Tropospheric Chemistry and Ground Level Ozone
Tropospheric Chemistry:

• The Formation of Ground Level Ozone
• Ozone Modeling and Air Quality
• Role of Trees in Ozone Formation

Reading:
Chapters 4&6 Environmental Chemistry, G. W. vanLoon. S. J. Duffy
The Troposphere
The Troposphere
Tropospheric Ozone

Natural background due to Troposphere Stratosphere exchange is 20-60 ppb

Often observe Ozone levels >120 ppb near urban centers
Photochemical Smog Event

![Graph showing the concentration of various pollutants over time.](image-url)

- **Concentration (Arb. Units)**
  - Y-axis: Concentration (Arb. Units)
  - X-axis: Time of Day

- **Pollutants**:
  - **Ozone (O$_3$)**
  - **Nitrogen Dioxide (NO$_2$)**
  - **Nitric Oxide (NO)**
  - **Hydrocarbons**
  - **Aldehydes**

The graph illustrates the peak concentrations of these pollutants during a photochemical smog event, with aldehydes reaching their peak around 10 AM and ozone around 12 PM.
Photochemistry of O$_3$

O$_3$ + hv $\rightarrow$ O($^3$P) + O$_2$

ground state, unexcited, atoms

O($^3$P) + O$_2$ $\rightarrow$ O$_3$

combination
The Formation of OH

\[ \text{O}_3 + \text{hv} \rightarrow \text{O}^{(1\text{D})} + \text{O}_2 \]

excited atoms

90% \[ \text{O}^{(1\text{D})} + \text{N}_2,\text{O}_2 \rightarrow \text{O}^{(3\text{P})} + \text{N}_2,\text{O}_2 \] ‘quenching’

10% \[ \text{O}^{(1\text{D})} + \text{H}_2\text{O} \rightarrow \text{OH} + \text{OH} \]
The Formation of OH

\[-\frac{d[O(1D)]}{dt} = k_r[H_2O][O(1D)]\]

\[-\frac{d[O(1D)]}{dt} = k_q[M][O(1D)]\]

\[\frac{k_r[H_2O][O(1D)]}{k_q[M][O(1D)]} = \frac{k_r[H_2O]}{k_q[M]}\]

\[\frac{k_r[H_2O]}{k_q[M]} \approx 0.12\]
Photochemistry of $O_3$

**Hartley Band**

\[ O_3 + h\nu \rightarrow O_2(1\Delta_g) + O(1D) \]

\[ O_3 + h\nu \rightarrow O_2(3\Sigma^-_g) + O(3P) \]

**Huggins Band (>320nm)**

\[ O_3 + h\nu \rightarrow O_2(1\Sigma^+_g \text{ or } 1\Delta_g) + O(1D) \]

**Chappius Band**

\[ O_3 + h\nu \rightarrow O_2(3\Sigma^-_g) + O(3P) \]
Quantum Yields

\[ \phi_i = \frac{\text{# of excited molecules proceeding by process } i}{\text{total # of photons absorbed}} \]

\[ O_3 + h\nu \xrightarrow{a} O_2 + O(3P) \]
\[ O_3 + h\nu \xrightarrow{b} O_2 + O(1D) \]

\[ \phi_a = \frac{\text{# of } O(3P) \text{ atoms formed}}{\text{total # of photons absorbed}} \]

\[ \sum_i \phi_i = 1.0 \]
Photochemistry of $O_3$

Output of $O^1D$ Quantum Yield vs. Wavelength (nm)
Actinic Flux

Actinic Flux (photons s$^{-1}$ cm$^{-2}$) vs Wavelength (nm)

- Wavelength range: 150 to 400 nm
- Actinic Flux range: $10^{10}$ to $10^{16}$ photons s$^{-1}$ cm$^{-2}$

Graph showing actinic flux at different altitudes, with a focus on the 0 km level.
The Formation of OH

\[ \text{O}_3 + \text{hv} \rightarrow \text{O}(^1\text{D}) + \text{O}_2 \]

\[ \text{O}(^1\text{D}) + \text{H}_2\text{O} \rightarrow \text{OH} + \text{OH} \]

Diurnal cycle

Average daytime concentration
\[ [\text{OH}] \sim 1 \times 10^6 \text{ molecules cm}^{-3} \]
The Role of NOx

\[
N_2 + O_2 \rightarrow NO + NO \quad \text{combustion 2500 K}
\]

\[
NO + O_3 \rightarrow NO_2 + O_2 \quad \text{destruction of O}_3
\]

NO, NO\textsubscript{2} are referred to as NO\textsubscript{x}
The Role of NOx

\[ \text{NO}_2 + \text{hv} \rightarrow \text{O}^{(3P)} + \text{NO} \]

ground state atoms

\[ \text{O}^{(3P)} + \text{O}_2 \rightarrow \text{O}_3 \]

formation of O$_3$
Other Sources of NOx

- Ammonia
- Ocean
- Stratosphere
- Fossil Fuel
- Soils
- Lightning
- Biomass Burning
Ozone deposition

NO$_x$ emissions

Clean Atmosphere

OH
The Role of VOC’s

Ozone

$O_2$

NO

$NO_x$ emissions

$OH$

$O_2$

VOC emissions

$OH$

$RO$

$RO_2$

$OH$

$HONO_2$

deposition

$NO_2$

$OH$

$NO_2$

$O_2$

$O_2$

$VOC$

$OH$

$OH$

$VOC$

$VOC$

$OH$
Hydrocarbon Oxidation - alkanes

\[ RH + OH \rightarrow R\cdot + H_2O \] ‘hydrogen abstraction’

\[ R\cdot + O_2 \rightarrow RO_2\cdot \] ‘dioxygen addition’

\[ RO_2\cdot + NO \rightarrow RO\cdot + NO_2 \] ‘oxygen abstraction’

peroxy radicals
Hydrocarbon Oxidation - alkanes

\[ \text{RO} \cdot + \text{NO}_2 \rightarrow \text{RCHO} + \text{HOO} \cdot \quad \text{‘formation of aldehyde’} \]

\[ \text{HOO} \cdot + \text{NO} \rightarrow \text{NO}_2 + \text{OH} \cdot \quad \text{‘regeneration of NO}_2\text{’} \]
Ozone deposition

NO

Ozone

NOx emissions

O2

OH

HONO2

deposition
The Role of VOC’s

Ozone

NO

O₂

NO₂

OH

HONO₂

deposition

NOₓ emissions

RO₂

RO

OH

O₂

VOC emissions
Secondary Reactions: PAN Formation

\[ \text{CH}_3\text{CHO} + \text{OH}\cdot \rightarrow \text{CH}_3\text{CO}\cdot + \text{H}_2\text{O} \]

\[ \text{CH}_3\text{CO}\cdot + \text{O}_2 \rightarrow \text{CH}_3\text{C(O)O}_2\cdot \quad \text{acetylperoxy} \]

\[ \text{CH}_3\text{C(O)O}_2\cdot + \text{NO}_2 \rightarrow \text{CH}_3\text{C(O)OONO}_2 \quad \text{peroxyacetic nitric anhydride (PAN)} \]
## Photochemical Smog

<table>
<thead>
<tr>
<th>Species</th>
<th>Concentration $\mu g m^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Polluted Areas</td>
</tr>
<tr>
<td>CO</td>
<td>10,000-30,000</td>
</tr>
<tr>
<td>$NO_2$</td>
<td>100-400</td>
</tr>
<tr>
<td>Hydrocarbons (not Methane)</td>
<td>600-3,000</td>
</tr>
<tr>
<td>Ozone</td>
<td>50-150</td>
</tr>
<tr>
<td>PANs</td>
<td>50-250</td>
</tr>
</tbody>
</table>


# VOCs in Taipei City

<table>
<thead>
<tr>
<th>Species</th>
<th>Concentration $\mu$g m$^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toluene</td>
<td>980</td>
</tr>
<tr>
<td>m,p-xylene</td>
<td>910</td>
</tr>
<tr>
<td>Benzene</td>
<td>370</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>310</td>
</tr>
<tr>
<td>Hexane</td>
<td>150</td>
</tr>
<tr>
<td>Heptane</td>
<td>130</td>
</tr>
</tbody>
</table>
Methane Oxidation

\[ \text{CH}_4 + \text{OH}\cdot \rightarrow \text{CH}_3\cdot + \text{H}_2\text{O} \]

\[ \text{CH}_3\cdot + \text{O}_2 \rightarrow \text{CH}_3\text{O}_2\cdot \]

\[ \text{CH}_3\text{O}_2\cdot + \text{NO} \rightarrow \text{CH}_3\text{O}\cdot + \text{NO}_2 \]

\[ \text{CH}_3\text{O}\cdot + \text{O}_2 \rightarrow \text{CH}_2\text{O} + \text{HO}_2 \]
Formaldehyde Photolysis

\[ \text{CH}_2\text{O} + \text{hv} (\lambda<330 \text{ nm}) \rightarrow \text{HCO}• + \text{H}• \]

\[ \text{HCO}• + \text{O}_2 \rightarrow \text{HO}_2• + \text{CO} \]

\[ \text{CO} + \text{HO}• \rightarrow \text{CO}_2 + \text{H}• \]
Hydrocarbon Oxidation

\[ \text{RH} \rightarrow \text{R} \cdot \]
\[ \text{RO} \cdot + \text{H}_2\text{O} \rightarrow \text{ROOH} \]

\[ \text{RH} + \text{O}_2 \rightarrow \text{ROO} \cdot \]
\[ \text{NO} + \text{ROO} \cdot \rightarrow \text{RONO}_2 \]

\[ \text{hv}, \Delta \]
\[ \text{RO} \cdot \]

\[ \text{hv} \]
\[ \text{ROOH} \]

\[ \text{O}_2, \Delta \]
\[ \text{R} \cdot \text{CHO} \]

\[ \text{CO}_2 + \text{H}_2\text{O} \]

\[ \text{NO} \]
\[ \text{HO}_2 \]
Alkene Oxidation

RR'C=CR''R''' + OH• → RR'C•-CR''R'''

OH

RR'C•-CR''R''' + O₂ → RR'C-CR''R'''

•O₂
Aromatic Oxidation

\[
\text{Cyclohexyl radical} + \cdot \text{OH} \rightarrow \text{Cyclohexadienyl radical}
\]

\[
\text{Cyclohexadienyl radical} + \text{O}_2 \rightarrow \text{Cyclohexadienyl peroxy radical}
\]

\[
\text{Cyclohexadienyl peroxy radical} \rightarrow \text{Cyclohexadienyl radical} + \text{HO}_2
\]

\[
\text{Cyclohexadienyl radical} + \cdot \text{OH} \rightarrow \text{Cyclohexadienyl radical}
\]

\[
\text{Cyclohexadienyl radical} + \text{O}_2 \rightarrow \text{Cyclohexadienyl peroxy radical}
\]

\[
\text{Cyclohexadienyl peroxy radical} \rightarrow \text{Cyclohexadienyl radical} + \text{HO}_2
\]
Tropospheric Chemistry:

• The Formation of Ground Level Ozone
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Reading:
Chapters 4&6 Environmental Chemistry, G. W. vanLoon. S. J. Duffy
Primary vs. Secondary Air Pollutants:

- Primary pollutants: released directly from sources. Ex. CO, SO$_2$, NOx

- Secondary pollutants: formed through chemical reactions of the primary pollutants. Ex. O$_3$
HO₂• Radical: Interconversion of OH • and HO₂•

\[
\text{HO}_2\bullet + \text{NO} \rightarrow \text{OH}\bullet + \text{NO}_2
\]

\[
\text{OH}\bullet + \text{RCH}_3 \rightarrow \text{H}_2\text{O} + \text{RCH}_2\bullet
\]

\[
\text{RCH}_2\bullet + \text{O}_2 \rightarrow \text{RCH}_2\text{OO}\bullet
\]

\[
\text{RCH}_2\text{OO}\bullet + \text{NO} \rightarrow \text{NO}_2 + \text{RCH}_2\text{O}\bullet
\]

\[
\text{RCH}_2\text{O}\bullet + \text{O}_2 \rightarrow \text{RCHO} + \text{HO}_2\bullet
\]
### Half-life for Reaction with OH and NO₃

<table>
<thead>
<tr>
<th>Molecule</th>
<th>OH</th>
<th>NO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-butane</td>
<td>5 days</td>
<td>205 days</td>
</tr>
<tr>
<td>acetylene</td>
<td>14 days</td>
<td>188 days</td>
</tr>
<tr>
<td>toluene</td>
<td>2 days</td>
<td>138 days</td>
</tr>
<tr>
<td>formaldehyde</td>
<td>1.2 days</td>
<td>16 days</td>
</tr>
</tbody>
</table>

NO₃ reaction rates $10^{-6}$ - $10^{-18}$ cm$^3$s$^{-1}$

OH reaction rates $10^{-13}$ cm$^3$s$^{-1}$
Reduce Hydrocarbon Emission or Reduce Nox Emissions?

“Control Strategies”
### Number of Days Exceeding the Ozone Standard 1984-1990

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas/Fort Worth</td>
<td>19</td>
<td>18</td>
<td>11</td>
<td>11</td>
<td>9</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Tyler/Longview</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>El Paso</td>
<td>8</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>6</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Beaumont/ Port Arthur</td>
<td>13</td>
<td>0</td>
<td>8</td>
<td>3</td>
<td>7</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Houston/Brazoria/Galveston</td>
<td>56</td>
<td>58</td>
<td>48</td>
<td>54</td>
<td>59</td>
<td>37</td>
<td>52</td>
</tr>
<tr>
<td>San Antonio</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Austin</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Corpus Christi</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: Totals include only state and local governmental ozone monitoring sites, not private networks. Source: Texas Natural Resource Conservation Commission, Data Management and Analysis Division, 1995.
Control Strategies for Ozone

- **Control of VOCs**
  - General too abundant to be brought low enough to be the limiting factor.
  - In certain areas, VOCs from biological sources could be significant.

- **Control of NOx**
  - Difficult to control as efficient energy conversion requires high combustion temperature.
Photochemical Smog Event

Concentration (Arb. Units)

Time of Day

O₃
NO₂
NO
Hydrocarbons
Aldehydes
<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Averaging Period</th>
<th>Primary NAAQS Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td>1-Hour</td>
<td>0.125 ppm</td>
</tr>
<tr>
<td></td>
<td>8-Hour</td>
<td>0.085 ppm</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>1-Hour</td>
<td>35.50 ppm</td>
</tr>
<tr>
<td></td>
<td>8-Hour</td>
<td>9.50 ppm</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>Annual</td>
<td>0.03 ppm</td>
</tr>
<tr>
<td></td>
<td>24-Hour</td>
<td>0.14 ppm</td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>Annual</td>
<td>0.053 ppm</td>
</tr>
<tr>
<td>Respirable Particulate Matter</td>
<td>24-Hour</td>
<td>155.00 μg/m(^3)</td>
</tr>
<tr>
<td>(PM10)</td>
<td>Annual</td>
<td>51.00 μg/m(^3)</td>
</tr>
<tr>
<td>Lead</td>
<td>Quarter</td>
<td>1.55 μg/m(^3)</td>
</tr>
</tbody>
</table>

Source: Texas Air Control Board, Texas Air Control Board Fact Sheets: National Ambient Air Quality Standards (Austin: TACB, 1993), 3.
1992 AIR EMISSION OF TOXICS IN MILLIONS OF POUNDS IN TEXAS, SELECTED STATES AND THE U.S.

<table>
<thead>
<tr>
<th></th>
<th>FUGITIVE AIR EMISSIONS</th>
<th>POINT AIR EMISSIONS</th>
<th>TOTAL</th>
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<tbody>
<tr>
<td>Texas</td>
<td>76.1</td>
<td>81.3</td>
<td>157.5</td>
</tr>
<tr>
<td>Tennessee</td>
<td>35.8</td>
<td>91.5</td>
<td>127.4</td>
</tr>
<tr>
<td>Alabama</td>
<td>14.8</td>
<td>80.2</td>
<td>94.9</td>
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<tr>
<td>Ohio</td>
<td>28.2</td>
<td>62.5</td>
<td>90.7</td>
</tr>
<tr>
<td>Louisiana</td>
<td>21.5</td>
<td>67.5</td>
<td>89.1</td>
</tr>
<tr>
<td>Indiana</td>
<td>28.1</td>
<td>57.9</td>
<td>85.9</td>
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<tr>
<td><strong>Top Six States</strong></td>
<td><strong>205</strong></td>
<td><strong>441</strong></td>
<td><strong>646</strong></td>
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<tr>
<td>Wyoming</td>
<td>0.9</td>
<td>1.4</td>
<td>2.3</td>
</tr>
<tr>
<td>New Mexico</td>
<td>0.5</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>North Dakota</td>
<td>0.5</td>
<td>1.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Nevada</td>
<td>0.4</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Vermont</td>
<td>0.3</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Hawaii</td>
<td>0.4</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Bottom Six</strong></td>
<td><strong>3.0</strong></td>
<td><strong>5.3</strong></td>
<td><strong>8.4</strong></td>
</tr>
<tr>
<td><strong>TOTAL U.S.</strong></td>
<td><strong>549.4</strong></td>
<td><strong>1,295.6</strong></td>
<td><strong>1,845</strong></td>
</tr>
</tbody>
</table>

Ozone Isopleth

Does not include transport

Does not include ozone production from previous days

Does not include natural sources of hydrocarbons (NMOC)
Kill Trees or Reduce NOx?: Reducing Ground Level Ozone
Biogenic Non-Methane Organic Compounds (NMOC) Emissions

• Estimated 1150 Tg of carbon yr$^{-1}$ from biogenic NMOCs is emitted worldwide

• NMOC emissions are ~10 times higher than anthropogenic NMOC emissions worldwide (~1.5 in North America)
Impact of Biogenic (non-methane,NMOC) Oxidation

• The contribution of NMOC oxidation to tropospheric $O_3$ formation is estimated to be approximately 75% in parts of the US

• Oxidation of natural hydrocarbons contributes ~20% of the global CO budget

• A significant contribution of submicron aerosol mass is organic matter of biogenic origin
<table>
<thead>
<tr>
<th>Biogenic NMOC</th>
<th>Lifetime(^a) for reaction with</th>
<th>(\text{OH})</th>
<th>(\text{NO}_3)</th>
<th>(\text{O}_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>isoprene</td>
<td></td>
<td>1.4 hr</td>
<td>50 min</td>
<td>1.3 day</td>
</tr>
<tr>
<td>camphene</td>
<td></td>
<td>2.6 hr</td>
<td>50 min</td>
<td>18 day</td>
</tr>
<tr>
<td>3-carene</td>
<td></td>
<td>1.6 hr</td>
<td>4 min</td>
<td>11 hr</td>
</tr>
<tr>
<td>limonene</td>
<td></td>
<td>50 min</td>
<td>3 min</td>
<td>2.0 hr</td>
</tr>
<tr>
<td>myrcene</td>
<td></td>
<td>40 min</td>
<td>3 min</td>
<td>50 min</td>
</tr>
<tr>
<td>(\alpha)-pinene</td>
<td></td>
<td>2.6 hr</td>
<td>5 min</td>
<td>4.6 hr</td>
</tr>
<tr>
<td>(\beta)-pinene</td>
<td></td>
<td>1.8 hr</td>
<td>13 min</td>
<td>1.1 day</td>
</tr>
<tr>
<td>sabinene</td>
<td></td>
<td>1.2 hr</td>
<td>3 min</td>
<td>4.6 hr</td>
</tr>
<tr>
<td>(\beta)-caryophyllene</td>
<td></td>
<td>40 min</td>
<td>2 min</td>
<td>2 min</td>
</tr>
<tr>
<td>longifolene</td>
<td>3.0 hr</td>
<td>50 min</td>
<td>&gt;33 day</td>
<td></td>
</tr>
<tr>
<td>methanol</td>
<td></td>
<td>12 day</td>
<td>1 yr</td>
<td>&gt;4.5 yr</td>
</tr>
<tr>
<td>2-methyl-3-butene-2-ol</td>
<td></td>
<td>2.1 hr</td>
<td>4 day</td>
<td>1.7 day</td>
</tr>
<tr>
<td>cis-3-hexen-1-ol</td>
<td></td>
<td>1.3 hr</td>
<td>2.1 hr</td>
<td>6 hr</td>
</tr>
<tr>
<td>linalool</td>
<td></td>
<td>50 min</td>
<td>3 min</td>
<td>55 min</td>
</tr>
<tr>
<td>1,8-cineole</td>
<td></td>
<td>1.0 day</td>
<td>270 day</td>
<td>&gt;4.5 yr</td>
</tr>
<tr>
<td>cis-3-hexenylacetate</td>
<td></td>
<td>1.8 hr</td>
<td>2.3 hr</td>
<td>7 hr</td>
</tr>
<tr>
<td>6-methyl-5-hepten-2-one</td>
<td>55 min</td>
<td>4 min</td>
<td>1.0 hr</td>
<td></td>
</tr>
<tr>
<td>methyl vinyl ketone</td>
<td></td>
<td>6.8 hr</td>
<td>&gt;1.0 yr</td>
<td>3.6 day</td>
</tr>
<tr>
<td>methacrolein</td>
<td></td>
<td>4.1 hr</td>
<td>14 day</td>
<td>15 day</td>
</tr>
<tr>
<td>3-methylfuran</td>
<td></td>
<td>1.5 hr</td>
<td>3 min</td>
<td>19 hr</td>
</tr>
<tr>
<td>pinonaldehyde</td>
<td></td>
<td>2.9 hr</td>
<td>2.3 day</td>
<td>&gt;2.3 yr</td>
</tr>
<tr>
<td>caronaldehyde</td>
<td></td>
<td>2.9 hr</td>
<td>1.9 day</td>
<td>&gt;2.3 yr</td>
</tr>
<tr>
<td>sabinaketone</td>
<td></td>
<td>2.3 day</td>
<td>130 day</td>
<td>&gt;0.9 yr</td>
</tr>
<tr>
<td>nopinone</td>
<td></td>
<td>10 hr</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>camphenilone</td>
<td></td>
<td>2.3 day</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

\(^a\)With concentrations (molecule cm\(^{-3}\)) of: \(\text{OH}\), 12-hr daytime average of 2.0 \times 10^6; \(\text{NO}_3\), 12-hr nighttime average of 5 \times 10^8; \(\text{O}_3\), 24-hr average of 7 \times 10^{11}.  

\(\text{CH}_4\) lifetime: 10 years
North American Continental Biogenic NMOC Emissions weighted by OH Reactivity

- Isoprene: 50.8%
- Terpenes: 30.9%
- Oxygenated: 16.1%
- Methanol: 0.2%
- Alkenes: 2.0%
North American Isoprene Emission

isoprene emission (nmol m^{-2}s^{-1})
Isoprene Oxidation
The distribution of first generation products has been identified by numerous environmental chamber studies.