Geospatial Problem Solving

Datums and Projections

Image from NASA:
https://commons.wikimedia.org/wiki/File:Earth_Western_Hemisphere_transparent_background.png#filelinks

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In this module we will discuss datums and projections.

Module Topics

1. Geodesy and the shape of the Earth
2. Geographic coordinate systems
3. Latitude and longitude
4. Projected coordinate systems
5. Projections for global, continental, and more local scales
6. Projection transformations

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These are the topics covered in this module.

Shape of the Earth

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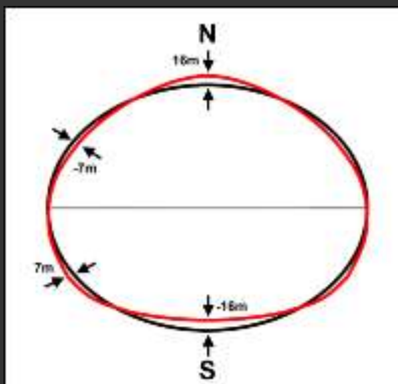
Geodesy



https://commons.wikimedia.org/wiki/File:Geoundnsrp.png

- Science of measuring Earth's shape

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All spatial data must be referenced to the surface of the Earth so that they draw at the correct location in the map space. This means that we need models of the Earth to which we can reference maps and data.

This is a component of the science of geodesy, which relates to measuring the Earth's shape and positions on it.

Shape of Earth

- Oblate spheroid
- Equator has larger circumference than meridians
- Mass not evenly distributed

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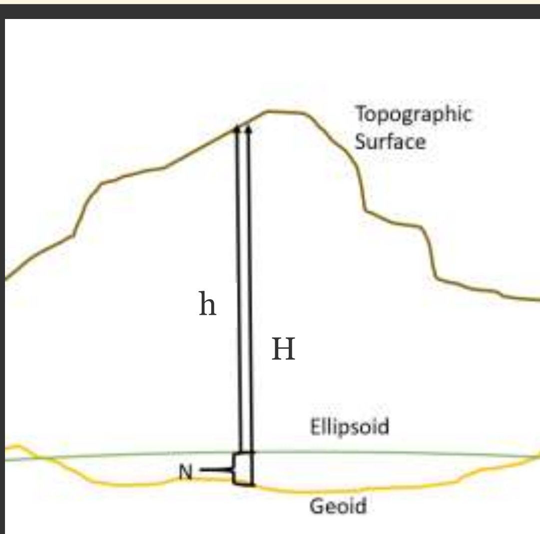
To begin, the Earth is not a perfect sphere. Instead, it is an oblate spheroid. It is wider than it is tall: the circumference of the equator is longer than the circumference of the prime meridian or any meridian.

This results from the centrifugal forces arising from the planet's rotation, especially as it cooled from a molten state. Further, mass is not evenly distributed throughout the Earth.

So, the Earth is actually a fairly irregular shape, which results in complexity in regards to producing reference systems by which to reference our maps and data against it.

Modeling the Earth



True Earth surface

Geoid

Ellipsoid

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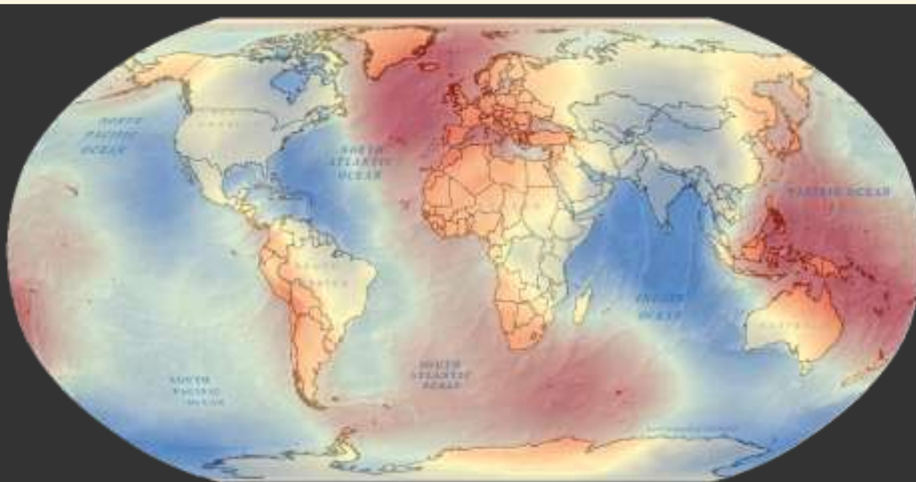
In order to model the Earth, simplification is required.

The true Earth surface needs to be generalized. It can be generalized to a geoid or an ellipsoid.

We will explore these concepts now.

The Geoid



Gravitational model from the US National Geospatial-Intelligence Agency (NGA) EGM Development Team

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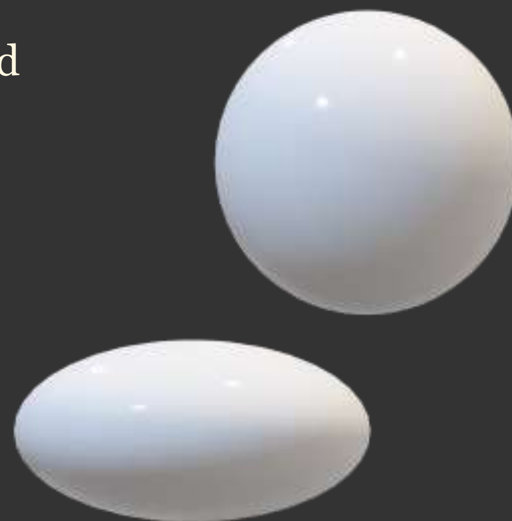
The geoid is a model of Earth's gravity field that accounts for the fact that mass is not distributed uniformly throughout the planet. Because Earth's internal density, topography, and other mass variations are uneven, gravitational attraction varies slightly from place-to-place.

One way to conceptualize the geoid is to imagine Earth covered entirely by ocean, with no continents, waves, tides, winds, or currents. The water surface would settle into a smooth but irregular shape controlled by gravity and Earth's rotation. This surface would not form a perfect sphere or ellipsoid; instead, it would gently undulate because gravity varies across the globe.

This smoothly undulating reference surface is called the geoid. It is commonly used as a reference for mean sea level and for defining elevations, or heights above sea level.

We need a mathematically simple model of the Earth's surface

- We use an ellipsoid/spheroid
- There are different ellipsoids/spheroids used
- We call these datums



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The geoid is a complex, smoothly undulating surface that reflects variations in Earth's gravity field. Because this surface is irregular, it cannot be represented easily using a simple mathematical equation. For many mapping and positioning applications, Earth's shape is instead approximated using an ellipsoid, or spheroid.

An ellipsoid is a smooth mathematical model of Earth's general shape. It is similar to a sphere, but slightly flattened at the poles and wider at the equator. This provides a simpler reference surface that can be described mathematically and used for coordinate calculations.

When an ellipsoid is combined with additional information about its size, orientation, position relative to Earth, and sometimes control points from ground surveys, it forms part of a geodetic datum. A datum provides the reference framework used to define coordinates and represent locations on Earth's surface.

Most maps and geospatial datasets are referenced to a specific datum, such as NAD83 or WGS84, which determines how coordinates relate to the real Earth.

Here is a note on oblate spheroids:

An ellipsoid is the broader term. It means a 3D shape whose cross-sections are ellipses. It can have three different axis lengths:

$$a \neq b \neq c$$

So, an ellipsoid can be stretched differently in the x, y, and z directions.

An oblate spheroid is a specific type of ellipsoid. It is formed by rotating an ellipse around its shorter axis. It has two equal horizontal axes and one shorter vertical axis:

$$a = b > c$$

This makes it look like a slightly flattened sphere: wider at the equator and compressed at the poles.

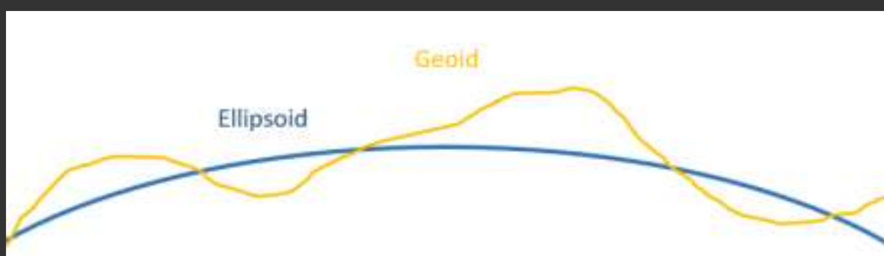
For Earth, the reference shape is usually described as an oblate spheroid or oblate ellipsoid because Earth is approximately flattened at the poles and bulged at the equator.

So, the relationship is: All oblate spheroids are ellipsoids, but not all ellipsoids are oblate spheroids.

In geodesy, people often use ellipsoid as the general term for Earth's mathematical reference surface, even though the specific shape is usually an oblate spheroid.

Datums

- The Earth is not perfectly round! It is an oblate spheroid
- Geoid = Accounts for the fact that the gravitational force differs over the Earth. Models Earth as a bumpy surface
- Ellipsoid (Oblate Spheroid) = Earth surface modelled as an oblate spheroid



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To summarize, the Earth is not perfectly round or spherical. It is an oblate spheroid that is wider than it is tall. Further, mass is not evenly distributed across the globe, which impacts the force of gravity. This is modeled as a smoothly undulating surface called a geoid.

In contrast, an ellipsoid or oblate spheroid is a simpler model of the Earth can be approximated using a mathematical equation.

An ellipsoid/oblate spheroid is combined with ground survey measurements to create a datum. Datums serve as models of the Earth. We reference our maps and geospatial data to one of these surfaces.

A fully defined datum requires:

1. Reference surface = oblate spheroid/ellipsoid
2. Terrestrial reference frame = realization of a datum using a network of precise positional measurements

A fully defined datum requires both an ellipsoid/oblate spheroid and a terrestrial reference frame.

The terrestrial reference frame is a set of ground survey measurements that help to tie the ellipsoid to the Earth's surface.

Datums

- There are different models:
  - NAD27 = North American Datum of 1927
  - NAD83 = North American Datum of 1983
  - WGS84 = World Geodetic System of 1984
- Think of these as different mathematical representations of the Earth

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There are different datums by which we reference our horizontal measurements or coordinates on the Earth.

Examples include the North American Datum of 1927 (NAD27), the North American Datum of 1983 (NAD83), and the World Geodetic System of 1984 (or WGS83).

In North America, it is common to reference data against NAD83 or WGS84.

Global Navigation Satellite Systems, or GNSS, often make use of WGS84 as a worldwide datum.

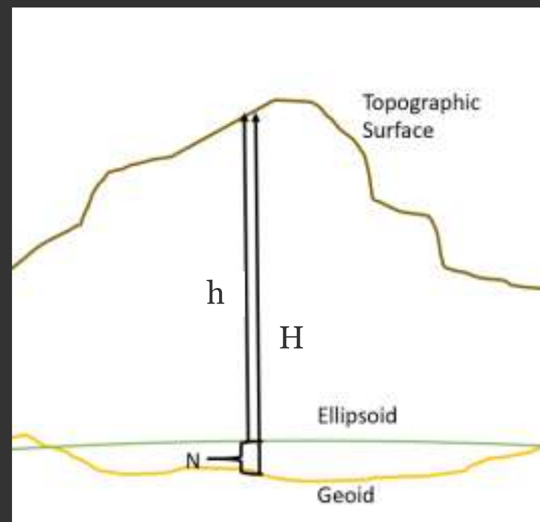
Again, think of these as different models of the Earth, all of which are simplifications.

Vertical Datums

- Orthometric Height (H) = height above geoid
- Ellipsoidal Height (h) = height above ellipsoid
- N: difference between ellipsoidal and orthometric heights

$$h = H + N$$

$$H = h - N$$



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There are separate vertical datums that height or elevation measurements are referenced to.

Further, elevations can be referenced against an ellipsoid model of the Earth or a geoid model.

Elevations referenced to a geoid are called orthometric heights whereas those referenced against an ellipsoid are called ellipsoidal heights.

N represents the difference between the orthometric and ellipsoidal heights at a location.

N varies based on the location on the Earth and the orthometric and ellipsoidal models used. Sometimes the ellipsoidal height is higher than the orthometric height and sometimes the orthometric height is higher.

When comparing elevation measurements, you should make sure that either orthometric or ellipsoidal heights are used for all surfaces so that this difference does not invalidate the comparison.

Common Vertical Datums

- National Geodetic Vertical Datum of 1929 (NGVD29)
- North American Vertical Datum of 1988 (NAVD88)

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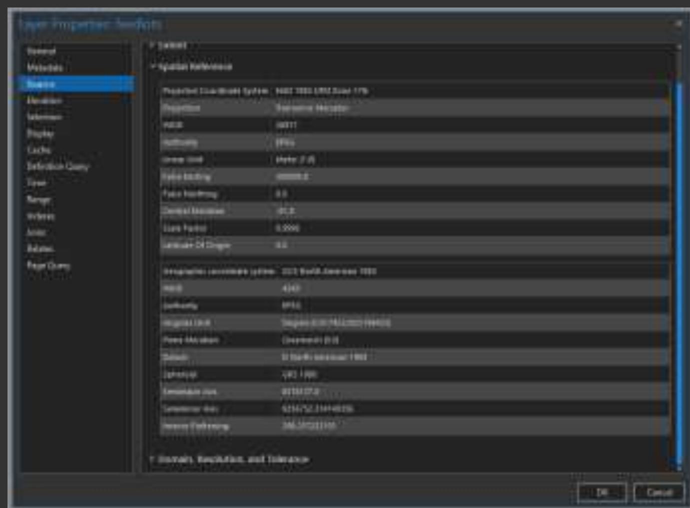
Example vertical datums in North America include the National Geodetic Vertical Datum of 1929 (NGVD29) and the more recent North American Vertical Datum of 1988 (NAVD88).

As technologies advance, updated versions of horizontal and vertical datums will be released.

Datum/Projection Info in ArcGIS



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Datum and sometimes projection information are associated with maps and geospatial data layers.

In ArcGIS Pro, datum and projection information for a layer can be found in the Source tab.

We will talk about projections later in this module.

Datum Transformations

- Differences between legacy datums (NAD27) and more modern datums (NAD83) can be substantial (10s to 100s of meters)
- Differences between modern datums are less substantial (meters)

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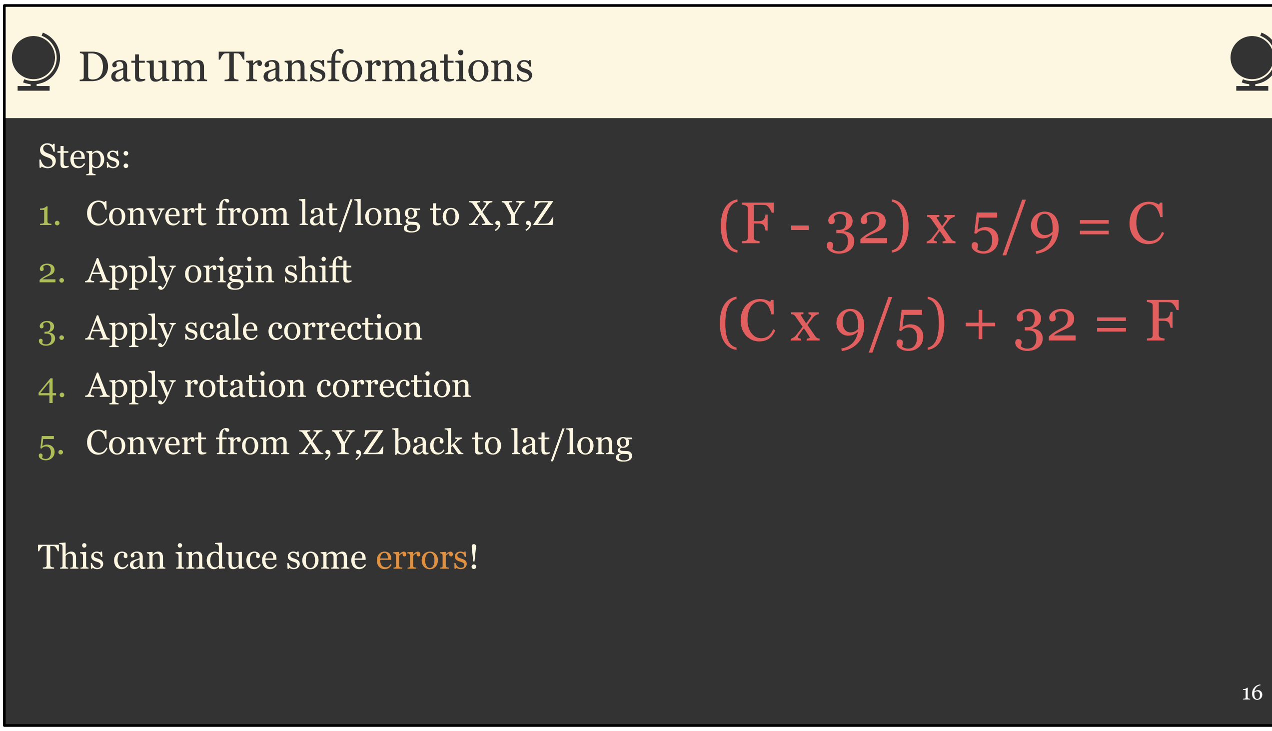
Spatial references for data layers can be converted from one datum to another using mathematical transformations.

Generally, differences between legacy datums (e.g., NAD27) and more modern datums (e.g., NAD83) can be substantial (on the order of 10s to 100s of meters).

In contrast, difference between modern datums are generally less substantial (on the order of meters or less).



Transforming datums involve multiple steps.

First, angular measurements, as latitude and longitude, must be converted to x, y, z space.

Next an origin shift will be applied. This is similar to subtracting or adding 32 when converting between Fahrenheit and Celsius temperature measurements. This is an adjustment that compensates for the fact that the measurements do not start or begin at the same location.

Scale correction must then be applied. This is analogous to multiply by 5/9 or 9/5 when converting between Fahrenheit and Celsius temperature measurements.

Next a rotation must be applied to compensate for different orientations.

Lastly, the data are converted back to latitude and longitude measurements.

Note that this transformation process can induce some errors since exact mathematical relationships do not always exist between different datums.

Best Practices

- Assume data transformation will cause positional errors/inaccuracies
- You should not mix datums
- If necessary, convert all datasets to same coordinate system/datum

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It is best to assume that any datum transformation will cause positional errors or inaccuracies.

However, it is generally best to not use data with different projections, especially if you plan to perform spatial analysis.

So, if necessary, it is best to convert all datasets to the same projection if they are going to be used together or compared.

Geographic Coordinate Systems

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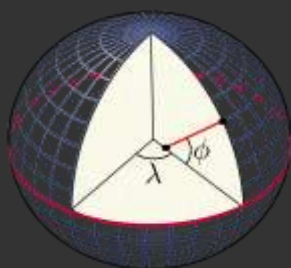
Coordinates on a Sphere

- ❖Latitude and Longitude
- ❖Specified as angles or degrees



https://commons.wikimedia.org/wiki/File:Latitude_and_longitude_graticule_on_an_ellipsoid.svg

Image from ArcGIS API for JavaScript

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Coordinates on Earth are measured in degree units relative to the center of the Earth.

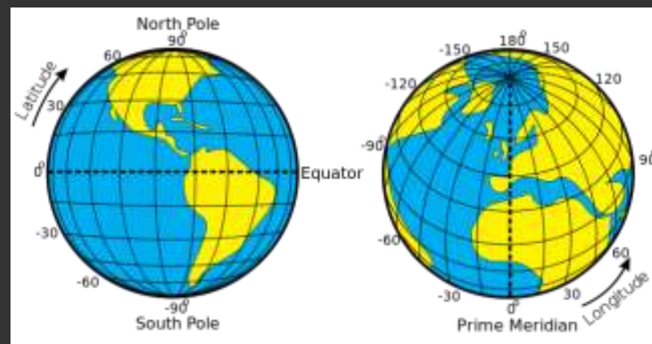
Latitude is measured as an angle of rise relative to the center of the Earth while longitude represents angles of rotation around the center of the Earth.

Note that it is not easy to make measures of distance using lengths on a spherical surface.

Geographic Coordinate Systems (GCS)

Latitude (Parallels)
- Measures north to south
- 90° in each hemisphere
- Increases as you go north in the northern hemisphere
- Increases as you go south in the southern hemisphere
- Zero is Equator

Longitude (Meridians)
- Measures east to west
- 180° in each hemisphere
- Increases as you go east in the eastern hemisphere
- Increases as you go west in the western hemisphere
- Zero is Prime Meridian



https://commons.wikimedia.org/wiki/File:Latitude_and_Longitude_of_the_Earth.svg

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Latitude measures north-to-south or up-and-down. There are 90° of latitude in each hemisphere. The value increases as you move north or south relative to the equator. The equator has a latitude of 0° and the poles have a latitude of 90°.

Longitude measures east-to-west or side-to-side. There are 180° of longitude in each hemisphere (east and west). Longitude increases as you move west in the western hemisphere and increases as you move east in the eastern hemisphere. 0° longitude is refined relative to the prime meridian which passes through Greenwich, England.

It makes sense to use the equator to represent 0° latitude. The 0° reference for longitude is somewhat arbitrary.

We can specify the northern or southern hemispheres for latitude by including an "N" or "S" with the measurements. For longitude, we can use "E" or "W". In software, this can be problematic due to the mix of numbers and letters. So, instead we tend to use positive angles to represent the northern or eastern hemispheres and negative angles to represent the southern or western hemispheres.

Coordinates referenced to a datum representing the 3D Earth or globe are known as geographic coordinate systems as opposed to projected coordinate systems, which will be discussed later.

Geographic Coordinate Systems (GCS)

- 1 Degree = 60 Minutes = 3,600 Seconds

- ° = Degrees
- ‘ = Minutes
- “ = Seconds

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One degree of latitude or longitude can be a large distance. So, in order to provide precise measurements, we need to be able to further divide degrees into smaller units.

A degree can be divided into minutes and second, similar to an hour on a clock. 1 degree equals 60 minutes or 3600 seconds.

We can also use decimal degrees as opposed to minutes and seconds. It is possible to convert between degrees, minutes, and seconds and degrees and decimal degrees.

The Globe

Advantages

- Accurate representation
- Latitude and longitude lines

Disadvantages

- Expensive to make
- Cumbersome to handle and store
- Difficult to measure
- Not fully visible at one view

Image from ArcGIS API for JavaScript

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There are some advantages to modeling the Earth as a 3D globe. First, this is an accurate representation in which map features and latitude and longitude lines can be plotted without distortion.

However, there are some disadvantages. Making globes can be expensive. They are also cumbersome to handle and store. It is also not easy to make distance measurements on the curved surface of the globe. Due to the 3D nature of a globe, it is not possible to view the entirety of Earth's surface from a single vantage point.

So, we need a means by which to represent the curved, 3D Earth in a flat map space. We do this using projections, which we will discuss next.

Time Zones

https://commons.wikimedia.org/wiki/File:World_Time_Zones_Map.png

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Before moving on to projections, I will make a quick note on time zones.

The Earth is broken into time zones based on longitude, the rotation of the Earth, and political boundaries as represented in this graphic.

Projected Coordinate Systems

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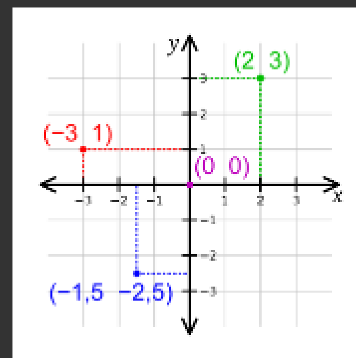
Viewing the 3D Earth on a 2D surface

- Map projections allow us to view the 3D Earth on a 2D surface
- Earth is mathematically projected to a surface that can be made flat
- We now make measurements in distance or length units as opposed to degrees
- A Cartesian coordinate system
- We call these surfaces Map Projections



https://commons.wikimedia.org/wiki/File:Cartesian_coordinate_system_(comma).svg

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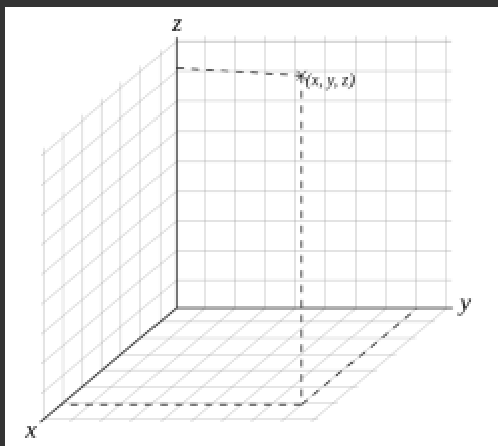
Instead of using a 3D spherical globe, we can mathematically transform the Earth into a flat map space. Now, instead of making measurements of distance or length in angles, we can make measurements in length units.

These 2D surfaces are known as projected coordinate systems or map projections. They allow us to make measurements in a Cartesian coordinate system on a plane.

Coordinates in 3-D space



https://commons.wikimedia.org/wiki/File:Cartesian_with_grid.svg

- X, Y, Z
- Length units
- Relative to an origin

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Cartesian coordinate systems can also be expanded to include a z component to make measurements in 3D space.

Geographic vs. Projected Coordinate Systems

Image from ArcGIS API for JavaScript

Image from ArcGIS API for JavaScript

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This slide provides an example of the difference between geographic and projected coordinate systems. The globe provides a 3D representation of the Earth where measurements are made in angles. In contrast, projections are 2D and allow for measurements to be made in Cartesian coordinate space.

Why do we use map projections?

- Allow us to represent the Earth of a flat surface
- Allow us to make measurements on flat maps (Distance, Area, X/Y Coordinates)
- Measures of length and angle are uniform

Geographic coordinate system (Degrees)

Latitude and longitude are not uniform across the Earth's surface

Image from ArcGIS API for JavaScript

Projected coordinate system (Cartesian)

Measures of length and angle are uniform

Image from ArcGIS API for JavaScript

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Using projections, measures of lengths and angles are uniform. In contrast, latitude and longitude measurements are not uniform across the globe.

For example, one degree of longitude is a greater distance at the equator than nearer to the poles. At the poles, longitude lines converge, so there is effectively no distance between longitude measurements.

Map Projections Distortions

- All map projections produce distortions of at least one of the following

1. Shape
2. Area
3. Distance
4. Direction

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Since the curved, 3D surface of the Earth is converted to a flat space, some distortions will be produced. It is not possible to convert a curved 3D surface into a flat surface without some distortions.

Specifically, map projections can produce distortions in feature shape, relative area of features, distance between features, and direction between locations.

The type and magnitude of the distortions produced depends on the projection used.

Map Projections

- All map projections produce distortions of at least one of the following:

1. Shape
2. Area
3. Distance
4. Direction

https://thetruesize.com

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Here is an example of a size distortion. In Mercator and Web Mercator projections, Greenland often appears very large. However, it is much smaller than Australia.

This image was generated using thetruesize.com. I would recommend exploring this site.

https://thetruesize.com

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Please take some time to explore the True Size Of web app.

The Tissot Indicatrix

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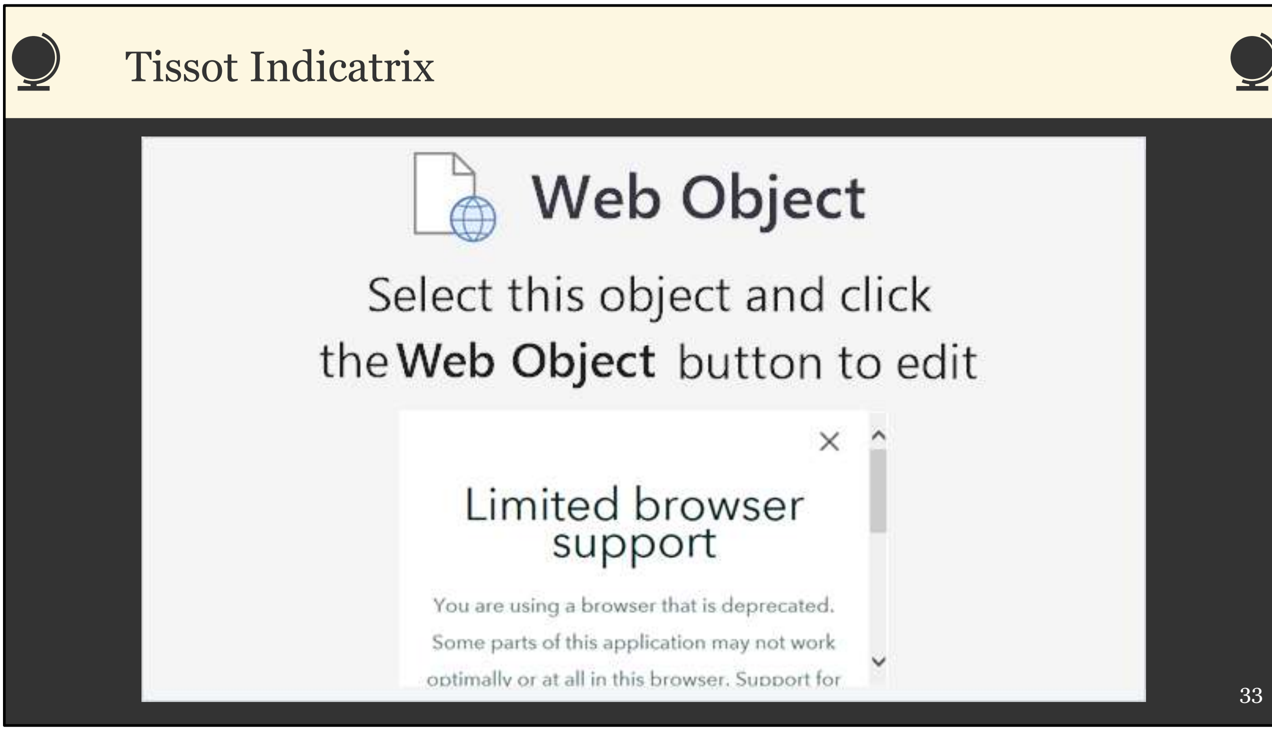
One tool that is commonly used to visualize size and shape distortions resulting from map projections is the Tissot Indicatrix. Without any distortions, or if these features are plotted on the globe, the circles will all be the same shape, perfect circles, and size. Any deviation in shape or size is a result of map projection distortions.

For example, the Mercator projection on the left distorts size, since the circles are not the same size, but not shape, since the circles are still circular.

The Mollweide projection to the right distorts shape, since the circles are no longer perfect circles, but not size, since each circle still has the same area.



This web app shows the Tissot Indicatrix for the entire globe and for the Web Mercator projection. This projection is conformal, meaning that shape is maintained but size is distorted.

Types of Map Projections

- Conformal Projections = preserves local angles and shape
- Equivalent Projections = represents areas in correct relative size
- Equidistant Projections = maintains consistent scale along certain lines
- Azimuthal Projections = maintains certain accurate directions

- Conformal and equivalent properties are mutually exclusive
- Conformal and equivalent properties are global properties
- Equidistant and azimuthal properties are local properties and may be true only from or to the center of the map projection

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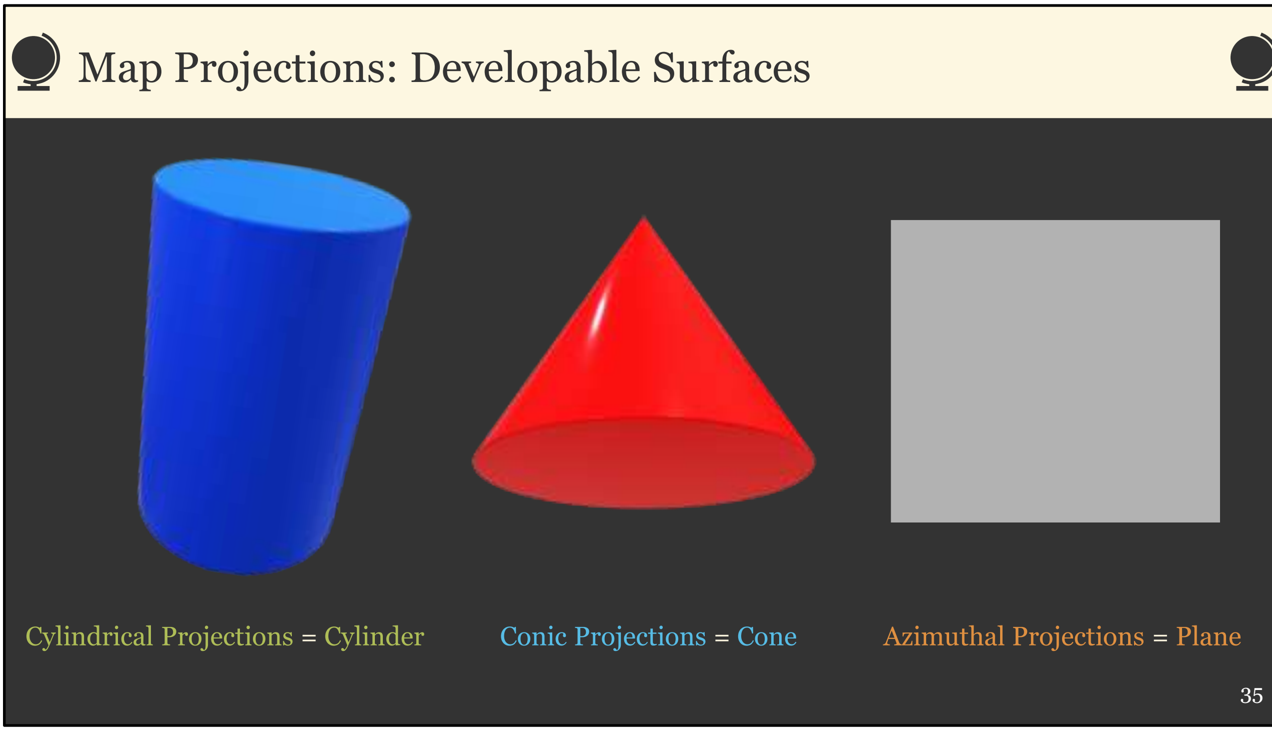
Four broad types of projections exist based on what map properties are maintained.

Conformal projections maintain local angles and shapes. Equivalent projections maintain areas of features in correct relative size. Both are global properties, or shape or size can be maintained across the entire globe not just for specific areas. Also, these properties are mutually exclusive: you cannot maintain both shape and relative size.

Equidistant projections maintain scale or distance along certain lines while azimuthal projections maintain accurate projections relative to a certain vantage point. Equidistant and azimuthal properties are local properties and may be true only from or to the center of the map projection. You cannot maintain distance or direction between all points in the map space.



In order to flatten the Earth, coordinates on the globe must be mathematically transformed or moved to a geometric surface that can be flattened. These are called developable surfaces.

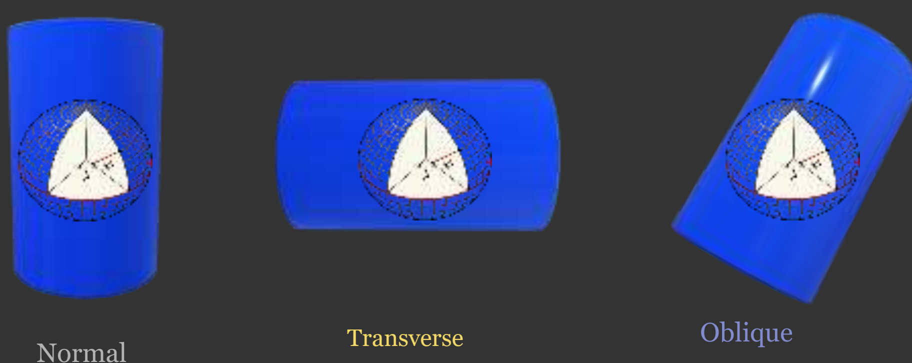
The most commonly used surfaces are cylinders, cones, and planes. Cylindrical projections use cylinders, conic projections use cones, and azimuthal projections use planes. There are other shapes available or shapes can be combined. Here, we will focus on just these most commonly used surfaces.

Note that all three of these surfaces can be flattened. If you cut a cylinder, it can be folded out to a plane. A cone can be folded out into a fan shape.

The developable surfaces: Orientations

- Planes, cones, and cylinders

https://commons.wikimedia.org/wiki/File:Latitude_and_longitude_graticule_on_an_ellipsoid.svg



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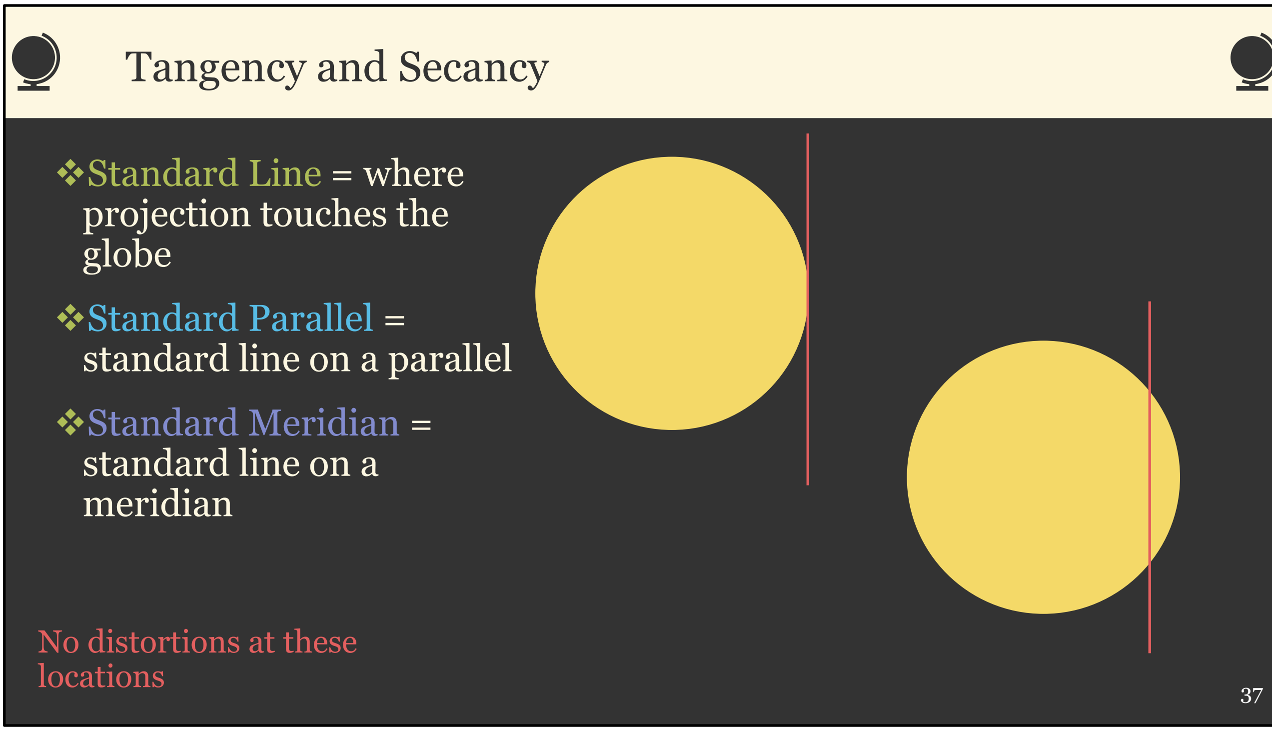
Orientation relates to how a developable surface is oriented or positioned relative to the globe. For example, for a cylinder the normal orientation is oriented up-and-down relative to the globe. In other words, the long axis will be placed perpendicular to the equator.

In contrast, the transverse orientation will be oriented parallel to the equator.

Oblique orientations are any other orientation other than normal or transverse.

So, given the wide variety of developable surfaces and orientations, the number of possible map projections are infinite.



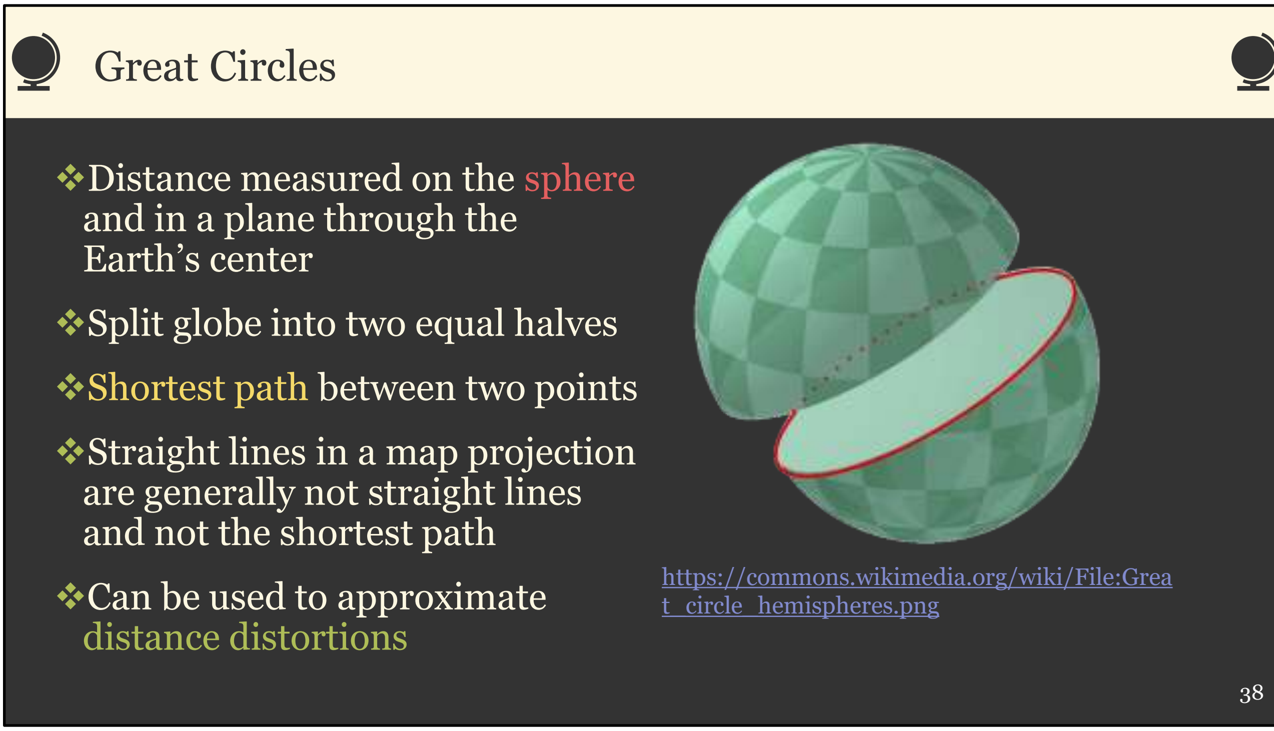
Projections can also vary in regards to where and how they intersect the surface of the Earth or globe.

Tangency occurs when the developable surface only touches the globe at a single location or along one parallel or meridian while secancy occurs when the surface touches the globe along two latitude or longitude lines.

Standard lines are where the projection touches or spatially co-occurs with the globe. Standard parallels are parallels or latitude lines where the projected surface intersects the globe while standard meridians are meridians or longitude lines.

Generally, there are no distortions where the globe and developable surface co-occur, since the coordinates do not need to be transformed or moved. Distortions tend to increase with distance from the standards.

Again, given the wide variety of developable surfaces, orientations, and standard lines, the number of possible map projections is infinite.



Great circles are defined on a sphere and represent the largest possible circles that can be drawn on that sphere. A great circle is formed where a plane passing through the center of the sphere intersects the spherical surface. Because the plane passes through the center, a great circle divides the sphere into two equal halves.

Great circles are important because the shortest path between two points on a sphere lies along a great circle. For Earth, great-circle distance is commonly used as an approximation of the shortest surface distance between locations. More precisely, because Earth is better represented as an ellipsoid than a perfect sphere, the shortest path on an ellipsoid is called a geodesic.

The equator is a great circle because its plane passes through Earth's center and divides Earth into two equal hemispheres. Other lines of latitude are not great circles because their planes do not pass through Earth's center and they do not divide Earth into equal halves. Lines of longitude, or meridians, form great circles when paired with the opposite meridian on the other side of the globe.

Due to map projection distortion, straight lines on maps are not always great-circle paths and therefore are not always the shortest routes between two points on Earth's surface. Great-circle distances are commonly used to approximate distances between locations on the globe and can also be used to assess distance distortion in map projections.

In navigation, great-circle routes are often useful because they represent the shortest path on a spherical Earth. However, planes and ships do not always follow exact great-circle paths. Actual routes may be influenced by weather, winds, currents, airspace restrictions, shipping lanes, safety considerations, and the practical difficulty of following a route whose bearing changes continuously.

Projection Examples

- Projection used is related to type of map and area covered by map (extent)
- Continental-scale data (North America)
  - Geographic projection (decimal degrees)
  - Lambert Conformal Conic
  - Albers Equal Area
- State-scale data (West Virginia)
  - UTM Projection, Zone 17
  - State Plane

Projected coordinate systems do not use longitude and latitude to measure locations

Instead, they use map units of the projection itself:

Meters (UTM, Albers, most others)
Feet (State Plane, few others)

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The best map projection to use partially depends on the extent being mapped or the scale of the map. We will now investigate some common map projections that can be used at different scales.

Note that all maps and spatial data layers will be referenced to a datum or geographic coordinate system. If the map or data have been projected, they will also have a projected coordinate system where measurements are made in length units as opposed to angles.

We will begin with a discussion of some common global-scale projections followed by continent- and state-scale options.

World Projections: Mercator

- Cylindrical projection
- Maintains shape
- Distorts size
- Parallels and meridians cross at right-angles

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Mercator projections are examples of cylindrical projections that are conformal, or maintain shape and local angles.

Relative size tends to be heavily distorted. For example, the Tissot Indicatrix suggests that sizes close to the poles are much larger than they should be in comparison to equatorial features. Remember from the example above that Greenland is actually smaller than Australia.

In Mercator projections, parallels and meridians will cross at right-angles.

World Projections: Web Mercator

- Modification of Mercator projection that is commonly used for web maps
- Bing Maps, OpenStreetMap, Google Maps, MapQuest, ArcGIS Online

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Web Mercator is a modification of the Mercator projection that is commonly used in web maps including Bing Maps, OpenStreetMap, Google Maps, MapQuest, and ArcGIS Online.

One reason this projection is used on the web is that it is easy to generate tiles from data since latitude and longitude lines intersect at right angles.

Web Mercator is the version used by most web maps, including Google Maps, OpenStreetMap, Bing Maps, and many ESRI basemaps. It uses the Mercator projection formulas on a sphere, not the full ellipsoidal Mercator formulas. However, its coordinates are usually based on WGS84 longitude and latitude as input. So, it is often described as a “spherical Mercator” projection applied to WGS84 geographic coordinates.

World Projections: Mollweide

- Equivalent projection
- Maintains area
- Distorts shape and angle
- Pseudocylindrical

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Mollweide is an example of an equivalent projection that maintains relative size or area but distorts shape and local angles.

It is pseudocylindrical, which means that it uses multiple cylinders as opposed to one in an attempt to further minimize distortions.

World Projections: Azimuthal Equidistant

- Azimuthal and equidistant
- Correct distance from center of map
- Correct angle from center of map

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The azimuthal equidistant projection maintains the correct distance and angle or compass bearing form the center of the map.

In the provided example, the center of the map occurs at 0° latitude and 0° longitude, or where the equator and prime meridian intersect. So, distance and direction relative to this location are correct.

Note that this projection distorts shape and relative size.

World Projections: Patterson

- Neither equivalent or conformal
- Strikes a balance between shape and scale distortion
- Meridians curve gently

44

The Patterson projection is neither equivalent nor conformal. Instead, it tries to strike a balance between shape and size distortions. Note that the meridians are gently curved.

World Projections: Eckert IV

- Equivalent
- Maintains area
- Distorts shape and angle
- Pseudocylindrical

45

Eckert IV is equivalent, or maintains relative size. However, it distorts shape and local angles. It is another example of pseudocylindrical projection.

World Projections: Goode Homolosine (Land)

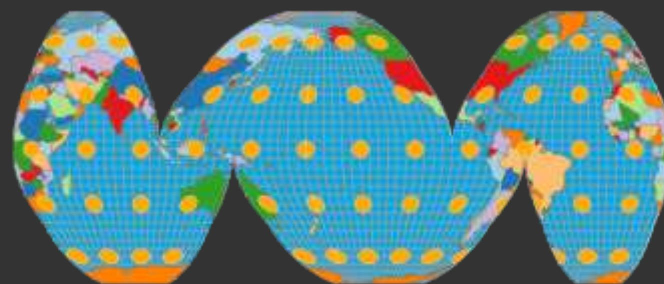
- Equivalent
- Maintains area
- Distorts shape and angle
- Pseudocylindrical
- Does not split contents

46

Goode Homolosine (Land) is used to show continental masses with no size distortion.

World Projections: Goode Homolosine (Ocean)

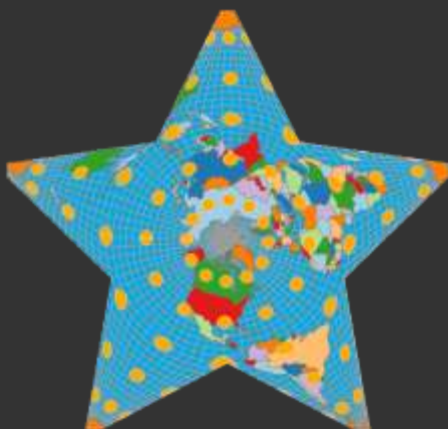
- Equivalent
- Maintains area
- Distorts shape and angle
- Pseudocylindrical
- Does not split oceans



47

In contrast to Goode Homolosine (Land), the Ocean version does not split up the ocean basins.

World Projections: Other Examples



Berghaus Star

Miller Cylindrical

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Here are some other examples of global projections: Berghaus Star and Miller Cylindrical.

World Projections: Other Examples

Robinson

Winkel II

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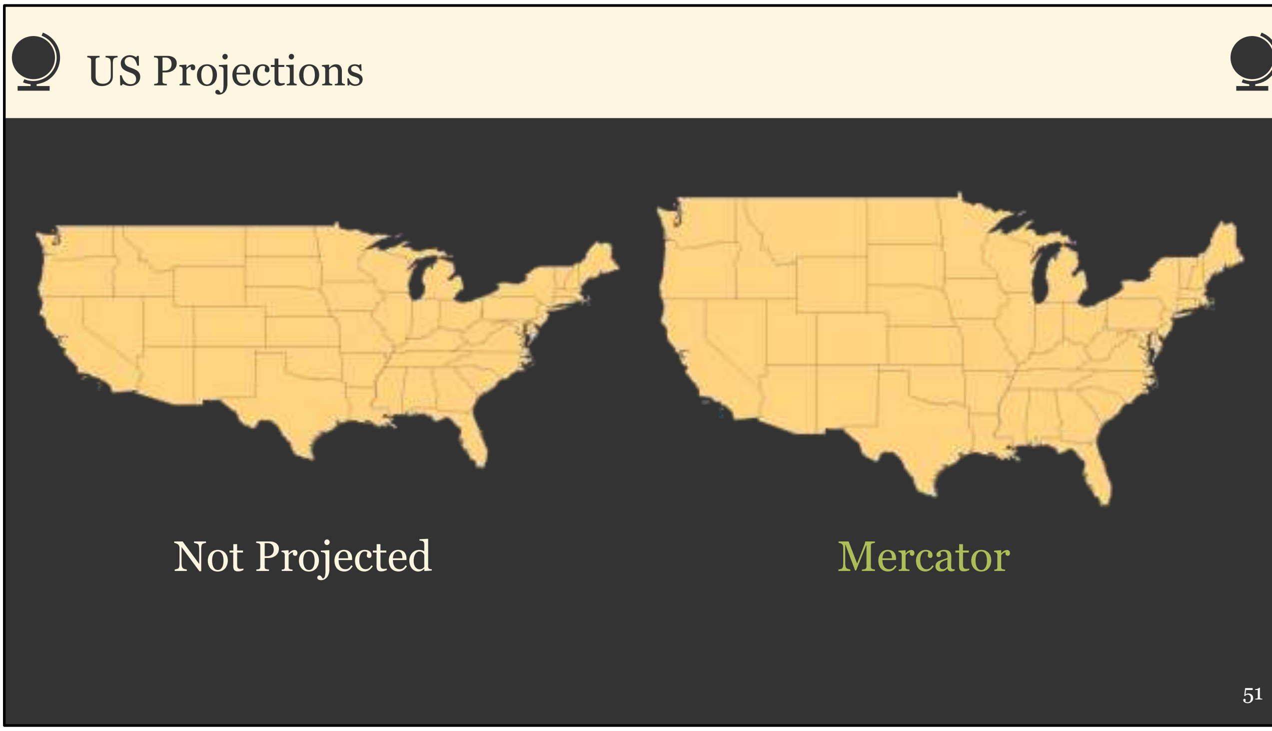
This slide shows the Robinson and Winkel II projections.

Polar Projections: North Pole Azimuthal Equidistant

- Maintains distance and direction from the North Pole

50

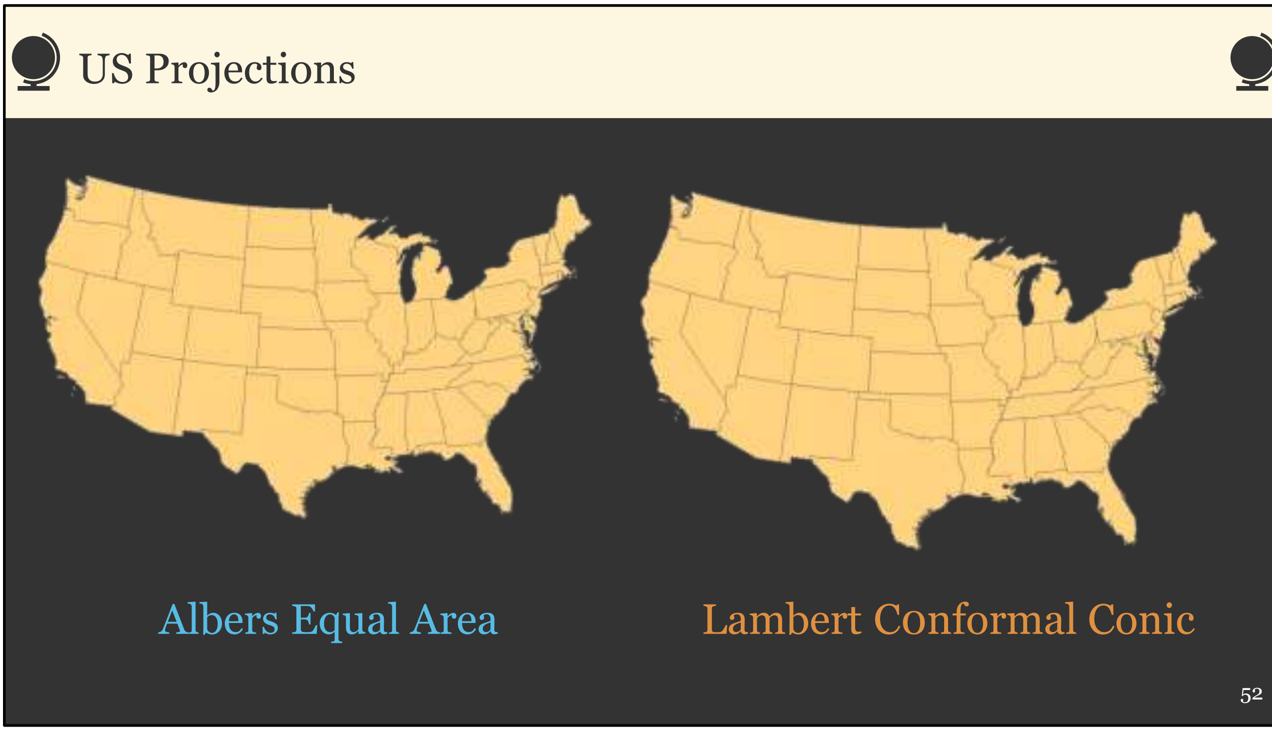
Polar projections are designed to show polar regions. As an example, the North Pole Azimuthal Equidistant projection is commonly used for Arctic mapping and maintains distance and direction relative to the North Pole.



We will now discuss continental-scale projections using the United States as an example.

The first image shows the US as not projected. In other words, latitude and longitude are being treated like Cartesian coordinates in flat space. This results in some extreme distortions and should be avoided.

The second image shows a Mercator projection for the US. Here, shape and local angles are maintained but relative size is distorted.



When creating maps of the US, I prefer to use Albers Equal Area or Lambert Conformal Conic.

US Projections: Albers Equal Area

- Conic
- Equivalent
- Maintains area
- Two standard parallels

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Albers Equal Area uses a conic developable surface with two standard parallels. It is equivalent, so it maintains relative size but distorts shape and local angles. However, distortions are generally pretty minimal.

US Projections: Lambert Conformal Conic

- Conic
- Conformal
- Maintains shape
- Two standard parallels

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Lambert Conformal Conic also uses a cone with two standard parallels. Since it is conformal it maintains shape and local angles but distorts local size. However, distortions are minimal.

So, if I want to create a map of the US that maintains relative size, I tend to use Albers Equal Area. If I want to maintain shape, I will use Lambert Conformal Conic.

Universal Transverse Mercator (UTM)

- Location provided in meters as Easting and Northing
- Northing = meters north of equator
  - In northern hemisphere, equator is assigned a value of 0 meters, add as you go up
  - In southern hemisphere, equator is assigned a value of 10,000,000 meters, subtract as you go down
- Easting = distance from central meridian in UTM zone
  - Central meridian is assigned a value of 500,000 meters
  - Add as you go east
  - Subtract as you go west

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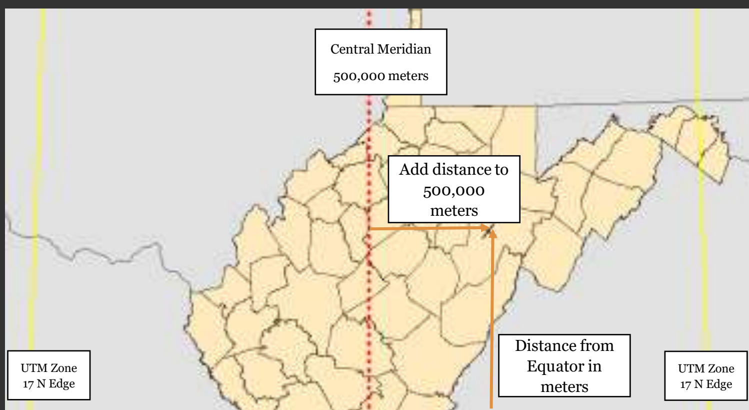
We will now discuss projections that are appropriate at more local scales, such as for states, counties, or cities. Universal Transverse Mercator is a set of projections that are commonly used at these scales. This is not one system but a set of systems in which the Earth is broken into 60 zones. Within each zone coordinates are provided in length units, generally meters, as northing and easting.

Northing measures up-and-down or north-to-south. In the northern hemisphere, the equator is assigned a value of 0 meters, and you add as you move north. So, this is effectively the distance from the equator. In the southern hemisphere, the equator is assigned a value of 10,000,000 meters, and you subtract as you move south.

Easting is calculated relative to the central meridian or center line in each zone. The central meridian is assigned a value of 500,000 meters, and you add as you move east of it and subtract if you move west.

Universal Transverse Mercator (UTM)



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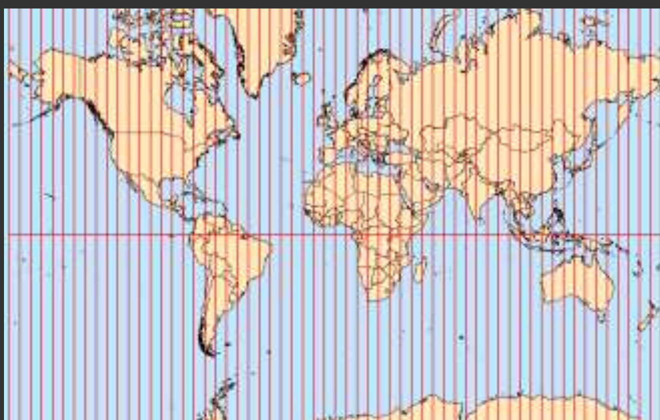
The UTM projections are cylindrical and use a transverse orientation. This slide provides an example of easting and northing for a coordinate in West Virginia.

This coordinate is east of the central line in the zone, so you add the distance to 500,000 meters. The northing would be the distance from the equator in meters.

Since this coordinate is in Zone 17 North, the easting and northing are defined relative to this zone. The yellow lines mark the edges of the 17 North zone.

UTM Zones



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The UTM systems break the Earth into 60 zones vertically. Each zone is only appropriate for areas within it. You should not project the entire Earth to a single UTM projection.

Easting values will be defined relative to the central meridian in each zone.

In the US, the zone number increases as you move east and decreases as you move west.

The majority of West Virginia is in UTM Zone 17 North. So, this is a common projection for West Virginia. West Virginia generally uses a geographic coordinate system of NAD83 or WGS84 and a projected coordinate system of UTM Zone 17 North.

Some states fit well into a single UTM zone, for example Nevada, Utah, and Alabama. Others do not, such as California or Pennsylvania.

For states that do not fit well into one UTM zone, other projections are generally used to display them.

UTM Zones

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This web app shows the UTM zones for the entire globe. If you click within a zone, the associated number will be displayed.

State Plane Coordinate System

- Used by surveyors
- Measurements in feet or meters
- Each zone has defined baseline (like northing) and false meridian
- Very good for accurate measurements
- Commonly used for mapping at the city- to county-scale

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For mapping smaller extents within states, state plane coordinate systems are commonly used.

It is common for surveyors to use these systems. Measurements are commonly made in feet or meters. Each coordinate system has a defined baseline, like northing, and a false meridian, like easting, to which the coordinate measurements are referenced. Different projections are used depending on the specific coordinate system.

These systems allow for very accurate measurements and are commonly used at the city- to county-scale.

West Virginia has two state plane coordinate systems defined: West Virginia State Plane North and West Virginia State Plane South. So, detailed mapping in the northern part of the state may use the WV North system while mapping in the south would use WV South. Neither of these projections are designed to be used for the entire state, so it would be inappropriate to created a map of the entire state in one of these projections. Instead, you could use UTM Zone 17 North.

Best Practices

1. Should use same projection for all data
2. Use projection appropriate for scale and extent
3. Think about what map properties are maintained or distorted

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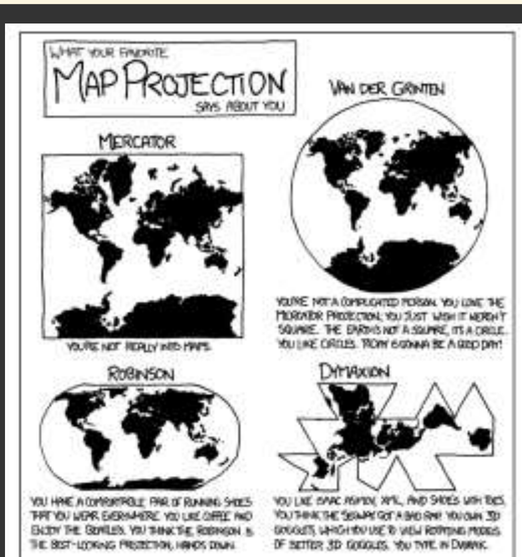
This slide highlights best practices for working with projections.

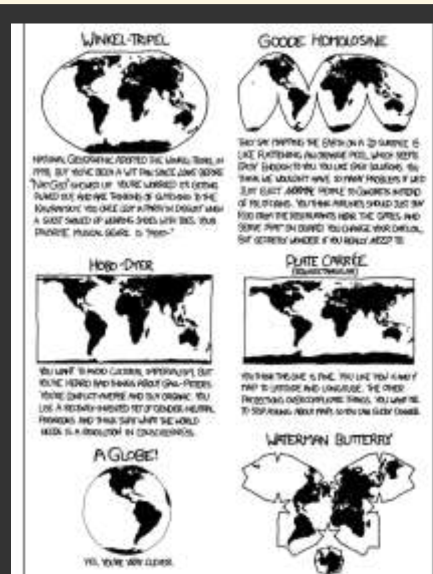
First, it is generally best to use the same projection for all data layers in a map or project to avoid any issues with misalignment.

You should use a projection appropriate for the scale and extent of the map. For example, you would not use a specific UTM zone to project the entire globe. On the other hand, a global projection would not be the best choice for data just within West Virginia.

You should also think about what map properties are maintained or distorted. If you are interested in maintaining relative size, then you should use an equivalent projection.

xkcd





https://xkcd.com/977/

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This slide provides a link to an xkcd comic about map projections.

Map Projections in ArcGIS Pro

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Projection-on-the-Fly (ArcGIS)

- ArcGIS Pro can apply a projection transformation on-the-fly
- So, it is not always necessary to re-project data
- Okay if you are visualizing the data
- May need to re-project if you plan to perform an analysis

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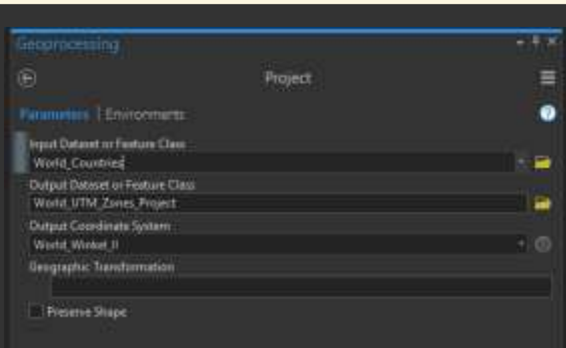
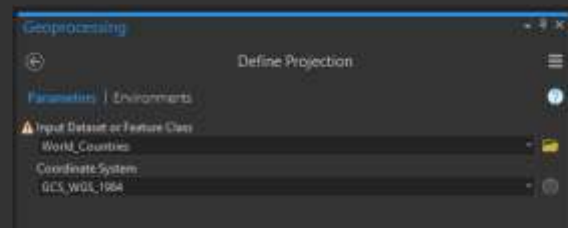
Note that ArcGIS Pro can apply a projection transformation on-the-fly or in memory. So, data that are read into a map that are in a different projection than the map can be re-projected to match the map on-the-fly. So, it is not always necessary to re-project data if you are simply visualizing it or making a map layout.

However, I suggest transforming all data layers into the same projection if you plan to perform spatial analysis.

Transforming Projections and Datums in ArcGIS





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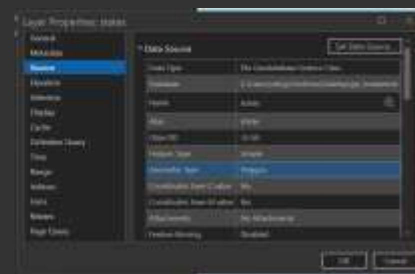
Tools are available in ArcGIS Pro for defining or changing the datum and/or projection using mathematical transformations. Note that since exact mathematical relationships are not always available between two specific systems, transformations can produce some positional errors or uncertainties. However, sometimes this is necessary and can’t be avoided.

Get Layer Projection Info

1. Navigate to the us map.
2. Right-click on the states layer in the Contents Pane and select Properties from the menu.
3. Navigate to the Source options.
4. Scroll down and expand the Spatial Reference section.



What is the projected coordinate system for this layer?

What is the geographic coordinate system for this layer?

65

The following exercises relate to map projections in ArcGIS Pro.

Get Map Projection Info

1. Navigate to the us map.
2. Right-click on the us map name in the Contents Pane.
3. Navigate to Properties followed by the Coordinate Systems information.

What is the projected coordinate system for this layer?

What is the geographic coordinate system for this layer?

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Change Map Projection

1. In the Coordinate Systems area of the Map Properties Pane activated in the last activity, change the map projection to "Albers Equal Area Conic" ("Projected Coordinate Systems → Continental → North America → North America Albers Equal Area Conic").
2. Click Okay to change the projection.

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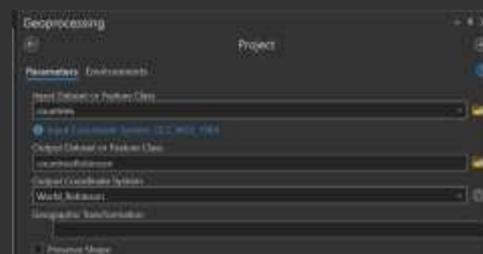
Reproject a Layer

1. Navigate to the world map.
2. Navigate to the Analysis Tab.
3. Click the Tools icon to open the Geoprocessing Pane.
4. In the search box in the Geoprocessing Pane, search for "Project"
5. Select Project (Data Management Tools)
6. Set the **Input Dataset or Feature Class** to the countries layer.
7. Name the **Output Dataset or Feature Class** countiesRobinson
8. Set the **Output Coordinate Reference System** to "Projected Coordinate System → World → Robinson (world)".
9. You do not need to define a **Geographic Transformation** or set the **Preserve Shape** option.
10. Click Run to execute the process.

Since layers are reprojected on-the-fly, it is not always necessary to reproject the layers to a consistent coordinate reference system, especially if they are just being viewed. !



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Fix Broken Projection

- Navigate to the us map.
- Make sure the projection is set to Projected Coordinate Systems → World → WGS 1984 Web Mercator (auxiliary sphere).
- Add the collegesUniversities.shp file from the rawData folder.
- When the layer is added, you should get a warning message because projection information is missing.
- Right-click on the collegesUniversities layer in the Contents Pane and select Zoom To Layer. The layer is not drawing in the correct location.
- Navigate to the Analysis Tab and click on the Tools icon to open the Geoprocessing Pane. Search for the Define Projection Tool (Data Management Tools → Projection and Tranformation → Define Projection). Set the **Input Dataset or Feature Class** to the collegesUniversities layer. Set the **Coordinate System** to *Projected Coordinate Systems → Continental → North America → North America Albers Equal Area Conic*. Click Run to execute the tool.

The data layer should now draw in the correct location because the tool added the correct projection information. Even though the layer has a different projection than the map, it still draws at the correct location due to reprojection-on-the-fly.

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Map Projections in QGIS

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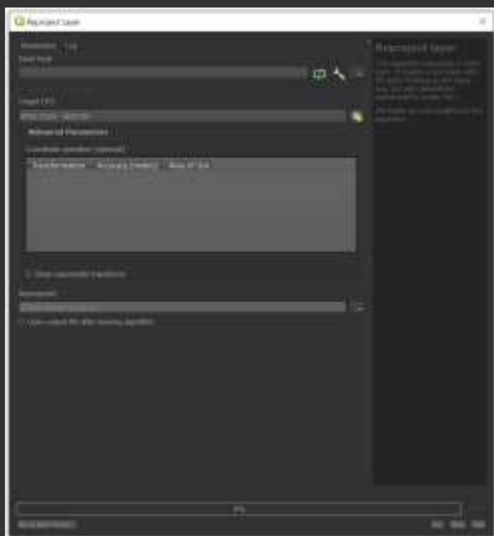
QGIS



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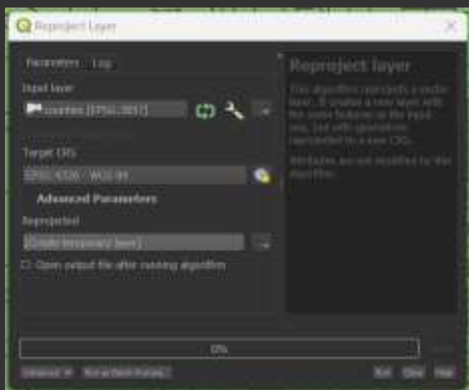
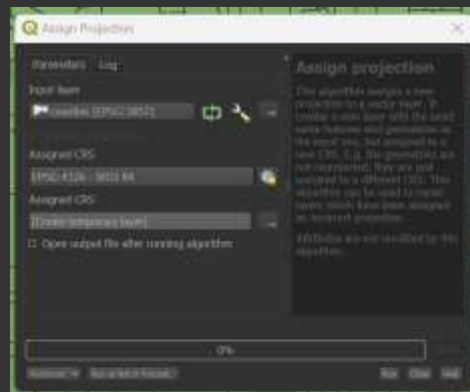
QGIS and GDAL also has tools for performing datum and/or projection transformations.

Project/Reproject

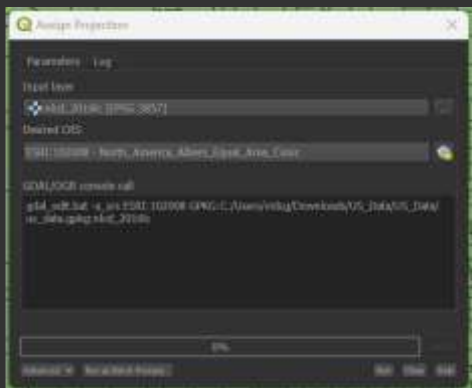


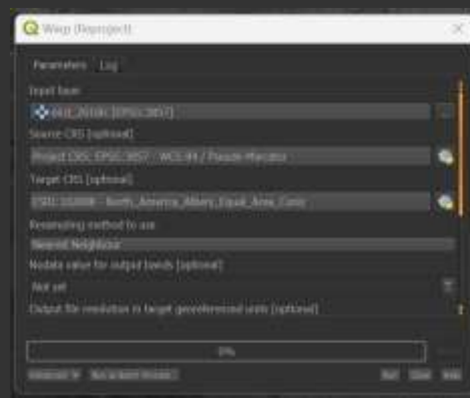


- Processing Toolbox → Vector General

Re-projection can be performed using tools available in the Vector General toolbox. Reproject Layer is used to transform the data to a new projection while Assign Projection is used to fix missing projection information.

Project/Reproject





❖Processing Toolbox → GDAL → Raster Projections

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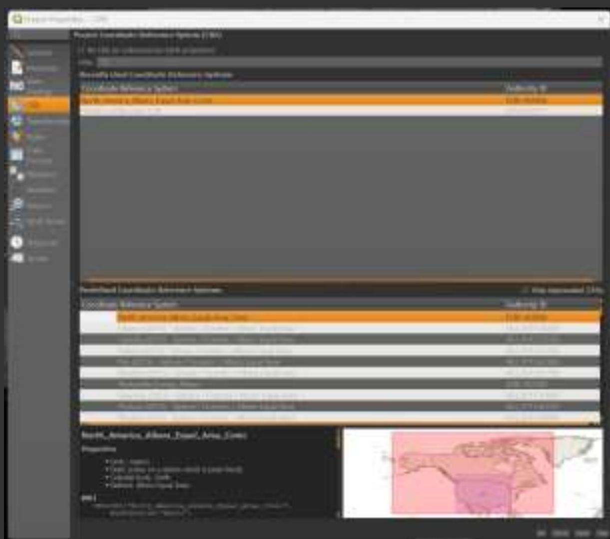
GDAL also offers tools to re-project data. Warp is used to perform re-projection while Assign Projection is used to assign missing projection information.

Change Map Projection



❖Project → Properties → CRS

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You can change the projection for the current map or project from the Project menu.

This is the end of this lecture module.

Please return to the West Virginia View Webpage for additional content.

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Thanks! Hope you found this useful.