Fundamentals of Air Dispersion Modelling

Fate and Transport Phenomena

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- Course overview
  - The earth's atmosphere
  - Basic air quality meteorology
  - Plume rise mechanics
  - The Gaussian Plume Model
  - Puff Models
  - Models Approved under O. Reg. 419/05
    - Models in the Appendix to O. Reg. 346
    - AERMOD
    - ASHRAE

THE ATMOSPHERE

The Atmosphere

The Atmosphere

- The atmosphere is the thin layer above the surface of the earth that sustains pretty much all life as we know it.
- Some liken it to the thickness of the skin on an apple, if the apple were the earth.
- Despite it's relative thinness, it is complex, and broken up into many different layers, defined by temperature, pressure and composition.

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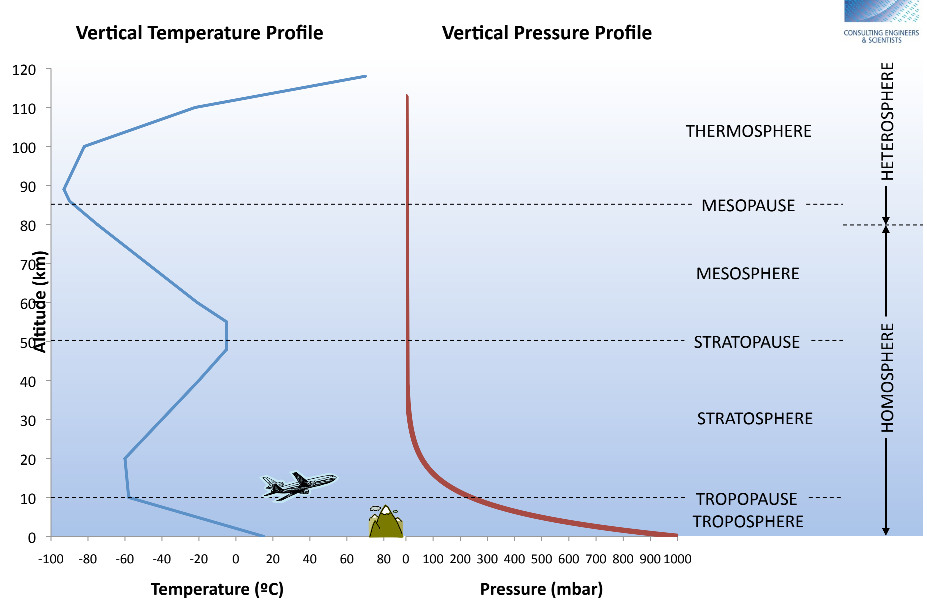
The Atmosphere



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The Atmosphere

- The temperature profile is perhaps the most complex.
- This has to do with the complex interaction of energy transfer and the changing chemistry of the atmosphere.
- By contrast, the pressure profile is quite simple.

The Atmosphere

- The composition is divided into only two main categories:
  - Homosphere: The lowest layer, up to ~80 km, where the composition of the atmosphere is generally homogeneous. It also includes the "ozone layer", between ~10 and 60 km.
  - Heterosphere: Layer above ~80 km and into space, where the chemical composition is layered according to the molecular weight of the gases, with the heaviest near the bottom.

The Atmosphere

SUBSTANCE	VOLUME (%)	CONCENTRATION (ppm)*
Nitrogen	78.084 ± 0.004	780 900
Oxygen	20.946 ± 0.002	209 400
Argon	0.934 ± 0.001	9 300
Carbon dioxide	0.033 ± 0.001	315
Neon		18
Helium		5.2
Methane		1.2
Krypton		0.5
Hydrogen		0.5
Xenon		0.08
Nitrogen dioxide		0.02
Ozone		0.01-0.04

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The Atmosphere

- For typical air quality studies, we are most interested in the lower levels of the atmosphere (the troposphere and the homosphere).
- This region is also most affected by the exchange of radiation between the sun and the earth.
- The radiation exchange is the driving force behind what we refer to as meteorology.

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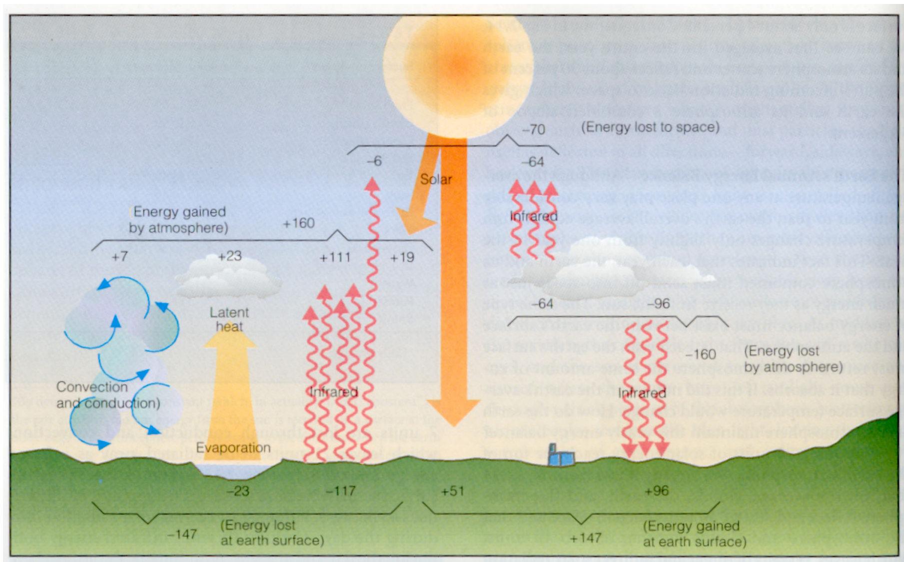
The Atmosphere



METEOROLOGY

Meteorology

- Within the lower levels of the troposphere and homosphere, yet another set of regions can be defined, this time based on meteorology.
- The meteorological conditions found in these regions will determine the transport of contaminants.
- In other words, the processes that drive meteorology will drive dispersion.

Meteorological Regions

Free Atmosphere		MACRO-METEOROLOGICAL REGION • Begins somewhere between 500 and 1000 metres above the earth. • Horizontal scales on the order of 10's to 100's of kilometers. • Surface friction does not affect wind velocity. • Winds determined by pressure gradient force and the Coriolis effect.
Planetary Boundary Layer		MESO-METEOROLOGICAL REGION • Horizontal scales on the order of 10's of kilometers. • Region of transition. • Surface friction has a varying effect on the wind velocity. • Winds are determined by a balance between the pressure gradient force, Coriolis effect, surface friction and temperature gradients.
	Surface Layer	MICRO-METEOROLOGICAL REGION • Usually extends from the surface to 50 to 100 metres above the earth. • Horizontal scales on the order of 100's of metres to a few kilometers. • Surface friction has the dominant effect on wind velocity. • Winds determined by surface friction and temperature gradients.

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Meteorological Regions - Boundary Layer

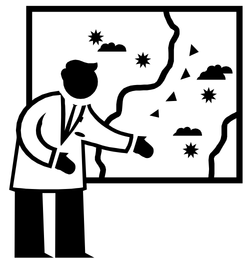
- The planetary boundary layer (PBL) is the region of the atmosphere that is adjusted to the surface underneath.
- The state of the PBL is determined by the properties of the surface (land use, Bowen ratio, roughness length, etc.)
- Quantities within the PBL, such as heat, momentum, water vapour or pollution tend to want to stay in the PBL.

Meteorological Regions – Horizontal Scales

- Each region also identifies a relevant horizontal scale at which we consider winds and temperature profiles.
- Meteorological conditions on one scale can be very different from those on another scale (consider regional winds versus those experienced in a downtown core, or right next to a stack).

Meteorological Regions – Horizontal Scales





Microscale (metres to 10's of m)

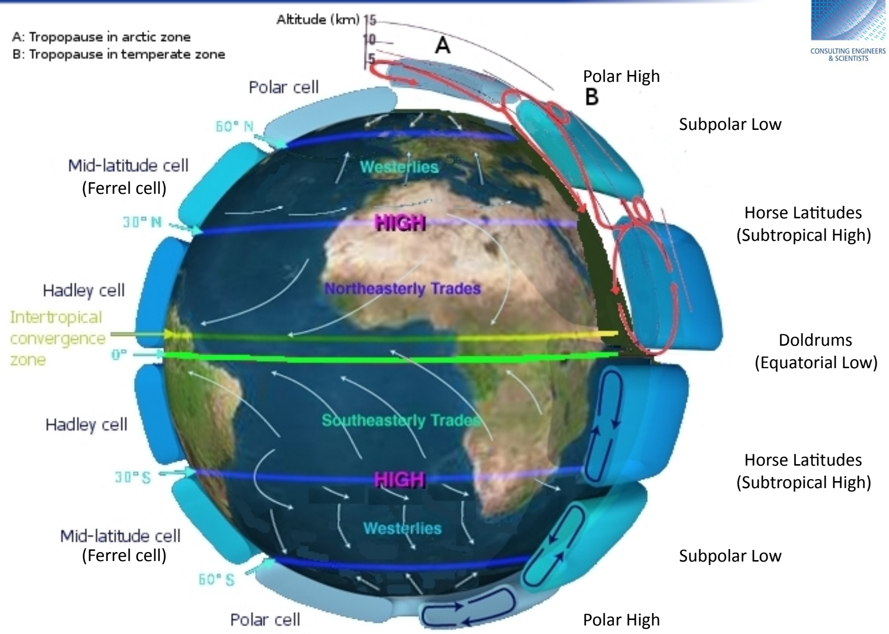
Mesoscale (10's of km)

Macroscale (10's to 100's of km)

Meteorology – Winds

- At the synoptic (macro) scale, winds are caused by the difference in pressure between one location to another.
- These differences are caused by uneven heating of the earth's surface.
- These "synoptic" winds are then "bent" due to the Coriolis effect, which causes winds to deflect to the right (in the northern hemisphere).

Meteorology – Winds



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Meteorology – Winds

- At the mesoscale level, winds will be impacted by geographical features, such as large bodies of water (e.g., sea breezes) and hills, mountains and valleys.
- At the microscale level, winds will be further impact by the influence of trees, buildings, and stacks (e.g., stack tip downwash).

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Meteorology – Atmospheric Stability

- Our knowledge of winds allows us to begin estimating the direction and speed at which a contaminant will move.
- The next step is to estimate how the contaminant spreads out (disperses) as it moves downwind.
- The mechanism that drives this dispersion is turbulence.

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Meteorology – Atmospheric Stability

- There are two major forms of turbulence:
  - Thermal turbulence – "the pilot has switched on the fasten seat-belts sign…"
  - Mechanical turbulence – "brace for impact"
- Both affect dispersion, at different scales.
- Thermal turbulence is linked to the vertical temperature profile in the PBL, and we'll discuss this first.

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Meteorology – Atmospheric Stability

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- Air temperatures normally decrease with height – the rate of decrease is called the lapse rate.
- Under dry, adiabatic (no heat flows in or out of a system) conditions, this lapse rate would be 9.8 °C/km.
- This is known as the Dry Adiabatic Lapse Rate (DALR), and serves as an “ideal” or reference value, and represented by Γ.

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Meteorology – Atmospheric Stability

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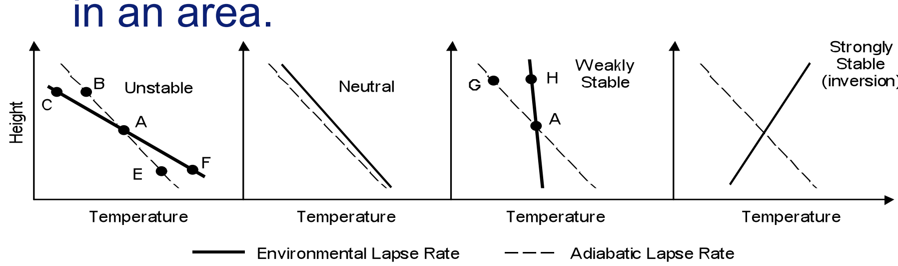
- In nature, what we actually observe is the “Actual Lapse Rate” or “Environmental Lapse Rate”, often represented by γ.
- The difference between the two gives us an idea of the level of thermal turbulence in an area.



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Meteorology – Atmospheric Stability

- Comparisons of actual lapse rate γ versus adiabatic lapse rate Γ provides information on atmospheric stability
  - Unstable conditions ($\gamma > \Gamma$) lead to enhanced vertical mixing and better dispersion of a plume
  - Neutral conditions ($\gamma \approx \Gamma$) lead to "normal" vertical mixing and "normal" dispersion of a plume
  - Stable conditions ($\gamma < \Gamma$) lead to diminished vertical mixing and retards dispersion of a plume

Meteorology – Atmospheric Stability

- Several methods of defining atmospheric stability have been developed.
- The most common was the Pasquill Gifford (P-G) stability class system, which ranks stability classes from A (extremely unstable) through to F (moderately stable).
- Pasquill also developed a fairly simple method for estimating stability based on direct observations.

Meteorology – Atmospheric Stability

A: Extremely unstable conditions	D: Neutral conditions*
B: Moderately unstable conditions	E: Slightly stable conditions
C: Slightly unstable conditions	F: Moderately stable conditions

Surface Wind Speed (m/s)	Daytime Insolation†			Night-time Conditions‡	
	Strong	Moderate	Slight	Thin overcast or > ½ low cloud	≤⅜ cloudiness
<2	A	A-B	B	--	--
2-3	A-B	B	C	E	F
3-4	B	B-C	D	D	E
4-6	C	C-D	D	D	D
>6	C	D	D	D	D

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Meteorology – Atmospheric Stability

- More advanced models (e.g., AERMOD), use a very different approach to estimating atmospheric stability.
- Mixing height and Monin-Obukhov length are the two parameters used for this.
- The mixing height is the vertical height in the atmosphere where the dispersion of pollutants can take place.

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Meteorology – Atmospheric Stability

- It rises during the day as solar radiation generates more and more turbulence.
- As the earth cools after the sun sets, the reverse happens, and the mixing height lowers back to near the surface.
- Above this layer, the atmosphere will be capped by a temperature inversion (stable layer).

Meteorology – Atmospheric Stability

- Monin-Obukhov length is the height at which mechanically-produced turbulence is in balance with the buoyancy-produced turbulence.
- Below this level, mechanically-produced turbulence dominates, while above it the reverse is true.
- Models such as AERMOD use this to help further define atmospheric stability.

Meteorology – Inversions

- An inversion is a rapid change in the vertical temperature profile, where there is a sudden transition into a stable layer.
- Inversions can act as a "lid" on lower regions of the atmosphere, restricting dispersion.
- Contaminants released above an inversion will also seldom impact the ground, however.

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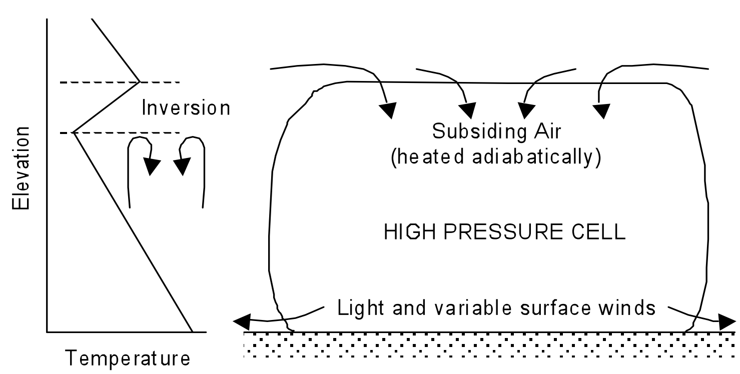
Meteorology – Subsidence Inversions



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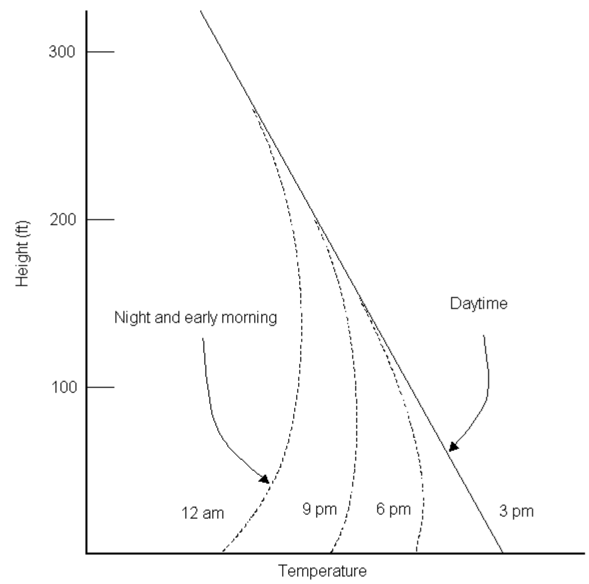
Meteorology – Radiation Inversions



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Meteorology – Wind Speeds

- One last item to consider is how obstacles, land use patterns and atmospheric stability combine to change the vertical wind speed profile.
- Obstacles or land-use patterns that produce friction near the surface, result in winds that are slower near the surface than relatively "smooth" areas.

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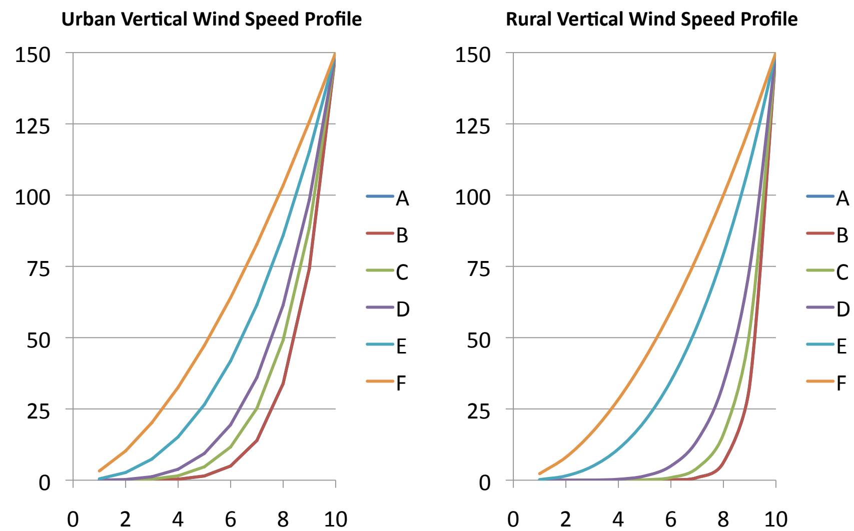
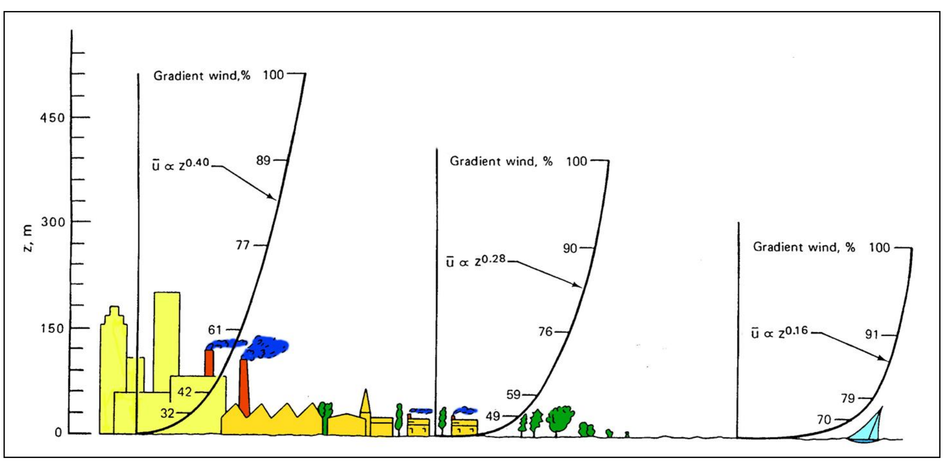
Meteorology – Wind Speeds



Meteorology – Wind Speeds

Wind Profiles in the Planetary Boundary Layer



PLUME RISE MECHANICS

Plume Rise

- Plume rise (Δh) increases the effective height (H) of a stack, according to this basic formula:

$$H = h_s + \Delta h$$

- The physical height of the stack, h_s, is constant, but plume rise can vary considerably.
- Momentum and buoyancy of the plume both contribute to this phenomenon.

Plume Rise

- Vertical momentum is a product of exit velocity (V_s) and the stack area (A_s), which can also be related to volumetric flow rate (Q_s) and stack diameter (D_s).
- The buoyancy force of an exhaust flow is created by a density differential between the exhaust gas and the ambient air.
  - Positive buoyancy corresponds to an exhaust that is lighter (less dense) than the surrounding air.

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Plume Rise

- Typically, momentum effects dominate initially, but these effects decay rapidly and are overtaken by buoyancy effects.
- If buoyancy effects are minor, momentum effects will dominate, and will be the primary mechanism for plume rise.
- If buoyancy effects are present however, they also tend to be longer-lived, and therefore tend to dominate.

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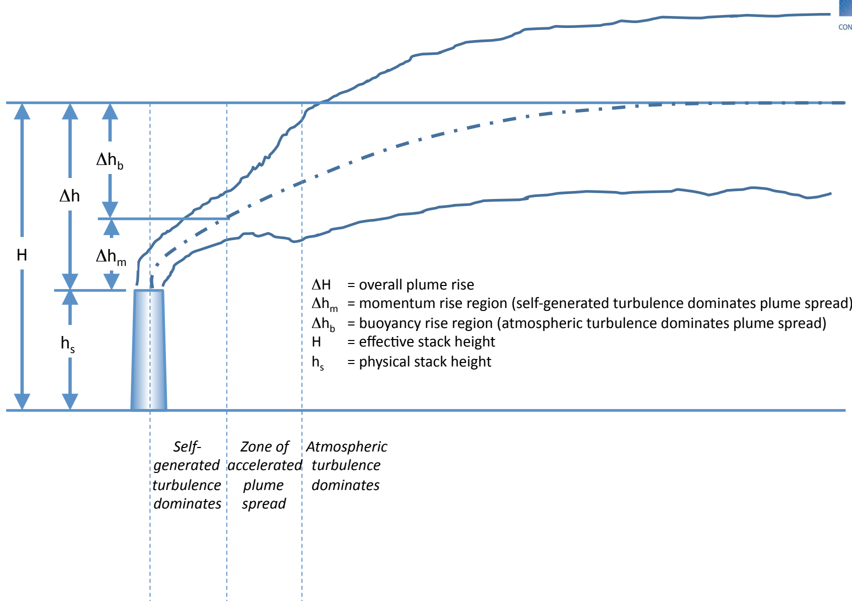
Plume Rise



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Plume Rise

- There are two main methods for calculating plume rise:
  - Briggs Plume Rise Model
    - more complicated
    - used in most current models (ISC, AERMOD)
  - Holland Plume Rise Model
    - extremely simplified
    - used in MOE "Regulation 346" model

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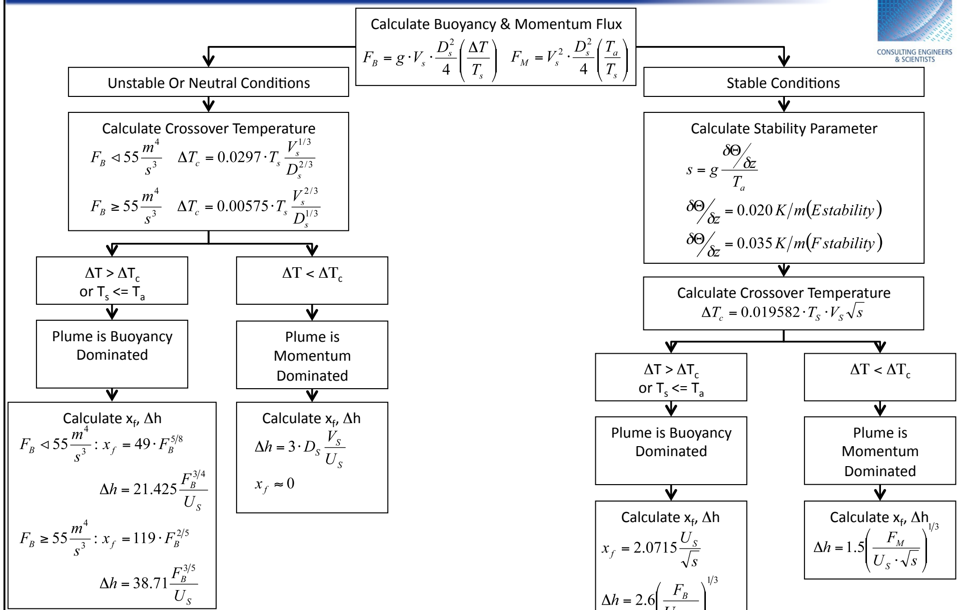
Plume Rise – Brigg's Plume Rise Model



Plume Rise – Holland Plume Rise Model

Calculate Δh

$$\Delta h = \frac{V_S \cdot D_S}{U_S}\left(1.5 + 2.68\frac{(T_S - 283) \cdot D_S}{T_S}\right)$$

This is a variation of the Holland Plume Rise model used by the old "Ontario Regulation 346" models. You can readily see that it assumes that the ambient temperature is always 10ºC (283K), which is the "Ontario reference temperature". Also note that there is absolutely no mention of the stability class. The reason for this approach is that the models in the Appendix to O. Reg. 346 didn't include ambient temperature as a variable, and only looked at C and D stability.

Reputation Resources Results

Plume Rise – Brigg's Plume Rise Model

- In both of the models shown in the preceding slides, the following variables and units are used:
  - F_B = buoyancy flux (m^4/s^3)
  - F_M = momentum flux (m^4/s^2)
  - g = acceleration of gravity (= 9.8 m/s^2)
  - V_s = stack exit velocity (m/s)
  - D_s = stack exit diameter (m)
  - T_s = stack exit temperature (K)
  - T_a = ambient temperature (K)
  - $\Delta T = T_s - T_a$ = temperature differential (K)
  - xf = distance to final plume rise (m)
  - Δh = final plume rise (m)
  - U_s = wind speed at stack tip (m/s)
  - s = stability parameter (s^{-2})

Reputation Resources Results

Plume Rise – Stack Tip Downwash

- Stack tip downwash is a phenomenon that works against plume rise, and is cause by high wind speeds at the stack tip relative to the source momentum
- This can draw the plume it into the low pressure region on the rear of the stack.
- It is determined using a simple equation:

$$\Delta h_{downwash} = 2 \cdot D_s \left[\frac{V_s}{U_s} - 1.5 \right] \quad f\, or V_s < 1.5 \cdot U_s$$

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Plume Rise – Stack Tip Downwash

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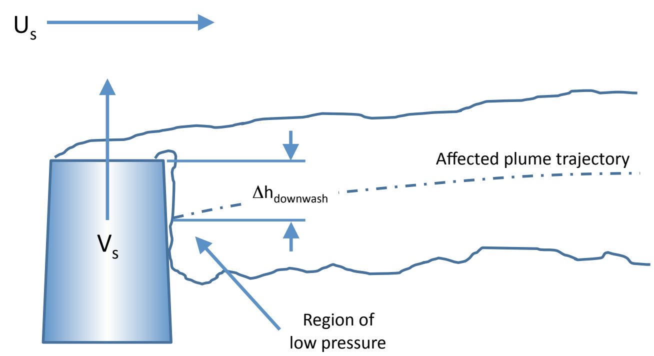

Note that when $V_s < 1.5U_s$, the downwash equation gives a negative value. A positive value indicates no downwash is occurring (i.e., $V_s >= 1.5U_s$).

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Plume Rise – Stack Tip Downwash

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- With stack tip downwash added in, we now have the following complete equation for overall stack height, H:

$$H = h_s + \Delta h + \Delta h_{downwash}$$

- H is the required parameter used in the dispersion models used in the next chapter.
- Computer models handle this internally, which is obviously convenient!

Reputation Resources Results

GAUSSIAN PLUME MODEL

Gaussian Plume Model

- A statistically derived model, developed through decades of research in wind tunnels, field experiments, and computer simulations.
- Currently the back-bone of the dispersion modelling field, and forms the basis of models such as AERMOD.
- Has limitations, but, for most of applications, it is extremely useful.

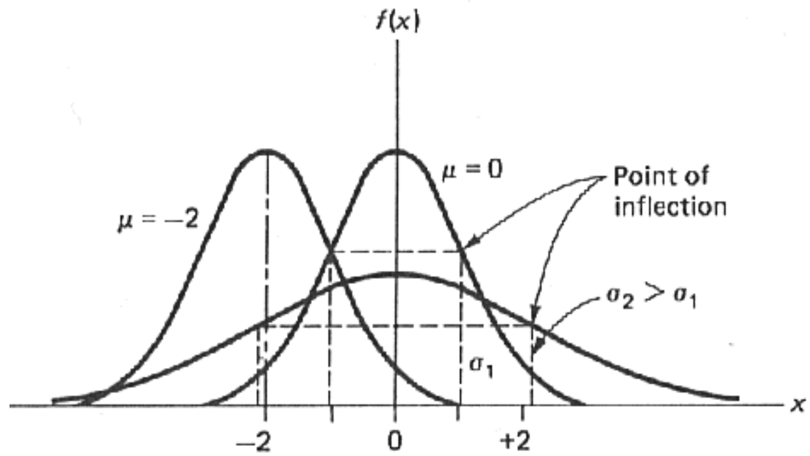
Gaussian Plume Model

- There are a number of underlying assumptions that must be considered:
  - Steady state (no change with time).
  - Pollutants emanate from a continuous source.
  - The wind is always aligned to the x-direction.
  - Mass diffusion in the x-direction is negligible relative to the bulk transfer due to advection.
  - A constant wind speed at all x, y, z positions.
  - Effective diffusion coefficients are constant.
  - Plume species are inert (unreactive).
  - No sources or sinks occur (this assumption can be altered somewhat depending on the model).

Gaussian Plume Model

- Based on the Gaussian distribution, it relies heavily on the level of standard deviation (sigma, σ), which affects the spread of the curve.
- The greater the σ, the wider the curve.
- For pollutant transport, the greater the sigma, the greater the dispersion, and hence, the lower the concentration.

Gaussian Plume Model



Gaussian Plume Model

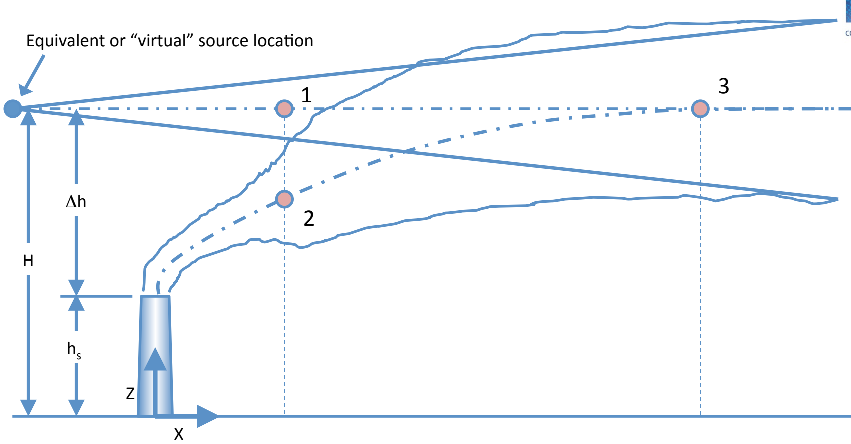
- The basic model looks at a traditional, unobstructed, vertically discharging stack, with effective height H.
- The dispersion of the contaminant in the vertical (z) and horizontal (y) directions is calculated as a function of downwind distance of the stack (x).
- Thus a prediction of the contaminant concentration at any location (x,y,z).

Gaussian Plume Model

- Picture a plume rising from a stack, slowly spreading downwind as it goes.
- Now forget that image.
- The model “reimagines” the plume as simply spreading from a single point in space, at a height “H” above ground, some distance upwind of the actual stack.
- Obviously , this causes problems near the stack (locations 1 and 2 on the next slide).

Reputation Resources Results

Gaussian Plume Model



Reputation Resources Results

Gaussian Plume Model

- The presence of the ground causes an issue because it is "impervious" to the spreading plume.
- While there could be deposition of material on the ground, either via dry or wet mechanisms, most of the plume hits the ground and is "reflected".
- The basic formula is modified to account for this "reflection".

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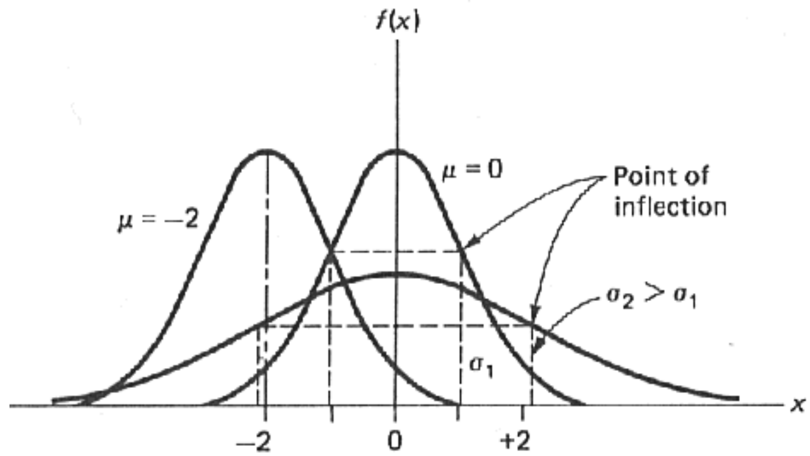

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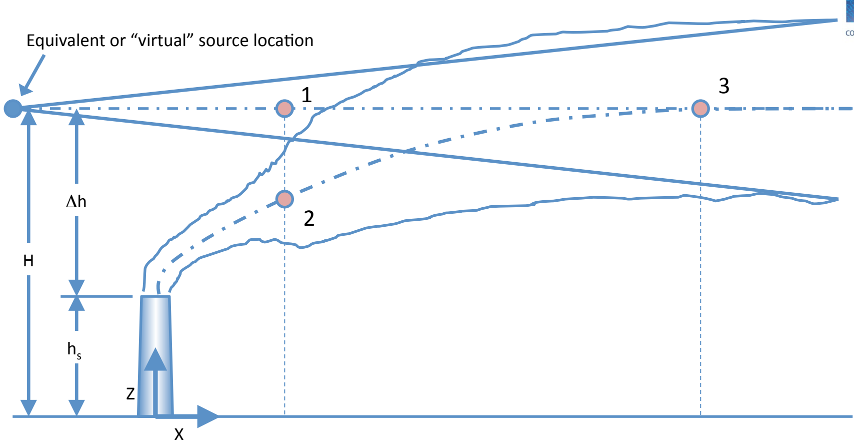

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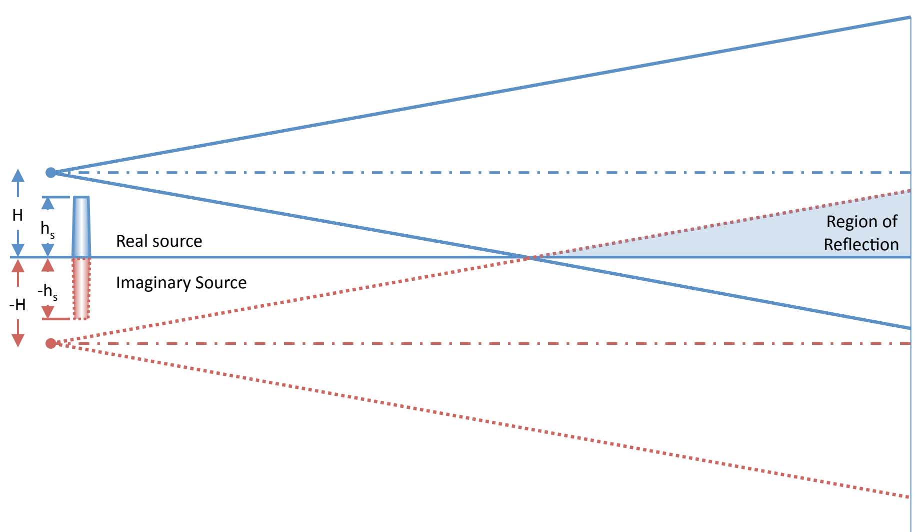

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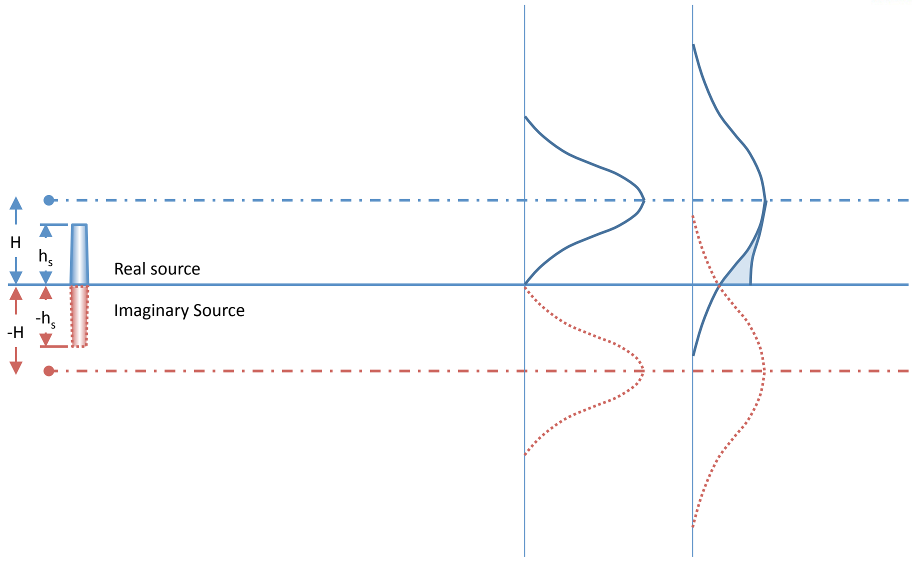
Gaussian Plume Model



Gaussian Plume Model

- This gives us the Gaussian plume model for concentrations at a specific location (with reflection):

$$C(x,y,z)=\frac{q}{2\pi U_s\sigma_y\sigma_z}\left[\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\right]\left[\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right]$$

Accounts for dispersion in the Y-direction when receptor is not along x-axis

Accounts for dispersion in the Z-direction when receptor is not at plume centreline

Reflection term

Gaussian Plume Model

- In the model shown in the preceding slide, the following variables and units are used:
  - C = contaminant concentration (g/m³)
  - x = receptor distance downwind from stack (m)
  - y = lateral (crosswind) distance between the receptor and the x-axis (m)
  - z = height of the receptor above grade (m)
  - q = contaminant emission rate (g/s)
  - U_s = wind speed at stack tip (m/s)
  - σ_y = lateral (cross-wind) dispersion coefficient (m)
  - σ_z = vertical dispersion coefficient (m)
  - H = effective stack height (m)

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Gaussian Plume Model

- $\sigma_{y\ \text{and}}\ \sigma_z$ are can be determined through one of two methods:
  - graphs of standard deviation as a function of downwind distance.
  - equations that represent the curves on the abovementioned graphs.
- In addition, there are separate equations for urban or rural conditions.

Reputation Resources Results

Gaussian Plume Model

- Rural conditions:

$$\sigma = e^{I + J\cdot\left[\ln\left(\frac{x}{1000}\right)\right] + K\cdot\left[\ln\left(\frac{x}{1000}\right)\right]^2}$$

- Urban Conditions:

$$\sigma = \left[L\left(\frac{x}{1000}\right)\right]\left[1 + M\left(\frac{x}{1000}\right)\right]^N$$

Gaussian Plume Model

Rural Equation Coefficients

	σ_x			σ_y		
Stability	I	J	K	I	J	K
A	6.035	2.1097	0.2770	5.357	0.8828	-0.0076
B	4.694	1.0629	0.0136	5.058	0.9024	-0.0096
C	4.110	0.9201	-0.0020	4.651	0.9181	-0.0076
D	3.414	0.7371	-0.0316	4.230	0.9222	-0.0087
E	3.057	0.6794	-0.0450	3.922	0.9222	-0.0064
F	2.621	0.6564	-0.0540	3.533	0.9191	-0.0070

McMullan, R.W., JAPCA, October 1975

Gaussian Plume Model

Rural Equation Coefficients

	σ_x			Σ_y		
Stability	L	M	N	L	M	N
A	240	1.00	0.50	320	0.40	-0.50
B	240	1.00	0.50	320	0.40	-0.50
C	200	0.00	0.00	220	0.40	-0.50
D	140	0.30	-0.50	160	0.40	-0.50
E	80	1.50	-0.50	110	0.40	-0.50
F	80	1.50	-0.50	110	0.40	-0.50

Gifford, F.A., Haugen, D.A. (Editor), AMS, September 1975

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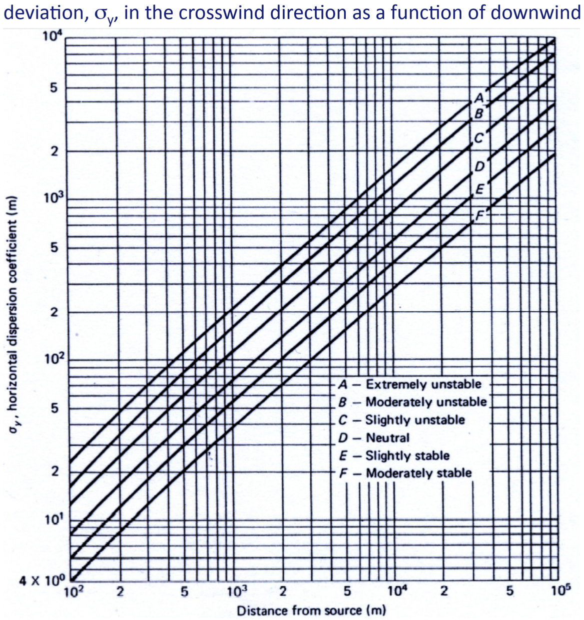
Gaussian Plume Model

Standard deviation, σ_y, in the crosswind direction as a function of downwind distance



Cooper, C.D., Alley, F.C., Air Pollution Control, A Design Approach, 3rd Ed., 2002.

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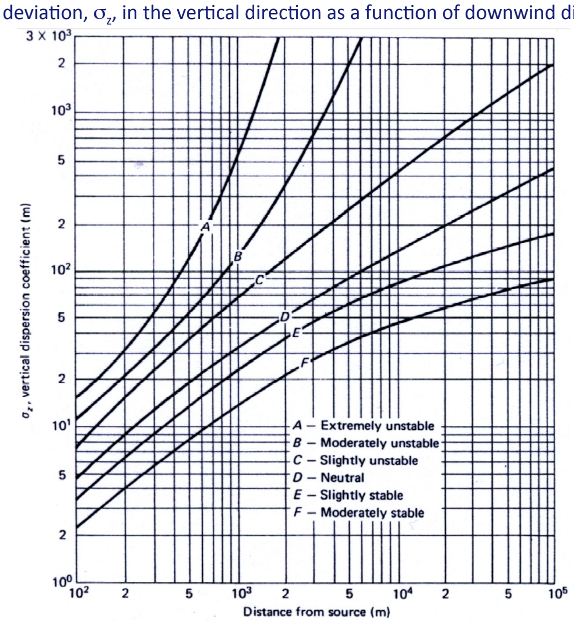
Gaussian Plume Model

Standard deviation, σ_z, in the vertical direction as a function of downwind distance



Cooper, C.D., Alley, F.C., Air Pollution Control, A Design Approach, 3rd Ed., 2002.

Gaussian Plume Model

- Often we're interested in simply finding where the maximum concentration occurs.
- Under neutral to near neutral conditions, the GPM can be re-written to give the maximum ground-level concentration at any point along the x-axis.
- This is possible because:
  - $z = 0$ and $y = 0$.
  - σ_y/σ_z is nearly independent of the distance, x.

Gaussian Plume Model

- Thus the Gaussian equation can be written so that C is solely a function of σ_z:

$$\sigma_z = \frac{H}{(2)^{1/2}} = 0.707 \cdot H \qquad C_{\max, ref\,lec} = \frac{0.1171 \cdot q}{U \cdot \sigma_y \cdot \sigma_z}$$

- H gives us σ_z.
- σ_z allows to calculate x, using the formulae presented earlier.
- x then allows us to find σ_y, also using the formulae presented earlier.

PUFF MODELS

Puff Models

- Puff models (e.g., CALPUFF, SCIPUFF) are commonly used in other jurisdictions, but are not yet as popular in Ontario.
- Puff models differ from plume models primarily on the basis of time:
  - Plume models look at steady-state conditions only – there is no time dependence, the plume is "eternal".
  - Puff models can handle non-steady-state conditions, with an hour-by-hour dependence.

Reputation Resources Results

Puff Models

- As a non-steady-state model, a puff model allows the user the flexibility of:
  - Continuous or variable source emission;
  - Variable meteorological conditions; and,
  - Three dimensional meteorology.
- This is balanced by a significant increase in set-up and processing time.
- Modelling a site with a puff model is often twice the cost of using a plume model.

Reputation Resources Results

Puff Models

- In situations where complex terrain or meteorological conditions are expected however, a puff model is usually far more accurate for predicting impacts.
- It would also be more reliable should the need arise for a forensic analysis, due to the ability to handle non-steady-state conditions.

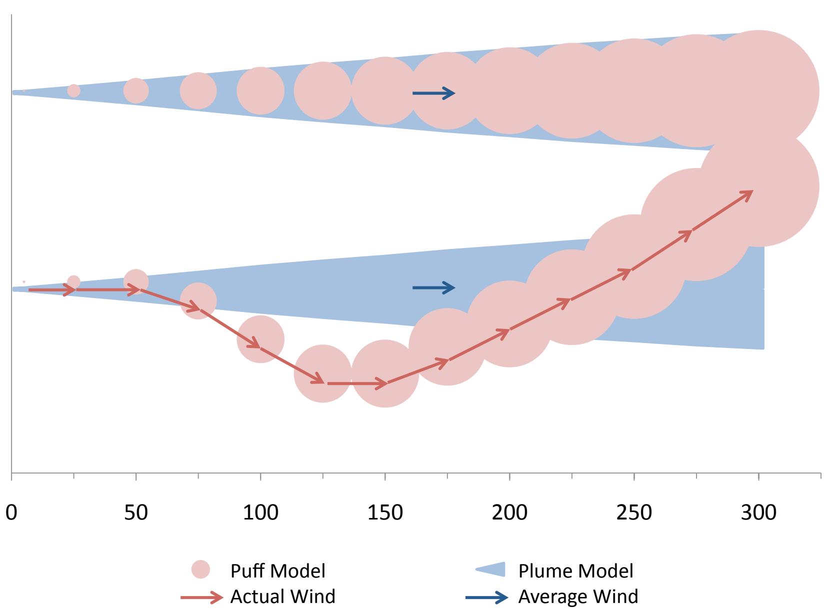
Puff Models

- At a very high level, a puff model uses the following approach:
  - At a given interval (from less than 1 minute, up to one hour), puffs are released from depending on their flow and emission rates.
  - The centre point of each puff (new and old) are calculated based on meteorology.
  - Plume heights are adjusted (plume rise, building downwash, terrain, etc.).
  - Dispersion of each plume is calculated

Puff Models

- Approach (continued):
  - Concentrations are adjusted for chemistry or deposition as required
  - Concentrations for all puffs impacting a receptor are summed together
  - Puffs that are very dispersed are removed from the model
  - And then we do it all again!

Puff vs. Plume Models



O. REG. 419/05 MODELS

Models Approved under O. Reg. 419/05

- There are currently four dispersion models approved under O. Reg. 419/05:
  - AERMOD
  - ASHRAE
  - SCREEN3
  - Models in the Appendix to O. Reg. 346
- Each of these will be discussed today.

Models Approved under O. Reg. 419/05

- There are also four “alternative” dispersion models identified in MOE Guideline A11 (Air Dispersion Modelling Guideline for Ontario):
  - CalPUFF
  - Cal3QHCR
  - SDM – Shoreline Dispersion Model
  - Physical Modelling (e.g., wind tunnel)

AERMOD

- AERMOD is the most advanced of the models currently approved under O. Reg. 419/05.
- It is a steady-state model that is best suited to short-range (<50km) modelling applications for stationary sources.
- It is based on a minimum 1-hour average, but can provide longer averaging periods, including monthly or annual averages.

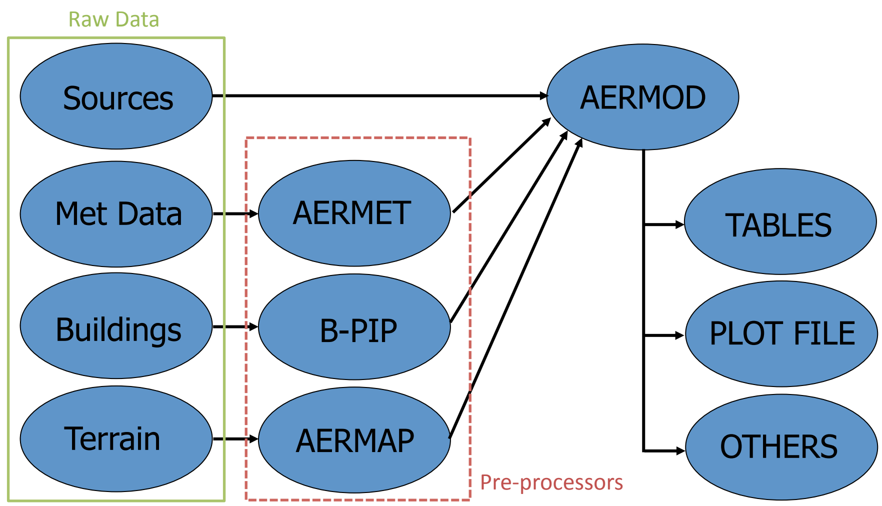
AERMOD

- AERMOD is developed and maintained by the U.S. EPA, and is available through "SCRAM", the Support Center for Regulatory Atmospheric Modeling
- Several Graphical User Interface (GUI) applications exist to help AERMOD users.
- These GUI applications are helpful tools, but should not replace an understanding of the model itself.

AERMOD

- AERMOD requires up to four different sets of inputs, depending on the application:
  - Source Information (required)
  - Meteorological Information (required)
  - Building Information (may be required)
  - Terrain Information (may be required)
- With the exception of the source data, pre-processing of this data is required.

AERMOD



AERMOD

- Once processed, this data is incorporated into an AERMOD input file, set up in a structured manner with 5 “pathways”:
  - Control Options (CO)
  - Source Information (SO)
  - Receptor Information (RE)
  - Meteorological Information (ME)
  - Output Options (OU)
- We’ll look at each pathway now.

AERMOD – Control Pathway

- The control pathway specifies over-arching model settings that affect how the run proceeds.
- Simple things such as project names and the contaminant of interest are specified here as well.
- Averaging times, desired units, and the calling of subroutines is done here as well.

AERMOD – Control Pathway

```
****************************************
** AERMOD Control Pathway
****************************************
**
**
CO STARTING
   TITLEONE TRAINING MODEL                         a name for the model run
   MODELOPT DFAULT CONC NODRYDPLT NOWETDPLT        "default" options [1], looking for a concentration
   AVERTIME 1 24                                   1 and 24 hour averaging times are being modelled
   URBANOPT 50000 SOMEWHERE_ONTARIO                the site is urban, and that gets listed here
   POLLUTID TSP                                               name the contaminant here, but some have additional meaning
[2]
   FLAGPOLE 0.00                                   receptors above grade are being considered
   RUNORNOT RUN                                               you can specify "not" to just do a test of the input file.
CO FINISHED
**
```

[1] NODRYDPLT AND NOWETDPLT refer to algorithms to estimate dry and wet deposition mechanisms, and the depletion of material from the plume as is deposits. This is usually turned off.

[2] The U.S. EPA has special built-in treatment of some pollutants (PM2.5, PM10, SO2 and NO2). Be sure to read the latest info from the U.S. EPA if you're going to use these special contaminant options.

AERMOD – Source Pathway

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- Basic source information is entered into an AERMOD file in two areas.
- The first provides spatial data (x, y, z)
- The second provides the source parameters such as emission rate, height, exit diameter, etc.
- For area or volume sources, there will be alternative source parameters, such as initial plume height, etc.

Reputation Resources Results

AERMOD – Source Pathway

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```
****************************************
** AERMOD Source Pathway
****************************************
**
SO STARTING
** Source Location **
** Source ID - Type - X Coord. - Y Coord. **
   LOCATION EF1 POINT 549766.970 4840878.750 424.0
** DESCRSRC Assembly Area General Exhaust
   LOCATION EF2 POINT 549789.555 4840857.509 424.0
** DESCRSRC Assembly Area General Exhaust
   LOCATION EF3 POINT 549811.110 4840837.800 424.0
** DESCRSRC Assembly Area General Exhaust
   LOCATION BLR1 POINT 549789.822 4840822.034 424.0
** DESCRSRC Main Boiler - Assembly Area
   LOCATION EF6 POINT 549974.157 4840575.585 418.0
** DESCRSRC Oven Exhaust
   LOCATION EF7 POINT 550001.689 4840553.563 418.0
** DESCRSRC Oven Exhaust
   LOCATION EF8 POINT 550026.664 4840530.164 418.0
** DESCRSRC Oven Exhaust
   LOCATION EF9 POINT 550054.196 4840508.142 418.0
** DESCRSRC Welding Exhaust
   LOCATION EF10 POINT 550079.171 4840484.743 418.0
** DESCRSRC Welding Exhaust
   LOCATION BLR2 POINT 550030.941 4840623.136 418.0
** DESCRSRC Main Boiler - Fabrication Area
   LOCATION GEN1 POINT 550032.518 4840624.653 418.0
** DESCRSRC Emergency Generator
** Source Parameters **
   SRCPARAM EF1 0.04 16.500 298.000 7.10000 0.600
   SRCPARAM EF2 0.04 16.500 298.000 7.10000 0.600
   SRCPARAM EF3 0.04 16.500 298.000 7.10000 0.600
   SRCPARAM BLR1 0.008 30.000 480.000 7.40000 0.600
   SRCPARAM EF6 0.05 24.000 348.000 12.40000 0.600
   SRCPARAM EF7 0.05 24.000 348.000 12.40000 0.600
   SRCPARAM EF8 0.05 24.000 348.000 12.40000 0.600
   SRCPARAM EF9 0.015 23.000 298.000 7.10000 0.600
   SRCPARAM EF10 0.015 23.000 298.000 7.10000 0.600
   SRCPARAM BLR2 0.008 33.000 480.000 7.40000 0.600
   SRCPARAM GEN1 0.18 32.000 423.000 42.00000 0.300
```

X and Y coordinate

Base elevation

gives source name, type and location, with base elevation, in metres
the second line gives a brief description of the source above

source parameters in the order of:
- emission rate (g/s)
- release height (m)
- exhaust temperature (K)
- exit velocity (m/s)
- exit diameter (m)

Reputation Resources Results

AERMOD – Source Pathway

- AERMOD also requires information on buildings, if present.
- Generally, buildings influence a stack if they are less than 5 times the height of the building from the source in question.
- Each level of the building must be identified, marked out by the footprint of each "tier".
- A good site plan is critical.

Reputation Resources Results

AERMOD – Source Pathway

- Building information is entered into another pre-processor called B-PIP.
- B-PIP takes the building height and footprint information, along with the point source locations, and determines the downwash effects of the buildings, for 36 wind directions (in 10º increments).
- It produces a data set that is imported directly into AERMOD.

Reputation Resources Results

AERMOD – Source Pathway

- It calculates the following:
  - BUILDHGT: height of the most dominant building upwind or downwind of stack.
  - BUILDWID: width of the most dominant building upwind or downwind of stack.
  - BUILDLEN: projected length of the building along flow
  - XBADJ: along-flow distance from stack to the center of upwind face of the projected building
  - YBADJ: across-flow distance from stack to the center of upwind face of the projected building

AERMOD – Source Pathway

```
'X:\BGS\AERMOD\TRAINING.isc'            file location
'P'                                     refers to the "PRIME" version of the model
'METERS'  1.00000000                    coordinate system is in metres, with a 1:1 scale
'UTMY'  0.0000                                  coordinate system is UTM, with no rotation
2                                       number of buildings in the model
'BLD_2'  9        424.000               building "name", number of tiers on the building, and the base elevation above sea level
    24          5.00                    number of vertices on this tier, and the height of this tier
            549854.98    4840754.85
            549815.81    4840791.96
            549807.17    4840782.84
            549751.50    4840835.55
            549761.67    4840846.22
            549750.24    4840857.08
            549743.85    4840850.31
            549740.48    4840853.43
            549729.73    4840841.99
            549715.82    4840855.17
            549726.64    4840866.55
            549715.43    4840877.18   24 individual x,y coordinates, one for each "corner" of the building tier
            549728.86    4840891.31
            549724.60    4840895.44
            549752.11    4840925.38
            549853.79    4840829.60
            549884.20    4840861.78
            549879.00    4840866.75
            549890.01    4840878.38
            549933.30    4840837.36
            549922.14    4840825.60
            549931.96    4840816.23
            549924.34    4840807.94
            549914.42    4840817.45
4           10.00                       beginning of the second tier (a 12m tall tier with 8 vertices, to be precise)
            549922.13    4840825.58
            549931.92    4840816.24
            549924.37    4840808.07
            549914.49    4840817.56
```

AERMOD – Source Pathway

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```
BPIP (Dated: 04274)                                BPIP executable version number
DATE :  3/26/2009                                  date of run
TIME : 12:39: 1                                    time of run


X:\BGS\AERMOD\TRAINING.isc                          file location

 BPIP output is in meters                          confirmation of units


    SO BUILDHGT EF1       25.00   25.00   20.00   20.00   20.00   20.00
    SO BUILDHGT EF1       20.00   20.00   20.00   20.00   20.00   20.00
    SO BUILDHGT EF1       20.00   20.00   25.00   25.00   25.00   25.00
    SO BUILDHGT EF1       25.00   25.00   20.00   20.00   20.00   20.00
    SO BUILDHGT EF1       20.00   20.00   20.00   20.00   20.00   20.00
    SO BUILDHGT EF1       20.00   20.00   25.00   25.00   25.00   25.00
    SO BUILDWID EF1       38.20   39.91   36.89   31.93   33.56   38.20
    SO BUILDWID EF1       41.68   43.90   44.78   44.29   42.47   39.35
    SO BUILDWID EF1       35.04   36.45   20.78   26.49   31.38   35.33
    SO BUILDWID EF1       38.20   39.91   36.89   31.93   33.56   38.20
    SO BUILDWID EF1       41.68   43.90   44.78   44.29   42.47   39.35
    SO BUILDWID EF1       35.04   36.45   20.78   26.49   31.38   35.33
    SO BUILDLEN EF1       32.93   28.10   39.35   35.04   36.45   40.41
    SO BUILDLEN EF1       43.14   44.56   44.63   43.34   40.74   36.89
    SO BUILDLEN EF1       31.93   33.56   41.27   41.00   39.48   36.77  the relevant parameters for the first source in the file
    SO BUILDLEN EF1       32.93   28.10   39.35   35.04   36.45   40.41
    SO BUILDLEN EF1       43.14   44.56   44.63   43.34   40.74   36.89
    SO BUILDLEN EF1       31.93   33.56   41.27   41.00   39.48   36.77
    SO XBADJ    EF1      -60.16  -53.09  -15.00  -16.51  -20.88  -26.47
    SO XBADJ    EF1      -31.26  -35.10  -37.87  -39.49  -39.91  -39.12
    SO XBADJ    EF1      -37.14  -37.83   27.59   28.82   29.17   28.63
    SO XBADJ    EF1       27.23   24.99  -24.35  -18.53  -15.57  -13.94
    SO XBADJ    EF1      -11.88   -9.47   -6.76   -3.85   -0.83    2.23
    SO XBADJ    EF1        5.21    4.27  -68.86  -69.82  -68.65  -65.40
    SO YBADJ    EF1      -23.79  -30.77   20.67   21.17   21.05   20.27
    SO YBADJ    EF1       18.87   16.89   14.40   11.48    8.20    4.68
    SO YBADJ    EF1        1.01   -2.66   -8.96   -0.55    7.89   16.08
    SO YBADJ    EF1       23.79   30.77  -20.67  -21.17  -21.05  -20.27
    SO YBADJ    EF1      -18.87  -16.89  -14.40  -11.48   -8.20   -4.68
    SO YBADJ    EF1       -1.01    2.66    8.96    0.55   -7.89  -16.08
```


AERMOD – Source Pathway

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- The source pathway also allows the user to enter information on:
  - Temporal variations in source emissions;
  - Data pertaining to wet or dry depletion; and,
  - Source groupings (allows the model to produce results for specific sources or sub-groups of sources).

Reputation Resources Results

AERMOD – Receptor Pathway

- Receptors must be entered for each location of interest, with a specific X, Y and Z (base elevation) coordinate.
- The base elevation refers to the elevation of the ground at that location above sea level.
- In addition, a "flagpole" height allows you to look at a location at a point somewhere above that base elevation (e.g. a balcony).

AERMOD – Receptor Pathway

- When not using terrain data, the receptors are listed in the AERMOD input file itself.
- When using terrain data (changing base elevations), an external file is created and called.
- The next slide shows how both options appear in the ME Pathway.

AERMOD – Receptor Pathway

```
****************************************
** AERMOD Receptor Pathway
****************************************
**
**
RE STARTING
   DISCCART     548200.00   4838700.00   0.00
   DISCCART     548400.00   4838700.00   0.00
   DISCCART     548600.00   4838700.00   0.00
   DISCCART     548800.00   4838700.00   0.00
   DISCCART     549000.00   4838700.00   0.00

   ...

   DISCCART     549088.31   4840428.00   2.00
   DISCCART     549088.00   4840428.00   4.00
   DISCCART     549088.00   4840428.00   6.00
   DISCCART     549088.00   4840428.00   8.00
   DISCCART     549088.00   4840428.00   10.00
   DISCCART     549088.00   4840428.00   12.00
   DISCCART     549088.00   4840428.00   14.00

****************************************
** AERMOD Receptor Pathway
****************************************
**
**
RE STARTING
   INCLUDED TRAINING.ROU
RE FINISHED
**
```

there could be thousands of these!
each represents a specific location, with an x, y and z (flagpole)
this is the same set of receptors we will see in the external file,
the second group are flagpole receptors at an apartment building

this shows the use of terrain data with an external file

Reputation Resources Results

AERMOD – Receptor Pathway

- Terrain data is sometimes required if the site is located in very hilly terrain (i.e., Niagara Escarpment)
- This data is normally obtained from Natural Resources Canada (NRCan) in "DEM" format, or the MOE's Ontario Digital Elevation Model Data.
  - www.geobase.ca
  - http://www.ene.gov.on.ca/environment/en/resources/STDPROD_078093.html

Reputation Resources Results

AERMOD – Receptor Pathway

- Terrain data is normally used to modify the base elevations of receptors, but you can also allow the pre-processor to alter source and building base elevations as well (this is usually a bad idea, however).
- In the end, you end up getting an external file that looks something like this:

Reputation Resources Results

AERMOD – Receptor Pathway

```
** AERMAP - VERSION 11103                                          07/24/13
**                                                                 14:34:19
**  Project: TRAINING
**
** A total of       4  DEM files were used
** A total of     567  receptors were processed
** No user-specifed DOMAIN; all available data used
** ANCHORXY  0.00  0.00  0.00  0.00  17 4
** TERRHGTS  EXTRACT

RE ELEVUNIT METERS
   DISCCART     548200.00   4838700.00     411.67     411.67       0.00
   DISCCART     548400.00   4838700.00     409.00     409.00       0.00
   DISCCART     548600.00   4838700.00     409.00     409.00       0.00
   DISCCART     548800.00   4838700.00     409.00     409.00       0.00
   DISCCART     549000.00   4838700.00     411.00     411.00       0.00

...

   DISCCART     549088.31   4840428.00     420.00     420.00       2.00
   DISCCART     549088.00   4840428.00     420.00     420.00       4.00
   DISCCART     549088.00   4840428.00     420.00     420.00       6.00
   DISCCART     549088.00   4840428.00     420.00     420.00       8.00
   DISCCART     549088.00   4840428.00     420.00     420.00      10.00
   DISCCART     549088.00   4840428.00     420.00     420.00      12.00
   DISCCART     549088.00   4840428.00     420.00     420.00      14.00
```

now we get x, y terrain information, and a flagpole height (first five DISCCART lines)

these are the same "flagpole" receptors (last seven DISCCART lines)

Reputation Resources Results

AERMOD – Meteorology Pathway

- AERMOD requires two external meteorological data files, known as the:
  - Profile File
  - Surface File
- These contain all the data required to model the emissions from the site in question.
- The formats for these text-based files are provided on the following slides.

AERMOD – Meteorology – Surface File Header

Field	Description
001	Latitude
002	Longitude
003	Upper air station identifier
004	Surface observation station identifier
005	On-site station identifier
006	Version date for AERMET pre-processor

AERMOD – Meteorology – Surface File Data

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Field	Description
001	Year
002	Month
003	Day
004	Julian Day
005	Hour ending
006	Sensible heat flux (W/m^2)
007	Surface friction velocity (m/s)
008	Convective velocity scale (m/s)
009	Vertical potential temperature gradient above planetary boundary layer
010	Height of convectively-driven mixing height (planetary boundary layer) (m)
011	Height of mechanically-driven mixing height (surface boundary layer) (m)
012	Monin-Obukhov length (m)
013	Surface roughness length (m)
014	Bowen Ratio
015	Albedo
016	Wind speed (m/s)
017	Wind direction (º)
018	Reference height for wind speed and wind direction (m)
019	Temperature (K)
020	Reference height for temperature (m)
021	Precipitation type code (0=none, 11=liquid, 22=frozen, 99=missing)
022	Precipitation amount (mm/hr)
023	Relative humidity (percent)
024	Station pressure (mb)
025	Cloud cover (tenths)
026	Wind speed adjustment and data source flag

Reputation Resources Results

AERMOD – Meteorology – Profile File Data

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Field	Description
001	Year
002	Month
003	Day
004	Hour ending
005	Measurement height (m)
006	indicator flag: 1=last level in profile for the hour, 0=not the last level
007	Wind direction at current level (º)
008	Wind speed at current level (m/s)
009	Temperature at current level (ºC)
010	σ_A – standard deviation in lateral wind direction
011	σ_W – standard deviation of the vertical wind speed

Reputation Resources Results

AERMOD – Meteorology Pathway

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- The Meteorology Pathway specifies these two files, as well as information regarding the meteorological stations from which this data was gathered.
- This pathway is pretty simple, although in some cases you can invoke other options, such as looking at specific periods within a meteorological data record.
- A sample is on the next slide.

Reputation Resources Results

AERMOD – Meteorology Pathway

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```
****************************************
** AERMOD Meteorology Pathway
****************************************
**
**
ME STARTING
   SURFFILE LONDONUR.SFC                    file name for surface file
   PROFFILE LONDONUR.PFL                    file name for profile file
   SURFDATA 61444 1996 LONDON               surface station World Meteorological Organization (WMO) ID and name
   UAIRDATA 726320 1996 WHITE_LAKE          upper air station WMO ID and name
   PROFBASE 278 METERS                      base elevation of the surface station (use 0m when not using terrain data)
ME FINISHED
```

Reputation Resources Results

AERMOD – Meteorology Pathway

- In order to generate the surface and profile files, we must run a pre-processor known as AERMET (or use pre-processed data).
- This data comes in a number of different file formats, but must contain:
  - Surface Data (e.g., from an airport)
  - Upper Air Data (e.g., weather balloons)
- AERMET adjusts the data to account for local conditions (land use, vegetation, etc.)

Reputation Resources Results

AERMOD – Meteorology Pathway

- The MOE has made this process a little easier by pre-processing the data for several regions in Ontario.
- These constitute a "screening" data set, and can be used in support of Certificates of Approval or the STAC initiative.
  - http://www.ene.gov.on.ca/environment/en/resources/STDPROD_078072.html

Reputation Resources Results

AERMOD – Output Pathway

- The output pathway specifies what files will actually be generated by the model.
- Most common are “receptor tables” which give the maximum value at all receptors, and “plot files” that allow us to generate contours.

AERMOD – Output Pathway

```
****************************************
** AERMOD Output Pathway
****************************************
**
**
OU STARTING
   RECTABLE ALLAVE 1ST
   RECTABLE 1 1ST
   RECTABLE 24 1ST
   PLOTFILE 1 ALL 1ST 01H1GALL.PLT
   PLOTFILE 24 ALL 1ST 24H1GALL.PLT
   PLOTFILE 1 BOILERS 1ST 01H1G001.PLT
   PLOTFILE 24 BOILERS 1ST 24H1G001.PLT
   PLOTFILE 1 GENSET 1ST 01H1G002.PLT
   PLOTFILE 24 GENSET 1ST 24H1G002.PLT
OU FINISHED
```

receptor tables for highest (1ST) concentration for each averaging time

plot files for each scenario and averaging time

AERMOD

- Overall, an AERMOD input file is akin to computer coding, with specific structure and syntax.
- It can be done in a text editor, but there are a few key items to remember:
  - Letters and numbers only.
  - If a line has a ** in the first two columns, the model ignores it – it's where you add comments.
  - D not use "tabs". Spaces only.

Reputation Resources Results

SCREEN3

- Published in 1995.
- Screening level version of the ISC3ST model, the ancestor of AERMOD.
- Based on fixed set of meteorological data.
- Gives 1-hour concentrations.
- Also includes cavity calculations that give a rough estimate of concentrations in the rear recirculation cavity of the building.

Reputation Resources Results

SCREEN3

- Models point sources, area sources, volume sources and flares.
- Can model single sources only!
- Able to predict the plume centre-line height at any distance downwind, which is very useful for looking at elevated receptors.

SCREEN3

- SCREEN3 can also model the special dispersion characteristics of flares.
- Because flares produce a great deal of heat, dispersion near the flare tip is dominated by this additional energy.
- Knowing the heating value of the gas being flared allows the model to adjust the stack parameters to account for this influence.

SCREEN3

- The model also performs building downwash calculations for both the "near wake" and far "wake regions".
  - "Near wake" extends from $3L_b$ to $10L_b$.
  - "Far wake" for distances greater than $10L_b$.
  - L_b is the lesser of the building height, h_b, and the maximum projected width.
  - The maximum projected width is calculated from the input minimum and maximum horizontal dimensions as $(L^2 + W^2)^{0.5}$.

Reputation Resources Results

SCREEN3

- In addition, SCREEN3 also performs inversion break-up fumigation calculations.
  - The distance to maximum fumigation is based on an estimate of the time required for the mixing layer to develop from the top of the stack to the top of the plume.
  - The mixing layer is the atmospheric layer between the Earth's surface and the bottom of the inversion aloft.

Reputation Resources Results

SCREEN3

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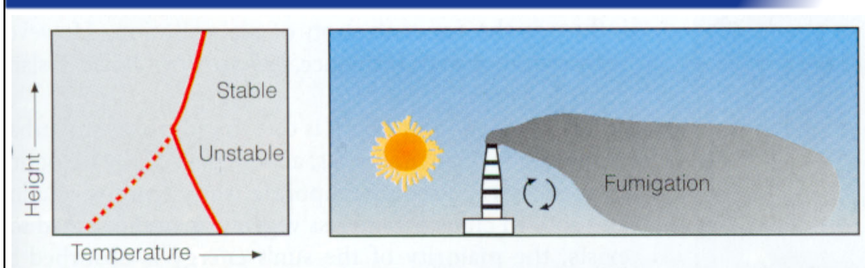
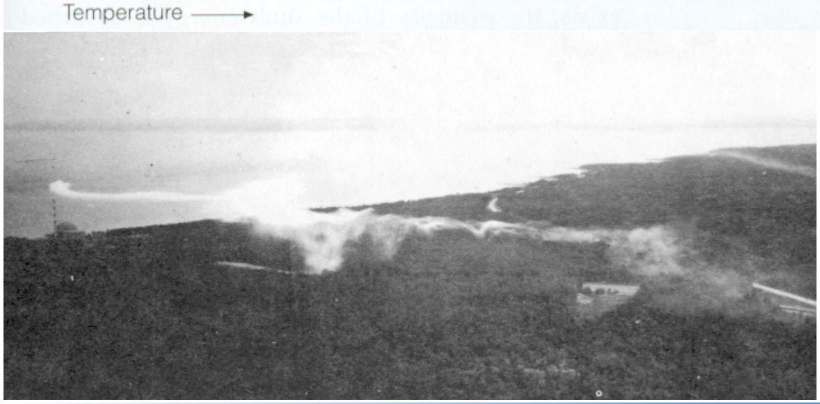
- SCREEN3 also performs shoreline fumigation calculations for rural sources within 3000m of a large body of water.
  - The maximum concentration is assumed to occur where the top of the stable plume intersects the top of the well-mixed thermal internal boundary layer (TIBL).
  - The TIBL is an internal boundary layer caused by advection of air across a discontinuity in surface temperature.

SCREEN3

RWDI CONSULTING ENGINEERS & SCIENTISTS





Reputation Resources Results

Models in the Appendix to O. Reg. 346

- Three main models were written into the old Ontario Regulation 346:
  - Scorer Barrett Equations (self-contamination)
  - Maximum Ground Level Concentration Model
  - Concentration at Points Model
- These models are still the regulatory models until the year 2020 for some facilities, even if they won't run on modern computers.

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Models in the Appendix to O. Reg. 346

- The Scorer-Barrett equation is the calculation for self-contamination:

$$C = \frac{0.6 \times 10^6 Q}{L^2}$$

- Where:
  - L = 1.57 times the stretched string distance in metres if the receptor is lower than the emission point, otherwise,
  - L = the stretched string distance if the receptor is higher than the emission point.
  - Q = emission rate in grams per second

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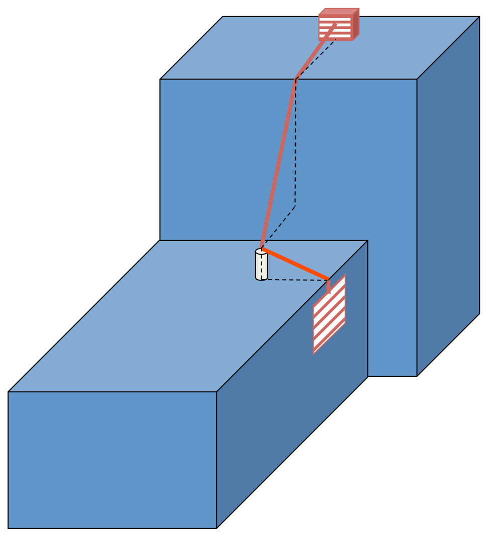
Models in the Appendix to O. Reg. 346



Models in the Appendix to O. Reg. 346

- The MOE provides a computer modelling package for off-site concentrations:
  - Maximum Ground Level Concentration Model
    - MAXGLC.exe
  - Concentration at Points Model
    - CAP.exe
- There are other applications in this package, but are not generally used.
- You will also likely need a DOS emulator to be able to run these models.

Models in the Appendix to O. Reg. 346

- Both models require site, property line and source information, stored in an "STK" file, generated by the Source Database Manager (SDBMGR.exe)
- The CAP model also requires receptor information, stored in a "PTI" file, generated by the Point Database Manager (PDBMGR.exe).

Models in the Appendix to O. Reg. 346

- When defining sources, point sources are:
  - Stacks with heights greater than twice the building height above grade; or,
  - Stacks with heights greater than 20m above the roof for buildings with a roof height greater than 20m above grade.
- Virtual sources are anything below that, unless a stack is greater than 100m away from any buildings.

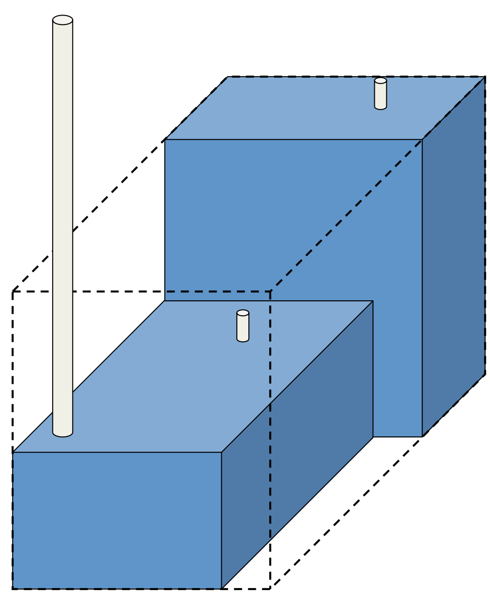
Reputation Resources Results

Models in the Appendix to O. Reg. 346

- The virtual source turns a building and it's (short) stacks into a large box.
- Multiple short sources with the same contaminant can be modelled as a single virtual source.
- For very large buildings, the MOE has accepted point sources based on the local roof, if taller portions of the building are located far away.

Reputation Resources Results

Models in the Appendix to O. Reg. 346



Reputation Resources Results

Models in the Appendix to O. Reg. 346

- Receptors of interest are incorporated into the model using the Point Database Manager.
- This tool requires that receptors be identified as either being "open" or "closed":
  - Open: finds maximum value anywhere between the ground and the height enetered
  - Closed: finds value at indicated height only

Models in the Appendix to O. Reg. 346

- These programs are very old, so be very careful when you type:
  - The arrow keys don't work.
  - Delete doesn't work.
  - If you type it wrong and hit enter blindly, you may end up starting over!
  - File names longer than 8 characters don't work!
  - Letters and numbers only!

Reputation Resources Results