

Introduction to GIS & Spatial Analysis in R

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GIS concepts

Types of spatial data

Vector data

Discrete objects

Examples: countries, roads, rivers, towns

Contain:
- geometry: shape & location of the objects
- attributes: additional variables (e.g. name, year, type)

Common file format: [GeoJSON](#), [shapefile](#)

Raster data

Continuous phenomena or spatial fields

Examples: temperature, air quality, elevation, water depth

Common file formats: [TIFF](#), [GeoTIFF](#), [NetCDF](#), Esri grid

Vector data

Types

- **point:** single set of coordinates
- **multi-point:** multiple sets of coordinates
- **polyline:** multiple sets for which the order matters
- **multi-polyline:** multiple of the above
- **polygon:** same as polyline but first & last sets are the same
- **multi-polygon:** multiple of the above

Raster data

Grid of equally sized rectangular cells containing values for some variables

Size of cells = resolution

For computing efficiency, rasters do not have coordinates of each cell, but the bounding box & the number of rows & columns

Coordinate Reference Systems (CRS)

A location on Earth's surface can be identified by its **coordinates** & some **reference system** called CRS

The coordinates (x , y) are called **longitude** & **latitude**

There can be a 3rd coordinate (z) for elevation or other measurement—usually a vertical one & a 4th (m) for some other data attribute—usually a horizontal measurement

In 3D, longitude & latitude are expressed in angular units (e.g. degrees) & the reference system needed is an **angular CRS** or **geographic coordinate system (GCS)**

In 2D, they are expressed in linear units (e.g. meters) & the reference system needed is a **planar CRS** or **projected coordinate system (PCS)**

Datums

Since the Earth is not a perfect sphere, we use spheroidal models to represent its surface. Those are called **geodetic datums**

Some datums are global, others local (more accurate in a particular area of the globe, but only useful there)

Examples of commonly used global datums:

- WGS84 (World Geodesic System 1984)
- NAD83 (North American Datum of 1983)

Angular CRS

An angular CRS contains a datum, an angular unit & references such as a prime meridian (e.g. the Royal Observatory, Greenwich, England)

In an angular CRS or GCS:

- Longitude (λ) represents the angle between the prime meridian & the meridian that passes through that location
- Latitude (ϕ) represents the angle between the line that passes through the center of the Earth & that location & its projection on the equatorial plane

Longitude & latitude are thus angular coordinates

Projections

To create a two-dimensional map, you need to project this 3D angular CRS into a 2D one

Various projections offer different characteristics. For instance:

- some respect areas (equal-area)
- some respect the shape of geographic features (conformal)
- some *almost* respect both for small areas

It is important to choose one with sensible properties for your goals

Examples of projections:

- Mercator
- UTM
- Robinson

Planar CRS

A planar CRS is defined by a datum, a projection & a set of parameters such as a linear unit & the origins

Common planar CRS have been assigned a unique ID called [EPSG](#) code which is much more convenient to use

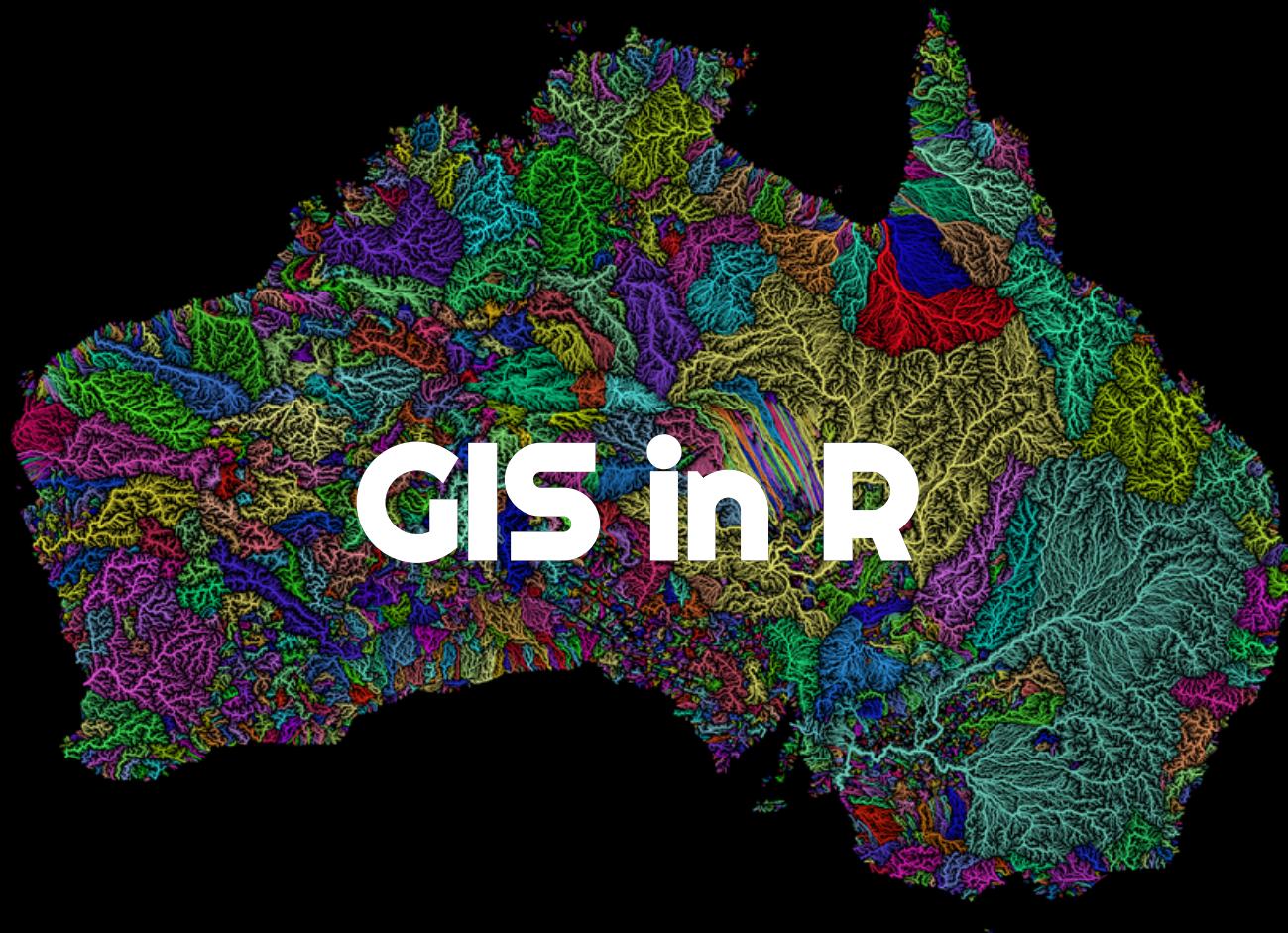
In a planar CRS, coordinates will not be in degrees anymore but in meters (or other length unit)

Projecting into a new CRS

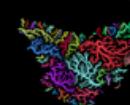
You can change the projection of your data

Vector data won't suffer any loss of precision, but raster data will

→ best to try to avoid reprojecting rasters: if you want to combine various datasets which have different projections, reproject vector data instead



GIS in R



Open GIS data

Free GIS Data : list of free GIS datasets

Books

Geocomputation with R by Robin Lovelace, Jakub Nowosad & Jannes Muenchow

Spatial Data Science by Edzer Pebesma & Roger Bivand

Spatial Data Science with R by Robert J. Hijmans

Using Spatial Data with R by Claudia A. Engel

Tutorial

An Introduction to Spatial Data Analysis and Visualisation in R by the CDRC

Website

r-spatial by Edzer Pebesma, Marius Appel & Daniel Nüst

CRAN package list

Analysis of Spatial Data

Mailing list

R Special Interest Group on using Geographical data and Mapping

Packages

There is now a rich ecosystem of GIS packages in R¹

1. Bivand, R.S. Progress in the R ecosystem for representing and handling spatial data. J Geogr Syst (2020). <https://doi.org/10.1007/s10109-020-00336-0>

Data manipulation

Older packages

- **sp**
- **raster**
- **rgdal**
- **rgeos**

Newer generation

- **sf** : vector data
- **terra** : raster data (also has vector data capabilities)

Mapping

Static maps

- **ggplot2 + ggspatial**
- **tmap**

Dynamic maps

- **leaflet**
- **ggplot2 + gganimate**
- **mapview**
- **ggmap**
- **tmap**



Simple Features in R

Geospatial vectors: points, lines, polygons

Simple Features

Simple Features—defined by the Open Geospatial Consortium (OGC) & formalized by ISO—is a set of standards now used by most GIS libraries

Well-known text (WKT) is a markup language for representing vector geometry objects according to those standards

A compact computer version also exists—well-known binary (WKB)—used by spatial databases

The package **sp** predates Simple Features

sf—launched in 2016—implements these standards in R in the form of sf objects: data.frames (or tibbles) containing the attributes, extended by sfc objects or simple feature geometries list-columns



Useful links

- [GitHub repo](#)
- [Paper](#)
- [Resources](#)
- [Cheatsheet](#)
- 6 vignettes: [1](#) , [2](#) , [3](#) , [4](#) , [5](#) , [6](#)

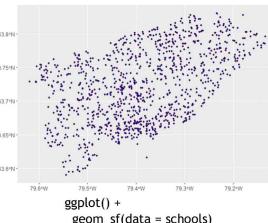
Spatial manipulation with sf: : CHEAT SHEET



The sf package provides a set of tools for working with geospatial vectors, i.e. points, lines, polygons, etc.

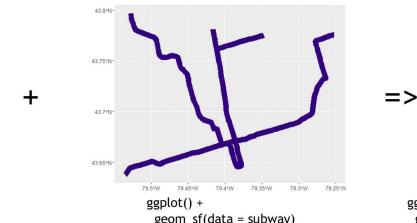
Geometric confirmation

- ⦿⦿ st_contains(x, y, ...) Identifies if x is within y (i.e. point within polygon)
- ⦿⦿ st_covered_by(x, y, ...) Identifies if x is completely within y (i.e. polygon completely within polygon)
- ⦿⦿ st_covers(x, y, ...) Identifies if any point from x is outside of y (i.e. polygon outside polygon)
- ⦿⦿ st_crosses(x, y, ...) Identifies if any geometry of x have commonalities with y
- ⦿⦿ st_disjoint(x, y, ...) Identifies when geometries from x do not share space with y
- ⦿⦿ st_equals(x, y, ...) Identifies if x and y share the same geometry
- ⦿⦿ st_intersects(x, y, ...) Identifies if x and y geometry share any space
- ⦿⦿ st_overlaps(x, y, ...) Identifies if geometries of x and y share space, are of the same dimension, but are not completely contained by each other
- ⦿⦿ st_touches(x, y, ...) Identifies if geometries of x and y share a common point but their interiors do not intersect
- ⦿⦿ st_within(x, y, ...) Identifies if x is in a specified distance to y



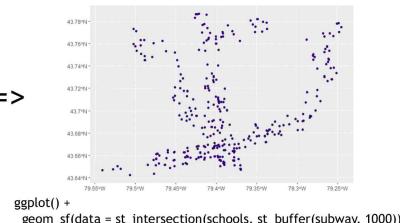
Geometric operations

- ⦿⦿ st_boundary(x) Creates a polygon that encompasses the full extent of the geometry
- ⦿⦿ st_buffer(x, dist, nQuadSegs) Creates a polygon covering all points of the geometry within a given distance
- ⦿⦿ st_centroid(x, ..., of_largest_polygon) Creates a point at the geometric centre of the geometry
- ⦿⦿ st_convex_hull(x) Creates geometry that represents the minimum convex geometry of x
- ⦿⦿ st_line_merge(x) Creates linestring geometry from sewing multi linestring geometry together
- ⦿⦿ st_node(x) Creates nodes on overlapping geometry where nodes do not exist
- ⦿ st_point_on_surface(x) Creates a point that is guaranteed to fall on the surface of the geometry
- ⦿⦿ st_polygonize(x) Creates polygon geometry from linestring geometry
- ⦿⦿ st_segmentize(x, dfMaxLength, ...) Creates linestring geometry from x based on a specified length
- ⦿⦿ st_simplify(x, preserveTopology, dTolerance) Creates a simplified version of the geometry based on a specified tolerance



Geometry creation

- ⦿⦿ st_triangulate(x, dTolerance, bOnlyEdges) Creates polygon geometry as triangles from point geometry
- ⦿⦿ st_voronoi(x, envelope, dTolerance, bOnlyEdges) Creates polygon geometry covering the envelope of x, with x at the centre of the geometry
- ⦿ st_point(x, c(numeric vector), dim = "XYZ") Creating point geometry from numeric values
- ⦿⦿ st_multipoint(x = matrix(numeric values in rows), dim = "XYZ") Creating multi point geometry from numeric values
- ⦿⦿ st_linestring(x = matrix(numeric values in rows), dim = "XYZ") Creating linestring geometry from numeric values
- ⦿⦿ st_multilinestring(x = list(numeric matrices in rows), dim = "XYZ") Creating multi linestring geometry from numeric values
- ⦿⦿ st_polygon(x = list(numeric matrices in rows), dim = "XYZ") Creating polygon geometry from numeric values
- ⦿⦿ st_multipolygon(x = list(numeric matrices in rows), dim = "XYZ") Creating multi polygon geometry from numeric values



This cheatsheet presents the sf package [Edzer Pebesma 2018] in version 0.6.3. See <https://github.com/r-spatial/sf> for more details.

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<https://creativecommons.org/licenses/by/4.0/>

Spatial manipulation with sf: : CHEAT SHEET

The sf package provides a set of tools for working with geospatial vectors, i.e. points, lines, polygons, etc.



Geometry operations

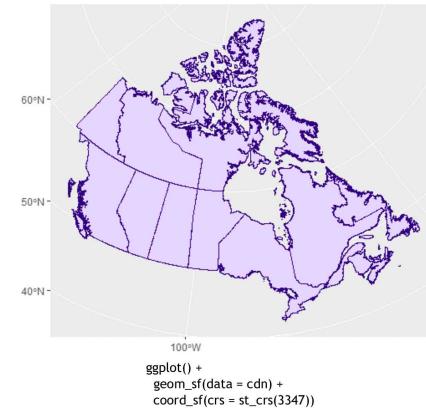
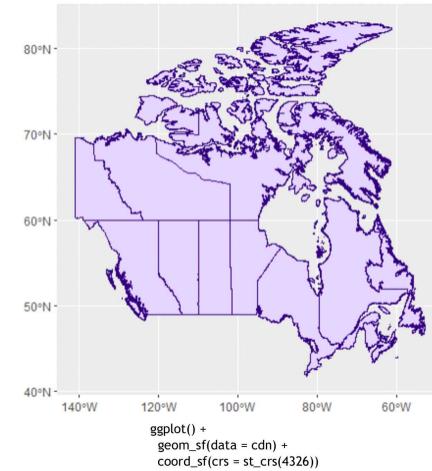
- `st_contains(x, y, ...)` Identifies if x is within y (i.e. point within polygon)
- `st_crop(x, y, ..., xmin, ymin, xmax, ymax)` Creates geometry of x that intersects a specified rectangle
- `st_difference(x, y)` Creates geometry from x that does not intersect with y
- `st_intersection(x, y)` Creates geometry of the shared portion of x and y
- `st_sym_difference(x, y)` Creates geometry representing portions of x and y that do not intersect
- `st_snap(x, y, tolerance)` Snap nodes from geometry x to geometry y
- `st_union(x, y, ..., by_feature)` Creates multiple geometries into a single geometry, consisting of all geometry elements

Geometric measurement

- `st_area(x)` Calculate the surface area of a polygon geometry based on the current coordinate reference system
- `st_distance(x, y, ..., dist_fun, by_element, which)` Calculates the 2D distance between x and y based on the current coordinate system
- `st_length(x)` Calculates the 2D length of a geometry based on the current coordinate system

Misc operations

- `st_as_sf(x, ...)` Create a sf object from a non-geospatial tabular data frame
- `st_cast(x, to, ...)` Change x geometry to a different geometry type
- `st_coordinates(x, ...)` Creates a matrix of coordinate values from x
- `st_crs(x, ...)` Identifies the coordinate reference system of x
- `st_join(x, y, join, FUN, suffix, ...)` Performs a spatial left or inner join between x and y
- `st_make_grid(x, cellsize, offset, n, crs, what)` Creates rectangular grid geometry over the bounding box of x
- `st_nearest_feature(x, y)` Creates an index of the closest feature between x and y
- `st_nearest_points(x, y, ...)` Returns the closest point between x and y
- `st_read(dsn, layer, ...)` Read file or database vector dataset as a sf object
- `st_transform(x, crs, ...)` Convert coordinates of x to a different coordinate reference system



sf objects

```
> Simple feature collection with 27108 features and 4 fields
Geometry type: POLYGON
Dimension:      XY
Bounding box:   xmin: -176.1425 ymin: 52.05727 xmax: -126.8545 ymax: 69.35167
Geodetic CRS:   WGS 84
First 10 features:
#   RGIId    CenLon    CenLat     Area geometry
1  RGI60-01.00001 -146.8230  63.68900  0.360 POLYGON ((-146.818 63.69081...
2  RGI60-01.00002 -146.6680  63.40400  0.558 POLYGON ((-146.6635 63.4076...
3  RGI60-01.00003 -146.0800  63.37600  1.685 POLYGON ((-146.0723 63.3834...
4  RGI60-01.00004 -146.1200  63.38100  3.681 POLYGON ((-146.149 63.37919...
5  RGI60-01.00005 -147.0570  63.55100  2.573 POLYGON ((-147.0431 63.5502...
6  RGI60-01.00006 -146.2440  63.57100 10.470 POLYGON ((-146.2436 63.5562...
7  RGI60-01.00007 -146.2295  63.55085  0.649 POLYGON ((-146.2495 63.5531...
8  RGI60-01.00008 -146.2960  63.54300  0.200 POLYGON ((-146.2992 63.5443...
9  RGI60-01.00009 -147.6000  63.65900  1.517 POLYGON ((-147.6147 63.6643...
10 RGI60-01.00010 -147.1700  63.51300  3.806 POLYGON ((-147.1494 63.5098...
```

sf objects

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```

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sf object

sf objects

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10 RGI60-01.00010 -147.1700 63.51300 3.806 POLYGON (((-147.1494 63.5098...
```

sfc object:
geometry list-column

sf objects

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```

sfg object: feature geometry

sf objects

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10	RGI60-01.00010	-147.1700	63.51300	3.806	POLYGON ((-147.1494 63.5098...	

sf functions

Most functions start with `st_` (which refers to “spatial type”)

terra

Geospatial rasters

Faster and simpler replacement for the **raster** package by the same team

Mostly implemented in C++

Can work with datasets too large to be loaded into memory

terra

Useful links

- [GitHub repo](#)
- [Resources](#)
- [Full manual](#)

tmap

Layered grammar of graphics GIS maps



Useful links

- [GitHub repo](#)
- [Resources](#)

Help pages and vignettes

```
?tmap_element  
vignette("tmap-getstarted")  
# All the usual help pages, e.g.:  
?tm_layout
```

tmap functions

Main functions start with `tmap_`

Functions creating map elements start with `tm_`

tmap functioning

Very similar to **ggplot2**

Typically, a map contains:

- One or multiple layer(s) (the order matters as they stack on top of each other)
- Some layout (e.g. customization of title, background, margins): `tm_layout`
- A compass: `tm_compass`
- A scale bar: `tm_scale_bar`

Each layer contains:

- Some data: `tm_shape`
- How that data will be represented: e.g. `tm_polygons`, `tm_lines`, `tm_raster`

tmap example

```
tm_shape(ak, bbox = nwa_bbox) +
  tm_polygons() +
  tm_shape(wes) +
  tm_polygons() +
  tm_layout(
    title = "Glaciers of Western North America",
    title.position = c("center", "top"),
    title.size = 1.1,
    bg.color = "#fcfcfc",
    inner.margins = c(0.06, 0.01, 0.09, 0.01),
    outer.margins = 0,
    frame.lwd = 0.2
  ) +
  tm_compass(
    type = "arrow",
    position = c("right", "top"),
    size = 1.2,
    text.size = 0.6
  ) +
  tm_scale_bar(
    breaks = c(0, 1000, 2000),
    position = c("right", "BOTTOM")
  )
```

tmap example

```
tm_shape(ak, bbox = nwa_bbox) +  
  tm_polygons() +  
  tm_shape(wes) +  
  tm_polygons() +  
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  ) +  
  tm_compass(  
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  ) +  
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  )
```

1st layer

tmap example

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    outer.margins = 0,  
    frame.lwd = 0.2  
  ) +  
  tm_compass(  
    type = "arrow",  
    position = c("right", "top"),  
    size = 1.2,  
    text.size = 0.6  
  ) +  
  tm_scale_bar(  
    breaks = c(0, 1000, 2000),  
    position = c("right", "BOTTOM")  
  )
```

1st layer

How 1st layer data is represented

tmap example

```
tm_shape(ak, bbox = nwa_bbox) +  
  tm_polygons() +  
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    outer.margins = 0,  
    frame.lwd = 0.2  
  ) +  
  tm_compass(  
    type = "arrow",  
    position = c("right", "top"),  
    size = 1.2,  
    text.size = 0.6  
  ) +  
  tm_scale_bar(  
    breaks = c(0, 1000, 2000),  
    position = c("right", "BOTTOM")  
  )
```

1st layer

How 1st layer data is represented

2nd layer

tmap example

```
tm_shape(ak, bbox = nwa_bbox) +  
  tm_polygons() +  
  tm_shape(wes) +  
  tm_polygons() +  
  tm_layout(  
    title = "Glaciers of Western North America",  
    title.position = c("center", "top"),  
    title.size = 1.1,  
    bg.color = "#fcfcfc",  
    inner.margins = c(0.06, 0.01, 0.09, 0.01),  
    outer.margins = 0,  
    frame.lwd = 0.2  
  ) +  
  tm_compass(  
    type = "arrow",  
    position = c("right", "top"),  
    size = 1.2,  
    text.size = 0.6  
  ) +  
  tm_scale_bar(  
    breaks = c(0, 1000, 2000),  
    position = c("right", "BOTTOM")  
  )
```

1st layer

How 1st layer data is represented

2nd layer

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  tm_polygons() +  
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    title.size = 1.1,  
    bg.color = "#fcfcfc",  
    inner.margins = c(0.06, 0.01, 0.09, 0.01),  
    outer.margins = 0,  
    frame.lwd = 0.2  
  ) +  
  tm_compass(  
    type = "arrow",  
    position = c("right", "top"),  
    size = 1.2,  
    text.size = 0.6  
  ) +  
  tm_scale_bar(  
    breaks = c(0, 1000, 2000),  
    position = c("right", "BOTTOM")  
  )
```

1st layer

How 1st layer data is represented

2nd layer

How 2nd layer data is represented

Layout

tmap example

```
tm_shape(ak, bbox = nwa_bbox) +  
  tm_polygons() +  
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    title = "Glaciers of Western North America",  
    title.position = c("center", "top"),  
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    inner.margins = c(0.06, 0.01, 0.09, 0.01),  
    outer.margins = 0,  
    frame.lwd = 0.2  
  ) +  
  tm_compass(  
    type = "arrow",  
    position = c("right", "top"),  
    size = 1.2,  
    text.size = 0.6  
  ) +  
  tm_scale_bar(  
    breaks = c(0, 1000, 2000),  
    position = c("right", "BOTTOM")  
  )
```

1st layer

How 1st layer data is represented

2nd layer

How 2nd layer data is represented

Layout

Compass

tmap example

```
tm_shape(ak, bbox = nwa_bbox) +  
  tm_polygons() +  
  tm_shape(wes) +  
  tm_polygons() +  
  tm_layout(  
    title = "Glaciers of Western North America",  
    title.position = c("center", "top"),  
    title.size = 1.1,  
    bg.color = "#fcfcfc",  
    inner.margins = c(0.06, 0.01, 0.09, 0.01),  
    outer.margins = 0,  
    frame.lwd = 0.2  
  ) +  
  tm_compass(  
    type = "arrow",  
    position = c("right", "top"),  
    size = 1.2,  
    text.size = 0.6  
  ) +  
  tm_scale_bar(  
    breaks = c(0, 1000, 2000),  
    position = c("right", "BOTTOM")  
  )
```

1st layer

How 1st layer data is represented

2nd layer

How 2nd layer data is represented

Layout

Compass

Scale

ggplot2

The standard in R plots

ggplot2

Useful links

- [GitHub repo](#)
- [Resources](#)
- [Cheatsheet](#)

Data Visualization with ggplot2 :: CHEAT SHEET



Basics

ggplot2 is based on the **grammar of graphics**, the idea that you can build every graph from the same components: a **data set**, a **coordinate system**, and **geoms**—visual marks that represent data points.



To display values, map variables in the data to visual properties of the geom (**aesthetics**) like **size**, **color**, and **x** and **y** locations.



Complete the template below to build a graph.

```
ggplot (data = <DATA>) +
  <GEO FUNCTION> (mapping = aes(<MAPPINGS>),
  stat = <STAT>, position = <POSITION>) +
  <COORDINATE FUNCTION> +
  <FACET FUNCTION> +
  <SCALE FUNCTION> +
  <THEME FUNCTION>
```

required
Not required, sensible defaults supplied

ggplot(data = mpg, aes(x = cyl, y = hwy)) Begins a plot that you finish by adding layers to. Add one geom function per layer.

aesthetic mappings **data** **geom**

qplot(x = cyl, y = hwy, data = mpg, geom = "point") Creates a complete plot with given data, geom, and mappings. Supplies many useful defaults.

last_plot() Returns the last plot

ggsave("plot.png", width = 5, height = 5) Saves last plot as 5' x 5' file named "plot.png" in working directory. Matches file type to file extension.



Geoms

Use a geom function to represent data points, use the geom's aesthetic properties to represent variables. Each function returns a layer.

GRAPHICAL PRIMITIVES

```
a <- ggplot(economics, aes(date, unemploy))
b <- ggplot(seals, aes(x = long, y = lat))

a + geom_blank()
#(Useful for expanding limits)

b + geom_curve(aes(yend = lat + 1,
xend = long + 1), curvearrow = TRUE)
x, y, end, alpha, angle, color, curvature, linetype, size

a + geom_path(lineend = "butt", linejoin = "round",
linemtire = 1)
x, y, alpha, color, group, linetype, size

a + geom_polygon(aes(group = group))
x, y, alpha, color, fill, group, linetype, size

b + geom_rect(aes(xmin = long - 1, ymin = lat - 1,
xmax = long + 1, ymax = lat + 1))
x, y, alpha, color, fill, linetype, size

a + geom_ribbon(aes(ymin = unemploy - 900,
ymax = unemploy + 900))
x, y, alpha, color, fill, group, linetype, size
```

LINE SEGMENTS

common aesthetics: x, y, alpha, color, linetype, size

```
b + geom_abline(aes(intercept = 0, slope = 1))
b + geom_hline(aes(yintercept = lat))
b + geom_vline(aes(xintercept = long))

b + geom_segment(aes(yend = lat + 1, xend = long + 1))
b + geom_spoke(aes(angle = 1:1155, radius = 1))
```

ONE VARIABLE continuous

```
c <- ggplot(mpg, aes(hwy)); c2 <- ggplot(mpg)

c + geom_area(stat = "bin")
x, y, alpha, color, fill, linetype, size

c + geom_density(kernel = "gaussian")
x, y, alpha, color, fill, group, linetype, size, weight

c + geom_dotplot()
x, y, alpha, color, fill

c + geom_freqpoly()
x, y, alpha, color, group, linetype, size

c + geom_histogram(binwidth = 5)
x, y, alpha, color, fill, linetype, size, weight

c2 + geom_qq(aes(sample = hwy))
x, y, alpha, color, fill, linetype, size, weight
```

discrete

```
d <- ggplot(mpg, aes(f1))
d + geom_bar()
x, alpha, color, fill, linetype, size, weight
```

TWO VARIABLES

continuous x , continuous y

```
e <- ggplot(mpg, aes(cty, hwy))

e + geom_label(aes(label = cty, nudge_x = 1,
nudge_y = 1, check_overlap = TRUE))
x, y, label, alpha, angle, color, family, fontface, hjust,
lineheight, size, vjust

e + geom_curve(aes(yend = lat + 1,
xend = long + 1), curvearrow = TRUE)
x, y, end, alpha, angle, color, curvature, linetype, size

e + geom_hex()
x, y, alpha, colour, fill, size

e + geom_jitter(height = 2, width = 2)
x, y, alpha, color, fill, shape, size

e + geom_point(), x, y, alpha, color, fill, shape, size

e + geom_quantile(), x, y, alpha, color, group,
linetype, size, weight

e + geom_rug(sides = "bl")
x, y, alpha, color, linetype, size

e + geom_smooth(method = lm)
x, y, alpha, color, fill, group, linetype, size, weight

e + geom_text(aes(label = cty, nudge_x = 1,
nudge_y = 1, check_overlap = TRUE))
x, y, label, alpha, angle, color, family, fontface, hjust,
lineheight, size, vjust
```

discrete x , continuous y

```
f <- ggplot(mpg, aes(class, hwy))

f + geom_col()
x, y, alpha, color, fill, group, linetype, size

f + geom_boxplot()
x, y, lower, middle, upper,
ymin, ymax, alpha, color, fill, group, linetype, size, weight

f + geom_dotplot(binaxis = "y", stackdir =
"center")
x, y, alpha, color, fill, group

f + geom_violin(scale = "area")
x, y, alpha, color, fill, group, linetype, size, weight
```

discrete x , discrete y

```
g <- ggplot(diamonds, aes(cut, color))

g + geom_count()
x, y, alpha, color, fill, shape, size, stroke
```

THREE VARIABLES

```
seals$z <- with(seals, sqrt(delta_long^2 + delta_lat^2));
l <- ggplot(seals, aes(long, lat))

l + geom_contour(aes(z = z))
x, y, z, alpha, colour, group, linetype, size, weight

l + geom_raster(aes(fill = z), hjust = 0.5, vjust = 0.5,
interpolate = FALSE)
x, y, alpha, fill

l + geom_tile(aes(fill = z)), x, y, alpha, color, fill,
linetype, size, width
```

continuous bivariate distribution

```
h <- ggplot(diamonds, aes(carat, price))

h + geom_bin2d(binwidth = c(0.25, 500))
x, y, alpha, color, fill, linetype, size, weight

h + geom_density2d()
x, y, alpha, colour, group, linetype, size

h + geom_hex()
x, y, alpha, colour, fill, size
```

continuous function

```
i <- ggplot(economics, aes(date, unemploy))

i + geom_area()
x, y, alpha, color, fill, linetype, size

i + geom_line()
x, y, alpha, color, group, linetype, size

i + geom_step(direction = "hv")
x, y, alpha, color, group, linetype, size
```

visualizing error

```
df <- data.frame(grp = c("A", "B"), fit = 4:5, se = 1:2)
j <- ggplot(df, aes(grp, fit, ymin = fit - se, ymax = fit + se))

j + geom_crossbar(fatten = 2)
x, y, ymax, ymin, alpha, color, fill, group, linetype, size

j + geom_errorbar()
x, y, ymax, ymin, alpha, color, group, linetype, size, width
  also geom_errorbarh()

j + geom_linerange()
x, ymin, ymax, alpha, color, group, linetype, size

j + geom_pointrange()
x, ymin, ymax, alpha, color, fill, group, linetype, size, shape, weight
```

maps

```
data <- data.frame(murder = USArrests$Murder,
state = tolower(rownames(USArrests)))
map <- map_data("state")
k <- ggplot(data, aes(fill = murder))

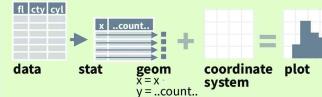
k + geom_map(aes(map_id = state), map = map)
  + expand_limits(x = map$long, y = map$lat),
map_id, alpha, color, fill, linetype, size
```



Stats

An alternative way to build a layer

A stat builds new variables to plot (e.g., count, prop).



Visualize a stat by changing the default stat of a geom function, `geom_bar(stat="count")` or by using a stat function, `stat_count(geom="bar")`, which calls a default geom to make a layer (equivalent to a geom function). Use `..name..` syntax to map stat variables to aesthetics.



```
c + stat_bin(binwidth = 1, origin = 10)
x, y | ..count.., ..ncount.., ..density.., ..ndensity..
c + stat_count(width = 1, ..count.., ..prop..)
c + stat_density(adjust = 1, kernel = "gaussian")
x, y | ..count.., ..density.., ..scaled..
e + stat_bin_2d(bins = 30, drop = T)
x, y, fill | ..count.., ..density..
e + stat_bin_hex(bins=30) x, y, fill | ..count.., ..density..
e + stat_density_2d(contour = TRUE, n = 100)
x, y, color, size | ..level..
e + stat_ellipse(level = 0.95, segments = 51, type = "t")
l + stat_contour(aes(z = z)) x, y, z, order | ..level..
l + stat_summary_hex(aes(z = z), bins = 30, fun = max)
x, y, z, fill | ..value..
l + stat_summary_2d(aes(z = z), bins = 30, fun = mean)
x, y, z, fill | ..value..
f + stat_boxplot(coef = 1.5) x, y | ..lower...
..middle..., ..upper..., ..width..., ..ymin..., ..ymax..
f + stat_ydensity(kernel = "gaussian", scale = "area") x, y |
..density.., ..scaled.., ..count.., ..n.., ..violinwidth.., ..width..
e + stat_ecdf(n = 40) x, y | ..x..., ..y...
e + stat_quantile(quantiles = c(0.1, 0.9), formula = y ~ log(x), method = "rd") x, y | ..quantile..
e + stat_smooth(method = "lm", formula = y ~ x, se=T, level=0.95) x, y | ..se..., ..x..., ..ymin..., ..ymax..
ggplot() + stat_function(aes(z = -3:3), n = 99, fun = dnorm, args = list(sd=0.5)) x | ..y...
e + stat_identity(na.rm = TRUE)
ggplot() + stat_qq(aes(sample=1:100), dist = qt, dparam=list(df=5)) sample, x, y | ..sample.., ..theoretical..
e + stat_sum() x, y, size | ..n.., ..prop..
e + stat_summary(fun.data = "mean_cl_boot")
h + stat_summary_bin(fun = "mean", geom = "bar")
e + stat_unique()
```

Scales

Scales map data values to the visual values of an aesthetic. To change a mapping, add a new scale.



GENERAL PURPOSE SCALES

Use with most aesthetics

- `scale_*_continuous()` - map cont' values to visual ones
- `scale_*_discrete()` - map discrete values to visual ones
- `scale_*_identity()` - use data values as visual ones
- `scale_*_manual(values = c(...))` - map discrete values to manually chosen visual ones
- `scale_*_date(date_labels = "%m/%d")`, `date_breaks = "2 weeks"` - treat data values as dates
- `scale_*_datetime()` - treat data x-values as date times. Use same arguments as `scale_x_date()`. See `?strptime` for label formats.

X & Y LOCATION SCALES

Use with x or y aesthetics (x shown here)

- `scale_x_log10()` - Plot x on log10 scale
- `scale_x_reverse()` - Reverse direction of x axis
- `scale_x_sqrt()` - Plot x on square root scale

COLOR AND FILL SCALES (DISCRETE)

```
n <- d + geom_bar(aes(fill = fl))
n + scale_fill_brewer(palette = "Blues")
For palette choices:
RColorBrewer::display.brewer.all()
n + scale_fill_grey(start = 0.2, end = 0.8,
na.value = "red")
```

COLOR AND FILL SCALES (CONTINUOUS)

```
o <- c + geom_dotplot(aes(fill = ..x..))
o + scale_fill_distiller(palette = "Blues")
o + scale_fill_gradient(low="red", high="yellow")
o + scale_fill_gradient2(low="red", high="blue",
mid="white", midpoint = 25)
o + scale_fill_gradient3(colours=topo.colors(6))
Also: rainbow(), heat.colors(), terrain.colors(),
cm.colors(), RColorBrewer::brewer.pal()
```

SHAPE AND SIZE SCALES

```
p <- e + geom_point(aes(shape = fl, size = cyl))
p + scale_shape() + scale_size()
p + scale_shape_manual(values = c(3:7))
p + scale_radius(range = c(1,6))
p + scale_size_area(max_size = 6)
```

Coordinate Systems

`r <- d + geom_bar()`

```
r + coord_cartesian(xlim = c(0, 5))
The default cartesian coordinate system
r + coord_fixed(ratio = 1/2)
ratio, xlim, ylim
```

```
r + coord_flip()
xlim, ylim
Flipped Cartesian coordinates
```

```
r + coord_polar(theta = "x", direction=1)
theta, start, direction
Polar coordinates
```

```
r + coord_trans(xtrans = "sqrt")
xtrans, ytrans, limx, limy
Transformed cartesian coordinates. Set xtrans and ytrans to the name of a window function.
```

```
r + coord_quickmap()
r + coord_map(projection = "ortho",
orientation=c(-41, -74, 0))projection, xlim, ylim
Map projections from the mapproj package
(mercator (default), aezequal, lagrange, etc.)
```

Position Adjustments

Position adjustments determine how to arrange geoms that would otherwise occupy the same space.

```
s <- ggplot(mpg, aes(fl, fill = drv))
s + geom_bar(position = "dodge")
Arrange elements side by side
s + geom_bar(position = "fill")
Stack elements on top of one another, normalize height
e + geom_point(position = "jitter")
Add random noise to x and y position of each element to avoid overplotting
e + geom_label(position = "nudge")
Nudge labels away from points
s + geom_bar(position = "stack")
Stack elements on top of one another
```

Each position adjustment can be recast as a function with manual `width` and `height` arguments

`s + geom_bar(position = position_dodge(width = 1))`

Themes

<code>r + theme_bw()</code> White background with grid lines	<code>r + theme_classic()</code>
<code>r + theme_gray()</code> Grey background (default theme)	<code>r + theme_light()</code>
<code>r + theme_dark()</code> dark for contrast	<code>r + theme_linedraw()</code>
<code>r + theme_minimal()</code>	<code>r + theme_void()</code> Empty theme

Faceting

Facets divide a plot into subplots based on the values of one or more discrete variables.



```
t <- ggplot(mpg, aes(cty, hwy)) + geom_point()
```

<code>t + facet_grid(cols = vars(f1))</code> facet into columns based on f1	<code>t + facet_grid(rows = vars(year))</code> facet into rows based on year
<code>t + facet_grid(rows = vars(year), cols = vars(f1))</code>	<code>t + facet_wrap(vars(f1))</code> wrap facets into a rectangular layout

Set `scales` to let axis limits vary across facets

`t + facet_grid(rows = vars(drv), cols = vars(f1),
scales = "free")`

x and y axis limits adjust to individual facets

`"free_x"` - x axis limits adjust

`"free_y"` - y axis limits adjust

Set `labeler` to adjust facet labels

<code>t + facet_grid(cols = vars(f1), labeler = label_both)</code>	<code>ft:c</code>	<code>ft:d</code>	<code>ft:e</code>	<code>ft:p</code>	<code>ft:r</code>
--	-------------------	-------------------	-------------------	-------------------	-------------------

<code>t + facet_grid(rows = vars(f1), labeler = label_bquote(alpha ^ .(f1)))</code>	<code>alpha^c</code>	<code>alpha^d</code>	<code>alpha^e</code>	<code>alpha^p</code>	<code>alpha^r</code>
---	----------------------	----------------------	----------------------	----------------------	----------------------

Labels

`t + labs(x = "New x axis label", y = "New y axis label", title = "Add a title above the plot", subtitle = "Add a subtitle below title", caption = "Add a caption below plot", AES = "New AES legend title")`

`t + annotate(geom = "text", x = 8, y = 9, label = "A")`

`geom to place` `manual values for geom's aesthetics`

Legends

`n + theme(legend.position = "bottom")`
Place legend at "bottom", "top", "left", or "right"

`n + guides(fill = "none")`
Set legend type for each aesthetic: colorbar, legend, or none (no legend)

`n + scale_fill_discrete(name = "Title", labels = c("A", "B", "C", "D", "E"))`
Set legend title and labels with a scale function.

Zooming

`Without clipping` (preferred)
`t + coord_cartesian(xlim = c(0, 100), ylim = c(10, 20))`

`With clipping` (removes unseen data points)
`t + xlim(0, 100) + ylim(10, 20)`

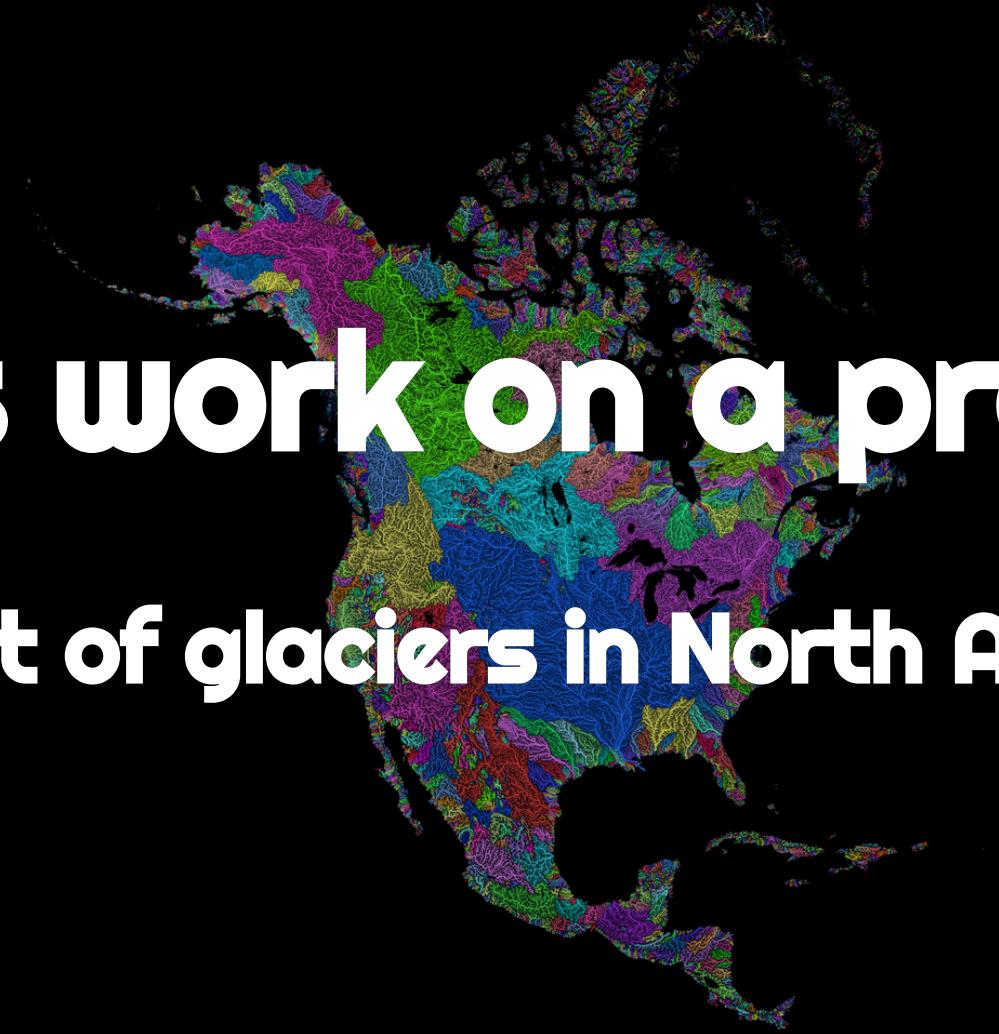
`t + scale_x_continuous(limits = c(0, 100)) + scale_y_continuous(limits = c(0, 100))`

ggplot2

`geom_sf` allows to plot `sf` objects (i.e. make maps)



Let's work on a project



Let's work on a project

Retreat of glaciers in North America

Data

For this workshop, we will use:

- the Alaska as well as the Western Canada & USA subsets of the **Randolph Glacier Inventory** version 6.0¹
- the **USGS time series of the named glaciers of Glacier National Park**²
- the Alaska as well as the Western Canada & USA subsets of the **consensus estimate for the ice thickness distribution of all glaciers on Earth dataset**³

The datasets can be downloaded as zip files from these websites

1. RGI Consortium (2017). Randolph Glacier Inventory – A Dataset of Global Glacier Outlines: Version 6.0: Technical Report, Global Land Ice Measurements from Space, Colorado, USA. Digital Media. DOI: <https://doi.org/10.7265/N5-RGI-60>.

2. Fagre, D.B., McKeon, L.A., Dick, K.A. & Fountain, A.G., 2017, Glacier margin time series (1966, 1998, 2005, 2015) of the named glaciers of Glacier National Park, MT, USA: U.S. Geological Survey data release. DOI: <https://doi.org/10.5066/F7P26WB1>.

3. Farinotti, Daniel, 2019, A consensus estimate for the ice thickness distribution of all glaciers on Earth - dataset, Zurich. ETH Zurich. DOI: <https://doi.org/10.3929/ethz-b-000315707>.

Packages

Packages need to be installed before they can be loaded in a session

Packages on CRAN can be installed with:

```
install.packages("<package-name>")
```

basemaps is not on CRAN & needs to be installed from GitHub thanks to devtools:

```
install.packages("devtools")
devtools::install_github("16EAGLE/basemaps")
```

Packages

We load all the packages that we will need at the top of the script:

```
library(sf)                      # spatial vector data manipulation
library(tmap)                     # map production & tiled web map
library(dplyr)                    # non GIS specific (tabular data manipulation)
library(magrittr)                 # non GIS specific (pipes)
library(purrr)                    # non GIS specific (functional programming)
library(rnaturalearth)            # basemap data access functions
library(rnaturalearthdata)         # basemap data
library(mapview)                  # tiled web map
library(grid)                     # (part of base R) used to create inset map
library(ggplot2)                  # alternative to tmap for map production
```



Reading & preparing data

Randolph Glacier Inventory

This dataset contains the contour of all glaciers on Earth

We will focus on glaciers in Western North America

You can download & unzip 02_rgi60_WesternCanadaUS & 01_rgi60_Alaska
from the **Randolph Glacier Inventory** version 6.0

Reading in data

Data get imported & turned into `sf` objects with the function `sf::st_read`:

```
ak <- st_read("data/01_rgi60_Alaska")
```

Make sure to use the absolute paths or the paths relative to your working directory (which can be obtained with `getwd`)

Reading in data

```
ak <- st_read("data/01_rgi60_Alaska")
```

> Output

```
Reading layer `01_rgi60_Alaska' from data source `./data/01_rgi60_Alaska'
      using driver `ESRI Shapefile'

Simple feature collection with 27108 features and 22 fields
Geometry type: POLYGON
Dimension:     XY
Bounding box:  xmin: -176.1425 ymin: 52.05727 xmax: -126.8545 ymax: 69.35167
Geodetic CRS:  WGS 84
```

Reading in data

Your turn:

Read in the data for the rest of north western America (from
02_rgi60_WesternCanadaUS) and create an sf object called wes

First look at the data

ak

> Output

Simple feature collection with 27108 features and 22 fields

Geometry type: POLYGON

Dimension: XY

Bounding box: xmin: -176.1425 ymin: 52.05727 xmax: -126.8545 ymax: 69.35167

Geodetic CRS: WGS 84

First 10 features:

	RGIId	GLIMSID	BgnDate	EndDate	CenLon	CenLat	O1Region
1	RGI60-01.00001	G213177E63689N	20090703	-99999999	-146.8230	63.68900	1
2	RGI60-01.00002	G213332E63404N	20090703	-99999999	-146.6680	63.40400	1
3	RGI60-01.00003	G213920E63376N	20090703	-99999999	-146.0800	63.37600	1

Structure of the data

```
str(ak)
```

> Output

```
Classes 'sf' and 'data.frame': 27108 obs. of 23 variables:  
 $ RGIId    : chr  "RGI60-01.00001" "RGI60-01.00002" "RGI60-01.00003" ...  
 $ GLIMSIId : chr  "G213177E63689N" "G213332E63404N" "G213920E63376N" ...  
 $ BgnDate   : chr  "20090703" "20090703" "20090703" "20090703" ...  
 $ EndDate   : chr  "-9999999" "-9999999" "-9999999" "-9999999" ...  
 $ CenLon    : num  -147 -147 -146 -146 -147 ...  
 $ CenLat    : num  63.7 63.4 63.4 63.4 63.6 ...  
 $ O1Region  : chr  "1" "1" "1" "1" ...  
 $ O2Region  : chr  "2" "2" "2" "2" ...  
 $ Area      : num  0.36 0.558 1.685 3.681 2.573 ...
```

Inspect your data

Your turn:

Inspect the `wes` object you created

Glacier National Park

This dataset contains a time series of the retreat of 39 glaciers of Glacier National Park, MT, USA
for the years 1966, 1998, 2005 & 2015

You can download and unzip the 4 sets of files from the [USGS website](#)

Read in and clean datasets

```
## create a function that reads and cleans the data
prep <- function(dir) {
  g <- st_read(dir)
  g %>% rename_with(~ tolower(gsub("Area....", "area", .x)))
  g %>% dplyr::select(
    year,
    objectid,
    glacname,
    area,
    shape_leng,
```

| We use `dplyr::select` because `terra` also has a `select` function

Combine datasets into one sf object

Check that the CRS are all the same:

```
all(sapply(  
  list(st_crs(gnp[[1]]),  
       st_crs(gnp[[2]]),  
       st_crs(gnp[[3]]),  
       st_crs(gnp[[4]])),  
  function(x) x == st_crs(gnp[[1]]))  
)
```

> Output

```
[1] TRUE
```

Combine datasets into one sf object

We can `rbind` the elements of our list:

```
gnp <- do.call("rbind", gnp)
```

You can inspect your new sf object by calling it or with `str`

Estimate for ice thickness

This dataset contains an estimate for the ice thickness of all glaciers on Earth

The nomenclature follows the Randolph Glacier Inventory

Ice thickness being a spatial field, this is raster data

We will use data in `RGI60-02.16664_thickness.tif` from the [ETH Zürich Research Collection](#)
which corresponds to one of the glaciers (Agassiz) of Glacier National Park

Load raster data

Read in data and create a SpatRaster object:

```
ras <- rast("data/RGI60-02/RGI60-02.16664_thickness.tif")
```

Inspect our SpatRaster object

```
ras
```

> Output

```
class      : SpatRaster
dimensions : 93, 74, 1 (nrow, ncol, nlyr)
resolution : 25, 25 (x, y)
extent     : 707362.5, 709212.5, 5422962, 5425288 (xmin, xmax, ymin, ymax)
coord. ref. : +proj=utm +zone=11 +datum=WGS84 +units=m +no_defs
source     : RGI60-02.16664_thickness.tif
name       : RGI60-02.16664_thickness
```

`nlyr` gives us the number of bands (a single one here). You can also run `str(ras)`

Our data

We now have 3 sf objects & 1 SpatRaster object:

- `ak`: contour of glaciers in AK
- `wes`: contour of glaciers in the rest of Western North America
- `gnp`: time series of 39 glaciers in Glacier National Park, MT, USA
- `ras`: ice thickness of the Agassiz Glacier from Glacier National Park



making maps

Let's map our sf object ak

At a bare minimum, we need `tm_shape` with the data & some info as to how to represent that data:

```
tm_shape(ak) +  
  tm_polygons()
```

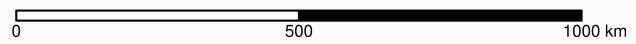


We need to label & customize it

```
tm_shape(ak) +  
  tm_polygons() +  
  tm_layout(  
    title = "Glaciers of Alaska",  
    title.position = c("center", "top"),  
    title.size = 1.1,  
    bg.color = "#fcfcfc",  
    inner.margins = c(0.06, 0.01, 0.09, 0.01),  
    outer.margins = 0,  
    frame.lwd = 0.2
```

Glaciers of Alaska

N



0 500 1000 km

A horizontal scale bar located at the bottom right of the map. It features a white rectangular area with black numbers '0', '500', and '1000 km' at its ends. A thin black line extends horizontally from the center of the rectangle.

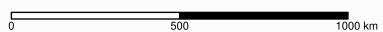
Make a map of the `wes` object

Your turn:

Make a map with the `wes` object you created with the data for Western North America excluding AK

Glaciers of Western North America excluding AK

N



Now, let's make a map with ak & wes

The Coordinate Reference Systems (CRS) must be the same

sf has a function to retrieve the CRS of an sf object: `st_crs`

```
st_crs(ak) == st_crs(wes)
```

> Output

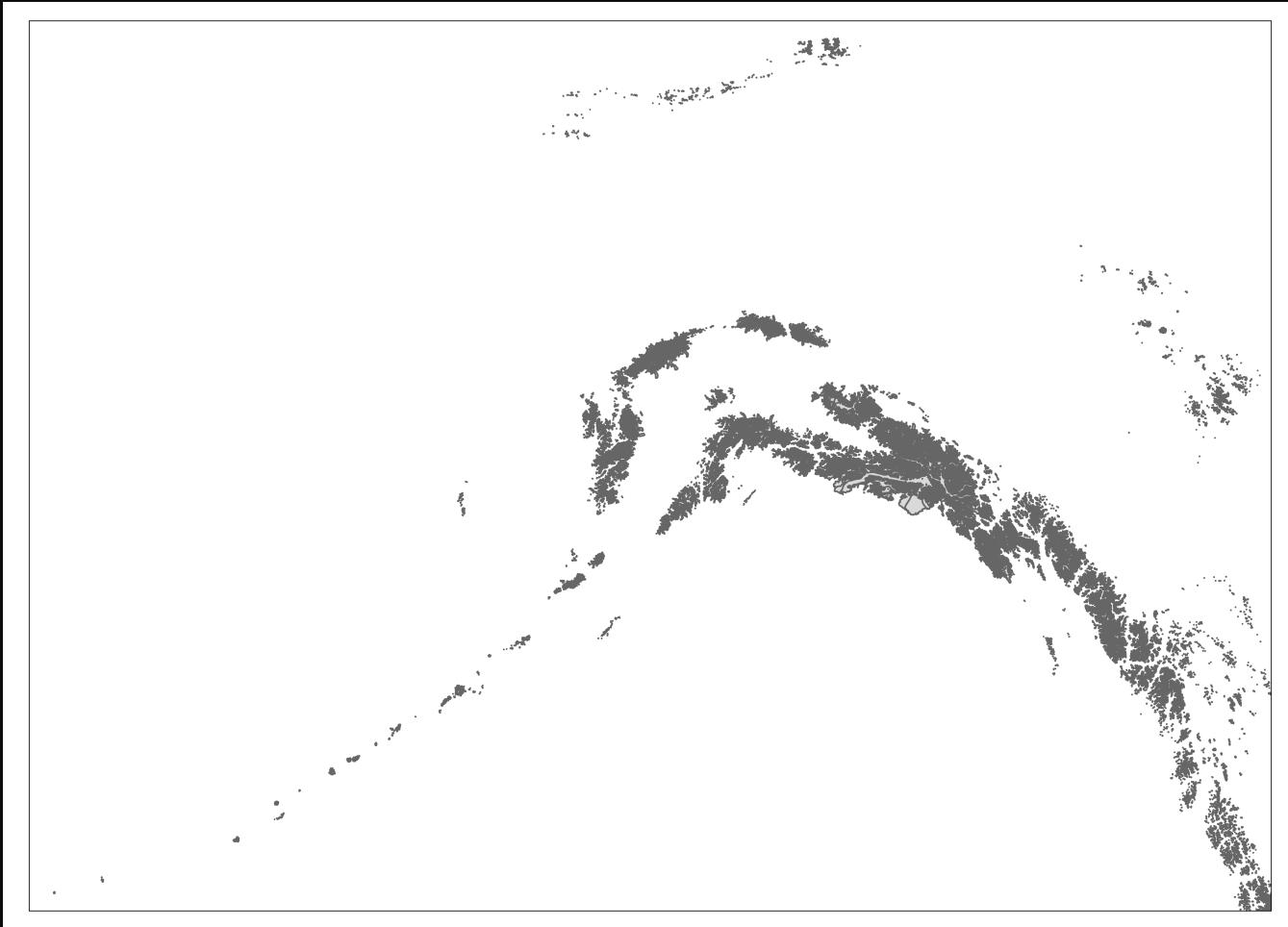
```
[1] TRUE
```

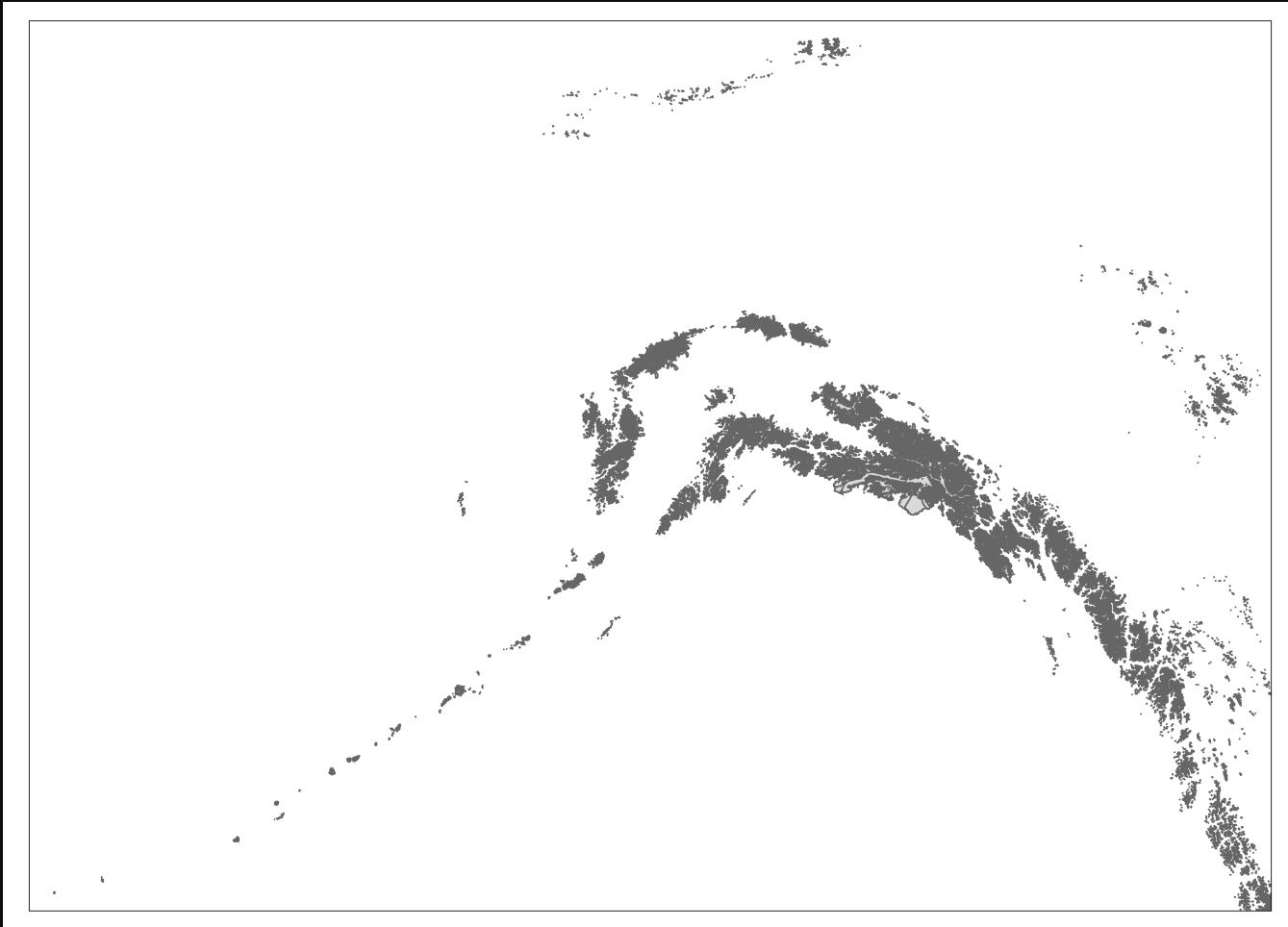
So we're good (we will see later what to do if this is not the case)

Our combined map

Let's start again with a minimum map without any layout to test things out:

```
tm_shape(ak) +  
  tm_polygons() +  
  tm_shape(wes) +  
  tm_polygons()
```





Uh ... oh ...

What went wrong?

Maps are bound by “bounding boxes”. In tmap, they are called `bbox`

tmap sets the bbox the first time `tm_shape` is called. In our case, the bbox was thus set to the bbox of the ak object

We need to create a new bbox for our new map

Retrieving bounding boxes

sf has a function to retrieve the bbox of an sf object: `st_bbox`

The bbox of ak is:

```
st_bbox(ak)
```

> Output

xmin	ymin	xmax	ymax
-176.14247	52.05727	-126.85450	69.35167

Combining bounding boxes

bbox objects can't be combined directly

Here is how we can create a new bbox encompassing both of our bboxes:

- First, we transform our bboxes to sfc objects with `st_as_sfc`
- Then we combine those objects into a new sfc object with `st_union`
- Finally, we retrieve the bbox of that object with `st_bbox`:

```
nwa_bbox <- st_bbox(  
  st_union(  
    st_as_sfc(st_bbox(wes)),  
    st_as_sfc(st_bbox(ak))  
  )  
)
```

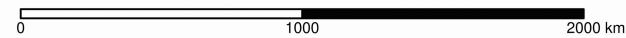
Back to our map

We can now use our new bounding box for the map of Western North America:

```
tm_shape(ak, bbox = nwa_bbox) +  
  tm_polygons() +  
  tm_shape(wes) +  
  tm_polygons() +  
  tm_layout(  
    title = "Glaciers of Western North America",  
    title.position = c("center", "top"),  
    title.size = 1.1,  
    bg.color = "#fcfcfc",  
    inner.margins = c(0.06, 0.01, 0.09, 0.01),
```

Glaciers of Western North America

N



Let's add a basemap

We will use data from [Natural Earth](#), a public domain map dataset

There are much more fancy options, but they usually involve creating accounts (e.g. with Google) to access some API

In addition, this dataset can be accessed directly from within R thanks to the [rOpenSci](#) packages:

- `rnatgeotools`: provides the functions
- `rnatgeodata`: provides the data

Create an sf object with states/provinces

```
states_all <- ne_states(  
  country = c("canada", "united states of america"),  
  returnclass = "sf"  
)
```

| ne_ stands for "Natural Earth"

Select relevant states/provinces

```
states <- states_all %>%  
  filter(name_en == "Alaska" |  
         name_en == "British Columbia" |  
         name_en == "Yukon" |  
         name_en == "Northwest Territories" |  
         name_en == "Alberta" |  
         name_en == "California" |  
         name_en == "Washington" |  
         name_en == "Oregon" |  
         name_en == "Idaho" |
```

Add the basemap to our map

| What do we need to make sure of first?

```
st_crs(states) == st_crs(ak)
```

> Output

```
[1] TRUE
```

Add the basemap to our map

We add the basemap as a 3rd layer

Mind the order! If you put the basemap last, it will cover your data

Of course, we will use our `nwa_bbox` bounding box again

We will also break `tm_polygons` into `tm_borders` and `tm_fill` for ak and wes in order to colourise them with slightly different colours

Add the basemap to our map

```
tm_shape(states, bbox = nwa_bbox) +
  tm_polygons(col = "#f2f2f2", lwd = 0.2) +
  tm_shape(ak) +
  tm_borders(col = "#3399ff") +
  tm_fill(col = "#86baff") +
  tm_shape(wes) +
  tm_borders(col = "#3399ff") +
  tm_fill(col = "#86baff") +
  tm_layout(
    title = "Glaciers of Western North America",
```



tmap styles

tmap has a number of styles that you can try

For instance, to set the style to “classic”, run the following before making your map:

```
tmap_style("classic")
```

Other options are:

“white” (default), “gray”, “natural”, “cobalt”, “col_blind”, “albatross”, “beaver”, “bw”,
“watercolor”



tmap styles

To return to the default, you need to run

```
tmap_style("white")
```

or

```
tmap_options_reset()
```

which will reset every **tmap** option

Inset maps

Now, how can we combine this with our `gnp` object?

We could add it as an inset of our Western North America map

First, let's map it

Let's use the same `tm_borders` and `tm_fill` we just used:

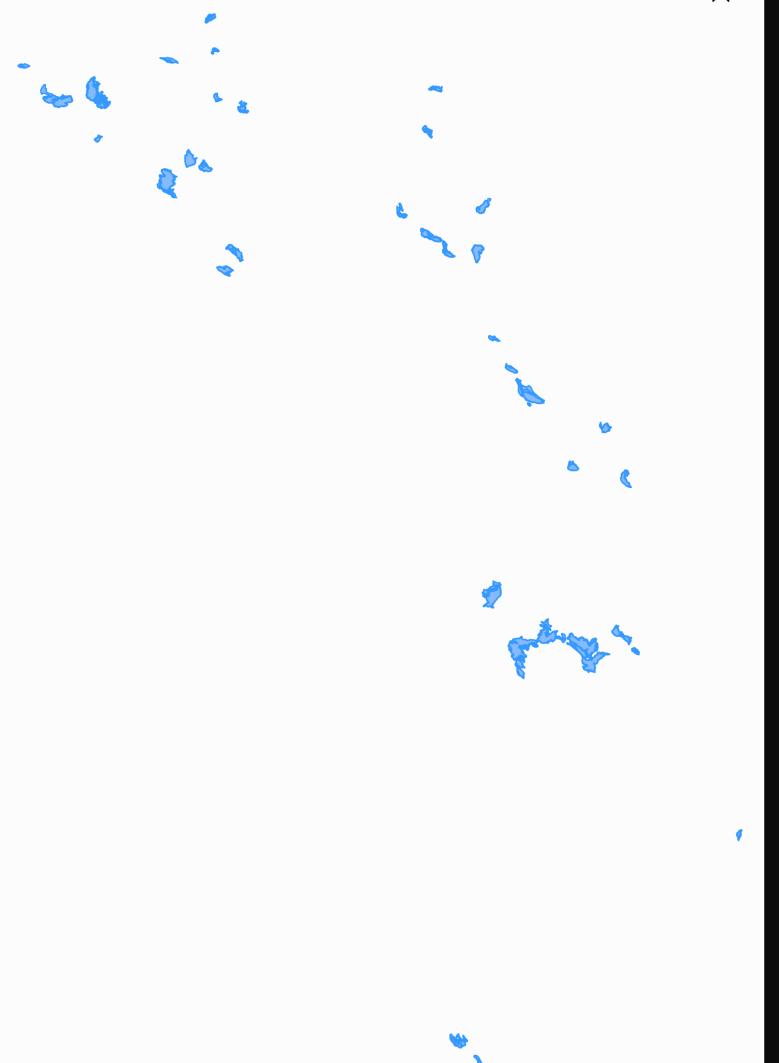
```
tm_shape(gnp) +  
  tm_borders(col = "#3399ff") +  
  tm_fill(col = "#86baff") +  
  tm_layout(  
    title = "Glaciers of Glacier National Park",  
    title.position = c("center", "top"),  
    legend.title.color = "#fcfcfc",  
    legend.text.size = 1,  
    bg.color = "#fcfcfc",  
    inner.margins = c(0.07, 0.03, 0.07, 0.03),
```

Glaciers of Glacier National Park

N



0 10 20 km



Create an inset map

As always, first we check that the CRS are the same:

```
st_crs(gnp) == st_crs(ak)
```

> Output

```
[1] FALSE
```

Create an inset map

As always, first we check that the CRS are the same:

```
st_crs(gnp) == st_crs(ak)
```

> Output

```
[1] FALSE
```

AH!

CRS transformation

We need to reproject `gnp` into the CRS of our other sf objects (e.g. `ak`):

```
gnp <- st_transform(gnp, st_crs(ak))
```

We can verify that the CRS are now the same:

```
st_crs(gnp) == st_crs(ak)
```

> Output

```
[1] TRUE
```

Inset maps

First step:

Add a rectangle showing the location of the GNP map in the main North America map

We need to create a new sfc object from the `gnp` bbox so that we can add it to our previous map as a new layer:

```
gnp_zone <- st_bbox(gnp) %>%  
  st_as_sfc()
```

Inset maps

Second step:

Create a tmap object of the main map

Of course, we need to edit the title. Also, note the presence of our new layer:

```
main_map <- tm_shape(states, bbox = nwa_bbox) +  
  tm_polygons(col = "#f2f2f2", lwd = 0.2) +  
  tm_shape(ak) +  
  tm_borders(col = "#3399ff") +  
  tm_fill(col = "#86baff") +  
  tm_shape(wes) +  
  tm_borders(col = "#3399ff") +  
  tm_fill(col = "#86baff") +  
  tm_shape(gnp_zone) +  
  tm_borders(lwd = 1.5, col = "#ff9900") +
```

Inset maps

Third step:

Create a tmap object of the inset map

We make sure to matching colours & edit the layouts for better readability:

```
inset_map <- tm_shape(gnp) +  
  tm_borders(col = "#3399ff") +  
  tm_fill(col = "#86baff") +  
  tm_layout(  
    legend.show = F,  
    bg.color = "#fcfcfc",  
    inner.margins = c(0.03, 0.03, 0.03, 0.03),  
    outer.margins = 0,  
    frame = "#ff9900",  
    frame.lwd = 3
```

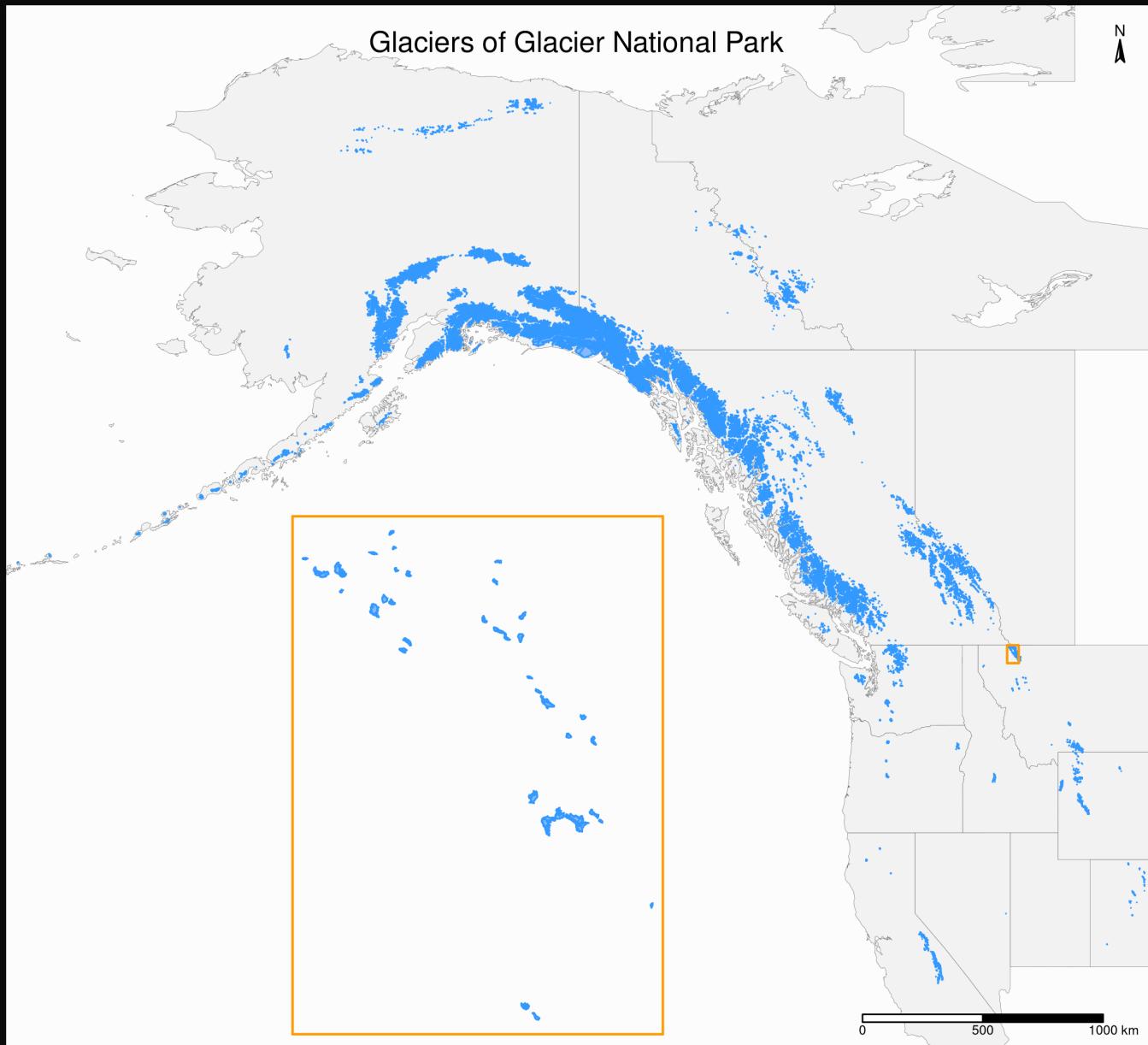
Inset maps

Final step:

Combine the two tmap objects

We print the main map & add the inset map with `grid::viewport`:

```
main_map  
print(inset_map, vp = viewport(0.41, 0.26, width = 0.5, height = 0.5))
```



Mapping a subset of the data

Mapping a subset of the data

To see the retreat of the ice, we need to zoom in

Let's focus on a single glacier: Agassiz Glacier

Map of the Agassiz Glacier

Select the data points corresponding to the Agassiz Glacier:

```
ag <- gnp %>% filter(glacname == "Agassiz Glacier")
```

Map of the Agassiz Glacier

```
tm_shape(ag) +
  tm_polygons() +
  tm_layout(
    title = "Agassiz Glacier",
    title.position = c("center", "top"),
    legend.position = c("left", "bottom"),
    legend.title.color = "#fcfcfc",
    legend.text.size = 1,
    bg.color = "#fcfcfc",
    inner.margins = c(0.07, 0.03, 0.07, 0.03),
```

Agassiz Glacier

N



0.0 0.5 1.0 km

Agassiz Glacier

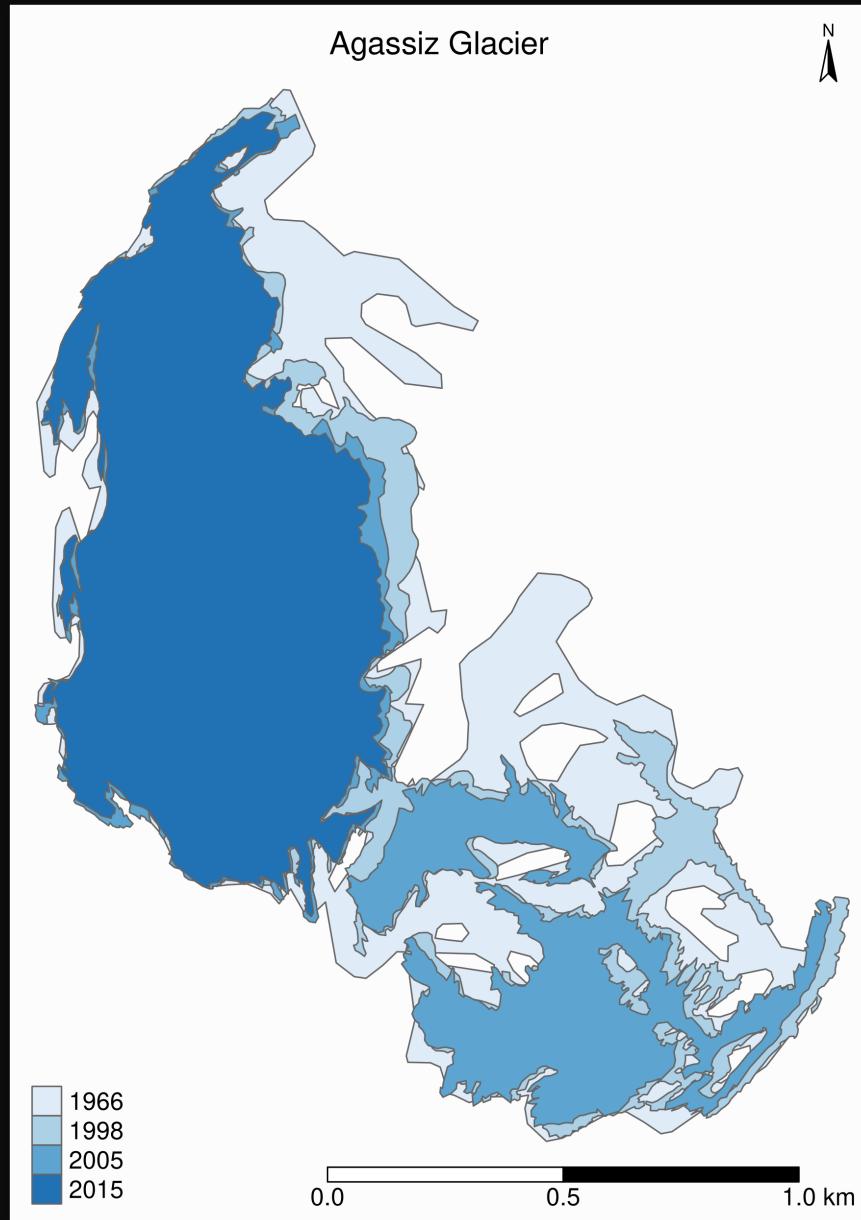
N



Not great ...

Map based on attribute variables

```
tm_shape(ag) +
  tm_polygons("year", palette = "Blues") +
  tm_layout(
    title = "Agassiz Glacier",
    title.position = c("center", "top"),
    legend.position = c("left", "bottom"),
    legend.title.color = "#fcfcfc",
    legend.text.size = 1,
    bg.color = "#fcfcfc",
    inner.margins = c(0.07, 0.03, 0.07, 0.03),
```



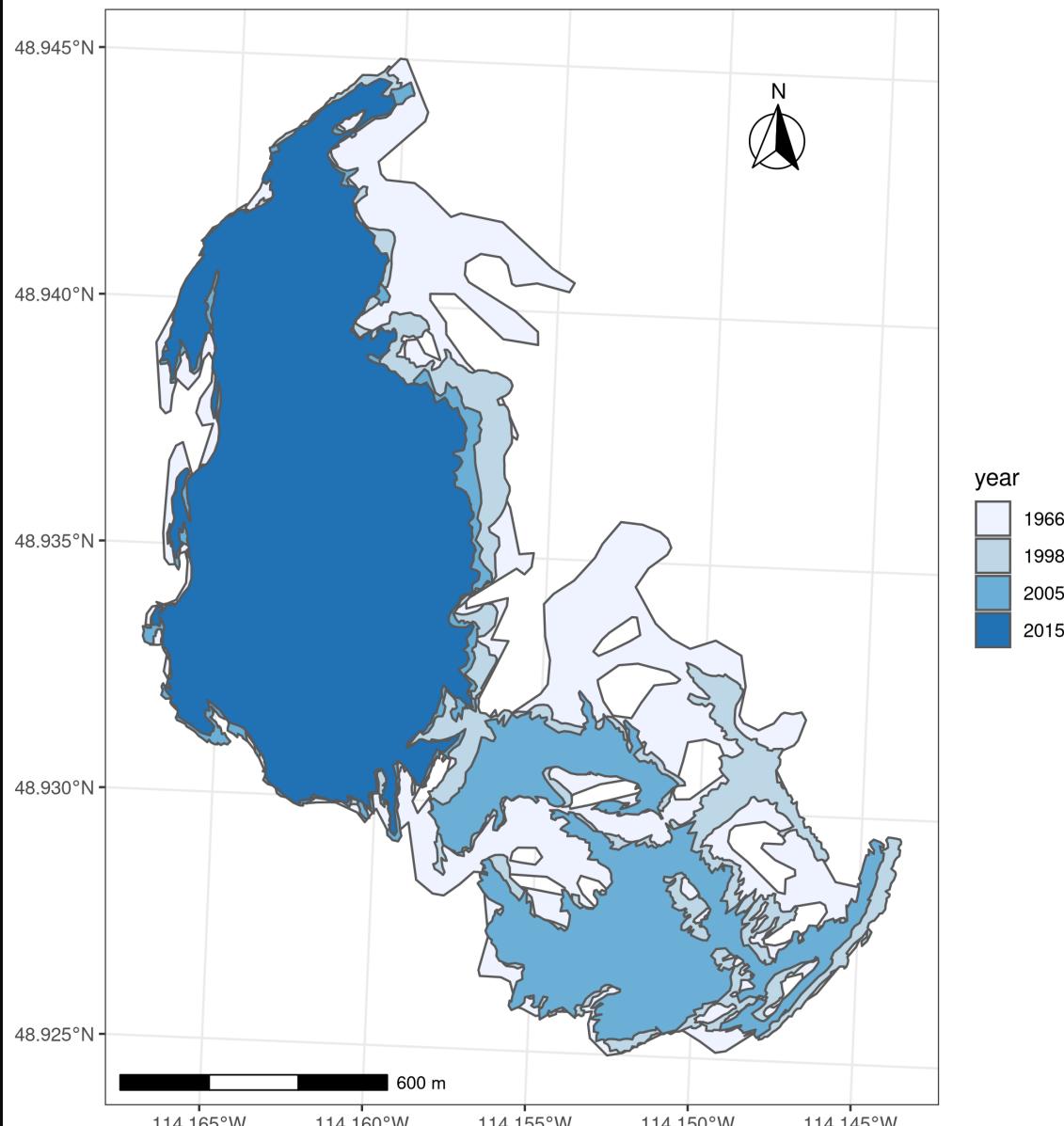
Using **ggplot2** instead of **tmap**

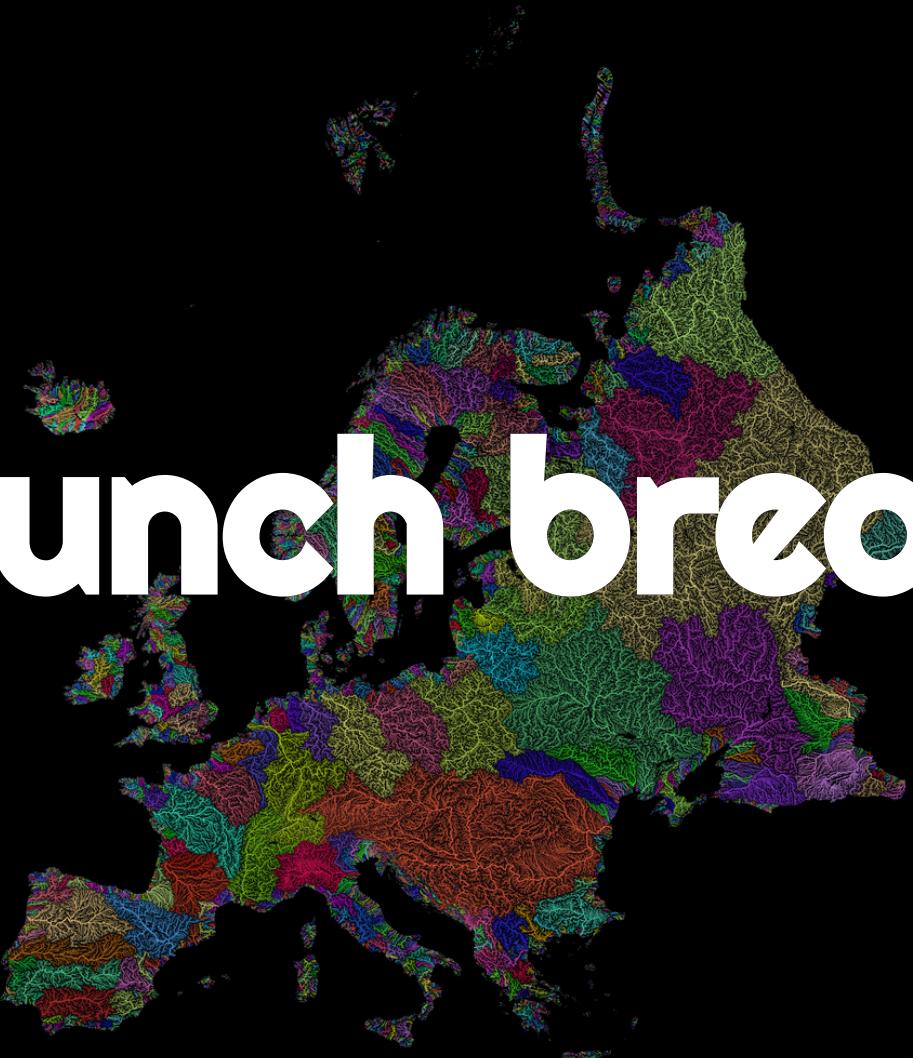
As an alternative to **tmap**, **ggplot2** can plot maps with the `geom_sf` function:

```
ggplot(ag) +  
  geom_sf(aes(fill = year)) +  
  scale_fill_brewer(palette = "Blues") +  
  labs(title = "Agassiz Glacier") +  
  annotation_scale(location = "bl", width_hint = 0.4) +  
  annotation_north_arrow(location = "tr", which_north = "true",  
    pad_x = unit(0.75, "in"), pad_y = unit(0.5, "in"),  
    style = north_arrow_fancy_orienteering) +  
  theme_bw() +  
  theme(plot.title = element_text(hjust = 0.5))
```

The package **ggspatial** adds a lot of functionality to **ggplot2** for spatial data

Agassiz Glacier





Lunch break

Faceted maps

Faceted map of the retreat of Agassiz

```
tm_shape(ag) +
  tm_polygons(col = "#86baff") +
  tm_layout(
    main.title = "Agassiz Glacier",
    main.title.position = c("center", "top"),
    main.title.size = 1.2,
    legend.position = c("left", "bottom"),
    legend.title.color = "#fcfcfc",
    legend.text.size = 1,
    bg.color = "#fcfcfc",
```

Agassiz Glacier

1966

1998

2005

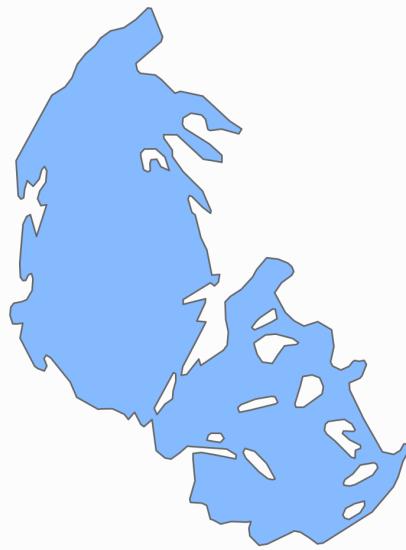
2015

N

N

N

N



0.0 0.5 1.0 km



0.0 0.5 1.0 km



0.0 0.5 1.0 km



0.0 0.5 1.0 km

Animated maps

Animated map of the Retreat of Agassiz

First, we need to create a tmap object with facets:

```
agassiz_anim <- tm_shape(ag) +  
  tm_polygons(col = "#86baff") +  
  tm_layout(  
    title = "Agassiz Glacier",  
    title.position = c("center", "top"),  
    legend.position = c("left", "bottom"),  
    legend.title.color = "#fcfcfc",  
    legend.text.size = 1,  
    bg.color = "#fcfcfc",  
    inner.margins = c(0.08, 0, 0.08, 0),
```

Animated map of the Retreat of Agassiz

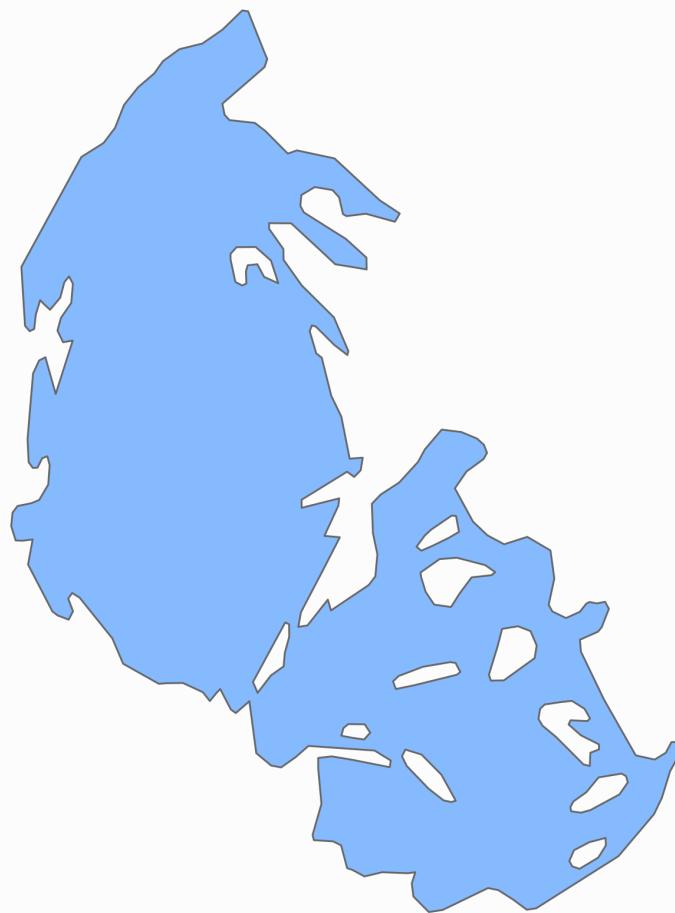
Then we can pass that object to `tmap_animation`:

```
tmap_animation(  
  agassiz_anim,  
  filename = "ag.gif",  
  dpi = 300,  
  inner.margins = c(0.08, 0, 0.08, 0),  
  delay = 100  
)
```

1966

Agassiz Glacier

N



0.0 0.5 1.0 km

Map of ice thickness of Agassiz

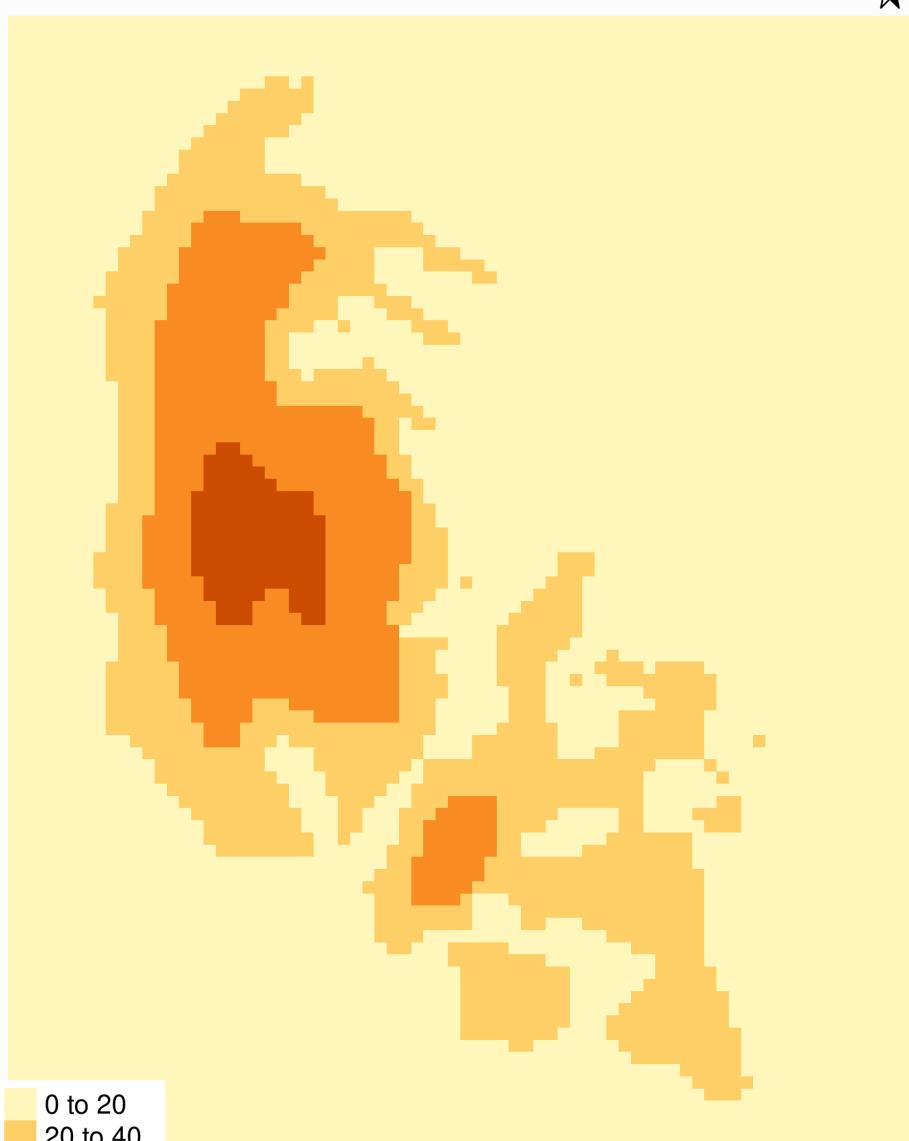
Now, let's map the estimated ice thickness on Agassiz Glacier

This time, we use `tm_raster`:

```
tm_shape(ras) +
  tm_raster(title = "") +
  tm_layout(
    title = "Ice thickness (m) of Agassiz Glacier",
    title.position = c("center", "top"),
    legend.position = c("left", "bottom"),
    legend.bg.color = "#ffffff",
    legend.text.size = 1,
    bg.color = "#fcfcfc",
    inner.margins = c(0.07, 0.03, 0.07, 0.03),
```

Ice thickness (m) of Agassiz Glacier

N



0 to 20
20 to 40
40 to 60
60 to 80

0.0 0.5 1.0 km

Combining with Randolph data

As always, we check whether the CRS are the same:

```
st_crs(ag) == st_crs(ras)
```

> Output

```
[1] FALSE
```

We need to reproject ag (remember that it is best to avoid reprojecting raster data):

```
ag %<>% st_transform(st_crs(ras))
```

Combining with Randolph data

The retreat & ice thickness layers will hide each other (the order matters!)

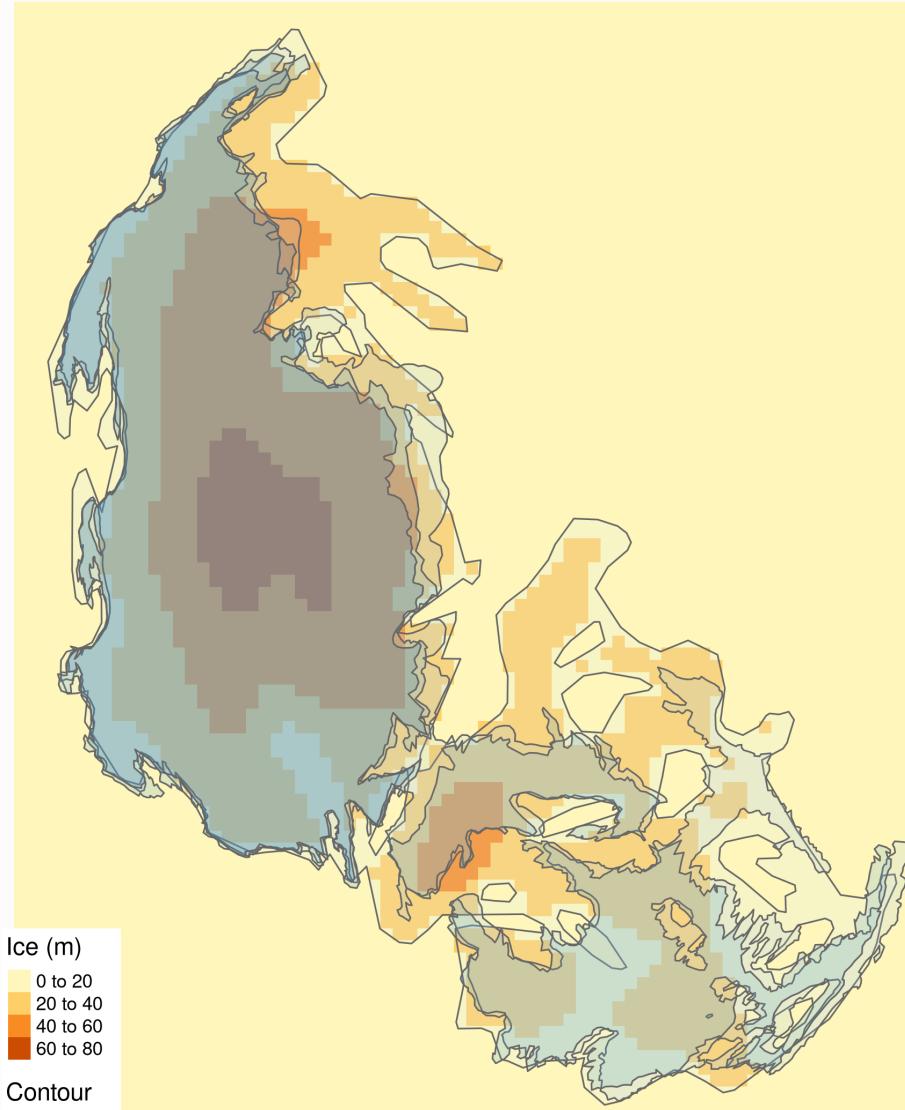
One option is to use `tm_borders` for one of them, but we can also use transparency (alpha)

We also adjust the legend:

```
tm_shape(ras) +
  tm_raster(title = "Ice (m)") +
  tm_shape(ag) +
  tm_polygons("year", palette = "Blues", alpha = 0.2, title = "Contour") +
  tm_layout(
    title = "Ice thickness (m) and retreat of Agassiz Glacier",
    title.position = c("center", "top"),
    legend.position = c("left", "bottom"),
    legend.bg.color = "#ffffff",
    legend.text.size = 0.7,
```

Ice thickness (m) and retreat of Agassiz Glacier

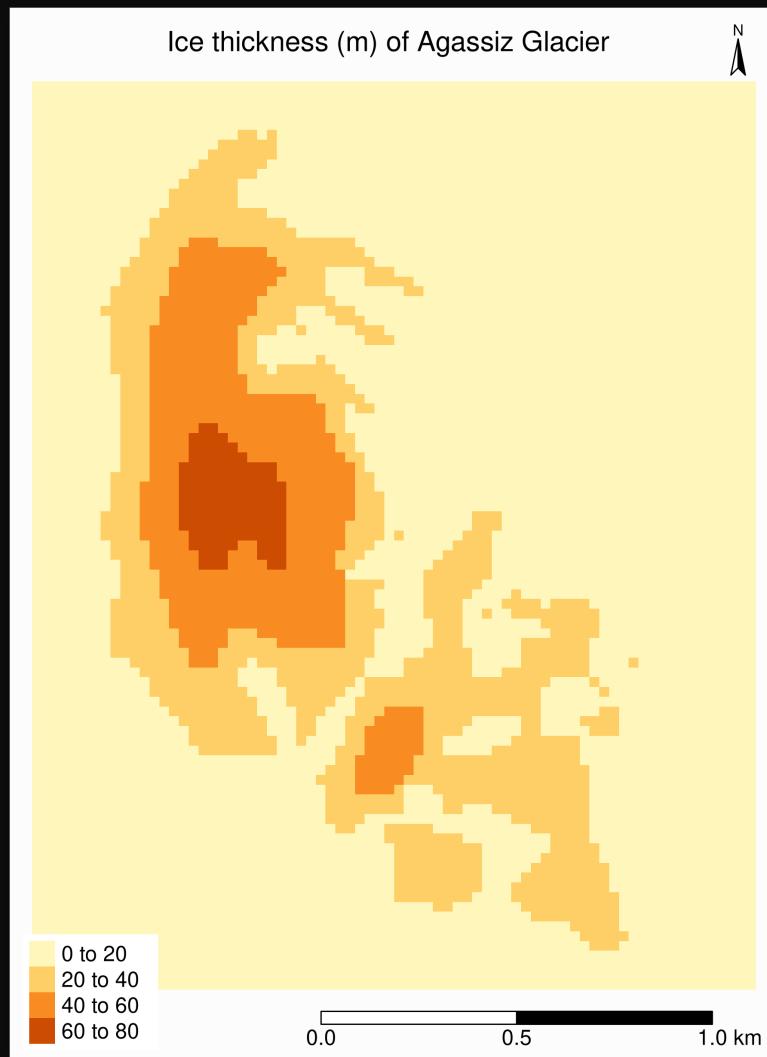
N



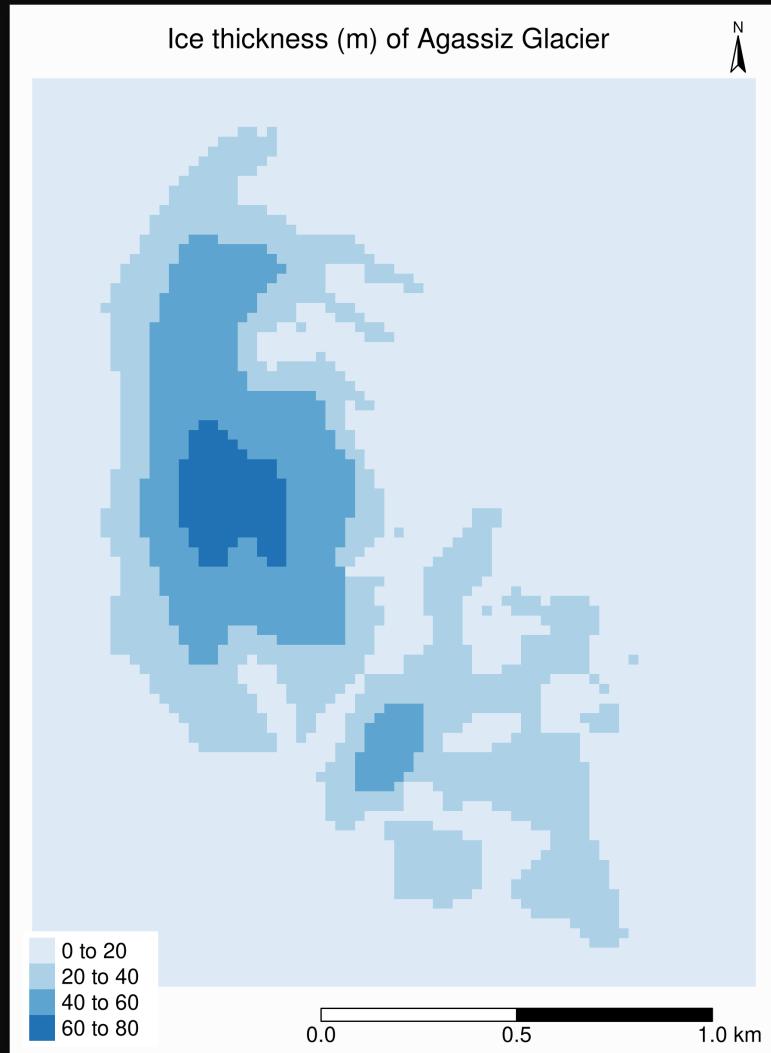
0.0 0.5 1.0 km

Refining raster maps

Let's go back to our ice thickness map:



We can change the palette to blue with `tm_raster(palette = "Blues")`:



We can create a more suitable interval scale:

First, let's see what the maximum value is:

```
global(ras, "max")
```

> Output

```
max
```

```
RGI60-02.16664_thickness 70.10873
```

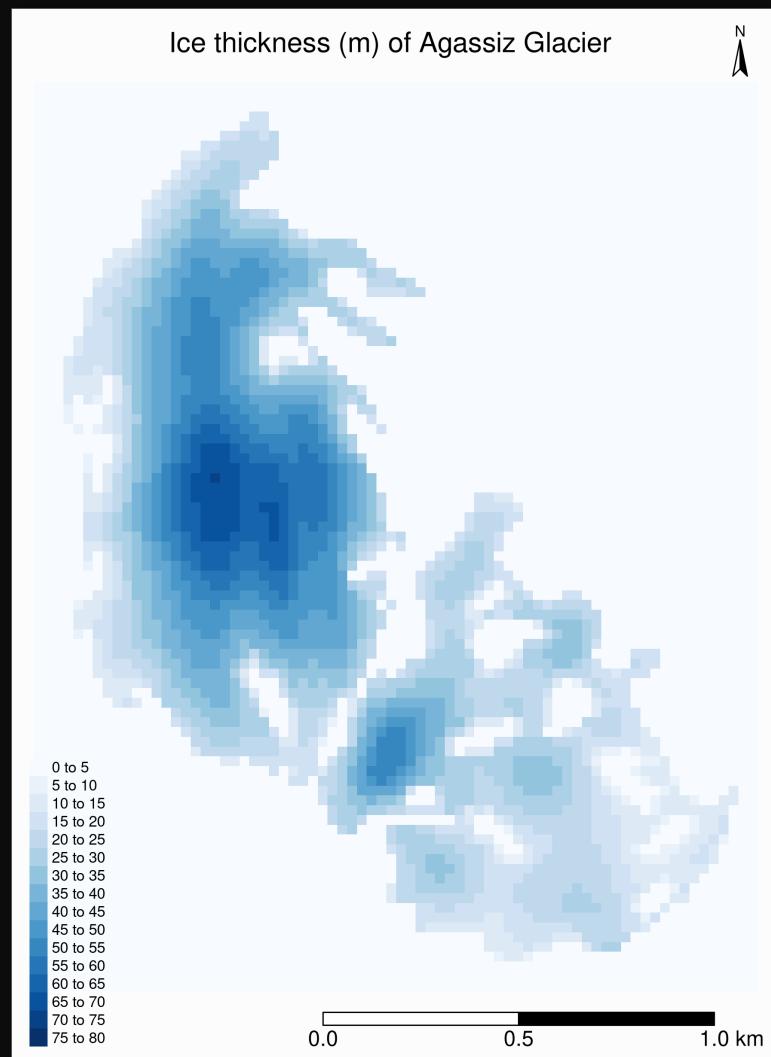
Then we can set the breaks with `tm_raster(breaks = seq(0, 80, 5))`

We can create a more suitable interval scale:

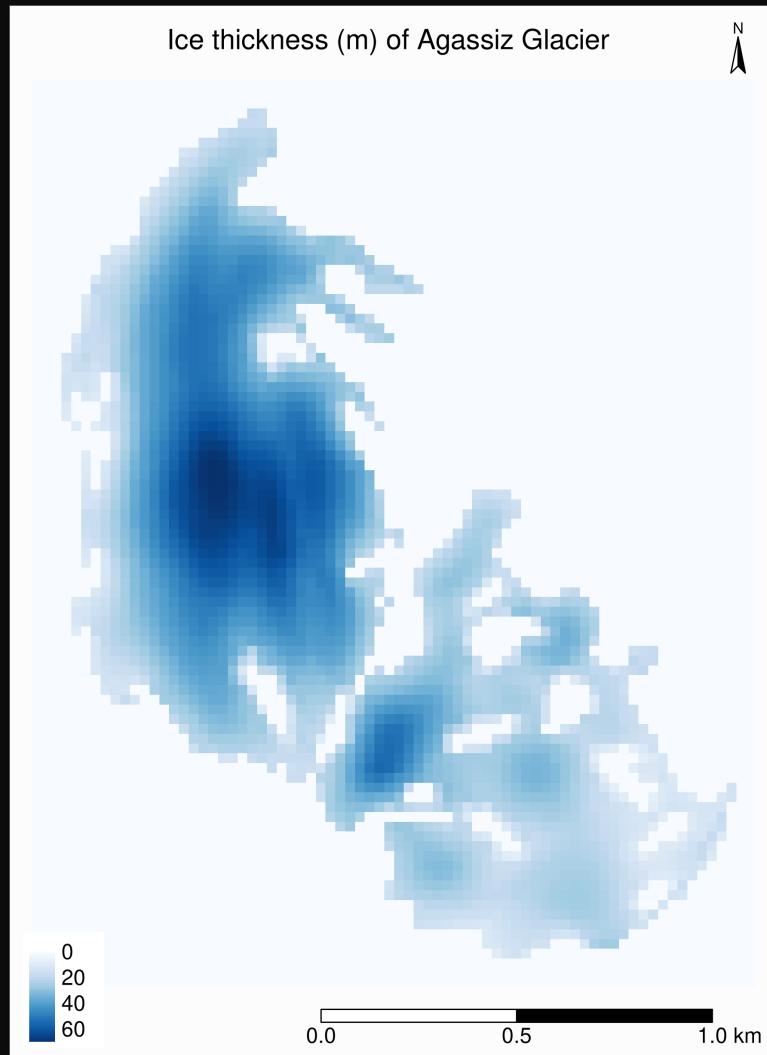
We also need to tweak the layout, legend, etc.:

```
tm_shape(ras) +  
  tm_raster(title = "", palette = "Blues", breaks = seq(0, 80, 5)) +  
  tm_layout(  
    title = "Ice thickness (m) of Agassiz Glacier",  
    title.position = c("center", "top"),  
    legend.position = c("left", "bottom"),  
    legend.bg.color = "#ffffff",  
    legend.text.size = 0.7,  
    bg.color = "#fcfcfc",  
    inner.margins = c(0.07, 0.03, 0.07, 0.03),
```

We can create a more suitable interval scale:



Or we can use a continuous colour scheme with `tm_raster(style = "cont")`:



Other ways to add a basemap

Basemap with ggmap

```
basemap <- get_map(  
  bbox = c(  
    left = st_bbox(ag)[1],  
    bottom = st_bbox(ag)[2],  
    right = st_bbox(ag)[3],  
    top = st_bbox(ag)[4]  
,  
  source = "osm"  
)
```

ggmap is a powerful package, but Google now requires an API key obtained through registration

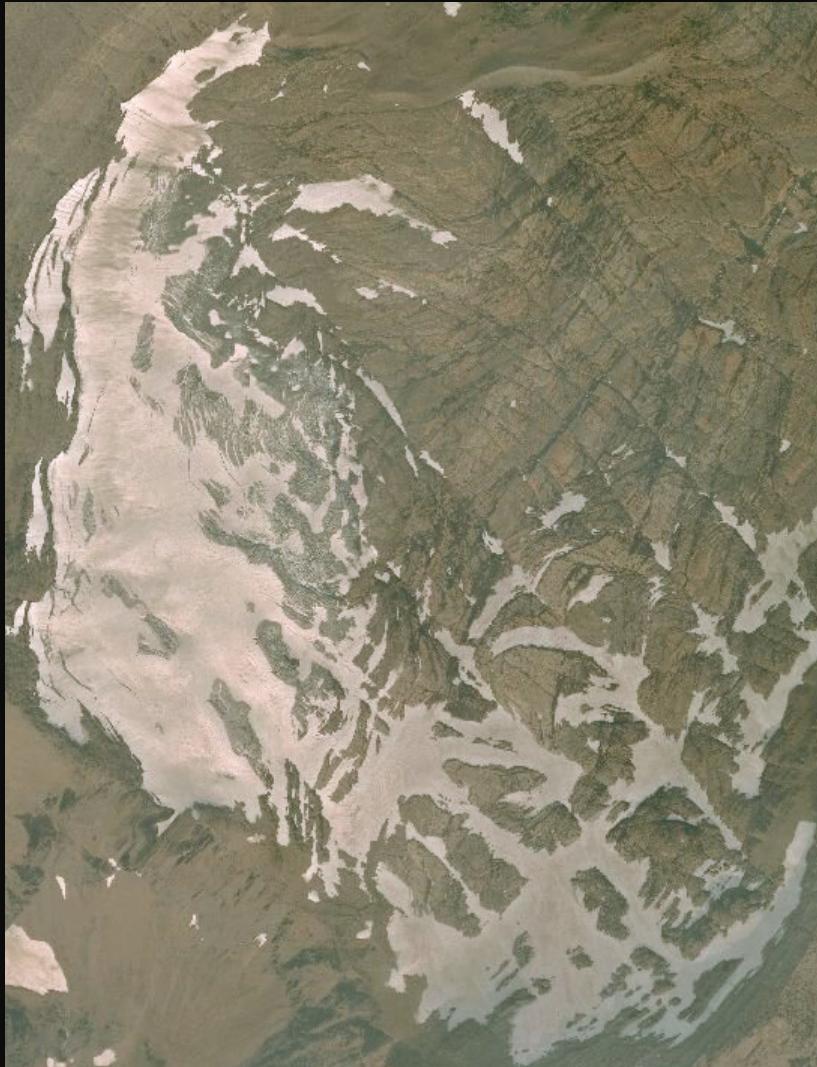
Basemap with basemaps

The package **basemaps** allows to download open source basemap data from several sources, but those cannot easily be combined with `sf` objects

This plots a satellite image of the Agassiz Glacier:

```
basemap_plot(ag, map_service = "esri", map_type = "world_imagery")
```

Satellite image of the Agassiz Glacier



Tiled web maps with Leaflet JS

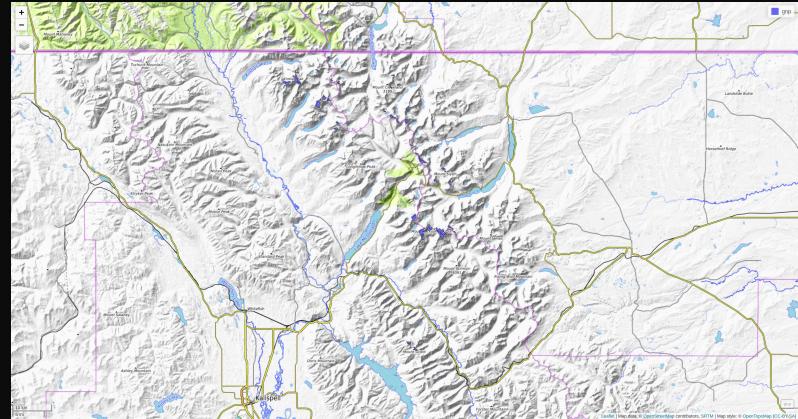
mapview

```
mapview(gnp)
```

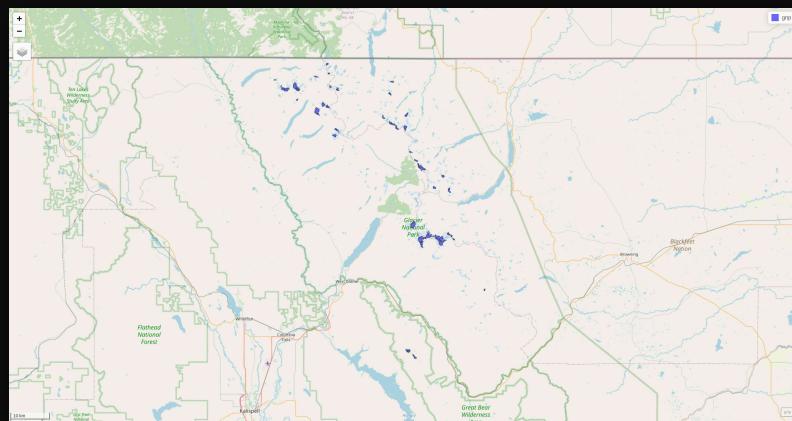
mapview



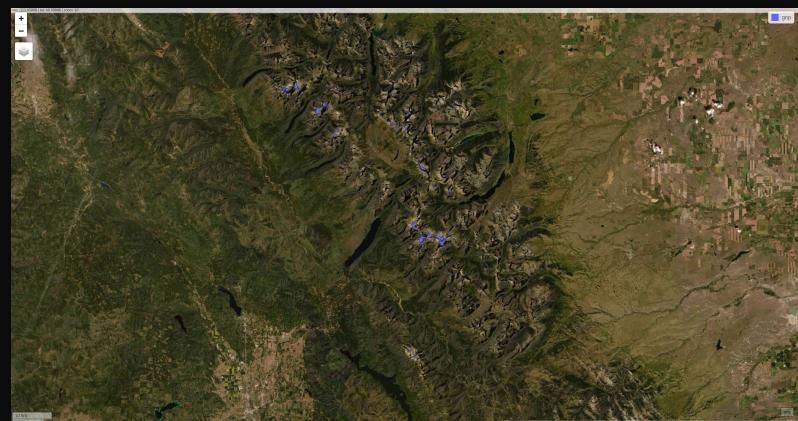
CartoDB.Positron



OpenTopoMap



OpenStreetMap



Esri.WorldImagery

tmap

So far, we have used the `plot` mode of **tmap**. There is also a `view` mode which allows interactive viewing in a browser through Leaflet

Change to `view` mode:

```
tmap_mode("view")
```

| you can also toggle between modes with `ttm`

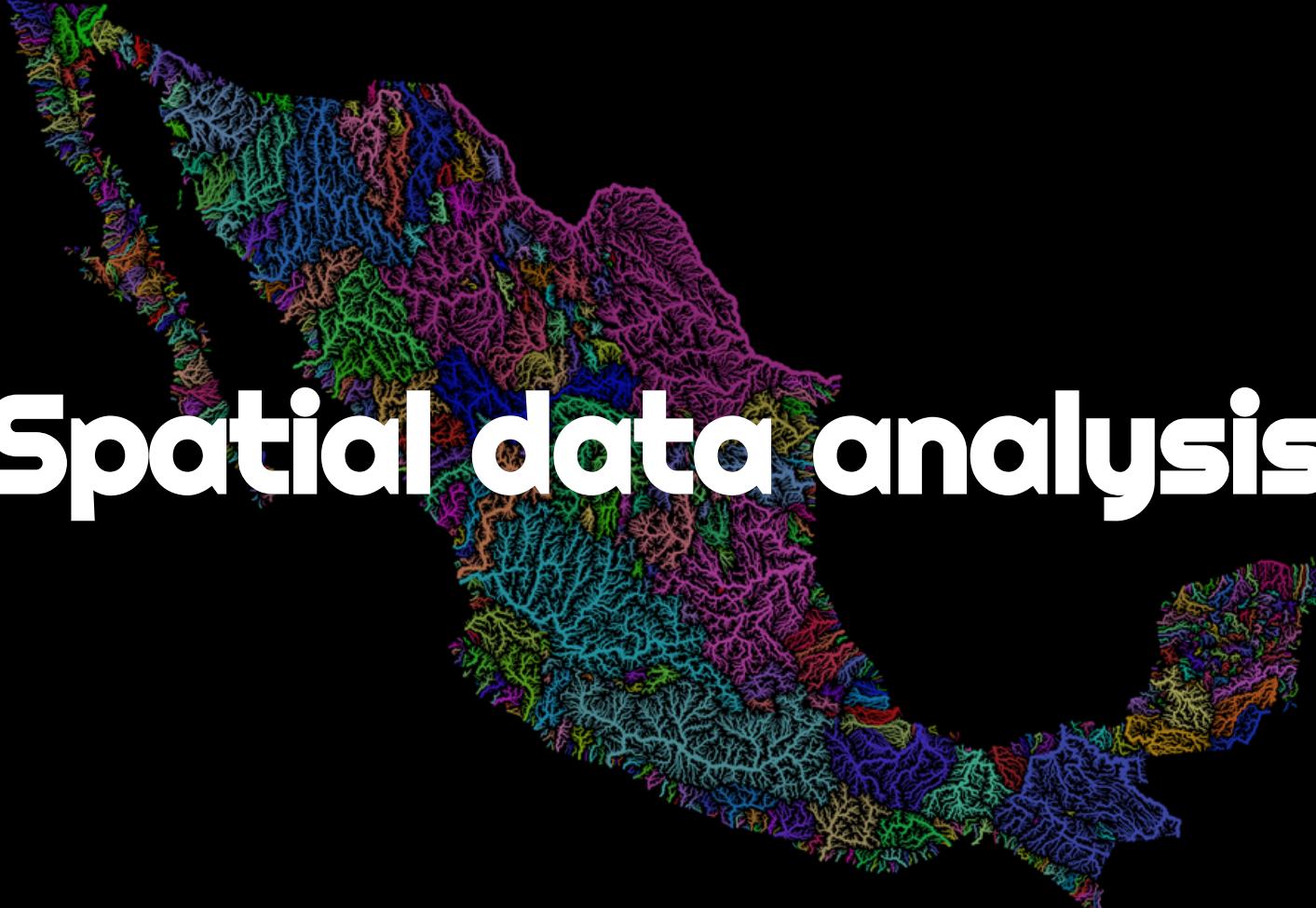
Re-plot the last map we plotted with **tmap**:

```
tmap_last()
```

leaflet

`leaflet` creates a map widget to which you add layers

```
map <- leaflet()  
addTiles(map)
```



Spatial data analysis

Resources

Maybe very disappointingly, I am leaving you to fend on your own here

But here are some great resources on the topic that should get you started
(& maybe I'll give another workshop on the subject some time?)

- [R companion to Geographic Information Analysis](#)
- [Spatial data analysis](#)

Image credits

Szűcs Róbert, Grasshopper Geography



Questions?