

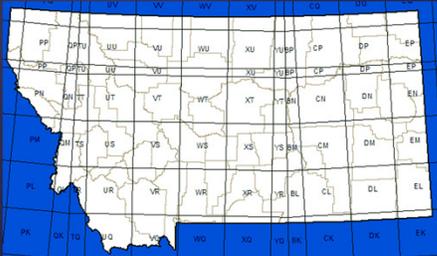
Map Projections and Coordinate Systems



Gerry Daumiller

Montana State Library
Geographic Information

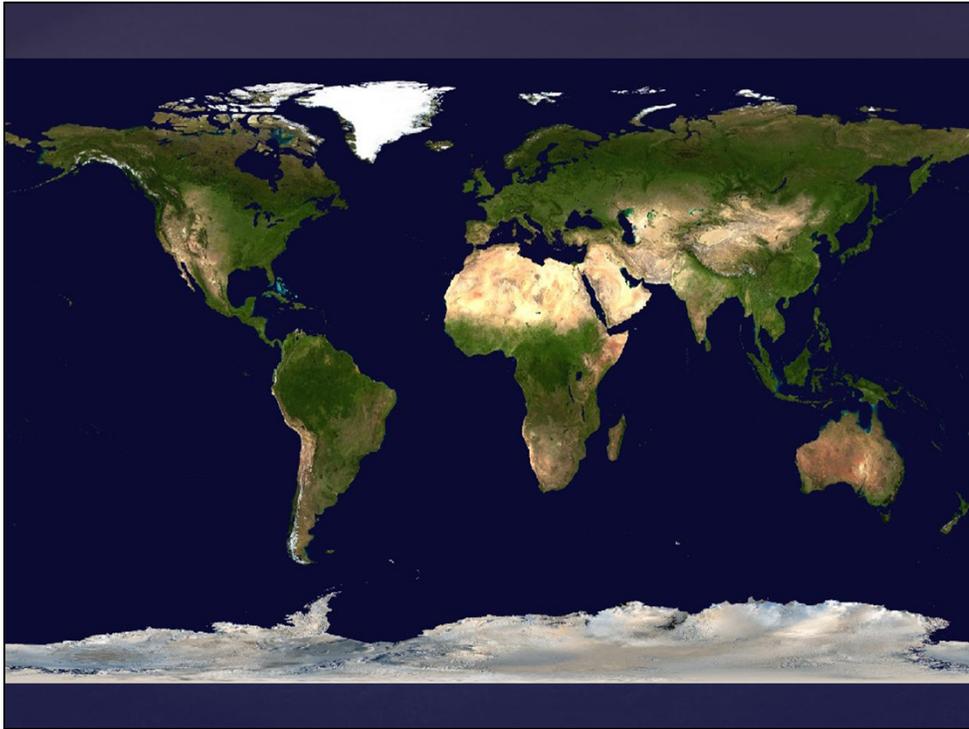
Please download this presentation and look at the Normal view to see explanations of the slides in the Notes





When you look at maps with an application like Google Earth and can see the world as a globe, it doesn't bother you that a place starts to look strange when you spin it away from the center of the map. Your brain interprets the two-dimensional image you are seeing as a three-dimensional object, and it knows that, on the right, Alaska is farther away from us and seen at an angle, and it should look smaller and distorted.

If you think about it, the image of Alaska on the left is also distorted. The middle of the state is closer to us than the Aleutian Islands or the panhandle, so the middle is bulging out towards us slightly. No matter how close you zoom in on one of these globes, the effect still exists, but it becomes more and more difficult to observe or measure. As soon as you stop seeing a globe in front of you, you forget that you are looking at a three dimensional object.



When you peel the skin from the globe and lay it out as a flat map, you can forget that a whole bunch of stretching has to be done, and that this is a representation of a 3-d object. You don't have many visual cues that tell you Antarctica isn't really ten times bigger than Australia.

Map projection is the process of controlling how the Earth's skin is stretched in order to make it lay flat.

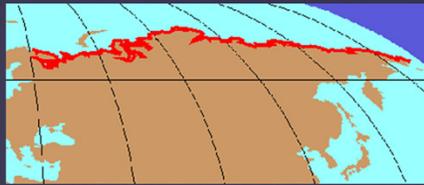
Map Projections

Why are they important?

An important thing to remember about map projections is that you can not generally measure distances and areas accurately from projected data. The next slides show some examples of this.

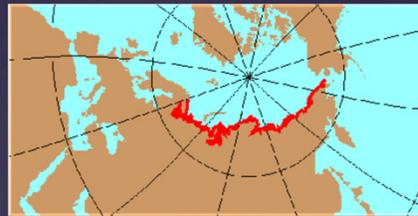
It would be possible for GIS and mapping applications to measure distances and areas using 3-dimensional geometry, but this is still very rare. When you make measurements with GIS, you should assume that the measurements are 2-dimensional and they have not been corrected to compensate for the errors created by the map projection.

Length Distortion on World Maps



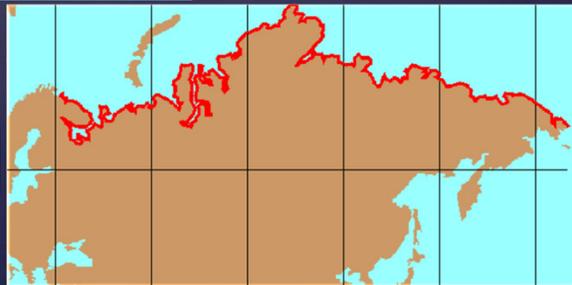
Robinson Projection -- 16,930 Miles

Length of the Arctic Coastline of
Russia



Oblique Mercator Projection --
10,473 Miles

Mercator Projection --
31,216 Miles



This was an actual question that someone called our office and asked us in the 1980s. The world data came with our GIS was in the Robinson projection, and I knew enough about projections to be wary of measuring such a long distance on a projected map.

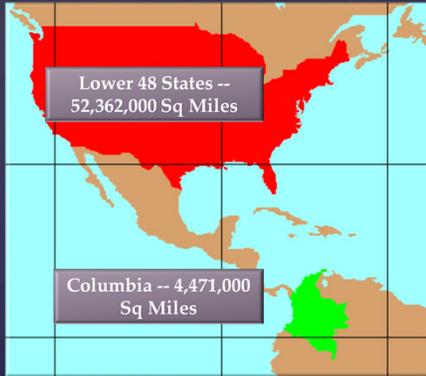
There are projections that preserve scale along certain lines or from certain points, but there is no such thing as a map where the scale is the same every place. As your area of interest becomes smaller, this problem decreases, but it always exists.

The Oblique Mercator projection can be customized to provide true scale on the line between any two points, so I used it on this and following slides to give me the true distance along the lines I wanted to measure.

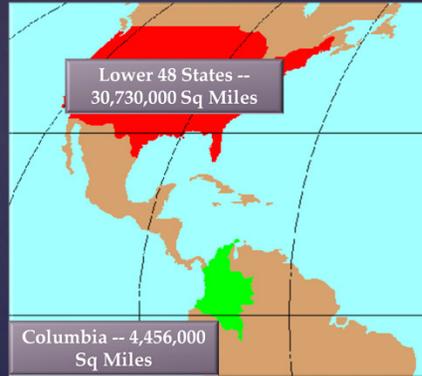
All of these maps were plotted at the same scale, as far as the GIS was concerned, but they are obviously all not at the same scale in northern Siberia.

Area Distortion on World Maps

Mercator Projection



Mollweide Projection
(equal-area)



You can't trust flat maps to give the correct lengths of lines, but there are projections that can show you the true area of regions.

Linear Distortion on National Maps



Albers Equal Area Projection --
2564.3 Miles



Oblique Mercator Projection --
2583.9 Miles

Difference = 19.6 Miles
One part in 132
0.76 Percent

When you look at a smaller area of the globe, distortion becomes less dramatic, but it still might be significant, depending on your accuracy needs.

Area Distortion on National Maps



Lambert Conformal Projection --
147,657 Square Miles



Albers Equal Area Projection --
148,993 Square Miles

Difference = 1336 Square Miles
One part in 111
0.90 Percent

This slide shows the area of Montana on two different coordinate systems. Neither of these is really the area of Montana, because the boundary of the state shown in the data used to make this map is not very accurate.

Linear Distortion on Local Maps

Montana State Plane Coordinates –
38,189.6 feet



Oblique Mercator Projection –
38,212.1 feet



Difference = 27.5 feet One part in 1742 0.0574 Percent

This is the distance between Carroll College and Bob's Valley Market. Even in coordinate systems used for large scale maps, the error is still potentially significant.

Area Distortion on Local Maps

Montana State Plane Coordinates --
122,314.3 Acres



Albers Equal Area Projection --
122,425.2 Acres

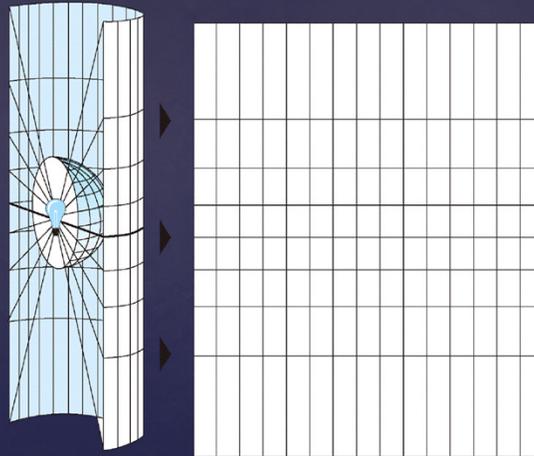


Difference = 110.9 Acres One part in 1104 0.091 Percent

This slide shows the area of Flathead Lake on two different coordinate systems.

Types of Map Projections

Cylindrical Projections

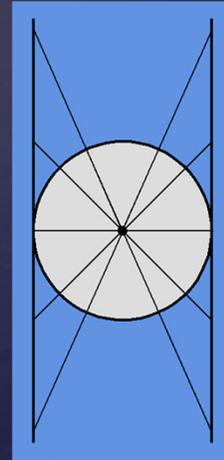
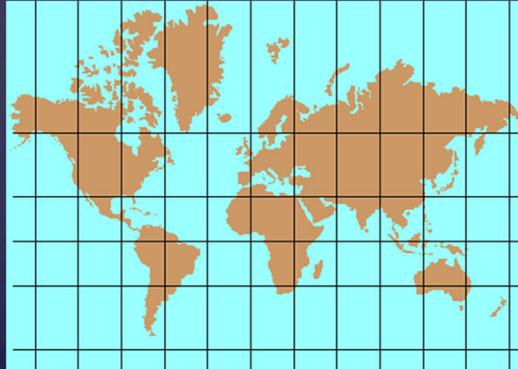


ESRI

Early projections, and most projections still used today, are based on models of what would happen if you projected light through a transparent globe onto a surface that could be laid out flat.

Types of Map Projections

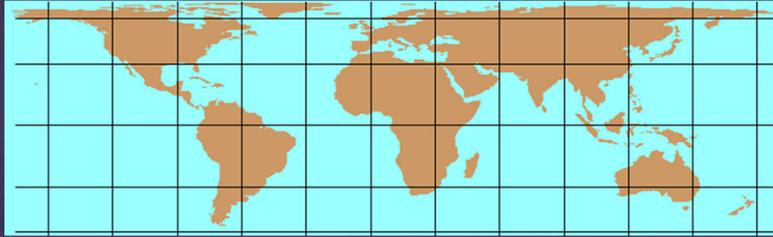
Mercator Projection



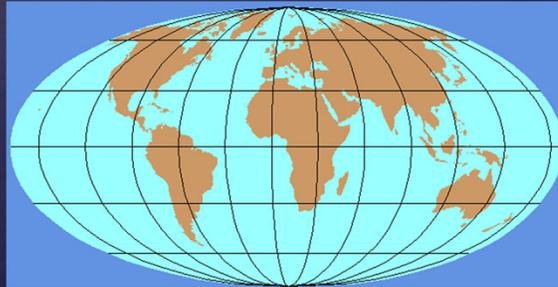
The continents are projected onto a cylinder by a light shining from the center of the earth. This is a conformal projection, and has the property that straight lines show the course you would follow if you maintained a constant compass heading.

Types of Map Projections

Cylindrical Equal-Area Projection



Mollweide Projection (equal-area, psuedo-cylindrical)

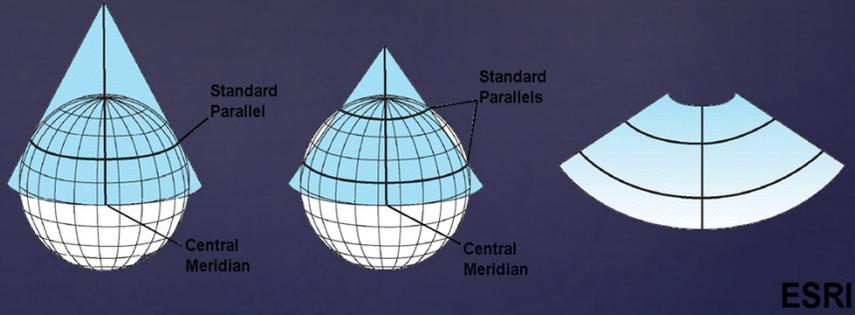


The Cylindrical Equal Area projection uses the same idea as the Miller projection, decreasing the spacing of the parallels as you move away from the equator to remove distortion of area. But this projection greatly distorts the shapes of northern and southern continents. The north-south scale in Alaska is so small that you probably couldn't plot Anchorage and Fairbanks as two separate dots.

The Mollweide projection is an attempt at making a more “natural” looking equal-area world map. The meridians are ellipses and the spacing of the meridians and parallels were chosen according to a formula that the author came up with in 1805. This is an example of the many projections that cannot be described by a physical model of light shining through the globe onto some kind of surface that you can flatten. It is called a psuedo-cylindrical projection because it looks more like a cylindrical projection than a planar or conic projection.

Types of Map Projections

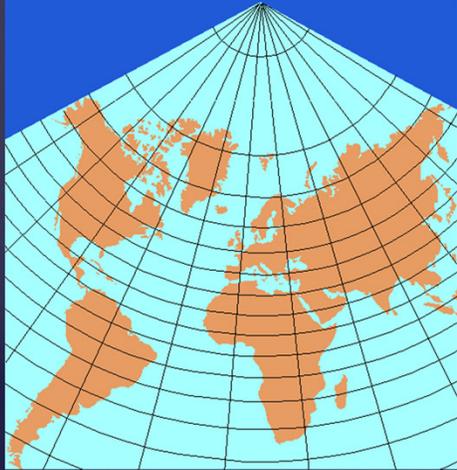
Conic Projections



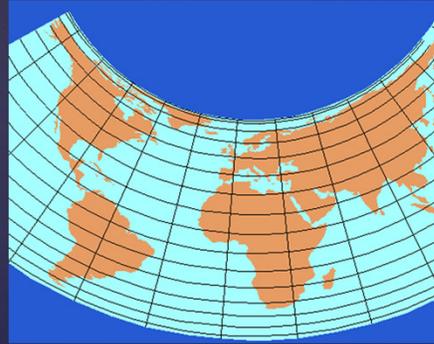
Types of Map Projections

Conic Projections

Lambert Conformal



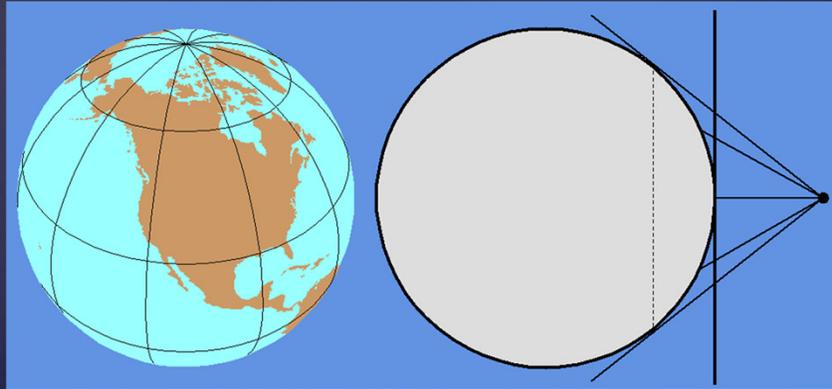
Albers Equal Area



The two most common conic projections in GIS are the Lambert Conformal and Albers Equal Area. For small areas, such as the Mediterranean Sea in the center of these images, they are visually almost identical. These images show that the spacing of the parallels in the Lambert projection increase as you move away from the standard parallels, while the parallel spacing decreases away from the standard parallels on the Albers projection.

Types of Map Projections

Perspective Projection



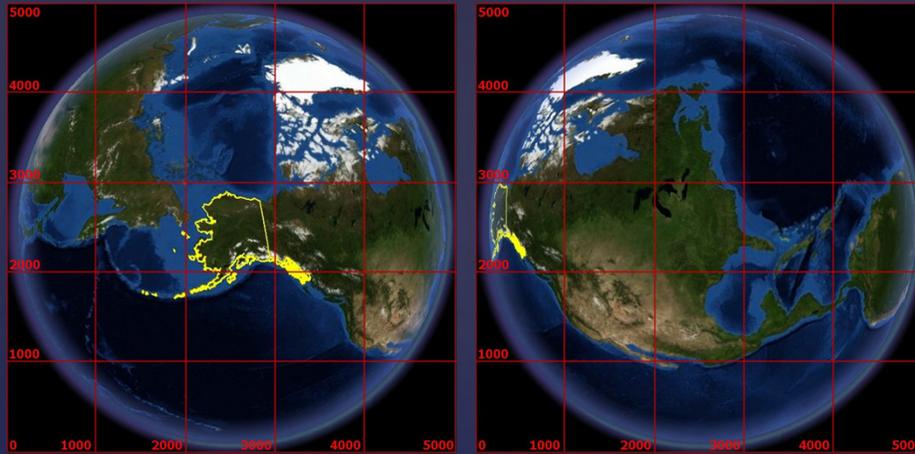
This projection shows what the earth would look like to someone in space. You specify the latitude and longitude of the point they are above and their height above the surface. It can never show more than half of the earth at one time.

Coordinate Systems vs. Map Projections

- A map projection is a method or a type of equation used to transform three-dimensional coordinates on the earth to two-dimensional coordinates on the map.
- A coordinate system usually includes the specification of a map projection, plus the three dimensional model of the Earth to be used, the distance units to be used on the map, and information about the relative positions of the two dimensional map and the model of the Earth.



Same map projection, two coordinate systems.



Look at our Google Earth views of the globe again. Both views use the same perspective map projection. A coordinate grid has been overlain on each map. Instead of measuring on the globe, we start measuring things with the grid, and you can see that the worlds seen on these two grids are totally different from each other.

On the left, the middle of Alaska is about 2500 miles “east” of the grid origin and 2500 miles “north”. On the left side, Alaska is still about 2500 miles “north” of the bottom of the grid, but it is only about 300 miles “east”. On the left side, Alaska is about 3000 miles wide and covers almost an entire 1000 mile square. On the right, it is only about 500 miles wide and covers less than a quarter of a square.

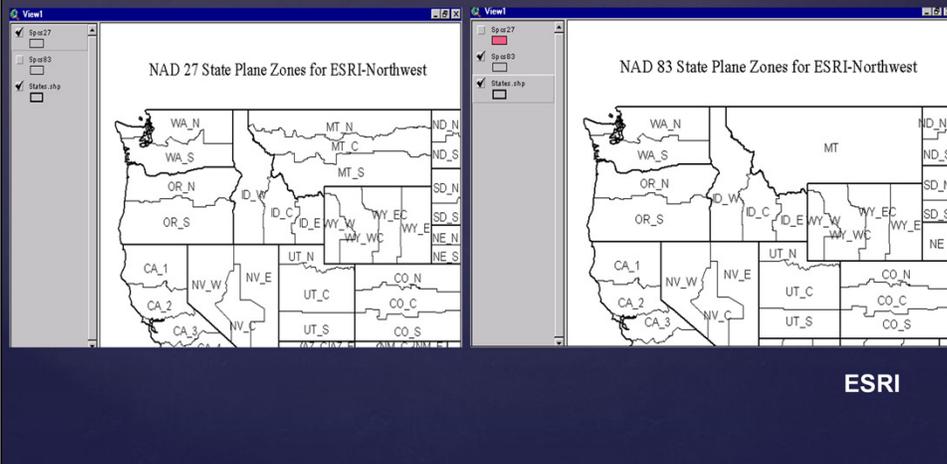
This slide also shows that the concepts of north, south, east, and west really can get messed up by a coordinate systems that use a map projection. On the left side, north is straight up in the middle of the map, but at the top center area oof the map, it is almost straight down.

Standardized Coordinate Systems

There are an infinite number of coordinate systems possible, which can be created by choosing a projection and then tailoring its parameters to fit any region on the globe.

Standardized coordinate systems have been developed to simplify the process of choosing a system. The two most common standard systems used in the United States are the State Plane Coordinate system and the Universal Transverse Mercator system.

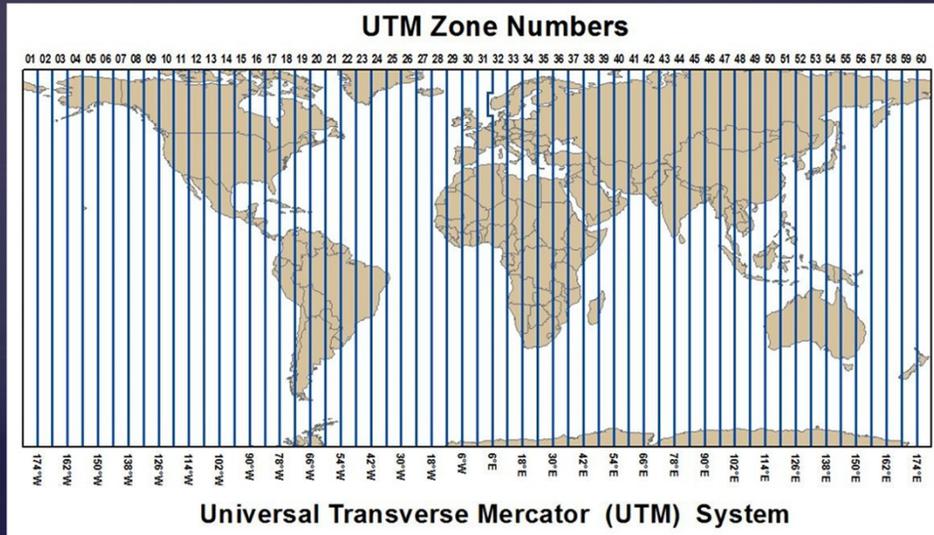
State Plane Coordinate Systems NAD27 & NAD83



When the State Plane coordinate system was first set up, the coordinate zones were designed to be small enough that you could measure distances within the zones and be accurate to within one part in 10,000.

With the advent of GIS, it is desirable to have a single coordinate system for each state, and it is easier now to have computers convert between ground measurements and measurements on the State Plane grids. This is why Montana now uses a single zone. Other states are starting to do this, also.

UTM



Choosing a Projection: Checking Accuracy

To find the true area of polygons, project them to an equal-area projection and recalculate their areas.

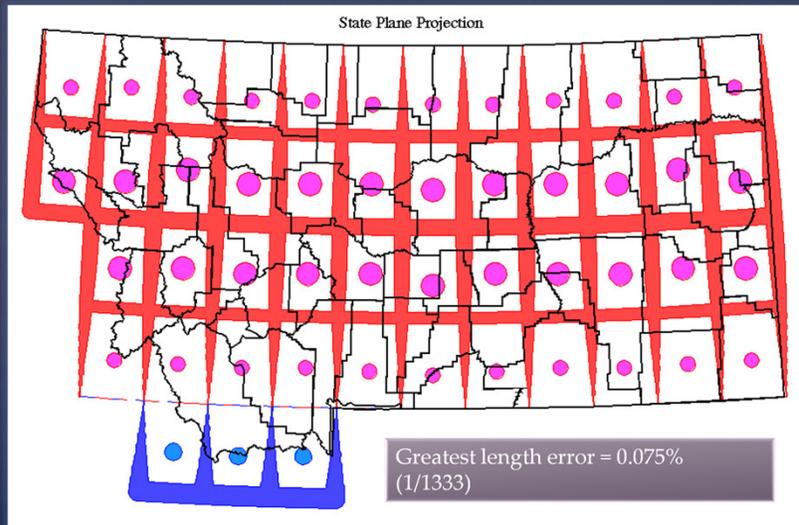
To find the true distance between two points, use http://www.ngs.noaa.gov/cgi-bin/Inv_Fwd/inverse.prl or the Geodesic distance option in the ArcMap measure tool

NRIS has an old AML program for making a coverage of 7.5-minute quadrangles with the errors for each arc and polygon figured as attributes. The formulas in this program only work for lengths along meridians and parallels. If you want me to run this and send you the data for any particular area, just let me know – gdaumiller@mt.gov. The following slides were created using the results of this program.

The NOAA web site for finding the distance between any two points uses a formula that I have not been able to find, but the Fortran code for the program can also be downloaded if you want to try to use it or read it to work out the formula for yourself.

Someday, all GIS should be sophisticated enough to use this formula to automatically report the true lengths and areas of its features.

Accuracy of Projections – State Plane Single Zone

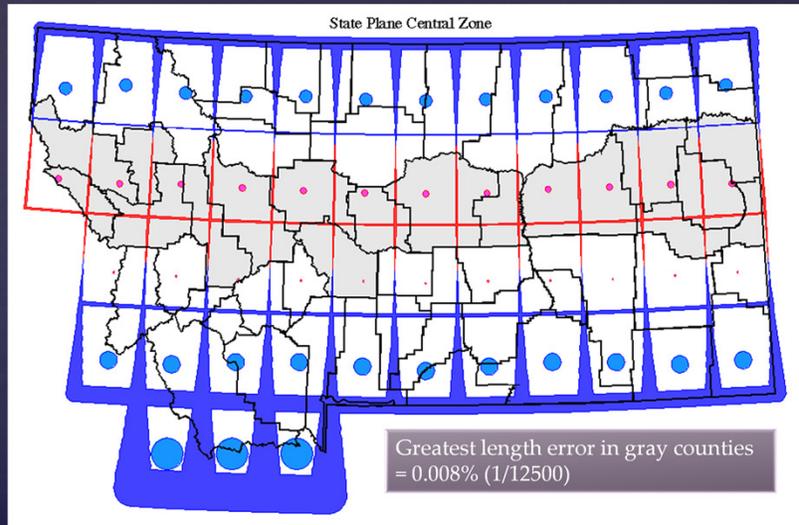


In this and the following slides, the width of the lines along the meridians and parallels shows the error in length measurement at the locations of the lines, and the size of the circles show the error in measuring area at the locations of the circles. Red or pink means the measurements on the coordinate grid are smaller than the measurements on the Earth, and blue means the grid measurements are too large.

The scale showing error is the same on this slide and the following ones.

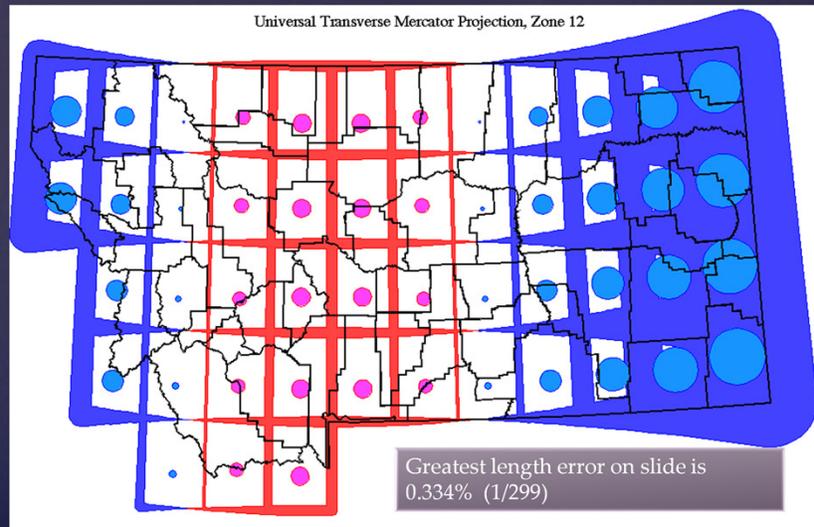
On this slide, the greatest error in length measurement in Montana is 0.075 percent (one part in 1333), and the greatest error in area measurement is 0.114 percent (1/877).

Accuracy of Projections – State Plane Central Zone



The greatest error **WITHIN THE CENTRAL ZONE** on this slide is 0.008% (1/12500) for length and 0.039% (1/2564) for area.

Accuracy of Projections – UTM Zone 12



The greatest error on this slide is 0.334% (1/299) for length and 0.554% (1/180) for area.

The Web Mercator Projection



Web sites and web services that are designed to let you zoom in close to any place in the world use the Web Mercator projection. The main reasons for this are: 1 – North is always straight up, and 2 – at any point, the scale is always the same in every direction, and this makes the shapes of small areas look correct.

But the Mercator projection has terrible trouble with the scale getting larger as you move away from the equator. If you add a web service that uses the Web Mercator projection to an empty ArcMap project, ArcMap will use the Web Mercator Projection and it will not understand that the scale is different in different parts of the world.

The Web Mercator Projection

ArcMap 10.2

Google Maps



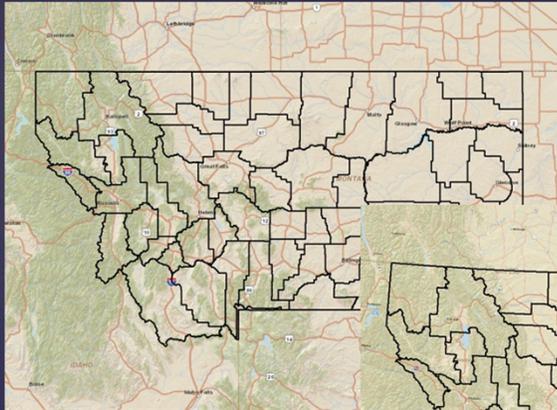
Static Scalebar

Dynamic Scalebar

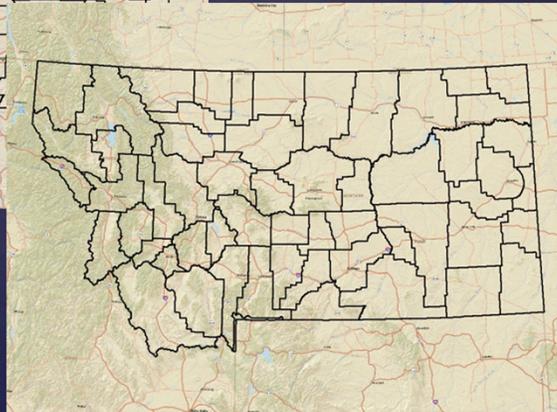
Most Web mapping applications understand the scale problems with the Web Mercator projection and they automatically adjust the map scale to something relatively accurate for the area you have zoomed into. The maps on the right are screen captures of Brazil and of Montana from a web map application. I panned the view all the way from the Equator to Fort Peck Lake without changing the zoom level. As you move north, the scalebar gets shorter and shorter.

I did the same thing in ArcGIS Desktop on the left, and the scalebar remains the same length. Most desktop GIS software assumes the scale is the same everywhere on the map, even though it isn't.

The Web Mercator Projection

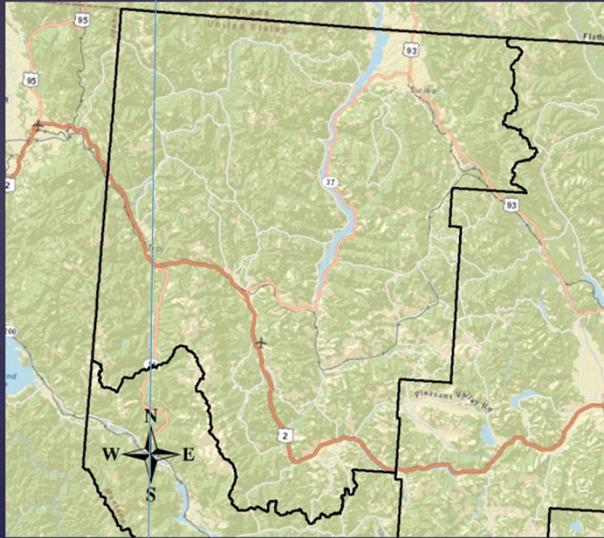


Web Mercator – North end of Montana looks pulled apart to me.



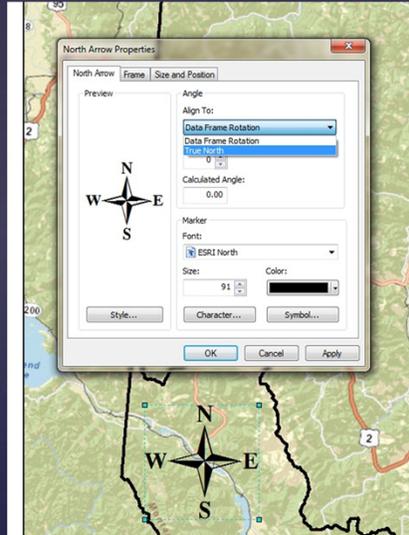
State Plane – Meridians correctly converge towards the North Pole

North is Which Direction?



Now we have zoomed in to the upper left section of the State Plane map from the previous slide and used ArcMap to add a north arrow. It does not point north, because north is different directions in different locations in the State Plane coordinate system.

North is Which Direction?



ArcMap has a tool for correcting the north arrow.

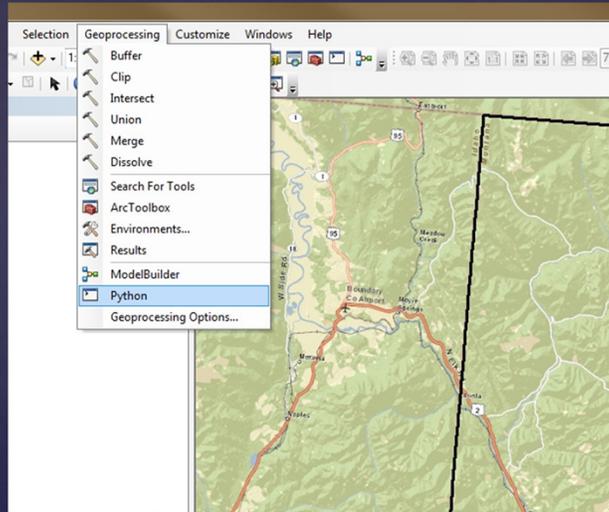
North is Which Direction?



The corrected arrow.

Most people want north to be straight up on their maps. In ArcMap you can *rotate the Data Frame* to any angle you desire. I've written a script to rotate the frame to make north, in the center of the map, straight up and down.

North is Which Direction?



This shows how to open the Python processing window so that you can run the script.

Python Script for True North

```
# Rotate Data Frame so that True North is straight up.
import arcpy, os, math

# Find the current map view and get its extent
mxd = arcpy.mapping.MapDocument("current")
df = mxd.activeDataFrame

# Figure the latitude and longitude of the top center of the map
mapRef = df.spatialReference
geoRef = arcpy.SpatialReference(4269)
ptTopY = df.extent.YMax
ptTopX = (df.extent.XMin + df.extent.XMax)/2
ptTop = arcpy.PointGeometry(arcpy.Point(ptTopX, ptTopY), mapRef)

# Project to geographic coordinates
ptTop = ptTop.projectAs(geoRef)

# Find the projected map coordinate 0.5 degrees of latitude south of the top center
ptBtmX = ptTop.centroid.X
ptBtmY = ptTop.centroid.Y - 0.5
ptBtm = arcpy.PointGeometry(arcpy.Point(ptBtmX, ptBtmY), geoRef)

# Project back to map coordinates
ptTop = ptTop.projectAs(mapRef)
ptBtm = ptBtm.projectAs(mapRef)

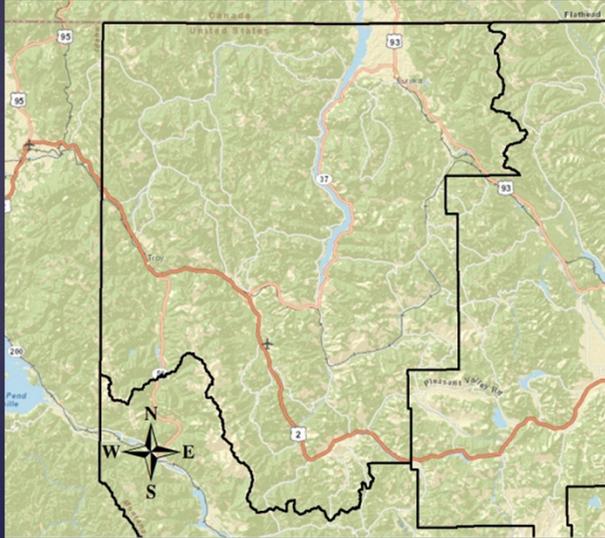
# Figure the angle between the top of the map and the point 0.5 degrees south of it
dX = ptBtm.centroid.X - ptTop.centroid.X
dY = ptBtm.centroid.Y - ptTop.centroid.Y
rAngle = math.atan(dX / dY) * 180 / 3.1415926
print rAngle

# Rotate the map to make north straight up and down
df.rotation = rAngle

# Refresh
arcpy.RefreshActiveView()
```

Copy the small text from here and paste it into the Geoprocessing window. Press return twice and the script should run.

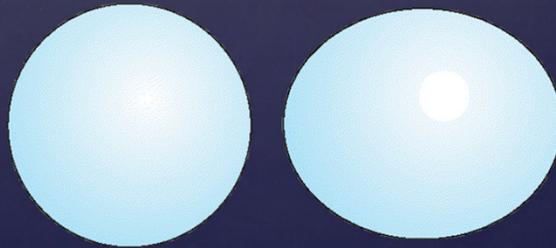
North is Which Direction?



The data frame has been rotated so that north is straight up.

Spheroids

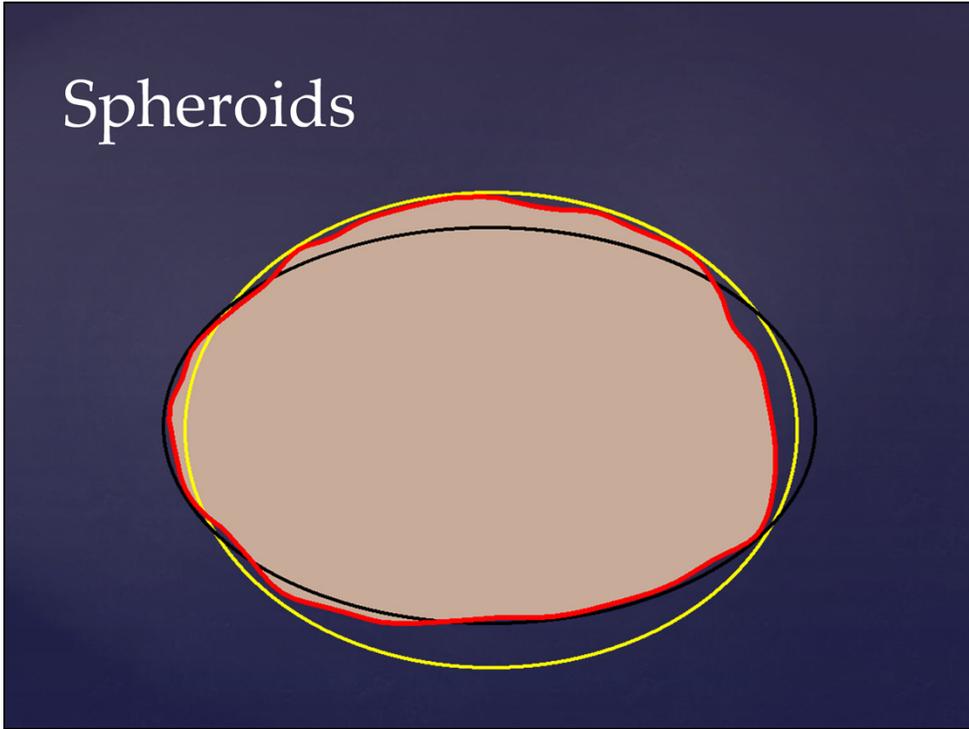
- Set of parameters that represent a model of the earth's size and shape
- Based on an ellipse with 2 radii
 - Semimajor axis (longer) and the semiminor (shorter)



Spheroids

- The Earth is not a perfect spheroid.
- Different spheroids are used in different parts of the world to create the best possible model of the Earth's curvature in each location.

Spheroids



In this image, the brown figure with the red boundary represents the true sea-level surface of the Earth, and there is a black ellipsoid and a yellow ellipsoid. Each ellipsoid is better than the other for certain parts of the Earth, and there are places where neither ellipsoid is very good.

Datums

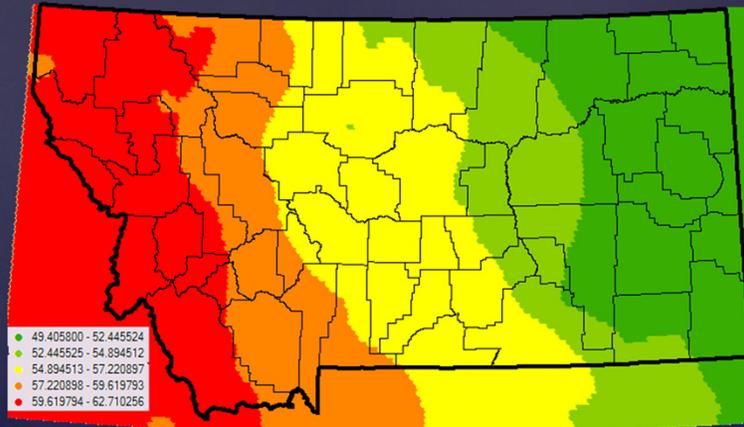
- A Datum is a spheroid, plus the definition of the relationship between the Earth and the coordinates on the spheroid.

Datums

- There are four datums commonly used in Montana: NAD27, WGS84, NAD83, and NAD83 HARN. The latitude and longitude of a point on the ground is different in each datum.

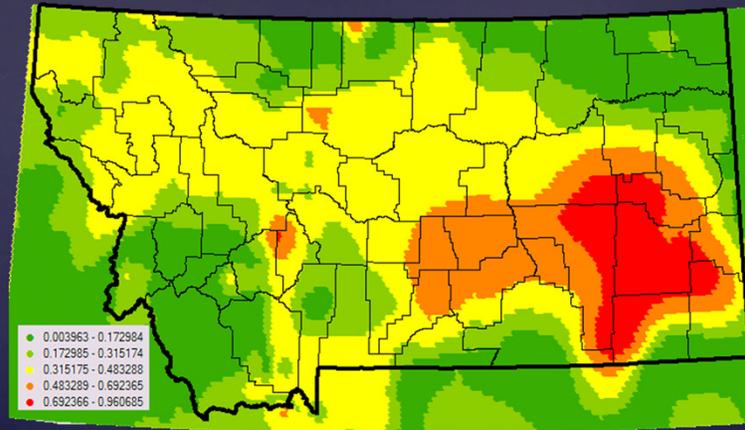
Datums

Difference (meters) between NAD27 and NAD83



Datums

Difference (meters) between NAD83 and NAD83 HARN



Using Datums Correctly in ArcMap

Data Frame Properties

Feature Cache | Annotation Groups | Extent Indicators | **Coordinate System** | Frame | Size and Position

General | **Data Frame** | Illumination | Grids

Type here to search

- Geographic Coordinate Systems
- Projected Coordinate Systems
 - ARC (equal arc-second)
 - Continental
 - County Systems
 - Gauss Kruger
 - National Grids
 - Polar
 - State Plane
 - NAD_1983_HARN (Meters)

Current coordinate system:
NAD_1983_StatePlane_Montana_FIPS_2500
WKID: 32100 Authority: EPSG

Projection: Lambert_Conformal_Conic
False_Easting: 600000.0
False_Northing: 0.0
Central_Meridian: -109.5
Standard_Parallel_1: 45.0
Standard_Parallel_2: 49.0
Latitude_Of_Origin: 44.25
Linear Unit: Meter (1.0)

Transformations...

OK Cancel Apply

State Plane

- NAD 1927 (US Feet)
- NAD 1983 (CORS96) (Intl Feet)
- NAD 1983 (CORS96) (Meters)
- NAD 1983 (CORS96) (US Feet)
- NAD 1983 (Intl Feet)
- NAD 1983 (Meters)
- NAD 1983 (US Feet)
- NAD 1983 HARN (Intl Feet)
- NAD 1983 HARN (Meters)
- NAD 1983 HARN (US Feet)
- NAD 1983 NSRS2007 (Intl Feet)
- NAD 1983 NSRS2007 (Meters)
- NAD 1983 NSRS2007 (US Feet)
- Other GCS
- State Systems
- UTM

NAD 1983 NSRS2007 StatePlane Missouri Central FIPS 2401

NAD 1983 NSRS2007 StatePlane Missouri East FIPS 2401

NAD 1983 NSRS2007 StatePlane Missouri West FIPS 2401

NAD 1983 NSRS2007 StatePlane Montana FIPS 2500 (Meters)

NAD 1983 NSRS2007 StatePlane Nebraska FIPS 2600 (Meters)

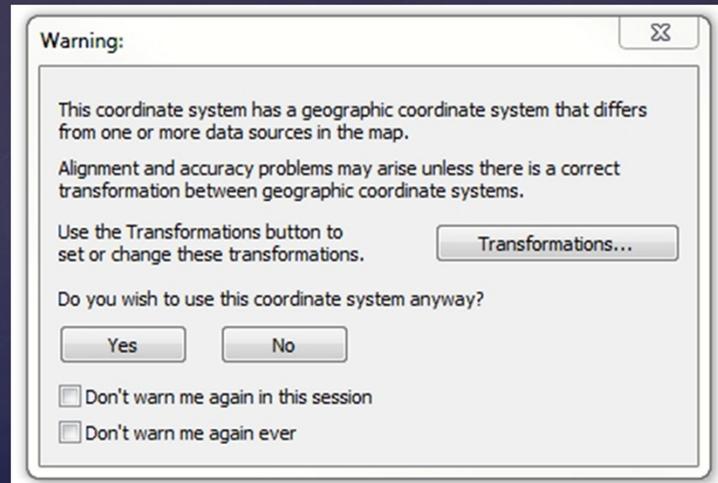
NAD 1983 NSRS2007 StatePlane Nevada Central FIPS 2701 (Meters)

NAD 1983 NSRS2007 StatePlane Nevada East FIPS 2701 (Meters)

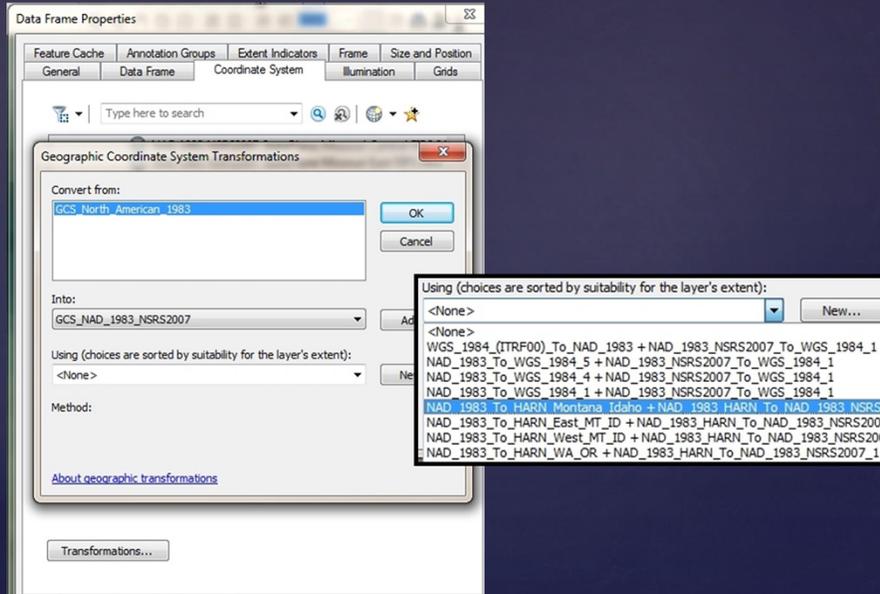
NAD 1983 NSRS2007 StatePlane Nevada West FIPS 2703 (Meters)

NAD 1983 NSRS2007 StatePlane New Hampshire FIPS 2901 (Meters)

Using Datums Correctly in ArcMap

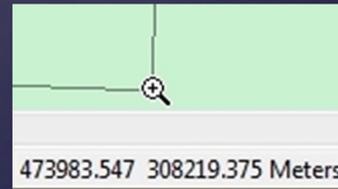
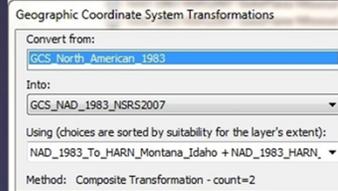
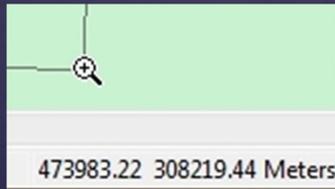


Using Datums Correctly in ArcMap



Using Datums Correctly in ArcMap

No Transformation



Distance = 0.353 m (1' 1.9")