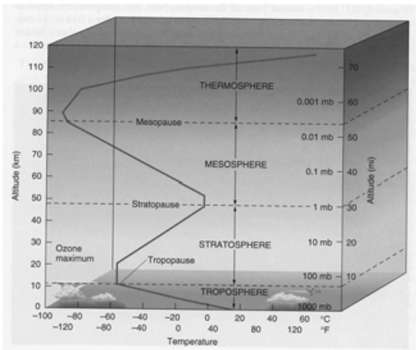
Chapter 1: Composition and Structure of the Atmosphere



- ❑ Composition
- ❑ Evolution
- ❑ Vertical Structure

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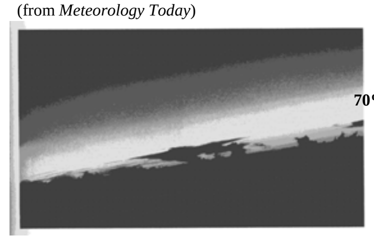
Thickness of the Atmosphere

(from *Meteorology Today*)



90%
70%

- ❑ Most of the atmospheric mass is confined in the lowest 100 km above the sea level.
- ❑ The thickness of the atmosphere is only about 2% of Earth's thickness (Earth's radius = ~6500km).

❑ 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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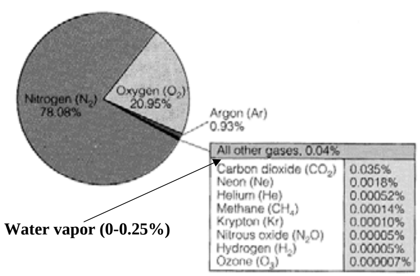
Composition of the Atmosphere

(inside the DRY homosphere)



Water vapor (0-0.25%)

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*)

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Permanent and Variable Gases

Table 1–2 • Permanent Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Nitrogen	N_2	78.08	28.01
Oxygen	O_2	20.95	32.00
Argon	Ar	0.93	39.95
Neon	Ne	0.002	20.18
Helium	He	0.0005	4.00
Krypton	Kr	0.0001	83.8
Xenon	Xe	0.00009	131.3
Hydrogen	H_2	0.00005	2.02

Those gases that form a constant portion of the atmospheric mass.

Table 1–3 • Variable Gases of the Atmosphere

Constituent	Formula	Percent by Volume	Molecular Weight
Water Vapor	H_2O	0.25	18.01
Carbon Dioxide	CO_2	0.037	44.01
Ozone	O_3	0.01	48.00

Those gases whose concentrations changes from time to time and from place to place. Some of those gases are important to weather and climate.

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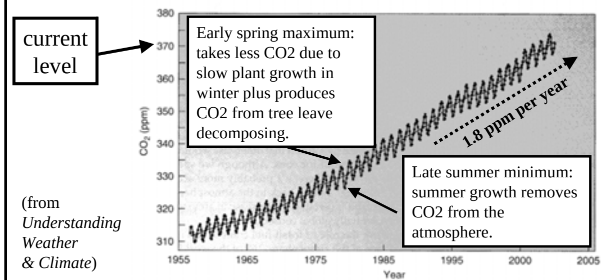
Water Vapor (H2O)

- The most abundant variable gas.
- Water vapor is supplied to the atmosphere by evaporation from the surface and is removed from the atmosphere by condensation (clouds and rains).
- The concentration of water vapor is maximum near the surface and the tropics (~ 0.25% of the atmosphere by volume) and decreases rapidly toward higher altitudes and latitude (~ 0% of the atmosphere).
- Water vapor is important to climate because it is a greenhouse gas that can absorb thermal energy emitted by Earth, and can release “latent heat” to fuel weather phenomena.

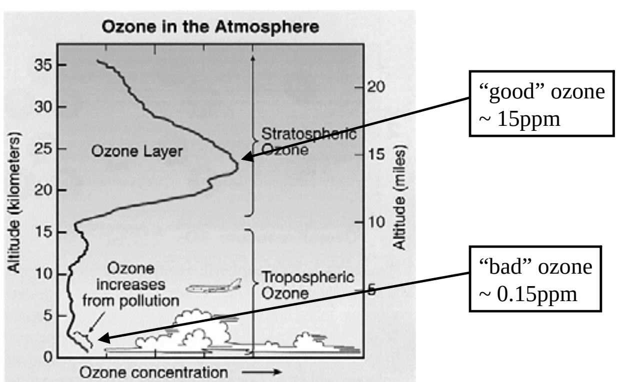
Carbon Dioxide (CO2)



(from *Understanding Weather & Climate*)

- Carbon dioxide is supplied into the atmosphere by plant and animal respiration, the decay of organic material, volcanic eruptions, and natural and anthropogenic combustion.
- Carbon dioxide is removed from the atmosphere by photosynthesis.
- CO2 is an important greenhouse gas.

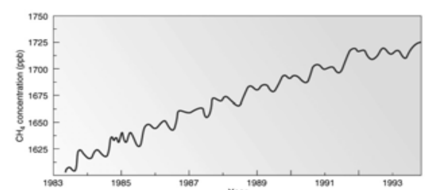
Ozone (O_3)



(from WMO Report 2003)

- Methane
  - A variable gas in small but recently increasing concentrations
  - Released to the atmosphere through fossil fuel activities, livestock digestion, and agriculture cultivation (esp. rice)
  - As a very effective absorber of terrestrial radiation it plays an active role in near surface warming

Annual increases in atmospheric methane



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.

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

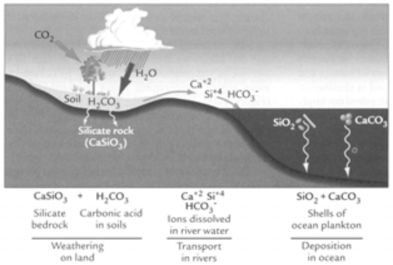
[a] Total mass = 1.36×10^{21} kg = 2.66×10^{6} kg m^{-2} over surface of earth.
[b] Based on data given in H. H. Lamb, "Climate: Present, Past and Future," Methuen Co. Ltd., London, 1972, p. 482.

(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.

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 biogeochemical process reduced CO2 in the atmosphere and locked carbon in rocks and mineral.

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.

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Where Did O_2 Come from?

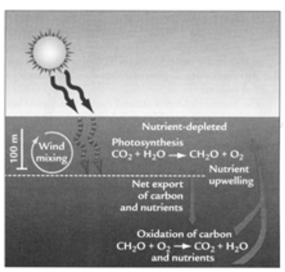

FIGURE 2-35 Photosynthesis in the ocean Sunlight penetrating the surface ocean causes photosynthesis by microscopic plants. As they die, their nutrient-bearing organic tissue descends to the seafloor. Oxidation of this tissue at depth returns nutrients and inorganic carbon to the surface ocean in regions 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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Formation of Ozone (O_3)

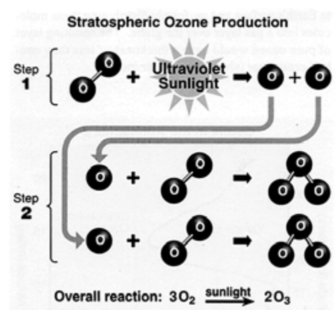

Figure Q2-1. Stratospheric ozone production. Ozone is naturally produced in the stratosphere in a two-step process. In the first step, ultraviolet sunlight breaks apart an oxygen molecule to form two separate oxygen atoms. In the second step, these atoms then undergo a binding collision with other oxygen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

(inside the DRY homosphere)

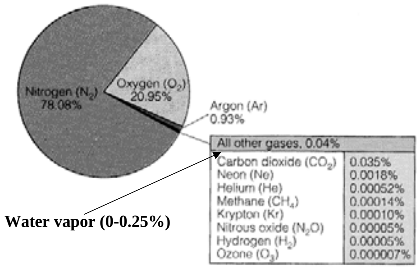

Figure 12.2 Composition of dry, aerosol-free air in volume percent. Three gases—nitrogen, oxygen, and argon—make up 99.96 percent of the air.

(from *The Blue Planet*)

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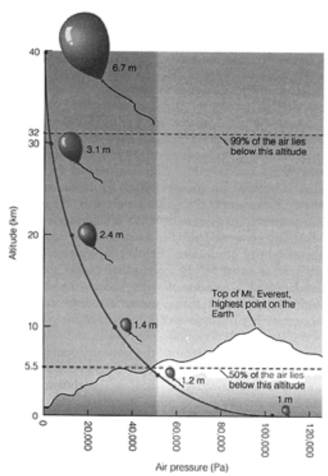

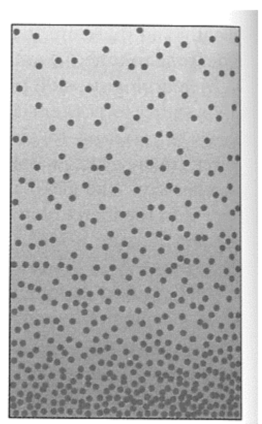

(from *The Atmosphere*)

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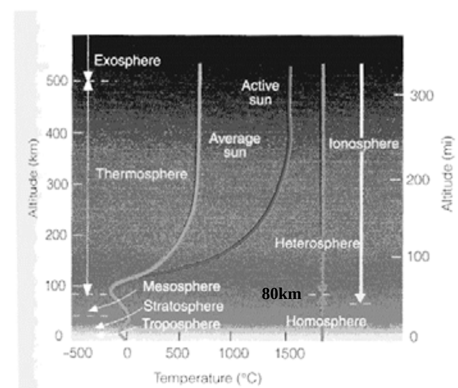
Vertical Structure of the Atmosphere



composition

temperature

electricity

(from *Meteorology Today*)

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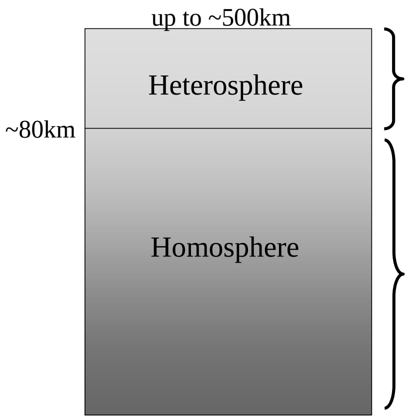
Vertical Structure of Composition



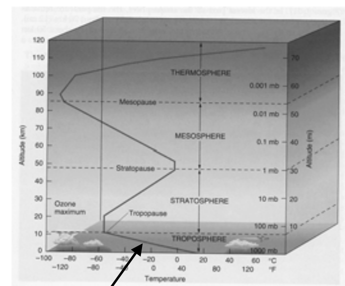
Dominated by lighter gases with increasing altitude, such as hydrogen and helium.

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.

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 (“in-between” sphere)
- heated by solar radiation at the base
- heat dispersed upward by vertical motion

Thermosphere (“heated” sphere)
- very little mass

Variations in Tropopause Height

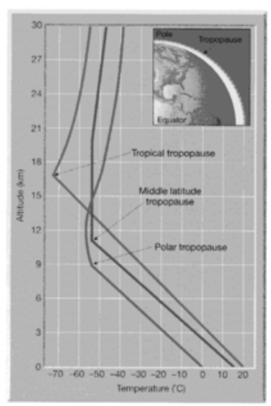
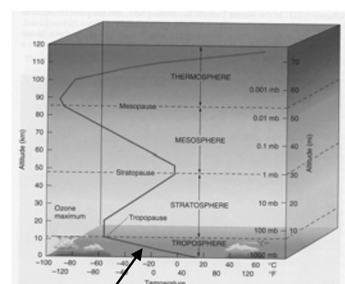


FIGURE 1-23 Differences in the height of the tropopause. The variation in the height of the tropopause, as shown on the small inset diagram, is greatly exaggerated.

(from *The Atmosphere*)

Stratosphere

Standard Atmosphere



(from *Understanding Weather & Climate*)

lapse rate = 6.5 C/km

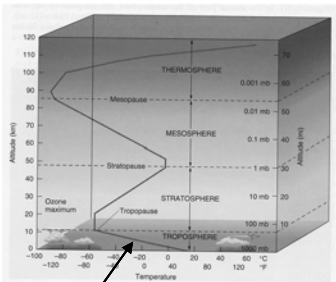
❑ The reasons for the inversion in the stratosphere is due to the ozone absorption of ultraviolet solar energy.

❑ 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.

Mesosphere

Standard Atmosphere



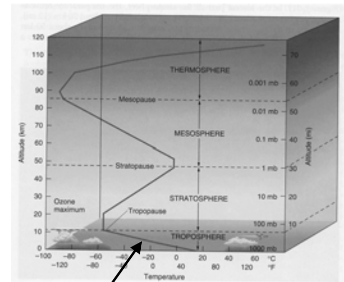
(from *Understanding Weather & Climate*)

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

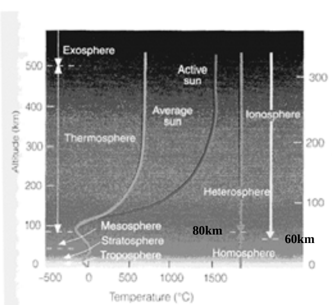


(from *Understanding Weather & Climate*)

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.

Ionosphere



(from *Meteorology Today*)

- ❑ The ionosphere is an electrified region within the upper atmosphere where large concentration of ions and free electrons exist.
- ❑ The ionosphere starts from about 60km above Earth's surface and extends upward to the top of the atmosphere. Most of the ionosphere is in the thermosphere.
- ❑ The ionosphere plays an important role in radio communication.