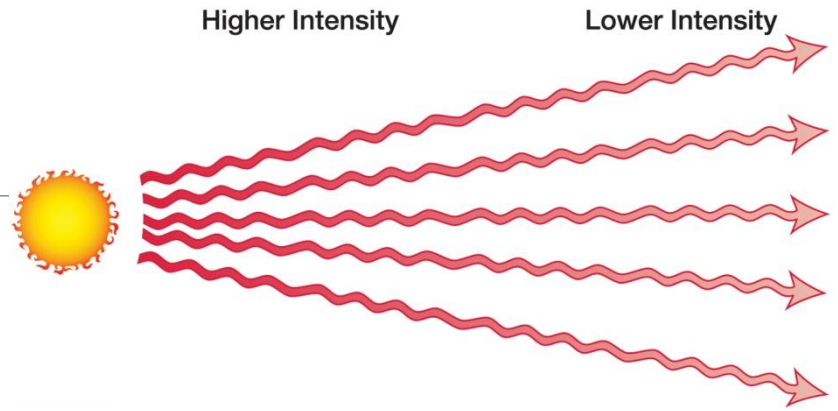
Global Energy Balance

June 14th, 2021

Solar Energy



Solar energy is electromagnetic energy

Wavelengths and frequency

Electromagnetic spectrum

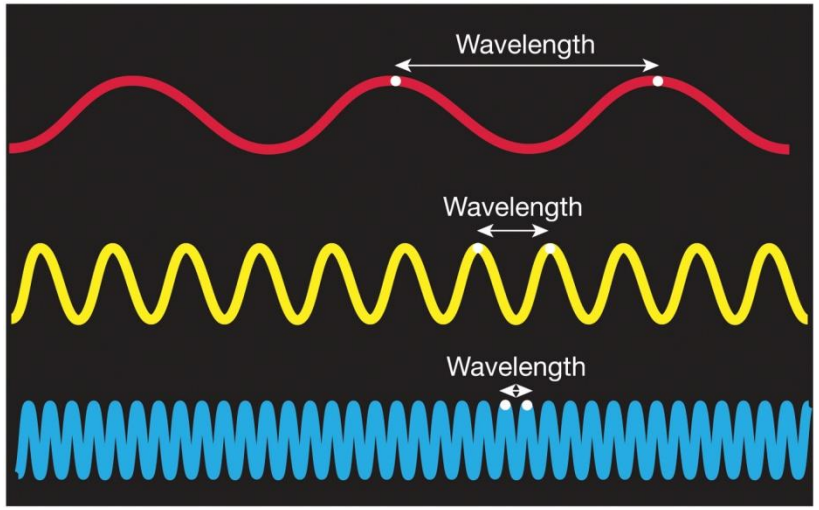
Three important areas on the spectrum

- Visible radiation
- Ultraviolet radiation
- Infrared radiation

Shortwave solar radiation, insolation

Radiation

- Movement of energy without a medium



What will happen to the Energy?

Absorption

- the ability of an object to assimilate (take up or hold) energy from the electromagnetic waves that strike.

Reflection

- the ability of an object to repel waves without altering either the object or the waves

Scattering

Transmission

- Electromagnetic waves pass completely through a medium

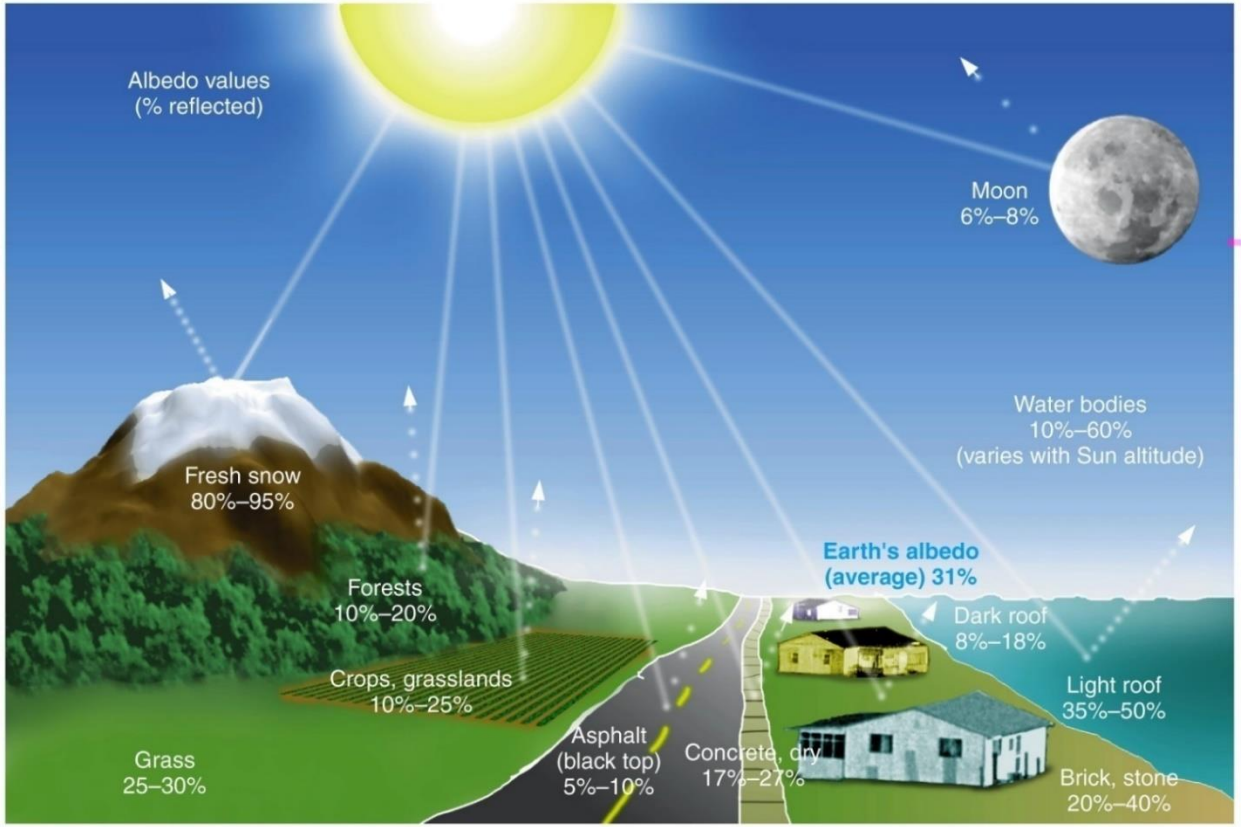
Reflection and Albedo

Albedo is the ability of a surface to reflect insolation - the reflective quality or intrinsic brightness of a surface.

It is an important control over the amount of insolation that is available for absorption.

Stated in terms of the percentage of insolation that is reflected (0% is total absorption; 100% is total reflectance).

Primarily controlled by an object's color.



Planetary Albedo

The reflectivity or albedo of Earth affects the heat budget of the planet.

- Surfaces
- Clouds
- Water
- Land
- Plants

Aerosols – natural sources are volcanoes, wildfires, windblown dust of soils, land and ocean emissions of biologically produced gases, and sea-salt spray.

http://pubs.usgs.gov/fs/1997/fs113-97/

Earth's Solar Radiation Budget

Budget = balance of incoming and outgoing radiation

Long term there is a balance of energy coming in and energy leaving the planet

Humans are likely altering this balance, but we ignore this for the purpose of understanding atmospheric warming.

Understanding this exchange is critical for grasping weather processes

Earth's Energy Budget

Earth's radiation budget can be described as follows:

Let's for simplicity consider that 100 units of energy represents total insolation (100 %) received at the outer edge of the atmosphere.

Let's assume too that these are annual averages for the entire globe, and do not apply to any specific location; values are approximate.

Earth's Energy Budget

Earth's radiation budget can be described as follows:

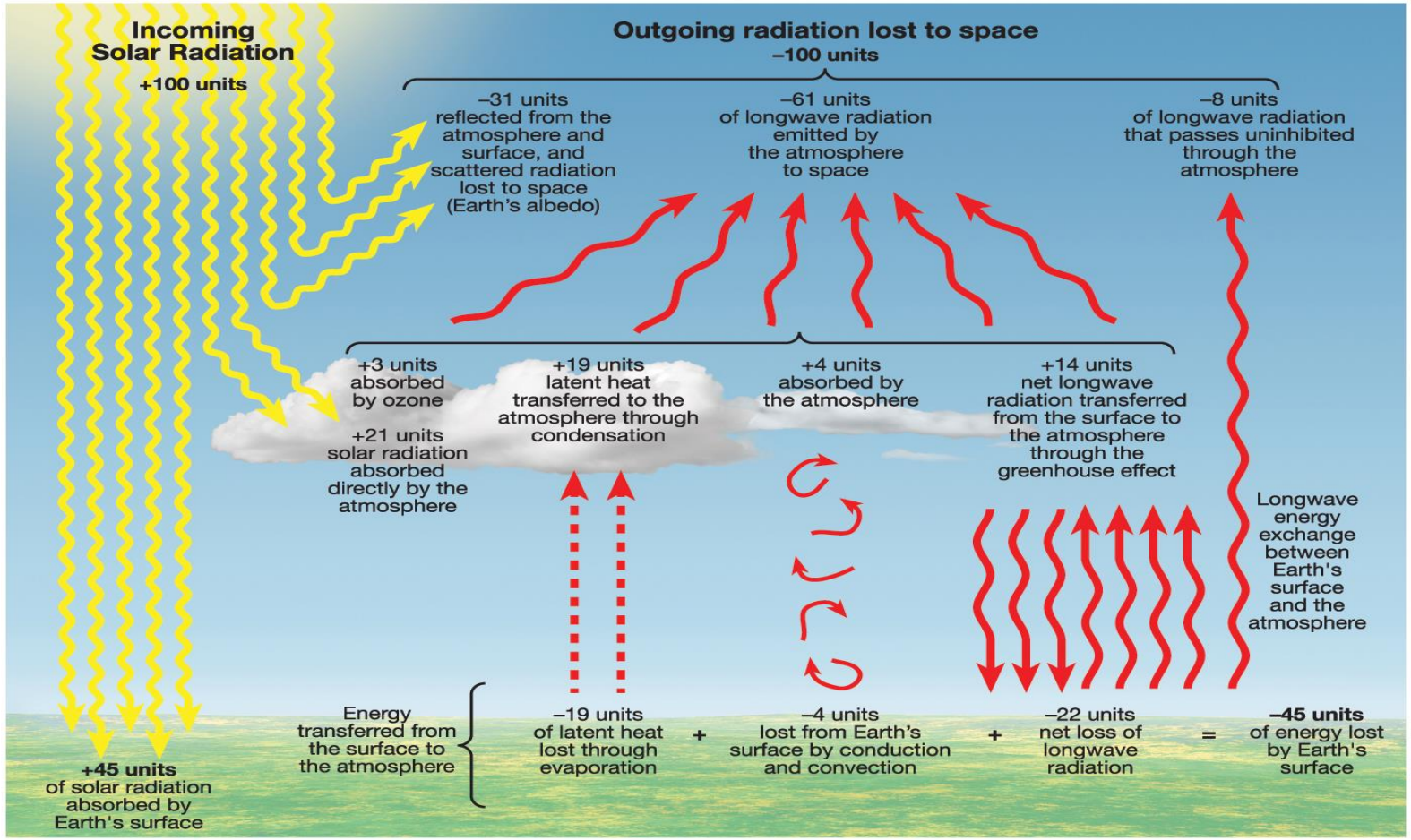
Radiation loss from reflection: About 31 units of total insolation are reflected back (or scattered) into space by the atmosphere (***Earth's Albedo = 31%***)

Direct Absorption of Solar radiation: 24 units heat the atmosphere directly = 3 heating the Ozone (UV energy) and 21 heating the remainder of the atmosphere (***gases and clouds***).

Surface-to-Atmosphere Energy Transfer: 45 units (nearly half the amount) transmits through the atmosphere and are **absorbed** by the Earth's surface where they regulate temperatures

Total energy input budget = 31 + 3+21 (24) + 45 = 100 units

Global Energy Budget



Global Energy Budget

Of the 100 units that arrived:

- **Conduction and convection:** 4 units are lost from Earth's surface via
- **Latent heat loss:** 19 units are lost via evaporation (latent heat) in water vapor.
  - **(¾ of all radiation falls on water surfaces).**
- Some of the **longwave radiation emitted** by Earth's surface is **transmitted directly back to space** (through the atmospheric window) = 8 units;
- Through the **absorption of terrestrial radiation by greenhouse gases** the atmosphere receives a net of 14 units.
  - Total longwave radiation emitted from the surface the Earth : 22 units

Surface longwave budget: 4 + 19 + 8 + 14 = 45 Units

Global Energy Budget

Atmospheric longwave budget (in units) :

- Longwave energy re-radiated by ozone = 3 PLUS Longwave energy reradiated by the atmosphere = 21. This gives 21 + 3 = **24** Units

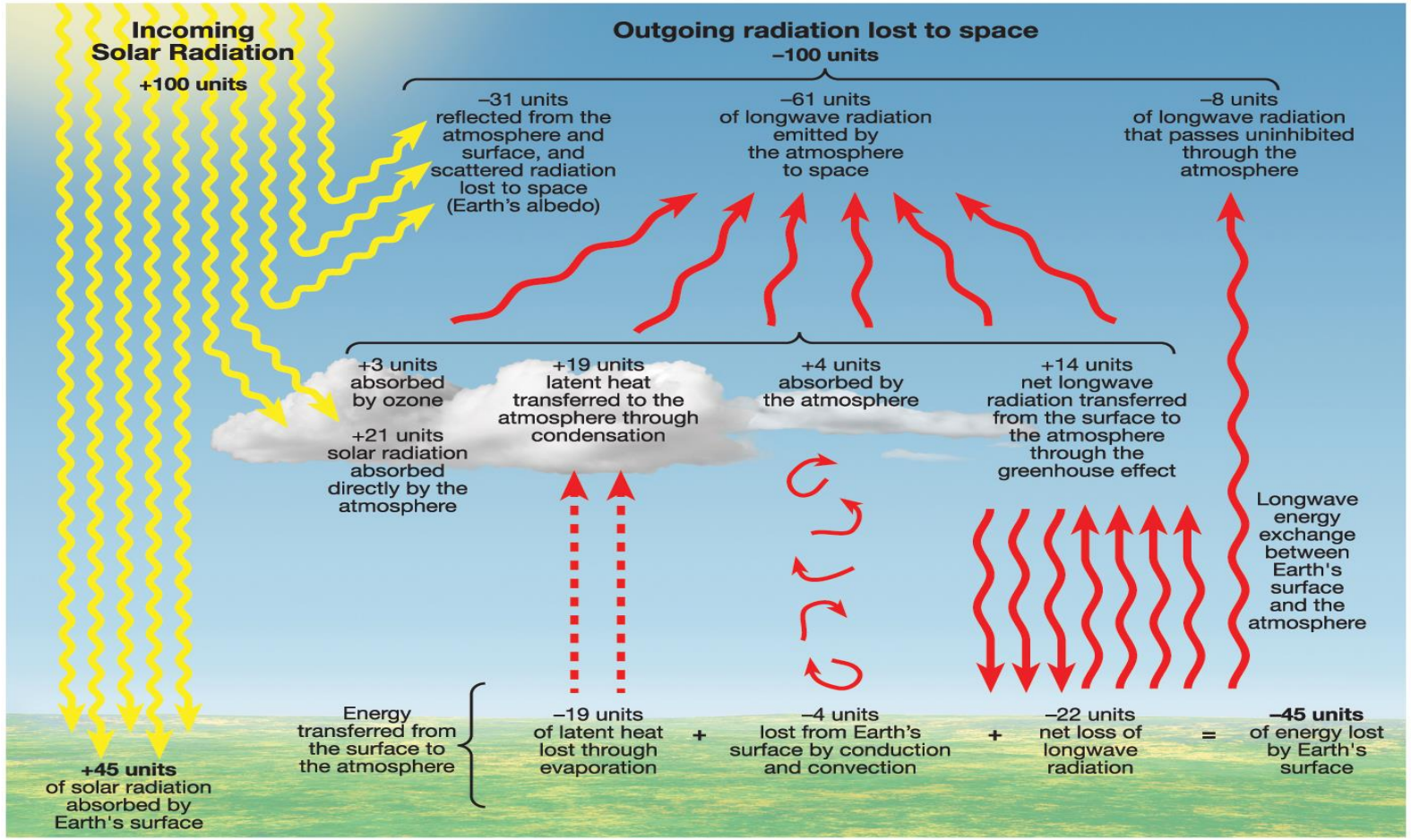
Total re-radiated surface and atmospheric **longwave energy** (in units):

45 + 24 = **69**

Total longwave re-radiated: 69; total shortwave reflected: 31

- 69 + 31 = **100**

Earth's Energy Budget



Earth's Energy Budget

In terms of annual balance, for every 110 units of energy radiated from the surface to the atmosphere, about 96 units of longwave radiation are returned to Earth .

Lost from Earth's surface as longwave radiation = 110; lost from atmosphere back to Earth's surface: 96; = 110 – 96 = **14**

Through the absorption of terrestrial radiation by greenhouse gases, the atmosphere **receives a net gain of 14 units** of energy.

The atmosphere' s greenhouse effect absorbs large amounts of energy and reradiates it back to the Earth – the surface heats the lower atmosphere and in turn the lower atmosphere reheats the surface == ***the greenhouse effect***.

Air Pollution:
Human-Induced Atmospheric Change

Air Pollution

Human-Induced Atmospheric Change

Pollutants, inefficient and wasteful fossil fuel use, and rapid population growth are all contributing to changes in Earth's atmosphere.

Consequences on global climate change have been of a larger concern in recent years.

Trends observed include rising temperatures, sea-level change, increasing heavy downpours, longer growing seasons, reductions in snow and ice, and changes in the amounts and timing of river flows.

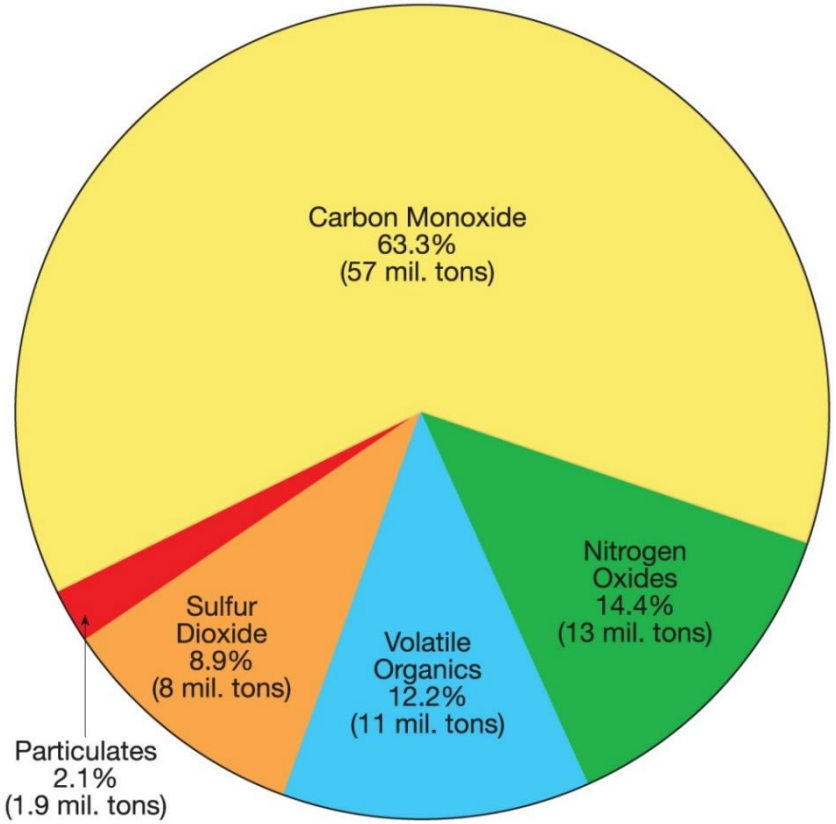
Human-Induced Atmospheric Change

Primary versus secondary pollutant

Primary pollutants – released directly into the air
- Particulates
- Carbon monoxide
- Nitrogen compounds
- Sulfur compounds

Secondary pollutants – form because of pollution
- Photochemical smog

Indoor pollutants



Primary Pollutants

- Particulates
  - Aerosols: tiny solid or liquid particles
  - Smoke from combustion, dust from industrial activities, secondary pollutants
- Carbon monoxide
  - Odorless, colorless
  - Incomplete combustion of carbon-based fuels
- Nitrogen compounds
  - Byproduct of biological process
- Sulfur compounds
  - Volcanoes, burning of fossils

Secondary Pollutant

Photochemical Smog:

Photochemical: pertaining to chemical reactions involving chemical compounds in the presence of radiant energy

Photochemical smog: the mix of natural and atmospheric chemicals with anthropogenic emissions derived mainly from fossil fuel burning produced in the presence of solar radiation.

Leads to reddish, yellow-brown, and gray hazes in the sky

Smog: smoke-fog; haze

Beijing, China

http://i.telegraph.co.uk/telegraph/multimedia/archive/00778/beijing-smog-404_778961c.jpg

Chemicals contributing to Photochemical smog

Carbon monoxide

Sulfur and nitrogen oxides

Lead

Toxic hydrocarbons

Particulates

Product of Photochemical Smog

Ozone

Where is smog a problem?

Cities where temperature inversions occur:

Denver

http://www.huffingtonpost.com/2010/01/08/denver-smog-crackdown-epa_n_416234.html

Mexico City

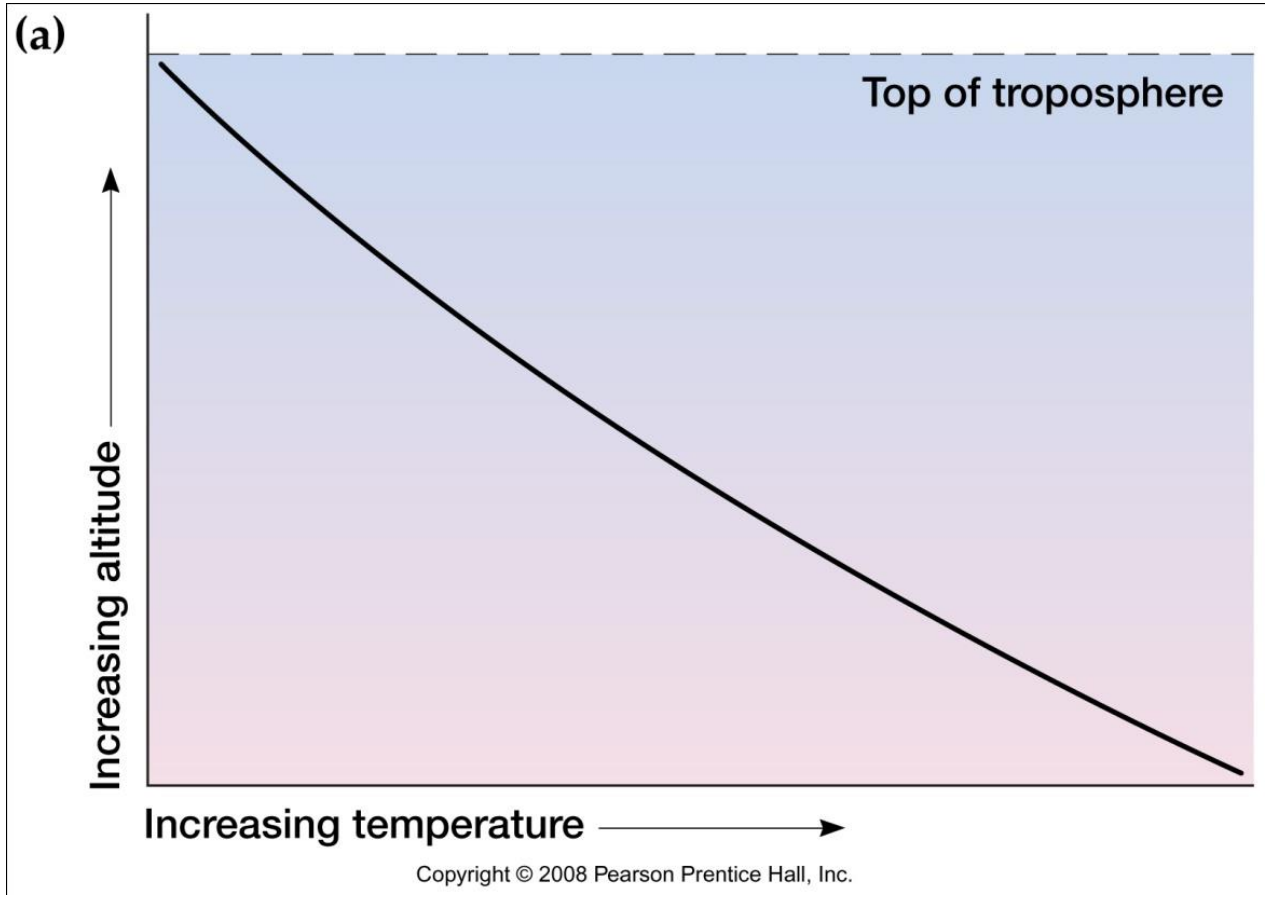
http://news.bbc.co.uk/2/hi/americas/1809705.stm

Los Angeles

http://www.flickr.com/photos/infinitewilderness/261718673/sizes/o/in/photostream/

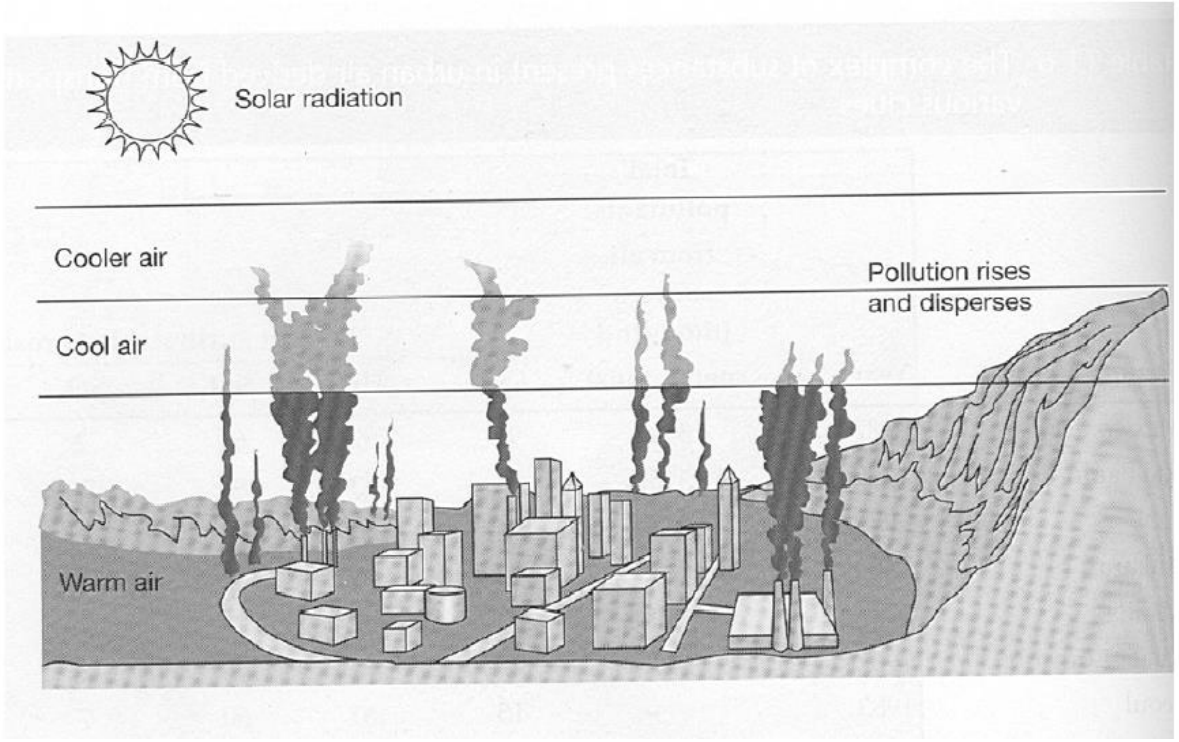
Vertical Temperature Patterns

- **Environmental Lapse Rate**
  - The observed rate of vertical temperature change in the atmosphere.
  - Rate at which temperature drops as altitude increases can vary according to season, time of day, amount of cloud cover, and other factors.
- **Average Lapse Rate**
  - normal vertical temperature gradient, with temperature dropping 3.6° F per 1,000 feet (6.5° C per kilometer)

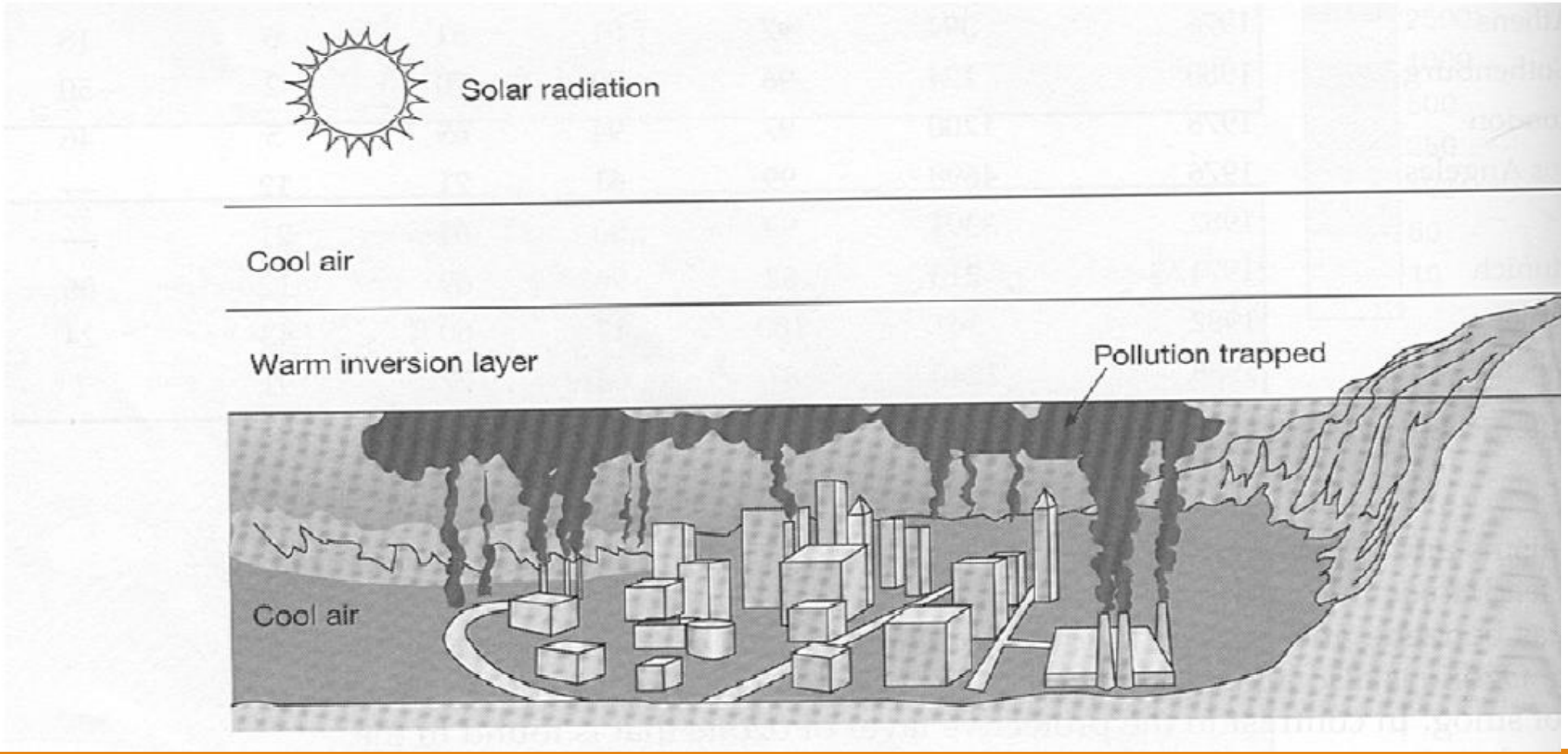


Temperature Inversions

a) Normal conditions



b) Temperature inversion conditions

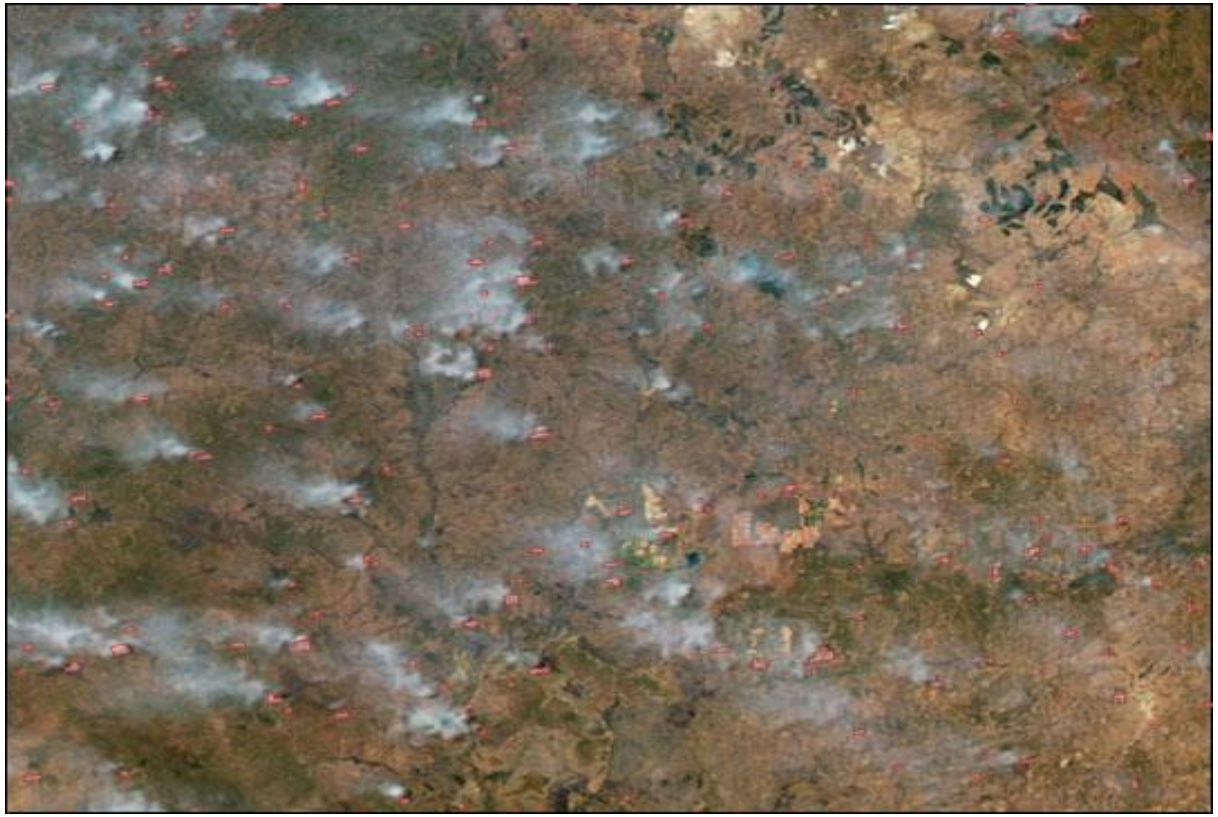


Where is smog a problem?

Cities where temperature inversions occur

Savanna grasslands and sugarcane areas

- NOx and other hydrocarbons released in the burning of biomass



Smoke plumes dot the African savanna in Zambia during the burning season (roughly September through April).

Where is smog a problem?

As a component of urban pollution

- Big problem especially in areas like Beijing, New Delhi where coal and oil are a source of energy
- Recently Dallas: http://thescoopblog.dallasnews.com/category/smog-2/

The Brooklyn and Manhattan bridges covered in Smog, NYC

Urban pollution

Gray air cities	Brown air cities
Sulfur oxides and particulates (from factories) important Smog generated in cold, wet (moist) climates (winters)	Warm, dry and sunny climates Ozone important Unburned hydrocarbons and nitrogen from automobiles and powerplants
Industrialized Heavy dependence on coal and oil	Relatively non-industrialized
E.g., Old industrialized cities: New York, St. Louis-Missouri, Philadelphia, Pittsburg, London	E.g., Newer relatively non-industrialized: Denver, LA, Salt Lake City, Albuquerque, Vancouver, Canada, Dallas, Texas

Ozone

Ozone is naturally produced in the **stratosphere (and troposphere)**, and it serves to protect life on Earth by shielding us from the deadly ultraviolet rays of the Sun.

- It is created by the action of UV radiation.
- UV radiation splits oxygen molecules into free oxygen atoms that then combine with oxygen molecules to form ozone.
- In the **stratosphere**, ozone molecules will be naturally broken down into oxygen molecules and free oxygen atoms by UV-B and UV-C radiation.
- The breakdown and formation of ozone is an ongoing process in this layer of the Earth's atmosphere.

Functions of Ozone

Name	Wavelength Range (nm)	Reaction to Ozone	Biological Effect
UV-A	320 – 400nm	Passes through ozone layer	Relatively harmless to life; causes tanning but not burning
UV-B	290- 320nm	Ozone absorbs most	Somewhat lethal to life: causes sunburn, skin cancer, and other disorders
UV-C	200-290nm	Nearly totally absorbed	Lethal to life: extremely harmful to life on Earth

Ozone layer depletion: The “Hole” in the Ozone layer

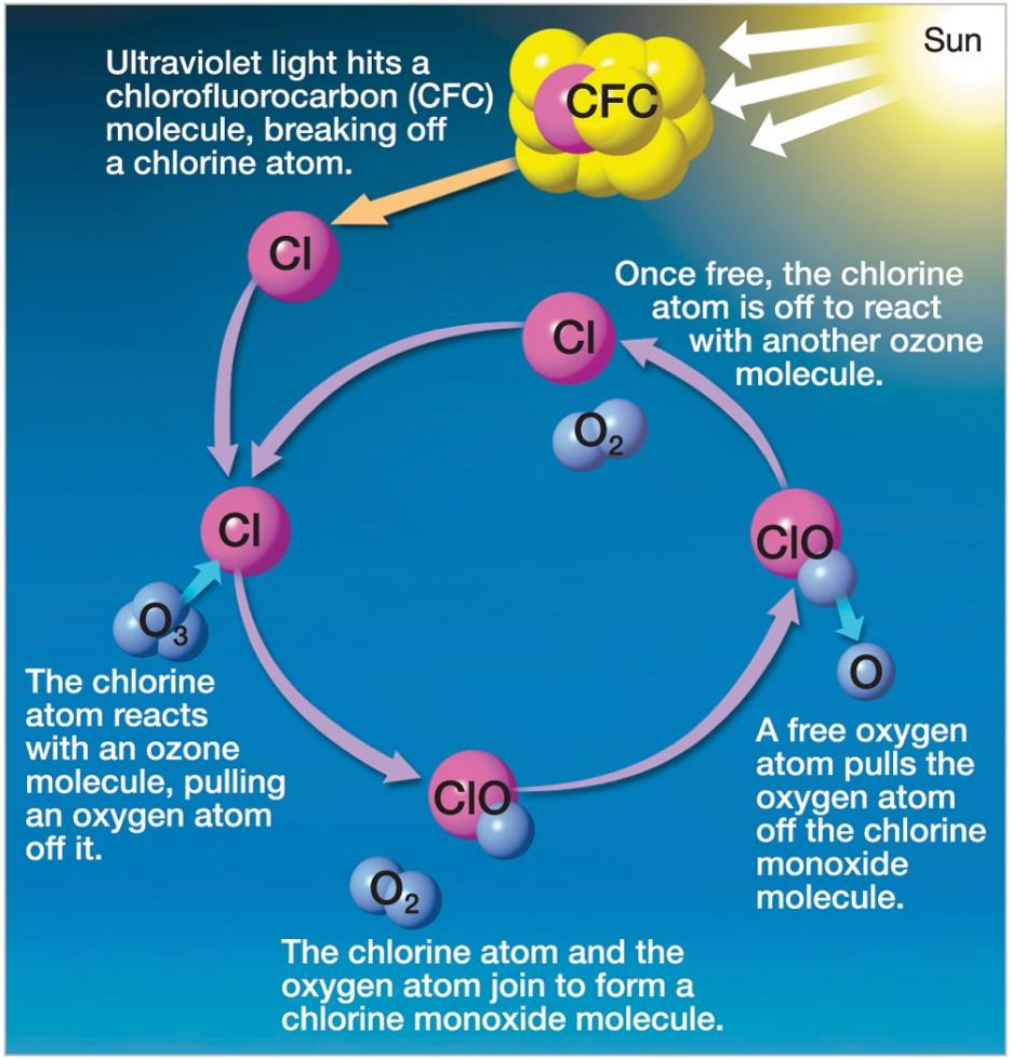
Ozone in the stratosphere, lying in the ozone layer, is being depleted through a combination of natural and human-produced factors.

The layer has not only thinned, but it has disappeared entirely in some areas.

Dramatic thinning of the ozone layer has been observed since the 1970s.

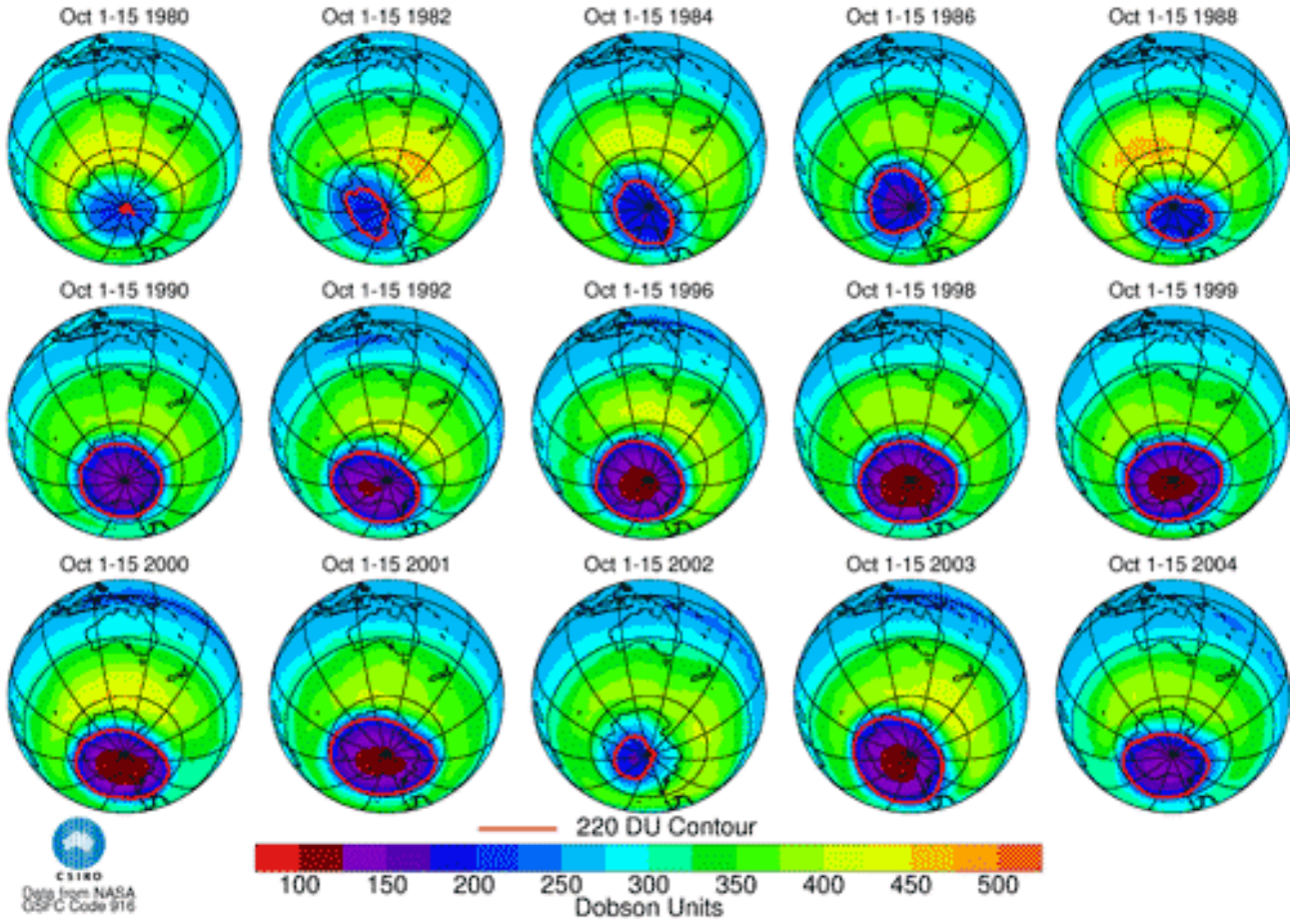
The major thinning has been caused by the release of human-produced chemicals such as CFCs.

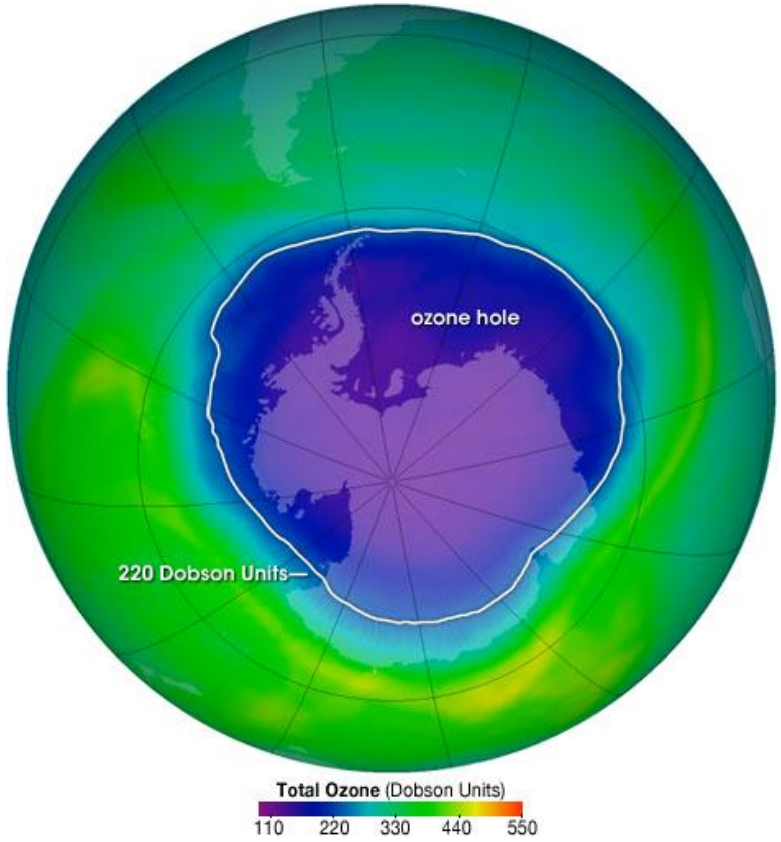
Ozone depletion has been correlated with increased levels of UV radiation reaching ground surfaces in Antarctica, Australia, mountainous regions in Europe, central Canada, and New Zealand.



Ozone cycle with CFCs

Ozone Hole in Antarctica





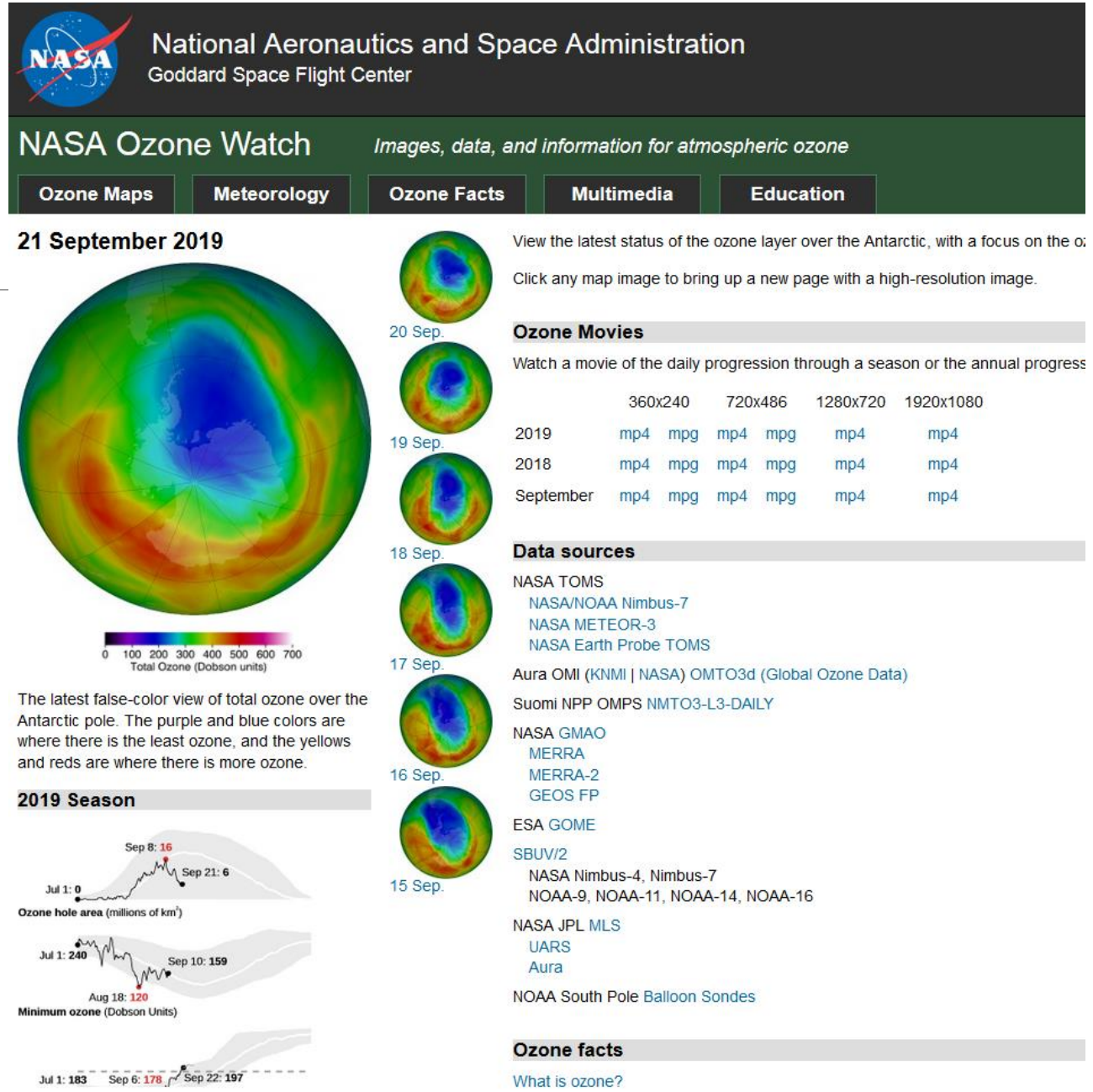
Close-up of spring 2004 data

Total ozone levels over the southern hemisphere in spring (October 1-15 averages) for 15 years, based on NASA TOMS satellite data

Current view

National Aeronautics and Space Administration; Goddard Space Flight Center:

- https://ozonewatch.gsfc.nasa.gov/
- https://ozonewatch.gsfc.nasa.gov/monthly/SH.html



Stratospheric “good” ozone

About 90 percent of all atmospheric ozone is found in the Stratosphere, where it forms a fragile shield by absorbing most of the potentially dangerous UV radiation from the Sun.

Prolonged exposure to **UV radiation can cause cancer**, suppress the immune system, diminish crop yields, and kill microscopic plankton on the ocean’s surface.

When produced in the **Troposphere**, ozone harms life, where it damages tissues in humans (eyes, lungs, noses); it also damages vegetation and corrodes buildings.

- **Ozone is produced naturally in the stratosphere, while the combination of human activity such as automobile emissions and incoming solar radiation leads to its (excessive) production in the troposphere.**

Tropospheric “bad” ozone

Major product of smog

Pollutant

- Harmful to plants, animals, humans

Acts as a greenhouse gas

Produced by complex chemical reactions, including…

- NOx
- Sunlight
- volatile organic compounds (VOCs)
  - Hydrocarbons, halogen-containing chemical compounds, alcohols, ethers, etc.
  - Methane is most important on a global scale.

Natural ozone cycle

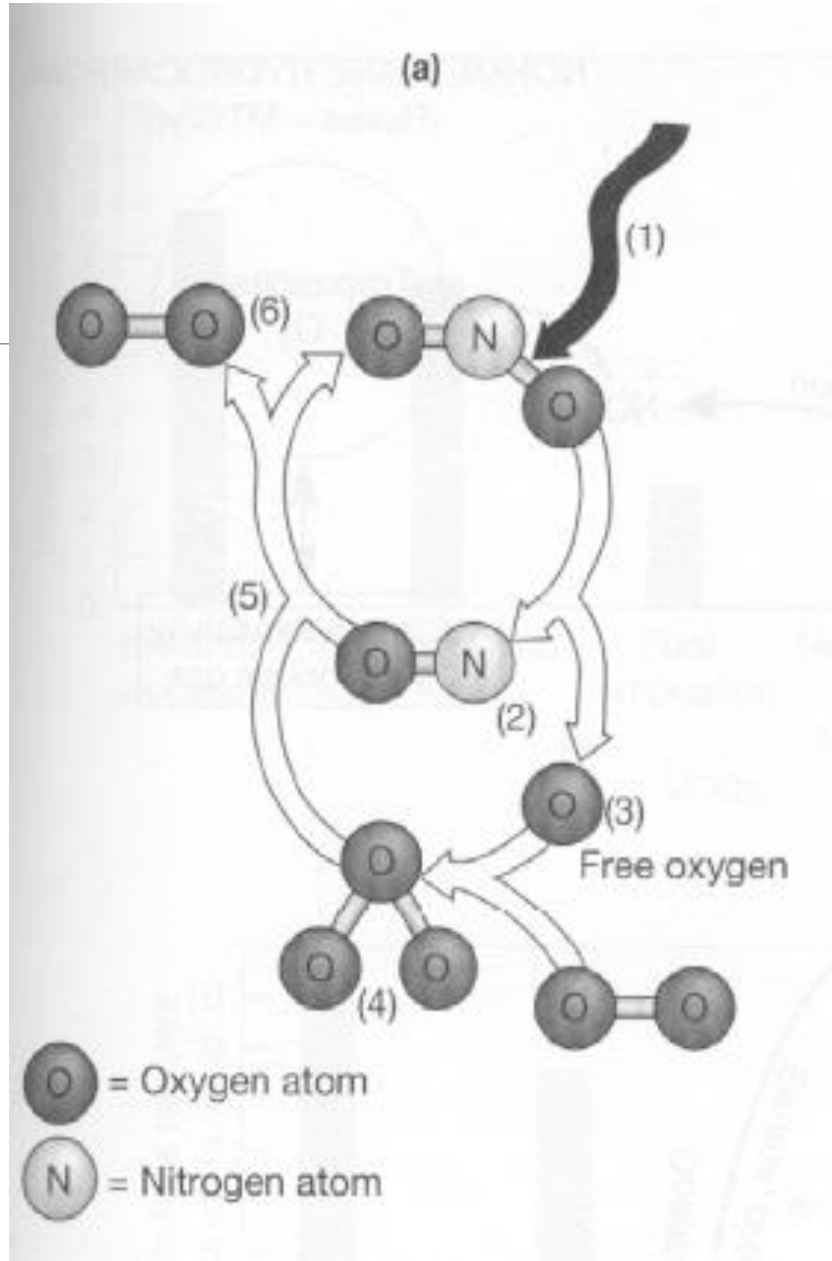
NO_2 + sunlight ⟶ NO + O

O_2 + O ⟶ O_3 (ozone)

NO + O_3 ⟶ NO_2 + O_2

- cycle repeats

i.e., ozone is produced and destroyed – no net increase or decrease



Ozone cycle with VOCs

NO_2 + sunlight ⟶ NO + O

O_2 + O ⟶ O_3 (ozone)

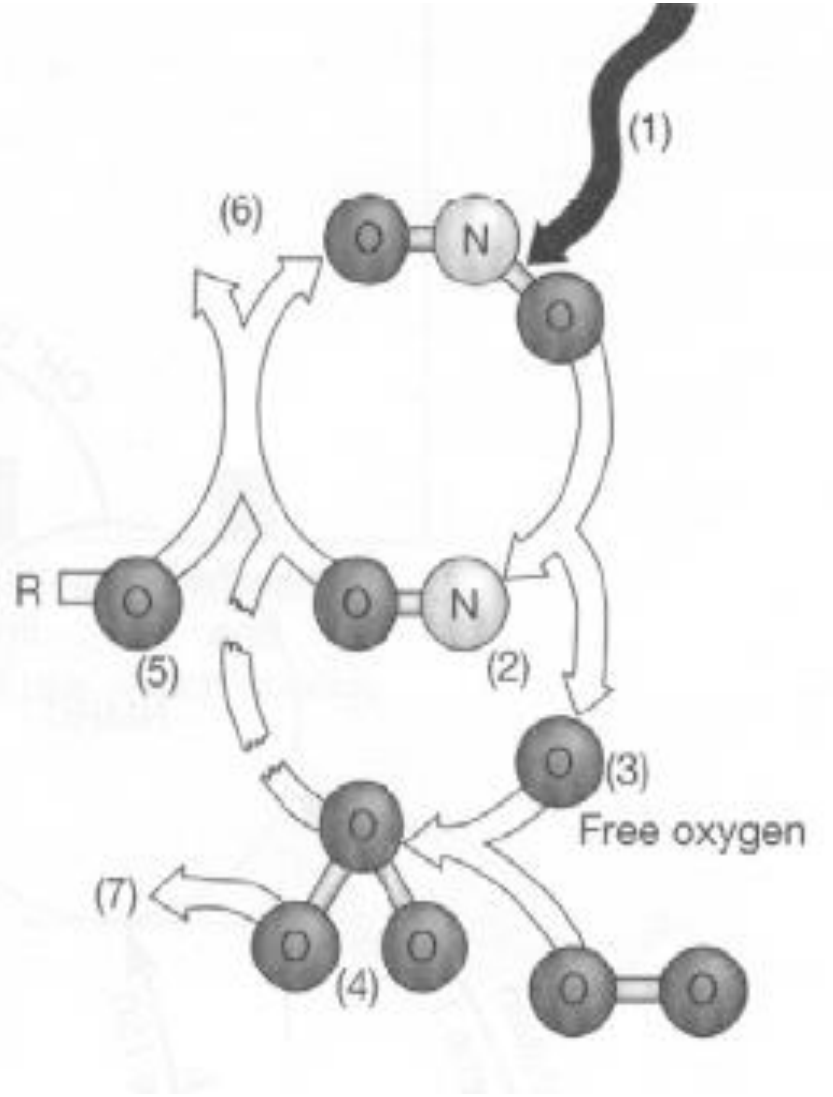
VOC + NO ⟶ NO_2 ⇒ O_3

i.e., no need for an ozone molecule

ozone accumulates

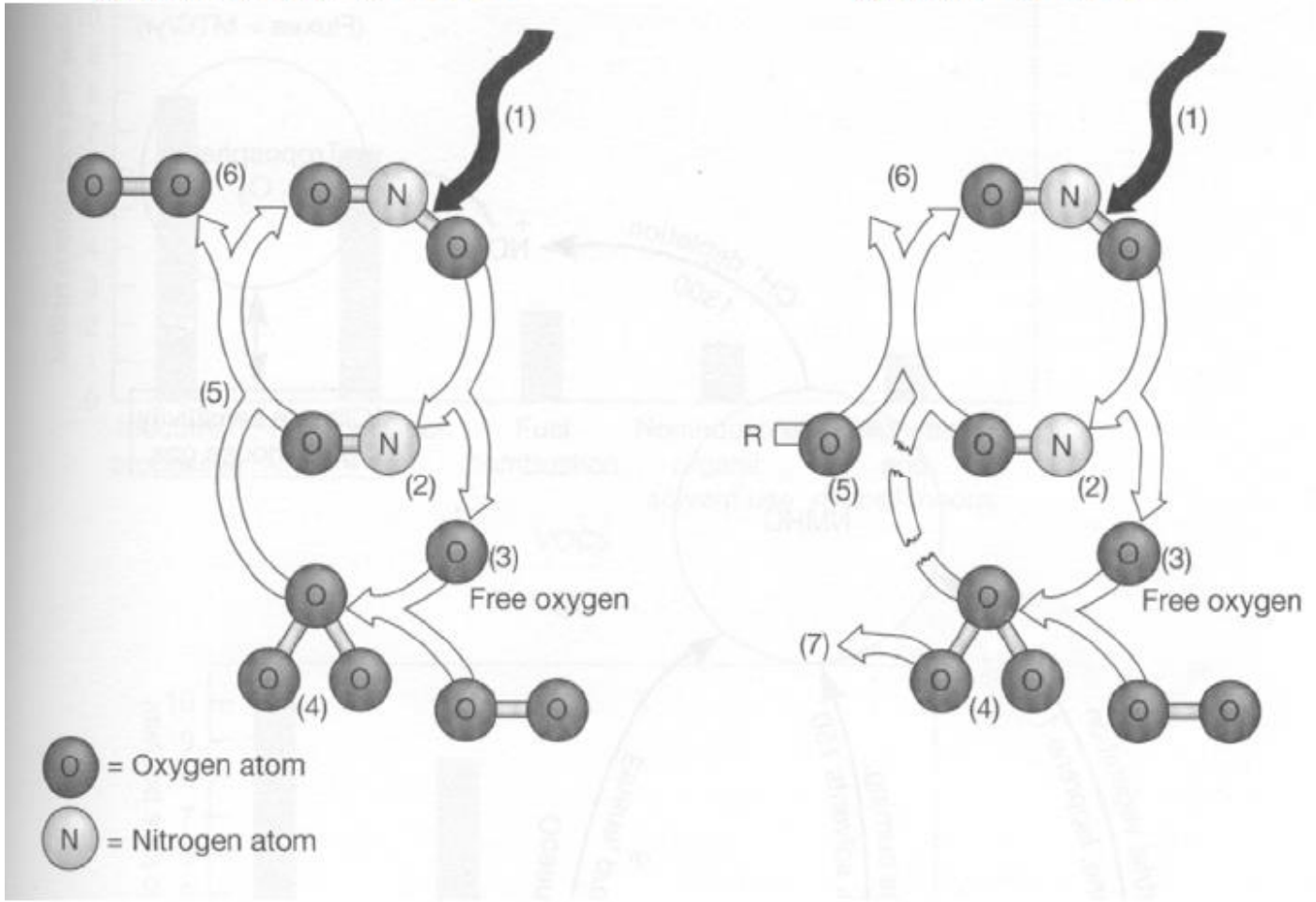
Amount of ozone formed depends on:

- Sunlight
- Weather conditions
- Ratio of VOCs to nitrogen oxides



without VOCs

with VOCs



Primary sources of nitrogen oxides

Natural	Anthropogenic
Soils	Motor Vehicles
Lightning	Electric power plants
Oxidation of atmospheric ammonia	
Forest Fires	

Primary sources of VOCs

Natural	Anthropogenic
Growing terrestrial vegetation	Industry
Ocean	Transportation
Forest fires	Fuel combustion

Health effects of air pollution

Table 11.8 Health effects of major air pollutants

Sulfur dioxide	Respiratory irritation, shortness of breath, impaired pulmonary function, increased susceptibility to infection, illness in the lower respiratory tract (particularly ir children), chronic lung disease, and pulmonary fibrosis. Increased toxicity in combination with other pollutants.
Respirable particulate matter	Irritation, altered immune defense, systemic toxicity, decreased pulmonary function, and stress on the heart. Acts in combination with SO_2; effects depend on the chemical and biological properties of the individual particles.
Oxides of nitrogen	Eye and nasal irritation, respiratory tract disease, lung damage, decreased pulmonary function, and stress on heart.
Carbon monoxide	Interferes with oxygen uptake into the blood (chronic anoxia). Can result in heart and brain damage, impaired perception, asphyxiation, or, in low doses, in weakness, fatigue, headaches, and nausea.
Lead	Kidney disease and neurological impairments. Primarily affects children. Lead in the environment has decreased dramatically, since regulations restricting its use as an antiknock agent in gasoline and use in paint were put in effect.
Photochemical oxidants (e.g., ozone)	Decreased pulmonary function, heart stress or failure, emphysema, fibrosis, and aging of lung and respiratory tissue.

(After Whelpdale, 1991.)

Controlling tropospheric ozone

Emission control devices - depend on source

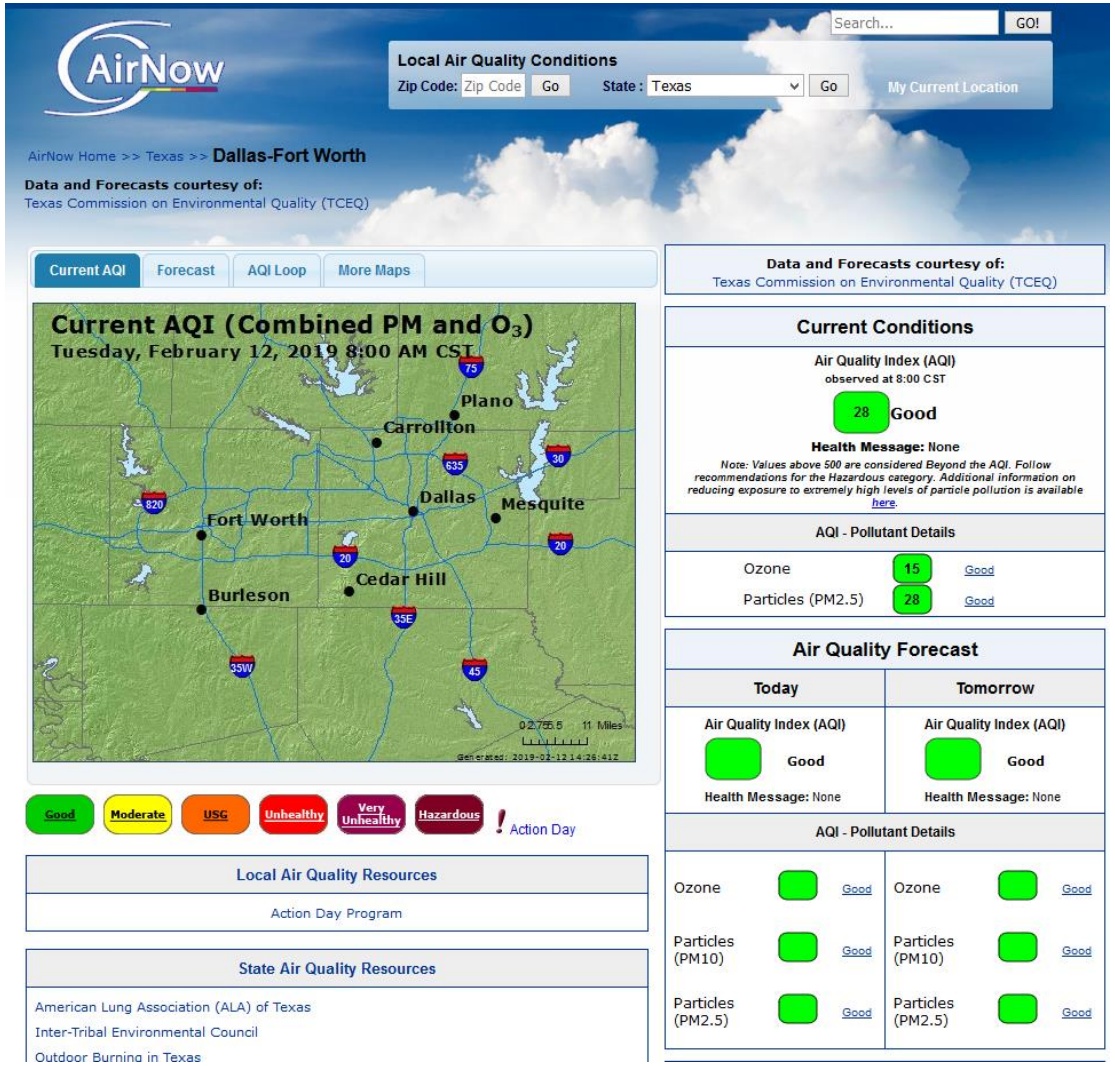
- Catalytic converters, vapor recovery systems (cars)
- Low-nitrogen oxide burners (power plants/engines)
- Improved vehicle design and use of alternative fuels
- Alternatives to fossil fuel combustion

Air Quality Index (AQI)

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in this range:	*..air quality conditions are:*	*...as symbolized by this color:*
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health warnings of emergency conditions. The entire population is more likely to be affected.
Hazardous	301 to 500	Health alert: everyone may experience more serious health effects

http://airnow.gov/index.cfm?action=airnow.local_city&cityid=234



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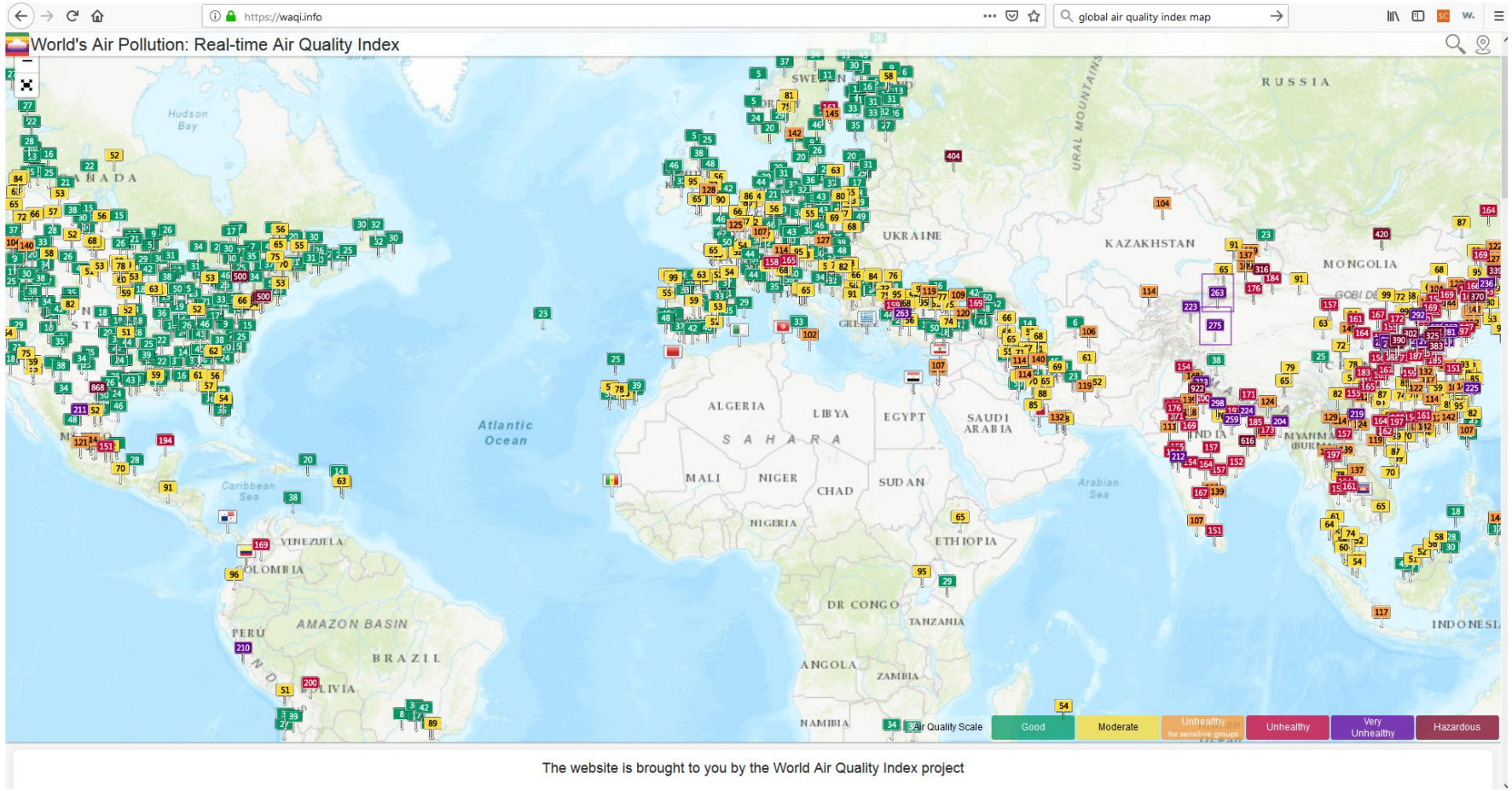
Global Air Quality



https://waqi.info/