AOSC400-2015
September 3, Lecture # 2

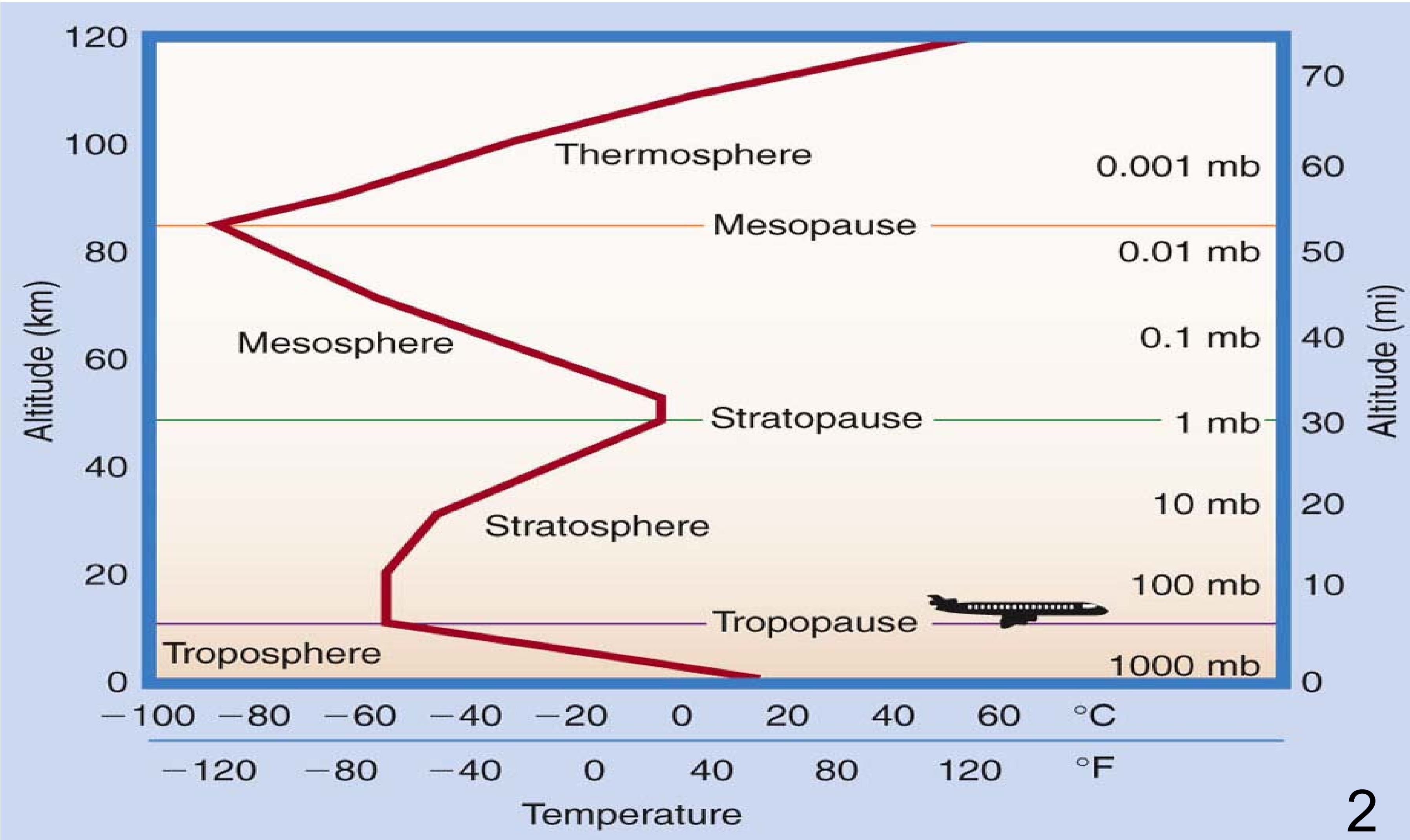
Atmosphere's role in heating of the Earth

- Atmospheric layers
- Atmospheric composition
- Important atmospheric greenhouse gases (ozone, CO_2)
- Probing vertical structure

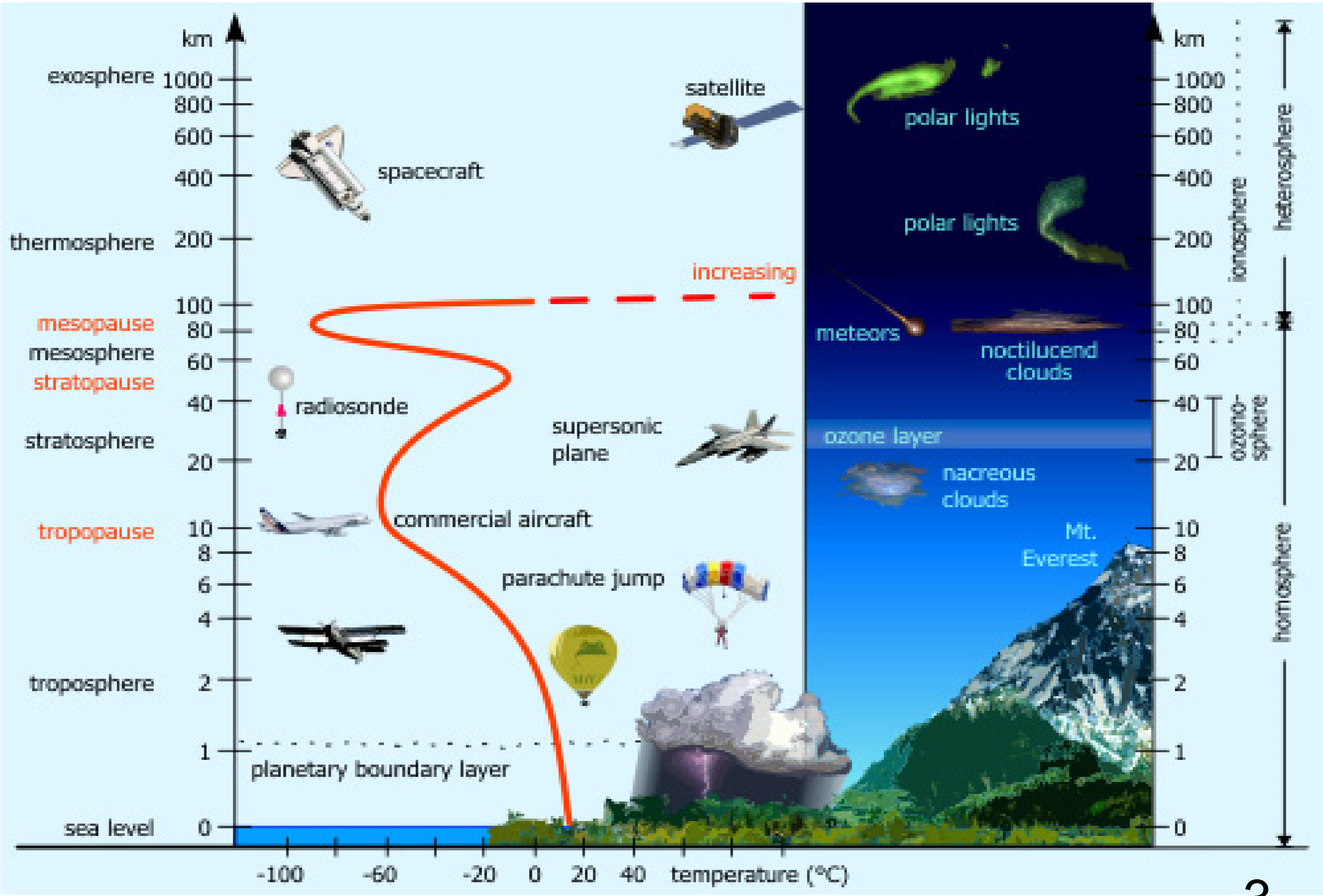
Main layers of the atmosphere

Troposphere, Stratosphere, Mesosphere, Thermosphere,

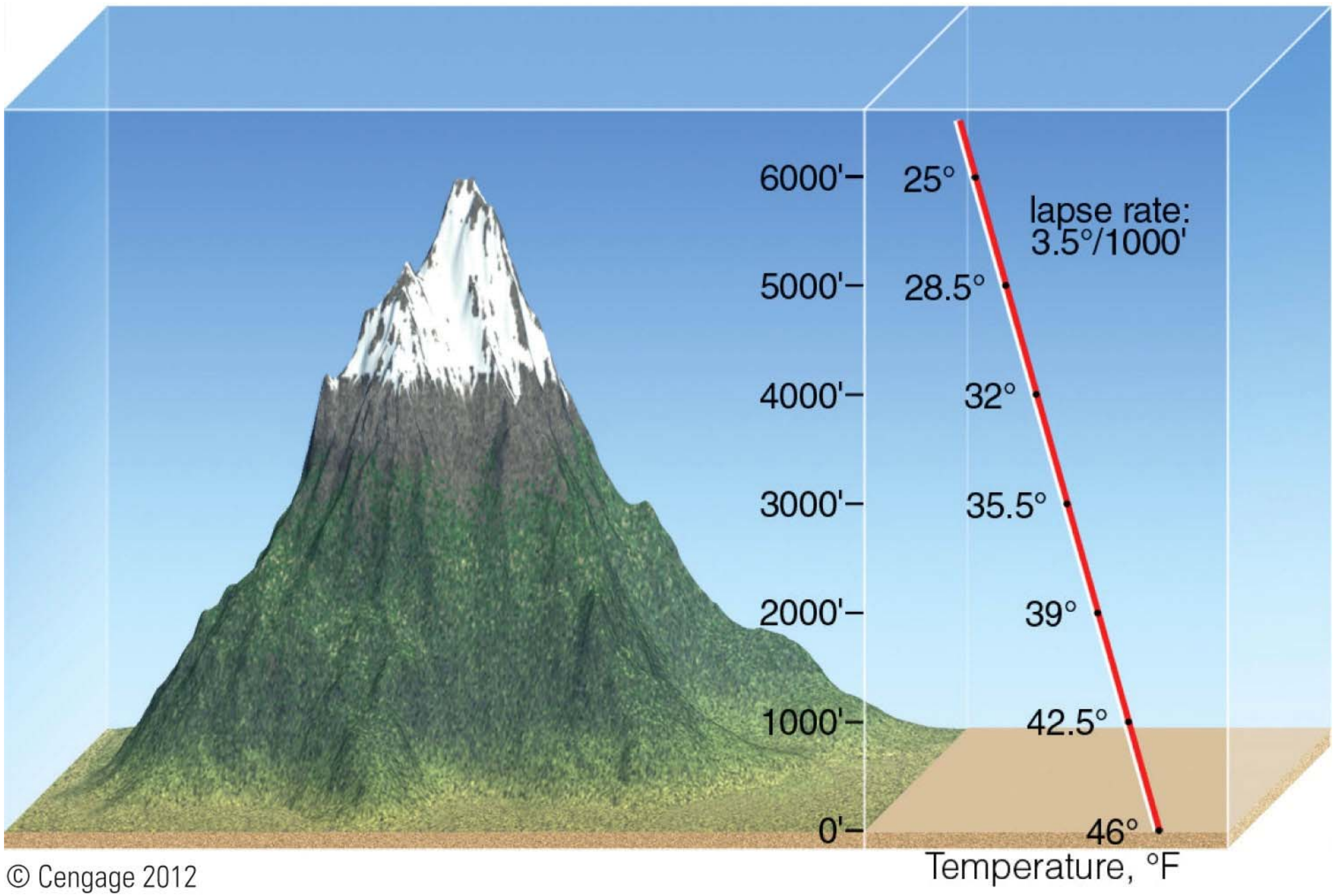
Separated by conceptual partitions-called pauses (tropopause)



Atmospheric structure and role of each layer



Average decrease in temperature as a function of height in the troposphere



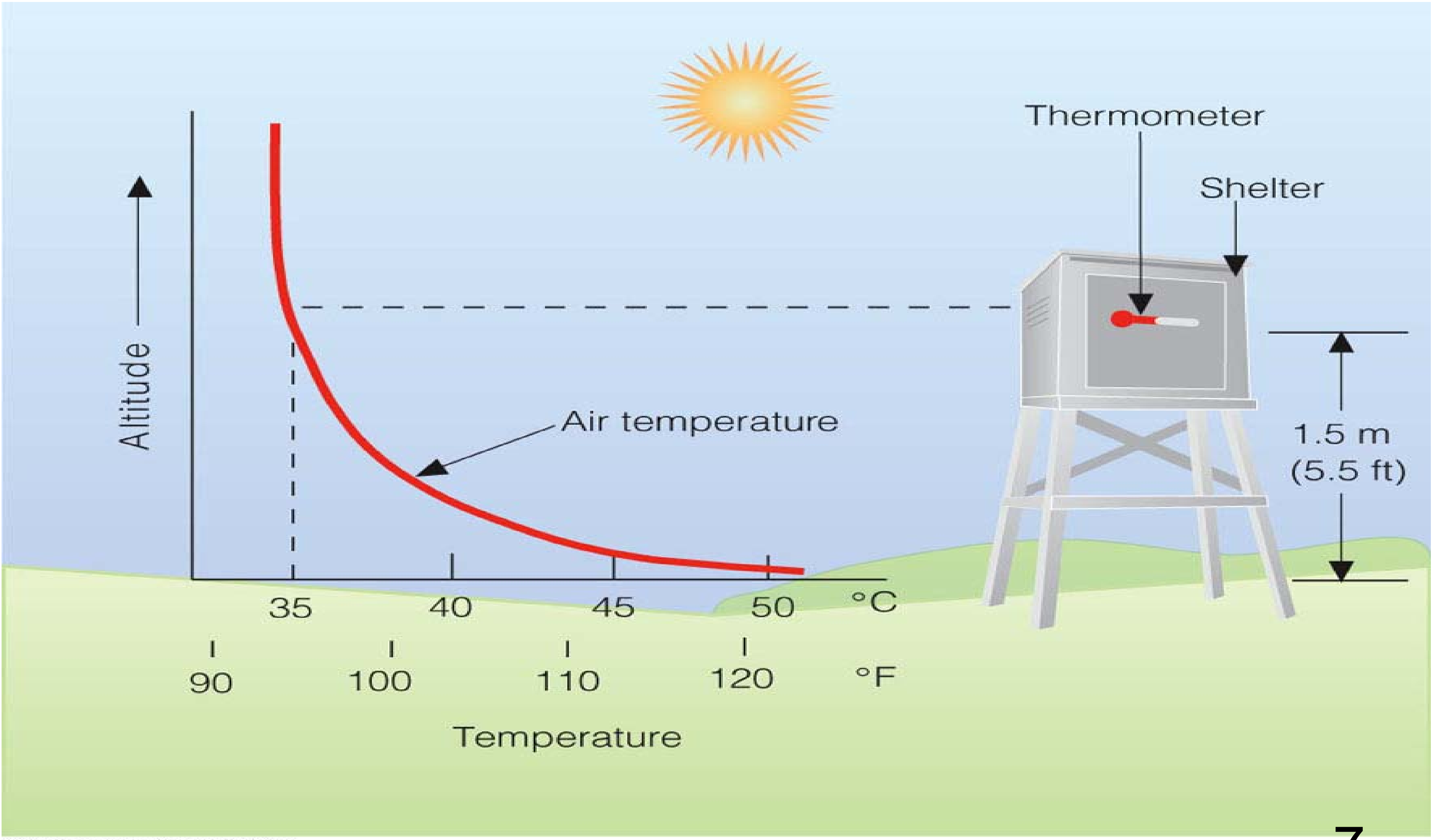
Lapse rate (rate of temperature decrease with height) on average is 6.5^0 C/1000 m.

- At about 20 km, air temperature increases. Increase of temperature with height called *inversion.*
- The inversion keeps the vertical currents of the troposphere from spreading into the stratosphere.
- Cause of inversion-for example, ozone plays a role in the heating of the air. Some of the absorbed energy increases the kinetic energy of ozone molecules-causes higher temperatures.
- At 50 km- temperature ~ 20^0 C (280^0 F) due to UV absorption.
- Above 50 km, temperature *isothermal* and then decreases-the mesosphere.
-

How do we measure temperature in the atmosphere?

Automated Surface (Weather) Observing Systems (ASOS or AWOS) are now used to make standard measurements of atmospheric properties at most location in North America.

Temperature reported - measured at about 2 m level in a protected and ventilated shelter.



Radiosonde-measures temperature, humidity and wind at higher levels of the atmosphere

Heating of the atmosphere

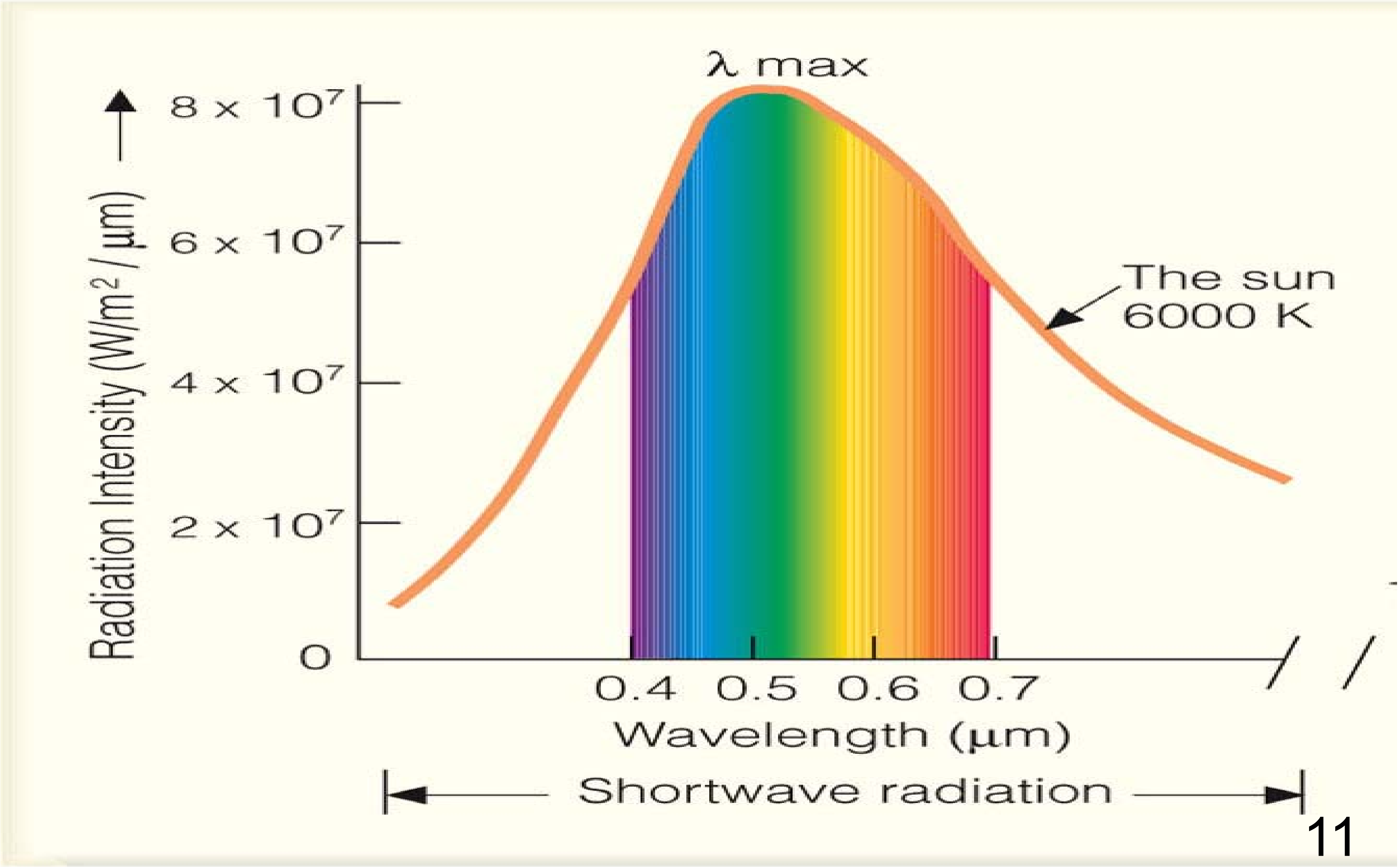
- The surface of earth is heated by absorbed radiation from the sun.
- Lower atmosphere is warmed from below by *conduction*. Heated air rises by *convection*, heats a deeper layer.
- Rising air expands and cools. At the same time, earth constantly emits infra-red (*IR) radiation* which is being absorbed and reemitted by HO_2 and CO_2. The concentration of these gases decreases above earth, most of the absorption-close to earth.
- At 5.5 km, temperature ~ -20^0 C
- *Isothermal zone*-tropopause-separates troposphere and stratosphere (altitude of troposphere depends on latitude)

Please note:

- The following two slides are introduced so you can easily follow the subsequent slides. They provide explanation what is meant by *wavelength of light* and the *units* used **(µm)** to describe different wavelengths (colors) of the spectrum from the sun.

- *This will be repeated later in more detail.*

The spectrum of radiation from the sun-propagates as electromagnetic radiation



- Electromagnetic waves can be described by their wavelengths, energy, and frequency. All three describe a different property of light, yet they are related to each other mathematically. The unit used to describe the wavelength of light is the micrometer   (μm)
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1 micrometers (μm)=10^{-6} m

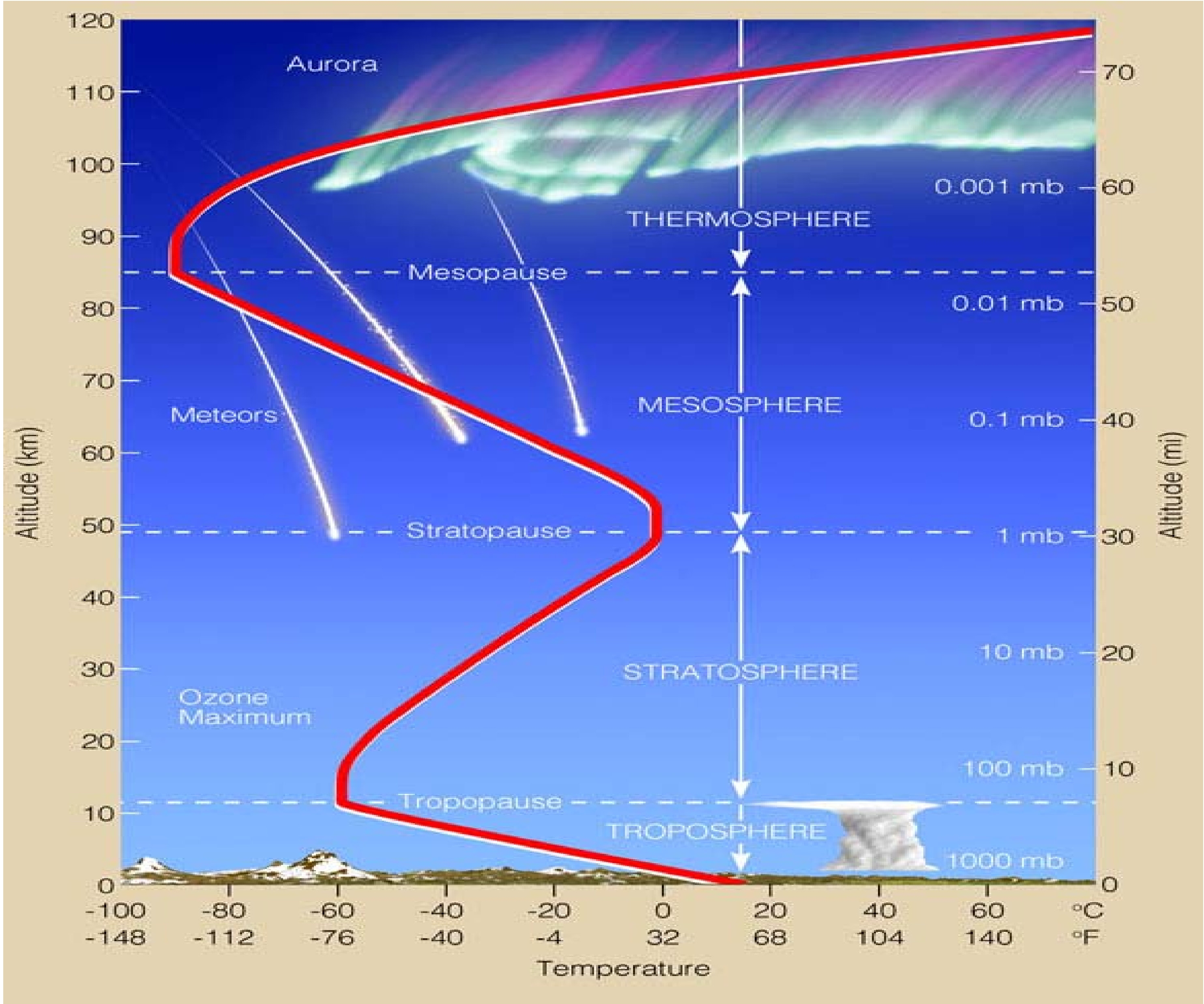
1 μm=1000 nm (nanometer)

1 nm= 10 A^0 (Angstrom)

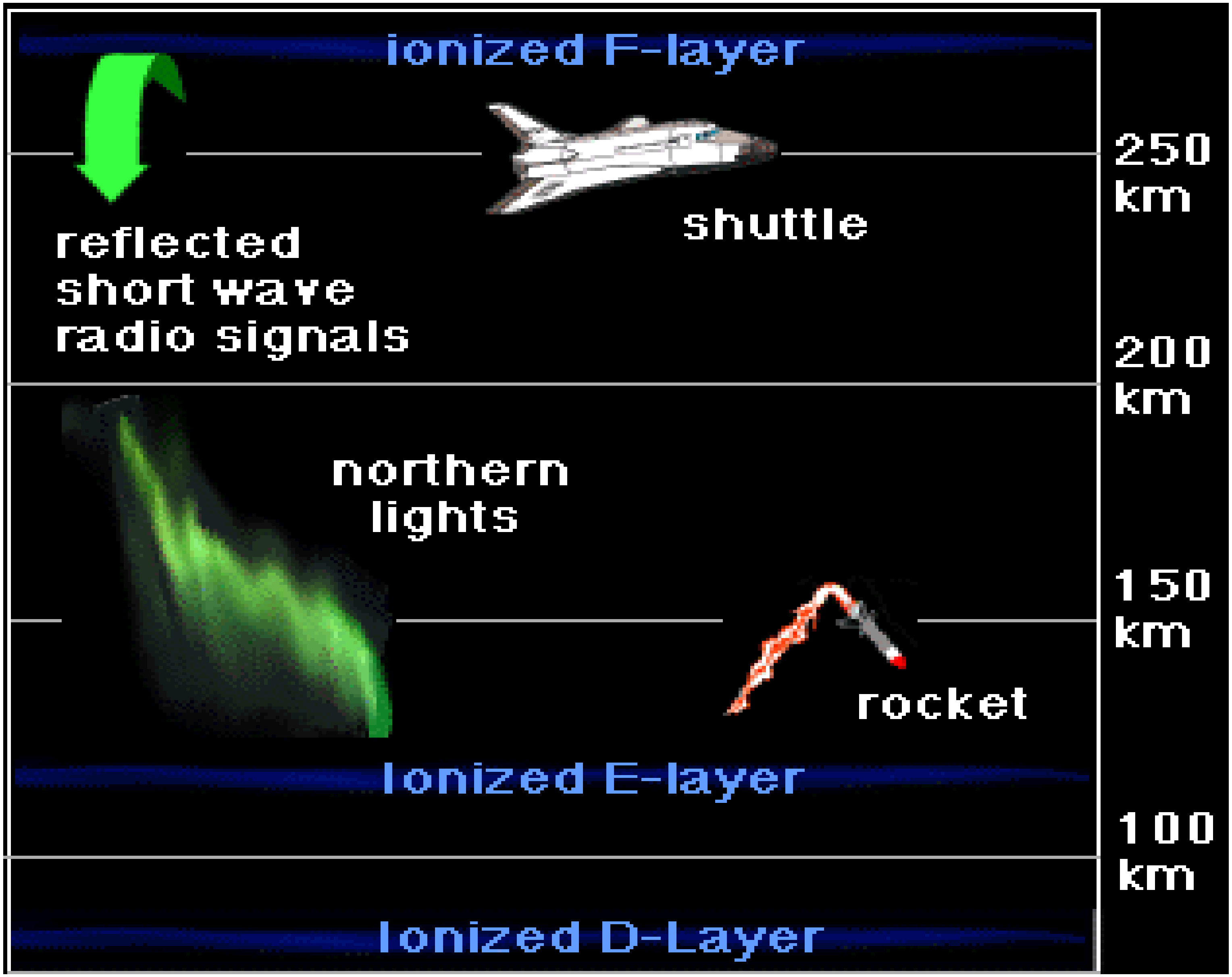
Temperature structure

- High-energy waves ionize certain atmospheric gases (e.g., nitric oxides and atomic oxygen)
- Above 80 km oxygen (O_2) absorbs radiation <0.2 μm
- At elevations between 20-50 km, O_3 absorbs between 0.2-0.3 μm (*this is differential heating*).
- Note: Speed of light is 300,000 km/sec
- Earth-sun distance 150 million km
- 8 min for sunlight to reach earth.

Another look at the vertical structure of atmospheric temperature

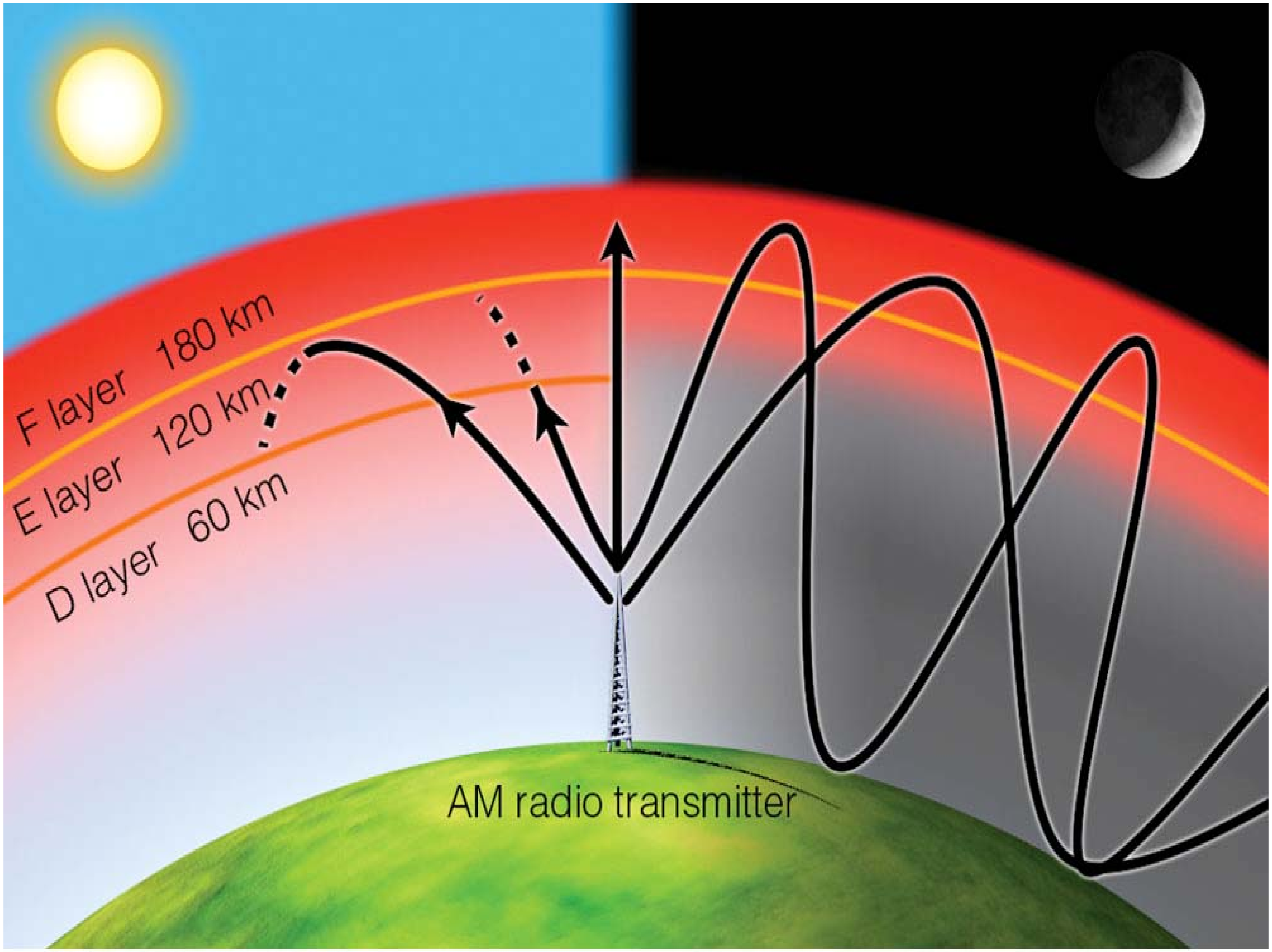


A look at the ionosphere



Regions of the Ionosphere

- The E region peaks at about 105 km. It absorbs soft x-rays.
- The F region starts around 105 km and has a maximum around 600 km. It is the highest of all of the regions. Extreme ultra-violet radiation (EUV) is absorbed there.
- The D and E regions *reflect* AM radio waves back to Earth. Radio waves with shorter lengths are reflected by the F region. Visible light, television and FM wavelengths are all too short to be reflected by the ionosphere. TV stations are possible by satellite transmissions.


F layer 180 km
E layer 120 km
D layer 60 km
AM radio transmitter

- Radio propagation is affected by the daily changes of water vapor in the troposphere and ionization in the upper atmosphere, due to the Sun.
- Since radio propagation is not fully predictable, such services as emergency locator transmitters, in-flight communication with ocean-crossing aircraft, and some television broadcasting have been moved to communications satellites. A satellite link, can offer highly predictable and stable line of sight coverage of a given area.

Composition of the Atmosphere

Gas	Percentage by Volume
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Trace Gases	
Carbon dioxide	0.038
Methane	0.00017
Ozone	0.000004
Chlorofluorocarbons	0.00000002
Water vapor	Highly variable (0–4%)

Composition of the Atmosphere

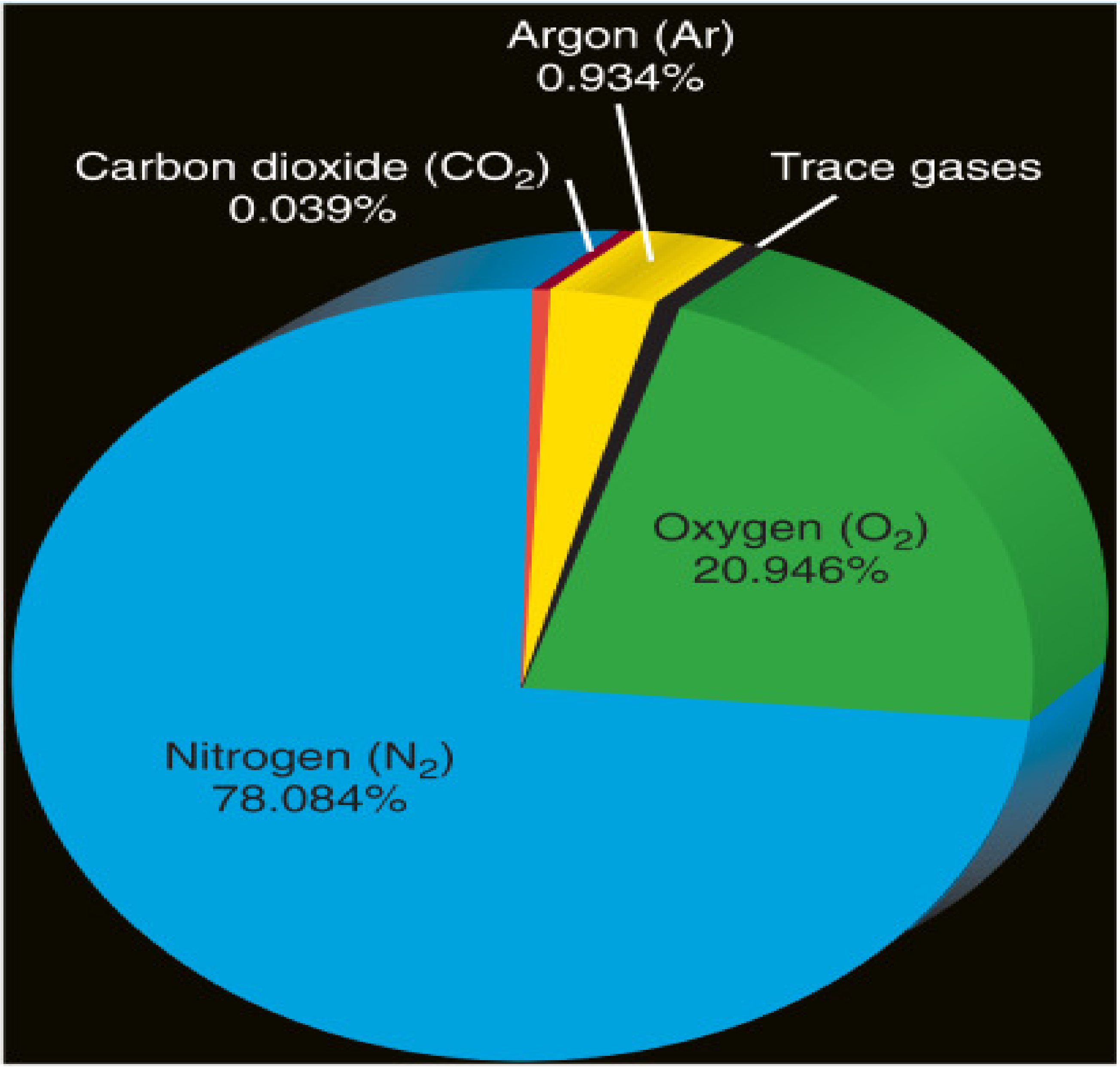
TABLE 1.1 Composition of the Atmosphere near the Earth's Surface

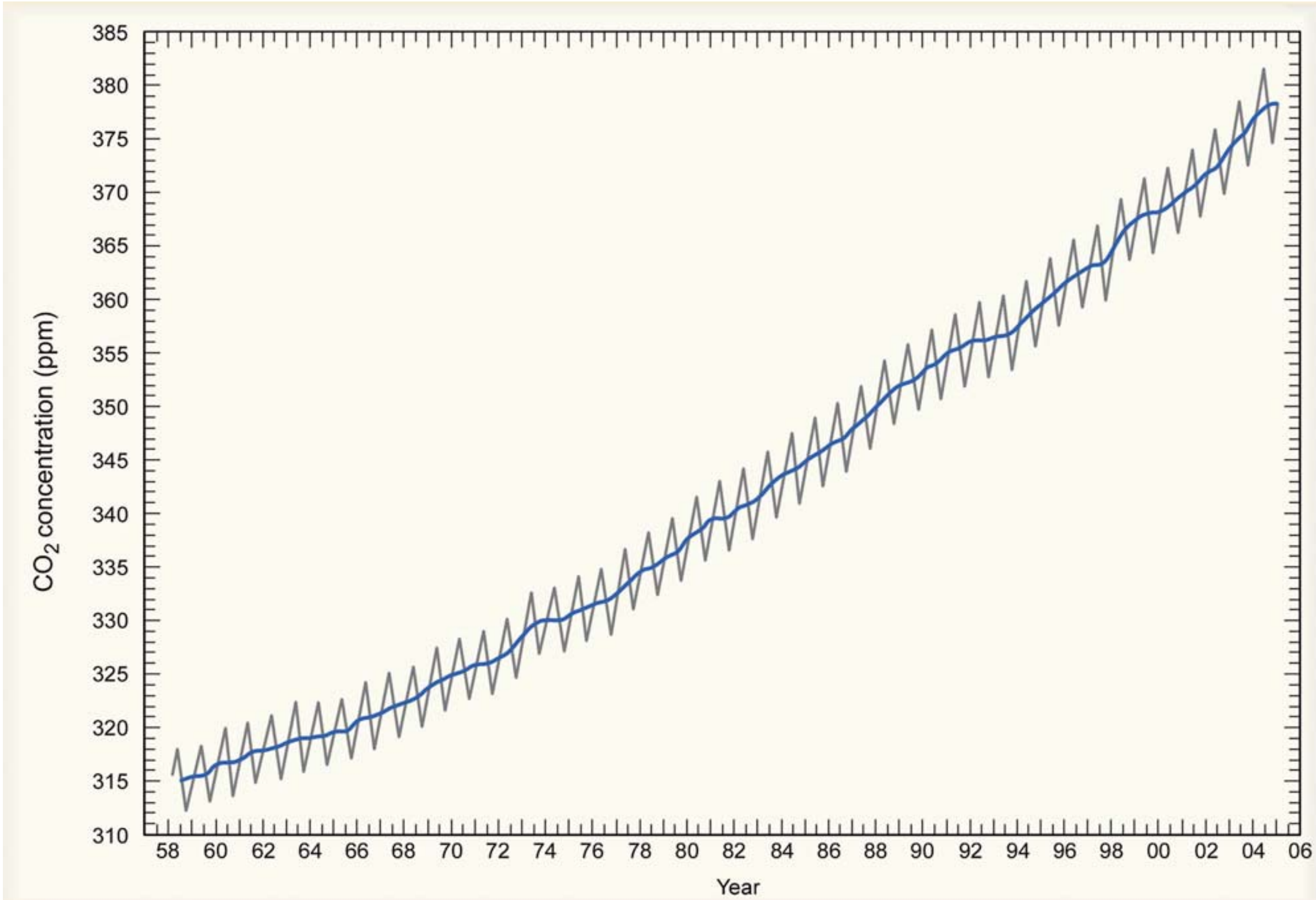
PERMANENT GASES			VARIABLE GASES			
Gas	Symbol	Percent (by Volume) Dry Air	Gas (and Particles)	Symbol	Percent (by Volume)	Parts per Million (ppm)*
Nitrogen	N_2	78.08	Water vapor	H_2O	0 to 4	
Oxygen	O_2	20.95	Carbon dioxide	CO_2	0.039	395*
Argon	Ar	0.93	Methane	CH_4	0.00018	1.8
Neon	Ne	0.0018	Nitrous oxide	N_2O	0.00003	0.3
Helium	He	0.0005	Ozone	O_3	0.000004	0.04†
Hydrogen	H_2	0.00006	Particles (dust, soot, etc.)		0.000001	0.01–0.15
Xenon	Xe	0.000009	Chlorofluorocarbons (CFCs)		0.00000002	0.0002

*For CO_2, 395 parts per million means that out of every million air molecules, 395 are CO_2 molecules.

†Stratospheric values at altitudes between 11 km and 50 km are about 5 to 12 ppm.

Table 1-1 p5


Argon (Ar)
0.934%
Carbon dioxide (CO_2)
0.039%
Trace gases
Oxygen (O_2)
20.946%
Nitrogen (N_2)
78.084%



Measurements of CO_2 made at Mauna Loa, Hawaii (started by Keeling in 1958).

http://www.esrl.noaa.gov/gmd/ccgg/trends/

C. D. Keeling, *The Concentration and Isotopic Abundances of Carbon Dioxide in the Atmosphere*, Tellus, 12, 200-203, 1960.

Reprinted from Tellus Volume 12, Number 2

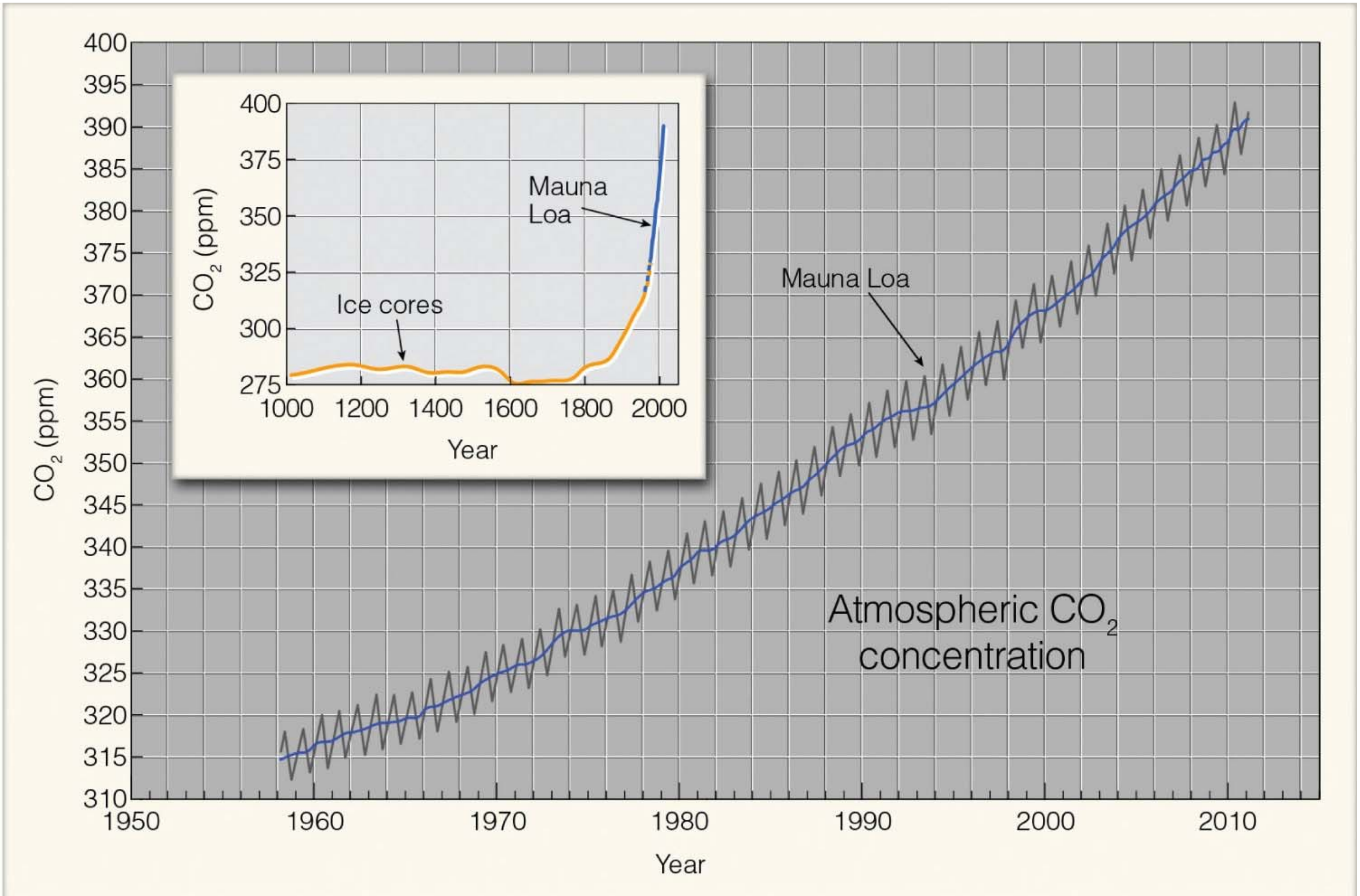
June 1960

The Concentration and Isotopic Abundances of Carbon Dioxide in the Atmosphere

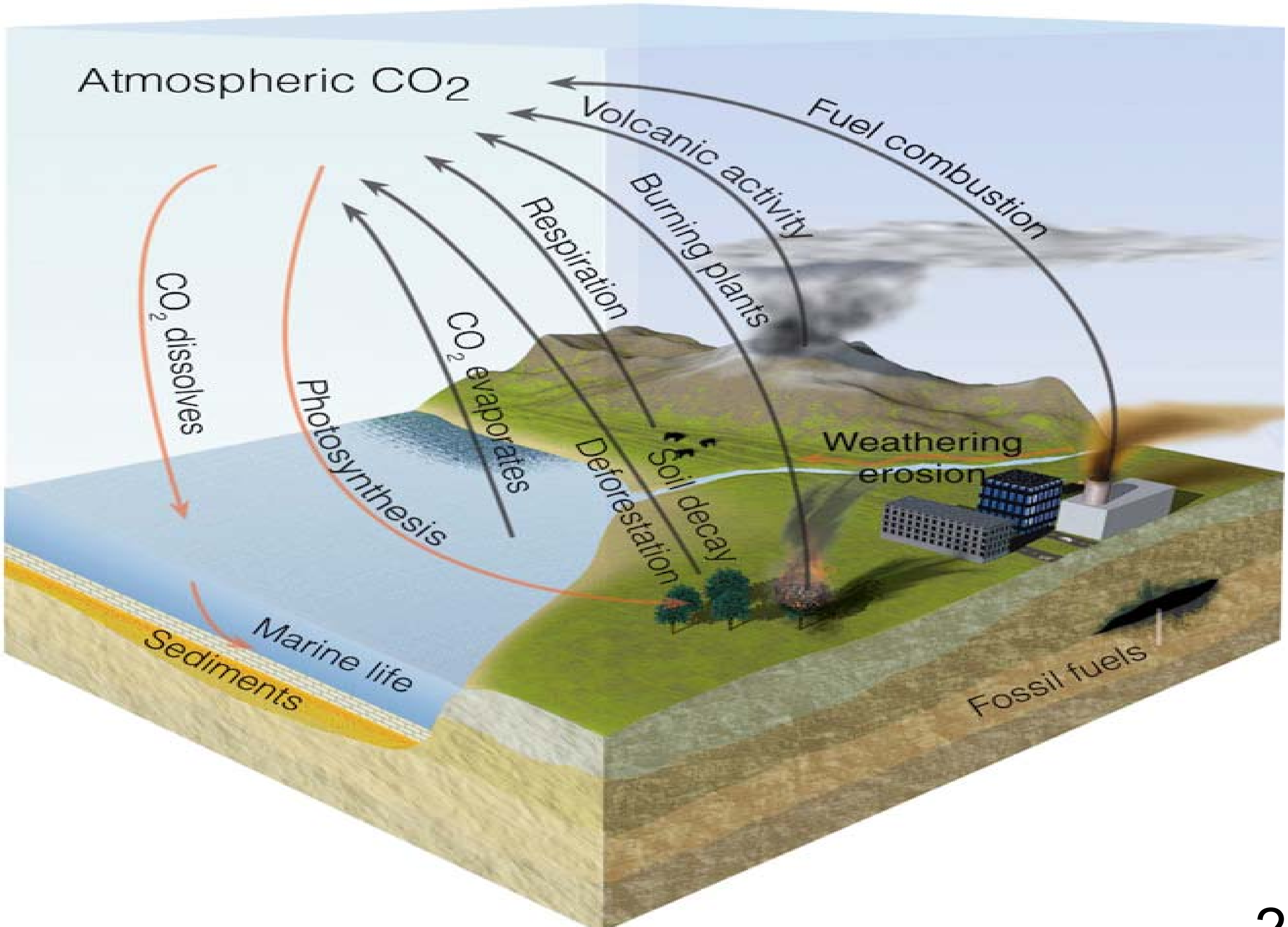
By CHARLES D. KEELING, Scripps Institution of Oceanography, University of California, La Jolla, California

Will provide this paper on ELMS.

Geological perspective on CO_2 concentration.

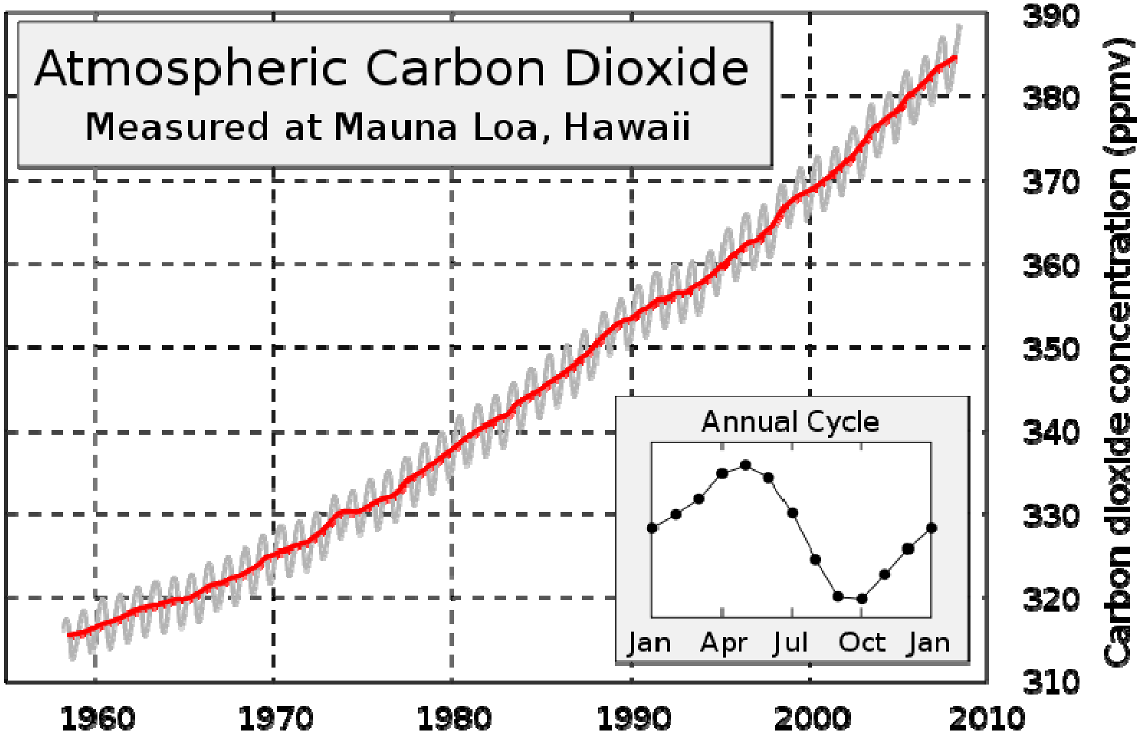


Sources/sinks of CO_2 in the atmosphere



- The world's oceans, plants and soils on land steadily absorb carbon and are called sinks.
- They serve to reduce the amount of CO_2 that remains in the atmosphere.
- The geographic distribution of carbon uptakes by the oceans and terrestrial ecosystems are still uncertain.
- Also, the effectiveness and efficiency of these sinks may change over time as more CO_2 is emitted into the atmosphere .

There is an annual cycle in the Carbon Dioxide variability due to vegetation changes.



Early spring maximum: Less uptake of CO_2 due to slow plant growth in Winter plus CO_2 produced from tree leave decomposing.

Late summer minimum: Summer growth removes CO_2 from the atmosphere.

Since the beginning of the industrial age, the concentration of CO_2 has increased from about 280 parts per million to over 390 parts per million to date. A global network of ground-based measurements has observed an increase in atmospheric CO_2 concentration by almost 20% over the past 50 years - the most dramatic change ever seen in human history. The amount of CO_2 added to the atmosphere through human activities, according to the Global Carbon Project (GCP), has been steadily climbing; and the level was at over 30 billion metric tons in 2005.

http://www.nasa.gov/mission_pages/oco2/overview/#.VAhnKaOH6fs

Carbon Inventory

Table 1.3

Inventory of carbon near the earth's surface[a]

Biosphere	marine	1
	nonmarine	1
Atmosphere (in CO_2)		70
Ocean (in dissolved CO_2)		4000
Fossil fuels		800
Shales		800,000
Carbonate rocks		2,000,000

[a] Given in relative units. After P. K. Weyl, "Oceanography," John Wiley & Sons, New York, 1970.

(from *Atmospheric Sciences: An Introductory Survey*)

Important Atmospheric Greenhouse Gases

Name and Chemical Symbol	*Concentration (ppm by volume)*
Water vapor, H_2O	0.1 (South Pole)–40,000 (tropics)
Carbon dioxide, CO_2	370
Methane, CH_4	1.7
Nitrous oxide, N_2O	0.3
Ozone, O_3	0.01 (at the surface)
Freon-11, CCl_3F	0.00026
Freon-12, CCl_2F_2	0.00054

Importance of water vapor

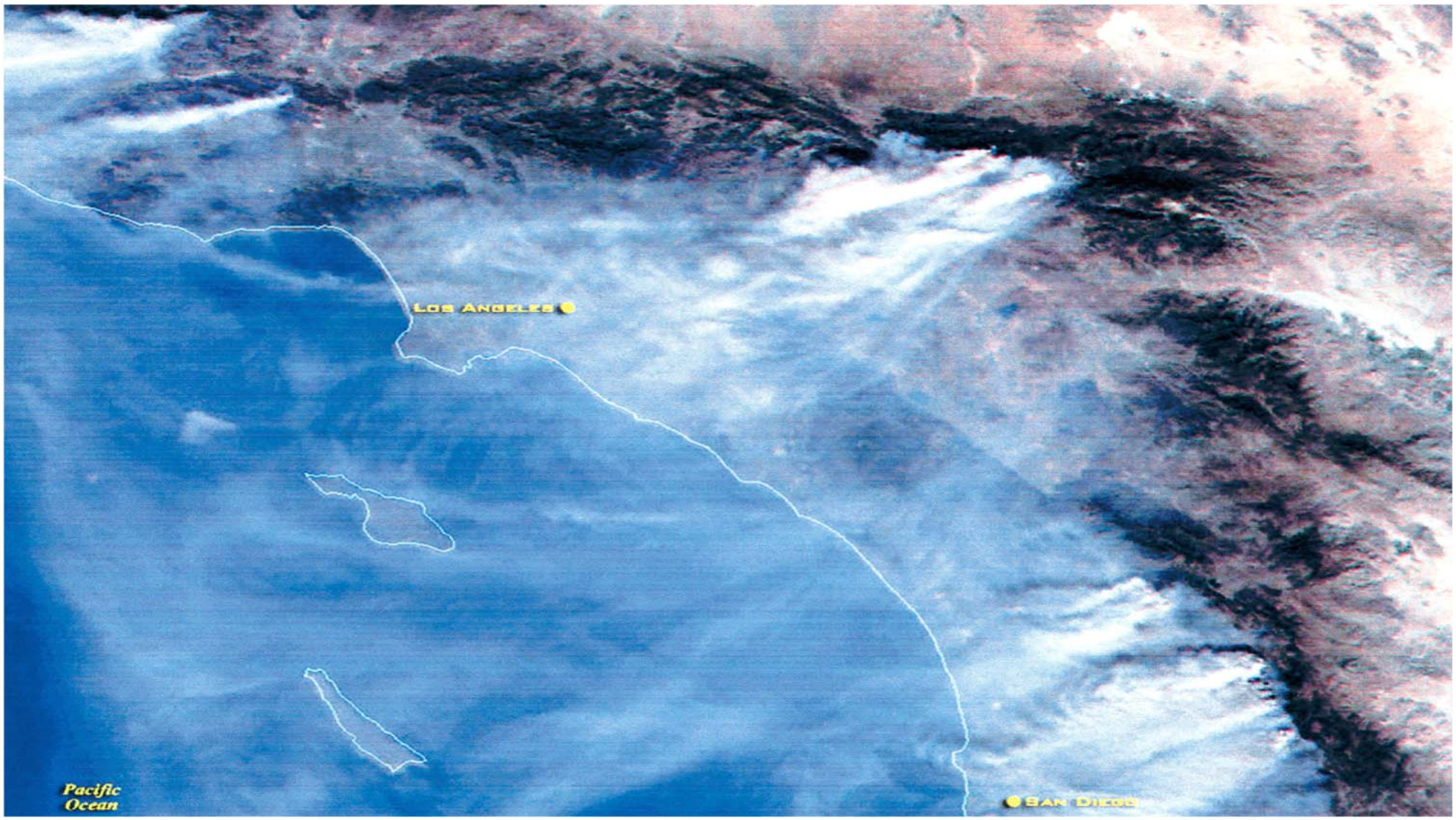
- Atmosphere is capable of *holding only a minute fraction* of the mass of water vapor that has been injected into it during volcanic eruptions
- Therefore, the earliest volcanic activity on the earth surface must have given rise to *clouds and rain*-the formation of water bodies on earth.
- The total amount of water in the atmosphere is measured in a unit of "precipitable water" which gives in cm the amount of water in a vertical infinite column if all the water vapor was condensed to liquid.

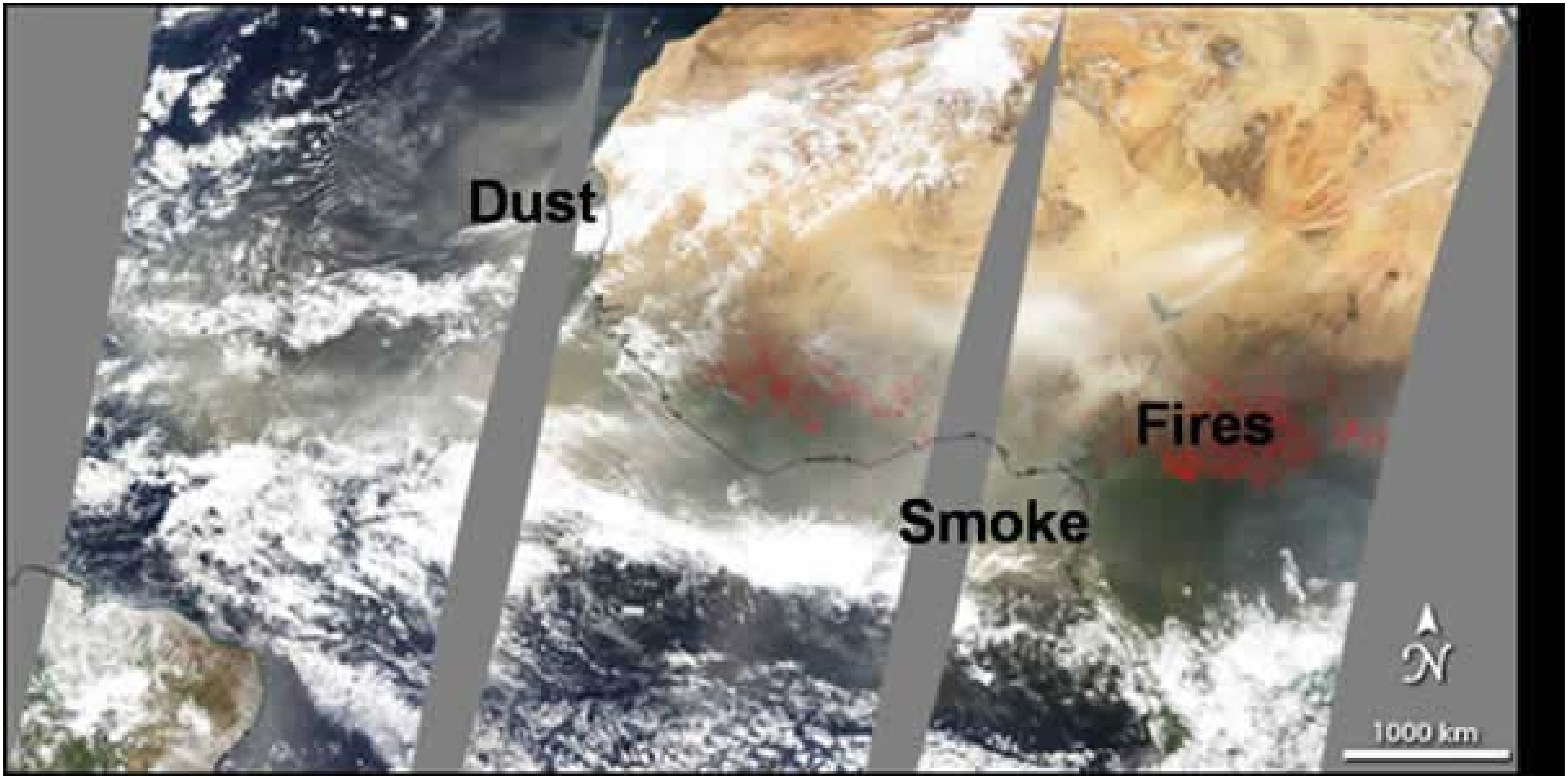
Table 3.3 Sources of Natural Variable Gases and Materials

Source	Contribution
Volcanoes	Sulfur oxides, particulates
Forest fires	Carbon monoxide and dioxide, nitrogen oxides, particulates
Plants	Hydrocarbons, pollens
Decaying plants	Methane, hydrogen sulfides
Soil	Dust and viruses
Ocean	Salt spray and particulates

Southern California wildfires fill the atmosphere with smoke. *Terra* image of wildfires in Southern California consuming thousands of acres of drought-damaged forests; image made October 28, 2003.

Courtesy of the MODIS Land Rapid Response Team, NASA





Dust outbreaks from African Continent

Anthropogenic Pollution

Air Pollutant: a gas or aerosol produce by human activity whose concentration threatens life, such as:

- Carbon monoxide
- Photochemical smog
- Industrial smog and sulfur oxides
- Ozone
- Particulates (aerosols):

small solid particles and liquid droplets in the air. They serve as condensation nuclei for cloud formation.

What is Ozone

Ozone is a natural trace ingredient of the atmosphere. Average concentration is 3 parts per million by volume. Concentration varies with season and latitude.

A pungent blue gas, detectable in small amounts

Ozone was discovered in a lab in the mid 1800s; in Greek *ozein* – "to smell"

Highly reactive with many chemicals

Chemical Formula: O_3

With oxygen emerging as a major component of the atmosphere, the concentration of ozone increased in the atmosphere through a photodissociation process.

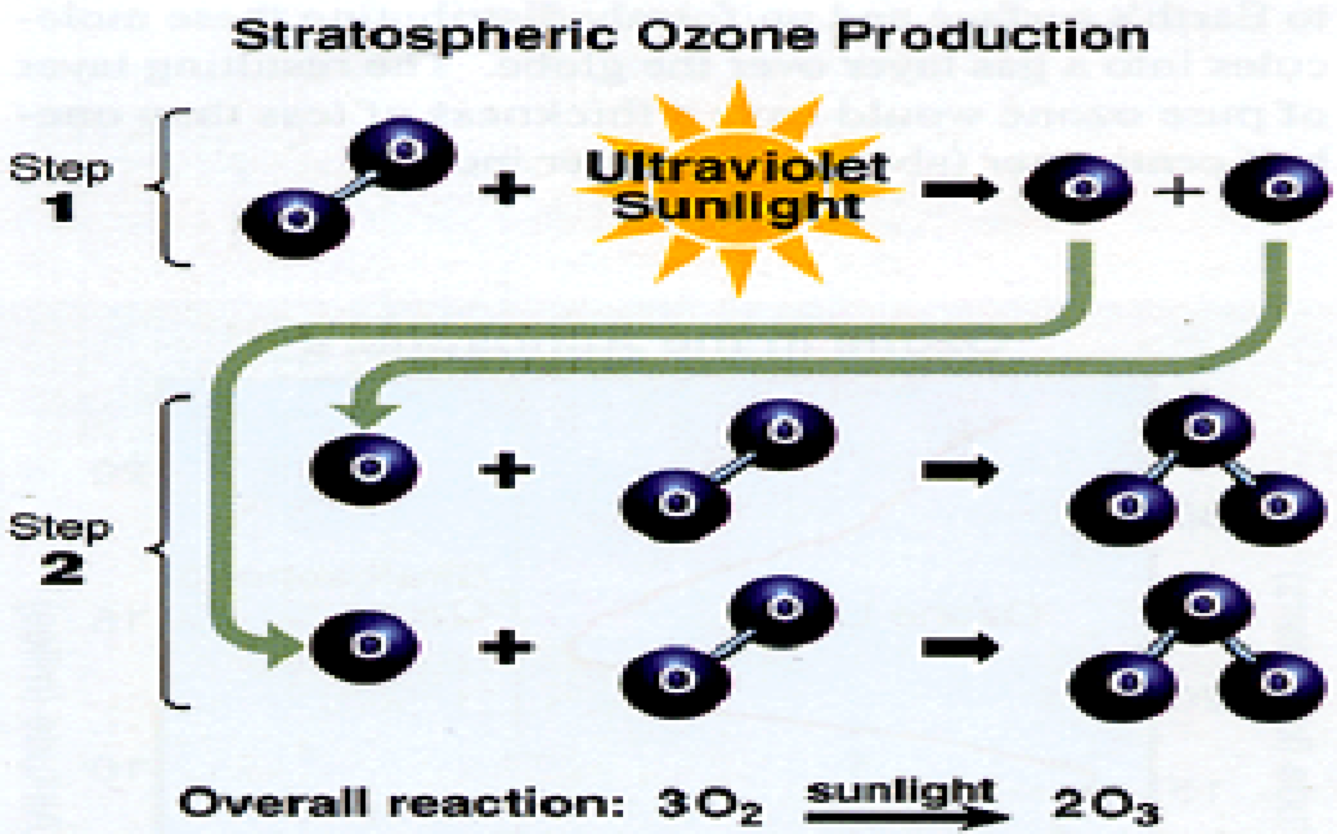


Figure Q2-1. Stratospheric ozone production. Ozone is naturally produced in the stratosphere in a two-step process. In the first step, ultraviolet sunlight breaks apart an oxygen molecule to form two separate oxygen atoms. In the second step, these atoms then undergo a binding collision with other oxygen molecules to form two ozone molecules. In the overall process, three oxygen molecules react to form two ozone molecules.

(from *WMO Report 2003*)

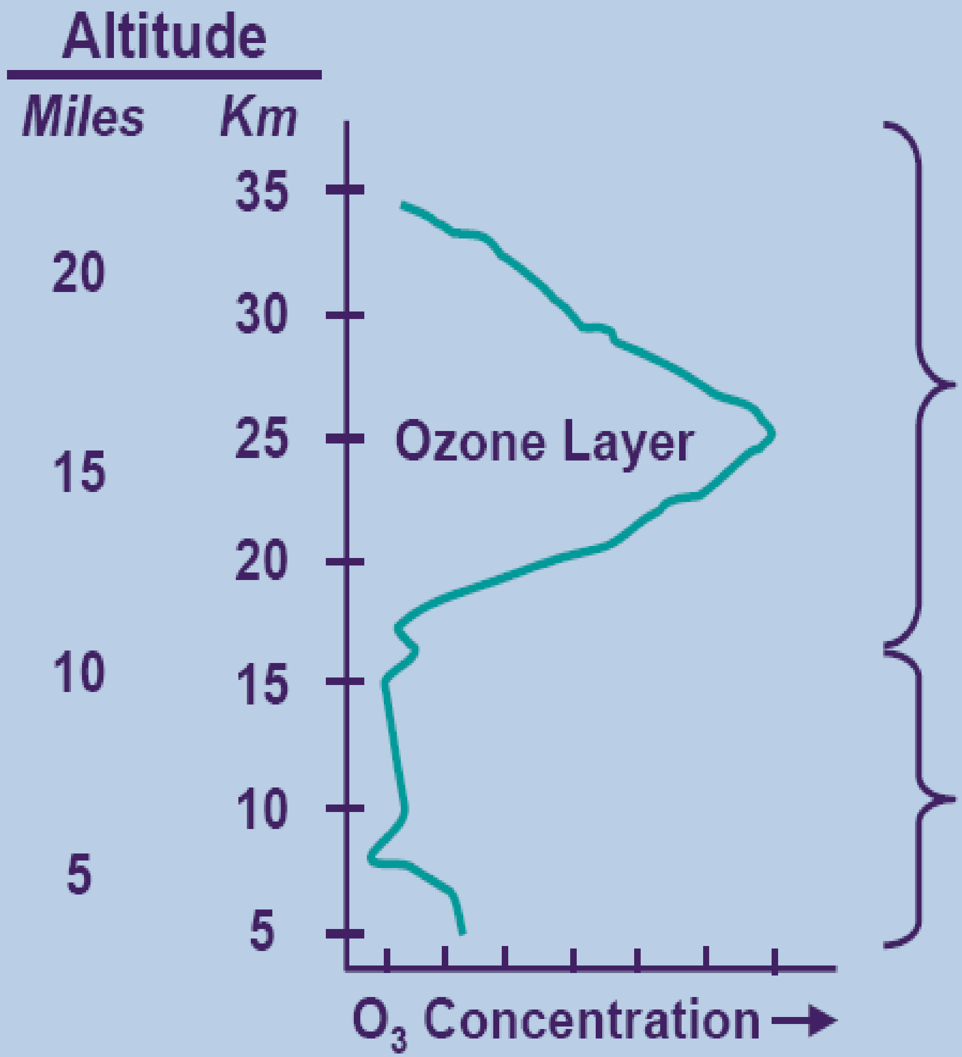
Ozone in the atmosphere

- The total mass of ozone in the atmosphere is about 3 billion metric tons. It is only 0.00006 percent of the atmosphere.
- The peak concentration of ozone

  occurs at an altitude of roughly 32 kilometers (20 miles) above the surface of the Earth.
- At that altitude, ozone concentration can be as high as 15 parts per million (ppm) (0.0015 percent).
- Ozone (O_3) absorbs UV energy and converts it to heat energy

"bad" ozone at surface ~ 0.15 ppm

The Earth's Atmosphere Can Be Generally Divided Into the Troposphere and Stratosphere



Stratosphere

- Temp rises – ozone absorbs UV
- Less vertical component mixing

Troposphere

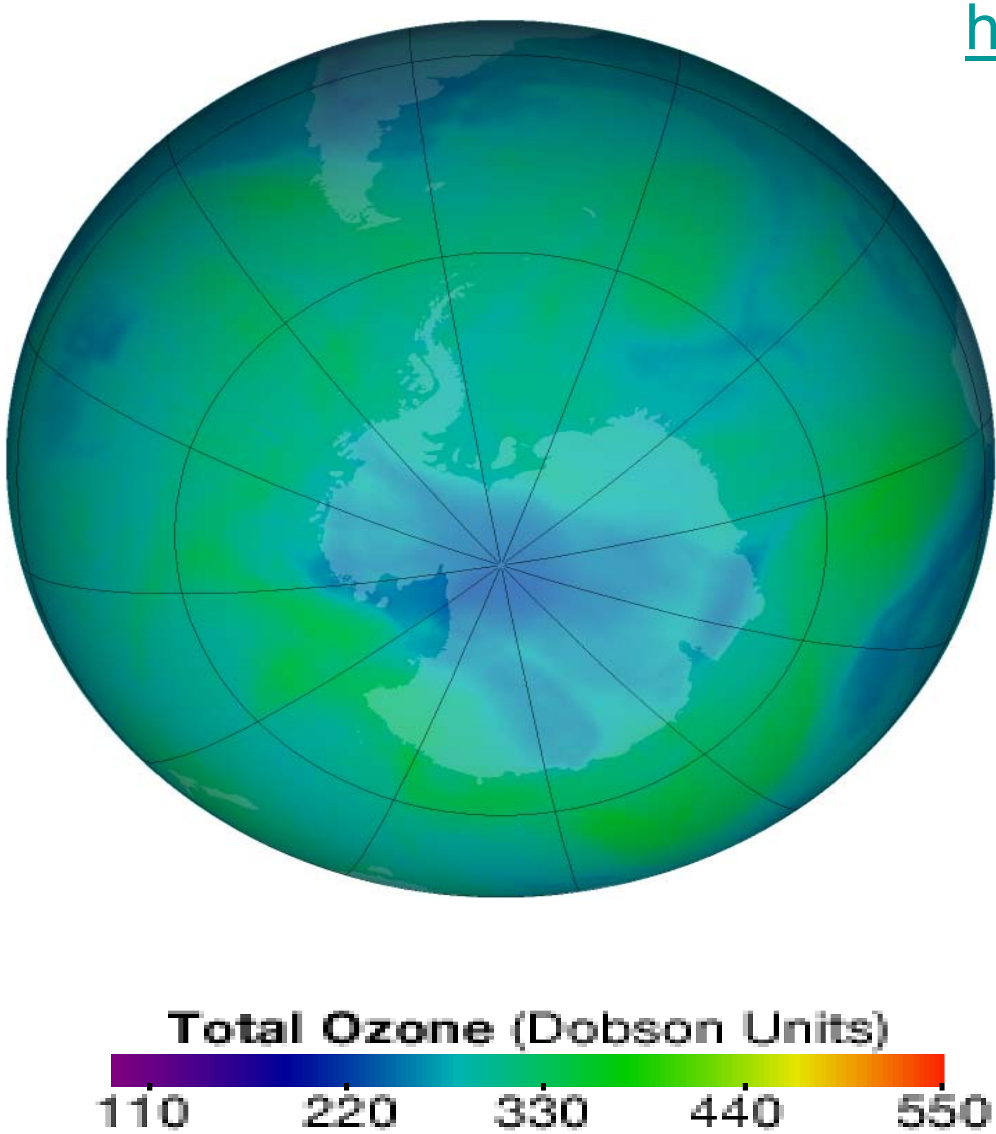
- Weather occurs
- Temp declines with altitude

What is a Dobson Unit?

The Dobson Unit is the most common unit for measuring ozone concentration. One Dobson Unit is the *number of molecules of ozone that would be required to create a layer of pure ozone 0.01 millimeters thick at a temperature of 0 degrees Celsius and a pressure of 1 atmosphere* (the air pressure at the surface of the Earth).

Over the Earth's surface, the ozone layer's average thickness is about 300 Dobson Units or a layer that is 3 millimeters thick.

December 31, 2006



Ozone Hole Watch Web:

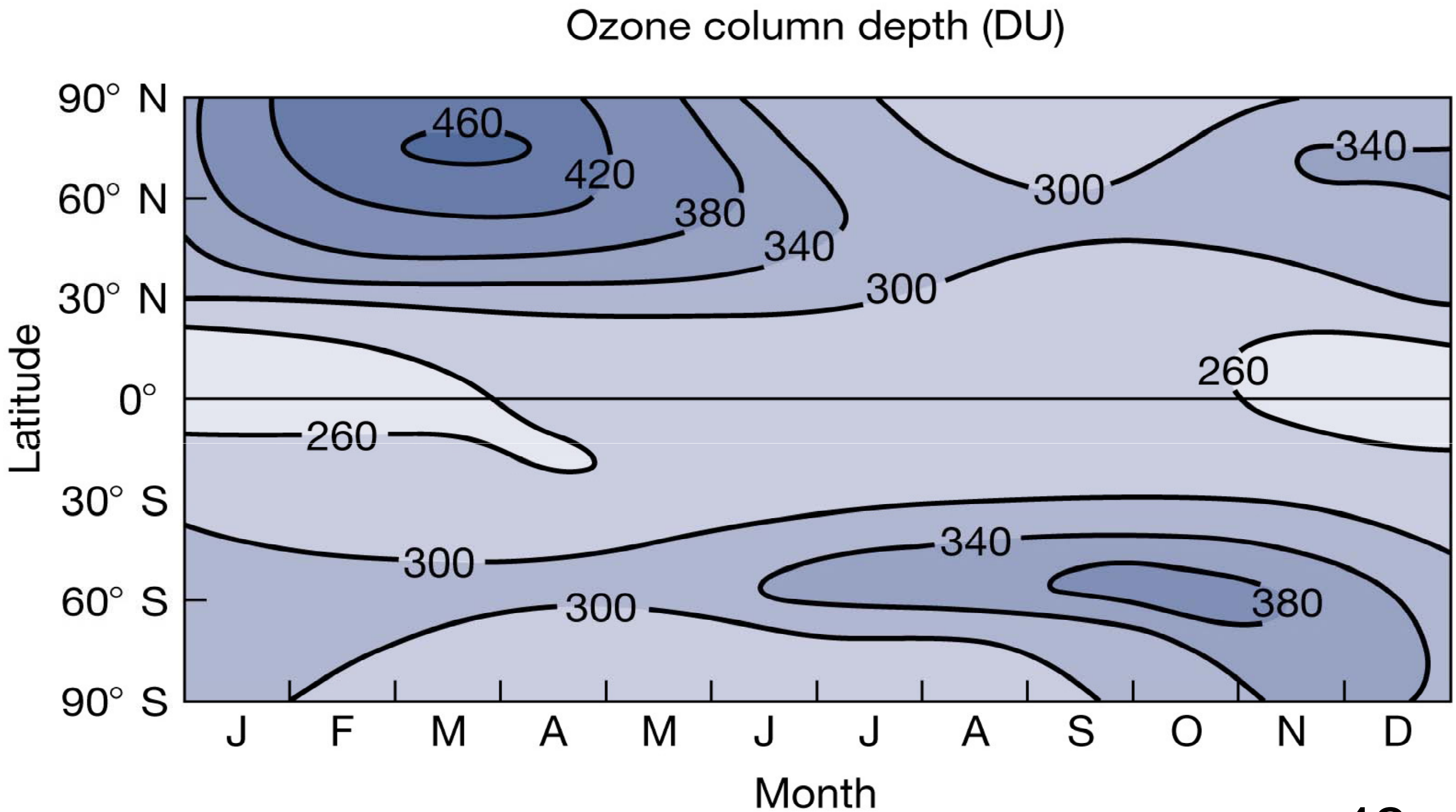
http://ozonewatch.gsfc.nasa.gov/

Gives
latest status of the ozone layer
over the South Pole.

Satellite instruments that
monitor the ozone layer:

OMI
TOMS
GOME
NOAA SBUV/2
MLS
Balloon Sondes

Average latitudinal and seasonal distribution of ozone column depth as measured by satellites. Contours represent column depths in Dobson units.



Stratospheric "good ozone"

- Protects the biosphere from potentially damaging doses of ultraviolet (UV) radiation.
- UV radiation shorter than 0.32 μm is largely screened by ozone (99 %).
- Depletion of stratospheric ozone, caused by the release of man-made ozone-depleting substances—such as chlorofluorocarbons (CFCs), halons, methyl bromide, and hydrochlorofluorocarbons (HCFCs)—could lead to significant increases in UV radiation reaching the Earth's surface-adverse human and ecosystem impacts.

What Are the Differences Between Ozone in the Stratosphere and the Troposphere?

Stratospheric Ozone

- **90% of all ozone exists in "ozone layer"**
  - Naturally forms during chemical reactions between UV sunlight and O_2
  - 12,000 ozone molecules per billion air molecules
  - Shields humans from harmful UV rays/stabilizes weather

Tropospheric Ozone

- **20–100 ozone molecules per billion air molecules**
- **It's the result of human pollution**
  - Irritates the heart and lungs and traps heat (global warming)

Ground-level, “bad,” ozone forms when nitrogen oxide gases from vehicle and industrial emissions react with volatile organic compounds (carbon-containing chemicals that evaporate easily into the air, such as paint thinners). Direct contact with ozone is harmful to plants and humans. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NOx and VOC.

The harmful effects can include throat and lung irritation or aggravation of asthma or emphysema.

High Ozone Levels in the Troposphere Increase the Risk of Premature Death

Ozone Limits

Maximum 8-hour standard of 80 parts per billion (ppb)

Study of 95 U.S. Cities (1987-2000)

Average daily ozone concentration: 26 ppb

Daily mortality increased .52% per 10 ppb increase in surface ozone

Age 65–75 Years: daily mortality increased .70%

These standards have been updated now.

Information for students that want to know more about air quality standards.

Health Risk and Exposure Assessment for Ozone First External Review Draft

http://www.epa.gov/ttn/naaqs/standards/ozone/data/20120816healthrea.pdf

"The last exposure and risk assessment helped to inform the last review and the final decision to revise the primary O_3 NAAQS to a level of 0.075 ppm"

NAAQS = National Ambient Air Quality Standards

Key points covered:

The atmosphere:

- Vertical structure up to 100 km;
- Important atmospheric constituents:

  nitrogen; oxygen; argon; trace gases: carbon; ozone-photochemical process and the formation of ozone layers; the ozone hole; pollutants in the atmosphere.