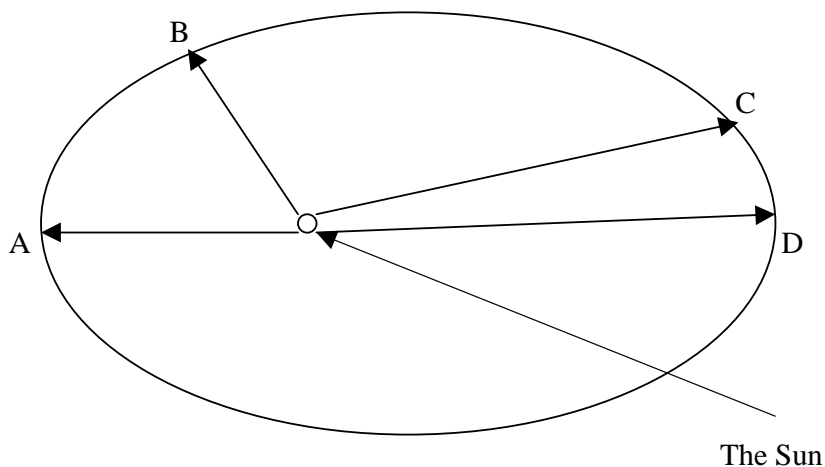


Seasonal and Daily Temperatures

This unit deals with factors that affect annual (yearly) and diurnal (daily) climatic cycles. We will begin our discussion with a look at the most obvious annual changes in climate and weather: the seasons.

The earth moves around the sun in an *elliptical* orbit, i.e., an orbit that isn't a perfect circle. The earth's orbit is elliptical is a consequence of gravitational interactions between the earth and the sun. Kepler's Laws describe the orbits of the planets about the sun.

- Kepler's 1st Law: The orbits of the planets are ellipses with the sun at one foci of the ellipse.
- Kepler's 2nd Law: The radius vector of each planet sweeps out equal areas in equal times. This means that when the planets are closest to the sun (approaching *perihelion*), they are traveling faster, and when they are further away (approaching *aphelion*), they travel slower.



In order for the radius vector to sweep out equal areas in equal times, the planet must move from A to B faster than from C to D. Hence the planets have orbital speeds that increase as they near perihelion. This means that planets spend less time in the portion of their orbits near the sun than they do farther away.

The *eccentricity* (e) of an ellipse is a measure of how much it varies from a perfect circle. For the earth, $e = 0.017$. This is a relatively small eccentricity. Comets, for instance, often have eccentricities of 0.97.

The mean distance from the earth to the sun is about 150×10^6 km. At perihelion (around January 3rd each year), the earth-sun distance is about 147×10^6 km. At aphelion (around July 4th each year), the earth-sun distance is about 152×10^6 km. The variation in these distances corresponds only to about a 3% difference in the distance from Earth to the sun over the course of the year. This minor variation in distance is not enough, by itself, to explain the dramatic climatic changes that occur with the change of seasons in most extratropical regions on Earth. What then, are the factors responsible for seasonal climatic changes?

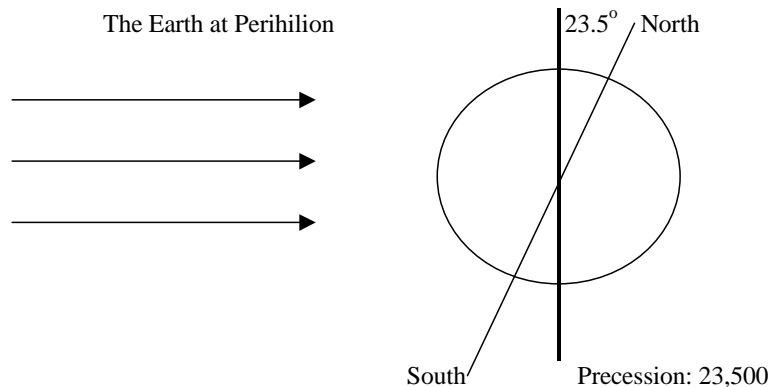
The seasons on earth are regulated by the amount of solar energy received at the earth's *surface*. As we have already learned, the atmosphere, by itself, does not directly absorb much incoming solar radiation. It is the *intensity* of solar radiation reaching the earth's surface that drives seasonal changes. Because the earth-sun distance varies by such a small amount over the course of a year, the amount of solar energy striking the earth's atmosphere at perihelion is only 7% greater than at aphelion. Again, this is not enough to produce dramatic climatic changes within a yearly

cycle. But the intensity of solar radiation at the earth's surface (outside of the Tropics) varies greatly over the course of the year due to the following factors:

- Solar energy that strikes the earth's surface perpendicularly is more intense than solar energy that strikes the earth at an angle.
- Solar energy entering the atmosphere at high angles travels through less atmosphere before striking the earth's surface than solar energy at a low angle.
- Longer days mean more sunlight is available.
- Clear days allow more sunlight to strike the earth than days where sun is obscured.

The primary cause behind each of these factors is linked to the tilt of the earth's rotational axis with respect to the plane of its orbit.

Consider the figure below.



The earth is tilted on its rotational axis 23.5° with respect to its orbital plane. This axis wobbles or *precesses* just the same as a top wobbles or precesses when its rate of spin slows below a certain point. The earth completes one "wobble" every 23,500 years. Precession itself is far too slow to have any discernable effect on seasonal changes in weather and climate. But the tilt of the earth's axis caused by precession has a huge influence on the intensity of solar radiation received at various portions of the earth at different times of the year. The tilting of the earth's

rotational axis with respect to the sun results in all extratropical regions of the earth receiving different amounts of sunlight, depending upon the season.

Seasons in the Northern Hemisphere

The *Summer Solstice*, June 21st, is the first day of summer. On this day in the Northern Hemisphere sun's rays strike the earth at the highest possible angle. At latitude of 23.5° N the sun appears to be directly overhead. Interestingly, the amount of solar radiation reaching the earth's surface actually peaks at 30° N instead of 23.5°. This is because sinking air at this latitude (due to global circulation patterns) produces drier climates, resulting in an abundance of clear days that allow more solar radiation to reach the earth's surface.

The farther north one goes during summer the longer the days. Areas above 66.5° N (the Arctic Circle), in fact, receive almost continuous sunlight during the summer months. Based on this fact alone, one might conclude that the farther north one goes during the summer months the warmer the earth should be. This, of course, is quite contrary to experience. Extreme northern latitudes are cooler than more southerly latitudes even though they receive more sunlight during the summer. This is due to many factors, primary among them being the low intensity of the available light and the transfer of heat by large scale atmospheric circulation. We'll delve into this in more detail later.

The *Autumnal Equinox*, September 20th, is the first day of fall. On this day the Sun is directly above the equator. Days and night are of equal length around the world (except at the poles due to *refraction* of sunlight). The *Winter Solstice*,

December 21st, is the first day of winter. The Sun is now directly over 23.5° S. The *Vernal Equinox*, March 20th, is the first day of spring. On this day the Sun is over the Equator once again.

Seasonal Temperature

The greatest annual temperatures are usually attained when incoming and outgoing rates of solar energy are in balance. This occurrence usually lags the astronomical beginnings of the seasons by several weeks. This is why July and August are usually warmer than June in the Northern Hemisphere is. When incoming solar radiation is greater than outgoing temperatures begin to rise, and vice versa.

Hemispheric Variations

Climate, in general, is more moderate in the Southern Hemisphere than in the northern, which experiences dramatic shifts in weather with the seasons. Why is this so? The answer lies in the fact that the Southern Hemisphere is largely ocean. Water has the ability to soak up large amounts of heat. During the summer months in the Southern Hemisphere the oceans absorb a great deal of the incoming solar energy. During the winter months this energy is slowly released back into the atmosphere. Hence the oceans of the Southern Hemisphere have a moderating effect on the atmosphere.

Local Seasonal Variations

Smaller scale seasonal variations also occur. In the Northern Hemisphere, for example, objects facing South receive more solar energy over the course of a year. For this reason, there is usually less snow on the southern flanks of mountains than on the northern side.

Diurnal Cycles

Temperature lag is an important factor in daily temperature cycles. As solar energy strikes the earth's surface each morning, a shallow (1-3cm) layer of air directly above the ground is heated by *conduction*. Heat exchange between this shallow layer of warm air and the cooler air above is very inefficient. On a warm summer's day, for example, air temperatures may vary by 30^oF from just above the ground to waist level. Incoming solar radiation exceeds outgoing heat energy for many hours after noon. Equilibrium is usually reached from 3-5 p.m. But this may be affected by a variety of different things such as large bodies of water, soil type and cover, wind, cloud cover/water vapor, and moisture on the ground.

Diurnal temperature variations are greatest very near the earth's surface. High desert areas typically have the greatest diurnal temperature variations. Low-lying, humid areas typically have the least. This explains why an area like the Snake River Plain can have high temperatures of 100^oF during a summer day, and then have lows in the 40's. At the same time, Washington D.C. (which is much more humid) will have temperature variations of only 15^o.

Radiational Cooling

Nighttime or *radiational* cooling is a mechanism by which the earth cools at night. Both the ground and the shallow layer of air above it lose heat during the night. The ground is a much better *black body* than the air and therefore cools much more quickly. The layer of air closest to the ground eventually becomes very cool (cooler than the air above) by conduction and a slight *temperature inversion* exists. *Nocturnal inversions* and *radiation inversions* are temperature inversions that are observed on calm, clear, long nights.

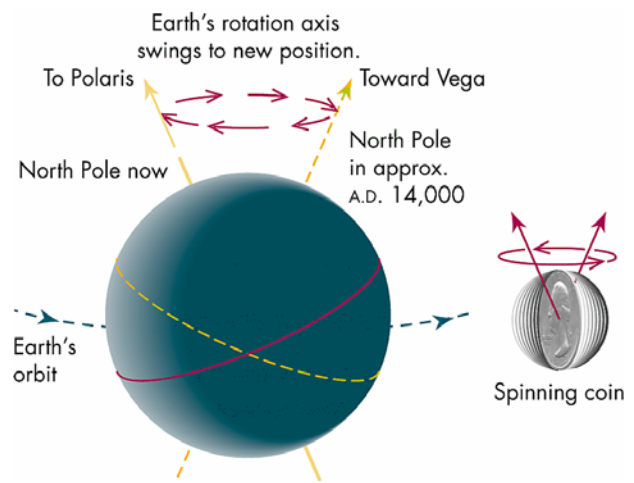
Summary of Controls of Temperature

Temperature is controlled by many factors including:

- Latitude
- Atmospheric circulation
- Intensity of solar radiation
- Land and water
- Ocean currents
- Elevation
- Clear skies

Summary of Motions of the Earth

- Earth spins on its own axis. This gives rise to a *diurnal* cycle. The period is a day. A *solar* day varies slightly from a *sidereal* day.
- The spin of the earth gives rise to the *Coriolis Force*. This may be measured with a Foucault Pendulum (Fig 5.26, p 173 - the greatest photo in your textbook). The Coriolis Force is responsible for jet streams and the rotation of large weather systems.
- Earth orbits the sun in along an elliptical path. The period is 1 year. The elliptical nature of the earth's orbit has very little to do with the change of seasons. The earth is closest to the sun at *perihelion* and farthest from the sun at *aphelion*. The earth's speed changes along its orbital path in accordance with Kepler's laws.
- Earth precesses, i.e., its rotational axis "wobbles" like that of a top. The period is about 26,000 years.
- Forces generated by collisions or gravity can affect the spin of planets. Precession occurs due to the presence of such outside forces
- The Earth's axis precesses because of the attraction of the Sun, the Moon and the planets.

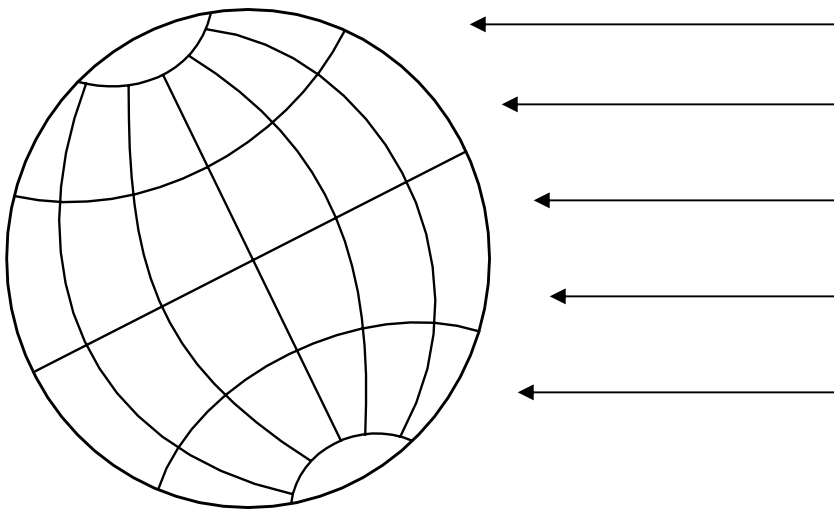


(Courtesy of Thomas Arny)

- Superimposed on the Earth's normal precession is a slow oscillation of the Earth's axial tilt over a period of about 41,000 years.
- Right now the Earth's axial tilt is decreasing. The tropics are moving toward the equator at about 15 meters a year.
- The Earth, which is not perfectly spherical, wobbles as it spins. Even weather systems can affect the wobble. This causes the precession of the earth's rotational axis to be fairly complex
- The Moon acts to keep the earth's axis tilt within moderate limits. Planets like Mars that lack moons can precess wildly due to the gravitational pull of other planets and the sun.

Summary of Seasonal Change

- The earth is at perihelion in early January each year. This is when its orbital speed is greatest. It gradually slows down until reaching aphelion in July when its orbital speed is at its minimum. *The earth is actually closer to the sun when temperatures are coldest in the northern hemisphere.* This is possible because even though the sun is much closer to the earth during our winter months, the sun's rays travel a greater distance through the atmosphere and strike the earth at a more oblique angle in the northern hemisphere due to the $23\frac{1}{2}^{\circ}$ tilt of the earth about its rotational axis.



- Energy from the sun that strikes the earth from directly overhead is more intense than energy that strikes the earth at an angle because the light at an angle is spread out over a greater area. You can verify this for yourself with a flashlight. Hold the flashlight about a foot above any flat surface and shine the beam directly onto the surface then from the same height shine the beam onto the surface at an angle of about 45° . It is easy to see that the same amount of light is spread out over a larger area in the latter case. This lowers the intensity.
- Even though the difference between the earth's perihelion and aphelion distances is less than 3%. The amount of solar energy striking the earth is 7% greater at perihelion (in January) than at aphelion (in July). This would lead one to conclude that summer in the southern hemisphere, which occurs at perihelion, is warmer than summer in the northern hemisphere. This, however, is not the case. Most of the land mass of the earth is concentrated in the northern hemisphere. The southern hemisphere, by

contrast, is 80% covered by water. Water has the ability to absorb large amounts of heat without changing temperature very much. The additional solar energy supplied by the sun at perihelion is absorbed by the large bodies of water in the southern hemisphere. The result is that temperatures are actually more moderate during summers in the southern hemisphere. On Mars, which does not have any oceans to absorb heat, the temperature fluctuations are much greater due to perihelion and aphelion.

- Spring and summer are shorter in the southern hemisphere than in the northern. This is because of the earth's varying orbital speed. The number of days from the *vernal equinox* (March 20) to the *autumnal equinox* (September 22) is about a week longer than from autumnal to vernal.