NATS 101
Section 13: Lecture 31

Air Pollution
Part II

Last time we talked mainly about two types of smog:

1*: *London-type smog

2. L.A.-type smog or photochemical smog

What are the necessary ingredients for each type?

Today's topics:

Acid rain
Ozone hole

Ohio River coal power plant

Though London-type smog in the eastern U.S. has lessened in recent years, coal burning in the Ohio Valley and surrounding areas is associated with another problem…

Why does most acid rain in North America occur north and east of this region?

Brief Review of Basic Chemistry of Acids and Bases

Acidity: Refers to the concentration of hydrogen (H+) ions.

Alkalinity: Refers to the concentration of hydroxide (OH-) ions.

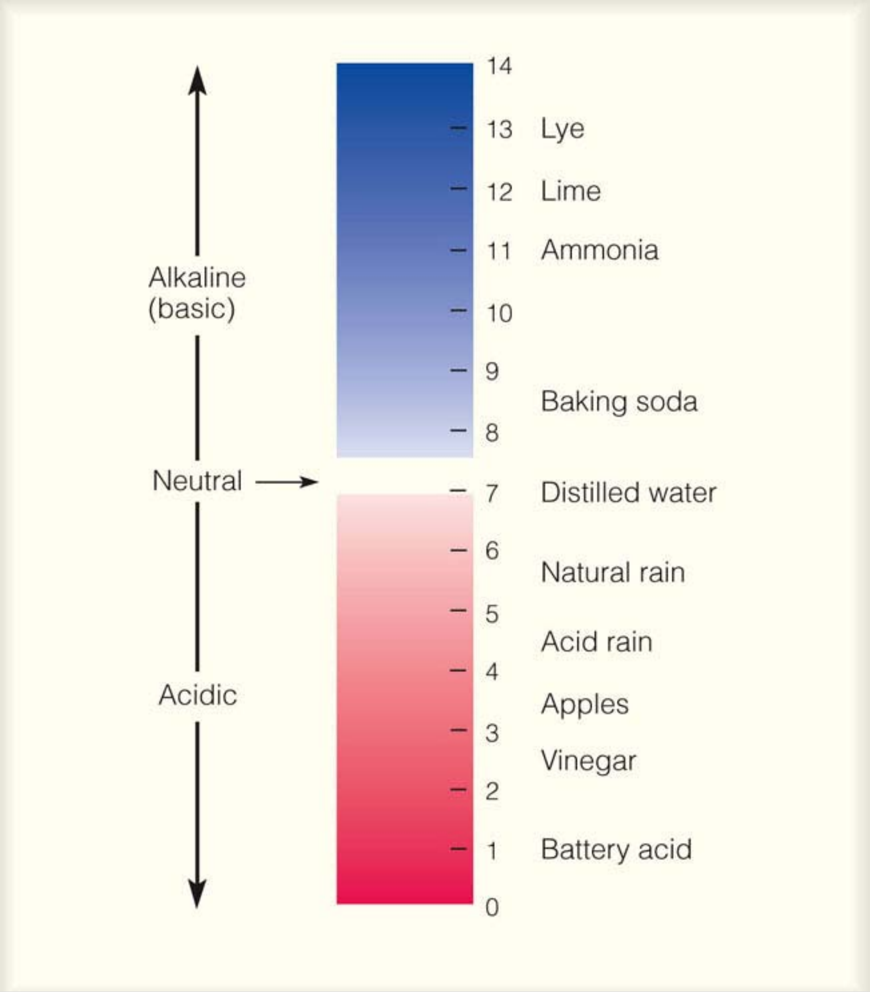
The degree of acidity or alkalinity is given by the pH scale (1-14).

Acids are at the low end of the scale
pH of 7 is neutral
Bases are at the high end of the scale

Characteristics of strong acids

Sting and burn the skin
Highly corrosive
Toxic

pH Scale: Degree of Acidity and Alkalinity



Natural rain is slightly very weakly acidic (pH = 5 to 6)

Acid rain has a pH of about 4 to 4.5

The pH is scale is LOGARITHMIC, so for each numerical value lower on the scale, it is ______ times more acidic.

Acid rain is about __________ times more acidic than natural rain.

Acid rain chemistry

1. **Sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are emitted as primary pollutants, mainly from coal burning.**

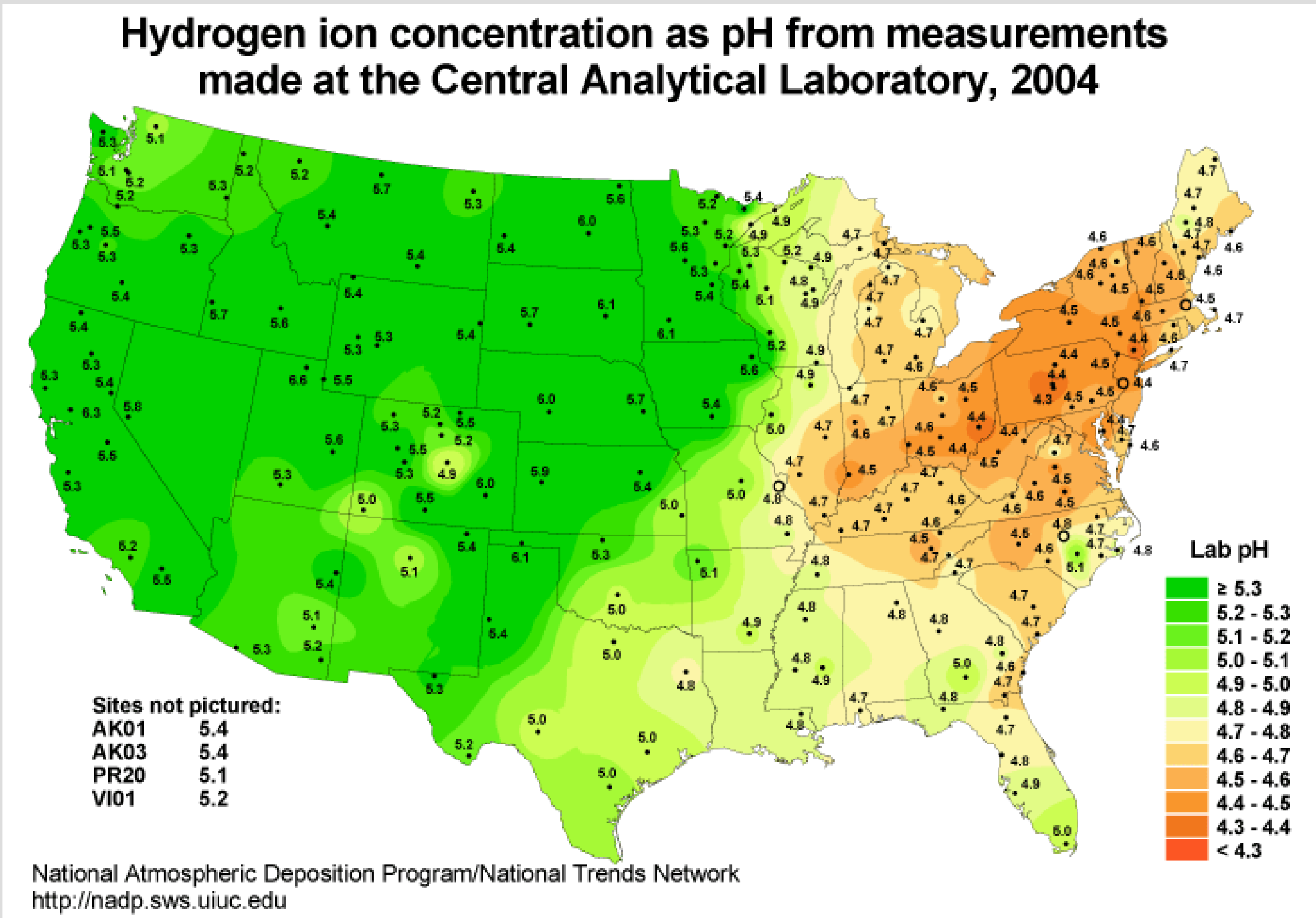
2. **When these primary pollutants interact with a cloud water drop, acidic particles are formed:**

   $SO_2 + H_2O \rightarrow H_2SO_4$ (Sulfuric acid)
   $NO_x + H_2O \rightarrow HNO_3$ (Nitric acid)

3. **The clouds carrying the acidic drops are carried downwind of the pollution source(s) by the prevailing winds.**

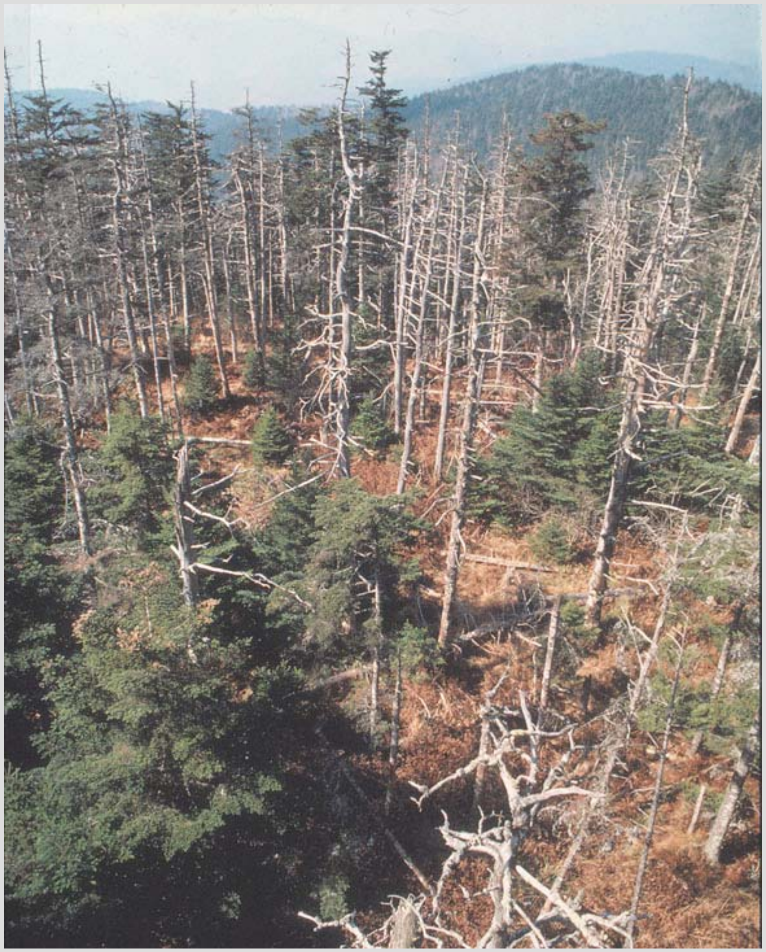
In the mid-latitudes, acid rain typically occurs _______________ of polluting sources because of the path of mid-latitude cyclones.

Acid Rain in the U.S.



Most acidic rain in the eastern part of the country, downwind of coal plants in the Ohio River Valley area. ***Where are the worst places?***

Effects of Acid Rain



Damaged trees in the Smoky Mountains

In many eastern U.S. forests, acid rain has lead to severe tree damage by changing the soil chemistry.

Freshwater aquatic ecosystems are particularly sensitive to changes in acidity.

Many small lakes in New York's Adirondack Park, for example, are no longer able to support fish populations.

Central and Eastern Europe have also been severely affected by the acid rain problem

<u>Factors:</u>

Downwind of Rhine industrial zone in Northern Germany

Old and highly polluting coal plants (that are *still* operating) in former communist countries, like Czechoslovakia, Poland, and former East Germany

Acid rain effects in Czech Republic

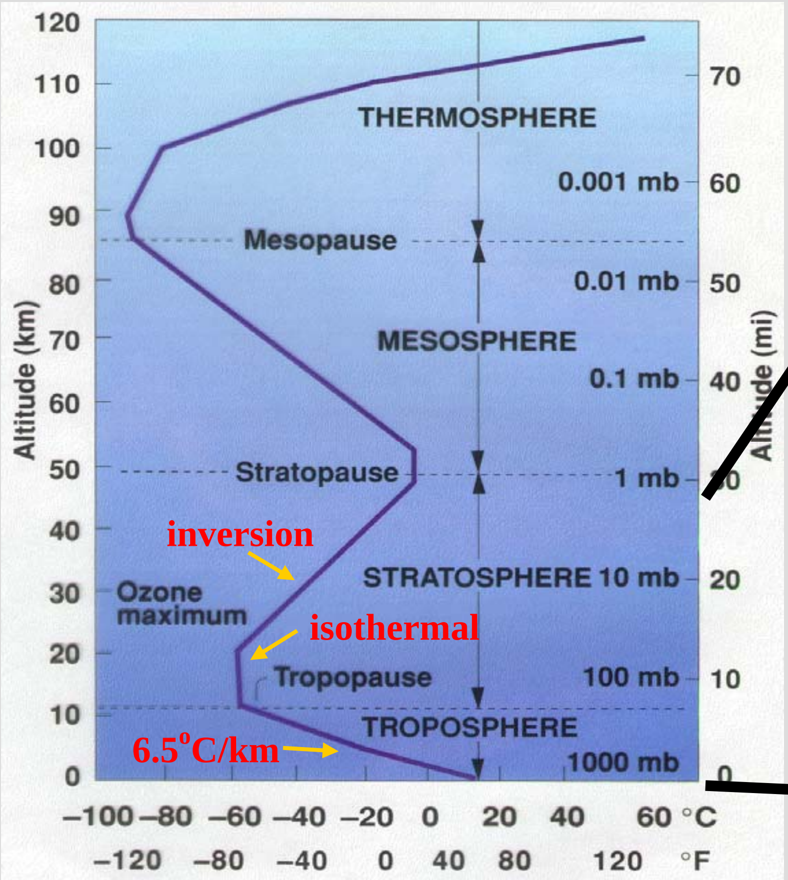
Acid Rain Effects on Buildings and Monuments

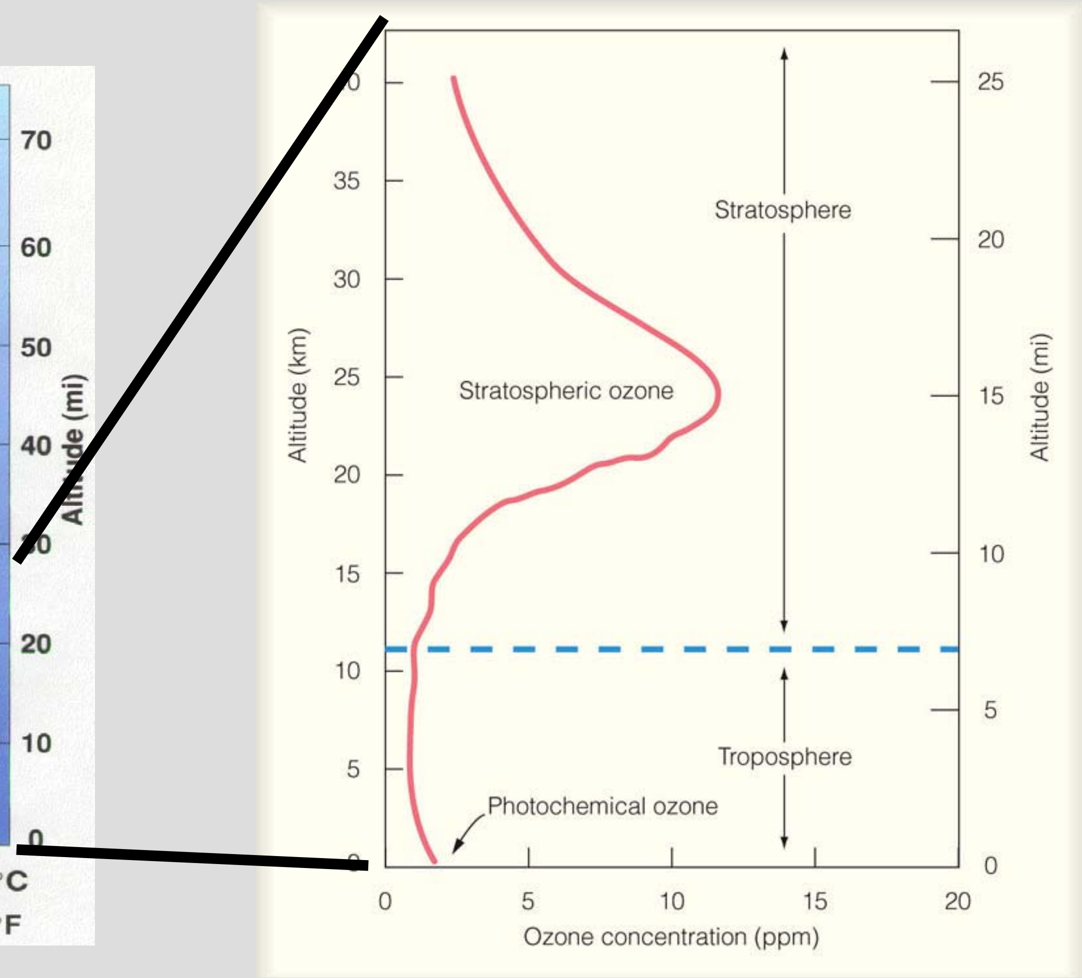
Sandstone figure in Germany
1908

Same figure
1968

Last air pollution topic we'll cover is the ozone hole.

Is stratospheric ozone good or bad? Why?

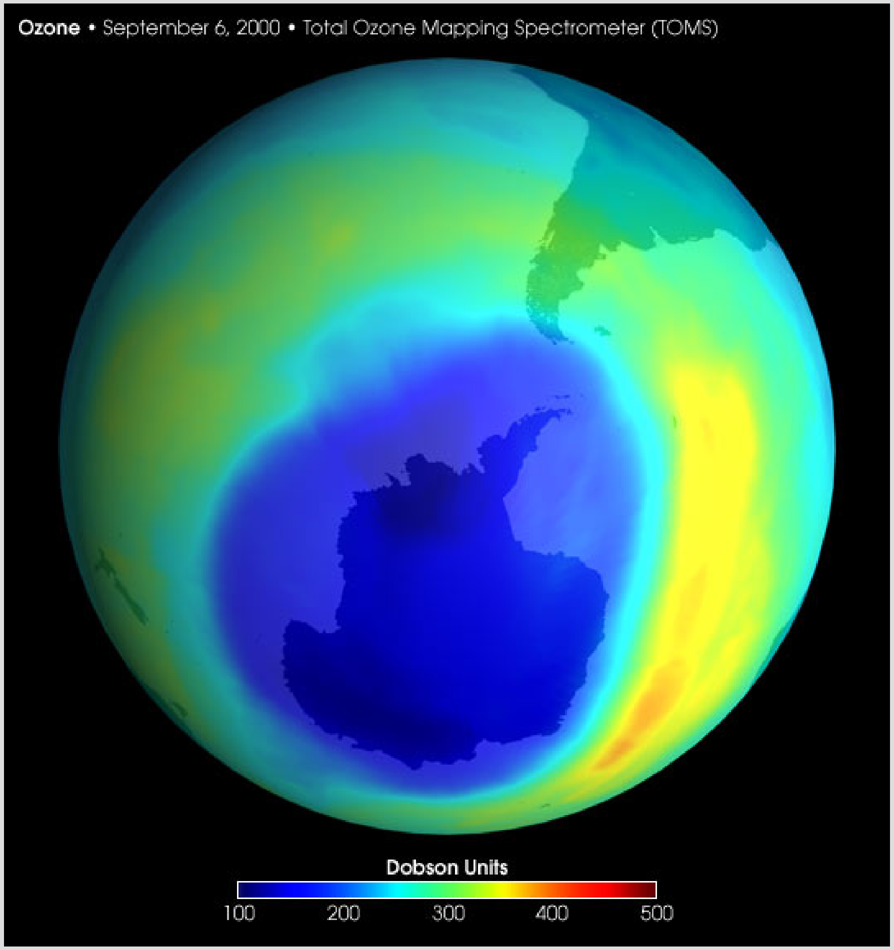




Recall that the warming in the stratosphere occurs due to the photodissociation of ozone and oxygen.

Photodissociation occurs because of absorption of the sun's UV rays.

Flashback to Lecture 2
Stratospheric Ozone and CFCs



(NASA imagery)

Stratospheric ozone protects from Sun's UV rays.

An ozone hole occurs over the polar regions because of the combination of CFCs, chemical reactions on polar stratospheric clouds, and the dynamics of the polar vortex.

Potential harmful effects of stratospheric ozone loss

Basically, UV radiation is strong enough to damage deoxyribonucleic acid (DNA), or the genetic material in all living organisms.

Health effects on humans

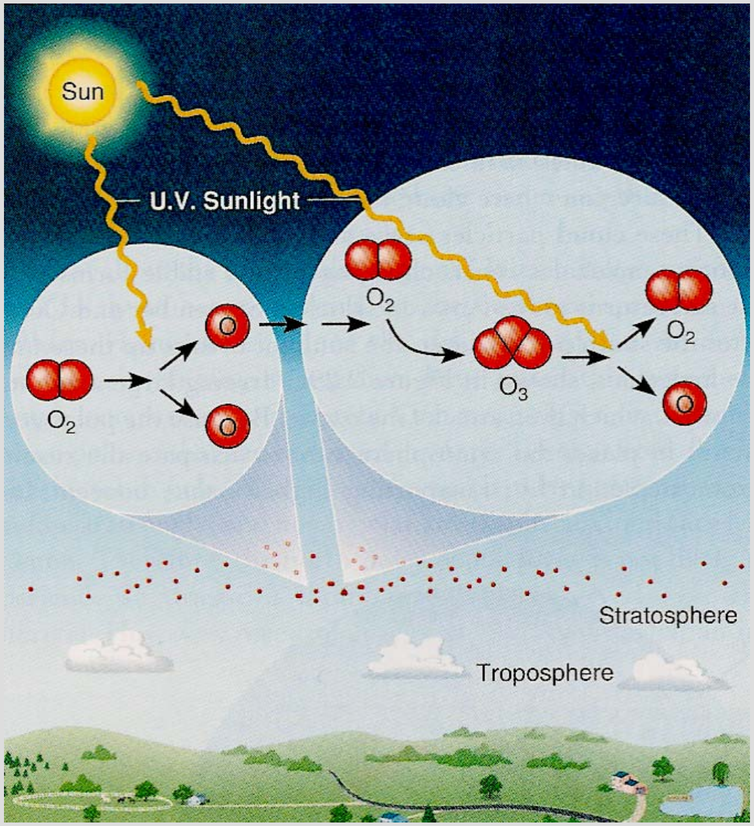
- Skin cancer
- Increase in eye cataracts
- Immune suppression

Damage to plants—including crops for food supply

Damage to animals

Reduction in ocean phytoplankton—the base of the food chain in the ocean.

Natural Balance of Stratospheric Ozone



(Danielson)

Photodissociation of molecular oxygen (O_2) by sun's UV rays, generating two oxygen radicals (O):

$$O_2 + UV \rightarrow O + O$$

Oxygen radical combines with oxygen molecule to form ozone (O_3):

$$O_2 + O \rightarrow O_3$$

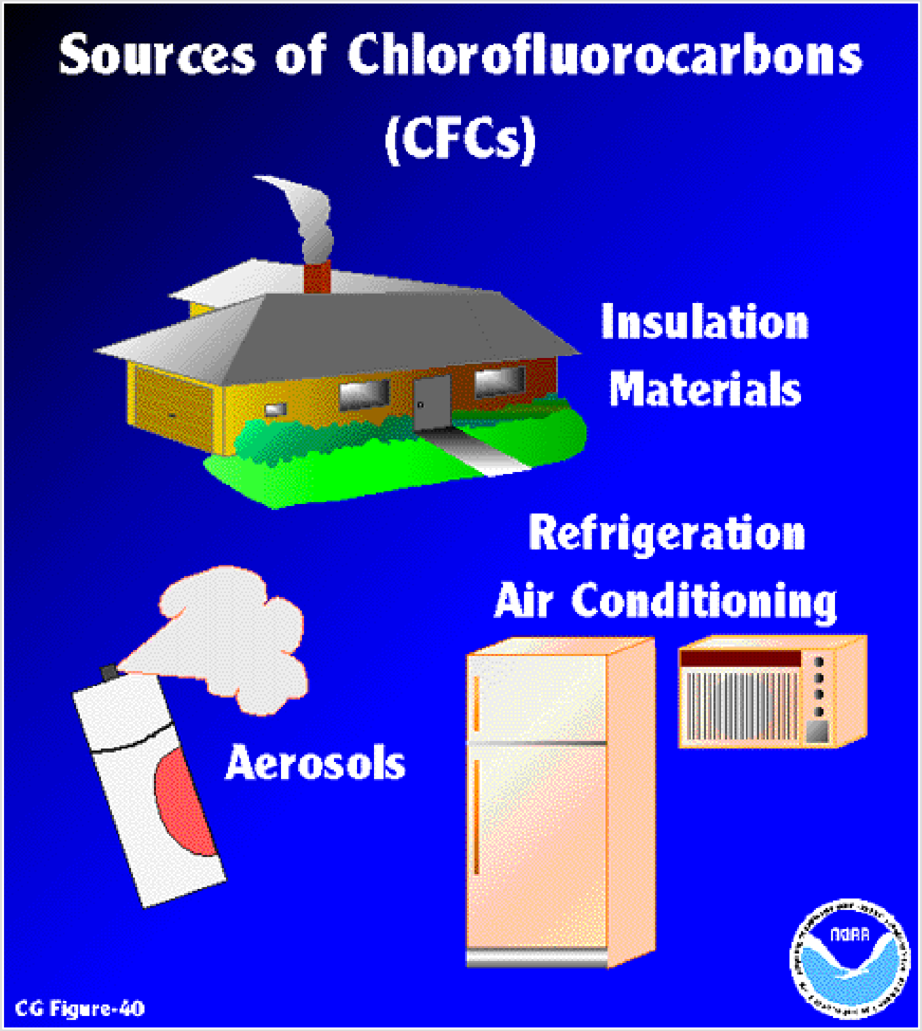
Ozone is photodissociated by sun's UV rays to form molecular oxygen and oxygen radical:

$$O_3 + UV \rightarrow O_2 + O$$

RESULT: There is a natural balance between ozone creation and destruction which keeps the stratospheric ozone concentration stable.

What can upset the natural balance of ozone is the presence of Chlorofluorocarbons (CFCs), or similar compounds.

<u>Chlorofluorocarbons (CFCs):</u> **Compounds consisting of methane or ethane with some or all of the hydrogen replaced by chlorine or fluorine.**



Why are CFCs used?

Relatively non-reactive materials, so very chemically stable.

Relatively cheap to mass produce.

Utility for a wide variety of applications.

Ignored caveats:

CFCs are fairly chemically stable UNTIL they reach the stratosphere.

Have extremely long lifetimes, like 100s of years.

What happens when CFCs reach stratosphere?

CFC molecules are photodissociated to generate atomic chlorine (Cl)

The presence of atomic chlorine DISRUPTS the natural ozone cycle

Ozone combines with atomic chlorine, creating chlorine monoxide (ClO) and atomic oxygen

$$O_3 + Cl \rightarrow ClO + O_2$$

Oxygen radical combines with chlorine monoxide, creating atomic oxygen and liberating chlorine atom—which can destroy more ozone:

$$O + ClO \rightarrow O_2 + Cl$$

RESULT: A SINGLE CHLORINE ATOM CAN DESTROY 100,000 OZONE MOLECULES BEFORE IT IS CHEMICALLY SEQUESTERED!

Sequestering Reactions

The chlorine atom eventually is sequestered by reacting with methane (CH_4) or nitrogen dioxide (NO_2), forming Chlorine nitrate ($ClONO_2$) and hydrogen chloride as by products.

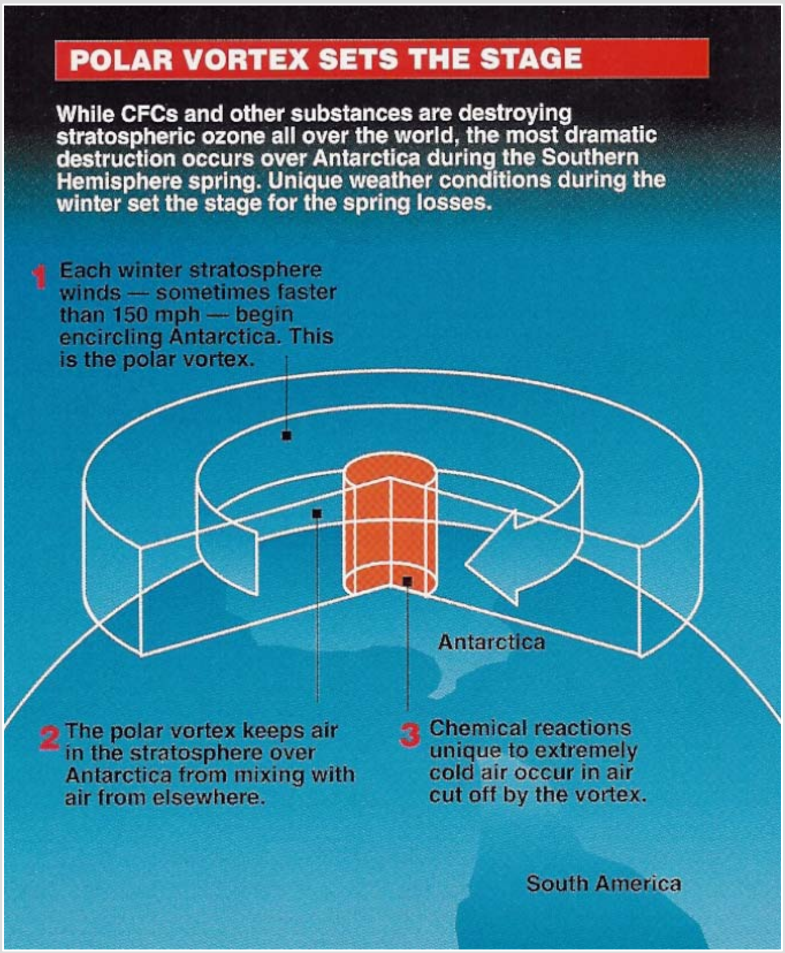
$$ClO + NO_2 \rightarrow ClONO_2$$

$$CH_4 + Cl \rightarrow HCl + CH_3$$

BUT THIS IS NOT THE END OF THE STORY!

OVER THE POLES SOMETHING SPECIAL HAPPENS—WHICH LIBERATES CHLORINE FROM THESE CHEMICAL BY PRODUCTS!

Ozone Hole Ingredient #1: The Polar Vortex



Circumpolar vortex keeps air over Antarctica from mixing with warmer air from middle latitudes.

Strongest in winter when Antarctic temperatures are coldest.

Temperatures drop to below -85°C in stratosphere.

Ozone Hole Ingredient #2: Polar Stratospheric Clouds

Form when the stratospheric temperatures within the polar vortex drop below -85°C

THESE CLOUDS ACT AS A CATALYST TO LIBERATE CHLORINE FROM ITS SEQUESTERED FORM.

Chemical reaction *on the cloud*:

$$ClONO_2 + HCl \rightarrow Cl_2 + HNO_3$$

Once chlorine gas (Cl_2) is liberated, it can be photodissociated in the presence of sunlight—liberating the chlorine atom (Cl) to destroy ozone!

What is the season of maximum ozone loss?

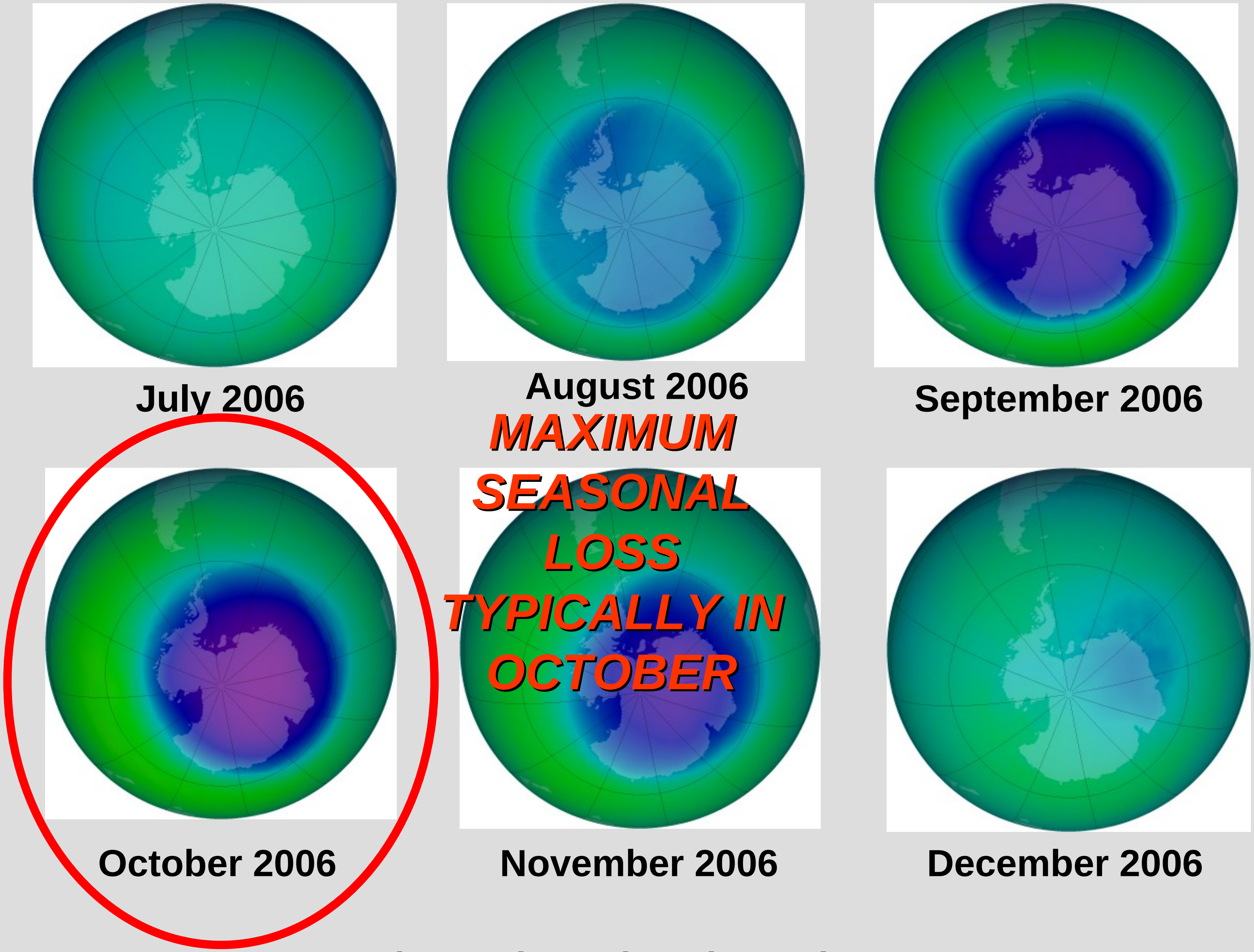
Maximum ozone loss over the South Pole occurs during the Antarctic spring (September-October)

REASONS

1. Temperatures still cold enough to support polar stratospheric clouds within the polar vortex

2. There is sunlight to photodissociate molecular chlorine.

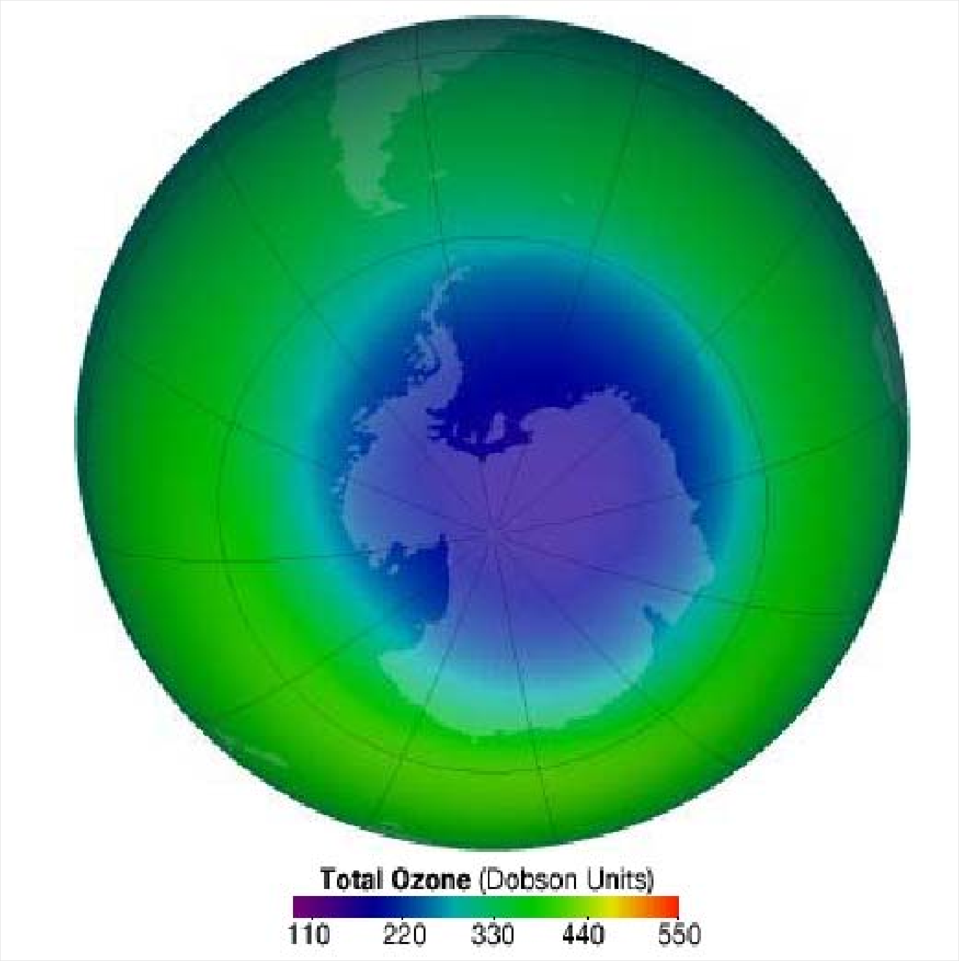
Seasonal Cycle of Ozone in Antarctic



NASA TOMS Imagery

Blue and purple colors = less ozone

Ozone Measurement: Dobson Units



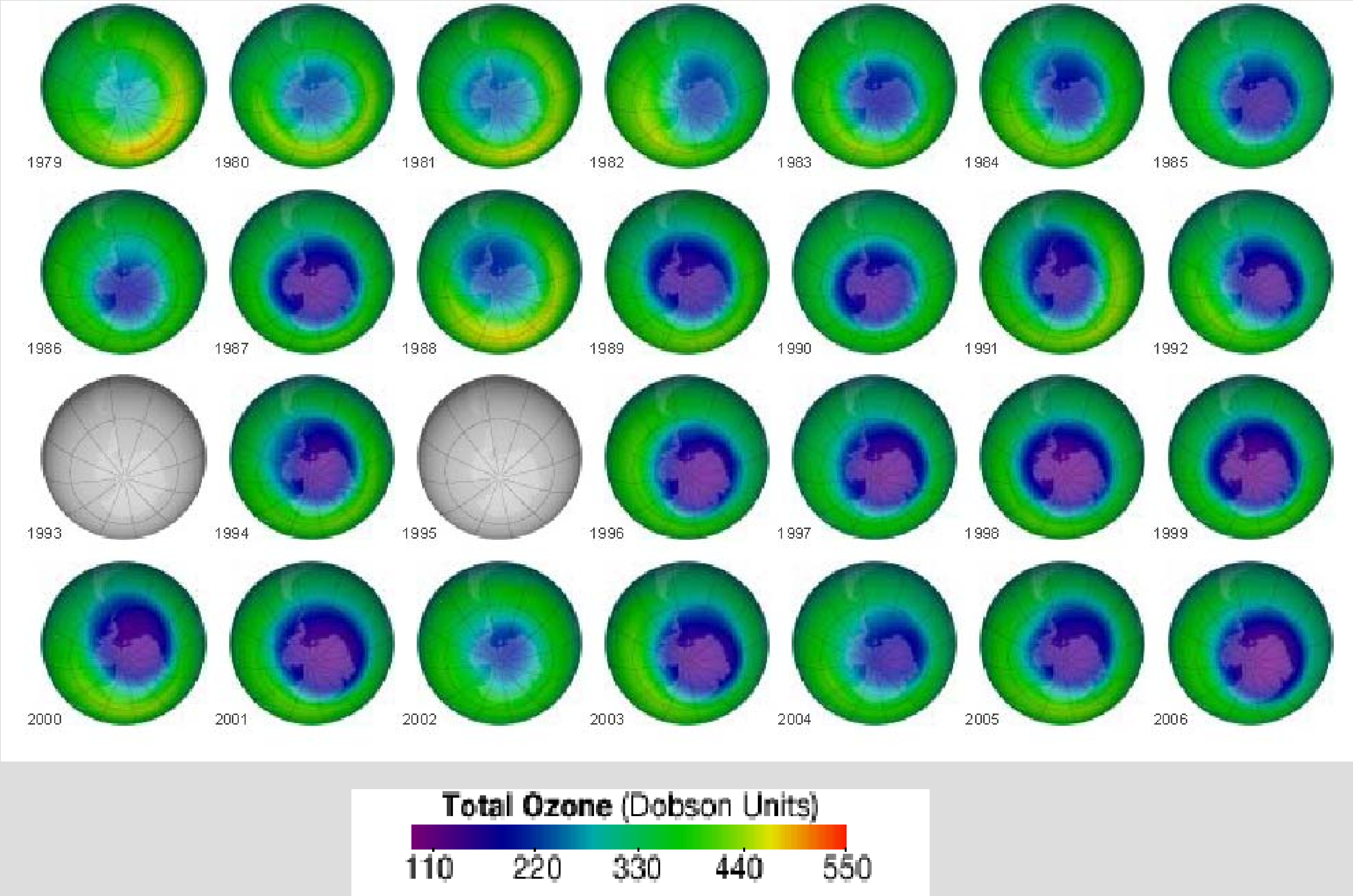
NASA TOMS Imagery

Ozone can be measured by the depth of ozone if all ozone in a column of atmosphere is brought to sea-level temperature and pressure.

One *Dobson unit* corresponds to a 0.01 mm depth at sea-level temperature and pressure.

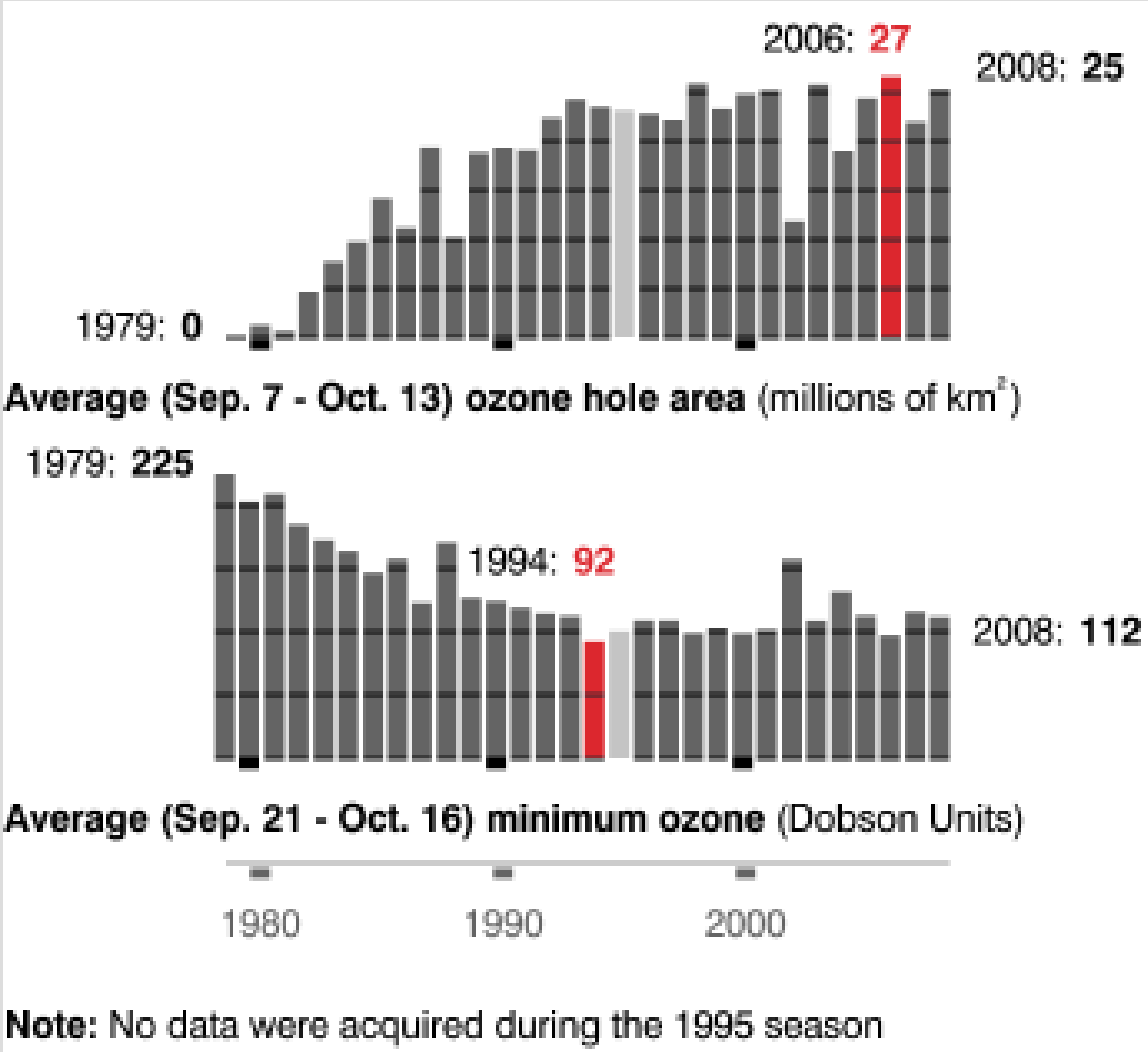
The "ozone hole" is defined where the total ozone is below 220 Dobson units.

Ozone Hole Evolution:
Antarctic October Ozone from 1979-2006



SIZE OF OZONE HOLE

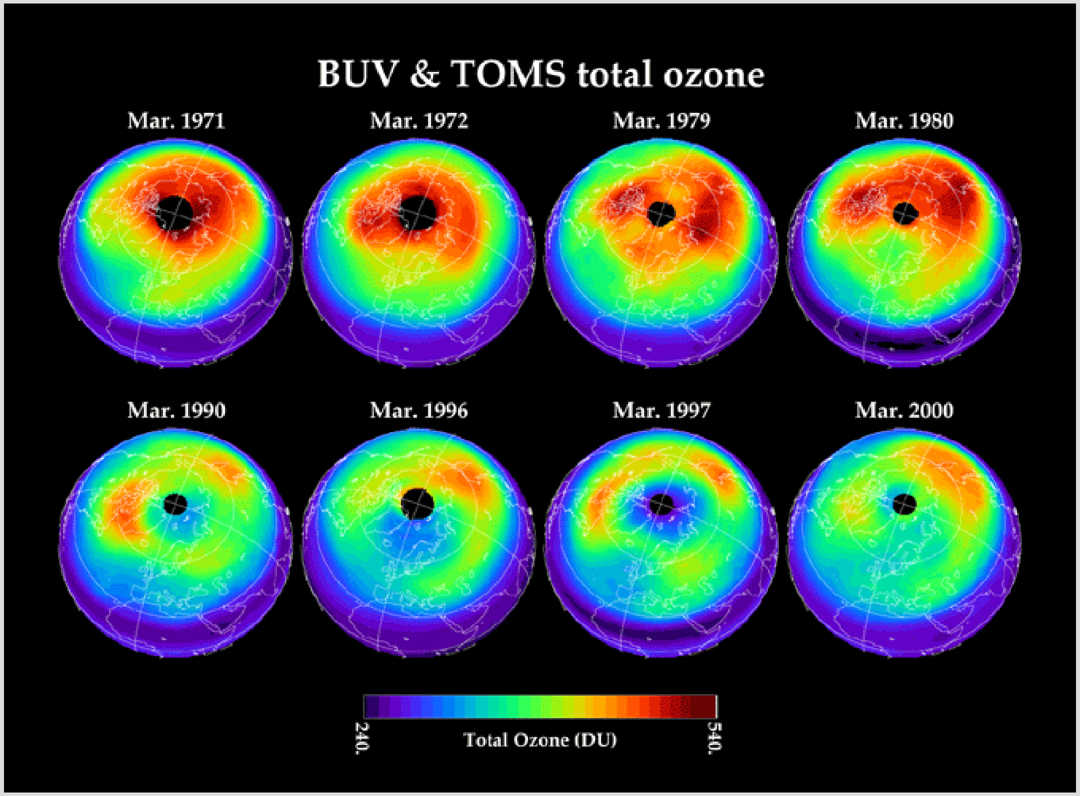
MINIMUM OZONE VALUE



NASA

There's an ozone hole in the Arctic too!

Ozone evolution in Northern Hemisphere



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Not as dramatic as Antarctica

<u>REASONS</u>:

Arctic polar vortex is not as strong in winter.

Harder to form the polar stratospheric clouds necessary to maximize the ozone loss.

Montreal Protocol (1987)

Nations met in Montreal in 1987 to come up with a global strategy to control CFC emissions.

Original protocol called for a 50% reduction in CFCs by 1998.

Subsequently amended to call for complete phase by 2000.

<u>A SUCCESS STORY!</u>

Most nations are largely abiding by the protocol, and a decrease in CFCs has been observed since the late 1990s. But it will take a long time for the ozone hole to “heal”—probably another 100 years.

Footnote: A credit to the person who helped figure out the ozone hole

Dr. Susan Solomon

Dr. Susan Solomon was the scientist who proposed the idea that chemical reactions on polar stratospheric clouds was a part of the ozone destruction in the Antarctic.

She is now one of the IPCC chairs.

Summary of Lecture 31

Acid rain forms when sulfur dioxide and nitrogen oxides interact within a cloud water drop. It is about 5 to 10 times more acidic than normal rain.

Acid rain occurs downwind of pollution sources (mainly coal plants). It causes damage to forests, aquatic ecosystems, and buildings and monuments.

Loss of stratospheric ozone permits the sun's UV rays to reach the ground. The UV radiation damages DNA, adversely affecting life.

There is a natural balance between stratospheric ozone creation and destruction which keeps the ozone concentration stable. CFCs disrupt this balance.

CFCs photodissociate in the stratosphere, resulting in chlorine atoms which destroy ozone before eventually being sequestered.

In polar regions, cold stratospheric temperatures cause the formation of polar stratospheric clouds. These clouds act as a catalyst to liberate chlorine from its sequestered form. Once photolyzed in the presence of sunlight, this liberated chlorine destroys even more ozone—causing the ozone hole.

Reading Assignment and Review Questions

Reading Assignment

Chapter 17

Chapter 18 Review Questions

Questions for Review: 9,10,11,12,25,26

Questions for Thought: 8