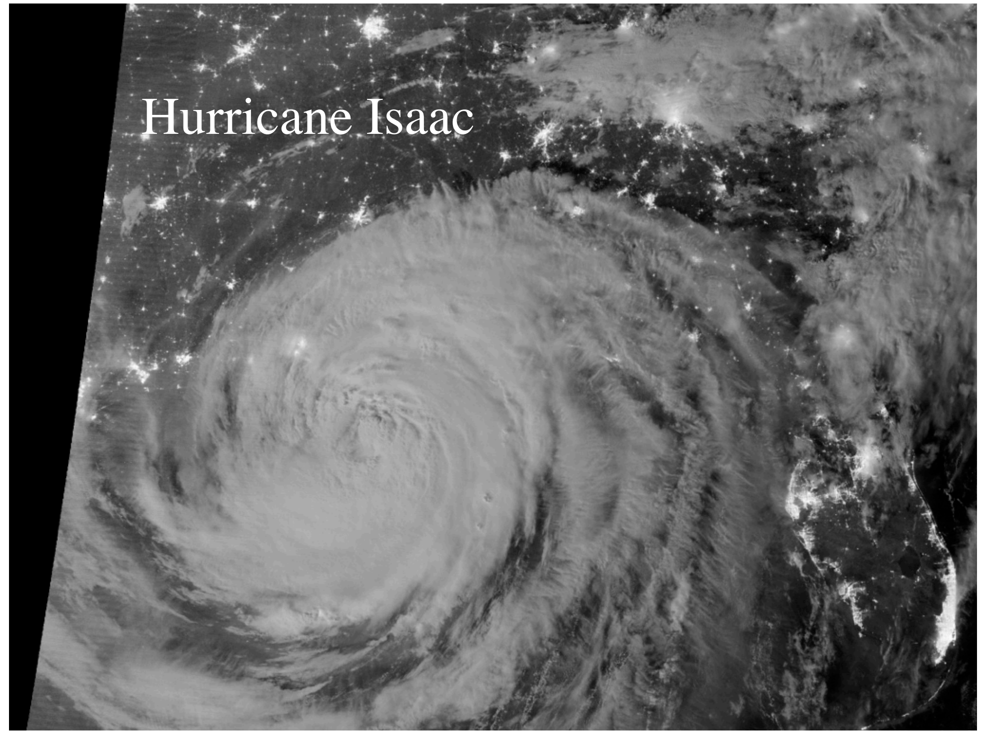
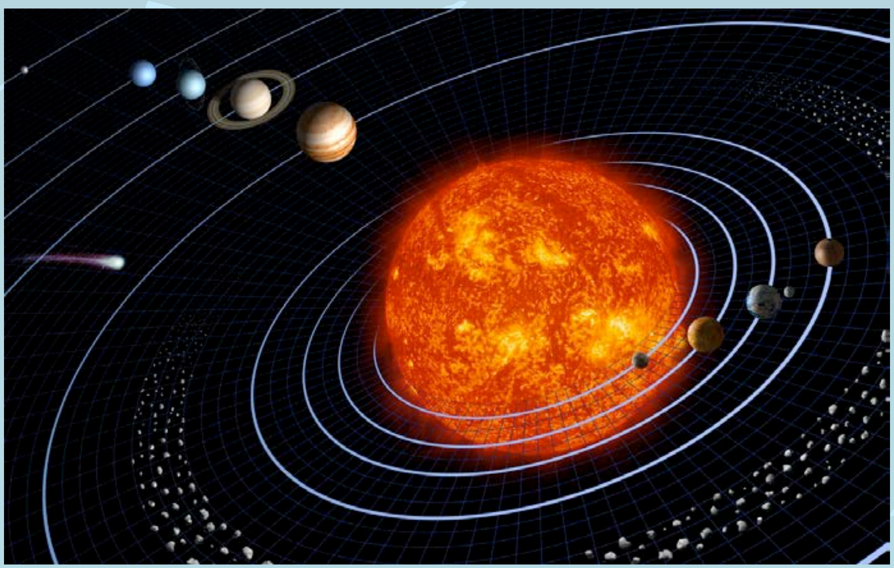
MET101 Lecture 5
Seasons and the Diurnal Cycle

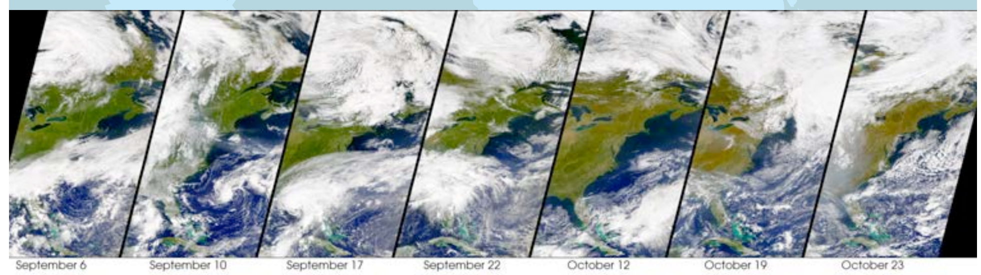
Hurricane Isaac



Previous Lecture: Radiation



MET 200 Lecture 4
Seasons and the Diurnal Cycle



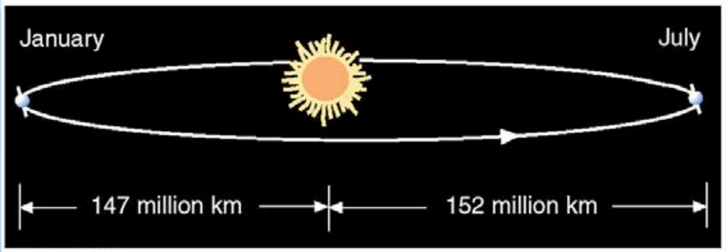
Outline

- Seasons
- The Diurnal (Daily) Temperature Cycle

What Causes the Seasons?

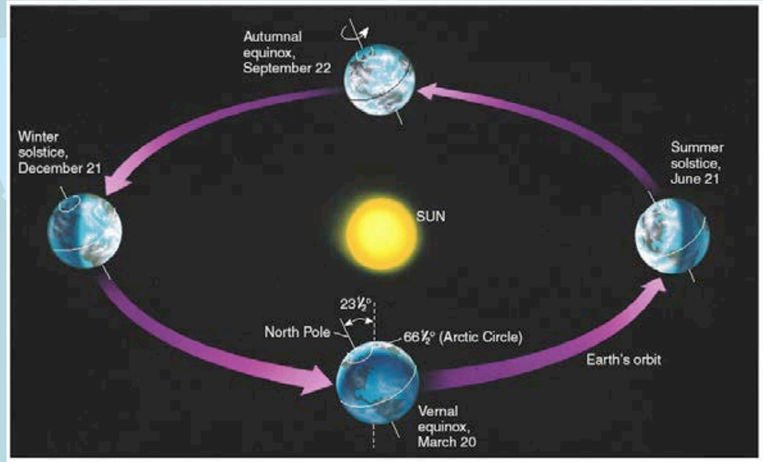
Why is summer warmer?
Hypothesis: closer to the sun?

Hypothesis test 1: Farther from sun in July!



Hypothesis test 2: When Northern Hemisphere is in summer, Southern Hemisphere is in winter.

The Earth's Orbit



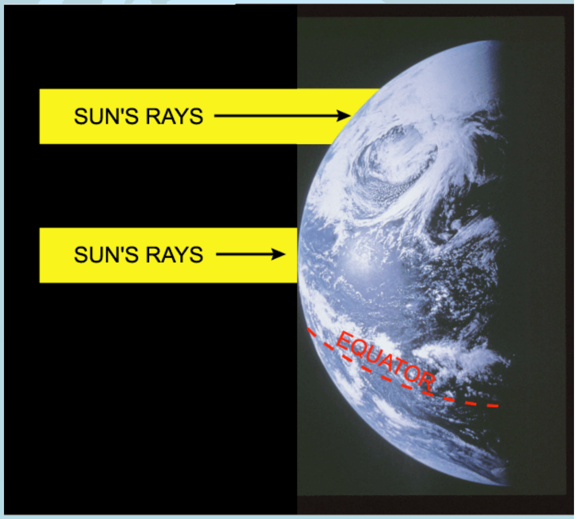
The earth's orbit around the sun leads to seasons because of the tilt of the Earth's axis and the changes in the distribution of sunlight across the Earth's surface during the year.

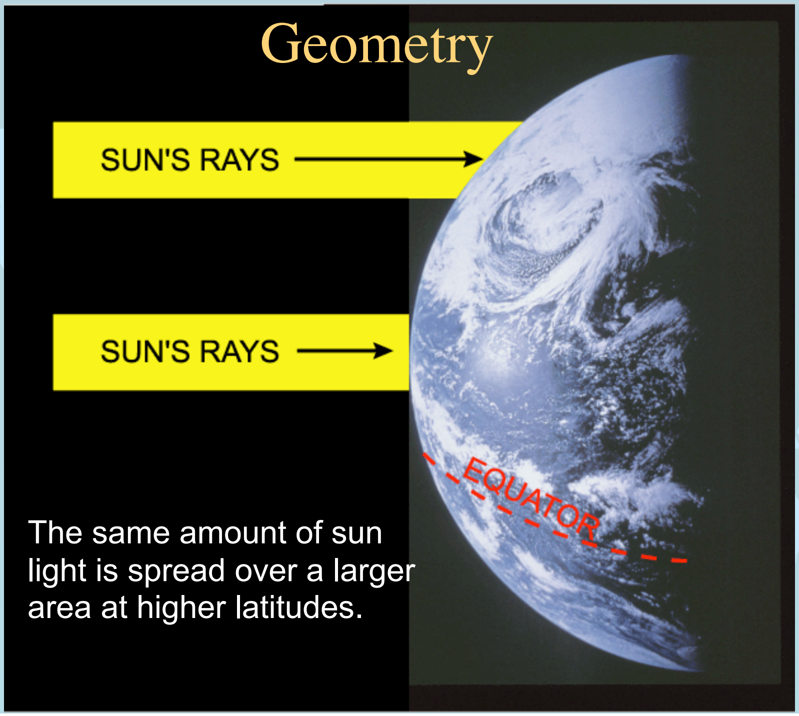
Reason for Seasons

1. Geometry – sunlight is distributed unequally over surface.
2. Reflection of sunlight by Earth's surface and clouds (Albedo).
3. Scatter and absorption of sunlight by atmosphere due to differing atmospheric path lengths.

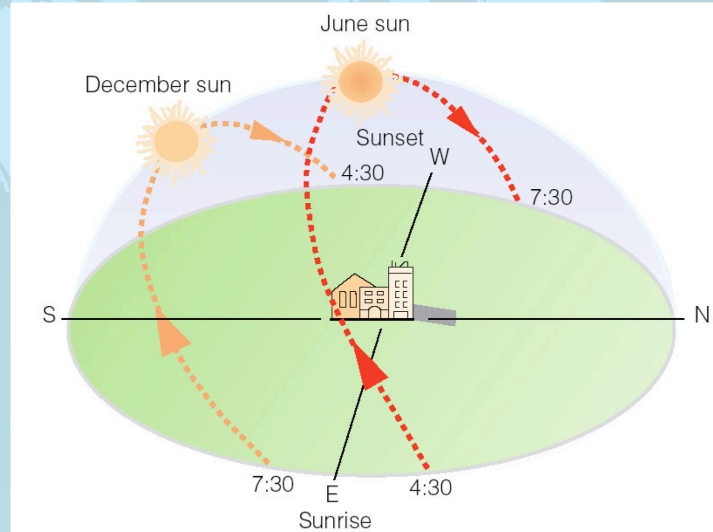
Reasons for Seasons

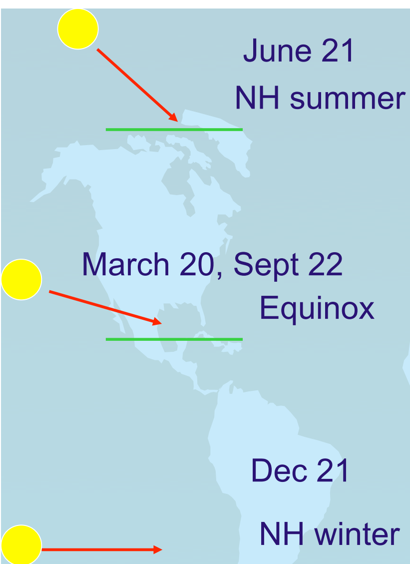
Geometry – sunlight is distributed unequally over surface.

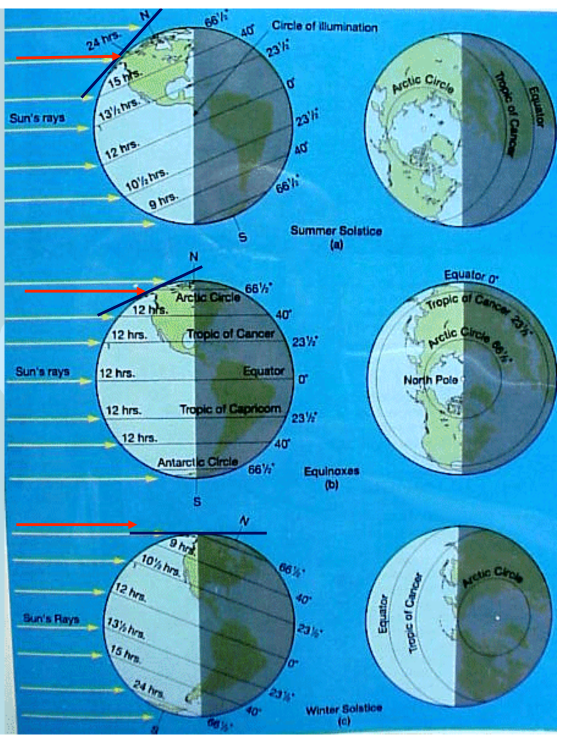




Changes in Length of Day



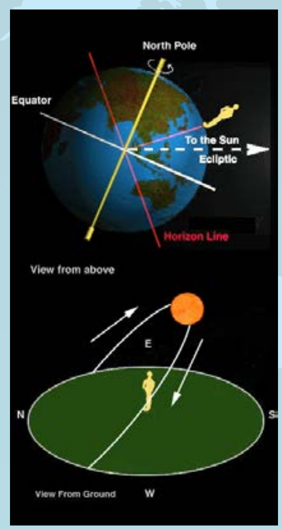




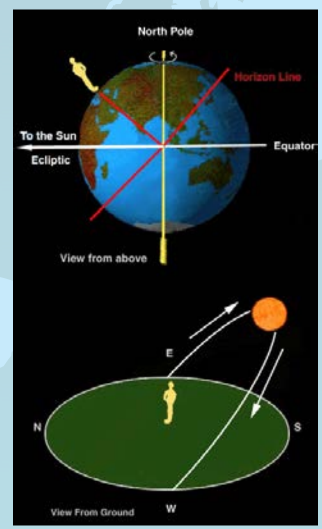
Geometry

Geometry

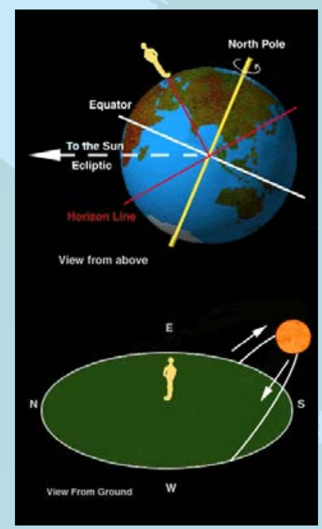
Summer



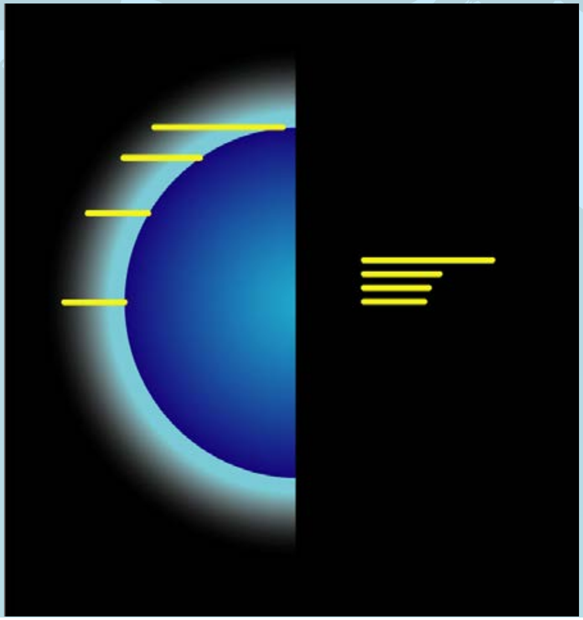
Fall



Winter



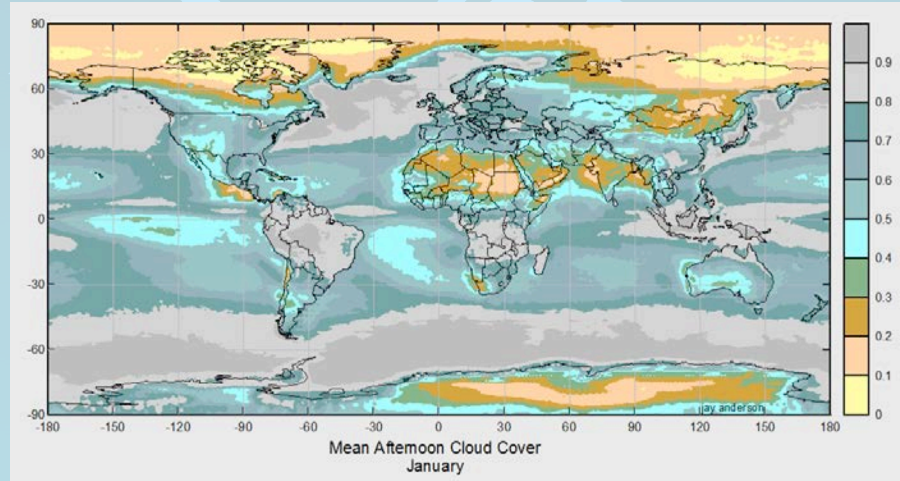
Path Length through Atmosphere



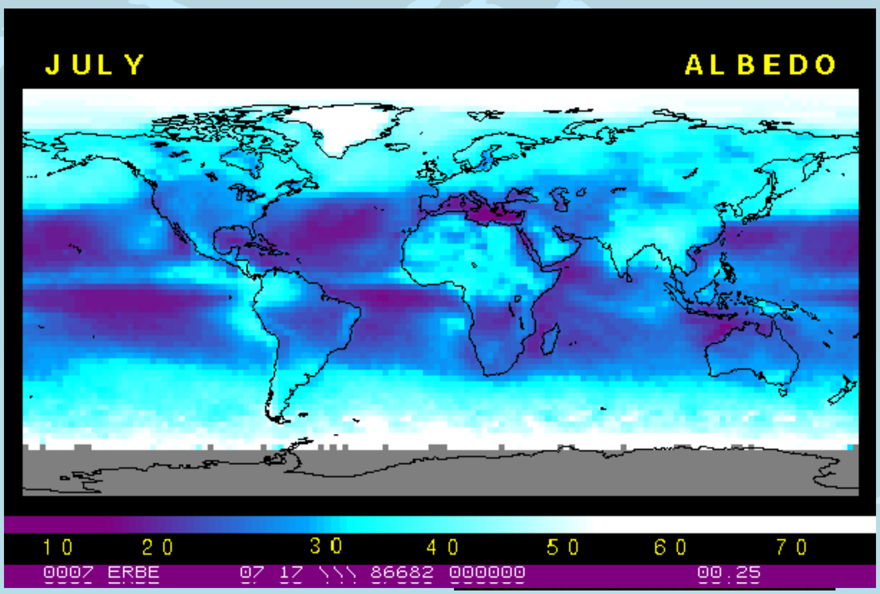
Path lengths for sun light through the atmosphere are longer at higher latitudes than at lower latitudes.

Therefore, more sunlight is absorbed and scattered away at higher latitudes.

Global Cloud Cover



Impact of Reflection (Albedo)



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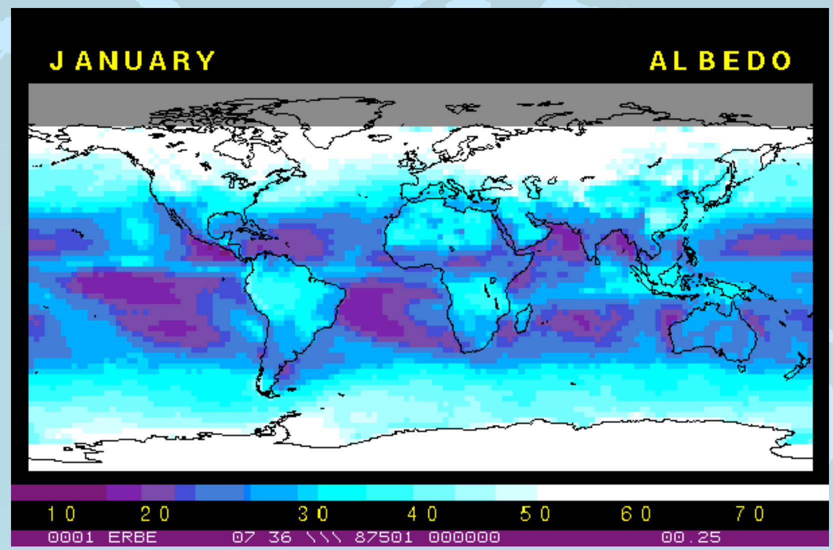


Radiation Imbalance

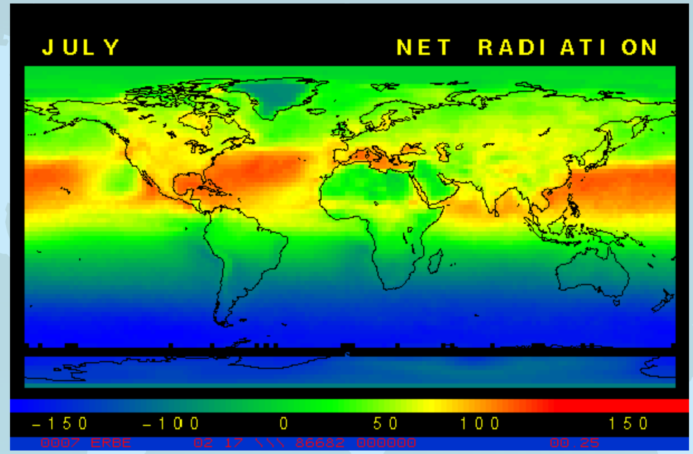
1. Geometry
2. Reflection/Albedo
3. Differing atmospheric path lengths

The factors that cause the seasons also lead to a local radiation imbalance whereby

- Incoming > outgoing at low latitudes
- Incoming < outgoing at high latitudes

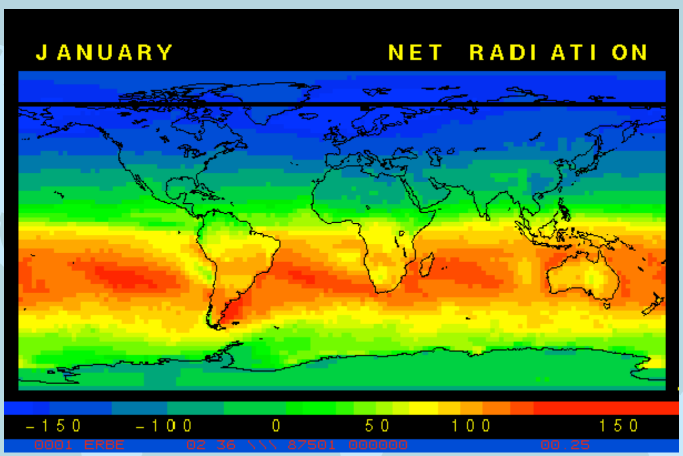
In turn the net radiation distribution drives the atmospheric circulation.

Radiation Imbalance



The difference between the absorbed sun light and the emitted outgoing long wave radiation of the Earth is referred to as the net radiation budget.

Radiation Imbalance

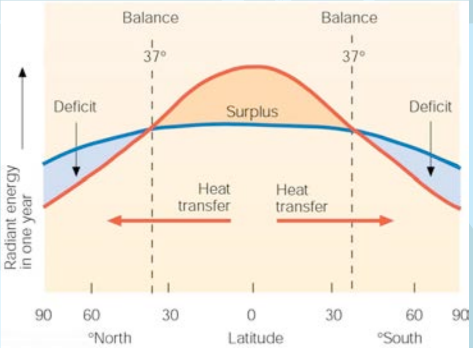


The difference between the absorbed sun light and the emitted outgoing long wave radiation of the Earth is referred to as the net radiation budget.

Radiation Imbalance

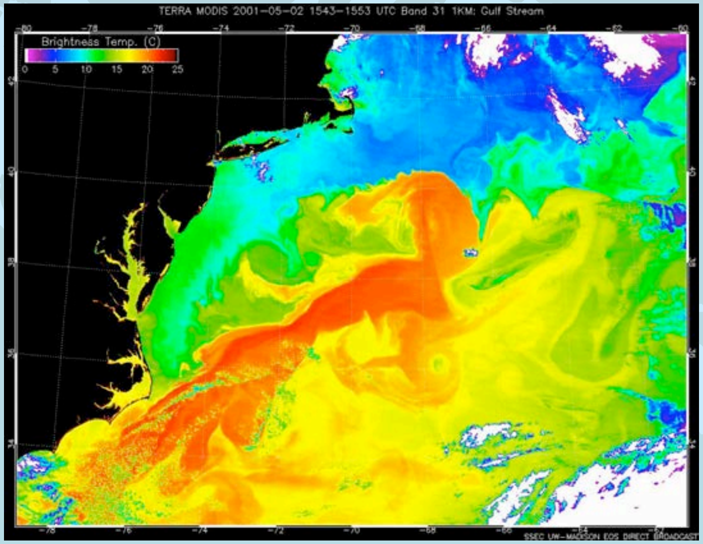
- The tropics would continually become warmer and the polar regions would continually become colder if temperatures were only dependent on the local radiation balance.
- Advection – horizontal movement of air accomplished mainly through global wind systems and oceanic currents help distribute the heat.

A Balancing Act



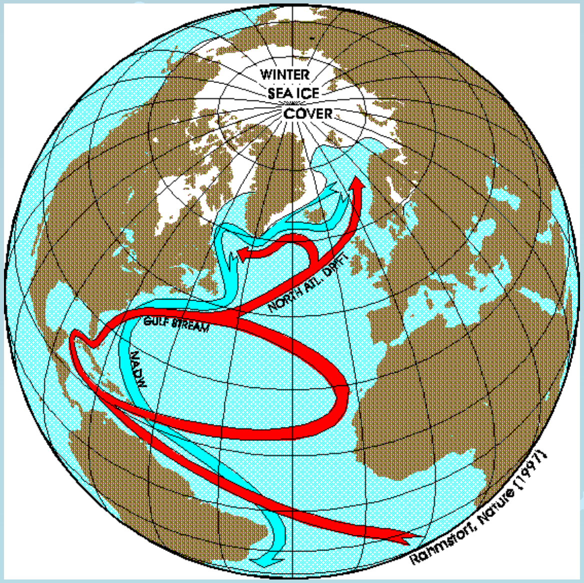
Winds in the atmosphere and currents in the oceans redistribute the excess energy, moving the energy from the lower latitudes to the poles to compensate for the radiation imbalance.

A Balancing Act



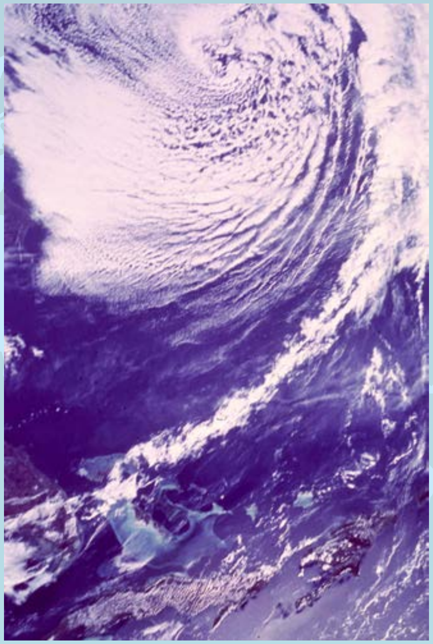
A Balancing Act

Europe's heating system. This highly simplified cartoon of Atlantic currents shows warmer surface currents (red) and cold north Atlantic Deep Water (blue).



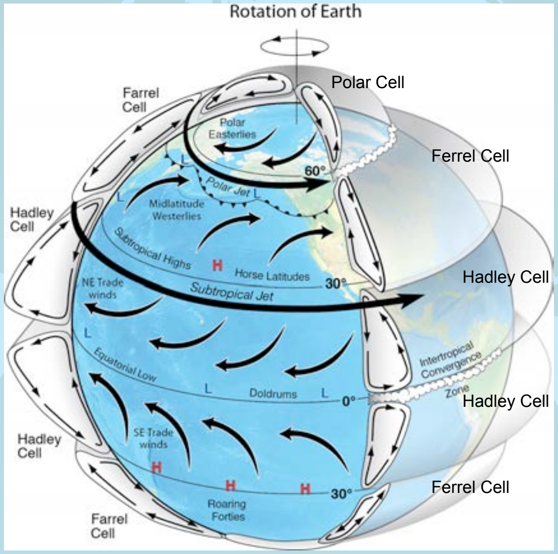
A Balancing Act

Winter storms bring warm moist air northward and cold dry air southward, transporting latent and sensible heat.

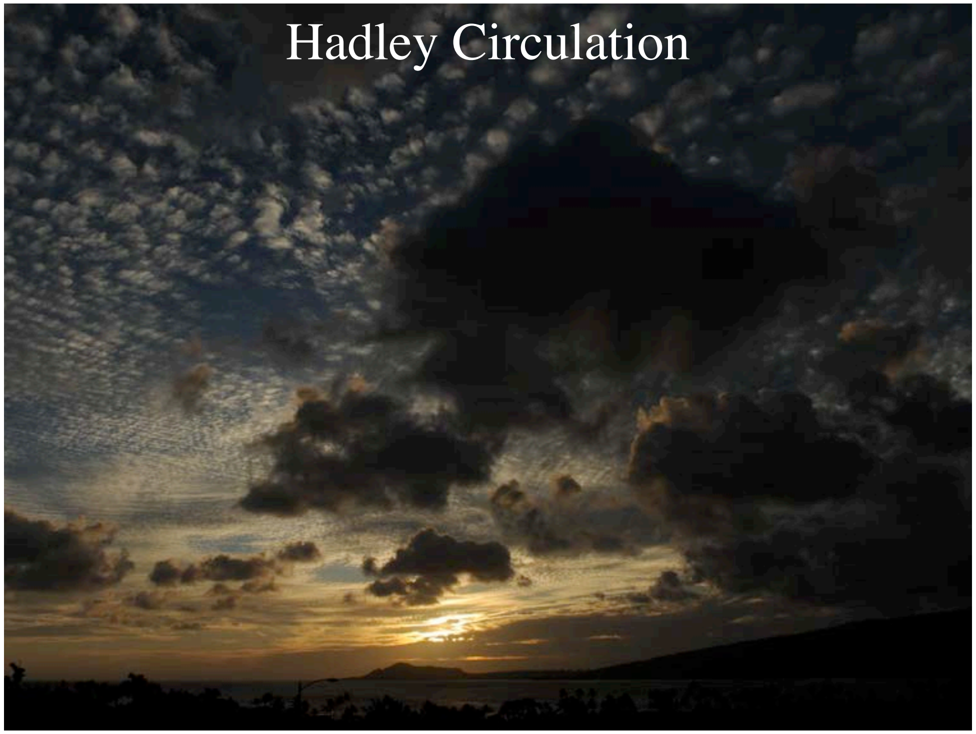


Idealized 3-Cell Model of Wind Patterns on a Rotating Earth

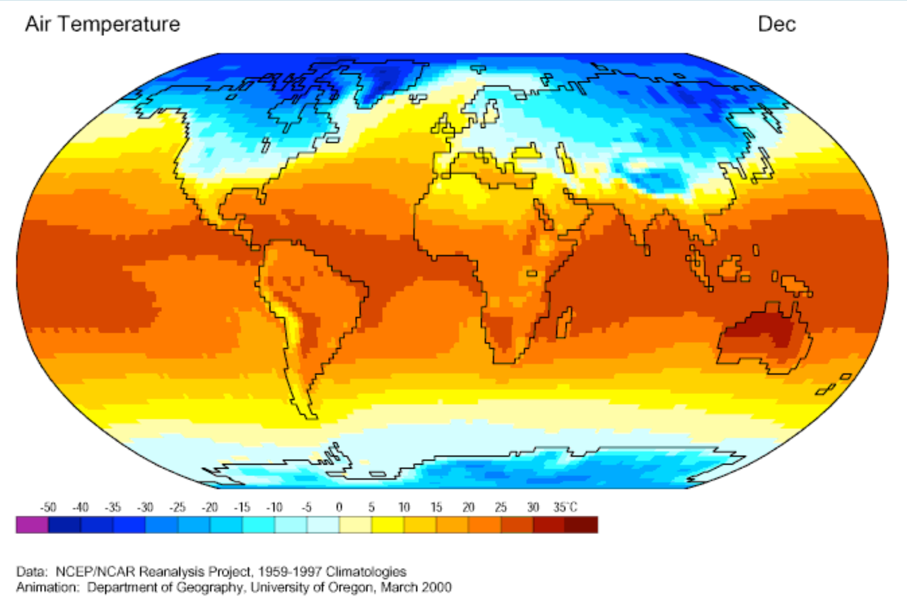
A schematic of the Earth's weather machine bringing warm moist air northward and cold dry air southward (latent and sensible heat).



Hadley Circulation



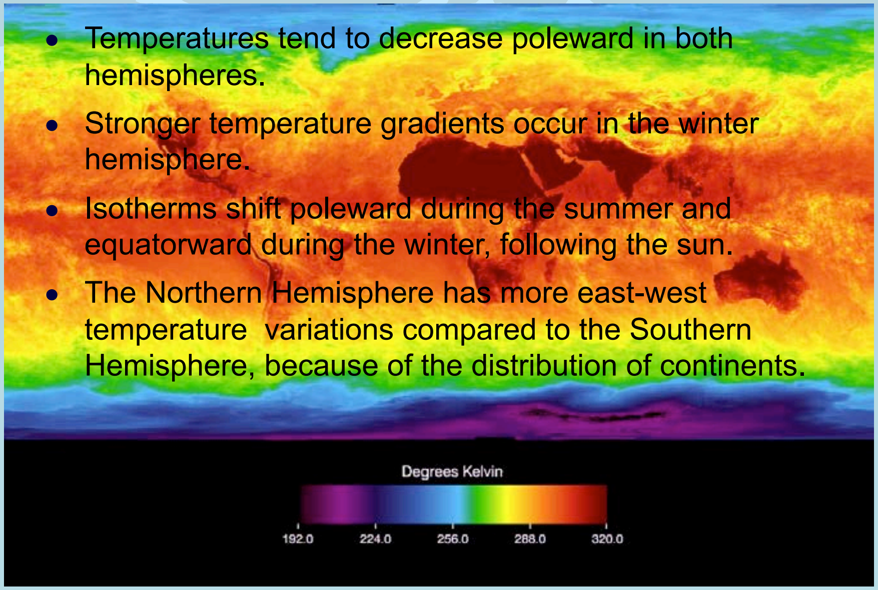
Seasonal Surface Temperature Variation



Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

Summary of Global Temperature Variations

- Temperatures tend to decrease poleward in both hemispheres.
- Stronger temperature gradients occur in the winter hemisphere.
- Isotherms shift poleward during the summer and equatorward during the winter, following the sun.
- The Northern Hemisphere has more east-west temperature variations compared to the Southern Hemisphere, because of the distribution of continents.



Reasons for Seasons

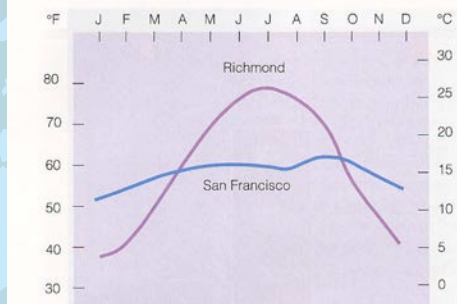
1. Geometry – sunlight is distributed unequally over surface.
2. Reflection of sunlight by Earth's surface and clouds (Albedo).
3. Scatter and absorption of sunlight by atmosphere due to differing atmospheric path lengths.

Food for Thought

Seasons are driven by variations in solar radiation.

These variations (angle of sun/amount of sunlight) are a function of latitude.

So…why are seasons so different at these two cities, even though they are at the same latitude?



	SAN FRANCISO		RICHMOND	
	°C	°F	°C	°F
Mean annual temperature	14	57	14	57
Annual temperature range	6	11	22	40
Record high	39	103	41	105
Record low	−3	27	−24	−12

FIGURE 3.24
Temperature data for San Francisco, California (37°N), and Richmond, Virginia (37°N)—two cities with the same mean annual temperature.

Moderation of Climate by Oceans

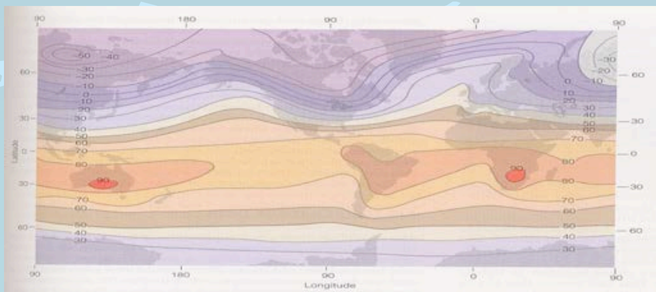


FIGURE 3.21
Average air temperature near sea level in January (°F).

Seasonally varying temperature

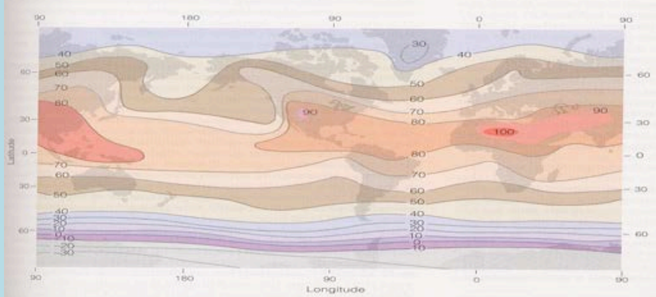


FIGURE 3.22
Average air temperature near sea level in July (°F).

Note:
Effect of oceans
E-W contrasts

Questions

Since polar latitudes receive the longest period of sunlight during summer, why aren't temperatures highest there?

Why aren't temperatures highest at the summer solstice?

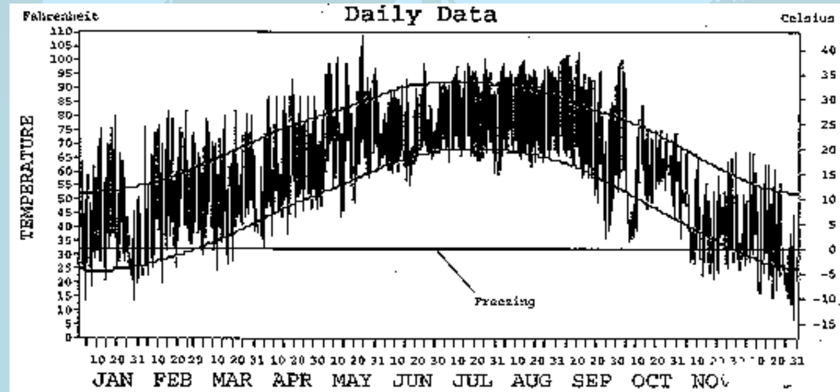
What would happen if we changed the tilt of the earth?

– Would we get a more/less pronounced seasonal cycle in the NH if the tilt was increased?

- What would happen if the tilt was 90 degrees? 0 degrees?

The Diurnal (Daily) Temperature Cycle

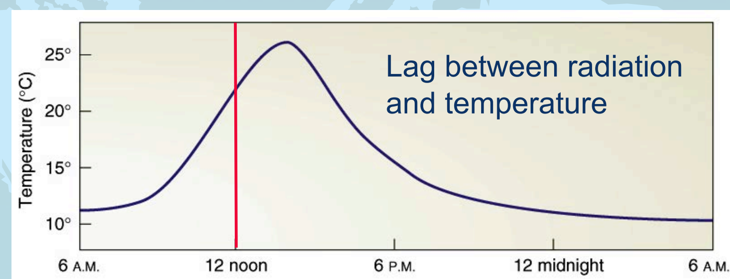
Annual vs Daily Variations in Temperature

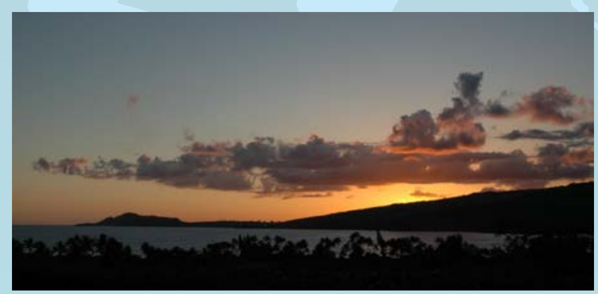


Daily Temperature Variations

- Each day is like a mini seasonal cycle
  - Sun rays are most intense around noon
  - As is the case with the seasons, the maximum temperatures lag the peak incoming solar radiation.
- An understanding of the diurnal cycle in temperature requires an understanding of the different forms of atmospheric heating and cooling:
  - Radiation
  - Conduction
  - Convection
  - Latent heat

The Diurnal (Daily) Temperature Cycle



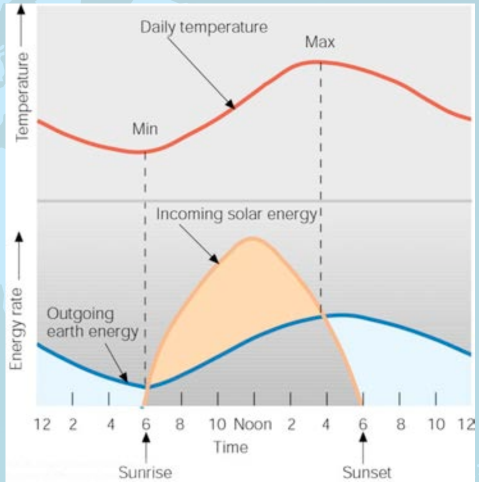


Diurnal Temperature Cycles

Incoming vs Outgoing Radiation

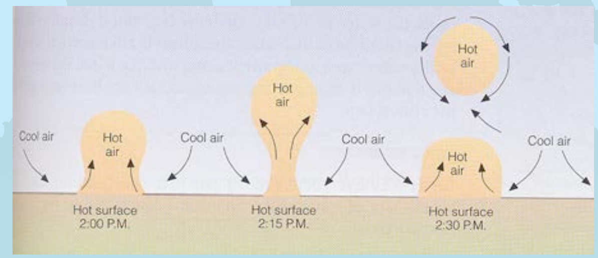
- Temperature rises as long as $E_{in} > E_{out}$
- T_{max} typically 3-5 PM for clear summer skies
- Temperature begins to fall when $E_{in} < E_{out}$
- T_{min} typically occurs near or just after dawn on clear nights

What factors could change the timing?



Atmospheric Heating

- Sunlight warms ground
- Ground warms adjacent air by conduction
  - Poor thermal conductivity of air restricts heating to a few cm
- Random motion of "hot" surface air molecules upward leads to heat transfer (conduction)
- Hot air forms rising air "bubbles" (thermals) leading to convection
  - Mechanical mixing due to wind enhances conduction and convection.



Vertical temperature profiles - day

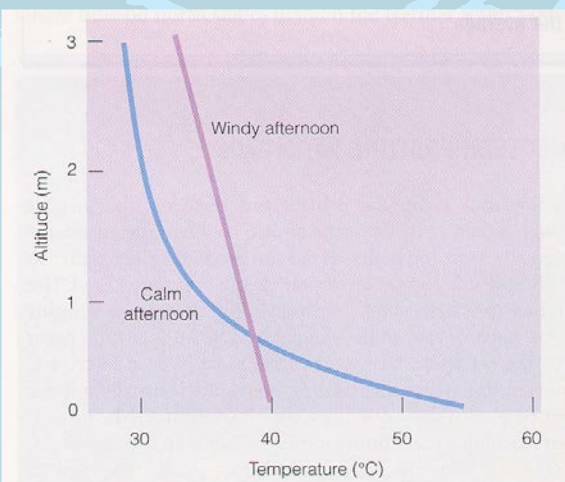


FIGURE 3.13
Vertical temperature profiles above an asphalt surface for a windy and a calm summer afternoon.

Jogger on calm, summer day may have 122˚ F at their feet and 90˚ F at their waist!

Land vs. Water

Temperatures change more slowly over water than over land.

- Specific heat (heat capacity) of water is larger
- Radiation received by water can penetrate several meters
- Evaporation (cools water surface)
- Easy mixing of water (advection and convection in the water)

Impact of Heat Capacity of Ocean

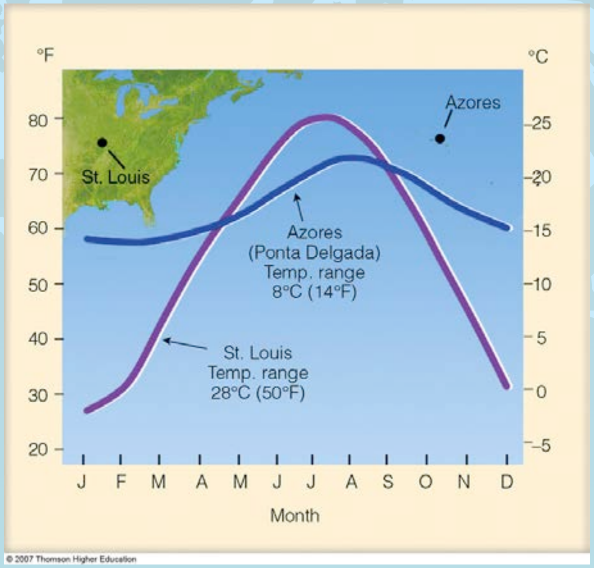


Fig. 3-12, p. 66

Temperature Means and Ranges

- Daily mean – The average of the maximum and minimum temperature for that day
- Daily temperature range – subtraction of maximum temperature from minimum
- Monthly mean – average of daily means
- Annual mean – average of monthly means

Daily High Temperature

T_{max} depends on

- Cloud cover
- Surface type
  - Absorption characteristics
    - Strong absorbers enhance surface heating
  - Vegetation/moisture
    - Available energy partially used to evaporate water
- Wind
  - Strong mixing by wind will mix heated air near ground to higher altitudes

Cooling at Night

- Lower sun angle in evening means $E_{in} < E_{out}$
- During night the ground and air radiate energy to space
- Ground is better radiator than air, so ground cools faster (Kirchoff's law).
- Ground cools adjacent air layer by conduction.
- Heat transfer from air above is slow due to poor thermal conductivity of air.
- Why isn't convection as important at night?

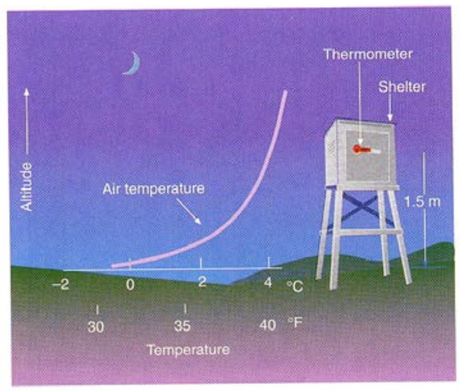


FIGURE 3.15
On a clear, calm night, the air near the surface can be much colder than the air above. The increase in air temperature with increasing height above the surface is called a radiation temperature inversion.

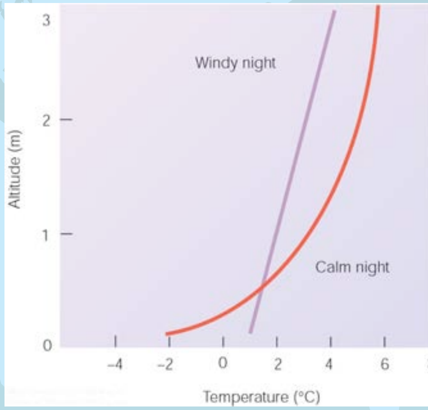
Radiation Inversions

Radiation inversions are an increase in T with height above ground.

Occur on most clear, calm nights (nocturnal inversion)

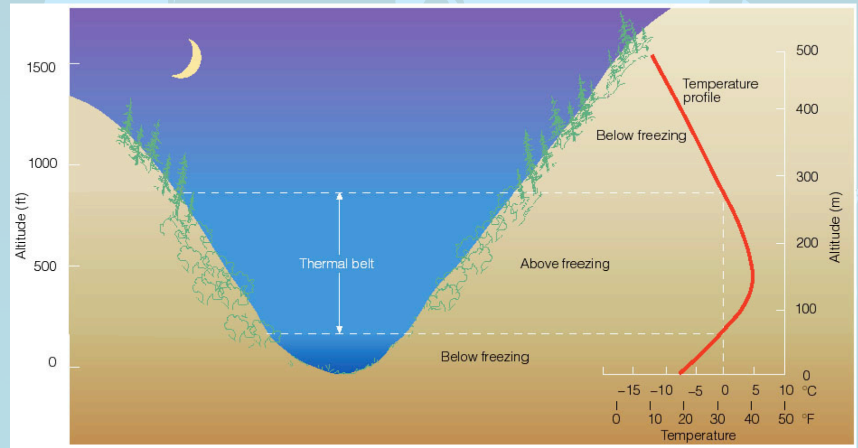
Are strongest when

- Night is long
- Winds are calm
- Sky is cloud free
- Air is dry
- - Less IR absorption
- - Less latent heat release from fog/dew formation



Cold air pooling

- As air cools, its density increases, leading to
  - Downslope flow
  - Cold air pooling in low spots/valleys



Inversions and agriculture

- Surface cooling can produce sub-freezing temperatures near ground
- Crop damage possible
  - Especially problematic for orchards in “warm” climates
- Mixing down of warmer air aloft can help limit temperature drop near surface
- Generating fog can reduce cooling from radiation.

Questions?

- Seasons
- The Diurnal (Daily) Temperature Cycle