Project 1:
Plotting Coordinates and Projections

Gretchen E. Knapp

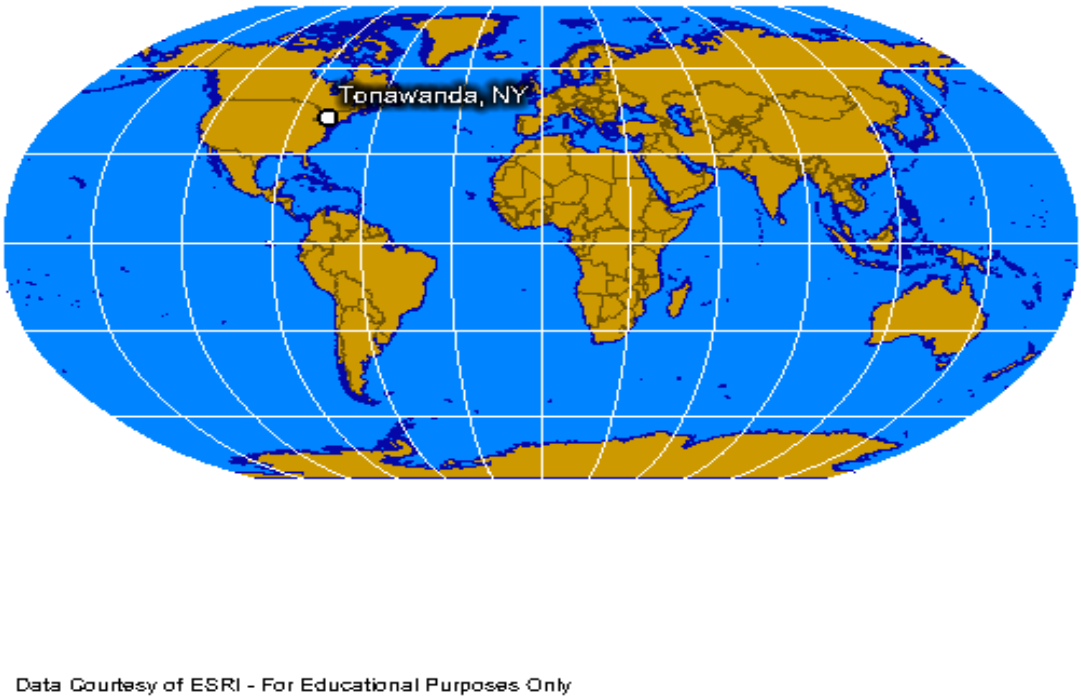

Figure 1 - Town of Tonawanda, NY, USA in a Robinson Map Projection (IAMP, 2005)

Geographic Coordinates

The place name shown in Figure 1 above represents the location of my home town (Town of Tonawanda, New York) on a world map retrieved from the Penn State Online GIS Education's *Interactive Album of Map Projections* (2005), hereafter known as IAMP. Western New York has three Tonawandas adjacent to each other: the town, the city, and North Tonawanda. The geographic coordinates of my home town are expressed in either of the following formats (USGS, 2006a):

Latitude: 42° 58 ' 57" N, Longitude: 78° 52' 31" W

Decimal Degrees: Latitude: 42.982 N, Longitude: -78.875 W

A map is a two-dimensional representation of selected locations, such as my home town, that exist on the surface of the three-dimensional space that is our Earth. The geographic coordinate system of interlocking lines (i.e. latitude and longitude) which are comprised of points, also known as coordinates, provides a method to fix a location on a more or less spherical representation of the Earth using Euclidean geometry.

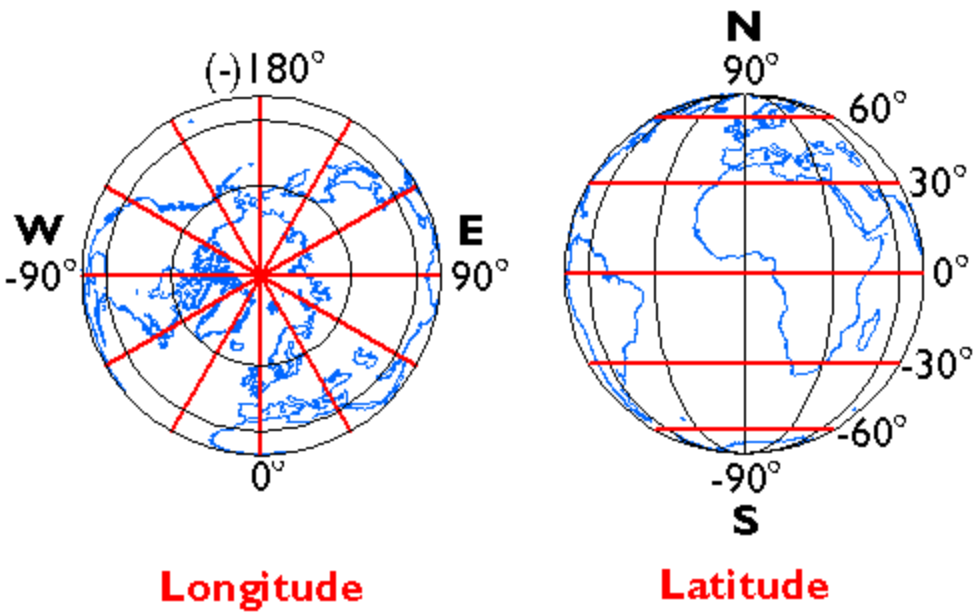

Figure 2 - Geographic Coordinate System (DiBiase, 2007)

Muehrcke (2001) point out that this geospatial measurement system assumes that the point of origin is the center of the Earth, and that an imaginary line bisects the Earth from one "end" of the sphere called the North Pole to its 180° opposite, the South Pole. This line is called the prime meridian. Between the poles is drawn another imaginary line called the equator, which is 90° from the prime meridian and the parallel lines, or longitude, that wrap around the Earth.

In Figure 2, the network of the horizontal lines symbolizes latitude and the vertical lines depict longitude. Latitude measures how many degrees a location is fixed north or south of the Equator. This network or grid is called the graticule. Longitude determines how many degrees a location is fixed east or west of the prime meridian. Together, latitude and longitude make up the "address" of a particular real-life point or feature on the Earth's surface.

Comparison of Geographic Coordinates to Library Catalogs

A simplistic analogy is to compare the geographic coordinate system to the cataloging system of your public library. Books are identified and organized by a rule-based system that produces a unique catalog number (also known as a "call number") to enable users to locate them efficiently. .

The Dewey Decimal Classification (DDC) system, the most widely used library cataloging system worldwide, arranges books in numeric sequence by subject. Like geographic coordinates, the catalog numbers are meaningful in relationship to each other: 972.976 Guadeloupe is adjacent to 972.9722 Virgin Islands of the United States (OCLC, 2007). They also can be converted to another coordinate system, such as that of the Library of Congress (LC), which is alphanumeric. Thus, 927.976 in Dewey is the same as F 2136 in Library of Congress classification (OCLC, 2007).

Just as longitude and latitude coordinates can be expressed in decimal degrees with increased precision by adding more decimal places, so can the Dewey classification systems more precisely locate a book by adding more decimal places, or in the case of LC, adding more letters and numbers. For example, F2136 .T18 is the call number for Charles Tansill's *Purchase of the Danish West Indies* (Tansill, 1932).

To draw out the analogy further, the U.S. Military Grid Reference System is similar to the Library of Congress classification system in using an alphanumeric code to define each grid cell. (Muehrcke, 2001).

Properties of Latitude and Longitude

Latitude and longitude coordinates are measured in Euclidean geometry as angles, or a measurement of intersecting planes, one of the equator and the other of the prime meridian. Angles are expressed in degrees. Geographic coordinates do not measure distances. Rather, they locate a point or coordinate in a one-to-one correspondence between the map and the Earth. Latitude and longitude are unprojected coordinates but can be projected by mathematical equations into georeferenced planar or Cartesian coordinates of x and y which then can be used by cartographer to produce a map for specific purposes (DiBiase, 2007; Lo, 2007).

Map Projections

Map projections involve a series of transformation via mathematical equations from one conceptual representation of the Earth's surface to another and so on until the final result is a two-dimensional planar surface – a map – that depicts a portion or the entire spherical surface of the Earth in a distorted manner. Muerhcke (2001) succinctly describes map projection as "a two-step process whereby the earth is first reduced to a globe of the desired scale and this globe is then transformed into a flat map". (p. 591) In the first step, the earth's mostly spherical shape is conceptually approximated as a geoid and then as an ellipsoid before being projected onto a spheroid and thence to a map. At each stage, the intent is to produce a more regular curved reference surface to produce a flat map that approximates the Earth's surface as accurately as possible in two dimensions.

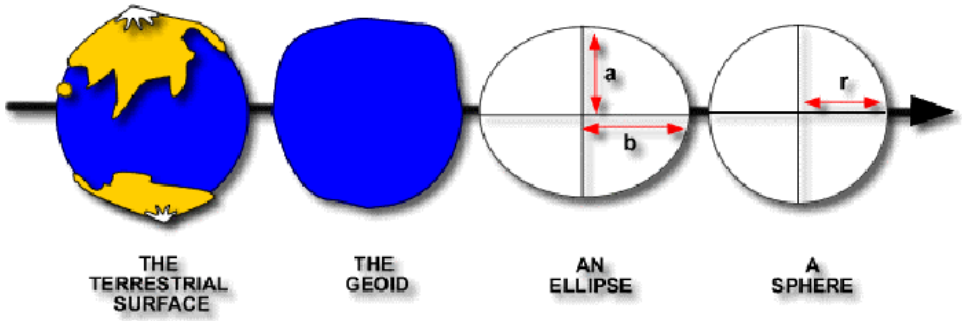

Figure 3 - Map Projection: Earth to Geoid to Ellipsoid to Spheroid (WCNR, 2007)

Slocum (2005) states that map projections occur in three commonly used classes: cylindrical, conic, and planar. For each class, there are two different ways in which the surface (i.e. a cylinder, cone, or plane) touches the reference globe (i.e. a conceptual spherical model of the Earth's surface). If only one point is in common between the surface and the reference globe, this is called a tangent case. A secant case occurs when the surface cuts through the reference globe. This produces two lines of contact for the cylindrical and conic classes, and a line of contact instead of a point for the planar class. From these the cartographer can choose from a wide variety of map projections to choose the one which best fits the informational needs of the map user.

Each map projection's metadata contains the projection name, the central meridian, the latitude of the projection's origin, the scale factor at the central meridian where the distortion is zero, and the standard lines, if the projection permits, where no scale distortions occurs (DiBiase, 2007)

If the Robinson map projection in Figure 1 looks familiar, you may have seen it used for world maps in educational settings or in Rand McNally and National Geographic products (Snyder, 1994). The purpose of Robinson is to produce a visually interesting map, not necessarily one that more or less accurately represents a particular property of a map (Robinson, 1997).

Because it is impossible to portray a three-dimensional irregular surface like the Earth in two dimensions without distortion, the map user must select which type of projection best preserves particular properties. . A map scale cannot be equal everywhere nor can any projection represent all directions as straight lines and still be accurate.

DiBiase (2007) states that equal area or equivalence projections distort the shape of features but preserve their size or area. Equidistant projections such as the Plate Carree preserve distance along straight lines from one or two points. Conformal projections such as the Lambert Conic Conformal and Transverse Mercator preserve shapes (i.e. angle measurements) but distorts their size as shown in Figure 4. The distortion pattern shown in red is also known as Tissot's indicatricies (Slocum, 2005).

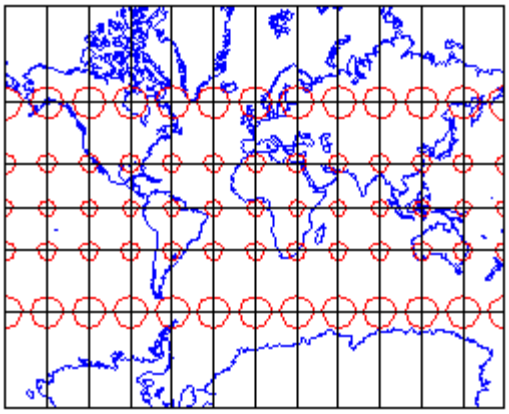

Figure 4 - Conformal Projection with Distortion Ellipses (DiBiase, 2007)

Robinson is a compromise map projection that was not created by the usual method of a mathematical equation but through a table of x-y (e.g. Cartesian) coordinates listing specificied intersections of latitude and longitude (Snyder, 1997). According to the Encarta World English Dictionary (2007), interpolation is the process of "estimating the value of a mathematical function that lies between known values".

Muerhcke (2001) and Lo (2007) explain that this pseudocylindrical projection is also known as sinusoidal because of the curved meridians shown in Figure 5. Because the projection is based on straight parallels lines that are spaced the same between 38° North and 38° South, the geographic poles are represented as lines instead of points. Those areas around the poles are the most distorted, but gradually become the least (but not zero) distorted along the equator.

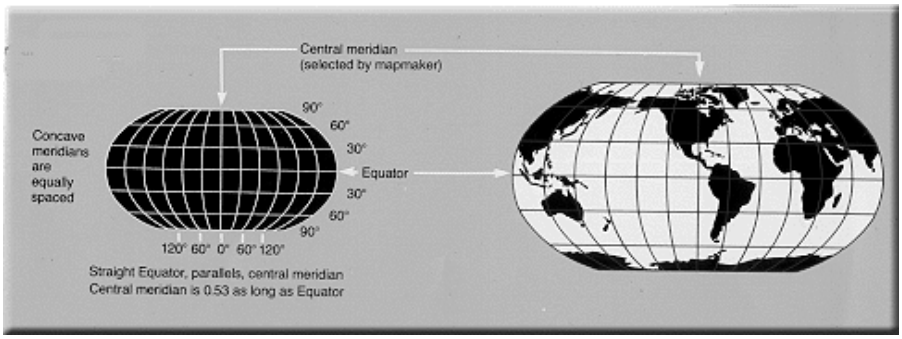

Figure 5 – Robinson Map Projection Diagram (ISGS, 2006b)

Robinson preserves the true directions along the central meridian and along all parallels, and the distances are constant along the equator and other parallels. However, the scales vary except along the 38° north and south parallels where the scale is true. This projection is preferred for world maps and remains popular today for small-scale reference maps (IAMP, 2005; Slocum, 2005).

Figure 6 represents a map of my home town in Robinson projection bounded by -79.70 West, 43.5 North, -77.8 East, and 42.0 South. Lake Ontario is north of Tonawanda while Lake Erie is southwest of the town. The dark line between the Great Lakes is the Niagara River, home to Niagara Falls, and the border between the state of New York in the United States and the province of Ontario, Canada.

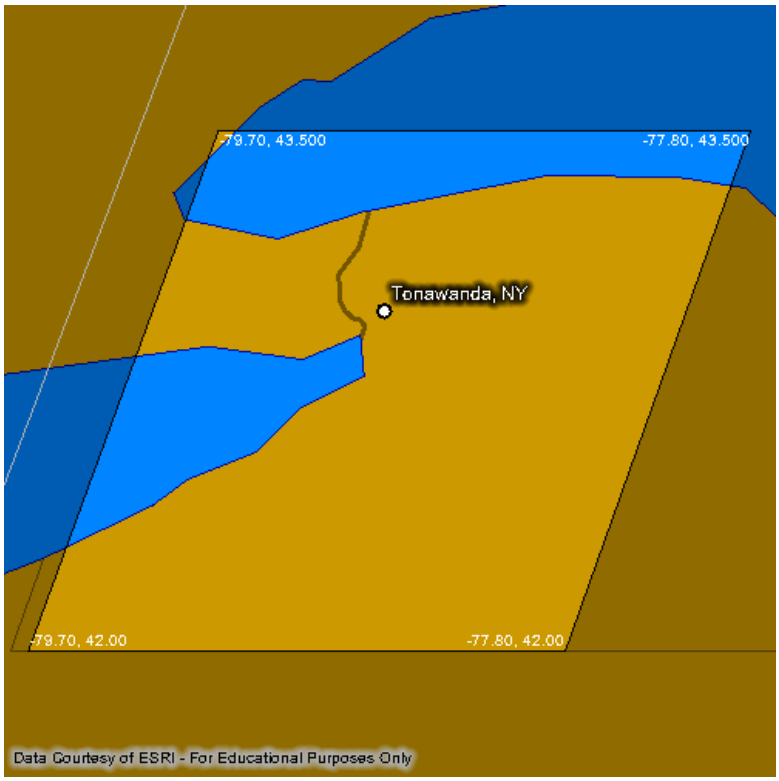

Figure 6 - Detail of Robinson Map Projection of the Town of Tonawanda, NY, USA (IAMP, 2005)

Horizontal Datum

DiBiase (2007) definies horizontal datums as "the geometric relationship between a coordinate system grid and the Earth's surface**".** Since map projections are mainly mathematical equations that "define how positions on the Earth's curved surface are transformed into a flat map surface" (Lo, 2007), coordinate systems are needed to provide the framework or set of rules by which positions are measured and fixed. The coordinate system is a sort of grid called a graticule that placed on top of the Earth's projection-transformed surface. What is important to remember is that coordinate systems are not the same as the map projections they are based upon. The horizontal datum also can be described as a geodetic reference system comprised of known control points defined by geodetic surveying placed on the Earth's surface (Slocum, 2005).

Many horizontal datum exist; however, the three utilized most frequently are the North American Datum of 1927 (NAD 27), the North American Datum of 1983 (NAD 83), and the World Geodetic System of 1984 (WGS 84).

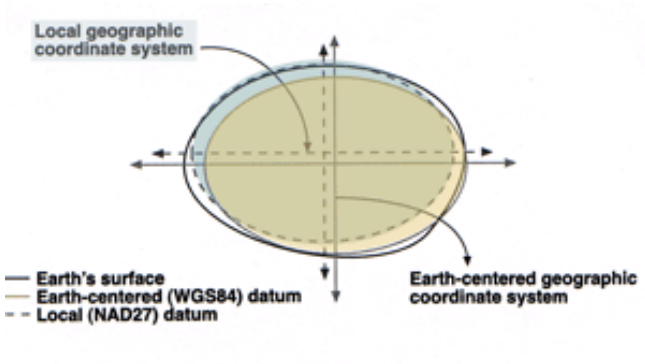

Figure 7 - NAD27 and WGS84 Horizontal Datum (Price, 2001)

The National Geospatial Intelligence Agency or NGIA (2007) maintains the WGS 84 datum (NGIA, 2007). Figure 7 illustrates the different fit between the Earth's surface and the NAD 27 and WGS 84 datums. NAD 27 was based on the Clarke 1866 ellipsoid and used feet as the distance unit. NAD 83 was based on the GRS 80 ellipsoid reference sphere and is measured in meters (Slocum, 2005). Both NAD datums are best used in North America. When the National Geodetic Survey made the switch from NAD 27 to NAD 83, the control point positions shifted from 10 to 400 meters (Slocum, 2005). WGS 84 is the standard for Geospatial Positioning Systems (GPS) and is worldwide (NGIA, 2007).

Table 1 – Comparison of NAD 27 and NAD 83 (DiBiase, 2007; Slocum, 2005)

Horizontal Datum	**NAD 27**	**NAD 83**
Intended use	North America	Worldwide (Slocum, 2005), actual use is North America
Reference globe	Clarke 1866 ellipsoid	GRS 80 ellipsoid
Measurement units	Feet	Meters
GCS origin	Meade's Ranch, Kansas	Earth's center of mass
Basis of USGS topo maps	Yes	Yes, updated in 1983

The most commonly used georeferenced plane coordinate systems today are Universal Transverse Mercator (UTM) Coordinate System and the State Plane Coordinate System (SPC). USGS topographic maps routinely include UTM and SPC gridlines (shown as ticks along the margins) because of its popularity

(DiBiase, 2007; Moore, 1997). Both coordinate systems express distance in meters, assuming NAD 83. SPC when based on NAD 27 measures distance in feet. UTM covers most, but not all, of the Earth. SPC covers the United States and its territories only. The next two sections describe the UTM and SPC coordinate systems.

UTM Coordinates

The UTM coordinates (NAD83) of my home town in Western New York are (ISGS, 2006a):

Easting: 673234.609 meters, Northing: 4761061.882 meters, Zone: 17

The Universal Transverse Mercator Coordinate System is based on a modified Transverse Mercator Projection, a conformal projection formed from a series of cylinders that come into contact with the spheroid 6° degrees apart to produce 60 separate projection zones (Slocum, 2007). The width of each zone is 6° longitude. These zones begin at the International Date Line with zone 1 and proceed east through zone 60. The vertical lines are parallel to the central meridian. Every zone is further divided horizontally into 8° layers of latitude beginning at 80° South and ending at 84° North as shown in Figure 8. These polar areas are not covered by UTM but require a separate map projection defined as Polar Stereographic (DiBiase, 2007).

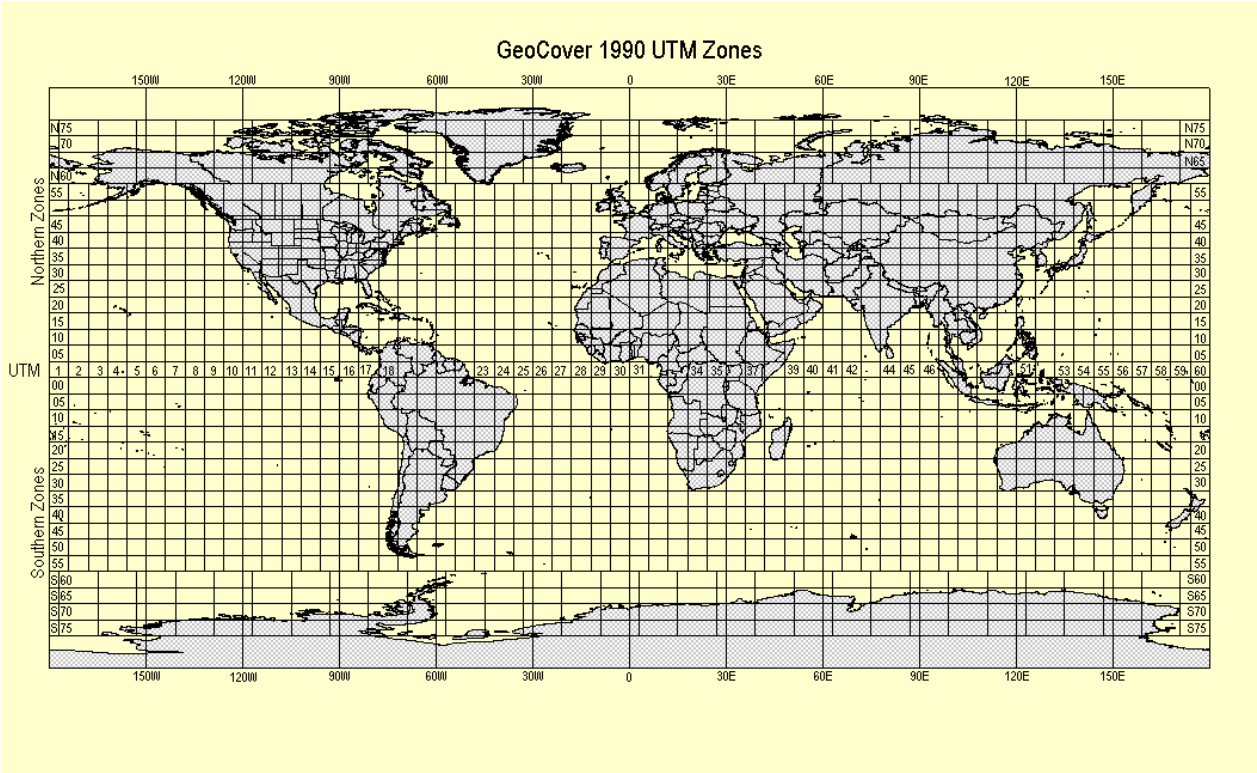

Figure 8 - Universal Transverse Mercator Map Zones (NASA, 1990)

The UTM assigns rectangular coordinates to fix any location by determining the zone number, the hemisphere (north or south of the Equator), and the easting and northing coordinates in meters.

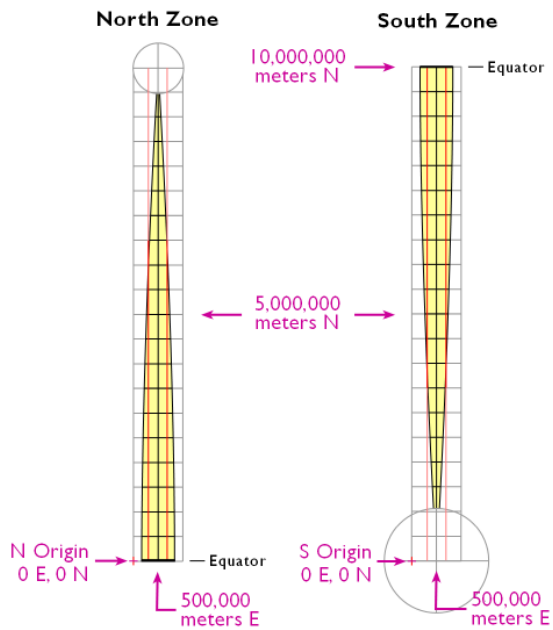

Figure 9 - UTM Zone Divided into North and South on the Equator (DiBiase, 2007)

In the North UTM zone, the northings run from zero at the northern origin to almost 9.4 million meters. In the South UTM zone, the northings are from 1 million meters at the southern origin to 10 million meters (Slocum, 2007). For both zones, the "false"origins are located 500,000 meters west of the central meridian and lie outside of the zones themselves. The spatial measurement grid is positioned to guarantee positive numbers only. The coordinates are distance units rather than geometric degrees.

According to DiBiase (2007), each "zone tapers from 666,000 meters at the Equator… to only about 70,000 meters at 84° North and about 116,000 meters at 80° South." The red lines in Figure 8 are the "two standard lines that are parallel to, and 180,000 meters east and west of, each central meridian" (DiBiase, 2007). Each zone is projected individually. Distortion is kept to 1 in 2,500 meters.

Both UTM and SPC rely on two standard lines for projection. Only along those lines is distortion zero. This can cause confusion for map users when a state spread across more than one zone. The conterminous United States covers 10 UTM zones. My home town of Tonawanda is in UTM Zone 17 while the majority of New York State is in Zone 18 (NGS, 2003b).

National or Regional Coordinates

The State Plane coordinates (NAD83) of my home town are (ISGS, 2006a):

Easting: 326189.293 meters, Northing: 331267.389 meters, Zone: 3101 (New York West)

According to Muerhcke (2005), the State Plane Coordinate System (SPCS) is a planar coordinate system that divides the United States and its territories into 125 zones based mainly on the Transverse Mercator and Lambert Conformal Conic projections. "Tall" states like Illinois have two Transverse Mercator-based zones while "wide" states like Wisconsin have three Lambert Conformal Conic zones. (The zone covering the Alaska panhandle is based on the Oblique Transverse Mercator.) Many states are divided into two or more zones that are projected independently. Like UTM, SPC coordinates are always positive so the origin is in the southwestern corner of the zone, and each zone has its own unique map projection. Within a zone, distortion is 1 in 10,000 meters (DiBiase, 2007).

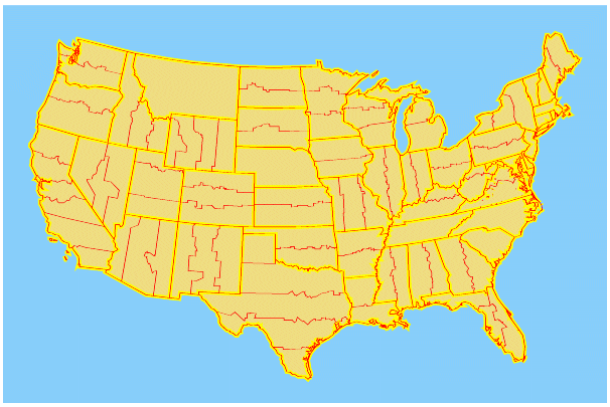

Figure 10 - State Place Coordinate System (WRNS, 2007)

Origins are placed on the central meridian, and like UTM, SPCS uses the easting and northing coordinates along with the zone. These zones, however, are not numbered eastward from the International Date Line. Each zone contains two standard parallels to minimize distortion as a whole. The origins from eastings may vary from 200,000 to 8,000,000 meters East**,** as the closer the coordinates are to the central meridian, the less distortion occurs (NGS, 2004a). Like UTM, SPC coordinates are measured in meters because they represent distance, not geometric angles.

Figure 11 - Illinois State Plane Zones (WCNR, 2007)

Two of the 125 SPC zones that cover the United States divide Illinois, my current state of residence (ISGS, 2007). Although each zone's unique map projection keeps distortion down to 1 in 10,000, projects that cover the entire state are more challenging due to two separate zones.

In recent years, Dr. Christopher Pearson, the National Geodetic Advisory liaison for Illinois, has argued for a unified and single zone projection for the state. In a white paper written for the now defunct Illinois Geographic Council, Pearson recommended "a new Transverse Mercator system for a statewide single zone

projection" to correct the current default Lambert Conformal datum which is both outdated and the cause of large-scale distortion (Pearson, 2002)

Illinois is one of several states without a state-defined projection. With the U.S. Geological Survey along with the National Geographic Data Committee (NGDC) spearheading the "Fifty States Initiative", many geographers and map users hope that the Illinois state legislature will adopt Pearson's ideas for a single zone project (NGDC, 2007).

In Figure 12 the challenges of geodysists to develop large-scale maps that minimize scale distortion as much as possible is illustrated. The east and west areas of the state approach exact scale while the majority of the state in between is 1:5,300 smaller than exact scale (Pearson, 2002).

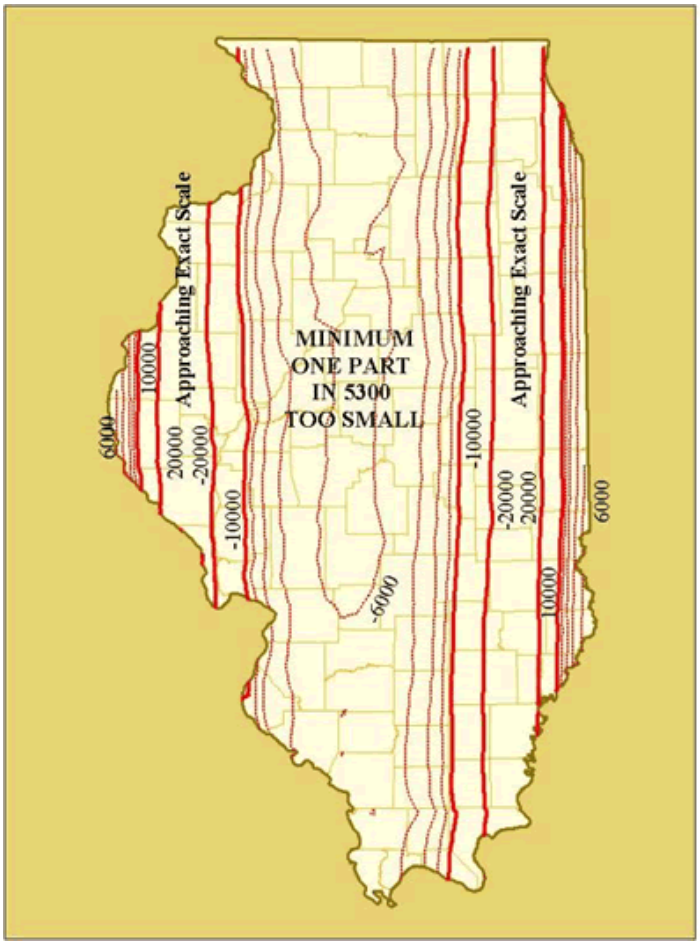

Figure 12 – Proposed Single Zone Projection for Illinois (Pearson, 2002)

Comparison of Coordinate Systems: Geographic Coordinates, UTM, and SPC

Each coordinate system was developed over time to meet a variety of cartographic objectives, but the main objective continues to be reducing distortions that accrue from map projections.

Table 2 – Comparison of GCS, UTM, and SPC Coordinate Systems (DiBiase, 2007; Lo, 2005)

Coordinate Systems	Geographic Coordinate System (GCS)	Universal Transverse Mercator (UTM)	State Plane Coordinate System (SPC)
Projection basis	None.	Modified Transverse Mercator.	Mainly UTM and/or Lambert Conformic Projection for lower 48 states.
Extent	Global.	Worldwide except for N & S polar regions.	United States.
Zones	None – not projected.	60 zones.	124 zones.
Units	Geometric angles: DMS or Decimal Degrees.	Meters (distance).	Meters (SPC83) or Feet (SPC27).
Uses **Advantages**	Fix position anywhere – easy to learn. On USGS maps. Universally used worldwide.	Geospatial plane grid for plotting position on flat paper maps . On USGS maps. Used in military and national maps.	Provide accurate large-size maps for states. On USGS maps. Far less distortion for large-scale state map regions than UTM.
Disadvantages	Unprojected. Must be projected to use on planar surface.	Need many zones across large regions.	Some states are divided into multiple zones.
Distortion & Accuracy	No distortion. Accuracy depends on instrument used and the user's skill.	Maximum distortion at points farthest from the two standard lines to 1 part in 2,500 error rate.	Maximum at points farthest from the two standard lines to 1 part in 10,000 error rate.
Ease of Calculation	Basic Euclidean geometry. Requires understanding of what negative numbers represent.	Positive numbers due to false northings and eastings. Easy to visualize.	Positive numbers due to false northings and eastings. Easy to visualize.
Global Positioning Systems Use	Yes. Different types of units will provide different levels of precision – surveying GPS is more precise than a mapping GPS device.	Yes – standard in most GPS units.	Can be loaded in units but not standard.

With all of these choices, how do we choose the best map projection for our project? Fortunately, several projections selection guidelines exist. Frederick Pearson's guide (1984) emphasizes the range of latitude. Arthur Robinson et al (1995) recommend examining the relationship between the properties map designer most desire to preserve and the map's purpose. John Snyder (1987) offers a detailed hierarchy of suggested projections based on world regions, class and case aspects, and projection properties such as conformal or equal area. Although no perfect distortion-free map projection exists, cartographers can produce interesting and informative maps to meet the informational needs of their audience.

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