Seminar assignment 3

SGO1910 – Introduction to Geographical Information Systems (GIS) – Fall 2021

Projections and georeferencing

One of the great challenges of map-making is how to represent a three-dimensional world on a flat two-dimensional paper. In this lab, you will experience the importance of projecting map data in a proper way. Coordinate systems and projections are also the cause of several usual pitfalls when working with spatial data. In this assignment, you will learn how to deal with some of the most usual problems.

What you will learn

- Explore map projections and measure distances
- Change projection of a shapefile
- Change projection of a map (as a project)
- Identify and give a map projection to spatial data with unknown coordinate systems
- Insert an inset map

What to submit

- Two files. One with two world maps: an angle-preserving projection and an area-preserving projection. The other file shall include a map of built up areas and centers in Oslo with an inset map of Norway.
- The maps should have titles, legends, north arrows, scale bars and source reference.
- Include a few sentences that describe what your maps are showing, and what tools or techniques you have used to make them.

The files have to be uploaded on the Submission 3 page on Canvas.

Instructions

Part 1: Measuring the world

Data used in this seminar assignment can be downloaded from Canvas under *Seminar assignment 3 - Projections and georeferencing* module. If you have trouble unpacking the file, see Seminar 1 instructions.

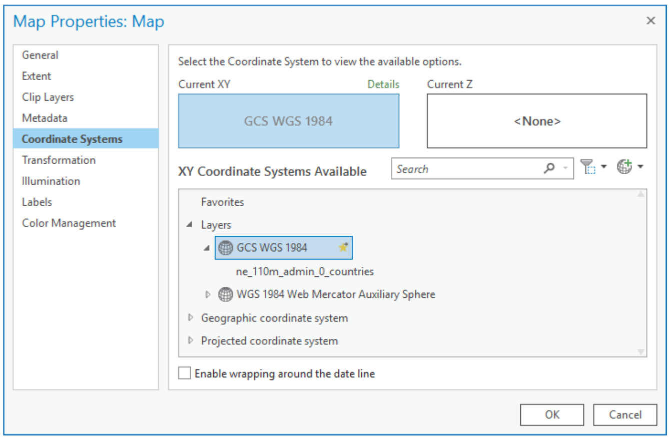
→ When you open ArcGIS and create a new project for this seminar, click on `Add data` and find the `ne_110m_admin_0_countries` shapefile in the `world` folder. You should see a world map. You can uncheck the boxes next the basemaps.[1] You can also remove them by right clicking and their names and then on `Remove`. We will not need them in this exercise.

→ Go to the `Insert` tab and add `New Layout`. In this assignment, we recommend using `A4` under `ISO – Portrait`. Now you need to add a new `Map Frame` and choose the map of the world from the available options. 'Draw' the frame in the upper part of the sheet. We do this in the Layout view, because that way we could also see a grid with latitudes and longitudes.

The map frame displays all the map layers (the spatial data) that are within the map frame. In this assignment you will learn how to work with and present several map frames simultaneously. If you do not see the entire world in the box, right-click on the layer name and then on `Zoom to Layer`.

[1] These basemaps may be called for example `World Topographic Map`, `World Hillshade` and/or `GeocacheBasis`. The default basemaps and coordinate systems may be different depending on whether or not you created the project while logged in to your ArcGIS Online account. If in doubt, ask the seminar leader.

Map properties – coordinate systems



Now you will investigate the properties of the map layer, and especially the properties regarding coordinate systems and projections.

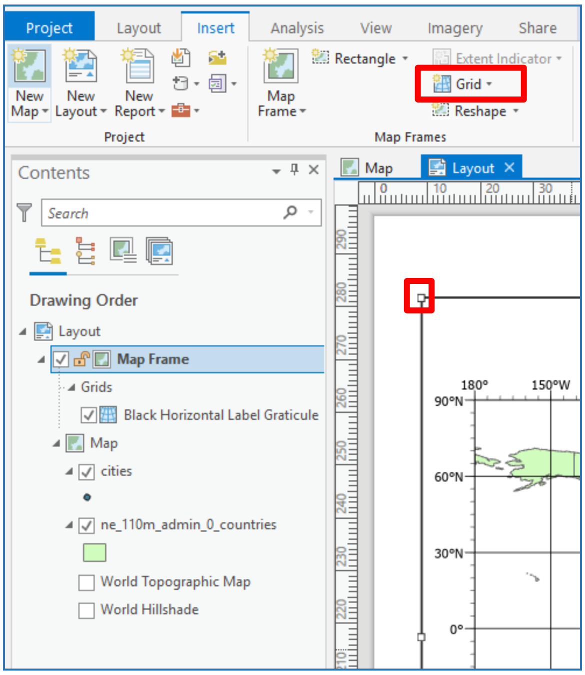
→ Right click on the `Map` in the `Contents` window and then on `Properties`. If the new window did not open automatically on the `Coordinate Systems` tab, click on `Coordinate Systems`.

Notice that you did not open the properties of a specific map layer but the properties of the map that is included in the frame. **The map frame adopts the coordinate system and projection of the very first spatial data that is imported to the map frame.**

For example, spatial data for all of Norway and data specifically on Oslo use (usually) two different projections. If you therefore are going to make an Oslo-oriented map but use some national data as well, it is smart to add some spatial data from Oslo first.

You can see that `GCS WGS 1984` is the current geographic coordinate system of the map frame and this is because it has been 'adapted' from the first and only shapefile we added to the map (`ne_110m_admin_0_countries`). Under the `XY Coordinate Systems Available`, you can find a number of different `Geographic` and `Projected` coordinate systems to choose from (you can show and hide them after you double click on any of the options). A geographic coordinate system locates spatial data on a spheroidal surface. In projected coordinate system, the spatial data, and the geographic coordinate system, is projected on a flat plane. We will leave the coordinate system for now. Close the map `Properties` dialog box.

Grid



→ When you have the map frame selected, open the `Grid` option (see picture to the right). We will add some 'guidelines', or a graticule to be specific, to help us see the difference between projections. You can choose any of the available grids from the list in the first group (`Graticule`), for example the first one on top to the left (`Black Horizontal Label Graticule`).

A grid with latitude and longitude values in degrees will cover the world map. Can you identify the approximate latitude and longitude of Oslo?

Measurement

→ Leave the `Layout` and go back to the `Map` view. Add the `cities` shapefile (`Map` tab, then `Add Data`) on top of the world map. The points represent five cities in the world. Symbolise the cities in such a way that they are visible (right click – *Symbology*). Right click on the name of the layer in the `Contents` window and click on `Label`. The city names should now pop up on the map.

→ Next, click on the `Measure` tool (you will find it in the `Map` tab). Click first on Oslo and then move the cursor to Cape Town. You will notice that the tool will not make a straight line between the two locations, but a slightly bended curve that follows the curvature of the earth's surface. This might look similar to the maps showing the routes of airplanes. Also, notice how the `Measure` tool displays both segment and accumulate distances if you click on multiple places on the map.

You will now project a well-known coordinate system. Do you remember which map projection was both preserving shapes locally and well suited to navigate by compass overseas, because straight lines always equal a constant heading (e.g. South-West)? The readings assigned for this week explain the some of the characteristics and differences of the different map projections.

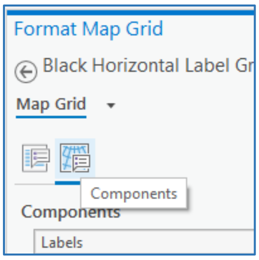
→ Open the `Properties` of the `Map` in the `Contents` window and go to the `Coordinate Systems` tab. Under the `XY Coordinate Systems Available`, go to `Projected coordinate system`, choose `World` and then the `Mercator (world)`. You can also use the search box to find the right coordinate systems. Click `OK`.

`Measure` again the distance from Oslo to Cape Town. Write down the result. Note that the line is straight.

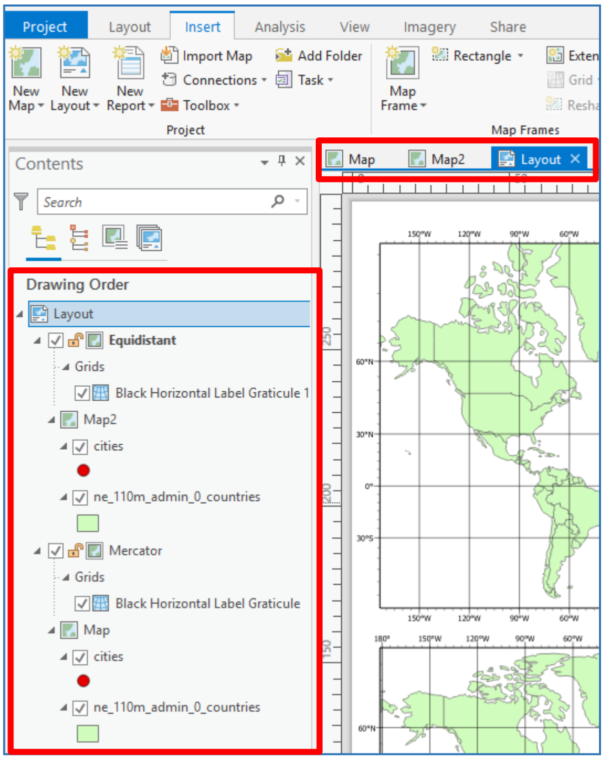
→ Go to the `Layout` view.

The first thing you will notice is that the shape of the grid has changed after you changed the projection. The map is much more distorted closer to the poles. The squares made up by the lines in the grid are turned into more skewed rectangles the further you get away from equator. The areas closer to the poles are therefore largely exaggerated in size. Notice for instance that Greenland is just as big as Africa on this map.

→ Before you do anything else, use the `Select` and `Activate` tools to resize the frame and get a nicer layout in which Antarctica does not cover half the map. You can use the scroll on your mouse or the scale box on the bottom left of the map to find the right scale of the map. See the upper map on the next page for an example. Remember to `Close Activation` (in the `Layout` tab) after you are done.



For more advanced users: If you want to change the settings of the grid, for example by increasing the number of gridlines, you can right click on the grid name in the `Contents` window (while in the `Layout` view) and choose `Properties`. You will have to uncheck the `Automatically adjust` option in the window on the right and then, in the `Components` tab, set the intervals of the different elements labels, lines etc.).



A second map frame

Because of its area distortions globally, Mercator is not the best-suited map projection to estimate distances. Let us use a projection that maintains distance better, at least in parts of the map. To make it easier to compare the two different projections, you will now add another map frame to the project and the layout with a new world map.

→ In the `Insert` tab, add a `New Map`. You should now get two tabs with maps and one with layout.

→ Go back to the `Layout` view. Add a new `Map Frame` and choose the new map, which by default should appear under the section called

`Map1` or `Map2`. ‘Draw’ the frame in the lower part of the sheet, below the Mercaor map. Using the `Select` function (`Layout` tab), adjust the frames to make them approximately the same size.

You should now see a new map frame with a background map. Disable or remove this layer (or layers) in the `Contents` window. The second map frame should now be blank.

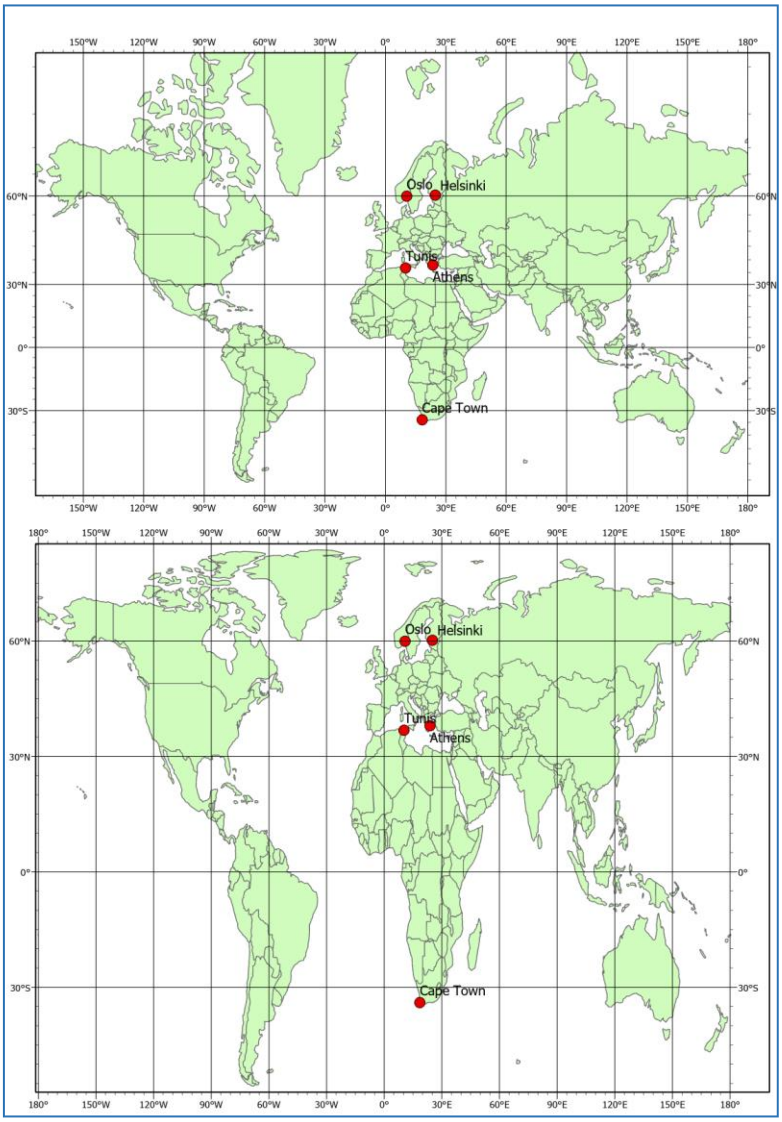
→ Right click on the `cities` layer in the old map (frame) in the `Contents` window, and click on `Copy`. Right click on the name of the new map frame (default should be `Map1` or `Map2`), and click `Paste`. Do the same with the other layer (representing countries) in the old data frame as well. Make sure the cities layer is ‘above’ the countries layer on the list.

→ Change the name of the map frames by double clicking (but not too fast) on their name (default should be `Map Frame` and `Map Frame 1`) in the `Contents` window. Name the old map frame with the Mercator projection `Mercator`, and name the new map frame `Equidistant`.

→ Add a graticule (`Insert` tab – `Grid`) to the new map frame.

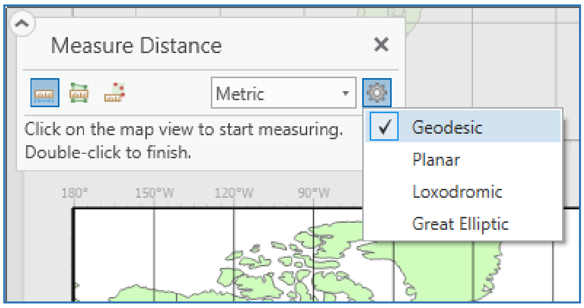
Comparing projections

→ Activate the `Equidistant` map frame, right click on the map name and open `Properties`. Find and apply the `Equidistant Cylindrical (world)` projection coordinate system to the map frame (you may use the search function). Adjust and fit the map in the frame. Follow the steps you made previously in this lab if you do not remember. It should now look something like this:



Notice the differences in shapes and sizes of continents between both maps. Also, notice the differences in the graticule grid. In the equidistant cylindrical projection, all graticule grid cells have not only the same width, but also the exact same height. This means that any true North-South ('vertical') distance is projected exactly correct anywhere on the globe. East-west ('horizontal') distances are however not necessarily correct, and neither are 'diagonal' directions. Notice the differences in shapes and sizes of continents between both maps.

Compare planar and geodesic measurements



→ Use the `Select` tool and click on the frame of the map with Equidistant cylindrical projection. Click on `Activate`. Now we can do the same operations as in the `Map` view without exiting the `Layout` view. Use the `Measure` tool (`Map` tab) to estimate the same distance that you estimated in the first map with Mercator projection, between Oslo and Cape Town.

What is the distance between Oslo and Cape Town in this map compared to the earlier Mercator projection? The difference between the two estimates is large. Why? Which one do you think is more correct?

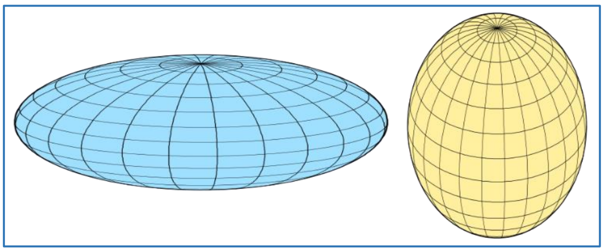


Figure 1: Examples of spheroids. Source: Wikimedia Commons.

→ Erase the measurement by clicking on the `Clear Results` icon or `Esc` on your keyboard. In the `Measure Distance` window, click on the `Mode` tool (next to `Metric`) and change the mode from `Planar` to `Geodesic`. Estimate the distance once again in both data frames (remember to `Activate` the frame where you want to do the measurement and `Close Activation` after you are done).

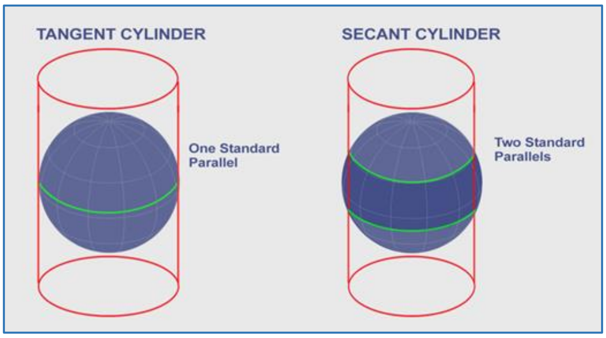


Figure 2: Cylindrical map projections with one standard parallel (left) and two standard parallels (right). Source: geogrpahy.com

You should now get the same Geodesic distance in both maps. You should also notice that the planar distance you measured in the Equidistant Cylindrical projection is much closer to the Geodesic distance than the planar distance in Mercator projection.

When you measure planar distances, as you did initially, you measure the distance in two-dimensions upon the (flat) map. Geodesic distances are measured in three dimensions upon the Earth's surface on a spheroid (see Figure 1).

The Equidistant Cylindrical projection is suitable to measure distance in the north-south axis and along the east-west axis at the standard parallels, which are the lines of latitude that actually touch the underlying globe (see Figure 2).

You will now see what it means that distances along the standard parallels are fairly correct in the Equidistant Cylindrical projection.

→ Measure both the geodesic and the planar distance between Oslo and Helsinki in the map with Equidistant Cylindrical projection. Make sure you have activated the right data frame. Did you notice that the deviation between the two measurements is not that large?

→ Now measure both the geodesic and the planar distance between Tunis and Athens in the map with Equidistant Cylindrical projection.

One final projection

The planar distance deviates much more from the geodesic distance between these two cities than between Oslo and Helsinki. The reason is that the standard parallel of this projection is the 60 degrees latitude line, which both Oslo and Helsinki are located along. See Figure 2 to get the idea.

You will now apply one last map projection that preserves area and to a certain degree the shape of the world.

→ Change projection in the Equidistant map into `Eckert IV (world)`. Update the name of the data frame, and adjust the map to fit inside the frame. Add titles to both maps that identify the map projections.

Notice the size of Greenland compared to Africa in the map with Mercator projection and the map with Eckert IV projection.

→ `Save` the project and export the maps (using the `Layout` function in the `Share` tab) as an image. If needed, see instructions for Seminar 1.

Before you move on to the second part of this lab, notice that you so far only have worked with and altered the projections of the map frames, and not the map layers or the spatial data specifically. The map layers are displayed with the map frame's projection, but the map layers do not inherit the projection as a property. If you open a new project and import the `ne_110m_admin_0_countries` shapefile, it will have an unprojected geographic coordinate system, just as in the beginning of this lab.

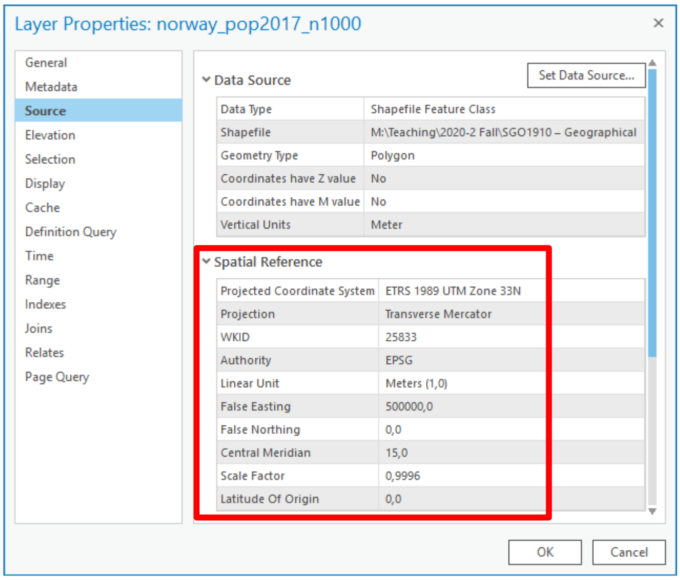
In the second part of this lab, you will learn how to work with the shapefile's and map layer's coordinate systems.

Part 2: Getting Norway right

You have now seen how much the three-dimensional world can be altered and skewed when we try to transform it into a flat two-dimensional map. Now we will zoom down to Norway and Oslo.

→ Go to the `Insert` tab on the top menu and open a `New Map`.

→ Find the `norway_pop2017_n1000` shapefile in the `norway` folder and add it to the map.



Layer properties – coordinate system

Previously you have checked the coordinate system and the projection of the map frame. This time, you will check the coordinate system of the map layer itself.

→ Right click on `norway_pop2017_n1000` shapefile in the `Contents` window and click on `Properties`. Then, click on the `Source` tab and expand the `Spatial Reference` information.

You can see that the map uses the geodetic datum `ETRS 1989` and the `UTM zone 33N` projection. The `ETRS 1989` is next to identical to the `WGS1984` datum that you used in the world maps (the mismatch is 40 cm). It is therefore no real danger in mixing up the two datums in this case.

→ Click OK to close the Layer Properties window. Next, you will learn another way you can identify the projection and coordinate system of a shapefile.

Catalog window

→ Go to the View tab in the top menu and click on Catalog Pane. On the Catalog window on the right side, right click on Folders and then on Add Folder Connection. Find and select the folder where you store your Seminar 3 data. Click OK.

You will see that you can now get a list of the folders and (after expanding) shapefiles. This might be similar to the list you get in the Contents window, but there is an important difference. The Contents window only displays shapefiles and layers that are added to the map, while in the Catalog window you can access all the relevant files on your computer, regardless of whether or not they are added to the map. This is especially useful when you work with a lot of data, as it can work as a shortcut to the folders of your choice.

→ Find the norway_pop2017_n1000 shapefile. Right click on it and then go to Properties. Expand the Spatial Reference information.

You can now see that the ETRS 1989 UTM Zone 33N is the current coordinate system. Click OK.

You will now map the urban settlement of Oslo (tettstedet Oslo) and the city centers within.

→ In the Catalog window, find the tettsted2016 shapefile in the norway folder in and move it (by dragging and releasing) into the map frame or the Contents window. Remember that the order of the layers in the Contents window defines which ones show up front and which are in the back of the map.

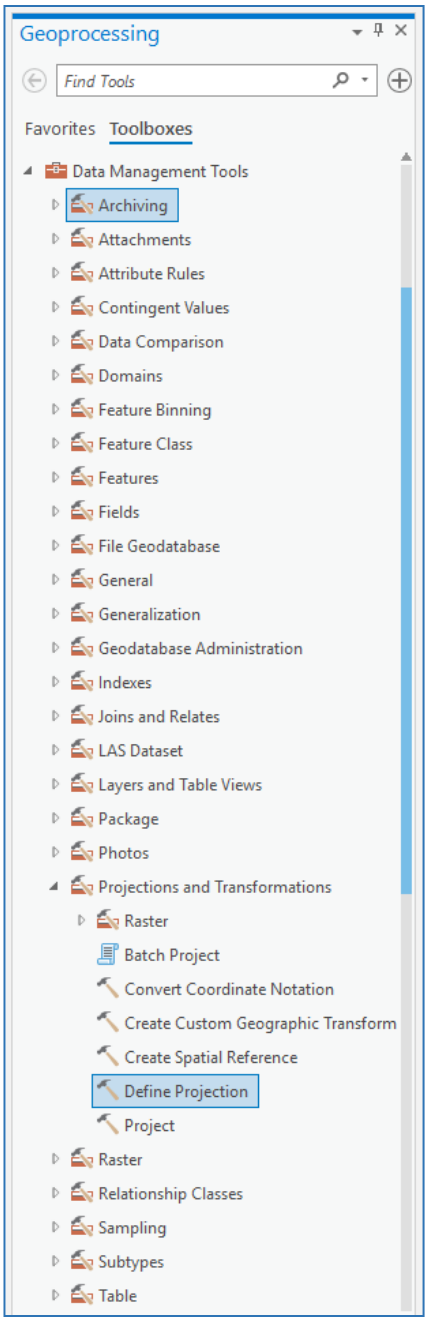
The tettsted2016 layer show populated areas in Norway, but as you can see on the map, these two layers do not overlap. The populated areas appear as if they were located in the sea. This is because these two shapefiles have different spatial reference. You can see this in the Properties of each of the layers. This is a common error when you combine shapefiles from completely different sources. Let's fix this.

Changing the projection

→ In the Analysis tab, click on Tools.

You will see a new window called Geoprocessing on the right. Here you can find a lot of different tools and functions for more advanced analysis. There is no need to learn all the tools here, but it is useful to know how to find what you need. You can do it by either typing the name of the tool in the Find Tools box, or searching manually in the Toolboxes tab (like on the picture).

If there is a tool you use particularly frequently, you can add it to the Favorites (right click on the tool and then Add to Favorites). In the following seminars, you will learn many of the basic and most often used tools in ArcGIS Pro.



→ In the `Find Tools` box, type `Define Projection`. You will see a list of tools arranged by relevance. The first one that shows on top is called exactly `Define Projection`. Click on it.

→ From the drop down list under `Input Dataset or Feature Class`, choose `tettsted2016`. This is the layer that has the wrong coordinate system. Under `Coordinate System`, choose `norway_pop2017_n1000`. The field will automatically change to `ETRS_1989_UTM_Zone_33N`. By doing this, the correct shapefiles 'lends' its coordinate system to the one with the error. Click on `Run` on the bottom right of the `Geoprocesing` window.

After a short while, all the polygons representing populated areas in Norway should move to the right place. This means that the tool worked and both layers have the correct projection.

Note: some shapefiles, especially those that were just exported from other programs, use an unknown, or do not have any particular spatial reference. When you add such files to the map, they usually adopt the spatial reference of the background topographic map. This may or may not cause problems.

You should always check whether a newly added layer is placed correctly on the map in relation to other layers. If it is not in the right place or is somehow distorted, try fixing the projection. If the problem still persists, go to the ArcGIS Pro Resources page:

https://pro.arcgis.com/en/pro-app/tool-reference/appendices/spatial-reference-and-geoprocessing.htm

Hopefully you will never have such problems!

Layout and symbology

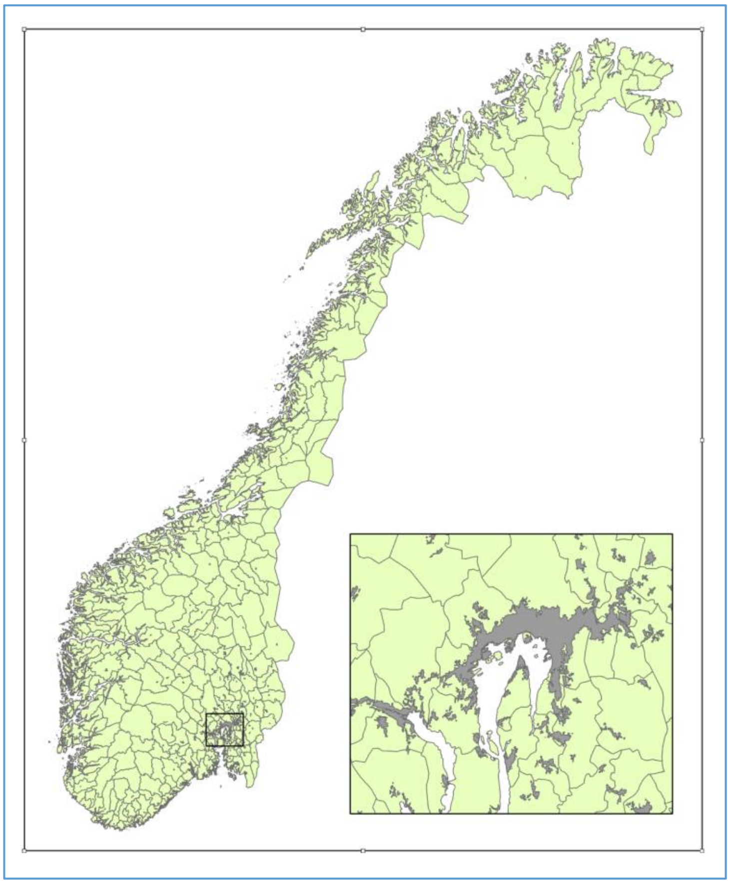
To wrap up, you will now prepare the layout of the final map. A main map should show the map of Norway. An inset map should show the Oslo region in a better scale. We will also add a box that will indicate which area does the inset box cover in the main map, i.e. where is the Oslo region in Norway.

→ Symbolize the `norway_pop2017_n1000` and `tettsted2016` layers with the colors you want. You can also uncheck or remove the background topographic and hillshade layers.

→ Open a `New Layout` (`Insert` tab) with a `Portrait` orientation

→ Add a new `Map Frame` and spread it over the entire page. In the `Activate` mode, adjust the scale and place the map of Norway on the page. You can also use the numeric scale box to type a round number. For example, if you have `A4` sheet and a big frame, the map of Norway would look fine at `1:6 500 000`. Close the activation after you are done.

→ Add another `Map Frame` with the same map and draw a smaller square or rectangle inside the empty space of the main frame. Again, activate this frame and find a good scale and placement that covers the Oslo region.



→ To show where Oslo is located in Norway, or the respective map frame, select the main frame and click on `Extent Indicator` (in the `Insert` tab). Since you should have only two data frames in your layout, the only option you will get is to show the extent of the other frame, in this case the one of the Oslo region. When you click on it, a black rectangle will appear on the Norway map (see picture on the previous page). If you make changes to the extent of the Oslo map, this rectangle will adjust automatically.

→ Remember to add titles, data sources and north arrows to both map packages. The map of Oslo should also have a legend and scale bar. To make legend, or other items to one out of two maps, make sure to have that map selected (use the `Select` tool in `Layout`) before you add elements from the `Insert` menu.

→ `Save` the project and export the map (using the `Layout` function in the `Share` tab) as an image or pdf.

→ Go to the Submission 3 page on Canvas and upload both image files from this seminar. Remember to do it before the deadline!

Data sources

`ne_100m_admin_0_countries.shp`	Natural Earth Data
`norway_pop2017_n1000.shp`	SSB - Statistics Norway (data) and Kartverket (map)
`tettsted2016.shp`	SSB - Statistics Norway[2]

[2] If you zoom in, you may notice how the edges of the polygons of tettsted2016 layer may look 'rough' or approximate. This is because we have reduced the quality of the original shapefile from Statistics Norway in order to make the file smaller and improve efficiency. If you want to use this in your group assignment, ask the teaching staff to provide you with a high quality file, or visit the Statistics Norway webpage.