Vertically and temporally resolved observations of a biomass burning even in Colorado's Yampa Valley

Claus C. Moberg, Gannet Hallar, Tracey Holloway, Ian McCubbin and Gregory Tripoli

Abstract

We here present the results of a coordinated atmospheric composition observation campaign conducted in Colorado's Yampa Valley from March 29th through April 2nd, 2010. During this time period, several concurrent observations of fine particulate matter ($PM_{2.5}$) mass concentration and total suspended particulate matter (TSP) number density were conducted at multiple vertically differentiated observation points ranging from 2075m amsl to 3203m amsl. On March 30th, a controlled burn wildfire occurred roughly 19.2 km SSW of the highest of the observation points. In the morning and early afternoon, emissions from this biomass-burning event appeared to be trapped by diurnal valley lapse rate inversion. In the afternoon, however, the inversion dissipated. This allowed the fire emissions to convect out of the surface boundary layer and mix into the free troposphere. Our network of meteorological observations illustrate well the dissipation of the valley lapse rate inversion, and our simultaneous, vertically-resolved $PM_{2.5}$ observations depict well the impact of the valley lapse rate inversion on transport of the biomass burning emissions.

1 Background

Lapse rate inversions are a phenomenon generally characterized by a vertical temperature profile that increases with height. In mountainous regions, a nighttime decoupling of valley bottom air from the free troposphere often leads to the formation of valley cold pools [Whiteman et al., 2001] and, as a result, lapse rate inversions within mountain valleys are a common occurrence in many areas of the western United States.

Because temperature profiles that increase with height are extremely stable and not conducive to vertical mixing, diurnal lapse rate inversions are one meteorological phenomenon that can lead to an increase in particulate matter (PM) exposure amongst human populations living in mountain valleys [Schwartz, 1994]. This is because surface emissions stagnate in the valley bottom cold pool air mass, increasing the average residence time of an average emitted particle, and, thus, leading to higher mean PM concentrations.

In the western United States, biomass-burning events release significant amounts of fine particulate matter (particulate matter with a diameter of less than 2.5 microns – $PM_{2.5}$) [*Zhang et al.*, 2008].

2 Methods

This experiment was conducted in and around the Desert Research Institute's Storm Peak Laboratory (SPL). SPL is an atmospheric observatory located at the peak of the Steamboat Ski Area (elevation: 3220 m M.S.L.) near Steamboat Springs, Colorado. SPL hosts a full suite of atmospheric composition observation equipment, including gas phase (e.g.

ozone, carbon monoxide, nitrogen oxide and mercury) and particulate (e.g. size-segregated condensation particle counter) observation platforms.

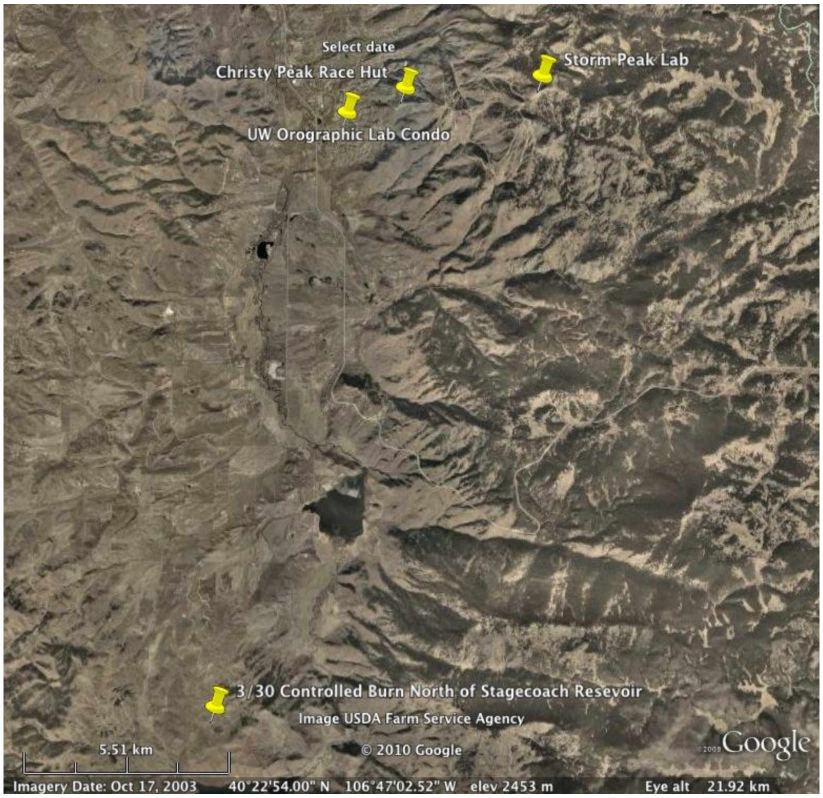

Figure 1: A map showing the relative locations of the three observation points and that of the controlled burn area.

For this study, and in addition to the normal suite of observations conducted at SPL, we employed three TSI model 5820 DustTrak Aerosol Monitors. DustTrak monitors use a 90° light scattering laser diode to detect particulate matter mass concentrations at a resolution of ±0.001mg/m^3.

The three DustTrak monitors were deployed at three different elevations ranging from the floor of the Yampa river valley up to SPL's location on the top of the Mt. Warner ridgeline. Figure 1 is a map depicting the relative location of the three observation points, as well as the location of the Stagecoach controlled burn area.

The lowest observation point (heretofore, the "valley location") was housed in a domestic dwelling at 2076m. Observations were conducted through a down-facing inlet approximately 7 m above the ground and one meter out from the side of the building. A 3 m length of continuous Tygan tubing led from the inlet to the monitor, which was housed inside the climate-controlled dwelling.

A second DustTrak monitor was set up at the "mid-mountain location." This observation site was located at 2439 m and 1.75 km ENE of the valley location. This location also employed a downward-facing Tygan inlet and 3 m length of tubing to lead from outside a climate controlled structure in to the DustTrak monitor. The point of observation here, however, was 1.3 m above the snowpack, and .2 m out from the side of the building.

The third DustTrak monitor was set up in the SPL building. SPL has a special purpose, aerodynamically designed aerosol inlet. A 3 m length of Tygan tubing led from a port on this inlet down to the DustTrak monitor.

The air inflow for all three monitors was run through an aerodynamic impactor plate nozzle to remove particles with diameters larger than 2.5 µg.

Figure 2: a photograph of the smoke plume emitted from the Stagecoach controlled burn. The photo was taken from SPL at 10:30CST on 3/30/2010, and faces SSW.

Figure 3: a photograph of the smoke plume emitted from the Stagecoach controlled burn. The photo was taken from SPL at 3:30CST on 3/30/2010, and faces S.

We set up our DustTrak monitors to conduct one observation per second. These one-per-second observations were then integrated at 60-second intervals to yield a final temporal observation resolution of one minute.

Observations were conducted continuously using all three monitors from 18:00 CDT on 3/29/2010 through 14:00 CDT on 3/31/2010. The weather during this time period was clear and generally spring-like in nature, with synoptic flow dominated by warm air advection from the southwest.

During the daytime hours of March 30th, 2010, a controlled forest fire was conducted in an area 19.2 km SSW of SPL. As is shown in figure 1, the location was up-valley from the area of our observations. The altitude of the burned area was roughly 2400 m.

3 Results

A smoke plume from the Stagecoach controlled burn first became visible from SPL around 10:30 CDT on 3/30/2010. During the morning hours, the fire plume failed rise above the top of ridgelines adjacent to the Yampa Valley. Figure 2 is a photograph of the fire taken from SPL at approximately 11:00am. This photo shows the smoke plume being transported due north of the burned area, with minimal vertical transport to elevations higher than that of SPL.

Shortly after 13:00 CDT, smoke from the stagecoach fire began rising above the maximum vertical height of transport observed during the morning hours. Figure 3 is a photograph of the smoke plume taken from SPL at approximately 15:30 CDT. Here the smoke plume appears to rise to an elevation well above that of SPL. Further, the dominant direction of transport at higher levels appears to be toward the NNE.

Figure 4 shows the observational time series recorded by each of the three DustTrak monitors from 6:00 CDT through 18:00 CDT on 3/30/2010. The red, purple and blue lines denote the valley, mid-mountain and SPL records, respectively.

During the first two hours of the depicted time period, all three records remain relatively stable, with mid-mountain and SPL $PM_{2.5}$ concentrations ranging between 2 and 5 μg/m^3, and valley $PM_{2.5}$ concentrations staying

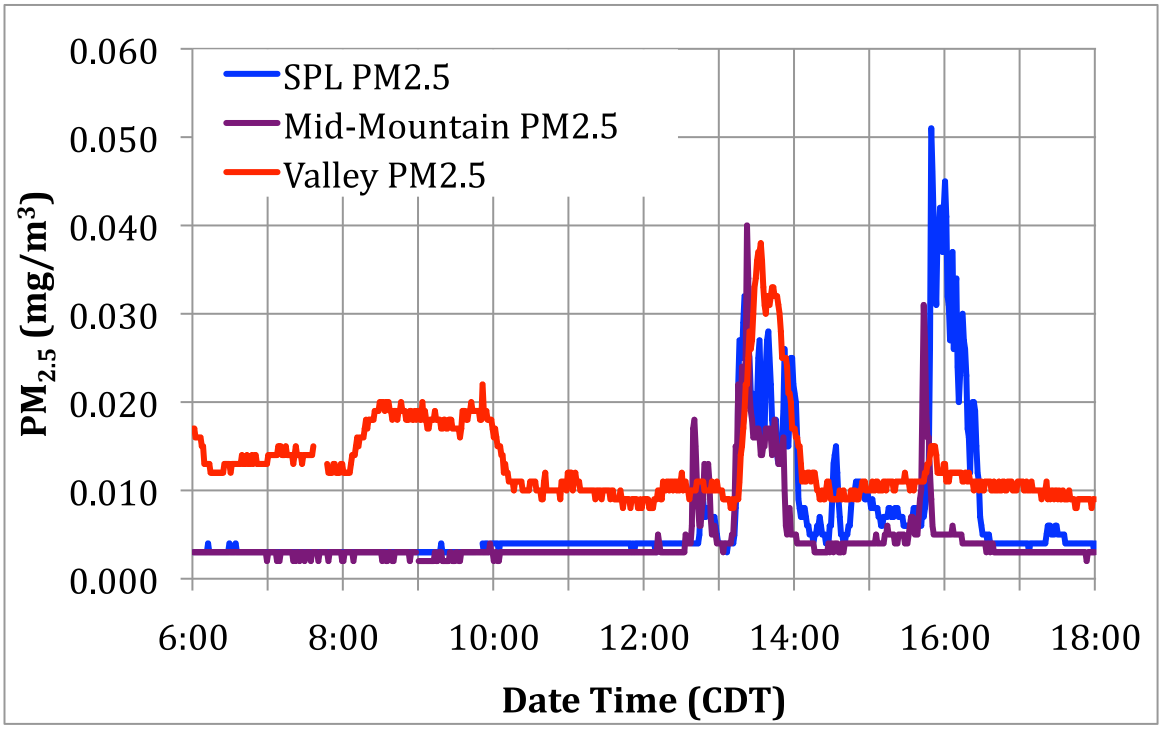

Figure 4: time series plots of PM2.5 concentration observed between 6:00 and 18:00 CDT on 3/30/2010 at SPL (blue line), mid-mountain (purple line) and valley (red line) locations.

between 12 and 15 μg/m³. While the SPL and mid-mountain observations remain stable at the early morning level through 12:30 CDT, the valley observations recorded a period of elevated concentration lasting from approximately 8:00 CDT through 10:10 CDT . During this time, the mean valley $PM_{2.5}$ concentration was 18 μg/m³, and the observations peaked at 22 μg/m³ at 9:51 CDT. After the initial period of elevated valley $PM_{2.5}$ concentration, the valley observations decreased to levels below those observed even in the early morning hours.

Starting at 12:29 CDT, all three records record a period of elevated $PM_{2.5}$ concentration. The SPL and mid-mountain locations record a sharp spike lasting from 13:06 CDT through 13:27 CDT wherein observed $PM_{2.5}$ concentrations reach 32 μg/m³ and 40 μg/m³, respectively. Following this plume, the SPL $PM_{2.5}$ concentration remains generally elevated and highly variable through 15:40 CDT . The mid-mountain observations, however, return to the 3-5 μg/m³ levels observed during the morning hours.

This plume of elevated $PM_{2.5}$ also appears to impact the valley observation site, albeit in a manner slightly different from that observed at higher elevations. The valley PM2.5 concentrations start increasing at approximately the same time (13:13 CDT) as the higher observation points. Though the maximum concentration of 37 μg/m³ is similar in magnitude to that of the other two records, the maximum is not reached as rapidly after the onset of concentration increases, and the elevated concentration initially persists longer and is higher than those observed at higher elevations.

Interestingly, however, while the SPL observations remain elevated and highly variable between 14:00 CDT and 15:40 CDT, the valley and mid-mountain $PM_{2.5}$ concentrations plummet back to pre-fire levels at roughly 14:00 CDT.

A little before 16:00 CDT, a second major peak in $PM_{2.5}$ is observed at SPL, with a maximum concentration of 54 μg/m^3. Unlike during the early afternoon plume, however, this late afternoon plume is not significantly reflected in the valley observations, and only a very short duration spike in concentration was observed at mid-mountain.

Discussion

We believe our observations depict the behavior of wildfire emissions under three distinct atmospheric conditions.

During the early morning, we posit that the fire emissions were trapped by a lapse rate inversion that prevented export of fire smoke above altitudes of more than a couple hundred meters. This is exhibited by the fact that only the valley $PM_{2.5}$ record exhibits elevated concentrations before 12:30 CDT.

Consistent with previous studies of lapse rate inversion dissipation (e.g. *Whiteman et al.*, 2001), the inversion capping the Stagecoach fire emissions lifted through the morning hours as solar insolation warmed the surface boundary layer.

The full dissipation of the lapse rate inversion is observed between 13:00 CDT and 14:30 CDT, where all three observational records exhibit a concurrent spike in $PM_{2.5}$ concentrations of between 30 and 40 μg/m^3.

After 14:30 CDT, the fire emissions are able to rise out of the valley and are thus exported to the NNE by the dominant synoptic flow pattern. Slight temporal variations in the mesoscale flow explain the increased variance in $PM_{2.5}$ concentration observed at SPL during this time. These variations not withstanding, the export of emissions from the surface boundary layer to the free troposphere is clearly exhibited by the return of the valley and mid-mountain observations to the relatively stable concentrations that had been observed during the early morning hours.

References

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