

Lab 03: You're projecting

Lab written by Ian Spangler
GEOG 260: Foundations of Geospatial Analysis
University of Richmond
Last edited: 2026-10-22

Assigned	Due	Submit
9/7/26	9/14/26	Section 1, Section 2

This activity will walk you through plotting XY data using the **Pleiades dataset**—a **gazetteer** of ancient place names—and then experimenting with how that data translates into a variety of projected coordinate systems.

This week, you do not need to submit a map! Just answers to the questions, in .doc or .pdf format or as a Google Doc (shared with me).

Note

Set up a workspace for this activity by using Windows File Explorer  to create a folder under your name in hemisphere. The structure could look something like:

```
hemisphere/geopower/STUDENTS/GEOG260/yourname/  
  lab03_ancient-places/  
    downloaded-data/      # this is original data that you downloaded from  
    lab-03_ancient-places/ # this folder would contain all of your working  
    for-submission/       # this folder for your submission/maps/answers
```

Download the data

To get started:

1. Go to <https://pleiades.stoa.org/> and click the “Downloads” tab in the upper-right hand corner.
2. Under the header “Single Format Snapshots” > “Pleiades Data for GIS (CSV)” and click the link to download the latest version. Note the warning that Microsoft Excel doesn’t reliably read the data. Unfortunately, that’s a common experience when working with spatial data in Excel. In fact, it’s a common experience when working with *any* data in Excel. If you have access to **LibreOffice**, an **open-source** alternative to the Microsoft suite, feel free to try it out!

3. I'm going to save this file to a folder called downloaded-data in my workspace.
4. Go ahead and extract the contents with Right-click > Extract all > Extract. Click through the "unzipped" folders until you get to the data itself.
5. You'll notice many data files suffixed with .csv. That's short for "comma separated values," which means it's a **plain text** file containing rows that represent *observations* and columns that represent *variables*. If you opened this file in a text editor, you'd see that the rows are separated by **carriage returns** and the columns are separated by—you guessed it—commas. Although there's tons of interesting stuff in this folder, we're only going to be using the places.csv file today.
6. Go ahead and **make a copy** of that file (ctrl+c) and paste it your downloaded-data directory (ctrl+v). We're doing this for two reasons: first, because it's easier to access at downloaded-data, and second, because it's really easy to mess up CSV/spreadsheet data in Excel, so it's helpful to have a clean backup copy.
7. Now, try opening the file in Excel. **If you see a message asking you to convert the data, choose "Don't Convert"!** You should see something like this:

	A	B	C	D	E	F	G	H	I	J	K	L
1	created	descriptio	details	provenan	title	uri	id	represent	represent	bounding	location	precision
2	2021-11-1	An ancien	<p>The Ba	Barrington	Gallia	https://pl	993	46.61861	1.14537	POLYGON	rough	
3	2020-01-1	A Roman l	<p>The hc	Pleiades	House of t	https://pl	1E+09	40.75001	14.48951	POLYGON	precise	
4	2015-05-2	The so-called	"House	Pleiades	House of t	https://pl	1E+09	40.75036	14.48929	POLYGON	precise	
5	2020-03-2	A necrop	<p>A necr	Pleiades	Monte Tai	https://pl	1E+09	44.27232	11.37588	POLYGON	precise	
6	2018-05-3	The megalithic	defe	Pleiades	Circuit wa	https://pl	1E+09	42.82909	11.16359	POLYGON	precise	
7	2016-12-0	An Ibero-Roman	opp	Pleiades	Alto Chac	https://pl	9.99E+08	40.34466	-1.15303	POLYGON	precise	
8	2023-08-1	The Mamluk arch		Pleiades	Yibna Brid	https://pl	99965183	31.86943	34.75226	POLYGON	precise	
9	2012-12-2	A family tomb of the		Pleiades	Sep. Scipi	https://pl	9.99E+08	41.8759	12.50041	POLYGON	precise	
10	2021-06-1	Archaeological site	c	Pleiades	Tel Mor	https://pl	9.99E+08	31.8231	34.65646	POLYGON	precise	
11	2009-11-0	An ancien	The Barrin	Barrington	Møllegård	https://pl	99010	55.132	10.70146	POLYGON	precise	
12	2009-11-0	An ancien	None	Barrington	Tubantes	https://pl	99047	52.5	6.5	POLYGON	rough	
13	2009-11-0	An ancien	The Barrin	Barrington	Mannarici	https://pl	99006	51.96624	5.42405	POLYGON	precise	
14	2009-11-0	An ancien	The Barrin	Barrington	Reudigni	https://pl	99026	53.94403	10.25981	POLYGON	precise	
15	2009-11-0	An ancien	The Barrin	Barrington	Rullstorf	https://pl	99030	53.28633	10.52976	POLYGON	precise	
16	2009-11-0	An ancien	The Barrin	Barrington	Wijster	https://pl	99066	52.81523	6.515659	POLYGON	precise	
17	2009-11-0	An ancien	The Barrin	Barrington	Marwedel	https://pl	99007	53.14396	11.03879	POLYGON	precise	
18	2009-11-0	An ancien	The Barrin	Barrington	(Ulme)Ru	https://pl	99050	54.18408	12.79749	POLYGON	precise	
19	2009-11-0	Traiectum	<p>The Ba	Barrington	Traiectum	https://pl	99046	52.09093	5.122099	POLYGON	precise	
20	2022-04-1	A Roman	<p>The Ba	Barrington	Kastell Op	https://pl	99061	52.08717	5.041778	POLYGON	precise	

Figure 1: Pleiades in Excel

As a point of comparison, open the file in a **text editing application**. If you're in Jepson, you can use **Visual Studio Code**, which makes the file a little easier to read. If you're in the SAL, open it using Notepad.

You should see something a little less immediately human-readable...

... but if you look carefully, you can sort of track the structure of the data. Again: commas separate each value. In instances where a comma needs to be **escaped**—e.g., where a comma actually does need

```

1 created,description,details,provenance,title,uri,id,representative_latitude,representative_longitude,bounding_box_wkt,location_precision
2 2021-11-14T03:44:08Z,"An ancient region covering a large part of southwestern Europe, roughly approximating the territory of modern France. It was bounded by the Atlantic ocean,
3 2020-01-10T20:52:08Z,"A Roman house in Pompeii (I, 6, 15), also known as the House of L. Ceius Secundus. It is also referred to as the House of Fabia and Tyrannus.",<p>The house
4 2015-05-28T11:48:45Z,"The so-called ""House of the Lararium of Achilles"" (I, 6, 4) lies on the Via dell'Abbondanza. Excavated in 1912 and 1913, it is also known as the ""House of
5 2020-03-28T15:26:53Z,A necropolis with inhumations dating to the fifth and fourth centuries B.C.,<p>A necropolis located close to Monte Bibele where over 100 fourth century B.C.
6 2018-05-30T03:08:22Z,The megalithic defensive circuit of Rusellae dates to the seventh and sixth centuries B.C. and represents an important early example of stone-built fortifica
7 2016-12-07T14:42:48Z,An Ibero-Roman oppidum located just west of modern Teruel in Spain.,,Pleiades,"Alto Chacón, Teruel",https://pleiades.stoa.org/places/999013462,999013462,40.3
8 2023-08-13T15:02:77Z,"The Mamluk arched bridge dating to the 1270s crosses the river Nahal Sorek near modern Yibna, Israel",,Pleiades,Yibna Bridge,https://pleiades.stoa.org/pla
9 2012-12-28T15:18:51Z,A family tomb of the Corneli Scipiones near the Porta San Sebastiano in use from the third century B.C. to the first century A.D.,,Pleiades,Sep. Scipionum,I
10 2021-06-14T19:27:48Z,Archaeological site on the northern bank of the Lachish River with signs of habitation dated from the Late Bronze Age to the Hellenistic period.,,Pleiades,T
11 2009-11-02T14:32:70Z,"An ancient place, cited: Batlas 10 G1 Møllegaardsmarken",,"The Barrington Atlas Directory notes: Møllegaardsmarken, DEN",Barrington Atlas: Batlas 10 G1 Møllega
12 2009-11-02T14:32:51Z,"An ancient place, cited: Batlas 10 C4 Tubantes",,None,Barrington Atlas: Batlas 10 C4 Tubantes,Tubantes,https://pleiades.stoa.org/places/99047,99047,52.5,6.5
13 2009-11-02T14:32:15Z,"An ancient place, cited: Batlas 10 B5 Mannaricum",,The Barrington Atlas Directory notes: Maurik,Barrington Atlas: Batlas 10 B5 Mannaricum,Mannaricum,https
14 2009-11-02T14:32:33Z,"An ancient place, cited: Batlas 10 G3 Reudigni",,The Barrington Atlas Directory notes: GER,Barrington Atlas: Batlas 10 G3 Reudigni,Reudigni,https://pleiades
15 2009-11-02T14:32:35Z,"An ancient place, cited: Batlas 10 G3 Rullstorf",,"The Barrington Atlas Directory notes: Rullstorf, GER",Barrington Atlas: Batlas 10 G3 Rullstorf,Rullstorf,I
16 2009-11-02T14:33:09Z,"An ancient place, cited: Batlas 10 C4 Wijster",,The Barrington Atlas Directory notes: Wijster,Barrington Atlas: Batlas 10 C4 Wijster,Wijster,https://pleiades
17 2009-11-02T14:32:16Z,"An ancient place, cited: Batlas 10 H3 Marwedel",,"The Barrington Atlas Directory notes: Marwedel, GER",Barrington Atlas: Batlas 10 H3 Marwedel,Marwedel,https
18 2009-11-02T14:32:53Z,"An ancient place, cited: Batlas 10 I2 (Ulme)Rugii",,The Barrington Atlas Directory notes: GER,Barrington Atlas: Batlas 10 I2 (Ulme)Rugii,(Ulme)Rugii,https://
19 2009-11-02T14:32:49Z,Traiectum (modern Utrecht) was a fortified site along the Roman frontier (Limes) of Germania Inferior. It may have been a crossing point on the Rhine river.,
20 2022-04-15T13:25:42Z,A Roman auxiliary fort with associated vicus and port at modern Vleuten-De Meern in the Dutch province of Utrecht.,<p>The Barrington Atlas Directory notes:

```

Figure 2: Pleiades in VS Code

to appear in the value of the data—it must be braced in quotation marks.

Before answering the question below, install the Rainbow CSV extension for VS Code (should only take a few clicks) so it is easier to visually separate the different columns:

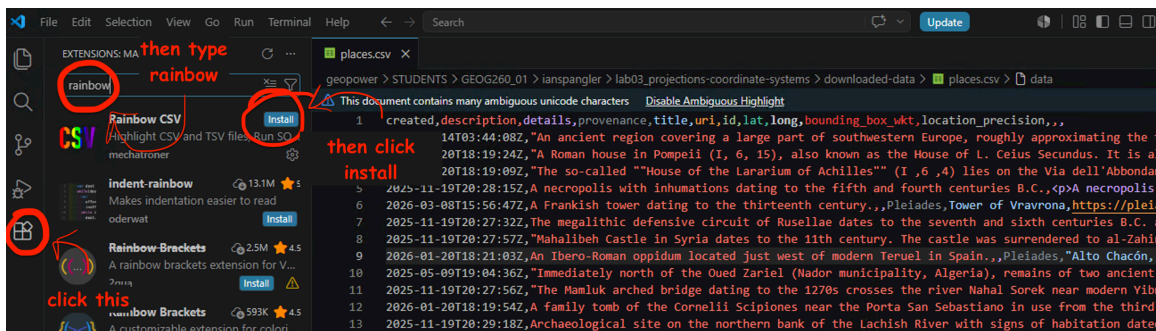


Figure 3: How to install Rainbow CSV extension

Question (1 pt)

Q1 In the .csv file you're examining, what do two commas directly next to one another (e.g., , ,) signify? You may need to compare the file in Excel against the file in VS Code to confirm your answer.

Make a new project

If you haven't already, open up ArcGIS Pro and create a new project file inside of your workspace. When you're done, your directory structure should resemble:

```

hemisphere/geopower/STUDENTS/GE0G260/yourname/
  lab03_ancient-places/
    downloaded-data/
      pleiades_gis_data/
        places.csv
        pleiades_gis_data.zip

```

```
lab03_ancient-places/
  multiple
  ArcGIS
  Pro
  folders
  and
  files
for-submission/
```

It's okay if your workspace doesn't look exactly like this, so long as you're making some intentional choices around **how you name stuff**.

Study the data

Our goal is to load this .csv into ArcGIS Pro and plot the locations of each observation (e.g., row)—but first, any time you're trying to load a table into ArcGIS Pro, you want to have a quick look through its contents.

1. Open the `places.csv` file in Microsoft Excel by double-clicking the file and make note of two important fields: `representative_latitude` and `representative_longitude`.
2. Thankfully, the dataset is really **tidy**, so we don't need to fuss with it a lot. However, it's best practice, when possible, to keep your field names to 10 characters or less. This specification is important because the **shapefile** format has a field name maximum character limit of 10, and shapefiles are encountered pretty commonly in geospatial workflows.
3. Rename each field name so that it contains 10 characters or less. (The destination format of this file is an **ArcGIS feature class** which has much longer field name limits, so it's not *super* important in this case, but this is best practice notwithstanding.) The result should resemble:

	A	B	C	D	E	F	G	H	I	J	K
1	created	desc	details	provenance	title	uri	id	lat	long	bound_box	precision
2	2021-11-1	An ancien	<p>The Ba	Barrington Atlas: B	Gallia	https://pl	993	46.61861	1.14537	POLYGON ((8.67222	rough
3	2020-01-1	A Roman I	<p>The hc	Pleiades	House of t	https://pl	1E+09	40.75001	14.48951	POLYGON ((14.4895	precise
4	2015-05-2	The so-called "House	Pleiades	House of t	https://pl	1E+09	40.75036	14.48929	POLYGON ((14.4892	precise	
5	2020-03-2	A necropc	<p>A necr	Pleiades	Monte Tai	https://pl	1E+09	44.27232	11.37588	POLYGON ((11.3758	precise
6	2018-05-3	The megalithic defe	Pleiades	Circuit wa	https://pl	1E+09	42.82909	11.16359	POLYGON ((11.1635	precise	

Figure 4: New field names for longitude and latitude

4. This was a very simple example of data **preprocessing**, or getting a dataset ready for analysis. Preprocessing will often be more complex than just renaming columns... but this still counts!

Geodesy

Let's turn that csv file—an example of *tabular* data—into real-life, bona fide *spatial* data. When we're done, we'll have a feature class of vector points that displays over 40,000 ancient place names.

Before diving in, we just need to take a moment to wrap our round heads around the round globe.

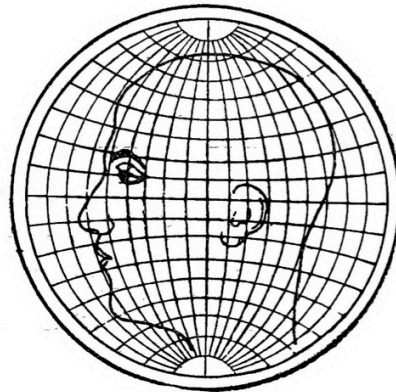


FIG. 42.—Man's head drawn on globular projection.

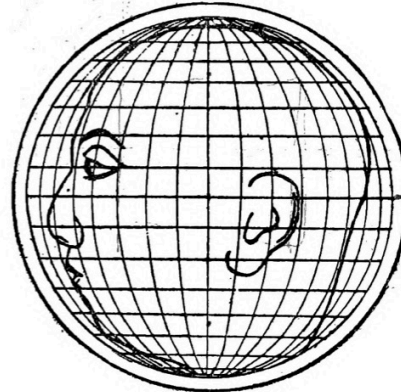


FIG. 43.—Man's head plotted on orthographic projection.

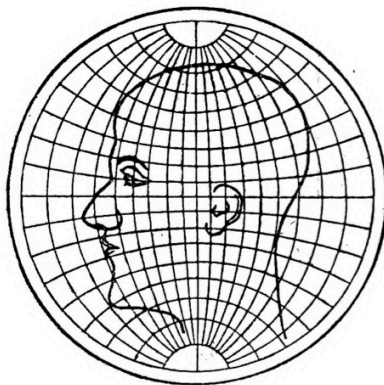


FIG. 44.—Man's head plotted on stereographic projection.

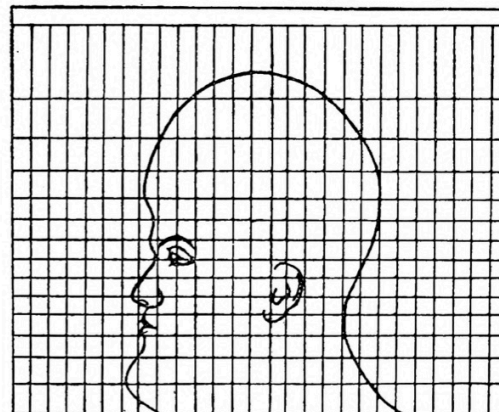


FIG. 45.—Man's head plotted on Mercator projection.

Figure 5: From Charles H. Deetz, *Elements of Map Projection With Applications to Map and Chart Construction* (Washington: Government Printing Office, 1921): 51. [HathiTrust/Cornell](#)

Geodesy is the study of the shape and size of the earth, including its gravitational and magnetic field. It's a pretty complicated science—made all the more so by the fact that the Earth is not *truly* a sphere, but in fact a **lumpy oblate spheroid**—so here's a quick and dirty highlight reel of geodesy.

Coordinates

We measure locations on the earth's surface in **coordinates**, most often described in terms of their position on an X-axis (horizontal) and Y-axis (vertical). You'll probably encounter XY data most commonly as latitudes and longitudes like the ones in the `places.csv` spreadsheet, but they can

also be represented in **DMS**, or “degrees-minutes-seconds” format: $0^{\circ} 0' 0''$, followed by a cardinal direction N, S, E, or W.

Sometimes you’ll need to convert from one to the other. If you’re ambitious, you can make those conversions **by hand**, but in these cases I prefer to use an **online lat-long converter**. Converted from lat-long to DMS, the first record in our `places.csv` would be $46^{\circ} 37' 6.96''$ N, $1^{\circ} 8' 43.08''$ E.

Coordinate systems

We’re speaking in terms of coordinates because when flattened out, the world essentially becomes a big coordinate grid. The lines of this grid are divided into latitudes and longitudes.

- On the X-axis, lines of **latitude** (also known as *parallels*) wrap horizontally around the earth. The **equator** is the largest parallel at 0° , but they become smaller as they approach $\pm 90^{\circ}$ at either of the poles. Lines of latitude remain fairly constant in distance, no matter where you are positioned on the globe; they are spaced evenly.
- On the Y-axis, lines of **longitude** (also known as *meridians*) wrap vertically around the earth, intersecting one another at the north and south poles. As a consequence of an **1884 political conference**, the **Greenwich Meridian** that passes through the Royal Observatory in Greenwich, England is arbitrarily designated at 0° —a decision that Giordano Nanni has described as “**the colonization of time**.”

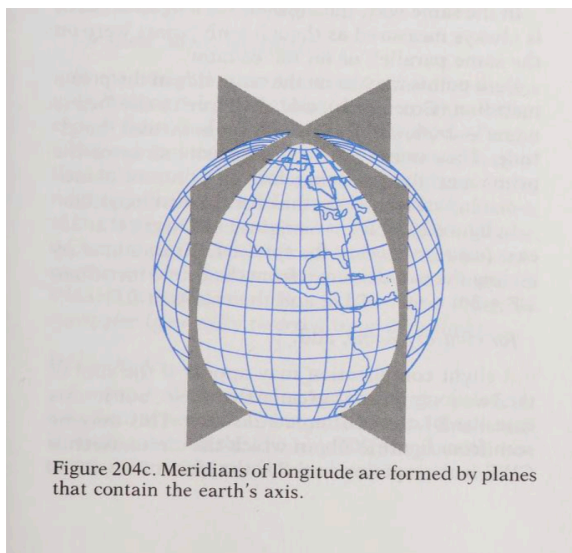


Figure 6: Lines of longitude, from (duttonDuttonsNavigationPiloting1985?)

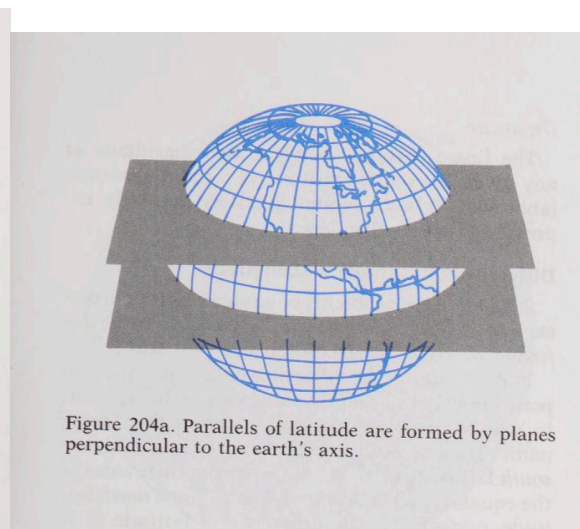


Figure 7: Lines of latitude, from (duttonDuttonsNavigationPiloting1985?)

The X and Y axes meet at the grid’s **origin**, and all other locations on the grid are specified relative to that origin. This is an example of a **Cartesian coordinate system**, or a grid formed by **juxtaposing two horizontal and vertical measurement scales**.

If you plot longitudinal distances on a chart, you'll get the gently sloping function shown in Figure 8. As latitude increases—or in other words, as you approach the poles—the distance of one degree of longitude (in nautical miles) decreases evenly:

[Image: /coursework/labs/lab-03/https://upload.wikimedia.org/wikipedia/en/3/30/Longitude_distance_graph.gif]

Figure 8: Distance across one degree of longitude, from *Wikimedia*

You'll most commonly encounter two kinds of coordinate systems when working with geospatial data: **geographic coordinate systems** and **projected coordinate systems**. They're closely related, but distinguishing them is really important.

Geographic coordinate systems

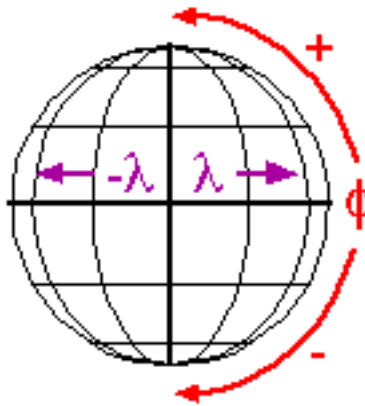


Figure 9: A *Geographic coordinate system*

A **geographic coordinate systems (GCS)** defines positions on the surface of the earth. It uses concrete, measured values to define global parameters, in the literal sense of the word “global.” An example is WGS84. Its global parameters are **defined as follows** (and you can scroll through many more “**useful constants**” **at this page**, if you wish):

Table 2: Global parameter transformations for the WGS84 GCS

Parameter notation value	Notation	Value
Semi-major Axis	a	6378137.0 meters
Flattening factor of the Earth	$1/f$	298.257223563
Nominal Mean Angular Velocity of the Earth	ω	7.292115×10^{-11} radians/second
Geocentric gravitational constant (Mass of Earth's atmosphere included)	GM	$3.986004418 \times 10^{14}$ meter ³ /second ²

Do you need to know the difference between a semi-major and semi-minor axis? No. Will you ever need to compute the flattening factor of the Earth in this class? Unless you really want to, absolutely not.

The purpose of seeing these parameters is not for you to memorize them, but to acknowledge that they are derived from real measurements about the Earth, derived by a person or people, some of whom gathered those measurements by walking around its landscapes.

Projected coordinate systems

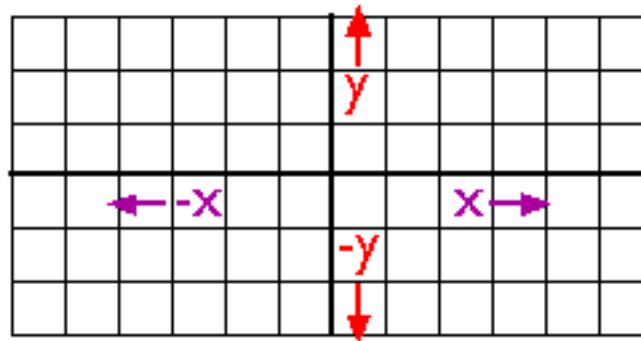


Figure 10: A *projected coordinate system*

A **projected coordinate system (PCS)** defines how to display that lumpy, oblate, spheroid surface as a flat map. It uses abstract, mathematical formulas to effect cartographic transformations that show certain areas on the globe with less distortion, and other areas with more. An example PCS is Mercator. Its **formula** is:

$$T(\phi, \theta) = (\theta, \ln(|\sec(\phi) + \tan(\phi)|))$$

GCS vs. PCS

In short, you could think of a GCS as the data and a PCS as the algorithm. A GCS defines the globe, while a PCS defines how you flatten it. A GCS deals with the actual territory, while a PCS deals with the map (which is, quite famously, **not the territory!**).

When you are working with spatial data, you **must** select a PCS that is appropriate for your study area, because doing any kind of calculation on data that has only been projected in a GCS will result in large and unexpected errors.

However you conceptualize these two different systems for understanding and representing the Earth, the making of maps requires both a GCS and a PCS working harmoniously with one another.

The table below highlights their differences:

Table 3: Differences between GCS and PCS

It is...	It represents...	It uses...	Examples...
<i>Geographic coordinate system</i>	Globe (e.g., the territory)	Angular/degree units (e.g., 40° W)	WGS84, NAD27
<i>Projected coordinate system</i>	Places (e.g., the map)	Flat/linear units (e.g., meters)	Mercator, Peters

 Question (1.5 pts)

Q2

1. What town does the Prime Meridian pass through?
2. What's one way you could distinguish lines of latitude and longitude?
3. Which of the two types of coordinate systems make more sense for displaying spatial data on a flat map?

XY data in ArcGIS Pro

The rest of this lab deals with XY data. By “XY” data, I simply mean gridded data that has an “X” position and a “Y” position—in other words, points with a latitude and longitude.

To view XY or any other spatial data in ArcGIS Pro, you don't need to use a PCS, but you *must* use a GCS. By default, a new ArcGIS Pro project will take on the coordinate system of the first data later you add, including a base map. Often this will be WGS 1984 Web Mercator.

When a geographic coordinate system is selected without a PCS, your map will be arbitrarily projected using the **pseudo-plate carrée projection**.

There are two places where you can learn information about your GCS and PCS:

1. You can view project-wide information about GCS and PCS by right-clicking the “Map” layer in your **Contents** pane > Properties > Coordinate Systems.
2. You can view layer-specific information about GCS and PCS by right-clicking an individual layer > Properties > Source > “Spatial reference.”

Loading tabular data as points

Under the **Map** tab in the banner, select Add Data > XY Point Data. This will open the **XY Table to Point** geoprocessing tool. (There are always multiple ways to do a thing in ArcGIS Pro; note that you could also access this tool by searching for it in the **geoprocessing toolbox**.)

In your tool, set the parameters to:

- Input Table = click the folder icon, navigate to where you saved places . csv, and select that file

- Output Feature Class = save the file as `pleiades_places` in your project geodatabase
- X Field = `long`, or whatever you named the **longitude** column
- Y Field = `lat`, or whatever you named the **latitude** column
- Z Field = this can stay empty (it refers to height)
- Coordinate system = You should always check the metadata to see what the data's source projection is. In our case, the right answer is in the **Pleiades metadata**, under the heading titled "Technical metadata." Refer to that.

Click Run and you should see this:

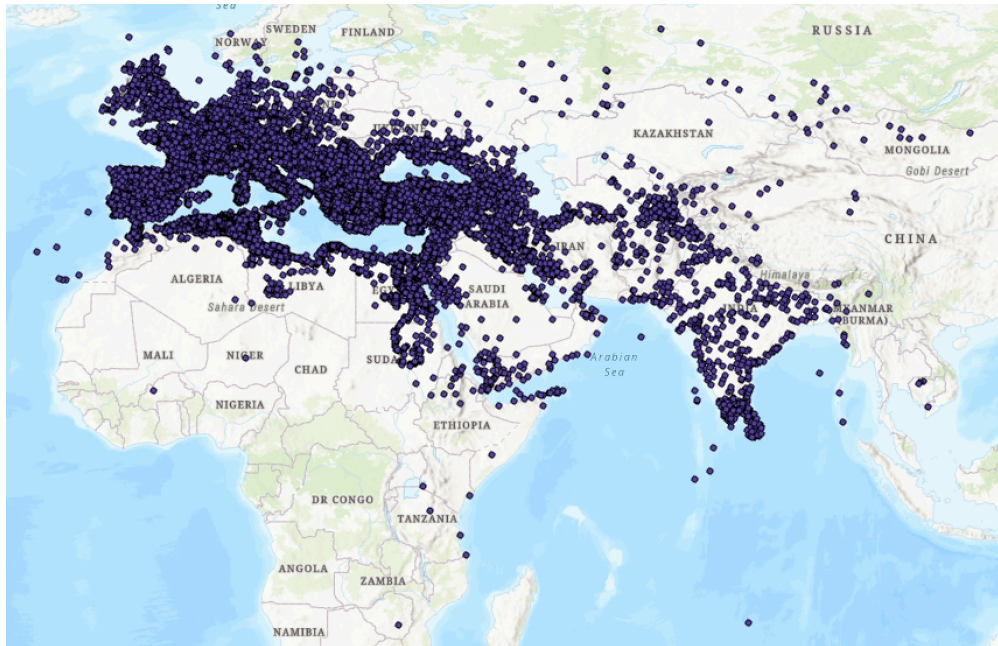


Figure 11: XY data, plotted

Nice! (It's okay if you get a warning message, that's normal for this dataset.)

Now we've got a full-fledged feature class containing over 40,000 points of ancient places, plotted from a `csv`. That said, it's kind of difficult to make sense of all this...

Querying Pleiades

... so let's see if we can break this data down and find any interesting patterns.

First, go ahead and open the attribute table. You can refer to the **Pleiades metadata** if you're confused by any of the fields (although note that the field names won't be exactly the same if you edited them before loading the data).

While the `title` field has the most obviously *mappable* information, the description or `desc` field has got lots of fascinating information:

- "A necropolis with inhumations dating to the fifth and fourth centuries B.C." (Monte Tumburino necropolis, OBJECTID: 4)

- “A nuragic complex consisting of a ‘megaron-type’ temple and a giant’s grave.” (Sa Carcaredda, OBJECTID: 248)
- “A major settlement mound along the Orontes river in Syria with over 10,000 years of occupational history from the Pre-Pottery Neolithic to the Mamluk period.” (Tell Qarqur, OBJECTID: 192)

What if we were able to search through the entire contents of this feature class for interesting words like “mound” or “grave” or “necropolis,” selecting only those features which include such terms?

Wait a minute: we can do that!

1. At the top of the attribute table, click the **Select by Attributes** button. It will open a little dialog box.
2. You can leave the Input Rows and Selection Type parameters as they are.
3. Click the  button in the middle of the dialog and then set the parameters of your new clause like so...

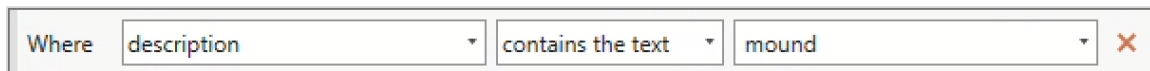


Figure 12: A clause searching for features where the `description` field contains the text “mound”

4. ... and click Apply. You should see a message pop up notifying you that “The input has a selection. Records to be processed: 168.”
5. This message just means that if you were to run some other tool, the tool would only apply to selected records. Also, all your selected records appear on the map in a light blue color. Neat! Click OK.
6. At the bottom-left hand side of the attribute table, toggle the view from “all records” to “selected records.”

Now the attribute table should show you only those records you selected.

7. Right-click on the `pleiades_places` layer in your **Contents** pane and choose “Zoom to layer.” This is a really handy shortcut for snapping a data layer to full screen in your map view. Just eyeballing it, do you notice any patterns in how the blue points are distributed?

Build your own query

Test out a couple of other keywords in your query. Replace “mound” if you want. Once you’ve found a few that you like, combine them with the “Add Clause” button in the **Select by Attributes** interface. **You should choose at least 3 queries in total.** Be conscious of how you’re using **boolean operators**; for example, if you string together multiple queries using AND, you’ll likely end up with few or zero results.

While you’re at it, toggle the SQL button  on and off to see how your queries are actually being composed behind the scenes. (We looked at this in Lab 02 as well.)

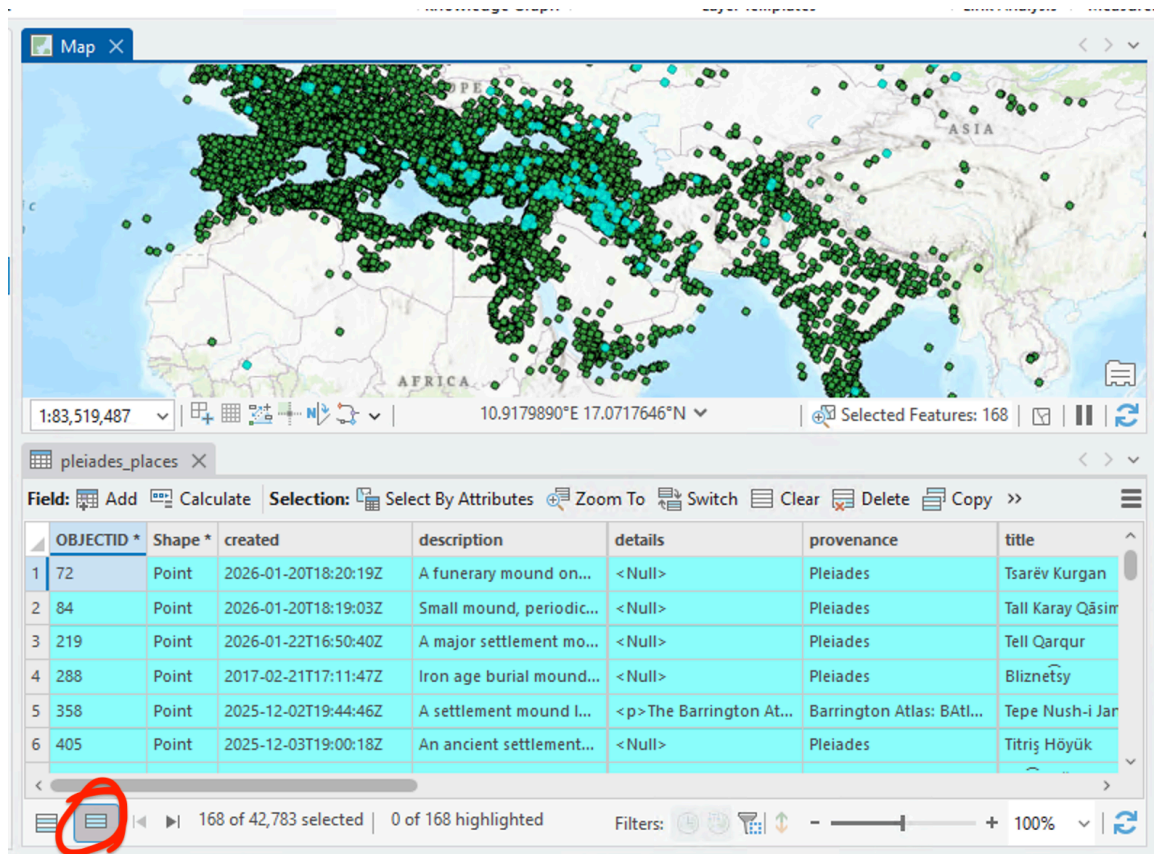


Figure 13: Selected records only; the blue in the attribute table matches the selected blue points on the map

Note that if your attribute table is set to only “Show Selected Records,” you won’t see the Select by Attributes tool.

 Question (1 pts)

Q3 Paste your full SQL query, as it appears in the dialog when you toggle the SQL button on. In no more than 2 sentences, consider why they are clustered the way they are.

Distortion

Now that you have a handle on what a GCS and PCS actually are, you can take the next step towards understanding how to use them. It all comes down to distortion: since the globe cannot be authentically represented as a flat surface, you must choose which parts of it to stretch and distort. A big decision! And with great power comes great responsibility. Time to learn about distortion.

Tissot circles

[Image: </coursework/labs/lab-03/images/image017.gif>]

Figure 14: A tool for exploring Tissot circles, [by Jason Davies](#)

Tissot’s indicatrix is a grid of *equidistantly placed* and *congruently sized* lines and circles. Overlaying it on maps helps visualize local distortion of different projections, as the [gif above of Jason Davies’ tool](#) demonstrates.

Take a moment to open his tool and drag your cursor around in it.

There are four properties of cartographic distortion: **area**, **distance**, **shape**, and **direction (or azimuth)**. Different projection types account for these distortions, always minimizing some at the expense of maximizing others. See below:

Projection type	What it preserves	Example
Conformal	Shape	Mercator
Equal area	Area	Peters
Equidistant	Distance	Plate Carrée
Azimuthal	Direction	Stereographic
Compromise	Nothing!	Robinson

Penn State has some excellent materials that do a great job of [distinguishing between these different kinds of distortion](#), if you want to learn more.

Let’s load Tissot’s indicatrix into our project so we can ascertain how and where different projections distort maps.

1. Download the Tissot.zip data by [clicking this link](#)
2. Move it into the downloaded-data folder in your directory
3. Load the data into your project
4. Right-click on one of the layers—Points, Admin, or Latlong—and click “Zoom to Layer”

When you’re done you should see something like this (ensure that things are “stacked” appropriately in the **Contents** pane):

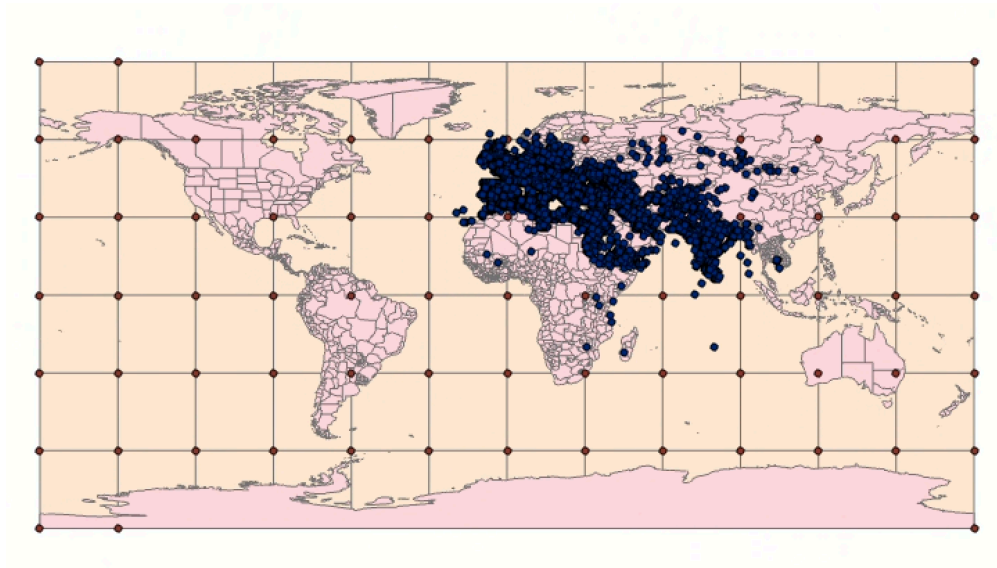


Figure 15: Tissot points on a graticular network

The buffer tool

The points and the grid that you loaded into your map don’t show us a fully-formed Tissot’s indicatrix—at least, not yet.

Note

Some of the material in this section is adapted from Matthew Gimond’s [ArcMap exercise about Tissot circles](#) and [selections and projections tutorial](#).

The **Buffer tool** is a classic tool in geographic information systems workflows. The tool creates buffer polygons to a specified distance around input features (either points, lines, or polygons).

Let’s create some buffers around those points and get a better visualization of how distortion is distributed throughout our map.

1. Click on the **Map** tab in the **Ribbon**
2. Click on the “Pairwise Buffer” tool from the “Tools” section, like below:

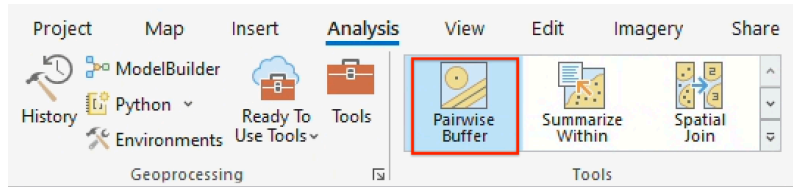


Figure 16: The “Pairwise Buffer” tool

If you don’t see the tool, you can also open the **Geoprocessing** window by clicking the **View** tab in the **Ribbon** > “Geoprocessing”, or by simply searching “Pairwise Buffer” in the **Command Search Bar**. Again: there are always **many ways to find a tool in ArcGIS Pro**.

3. The “Pairwise Buffer” tool should open in the **Geoprocessing** pane on the right-hand of your interface (similar to the “**XY**” tool you ran earlier). Populate the parameters like so:

- Input Features = “Points”
- Output Feature Class = “geodesicBuffer600km”
- Distance = 600 kilometers (Linear unit)
- Method = “Geodesic”
- Dissolve type = “No dissolve”
- Maximum offset deviation = “0”

Buffer creation is sensitive to coordinate systems used. If you want to create a perfect circle that covers a relatively large region while avoiding distortions that can accompany some projected coordinate systems, it’s best to create a **geodesic buffer output**. A geodesic feature is one that is created on a sphere or ellipsoid (e.g., based on a GCS) and not on a plane (e.g., based on a PCS).

4. If you haven’t already, click “Run.” When the Pairwise Buffer finishes running, you should see something like this:

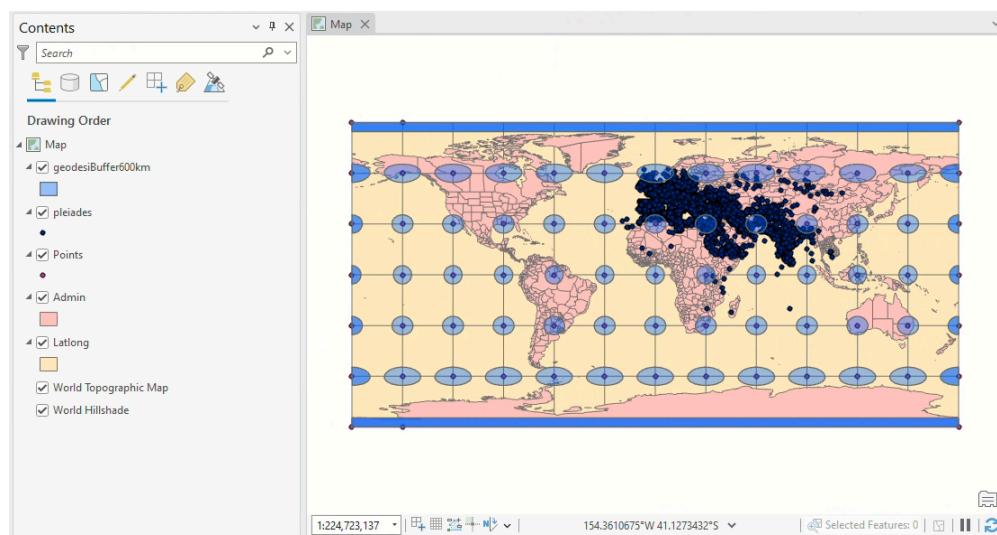


Figure 17: Tissot circles in ArcGIS Pro

It's a bit weird that we used a standard 600 kilometer buffer for all points, but the circles towards the poles are squished. What's happening here?

Understanding distortion

Think back to Figure 8, which showed us that as you approach the poles, the distance between degrees of longitude (Y-axis) will shrink. This function is on display in Figure 17. Basically, those “squished” buffers are still perfect circles—but their representation has been altered by the pseudo-plate carrée projection, which preserves distance, but not shape. The points are spaced evenly (no distance distortion!) but the shape has been really messed up (shape distortion!). Even though they look misshapen, their actual areas shouldn't be disturbed. We can expect the circles to equal πr^2 , or: $3.14 \times 600^2 = 1,130,973 \text{ km}^2$.

Try using the “Measure Distance” tool (under “Map” > the “Inquiry” group), measure in geodesic kilometers the diameter of both a smaller circle and a wider oval. Then, try using the “Measure Features” tool (in the same place) to click on a circle and measure its area in geodesic kilometers.



Question (1.5 pts)

Q4

1. What's the diameter of a smaller circle?
2. What's the diameter of a larger oval?
3. What's the total area, in square kilometers, of any circle?

Projections from Baghdad

Different projections also have implications for how spatial data is measured, so in the following sections, we'll see how spatial selection queries are affected by different kinds of distortion. We'll build these selection queries using Baghdad as a central point.

This will just take a few clicks. Under the “Inquiry” group of the **Ribbon**, click the “Search” tool (binoculars). This will open ArcGIS Pro's **World Geocoding Service**.



Caution

If you are not prompted to log into ArcGIS online, you'll need to do so through a web browser (click “sign in” > use “urichmond” as the organization URL > then use your UR ID): <https://www.arcgis.com/index.html>

Type “Baghdad” into the search bar, select the first option, let the service run, and then save the output as a feature class:

The feature class will end up in your project geodatabase. In my **Contents** pane, I renamed it “Baghdad” and gave it big red star icon so it was easier to see on the map.

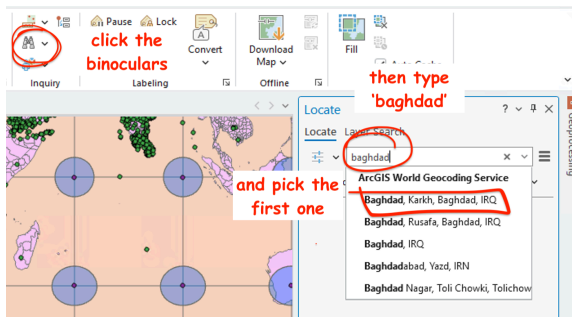


Figure 18: Locating Baghdad

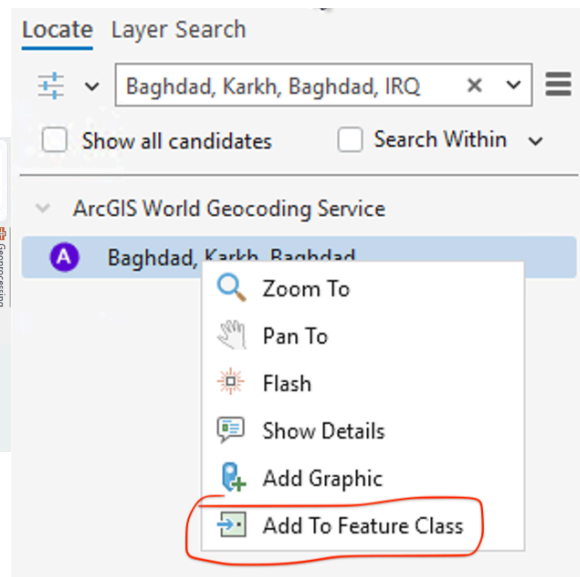


Figure 19: Making it a feature class

You will need to click into the “Edit” tab of the Ribbon and click “Save” to avoid any feature class editing funny business!

Make some new maps

Let’s make three new Map views, apply different projections to each, and test how those projections distort spatial selection queries:

1. Open the catalog pane and rename your current map to “WGS84”
2. Then, right-click “Maps” and duplicate your “WGS84” map three times
3. Rename the first duplicated maps “Web mercator”; rename the second “Gall”; and rename the third “Azimuthal.” Then, open the maps, and you should see something like this:
4. While we’re at it, let’s also make a new geodatabase for each of these maps, titled “mercator,” “gall,” and “azimuthal.” You can do this by going into the **Catalog** > right-click “Databases” > “New File Geodatabase” > name it and save it! These new geodatabases will hold some reprojected data in the next section.

Reprojecting data in Web Mercator

Open your map called “Web mercator.” In the **Contents** pane, right-click “Map” > “Properties.” Click “Coordinate Systems,” select “Web Mercator,” and click “OK”:

Now, all of the data layers in your map will project “on the fly” in Web Mercator, no matter how their underlying spatial data is projected:

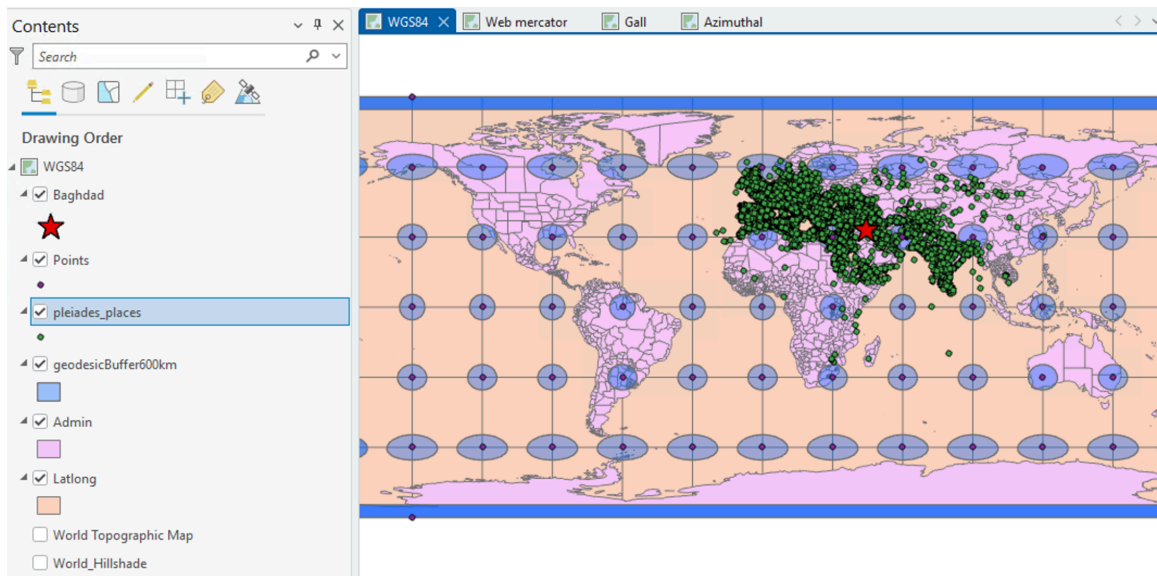


Figure 20: Four different maps, soon to be four different projections

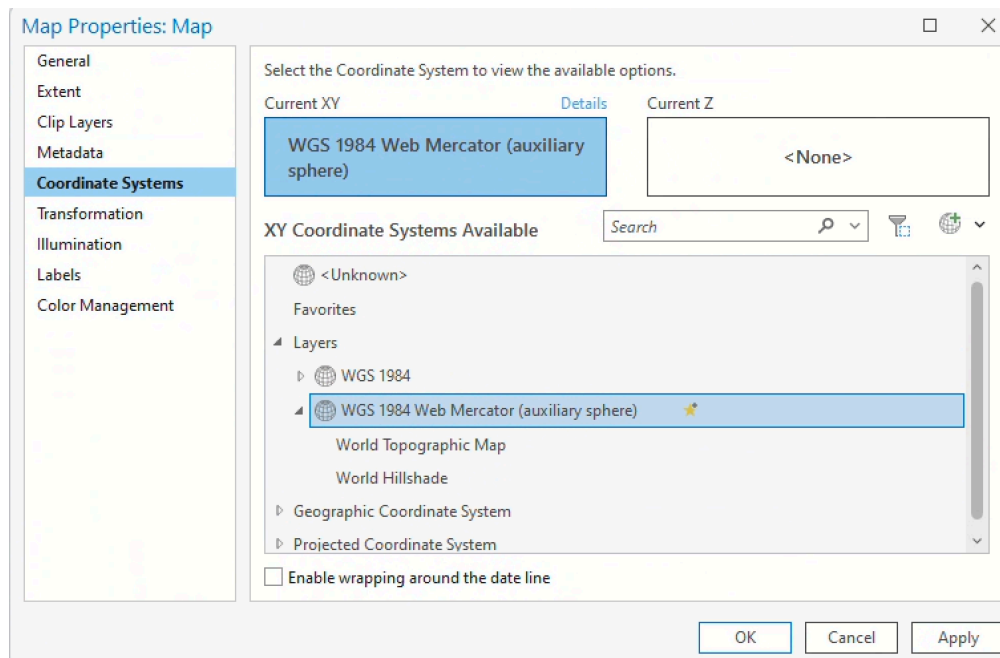


Figure 21: Change projection to Web Mercator

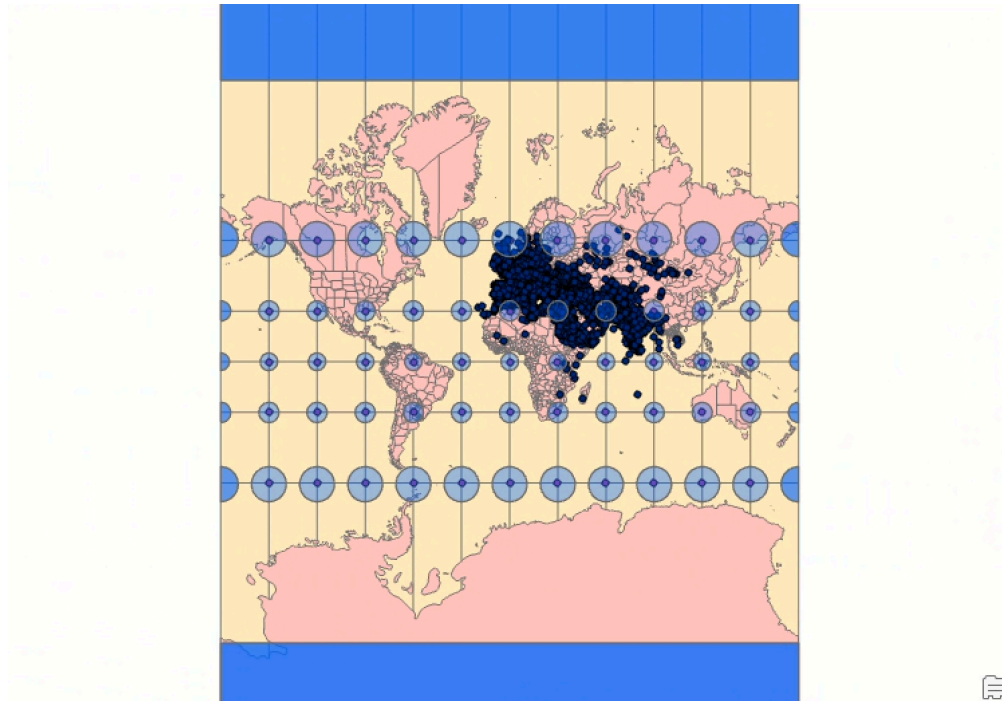


Figure 22: Tissot circles in Web Mercator

Web Mercator is a **conformal projection**. That means it preserves shape, but significantly distorts area. As a result, our Tissot circles all stay circular, but some are much bigger looking than others (hence the **Mercator projection's famous inflation of Greenland to appear as large as Africa**).

Right now, all of our underlying data is... well, it's not really projected at all! Everything is in WGS 84, which is a geographic coordinate system (GCS). **But any time you are working with spatial data and you need to measure things, do math, or compute stuff geographically, you must reproject data into an appropriate projected coordinate system (PCS). Otherwise you'll get big errors.**

So, let's reproject this data:

1. First, search for "batch project" in the **Command Search Bar** and open it. The **Batch Project** tool makes it easy to export multiple data layers to a new projection in a single go
2. The settings should resemble:
 1. Input feature classes = all of your active layers!
 2. Output workspace = `mercator.gdb`
 3. Output coordinate system = you should be able to select Current map [Web mercator], and if you don't see that, select it by clicking the globe
 4. Click "Run"

After the tool runs:

1. Select all the layers in your **Contents** pane > right-click > "Group" (this will help you keep things organized)
2. Then, from the **Catalog**, select all the feature classes inside of `mercator.gdb` and add them

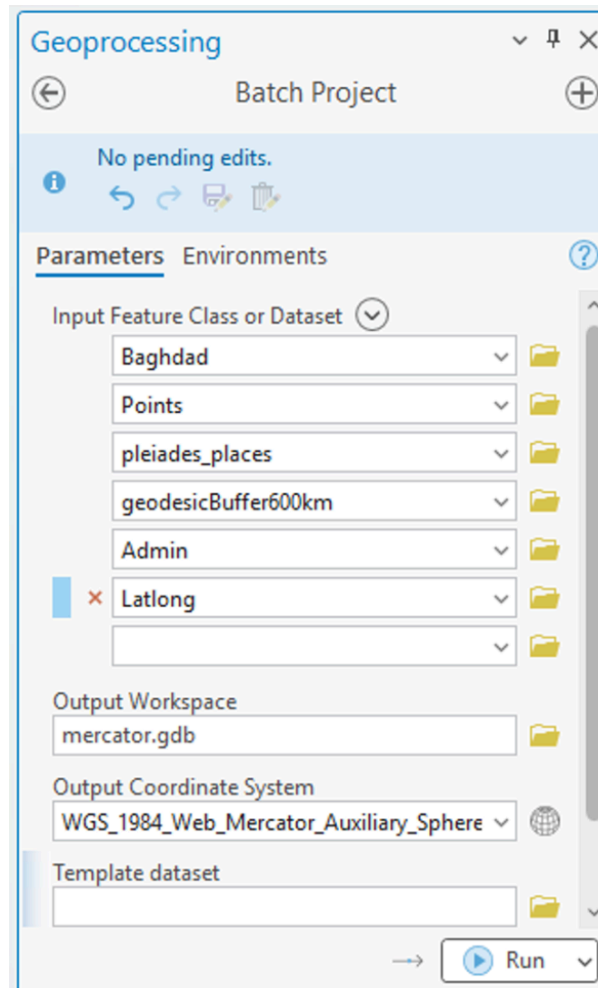


Figure 23: Batch project settings

to the map

You should see something like this:

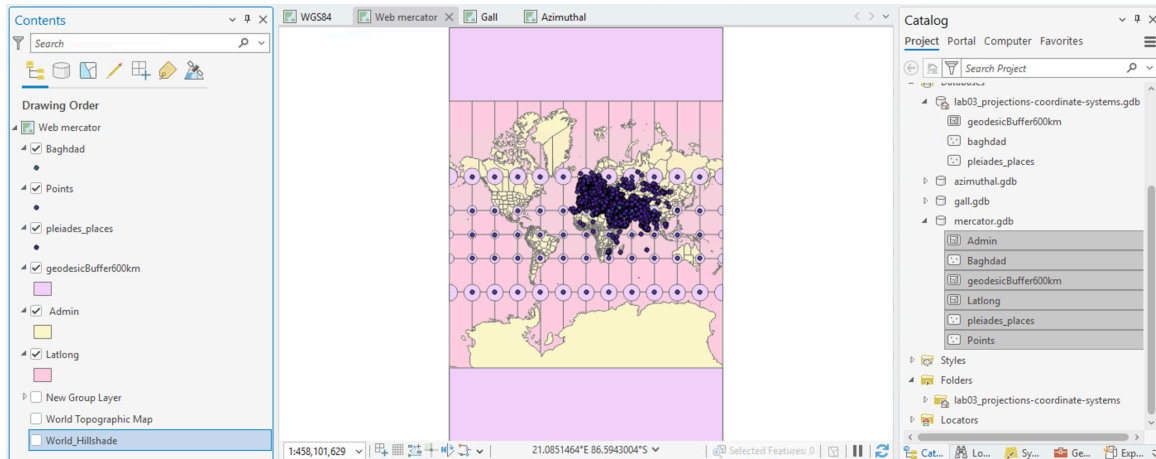


Figure 24: Mercator layers reprojected

Double-click one of the newly projected layers to open its layer properties, click “Source,” and examine the spatial reference. It should say “Mercator Auxiliary Sphere.” Compare this to the corresponding input layer that you used, which should say “WGS 84.”

Question (1 pt)

Q5 In 1 sentence, what is the main difference between units of measurement in WGS 84 versus Mercator?

Repeat for Gall and Azimuthal

Now, repeat each of those steps from reprojecting data in Web Mercator, but for Gall and Azimuthal. It should include:

1. Setting the Map’s projection to Gall Stereographic (world) and Azimuthal Equidistant (world), respectively
2. Batch reprojecting each layer to its respective geodatabase
3. For data management purposes, grouping the old layers together before adding the reprojected ones to the map
4. Checking a new reprojected layer’s spatial reference properties to confirm that it has the expected projection

Reprojections and new selections

Finally, let’s execute a few spatial selection queries to get a sense for how much distortion these projections create:

1. Starting in your WGS84 map, open the “Select by Location” tool
2. Build a query like so:
 1. Input features = pleiades_places
 2. Relationship = “Within a distance”
 3. Selecting features = Baghdad
 4. Search distance = 2000 Kilometers
 5. Selection type = New selection

Click “Run” and check the output in your attribute table for pleiades_places. You should have 9,613 features.

Now, re-run this query for each of the other 3 maps. **I recommend closing the pleiades_places tab each time because you’ll need to re-open the attribute table for each new map!**

Question (3 pts)

Q6 How many Pleiades places are within 2,000 kilometers of Baghdad in the...

1. Mercator-projected map?
2. Gall-projected map?
3. Azimuthal-projected map?

To conclude, run those three selection queries back again, but this time, use the relationship “within a distance geodesic.”

Question (1 pt)

Q7 By comparison, how many Pleiades places are within 2,000 *geodesic kilometers* of Baghdad in the...

1. Mercator-projected map?
2. Gall-projected map?
3. Azimuthal-projected map?

The key takeaway is this: projections matter. Using different projections can *vastly* impact distance and area calculations within a GIS environment. Take care to use the correct projections, and when possible, use the “geodesic” option, which minimizes the planar distortion that projected coordinate systems introduce to maps.

Submission details

Assigned	Due	Submit
9/7/26	9/14/26	Section 1, Section 2

Submit your work to Canvas as a .doc or .pdf file. No map due this week! Just answers to the questions.

Table 6: Rubric

Question	Point Value
Question 1	1
Question 2	1.5
Question 3	1
Question 4	1.5
Question 5	1
Question 6	3
Question 7	1