Aerosol Chemistry and Processing at Mt. Bachelor Summit during the Biomass Burning Observation Project (BBOP): Influences from Wildfire Plumes

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Mt. Bachelor Observatory (MBO), Oregon, 2.7 km a.s.l.

- The only high elevation/free trop. research site in western U.S.
- Continuous observations of CO, O₃, aerosols and Hg since 2004;
- Frequent detection of Asian pollution and biomass burning plumes;
- In summer 2013 added a High-Resolution Aerosol Mass Spectrometer
Mt. Bachelor Observatory (MBO), Oregon, 2.7 km a.s.l.

- Nafion Dryer
- Bypass: ambient T
  - Thermodenunder (30 – 200 °C)
- High Resolution Aerosol Mass Spectrometer
- LiCOR
- Aerosol light extinction, EC/OC, BC
- $O_3$, CO, $CO_2$, $NO_x$, $NO_y$, VOCs, PAN
- Meteorological data
- Mercury ...
Past Studies on Fires, PM and $O_3$

- MBO is an ideal location to study wildfire plumes due to frequent fires in the PNW and N. Calif.
- 9 publications with MBO data on the relationships between PM, $O_3$ and a variety of wildfire tracers;
- Large uncertainties remain about primary and secondary aerosol production, ozone production and radiative effects of smoke plumes.

Past work by Jaffe’s group has demonstrated large variability in emissions and chemistry from fire to fire. Why? What are the controlling factors?

No BB

PM$_1$ = 2.94 µg/m$^3$

BB

PM$_1$ = 14.8 µg/m$^3$

SO$_4^{2-}$, NH$_4^+$

NO$_3^-$, Cl$^-$

EC (µg/C/L cm$^3$)

CO (ppbv)

Date & Time (PDT)
Whiskey Complex Fire, Aug. 6, 2013

Overlay of G1 and DC8 flight tracks, with MODIS AOD (left) and HYSPLIT Dispersion model (right)
Modified Combustion Efficiency (MCE)

\[ \frac{\Delta CO_2}{\Delta CO + \Delta CO_2} \]

**Smoldering combustion:**
CO, CH4, OVOC, OC, etc.

**Flaming combustion:**
NO, CO2, EC, etc.

smoldering MCE \( \sim 0.80 \)

flaming MCE \( \sim 1.00 \)

Wildland fires vary along a spectrum over time.
Plume Identification & MCE Calculation

Method (Wigder, Jaffe et al.):
- Significant enhancement in CO and aerosol scattering ($\sigma_{sp}$)
- $R^2$ of CO/CO$_2$ > =0.85
- Distinct plume in CO and CO$_2$ that begins and ends at approximately the same concentration (to minimize impact of change in background)
- Fire source identified using satellite imagery and model
- calculate transport time using HYSPLIT trajectories

<table>
<thead>
<tr>
<th>Plume #</th>
<th>Plume Period (PDT)</th>
<th>Duration (hr)</th>
<th>MCE</th>
<th>Suggested Origin</th>
<th>Approx. Transport hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>2013/8/05 09:50 – 11:10</td>
<td>1.3</td>
<td>0.93</td>
<td>SW OR &amp; NW CA</td>
<td>14-34</td>
</tr>
<tr>
<td>19</td>
<td>2013/8/13 05:20 – 09:40</td>
<td>4.3</td>
<td>0.95</td>
<td>N CA</td>
<td>24-30</td>
</tr>
<tr>
<td>20</td>
<td>2013/8/13 09:40 – 12:00</td>
<td>2.3</td>
<td>0.85</td>
<td>N CA</td>
<td>24-30</td>
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<tr>
<td>21</td>
<td>2013/8/15 00:20 – 02:35</td>
<td>2.3</td>
<td>0.89</td>
<td>N CA</td>
<td>10-12</td>
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<tr>
<td>22</td>
<td>2013/8/15 05:00 – 07:05</td>
<td>2.1</td>
<td>0.86</td>
<td>N CA</td>
<td>10-12</td>
</tr>
<tr>
<td>23</td>
<td>2013/8/21 17:30 – 22:30</td>
<td>5.0</td>
<td>0.98</td>
<td>SW OR &amp; NW CA</td>
<td>25-45</td>
</tr>
</tbody>
</table>
Aged fire plumes (1-2 days) at MBO from 2012-2013 shows negative correlation between aerosol scattering enhancement ratio ($\Delta \sigma_{sp}/\Delta CO_2$) and MCE due to:

1) Greater primary emissions of aerosols at low MCE

2) Greater SOA formation at low MCE due to greater emissions of oxygenated VOCs
Influence of MCE on Aerosol Chemistry

P21: MCE = 0.89

P22: MCE = 0.86

P23: MCE = 0.98
Influence of MCE on Aerosol Chemistry

$C_2H_4O_2^+ (m/z = 60)$ is an AMS tracer ion for BBOA

$$f_{60} = \frac{\text{Signal}_{m/z=60}}{\text{overall OA mass}}$$
Influence of BB on Aerosol Chemistry

- BB plume
- No BB

- 8/05 08:00 - 8/06 00:00
- 8/06 03:00 - 8/06 08:00
- 8/06 12:00 - 8/06 22:00 (G1)
- 8/09 08:00 - 8/09 16:00
- 8/12 11:00 - 8/12 17:00
- 8/14 10:30 - 8/14 18:30
- 8/15 06:00 - 8/15 17:30
- 8/16 04:00 - 8/16 14:00 (G1)
- 8/17 07:30 - 8/17 18:00
- 8/21 06:30 - 8/22 11:30
- 8/25 07:00 - 8/25 11:00
PM enhancement ($\Delta PM_{1}/\Delta CO$) in BB Plumes

<table>
<thead>
<tr>
<th></th>
<th>$\Delta Org/\Delta CO$</th>
<th>Transport time</th>
<th>MCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($\mu g \text{ m}^{-3} \text{ ppb}^{-1}$)</td>
<td>(hr)</td>
<td></td>
</tr>
<tr>
<td>P18</td>
<td>0.19</td>
<td>14 - 34</td>
<td>0.93</td>
</tr>
<tr>
<td>P21</td>
<td>0.23</td>
<td>10 - 12</td>
<td>0.89</td>
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<td>0.86</td>
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<td>P23</td>
<td>0.22</td>
<td>25 - 45</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Fresh plume $\sim 0.17$ (G1)
PM enhancement ($\Delta PM_1/\Delta CO$)

- 32 fire plumes observed in 2004-2011
- $\Delta PM_1/\Delta CO$ ratio varied from 0.06-0.42 $\mu g/m^3$ ppb$^{-1}$
- Initial emissions $\rightarrow$ Near-field $\rightarrow$ More distant transport
Conclusions

• Wild fire plumes were frequently observe at Mt. Bachelor summit

• Wild fire plumes characteristics
  – > 90% of PM is organic
  – Variable MCE
  – MCE correlates well with $\Delta$PM/$\Delta$CO$_2$, O/C

• Significant ↑ of $\Delta$PM/$\Delta$CO 1-2 days downwind compared to at sources → indicating SOA formation.
Ozone enhancement in wildfire plumes at the Mount Bachelor Observatory: Role of NOx (Baylon, Jaffe et al., in preparation)

- Analysis of more than 20 fire plumes at MBO in 2012-2013.
- **Negative correlation** between $\Delta O_3/\Delta CO$ and $\Delta NOx/\Delta NOy$ enh. ratios. This shows that degree of oxidation is a primary determinant of $O_3$ production.
- Size of markers proportional to absolute ozone enh. ($\Delta O_3$). This shows that even if $\Delta O_3/\Delta CO$ is low, $\Delta O_3$ may still be significant if CO enhancement is large.