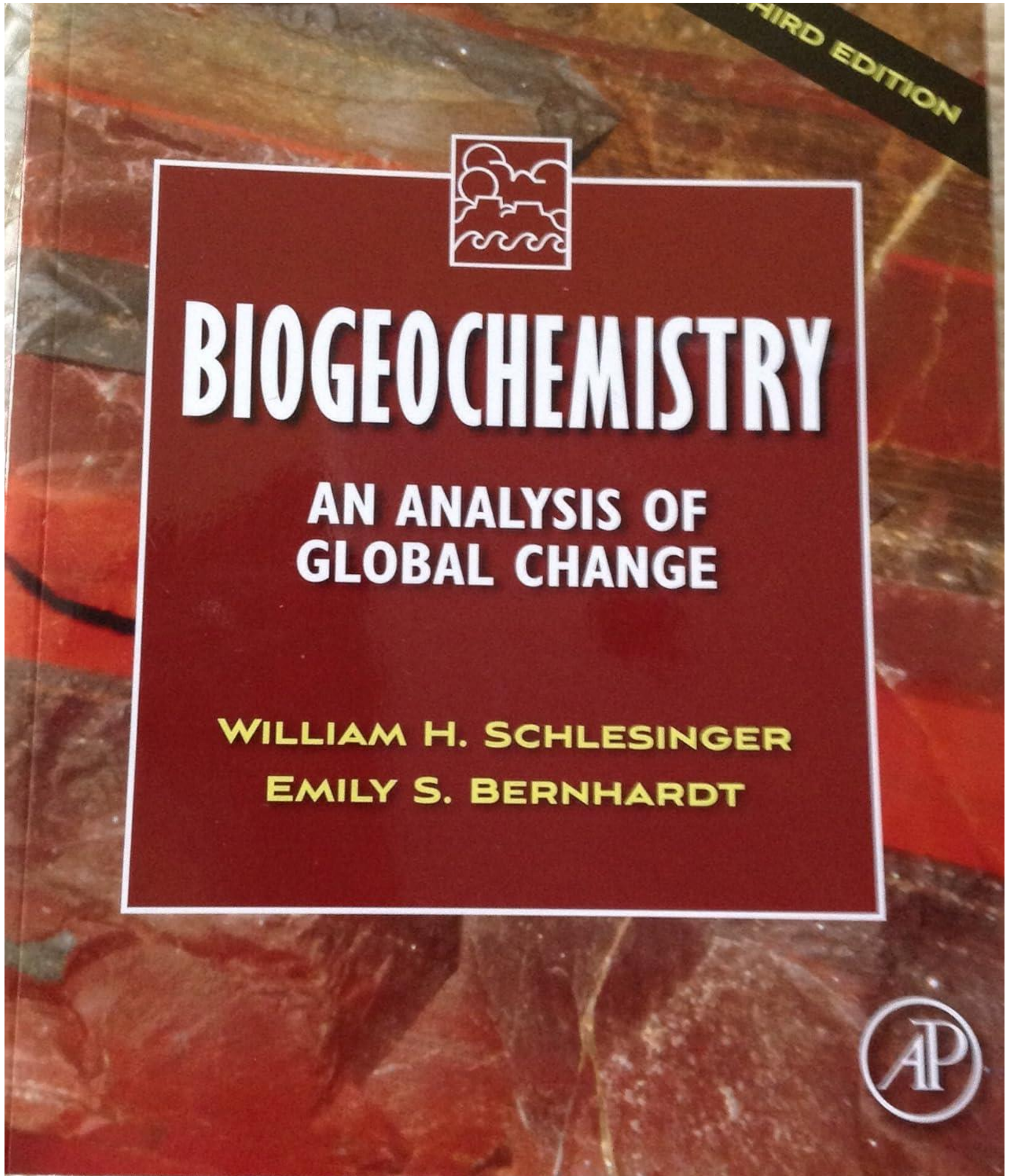
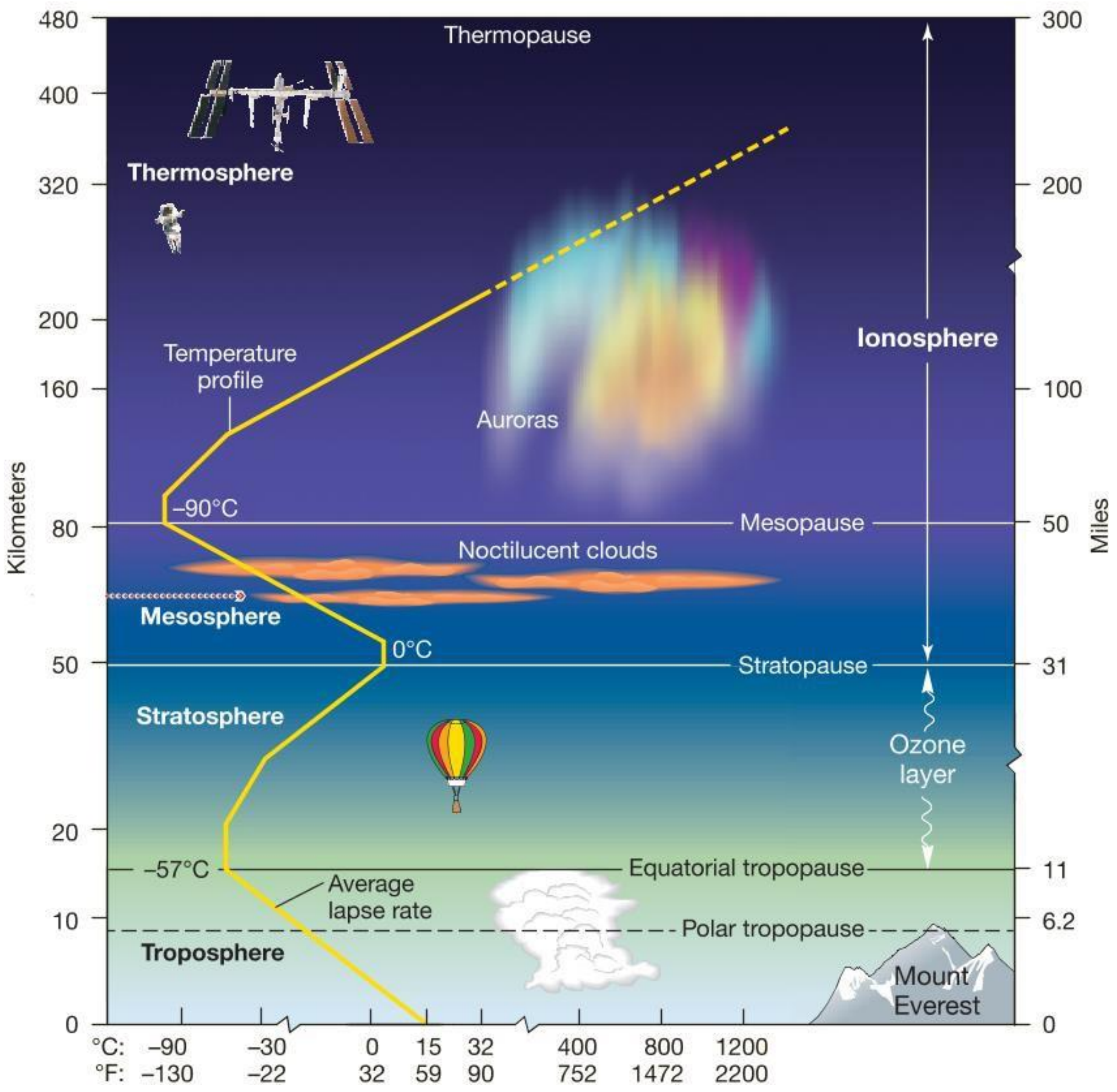
Chapter 3 - The Atmosphere





Reflection 2

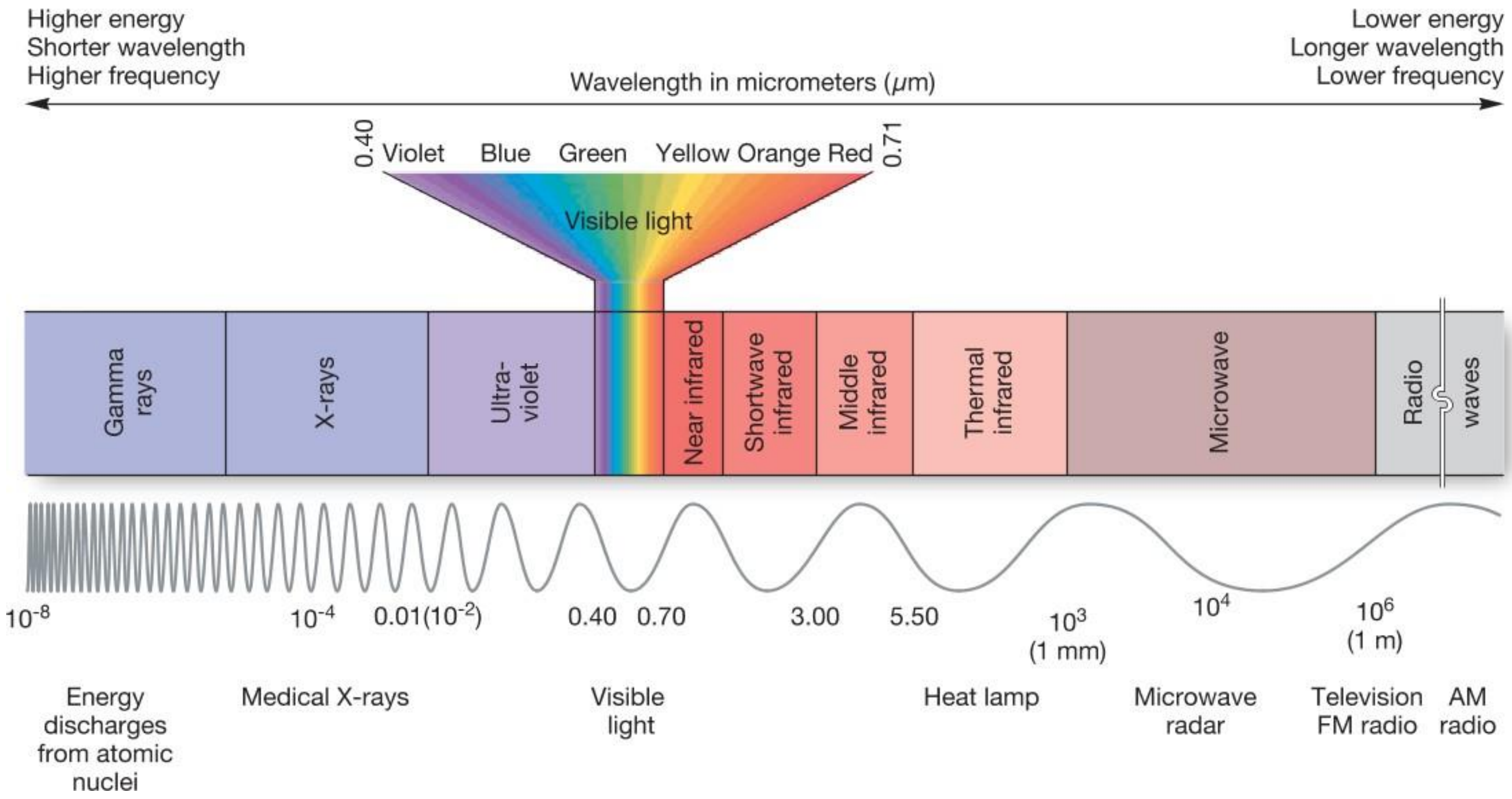
Through the use of stoichiometric ratios, we can track the movement of elements through the pools in any given system but to do this we have to be aware of the additional factors at play. Factors such as light, temperature, location, and what organisms are present. Even though steady state models make these processes seem simple, they are actually very complex, and steady state models are limited. we discussed tracking the movement of nitrogen through a system based on the carbon to nitrogen ratio of whatever it is we are studying. If we know how much carbon is released, we can calculate how much nitrogen will be utilized using the C:N ratio of the prey or predator (dependent on what is being studied). Additionally, this is possible because only a percentage of what is being consumed will become viable biomass and provide enough resources to prevent death, the rest is excreted. This is called the assimilation efficiency. We can utilize equations, like the assimilated biomass equation, to see how these factors affect the system, and they can be used track how much carbon will be released by an organism furthering our understanding of how these resources move. The book said, "life is so pervasive that there is no pure science" to study it. I think I understand this now. Our systems are so complex, with varying ranges in scale, that we may never have definitive answers about how things truly work but we can utilize multiple disciples and techniques to provide additional proof to back our findings. This honestly is a little maddening because science has always seemed like such a definitive thing. It does remove some pressure I have felt about doing my own research and I am gaining a deeper appreciation for the complexity of our planet.

The most interesting thing I learned this week was honestly from the debrief of the RFP we have due in a couple of weeks. Grad school is something I'm considering a little more seriously now, and the exposure to that kind of process has been really insightful. Content wise, I enjoyed the exercise with the cats and mice- while it was a little abstract, I think it was a valuable exercise to be able to practice recognizing the components of any system. I've been doing some brainstorming for a GIS project that I want to work with water quality indicators, and bringing in the perspective of looking at these watersheds and drainages in terms of their boundaries, controls, and feedbacks has been a really applicable process.

This week I found the reasoning behind the 10% rule of trophic structure especially fascinating, since I had heard of it before but never understood the systems behind it. Learning about the assimilation and production efficiencies, and how each represent around 30% efficiency was fascinating as it leads to how the math turns a 9% efficiency of a trophic level. This perspective made me think more deeply about how that 10% rule which I always thought represented inefficiency actually represents a benefit to ecosystems diversity, which I know from other classes helps keep an ecosystem strong.

I also enjoyed the Egyptian math problem. It's crazy to think that humans have been curious about ecosystems for thousands of years and how old the understanding of resource flows through food chains is.

I also thought the statistic that the biomass of nematodes in the Great Plains equals five million cattle really highlighted the hidden scale of life in ecosystems.

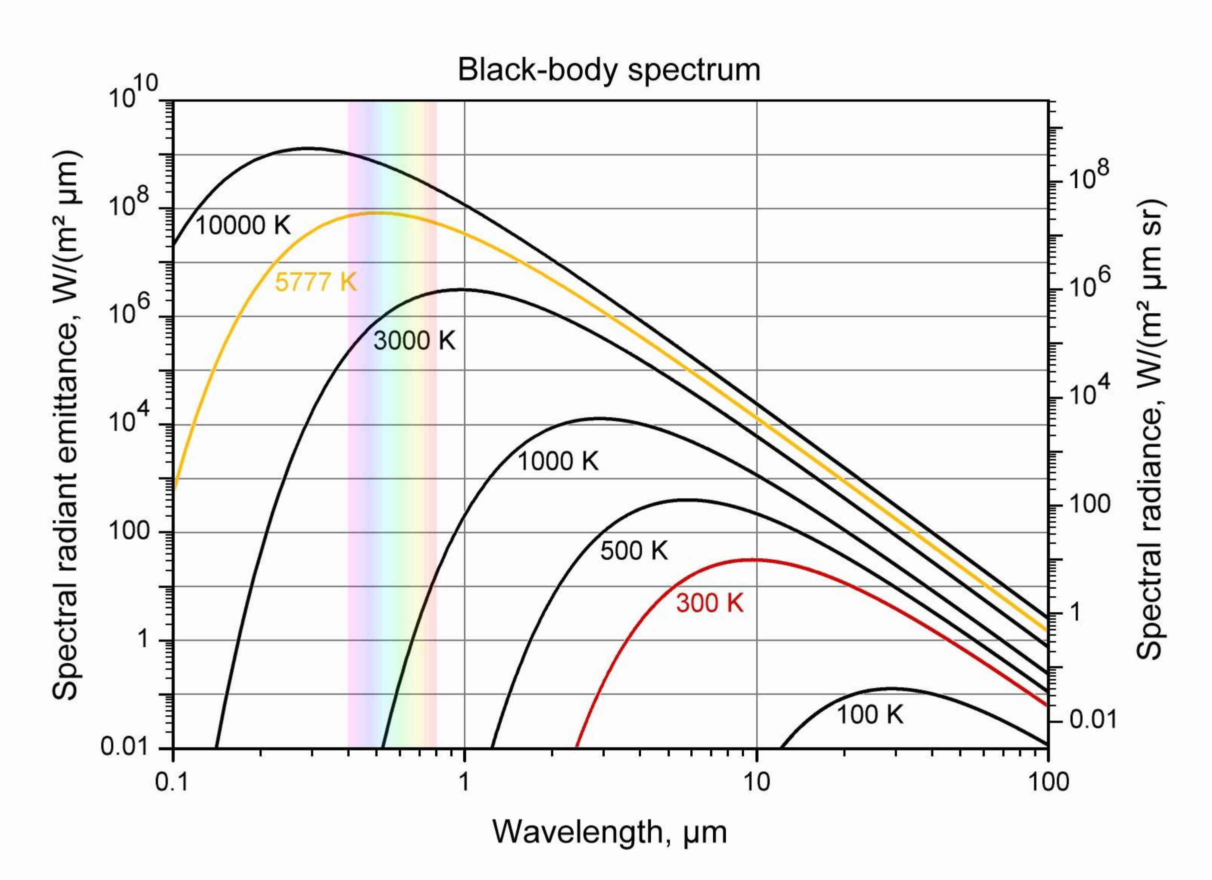


Higher energy
Shorter wavelength
Higher frequency
Lower energy
Longer wavelength
Lower frequency
Wavelength in micrometers (μm)
0.40
Violet
Blue
Green
Yellow
Orange
Red
0.71
Visible light
Gamma rays
X-rays
Ultra-violet
Near infrared
Shortwave infrared
Middle infrared
Thermal infrared
Microwave
Radio waves
10^{-8}
10^{-4}
$0.01 (10^{-2})$
0.40
0.70
3.00
5.50
10^{3} (1 mm)
10^{4}
10^{6} (1 m)
Energy discharges from atomic nuclei
Medical X-rays
Visible light
Heat lamp
Microwave radar
Television FM radio
AM radio

Electromagnetic Radiation

There are two important physical principle to remember about the emission of electromagnetic radiation.

The first is that ***hot objects*** radiate much ***more energy*** than ***cooler objects***. The second principle is that the ***hotter the object***, the ***shorter*** are the ***wavelengths of radiation*** that it emits.



Earth’s Energy Budget Simplified

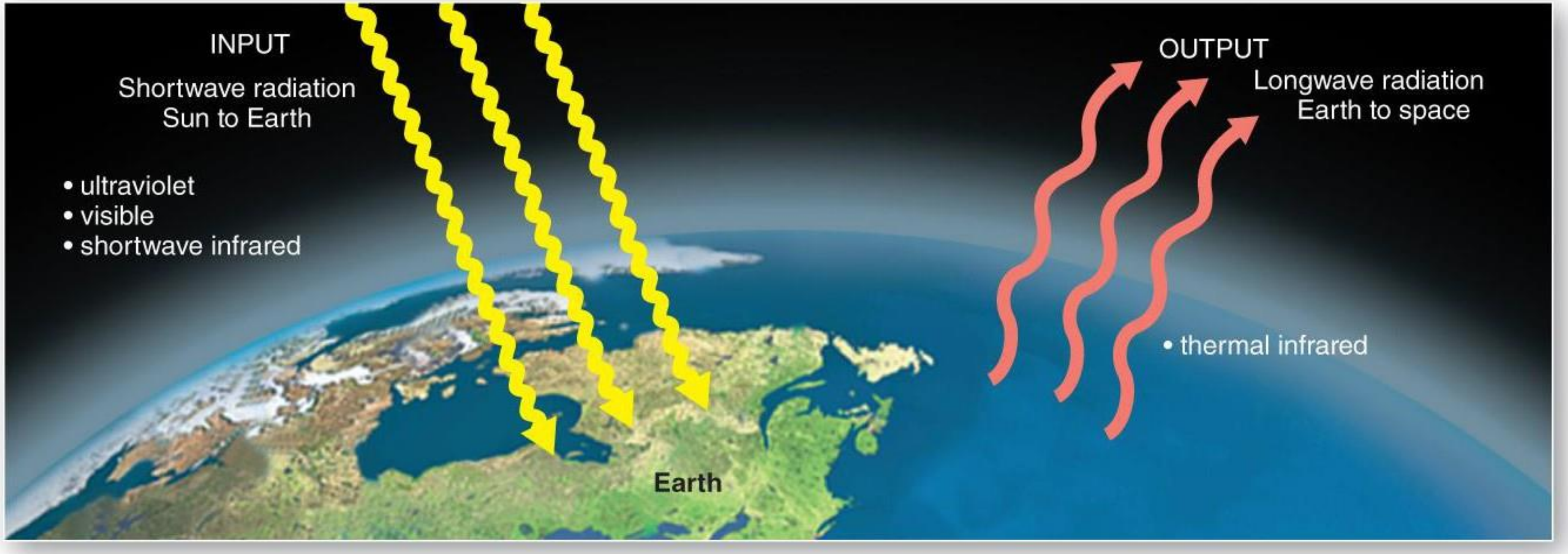


Figure 2.9

Energy Emitted by Sun and Earth

- The Sun emits shortwave energy
- Solar radiation is mainly:
  - gamma rays, X-rays, and UV (8%)
  - visible light (47%) and
  - infrared (45%)
- Earth emits longwave energy

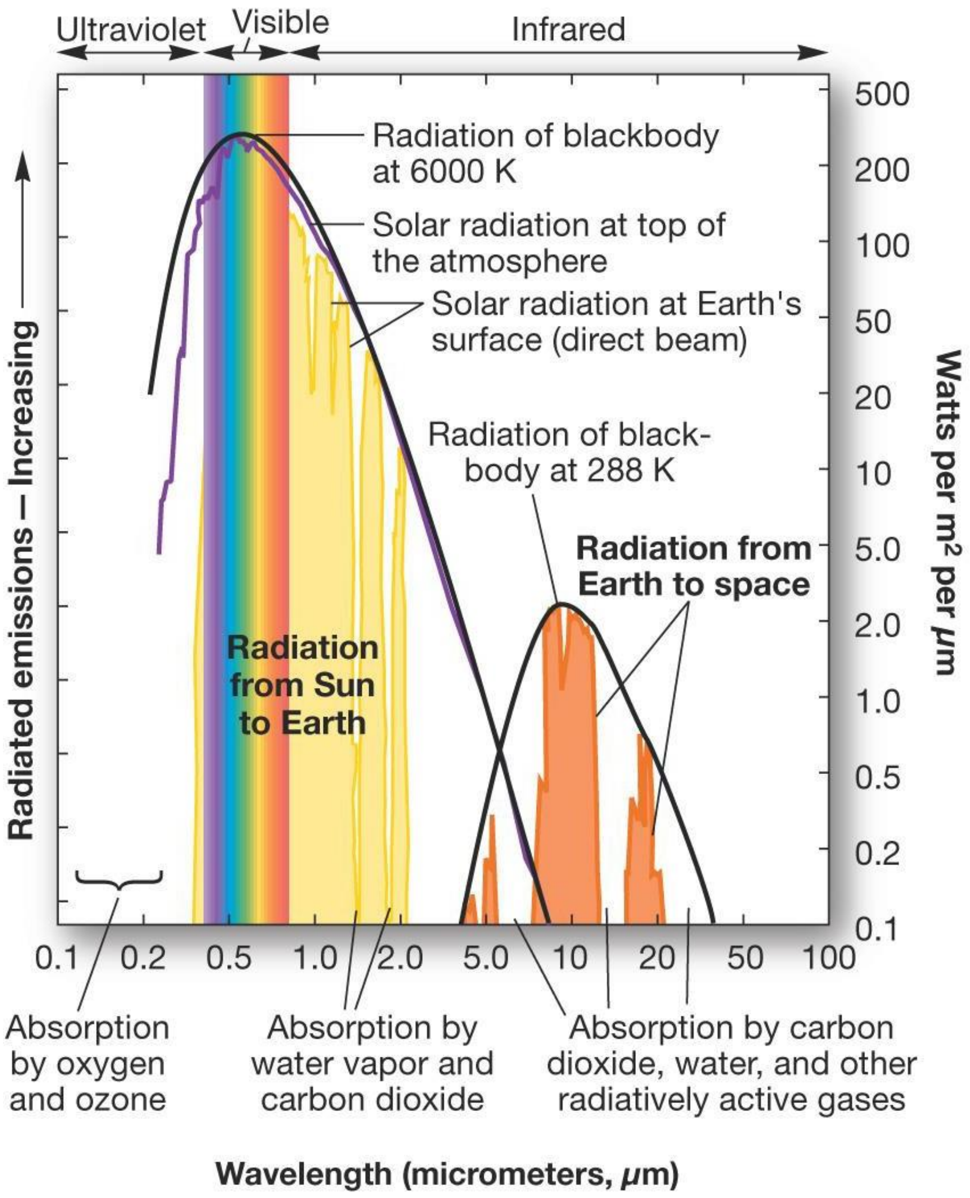


Figure 2.8

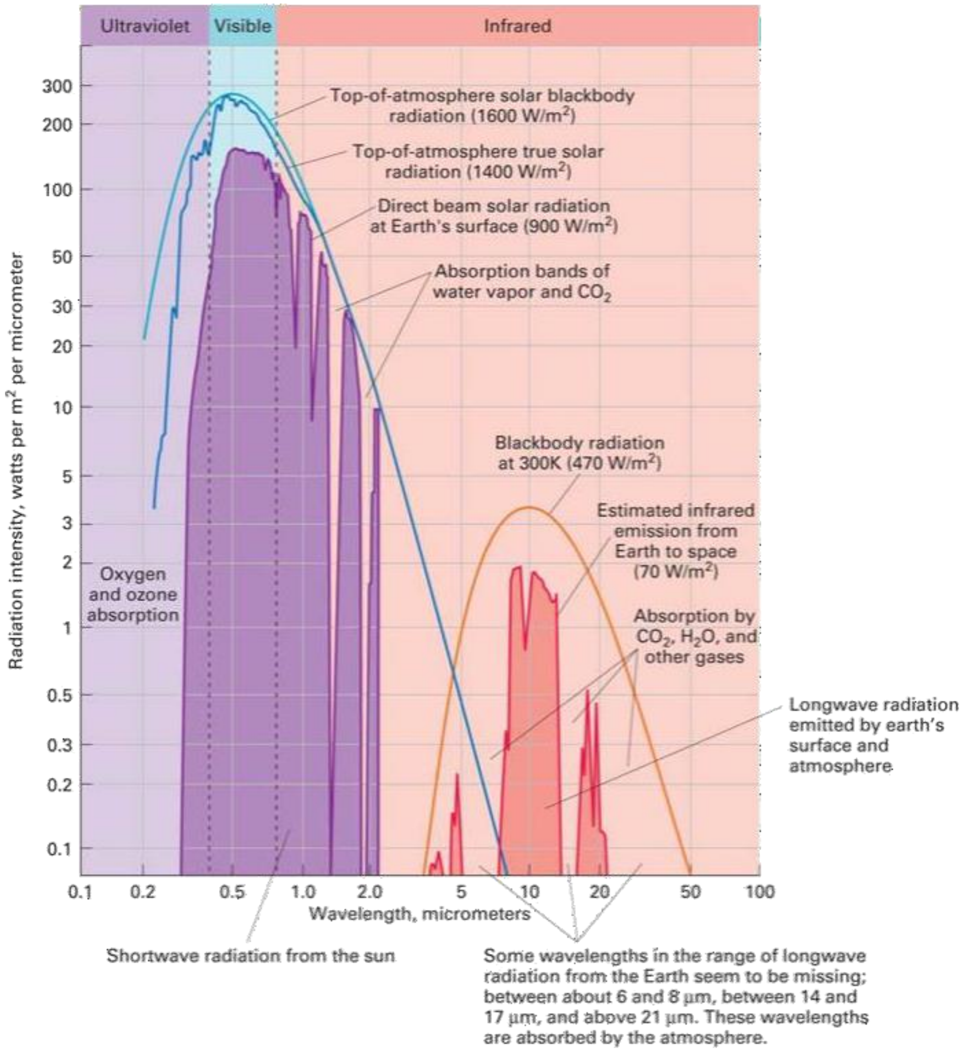
Electromagnetic Radiation

Characteristics of Solar Energy

Absorption and scattering in the atmosphere:

•Absorption warms the atmosphere directly
•Solar rays can be scattered back to space or down toward Earth

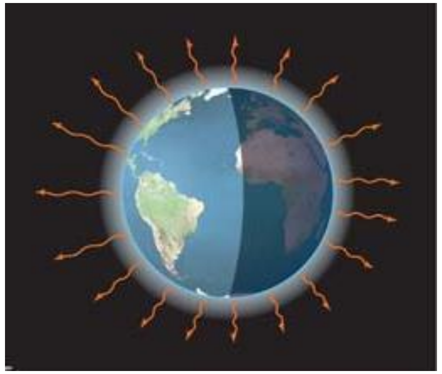
Shortwave radiation: electromagnetic energy in the range from 0.2 to 3 μm



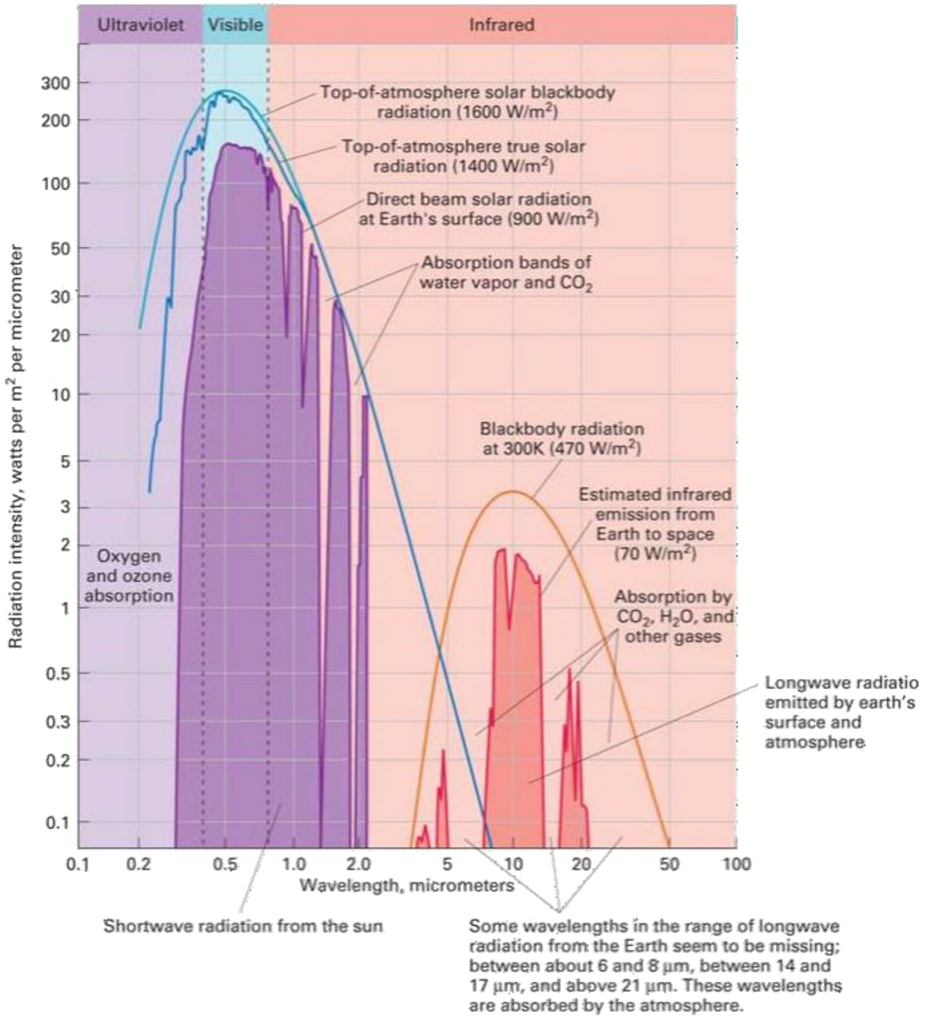
Electromagnetic Radiation

Longwave Radiation from the Earth

- Earth radiates less energy than the sun
- Energy from Earth is radiated at longer wavelengths
- Some wavelengths emitted by Earth are absorbed in the atmosphere

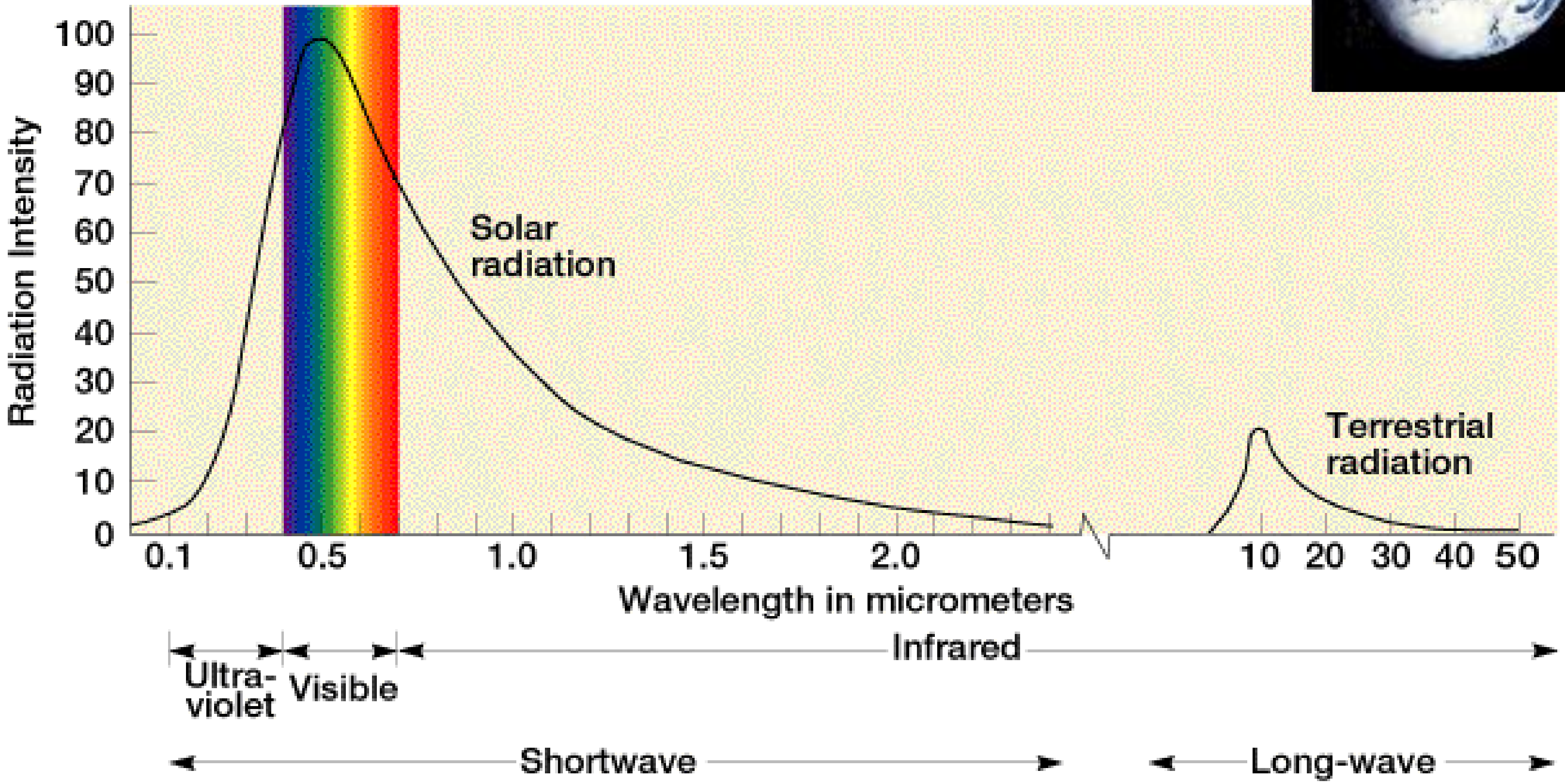


Longwave radiation: electromagnetic radiation in the range from 3 to 50 μm

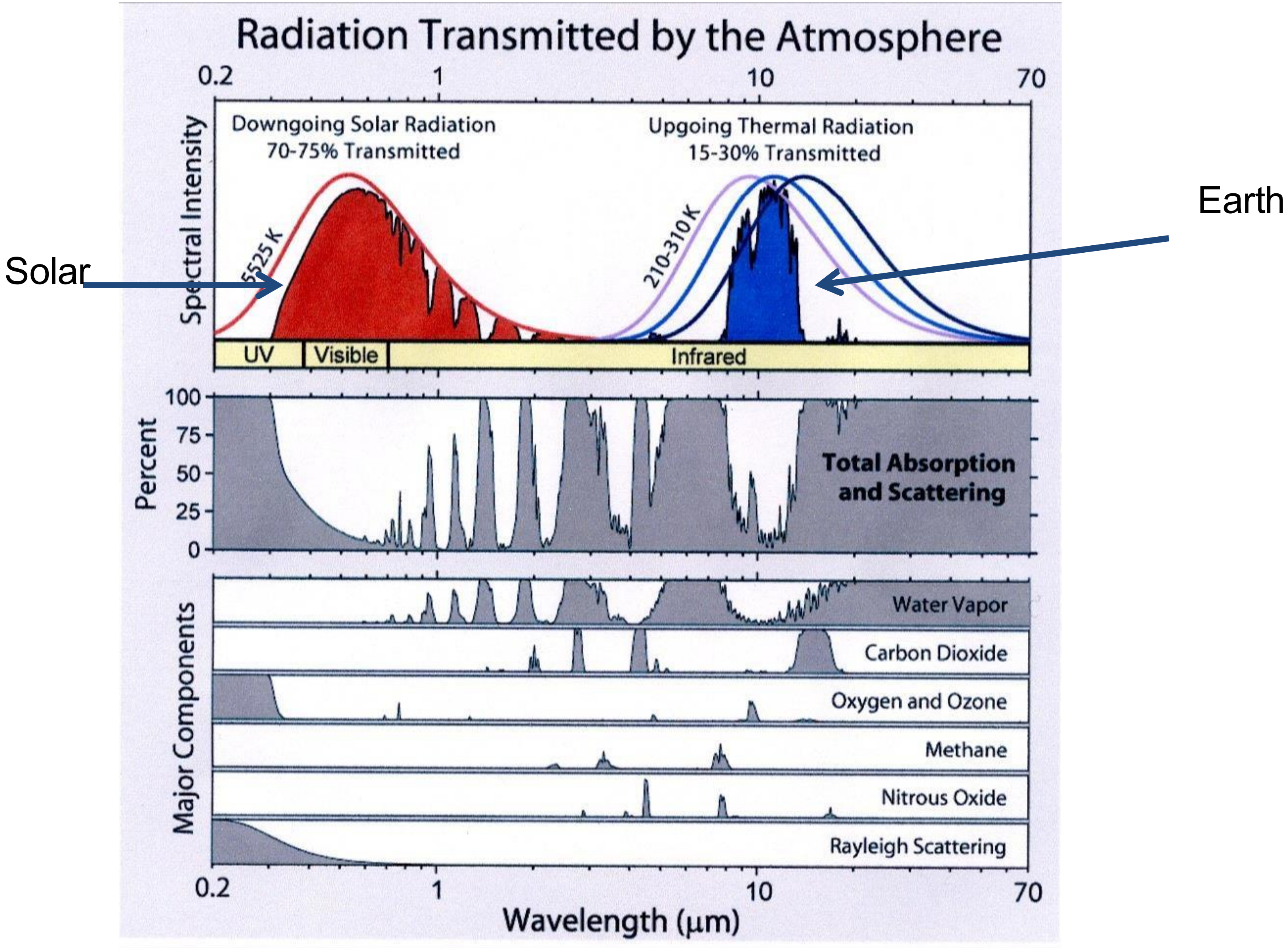


Radiation Laws

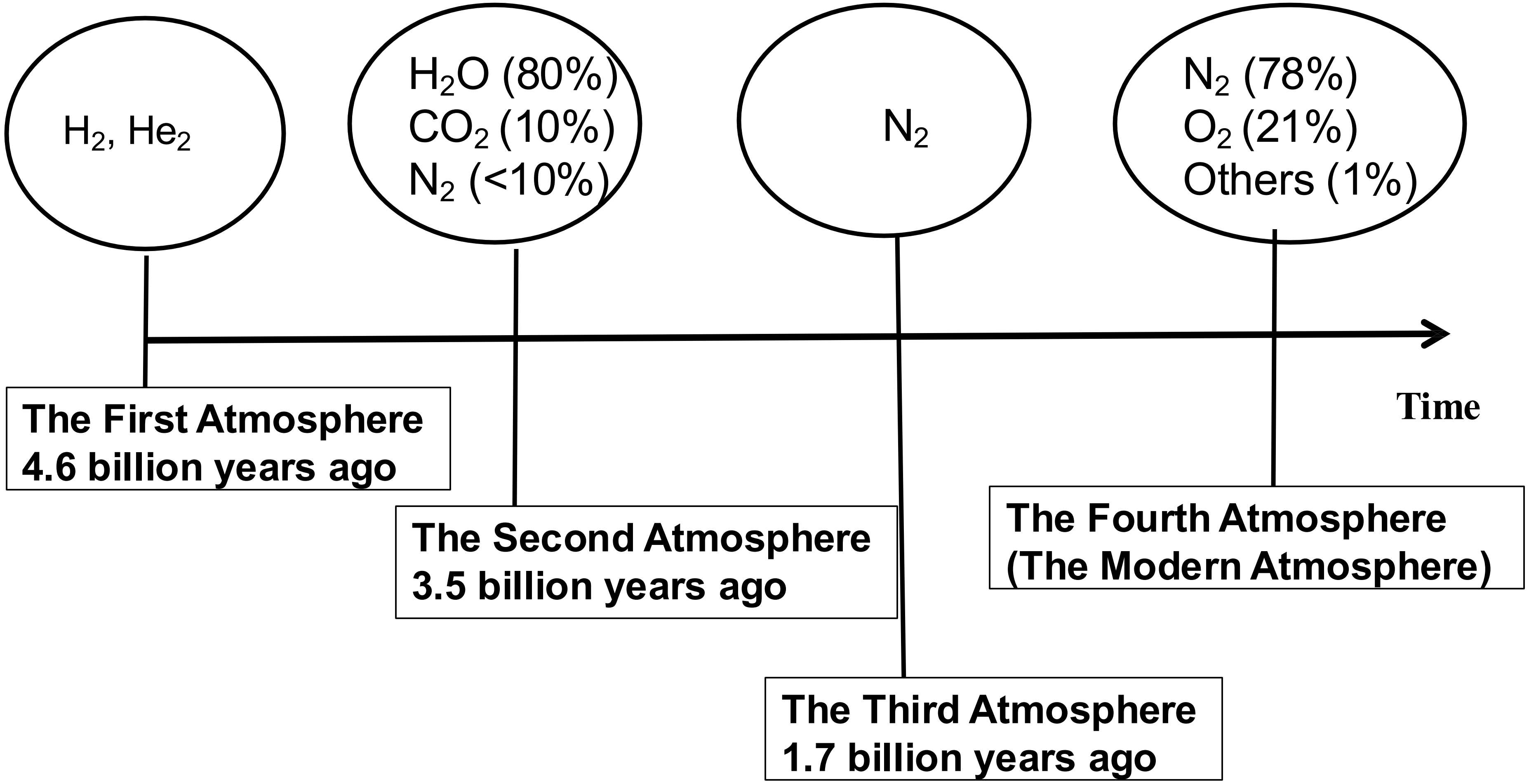
(Wein's Law) The hotter the radiating body, the shorter the wavelength of maximum radiation.



Electromagnetic Radiation



The history of the atmosphere



How thick is the atmosphere?

(c) A sunset from orbit shows a silhouetted cumulonimbus thunderhead cloud topping out at the tropopause.

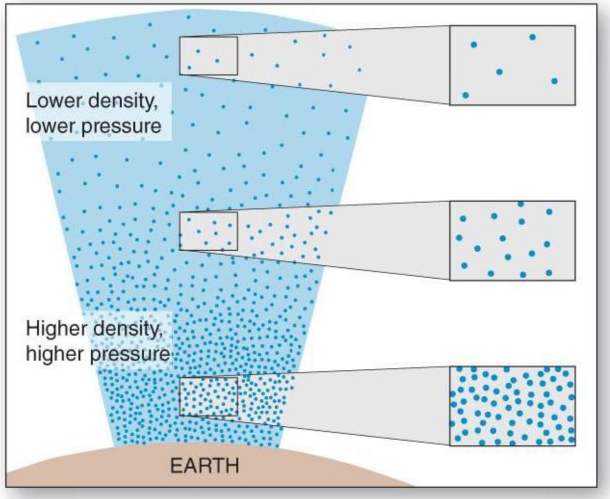
The thickness of the Earth's atmosphere is about 480km (Thermopause). Beyond that altitude is the exosphere (outer sphere) which extends from 480 km to 32,000 km (20,000 mi)

Air Density

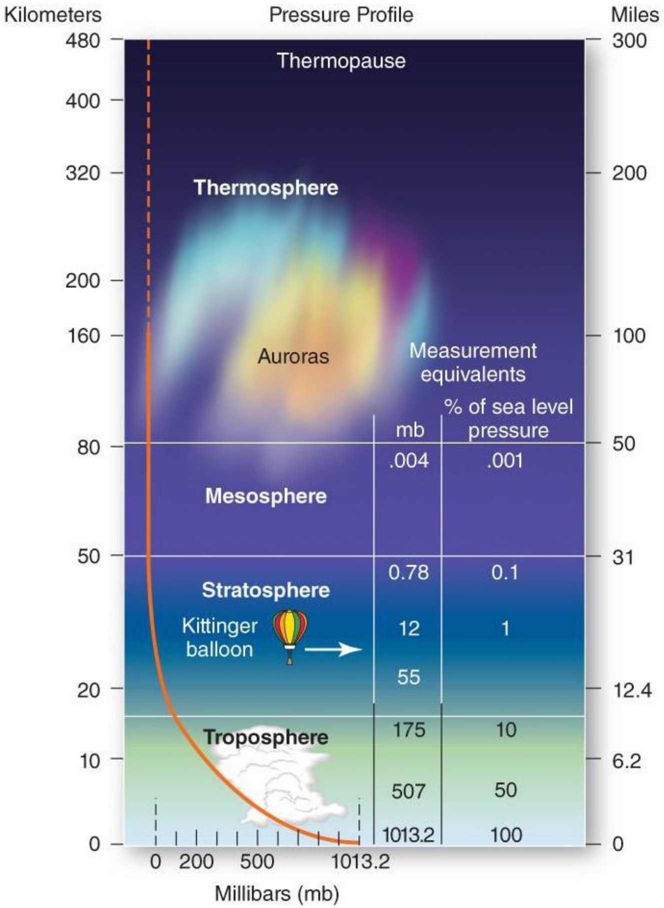
$$Density = \frac{mass}{volume}$$

- Air density: 1.2 kg/m^3
- Liquid water density: 1000kg/m^3
- Air pressure is highest at surface and decreases with altitude

Air Density Profile



(a) Density is higher nearer Earth's surface, and decreases with altitude.



(b) Pressure profile plots the decrease in pressure with increasing altitude. Pressure is in millibars and as a percentage of sea level pressure. Note that the troposphere holds about 90% of the atmospheric mass (far-right % column).

Air density decreases with increase of altitude.

Atmospheric Composition

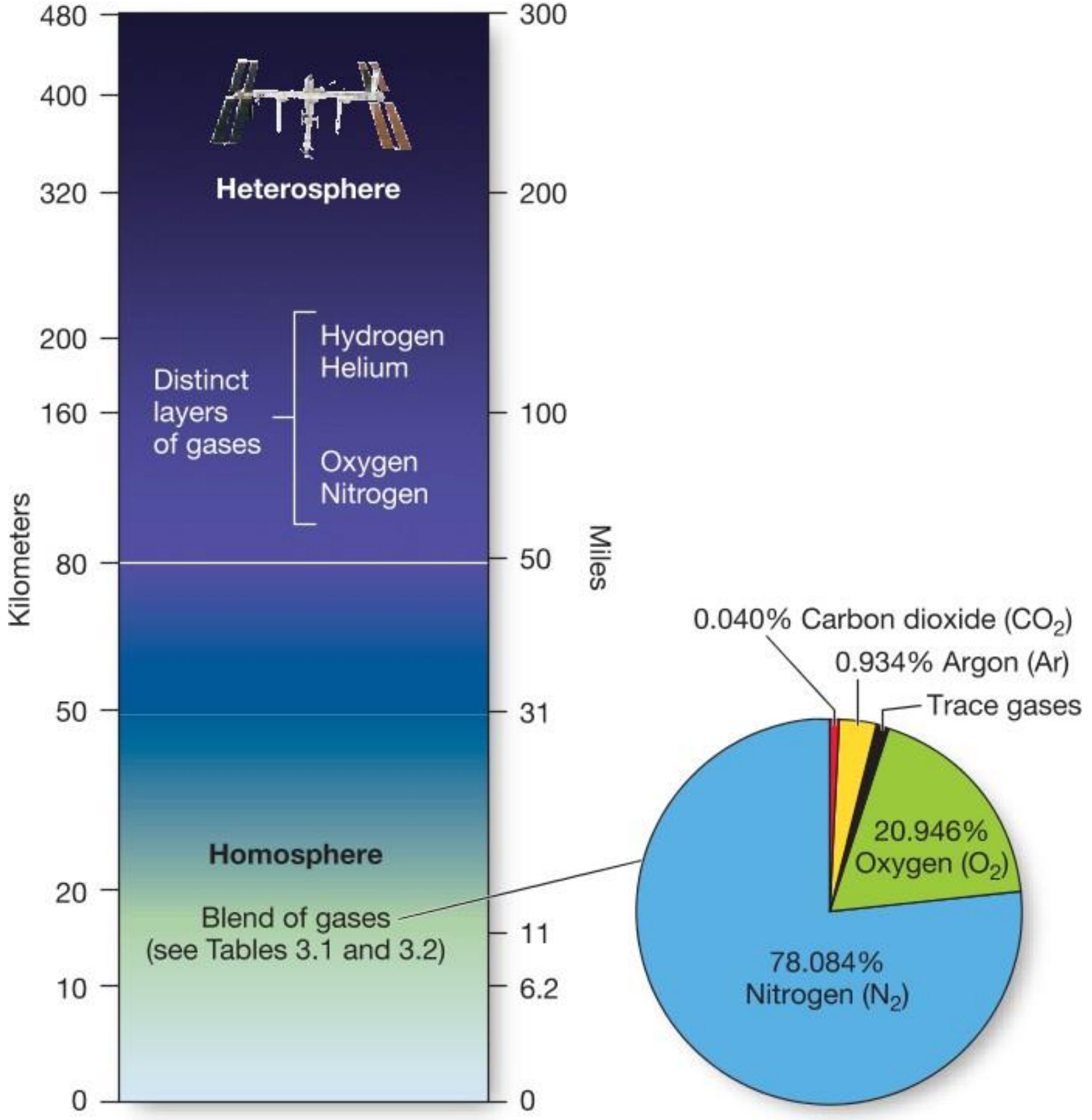


TABLE 2.2 Constant Gases of the Homosphere

Gas (Symbol)	Percentage by Volume	Parts per Million (ppm)
Nitrogen (N_2)	78.084	780,840
Oxygen (O_2)	20.946	209,460
Argon (Ar)	0.934	9,340
Neon (Ne)	0.001818	18
Helium (He)	0.000525	5.2
Krypton (Kr)	0.00010	1.0
Xenon (Xe)	Trace	~0.1

TABLE 2.3 Variable Gases That Affect Earth's Radiation Budget

Gas (Symbol)	Percentage by Volume	Parts per Million (ppm)	Sources
Water vapor (H_2O)	0–4% (max. at tropics, min. at poles)		Evaporation, photosynthesis,
Carbon dioxide (CO_2)*	0.0410	410	Fossil fuel combustion, volcanic eruptions, plant respiration
Methane (CH_4)	0.00018	1.8	Bacterial activity
Nitrous oxide (N_2O)	Trace	~0.3	Soil bacteria, human activity
Ozone (O_3)	Variable		Ultraviolet radiation, fossil fuel combustion

*May 2017 average CO_2 measured at Mauna Loa, Hawai'i (see http://www.esrl.noaa.gov/gmd/ccgg/trends).

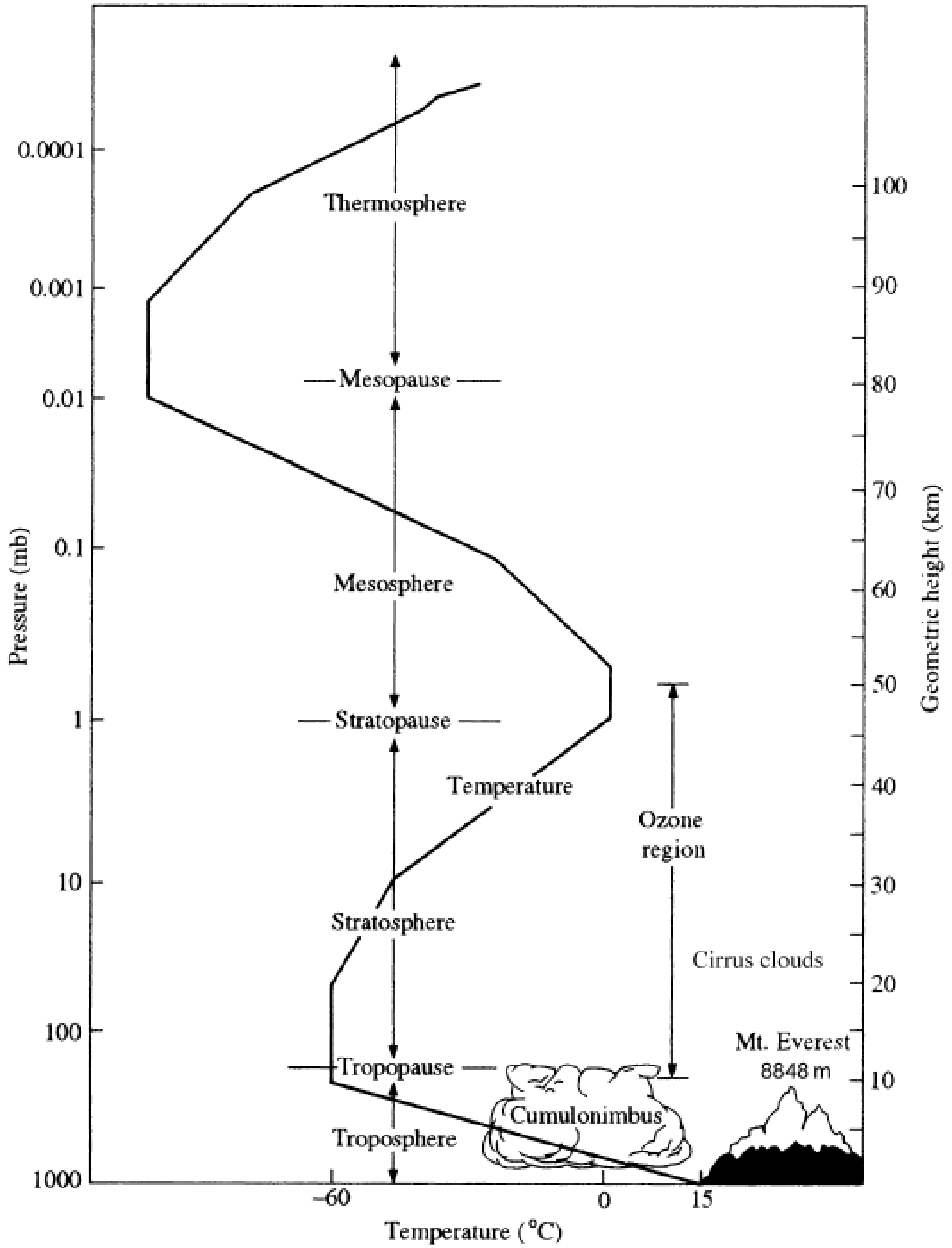
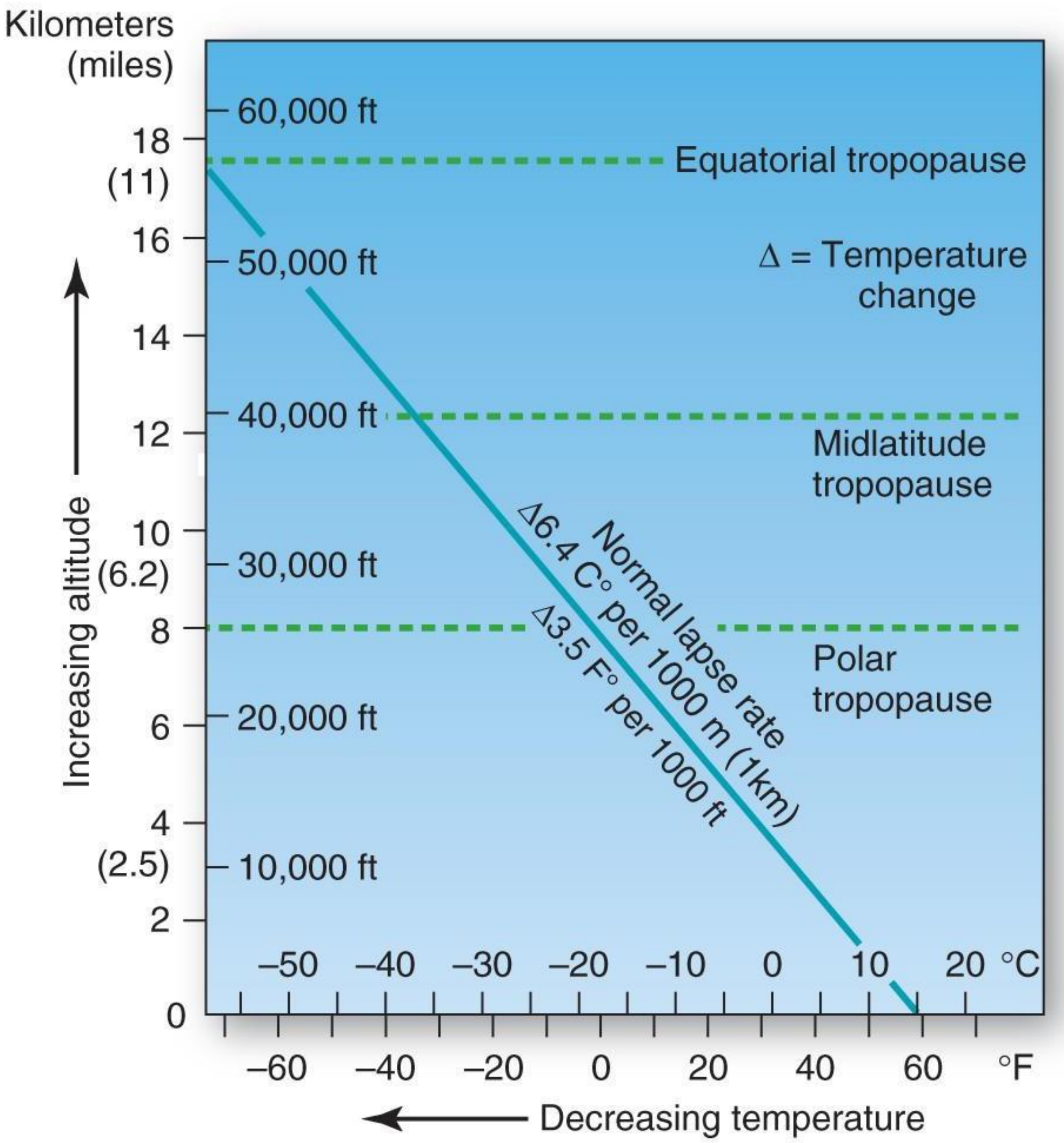


FIGURE 3.1 Vertical structure and zonation of the atmosphere, showing the temperature profile to 100-km altitude. Note the logarithmic decline in pressure (*left axis*) as a function of altitude.

Normal Lapse Rate



(b) Temperature decreases with increased altitude at the *normal lapse rate.*

Atmospheric Temperature Profile

- Thermosphere
- Mesosphere
- Stratosphere
- Troposphere

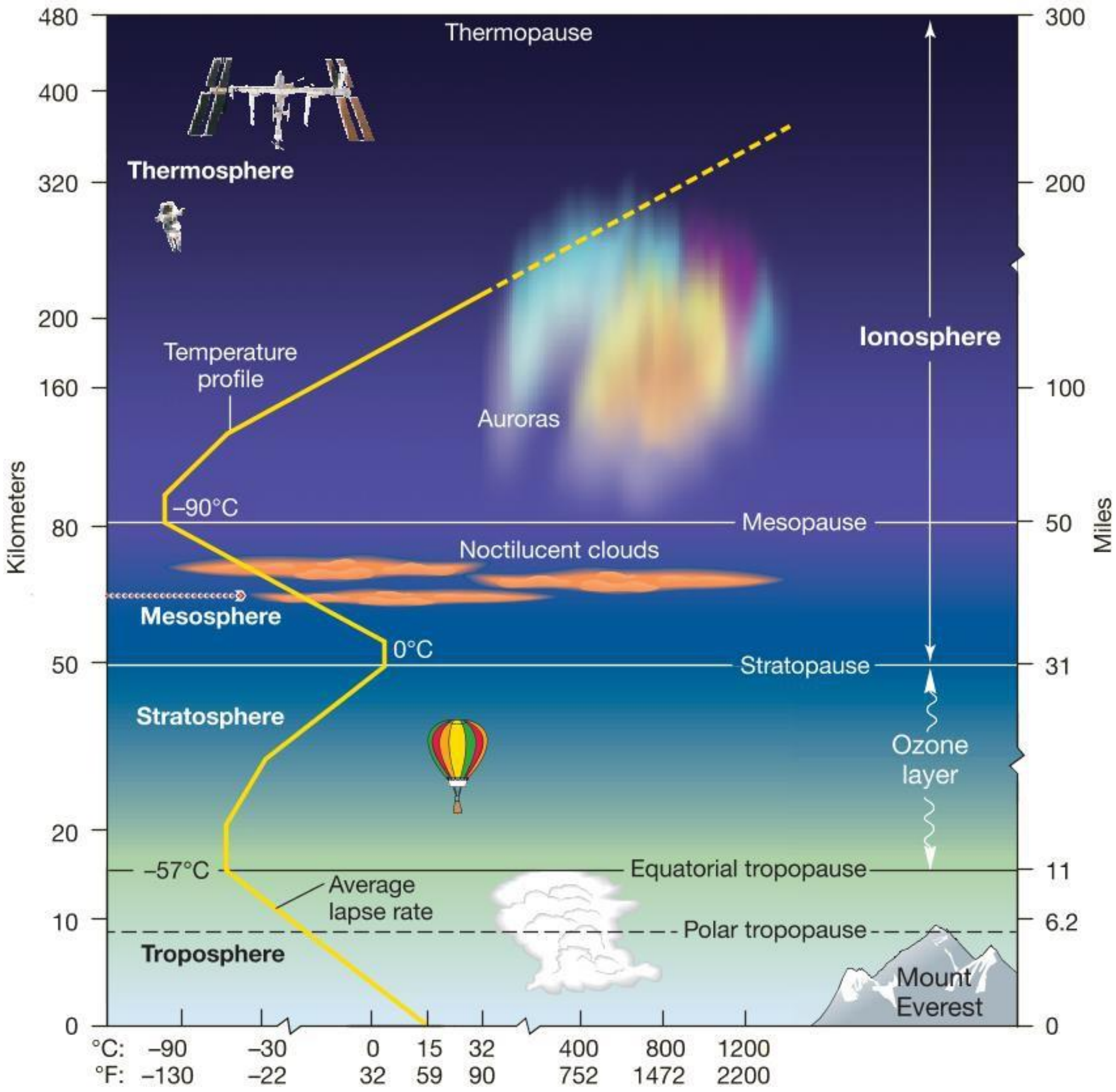
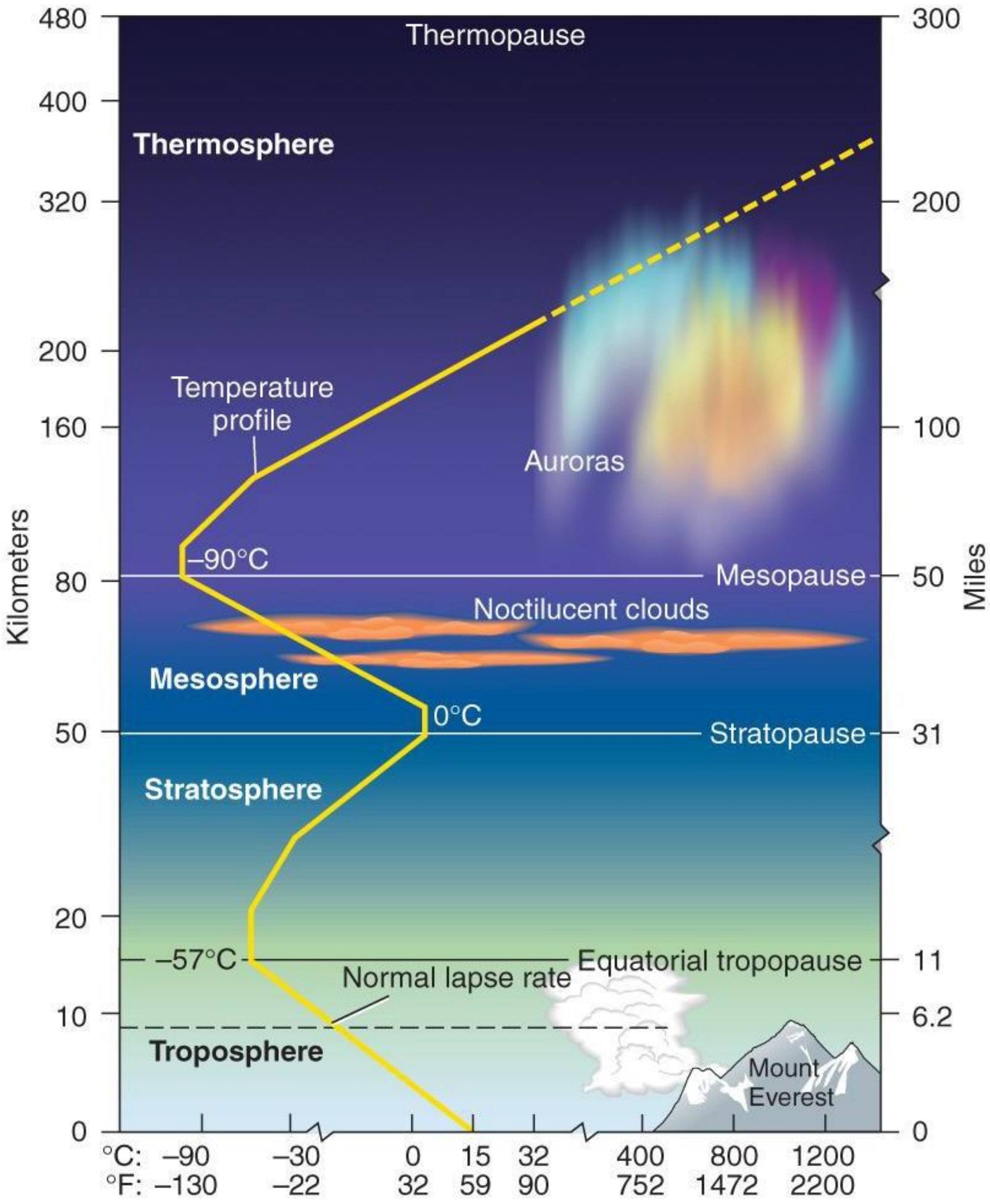


Figure 2.20

Troposphere

- Surface to 18 km
- 90% mass of atmosphere
- Normal lapse rate – average cooling at rate of 6.4° C/km
- Environmental lapse rate – actual local lapse rate
- Tropopause at −57° C (18km near equator, 8km at Poles)

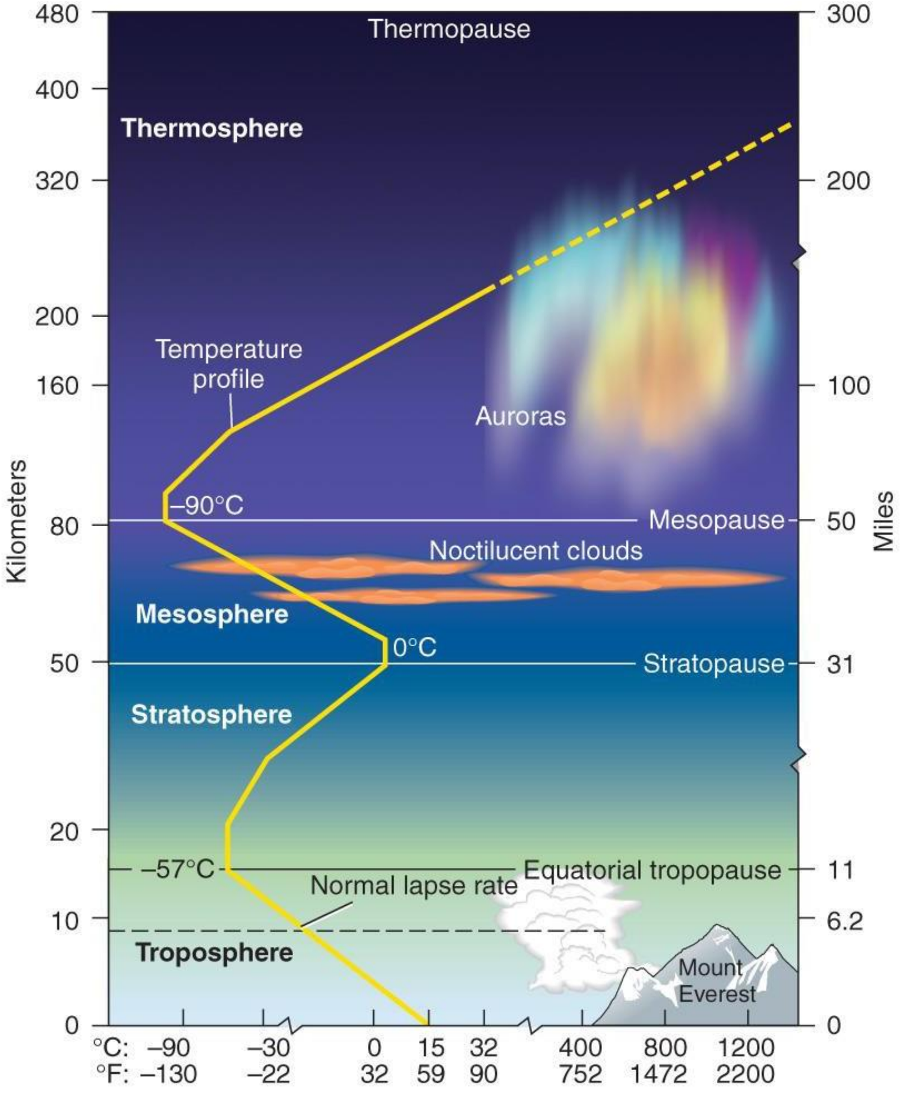


(a) Temperature profile plots temperature changes with altitude.

Figure 2.20

Stratosphere

- 18 km to 50 km
- Stratopause at 50 km (0° C)
- Temperature increases with altitude because of the absorption of ultraviolet radiation by ozone molecules

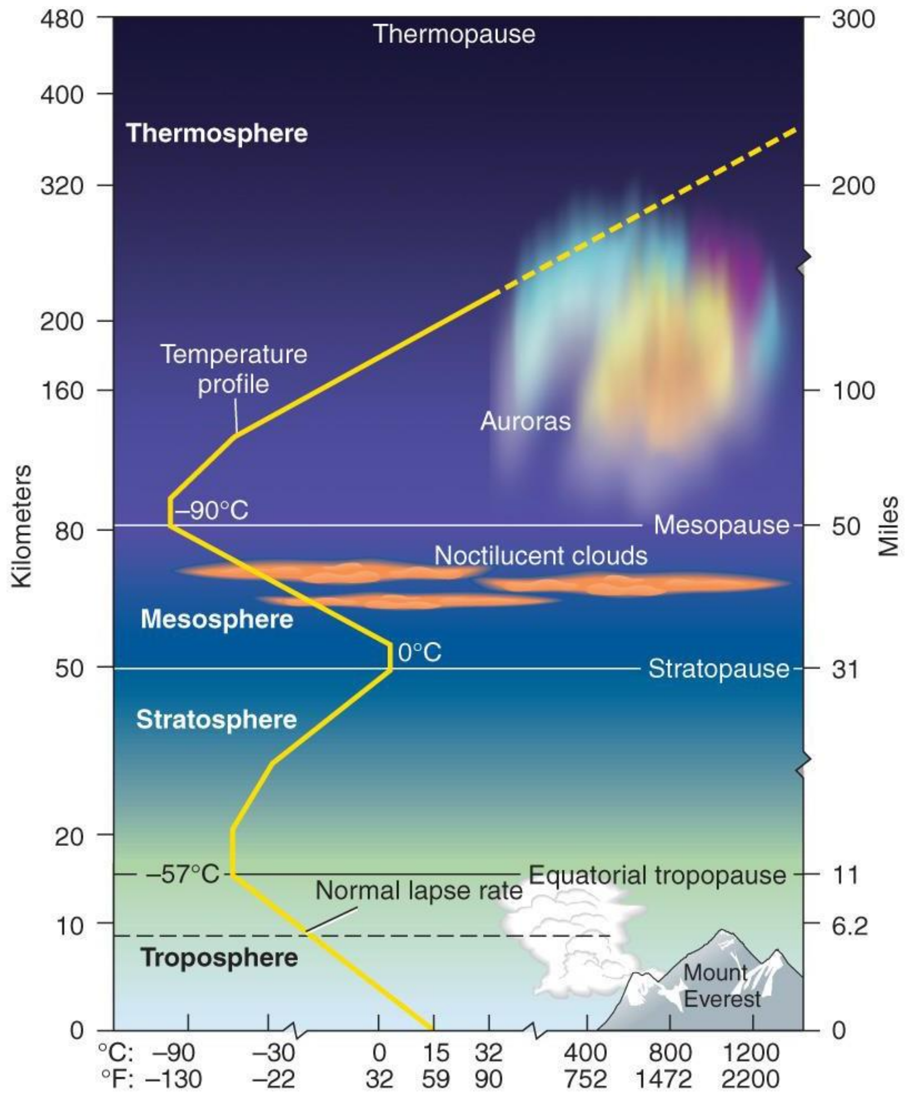


(a) Temperature profile plots temperature changes with altitude.

Figure 2.20

Mesosphere

- 50 km to 80 km
- Mesopause at 80 km (−90° C)
- Temperature decreases with altitude

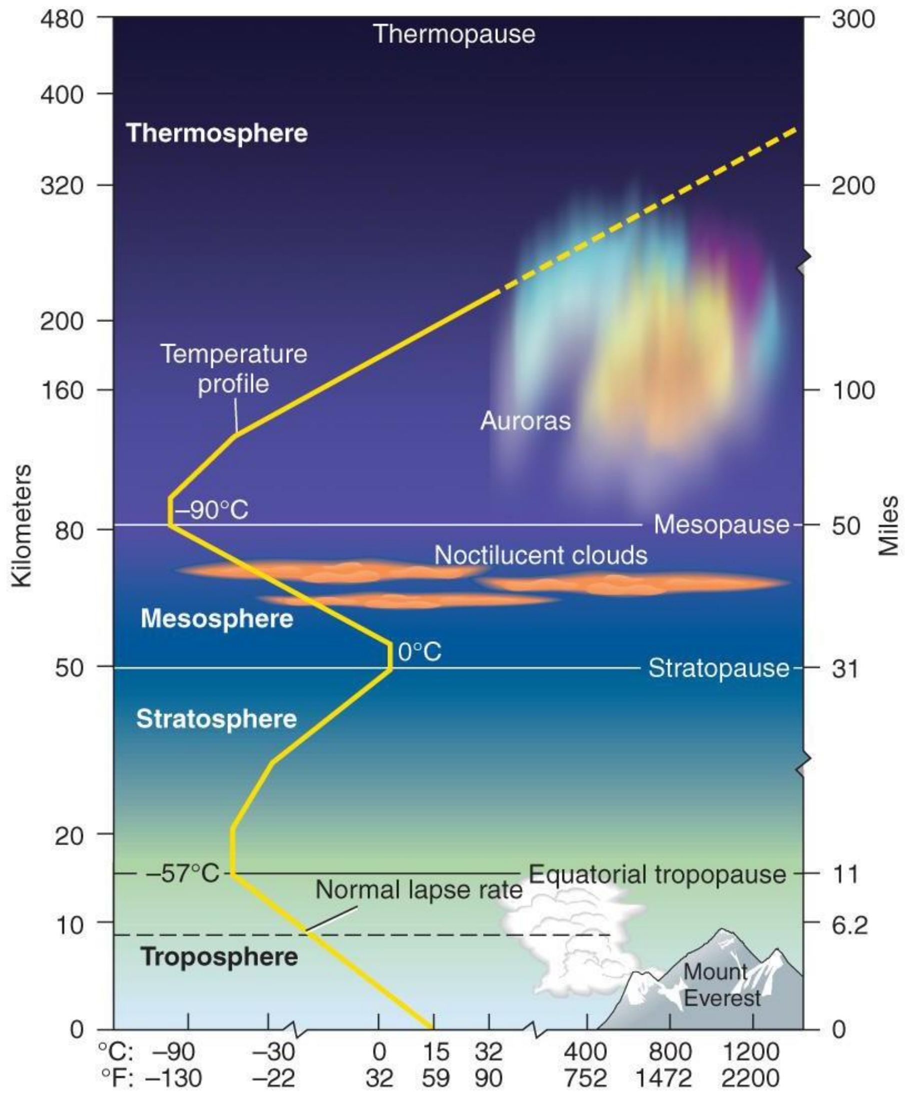


(a) Temperature profile plots temperature changes with altitude.

Figure 2.20

Thermosphere

- Roughly same as heterosphere
- 80 km outwards
- Temperature increases with altitude because of direct contact with high energy solar radiation
- Thermopause is at 480 km
- High temperature, but not “hot”



(a) Temperature profile plots temperature changes with altitude.

Figure 2.20

the Earth’s Atmosphere

Layers of the Atmosphere by Temperature

Troposphere

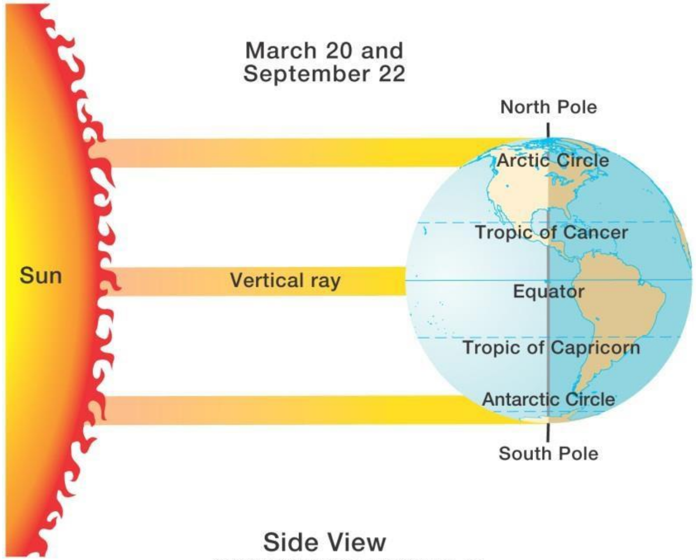
- **Lowest layer of the atmosphere, where human activity and most weather takes place**
- **Temperature usually decreases with height**

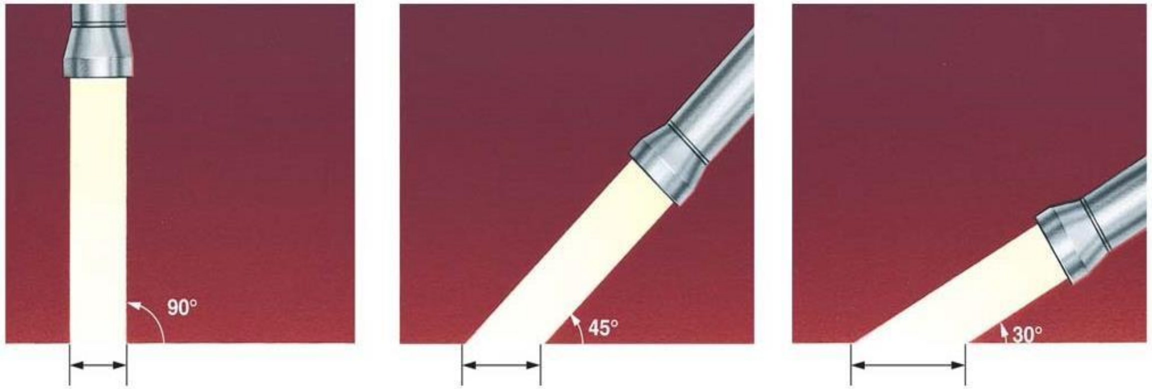
Stratosphere

- **Layer of atmosphere directly above the troposphere, where temperature slowly increases with height**
- **Ozone layer protects humans from ultraviolet adiation**

Mesosphere = coldest near top of this layer

Thermosphere = hottest layer





1 unit of surface area

One unit of light is concentrated over one unit of surface area.

1.4 units of surface area

One unit of light is dispersed over 1.4 units of surface area.

2 units of surface area

One unit of light is dispersed over 2 units of surface area.

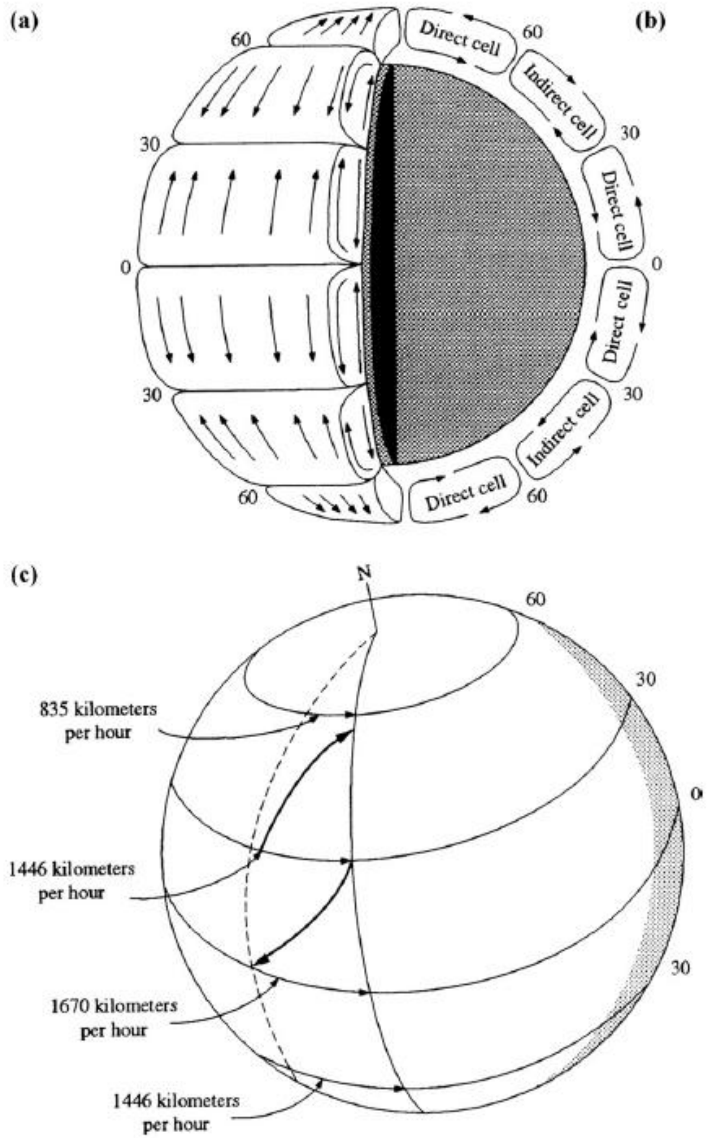


FIGURE 3.3 Generalized pattern of global circulation showing (a) surface patterns, (b) vertical patterns, and (c) the origin of the Coriolis force. As air masses move across different latitudes, they are deflected by the Coriolis force, which arises because of the different speeds of the Earth's rotation at different latitudes. For instance, if you were riding on an air mass moving at a constant speed south from 30° N latitude, you would begin your journey seeing 1446 km of the Earth's surface pass to the east every hour. By the time your air mass reached the equator, 1670 km would be passing to the east each hour. While moving south at a constant velocity, you would find that you had traveled 214 km west of your expected trajectory. The Coriolis force means that all movements of air in the Northern Hemisphere are deflected to the right; those in the Southern Hemisphere are deflected to the left. *Source: Modified from Oort (1970) and Gross (1977).*

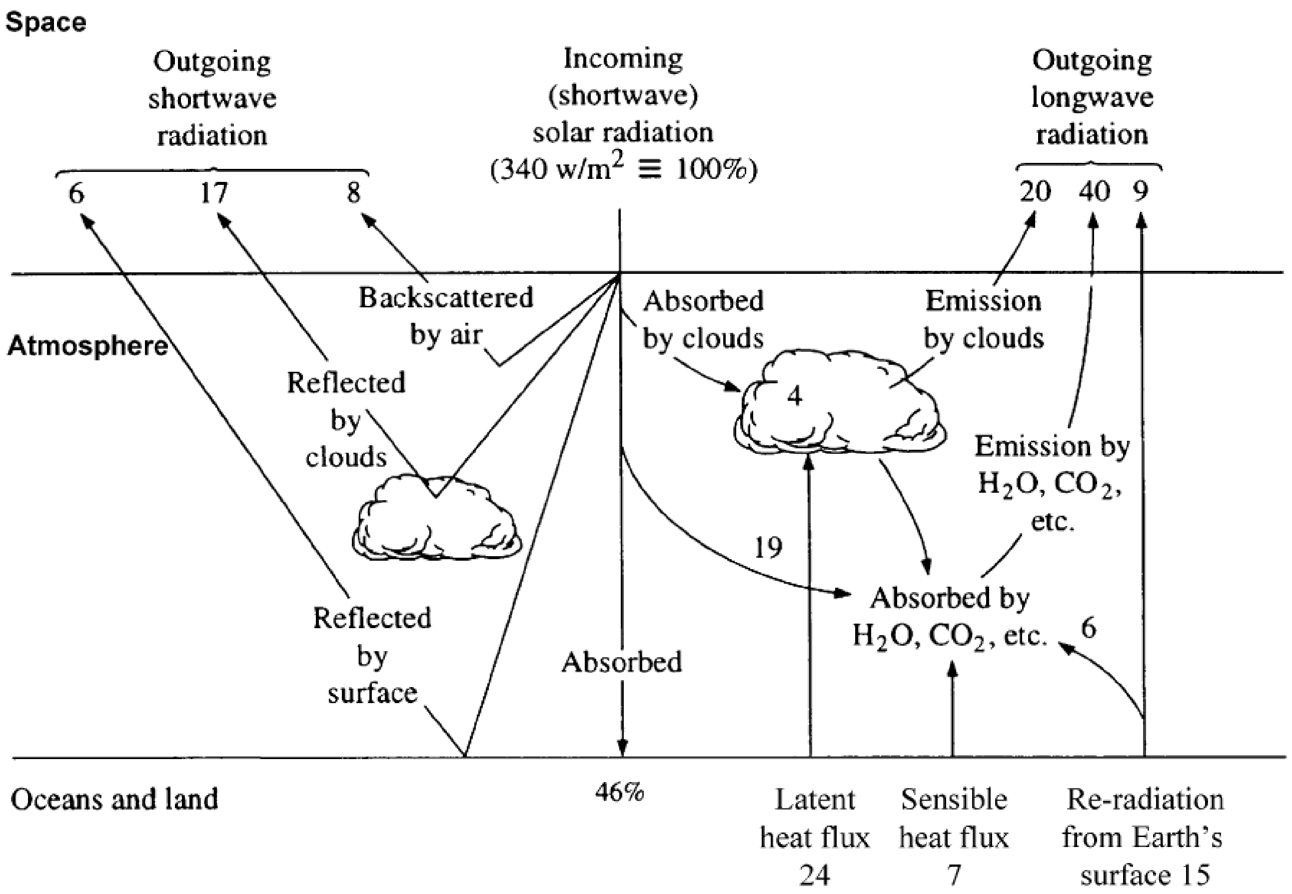


FIGURE 3.2 The radiation budget for Earth, showing the proportional fate of the energy that Earth receives from the Sun, about 340 W/m^2 largely in short wavelengths. About one-third of this radiation is reflected back to space and the remaining is absorbed by the atmosphere (23%) or the surface (46%). Long-wave radiation (infrared) is emitted from the Earth's surface, some of which is absorbed by atmospheric gases, warming the atmosphere (the greenhouse effect). The atmosphere emits long-wave radiation, so that the total energy received is balanced by the total energy emitted from the planet. *Source: Modified from MacCracken (1985).*

Mean Residence Time (MRT)

$$\mathrm{MRT} = \mathrm{Mass}/\mathrm{flux}, \tag{3.3}$$

where flux may be either the input or the loss from the reservoir.[1] Since the stratosphere is not well mixed vertically, the mean residence time of stratospheric air increases with altitude (Waugh and Hall 2002). However, the return of stratospheric air to the troposphere, about 4×10^{17} kg/yr (Seo and Bowman 2002), amounts to about 40% of the stratospheric mass each year, leading to an overall mean residence time of 2.6 years for stratospheric air. Thus, when a large volcano injects sulfur dioxide into the stratosphere, about half of it will remain after 2 years and about 5% will remain after 7.5 years.

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$$\frac{dX}{dt} = rX - sX^2 - cXY$$

$$\frac{dY}{dt} = -dY + apcXY$$

Modeling Feeding Rates

Steady state: production of a population balances the losses through natural death and predation

$$F_j = \frac{d_j B_j + M_j}{a_j p_j}$$

Prey$_i$ ⟶ *Predator$_j$*

B_i B_j

F_j : feeding rate (kg ha^{-1} yr^{-1})
D_j : natural death rate (yr^{-1})
B_j : biomass (kg ha^{-1})
M_j : mortality due to predation (kg ha^{-1} yr^{-1})
a_j : assimilation efficiency (%)
p_j : production efficiency (%)

Consumed Biomass

$$F_j = \frac{d_j B_j + M_j}{a_j p_j}$$

Assimilated Biomass

$a_j F_j$

Unassimilated Biomass (e.g., leavings & feces)

$(1 - a_j)F_j$

Production Biomass (Growth & Reproduction)

$a_j p_j F_j$

Mineralized Biomass (e.g., CO_2 & NH_4^+)

$$C_{ij} = a_j(1 - p_j)F_{ij}$$

$$N_{ij} = a_j\left(\frac{1}{CN_i} - \frac{p_j}{CN_j}\right)F_{ij}$$

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Table 1: *Examples of greenhouse gases that are affected by human activities. [Based upon Chapter 3 and Table 4.1]*

	CO_2 (Carbon Dioxide)	CH_4 (Methane)	N_2O (Nitrous Oxide)	CFC-11 (Chlorofluoro-carbon-11)	HFC-23 (Hydrofluoro-carbon-23)	CF_4 (Perfluoro-methane)
Pre-industrial concentration	about 280 ppm	about 700 ppb	about 270 ppb	zero	zero	40 ppt
Concentration in 1998	365 ppm	1745 ppb	314 ppb	268 ppt	14 ppt	80 ppt
Rate of concentration change [b]	1.5 ppm/yr [a]	7.0 ppb/yr [a]	0.8 ppb/yr	-1.4 ppt/yr	0.55 ppt/yr	1 ppt/yr
Atmospheric lifetime	5 to 200 yr [c]	12 yr [d]	114 yr [d]	45 yr	260 yr	>50,000 yr

[a] Rate has fluctuated between 0.9 ppm/yr and 2.8 ppm/yr for CO_2 and between 0 and 13 ppb/yr for CH_4 over the period 1990 to 1999.

[b] Rate is calculated over the period 1990 to 1999.

[c] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.

[d] This lifetime has been defined as an adjustment time that takes into account the indirect effect of the gas on its own residence time.

TABLE 3.5 Some Trace Biogenic Gases in the Atmosphere

Compound	Formula	Concentration (ppb) Expected[a]	Concentration (ppb) Actual[b]	Mean residence time	Percentage of sink due to OH
Carbon compounds					
Methane	CH_4	10^{-148}	1830	9 years	90
Carbon monoxide	CO	10^{-51}	45–250	60 days	80
Isoprene	$CH_2{=}C(CH_3){-}CH{=}CH_2$		0.2–10.0	<1 day	100
Nitrogen compounds					
Nitrous oxide	N_2O	10^{-22}	320	120 years	0
Nitric oxides	NO_x	10^{-13}	0.02–10.0	1 day	100
Ammonia	NH_3	10^{-63}	0.08–5.0	5 days	<2
Sulfur compounds					
Dimethylsulfide	$(CH_3)_2S$		0.004–0.06	1 day	50
Hydrogen sulfide	H_2S		<0.04	4 days	100
Carbonyl sulfide	COS	0	0.50	5 years	20
Sulfur dioxide	SO_2	0	0.02–0.10	3 days	50

[a] *Approximate values in equilibrium with an atmosphere containing 21% O_2 (Chameides and Davis 1982).*

[b] *For short-lived gases, the value is the range expected in remote, unpolluted atmospheres.*

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[b] *For short-lived gases, the value is the range expected in remote, unpolluted atmospheres.*

Radiant Forcing (Climate Forcing)

The change in the net, downward minus upward, radiative flux (expressed in W/m2) due to a change in an external driver of climate change.