Part 1. Energy and Mass

Chapter 3.

Energy Balance and Temperature

Introduction

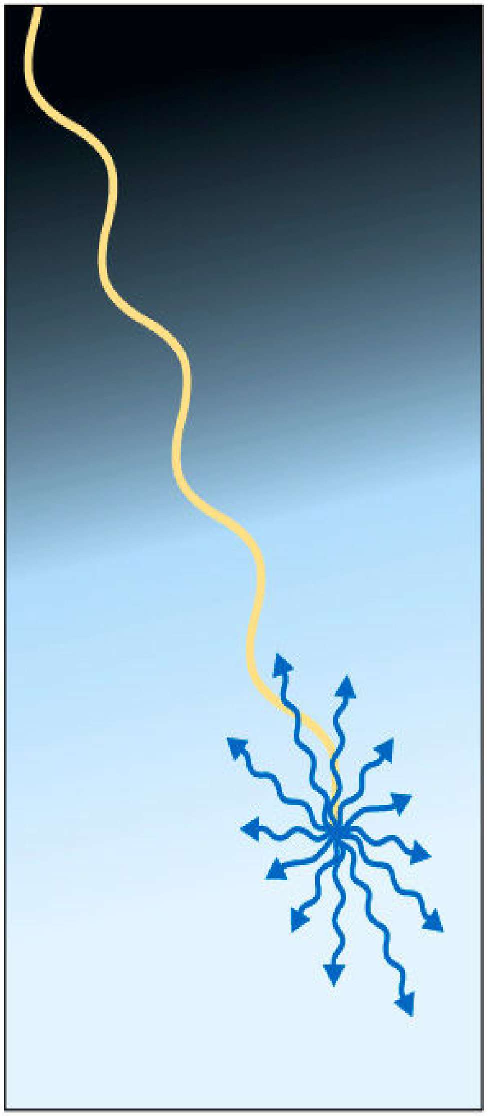
- Solar radiation is the atmosphere's heat source
- Most gases are transparent to solar radiation
  - They do absorb terrestrial radiation
- Gases also scatter energy
- The global energy budget
  - A balance between incoming solar radiation and outgoing terrestrial radiation

- Atmospheric Influences on Insolation
  - Radiant energy is *absorbed*, *reflected*, or *transmitted* (scattered)
- Absorption
  - Particular gases, liquids, and solids absorb energy
  - Heat increases
  - Gases are poor selective absorbers of energy

- Reflection
  - Redirection of energy
    - Does not increase heat
  - *Albedo* = percentage of reflected energy
- Scattering
  - Scattered energy diffuses radiation
    - Reduces intensity
    - Type determined by size of scattering agents

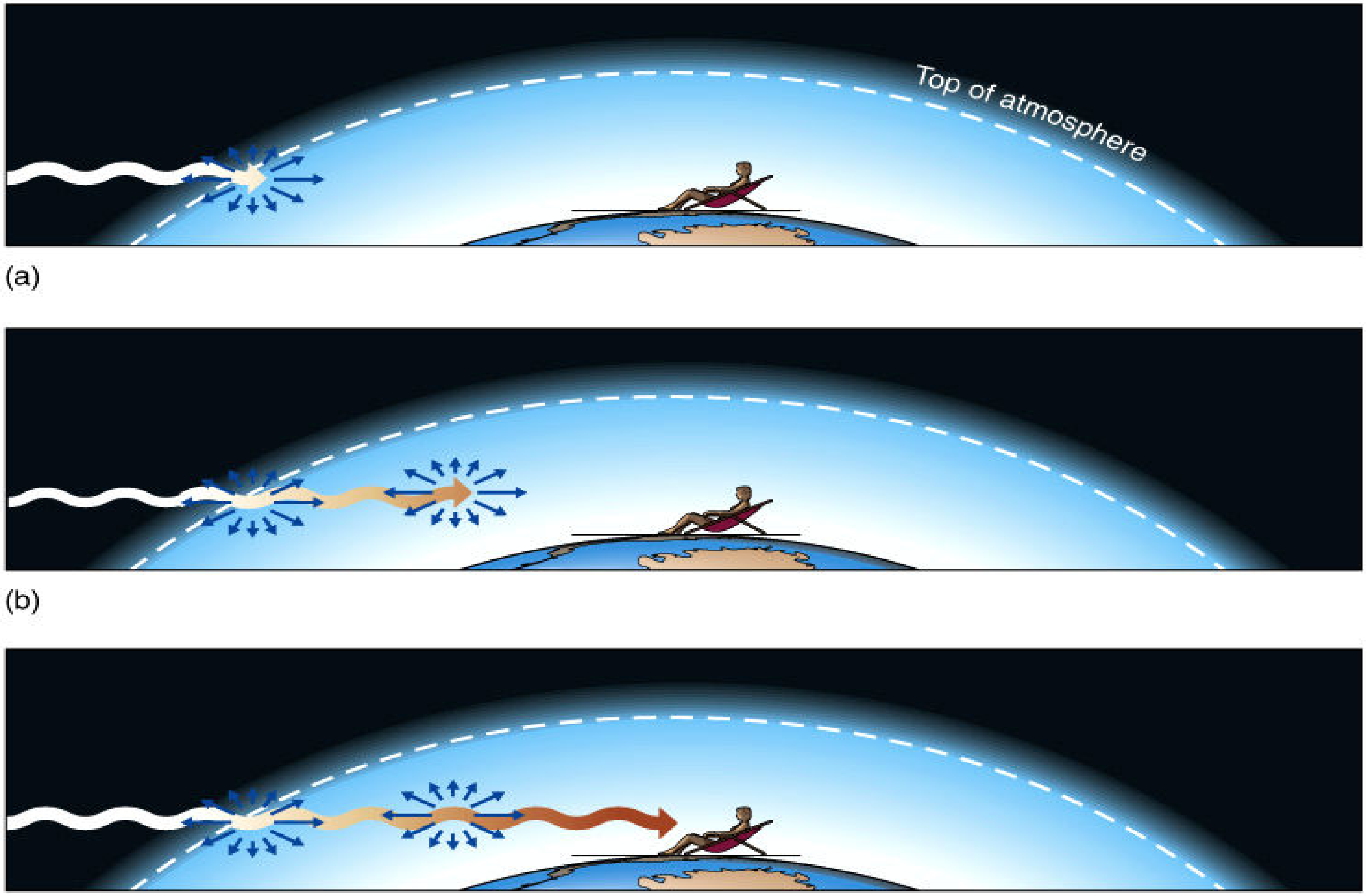
- Rayleigh Scattering
  - Scattering agents are smaller than energy wavelengths
    - Forward and backward scattering
  - Partial to shorter wavelengths
    - Causes blue sky

Rayleigh Scattering

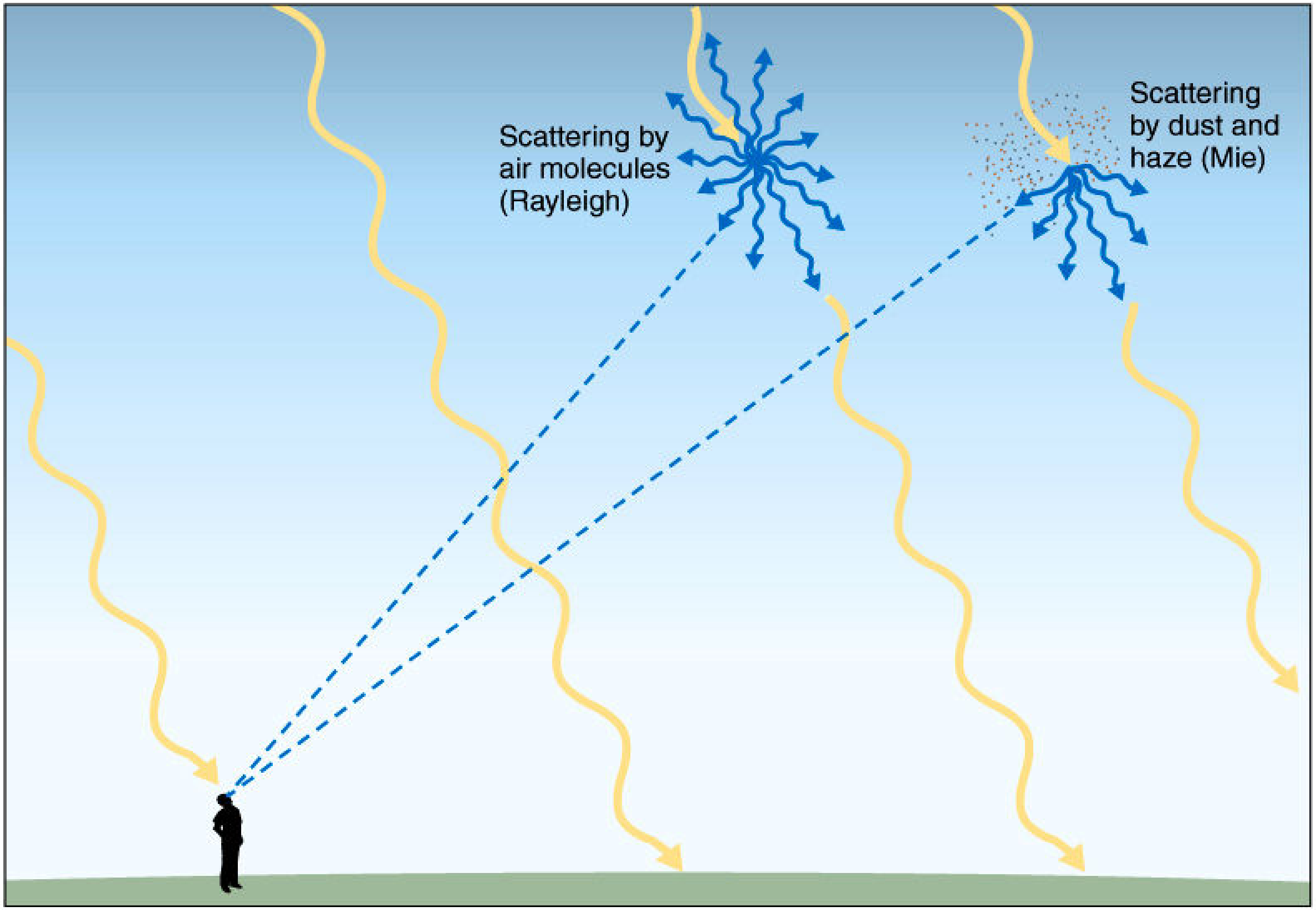


- Mie Scattering
  - Larger scattering agents (aerosols)
  - Interacts with wavelengths across visible spectrum
    - Hazy, grayish skies
    - Sunrise/sunset color enhancement

Longer radiation path lengths = greater Mie Scattering and reddish skies



(a) (b) (c)

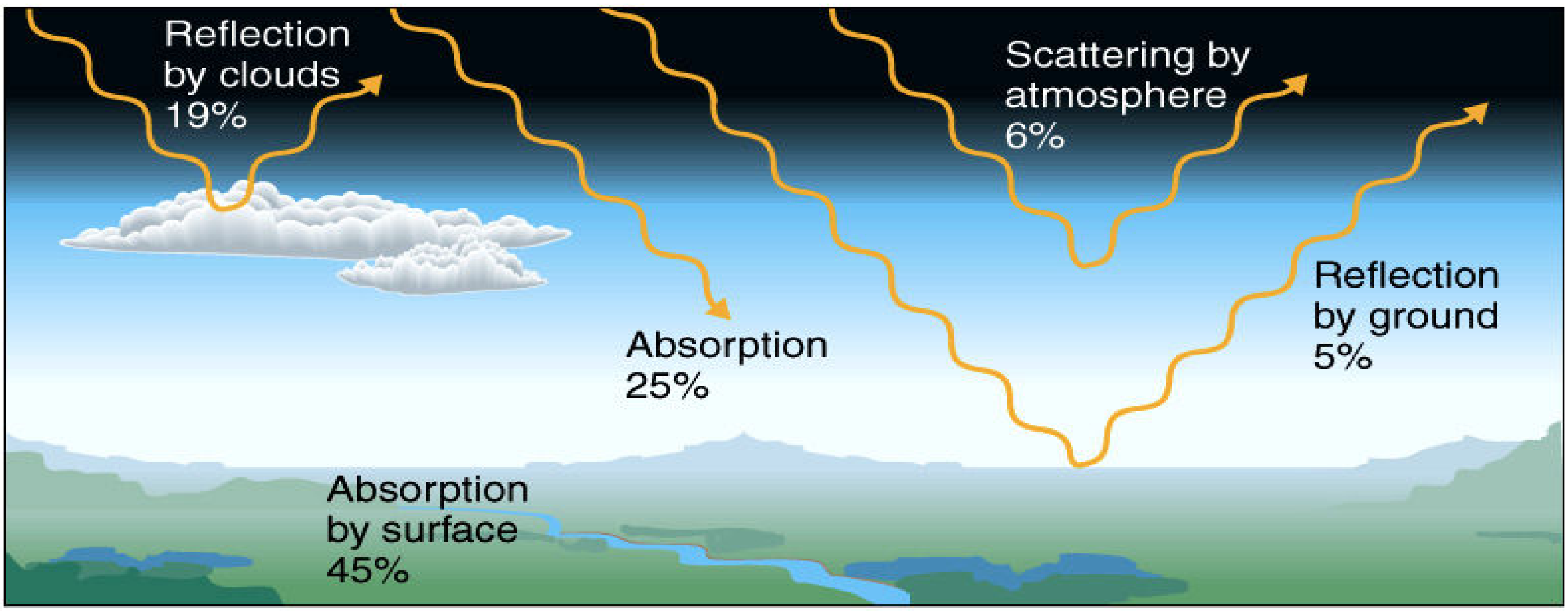

Scattering by air molecules (Rayleigh)
Scattering by dust and haze (Mie)

- Nonselective Scattering
  - Very large scattering agents (water)
  - Scatter across the visible spectrum
    - White or gray appearance
  - No wavelength especially affected
- Transmission
  - Energy transmitted through objects
    - Varies diurnally from place to place

- The Fate of Solar Radiation
  - A constant supply of radiation at top of the atmosphere
  - Entering energy is transmitted, absorbed, or scattered
- A Global Energy Budget
  - Assumes global annual insolation = 100 units
  - Atmosphere absorbs 25 units
    - 7 units absorbed by stratospheric ozone

- Reflection = 25 units
  - 19 reflected to space by clouds
  - 6 units back-scattered to space
- Remaining 50 units are available for surface absorption

Incoming Radiation

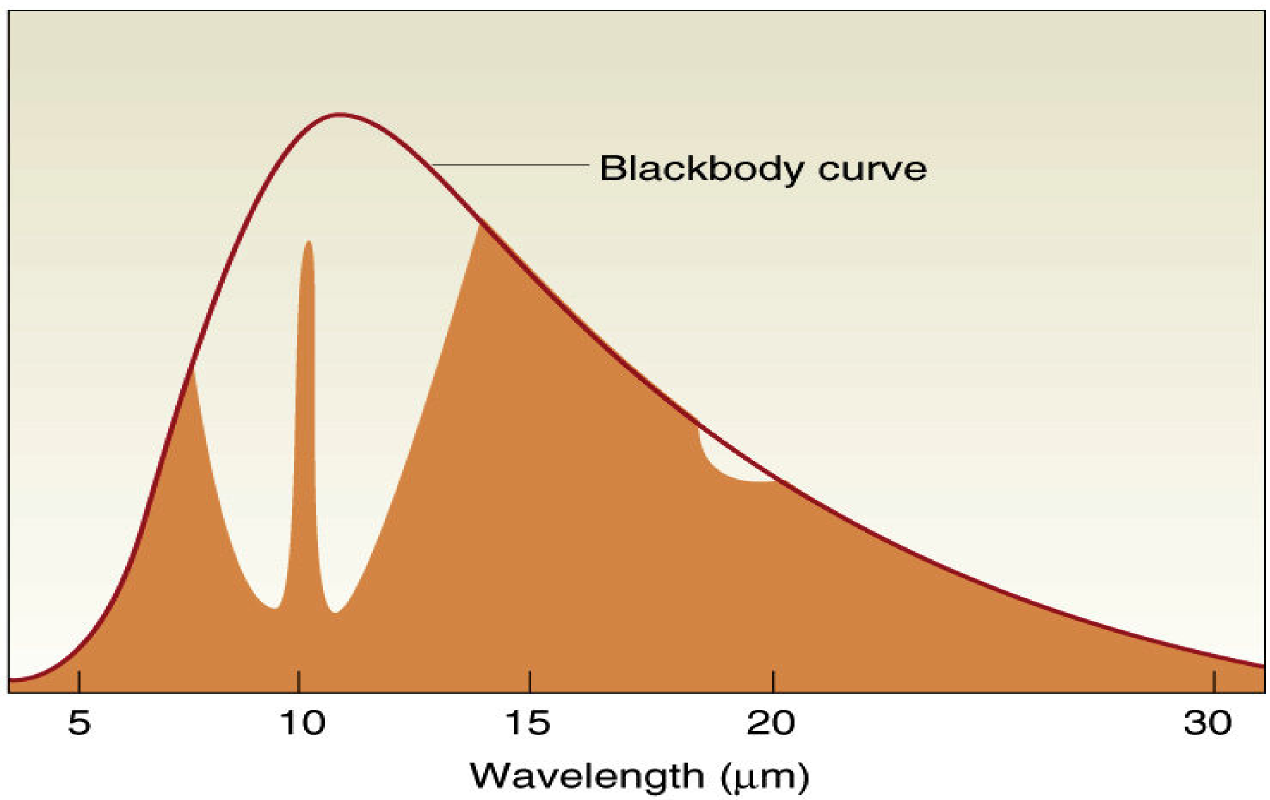


- 50 Units of Surface Energy
  - 5 reflected back to space
  - Remaining 45 absorbed at surface
    - Heats surface and overlying air

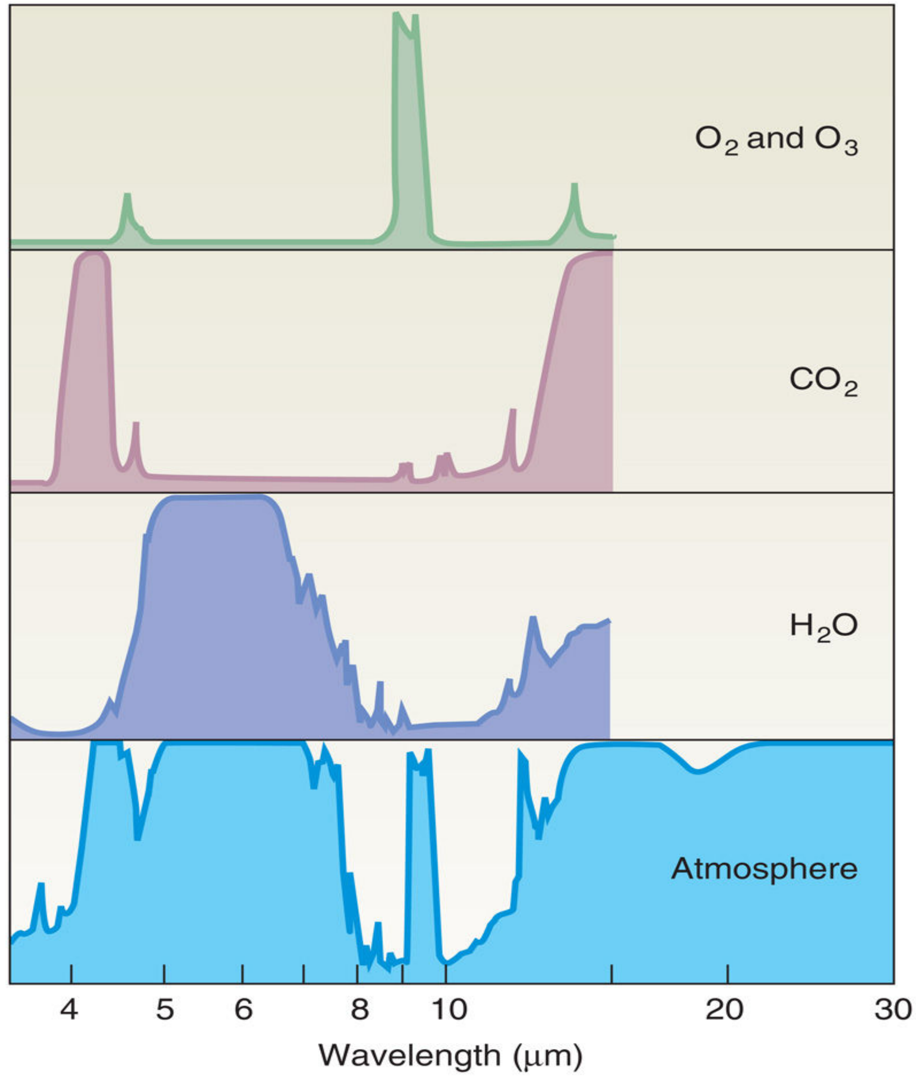
- Surface-Atmosphere Radiation Exchange
  - Surface emission (*terrestrial/longwave radiation*)
    - Much is absorbed by atmospheric gases
      - H_2O and CO_2
    - Increases air temperature
  - Some energy is reabsorbed at the surface
    - Additional surface heating

- *Greenhouse gases* absorb terrestrial radiation
- The *atmospheric window* - non-absorption of wavelengths between 8-15 *μm*

The atmospheric window

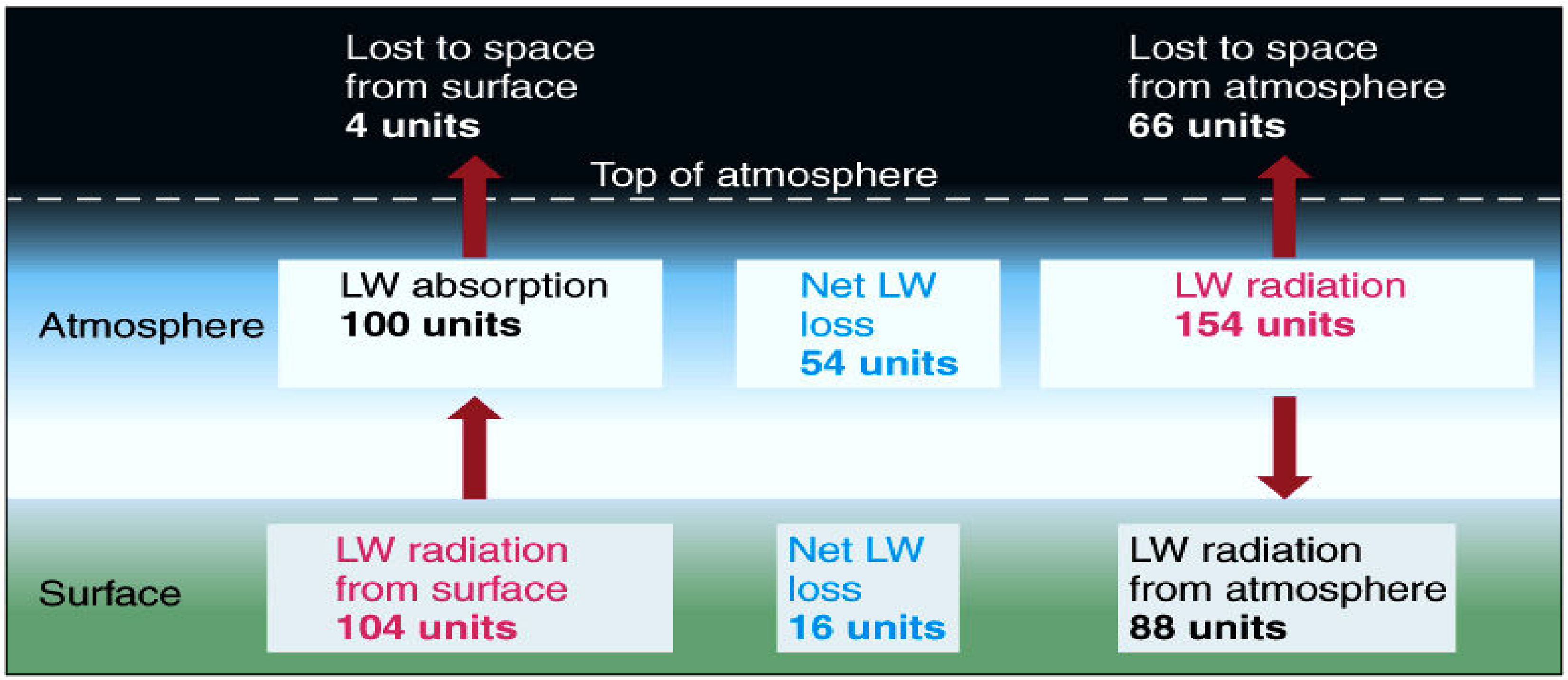


The atmospheric window



(b)

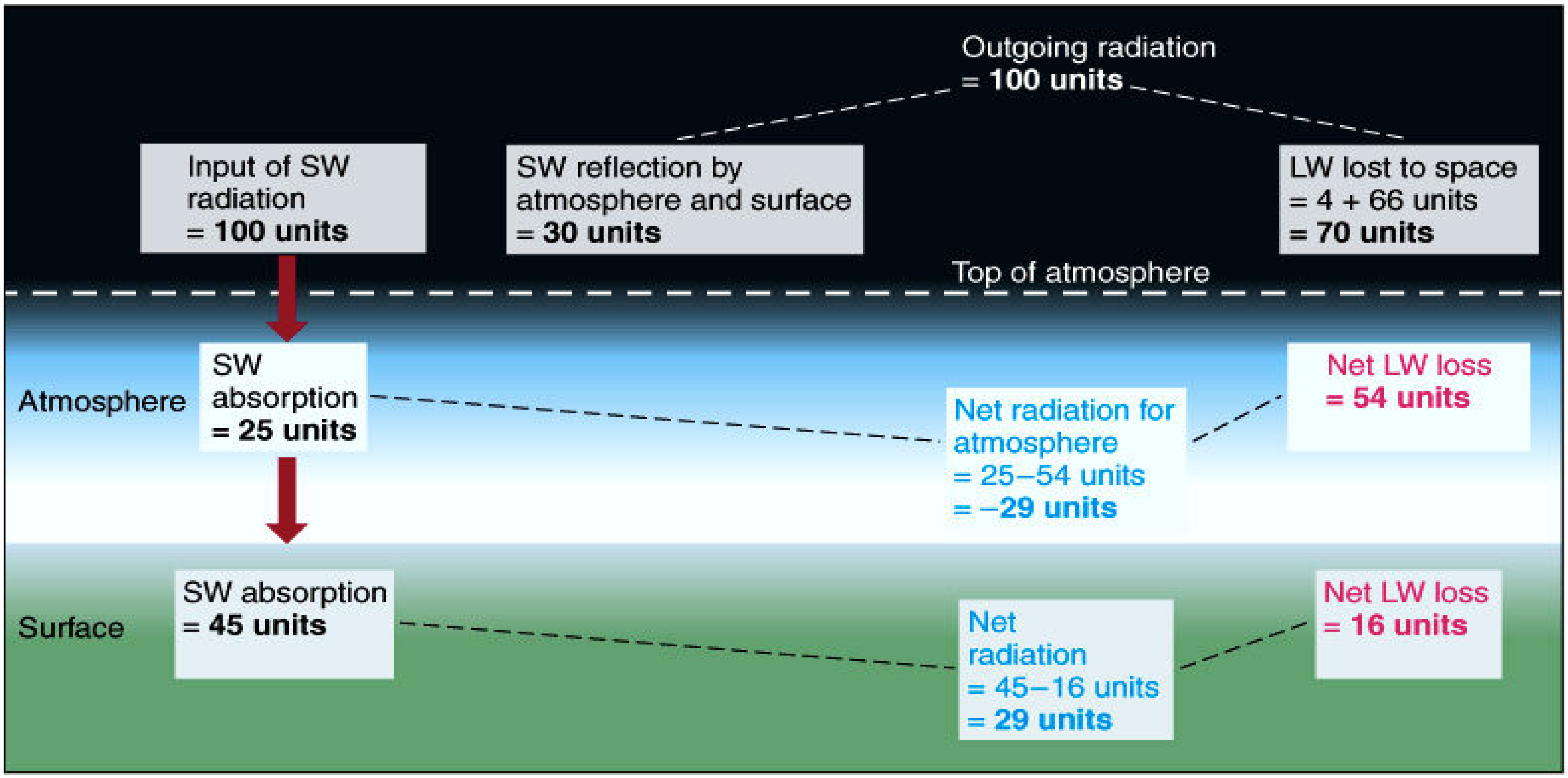
- Clouds absorb virtually all longwave radiation
  - Results in warmer cloudy nights



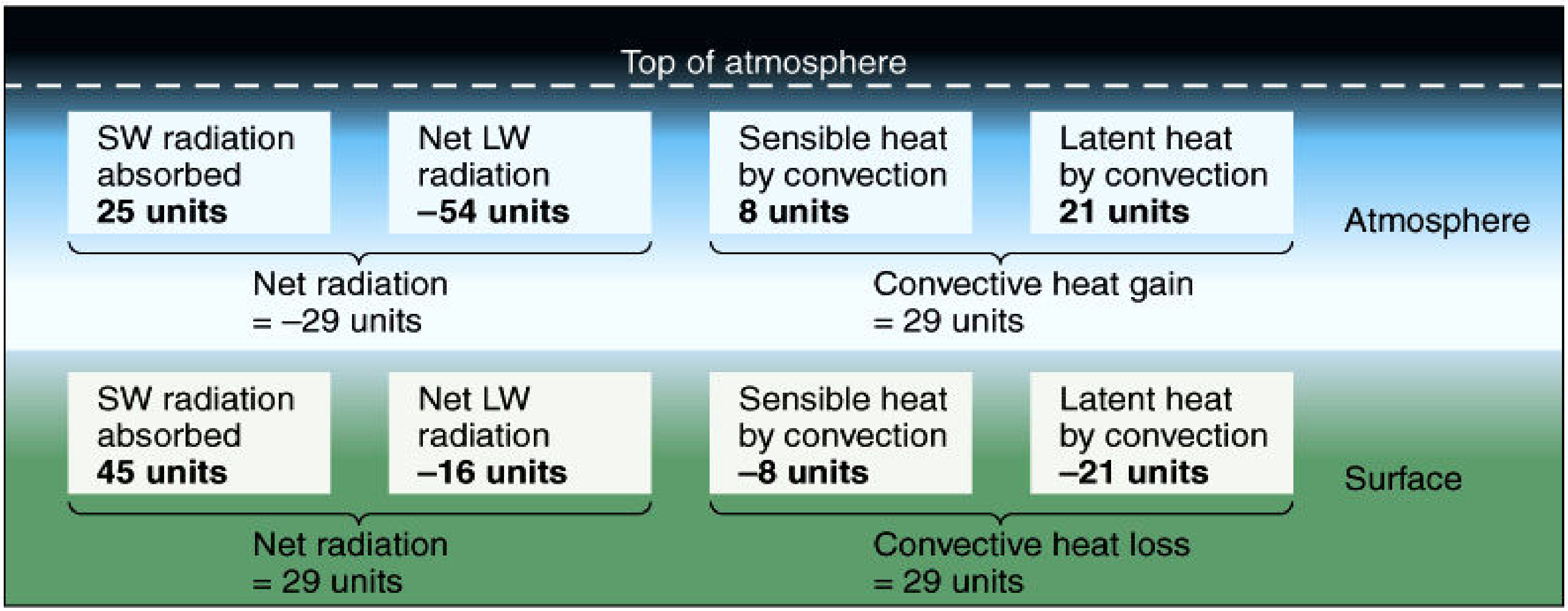
- *Net radiation* = difference between absorbed and emitted radiation
  - The atmosphere absorbs 25 units of solar radiation but undergoes a net loss of 54 units
    - net deficit = 29 units
  - The surface absorbs 45 units of solar radiation but has a longwave deficit of 16
    - net surplus = 29 units
- Net radiation deficit equals net surplus

    - Energy is transferred from the surface to the atmosphere
    - The surplus and deficits offset
- Conduction
    - Energy transferred to the *laminar boundary* layer

Net radiation

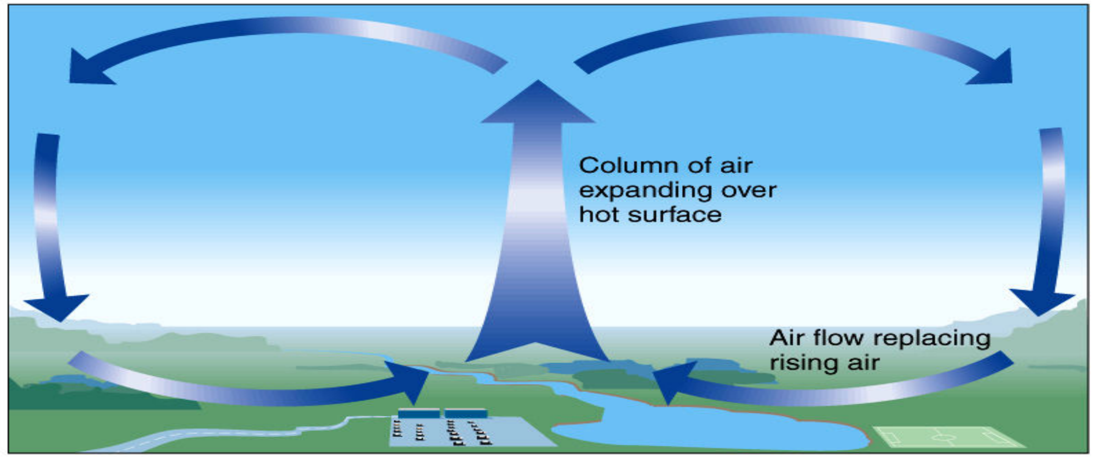


Energy surplus/deficit offsets between air and surface

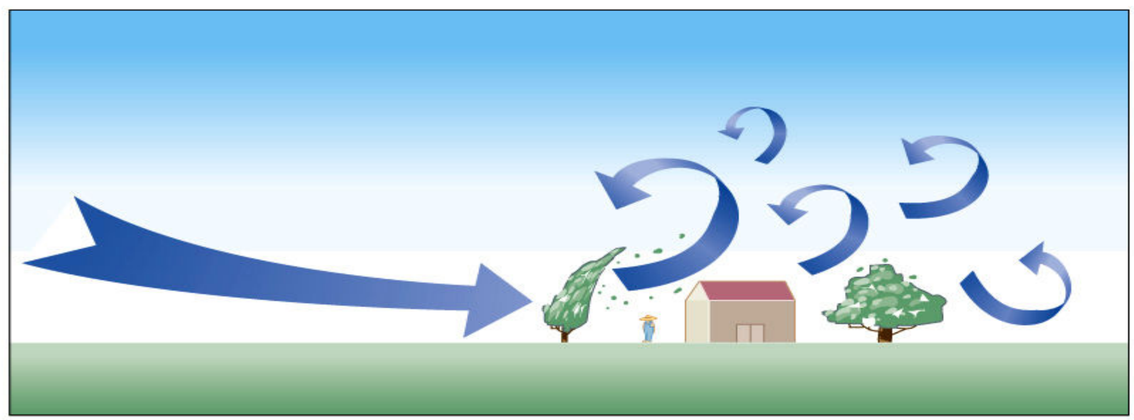


- Convection
  - When the surface temperature exceeds the air temperature
    - Normal during the day
- Convection from
  - ***Free convection***
    - Warmer, less dense fluids rise
  - ***Forced convection***
    - Initiated by ***eddies*** and disruptions to uniform airflow

Free Convection



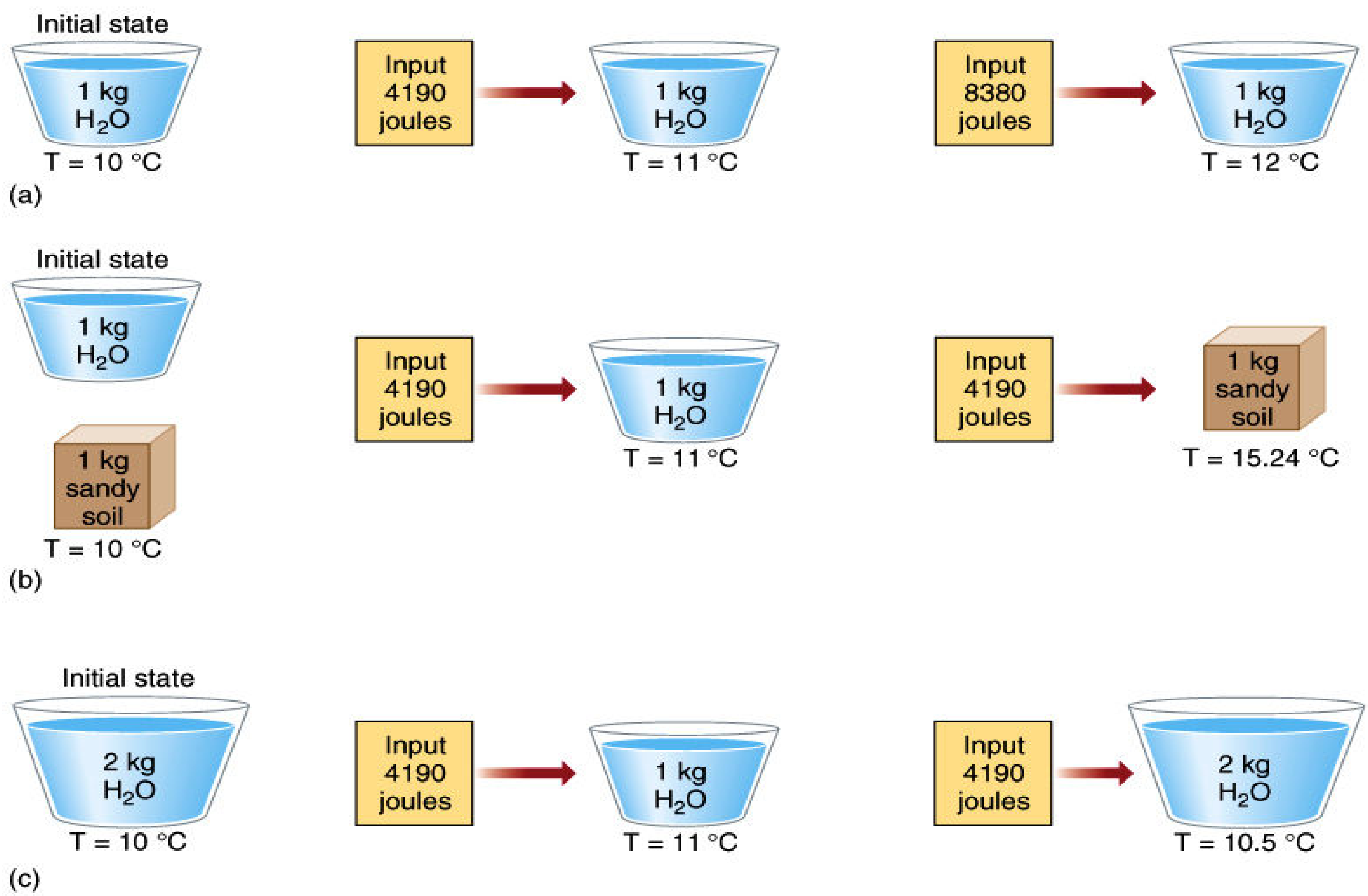
Forced Convection



- Sensible Heat
  - Readily detected heat energy
  - Related to object's specific heat and mass
  - 8 units transferred to the atmosphere as sensible heat
- Latent Heat
  - Energy which induces a change of state (usually in water)
  - Redirects some energy which would be used for sensible heat

- Latent heat of evaporation is stored in water vapor
  - Released during condensation
- Globally, 21 units of energy are transferred to the atmosphere as latent heat

Heat content of substances

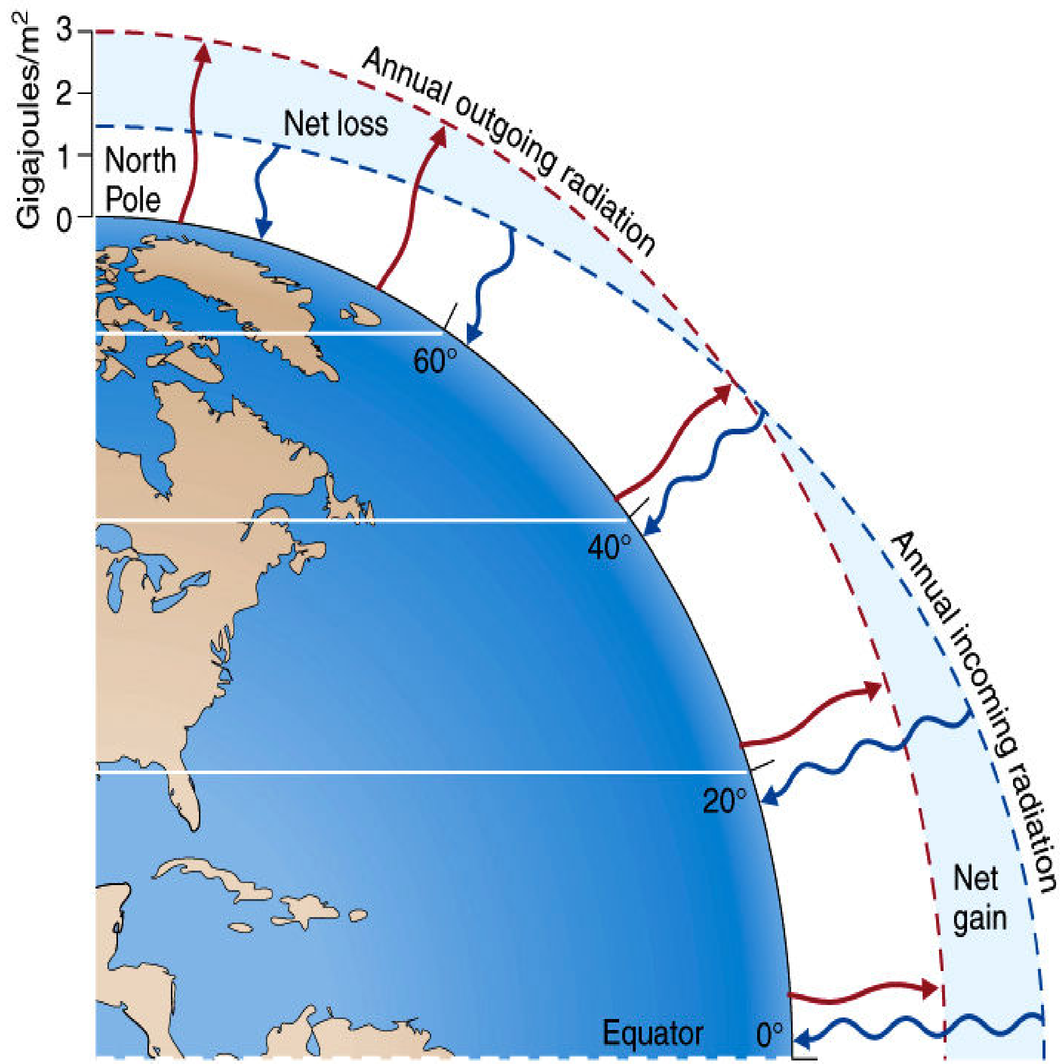


- Net Radiation and Temperature
  - Incoming radiation balances with outgoing
  - If parameters are changed, a new equilibrium occurs
  - Balances
    - Global
    - Diurnal
    - Local

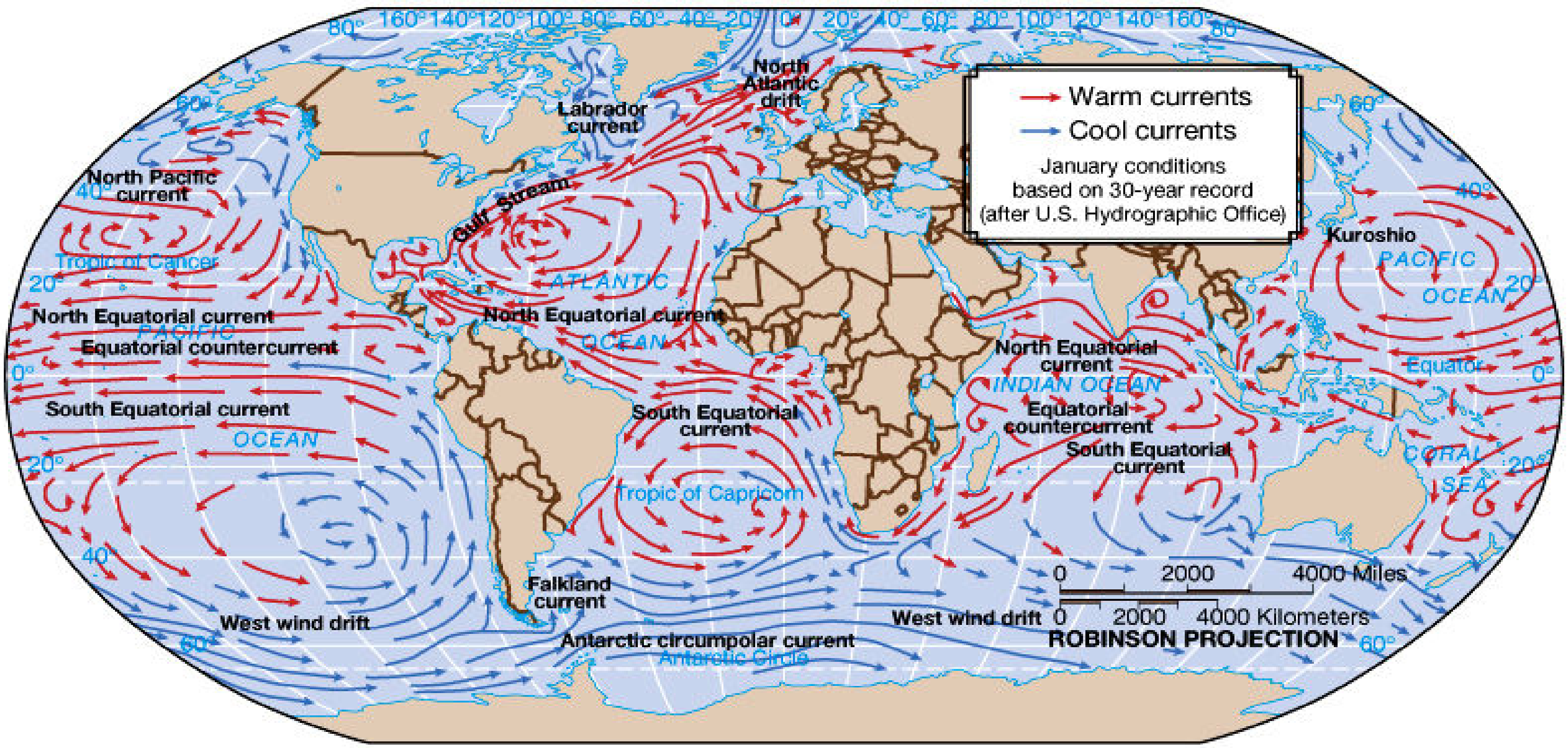
Latitudinal Variations

- Between 38^{o}N and S = net energy surpluses
- Poleward of 38^{o} = net energy deficits
- Winter hemispheres
  - Net energy deficits poleward of 15^{o}
- Mass advection neutralizes energy imbalances

Annual average net radiation

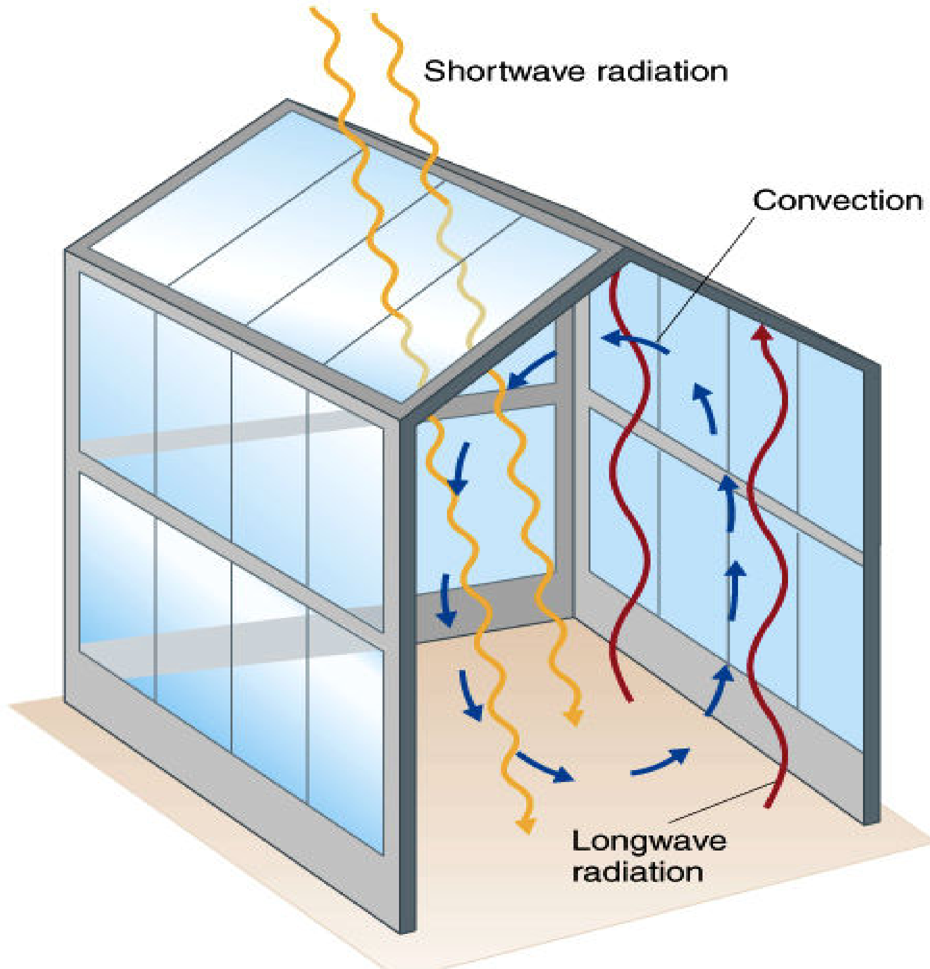


Ocean circulation

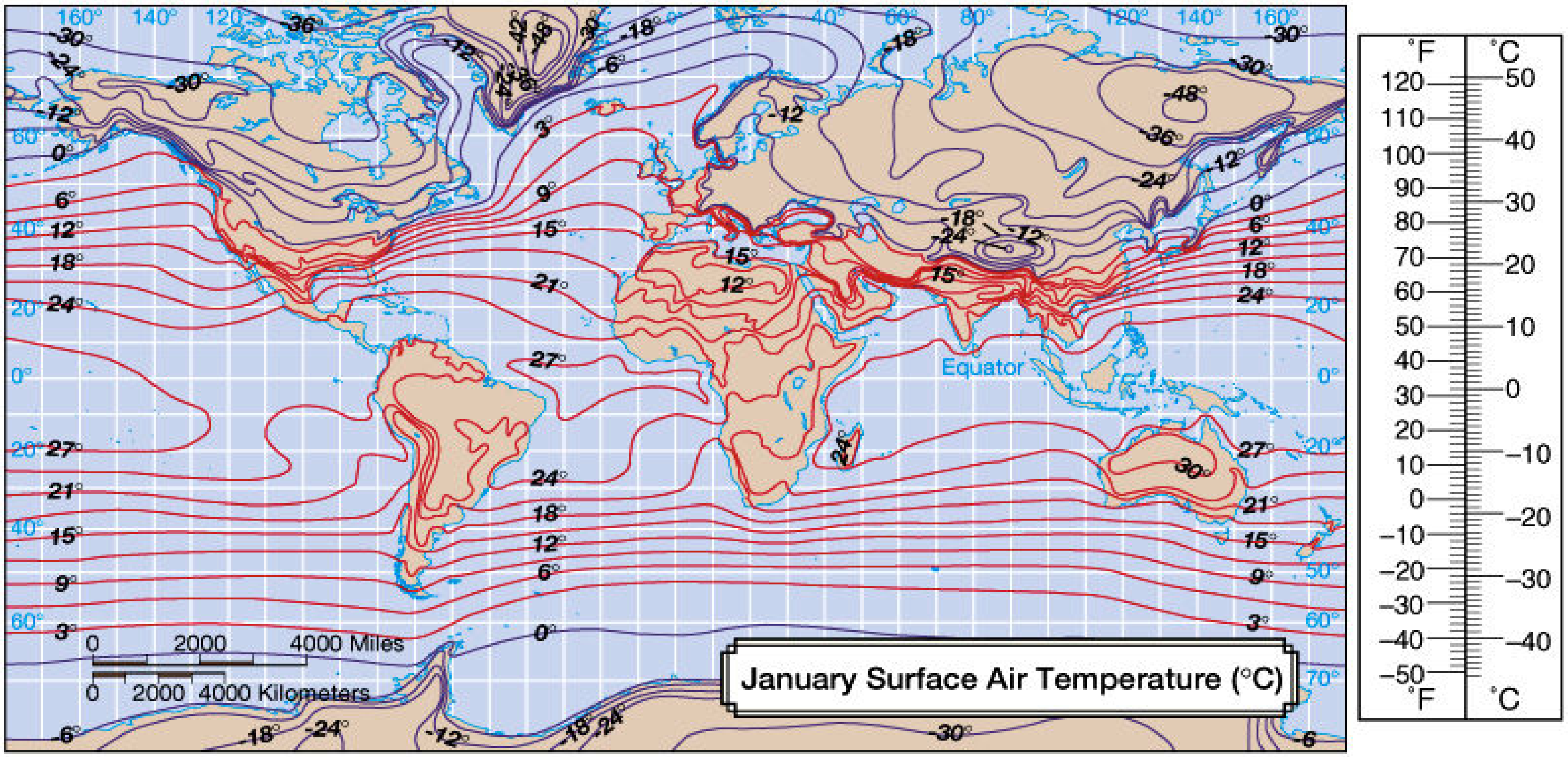


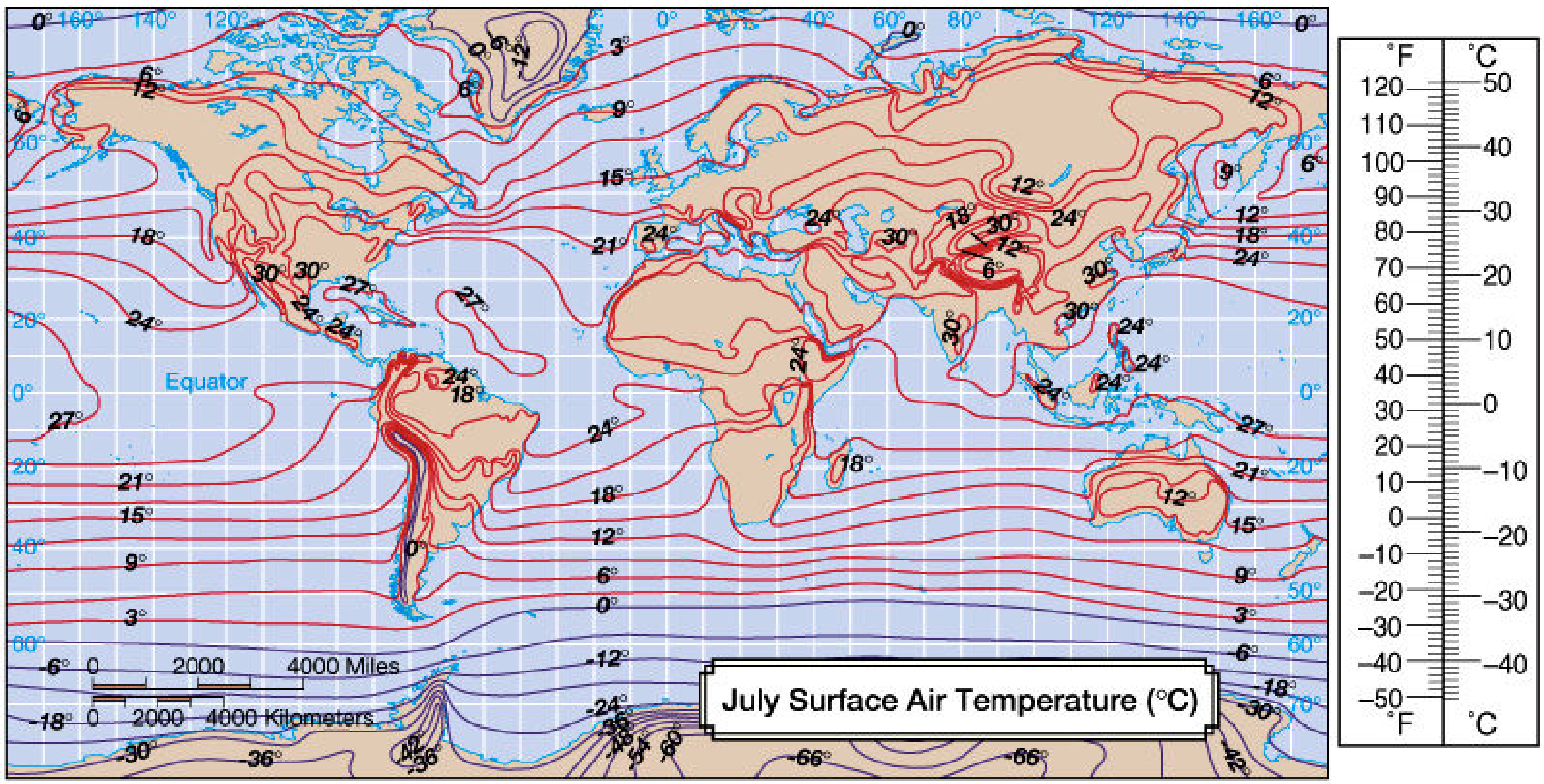
- The Greenhouse Effect
  - Gases trapping terrestrial radiation
    - H_2O, CO_2, and CH_4
  - Without the greenhouse effect
    - average Earth temperature = -18^oC (0^oF)
  - Human activities play a role

A true greenhouse stems convection

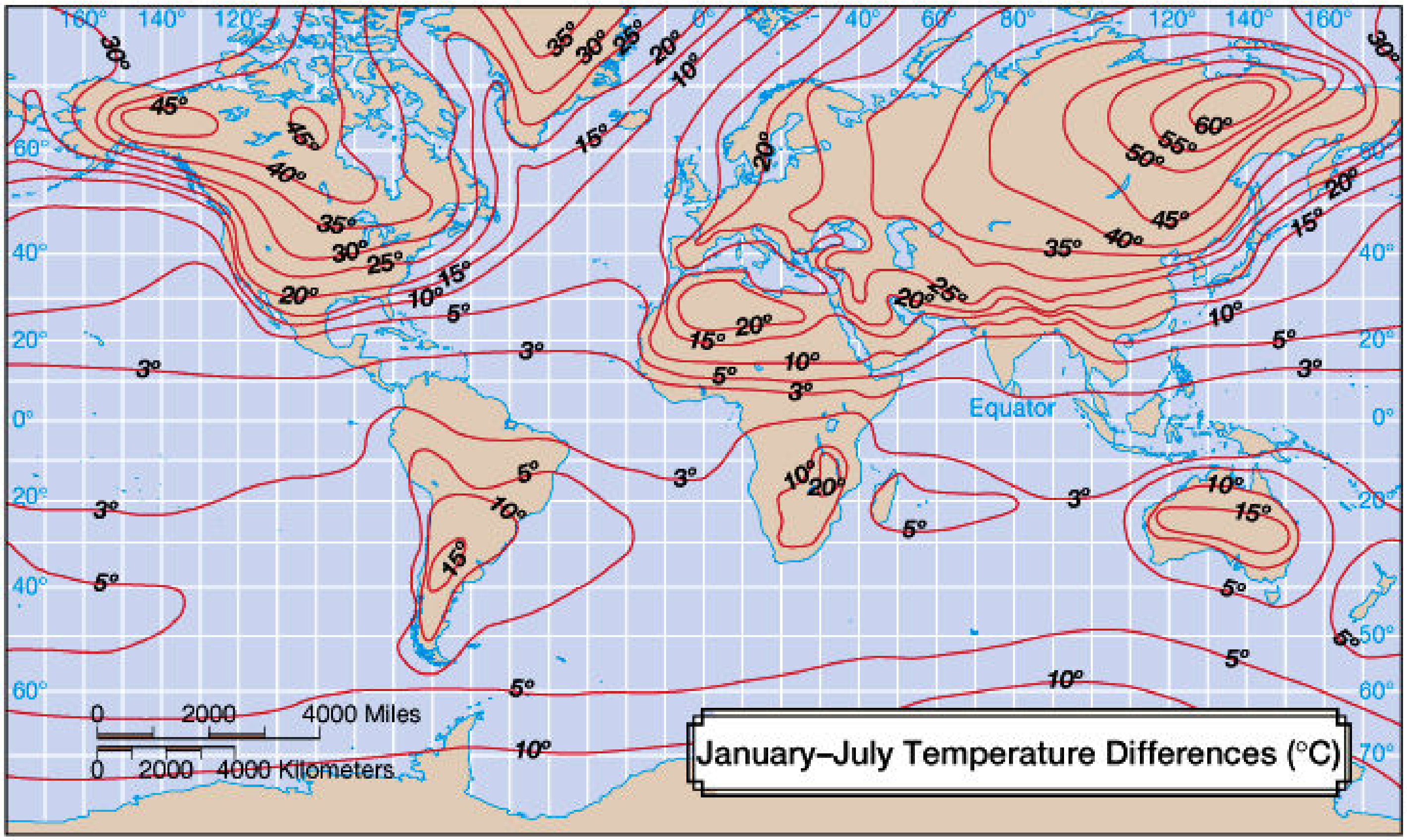


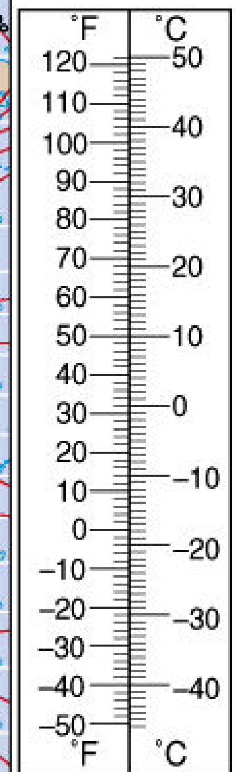
- Global Temperature Distributions
  - Temperatures decrease with latitude
  - Strong thermal contrasts occur in winter
  - Isotherms shift seasonally
    - Greater over continents
    - More pronounced in the northern hemisphere


January Surface Air Temperature (°C)
Equator
0 2000 4000 Miles
0 2000 4000 Kilometers
160° 140° 120° 40° 60° 80° 120° 140° 160°
60° 40° 20° 0° 20° 40° 60° 70°
°F °C
120 110 100 90 80 70 60 50 40 30 20 10 0 −10 −20 −30 −40 −50
50 40 30 20 10 0 −10 −20 −30 −40



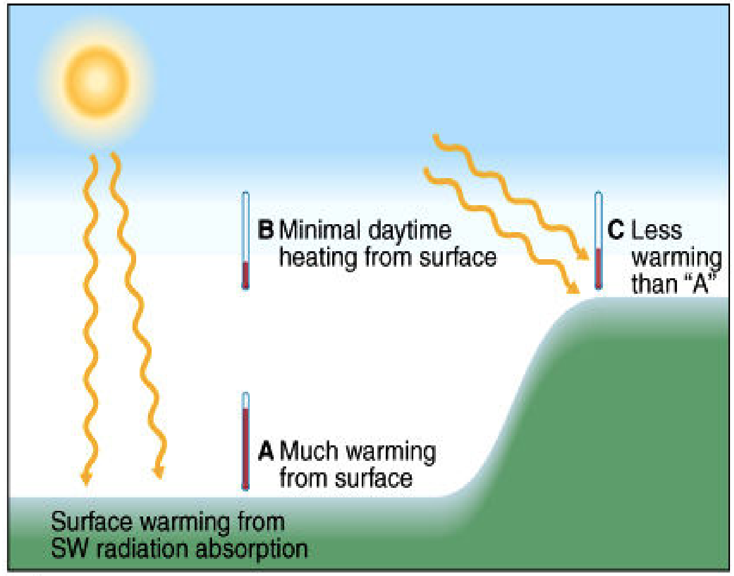
July Surface Air Temperature (°C)
Equator
0 2000 4000 Miles
0 2000 4000 Kilometers
°F
°C
120
110
100
90
80
70
60
50
40
30
20
10
0
–10
–20
–30
–40
–50
50
40
30
20
10
0
–10
–20
–30
–40

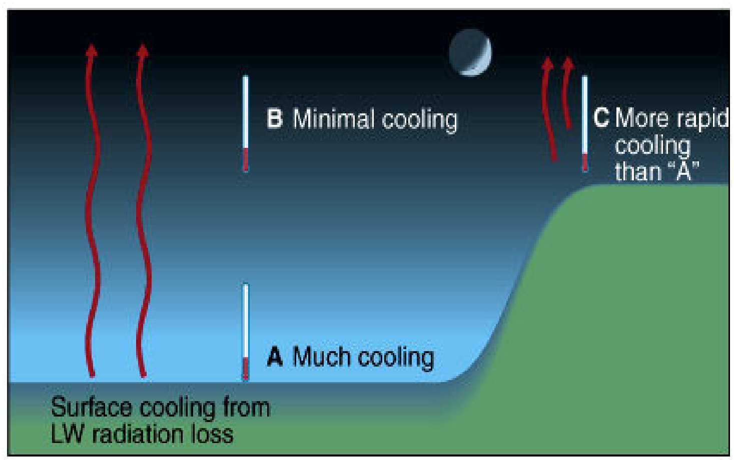

January–July Temperature Differences (°C)
0 2000 4000 Miles
0 2000 4000 Kilometers
Equator


°F
°C

Influences on Temperature

- Latitude
  - Due to axial tilt
    - Solar angles, daylengths, beam depletion, beam spreading
- Altitude
  - Temperatures decline with altitude
  - High altitudes have fairly constant temperatures
    - More rapid diurnal fluxes


B Minimal daytime heating from surface
C Less warming than "A"
A Much warming from surface
Surface warming from SW radiation absorption
(a)

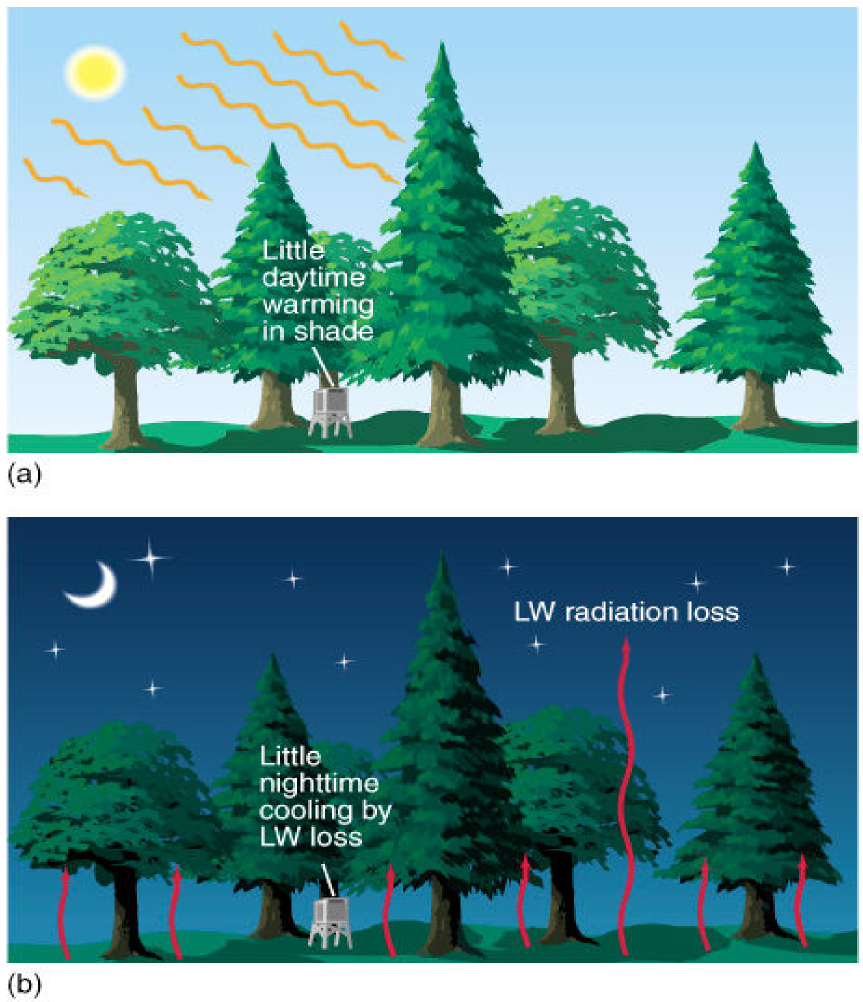

B Minimal cooling
C More rapid cooling than "A"
A Much cooling
Surface cooling from LW radiation loss
(b)

- Atmospheric Circulation
  - Latitudinal temperature and pressure differences cause large-scale advection
- Contrasts between Land and Water
  - *Continentality* versus *maritime* effects

- Warm and Cold Ocean Currents
  - Western ocean basins are warm
  - Eastern ocean basins are cold
- Local Conditions
  - Small spatial scale features impact temperatures

South-facing slopes have more vegetation

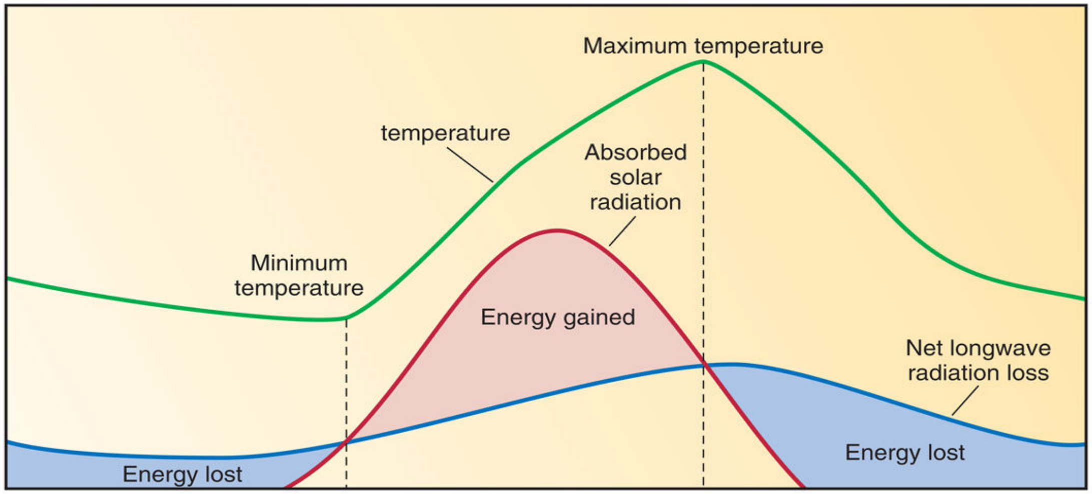
The role of vegetation in a local energy balance



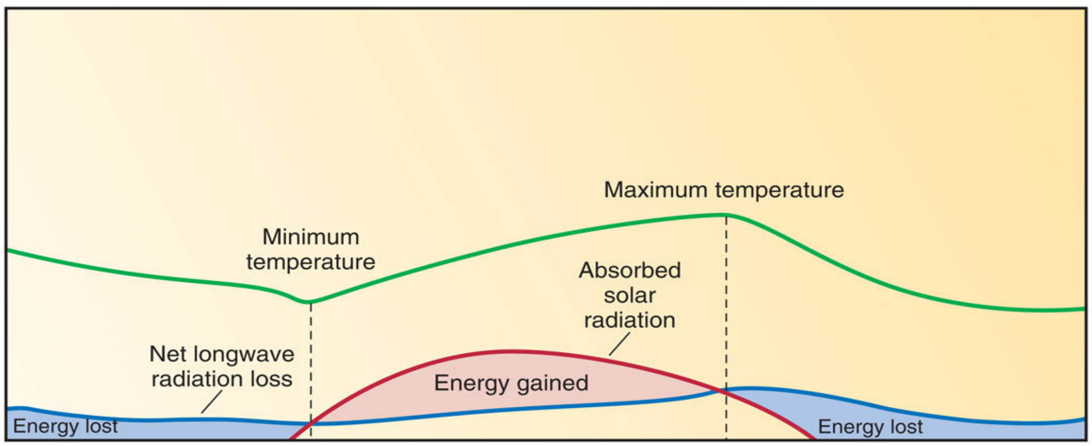
Daily and Annual Temperature Patterns

- Diurnal temperatures lag energy receipt
- Surface cooling rate is lower than the warming rate
  - Due to stored surface energy
- Winds moderate temperature ranges
  - Transfer energy through large mass of air

Diurnal energy



(a)

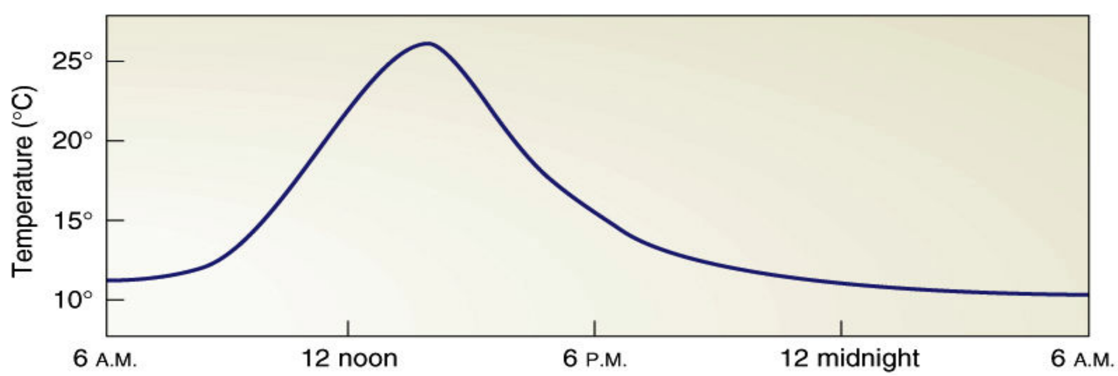


(b)

Temperature Means and Ranges

- Standard averaging procedures used to obtain daily means
- Observation biases may occur

Continuous temperature plot



Global Extremes

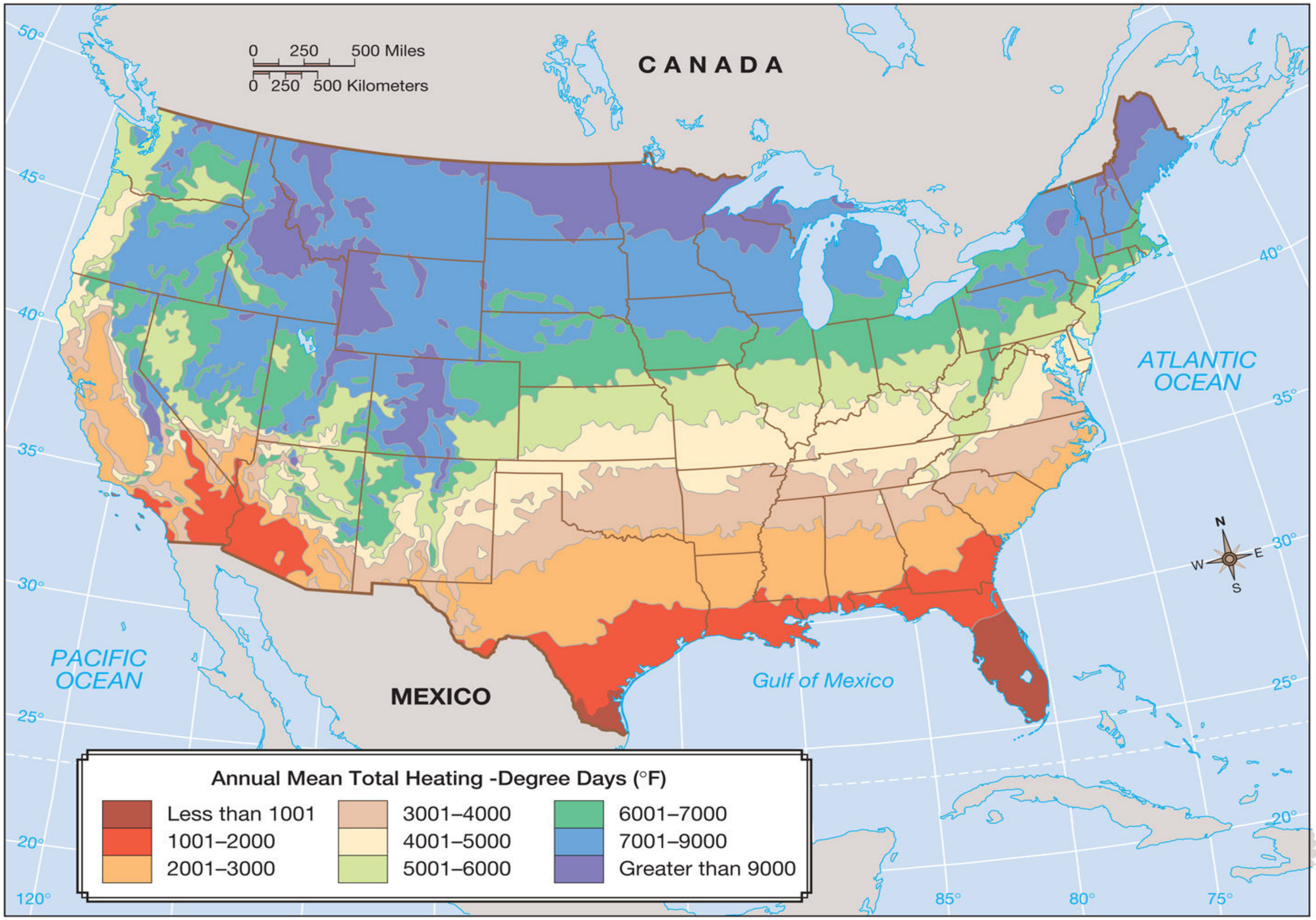
- Greatest extreme temperatures in continental interiors
  - World record high = 57^{o}C (137^{o}F) at Azizia, Libya, 1913
  - World record low = -89^{o}C (-129^{o}F) Antarctica, 1960

- Temperature and Human Comfort
  - Human discomfort due to temperature compounded by other weather factors
  - ***Wind Chill Temperature Index***
    - Effect of wind speed
  - ***Heat Index***
    - Effect of humidity

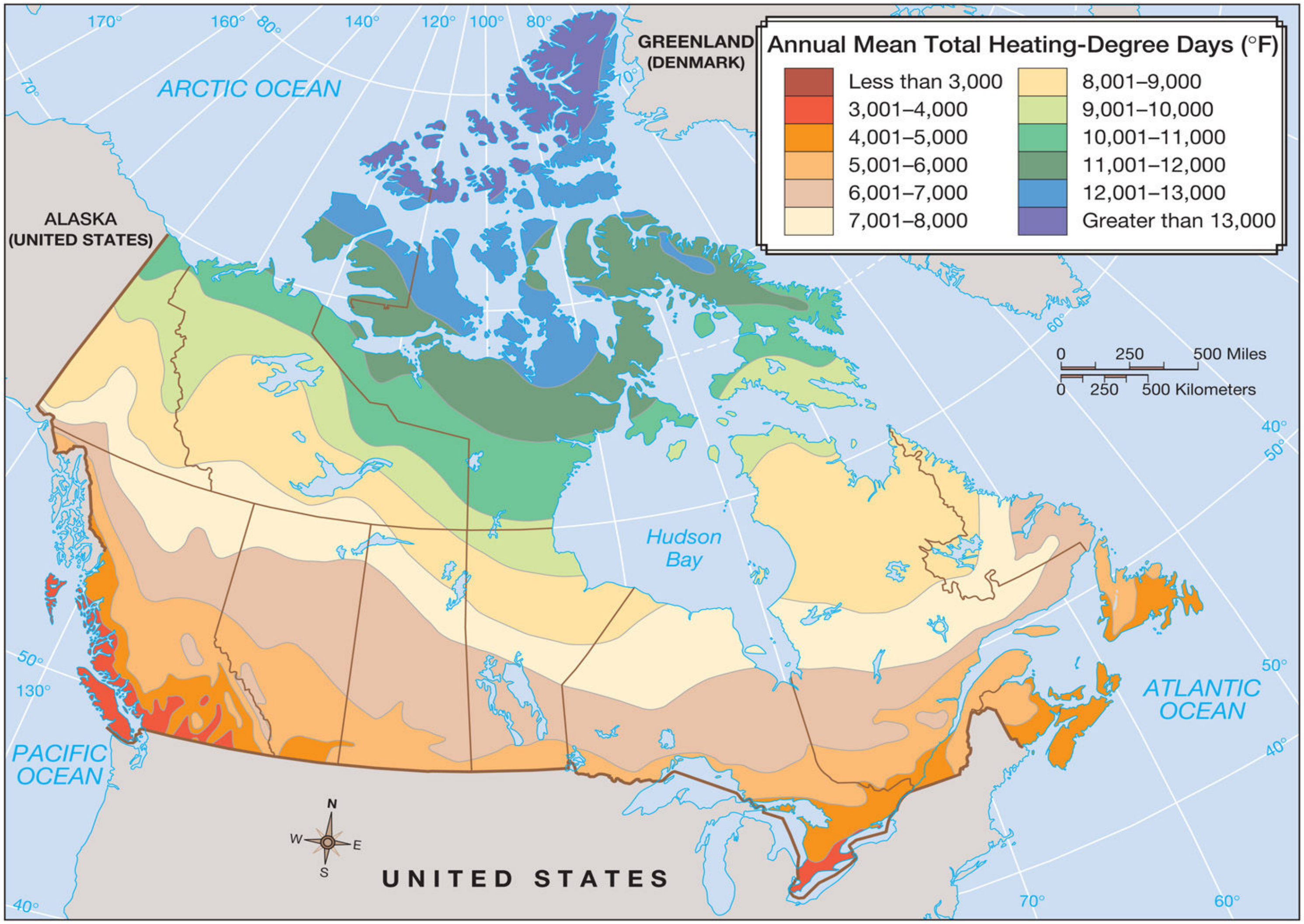
TABLE 3–1 Wind Chill Temperature (°C)

WIND (km/hr)	TEMPERATURE (°C)									
	5	0	−5	−10	−15	−20	−25	−30	−35	−40
5	4	−2	−7	−13	−19	−24	−30	−36	−41	−47
10	3	−3	−9	−15	−21	−27	−33	−39	−45	−51
15	2	−4	−11	−17	−23	−29	−35	−41	−48	−54
20	1	−5	−12	−18	−24	−31	−37	−43	−49	−56
25	1	−6	−12	−19	−25	−32	−38	−45	−51	−57
30	0	−7	−13	−20	−26	−33	−39	−46	−52	−59
35	0	−7	−14	−20	−27	−33	−40	−47	−53	−60
40	−1	−7	−14	−21	−27	−34	−41	−48	−54	−61
45	−1	−8	−15	−21	−28	−35	−42	−48	−55	−62
50	−1	−8	−15	−22	−29	−35	−42	−49	−56	−63
55	−2	−9	−15	−22	−29	−36	−43	−50	−57	−63
60	−2	−9	−16	−23	−30	−37	−43	−50	−57	−64
65	−2	−9	−16	−23	−30	−37	−44	−51	−58	−65
70	−2	−9	−16	−23	−30	−37	−44	−51	−59	−66
75	−3	−10	−17	−24	−31	−38	−45	−52	−59	−66
80	−3	−10	−17	−24	−31	−38	−45	−52	−60	−67

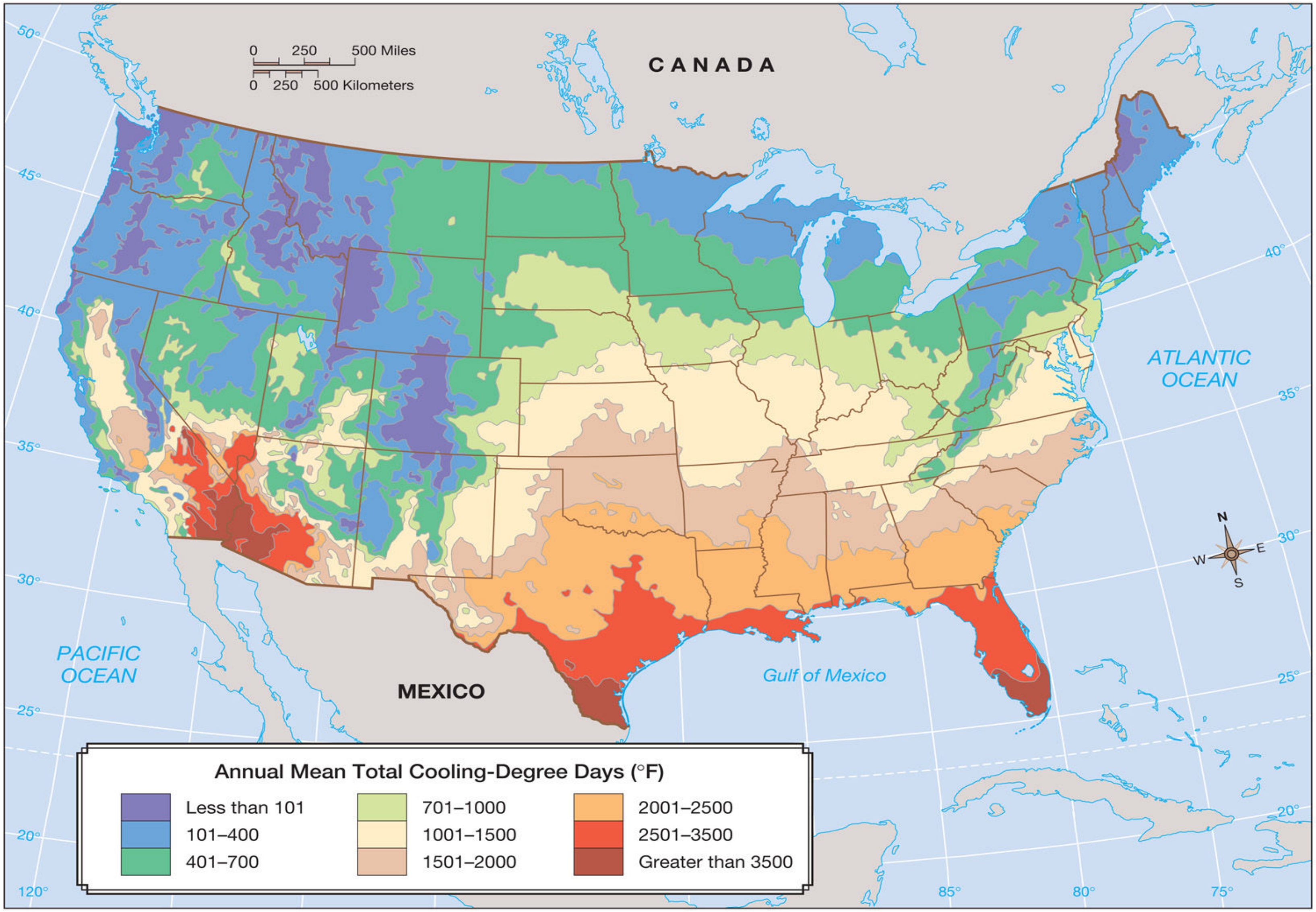
- Heating Degree Days
  - Index to determine energy needed to heat interiors
- Cooling Degree Days
  - Same as above but relative to cooling
- Growing Degree Days
  - Agricultural version


0 250 500 Miles
0 250 500 Kilometers
CANADA
MEXICO
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico
N
S
E
W
50°
45°
40°
35°
30°
25°
20°
120°
85°
80°
75°
Annual Mean Total Heating -Degree Days (°F)
Less than 1001
1001–2000
2001–3000
3001–4000
4001–5000
5001–6000
6001–7000
7001–9000
Greater than 9000

(a)


Annual Mean Total Heating-Degree Days (°F)
Less than 3,000
3,001–4,000
4,001–5,000
5,001–6,000
6,001–7,000
7,001–8,000
8,001–9,000
9,001–10,000
10,001–11,000
11,001–12,000
12,001–13,000
Greater than 13,000
ARCTIC OCEAN
GREENLAND (DENMARK)
ALASKA (UNITED STATES)
Hudson Bay
ATLANTIC OCEAN
PACIFIC OCEAN
UNITED STATES
0 250 500 Miles
0 250 500 Kilometers
N
S
E
W
170°
160°
140°
120°
100°
80°
70°
60°
50°
40°
130°

(b)



CANADA
0 250 500 Miles
0 250 500 Kilometers
MEXICO
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico
N
E
S
W
50°
45°
40°
35°
30°
25°
20°
120°
85°
80°
75°
Annual Mean Total Cooling-Degree Days (°F)
Less than 101
101–400
401–700
701–1000
1001–1500
1501–2000
2001–2500
2501–3500
Greater than 3500

- Thermodynamic diagrams
  - Depict temperature and humidity with height
  - ***Stuve diagrams*** plot temperatures as a function of ***pressure levels***
    - Important for forecasting

Simplified Stuve Diagram