

Coordinate Systems

Orbits and Rotation

Earth orbit. The earth's orbit around the sun is nearly circular—but not quite. It's actually an ellipse whose average distance from the sun is one AU (150 million kilometers). Its closest point to the sun (147 million kilometers) happens to occur in January; its farthest point (152 million kilometers) occurs in July. This ellipse also defines the *ecliptic plane*. The *ecliptic* is the apparent annual path of the sun against the background stars. It is along this plane that we find the constellations of the Zodiac.

Earth's inclination. Earth rotates on its axis once every sidereal day (23h 56m 4s). This axis of rotation is inclined (tilted) away from a line perpendicular to the ecliptic by about $23\frac{1}{2}^\circ$. It is this tilt that is responsible for our seasons. In June, the earth's northern hemisphere is tilted $23\frac{1}{2}^\circ$ toward the sun. In December, the earth's southern hemisphere is tilted $23\frac{1}{2}^\circ$ toward the sun. This variation of solar angle in our skies accounts for the difference in solar heating at the earth's surface—hence the seasons. Incidentally, the earth's tilt contributes more to seasonal changes than does the variation of the earth's distance to the sun.

Sun's inclination. The sun also rotates on its axis, and it rotates in the same sense as the earth revolves about the sun—that is, counterclockwise as viewed from the north side of the ecliptic plane. Recall that the sun does not rotate as a solid body. The solar equator rotates faster—it takes 25 days to complete a rotation around the solar axis. The poles, on the other hand, take up to 35 days to rotate around the axis. The sun's axis of rotation is inclined away from a line perpendicular to the ecliptic by about $7\frac{1}{4}^\circ$. The tilt direction results in our being able to best view the sun's north pole in September and its south pole in March. The following diagram illustrates all these relations and is not drawn to scale.

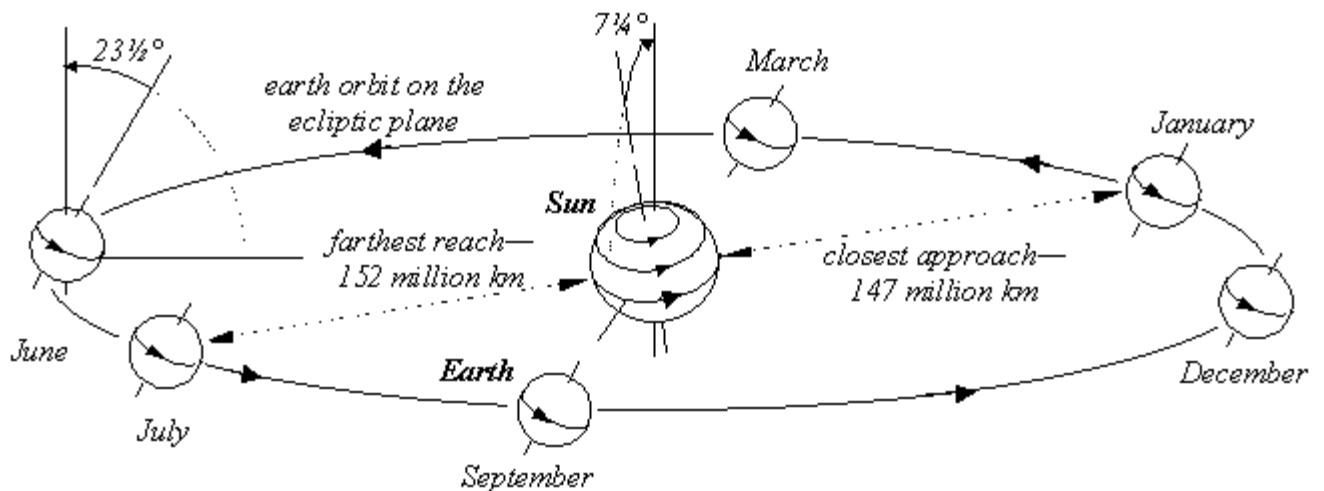


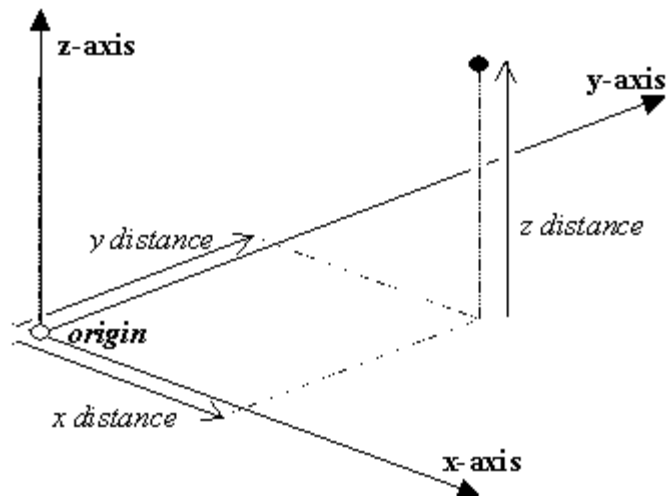
Figure 1 - Earth Orbit and Rotation Solar Rotation

General Cartesian Coordinates

Let's review some systems in which we may already be familiar. These basic systems will springboard us into understanding the concepts of the more complicated systems. Let's first review the Cartesian coordinate system—perhaps the first system we learned in school.

To identify a general position anywhere in three-dimensional space (or the components of a vector), we can use *Cartesian coordinates*. The diagram below shows how we use three variables (in this case x , y , and z) in this coordinate system to locate a point in reference to an *origin*. We can think of the x -axis as being easterly, the y -axis as northerly, and the z -axis as elevation.

This system is useful and convenient for identifying points on a scale that doesn't consider the earth as a sphere (such as a building plan or a town layout). However, Cartesian coordinates become impossibly cumbersome in describing the positions of things where spherical curvature becomes important.



Heliographic Coordinates

The heliographic coordinate system facilitates describing the position of things located on the sun. The diagram below summarizes how we use two variables in this coordinate system to locate a point on the sun's surface.

Carrington Longitude (L) is the “east-west” angular distance measured from a prime meridian, which is a predetermined point of origin that *rotates with the sun*. Since the sun rotates at different rates according to latitude (differential rotation), we choose the *average* rotation rate: 13.2° per day, or one rotation every 27.2753 days. Also, there is no regular feature on the sun to help us identify the prime meridian by sight alone, so we simply keep track of its position by timing. On 9 November 1853 at 0000Z, Carrington arbitrarily assigned the north-south centerline on the visible solar disk as the

meridian $L_0 = 0^\circ$, and we've been keeping track of the prime meridian ever since. The *Carrington Rotation Number* is the number of times the prime meridian has rotated around the sun since 1853. At a rate of about 13.39 Carrington Rotations per year, the Carrington Rotation Number is now over 1,955. Carrington Longitude ranges from 0° to 360° , increasing in the direction of the sun's rotation. The *Astronomical Almanac* lists L_0 by date at 0000Z.

Latitude (B) is the angular distance from the solar equator, which is defined as the line equidistant from the two poles. We measure solar latitude from $B = -90^\circ$ (solar south pole) to $B = +90^\circ$ (solar north pole). The solar equator is at $B = 0^\circ$.

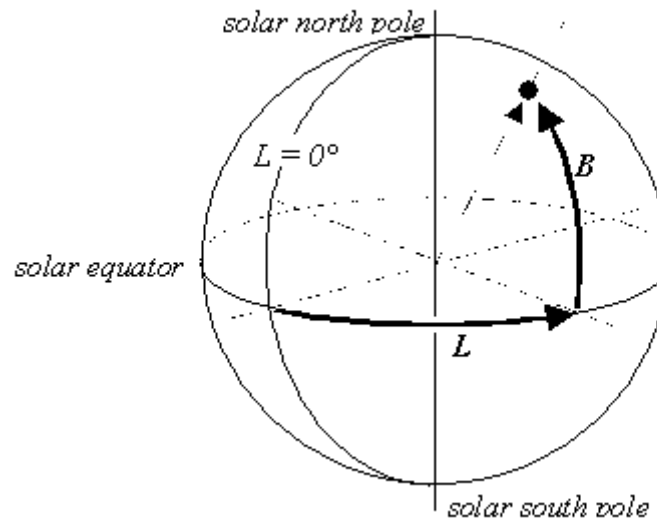


Figure 2 - Heliographic Coordinate System

Geocentric Solar Coordinates

The geocentric solar coordinate system facilitates describing the position of things located on the visible disk of the sun *as viewed from the earth and oriented according to directions on the earth*.

Solar disk hemispheres. The *north point* on the solar disk is the point on the solar limb closest to the northern direction on the earth. In other words, the north point of the noonday northern hemisphere solar disk is at the top of the sun, *regardless of where the rotational north pole of the sun is located*. Conversely, in the southern hemisphere, the bottom edge of the noonday sun is the north point of the solar disk. It follows that the eastern solar hemisphere is that side of the sun closest to the earth's eastern horizon; the western solar hemisphere is the side of the sun closest to the earth's western horizon. The western limb of the sun is the first part of the sun to rise in the morning and the eastern limb is the last part to set in the evening. Therefore, the directions on the sun are *backwards* compared to the directions on a map of the earth's surface. East and west are reversed—not north and south! Learn this convention.

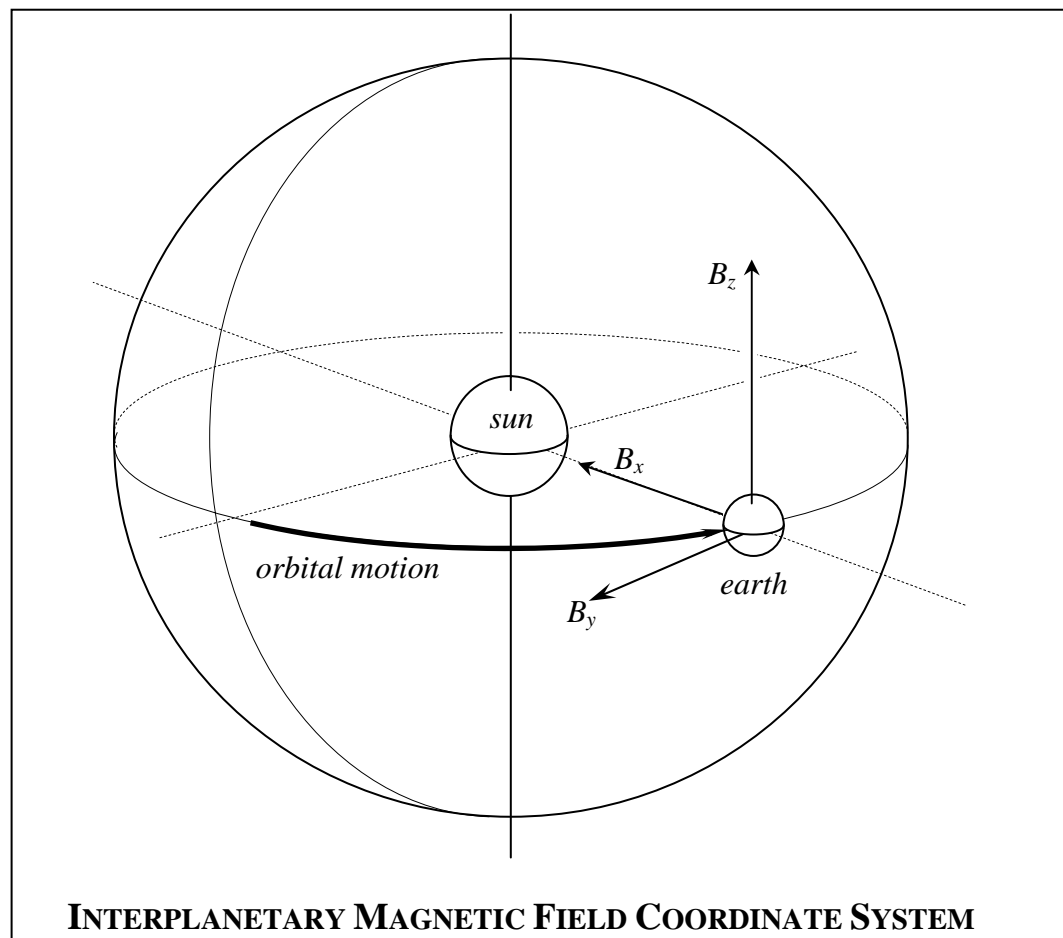
Interplanetary Magnetic Field Coordinates

IMF coordinates are patterned after Cartesian coordinates that move with the earth in its orbit.

B_x is the equivalent of the x-axis in Cartesian coordinates. It always points toward the center of the sun from the vantagepoint of the earth in its orbit.

B_y is the equivalent of the y-axis in Cartesian coordinates. It lies at a right angle to B_x and points in the anti-orbital direction of the earth's orbit.

B_z is the equivalent of the z-axis in Cartesian coordinates. It lies at a right angle to both B_x and B_y ; it points straight north, or perpendicular to the ecliptic plane.



Geographic Coordinates

The geographic coordinate system facilitates describing the position of things located on the surface of the spherical earth. We are all familiar with this system. The diagram below summarizes how we use three variables in this coordinate system to locate a point at or above the earth's surface.

Longitude, often designated by the Greek letter theta (θ), is the east-west angular distance measured from a prime meridian, which is a predetermined north-south line of origin that *rotates with the earth*. On the earth it is the north-south arc running through Greenwich, England. Longitude is usually measured toward the east from 0° to 360° , although sometimes it is measured east *or* west from the meridian and then designated as such. For example, longitudes of 100° and 200° are equivalent to 100°E and 160°W respectively.

Latitude, often designated by the Greek letter phi (ϕ), is the north-south angular distance from the equator. The earth's north and south poles mark the rotational axis of the planet; the equator is equidistant between the poles. Latitude is measured from -90° (south pole) to $+90^\circ$ (north pole). The equator is at zero degrees latitude.

Altitude and elevation (z) is the radial distance from the earth's center. By convention, either mean sea level (MSL) or ground level is used as a reference level.

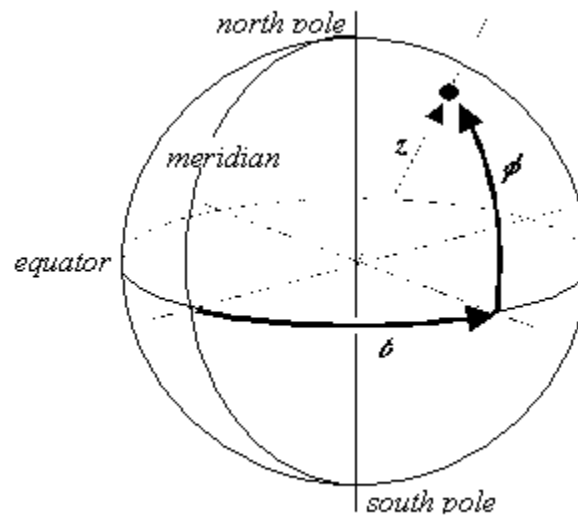
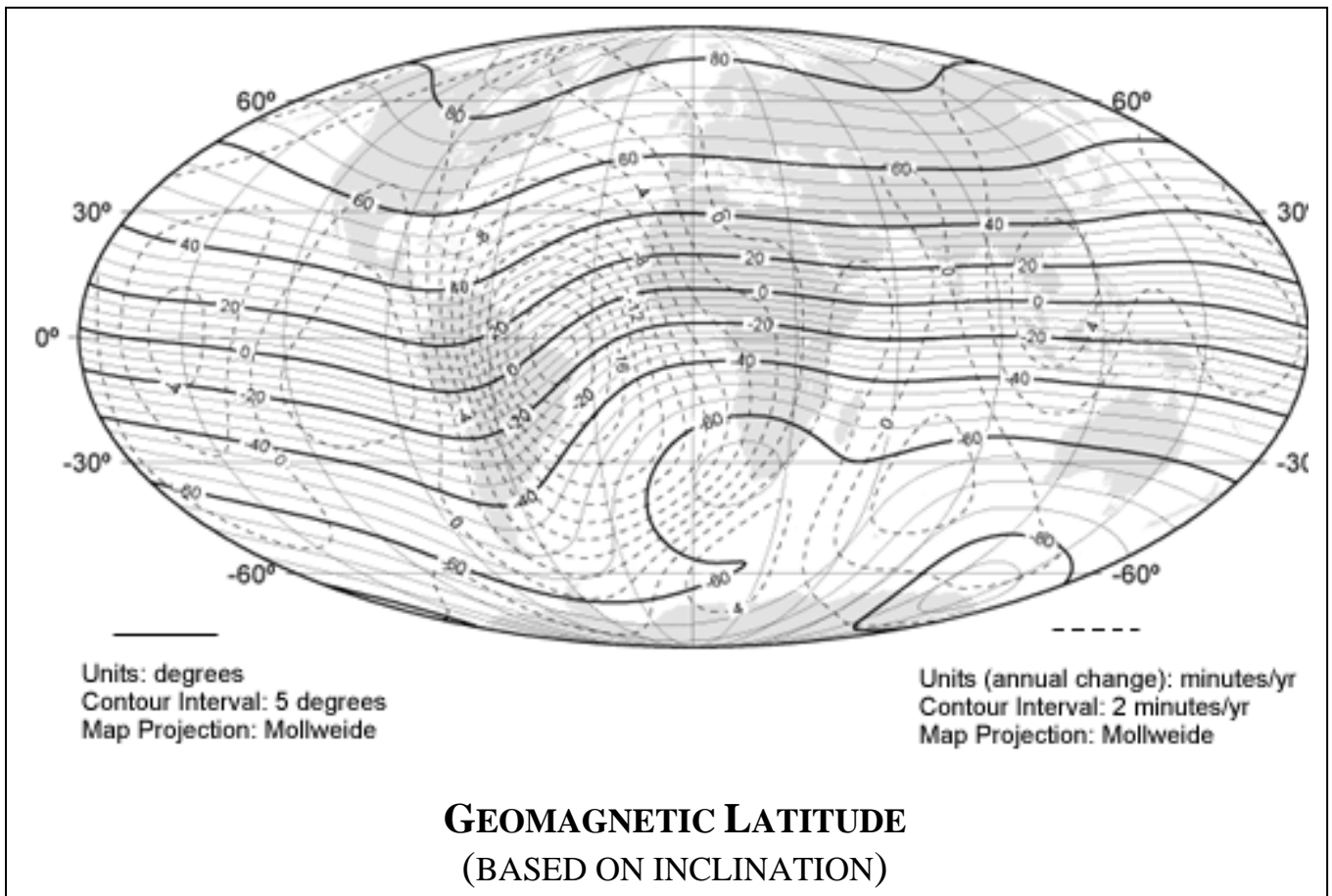


Figure 3 - Geographic Coordinate System

Magnetic Coordinate Systems

Global Magnetic Coordinates. The *geographic* coordinates of the earth are measured in latitude and longitude, where the equator and poles are defined as 0° and $\pm 90^\circ$ latitudes respectively. Since the magnetic field also suggests an equator and poles, we can therefore define geomagnetic latitude and longitude. However, while *geographic* latitude and longitude lines are perfectly circular, *geomagnetic* latitude is defined by the strength and direction of the magnetic field at each point on the earth's surface. Geomagnetic longitude is defined by the relative position of the sun. So when we speak of geomagnetic latitude, we are referring to a location on the earth's surface relative to the earth's magnetic equator and poles. When we speak of geomagnetic longitude, we are referring to a location on the earth's surface relative to the sun's position.

| IMPORTANT GEOMAGNETIC COORDINATE FEATURES | | |
|---|--|-----------------------------------|
| Geomagnetic Latitude | Magnetic Equator | 0° geomagnetic latitude |
| | Magnetic North Pole | $+90^\circ$ geomagnetic latitude |
| | Magnetic South Pole | -90° geomagnetic latitude |
| Geomagnetic Longitude | Local Noon (sunward direction) | 0° geomagnetic longitude |
| | Local dusk | 90° geomagnetic longitude |
| | Local midnight (ant-sunward direction) | 180° geomagnetic longitude |
| | Local dawn | 270° geomagnetic longitude |



Local Magnetic Coordinates. When we measure the strength, direction, and variations of the magnetic field at a particular point on the earth's surface by a magnetometer, we use local magnetic coordinates. There are two schemes: geomagnetic elements and SEC reported units.

Geomagnetic elements. The following define the various geomagnetic components; the diagram below illustrates these.

F is the *total* field strength; it points along the magnetic field line; it is measured in nT (nanotesla).

X is the northward (geographic) component of the magnetic field; it is measured in nT.

Y is the eastward (geographic) component of the magnetic field; it is measured in nT.

Z is the local vertical component of the magnetic field; it is measured in nT.

H is the horizontal strength of the magnetic field; it is measured in nT.

D is the declination of the magnetic field, the angle between true north and **H**—measured in degrees.

I is the inclination of the magnetic field, the “dip” angle, or the angle between **H** and **F**—also measured in degrees.

