^3 kPa $kmol^{-1}$ K^{-1}), e_w is the vapor pressure of water (kPa) and T_a is the air temperature (K). The calculation of evaporation is not a necessary step for solid aerosols such as dust from field operations.

After particle size from evaporation is determined, settling velocities are calculated for

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each size bin. From this it is possible to determine approximately how far a particle has fallen. If this distance is greater than the release height of the plume, it is removed from distributions for subsequent time steps. The volume fraction of each size class is then determined by assuming that the number of particles in each size bin remained the same, unless they had fallen to the ground, in which case the number is replaced by zero. Figure 1 shows a sample of this calculation for an aerial spray plume with initial drop size distribution with volume mean diameter of 37.3 μm and a DV0.1 and DV0.9 of 13.3 μm and 82.8 μm respectively.

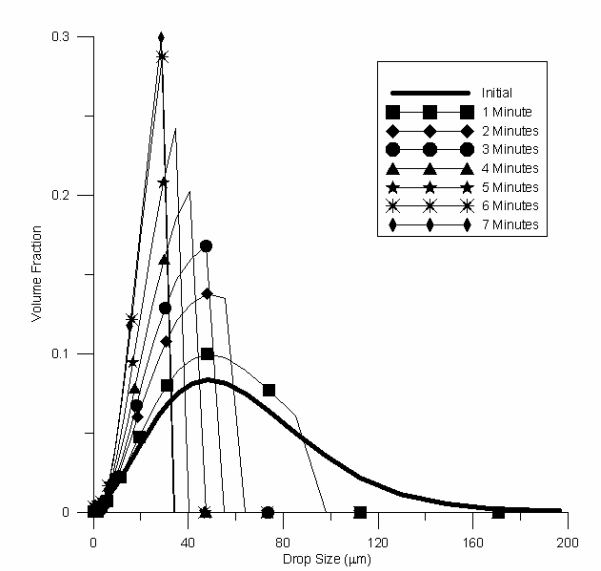


Figure 1: Calculated drop size distributions over time. Drop size distributions are presented for 1 minute intervals for 7 minutes following a source release. The sharp drops are due to the removal of size bins based on settling.

For all source types, it is next necessary to change the volume distribution at any time, t, to a calculated mass aloft value of :

$$M(t) = \sum_i N_i M_i(t) \qquad (2)$$

where, i represents each size classification, N is the number of particles and M_i is the mass of a single particle in size classification, i, found from the density of the particle multiplied by the volume of the particle. These mass values can be changed to a concentration by combining them with plume volumes measured from the lidar.

The next step is to find a calibration that relates the lidar backscatter signal to the calculated concentration. The most complicated example of this is for a single release from aerial spraying. The concentration over time was compared to the lidar backscatter per unit volume versus time (Figure 2) to derive a calibration factor, α, which represents the slope of a linear fit to the relationship.

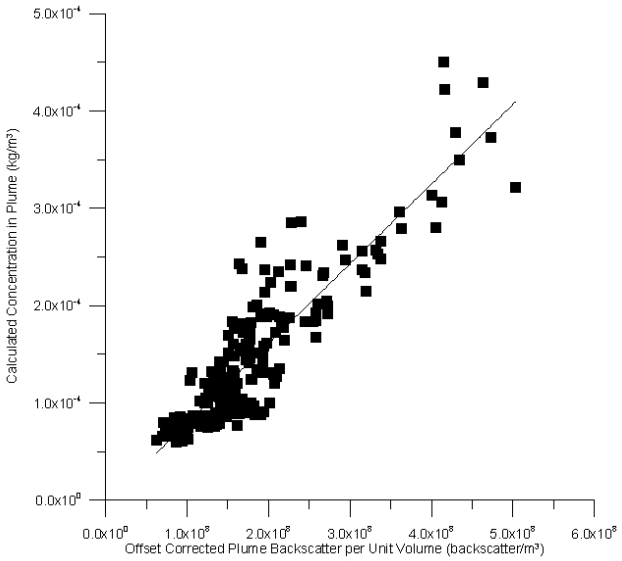


Figure 2: Calculated concentration aloft vs. lidar backscatter per unit volume. All three passes were shifted to a zero intercept to find the relationship. The slope of the linear fit shown on the graph is α = 8e-13, R^2=0.8.

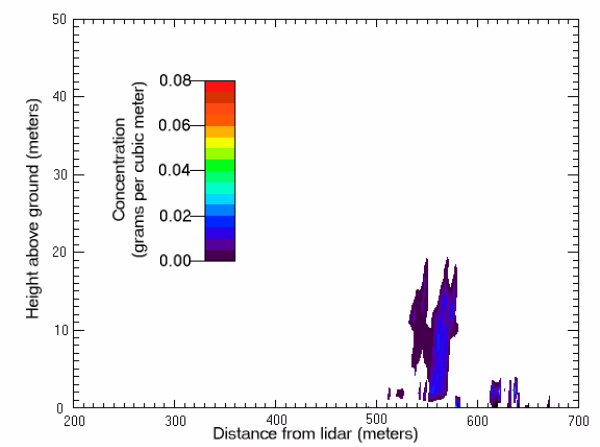
This conversion is then applied to the lidar backscatter values to determine concentration across the plume:

$$Q_{lidar}(t) = \frac{\beta_{lidar}(t)}{V_t} * \alpha \qquad (3)$$

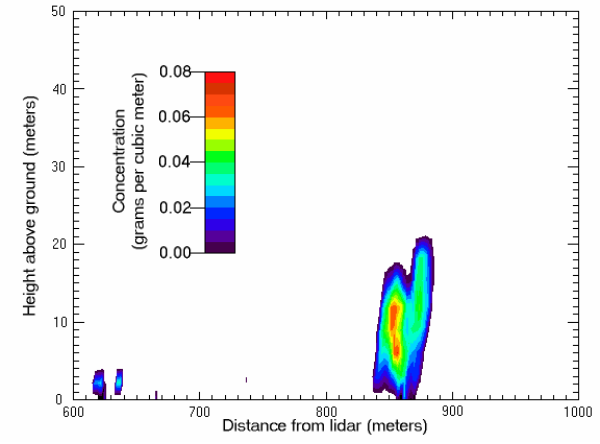
3. RESULTS

Results are presented here for an experiment performed on April 27, 2005 at the USDA Jornada Research Experimental Ranch. The New Mexico State University Cessna T188C airplane was flown in a controlled flight path, which allowed for the lidar to continuously scan the spray cloud until it was completely dissipated. Figure 4 shows the lidar slice taken 43 seconds after the spray release for three separate passes of the aircraft. The slices have been converted into the actual concentration values as indicated by the different contour levels.

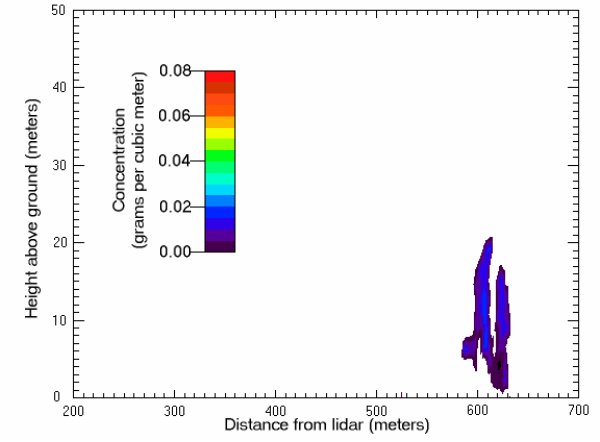
This same technique can also be applied to smoke plumes and results from an experiment over hardwood forest canopy will be presented.



(a)



(b)



(c)

Figure 3: Each image is taken 43 seconds after a pass of the airplane. Concentration values are in g m^{-3}.

4. CONCLUSIONS

Plume concentrations above forest and agriculture canopies can be measured "in situ" with an aerosol scanning lidar which has been calibrated with an independent sampler measurement of the plume. The plume's dynamics, including dispersion parameters and meandering, can be measured directly with the lidar alone.

5. ACKNOWLEGEMENTS

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