Lesson 3: Understanding Coordinate Systems and Map Projections

## INTRODUCTION

In this lesson you will be introduced to coordinate systems and map projections. You will gain an understanding of coordinate systems, developable surfaces, and map projection parameters. This lesson will help you understand how to determine deformation and its distribution on a map projection.

## LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Select the appropriate coordinate system using provided metadata to determine spatial reference.

## LEARNING SEQUENCE

|  |  |
| --- | --- |
|  | |
| Required Reading | Read the following:  Understanding Coordinate Systems and Map Projections   * Coordinate Systems and Map Projections * Coordinates and Coordinate Systems * Map Projections * Developable Surfaces * Map Projection Parameters * Map Projections Properties * Determining Deformation and its Distribution |
| Resources | View the following:   * Map Projections |
| Assignments | Complete the following assignments:   * Lab: Exploring Coordinate Systems and * Map Projections * Quiz: Understanding Coordinate Systems |

## INSTRUCTION

**Coordinate Systems and Map Projections**

## What is a datum?

A datum is a reference surface for measuring locations on the earth. A datum has two major components: the specification of an ellipsoid, which is an ellipsoid that has been surveyed and defines the origin and orientation of latitudes and longitude lines. We cannot assign any coordinates to a location without first specifying a datum and linking that datum to the shape of the earth through field measurements. There are three common datums that you will use in GIS: North American Datum of 1927 (NAD 27), North American Datum of 1983 (NAD 83), and The World Geodetic System of 1984 (WGS 84). It is very important that you read the documentation of the datasets that you using in your GIS to determine exactly which datum was used to determine locations.

### North American Datum of 1927 (NAD 27)

The first datum we will discuss is the North American datum of 1927 also referred to as NAD 27. The NAD 27 datum is based on the Clarke 1866 ellipsoid which holds a fixed latitude and longitude in Kansas. The locations were adjusted based on about 26,000 measurements across North America. Quite a bit of GIS data is still available in NAD 27, however, more recent data should use North American datum of 1983. Datums are not static, and often see updates and adjustments throughout time. In fact, both NAD 83 and WGS 84 have been updated multiple times.

### North American datum of 1983 (NAD 83) slide 3

The North American datum of 1983, or NAD 83, is the successor of NAD 27, and uses an earth centered reference ellipsoid rather than a fixed station in Kansas. Additionally, 250,000 points were measured to adjust the latitude and longitude locations.

It is worth mentioning that it is okay to use NAD 27 or NAD 83 data, however, when performing analysis, you should convert all the data into a single datum for analysis purposes.

### The World Geodetic System of 1984 (WGS 84)

The third common datum is the world geodetic system of 1984 commonly referred to as WGS 84. WGS 84 is based on satellite measurements and the WGS 84 ellipsoid which is similar to another ellipsoid named GRS 80. The major difference between the WGS 84 ellipsoid and the NAD 27 and NAD 83 datum is at the WGS 84 data has worldwide coverage, where NAD 27 and NAD 83 should only be used in North America. You should also note that the WGS 84 datum is used by the GPS system to report latitudes and longitudes.

## Vertical Datums for North America

Vertical datums also exist as a reference to specify heights and, like horizontal datums, such as NAD 27, they are used to establish elevation.

There are two common vertical datums for North America: the national geodetic vertical datum of 1929 and the North American vertical datum of 1988. If you’re working with three-dimensional information, in addition to reading about the horizontal datum of the data set, you should also read about the vertical datum to determine which data was used to derive the heights of the dataset.

|  |
| --- |
| **Key Facts**  **Vertical Datum**   * A vertical datum is a reference for specifying heights established through a set of surveyed control points and are used to establish elevation. * Two most common vertical datums for North America   + National Geodeteic Vertical Datum of 1929 (NGVD29)   + North American Vertical Datum of 1988 (NAVD88) |

**Coordinates and Coordinate Systems**

## Representing Space

Representing space is very important in a GIS, as we will want to overlay information for visualization and analysis purposes. The question we must answer is how can we represent the space numerically, so that it can be stored, and manipulated by a computer? The answer is through the use of 2-D and 3-D coordinate systems. This section will discuss 2-D and 3-D coordinate systems commonly used in a Geospatial Interface System (GIS) in the United States.

## 3D Coordinate Systems

As it pertains to Earth, we use 3-D coordinate systems which represent a sphere such as the earth. The important thing to note about the 3-D coordinate systems that we are going to discuss is that it will not ignore the curvature of the earth, which makes it ideal for displaying locations and measuring across long distances where the curvature of the earth will become a factor. The 3-D coordinate system uses two angles of rotation commonly known as latitude and longitude, and a radius to specify a location. The angles of rotation will determine whether the location is north or south of the equator or east or west of the prime Meridian and the radius will specify how far from the center of the earth that location is.

|  |
| --- |
| **Key Facts**  Spherical Coordinates   * 3D only * do not ignore curvature of Earth * uses two angles of rotation (latitude/longitude) and radius to specify locations |

## Longitude

Longitude, also known as Meridian, is the angle of rotation measured East and West around the globe. What may be confusing is that the lines of longitude run north-south from the North Pole to the South Pole. Lines of longitude will vary from positive 180° East to -180° West measured relative to the line of longitude of 0°, which is known as the Prime Meridian. The Prime Meridian runs through Greenwich England. Lines of longitude west of Greenwich England up to and including 180° are represented as a negative number and/or as a Western longitude. Lines of longitude east of Greenwich England up to and including 180° is represented as a positive number and/or as an Eastern longitude.

|  |  |
| --- | --- |
|  | **Key Facts**   * Measures East-West * Vary from +180° E to -180° W |

## Latitude

The second angle of rotation is known as latitude, and is also referred to as a parallel. Parallels measure North to South on the globe, and the lines run in parallel to each other East and West from the North Pole to the South Pole. The equator is the latitude of 0°. Lines of latitude measure from positive 90°North, which is located at the north pole, to -90° South, which is located at the south pole.

|  |  |
| --- | --- |
|  | **Key Facts**   * Measures North-South * Vary from +90° N to -90° S |

Displaying Latitude and Longitude Coordinates

There are two common formats that are used to display latitude and longitude coordinates: One format being degrees, minutes, and seconds, while the second format is decimal degrees. The degree, minute, second, format displays latitude and longitude broken down into the three separate measures of degrees, minutes, and seconds. The degrees number is represented by the degree symbol, the minutes number is followed by a single apostrophe, while the second’s number is followed by two apostrophes. For example, degrees, minutes, seconds can be represented as -34° 23 minutes 45.23 seconds latitude, and positive 124° 12 minutes 45.32 seconds longitude.

|  |
| --- |
| **Key Facts**  Both latitude and longitude are typically represented in two ways:   * + **Degrees, Minutes, Seconds** (DMS)   -34°23’45.23” , +124°12’45.32”   * + **Decimal Degrees** (DD) used by computers   -34.395897 , 124.212589 |

Another way latitude and longitude are represented is using decimal degrees. Decimal degrees are most commonly used by computers, as they can easily be stored in the float data type. Both latitude and longitude are simply represented as a decimal number in the decimal degrees format.

## 2-D Coordinate Systems

2-D coordinate systems are more commonly known as a Cartesian coordinate system. The Cartesian coordinate system defines spatial location and extent and can display data in two or three dimensions.

The difference between a 2-D and 3-D coordinate system, is the fact that the 2-D coordinate system ignores the curvature of the earth. Even if a 2-D coordinate system includes height, or elevation information, it is still assumed to be a height above a flat plane.

|  |  |
| --- | --- |
| 2D (x,y) | 3D (x,y,z) |

## 2-D Cartesian Coordinate System

GIS data typically uses the 2-D Cartesian coordinate system for simplicity. Additionally, for small areas, the curvature of the earth is typically not a factor for analysis or distance measurement, so we can safely ignore the curvature of the earth.

The 2-D Cartesian coordinate can represent many possible locations at many possible scales, and it is so flexible you can even create your own. However, there are two common representations that are widely used in North America, and the world. The first representation being the state plane coordinate system and the second being the Universal Transverse Mercator Coordinate System or UTM system.

|  |
| --- |
| **Key Facts**   * GIS data typically uses Cartesian system for simplicity. * *Ignores curvature of Earth*   + For small areas, usually acceptable * Many possible representations   + could even make your own   + common representations   + State Plane Coordinate System (SPCS)   + Universal Transverse Mercator Coordinate System (UTM) |

## State Plane Coordinate System

The state plane coordinate system is a set of 126 geographic zones that cover the United States of America. Each zone is designed specifically for the region of the United States of America that it covers, and is useful because it allows for simple calculations, and is reasonably accurate within each zone. In the state plane coordinate system, coordinates are always positive inside each zone. The state plane coordinate system can be based off of NAD 27 and NAD 83 datums, and the coordinates are represented and measured in feet.

State Plane Zones

Each state may have multiple state plane zones, but this is not required. Each zone is strategically placed to minimize the amount of error within each zone. Additionally, each zone provides a common coordinate reference for horizontal coordinates over area such as counties while limiting error to specified maximums. Depending on the shape of the state, the state plane zone can be based on two types of map projections, the Lambert conformal conic, or the transverse Mercator.

This is an illustration of the state plane zones in the contiguous lower 48 United States of America. Notice that most states have multiple zones, and that zones typically either run north to south, or east to west. Also note that most of the smaller states, particularly in the New England area, only have one state plane zone covering the entire state, while larger states, such as California, and Texas, have multiple zones, so that the error can be minimized throughout the state. A notable exception to this is Montana, it is a large state, but only has a single zone.

State plane zones are typically designated with the name of the state, followed by a section indicator, such as north, central, or south, or combination of those, or, west, central, east. A notable exception is California, which specifies each zone using a different number.

## Universal Transverse Mercator Coordinate System

The Universal Transverse Mercator Coordinate System is a worldwide 2-D coordinate system that splits the world into 60 zones. The Universal Transverse Mercator Coordinate System is useful because it provides for simple calculations, and manages error within each zone. Unlike the state plane coordinate system, which is measured in feet, and the Universal Transverse Mercator Coordinate System, is specified and measured in meters.

The Universal Transverse Mercator Coordinate System, commonly referred to as UTM, is a global coordinate system where each zone is 6° wide at the equator and extends from 80° South to 84° North. Each zone is numbered 1 to 60 heading east from 180° west, that is, on the opposite side of the earth from the prime Meridian. Those are also split in the north and south about the equator. So, zone three, for instance, will have both a zone three north, and zone three south designation.

UTM is common for data and study areas that cover large regions, or regions outside of the United States. It is important to note that coordinates are always positive, and specified in eastings, which is the vertical axis, and northings, which is the horizontal axis.

**State Plane Zones from 80° South 84° North**

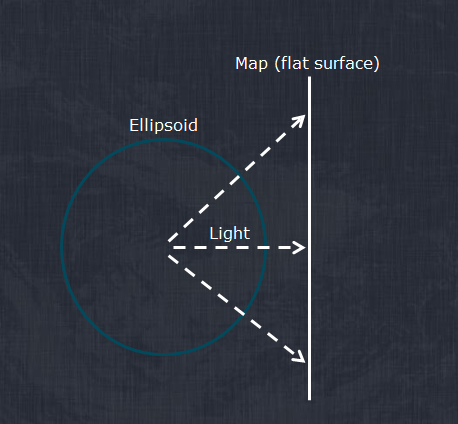
|  |  |
| --- | --- |
|  | This is an illustration of the state plane zones covering the world from 80° South 84° North. Note the line running along the equator, which splits zones into North, and South. |

**Map Projections**

## What is a Map Projection?

A map projection is defined as a systematic rendering of locations from the curved earth surface onto a flat map surface. This allows us to flatten the curved surface onto a flat surface such as a piece of paper, or computer screen. The reason why we employ map projections is because globes are not very portable, or practical to use in some cases, therefore, we use map projections to flatten the earth into a map. For a broad overview of what a map projection is watch the video.

 [Map Projections](http://www.youtube.com/watch?v=2LcyMemJ3dE) (1:00)

Basic Illustration of a Map Projection

This basic illustration displays the concept of a map projection. The map projection is broadly composed of three parts, the ellipsoid, which models the shape of the earth, a light source which is used to project features on the earth surface, and a developable surface, commonly a flat piece of paper, onto which the Earth’s features are projected, and flattened, to be used as a map.

**Developable Surfaces**

## What is a Developable Surface?

A developable surface is a geometric surface on which the curved surface of the earth is projected; the end result being what we know of as a map. Geometric forms that are commonly used as developable surfaces are planes, cylinders, cones, and mathematical surfaces.

No matter which developable surface is used to create a map, the basic idea remains the same. The features of the curved Earth are projected onto one of the four geometric forms to produce a flat map.

|  |
| --- |
| Four common geometric forms used as developable surfaces.  Plane Cylinder Cone Mathematical |

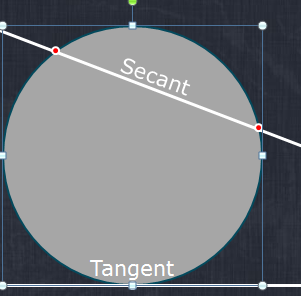
## Developable Surfaces: Interaction

The way in which an ellipsoid and developable surface interact with each other is to place the ellipsoid in different locations and different rotations to gain a desired view of map properties. In this illustration, the blue circle is an ellipsoid representing the earth. The triangle represents a cone, although we are representing it in 2-D. The idea is that the developable surface can be placed on top of the ellipsoid as a hat, or pulled down through the surface of the earth, and even rotated side to side, or forwards and backwards, to create the desired view that we are looking for in a flat map.

|  |  |
| --- | --- |
|  | Developable surfaces are placed relative to the spheroid/ellipsoid in different locations and at different rotations to gain the desired view and map properties. |

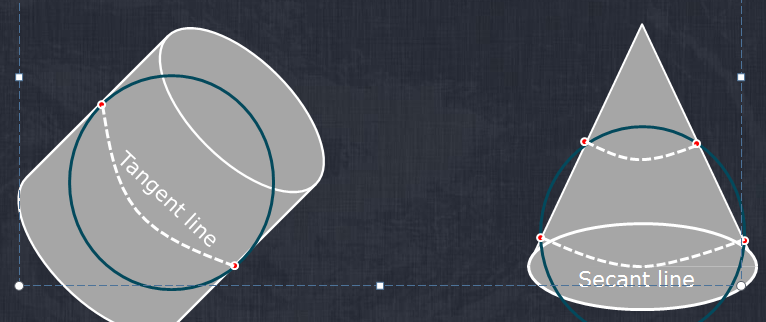
## Developable Surfaces: Interacting with the Ellipsoid

These developable surfaces will interact in a few different ways with the ellipsoid. Generally, the developable surfaces will touch the ellipsoid in either two places, which creates two secant lines, or at a single location, a single tangent line. In the illustration shown, the tangent line is touching the ellipsoid of the South Pole, which should give us a polar view of the earth. The secant intersection is intersecting the earth at two locations which provides us with an abnormal view of the northern portion of the ellipsoid. Both types of interactions are correct, as they depend on the purpose of the map, and the way in which we want to portray the earth on a flat map.

 A developable surface touches a spheroid/ellipsoid in either two secant lines or one point or tangent line.

Example: Tangent and Secant Intersection

To further illustrate the idea of a tangent and secant intersection, two more illustrations are provided. For the tangent interaction, there is a line that can be drawn around the earth at its widest point that is perpendicular to the point tangents. This is known as the tangent line. For secant interactions, two lines are drawn following the earth’s curvature between the secant intersection points.



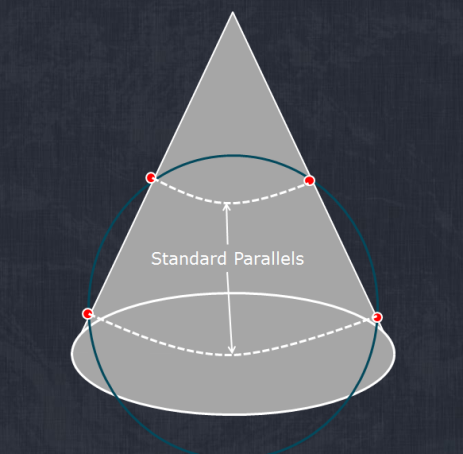
**Map Projection Parameters**

## Types of Map Projection Parameters

There are five map projection parameters. They are: standard points and lines, projection aspect, central Meridian, latitude of origin, and light source location. Let’s start with a standard points and lines and work our way down.

## Standard Points and Lines

A standard point and line is defined as a point or line of intersection between the developable surface and the spheroid or ellipsoid. In the case of a secant intersection, there will be two standard lines that would define where the developable surface intersects with the spheroid. If the developable surface happens to intersect the spheroid along a line of latitude, it is known as a standard parallel. Additionally if a standard line falls on a line of longitude exactly, it is known as a standard Meridian. When defining a map projection, you must define the standard points and lines. It is not uncommon to have a map projection follow a standard parallel or standard Meridian.



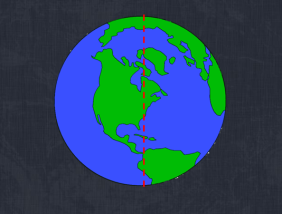
In this illustration, the cone is in a normal aspect, and with the secant intersection, the secant intersecting lines follow parallels, therefore, they are both known as standard parallels.

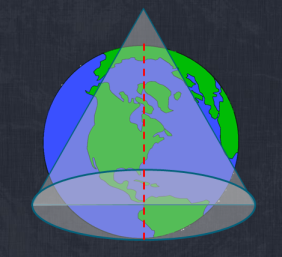
So the question is why are standard points and lines important? The reason why standard points and lines are important is because the corresponding places on the map or along the standard point to lines will have no scale distortion. That means that where the developable surface intersects with the spheroid, there is little to no distortion on our flat map. The further away from the standard point or lines, the greater the distortion or deformation that will occur on the map. Secant intersection between the developable surface and the spheroid can help minimize distortion over a large area by providing more control than a tangent intersection at a single point or line. Therefore, placement of standard points and lines is one of the most important parameters to consider when defining a map projection.

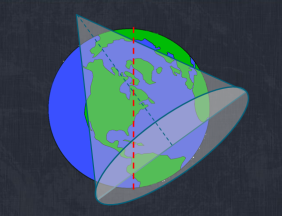
|  |
| --- |
| **Why are Standard Points and Lines Important?**   * Those corresponding places on the map will have no scale distortion. * The father away from the standard point or line(s), the greater the distortion or deformation occurs. * Secants can help minimize distortion over a large area by providing addition control. |

## Projection Aspect

The next projection parameter to discuss is the projection aspect. A projection aspect is the position of the projected graticule relative to ordinary position of the geographic grid on earth. What that means is that if the developable surface’s vertical axis coincides with the vertical axis of the earth, then this defines a normal aspect. Should the vertical axis of the developable surface differ from the vertical axis of the earth, then this would be an abnormal aspect.

This illustration displays the normal axis of the globe, which runs from the North Pole through the center of the Earth to the South Pole.

This illustration shows a cone developable surface at a secant intersection with the earth. As the vertical axis of the cone, which is displayed as a blue – line, coincides with the vertical axis of the earth, which is displayed as a red dotted line; this is considered a normal aspect. Remember normal aspect.

This illustration shows a non-aspect. Note that the vertical axis of the cone does not coincide with the vertical axis of the earth thus creating a non-aspect.

|  |
| --- |
| **Definition**  **Central Meridian**  The meridian that defines the center of the projection. |

## Central Meridian

The next projection parameter to discuss is the central Meridian. The central

Meridian defines the center point of the projection. That means that this is the Meridian, or longitude line, that displays in the center of the map. Essentially, this allows you to rotate the earth about the vertical axis to determine what portion of the earth you want to have in the center of the

map.

## Latitude of Origin

|  |
| --- |
| **Definition**  **Latitude of Origin**  The Latitude that defines the center of the projection. |

Related to the central Meridian is latitude of origin. Latitude of origin is latitude that defines the center of the projection. That means that this is the latitude that will be in the center of the map projection. Changing the latitude of origin moves the projection about the horizontal axis to determine which portion of the earth will be shown in the middle the map.

## Light Source Location

|  |
| --- |
| **Definition**  **Light Source Location**  The location of the hypothetical light source in reference to the globe being projected. |

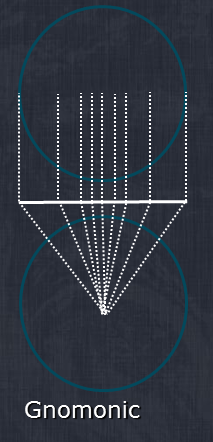
The light source location map projection parameter is the location of the

hypothetical light source in reference to the globe being projected. Remember that there are three parts of a map projection: the ellipsoid, the light source, and the developable surface. The light source is what projects the surface of the earth onto the developable surface. There are three primary positions in which we can place the light source.

## Three Primary Positions of Light Sources

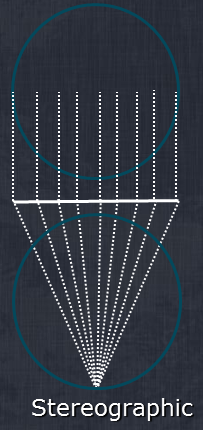
The three primary positions of my sources are gnomonic, stereographic, and orthographic.

### Gnomonic

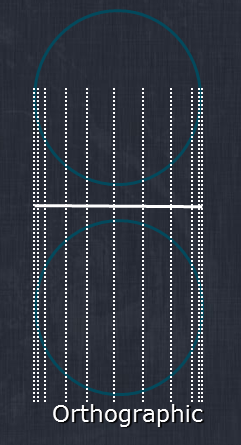
****In the gnomonic light source position, the light source is placed at the center, or core, of the earth. The light is then projected through the Earth’s surface and projects the landmasses onto the developable surface. In the illustration, the earth is the bottom circle, the lines are the light source, and the solid white line is the developable surface, in this case a plane. The top circle and the dotted lines represent where the earth will be compressed, or stretched, based on the position of the light source.

In the case of the gnomonic light source, looking at a polar projection, locations at the center of the earth are held closer to true, however, the locations towards the extremities, are elongated as they are stretched out to meet the developable surface.

### Stereographic

In the stereographic projection, the light sources placed at the opposite side of the earth from where the developable surface has its secant or tangent intersection. In this case, we see a less severe differential between where the earth is compressed and elongated, but no location is clearly free from distortion.

### Orthographic

In the orthographic position, the light is placed at a theoretical infinite distance from Earth opposite from the point of intersection or tangency. This allows formidable distortion in the center the projection, however significant compression at the extremities of the map.

Together, these five map projection properties allow us to selectively display, and distort the earth to create a map that is suitable for our needs.

**Map Projection Properties**

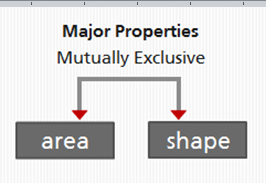
## What is Map Projection Property?

A map projection property is defined as an alteration of area, shape, distance, and direction on a map projection. Map projection properties exist because of the required conversion from a three dimensional object, for example the Earth, to a two-dimensional representation, such as a flat paper map, require the deformation of the three-dimensional object to fit onto a flat map. The three-dimensional spherical surface is torn, sheared, or compressed in order to level it into a flat developable surface.

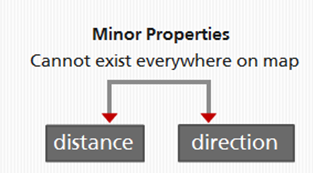
|  |
| --- |
| **Key Facts**  **Map Projection Property**  **Definition**  Alterations of area, shape, distance, and direction on map projections.  **Why?**  All maps contain error because of the 3D -> 2D transformation process.  **How?**  Rendering a spherical surface on a plane causes tearing, shearing, or compression of the surface. |

## Four Map Projection Properties

There are four map projection properties: area, shape, distance, and direction. These four map projection properties describe four facets of a map projection that can either be held true, or be distorted.



Area and shape are considered major properties and are mutually exclusive. This means, that if area is held to its true form on a map, shape must be distorted, and vice versa.

Distance and direction, on the other hand, are minor properties, and can coexist with any of the other projection properties. However, distance and direction cannot be true everywhere on a map as will be discussed soon.

## Map Distortion

Anytime we create a flat map of a three-dimensional object, we must distort the three-dimensional object. Distortions are unavoidable when making flat maps of the earth. Distortion is not constant across the map, as distortion may take different forms in different parts of the map. There are few points where distortions are going to be zero, however, distortion is usually less near the points or lines of intersection where the developable surface intersects the globe. By determining where the standard points and lines are placed will directly affect where the map will have the least and most amount of distortion.

|  |
| --- |
| **Key Facts**  **Map Distortion**  A map can show one or more but never all of the following at the same time:   * + True directions   + True distances   + True areas   + True shapes |

Equal Area Map Projection

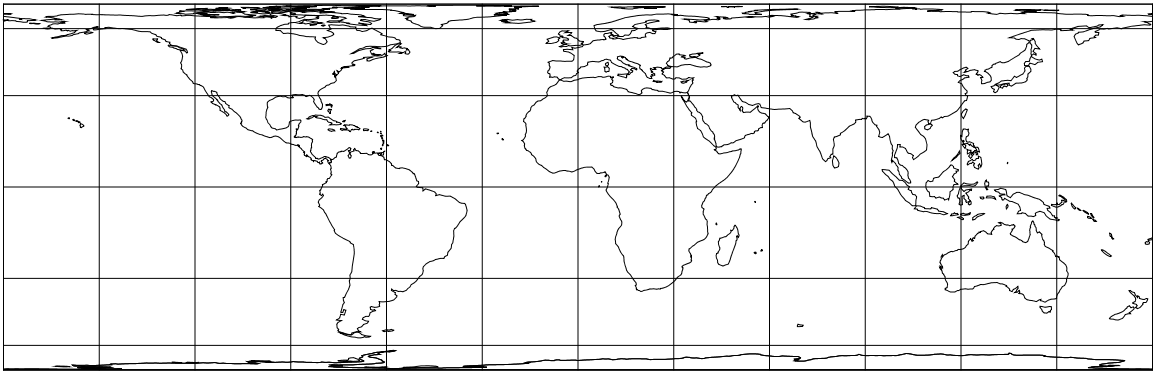
The equal area map projection, also known as the equivalent map projection, aims to preserve the area relationships of all parts of the globe. You can easily identify most equal area map projections by noting that the meridians and parallels are not at right angles to each other. Additionally, distance distortion is often present on an equal area map projection, and, shape is often skewed.

Even with the distortion of distance and shape, equal area map projection is useful for general quantitative thematic maps when it is desirable to retain area properties. This is especially useful for choropleth maps, when the attribute is normalized by area. Holding areal properties to be true, allows for an apples to apples comparison of density between different enumeration units, such as counties.

|  |
| --- |
| **Key Facts**  **Equal Area Map Projection**  **Also Known As (AKA)**  Equivalent Map Projection  **Goal**   * Preserve area relationships of all parts of globe   **Identifying Marks**   * Meridians and parallels are not at right angles. * Distance distortion is often present. * Shape is often skewed. |

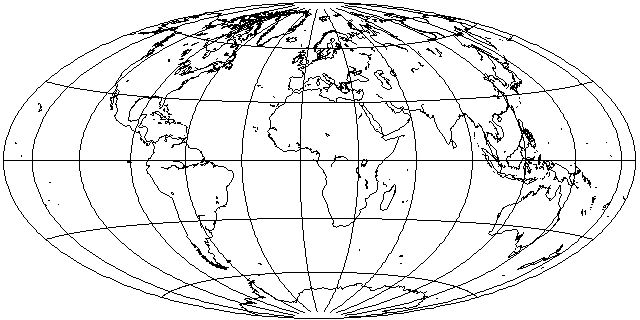
## Cylindrical Equal Area Map Projection

The cylindrical equal area map projection is an example of an equal area, or equivalent map projection, which aims to keep the areal relationships of all parts of the globe correct.



Hammer-Aitoff Map Projection

A second example of an equal area projection is the Hammer-Aitoff map projection. Again, like the cylindrical equal area projection, this map projection aims to hold areas true. Also note that on this map projection, the parallels and meridians do not intersect at 90° angles, which is a hint that lets us know that this may be an equal area projection.



## Conformal Map Projections

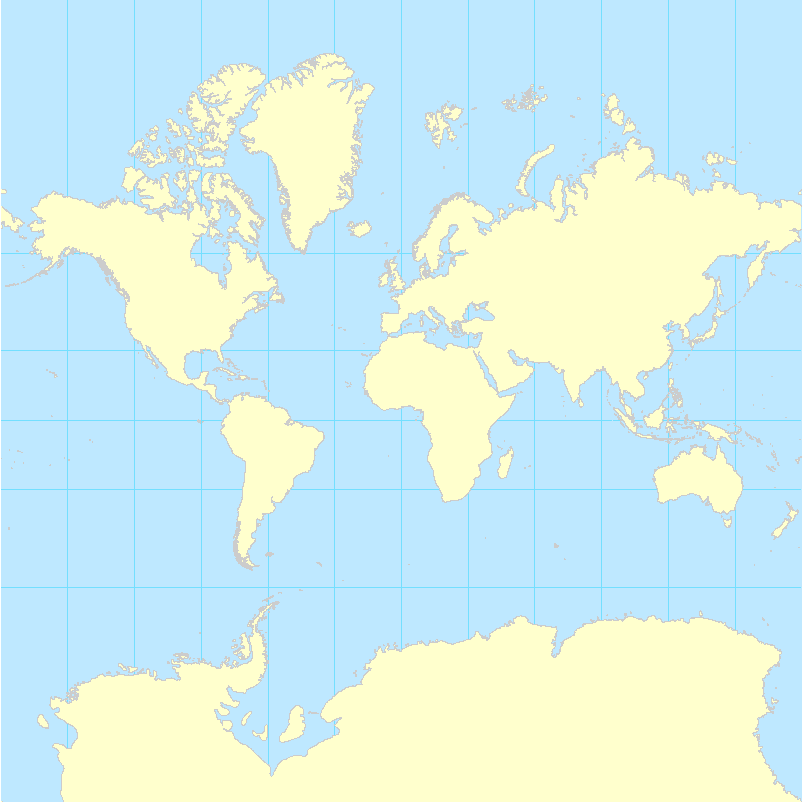
Conformal map projections, also known as orthomorphic map projection, preserves angles around points, and shape of small areas. Additionally, it allows for the same scale in all directions to or from a single point on the map. Conformal map projections can usually be identified by the fact that meridians intersect parallels at right angles, areas are distorted significantly, its small scales, and shapes of large regions may be severely distorted.

Even with the potential for large shape distortion. Conformal map projections are useful for large scale mapping and phenomenon with circular radial patterns such as radio broadcasts for average wind directions.

|  |
| --- |
| **Key Facts**  **Conformal Map Projection**  **Also Known As (AKA)**  Orthomorphic Map Projection  **Goal**   * Preserves angles around points and shape of small areas * Same scale in all directions from or to a point.   **Identifying Marks**   * Meridians intersect parallels at right angles. * Areas distorted significantly at small scales. * Shapes of large regions may be severely distorted. |

## Mercator Map Projection

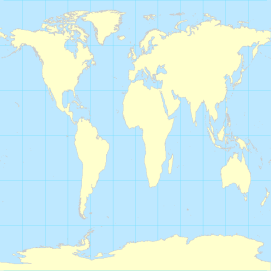
The Mercator projection, perhaps the most famous of all map projections, is a conformal map projection that preserves shape. However, notice the massive amount of distortion in the lower latitudes towards the South Pole, and the northern latitudes, near the North Pole. Also note that the parallels and meridians intersect at 90° angles.



## Equidistant Map Projection

The third map projection family is the equidistant map projection which aims to preserve great circle distances. That means a distance can be held true from one point to all other points, or from a few select points, to others, but not from all points to all other points. It is also important to note the scale is uniform along these lines a true distance from the select points on the map. Identifying marks of the equidistant map projection are that they are neither conformal nor equal area, and look less distorted.

Equidistant map projections are useful for general purpose maps and Atlas maps.

An example of an equidistant map projection is the equidistant cylindrical map projection. Notice that compared to the conformal map projection, there is less distortion at the North and South Pole, and also notices that the shapes do not look overly distorted.

|  |
| --- |
| **Key Facts**  **Equidistant Map Projection**  **Goal**   * Preserves great circle distances. * Distance can be held true from one to all other points or from a few points to others, but not from all points to all other points. * Scale is uniform along lines of true distance.   **Identifying Marks**   * Neither conformal nor equal area; looks less distorted. |

## Azimuthal Map Projection

The azimuthal map projection, also known as the true direction map projection, preserves direction from one point to all other points in the map. It is important to note that direction is not true between non-central points. Direction is only true when measured to or from the specific points chosen. Azimuthal map projection is most useful for preserving direction two or from one point, often used for navigation.

The azimuthal equidistant map projection is an example of a true direction map projection that also holds distance to be true. While not all azimuthal map projections look like this, this particular map projection allows you to measure across the poles, and around the world, to determine true distance and direction from a single point.

|  |
| --- |
| **Key Facts**  **Azimuthal Equidistant Map Projection**  **Also Known As (AKA)**  True Direction  **Goal**  Preserve true direction from one point to all other points.  Direction not true between non-central points.  **Useful for:**  Preserving direction from one point. |

## Combining Map Projection Properties

As seen on a few example map projections previously, we can combine map projection properties onto a single projection. For example, an equal area map projection can also combine parts of it azimuthal map projection. Conformal can combine with azimuthal, equidistant can combine with azimuthal, and azimuthal can combine with equal area, conformal, and/or equidistant.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Equal Area** | **Conformal** | **Equidistant** | **Azimuthal** |
| **Equal Area** | -- | No | No | Yes |
| **Conformal** | No | -- | No | Yes |
| **Equidistant** | No | No | -- | Yes |
| **Azimuthal** | Yes | Yes | Yes | -- |

**Yes** denotes they can be combined.

**No** denotes they cannot be combined.

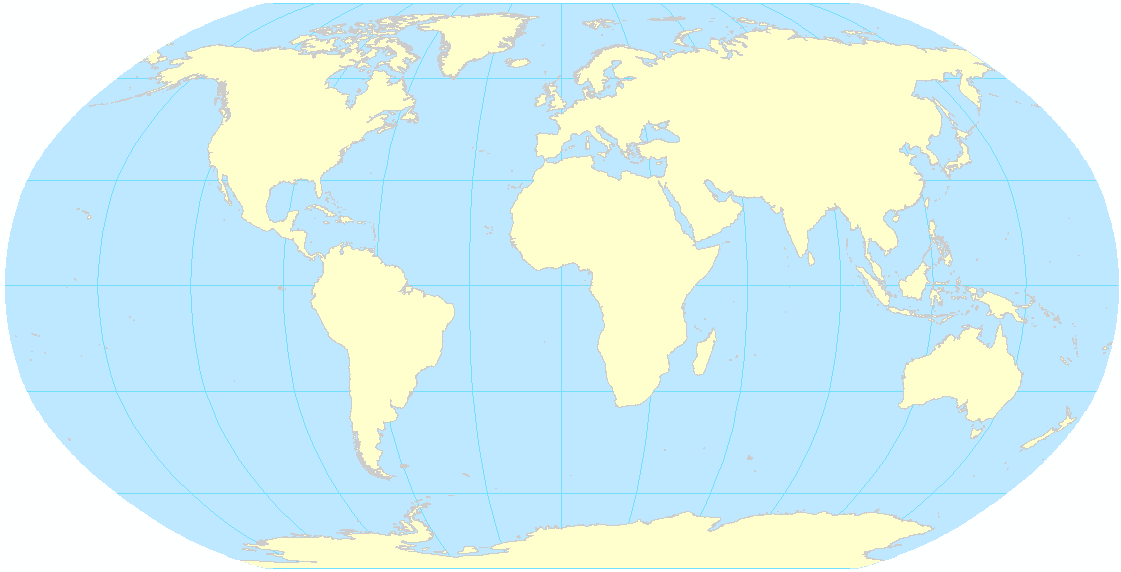
## Minimum Error or Compromise Map Projection

There is another map projection family that does not try to hold a single map projection property true. This map projection family is known as the minimum error, or compromise, map projection. The goal of the compromise map projection is to simultaneously minimize all four map projection properties, but may not hold any of the four map projection properties as true. The compromise map projection is useful for general geographic cartography.

|  |
| --- |
| **Key Facts**  **Minimum Error Map Projection**  **Also Known As (AKA)**  Compromise Map Projection  **Goal**  Simultaneously minimize all four map projection properties  **Useful for:**  General Geographic Cartography |

## Robinson Map Projection

An example of a compromise map projection is the Robinson map projection. It does not greatly distort any of the four map projection properties nor does it hold any of the four properties true. However what is nice about the Robinson map projection is that it does a reasonable job of showing the true shape, distance, direction, and size of the features of the earth.



**Determining Deformation and its Distribution over the Projection**

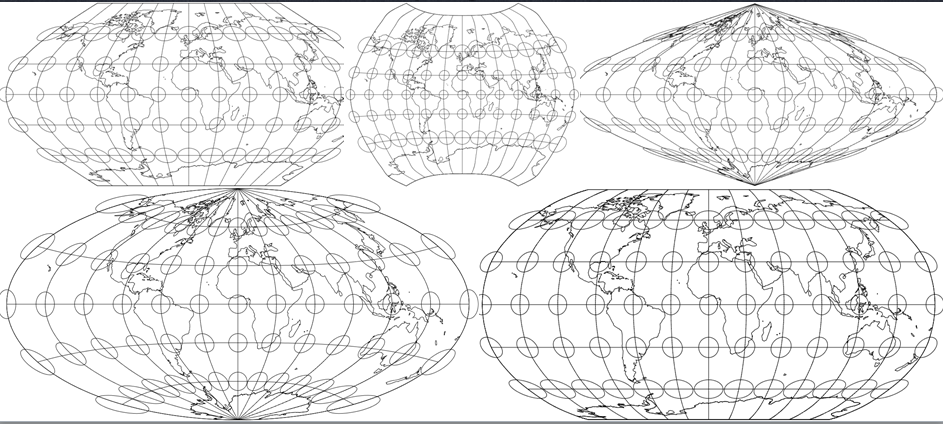
## Tissot’s Indicatrix

A common method to determine deformation on a map projection is called Tissot’s indicatrix. As we know, all flat maps distort shape, area, direction, or length when displaying features of a three-dimensional object, such as the earth. Tissot’s indicatrix helps to quantify the distortion and projection properties shown on the map projection. Tissot’s indicatrix is composed of immeasurably small circles centered at points on the earth. The earth is then projected onto a map using a map projection, and we consider the shape of the circles after projecting the map to determine the deformation and distribution of error throughout the map.

|  |
| --- |
| **Key Facts**  **Tissot’s Indicatrix:**   * helps to quantify distortion and projection properties * is composed of infinitesimally small circles centered at points on the Earth * considers the shape of the circle after projecting the map |

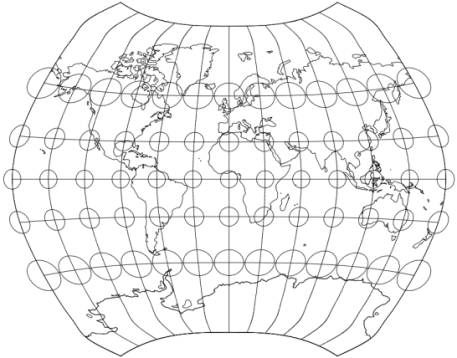
## Interpreting Tissot’s Indicatrix

As a quick illustration, if you look at the five map projections, remember that the circles were all originally the same size and were perfect circles. We will interpret Tissot’s indicatrix by seeing what happens to the circles when the earth is projected.



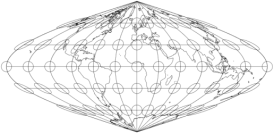
Let’s start with considering how the circles change on an equal area and conformal map projection. On equal area map projection, the circles will be transformed into ellipses, but the area of the ellipses, will be the same as the area of the original circles. That is, although they will change shape, it will not change size. On a conformal map projection, the circles will continue to be perfect circles, but their size will vary over the map.

## Tissot’s Indicatrix: Interpreting Map Projections

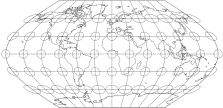


If we look at this map projection, we must consider how the circles look compared to the original size and shape of the circles. On this map projection, even if the circles are varying in size, they are all still generally perfect circles. That tells us that this is a conformal map projection, as it preserves shape.

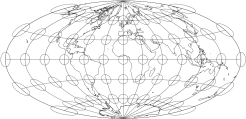
The size of the circles lets us know where deformation is greater. So for instance, on this map projection, we can see that as we move towards the north or south pole, the circles are growing greater in size very quickly, which tells us that this is where we are seeing more distortion.



Let us consider Tissot’s indicatrix on this map projection. As we move north and south, or east or west, from the Prime Meridian and the equator intersection, the circles are deforming and shape however, the size of the ellipses and circles tend to stay the same. This lets us know that this is an equal area map projection, as area is preserved throughout the map projection, even though shape is not. Again, by considering how the circle is changing throughout the map projection, we can note that there is severe shape distortion points at the North and South Pole and towards the east and west extremities.

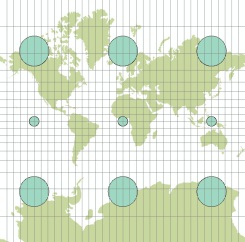


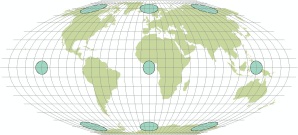
Now let us consider this map projection. It is immediately apparent that the size of the circles is not staying the same, which would indicate that we do not have an equal area projection. However, additionally, the shape of the circles is also being deformed near the extremities of the map. This lets us know this map is neither conformal nor equal area, however, it does still indicate the pattern and distribution of deformation over this map projection.

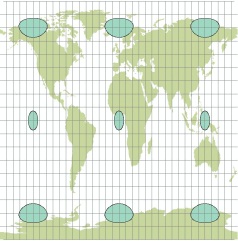
This map projection also does not hold shape or size to be true based on the interpretation of Tissot’s indicatrix. On this map projection, it is clear that shape, and area, become distorted as you near the extremities of the map, and are only held fairly well when you intersect the equator and the prime Meridian.

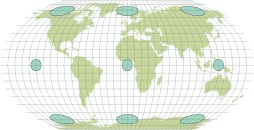
## Conformal Projection Property

Now that we have a little bit of practice interpreting Tissot’s indicatrix, let’s look at a few common map projections and see how Tissot’s indicatrix performs.

On the Mercator map projection, which is a conformal map projection, the perfect circles would continue to remain circular however they will be larger or smaller than the original circle size. This because, again, the conformal map projection property keeps shape true, but must distort size, as shape and size are two major map projection properties, and are mutually exclusive.

Now let’s consider the flat polar quartic projection, and how Tissot’s indicatrix performs on it. As the flat polar quartic projection is an equal area projection, circles will not have the same shape as a perfect circle; however, they will have the same area as the original circle. As we see on this map projection, the circles roughly have the same size; however we are still seeing some areal distortion towards the North and South Poles.

Now let us look at how Tissot’s indicatrix performs on other projection properties. On an equidistant map projection, such as the equidistant cylindrical projection, where distances are true between two points, the circles are formed into different shapes throughout the map projection. This tells us that this map projection distorts both shape, and size, however, we are not able to immediately tell that this is an equidistant map projection based solely on the size and shape of the circles.

If we look at an aphylactic map projection, which is another way of referring to a compromise map projection, note that we do not have perfect circles anywhere on the map, however, the distortion is not severe anywhere on the map. Again, this is because the aphylactic map projection distorts all four properties, but no one property distorted much greater than the other.

## Map Projection Reference Websites

These are three recommended map projection reference websites. The [USGS Map Projections](http://egsc.usgs.gov/isb/pubs/MapProjections/projections.html) poster provides illustrations and information about many common map projections, and useful matrices to show when the use of a particular map projection is appropriate. The [Radical Cartography Projection Reference](http://www.radicalcartography.net/?projectionref) also shows helpful illustrations, and information about when to use certain map projections. [Flex projector](http://www.flexprojector.com/) is a free piece of software that allows you to create your own map projections, and export them into projection files for use elsewhere.

## SUMMARY

In this lesson you learned about coordinate systems and map projections. Here are some important points to review.

* A datum is a reference surface for measuring locations on the earth.
* 2-D and 3-D coordinate systems are used to represent space and are commonly used in a Geospatial Interface System in the United States.
* A map projection is defined as a systematic rendering of locations from the curved earth surface onto a flat map surface.
* A developable surface is a geometric surface on which the curved surface of the earth is projected; the end result being what we know of as a map.
* A projection aspect is the position of the projected graticule relative to ordinary position of the geographic grid on earth.
* There are four map projection properties: area, shape, distance, and direction.

## ASSIGNMENTS

1. Lab: Exploring Coordinate Systems and Map Projections

2. Quiz: Understanding Coordinate Systems