BASIC METEOROLOGY AND ATMOSPHERIC TRANSPORT MODELING

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Purpose

- Present an overview of atmospheric dispersion principles and applications appropriate for environmental radiological risk assessment activities

Outline of Presentation

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- Fundamentals of meteorology
- Introduction to atmospheric modeling
- Gaussian plume model
- Alternative dispersion models
- Model validation studies

Basic Questions

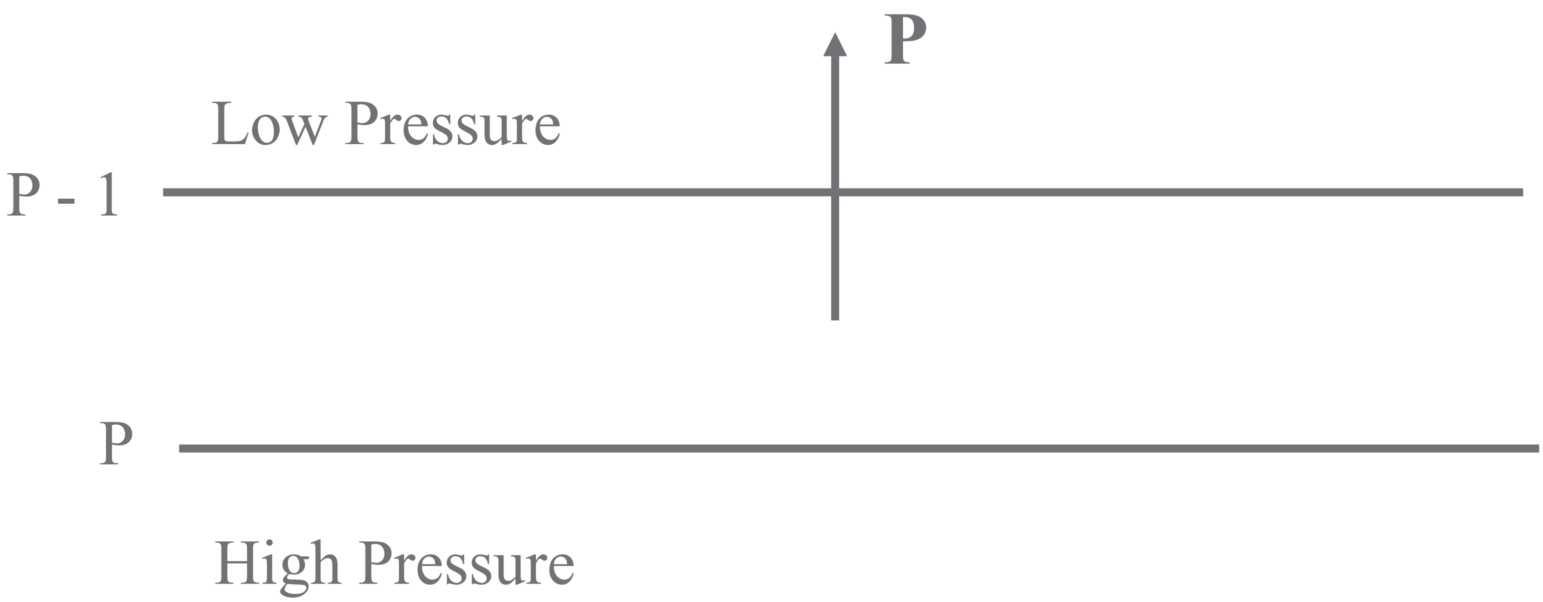
Magnitude of an Airborne Exposure

- WHERE is the release going?
  -- Wind direction
- WHEN will the release arrive at a location?
  -- Wind speed
- WHAT is the release concentration?
  -- Atmospheric diffusion

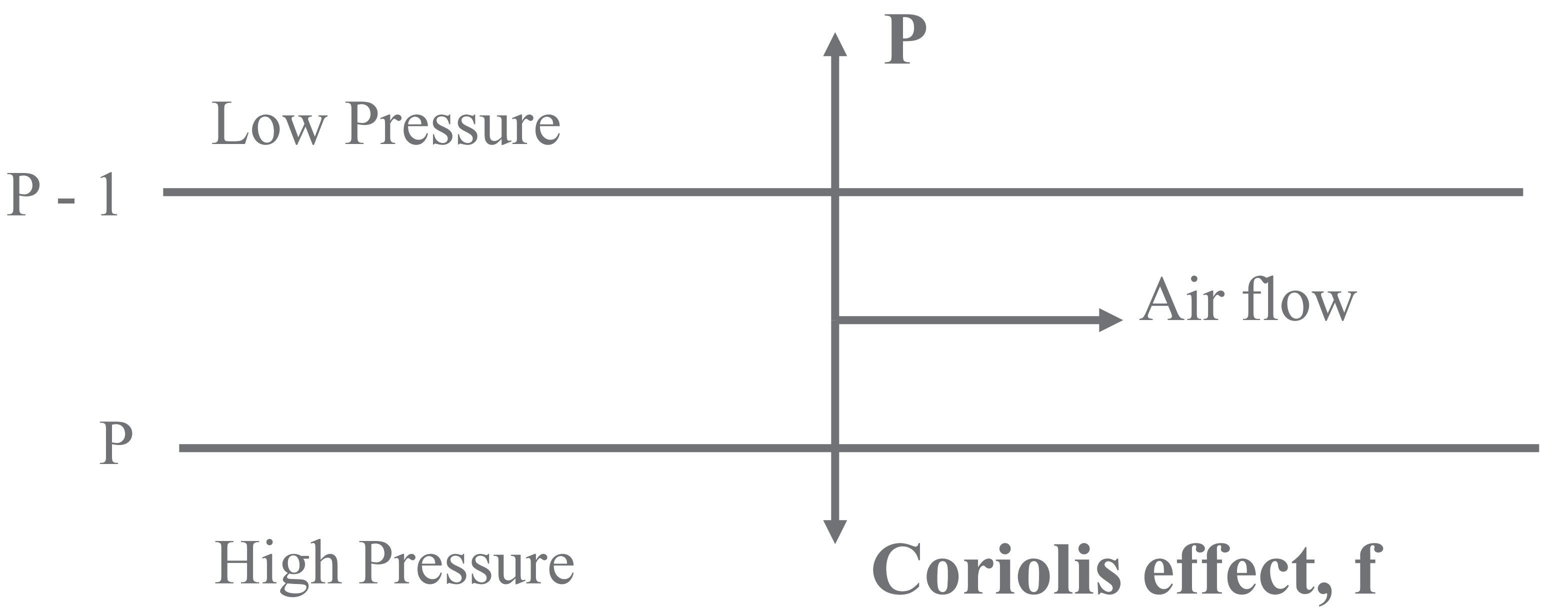
Physical Concepts
Atmospheric Motion

- Mass
- Energy
- Heat
- Momentum

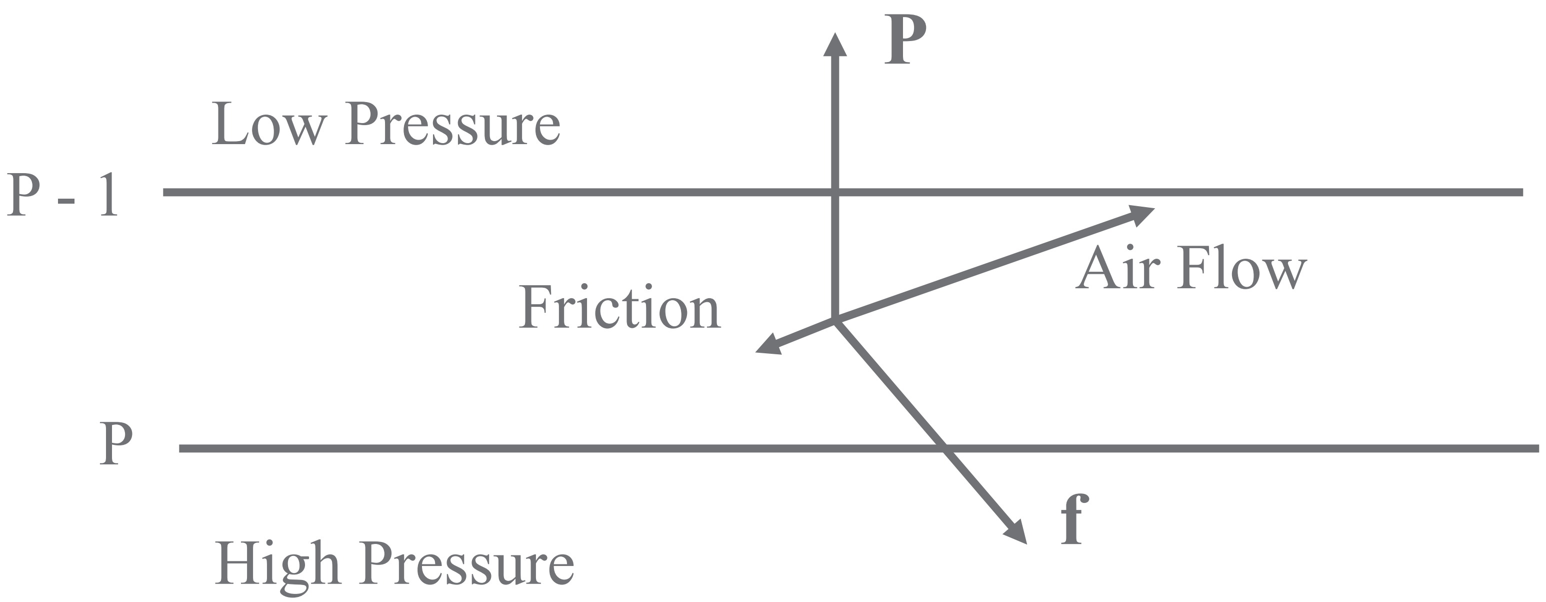
Pressure Gradient Force



Geostrophic Wind



Frictional Effects



Representative Surface Roughness Lengths

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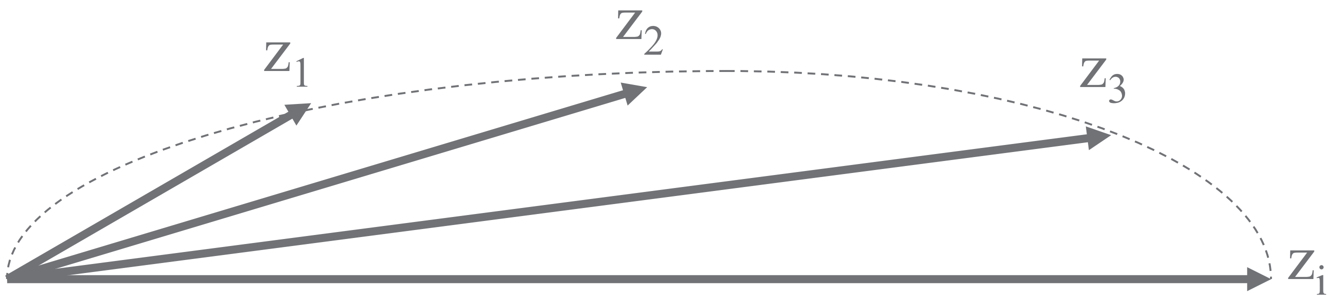
Type of surface	Surface Roughness (m)
Very smooth (ice, mud flats)	0.00001
Grass lawn	0.001 – 0.01
Thin grass up to 50 cm high	0.05
Thick grass up to 50 cm high	0.1
Woodland forest	0.2
Urban areas	1 - 3

Wind Direction vs. Height, z

The Ekman Spiral



Geostrophic Wind Speed

Early Morning Winter Plumes
Springfield, Illinois January 31, 1990

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Flow Around a Large Structure

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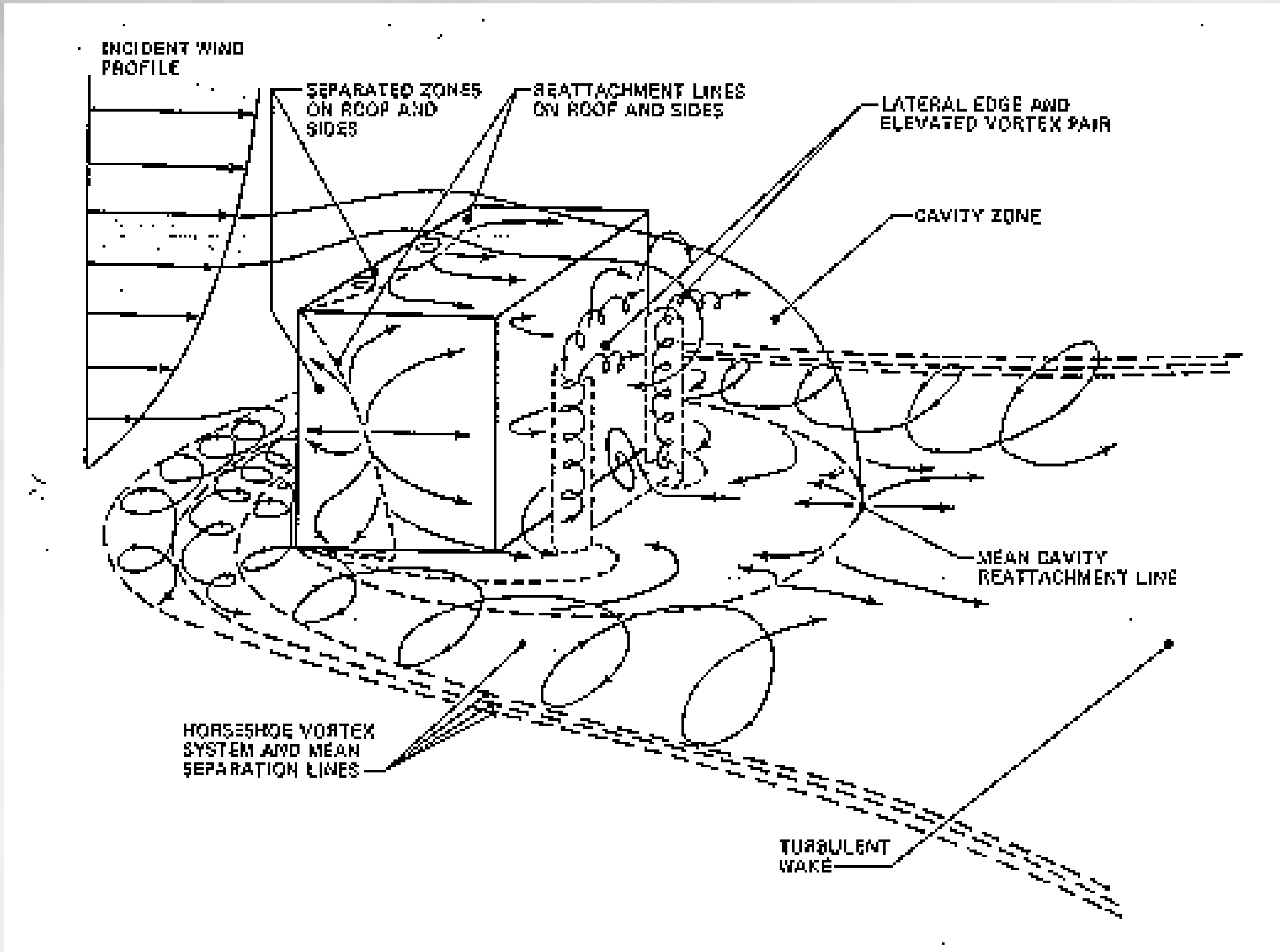
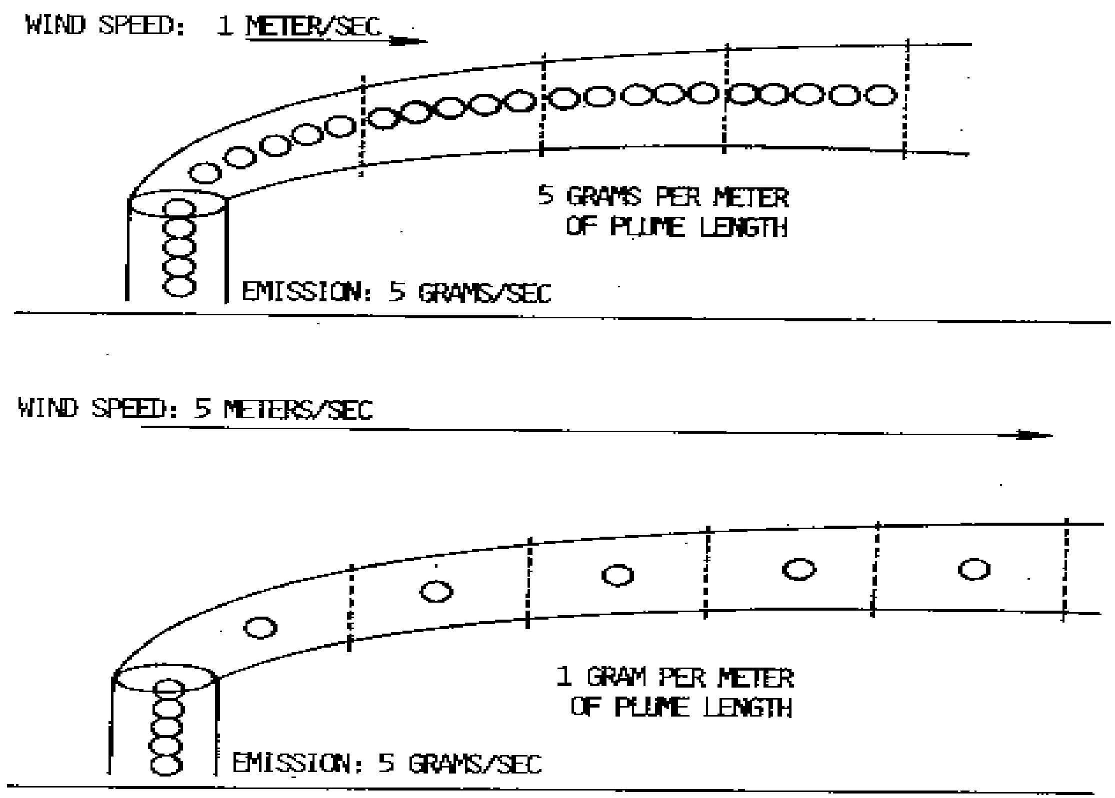


Effect of Wind Speed on Air Concentration



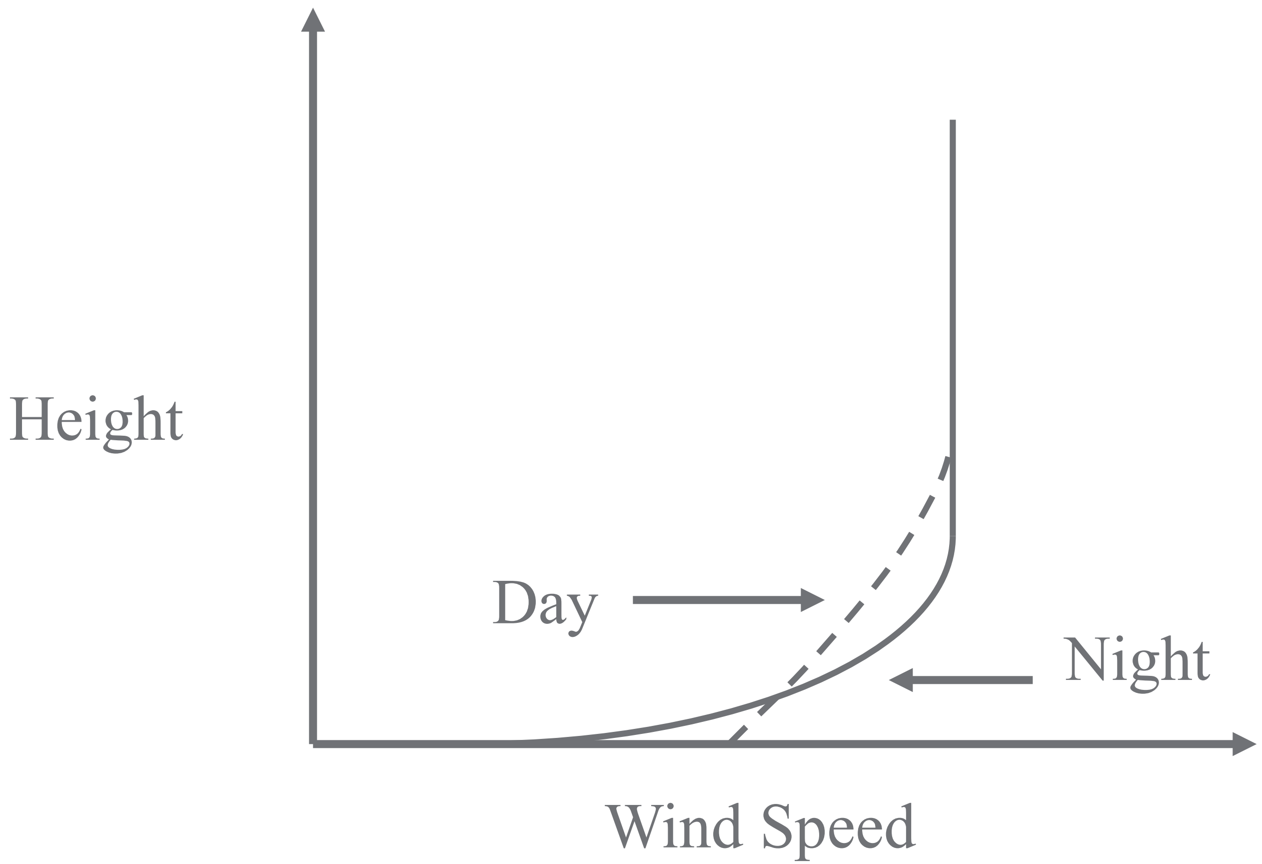
DILUTION ≈ WIND SPEED

OR

$$\text{CONCENTRATION} \approx \frac{1}{\text{WIND SPEED}}$$

Wind Speed vs. Height

Diurnal Variations



Turbulence

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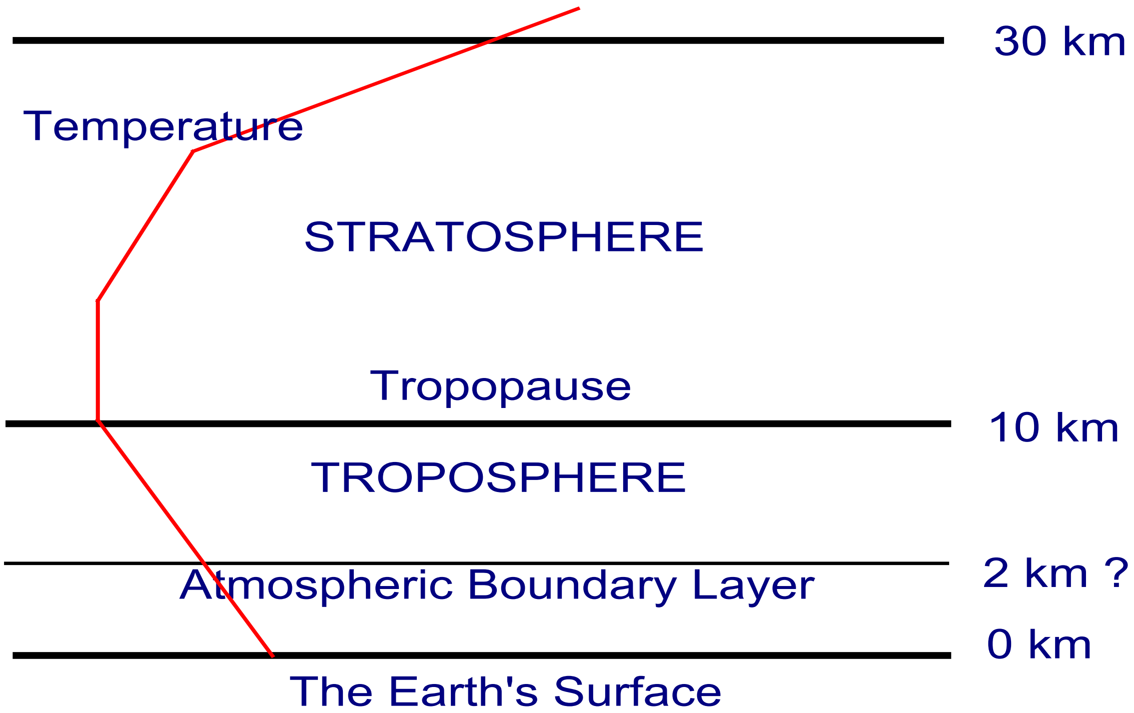
- A very disorganized motion of the air
- Studied as a statistical random process
- Fluctuations of the wind velocity about its mean value

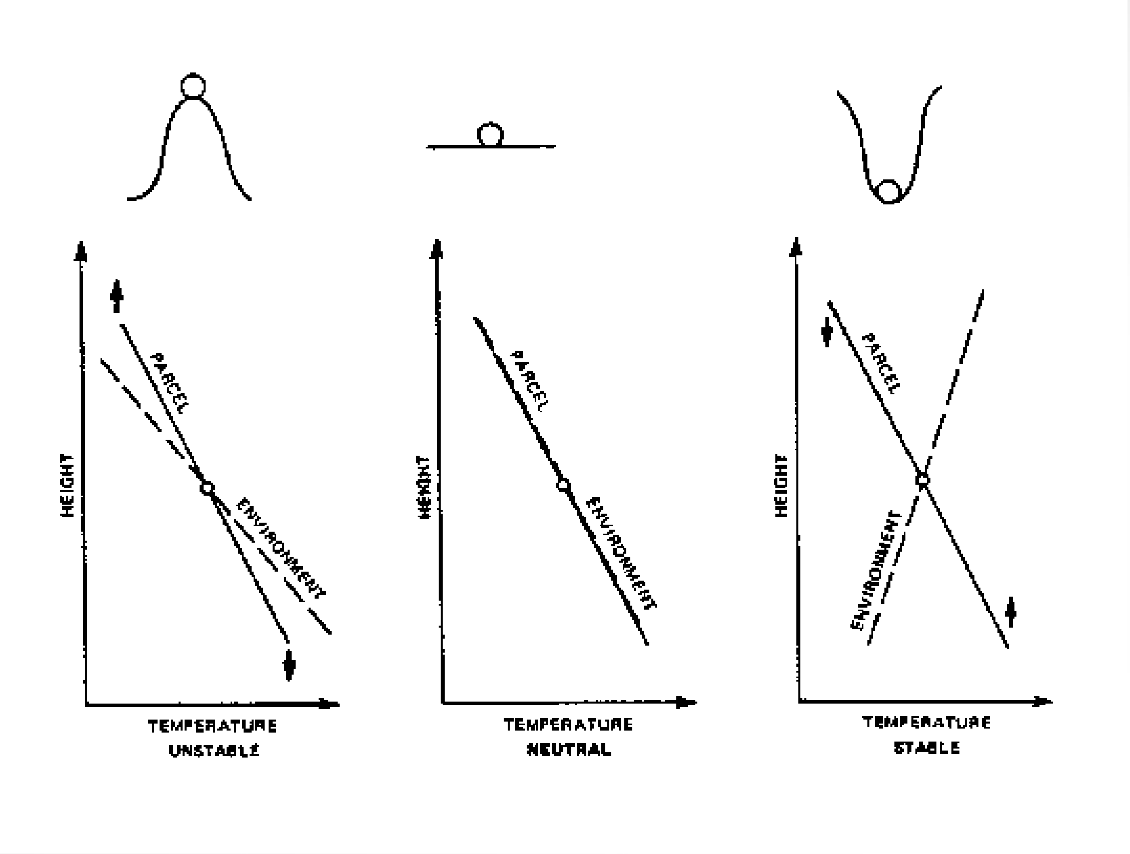
Types of Turbulence

- Mechanical
  - Result of frictional drag of earth's surface
  - Proportional to the wind speed and the roughness of the underlying surface
- Thermal
  - Result of heating of earth's surface by sun
  - Creates rising thermals
  - Depends on strength of incoming insolation and nature of underlying surface

The Lower Atmosphere



Atmospheric Stability



Measuring Atmospheric Stability

- Should be continuously measurable
- Often divided into finite classes, A -G
- Often inferred, e.g. from solar insulation
- Methods of determination do not always agree

Pasquill Stability Categories

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Wind speed at 10 m ($m\ s^{-1}$)	Daytime Insolation			Nighttime Conditions	
	Strong	Moderate	Slight	>3/8 clouds	<3/8 clouds
<2	A	A – B	B		
2 – 3	A – B	B	C	E	F
3 - 5	B	B – C	C	D	E
5 – 6	C	C – D	D	D	D
>6	C	D	D	D	D

Plumes vs. Stability Class

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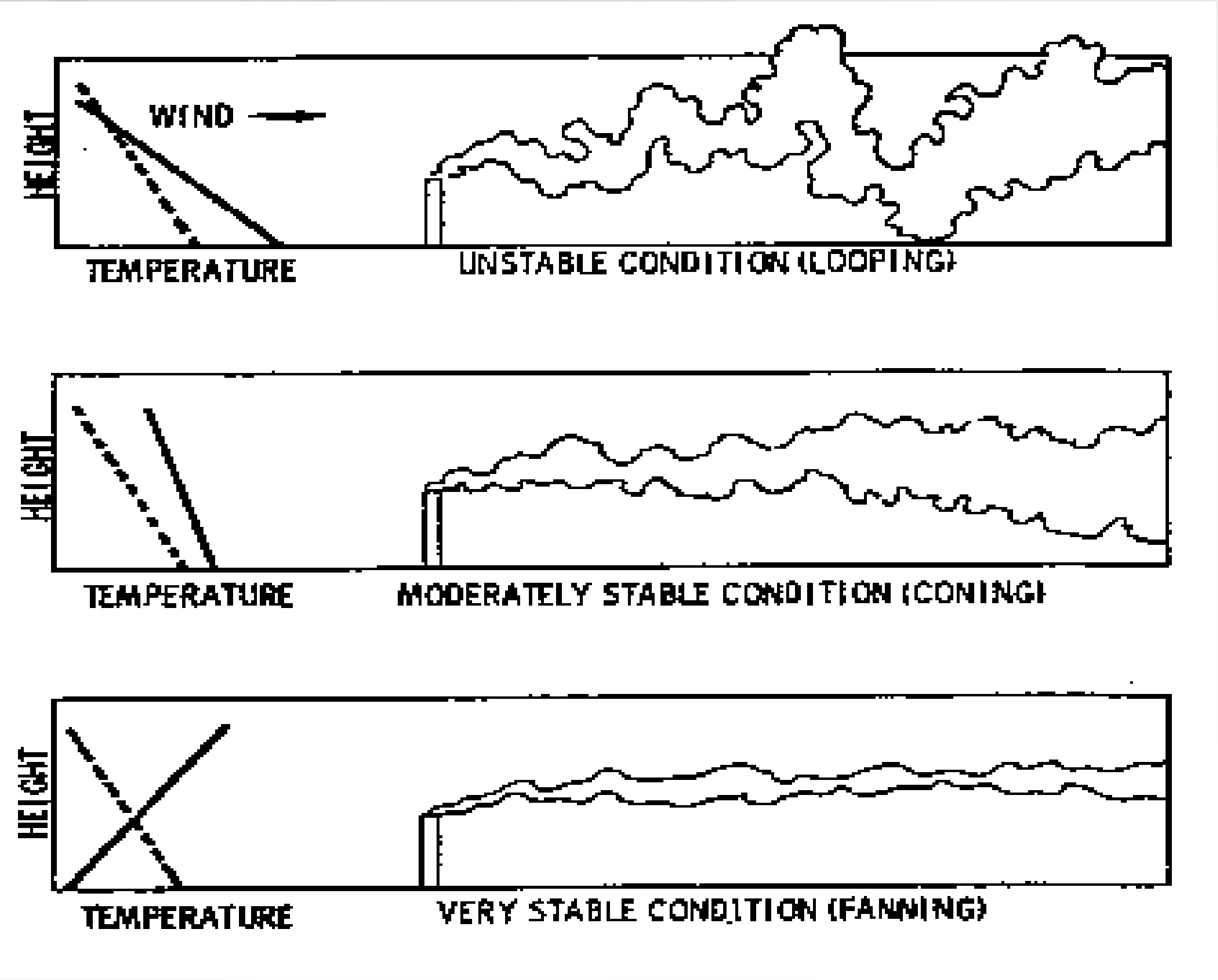
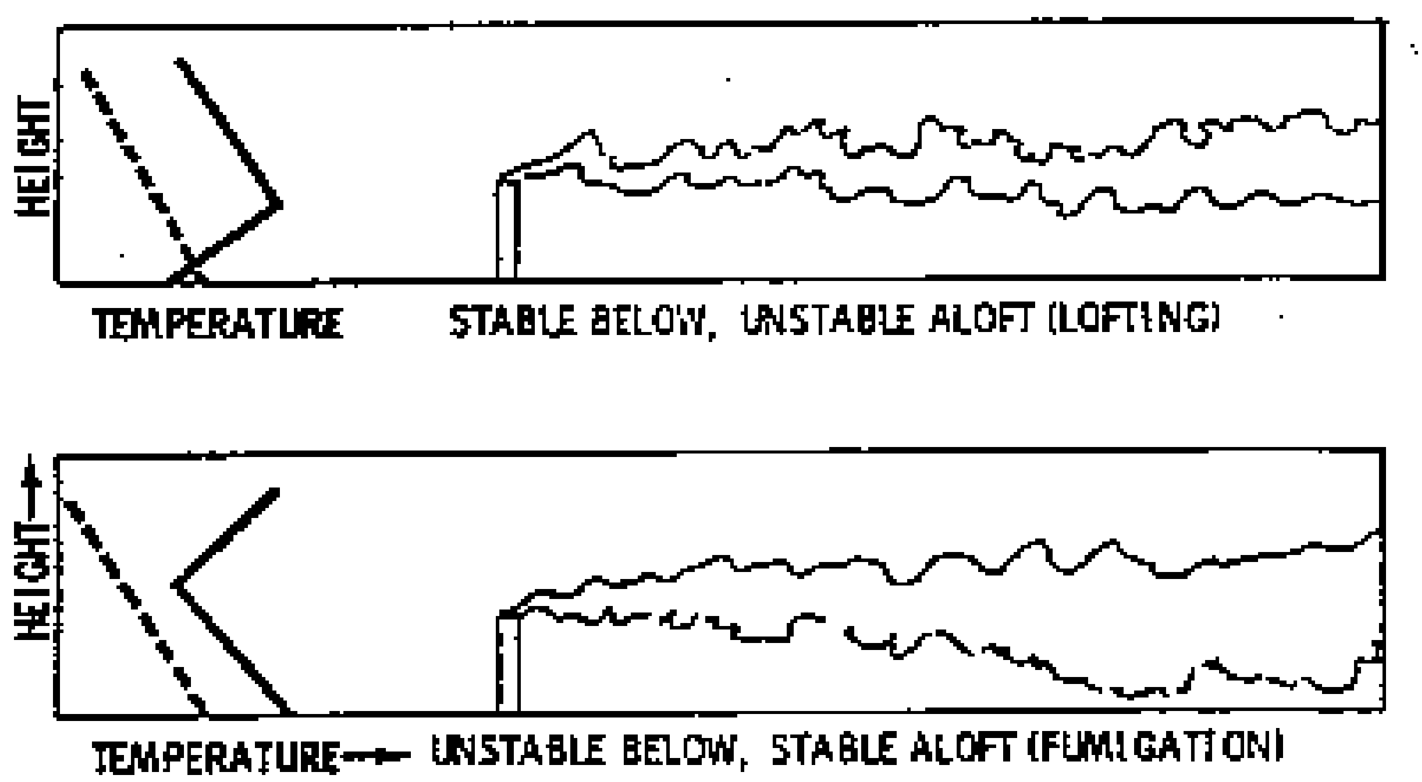


Plumes vs. Stability Class
Continued



Monin-Obukhov Length

- A measure of atmospheric stability
- Absolute value is depth of mechanically mixed layer near the surface
- Continuous rather than discreet
- Can be related to the Pasquill stability classes

Advection - Diffusion Equation

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$$\frac{\partial C}{\partial t} = K_x \frac{\partial^2 C}{\partial x^2} + K_y \frac{\partial^2 C}{\partial y^2} + K_z \frac{\partial^2 C}{\partial z^2} - \bar{u} \frac{\partial C}{\partial x} \pm S$$

C = air concentration (activity m^{-3})
t = time (s)
K_x, K_y, K_z = diffusion coefficients in the x, y, and z directions, respectively
S = sources and sinks
$\bar{u}$ = average wind speed (m s^{-1})

Solution Approaches

- Analytical (Closed Solutions)
  - Exact solution
  - Easy to program, fast to run
  - Limited to simple cases
- Numerical
  - More general & flexible
  - Complex geometries
  - Temporal variations
  - Treat more processes explicitly
  - Often need extensive data and resources

Important Source Term Characteristics

- Height of release above ground
- Time and duration of release
- Geographical location of release
- Structures near release
- Buoyancy of release

Source Term Characteristics
(Continued)

- Point, line, or area source
- Gaseous or particulate
- Chemically reactive in atmosphere
- Radioactive

Theories of Diffusion

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- Statistical theory
- Gradient transport, or K-theory
- Similarity theory
- Higher-order closure theory

Gaussian Plume Model

- Most commonly used atmospheric dispersion model
- It is consistent with the random nature of turbulence
- It is a solution to the Fickian (K-theory) diffusion equation for constants K and u

Gaussian Plume Model

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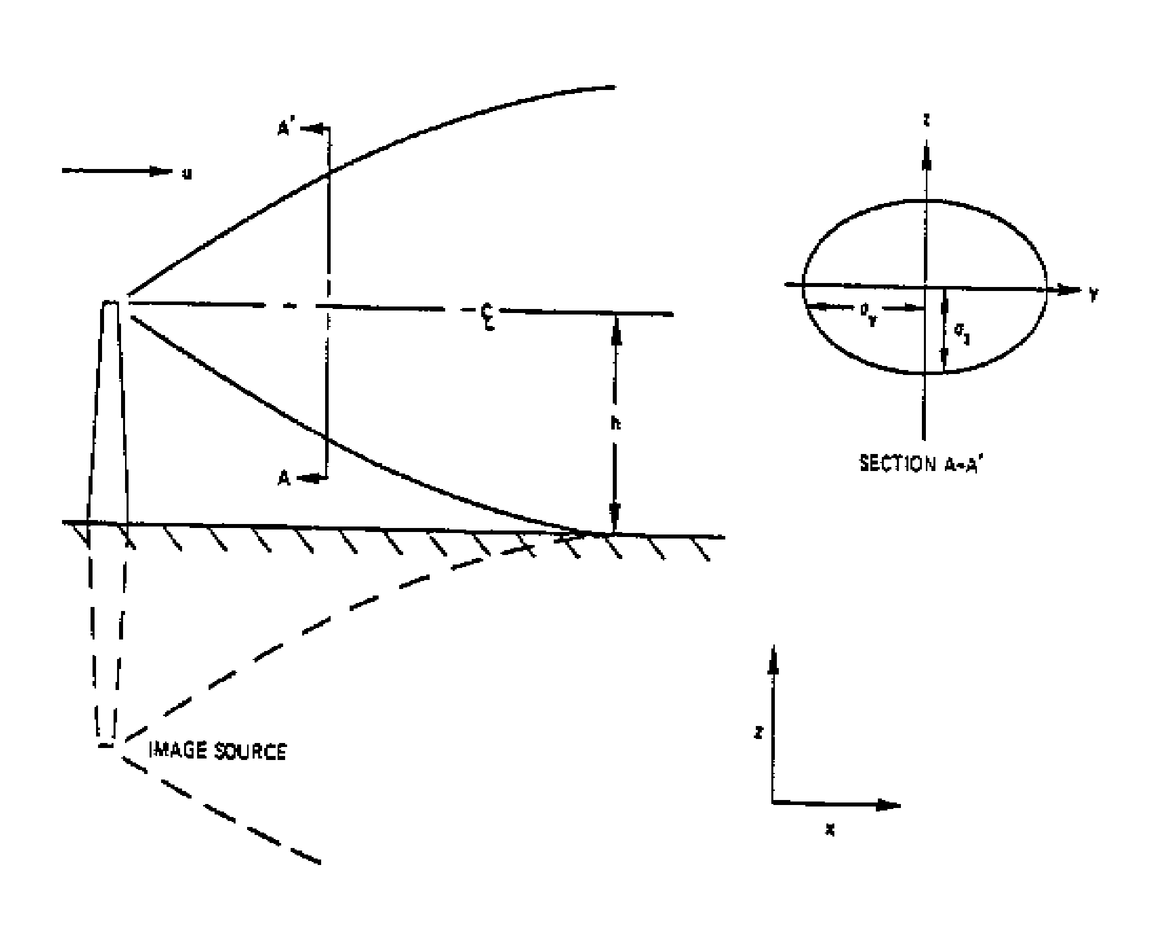

Gaussian Plume Model
Ground-level, Centerline

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$$\frac{\chi(x)u}{Q} = \frac{1}{\pi\sigma_y(x)\sigma_z(x)} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z(x)}\right)^2\right]$$

χ(x) = Air concentration (activity m^{-3})
u = Wind speed (m s^{-1})
Q = Total release of radionuclide (activity) or release per unit time (activity s^{-1})

$$\frac{\chi(x)u}{Q} = \text{The Gaussian diffusion factor}$$

$\sigma_y(x), \sigma_z(x) =$ The Gaussian plume diffusion factors in the crosswind (y) and vertical (z) directions, respectively, as a function of the downwind distance (x) (m)
H = height of the release (m)

Gaussian Plume Model
Ground-level, Sector-averaged

$$\frac{\chi(x)u}{Q} = \frac{2.032}{\pi x \sigma_z(x)} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z(x)}\right)^2\right]$$

$\chi(x)$ = Air concentration (activity m^{-3})
u = Wind speed (m s^{-1})
Q = Total release of radionuclide (activity) or release per unit time (activity s^{-1})

$\frac{\chi(x)u}{Q}$ = The Gaussian diffusion factor

$\sigma_z(x)$ = The Gaussian plume diffusion factors in the vertical (z) direction as a function of the downwind distance (x) (m)

H = Height of the release (m)

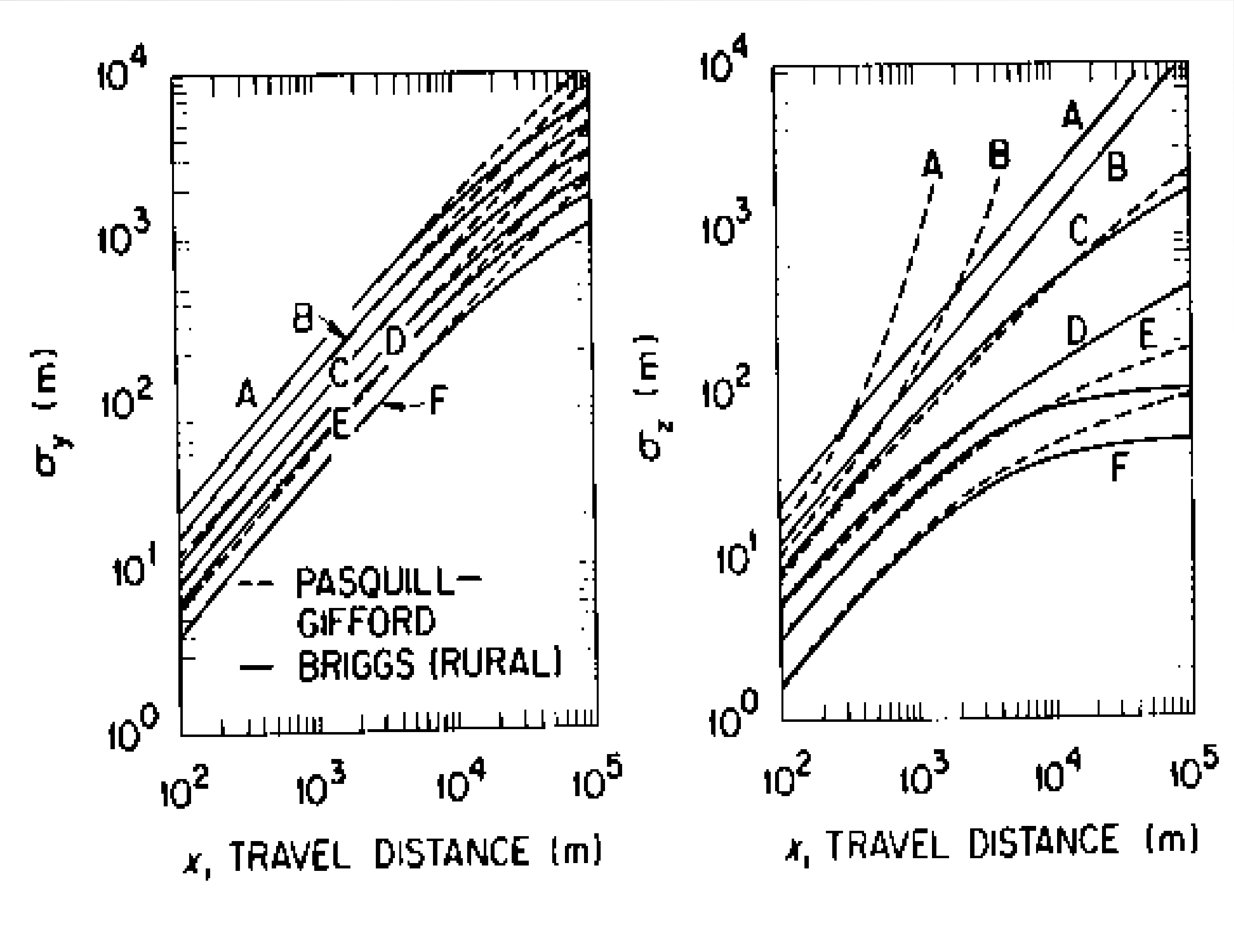
Limitations of the Gaussian Plume Model

- Low wind speeds
- Complex terrain
- Spatial and temporal changes in wind velocity
- Deposition and transformation within the plume during travel

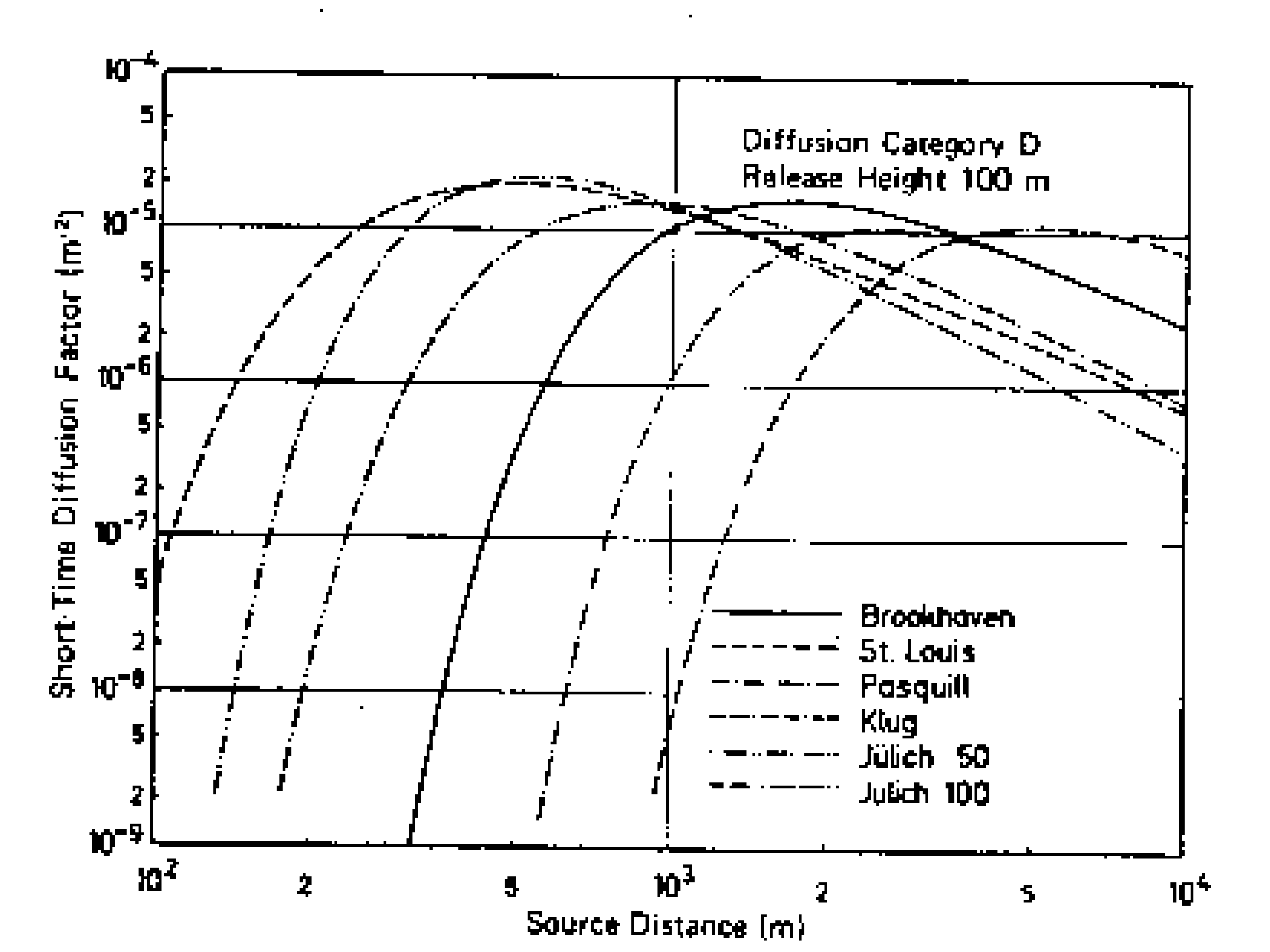
Why is the Gaussian Plume Model Used Today?

It works!!

Diffusion Parameters



Comparison of Diffusion Factors



Uncertainty in Gaussian Plume Model

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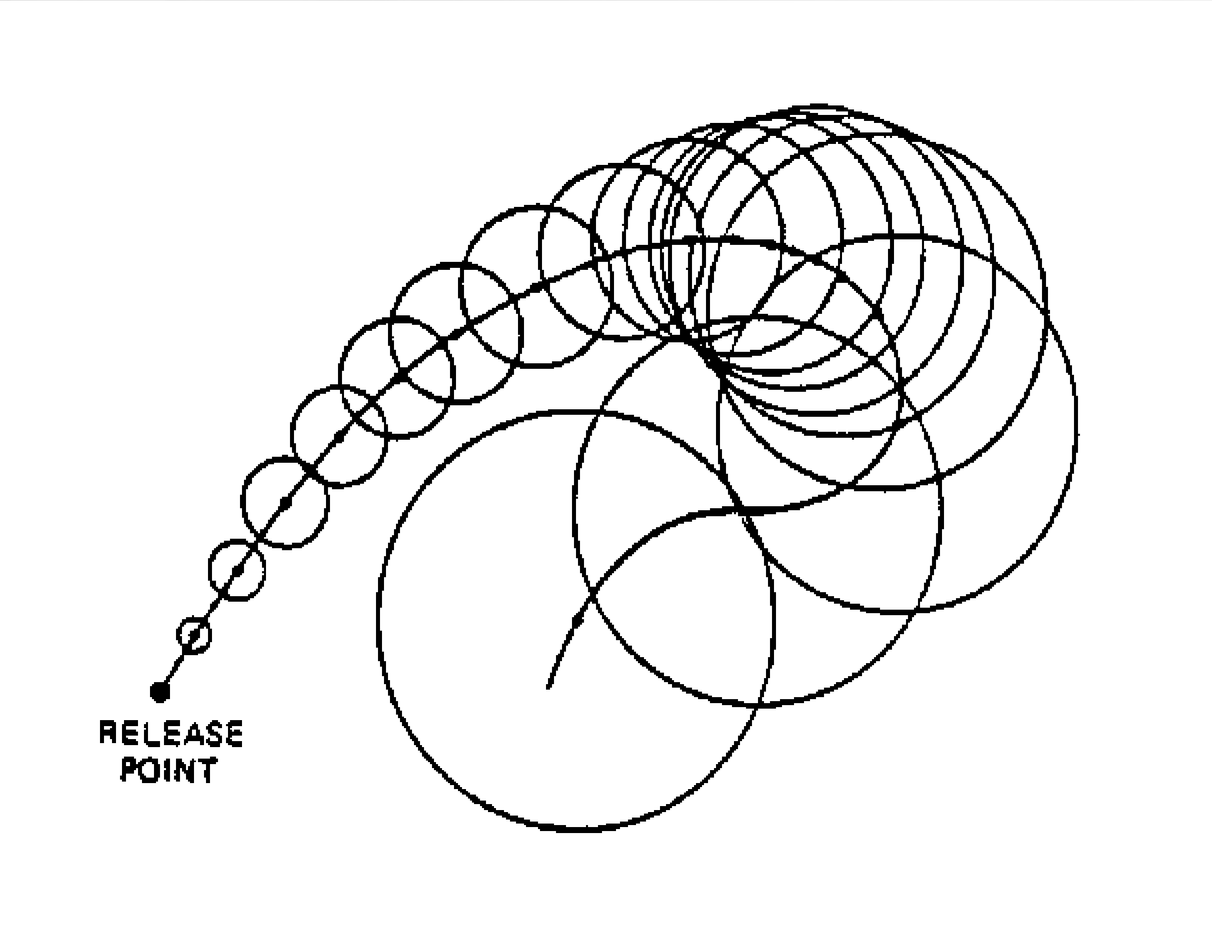
Conditions	Range, Predicted over Observed air concentration (P/O)
Highly instrumented site; ground-level, centerline; within 10 km of a continuous point source	0.65 to 1.35
Specific time and location, flat terrain, steady meteorology, within 10 km of release point	0.1 to 10
Annual average, specific location, flat terrain, within 10 km of release point	0.5 to 2
Annual average, specific location, flat terrain, 10 m to 150 km downwind	0.25 top 4
Complex terrain or meteorology, episodic releases	0.01 to 100
Episodic, surface-level releases, wind speeds less than 2 m s^{-1}	1 to 100

Puff Trajectory Model



Puff Trajectory Model

- Series of discrete puffs used to approximate a continuous plume
- Wind direction, wind speed, mixing depth, and stability updated regularly
- Allows temporal variations in source characteristics
- Allows spatial and temporal variations in meteorological conditions
- Diffusion within each circular puff generally assumed to be Gaussian in nature

Particle-in-Cell Model

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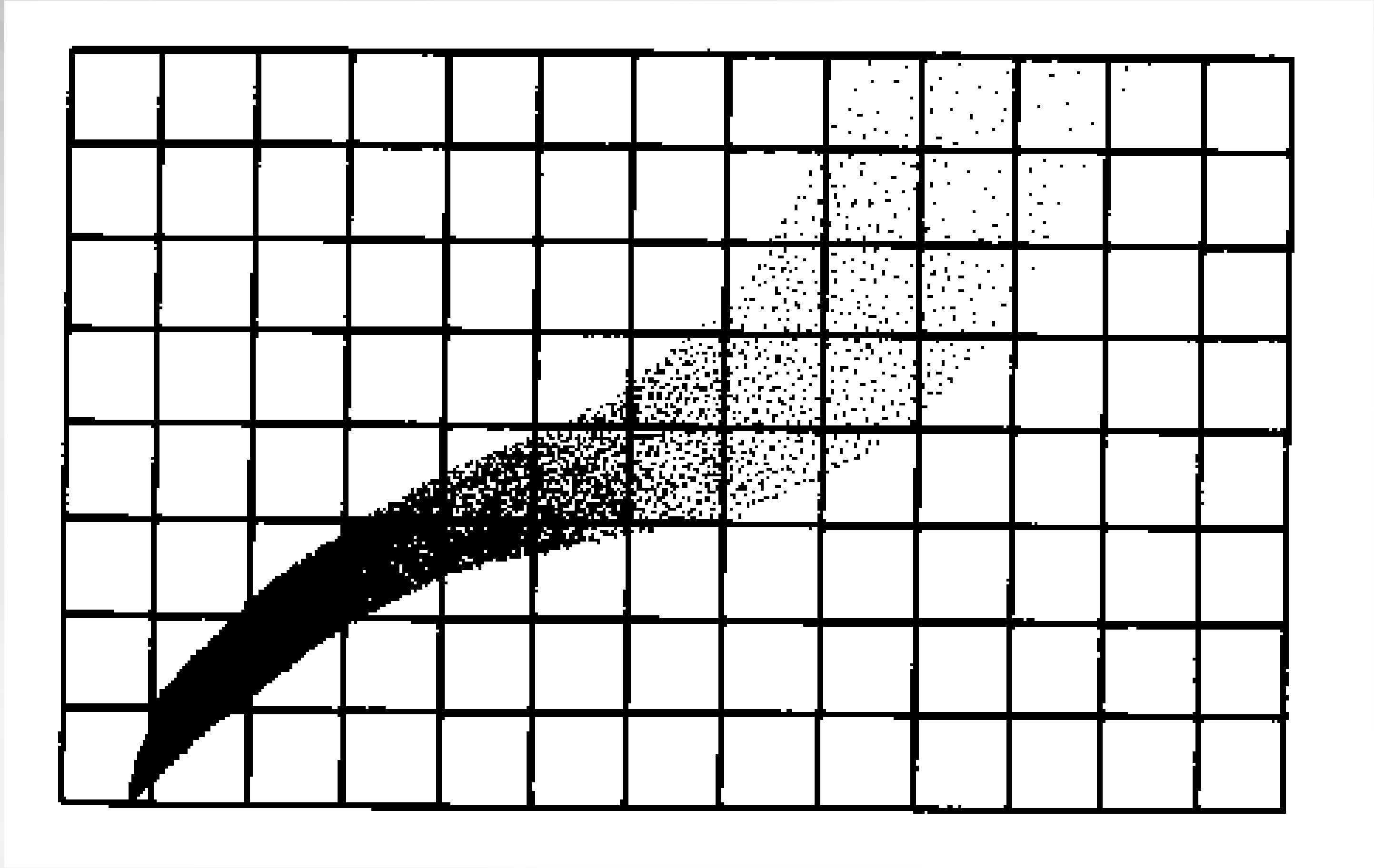

Particle-in-Cell Model

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- Source emissions approximated by a large number of particles
- Each particle is followed over a fixed coordinate system
- Concentration in each grid square is found by adding the contribution from each particle
- Requires specification of a wind field
- Specified wind velocity is three-dimensional, and may vary from cell to cell
- Terrain effects may be incorporated

More Complex Models Require More Resources

- Data input requirements are larger and more complex
- Larger computer capacity required
- Generally longer computer running times
- Model predictions more difficult to verify

Conclusions

- The atmosphere is complicated
- Wind direction is a key variable in atmospheric dispersion modeling
- Turbulence theory is being incorporated into assessment models
- Empirically-based Gaussian plume models are still widely used

Atmospheric Models in GENII