Fundamentals of Spray Cloud Dispersal

SprayAdvisor Workshop
Mattawa, ON
May 20, 2008
Acknowledgments

- Steve Edburg, Washington State University
- Mike Greer, Florida A&M
- Jim Kautz and Ian Grob, Missoula Tech. and Dev. Ctr., USDA-FS
Dispersal ?
Dispersal?

- **Deposition Near Field (On target, near target)**
- **Deposition Far Field (Drift, Off target)**
- **Evaporation**
- **Other Chemical Transformation**
- **Secondary Movement (Re-entrainment by wind, other physical transport (water, vehicles etc.), contagion)**
Cloud?
Cloud?

• Droplets are modeled individually and then statistically aggregated
• ‘Neighborhood’ effects may be important
• Droplet movement largely dependent on droplet size
• Aggregate movement of airborne ‘cloud’ may be misleading because it may contain small percentage of mass
3-D GAUSSIAN DISPERSION
Control of Spray

- Droplet Size
- Release Height
- Wind Speed
Aircraft Information
Aircraft Type (fixed wing, biplane, helicopter)
Aircraft Semispan or Rotor Radius
Spraying Speed
Rotor Blade RPM (helicopter)
Aircraft Weight
Aircraft Drag Coefficient
Aircraft Planform Area
Engine Efficiency
Propeller RPM
Propeller Blade Radius
Propeller Location
Nozzle Information
Number of Nozzles
Nozzle Type
Nozzle Locations

Droplet Size Distribution
Spray Material Information
Tank Mix Specific Gravity
Tank Mix Flow Rate
Tank Mix Nonvolatile Fraction
Tank Mix Active Fraction
Evaporation Rate

Meteorological Information
Wind Speed
Height of Wind Speed Measurement
Surface Roughness
Wind Direction
Wetbulb Temperature Depression (Temperature and Relative Humidity)
Cloud Cover
Time of Day
Operational
Spraying Height
Number of Swaths
Swath Width
Swath Displacement

Canopy
  Canopy Height
  Canopy Density
  Element Size
Ft. Myers Larvicide 1

1 m/s
Fort Myers-Larvicide 1
2.5 m/s
Ft. Myers Larvicide 1

5 m/s
Humidity

Atmospheric humidity influences the evaporative environment around liquid droplets. This can effect atmospheric transport by influencing droplet size. Atmospheric water vapor also has the more subtle effects of changing the radiative energy balance and storing latent thermal energy.
Temperature

The vertical temperature gradient determines stability while the absolute temperature influences evaporation.
<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Bell 206B Jet Ranger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release Height</td>
<td>9.14 m</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>3.13 ms⁻¹</td>
</tr>
<tr>
<td>Number of Nozzles</td>
<td>47</td>
</tr>
<tr>
<td>Spray Volume Rate</td>
<td>93.5 Lha⁻¹</td>
</tr>
<tr>
<td>Non-Volatile Fraction</td>
<td>.5</td>
</tr>
<tr>
<td>Active Fraction</td>
<td>.075</td>
</tr>
<tr>
<td>Temperature</td>
<td>21.1°C</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>75%</td>
</tr>
<tr>
<td>VMD</td>
<td>852 µm</td>
</tr>
<tr>
<td>Swaths</td>
<td>20</td>
</tr>
</tbody>
</table>
Wind Speed Dependence

• The following graph shows the modeled results of deposition downwind of the spray block for four wind speed scenarios. The solid line is the base case, the wind speeds progressing from finer dash to coarser are 4.47ms$^{-1}$, 1.79ms$^{-1}$ and .45ms$^{-1}$ respectively.
Humidity Dependence

• This graph shows the dependence of downwind deposition on humidity (modeled as relative humidity). The base case is the solid line. The modeled humidity varies from coarser dash to finer as 15%, 35%, 55% and 95% respectively.
Comparison of Low Drift and High Drift Scenarios

• The following graph shows a comparison of drift results between the base case (solid line), a high drift scenario with release height of 13.7 m, VMD of 521µm, relative humidity of 35% and wind speed of 4.5 ms-1 (dotted line) and a low drift scenario with release height of 4.6m, VMD of 1182µm, relative humidity of 100% (simulating a non-volatile spray) and wind speed of 1.8 ms-1 (dashed line).
Atmospheric Stability

Atmospheric Stability is a measure of the temperature change with height in the atmosphere. The Atmospheric Stability influences the Turbulence and thereby the dispersion of the released droplets.
An equivalent volume of warm air is lighter than cold air.
Shortwave Radiation

\[ (\lambda)_{\text{max}} = \frac{C_w}{T} \]

Longwave Radiation
\[ T_2 \approx 0^\circ \]

\[ \Delta E = \sigma (T_1^4 - T_2^4) \]
The term ‘inversion’ is synonymous with a stable layer in the atmosphere. In stable thermal layers, mixing is suppressed and both dispersion and translation (movement with the mean wind) is slow. This is typical of clear nocturnal conditions.
### Pasquill Stability Categories

<table>
<thead>
<tr>
<th>Surface wind speed (at 10 m) m/sec</th>
<th>Insolation</th>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strong</td>
<td>Moderate</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>A-B</td>
</tr>
<tr>
<td>2-3</td>
<td>A-B</td>
<td>B</td>
</tr>
<tr>
<td>3-5</td>
<td>B</td>
<td>B-C</td>
</tr>
<tr>
<td>5-6</td>
<td>C</td>
<td>C-D</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>D</td>
</tr>
</tbody>
</table>

The neutral category, D, should be assumed for overcast conditions during day or night.

- A—Extremely unstable
- B—Moderately unstable
- C—Slightly unstable
- D—Neutral
- E—Slightly stable
- F—Moderately stable
Winnfield SF6 Trials

LEGEND

- Sampling mounts at 1.5m
- Sampling mounts at 1.5 and 3m
- Sampling mounts at 3.5 and 5m
- Sun tower with mounts at 1.5m, 3m, 10m, 30m

SOURCE

50 samples will be deployed each test. Sampler positions will be based on wind direction.

A  1-5
B  6-12
C  13-20
D  > 20

(S)
Aircraft Wake Vorticity vs. Atmospheric Stability

Unstable

Neutral

Stable

T=20

T=30
The diagram shows the relationship between $f_{S_u}(f)/\sigma^2$ and $f_{h_c}/u_{hc}$ for different values of $f_{h_c}/u_{hc}$, represented by lines with different colors and styles. The graph is labeled "u at 22.9 meters for Unthinned." A green line with a slope of $-2/3$ is also plotted on the graph.
Four Primary Wavelengths

Kaingaroa Forest, February 1, 2002

1:45 pm
Discussion

• 50μm drops have nearly circular trajectories in the larger vortices analyzed here.

• 350μm drop trajectories are not substantially altered by the smallest vortices analyzed here.
Uncertainty

• Typical forestry herbicide drop is ASAE Coarse (VMD 380 micron)
• ASAE Coarse shows a CVF <40 microns of .0004
• A 400 micron drop has a settling velocity of 1.6 m/s
• A 40 micron drop has a settling velocity of .012 m/s
Uncertainty

• Landing position of large drops can be accurately known
• Landing position of small drops is known with less accuracy
• The landing position of the vast majority of the mass is well known
• There will always be some small fraction of the mass that will be tracked with less certainty
Spray On Time (sec)

$D_{V0.5}$ (µm)
What is AGDISP?

AGDISP is a computer model that simulates the fate, transport and deposition of spray or granular material released from aircraft or ground rigs. It is used primarily to calculate the amount and location of material deposited on the target area to evaluate coverage and to evaluate the amount of material that misses the target (drift).

AGDISP is used by the FS and states to develop environmental documentation and for training purposes.

It is used by the regulators as a risk assessment tool.

Applicators use the model as a planning and evaluation tool.

It is occasionally used in litigation.

It is routinely used to identify data gaps and quantify the state-of-the-art in applied application technique.
Utility

- Around 850 registered users of AgDRIFT/AGDISP models.
- Used routinely by EPA for risk assessment input.
- Used routinely in applicator training worldwide.
- Used in Environmental Assessments, EIS and other environmental documentation.
- Used in design, planning and evaluation of spray projects in forestry, agriculture and disease vector control.
- Identifies data gaps in the understanding of the science and engineering.
- Provides a platform to quantify and understand new application techniques and approaches.
- Used in off-the-shelf in-cockpit systems to allow applicator adjustment on the fly.
AGDISP

Title: Mattawa

Application Method:
- Method: Aerial
  - Aircraft: Air Tractor AT-401
  - Release Height: 30.48 m
  - Spray Lines: 20

Application Technique:
- Liquid
  - Nozzles: 42 nozzles
- Dry
  - Details: Venturi Spreader

Meteorology:
- Wind Speed: 2.24 m/s
- Wind Direction: 90 deg
- Temperature: 18.33 deg C
- Rel. Humidity: 50%

Surface:
- Upslope Angle: 0 deg
- Sideslope Angle: 0 deg
- Canopy: 21.34 m (Height)

Spray Material:
- Material: Water
  - Details:

Atmospheric Stability:
- Stability: Overcast

Transport:
- Distance: 0 m
- Height: m

Advanced Settings:
- Advanced
Line Source Projection

- AGDISP originally two dimensional (x,z)
- GIS applications require x and y (z is still necessary in the modeling)
To correct for this effect, the line source is projected and $Q_L$ is adjusted so that

$$Q_{LP} = Q_L \left(\sin(\Theta)\right)^{-1}$$

Note that with a perpendicular wind ($\Theta=90^\circ$),

$$Q_{LP} = Q_L$$

In the limit as $\Theta \to 0^\circ$, $L'$ is set to the aircraft span length ($S$).
<table>
<thead>
<tr>
<th>Drop Distribution Name</th>
<th>ASAE Fine to Medium</th>
</tr>
</thead>
</table>

**Drop Distribution Type**

- **User-defined**
  - Interpolate
  - Import
  - Parametric

- **Reference Distributions**
  - ASAE Fine to Medium

**Drop Distribution**

<table>
<thead>
<tr>
<th></th>
<th>Average Diameter [μm]</th>
<th>Incremental Volume Fraction</th>
<th>Cumulative Volume Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.77</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>2</td>
<td>16.73</td>
<td>0.0003</td>
<td>0.0013</td>
</tr>
<tr>
<td>3</td>
<td>19.39</td>
<td>0.0007</td>
<td>0.002</td>
</tr>
<tr>
<td>4</td>
<td>22.49</td>
<td>0.0003</td>
<td>0.0023</td>
</tr>
<tr>
<td>5</td>
<td>26.05</td>
<td>0.0007</td>
<td>0.003</td>
</tr>
<tr>
<td>6</td>
<td>30.21</td>
<td>0.001</td>
<td>0.004</td>
</tr>
<tr>
<td>7</td>
<td>35.01</td>
<td>0.001</td>
<td>0.005</td>
</tr>
<tr>
<td>8</td>
<td>40.57</td>
<td>0.002</td>
<td>0.007</td>
</tr>
<tr>
<td>9</td>
<td>47.03</td>
<td>0.0033</td>
<td>0.0103</td>
</tr>
<tr>
<td>10</td>
<td>54.5</td>
<td>0.0053</td>
<td>0.0156</td>
</tr>
<tr>
<td>11</td>
<td>63.16</td>
<td>0.0067</td>
<td>0.0223</td>
</tr>
<tr>
<td>12</td>
<td>73.23</td>
<td>0.009</td>
<td>0.0313</td>
</tr>
<tr>
<td>13</td>
<td>84.85</td>
<td>0.0133</td>
<td>0.0446</td>
</tr>
<tr>
<td>14</td>
<td>98.12</td>
<td>0.0223</td>
<td>0.0669</td>
</tr>
</tbody>
</table>

- **Dv0.5**: 254.72 μm
- **Relative Span**: 1.3

**Buttons**

- Insert
- Delete
- Clear
- OK
- Cancel
Swath Width

Prior to a project, the relationship (use units of mass)

\[ Q = S_w \cdot V \cdot A_R \]

Where \( Q \) is the flow rate (source strength, kgs\(^{-1}\)), \( S_w \) is the swath width (m), \( V \) is the aircraft speed (ms\(^{-1}\)) and \( A_R \) is application rate (not actually a rate strictly speaking, kgm\(^{-2}\)), is evaluated.
Swath Width

For the purposes of modeling

\[ Q_L = S_w \ A_R \]

where \( Q_L \) is lineal source strength (kgm\(^{-1}\)).
Swath Width = 20m

Swath Width = 40m
This has been addressed in AGDISP Version 8.15 by allowing the user to input Q directly. In this approach,

\[ Q_L = QV^{-1} \]

where V is obtained from the aircraft library. This then eliminates \( S_w \) from the calculation of \( Q_L \).
Canopy Height: 21.34 m
AGDISP Stakeholders

- US Environmental Protection Agency
- USDA Forest Service
- Canadian Forest Service
- Agricultural Chemical Manufacturers (SDTF, CLA)
- Pest Management Regulatory Authority (PMRA)
- SERG, International (MN, NB, ON, US)
- Forest Protection Limited (FPL)
- National Council of Air and Stream Improvement (NCASI)
- SCION (NZ)
- American Mosquito Control Association
- US Army