GIS Concepts Review

Students taking the GISS Introductory Class are expected to have a solid understanding of GIS concepts and software as a prerequisite. This document is intended to review some of the mistakes and points of confusion that are common even among full time GIS professionals.

The GISS Training website and GISS Introductory Class will use these terms as consistently as possible. However, if there is something incorrect or confusing, please contact **wildfireresponse@firenet.gov** so that it can be reviewed.

Spatial Reference

Datums, Coordinate Systems, and Projections, oh my!
On the GISS Training site and in most instances, Spatial Reference is used as a broad term to describe all the information required to define a location. Sometimes also referred to as Coordinate Reference System.

It consists of a Coordinate System (Geographic or Projected, explained below), and tolerance and resolution (which will not be discussed, the default values should be used in all cases).

Images: Spatial Reference information for ArcMap (above) and ArcGIS Pro (right). This information can be found in the Layer Properties, on the Source tab.

Datum

Datum is sometimes (incorrectly) used interchangeably with Geographic Coordinate System. However, a Datum is defined as a spheroid and its reference points and orientation. This is what determines the origin and orientation of latitude and longitude lines. It is only one component of a Geographic Coordinate System.

(A spheroid or ellipsoid is a three dimensional shape like a sphere, but based on an ellipse instead of a circle)

Sphere   **Spheroid (Ellipsoid)**
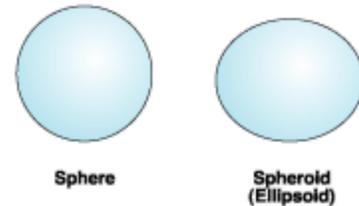
A spheroid is chosen to best represent the Earth's surface for the area where the Datum will apply. This can be the entire Earth (Earth-Centered) or one specific region (Local). A spheroid's origin and axes define its position relative to the Earth's center (Earth-Centered) or surface (Local).

The image below demonstrates this concept. The Earth's surface is depicted using the black line. The Earth-Centered Datum (WGS84) uses the Earth's center of mass as the origin and can be used for locational measurements worldwide. The Local Datum (NAD27), shown in dashed red, aligns its spheroid to closely fit the Earth's surface in North America, using a point on the surface as its origin. As a result, its center is offset from the Earth's and it does not closely align with the rest of the world..

Earth's Center of Mass

North America

Earth's Surface (variation highly exaggerated)

Earth-Centered Datum (WGS84)

Local Datum (NAD27)
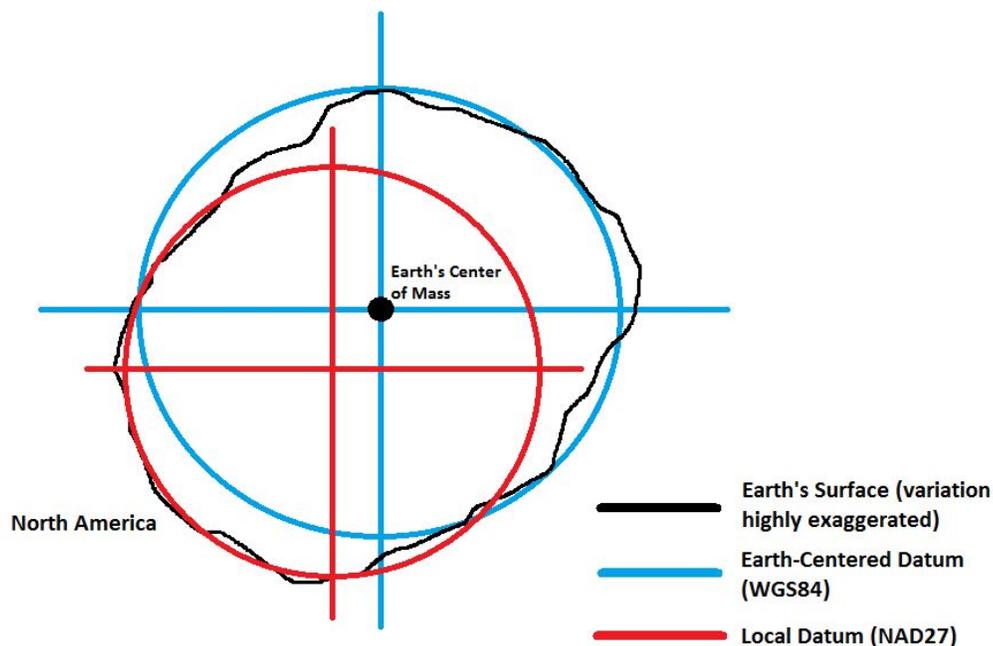
Geographic Coordinate System (GCS)
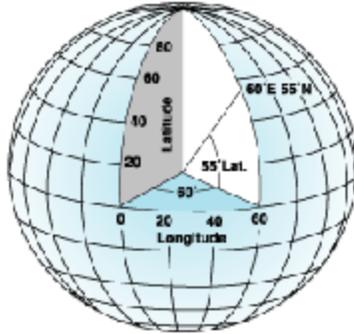
A Geographic Coordinate System (GCS) uses a three-dimensional surface to define locations.

It is made up of a Datum, Prime/Reference Meridian, and Angular Unit (usually degrees).

Positions are measured by the angle out from the center and up or over from the lines zero-latitude and zero-longitude (prime meridian).

Projected Coordinate System (PCS)
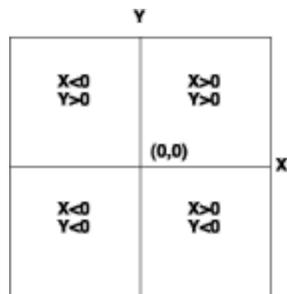
A Projected Coordinate System (PCS) uses a two-dimensional surface to define locations.

It is always based on a GCS and consists of the GCS, a projection (and projection parameters), and a linear unit of measure.

The projection and projection parameters define how the 3D surface of the GCS is converted to the 2D grid of the PCS and the measurements are defined by the linear unit.

Projection

A projection defines how the three-dimensional surface of the Earth is converted to a two-dimensional representation.

There are many different methods and a lot of complicated math. For the purposes of the GISS position, only a broad understanding is necessary, but some key factors are particularly important because a GISS could be producing maps and data all across the country.

Below are two examples of common projection types, Conical and Cylindrical. The important thing to understand about these visualizations is that projections are most accurate where the flat plane 'contacts' the sphere's surface.
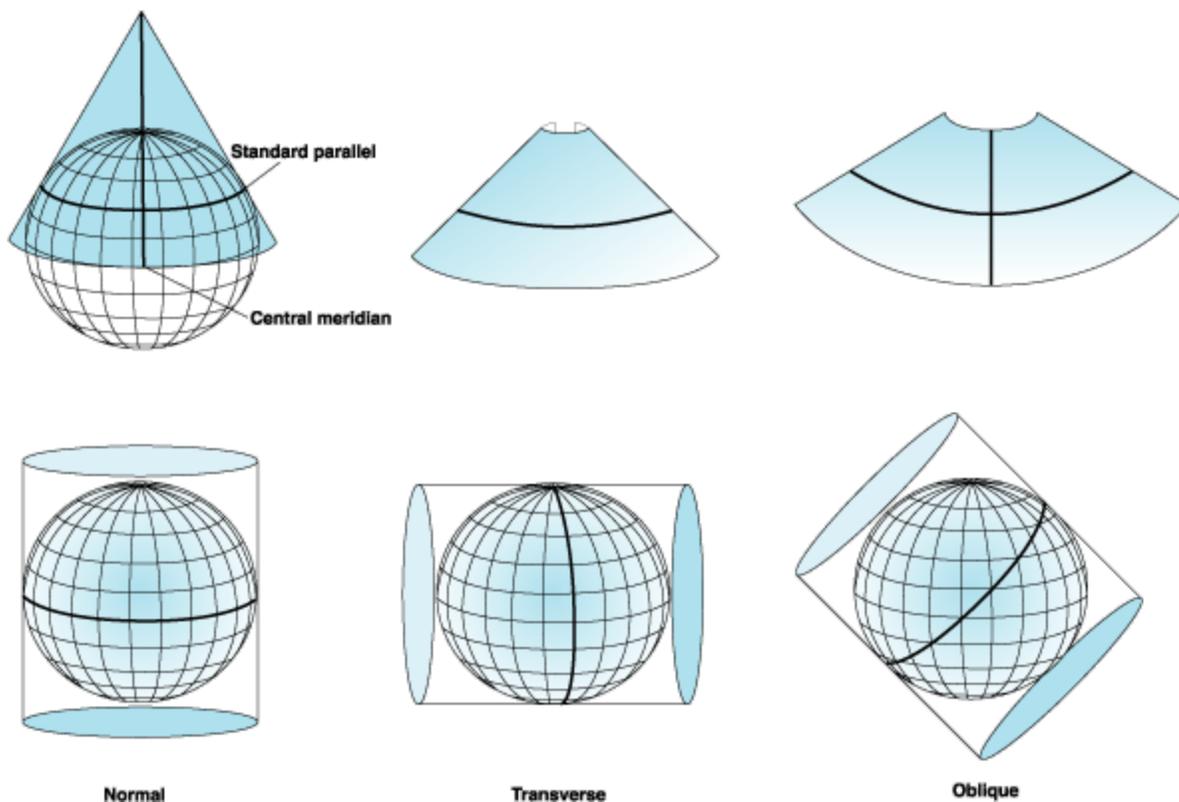
Not all projections are created equal. Transforming from a three-dimensional surface (Earth) to two-dimensions introduces errors (shape, area, distance, direction). Some projections are designed to preserve certain measurements better, sometimes at the expense of other measurements.

This is why there are so many projections and why the use of a local, projected coordinate system is so important for incident maps (the more localized the projection, the less distortion introduced).

Distortion Example

The ubiquitous Mercator Projection (a cylindrical projection).
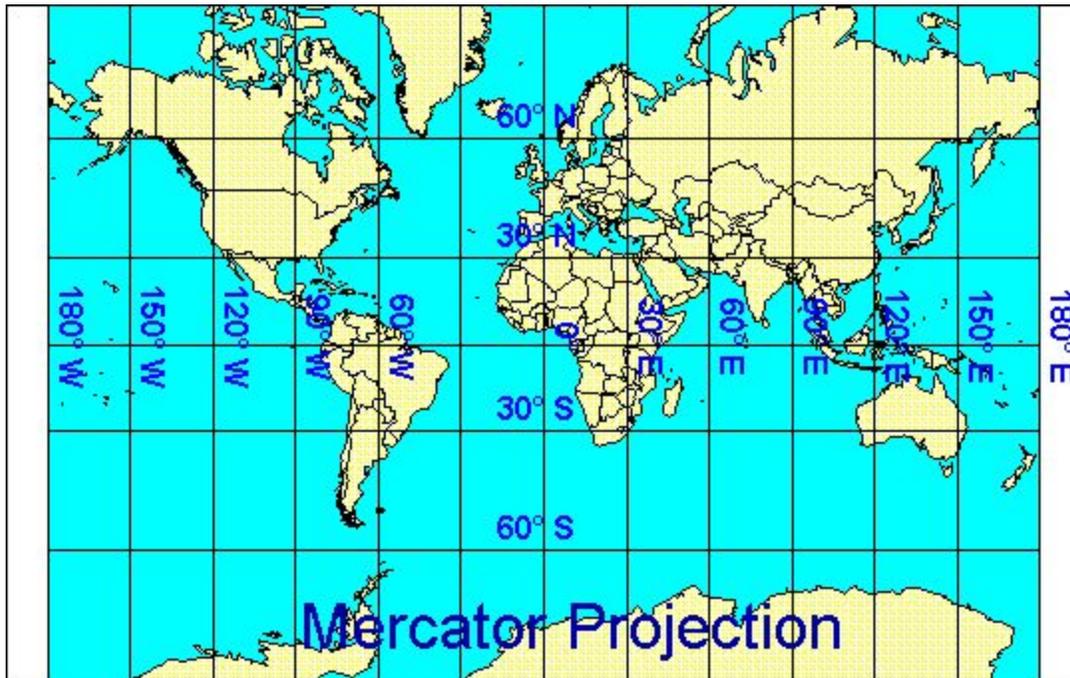
Popularized because of advantages when used for nautical navigation and perpetuated by its use in many web maps, this projection is not an accurate visual representation of the Earth's land masses. Drawing lines of longitude as parallel, when they actually converge at the poles, causes massive distortion at the higher latitudes. Greenland appears as large as South America, when it would actually easily fit within just Brazil.

For more exploration of this topic, the web site thetruesize.com provides a great visualization of area distortion caused by the Mercator projection.

WGS84

There is often confusion surrounding this term, and rightly so. The name has been used for, or as part of, many of the terms previously discussed.

WGS84 (Ellipsoid) - Established in 1984 as part of the new World Geodetic System
WGS84 (Datum) - The WGS84 Ellipsoid plus its reference to the Earth's center

WGS84 (GCS) - The WGS84 Datum plus a Reference Meridian and Degrees as a unit of measure

In all cases on the GISS Training Site, when the term is used without explicitly specifying datum or GCS, WGS84 refers to the Geographic Coordinate System.

The Event Features are distributed in the WGS84 GCS.

Data Frame 'Projection' vs Feature Class 'Coordinate System'

What is really meant by the two commonly used terms Data Frame "Projection" and Feature Class "Coordinate System" is Coordinate Reference System or Spatial Reference. These technical misnomers are common but should always make sense within the context.

Every spatial data set will have spatial reference (SR) information associated with it. This tells the software how to interpret the coordinates in the data. This information is stored in the data properties. If the SR is "Unknown" it must be *defined* (see below) prior to using the data.

A data frame also has its own SR information. This is stored in the MXD (ArcMap) or Map View (ArcGIS Pro) properties.

A data frame in ArcMap or ArcGIS Pro can be set to a different spatial reference than the data displayed in said data frame. The software will 'project on the fly' from the feature's SR to the data frame's SR.

Note: In a new MXD, the data frame SR will be set to SR of the first data added to it.

Best practice when using the Event Features is to leave the data in the WGS84 GCS and only set the Data Frame to the local PCS. In addition to saving time and preventing human error in the conversion, this allows the geometry of the Event Line and Polygon to be calculated in the local PCS while the Lat/Long of the Event Points can be calculated in WGS84 GCS.

Geographic Coordinate Systems Warning

When data is added to a map that uses a different GCS than the data frame, the following warning message will appear (unless it has been disabled).
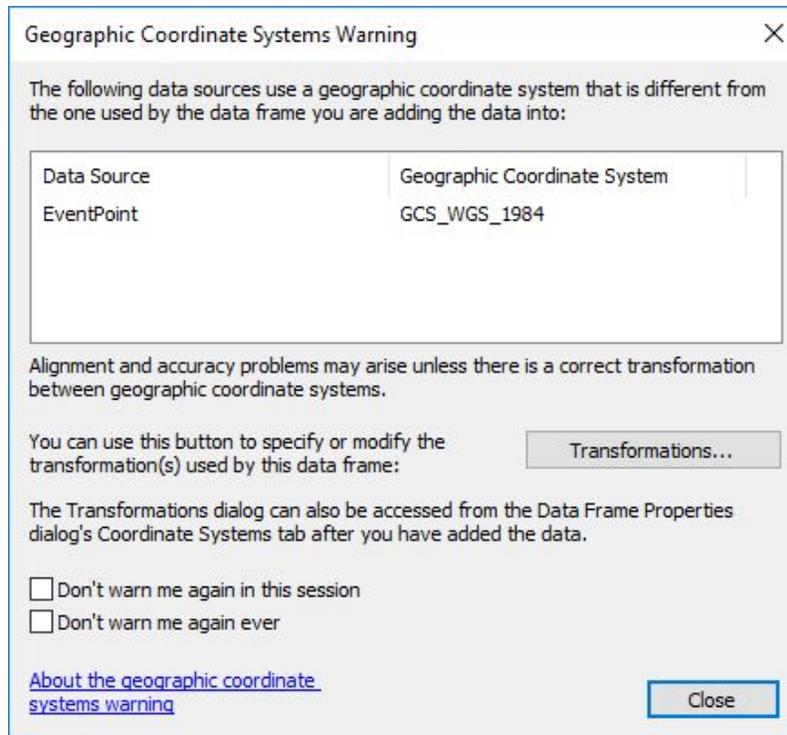
This warning is prompting the selection of a geographic transformation. A transformation is essentially the math that converts coordinates from one datum to coordinates in another because the same coordinates in different datums will result in different locations.

See the ArcGIS Blog post About geographic transformations and how to choose the right one for an excellent write up on this topic.

Selecting a Projection for Incident Maps

There is no single correct projection to choose for an incident. It should be a local (not global), projected coordinate system and the same PCS should be used across all maps.

There are, however, some incorrect choices.
- Geographic Coordinate Systems should not be used for incident maps.
- The PCS should be designed for use in the geographic area of the incident (ie don't use *Colorado State Plane North* for southern Colorado).
- Avoid Mercator (or other global PCS) and other conformal (angle preserving) projections in favor of more localized, equal-area projections.

UTM is usually a good choice as it covers a large area and people are familiar with it, except if the incident straddles two zones (remember, the further from a PCS's origin, the greater the distortion). Also be certain that the correct zone is used.

State Plane covers a smaller area but is highly accurate. Local data will often be in State Plane and may be easiest to use if there is an abundance of data available. However, the smaller coverage makes it more likely for an incident to leave the area of accuracy.

Some areas have specialized regional projections. *California Teale Albers* is based on Albers Equal Area Conical projection and popular in California because it can be used for the whole state with reasonable accuracy.

It is encouraged and always acceptable to reach out to local GIS resources if there is any question as to which projection is best suited for the incident area.

Project vs Define Projection (Geoprocessing Tools)

These two tools are often confused which can lead to major data issues.
To put it simply, the Project tool is used to **change** the projection of a feature class or shapefile from one to another and the Define Projection tool is used to **assign** a projection when it is *Undefined.*

When Define Projection is used on data that already has a defined projection, it does not convert anything, it simple changes the metadata.
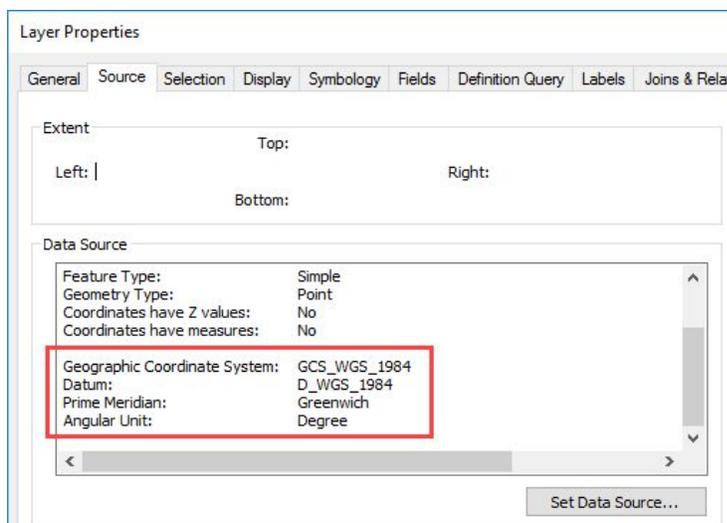
Use **Project** when the feature class or shapefile already has a defined coordinate system.
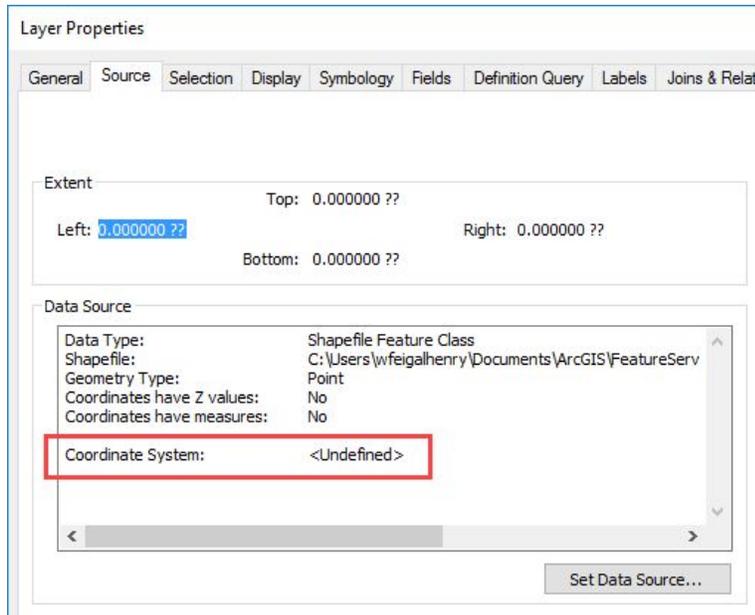
Use **Define Projection** when the coordinate system of the feature class or shapefile is <Undefined>. **Note:** The features will only display correctly if the correct coordinate system is used. Not just any system can be applied.

Example

A point in WGS84 GCS at 39.7° Lat by -105.1° Long (Denver, CO) that has Define Projection run on it to change the projection to NAD83 UTM Zone 13 will be moved to the middle of the Pacific Ocean.

This is because the software isn't changing the locations, just how they are interpreted. Lat/Long is referenced from the intersection of the Equator and the Prime Meridian, off the coast of Africa, while UTM coordinates are referenced from the center of each Zone (which is why each zone has its own projection). The issue is compounded further by the use of different units

of measurement, degrees vs meters. One degree is of Latitude is approximately 111,000 meters.

When the Project tool is used with the same input and output coordinate systems, there will be no appreciable change in the point's map location. This is because the tool takes both the input and output coordinate systems into account and and actually converts from one to the other.

Working with GPS data

There are several ways to receive GPS data each with its own concerns to keep in mind as it is processed.

Called-In Coordinates

Coordinates will often be provided for things like Helispots and Drop Points from the field as just an X and a Y.

It is very important to know the datum set in in the GPS unit used to collect the point because, as discussed previously, the same coordinate values can be in completely different locations depending on the datum.

The WGS84 Datum is the default standard for GPS, but this should not be assumed as the coordinate format and datum can be changed in the settings. The datum set in the GPS unit should always be confirmed with whomever is supplying the coordinates.

GPX Files

GPX files are always stored in WGS84 GCS.

The *GPX To Features* geoprocessing tool will convert a GPX file to an Esri feature class. This feature class can then be treated like any other incident data.

MXDs, APRXs, and LYRs

The most important thing to remember is that none of these files actually store any data (as in features, with a location and attributes). They only store the file path where the data should be found, which can cause its own problems in the way we use them as GISS. It is crucial to always be aware of where your layers are "pointing" so that you do not edit or create products with data you did not intend to.

MXDs

Often referred to as Maps or Map Documents in ArcMap, and in the case of the incident file structure, Projects (they go in the \projects folder).
Each one consists of a map and a layout that are directly tied to each other, so every product will require its own MXD.
MXDs store everything that makes data into communicable information: links to all the data files displayed, symbology, labels, and a Layout that can have other crucial elements like a graticule, legend, logo, and text elements (title, credits, callouts).
More information can be found in the Esri documentation.

APRXs

A crucial change that comes with ArcGIS Pro is the switch from MXDs to APRXs. While the APRX can be thought of as the new MXD, it is also so much more, deserving of the new title, "Project," instead of just "Map." A single APRX is more like Catalog plus many MXDs all rolled into one.
Just like in Catalog, folder and server connections can be stored in an APRX, but they can be project specific and will not automatically show up in a new APRX.

Two main components of the APRX are the Map View and the Layout View. Together, they are similar to an MXD except that they are not directly tied together. A single Map View can be used in multiple Layout Views. This allows multiple products to be produced from a single APRX.
For example: a set of division maps that all use the same data, are symbolized and labeled the same, are in a single Map View which is then added to multiple Layout Views, each covering a different division. This allows updates to be made in a single location, improving efficiency and consistency.
More information can be found in the Esri documentation.

Layer Files

Layer files store the data path and all the properties that can be set in an MXD or Map View. They can be saved from both ArcMap and ArcGIS Pro (*.lyr* and *.lyrx* respectively) from both a single layer or a group layer.

There is no interface to a layer file, it cannot be opened on its own and is meant to be used by ArcMap or ArcGIS Pro. They are very useful for both sharing actual data (when the data is stored in a shared location such as a network drive, like a group layer of Topos used in many incident maps) or sharing just the settings (for applying to new data, like the Template Layer Files that store the Event Symbology).

More information on using Layer Files as a GISS can be found in the Using Event LYR Files job aid.