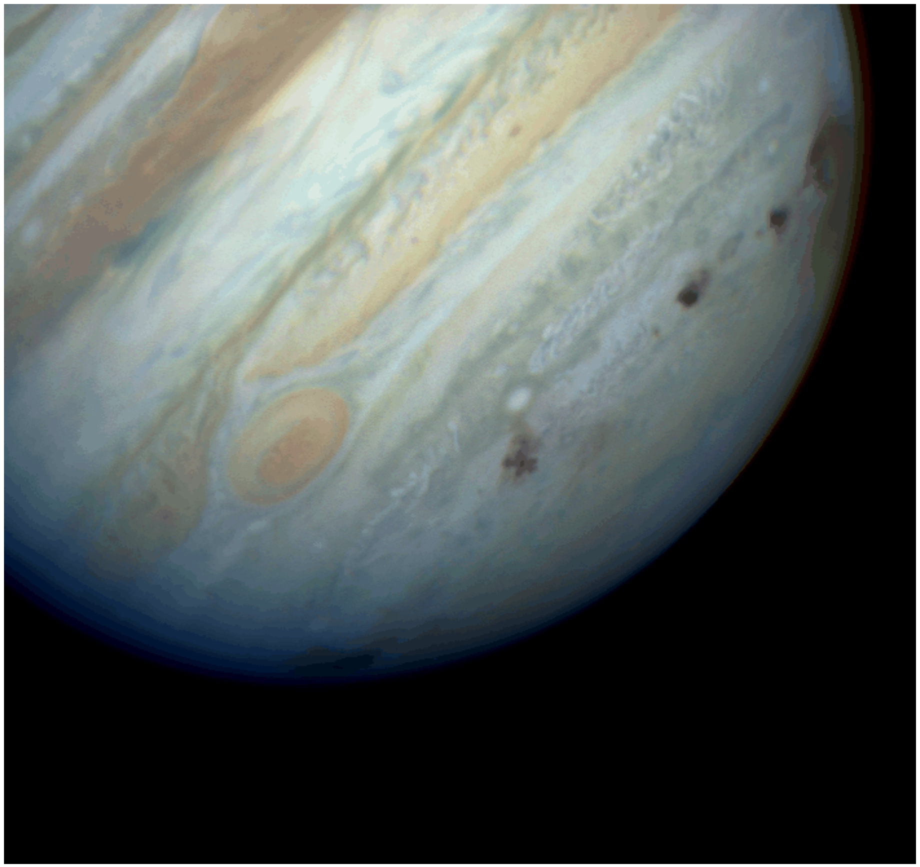
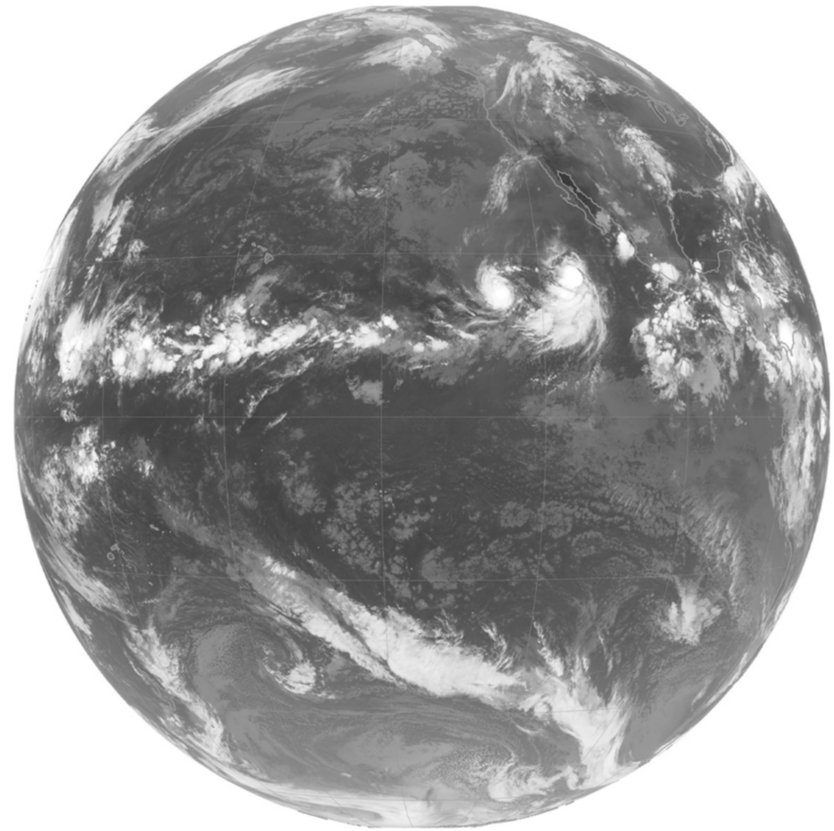
Chapter 4: Atmospheric Circulation





Some materials from Prof. Bart Geerts, UW Atmospheric Science

Book mentions "pumps" that keep Earth's circulation going

…analogous, the book says, to the role of your heart in keeping your blood circulation going - the circulatory system distributes heat, oxygen, and nutrients throughout your body, carries away wastes, and is key to chemical regulation of your system.

Earth's pumps:

1) Tropical oceans (warming water, air evaporation: Sun driven)
2) Thermohaline - density effect of salty water: Sun driven
3) Radioactive decay in Earth's interior - drives plate tectonics (lubricated with water)

Life as we know it depends on all of these pumps!

Fig. 4-1

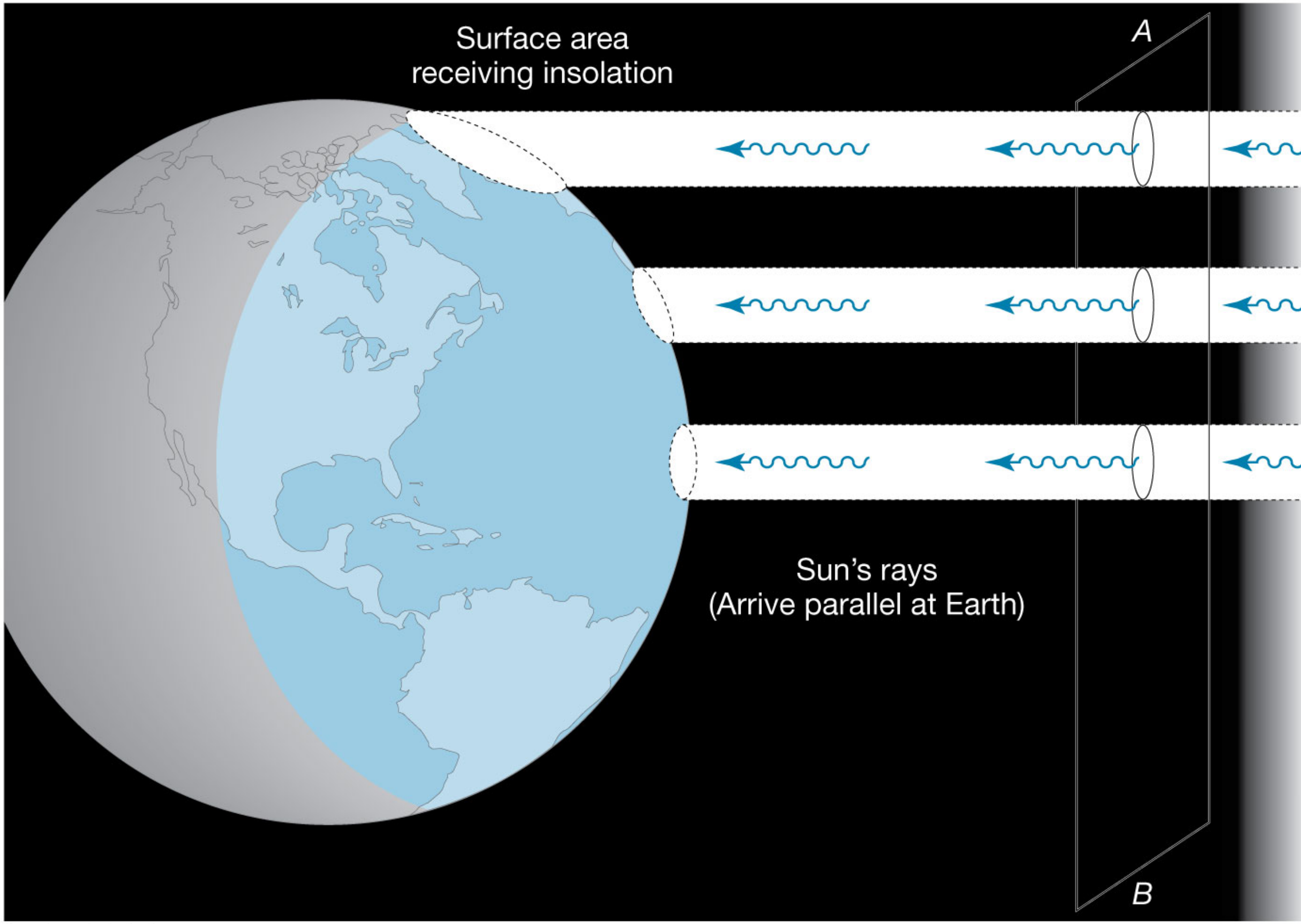
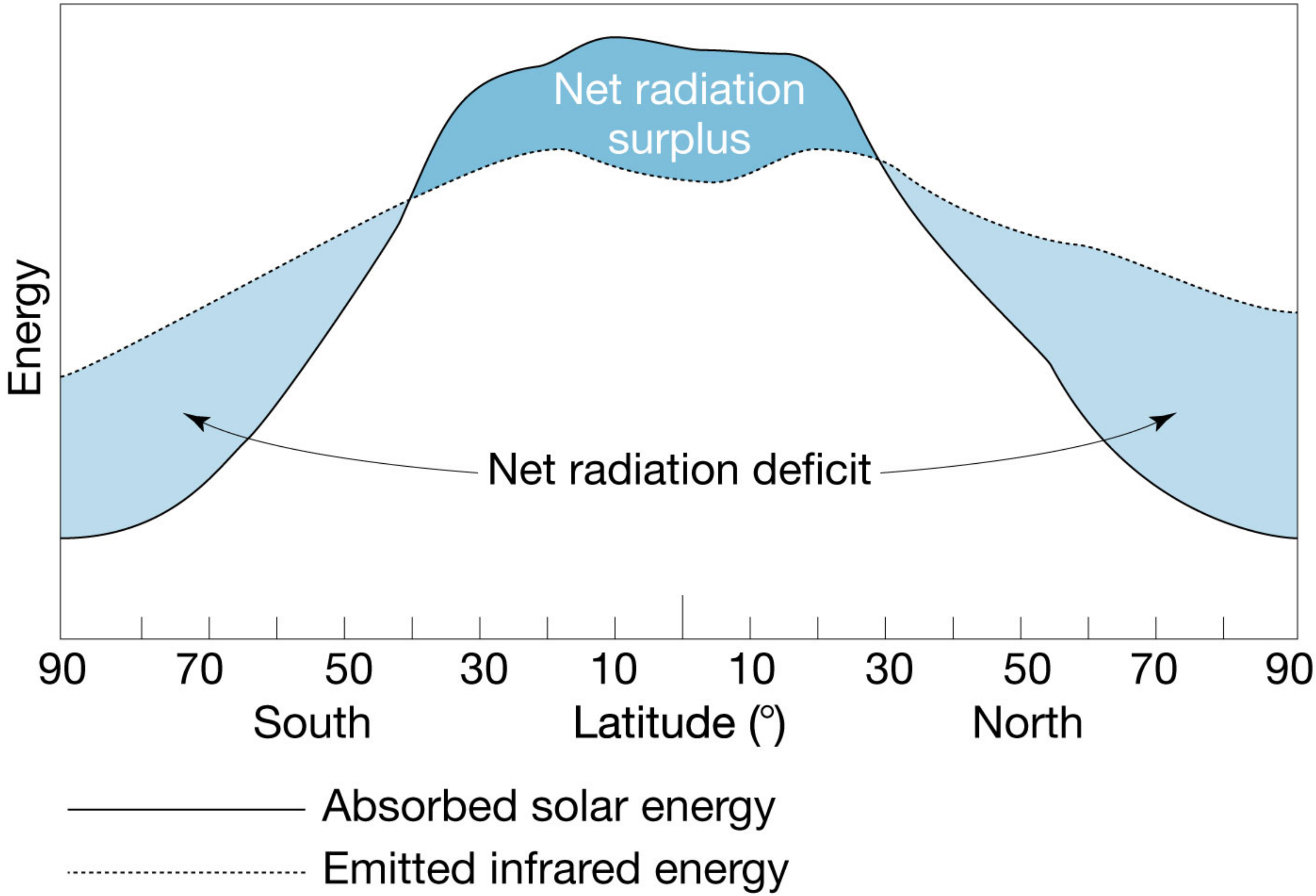

Surface area
receiving insolation
A
B
Sun's rays
(Arrive parallel at Earth)

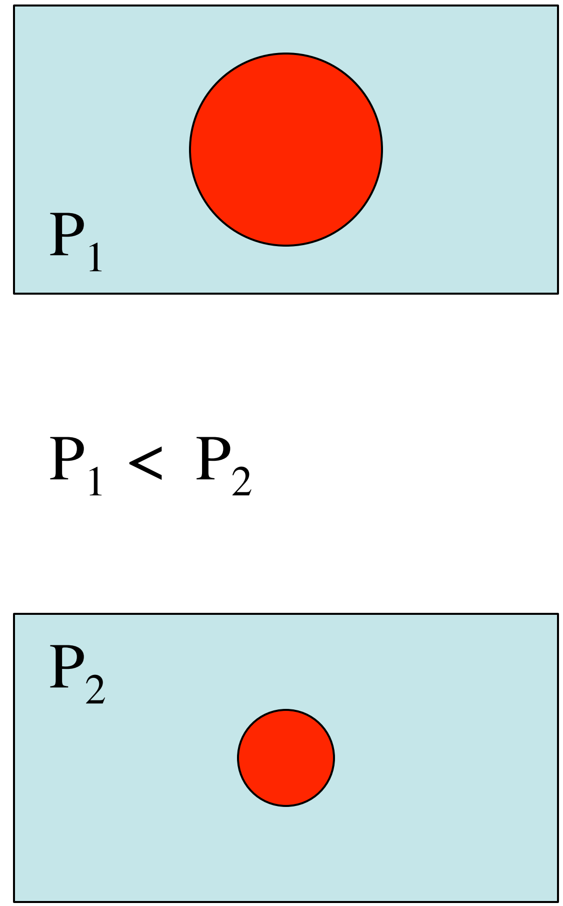
Fig. 4-2


Net radiation surplus
Energy
Net radiation deficit
90
70
50
30
10
10
30
50
70
90
South
Latitude (°)
North
Absorbed solar energy
Emitted infrared energy

Horizontal and Vertical Air Movement

- Bouyancy: density difference from surroundings
- **PV = nRT**
- P = pressure
- V = volume
- n = number of molecules in gas
- R = the "gas constant" (8.314 J/(mole K))
- T = temperature (K)

T constant
n fixed in
red balloon

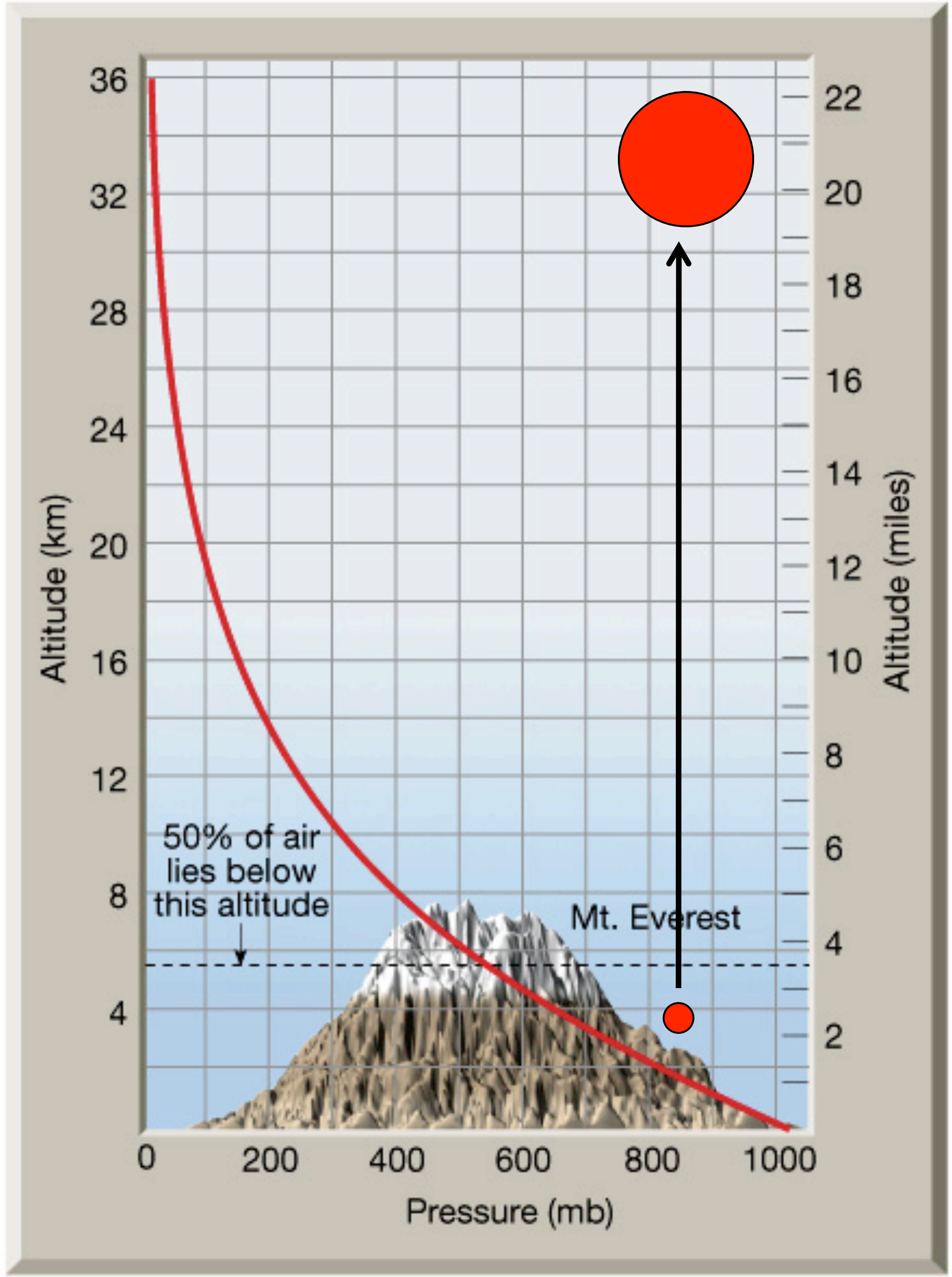


Hot air is less dense than cooler air…

Atm pressure decreases quickly with altitude

What would you expect the pressure to be at Laramie’s altitude?

Check out your thinking at uwyo atm science “weather web”!



Air expands if pressure is Lower:

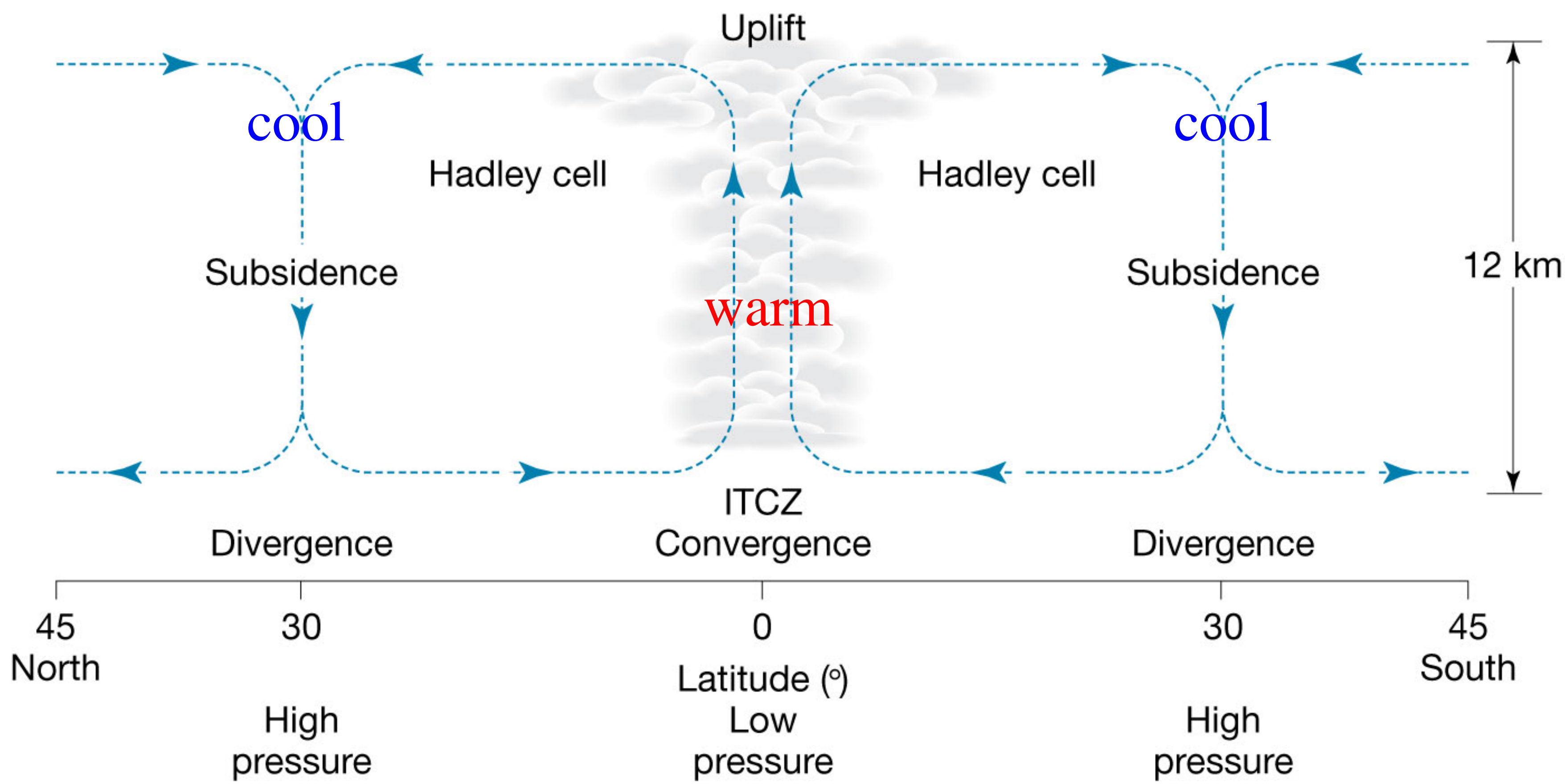
PV=nRT

Air compresses if pressure is increased

Earth's Latitude-Related Pattern

Acts as energy "conveyor belt"

Thermally driven convection cells at low latitude



Horizontal: Pressure difference and Coriolis…

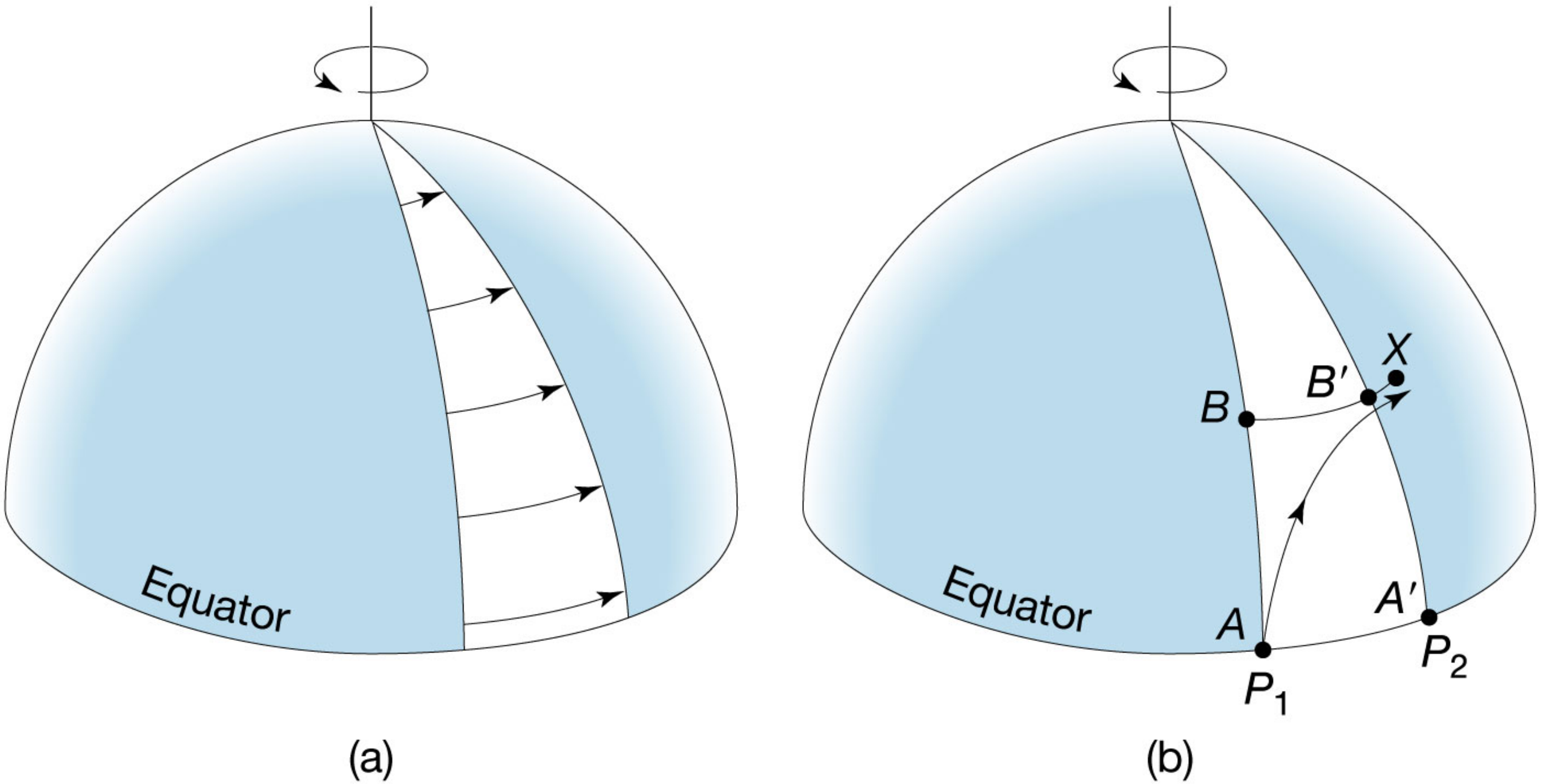


Fig. 4-9

Fig. 4-10

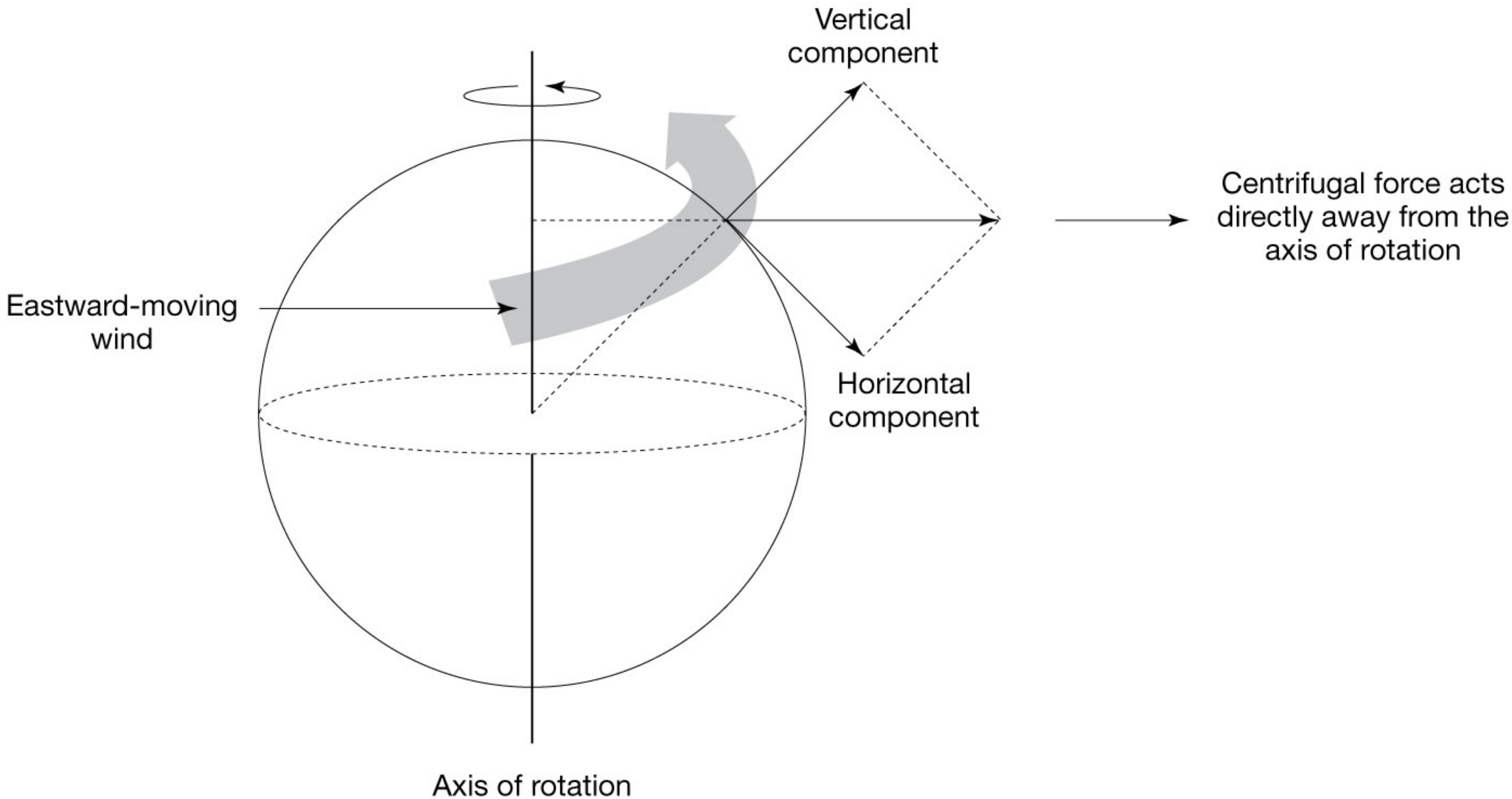
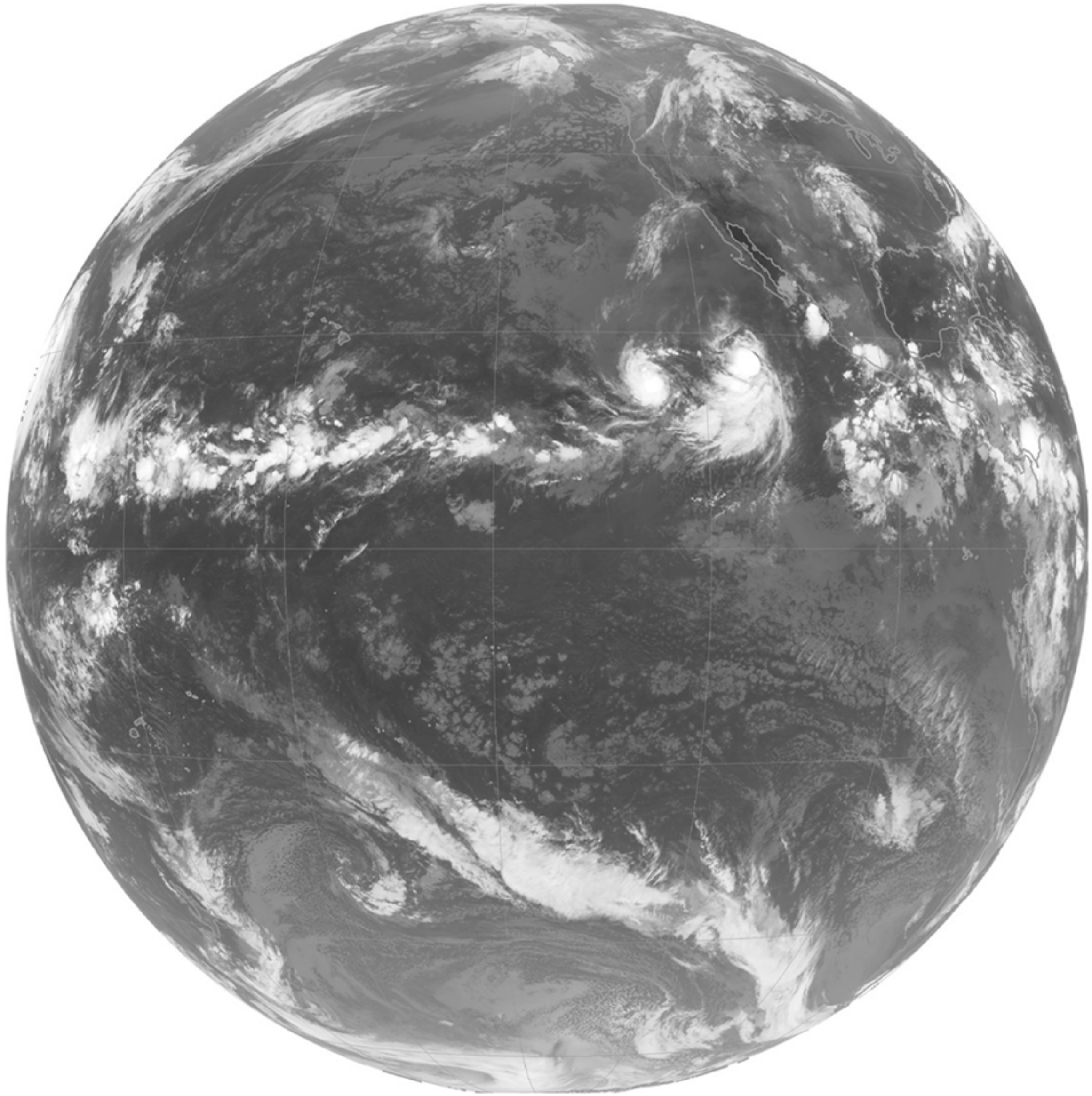
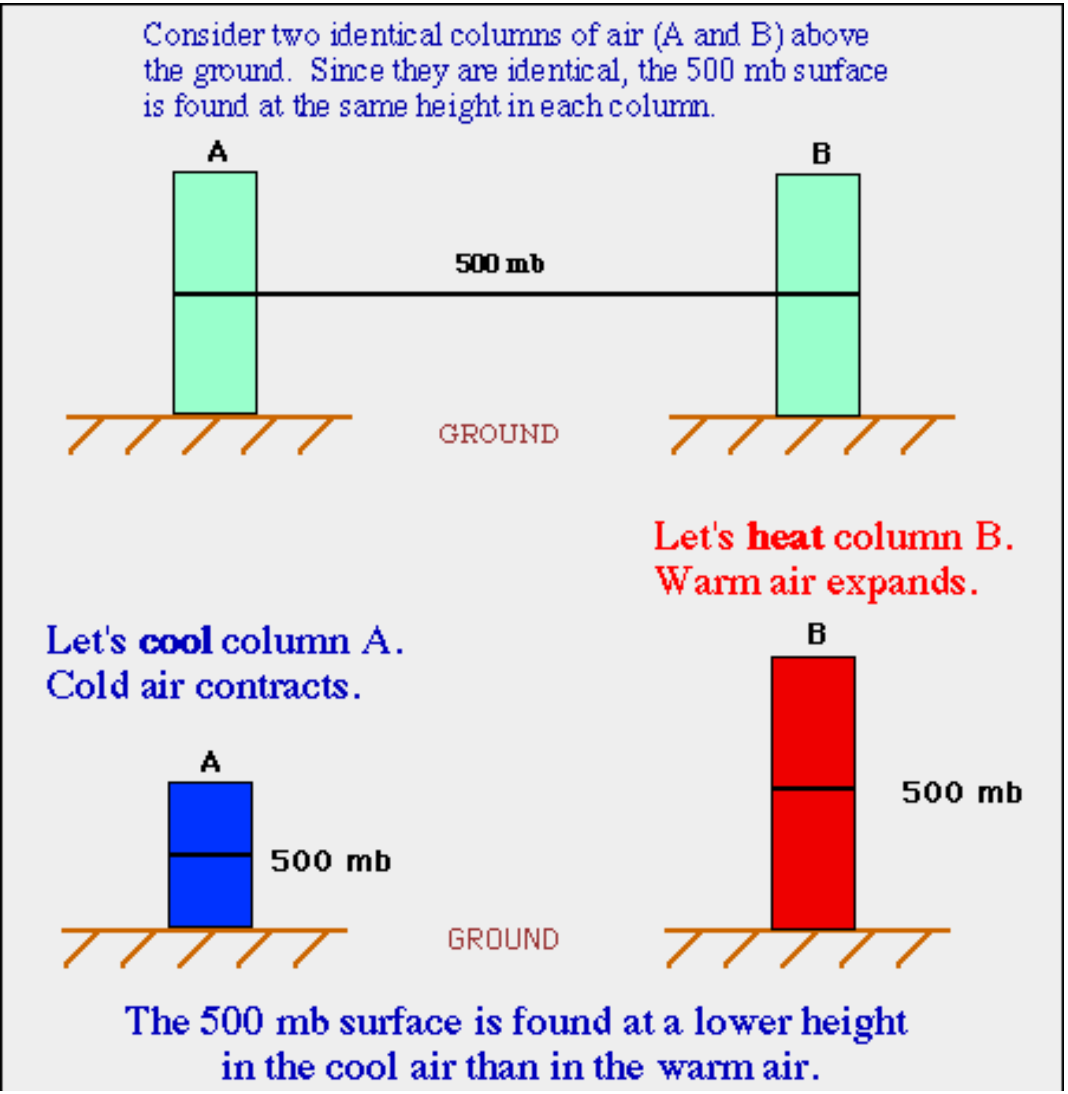

Vertical component
Centrifugal force acts directly away from the axis of rotation
Eastward-moving wind
Horizontal component
Axis of rotation

Fig. 4-4

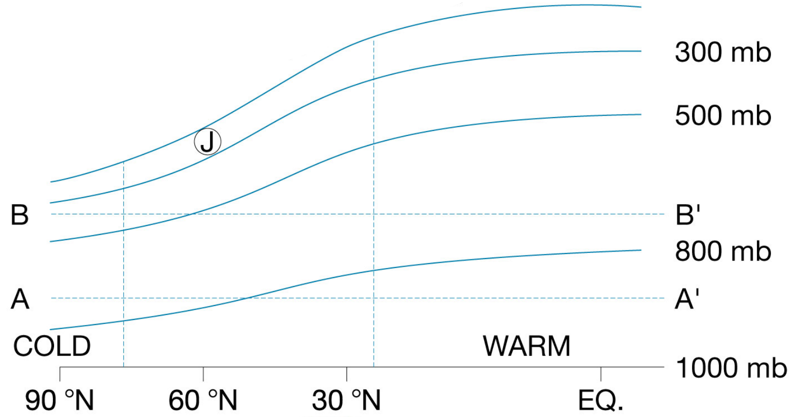


Why is the wind coupled to temperature in the atmosphere?

Figs. 4-12, 4-14



- Cool air is denser than warm air.
- Thus the upper-atmosphere "isobaric" surfaces are tilted.



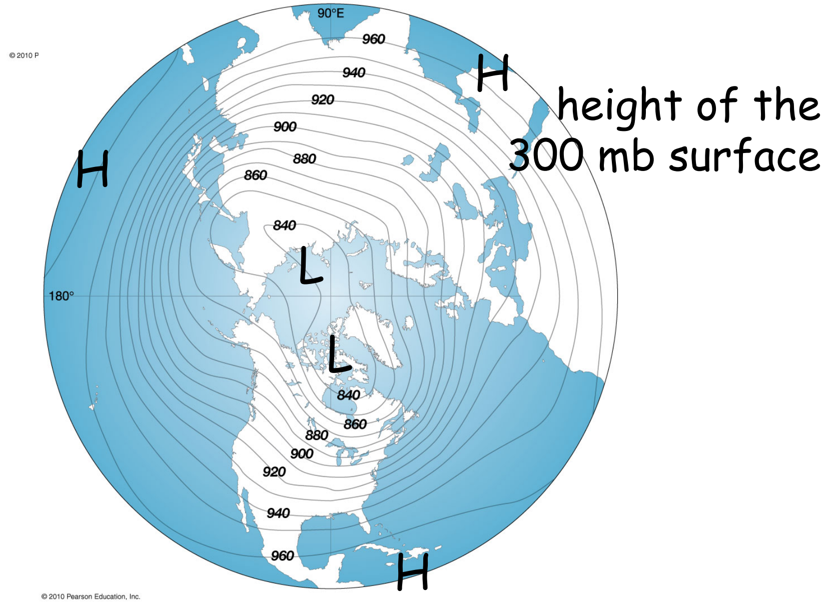
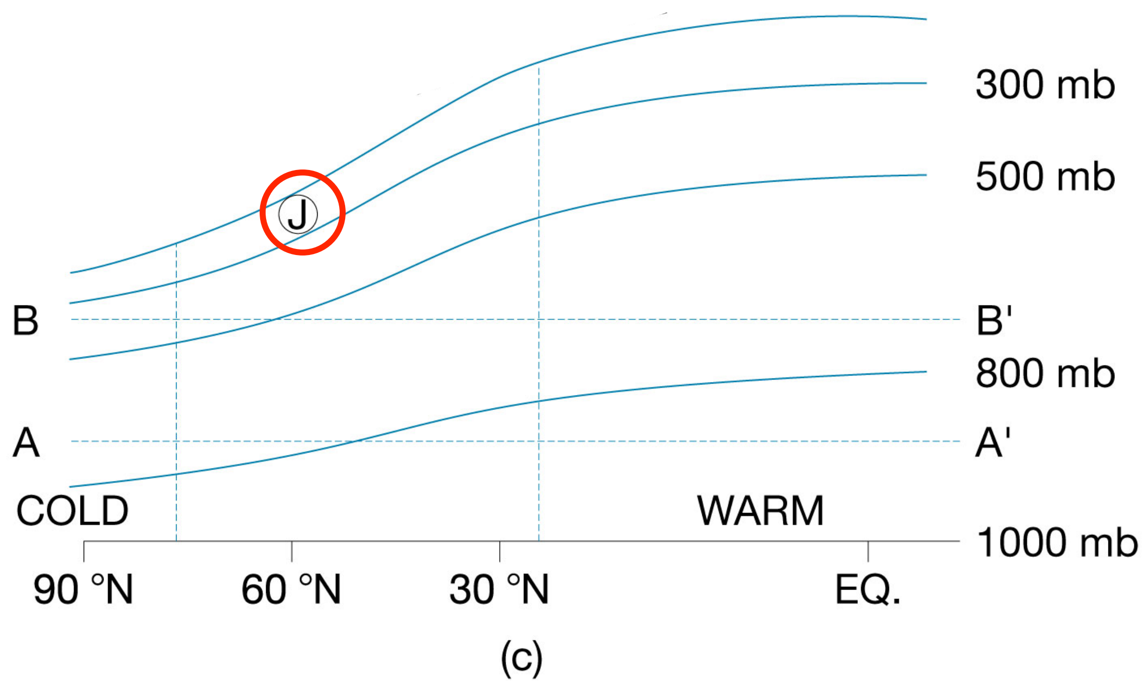


Fig. 4-12

PV = nRT (ideal gas law)
If P is roughly equal everywhere, if T goes down V must go down too.



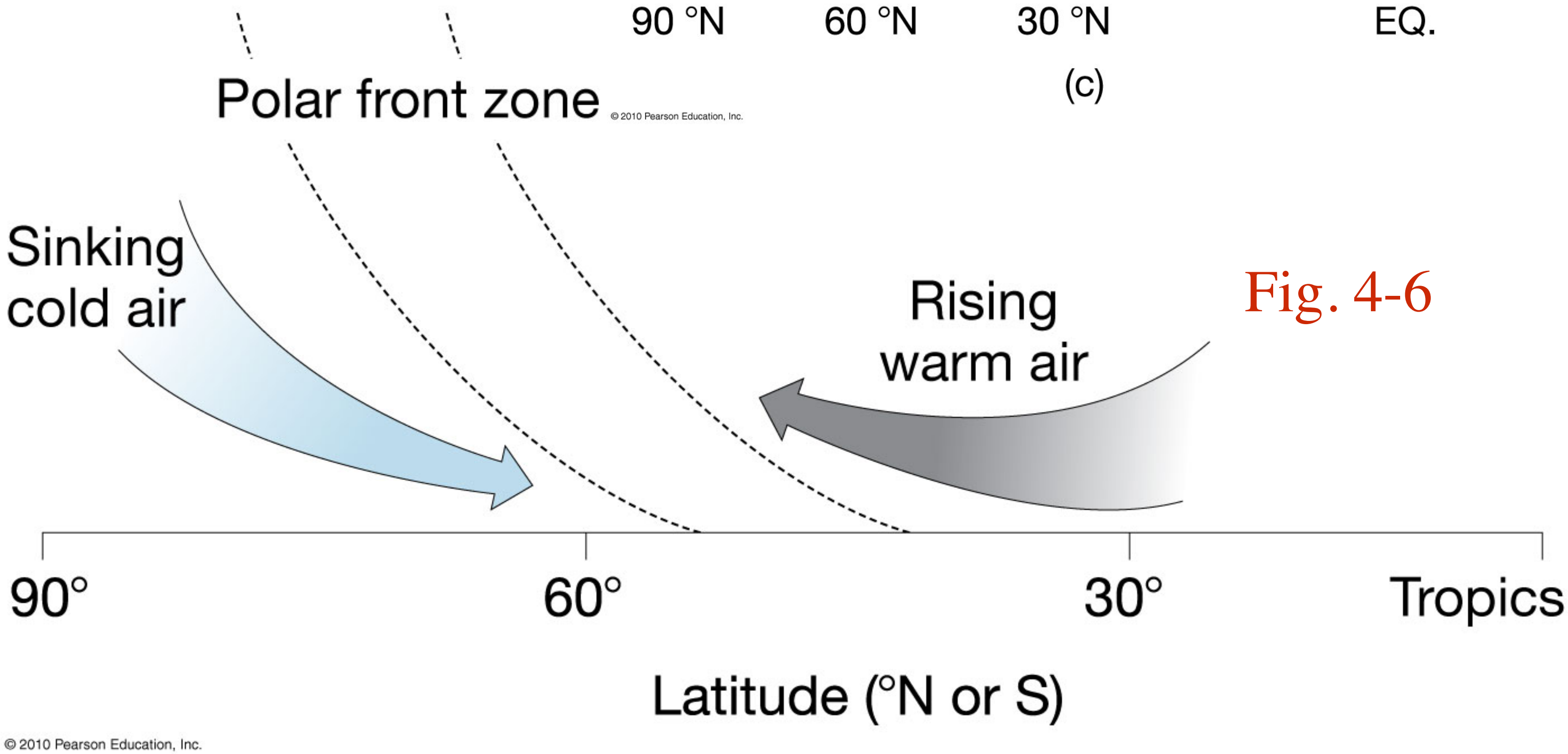
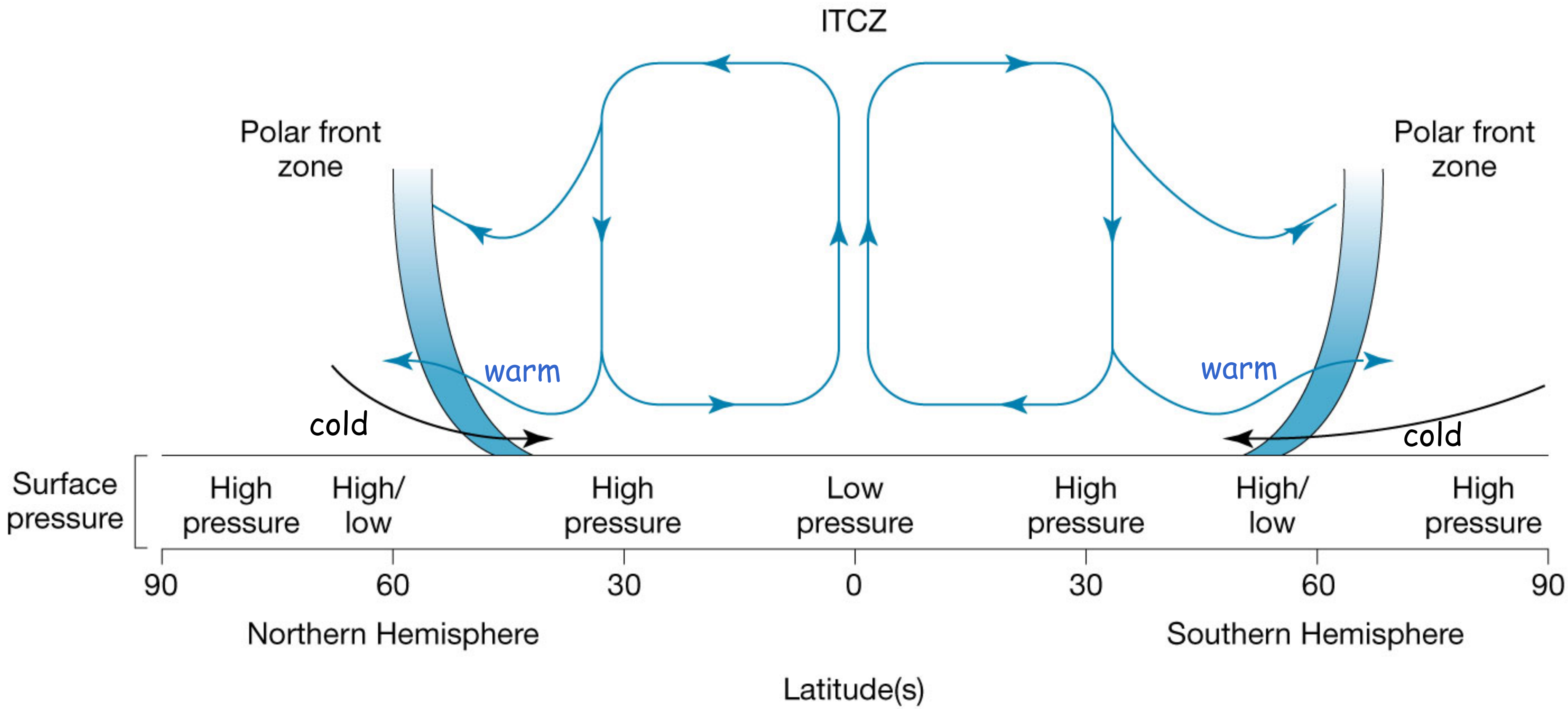


Fig. 4-6

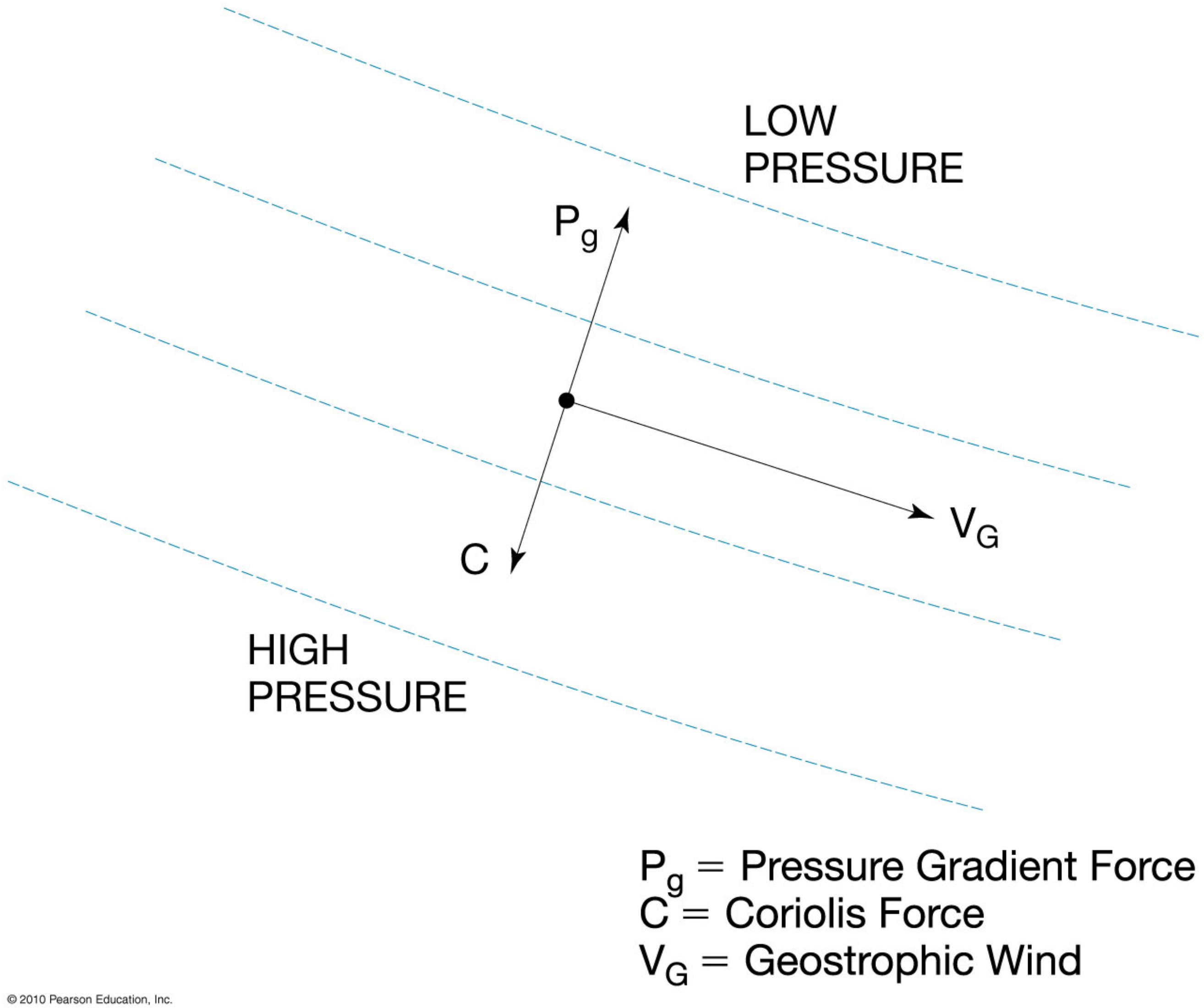
Key wind patterns

- At low latitudes, seasonally shifting trade winds dominate.
- At mid/high latitudes, the position of the polar front is key.
  - the jet and the polar front are highly unstable (esp. in winter), "baroclinic instability"
  - this leads to weather as we experience it (frontal passages …)

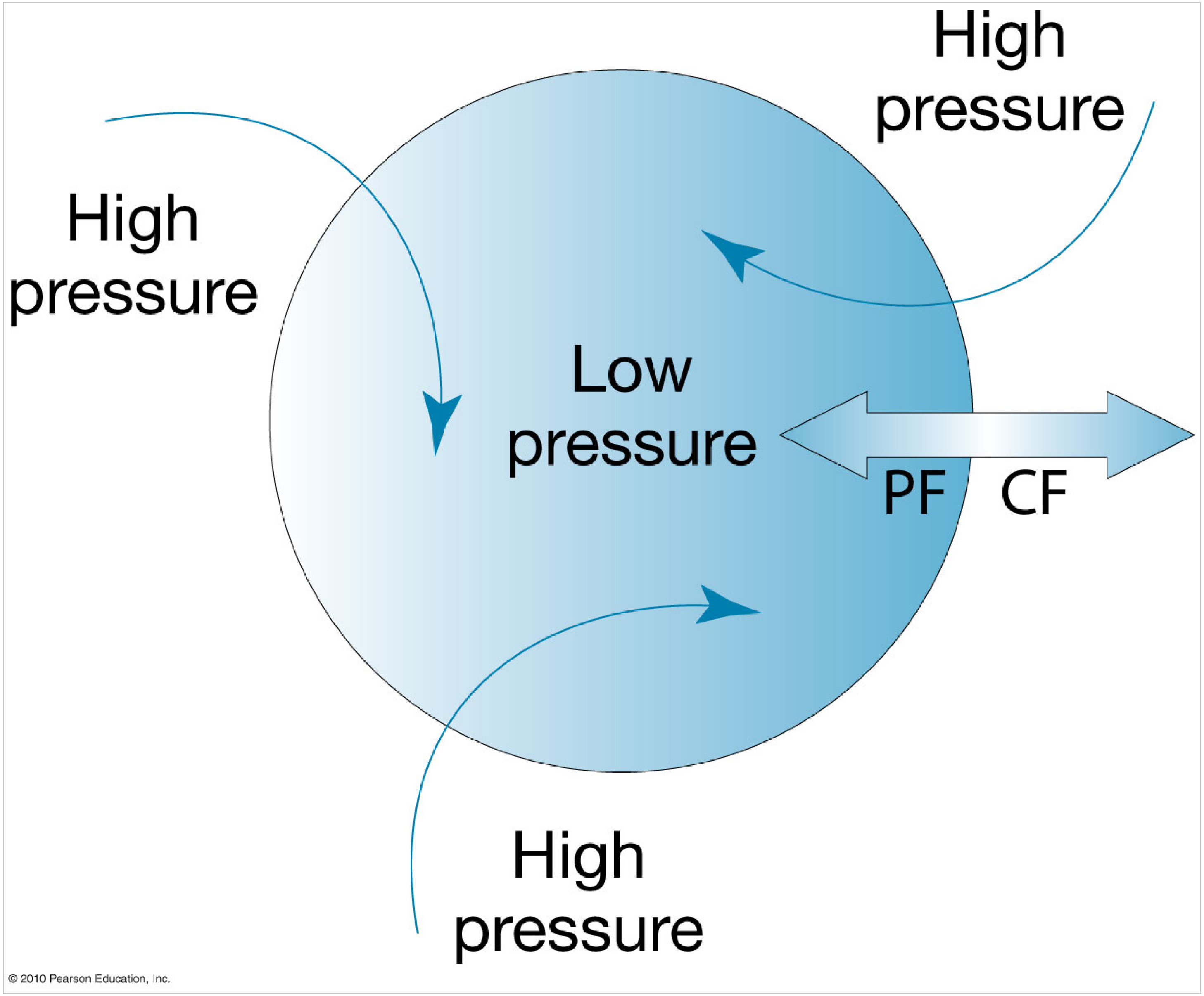


Why air moves along isobars, not across them…

Fig. 4-13:



Air circulation around a low pressure center

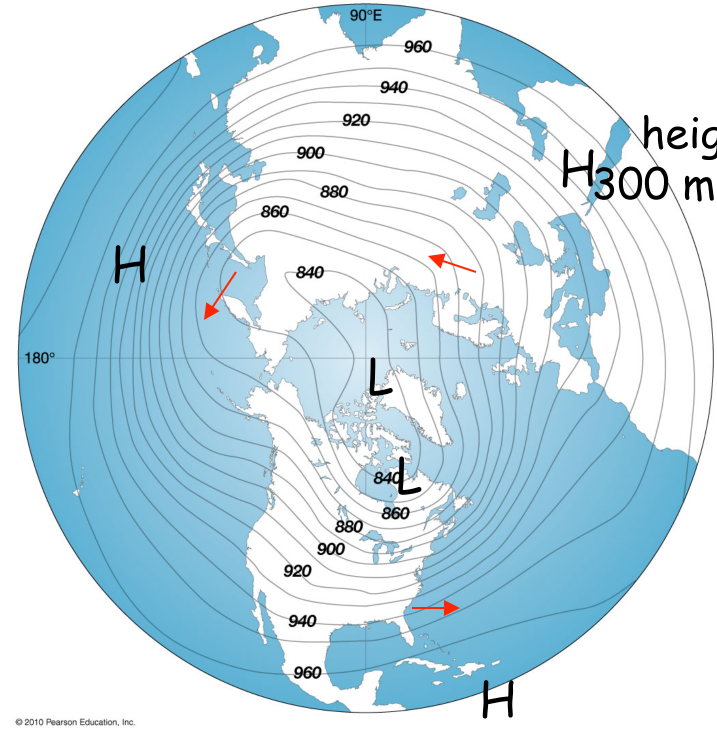


Forces driving the wind

- Like water, air will drain downhill, i.e. down the isobaric surfaces.
- But the Earth spins around its axis, and therefore the drainage current is deflected along the height contours ("geostrophic wind").
- The reason for this deflection is the same one that explains why a ball on a merry-go-round does not go straight (as seen while sitting on the merry-go-round) (the "Coriolis force").

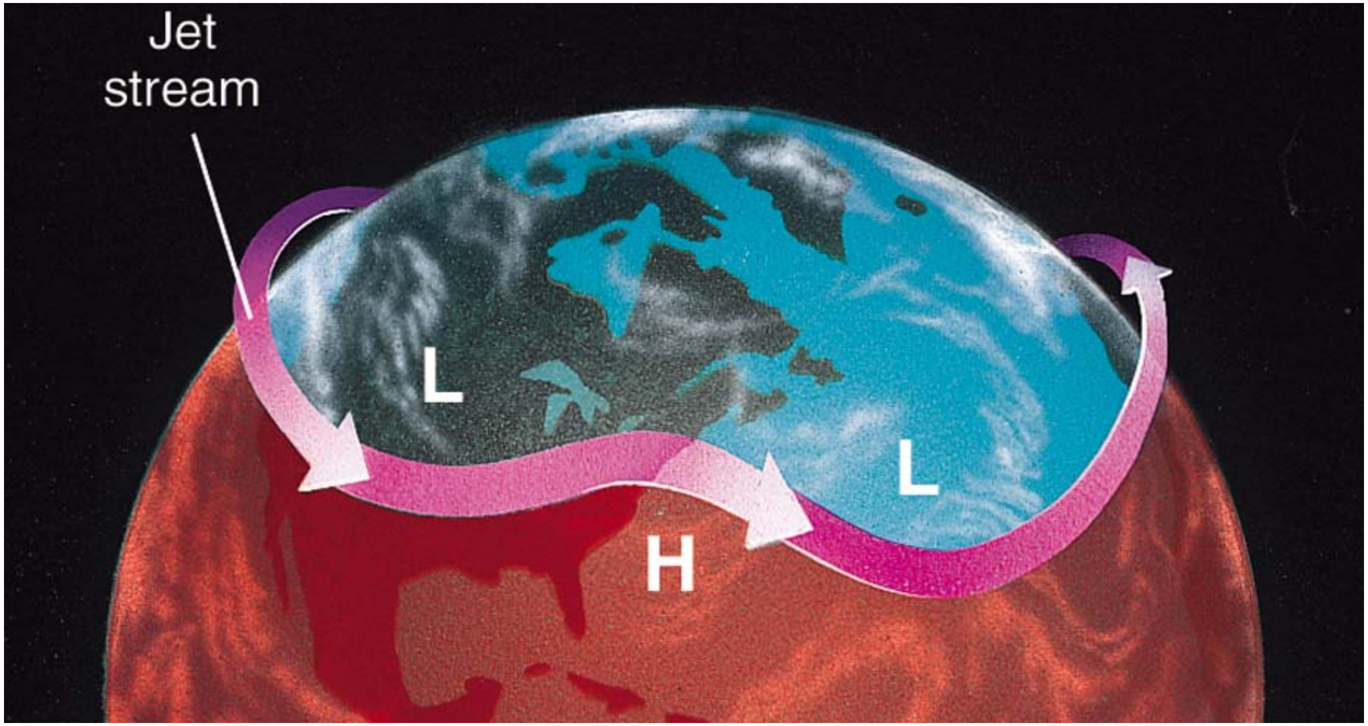
Thus the wind blows around lows, counterclockwise in the NH, and clockwise in the SH, and is stronger when the slope is steeper (more height contours)

The larger the temperature gradient below, the stronger the jet stream



height of the 300 mb surface

Mid-latitude atmospheric circulations

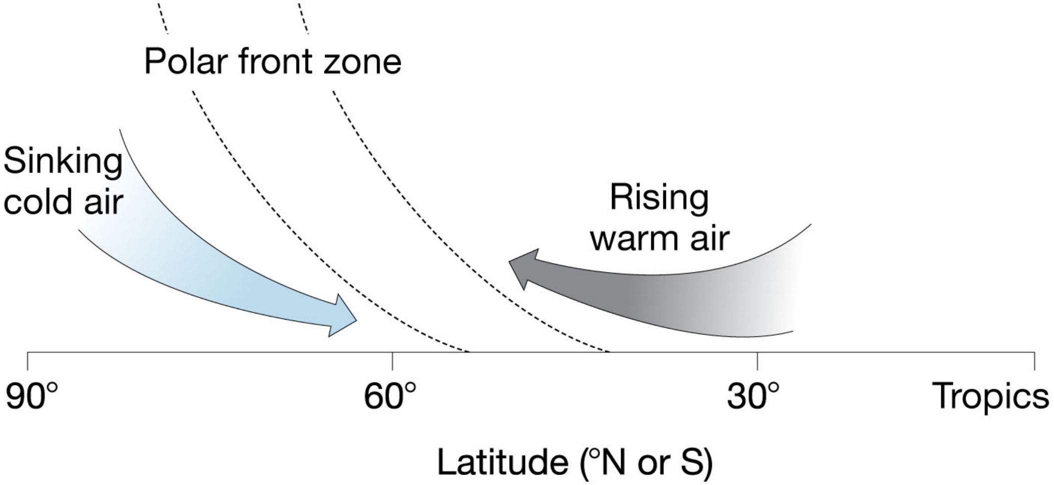


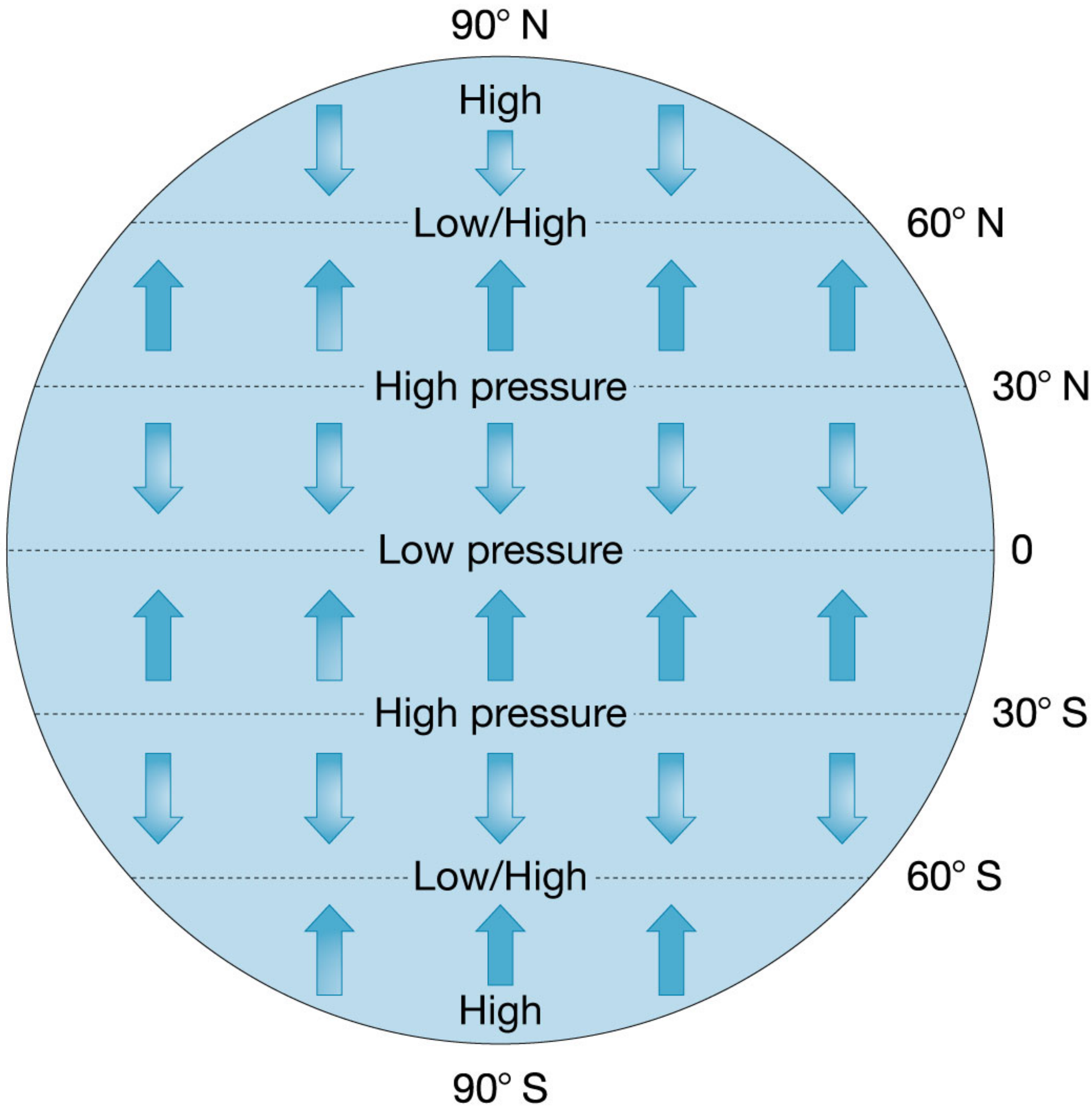
"polar front jet"
~10-12 km high
(33-39 kft)

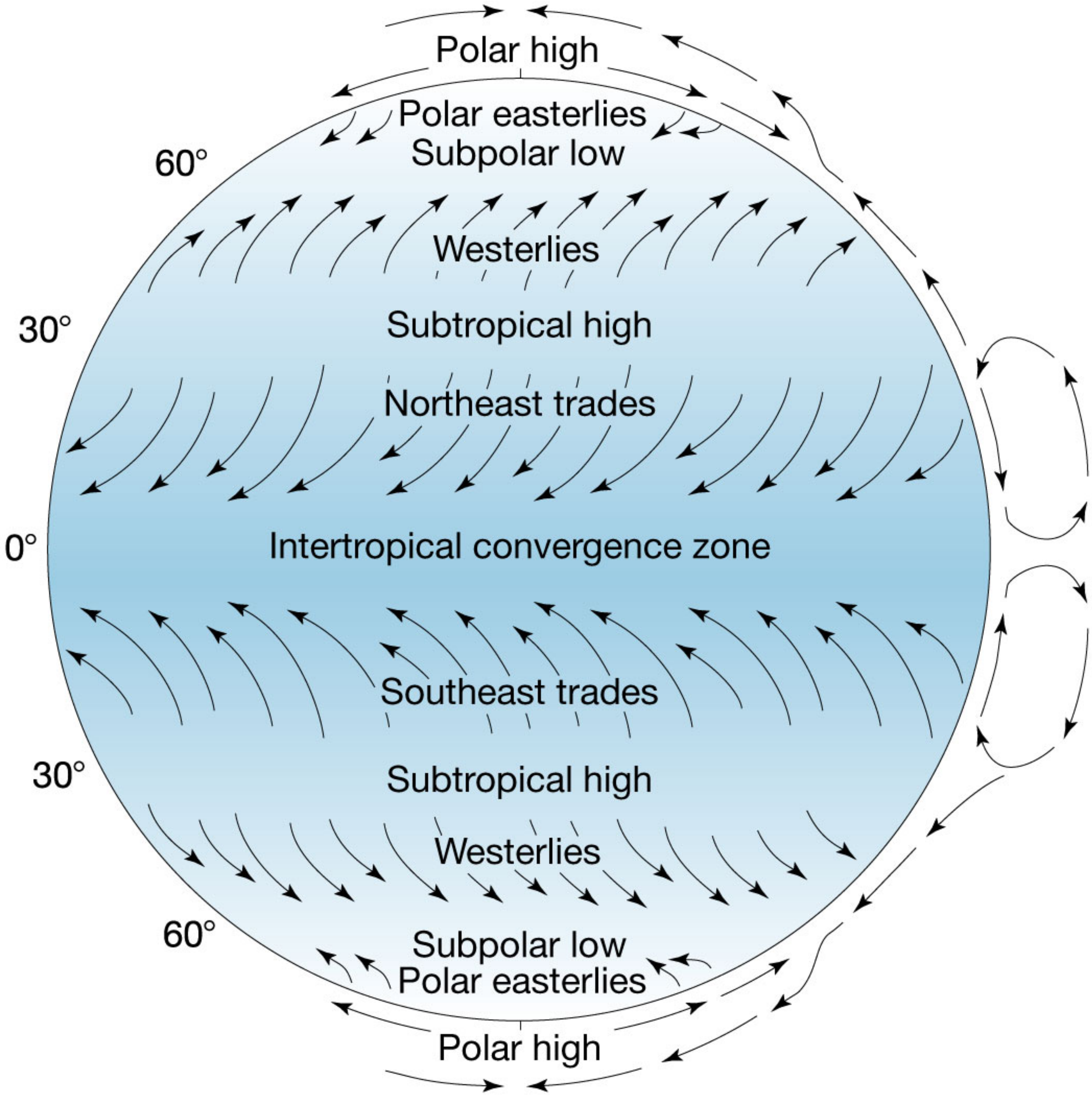
the jet is located above the polar front, a region of largest temperature gradient

In what season is the jet stream strongest?

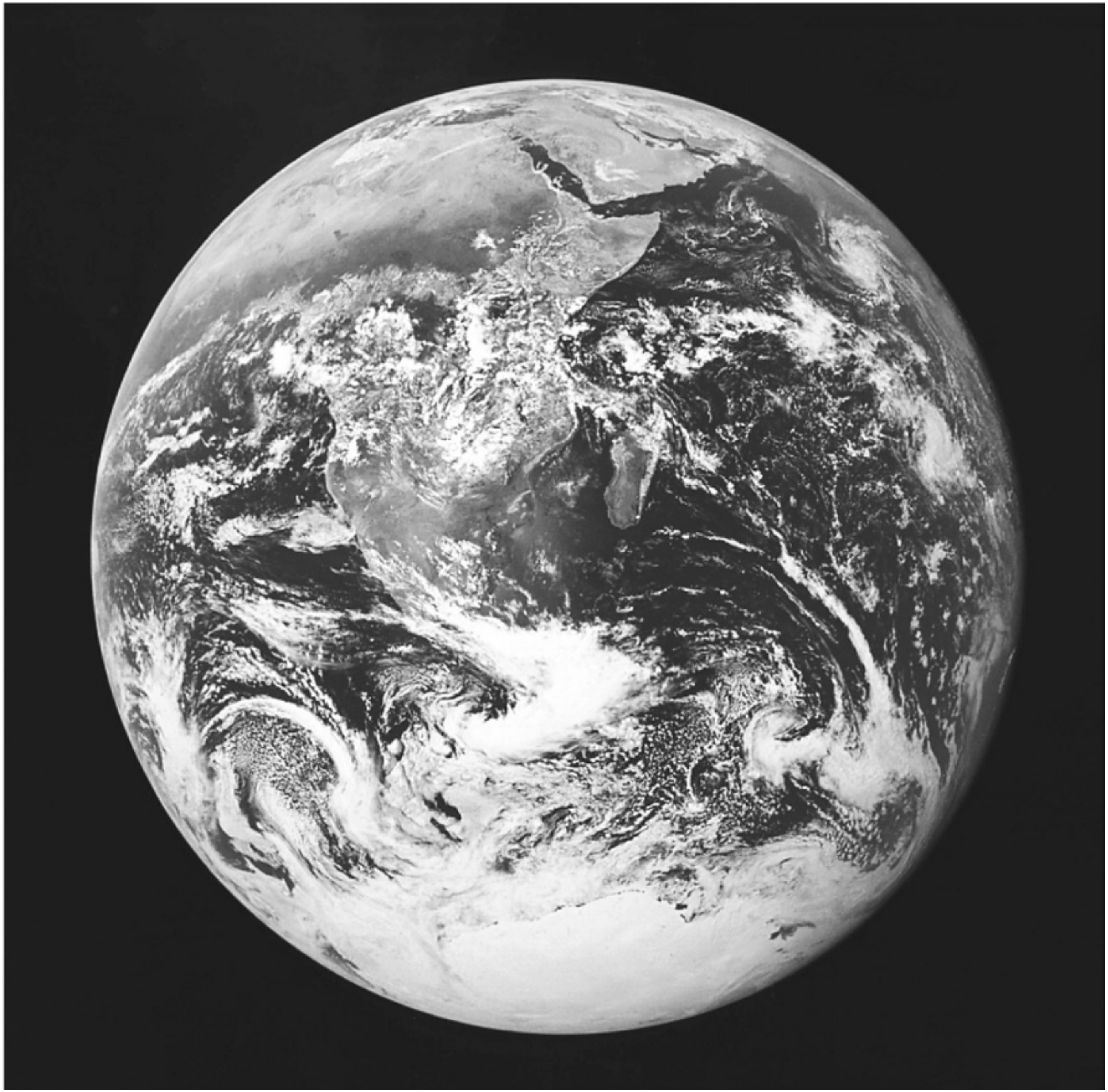
In winter, because the "meridional" temperature gradient is greatest.




90° N
High
Low/High
60° N
High pressure
30° N
Low pressure
0
High pressure
30° S
Low/High
60° S
High
90° S


Polar high
Polar easterlies
Subpolar low
60°
Westerlies
30°
Subtropical high
Northeast trades
0°
Intertropical convergence zone
Southeast trades
30°
Subtropical high
Westerlies
60°
Subpolar low
Polar easterlies
Polar high

Apollo 8: Out first image of Earth from a distance – Dec. 1968



Regional Winds (not global)

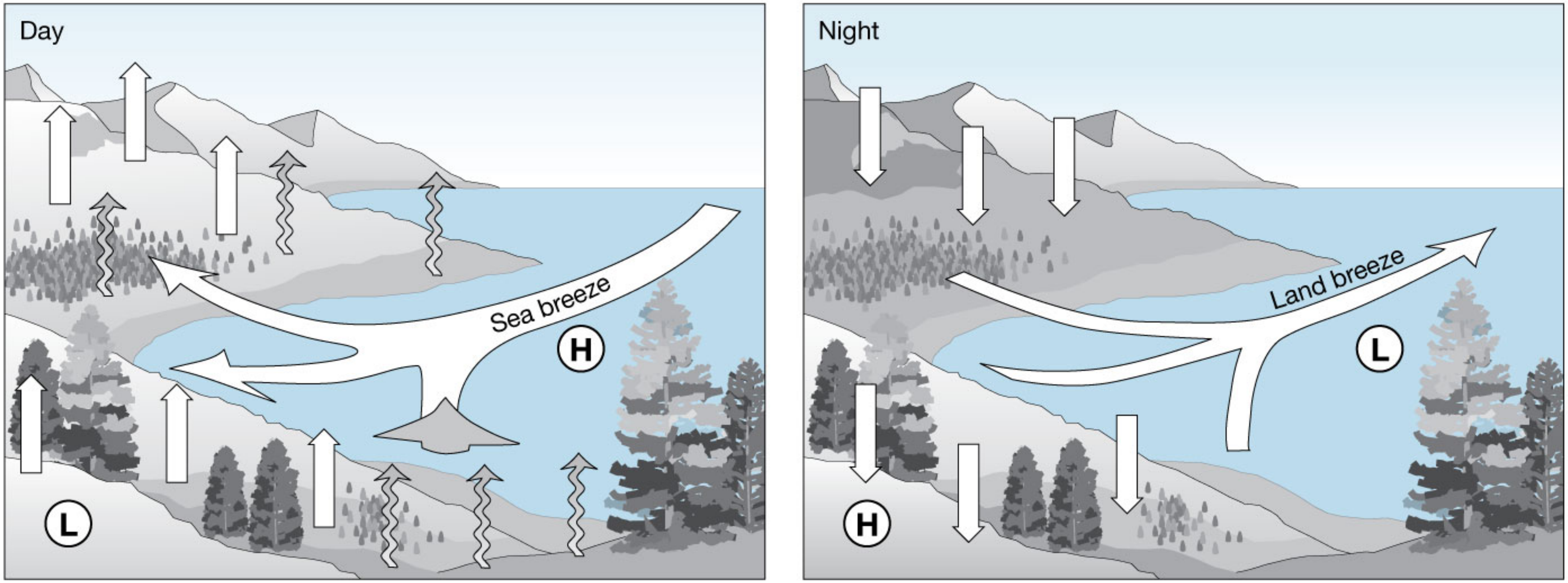


Fig. 4-17

Fig. 4-15:

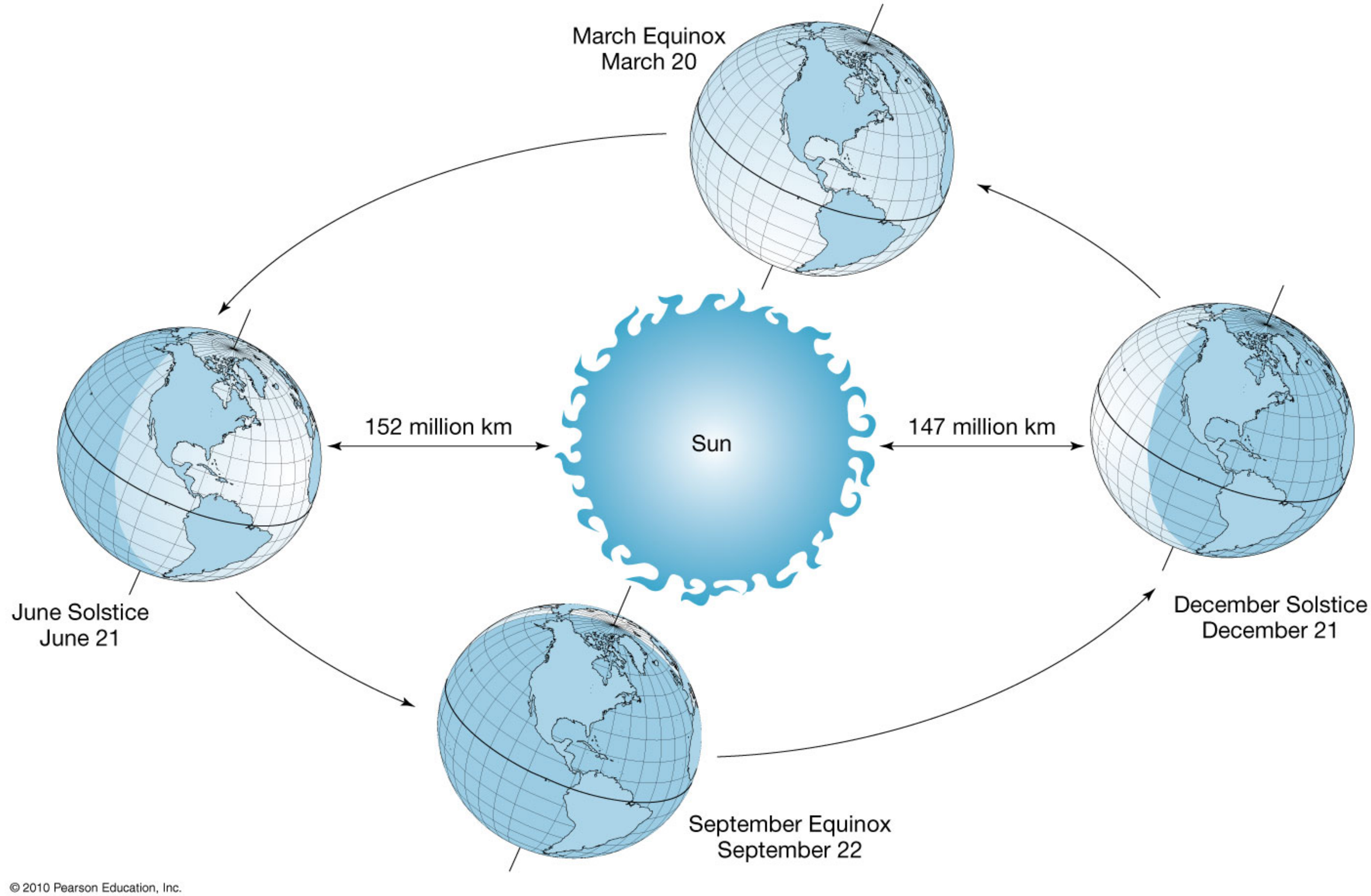
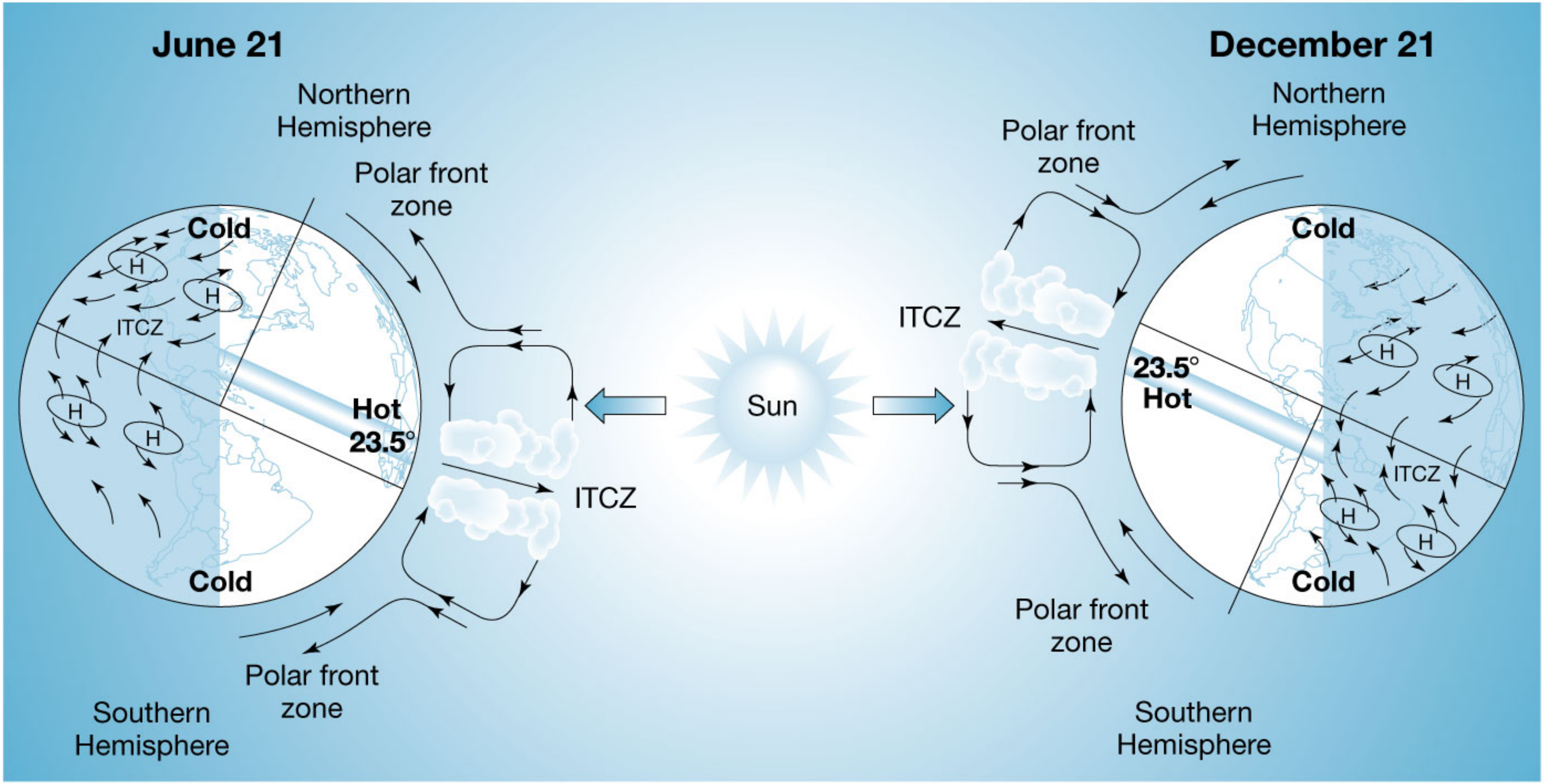
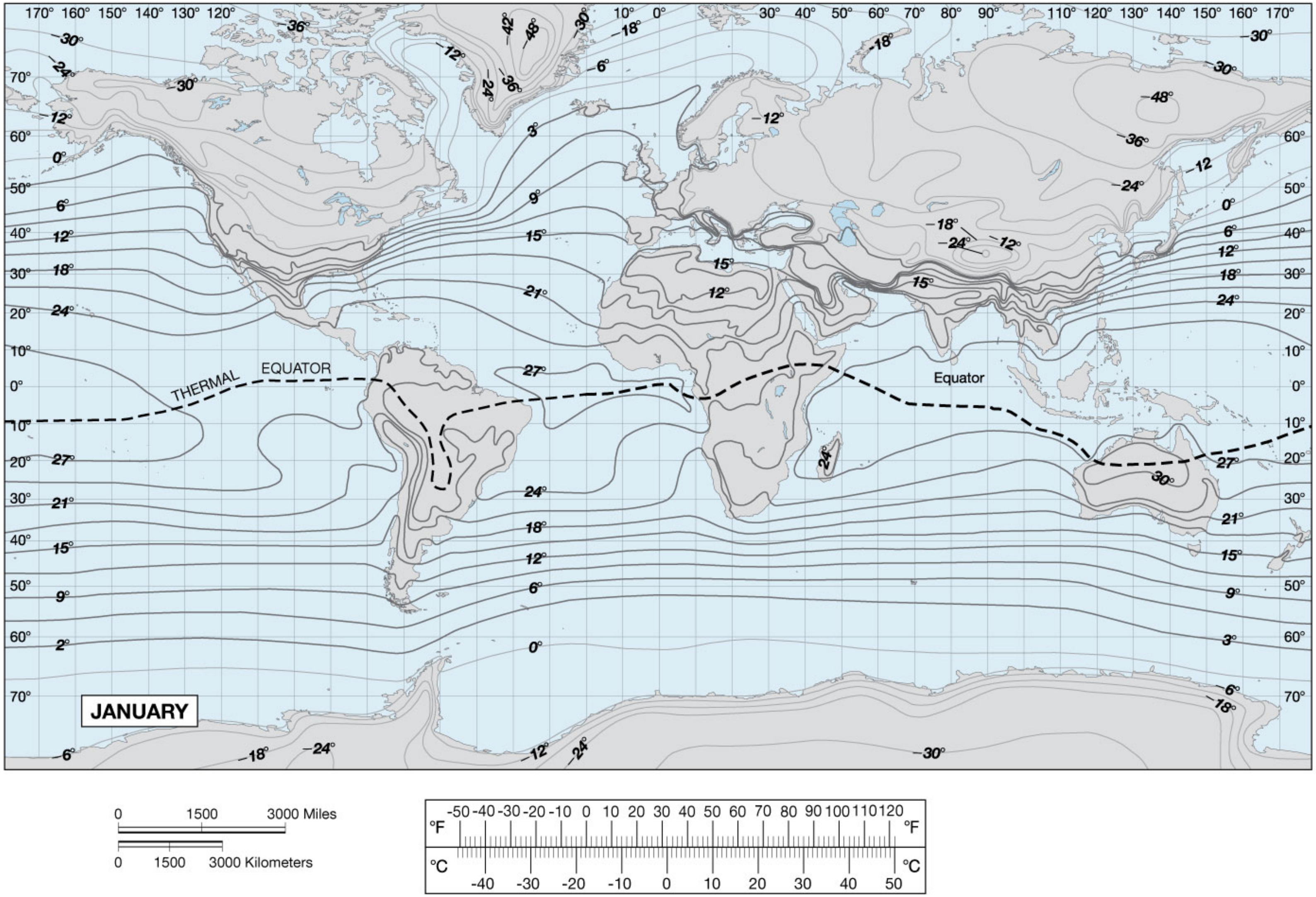

March Equinox
March 20
152 million km
Sun
147 million km
June Solstice
June 21
December Solstice
December 21
September Equinox
September 22
© 2010 Pearson Education, Inc.

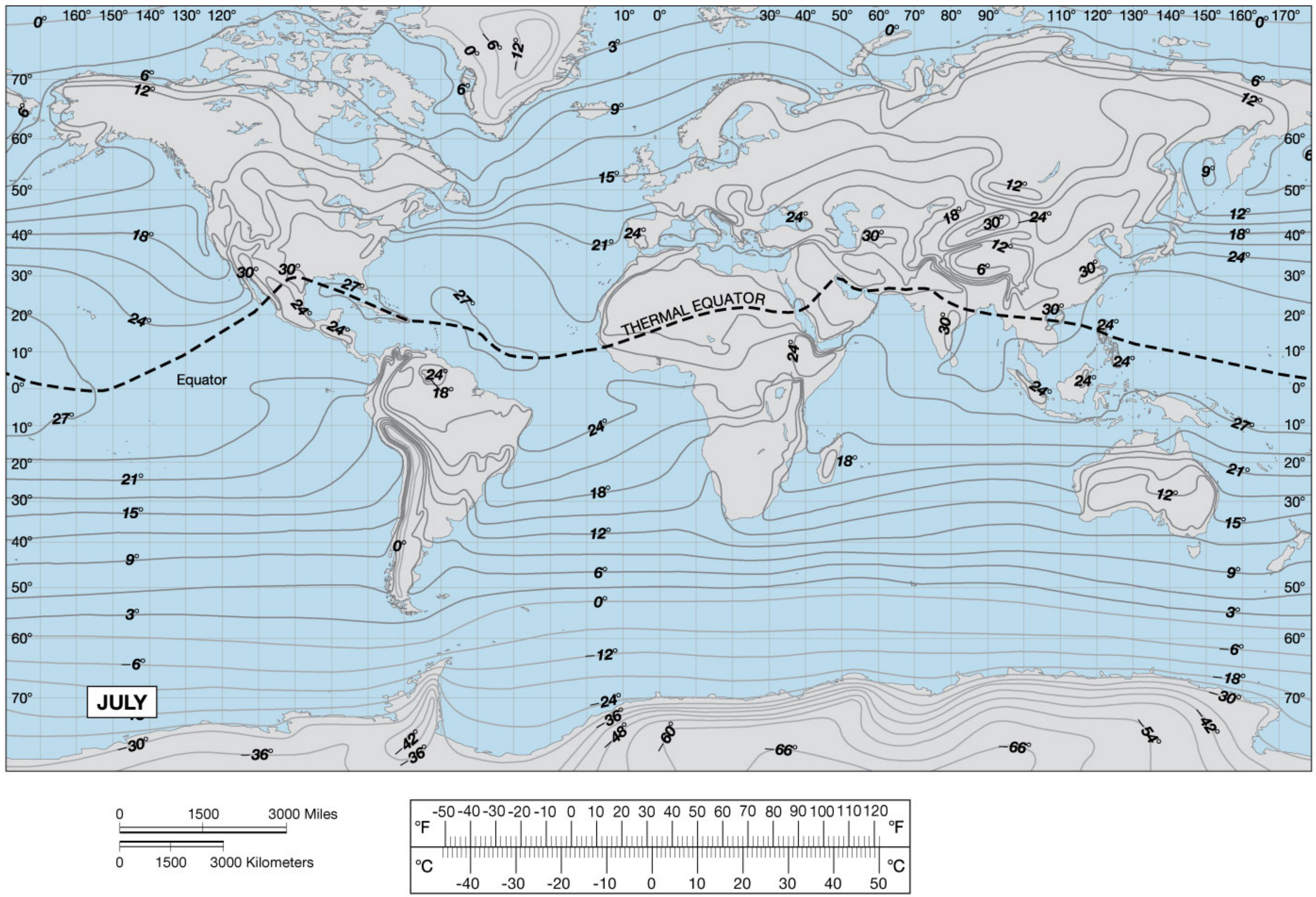
Fig. 4-16:


June 21
Northern Hemisphere
Polar front zone
Cold
H
H
ITCZ
H
H
Hot
23.5°
Cold
ITCZ
Polar front zone
Southern Hemisphere
Sun
December 21
Northern Hemisphere
Polar front zone
ITCZ
Cold
23.5°
Hot
H
H
ITCZ
H
H
Cold
Polar front zone
Southern Hemisphere



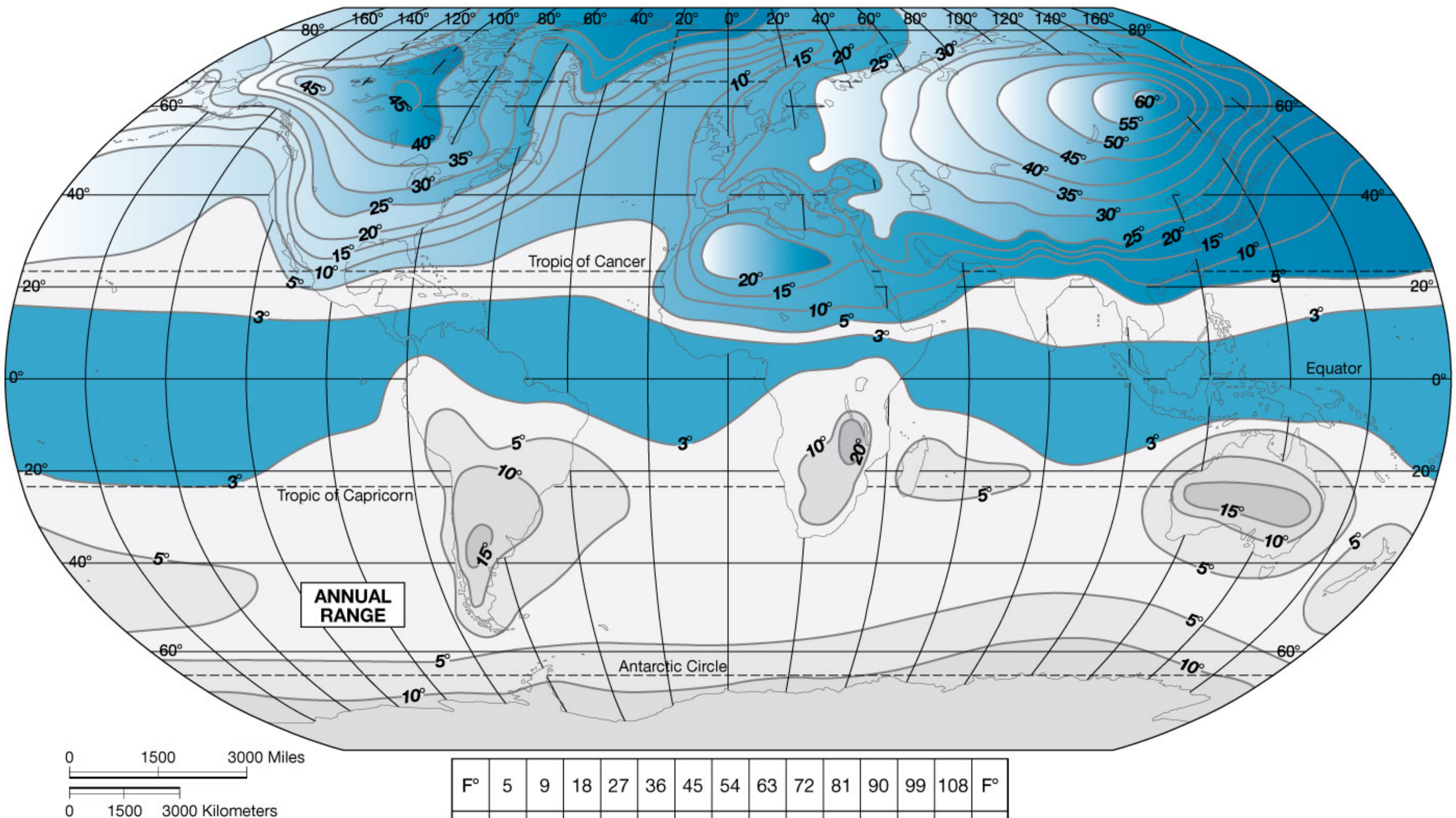
JANUARY
THERMAL EQUATOR
Equator
0 1500 3000 Miles
0 1500 3000 Kilometers
°F -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 °F
°C -40 -30 -20 -10 0 10 20 30 40 50 °C

(a)


JULY
THERMAL EQUATOR
Equator
0 1500 3000 Miles
0 1500 3000 Kilometers
°F
°C

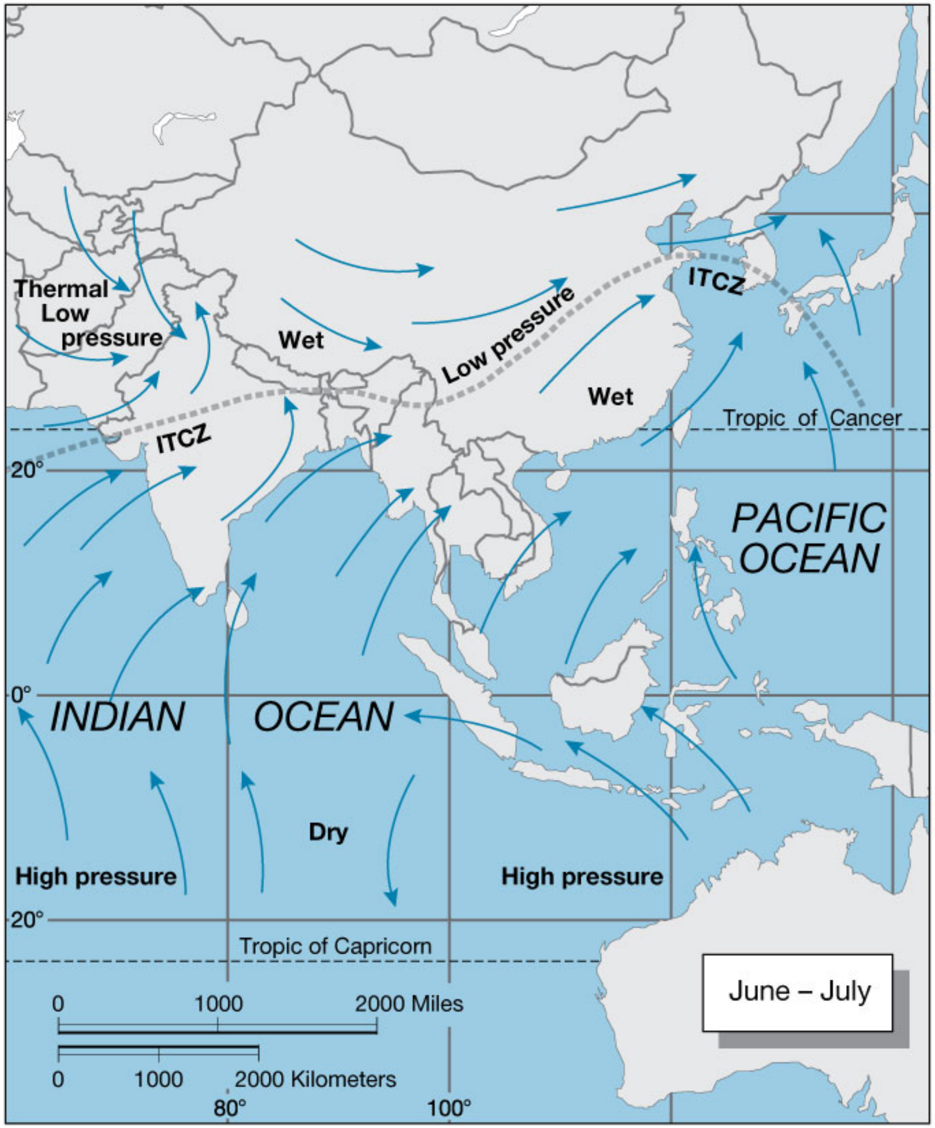
(b)

Annual range of temperatures:



F°	5	9	18	27	36	45	54	63	72	81	90	99	108	F°
C°	3	5	10	15	20	25	30	35	40	45	50	55	60	C°

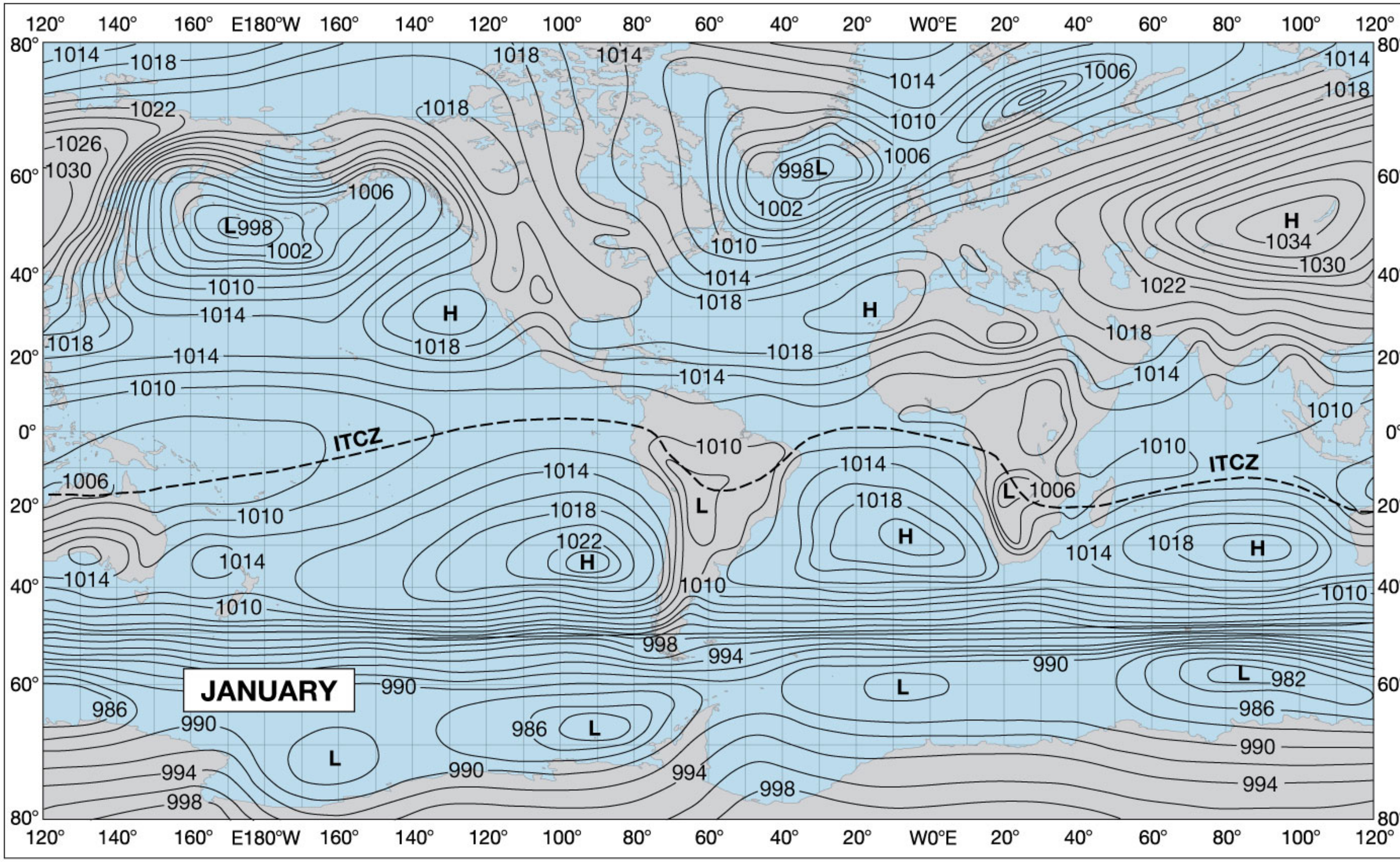
(c)


Thermal
Low
pressure
Wet
Low pressure
ITCZ
Wet
ITCZ
Tropic of Cancer
20°
PACIFIC
OCEAN
0°
INDIAN
OCEAN
Dry
High pressure
High pressure
20°
Tropic of Capricorn
0
1000
2000 Miles
0
1000
2000 Kilometers
80°
100°
June – July

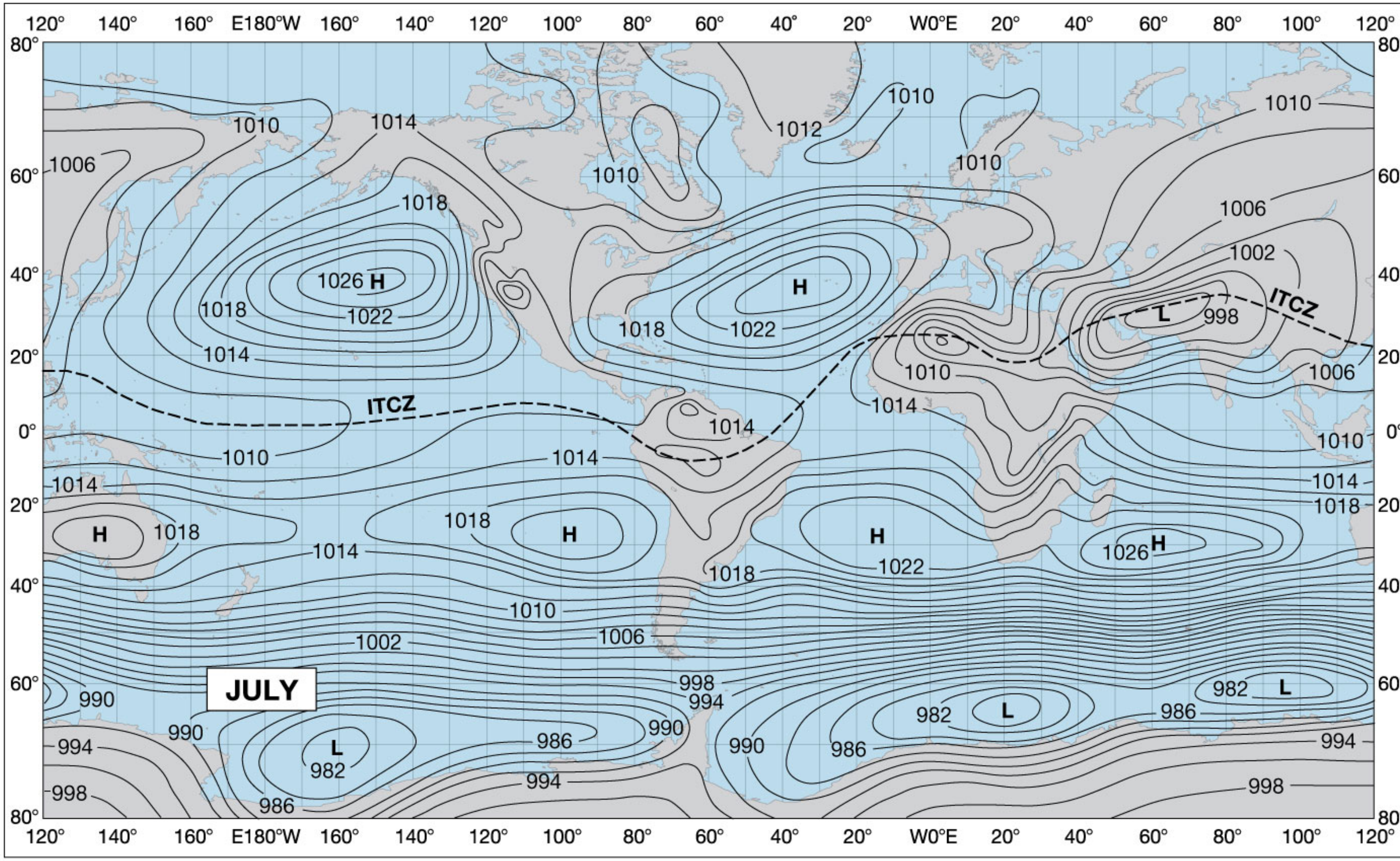
(a)


High pressure
Dry
Dry
Tropic of Cancer
20°
Dry
PACIFIC
OCEAN
0°
INDIAN
OCEAN
ITCZ
Low pressure
ITCZ
High pressure
20°
Tropic of Capricorn
0
1000
2000 Miles
0
1000
2000 Kilometers
80°
100°
December – January

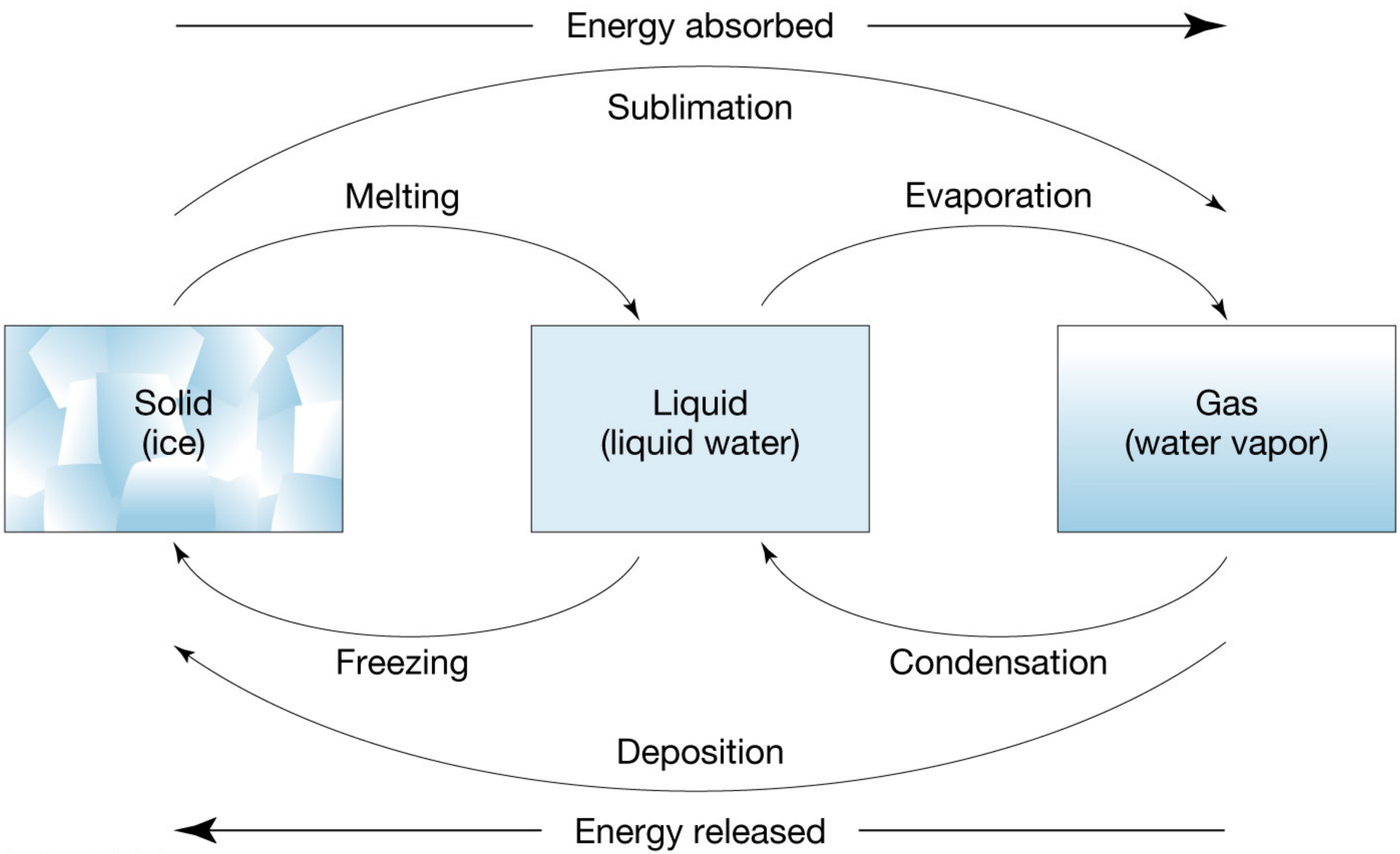
(b)


JANUARY
ITCZ
120° 140° 160° E180°W 160° 140° 120° 100° 80° 60° 40° 20° W0°E 20° 40° 60° 80° 100° 120°
80° 60° 40° 20° 0° 20° 40° 60° 80°
H
L
1034
1030
1022
1018
1014
1010
1006
1002
998
994
990
986
982

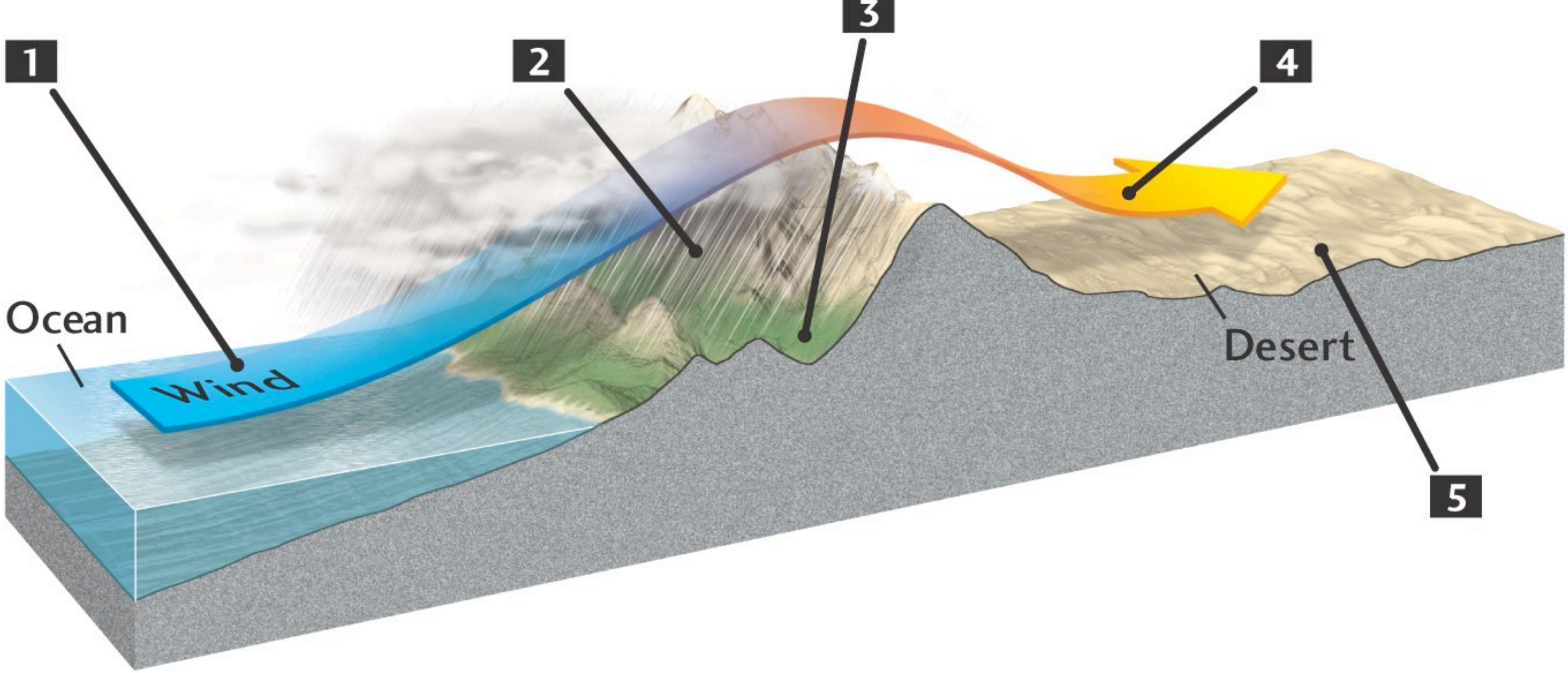
(a)


JULY
ITCZ
ITCZ
1026 H
1022
1018
1014
1010
1006
1002
998
994
990
986
982
H
L
120° 140° 160° E180°W 160° 140° 120° 100° 80° 60° 40° 20° W0°E 20° 40° 60° 80° 100° 120°
80° 60° 40° 20° 0° 20° 40° 60° 80°

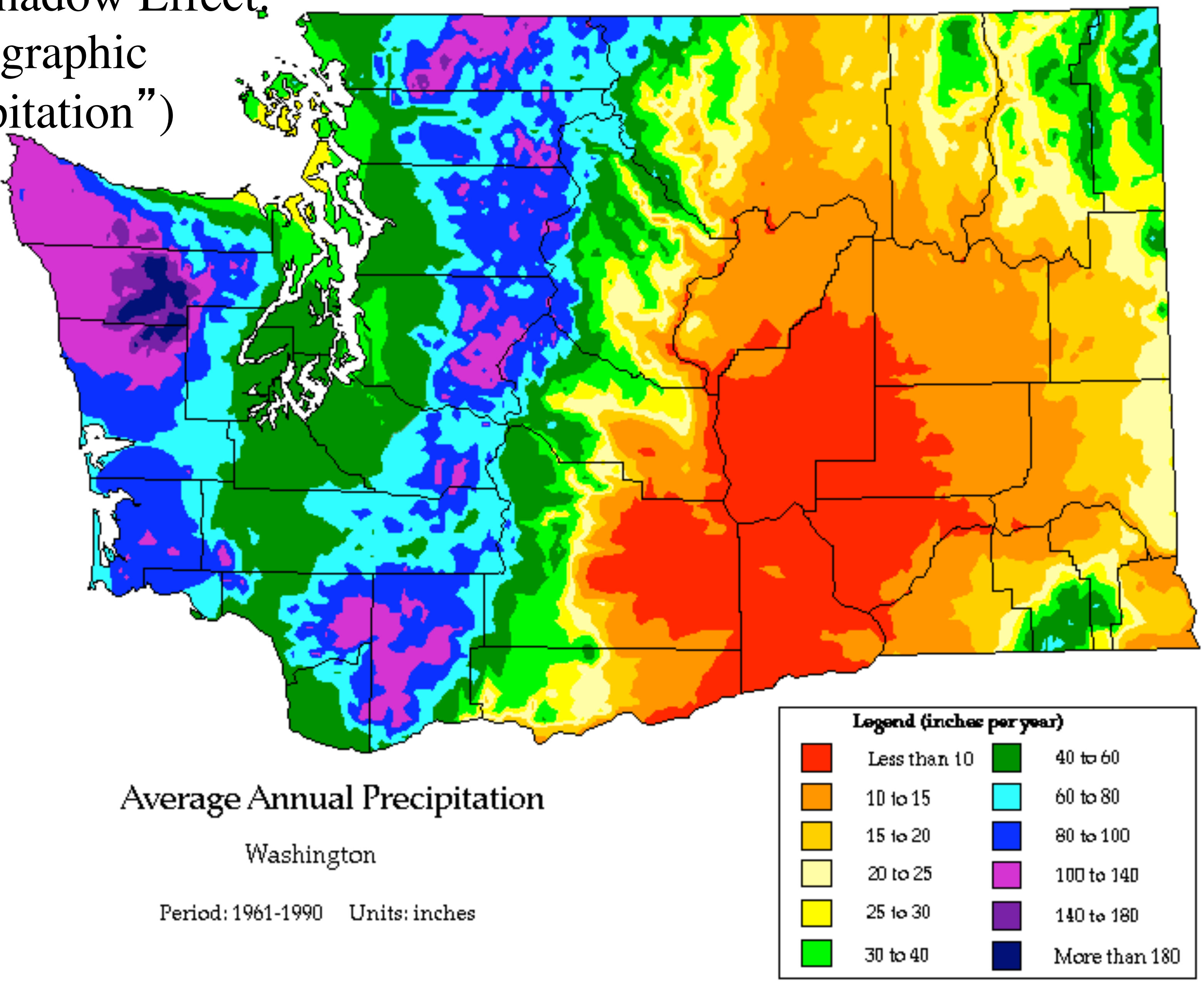
(b)


Energy absorbed
Sublimation
Melting
Evaporation
Solid
(ice)
Liquid
(liquid water)
Gas
(water vapor)
Freezing
Condensation
Deposition
Energy released

Orographic Precipitation

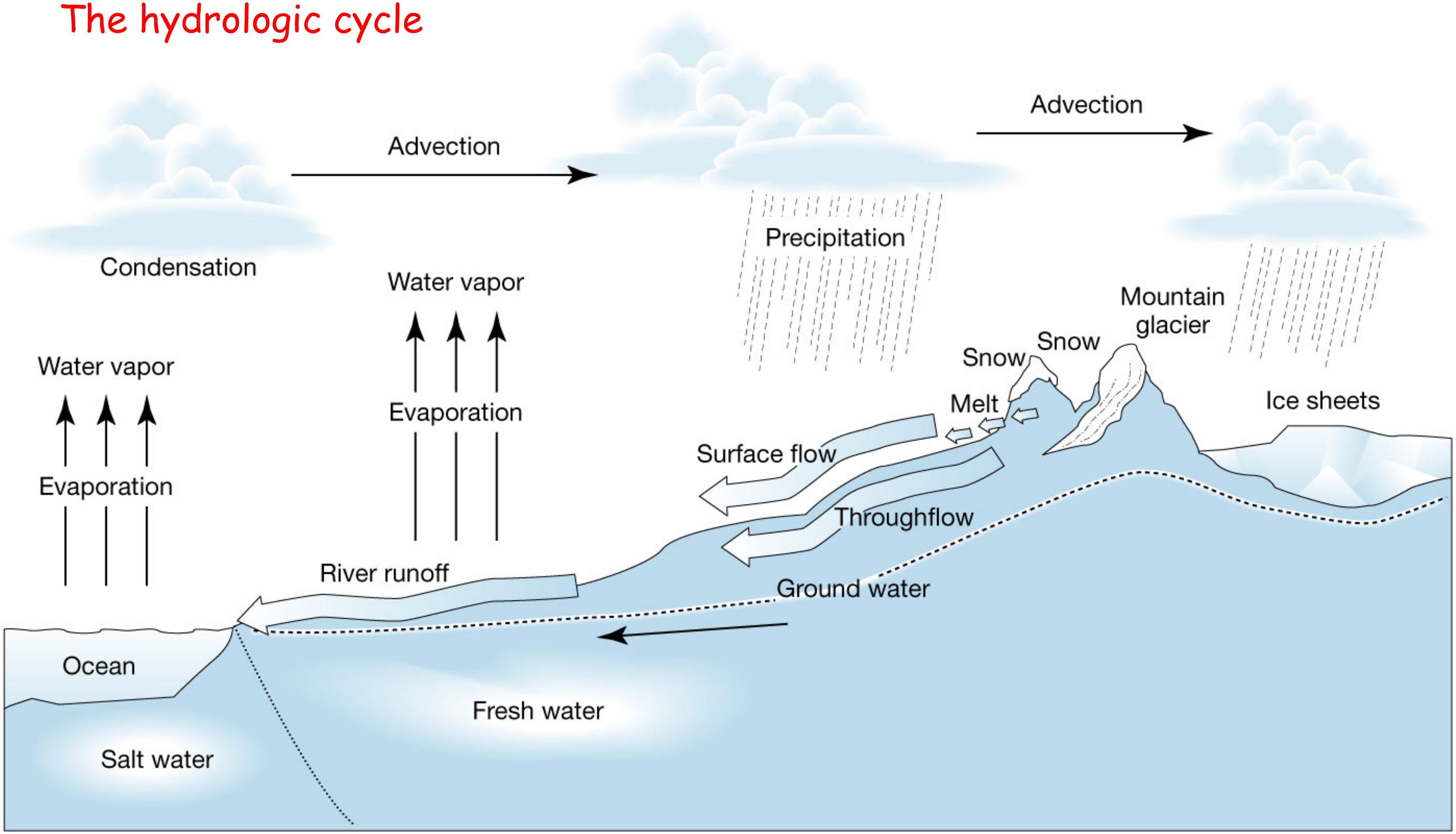


Rainshadow Effect:
("Orographic
Precipitation")



5. Precipitation: why it rains, or doesn't rain

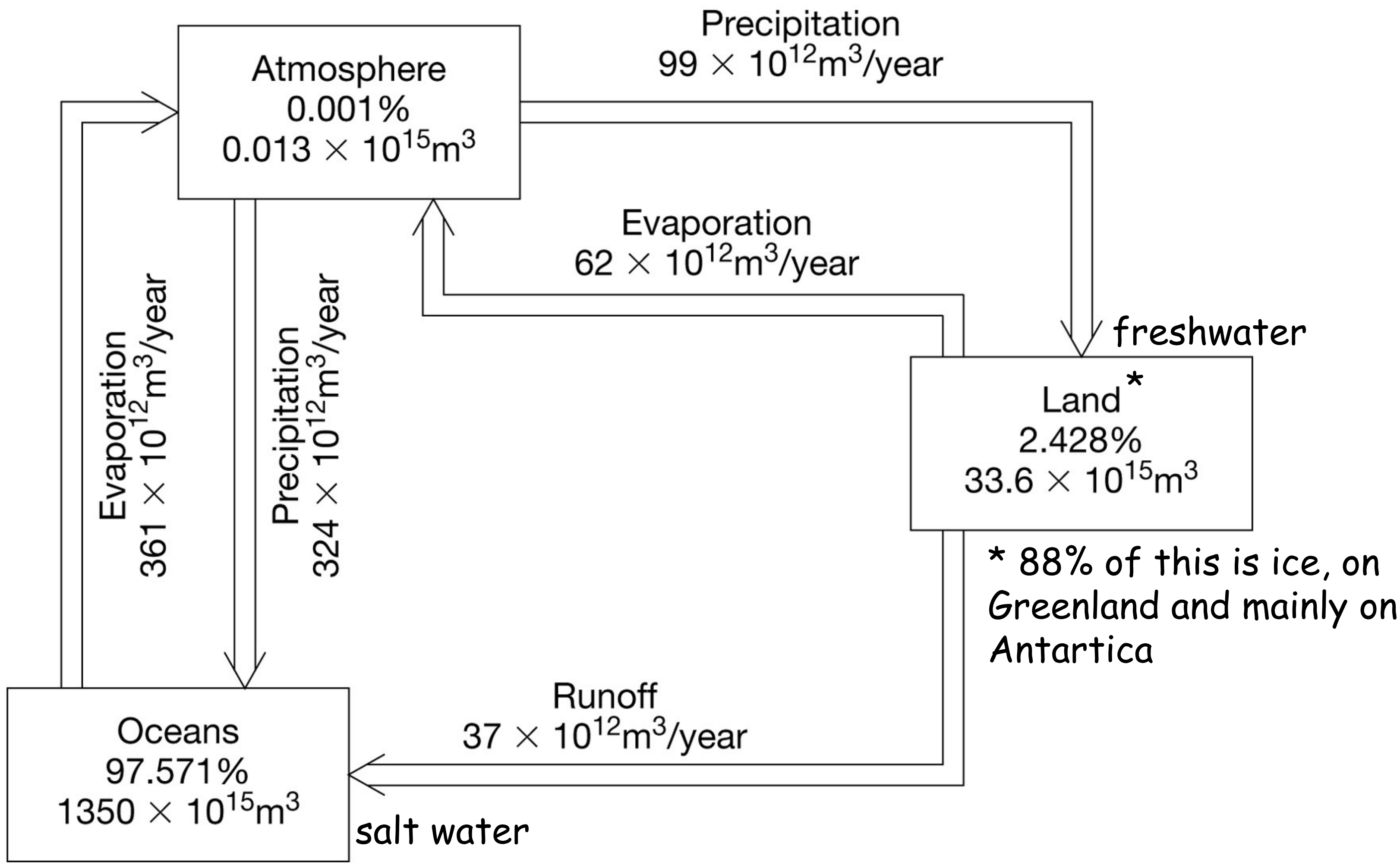
The hydrologic cycle



(a)

Water reservoirs and fluxes

list the key reservoirs, and rank them

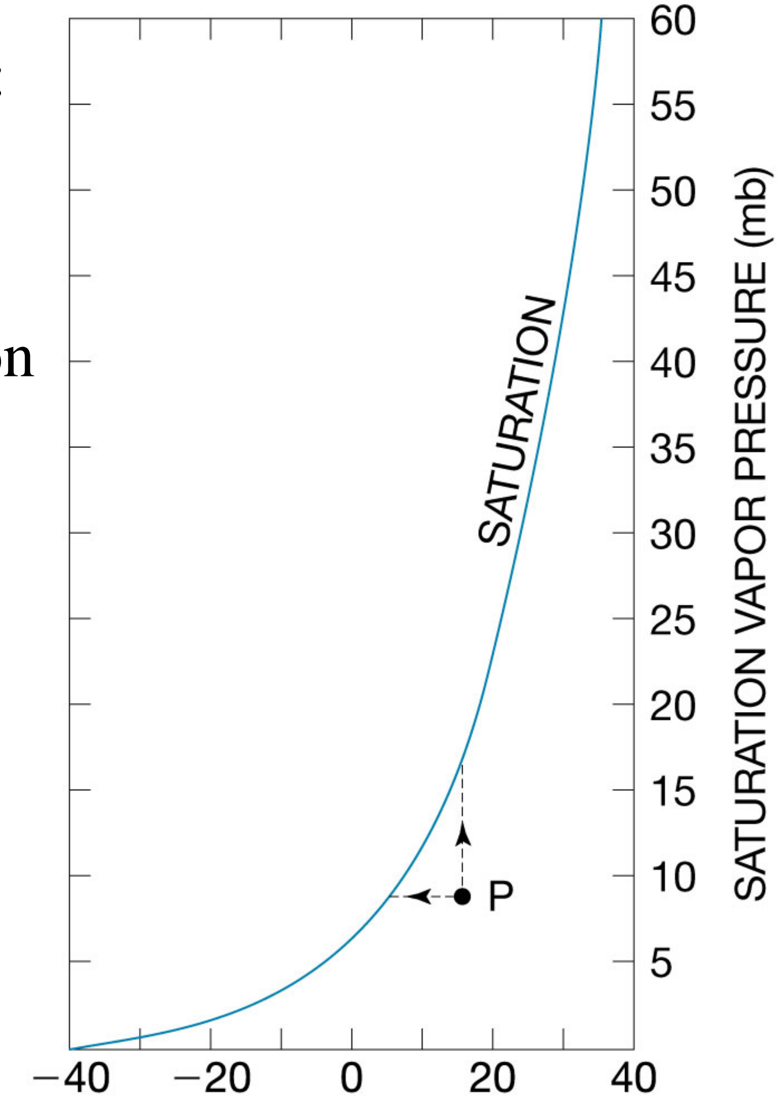


Atmospheric water vapor

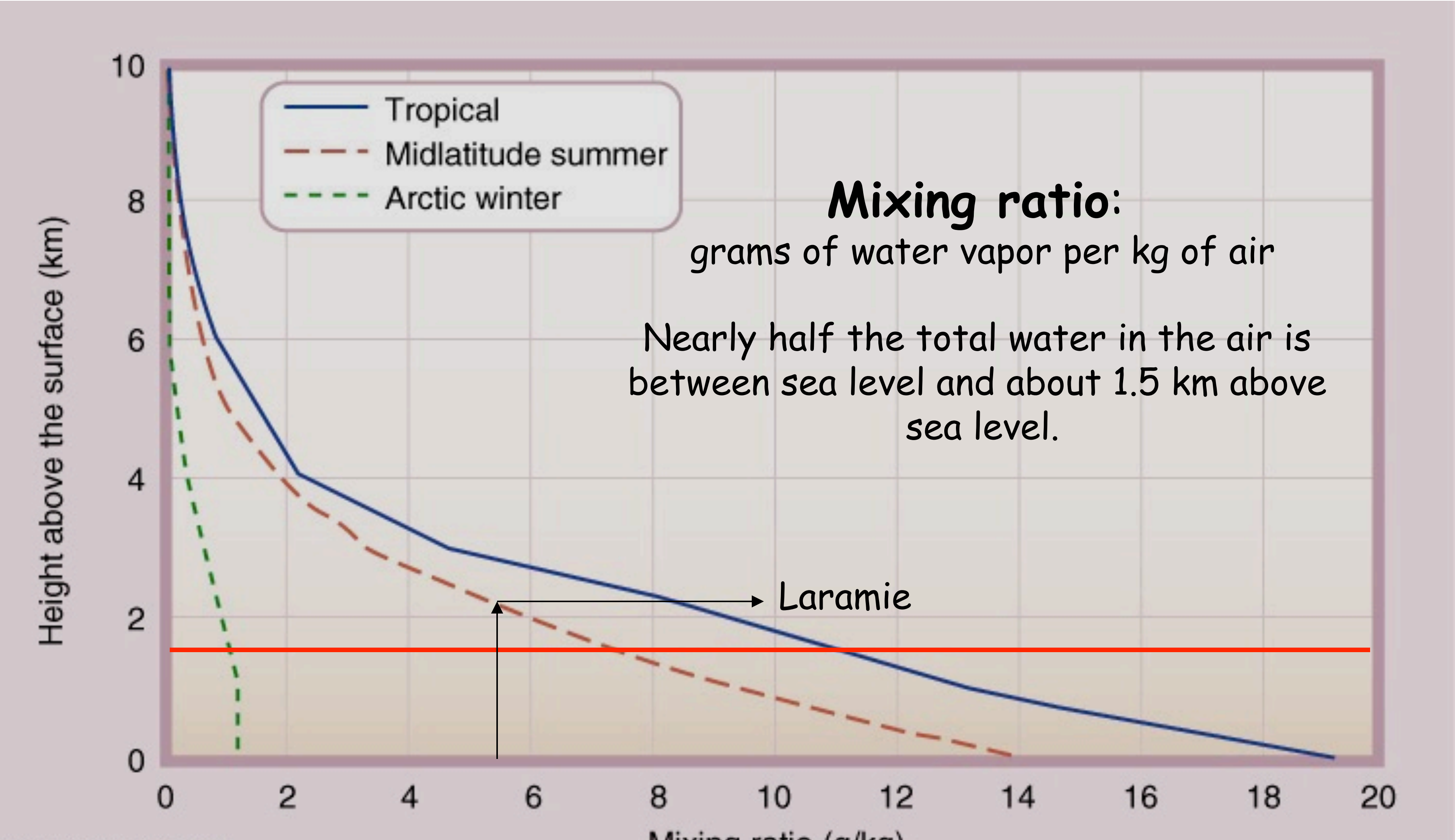
- The atmospheric water reservoir is tiny:
  - on average the precipitable water PW is 1’’ (25 mm).
- When air becomes saturated, water vapor condenses, leading to precipitation
- The global mean annual precip P is 40’’ (1000 mm)
- What is the average residence time of water vapor?
  - reservoir capacity/flux

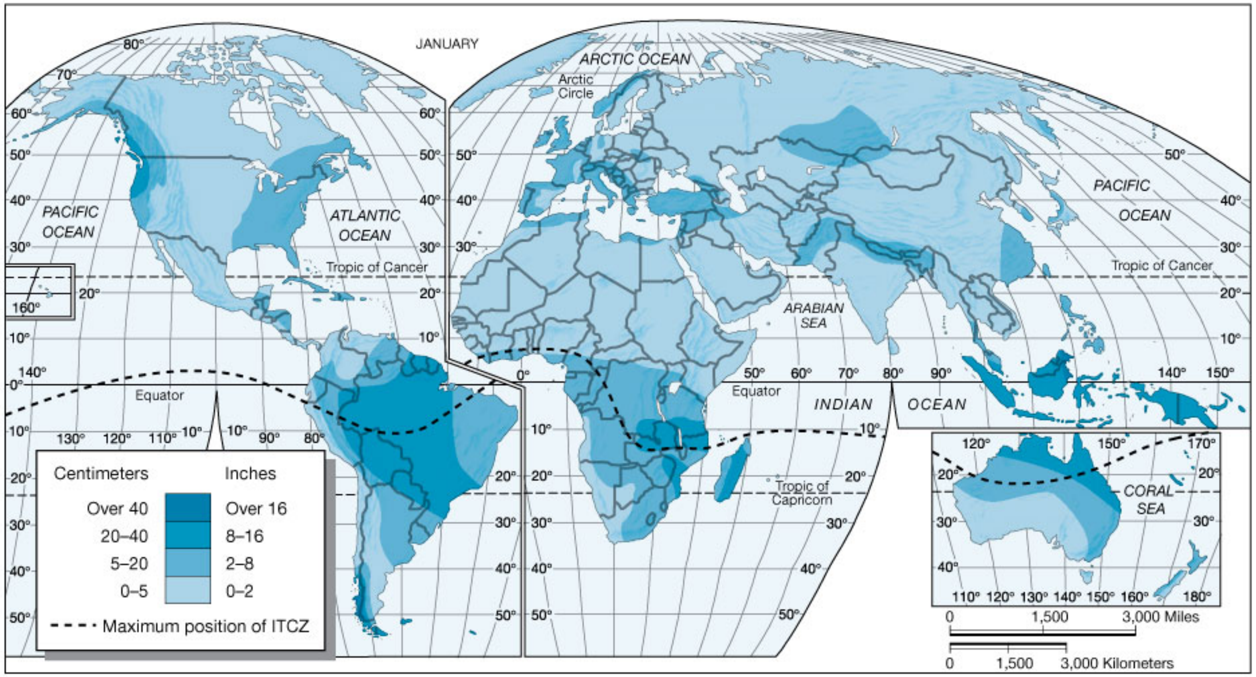
$$\frac{PW}{P} = \frac{1''}{40''/year} = 1/40\, year = 9\, days$$

- Water vapor cycles fast, and its concentration varies widely.

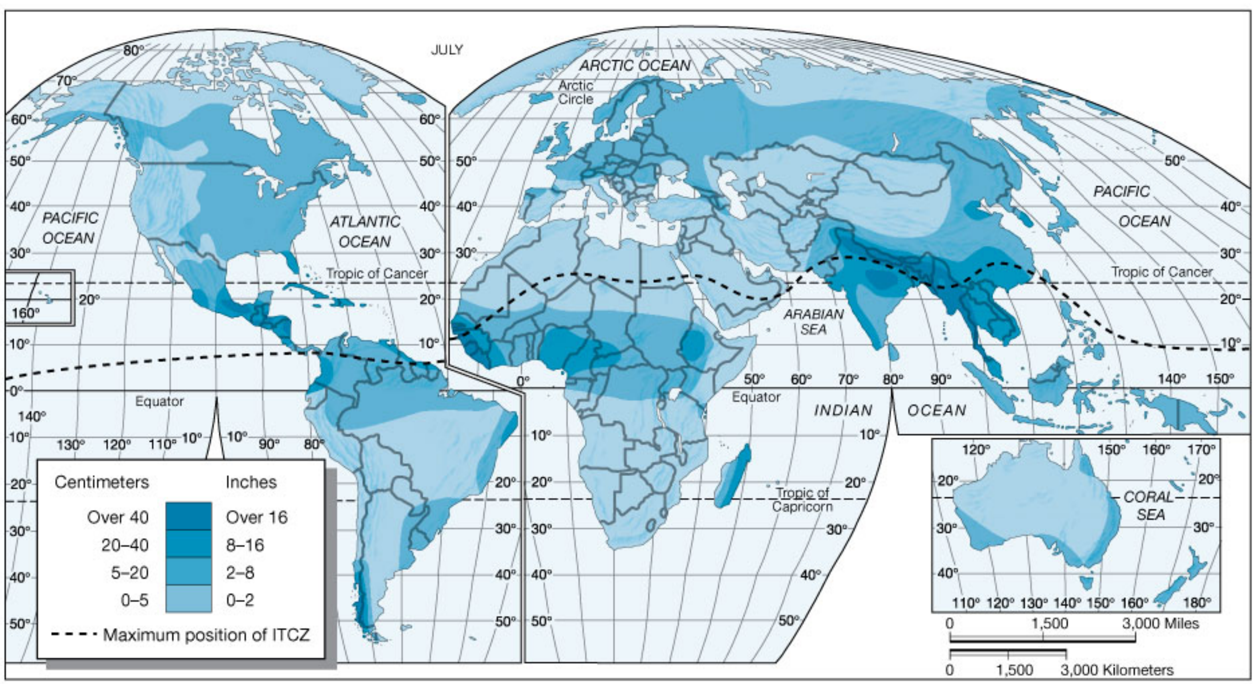


Almost all the atmospheric water vapor is close to sea level





MODIFIED GOODE'S HOMOLOSINE EQUAL-AREA PROJECTION

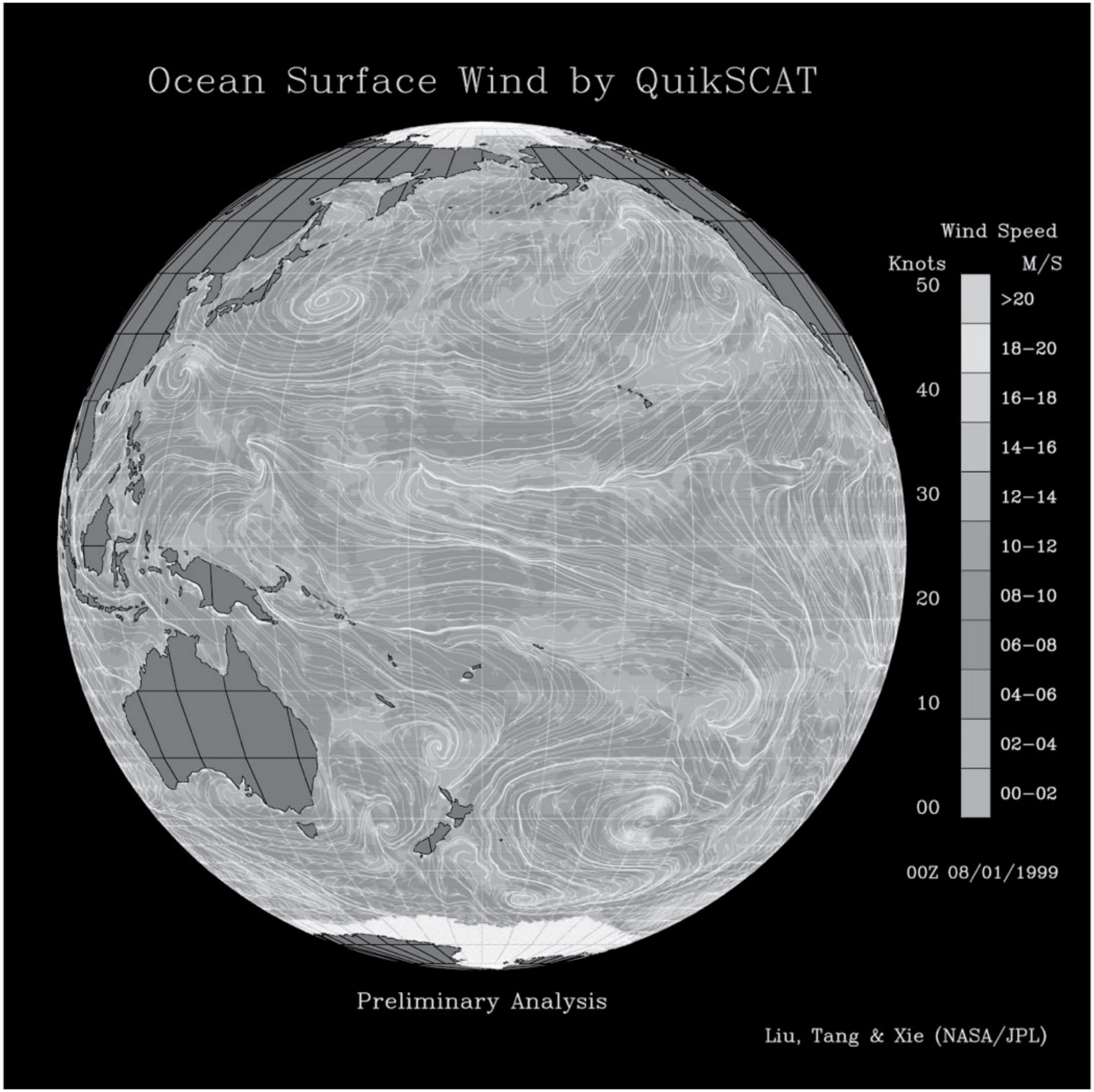


Global mean precipitation

In the Tropics, the ITCZ and the wet season move with the sun (zenithal rains).

In Mid-latitude regions,
- summers may bring thunderstorms over land
- the jet stream, frontal systems, and frontal precip are more intense in winter

High-latitude regions are quite dry.


Ocean Surface Wind by QuikSCAT
Wind Speed
Knots
M/S
50
40
30
20
10
00
>20
18–20
16–18
14–16
12–14
10–12
08–10
06–08
04–06
02–04
00–02
00Z 08/01/1999
Preliminary Analysis
Liu, Tang & Xie (NASA/JPL)