Lab 4: Projections and Coordinate Systems

Overview:

Any planar coordinate system is based on a map projection, which is the orderly transfer of positions or places on the surface of the Earth to corresponding points on a two-dimensional surface, like a sheet of paper. Several elements go into defining a projection. To start with, Earth is nearly spherical. In fact, to better describe the shape of Earth, we use the geometrical figure called a spheroid, which is a flattened sphere and can also be called an ellipsoid. The elliptical nature of the spheroid is defined by two parameters: the semi-minor (polar) and the semi-major (equatorial) axes of the spheroid. These axes are measured from the center of the earth to either the North Pole (polar) or a point along the equator (equatorial). Over the years and with the advancement of measurement technologies, the distances measured for the semi-major and semi-minor axes have changed. The two most commonly used spheroids for North America are the Clarke spheroid of 1866 (Clarke 1866) and the Geodetic Reference System spheroid of 1980 (GRS80).

When projecting from a geographic coordinate system (latitude, longitude) to a planar coordinate system (UTM, state plane, etc.), there have been several standards developed that provide a frame of reference for measurement. These standards (datums) define the origin and orientation of the grid that makes up each particular coordinate system. Datums that are frequently used within North America include: the North American Datum of 1927 (NAD27), which is defined based upon the Clarke 1866 spheroid and has its origin in Meade’s Ranch, Kansas, and North American Datum of 1983 (NAD83), which is defined on the GRS80 spheroid and uses the center of Earth’s mass as its origin. When specifying the parameters of a projection, you will typically specify either the spheroid or the datum but not both.

Finally, it must be understood that distortions of shape, area, distance and direction are inherent to all projections. Projections can be conformal, equal-area, equidistant, or true-direction. Projections may minimize distortion in various categories, but no projection can minimize distortion in all the categories. The attempt to minimize the distortions is approached by looking at various ways of projecting a spheroid onto a flat piece of paper. Projections that are cylindrical, conical, or planar in nature use various points of intersection or tangency with the spheroid upon which to minimize the distortion. In defining these points of tangency, or standard parallels, we are specifying the extent of our study area for which distortions will be minimized. The further away you move from these defined areas (standard lines), the more distortion you will encounter.

For more detailed discussion, see the appropriate chapter in your textbook.

Learning Objectives:
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- To explore the basic structure of a planar coordinate system;
- To learn to re-project geographic data into various coordinate systems;
- To understand the distortions of shape, area, distance, and direction that are inherent to the various types of projections;
- To work with multiple data frames in a map layout

To be submitted in a single PDF document:

1. (15 pts) A write-up (500 word maximum) answering the questions throughout the lab; inclusion of graphics to illustrate your answers may extend the 500 word limit.

2. (5 pts) A single map layout with multiple data frames that depicts the United States in six different projections as detailed in the lab.

Procedure:

1. Exploring a Cartesian coordinate system

   a. Start ArcCatalog and connect to your working directory
   b. Launch ArcMap with the appropriate icon from the toolbar
   c. Drag and drop (by highlighting, holding down a left-click, and dragging to ArcMap) the triangle and grid coverages (in this order) into ArcMap from your working directory. Or add the coverages using the technique used in earlier labs. Click OK if you get the following error message:

   **It is important to note that this error will be displayed any time a layer is added without a defined projection.

   d. Use the identify tool to determine the coordinates of the triangle points as well as the size of the area created by the boundary of the triangle (think of how to do this without calculating the area manually)

Question 1 (3 points):
   a. What is the difference between geographic and projected coordinates? Which utilizes a Cartesian coordinate system?
   b. In what situations might each coordinate type be most appropriate?

2. Understanding distortions of projections using Tissot Indicatrix figures

   ...
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A Tissot (“Tiss-oh”) Indicatrix is a figure that shows how a projection distorts the geometric properties at a point. To understand how distortion affects a single point on a GIS layer, you will employ a Tissot’s Indicatrix where a circle on a sphere is projected onto a plane:

“The resulting shape is always an ellipse. The ratio of the lengths of the semi-major axis, \(a\), and the semi-minor axis, \(b\), of this ellipse (Fig. 1) represents the maximum and minimum distortion at the point being considered (Hradý’lek and Hamilton, 1973; McDonnell, 1979). If the ellipse is circular \((a = b)\), the projection is conformal; if the ellipse has an area equal to that of the generating circle, the projection is equal-area; finally, if either \(a\) or \(b\) is constant, the projection is equal-distant in the corresponding direction. For many common map projections, \(a\) and \(b\) occur along the meridians and parallels of the earth making it relatively easy to calculate the scale factors associated with length, area, and angle. It should be remembered that no projection of a sphere onto a plane can preserve both shape and area simultaneously.” (Finlayson and Montgomery, 2002)

A reference circle shows what the circle would look like if the projection did not distort geometry.

The figure shows what a projected circle would look like on a map.

By displaying many Tissot Indicatrix figures on a map, you can readily understand how a projection changes geometry.

a. Go to http://www.jhlabs.com/java/maps/proj/, a java applet that demonstrates distortions found within map projections using the Tissot Indicatrix. Accept and allow Run.
b. Scroll down to The Globe Applet
c. Read the instructions.
d. Check the Tissot Indicatrix box below the map display.
e. Select several different map projections. Using the Tissot indicatrix and your own sense of proportion and direction, study how each map projection affects area, shape, and direction.
f. Use your mouse to drag the map from left to right and (when possible) from top to bottom and observe how changing the center of the view affects the distortion in different regions of the world. Try zooming in to areas with which you are familiar. Remember that although the java applet you are using allows you to dynamically adjust the projection to best observe each region in the world, if you were going to produce a static print map you would have to settle on a single viewpoint to represent all areas of interest.

3. Displaying data layers of different projections in ArcMap
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a. Start a new view within ArcMap by selecting the New Map File icon (do not save the previous view of the grid and triangle).

b. Drag and Drop (or any other method to add data) mystery1 first. Then add mystery2 from your working directory into the display area of ArcMap. Drop in the mystery1 layer first. (If you add mystery 2 first, the data will be slightly offset; this is due to an unusual discrepancy in converting between these two particular datums.)

c. These layers are in two different projections (Note the “Geographic Coordinate Systems Warning”). ArcMap automatically re-displays all layers in the data view to the projection of the first layer added, also referred to as “projecting on-the-fly.” (In the future be sure to add the data with your projection of interest to the data frame first).

d. To find out the projections of mystery1 and mystery2, right-click on the layer in the table of contents (TOC) and navigate to “Properties” then the “Source” tab.

e. You can also find out the projection of a shapefile within ArcCatalog by right-clicking on the data layer, selecting “Properties”, and clicking “XY Coordinate System”. The projection is specified by the highlighted projected system in the list with full details in the “Current coordinate system” box below.

Question 2 (2 points): What is the projection of mystery1? Of mystery2?

Make sure you understand the different functions of on-the-fly projection (what ArcMap just did to mystery2 so that it could be displayed with mystery1), projecting using ArcToolbox (what you are going to do next), and defining a projection. If the projection is not defined to begin with, ArcMap has no idea how to re-project the data or project them on-the-fly. (ArcMap will display data with undefined projections, but only as data on a meaningless coordinate system that cannot be mapped to any of the coordinate systems it knows). When two layers have different coordinate systems, why would we bother to re-project them if ArcMap can automatically redisplay differently projected layers just fine using on-the-fly projection? (Answer: Because many analysis tools within ArcToolbox require datasets to have the same defined projection, and other GIS software, such as ArcView and ArcInfo, do not automatically redisplay differently projected layers)
4. Re-projecting GIS data with ArcToolbox

In this section, you will re-project a feature class, states, to observe how different projections affect the form of the United States.

- Launch ArcToolbox from the ArcCatalog toolbar or ArcMap toolbar. (The ArcMap Toolbar is shown below)
- Select Data Management Tools | Projections and Transformations | Feature | Project and double-click to open the tool.
- For the Input Dataset or Feature Class, navigate (using the folder button on the right) to the states feature class within the us_states.gdb (located in your working directory). This is the feature class you will be re-projecting throughout this section. Click Add.
- Type a name for your new geodatabase feature class under Output Dataset or Feature Class (something like states_lamb for Lambert conformal conic). Be sure you save this and all further projections to your working directory under the us_states.gdb geodatabase by clicking on the folder to the right and navigating to the appropriate directory. Click Save.
- Click the button next to Output Coordinate System.
- Expand the Projected Coordinate Systems folder (double-click or click the plus sign) and then select Continental | North America.
- Right-click on USA Contiguous Lambert Conformal Conic and select Copy and Modify within the Spatial Reference Properties window. This brings up the Projected Coordinate System Properties.

**Notice where the default center of the projection falls. What state would this default be best suited for? We will now shift the focus of the projection to center on Michigan. Knowing that Lower Michigan is approximately 84.00W and 42.25N, you should adjust the parameters accordingly (see below, making sure you understand each parameter as you follow the steps).**
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- Leave the False Northing and Easting at: 0.0000
- Change the Central Meridian to: -84.0000
- Change Standard Parallel 1 to: 27.6716
- Change Standard Parallel 2 to: 62.6593
- Change the Latitude Of Origin to: 42.2500
- Leave the linear units as Meters
- Click Apply, OK and OK
- Click OK one more time to run the project operation
- If the results dialogue remains open, close it and proceed to the next step

Note:
- If you are projecting in ArcCatalog, you may need to refresh ArcCatalog from the contents tab before you can see the new dataset; to do this, go to the directory of interest and press F5, then double check that the geodatabase feature class is created by inspecting it within ArcCatalog (use the preview tab to look at the newly created data – select the file then click preview).
- If you are projecting in ArcMap, open up ArcCatalog to inspect your geodatabase feature class (use the preview tab to look at the newly created data – select the file then click preview).

5. Creating layouts with multiple data frames:
Instead of opening up four separate ArcMap sessions, or clearing the data frame coordinate system (View | Data Frame Properties | Coordinate System tab | Clear button), this section will demonstrate how to add additional data frames to ArcMap. You will then use these six data frames to produce a single layout with six inset data frames, one for each projection of the states layer.

a. Add a data frame to your map for each new re-projection by clicking Insert and selecting Data Frame.

b. Follow the same re-projection procedure as above for each projection on the next page. In general, each new data frame can be populated by using the Add function (in ArcMap) or drag and drop (from ArcCatalog).

c. Note that when in data view, only one data frame can be viewed at once. To switch between data frames, you need to activate the frame you want to view by right-clicking on the frame’s name (here, “New Data Frame”) and selecting Activate from the menu.

e. In layout view, you should be able to see the frames. (You may need to drag the new data frame off of the old one to see it).

f. Arrange the data frames in your layout before adding other layout elements. It is a good idea to make the data frames equal sizes in this case by reducing the first to the size you think you want, then overlaying the new frame on top of it, stretching/shrinking it to match up exactly, then dragging it to where you want it. Make sure the two frames do not overlap anywhere data will be. Also make sure to leave room for other layout elements.
g. Use the scale pull-down window (see below) to ensure that the scales are the same for the maps (Note: with projections not including Alaska and Hawaii, a larger scale may be appropriate).

h. If your scale is the same for each data frame, there is no need for multiple scale bars. However, different projections will likely have different scales, requiring a scale bar for each data frame. Likewise, if your symbology is the same for all data frames, there is no need for multiple legends. If there are differences, you need to be aware that map elements are linked to their data frame, so you need to know which data frame you are in when adding elements (e.g. don’t make a scale bar for one frame and place it next to a different frame at a different scale).

i. If you want to make all data frames with the same scale units (i.e. all scale bars end with 1000 miles), you can specify this in the Scale Line Properties by double clicking the scale. Under the Scale and Units tab, choose “Adjust width” from the When resizing pull down box and set your desired Division Value (e.g. 1000 miles). Make sure your units are appropriate. Under the Numbers and Marks tab, you can specify the frequency of numbers and marks of the scale as appropriate for your chosen divisions and subdivisions (e.g. Frequency: “ends (and zero)”).

Re-project the states feature class four more times using the following projection definitions and following the procedures from the steps above each time. Assign an appropriate name to each of the outputs from the projection procedures, states_<projection>.

(Remember: never put spaces in the names of files, and keep names short!)

1- USA Contiguous Albers Equal Area Conic Projection
   Use the same procedure as above, but modify USA Contiguous Albers Equal Area Conic.

2- Mercator projection (found in the World folder)
   In this case you will have a few deviations:
   - Defining the Mercator projection only requires one standard parallel and a central meridian. Use -84.00 for the central meridian and 45.00 for the standard parallel (both approximately the center of Michigan).
   - Additionally you will have to perform a transformation because the datums of the input and output are different (NAD83 vs. WGS84 [World Geodetic System 1984])

3- UTM (Universal Transverse Mercator)
   The process is again similar to that above; however, this time selecting the appropriate UTM zone will shift the focus to the area around Michigan so you do not have to alter any parameters. The UTM projection can be found in the projected coordinate systems folder under UTM | NAD 1983. Then, you need to determine what the appropriate zone is (your lecture notes may be helpful here). Note that Alaska and Hawaii do not appear on the UTM map, which is fine for this lab exercise.

4- Michigan GeoRef coordinate system (an Oblique Mercator projection)
   This time, we will use a slightly different method to define the projection. As an
alternative to manually defining a dataset’s projection it is possible to ‘import’ the coordinate system of a second dataset. This ensures that their projections will match. That is what you will do here. We have given you a shapefile (city_obmerc) that is already in the Michigan GeoRef coordinate system. You will use it to define the coordinate system for your final projection procedure.

- After selecting the dataset you’d like to project (states) and the name of the layer you will create in the Project tool (as before), click the Output Coordinate System button. In the Spatial Reference Properties window, click the Add Coordinate System button (see below) and then Import... (opposed to selecting it from the list as before).

- Browse for the shapefile city_obmerc within your data folder, click on it and select Add, click Apply and OK and then proceed as in previous steps (that is, perform the transformation step exactly as before). You may need to do the Geographic Transformation – select NAD_1983_To_WGS_1984_1.

**All together you should end up with the original states file and the 5 re-projected datasets all in the same directory. See graphic below.

**

**Question 3 (3 points):**

a. What are the “longitude of origin” and “central parallel” projection parameters? What purposes do these parameters serve?

b. Why are false easting and false northing values usually used? (Lecture notes and the help menu could be useful for these questions; help system - contents - map projections - projected coordinate systems - projection parameters - then expand, and read, the various paragraphs).

6. Examining the effect of the different projections

Use ArcMap to explore the various outcomes of the projections processes

- Within each data frame of your ArcMap session, make sure you have added one of your projected views of the United States, and make sure it is not projecting on-the-fly
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by checking the Data Frame Properties | Coordinate System tab.

• For each of the projections, you can Activate each of the data frames individually, toggle
back and forth between the data frames to compare them (and look at the Layout view) and
use the identify tool to fill in the table (please make sure you use the correct area
attribute— the Shape_Area, and not Area).

• Note the differences between how the areas of Michigan and Alaska changed with
each changing projection. You should have an understanding of why these
differences occur.

**Question 4 (2 points):** Complete the following table. Use the attribute named Shape_Area (not
Area). Additionally, describe why there are differences in area among the different projections.

<table>
<thead>
<tr>
<th>Projection</th>
<th>Area (meters squared)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Peninsula of Michigan</td>
</tr>
<tr>
<td>Albers Equal-Area</td>
<td></td>
</tr>
<tr>
<td>Lambert Conformal</td>
<td></td>
</tr>
<tr>
<td>Michigan GeoRef</td>
<td></td>
</tr>
<tr>
<td>Mercator</td>
<td></td>
</tr>
<tr>
<td>UTM</td>
<td></td>
</tr>
</tbody>
</table>

**Question 5 (5 points):** Think about the research questions you identified in Lab 1, or related
questions in your field. What projection makes the most sense for spatial data you have gathered
to answer your questions? (It is not enough to say, for example, equal-area projection; pick a
specific equal-area projection). Explain your projection choice using technical reasons (e.g.
references to shape, area, direction, etc.), cultural reasons (e.g. reference to center of focus, etc.),
historical reasons (e.g. protocols, convention, etc.) or other non-aesthetic reasons. You can
search “choosing a map projection” in the Help to get started. Keep in mind that the original
projection of your layers may not be the optimal projection for your research questions.

**Map to Submit (5 points):** You will show each of the six projections of the United States on one
layout using multiple data frames. The source for the states layer is ESRI. Each projection
should be correctly labeled (i.e. Lambert conformal conic, not states_lamb). Include map
elements of title, north arrow, scale(s), legend(s), source, and “layout by”. Patch outlines should
be included to visualize state boundaries. Be sure to adhere to the cartographic principles
detailed in Lab 2 and include the appropriate layout elements.

-- End Lab 4