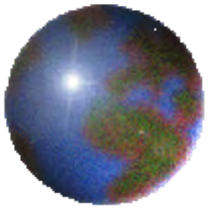


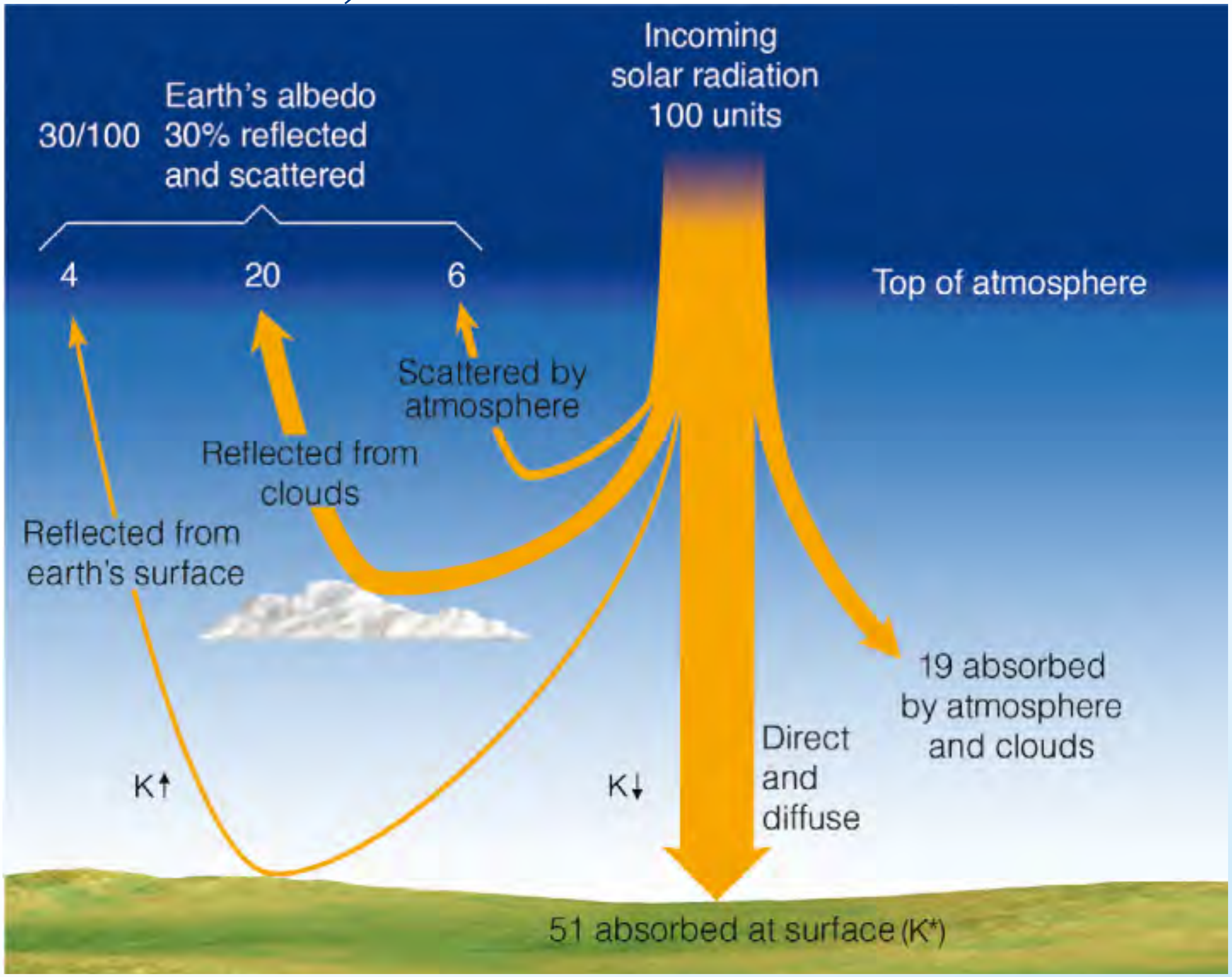
Global Energy Balance

GEOG/ENST 2331: Lecture 4

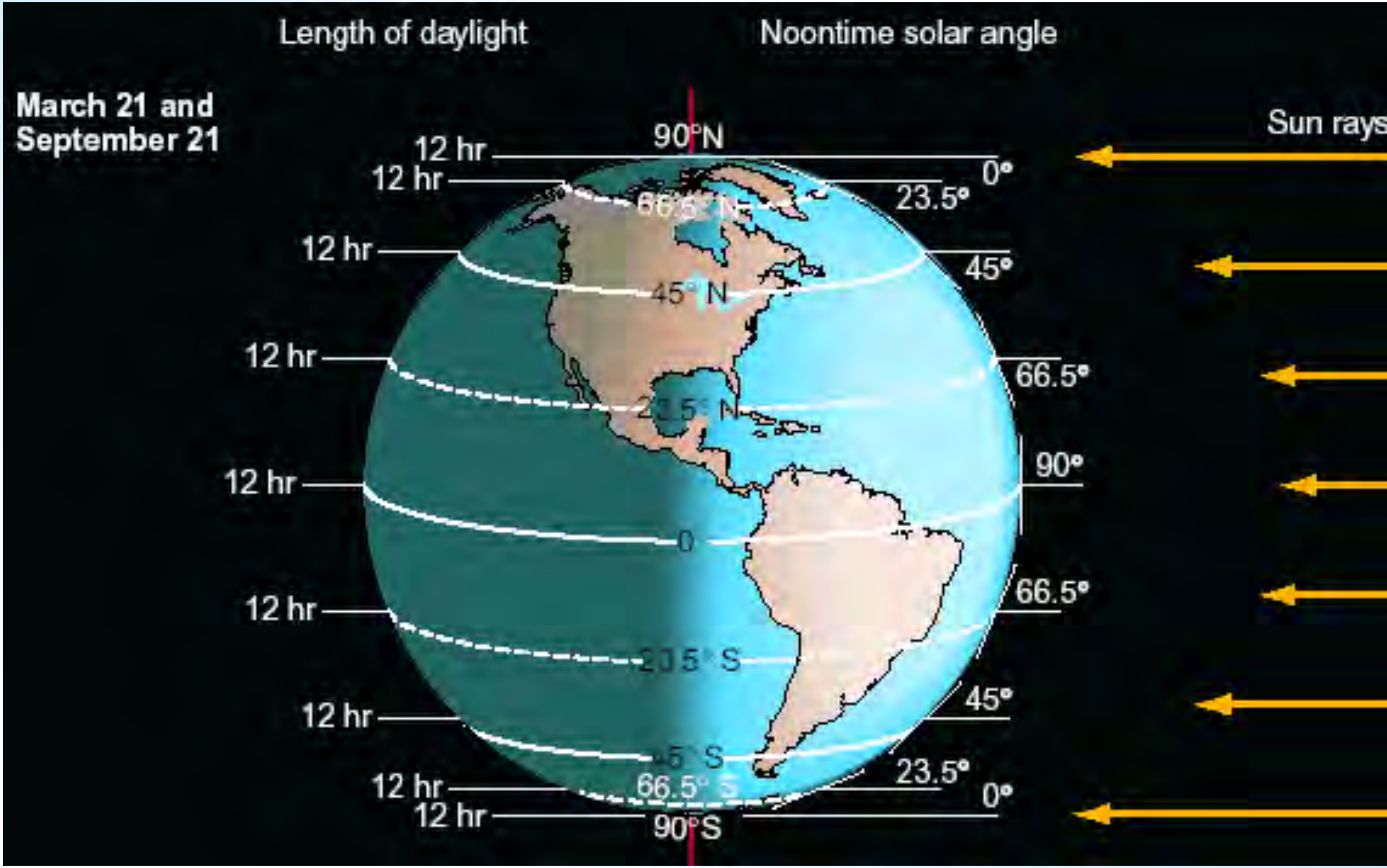
Ahrens: Chapter 2

Lab 1

Shortwave Radiation (imagine 100 total units)



Ahrens: Figure 2.15



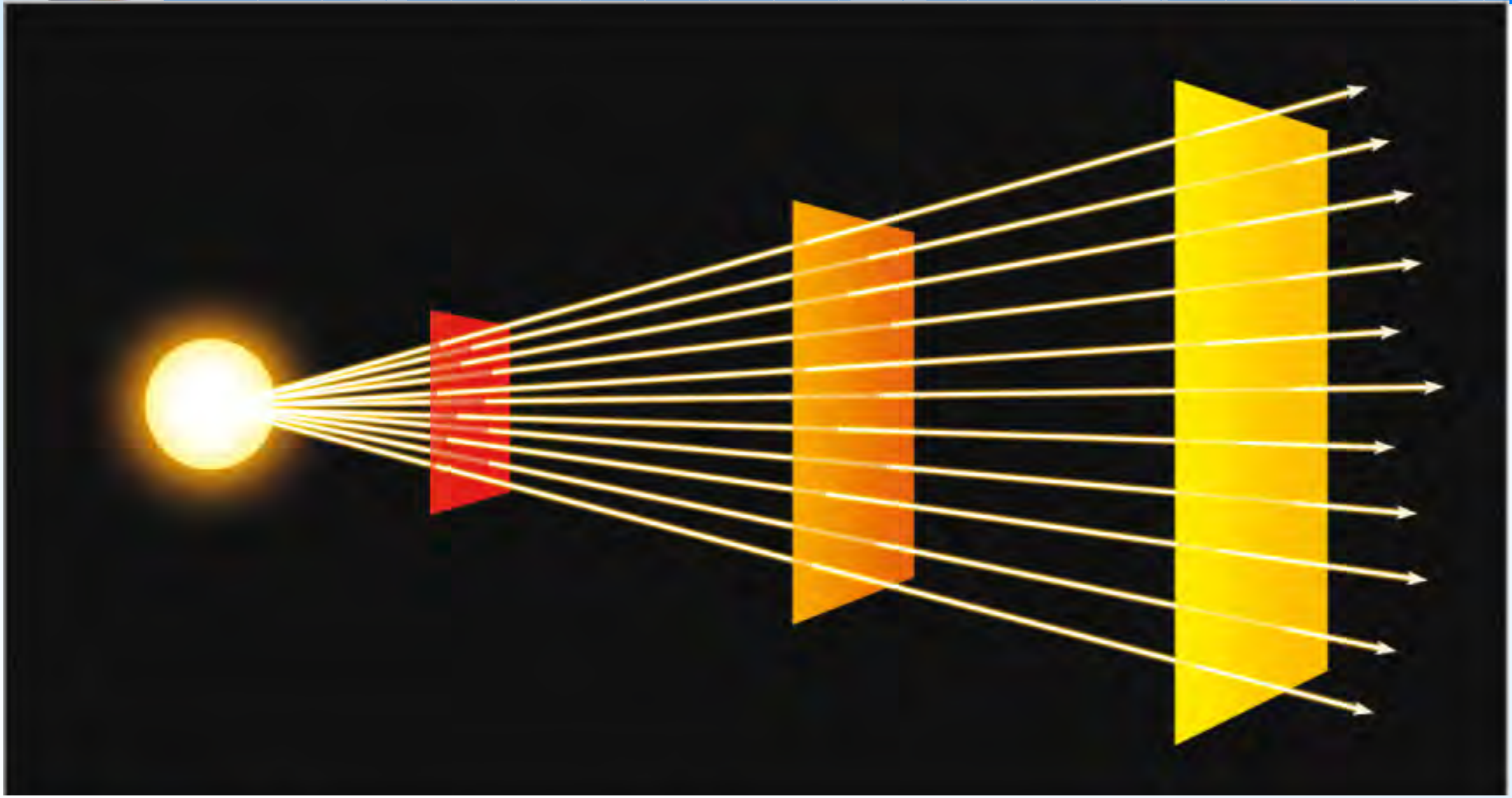
Length of daylight
Noontime solar angle
March 21 and
September 21
Sun rays
12 hr
12 hr
12 hr
12 hr
12 hr
12 hr
12 hr
12 hr
12 hr
90°N
66.5° N
45° N
23.5° N
0
23.5° S
45° S
66.5° S
90°S
0°
23.5°
45°
66.5°
90°
66.5°
45°
23.5°
0°

The atmospheric greenhouse effect is mainly produced by?

1. Gases in the atmosphere absorb/emit visible light
2. Gases in the atmosphere absorb/emit ultraviolet radiation
3. Clouds absorb/emit visible light
4. Gases in the atmosphere absorb/emit longwave radiation
5. Interaction between x-rays and the ozone layer

Absorption and Transmission

- When radiation reaches the atmosphere, it can be scattered, reflected, absorbed or transmitted
  - *Albedo* determines how much is reflected/scattered
  - *Absorptivity* determines how much of what is left is absorbed or transmitted
- *Black bodies* absorb all non-reflected radiation
- *Selective absorbers* absorb only specific wavelengths, remainder is transmitted



Radiation travelling outward from a point on the Sun
Same amount of radiation is spread over a larger and larger area
Ahrens: Ch. 2 Fig. 3

Total Solar Irradiance (S)

- *Quantity* of electromagnetic radiation is not reduced with distance through a vacuum
- *Intensity* is reduced as energy becomes distributed over a larger area
- Therefore, radiation intensity decreases in proportion to the square of the distance

Irradiance

- ***Inverse square law***

S is proportional to $\frac{1}{d^2}$

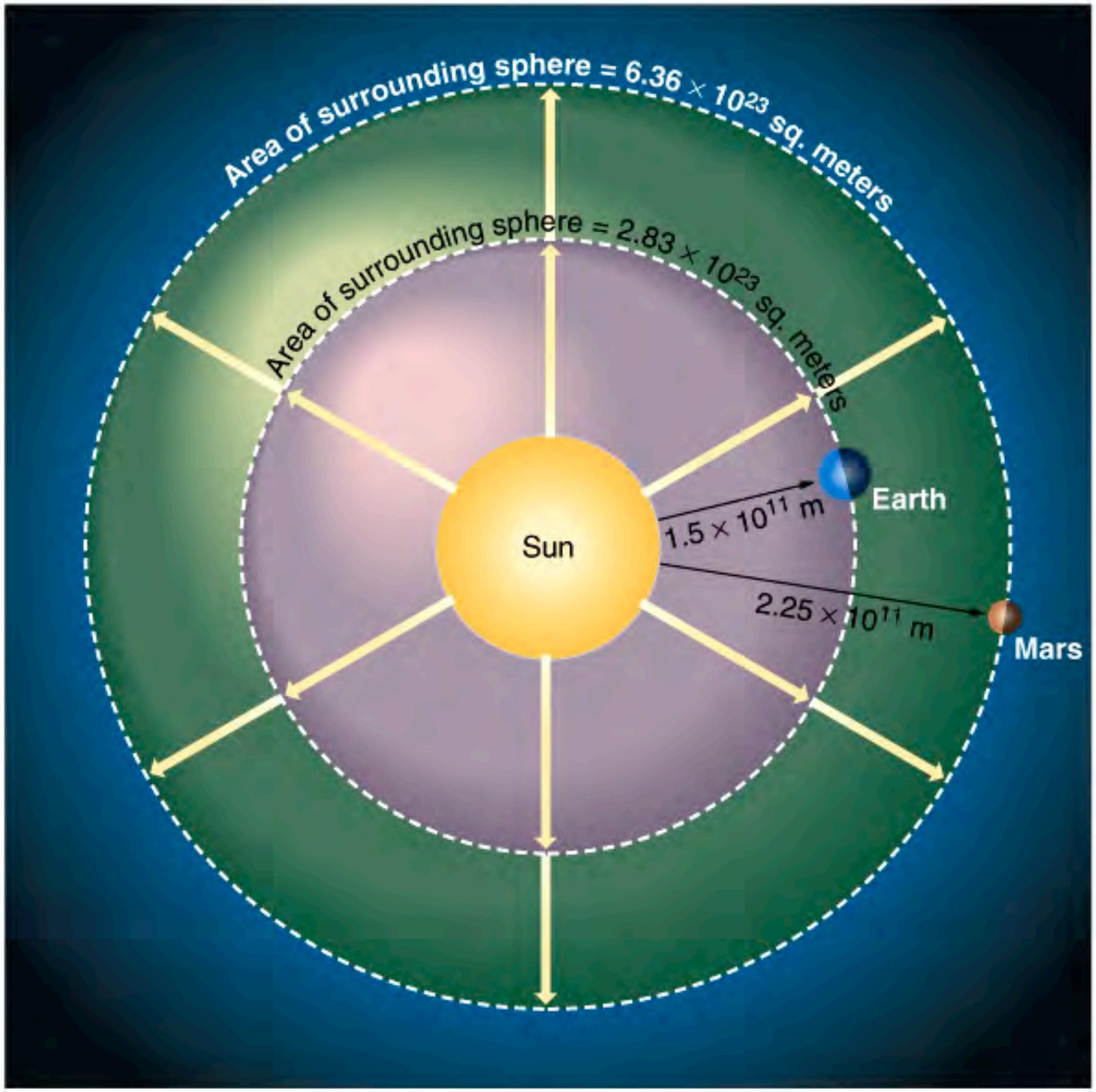
- **Earth:**

$S = 1380\ Wm^{-2}$

- **Mars:**

$S = 445\ Wm^{-2}$

Mars is 1.5 times as far
Earth's irradiance is
2.25 times as large



A&B: Figure 2.9

Area of intereption

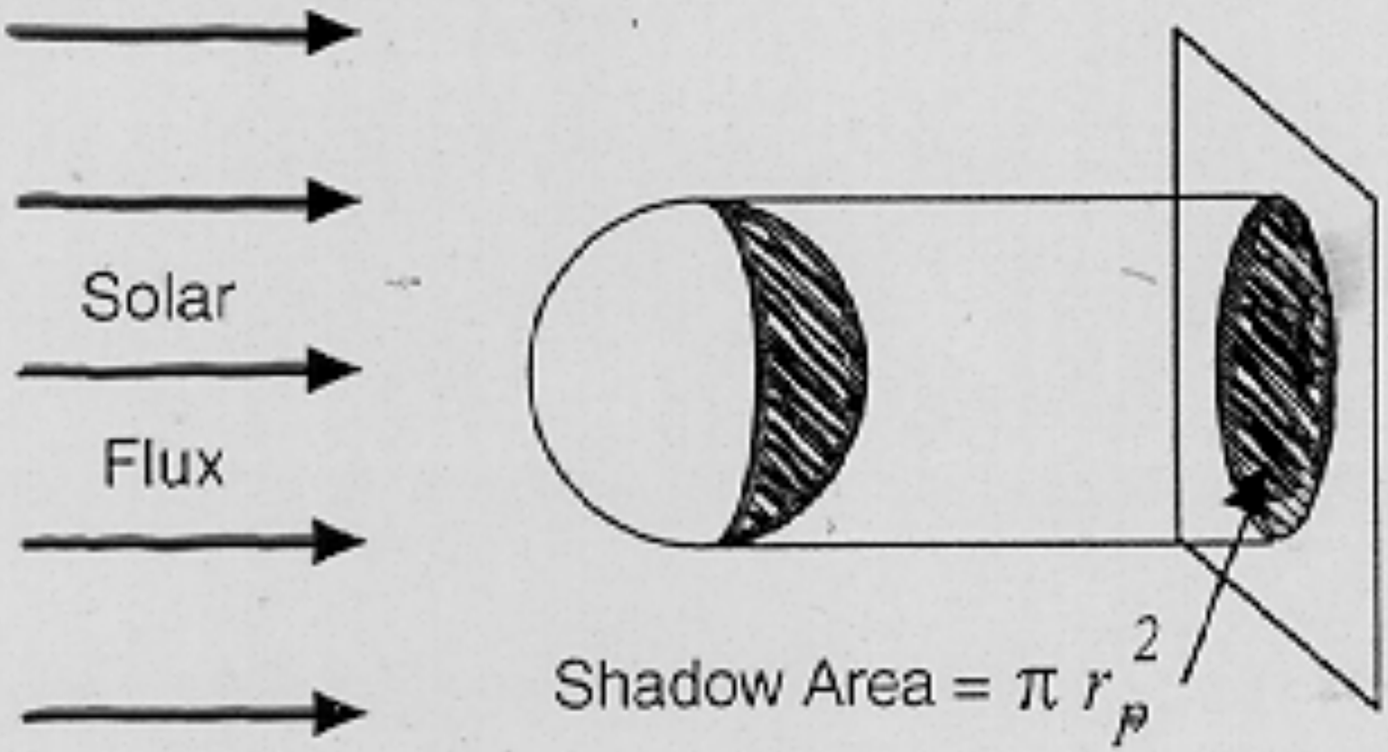


Fig. 2.2 Diagram showing the shadow area of a spherical planet.

First Law of Thermodynamics

- Energy cannot be created or destroyed
- If a system is at equilibrium, the amount of energy coming in must be equal to the amount of energy going out.

Total solar irradiance

- 1380 W m^{-2}
  - Incoming shortwave radiation
  - 30% reflected, 70% is absorbed

- $1380 \times 0.7 = 967$ Wm^{-2}
  - *Absorbed* incoming radiation
  - Must be matched by outgoing IR radiation

Lab 1: Earth's energy budget

Step 1: The energy emitted by the Sun

Step 2: The energy received by the Earth

Step 3: The energy absorbed by the Earth

Step 4: The energy emitted by the Earth.

Reading: Ahren's Text Pages 44 to 53 and Manual Lab 1

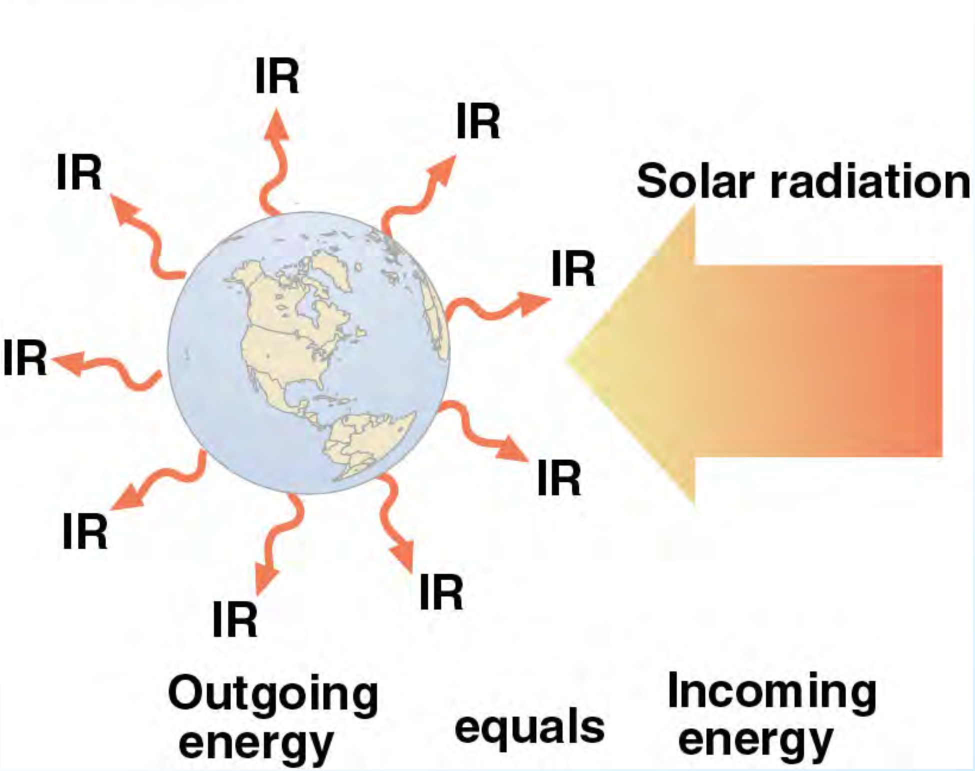
Incoming and Outgoing

- Incoming radiation
  - Intercepted on a circle

$$\text{area} = \pi r_e^2$$

- Outgoing radiation
  - Radiated over a sphere

$$\text{area} = 4\pi r_e^2$$



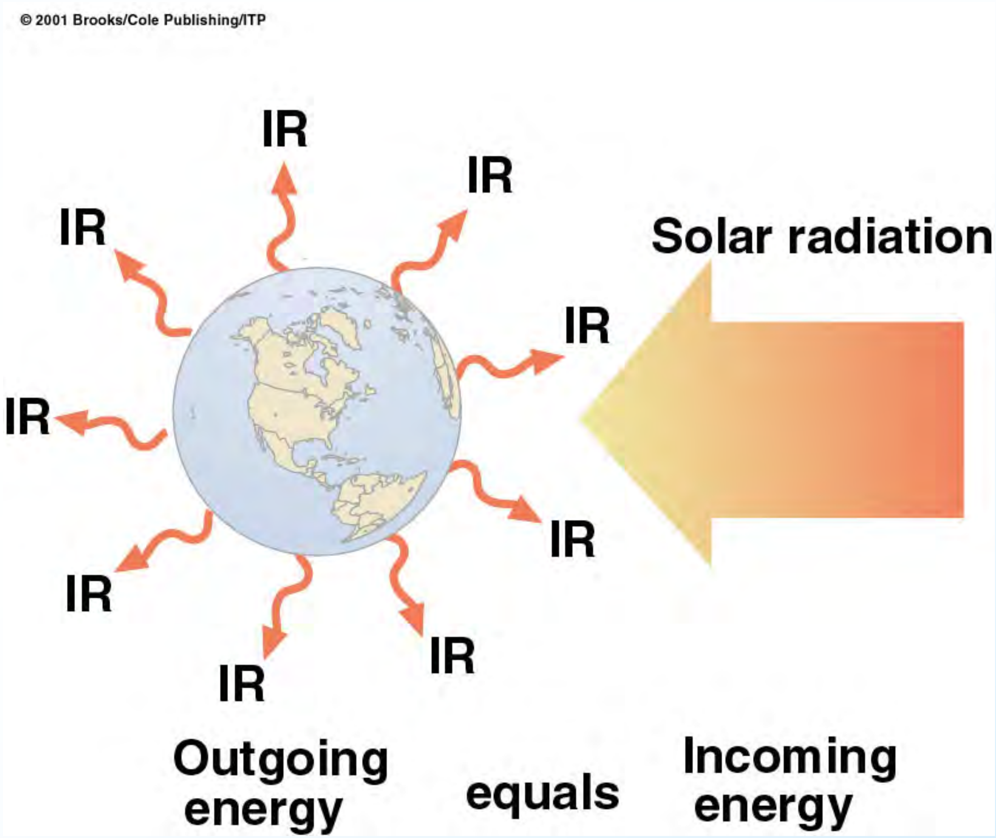
Energy Balance

Incoming = $967 \times \pi r_e^2$

Outgoing = $\sigma T_e^4 \times 4\pi r_e^2$
(Earth is a blackbody)

Therefore: $\sigma T_e^4 = 967/4$
$= 242\ \mathrm{Wm^{-2}}$

Solve to get $T_e = 255$ K



Radiative Equilibrium Temperature

- Longwave emission matches shortwave absorption
- If you measured the Earth's outgoing radiation from space, this would be the temperature you would calculate
- 255 K = -18°C ????

Exchange with the atmosphere

- Objects radiate in all directions
  - Earth and Sun radiate outward from all around their spherical surface
  - Atmosphere is a hollow sphere; radiates both out (up) and in (down)

- There is an exchange of radiation between Earth and atmosphere

  i.e. the Greenhouse Effect

Greenhouse calculation

- Model the atmosphere as one thin layer that:
  - Absorbs 10% of the incoming solar radiation
  - Absorbs 80% of the outgoing terrestrial radiation
- For the entire sphere, let:
  - x be the radiation emitted from the surface,
  - y be the radiation emitted from the atmosphere, and
  - I be non-reflected radiation entering the top of the atmosphere from the Sun.

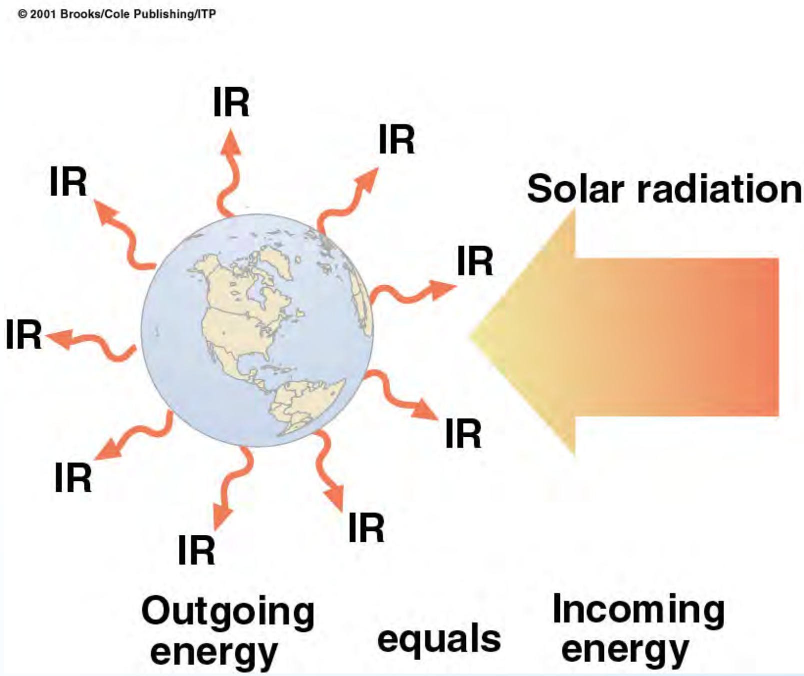
I: *non-reflected incoming radiation*

Total solar irradiance

S = 1380 W m^{-2}

The average albedo A = 0.3

Ratio of area of absorption (circle) to area of emission (sphere) is 1/4



$I = S(1-A)/4 = 967/4 = 242$ Wm^{-2}

Greenhouse calculation

What do we know about x and y?

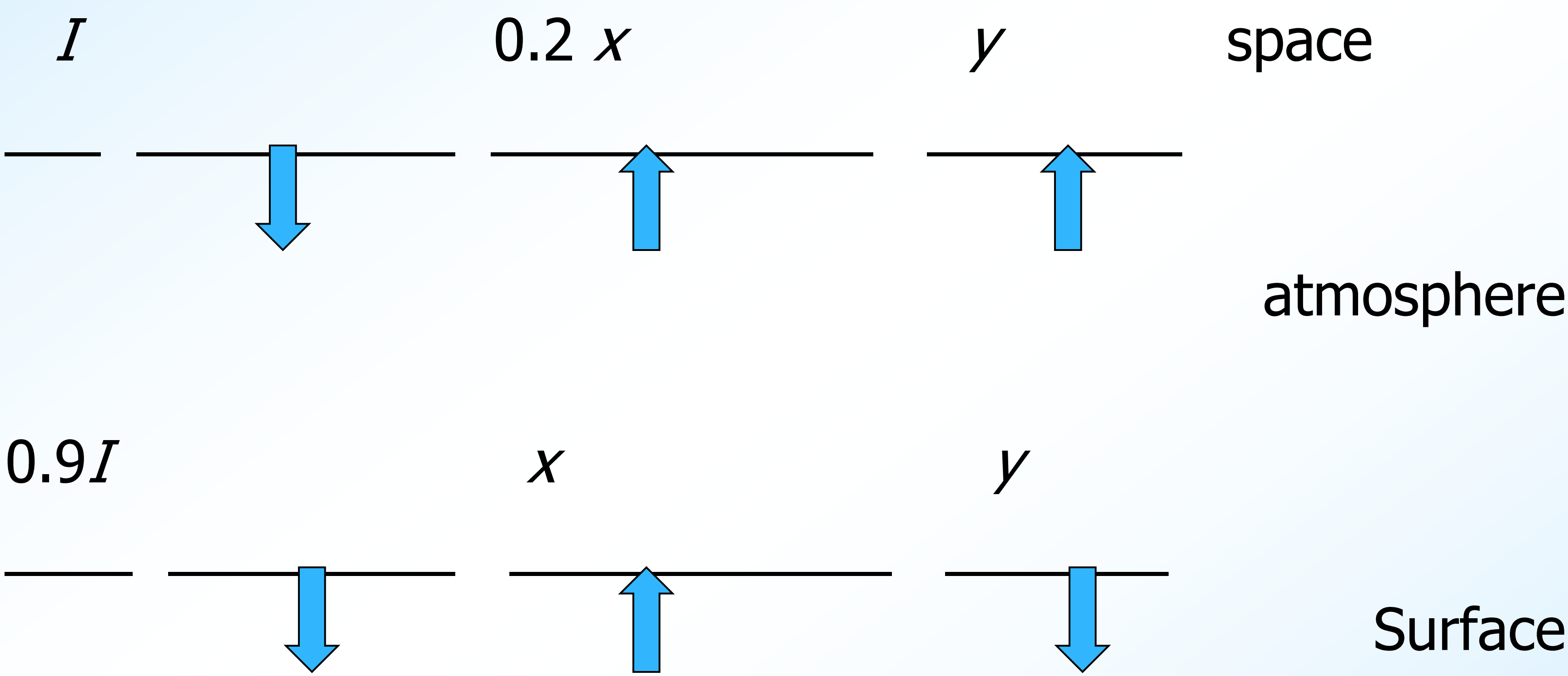
Stefan-Boltzmann law:

$x = \sigma T_s^4$

$y = \varepsilon\sigma T_a^4 = 0.8\ \sigma T_a^4$

Why 0.8? Kirchhoff's law: $\varepsilon_\lambda = a_\lambda$

Greenhouse model



Atmosphere allows 20% of longwave radiation through, and 90% of shortwave radiation through

Greenhouse calculation

Balance for each level

Space: $I = 0.2x + y$

Surface: $0.9I = x - y$

Two equations, two unknowns

Greenhouse gas calculation

- Solve for *x* and *y*

$$1.9I = 1.2x$$

$$x = \frac{1.9}{1.2}I = 382.8\ \mathrm{Wm}^{-2}$$

$$y = I - 0.2x = 165.2\ \mathrm{Wm}^{-2}$$

Greenhouse calculation

We now have:

$x = \sigma T_s^4 = 382.8\ \text{Wm}^{-2}$

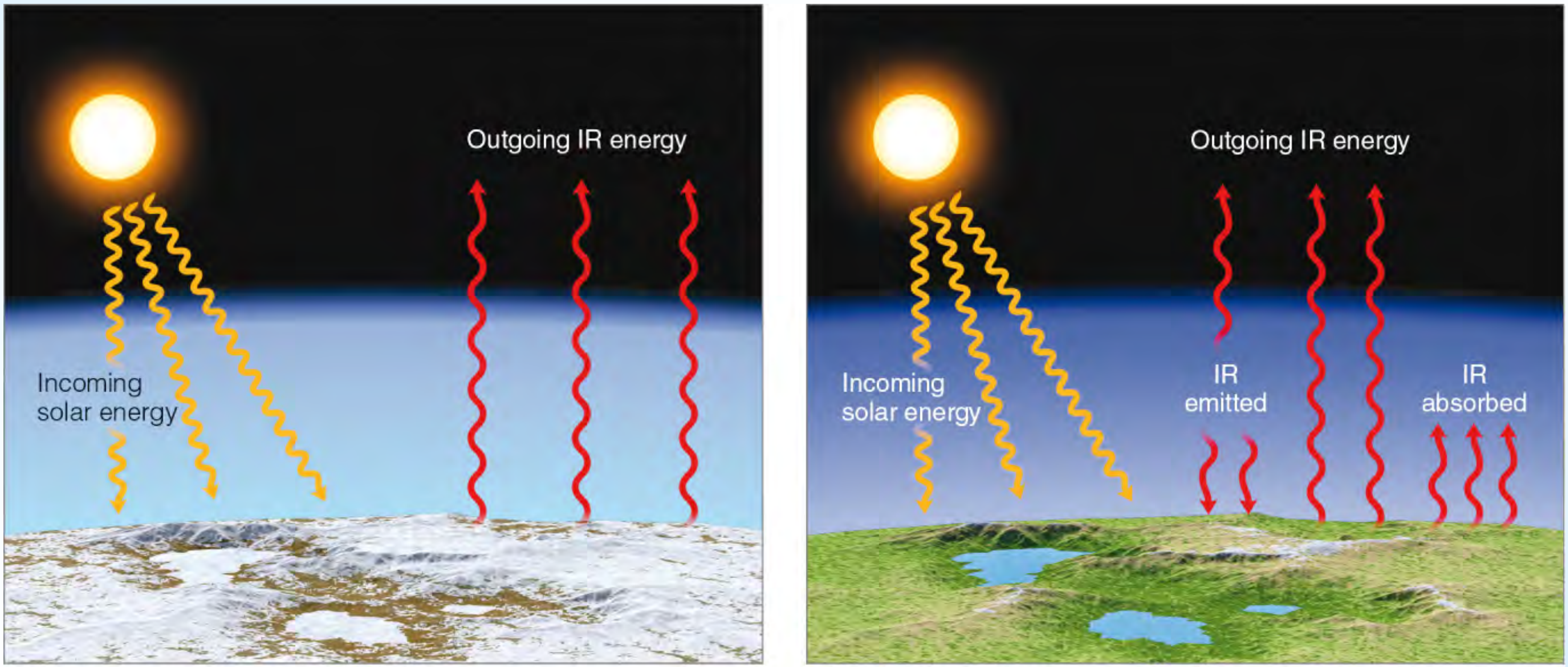
$y = 0.8\sigma T_a^4 = 165.2\ \text{Wm}^{-2}$

Therefore:

$T_s = 287$ K, $T_a = 246$ K

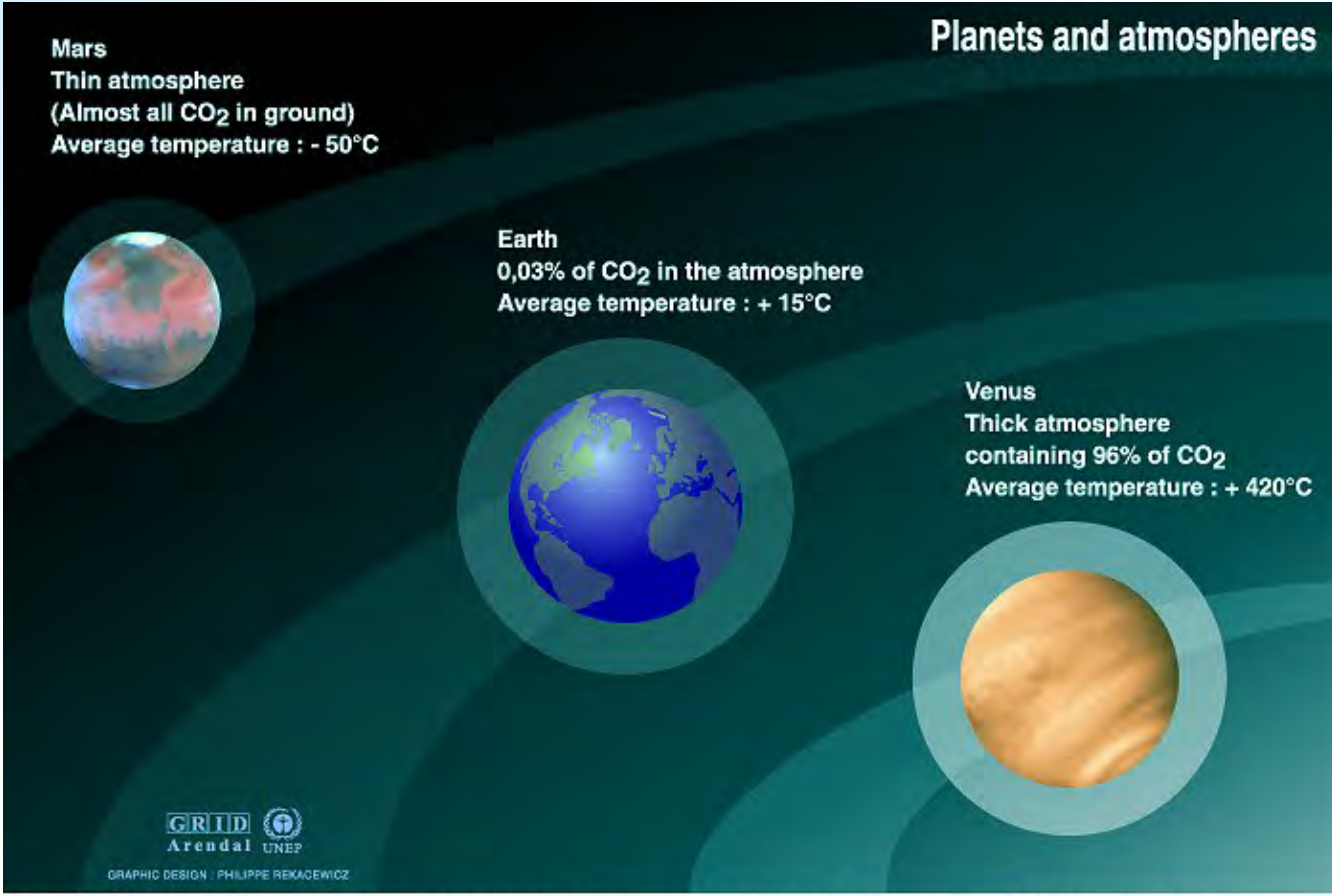
Note: Surface temperature is higher than 255 K calculated without atmosphere i.e. 288 K

The Greenhouse Effect



255 K 288 K

Ahrens, Fig. 2.12



Sources: Calvin J. Hamilton, Views of the solar system, www.planetscapes.com; Bill Arnett , The nine planets, a multimedia tour of the solar system, www.seds.org/billa/tnp/nineplanets.html

Early history of research into the greenhouse effect

- In the 1820s, **Joseph Fourier** calculated that the Earth at its distance from the Sun should be considerably colder if warmed by only solar radiation.
- Irish chemist **John Tyndall** demonstrated in a laboratory experiment in 1861 that carbon dioxide and water vapour intercepted energy in the form of heat
- Swedish chemist **Svante Arrhenius** in 1896 did the first calculations of how much the world would warm if the content of carbon dioxide in the atmosphere was increased. Doubling the amount of carbon dioxide (2 x CO_2) in the atmosphere would increase the Earth's average temperature by 3 to 4° C.

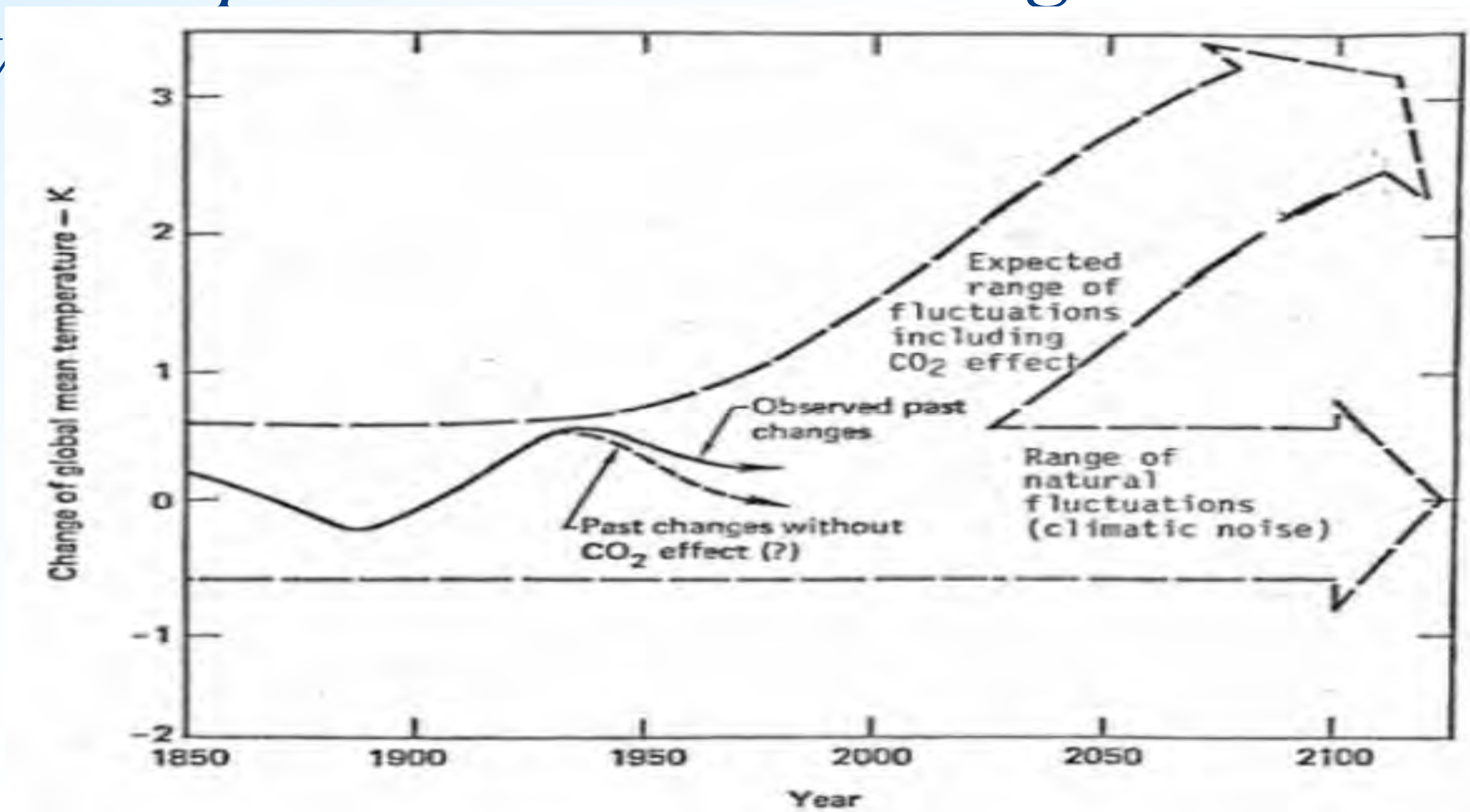
When did global warming/climate change cease being merely a computer simulation?

- In 1956 the Canadian physicist Gilbert Plass reconfirmed the effect of increasing carbon dioxide on global temperatures in “'The Carbon Dioxide Theory of Climatic Change” http://onlinelibrary.wiley.com/doi/10.1111/j.2153-3490.1956.tb01206.x/abstract

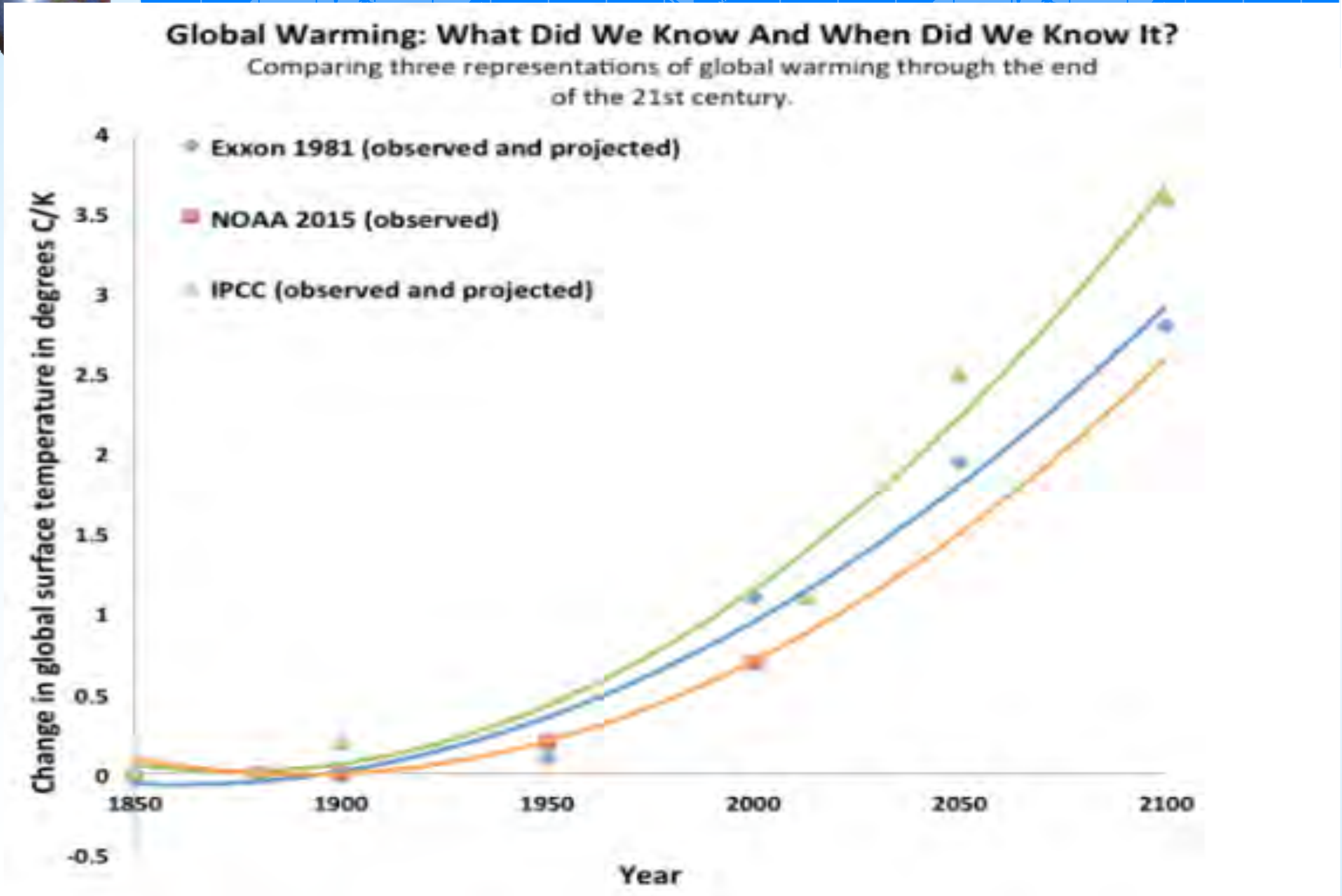
When did global warming/climate change cease being merely a computer simulation?

- In a book published by the Massachusetts Institute of Technology in 1970, “Man's impact on the global environment”, a group of eminent atmospheric scientists predicted that increases in carbon dioxide would lead to warming of about 0.5º C by the year 2000 (the world warmed by 0.45º C).

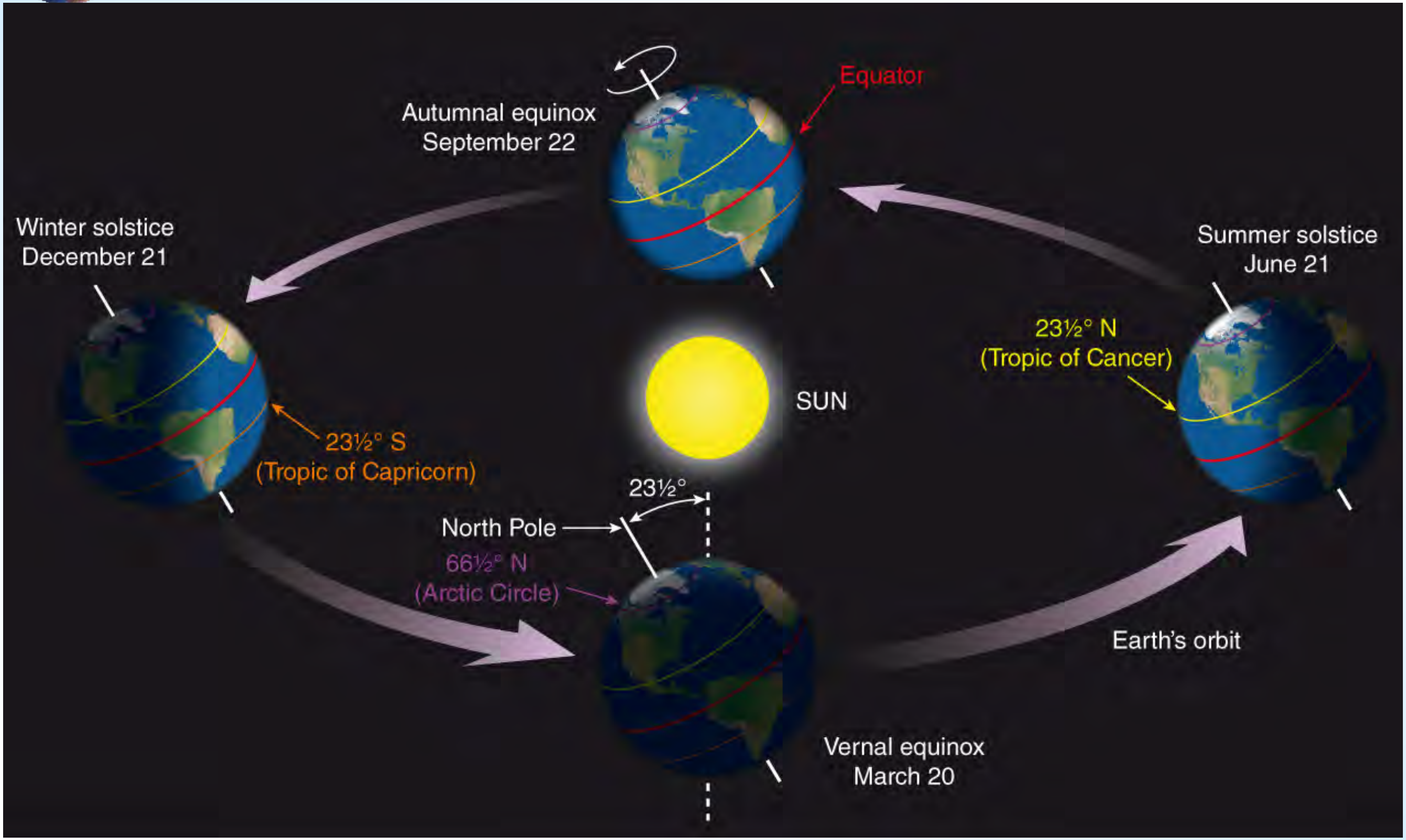
Anthrophonic Climate Change
W



Graph from Exxon documents in 1981



Global Warming: What Did We Know And When Did We Know It?
Comparing three representations of global warming through the end of the 21st century.
Exxon 1981 (observed and projected)
NOAA 2015 (observed)
IPCC (observed and projected)
Change in global surface temperature in degrees C/K
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
1850
1900
1950
2000
2050
2100
Year



Ahrens: Fig. 3.3

Equinoxes

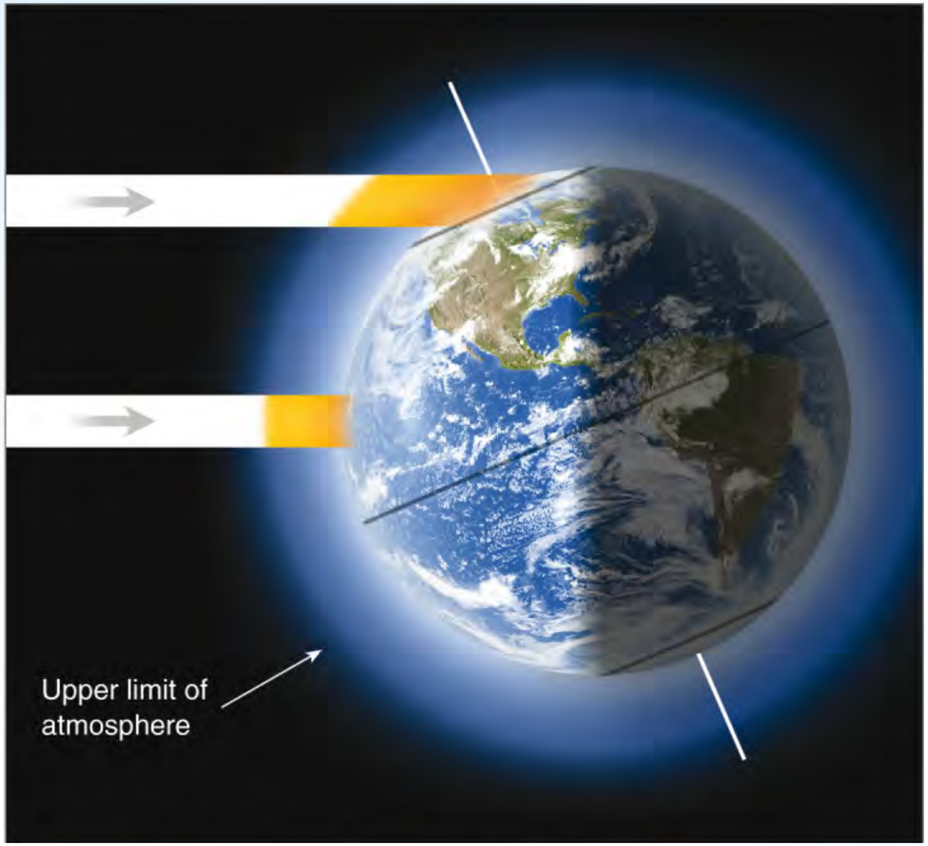
- March (Vernal) Equinox
  - On or about March 20
- September (Autumnal) Equinox
  - September 23

- The sun is visible for 12 hours everywhere

Solstices

- One hemisphere axis of rotation is pointed toward the Sun; the other is pointed away
- The hemisphere pointed toward the Sun receives its maximum insolation on this date
- Astronomically, these dates designate the first day of winter or summer

Axial tilt: beam spreading



Ahrens: Fig. 3.9

- A beam of sunlight spread over a large area is less intense
- Higher latitudes receive less solar energy per unit area
- As well - beam passes through more air

- Beam depletion
  - Solar radiation is diminished relative to the *amount* of atmosphere the radiation passes through (distance through the air)
  - Significant beam reduction occurs at low solar angles
- Period of Daylight
  - Axial tilt influences day length
  - Days are longer in summer and shorter in winter
  - Effect is more pronounced at high latitudes

Table 3.1 Length of Time from Sunrise to Sunset for Various Latitudes on Different Dates in the Northern Hemisphere

Latitude	March 20	June 21	September 22	December 21
0°	12 hr	12.0 hr	12 hr	12.0 hr
10°	12 hr	12.6 hr	12 hr	11.4 hr
20°	12 hr	13.2 hr	12 hr	10.8 hr
30°	12 hr	13.9 hr	12 hr	10.1 hr
40°	12 hr	14.9 hr	12 hr	9.1 hr
50°	12 hr	16.3 hr	12 hr	7.7 hr
60°	12 hr	18.4 hr	12 hr	5.6 hr
70°	12 hr	2 months	12 hr	0 hr
80°	12 hr	4 months	12 hr	0 hr
90°	12 hr*	6 months	12 hr*	0 hr

*The sun rises on March 20 and sets on September 20.

Ahrens: Table 3.1

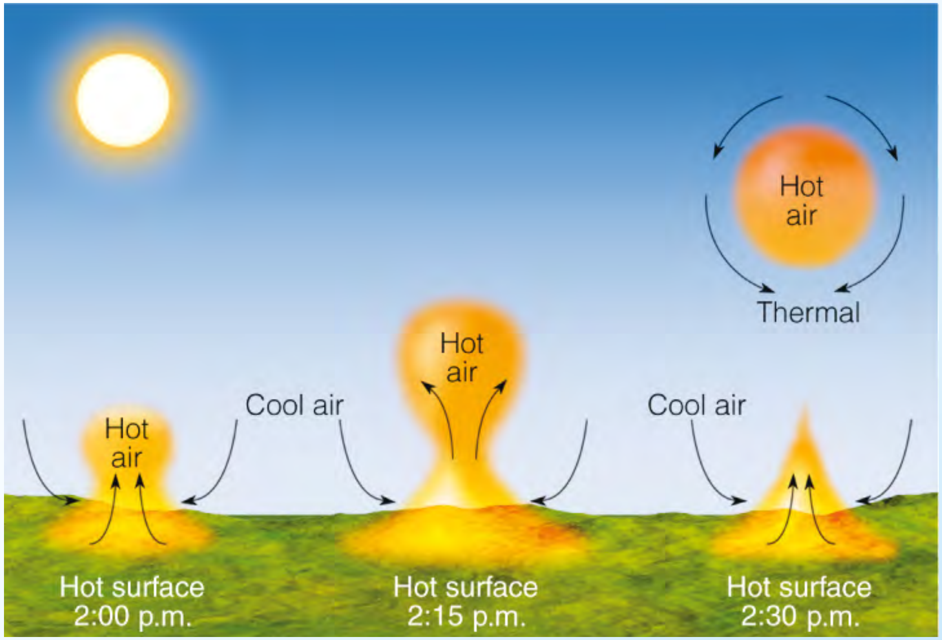
Table 2–2 Variations in Solar Angle and Daylength

	Solar Angle at Noon	Length of Day	Total Radiation for Day (Megajoules/m^2)
December 21			
Winnipeg	25.5°	8 hr, 34 min	7.44
Austin	45.5°	10 hr, 04 min	12.18
June 21			
Winnipeg	63.5°	16 hr, 10 min	37.15
Austin	83.5°	13 hr, 56 min	35.97

A&B: Table 2-2

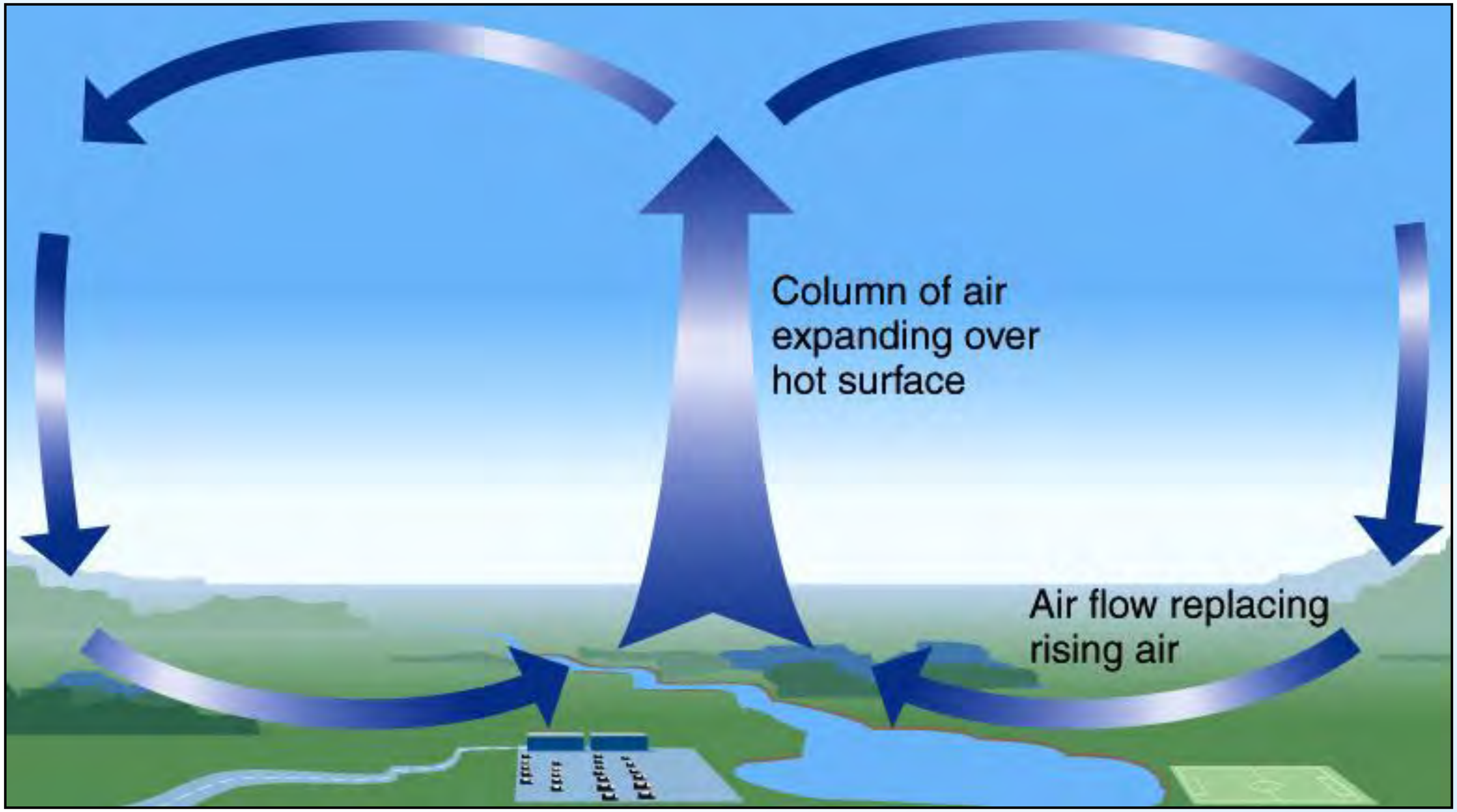
Convection

- Conduction: direct heat exchange
  - Warm air becomes less dense
- Convection:
  - Rising air carries heat away from the surface



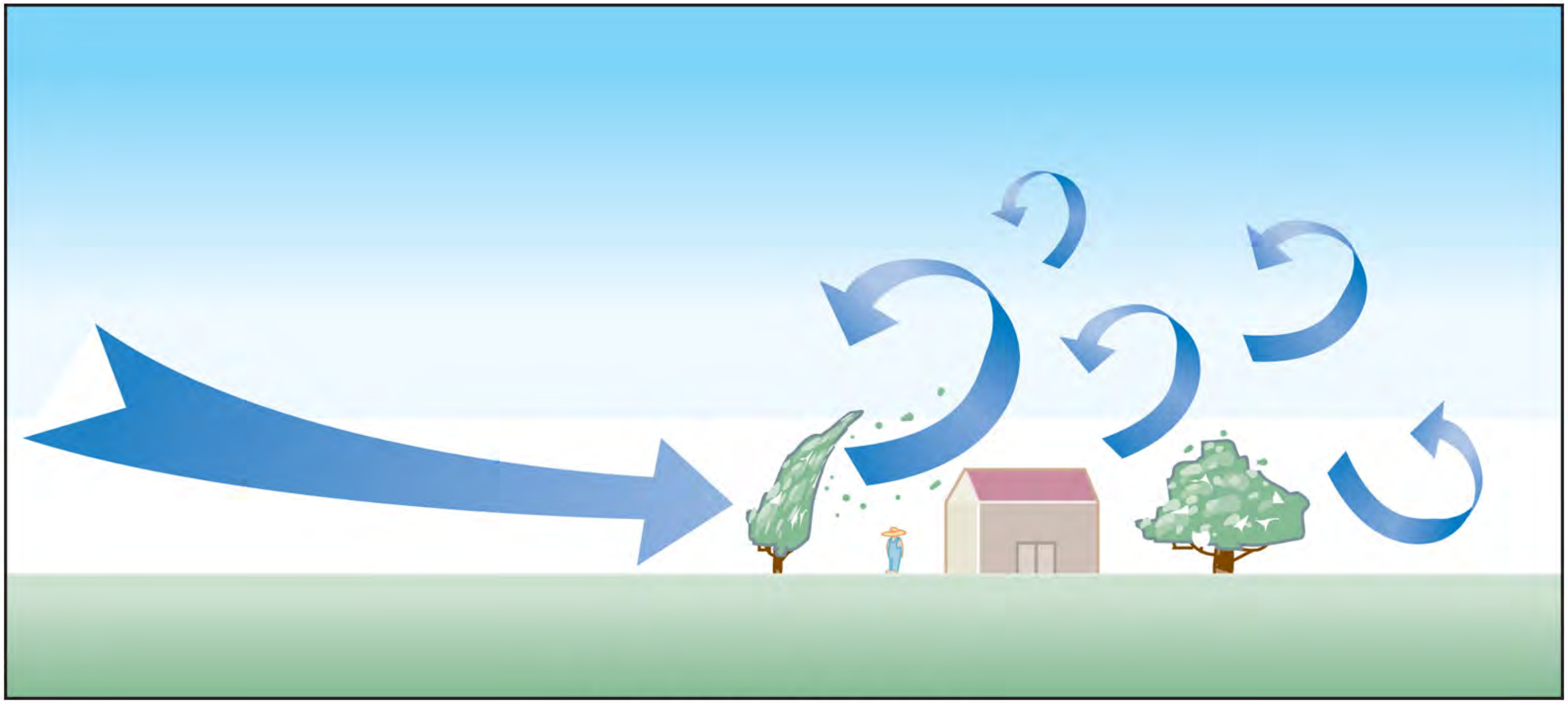
Ahrens: Fig. 2.4

Free Convection



A&B: Figure 3-12

Forced Convection

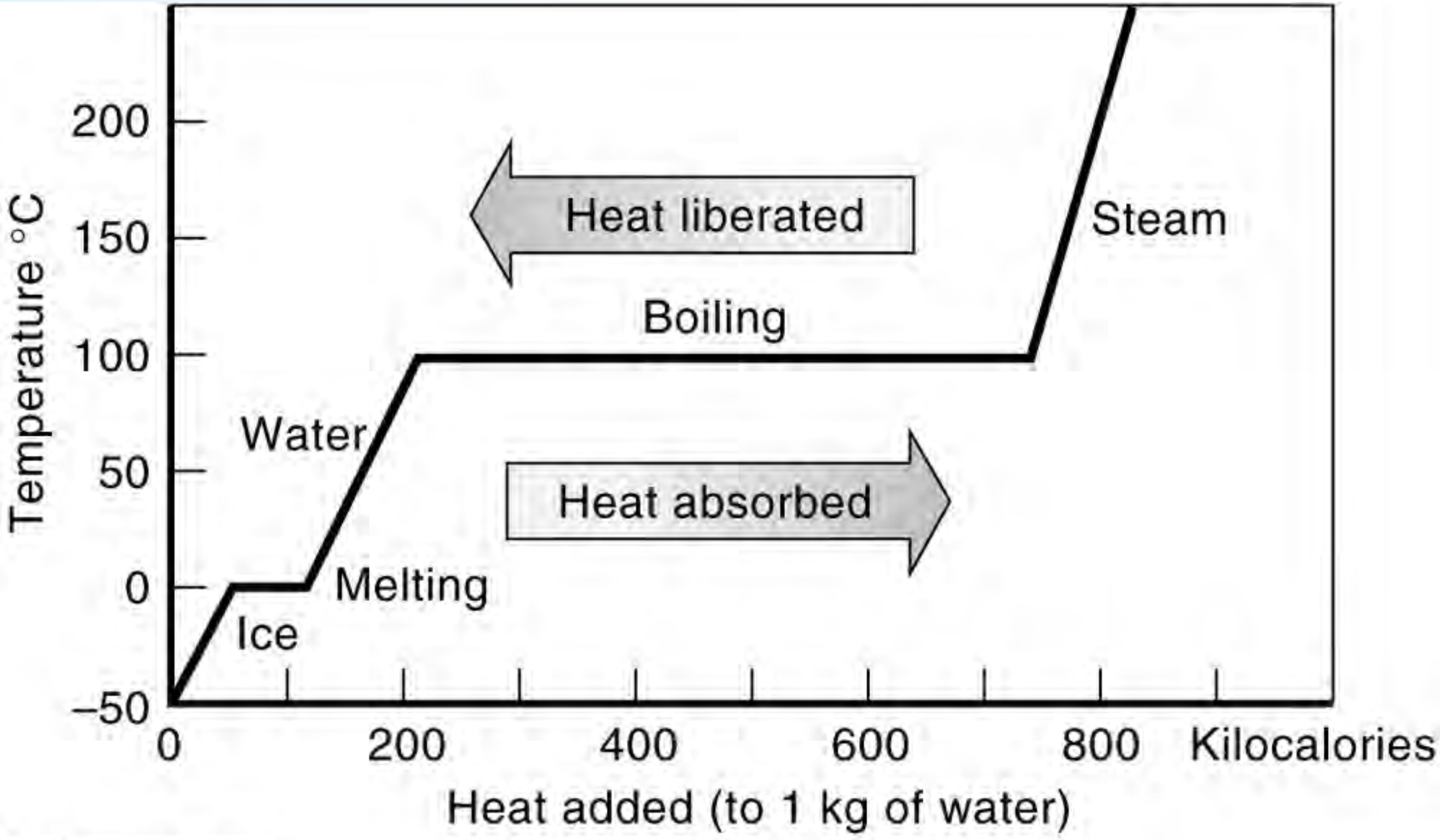


A&B: Figure 3-13

Latent heat

- Energy required to change the state of a substance
  - Liquid to gas: heat of evaporation
  - Solid to liquid: heat of fusion
- Heat is ‘hidden’
  - No change in temperature

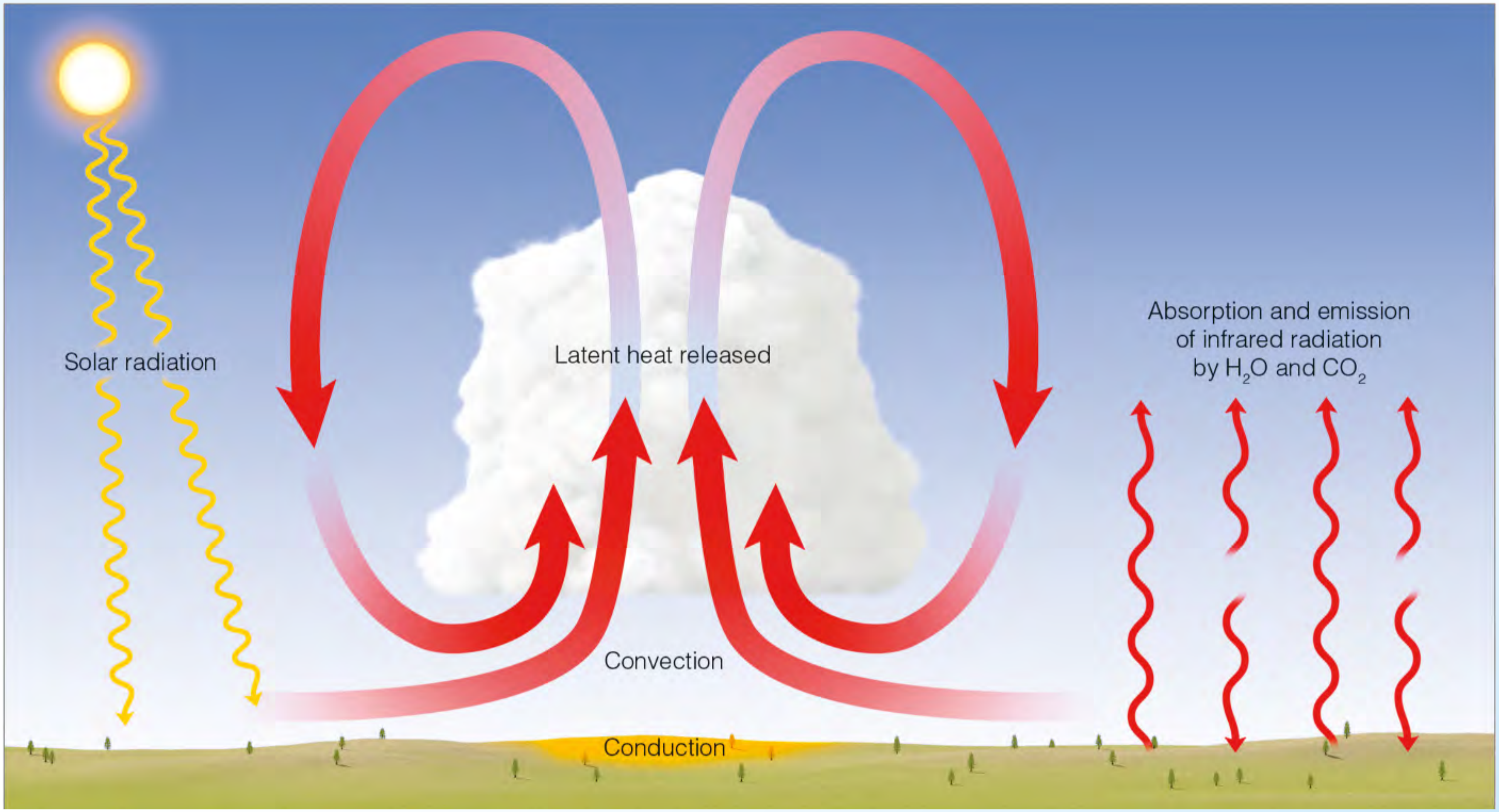
Thermal Storage and phase change



Latent heat

- Liquid to gas
  - Absorbs heat (at the surface)
- Gas to liquid
  - Releases heat (in the atmosphere)

Radiative, convective and latent transfers



Next lecture

- Temperature distribution
  - Not uniform in time and place
- Ahrens: Chapter 3