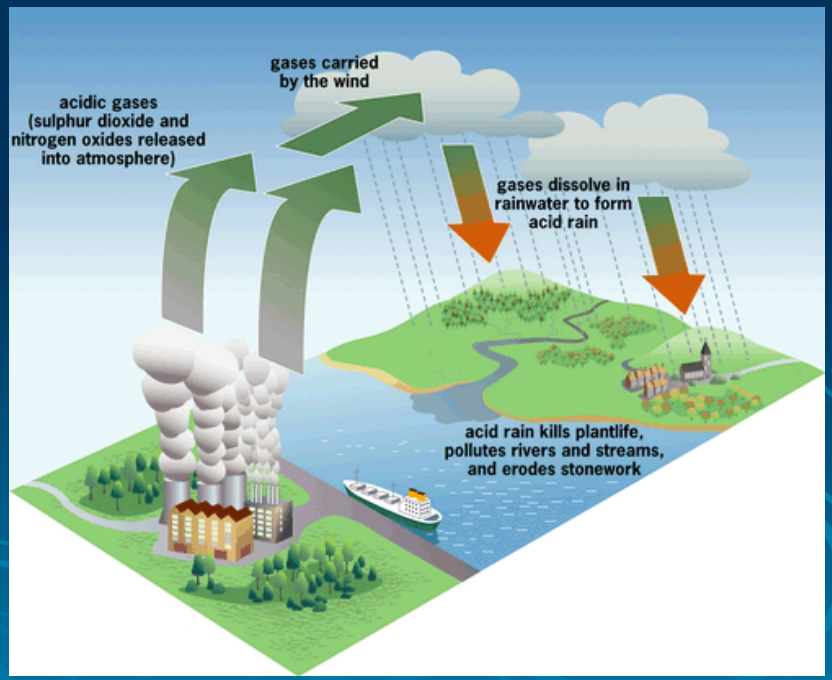
GGS 319
Air Pollution Fundamentals

- ✓ ACID RAIN

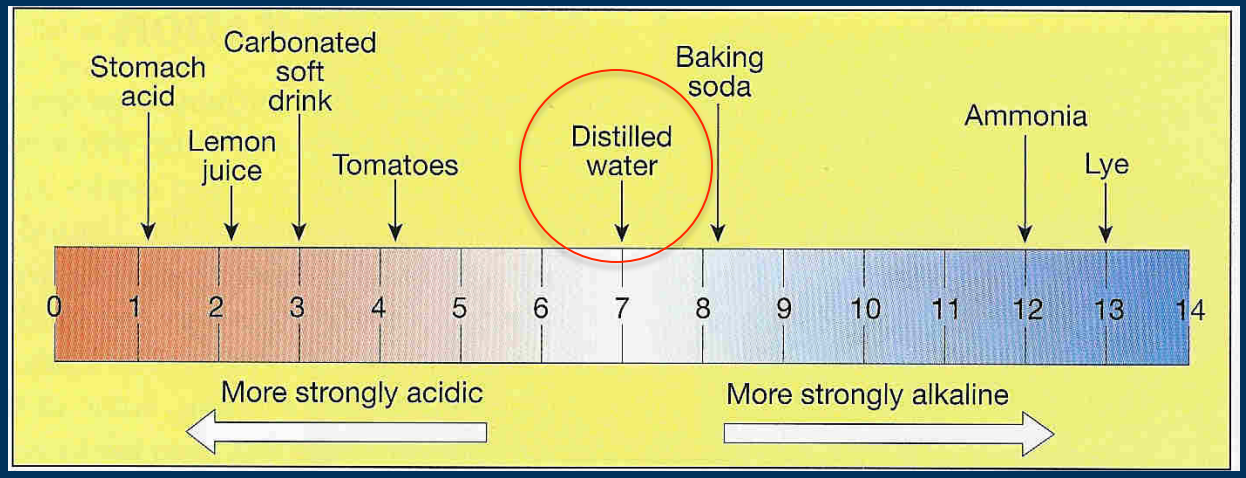




Acid Rain

- Little attention was paid to acid rain until the 1950s, when biologists noticed an alarming decline of fish populations in the lakes of southern Norway and traced the problem to acid rain.
- Similar findings were made in the 1960s in North America and acidity of precipitation in the US was characterized
- These findings spurred intense research about acid rain.
- The industrial revolution greatly increased the amount of acid in the atmosphere.
- These acids accelerate the rate of “weathering” of both natural and man-made materials.

The pH Scale of Acidity or Alkalinity



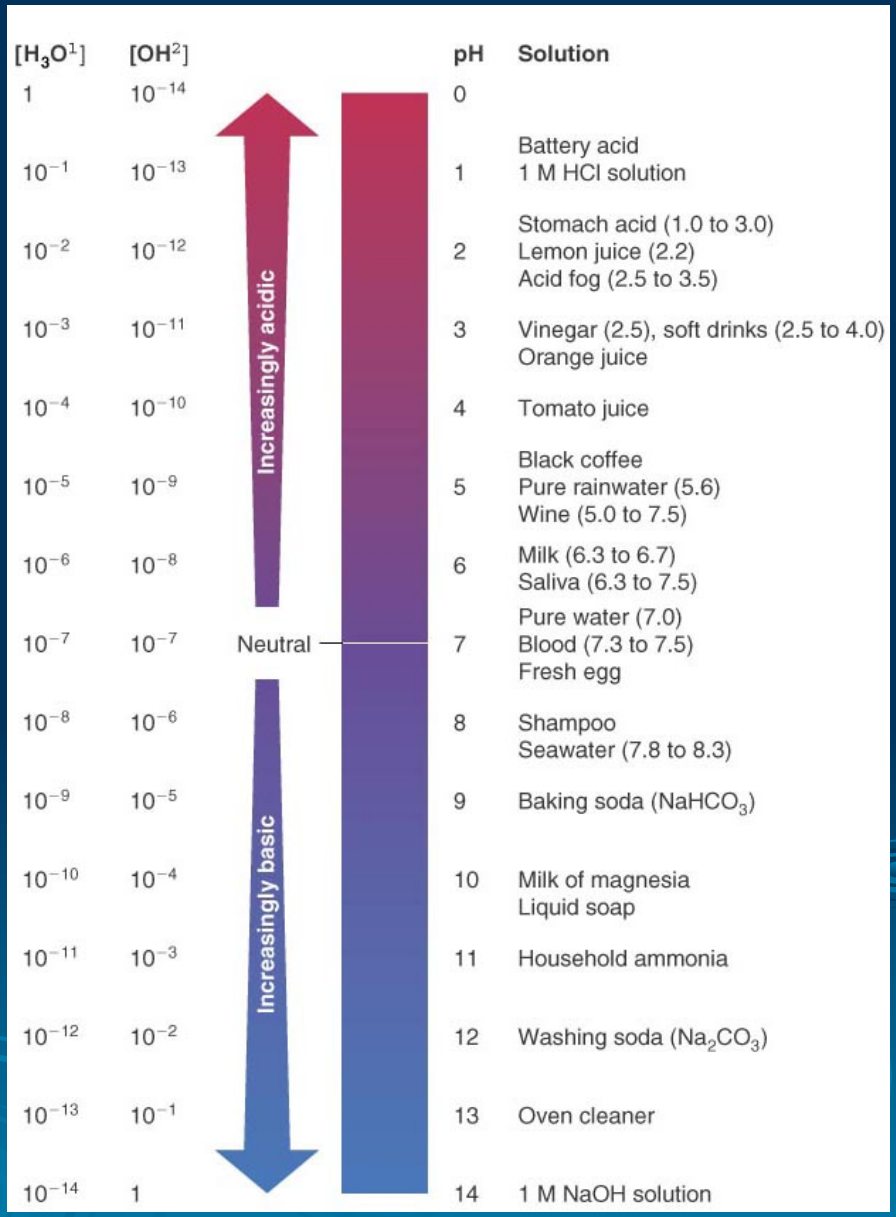
- The pH scale is a common measure of the degree of acidity and alkalinity of a solution
- Alkalinity is a measure of ability of a solution to neutralize acids to the equivalence point of carbonate
- The pH scale ranges from 0 to 14
- The pH scale is logaritmic, that is, each whole number increment indicates a tenfold difference.
- Thus, pH4 is 10 times more acidic than pH5 and 100 times (10X10) more acidic than pH6

The pH Scale of Acidity or Alkalinity

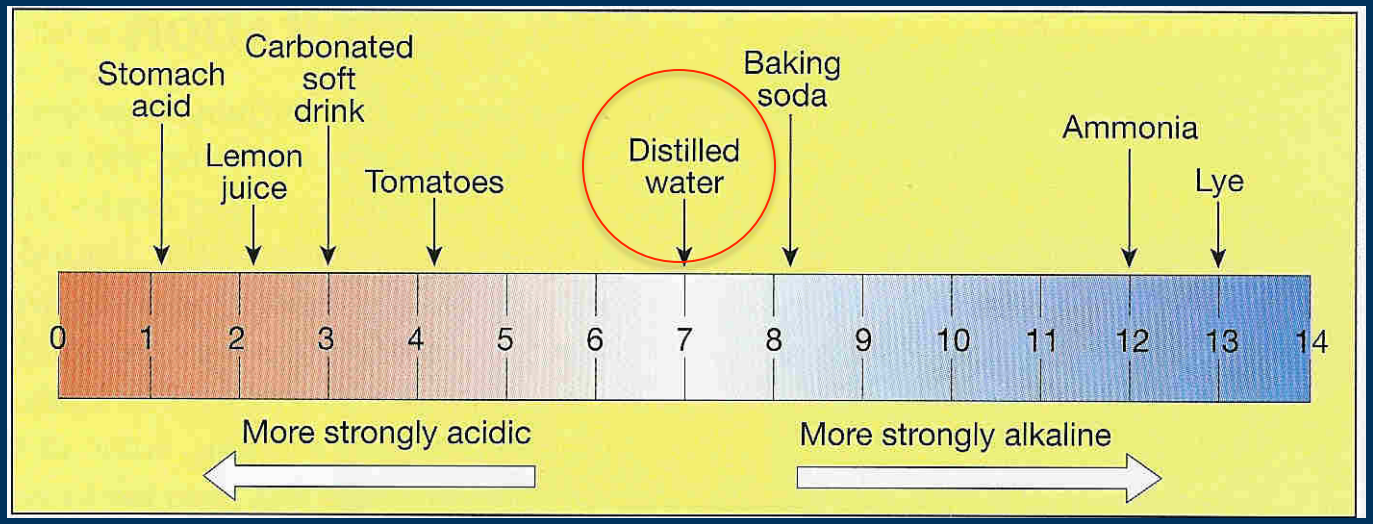
pH = -log[H+]

- So, if a strong acid has a total concentration in water of 0.01 moles/L, it's pH will be

  pH = -log(0.01) = -(-2) = 2



The pH Scale of Acidity or Alkalinity



- Pure water is neutral and has a pH value of 7 determined by separation of H_2O molecules

$$H_2O \leftrightarrow H + OH$$

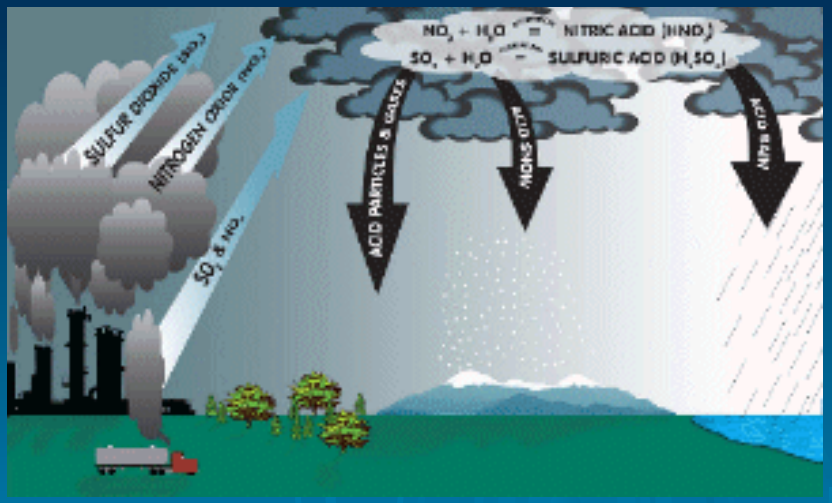
- Rainwater falling in the atmosphere always contains impurities, even in the absence of human influence
- Generally, in case of human influence acid rain forms.

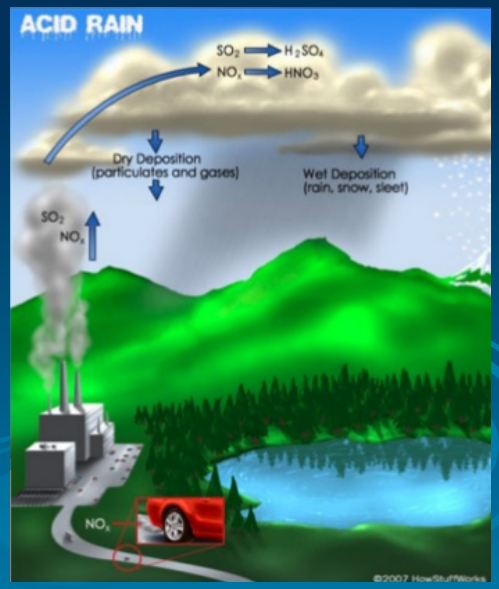
Acid Rain

- One can calculates an natural acidity of rainwater as pH 5.7 from the concentration level of pollutants.
- In general, the pH of natural rain is found to be in the range from 5 to 7.
- The term acid rain is customarily applied to precipitation with a pH below 5.
- Such low pH values are generally possible only in the presence of large amounts of anthropogenic pollution.

What is Acid Rain?

- Forms when gases, such as CO_2, SO_2, and NO_2 react with the water, H_2O, in the atmosphere
- The pH of rain drops can be
  - as low as pH of 2 (equivalent to pH level of lemon juice)
  - very harmful to our living environment





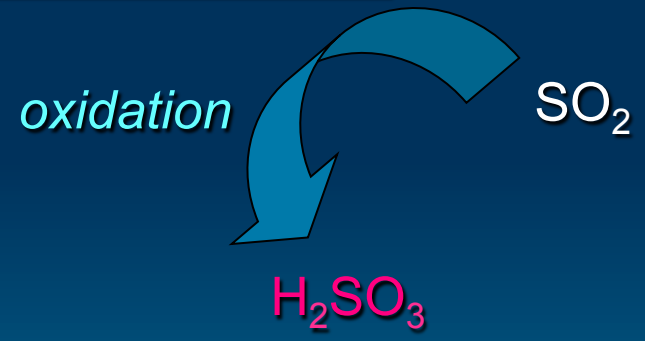
Acid Rain Examples

- When CO_2 reacts with water, carbonic acid is formed (weak acid).

  $CO_2 + H_2O \rightarrow H_2CO_3$

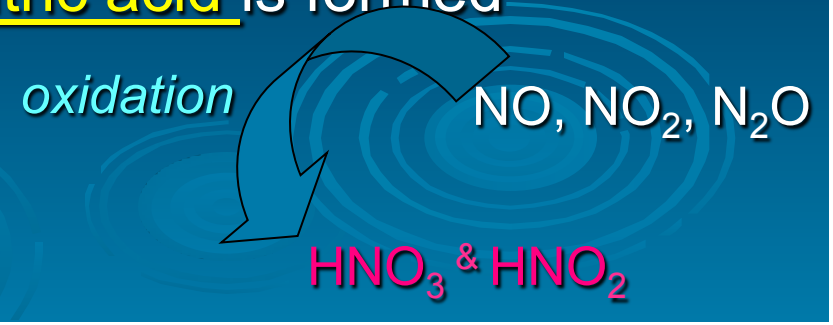
- When SO_2 reacts with water, sulfurous acid is formed (strong acid).

  $SO_2 + H_2O \rightarrow H_2SO_3$



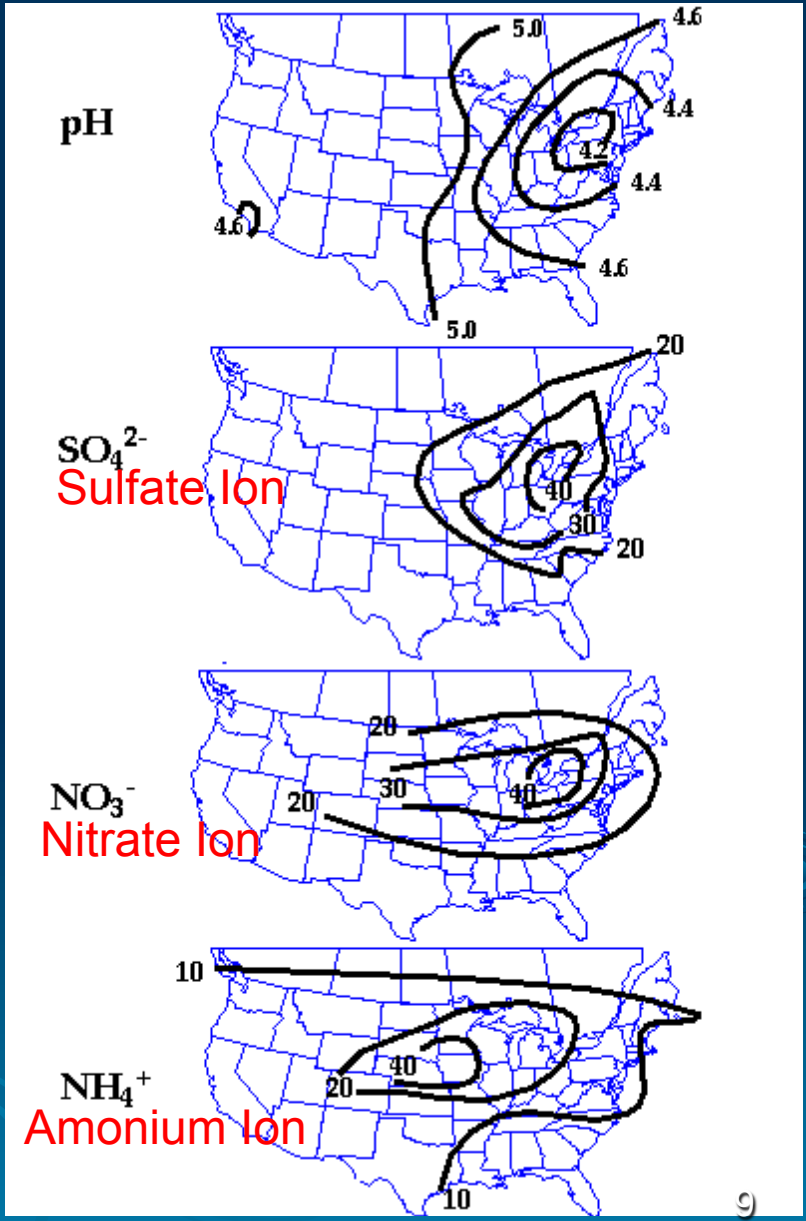
- When NO_2 reacts with water, nitric acid is formed (strong acid).

  $2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$



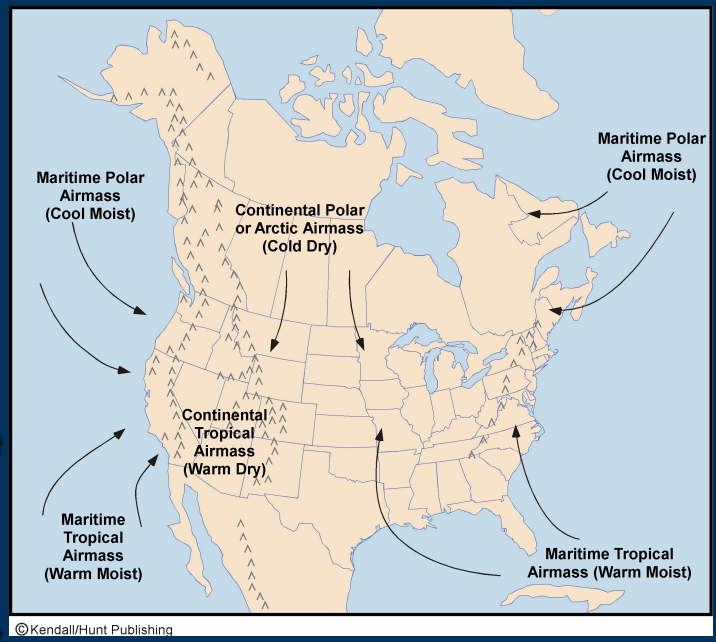
pH Distribution over North America

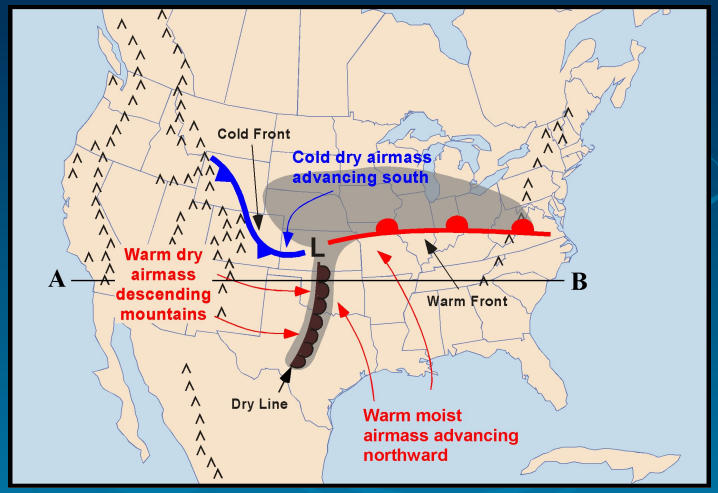
- The mean pH values of precipitation measured over North America show less than 5 pH values over the eastern half of the US
- The relatively high pH of rain in the central US reflects the large amount pollutants emitted from agricultural activities (i.e., NH4)



North America Weather Producers

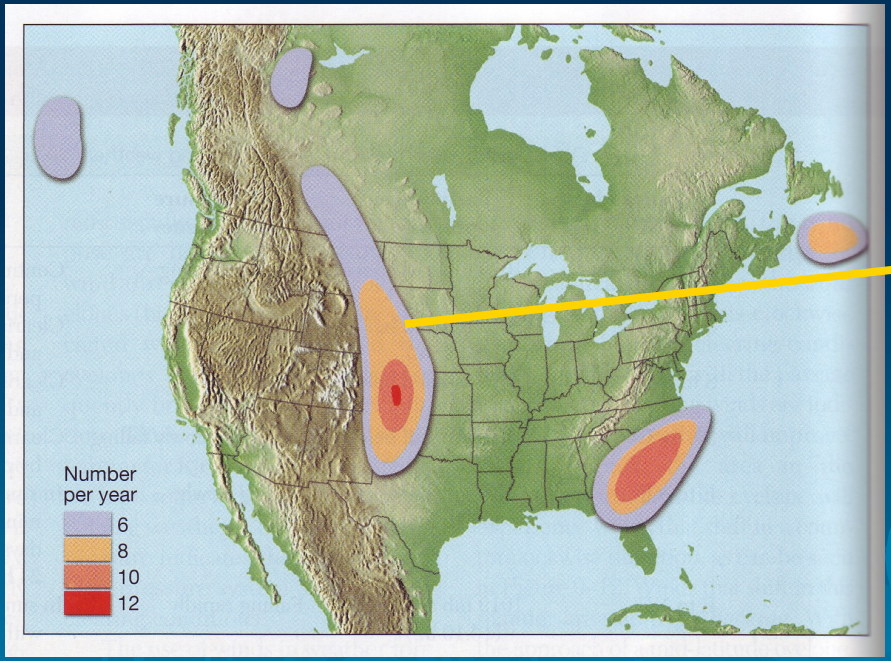
- The figure shows the regions that produce the air masses that most often influence North America.
- The Gulf of Mexico and Caribbean Sea yield warm air masses.
- In contrast, the snow and ice covered areas and adjacent ocean yield cold air masses.
- The size and intensity of the source regions change seasonally.
- No major source regions in the middle latitudes.
- The middle latitudes are the site where cold & warm air masses clash and form cyclones, the stormiest region on the planet.





Traveling Cyclones: The Weather Producers
(The Main Formation Areas)

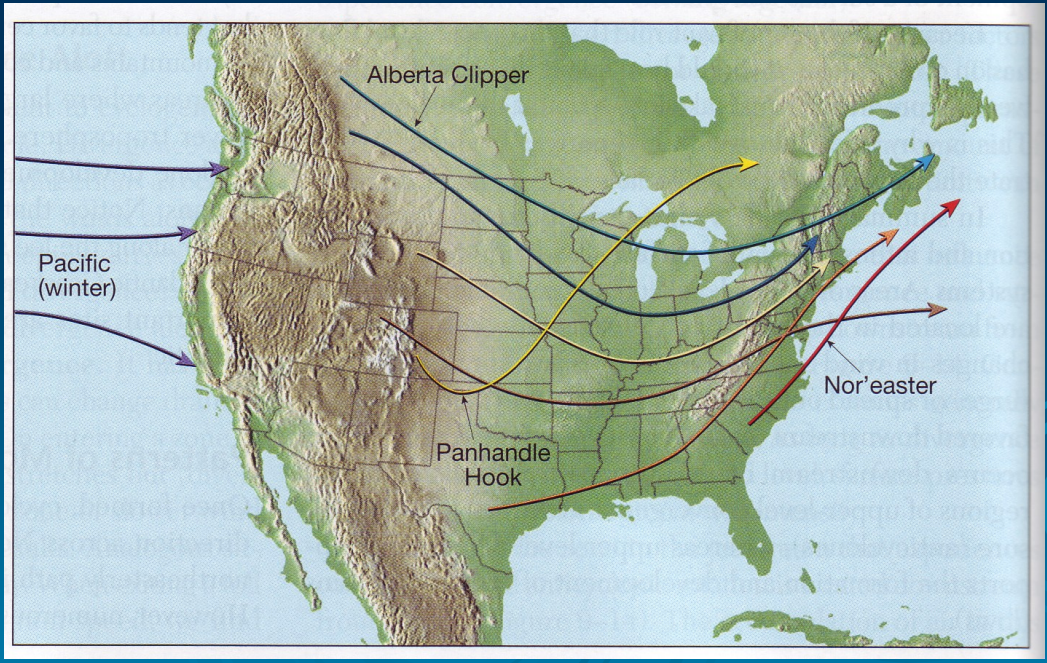
- ✓ Cyclone development does not occur uniformly over Earth, but tends to favor certain locations, such as the leeward sides of **mountains** and **coastal** regions.
- ✓ In general, cyclones form in areas where large temperature contrasts occur in the lower troposphere.



Main formation area, the lee side of the Rocky Mountains

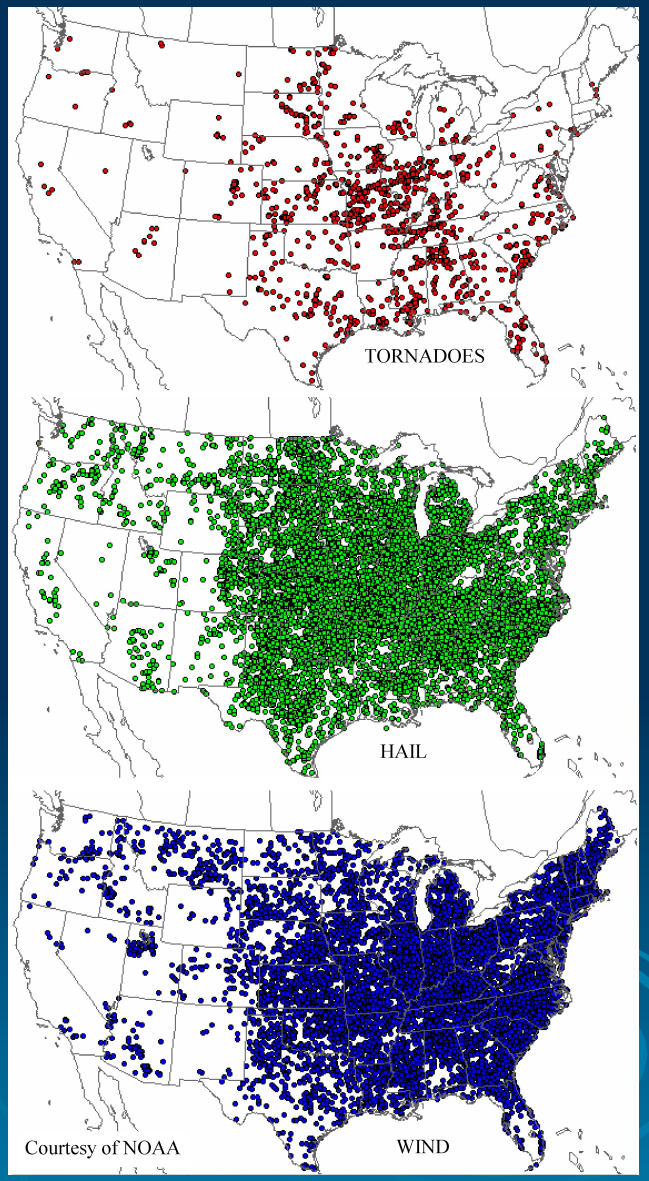
Traveling Cyclones: The weather Producers
(Patterns of Movement)

- Most pacific storms do not cross the Rockies intact, but they redevelop on the lee (eastward) side of these mountains.
- The cyclones that form in Canada tend to move southeastward and then turn northeastward and move out into Atlantic.
- Most of these storms traverse the Great Lakes region, making it the most storm-ridden portion of the country.

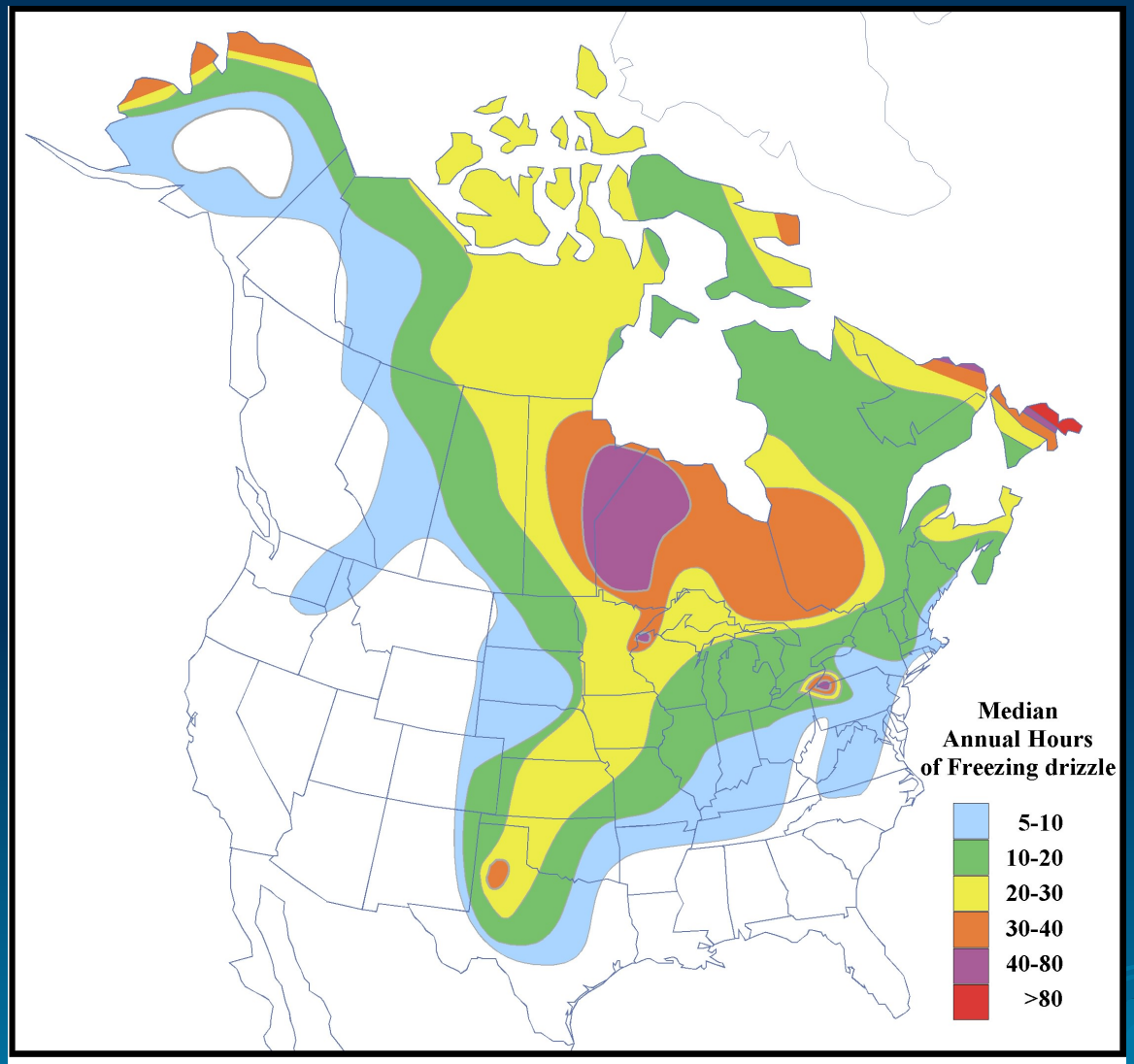


Locations of Severe Weather Events over the US

- Locations of severe weather events in year 2006
- Each circle represents a report
- Thunderstorms are important in the redistribution of moisture and heat



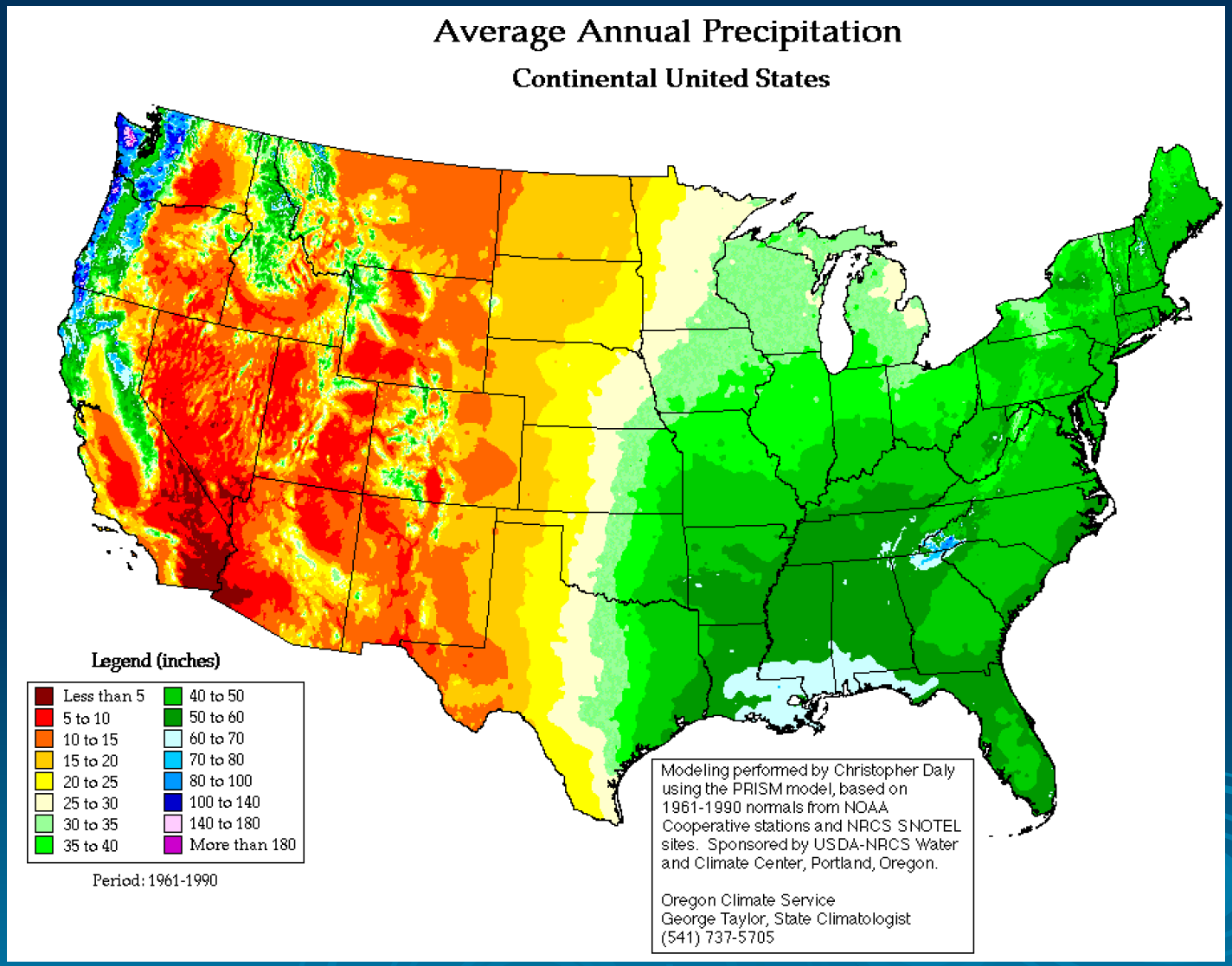
Distribution of Freezing Drizzle in North America



Courtesy of the American Meteorological Society

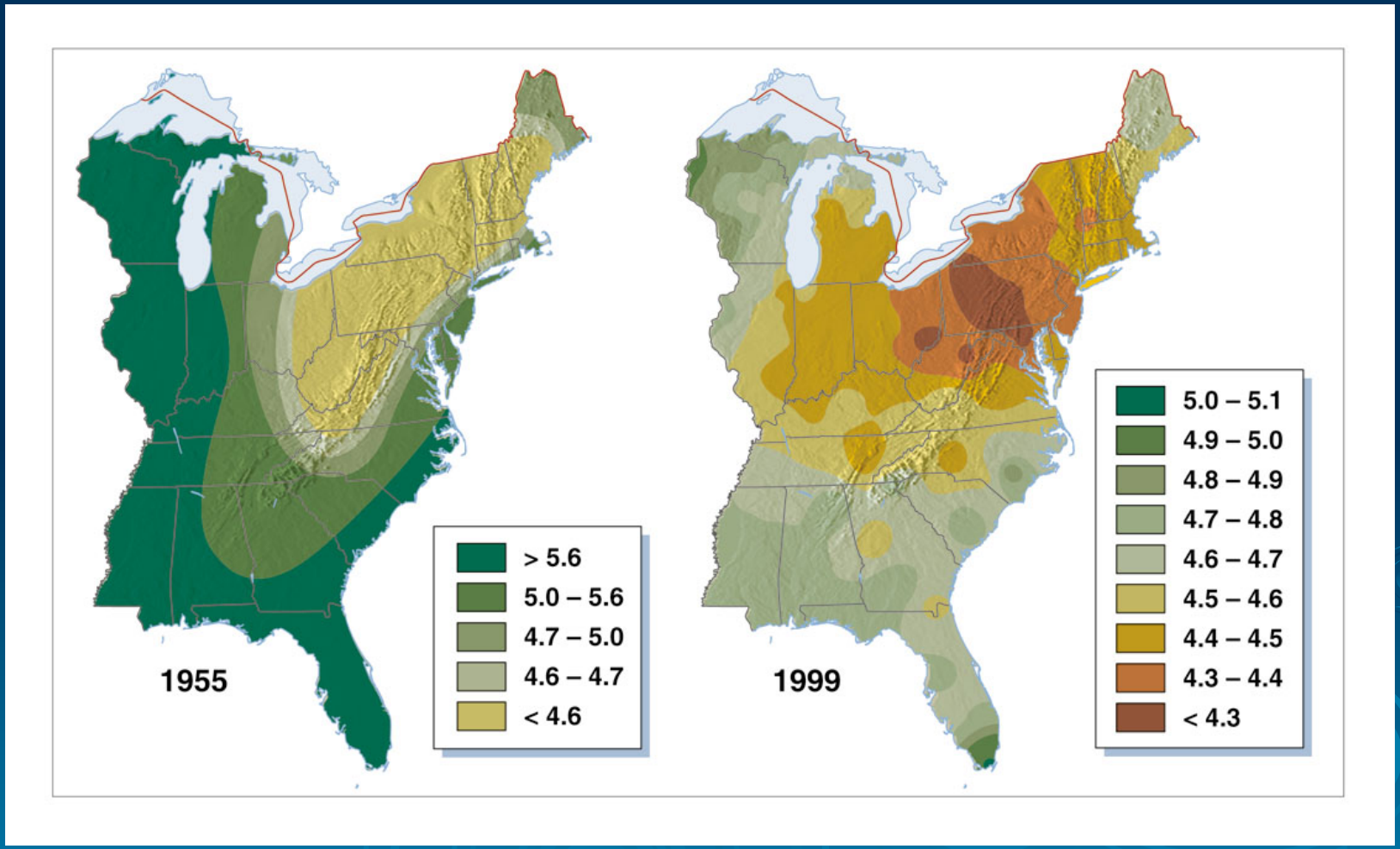
- ✓ Median number of hours per year that freezing drizzle is reported at stations across north America

Average Annual Precipitation over the US



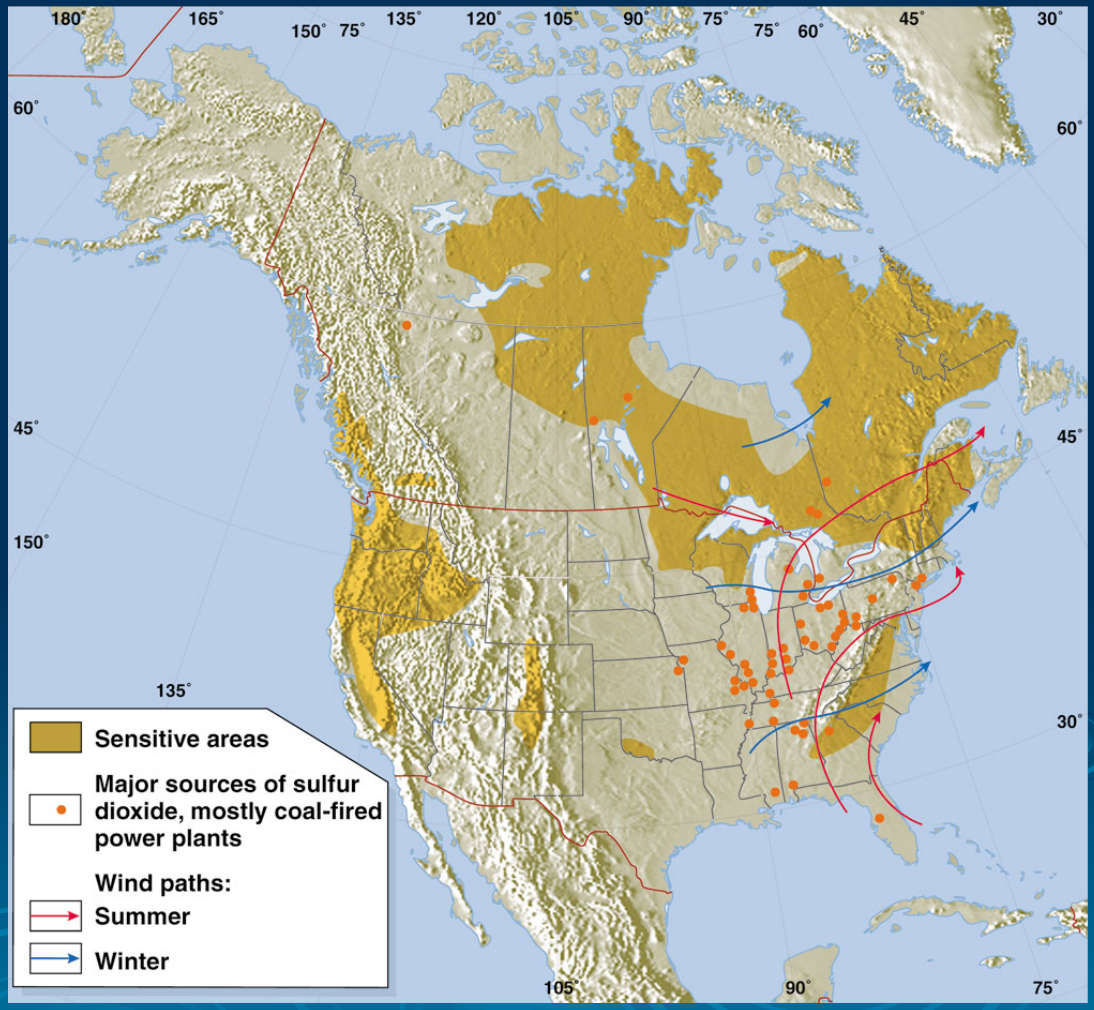
Acid Rain distribution in the US (1955 - 1999)

- pH of clean rainfall ~5.6



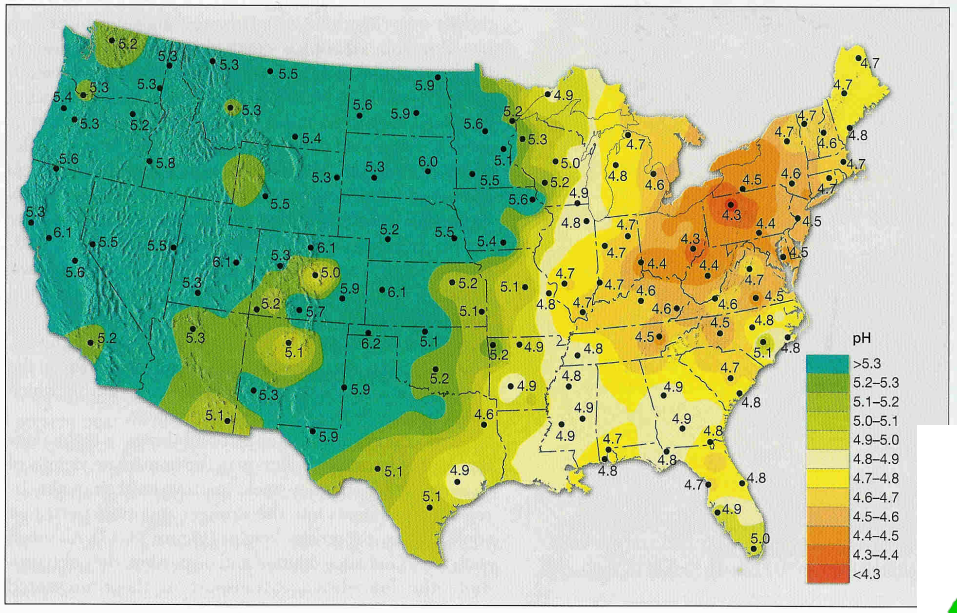
Areas Sensitive to Acid Rain in the US

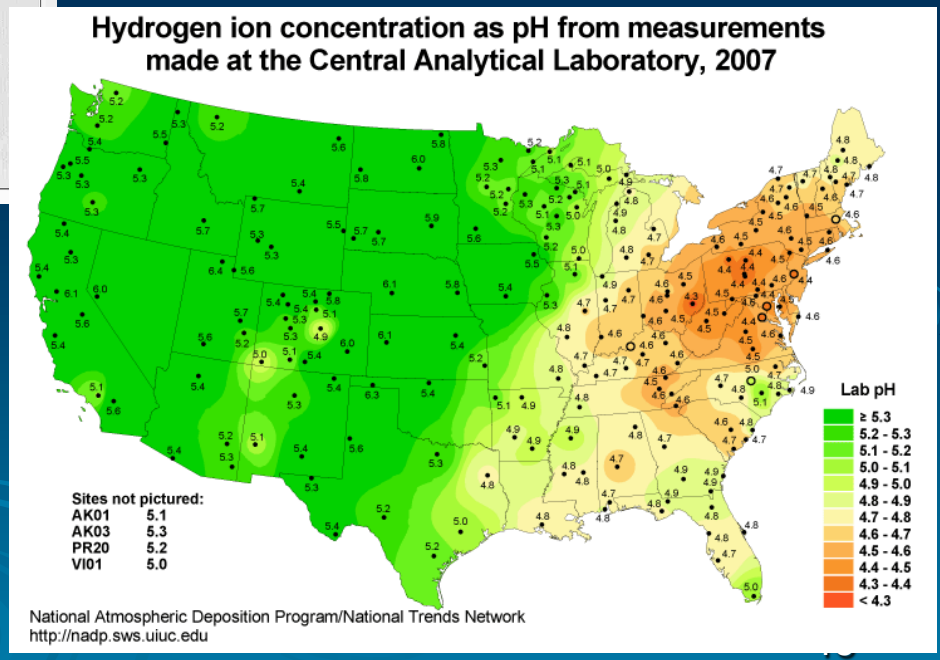
- Sensitive areas
  - Exposed silicate bedrock
  - No significant carbonates
- Other areas
  - Carbonates (mostly limestone) exposed at surface



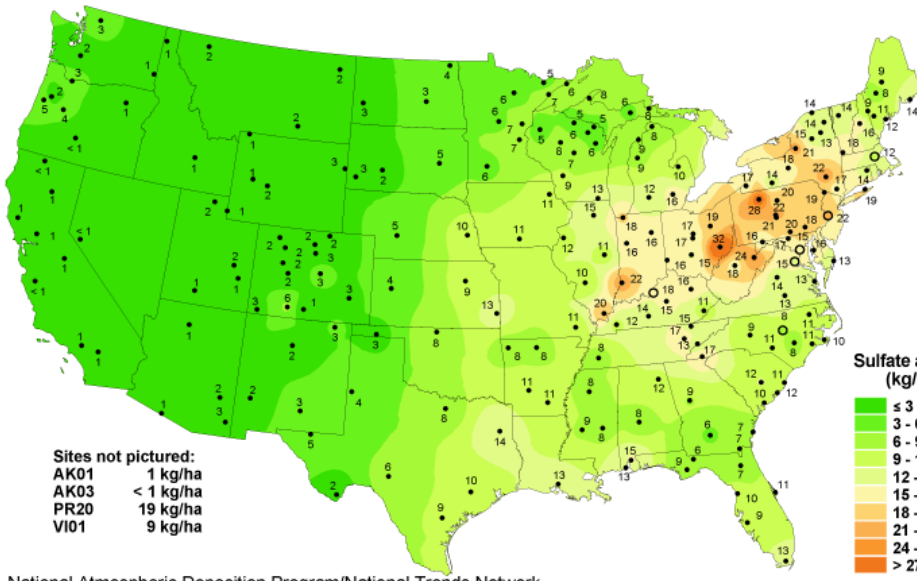
Precipitation pH in the US (2003 & 2007)

FIGURE 13-16 Precipitation pH values for the United States in the year 2003. Unpolluted rain has a pH of about 5. In the United States acid precipitation is most severe in the Northeast. *(Data from National Atmospheric Deposition Program)*



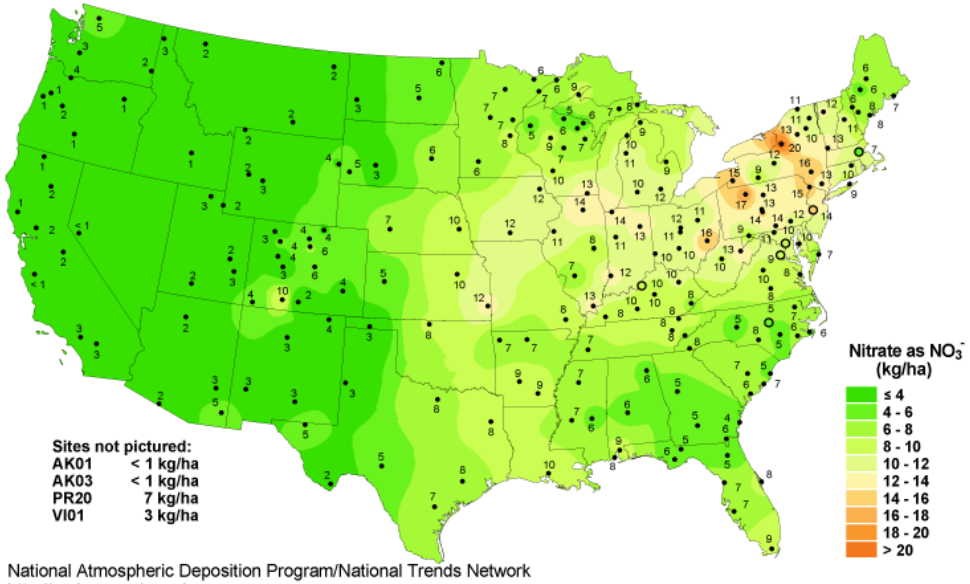


Sulfate ion wet deposition, 2007



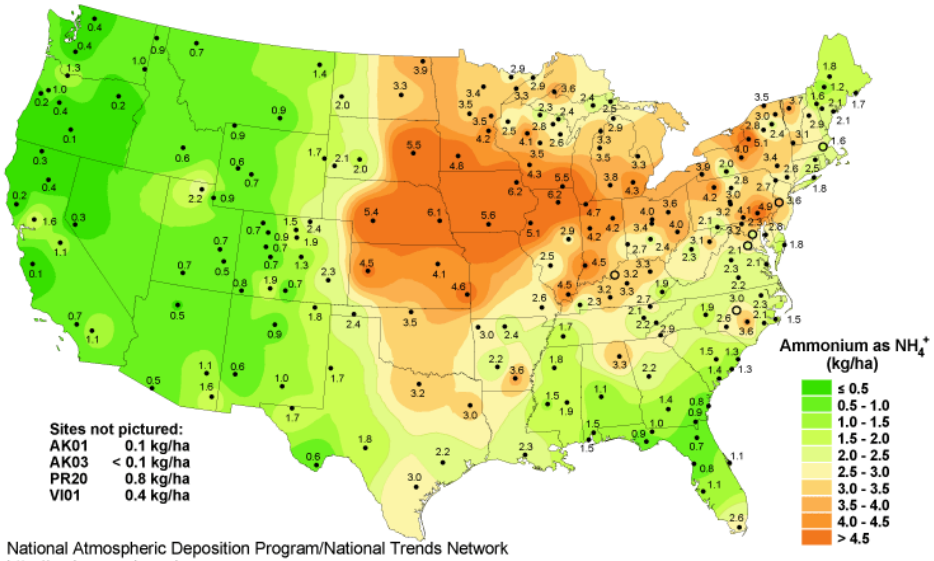
National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Nitrate ion wet deposition, 2007



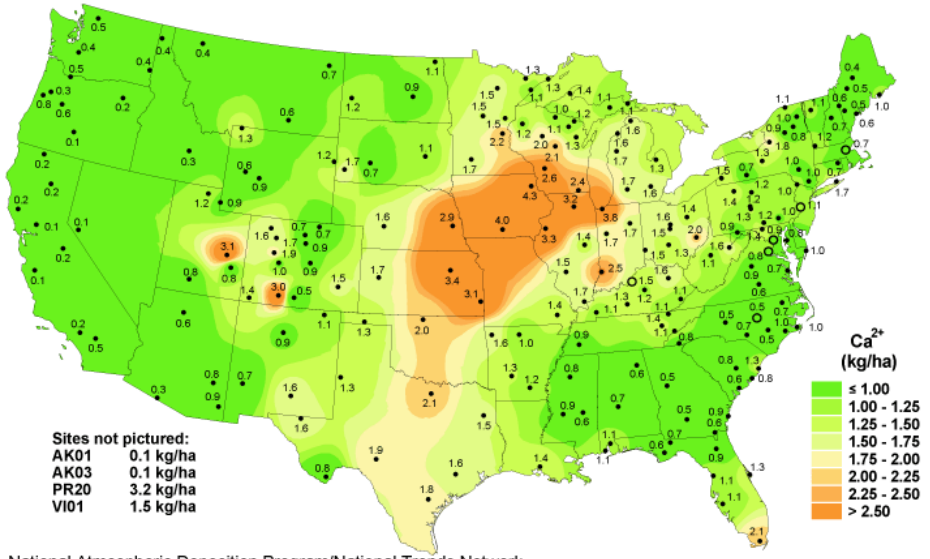
National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Ammonium ion wet deposition, 2007



National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Calcium ion wet deposition, 2007



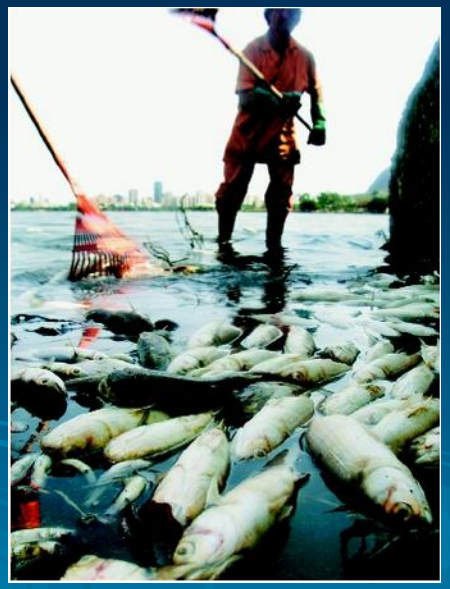
National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Effects of Acid Rain

- Beyond possible impacts on health
- It kills micro-organisms
- It poisons plants
- It damages metals and limestone
- It kills fish by producing toxic water
- It alters complex ecosystems



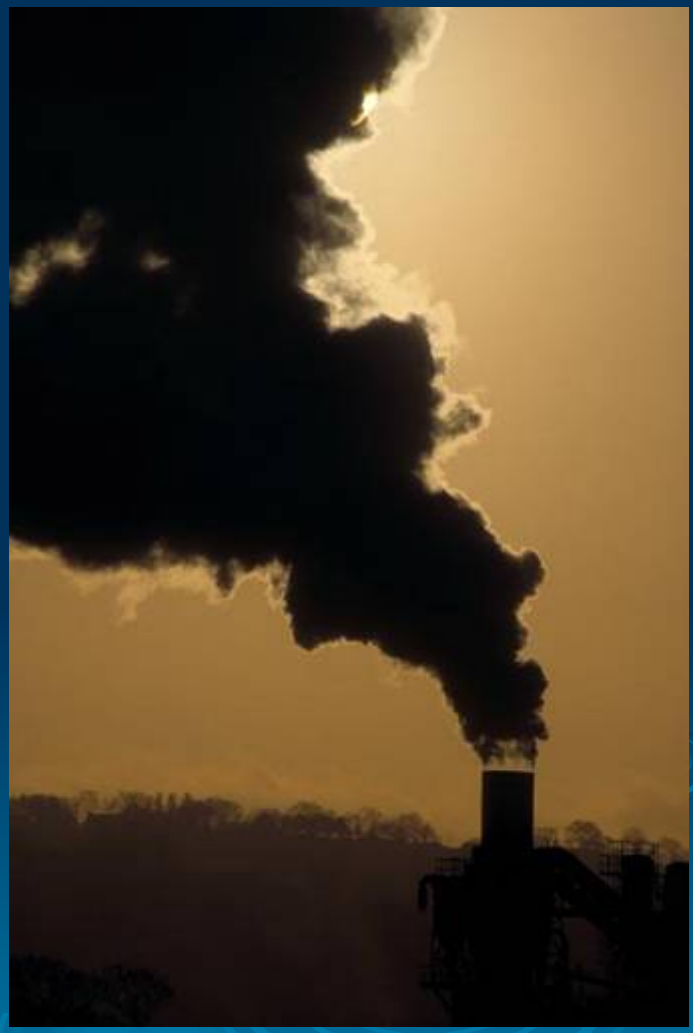






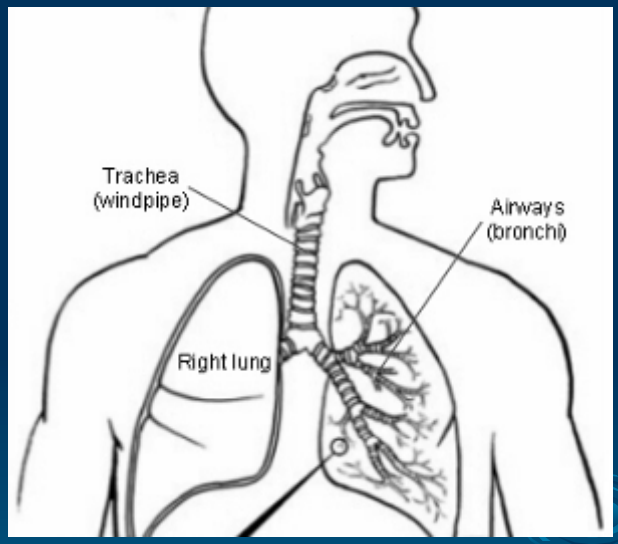
More problems!!!

- Acid rain can travel long distances.
- Often it doesn't fall where the gas is produced. High chimneys disperse (spread) the gases and winds blow them great distances before they dissolve and fall to Earth as rain.
- For example gases produced in Western Europe can result in acid rain in Eastern Europe.



Effects of Acid Rain (Human)

- Humans can become seriously ill, and can even die from the effects of acid rain.
- One of the major problems that acid rain can cause in a human being is respiratory problems.
- Many can find it difficult to breathe, especially people who have asthma.
- Asthma, along with dry coughs, headaches, and throat irritations can be caused by the sulphur dioxides and nitrogen oxides from acid rain.



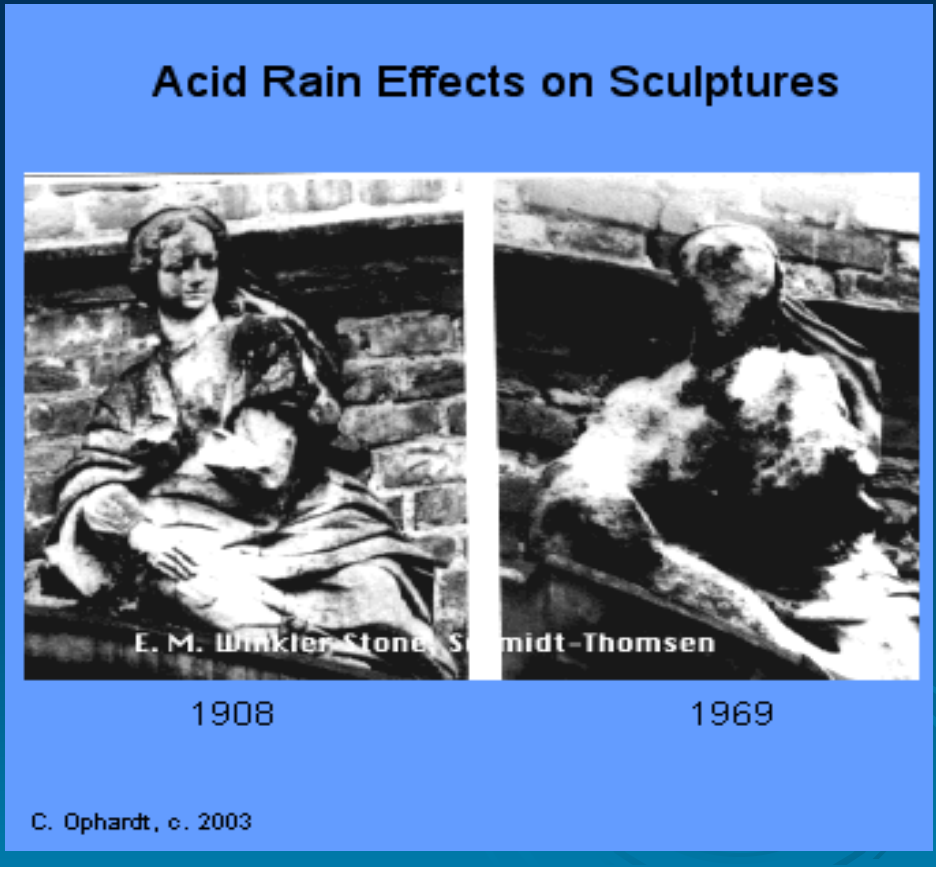
Effects of Acid Rain (Human)

- Acid rain can be absorbed by both plants (through soil and/or direct contact) and animals (from things they eat and/or direct contact).
- When humans eat these plants or animals, the toxins inside of their meals can affect them.
- Brain damage, kidney problems, and Alzheimer's disease has been linked to people eating "toxic" animals/plants.



Effects of Acid Rain (Structures)

- Acid rain dissolves the stonework and mortar of buildings (especially those made out of sandstone or limestone).
- It reacts with the minerals in the stone to form a powdery substance that can be washed away by rain.



- Sandstone portal Figure on Herten Castle in Ruhr district of Germany. Sculpted 1702 and photographed in 1908.
- Same sandstone portal figure photographed in 1969.

Effects of Acid Rain (Trees)

- Acid rain is an extremely destructive form of pollution
- The environment suffers from its effects. Forests, trees, lakes, animals, and plants suffer from acid rain.
- The needles and leaves of the trees turn brown and fall off.
- Trees can also suffer from stunted growth and have damaged bark and leaves, which makes them vulnerable to weather, disease, and insects.
- Meaning “forest decline” caused by soil exhaustion through acid leaching of nutrients

Acid rain, woods, Jizera Mountains, Czech Republic



Effects of Acid Rain (Trees)

- All of this happens partly because of direct contact between trees and acid rain.
- But it also happens when trees absorb soil that has come into contact with acid rain.
- The soil poisons the tree with toxic substances that the rain has deposited into it.



Effects of Acid Rain (Fish)

- Lakes are also damaged by acid rain. Fish die off, and that removes the main source of food for birds. Acid rain can even kill fish before they are born when the eggs are laid and come into contact with the acid.
- Fish usually die only when the acid level of a lake is high; when the acid level is lower, they can become sick, suffer stunted growth, or lose their ability to reproduce.
- Also, birds can die from eating "toxic" fish and insects.





Effects of Acid Rain (Transportation)

- ✓ Currently, both the railway industry and the aeroplane industry are having to spend a lot of money to repair the corrosive damage done by acid rain.
- ✓ Also, bridges have collapsed in the past due to acid rain corrosion.



Effects of Acid Rain

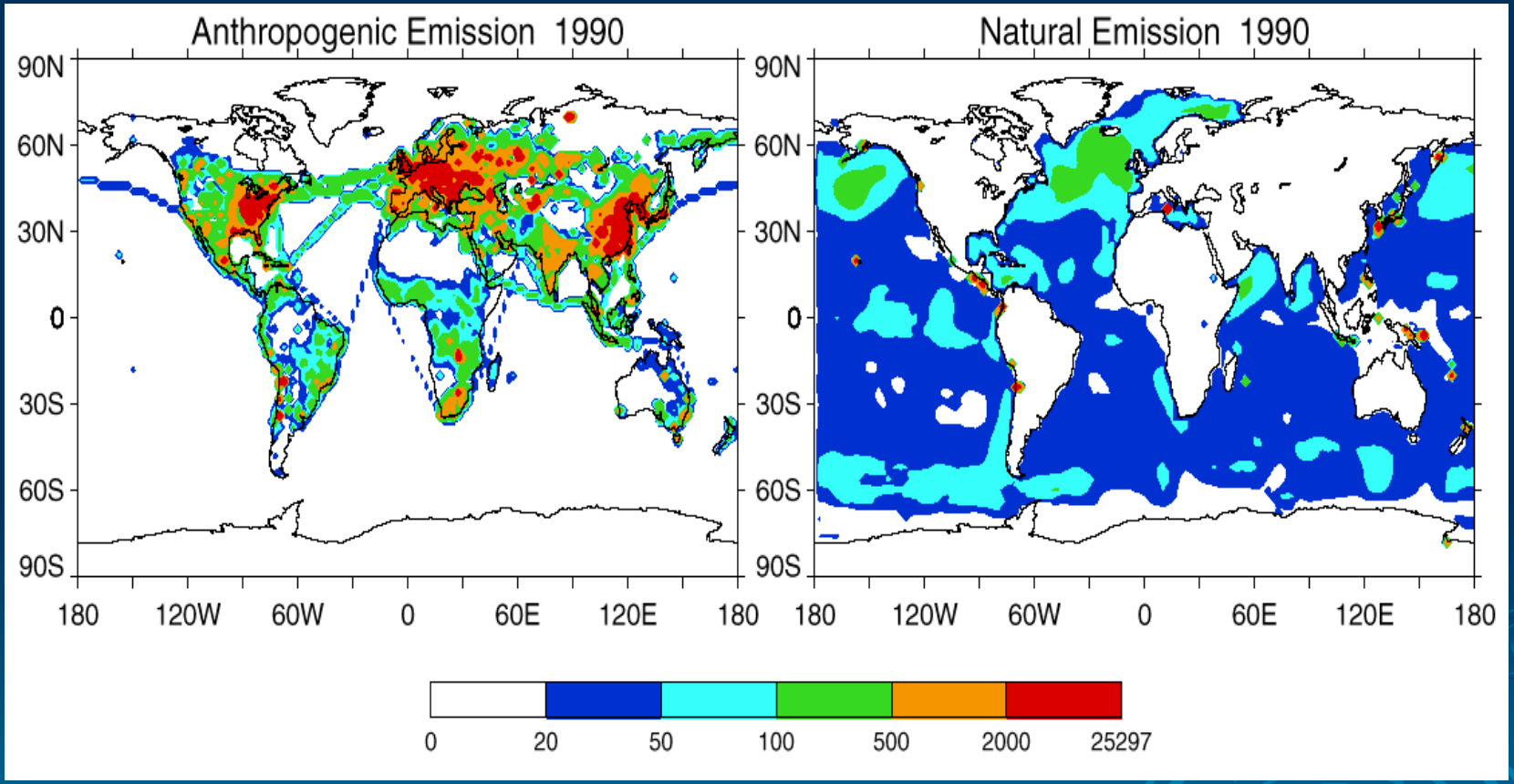
- The acid rain falling over most of the world has little environmental effect on the biosphere because it is rapidly neutralized after it falls
- Particularly acid rain falling over the oceans is rapidly neutralized by the large supply of carbonate ions (CO_3^{2-}).
- Acid rain falling over regions with alkaline soils and rocks is quickly neutralized
- For example, regions of North America with low soil alkalinity to neutralize acid rain (which have granitic bedrock and thin soils)



Emission Trends

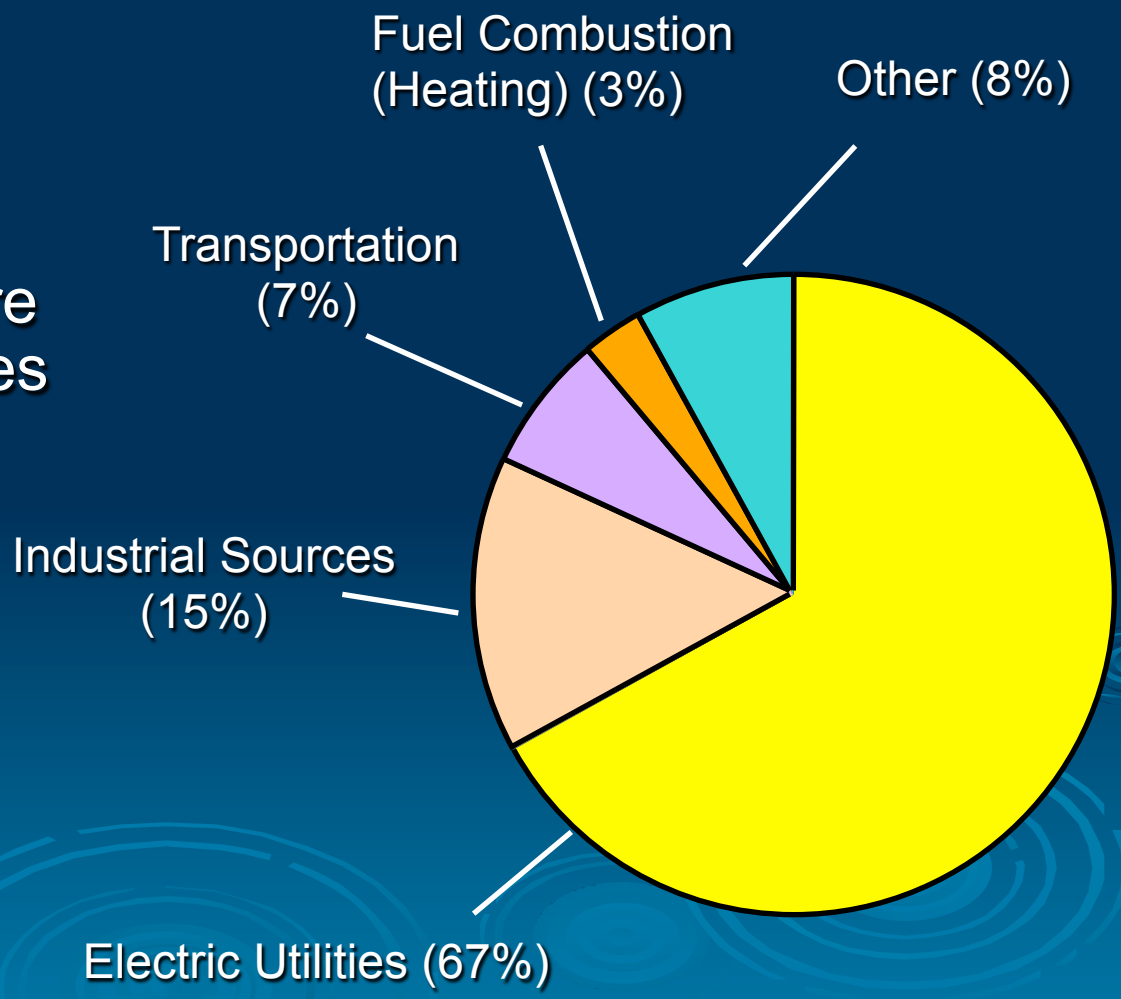
- Emission of SO2 and NOx in the US and other industrial countries have increased considerably over the past ceuntry due to fossil fuel combustion
- Since 1970s, however, emissions in the US and Europe have leveled off due to pollution control efforts
- By contrast, emissions in eastern Asia are on a rapid rise fueled in large part by the industrialization of China and India relying on coal combustion as a source of energy

Global Sulfur Emission to the Atmosphere



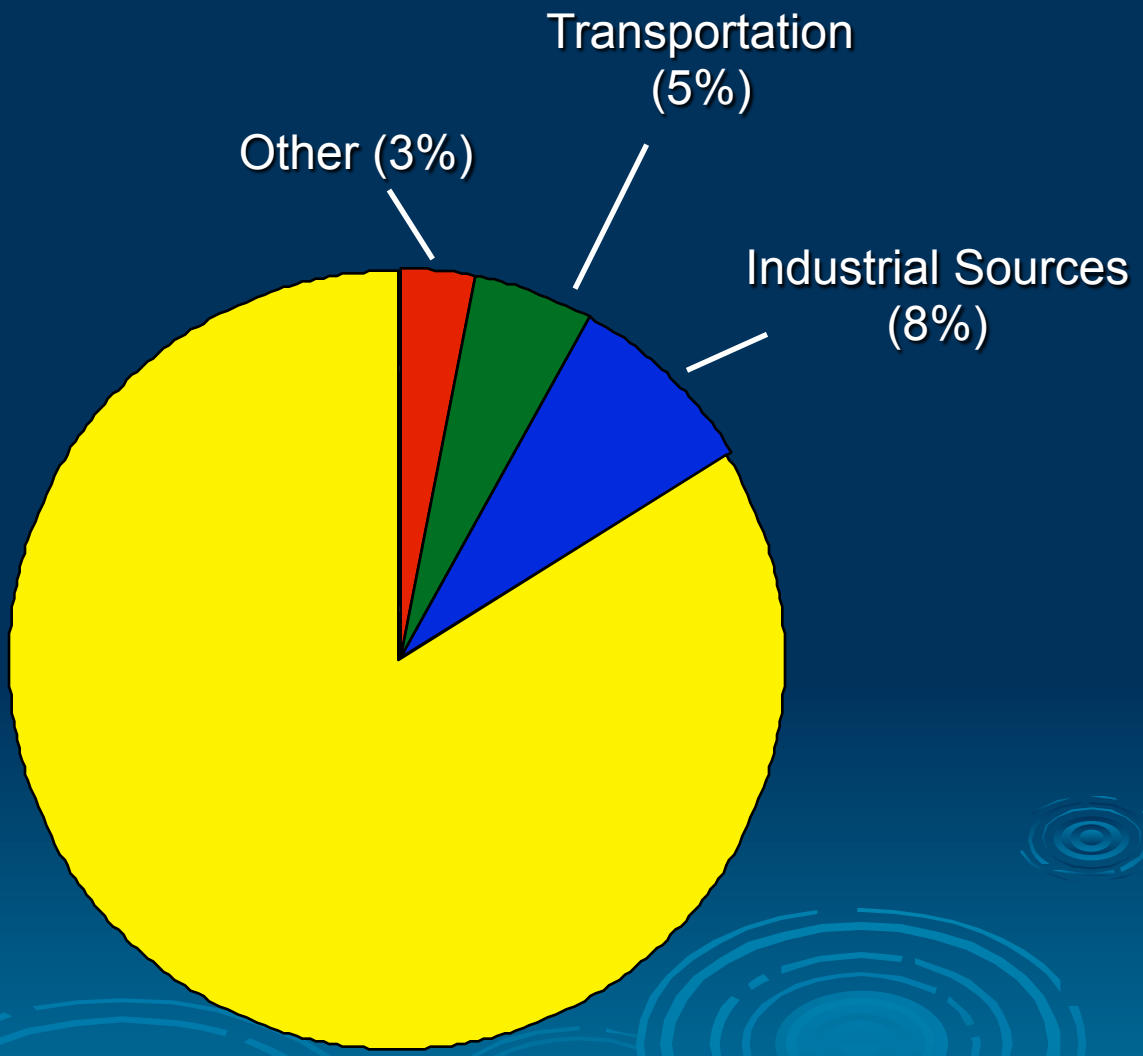
Sources of Sulfur Pollution in the US

- Data from 1998
- Most emissions are from electric utilities (Coal burning)



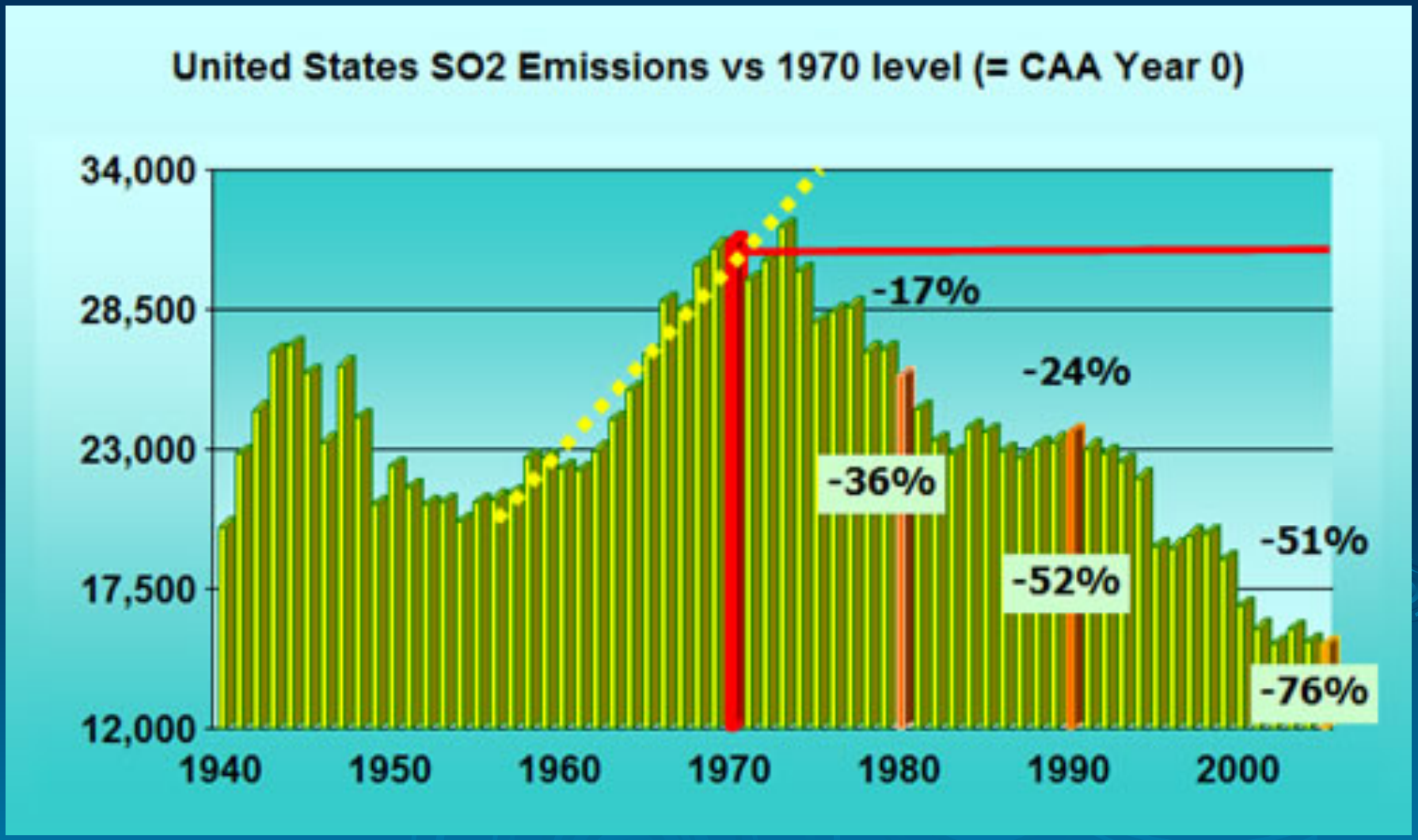
Sources of Sulfur Pollution in the US

- Data from 2002
- Total emissions down 34% since 1990
- Most emissions are from electric utilities (Coal burning)

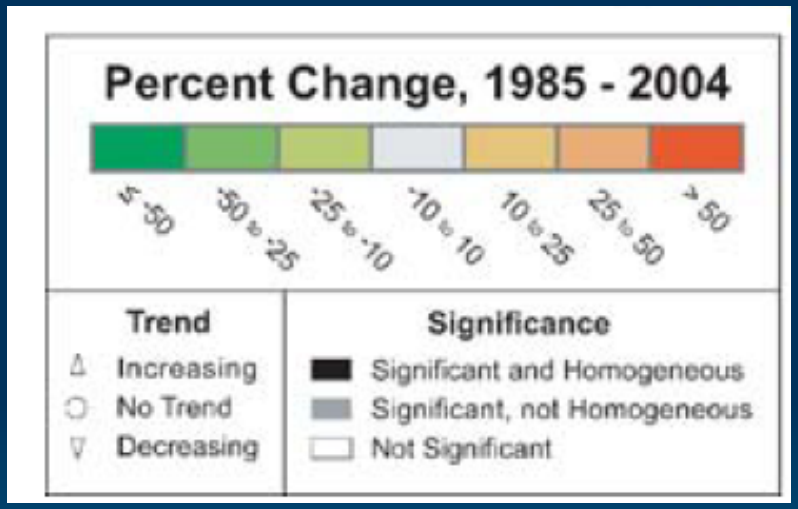


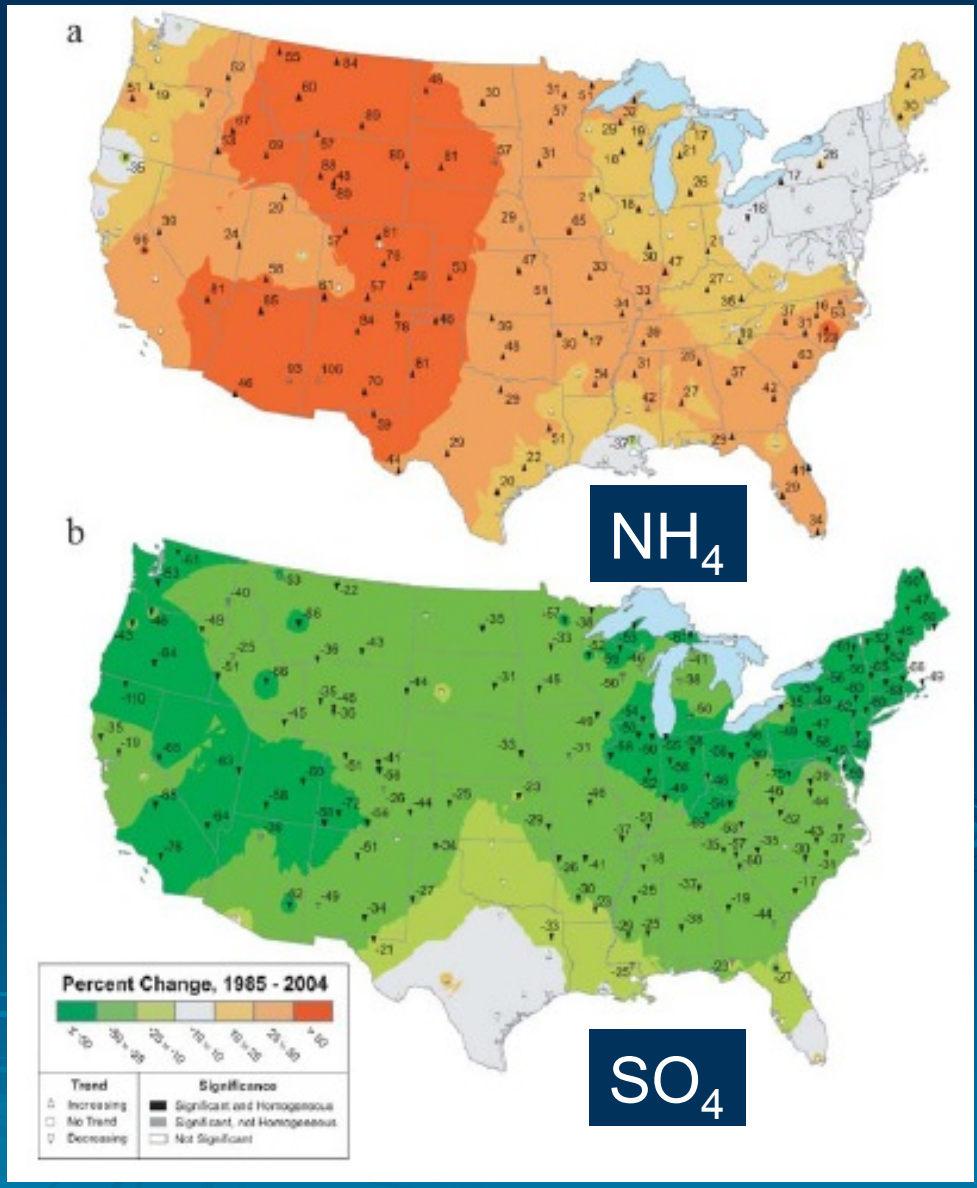
Fuel Combustion (84%) - 70% of this is electrical utilities

Long-Term Trend In US SO_2 Emissions



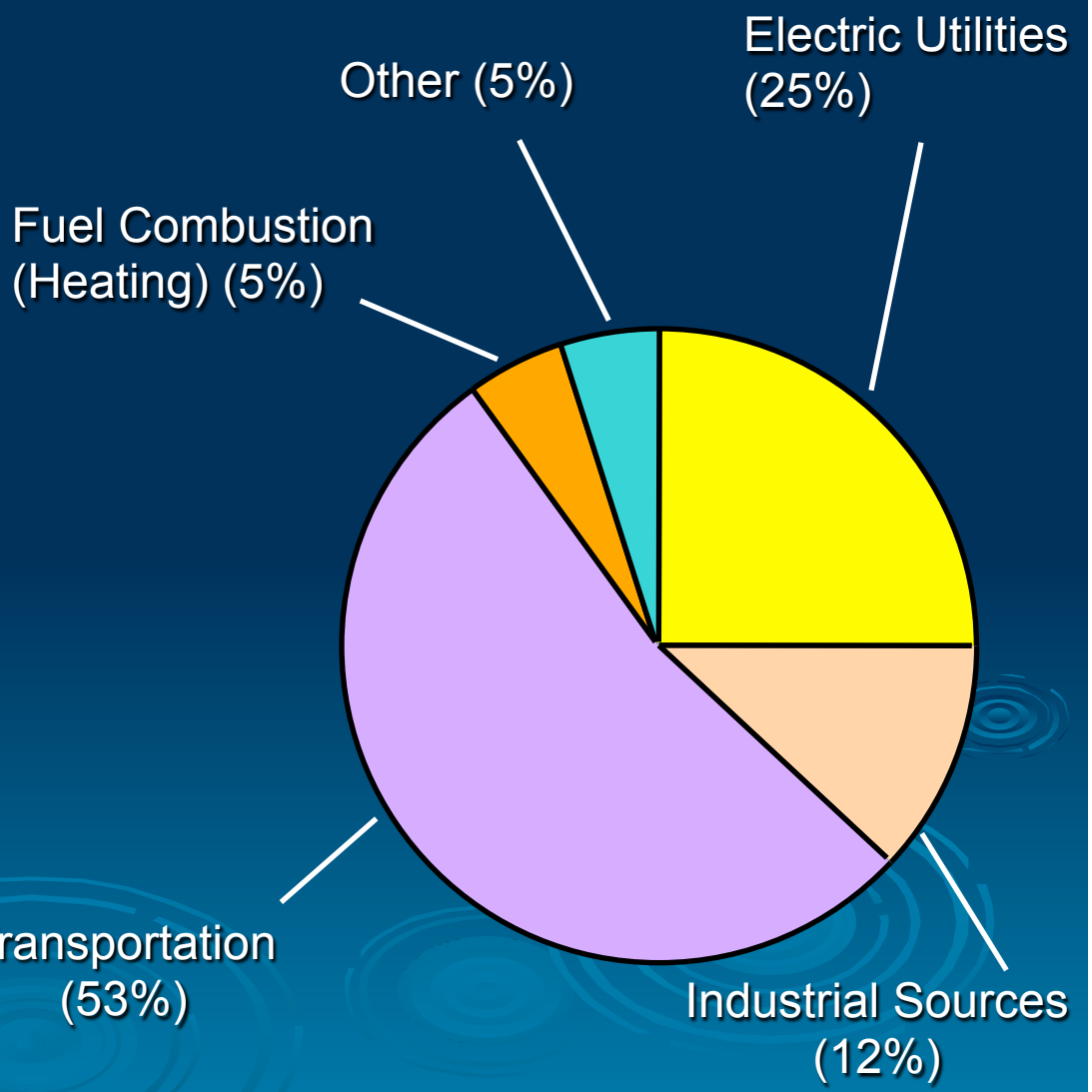
Ammonium and Sulfate Trends, 1985-2004





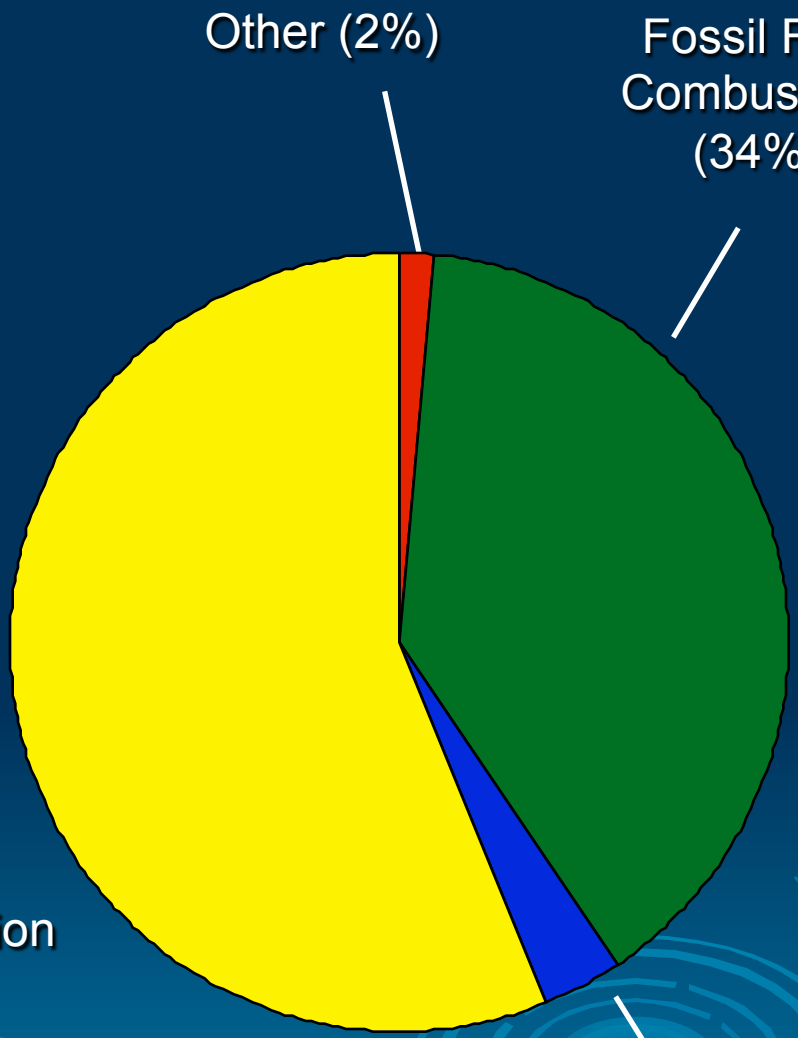
Sources of NO_X Pollution in the US

- Data from 1998
- Most emissions are from transportation (Nitrogen oxide emissions from automobiles)



Sources of NO_X Pollution in the US

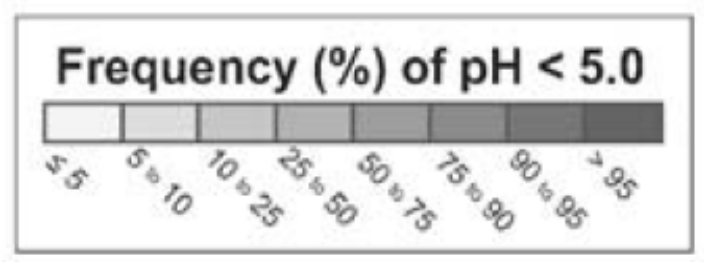
- Data from 2002
- Total: 16% decrease since 1990
- Most emissions are from transportation
- (Nitrogen oxide emissions from automobiles)



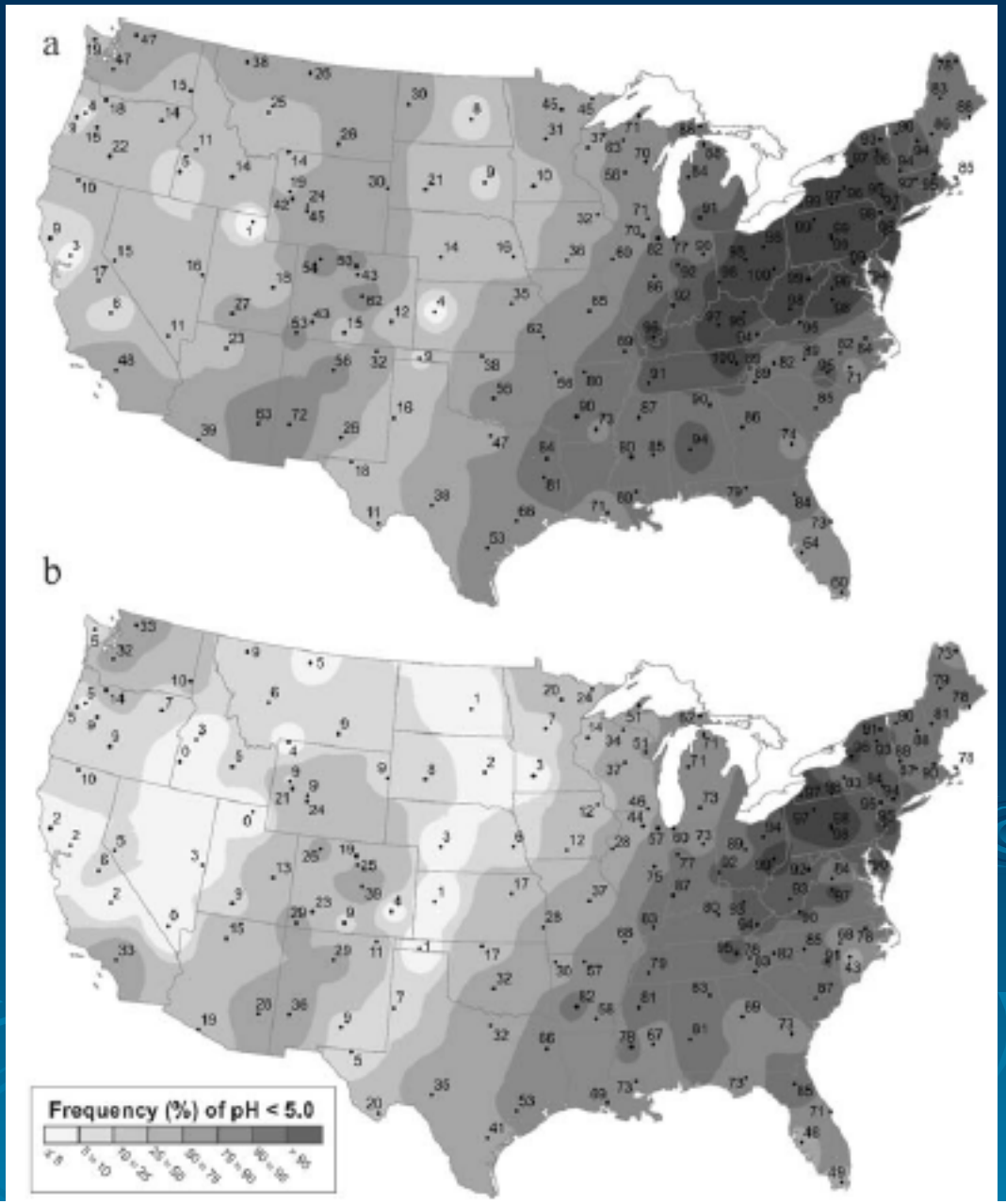
*22% electrical; 12% heating fuels

Trend in Frequency of Acid Rain (pH < 5)

1994-1996



2002-2004



Emission Trends

- In the US, control measures will provide significant environmental relief over the next decades
- But this can not be expected to solve the acid rain problem
  - First, little decrease in NOx emissions
  - Second, acid rain is in part a cumulative problem, as the acid-neutralizing capacity of soils gets depleted the ecosystems become increasingly sensitive to additional acid inputs
- Recently, there has been considerable interest in the possibility that reductions of SO2 emissions to combat the acid rain problem might have negative side effects on climate (cooling effect)