7.0 OZONE DEPOSITION VELOCITY DURING SNOW-COVERED AND NON-SNOW-COVERED PERIODS BY EDDY COVARIANCE

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7.1 Objective

The goal of this project was to directly measure the ozone surface flux in the Uinta Basin by eddy covariance to determine the rate of ozone deposition to the snow to allow for more accurate parameterization in models. The eddy covariance method utilizes fast (10 Hz) measurements of turbulence and ozone and calculates the correlation between the fast fluctuations of vertical wind velocity and ozone mole fraction to determine the magnitude and direction of the surface flux.

7.2 Experimental Methods and Instrumentation

7.2.1 Study Site and Duration

Flux measurements were conducted by CU-INSTAAR researchers at the Horsepool site (~1569 m a.s.l.) in the Uinta Basin from January 25 through April 2, 2013. This time period allowed for flux measurements to be made during both the snow-covered study intensive measurement period and following the snow melt and subsequent exposure of the dirt surface, as shown by the albedo plot in Figure 7-1. During the intensive period (January 25 – February 19), between two to four CU researchers were on-site at all times. Following the intensive period, the flux instrumentation continued running and was monitored remotely from the INSTAAR lab in Boulder, CO. Two trips were made back to the site for instrument maintenance and the instrumentation was dismantled on April 2.

7.2.2 Experimental Set-Up and Instrumentation

Flux measurements were conducted using a 2 m flux tower. To this tower was mounted a Campbell Scientific CSAT-3 three-dimensional sonic anemometer and the inlet to the fast response ozone instrument (FROI). The FROI and computer systems were housed in a temperature-controlled trailer located approximately 10 m from the flux tower.

The FROI is a custom-built instrument that is capable of 10 Hz measurements of ozone mole fraction. It utilizes NO reagent gas to react with ozone to generate a chemiluminescence signal that is detected with a photomultiplier (PMT) detector. The instrument and operation is described in full detail in Bariteau et al. (2010).

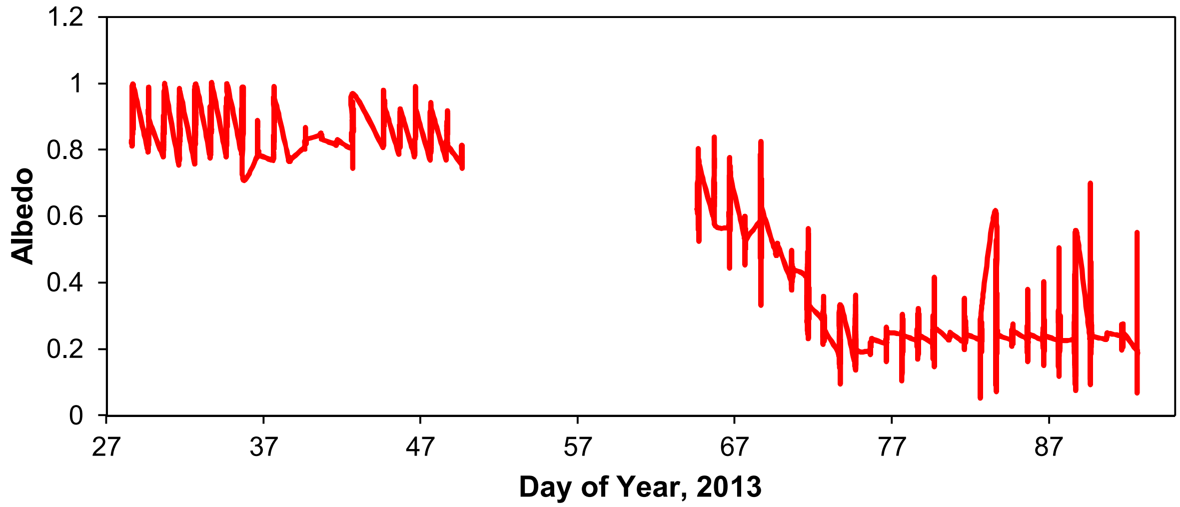

Figure 7-1. Albedo measured as an indicator of surface snow cover at the Horsepool site during the study period.

7.3 Results and Discussion

Over 1600 hours of ozone flux data were collected during this campaign. Data were filtered for periods of instrument maintenance and calibration, obstructed wind direction, very low winds speeds (< 0.5 m/s), unstable wind direction during the averaging period, and non-stationarity. Ozone data were time-corrected for the sampling lag time resulting from transport time though the sampling line and detrended over the averaging period to remove the influence of strong daytime photochemical ozone formation in this environment.

7.3.1 Snow-Covered Period

The land surface in the Uinta Basin consists of dry, sandy soil and low-lying sage brush. During the campaign intensive period, snow cover persisted that was less than half a meter deep. The snow sufficiently covered the soil, but the leaf-less and dry sage brush still protruded well above the snowpack. A histogram of ozone deposition velocity for a portion of the snow-covered period is shown in Figure 7-2. The median daytime deposition velocity is 0.003 cm s^{-1} with a 2-σ window ranging from -0.071 – 0.079 cm s^{-1}. This result is in the lower end of the range of previous determinations for snow-covered sites (Helmig et al., 2007). In general, ozone fluxes in and out of snow vary widely, with reported exchange velocity results from previous studies over seasonally snow-covered sites in the range of -3.3 to 1.7 cm s^{-1}, however, most data are within the range of 0.0 to 0.2 cm s^{-1} (Helmig et al., 2007). In the Arctic, another environment where stably-stratified boundary layer conditions predominate, values were lower, on the order of <0.01 - 0.07 cm s^{-1} depending on the time of year (Helmig et al.,2009). In comparison, midsummer values for lush vegetation surfaces have a much greater ozone deposition velocity of 0.2 – 1.0 cm s^{-1} (Wesely and Hicks, 2000).

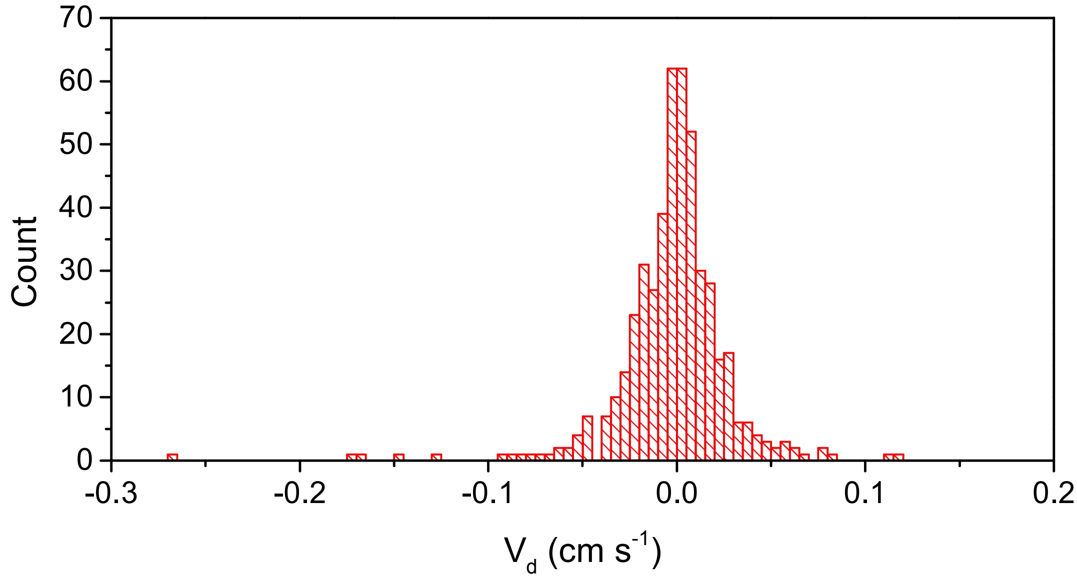

Figure 7-2. Histogram of ozone deposition velocity calculations for the snow-covered period (early February) inclusive of both nighttime and daytime data. Mean and median ozone deposition velocity were -0.002 and 0.0 cm s^{-1}, respectively, with the 2-σ window extending from -0.063 – 0.059 cm s^{-1}.

7.3.2 Snow Free Period

The flux experiment continued ~ 2 weeks after the completion of snow melt to capture ozone fluxes during exposure of the bare soil. The sage brush during this period was still dry and leafless, thus the only difference between the two periods studied was the presence of the snow cover on the ground. Here, we use data for the period of March 26 through April 2, which is one week after the measured albedo indicates the snow has melted, to ensure a period of dry (rather than wet or muddy) soil. Figure 7-3 shows a histogram of the deposition velocities from this period. Here, determined ozone deposition velocity values have a wider distribution. The maximum daytime deposition velocity (V_d) is 0.14 cm s^{-1}, with a median daytime value of 0.02 cm s^{-1}. The overall median value, including nighttime data is 0.002 cm s^{-1}. The period of wetted soil, between March 17 and March 25, yielded a lower median deposition velocity of 0.001 cm s^{-1}.

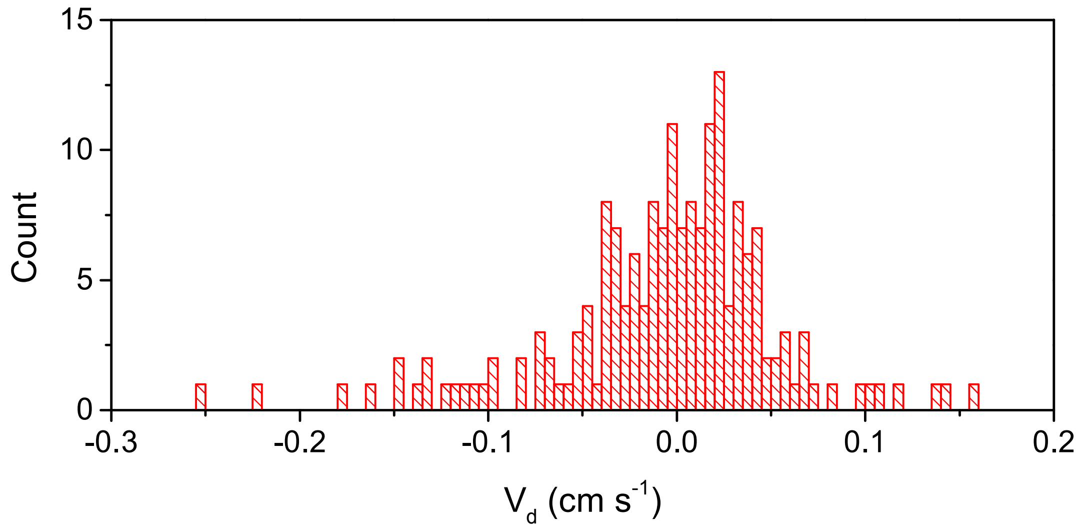

Figure 7-3. Histogram of ozone deposition velocity calculations for the non-snow-covered period (late March) inclusive of nighttime and daytime data. Mean and median ozone deposition velocities were -0.006 and 0.002 cm s^{-1}, respectively, with the 2-σ window extending from -0.066 – 0.054 cm s^{-1}.

Reported ozone deposition velocity measurements to soil surfaces in the literature vary widely, and are roughly dependent upon soil type, composition, and moisture content. It has been generally considered that wetted soil is more resistant to ozone uptake than dry soils due to the low water solubility of ozone (Erisman and Van Pul, 1994), but recent studies have found that the controlling factors are much more complex (Stella et al., 2011). Deposition velocities over wet bare soil in Illinois were determined via the gradient method to be 0.04 to 0.2 cm s^{-1} (Wesely et al., 1980). In comparison, eddy covariance determinations of ozone deposition velocity over the Sahara Desert were found to have a maximum daytime V_d of 0.15 cm s^{-1} and a mean of 0.065 cm s^{-1} (Gusten et al., 1996). These authors recommended a daytime V_d of 0.1 cm s^{-1} and a nighttime V_d of 0.04 cm s^{-1} for modeling of desert ecosystems. Our results for the Horsepool site are at the lower end of these previously reported bare soil ozone deposition velocities. These results illustrate that this environment with its dry, sandy soil conditions shows similar ozone uptake behavior as desert-like environments.

7.4 References

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