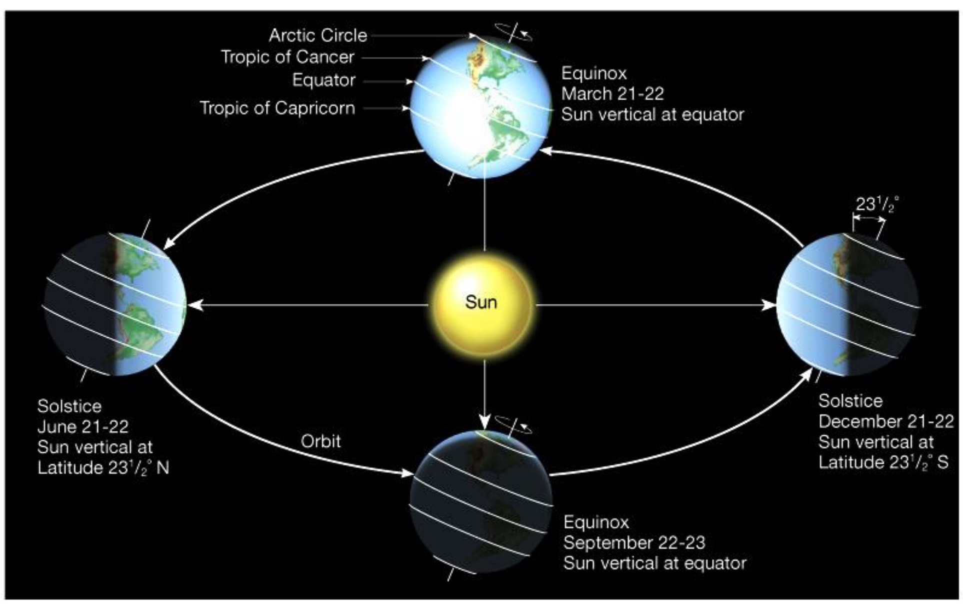
IV. Heat Transfer and Sphericity:

A. Radiation is not equally distributed across the Earth's surface.

1. Instead, the tropics receive much more solar radiation than the poles. This creates a temperature difference between equator and pole.
    a. Since temperature differences make pressure differences, and pressure differences drive wind, the equator to pole temperature difference is the primary driver of the atmospheric circulation, and it's all a consequence of the fact that the Earth is spherically shaped.
2. Since the Earth is spherical, the Sun's rays are less concentrated at the poles.
    a. They're making a more acute angle to the ground, and that's the primary reason why the poles are colder.
    b. This would be true even if the Earth didn't have an atmosphere, but atmospheric effects compound this problem in direct and indirect ways.
3. While absorption of sunlight by the air is pretty limited, the amount of solar energy that reaches the ground can be reduced by reflection and scattering, so the potential for this loss depends on sunlight's path through the atmosphere.

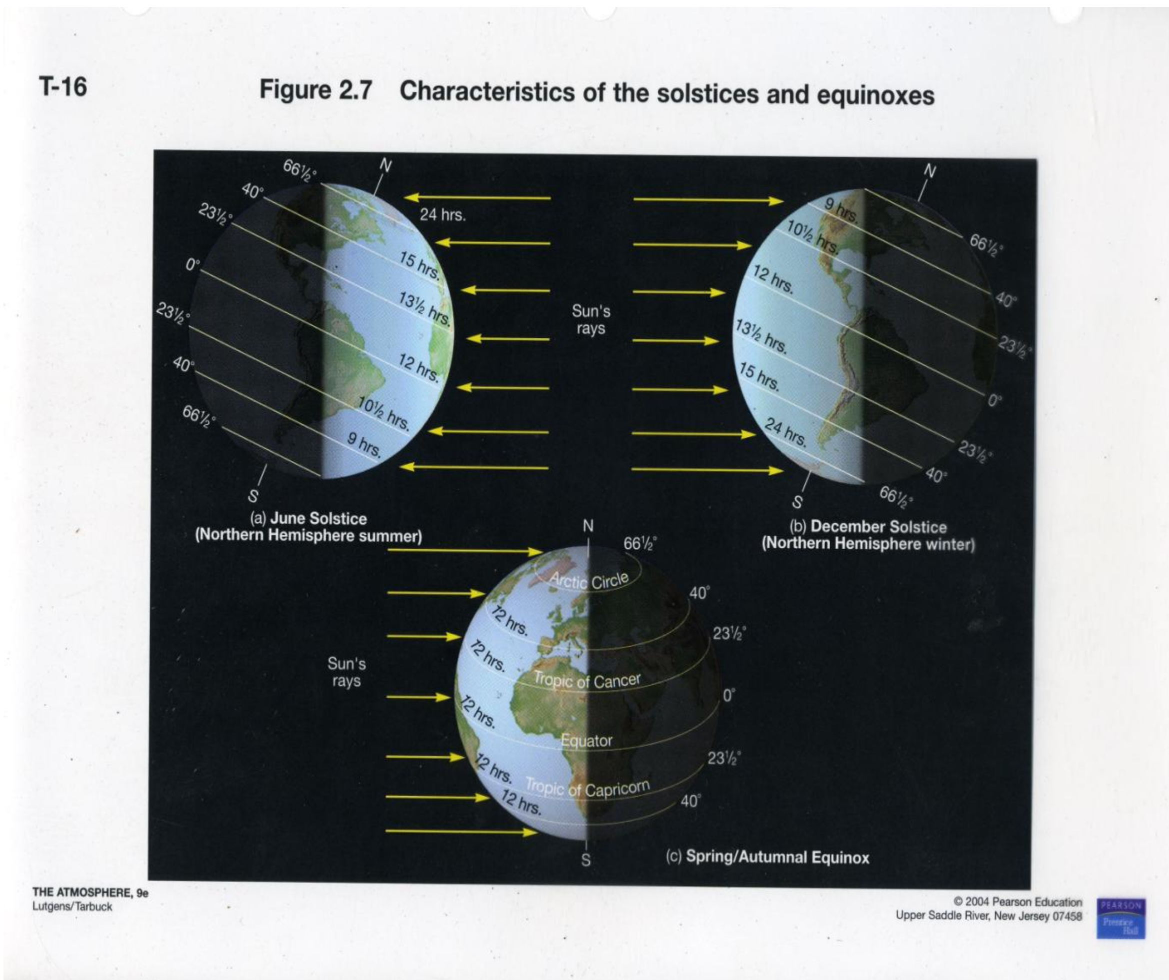


4. A further complication arises from the fact that the Earth's axis is tilted.
    a. We call this "obliquity".
    b. Our present tilt to the Earth's axis is 23.5 degrees from the vertical, but this varies between 22-24 degrees over a period of about 41,000 years.

c. Owing to this tilt, both hemispheres spend part of the year inclined towards the Sun and part inclined away, and this causes the seasons.

5. Because the earth is tilted, its relationship to the sun changes as it travels in its orbit.
    a. During the summer, the northern hemisphere is tilted toward the sun. Below the equator, the southern hemisphere is having winter because it is tilted away from the sun.

    b. The hemisphere that is tilted toward the sun receives the sun's energy more directly. Also, the days are longer. The combination causes the earth to receive more heat in that hemisphere, and the result is summer.
    c. During the summer season in the northern hemisphere, the earth is tilted toward the sun.



    d. During the winter season, the earth is on the opposite side of the sun and the northern hemisphere is tilted away from the sun.

i) The summer solstice is the longest day of the year and the first day of summer. The winter solstice is the shortest day of the year and the first day of winter.

ii) The sun is over the Tropic of Cancer, 23½° north latitude on about June 22, or over the Tropic of Capricorn, 23½° south latitude on about December 22.

e. As the earth moves in its orbit around the sun, it passes two points at which the length of day and night are equal.
   i) On these two days the earth's axis is straight up and down in the direction of the sun.
   ii) The sun is directly over the equator.
f. The VERNAL EQUINOX, or first day of spring, occurs on March 20.
g. The AUTUMNAL EQUINOX, or first day of fall, occurs on September 22 or 23.
h. North or south of 23½° latitude, the sun is never directly overhead .
i. The maximum insolation moves seasonally from the equator (equinox) to the Tropic of Cancer (solstice), back to the equator (equinox) and on to the Tropic of Capricorn (solstice) and back to the equator (equinox). The earth climate bands move accordingly.
j. People pole-ward of the tropics see seasons as cold versus warm; people in the tropics and subtropics see seasons as wet versus dry.
k. But that's not the only complication. The Earth's orbit is also eccentric.
   i) Eccentric means that the Earth's orbit is not perfectly circular.
   ii) There are periods of the year when we're relatively closer or farther away than our mean distance of 93.5 million miles. In January, during the Northern Hemisphere's winter, the Earth is closer to the sun.

6. Temperature differences make pressure differences. Pressure differences drive winds. The intent of winds is to reduce the temperature differences that gave rise to the pressure differences in the first place.
   a. One major source of the temperature difference is unequal heating of the Earth's surface, owing to the Earth's round shape.
   b. There is a seasonal variation as well. The temperature difference is relatively smaller in the summer than the winter, owing to obliquity, but at no time is the pole ever warmer than the equator.
   c. The average winter surface temperature at the North Pole is -30°C, or -22°F. An average year-round temperature in the tropics is about 25°C or 77°F. This makes an equator to pole temperature difference of almost 100°F during wintertime.
   d. Note that the Moon is also an unequally heated sphere, but the Moon has no atmosphere. There are no winds to move heat energy around. The Moon's equator to pole temperature difference is closer to 500°F.
   e. Nature may not be as successful as we might like on the Earth, but it has already accomplished a great deal with the atmosphere, it's winds, clouds, storms, and all her other tools. Yet it's still worth considering why Nature hasn't done better for us. This leads us to study the obstacles and frustrations that Nature faces.
      i) One of these is the fact that the Earth rotates.
      ii) The other is the complication of heat transfer.

f. The Sun's energy reaches us through the empty vastness of space via radiation. This is a very efficient means of energy transport that does not require mass as a medium.
g. There are 2 other mechanisms of heat transfer we need to consider: conduction and convection. Both require a medium. In our case, we're concerned with air and water, but first, let's consider a question. What is heat?

B. Heat is a flow of energy between objects.
   1. The property we're thinking of is actually internal energy, and temperature helps us measure that property. We want to move that property around and that is the subject of what we call "heat transfer".

C. Conduction is heat transfer by direct atomic contact, atoms and molecules touching each other.
   1. Conduction operates in one direction, from warm to cold.
   2. Temperature is a measure of microscopic kinetic energy of atoms and molecules, vibration translation. For us, we can just think about the vibration part of that.
   3. When warmer or more vibrant molecules and atoms come in contact with cooler, les vibrant ones, some microscopic kinetic energy is transferred from the warmer object to the cooler one. So heat is transferred from warm to cold.
   4. Conduction involves transferring microscopic kinetic energy, as measured by temperature, from the object with more to the object with less. In this way, conduction moves heat from warm to cold.
   5. Objects differ in their ability to conduct heat. (i.e. the metal spoon and ceramic cup)
      a. Materials that are dense and with highly ordered atomic structures, like metal, are generally very good conductors.
         i) This is why we use metal pots and pans in cooking.
         ii) Iron is good, aluminum is better, and copper and silver are the best heat conductors of all to heat food up in a glass pan. But food stored in glass will keep it's high temperature longer since the glass is slower to conduct that extra heat away.
      b. Now, let's consider an example using water and air. You're perfectly comfortable in 70°F air, wearing light clothing, but if you were immersed in water at that same temperature, you would feel very cold. Why?
         i) Water at this temperature is 26X better at conducting heat than air is, and since the temperature of the water is lower than your body temperature, you're losing heat to the surroundings.
      c. Air is a terrible conductor of heat. Now, that's not all bad. Air is actually a very good insulator. It's good at slowing heat loss.
         i) In fact, air is the secret to some of our very best insulators.
         ii) What makes fiberglass insulation a great insulator is the fact that there are many air pockets between the fibers of the insulation.
      d. Air is a much worse conductor than water is. A hot Mexico beach can trap heat in it until a water wave comes in to cool it off. But in thinking about heat transfer, conductivity isn't the only property we need to be concerned with. The next concept is called "thermal inertia".

6. Inertia is a resistance to change. By analogy, what I will call "thermal inertia" is resistance to temperature change.
   a. Objects with large thermal inertia can absorb a lot of energy without their temperatures rising very much.
   b. You've probably observed that objects that tend to warm up quickly also cool off very quickly as well, and vice versa. That's thermal inertia at work, resistance to temperature up or down.
   c. This concept is usually called "heat capacity", the ability to contain heat as if it were a property.
   d. Heat conductivity and thermal inertia are not the same thing.
   e. Consider the hot Mexico beach again. The sand feels hot because it is a good conductor, and it's giving you its heat very quickly. The sand is hot because its thermal inertia is low. In fact, if the sand did not have a low thermal inertia, it would not have gotten so hot in the first place. In fact, it might have even felt cold to you instead of hot it its thermal inertia were very high.
   f. If air were a better conductor of heat, would the sand get as hot as it does? The sand is a far better absorber of solar radiation than the air above it, so the sand is absorbing energy that the air is not.
   g. Sand is a pretty good conductor and it's willing to share its heat with the cooler air molecules than come bumping on by. But air is a poor conductor, so it does not share it's bounty of heat energy acquired from the sand with other air molecules above very quickly.
   h. Air is not a good conductor, so heat transferrin any direction needs some help, and we call that help "convection", heat transport by mass fluid motion.

D. "Convection" comes from the Latin word to carry, to convey. Basically, I'm talking about the wind.
   1. One way that the wind can cause vertical mixing and vertical heat transport occurs as the wind courses over irregular surfaces, mountains, hills, trees, houses, buildings, things like that.
   2. This creates eddies that transport hot air up from the ground and transport cooler air down to the surface.
      a. The same can occur as air passes over land that has been irregularly heated, some places getting warmer others, perhaps because you have concrete, you have grass, and places with different thermal inertias.
   3. Due to convection, a windy day can accomplish what conduction cannot, and that is to make the sandy surface cooler than it otherwise would have been.
      a. At night, sand's low thermal inertia permits the sand to get cold and this will chill the air near the ground, but the warmth from above is not conducted downward very quickly. We're seeing what we call a "temperature inversion", when temperature increases with height. "Inversion" because it's the opposite of what we've come to expect, which is that temperature decreases with height above the ground.

b. Technically, this is called a "radiation inversion", as it's caused by radiative cooling on the sandy surface, exacerbated by the low thermal inertia of sand. But as we've also seen, it's also exacerbated by air's poor conductivity.
    i) However, when the wind kicks up, there's more likely to be vertical mixing, this time leading to relatively warmer temperatures near the ground and cooler temperatures farther aloft.

E. Under what conditions are we most likely to get really cold temperatures at the ground? (4 possibilities)
    1. When the air is relatively dry, there's less water vapor to trap outgoing longwave radiation, which is par of the greenhouse effect. [Less humid nights are cooler than more humid nights]
    2. When the sky is clear, no clouds to absorb outgoing long-wave radiation and return some of that to the surface. [Clear nights are cooler than cloudy nights]
    3. When the surface has a low thermal inertia. [Sand and concrete will get colder at night than grass and water]
    4. When the winds are calm because this limits the vertical mixing of air and helps to maintain the surface cooling.

F. Summary:
    1. We have a large temperature difference between equator and pole because the Earth is spherical.
        a. That temperature difference is exaggerated in the winter season because our half of the sphere is tilted away from the Sun at the point in time.
    2. Axial tilt causes the seasons.
        a. The winter equator to pole temperature difference is 100°F.
    3. Without the atmosphere and its circulation, though that temperature difference would be a heck of a lot larger.
    4. There are two other ways of moving heat around. Both require a medium.
        a. Conduction, atomic billiards. Is slow, in air because air is a lousy conductor. But that makes air a great insulator.
           Convection, carried by the wind.
    5. Thermal inertia: The resistance to temperature change.
        a. Objects that heat up slowly tend to cool off slowly as well.
    6. Liquid water has a huge thermal inertia and, as a consequence, our oceans are also huge reservoirs of heat energy, and not just water.
        a. Many land surfaces, in contrast---(I've been using sand as an example)—have low thermal inertia.
           Land heats up fast during the day and cools off fast at night.

7. Temperature differences play a critical role in meteorology.
    a. One way to make temperature differences is to provide surfaces that differ in some critical aspect.
    b. Suppose they receive more or less solar radiation, owing to Earth's curvature and tilt, such as the equator and the pole, winter and summer.

c. They can also differ in how they absorb solar radiation, due to difference in reflectants. Consider a shiny (snow) surface versus a dark surface (asphalt).
d. These surfaces could also respond to the energy that they absorb differently, owing to differences in thermal inertia.
e. They also can differ in how they conduct heat away when they're hot, and receive heat when they're not.

8. One way to mitigate temperature differences created by differences in latitude, differences in season, or differences in surface characteristics is to transport heat by mass fluid motion by convection, (winds).
9. Temperature differences make pressure differences, and pressure differences drive winds.

G. Questions:

2. What causes the seasons?

3. Why does a metal spoon feel cooler than a drinking glass, when both have the same temperature?

4. When we touch it with our hand, why do we tend to dramatically underestimate the temperature of the ocean?

5. Why does beach sand get so hot on a sunny summer day?(Explain two reasons)

6. Why does that same sand so cold just before sunrise? (Explain two reasons)

7. Seasons are caused by the fact that the Earth's axis is tilted. Presently, that tilt is 23.5 degrees, but this value varies over a long period of time. When would you expect an ice age to be most likely, when the tilt is greater than the present value or smaller? Why?

8. Consider a blanket of snow on the ground. It is often noticed that snow melts faster from below than above, resulting in air pockets beneath the crust that cause the snow to crunch when you walk on it. Why?

9. Which direction does the wind blow in relationship to pressure differences? Why?

10. What do the temperature differences got to do with the direction of the wind?

11. How does convection cool the hot sand on the beach?

12. How is heat capacity and thermal inertia related?

13. How does snow and asphalt tell you the direction of the blowing wind on a cloudless day?

14. What does the length of night got to do with the tilt of the earth and the seasons?

15. Why do the leaves on the trees turn yellow or red in the fall? (Hint: Temperature change is not the primary reason).