Deposition processes
Deposition processes

- In-cloud scavenging (rainout)
- Below-cloud scavenging (washout)
- Dry deposition
- Bi-directional exchange
Aerosol scavenging processes

CCN activation
coalescence

interception

raindrop

diffusion

impaction

interception

diffusion

impaction

Collision efficiency vs. Aerosol diameter, $d_\alpha$ (μm)
Scavenging of gases by liquid clouds and rain

Consider equilibrium

\[ X(g) \rightleftharpoons X(aq) \]

where \( X(aq) \) includes all dissolved species in fast equilibrium. Define effective Henry’s law constant \( K_H^* = \frac{[X(aq)]}{p_X} \)

Then the fraction \( f \) of \( X \) incorporated into the liquid phase is

\[
f = \frac{\{X(aq)\}}{\{X(g)\} + \{X(aq)\}} = \frac{1}{1 + \frac{1}{K_H^* LRT}}
\]

where \( \{ \} \) is concentration in moles per liter of air and \( L \) is the liquid water content (volume water per volume of air)
Effective Henry’s law constants and gas-cloud partitioning

<table>
<thead>
<tr>
<th>Species</th>
<th>$K_H^*$, M atm$^{-1}$ (pH=4.5, $T=280K$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O$_3$</td>
<td>1.8x10$^{-2}$</td>
</tr>
<tr>
<td>PAN</td>
<td>1.1x10$^1$</td>
</tr>
<tr>
<td>CH$_3$OOH</td>
<td>9.5x10$^2$</td>
</tr>
<tr>
<td>CH$_2$O</td>
<td>1.4x10$^4$</td>
</tr>
<tr>
<td>H$_2$O$_2$</td>
<td>4.1x10$^5$</td>
</tr>
<tr>
<td>NH$_3$</td>
<td>5.0x10$^6$</td>
</tr>
<tr>
<td>HNO$_3$</td>
<td>4.3x10$^{11}$</td>
</tr>
</tbody>
</table>

mostly in gas

mostly in cloud
($L \sim 10^{-7}$ v/v)
Variable gas/aerosol scavenging efficiencies in deep convection

**INFLOW:** soluble gases and aerosols

**ENTRAINMENT**

**OUTFLOW**

**precipitation**

**Warm cloud:** scavenging relatively well understood

**Cold cloud:** co-condensation, surface uptake, aerosol scavenging?

**Riming mixed cloud:** retention efficiency upon drop freezing?

Model intercomparison deep convective outflow

Barth et al. [2007]

$\text{H}_2\text{O}_2$

$\text{HNO}_3$
CALIOP satellite data show variable aerosol scavenging

Scavenging is often less efficient than simulated in GEOS-Chem

Mean aerosol vertical profiles, April 2008

Patrick Kim (Harvard)
Dry deposition processes

Standard resistance-in-series model

Deposition flux $F = V(z_1)n(z_1)$

where deposition velocity $V(z_1) = 1/(R_A(z_1) + R_B + R_C)$
Dry deposition velocity of ozone

Monthly mean July values, MOZART model

Louisa Emmons, NCAR
Dry deposition velocity of HNO$_3$

Monthly mean July values, MOZART model

Louisa Emmons, NCAR
Bi-directional exchange

ATMOSPHERE

SEA/LAND

Air resistance \( R_A \)

Sea resistance \( R_S = f(U) \)

Net deposition flux

\[
F = \frac{1}{R_A + \frac{R_S}{K_H}} \left( n_A - \frac{n_S}{K_H} \right)
\]