LECTURE 4: DATUMS AND PROJECTIONS

Section I - Datums

• What is the shape of the earth?

In our previous exploration of latitude and longitude (a global means of georeferencing) we made the assumption that the earth is a sphere. However, the earth is not a sphere but instead an oblate ellipsoid where there is a bulge in the earth at the equator (Figure 1). However, it is even more complex because an ellipsoid does not capture all of the complexities in the shape of the earth.

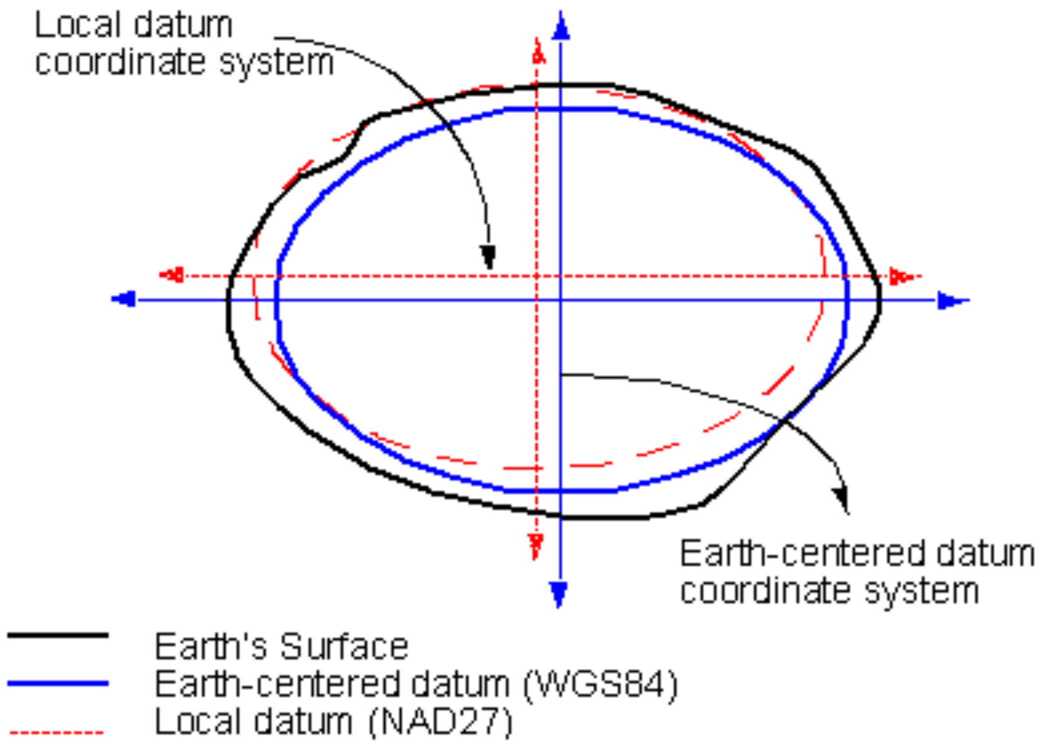

Figure 1. The shape of the earth and two mathematically models (WGS 84, NAD 27) developed to represent the irregular nature of the actually shape of the planet. From ESRI.

• How is a geoid different from an ellipsoid?

There are places on the planet that locally bulge upward and downward. Geoscientists define this complex shape of the earth as a geoid, which is illustrated on (Figure 2), and roughly corresponds with global mean sea level. The departure between the ellipsoid and geoid can be significant. Over India the geoid is 104 meters lower than the ellipsoid and near New Guinea it is 75 meters higher.

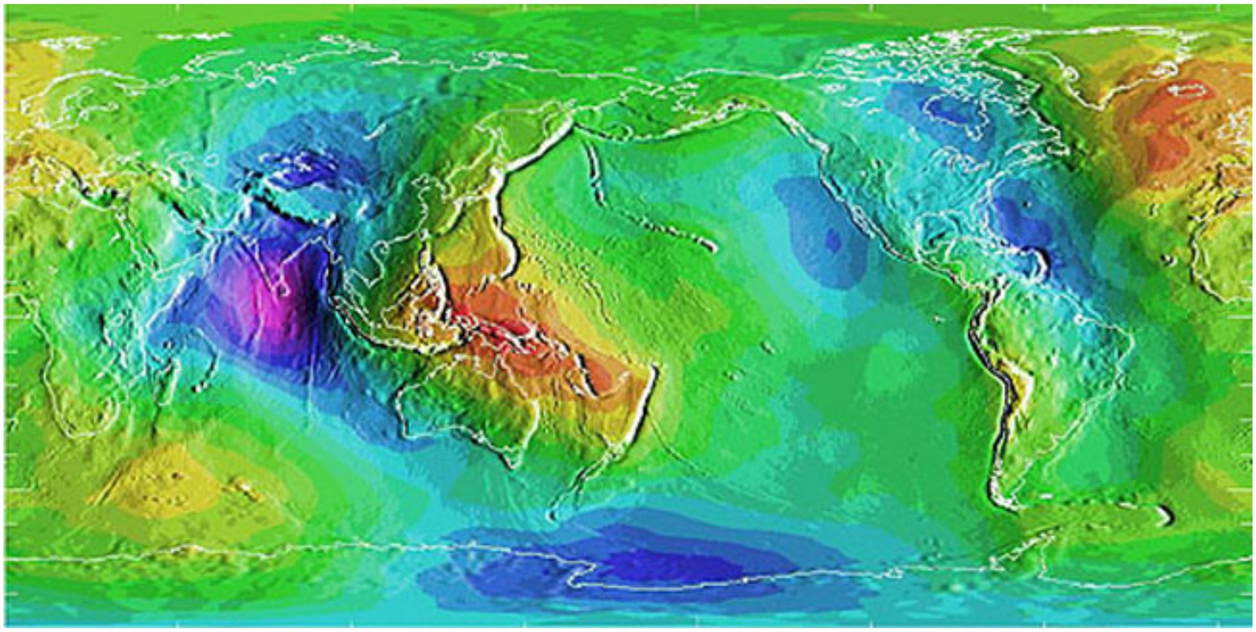

Figure 2. Deviations between a simple ellipsoid and a more complex geoid, from National Geodetic Survey, 1997.

Know the commonly used regional and global datums

There are different systems that have been developed to account for the irregular shape of the earth. A datum is based on a network of precisely surveyed control points (**benchmarks**). The spatial position of control points is measured relative to a particular ellipsoid. The datum defines irregularities in the simple ellipsoid through a complex mathematical representation of the exact shape of the earth.

There are both regional and global datum systems that have been developed. The most common global datum is the **WGS 84 datum**, which is based on the WGS 84 ellipsoid where coordinates are based on their location relative to the center of the mass of the earth. Most detailed GIS applications utilize a regional datum that fit the shape of the earth for a specific region. The two datum systems frequently applied to GIS data in the United States are:

North American Datum 27 (**NAD 27**)
North American Datum 83 (**NAD 83**)

which are based on slightly different ellipsoids. The NAD 27 datum is based on the Clark (1866) ellipsoid, which was optimized to fit North America. The NAD 83 datum is based on the GRS 80 ellipsoid.

• What problems can arise when overlaying two layers that are defined with different datums?

The problem is that GIS data layers use all of these different datum systems. It is impossible to overlay two GIS data sets with different datum systems as there can be errors of up to 10's to 100's of meters. Especially large errors result from overlay of data sets based on NAD 27 versus NAS 83 datums. We in CEES have ran into this problem when trying to line up datasets along the border between US and Mexico. This can be embarrassing if you are trying to develop a seamless product.

On-line convertors and GIS software can convert coordinate system sets that are in different datums into a common datum. Some GIS software has the ability to convert datums for data layers on-the-fly. For example, ArcGIS (ESRI) can convert newly added data so that its datum (say NAD 27) is consistent with the datum defined for the overall project (NAD 83) for visualization purposes and yet does not affect the datum definition of the data layer so that it can be used in another project with its original datum. Using the Projections Tool you can permanently alter the datum of a layer. In conclusion, it is generally a good idea to have all data for a project in the same datum to avoid any of these uncertainties. Note: Sometimes data in a GIS can be represented in unprojected geographic coordinates (**GPC**). However, all maps and geographic data that is georeferenced in planar coordinates has been projected.

Section 2 - Projections

• What is a map projection?

Most maps are two-dimensional representations of our three-dimensional planet. For hundreds of years geographers have struggled with representing a 3-D object such as the world in 2-D on a map. To produce a map requires us to conceptually peel the planet and flatten the world out to get a paper map. The classic example of this process involves a three-dimensional orange peel that is flattened out into a two-dimensional object. The process of the dimensional transformation involved in making a map is called a map projection. There are hundreds different ways to project a map with each projection having various advantages and disadvantages. In reality, as a GIS user you will likely only see less than ten projection types.

The following discussion is not intended to provide a comprehensive discussion of the topic of map projections but provide a basic awareness so that you can operate in a GIS environment and not be surprised when layers do not overlay properly because of they are not in the same projections and datum's. One of the real powers of a GIS is its ability to overlay different layers (Lecture 1, Figure 2) of data and this will not properly happen if layers are not transformed into the same coordinate systems, projection, and datum.

• How can geographers quantify distortions in their maps?

The fact of the matter is that there is no perfect manner to transform a globe into a planar (flat) surface. Cartographers need to make decisions when making a map. To understand this fact, we need to know something about the properties associated with a map projection. There are four basic properties that can be preserved on a map. Note that not all of these properties can be preserved. By selecting to conserve a property means another property of the map will be sacrificed. Map making is a constant series of trade offs.

• What is the importance of the scale factor

A parameter that is commonly defined in the definition of a map projection is the **scale factor (SF).** The scale factor is a metric that describes the degree of distortion on a given point (or line) of a map. A SF = 1.0000 indicates that there is no distortion. Everywhere else on the map there is varying degrees of distortion that increase away from the location with a SF =1.0000.

• What are the four properties that can be preserved in a map projection?

Equivalence Property - Preserves the size of the areas of objects on the globe. Projections that preserve this property are referred to as equal area. (Fig. 3) Red circles on these figures indicate distortion ellipses that help to visualize the type of distortion inherent in each map projection.

Equidistance Property - Preserves scale and distance in any direction from a point or in one direction from a line. (Fig. 4)

Conformal Property - Preserves angular relationships so that parallels and meridians meet at a right angle. Scale is not preserved and changes with distance away from the line with no distortion. (Fig. 5)

Azimuthality Property - Does not preserve shape and distance across the globe but has a projection center, the one point from which direction measurements are not distorted. This property preserves directional measurements from all points on the map (Fig. 6).

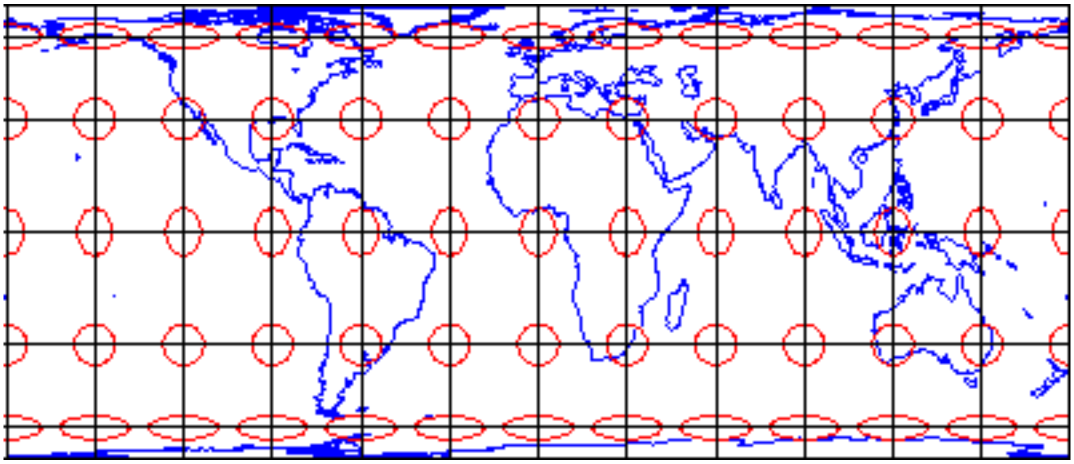

Figure 3. Equivalence property where the areas of objects are preserved. From Penn State Geography Program.

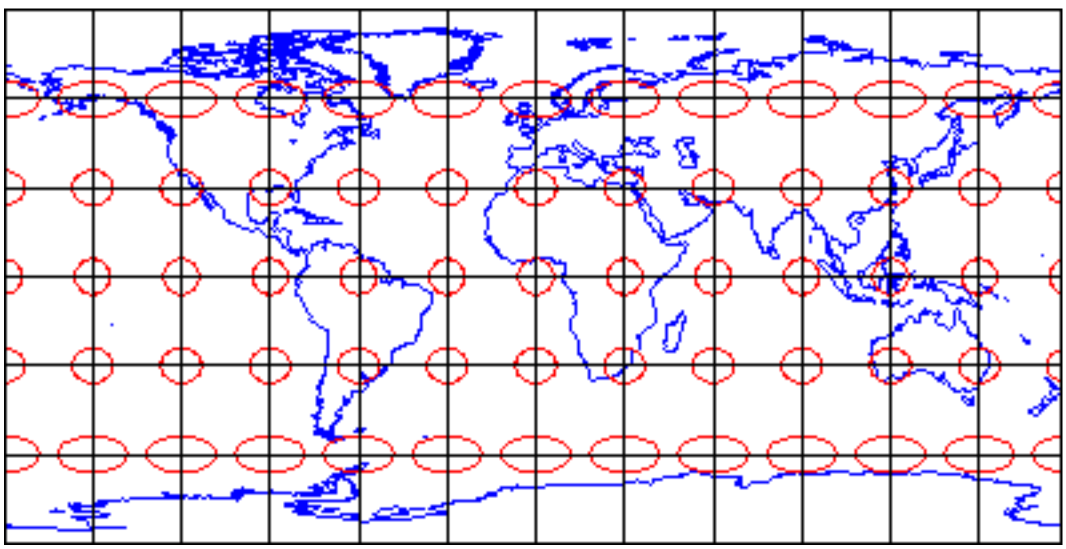

Figure 4. Equidistant property where the distance between parallels and meridians are consistent. From Penn State Geography Program.

Additionally, note that these properties can be mutually exclusive such as the conformal and equivalence properties. Finally, there are some map projections that do not preserve any of the above properties but instead attempts to minimize distortion as much as possible through trade-offs between the above properties. Red circles indicate the degree of distortion in below figures.

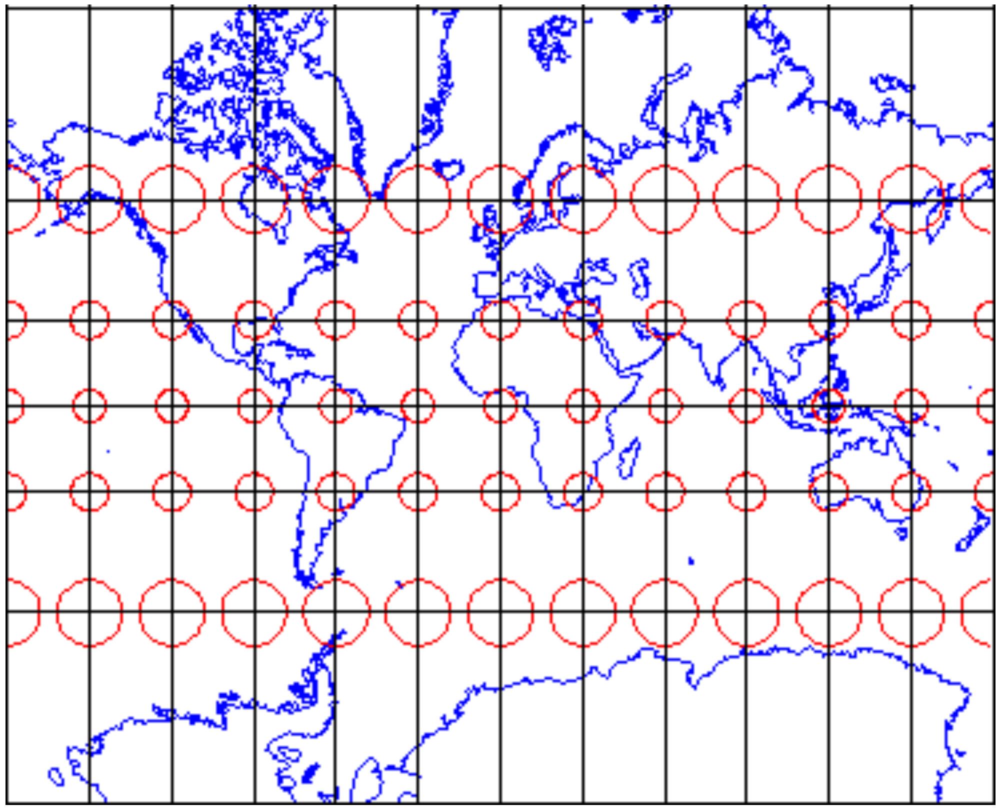

Figure 5. Conformal property where angular relations between parallels and meridians are preserved. From Penn State Geography Program.

• What are the four classes of map projection?

A projection is like a datum in that it involves complex mathematical formula that transforms a three-dimensional object into two dimensions. Instead embarking on a journey into arcane mathematics let's instead see if we can visualize the different types of map projections. There are four basic classes of map projections; three other which are illustrated in Figure 7.

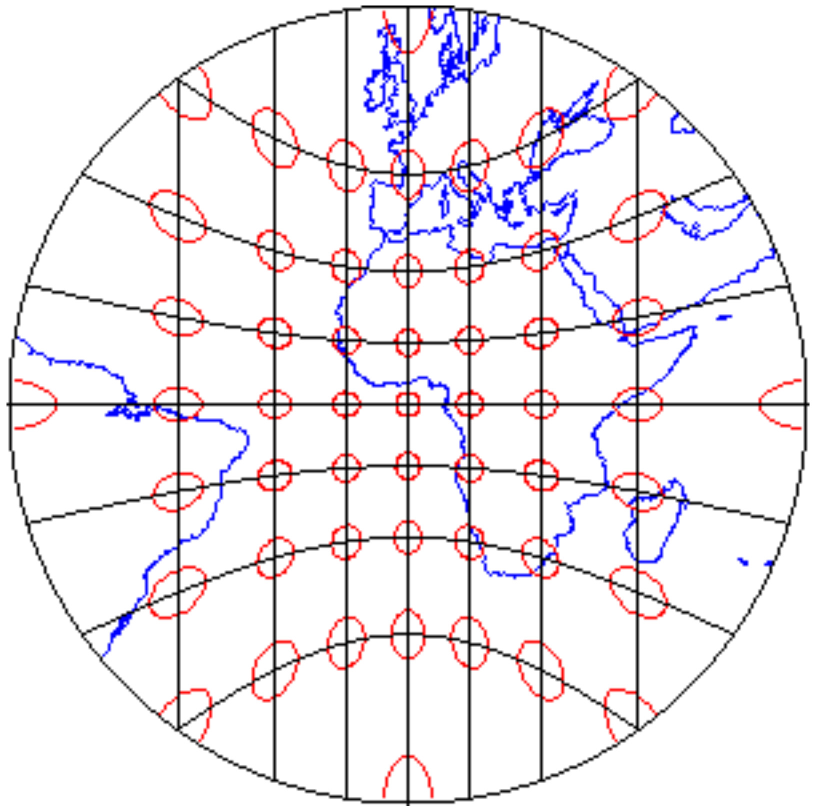

Figure 6. Azimuthality property where from one point from which direction measurements are not distorted. In this case where the equator and prime meridian meet. From Penn State Geography Program.

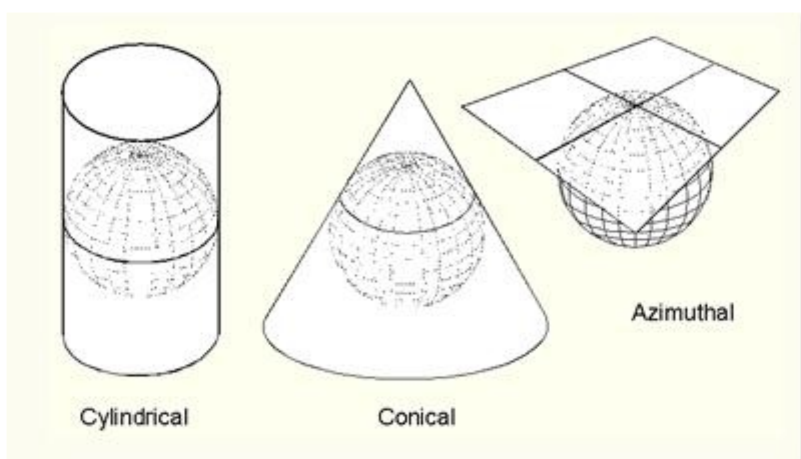

Figure 7. Physical visualization of different classes of map projections. From USGS.

Cylindrical class of projection is based on wrapping a cylinder around the earth. Where the cylinder touches the earth there is zero distortion and map distortion increases away from the line of zero distortion. A common type of cylindrical projection is a **Mercator** where the cylinder touches the earth at the equator; this projection preserves the conformal property of a map having parallels and meridians that meet each other at right angles. Additionally, at the equator there is zero distortion and distortion will increase away from the equator. A **Transverse Mercator** is based on a cylinder that touches the earth along a meridian This type of projection is used for the **Universal Transverse Mercator (UTM)** coordinate system. Another type of cylindrical projection is a **Plate Carrée**, in which north-south distances are not distorted preserving the equidistant property.

A variant class of projection is based on a **pseuduocylindrical** geometry. Pseudocylindrical projections represent the central median and each parallel where right angle geometry is preserved but geometric relationships are not preserved for other meridians. The parallels are made proportional to their real length minimizing distortion. A common type of pseudocylindrical projection is a **Sinusoidal** projection where the north-south scale and the east-west scale are the same throughout the map, creating an equal-area map. This type of projection can depict the earth as one continuous map or several discrete slices (Fig. 8).

A **conic** projection uses a cone to project into a map. Conic projections touch the earth at a single parallel - these are referred to as tangent conic projections or have two points of contact (secant conic projections; Fig. 9). Where the cone touches the earth forms a line with minimal distortion referred to as standard parallel (SF=1.000). The principal type of projection is a **Lambert Conformal Conic**, which forms the basis of **State Plane Coordinate systems (SPC)**, especially in states that are long in the east-west dimension; including Texas and obviously preserves the conformal property. Another common conic projection type is the **Albers Equal Area** projection.

The final class of projection is the **azimuthal** projections, which have the property that directions from a central point are preserved. The projection is based on projecting the earth onto a flat plane. There are several types of azimuthal projections as shown in Fig. 10, which includes polar (looking down on a pole), equatorial, and oblique. Azimuthal projections can also be tangent (touching the earth at on point) and secant making contact with the earth along a parallel or meridian.

You want to refer to the Interactive Album of Map Projections, which provides a good overview of ten of the most common map projections (http://projections.mgis.psu.edu). You will use this tool for your homework and next week's quiz. Also check out the following USGS website that has details about some of the more common map projections. (https://egsc.usgs.gov/isb//pubs/MapProjections/projections.html)

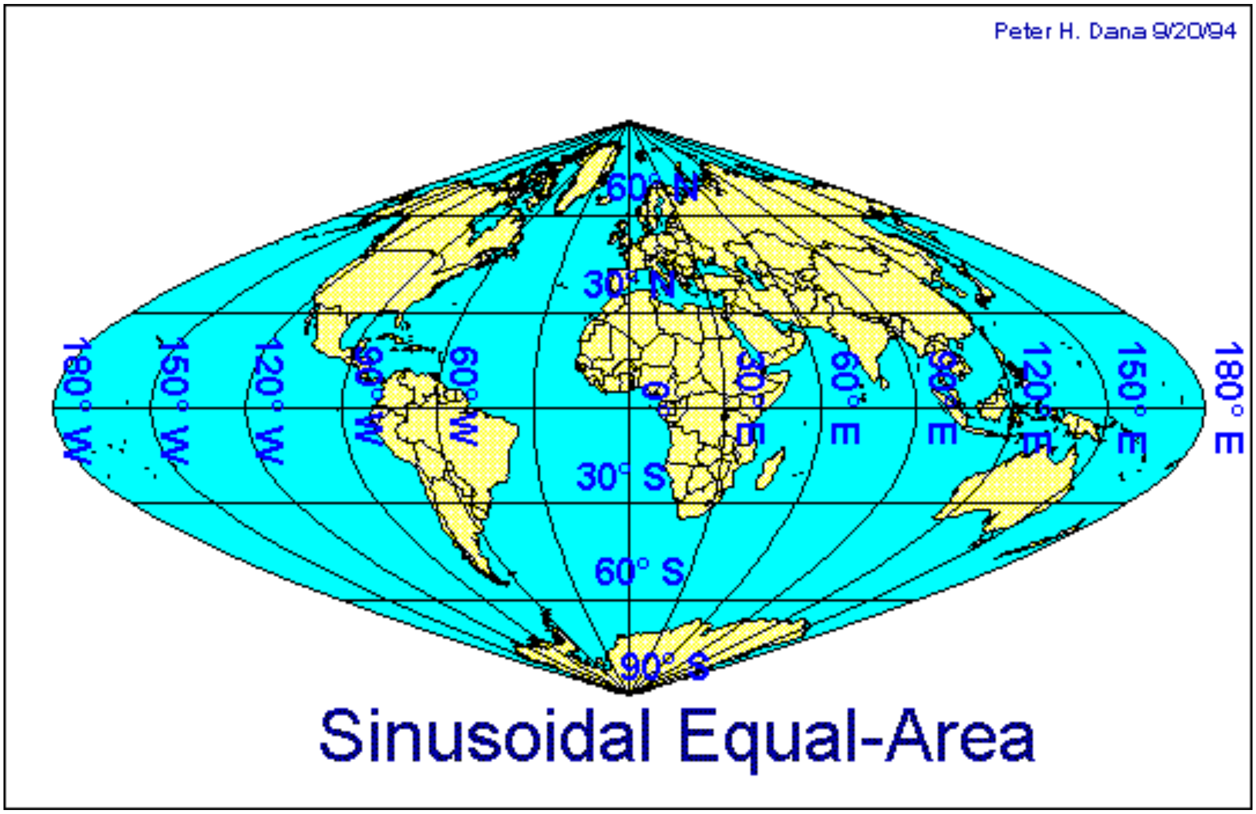

Fig. 8, Sinusoidal Equal Area projection an example of an azimuthal projection. From From University of Colorado Geography Program.

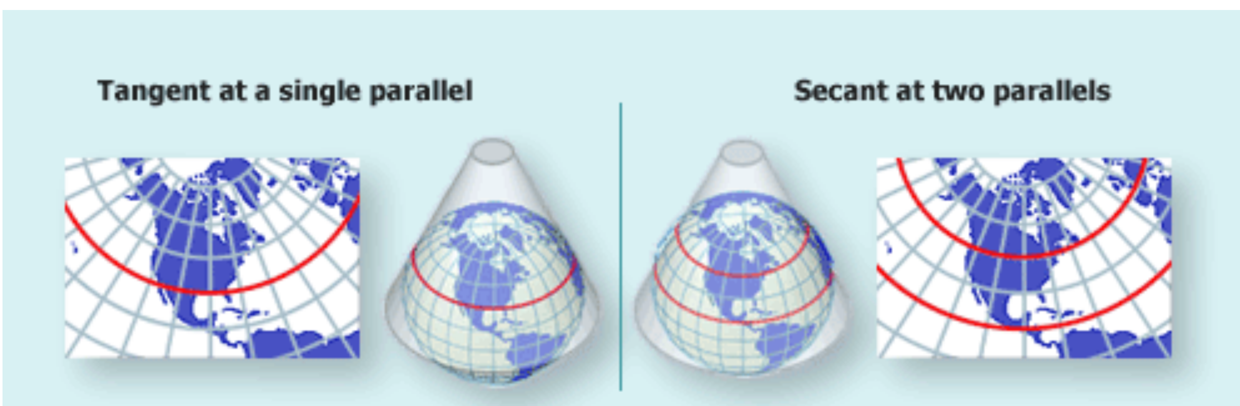

Figure 9. Tangent and Secant Conic Projections - From USGS

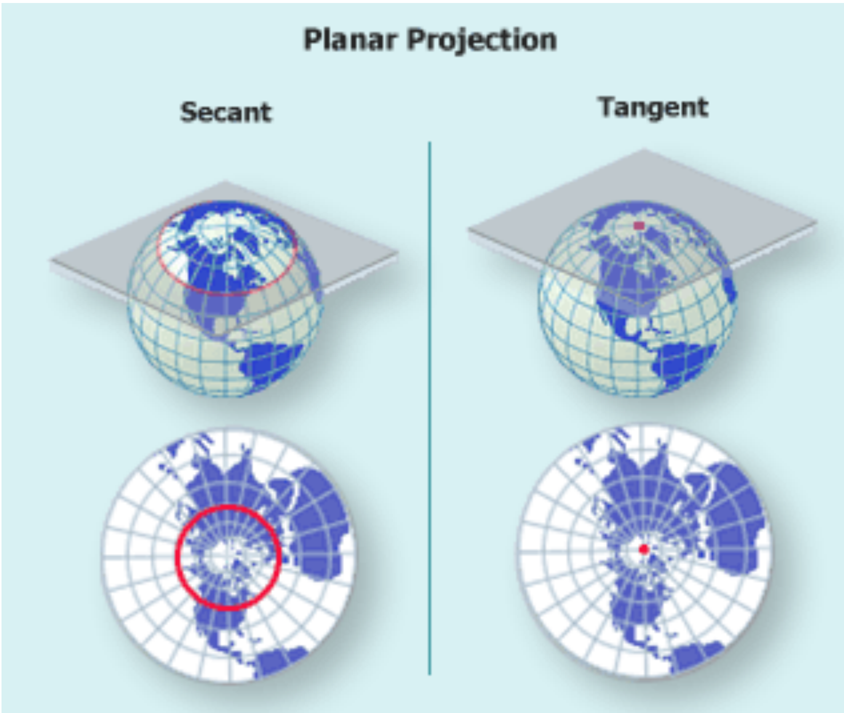

Figure 10 -

Azimuthal or Planar

Projections

- From USGS

Readings
DiBiase, D., 2014, Nature of Geographic Information Systems. Sections 2.12 to 2.29

Terms

Datum	Geoid	Ellipsoid	WGS 84
NAD 27	NAD 83	Map Projections	Scale Factor (SF)
Equidistance	Equivalence	Conformal	Azimuthality
Cylindrical	Conic	Pseudo-Cylindrical	Azimuthal
Universal Transverse Mercator		Lambert Conformal Conic	
Albers Equal Area	Tangent	Secant	

Concepts
What is the difference between a geoid and an ellipsoid
Why is it critical for GIS layers to share a common datum?
What is the importance of the scale factor?
Why can you not have a map projection that preserves all four properties?
Know in detail the map projections used for UTM and SPC systems.
Be sure to check out the Interactive Album of Map Projections and the USGS map projections website

HOMEWORK

1. Examine your data layers from Exercise 1 and answer the following questions.

Datum Type ______________________________

Coordinate System Geographic or Planar

2. From the lecture notes and readings determine the following information. Click on view projection documentation for useful information.

Projection Type	Projection Class	Properties Preserved
Transverse Mercator		
Lambert Conformal Conic		
Albers Equal Area Conic		
Azimuthal Equidistant		
Robinson		

Select from:

Projection Class: Cylindrical Pseudo-cylindrical Conic Azimuthal
(Choose One)

Property Preserved Equivalence Equidistant Conformal Azimuthal
(Choose None, One, or Two)

3. A tangent conic project has how many standard parallels?

(a) 0 (b) 1 (c) 2 (d) None of the above

4. Along a standard parallel the SF=1.2000. True or False

5. Contrast in terms of the properties preserved and projection class the Transverse Mercator and Lambert Conformal Conic projections. Which type of map projection would be best suited for large-scale applications. Explain in detail.

6. What is the difference between an ellipsoid and geoid. Describe in detail.