Sustainability: Principles and Practices
Spring 2014

PPT Set 2

Professor Anthony Serianni

The **biosphere** (Edward Suess, 1831-1914; an early practitioner of ecology) is the global sum of all ecosystems; the zone of life on Earth; the thin film of air, water and soil where all life exists on Earth (about 1/1000 of the planet's diameter); it is a closed, self-regulating system.

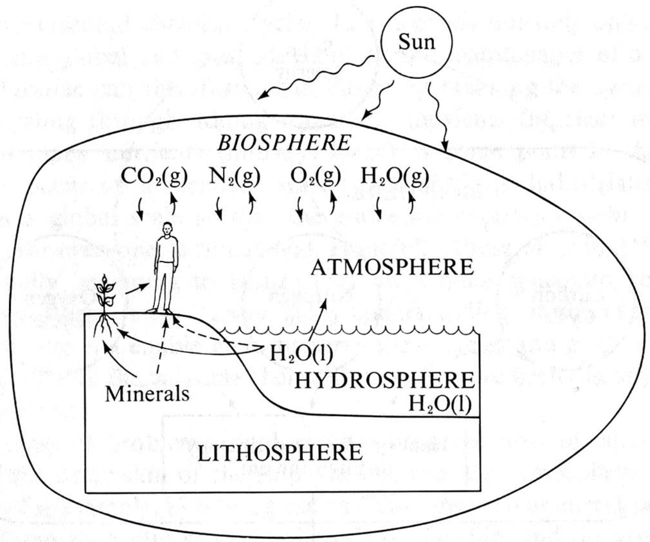


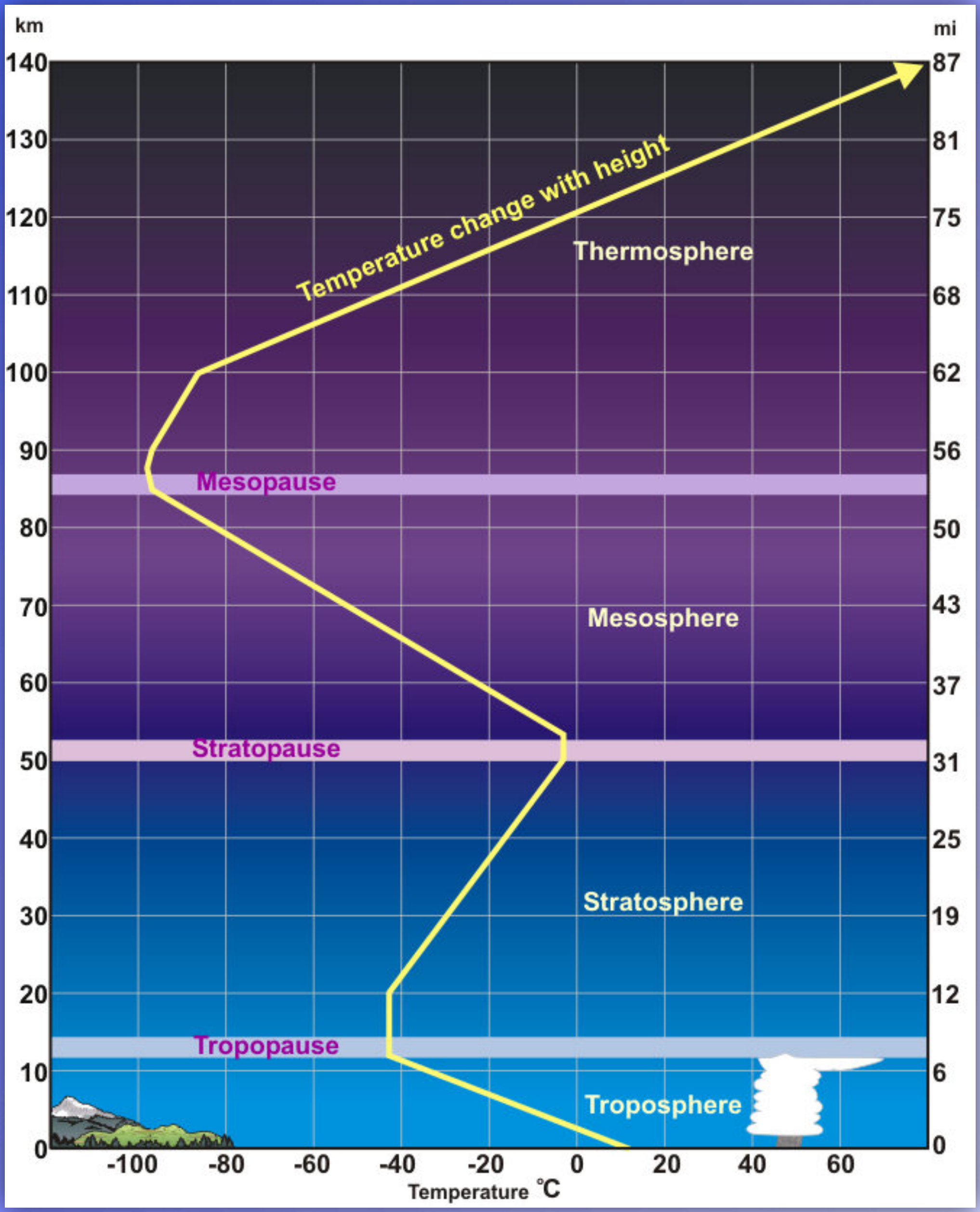
Figure 10-1 Spaceship Earth and the Major Components of Our Life-Support System—the Biosphere.

The three major components of the biosphere:

atmosphere
hydrosphere
lithosphere

"…one thing seems to be foreign on this large celestial body consisting of spheres, namely, organic life. But this life is limited to a determined zone at the surface of the lithosphere. The plant, whose deep roots plunge into the soil to feed, and which at the same time rises into the air to breathe, is a good illustration of organic life in the region of interaction between the upper sphere and the lithosphere, and on the surface of continents it is possible to single out an independent biosphere."

(*The Face of the Earth*,1885-1901 – three volumes)



The atmosphere of Earth – Effect of height on atmospheric temperature

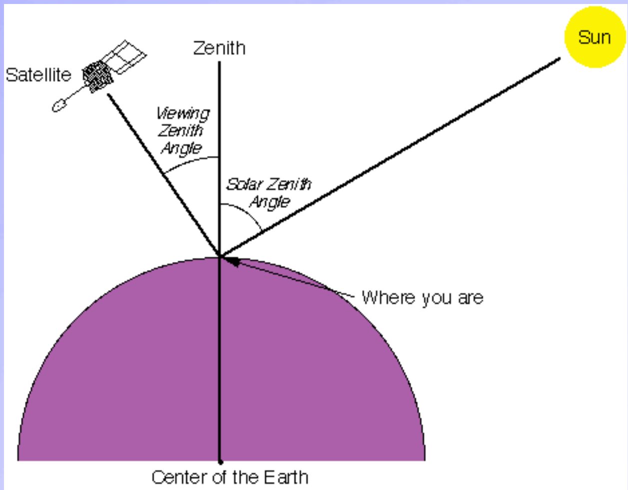
10 km = 6.2 miles

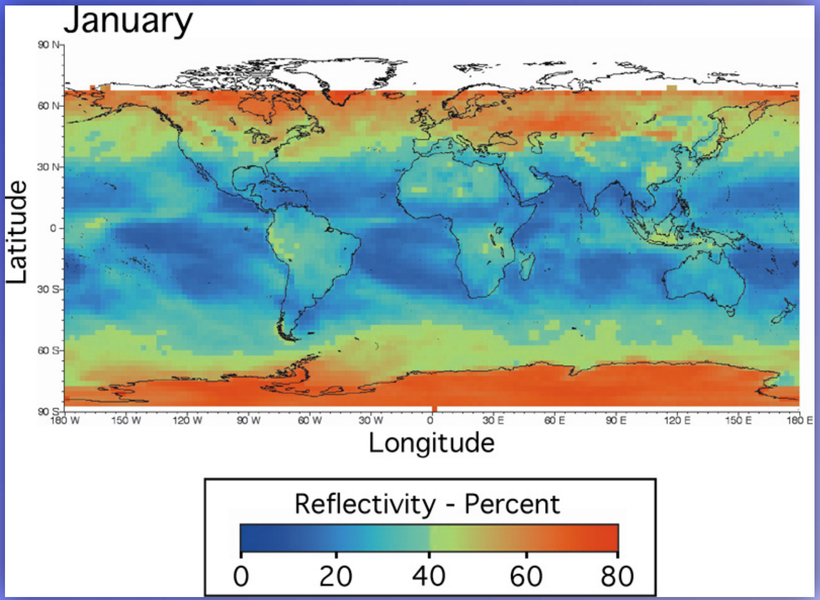
<u>Albedo</u> is the fraction of the Sun's radiation reflected from a surface; it varies from 1 (100% reflected) to 0 (0% reflected).

Table 1. Reflectivity values of various surfaces.

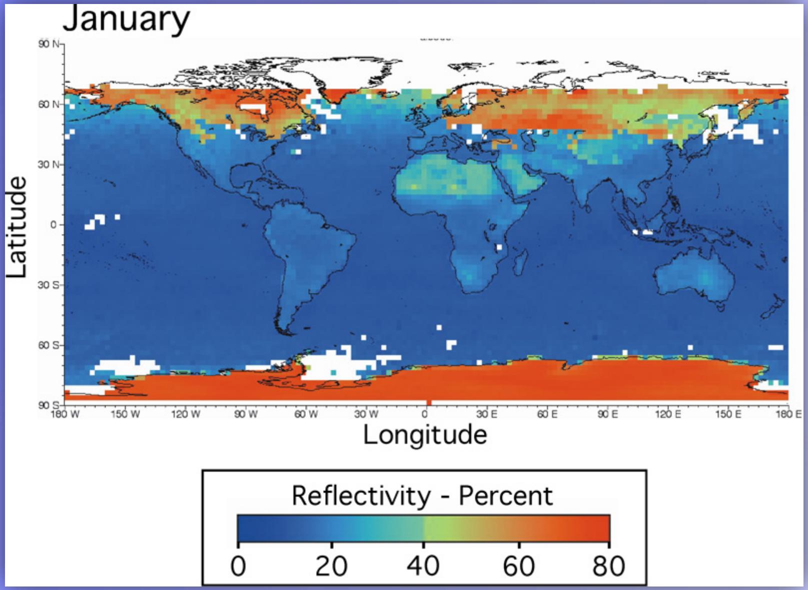
Surface	Details	Albedo
Soil	Dark and Wet	0.05 –
	Light and Dry	0.40
Sand		0.15 - 0.45
Grass	Long	0.16 –
	Short	0.26
Agricultural Crops		0.18 – 0.25
Tundra		0.18 – 0.25
Forest	Deciduous	0.15 – 0.20
	Coniferous	0.05 – 0.15
Water	Small Zenith Angle	0.03 – 0.10
	Large Zenith Angle	0.10 – 1.00
Snow	Old	0.40 –
	Fresh	0.95
Ice	Sea	0.30 – 0.45
	Glacier	0.20 – 0.40
Clouds	Thick	0.60 – 0.90
	Thin	0.30 – 0.50

Sources: Oke, 1992; Ahrens, 2006.

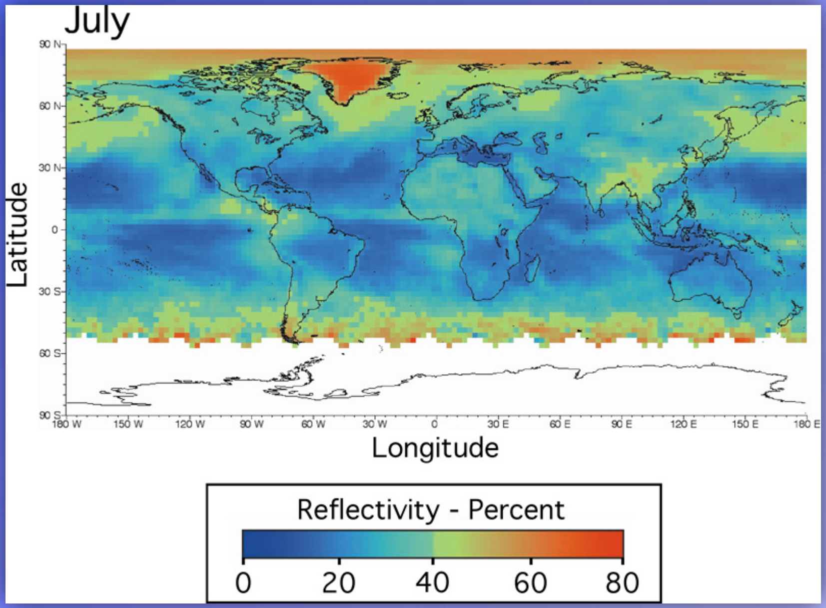




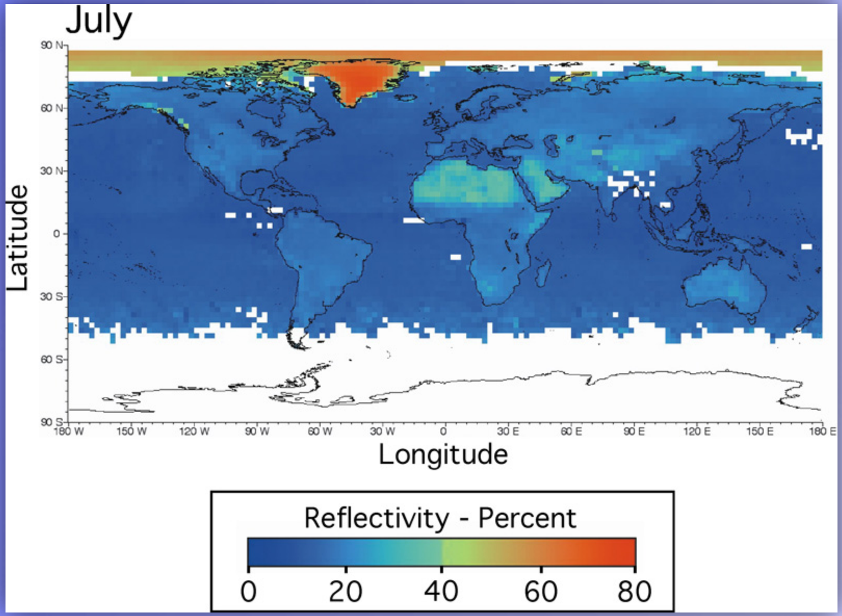
surface reflectivity only



combined
surface and atmospheric
reflectivity (effect of clouds)



surface reflectivity only



combined
surface and atmospheric
reflectivity (effect of clouds)

Other factors that contribute to planetary albedo

TABLE 2.18 Terminology Relating to Atmospheric Particles

Aerosols, aerocolloids, aerodisperse systems	Tiny particles dispersed in gases
Dusts	Suspensions of solid particles produced by mechanical disintegration of material such as crushing, grinding, and blasting; $D_p > 1\ \mu m$
Fog	A term loosely applied to visible aerosols in which the dispersed phase is liquid; usually, a dispersion of water or ice, close to the ground
Fume	The solid particles generated by condensation from the vapor state, generally after volatilization from melted substances, and often accompanied by a chemical reaction such as oxidation; often the material involved is noxious; $D_p < 1\ \mu m$
Hazes	An aerosol that impedes vision and may consist of a combination of water droplets, pollutants, and dust; $D_p < 1\ \mu m$
Mists	Liquid, usually water in the form of particles suspended in the atmosphere at or near the surface of the Earth; small water droplets floating or falling, approaching the form of rain, and sometimes distinguished from fog as being more transparent or as having particles perceptibly moving downward; $D_p > 1\ \mu m$
Particle	An aerosol particle may consist of a single continuous unit of solid or liquid containing many molecules held together by intermolecular forces and primarily larger than molecular dimensions ($>0.001\ \mu m$); a particle may also consist of two or more such unit structures held together by interparticle adhesive forces such that it behaves as a single unit in suspension or on deposit
Smog	A term derived from smoke and fog, applied to extensive contamination by aerosols; now sometimes used loosely for any contamination of the air
Smoke	Small gasborne particles resulting from incomplete combustion, consisting predominantly of carbon and other combustible materials, and present in sufficient quantity to be observable independently of the presence of other solids. $D_p \geq 0.01\ \mu m$
Soot	Agglomerations of particles of carbon impregnated with "tar," formed in the incomplete combustion of carbonaceous material

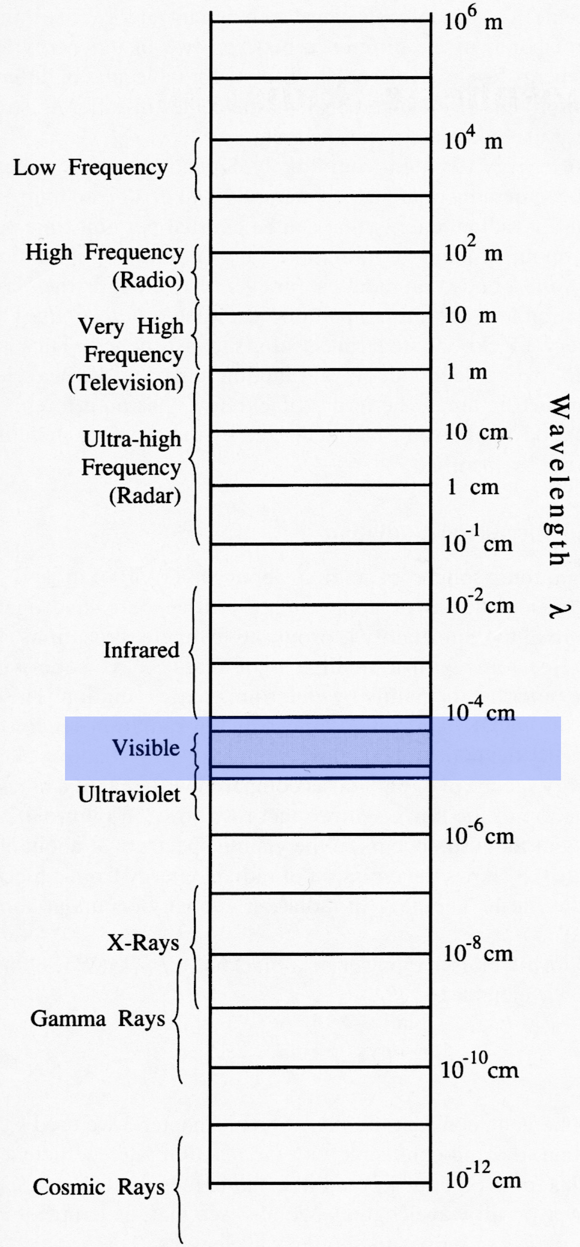
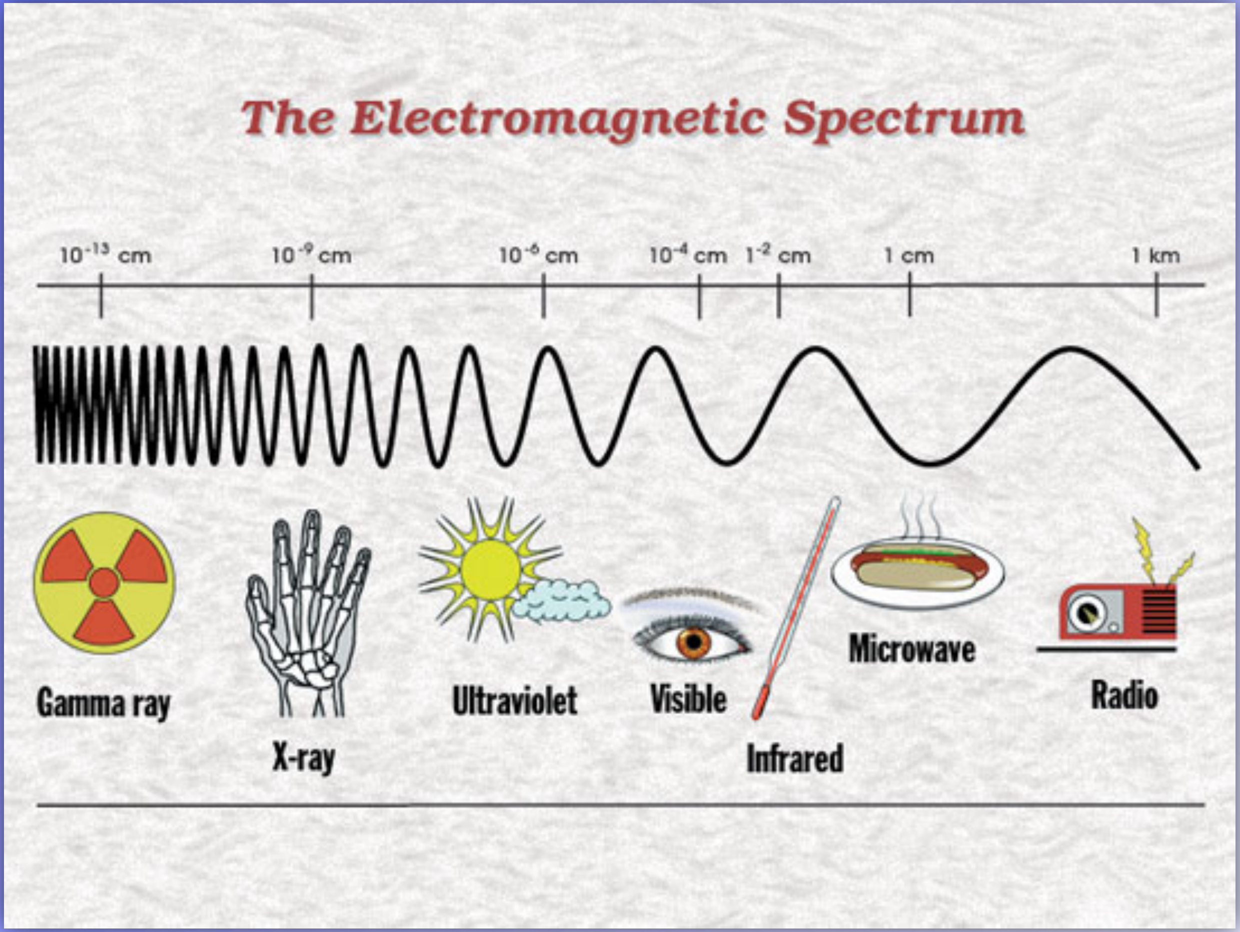
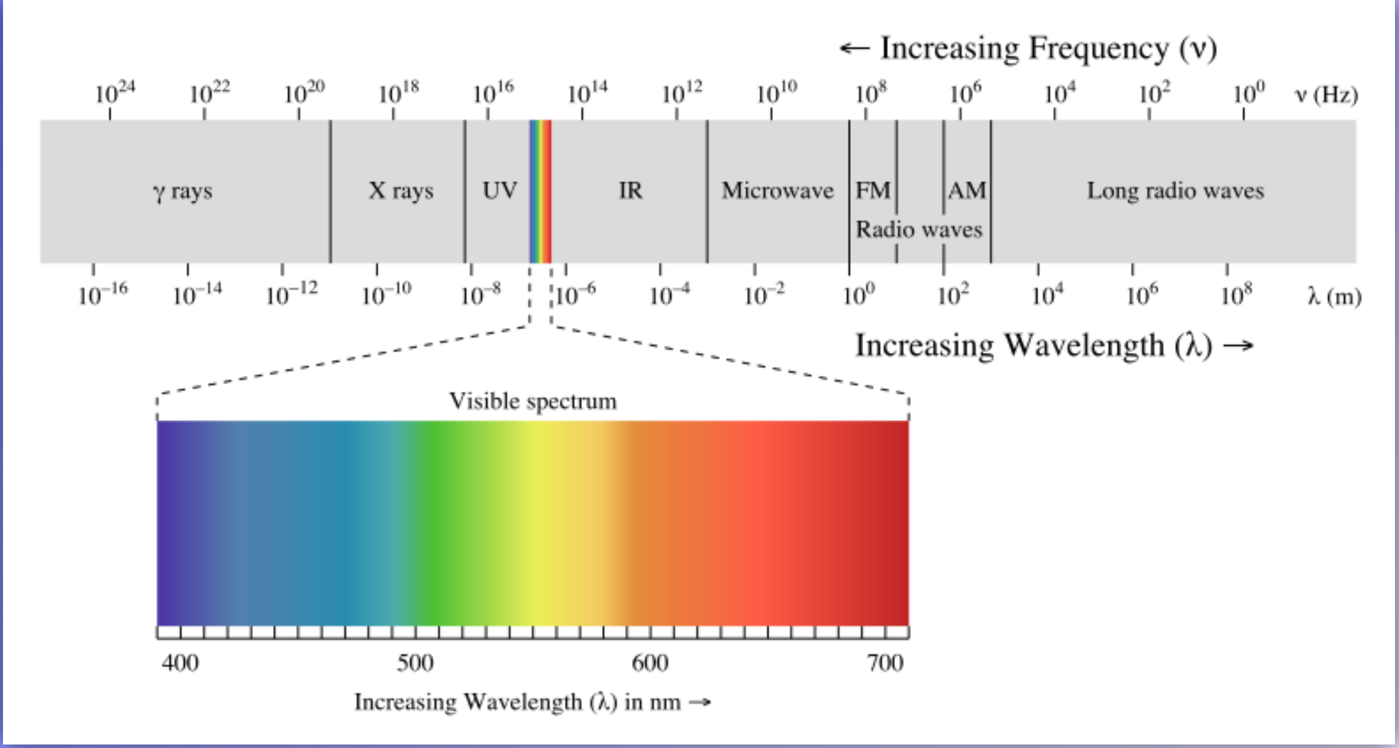


FIGURE 4.1 Electromagnetic spectrum.

The electromagnetic spectrum (inverse relationship between the frequency of light and the wavelength of light)


The Electromagnetic Spectrum
10^-13 cm
10^-9 cm
10^-6 cm
10^-4 cm
1^-2 cm
1 cm
1 km
Gamma ray
X-ray
Ultraviolet
Visible
Infrared
Microwave
Radio


← Increasing Frequency (ν)
10^{24} 10^{22} 10^{20} 10^{18} 10^{16} 10^{14} 10^{12} 10^{10} 10^{8} 10^{6} 10^{4} 10^{2} 10^{0} ν (Hz)
γ rays
X rays
UV
IR
Microwave
FM
AM
Radio waves
Long radio waves
10^{-16} 10^{-14} 10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8} λ (m)
Increasing Wavelength (λ) →
Visible spectrum
400
500
600
700
Increasing Wavelength (λ) in nm →

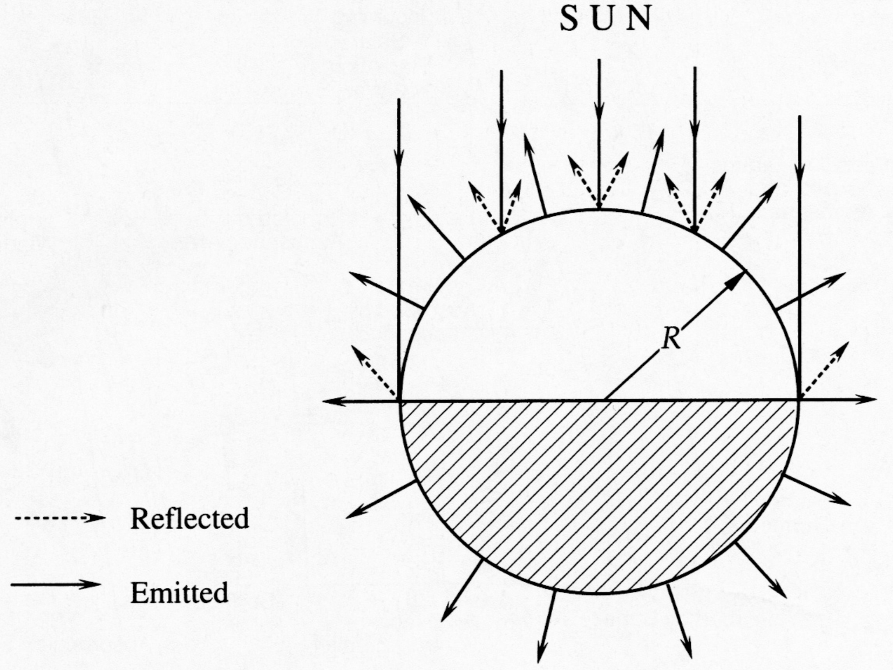


FIGURE 4.5 Global radiative equilibrium.

The equilibrium temperature of the Earth can be estimated by a simple model that equates <u>incoming</u> and <u>outgoing</u> energy.

$1370\ W/m^2$ = solar constant = S_o

cross-sectional area of Earth irradiated by Sun = πr^2

surface area of Earth = $4\pi r^2$

fraction of solar constant received by Earth = $\pi r^2/4\pi r^2$ = 1/4 x $1370\ W/m^2$ = **$342\ W/m^2$**

R_p = global mean planetary reflectance = albedo = 0.3

$342\ W/m^2$ x 0.7 = **~$235\ W/m^2$**

R_p = clouds; scattering by air molecules; scattering by atmospheric aerosol particles; reflection from the surface itself (surface albedo is denoted R_s)

If S_o was reduced by 5-10%, ice would engulf the planet within 100 years.

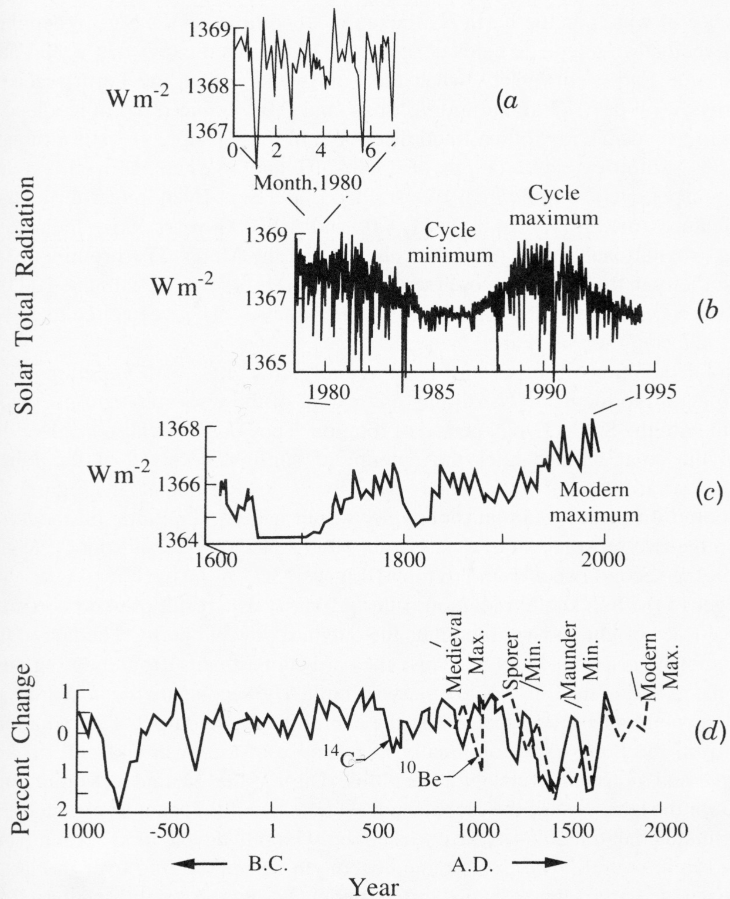


FIGURE 23.7 Variations in solar total radiation incident on the Earth (in W m^{-2}), on different timescales (Lean and Rind 1996). (a) Recorded day-to-day changes for a period of 7 months at a time of high solar activity. The largest dips of up to 0.3% persist for about a month and are the result of large sunspot groups that are carried across the face of the Sun with solar rotation. (b) Observed changes for the 15-year period over which direct measurements have been made, showing the 11-year cycle of amplitude about 0.1%. (c) A reconstruction of variations in solar radiation since about 1600, based on historical records of sunspot numbers and postulated solar surface brightness during the 70-year Maunder Minimum. Estimated variations are of larger amplitude than have yet been observed. (d) A longer record of solar activity based on postulated changes in solar radiation that are derived from measured variations in ^{14}C and ^{10}Be.

Variability in S_o: 11-year cycle

Correlation between S_o variability (see preceding slide) and variability in annual mean sunspot number

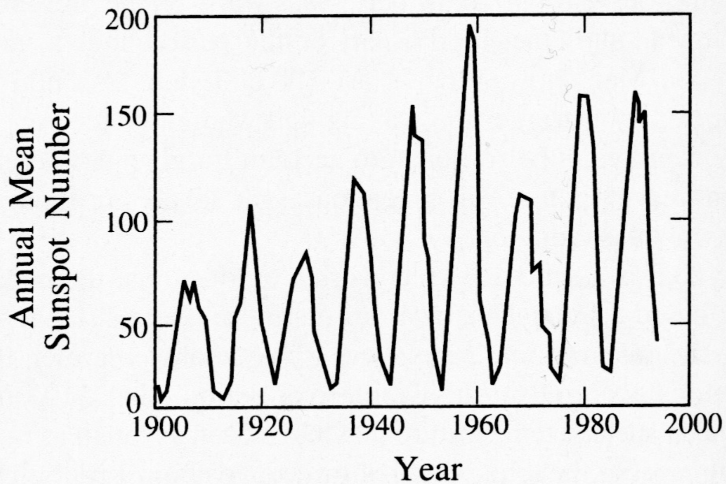


FIGURE 23.6 Annual averages of *sunspot number*—a measure of how many spots appear on the Sun—during the twentieth century (Lean and Rind 1996).

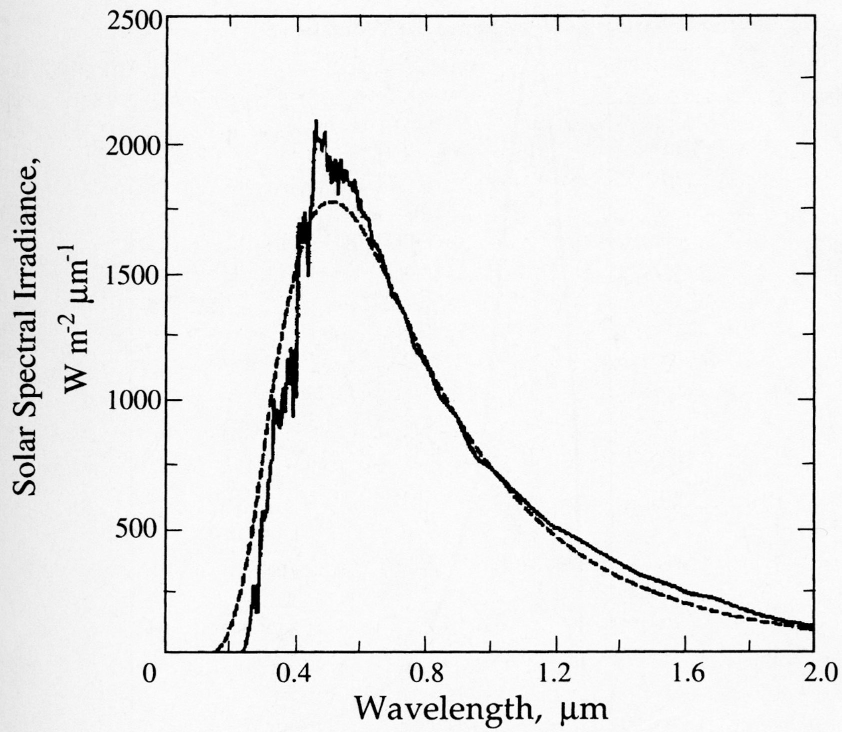


FIGURE 4.2 Solar spectral irradiance (W m^{-2} μm^{-1}) at the top of the Earth's atmosphere compared to that of a blackbody at 5777 K (dashed line) (Iqbal 1983). There is a reduction in total intensity of solar radiation from the Sun's surface to the top of the Earth's atmosphere, given by the ratio of the solar constant, 1370 W m^{-2} to the integrated intensity of the Sun [see (4.4)]. That ratio is about 1/47 000. (Reprinted by permission of Academic Press.)

Blackbody irradiation for a body at ~6000 K (Sun); note the maximum at a wavelength of ~0.5 μm = 10^{-5} cm.

0.0 ^{o}C = 273.15 K

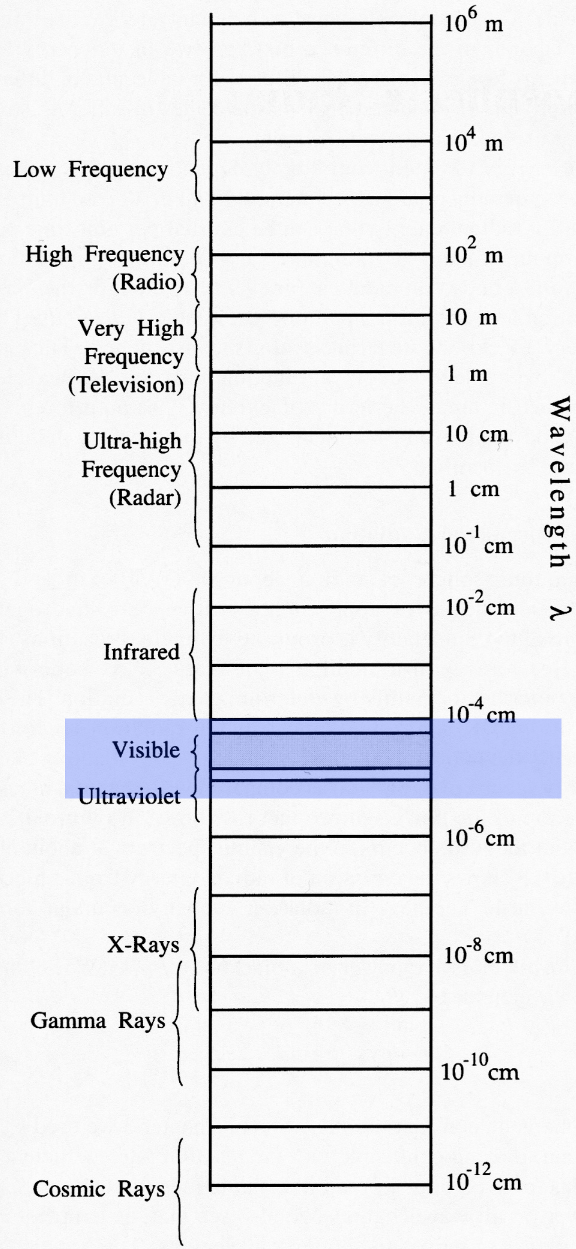


FIGURE 4.1 Electromagnetic spectrum.

Light emission from the Sun occurs mainly in the visible-ultraviolet region of the electromagnetic spectrum.

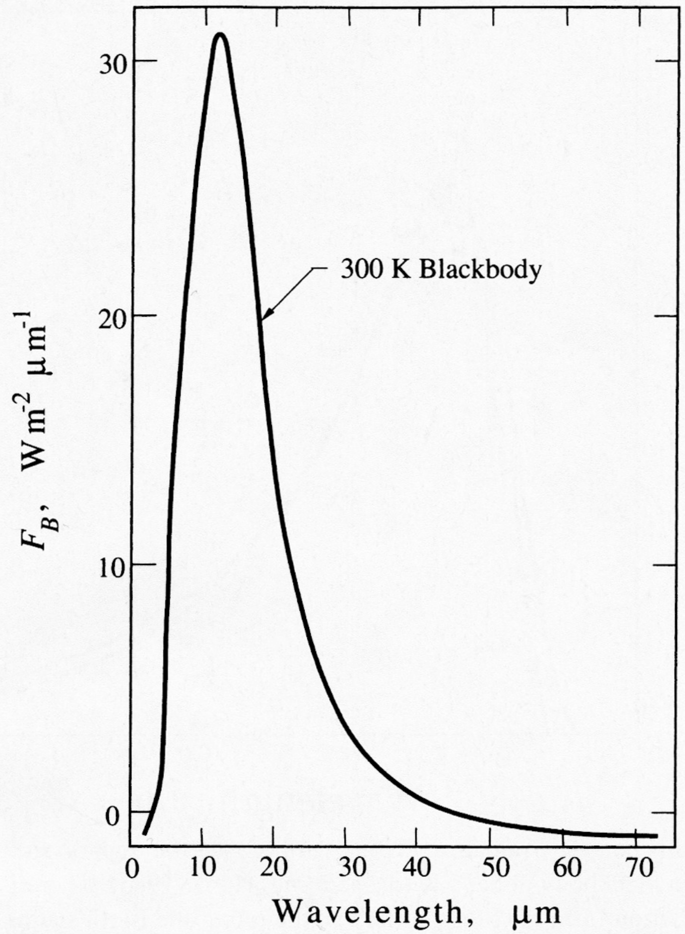


FIGURE 4.3 Spectral irradiance (W m^{-2} μm^{-1}) of a blackbody at 300 K.

Blackbody irradiation for a body at 300 K (Earth); note the maximum at a wavelength of ~10 μm = 10^{-3} cm.

0.0 ^{o}C = 273.15 K

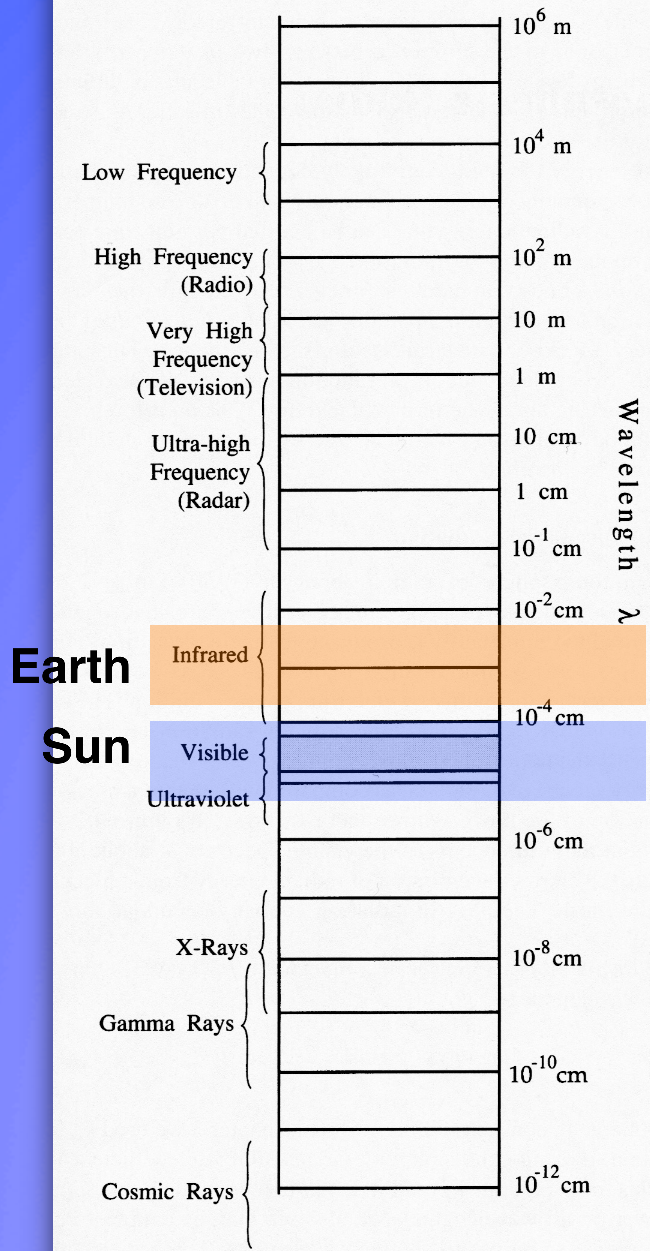
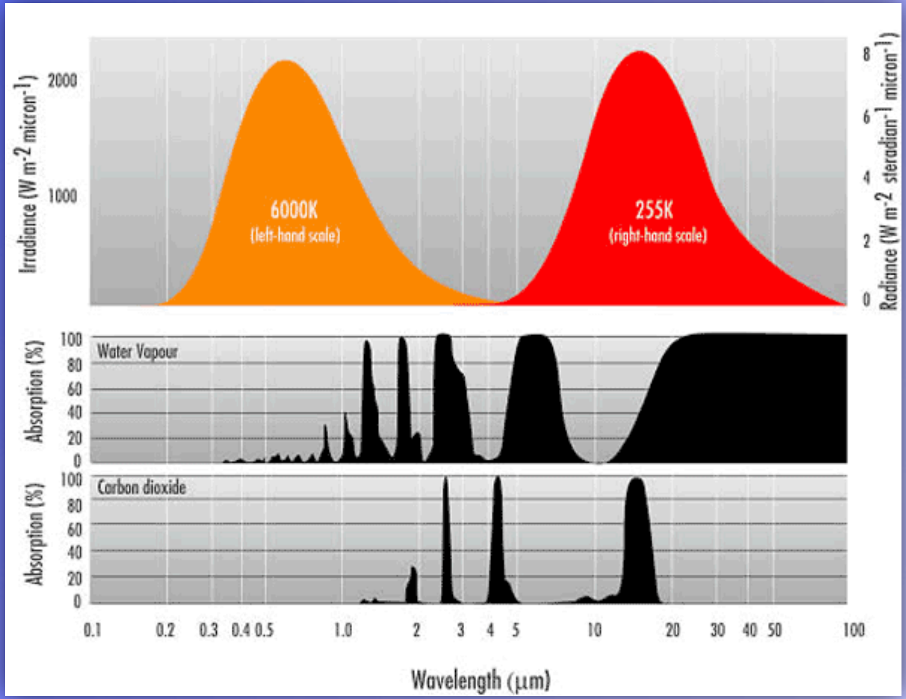
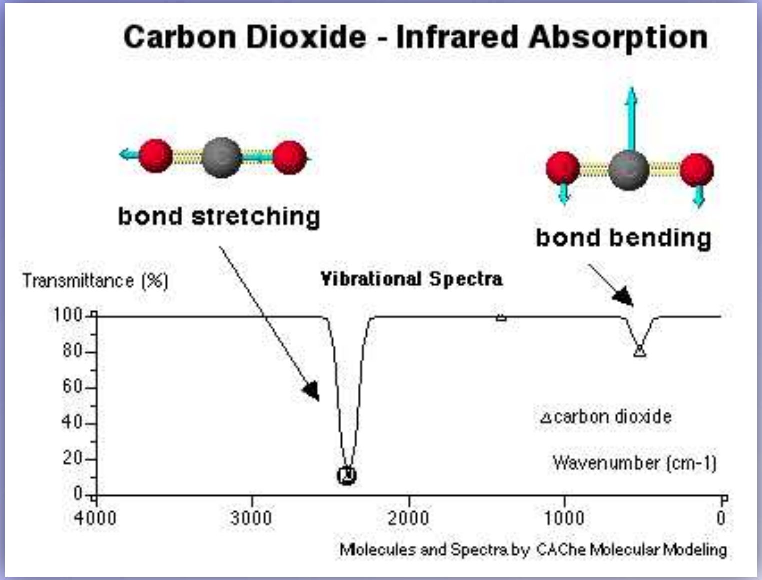


FIGURE 4.1 Electromagnetic spectrum.

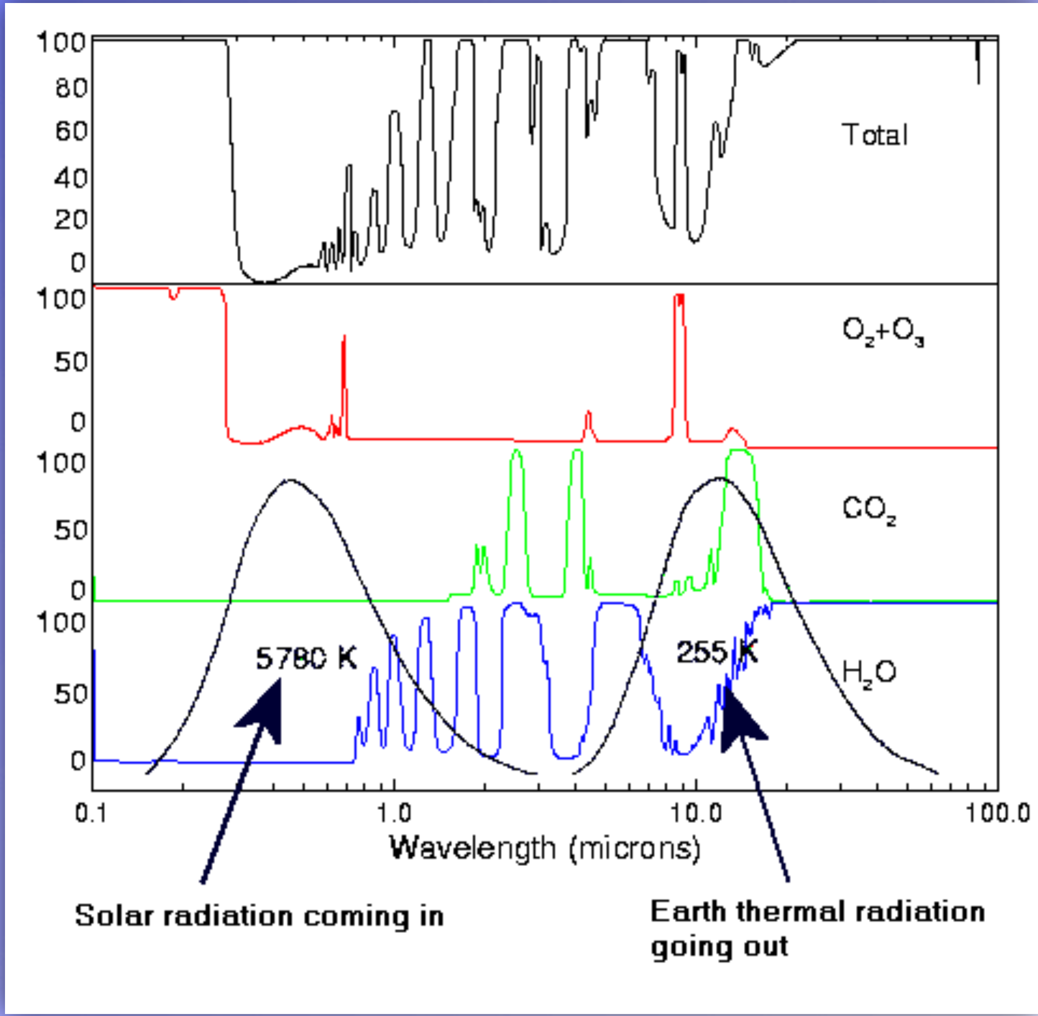
Light emission from the Earth occurs mainly in the infrared region of the electromagnetic spectrum.



Irradiance (W m-2 micron-1)
2000
1000
6000K
(left-hand scale)
255K
(right-hand scale)
Radiance (W m-2 steradian-1 micron-1)
8
6
4
2
0
Absorption (%)
Water Vapour
Carbon dioxide
100
80
60
40
20
0
0.1 0.2 0.3 0.4 0.5 1.0 2 3 4 5 10 20 30 40 50 100
Wavelength (μm)



Carbon Dioxide - Infrared Absorption
bond stretching
bond bending
Transmittance (%)
Vibrational Spectra
100
80
60
40
20
0
carbon dioxide
Wavenumber (cm-1)
4000 3000 2000 1000 0
Molecules and Spectra by CAChe Molecular Modeling



100
80
60
40
20
0
Total
100
50
0
O_2+O_3
100
50
0
CO_2
100
50
0
H_2O
5780 K
255 K
0.1
1.0
10.0
100.0
Wavelength (microns)
Solar radiation coming in
Earth thermal radiation going out

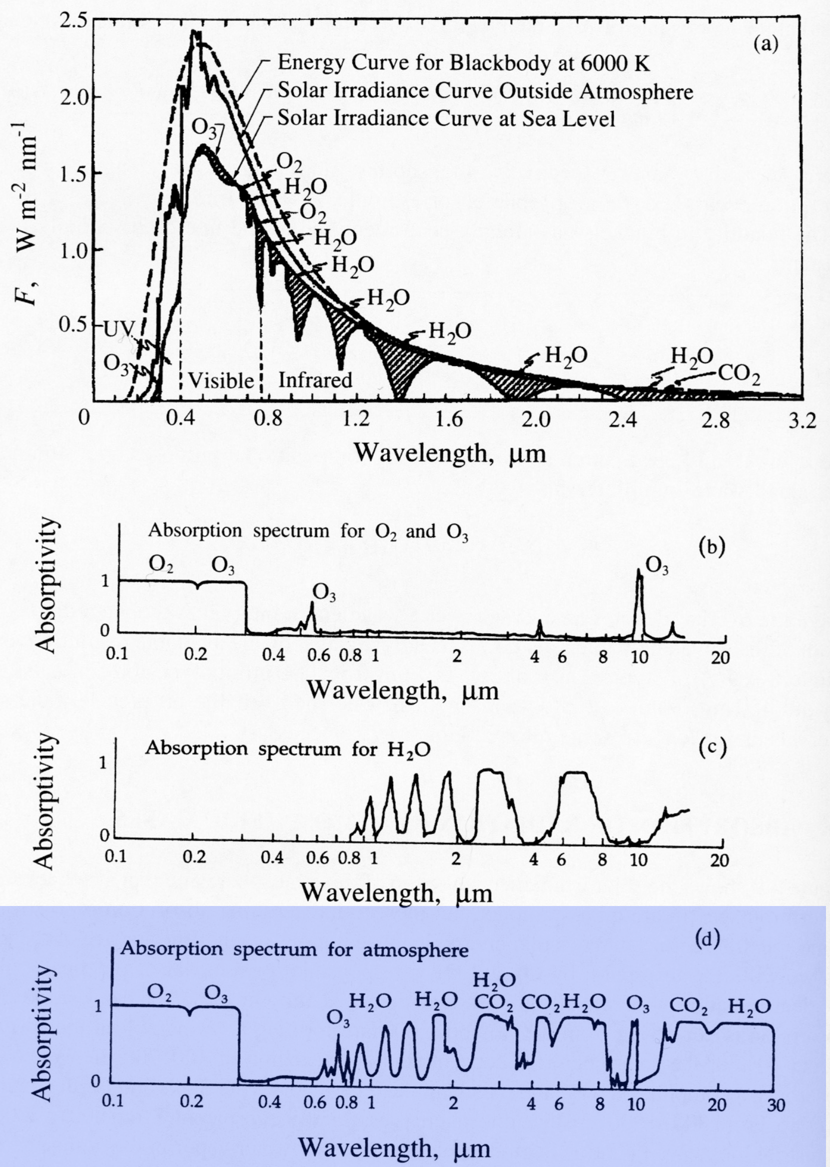


FIGURE 4.9 (a) Solar spectral irradiance at the top of the atmosphere and at sea level. Shaded regions indicate the molecules responsible for absorption. Absorption spectra for (b) molecular oxygen and ozone, (c) water vapor, and (d) the atmosphere, expressed on a scale of 0–1.

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If S_o was reduced by 5-10%, ice would engulf the planet within 100 years.

The Big Picture

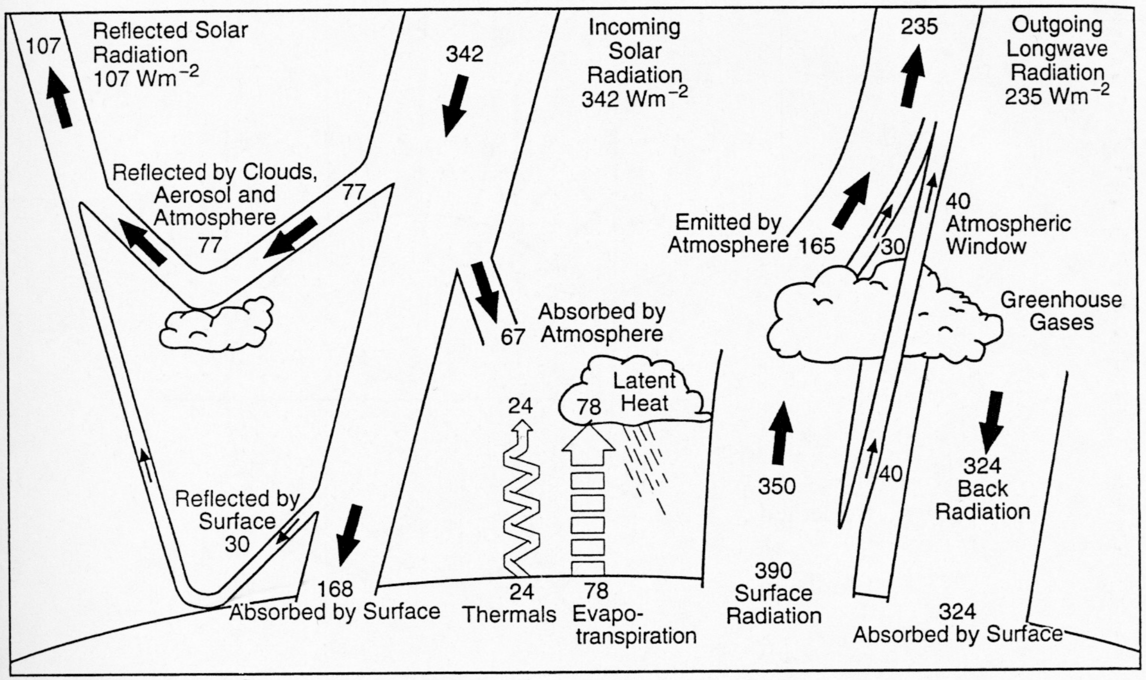


FIGURE 4.4 The Earth's annual and global mean energy balance (Kiehl and Trenberth 1997). Of 342 W m^{-2} incoming solar radiation, 168 W m^{-2} is absorbed by the surface. That energy is returned to the atmosphere as sensible heat, latent heat via water vapor, and thermal infrared radiation. Most of this radiation is absorbed by the atmosphere, which, in turn, emits radiation both up and down. (Reprinted by permission of the American Meteorological Society.)

77 + 30 = 107 Wm^{-2}

107/342 = 0.31 Wm^{-2}

168 + 67 = 235 Wm^{-2}

390 Wm^{-2} surface radiation

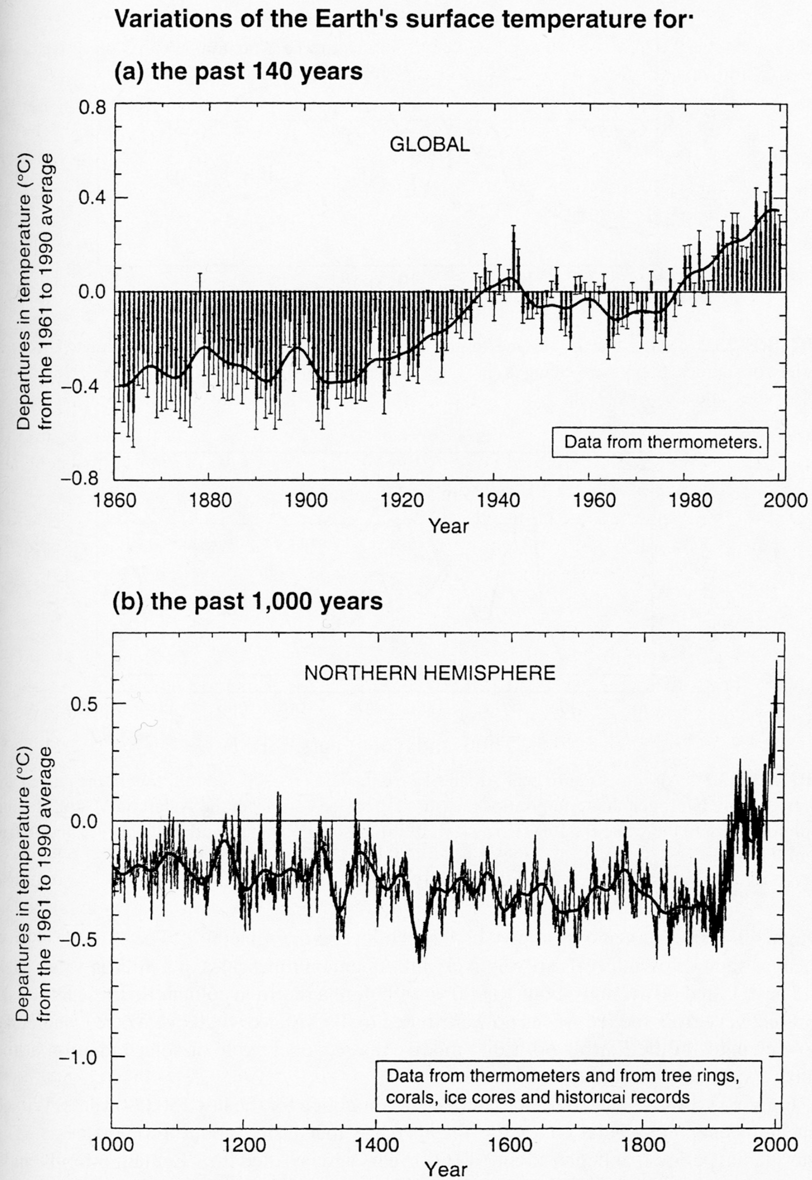
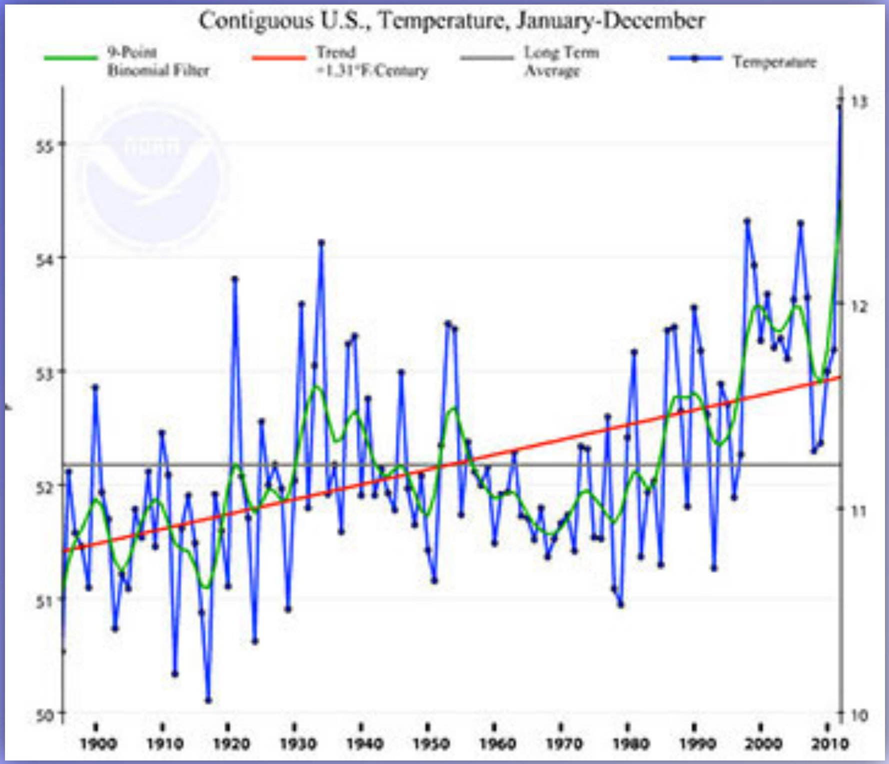
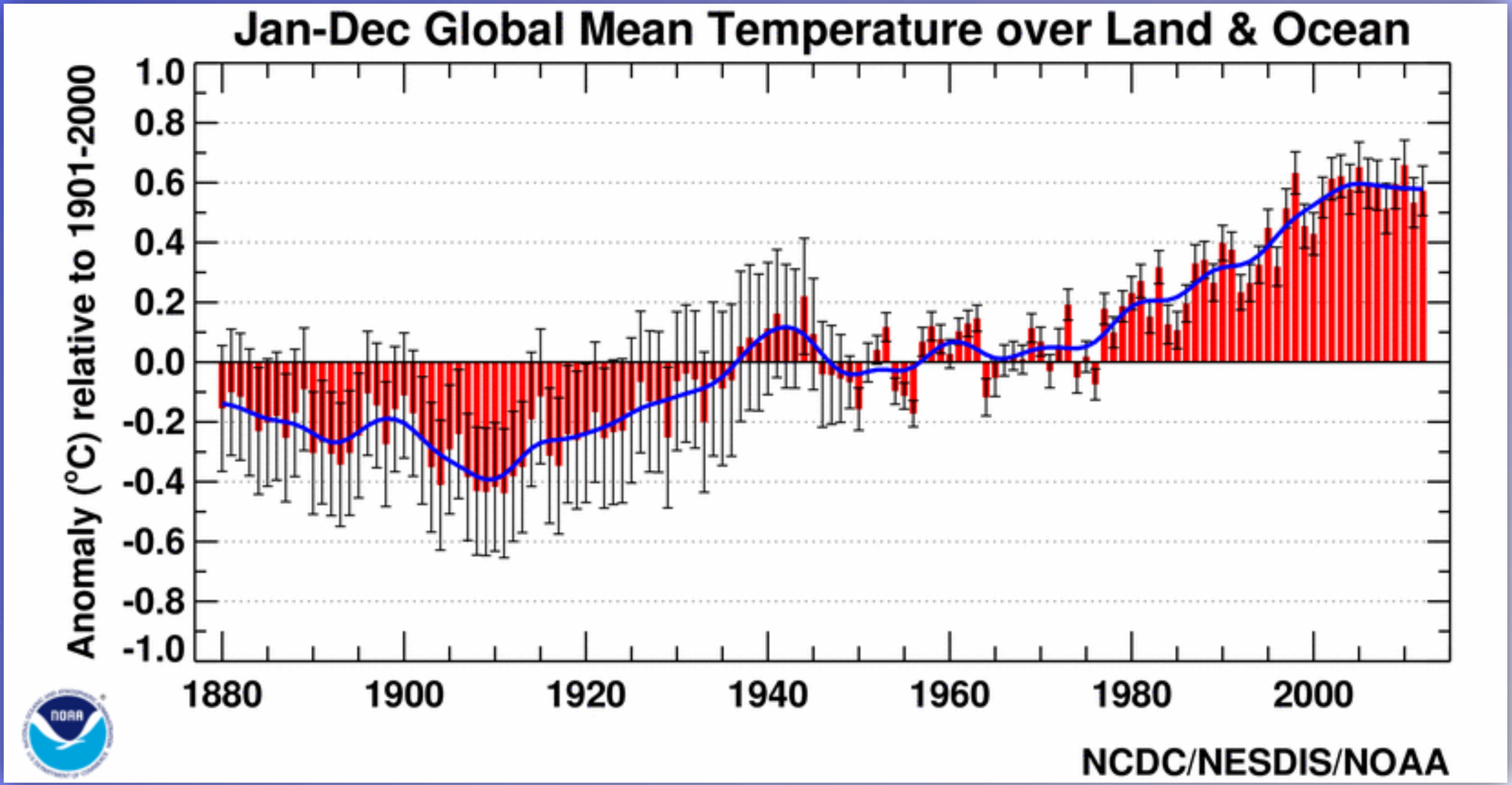
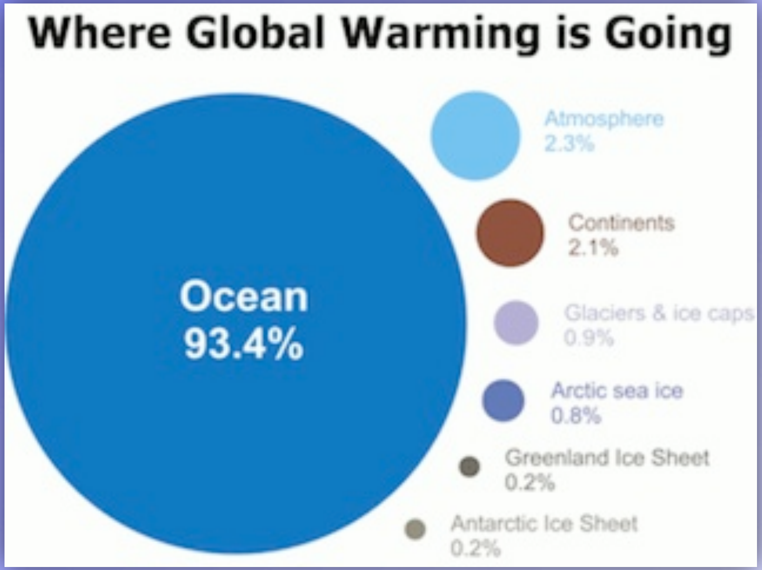


FIGURE 23.1 Variations of the Earth's surface temperature over the last 140 years (a) and the past 1000 years (b) (IPCC 2001).


Contiguous U.S., Temperature, January-December
9-Point
Binomial Filter
Trend
+1.31°F/Century
Long Term
Average
Temperature
55
54
53
52
51
50
13
12
11
10
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010



Jan-Dec Global Mean Temperature over Land & Ocean
Anomaly (°C) relative to 1901-2000
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1880
1900
1920
1940
1960
1980
2000
NCDC/NESDIS/NOAA

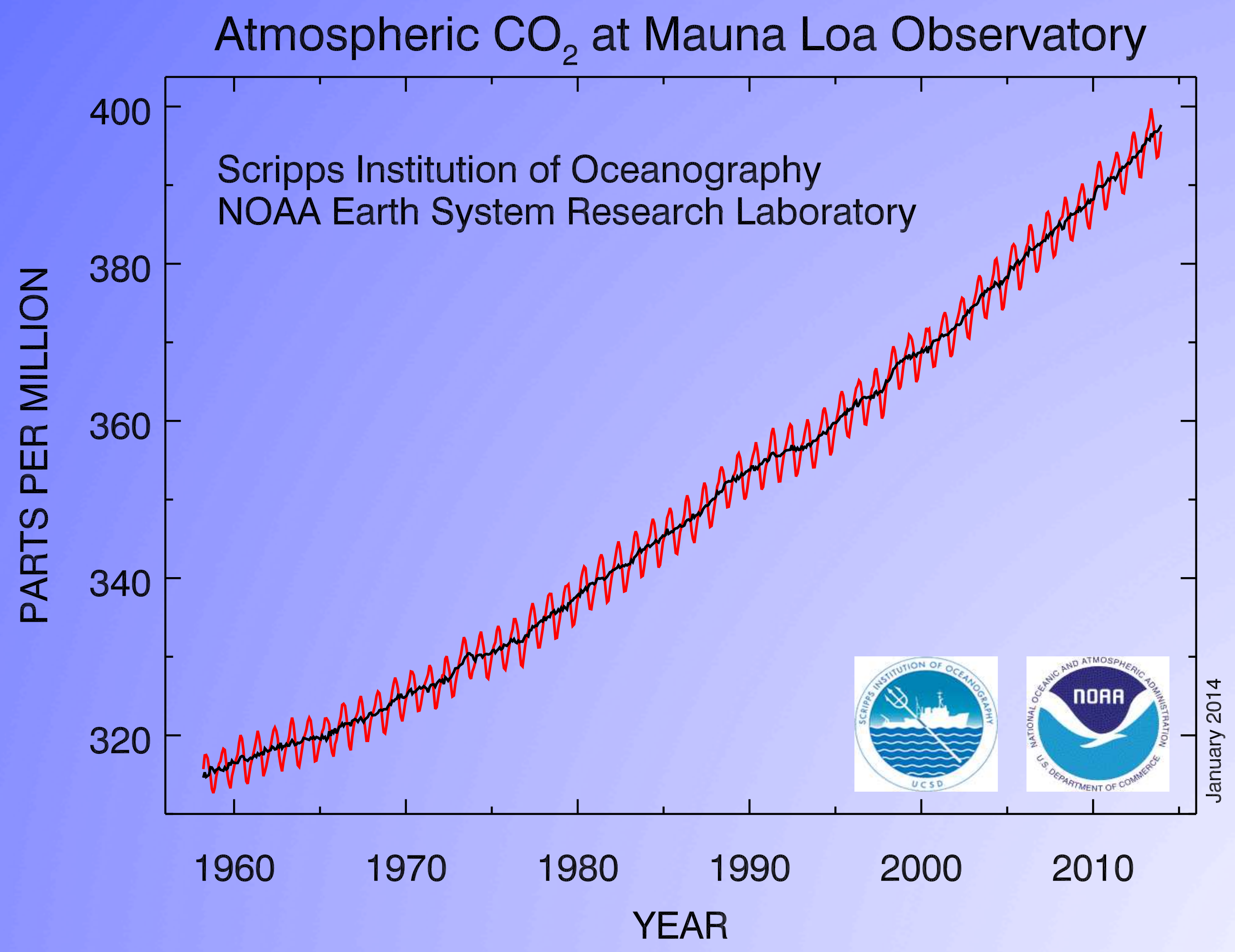

Where Global Warming is Going
Ocean
93.4%
Atmosphere
2.3%
Continents
2.1%
Glaciers & ice caps
0.9%
Arctic sea ice
0.8%
Greenland Ice Sheet
0.2%
Antarctic Ice Sheet
0.2%

What is climate sensitivity?

It is the equilibrium temperature change in response to changes of the radiative forcing.

<u>Radiative forcing</u> is defined as the difference of radiant energy received by the Earth and energy radiated back to space.

<u>Examples of radiative forcing</u>: changing atmospheric CO_2 concentration; changing cloud behavior; changing atmospheric soot particles (*e.g.*, from volcanoes)



Atmospheric CO2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
400
380
360
340
320
1960
1970
1980
1990
2000
2010
YEAR
January 2014

On average, Earth absorbs approximately **240 W** of sunlight per square meter (240 Wm^{-2}). A doubling of atmospheric CO_2 [concentration] causes a radiative forcing of ~4 Wm^{-2}. Therefore, to offset the 4 Wm^{-2} forcing requires reflection of approximately 4/240, or ~1.7%, of incoming solar radiation. Precise numbers depend on uncertain climate system feedbacks and differences in climate system response to different types of radiative forcing [climate sensitivity].

Geoengineering

Caldeira *et al*., *Ann. Rev. Earth Planet. Sci.* **2013**, *41*, 231-56

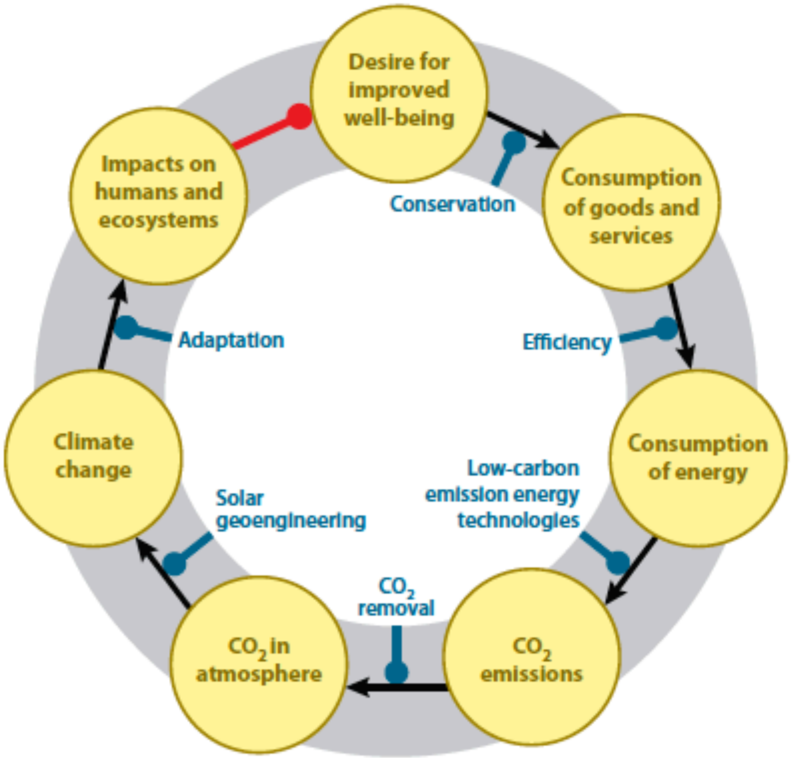


Figure 1

Most geoengineering approaches fall into one of two categories: carbon dioxide removal or solar geoengineering. These approaches can be viewed as part of a portfolio of strategies for diminishing climate risk and damage. Carbon dioxide removal attempts to break the link between CO_2 emissions and accumulation of CO_2 in the atmosphere. Solar geoengineering (also known as solar radiation management) attempts to break the link between accumulation of CO_2 in the atmosphere and the amount of climate change that can result.

Caldeira *et al.*, *Ann. Rev. Earth Planet. Sci.* **2013**, *41*, 231-56

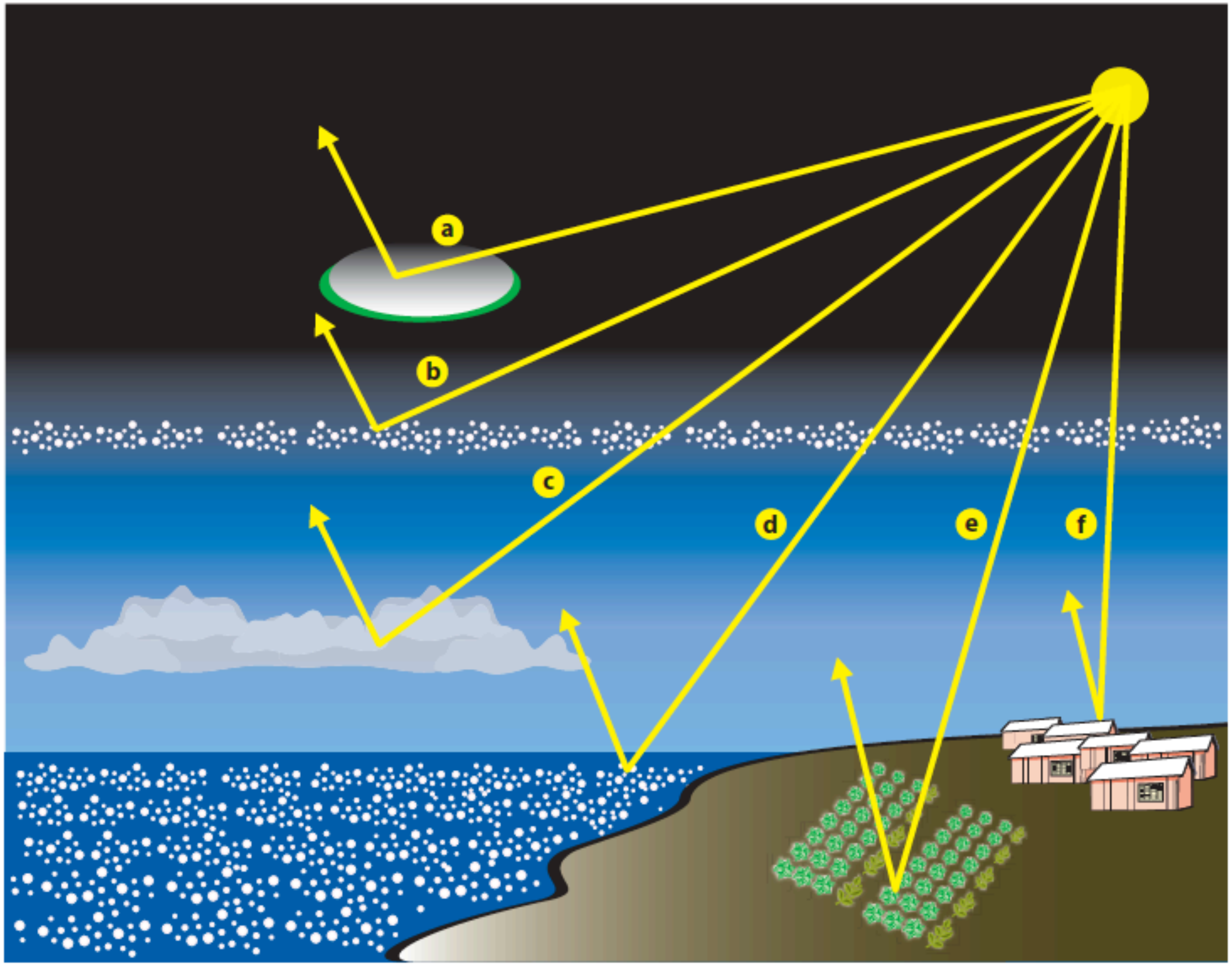


Figure 2

Solar geoengineering/solar radiation management approaches work by reflecting to space sunlight that would otherwise have been absorbed. Illustrated methods are (*a*) using satellites in space, (*b*) injecting aerosols into the stratosphere, (*c*) brightening marine clouds, (*d*) making the ocean surface more reflective, (*e*) growing more reflective plants, and (*f*) whitening roofs and other built structures.

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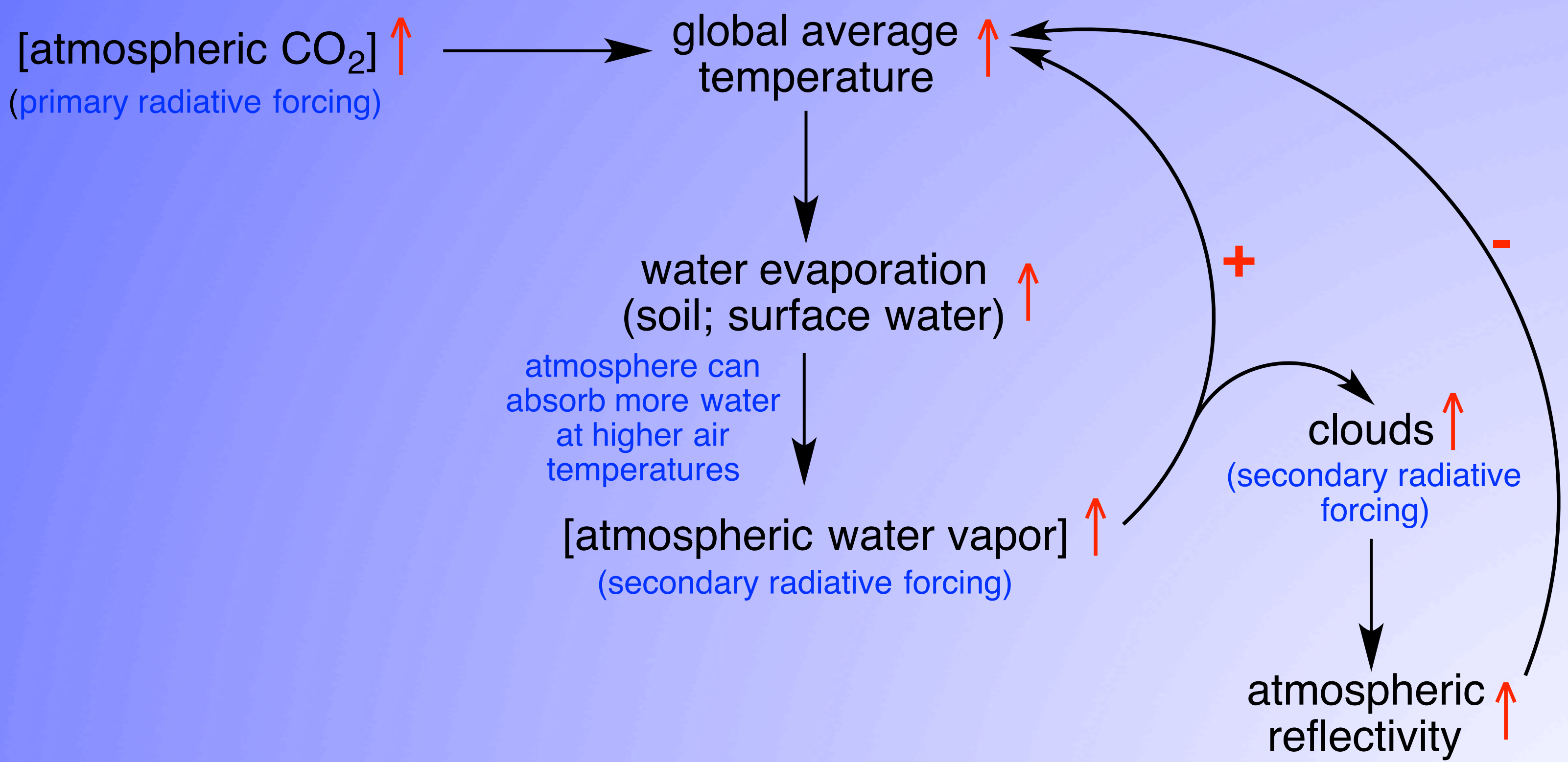
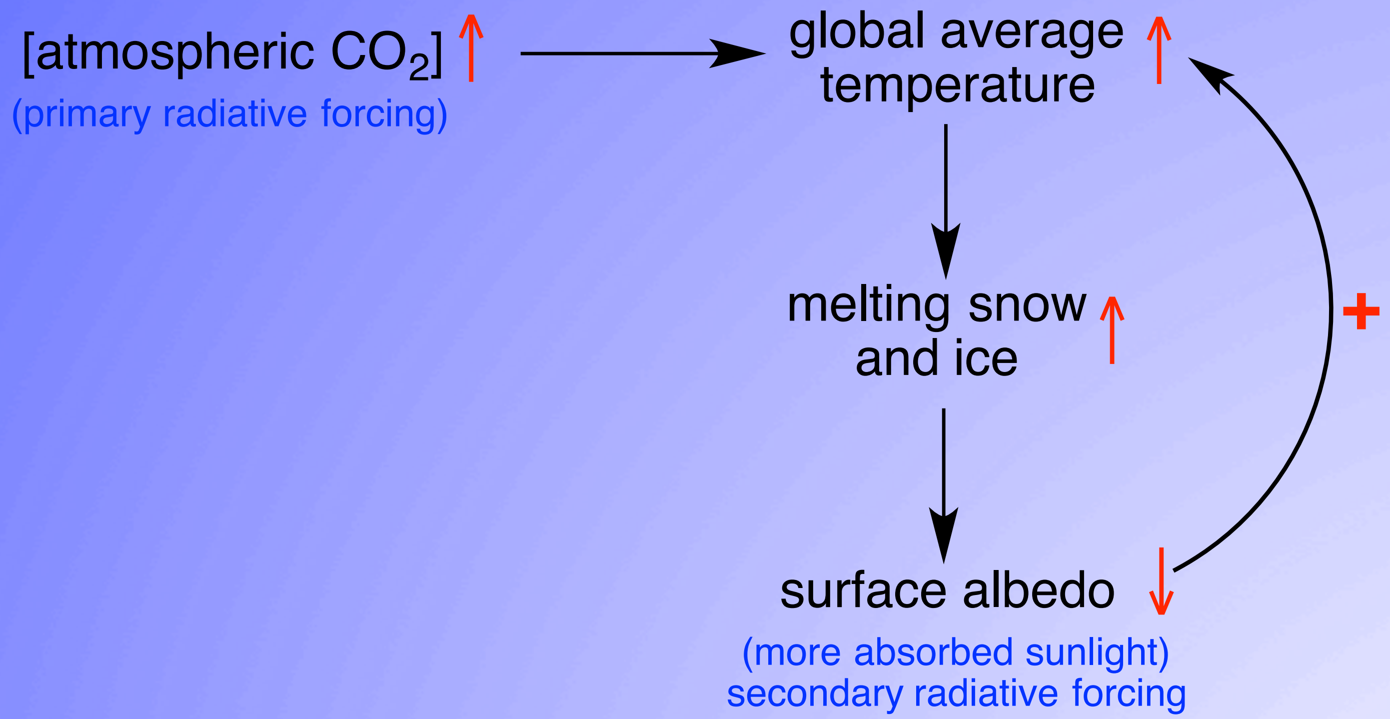
Examples of positive and negative feedbacks on global atmospheric temperature





Importance of systems thinking

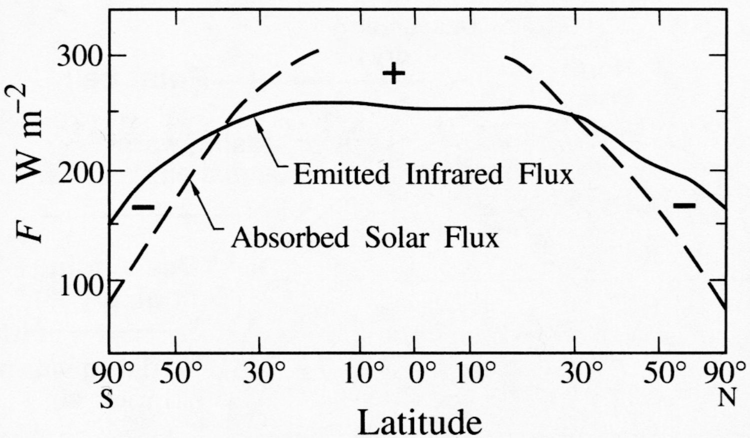


FIGURE 21.1 Zonally averaged components of the absorbed solar flux and emitted thermal infrared flux at the top of the atmosphere. The + and – signs denote energy gain and loss, respectively. (From *Radiation and Cloud Processes in the Atmosphere: Theory Observation and Modeling* by Kuo-Nan Liou. Copyright © 1992 by Oxford University Press, Inc. Used by permission of Oxford University Press, Inc.)

Note: 0º latitude = equator; ±90º latitude = poles

As a result of the net gain of radiative energy in the tropics and the net loss in the polar regions, an equator-to-pole temperature gradient is generated. This gradient largely drives Earth's <u>atmospheric circulation</u>.

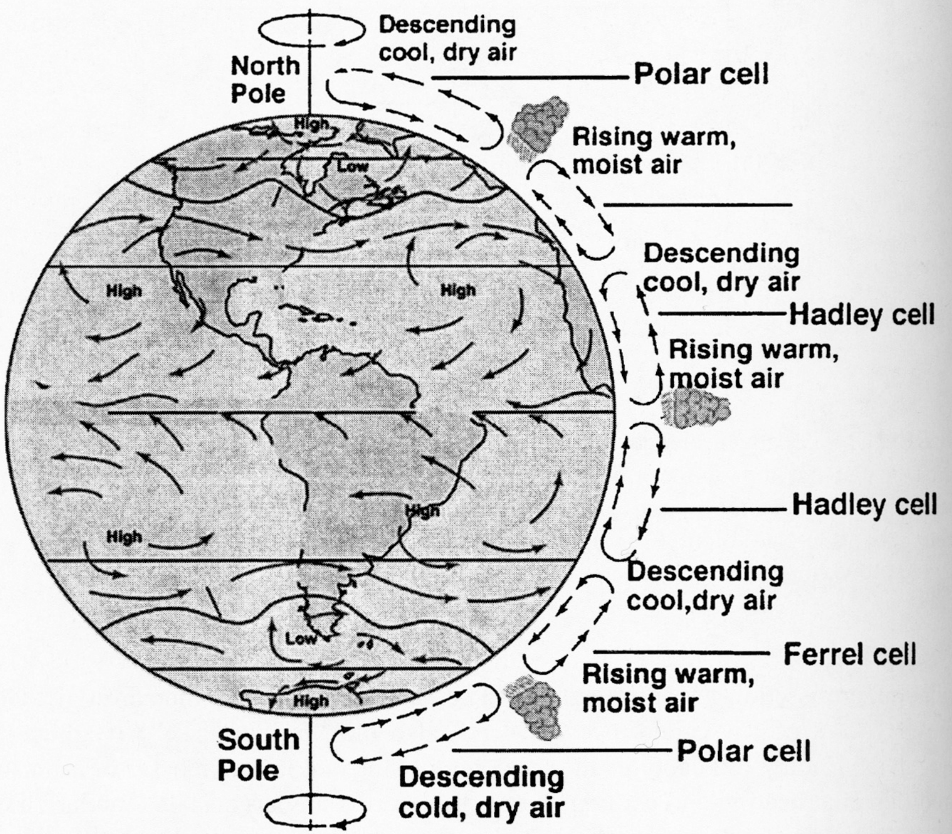
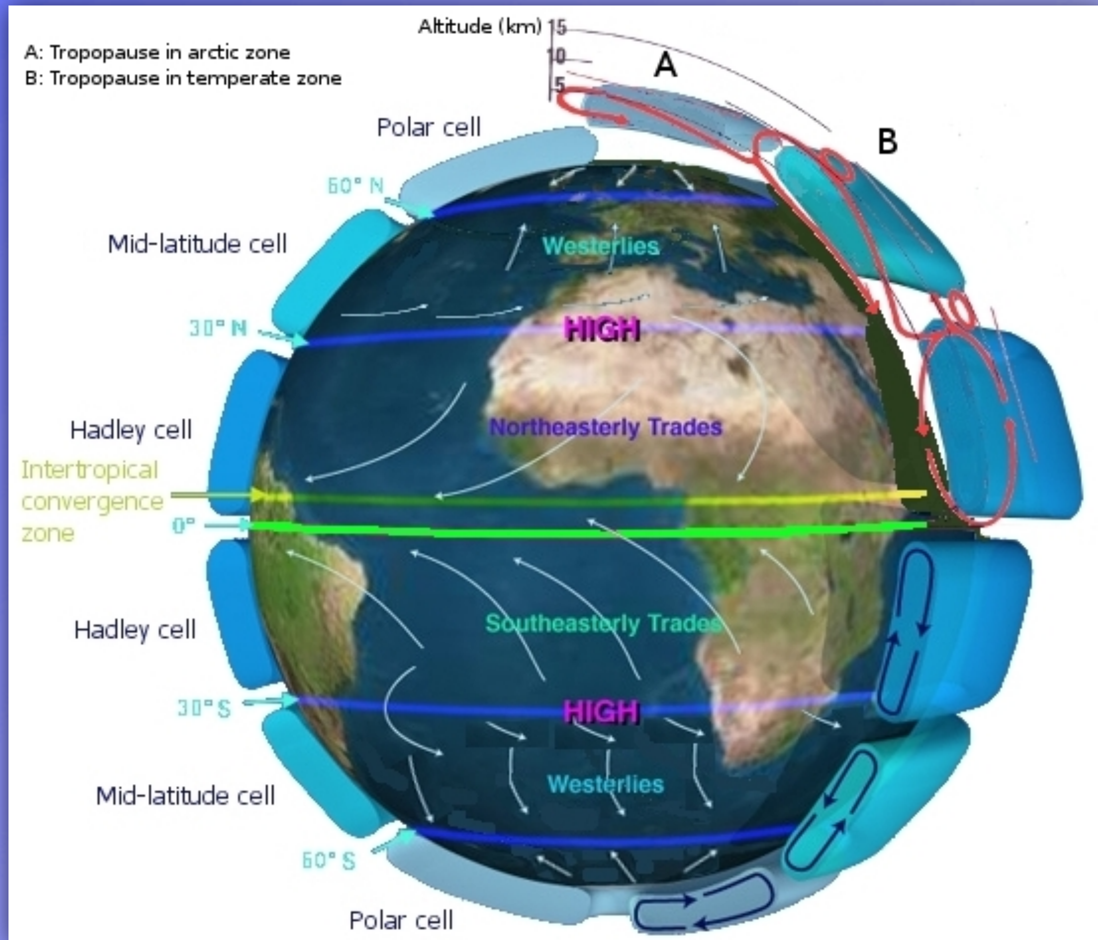


FIGURE 21.2 Three-cell representation of global circulation of the atmosphere.

Equator-to-pole temperature gradient driven global circulation of Earth's atmosphere


A: Tropopause in arctic zone
B: Tropopause in temperate zone
Altitude (km) 15
10
5
A
B
Polar cell
60° N
Mid-latitude cell
Westerlies
30° N
HIGH
Hadley cell
Northeasterly Trades
Intertropical convergence zone
0°
Hadley cell
Southeasterly Trades
30° S
HIGH
Mid-latitude cell
Westerlies
60° S
Polar cell