Chapter 2 *Map Projections*

Objectives:

This chapter will explain some cartographic principles as well as define the meaning of several map projections. The information provided is useful to either manual or computer aided mapping. It should also help you understand a few of the map projections used by the U.S.G.S. (United States Geological Survey).

At the end of the chapter you should be able to:

1. Define the following terms:

    - geocentric
    - geoid
    - graticule
    - grid
    - projection
    - spheroid/ellipsoid
    - UTM

2. Explain the difference between a grid and a graticule.

3. Locate the projection, grid/graticule and datum information on a map.

4. Name the most common map projections used by cartographers as well as name the projection used by GRASS.

The text in this chapter is extracted primarily from a training manaul used by the Soil Conservation Service for teaching GRASS. Several changes have been made to the text for inclusion in this manual.

Development of Coordinate Systems:

Several methods for representing the spherical earth on a flat surface have been developed from the time of the Greek philosophers. Mathematical representations were developed through the efforts of Mercator and others in the 1600's. Since then refinements to various projections have occurred in attempt to better represent the true surface form of the earth. Several such projections are represented in the reading which follows.

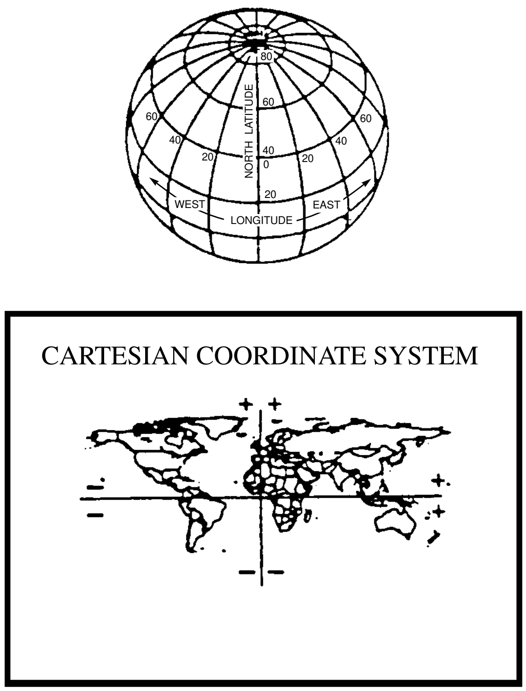
Before we can understand coordinate systems on maps, we must tale a look at a globe, a scaled representation of the earth, and note its characteristics. Essentially, the earth is a sphere which has two points that will help us to develop a reference system for points we wish to locate on its surface. The earth rotates on its axis and the two ends of this axis form our north and south reference points, the poles. Between these poles we can determine an ***equator***, a line equidistant from the poles and forming a ***great circle***. This great circle divides the sphere into two equal hemispheres as it passes through the center of the earth.

With the polar points and the equator, we now have a method of labelling locations north and south of the equator, called ***latitude***. By convention, we use a ***sexagesimal*** system of assigning coordinate values; we call the equator zero and count northward or southward to 90 degrees, which is the value given the poles. Each of these degrees may then be broken into 60 minutes, each minute into 60 seconds, and each second into decimal tenths, hundredths, etc. to attain any desired accuracy. This is not the only way we could count, but it is a time honored convention.

A latitude, however, is only half a coordinate. At 40 degrees north latitude, we could be anywhere around the globe, in the U.S., Spain, Italy, Greece, Turkey, the Soviet Union, China, Korea or Japan. An east-west reference is also necessary to define a point. Unfortunately, there is no point in the east-west direction which easily defines the starting point for ***longitude***. For years, countries set their own starting point, their ***prime meridian***, the French in Paris, the Americans in Washington, etc. It was not until the late 1800,s that the major mapping nations arbitrarily chose a longitude line passing through England's Greenwich Observatory to use as the international prime meridian, zero degrees longitude. Sexagesimal values were then assigned from zero degrees to 180 degrees both east and west, meeting at a line in mid-Pacific Ocean. Again, this is a conventional numbering choice.

The latitude and longitude lines, then, apply a Cartesian coordinate system to the globe.

Figure 1. The Cartesian Coordinate System



This is important when working with geographic coordinates (latitude and longitude) in GIS. The United States, for example, falls in the quadrant where latitude is always north of the equator (+) and longitude is always west of the prime meridian (-). A computer, given north longitude values in the United States would be able to "flip" the product - a map of the contiguous U.S. could show California on the east coast, Florida on the west. Maine and Texas would remain in the north and south, respectively, even though they would be plotted in reverse orientation laterally.

While you are looking at the globe, notice also that the latitude lines form ***parallels*** and that the equator is the only latitudinal great circle, dividing the globe equally into two half-spheres or hemispheres. The remaining parallels are ***small circles***, decreasing in size northward or southward to the poles which are a point rather that a small circle. All longitudes included with their counterparts on the other side of the globe, form great circles and each longitude line, or ***meridian***, converges with the others at the poles. As we shall see later, these fundamental relationships may change as we construct flat representations (projections) from the spherical earth.

This, then, is the most basic of earth's reference systems, latitude and longitude. The units are usually sexagesimal (based on units of 60) but degrees can be quoted in decimals, i.e., 40.50, 40 degrees and five tenths of a degree, or 40 degrees and 30 minutes.

Definitions of Basic Terms:

The problem presented in this portion of the course is to transfer the referencing system on the spherical earth to a flat plane, the computer screen or a map, with an acceptable degree of accuracy. Once the general principles of this process are understood, we can discuss some alternate referencing systems, the grids, which are related both in theory and positioning to the geographic coordinate system.

To know our position on the earth with any reasonable degree of precision, we must know the size and shape of the earth to which the coordinate systems has been applied. As the earth rotates around its axis, it forms an ***ellipsoid*** due to centrifugal force, bulging at the equator and flattening at the poles. This polar flattening is approximately one part in 300.

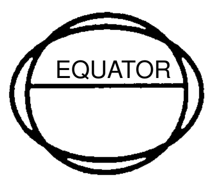


Figure 2. An approximation of the true figure of the Earth as an oblate Spheroid. The flattening at the poles and bulging at the Equator results from the forces of centrifugal rotation.

The earth in this rotational form can also be referred to as spheroidal. (***spheroid*** and ellipsoid are often used interchangeably.)

There have been many estimates of the size of the earth and the polar flattening, but the estimate which best fits the globe in the North American area, until recently, is called the Clarke 1866 Spheroid or Clarke 66 for short. This spheroid is the basis for much U.S. mapping and is the default choice on many ellipsoid menus in GIS. The Hawaiian Islands, falling as they do in mid-Pacific, use the International Spheroid and foreign areas have been placed on still other ellipsoids, depending on which estimate of size and shape best fits their particular geographic location.

In the last two decades, using highly advanced earth measurement techniques, a new "best fit" estimate for the entire world has been derived. It is called the Geodetic Reference System, 1980 or GRS 80. It is also a choice on ellipsoid menus, but should be used only with newer U.S. materials which state that they are on North American Datum 1983.

Another basic word describing the shape of the earth is ***geoid***. The geoid is an equipotential surface of the earth's gravity field; it can be envisioned as a continuous sea level surface extending below the continents. The geoid undulates in response to distribution of the earth's mass and is, therefore, not useful for horizontal surveying and mapping measurements although it is used in levelling (height determination). For horizontal measurement, the ellipsoid is used.

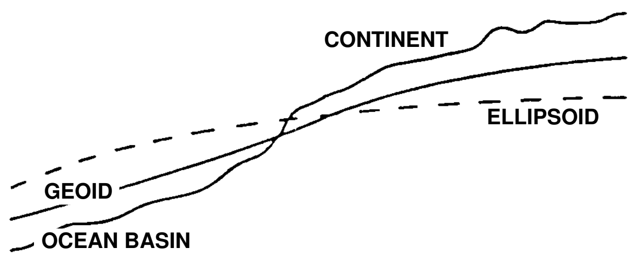


Figure 3. Relationship (exaggerated between an ellipsoid, such as Clarke 1866 and the geoid. Deviations are due to variations in the gravitational field caused, in part, by unequal mass distribution of crustal materials.

Once we know the size and shape of the ellipsoidal earth and can measure thereon, we are faced with the problem of flattening the curved surface onto a plane such as a map. This flattening process creates a projection, the basis framework of reference lines for a map.

A ***projection*** (with longitude and latitude lines is called a ***graticule***) may have some measurement disadvantages caused by curved parallels and meridians and the sexagesimal numbering system. To alleviate some of these problems, another type of referencing system, a ***grid***, has been developed. A grid consists of two sets of straight parallel lines, equally spaced and perpendicular to each other. This system may be overlaid upon, and mathematically related to the projection. It offers the advantages of straight lines for measurements and decimal numbering and, since it is designed to use only the upper right hand quadrant of the Cartesian coordinate system, all values may be read in a plus direction. Values should always be read "right and up."

One last term should be defined before we look at specific projections. This is the word ***datum***, a quantity or set of quantities which serve as a referent or basis for calculation of further quantities. In the cartographic sense of the word, we speak of a datum as the reference point or plane for the horizontal and vertical surveys which establish the position of features on the earth.