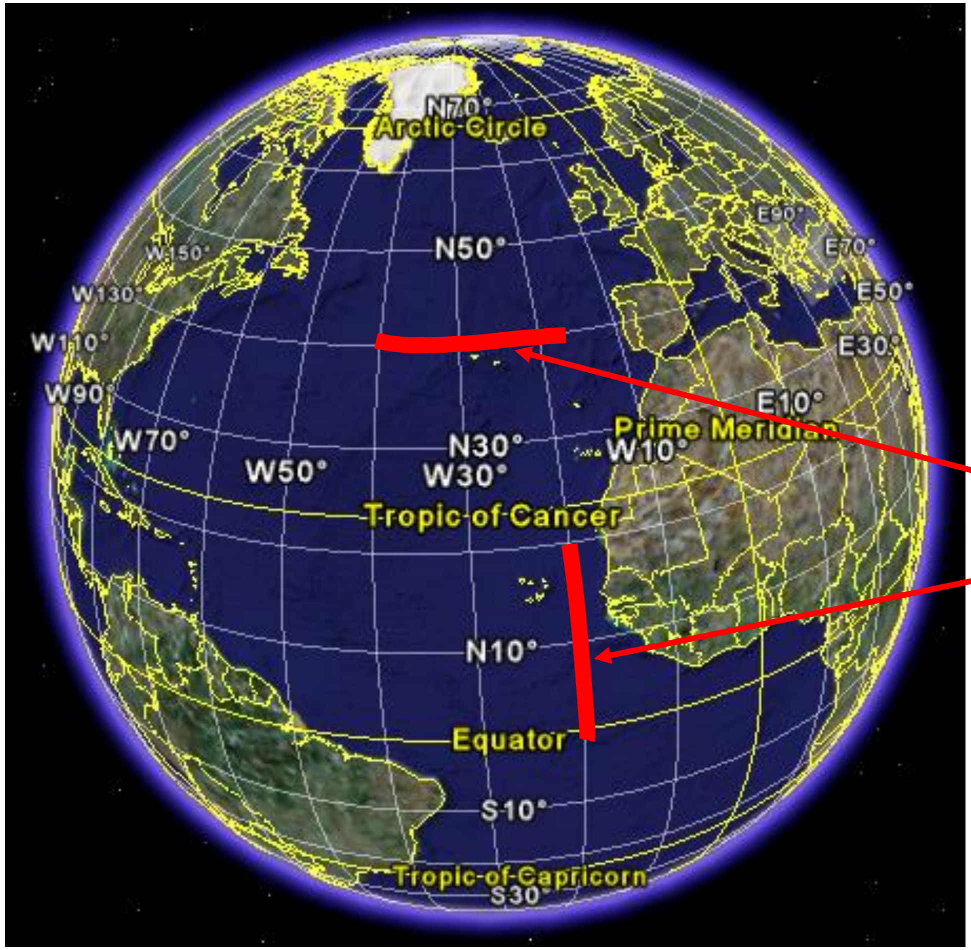
Geographic Coordinate System



Latitudes (Y axis) values change from south to north

Longitudes (X axis) values change from east to west

Parallels (lines of equal latitudes, parallle to equator)

Meridians (lines of equal longitudes, parallel to Prime meridian)

Example of coordinate system definition:

Units: degree
Name: WGS84
Datum: WGS84

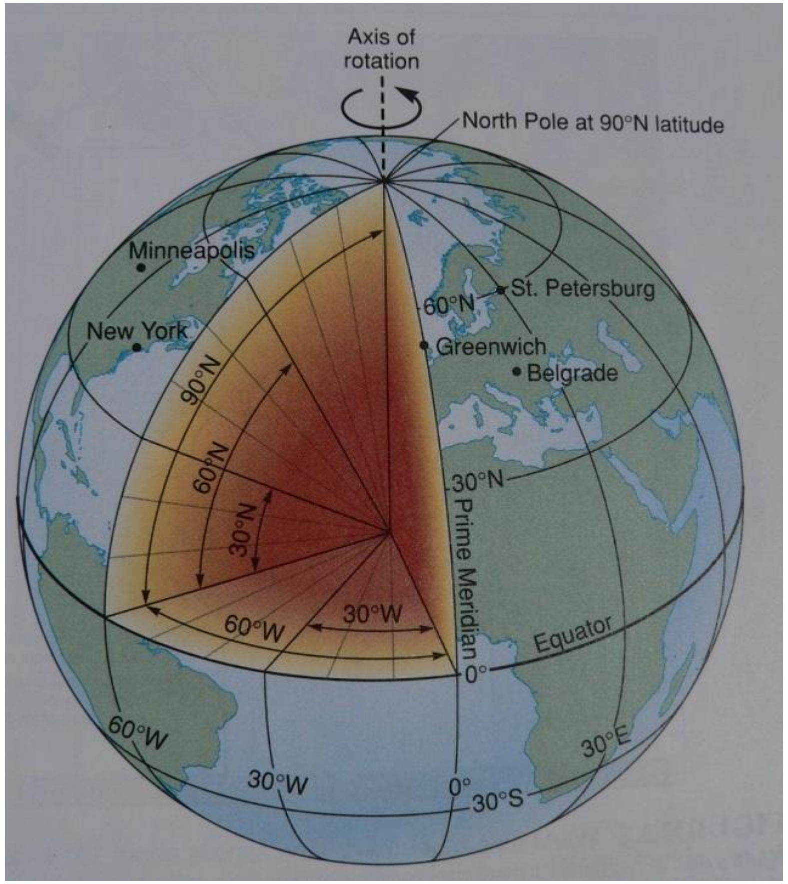
Units: decimal degree (1 degree on equator = 111.32 km; 45 deg latitude = 78.85 km); Units define precision of your GIS data. For example, loss of one decimal in decimal degree will result in 10-12 km error, three digits – 111 m. So, keep minimum number at 5 or 6 to be within 1 or less meters.

Spatial structure: Longitudes and latitudes; Earth radius (semimajor: 6,378,137 m; semiminor: 6,356,752.3 m); Prime meridian: Greenwich

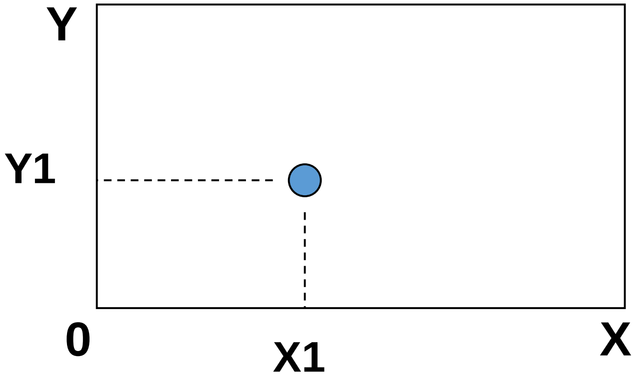
Main parameters you need to know of any coordinate system: Name of coordinate system; Units; Horizontal/Vertical Datum

Geographic Space in GIS:

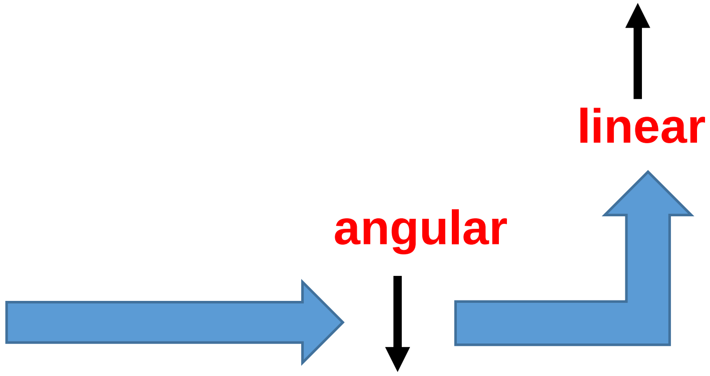
Sphere (unprojected)



Euclidian/Cartesian Space (projected)



Units: meters, feet



Units: degree, minutes, seconds or decimal degree

<u>Projections are needed to calculate areas and distances with certain accuracy</u>

Since computers are based on binary system, <u>GIS can not use Deg. Min. Sec.; it uses decimal degree</u>

Geographic Projections:

Transformation of globe to flat surface **cannot** preserve all properties of the original sphere.

Some of these sphere properties are:

1. All meridians converge at poles
2. Parallels decrease in length toward the poles
3. The scale of the surface of the globe is the same in all directions

During projection process these three properties are distorted.

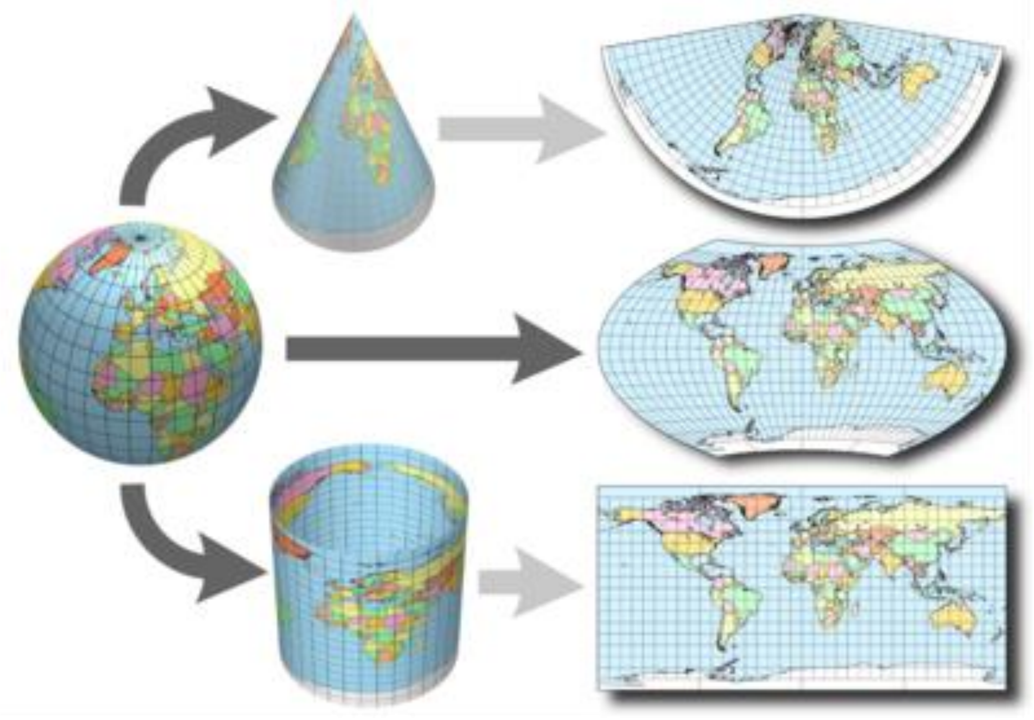


Image source: https://www.slideshare.net/shamjithkeyem/surveying-ii-ajith-sir-class-234

Geographic Projections:

Conformal: preserves **angles** and **shapes**;

Equivalent (or Equal Area): preserves **areas**

Equidistant: preserves **distances**

Azimuthal: preserves **directions**

Conformal and Equivalent are mutually exclusive and represent global properties (i.e. apply to the entire map projection)

Equidistant and Azimuthal represent local properties (i.e. apply to the center of projection)

Geographic Datums:

Datum is mathematical model of the Earth which serves as the reference or base for calculating the geographic coordinates of a location

Uses: semimajor (equatorial) and semiminor (polar) radius measures; flattening ratio.

Datum examples:

Clarke 1866
NAD27 (North American datum1927)
NAD83 (North American datum 1983)
GRS80 (Geodetic Reference System 1980)
WGS4 (World Geodetic System 1984)

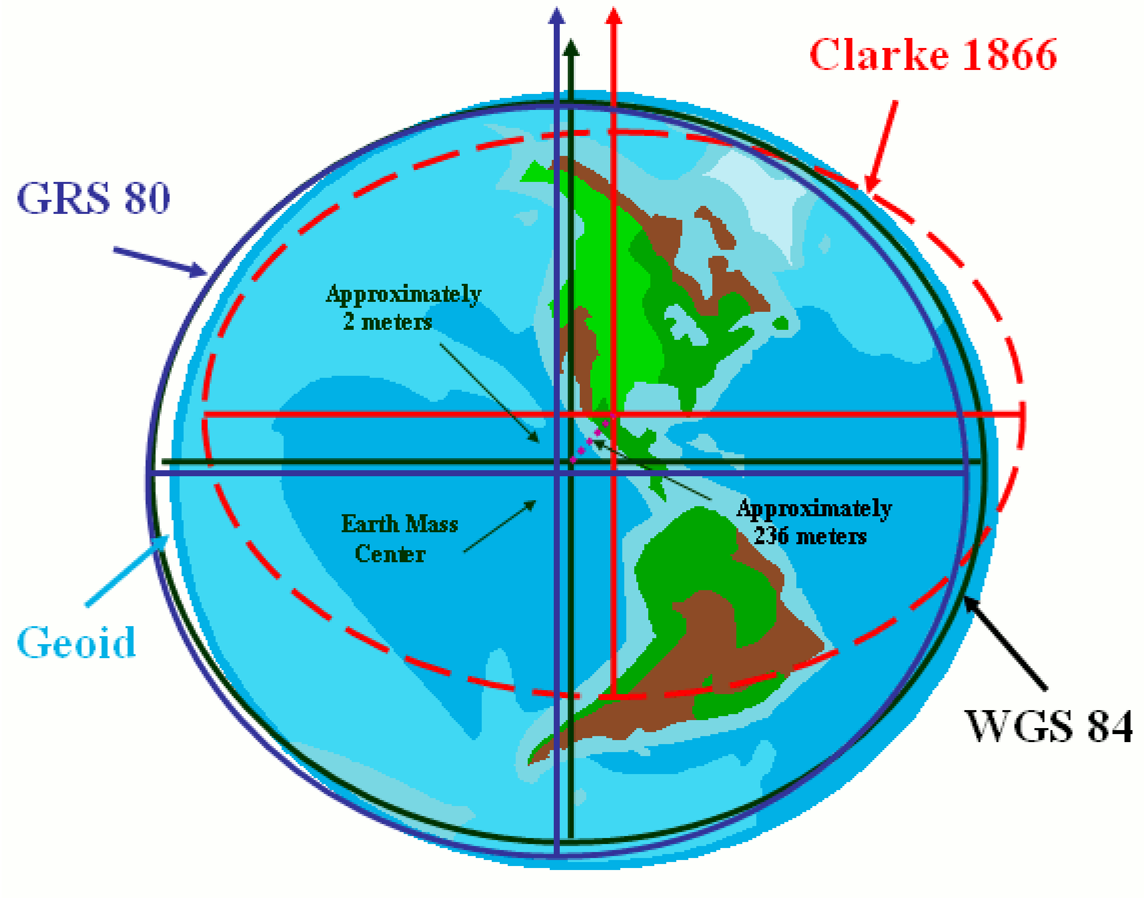


Image source: https://vdatum.noaa.gov/docs/datums.html

Things to remember and understand while using GIS:

1. **Geographic coordinate system** is based on a datum. It includes datum definition as a part of spatial reference. Always know your datum! Most typical one now is WGS84.
2. **Geographic projection is based on coordinate system and datum**. **It includes coordinate system and datum** as a part of its spatial reference structure.
3. **Both, geographic coordinate systems and projections** are generally referred in GIS as a “**spatial reference**”
4. In ArcGIS spatial reference of GIS raster data (grids, images) can be accessed by right-click on data (in ArcMap or ArcCatalog) → Properties → Source (Tab).
5. Spatial reference of GIS vector data (shapefiles) can be accessed through:
   a) .PRJ files (shapefile structure) or .TFW, JPW (images); these file can be either present or not;
   b) View shapefile spatial reference right-click in ArcMap TOC (or in ArcCatalog) → Properties → Source (Tab).
6. Spatial reference of your ArcGIS project can be viewed through ArcMap View properties: ArcMap → View → Data Frame Properties→ Coordinate System (Tab)

Universal Transverse Mercator (UTM) Projection

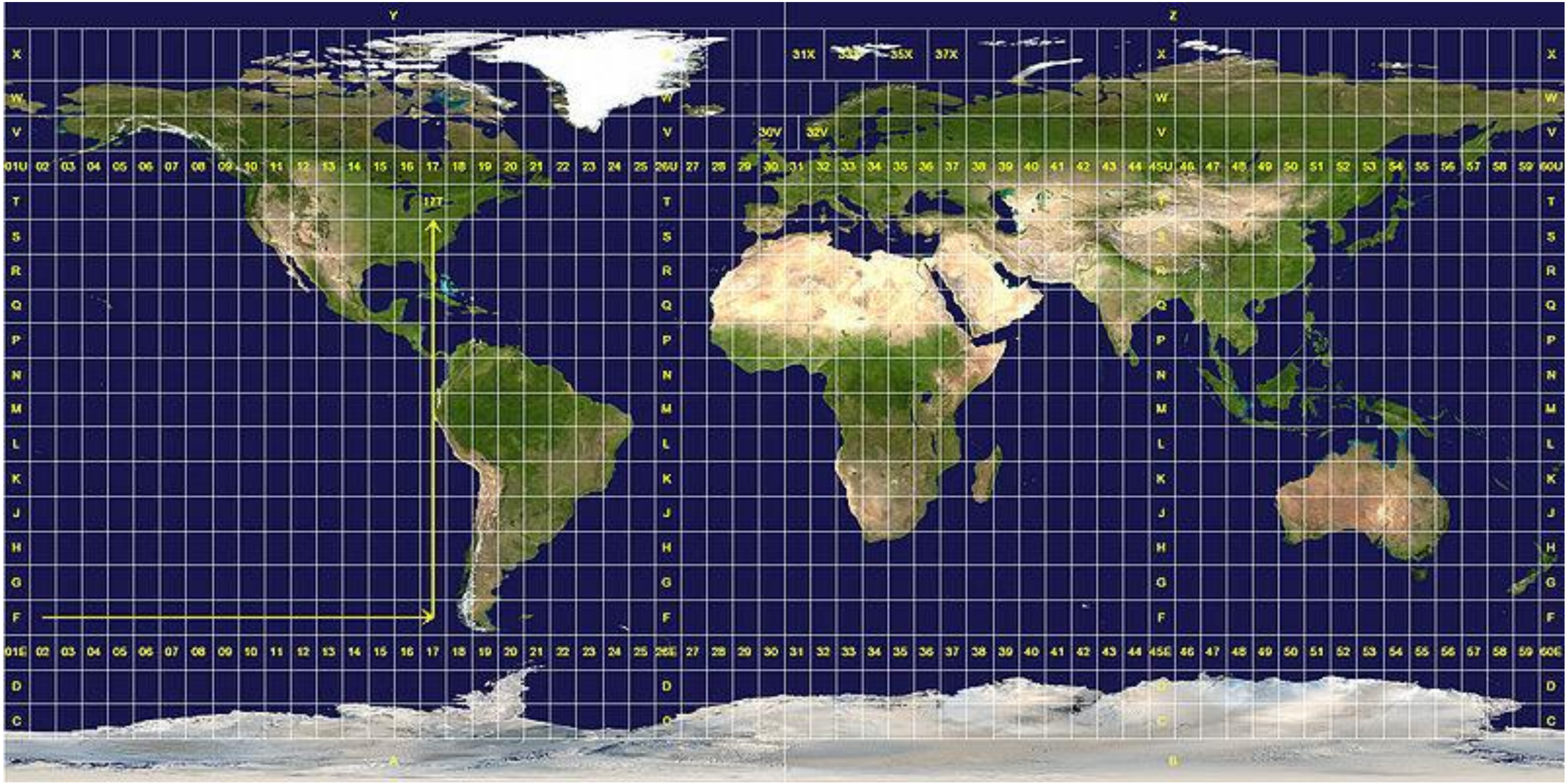


Image source: http://wiki.gis.com/wiki/index.php/File:Utm-zones.jpg

One of the most commonly used for up to few hundred kilometers segments

Universal Transverse Mercator (UTM) Structure:

Units: meters or feet;

Spatial structure: 60 zones, each zone = 6 degree (i.e. approx. 674,000 m wide).

Main parameters you need to know:

1. Zone number and orientation (north or south, i.e. 18N or 18S);
2. Units (meters or feet); X – easting; Y - northing
3. Datum (e.g. NAD27, NAD83, NAD84 or WGS84)

   where NAD – North American Datum.

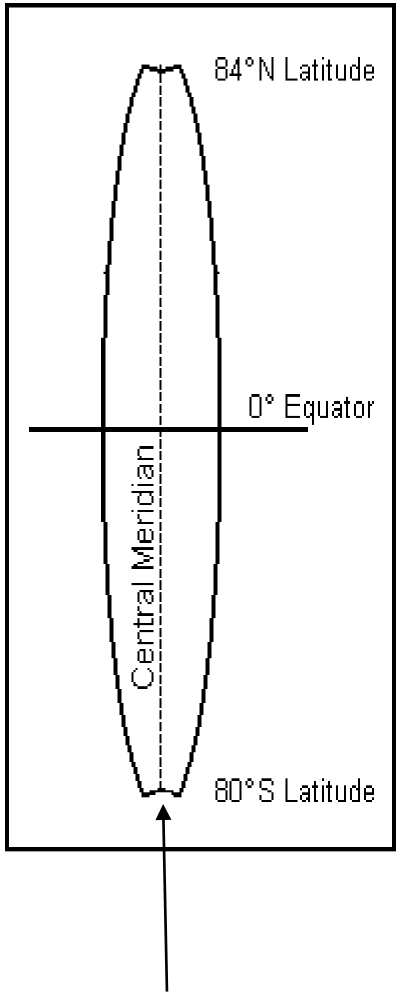
   WGS – World Geodetic System

Accuracy: meter/sub-meter

Example for New York:

Units: meters;
Zone: 18 North or 18N;
X: 587420 (distance from the beginning of the zone, i.e. 587 km east);
Y: 4517571 (distance from equator, i.e. 4,518 km north) ;
Datum: NAD27

UTM Zone



False easting = 500,000 m

State Plane Coordinate System (SPCS)

The State Plane Coordinate System (SPCS) is a system that uses **plane rectangular coordinates**. It was developed in the 1930s by the U.S. Coast and Geodetic Survey to provide a common reference system to surveyors and mappers. This coordinate system divides all fifty states of the United States, Puerto Rico and the U.S. Virgin Islands into over 120 numbered sections, referred to as zones (or FIPS, Federal Information Processing Standard). In the SPCS, each state has its own zone(s). Each zone has an assigned code number that defines the projection parameters for the region. The SPCS does not work across states.

One of the most commonly used for local surveys and engineering applications

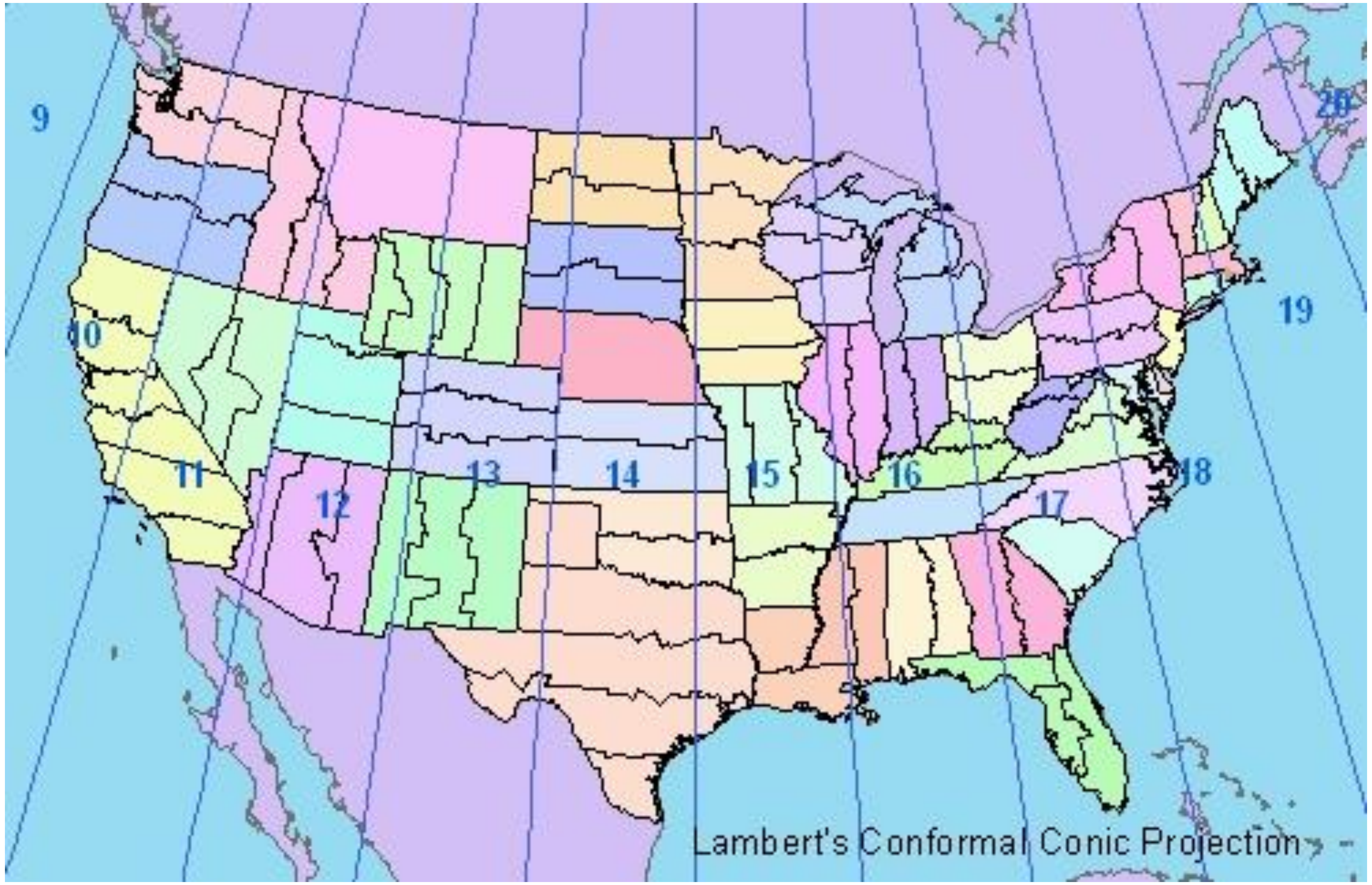


Image source: http://wiki.gis.com/wiki/index.php/File:StatePlane.jpg

State Plane Coordinate System (SPCS)

Units: feet (in general) and meters (less common);

Spatial structure: over 120 zones in US; Each **zone** or **FIPS** has its own central meridian or standard parallels to maintain accuracy. States that are elongate from north to south, such as California, use a Lambert conformal conical projection. States that are elongate from east to west, such as New York, use a transverse Mercator projection. This is done to minimize the distortion within each zone.

Main parameters you need to know:

1. Zone number: 3102 (New York Central) or 3101 (New York East).
2. Units (meters or feet);
3. Datum (e.g. NAD27 or NAD83), where NAD – North American Datum.

Accuracy: meter/sub-meter/sub-foot

Example for New York:

Units: feet;
Zone: 3102, New York Central;
X: 750675 (distance from the western beginning of the zone);
Y: 555107 (distance from southern beginning of the zone) ;
Datum: NAD83;

Difference in spatial reference of data can result in errors and problems while using GIS. You need to know your spatial reference!

An example for New York City:

		X	Y
Geographic Coordinates:	degrees, min, sec:	-73^o 55’ 31’’	40^{o}48’ 07’’
	decimal degrees:	-73.92	40.80
UTM, NAD27, zone 18N, meters:		590641	4517333
SPC, New York Central, feet:		1235867	303312

Practical advice: It is useful to know latitude (Y) and longitude (X) ranges of various spatial reference’ values related to your location or area of interest to be able to “guess” spatial reference of data without metadata or associated “projection” files. This usually comes from experience by working in certain area with variety of data in different spatial reference systems.

General Hints on spatial reference in New York area:

This is an example of useful information on spatial reference if you work in New York area. I used it a lot while working with data without spatial reference. This happens because people are generally sloppy and control is not always there. So, be prepare to fix problems yourself!

	Longitude	Latitude
Geographic Coordinates: degrees, min, sec:	-73^o 55’ 31’’	40^{o}48’ 07’’
decimal degrees:	-73.92	40.80

For this spatial reference the max number of digits in longitude will be always 3, i.e. 180 (eastern or western hemisphere). The max latitude will be always 2 digits (southern or eastern hemisphere).

UTM, NAD27, zone 18N, meters:	590641	4517333

For this spatial reference of New York state the maximum number of digits in longitude is always 6 and number of digits in latitude is always 7 (i.e. distance in meters from equator)

SPC, New York Central, feet:	1235867	303312

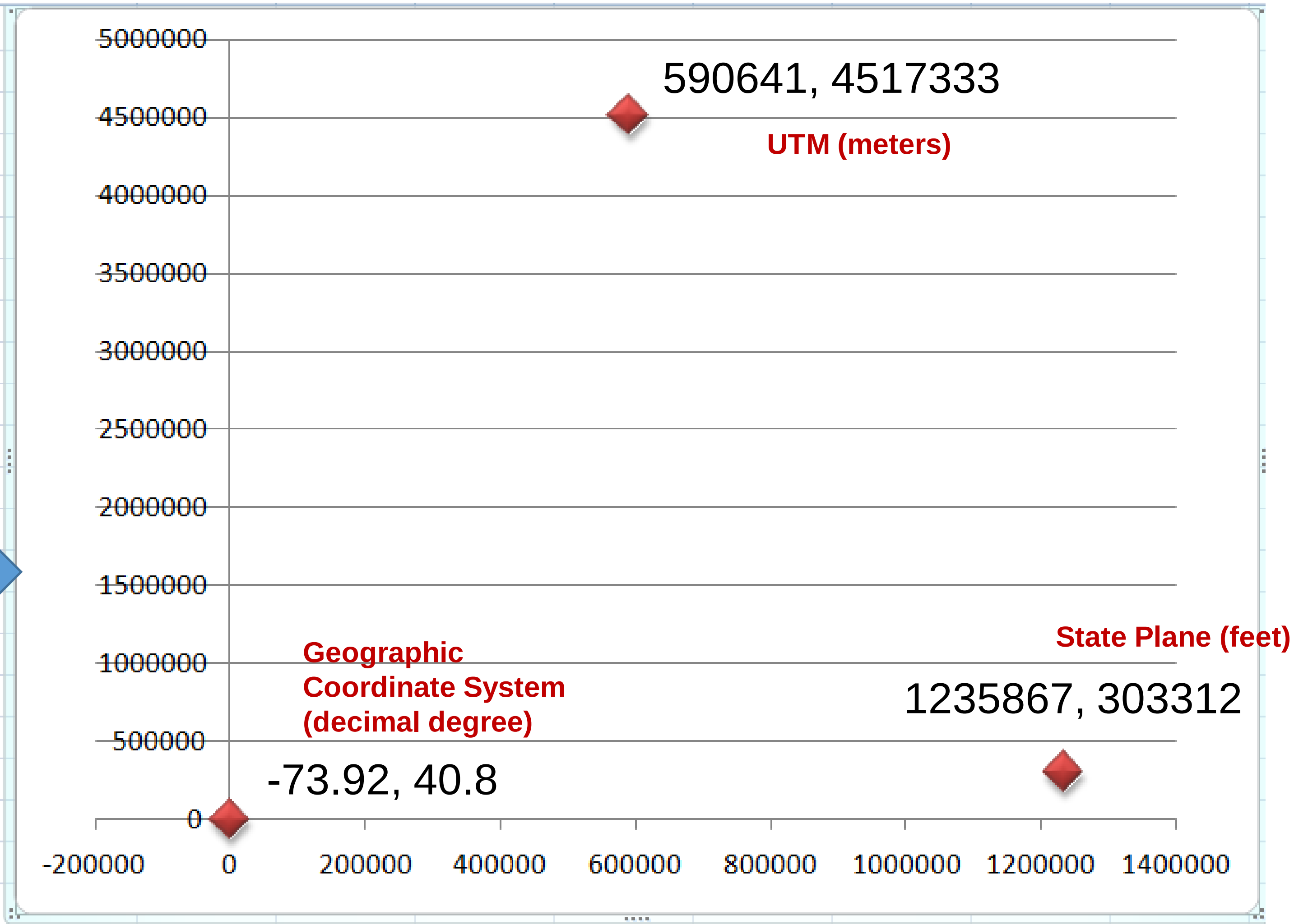
This spatial reference will generally have up to 7 digits in longitude and 6 digits in latitude

Difference in spatial reference units OR why the same place in different spatial reference system is not in the same location?

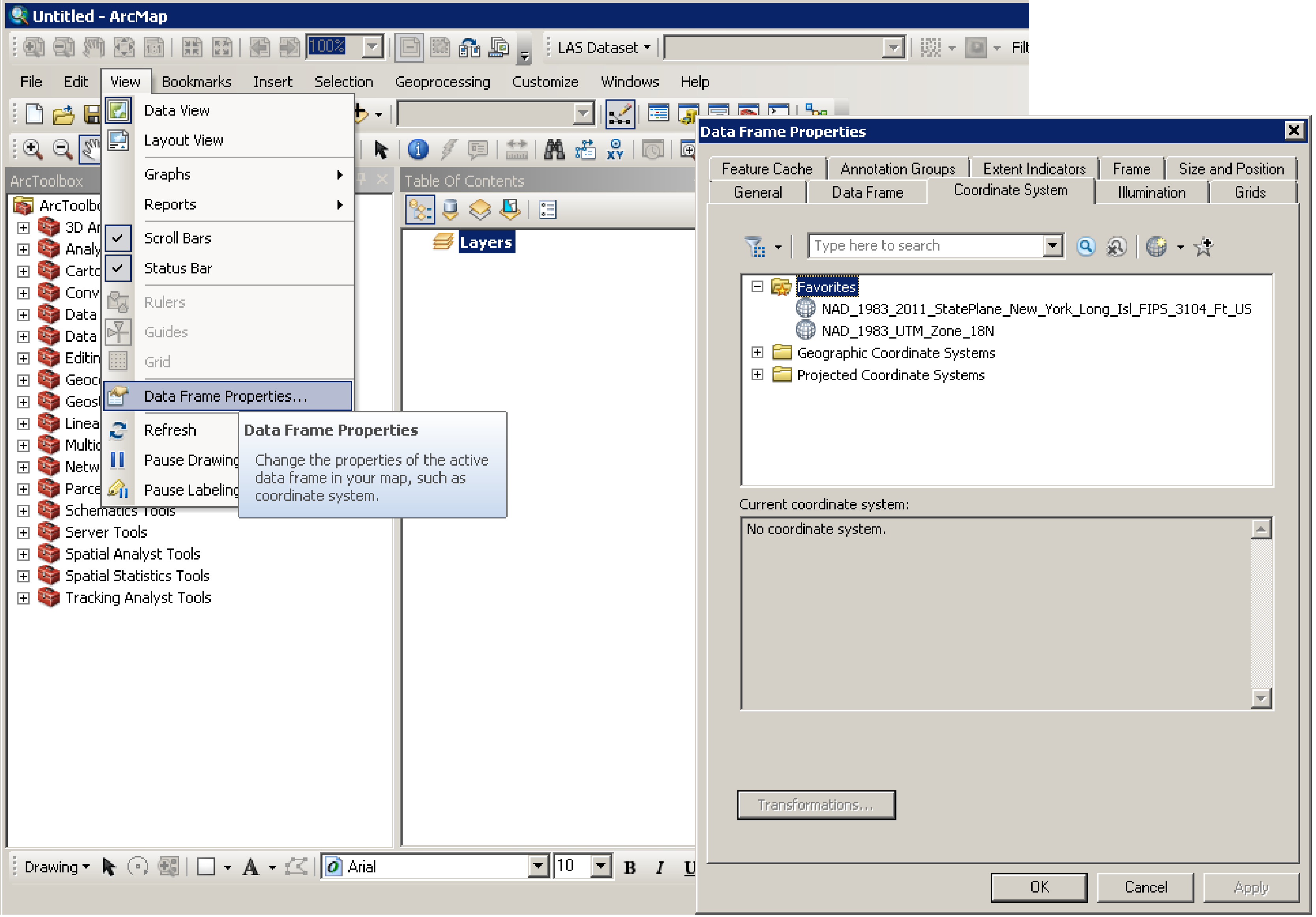
New York City – one place – three different locations

X	Y
-73.92	40.8
590641	4517333
1235867	303312

An abstract Coordinate System when you start your GIS software



Difference in spatial reference units: how ArcGIS reconciles differences in spatial reference of various GIS data?



Difference in spatial reference units: how ArcGIS reconciles differences in spatial reference of various GIS data?

The first layer with corresponding .prj file added to TOC defines the Data Frame's coordinate system.

For example, if the first layer added contains a UTM system, all other layers will **re-project on the fly** to match it regardless of their spatial reference. **If .prj file is absent, then ArcMap will issue a warning message that spatial reference is missing.**

Similarly, if the first layer added to the TOC contains data that uses a WGS84 geographic coordinate system, all other layers will be adjusted by software to match this. Even data with UTM will be **re-projected on the fly**, but not permanently, only for visualization.

Questions to consider:

1. What will happen if I add a second dataset without .prj file?
2. What will happen if the first added dataset does not have .prj file?
3. What will happen if your .prj file is wrong?

Coordinate System / Projection Issues in ArcGIS

TWO CHECK POINTS FOR THE SUCCESFUL "PROJECTION ON A FLY" in ArcGIS

1. View → Data Frame Properties:
   - "Coordinate System" tab cannot have Coordinate system as "No coordinate system"!!!
   - "General" tab cannot have "Unknown Units" for Map

2. Layer → right-click → Properties → Source:
   - Cannot have Coordinate System as "Undefined"
   - Cannot have question marks (?) next to coordinate values in "Extent" box

Tip of the Day:

.PRJ (PROJECTION) FILE SHOULD EXIST FOR EVERY SHAPEFILE!!!!!!!!!!!!!!! IF YOU USE ARCGIS

If projection file does not exist, you can create it (use Define Projection tool in ArcToolBox) if you know spatial reference or can just guess it.

For example, values like -70.345, 34.2391, etc. are most likely decimal degree units of the Geographic Coordinate System. Any kind of values like 346756.2 or 1654346 are large and will be either meters or feet, i.e. UTM or State Plane Projected Coordinate System. It is easy and fast to experiment and create a correct "projection" file in ArcGIS.

After creating .prj file check View → Data Frame Properties and make sure that your spatial reference is defined as well (**especially if the shapefile without .prj was added to the TOC first)** You can also use an option **Import** and use your newly updated shapefile to set a spatial reference in Data Frame.

More on map projections:

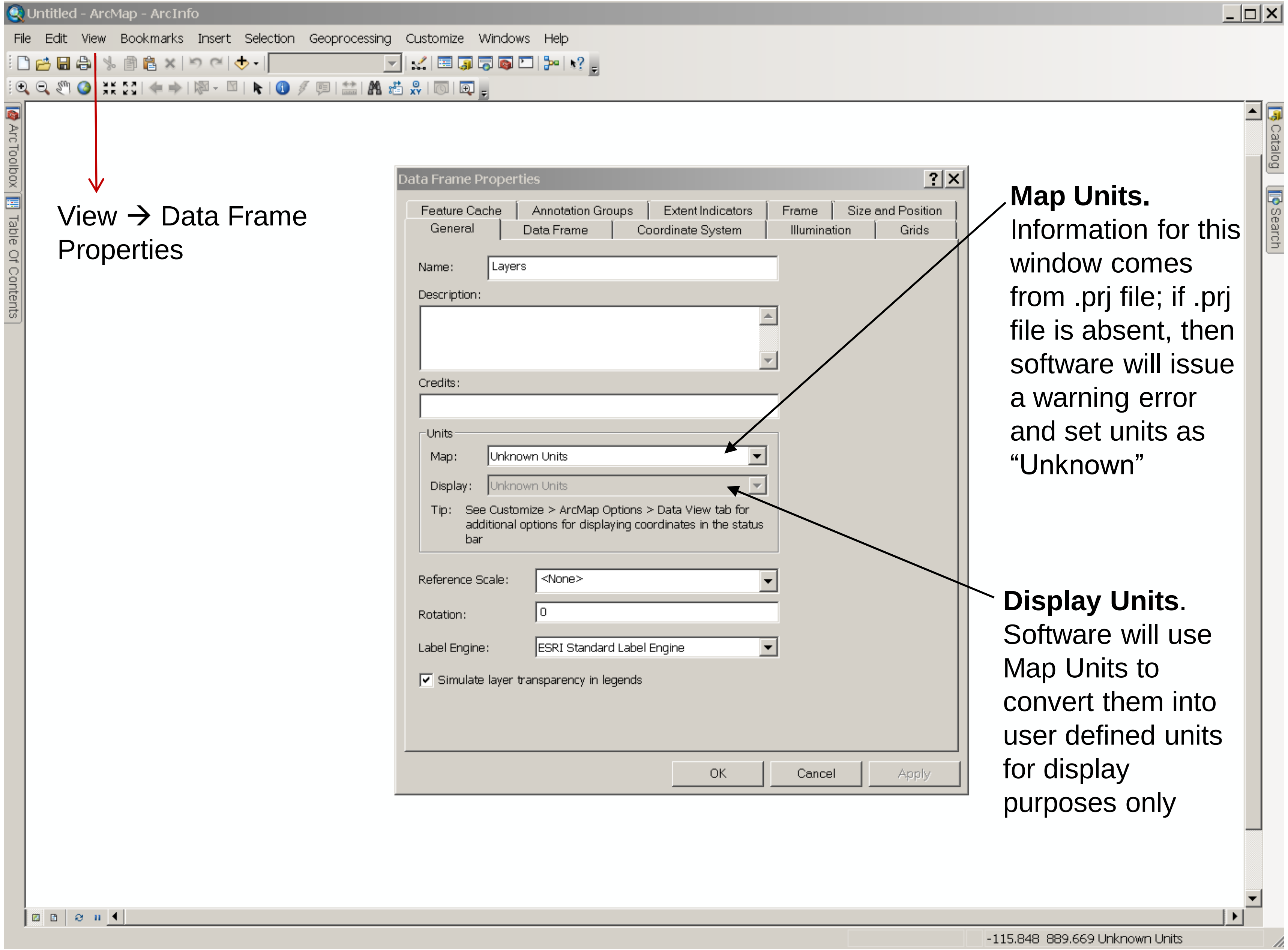
ESRI documentation:

http://resources.esri.com/help/9.3/arcgisengine/dotnet/89b720a5-7339-44b0-8b58-0f5bf2843393.htm

Peter Dana, Colorado State University, (one of the most comprehensive, can be overwhelming at times):

http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj_f.html

Coordinate System / Projection in ArcGIS



View → Data Frame Properties

Map Units. Information for this window comes from .prj file; if .prj file is absent, then software will issue a warning error and set units as “Unknown”

Display Units. Software will use Map Units to convert them into user defined units for display purposes only

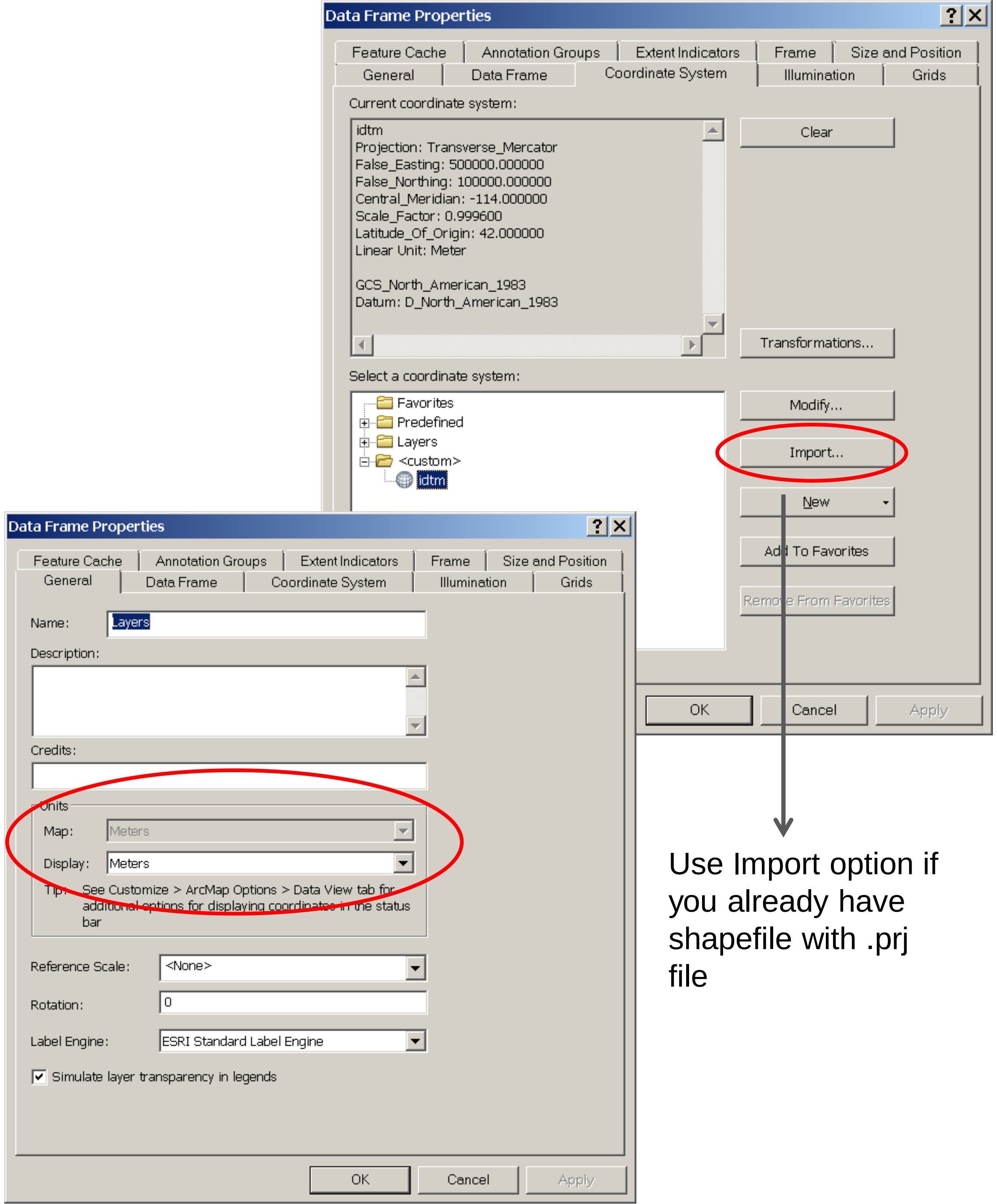
Data Frame Properties

- In Data Frame Properties tab Coordinate System sets a coordinate system for the whole ArcMap project and NOT for individual layers

- Map units:

  horizontal measures in which distances are calculated in a data frame
  - Feet, meters, etc.

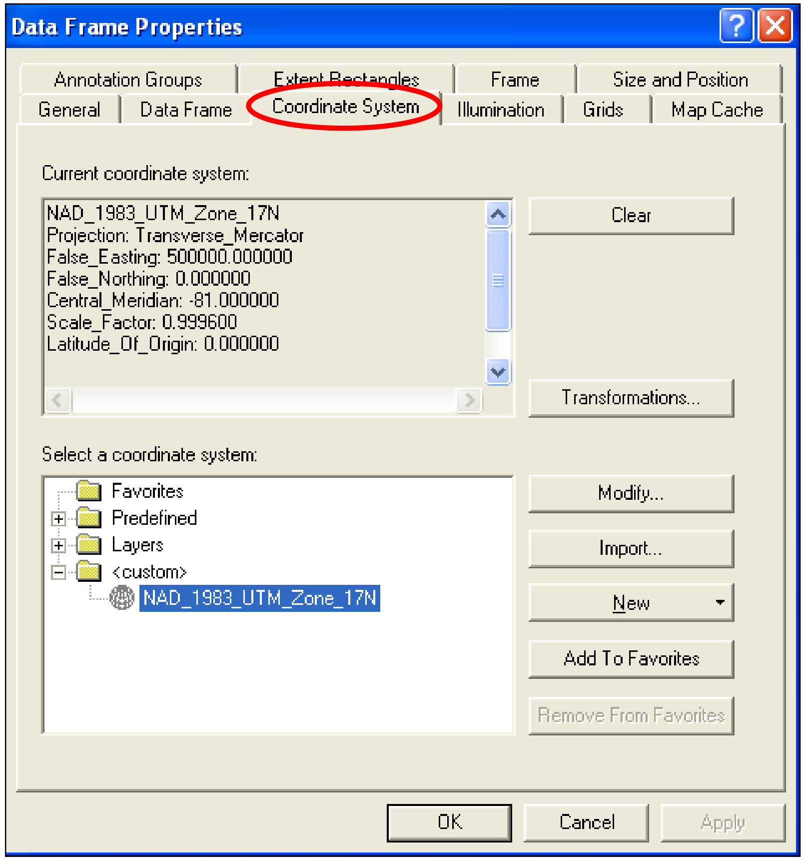
- Display units: horizontal measures in which distances are actually displayed on the screen
  - Feet, meters, etc.

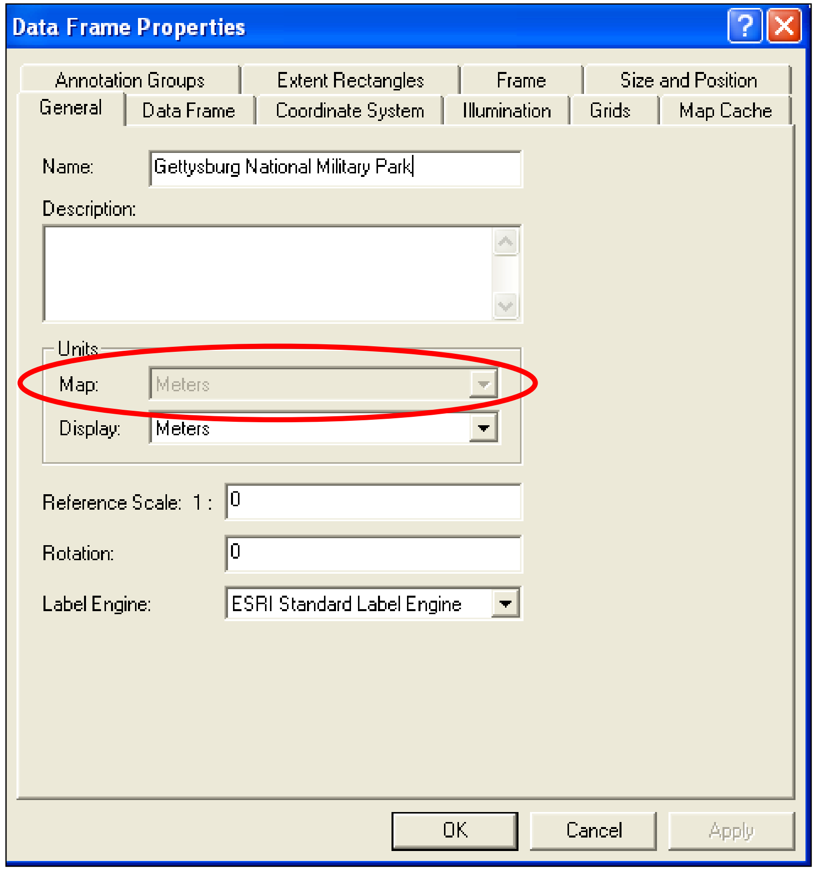


Use Import option if you already have shapefile with .prj file

Data Frame Properties (cont.)

- Map units are set when a coordinate system is specified for a data frame





The settings for Coordinate System come from .prj file from the very first shapefile added to ArcMap. If you add a first shapefile without .prj component, then Data Frame Properties will have "Unknown units" for Map

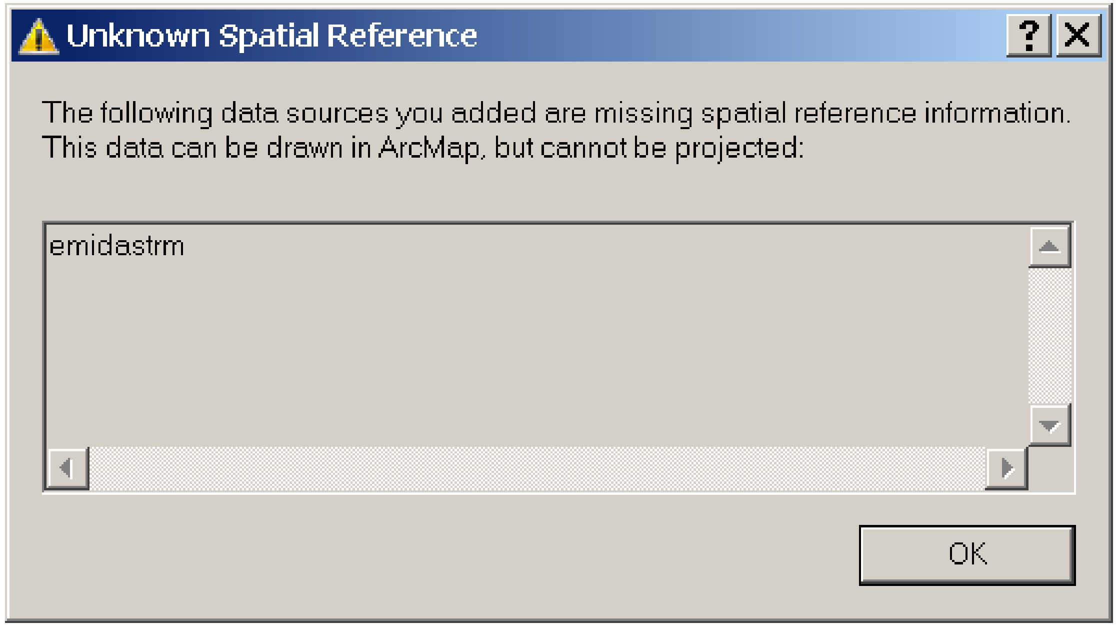
Data Frame Properties (cont.)

- **<u>On-the-fly</u>** projection requires spatial reference definition:
  - For shapefiles: stored in .prj file
  - For images: stored in the header of image file or in a separate file (e.g. .jpgw, .tifw, etc.)

Unknown Spatial Reference Warning:

This happens when shapefile does not have .prj file

This is a warning, not error message so you can proceed and view layer but **you will not be able** to experience “on-the-fly” capability of ArcMap.



Layer Properties

Layer → Properties → Source

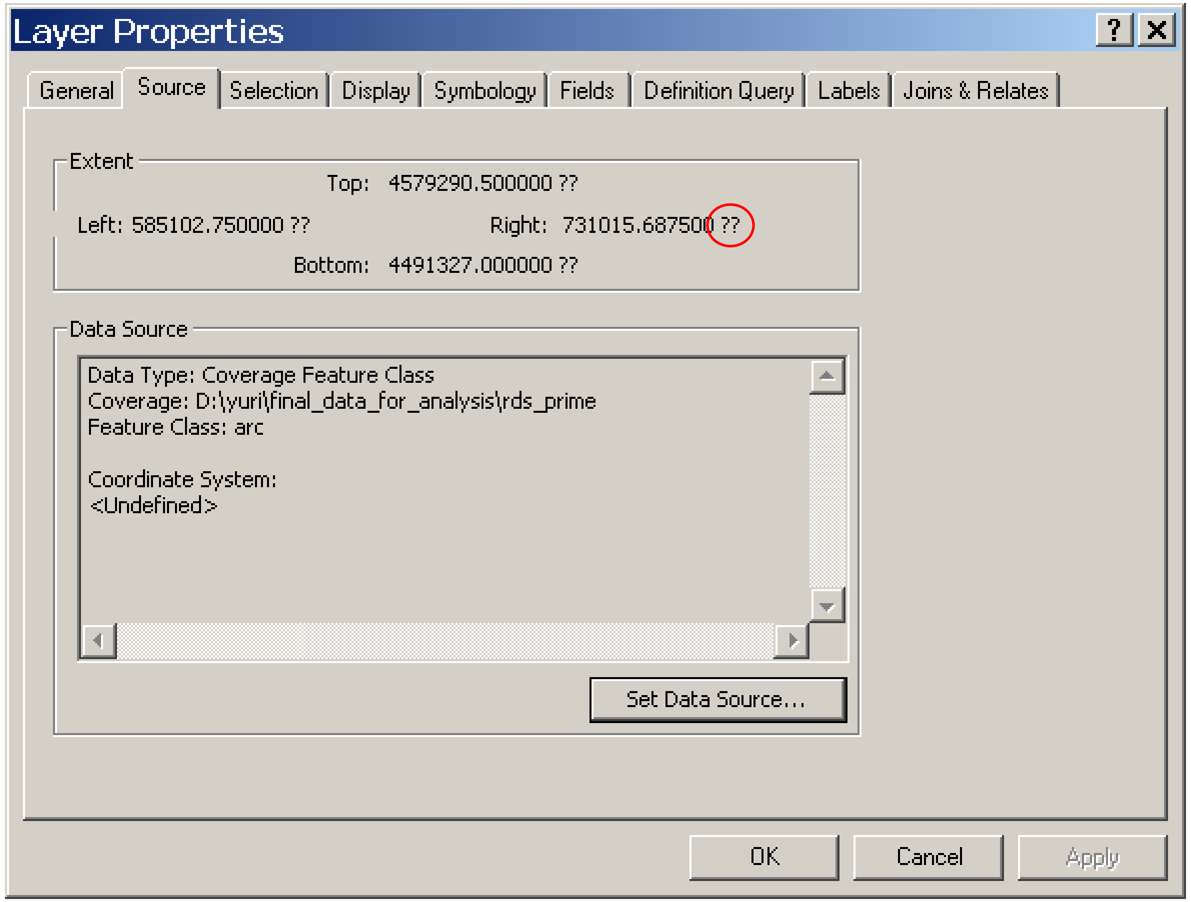
Layer Properties tab Source shows a coordinate system for individual layer

If you can not see all attributes of the coordinate system defintion, then your layer has no defined projection. In the case of shapefiles this means that you do not have a .prj file.

In this specific example the solution is following:

1. Guess what projection is: ?????
2. Use Define tool to create .prj file

Unknown Spatial Reference in ArcMap: notice “?” marks



Layer Properties

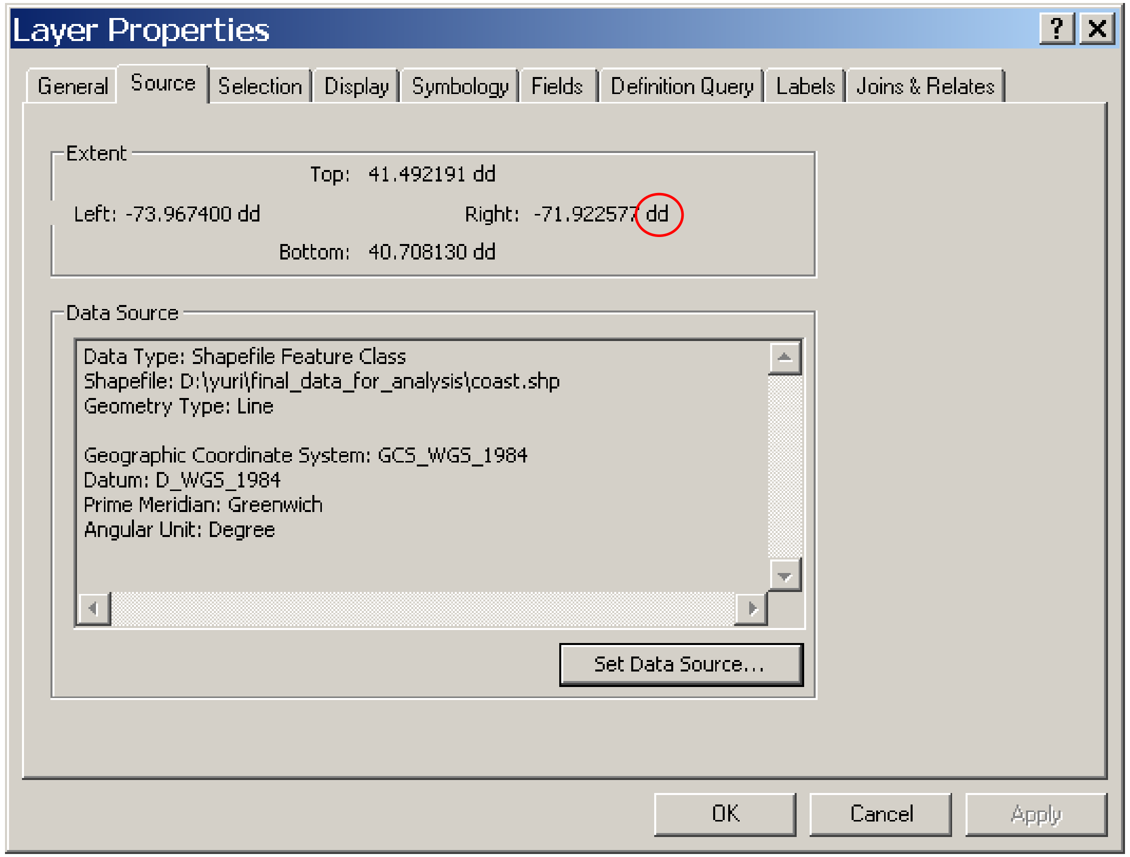
Layer → Properties → Source

Layer Properties tab Source shows a coordinate system for individual layer

If you can see coordinate system for the Layer with all necessary attributes of coordinate system definition then your layer has a defined projection.

In case of shapefiles this information is stored in .prj file or within the header of the image or GRID.

Known Spatial Reference in ArcMap:

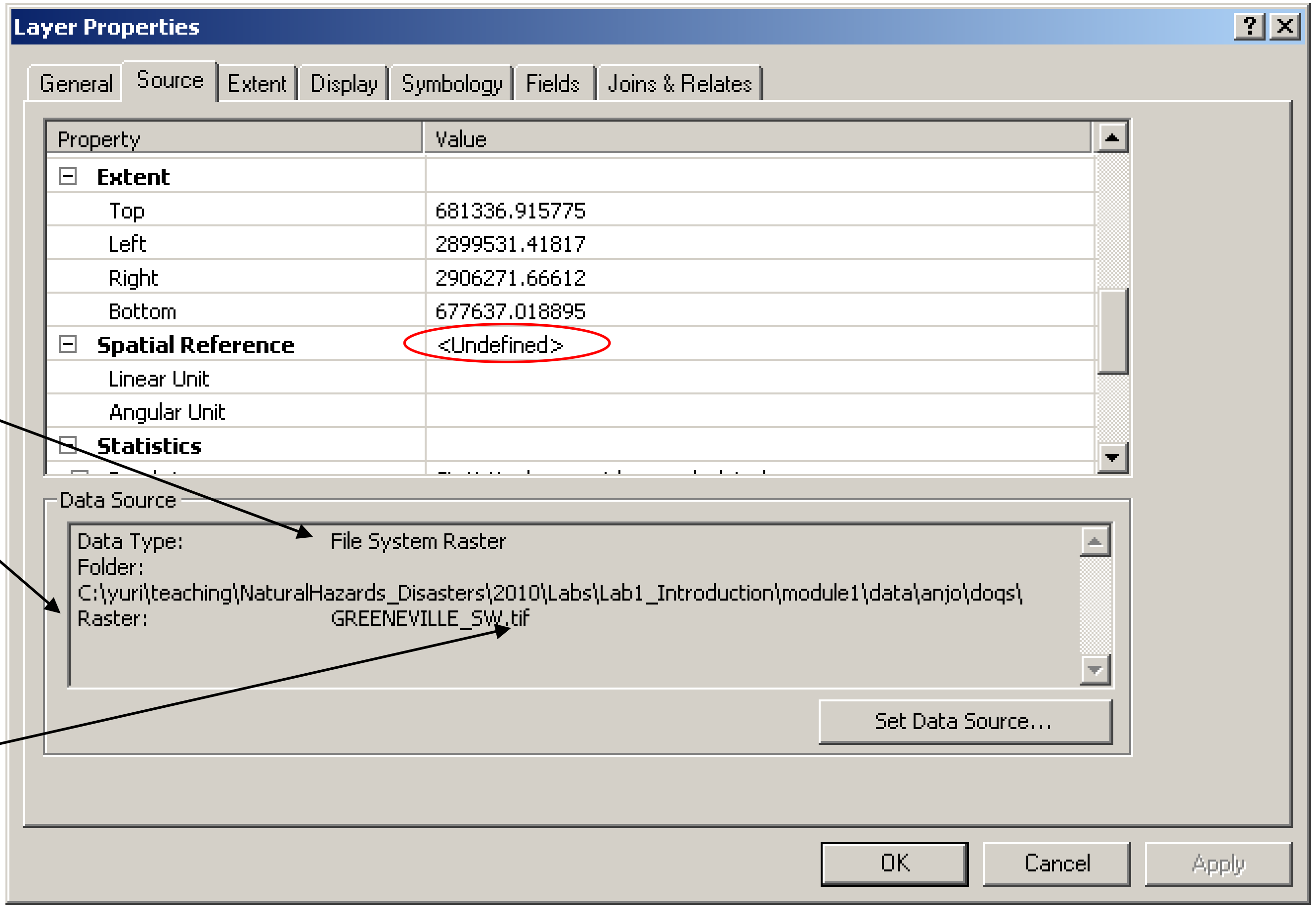


Layer Properties (raster data)

If data misses spatial reference you can check it via:

Layer Properties → Source

In this example, the dataset that misses spatial reference is raster image



Notice extension .tif

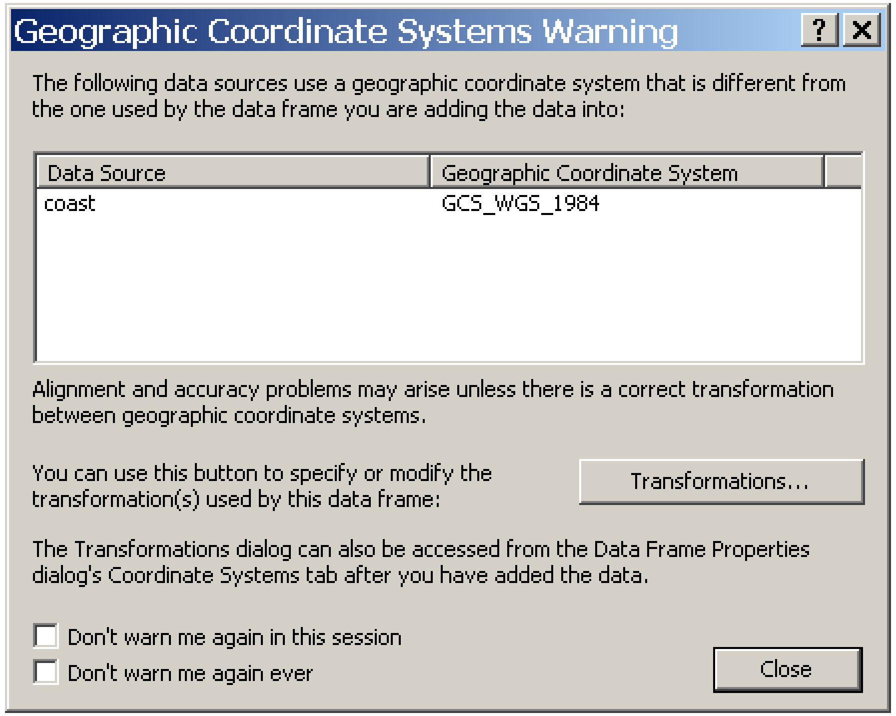
Layer Properties: different spatial references in your data

What does this mean to you? Practical advice:

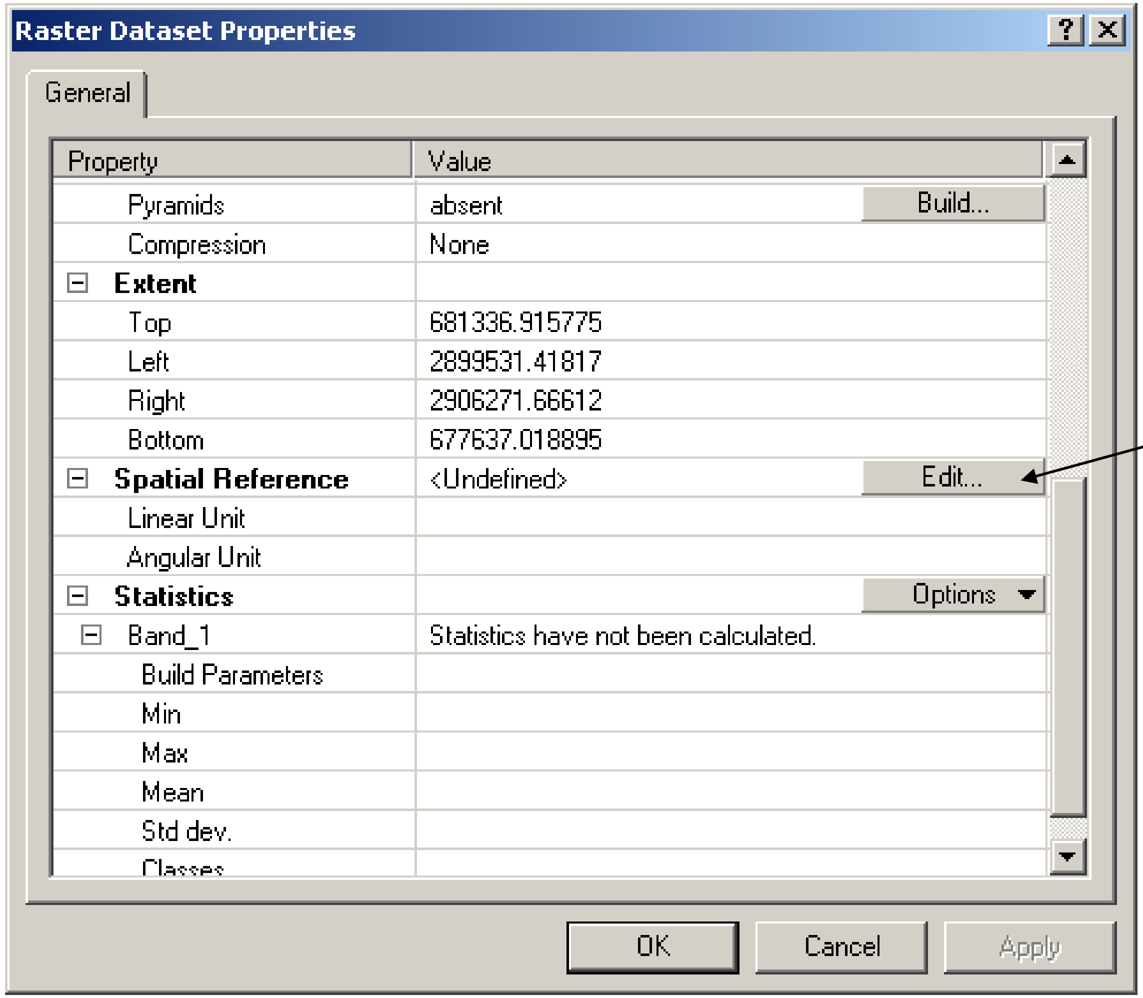
1. **If you produce a map, no problem**; The software will automatically "re-project on the fly" your data and all layers will match

2. If you intend to do **spatial analysis using "overlay" functions or any other function that requires calculations between two geographic datasets**, you might want to consider using Project tool to change coordinate system/projections of each dataset to **one uniform type** because **certain analytical functions in ArcMap ToolBox might not work correctly with multiple spatial references and produce error messages.**

<u>**Warning message about coordinate system**</u>

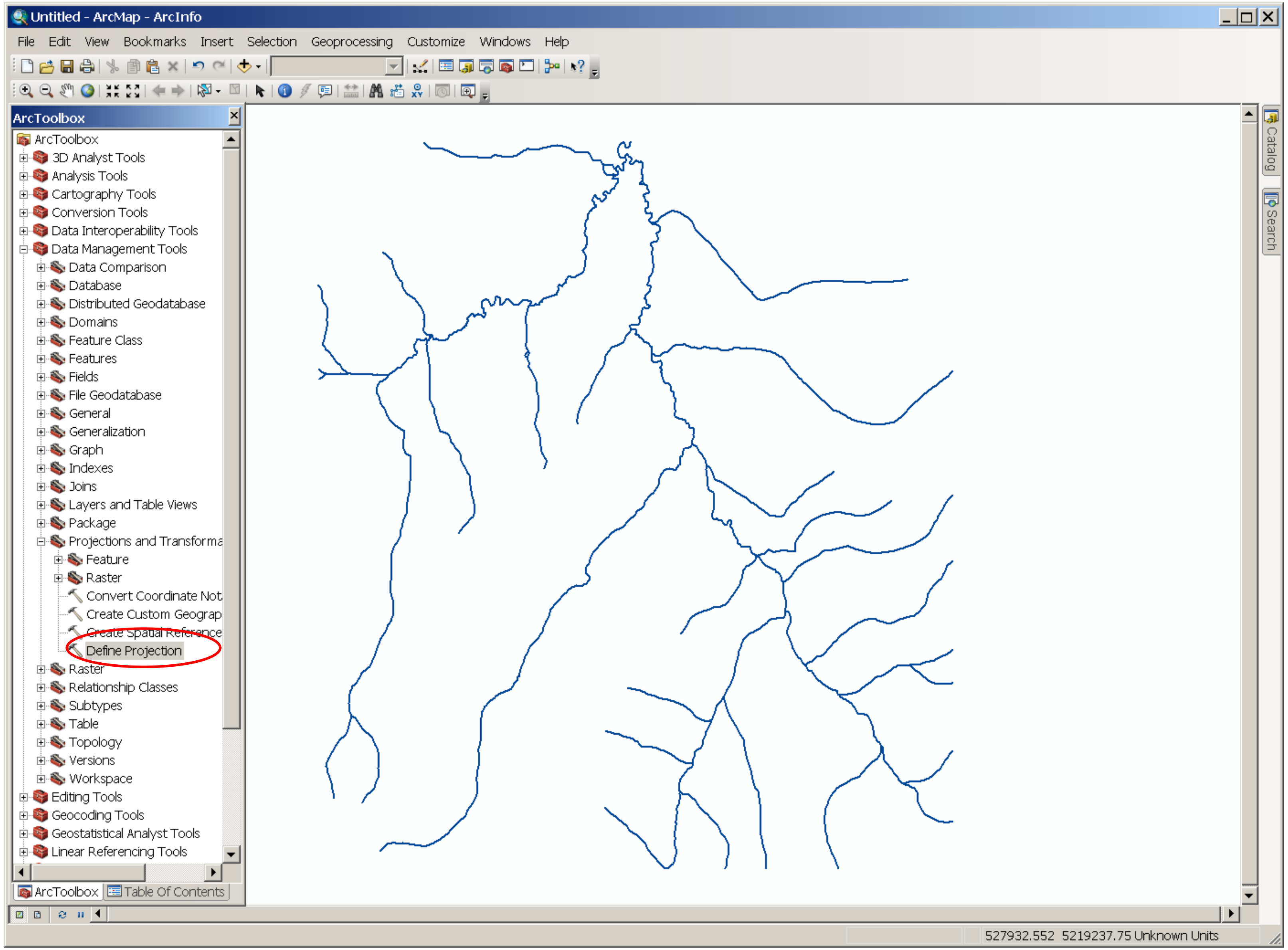


Adding spatial reference info to raster dataset (image, GRID)

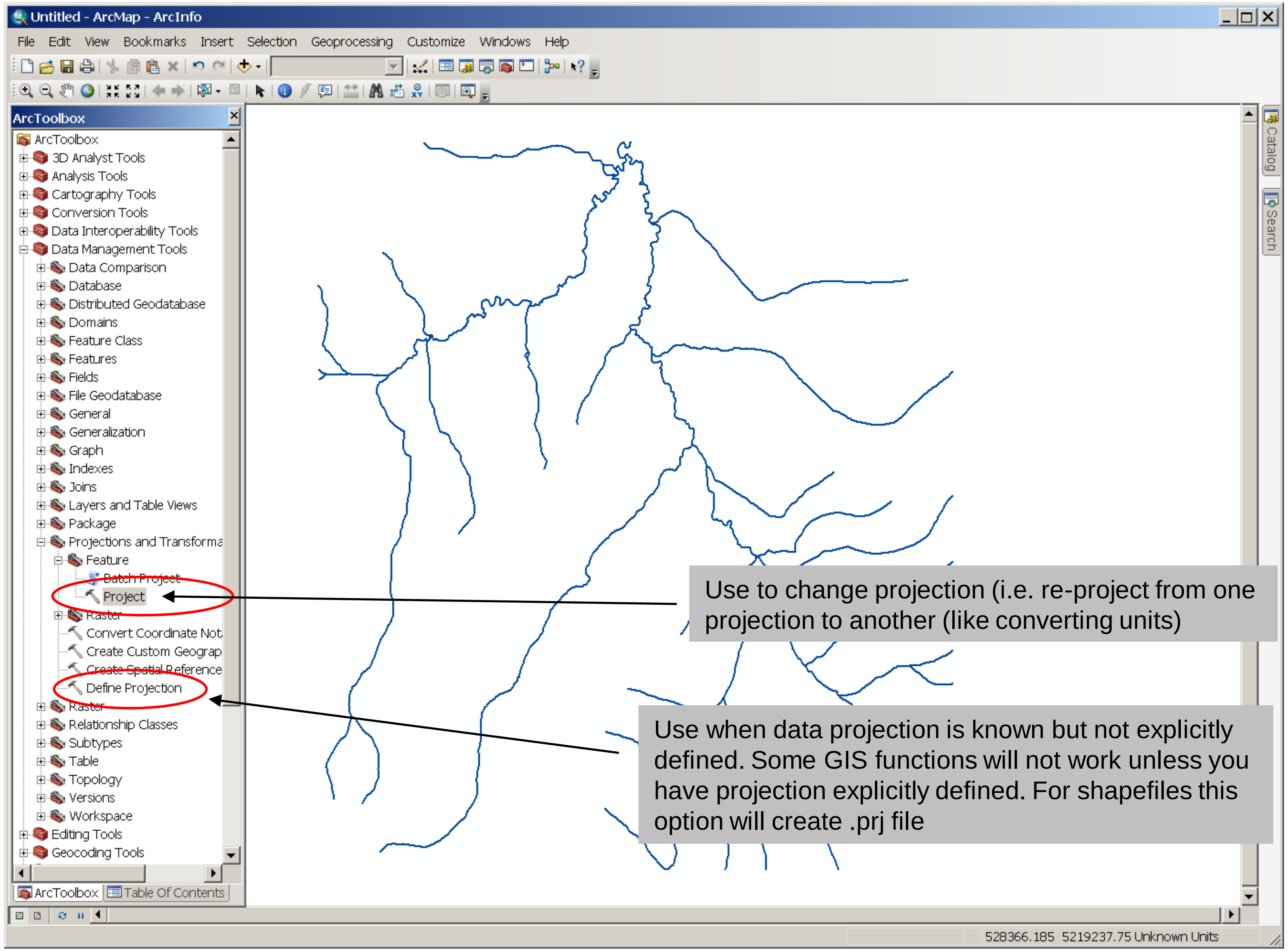


ArcCatalog: right-click on dataset and select Raster Dataset Properties → Edit button

Adding spatial reference to shapefiles (creating .prj file)

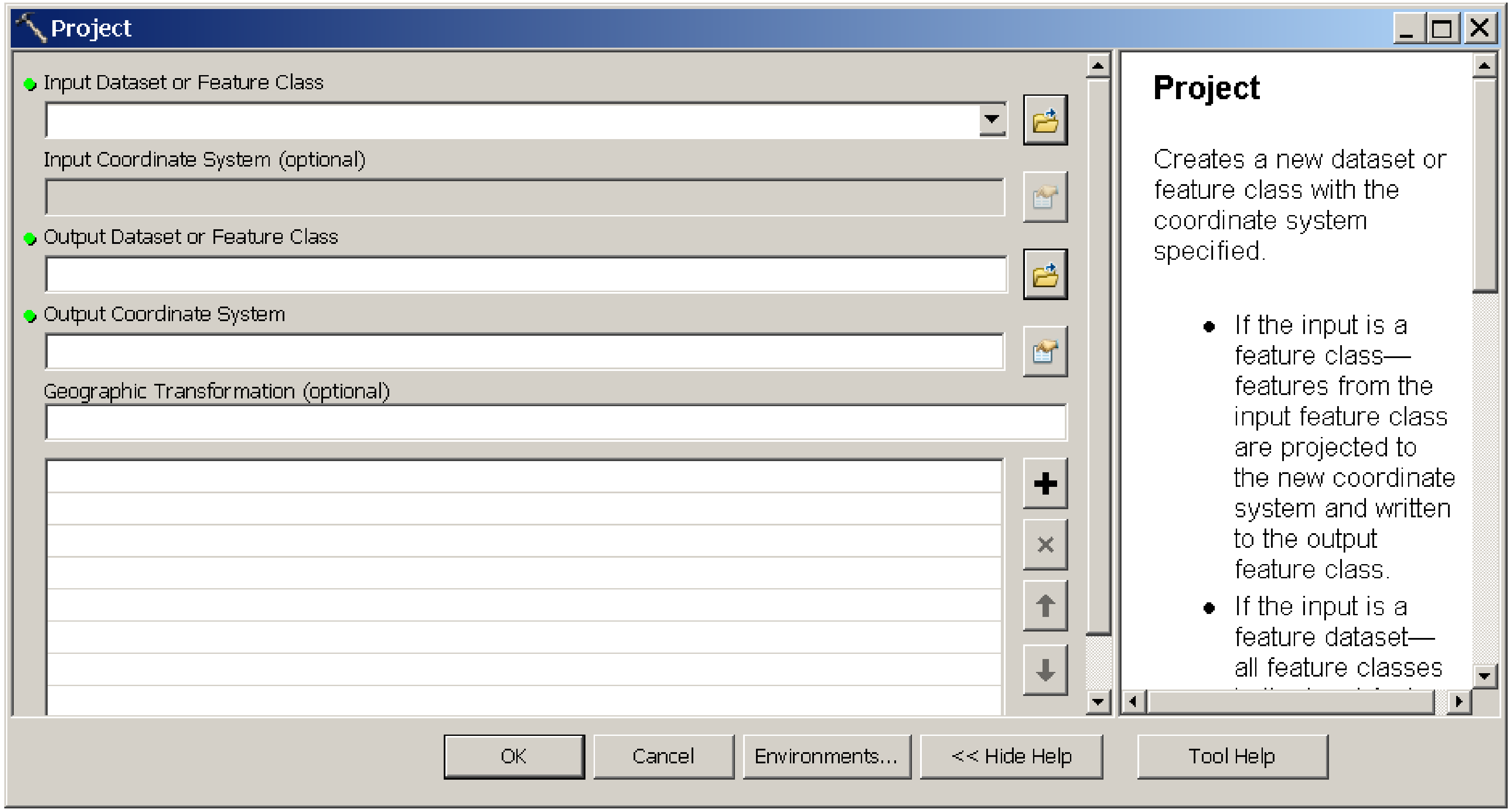


Do Not Get Confused by Mixing These Tools !!!!



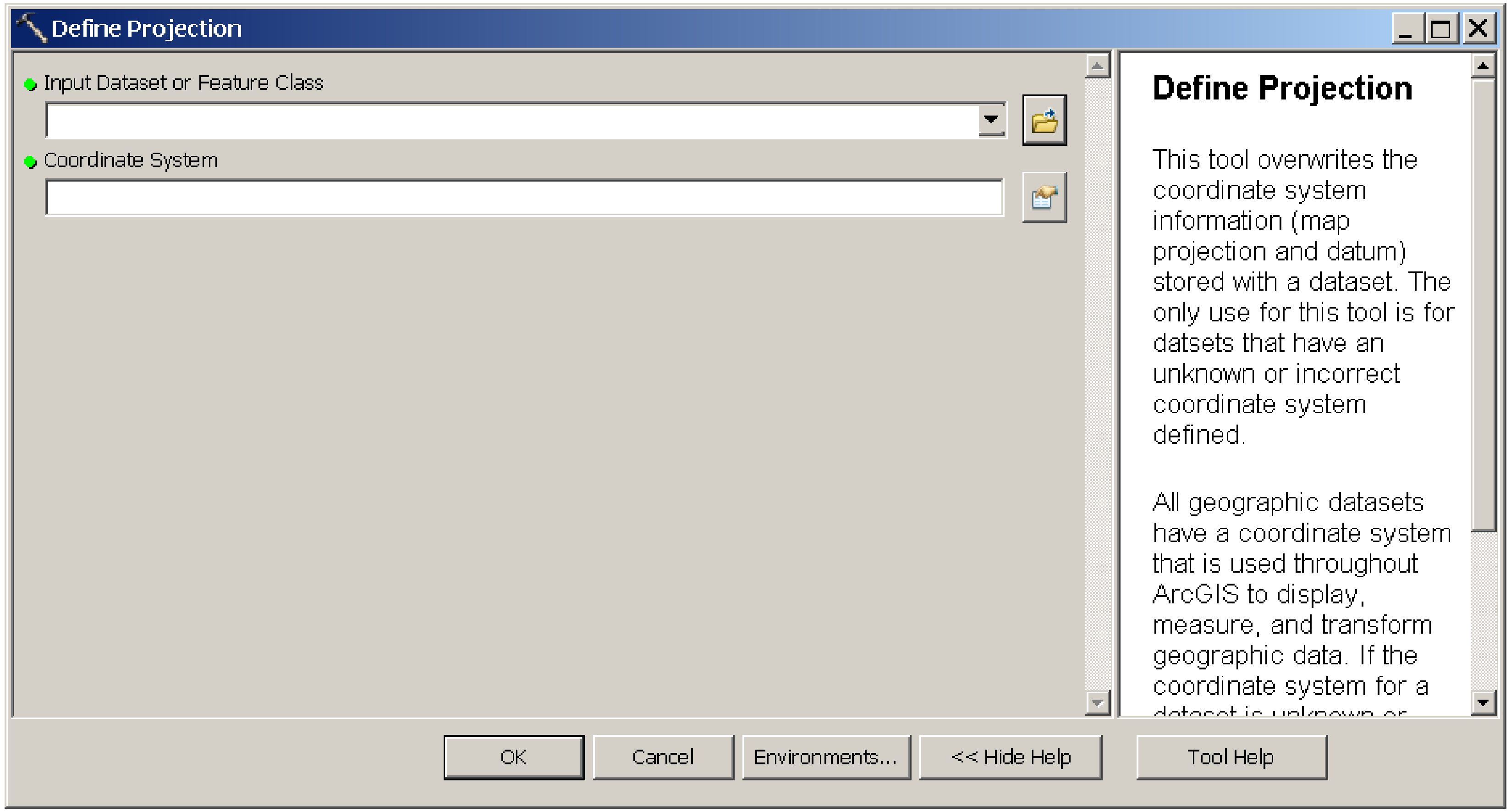
Projection (Datum) Change in ArcMap:

This tool is used only if your spatial references are defined in both datasets and you need to convert one type of spatial reference into another

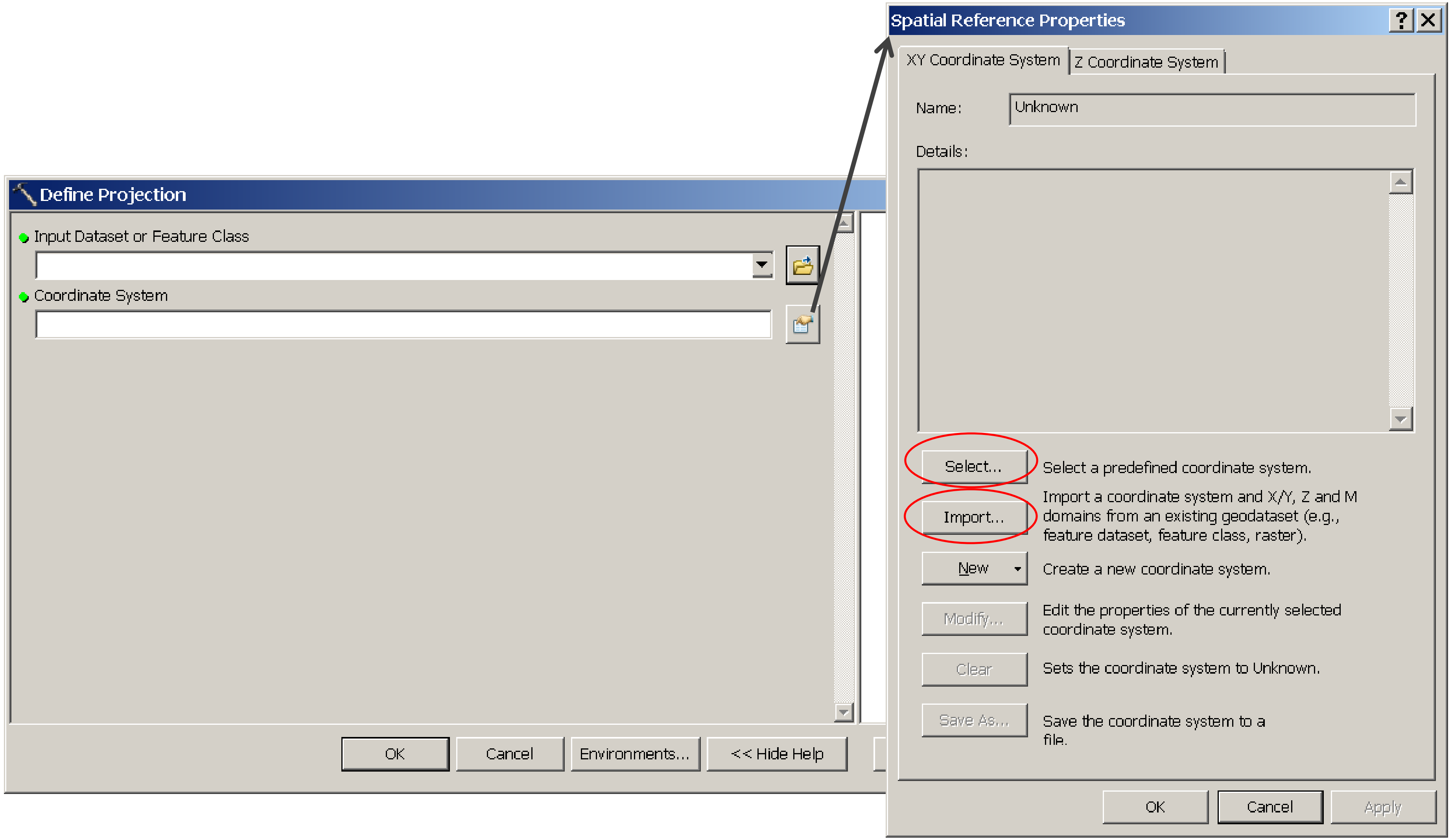


How to create .prj file (or change one) in ArcMap:

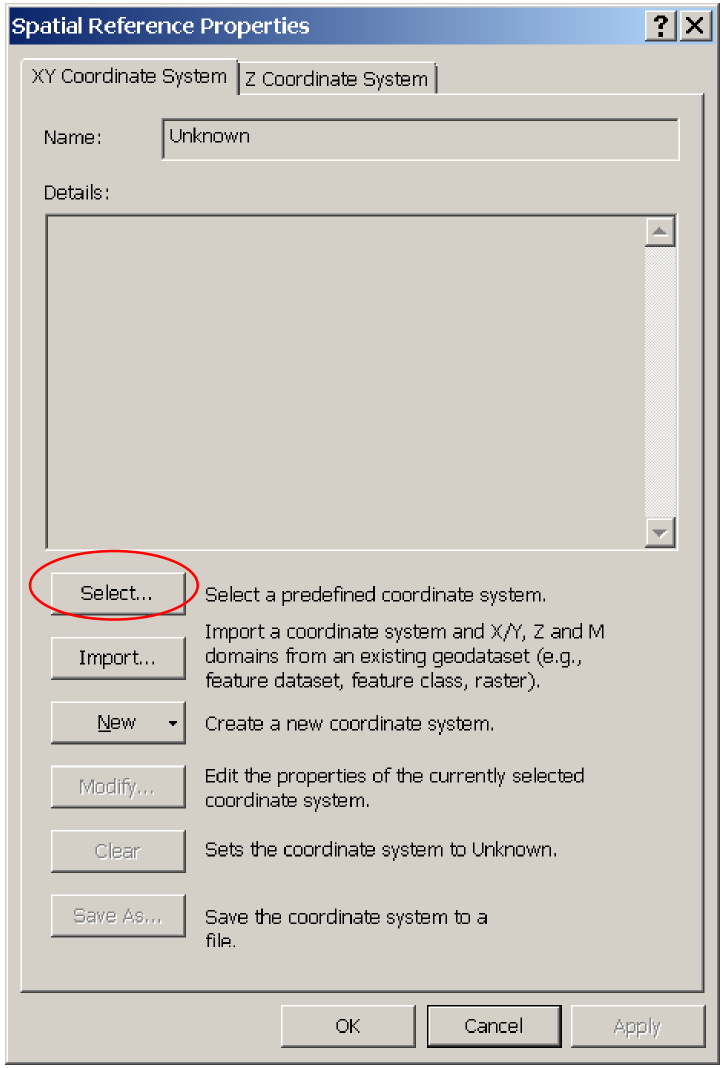
This tool is used only if your spatial reference is not defined (i.e. .prj file is absent) or existing .prj file is incorrect. It can be also used for raster data.

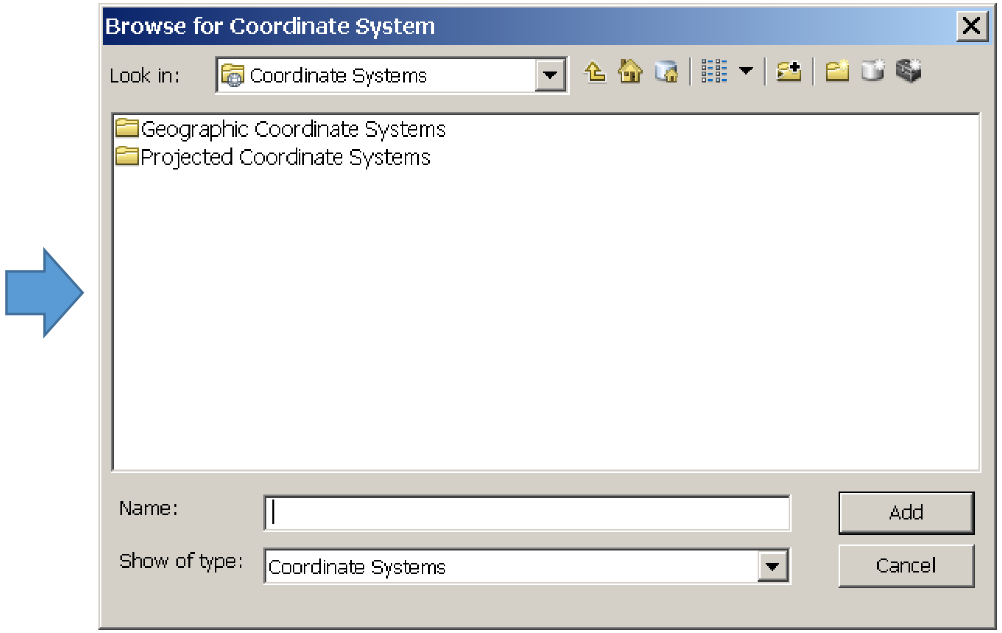


How to create .prj file (or change one) in ArcMap:



How to create .prj file (or change one) in ArcMap:



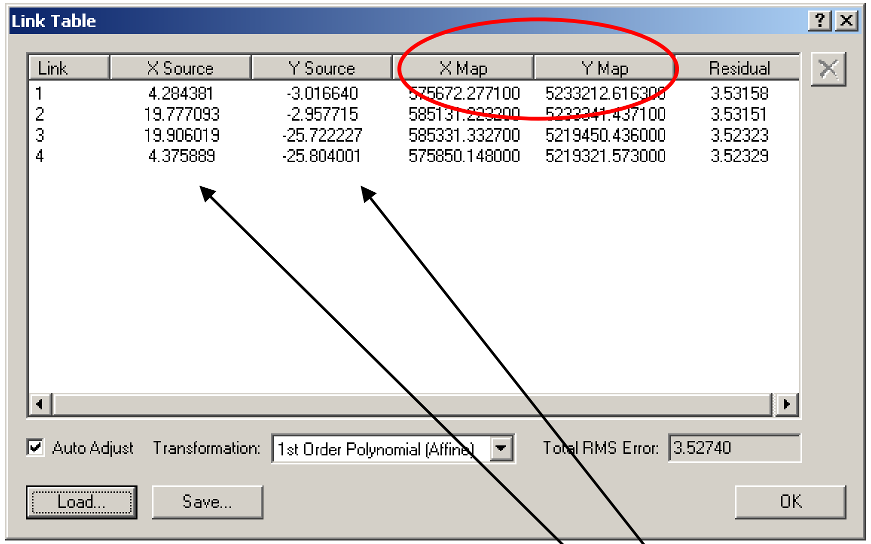


Georeferencing Raster Data & Images Using Affine Transformation

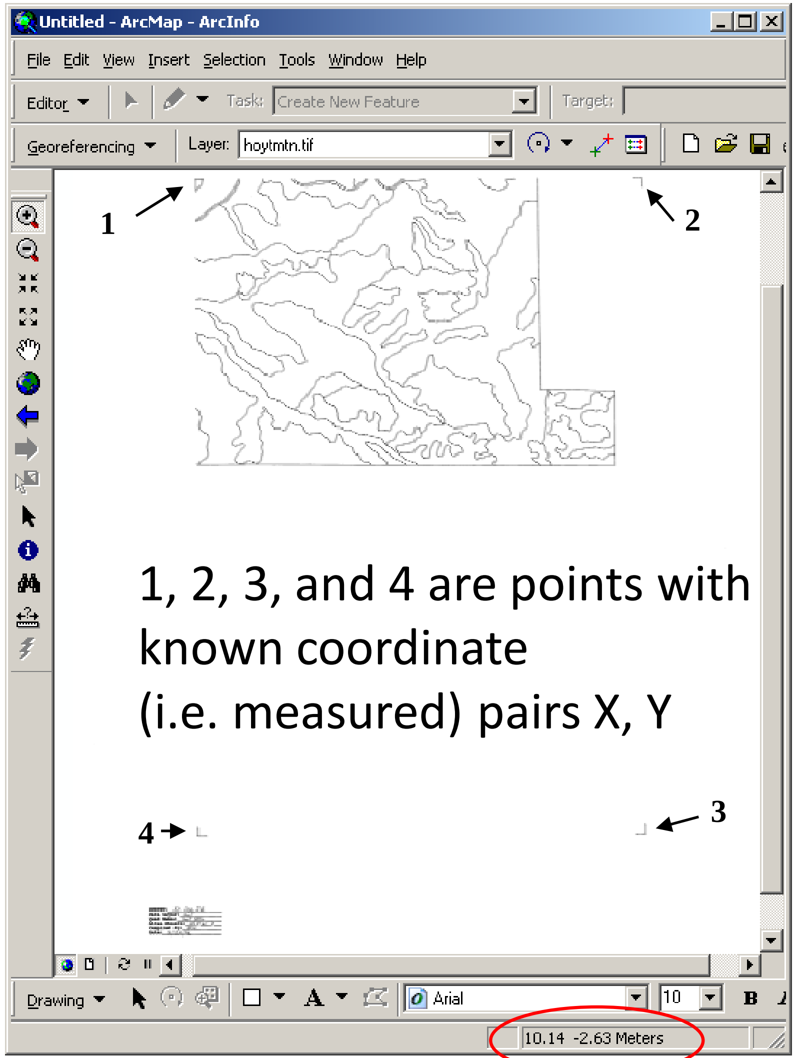
Customize → Toolbar → Georeferencing

Establishing control points:

measured units



Link	X Source	Y Source	X Map	Y Map	Residual
1	4.284381	-3.016640	575672.277100	5233212.616300	3.53158
2	19.777093	-2.957715	585131.223200	5233341.437100	3.53151
3	19.906019	-25.722227	585331.332700	5219450.436000	3.52323
4	4.375889	-25.804001	575850.148000	5219321.573000	3.52329

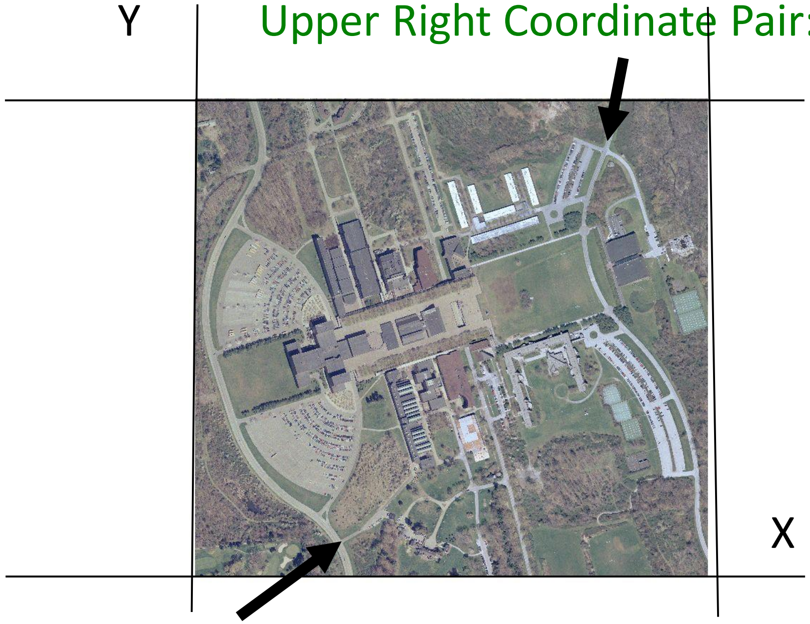


Source units
(for example, they can be units of scanning device, like 11 x 18, etc.)

Georeferencing of digital images:

Assigning coordinate system to hard copy (e.g. standard map) or digital media (e.g. satellite image); For digital images this process creates so-called “world file” or writes information in the image itself (e.g. GeoTIFF)

Upper Right Coordinate Pair: X_2, Y_2

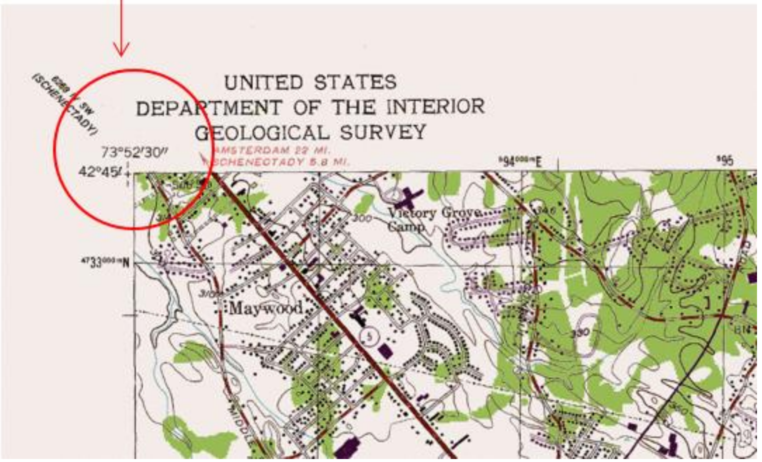


Lower Left Coordinate Pair: X_1, Y_1

Points for georeferencing come from:

1. GPS measurements
2. Another map or digital source (e.g. Google Earth); GIS data with known coordinate system;

TIC mark that can be used for georeferencing/registration

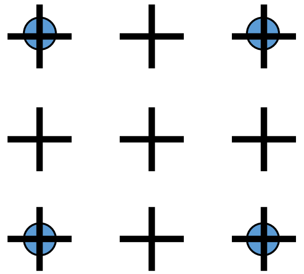


Reference Table

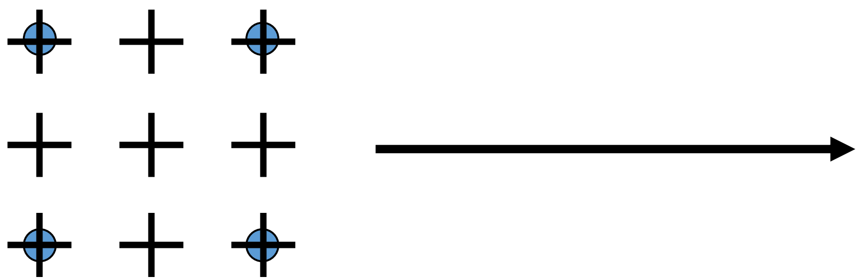
X, Y Map (measured)	X,Y Computer Screen/Media
-75.43287 , 43.8751	0.9, 0.8
-75.43459 , 43.8231	0.01, 0.1
……….	………..

Georeferencing Raster Data & Images

X,Y of control points in scanned/or other source (image) units

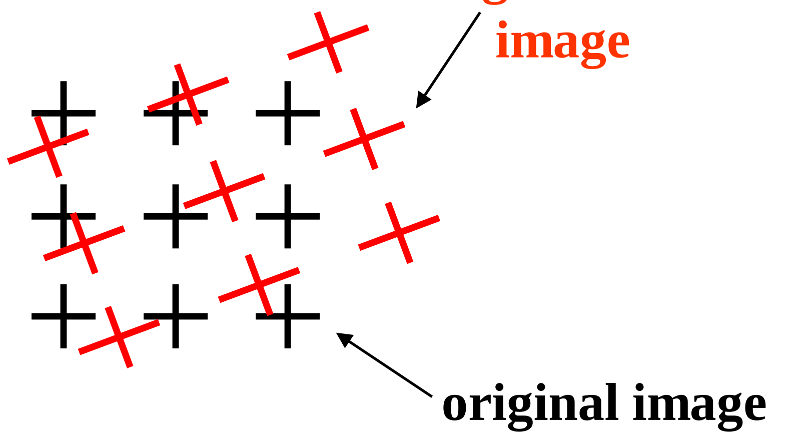


1. Establish control points and their real-world coordinates;
2. Run transformation on control points and apply transformation to map features (Rectify).



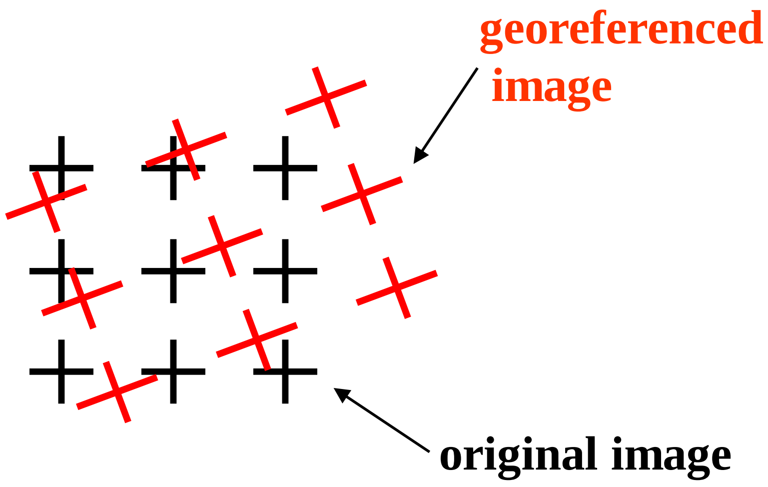
X,Y of control points in desired coordinate units (usually measured in the field or derived from other data)

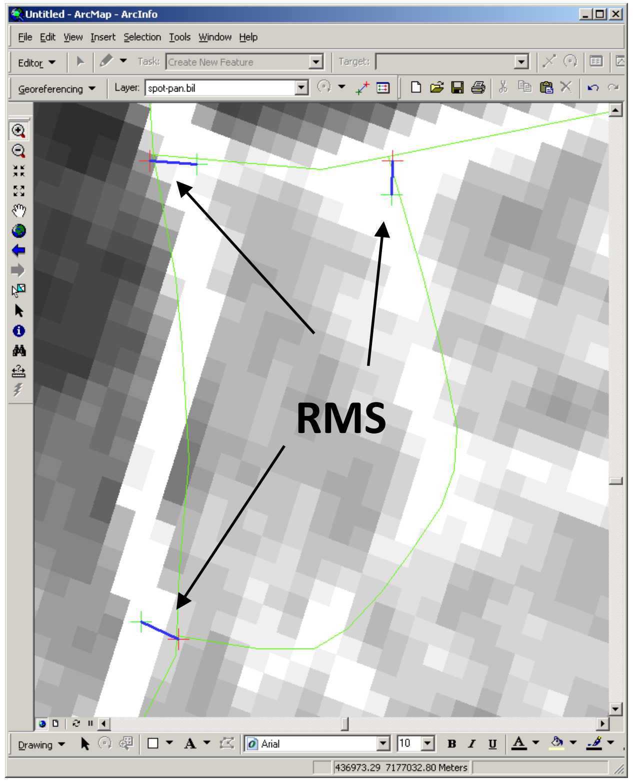
Rectification



Georeferencing Raster Data & Images

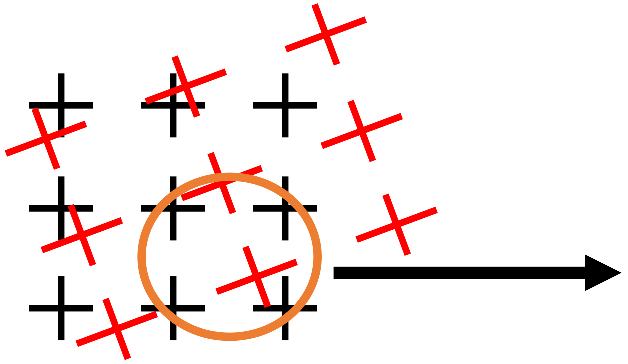
Root mean square error (RMS) – measures deviation between original and georeferenced (estimated) locations. = $\sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2}$

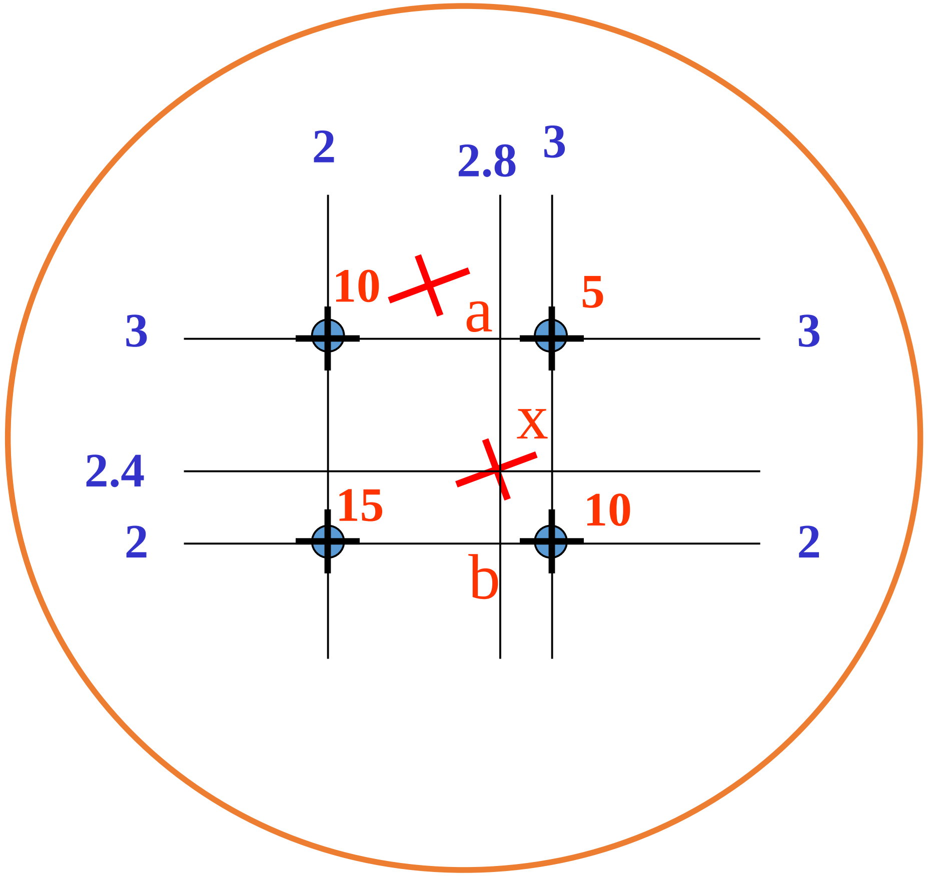




Transformation Process: Bilinear Interpolation

Considers closest 2x2 neighborhood of pixels with known values surrounding pixel with unknown value. Then it takes weighted averages of four known values in two directions (i.e. bi-linear).





a = (0.8 * 5) + (0.2 * 10) = 6
b = (0.8 * 10) + (0.2 * 15) = 11
x = (0.4 * 6) + (0.6 * 11) = 9

Red color – grid (pixel) values
Blue color – coordinate system values

More on Georeferencing in ArcGIS:

http://desktop.arcgis.com/en/arcmap/10.3/manage-data/raster-and-images/fundamentals-for-georeferencing-a-raster-dataset.htm