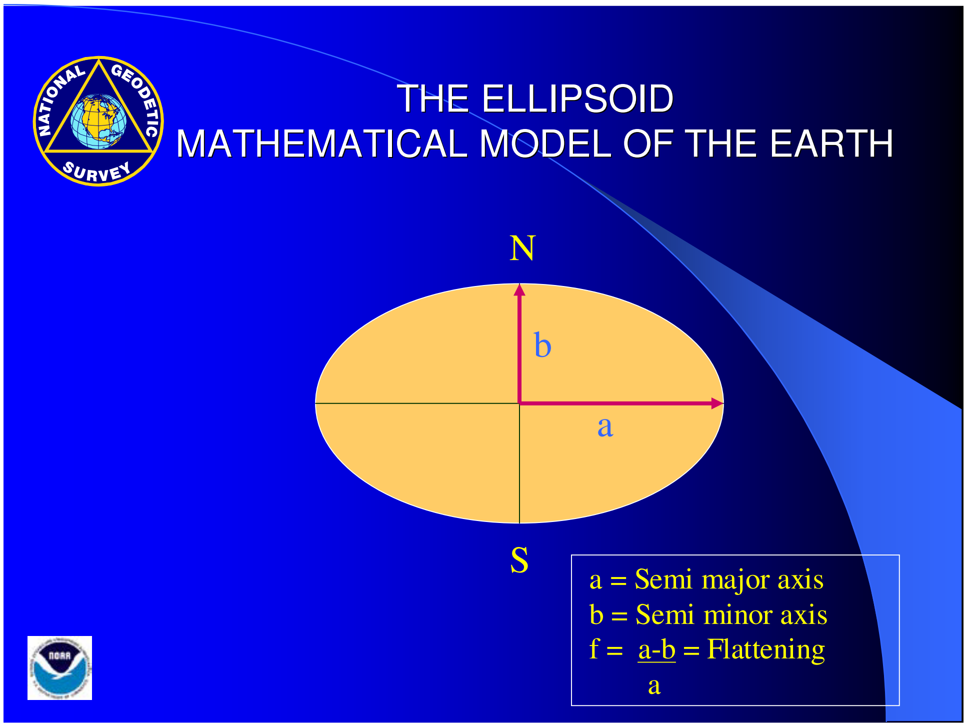
EIGHTH PERIOD: Topic 1(b) *2005*

Horizontal Geodetic Datums, Latitudes, and Longitudes

Reading: Pages 27-33 and 83-99 of “Introduction to Geodesy – The History and Concepts of Modern Geodesy” by James R. Smith.

Horizontal Geodetic Datums

All horizontal geographic coordinates (latitudes and longitudes), and state plane coordinates (northings and eastings) are based on an underlying oblate ellipsoid. An oblate ellipsoid is a mathematical model representing the earth and is defined by values for the semi-major axis, semi-minor axis, and a flattening constant.



THE ELLIPSOID
MATHEMATICAL MODEL OF THE EARTH

a = Semi major axis
b = Semi minor axis
f = $\frac{a-b}{a}$ = Flattening

The ellipsoid is then rotated about the north-south axis to form an ellipsoid of revolution. From a selected oblate ellipsoid of revolution a geodetic datum can be created.

What is a horizontal geodetic datum?

The *Geodetic Glossary* (National Geodetic Survey, National Ocean Service, National Oceanic and Atmospheric Administration, Rockville, MD, September 1986) pp. 54, defines a horizontal geodetic datum as:

1. "A set of constants specifying the coordinate system used for horizontal geodetic control, i.e., for calculating the coordinates of points on the Earth."

> 2. "The datum, as defined in (1), together with the coordinate system and the set of all points and lines whose coordinates, lengths, and directions have been determined by measurement or calculation."
>
> These differing definitions require caution when using the word "datum." The first definition makes horizontal datum synonymous with the selection of a horizontal reference coordinate system (origin and orientation). The second definition makes horizontal datum synonymous with a list of coordinates of the control points. When the first definition is used, the published coordinates of control points can change when better measurements allow better determinations. With the second definition, a change in coordinates should result in a new datum.

Another definition is: A datum is defined as any numerical or geometrical quantity or set of such quantities which serve as a reference or base for other quantities. In geodesy two types of datums must be considered: a horizontal datum which forms the basis for the computations of horizontal control surveys in which the curvature of the earth is considered, and a vertical datum to which elevations are referred (vertical datums will be discussed in later topics of this Eighth Period). In other words, the coordinates for points in specific geodetic surveys and triangulation networks are computed from certain initial quantities.

So, a horizontal geodetic datum is based on an oblate ellipsoid of revolution and defines a horizontal coordinate system to reference objects above, on, or below the surface of the earth. It is, until the advent of satellite geodesy, positioned with respect to the earth by a horizontal coordinate value at a station, known as an initial point, and an azimuth from that station. Note that defining a reference ellipsoid does not form a horizontal geodetic datum on its own. The discussion in the rest of this portion of topic 1(b) will focus on horizontal geodetic datums used by the United States.

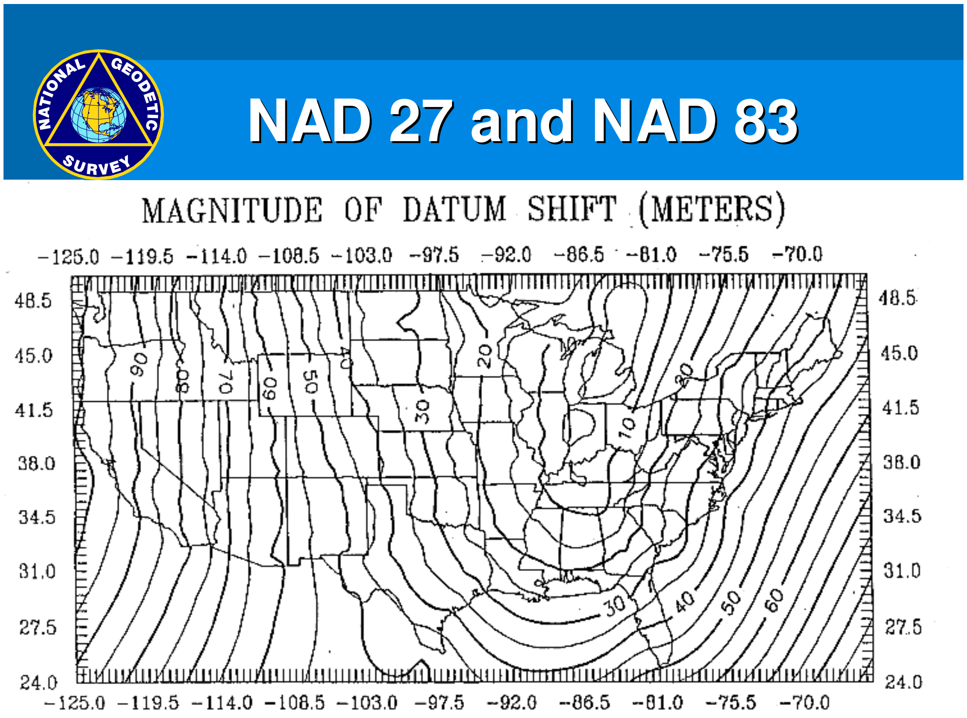
North American Datum of 1927 (NAD27)

From the early part of the 20th century Clarke's spheroid (ellipsoid) of 1866 was used to formulate the national geodetic datum known as the North American Datum of 1927 (NAD27). This datum was created and maintained by the U.S. Coast and Geodetic Survey. The origin of NAD27 was a single triangulation station named "Meades Ranch" and an azimuth to Station Waldo, which are located in North Central Kansas. From this station and azimuth over 50,000 stations were coordinated throughout the contiguous United States and Alaska.

Over time, as the national network grew, distortions were introduced and advances in surveying and computing technologies presented an opportunity to more precisely measure the earth. Additionally, the world has become a more global oriented society requiring the creation of a better horizontal geodetic datum.

North American Datum of 1983 (NAD83)

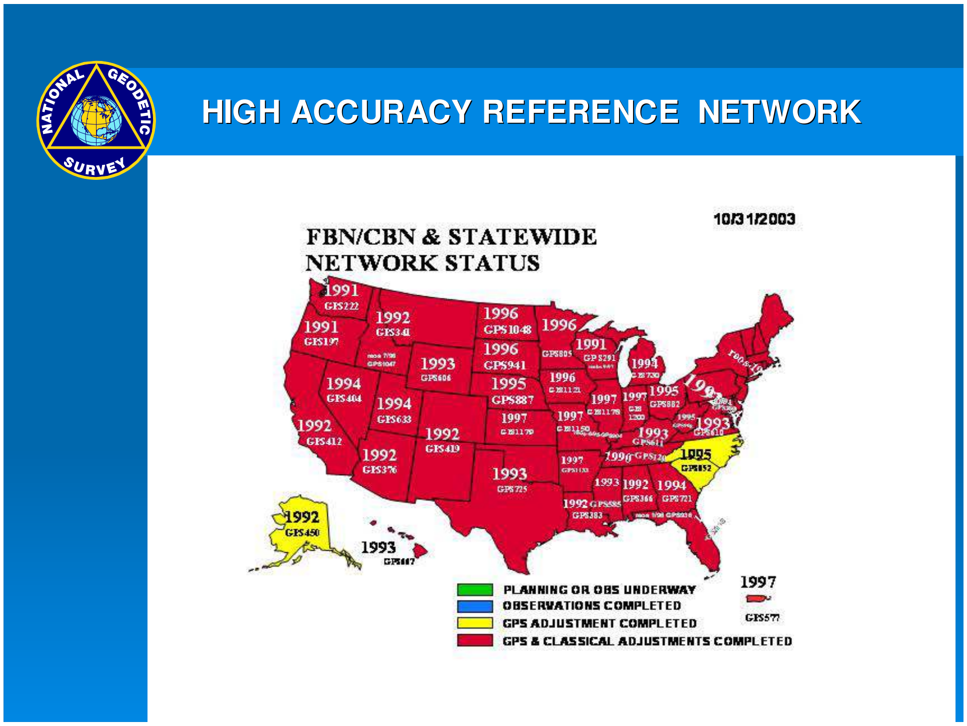
The North American Datum of 1983 (NAD83) is an earth-centered datum based on the oblate ellipsoid of revolution known as the Geodetic Reference System of 1980 (GRS80) and is intended to replace NAD27. It was established as a result of an international project involving the National Geodetic Survey (NGS), the Geodetic survey of Canada, and the Danish Geodetic Institute (responsible for surveying in Greenland). The size and shape of the earth was determined through measurements made by satellites and other sophisticated electronic equipment. It is based on measurements at over 250,000 stations that were adjusted simultaneously in a least squares adjustment. The adjustment produced a “datum shift” in coordinate values between NAD27 and NAD83 represented across the U.S. by the following diagram:



In order to realize NAD83 at a very high level of accuracy, NGS produced High Accuracy Reference Networks (HARN) across the United States for statewide geodetic network upgrades. In California the HARN is known as the High Precision Geodetic Network (HPGN). The generic acronym HARN is now used for both HARN and HPGN and was adopted to remove the confusion arising from the use of two acronyms. However, in California we use the acronym HPGN anyway.

A HARN is a statewide or regional upgrade in accuracy of NAD83 coordinates using Global Positioning System (GPS) observations. HARNs were observed to support the use of GPS by Federal, state, and local surveyors, geodesists, and many other applications. The cooperative network upgrading program began in Tennessee in 1986. The last field observations were completed in Indiana in September 1997 after horizontally upgrading some 16,000 survey stations to A-order or B-order status. Horizontal A-order stations have a relative accuracy of 5 mm +/- 1:10,000,000 relative to other A-order stations. Horizontal B-order stations have a relative accuracy of 8 mm +/- 1:1,000,000 relative to other A-order and B-order stations. Of these 16,000 stations, NGS has committed to maintaining about 1,400 survey stations, named the Federal Base Network (FBN), and the various states maintain the remainder.

The following illustration shows the completion dates of the statewide and regionwide HARNs. Notice that California is shown as completed in 1992, which is when the values were published, even though the average observation date of the data was 1991.35.



HIGH ACCURACY REFERENCE NETWORK

10/31/2003

FBN/CBN & STATEWIDE NETWORK STATUS

🟩 PLANNING OR OBS UNDERWAY
🟦 OBSERVATIONS COMPLETED
🟨 GPS ADJUSTMENT COMPLETED
🟥 GPS & CLASSICAL ADJUSTMENTS COMPLETED

Coordinate values in NAD83 are represented by the datum, a “datum tag”, and an “epoch date”. A datum tag is a value that indicates the date of an adjustment of the datum and an epoch date denotes the date for which positions correspond to a datum adjustment. A coordinate value will have a corresponding datum, datum tag and epoch date that is represented as NAD83 (*datum tag*) *epoch date xxxx.yy*. For example, NAD83 (1992) epoch date 2004.00 represents the NAD83 datum with the datum tag of 1992 (HPGN date) and an epoch date of 2004.00.

In general, do **not** mix values for control stations that have different datum tags in an adjustment. Also, do not mix values on control stations that have the same datum tag but different epoch dates unless you make use of a crustal motion modeling program such as the Horizontal Time Dependent Positioning (HTDP) program published by Dr. Snay of NGS and you perform a thorough analysis of your adjustment results.

Information on stations with NAD83 values can be retrieved at your local County Surveyor’s office, from “data sheets” published by NGS at NGS’s web site: http://www.ngs.noaa.gov or from the California Spatial Reference Center’s web site: http://csrc.ucsd.edu . The following shows where to find the data sheets on NGS’s web site.

Geodetic Data Sheets

Check these out...

NOAA-LSU Study: Portions of Gulf Coast Sinking at Significant Rate: Increased Attention Given to Address Public's Vulnerability to Severe Weather.

Datasheets On CD-ROM: NGS has discontinued selling datasheets on CD-ROM.

New VDatum Utility: VDatum is a tool for the conversion of elevation data among 28 different vertical datums... *more*

OPUS Upgraded: NGS recently introduced a new version of OPUS that allows users to submit compressed GPS data ...*more*

NGS Report to Congress: "Geodetic Programs Needs of

As a point of interest, NGS will perform a new NAD83 datum adjustment for the entire United States. It will be published sometime in 2007 and will be designated NAD83 (NSRS). NSRS stands for the National Spatial Reference System. The following is taken from NGS's web site on this subject:

> "On September 24, 2003, NGS's Executive Steering Committee approved a plan for the readjustment of horizontal positions and ellipsoid heights for GPS stations in the contiguous United States. Some of the key points are:
>
> - Only GPS will be adjusted. Classical geodetic observations will not be included.
>
> - The National Continuously Operating Reference Stations (CORS) stations will serve as control, ie, CORS positional coordinates will be held fixed.
>
> - Both NAD 83 and ITRF coordinates will be produced and published. The former will be designated *NAD 83 (NSRS)*.
>
> - User densification projects will be included if observed with GPS and tied to the HARNs.
>
> - Network and local accuracies will be implemented with the Readjustment of the NSRS.
>
> - In the event of a delay in software development, testing, and implementation of the new network and local accuracies, a contingency option was adopted. This option endorses immediate

> statewide GPS readjustments of both horizontal positions and ellipsoid heights."

This points out that when you are doing geodetic surveying you need to stay up on the current datum, datum adjustment (datum tag), and epoch date information. The use of CORS stations and the concepts of network and local accuracies will be discussed in later topics in this Eighth Period.

World Geodetic System of 1984 (WGS84)

WGS84 is the World Geodetic System of 1984. It is the reference frame used by the U.S. Department of Defense (DoD) and is defined by the National Imagery and Mapping Agency (NIMA) (formerly the Defense Mapping Agency). WGS84 is used by DoD for all its mapping, charting, surveying, and navigation needs, including its Global Positioning System "broadcast" and "precise" satellite orbits. In other words, it is the reference ellipsoid that forms the basis of the GPS system. WGS84 was defined in January 1987 using Doppler satellite surveying techniques. WGS84 was redefined in 1997 to be more closely aligned with the International Earth Rotation Service (IERS) Terrestrial Reference Frame (ITRF) 94. Transformations from this system can be made to horizontal geodetic datums including NAD83.

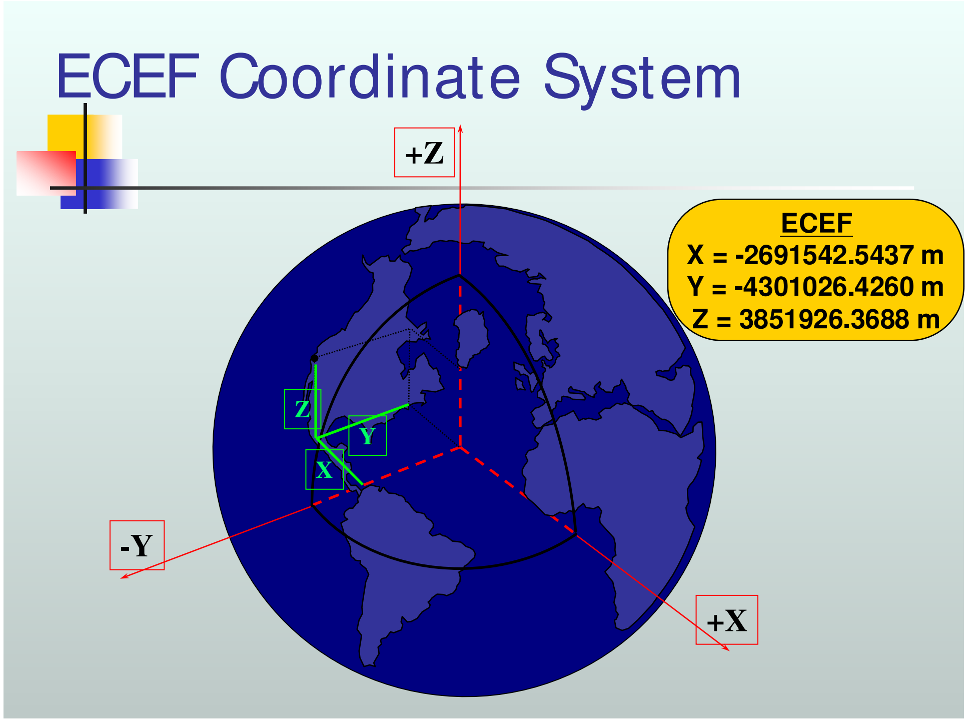
International Terrestrial Reference System

This reference frame is only being discussed as many future developments in horizontal geodetic datums will be based on it. The ITRF origin is at the center of mass of the whole Earth, including the oceans and the atmosphere. It is the best model representing the earth available today and is constantly being updated with the collection of more information. Its time evolution in orientation is such that it has no residual rotational horizontal velocity relative to the Earth's crust. This makes it a better reference system for the whole world. Transformations from this system can be made to horizontal geodetic datums including NAD83. Note that the 2007 NAD83 adjustment described above will also produce ITRF values.

Earth Centered Earth Fixed (ECEF) Coordinates

Ok, so a horizontal geodetic datum is based on an oblate ellipsoid of revolution (reference ellipsoid) and has values on control stations that are Cartesian coordinates (ECEF), geographic coordinates (latitudes and longitudes), and state plane coordinates. This segment will discuss the ECEF Cartesian coordinates and geographic coordinates. State plane coordinates will be discussed at length in subsequent topics.

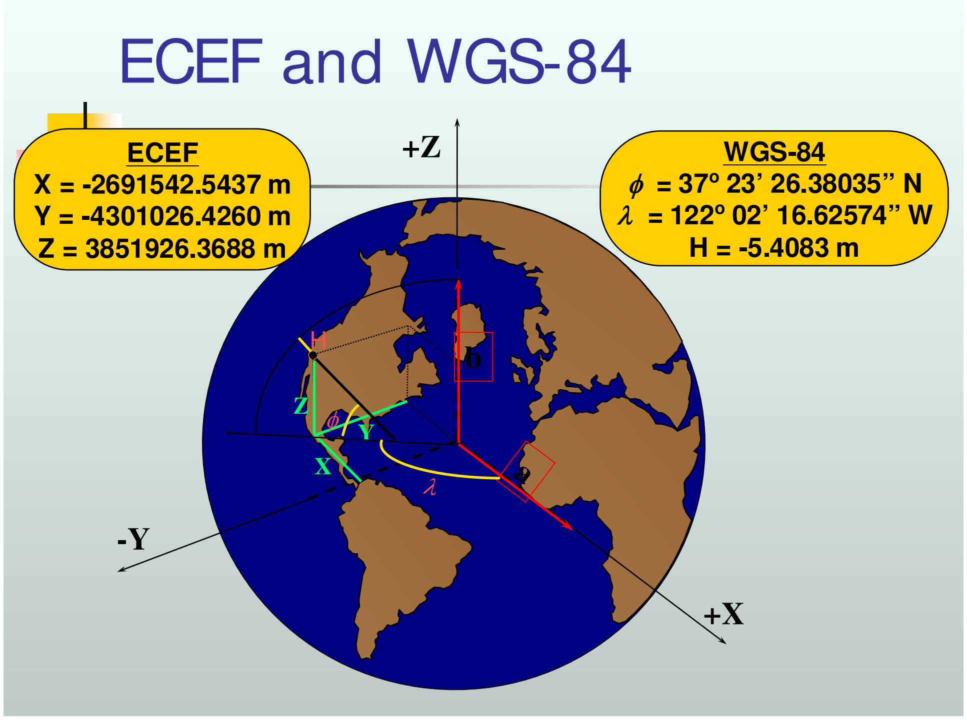
Cartesian coordinates are coordinates that are shown as an ordered pair. For example, (x,y) or (X,Y,Z). The ECEF are listed as (X,Y,Z). The ECEF coordinates (in meters) are used to describe the location of a GPS user or satellite. The term "Earth-Centered" comes from the fact that the origin of the axis (0,0,0) is located at the mass center of gravity (determined through years of tracking satellite trajectories). The term "Earth-Fixed" means that the axes are fixed with respect to the earth (that is, they rotate with the earth). The Z-axis pierces the North Pole, and the XY-axis defines the equatorial plane. The following illustration shows a point in California and its ECEF coordinates. Note the magnitude of the values. This is because the coordinate system begins at the center of the earth.



ECEF Coordinate System

ECEF
X = -2691542.5437 m
Y = -4301026.4260 m
Z = 3851926.3688 m

ECEF coordinates are expressed in a reference system that is related to GPS/GLONAS satellites. The use of a reference ellipsoid allows for the conversion of the ECEF coordinates to the more commonly used geographic coordinates of Latitude, Longitude, and Ellipsoid Height (LLE), where the latitude and longitude are the horizontal component. The reference ellipsoid used for GPS purposes is the WGS84. The following illustration shows the relationship between ECEF Cartesian coordinates and WGS84 geographic coordinates.



ECEF and WGS-84

ECEF
X = -2691542.5437 m
Y = -4301026.4260 m
Z = 3851926.3688 m

WGS-84
ϕ = 37° 23’ 26.38035” N
λ = 122° 02’ 16.62574” W
H = -5.4083 m

Latitudes and Longitudes

Ok, to this point ECEF Cartesian coordinates and their relationship to WGS84 geographic latitudes and longitudes have been described. Now the discussion will turn to general concepts about latitudes and longitudes.

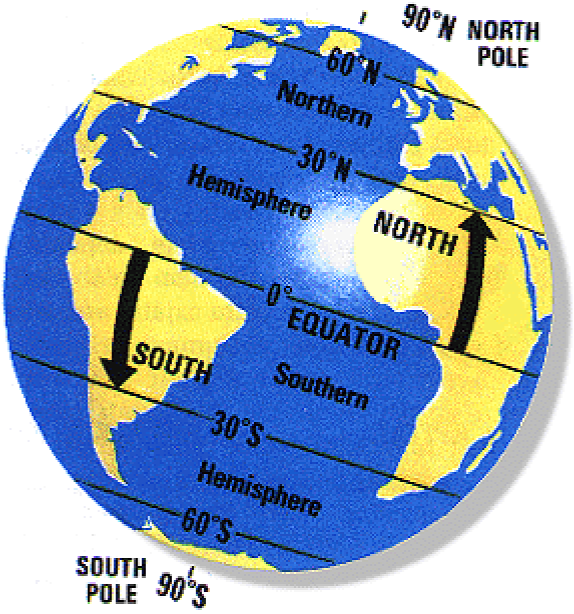
Any horizontal location on Earth can be described by two numbers--its **latitude** and its **longitude**. If a pilot or a ship's captain wants to specify their position on a map, these are the "coordinates" they would use. Note that latitudes and longitudes depend on the reference ellipsoid that is being using.

Actually, latitude and longitude are two angles, measured in degrees, "minutes of arc" and "seconds of arc." These are denoted by the symbols (°, ', "). For example, 35° 43' 9" means an angle of 35 degrees, 43 minutes and 9 seconds (do not confuse this with the notation (', ") for feet and inches!). A degree contains 60 minutes of arc and a minute contains 60 seconds of arc. You may omit the words "of arc" where the context makes it absolutely clear that these are not units of time.

The standard convention for representing latitude and longitude is by use of small letters of the Greek alphabet. The standard representation of latitude is by φ (phi, Greek F), and the standard representation of longitude is by λ (lambda, Greek L).

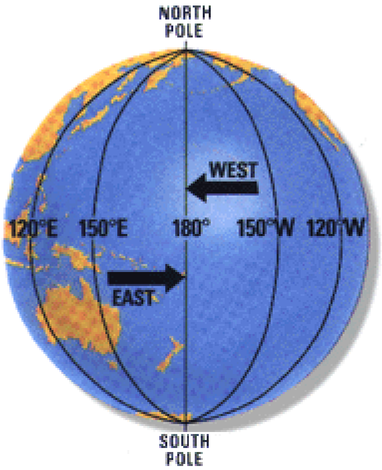
For latitude (or parallel), imagine the Earth to be a transparent sphere. Then imagine a plane that cuts through the earth’s equator and the center of the Earth, point O. To specify the latitude of some point P on the surface, a line is drawn from the radius to that point, line OP. Then the elevation angle of that point above the equator is its latitude (φ). A positive latitude denotes a point north of the equator and a negative latitude denotes a point south of it.

On a reference ellipsoid of the Earth, lines of latitude are circles of different size. The longest is the equator, whose latitude is zero, while at the poles, at latitudes 90° north and 90° south (or -90°), the circles shrink to a point.

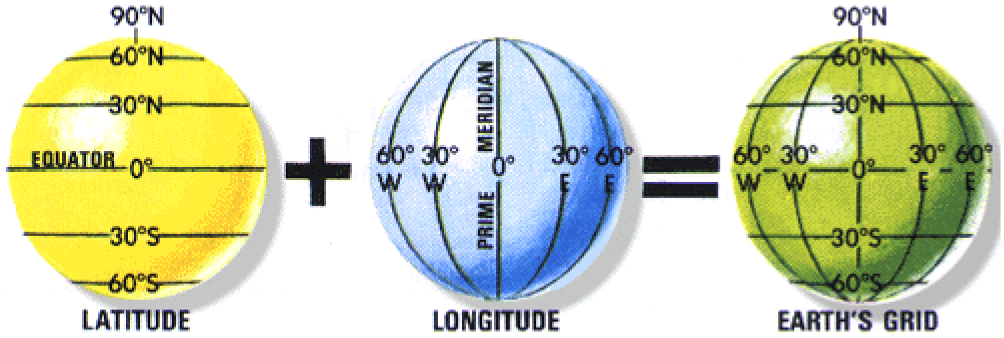


On the reference ellipsoid, lines of constant longitude, which are also called meridians, extend from pole to pole, like the segment boundaries on a peeled orange.

Every longitude must cross the equator. Since the equator is a circle, we can divide it into 360 degrees, and the longitude (λ) of a point is then the marked value of that division where its meridian meets the equator. What that value is depends of course on where we begin to count;

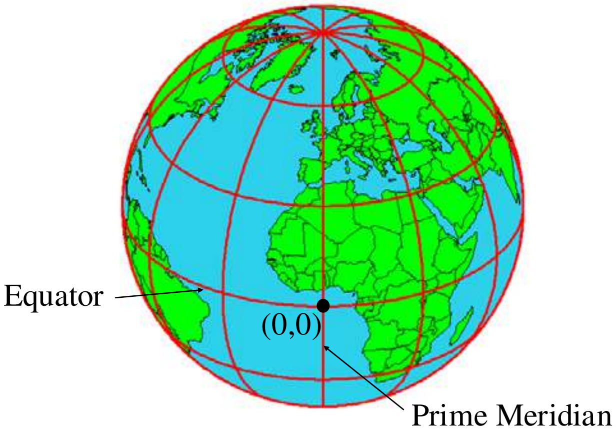


namely, on where zero longitude is. For historical reasons, the meridian passing the old Royal Astronomical Observatory in Greenwich, England, is the one chosen as zero longitude. Located at the eastern edge of London, the British capital, the observatory is now a public museum and a brass band stretching across its yard marks the "prime meridian", which is zero longitude. Tourists often get photographed as they straddle it--one foot in the eastern hemisphere of the Earth, the other in the western hemisphere. Longitudes east of Greenwich have positive values, while longitudes west of Greenwich have negative values.



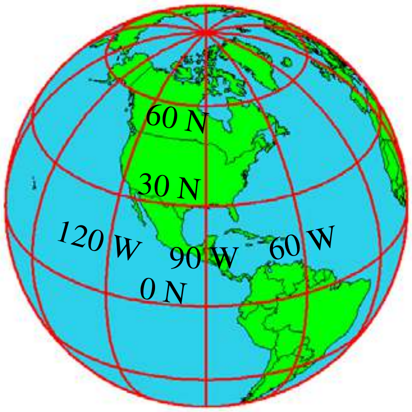
The following illustration shows the origin of geographic coordinates. Notice that zero latitude and zero longitude are at the intersection of the equator and the prime meridian, which passes through Greenwich.

Origin of Geographic Coordinates



The following picture shows the limits of latitudes and longitudes in North America.

Latitude and Longitude in North America



The next topic will discuss transformations between geodetic datums and projections within a geodetic datum.