Atmospheric Air Pollutant Dispersion

Estimate air pollutant concentrations downwind of emission point sources.

Downwind Air Pollution Concentrations Are a function of:

- Atmospheric Stability
- Air Temperature Lapse Rates
- Atmospheric Air Inversions
- Atmospheric Mixing Height
- Dispersion from Point Emission Sources
- Dispersion Coefficients

In CEE490/ENVH 461 class we will Primarily use EPA SCREEN software

Atmospheric Air Vertical Stability

$$\frac{\textbf{Dry Adiabatic}}{\textbf{Lapse Rate}} = \frac{\Delta\textbf{Temp}}{\Delta\textbf{Altitude}} = \frac{\Delta\textbf{T}}{\Delta\textbf{Z}} = \frac{\textbf{9.76 K}^{\textbf{o}}}{\textbf{1000 meters}} = \frac{\textbf{5.4F}^{\textbf{o}}}{\textbf{1000 ft}}$$

- Adiabatic vertical air movement causes a change in pressure and temperature:
  - $dT/dz = g/C_p = \gamma_d$ (dry adiabatic lapse rate)

$$\gamma_d = 9.8 \text{ K/km}$$

--Stable lapse rate: $\gamma < \gamma_d$

- Unstable lapse rate: $\gamma > \gamma_d$

Atmospheric Stability

Characterized by vertical temperature gradients (Lapse Rates)

- **Dry adiabatic lapse rate (Γ) = 0.976 ^{o}C/100 m ~ 1 ^{o}C/100 m**
- **International standard lapse rate = 0.0066 ^{o}C/m**

Does the air temperature lapse rate have anything to do with air quality?

Yes, because it is related to amount of vertical mixing of emitted air pollutants.

- **First Law of Thermodynamics**

= 0 for adiabatic expansion

$$\cancel{dq} = dh - \upsilon dP = C_p dT - \frac{1}{\rho} dP$$

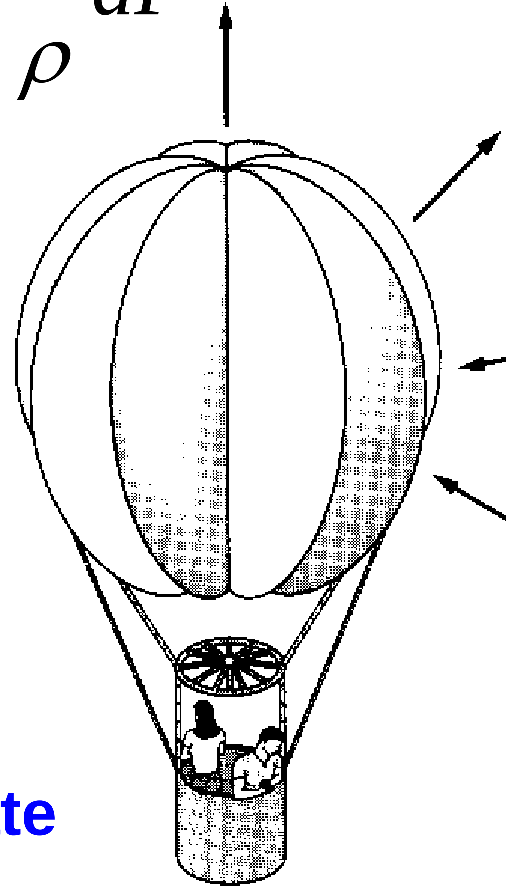
- Barometric Equation

$$\frac{dP}{dZ} = -\rho g$$

$$\Rightarrow C_p dT = \frac{1}{\rho} dP = -g dZ$$

$$\Rightarrow \frac{dT}{dZ} = -\boxed{\frac{g}{C_p}}$$

Lapse Rate

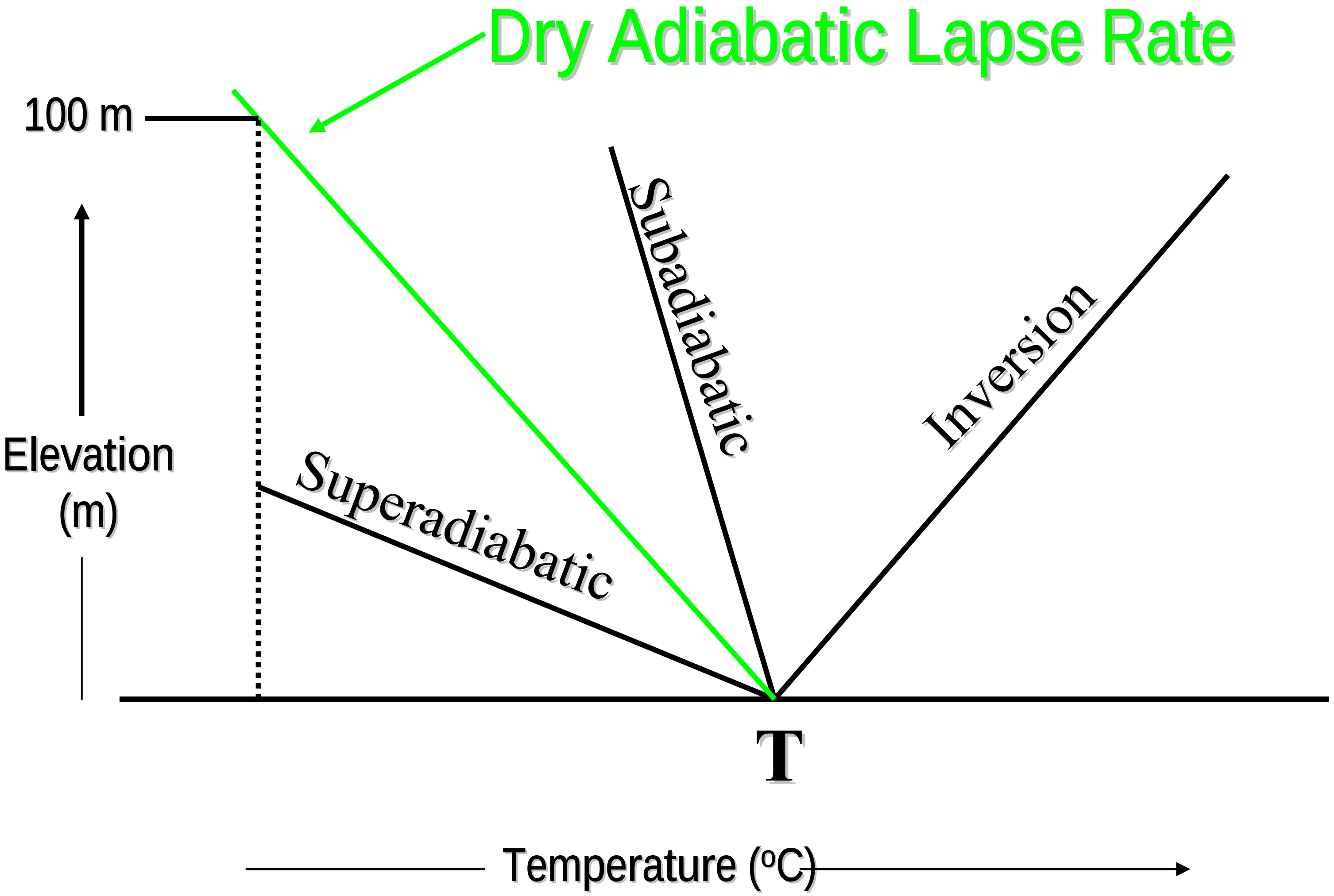


Balloon expands as it rises and thus does work on its surroundings.

Accordion-pleated balloon requires no work to stretch.

Heat transfer between balloon and surroundings is not zero, but is slow enough to ignore.

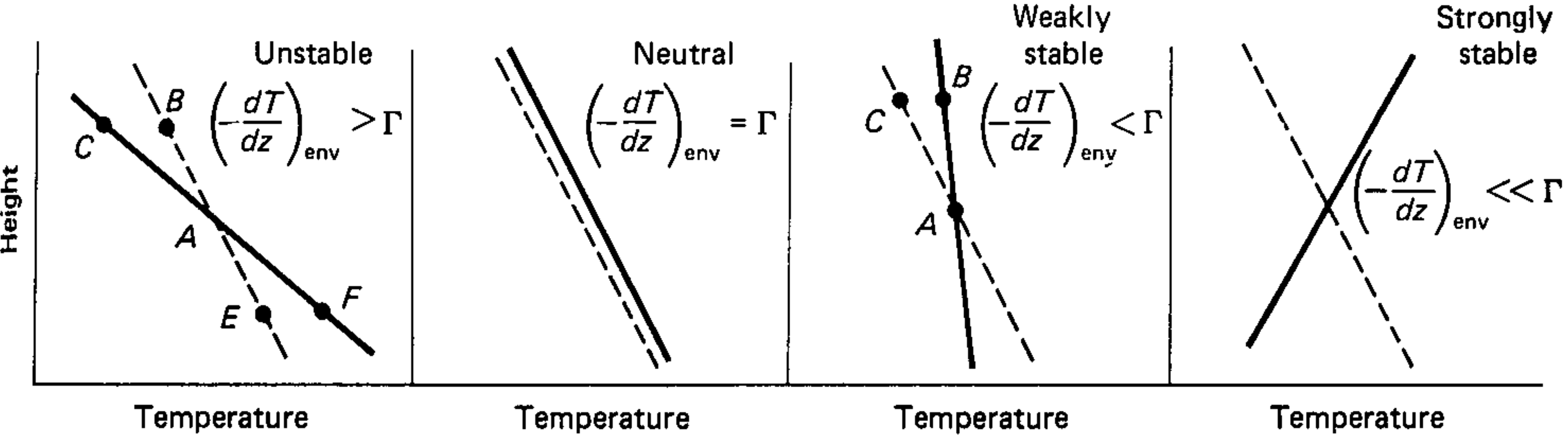
Air Temperature Lapse Rates



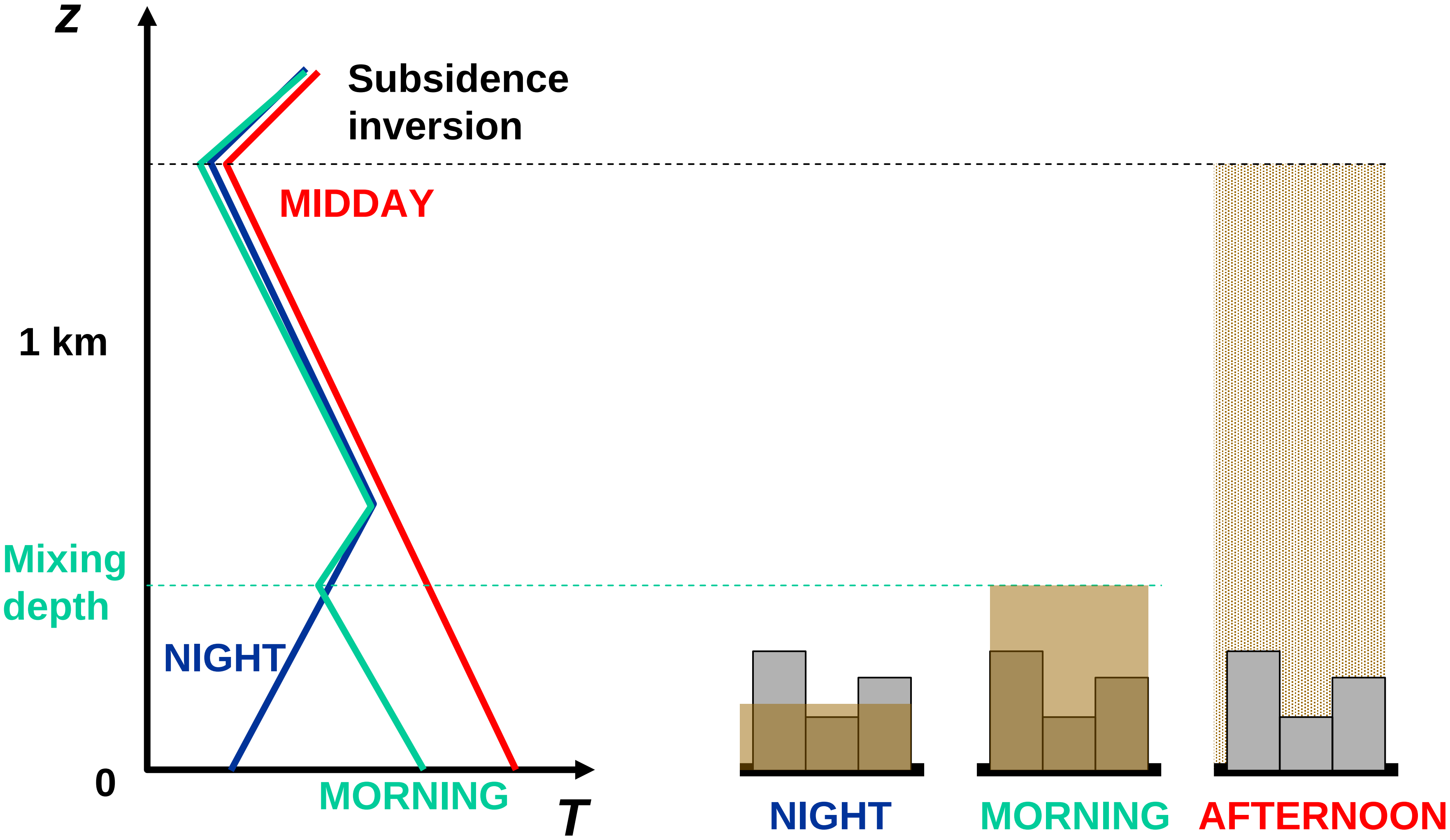
Stability Conditions

- - - - - - **Adiabatic lapse rate**

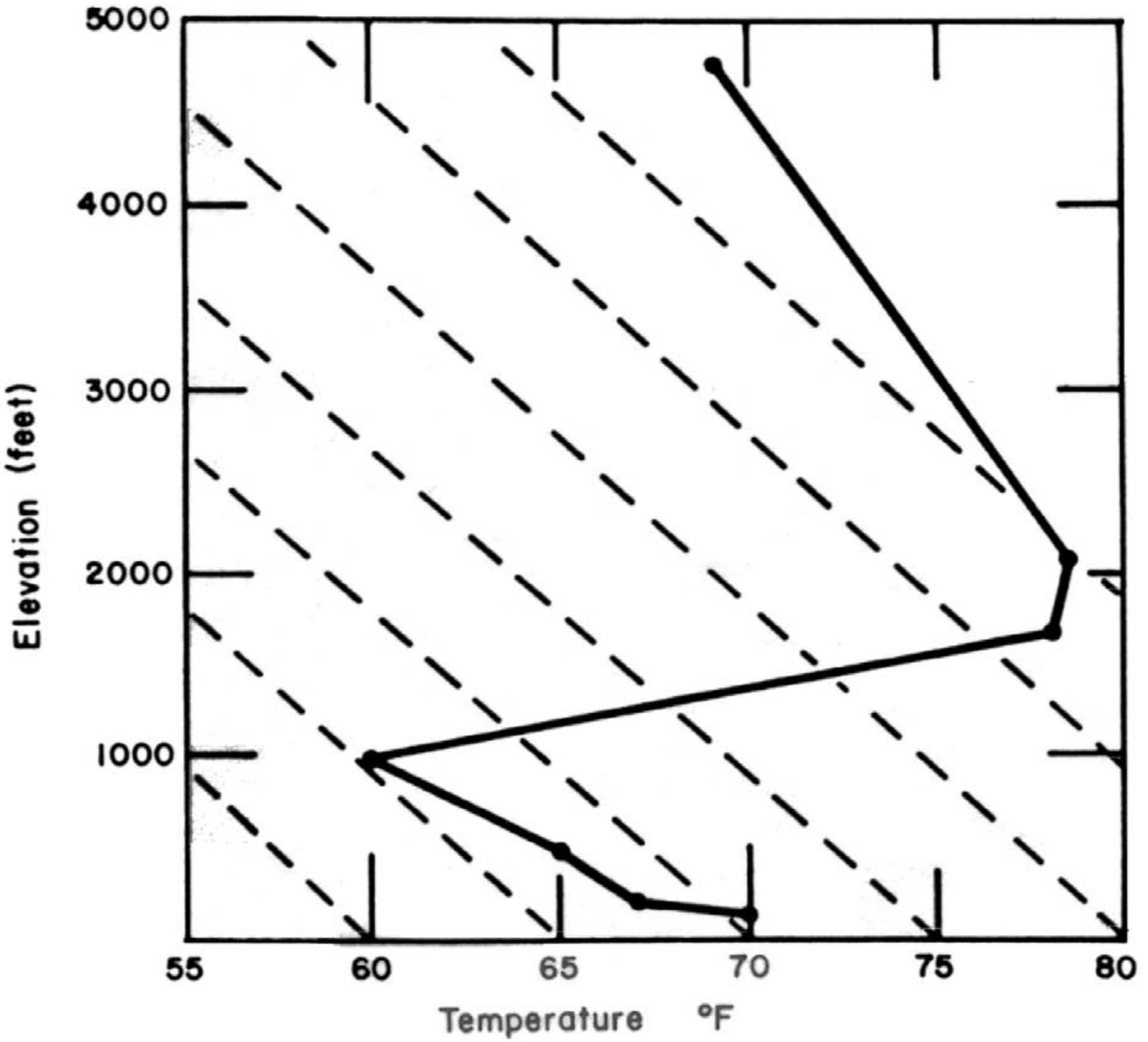
—— **Actual Air Temperature lapse rate**



Diurnal Cycle of Surface Heating /Cooling

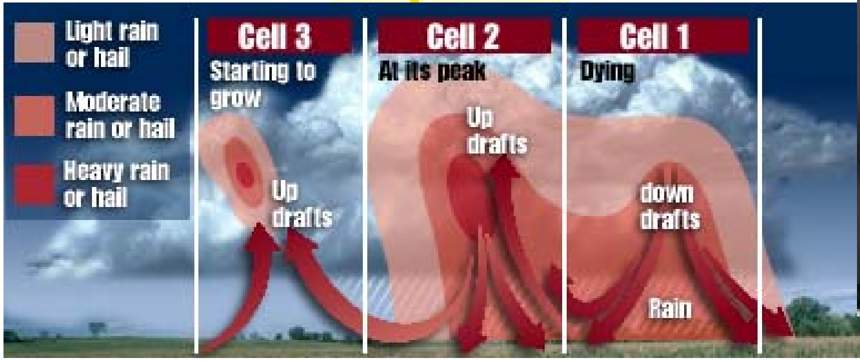


Actual Temperature Sounding

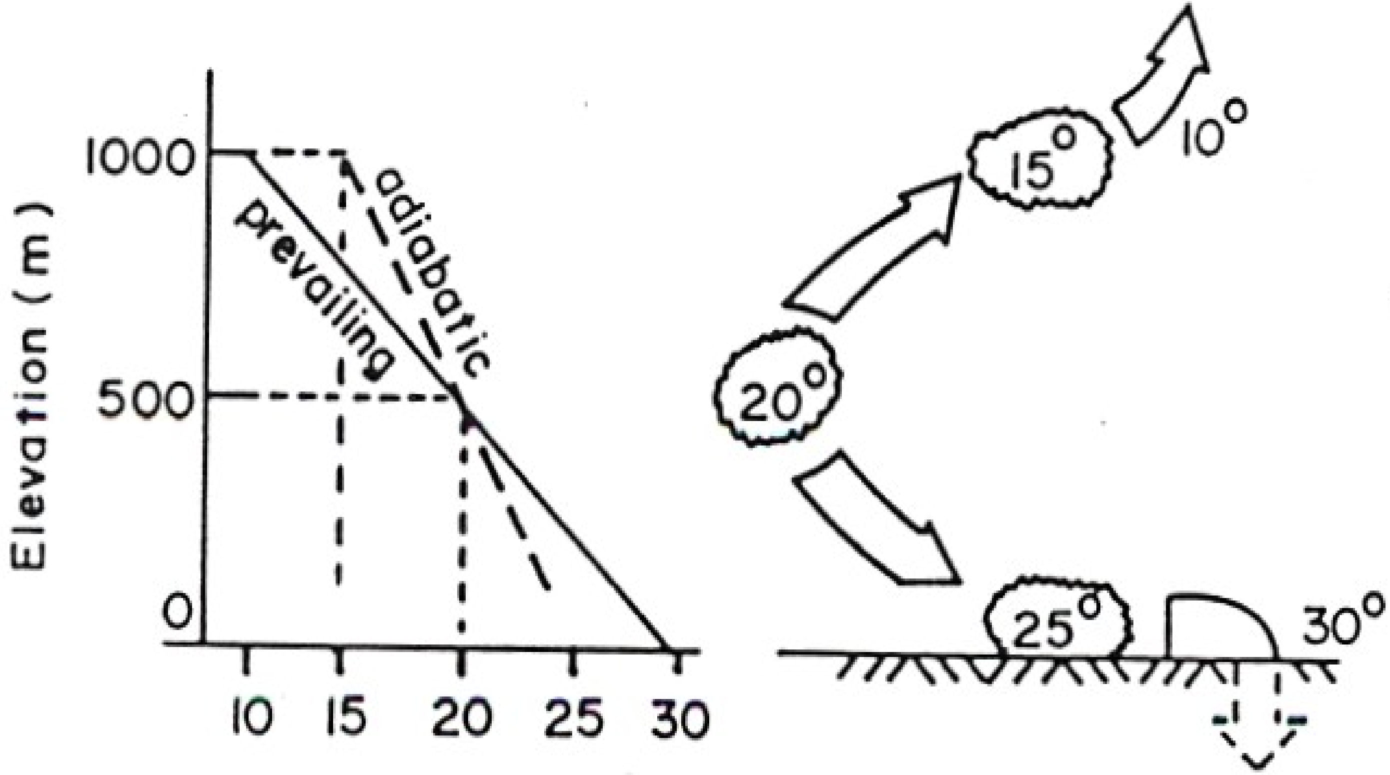


Superadiabatic Lapse Rates (Unstable air)

- Temperature decreases are greater than -10^{o} C/1000 meters
- Occur on sunny days
- Characterized by intense vertical mixing
- Excellent dispersion conditions



Atmospheric Stability
Superadiabatic – Strong Lapse Rate
Unstable Conditions



A. Superadiabatic conditions (unstable)

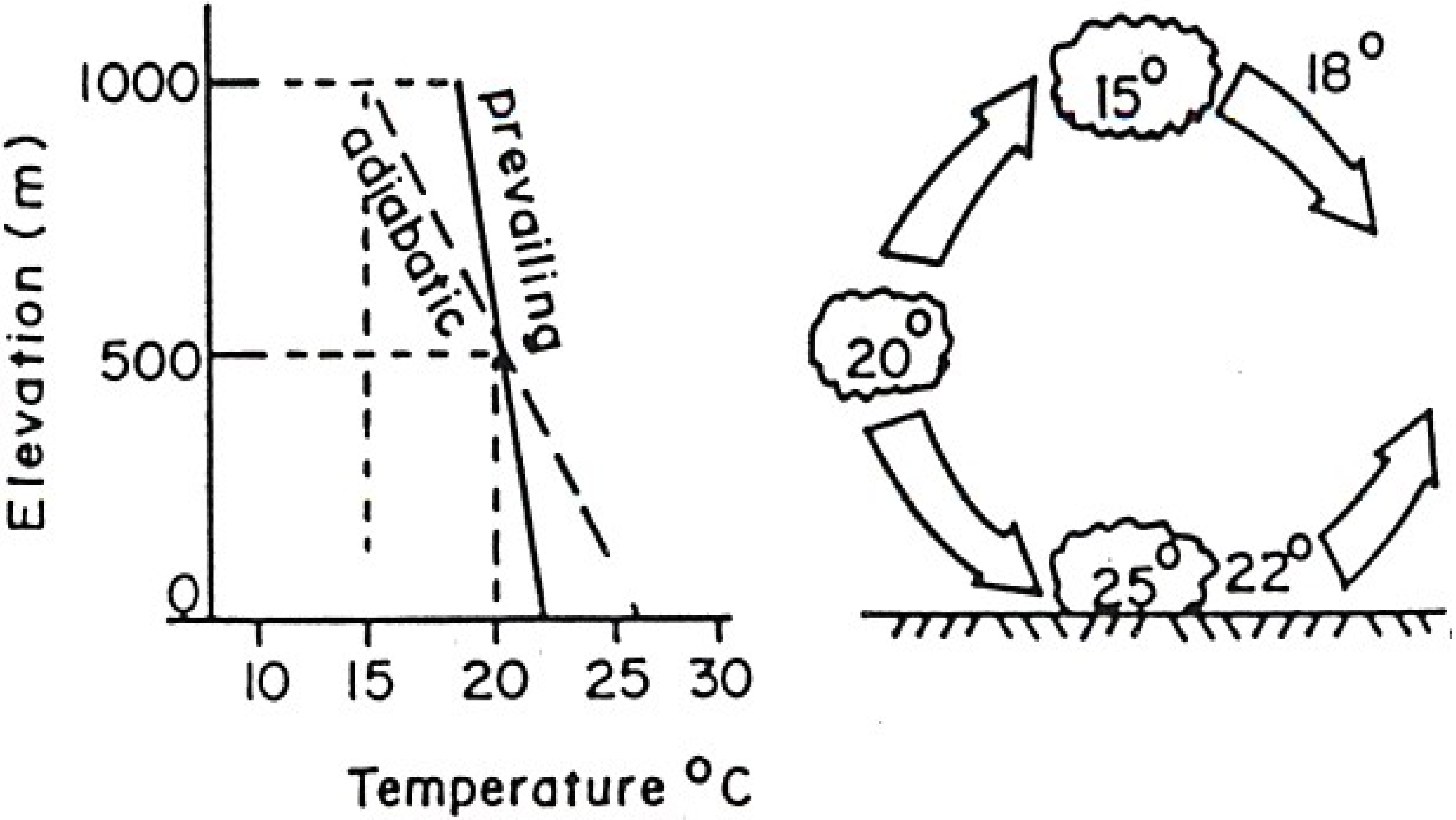
Neutral Air Temp Lapse Rates

- **Temperature decrease with altitude is similar to the adiabatic lapse rate**
- **Results from:**
  - **Cloudy conditions**
  - **Elevated wind speeds**
  - **Day/night transitions**
- **Describes OK dispersion conditions**

Isothermal Lapse Rates (Weakly Stable)

- **Characterized by no temperature change with height**
- **Atmosphere is somewhat stable**
- **Dispersion conditions are moderate**

Atmospheric Stability
Subadiabatic – Weak Lapse Rate
Stable Conditions

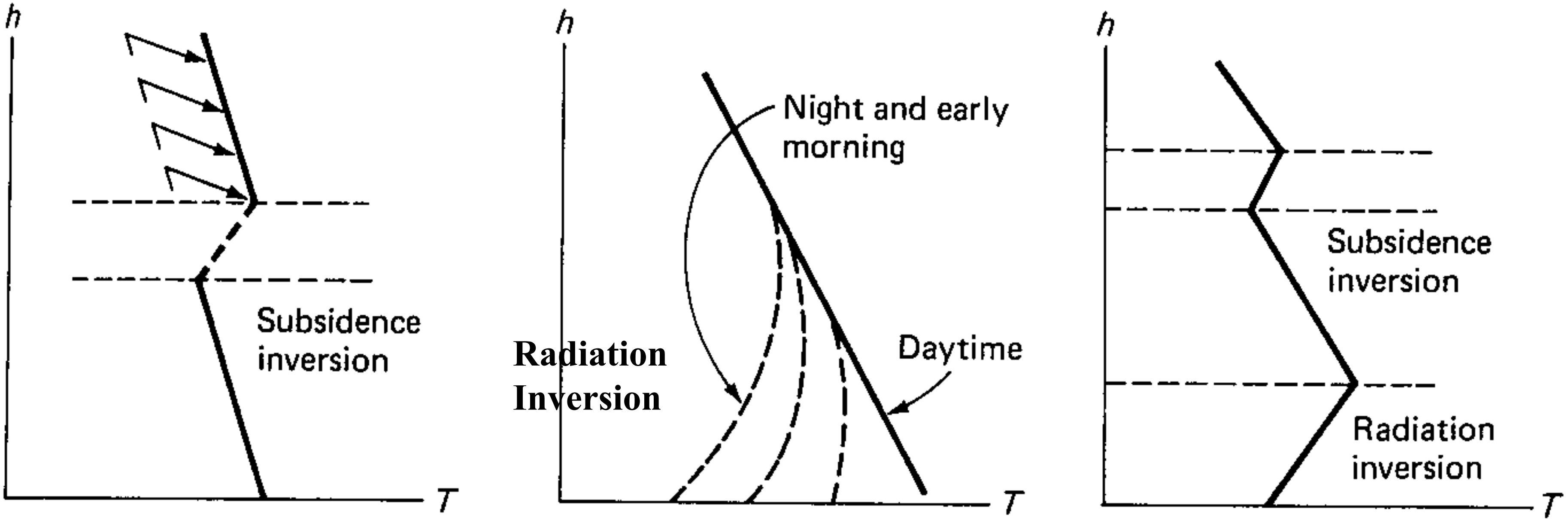


B. Subadiabatic conditions (stable)

- **2 major types of inversion:**

  Subsidence: descent of a layer of air within a high pressure air mass (descending air increases pressure & temp.)

  Radiation: thermal radiation at night from the earth’s surface into the clear night sky

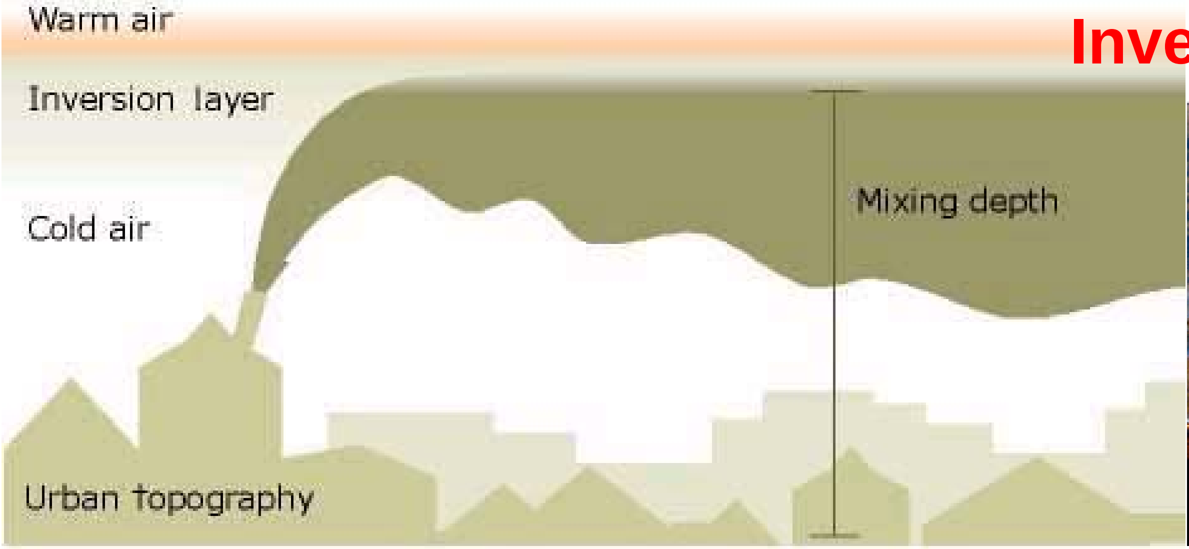


(a) (b) (c)

Inverted Air Temp Lapse Rates (Strongly Stable)

Characterized by increasing air temperature with height

Does it occur during the day or at night? (Both)
Is it associated with high or low air pressure systems? (High)
Does it improve or deteriorate air quality? (deteriorate)



Winter inversion layer trapping smoke from home fires

www.ew.govt.nz/enviroinfo/air/weather.htm

Inversion

www.co.mendocino.ca.us/aqmd/Inversions.htm

- **Inversion: Air Temperature increases with altitude**

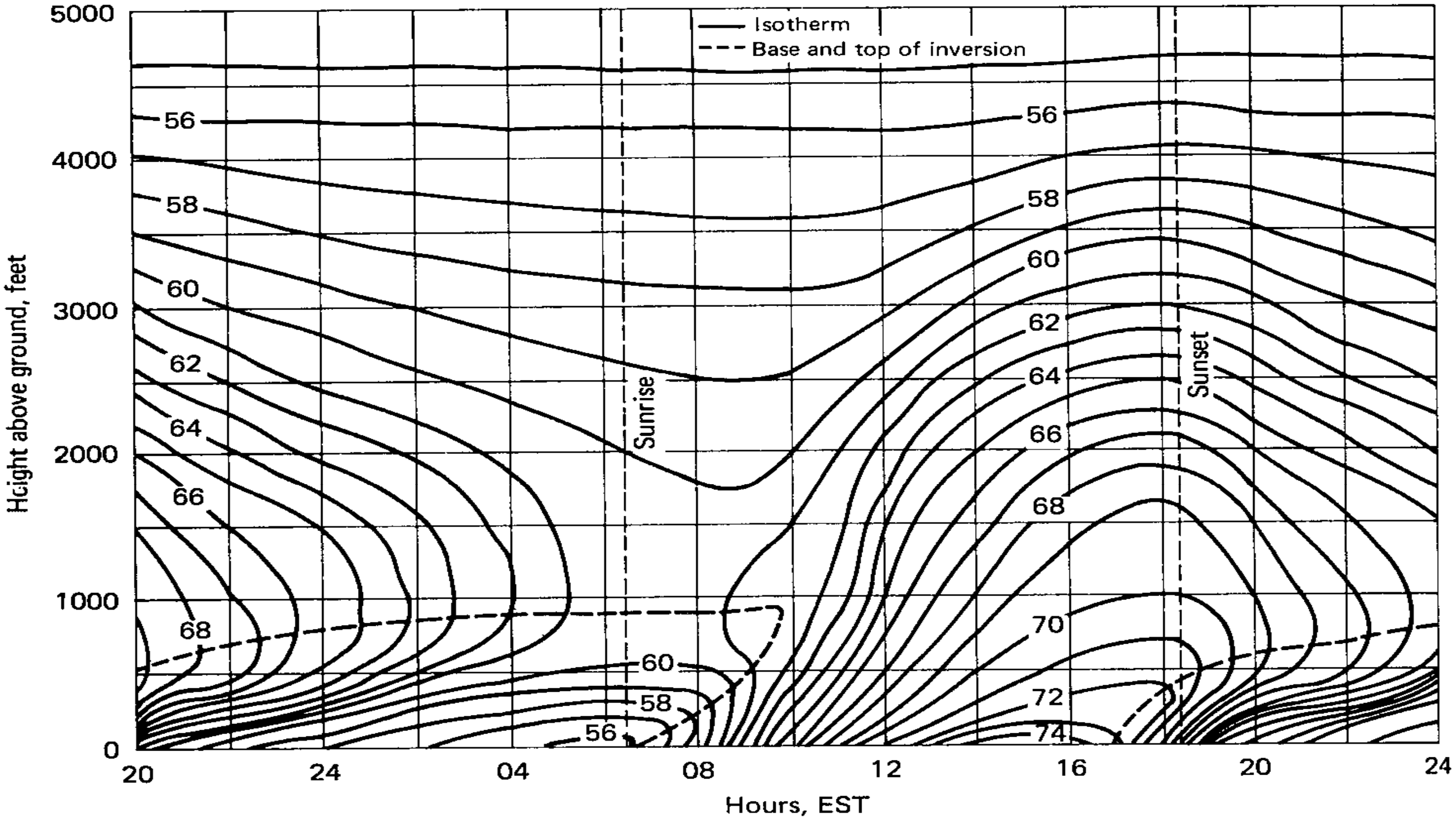
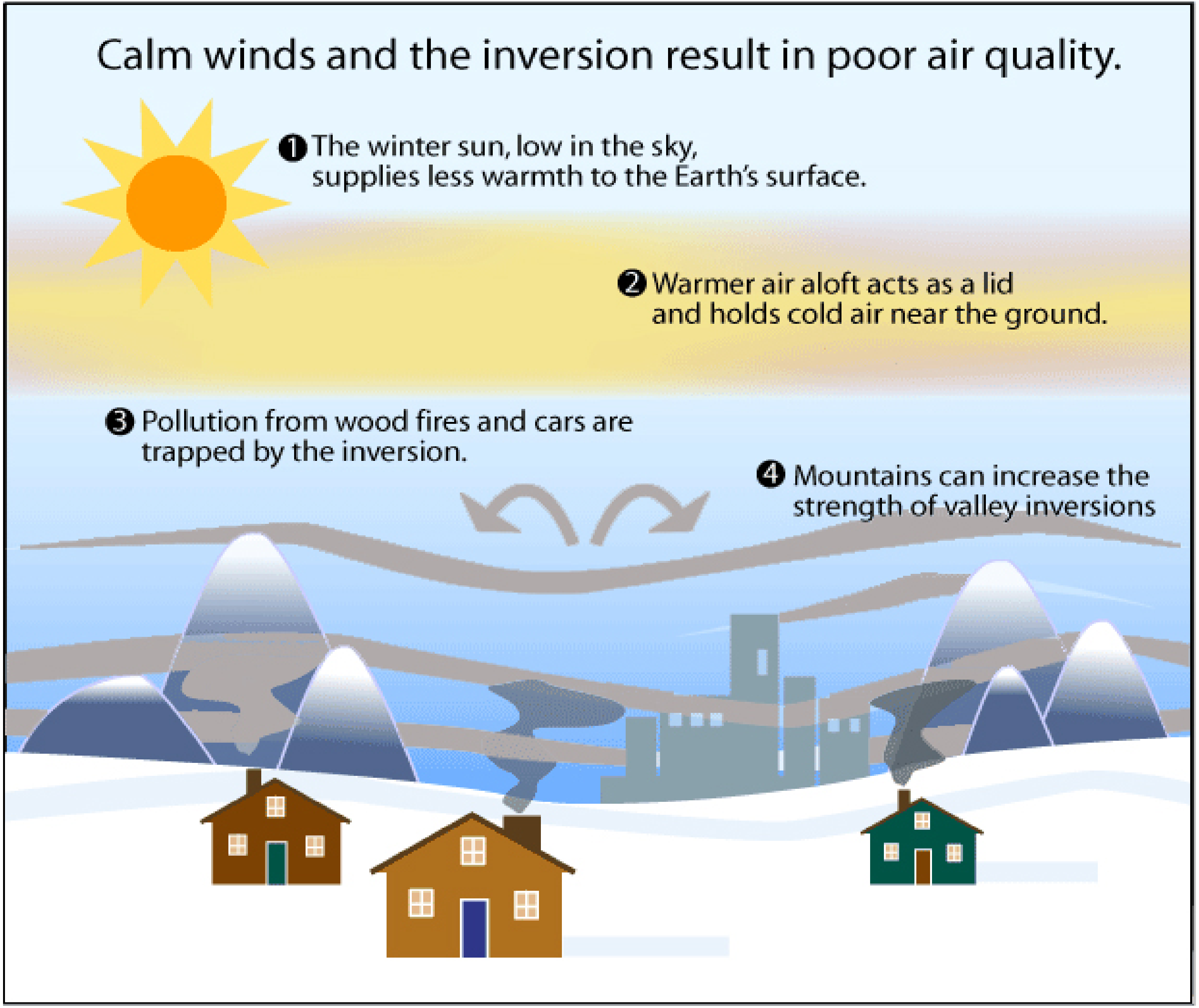


Figure 3-11 Time cross section of average temperature (°F) up to 5000-ft altitude, September, October, 1950, Oak Ridge, Tenn. (SOURCE: U.S. Weather Bureau, *Meteorological Survey of the Oak Ridge Area*. Report ORO-99. Oak Ridge, Tenn.: AEC, 1953.)



Calm winds and the inversion result in poor air quality.

❶ The winter sun, low in the sky, supplies less warmth to the Earth's surface.

❷ Warmer air aloft acts as a lid and holds cold air near the ground.

❸ Pollution from wood fires and cars are trapped by the inversion.

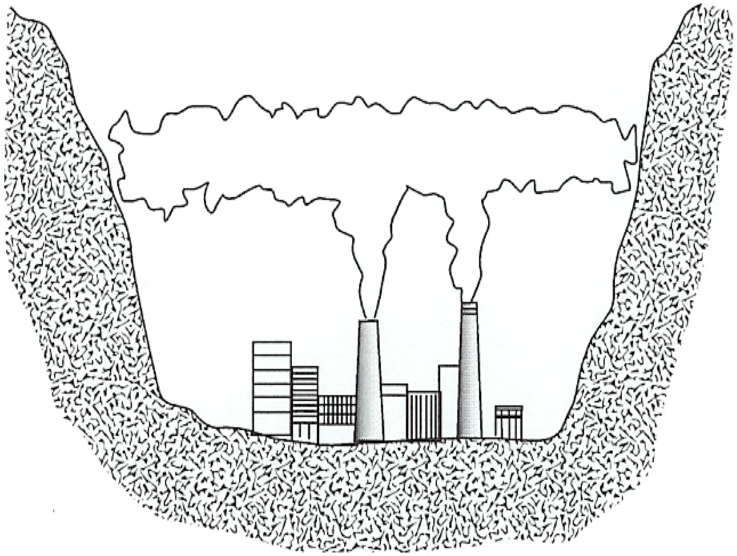
❹ Mountains can increase the strength of valley inversions

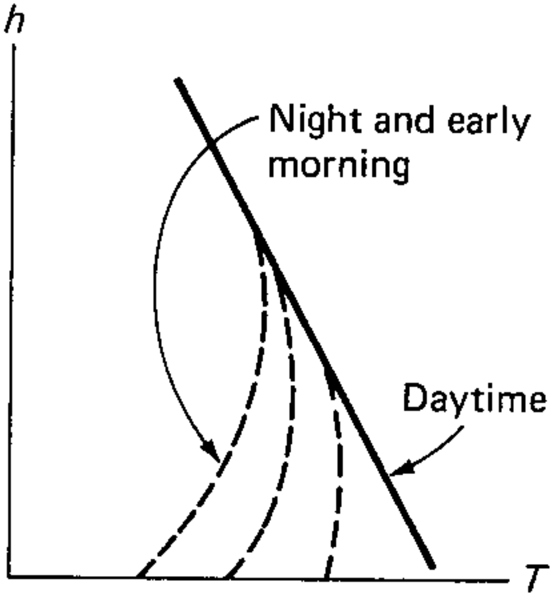
http://www.co.mendocino.ca.us/aqmd/pages/Inversion-Art-(web).jpg

Radiation Inversions

- **Result from radiational cooling of the ground**
- **Occur on cloudless nights and clear sky – nocturnal**
- **Are intensified in valleys (heavier cooled air descends to valley floor)**
- **Cause air pollutants to be “trapped” (poor verti**

www.co.mendocino.ca.us/aqmd /Inversions.htm

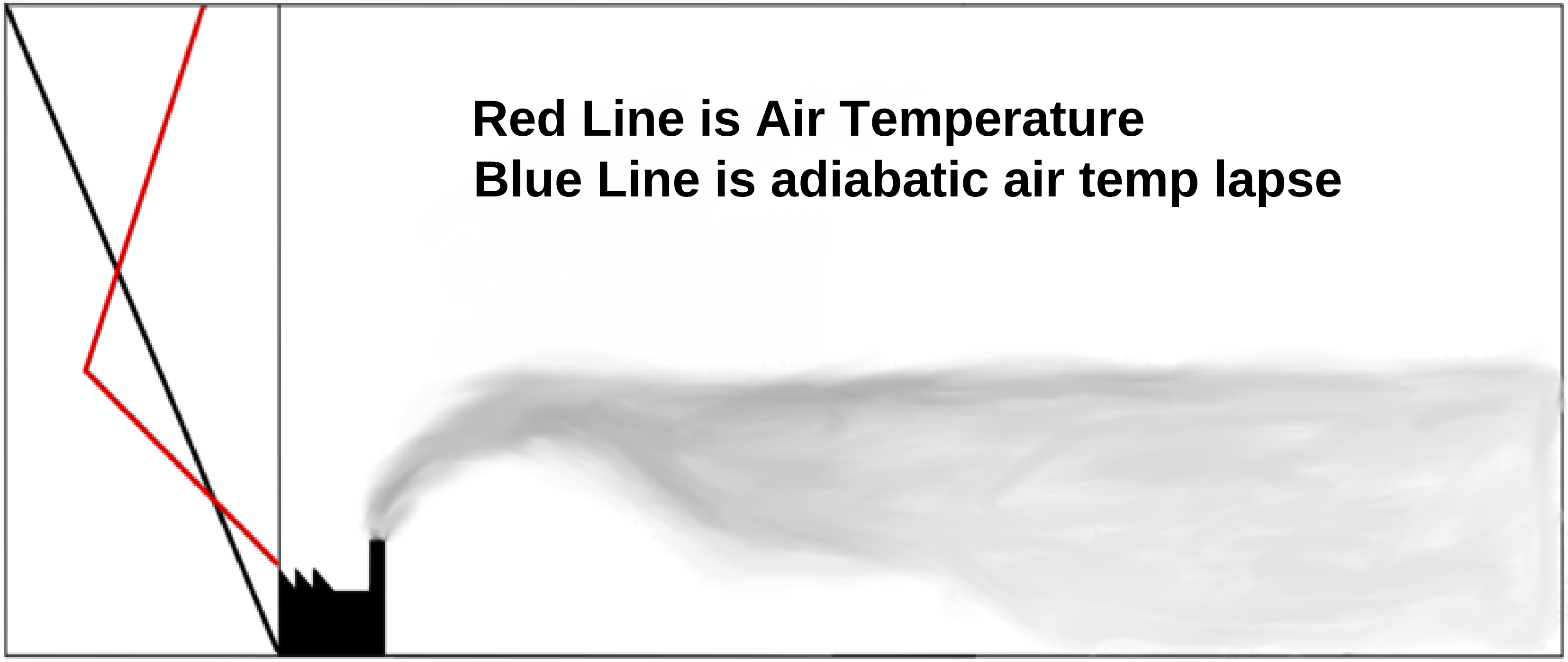




What happens to inversion when sun rises?

Radiation Inversions

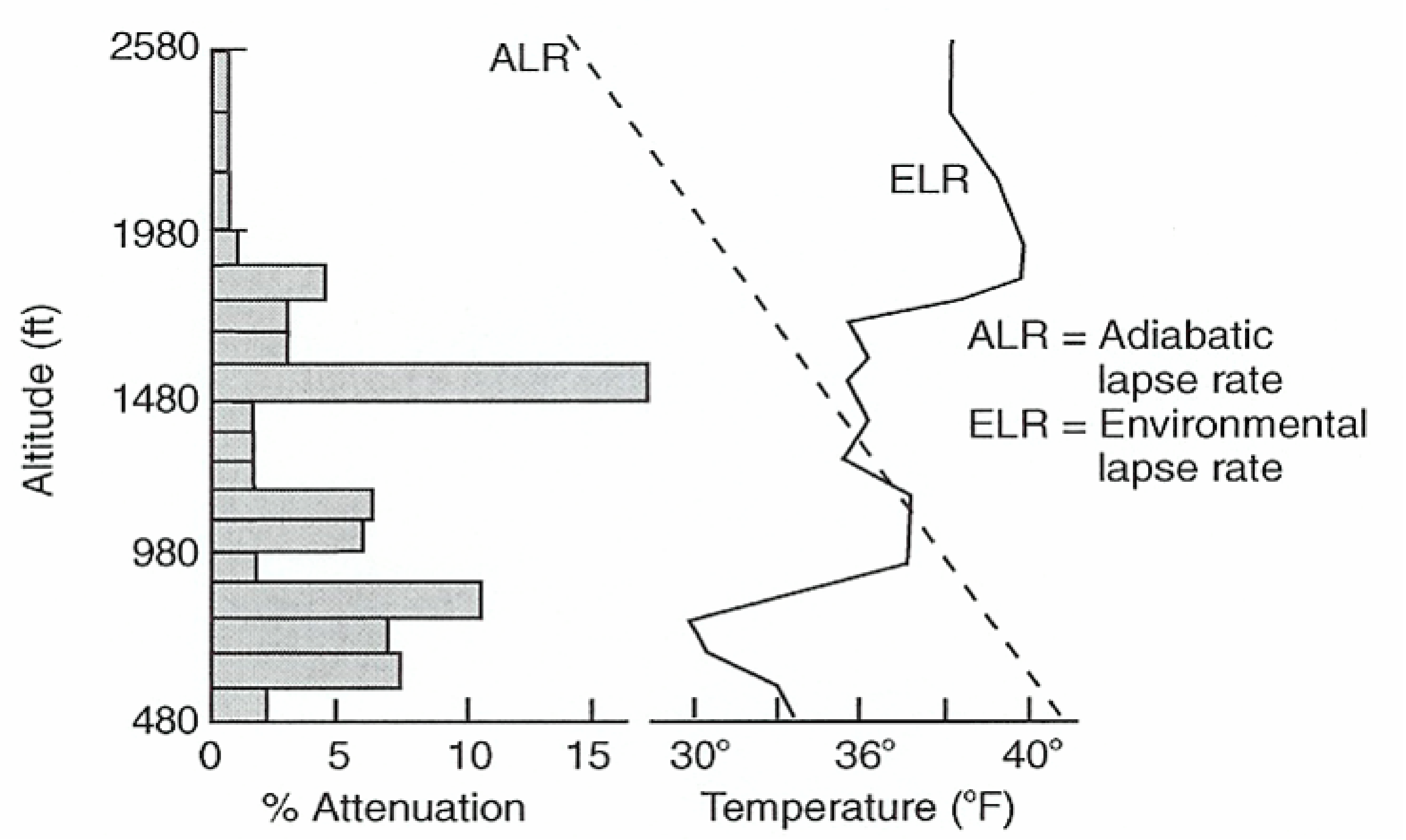
- Inversion Breaks up after sunrise
- Breakup results in elevated ground level concentrations
- Breakup described as a fumigation



Red Line is Air Temperature
Blue Line is adiabatic air temp lapse

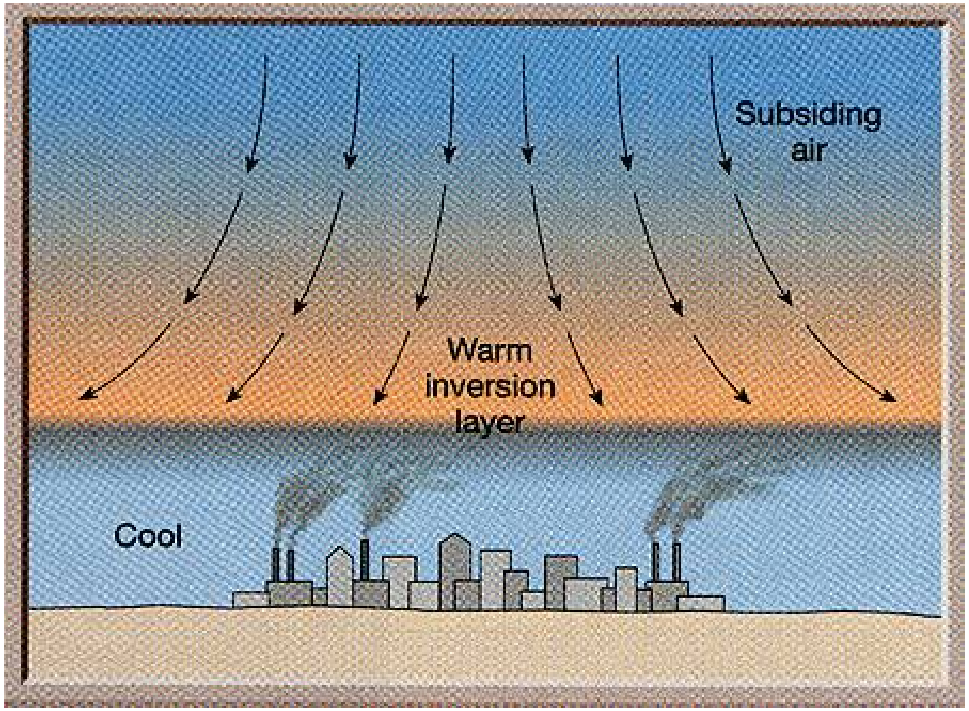
Radiation Inversions

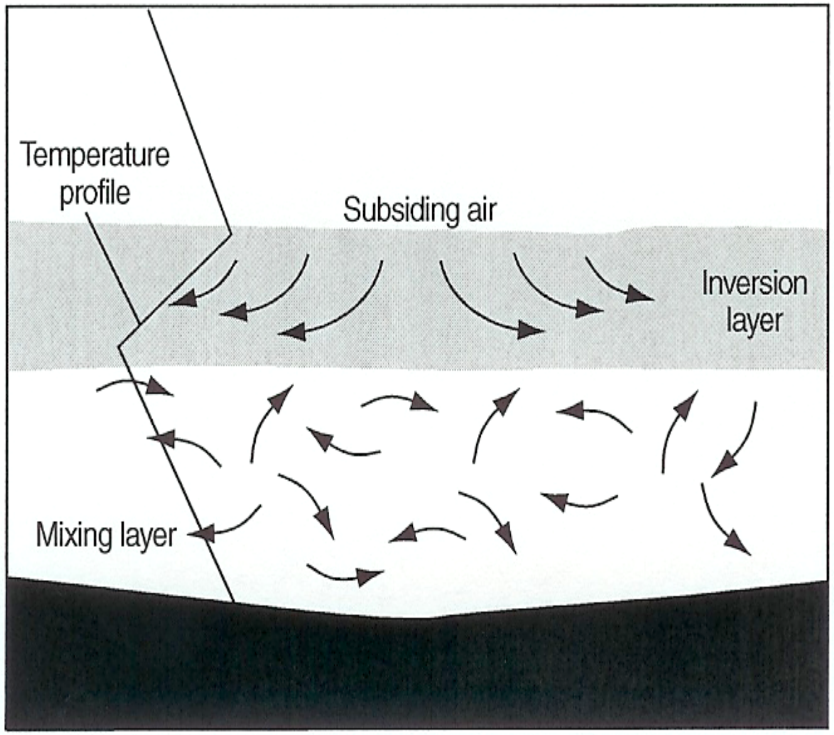
- **Elevated inversions are formed over urban areas**
  - **Due to heat island effect**



Subsidence Inversion

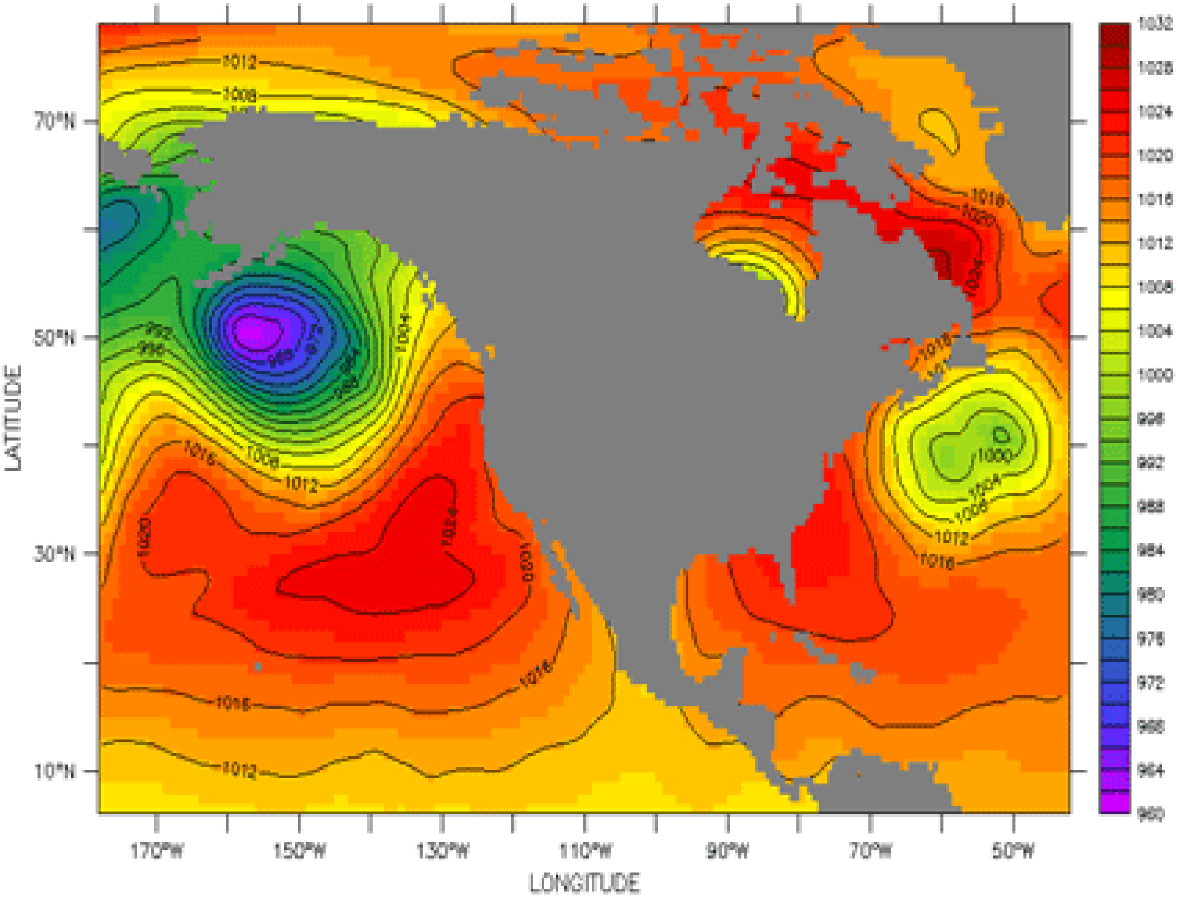
- Associated with atmospheric high-pressure systems
- Inversion layer is formed aloft due to subsiding air
- Persists for days





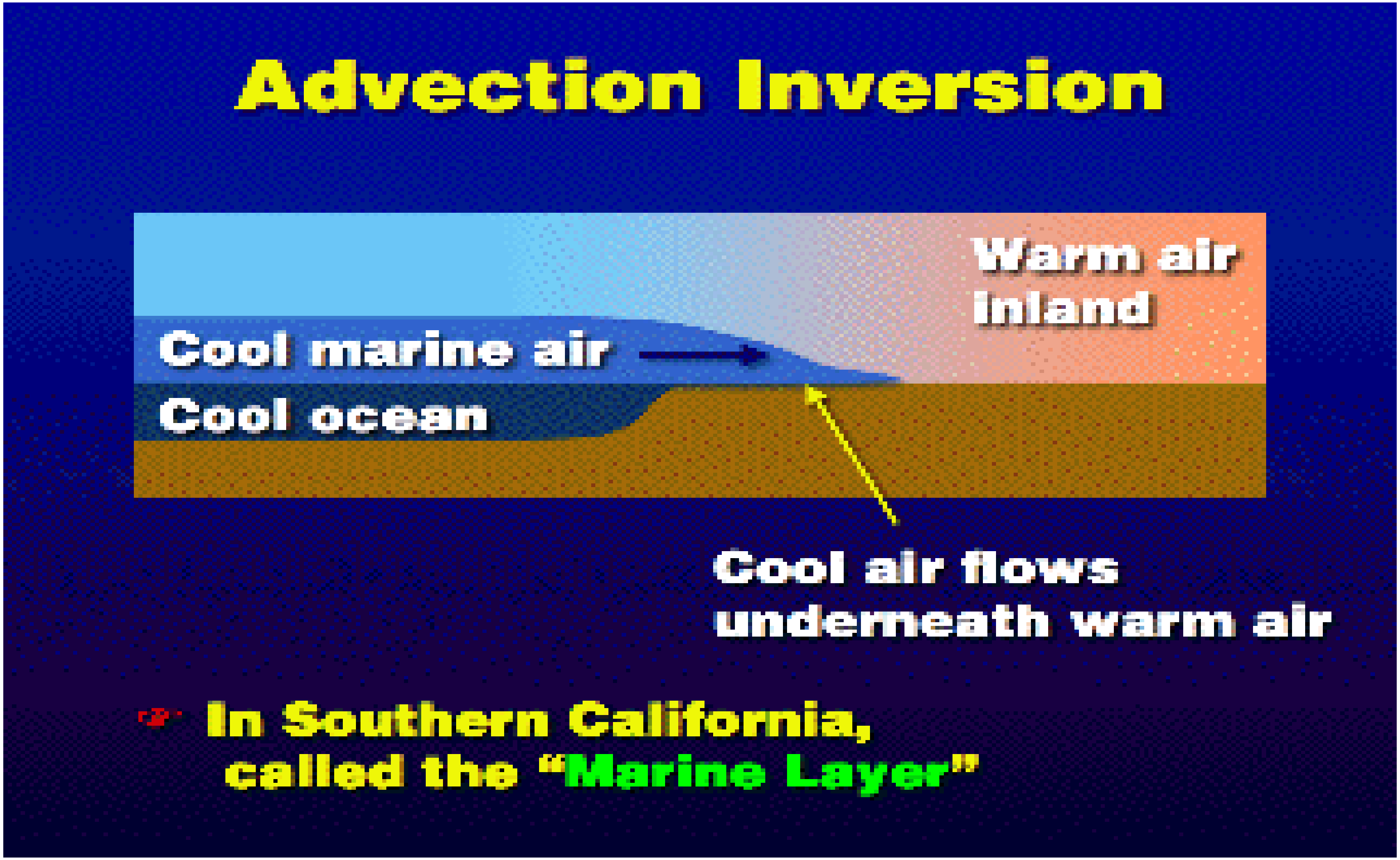
Subsidence Inversion

- Migrating high-pressure systems: contribute to the hazy summer conditions
- Semi-permanent marine high-pressure systems
  - Results in a large number of sunny calm days
  - Inversion layer closest to the ground on continental side
  - Responsible for air stagnation over Southern California



www.oceansatlas.org/.../datard.htm

- **Advective** - warm air flows over a cold surface



Advection Inversion

In Southern California, called the "Marine Layer"

- **Mixing Height = Height of air that is mixed and where dispersion occurs**

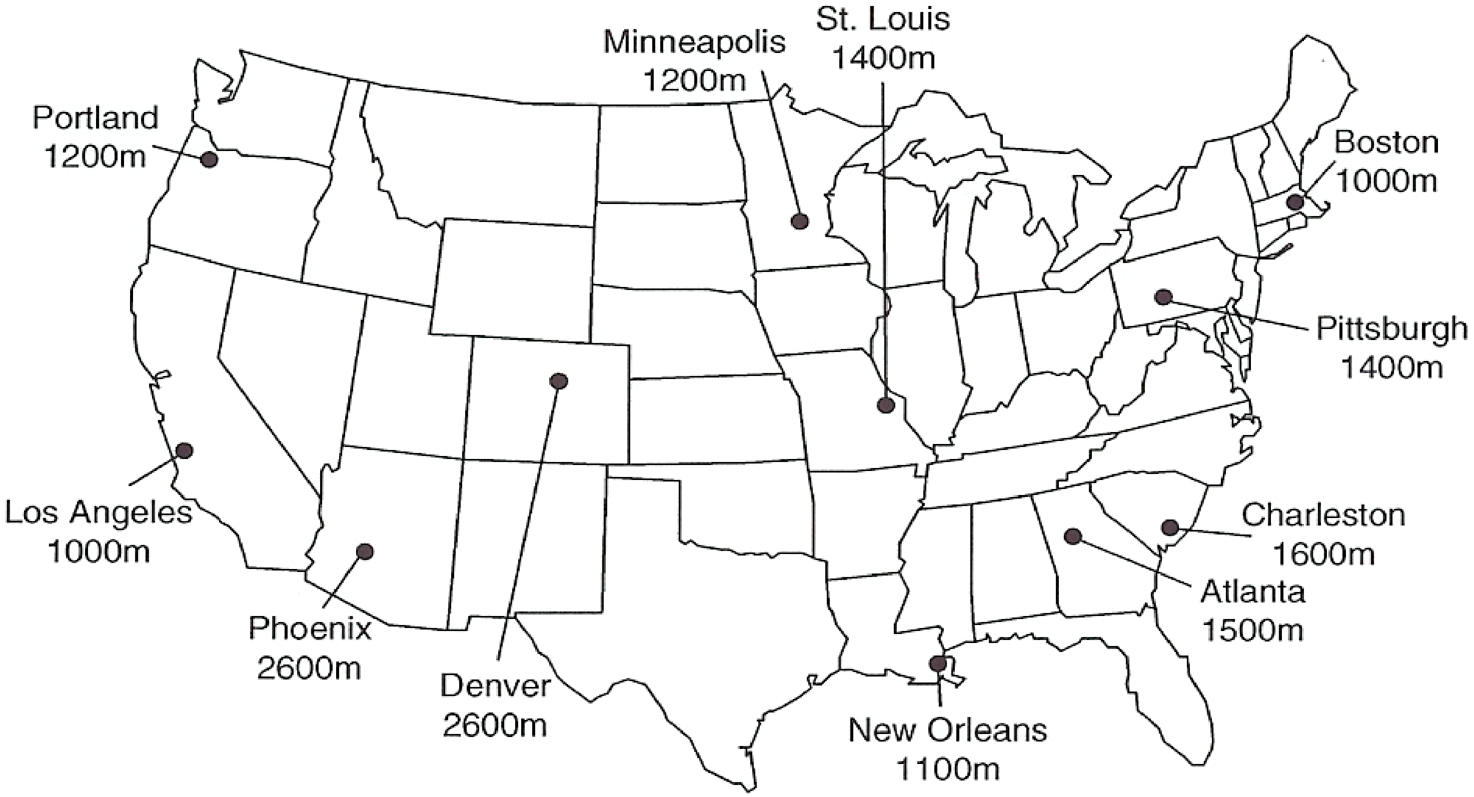
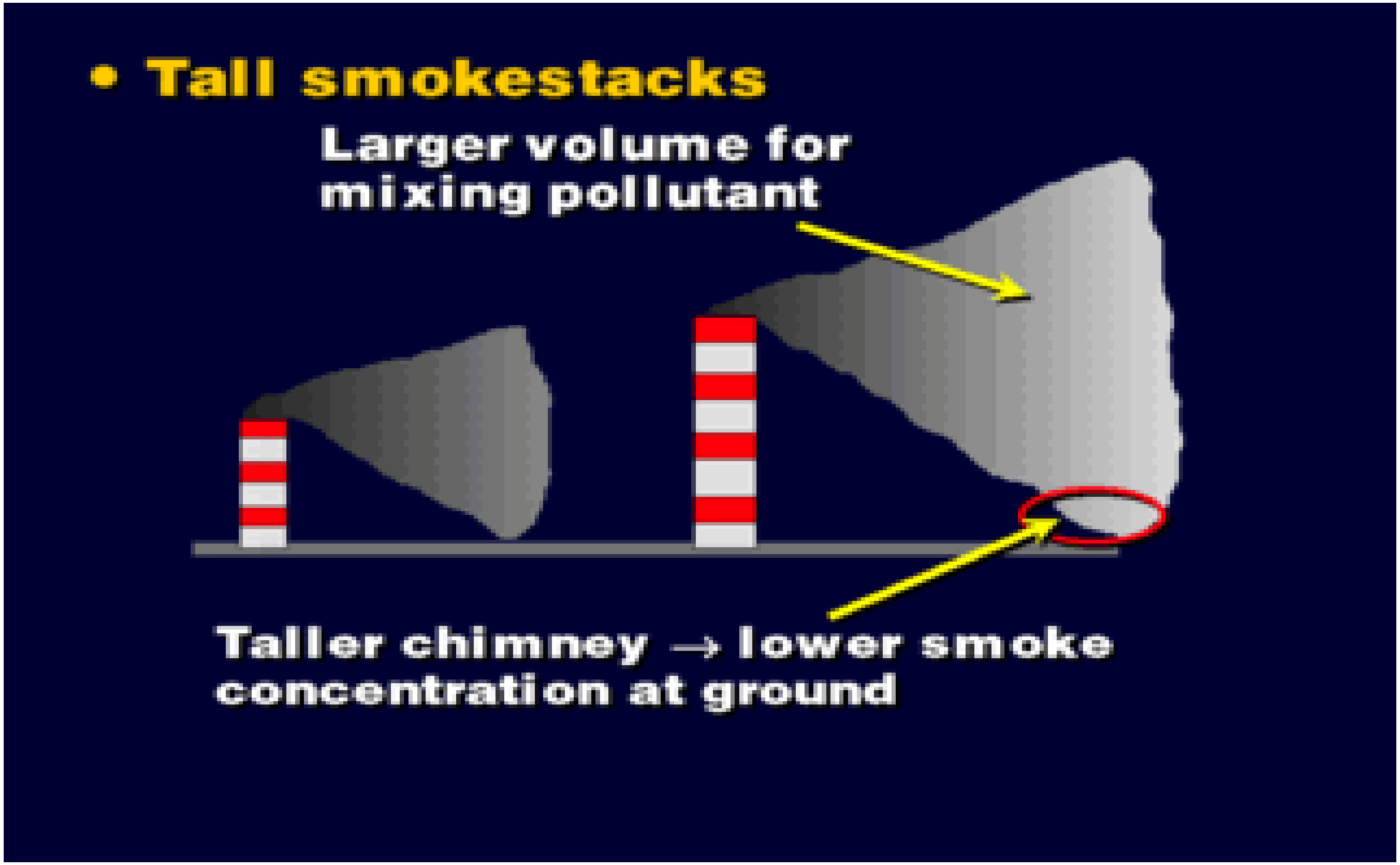


Figure 3.6 Average summertime MHs for selected U.S. cities.

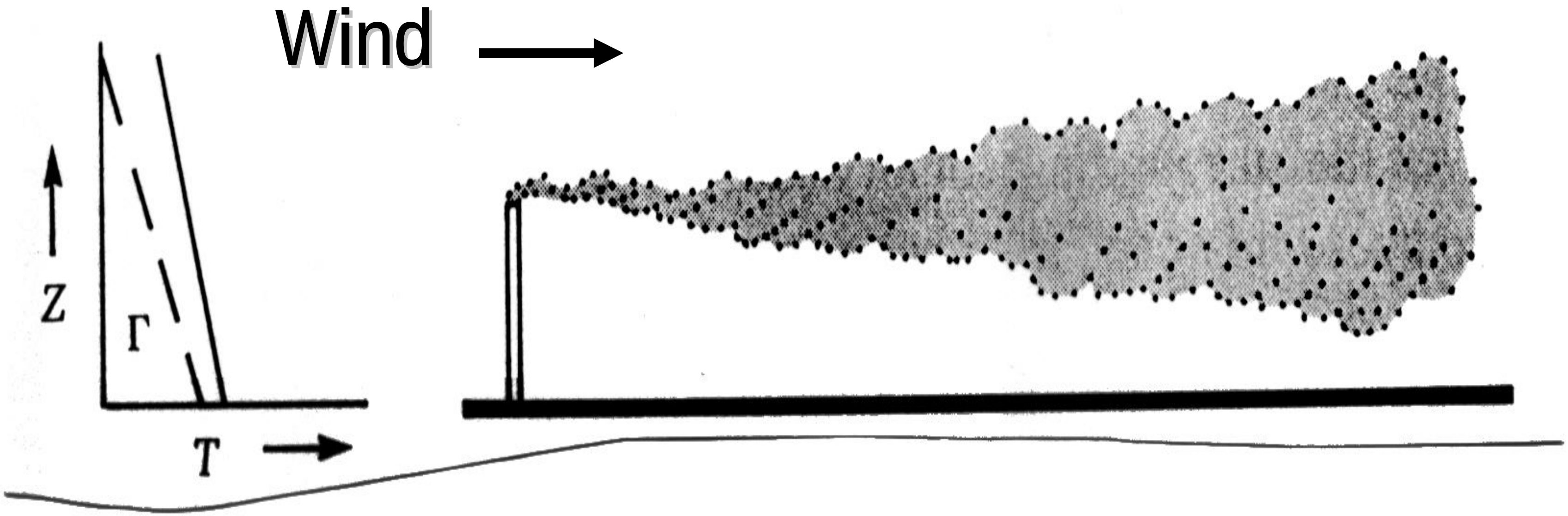
What is the Mixing Height in a radiational inversion?
When does the max MH occur during a day? Min MH?
Which season has the max MH? Min MH?
Why does Phoenix have a larger MH than New Orleans?
Why is agricultural burning allowed only during daytime?

Air Pollutant Dispersion from Point Sources

- Plume rise affects dispersion and transport
  - Affects maximum ground level concentrations
  - Affects distance to maximum ground level conc.

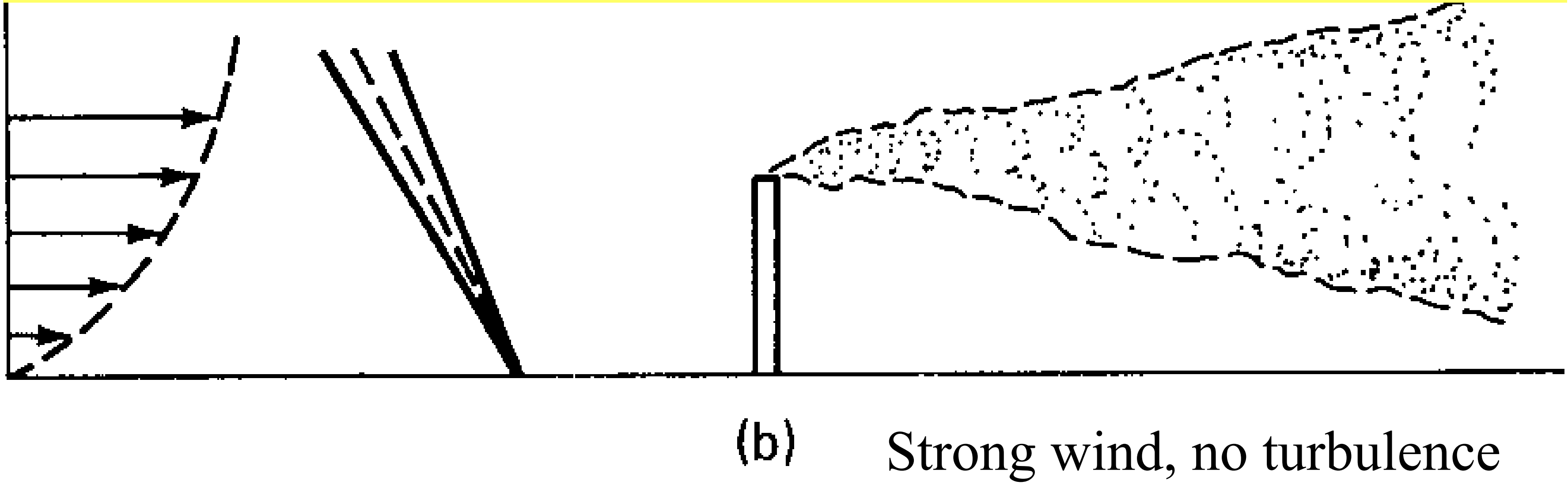


Lapse Rates and Atmospheric Stability
Weak Lapse Condition (Coning)



Z = altitude
T = Temp
Γ = adiabatic lapse rate

Stack Plume: Coning



Strong wind, no turbulence

What is the stability class? (dashed line is adiabatic lapse rate) C

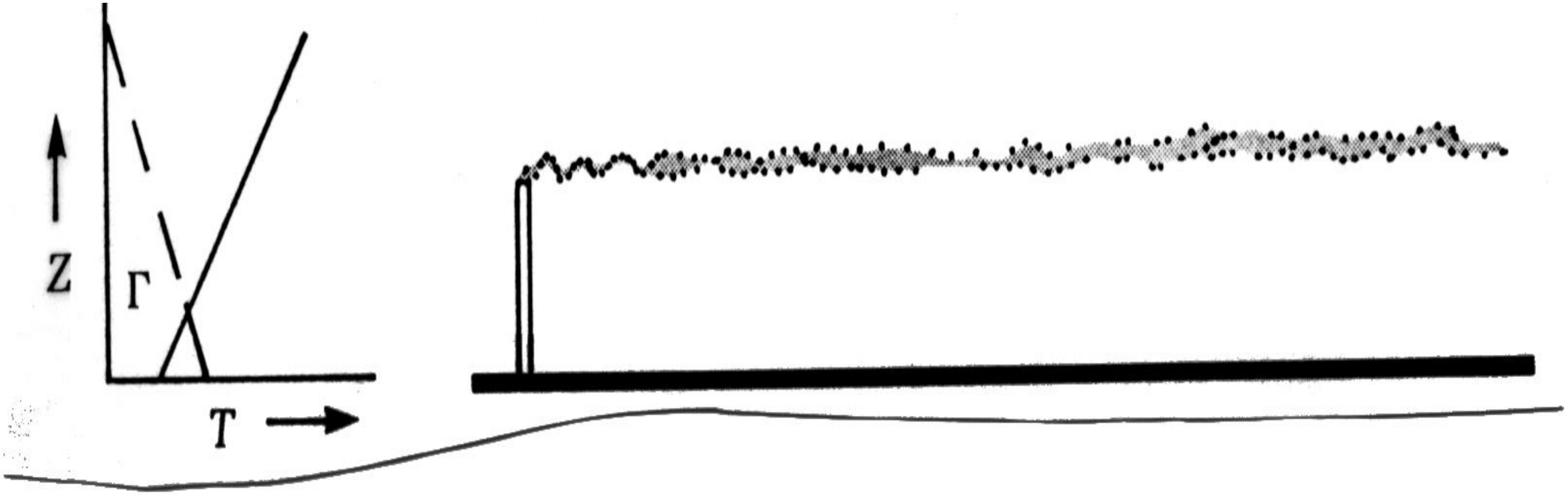
Is there good vertical mixing? OK

On sunny or cloudy days? Partly cloudy

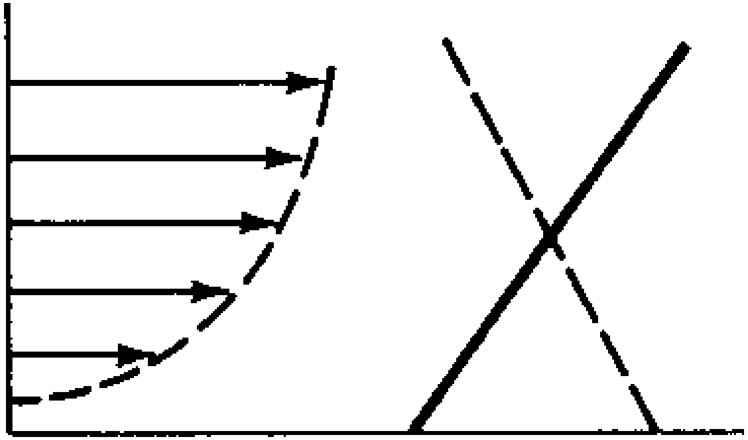
Good for dispersing pollutants? OK

Lapse Rates and Atmospheric Stability
Inversion Condition (Fanning)

Wind →



Stack Plume: Fanning

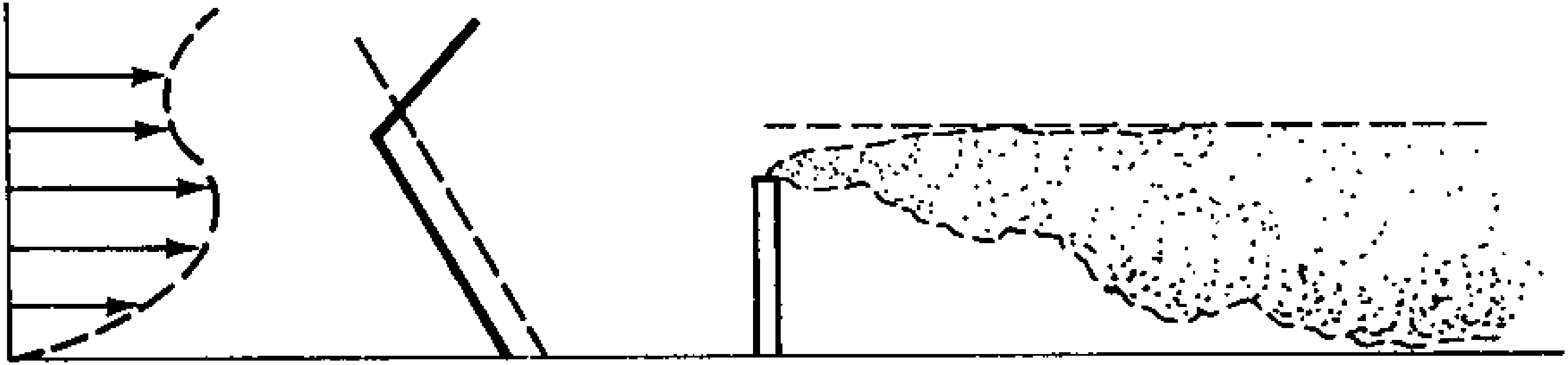


http://www.med.usf.edu/~npoor/4

What is the stability class? (solid line is actual air temperature with altitude air temp lapse rate)

What is the top view of the plume?

Stack Plume: Fumigation

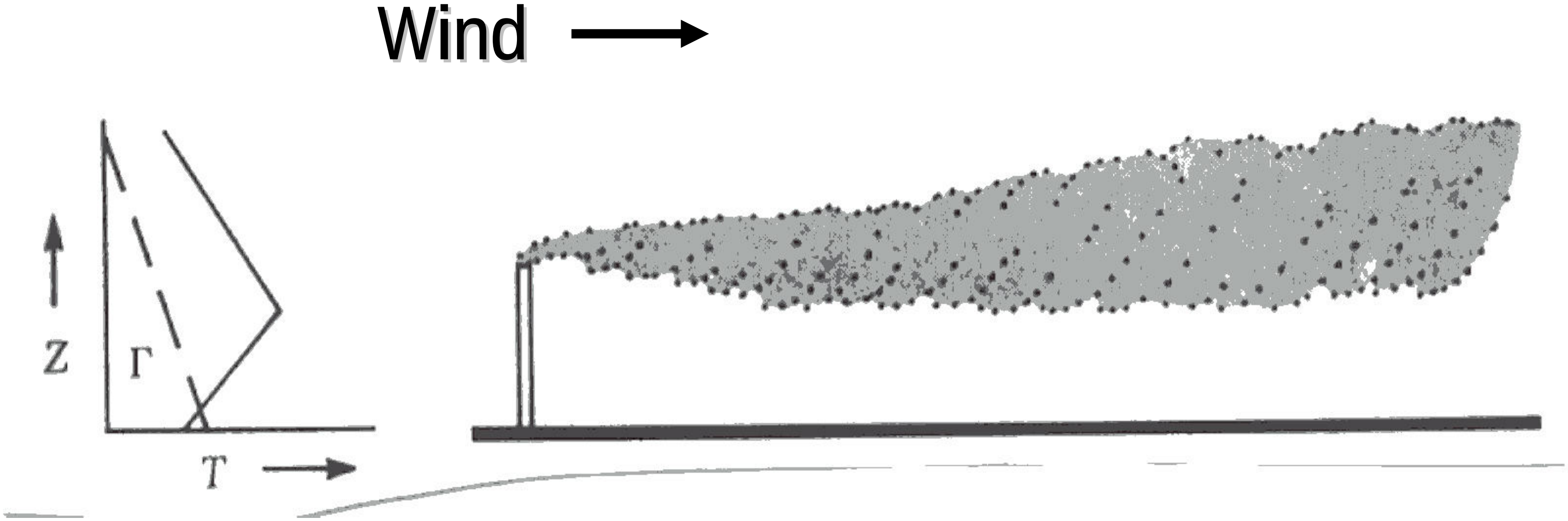


(d)

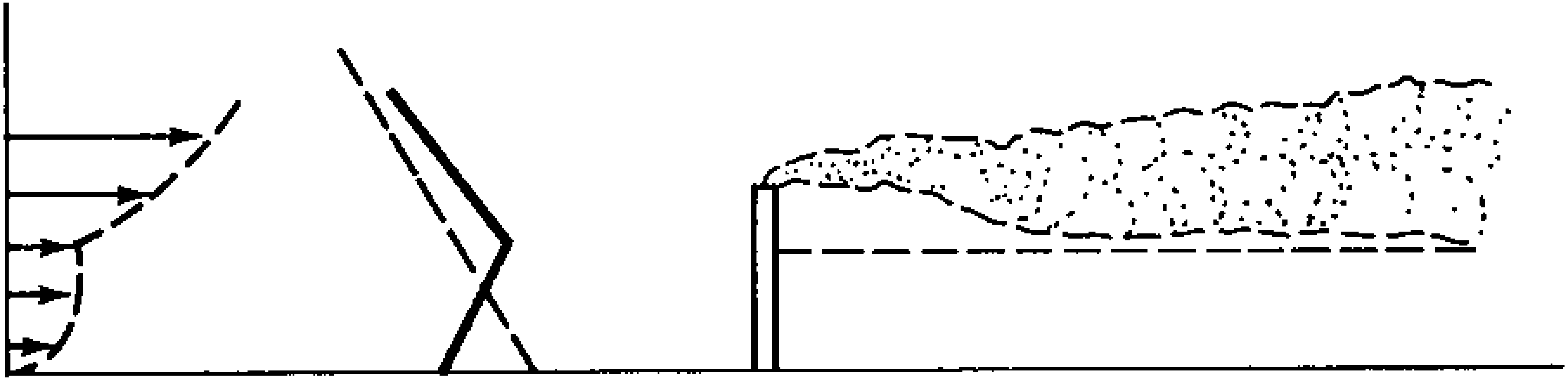
Why can't the pollutants be dispersed upward?
Plume trapped by inversion above stack height.

Does it happen during the day or night?   Morning

Lapse Rates and Atmospheric Stability Inversion Below, Lapse Aloft (Lofting)



Stack Plume: Lofting

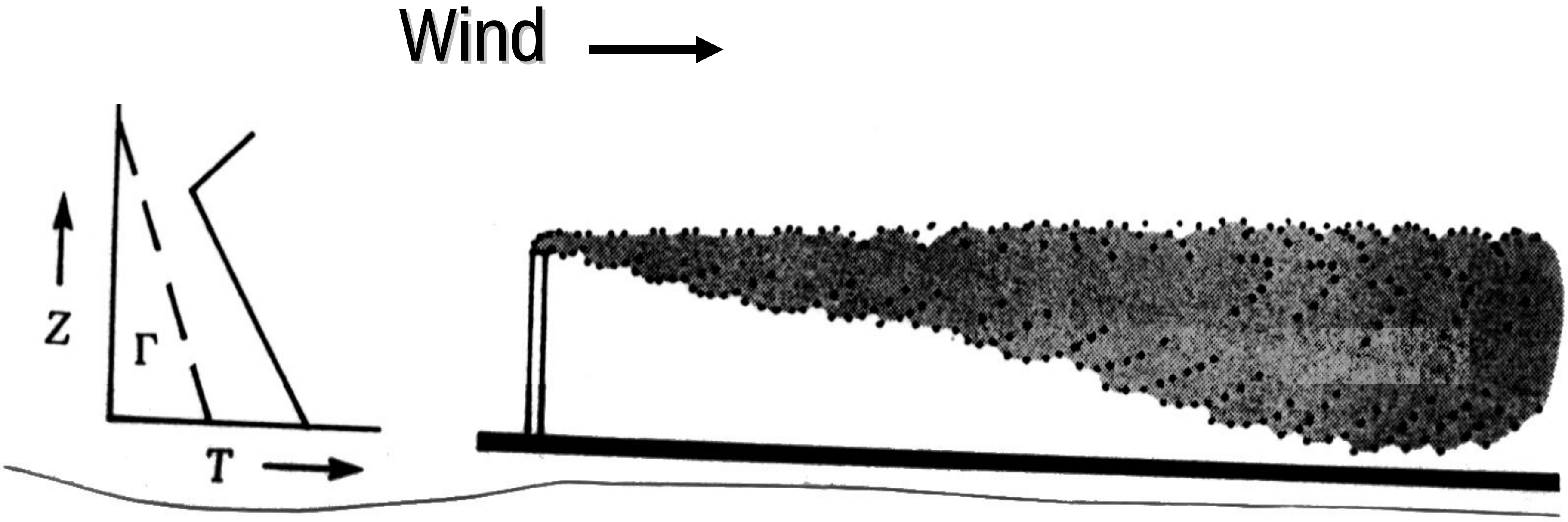


Why can't the pollutants be dispersed downward?

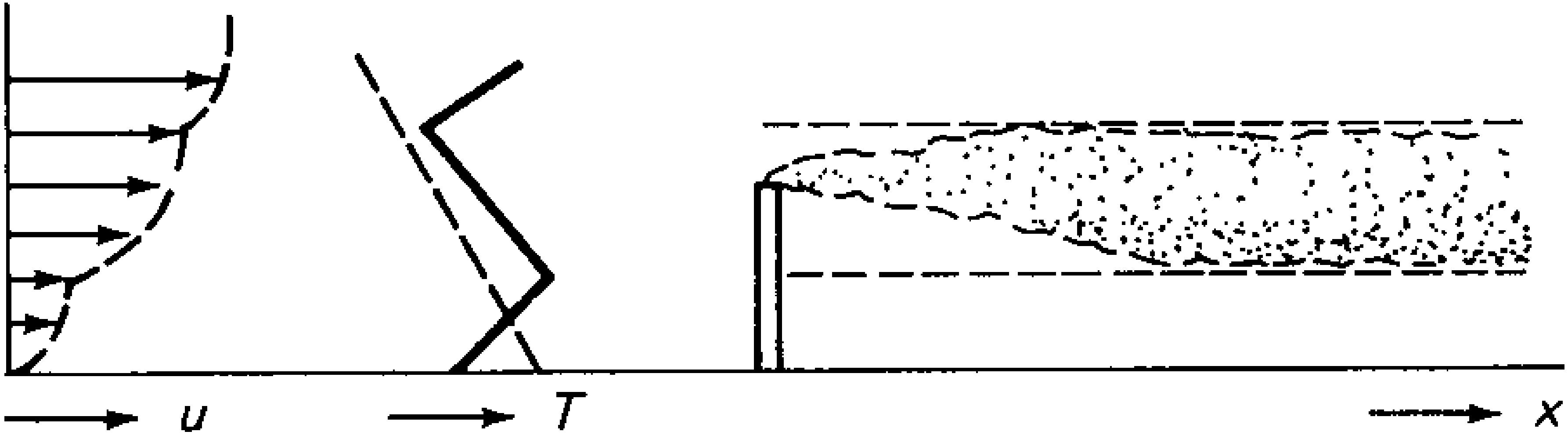
What time of the day or night does this happen?

Evening – night as radiation inversion forms

Lapse Rates and Atmospheric Stability
Weak Lapse Below, Inversion Aloft (Trapping)



Stack Plume: Trapping

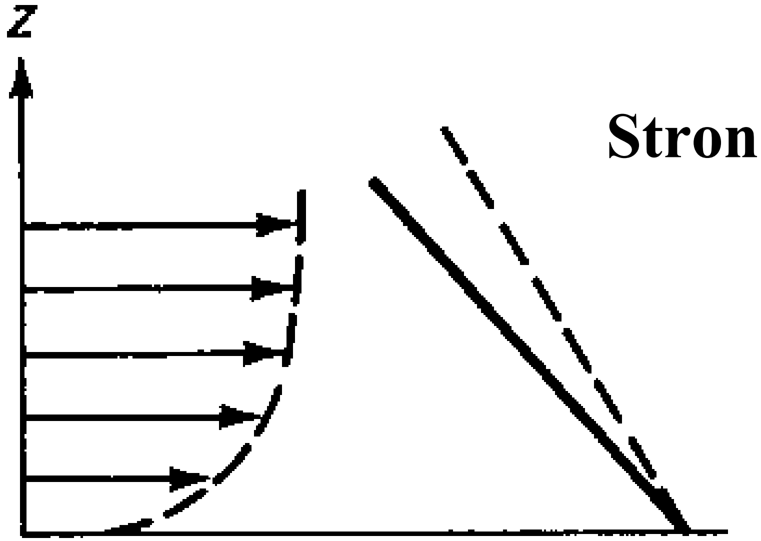


(f)

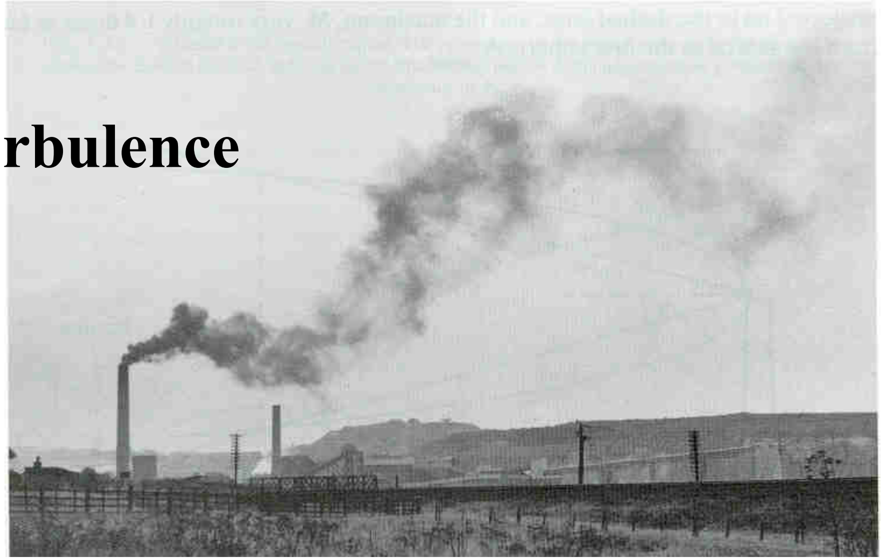
What weather conditions cause plume trapping?

Radiation inversion at ground level, subsidence inversion at higher altitude (evening – night)

Stack Plume: Looping



Strong turbulence



http://www.med.usf.edu/~npoor/3

Is it at stable or unstable condition? Unstable

High or low wind speed? Low wind speed.

Does it happen during the day or night? Day

Is it good for dispersing pollutants? Yes

Dilution of Pollutants in the Atmosphere

- **Air movement can dilute and remove pollutants (removal by absorption and deposition by snow, rain, & to surfaces)**
- **Pollutant dilution is variable, from quite good to quite poor, according to the wind velocity and the air stability (lapse rate).**

Characteristics of Dispersion Models

- **The accuracy of air pollutant dispersion models varies according to the complexity of the terrain and the availability of historic meteorological data.**
- **The acceptability of the results of dispersion models varies with the experience and viewpoint of the modeler, the regulator and the intervener.**

Air Quality Modeling

Gaussian Dispersion Model

EPA Air Quality Models (SCREEN TSCREEN,ISC, AERMOD, etc.) are computer software with equation parameters that include pollutant emission rate Q (gms/sec), stack height (meters), stack inside diameter at exit, stack gas temp, stack gas exit velocity (m/s) ambient air temp, receptor height (m), topography, etc. and calculate the downwind air pollutant concentrations.

The EPA dispersion software models are used to:

1. **Evaluate compliance with NAAQS & prevention of significant air quality deterioration (PSD required for permit to construct)**
2. **Find pollutant emission reductions required.**
3. **Review permit to construct applications**.

Is the Air Quality OK?

What is the level of my exposure to these emissions?
Is my family safe?
Where is a safe location with regards to air quality?
How about the adverse impact on the environment (plants, animals, buildings)?
How to predict the impact of air pollutant emissions resulting from population growth?
Where is the cleanest air; in city center, in rural area?

Note: Children health (respiratory effects) has been correlated to the distance from their home to nearest highway or busy street (diesel engine emissions)

When are model applications required for regulatory purposes?

- **SCREEN3, TSCREEN,**
- **ISC (Industrial Source Complex),**
- **AERMOD**

AERMOD stands for American Meteorological Society

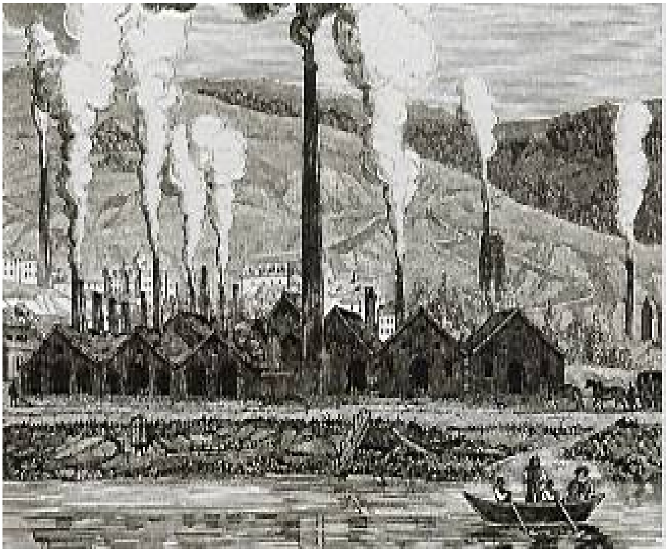
Environmental Protection Agency Regulatory Model

Formally Proposed as replacement for ISC in 2000

Adopted as Preferred Model November 9, 2005

Regulatory Application of Models

- **PSD: Prevention of Significant Deterioration of Air Quality in relatively clean areas (e.g. National Parks, Wilderness Areas, Indian Reservations)**
- **SIP: State Implementation Plan revisions for *existing sources* and for *New Source Reviews* (NSR)**

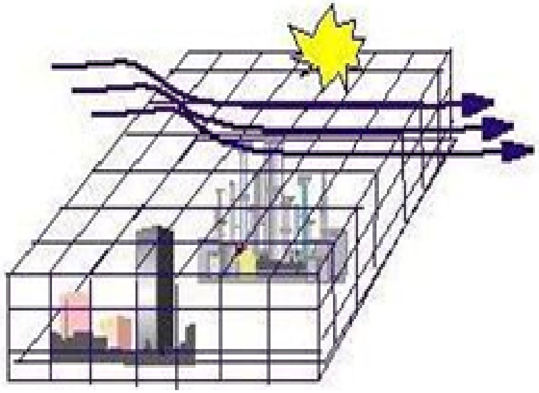


Classifications of Air Quality Models

- **Developed for a number of air pollutant types and time periods**
  - **Short-term models – for a few hours to a few days; worst case episode conditions**
  - **Long-term models – to predict seasonal or annual average concentrations; health effects due to exposure**
- **Classified by**
  - **Non-reactive models – pollutants such as SO_2 and CO**
  - **Reactive models – pollutants such as O_3, NO_2, etc.**

Air Quality Models

- Classified by coordinate system used
  - **Grid-based**
    - Region divided into an array of cells
    - Used to determine compliance with NAAQS
  - **Trajectory**
    - Follow plume as it moves downwind
- Classified by sophistication level
  - **Screening**: simple estimation use preset, worst-case meteorological conditions to provide conservative estimates.
  - **Refined**: more detailed treatment of physical and chemical atmospheric processes; require more detailed and precise meteorological and topographical input data.



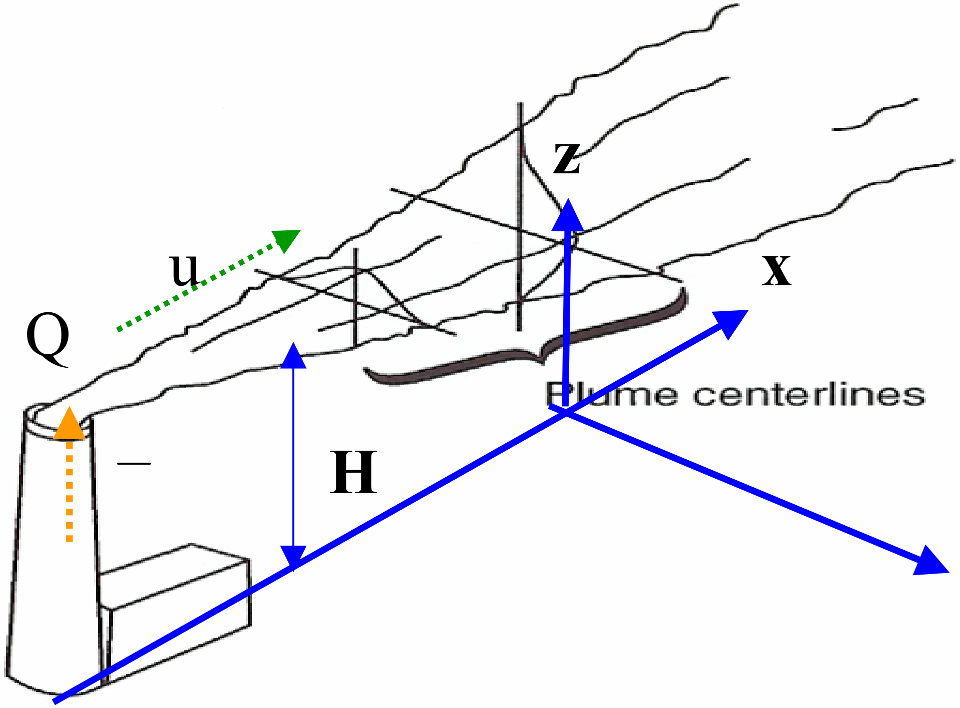
http://www.epa.gov/scram001/images/smokestacks.jpg

US EPA Air Quality Models

- Screening models available at: www.epa.gov/scram001/tt22.htm#screen
- Preferred models available at: http://www.epa.gov/scram001/tt22.htm#rec
  - A single model found to outperform others
    - **Selected on the basis of other factors such as past use, public familiarity, cost or resource requirements and availability**
    - **No further evaluation of a preferred model is required**

Gaussian Dispersion Models

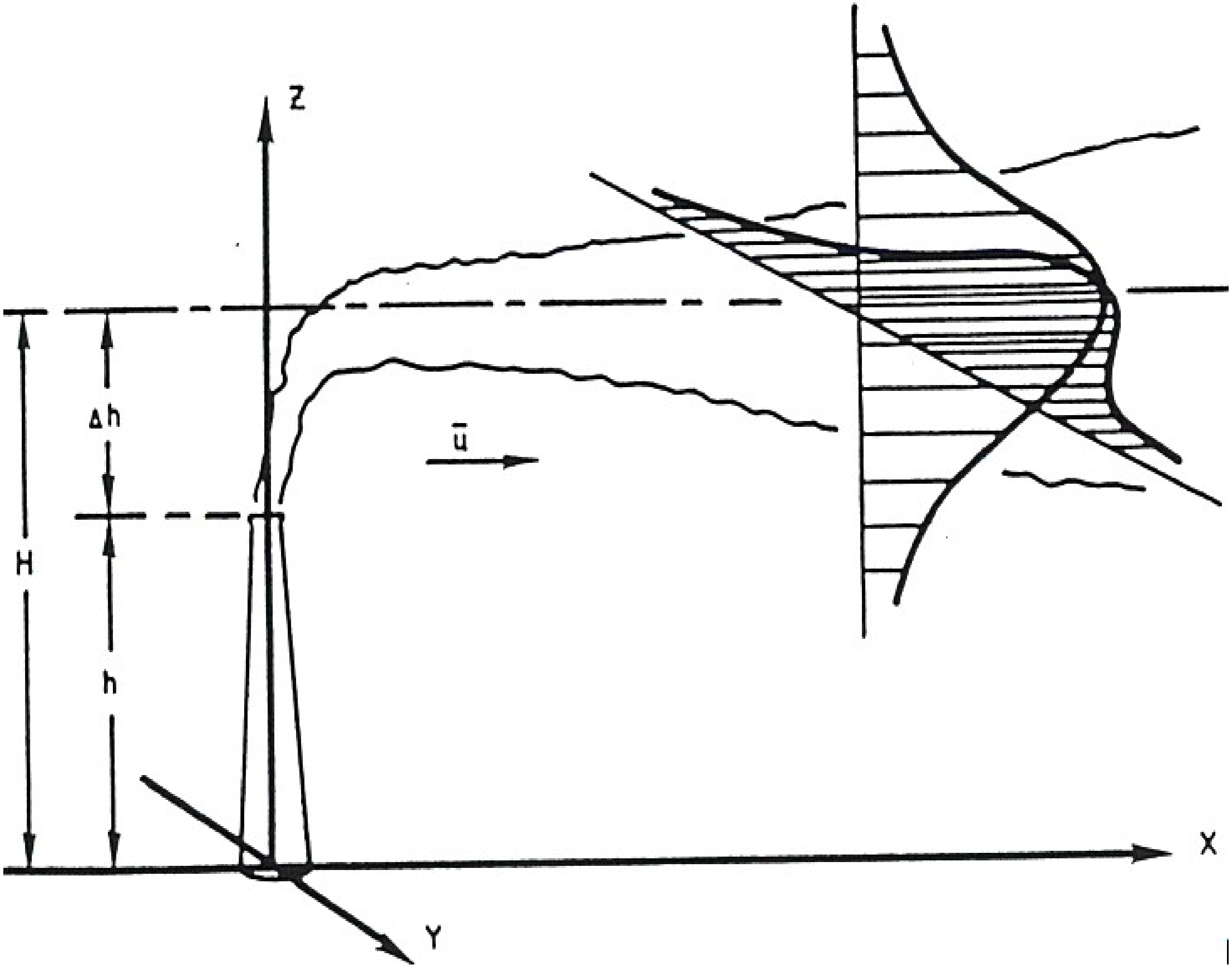
- **Most widely used**
- **Based on the assumption**
  - **plume spread results primarily by diffusion**
  - **horizontal & vertical pollutant concentrations in the plume have**



Gaussian Model Assumptions

- Gaussian dispersion modeling based on a number of assumptions including
  - Source pollutant emission rate = constant (Steady-state)
  - Constant Wind speed, wind direction, and atmospheric stability class
  - Pollutant Mass transfer primarily due to bulk air motion in the x-direction
  - No pollutant chemical transformations occur
  - Wind speeds are $\geq$1 m/sec.
  - Limited to predicting concentrations > 50 m downwind

Gaussian Dispersion Model

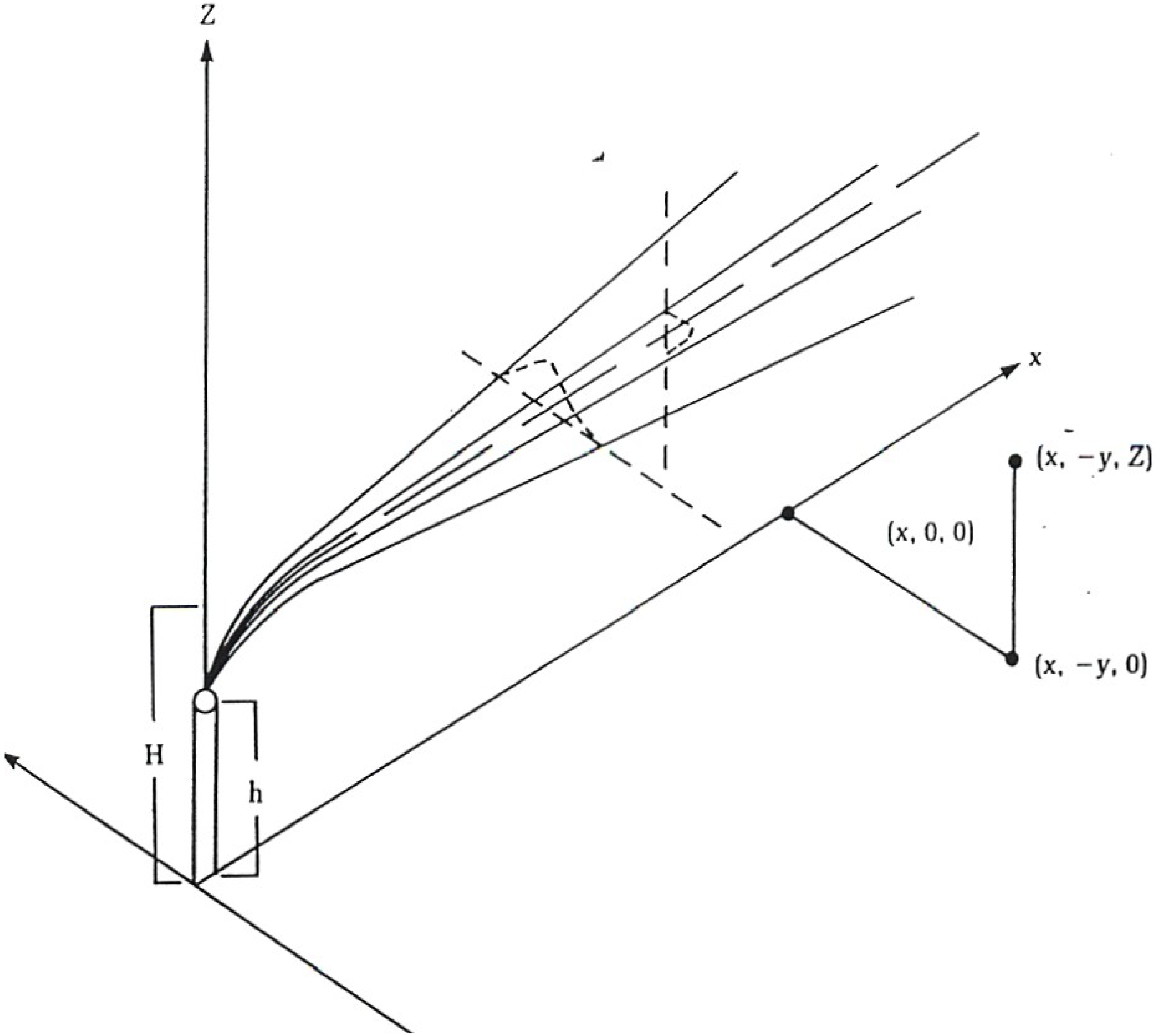


Characteristics of Pollutant Plume

Horizontal (y) and vertical (z) dispersion, is caused by eddies and random shifts of wind direction.

- Key parameters are:
  - Physical stack height (h) – Plume rise (Δh)
  - Effective stack height (H) – Wind speed (u_x)

Plume Dispersion Coordinate System



The Gaussian Model

- **C = C(x, y, z, stability)**

$$C = \frac{Q}{2\pi\sigma_y\sigma_z}\exp\left(-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right)\left\{\exp\left(-\frac{1}{2}\frac{(z-H)^2}{\sigma_z^2}\right)+\exp\left(-\frac{1}{2}\frac{(z+H)^2}{\sigma_z^2}\right)\right\}$$

- **σ_y and σ_z depend on the atmospheric conditions**
- **Atmospheric stability classifications are defined in terms of surface wind speed, incoming solar radiation and cloud cover**

Gaussian Dispersion Equation

$$C(x, y, z) = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}}\exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{(z-H)^2}{\sigma_z^2}\right)\right]$$

σ_y & σ_z = f(downwind distance x & atmos stability)

- **Q = pollutant emission rate (grams/sec)**
- **H = effective stack height (meters) = stack height + plume rise**
- **u = wind speed (m/sec)**

☐ **σ_y = horizontal crosswind dispersion coefficient (meters)**

☐ **$\sigma_{z\,=}$ vertical dispersion coefficient (meters)**

Plume Dispersion Equations

General Equation – Plume with Reflection for Plume Height H

$$C(x,y,z;H)=\frac{Q}{2\pi u\sigma_y\sigma_z}\bullet\left[\mathbf{exp}\left(-\frac{y^2}{2\sigma_y^2}\right)\bullet\left\{\mathbf{exp}\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)+\mathbf{exp}\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right\}\right]$$

Ground Level Concentration – Plume at Height H

$$C(x,y,0;H)=\frac{Q}{\pi u\sigma_y\sigma_z}\bullet\left[\mathbf{exp}\left(-\frac{y^2}{2\sigma_y^2}\right)\bullet\mathbf{exp}\left(-\frac{H^2}{2\sigma_z^2}\right)\right]$$

Ground Level Center Line Conc (y = 0) – Plume Height H

$$C(x,0,0;H)=\frac{Q}{\pi u\sigma_y\sigma_z}\bullet\left[\mathbf{exp}\left(-\frac{H^2}{2\sigma_z^2}\right)\right]$$

Ground Level Center Line – Ground Point Source (y = 0, H = 0)

$$C(x,0,0;0)=\frac{Q}{\pi u\sigma_y\sigma_z}$$

Gaussian Dispersion Equation

If the emission source is at ground level with no effective plume rise then

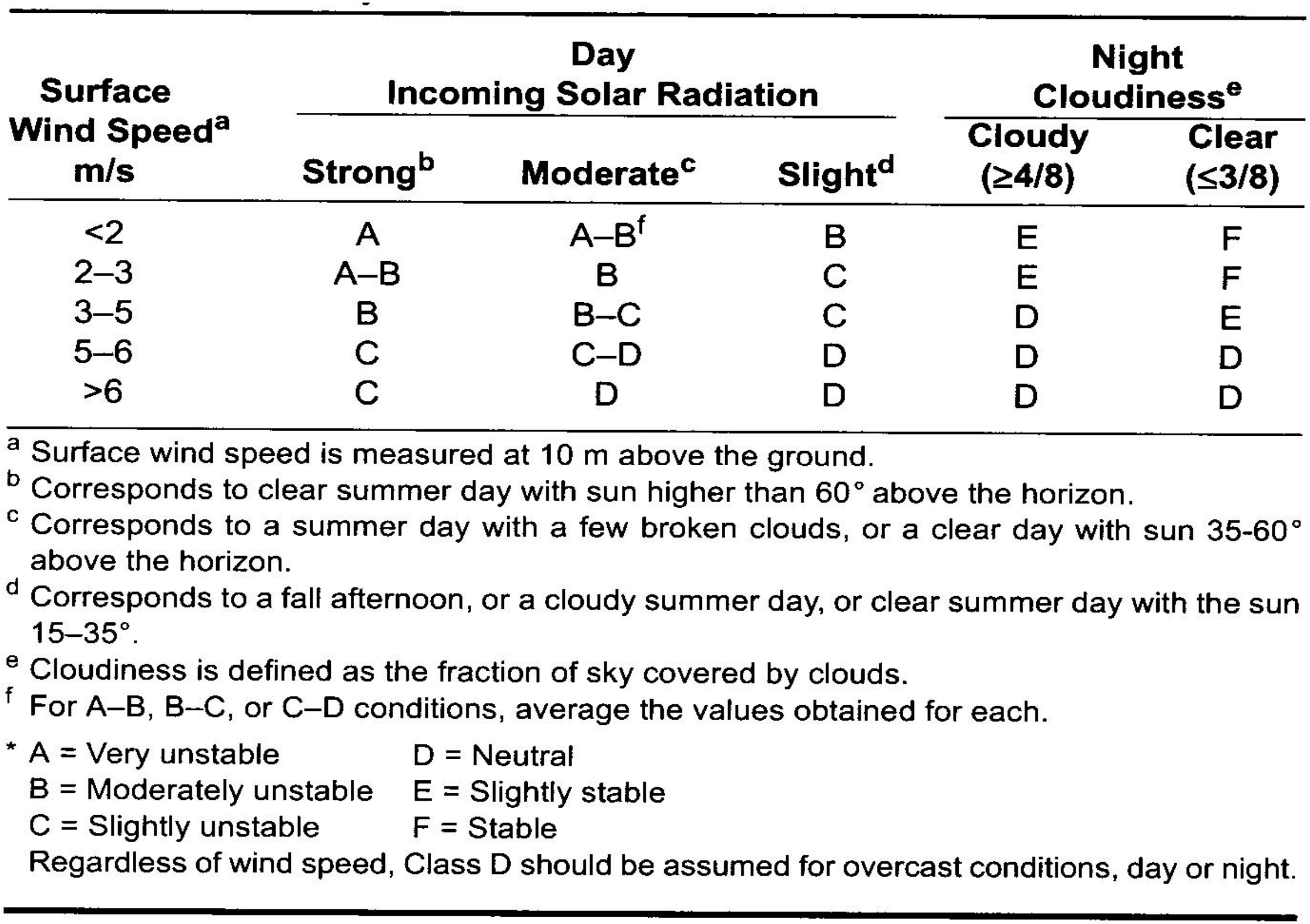
$$C(x,y,z)=\frac{Q}{\pi\sigma_y\sigma_z\bar{u}}\exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2}+\frac{z^2}{\sigma_z^2}\right)\right]$$

Plume Rise

- **H is the sum of the physical stack height and plume rise.**

$$H=\Delta h_{plume\ rise}+h_{actual\ stack}$$

Key to Stability Categories



Surface Wind Speed[a] m/s	Day Incoming Solar Radiation			Night Cloudiness[e]	
	Strong[b]	Moderate[c]	Slight[d]	Cloudy (≥4/8)	Clear (≤3/8)
<2	A	A–B[f]	B	E	F
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

[a] Surface wind speed is measured at 10 m above the ground.

[b] Corresponds to clear summer day with sun higher than 60° above the horizon.

[c] Corresponds to a summer day with a few broken clouds, or a clear day with sun 35-60° above the horizon.

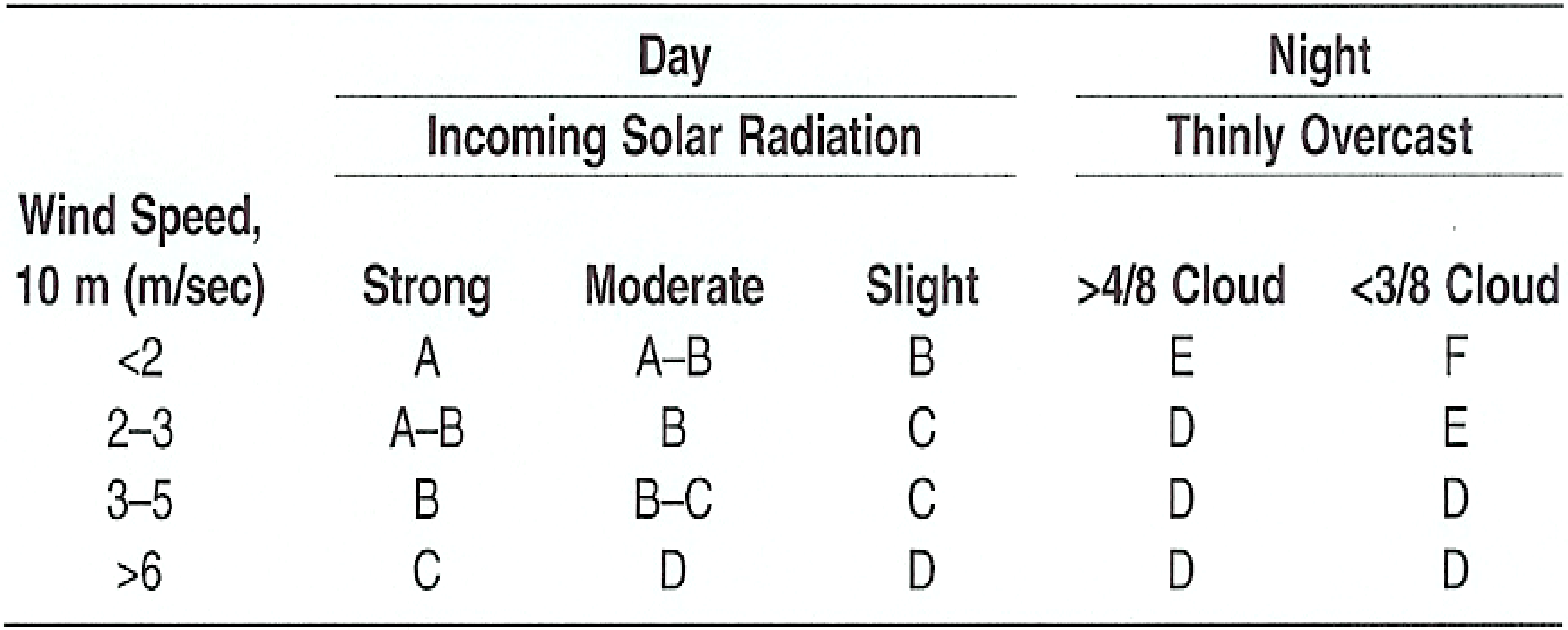
[d] Corresponds to a fall afternoon, or a cloudy summer day, or clear summer day with the sun 15–35°.

[e] Cloudiness is defined as the fraction of sky covered by clouds.

[f] For A–B, B–C, or C–D conditions, average the values obtained for each.

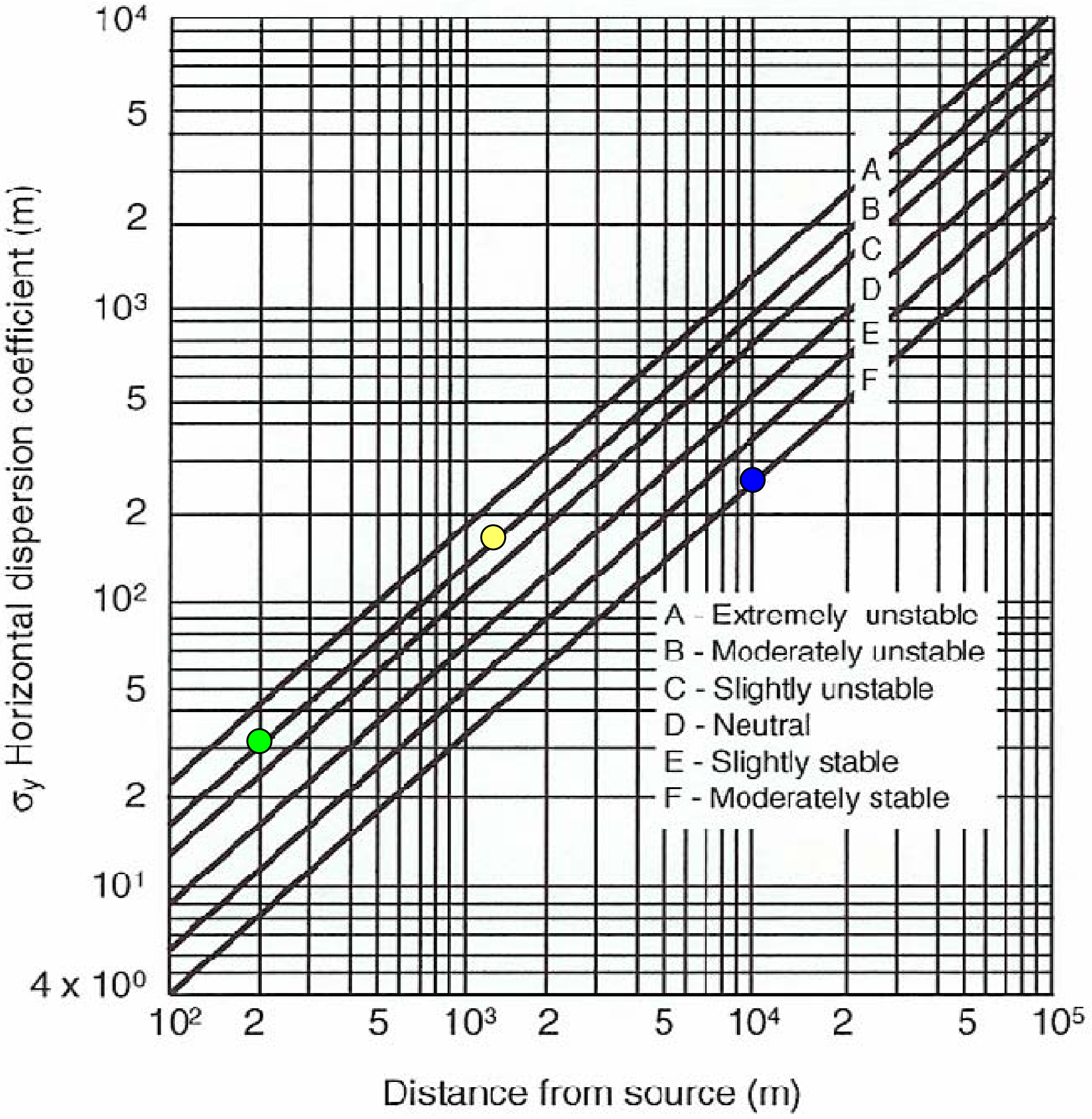
* A = Very unstable D = Neutral
B = Moderately unstable E = Slightly stable
C = Slightly unstable F = Stable
Regardless of wind speed, Class D should be assumed for overcast conditions, day or night.

Atmospheric Stability Classes

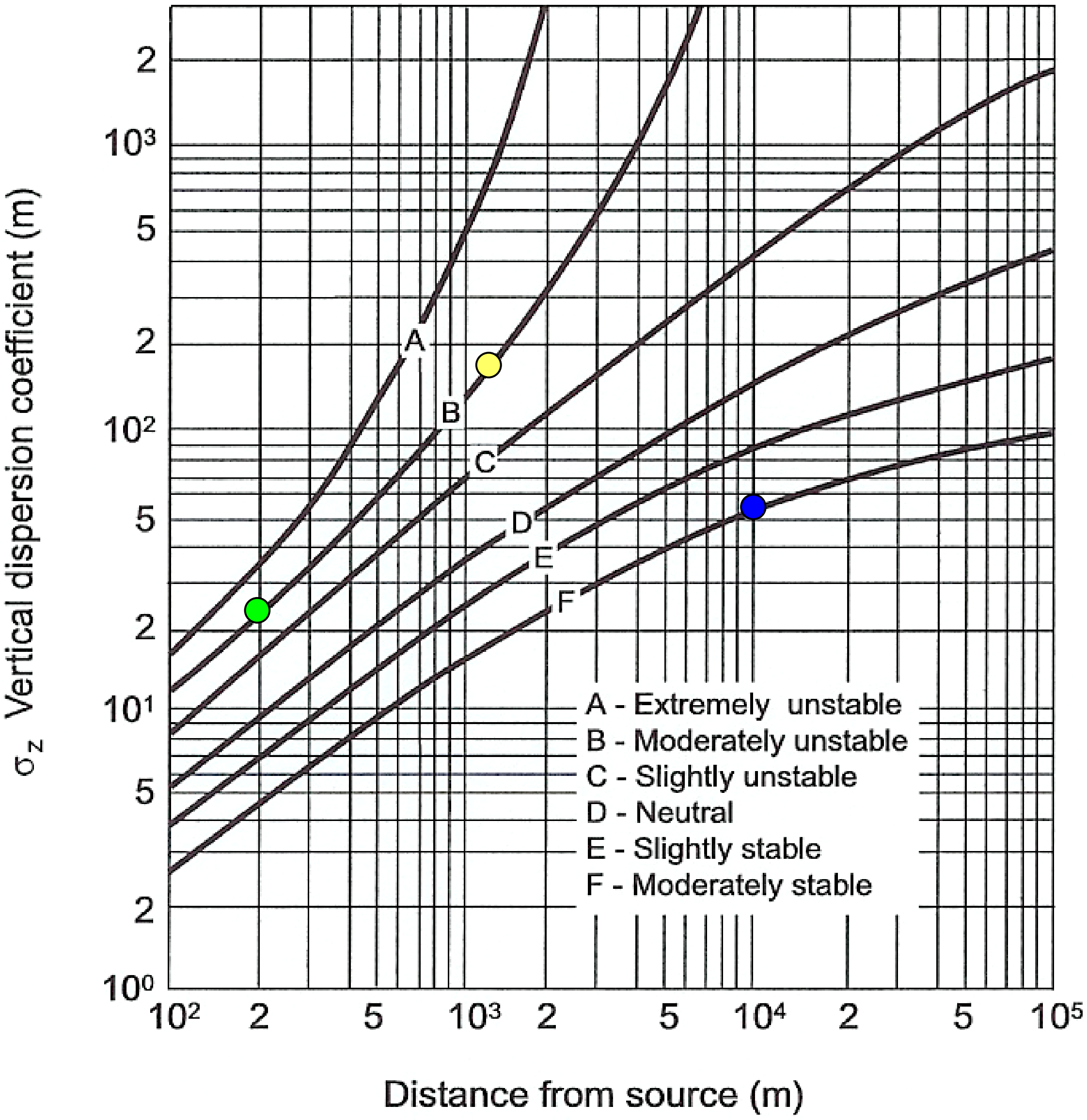


	Day			Night	
	Incoming Solar Radiation			Thinly Overcast	
Wind Speed, 10 m (m/sec)	Strong	Moderate	Slight	>4/8 Cloud	<3/8 Cloud
<2	A	A–B	B	E	F
2–3	A–B	B	C	D	E
3–5	B	B–C	C	D	D
>6	C	D	D	D	D

Horizontal Dispersion Coefficient σ_y

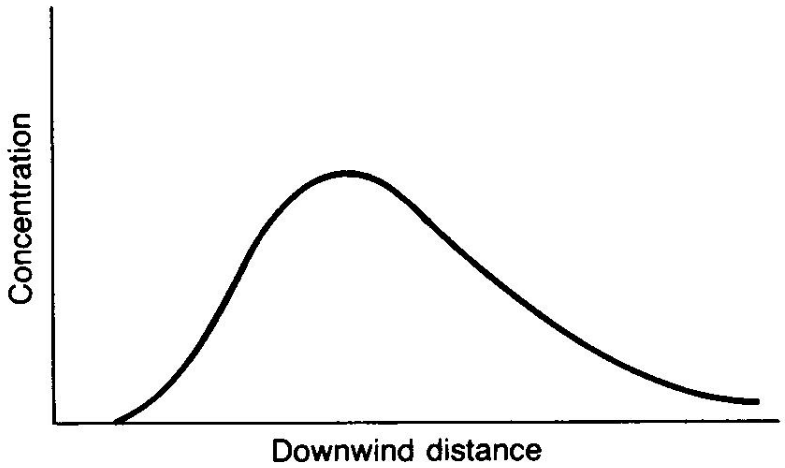


Vertical Dispersion Coefficient σ_z



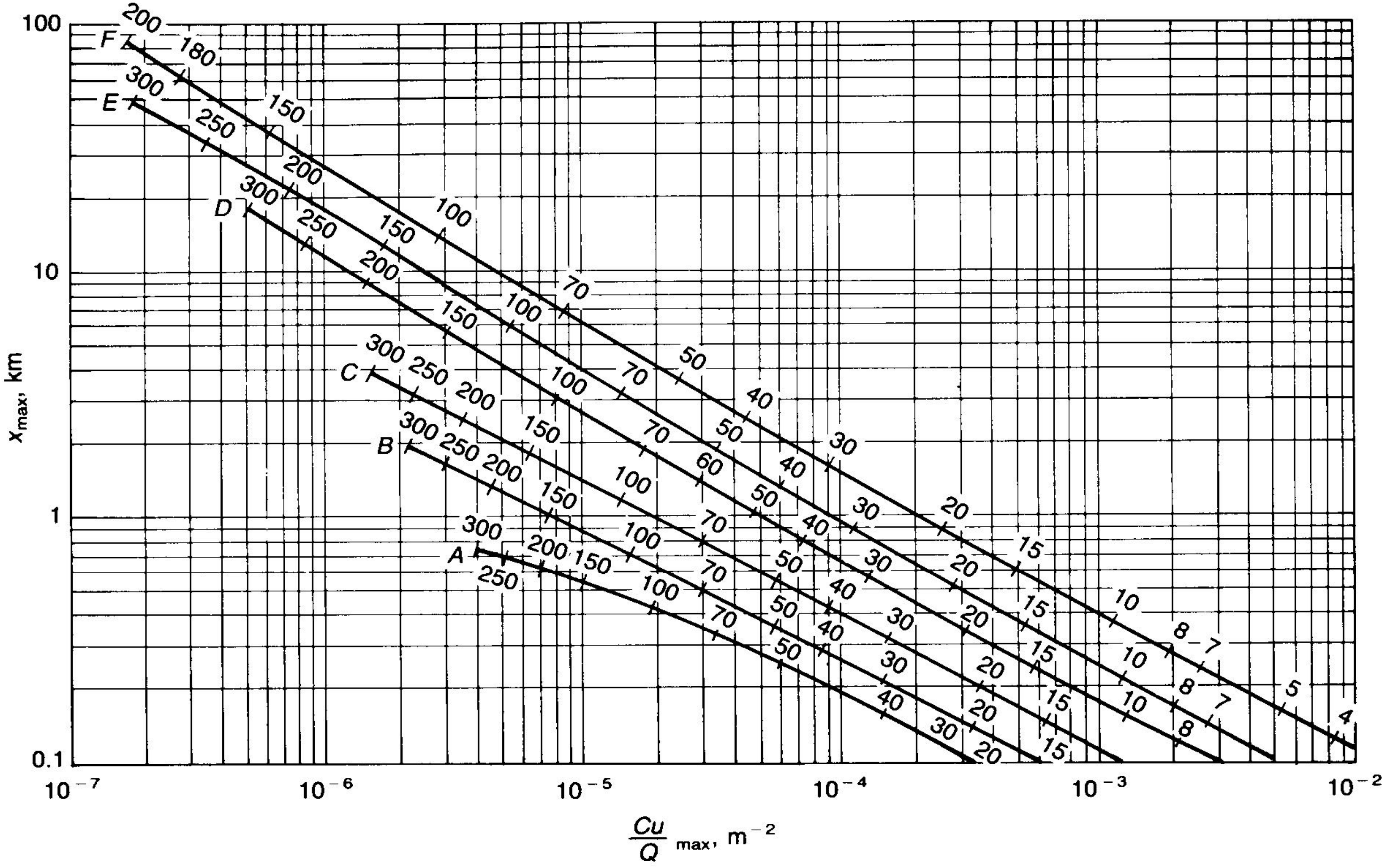
Maximum Downwind Ground-Level Concentration (C_{max})

- **Pollutants require time (and distance) to reach the ground.**



- **C_{max} decreases as effective plume height H increases.**
- **Distance to C_{max} increases as H increases.**

Maximum Concentration (C_{max}) and Distance to C_{max} (x_{max})



Maximum Ground Level Concentration

Under moderately stable to near neutral conditions,

$$\sigma_y = k_1 \sigma_z$$

The ground level concentration at the center line is

$$C(x,0,0) = \frac{Q}{\pi k_1 \sigma_z^2 u} \exp\left[-\frac{H^2}{2\sigma_z^2} \right]$$

The maximum occurs at

$$dC / d\sigma_z = 0 \qquad \Rightarrow \sigma_z = \frac{H}{\sqrt{2}}$$

Once σ_z is determined, x can be known and subsequently C.

$$C(x,0,0) = \frac{Q}{\pi \sigma_y \sigma_z u} \exp[-1] = 0.1171 \frac{Q}{\sigma_y \sigma_z u}$$

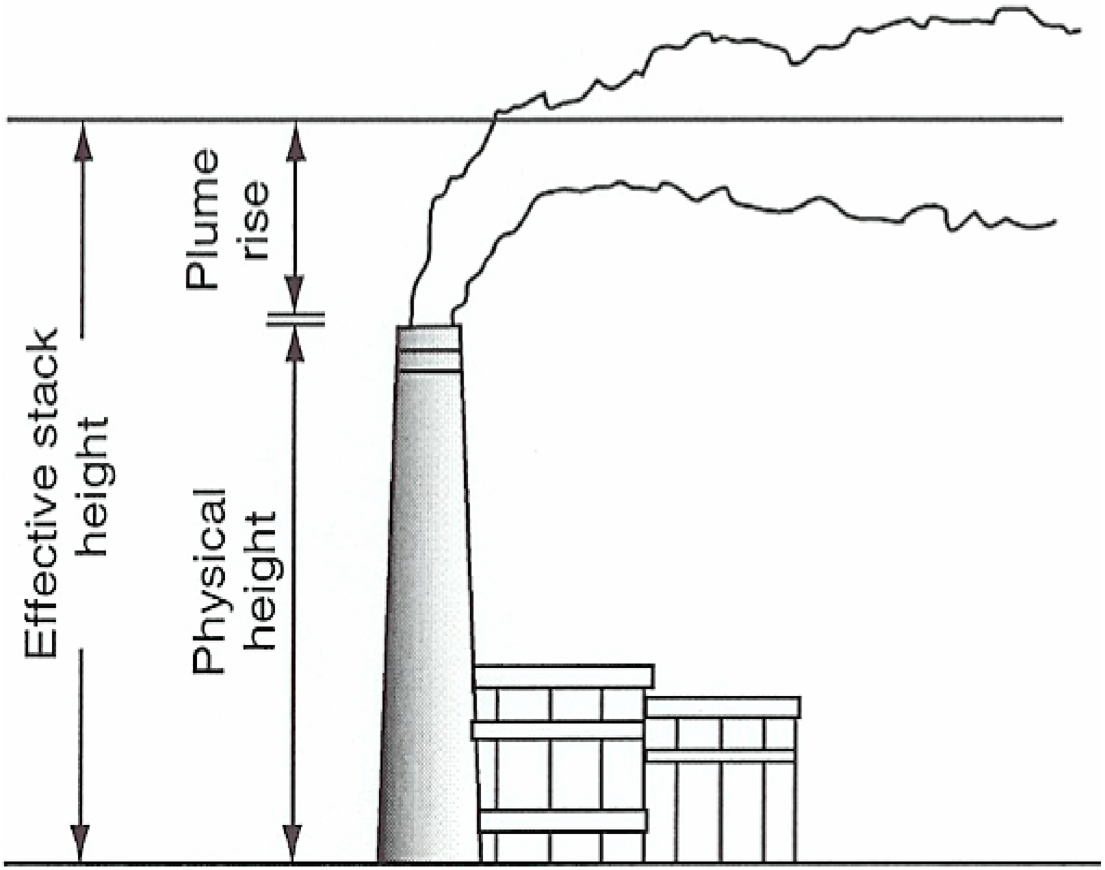
Plume Rise

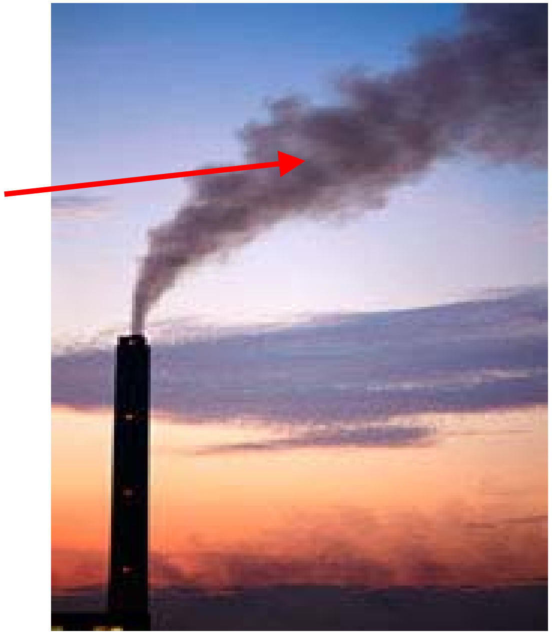
- **H is the sum of the physical stack height and plume rise.**

$$H = \Delta h_{plumerise} + h_{actualstack}$$

Pollutant Plume Rise

- Plume rises from stack exit.





Plume Rise

Buoyant plume: Initial buoyancy >> initial momentum
Forced plume: Initial buoyancy ~ initial momentum
Jet: Initial buoyancy << initial momentum

- For neutral and unstable atmospheric conditions, **buoyant rise** can be calculated by

$$\Delta h_{plume\ rise} = \frac{21.425 F^{0.75}}{\bar{u}} \qquad (\mathrm{F} < 55\ m^4/s^3)$$

$$\Delta h_{plume\ rise} = \frac{38.71 F^{0.6}}{\bar{u}} \qquad (\mathrm{F} > 55\ m^4/s^3)$$

where **buoyancy flux** is

$$F = gV_s d^2 (T_s - T_a)/4T_S$$

$\mathrm{V_s}$: Stack exit velocity, m/s
d: top inside stack diameter, m
$\mathrm{T_s}$: stack gas temperature, K
$\mathrm{T_a}$: ambient temperature, K
g: gravity, 9.8 $\mathrm{m/s^2}$

Carson and Moses: vertical momentum & thermal buoyancy, based on 615 observations involving 26 stacks.

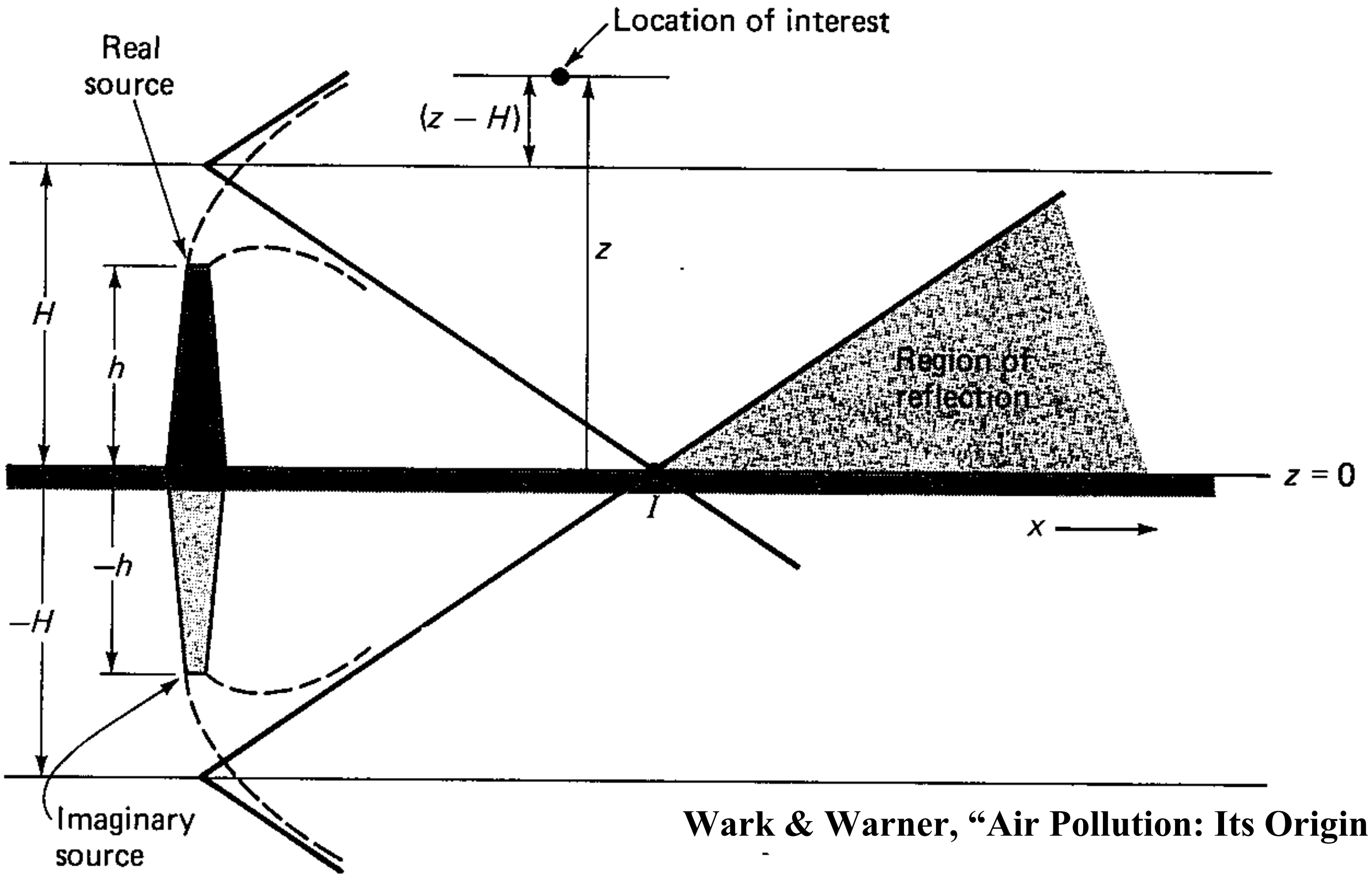
$$\Delta h_{plume\ rise} = 3.47\frac{V_s d}{\bar{u}} + 5.15\frac{\sqrt{Q_h}}{\bar{u}} \qquad \text{(unstable)}$$

$$\Delta h_{plume\ rise} = 0.35\frac{V_s d}{\bar{u}} + 2.64\frac{\sqrt{Q_h}}{\bar{u}} \qquad \text{(neutral)}$$

$$\Delta h_{plume\ rise} = -1.04\frac{V_s d}{\bar{u}} + 2.24\frac{\sqrt{Q_h}}{\bar{u}} \qquad \text{(stable)}$$

$$Q_h = \dot{m} C_p \left(T_s - T_a\right) \qquad \text{(heat emission rate, kJ/s)}$$

$$\dot{m} = \frac{\pi d^2}{4} V_s \frac{P}{R T_s} \qquad \text{(stack gas mass flow rate. kg/s)}$$



Wark & Warner, "Air Pollution: Its Origin & Control"

Figure 4-3 Use of an imaginary source to describe mathematically gaseous reflection at surface of the earth.

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

Plume is Reflected when it touches ground surface.

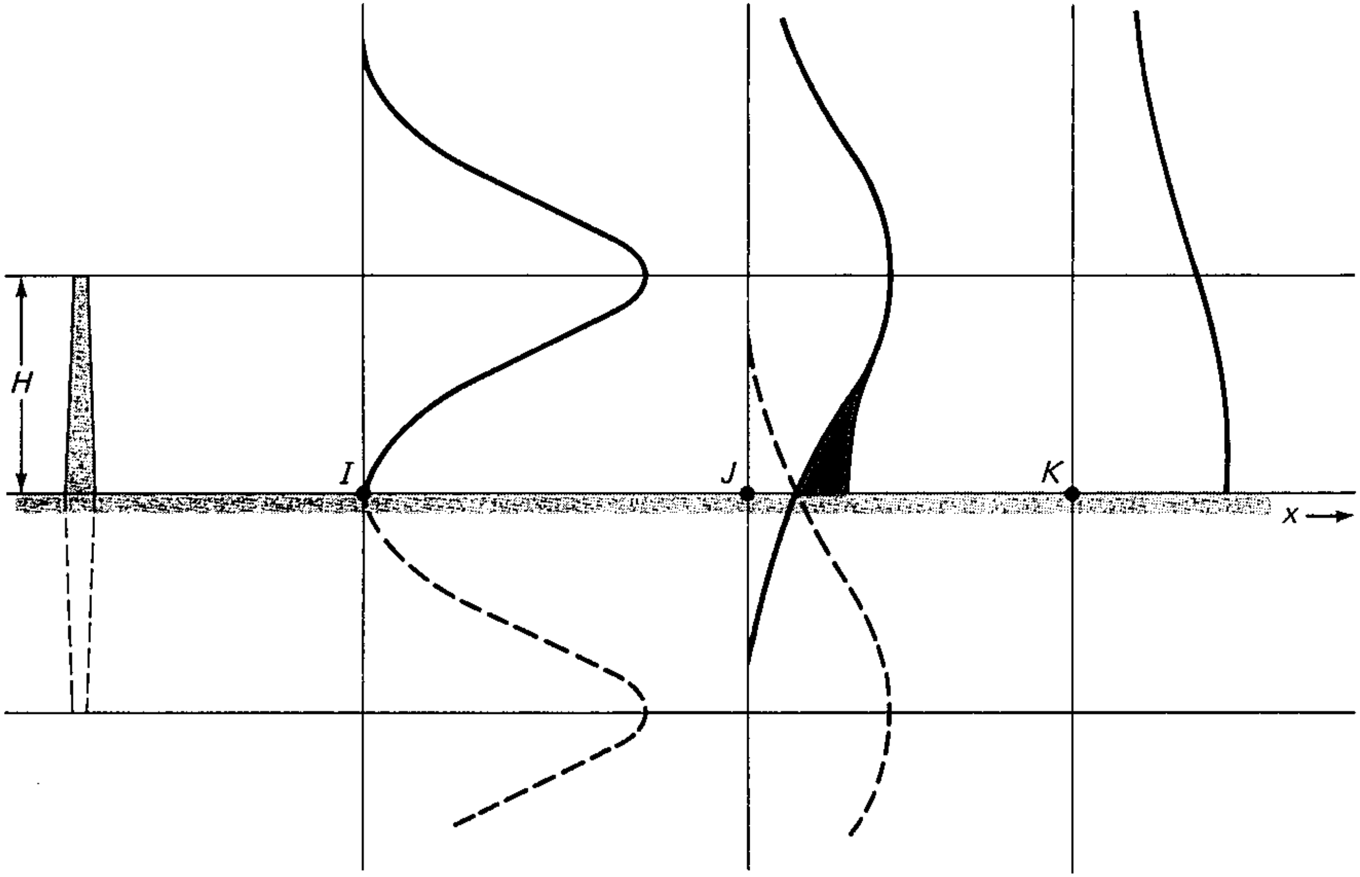


Figure 4-4 Effect of ground reflection on pollutant concentration downwind.

Ground level concentration

$$C = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp\left[-\frac{y^2}{2\sigma_y^2} \right] \exp\left[-\frac{H^2}{2\sigma_z^2} \right]$$

Dispersion of SO_2 from Stack

- An industrial boiler is burning at 12 tons of 2.5% sulfur coal/hr with an emission rate of 151 g/s. The following exist : H = 120 m, u = 2 m/s, y = 0. It is one hour before sunrise, and the sky is clear. Find the downwind ground level SO_2 concentration at x =2 km, y = 0, and z = 0.

Stability class =

σ_y =

σ_z =

C(x=2 km, y=0, z=0) =

$$C = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp\left[-\frac{y^2}{2\sigma_y^2}\right] \exp\left[-\frac{H^2}{2\sigma_z^2}\right]$$

Dispersion of Ground Level Air Pollutant Emissions

- **Air pollutant emissions are from a ground level source with H = 0, u = 4 m/s, Q = 100 g/s, and the stability class = B, what is downwind concentration at x = 200 m, y = 0, and z = 0?**

At 200 m:

σ_y =

σ_z =

C(x=200 m, y=0, z=0) =

Plume Rise and Max Conc

- **Calculate H using plume rise equations for an 80 m high stack (h) with a stack diameter = 4 m, stack gas velocity = 14 m/s, stack gas temperature = 90° C (363 K), ambient temperature = 25 °C (298 K), 10 meter high wind speed u at 10 m = 4m/s, and stability class = B. Find the Max Ground Level air pollutant concentration & its (location downwind distance x).**

F =

$\Delta h_{\textit{plume rise}}$ =

H =

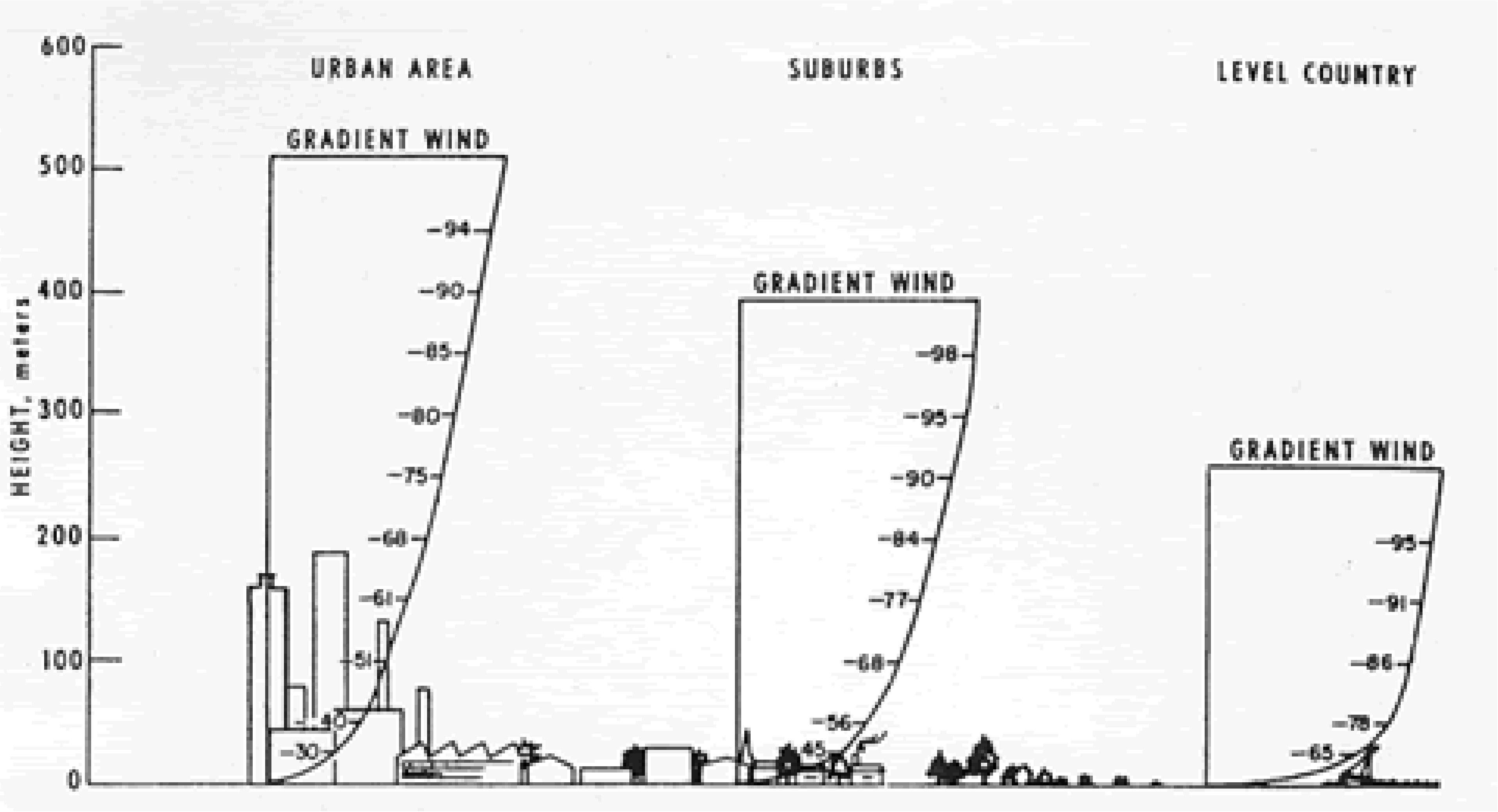
σ_z =

σ_y =

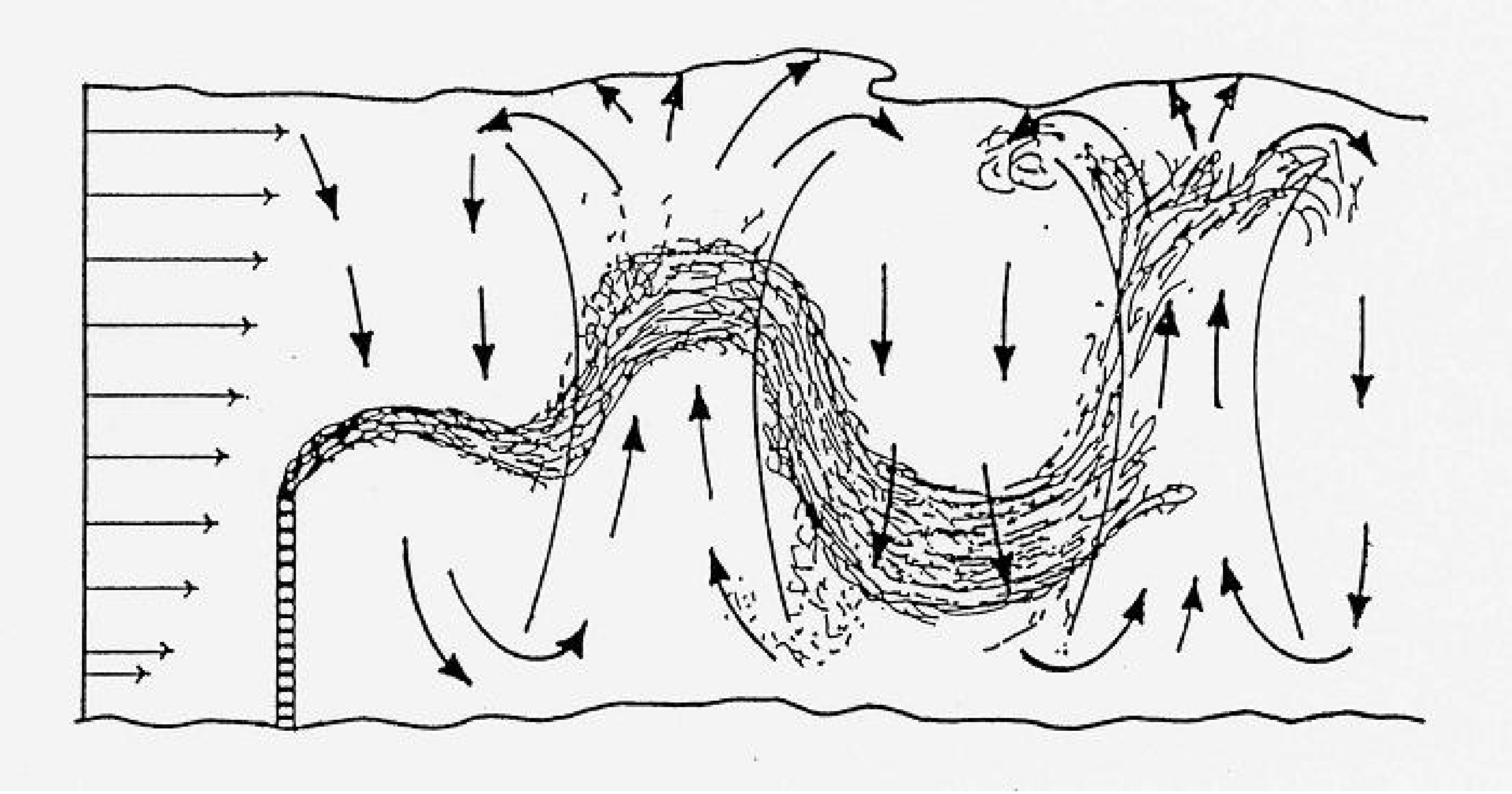
C_{max} =

Residents around the Rock Cement Plant are complaining that its emission are in violation and the ground level concentrations exceed the air quality standards. The plant has its facility within 0.2 km diameter fence. Its effective stack height is 50 m. You are a government agency environmental engineer. Where are you going to locate your air quality monitors? Why?

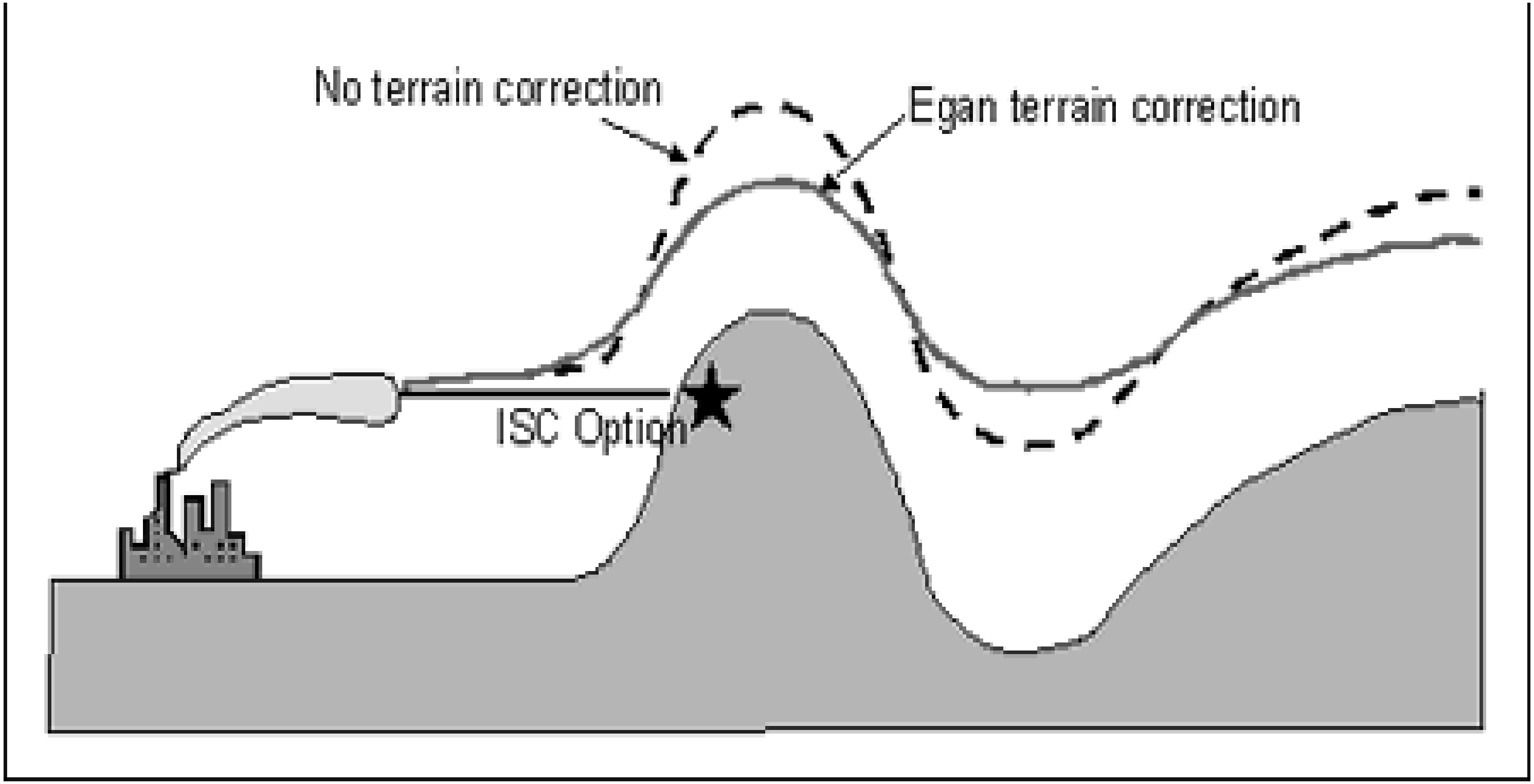
Complex Horizontal, Vertical, and Temporal Wind Structure
Winds aloft have no continuous measurements



Meteorology

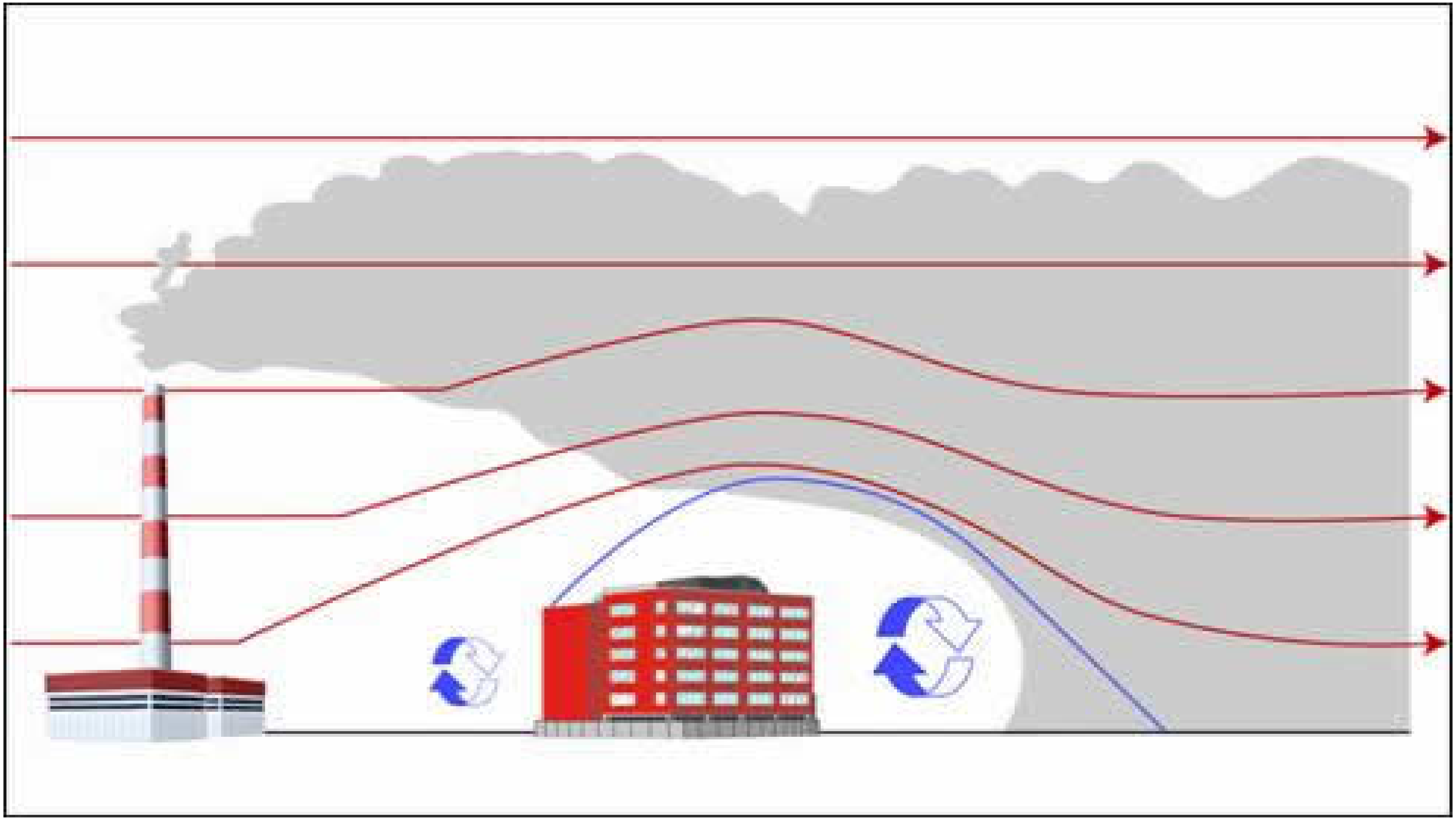


In most of cases terrain is not flat terrain – topographic complexity

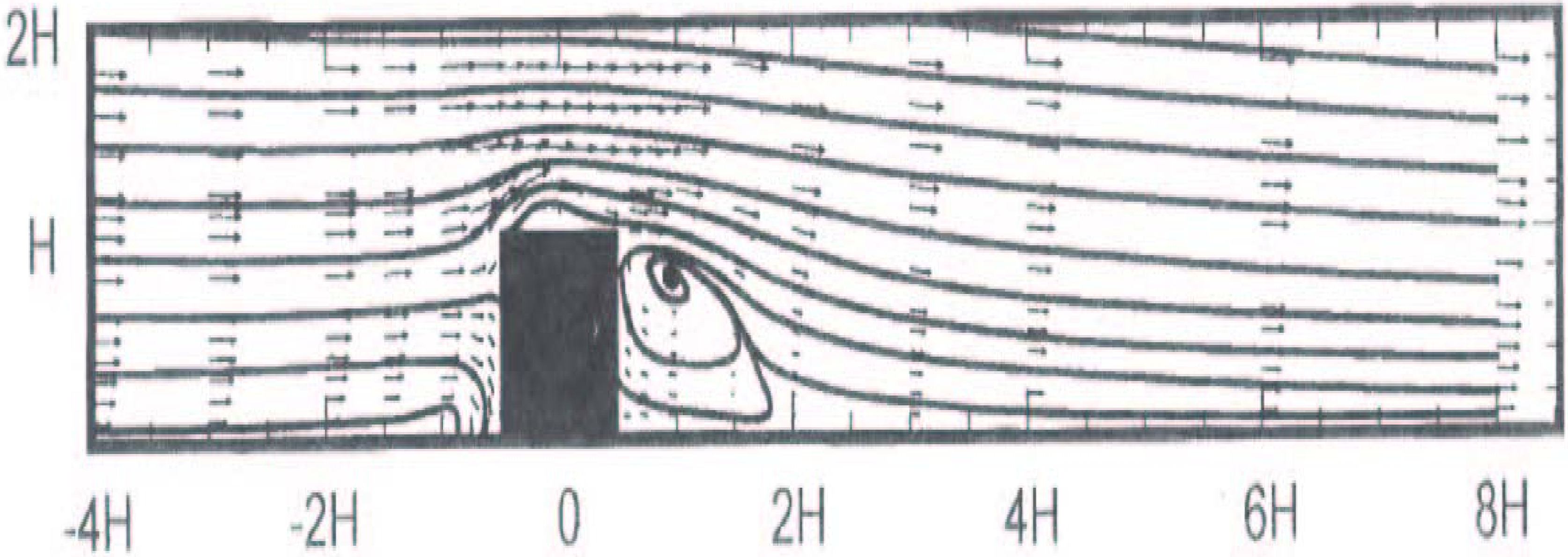


Complex horizontal, vertical, and temporal dispersion

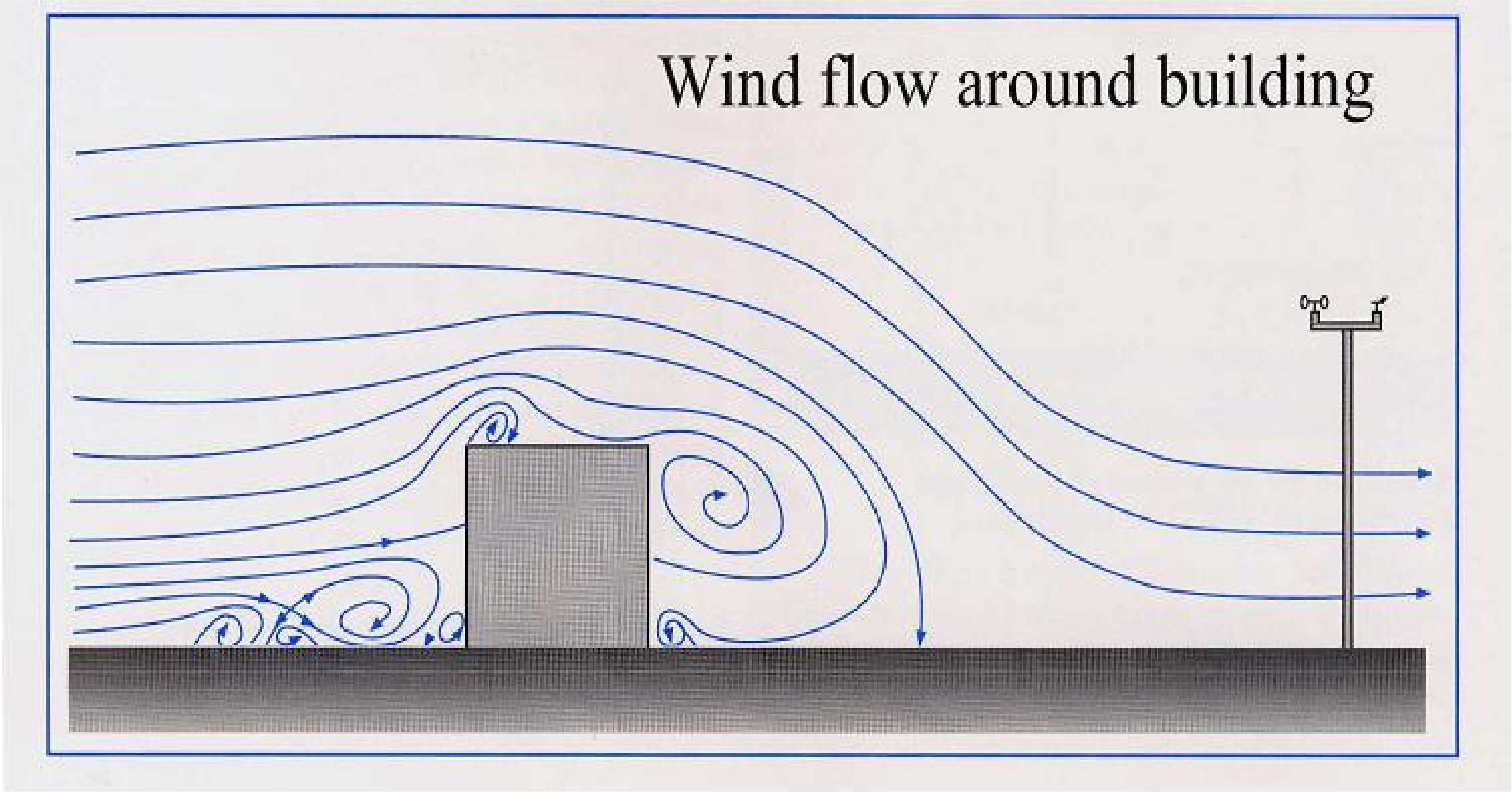
Plume Air Pollutant Building Downwash



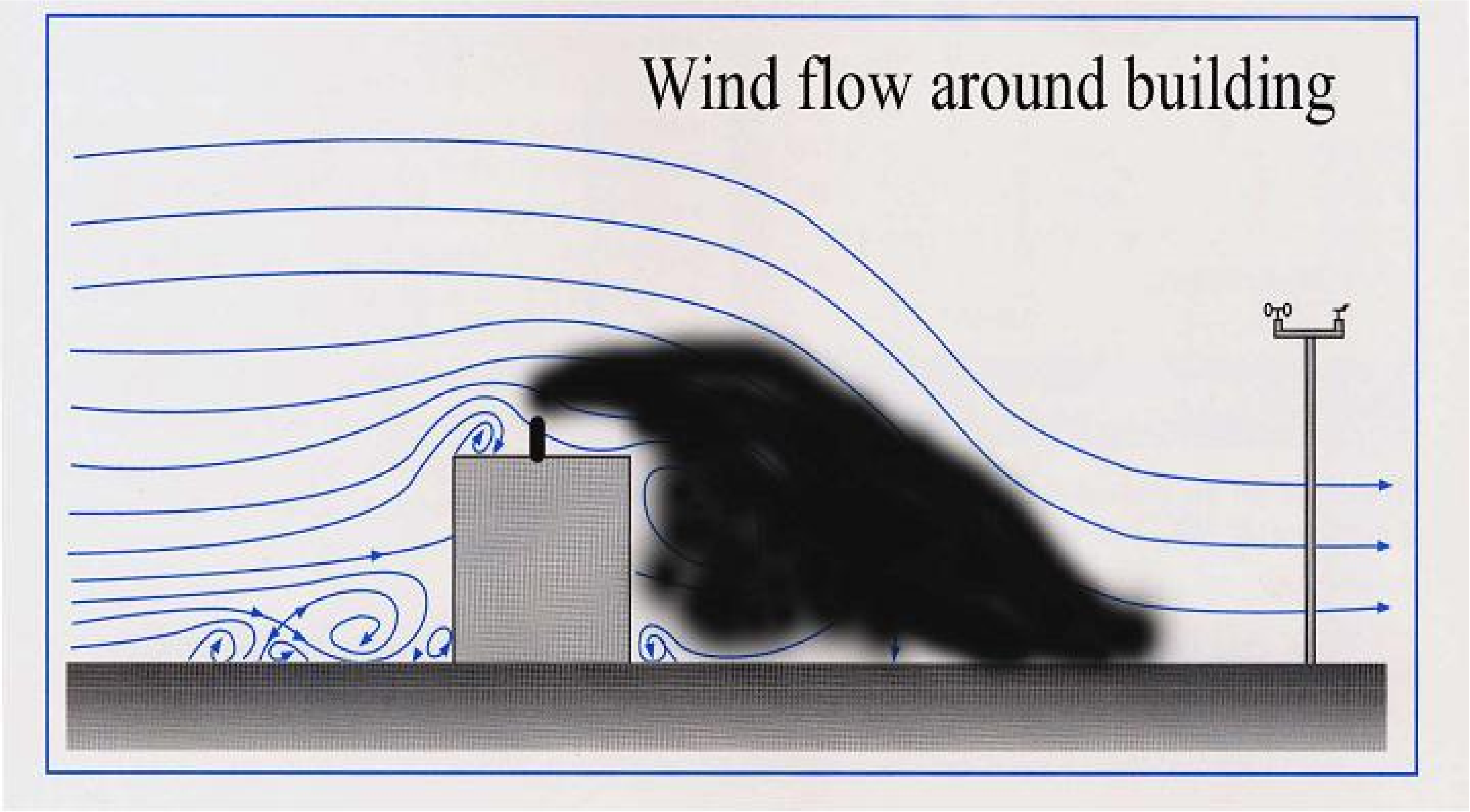
Building Downwash



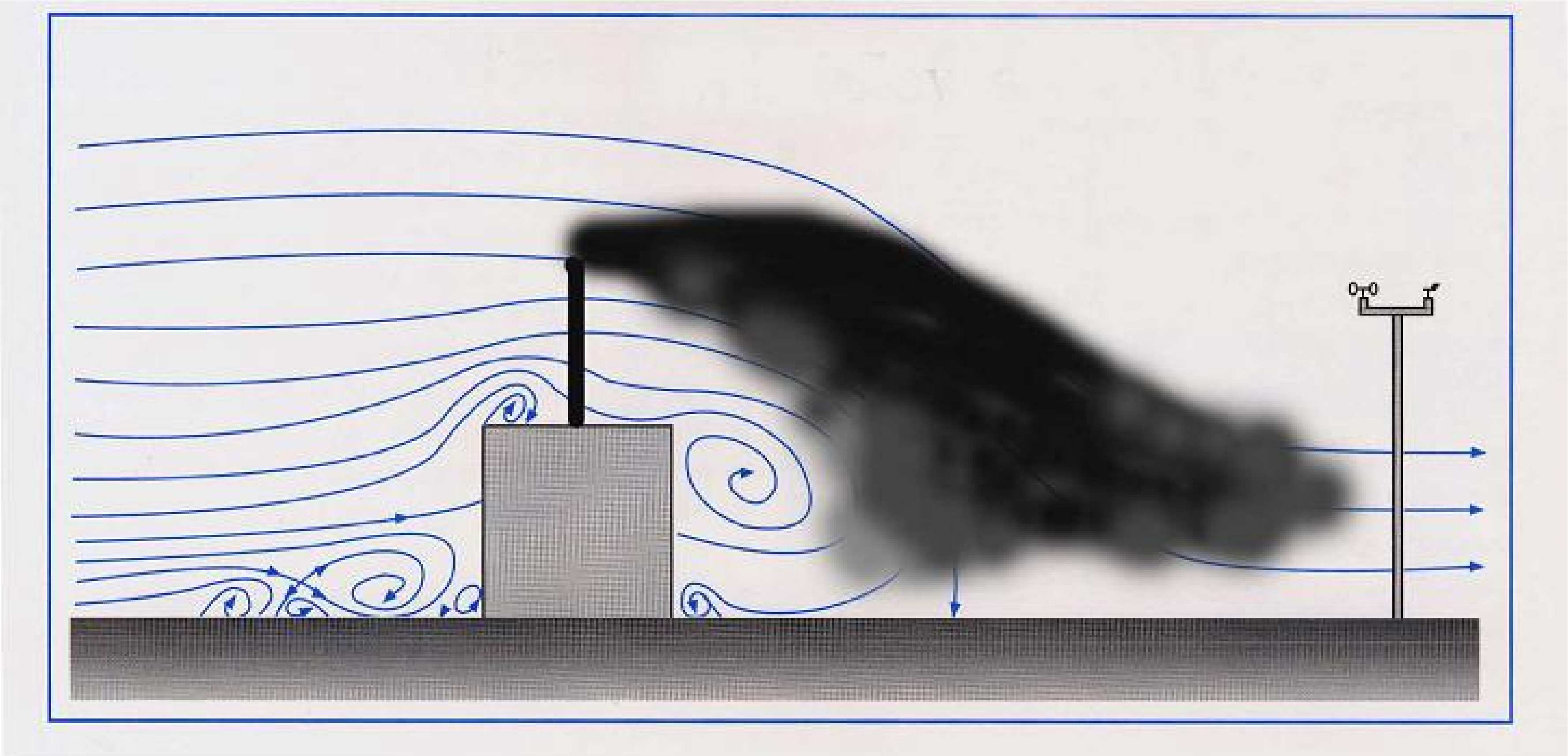
Building Downwash



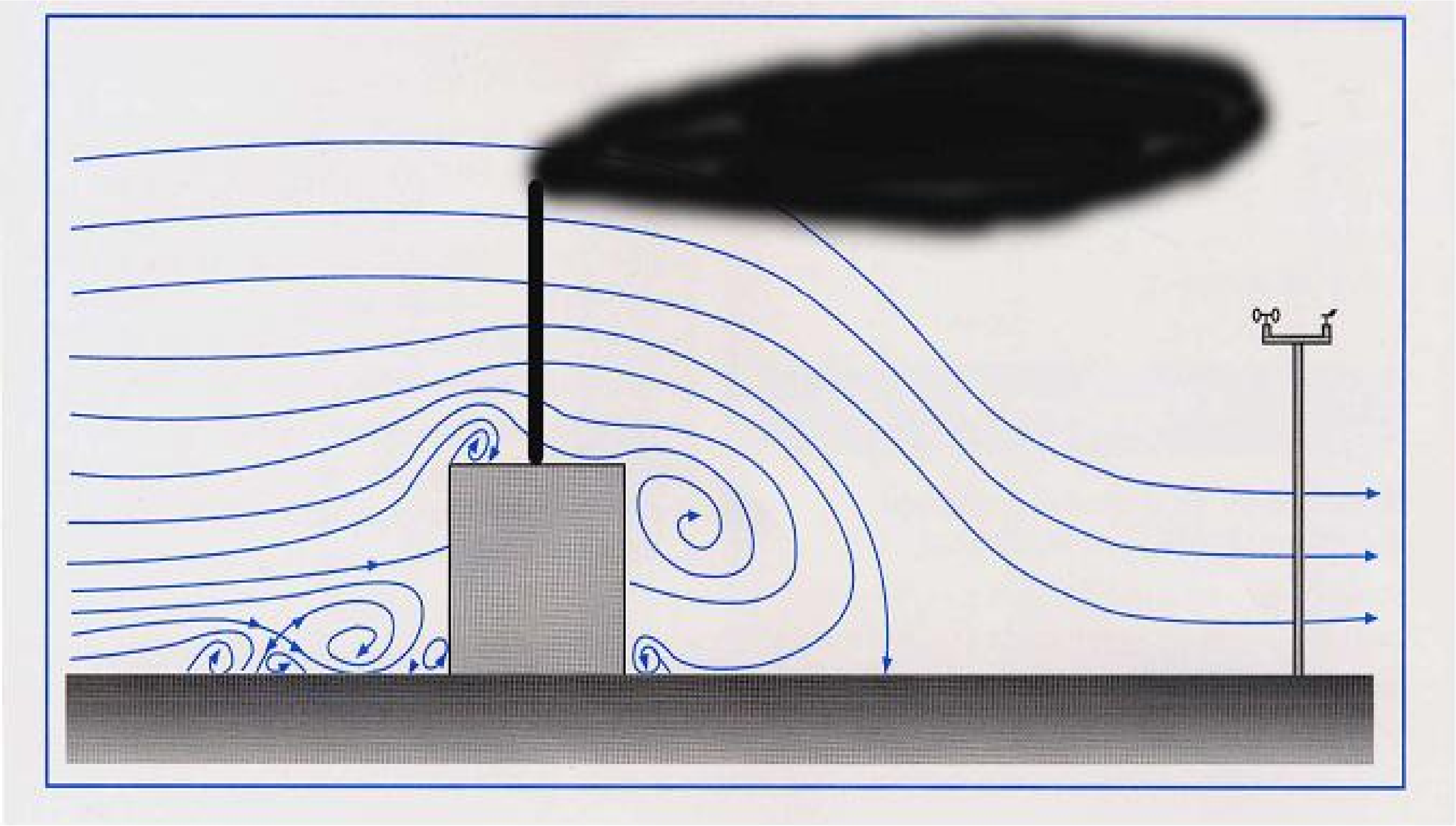
Building Downwash – Short Stack



Building Downwash – Taller Stack (Not GEP)

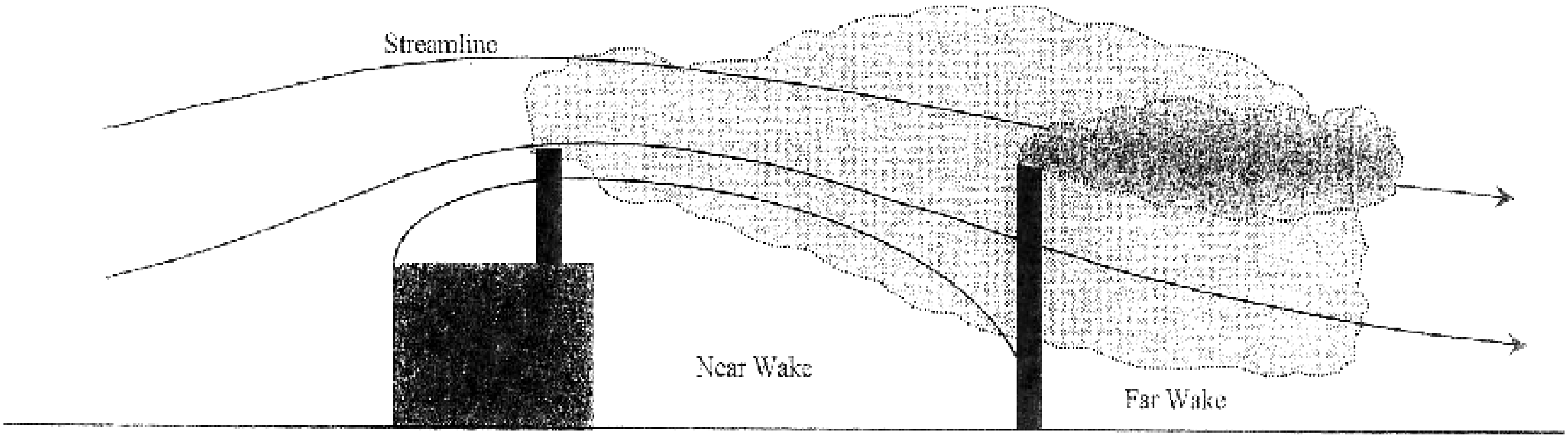


Building Downwash – Tallest Stack



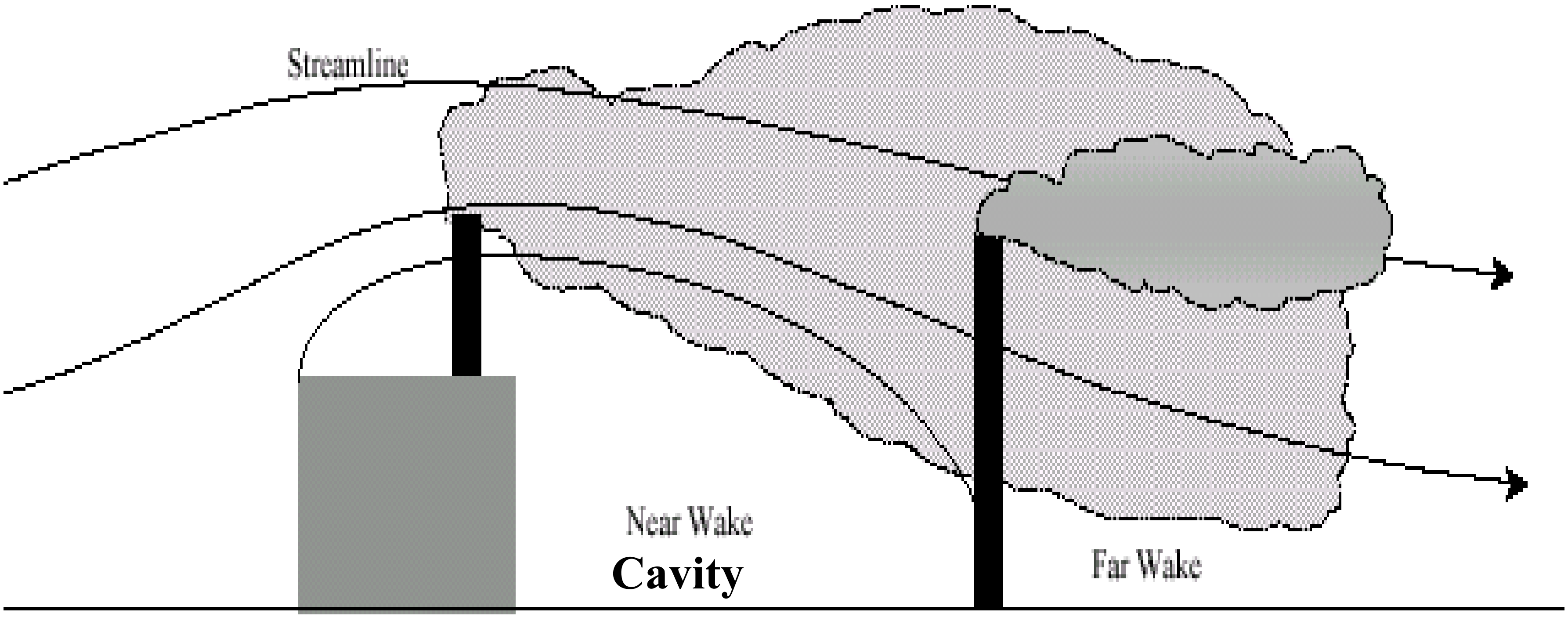
$H_{GEP} = 2.5\ H_{Bldg}$ Prior to 1979

$H_{GEP} = H_{Bldg} + 1.5\ L$

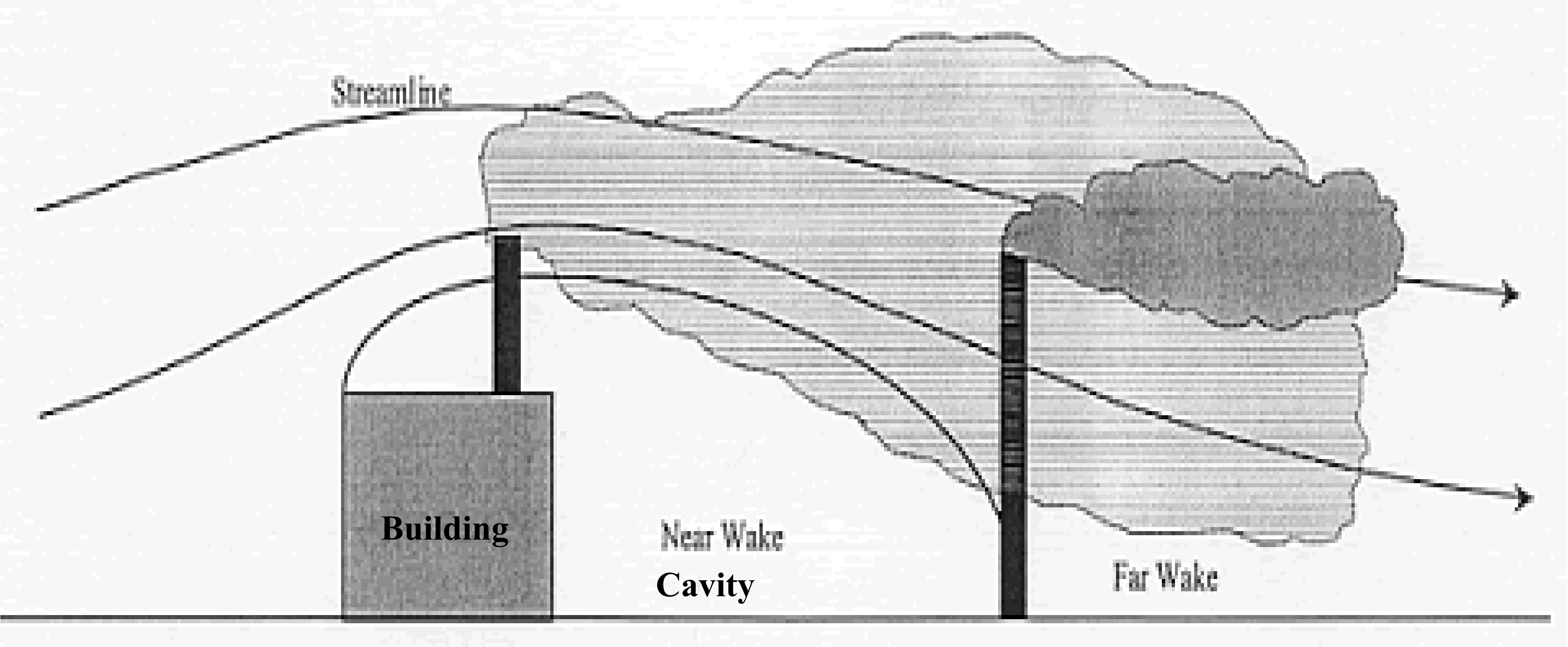


Cavity and Wakes

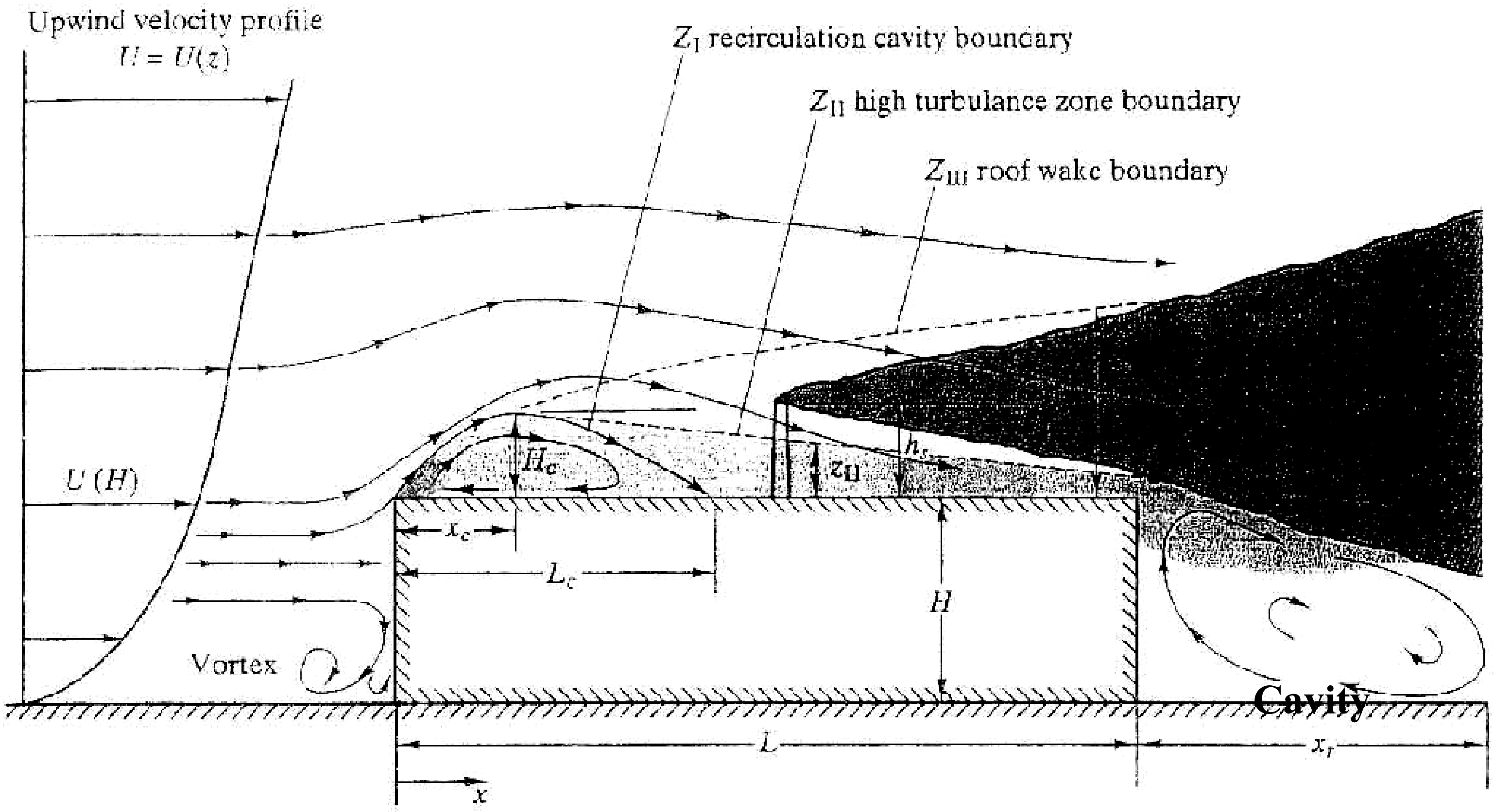
Cavity and Far Wake



Building Downwash for 2 Identical Stack Emissions at Different Locations

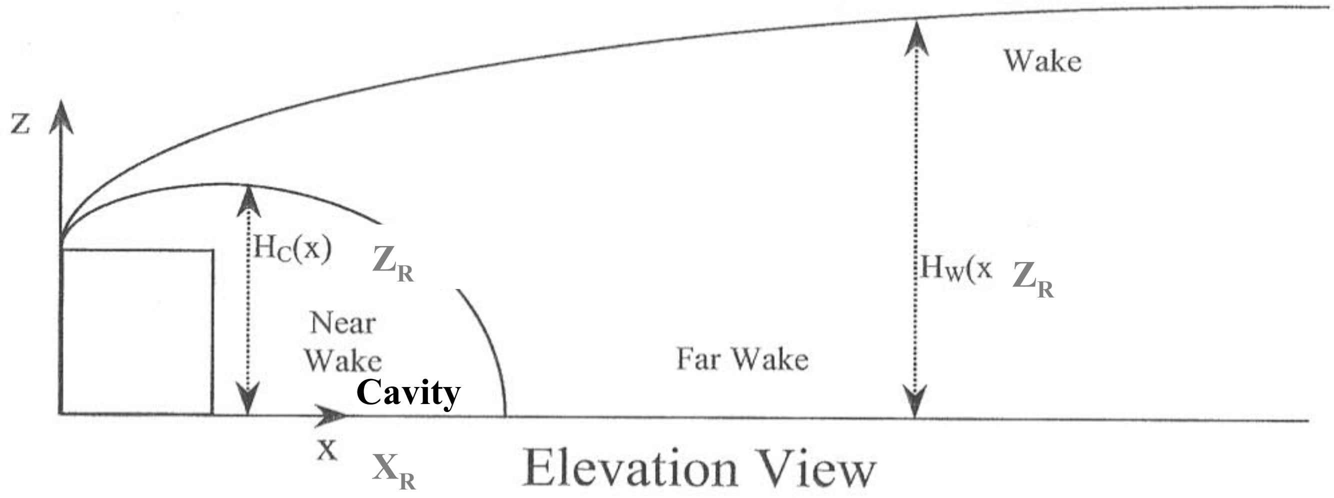


The stack on the left is located on top of a building and this structure affects the wind-flow which, in turn, affects the plume trajectory, pulling it down into the cavity zone (near wake) behind the building. The stack on the right is located far enough downwind of the building to be unaffected by the cavity (near wake) effects and is only affected by the air flow in the far wake.

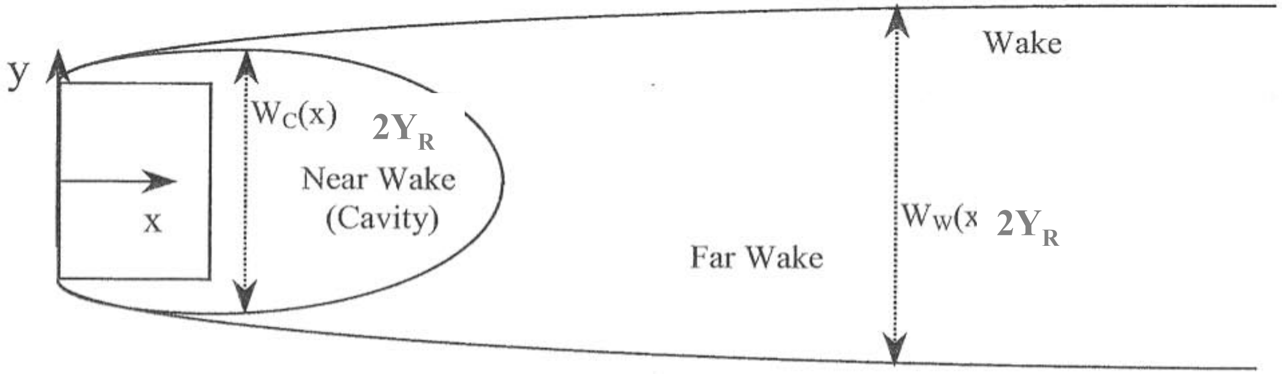


Building Downwash

Cavity and Wakes



Elevation View



Plan View

Aerodynamic Wake

- Region where local air velocities are different from the free stream values
- Streamline Separation – at an object
  - Eddy Recirculation (generally lower velocity region)
  - Turbulent Shear Region (generally higher velocity)
- Reattachment of Streamlines
- Near Wake (Cavity)
  - Usually on the ‘lee’ side of the object.
- Far Wake
  - Effect of another object on the separated streamlines
- Estimation of Wake/Cavity Boundary
  - Effect of Building geometry

Two Points of Concern

- Dispersion of Air Pollutant Plume in the presence of Buildings
  - What happens to the plume from an existing stack and existing buildings?
- Design of Stacks in the Presence of Building
  - What are the design guidelines if a new emission source is being proposed in an area full of buildings?

Good Engineering Practice GEP Analysis

- H_{GEP} = good engineering practice height
- $H_{GEP} = H + 1.5\ L$
  - H = height of adjacent or nearby structure
  - L = lesser dimension height or proj. width
  - 5L = region of influence
- The structure with the greatest influence is then used in the model to evaluate wake effects and downwash.

Good Engineering Practice Stack Height

1985 Regulations -

GEP Stack height – greater of the following

- a) 65 m from the base of the stack
- b) $H_{GEP} = 2.5\ H$

for stacks in existence before Jan, 1979.

For All Other Stacks:

$$H_{GEP} = H + 1.5\ L$$

Where H is the height of the nearest building and

L = lesser dimension height or projected building width

GEP stack height

- **Building downwash can occur when**

  $H_{Stack} = H_S < H_b + 1.5L$

  H_{Stack} = Height of Stack

  H_b = Height of Building

  L = lesser of H_b or PBW

  PBW = Maximum Projected Building Width

Screen models will do this calculation when the building downwash option is used. If $H_S > H_b + 1.5L$, then building downwash will not be shown in SCREEN results

Getting Started – Screen 3

- **Convert all lengths and distances to meters**
- **Convert temperatures to degrees Kelvin**
- **Identify building contributions to air dispersion (stack emissions)**
- **Screen 3 should be run in regulatory default mode**
- **Note that SCREEN3 differs from TSCREEN (SCREEN3 can select atmospheric stability classes or run Full Meteorology, will not calculate concentrations at other averaging times, etc.)**

Information Required to run Screen Models for Point Source

- **Emission rate (g/s)**
- **Stack Height (m)**
- **Shortest distance to property line**
- **Stack velocity (or volumetric airflow SCREEN3)**
- **Stack gas temperature (^{o}K)**
- **Stack Inside Diameter**
- **Building Height, Length, Width**

SCREEN Example – Stack emissions

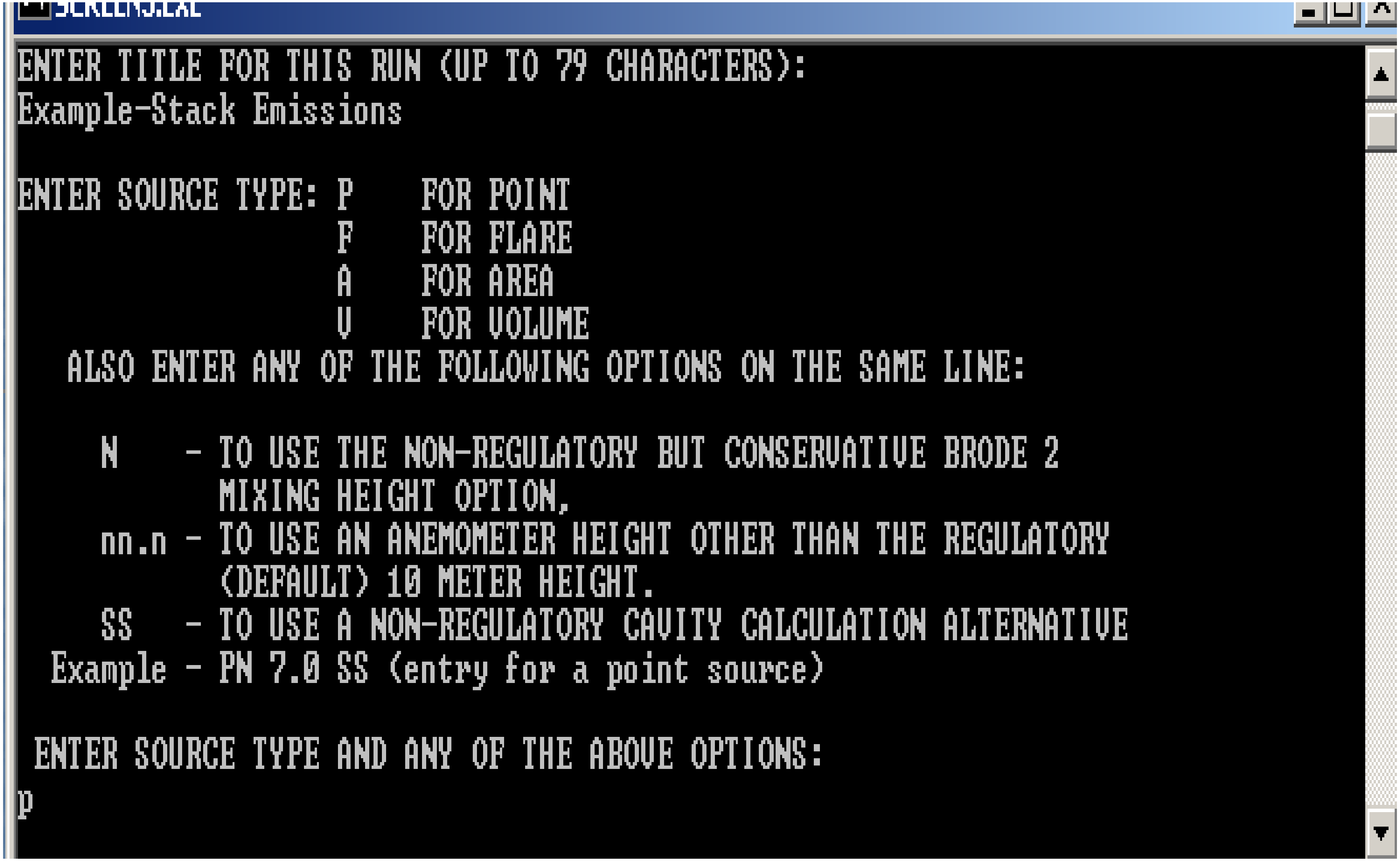
Emission rate (g/s)	.01 g/s
Stack Height	15.24m
Building Height	6.096m
Shortest Distance to property line	91.44m
Stack airflow in acfm	20,000 acfm
Stack gas temperature	294.3° K
Stack inside diameter	1.143m
Building dimensions	30.48m L, 30.48m W, 10.67m H

SCREEN Example – Stack emissions

```
 ******  SCREEN3 MODEL  ******
 **** VERSION DATED 96043 ****

ENTER TITLE FOR THIS RUN (UP TO 79 CHARACTERS):
Example-Stack Emissions_
```

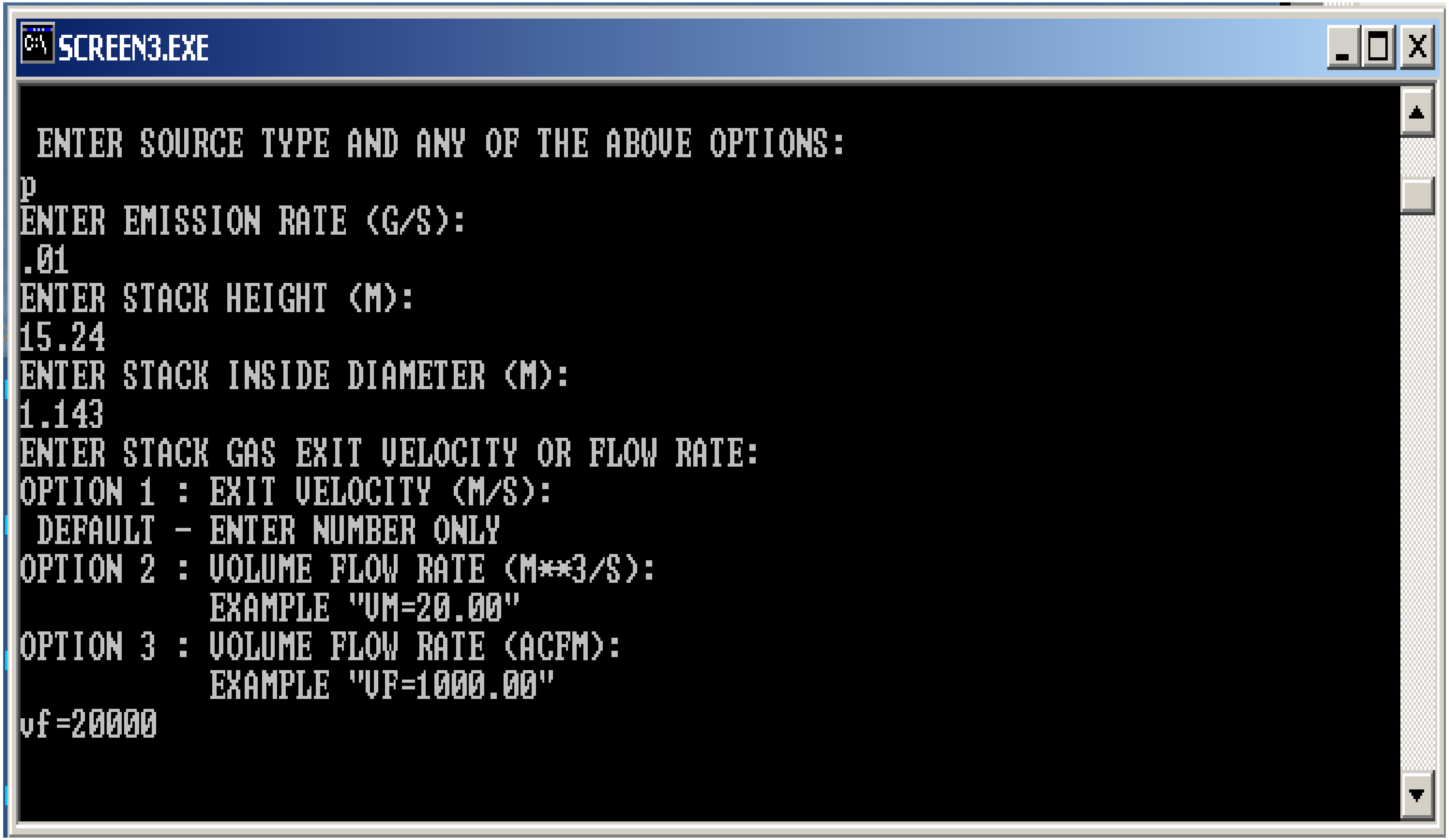
Note that this is the output from SCREEN3 software (not TSCREEN)

SCREEN Example – Stack emissions



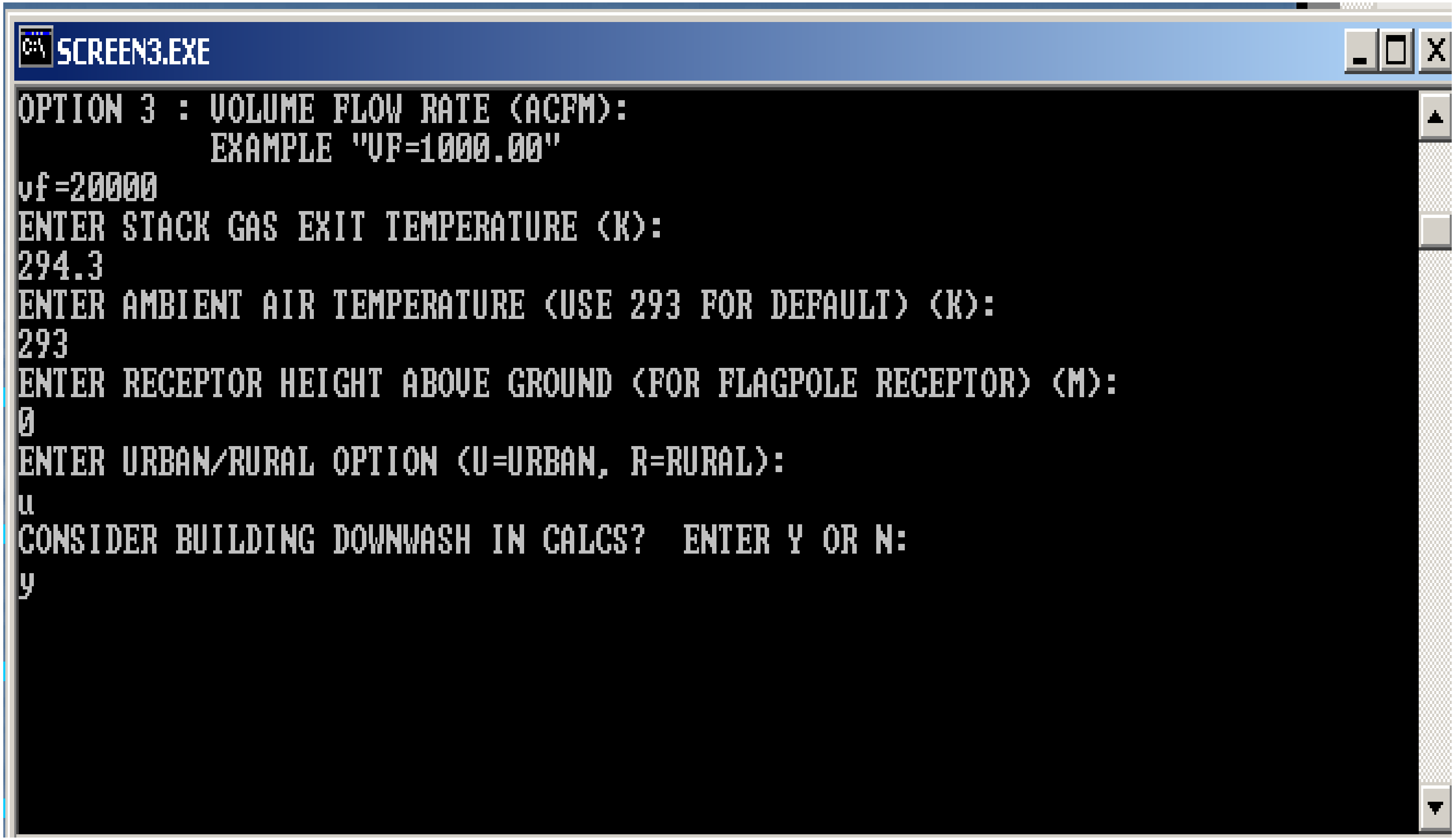
```
ENTER TITLE FOR THIS RUN (UP TO 79 CHARACTERS):
Example-Stack Emissions

ENTER SOURCE TYPE: P    FOR POINT
                   F    FOR FLARE
                   A    FOR AREA
                   V    FOR VOLUME
   ALSO ENTER ANY OF THE FOLLOWING OPTIONS ON THE SAME LINE:

     N    - TO USE THE NON-REGULATORY BUT CONSERVATIVE BRODE 2
            MIXING HEIGHT OPTION,
     nn.n - TO USE AN ANEMOMETER HEIGHT OTHER THAN THE REGULATORY
            (DEFAULT) 10 METER HEIGHT.
     SS   - TO USE A NON-REGULATORY CAVITY CALCULATION ALTERNATIVE
  Example - PN 7.0 SS (entry for a point source)

 ENTER SOURCE TYPE AND ANY OF THE ABOVE OPTIONS:
p
```

SCREEN Example – Stack emissions



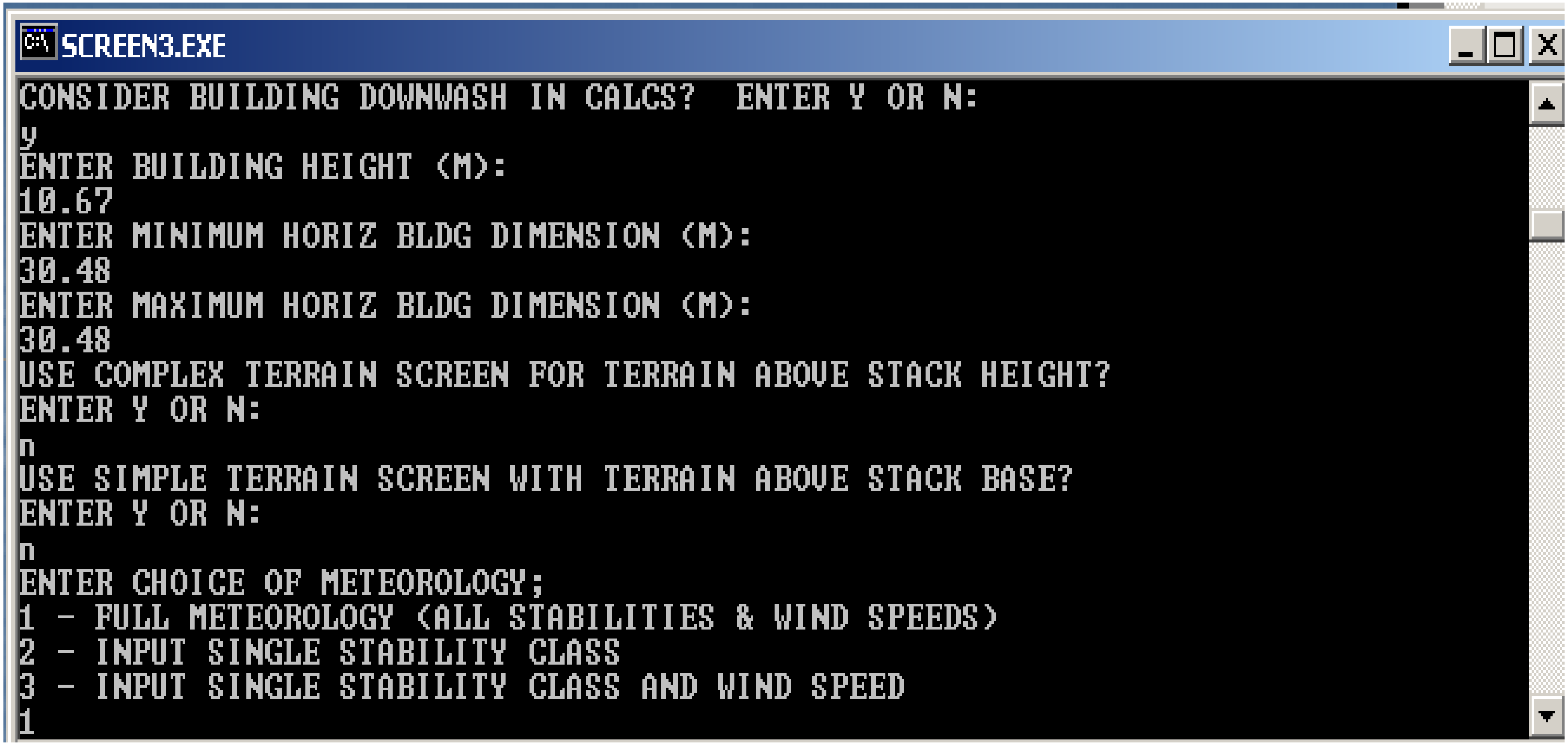
```
 ENTER SOURCE TYPE AND ANY OF THE ABOVE OPTIONS:
p
ENTER EMISSION RATE (G/S):
.01
ENTER STACK HEIGHT (M):
15.24
ENTER STACK INSIDE DIAMETER (M):
1.143
ENTER STACK GAS EXIT VELOCITY OR FLOW RATE:
OPTION 1 : EXIT VELOCITY (M/S):
 DEFAULT - ENTER NUMBER ONLY
OPTION 2 : VOLUME FLOW RATE (M**3/S):
           EXAMPLE "VM=20.00"
OPTION 3 : VOLUME FLOW RATE (ACFM):
           EXAMPLE "VF=1000.00"
vf=20000
```

SCREEN Example – Stack emissions



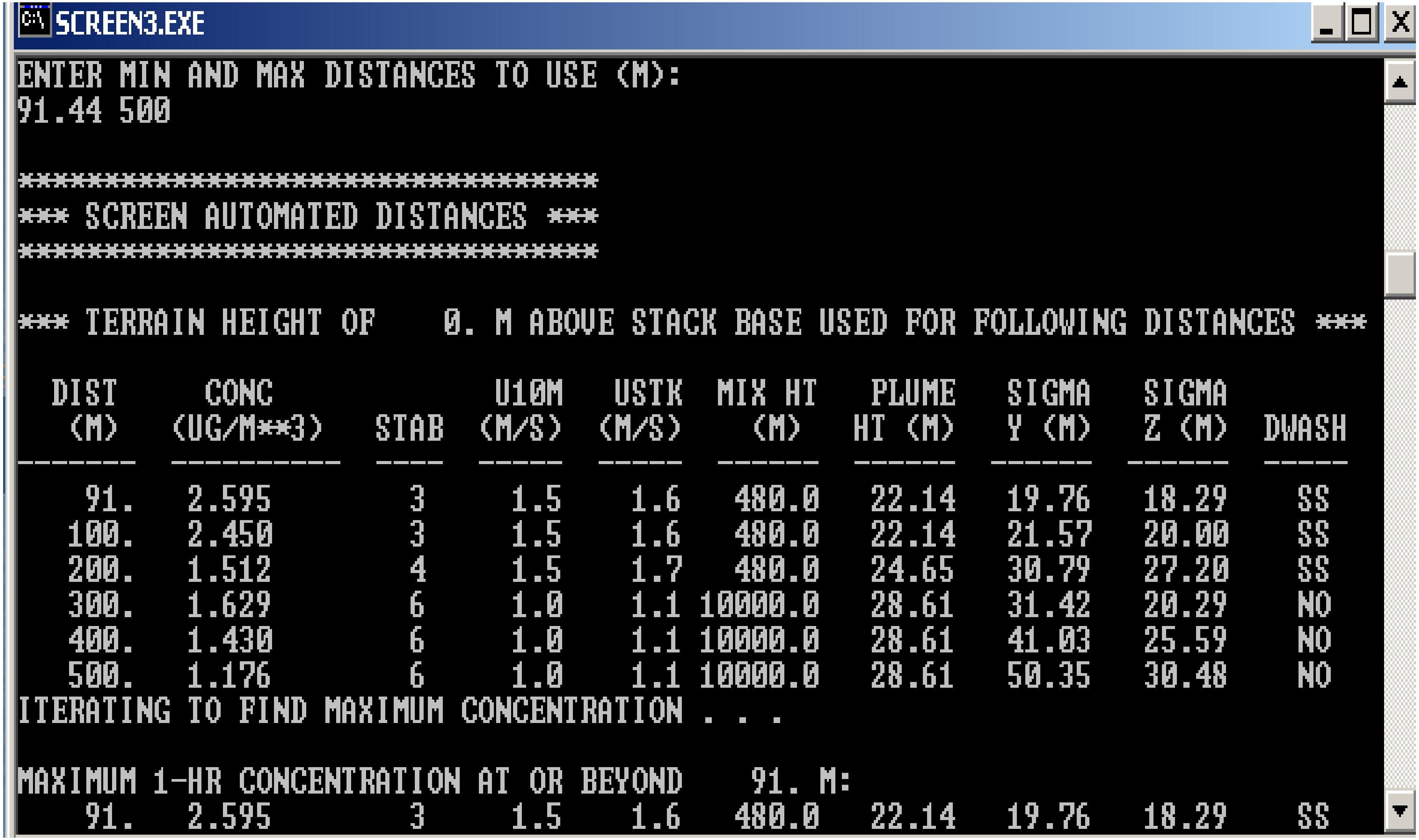
```
OPTION 3 : VOLUME FLOW RATE (ACFM):
           EXAMPLE "VF=1000.00"
vf=20000
ENTER STACK GAS EXIT TEMPERATURE (K):
294.3
ENTER AMBIENT AIR TEMPERATURE (USE 293 FOR DEFAULT) (K):
293
ENTER RECEPTOR HEIGHT ABOVE GROUND (FOR FLAGPOLE RECEPTOR) (M):
0
ENTER URBAN/RURAL OPTION (U=URBAN, R=RURAL):
u
CONSIDER BUILDING DOWNWASH IN CALCS?  ENTER Y OR N:
y
```

SCREEN Example – Stack emissions



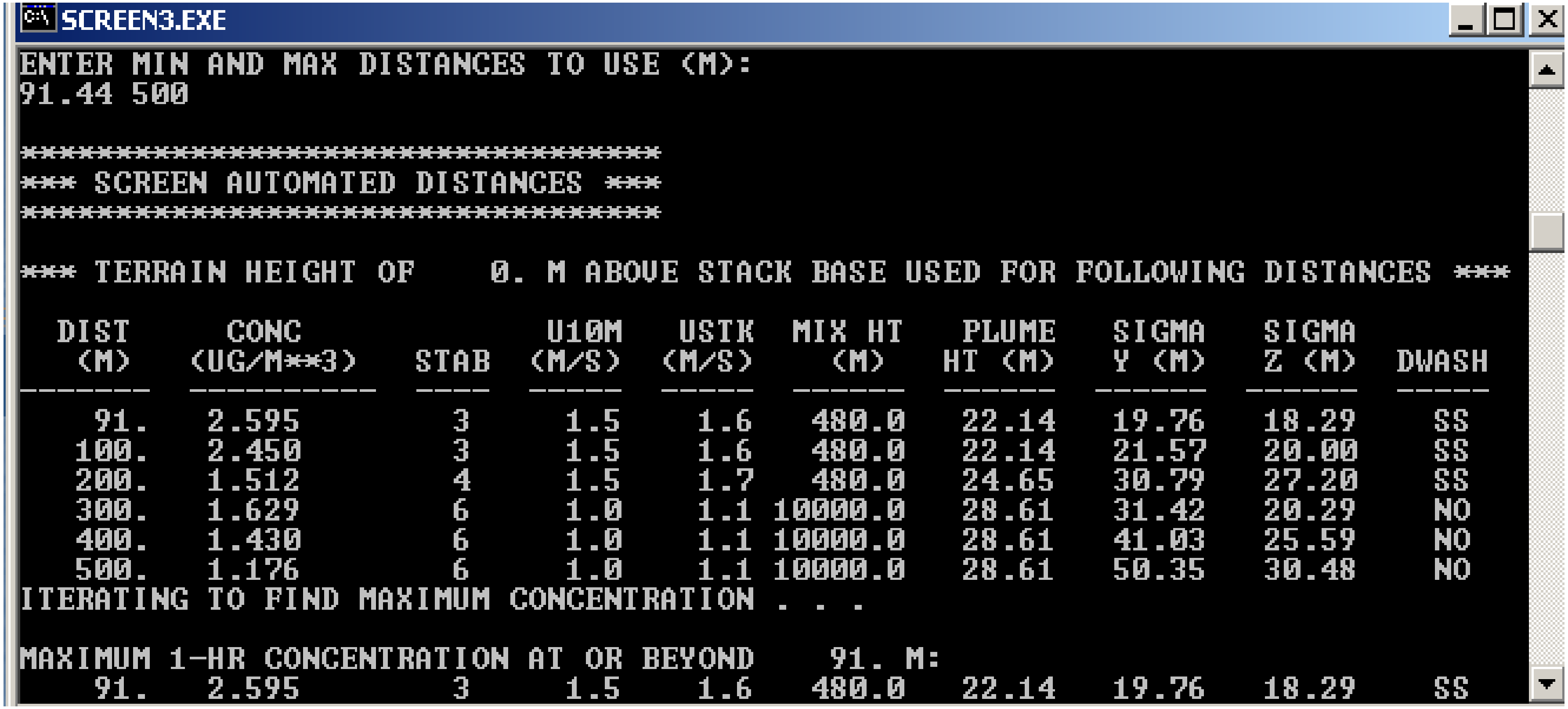
```
CONSIDER BUILDING DOWNWASH IN CALCS?  ENTER Y OR N:
y
ENTER BUILDING HEIGHT (M):
10.67
ENTER MINIMUM HORIZ BLDG DIMENSION (M):
30.48
ENTER MAXIMUM HORIZ BLDG DIMENSION (M):
30.48
USE COMPLEX TERRAIN SCREEN FOR TERRAIN ABOVE STACK HEIGHT?
ENTER Y OR N:
n
USE SIMPLE TERRAIN SCREEN WITH TERRAIN ABOVE STACK BASE?
ENTER Y OR N:
n
ENTER CHOICE OF METEOROLOGY;
1 - FULL METEOROLOGY (ALL STABILITIES & WIND SPEEDS)
2 - INPUT SINGLE STABILITY CLASS
3 - INPUT SINGLE STABILITY CLASS AND WIND SPEED
1
```

SCREEN Example – Stack emissions



```
ENTER MIN AND MAX DISTANCES TO USE (M):
91.44 500

**********************************
*** SCREEN AUTOMATED DISTANCES ***
**********************************

*** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

  DIST     CONC             U10M   USTK  MIX HT   PLUME   SIGMA   SIGMA
   (M)   (UG/M**3)   STAB  (M/S)  (M/S)    (M)   HT (M)   Y (M)   Z (M)  DWASH
-------  ----------  ----  -----  -----  ------  ------  ------  ------  -----
    91.   2.595        3     1.5    1.6   480.0   22.14   19.76   18.29    SS
   100.   2.450        3     1.5    1.6   480.0   22.14   21.57   20.00    SS
   200.   1.512        4     1.5    1.7   480.0   24.65   30.79   27.20    SS
   300.   1.629        6     1.0    1.1 10000.0   28.61   31.42   20.29    NO
   400.   1.430        6     1.0    1.1 10000.0   28.61   41.03   25.59    NO
   500.   1.176        6     1.0    1.1 10000.0   28.61   50.35   30.48    NO
ITERATING TO FIND MAXIMUM CONCENTRATION . . .

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND    91. M:
    91.   2.595        3     1.5    1.6   480.0   22.14   19.76   18.29    SS
```

SCREEN Example – Stack emissions



```
ENTER MIN AND MAX DISTANCES TO USE (M):
91.44 500

**********************************
*** SCREEN AUTOMATED DISTANCES ***
**********************************

*** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

  DIST     CONC             U10M   USTK  MIX HT   PLUME   SIGMA   SIGMA
   (M)   (UG/M**3)   STAB  (M/S)  (M/S)    (M)   HT (M)   Y (M)   Z (M)  DWASH
-------  ----------  ----  -----  -----  ------  ------  ------  ------  -----
    91.   2.595        3     1.5    1.6   480.0   22.14   19.76   18.29    SS
   100.   2.450        3     1.5    1.6   480.0   22.14   21.57   20.00    SS
   200.   1.512        4     1.5    1.7   480.0   24.65   30.79   27.20    SS
   300.   1.629        6     1.0    1.1 10000.0   28.61   31.42   20.29    NO
   400.   1.430        6     1.0    1.1 10000.0   28.61   41.03   25.59    NO
   500.   1.176        6     1.0    1.1 10000.0   28.61   50.35   30.48    NO
ITERATING TO FIND MAXIMUM CONCENTRATION . . .

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND    91. M:
    91.   2.595        3     1.5    1.6   480.0   22.14   19.76   18.29    SS
```

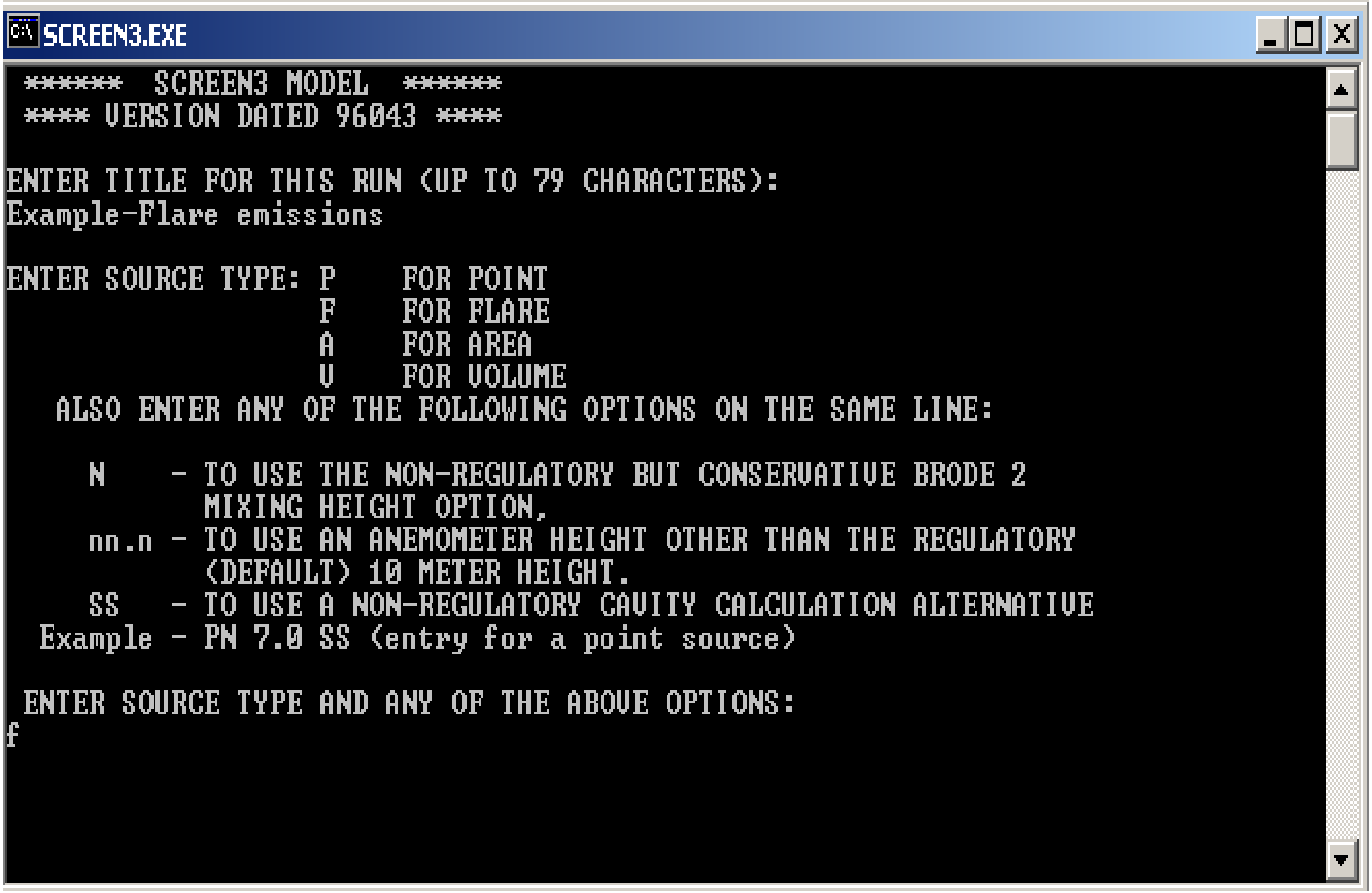
The most conservative scenario gives a maximum 1-hr concentration of 2.595 ug/m³ at a distance of 91 meters

Flare Emissions Elevated point source

Screen Model for Flare Source

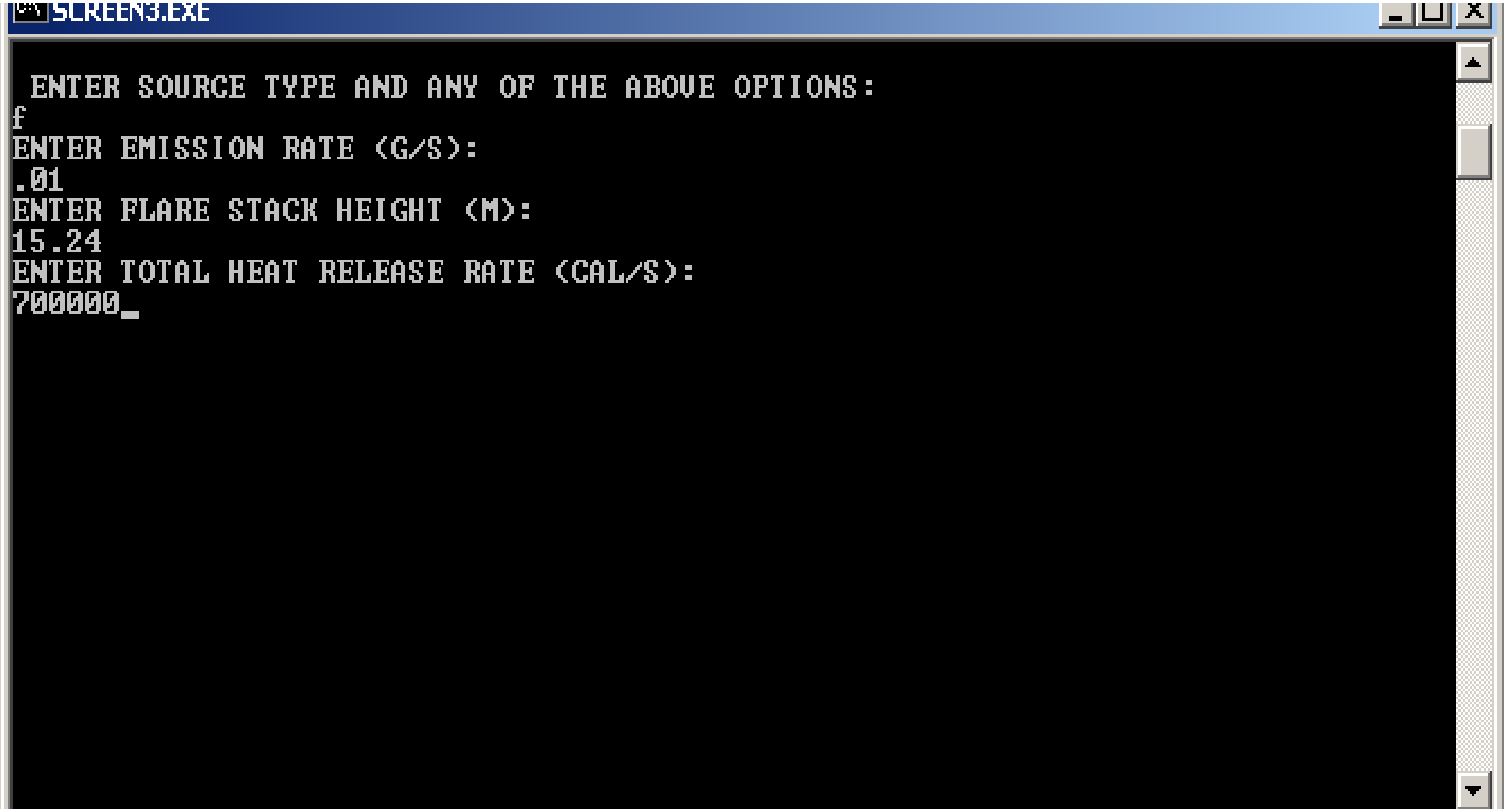
- **Emission Rate**
- **Flare Stack Height**
- **Total Heat Release Rate**
- **Shortest Distance to property line**
- **Influential Building Dimensions**

SCREEN Example – Flare emissions



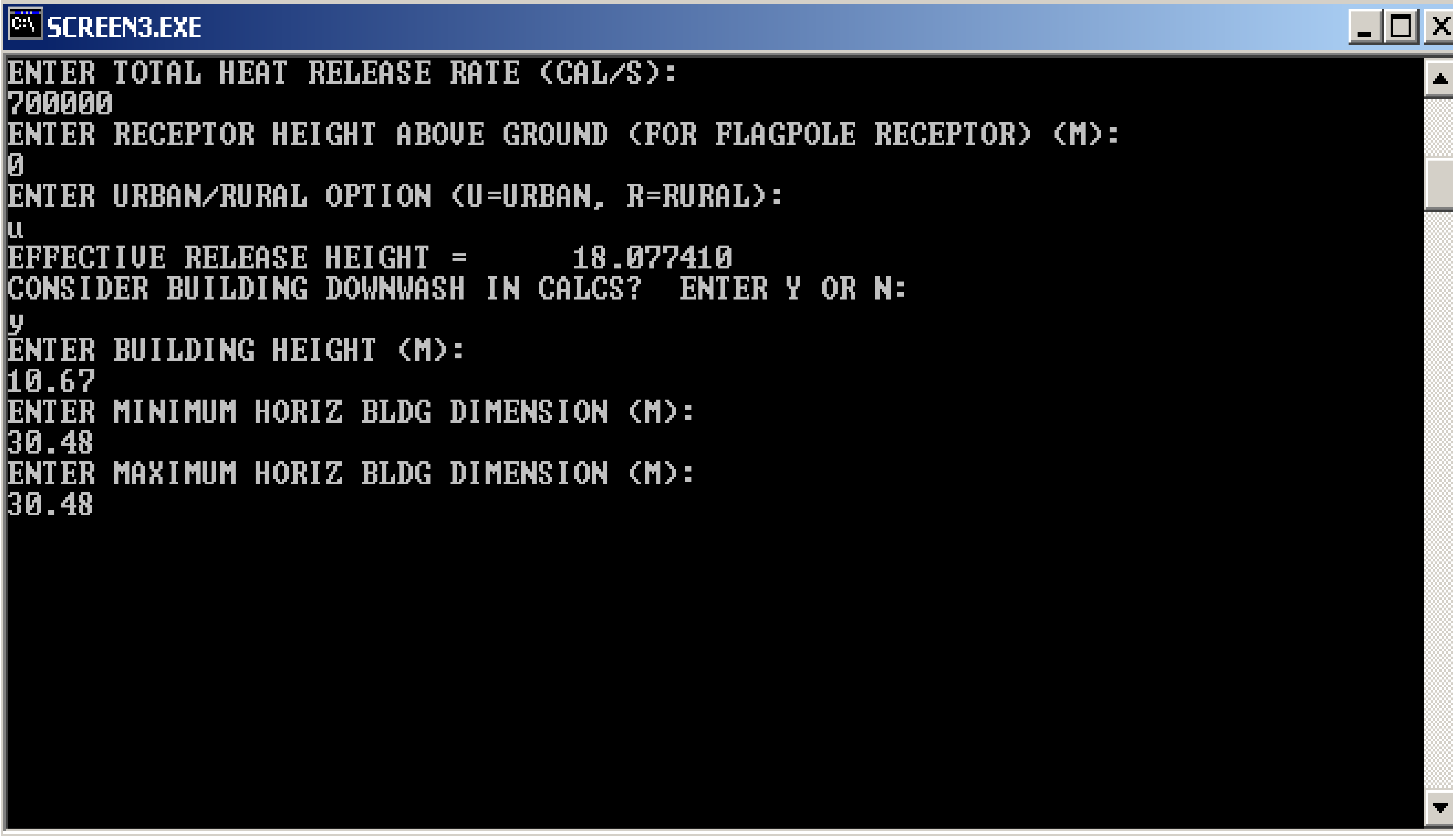
```
 *******  SCREEN3 MODEL  *******
 ***** VERSION DATED 96043 *****

ENTER TITLE FOR THIS RUN (UP TO 79 CHARACTERS):
Example-Flare emissions

ENTER SOURCE TYPE: P    FOR POINT
                   F    FOR FLARE
                   A    FOR AREA
                   V    FOR VOLUME
   ALSO ENTER ANY OF THE FOLLOWING OPTIONS ON THE SAME LINE:

     N    - TO USE THE NON-REGULATORY BUT CONSERVATIVE BRODE 2
            MIXING HEIGHT OPTION.
     nn.n - TO USE AN ANEMOMETER HEIGHT OTHER THAN THE REGULATORY
            (DEFAULT) 10 METER HEIGHT.
     SS   - TO USE A NON-REGULATORY CAVITY CALCULATION ALTERNATIVE
  Example - PN 7.0 SS (entry for a point source)

 ENTER SOURCE TYPE AND ANY OF THE ABOVE OPTIONS:
f
```

SCREEN Example – Flare emissions



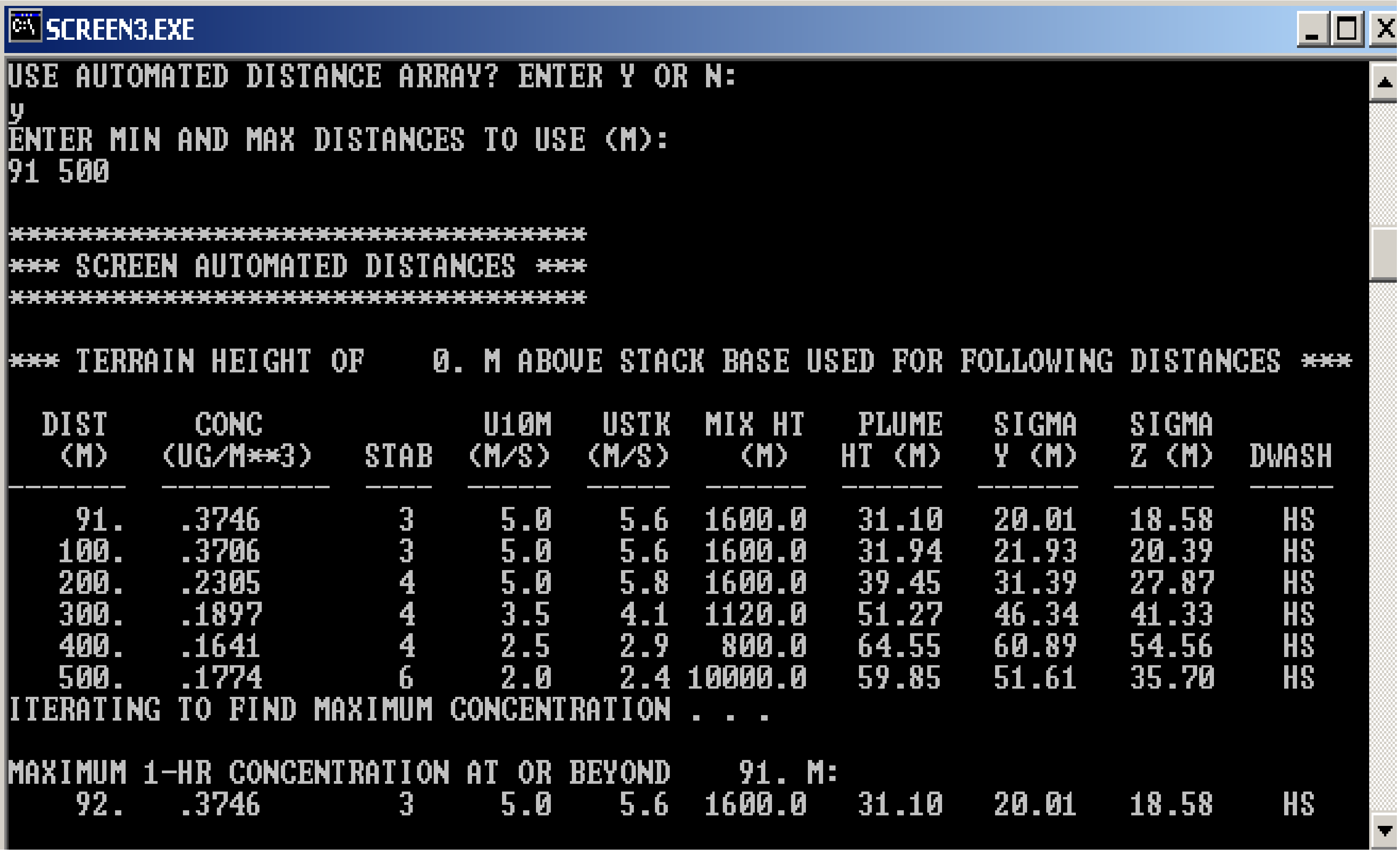
```
 ENTER SOURCE TYPE AND ANY OF THE ABOVE OPTIONS:
f
ENTER EMISSION RATE (G/S):
.01
ENTER FLARE STACK HEIGHT (M):
15.24
ENTER TOTAL HEAT RELEASE RATE (CAL/S):
700000_
```

SCREEN Example – Flare emissions



```
ENTER TOTAL HEAT RELEASE RATE (CAL/S):
700000
ENTER RECEPTOR HEIGHT ABOVE GROUND (FOR FLAGPOLE RECEPTOR) (M):
0
ENTER URBAN/RURAL OPTION (U=URBAN, R=RURAL):
u
EFFECTIVE RELEASE HEIGHT =       18.077410
CONSIDER BUILDING DOWNWASH IN CALCS?  ENTER Y OR N:
y
ENTER BUILDING HEIGHT (M):
10.67
ENTER MINIMUM HORIZ BLDG DIMENSION (M):
30.48
ENTER MAXIMUM HORIZ BLDG DIMENSION (M):
30.48
```

SCREEN Example – Flare emissions

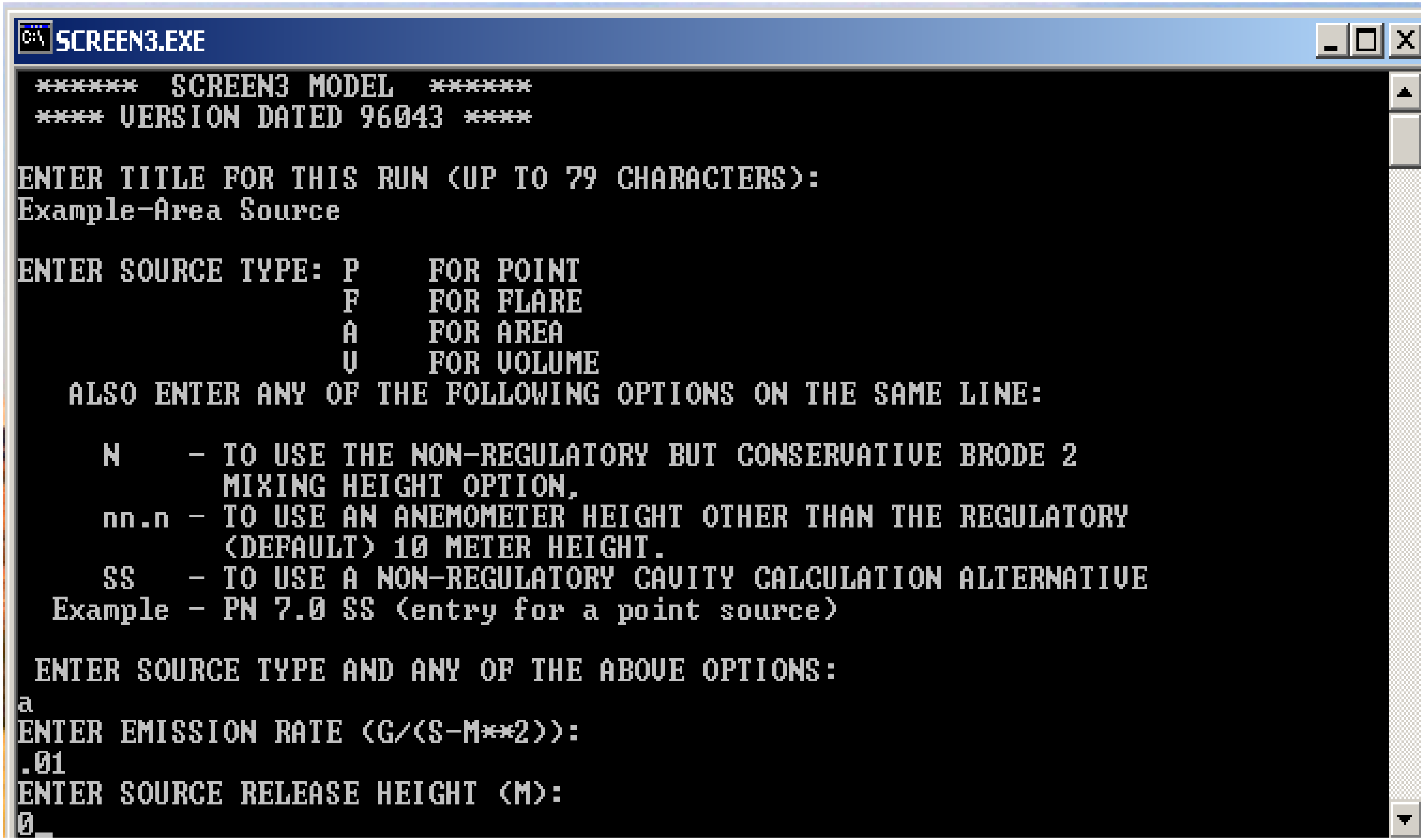


```
USE AUTOMATED DISTANCE ARRAY? ENTER Y OR N:
y
ENTER MIN AND MAX DISTANCES TO USE (M):
91 500

**********************************
*** SCREEN AUTOMATED DISTANCES ***
**********************************

*** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

  DIST      CONC              U10M   USTK  MIX HT   PLUME   SIGMA   SIGMA
   (M)    (UG/M**3)    STAB   (M/S)  (M/S)   (M)    HT (M)   Y (M)   Z (M)  DWASH
-------  ----------    ----   -----  -----  ------  ------  ------  ------  -----
    91.    .3746         3     5.0    5.6  1600.0   31.10   20.01   18.58    HS
   100.    .3706         3     5.0    5.6  1600.0   31.94   21.93   20.39    HS
   200.    .2305         4     5.0    5.8  1600.0   39.45   31.39   27.87    HS
   300.    .1897         4     3.5    4.1  1120.0   51.27   46.34   41.33    HS
   400.    .1641         4     2.5    2.9   800.0   64.55   60.89   54.56    HS
   500.    .1774         6     2.0    2.4 10000.0   59.85   51.61   35.70    HS
ITERATING TO FIND MAXIMUM CONCENTRATION . . .

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND    91. M:
    92.    .3746         3     5.0    5.6  1600.0   31.10   20.01   18.58    HS
```

Screen Model for Area Source

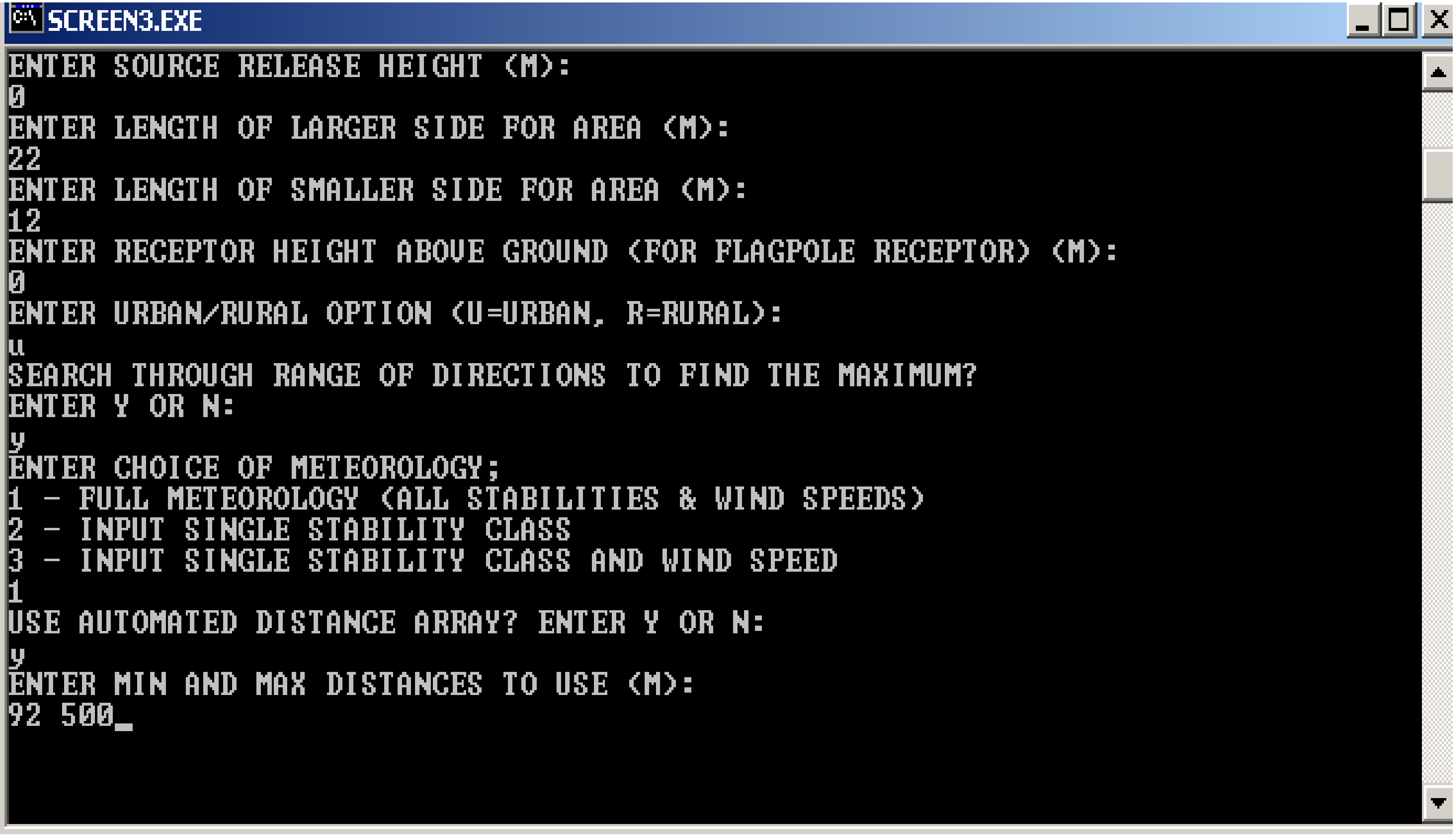
- **Emission Rate**
- **Source Release Height**
- **Larger Side Length of Rectangular Area**
- **Smaller Side Length of Rectangular Area**
- **Shortest Distance to property line**

SCREEN Example – Area Source



```
 *******  SCREEN3 MODEL  *******
 **** VERSION DATED 96043 ****

ENTER TITLE FOR THIS RUN (UP TO 79 CHARACTERS):
Example-Area Source

ENTER SOURCE TYPE: P    FOR POINT
                   F    FOR FLARE
                   A    FOR AREA
                   V    FOR VOLUME
   ALSO ENTER ANY OF THE FOLLOWING OPTIONS ON THE SAME LINE:

     N    - TO USE THE NON-REGULATORY BUT CONSERVATIVE BRODE 2
            MIXING HEIGHT OPTION.
     nn.n - TO USE AN ANEMOMETER HEIGHT OTHER THAN THE REGULATORY
            (DEFAULT) 10 METER HEIGHT.
     SS   - TO USE A NON-REGULATORY CAVITY CALCULATION ALTERNATIVE
  Example - PN 7.0 SS (entry for a point source)

 ENTER SOURCE TYPE AND ANY OF THE ABOVE OPTIONS:
a
ENTER EMISSION RATE (G/(S-M**2)):
.01
ENTER SOURCE RELEASE HEIGHT (M):
0
```

SCREEN Example – Flare emissions



```
ENTER SOURCE RELEASE HEIGHT (M):
0
ENTER LENGTH OF LARGER SIDE FOR AREA (M):
22
ENTER LENGTH OF SMALLER SIDE FOR AREA (M):
12
ENTER RECEPTOR HEIGHT ABOVE GROUND (FOR FLAGPOLE RECEPTOR) (M):
0
ENTER URBAN/RURAL OPTION (U=URBAN, R=RURAL):
u
SEARCH THROUGH RANGE OF DIRECTIONS TO FIND THE MAXIMUM?
ENTER Y OR N:
y
ENTER CHOICE OF METEOROLOGY;
1 - FULL METEOROLOGY (ALL STABILITIES & WIND SPEEDS)
2 - INPUT SINGLE STABILITY CLASS
3 - INPUT SINGLE STABILITY CLASS AND WIND SPEED
1
USE AUTOMATED DISTANCE ARRAY? ENTER Y OR N:
y
ENTER MIN AND MAX DISTANCES TO USE (M):
92 500_
```

Screen Model for Volume Source

- Emission Rate
- Source Release Height
- Initial Lateral Dimension
- Initial Vertical Dimension
- Shortest Distance to Property Line

Volume Source

- **Source Release Height is the center of the Volume Source:**

  If the Source is from a building, the release height is set equal to one half of the building height.
- **Volume sources are modeled as a square in Screen3. If the source is not square, the width should be set to the minimum length.**

Volume Source
Initial Lateral Dimension (σ_{y0})

Single Volume Source **σ_{y0} = length of side divided by 4.3**
Line Source composed of several volume sources **σ_{y0} = length of side divided by 2.15**
Line Source composed of separated volume sources **σ_{y0} = center to center distance divided by 2.15**

Volume Source
Initial Vertical Dimension (σ_{z0})

Surface-Based Source

σ_{z0} = vertical dimension of source divided by 2.15

Elevated Source on or adjacent to a building

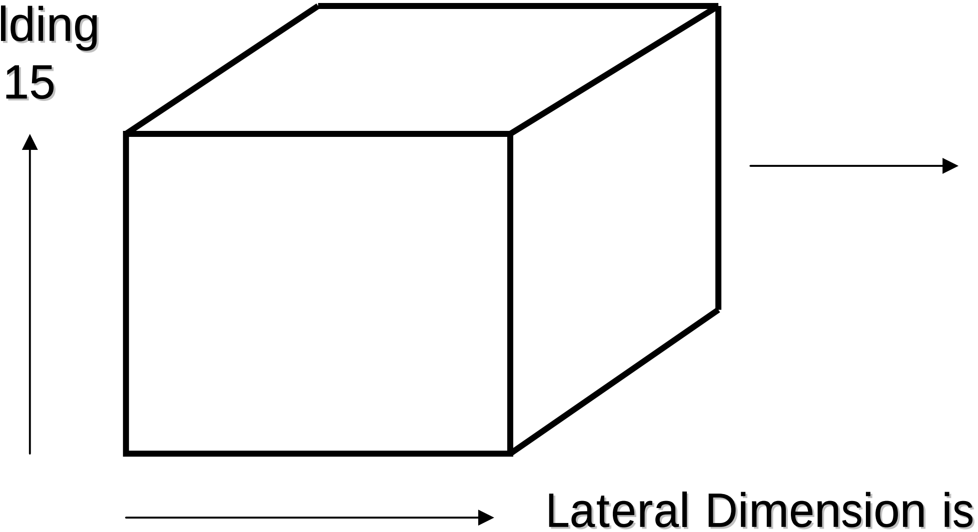
σ_{z0} = building height divided by 2.15

Elevated Source not on or adjacent to a building

σ_{z0} = vertical dimension of source divided by 4.3

Example – Volume Source

Volume Source from a Building

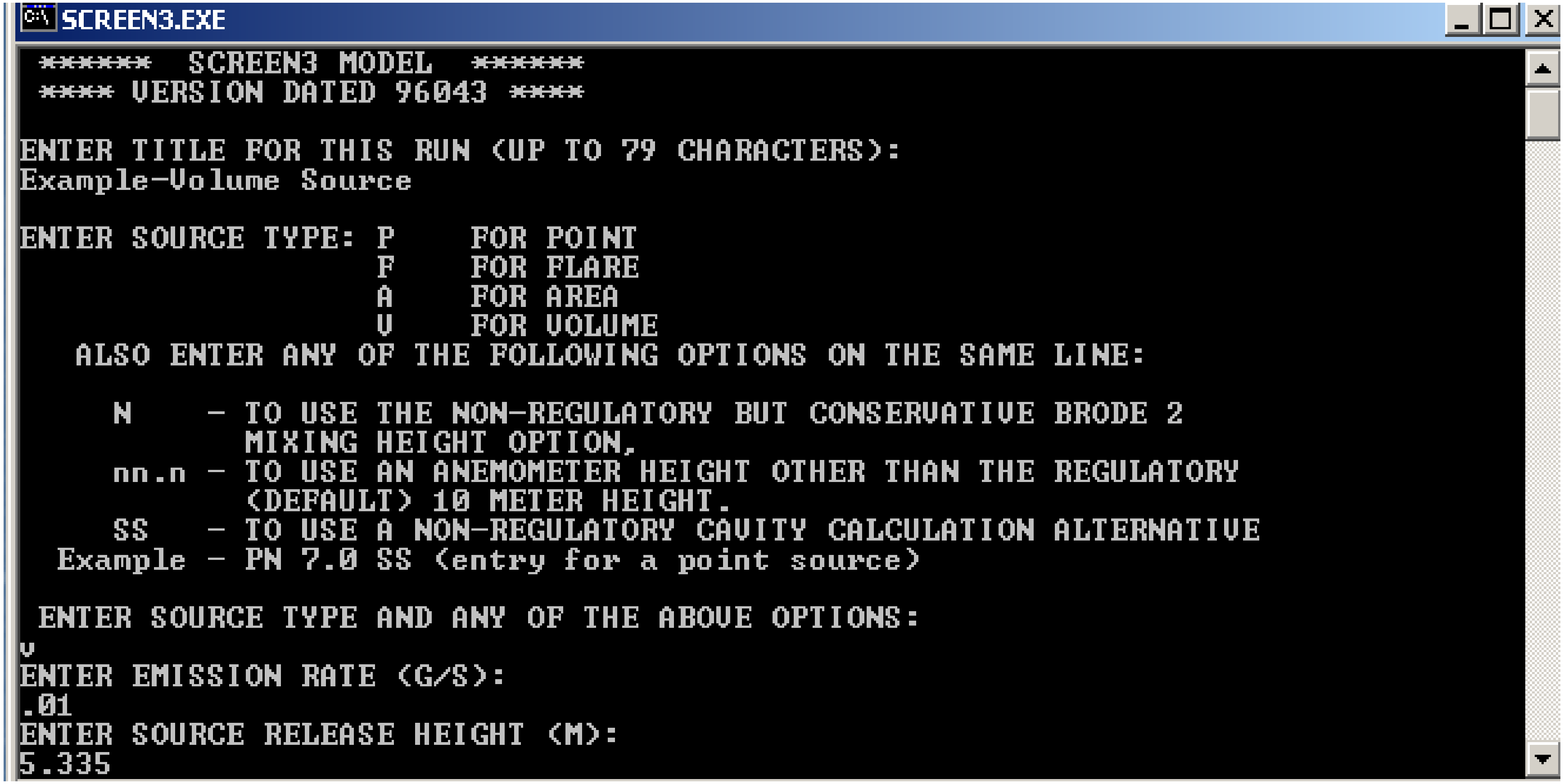


Vertical Dimension is height of building divided by 2.15

Release Height is ½ of Building Height

Lateral Dimension is minimum length of building divided by 4.3

SCREEN Example – Volume Source



```
 *******  SCREEN3 MODEL  *******
 ***** VERSION DATED 96043 *****

ENTER TITLE FOR THIS RUN (UP TO 79 CHARACTERS):
Example-Volume Source

ENTER SOURCE TYPE: P    FOR POINT
                   F    FOR FLARE
                   A    FOR AREA
                   V    FOR VOLUME
   ALSO ENTER ANY OF THE FOLLOWING OPTIONS ON THE SAME LINE:

     N    - TO USE THE NON-REGULATORY BUT CONSERVATIVE BRODE 2
            MIXING HEIGHT OPTION.
     nn.n - TO USE AN ANEMOMETER HEIGHT OTHER THAN THE REGULATORY
            (DEFAULT) 10 METER HEIGHT.
     SS   - TO USE A NON-REGULATORY CAVITY CALCULATION ALTERNATIVE
  Example - PN 7.0 SS (entry for a point source)

 ENTER SOURCE TYPE AND ANY OF THE ABOVE OPTIONS:
v
ENTER EMISSION RATE (G/S):
.01
ENTER SOURCE RELEASE HEIGHT (M):
5.335
```

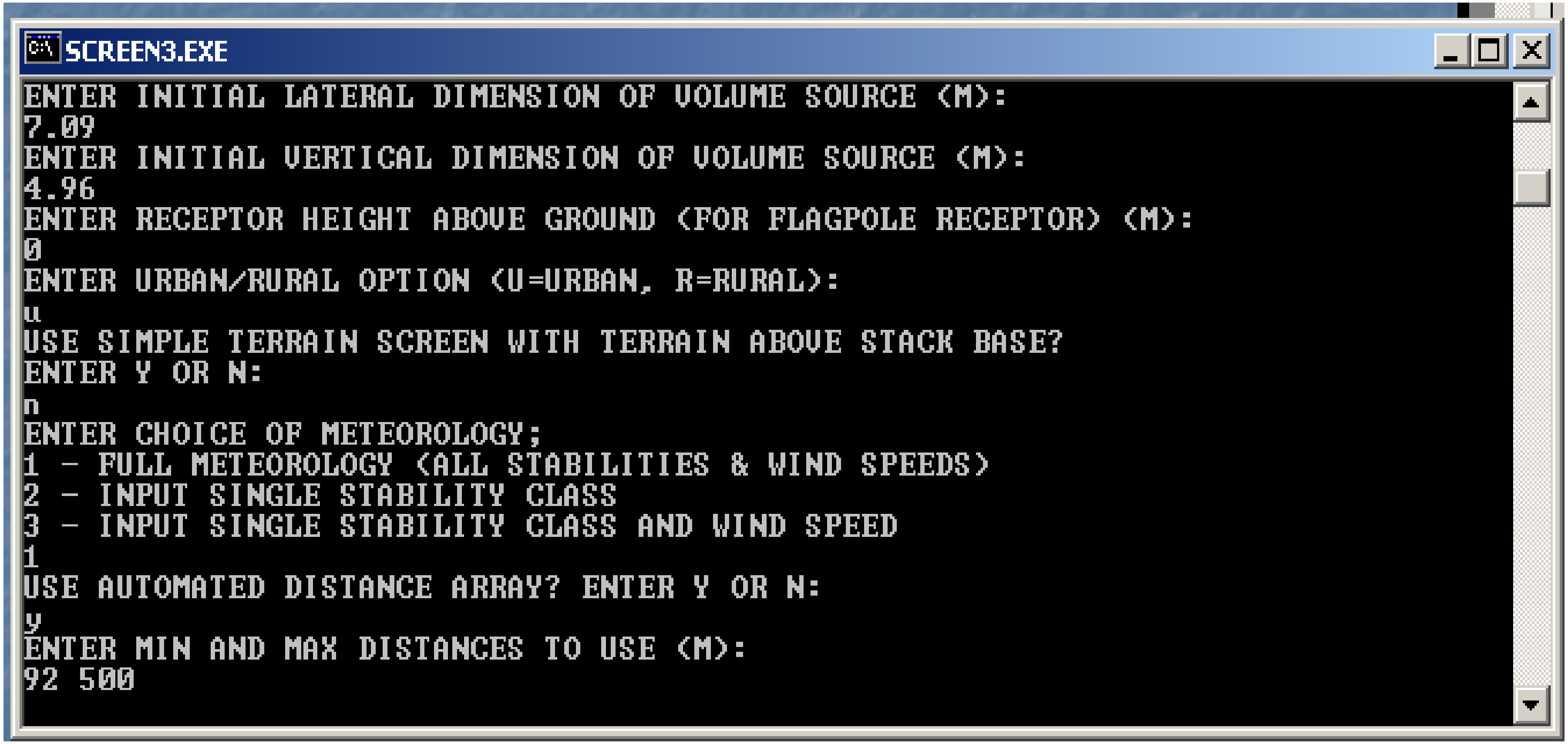
SCREEN Example – Volume Source

```
ENTER INITIAL LATERAL DIMENSION OF VOLUME SOURCE (M):
7.09
ENTER INITIAL VERTICAL DIMENSION OF VOLUME SOURCE (M):
4.96
```

Initial Lateral Dimension obtained by taking building length of 30.48m divided by 4.3

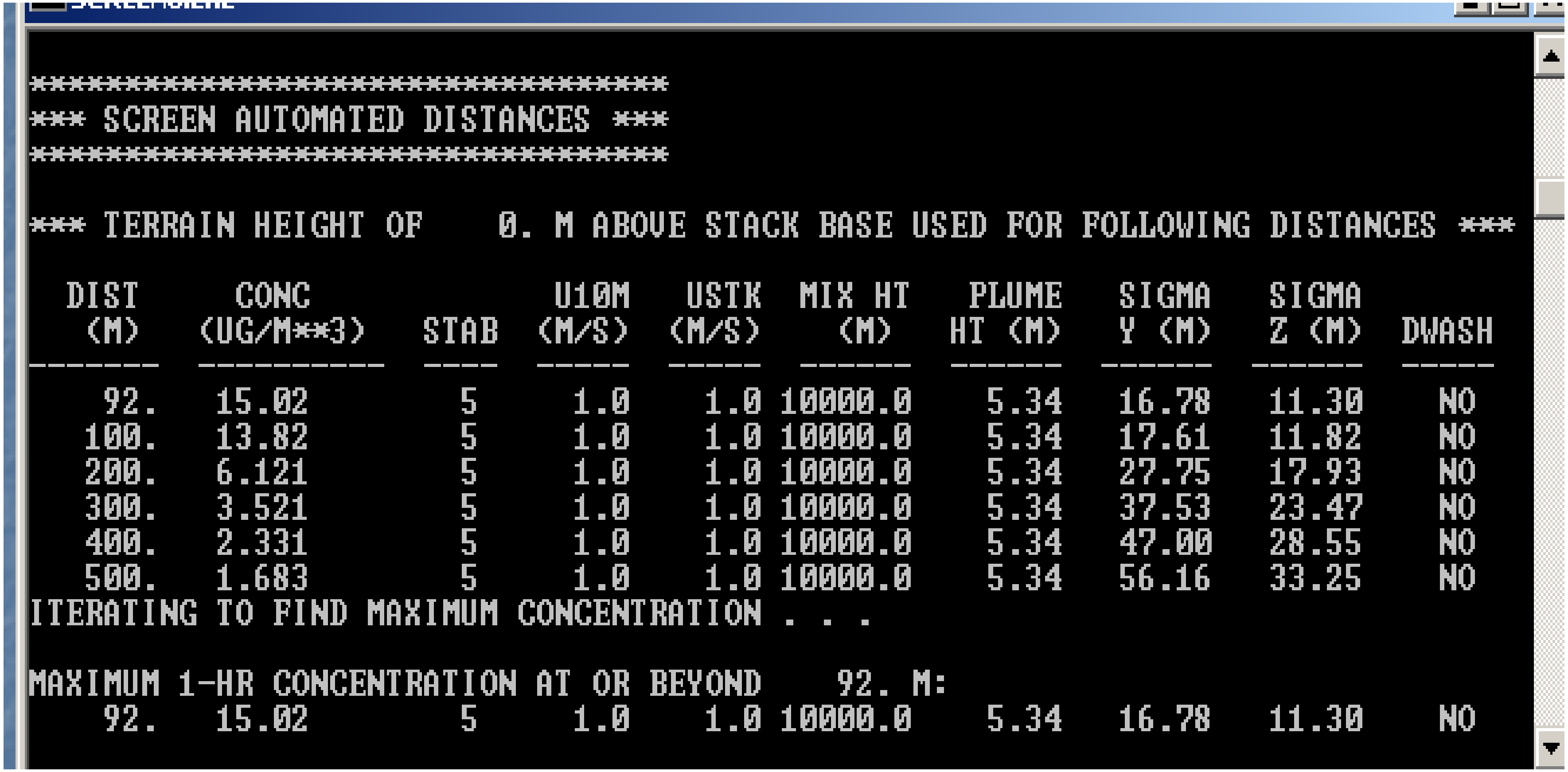
Using a building as the volume source, so the initial vertical dimension is the height of the building divided by 2.15

SCREEN Example – Volume Source



```
ENTER INITIAL LATERAL DIMENSION OF VOLUME SOURCE (M):
7.09
ENTER INITIAL VERTICAL DIMENSION OF VOLUME SOURCE (M):
4.96
ENTER RECEPTOR HEIGHT ABOVE GROUND (FOR FLAGPOLE RECEPTOR) (M):
0
ENTER URBAN/RURAL OPTION (U=URBAN, R=RURAL):
u
USE SIMPLE TERRAIN SCREEN WITH TERRAIN ABOVE STACK BASE?
ENTER Y OR N:
n
ENTER CHOICE OF METEOROLOGY;
1 - FULL METEOROLOGY (ALL STABILITIES & WIND SPEEDS)
2 - INPUT SINGLE STABILITY CLASS
3 - INPUT SINGLE STABILITY CLASS AND WIND SPEED
1
USE AUTOMATED DISTANCE ARRAY? ENTER Y OR N:
y
ENTER MIN AND MAX DISTANCES TO USE (M):
92 500
```

SCREEN Example – Volume Source



```
**********************************
*** SCREEN AUTOMATED DISTANCES ***
**********************************

*** TERRAIN HEIGHT OF    0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

   DIST     CONC               U10M   USTK  MIX HT   PLUME   SIGMA   SIGMA
    (M)   (UG/M**3)    STAB   (M/S)  (M/S)    (M)    HT (M)   Y (M)   Z (M)  DWASH
 -------  ----------   ----   -----  -----  ------   ------  ------  ------  -----
     92.    15.02        5     1.0    1.0 10000.0    5.34    16.78   11.30    NO
    100.    13.82        5     1.0    1.0 10000.0    5.34    17.61   11.82    NO
    200.    6.121        5     1.0    1.0 10000.0    5.34    27.75   17.93    NO
    300.    3.521        5     1.0    1.0 10000.0    5.34    37.53   23.47    NO
    400.    2.331        5     1.0    1.0 10000.0    5.34    47.00   28.55    NO
    500.    1.683        5     1.0    1.0 10000.0    5.34    56.16   33.25    NO
ITERATING TO FIND MAXIMUM CONCENTRATION . . .

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND    92. M:
     92.    15.02        5     1.0    1.0 10000.0    5.34    16.78   11.30    NO
```

Screen model results

- Screen model results are all maximum 1-hr concentrations (except for complex terrain and if SCREEN is run inside of TSCREEN can obtain concentrations in other averaging times).