Dispersion of Buoyant Emissions from a Low Level Urban Source

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What are needed to know?

- Emissions
- Source characteristics
- Building geometry
- Urban meteorology
What is the significance of urban boundary layer?

Presence of buildings. Decreased mean wind. Increased turbulence.
Tracer Study

Conducted in Palm Springs, CA to obtain data on dispersion from low level and buoyant releases in an urban area

Stack height: 9.3 m
Exit temperature: 460 k
Exit velocity: 11 m/s
Emission rate: 3.3 kg/hr
Sampling Sites

Flagpole: 1 m

48 samplers arranged in arcs at distances from 60 to 2000 m from the source;
Three daytime and four nighttime releases.
Meteorology during releasing periods

<table>
<thead>
<tr>
<th></th>
<th>$U$ (m/s)</th>
<th>$Hs$ (W/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The percentile</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>95$^{th}$</td>
</tr>
<tr>
<td>Daytime</td>
<td>1.1</td>
<td>2.6</td>
</tr>
<tr>
<td>Nighttime</td>
<td>0.8</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Turbulent levels
## Turbulent levels

<table>
<thead>
<tr>
<th></th>
<th>$\sigma_{-w}$ (m/s)</th>
<th>$\sigma_{-v}$ (m/s)</th>
<th>$\sigma_{-w}/U$</th>
<th>$\sigma_{-v}/U$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The percentile Mean</td>
<td>The percentile Mean</td>
<td>The percentile</td>
<td>The percentile</td>
</tr>
<tr>
<td></td>
<td>5th 50th</td>
<td>5th 50th</td>
<td>5th 50th</td>
<td>5th 50th</td>
</tr>
<tr>
<td>Daytime</td>
<td>0.2 0.3 0.4 0.3 0.6 0.7</td>
<td>0.2 0.3 0.3 0.4 0.6</td>
<td>0.2 0.3 0.4 0.6</td>
<td>0.2 0.3 0.4 0.6</td>
</tr>
<tr>
<td>Nighttime</td>
<td>0.06 0.1 0.2 0.1 0.3 0.3</td>
<td>0.1 0.2 0.2 0.3 0.3</td>
<td>0.1 0.2 0.3 0.3</td>
<td>0.2 0.3 0.5 0.5</td>
</tr>
</tbody>
</table>

Meandering is important.
Spatial variation of Observed Concentrations

<table>
<thead>
<tr>
<th></th>
<th>Upwind concentration (µg/m³)</th>
<th>Downwind concentration (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The percentile</td>
<td>Maximum</td>
</tr>
<tr>
<td></td>
<td>30⁰th</td>
<td>50⁰th</td>
</tr>
<tr>
<td>Nighttime</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Daytime</td>
<td>0</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Spatial variation of Observed Concentrations

Daytime

Maximum concentration ($\mu g/m^3$) vs Radial distance (m)

Slope = -1.40

Nighttime

Maximum concentration ($\mu g/m^3$) vs Radial distance (m)

Slope = -0.63
AERMOD

\[
C(x, y, z) = \frac{1}{\sqrt{2\pi}\sigma_z U} H(x, y) \left[ \exp \left( -\frac{(z - h_{eff})^2}{2\sigma_z^2} \right) + \exp \left( -\frac{(z + h_{eff})^2}{2\sigma_z^2} \right) \right]
\]

\[
H(x, y) = f_p H_p(x, y) + \left( 1 - f_p \right) H_r(x, y)
\]

\[
H_p = \frac{1}{\sqrt{2\pi}\sigma_y} \exp \left( -\frac{y^2}{2\sigma_y^2} \right), \quad H_r = \frac{1}{2\pi r}.
\]

Venkatram (2008, CEC)
AERMOD Performance

Including meandering

High plume rise, mixing height, vertical spread?
Sensitivity Studies on Nighttime Prediction

Q-Q plots compare distributions to minimize the scatter associated with inherent uncertainty.

Average plume rise: 35 m
Sensitivity Studies on Nighttime Prediction

Nighttime; urban option off
predicted met. using NWS data

Observed concentration (μg/m³)

AERMOD concentration (μg/m³)

- W/ building downwash
- W/O building downwash
Sensitivity Studies on Nighttime Prediction

Fixed mixing height does not improve the performance. Right panel indicates the mixing heights estimated by AERMET are equivalent to fixed mixed layer height of 120 m.

Vertical spread is too high? Pollutants are trapped?
Modification to AERMOD

Model to estimate dispersion of elevated releases into a shear-dominated boundary layer

Venkatram and Paine (1985)

Fig. 1. Simplified picture of vertical dispersion in the neutral boundary layer.

\[
\begin{align*}
\sigma_{zu} &= \min(\sigma_{zu}, z_i - H_e) \\
\sigma_{zl} &= \min(\sigma_{zl}, H_e) \\
\sigma_z &= \min\left(\frac{\sigma_{zu} + \sigma_{ul}}{2}, \sqrt{\frac{2}{\pi z_i}}\right)
\end{align*}
\]
Conclusions

- AERMOD provides an adequate description of concentrations associated with a buoyant release from the low level source during the daytime.
- AERMOD underestimates concentrations during the night when turbulence is generated by wind shear. A simple modification and onsite meteorology can improve its performance.
Thanks!

www.breeze-software.com