
Transformations and Mapping Projections

Reading: Reading: Pages 87-94 of “Introduction to Geodesy – The History and Concepts of Modern Geodesy” by James R. Smith.

Introduction

In previous topics, the concepts of a mathematical model representing the earth, horizontal geodetic datums, and geographic coordinates were discussed. This topic will build on those concepts and discuss transformations and projections.

The meaning of the terms transformation and mapping projection are often used interchangeably by geodesist and surveyors. That meaning is best stated as the changing of a system of coordinates to a different system of coordinates. This is accomplished by utilizing mathematical equations that have well defined constants. However, this discussion will build upon that similarity and also make some important distinctions.

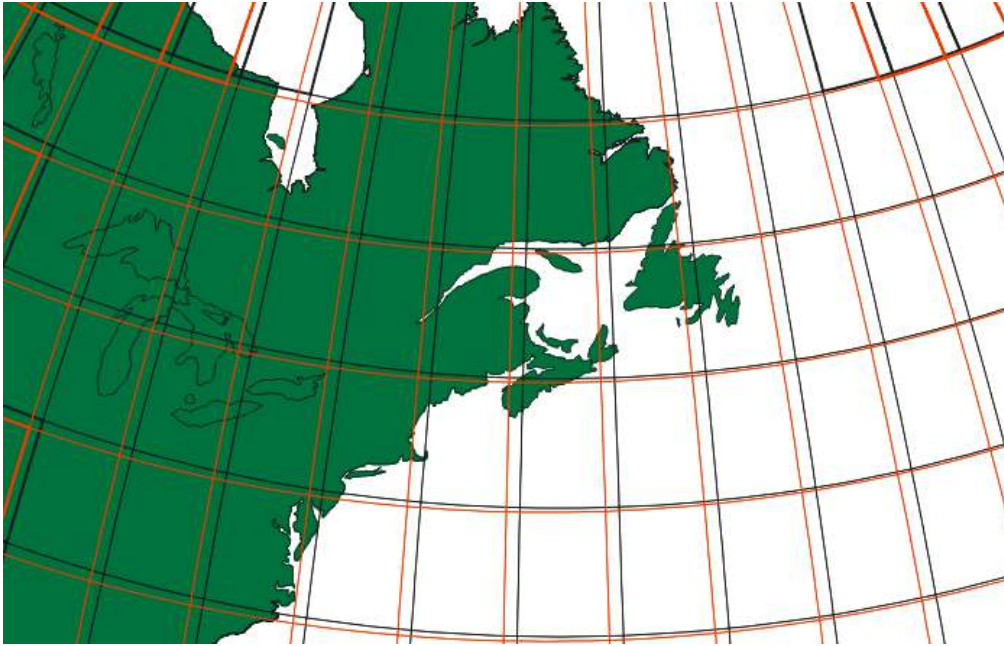
Transformations

Transformations can simply be defined as: a complete change, usually into something resulting in an improved appearance or usefulness. By this definition, the different transformations that may be used by the surveyor can be listed under the three following headings.

- Change in medium
- Change in datum
- Change in projection

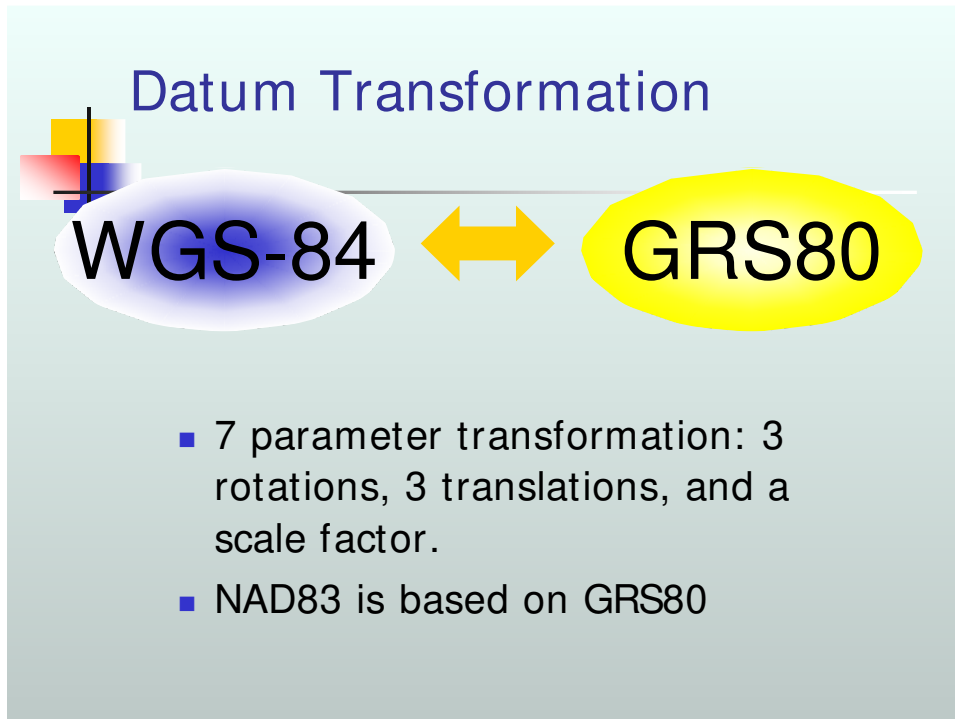
Under the heading of *change in medium* there are those changes which may be caused from converting a map, etc. from one environment to another. For example, the converting (transforming) of photographic or other remotely sensed images from the film or computer file into a conventional map or GIS file. A *change in medium* transformation is used by surveyors all the time to produce products that are useful to their final customer.

A *change in datum* transformation is the change in coordinate values from one geodetic datum to another. It requires two principle components: a change in the origin of the coordinate system and a change in the reference ellipsoid. It is typically difficult to create the transformation parameters from one geodetic datum to another as it requires coordinate information on large numbers of stations in common to both datums that have a very high degree of accuracy. For example, no precise transformation exists between NAD27 and NAD83 – only approximate transformations. Also note that the NAD27 and NAD83 latitudes and longitudes of points are different. This is because of the different underlying reference ellipsoid. The following picture shows the difference between the same NAD27 and NAD83 latitude and longitude values for part of North America.



An approximate transformation of coordinates between NAD27 and NAD83 can be accomplished by the use of the computer program NADCON. The resultant values from the use of NADCON (and other similar programs) can have up to 18 cm (0.6 foot) error. This error level may fit within requirements for the intended use of the resultant coordinates. For example, NAD27 to NAD83 transformed coordinate values that will be used for searching for control or boundary monuments or to be included in a GIS may be sufficient. The NADCON documentation and program can be downloaded from the web site: <http://www.ngs.noaa.gov/TOOLS/Nadcon/Nadcon.html> .

Another *change in datum* transformation occurs in the use of the Global Positioning System (GPS). GPS is based on the WGS84 reference ellipsoid and coordinate system; however, the national geodetic datum in the U. S. is NAD83. So, a datum transformation has to be performed on the GPS data to get resultant NAD83 coordinates. This is accomplished via a seven parameter transformation. Three of the parameters are rotations about each of the three coordinate system axes; three of the parameters are translations of the three coordinate system axes; and a scale factor. The following picture depicts the transformation from the GPS system to NAD83.



Additionally, well defined parameters have been developed to transform ITRF coordinates to NAD83 values and the reverse.

The third type of transformation is the *change in projection*. This type involves the changing of a projection of latitudes and longitudes to plane coordinates to another projection. This may be from a Mercator projection to a Lambert projection (these will be discussed in the next section). Other *changes in projection* include:

- Change in aspect: For example, from a normal to oblique aspect
- Change from one grid zone to another
- Change in the origin of similar grids
- Change in scale from one grid to another
- Change in orientation of grid axes

Mapping Projections

The earth is round; maps are flat. A mapping projection is a systematic representation of all or part of the surface of a round body, especially the earth, on a plane. For surveyors this means maps. They are mathematical formulas with well defined constants and parameters that allow for latitudes and longitudes to be converted to plane Cartesian coordinates. There have been many mapping projection techniques throughout history that have different characteristics.

The purpose of a map projection is to represent features on the Earth's surface as accurately as possible in relationship to the spatial properties of shape, area, scale and direction. Map projections that preserve these properties are known as conformal, equal-area, equidistant,

and azimuthal respectively. The following illustrates the different types of projections and their characteristics.

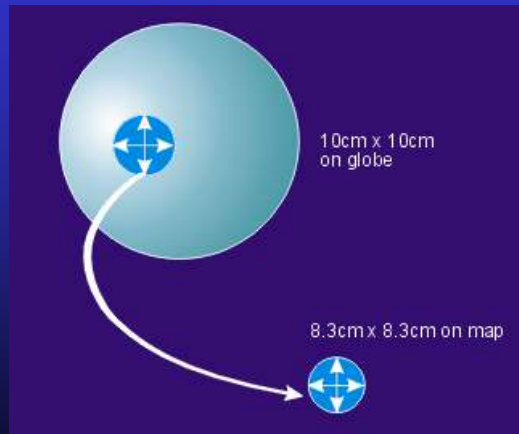
Projection Properties	
SHAPE	Conformal maps preserve local shape,
AREA	Equal-area or equivalent maps retain all areas at the same scale
SCALE	Equidistant maps maintain certain distances
DIRECTION	Azimuthal maps express certain accurate directions.

Projections - Making it Fit

The following discussion will address the above types of mapping characteristics in more detail:

- 1.) **Shape:** Many of the most common and most important projections are conformal mapping projections, which means that normally the relative local angles about every point on the resultant map are shown correctly. I.e. the angles are the same on the map as they are on the reference ellipsoid. Although a large area will still shown with distortion in the shape. Its small features are shaped essentially correctly. One of the important features of a conformal mapping projection is that the local scale in every direction is constant. Because local angles are correct, longitudes (meridians) intersect latitudes (parallels) at right angles on the conformal mapping projection, just as they do on the reference ellipsoid. Areas are generally enlarged or reduced throughout the map. Nearly all large scale maps of mapping agencies throughout the world are now prepared with a conformal mapping projection. No map can be equal-area and conformal. Surveyors prefer the use of a conformal mapping projection. As a matter of fact, the state plane coordinate system in California is based on a conformal mapping projection.

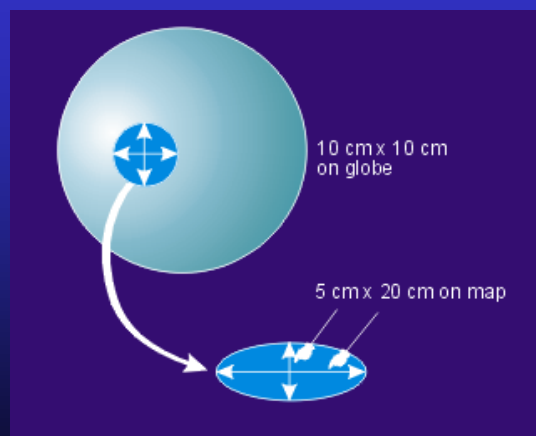
SHAPE - Conformal



Projections - Making it Fit

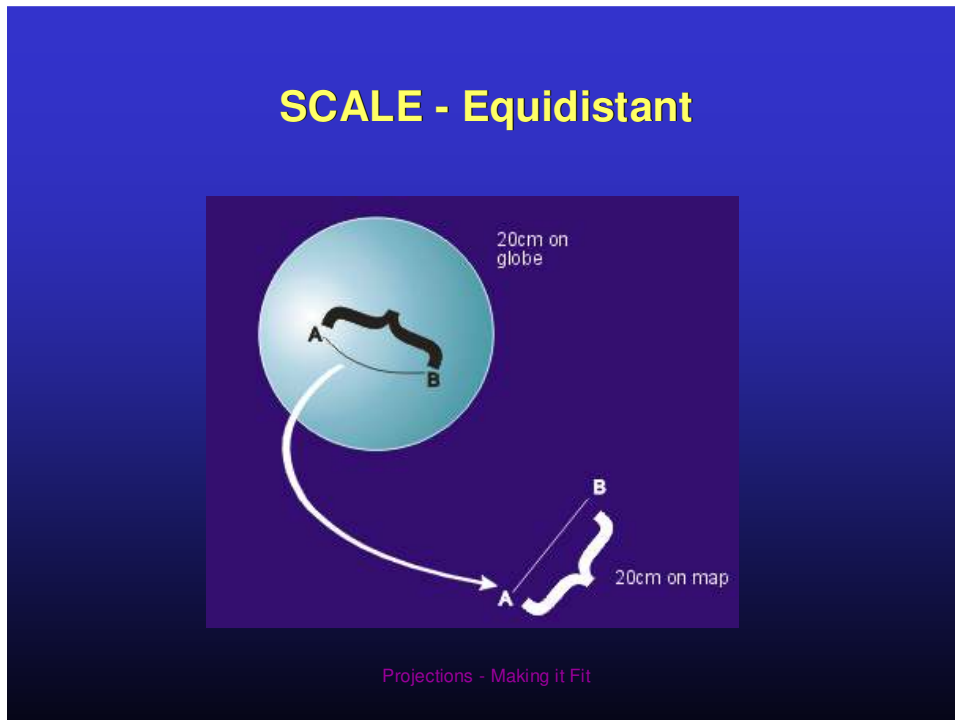
- 2.) **Area:** Some mapping projections are designed to be equal-area, so that a two dimensional object of any size on one part of the map will cover the same area of the reference ellipsoid as the same object on any other part of the map. Shapes, angles, and scale will be distorted in these projections. Equal-area mapping projections are commonly used by the creators of Geographic Information Systems (GIS). The projection that they often use is known as the Albers' projection. Less common terms for equal-area projections are: equivalent, homographic, and equiareal.

AREA - Equal-Area



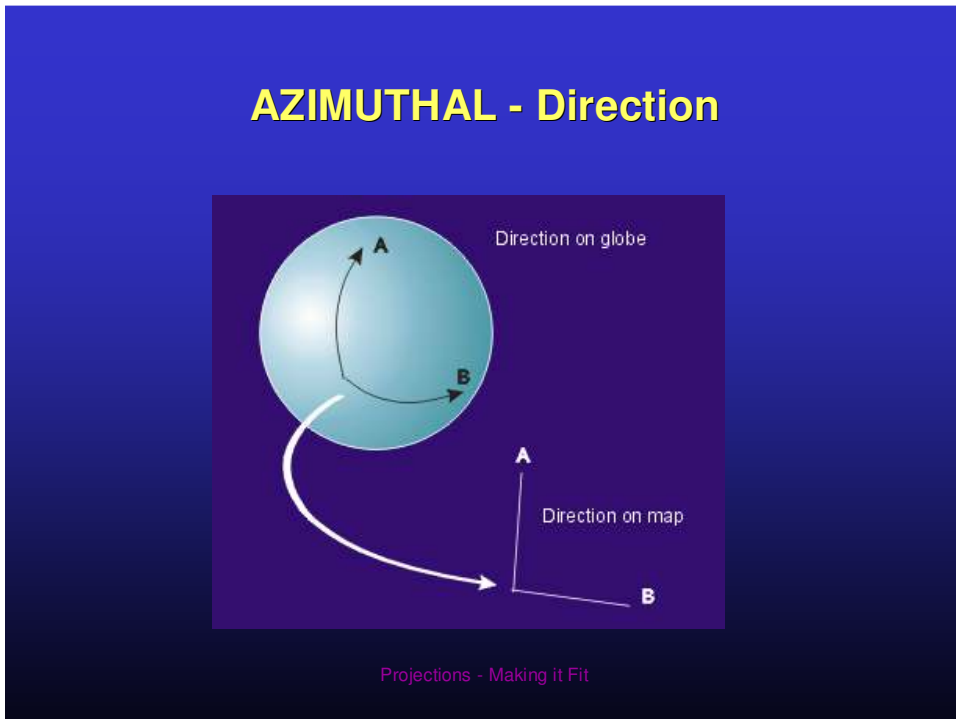
Projections - Making it Fit

- 3.) **Scale:** No mapping projection shows scale correctly throughout the entire map. However, there are generally one or more lines on the map along which scale is correct. By choosing the locations of those lines properly, the scale errors on the rest of the map can be minimized. Some of these types of mapping projections depict true scale between one or more points and every other point on the map, or along every meridian. They are called equidistant mapping projections.



- 4.) **Direction:** While conformal mapping projections result correct relative local directions at any point on the map, there is another group of mapping projections, called azimuthal, that preserve the directions or azimuths of all points on the map with respect to the center. These projections can also be conformal, equal-area, or equidistant.

AZIMUTHAL - Direction

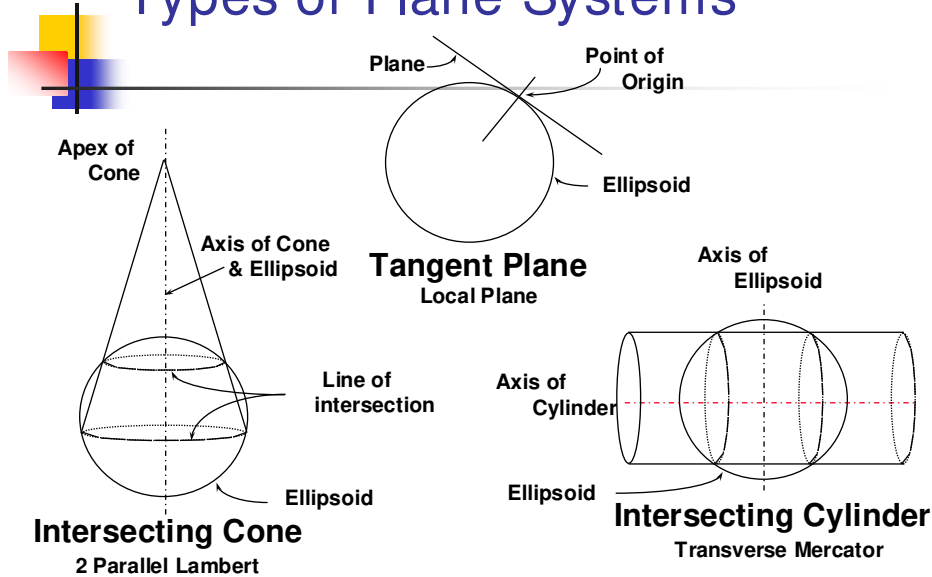


By definition, mapping projections are a compromise of error and distortion. The mapping projection that is chosen for a particular set of data will be chosen based on the characteristics that the resultant map should have as well as the choice of where the error in the map will lie.

Creating a Mapping Projection

There are several different ways to create a mapping projection. This discussion will focus on three of them. These methods begin by creating developable projection surfaces. The first is to assume a coordinate at a particular point and then create a plane tangent to the earth at that point. This amounts to having no mapping projection at all. The second “cuts” the reference ellipsoid with a cylinder and then “unrolls” the surface to form the map. The third “cuts” the reference ellipsoid with a cone and then unrolls the surface to form the map. The following picture depicts these three types of mapping projections that create a plane coordinate system.

Types of Plane Systems



The three main mapping projections used by surveyors are the Transverse Mercator, the Universal Transverse Mercator, and the Lambert Conformal mapping projections.

Transverse Mercator

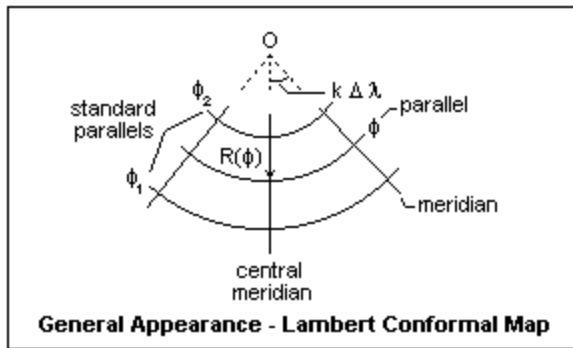
Transverse Mercator mapping projections are utilized by many states for their state plane coordinate systems. These states are the ones that are long in the north-south direction. All of these states are divided into two to eight zones each of which has a different central meridian. Each zone is designed to maintain scale distortion to be within 1 part in 10,000. The parameters for the projection are well defined and are published for the states that use the Transverse Mercator projection. These projections have the following additional characteristics:

- Cylindrical (transverse)
- Conformal
- The central meridian, each meridian 90 degrees from the central meridian, and the equator are straight lines
- Other meridians and parallels are complex curves
- Scale is true along the central meridian
- Used extensively for quadrangle maps at scales from 1:24,000 to 1:250,000

Universal Transverse Mercator

The Universal Transverse Mercator (UTM) projection is a subset of the Transverse Mercator projections described previously. It is a grid that was adopted by the U.S. Army in 1947 for designating rectangular coordinates on large-scale military maps of the entire world. The UTM is the ellipsoidal Transverse Mercator projection to which specific parameters, such as

Lambert Conformal mapping projections are utilized by many states for their state plane



coordinate systems. These states are the ones that are long in the east-west direction. All of these states are divided into one or more zones each of which has a different central meridian. Each zone is designed to maintain scale distortion to be within 1 part in 10,000. The first state to use this projection was North Carolina in 1933. California has legally defined the Lambert Conformal mapping projection in the Public Resources Code. It has two standard parallels for

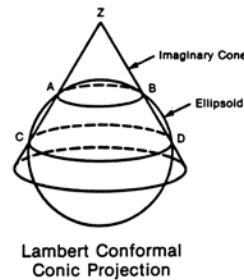
each zone and a defined central meridian. There are 7 zones for NAD27 and 6 zones for NAD83. Even though California is long in the north-south direction the defined zones are long in an east-west direction making the Lambert Conformal mapping projection the appropriate one for use in California.

The following is a list of the Lambert Conformal mapping projection characteristics:

- Conic
- Conformal
- Parallels are unequally spaced arcs of concentric circles that are more closely spaced near the center of the map
- Meridians are equally spaced radii of the same circles, thereby cutting parallels at right angles
- Scale is true along the standard parallels
- Used for regions that have a predominately east-west expanse

Characteristics of the Lambert Projection

- The secant cone intersects the surface of the ellipsoid at two places.
- The lines joining these points of intersection are known as standard parallels. By specifying these parallels it defines the cone.
- Scale is always the same along an East-West line.
- By defining the central meridian, the cone becomes orientated with respect to the ellipsoid



In subsequent lessons, the relationship of the GRS80 reference ellipsoid (the basis of NAD83) and the Lambert Conformal mapping projection and the state plane coordinate calculations for California. These calculations will include projecting NAD83 geographic coordinates (latitudes and longitudes) to state plane NAD83 grid coordinates, projecting state plane NAD83 grid coordinates to NAD83 geographic coordinates, calculating mapping angles, calculating elevation factors, calculating scale factors, and zone to zone transformations.