# Rasters

## Manipulate rasters with R

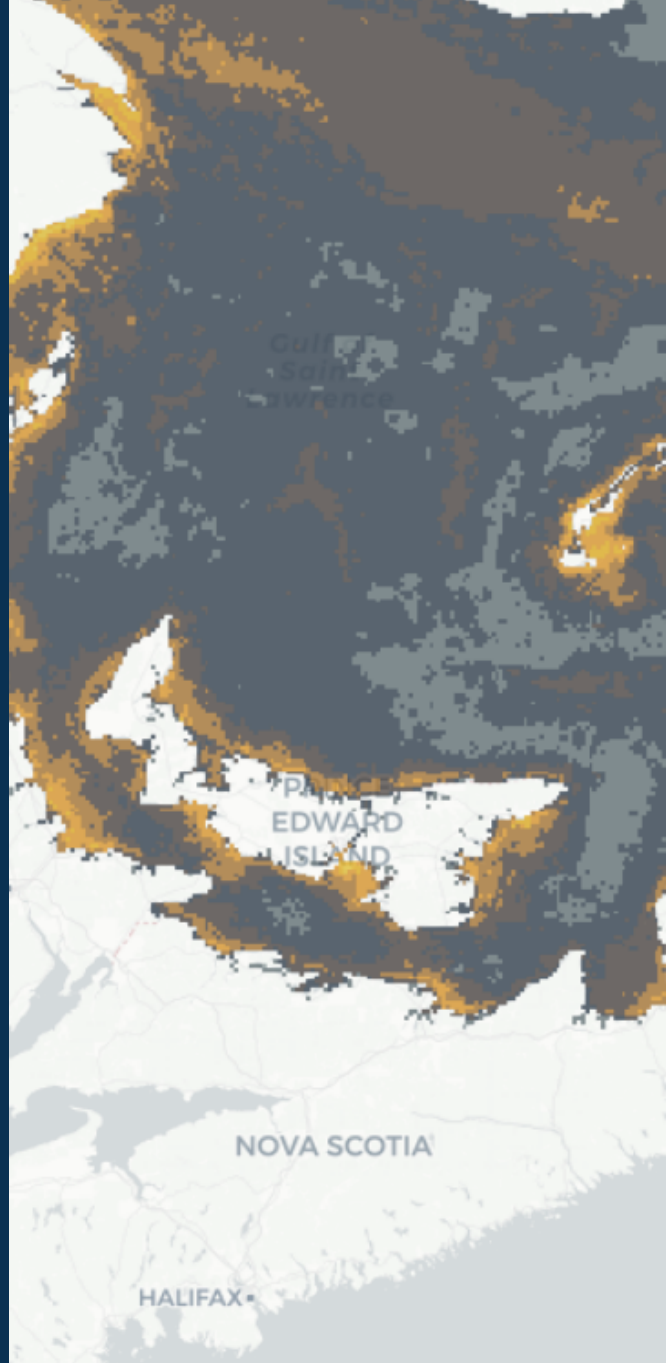
David Beauchesne & Kevin Cazelles

January 13, 2021

inSileco

deploy workshop passing





# Learning objectives

# Learning objectives

Learn how to visualize raster interactively with R

1. Understand the benefits of manipulating raster files with R
2. Learn how to read and write raster files with R
3. Learn how to manipulate rasters R
4. Learn how to visualize rasters with R

# Rationalize

Why use R for rasters? (~15min)

# Raster files

Raster files are grids of equally sized (most often) cells (or pixels).

Every cell has one or several values (or missing values).

Cells are georeferenced: coordinates + CRS

Commonly used to represent continuous phenomena (e.g. temperature, elevation) and images (airborne or satellite imagery).

# Raster files

- Examples of raster file formats:
  - **GeoTIFF** (see https://trac.osgeo.org/geotiff)
  - **NetCDF** (see https://www.unidata.ucar.edu/software/netcdf/)
  - **KML** (also supports vector objects, see https://www.ogc.org/standards/kml/)
  - **GeoPackage** (also supports vector objects, see https://www.ogc.org/standards/geopackage)
- ℹ More details :
  - https://gisgeography.com/gis-formats/
  - https://gdal.org/drivers/raster/index.html

# About

> R is a programming language and free software environment for statistical computing and graphics supported by the R Foundation for Statistical Computing. Wikipedia

# Coding vs clicking

1. Programming/coding allows to automate what is frequently done!
2. Allow to make analyses/reports reproducible
   - create data pipeline
   - for colleagues and future you
3. Increase efficiency (spend more time thinking)
4. Feeling empowered

# Why R?

1. Freeware + Open source
2. **Package ecosystem** is rich and under active development
3. Many packages connect R to other software/language
4. Community is wide, quite involved, responsive
5. You are most likely already using it! You are not starting from scratch

→ **Very little cannot be done with R**

# Input/Ouput

Read and write raster files (30min)

# packages ecosystem for spatial objects

**Classes and Methods**

**Statistical Analyses**

**Visualisation**

**Data Retrieval**

## Classes and Methods

Vectors

- `sp`
- `sf` ✔

**Rasters** (our main focus)

- `raster` ✔
- `stars` ✔
- `terra`

https://keen-swartz-3146c4.netlify.app/raster.html#package-stars

https://github.com/rspatial (15 packages)

# Raster packages

`raster` 03/2010 (1.0.0) // 11/2020 (3.3-7)

`terra` 03/2019 (0.5-2) // 11/2020 (0.9-11)

> terra is an R package that replaces raster. It has a very similar interface, but it is simpler and much faster.

`stars` 07/2018 (0.1-1) // 07/2020 (0.4-3)

> Reading, manipulating, writing and plotting spatiotemporal arrays (raster and vector data cubes) in 'R'.

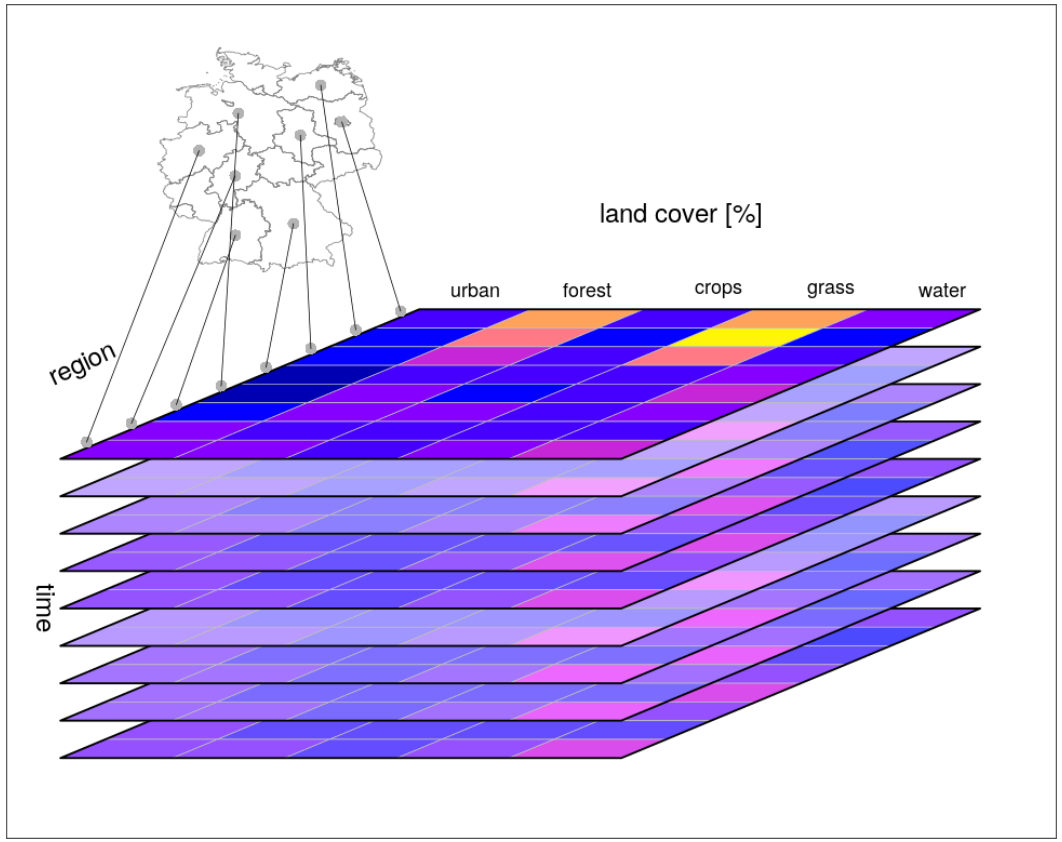
Depends on `sf`. Note that `stars` and `sf` are Tidyverse friendly.

# Package `raster`

- Well documented
  - see https://rspatial.org/raster/
  - many blog posts and tutorials (e.g. https://datacarpentry.org/r-raster-vector-geospatial/01-raster-structure/)
- 383 packages depend on or import `raster`
- Depends on `sp` but also works with `sf`.

# Package `stars`: SpatioTemporal ARrayS

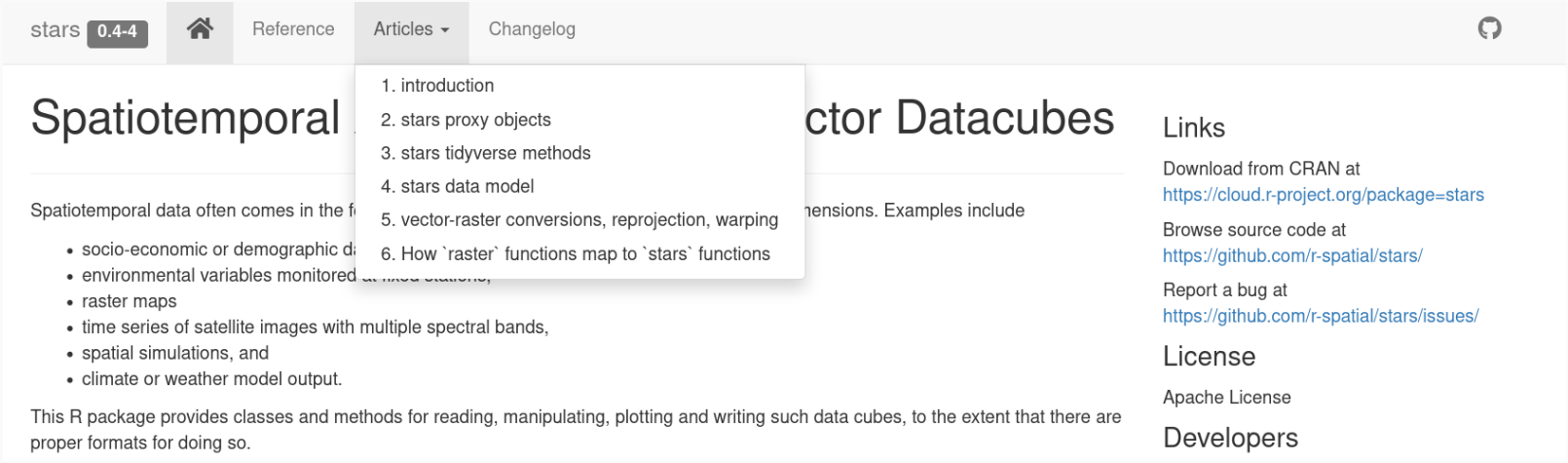
## Extent `sf` to Raster and Vector Datacubes




see https://r-spatial.github.io/stars/index.html

# Package `stars`: SpatioTemporal ARrayS

- Well documented too




see https://r-spatial.github.io/stars/index.html

- 9 packages depend on `stars`

- So far, less material available online.

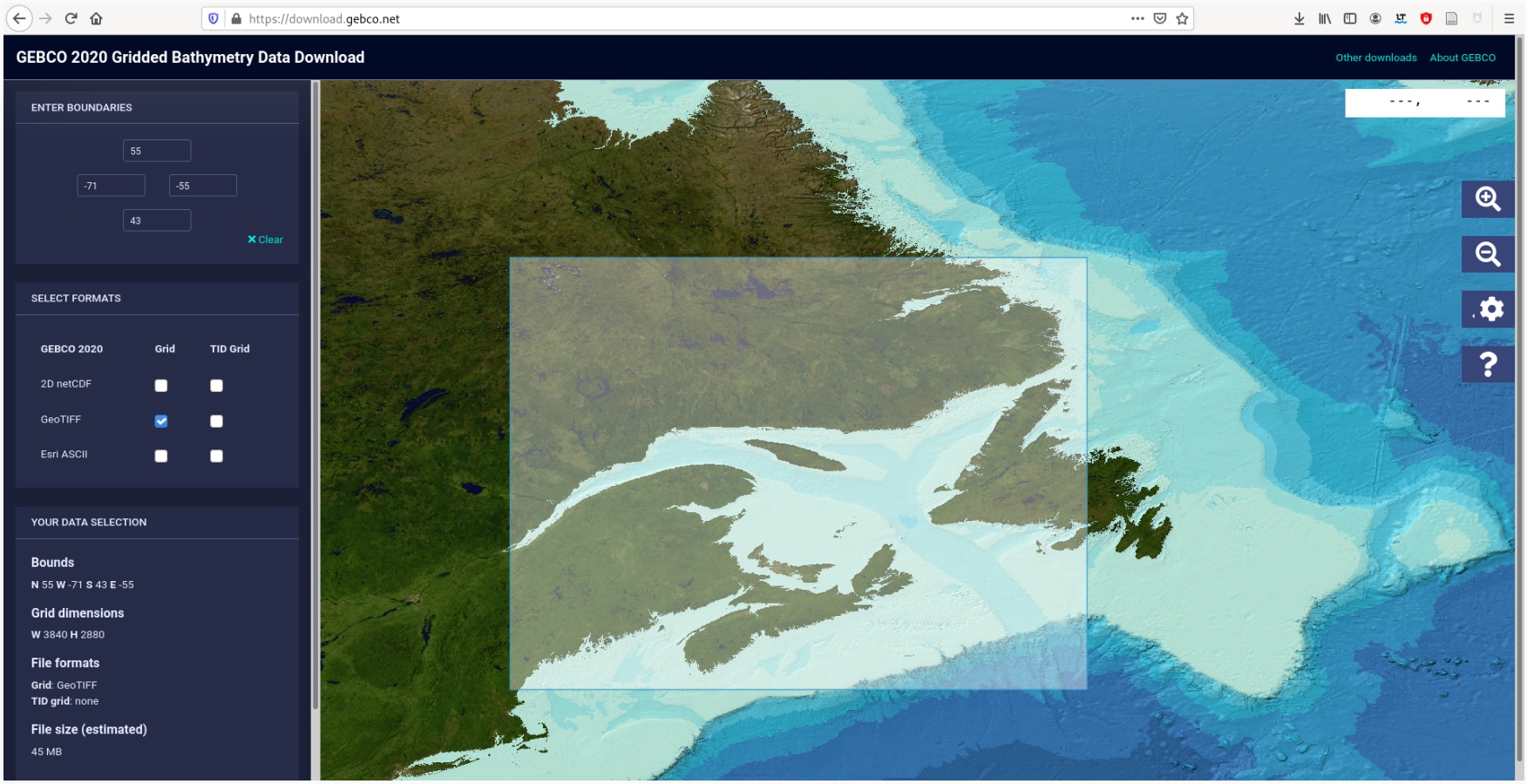
--

We'll talk about both!

# Read a raster file

1. Files you created
2. Files you found on the Internet
3. packages to download raster files

# Example file



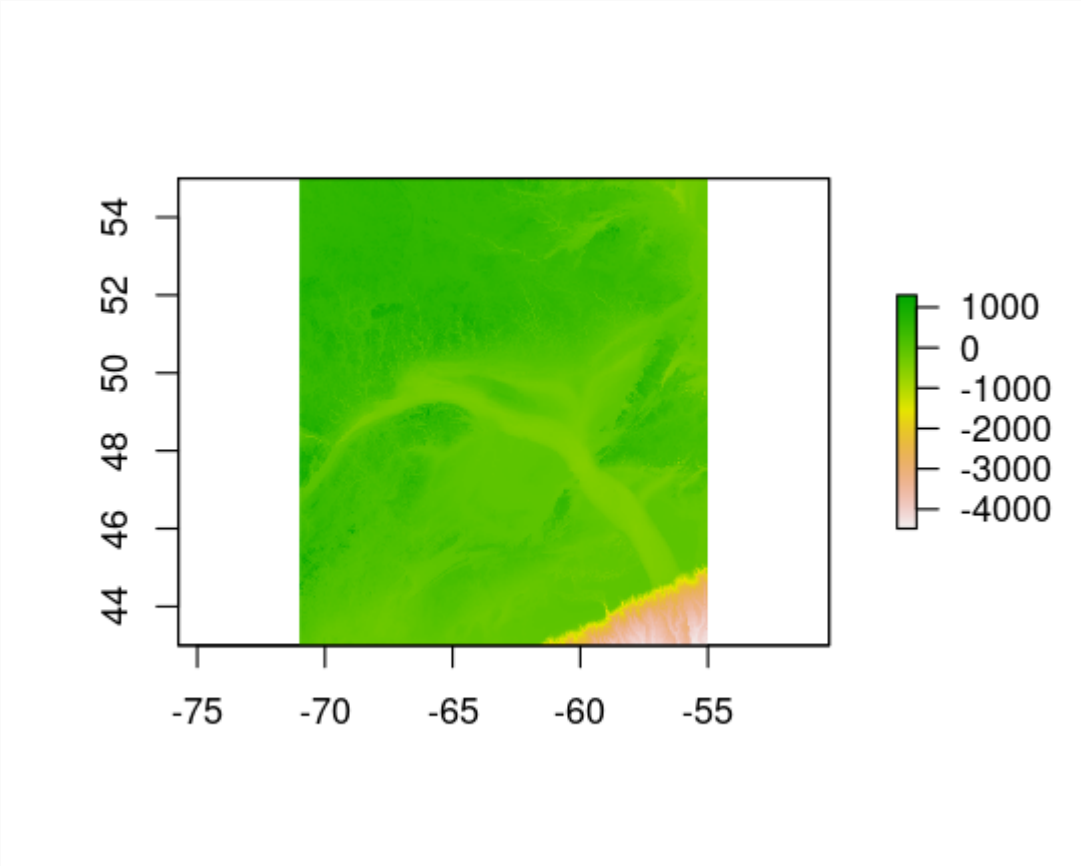

- https://download.gebco.net/
- 🔗 data_and_script.zip

# Read with `raster`

```
library(raster)
rar ← raster("data/bathy.tif")
class(rar)
#> [1] "RasterLayer"
#> attr(,"package")
#> [1] "raster"
```

# Read with `raster`

```
plot(rar)
```

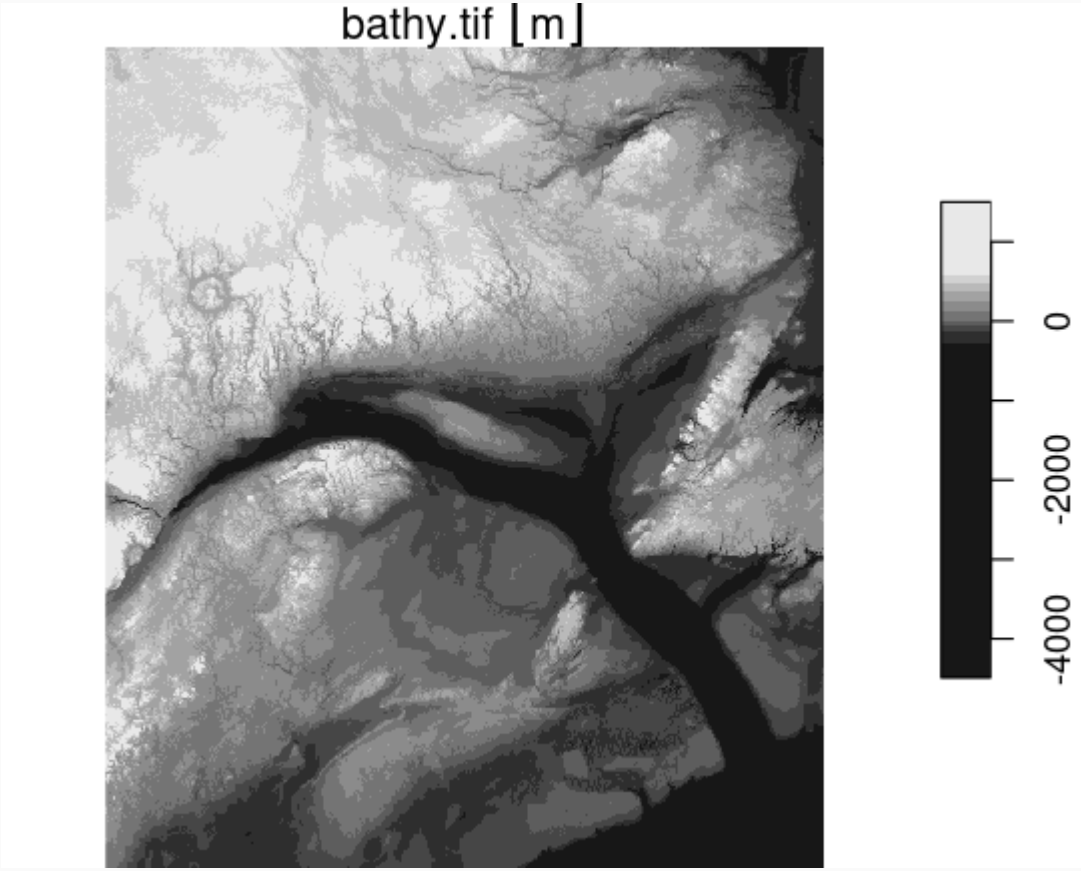


# Read with `stars`

```
library(stars)
ras ← read_stars("data/bathy.tif")   # argument `driver` to specify the driver
class(ras)
#> [1] "stars"
```

# Read with `stars`

```
plot(ras)
```



# So ...

- **GeoTIFF ✔**

- **Other formats, how do we know?**

# Check read/write capabilities with `raster`

`rgdal` is required

```
ra_dr ← rgdal::gdalDrivers()
head(ra_dr)
#>      name                      long_name create  copy isRaster
#> 1 AAIGrid           Arc/Info ASCII Grid  FALSE  TRUE     TRUE
#> 2    ACE2                         ACE2  FALSE FALSE     TRUE
#> 3    ADRG ARC Digitized Raster Graphics   TRUE FALSE     TRUE
#> 4     AIG           Arc/Info Binary Grid  FALSE FALSE     TRUE
#> 5  AirSAR     AirSAR Polarimetric Image  FALSE FALSE     TRUE
#> 6     ARG     Azavea Raster Grid format  FALSE  TRUE     TRUE
```

```
ra_dr[which(ra_dr$name == "GTiff"), ]
#>     name long_name create copy isRaster
#> 57 GTiff   GeoTIFF   TRUE TRUE     TRUE
```

# Check read/write capabilities with `stars`

`sf` is required

```
st_dr ← sf::st_drivers(what = "raster")
head(st_dr)
#>            name                                    long_name write
#> VRT         VRT                                 Virtual Raster  TRUE
#> DERIVED DERIVED Derived datasets using VRT pixel functions FALSE
#> GTiff     GTiff                                      GeoTIFF  TRUE
#> COG         COG           Cloud optimized GeoTIFF generator FALSE
#> NITF       NITF        National Imagery Transmission Format  TRUE
#> RPFTOC   RPFTOC             Raster Product Format TOC format FALSE
#>          copy is_raster is_vector   vsi
#> VRT      TRUE      TRUE     FALSE  TRUE
#> DERIVED FALSE      TRUE     FALSE FALSE
#> GTiff    TRUE      TRUE     FALSE  TRUE
#> COG      TRUE      TRUE     FALSE  TRUE
#> NITF     TRUE      TRUE     FALSE  TRUE
#> RPFTOC  FALSE      TRUE     FALSE  TRUE
```

# Check read/write capabilities with `stars`

```
st_dr[which(st_dr$name == "GTiff"), ]
#>        name long_name write copy is_raster is_vector  vsi
#> GTiff GTiff   GeoTIFF  TRUE TRUE      TRUE     FALSE TRUE
```

https://gdal.org/drivers/raster/index.html

https://keen-swartz-3146c4.netlify.app/intro.html#reading

# Write raster files

- **Share the output file**

- **Use another software (e.g. QGIS)**

❗ Create an `output` directory

```
dir.create("output", showWarnings = FALSE)
```

# Write with `raster`

```
ra_dr$name[ra_dr$create]
#>  [1] "ADRG"      "BAG"       "BMP"       "BT"        "BYN"
#>  [6] "CTable2"   "EHdr"      "ELAS"      "ENVI"      "ERS"
#> [11] "FITS"      "GPKG"      "GS7BG"     "GSBG"      "GTiff"
#> [16] "GTX"       "HDF4Image" "HFA"       "IDA"       "ILWIS"
#> [21] "INGR"      "ISCE"      "ISIS2"     "ISIS3"     "KRO"
#> [26] "LAN"       "Leveller"  "MBTiles"   "MEM"       "MFF"
#> [31] "MFF2"      "MRF"       "netCDF"    "NGW"       "NITF"
#> [36] "NTv2"      "NWT_GRD"   "PAux"      "PCIDSK"    "PCRaster"
#> [41] "PDF"       "PDS4"      "PNM"       "RMF"       "ROI_PAC"
#> [46] "RRASTER"   "RST"       "SAGA"      "SGI"       "Terragen"
#> [51] "VICAR"     "VRT"
```

# Write with `raster`

```
writeRaster(rar, filename = "output/rar.gpkg", format = "GPKG", overwrite = TRUE)
```

# Write with `stars`

```
sort(st_dr$name[st_dr$write])
#>  [1] "ADRG"      "BAG"       "BMP"       "BT"        "BYN"
#>  [6] "CTable2"   "EHdr"      "ELAS"      "ENVI"      "ERS"
#> [11] "FITS"      "GPKG"      "GS7BG"     "GSBG"      "GTiff"
#> [16] "GTX"       "HDF4Image" "HFA"       "IDA"       "ILWIS"
#> [21] "INGR"      "ISCE"      "ISIS2"     "ISIS3"     "KRO"
#> [26] "LAN"       "Leveller"  "MBTiles"   "MEM"       "MFF"
#> [31] "MFF2"      "MRF"       "netCDF"    "NGW"       "NITF"
#> [36] "NTv2"      "NWT_GRD"   "PAux"      "PCIDSK"    "PCRaster"
#> [41] "PDF"       "PDS4"      "PNM"       "RMF"       "ROI_PAC"
#> [46] "RRASTER"   "RST"       "SAGA"      "SGI"       "Terragen"
#> [51] "VICAR"     "VRT"
```

# Write with `stars`

```
write_stars(ras, dsn = "output/ras.gpkg", driver = "GPKG")
```

dsn stands for **data source name**.

# Recap

| Action | *raster* | *stars* |
|---|---|---|
| list drivers | `rgdal::gdalDrivers()` | `sf::st_drivers()` |
| read files | `raster()` | `read_stars()` |
| write files | `writeRaster()` | `write_stars()` |

# R as a raster file converter

```
<div class="countdown" id="timer_5fff0d59" style="right:0;bottom:0;" data-warnwhen="0">
<code class="countdown-time"><span class="countdown-digits minutes">10</span><span class=
</div>
```

☆ Convert `bathy.tif` into `bathy.grd` (https://gdal.org/drivers/raster/rraster.html#raster-rraster)

☆ ☆ Create a function `conv_raster()` that handles any conversion supported.

☆ ☆ ☆ Create a function that converts a object of class `RasterLayer` object to a `stars` one (and conversely)

# Solution ☆

## Convert `bathy.tif` into `bathy.grd`

```
# raster
rr ← raster("data/bathy.tif")
writeRaster(rr, filename = "output/rar.grd", overwrite = TRUE)
```

```
# stars
rs ← read_stars("data/bathy.tif")
write_stars(rs, dsn = "output/ras.grd", driver = "rraster")
```

# Solution ☆ ☆

Create a function `conv_raster()` that handles any conversion supported.

```
# raster
conv_raster_r ← function(input, output, ...) {
  rr ← raster(input)
  writeRaster(rr, filename = output, ...)
}
conv_raster_r("data/bathy.tif", "output/rar2.grd", overwrite = TRUE)
```

```
# stars
conv_raster_s ← function(from, to, ...) {
  rs ← read_stars("data/bathy.tif")
  write_stars(rs, dsn = "output/ras.grd", ...)
}
conv_raster_s("data/bathy.tif", "output/ras2.grd", driver = "rraster")
```

# Solution ☆ ☆ ☆

Create a function that converts a object of class `RasterLayer` object to a `stars` one (and conversely)

```
conv_raster_stars ← function(x) {
  if (class(x) == "RasterLayer") {
    tmp ← tempfile(fileext = ".tif")
    writeRaster(x, tmp)
    read_stars(tmp)
  } else if (class(x) == "stars") {
    tmp ← tempfile(fileext = ".tif")
    write_stars(x, tmp)
    raster(tmp)
  } else {
    warning("x should be of class `stars` or `RasterLayer`")
    NULL
  }
}
ras_n ← conv_raster_stars(rar)
rar_n ← conv_raster_stars(ras)
# conv_raster_stars(1)
```

# Manipulate

Do whatever you need with raster files (~1h15)

# Common operations

# Common operations

- change projection
- basic calculations (e.g. average per regions, min/max)
- crop/mask
- extraction
- resample
- etc.

# What do we have? `raster`

```
class(rar)
#> [1] "RasterLayer"
#> attr(,"package")
#> [1] "raster"
rar
#> class      : RasterLayer
#> dimensions : 2880, 3840, 11059200  (nrow, ncol, ncell)
#> resolution : 0.004166667, 0.004166667  (x, y)
#> extent     : -71, -55, 43, 55  (xmin, xmax, ymin, ymax)
#> crs        : +proj=longlat +datum=WGS84 +no_defs
#> source     : /home/kevcaz/Projects/inSilecoInc/workshop_raster/data/bathy.tif
#> names      : bathy
#> values     : -32768, 32767  (min, max)
```

# What do we have? `raster`

```
values(rar)
#>    [1] 457 461 463 463 467 474 484 490 478 460 452 455 456 454 451
#>   [16] 450 449 447 446 442 443 453 459 452 437 429 432 440 446 451
#>   [31] 460 465 466 472 485 498 506 502 493 493 498 502 507 506 479
#>   [46] 457 453 453 453 455 458 460 460 457 455 453 454 456 457 464
#>   [61] 472 484 508 537 555 557 560 567 565 564 563 558 558 566 565
#>   [76] 559 555 547 541 549 557 560 556 557 568 575 573 567 564 565
#>   [91] 568 569 570 570 569 561 549 547 564 582 583 582 586 588 583
#>  [106] 572 562 554 547 543 540 540 551 560 560 555 562 576 573 561
#>  [121] 553 554 556 554 553 556 556 550 536 522 515 512 510 510 509
#>  [136] 507 506 505 505 507 510 514 519 524 529 536 539 531 522 520
#>  [151] 521 522 527 538 550 559 560 552 542 534 532 537 543 544 545
#>  [166] 545 542 535 533 533 535 544 556 568 580 590 596 603 604 604
#>  [181] 610 609 600 591 585 570 558 554 543 538 546 558 566 563 547
#>  [196] 537 538 541 536 524 518 518 514 506 504 505 506 507 512 522
#>  [211] 529 521 505 499 502 505 505 502 498 499 496 500 518 532 523
#>  [226] 503 496 492 489 492 505 522 531 515 498 502 511 520 519 511
#>  [241] 494 488 481 477 476 476 477 476 475 475 475 475 475 475 477
#>  [256] 482 489 492 495 499 504 506 505 507 512 513 504 492 488 495
#>  [271] 511 517 505 491 491 504 530 552 560 571 576 556 526 504 495
#>  [286] 490 483 476 471 469 473 480 482 483 483 483 482 480 481 483
#>  [301] 484 484 485 487 485 482 488 501 500 488 486 493 507 526 541
#>  [316] 550 563 566 557 550 549 553 561 558 546 532 511 489 484 497
```

# What do we have? `raster`

```
dim(rar)
#> [1] 2880 3840    1
ncell(rar)
#> [1] 11059200
projection(rar)
#> [1] "+proj=longlat +datum=WGS84 +no_defs"
bbox(rar)
#>    min max
#> s1 -71 -55
#> s2  43  55
extent(rar)
#> class       : Extent
#> xmin        : -71
#> xmax        : -55
#> ymin        : 43
#> ymax        : 55
```

# What do we have? `stars`

```
class(ras)
#> [1] "stars"
ras
#> stars object with 2 dimensions and 1 attribute
#> attribute(s), summary of first 1e+05 cells:
#>  bathy.tif [m]
#>  Min.   :-435.0
#>  1st Qu.:  23.0
#>  Median : 479.0
#>  Mean   : 299.5
#>  3rd Qu.: 540.0
#>  Max.   : 812.0
#> dimension(s):
#>   from   to offset       delta refsys point values
#> x    1 3840    -71  0.00416667 WGS 84 FALSE   NULL [x]
#> y    1 2880     55 -0.00416667 WGS 84 FALSE   NULL [y]
```

# What do we have? `stars`

```
class(ras[[1]])
#> [1] "units"
ras[[1]]
#> Units: [m]
#>          [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10] [,11]
#>         [,12] [,13] [,14] [,15] [,16] [,17] [,18] [,19] [,20] [,21]
#>         [,22] [,23] [,24] [,25] [,26] [,27] [,28] [,29] [,30] [,31]
#>         [,32] [,33] [,34] [,35] [,36] [,37] [,38] [,39] [,40] [,41]
#>         [,42] [,43] [,44] [,45] [,46] [,47] [,48] [,49] [,50] [,51]
#>         [,52] [,53] [,54] [,55] [,56] [,57] [,58] [,59] [,60] [,61]
#>         [,62] [,63] [,64] [,65] [,66] [,67] [,68] [,69] [,70] [,71]
#>         [,72] [,73] [,74] [,75] [,76] [,77] [,78] [,79] [,80] [,81]
#>         [,82] [,83] [,84] [,85] [,86] [,87] [,88] [,89] [,90] [,91]
#>         [,92] [,93] [,94] [,95] [,96] [,97] [,98] [,99] [,100]
#>        [,101] [,102] [,103] [,104] [,105] [,106] [,107] [,108]
#>        [,109] [,110] [,111] [,112] [,113] [,114] [,115] [,116]
#>        [,117] [,118] [,119] [,120] [,121] [,122] [,123] [,124]
#>        [,125] [,126] [,127] [,128] [,129] [,130] [,131] [,132]
#>        [,133] [,134] [,135] [,136] [,137] [,138] [,139] [,140]
#>        [,141] [,142] [,143] [,144] [,145] [,146] [,147] [,148]
#>        [,149] [,150] [,151] [,152] [,153] [,154] [,155] [,156]
#>        [,157] [,158] [,159] [,160] [,161] [,162] [,163] [,164]
#>        [,165] [,166] [,167] [,168] [,169] [,170] [,171] [,172]
```

# What do we have? `stars`

```
dim(ras)
#>    x    y
#> 3840 2880
ncell(ras)
#>        x
#> 11059200
st_bbox(ras)
#> xmin ymin xmax ymax
#>  -71   43  -55   55
```

# What do we have? `stars`

```
ras_crs ← st_crs(ras)
class(ras_crs)
#> [1] "crs"
ras_crs
#> Coordinate Reference System:
#>   User input: WGS 84
#>   wkt:
#> GEOGCRS["WGS 84",
#>     DATUM["World Geodetic System 1984",
#>         ELLIPSOID["WGS 84",6378137,298.257223563,
#>             LENGTHUNIT["metre",1]]],
#>     PRIMEM["Greenwich",0,
#>         ANGLEUNIT["degree",0.0174532925199433]],
#>     CS[ellipsoidal,2],
#>         AXIS["geodetic latitude (Lat)",north,
#>             ORDER[1],
#>             ANGLEUNIT["degree",0.0174532925199433]],
#>         AXIS["geodetic longitude (Lon)",east,
#>             ORDER[2],
#>             ANGLEUNIT["degree",0.0174532925199433]],
#>     ID["EPSG",4326]]
```

# What do we have? `stars`

```
ras_crs$input
#> [1] "WGS 84"
ras_crs$proj4string
#> [1] "+proj=longlat +datum=WGS84 +no_defs"
ras_crs$epsg
#> [1] 4326
```

- https://epsg.io/
- https://epsg.io/4326

# Conversion between `stars` and `raster`

## Use a temporary file (see above)

```
rar_c ← st_as_stars(rar)
class(rar_c)
#> [1] "stars"
```

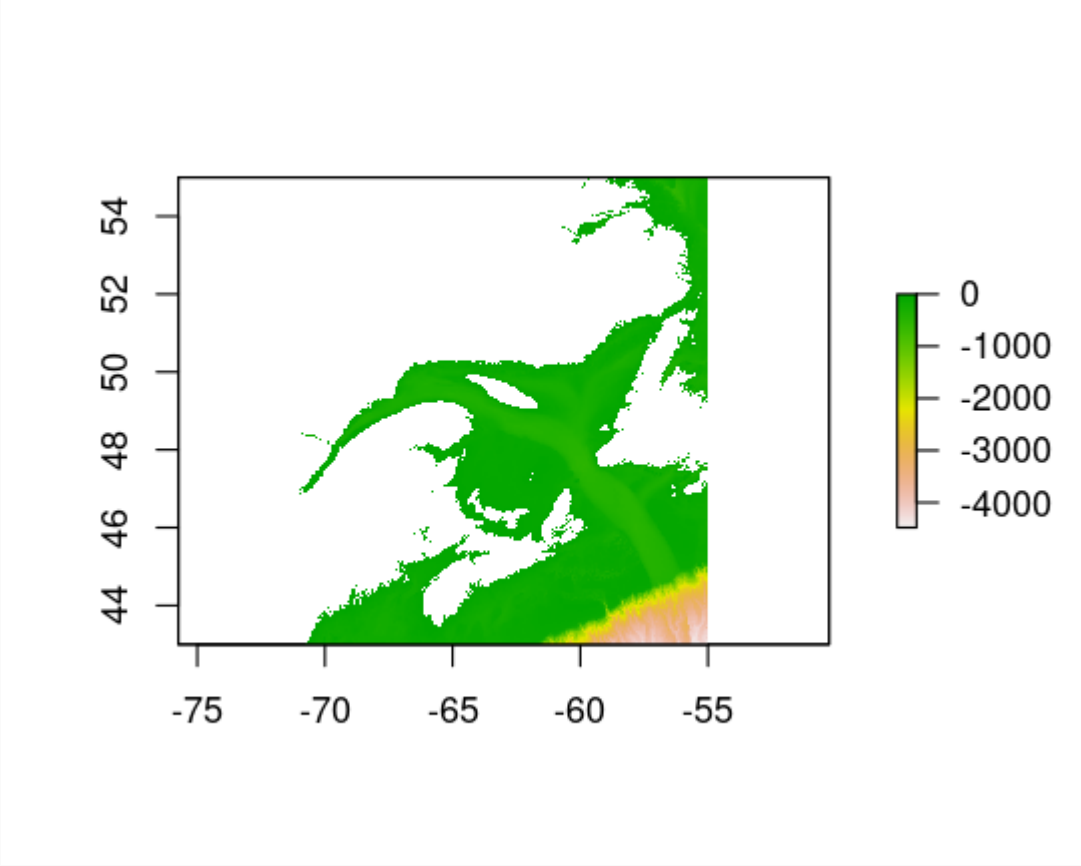
```
ras_c ← as(ras, "Raster")
class(ras_c)
#> [1] "RasterLayer"
#> attr(,"package")
#> [1] "raster"
```

# Basic computations with `raster`

```
class(rar[,])
#> [1] "integer"
rar[1, 1]
#>
#> 457
rar[1:10, 11:20]
#>   [1] 452 455 456 454 451 450 449 447 446 442 493 502 512 507 484 472
#>  [17] 468 462 450 440 529 532 536 523 491 468 459 454 440 431 504 507
#>  [33] 503 485 464 451 441 435 431 428 459 455 445 438 434 431 429 429
#>  [49] 429 428 444 439 434 431 434 435 431 430 433 441 438 435 436 443
#>  [65] 449 445 441 441 445 449 439 444 447 449 450 447 443 440 439 440
#>  [81] 441 442 443 444 444 444 441 440 443 452 469 460 448 443 443 447
#>  [97] 446 445 447 454
mean(rar[,]) # or mean(as.matrix(rar))
#> [1] 59.65972
quantile(rar[,])
#>    0%   25%   50%   75%  100%
#> -4490   -94   114   439  1502
```

# Basic computations with `raster`

```
rar2 ← rar # create a copy
rar2[rar > 0] ← NA  # filter
plot(rar2)
```



# Basic cell-based computations with `stars`

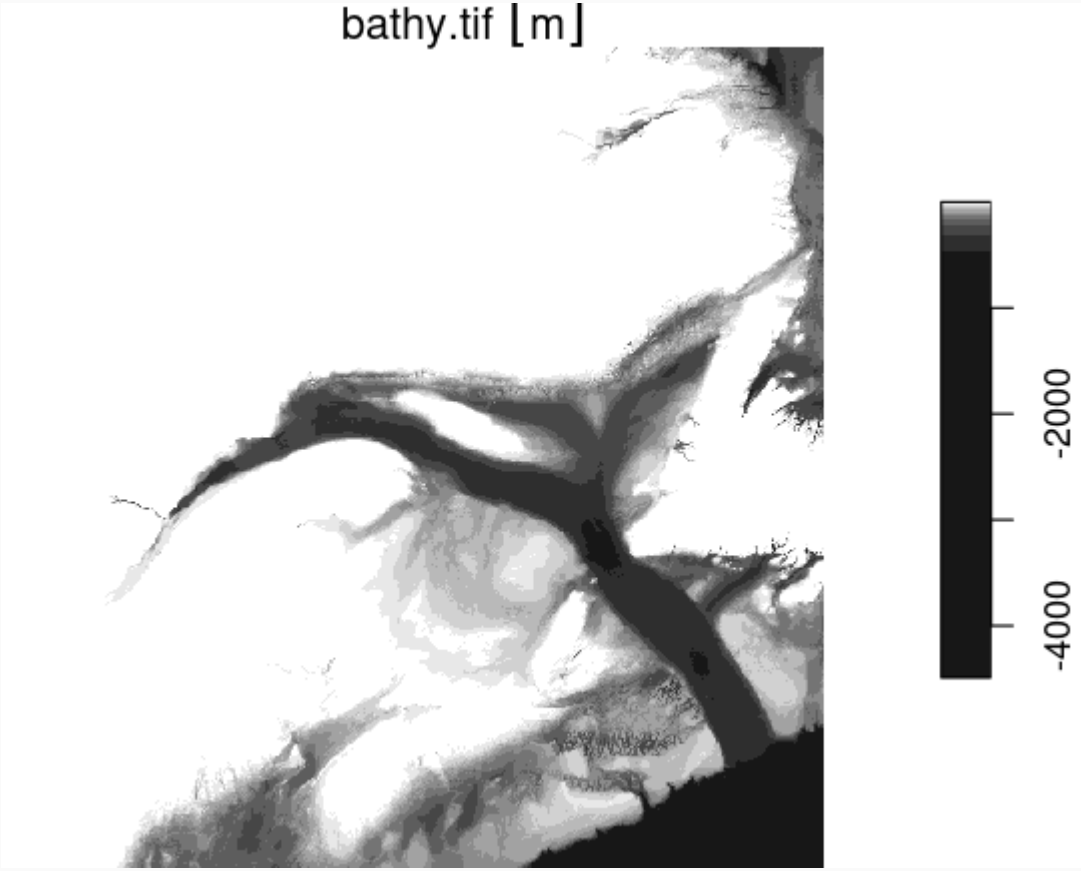
```
# extract value
class(ras[[1]])
#> [1] "units"
ras[[1]][1, 1]
#> 457 [m]
ras[[1]][1:10, 11:20]
#> Units: [m]
#>       [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10]
#>  [1,]  455  475  479  476  474  473  488  529  525   521
#>  [2,]  453  472  473  471  476  474  494  533  533   518
#>  [3,]  454  471  471  471  477  475  493  539  536   515
#>  [4,]  454  469  470  472  472  473  487  530  528   511
#>  [5,]  456  469  470  475  472  476  493  519  520   508
#>  [6,]  459  474  471  481  478  488  508  523  525   507
#>  [7,]  459  484  473  494  487  502  519  537  537   513
#>  [8,]  467  497  479  514  495  502  525  554  542   522
#>  [9,]  483  506  483  526  497  495  531  554  535   525
#> [10,]  508  507  485  520  490  485  530  543  527   513
```

# Basic cell-based computations with `stars`

```
mean(ras[[1]])
#> 59.65972 [m]
quantile(ras[[1]])
#> Units: [m]
#>    0%   25%   50%   75%  100%
#> -4490   -94   114   439  1502
```

# Basic cell-based computations with `stars`

```
ras2 ← ras # create a copy
ras2[[1]][ras[[1]] > units::as_units(0, "m")] ← NA # filter
plot(ras2)
```



# Mean along latitude and longitude

```
<div class="countdown" id="timer_5fff0eb2" style="right:0;bottom:0;" data-warnwhen="0">
<code class="countdown-time"><span class="countdown-digits minutes">15</span><span class=
</div>
```

☆ Compute the mean elevation (values > 0) and depth (values < 0) for `bathy.tif`.

☆ ☆ Create a function `mean_long_lat()` that computes mean elevation/depth along longitude (x axis) and latitude (y axis) (☆ ☆ ☆ include an argument to set an elevation/depth filter).

# Solution ☆

Compute the mean elevation/depth along the latitude or/and longitude (optional: use elevation/depth filter)

```
# raster
rr_d ← rr_e ← rar
rr_d[rar > 0] ← NA
rr_e[rar < 0] ← NA
mean(values(rr_d), na.rm = TRUE)
#> [1] -392.727
mean(values(rr_e), na.rm = TRUE)
#> [1] 364.2634
```

# Solution ☆

Compute the mean elevation/depth along the latitude or/and longitude (optional: use elevation/depth filter)

```
# stars
rs_e ← rs_d ← ras
rs_d[[1]][ras[[1]] > units::as_units(0, "m")] ← NA # filter
rs_e[[1]][ras[[1]] < units::as_units(0, "m")] ← NA
mean(rs_d[[1]], na.rm = TRUE)
#> -392.727 [m]
mean(rs_e[[1]], na.rm = TRUE)
#> 364.2634 [m]
```

# Solution ☆☆/☆☆☆

Create a function `mean_long_lat()` that computes mean elevation/depth along longitude and latitude (include an argument to set an elevation/depth filter).

```
# raster
mean_long_lat_r ← function(x, gt_na = NULL, lt_na = NULL) {
  m ← as.matrix(x)
  if (!is.null(lt_na)) m[m < lt_na] ← NA
  if (!is.null(gt_na)) m[m > gt_na] ← NA
  list(
    m_lat = apply(m, 1, mean, na.rm = TRUE),
    m_lon = apply(m, 2, mean, na.rm = TRUE)
  )
}
```

# Solution ☆☆/☆☆☆

```
res1 ← mean_long_lat_r(rar)
par(mfrow = c(1, 2))
plot(res1$m_lat, main = "Along latitude", ylab = "elevation", xlab = "lat_index")
plot(res1$m_lon, main = "Along longitude", ylab = "elevation", xlab = "lon_index")
```

# Solution ☆☆/☆☆☆

```
res2 ← mean_long_lat_r(rar, gt_na = 0)
par(mfrow = c(1, 2))
plot(res2$m_lat, main = "Along latitude", ylab = "elevation", xlab = "lat_index")
plot(res2$m_lon, main = "Along longitude", ylab = "elevation", xlab = "lon_index")
```

# Solution ☆☆/☆☆☆

```
# stars
mean_long_lat_s ← function(x, gt_na = NULL, lt_na = NULL) {
  m ← units::drop_units(ras[[1]])
  if (!is.null(lt_na)) m[m < lt_na] ← NA
  if (!is.null(gt_na)) m[m > gt_na] ← NA
  list(
    m_lon = apply(m, 1, mean, na.rm = TRUE),
    m_lat = apply(m, 2, mean, na.rm = TRUE)
  )
}
```

# Solution ☆☆/☆☆☆

```
res1 ← mean_long_lat_s(ras)
par(mfrow = c(1, 2))
plot(res1$m_lon, main = "Along latitude", ylab = "elevation", xlab = "lat_index")
plot(res1$m_lat, main = "Along longitude", ylab = "elevation", xlab = "lon_index")
```

# Solution ☆☆/☆☆☆

```
res2 ← mean_long_lat_s(ras, gt_na = 0)
par(mfrow = c(1, 2))
plot(res2$m_lon, main = "Along latitude", ylab = "elevation", xlab = "lat_index")
plot(res2$m_lat, main = "Along longitude", ylab = "elevation", xlab = "lon_index")
```

# Change map projection

- Reminder
  - W List of map projections
  - Interactive examples
- Let's use the spherical Mercator
  - https://epsg.io/
  - https://epsg.io/3857

# Change map projection with `raster`

- `raster` uses Proj strings
- https://epsg.io/3857

```
rar_crs ← CRS("+proj=merc +a=6378137 +b=6378137 +lat_ts=0.0 +lon_0=0.0 +x_0=0.0 +y_0=0 +
```

# Change map projection with `raster`

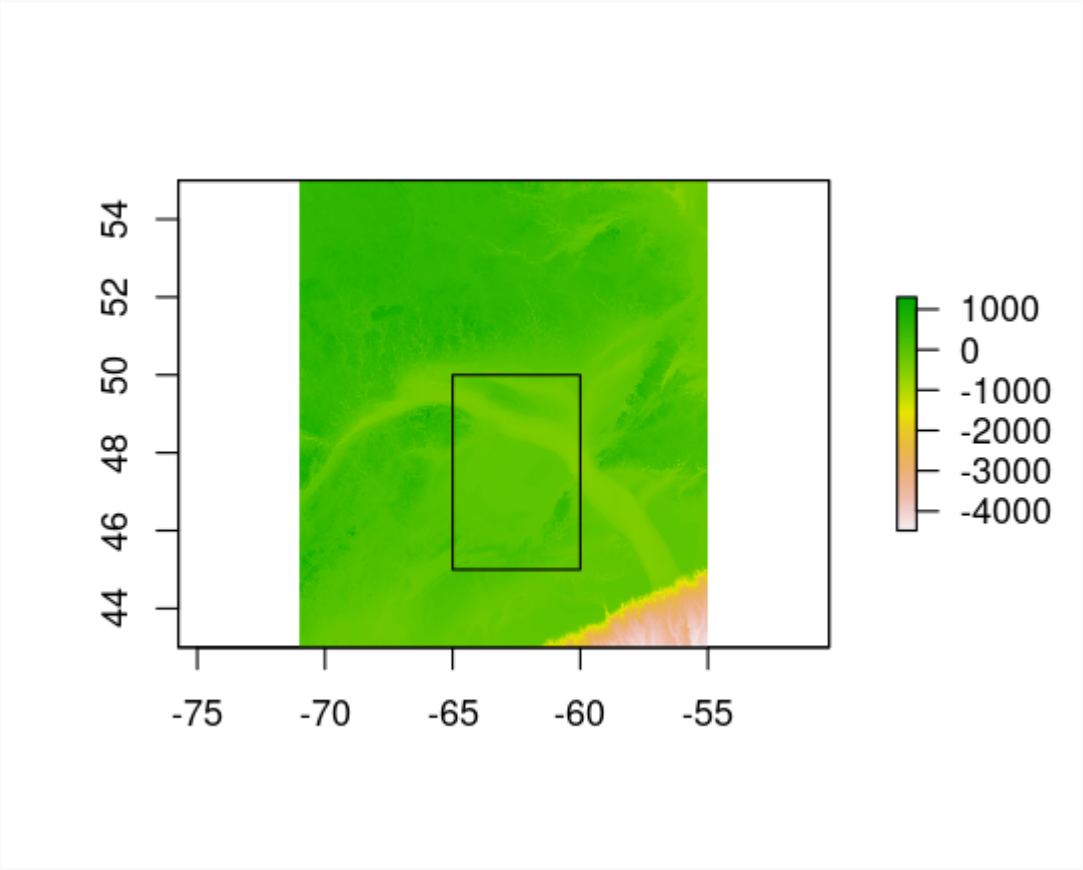
```
rar_t ← projectRaster(rar, crs = rar_crs)
projection(rar_t)
#> [1] "+proj=merc +a=6378137 +b=6378137 +lat_ts=0 +lon_0=0 +x_0=0 +y_0=0 +k=1 +units=m +
plot(rar)
```

# Change map projection with `stars`

```
ras_t ← st_transform(ras, crs = 3857)
st_crs(ras_t)
#> Coordinate Reference System:
#>   User input: EPSG:3857
#>   wkt:
#> PROJCRS["WGS 84 / Pseudo-Mercator",
#>     BASEGEOGCRS["WGS 84",
#>         DATUM["World Geodetic System 1984",
#>             ELLIPSOID["WGS 84",6378137,298.257223563,
#>                 LENGTHUNIT["metre",1]]],
#>         PRIMEM["Greenwich",0,
#>             ANGLEUNIT["degree",0.0174532925199433]],
#>         ID["EPSG",4326]],
#>     CONVERSION["Popular Visualisation Pseudo-Mercator",
#>         METHOD["Popular Visualisation Pseudo Mercator",
#>             ID["EPSG",1024]],
#>         PARAMETER["Latitude of natural origin",0,
#>             ANGLEUNIT["degree",0.0174532925199433],
#>             ID["EPSG",8801]],
#>         PARAMETER["Longitude of natural origin",0,
#>             ANGLEUNIT["degree",0.0174532925199433],
#>             ID["EPSG",8802]],
#>         PARAMETER["False easting",0,
```

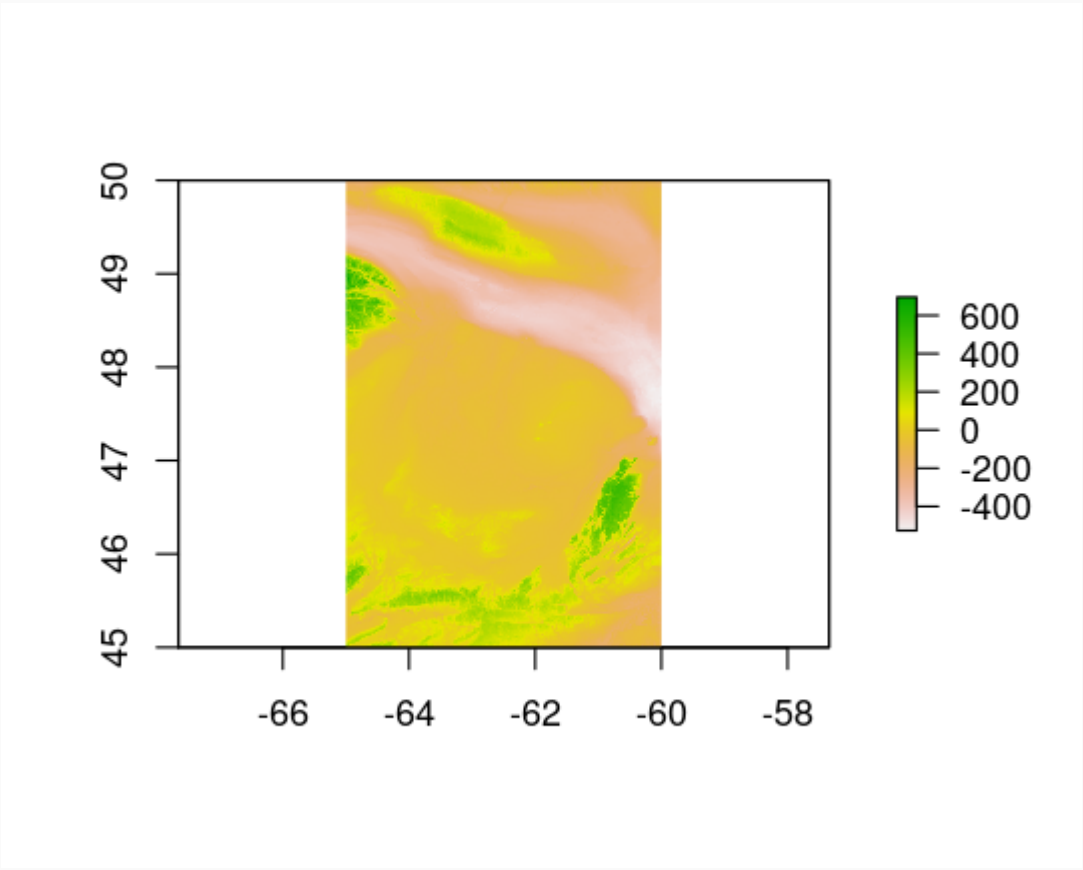
# Crop

```
plot(rar)
rect(-65, 45, -60, 50)
```



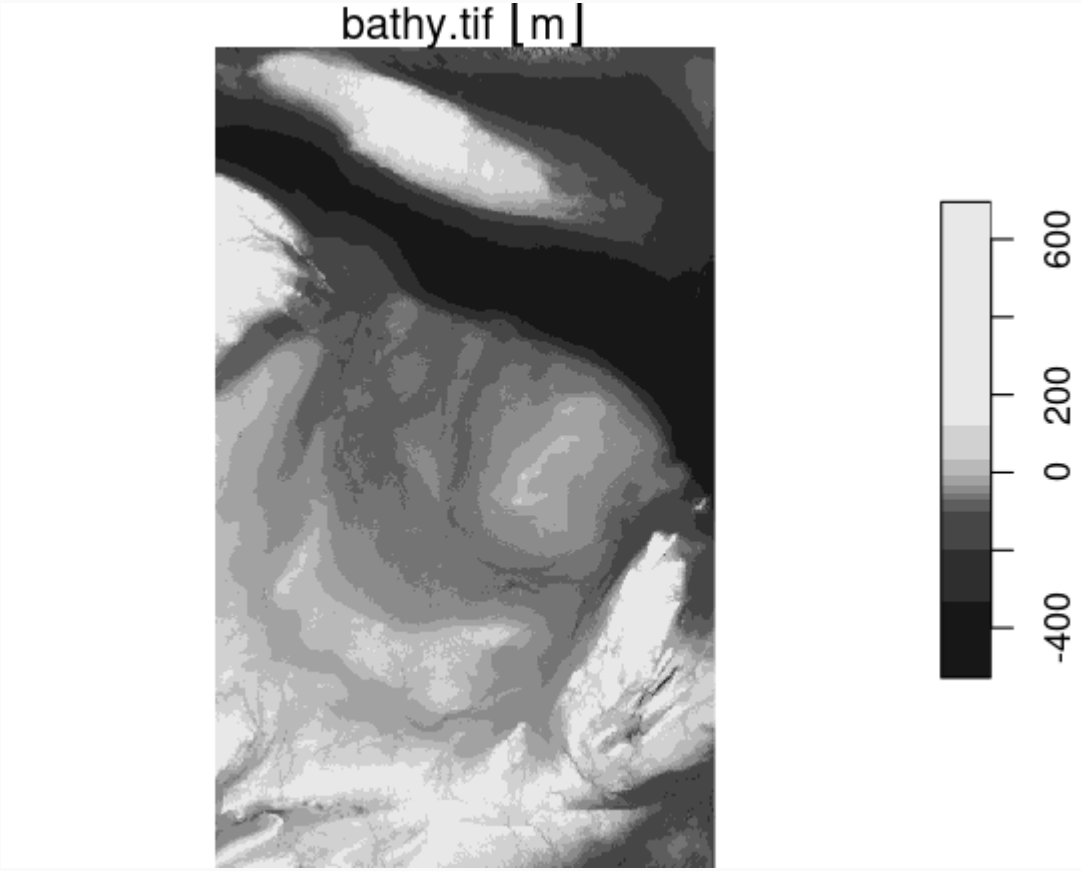
# Crop with `raster`

```
rar_c ← crop(rar, extent(-65, -60, 45, 50))
plot(rar_c)
```



# Crop with `stars`

```
ext ← st_bbox(c(xmin = -65, xmax = -60, ymin = 45, ymax = 50), crs = 4326)
ras_c ← st_crop(ras, ext)
plot(ras_c)
```



# Mask

Let's use a shapefile of the Gulf of the St-Lawrence

🔗 https://www.marineregions.org/gazetteer.php?p=details&id=4290

```
(stl ← sf::st_read("data/st_laurence.geojson"))
#> Reading layer `data_stl2' from data source `/home/kevcaz/Projects/inSilecoInc/worksho
#> Simple feature collection with 1 feature and 10 fields
#> geometry type:  POLYGON
#> dimension:      XY
#> bbox:           xmin: -74.86481 ymin: 44.9585 xmax: -54.70345 ymax: 52.22242
#> geographic CRS: WGS 84
#> Simple feature collection with 1 feature and 10 fields
#> geometry type:  POLYGON
#> dimension:      XY
#> bbox:           xmin: -74.86481 ymin: 44.9585 xmax: -54.70345 ymax: 52.22242
#> geographic CRS: WGS 84
#>                   name id longitude latitude     min_x   min_y
#> 1 Gulf of St. Lawrence 24 -61.56657 48.38072 -74.86481 44.9585
#>       max_x    max_y   area mrgid                       geometry
#> 1 -54.70345 52.22242 290874  4290 POLYGON ((-64.67242 47.7168 ...
```

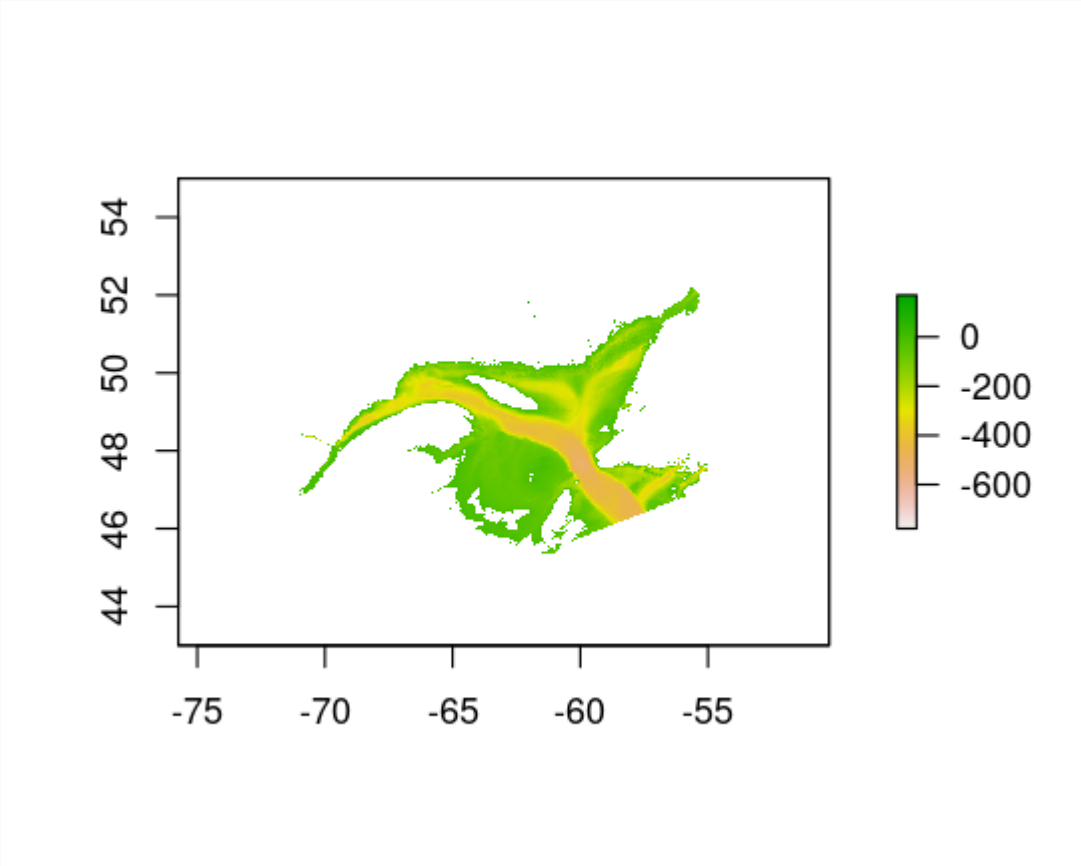
# Mask

Values outside of a given geometry set to `NA`

```
plot(sf::st_geometry(stl))
```

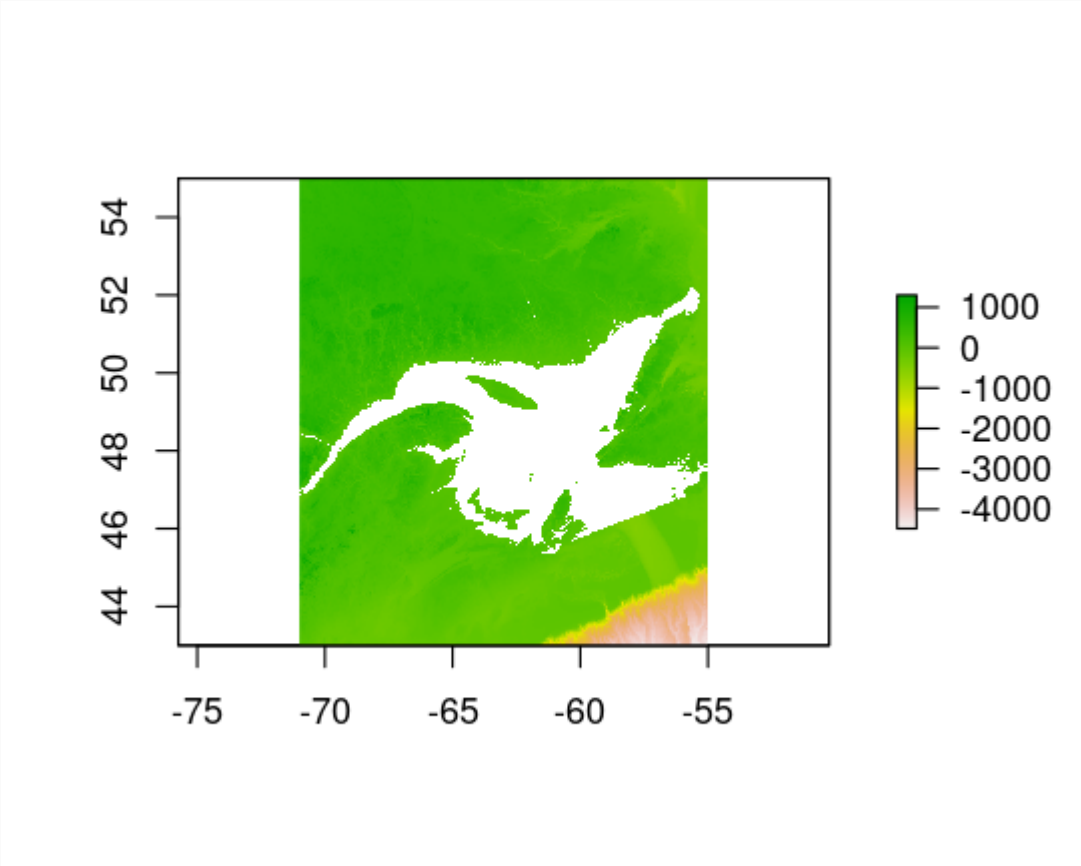
# Mask with `raster`

```
rar_m ← mask(rar, stl)
plot(rar_m)
```



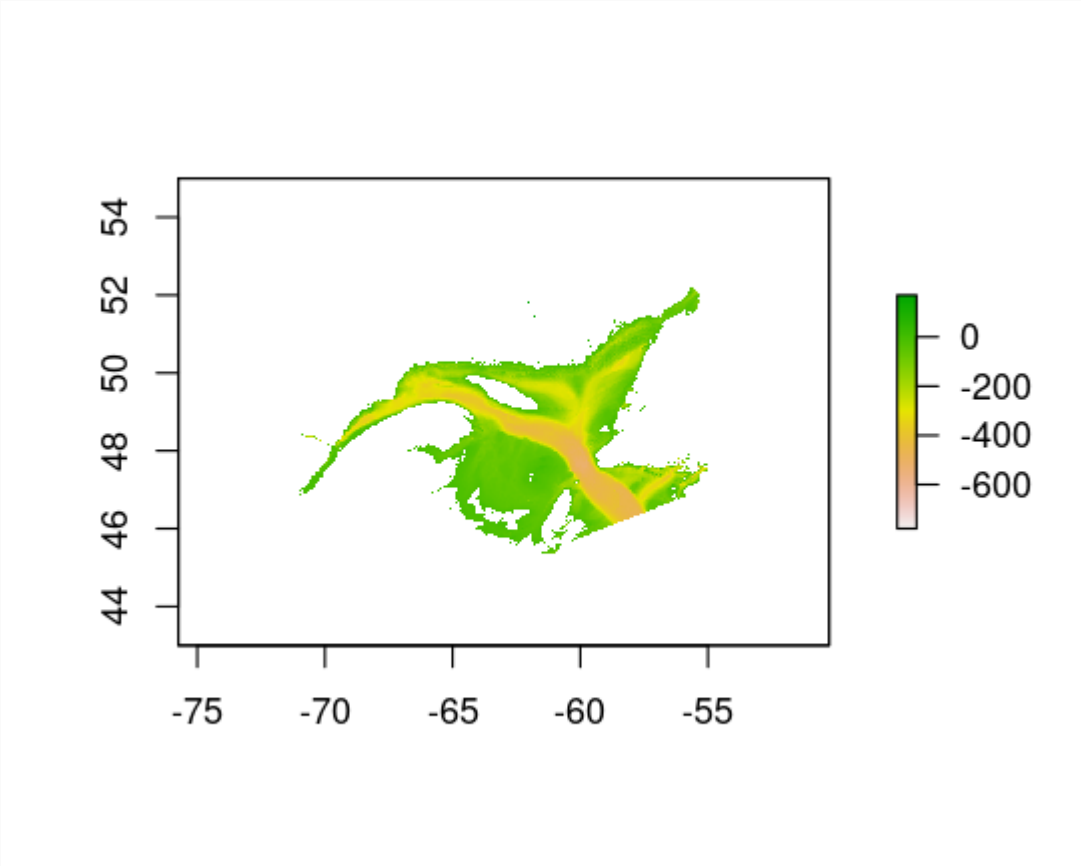
# Mask with `raster`

```
rar_mi ← mask(rar, stl, inverse = TRUE)
plot(rar_mi)
```



# Mask with `stars`

```
ras_m ← ras[stl]
plot(rar_m)
```

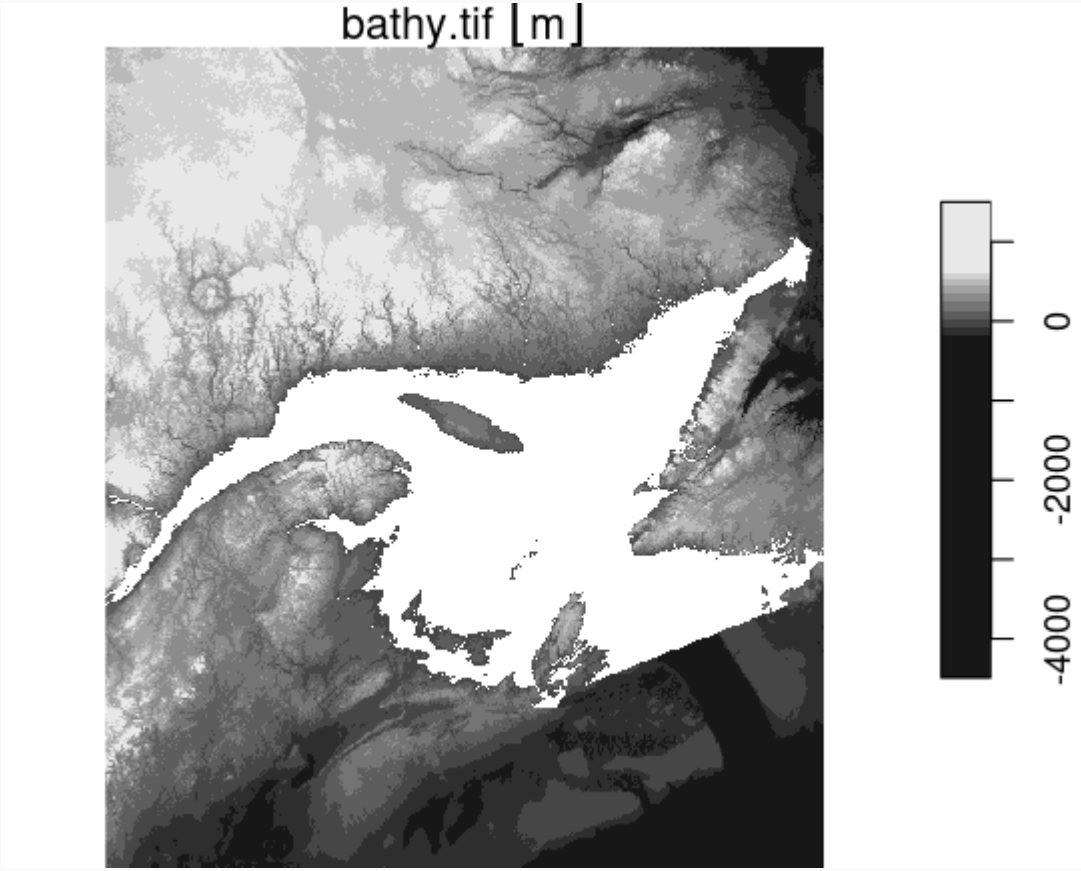


# Mask with `stars`

```
stl_i ← sf::st_difference(sf::st_as_sfc(st_bbox(ras)), stl)
plot(stl_i, col = 2)
```

# Mask with `stars`

```
ras_mi ← ras[stl_i]
plot(ras_mi)
```



# Mean depth of the St-Lawrence

- ☆ Compute the mean depth of the St-Lawrence (Gulf and river)
- ☆ ☆ Compare the depth of the Gulf of the St-Lawrence and the depth of the St-Lawrence river (various solutions!)

```
<div class="countdown" id="timer_5fff0cd7" style="right:0;bottom:0;" data-warnwhen="0">
<code class="countdown-time"><span class="countdown-digits minutes">10</span><span class=
</div>
```

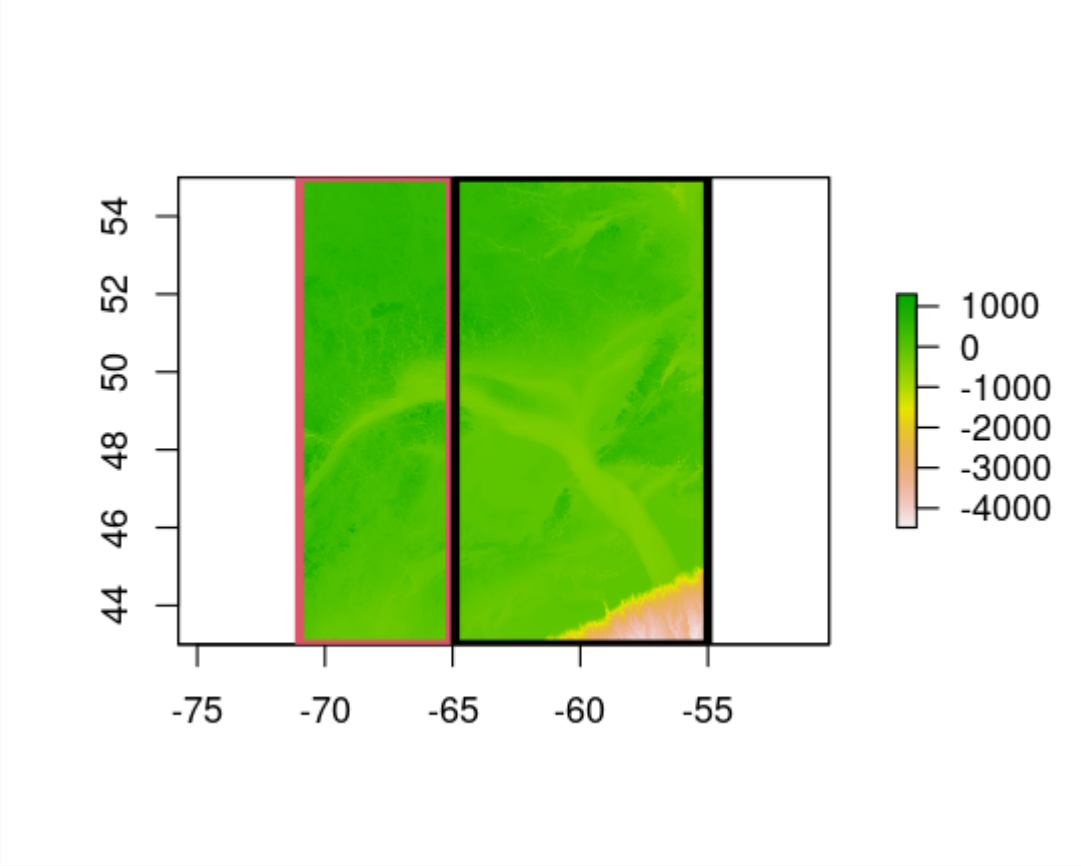
# Solution ☆

```
# raster
rar_m ← mask(rar, stl)
mean(rar_m[[1]], na.rm = TRUE)
#> class      : RasterLayer
#> dimensions : 2880, 3840, 11059200  (nrow, ncol, ncell)
#> resolution : 0.004166667, 0.004166667  (x, y)
#> extent     : -71, -55, 43, 55  (xmin, xmax, ymin, ymax)
#> crs        : +proj=longlat +datum=WGS84 +no_defs
#> source     : memory
#> names      : layer
#> values     : -785, 282  (min, max)
```

```
# stars
ras_m ← ras[stl]
mean(ras_m[[1]], na.rm = TRUE)
#> -162.9211 [m]
```

# Solution ☆ ☆

```
plot(rar)
rect(-71, 43, -65.1, 55, border = 2, lwd = 4)
rect(-64.9, 43, -55, 55, lwd = 4)
```

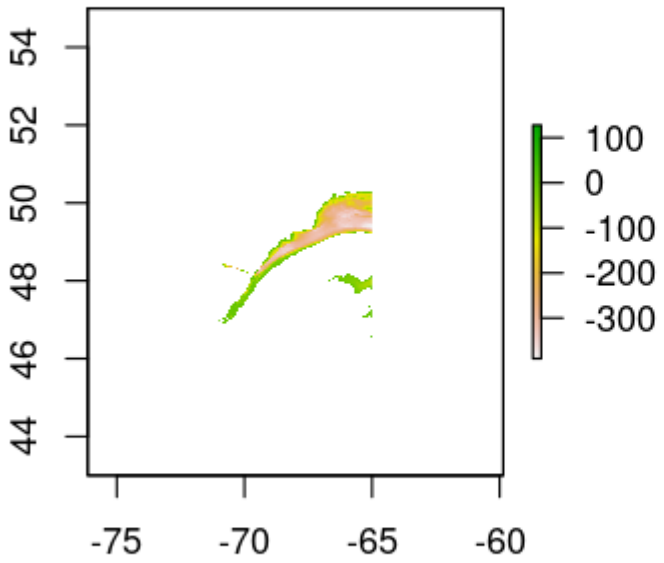


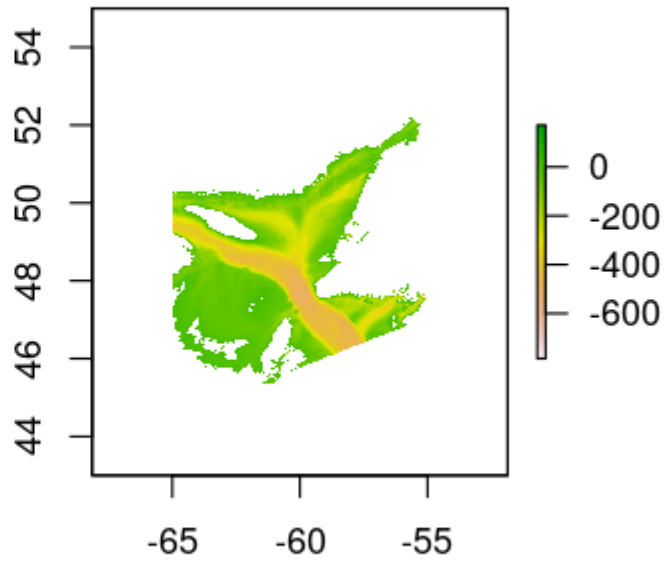
# Solution ☆☆

```
# raster
rar_m ← mask(rar, stl)
rar_river ← crop(rar_m, extent(-71, -65, 43, 55))
rar_gulf ← crop(rar_m, extent(-65, -55, 43, 55))
mean(values(rar_river), na.rm = TRUE)
#> [1] -176.0915
mean(values(rar_gulf), na.rm = TRUE)
#> [1] -161.125
```

# Solution ☆ ☆

```
plot(rar_river)
plot(rar_gulf)
```



# Solution ☆☆

```
mean(values(rar_river), na.rm = TRUE)
#> [1] -176.0915
mean(values(rar_gulf), na.rm = TRUE)
#> [1] -161.125
```

# Solution ☆ ☆

```
# stars
ras_m ← ras[stl]
ras_river ← st_crop(ras_m,
    st_bbox(c(xmin = -71, xmax = -65, ymin = 43, ymax = 55), crs = 4326)
)
ras_gulf ← st_crop(ras_m,
  st_bbox(c(xmin = -65, xmax = -55, ymin = 43, ymax = 55), crs = 4326)
)
mean(ras_river[[1]], na.rm = TRUE)
#> -176.0915 [m]
mean(ras_gulf[[1]], na.rm = TRUE)
#> -161.125 [m]
```

# Warping/Resampling

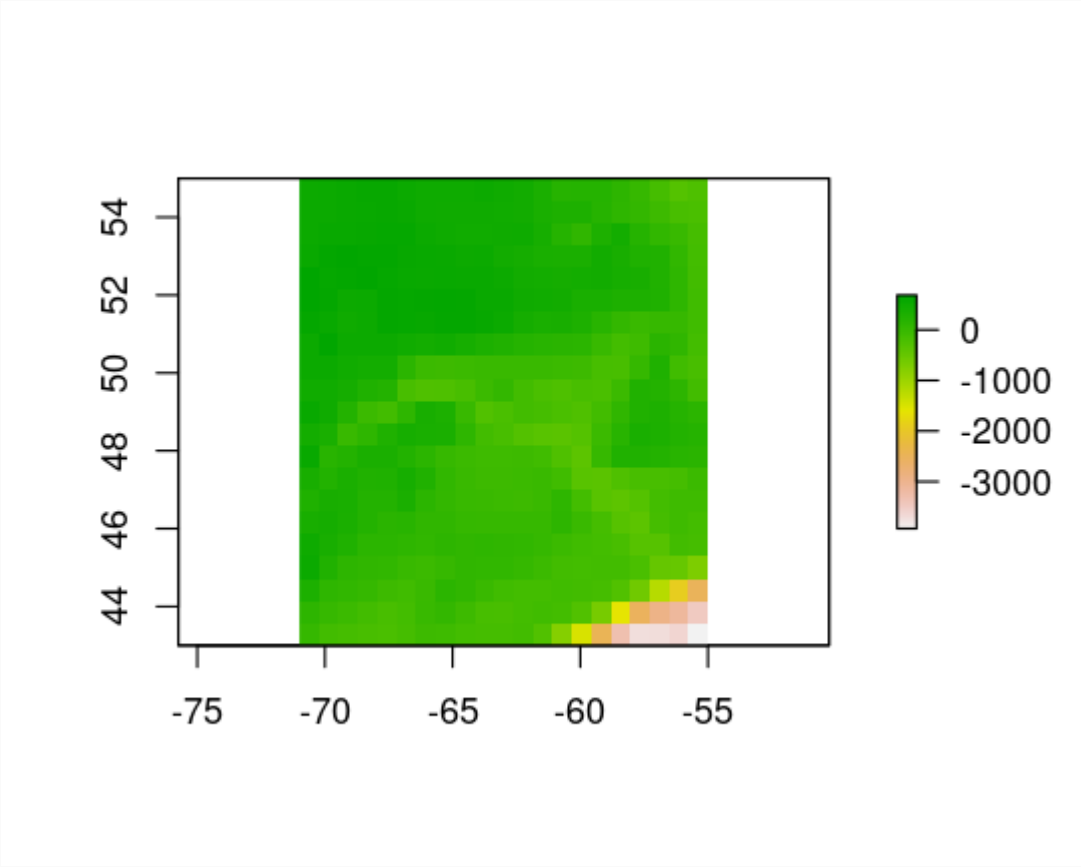
## Work with rasters of different resolutions

# Warping/Resampling with `raster`

```
# create a raster with the given resolution
mr ← matrix(runif(21*21), 21, 21)
rar_template1 ← raster(mr, xmn = -71, xmx = -55, ymn = 43, ymx = 55,
    crs = projection(rar)) # create template
plot(rar_template1)
```

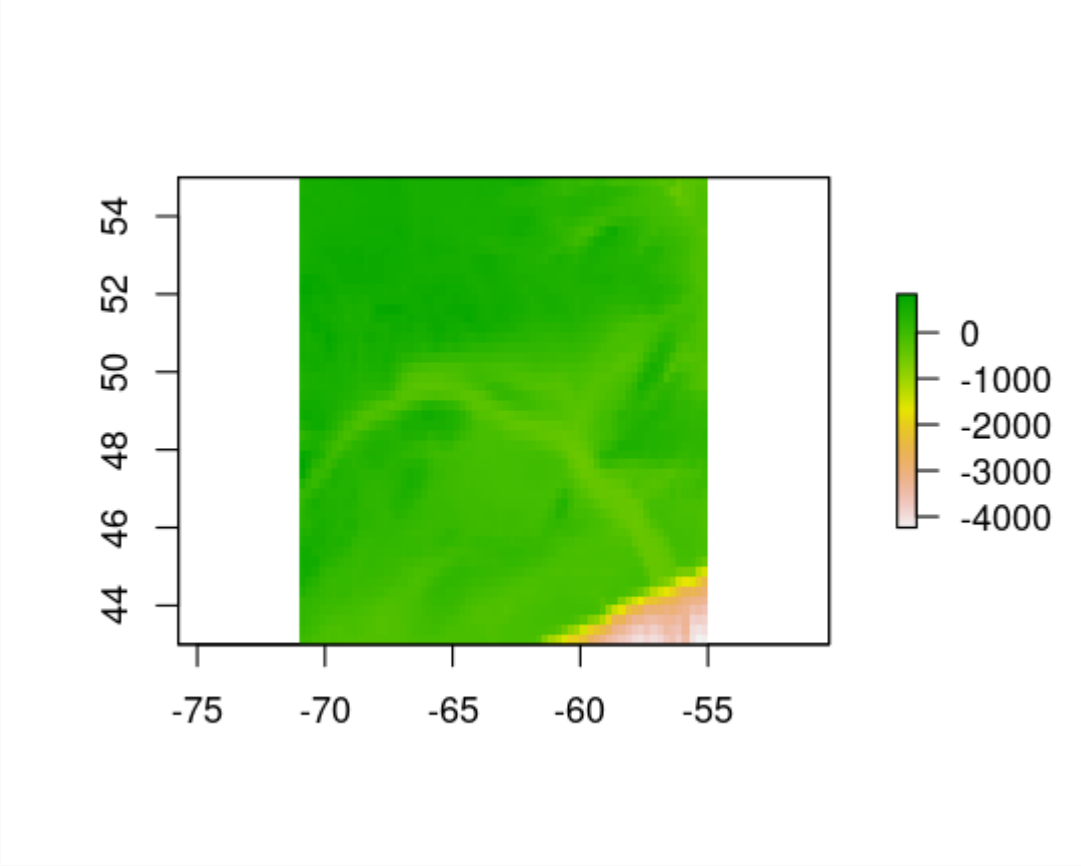
# Warping/Resampling with `raster`

```
rar_w1 ← resample(rar, rar_template1)
plot(rar_w1)
```



# Warping/Resampling with `raster`

```
rar_template2 ← raster(xmn = -71, xmx = -55, ymn = 43, ymx = 55,
  crs = projection(rar), resolution = .25) # create template
plot(resample(rar, rar_template2))
```

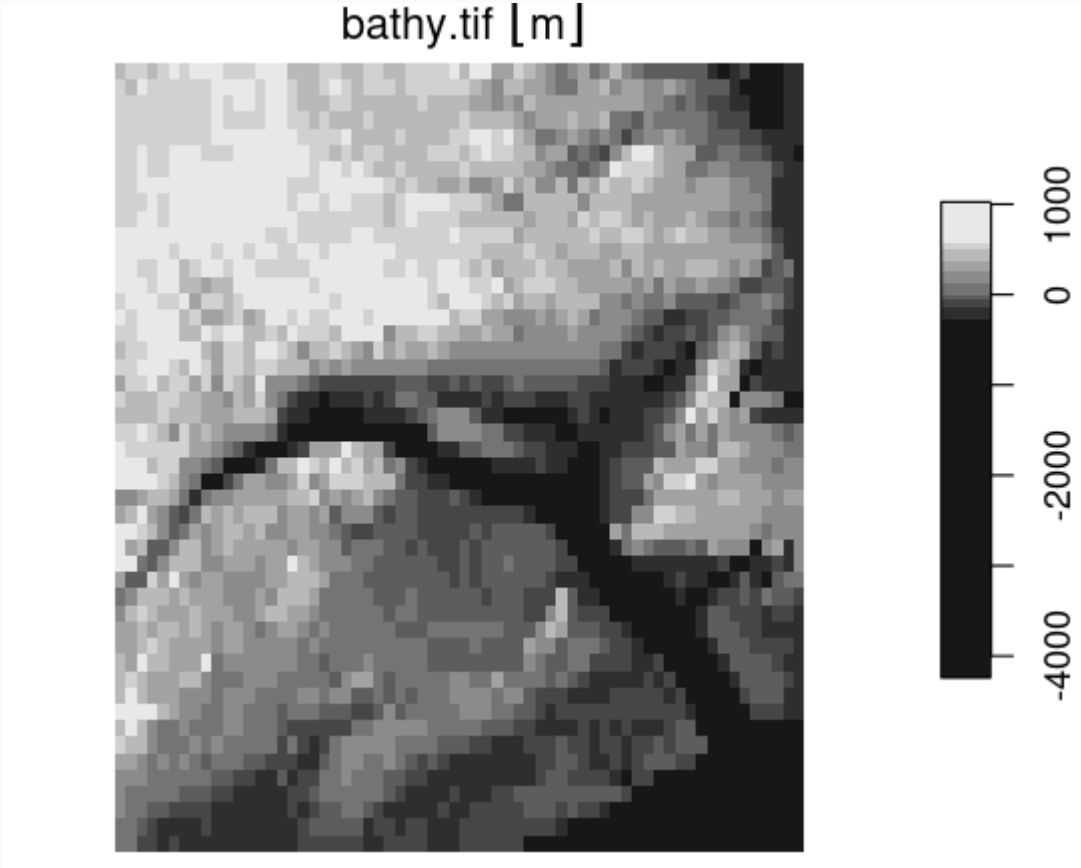


# Warping/Resampling with `stars`

```
ras_template1 ← st_as_stars(st_bbox(ras), nx = 21, ny = 21,
  values = runif(21 * 21)) # create template
ras_w1 ← st_warp(ras, ras_template1)
plot(ras_w1)
```

# Warping/Resampling with `stars`

```
ras_w2 ← st_warp(ras, cellsize = 0.25, crs = st_crs(ras))
plot(ras_w2)
```



# Rasterize

## Vectors → Raster

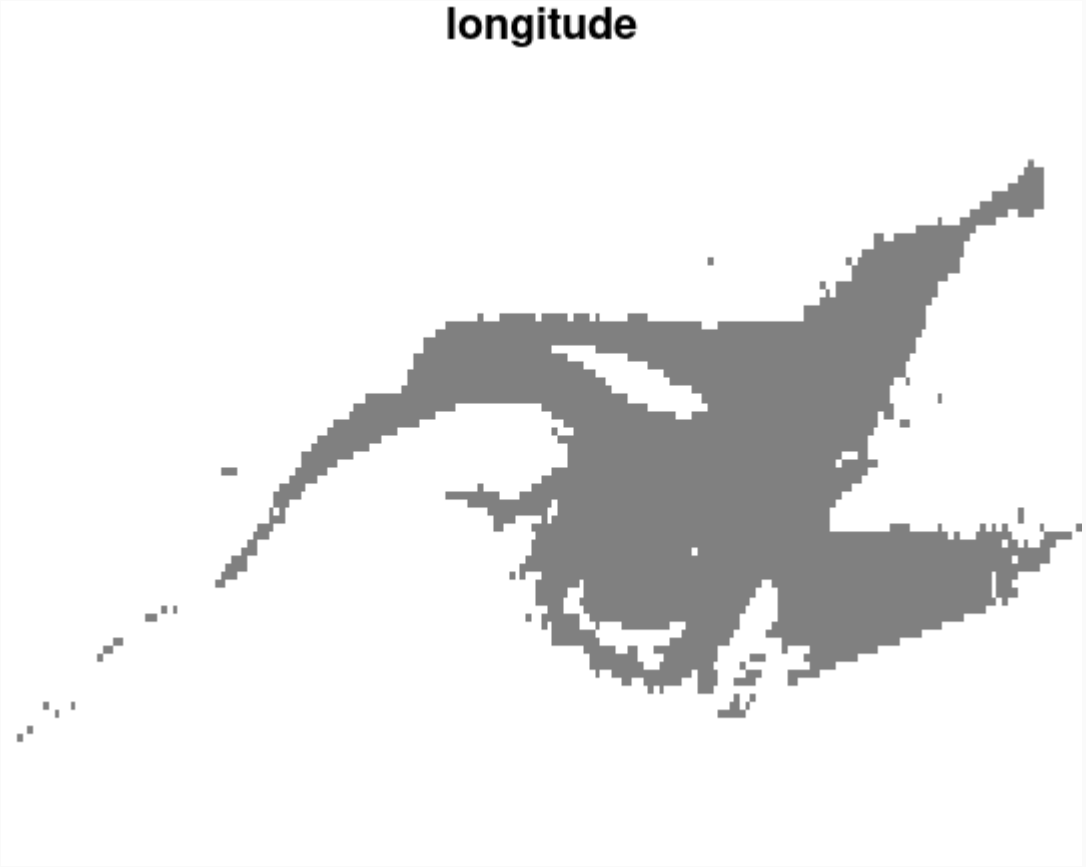
## Create a raster template

# Rasterize with `raster`

```
# not run
stl_r ← rasterize(stl, rar)
plot(stl_r)
```

# Rasterize with `stars`

```
stl_s ← st_rasterize(stl, dy = .1, dx = .1)
plot(stl_s)
```



# Stack

- Collection of rasters
- Same extent/resolution
- Multi-band rasters (satellite images)
- Handle several rasters at once

# Stack with `raster`

2 classes : `RasterBrick` and `RasterStack`

> The main difference is that a RasterStack is loose collection of RasterLayer objects that can refer to different files (but must all have the same extent and resolution), whereas a RasterBrick can only point to a single file.

https://rspatial.org/raster/spatial/4-rasterdata.html#rasterstack-and-rasterbrick

We'll focus on `RasterStack`

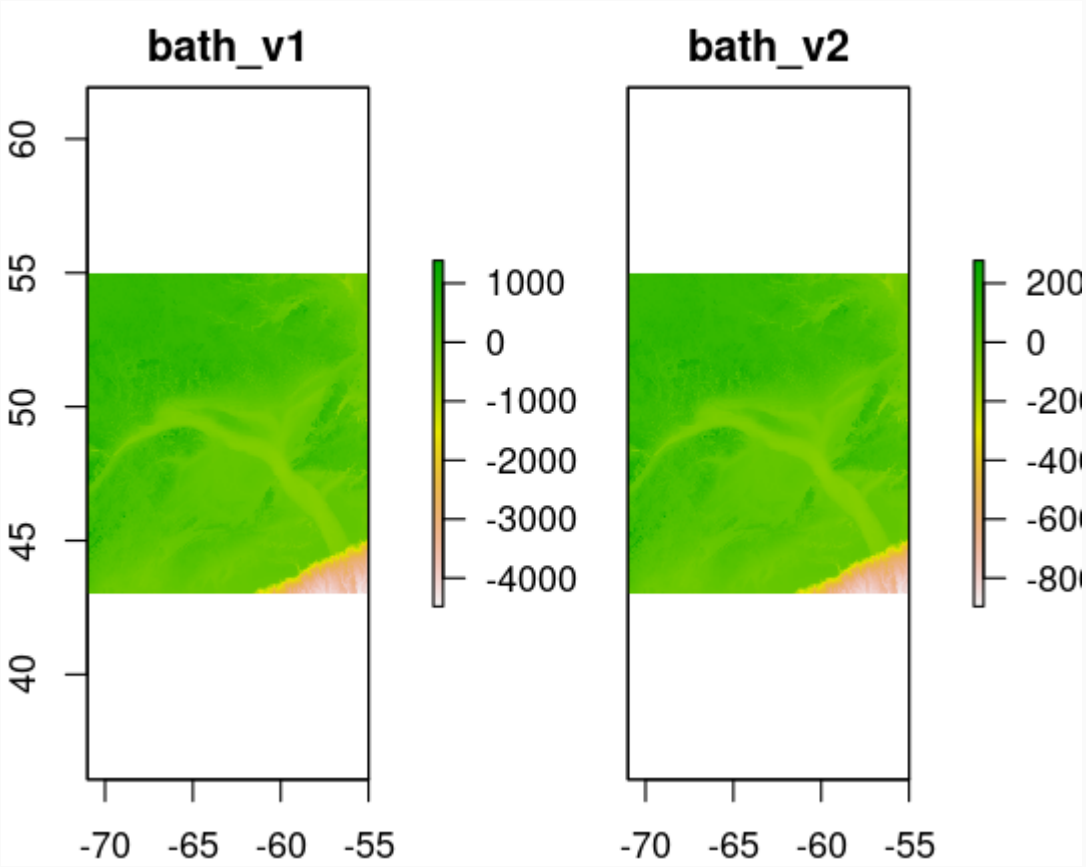
# Stack with `raster`

```
rar_stc ← stack(list(bath_v1 = rar, bath_v2 = rar * 2)) # could be a file path
class(rar_stc)
#> [1] "RasterStack"
#> attr(,"package")
#> [1] "raster"
nlayers(rar_stc)
#> [1] 2
```

```
class(rar_stc[[1]])
#> [1] "RasterLayer"
#> attr(,"package")
#> [1] "raster"
class(rar_stc[[2]])
#> [1] "RasterLayer"
#> attr(,"package")
#> [1] "raster"
```

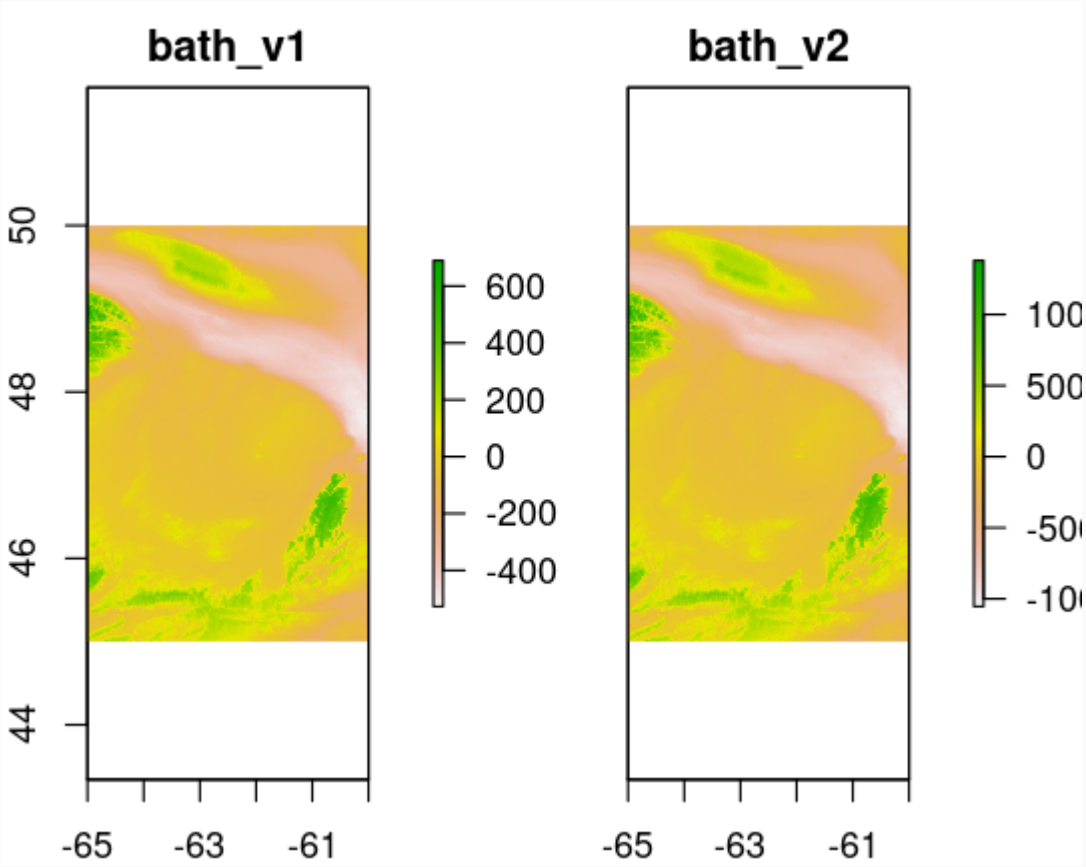
# Stack with `raster`

```
plot(rar_stc)
```



# Stack with `raster`

```
plot(crop(rar_stc, extent(-65, -60, 45, 50)))
```

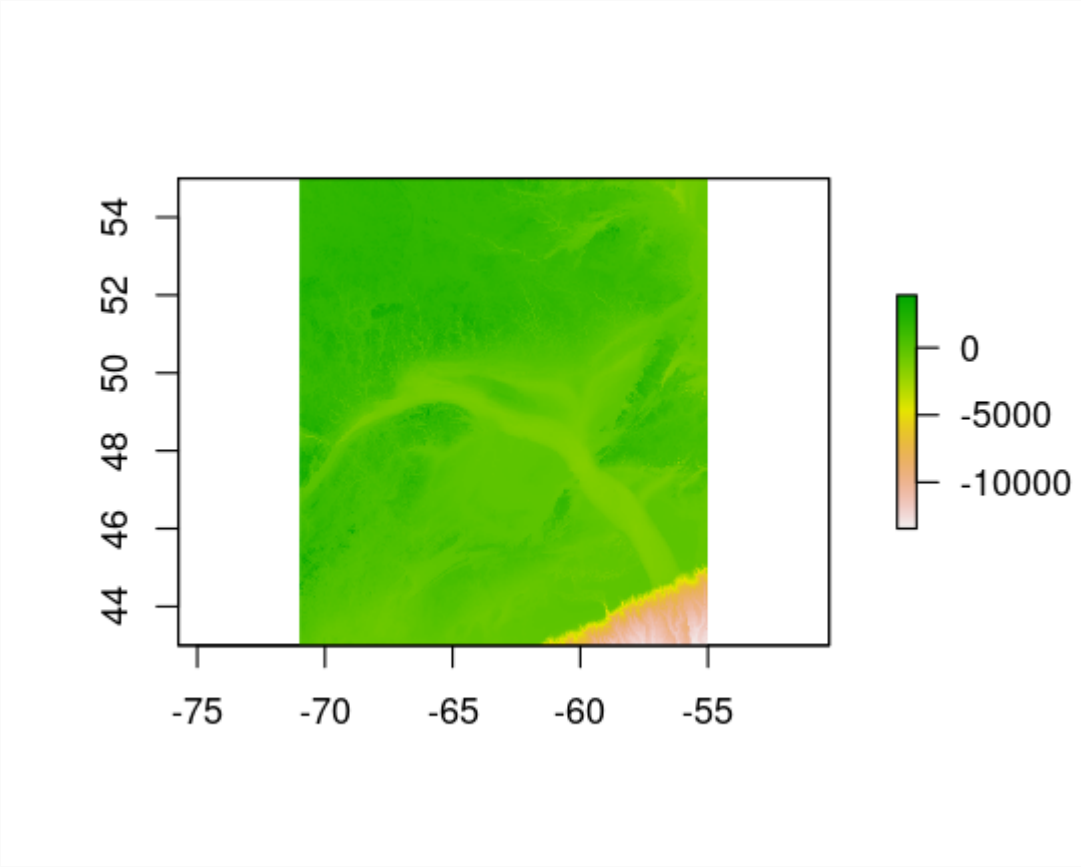


# Stack with `raster`

```
rar_sum ← calc(rar_stc, fun = sum)
rar_sum
#> class      : RasterLayer
#> dimensions : 2880, 3840, 11059200  (nrow, ncol, ncell)
#> resolution : 0.004166667, 0.004166667  (x, y)
#> extent     : -71, -55, 43, 55  (xmin, xmax, ymin, ymax)
#> crs        : +proj=longlat +datum=WGS84 +no_defs
#> source     : memory
#> names      : layer
#> values     : -13470, 4506  (min, max)
```

# Stack with `raster`

```
plot(rar_sum)
```



# Stack with `stars`

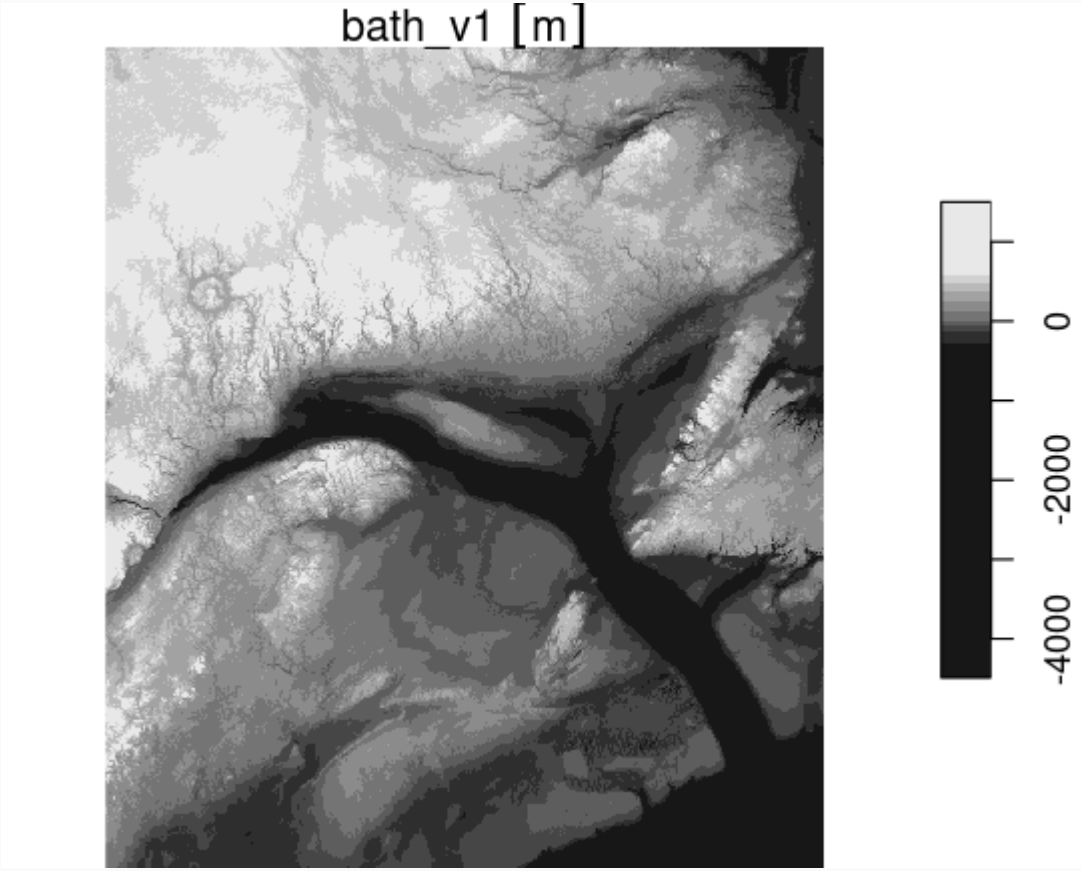
```
ras
#> stars object with 2 dimensions and 1 attribute
#> attribute(s), summary of first 1e+05 cells:
#>  bathy.tif [m]
#>  Min.   :-435.0
#>  1st Qu.:  23.0
#>  Median : 479.0
#>  Mean   : 299.5
#>  3rd Qu.: 540.0
#>  Max.   : 812.0
#> dimension(s):
#>   from   to offset       delta refsys point values
#> x    1 3840    -71  0.00416667 WGS 84 FALSE   NULL [x]
#> y    1 2880     55 -0.00416667 WGS 84 FALSE   NULL [y]
```

# Stack with `stars`

```
ras_stc1 ← c(ras, ras * 2)
names(ras_stc1) ← c("bath_v1", "bath_v2")
ras_stc1
#> stars object with 2 dimensions and 2 attributes
#> attribute(s), summary of first 1e+05 cells:
#>   bath_v1 [m]      bath_v2 [m]
#>  Min.   :-435.0   Min.   :-870
#>  1st Qu.:  23.0   1st Qu.:  46
#>  Median : 479.0   Median : 958
#>  Mean   : 299.5   Mean   : 599
#>  3rd Qu.: 540.0   3rd Qu.:1080
#>  Max.   : 812.0   Max.   :1624
#> dimension(s):
#>   from   to offset       delta refsys point values
#> x    1 3840    -71  0.00416667 WGS 84 FALSE   NULL [x]
#> y    1 2880     55 -0.00416667 WGS 84 FALSE   NULL [y]
```

# Stack with `stars`

```
plot(ras_stc1)
```



# Stack with `stars`

```
ras_stc1[1] # or ras_stc1["bath_v1"]
#> stars object with 2 dimensions and 1 attribute
#> attribute(s), summary of first 1e+05 cells:
#>   bath_v1 [m]
#>  Min.   :-435.0
#>  1st Qu.:  23.0
#>  Median : 479.0
#>  Mean   : 299.5
#>  3rd Qu.: 540.0
#>  Max.   : 812.0
#> dimension(s):
#>   from   to offset       delta refsys point values
#> x    1 3840    -71  0.00416667 WGS 84 FALSE   NULL [x]
#> y    1 2880     55 -0.00416667 WGS 84 FALSE   NULL [y]
```

# Stack with `stars`

```
ras_stc1[2] # or ras_stc1["bath_v2"]
#> stars object with 2 dimensions and 1 attribute
#> attribute(s), summary of first 1e+05 cells:
#>   bath_v2 [m]
#>  Min.   :-870
#>  1st Qu.:  46
#>  Median : 958
#>  Mean   : 599
#>  3rd Qu.:1080
#>  Max.   :1624
#> dimension(s):
#>   from   to offset       delta refsys point values
#> x    1 3840    -71  0.00416667 WGS 84 FALSE   NULL [x]
#> y    1 2880     55 -0.00416667 WGS 84 FALSE   NULL [y]
```

# Stack with `stars`

```
library(dplyr)
ras_stc1 %>% select("bath_v1")
#> stars object with 2 dimensions and 1 attribute
#> attribute(s), summary of first 1e+05 cells:
#>   bath_v1 [m]
#>  Min.   :-435.0
#>  1st Qu.:  23.0
#>  Median : 479.0
#>  Mean   : 299.5
#>  3rd Qu.: 540.0
#>  Max.   : 812.0
#> dimension(s):
#>   from   to offset       delta refsys point values
#> x    1 3840    -71  0.00416667 WGS 84 FALSE   NULL [x]
#> y    1 2880     55 -0.00416667 WGS 84 FALSE   NULL [y]
```

# Stack with `stars`

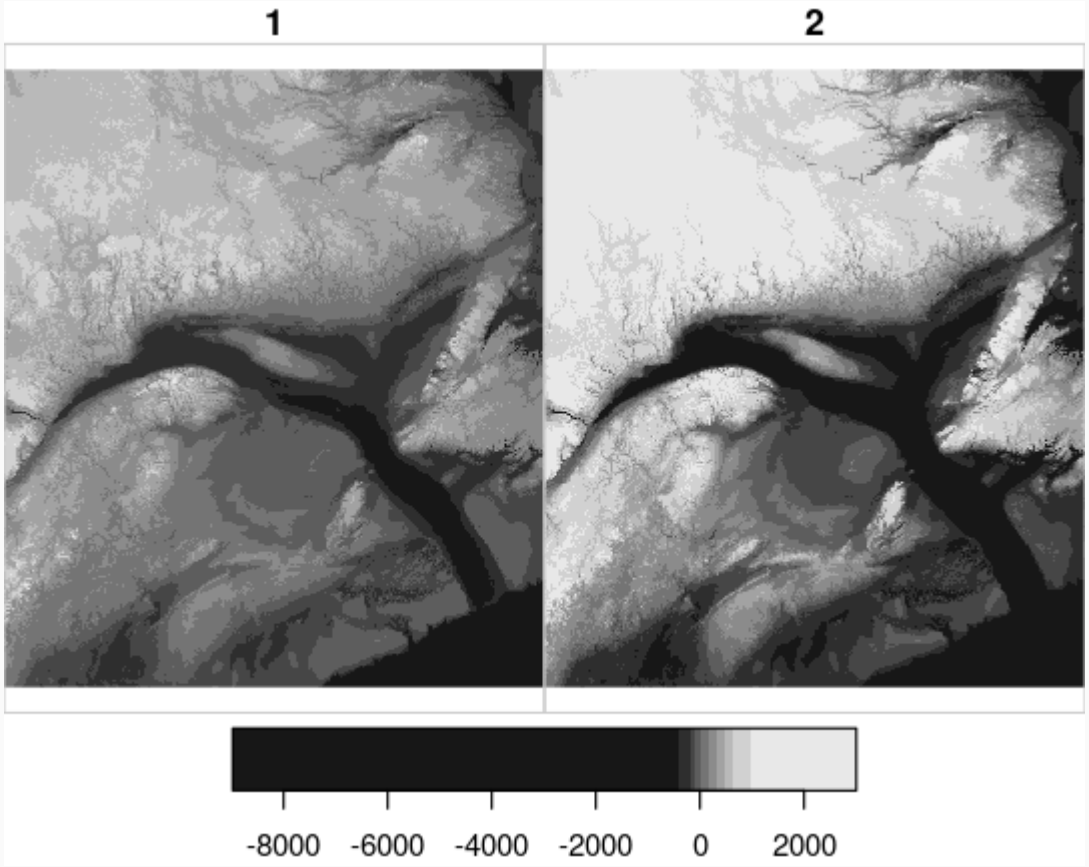
```
ras_stc1 %>% mutate(bath_v3 = bath_v2 * 2)
#> stars object with 2 dimensions and 3 attributes
#> attribute(s), summary of first 1e+05 cells:
#>   bath_v1 [m]      bath_v2 [m]    bath_v3 [m]
#>  Min.   :-435.0   Min.   :-870   Min.   :-1740
#>  1st Qu.:  23.0   1st Qu.:  46   1st Qu.:   92
#>  Median : 479.0   Median : 958   Median : 1916
#>  Mean   : 299.5   Mean   : 599   Mean   : 1198
#>  3rd Qu.: 540.0   3rd Qu.:1080   3rd Qu.: 2160
#>  Max.   : 812.0   Max.   :1624   Max.   : 3248
#> dimension(s):
#>   from   to offset       delta refsys point values
#> x    1 3840    -71  0.00416667 WGS 84 FALSE   NULL [x]
#> y    1 2880     55 -0.00416667 WGS 84 FALSE   NULL [y]
```

# Stack with `stars`

```
ras_stc2 ← c(ras, ras*2, along = "z")
ras_stc2
#> stars object with 3 dimensions and 1 attribute
#> attribute(s), summary of first 1e+05 cells:
#>  bathy.tif [m]
#>  Min.   :-435.0
#>  1st Qu.:  23.0
#>  Median : 479.0
#>  Mean   : 299.5
#>  3rd Qu.: 540.0
#>  Max.   : 812.0
#> dimension(s):
#>   from   to offset       delta refsys point values
#> x    1 3840    -71  0.00416667 WGS 84 FALSE   NULL [x]
#> y    1 2880     55 -0.00416667 WGS 84 FALSE   NULL [y]
#> z    1    2     NA          NA     NA    NA   NULL
```

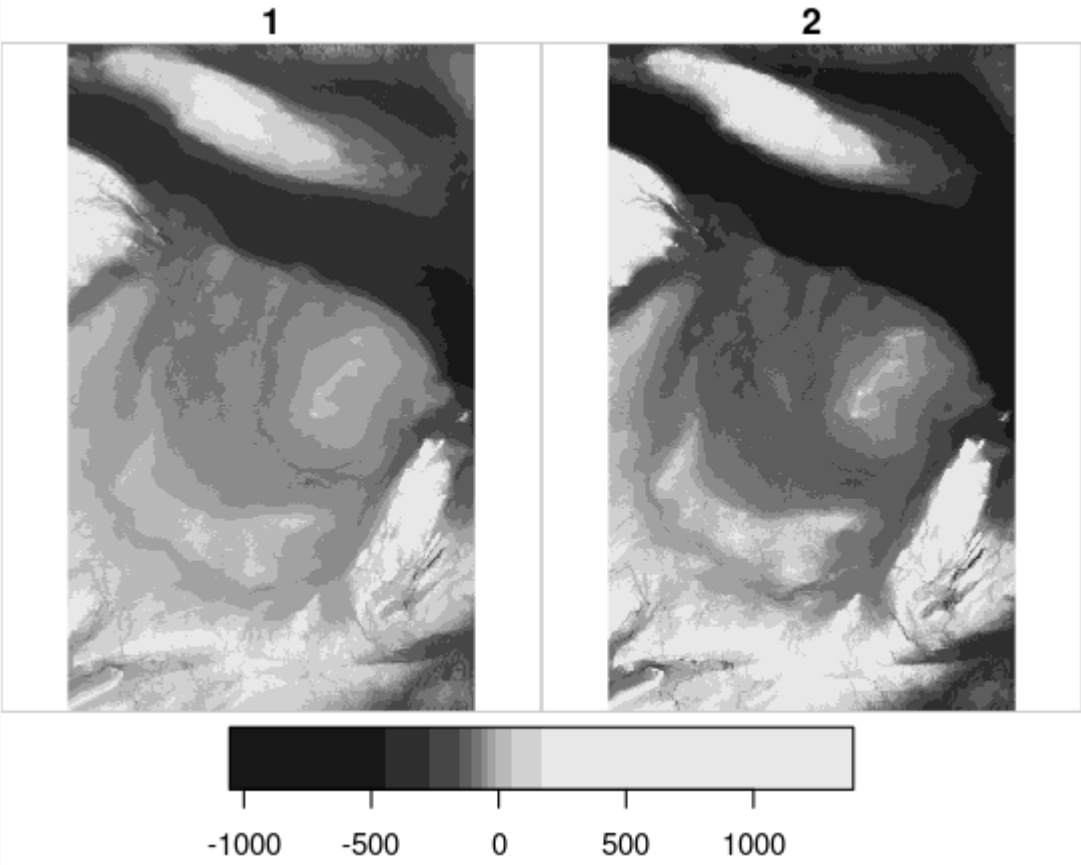
# Stack with `stars`

```
plot(ras_stc2)
```



# Stack with `stars`

```
ext ← st_bbox(c(xmin = -65, xmax = -60, ymin = 45, ymax = 50), crs = 4326)
plot(st_crop(ras_stc2, ext))
```

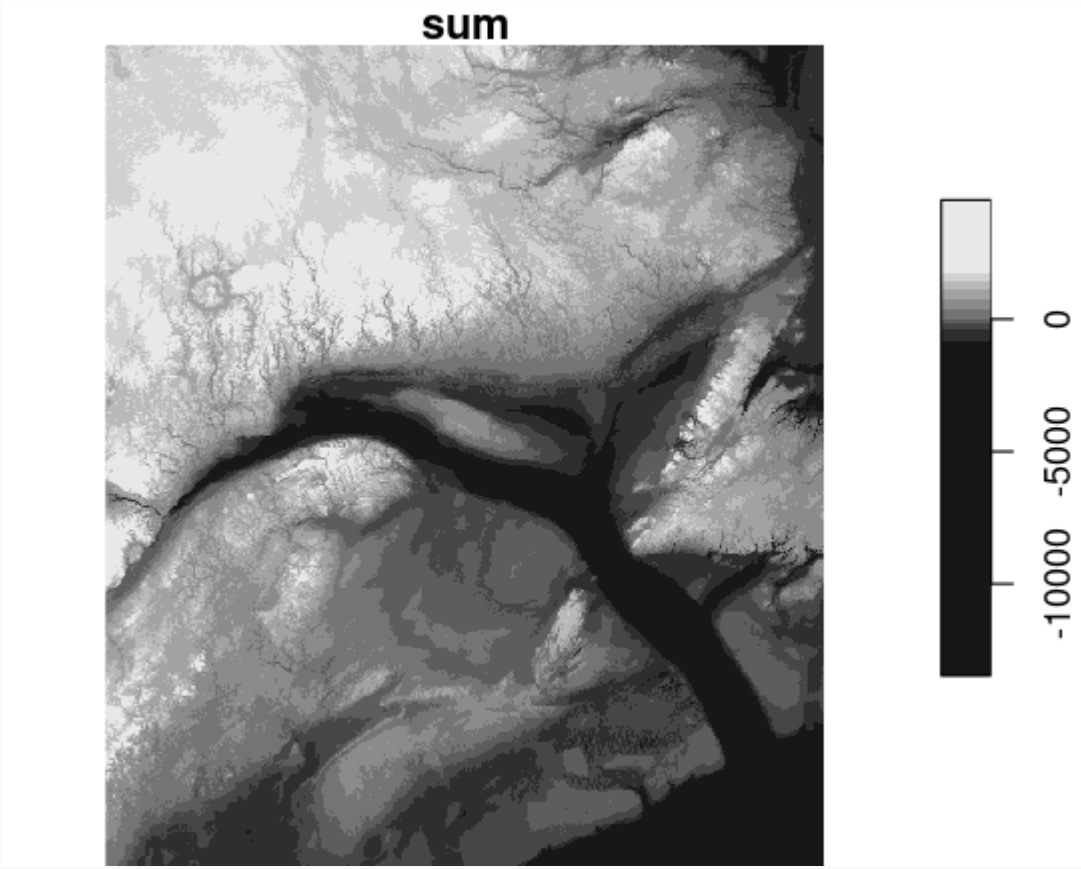


# Stack with `stars`

```
(ras_ap ← st_apply(ras_stc2, c(1, 2), sum))
#> stars object with 2 dimensions and 1 attribute
#> attribute(s), summary of first 1e+05 cells:
#>       sum
#>  Min.   :-1305.0
#>  1st Qu.:   69.0
#>  Median : 1437.0
#>  Mean   :  898.6
#>  3rd Qu.: 1620.0
#>  Max.   : 2436.0
#> dimension(s):
#>   from   to offset       delta refsys point values
#> x    1 3840    -71  0.00416667 WGS 84 FALSE   NULL [x]
#> y    1 2880     55 -0.00416667 WGS 84 FALSE   NULL [y]
```

# Stack with `stars`

```
plot(ras_ap)
```



# Recap

| Action | `raster` | `stars` |
|---|---|---|
| Get projection | `projection()` | `st_crs()` |
| Get bounding box | `bbox()` | `st_bbox()` |
| Change projection | `projectRaster()` | `st_transform()` |
| Crop | `crop()` | `st_crop()` |
| Mask | `mask()` | `[]←` |
| Resample | `projectRaster()` | `st_warp()` |
| Rasterize | `rasterize()` | `st_rasterize()` |
| Stack | `stack()` or `brick()` | `c(along= ... )` |
| Apply functions on stacks | `calc()` | `st_apply()` |

https://r-spatial.github.io/stars/articles/stars6.html

# Visualize

Static visualization (~45min)

# packages for raster visualization

## Static

- `tmap` ✔
- `ggplot2`
  - https://r-spatial.github.io/stars/reference/geom_stars.html
  - https://ggplot2.tidyverse.org/reference/geom_tile.html
- `ggmap`
  - https://github.com/dkahle/ggmap
- `rasterVis`
  - https://oscarperpinan.github.io/rastervis/

## Interactive

- `tmap`
- `leaflet`
- `mapview`

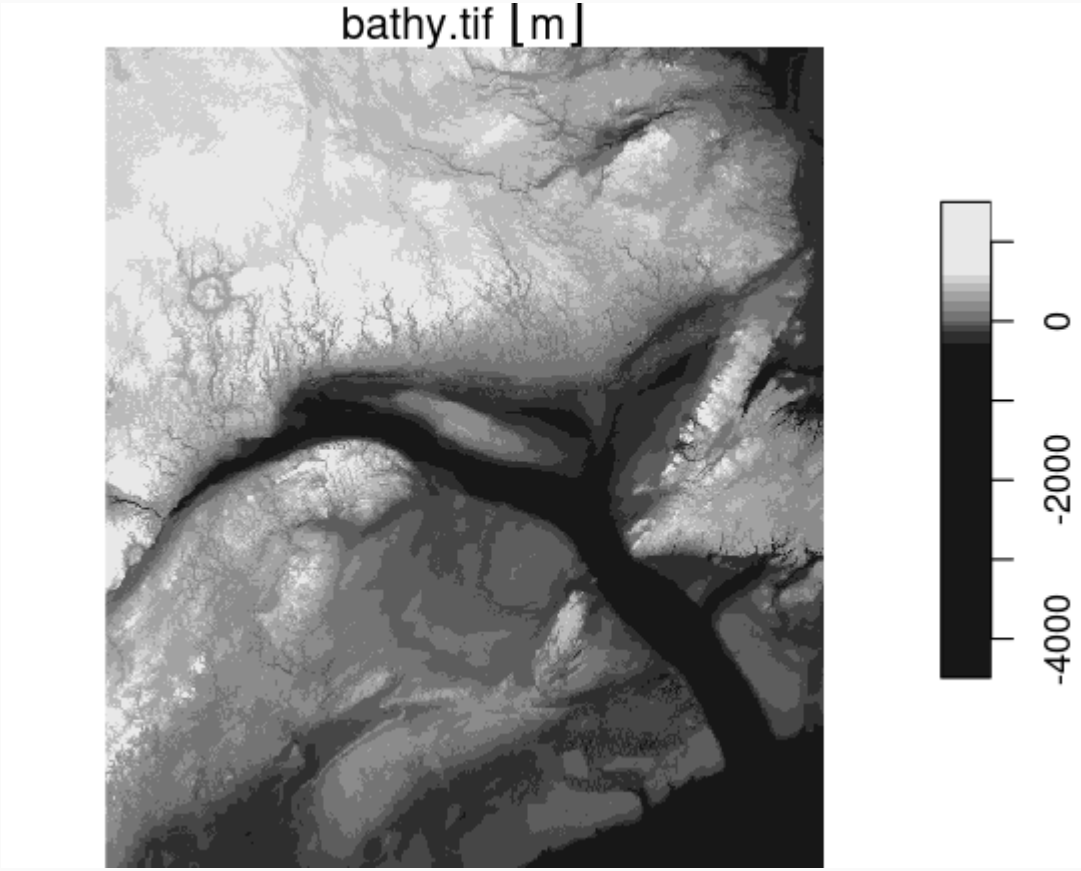
day 2 of the workshop.

# Using `plot()` and `image()`

- `plot()`
  - → `?plot.stars`
  - → `?raster::plot`
- `image()`
  - → `?image.stars`
  - → `?raster::image`
- `par()` : margins, background color, ....

# Using `plot()` and `image()`

```
plot(ras)
```

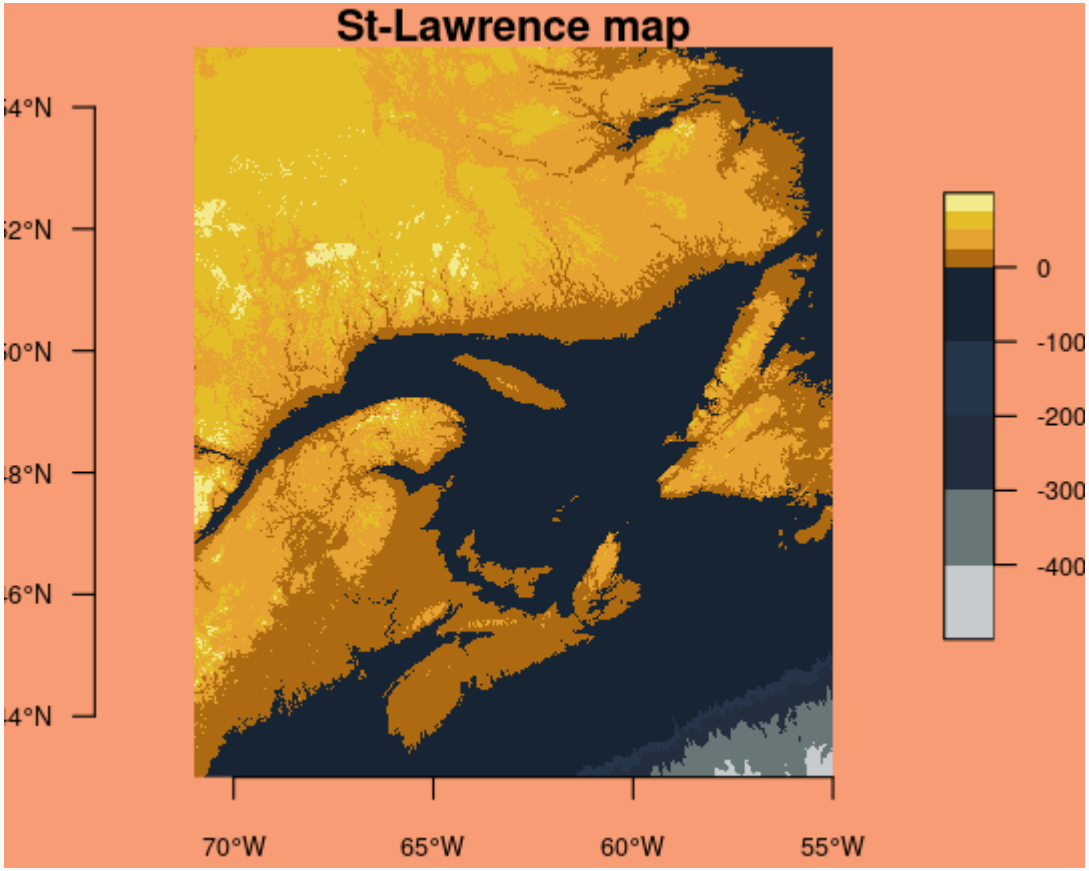


# Using `plot()` and `image()`

```
# breaks
bks ← c(seq(-5000, 0, 1000), 250, 500, 750, 1000)
# cols
cls ← c("#c7cbce", "#687677", "#222d3d", "#25364a", "#172434",
  "#ad6a11", "#e6a331", "#e4be29", "#f2ea8b")
```

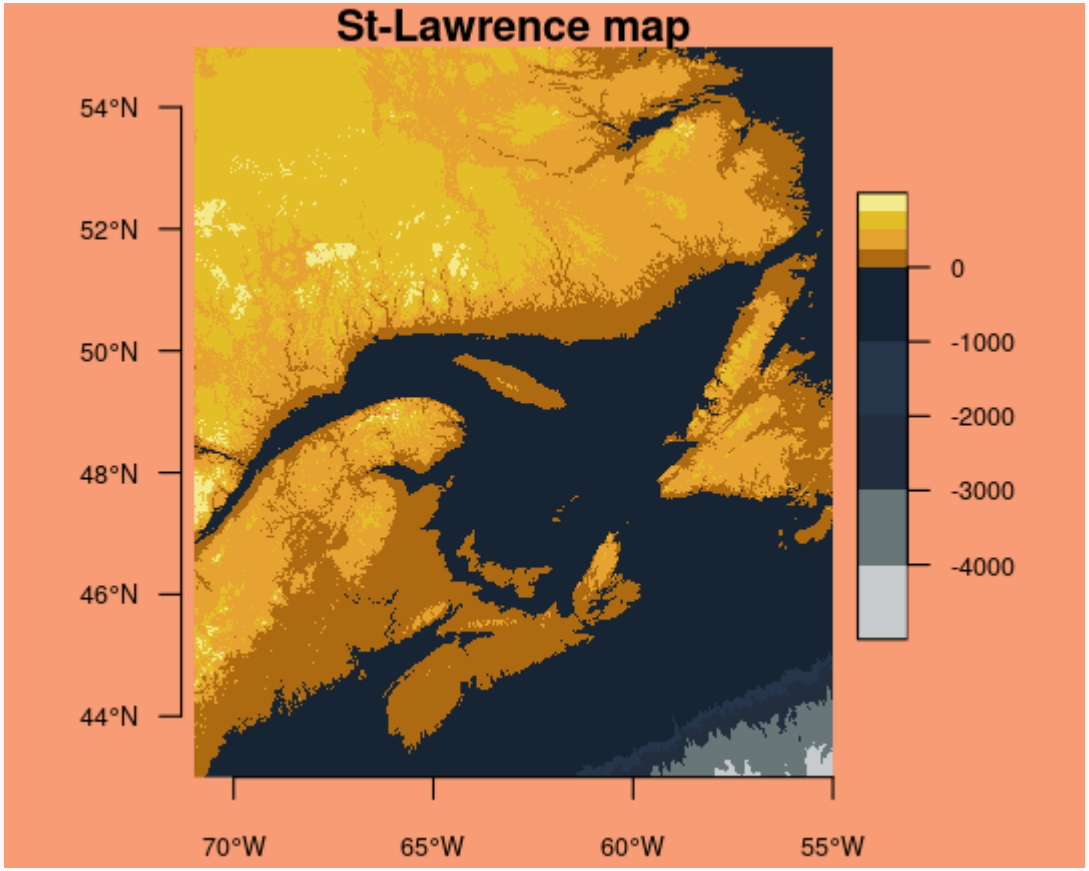
# Using `plot()` and `image()`

```
par(las = 1, bg = "#f79c74", cex.axis = .7, mar = c(2, 2, 2, 4))
plot(ras,  breaks = bks, col = cls, main = "St-Lawrence map", axes = TRUE)
```



# Using `plot()` and `image()`

```
par(las = 1, bg = "#f79c74", cex.axis = .7, mar = c(2, 2, 2, 4), oma = c(0, 2, 0 ,2))
plot(ras,  breaks = bks, col = cls, main = "St-Lawrence map", axes = TRUE)
```



# Masking faster

- Crop first
- Use `simplify` or `st_simplify`
- Rasterize instead

# Masking faster

## Solution proposed by Dewey Dunnington

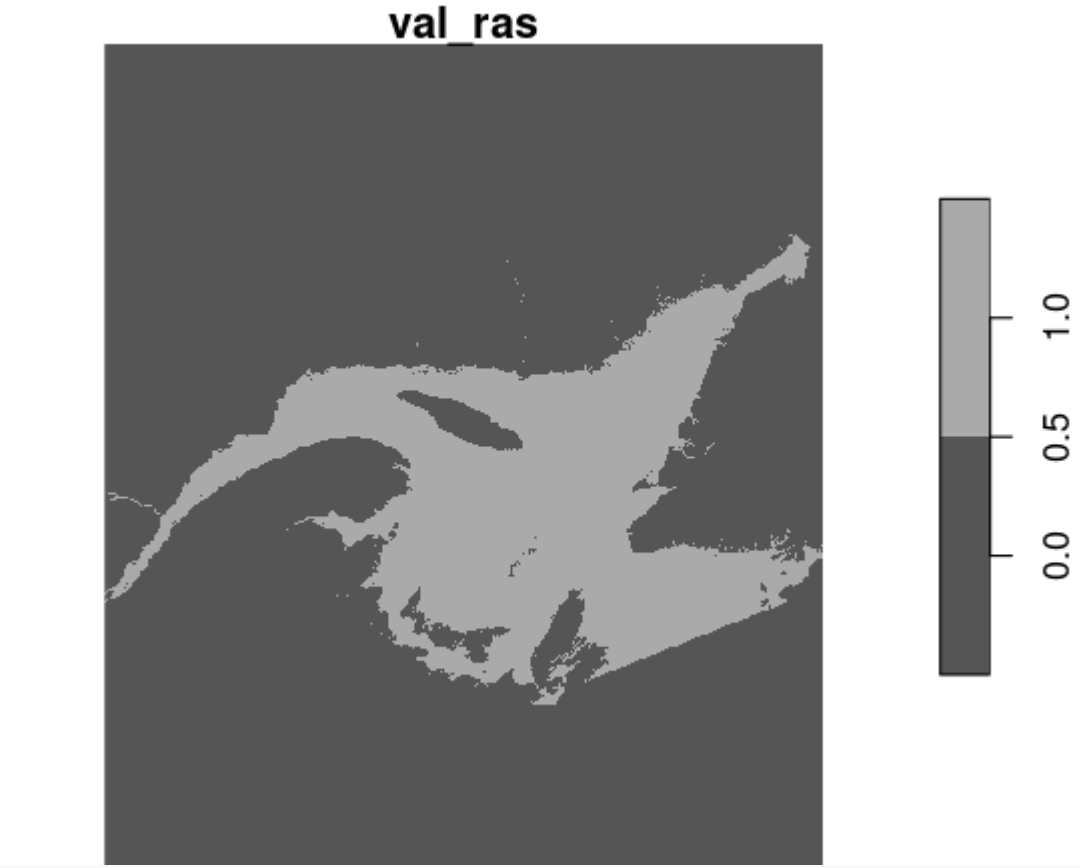
```
# load files
gulf_region ← sf::read_sf("data/st_laurence.geojson")
strs ← stars::read_stars("data/bathy.tif")
# create raster mask
template ← strs
template[[1]][] ← 0
gulf_region$val_ras ← 1

rasterized ← stars::st_rasterize(gulf_region["val_ras"], template = template)
range(rasterized[[1]])
#> [1] 0 1
```

# Masking faster

## Solution proposed by Dewey Dunnington

```
plot(rasterized)
```



# Masking faster

## Solution proposed by Dewey Dunnington

```
# apply raster mask
strs[rasterized == 0] ← NA
plot(strs)
```

# mapedit

README.md

## mapedit

CRAN 0.6.0 | downloads 2369/month | downloads 90K

Interactive editing of spatial data in R | an RConsortium funded project. For additional detail, please see the original proposal.

### Status

`mapedit` is still in active development. We would very much appreciate feedback, ideas, and use cases. The API has stabilized, and wee will use semantic versioning with Github tagged releases to track changes and progress. All changes will also be documented in NEWS.md.

https://github.com/r-spatial/mapedit

# `mapedit` *live*

```
install.packages("mapedit")
library(mapedit)
anticosti ← editMap()
```

# mapedit

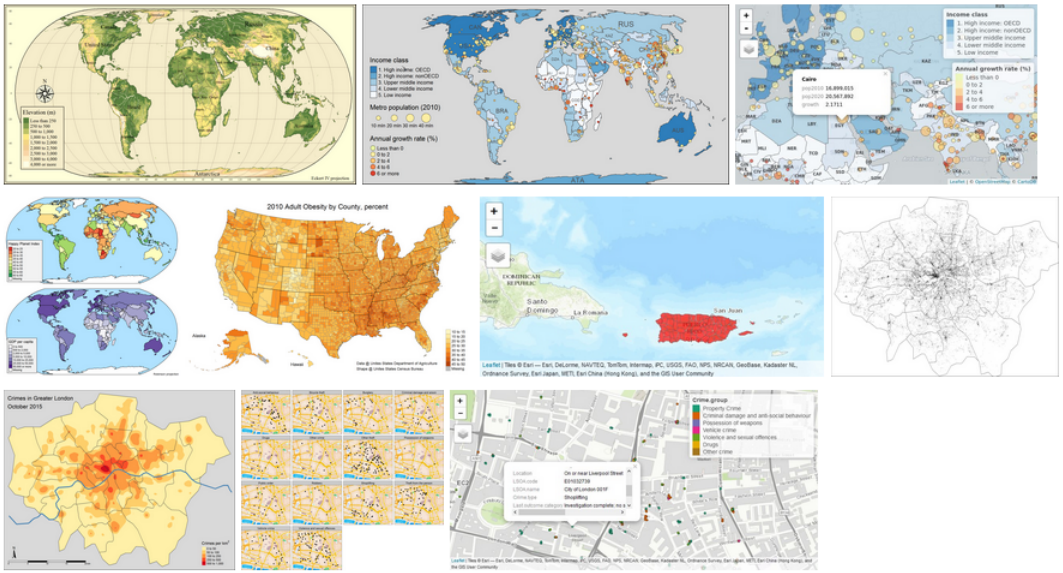
```
stl ← sf::st_read("data/st_laurence.geojson")
png("output/anticosti.png", width = 7, height = 5, units = "in", res = 300)
plot(st_geometry(stl))
plot(st_geometry(anticosti), col = 2, add = TRUE)
dev.off()
```

README.md

# tmap: thematic maps in R

build failing | License GPL v3 | CRAN 3.2 | CRAN NOTE | downloads 15K/month

`tmap` is an actively maintained open-source R-library for drawing thematic maps. The API is based on *A Layered Grammar of Graphics* and resembles the syntax of `ggplot2`, a popular R-library for drawing charts.

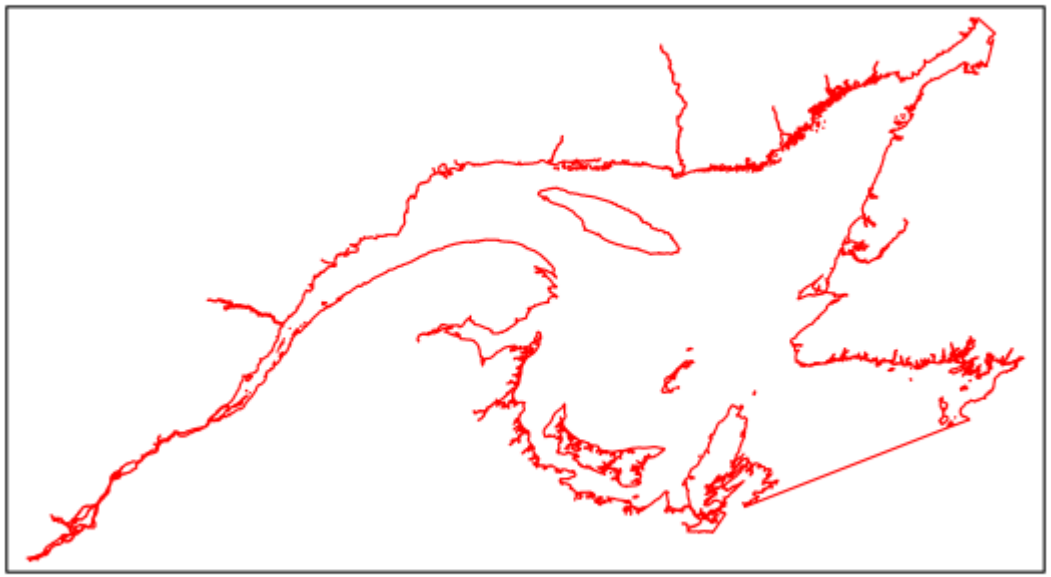


See below the source code for these images.

https://github.com/mtennekes/tmap

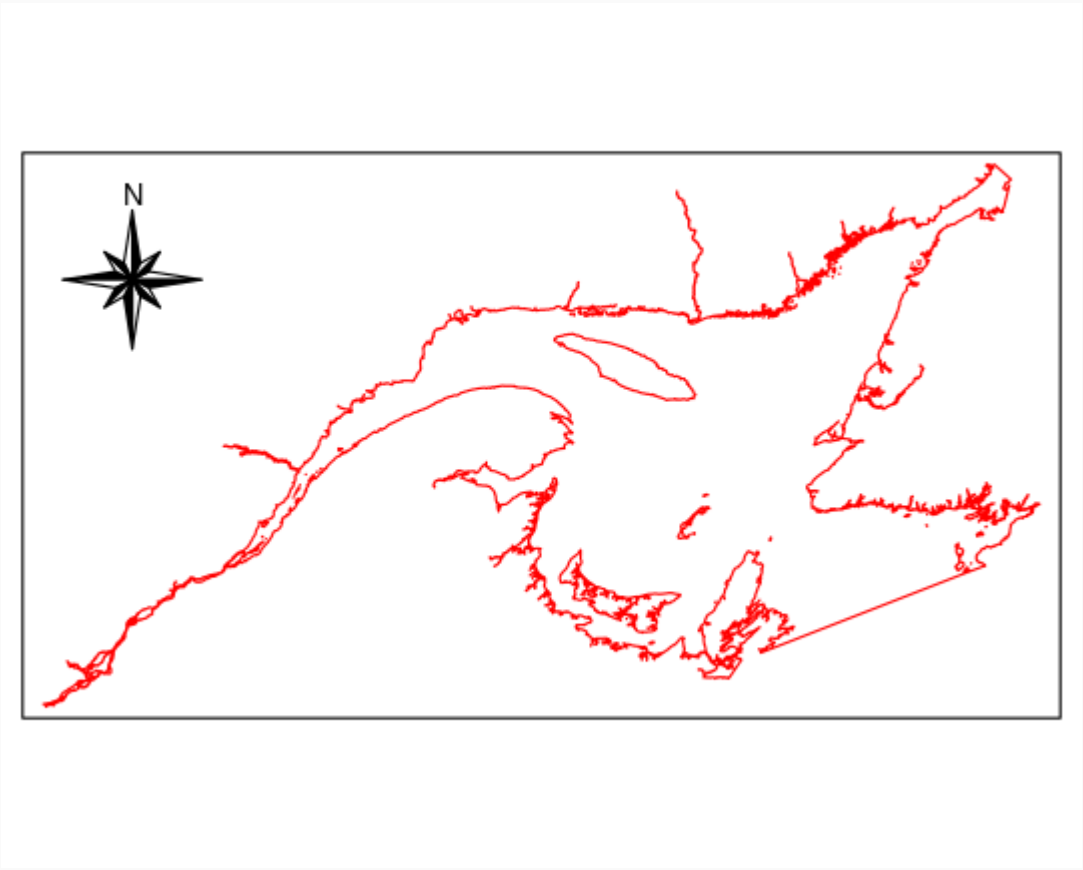
# tmap

```
library(tmap)
map0 ← tm_shape(stl) + tm_borders(col = "red")
map0
```



# tmap

```
map1 ← map0 + tm_compass(type = "8star", position = c("left", "top"))
map1
```



# tmap

- works with `raster` and `stars` (the latter is recommended)

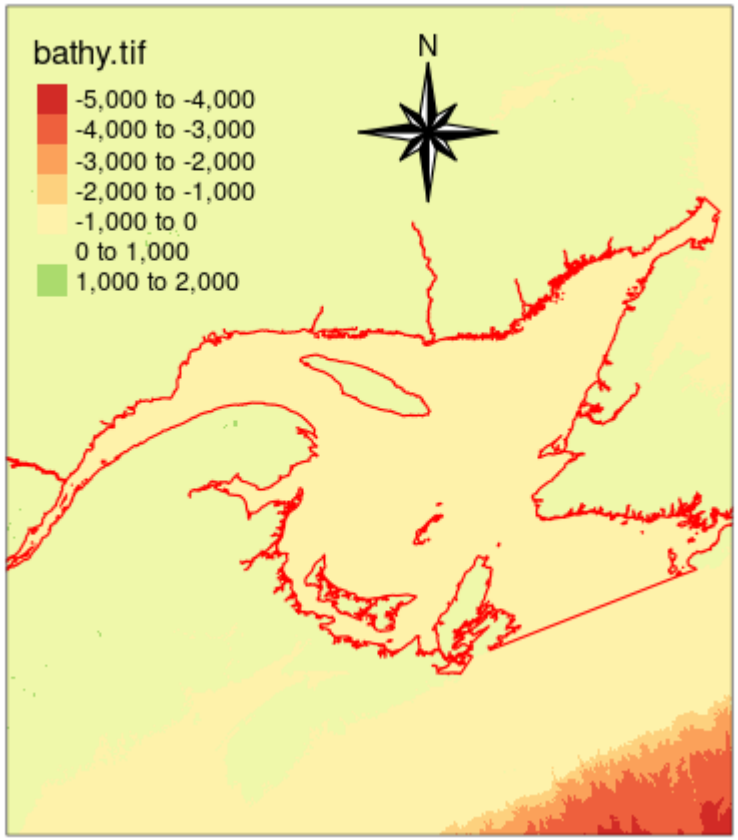
```
# create a stars object from a raster object
st_as_stars(rar)
```

# tmap

```
names(ras)
#> [1] "bathy.tif"
map2 ← tm_shape(ras) + tm_raster("bathy.tif")
```

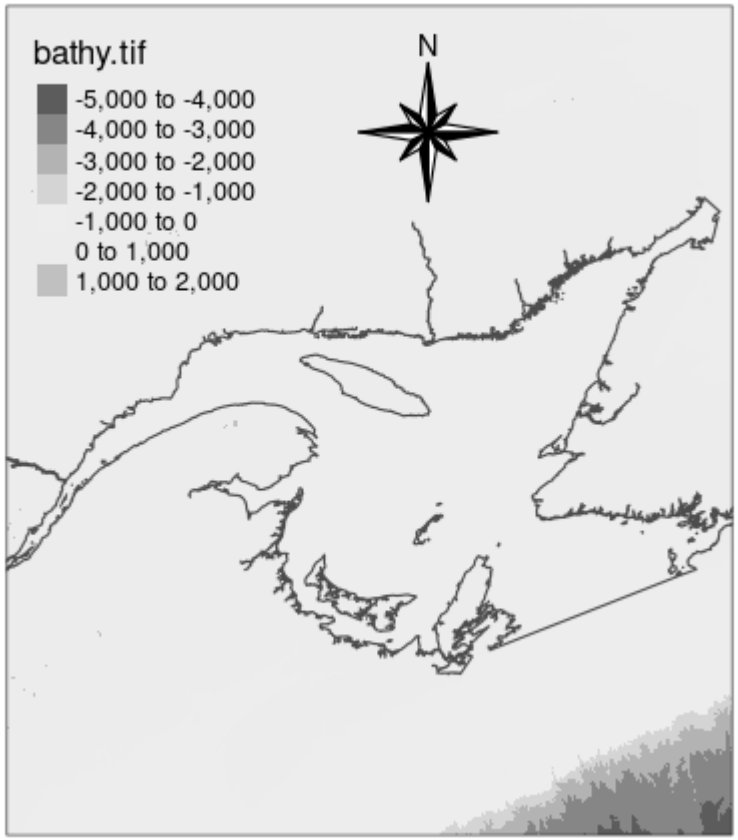
# tmap

```
map3 ← map2 + map1  # the order matters
map3
```



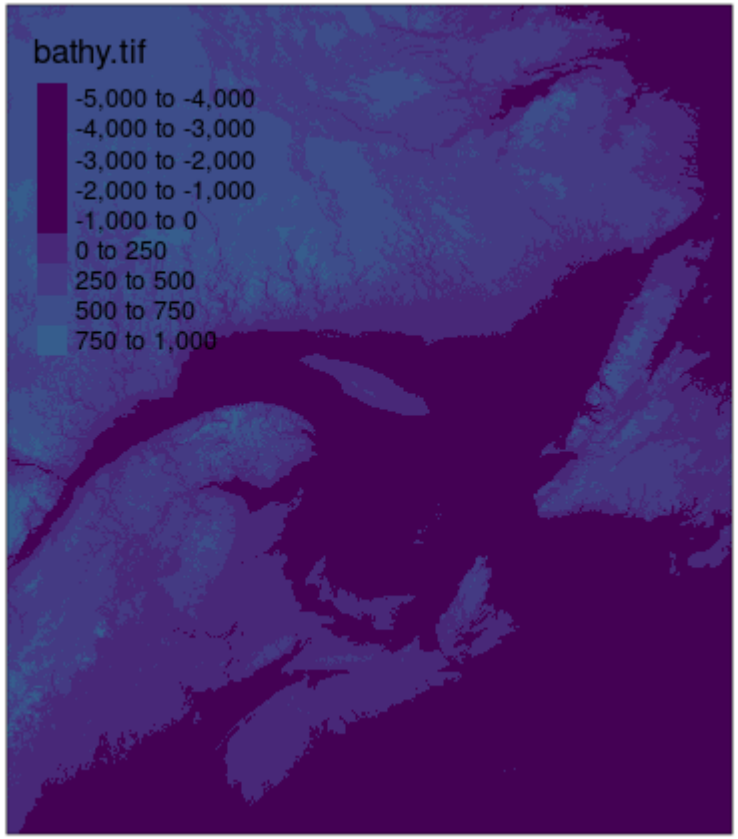
# tmap

```
map4 ← map2 + map1 + tm_style("bw")
map4
```



# tmap

```
map5 ← tm_shape(ras) + tm_raster("bathy.tif", breaks = c(seq(-5000,
    0, 1000), 250, 500, 750, 1000), palette = "viridis")
map5
```



# tmap

- https://geocompr.robinlovelace.net/adv-map.html
- https://github.com/mtennekes/tmap
- https://www.rdocumentation.org/packages/tmap/versions/3.2/topics/tm_layout

# ☆ ☆ Reproduce this map

```
<div class="countdown" id="timer_5fff0bb0" style="bottom:0;left:0;" data-warnwhen="30">
<code class="countdown-time"><span class="countdown-digits minutes">12</span><span class=
</div>
```

# Solution

# Solution

# Resources 🔗

- Geocomputation with R
- Spatial Data Science
- Blog R-spatial
- Open Geospatial Consortium
- https://nowosad.github.io/BioGIS_19/workshop/#64