GEOGRAPHIC COORDINATE SYSTEMS

A geographic coordinate system (GCS) uses angular units of measure; they are most often degrees. The first angle that indicates the location of data is given as longitude, the x-coordinate as measured from the prime meridian with its longitude value of 0. Any line of longitude can be used as a prime meridian in a GCS, but a mark at the Greenwich Naval Observatory in Greenwich, England, is most often used.

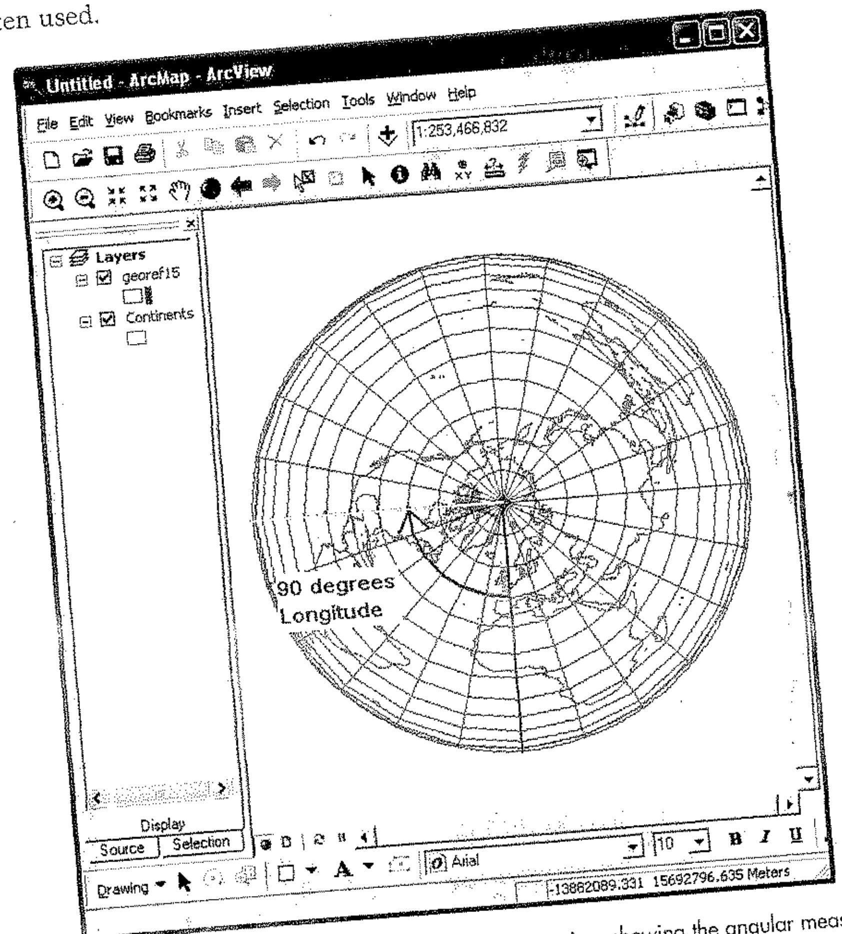

Figure 9–1 Lambert azimuthal equal area projection, showing the angular measurement of longitude, the x-coordinate, from Greenwich, England, to the point of interest. The yellow line indicates 90° west longitude, or -90°.

In figure 9–1 you are looking down on the earth from above the North Pole. The red line is the location of the prime meridian, which extends from the North Pole to the South Pole, passing through Greenwich, England. In our sample geographic coordinate system this is the prime meridian, assigned the value of 0 degrees of longitude. The yellow line represents the line of longitude that extends from the North Pole to the South Pole, passing through the point of interest that lies at 90° west longitude or -90°. The angle shown between the two lines of longitude is the value of the x-coordinate for the point of interest.

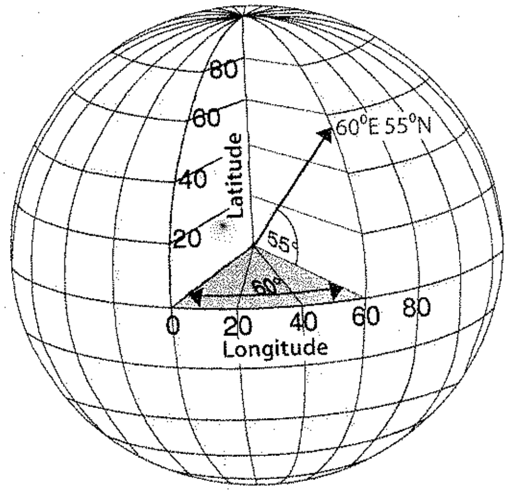

Figure 9-2 This is a 3D view of the earth, showing the east-west angle of longitude and the north-south angle of latitude.

In figure 9-2 you are viewing the earth in three dimensions. The angle of longitude in the easterly direction from the prime meridian is the x-coordinate for the point of interest, at 60° east longitude. The angle of latitude upward from the equator is the y-coordinate for the point of interest, at 55° north latitude. Note that the diagram in figure 9-2 does not specify a GCS.

LENGTH OF A DEGREE ON THE GROUND

There are 360 degrees in a circle. The linear distance that is represented by 1° along the outside edge of the circle depends on the size of the circle. A 1° angle is the same angle whether the circle has a radius of one meter or 6,378,137 meters, the latter of which is the radius of the earth at the equator as calculated for the WGS 1984 and GRS 1980 spheroids.

Spheroid definitions

Sources for WGS 1984 and GRS 1980 spheroid definitions are available at

`http://earth-info.nga.mil/GandG/publications/tr8350.2/wgs84fin.pdf`

An Album of Map Projections, by John P. Snyder and Philip M. Voxland. U.S. Geological Survey professional paper 1453, USGS: Washington D.C.,1989.

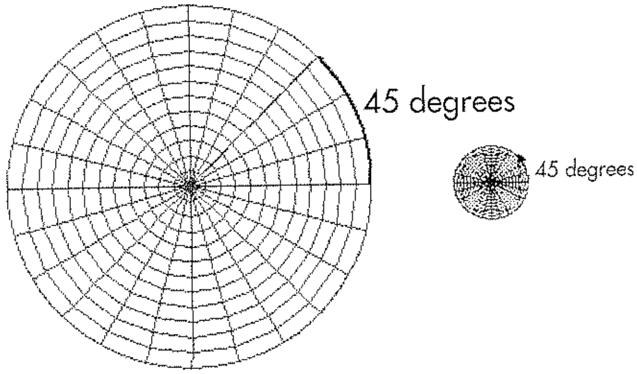

Figure 9–3 The angles in the diagram are both 45 degrees, but the linear distance around the outside of the circle, across the angle, is much longer on the large circle than on the small circle.

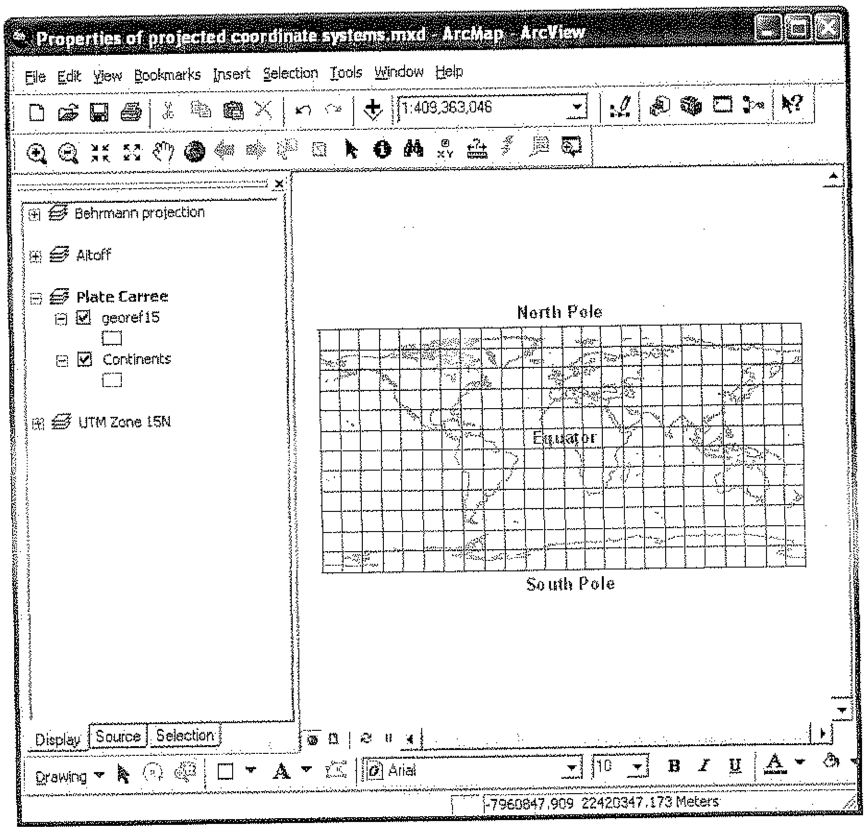

Figure 9–4 Displayed as a GCS, using the pseudo-plate carrée projection, the North Pole and South Pole, which are points, appear as long as the equator.

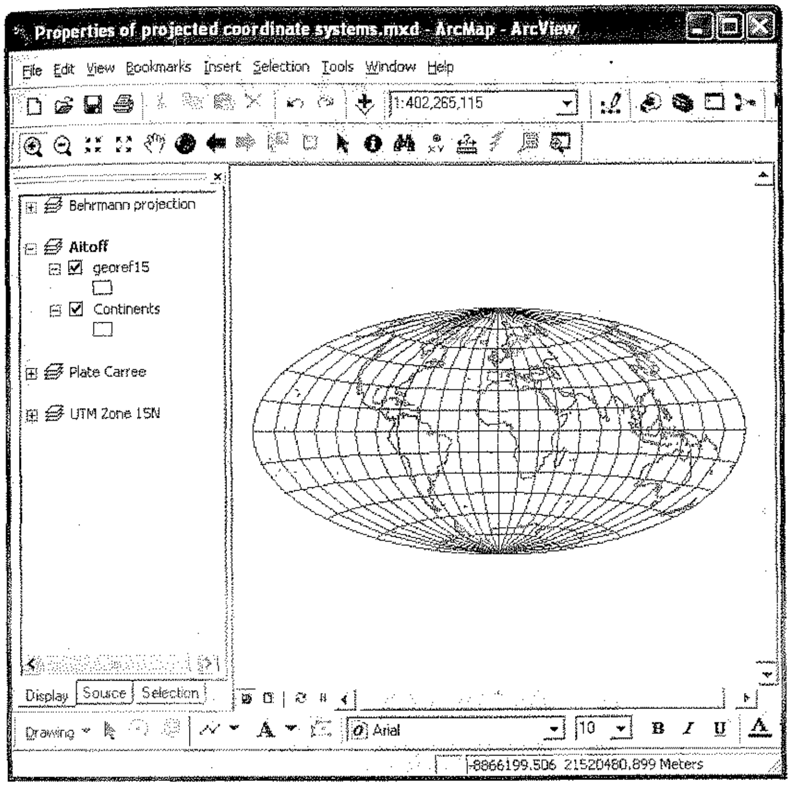

Figure 9-5 Displayed in a PCS, in this case the Aitoff (world) projection, the North Pole and South Pole appear correctly as points. Note how the lines of longitude converge toward the poles, and how the distance between the lines of longitude east to west decreases the farther north or south of the equator the latitude lies.

Lines of longitude, which wrap around the earth from the North to the South Pole and back again, and the equator are called great circles. These are lines of maximum distance around the earth. Along these lines around the earth, 1° represents a distance of approximately 111 km (69 miles) on the ground.

Lines of latitude are parallel to the equator. Because the earth is roughly spherical, the largest circumference is at the equator. Lines of latitude north or south of the equator represent shorter distances on the ground, depending on how far north or south of the equator those lines lie. At the North or South Poles, you have a point. The ground distance represented by 90° north latitude at the North Pole or -90° south latitude at the South Pole is zero.

Because the length of a degree is an angle, units of degrees cannot be used to measure distance on the ground between points, or the length of a line, because degrees of longitude and latitude represent different distances on the ground as the lines of longitude converge toward the Poles. An area of a polygon cannot be calculated in units of degrees because the angles have no relation to surface distances.

PROJECTED COORDINATE SYSTEMS

The problem of accurately measuring distances, lengths, or areas on the earth's surface led to the development of projected coordinate systems. Projected coordinate systems were needed so that distances and areas on the earth's surface could be measured in linear units like feet or meters.

LINEAR UNITS OF MEASURE

Linear units were needed for such diverse applications as navigation, taxation, and determining the area of a field to buy seed. Over the centuries, many different units have been used to measure distance and area, and different definitions of these units were proposed and applied, but eventually most of the world settled on the unit "meter." The standard definition of the meter today is based on the speed of light in a vacuum: exactly 299,792,458 meters per second. The meter is defined as the distance light travels in a vacuum in exactly 1/299,792,458 of a second. This converts to 39.37 U.S. inches. (See **`http://www.mel.nist.gov/div821/museum/timeline.htm`**)

There are many definitions of the unit "foot" used throughout the world. The unit known as the international foot, called "Foot" in ArcGIS Desktop, is equal to exactly 0.3048 of a meter. The U.S. survey foot, or "Foot_US," is equal to exactly 1,200/3,937 of a meter, or 0.3048006096012192024384 0487680975... , which is an infinite, nonrepeating decimal. Because the international foot can be converted precisely to a meter when projecting data, some states have passed legislation that this unit of measure can or will be used with the state plane coordinate system for that state.

PROPERTIES OF PROJECTED COORDINATE SYSTEMS

Different types of projected coordinate systems were calculated to preserve different properties of data. The primary types of projected coordinate systems are:

- Conformal
- Equal area
- Equidistant
- True direction

In most cases, preserving one of these spatial properties of the data decreases accuracy of the other properties. In the case of small geographic areas such as a city or county, differences in distance or area calculated using these different types of projections for the same data can be very slight. When calculations are performed on data covering a large geographic area, differences in distance or area calculations can be substantial. The decision about what type of projection to use is critical when planning a project.

• Conformal

The most commonly used projected coordinate systems are conformal projections. These projections preserve the shape of the data but distort area, distance, and direction. A map of the earth using the Mercator projection in which Greenland appears as large as South America, and in which Antarctica is simply huge, is an extreme example of a conformal projection. Figure 9-6 displays the continents of the world with a 15° × 15° grid in this projection.

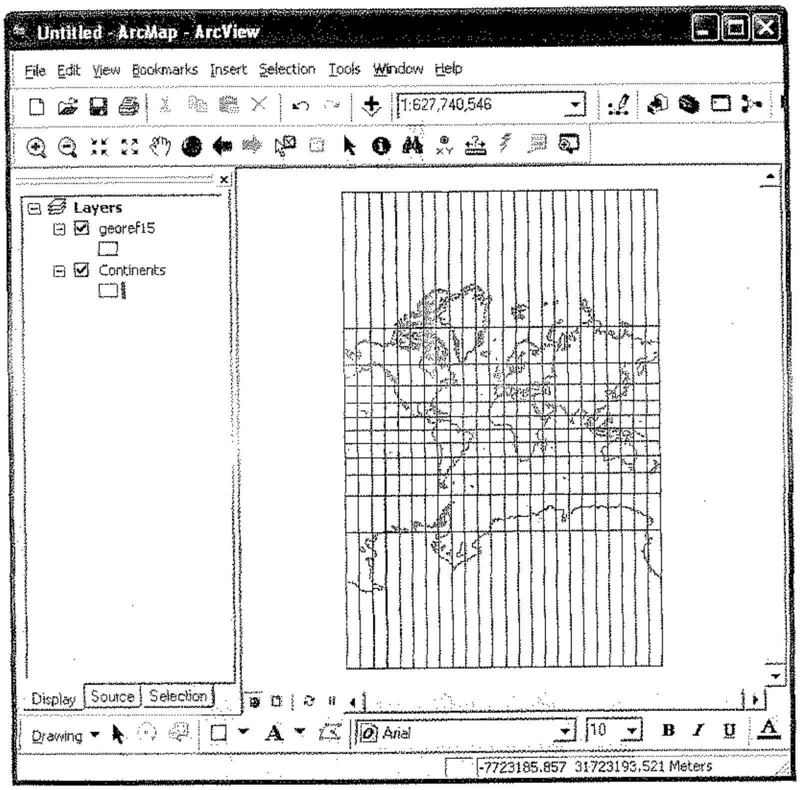

Figure 9-6 The 15°×15° grid of the earth's surface and continents displayed in the Mercator projection, which is conformal. Compare the relative sizes of Greenland and South America and note the disproportionate extent of Antarctica in relation to the other continents.

- **Equal area**

In a case where accurate area measurements are most important, you should consider the use of an equal area projected coordinate system. The equal area property of this projection type is calculated so that the most accurate comparisons between the areas of polygons can be made. When utilizing an equal area projection for data, keep in mind that the shape, distance, and direction are distorted. The distortion in these other properties will increase as areas being examined become larger. Fortunately, some common uses for equal area projections, such as the land use comparison example for a city cited in chapter 8, affect such a small area that these distortions are not significant.

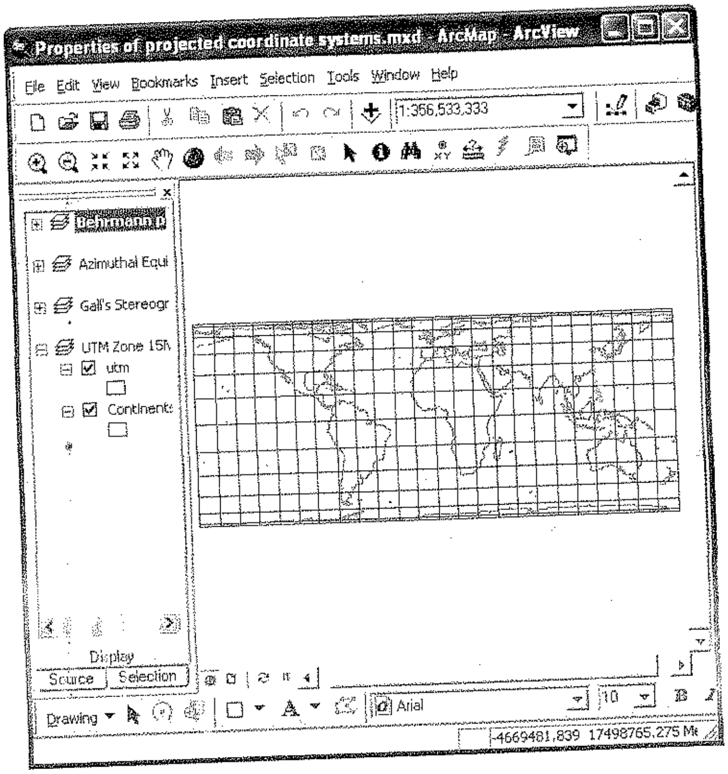

Figure 9-7 The continents of the world are shown with a 15°×15° geographic grid in the Behrmann projection, an equal area projection suitable for use in displaying data for the entire world. Notice that the black grid cells, which all measure 15° by 15°, are compressed in the north-south direction the farther the data lies from the equator.

• Equidistant

Calculating accurate distance measurements can be difficult. An equidistant projection will maintain only some distances. For instance, all north-south lines might have the correct length, or all distances calculated from the center point are accurate. Selection of an appropriate equidistant projection, therefore, should include testing various options and comparing the results from the tests with known measured or surveyed distances. The specific distortion will depend on the properties of the projection selected. Use of an equidistant projection will distort shape, area, and direction in the data.

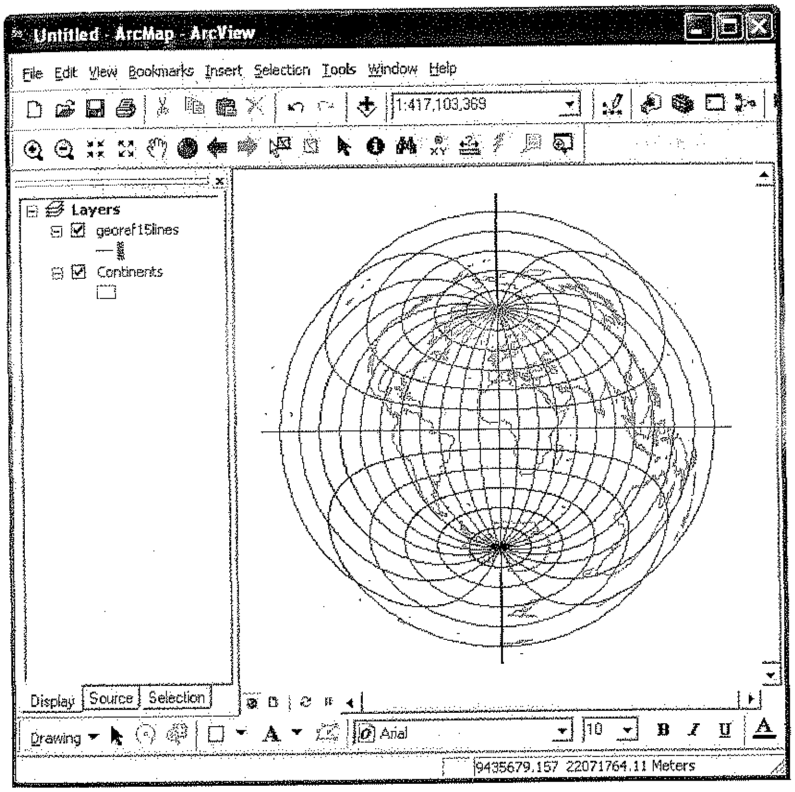

Figure 9-8 Displays continents and a 15° × 15° grid in the azimuthal equidistant projection, centered at the prime meridian and the equator. Distances measured from the center of the projection are most accurate. This projection also approximates true direction on a world scale from the center of the projection.

• True direction

A true direction projection is sometimes used for navigation. In a true direction projection, the angle between magnetic north and a line drawn on the map between the point of departure and the destination is the compass-bearing the captain will use to set the course for the ship or plane.

Further limitations exist for specific conformal, equal area, equidistant, and true direction projections. Some of these projections were calculated to preserve their respective properties over large geographic areas (small-scale map), while other projections will only preserve the desired properties over small areas (large-scale map).

In figure 9–9 the data is projected to universal transverse Mercator (UTM), zone 15 north (UTM zone 15N). UTM is a conformal projection that minimizes distortion in north-south trending areas. Each zone is 6° wide, except for some areas in Scandinavia. Use of the UTM coordinate system is limited to areas extending no more than 18° east to west. That will include the neighboring zones, in this case zone 14 to the west and zone 16 to the east. Beyond those limits, too much distortion is introduced into the data, so this coordinate system is not suitable for large east-west trending areas.

When the ArcMap data frame coordinate system is set to a specific UTM zone, as in this example, the display is limited to 45° east or west of the central meridian for the selected UTM zone. The central meridian for UTM Zone 15 is -87° west longitude, so the display at the western margin is cut off at -132° west longitude, while the eastern border of the display is at -42° west longitude.

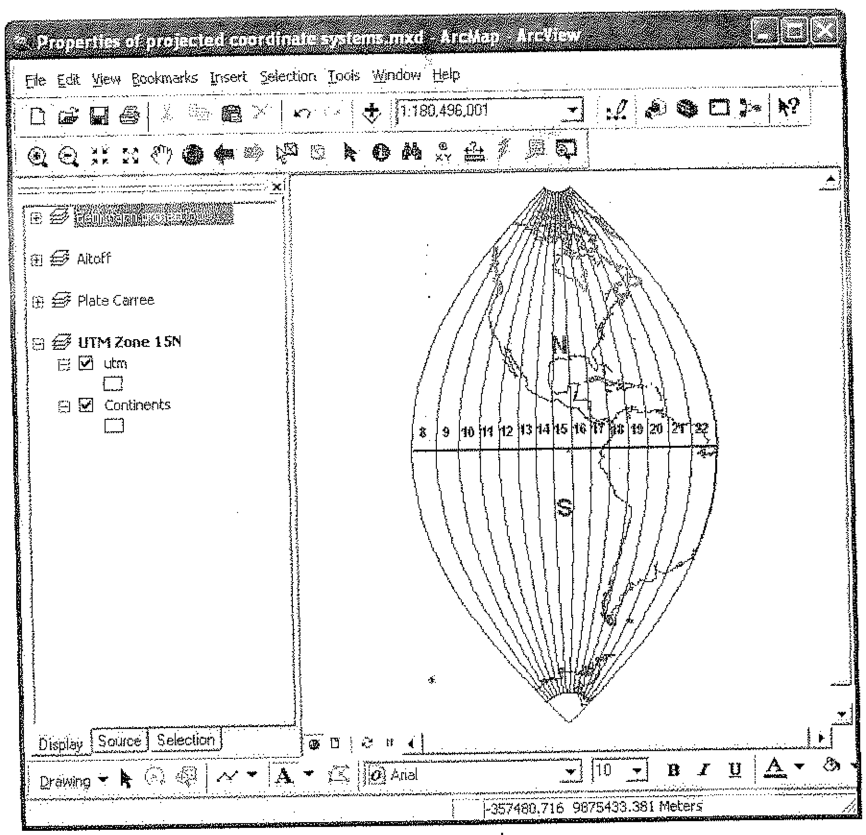

Figure 9–9 The UTM coordinate system, based on transverse Mercator, centered on UTM zone 15N. This image shows the display limits of the UTM coordinate system in the east-west direction as shown in ArcMap. The "N" and "S" denote zone numbers north or south of the equator, the red line in the image. To see the complete worldwide extent of the UTM coordinate system zones, refer to figure 3–7 (page 32).

DECIDING ON THE PROJECTION TO USE FOR YOUR PROJECT

You have been assigned a project for a client. The assignment is to make maps that allow you to compare historic land use for the county in 1979 with the present day. The client wants to know the areas of land in the county currently used for agriculture, residential, parks and recreation, industrial, roadways, schools and colleges, and public buildings such as government offices, police, and fire. What is the percentage change that has taken place in land use within the county over the past thirty years?

The *first* thing you need to do is decide on the map projection you will use for the project, in discussion with your boss and the client. In order to provide information so that the client can make an informed decision, you will need to project data for the task to different coordinate systems for comparison.

You cannot use a geographic coordinate system for the project because you are measuring and comparing *areas* and areas cannot be measured in decimal degrees. You must use a projected coordinate system with linear units such as feet or meters. Since more than fifty different projections are supported in ArcGIS Desktop, deciding on the PCS to use for the project appears complex.

Refer to appendix A and the Knowledge Base article 24646. The Projections Table referred to in the Related Information section of the article includes the names of supported map projections and information about the properties of each projection. Some projections are suitable for use in large-scale mapping—remember, large scale = small area—while other projections are suitable only for small-scale mapping—small scale = large area. In addition, some map projections are calculated for use within specific geographic regions of the globe. For example, Albers equal area conic, best applied in the midlatitudes and used for medium- to continental-scale mapping, is one projection that can be used within the forty-eight contiguous states.

Reviewing the table, you also see that these projections have different properties. Some preserve shape (conformal); others preserve distance (equidistant); others preserve direction (true direction); while still others preserve area (equal area). Under the "Properties" section of the table, look down the "Equal Area" column. You will see that there are a number of equal area projections: Albers equal area conic, Behrmann equal area cylindrical, Bonne, and Craster parabolic, to name just a few.

For this project, covering a small area, and comparing areas of land use, you want to select an equal area projection suitable for large-scale mapping. In the "Suitable Extent" section of the table, compare the areas of use for each projection checked in the Equal Area column under Properties. There is no equal area projection indicated as suitable for large-scale mapping, although Albers equal area conic indicates, "Distortion is moderate for most of the area" when this PCS is used for large-scale mapping. For comparison's sake, this will be a projection to try.

Here are some points to take into consideration in the initial planning stages of the project:

How accurate is your data? Your recent data could be extremely accurate, but how about the data from thirty years ago? How was that historic data created? Was the data digitized on-screen from older, scanned paper maps, a common method? Paper maps can stretch and be distorted from normal use; they are affected by humidity; and the scanning process itself can introduce distortion into the data.

Would using a standard coordinate system, such as state plane or UTM, provide results that are sufficiently accurate for your purposes? Remember that state plane and UTM, from the Supported Map Projections table (appendix A) are both conformal projections that preserve the shape of the data, but not direction, distance, or area. Over small areas, though, the distortion in these projections may not be large enough to affect the results.

In order to make a meaningful decision, you will need to do the following two things:

1. Overlay the historic data with the current data for the area of interest in ArcMap and compare the data. How good is the alignment of the data? Do major streets and tax parcels line up? If obvious distortions occur in the historic data, after allowing for rerouting of roads and other adjustments, it may be necessary to perform spatial adjustments on the historic data so that accurate comparisons can be made. It may also be necessary to create a custom projection file to align the historic data with current information, then project the older data and the current data to the same coordinate system.
2. Within the area of interest, obtain access to a surveyed area that is known to have an extremely accurate area measurement. For our purposes here, a fairly large area of 100 acres or more will be most useful. One acre is equal to 43,560 square feet (U.S. survey foot) or approximately 4,046.82 square meters.

Assuming that the historic and current data have reasonable alignment, project the current data to NAD 1983 StatePlane for the zone in which the data is located, or to NAD 1983 UTM for the correct zone. Units of feet or meters can be used. Compare the area of the polygon in that coordinate system with the area reported from the survey. Remember that both state plane and UTM are conformal projections, but over a small area the distortion in area is small. You may also need to compare the parcel boundaries in the current data with the survey, to ensure that the bearings and distances (metes and bounds) of the polygon correctly reflect the surveyor's work.

Calculating area for a shapefile in ArcMap

The attribute table of a polygon shapefile does not always include an area (SHAPE_AREA) field. Even if an area field exists, the values will not be recalculated when the data is projected to a different coordinate system. If the area field exists, you will need to recalculate the values after projecting the data to the new coordinate system. If an area field does not exist, you will have to add the field to the attribute table, and calculate the areas of the polygons manually.

Open the polygon shapefile attribute table, and check for an area field. If none exists, click Options > Add Field.

The field name must not exceed ten characters, must not contain spaces, cannot begin with a number, and cannot include special characters. It is useful to include an abbreviation for the units of measure in the field name, and assign names like AREA_usft or AREA_m.

Define the new area field as DOUBLE.

PRECISION is the total length of digits that can be stored in the field. Taking the default of 0 allows the maximum number of digits (19) to be stored in the field.

SCALE is the number of decimal places stored in the field. Taking the default of 0 allows the maximum number of decimal places (11) to be stored. Since the data is now in a projected coordinate system, using linear units, you may want to reset the SCALE value to a more realistic number such as 3.

To calculate the AREA, right click the field name, select Calculate Geometry, and select the units to be used for the calculation. The units need to match the units of the projected coordinate system.

Area, perimeter, and length are calculated automatically if data is stored in a file or personal geodatabase.

What is the difference between the areas? Is there a significant difference between the area calculated in the software and the surveyed area? Is the difference small enough that the analysis will not be affected, or is the difference large enough that the results of the analysis will be questionable?

If the data projected to standard state plane or UTM coordinate systems does not appear to match the surveyed extent of the test parcel closely enough, the next step will be to create a custom projection file for the area of interest, using the Albers equal area conic projection. Then you will project the current data to that custom coordinate system, and compare the area for your test parcel with the survey results as well as with the area in state plane or UTM. The client can then look at these samples and make an informed decision about which projection to use for the project.

CREATING THE CUSTOM PROJECTION FILE IN ARCMAP

Start ArcMap with a new, empty map, and add the current data that is projected to state plane or UTM.

To create the custom Albers equal area conic projection for your area of interest, you need to collect the following information to fill in the projection parameters.

Standard parallel 1
Standard parallel 2
Central meridian
Latitude of origin

Projection parameters

Projected coordinate systems have different parameters depending on the type of projection, extent of the area for which the projection is intended to be used, and other considerations. Here are some map projection parameters that may be required for various projected coordinate systems:

Standard parallel 1
Standard parallel 2
Central meridian or longitude of center
Latitude of origin or latitude of center
False easting and units of measure
False northing and units of measure

A complete list of supported projections and required parameters for each projection is available online at

`http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=113&pid=112&topicname=List_of_supported_map_projections`

With the current data displayed in ArcMap, go to View > Data Frame Properties > General tab, and change the Display Units to Decimal Degrees, then click Apply and OK. The display of units in the status bar at the bottom of the ArcMap Window will change from feet or meters to decimal degrees.

If the status bar is not displayed, click on View > Status Bar.

The central meridian for the projection is a line of longitude extending north to south through the approximate center of the data, dividing the data into an east half and a west half. Move your cursor across the data on the screen to a point that is at the approximate center of the data. It is convenient to round the central meridian value to an even decimal. For example, if the longitude value for the

STATE PLANE COORDINATE SYSTEM

The state plane coordinate system (SPCS) was designed by the U.S. Coast and Geodetic Survey of the United States in the 1930s, in order to provide a standard for map projections within the United States. The SPCS provides mapping accuracy of 1:10,000 within the area of each zone.

ORIGINAL ZONES IN THE STATE PLANE COORDINATE SYSTEM

In creating the SPCS, larger states were divided into zones while small states were assigned to a single zone. In some cases, such as New England, several small states were grouped into a single zone. The zone boundaries were defined along state lines and almost always along county boundaries within the state. When originally defined, the SPCS was based on the NAD 1927 datum and Clarke 1866 spheroid.

Three different base projections were selected for these zones, depending on the shape of the zone. These projections were selected in order to minimize distortion of data within the zone. For zones that have an extent greater in the east-to-west direction, the Lambert conformal conic projection is used as the base projection. For zones that have an extent that is greater in the north-south direction, the transverse Mercator projection is used. Hotine oblique Mercator is a special case, used only for the Alaska Panhandle, because this zone lies at an angle, instead of being oriented either north-south or east-west.

Figure 3-1 shows the state plane coordinate system zones as they were originally defined on the NAD 1927 datum by the U.S. Coast and Geodetic Survey.

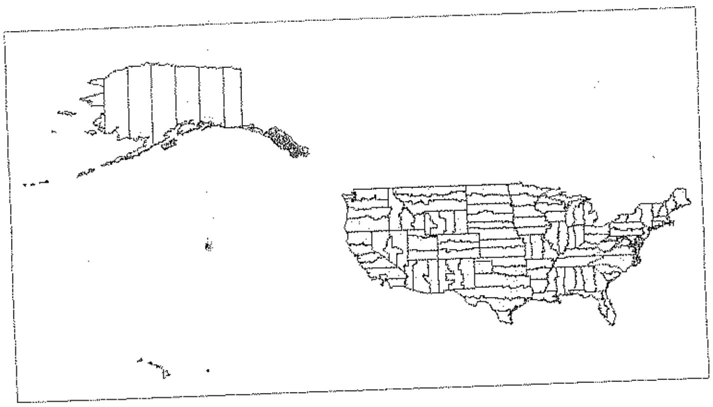

Figure 3-1 Original state plane coordinate system zones, defined on the NAD 1927 datum.

Viewing the zone shapes in the diagram, it is easy to see which base projection is used for each state plane coordinate system zone. The zones that are wider east to west are projected in Lambert conformal conic. Zones with a greater extent north to south are projected in transverse Mercator. The Alaska Panhandle, which lies at an angle, is projected in Hotine oblique Mercator. These projections minimize distortion in the areas thusly shaped.

Each zone has projection parameters calculated specifically for that geographic area. The SPCS projection for one zone should not be used for data in another zone in the same state or for data in another state.

FIPS ZONES IN THE STATE PLANE COORDINATE SYSTEM

The GRS 1980 spheroid was calculated from satellite measurements of the earth's surface, and the North American Datum 1983 is based on GRS 1980. Figure 3-2 illustrates the distribution of the state plane coordinate system FIPS zones, as defined on North American Datum 1983 (NAD 1983).

When the NAD 1983 datum was incorporated into the SPCS, the new keyword FIPS was used to designate each area. The acronym FIPS stands for Federal Information Processing Standard. Although the standard was never officially accepted, the zone numbers with the FIPS keyword are used regularly. What's important to remember is that the FIPS keyword, along with the associated FIPS zone number, is used in ArcGIS Desktop.

In ArcInfo Workstation, either ZONE or FIPS keywords can be used with the associated number, when defining the coordinate system for data projected to the state plane coordinate system. When ArcInfo coverage or grid data projected to the SPCS is added to ArcMap, and the coverage/grid has the coordinate system defined using the ZONE keyword, ArcMap automatically translates that zone number into the corresponding ArcGIS coordinate system and FIPS zone number.

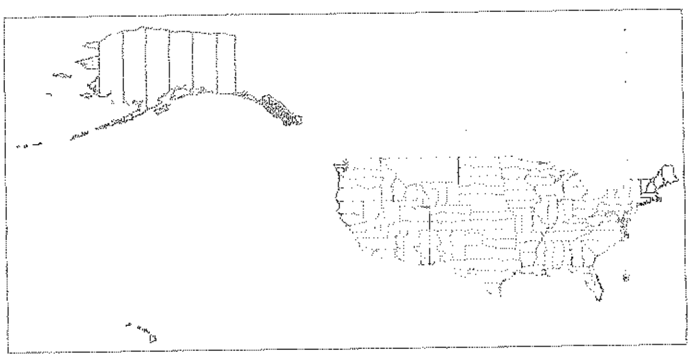

Figure 3-2 Updated state plane coordinate system zones, as defined on the NAD 1983 datum. Comparing these zones with those in figure 3-1, you can see evidence of the realignment of certain zone boundaries here: Montana has become one zone, for example, and Los Angeles County is now merging into California zone 5.

If the coordinate system of the unknown data is state plane, and the data lies in a zone that uses the Lambert conformal conic projection, Left and Right coordinate values will be larger numbers than the Top and Bottom, *unless the data is in eastern Texas.* Because the east-west extent of Texas is so large, in eastern Texas the Top and Bottom coordinate values will be larger than the Left and Right with the Lambert conformal conic projection. All other zones using the Lambert conformal conic projection will have larger extent values on the Left and Right.

If the data is projected to the SPCS, and lies in an area in which the base projection is transverse Mercator, the Top and Bottom coordinate values will almost always be larger numbers than the Left and Right.

The state of Florida (in figure 3-3) provides an excellent means of comparison between the SPCS base projections, because Florida is divided into zones that use Lambert conformal conic as well as transverse Mercator projections for different areas of the state.

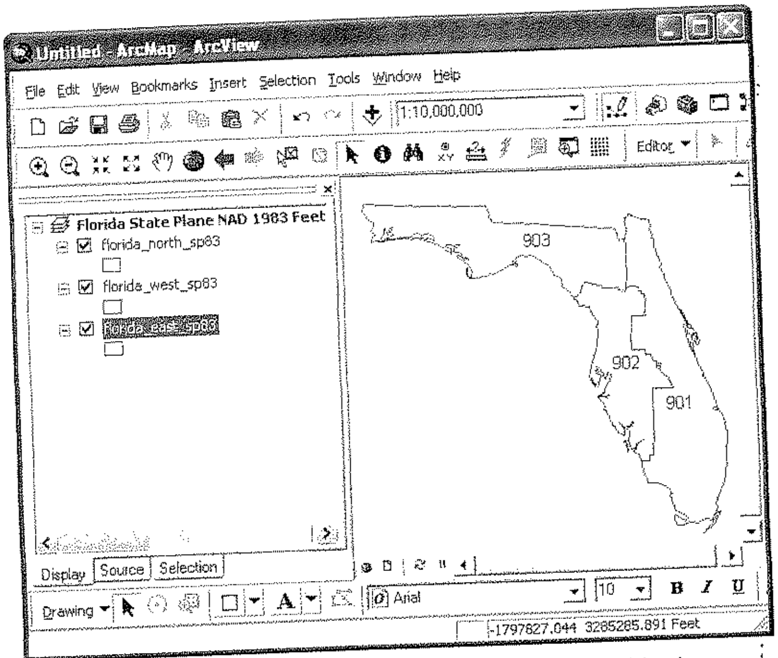

Figure 3–3 Zone boundaries for the state of Florida. Because of the shape and orientation of these areas, FIPSzones 901 and 902 are projected using transverse Mercator. FIPSzone 903 is projected using Lambert conformal conic.

Examining the shape of each zone, you can see that Florida North, FIPS 903, uses Lambert conformal conic as the base projection because the extent of the zone is greater east to west. Florida East and Florida West, 901 and 902, on the other hand, uses transverse Mercator as the base projection because these zones have a greater extent north to south.

Examine the coordinate extents for these three zones in figures 3–4, 3–5, and 3–6 and compare them.

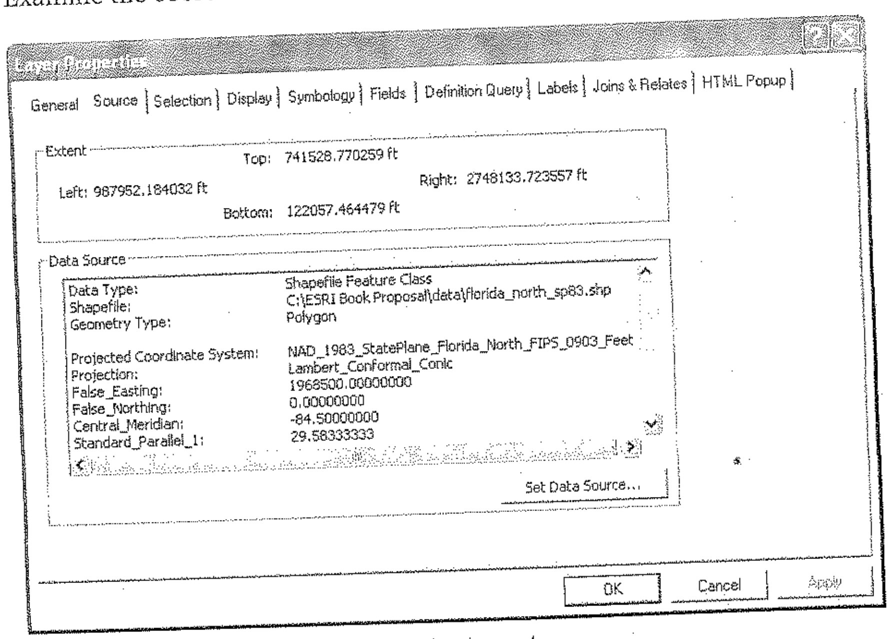

Figure 3–4 Coordinate Extent for 903, Florida North.

For Florida North (Figure 3-4), the Left and Right (longitude) coordinates are the larger numbers. Note that the projection is Lambert conformal conic.

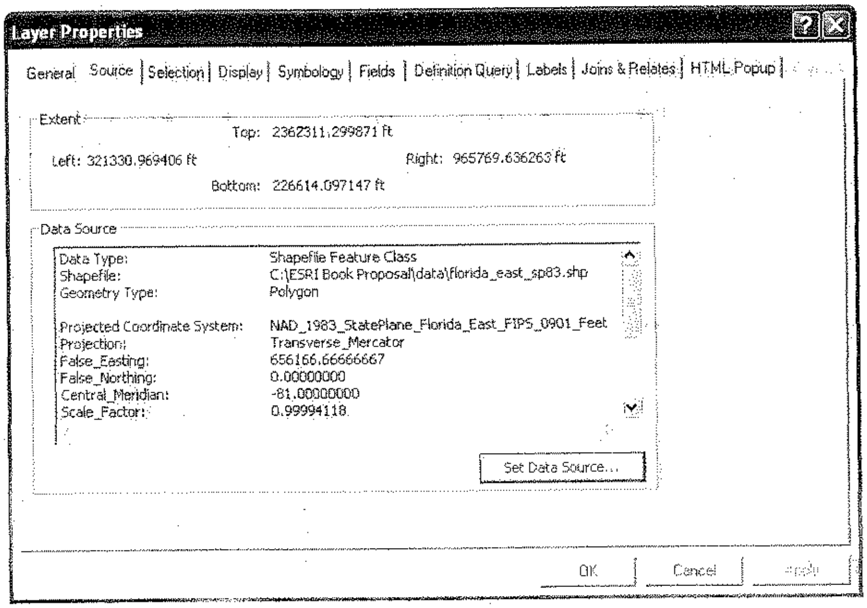

Figure 3-5 Coordinate extent for 901, Florida East.

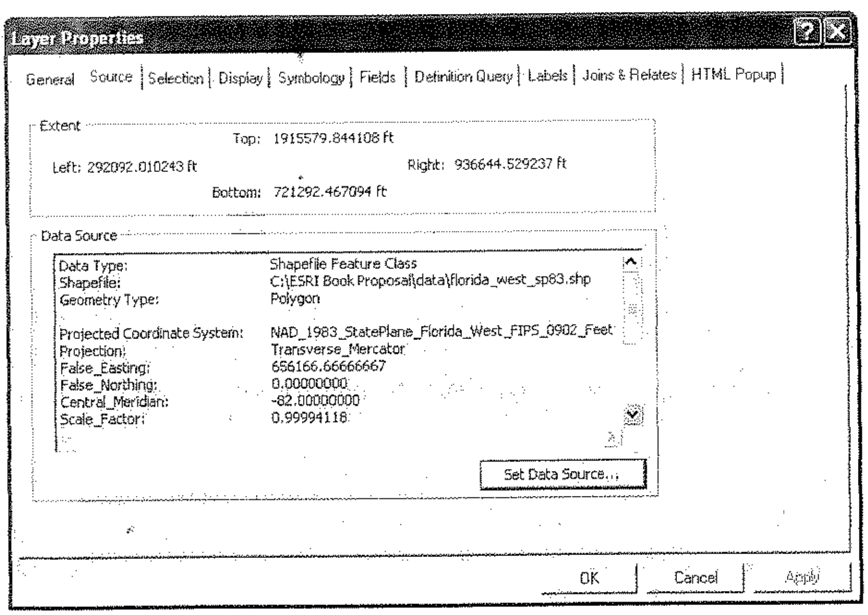

Figure 3-6 Coordinate extent for 902, Florida West.

For Florida East and Florida West, which are projected to the transverse Mercator projection, the Top coordinates are larger numbers than the Left and Right.