What features of bushfire smoke should be considered in the assessment of public health risk?

Fabienne Reisen | Senior Research Scientist
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Features that influence smoke exposure

1. Fire and fuel characteristics

2. Smoke plume distribution near populated areas

3. Pollutants
**Fire characteristics – Type, size, intensity**

Fires in savannas (grassland) are less intense and have short duration.

Fires in eucalypt forest range from surface to crown fires with varying intensities.

Peat lands possess high fuel loads and can burn over extended periods of time.
# Smoke events in Northeast VIC (2006-2008)

<table>
<thead>
<tr>
<th></th>
<th>Prescribed burns</th>
<th>Wildfires</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Duration</strong></td>
<td>3-48 hrs (average of 15 hours)</td>
<td>69 days</td>
</tr>
<tr>
<td><strong>Intensity</strong></td>
<td>PM$_{2.5}$: 2-30 fold increase</td>
<td>Max daily PM$_{2.5}$: 540 mg/m$^3$</td>
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<tr>
<td></td>
<td>Max hourly PM$_{2.5}$: 39-377 mg/m$^3$</td>
<td>Max hourly PM$_{2.5}$: 1780 mg/m$^3$</td>
</tr>
</tbody>
</table>

![Bar chart showing number of days and hours for prescribed burns and wildfires in Northeast VIC (2006-2008)]
Combustion process

Fuel characteristics (size, structure, moisture)

Oxygen supply
Heat transfer

Ignition

Flammable mixture of tar & gas products

Flaming

CO₂ and H₂O
VOCs, NOₓ, N₂O
EC or BC

Smouldering

CO, CH₄
NMOC, NH₃
PM

Extinction

MCE = \frac{\Delta CO₂}{(\Delta CO + \Delta CO₂)}
## Emission factors (g/kg) for species emitted

<table>
<thead>
<tr>
<th></th>
<th>Tropical forest</th>
<th>Savanna</th>
<th>Boreal forest</th>
<th>Temperate forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$</td>
<td>1643 ± 58</td>
<td>1686 ± 38</td>
<td>1489 ± 121</td>
<td>1637 ± 71</td>
</tr>
<tr>
<td>CO</td>
<td>93 ± 27</td>
<td>63 ± 17</td>
<td>127 ± 45</td>
<td>89 ± 32</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>5.1 ± 2.0</td>
<td>1.9 ± 0.9</td>
<td>6.0 ± 3.1</td>
<td>3.9 ± 2.4</td>
</tr>
<tr>
<td>N$_2$O</td>
<td></td>
<td>0.41</td>
<td>0.16 ± 0.21</td>
<td></td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>9.1 ± 3.5</td>
<td>7.2 ± 3.4</td>
<td>15.3 ± 5.9</td>
<td>12.7 ± 7.5</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>18.5 ± 4.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BC</td>
<td>0.52 ± 0.28</td>
<td>0.37 ± 0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OC</td>
<td>4.7 ± 2.7</td>
<td>2.6 ± 1.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Emissions measurements

- **Laboratory studies**
  - Controlled conditions
  - Detailed studies of chemistry
  - BUT: assume that fire properties in the lab represent combustion properties in the field

- **Field studies – ground level sampling**
  - Sample real fires in undisturbed fuel beds
  - BUT: issue of heterogeneity of smoke

- **Aircraft plume sampling**
  - No heterogeneity of smoke
  - BUT: expensive, complex and requires extensive plumes; need to take into account ageing of the plume
Ground level sampling at prescribed burns

Smouldering combustion of coarse fuels

Flaming combustion of fine fuels
Controlled experiments in the field

Experimental burning of pure samples of each fuel/size class
Laboratory studies

**Pyrotron** – 25 m long fire-proof wind tunnel
- heading/backing fires
- fuel/size class

Working section
1.5 m wide and
4.8 m long
Volkova et al. (2014) Fuel reduction burning mitigates wildfire effects on forest carbon and greenhouse gas emission, IWF.

- Fuel load and fuel moisture used to determine MCE
- MCE used to determine EFs
PM$_{2.5}$ measurements

Leaf litter burn more slowly and produces more smoke with lower MCE

Well-aerated grass burns fiercely and efficiently
Much of the variation in combustion products between fires is due to the way the fuel burns rather than the composition of the fuel.

Combustion properties are critical to determine emission characteristics and are driven by fuel characteristics.
Smoke plumes and exposures

Fresh smoke plume
Complex mixture of toxic air contaminants (gases & particles)
CO, PM, VOCs and SVOCs, NO$_y$, Hg

Aged smoke plume
Ozone formed by photochemical reactions
Secondary organic aerosols
CO, fine particles

Thick smoke (limited photochemistry)
Victorian Alpine fires 2006/07

- Fires started by lightning on Dec 1, 2006
- Area burned: 1,048,238 hectares
- Duration: 69-days
Ozone concentrations in smoke plumes

Victorian Alpine fires 2006/07
- Photochemical formation of ozone in smoke trapped in valley
- Max hourly $O_3 = 150$ ppb
- Max hourly $PM_{2.5} = 1893 \ \mu g/m^3$

Burn ~ 60 km from Manjimup (WA)
- Photochemical formation of ozone in smoke plume
- Elevated $PM_{2.5}$ concentrations for 7-9 hrs
- Max hourly $O_3 = 65.2$ ppb
- Max hourly $PM_{2.5} = 227 \ \mu g/m^3$

Southern California wildfires 2003
(Phuleria et al. (2005) J Geophys Res 110, D07S20)
- Limited photochemistry due to thick smoke
- Hourly $O_3$ decreased from 29 ppb to 15 ppb

Reisen et al. (2011), Atmos Environ, 45, 3944
What pollutants should we consider?
## Particle levels during wildfire events

<table>
<thead>
<tr>
<th>Location</th>
<th>Max hourly PM $[\mu g/m^3]$</th>
<th>Max daily PM $[\mu g/m^3]$</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern CA (2003)</td>
<td>769 (PM$_{10}$)</td>
<td>~ 400 (PM$_{10}$)</td>
<td>7 days</td>
</tr>
<tr>
<td>Montana (2000)</td>
<td></td>
<td>340 (PM$_{2.5}$)</td>
<td>&gt; 30 days</td>
</tr>
<tr>
<td>British Columbia (2003)</td>
<td></td>
<td>200 (PM$_{2.5}$)</td>
<td>&gt; 30 days</td>
</tr>
<tr>
<td>Portugal (2003)</td>
<td></td>
<td>250 (PM$_{10}$)</td>
<td></td>
</tr>
<tr>
<td>Northern CA (1999)</td>
<td>&gt; 1000 (PM$_{10}$)</td>
<td>&gt; 500 (PM$_{10}$)</td>
<td></td>
</tr>
<tr>
<td>Indonesia (1997)</td>
<td></td>
<td>1800 (PM$_{10}$)</td>
<td></td>
</tr>
<tr>
<td>Sydney (1994)</td>
<td>250 (PM$_{10}$)</td>
<td>210 (PM$_{10}$)</td>
<td>8 days</td>
</tr>
<tr>
<td>Victorian Alpine fires (2006/07)</td>
<td>1800 (PM$_{2.5}$)</td>
<td>1100 (PM$_{2.5}$)</td>
<td>69 days</td>
</tr>
<tr>
<td>Melbourne</td>
<td></td>
<td>~ 120 (PM$_{2.5}$)</td>
<td></td>
</tr>
</tbody>
</table>
Chemical composition of particles

- ToF- Aerosol Chemical Speciation Monitor
- Unit mass resolution, no sizing
Gunn Point – Savanna fire season

expect to see ~ 80-90% of PM1 through ACSM lens
PMF analysis applied to ACSM data sets

Deconvolution of mass spectra into component spectra

- HOA – Hydrocarbon-like organic aerosol
- OOA – Oxidized organic aerosol
- BBOA – Biomass burning organic aerosol
- COA – Cooking organic aerosol
Summary

❖ Combustion and fuel characteristics influence smoke production and composition

❖ Emission factors are critical to determine amount of toxic compounds released into the atmosphere

❖ Plume distribution is affected by meteorological conditions and topography

❖ The main hazardous component for public health is fine particulate matter (size and composition)

❖ Impact of other pollutants (e.g. mercury, VOCs) on public health is uncertain
Thank you

CSIRO Oceans and Atmosphere Flagship
Fabienne Reisen
Senior Research Scientist

t +61 3 9239 4435
e fabienne.reisen@csiro.au
Size distribution of bushfire smoke particles

Number distributions on a bushfire day and on a day without strong smoke impact

24-hour MOUDI distributions on two bushfire days and two days without strong smoke impact