Exercise 1

Working with climate simulation output in GIS

Background

As stated in the Climate Change Global Food Security and the U.S. Food System Executive Summary on page 3:

> ***Climate risks to food security increase as the magnitude and rate of climate change increase. Higher emissions and concentrations of greenhouse gases are much more likely to have damaging effects than lower emissions and concentrations.*** *Worst-case projections based on high greenhouse-gas (GHG) concentrations (~850 ppm), high population growth, and low economic growth imply that the number of people at risk of undernourishment would increase by as much as 175 million above today's level by 2080. The same socioeconomic conditions with GHG concentrations of about 550 ppm result in up to 60 million additional people at risk, while concentrations of about 350 ppm—less than today's level—do not increase risk. Scenarios with lower population growth and more robust economic growth result in large reductions in the number of food insecure people compared to today, even when climate change is included, but higher emissions still result in more food insecurity than lower emissions.*
> *(http://www.usda.gov/oce/climate_change/FoodSecurity2015Assessment/CCFS_Executive_Summary.pdf)*

GLOSSARY

Climate Models

Climate models are computerized simulations of the climate system developed to understand and predict climate behavior. "Climate models incorporate the physics and chemistry of the atmosphere and the oceans and aim to answer questions such as when the next El Niño might occur, and what might happen if greenhouse gas concentrations double." You can find more information on climate models at the World Meteorological Organization (WMO) website. https://www.wmo.int/pages/themes/climate/climate_models.php

Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess scientific, technical, and socio-economic information relevant for the understanding of climate change and its impacts. The IPCC produces assessment reports on climate change and related topics. The 4th Assessment Report (AR4) on Climate Change was released in 2007 and the 5th Assessment Report (AR5) was released in 2013.

Community Climate System Model (CCSM)

The Community Climate System Model (CCSM) is a community-wide effort led by the National Center for Atmospheric Research (NCAR). The CCSM is a coupled climate model for simulating the earth's climate system. It is composed of four separate models simultaneously simulating the earth's atmosphere, oceans, land surface, sea-ice, and one central coupler component. The CCSM allows researchers to conduct fundamental research into the earth's past, present, and future climate states.

Representative Concentration Pathways (RCPs)

Representative Concentration Pathways (RCPs), are four possible future climates depending on how much greenhouse gases are emitted in the years to come. RCPs represent potential greenhouse gas concentration scenarios projected into the future. Four tiers of RCPs were developed, and each is named according to the level of radiative forcing (enhanced greenhouse effect or warming) anticipated by the year 2100. The four RCPs include one peak pathway in which radiative forcing reaches 8.5 Watts per square meter (Wm-2) by the year 2100; two intermediate "stabilization pathways" in which radiative forcing stabilizes at 6 Wm-2 and 4.5 Wm-2 after the year 2100, and one low pathway in which radiative forcing peaks around 3 Wm-2 before 2100 and then declines. This low scenario describes GHG emissions that drop below zero around 2070 and continue to decrease (carbon-negative) into the future.

For more information: http://sedac.ipcc-data.org/ddc/ar5_scenario_process/index.html

Ensembles

Climate models can be run multiple times and each time using a slightly different initial state of the atmosphere. Each run is called an ensemble member. Each ensemble member is a plausible representation of the real world and each produce slightly different future outcomes. Ensembles give us a better understanding of the uncertainty in the model based on its initial atmospheric state. In these exercises you will use the ensemble average for the climate model.

Climate Anomalies

A climate anomaly is the difference between a plausible future climate when compared to present-day climate. In this exercise the present day climate is a 20-year average of 1986-2005 climate data. Anomalies are useful to determine the magnitude of change.

NetCDF

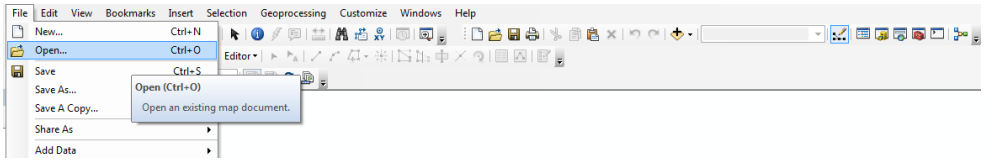
NetCDF is a popular atmospheric data format because it can easily store multidimensional data (X, Y, time, and/or altitude).

Opening and Exploring ArcMap

Step 1 Starting ArcMap and open a Map Document file.

In this first step you will open an existing map in ArcMap.

- Click **Start > All Programs > ArcGIS > ArcMap 10.X.**
- If a dialog box appears prompting you to select a map, click **Cancel**.
- From the **File** menu in the upper left, click **Open...**

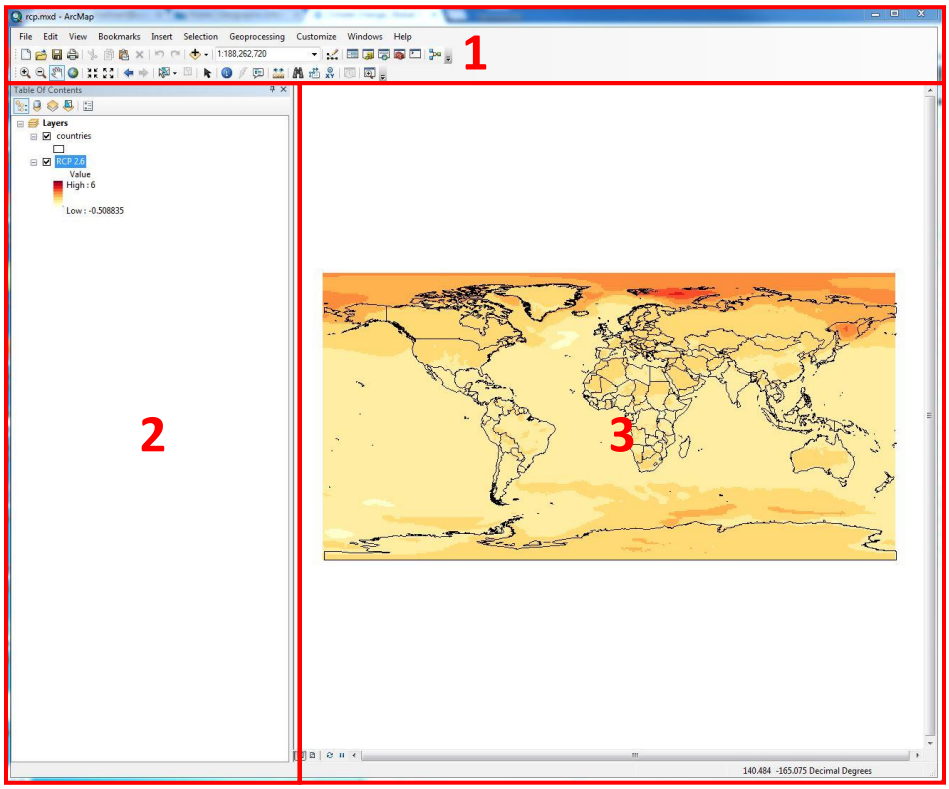


- Browse to ***C:\USDA_NCAR \exercise1\maps*** and select the ***GlobalAnomalies.mxd*** file (if using ArcGIS 10.4), and open ***GlobalAnomalies10_3.mxd*** (if using ArcGIS 10.3).

TIP: The .mxd file extension identifies ArcMap document files.

- Click **Open** to open the map document**.**

When the document opens, you'll see the basic ArcMap interface. It offers three key sections: 1) the menu tabs and toolbars at the top, 2) the Table of Contents on the left, and 3) the map display in the middle.



This map displays a layer called countries and another layer called "RCP 2.6" which contains information for Air Temperature Anomalies for RCP 2.6. An air temperature anomaly is the difference between a plausible future temperature when compared to present-day climate. Anomalies show change and are a good way to display how temperature change varies in space and time. RCP 2.6 is an emission scenario used to represent potential greenhouse gas concentration scenarios projected into the future (as explained above in the Glossary).

- Take a moment to explore the various menu tabs at the top. Notice that some of these are similar to other Windows-based programs such as Microsoft Office. Hover your mouse over a tool to see the tools name and short description.

- Now save the document by clicking **File**, and then **Save As**. Save the map document in ***C:\USDA_NCAR\exercise1\maps*** as ***exercise1_<your name>.mxd.***

TIP: It is good practice to use only alpha-numeric characters or underscores in your file names and leave no spaces.

Step 2 Exploring toolbars and windows

Toolbars organize the tools available in ArcMap.

- Click the **Customize** menu.
- Then hover your mouse over **Toolbars.**

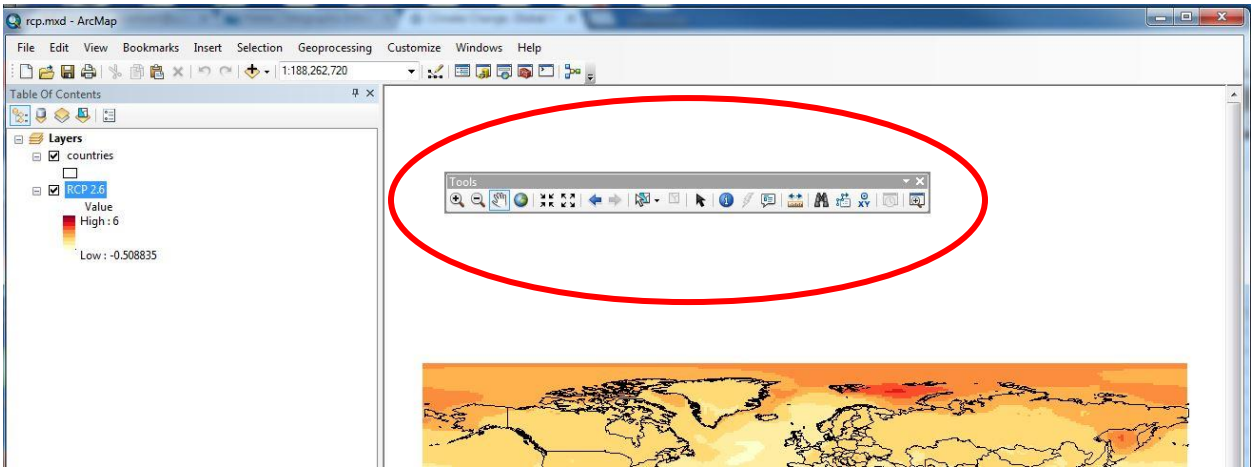
The toolbars allow you to access many of the ArcMap functions and tasks. The **Standard** and **Tools** are the key toolbars. Notice a checkmark beside each of them, indicating that they are already turned on. You can turn toolbars on and off by clicking on them in this menu.

- Click anywhere outside the toolbar menu to close it.

Once turned on, toolbars can be moved around to best fit within the ArcMap interface. More specifically, they can either be docked to the side of the screen or they can be left floating in the middle. Currently, all three of the main toolbars are docked above the Table of Contents and Map Display section of the ArcMap interface (section 1 in the image above).

- Click on the grey handle of the Tools toolbar, indicated by the vertically aligned dots on the left edge of the toolbar, and drag the toolbar to the Map Display area.

Note that the name of the toolbar now appears, along with the option to close the toolbar completely.



- Click on the grey bar at the top of the Tools toolbar and drag it back to the top of the screen to re-dock it.

TIP: Another way to dock a toolbar is to double-click on the grey top part of the toolbar.

Try expanding the Map Display area for a better view. Turning off the Table of Contents is one way to do this.

- Click the **X** in the upper-right corner of the Table of Contents (TOC) window.
- To turn it back on, click on the **Windows** menu at the top, and then **Table of Contents.**

Alternatively, you can set the window so that it disappears automatically when you don't need it.

- In the upper-right corner of the Table of Contents window, click the thumbtack icon (**Auto Hide**) to create a quick access tab for the Table of Contents.
- Hover your mouse over the new tab. This will open the Table of Contents window. Once you move your cursor away, the display minimizes again.

- Click the **Table of Contents** tab and then the **Auto Hide** button to restore the window to its original docked position.

Windows, such as the Table of Contents, can be docked in multiple locations or they can be left to float, similar to toolbars.

- Click the Title Bar (top) of the Table of Contents window and drag it away from the left side of the Map Display and drop it on your map.
- Double click the Title Bar to dock the Table of Contents (TOC).

Step 3 Navigating and using the zoom and pan tools

Explore your layers interactively by zooming in closer to a particular location or panning to nearby areas.

- Click the **Zoom In** button on the left side of the Tools toolbar.

TIP: For a description of each tool in the toolbars, simply hover your mouse over the tool and a tool-tip window will appear.

- Click once near the northwest corner of North America and keep holding down the mouse.
- Drag a box around the rest of North America and release the mouse.

- Click the **Pan** button on Tools toolbar (notice that the cursor becomes a hand).
- Click and drag the map upwards to see South America.

TIP: Another option for zooming in and out is the **Fixed Zoom In** and **Fixed Zoom Out** buttons found on the Tools toolbar. Yet another, and perhaps more convenient option, is to use the scroll wheel on your mouse. Place your cursor over the area that you want to zoom to and then roll the scroll wheel backwards. Hold down **Ctrl** while rolling to zoom at finer increments.

Now that you have explored the area up close, zoom back out to get a wider picture. You can zoom out in small increments using the **Zoom Out** button on the Tools toolbar (similar to the Zoom In function), or you can zoom out to the furthest extent of the data in your ArcMap document. Zoom to the full extent to view all of your data at once.

- Click the **Full Extent** button (globe icon) on the **Tools** toolbar.

If you want to return to the previous close-up view, you can use the Back to Previous Extent button.

- Click the **Go Back To Previous Extent** button (left arrow icon) on the **Tools** toolbar.

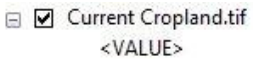
- Now your map view is back to wherever you were just prior to zooming to the full extent. When you have finished exploring the data, zoom back to the full extent.

Step 4 Getting to Know Layers and Data Frames

Let's look more closely at the items in the Table of Contents. Notice that there are two collections of layers called ***Layers*** and ***Drought***. These are called **Data Frames**. While both Data Frames are listed in the Table of Contents window, we currently only see the global map with temperature change. The second one shows croplands.

- Right-click on the title of the second Data Frame, **Drought**.
- Click **Activate**.

The map of countries appears in the Map Window and the title, ***Drought***, assumes a bold type-face indicating that it is the active Data Frame.



- In the **Drought** Data Frame, click the check-box next to the ***Current Cropland.tif*** layer. This will toggle the layer on.

Now the ***Current Cropland*** layer is turned on.

- Click the ***Current Cropland*** layer and, while holding the mouse down, drag it below the ***countries*** layer.

Layers are drawn from the bottom up. So, ***Current Cropland*** is hidden because this layer is drawn below the countries.

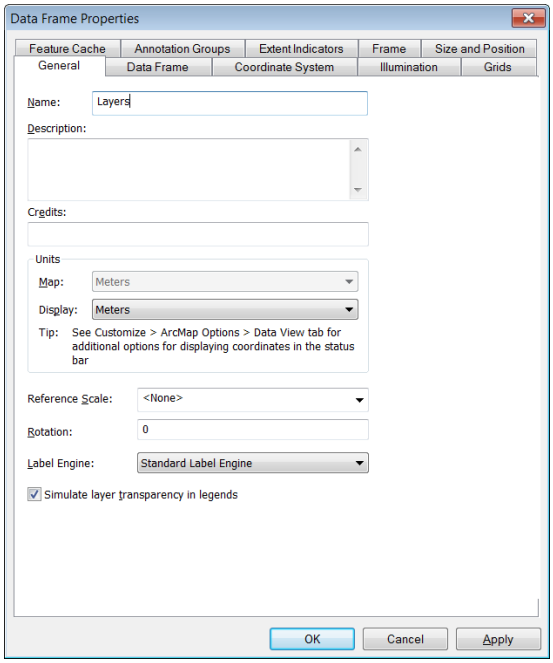
- Re-activate the ***Layers*** Data Frame by right-clicking on the Data Frame and selecting **Activate**.

Step 5 Data Frame Properties

When a new Data Frame is created, it is given the default name, ***Layers***. This can be changed in the Data Frame Properties.

- To access the Data Frame Properties, double-click on ***Layers,*** or click the **View** menu and then click **Data Frame Properties...**

In the Data Frame Properties window, there are ten different menu tabs that allow you to view and edit various properties of the Data Frame.



- Click the **General** tab and enter "*Climate Simulations"* into the **Name** box. You could also enter a description and credits, but for now, we'll leave these blank.
- Click **Apply** to set the new name.

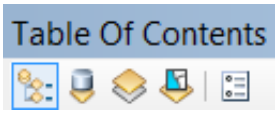
You can see that the Name has been updated in the Table of Contents. You can explore the other tabs in the Data Frame Properties window on your own.

- Close the Data Frame Properties dialog box by clicking **OK**.

Step 6 Viewing Layers in the Table of Contents

A map document consists of a collection of layers that are displayed, managed, and accessed from the ArcMap Table of Contents window. The layers themselves are not actually stored within the map document; rather, they are accessed through the map document.

ArcMap offers a few different options for how layers in the Table of Contents are displayed. Notice the five small icons in the upper-left corner of the Table of Contents window.



The blue box surrounding the left-most icon indicates that this is the active view. In this view, the layers are listed by drawing order – the layer drawn on top is on the top of the list.

- Click on the second icon from the left, the **List by Source** option.

In this view, the path names appear, indicating where the layer is stored. This can be helpful if you forget where the dataset behind the layer in your map resides.

- Click on the layer ***countries*** and try to drag it below ***RCP 2.6***.

Notice that you are unable to reorder layers when the Table of Content is displaying layers by List by Source.

- Change back to the **List by Drawing Order** view.
- Click on the layer ***countries*** and try to drag it below ***RCP 2.6***.

When the data are displayed by List by Drawing Order, you are able to reorder layers.

- Reorder the data so that ***countries*** goes to the top of the list.

Step 7 Layer Properties

Similar to the Data Frame Properties of ArcMap, each layer contains its own properties that can be viewed and changed. To access these properties, you will right-click on the layer name in the Table of Contents.

- Right-click on the ***countries*** layer.
- Select **Properties**…

In the Layer Properties window, there are several tabs that allow you to view and edit the layer's properties. Commonly used tabs include General, Source, Symbology, and Labels.

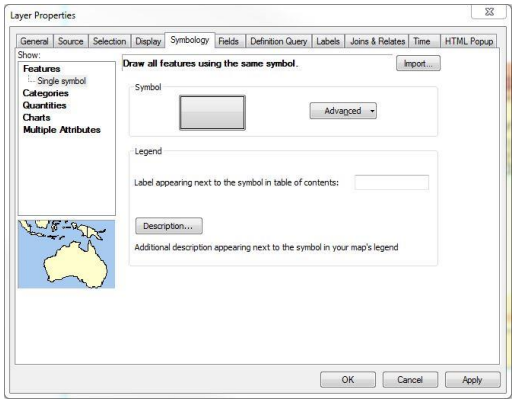
- Click the **General** tab.
- Change the Layer Name to **Boundaries**

Changing the Layer Name only affects how the name appears in the Table of Contents. It does not change the name of the underlying data. **Keep this in mind as the layer name in the Table of Contents will not always match the file name where the data are stored.** As previously mentioned, the map document is just accessing the layers, not storing them.

- Click the **Source** tab.

The source tab displays basic metadata information about a layer, including the type of layer, its actual file or source name, and coordinate system information. Metadata is "data about data" and is critical for understanding the details of a particular dataset such as where the dataset came from, how it was created, the date it was created, among other details.

- Click the **Symbology** tab.

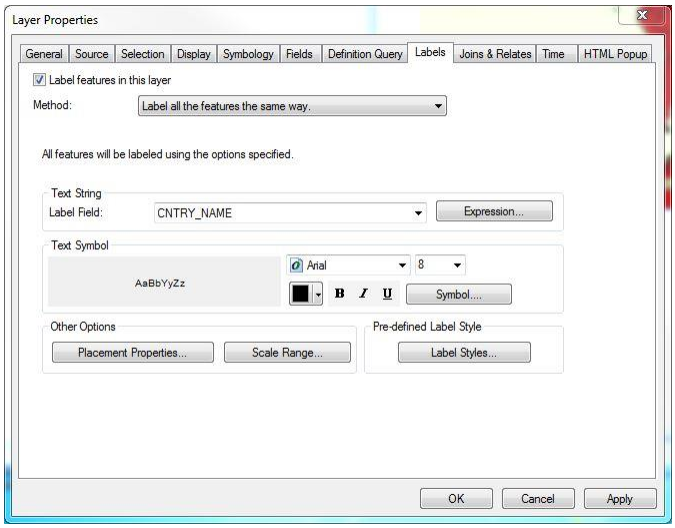


- In the middle of the display window under Symbol, click the **symbol** button.
- Change the **Fill Color** to red.
- Click **OK** in the Symbol Selector window.
- Click **Apply** in the Layer Properties window.

This will apply the rendering, but not close the window.

Notice that all of the countries on the map have turned red. There are many symbology options available for choosing how you want to display a layer on a map.

- Click on the symbol button again.
- This time, make the fill **No Color** and change the outline color to Purple.
- Click **OK** to close the Symbol Selector.
- Click **Apply**.
- Click the **Labels** tab.
- Place a checkmark next to “Label features in this layer.”
- Make sure the “Text String, Label Field:” is set to **CNTRY_NAME**.
- Close the Layer Properties window by clicking **Apply**.



TIP: You can also turn a layer’s labels on and off by right-clicking on the layer name in the Table of Contents and then clicking Label Features.

- Turn off the labels by unchecking the box.
- Click **OK** to close the Layer Properties window.
- **Save** ArcMap.

Step 8 Adding NetCDF data through the Multidimension Toolbox

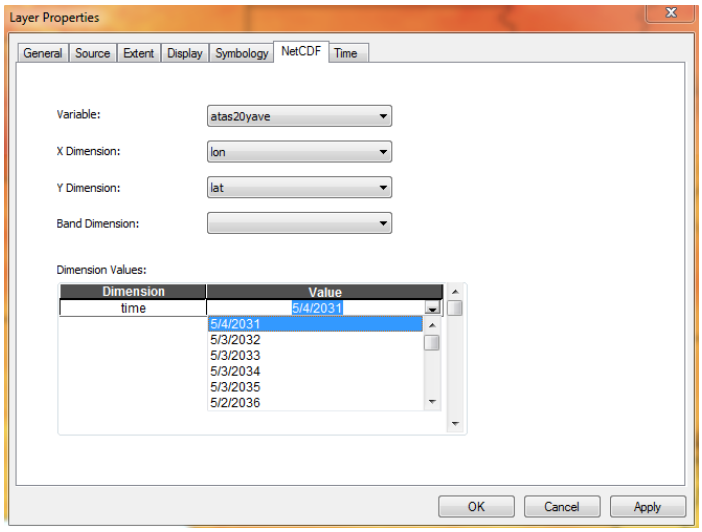
- Right click on the layer ***RCP 2.6*** and select ***Properties…***

The Layer Properties window will open.

- Click on the **NetCDF** tab.

Notice that the time is 4/19/2091.

- Change the date to **05/04/2030** using the dropdown menu.
- Click **Apply**.

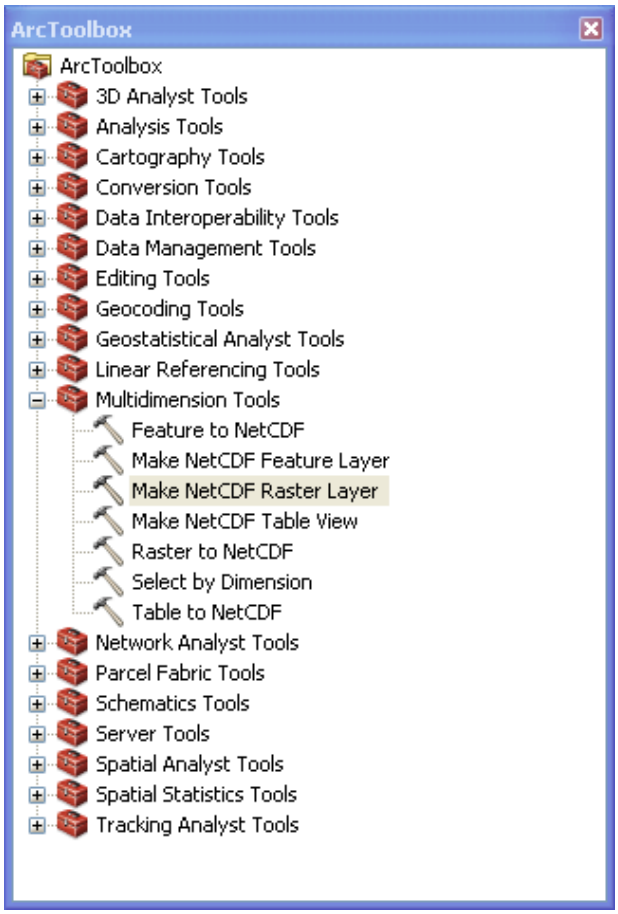


- Explore different dates.
- Reset the date to **04/19/2091** and click **OK** to close the Layer Properties window.

You have explored only one plausible emissions scenario so far. You will now add the other RCPs and compare future temperature change based on different emission scenarios.

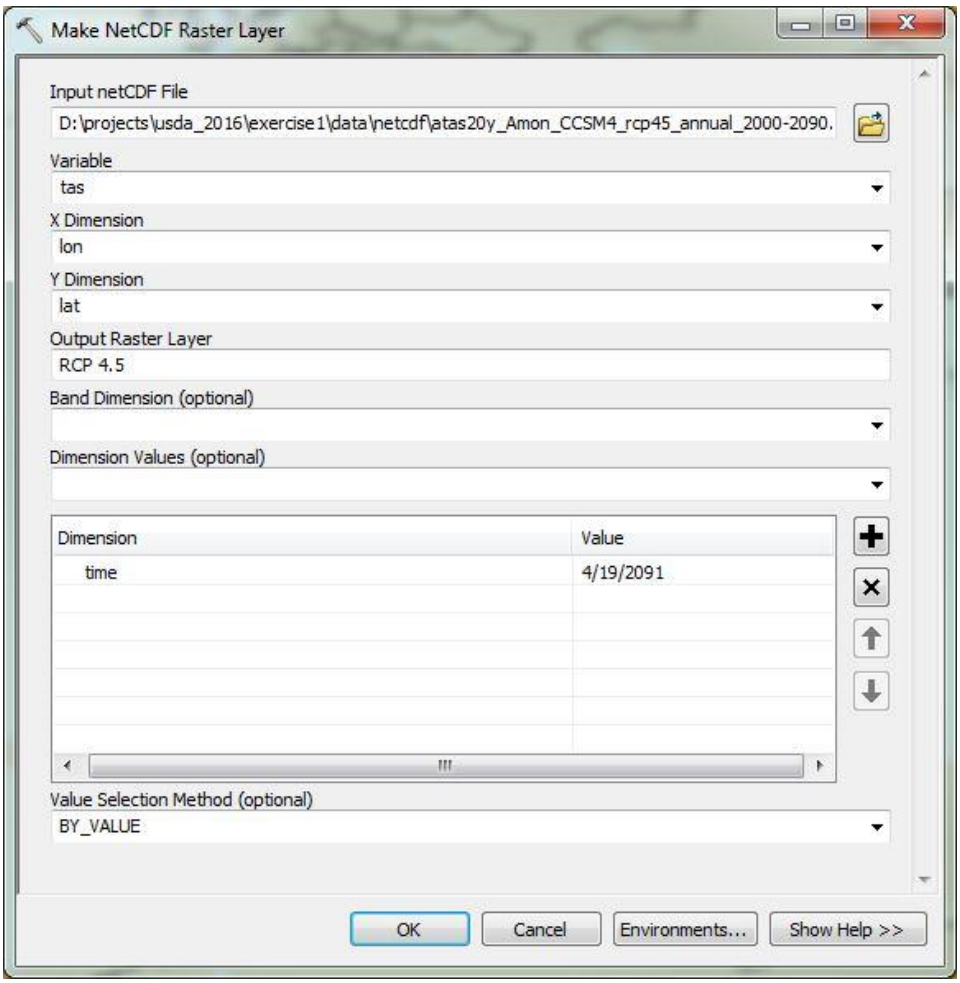
- Click the Show/Hide ArcToolbox button on the main toolbar to open ArcToolbox as a window in ArcMap.

- In the ArcToolbox window, expand the **Multidimension Tools** toolbox.
- Double click on **Make NetCDF Raster Layer** to open the tool dialog box.



- In the new dialog box click the browse button. 
- Navigate to **C:\USDA_NCAR\exercise1\data\netcdf\atas20y_Amon_CCSM4_rcp45_annual_2000-2090.nc**.
- Click **Open**.

Make sure the following parameters are selected for the dialog box:



Variables	**tas**
X Variables	**lon**
Y Variables	**lat**
Output Raster Layer	**RCP 4.5**
Band Dimension (optional)	**<none>**
Dimension Value (optional)	**time** (select from dropdown)

Time will appear in the Dimension list below the Dimension Value. In the corresponding Value list, click once.

Select the last time value which is **4/19/2091**

Value Selection Method	**BY_VALUE**

- Click **OK** to bring in the netCDF file when you have set all the parameters.

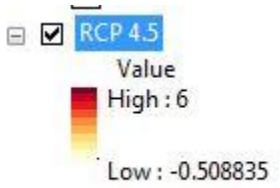
You should now see the annual temperature anomaly for 2091 displayed in your map.

- Explore the map.

In order to compare the temperature change between the two scenarios, it is best to use the same symbology scale for each layer.

- Right click on ***RCP 4.5*** in the TOC and select **Properties.**
- In the Layer Properties dialog box, select the **Symbology** tab.

- Click the **Import** button.
- Select the layer ***RCP 2.6.***
- Click **OK**.
- Click **OK** to close the Layer Properties window.
- Click **File > Save.**
- To compare the two layers, turn the layer ***RCP 4.5*** on and off by clicking the box in the Table of Content next to the layer name.

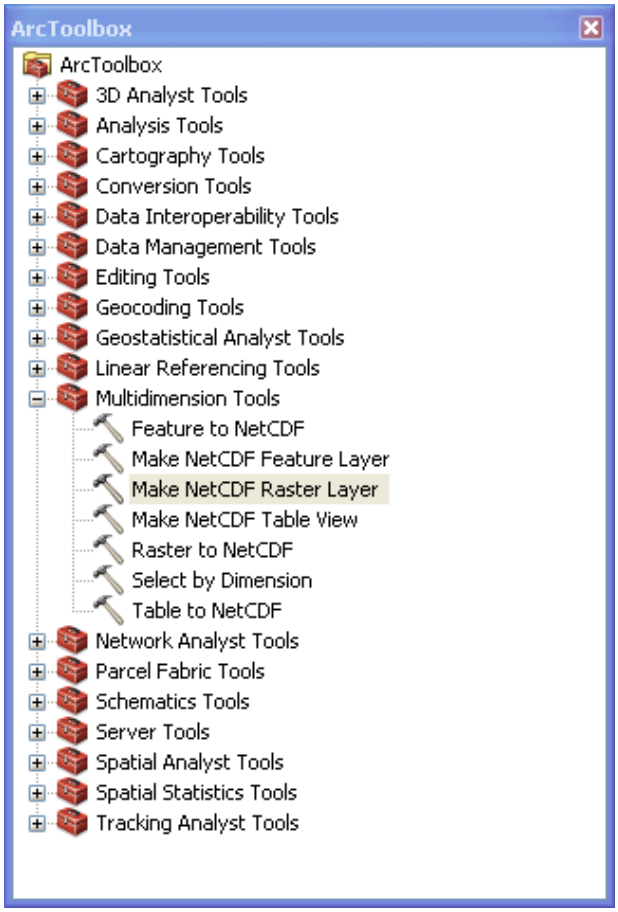


These maps show the annual air temperature anomaly for 2091 (2081-2100). The RCP 4.5 map indicates hotter temperatures than the RCP 2.6 map. This is due to the different greenhouse gas concentrations used by each scenario. RCPs should not be viewed as forecasts or absolute bounds. They are representations of plausible alternative scenarios of the future, but are not predictions or forecasts. No single RCP is intended as a best guess or most likely outcome. In this exercise, you will look at three scenarios: a high emissions scenario – RCP 8.5, a neutral emissions scenario – RCP 4.5, and a low emissions scenario – RCP 2.6. By looking at the range of possible future climates, one can better understand and prepare for future climate change. There are two more RCPs (6.0 and 8.5). We will now look at these two simulations.

Step 9 Reading RCP 6.0 and RCP 8.5 into ArcMap

You will now bring in two more netCDF files into ArcMap. These two files contain air temperature anomalies for the RCP 6.0 and 8.5.

- In the ArcToolbox window, expand the **Multidimension Tools** toolbox.
- Double click on **Make NetCDF Raster Layer** to open the tool dialog box.



- In the new dialog box click the browse button. 
- Navigate to **C:\USDA_NCAR\exercise1\data\netcdf\atas20y_Amon_CCSM4_rcp60_annual_2000-2090.nc**.
- Click **Open**.

Make sure the following parameters are selected for the dialog box:

Variables	**tas**
X Variables	**lon**
Y Variables	**lat**
Output Raster Layer	**RCP 6.0**
Band Dimension (optional)	**<none>**
Dimension Value (optional)	**time** (select from dropdown)

- **Time** will appear in the Dimension list below the Dimension Value. In the corresponding Value list, click once.

Select the last time value which is **4/19/2091**

Value Selection Method	**BY_VALUE**

- Click **OK** to bring in the netCDF file when you have set all the parameters.

You should now see the annual temperature anomaly for 2091 displayed in your map.

- Explore the map.

In order to compare the temperature change between the two scenarios, it is best to use the same symbology scale for each layer.

- Right click on ***RCP 6.0*** in the TOC and select **Properties.**
- In the Layer Properties dialog box, select the **Symbology** tab.

- Click the **Import** button.
- Select the layer ***RCP 2.6.***
- Click **OK**.
- Click **OK** to close the Layer Properties window.
- Click **File > Save.**

To bring in the last netCDF file you will open the Results window and change the last geoprocessing tool you used.

- Click Geoprocessing > Results.
- Open the Current Sessions folder
- Double click on the top Make NetCDF Raster Layer tool.

You have opened the tool that you just ran.

- Change the input netCDF file to ***atas20y_Amon_CCSM4_rcp85_annual_2000-2090.nc***
- Change the Output Raster Layer to ***RCP 8.5***.
- Leave all other parameters the same and click **OK**.
- Right click on ***RCP 8.5*** in the TOC and select **Properties.**
- In the Layer Properties dialog box, select the **Symbology** tab.

- Click the **Import** button.
- Select the layer ***RCP 2.6.***
- Click **OK**.
- Click **OK** to close the Layer Properties window.
- Click **File > Save.**

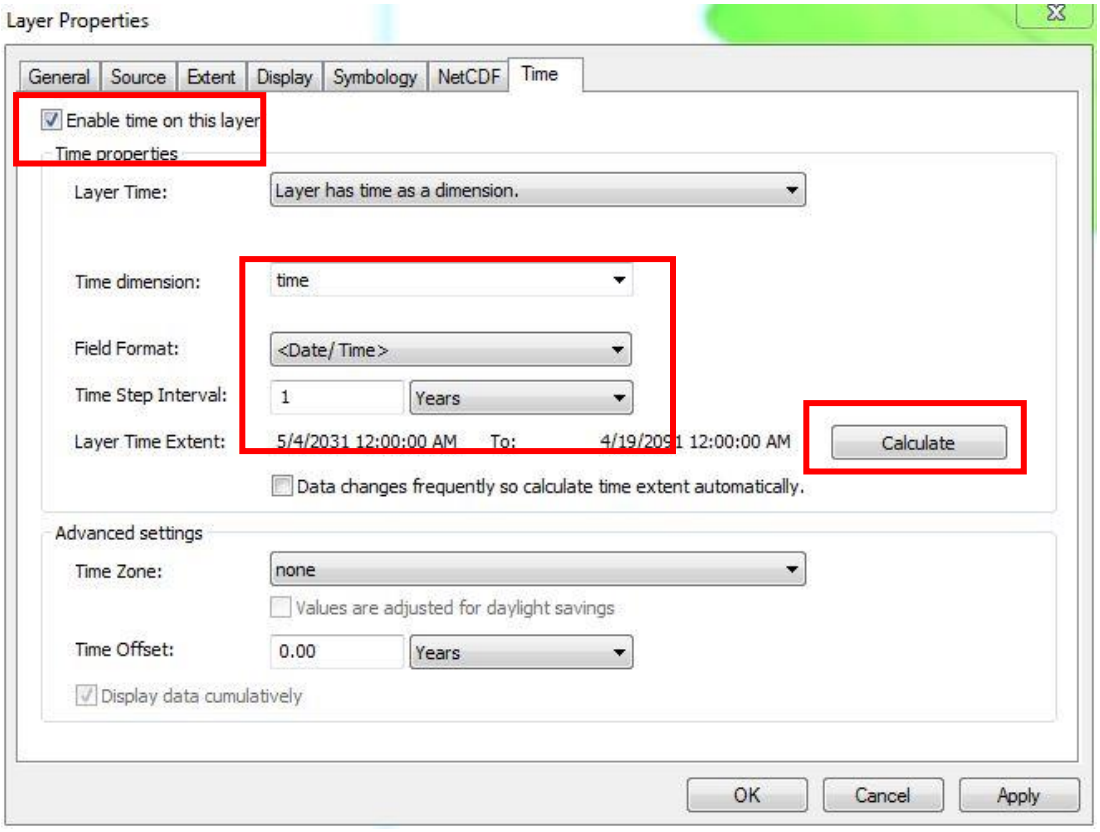
Now that you have all 4 RCPs in your map document, you can see how different the air temperature change may be based on the different greenhouse gas concentrations.

- Explore the different layers.

Step 10 Animating a NetCDF File Over Time

So far we have taken a look at a single time period in our data (2081-2099). However, visualizing data over time allows us to observe patterns and trends. NetCDF is an ideal data format to visualize changes over time because it stores multidimensional information so efficiently. In this next step, we will set up a time animation and examine how our data changes over the century.

- Turn on the layer ***RCP 8.5***.
- Turn off the layers for ***RCP 2.6, RCP 4.5, and RCP 6.0.***
- Double click on the layer ***RCP 8.5*** in the Table of Content.
- Click the **Time** tab in the Layer Properties dialog box.
- Check the box "**Enable time on this layer**".
- For the Time dimension: choose **time**.
- Click the **Calculate** button for ArcMap to read all time steps in the data set.
- Change the Time Step Interval: to **1** Years.
- Click **OK**.



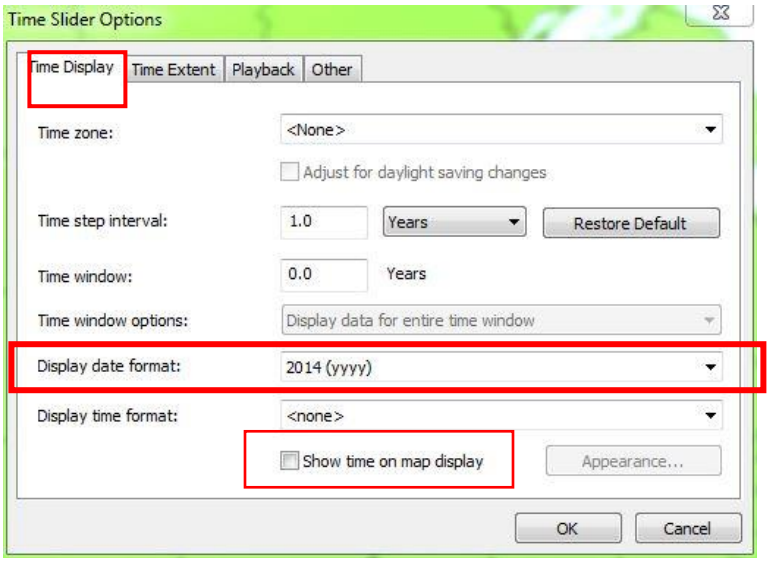
- Click the Open Time Slider Window  button on the Main Toolbar.

- Click the Time Slider Options button.

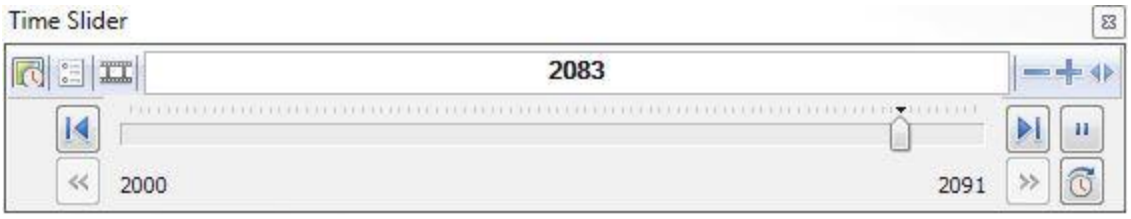
The first tab, "**Time Display,**" allows you to change the time interval and how the date and time are formatted.

Because our data represent annual averages, all we want to display is the year. Choose 2016(yyyy) for **Display date format:**

Check the box to **Show time on map display.**



- Click the **Time Extent** tab.
- Click the Min Time Button.
- Check the box to **Show time on map display**.
- Click **OK** to close the Time Slider Options dialog box.
- Notice that the time slider now just shows the year in the Time Slider time display box.
- Click **Save** to save your map document.
- Move the time slider to first time 2000 (if needed).
- Click the Play button on the Time Slider to start the animation.



You should see the data change with each year over the century. This is a good method to look for trends or patterns in your temporal data.

Challenge (if time permits): Explore future drought conditions

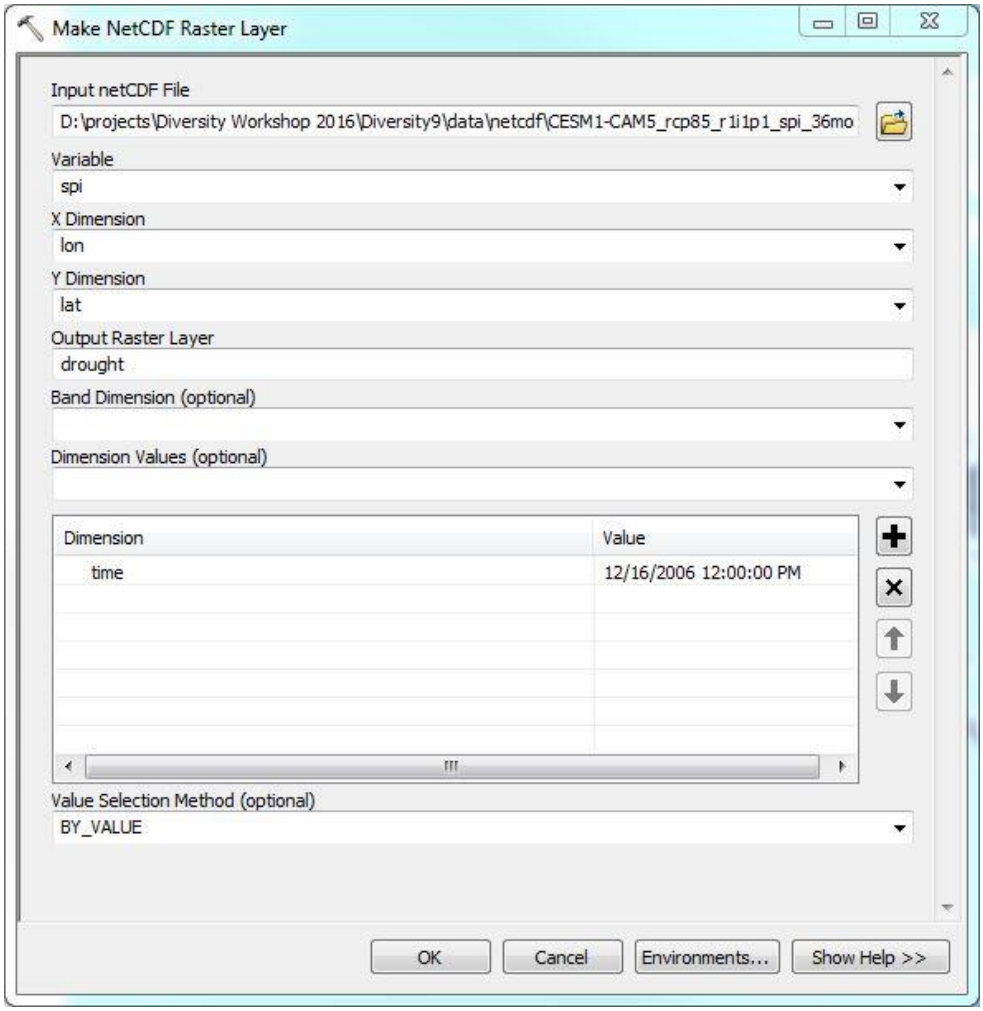
You are now going to add a new layer to your map. This new layer will have annual projected Standardized Precipitation Index (SPI) from 2006-2100. These data are stored in a netCDF data format.

- Click **Windows > Catalog**, to open the Catalog window in ArcMap.
- Pin this window in ArcMap by clicking the PIN icon in the top right corner.
- Click the **Connect to Folder** button in the Catalog window and make a folder connection to ***C:/USDA/exercise1***.
- Navigate to the ***data*** folder.
- Drag the following layer packages into the map display;
    - Current Cropland.lpk
    - oceanmask.lpk.

You are now looking at a map of current croplands. These data were downloaded from CIESIN at the University of Columbia. It is the Global Cropland v1 dataset from 2000. (http://sedac.ciesin.columbia.edu/data/set/aglands-croplands-2000/data-download). The areas in gray use less than 10% of their lands as crops.

- In the ArcToolbox window, expand the **Multidimension Tools** toolbox.
- Double click on **Make NetCDF Raster Layer** to open the tool dialog box.
- In the new dialog box click the **browse** button.
- Navigate to ***C:\USDA_NCAR\exercise1\data\netcdf\CESM1-CAM5_rcp85_r1i1p1_spi_36month_annual_2006-2100_lonFlip.nc.***
- Click **Open**.

Make sure the following parameters are selected for the dialog box:



Variables	***spi***
X Variables	***lon***
Y Variables	***lat***
Output Raster Layer	***drought***
Band Dimension (optional)	***<none>***
Dimension Value (optional)	***time*** (select from dropdown)

Time will appear in the Dimension list below the Dimension Value. In the corresponding Value list, click once.

Select the last time value which is ***12/16/2006 12:00 PM***

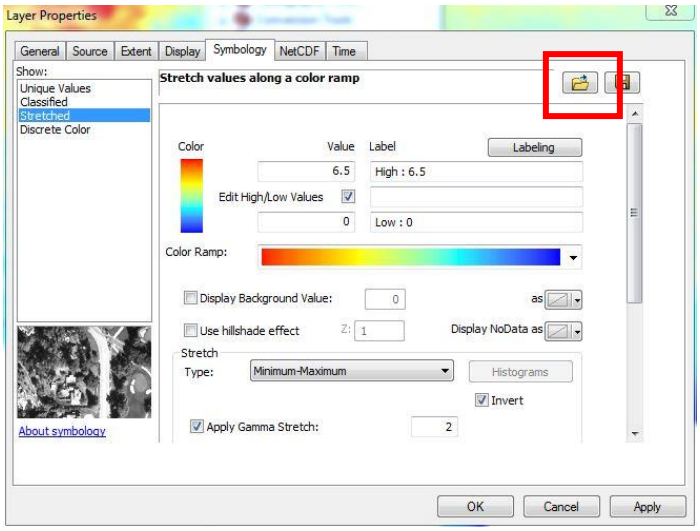
Value Selection Method ***BY_VALUE***

- Click **OK** to bring in the netCDF file when you have set all the parameters.

You should now see the SPI for the year 2006 in your map display. Notice that this netCDF is also based on RCP 8.5.

You will apply symbology to this layer using a classified categorization.

- Open the properties dialog box for the ***drought*** layer and click on the **Symbology** tab.



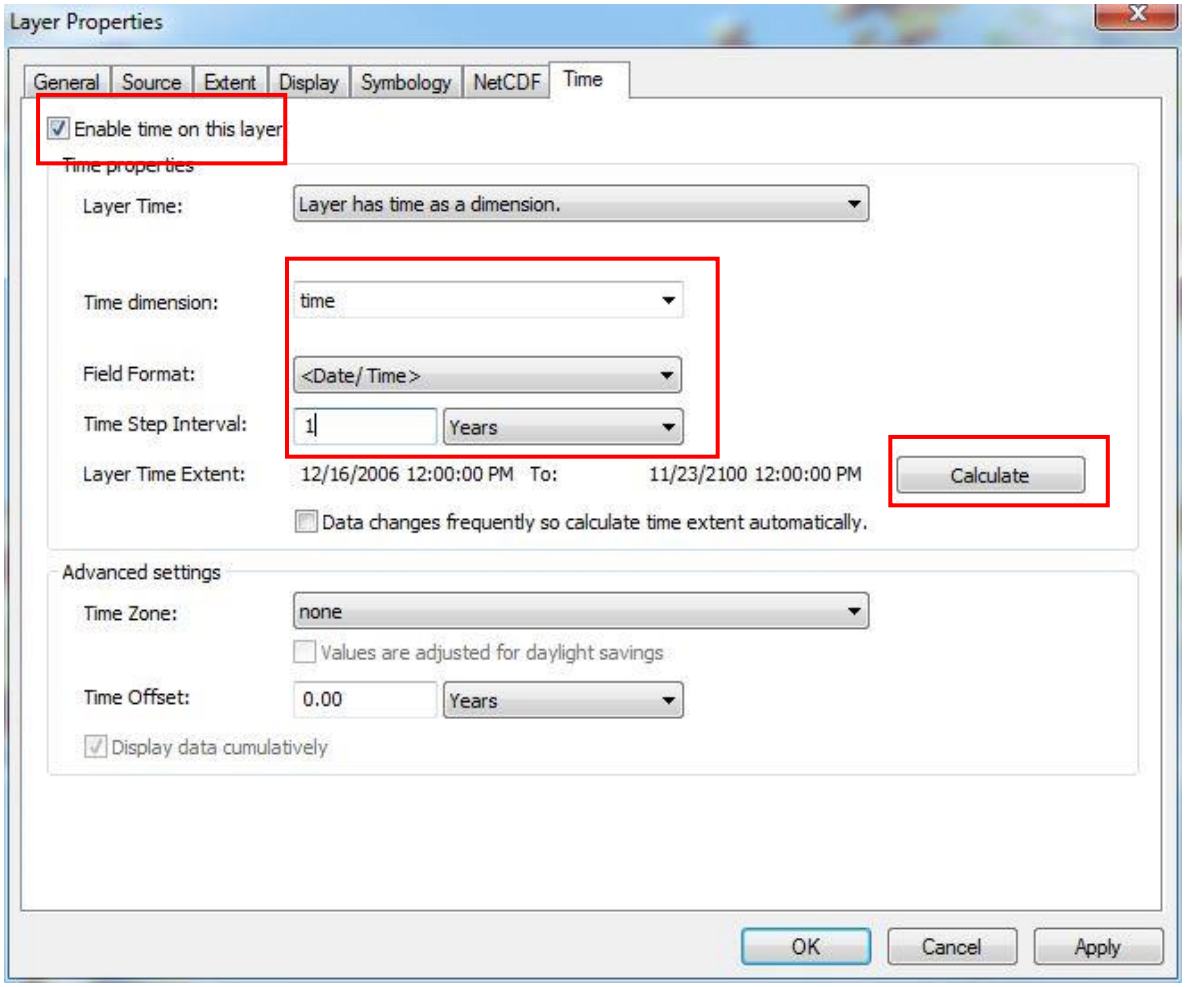
Apply the symbology from the layer file

- On the left side of the Layer Properties window, under **Show:** change your classification to ***Classified.***
- Click the ***Import… button*** and browse to ***C:\exercise1\data\drought.lyr***, click **Add**.
- Click **OK** in the Import Symbology window, then click **OK** again in the Layer Properties window to apply the symbology and close the window.
- Now in the Table of Contents, drag the ***Current Cropland.tif*** layer above the ***drought*** layer.
- Turn off the layer ***RCP 8.5*** in the Table of Contents.
- Once you have applied the new symbology to the drought layer save your map.

Step 11 Animating Over the Future Drought File

In earlier steps, you animated the map. In this step, you will add an animation for a graph. This way, you can watch the map and graph move through time.

- Double click on the layer ***drought*** in the Table of Content.
- Click the **Time** tab in the Layer Properties dialog box.
- Check the box "**Enable time on this layer**".
- For the Time dimension: choose **time**.
- Click the **Calculate** button for ArcMap to read all time steps in the data set.
- Change the Time Step Interval: to 1 Years.
- Click **OK**.



- Click **Save** in order to save your map document.
- Turn on the Time Slider. 
- Move the time slider to first time 2006 (if needed).
-  Click the **Play** button on the Time Slider to start the animation.

In this exercise you explored climate model simulations for Air Temperature Anomalies and for a Drought Index using Esri ArcMap interface. You displayed and animated these data over time to explore spatial patterns of warming and drought over the global cropland regions.