A Statistical Model of Atmospheric Transport of Contamination over a Long Distance

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Development of the Atmospheric Transport Model

1. Identify the controlling processes
2. Determine statistical relationships among the processes
3. Formulate the model mathematically
4. Demonstrate the model simulations for a hypothetical source
5. Summary
1. Time-averaged regional wind rose (wind speed and direction)

2. Statistics on wet and dry synoptic regions and the associated wet and dry deposition velocities

3. Resuspension caused by wind erosion

4. Soil fixation due to physical, chemical and biological interactions, and downward leaching
Physical processes included in the model

Total Air Concentration

- Primary $X_g$
  - Deposition $(V_w+V_d)X_0$

- Resuspended $X_r$
  - Resuspension $RX_g$

Ground Concentration $X_g$

- Deposition $(V_w+V_d)X_r$
- Soil fixation $\alpha X_g$
### Parameters and their most likely values used in the atmospheric transport model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
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<tbody>
<tr>
<td>$\tau_d$ (46 h)</td>
<td>Expected length of time from an arbitrary moment in a dry period until precipitation begins</td>
</tr>
<tr>
<td>$\tau_w$ (7 h)</td>
<td>Expected length of time from an arbitrary moment in a wet period until dry period begins</td>
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<tr>
<td>$\lambda_d$ ($10^{-5}$ s)</td>
<td>Dry scavenging rate</td>
</tr>
<tr>
<td>$\lambda_w$ ($10^{-4}$ s)</td>
<td>Wet scavenging rate</td>
</tr>
<tr>
<td>R ($10^{-9}$ s)</td>
<td>Resuspension rate</td>
</tr>
<tr>
<td>$\alpha$ (3x$10^{-8}$s)</td>
<td>Soil fixation rate</td>
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</tbody>
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Environmental Compartments

Dry Air \leftrightarrow Ground \leftrightarrow Wet Air

Ground \leftrightarrow Soil
Concentration = Release rate \times Residence time per unit volume
Model Formulation

\[ C_n(r) = Q(r_0) \int_0^\infty P_n(r, t|r_0) dt \]

- \( Q(r_0) \): release rate
- \( P_n(r, t|r_0) \): probability density function
\[ P_n(r,t|r_0) = G_n(t|r_0)D_n(r|r_0) \]

**Gain or loss probability**

**Distribution function**
Modeling the gain or loss probability

Dry air $G_d(t)$ \(-\frac{1}{\tau_d}\) Wet air $G_w(t)$

$1/\tau_d$ \(-\frac{1}{\tau_w}\)$

Dry air $G_d(t)$ to Wet air $G_w(t)$

Soil $G_s(t)$ to Surface $G_g(t)$

$R$ \(-\gamma_v\)$\gamma_s$
Modeling the gain and loss probability functions

\[
\frac{dG_d}{dt} = \frac{1}{\tau_w} G_w + R G_s - \lambda_d G_d - \frac{1}{\tau_d} G_d
\]

\[
\frac{dG_w}{dt} = \frac{1}{\tau_d} G_d - \lambda_w G_w - \frac{1}{\tau_w} G_w
\]

\[
\frac{dG_g}{dt} = \lambda_d G_d + \lambda_w G_w - (R + \alpha)G_g
\]

\[
\frac{dG_s}{dt} = \alpha G_g
\]
Temporal evolutions of the gain and loss probabilities

Initial condition: $G_d(0) = 1$, $G_w(0) = G_g(0) = G_s(0) = 0$
Temporal variations of gain and loss probabilities

Initial condition: $G_g(0) = 1$, $G_d(0) = G_w(0) = G_s(0) = 0$
Modeling the distribution functions

1. Air

\[ D(r|r_0) = P_V(r|r_0) \ P_H(r|r_0) \]

\[ P_V(r|r_0) = 1 \]

\[ P_H(r|r_0) = f(u, \theta)/2\pi r \]

where \( f(u, \theta) \) describes relative frequency with which the wind blows from \( \theta \) direction at a speed \( u \).
Modeling the distribution functions

2. ground and soil

\[ \frac{dC_g}{dt} = \left( P_d V_d + P_w V_w \right) C_s - (R + \alpha) C_g \]

\[ \frac{dC_s}{dt} = \alpha C_g \]

where \( P_d = \frac{\tau_d}{\tau_d + \tau_w} \) and \( P_w = \frac{\tau_w}{\tau_d + \tau_w} \) are the local probabilities of dry and wet states, respectively.
Variations of concentrations with time at 10 km from the source
Normalized air concentration $C_a/Q$ [a km$^{-3}$]
Normalized ground concentration $C_g/Q$ [a km$^{-2}$]

$T = 100$ years
Normalized soil concentrations $C_s/Q$ [a km$^{-2}$]

T=100 years

T=1000 years
Summary

- A statistical long-term atmospheric transport model for assessing environmental impact has been developed
- The model emphasizes the role of the atmosphere in redistributing contamination between the air and the underlying surfaces
- It explicitly accounts for dispersion, deposition and resuspension of contaminated tracer material, using a set of statistical parameters
- The model is time-dependent, and is best suited for long-term environmental assessments of air and ground contamination