GIS Tutorial for Atmospheric Sciences

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Exercise 5

Coordinate Systems and Map Projections

Use Case: Climate Simulations in ArcMap

You will be accessing and combining geographic datasets or layers from a wide array of sources in GIS. ArcMap allows you to overlay these layers to perform GIS analysis and mapping. However, when overlaying two or more layers, aligning them correctly is not an automatic or arbitrary function. Geographic layers need particular information about their origins to overlay correctly with other datasets. This information is referred to as *coordinate systems* or *spatial reference information*. This information varies depending on your location and area of interest. Layers often have varying coordinate systems and need to be processed using tools in ArcMap so that they overlay correctly. In this section you will learn more about different coordinate systems and why they are important when working with spatial data.

Sub-Sections in Exercise 5:

1. *Understanding Basic Coordinate System Information*
2. *Using ArcToolbox tools to Manually Alter the Coordinate System Information of a Layer*

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Understanding Basic Coordinate System Information

A coordinate system is a reference system used to determine the location of geographic features. There are two common reference systems: geographic coordinate systems, and projected coordinate systems. In Step 1 you will explore these two types of coordinate systems.

Step 1 Viewing a layer's coordinate system information in ArcMap

When you begin to work with a new geographic layer, it is a good idea to view its spatial reference information stored in the metadata so that you better understand the layer and how it can be used.

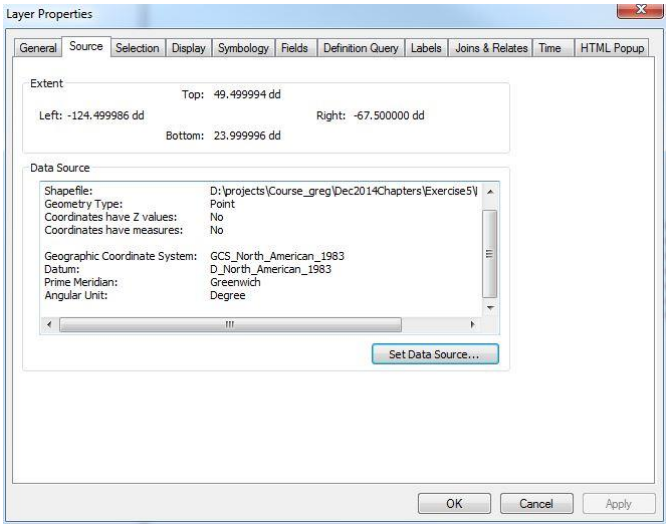
- Start ArcMap.

- Make a folder connection to ***C:\Exercise5.***

- Add the ***Precip*** layer located in the ***C:\Exercise5\Data*** directory to the Data Frame.

The *Precip* layer is a point data layer from the CMIP5 RCP 2.6 annual temperature dataset. Its coverage is the Continental U.S. This type of point layer could be interpolated into a smooth raster layer commonly seen in climate change maps. We will learn how to do that in a later exercise.

- Open the **Layer Properties** window and click the **Source** tab.
- In the **Data Source window**, scroll to the bottom so that you can see the **Geographic Coordinate System** information.



The coordinate system here is a Geographic Coordinate System (GCS). The datum used is North American 1983. A datum is the shape of the Earth upon which the coordinate system is based. The prime meridian is Greenwich and the angular unit is degrees. Because GCS units are degrees of latitude and degrees of longitude, they are measurements of the angles from the prime meridian. This angle would change depending on the shape of the Earth from which it is referenced. Therefore, knowing the datum from which data are referenced is very important.

- Close the Layer Properties window.
- Add the ***States*** layer from the ***C:\Exercise5\Data*** directory to the data frame.
- Open the Layer Properties window for the layer ***States*** and inspect this layer's spatial reference information from the **Source** tab.

What is the GCS of the States layer?

- Close the Layer Properties Window.

The two layers above are in the exact same coordinate system so they overlay correctly without any medication needed.

Step 2 Viewing the coordinate system of the Data Frame

The Data Frame contains a Coordinate System property. The Data Frame will inherit the coordinate system from the first layer added to ArcMap. In this case we added Precip first, which has a North American 1983 (NAD83) coordinate system defined. Therefore, our Data Frame will be NAD83 as well.

- Right-click on the Data Frame name ***Layers*** and select **Properties…**
- Click on the **Coordinate System** tab.
- Leave the Data Frame Properties window open.

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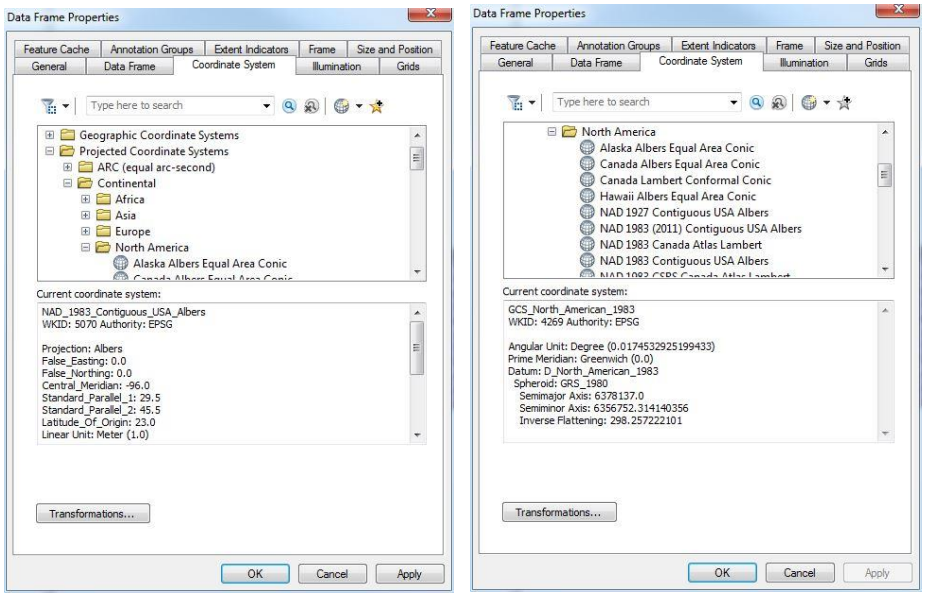
Step 3 Changing the coordinate system of the Data Frame

You can set the coordinate system for the Data Frame. When the Data Frame's coordinate system is different from the data layers' coordinate system(s), then the data will be "projected on the fly" to match the Data Frame's coordinate system. The actual data will not change but the way the data are viewed will change. We will now change the coordinate system for the Data Frame to a projected coordinate system and see how our map changes.

- Click the "**+**" sign beside the folder ***Projected Coordinate Systems***
- Expand the folder ***Continental***.
- Expand the folder ***North America***.
- Select the projection ***NAD 1983 Contiguous USA Albers***.



- Click **OK** to apply the changes and close the Data Frame Properties window.

Notice that the map has now changed its appearance. You have not changed the underlying data but you are simply viewing the data in a different manner. The map is now displayed in an Albers projection. Changing the coordinate system of the Data Frame is a way to display data from diverse coordinate systems in one common system.

ArcMap tries to resolve the issue of layers with different coordinate systems when they are first added to ArcMap. This is referred to as "projection on the fly" and is ArcMap's way of recognizing that two or more layers may have different coordinate systems but still need to overlay correctly with each other.

- Close ArcMap.

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Step 4 Projection on the Fly

- Start a new ArcMap blank document.
- Add the ***Precip*** layer to the data frame from the ***C:\Exercise3\Data*** directory.
- Examine the Coordinate System Properties of the Data Frame as you did in Step 2.
- Add the ***States_AWIPS_48*** layer to the data frame from the ***C:\Exercise3\Data*** directory.

Notice that this dataset lines up perfectly with the Precip layer in the map.

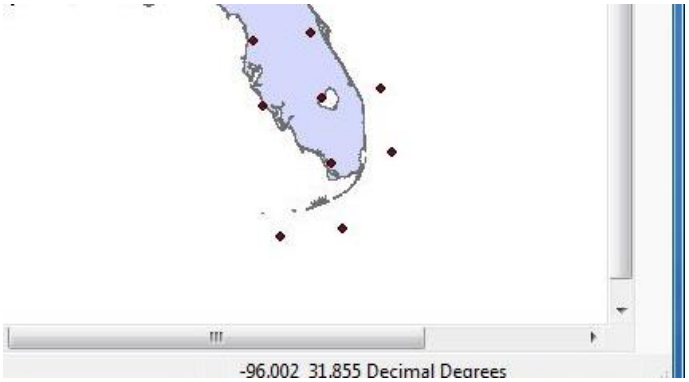
- Open the Layer Properties window and examine the spatial reference system information in the Layer Properties window.

What is the projection of this layer?

- Close the Layer Properties window.

This layer is projected to Albers Equal Area Conic projection. However, the data is projected on the fly to GCS North American 1983 geographic coordinates because this is the projection of the Data Frame. The linear units are in meters. A map projection is a way of representing three-dimensional Earth coordinates in a two-dimensional planar surface.

- In the lower right corner of the data frame, notice the units are in Decimal Degrees.



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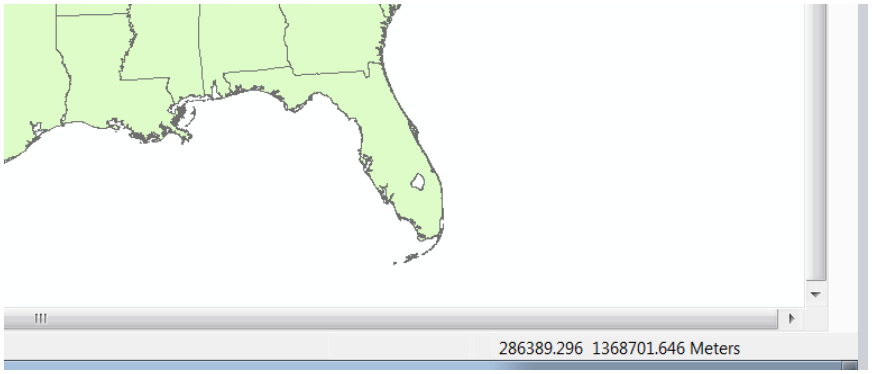
TIP: "Projection on the Fly" only works if the coordinate system information of the layer is already defined. If the layer is missing the coordinate system information, ArcMap will not be able to project the layer on the fly.

Step 5 Adjusting the Display Units of the Data Frame

- Open the Properties window for the Data Frame.
- Click the General tab.
- Change the Display Units to **Meters**.
- Click **OK**.

Move your cursor around the map and watch the units change. These units are referred to as *display units*.



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Using ArcToolbox tools to Manually Alter the Coordinate System Information of a Layer

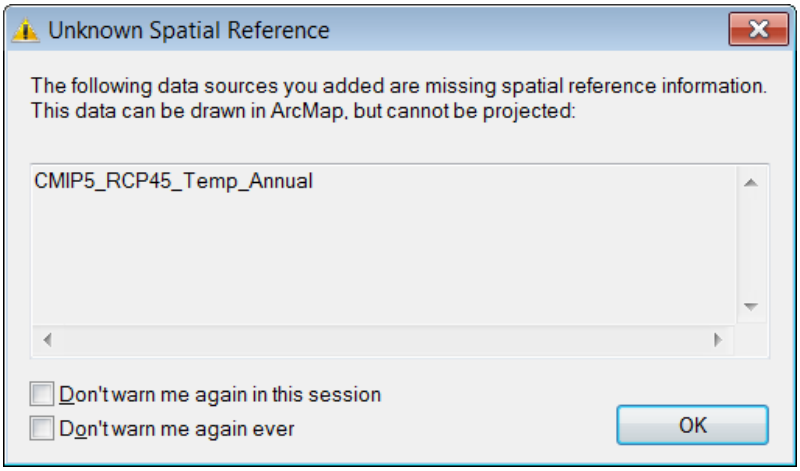
There are tools in ArcToolbox for manually changing the coordinate system information of individual layers to ensure that all layers you are working with have the same coordinate system information.

Step 6 Using the Define Projection tool to add coordinate system information to a layer

It is not uncommon to have a layer that has no coordinate system information. You can still view such a layer in ArcMap, but it won't align correctly with your other layers that do include coordinate system information.

- Click File > New.
- Select **Blank Map** and click **OK**.
- Click **No** when asked if you wish to save changes to your map.
- Add the ***CMIP5_RCP45_Temp_Annual*** to the Data Frame.

You should see a warning message similar to the one below:



- Click **OK**.

The *CMIP5_RCP45_Temp_Annual* layer is point data layer from the CMIP5 RCP 4.5 annual temperature dataset. It is global in coverage.

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- Open the Layer Properties window and click the **Source** tab.

Notice that the Coordinate System is "Undefined." Also notice that the display units that you saw in Step 2 are shown as unknown units.

- Close the Layer Properties window.
- Add the ***CONUS_Sates_GCS*** layer to the Data Frame.

This layer is added in the Table of Contents, but you do not see this layer in the Data Frame. ArcMap will let you add layers that are undefined, but they may not line up with your other data layers.

- Click the **Full Extent** button on the Tools toolbar. 

Now the state boundary layer appears to the left of the point data, but it should be located in the northeastern portion of the point data. Examining the coordinate system information would tell you that the layer is in geographic coordinates. You will now manually apply a projection to the *CMIP5_RCP45_Temp_Annual* layer so it will align correctly with the state boundary layer.

- Open ArcToolbox by clicking the **ArcToolbox** button on the Standard toolbar. 

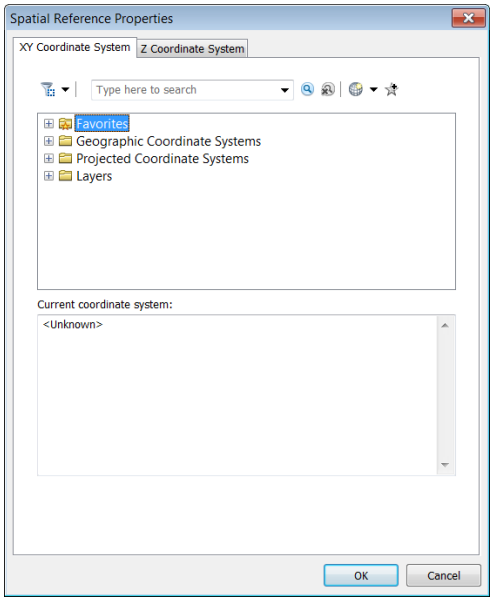
ArcToolbox is a collection of tools designed for editing, processing, and working with GIS data. These tools are used to perform a variety of operations on vector and raster data. We will explore more functionality of ArcToolbox in later exercises.

- Navigate to the **Data and Management Tools** toolbox and then to the **Projections and Transformations** tool tray.
- Expand the Projections and Transformations tool tray.
- Open the **Define Projection Tool** by double-clicking it.

TIP: If you don't know where a tool is in ArcToolbox, you can click the Search button on the Standard toolbar and search for the tool you need.

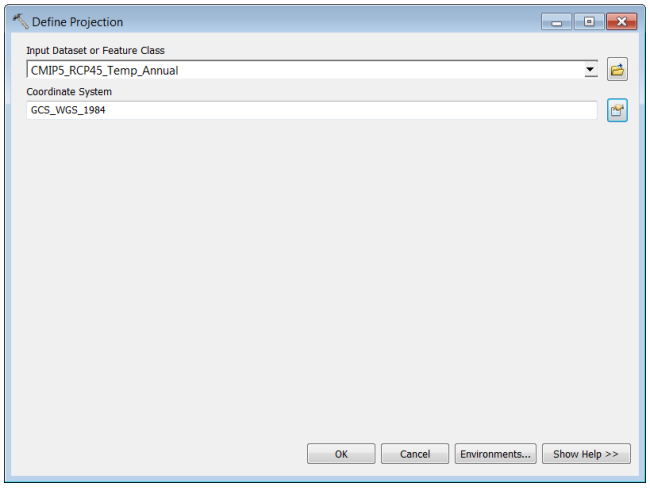
- Click the dropdown arrow in the **Input Dataset** or **Feature Class** box and select the *CMIP5_RCP45_Temp_Annual* layer.

- Click the icon to the right of the **Coordinate System** box to open the **Spatial Reference Properties** window.



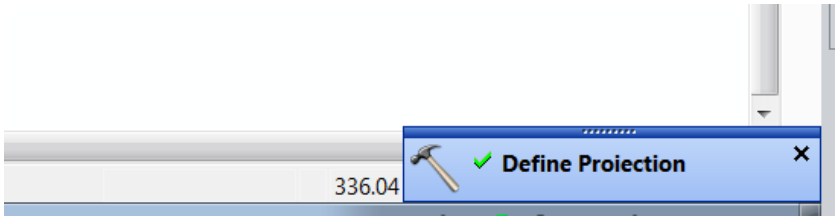
- Click to expand the ***Geographic Coordinate Systems*** folder.
- Click to expand the ***World*** sub-folder.
- Select the ***WGS 1984*** coordinate system at the bottom of the list and click **OK**.

Your **Define Projection** window should now resemble the example below:



- Click **OK**.

When the tool has completed, you should see a blue box appear momentarily in the lower right side of ArcMap.



In order to see these changes, you will have to insert a new Data Frame to ArcMap or start a new ArcMap document.

- From the Menu Bar, click **Insert > Data Frame**.

This new Data Frame is essentially a new blank map in your map document.

- Add the ***CMIP5_RCP45_Temp_Annual*** *to the New Data Frame.*
- Open the Layer Properties window and click the **Source** tab.
- Close the window.

The coordinate system information is now in WGS 1984, indicating that it is a geographic coordinate system.

- Add the ***CONUS_States_GCS*** layer to the Data Frame.
- Click Close in the Geographic Coordinate System Warning window.
- In the Table of Contents, drag the ***CONUS_States_GCS*** layer above the ***CMIP5_RCP45_Temp_Annual*** layer.

The two data layers now align correctly.

TIP: You should always create a copy of the original layer before you define a projection for it with the Define Projection tool. The Define Projection tool is a permanent edit to the original layer and **does not** create a new layer like most other tools. If you apply the incorrect coordinate system, it will be permanently changed.

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Step 7 Using the Project tool to change the coordinate system of a vector layer

Unlike the previous two steps, it is more likely that data you work with will already have a coordinate system. However, it may not be the coordinate system that you want to work with. The Project tool is used to "project" a layer from one geographic or projected coordinate system to another, or for switching between the two types of coordinate systems.

- Click **File > New**.
- Double click on **Blank Map**.
- Click **No** when asked to save the map.
- Add the ***NCA_Regions_CONUS*** layer to the Data Frame.
- Examine the coordinate system information of this layer.

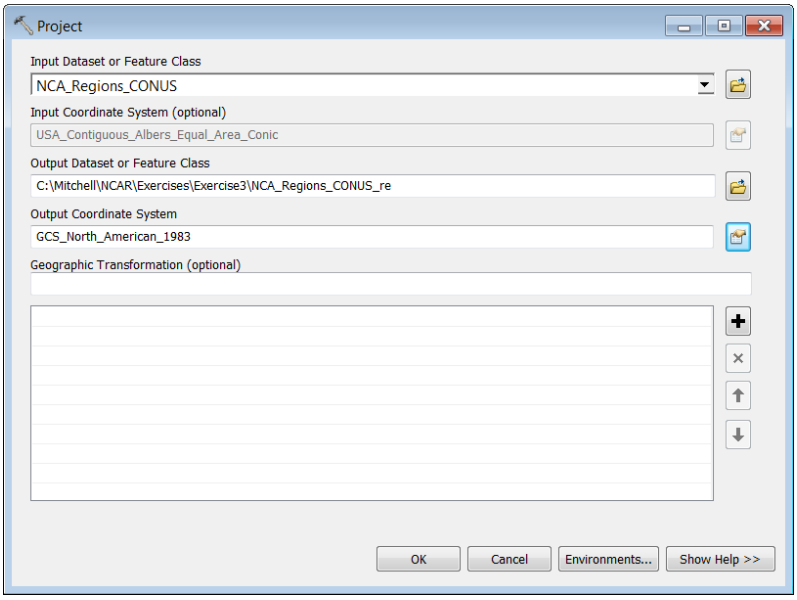
The coordinate system of this layer is USA Contiguous Albers Equal Area Conic, indicating the layer is in projected coordinates. You will now change this to a geographic coordinate system.

- Close the Layer Properties window.
- Open ArcToolbox by clicking the **ArcToolbox** button on the Standard toolbar. 
- Navigate to the **Data and Management Tools** toolbox and then to the **Projections and Transformations** tool tray.
- Expand the Projections and Transformations tool tray.
- Open the **Project** tool.

The Project tool window appears.

- Click the dropdown arrow in the **Input Dataset** or **Feature Class** box and select the *NCA_Regions_CONUS* layer.
- Save the new layer in **Output Dataset** or **Feature Class** box to the by clicking the folder icon to the right of the box and navigating to your ***C:\Exercise5\Data*** directory.
- Enter the output layer name as *NCA_Regions_CONUS_re*.
- Click the icon to the right of the **Output Coordinate System** box to open the **Spatial Reference Properties** window.
- Click to expand the **Geographic Coordinate Systems** folder.
- Click to expand the **North America** sub-folder.
- Select the *NAD 1983* coordinate system and click **OK**.

Your Project window should now resemble the example below:



- Click **OK**.

The tool automatically added this new layer to the Data Frame. However, the new layer looks exactly the same as the original layer. This is because when it was added, ArcMap automatically projected it on the fly to align with the original layer in your Data Frame that had already set the coordinate system of the Data Frame.

- Examine the spatial reference information of the new layer by opening the Layer Properties and clicking the **Source** tab.

The Project tool did in fact work and the new layer is no longer in projected coordinates, just geographic coordinates using the NAD 1983 coordinate system.

- Click **Insert > Data Frame**.
- Add the ***NCA_Regions_CONUS_re*** layer to the new Data Frame.
- Right-click on the first Data Frame called ***Layers*** and select **Activate**.

Now you see the difference between the two layers of the geographic and projected coordinate systems.

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Projected Coordinates –
Albers Equal Area Conic

Geographic Coordinates –
NAD 1983

- Right-click on the second Data Frame called ***New Data Frame*** and select **Activate**.
- Add the ***NCA_Regions_CONUS*** layer to the second Data Frame.

The original *NCA_Regions_CONUS* layer is now the layer projected on the fly to align with the new layer you manually projected in this step.

- Explore both Data Frames.
- Close the ArcMap document without saving it.

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Step 8 Using the Project Raster tool to change the coordinate system of a raster layer

When changing the coordinate systems of layers, there are different sets of tools for working with your data depending on the data format of your layers. Vector and raster data each have their own set of tools for working with and changing coordinate systems.

- Open a new blank ArcMap document.
- Add the ***p_cmip5rcp85*** raster layer to the Data Frame.

This is a raster layer showing the CMIP5 RCP 8.5 projected winter season average temperature for the time period 2021-2050.

- Examine the spatial reference information of this layer within the Layer Properties window under the **Source** tab.

The raster layer contains the geographic coordinate system of WGS 1984. Now you will change this layer to a projected coordinate system.

- Open **ArcToolbox** in the same way you did in Step 5.
- Navigate to the **Data Management Tools** toolbox.
- Expand the **Projections and Transformations** tool tray.
- Expand the tools under the **Raster** sub-tool tray.
- Open the **Project Raster** tool.

The Project Raster tool works essentially the same way as the Project tool did for vector data in Step 5.

- Click the dropdown arrow in the **Input Dataset** or **Feature Class** box and select the *p_cmip5rcp85* layer.
- Save the new layer in **Output Dataset** or **Feature Class** box to the by clicking the folder icon to the right of the box and navigating to your ***C:\Exercise3\Data*** directory.
- Enter the output layer name as p_rcp85_re.

When raster layers are not stored in a geodatabase, ArcGIS for Desktop limits their file name to 13 characters.

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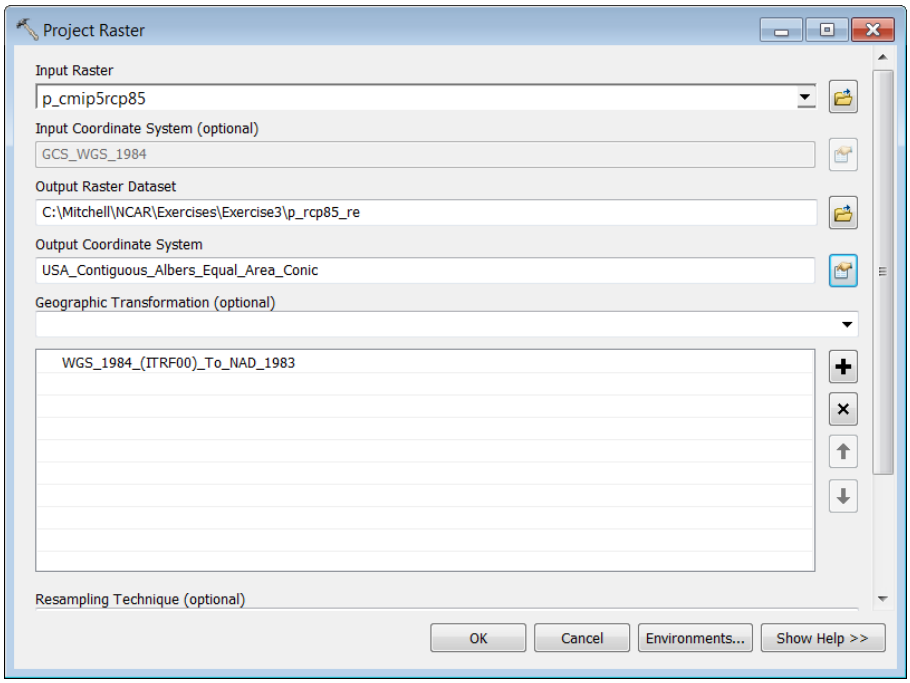
- Click the icon to the right of the **Output Coordinate System** box to open the **Spatial Reference Properties** window.
- Click to expand the **Projected Coordinate Systems** folder.
- Click to expand the **Continental sub-folder** and then the **North America sub-folder**.
- Scroll down and select the USA Contiguous Albers Equal Area Conic and click **OK**.

Your Project Raster window should now resemble the example below.



- Click **OK**.

The tool automatically adds the new layer to the Data Frame.

The Data Frame is in geographic coordinates due to the initial layer that was added to the map. All other layers are projected on the fly to match this coordinate system.

- Open a new blank ArcMap document.
- Add the ***p_rcp85_re*** layer that you just created to the Data Frame.

The raster layer now appears as it should for a layer with an Albers Equal Area Conic projection, which is a projected coordinate system.

- Close ArcMap without saving your document.

TIP: While there are different projection and transformation tools for working with vector and raster layers, the Define Projection tool, from Step 6, is the tool that works with both types of data.