Wk10

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```
# install and load the following packages.

#install.packages(c("cowplot", "googleway", "ggplot2", "ggrepel",
#"ggspatial", "sf", "rnaturalearth", "rnaturalearthdata", "maps", "lwgeom"))

library(lwgeom)
library(cowplot)
#library(googleway)
library(ggplot2)
library(ggrepel)
library(ggspatial)
library(rnaturalearth)
library(rnaturalearthdata)
library(sf)
library(maps)
library(ggrepel)
library(maptools)
```

Spatial Visualisations - Maps

Spatial data format – `sf`, `ggplot`, `ggspatial`

The recently developed `sf` package combined with `ggspatial` allows 2D maps to be created using `ggplot2`.

The `ggspatial` package allows spatial data with longitude and latitude columns to be used with `ggplot2`. Genearlly, without this package, `ggplot2` does not handle spatial data well. the `geom_sf()` and `coord_sf()` functions in `ggplot2` (version 3) lets users pass simple features (spatial data from the `sf` package) objects as plottable and manipulable layers. You can read more about the package here.

The `sf` package enables simple spatial features to be added to data frames and tibbles (which are the two very similar R data types we have been using, which differ a little bit in shape). Thus transforming data frames with longitude/latitude coordinates or other spatial features into spatial data object. You can read more about the `sf` package here.

In this worksheet we will focus on data frames with coordinates. There are other types of spatial objects, but these will not be explored in this workshop.

Polygons (vs lines, points)

The basic elements of a map are: polygons, points, lines, and text (see lecture).

Polygons - are closed shapes such as state borders.
Lines - are linear shapes that are not filled, for example highways, streams, or roads.
Points - highlight specific positions, for example cities or landmarks. *text* - is used to annotate maps and add extra details.

Lets get started!

TASK: Ensure all packages area installed and loaded. TASK: Set the `ggplot2` theme to black and white. This is not always necessary (you can play with aesthetic choices in your own maps), but is great for for learning the methods since it improves the clarity of the maps.

```
# set ggplot2 theme to black and white.
theme_set(theme_bw())
```

The package `rnaturalearth` is a data package that provides spatial data for the boundaries of the world at different scales. Use the `ne_countries()` function to pull country data and choose the scale (medium is generally sufficient for most applications). The `returnclass()` function can return outputs as either 'sp' (default) or 'sf' class objects. The `sf` class is needed to use `ggplto2` for mapping.

The `ne_coastline()` function can be used to pull coastline data in the same way as `ne_countries()` pulls the borders between countries.

TASK: create an object called `world` using the `ne_countries()` function. Check that it is in the right class (sf).

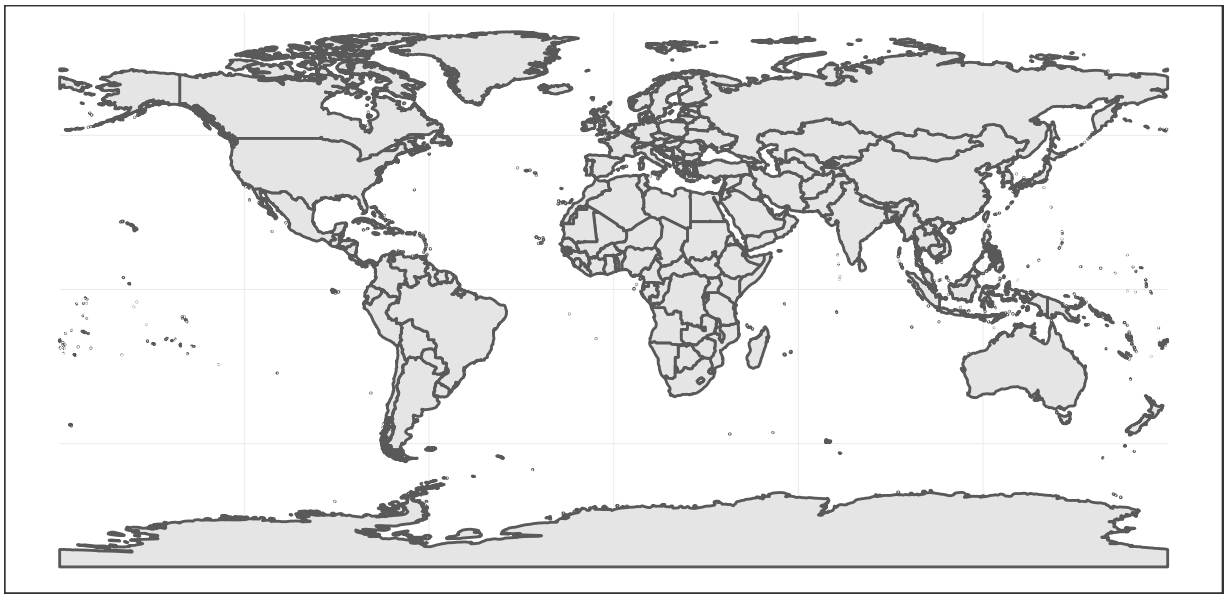
```
## [1] "sf"         "data.frame"
```

Basic plots (using `geom_sf` in `ggplot`)

The basic `ggplot` grammar works the same for plotting spatial data as all the other plots we have seen before. The relevant geom is `geom_sf()`. As we will continue to explore below, we can layer all of the elements we know so well from `ggplot` into maps very easily through this same structure.

The basic call for creating maps is

```
ggplot(data = world) +
    geom_sf()
```



TASK: explore other scales, and 'ne_countries()' instead.

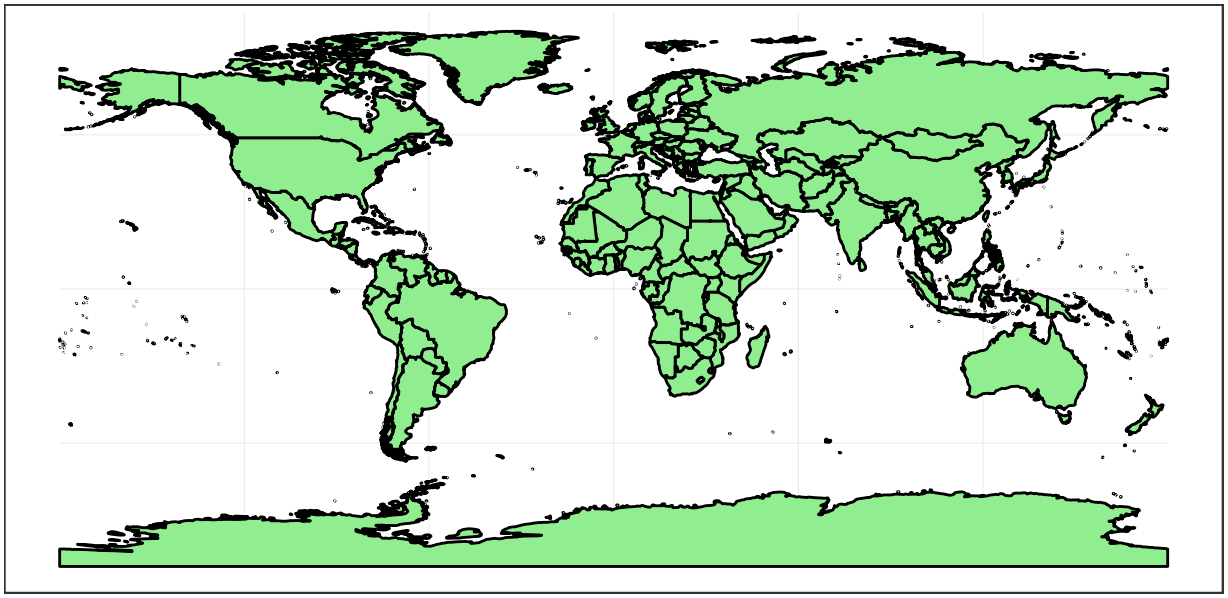
Titles and subtitles As in other `ggplot` graphics, `ggtitle()` can be used to add a title and subtitles. Axis names are absent by default, but can be added using `xlab()`.**

TASK: add the axis titles "Longitude" and "Latitude" in the relevant places (look back at the lecture if you're not sure what order they are in), and a title for the plot "World map".

Colour (`geom_sf()`)

Polygons on a map can be easily coloured in using the `fill =` and `colour =` arguments within the `geom_sf()` fuinction.

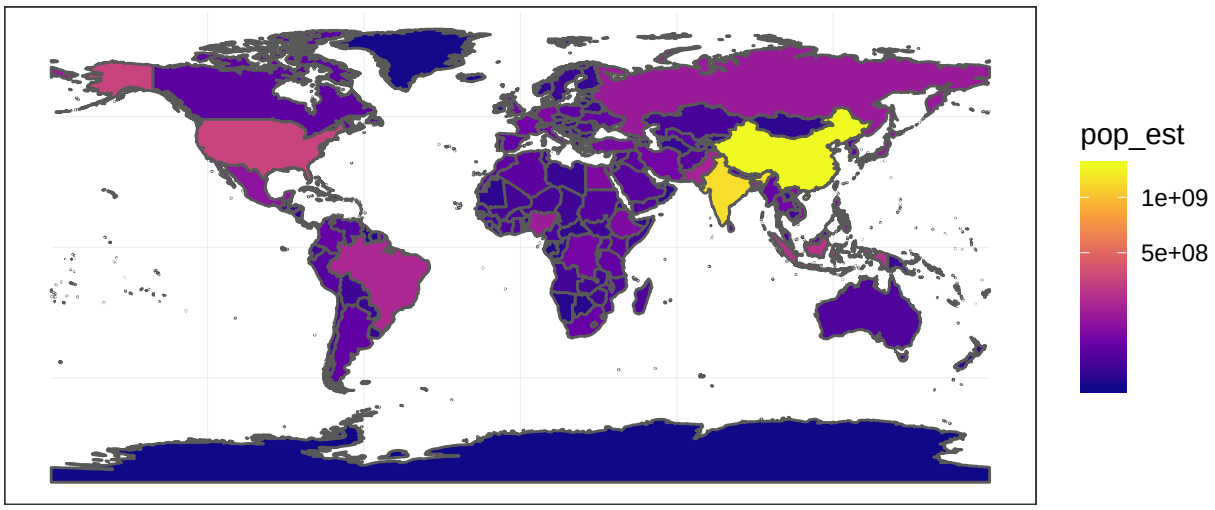
```
ggplot(data = world) +
    geom_sf(color = "black", fill = "lightgreen")
```



Colouring polygons by quantitative data

Polygons can also be coloured by a different variable. For example, `scale_fill_viridis_c()` is used to colour polygons by the square root of the population (which is stored in the variable `POP_EST` of the `world` object). This is a colorblind-friendly palette and is added by adding the `option = "plasma"` to the `scale_fill_viridis_c()` function.

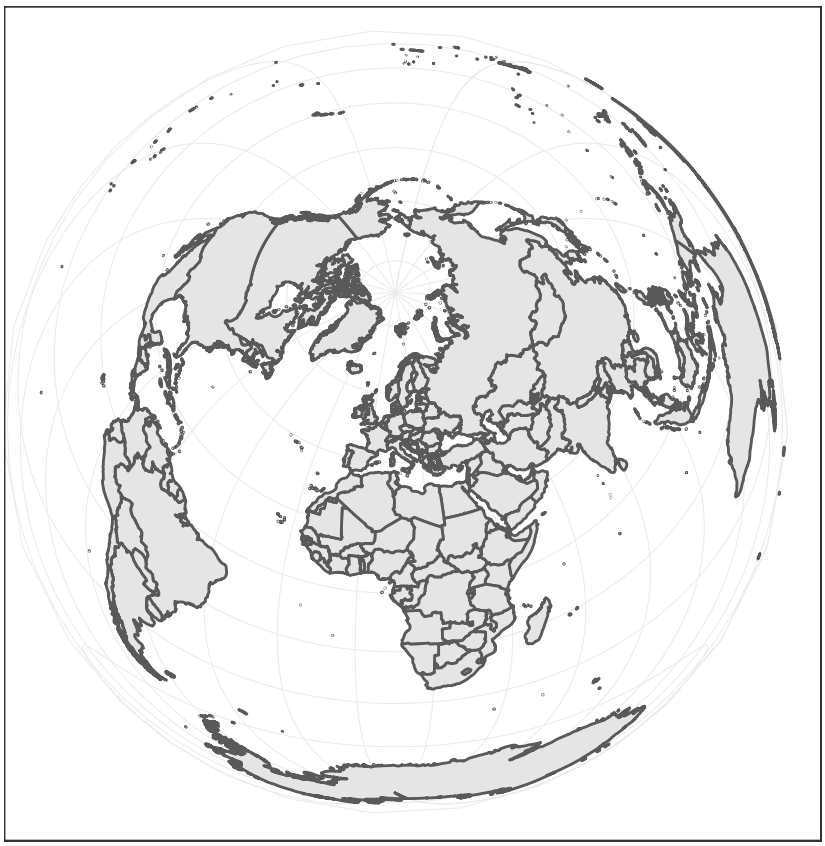
```
ggplot(data = world) +
    geom_sf(aes(fill = pop_est)) +
    scale_fill_viridis_c(option = "plasma", trans = "sqrt")
```



Projection and extent

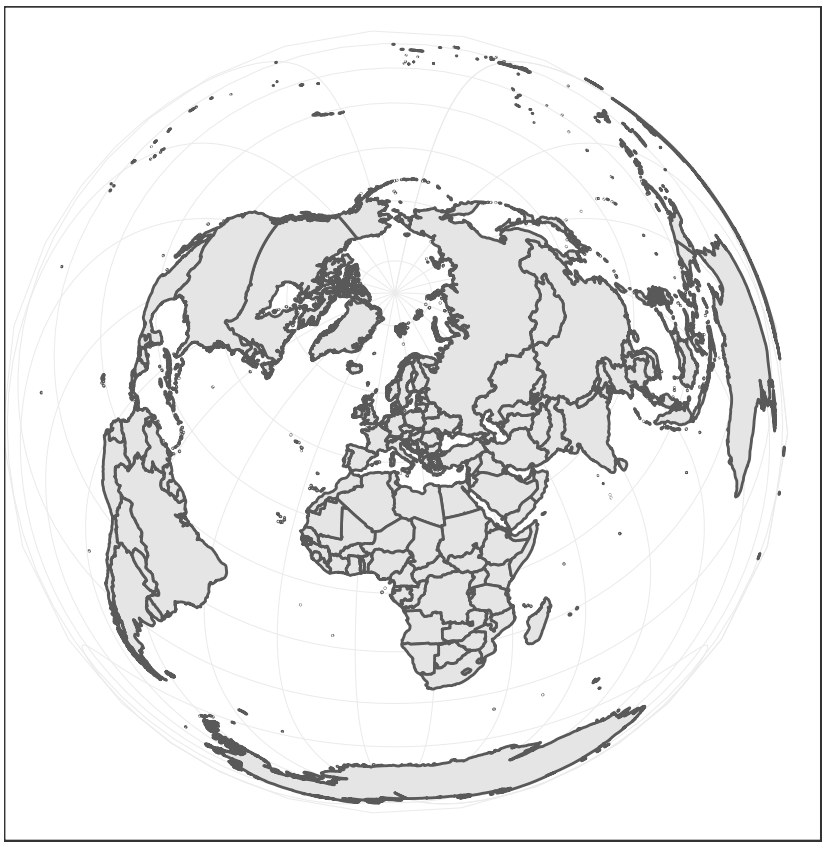
A map extent is the portion or area of the geography visible in the map. The map extent is defined using coordinate systems, which can be added using the `coord_sf()` function. This function can manipulate both the projection and extent of the map. By default, the map will use the coordinate system of the first layer defined, or if none, fall back on WGS84 (latitude/longitude, the reference system used in GPS). Using the argument `crs` within `coord_sf()`, it is possible to override this setting, and project on the fly to any Proj4 string (converting between any coordinate reference system (crs)). The example below uses the European-centric ETRS89 Lambert Azimuthal Equal-Area projection.

```
ggplot(data = world) +
    geom_sf() +
    coord_sf(crs = "+proj=laea +lat_0=52 +lon_0=10 +x_0=4321000 +y_0=3210000 +ellps=GRS80 +units=m +no_
```



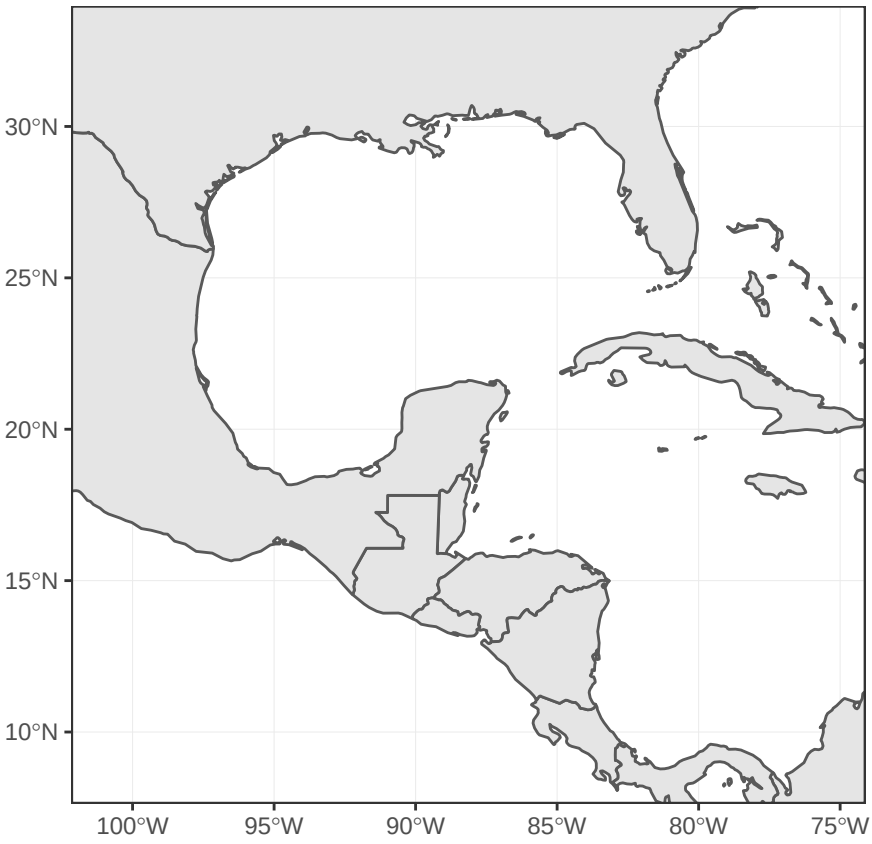
If Spatial Reference System Identifier (SRID) or an European Petroleum Survey Group (EPSG) code are available, they can be used instead of the full PROJ4 string.

```
ggplot(data = world) +
    geom_sf() +
    coord_sf(crs = "+init=epsg:3035")
```



`coord_sf()` can also be used to "zoom" into an area of interest, using the `xlim =` and `ylim =` arguments. Note that the limits are automatically expanded by a fraction to ensure that data and axes don't overlap. This can be turned off to exactly match the limits provided using `expand = FALSE`.

```
ggplot(data = world) +
    geom_sf() +
    coord_sf(xlim = c(-102.15, -74.12), ylim = c(7.65, 33.97), expand = FALSE)
```



Scale bar and north arrow (ggspatial package)

We will use the `ggspatial` package to add a scale bar. There are other packages that can do this (e.g. `prettymapr`, `vcd`, `ggsn`, or `legendMap`), however `ggspatial` is much more user friendly.

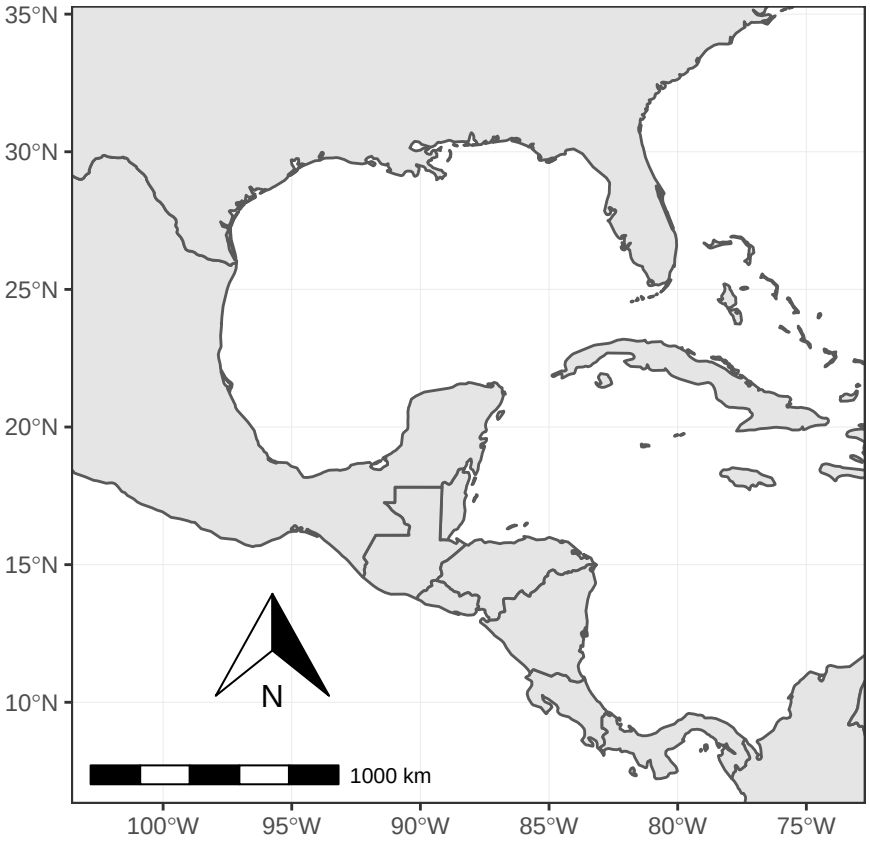
The location of the scale bar must be specified in longitude/latitude in the `lon =` and `lat =` arguments. The shaded distance inside the scale bar can be adjusted with the `distance_lon =` argument and it's width is determined by the `distance_lat =` argument. These are not included in the example below.

Additional freatures that can be modified include: * Legend size - `legend_size =` (defaults to 3) * The North arrow behind the "N" symbol - `arrow_length =` * Arrow distance to the scale - `arrow_distance =` * Size the N north symbol itself with `arrow_north_size =` (defaults to 6)

Note that all distances are set to "km" by default, the `distance_unit =` argument can change to nautical miles ("nm") or miles ("mi").

```
library("ggspatial")
ggplot(data = world) +
    geom_sf() +
     ggspatial::annotation_scale(location = "bl", width_hint = 0.5) +
     ggspatial::annotation_north_arrow(location = "bl", which_north = "true",
        pad_x = unit(0.75, "in"), pad_y = unit(0.5, "in")) +
    coord_sf(xlim = c(-102.15, -74.12), ylim = c(7.65, 33.97))
```

```
## Scale on map varies by more than 10%, scale bar may be inaccurate
```




```
## Scale on map varies by more than 10%, scale bar may be inaccurate
```

Note the warning message. Since the map uses unprojected data in longitude/latitude (WGS84) on an equidistant cylindrical projection, length in (kilo)meters on the map directly depends mathematically on the degree of latitude.

Annotating

The `world` object we created above already contains country names and their centroid coordinates. We can use `geom_text()` to add notations.

Usefull arguments of `geom_text()` are:

- `size =`
- horizontal and vertical alignment `hjust =` and `vjust =`. Which can be a number between 0 (right/bottom) and 1 (top/left) or a character ("left", "middle", "right", "bottom", "center", "top"). The text can also be offset horizontally or vertically with the `nudge_x` `nudge_y` arguments
- `color =` and `fontface =`
- `check_overlap =` checks for overlap in text. Alternatively, when there is a lot of overlapping labels, the package `ggrepel` provides a `geom_text_repel()` function that moves label around so that they do not overlap.
- `annotate()` is not an argument but an additional function that can be used to add a single character string at a specific location, as demonstrated in the Gulf of Mexico map below.

```
world_points<- st_centroid(world)
```

```
## Warning in st_centroid.sf(world): st_centroid assumes attributes are
## constant over geometries of x
```

```
## Warning in st_centroid.sfc(st_geometry(x), of_largest_polygon =
## of_largest_polygon): st_centroid does not give correct centroids for
## longitude/latitude data
```

```
world_points <- cbind(world, st_coordinates(st_centroid(world$geometry)))
```

```
## Warning in st_centroid.sfc(world$geometry): st_centroid does not give
## correct centroids for longitude/latitude data
```

```
ggplot(data = world) +
geom_sf() +
geom_text(data= world_points,aes(x=X, y=Y, label=name),
    color = "darkblue", fontface = "bold", check_overlap = FALSE) +
annotate(geom = "text", x = -90, y = 26, label = "Gulf of Mexico",
    fontface = "italic", color = "grey22", size = 6) +
coord_sf(xlim = c(-102.15, -74.12), ylim = c(7.65, 33.97), expand = FALSE)
```

Aesthetic elements

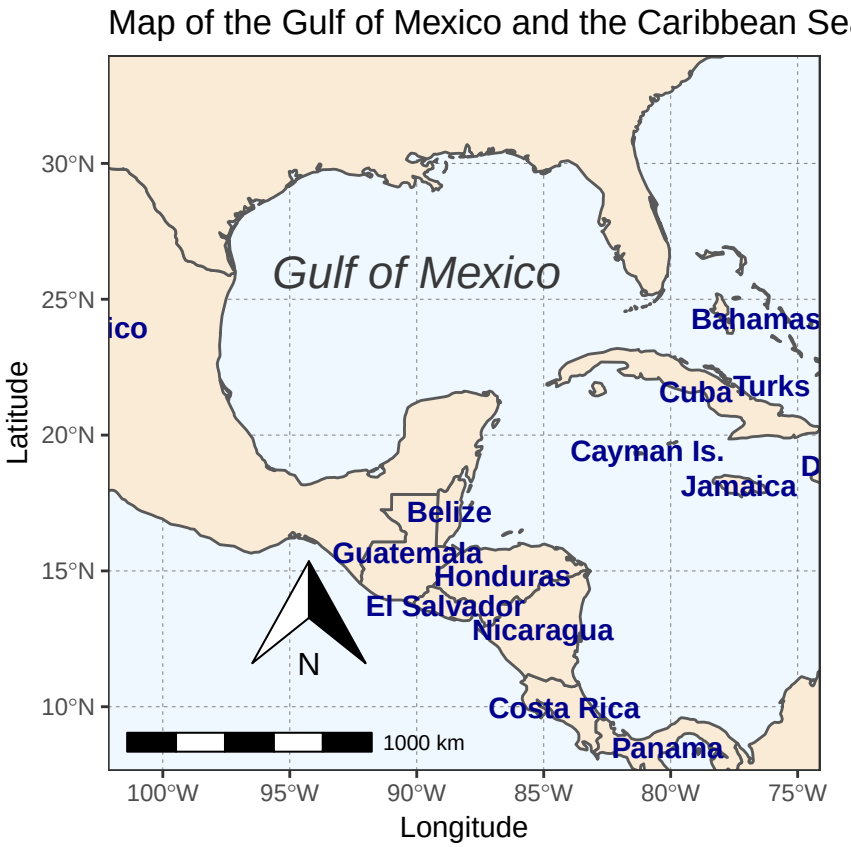
```
#is this what you meant by aeesthetic elements? or is this section in part two?
```

The map theme can be edited to make it more appealing. We suggested the use of `theme_bw()` for a standard theme, but there are many other themes that can be used (see `?ggtheme()`). Specific theme elements can also be adjusted using the following.

```
#scales seem to be different that what is shown on the website. Maybe come back and tinker with the map
```

```
ggplot(data = world) +
      geom_sf(fill= "antiquewhite") +
      geom_text(data= world_points,aes(x=X, y=Y, label=name), color = "darkblue", fontface = "bold", ch
      coord_sf(xlim = c(-102.15, -74.12), ylim = c(7.65, 33.97), expand = FALSE) +
      xlab("Longitude") + ylab("Latitude") + ggtitle("Map of the Gulf of Mexico and the Caribbean Sea")
```

```
## Scale on map varies by more than 10%, scale bar may be inaccurate
```



Saving the map (`ggsave()`)

The `ggsave()` function makes it easy to save these maps ina variety of formats including PNG (raster bitmap) and PDF (vector graphics), and provids control over the size and resolution. Below we save a PDF version of the map, with the best quality, as well as a PNG version for web purposes:

```
ggsave("map.pdf")
```

```
## Saving 6.5 x 4.5 in image
```

```
## Scale on map varies by more than 10%, scale bar may be inaccurate
```

```
ggsave("map_web.png", width = 6, height = 6, dpi = "screen")
```

```
## Scale on map varies by more than 10%, scale bar may be inaccurate
```

Now you've learnt the basics, let try a different map and adding a few more details.

Adding points using coordinates

Let's start by defining two study sites according to their longitude and latitude and store them in a regular data.frame.

```
(sites <- data.frame(longitude = c(-80.144005, -80.109), latitude = c(26.479005,
    26.83)))
```

```
##   longitude latitude
## 1 -80.14401 26.47901
## 2 -80.10900 26.83000
```


```
##   longitude latitude
## 1 -80.14401 26.47901
## 2 -80.10900 26.83000
```

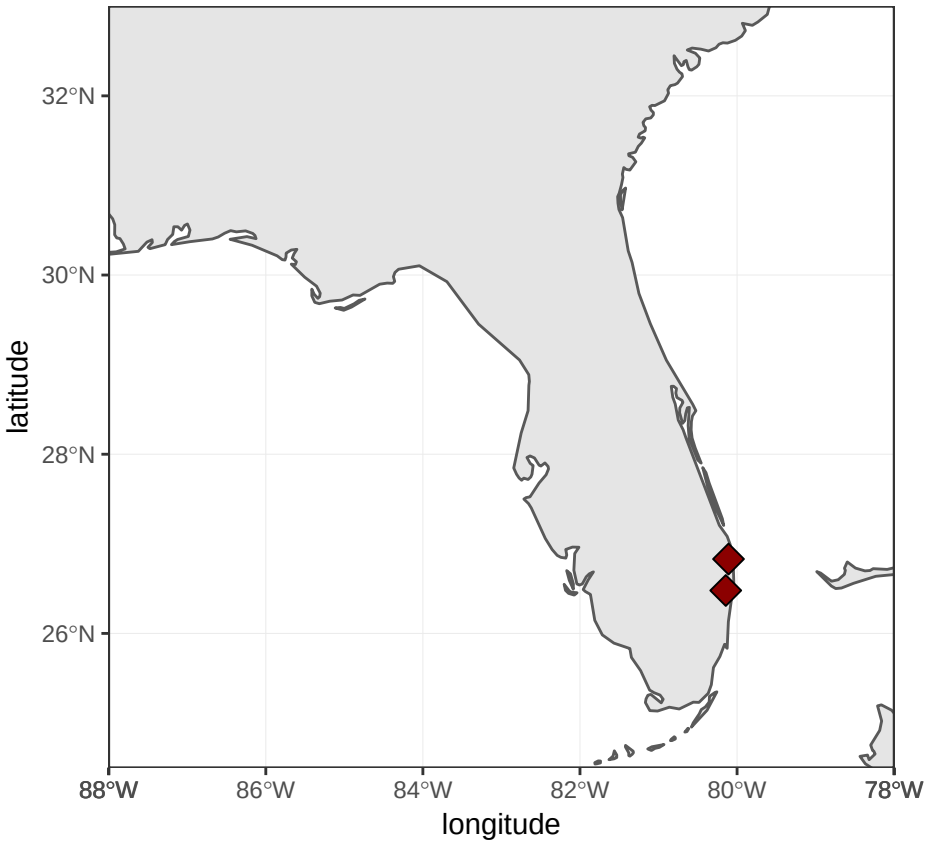

Using the `geom_point()` function

```
#maybe take this first way out so not to confuse people when it comes to the assessment
```

The quickest way to add point coordinates is with `geom_point()`. Characteristics of the points can be adjusted as for any other use of `geom_point()` (e.g. color of the outline and the filling, shape, size, etc.). This can be achieved for all points or using groupings from the data (i.e defining their "aesthetics").

In this example, we zoom in a little further into the Gulf of Mexico and add two diamond shaped points (`shape = 23`), filled in dark red (`fill = "darkred"`) and increase the size (`size = 4`), Location defined above.

```
ggplot(data = world) +
    geom_sf() +
    geom_point(data = sites, aes(x = longitude, y = latitude), size = 4,
        shape = 23, fill = "darkred") +
    coord_sf(xlim = c(-88, -78), ylim = c(24.5, 33), expand = FALSE)
```



Using the `sf` package

An alternative and more flexible way to add points is using the `sf` package.

Fist the data.frame must be converted to an `sf` object using the `st_as_sf()` function. The argument `coords =` should be fed the names of columns containing the coordinates. This can be very useful if the two objects (here `world` and `sites`) are not in the same projection. To achieve the same result the projection (WGS84, which is the CRS code #4326) has to be defined in the `sf` object.

Note: the `arg` argument in the map below stands for 'attribute-geometry-relationship'. It defines how the non-geometry columns relate to the geometry and it can have the values: "constant" (e.g. lang use), "aggregate" (e.g. population density or count) or "identity" (e.g. city name). In the example below the `world` object is the geometry and `sites` are specific locations. The `crs = 4326` argument defines the coorindate reference system. 4326 is the standard system for an elipsoid world map and can be used in all projects for this unit.

```
## kate - check that the assessment won't need anything other than crs = 4326.
```

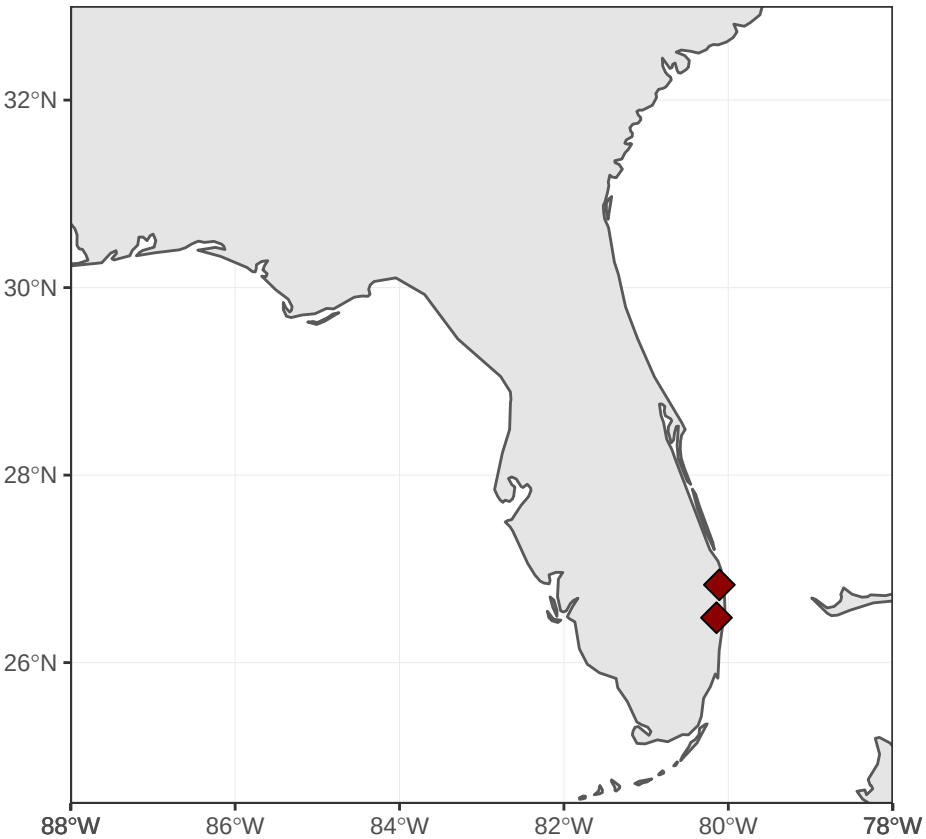
```
(sites <- st_as_sf(sites, coords = c("longitude", "latitude"),
    crs = 4326, agr = "identity"))
```

```
## Simple feature collection with 2 features and 0 fields
## geometry type:  POINT
## dimension:      XY
## bbox:           xmin: -80.14401 ymin: 26.479 xmax: -80.109 ymax: 26.83
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
##                     geometry
```

```
## 1 POINT (-80.14401 26.47901)
## 2      POINT (-80.109 26.83)
```

```
## Simple feature collection with 2 features and 0 fields
## geometry type:  POINT
## dimension:      XY
## bbox:           xmin: -80.14401 ymin: 26.479 xmax: -80.109 ymax: 26.83
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
##                     geometry
## 1 POINT (-80.14401 26.47901)
## 2      POINT (-80.109 26.83)
```

```
ggplot(data = world) +
    geom_sf() +
    geom_sf(data = sites, size = 4, shape = 23, fill = "darkred") +
    coord_sf(xlim = c(-88, -78), ylim = c(24.5, 33), expand = FALSE)
```



Note that `coord_sf()` has to be called after all `geom_sf()` calls, in order to supersede any former input.

Adding Polygons

Polygons are used to show states, counties, electorates, suburbs or other relevant regions on a mal. The package `maps` (which is automatically installed and loaded with `ggplot2`) provides polygon data for US state and county boundaries.

States

```
states <- st_as_sf(map("state", plot = FALSE, fill = TRUE))
head(states)
```

```
## Simple feature collection with 6 features and 1 field
## geometry type:  MULTIPOLYGON
## dimension:      XY
## bbox:           xmin: -124.3834 ymin: 30.24071 xmax: -71.78015 ymax: 42.04937
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
##                         geometry          ID
## 1 MULTIPOLYGON (((-87.46201 3...     alabama
## 2 MULTIPOLYGON (((-114.6374 3...     arizona
## 3 MULTIPOLYGON (((-94.05103 3...    arkansas
## 4 MULTIPOLYGON (((-120.006 42...  california
## 5 MULTIPOLYGON (((-102.0552 4...    colorado
## 6 MULTIPOLYGON (((-73.49902 4... connecticut
```


```
## Simple feature collection with 6 features and 1 field
## geometry type:  MULTIPOLYGON
## dimension:      XY
## bbox:           xmin: -124.3834 ymin: 30.24071 xmax: -71.78015 ymax: 42.04937
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
##                         geometry          ID
## 1 MULTIPOLYGON (((-87.46201 3...     alabama
## 2 MULTIPOLYGON (((-114.6374 3...     arizona
## 3 MULTIPOLYGON (((-94.05103 3...    arkansas
## 4 MULTIPOLYGON (((-120.006 42...  california
## 5 MULTIPOLYGON (((-102.0552 4...    colorado
## 6 MULTIPOLYGON (((-73.49902 4... connecticut
```


The ID variable contains the State names. A simple way to add State names to the map, is to compute the centroid of each state polygon and use this as the coordinates for the annotated names. Centroids are computed with the function `st_centroid()` and their coordinates extracted with `st_coordinates()`, both from the package `sf`, and attached to `states`

```
states <- cbind(states, st_coordinates(st_centroid(states)))
```

```
## Warning in st_centroid.sf(states): st_centroid assumes attributes are
## constant over geometries of x
```

```
## Warning in st_centroid.sfc(st_geometry(x), of_largest_polygon =
## of_largest_polygon): st_centroid does not give correct centroids for
## longitude/latitude data
```

Note the warning, which basically says that centroid coordinates using longitude/latitude data (i.e. WGS84) are not exact, which is perfectly fine for our drawing purposes. State names, which are not capitalised in the data from `maps`, can be changed to title case using the function `toTitleCase()` from the package `tools`.

```
library("tools")
states$ID <- toTitleCase(states$ID)
head(states)
```

```
## Simple feature collection with 6 features and 3 fields
## geometry type:  MULTIPOLYGON
```

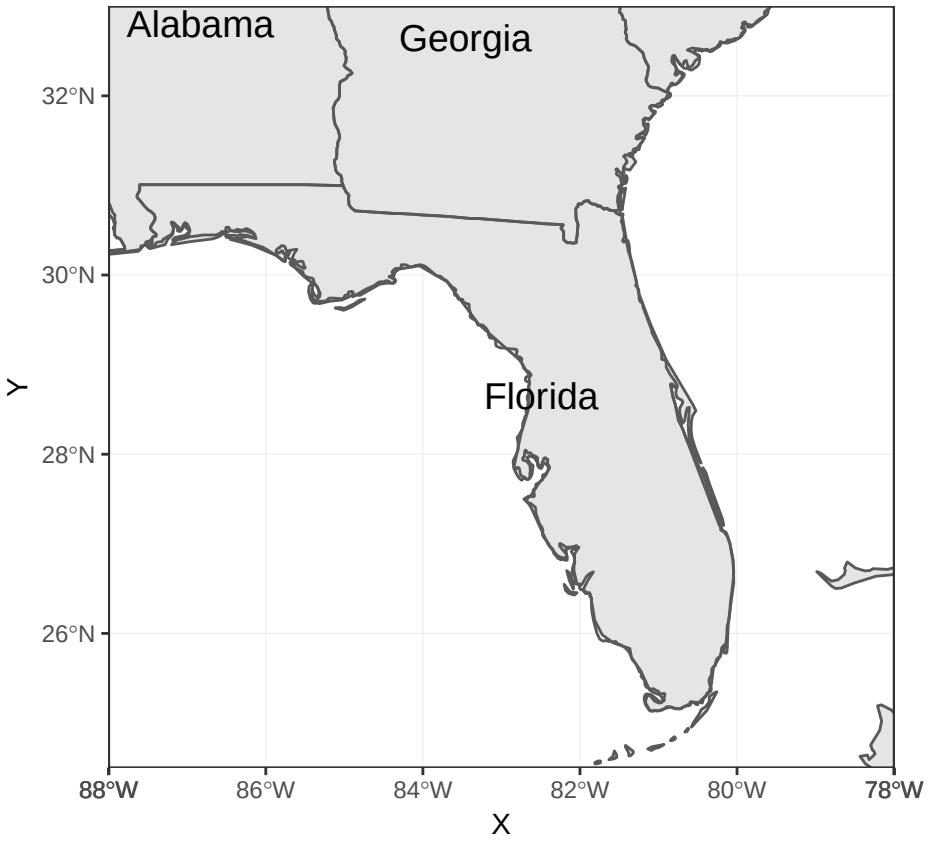
```
## dimension:      XY
## bbox:           xmin: -124.3834 ymin: 30.24071 xmax: -71.78015 ymax: 42.04937
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
##            ID          X        Y                       geometry
## 1     Alabama  -86.83042 32.80316 MULTIPOLYGON (((-87.46201 3...
## 2     Arizona -111.66786 34.30060 MULTIPOLYGON (((-114.6374 3...
## 3    Arkansas  -92.44013 34.90418 MULTIPOLYGON (((-94.05103 3...
## 4  California -119.60154 37.26901 MULTIPOLYGON (((-120.006 42...
## 5    Colorado -105.55251 38.99797 MULTIPOLYGON (((-102.0552 4...
## 6 Connecticut  -72.72598 41.62566 MULTIPOLYGON (((-73.49902 4...
```

```
## Simple feature collection with 6 features and 3 fields
## geometry type:  MULTIPOLYGON
## dimension:      XY
## bbox:           xmin: -124.3834 ymin: 30.24071 xmax: -71.78015 ymax: 42.04937
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
##            ID          X        Y                       geometry
## 1     Alabama  -86.83042 32.80316 MULTIPOLYGON (((-87.46201 3...
## 2     Arizona -111.66786 34.30060 MULTIPOLYGON (((-114.6374 3...
## 3    Arkansas  -92.44013 34.90418 MULTIPOLYGON (((-94.05103 3...
## 4  California -119.60154 37.26901 MULTIPOLYGON (((-120.006 42...
## 5    Colorado -105.55251 38.99797 MULTIPOLYGON (((-102.0552 4...
## 6 Connecticut  -72.72598 41.62566 MULTIPOLYGON (((-73.49902 4...
```

Using `geom_text()`, State names can be added, including coordinates on the X-axis and Y-axis, as well as the label (from ID) and a relatively big font size.

```
#the paragraph above doesn't make sense.. Edit
```

```
ggplot(data = world) +
    geom_sf() +
    geom_sf(data = states, fill = NA) +
    geom_text(data = states, aes(X, Y, label = ID), size = 5) +
    coord_sf(xlim = c(-88, -78), ylim = c(24.5, 33), expand = FALSE)
```



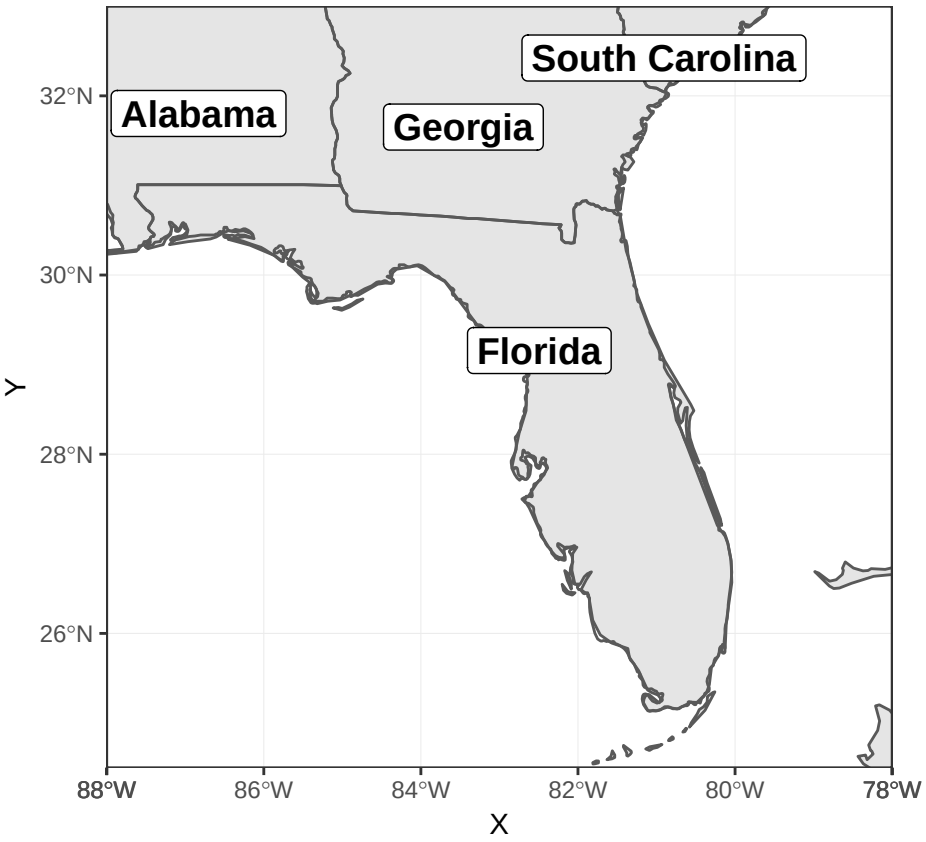
State names can be re-aligned slightly on the y-axis byt creating a new variable `nudge_y`, which is -1 for all states (moved slightly South), 0.5 for Florida (moved slightly North), and -1.5 for South Carolina (moved further South):

```
states$nudge_y <- -1
states$nudge_y[states$ID == "Florida"] <- 0.5
states$nudge_y[states$ID == "South Carolina"] <- -1.5
```

We can also draw a rectangle behind the state name, using the function `geom_label()` instead of `geom_text()`.

```
ggplot(data = world) +
    geom_sf() +
    geom_sf(data = states, fill = NA) +
    geom_label(data = states, aes(X, Y, label = ID), size = 5, fontface = "bold",
        nudge_y = states$nudge_y) +
    coord_sf(xlim = c(-88, -78), ylim = c(24.5, 33), expand = FALSE)
```

```
## Warning in if (params$y != 0) {: the condition has length > 1 and only the
## first element will be used
```



Counties (polygon data)

County area can be computed using the `st_area()` function within the `sf` package

```
counties <- st_as_sf(map("county", plot = FALSE, fill = TRUE))
counties <- subset(counties, grepl("florida", counties$ID))
counties$area <- as.numeric(st_area(counties))
head(counties)
```

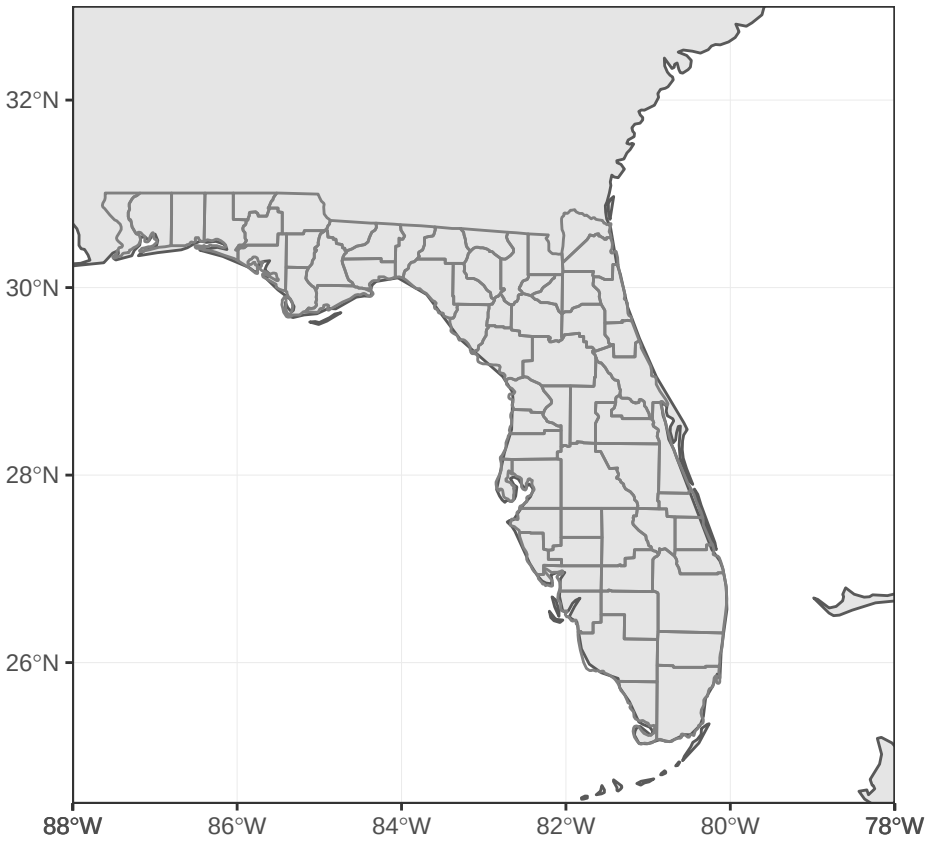
```
## Simple feature collection with 6 features and 2 fields
## geometry type:  MULTIPOLYGON
## dimension:      XY
## bbox:           xmin: -85.98951 ymin: 25.94926 xmax: -80.08804 ymax: 30.57303
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
##                            geometry              ID       area
## 292 MULTIPOLYGON (((-82.66062 2...  florida,alachua 2498863359
## 293 MULTIPOLYGON (((-82.04182 3...    florida,baker 1542466064
## 294 MULTIPOLYGON (((-85.40509 3...      florida,bay 1946587533
## 295 MULTIPOLYGON (((-82.4257 29... florida,bradford  818898090
## 296 MULTIPOLYGON (((-80.94747 2...  florida,brevard 2189682999
## 297 MULTIPOLYGON (((-80.89018 2...  florida,broward 3167386973
```

```
## Simple feature collection with 6 features and 2 fields
## geometry type:  MULTIPOLYGON
## dimension:      XY
## bbox:           xmin: -85.98951 ymin: 25.94926 xmax: -80.08804 ymax: 30.57303
```

```
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
##                            geometry               ID       area
## 292 MULTIPOLYGON (((-82.66062 2...  florida,alachua 2498863359
## 293 MULTIPOLYGON (((-82.04182 3...    florida,baker 1542466064
## 294 MULTIPOLYGON (((-85.40509 3...      florida,bay 1946587533
## 295 MULTIPOLYGON (((-82.4257 29... florida,bradford  818898090
## 296 MULTIPOLYGON (((-80.94747 2...  florida,brevard 2189682999
## 297 MULTIPOLYGON (((-80.89018 2...  florida,broward 3167386973
```

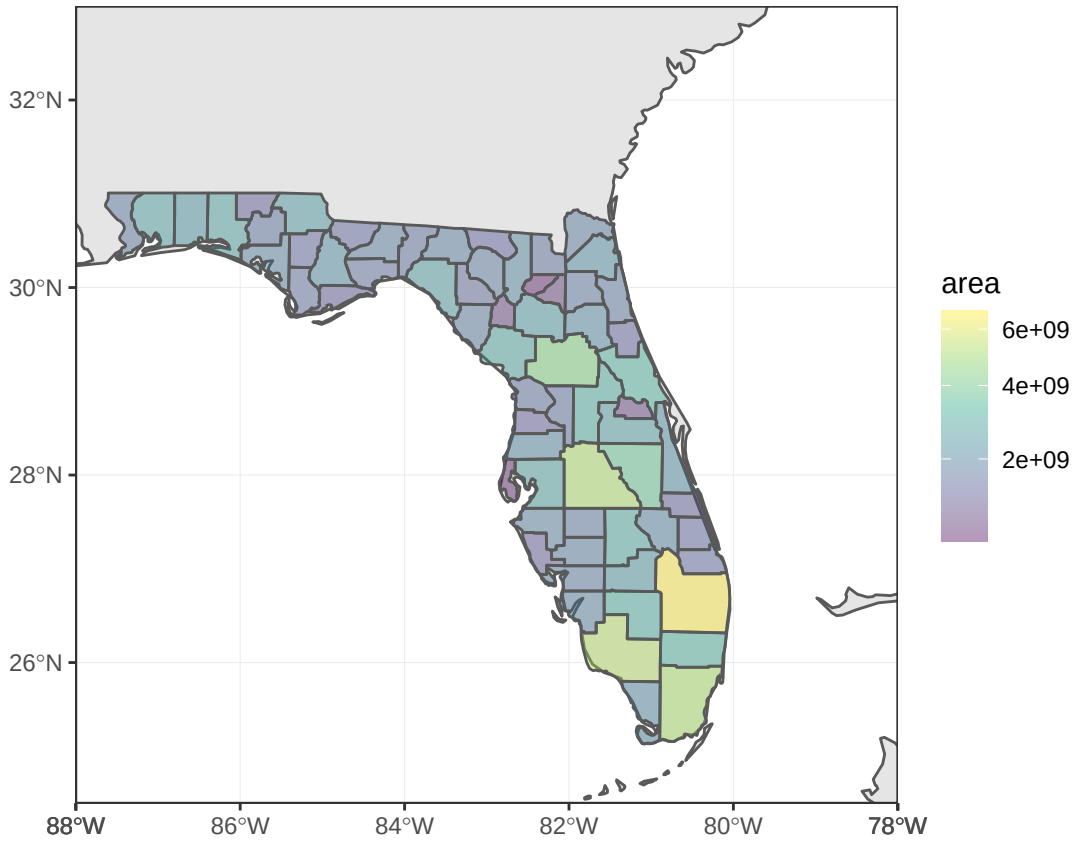
A grey outline of county lines can now be added.

```
ggplot(data = world) +
    geom_sf() +
    geom_sf(data = counties, fill = NA, color = gray(.5)) +
    coord_sf(xlim = c(-88, -78), ylim = c(24.5, 33), expand = FALSE)
```



These polygons can be coloured on any data available at that level. The map below shows area of each region using the "viridis" colorblind-friendly palette, transparency has also been added.

```
ggplot(data = world) +
    geom_sf() +
    geom_sf(data = counties, aes(fill = area)) +
    scale_fill_viridis_c(trans = "sqrt", alpha = .4) +
    coord_sf(xlim = c(-88, -78), ylim = c(24.5, 33), expand = FALSE)
```



Cities (point data)

Next we will add city names for the five largest cities in florida.

```
# First prepare a data frame with the five largest cities including their geographic coordinates. To sa

flcities <- data.frame(state = rep("Florida", 5), city = c("Miami",
    "Tampa", "Orlando", "Jacksonville", "Sarasota"), lat = c(25.7616798,
    27.950575, 28.5383355, 30.3321838, 27.3364347), lng = c(-80.1917902,
    -82.4571776, -81.3792365, -81.655651, -82.5306527))
```

Convert the data frame with coordinates to an `sf` object.

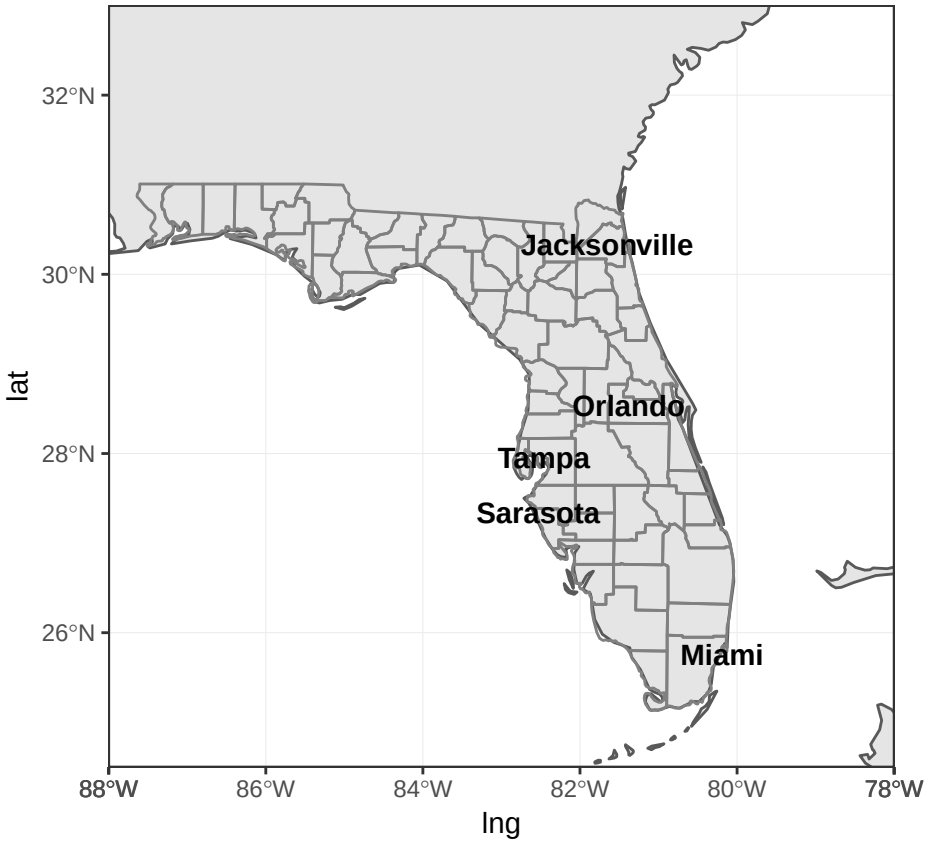
```
(flcities <- st_as_sf(flcities, coords = c("lng", "lat"), remove = FALSE,
    crs = 4326, agr = "constant"))

## Simple feature collection with 5 features and 4 fields
## Attribute-geometry relationship: 4 constant, 0 aggregate, 0 identity
## geometry type:  POINT
## dimension:      XY
## bbox:           xmin: -82.53065 ymin: 25.76168 xmax: -80.19179 ymax: 30.33218
## epsg (SRID):    4326
## proj4string:    +proj=longlat +datum=WGS84 +no_defs
##     state         city      lat       lng                   geometry
## 1 Florida        Miami 25.76168 -80.19179 POINT (-80.19179 25.76168)
## 2 Florida        Tampa 27.95058 -82.45718 POINT (-82.45718 27.95058)
## 3 Florida      Orlando 28.53834 -81.37924 POINT (-81.37924 28.53834)
## 4 Florida Jacksonville 30.33218 -81.65565 POINT (-81.65565 30.33218)
```

```
## 5 Florida     Sarasota 27.33643 -82.53065 POINT (-82.53065 27.33643)
```

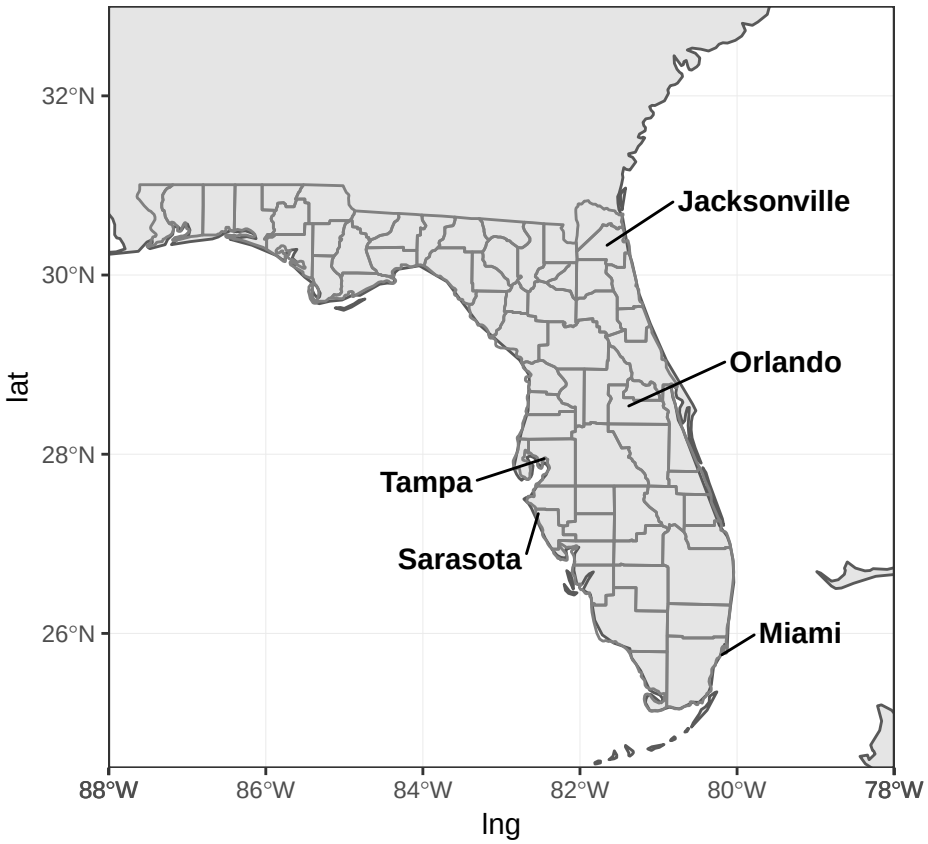
Add city locations and names to the map.

```
ggplot(data = world) +
    geom_sf() +
    geom_sf(data = counties, fill = NA, color = gray(.5)) +
    geom_text(data = flcities, aes(x = lng, y = lat, label = city),
        size = 3.9, col = "black", fontface = "bold") +
    coord_sf(xlim = c(-88, -78), ylim = c(24.5, 33), expand = FALSE)
```



The package `ggrepel` can adjust the label placement (`geom_text_repel()` and `geom_label_repel()`). It will automatically correct any overlap, "nudge" the labels away from land into the see, and connect them to the city locations.

```
ggplot(data = world) +
    geom_sf() +
    geom_sf(data = counties, fill = NA, color = gray(.5)) +
    geom_text_repel(data = flcities, aes(x = lng, y = lat, label = city),
        fontface = "bold", nudge_x = c(1, -1.5, 2, 2, -1), nudge_y = c(0.25,
            -0.25, 0.5, 0.5, -0.5)) +
    coord_sf(xlim = c(-88, -78), ylim = c(24.5, 33), expand = FALSE)
```

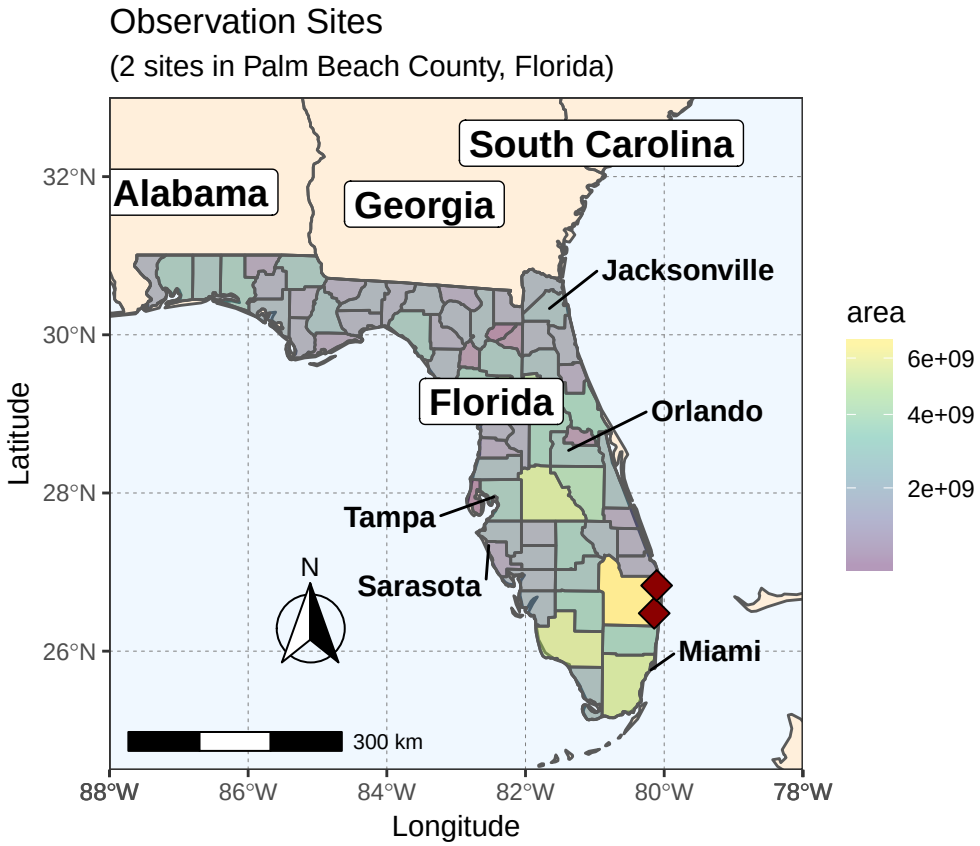


Final map

Add or adjust the theme, titles, subtitles, axis labels, and add a scale bar:

```
ggplot(data = world) +
    geom_sf(fill = "antiquewhite1") +
    geom_sf(data = counties, aes(fill = area)) +
    geom_sf(data = states, fill = NA) +
    geom_sf(data = sites, size = 4, shape = 23, fill = "darkred") +
    geom_text_repel(data = flcities, aes(x = lng, y = lat, label = city),
        fontface = "bold", nudge_x = c(1, -1.5, 2, 2, -1), nudge_y = c(0.25,
            -0.25, 0.5, 0.5, -0.5)) +
    geom_label(data = states, aes(X, Y, label = ID), size = 5, fontface = "bold",
        nudge_y = states$nudge_y) +
    scale_fill_viridis_c(trans = "sqrt", alpha = .4) +
    annotation_scale(location = "bl", width_hint = 0.4) +
    annotation_north_arrow(location = "bl", which_north = "true",
        pad_x = unit(0.75, "in"), pad_y = unit(0.5, "in"),
        style = north_arrow_fancy_orienteering) +
    coord_sf(xlim = c(-88, -78), ylim = c(24.5, 33), expand = FALSE) +
    xlab("Longitude") + ylab("Latitude") +
    ggtitle("Observation Sites", subtitle = "(2 sites in Palm Beach County, Florida)") +
    theme(panel.grid.major = element_line(color = gray(0.5), linetype = "dashed",
        size = 0.5), panel.background = element_rect(fill = "aliceblue"))
```

```
## Warning in if (params$y != 0) {: the condition has length > 1 and only the
## first element will be used
```



Additional layers can be added to the map using additional calls to `geom_sf()` at the right place in the `ggplot2` sequence.

GIS Visualisations - Hexmaps