Chapter 7

A Guide to Coordinate Systems

As discussed in Chapter 7 of *The Data Journalist*, there are a great many possible coordinate systems available, depending on where you are in the world. The question of which one to use will often be answered for you, if a map layer comes in a particular coordinate system that is optimized for the area the layer covers. It may be best to simply stick with what works.

Very often, map data will come already projected, and it may well be optimized for the area. In that case, you may well want to retain the projection.

But sometimes data comes unprojected, or you have two or more layers that you want to use in the same map that have different projections (of course, there can be complications in trying to reconcile different projections if they are based on different underlying datums, due to the need for a datum transformation).

This is a guide to some of the coordinate systems used in English-speaking countries.

For maps of the world

For maps that need to produce reasonably accurate results anywhere in the world, the most common scenario will be maps that use the WGS84 datum, which is intended to be global in scope, projected using the Web Mercator projection. For online display, this combination works well because map tiles fit neatly together, as discussed in Chapter 6 of *The Data Journalist*. Unfortunately, this projected coordinate system doesn't facilitate accurate distance or area measurement, because of the distortion inherent in Web Mercator (https://blogs.esri.com/esri/arcgis/2010/03/05/measuring-distances-and-areas-when-your-map-uses-the-mercator-projection/). All projections produce distortion, but by preserving angles and shapes, Web Mercator sacrifices distances and area, and the distortion worsens the farther you get from the Equator. In mid and high latitude areas, this is a problem.

There are other projections intended to that show the entire world, such as Winkel Tripel, which is a compromise projection designed to provide a pleasing view of the entire globe (http://www.winkel.org/other/Winkel%20Tripel%20Projections.htm). The projection tries to minimize distortion at any one point, but does not allow for accurate measurements.

The Azimuthal Equidistant projection is a planar projection that allows accurate measurements of distance from the central point of the map (http://desktop.arcgis.com/en/arcmap/10.3/guide-books/map-projections/azimuthal-equidistant.htm), but it is not accurate for east west distances away from the central point. This projection and the associate projected coordinate system (which in ArcMap uses the WGS84 datum) is often used for polar maps that would be severely distorted by such projections as Mercator.

In truth, it is difficult to find a projected coordinate system that will allow for truly accurate measurements of distance anywhere on the map, however if you wish to make measurements of areas, you can choose a projected coordinate system based on an equal area projection such as Behrmann Equal Area Cylindrical for maps of the world (http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Behrmann_Equal_Area_Cylindrical), or Albers Equal Area Conic for mid latitude areas (http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Albers_Equal_Area_Conic). This projection does a reasonable job of preserving distances in these areas as well.

Regional choices

Probably, most GIS analysis that you are likely to do will be at a national, regional or local scale, and because of the smaller areas covered, it is possible to use projections (and projected coordinate systems) that produce more minimal distortion, as long as they are used in the areas intended.

For maps of North America

If you are doing your analysis within North America, the most common datums underlying coordinate systems are NAD27, NAD83, and WGS84, with different variations of the latter two having been developed to improve accuracy in specific areas. You will find a discussion of these datums in Chapter X of the data journalist. The most important thing to know is that while NAD83 and WGS84 are nearly identical in where they place latitude and longitude points (though they have drifted apart slightly over time), NAD27 can be off by hundreds of metres from both. This won't matter if you do your entire analysis using coordinate systems based on NAD27, but it will matter a lot if you try to combine layers based on NAD27 with those based on the more recent datums. A datum transformation will be required to avoid alignment problems (see Chapter 7 for a more complete discussion of this issue).

There are some local datums, such as ATS77. This datum predated NAD83, but was based on a preliminary version of the same specifications (SOURCE). ArcMap does not have a built in datum transformation from ATS77 to one of the commonly used datums, such as NAD83. There is actually little difference between the two. You can read more about this issue here:

http://esri.ca/sites/default/files/faq/Projections%20and%20Transformations%20for%20Canada_3.pdf

An updated version of NAD83 called NAD83 (CSRS), used in Canada, (http://www.nrcan.gc.ca/earth-sciences/geomatics/geodetic-reference-systems/9052) is more accurate than the original NAD83, but the differences are small (http://www.naref.org/transf/nad83_geomatica2006.pdf) but could be important if absolute accuracy in alignment of features is critical. Transformation files are available, often from provincial authorities, if you want to create a custom transformation method in ArcMap (http://www.spatialtimes.com/2016/05/projecting-nad83-csrs-original/) Similarly, updated versions of NAD83 are used in the United States, such as NAD83 HARN. As with CSRS, differences are small, though in time updated datums will shift more from NAD83.

Various projections and Cartesian coordinate systems are used with these underlying datums.

For areas that do not have a great east-west extent, you will frequently see projected coordinate systems that use Universal Transverse Mercator coordinates. As its name indicates, UTM is based on the Transverse Mercator Projection, which is a conformal cylindrical projection that flips the cylinder on its side, so the "tops" of the cylinder are oriented east and west instead of north and south. This allows the line "contact" for the cylinder to run north and south, minimizing distortion along that line, with distortion increasing the farther east and west you go from that central meridian. Like the Mercator projection of which it is a variant, shapes and angles are largely preserved, but distance and area are distorted. In the UTM system, the world is divided up into 60 north south bands, each six degrees of longitude wide. Each zone has its own central meridian, at which distortion is minimized, located halfway across the band. If you think of UTM as defining 60 separate projections, you'd be correct.

Each band is further divided into north and south subzones, at the equator. As examples, Toronto is in UTM zone 17 N, New York City 19N, San Francisco 10N, London, UK 30N, Rio di Janeiro 23S, and Johannesburg 30 S (check all these).

Because of this choice, distortion is minimal within each band, or UTM zone, so if the area you want o map is of relatively small east-west extent, such as a city, a state or other regional area that is oriented north to south, UTM is an excellent choice for your analysis. You can find the UTM zone for any point in the world on this map: http://www.dmap.co.uk/utmworld.htm

UTM has its own coordinate system, unique to each zone, so if you are working with UTM coordinates, you need to know which zone the coordinates are for.

Generally speaking, you can use three UTM zones together, and still get acceptable results if you use the projection for the centre zone of the three (check). But accuracy falls of dramatically if you try to go beyond this.

If you are working with maps in Canada, you may also run into the Modified Transverse Mercator, or MTM, coordinate system. MTM is similar to UTM (hence "modified"), in that it is based on the Transverse Mercator projection, and has north-south oriented zones with a central meridian at which distortion is minimized (http://what-when-how.com/gps/datums-coordinate-systems-and-map-projections-gps-part-2/). However, in MTM, zones at 3 degrees of longitude wide. Toronto is one large city that uses MTM; in its case, based on the NAD27 datum, though on its open data site it offers the choice of downloading layers based on NAD27 or WGS84. You may also find the MTM coordinate system in use in the Maritime provinces, with layers based on the ATS datum.

For east west extents, such as the entirety of the United States or Canada, you will need to use a projection that minimized distortion, and one that is very commonly used in both countries is Lambert Conformal Conic. It has two points of contact, or standard parallel, at which distortion is minimized. These can be varied depending on the area used. For example, in the United States, these parallels are commonly at 33° and 45° N (http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=Lambert_Conformal_Conic), while in Canada, standard parallels at 49° N and 77° N are commonly used (http://www.statcan.gc.ca/pub/92-195-x/2011001/other-autre/mapproj-projcarte/m-c-eng.htm).

A projected coordinate system using Lambert Conformal Conic uses a Cartesian coordinate system with metres as the typical unit of measurement, though this will not always be the case, such as with the U.S. State Plane System.

Albers Conic Equal Area is a similar project to Lambert Conformal conic, and you will sometimes see it.

The **State Plane** system is not itself a map projection, but instead is a grid system that divides the United States into a series of zones, usually made up of multiple contiguous counties.

Each state has one or more zones, and within each zone, measurements are extremely accurate, originally set as being at least as accurate as 1 in 10,000. Coordinates are specific to each zone and the unit of measurement may be feet or metres (http://www.ngs.noaa.gov/PUBS_LIB/ManualNOSNGS5.pdf) There are versions of the state plane system based on the NAD27 and NAD83 datums.

The State Plane system is used with two conformal projections, Transverse Mercator for the zones of north south extent, and Lambert Conformal Conic projection for east-west zones. Depending on the general orientation of a zone, two adjacent zones may be based on one or the other projection. The state plane system is widely used by municipal and state governments in the U.S. (http://www.ngs.noaa.gov/PUBS_LIB/ManualNOSNGS5.pdf) because of its exceptional local accuracy. Projected coordinate systems based on state plane are also an excellent choice if you have a map that uses the common WGS80/Web Mercator combination for its projected coordinate system and you want to reproject the layer for accurate local analysis. A datum transformation is required to make this conversion, though the differences between WGS80 and NAD83 remain small (you would not, as a rule, want to reproject to a version of state plane that uses NAD27).

For maps of the United Kingdom

If you are working in the United Kingdom, there are three datums you are likely to encounter. The first is WGS84, which can be used anywhere in the world. The OSGB36 datum is based on the Airy ellipsoid of 1830 (http://www.bnhs.co.uk/focuson/grabagridref/html/OSGB.pdf) and is used only in Great Britain. A more recent datum is the European Terrestrial Reference System 1989, shortened to ETRS89, which is fixed to the European continental mass. Originally identical to WGS84, it has slowly shifted away since, much the way NAD83 and WGS84 are no longer identical.

The most common projection used in Britain is Transverse Mercator, as this is the projection used along with the British National Grid projected coordinate system. UTM is also used, with zones 29, 30 and 31 N covering Great Britain, which is well suited for UTM with its generally north-south orientation