**History of significant air pollution events**

- **many of the worst air pollution episodes occurred in the last two centuries in London**
  - **key ingredients - calm winds, fog, smoke from coal burning**
  - **1873 - 700 deaths**
  - **1911- 1150 deaths**
  - **1952 - over 4000 deaths**
    - **this last event prompted the parliament to pass a Clean Air Act in 1956**
- **other events around the world:**
  - **1930 - Meuse Valley**
    - **pollution became trapped in a narrow valley - 600 people became ill, 63 were killed.**
- In the U.S., air quality degraded quickly shortly after the industrial revolution
- again, the problem was coal burning in the central and mid-western U.S.
  - 1948 - Donora, PA in the Monongahela River Valley
  - five-day episode - 1000's became ill, 20 were killed
- 1960s - NYC experience several dangerous episodes
- 1960s-70s - Los Angeles - increase in industry and automobile usage led to many pollution episodes
- The above events led to passing the **Clean Air Act of 1970** (updated in 1977 and again in 1990)
  - empowered the federal government to set emission standards that each state would have to meet

Even the most remote areas are affected by air pollution..... like the grand canyon....

**Air Pollution in the Grand Canyon**

The Grand Canyon on a good day.......

The Grand Canyon on a bad day......

**Sources of Pollutants**

- **Air pollutants** - airborne substances that occur in concentrations high enough to threaten the health of people and animals, to harm vegetation and structures, or to toxify a given environment (*from Ahrens*).

**Natural Sources:**

| | |
|---|---|
| wind picking up dust | suspended particles |
| volcanic eruptions | dust, ash, gases like $SO_2$, $CO_2$ |
| forest fires | smoke, ash, unburned hydrocarbons, $CO_2$ |
| Vegetation | VOCs, pollen |
| Ocean Waves | salt particles |

**Anthropogenic Sources:**

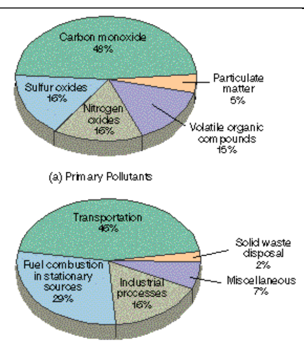
| | |
|---|---|
| industry<br>• paper mills<br>• power plants<br>• refineries<br>• manufacturing | particulate matter, SOx, NOx, ash |
| personal:<br>• transportation<br>• home furnaces<br>• fireplaces | CO, NOx, VOCs, particulate matter |

| | |
|---|---|
| • open burning of refuse | |
| forest fires | smoke, ash, unburned hydrocarbons, $CO_2$ |

## Primary Pollutants

injected into the atmosphere directly..... examples include:

- carbon monoxide (CO)
  - odorless, colorless, poisonous gas
  - created by incomplete combustion (especially bad with older cars)
  - generates headaches, drowsiness, fatigue, can result in death
- oxides of nitrogen ($NO_x$, NO)
  - NO - nitric oxide
  - emitted directly by autos, industry
- sulfur oxides ($SO_x$)
  - $SO_2$ - sulfur dioxide
  - produced largely through coal burning
  - responsible for acid rain problem
- volatile organic compounds (VOCs)
  - highly reactive organic compounds
  - release through incomplete combustion and industrial sources
- particulate matter (dust, ash, salt particles)
  - bad for your lungs

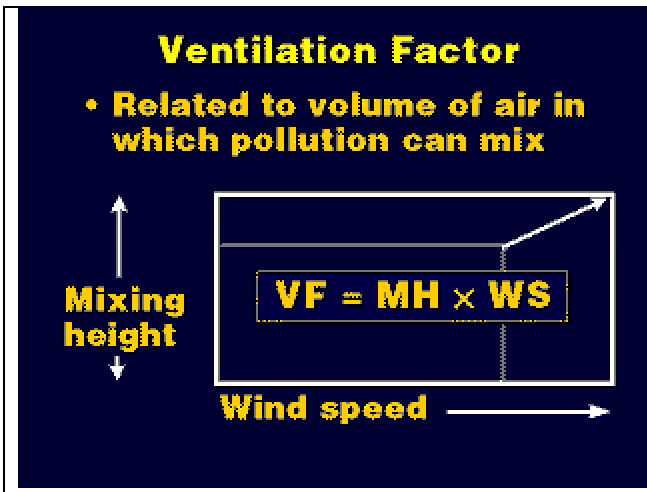


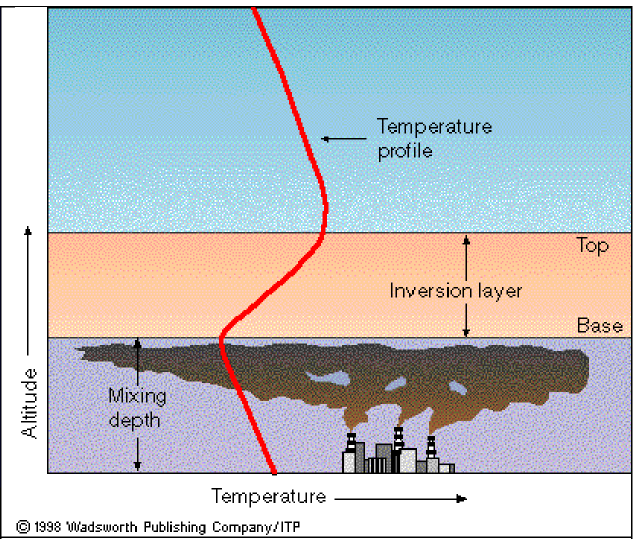

(a) Primary Pollutants

(b) Primary Sources

## Air Pollution Dispersion

- Air pollution dispersion is often studied with simple models called box models. How is the box defined for the Los Angles area????
- Map of the LA Basin
- Here is a 3D map of the LA Basin
- The ventilation factor gives us a way of relating the pollution concentration to the parameters that control dispersion of the pollution in the local environment.
- Basically, increasing either the mixing height or the wind speed increases the effective volume in which pollutants are allowed to mix.
- The larger the volume, the lower the pollution concentration



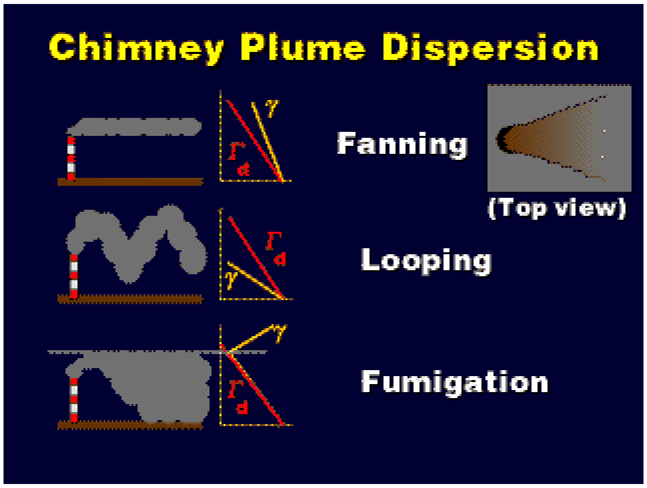




### Chimney Plume Dispersion

In the stable atmosphere case (producing a fanning plume), there is horizontal dispersion at a right angle to the wind due to turbulence and diffusion. In the vertical, dispersion is suppressed by the stability of the atmosphere, so pollution does not spread toward the ground. This results in very low pollution concentrations at the ground.

In unstable air, the plume will whip up and down as the atmosphere mixes around (whenever an air parcel goes up, there must be air going down someplace else to maintain continuity, and the plume follows these air currents). This gives the plume the appearance that it is looping around.

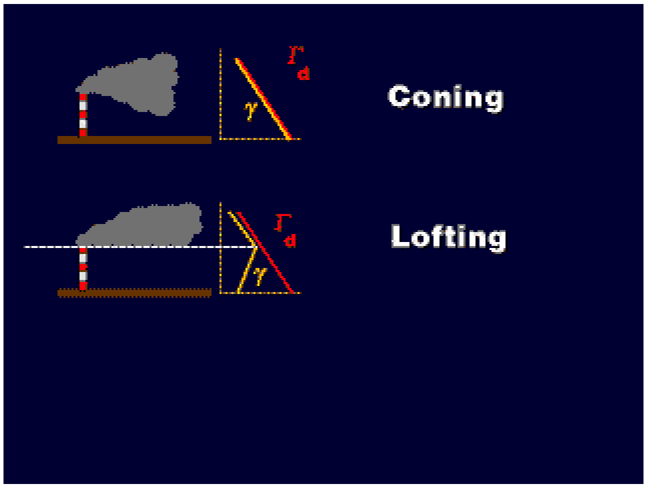
An inversion aloft will trap pollutants underneath it, since the stable inversion prevents vertical dispersion. Pollution released underneath the inversion layer will fumigate the mixed layer. Note that if the smokestack was high enough to release the pollution within the inversion layer, the plume would fan because the plume occurs within stable air.




## More on Chimney Plume Dispersion

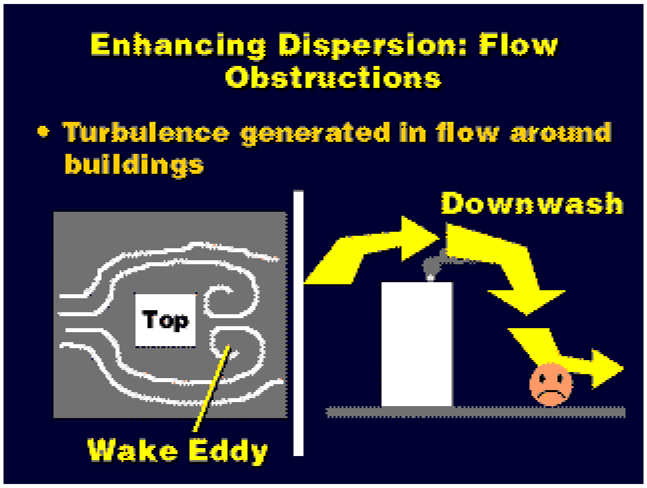
In the neutral atmosphere case, the horizontal dispersion at a right angle to the wind is due to turbulence and diffusion, which occurs at the same rate as the vertical dispersion, which is not being opposed nor encouraged by the stability (or lack of it) in the atmosphere. So, the plume spreads equally in the vertical and horizontal as it propagates downstream, forming a coning plume.

In the lofting case, pollution dilutes upward. This produces much lower pollution concentrations at the ground at a distance downstream than the straight stable case (fanning plume), because molecular diffusion and some turbulence allow smoke to reach the ground eventually, and the fanning plume does not have the upward dispersion that the lofting plume has.




## Enhancing Dispersion: Flow Obstructions

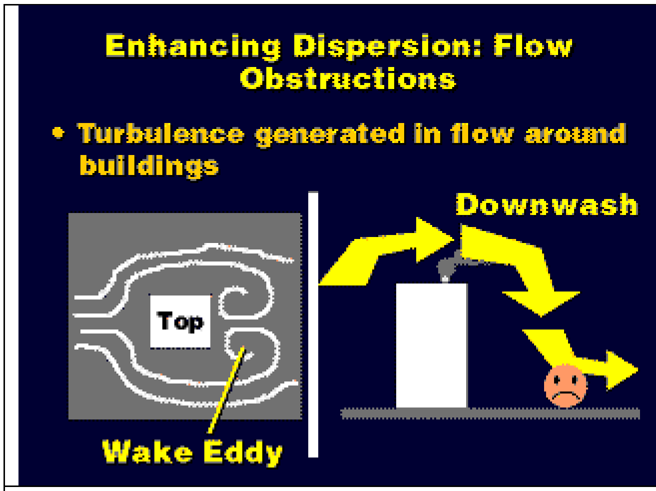
- The turbulent wake behind a building helps mix pollutants to the ground that might not have been there normally, in a stable atmosphere.
- Downwash is especially bad when there are pollution sources on the top of the building.
- It is important to get the pollution emitted high enough above the building so that it does not get caught in the downwash and get carried down to the ground

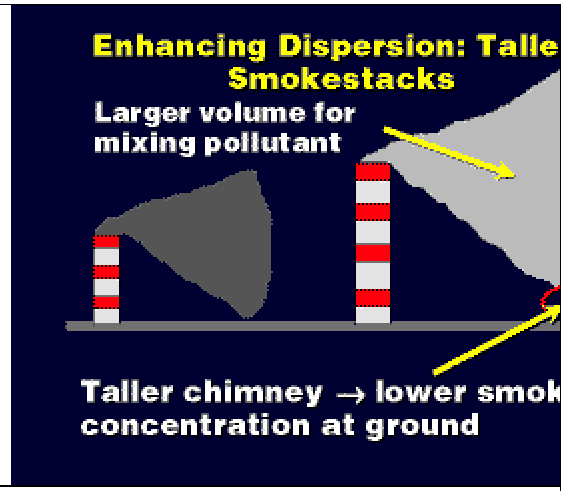


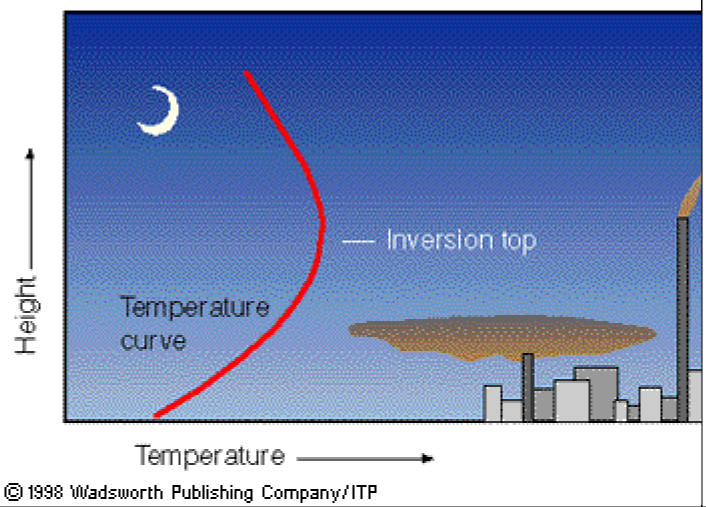

## Enhancing Dispersion with Smokestacks

Pollution emitted from a taller stack has to travel a longer distance to get to the ground, so it will become more dilute.

Also, it may be possible for taller stacks to get above low-level inversions....

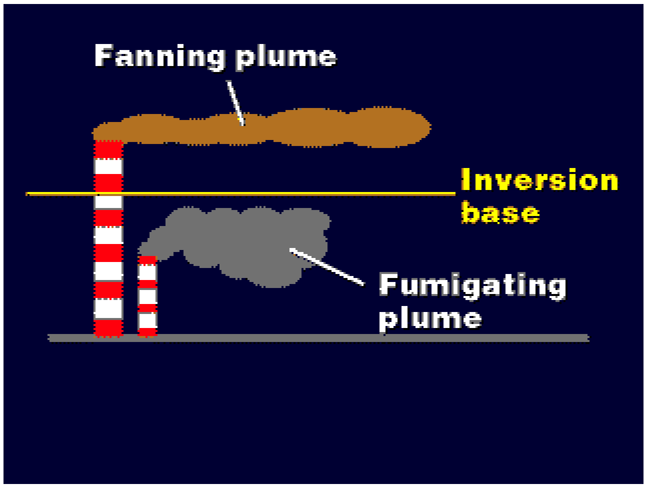


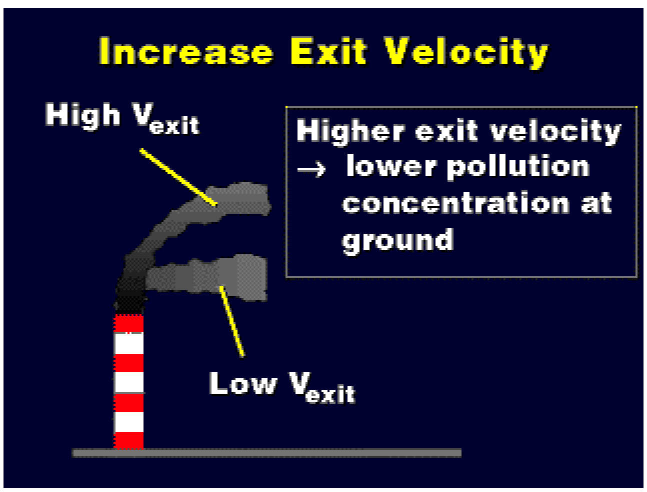

## Tall and Short Smoke Stacks

- With a tall enough smokestack, pollution is emitted within the inversion aloft, forming a fanning plume that does not pollute the area near the smokestack. If it's not tall enough, it will fumigate the countryside.
- Switching the layers so that the inversion is at the ground, we need the smokestack tall enough to be above the ground inversion, so that a lofting plume is formed. Architects will need to know the average depth of the nocturnal radiation inversion in order to know how tall to build the smokestack.



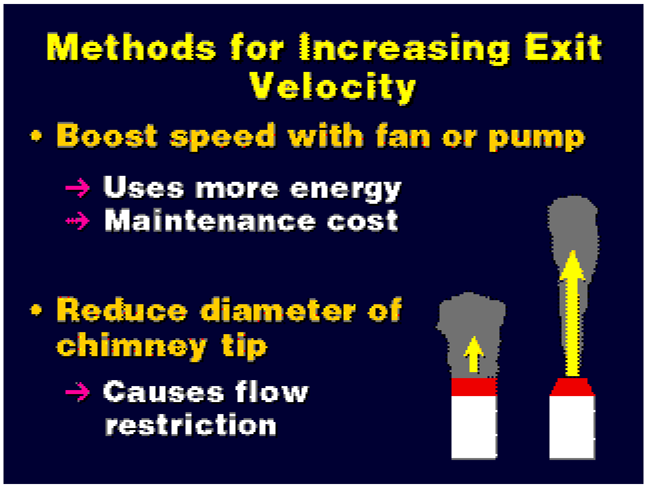

## Exit Velocity

The faster the smoke gushes out, the more momentum it has, and the higher it will fly before it levels out and disperses toward the ground.



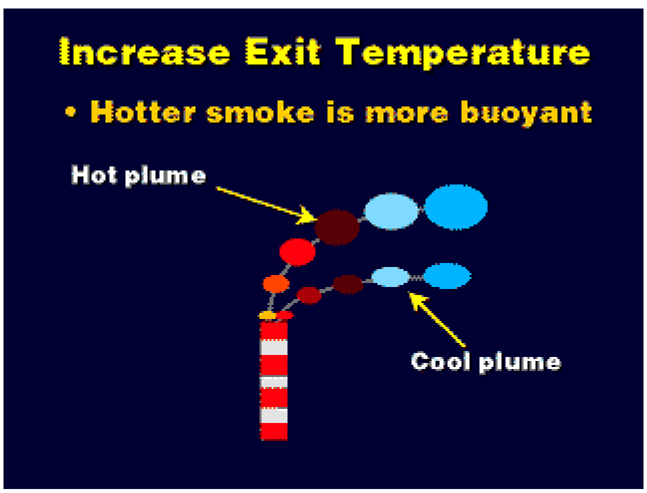

## Methods for Increasing Exit Velocity

- Narrowing the smokestack's opening forces the smoke out as a faster streaming, narrower jet.
- Backpressure from the smaller opening may reduce the efficiency of the flow of smoke out of the chimney, however, partially offsetting the increasing in plume momentum.

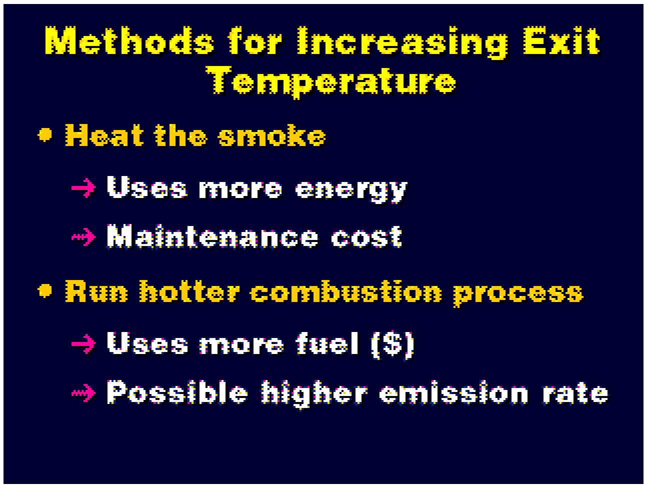



Exit Temperature

- The higher the temperature, the greater the positive buoyancy in smoke streaming out of the smokestack.
- The smoke has to rise higher before it has adiabatically cooled to a neutral buoyancy temperature




## Methods for Increasing Exit Temperature




## Air pollution trends

- notice the general increase in concentrations prior to 1970
- after 1970, notice the general decline in pollution concentrations
- in 1970, the Clean Air Act of 1970 was passed
- the Clean Air Act was updated in 1990
- clean air standards are established by the EPA, though many states have their own standards that are more strict than the federal standards.

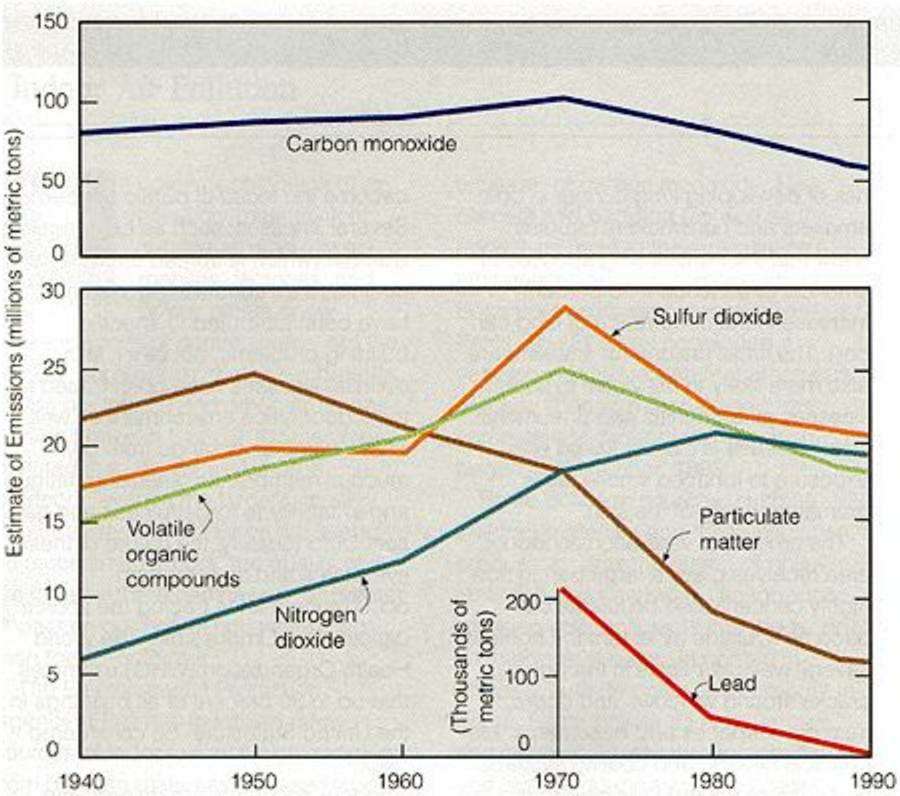
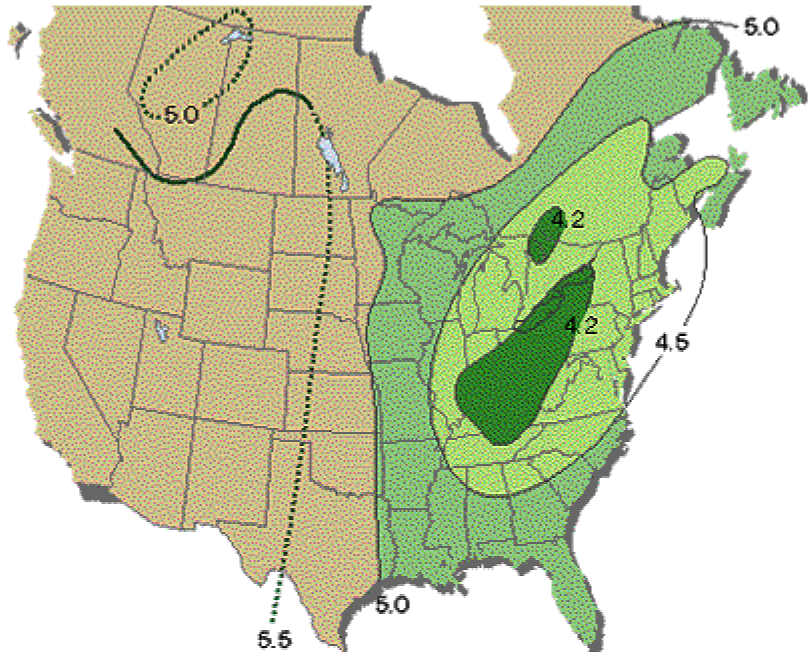



*image adopted from Meteorology Today by C. Donald Ahrens � 1994 West Publishing Company*

## Acid Rain and deposition

- within clouds (including fog) sulfur dioxide ($SO_2$) and oxides of nitrogen (NOx) can form acidic particles when they react with water:
  - $SO_2 + H_2O$ --> $H_2SO_4$ (sulfuric acid)
  - $NO_x + H_2$) --> $HNO_3$ (nitric acid)
- problem is worse downstream of the source **-->**
- affects:
  - trees
  - lakes
  - architecture
- it's a world-wide problem:
  - Germany
  - China
  - Italy
  - Canada






## Ozone in the Stratosphere

- Ozone in the boundary layer causes adverse health effects
- Ozone in the stratosphere, however, in necessary for our survival
    - absorbs UV radiation before it reaches the ground
    - maximum concentrations of about 12 ppm are at about 25 km AGL

## Anticipated health effects due to ozone layer depletion:

- increase in skin cancer cases
- increase in eye cataracts and sun burns
- suppression of the human immune system
- an adverse impact on crops and animals due to increased UV radiation reaching the ground
- reduction in the growth of ocean phytoplankton
- cooling of the stratosphere that could alter stratospheric wind patterns, possibly affecting the production (and destruction) of ozone.

## Ozone in the Stratosphere - Formation and Destruction

- In an unpolluted stratosphere, the production and destruction of $O_3$ are in balance, and hence the concentration of $O_3$remains constant with time
- When CFCs are released into the lower troposphere, they diffuse up into the stratosphere since their lifetime is 50-100 years
- When the CFCs reach the middle stratosphere, UV radiation liberates the chlorine atom:
    - CFC + UV --> Cl
- Cl is then able to destroy as many as 100,000 $O_3$ molecules before it is itself destroyed

Production = Destruction

$O+O_2+M$ --> $O_3$

$O_3$ + UV -->> O + $O_2$ or $O_3$ + O --> $2O_2$ or $O_3$ + $O_3$ --> $2O_2$

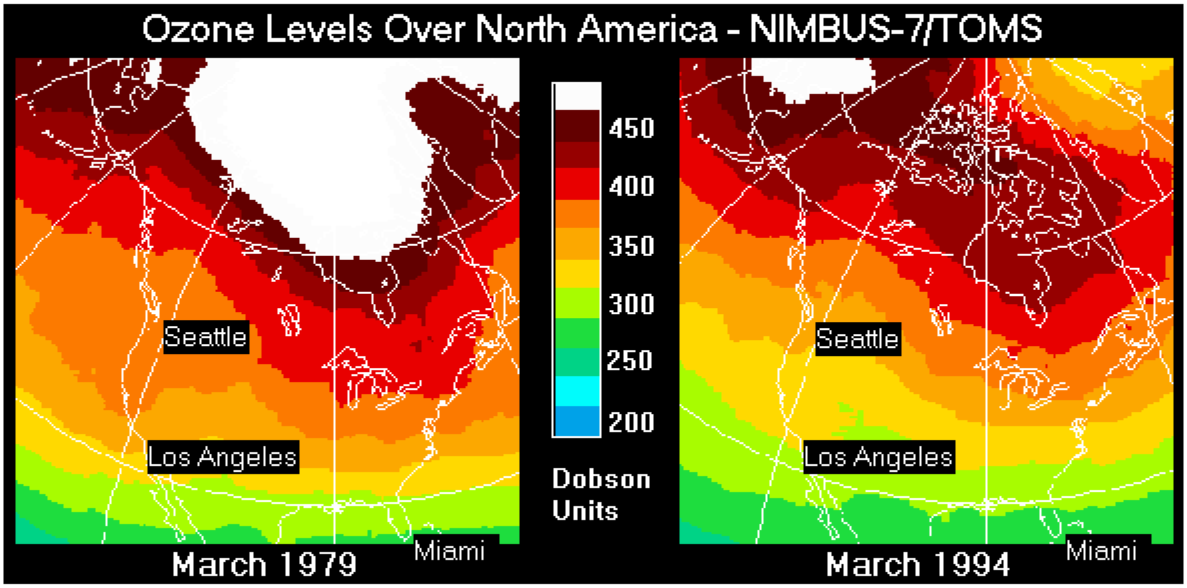
Production < Destruction

Cl + $O_3$ --> ClO + $O_2$

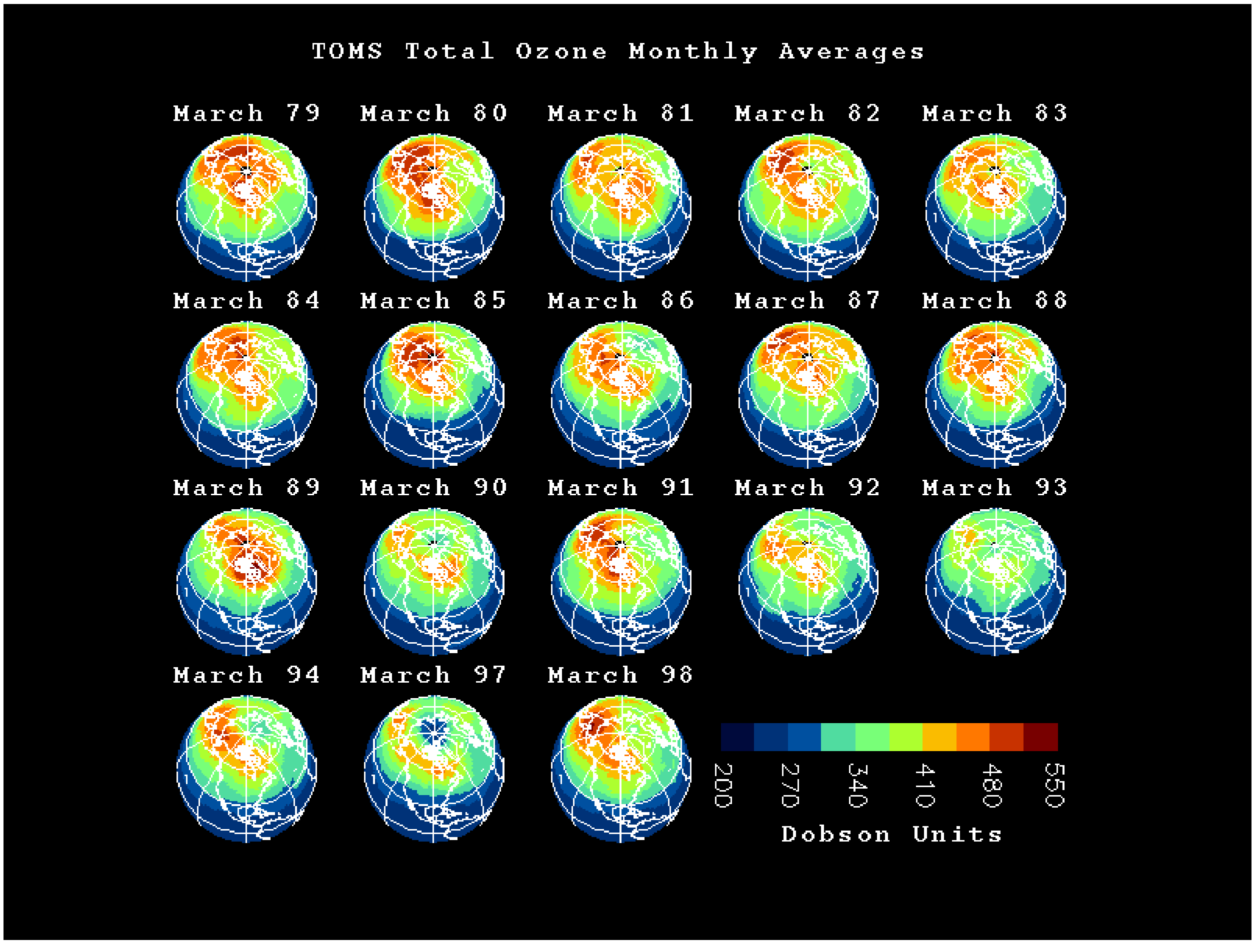
ClO + O --> Cl + $O_2$

## Depletion of Stratospheric Ozone - Observations

- Observations over the U.S. -->



- Observations over the N.H. from 1979 through 1998




- Quicktime movie of the 1998 Antarctic Ozone Hole

## Review Questions for Chapter 17 - Air Pollution

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- What are some examples of significant air pollution events over the last 200-300 years?
- What are the dominant natural and anthropogenic sources of air pollution?
- What are primary pollutants? What are some examples of primary pollutants, their sources, and their health effects?

- What are secondary pollutants? What are some examples of secondary pollutants and their health effects?
- What is smog?
- What are the key differences between photochemical and London-type smog?
- What conditions favor both types of smog?
- What are the key primary and secondary pollutants in photochemical (L.A.) smog?
- What is a "null" cycle?
- What is the "null" cycle in LA smog?
- How is ozone allowed to build up in the LA smog scenario?
- What physical factors affect smog concentrations?
- How does terrain and source location affect smog concentrations?
- What is the diurnal variation of ozone?
- How do concentrations of CO and ozone vary seasonally?
- How does the ventilation factor and mixing height affect smog concentrations?
- What meteorological conditions produce the fanning, fumigation, lofting, coning, and looping plume patterns?
- how can obstacles affect dispersion?
- What is the advantage of using taller smoke stacks for dispersing polllutants?
- How does increasing the exit velocity affect pollutant concentrations? How can one increase the exit velocity?
- How does increasing the exit temperature affect pollutant concentrations? How can one increase the exit temperature?
- What is the general air pollution trend here in the US since the 1940s?
- How is acid rain produced?
- What is the spatial distribution of ph over the US?
- Where else around the world are there acid rain problems?

## Homework Questions for Chapter 18 - Air Pollution

Consult Syllabus for Due Date

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*Questions 1 and 2 will be turned in for a grade. Questions 3-9 will be discussed by the discussion groups in class so please look them over before the discussion session.*

*SHOW ALL WORK , CIRCLE THE CORRECT ANSWER, PLEASE BE NEAT AND STAPLE YOUR HOMEWORK!*

*ALSO, PLEASE USE A SPREADSHEET FOR ALL GRAPHS*

*Follow the Problem solving steps discussed in class*

---

1. a. Mathematically, how do you define the percentage change of any quantity?

b. Let's assume that the density of ozone in the LA basin area on a given summer morning is 1 gram $m^{-3}$ at 10 AM. Also assume that the mixing height is 0.5 km. Within the next hour, the mixing height increases to 1.5 km while the mass of ozone in the LA basin area is constant. What is the percentage change in ozone density from 10 AM to 11 AM?

c. Does your answer make physical sense? Explain.

2. Given a surface temperature of 30 degrees Celsius. Write down equations for the vertical profile of environmental temperature that would support the following plume patterns:

- fanning
- coning
- looping

For each plume pattern, what is the environmental air temperature at 2 km?

---

3.

a. Suppose clouds of nitrogen dioxide drift slowly from a major industrial complex over a relatively unpopulated area. If the area is essentially "free" of hydrocarbons, would you expect high levels of tropospheric ozone to form? Explain.

b. Now suppose that the clouds of nitrogen dioxide drift slowly over an area that has a high concentration of hydrocarbons from both natural and industrial sources. Would you expect high levels of tropospheric ozone to form under these conditions? Explain your reasoning.

4. For least-polluted conditions, what would be the best time of day for a farmer to burn agricultural debris? Explain why you chose that time of the day.

5. Why are most severe air pollution episodes associated with subsidence inversions rather than radiation inversions?

6. What surface and upper-air conditions lead to atmospheric stagnation?

7. Urban areas tend to be more cloudy than the surrounding rural areas. Since clouds reflect incoming short wave radiation, why are urban areas generally warmer than the surrounding rural areas?

8. Why do we want to reduce high ozone concentrations at the Earth's surface while also wishing to increase ozone concentrations in the stratosphere?

9. Acid snow can be a major problem. In the high mountains of the western U.S., especially downwind of a major metropolitan or industrial area, explain why, for a high-mountain lake, acid snow can be a greater problem than acid rain, even when both have the same pH.

10. What atmospheric conditions would produce a lofting smoke plume pattern during the *middle* of the afternoon?

__ 2. The smoke in London smogs came primarily from:

a. exhaust from diesel engines
b. trash fires
c. factories in Eastern Europe
d. coal combustion

____ 3. Collectively, particles of soot, smoke, dust and pollen are called:

a. hydrocarbons
b. aerosols
c. carcinogens
d. haze

____ 4. Which of the following gases will replace oxygen in blood hemoglobin and thereby reduce the transport of oxygen to the brain?

a. sulfur dioxide ($SO_2$)
b. carbon monoxide (CO)
c. carbon dioxide ($CO_2$)
d. methane ($CH_4$)

____ 5. A primary component of photochemical smog is:

a. ozone
b. carbon monoxide

c. sulfur dioxide
d. chlorofluorocarbons

____ 7. A mixing layer is characterized by:
a. enhanced vertical air motions
b. suppressed vertical air motions
c. strong horizontal winds
d. high concentrations of pollutants

____ 8. Which of the following conditions would act to prevent a buildup of pollutants near the surface?
a. light surface winds
b. a strong subsidence inversion
c. a large, slow-moving anticyclone
d. a deep mixing layer

____ 9. Atmospheric stagnation is a condition normally brought on by:
a. thunderstorms
b. slow-moving anticyclones
c. overcast skies
d. tall buildings in a city
e. movement of an upper level trough overhead

____ 10. Sunshine in a city is typically less intense than in surrounding rural areas because:
a. of the higher pollution levels in cities
b. of the air temperature in cities
c. tall structures in cities block our view of the horizon
d. cement and asphalt in cities absorb a larger percentage of the incident sunshine

____ 11. On clear, cold winter nights, cities tend to cool ____ than rural areas and have ____ temperatures.
a. more slowly, higher
b. more quickly, higher
c. more slowly, lower
d. more quickly, lower

____ 12. Rain with a pH of 5.6 would be considered:
a. acidic
b. alkaline
c. neutral
d. polluted
e. harmful

____ 13. The ozone hole is found in this atmospheric layer:
a. thermosphere
b. troposphere
c. stratosphere
d. ionosphere
e. mesosphere

____ 14. If the concentration of ozone were to decrease significantly, which of the following might also occur?
a. less absorption of ultraviolet radiation in the stratosphere.
b. an increase in the number of cases of skin cancer
c. the stratosphere would cool
d. more ultraviolet radiation would be absorbed at the earth's surface
e. all of the above