Using In Situ and Satellite Measurements to Track Wildfire Impacts on Air Quality at Mount Bachelor Observatory

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I Introduction

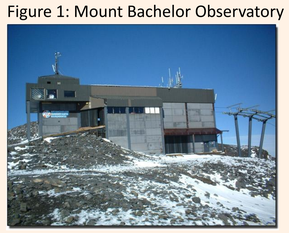
Biomass burning is a significant source of air pollution and can contribute to enhanced levels of aerosols and trace gases including carbon dioxide (CO_2), carbon monoxide (CO), nitrogen and sulfur oxides, methane, and ozone (O_3) [Andreae and Merlet, 2001]. The emissions from North American wildfires have been shown to impact both rural and urban air quality measurements, most notably fine particulate matter ($PM_{2.5}$) and O_3 levels [e.g. Jaffe et al., 2008a; Jaffe et al., 2008b]. Rising temperatures provide increasingly favorable conditions for wildfires in the western United States and there has been a corresponding rise in fire activity in recent years [Westerling et al., 2006]. The potential for further increases in wildfire pollution, as well as a proposed decrease to the U.S. National Ambient Air Quality Standard (NAAQS) for O_3, highlights the necessity of additional studies aimed at quantifying the air quality impacts of fire emissions.

A significant fraction of North American wildfire plumes are injected above the boundary layer [Kahn et al., 2008; Val Martin et al., 2010], which could increase the transport distance of fire emissions. In a study of five years of North American fire events, Val Martin et al. (2010) found a correlation between Multi Angle Imaging SpectroRadiometer (MISR) derived plume injection heights and Moderate Resolution Imaging Spectroradiometer (MODIS) derived fire radiative power. This implies that fires that burn with greater intensity are more likely to be injected higher into the atmosphere.

This study focuses on the air quality impacts of wildfires through an analysis of in situ chemistry measurements and satellite data products. The research questions addressed are:

1. Do fires produce significant O_3 enhancements, and if so, what factors are involved? Do wildfires contribute to O_3 enhancements above U.S. regulatory limits?
2. Is there a correlation between fire chemistry and fire plume injection height?

Figure 1: Mount Bachelor Observatory

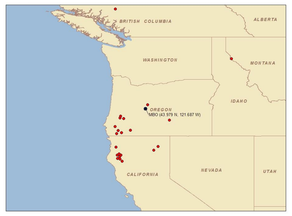


II Study Region

The Mount Bachelor Observatory (MBO) is a mountaintop research station operated by the University of Washington. MBO samples air from the free troposphere and boundary layer and has been used for research on global and regional air quality. Observations of CO, O_3, nitrogen oxides, PAN, aerosols, and mercury have been made since 2004 using a variety of methods documented in previous publications [e.g. Jaffe et al., 2005; Weiss-Penzias et al., 2007]

This study focuses on the emissions from twenty-four wildfires measured at MBO during the summers of 2008-2010. These wildfires originated from the Pacific Northwest region, including northern California (CA), Oregon (OR), Idaho (ID), western Montana (MT), and British Columbia (BC). The map to the right shows the location of these events in relation to MBO.

Figure 2: Map of MBO and Approximate Wildfire Locations



III Methods

Potential fire events were identified in the MBO data as time periods when at least three consecutive hourly averages of CO and aerosol scattering coefficients (σ_{sp}) were measured above a threshold. The thresholds were set at CO ≥ 125 ppbv and σ_{sp} ≥ 20 Mm^{-1}. For each potential fire event, the source was identified using a combination of air parcel back trajectories from the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model, the MODIS-based FIRMS fire mapper (http://firefly.geog.umd.edu/firemap/), MODIS satellite images, and on-the-ground fire incident reports. Only fires that could be verified using a combination of several of these products were included in the analysis. Twenty-seven fires were identified during the summers of 2008-2010 using this process. Next, a linear regression was performed on the CO and σ_{sp} data for each fire and only the twenty-four fires with a significant correlation between the two variables (R^2 ≥ 0.70) were included in this analysis. Figure 3 below shows an example of this correlation analysis.

To test the relationship between O_3 measured at MBO during the wildfire events and the other fire emissions, linear regressions were run between the O_3 data and the CO and σ_{sp} data for each fire event. Two statistical tests were used to assess the degree of correlation: the coefficient of determination (R^2) and the significance value (p-value).

Imagery from MISR were compared with each fire location identified by the process above. Eight of the twenty four fire events identified during this study had MISR overpasses with non-obscured images of the fire plumes. The plume injection height of each of these fires was retrieved from the MISR data using the MINX v1.2 software and methods available through the Open Channel Foundation (www.openchannelsoftware.com/).

Figure 3: Example of Fire Chemistry Correlation Analysis for the September 18-19, 2009 Fire Plume

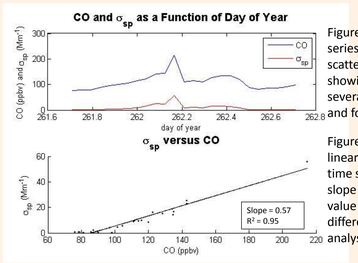


Figure 2, top panel: time series of CO and aerosol scattering coefficient (σ_{sp}), showing the fire event and several hours preceding and following the event.

Figure 2, bottom panel: linear regression of the time series data. The slope of σ_{sp}/CO is the value used to compare different fires in this analysis.

Table 1: Summary of Wildfire Events Analyzed in This Study

Number of wildfire events measured at MBO during the summers of 2008-2010 with statistically significant correlations between CO and σ_{sp}	24
Average σ_{sp}/CO of those events (Mm^{-1}/ppbv)	0.72
One standard deviation of that average (Mm^{-1}/ppbv)	0.30
Number of wildfire events measured at MBO during the summers of 2008-2010 with statistically significant correlations between O_3 and CO	11

IV Ozone Production from Wildfire Emissions

There is a statistically significant ($p<0.05$) correlation between the O_3 and CO data for eleven of the events studied. Of these eleven, events #1 and #11 showed strong correlations (R^2> 0.80). These two events appear to represent different scenarios for O_3 production and transport to MBO. HYSPLIT back trajectories for event #1 show that transport time between the wildfire location and MBO was about three days and that the air mass descended to MBO from higher in the atmosphere, suggesting that the O_3 measured at MBO was produced in transport. Back trajectories for event #11 show that the fire emissions traveled less than one day to reach MBO and remained at about the same atmospheric height throughout this transport. There are several possible origins of the O_3 in this plume: it could have originated from urban areas south of the fire location, it could have been produced from ongoing fires in southwestern OR, or it could have been produced in transport from urban and/or fire primary emissions.

Table 2: Wildfire Events with Statistically Significant Correlations between O_3 and Primary Fire Emissions

Event Number	Location	Date and Time (UTC)	O_3/CO (ppbv/ppbv)	R^2 of O_3/CO	O_3/σ_{sp} (ppbv/ Mm^{-1})	R^2 of O_3/σ_{sp}
1	British Columbia	8/1/2010 8:00 – 8/1/2010 16:00	0.09	0.83	0.31	0.90
2	Central OR	8/5/2010 0:00 – 8/6/2010 0:00	0.08	0.25	0.11	0.33
3	Southwestern OR	8/25/2010 15:00 – 8/26/2010 21:00	0.09	0.24	0.07	0.12
4	ID/ western MT	9/23/2009 18:00 – 9/25/2009 17:00	0.01	0.19	0.01	0.16
5	Northern CA	6/30/2008 0:00 – 7/4/2008 23:00	0.09	0.34	0.11	0.34
6	Northern CA	7/15/2008 14:00 – 7/16/2008 17:00	0.13	0.42	0.20	0.39
7	Northern CA	7/19/2008 18:00 – 7/23/2008 1:00	0.05	0.37	0.04	0.27
8	Northern CA	7/28/2008 16:00 - 7/29/2008 12:00	0.13	0.43	0.13	0.49
9	Northern CA	8/7/2008 15:00 – 8/9/2008 18:00	0.05	0.51	0.05	0.48
10	Southwestern OR	9/14/2008 8:00 – 9/15/2008 12:00	0.06	0.73	0.14	0.74
11	Southwestern OR	9/17/2008 10:00 – 9/18/2008 10:00	0.01	0.85	0.01	0.86

Figure 4: HYSPLIT Back Trajectories of Fire Events #1 and #11

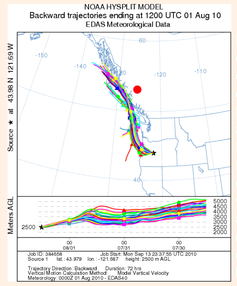


Figure 4, top panel, shows an ensemble of back trajectories for event #1. In this event, fire emissions originating in BC were sampled at MBO. The back trajectories show an air mass high in the atmosphere over BC that descended to the height of MBO over a period of about three days. This suggests that fire emissions were injected high into the atmosphere in BC and the O_3 measured at MBO was produced during the three day transport time between the two locations.

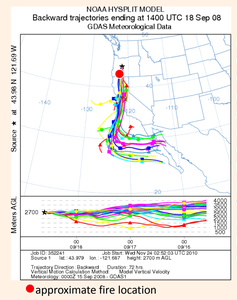


Figure 4, bottom panel, shows an ensemble of back trajectories for event #11. In this event, fire emissions from southwestern OR were sampled at MBO. The ratios of O_3/CO and O_3/σ_{sp} are much lower than in event #1, which could mean that very little O_3 was produced in transport to MBO because of the relatively short transport time (≤1 day). However, it is also possible that the O_3 was produced from urban emissions originating south of the fire.

V Plume Chemistry and Plume Injection Height

MISR imagery is available for eight of the wildfires studied. Using the aerosol and CO data collected at MBO, four of these events can be categorized as having low (<0.65) σ_{sp}/CO ratios and four as having high (>0.90) σ_{sp}/CO ratios. As shown in figure 5, there is a positive correlation between plume chemistry and average plume height, although it is only statistically significant at a 93% confidence level (p=0.07). Future research directions to supplement this initial analysis are discussed in Section VI (Future Work).

Table 3: Wildfire Plume Injection Height and Pollutant Enhancement Ratios

Event Number	Location	Date and Time (UTC)	σ_{sp}/CO (Mm^{-1}/ppbv)	R^2 of σ_{sp}/CO	Plume Injection Height (m)	Mode of Plume Injection Height (m)
1	Southwestern OR	9/18/2009 17:00 – 9/19/2009 17:00	0.57	0.95	750 – 3500	1750
2	Northern CA	7/15/2008 14:00 – 7/16/2008 17:00	0.63	0.92	250 – 3250	2250
3	Northern CA	7/19/2008 18:00 – 7/23/2008 1:00	0.94	0.93	500 – 2750	2000
4	Northern CA	7/24/2008 14:00 – 7/26/2008 7:00	1.02	0.82	1000- 2750	2250
5	Northern CA	8/4/2008 2:00 – 8/6/2008 17:00	0.99	0.94	50 – 2500	2000
6	Northern CA	8/7/2008 15:00 – 8/9/2008 18:00	1.13	0.97	750 – 5250	3250
7	Southwestern OR	9/17/2008 10:00 – 9/18/2008 10:00	0.55	1.00	500 – 3500	1500
8	Southwestern OR	9/24/2008 0:00 – 9/26/2008 1:00	0.48	0.98	1000-2000	2000

Figure 5: Linear Regression of Average Plume Injection Height and Plume Enhancement Ratios

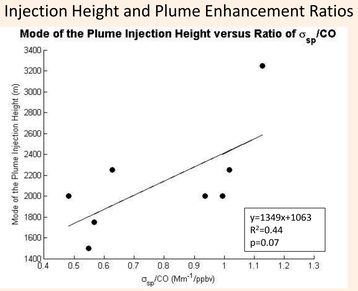
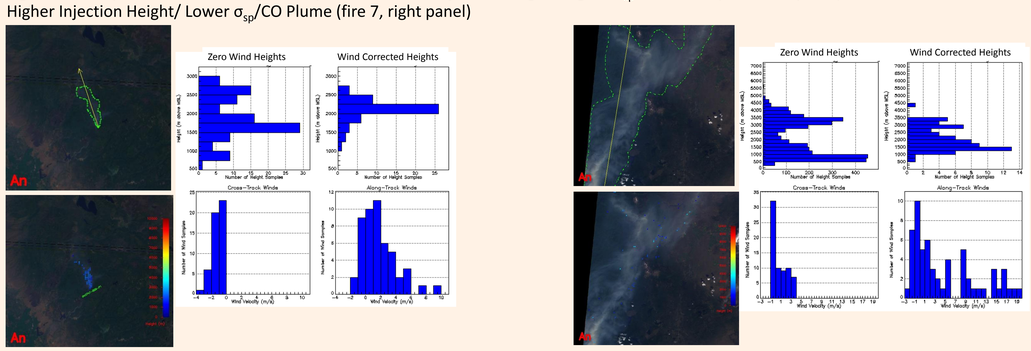


Figure 6: Example MISR Plume Height Analyses for a Lower Injection Height/ Higher σ_{sp}/CO Plume (fire 4, left panel) and a Higher Injection Height/ Lower σ_{sp}/CO Plume (fire 7, right panel)



VI Future Work

Ozone Production from Wildfire Emissions

Future work in this area will focus on refining our understanding of why O_3 is correlated with some wildfire plume emissions measured at MBO, but not others. An unanticipated result of the initial analysis was that measurable enhancements of O_3 may be produced in fire plumes transported in less than one day to MBO. Further analyses will focus on whether the O_3 measured for fire #11 (see Table 2) resulted from fire or urban emissions. One idea to address this point is to calculate the probability of urban emissions producing measureable enhancements of O_3 at MBO. This could be accomplished by comparing numerous back trajectories originating over Californian urban areas with O_3 values measured at MBO on days when no fire plumes were recorded.

Plume Chemistry and Plume Injection Height

We found a positive relationship between plume height and the σ_{sp}/CO ratio, although the result is only statistically significant at a 93% confidence level. Future work in this area will focus on analyzing additional factors that may influence the relationship between plume chemistry and plume injection height. Factors to be considered include atmospheric stability, the type of vegetation in the fire region, wet and dry deposition of aerosols during transport to MBO, and secondary organic aerosol formation during transport. Additionally, in future years, CO_2 measurements will be added the suite of measurements at MBO to allow for the calculation of CO_2/CO ratios in fire plumes.

VII Conclusions

1. Significant enhancements of O_3 due to fire emissions were observed in plumes that arrived at MBO after three days of transport.
2. It is possible that fire plumes traveling over shorter timeframes produce significant enhancements of O_3 at MBO, but further analysis is needed on this point.
3. The data suggest a positive correlation between average plume injection height and the plume chemistry (σ_{sp}/CO).

VIII Selected References

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