Coordinate Systems, Datums, and Map Projections

by Marc Mullaney

To truly understand how to properly use or make a map, you must understand how datums, coordinate systems and map projections tie together. With GPS, and other improved surveying techniques, coordinate accuracy and precision is better today that in the past. Due to these technological changes and earth processes, such as plate tectonics and isostatic rebound, coordinates on the earth's surface shift over time. This shift, known as a datum shift, is a change of the parameters determining the latitude, longitude, and elevation of points on the earth's surface. The following is a very simplified explanation of the topic.

Datums

There are two general types of datums: vertical and horizontal. A vertical datum is a calculation based on a mean sea level calculated over several years. The U. S. uses the National Geodetic Vertical Datum of 1929 (NGVD29). Horizontal datums are calculated using a mathematical calculation for the approximation of the shape of the earth, known as an ellipsoid. Most ellipsoids are calculated for a geographic region such as North America, India, or Australia. The U. S. uses the North American Datum of 1927 (NAD27) based on Clarke's ellipsoid of 1866 (Clarke 1866). Today, most newly generated geographic data sets use North American Datum of 1983 (NAD83) based on the Geodetic Reference System ellipsoid (GRS80). Using different datums causes an error known as a datum shift and causes some confusion due to the adoption of NAD83 for newly mapped data by federal agencies and everyone else who still use the older NAD27. A datum shift is not a simple mathematical calculation. Changes in surveying techniques (GPS), levels of accuracy and precision, earth changes, and other error generators all lead to difficulty in matching surveys conducted under different datums (Bower 1996).

Coordinate Systems

The most popular coordinate system for the earth is latitude and longitude. This system is a spherical coordinate system. Latitude is a trigonometric calculation, based on the angle of the sun or the polestar. A point's latitude is determined by calculating the angle from the center of the earth at the equator out to the point on the earth's surface. The poles are 90 degrees, or right angles, to the equator (0 degrees). The North Pole, not magnetic, is 90 degrees North; the South Pole, not magnetic, is 90 degrees South. Longitude is based on difference in time of two points on the earth, not angles. Without the invention of a ship worthy chronometer, a timepiece that withstood rolling, rocking, and temperature-, humidity-, pressure- variations, determining your exact location was extremely difficult. Because Great Britain was a sea power in the last few centuries, and because the British Admiralty wanted to solve this problem, it was a Britisher who invented a timepiece that could be used to determine longitude. Remember that distance = rate x time. Because the earth revolves on its axis there is no starting point like finding latitude. So the British stepped in. The origin of lines of longitude has been set, arbitrarily, as passing through the Royal Observatory, Greenwich, England. One Hundred Eighty degrees from Greenwich is the International Date Line. An American invention, the Public Land Survey System (PLSS), is a land survey system. PLSS was started by Thomas Jefferson for the equal share of land for the yeoman farmer. This coordinate system is based on surveyed baselines and meridians. Also known as Township and Range, PLSS is used in all states except Texas, the thirteen original colonies, and areas of pre-American ownership, such as parts of California. A starting point is located on the earth's surface and a baseline and meridian is established. Townships are mapped out in six-by-six mi. sq. sections until another PLSS grid, other survey system, or no more land is encountered. Each township is divided into thirty-six square mile grids and are numbered starting in the northwest and snaking down to section 36 in the southeast. Each section makes up 640 acres. Each section could be subdivided by quarters down 10 acres. This survey system is still seen in the U. S. The characteristic checkerboard patterns of the

American Midwest are indicative of this.

Map Projections

The perfect map is a globe, that is, a spherical representation of the earth. But because a globe is hard to carry around, mapmakers develop coordinate systems based on a plane, like a flat sheet of paper. These are commonly known as map projections. Cartographers, or mapmakers, develop projections from three basic geometric forms: cylinder, cone, and plane. A projection developed from a cylinder has a line of tangency, or secantcy, at the widest part. A projection developed from a cone has a point above a set distance above a point on the earth's surface, usually the North Pole. The line of tangency, or secantcy, is the line that the cone touches the earth's surface. . A projection developed from a plane has a point of tangency at that point on the earth's surface. A map projection name may have one of the three above geometric forms in its title to describe from what surface it was developed from. For example, the Lambert Conformal Conic is a projection developed from a cone. To choose the optimal map projection, one must understand the characteristics of projections. Projection systems either maintain or distort one or more of these elements.

1. Equal Area-sizes on the earth's surface are the same size on the map
2. Conformal-shapes on the earth's surface are not distorted
3. Equidistant-distances on the earth's surface are not distorted
4. Azimuthal--directions on the earth's surface are shown correctly with respect to point of tangency
5. Special Characteristics-Example: Mercator projection was popular for navigation, can set a course along a rhumb line, or straight line, to your destination. Ease of Construction-before computers all calculations had to be done by hand

Just as a map projection name may have a geometric form in its title, so too the map characteristics. Going back to the Lambert Conformal Conic, we know that this projection maintains shapes, that is, a conformal projection. There are some projections that are not developed mathematically. These are known as compromise projections. One example is the Robinson. The cartographer, Arthur Robinson, developed this projection to replace the Mercator. Although its purpose is navigational, Mercator maps were used in the classroom as all-purpose wall maps. This produced generations of children with the misperception that Greenland is bigger than South America, the opposite is true. Robinson tried to develop a world map that maintains size, shape, directions, and true distances. But because it is impossible to maintain all of these mathematically, he compromised some of the calculations and characteristics of the map. Today, you see his projection on many National Geographic world maps. Map Coordinate Systems Because latitude and longitude is designed for a sphere, not on a plane, rectilinear coordinates need to be used. These coordinates are positive x,y pairs, also known as eastings (x) and northings (y). Many disciplines use the most common coordinate system known as the Universal Transverse Mercator (UTM). This coordinate system is based on the Transverse Mercator, a cylindrical projection. A series of cylinders are wrapped around the globe to create a grid, or Grid Zone Designation (GZD) that is unique for the world. Each GZD is broken up into 100,000m sq. cells. The units of measurement are meters and depending on the scale of the map, you can get submeter accuracy. A common U. S. coordinate system is the State Plane Coordinate System. This is based on each state's coordinate system. The organization depends on the directional extent of each state. States that are longer in the N-S direction uses the Transverse Mercator projection. States that are longer in the E-W direction uses the Lambert Conformal Conic projection. Many states are subdivided into sections called zones. California has seven such zones. So based on your need, you can generate a coordinate system or a map projection for your specific needs or choose one of the hundreds already in use.

For more detail see the links and the bibliography.

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