The Reference Library

Coordinates, Coordinate Systems and LIDAR Data (Part 2)

GeoCue

Summary: In the previous article, we briefly mentioned coordinate systems while looking at how they played a role when defining the MicroStation design cube and setting up the Terrasolid software. A brief mention was fine for that setup, but if we wish to delve into more details on transformations and changing projections in the various software packages to help you do more with LIDAR data, then it is helpful to start with some of the basics. As such, this article will provide an introduction to coordinate systems, geoids, datums and projections.

Understanding the Earth

The shape of the Earth can be thought of either as a sphere or a spheroid, depending upon the scale in which the user is interested. A sphere is based upon a circle and is often used to define the shape of the Earth on a small scale. A spheroid is based upon an ellipsoid and is used to define the shape of the Earth on a large scale.

The decision on whether or not to define the Earth using a sphere or spheroid shape will determine how coordinates are defined and what type of coordinate system is used. Figure 1 shows the difference between a sphere and a spheroid (ellipsoid), where 'a' and 'b' within the image represent the semi major axis and the semi minor axis. In a sphere, the semi major axis is going to equal the semi minor axis, while in an ellipsoid, the semi major axis is going to be larger than the semi minor axis. An ellipsoid is centered at the predicted Earth center and different ellipsoid models have different semi major and semi minor axes.
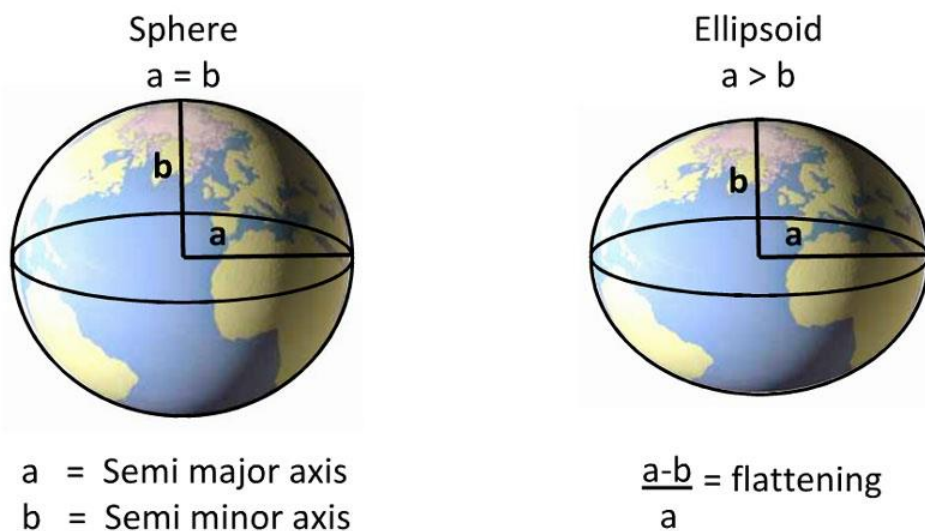

Figure 1 - NOAA: http://coast.noaa.gov/digitalcoast/training/datums: Sphere Versus Spheroid

Three common spheroids are Clarke 1866, GRS80 1980 and WGS84 1984 (not to be confused with the WGS84 datum). Each ellipsoid has slightly different semi major and semi minor axes, but may work better for certain areas of the world. For instance, Table 1 shows the differences for each spheroid.

Spheroid	Semi Major Axis (M)	Semi Minor Axis (M)
Clarke 1866	6378206.4	6356583.8
GRS80 1980	6378137	6356752.31414
WGS84 1984	6378137	6356752.31424518

Table 1 - Differences for Semi Major and Semi Minor Axes for different Spheroids

The problem with thinking about the Earth as a sphere or even a spheroid is the fact that the Earth has a multitude of mountains, valleys and plains which help to make up its irregular shape, and thus makes it difficult to make calculations. In part, due to this reason, it is much easier, and more convenient, to think about the shape of the Earth with respect to sea level. Imagine for a moment that the oceans are allowed to settle completely under the influence of gravity, and are not affected in any way by tidal or atmospheric forces. The result of this is an equipotential, or level surface, which reflects the Earth's gravity field and is known as a geoid. The geoid most closely corresponds, or is approximately equal, to mean sea level (MSL). The geoid is an irregular shape due to the difference in the Earth's gravity field.

The difference between the geoid model and the ellipsoid surface is known as the geoid height. The height value can be either negative or positive, and ranges from roughly between -100 meters and +100 meters. There are actually places within the United Kingdom where the geoid and the ellipsoid differ by less than 5 meters[1].
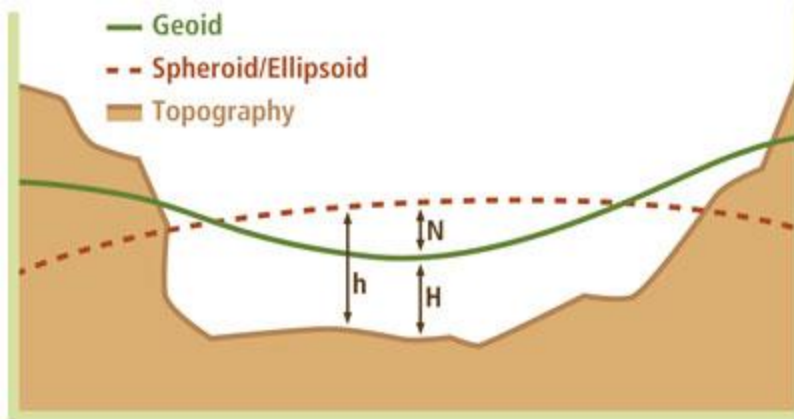

Figure 2 - Green is Geoid Surface, Red is Ellipsoid. Height above Ellipsoid=h. Geoid Undulation=N. Orthometric Height=H

In the past, an ellipsoid that best fit the geoid for the area in question was chosen. Since the introduction of Earth-orbit satellites, the way ellipsoids are compared to the Earth has changed. The first change is that there is now an accepted ellipsoid that is considered to best fit the Earth's surface: GRS 1980. The

second change is that a system called the International Terrestrial Reference System (ITRS) was created; it is a "three-dimensional geocentric Cartesian coordinate system in which the direction of the Earth's rotation axis and its speed of rotation are determined by the International Earth Rotation and Reference Systems Services, IERS[2]". ITRS does not actually require that an ellipsoid be specified, however when converting Cartesian coordinates to ellipsoid coordinates, the GRS 1980 ellipsoid is used during the conversion process.

Datums

If there is a WGS84 ellipsoid and it is not the same as the WGS84 datum, then what is a datum?

A datum is a starting point and gives context to locations and heights on the surface. A datum defines the position of the ellipsoid with respect to the center of the Earth. Because the ellipsoid is a smooth surface, it does not accurately represent the Earth's surface; the datum is designed to account for local variations in elevation.

There are multiple datums available, and changing a datum will change the coordinate values of your dataset. Three common datums used in the United States are the North American Datum of 1927 (NAD27), the North American Datum of 1983 (NAD83) and the World Geodetic System of 1984 (WGS 1984). NAD83 is the official datum for the United States Government. (NOAA - http://coast.noaa.gov/digitalcoast/training/datums). Figure 4 shows different ellipsoids with the corresponding datums.
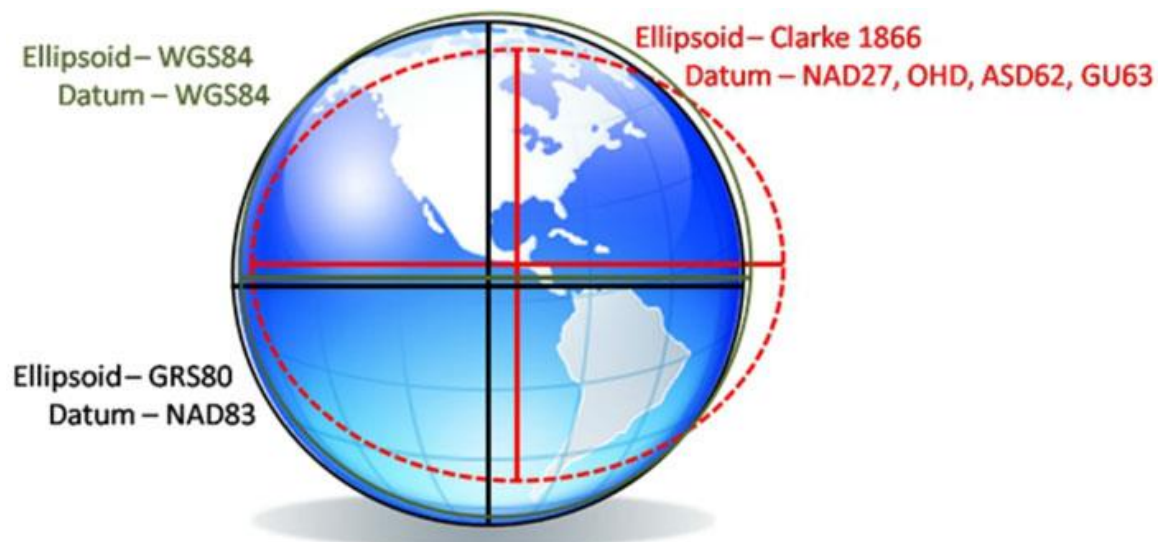

Figure 3 - NOAA - http://coast.noaa.gov/digitalcoast/training/datums: Ellipsoid and Datum

Table 2, provided by ESRI[3], shows the different longitude and latitude values for the same location in Bellingham, Washington using the three common datums. NAD 1983 and NAD 1984 are almost identical, while NAD 1927 is off by several seconds.

Datum	Longitude	Latitude
NAD 1927	-122.46690368652	48.7440490722656
NAD 1983	-122.46818353793	48.7438798543649
NAD 1984	-122.46818353793	48.7438798534299

Table 2 - Longitude and Latitude for the same coordinate in different datums

Coordinate Systems

How can the same location have different coordinates? Let's first look at what a coordinate is to try and answer that. At its most basic, a coordinate is a set of N numbers that designate the location of a point in N space. In the case of LIDAR, a coordinate contains three numbers: X, Y and Z and is located in 3-dimensional space.

A coordinate reference system is an easy way to find the point which is designated by the set of coordinates. There are thousands of coordinate systems that exist throughout the world. They can be based upon a local, national or global datum. Some of the systems might use imperial (feet, survey feet or international feet) linear units of measurement, while many more are designed to use metric (meters) linear units of measurement.

There are two types of coordinate reference systems: Geographic Coordinate Systems (GCS) and Projected Coordinate Systems (PCS).

Geographic Coordinate Systems

A geographic coordinate system is used to describe a geographic location on the Earth's surface using spherical measures of latitude and longitude. Think of a globe. Both latitude and longitude are measures of angles (in degrees) from the center of the Earth. The sphere makes up 360 degrees; each degree is divided by 60 minutes, while each minute is divided by 60 seconds. Lines of longitude run North-South and measures the number of degrees to the east or west of the Prime Meridian, with values ranging from -180° to +180°. The Prime Meridian is an imagery line which runs from the North Pole and goes through Greenwich, England straight through to the South Pole. Lines of latitude run from East-West and measure the number of degrees north or south of the equator with values ranging from +90° at the North Pole to -90° at the South Pole.

Coordinates, Coordinate Systems and
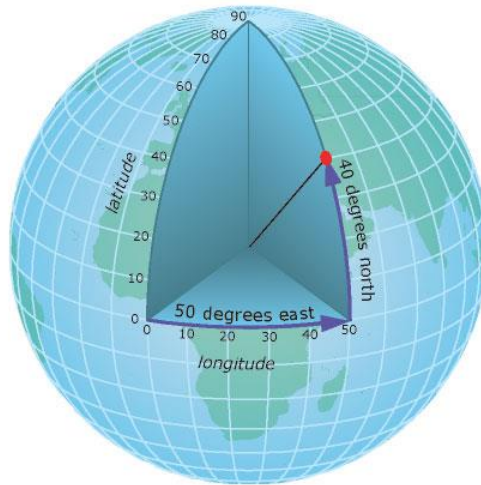# LIDAR Data (Part 2)

Figure 4 - Latitude and Longitude

Some common Geographic Coordinate Systems include: GCS(WGS 1984), GCS(ITRF 2008), GCS(GRS 1980), GCS(NAD 1927) and GCS(NAD 1983).

Projected Coordinate Systems

A projected coordinate system, unlike a geographic coordinate system, is defined using a two-dimensional surface. Think of a map. Thus, projected coordinate systems always deal with distortion of one kind or another as the sphere is unraveled to represent a flat sheet. Figure 5 shows various ways in which a curved surface can be represented on a flat plane.
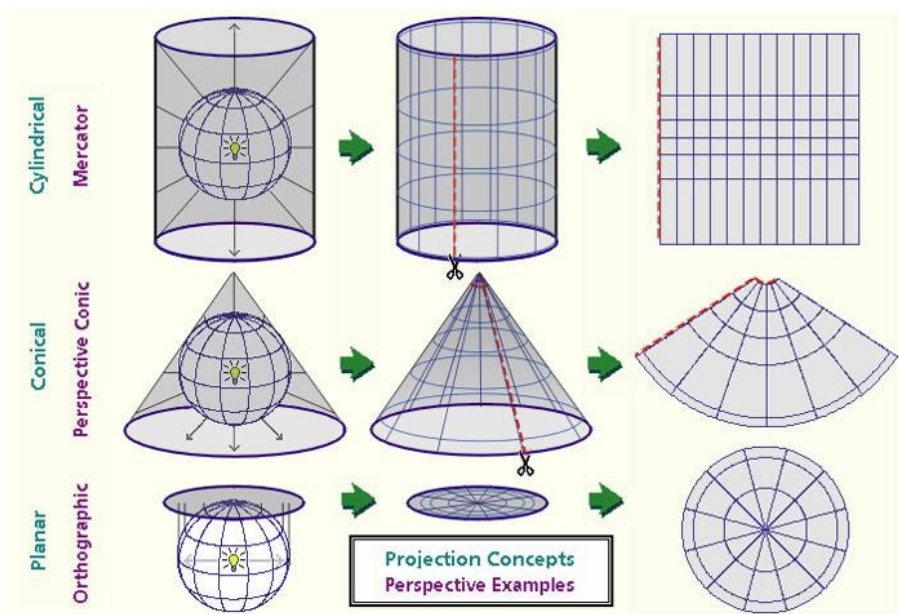

Figure 5 - Map Projections - http://www.geog.ucsb.edu/~dylan/mtpe/geosphere/topics/map/map1.html

There are four different projections which can be used to generate a Projected Coordinate System, and each system can be used to help preserve a specific aspect of the surface, area or distance, for instance: Conformal Projection, Equal Area Projection, Equidistant Projection and True-direction Projection.

Conformal Projection is designed to preserve the local shape. Lambert Conformal Conic is an example of this type of projection.

Equal Area Projection is designed to preserve the area of displayed features. Albers Equal-Area Conic is an example of this type of projection.

Equidistant Projection is designed to preserve the distances between certain points. Azimuthal Equidistant is an example of this type of projection.

True-direction Projection is designed to maintain the directions or azimuths of all points on a map correctly with respect to the center of the map[4]. Mercator is an example of this type of projection.

Two of the most common projection systems in the United States are the State Plane Coordinate System (Figure 6) and Universal Transverse Mercator (UTM) (Figure 7). Both coordinate reference systems are based upon the North American 1983 Geographic System. UTM always uses the Transverse Mercator Projection, while some of the State Plane Coordinate systems use the Transverse Mercator projection, and others use the Lambert Conformal Conic projection.
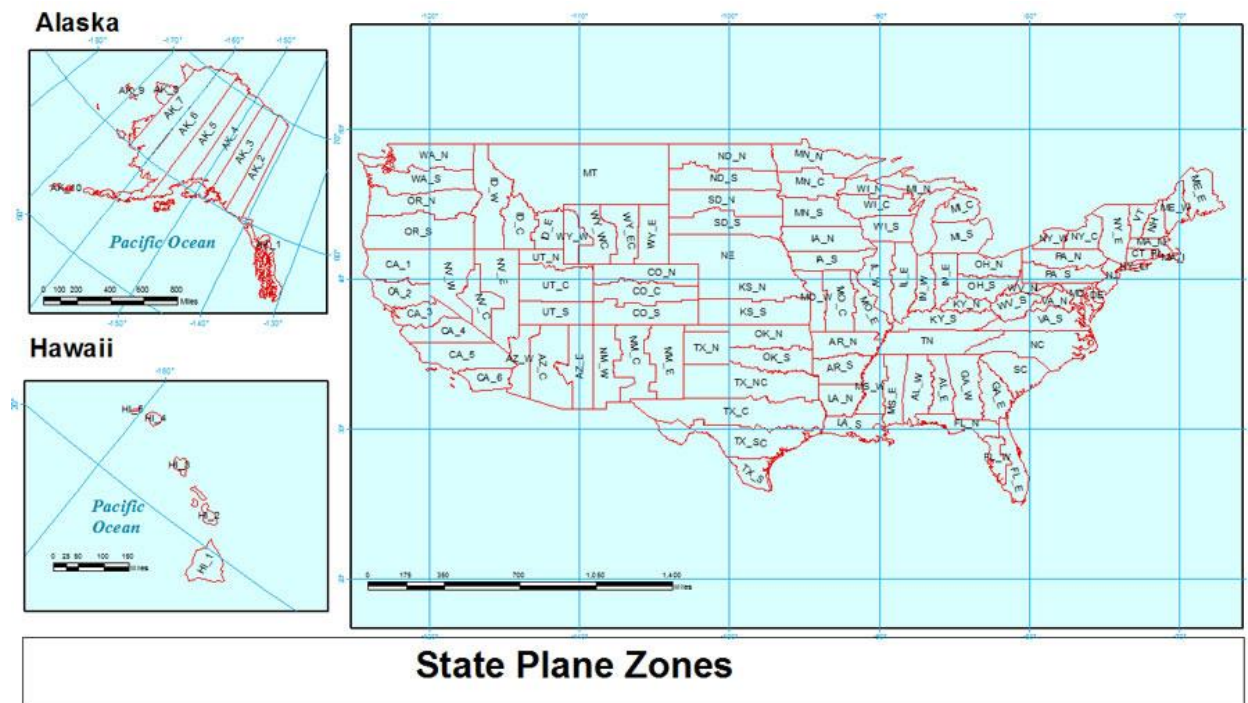

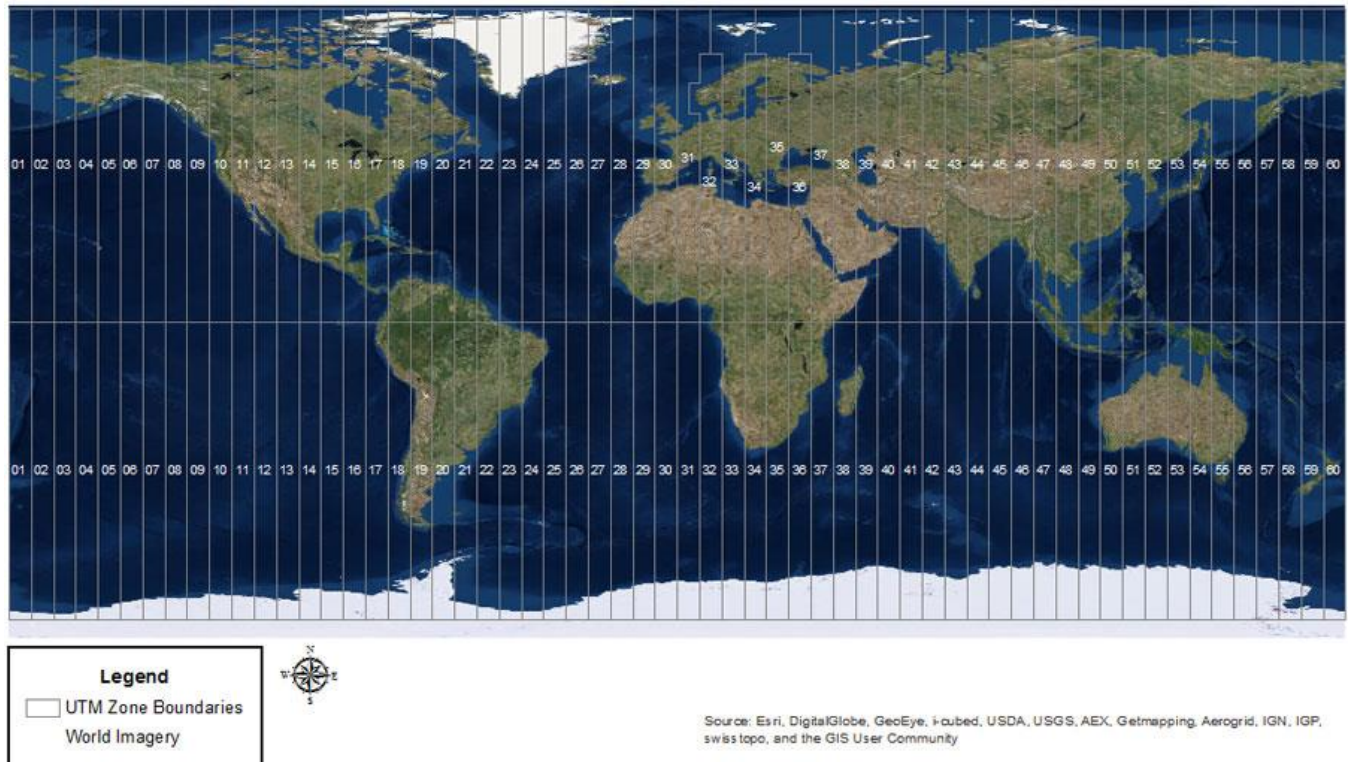*Figure 6 - State Plane Projected Coordinate System*

Figure 7 - UTM Projected Coordinate System

These are just the basics, but hopefully one can now see that a single location could be easily represented by numerous coordinate values simply by referencing different coordinate systems. Hopefully, one can also garner from this article that when referencing maps, a coordinate reference system generally consists of a projection which has both a datum and linear units. And since the datum for a single projection may vary, then it is important to know all of the components of the coordinate reference system to ensure that the data can be used together without having to perform transformations. For example, if someone tells you their data is in UTM zone 11N, it is prudent to ask, "Which UTM 11N?" as it could be UTM(NAD83) 11N, or possibly UTM(WGS84) 11N, et cetera. For some more information on the differences between NAD83 and WGS84, please refer to our CueTip entitled, "Transforming WGS 84 (G1150) Coordinates to NAD 83 (CORS96) Coordinates". In a future article, we'll discuss using these coordinate reference systems with your LIDAR data, and also delve into transformations and some of the special projections commonly encountered in mapping.

[1]*ESRI 10.3 Help Guide*
[2]*Iliffe, J., & Lott, R. (2008). Datums and Map Projections: For Remote Sensing, GIS and Surveying 2nd Edition. Scotland, UK: Whittles Publishing.*
[3]*ESRI 10.3 Help Guide*
[4]*ESRI 10.3 Help Guide*