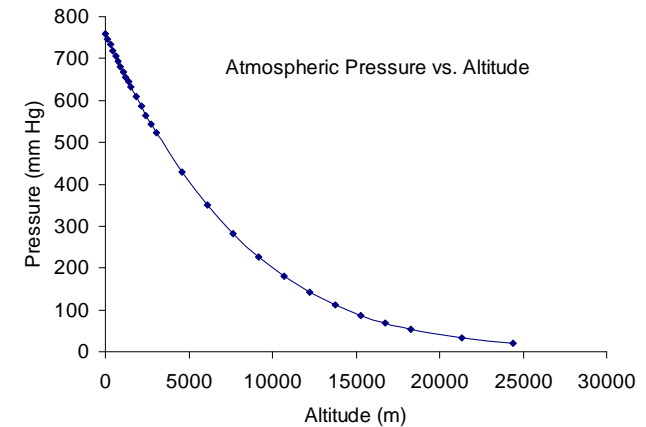


Atmospheric Transport & Dispersion

HPHY 6605
2012



Atmospheric Properties

- Transport and shielding properties are of interest
- Atmosphere consists of N_2 , O_2 , Ar, plus water vapor and trace gases such as CO_2
- Mass is 5×10^{18} kg plus about 1.5×10^{17} kg of water
- Atmosphere is divided into
 - troposphere (<7 miles),
 - stratosphere (7-20 miles),
 - mesosphere (20-40 miles) and
 - ionosphere (>40 miles)
- Pressure and density drop markedly with altitude

Atmospheric Properties

- Atmosphere contains natural and man-made aerosols, vapors and trace gases
- Emissions are transported by wind and diluted primarily by turbulent diffusion, resulting in dispersion
- Everyday experience with weather forecasts shows that predictions of atmospheric processes are inexact
- This is true for pollutant transport and dispersion as well as weather forecasts
- Transport and dispersion cannot be treated well from first principles so phenomenological models are used

Some Definitions

- Airborne: carried by the air, as a dust
- Diffusion: movement of a substance from a region of higher concentration to lower concentration, thus mixing the substance
 - may be molecular or turbulent
- Dispersion: Spreading widely; generally, the combined influences of diffusion and transport are called dispersion

Atmospheric Properties

Randerson, 1984

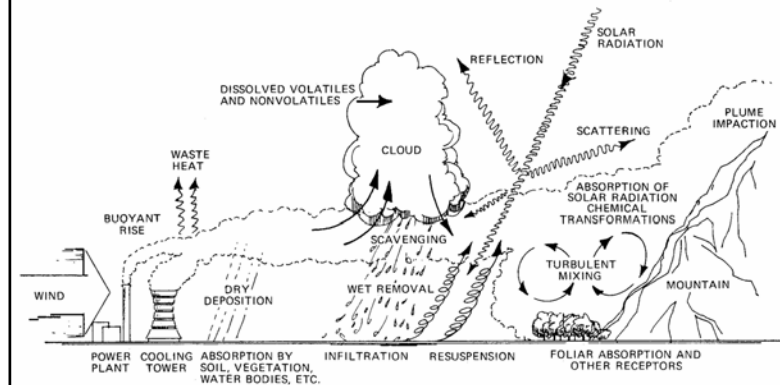


Fig. 1.3 Conceptual view of atmospheric processes that can act upon effluents released into the atmosphere.

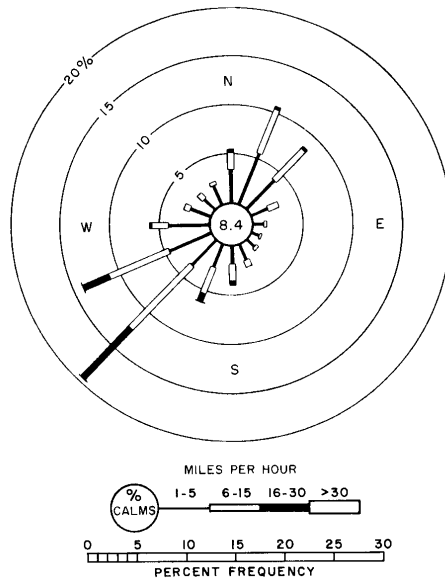
Atmospheric Removal Mechanisms

- **Rainout:** Gaseous and particulate materials entrained during precipitation formation within a cloud
- **Washout:** Gaseous and particulate materials removed below cloud by falling precipitation (scavenging)
- **Dry Deposition:** Gaseous and particulate materials removed by
 - gravitational settling
 - contact with ground or vegetation
- **Decay:** Radioactive decay of radionuclides in gaseous or particulate effluents during transport
- **Chemical Transformations:** Some effluents may undergo chemical binding/changing during transport

Atmospheric Properties

- The transport and dispersion of pollutants in the atmosphere are affected by
 - wind direction
 - wind speed
 - terrain and buildings
 - vertical stability
 - Mixing depth
- Averages of wind speed, direction and velocity are represented by wind roses

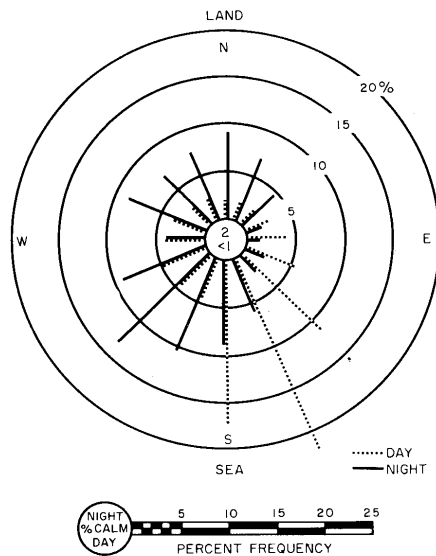
Wind Rose with Velocity



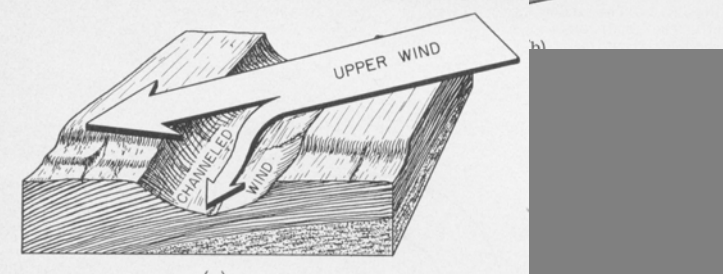
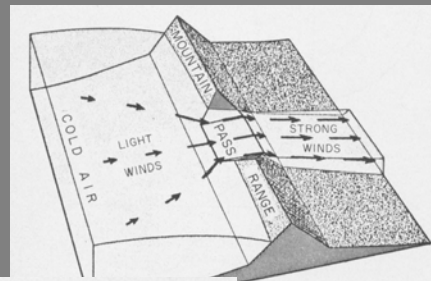
Atmospheric Properties

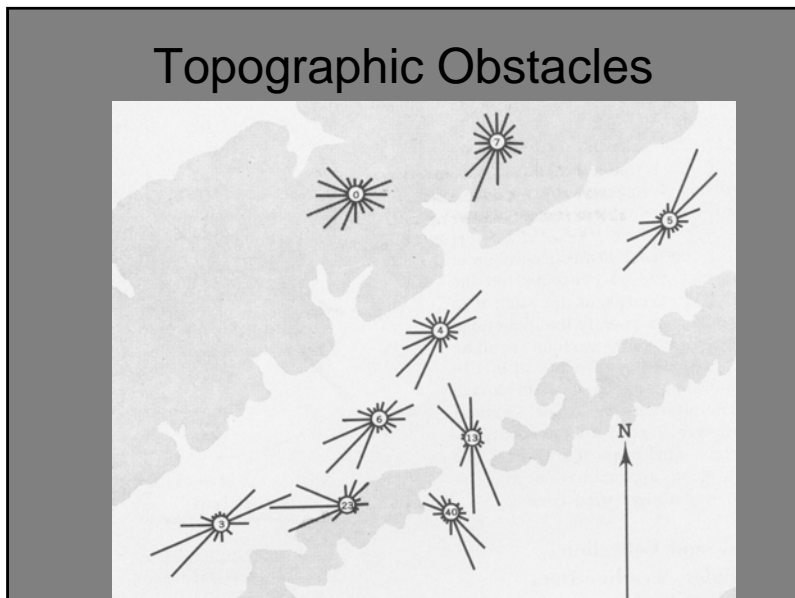
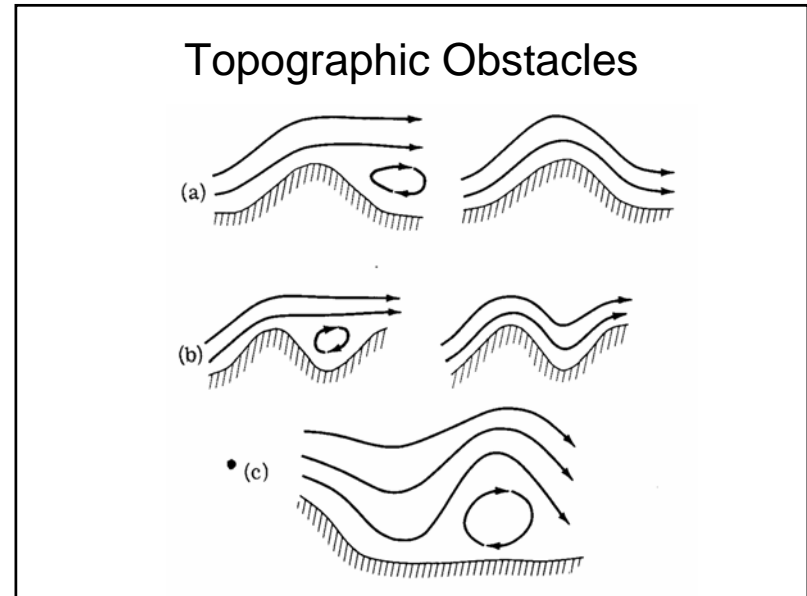
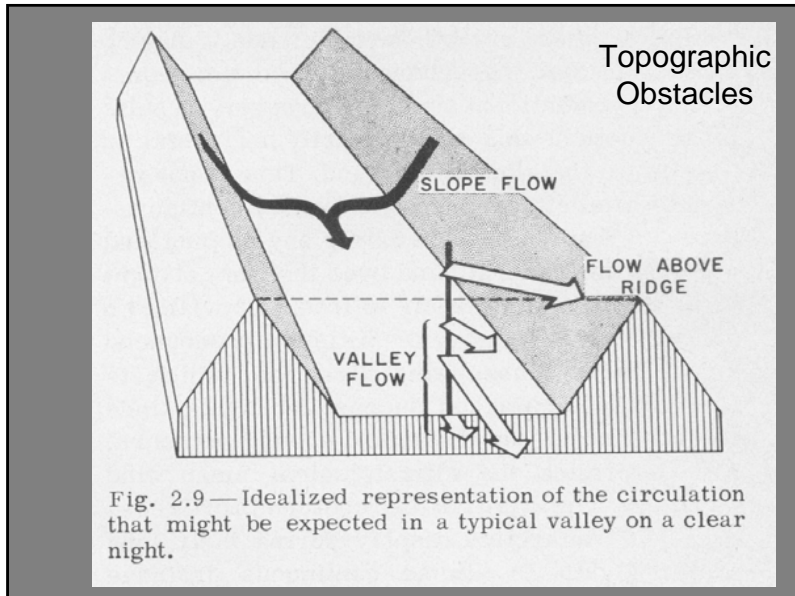
- The prevailing wind speed and direction are affected by terrain features
 - Valleys
 - Mountain passes
 - Hills
 - Mountains

Day-night Wind Rose



Topographic Obstacles





- ### Terminology
- Lapse rate: The rate of change in atmospheric temperature with height
 - The adiabatic or “normal” lapse rate
 - Cooling in temperature due to expansion of a mass of air as it moves upwards without heat exchange
 - as **predicted** by the ideal gas law
 - The environmental lapse rate
 - Actual change of temperature with altitude for the stationary atmosphere - the **measured** temperature gradient

Terminology

- Temperature inversion
 - An increase in atmospheric temperature with height rather than a decrease
 - Creates a stable atmosphere with little mixing
 - An inversion can lead to pollution emitted from or near the ground being trapped close to the ground, e.g.
 - Particulate matter from emissions or re-suspension
 - Radon and its decay products

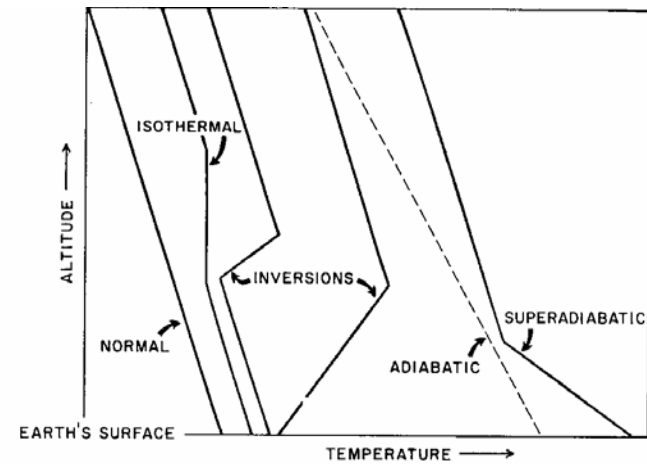
Vertical Stability

- Vertical stability is an important factor in transport and dilution
- Vertical stability is controlled primarily by the "lapse rate" of temperature compared to the adiabatic lapse rate (chart)
- Adiabatic lapse rate corresponds to cooling at about 6.5 °C per km of altitude

Terminology

- Superadiabatic lapse rate
 - An environmental lapse rate greater than the adiabatic lapse rate
 - Results in temperatures cooler than a "normal" atmosphere as height increases
 - The air is very unstable - a parcel of air will gain buoyancy as it rises
 - Results in good mixing

Vertical Stability and Lapse Rate

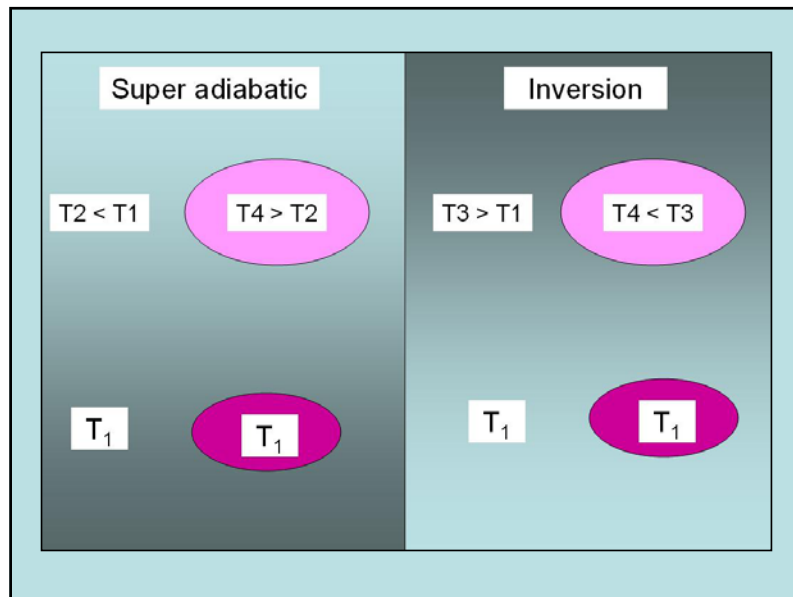


Vertical Stability

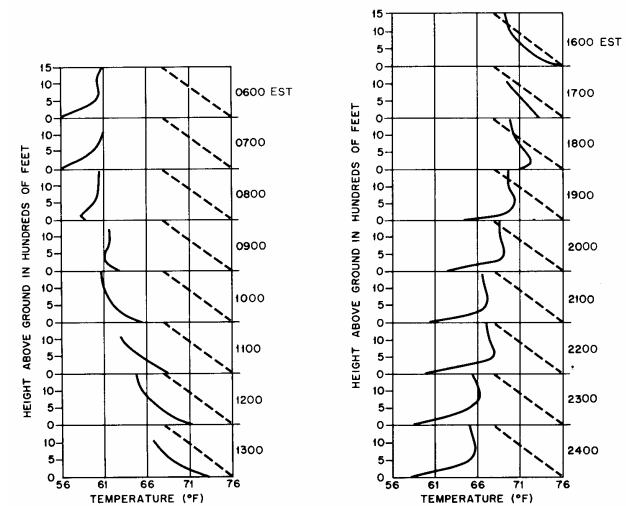
- Super adiabatic lapse rates lead to an unstable atmosphere and good mixing
- Sub-adiabatic and inverted lapse rates lead to stability and poor mixing (drawing)
- Inverted lapse rates occur because of warm air overrunning cool air at frontal boundaries and sea breezes and because of diurnal cooling

Diurnal Effects

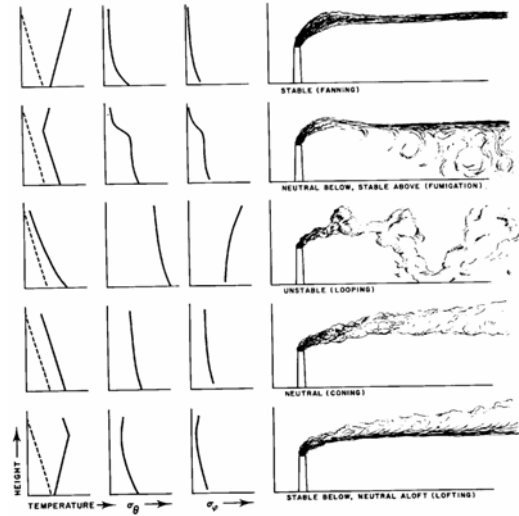
- Diurnal warming and cooling affects lapse rates (chart)
- The lapse rates affect dispersal of plumes (chart, photographs)
- A ceiling for mixing exists in the atmosphere which is dependent on geography and season (chart)



Diurnal effects on Lapse Rates



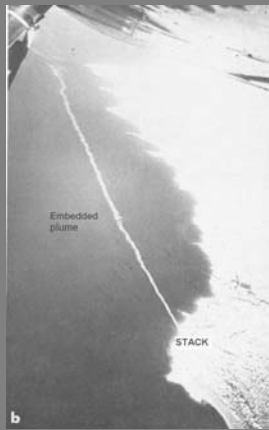
Lapse Rate Effects on Plumes



Examples of Looping



Plume behavior in vertically stable air



No wind shear - coning



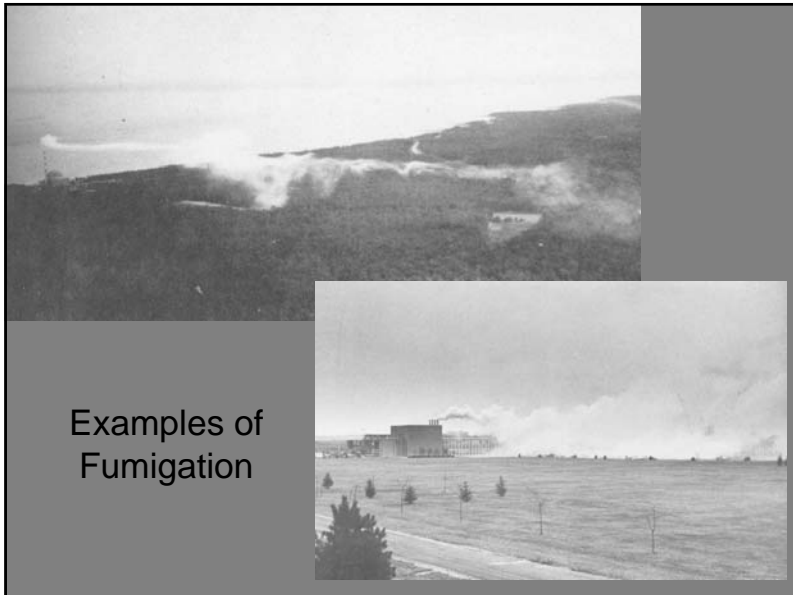
Wind shear - fanning

Coning with time-lapse view



Instantaneous photo

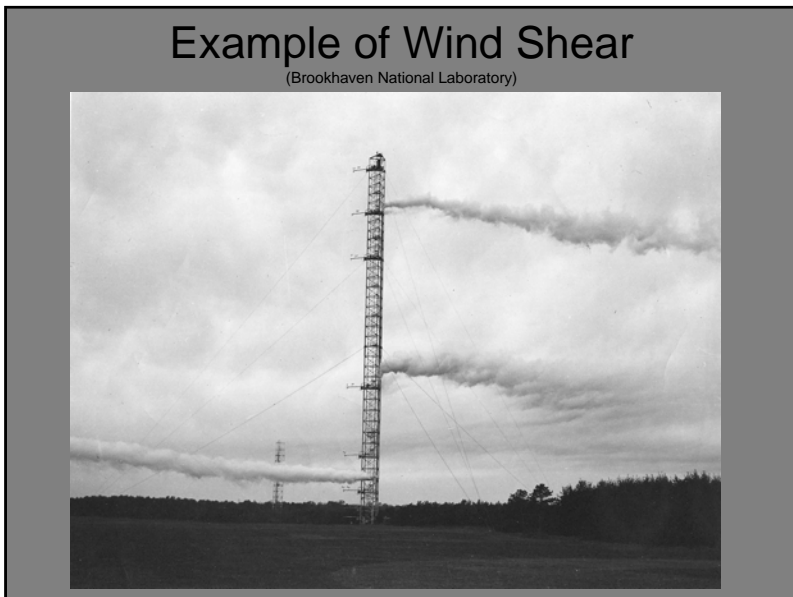
Time lapse photo



Examples of Fumigation

Mixing Depth

- Mixing depth, also called “ceiling,” represents the height of an atmospheric barrier to good mixing
- Mixing depth varies with location season and time of day



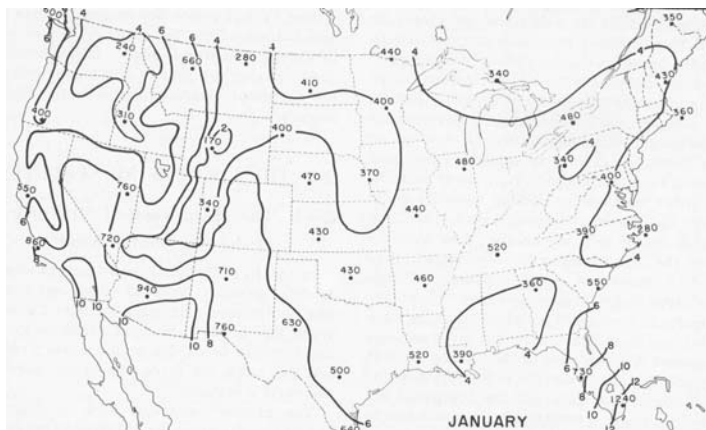
Mixing Depths at INL

(meters above ground level)

Season	Morning	Afternoon
Spring	480	2330
Summer	260	2900
Autumn	330	1550
Winter	400	730
ANNUAL AVERAGE	370	2090

Courtesy of Gene Start

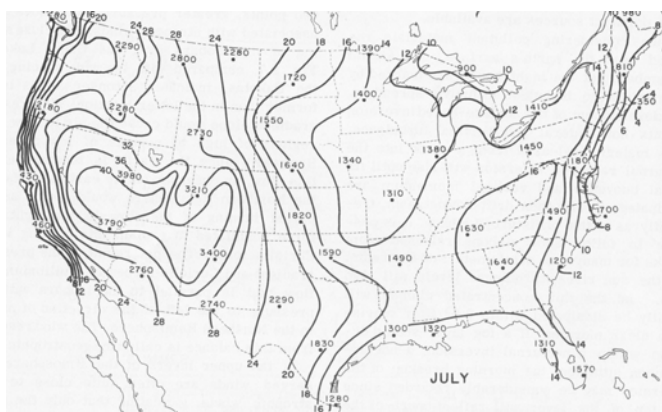
Ceiling - winter



Meteorological models

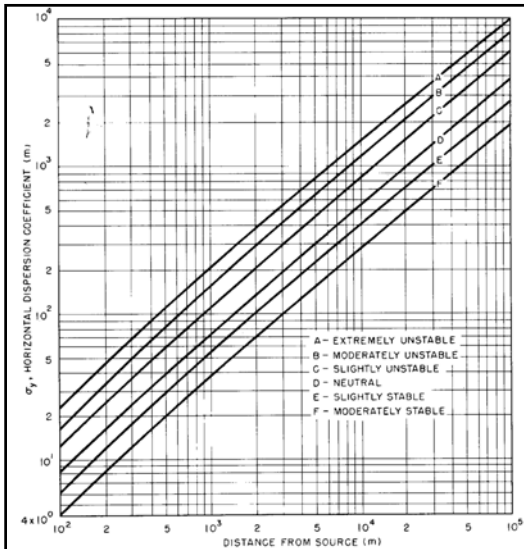
- A central question is what is the concentration of a radionuclide in air at a distance from the emission source?
- Models are used for predicting pollutant concentrations; they can be complex and are usually computerized
- Examples are Airdose, CAP-88, MDIF
- Examine relatively simple “straight line” Gaussian diffusion model in text (equation)

Ceiling - summer



Equation for the Gaussian Diffusion Model

$$\chi(x,y) = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \cdot \exp - \left(\frac{h^2}{2\sigma_z^2} + \frac{y^2}{2\sigma_y^2} \right)$$



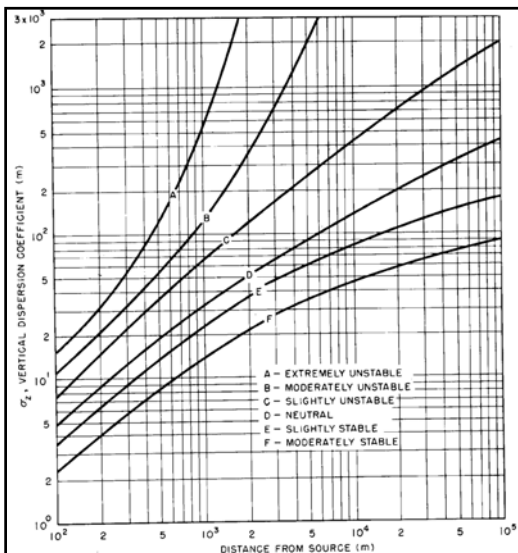
Coefficients for the Gaussian Model Lateral Diffusion

$$\sigma_y$$

Fig. 3.10—Lateral diffusion, σ_y , vs. downwind distance from source for Pasquill's turbulence types.

Aspects of the Gaussian Model

- Cannot deal with changing wind speeds or directions
- Useful distance is limited to that which the plume travels under fairly constant meteorological conditions
- Buildings and sharp terrain features reduce accuracy of the Gaussian model
- Mixing depths, which vary with time of day and season, bound vertical mixing

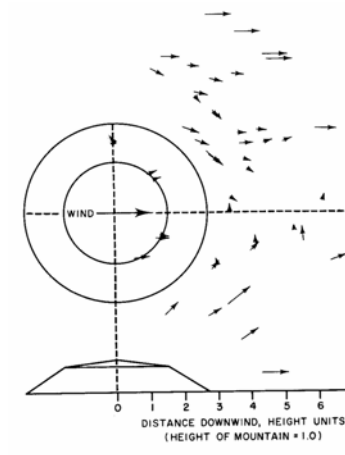


Coefficients for the Gaussian Model Vertical Diffusion

$$\sigma_z$$

Fig. 3.11—Vertical diffusion, σ_z , vs. downwind distance from source for Pasquill's turbulence types.

Behavior around an obstacle



Puff Models

- Puff models are replacing straight line Gaussian diffusion models in the more sophisticated codes
- Puff models transport and “grow” a series of puffs to a receptor location
- Although more complex than the straight line Gaussian diffusion models, a significant advantage is that changing atmospheric conditions such as wind direction can be modeled

Deposition

- Particles carried in the plume deposit primarily by gravitational settling and interception
- Particle deposition can be characterized in terms of deposition velocity
- Deposition velocity is determined empirically as amount deposited per centimeter squared per second divided by the concentration in amount per centimeter cubed
- Once deposition quantities are known, additional transport through the environment can be modeled

Puff Model

