Chapter 02: Fundamentals of Geography

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Introduction

Back in my day, kids, geospatial technology cost thousands of dollars. If you wanted to make a digital map or get coordinates from GPS you had to get a degree in geography and then get hired by a large company or the federal government. It was hard as a struggling GIS student to gain experience on the latest equipment. I remember being at a conference at which ESRI revealed their latest program, ArcGlobe. It was a 3D globe on which you could overlay feature classes. You could zoom and spin the globe and we all were in awe. Of course it cost money. Assuming you already had at least the cheapest version of ArcGIS, ArcGlobe would cost you another $2,500. So I resigned myself to only admiring the program from afar until I landed that fancy job.

But then Google Earth happened! It was effectively the same piece of software, but completely free. Such a thing was hailed as true democratization of cartography and spatial analysis. Geospatial students around the world downloaded the software and thought it was incredible that we had such a powerful tool for free. In the following years however, I realized this wasn't necessarily a good thing. I'm all for keeping costs low and letting poor folks have access to elite tools. The problem comes from the fact that this giving away of software seemed to give people the feeling that geography wasn't hard. You didn't have to be a geographer to have access to the tools, which meant no one was concerned to learn the nuances of coordinate systems and cartographic generalization. If we want to drive a car, we get trained and then get tested. If we want to drive the Earth in a virtual environment, we simply have to click "I agree."

As I began working in the geospatial industry I ran into average folks who where frustrated with the answers they were getting from their GPS receivers and Google Earth. When I asked them which datum they used on their receiver they looked at me like I was crazy. "What's a datum?" they would ask not realizing that this crucial bit of information was why they could never get consistent results from their equipment.

This chapter will introduce you to some fundamental concepts in geography. It doesn't mean you will be a master of geography at the end, but you should at least know enough to keep you from making easily avoidable mistakes.

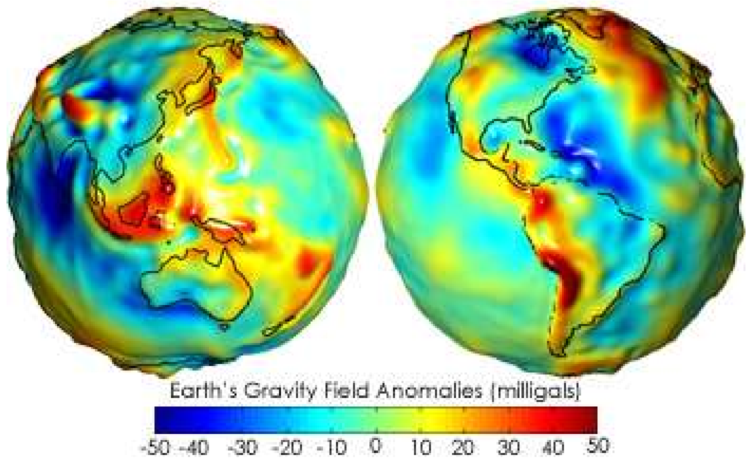
The Earth's Shape

Early on we are taught that the Earth is a sphere and we know this because of Christopher Columbus. Technically, both of these things are wrong. Humans knew the Earth was "round" at least 1,500 years prior to Columbus's voyage and we today know that it is best described as *roundish*.

Geodesy is the science dealing with the measurement of the shape of and locations on the Earth. This may sound like a simple field of study, but actually requires a tremendous amount of math to make sure we have accurate as well as precise descriptions of the Earth. Initial logical and mathematical work by the Ancient Greeks proved that the Earth was round by at least 500 BC. Eratosthenes even calculated the circumference of the Earth in 247 BC. By simply using a section of Egypt and the angle of the sun's rays, he measured the Earth to be roughly 24,662 miles. We today measure it at 24,901 miles. Not too shabby for working without computers and satellites.

Sir Isaac Newton later reasoned that the Earth was not a perfect sphere, but instead an oblate spheroid. The idea is that the entire Earth rotates once every 24 hours, but at the North Pole the Earth doesn't actually need to move. It's a simple, dimensionless point. At the Equator however, it has to travel the 24,901 miles in that same 24-hour period. This means that the Equator has to fly; it moves at a little over 1,000 miles per hour. This difference in speed causes a bulge at the Equator that is pretty imperceptible to our eyes, but the width of the Earth is a little larger than its height. The term "oblate spheroid" effectively means "squished sphere." Ellipsoid is another term that essentially means the same thing.

But even the oblate spheroid is too simple a model to accurately represent the shape of the Earth. The true shape of the Earth is described as a geoid. Geoid means that the Earth is Earth-shaped… which is stupid, but it truly is the best we got. The geoid is a complicated shape due to the fact that the Earth is bumpy, has a mix of liquid and solid material on the surface, and gravity can effect it differently. So the geoid as we use it for mapping is a way of averaging out global mean sea level, assuming the planet was entirely water. In GIS, we use an ellipsoid model to represent this, which will make a little more sense in the following section.



Visualization of the lumpiness of the geoid based on gravitational differences. "Geoids sm". Licensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Geoids_sm.jpg#mediaviewer/File:Geoids_sm.jpg

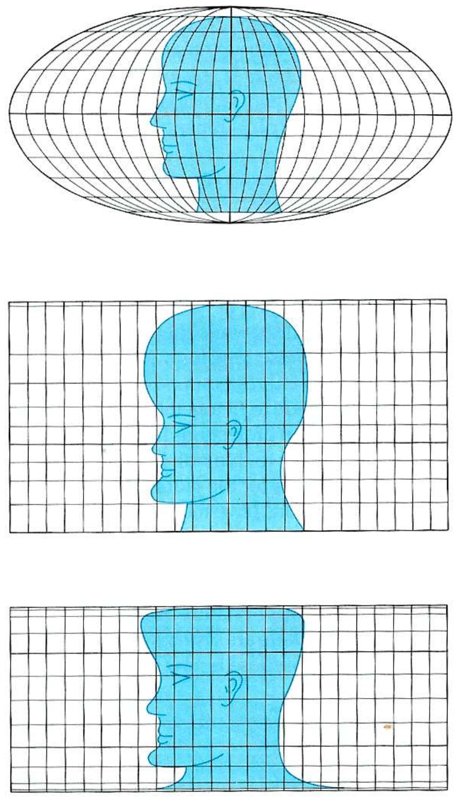
Projections and Coordinate Systems

So we know that the Earth is a geoid, but rarely do we look at it as such. Globes are wonderful devices in that they accurately represent the geoidal shape of the Earth. Globes are limited in scale, however, and therefore detail, and aren't really useful on a hike or driving in a car. Typically when we study the Earth, whether we try to find directions from one point to another or we want to compare the size of deserts in the Western Hemisphere, we use a map. A map is simply a scaled representation of the geoid placed onto a flat piece of paper. But that's the trick!

Picture an orange, relatively round just like our Earth. The peel is the crust of this citrus planet, a thin surface, and we want to take that surface and lay it out flat. Unfortunately we cannot peel the orange without tearing and stretching it to make it a flat surface. This is the same with a flat map. The round globe represents the true shape and size of the Earth's surface; the map represents a stretched and distorted version of it.

So does that mean all maps are bad? Not exactly. It just means we need to be aware of that distortion. All maps have it, but not always the same type and not in the same locations. A map projection is a systematic way of flattening our Earth and turning it into a usable map.

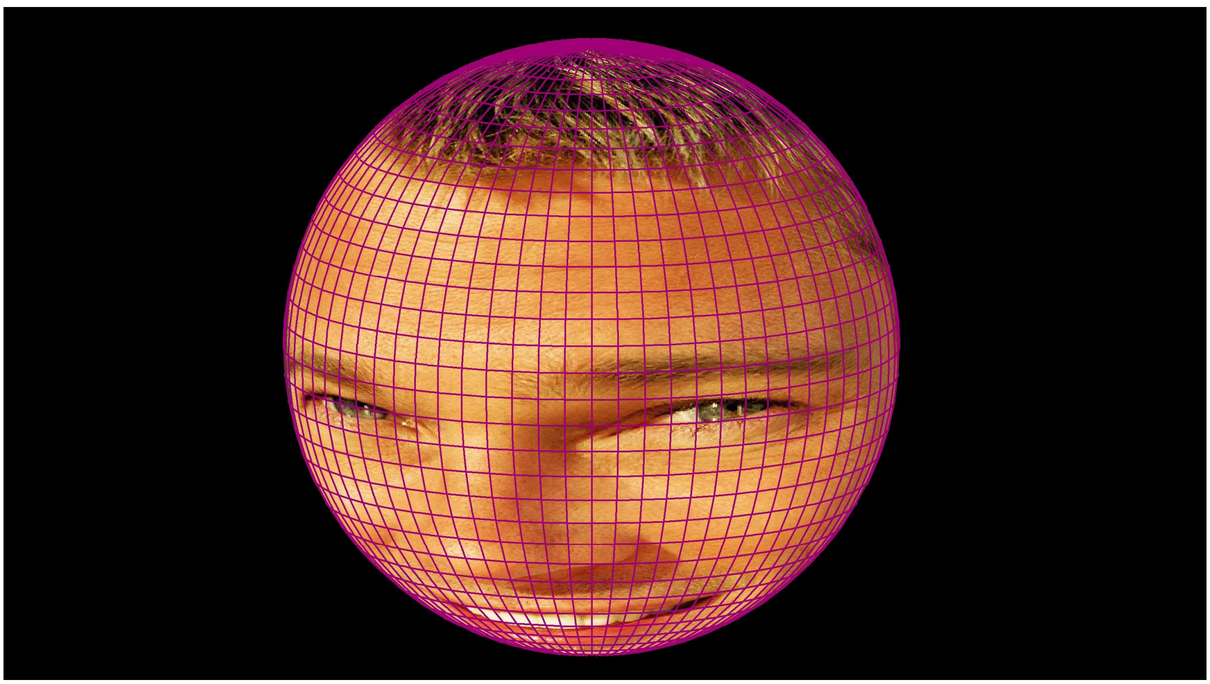
The following image comes from a classic work of cartography by Arthur Robinson. The bald blue man in the first map represents "normal." It is drawn using the a 19th century German projection called the *Mollweide*. Robinson points out that this doesn't mean the Mollweide is the best projection, just the one from which we are starting. The image is then reprojected using a *Mercator* projection (in the middle) and the cylindrical equal-area projection (the bottom map). The graphic was done to illustrate how different map projections can exaggerate and alter objects in different ways.



Map distortion, from Robinson et al., 1995

While I've always liked this image, I've also hated it because the blue guy never really looks "normal." So I made my own version. We all know what this guy is supposed to look like…

So let's use his face to help us understand this distortion idea.

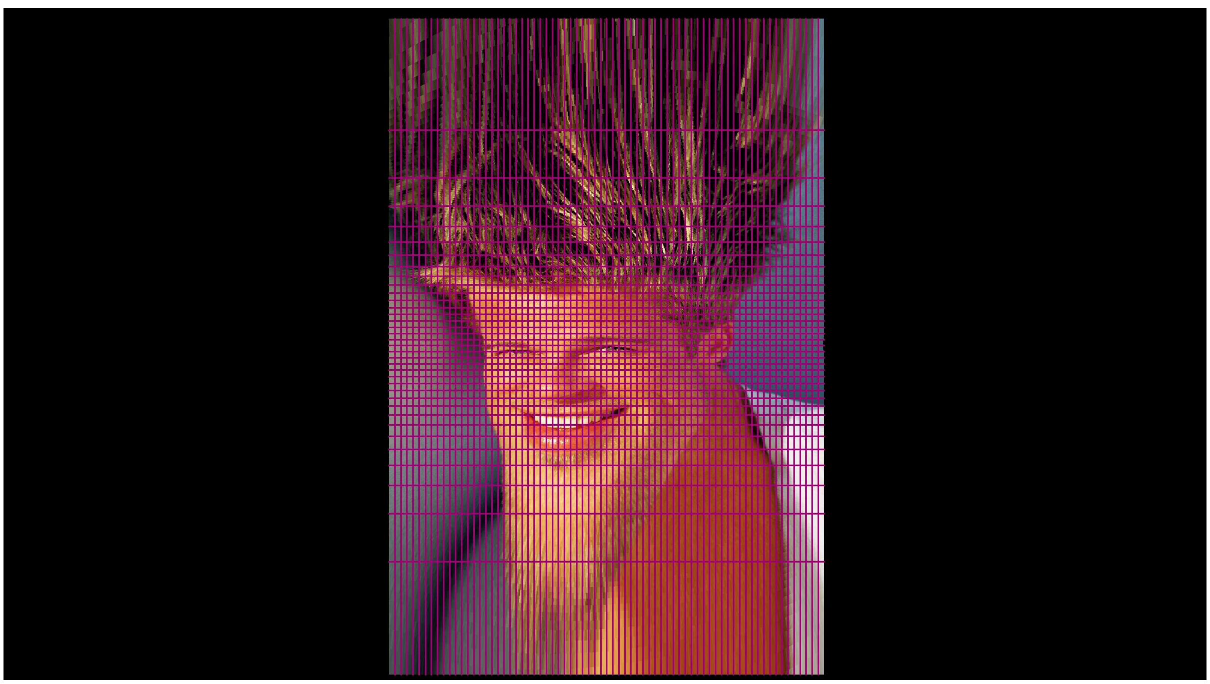


Map projections take that roundish Earth and systematically flatten it into a map. This was initially done using light to "project" the continental shapes onto a piece of paper. Now we can use sophisticated computer algorithms to achieve even better projections.

We have hundreds of such projections, many of which look radically different from one another. The thing to remember is that not one of them is the "best" projection. They each have their benefits and their problems. Each projection has its own type of distortion. Some maps maintain proper sizes, others maintain proper shapes. The challenge is that if it does maintain the sizes of countries, it will not maintain the right shapes. You can't have both traits perfectly transferred from the globe to the map.

Conformal projections

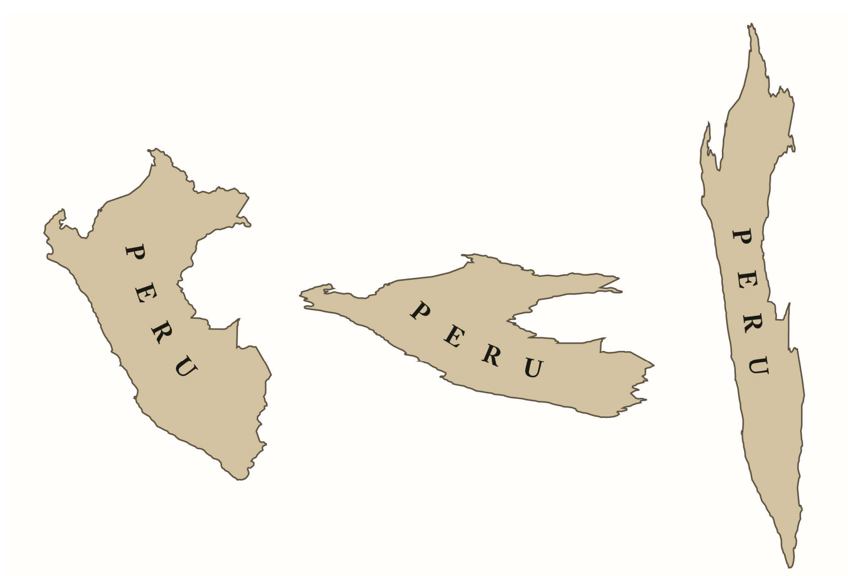
Conformal projections are those that maintain the proper shapes of things. A clue that you are looking at a conformal map is that the latitude and longitude lines will cross at a 90° angle, which is what they do on the globe. The first truly conformal map projection is the Mercator, developed by Gerardus Mercator back in 1569. This was a wonderful map because it allowed a sailor to plot a line on the map, find the compass direction, and then point his ship in that same direction to get to his destination. That may sound simple enough, but maps were not able to do that before, and even today many aren't useful for navigation in that way. The map projection has two big problems though. Because its shapes are great, the sizes of some of the continents are horribly distorted. The distortion increases as you move closer to the poles. Also, while direction is maintained, distances are not. This also means that a straight line on a Mercator map isn't always the shortest distance between Point A to Point B.



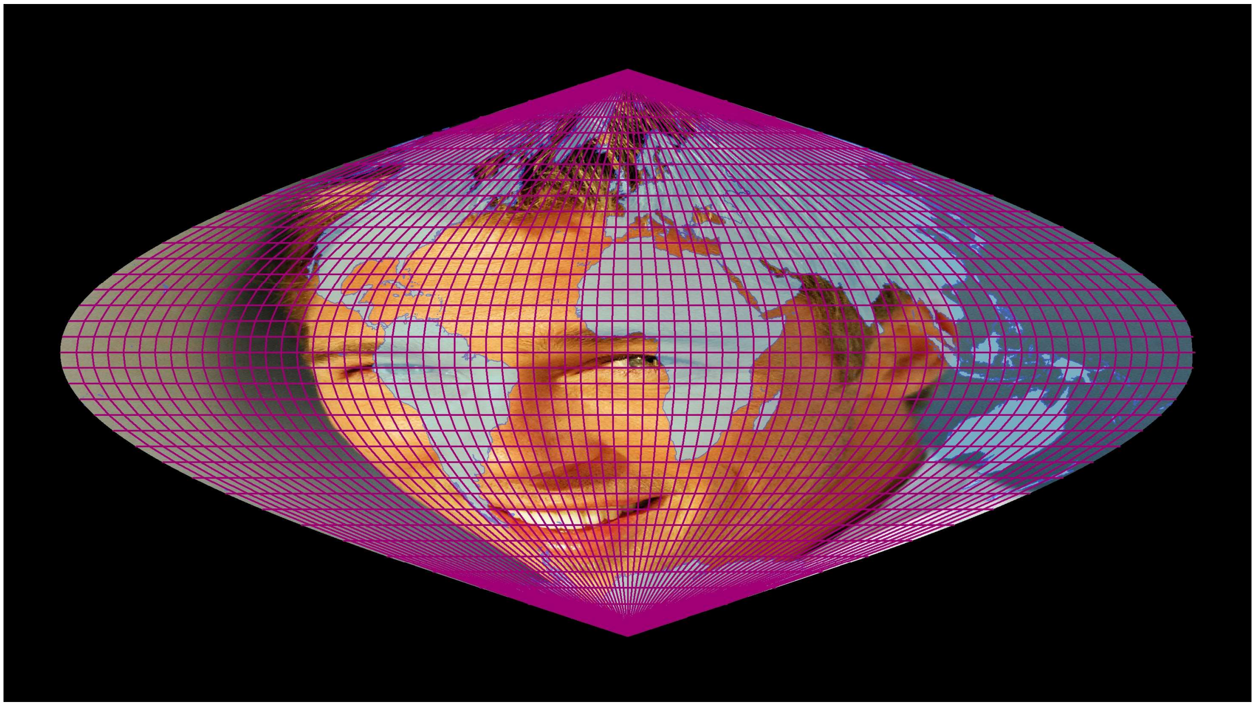
Above you see Mr. Pitt projected using the Mercator projection, and yes, he is hideous. If we add the continents of the world you can begin to see what that means for actual map distortion. You may not know what shape or size Greenland is supposed to be, but you can tell when Brad Pitt isn't looking so hot. See where his forehead begins to take off? That means that North America is also drastically altered.

Equivalent Projections

Another type of map projection is called equivalent. This is a fancy way of saying things on the map are the right size. But as mentioned above, we can't maintain everything on a map, so with accurate size comes weird shapes. Look at the image below of the three Perus. The first one has the truest "Peru shape," but the other two are still the same size of the first.



Why would we want an equivalent map? We often use these maps to measure areas of features across the globe. For example, maybe we are climate scientists responsible for measuring the remaining glacial ice in both the Arctic and Antarctic. Using a conformal map would give us terrible results, as the poles would have so much distortion. And also, we don't care about the shape of the ice, we just need to know the size.

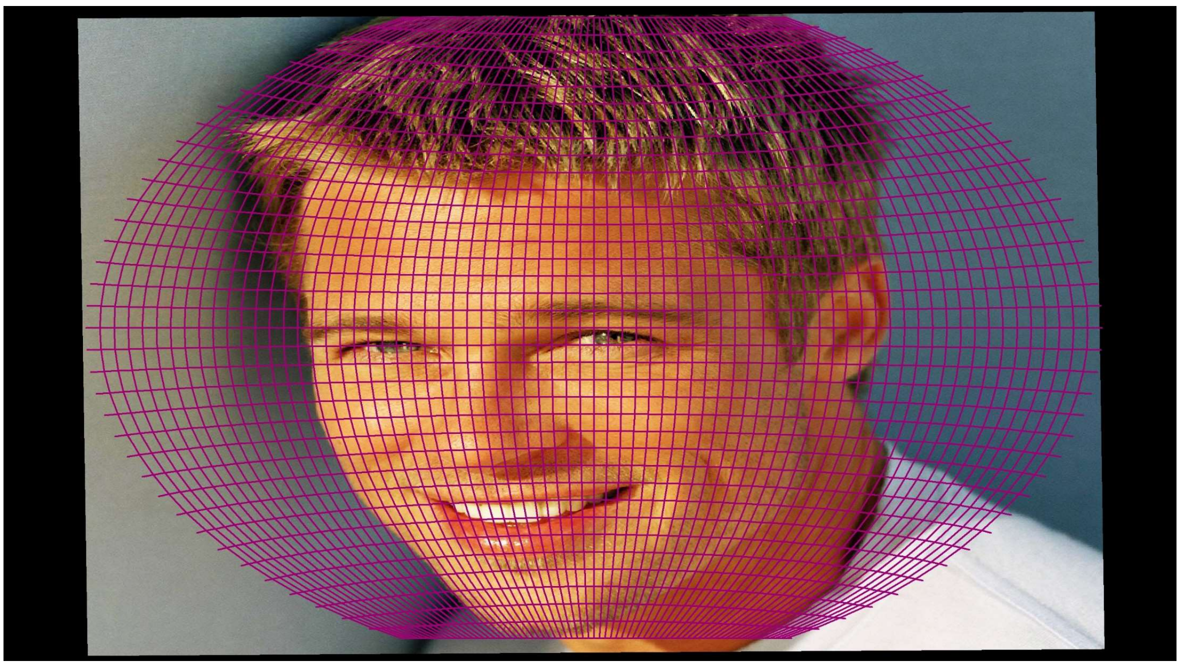


Sinusoidal Map Projection, an example of an equivalent projection.

If you aren't sure if the map you are using is equivalent, a simple test is to check both Mexico and Greenland. They are effectively the same size in reality (as shown below), but typically on a conformal map, Greenland is ten times the size of Mexico. You can also look at the latitude and longitude lines. They are at 90° angles in reality and on conformal maps; equivalent maps show them at a mix of oblique and acute angles.

Compromise Projections

We don't always need a map for navigation or for area comparisons; sometimes we just want to see where things are around the world. Maybe you need a map as a reference for a report to show the location of Asian countries. This is when you should use a compromise projection, which is a blend of the previous two types. The distortion of shape and size meets in the middle and the result is an attractive map that will work as a reference tool.



Winkel Tripel Projection, a compromise projection that gets both shape and size good enough for an attractive map.

Using projections in ArcGIS

In ArcGIS, map projections are blended with coordinate systems. A coordinate system is a grid that we use to locate objects on the globe or the map, like latitude and longitude. ArcGIS isn't perfect for using projections. For example, as of this writing, there is no way to adjust the map scale by latitude for a map using the Mercator projection. In other words, your scale bar will look the same at the Equator and the North Pole, which is wrong. This must be kept in mind if you are planning on crafting a map for navigation or other field use.

A datum is the starting point of the coordinate system, or in other words the 0,0 coordinate pair. The usual ones we use in the United States are the North American

Datum (NAD) of 1983 (or 1927 for older data) or the World Geodetic System (WGS) of 1984. You really don't need to know how they work, just always be aware of the one to which your GIS data is set. Keeping everything with the same datum will be crucial as we explore more complex analysis. Not being aware of your datum can lead to errors of hundreds of feet.

But which projection/coordinate system to use for our maps? We can select anyone we wish with the map document's "data frame," but we need to make sure that we are choosing the proper one for the map's purpose. I should also note that this is different from "defining a projection" for data; this is simply for aesthetic purposes. In other words, we aren't doing complex spatial analysis; we want a sexy map.

As with everything in geography, choosing the right coordinate system in ArcGIS is an issue of scale (which will be discussed more thoroughly below). You will always want to display maps using the "projected coordinate systems" folder, but use the following list to help make the right decision for the map in question.

Small scale (global, continental maps)
A small scale map covers a large area. Since such a map will cover a large area we want a projected coordinate system that will show the entire world in an attractive way, but also minimizes distortion from the projection process. You can find all of the appropriate systems in the "world" folder (use the plain one, not "sphere-based") or the "continental" folder.

Global maps that need to show conformity (proper shape)
- *Mercator*
- *Miller Cylindrical*

Global maps that need to show equivalence (proper size)
- *Bonne*
- *Goode Homolosine*
- *Hammer-Aitoff*
- *Mollweide*
- *Sinusoidal*

Global maps that need to show compromise (a mix of shape and size)
- *Aitoff*
- *Robinson*
- *Van der Grinten I*
- *Winkel Triple*

For maps of a continent or large region, look in the specific folder (e.g. open "continental" folder, then the "Asia" folder) and look for the key words to determine which to choose:

- Equal area – refers to showing consistent sizes of places
- Conformal – refers to showing consistent shapes of places

Medium scale (country, state maps)

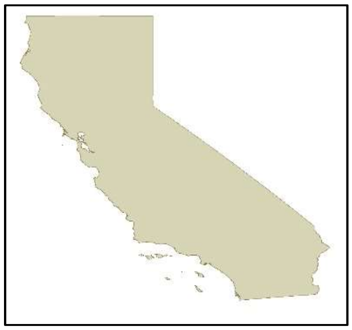
As the scale of a map gets larger (i.e. we zoom into the Earth), distortion becomes less of an issue. You can still use one of the above projections from the small scale section, or you can use a state or country's official projection and coordinate system. For example, the State of California uses the *NAD 1983 California (Teale) Albers* projection located in the State Systems folder.

Large scale (county, city, local maps)

Most county and city agencies use specific coordinate systems to ensure consistency across data and maps. If you are working for a government agency always check to see if there is a standard system you are using.

A safe choice in California is Universal Transverse Mercator (UTM) NAD 1983, Zone 10 or 11.

Remember…



Dumpy California (unprojected data)

Sexy California (Albers equal area conic projection)

Scale

Map scale refers to the ratio of the size of an object on the map to the size of that object in reality. Most people are familiar with a phrase like

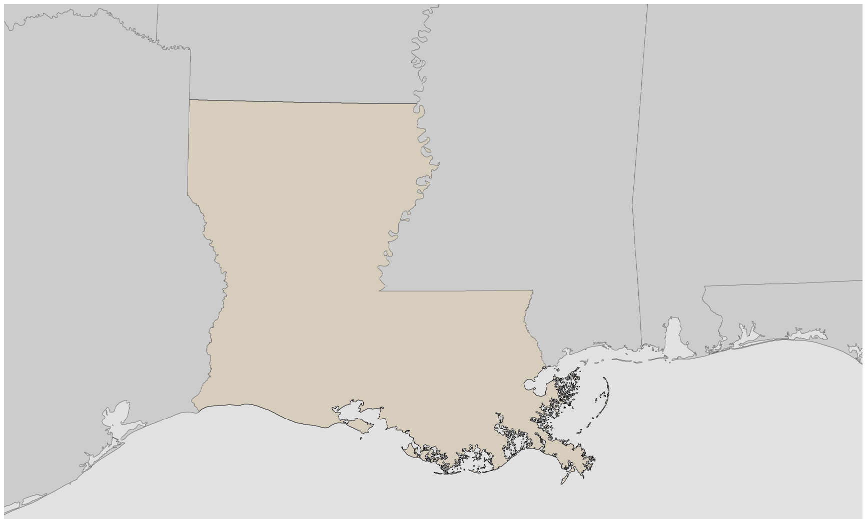
one inch equals one mile.

That can be a useful way to quickly envision a map's distance as it exists in reality. We call this a "verbal scale." The problem though is that such a scale isn't quite as useful for geographers and cartographers. A more useful expression would be

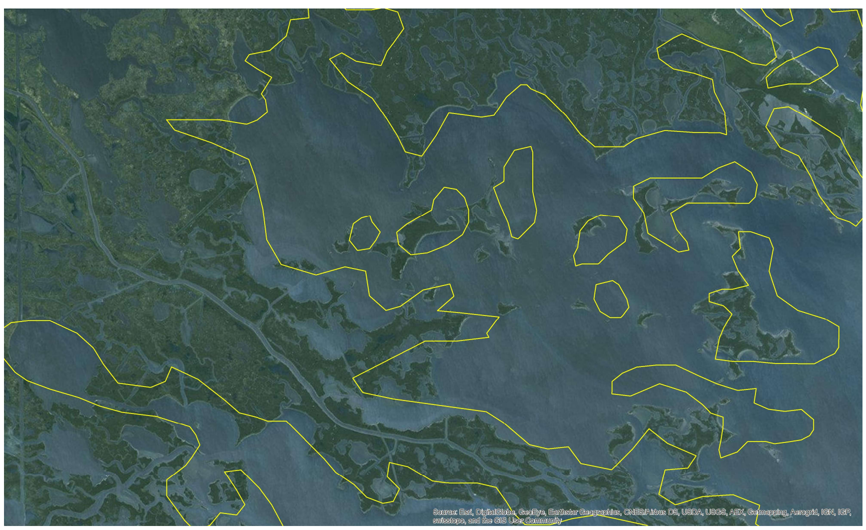
1:63,360

This is a ratio that says "one inch on the map equals 63,360 inches in reality." We call this the "fractional scale." That big number on the right is the total number of inches in one mile, but if you don't know that, envisioning 63,360 inches can be difficult. But here's what is cool. This ratio can be used with any units. In other words, we can also say of this map scale that one centimeter equals 63,360 centimeters. One foot on the map equals 63,360 feet in reality. The width of one of your fingers equals 63,360 of your finger-widths in reality. This allows for more flexibility with map scale and you should think of your maps using this fractional scale. Also, if you don't need to make a map at a specific scale, you should pick something that is nice and round. Zooming in and out of ArcMap can lead to weird looking scales, something like 1:839,598. Such a scale can just make for headaches later on, so always round to a number that is easier to use, yet doesn't really change the extent of the map. 1:840,000 or 1:839,600 would be better choices.

We tend to forget about scale since we can zoom in and out of digital maps. It would seem that we can change the map's scale to suit our needs. However, we should always be aware of the scale at which our map layers were drawn. Map data drawn to be used at a scale of 1:25,000 will be much more detailed than data drawn for a scale of 1:2,500,000. Using the 1:2,500,000 data, you could zoom to an extent of 1:25,000, but that doesn't make the data any better. Coastlines will be coarse and boundary lines will be fuzzy in their legal precision. At the same time, if you are making a map at a scale of 1:2,500,000, you don't want to use the 1:25,000 data assuming your map will be more accurate. All of that detail may actually make for a confusing map and could slow down your computer's processing abilities.



This map shows Louisiana at a scale of 1:3,000,000. Note the complexity of the Mississippi River's Delta (southeast of the state). At this scale, everything looks fine.



The same feature class of Louisiana, overlaid with aerial imagery for reference, and shown at a scale of 1:62,500. What was once a decent representation of the coastline is now a coarse, ugly map that is of little use.

Summary

One of the most crucial things to remember when not only making a map, but using one as well is that maps are representations of the Earth. In other words, they are not perfect copies of reality. A map is the result of many decisions made by the cartographer. Yes, GIS software has given us many powerful tools to make mapping easier and more dynamic, but we still need a fundamental grasp of the underlying concepts of geodesy and cartography. As you begin to make map products or analyze data you should always ask yourself if your final result makes sense based on the basic concepts outlined above. For example, if you are studying square mileage of deserts across the world are you using an equivalent projection? Are the data you are using drawn to a scale that makes sense for your analysis? Asking such questions will save you embarrassment and ensure that you are a GIS Professional rather than just somebody with a copy of Google Earth. You should also remember that we all feel that as we start studying this material, remembering this information seems terrifying. I always thought it would be impossible to grasp the differences in the hundreds of coordinate systems and projections out there. Then one day, it all just clicked. Stick with it, experiment, and don't be afraid to fail!

References and further reading

Robinson, A., J.L. Morrison, P.C. Muehrcke, A.J. Kimerling, S.C. Guptill. (1995) *Elements of Cartography*. (Hoboken, New Jersey: Wiley)