Earth System Climatology (ESS220)

- Course Time
  Lectures: Tu, Th 9:30-10:50
  Discussion: 3315 Croul Hall
- Text Book
  The Earth System, Kump, Kasting, and Crane, Prentice-Hall
- Grade
  Homework (40%), Final (60%)
- Homework
  Issued and due every Tuesday

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Course Description

- This course offers an overview of Earth's climate system by describing the major climatological features in the atmosphere and oceans and by explaining the physical principals behind them.
- The course begins with an introduction of the global energy balance that drives motions in the atmosphere and oceans, then describes the basic structures and general circulations of the atmosphere and oceans, and finally look into major climate change and variation phenomena.

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Syllabus

SYLLABUS		
Week 1	9/23 & 9/28	**Overview & Global Energy Balance** Atmosphere Composition; Planetary Energy Balance Greenhouse Effect; Role of Cloud
Week 2	9/30 & 10/5	**Atmospheric General Circulation** General Circulation in the Troposphere and Stratosphere Jetstreams; Walker Circulation Monsoon, Sea-land Breeze, Santa Ana Wind
Week 3	10/7 & 10/12	**Oceanic General Circulation** Ocean Structure; Mixed layer, Ekman Layer, and Thermocline Water Mass Formation, Ekman Pumping, and Subduction Surface Ocean Circulation: Wind-Driven Deep Ocean Circulation: Density-Driven Pacific Ocean, Atlantic Ocean, and Indian Ocean Cryosphere
Week 4	10/14 & 10/19	**Climate Variability** Feedback and Sensitivity El Niño Southern Oscillation Arctic Oscillation; North Atlantic Oscillation; Ozone Hole
Week 5	10/21	**Past and Future Climate Changes** Tectonic-Scale, Orbital-Scale Climate Changes Future Climate Projection
Final	**10/26**	

ESS220: EARTH SYSTEM CLIMATOLOGY

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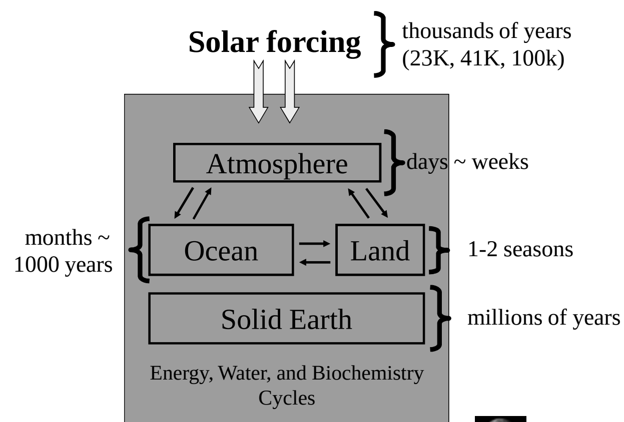
Earth Climate System



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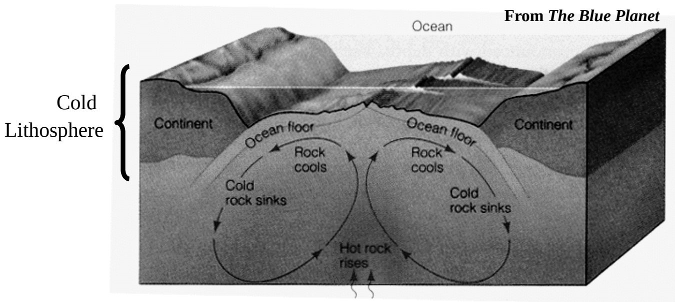
Circulation of the Solid Earth

From *The Blue Planet*



- ❑ The rising hot rocks and slid-away flows are thought to be the factor that control the positions of ocean basins and continents.

➔ The convection determines the shape of the Earth.

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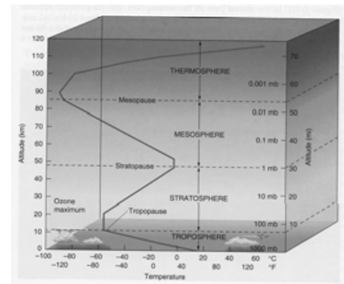
Lecture 1: Atmosphere Composition



(from *Understanding Weather & Climate)*

- **Composition**
- **Origin and Evolution**
- **Vertical Structure**

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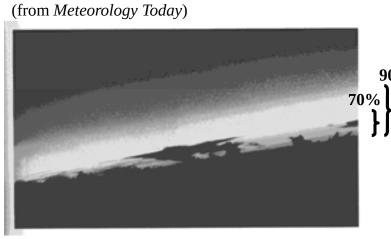
Thickness of the Atmosphere

(from *Meteorology Today*)



- ❑ The thickness of the atmosphere is only about 2% of Earth's thickness (Earth's radius = ~6400km).
- ❑ Most of the atmospheric mass is confined in the lowest 100 km above the sea level.

- ❑ Because of the shallowness of the atmosphere, its motions over large areas are primarily horizontal.

➔Typically, horizontal wind speeds are a thousands time greater than vertical wind speeds.

(But the small vertical displacements of air have an important impact on the state of the atmosphere.)

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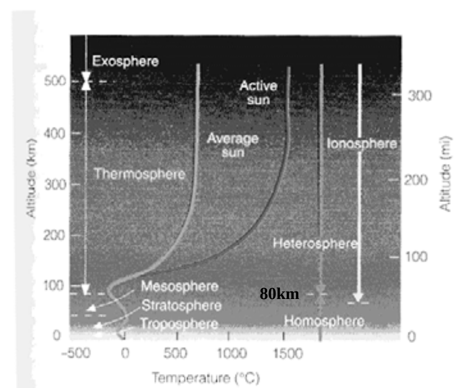
Vertical Structure of the Atmosphere



(from *Meteorology Today*)

composition

temperature

electricity

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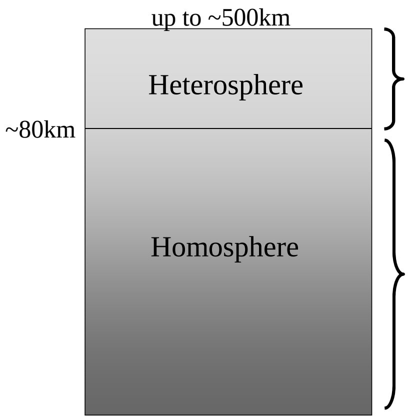
Vertical Structure of Composition

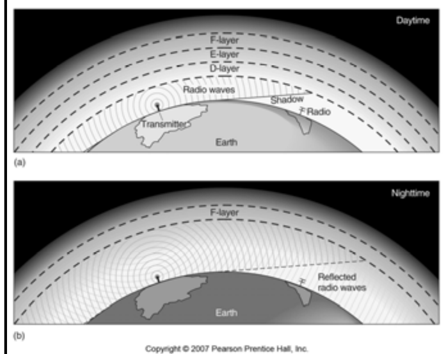


Dominated by lighter gases with increasing altitude, such as hydrogen and helium.

This part of the atmosphere continually circulates, so that the principal atmospheric gases are well mixed.

➔ For most purpose, we consider the homosphere virtually the entire atmosphere.

Ionosphere and AM Radio

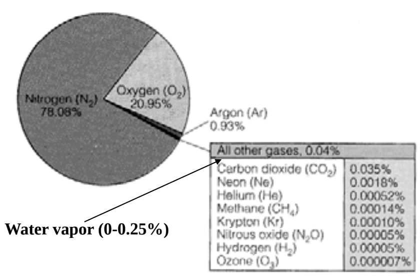


(from *Understanding Weather & Climate*)

- The D- and E-layers absorb AM radio, while the F-layer reflect radio waves.
- When night comes, the D-layer disappears and the E-layer weakens. Radio waves are able to reach the F-layer and get reflected further.
- The repeated refection of radio waves between Earth surface and the F-layer allows them to overcome the effect of Earth's curvature.

Composition of the Atmosphere

(inside the DRY homosphere)



All other gases, 0.04%	
Carbon dioxide (CO_2)	0.035%
Neon (Ne)	0.0018%
Helium (He)	0.00052%
Methane (CH_4)	0.00014%
Krypton (Kr)	0.00010%
Nitrous oxide (N_2O)	0.00005%
Hydrogen (H_2)	0.00005%
Ozone (O_3)	0.000007%

Figure 12.2 Composition of dry, aerosol-free air in volume percent. Three gases—nitrogen, oxygen, and argon—make up 99.96 percent of the air.

(from *The Blue Planet*)

Origins of the Atmosphere

- When the Earth was formed 4.6 billion years ago, Earth's atmosphere was probably mostly hydrogen (H) and helium (He) plus hydrogen compounds, such as methane (CH_4) and ammonia (NH_3).

➔ Those gases eventually escaped to the space.

- The release of gases from rock through volcanic eruption (so-called outgassing) was the principal source of atmospheric gases.

➔ The primeval atmosphere produced by the outgassing was mostly carbon dioxide (**CO_2**) with some Nitrogen (**N_2**) and water vapor (**H_2O**), and trace amounts of other gases.

What Happened to H_2O?

Table 1.2
An inventory of the hydrosphere[a,b]

Component	Percentage of mass of hydrosphere
Oceans	97.
Ice	2.4
Fresh water (underground)	0.6
Fresh water in lakes, rivers, etc.	0.02
Atmosphere	0.001

[a] Total mass = 1.36×10^{21} kg = 2.66×10^{6} kg m^{-2} over surface of earth.
[b] Based on data given in H. H. Lamb, "Climate: Present, Past and Future," Methuen Co. Ltd., London, 1972, p. 482.

(from *Atmospheric Sciences: An Introductory Survey*)

- ❑ The atmosphere can only small fraction of the mass of water vapor that has been injected into it during volcanic eruption, most of the water vapor was condensed into clouds and rains and gave rise to oceans.

➔ The concentration of water vapor in the atmosphere was substantially reduced.

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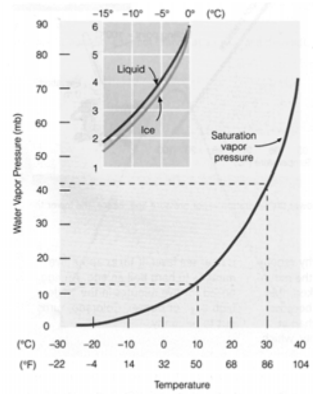
Saturation Vapor Pressure



- ❑ Saturation vapor pressure describes how much water vapor is needed to make the air saturated at any given temperature.
- ❑ Saturation vapor pressure depends primarily on the air temperature in the following way:

$$\frac{de_s}{dT} = \frac{L}{T(\alpha_v - \alpha_l)}$$

The Clausius-Clapeyron Equation

➔
$$e_s \cong 6.11 \bullet \exp\left\{\frac{L}{R_v}\left(\frac{1}{273} - \frac{1}{T}\right)\right\}$$

- ❑ Saturation pressure increases exponentially with air temperature.

L: latent heat of evaporation; α: specific volume of vapor and liquid

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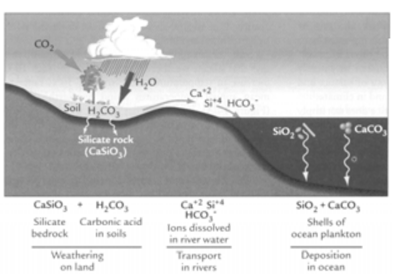
What happened to CO_2?



(from *Earth's Climate: Past and Future*)

- ❑ Chemical weather is the primary process to remove CO2 from the atmosphere.

➔ In this process, CO2 dissolves in rainwater producing weak carbonic acid that reacts chemically with bedrock and produces carbonate compounds.

- ❑ This process reduced CO2 in the atmosphere and locked carbon in rocks and mineral.

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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*)

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What Happened to N_2?

- Nitrogen (N2):
  (1) is inert chemically,
  (2) has molecular speeds too slow to escape to space,
  (3) is not very soluble in water.

➔ The amount of nitrogen being cycled out of the atmosphere was limited.

➔ Nitrogen became the most abundant gas in the atmosphere.

Where Did O_2 Come from?

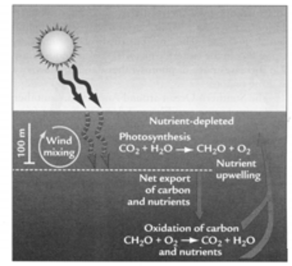

FIGURE 2-35 **Photosynthesis in the ocean** Sunlight penetrating the surface ocean causes photosynthesis by microscopic plants. As they die, their nutrient-bearing organic tissue descends to the seafloor. Oxidation of this tissue at depth returns nutrients and inorganic carbon to the surface ocean in regions of upwelling.

(from *Earth's Climate: Past and Future*)

- Photosynthesis was the primary process to increase the amount of oxygen in the atmosphere.

➔ Primitive forms of life in oceans began to produce oxygen through photosynthesis probably 2.5 billion years ago.

➔ With the concurrent decline of CO2, oxygen became the second most abundant atmospheric as after nitrogen.

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Where Did Argon Come from?

- Radioactive decay in the planet's bedrock added argon (**Ar**) to the evolving atmosphere.

➔ Argon became the third abundant gas in the atmosphere.

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Formation of Ozone (O_3)

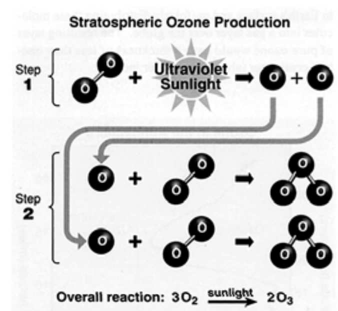

Figure Q2-1. Stratospheric ozone production. Ozone is naturally produced in the stratosphere in a two-step process. In the first step, ultraviolet sunlight breaks apart an oxygen molecule to form two separate oxygen atoms. In the second step, these atoms then undergo a binding collision with other oxygen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

(from *WMO Report 2003*)

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

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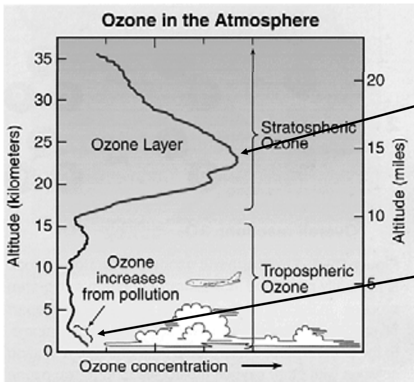
Ozone (O_3)



"good" ozone
~ 15ppm

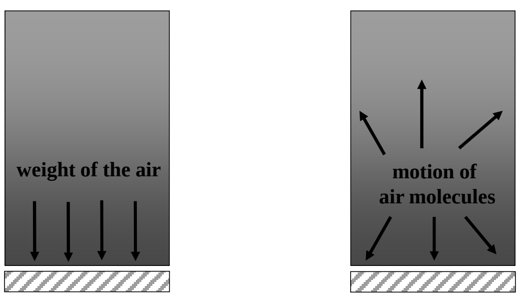
"bad" ozone
~ 0.15ppm

(from WMO Report 2003)

Other Atmospheric Constituents

- **Aerosols**: small solid particles and liquid droplets in the air. They serve as condensation nuclei for cloud formation.
- **Air Pollutant**: a gas or aerosol produce by human activity whose concentration threatens living organisms or the environment.

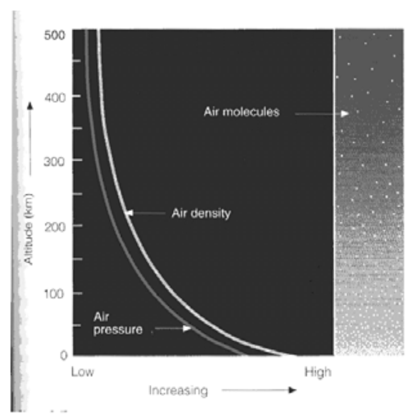
Air Pressure Can Be Explained As:



The weight of air above a surface (due to Earth's gravity)

The bombardment of air molecules on a surface (due to motion)

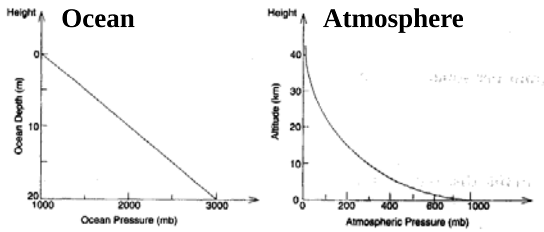
Air Pressure and Air Density



- Weight = mass x gravity
- Density = mass / volume
- Pressure = force / area
  = weight / area

(from *Meteorology Today*)

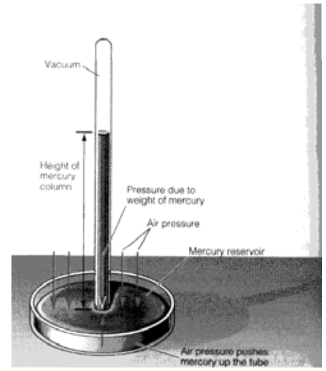
How Soon Pressure Drops With Height?



(from ***Is The Temperature Rising?***)

- ❑ In the ocean, which has an essentially constant density, pressure increases linearly with depth.
- ❑ In the atmosphere, both pressure and density decrease exponentially with elevation.

One Atmospheric Pressure



(from *The Blue Planet*)

- ❑ The average air pressure at sea level is equivalent to the pressure produced by a column of water about 10 meters (or about 76 cm of mercury column).
- ❑ This standard atmosphere pressure is often expressed as 1013 mb (millibars), which means a pressure of about 1 kilogram per square centimeter.

Units of Atmospheric Pressure

- ❑ **Pascal (Pa):** a SI (Systeme Internationale) unit for air pressure.

  1 Pa = a force of 1 newton acting on a surface of one square meter

  1 hectopascal (hPa) = 1 millibar (mb) [hecto = one hundred =100]

- ❑ **Bar:** a more popular unit for air pressure.

  1 bar = a force of 100,000 newtons acting on a surface of one square meter

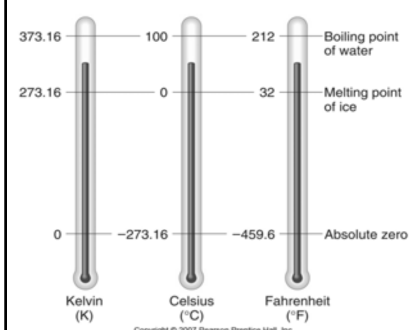
  = 100,000 Pa

  = 1000 hPa

  = 1000 mb

- ❑ **One atmospheric pressure** = standard value of atmospheric pressure at lea level = 1013.25 mb = 1013.25 hPa.

Units of Air Temperature

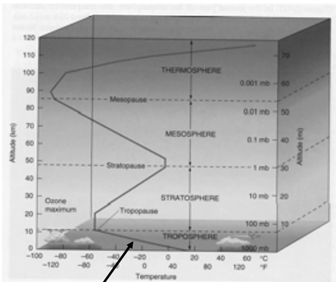


- ❑ Fahrenheit (ºF)
- ❑ Celsius (ºC)
  ➔ ºC = (ºF-32)/1.8
- ❑ Kelvin (K): a SI unit
  ➔ K= ºC+273

1 K = 1 ºC > 1 ºF

Vertical Thermal Structure

Standard Atmosphere



(from *Understanding Weather & Climate*)

lapse rate = 6.5 C/km

Troposphere (“overturning” sphere)
- contains 80% of the mass
- surface heated by solar radiation
- strong vertical motion
- where most weather events occur

Stratosphere (“layer” sphere)
- weak vertical motions
- dominated by radiative processes
- heated by ozone absorption of solar ultraviolet (UV) radiation
- warmest (coldest) temperatures at summer (winter) pole

Mesosphere
- heated by solar radiation at the base
- heat dispersed upward by vertical motion

Thermosphere
- very little mass

Variations in Tropopause Height

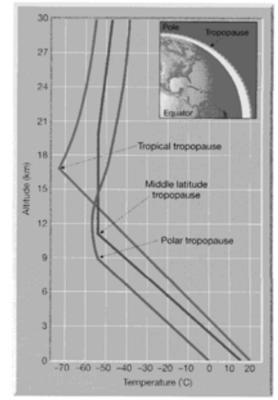
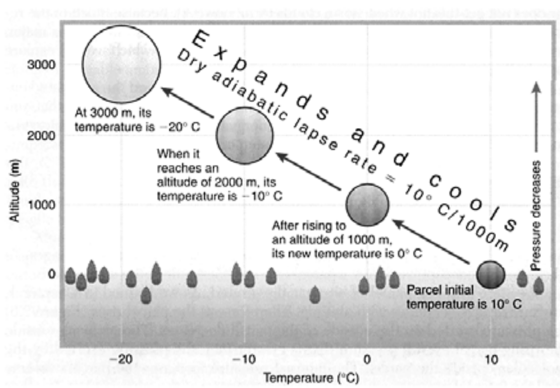


FIGURE 1-23 Differences in the height of the tropopause. The variation in the height of the tropopause, as shown on the small inset diagram, is greatly exaggerated.

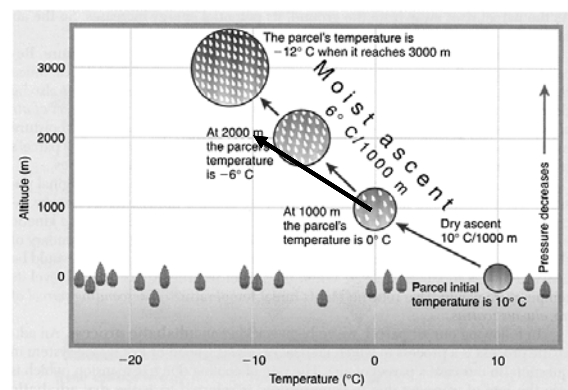
(from *The Atmosphere*)

Dry Adiabatic Lapse Rate



(from *Meteorology: Understanding the Atmosphere*)

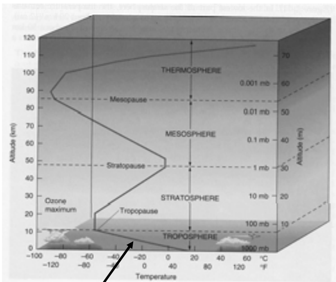
Moist Adiabatic Lapse Rate



(from *Meteorology: Understanding the Atmosphere*)

Stratosphere

Standard Atmosphere

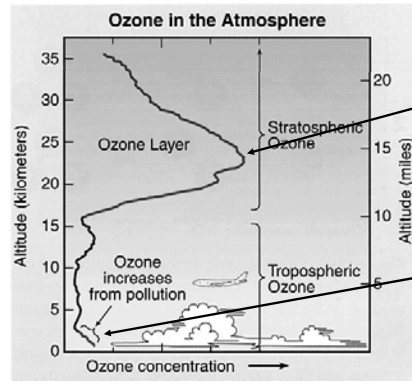


(from *Understanding Weather & Climate*)

lapse rate = 6.5 C/km

- ❑ The reasons for the inversion in the stratosphere is due to the ozone absorption of ultraviolet solar energy.
- ❑ Although maximum ozone concentration occurs at 25km, the lower air density at 50km allows solar energy to heat up temperature there at a much greater degree.
- ❑ Also, much solar energy is absorbed in the upper stratosphere and can not reach the level of ozone maximum.

Ozone (O_3)

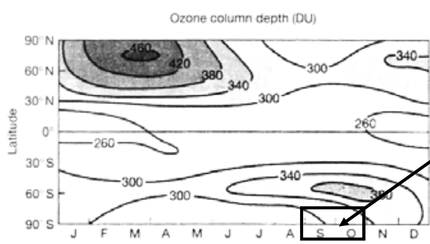


"good" ozone ~ 15ppm

"bad" ozone ~ 0.15ppm

(from WMO Report 2003)

Ozone Distribution



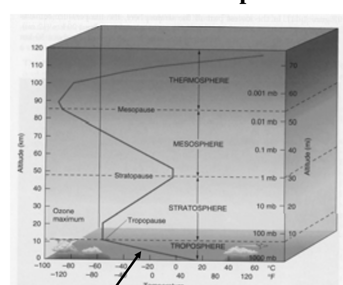
Antarctic Ozone Hole

(from *The Earth System*)

- ❑ The greatest production of ozone occurs in the tropics, where the solar UV flux is the highest.
- ❑ However, the general circulation in the stratosphere transport ozone-rich air from the tropical upper stratosphere to mid-to-high latitudes.
- ❑ Ozone column depths are highest during springtime at mid-to-high latitudes.
- ❑ Ozone column depths are the lowest over the equator.

Mesosphere

Standard Atmosphere



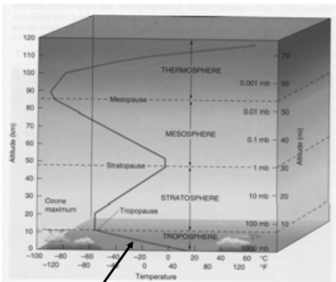
(from *Understanding Weather & Climate*)

lapse rate = 6.5 C/km

- ❑ There is little ozone to absorb solar energy in the mesosphere, and therefore, the air temperature in the mesosphere decreases with height.
- ❑ Also, air molecules are able to lose more energy than they absorb. This cooling effect is particularly large near the top of the mesosphere.

Thermosphere

Standard Atmosphere



(from *Understanding Weather & Climate*)

lapse rate = 6.5 C/km

❑ In thermosphere, oxygen molecules absorb solar rays and warms the air.

❑ Because this layer has a low air density, the absorption of small amount of solar energy can cause large temperature increase.

❑ The air temperature in the thermosphere is affected greatly by solar activity.