

# Seascape Ecology

## Lab 04 - Raster Analysis

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## Introduction

Welcome to Seascape Ecology Lab 4. Today we will practice reading in raster data, performing some analyses on those data, making simple maps, and writing out (saving) rasters in different formats.

Remember to refer to the [Geocomputation with R](#) book for more help, as well as [terra's website](#), especially the [tutorials](#).

Remember that these tutorials are all hosted on github (<https://github.com/ryanreisinger/SOES3056>), where you can also find the data and see the R Markdown file used to make the PDF and HTML output. This will be useful for your assessment.

**Remember to set your working directory with `setwd()` before we start.**

## Bathymetry data

You'll often want to use bathymetry data in your work, be it simple for maps, or for seascape analyses. Bathymetry data are 3D: we have x (longitude) and y (latitude) coordinates, and depth values.

There are a few commonly-used sources for global bathymetry data, including ETOPO (<https://www.ngdc.noaa.gov/mgg/global/global.html>) and GEBCO (<https://www.gebco.net/>). You can manually download these data from the websites, but today we'll try and use the `marmap` package () to download data from inside RStudio.

If you can't get `marmap` to work, I have uploaded the files to Blackboard.

First, we need to install `marmap`.

```
# Install marmap library
# By setting 'dependencies = TRUE', I am asking R to also install all the packages marmap needs
# to work
install.packages("marmap",
                  repos = "https://cran.rstudio.com/",
                  dependencies = TRUE)

##
## The downloaded binary packages are in
## /var/folders/yy/g9_xx9fn2dj3b58c1_cxqcrw0000gq/T//RtmpxNIn6B downloaded_packages

# Load (attach) the library
library(marmap)

## Registered S3 methods overwritten by 'adehabitatMA':
##   method           from
```

```

##   print.SpatialPixelsDataFrame sp
##   print.SpatialPixels           sp
##
## Attaching package: 'marmap'
## The following object is masked from 'package:grDevices':
##   as.raster

```

If that worked, we can now download some bathymetry data.

In their [vignette on importing and exporting data with marmap](#), the authors say:

`getNOAA.bathy()` is the easiest way to load data into R, but it depends on the NOAA download protocol, and one must have an internet connection. However, setting the `keep` argument to `TRUE` will save on disk the data downloaded from the NOAA servers when the function is called for the first time. Any subsequent call to `getNOAA.bathy()` with the same list of arguments (i.e. same longitudes, latitudes and resolution) will preferentially load the dataset saved on disk in the current working directory. This allows the users to run scripts without having to query the NOAA servers and download the same data again and again, making the use of `getNOAA.bathy()` possible even off-line.

NOAA hosts the ETOPO dataset, so this function is going to download it.

Let's reproduce the example in the `marmap` vignette '[Analysing bathymetric data in R with marmap](#)'.

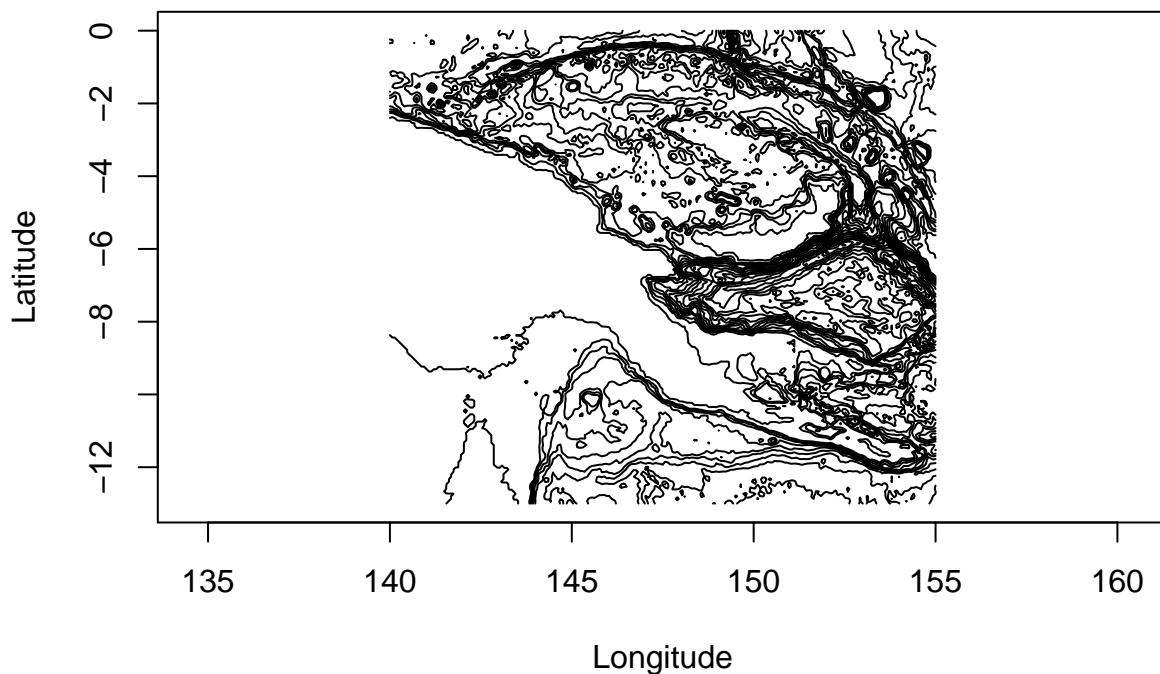
```

# We pass two longitude values and two latitude values to the function to define the extent of the area
papoue<-getNOAA.bathy(lon1=140,lon2=155, lat1=-13,lat2=0,resolution=4)

## Querying NOAA database ...
## This may take seconds to minutes, depending on grid size
## Building bathy matrix ...
# This object is a special kind of raster in marmap's own format. We can see that by asking R about the
class(papoue)

## [1] "bathy"
# marmap has its own plotting method, so we can simply type:
plot(papoue)

```

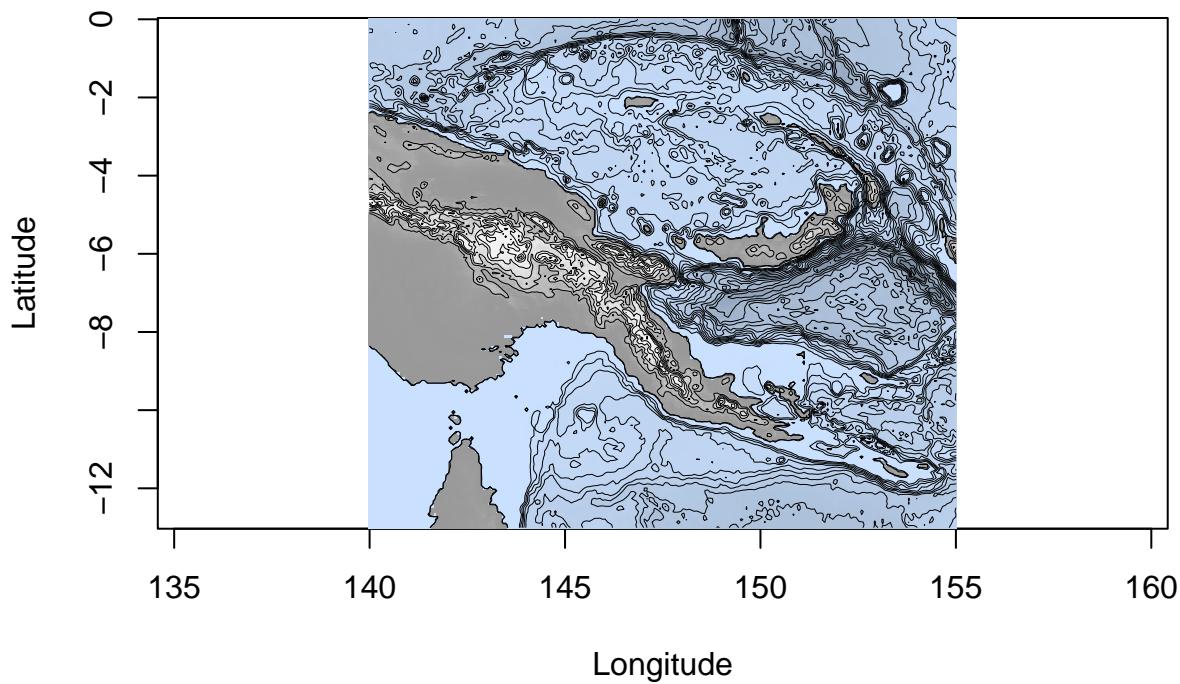


```
# Or we can make the plot a bit nicer, using the examples from marmap
```

```
#Creating color palettes
blues <- c("lightsteelblue4", "lightsteelblue3", "lightsteelblue2", "lightsteelblue1")
greys <- c(grey(0.6), grey(0.93), grey(0.99))

plot(papoue, image = TRUE, land = TRUE, lwd = 0.03, bpal = list(c(0, max(papoue), greys), c(min(papoue)

# Add coastline
plot(papoue, n = 1, lwd = 0.4, add = TRUE)
```



You can work through the marmap vignettes to learn more about making nice bathymetry plots, and doing some simple analyses.

For the moment, we're going to continue our analyses. However, we want to work with a raster in the `terra` package, so let's first convert the class of this object.

```
# First, we'll use one of marmap's functions to convert this object into a raster.  
papoue_raster <- marmap::as.raster(papoue)
```

```
# See, the class has changed  
class(papoue)
```

```
## [1] "bathy"
```

```
class(papoue_raster)
```

```
## [1] "RasterLayer"
```

```
## attr(,"package")
```

```
## [1] "raster"
```

```
# We could use the raster package to analyse this raster now, but remember last week I said that the te
```

```
# First, load terra  
library(terra)
```

```
## terra 1.6.7
```

```
# Then, convert
```

```
papoue_terra <- terra::rast(papoue_raster)
```

```
# Notice the class has changed
```

```
class(papoue_terra)
```

```
## [1] "SpatRaster"
```

```
## attr(,"package")
```

```
## [1] "terra"
```

```
# Now we can plot it with terra
```

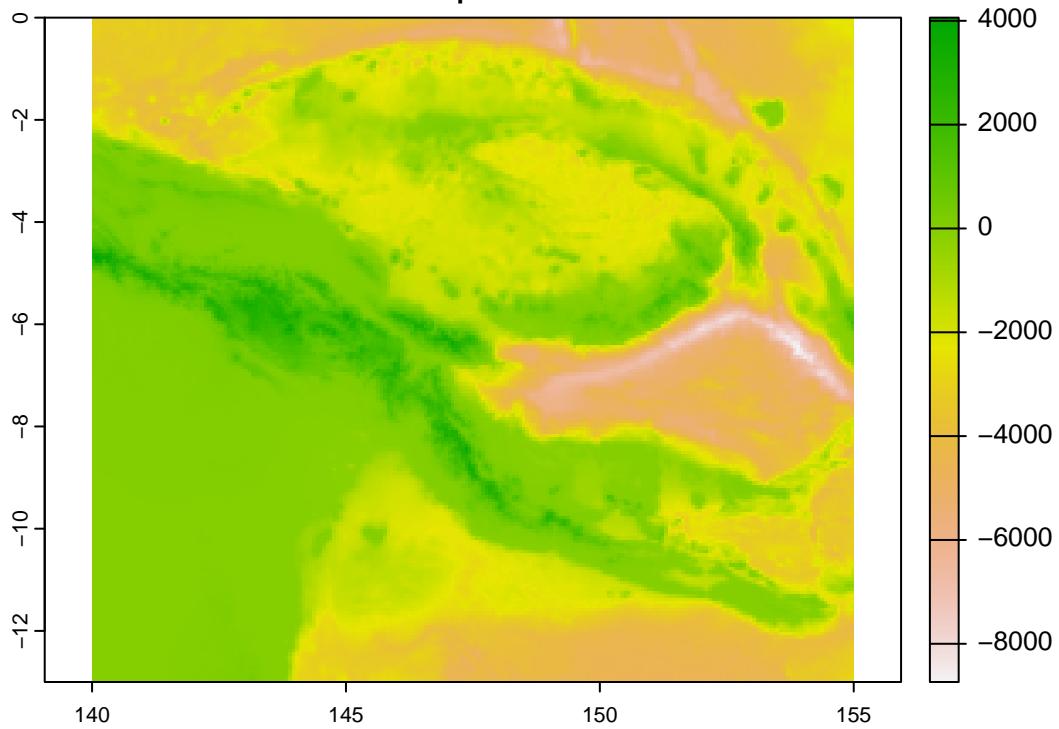
```
# The argument 'main' allows me to give the plot a title
```

```
plot(papoue_terra,
```

```
    axes = TRUE,
```

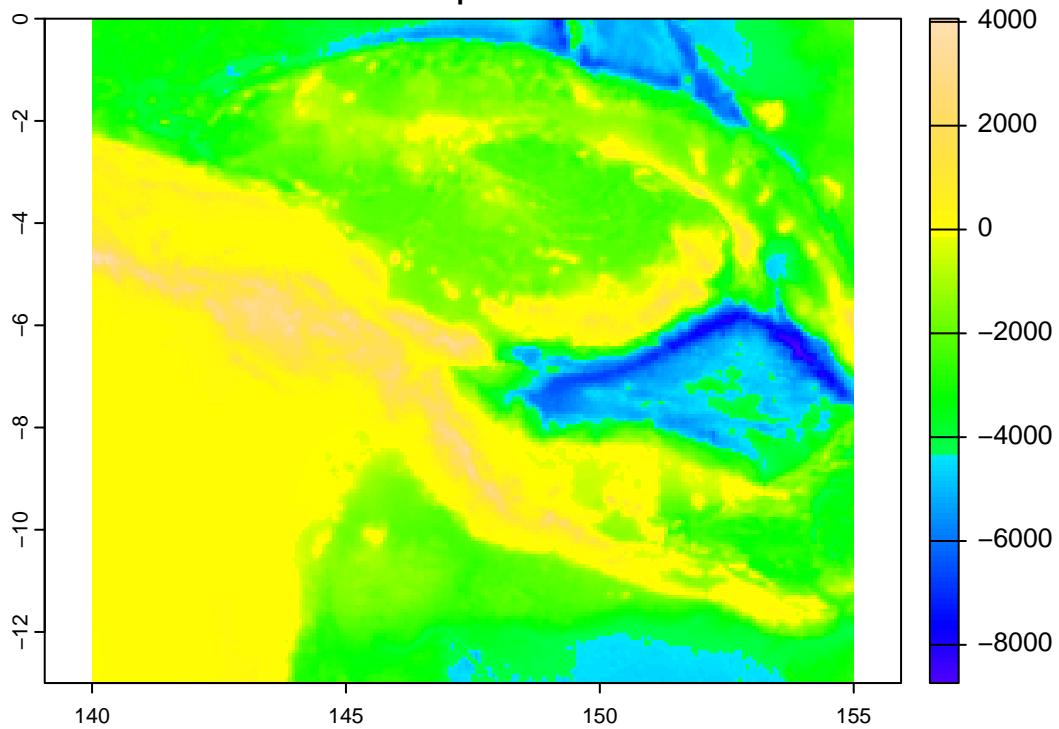
```
    main = "Papoue")
```

Papoue



```
# Let's choose better colours
plot(papoue_terra,
      axes = TRUE,
      main = "Papoue",
      col = topo.colors(125))
```

Papoue



```
# The colour palette is not that smart, it doesn't understand that negative values should be blue. We'll
```

Let's take a look at some of the characteristics of the data we downloaded. Remember in seascape analyses we're interested in the *extent* and *grain* of the data.

We can get all sorts of information simply by 'printing' the object (typing the name into the R console or running the name from RStudio, or we can use functions to get only the information we want.

```
# Print the object to get some information about it
```

```
papoue_terra
```

```
## class : SpatRaster
## dimensions : 195, 225, 1 (nrow, ncol, nlyr)
## resolution : 0.06666667, 0.06666667 (x, y)
## extent : 140, 155, -13, 0 (xmin, xmax, ymin, ymax)
## coord. ref. : +proj=longlat +datum=WGS84 +no_defs
## source : memory
## name : layer
## min value : -8736
## max value : 4061
# Notice the extent and the resolution. Remember that the raster is not projected, so the measurements
# We can also get the values using functions.
```

```
# Resolution
```

```
res(papoue_terra)
```

```
## [1] 0.06666667 0.06666667
```

```
# Extent
```

```
ext(papoue_terra)
```

```
## SpatExtent : 140, 155, -13, 0 (xmin, xmax, ymin, ymax)
```

```
# Minimum and maximum value (this is in meters - the values, or z dimension, of the raster can be in any unit)
```

```
minmax(papoue_terra)
```

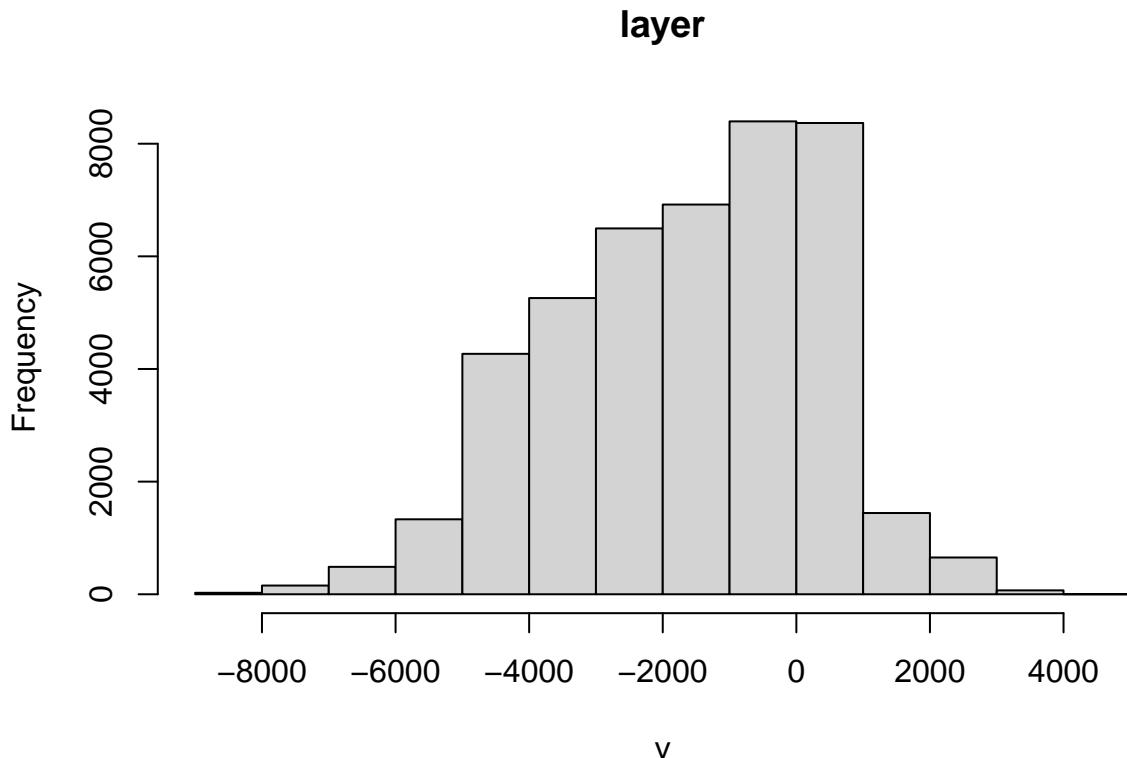
```
## layer
```

```
## min -8736
```

```
## max 4061
```

```
# We could also look at the distribution of values in a histogram
```

```
# notice that I type 'terra::hist()' - this tells R I want to specifically use the 'hist()' function from the terra package
```



## Conceptual models for seascape analyses

We've talked a lot previously about the two models for seascape analyses:

1. The patch-mosaic model
2. The spatial gradient model

### Patch-mosaic

Recall, for the patch-mosaic model we often convert continuous input into **categorical** input by **classification**.

Let's classify our bathymetry raster. For a simple classification exercise, we can decide *a-priori* what we want our categories to be. Although this is simply an example in this lab, you might well do this in practice if you have some basis for the classification.

To use the classification function in `terra`, we first have to define the values.

```
# The classify function in terra has an argument 'rcl', where we can pass a matrix that defines how we want to classify the raster.
# So, let's make a simple one to classify the raster as land and sea. Land values will be positive, and sea values will be negative.
# We can adapt the example given in the 'classify' functions help page:
?classify # scroll down to the examples

## from-to-becomes
# classify the values into land and sea.
# we can't mix numeric and character values here, so we use 1 to indicate sea and 2 to indicate land.
# all values >= -15,000 and <= -1 become 1, etc.
m <- c(-15000, -1, 1,
       0, +15000, 2)
rclmat <- matrix(m, ncol=3, byrow=TRUE)
```

```

# We used huge values for the minum (-15,000) and maximum (+15,000), but remember that we can look up t

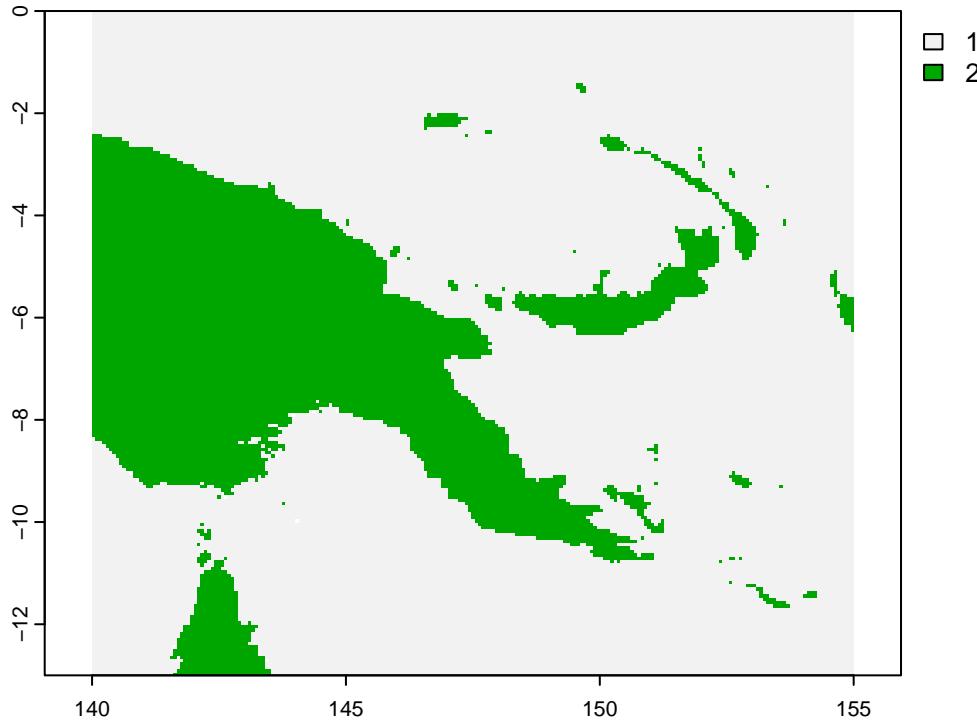
# Have a look at what the matrix looks like
rclmat

##      [,1]  [,2]  [,3]
## [1,] -15000    -1     1
## [2,]       0 15000     2

# Now we can classify our raster
papoue_classified <- classify(papoue_terra, rclmat, include.lowest=TRUE, others = NA) # the argument 'o

# And let's see what happens when we plot it
plot(papoue_classified)

```

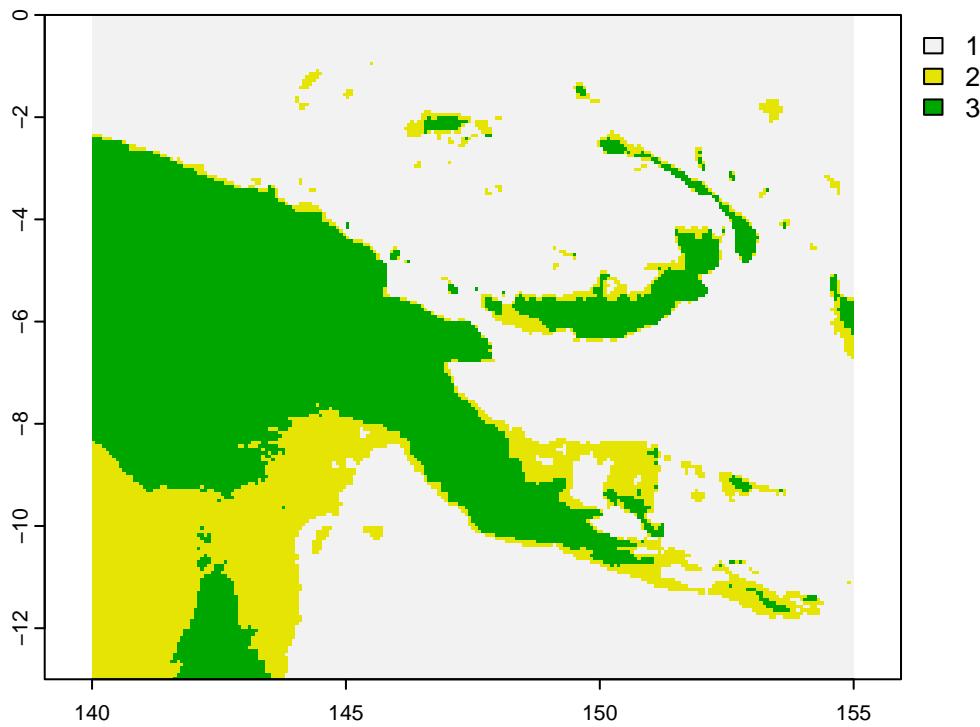


```

# Let's try a slightly more complicated example, where we classify a few bathymetric categories.

# First, we redefine the matrix, then we classify and plot
m <- c(-15000, -200, 1,
       -200, 0, 2,
       0, 15000, 3)
rclmat <- matrix(m, ncol=3, byrow=TRUE)
papoue_classified <- classify(papoue_terra, rclmat, include.lowest=TRUE, others = NA)
plot(papoue_classified)

```

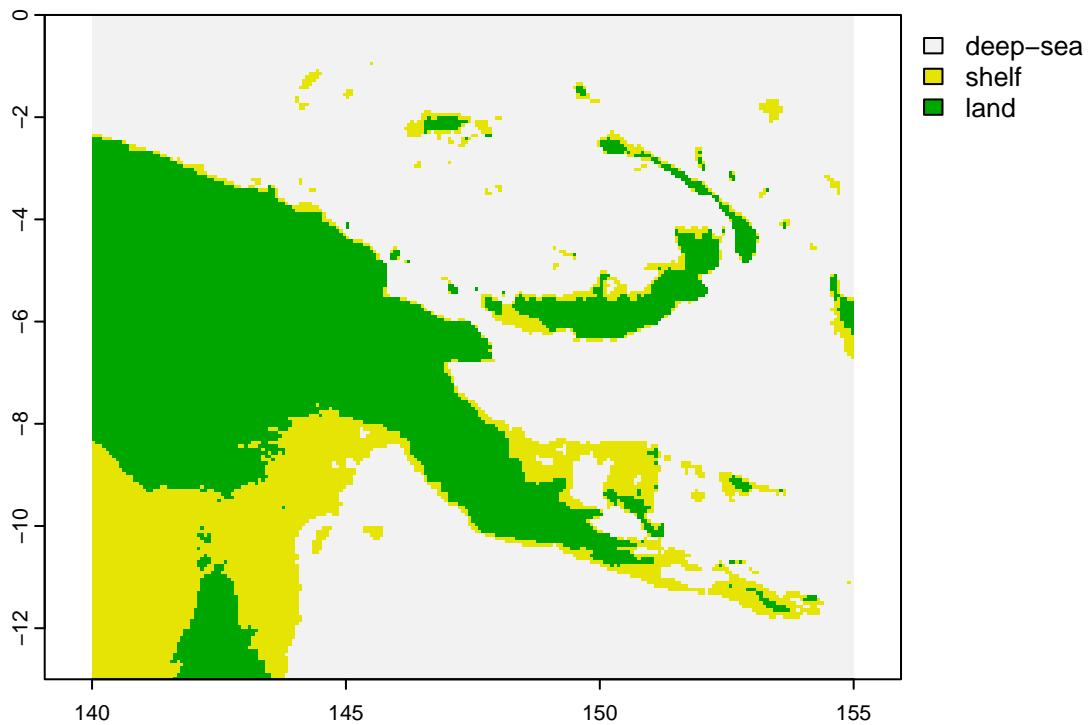


```
# I chose 200 m (-200) to approximately represent the continental shelf edge.
```

```
# We can turn the raster into a truly categorical raster with levels (which work similarly to other factors)
```

```
cls <- data.frame(id=1:3, cover=c("deep-sea", "shelf", "land"))
levels(papoue_classified) <- cls
```

```
# When we plot now, the category names are shown
plot(papoue_classified)
```



### Spatial gradient

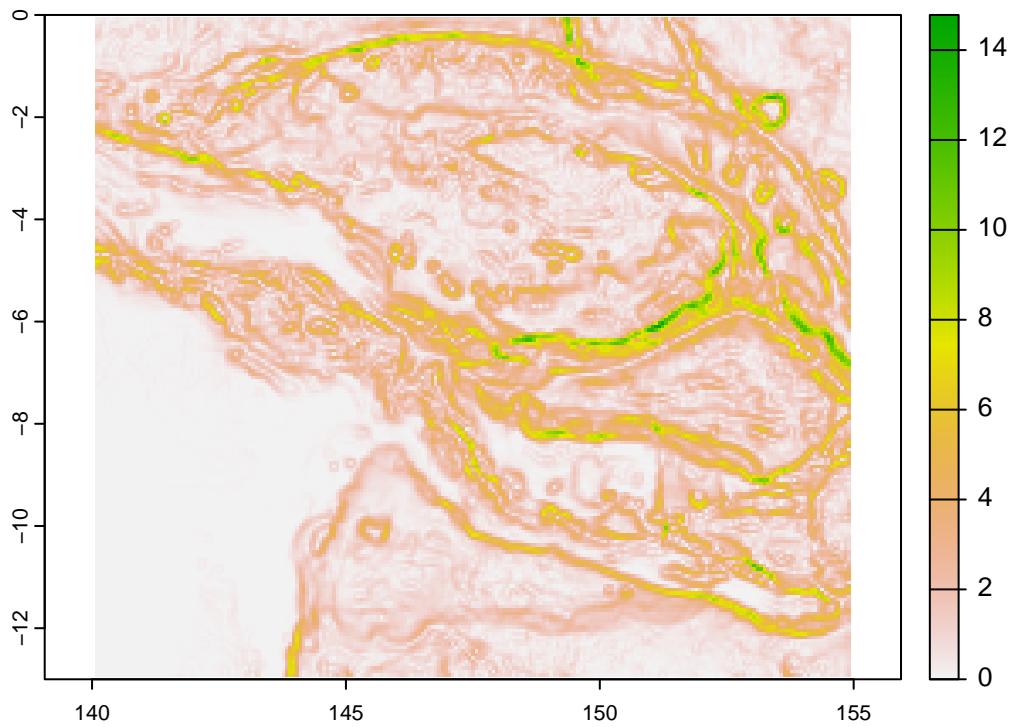
We can also analyse the bathymetry data using the spatial gradient conceptual model. To do this, we use the continuous-value raster - `papoue_terra`.

Recall from Chapter 2 of the seascape ecology textbook (and Lecture 04), that we are often interested in *morphometrics* of the seafloor.

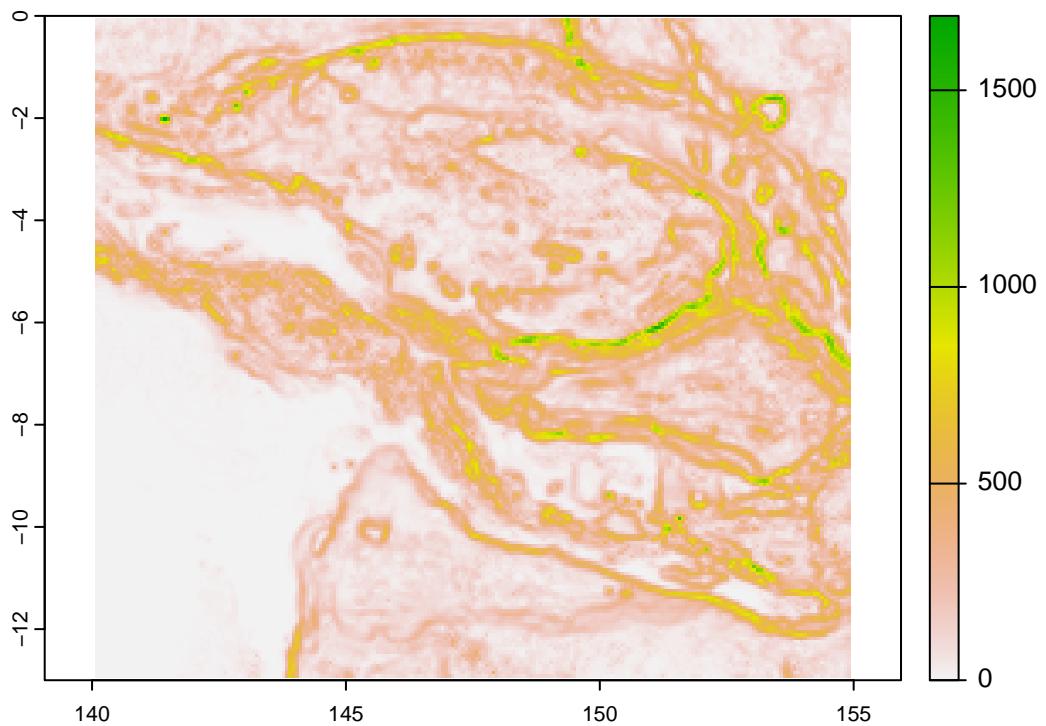
We can easily calculate some simple morphometrics using the `terrain` function in `terra`.

```
# The specific metric we want is set by passing different values to the 'v' argument in the function.

# Slope
plot(terrain(papoue_terra, v = "slope"))
```



```
# notice that I am wrapping the function in a plot call to immediately visualise the result. It is not
# Terrain Roughness Index (TRI)
plot(terrain(papoue_terra, v = "TRI")) # the output is very similar to slope
```



The paper by Phil Bouchet et al., which I mentioned in Lecture 04, has a detailed discussion of different morphometrics and their importance to marine predators: <https://doi.org/10.1111;brv.12130>.

## Saving rasters

At some stage we might like to save the rasters we've worked on. We can do that using `writeRaster` (from <https://r-spatial.org/terra/spatial/5-files.html#writing-raster-data>).

Use ‘`writeRaster`’ to write raster data. You must provide a `SpatRaster` and a filename. The file format will be guessed from the filename extension. If that does not work you can provide an argument like ‘`format=GTiff`’. Note the argument ‘`overwrite=TRUE`’ and see ‘`?writeRaster`’ for more arguments, such as ‘`datatype=`’ to set the a specific datatype (e.g., integer).

Notice that I am writing the file to a folder called ‘output’, so I can keep my working folder neat and tidy.

```
x <- writeRaster(papoue_terra, "output/test_output.tif", overwrite = TRUE)  
x
```

```
## class       : SpatRaster  
## dimensions : 195, 225, 1  (nrow, ncol, nlyr)  
## resolution : 0.06666667, 0.06666667  (x, y)  
## extent     : 140, 155, -13, 0  (xmin, xmax, ymin, ymax)  
## coord. ref. : lon/lat WGS 84 (EPSG:4326)  
## source      : test_output.tif  
## name        : layer  
## min value   : -8736  
## max value   : 4061
```

And we can read raster files into R thus.

```
rm(x) # remove x from the environment.  
x <- rast("output/test_output.tif") # and try reading our file in.
```

## Sea surface temperature

Let's take a look at a dynamic variable – sea surface temperature (SST).

There are many sources for sea surface temperature. In a future Lab we will look at finding environmental data for your analyses. There are also some R packages that can make the job of downloading and managing those data easier. For example, have a look at [this tutorial](#) and [this one](#) – both use the `rerddap` package (<https://docs.ropensci.org/rerddap/>). Also look at `bowerbird` (<https://docs.ropensci.org/bowerbird/articles/bowerbird.html>), a package designed to create and maintain your own local (i.e., on your own computer) copies of environmental datasets. Today, we'll keep it simple.

I went to the NASA Earth Observations website for sea surface temperature data from Aqua/MODIS: <https://neo.gsfc.nasa.gov/view.php?datasetId=MYD28M>.

MODIS (Moderate Resolution Imaging Spectroradiometer) is a sensor on board NASA's Aqua satellite: <https://modis.gsfc.nasa.gov/>

I chose monthly ('1 mo') data for August 2022, downloaded this as ‘GeoTIFF (raster)’, at 0.1 degrees resolution.

We then click on ‘Download Raw Data’ (double red underline in the screenshot below). You'll need to register (quick and free) to download the data.

I saved the file, called `AQUA_MODIS.20220801_20220831.L3m.M0.SST.sst.9km.nc` in a folder called `data` in my working folder. Remember, we don't want to touch our raw data and we want to keep it separate from things we are working on and manipulating (e.g, the derived raster `papoue_terra` that I wrote to a file called `test_output.tif` in the `output` folder).

I've put this file on Blackboard if you want to download it from there instead. Remember to put it in a folder called `data` in your working directory.

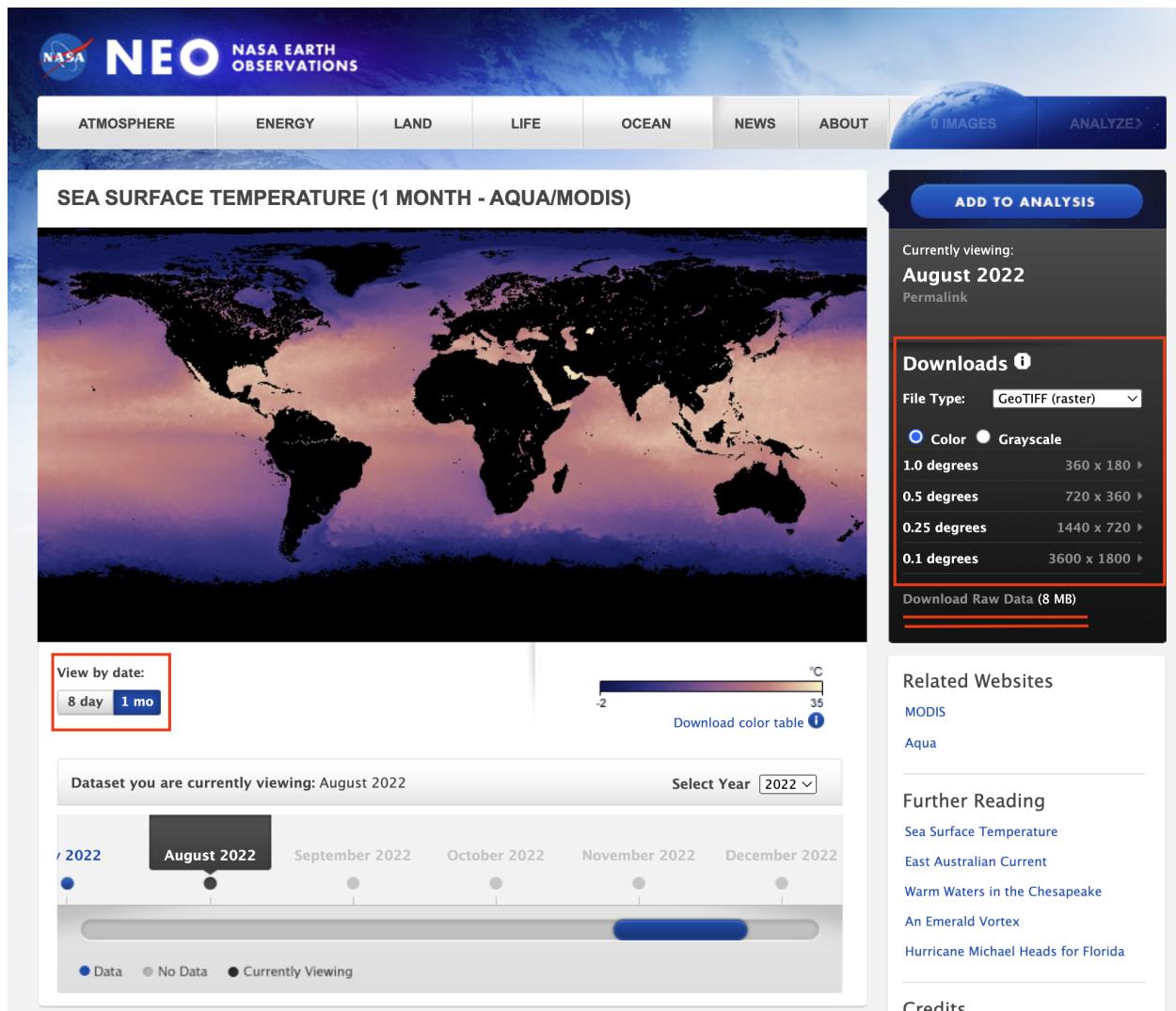


Figure 1: A screenshot of the download page. I've highlighted with red boxes and underling some of the options I chose.

The file has the extension .nc, which means it is a NetCDF file, a really common format in oceanography and environmental science. But, this format can be really complicated. Sometimes you are lucky and `terra` can easily understand it. Let's try...

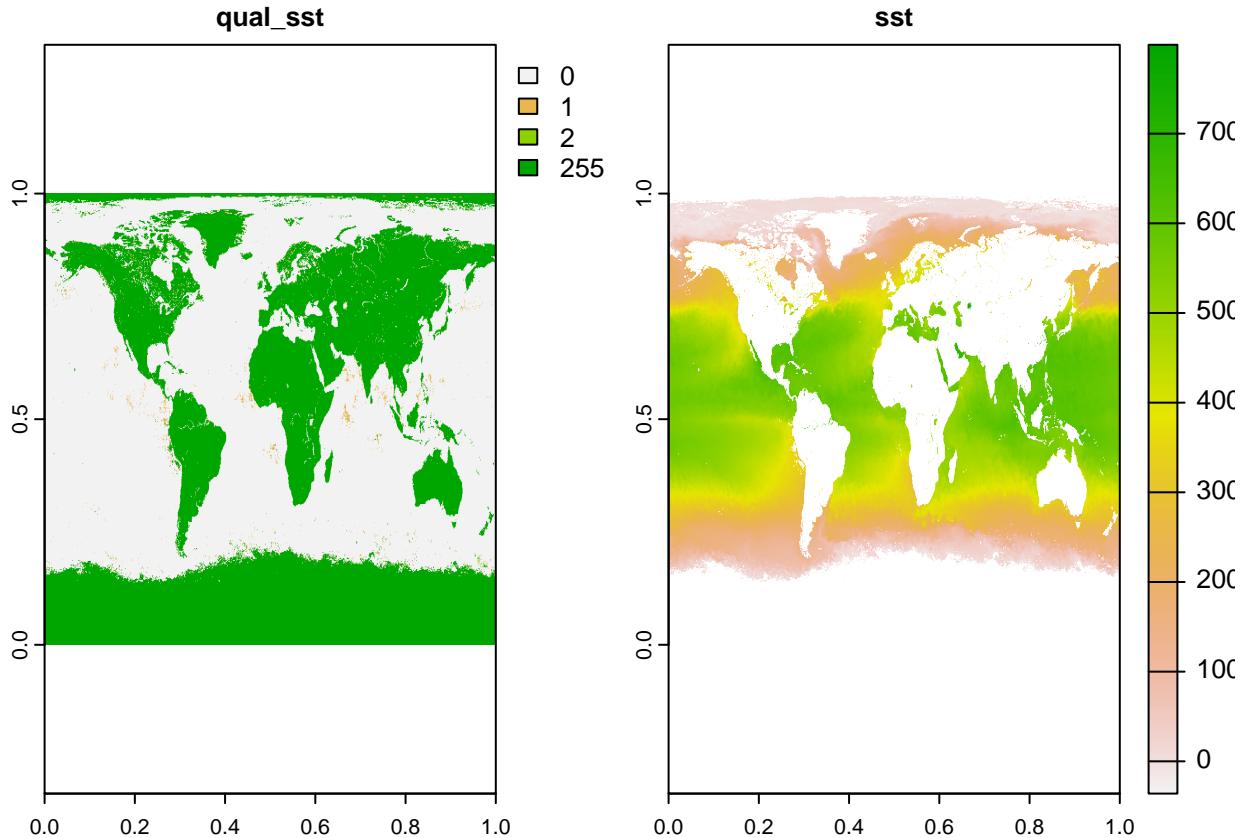
```
# Read in the NetCDF file
sst <- rast("data/AQUA_MODIS.20220801_20220831.L3m.MO.SST.sst.9km.nc")

## Warning: [rast] unknown extent

# Look at some properties
sst

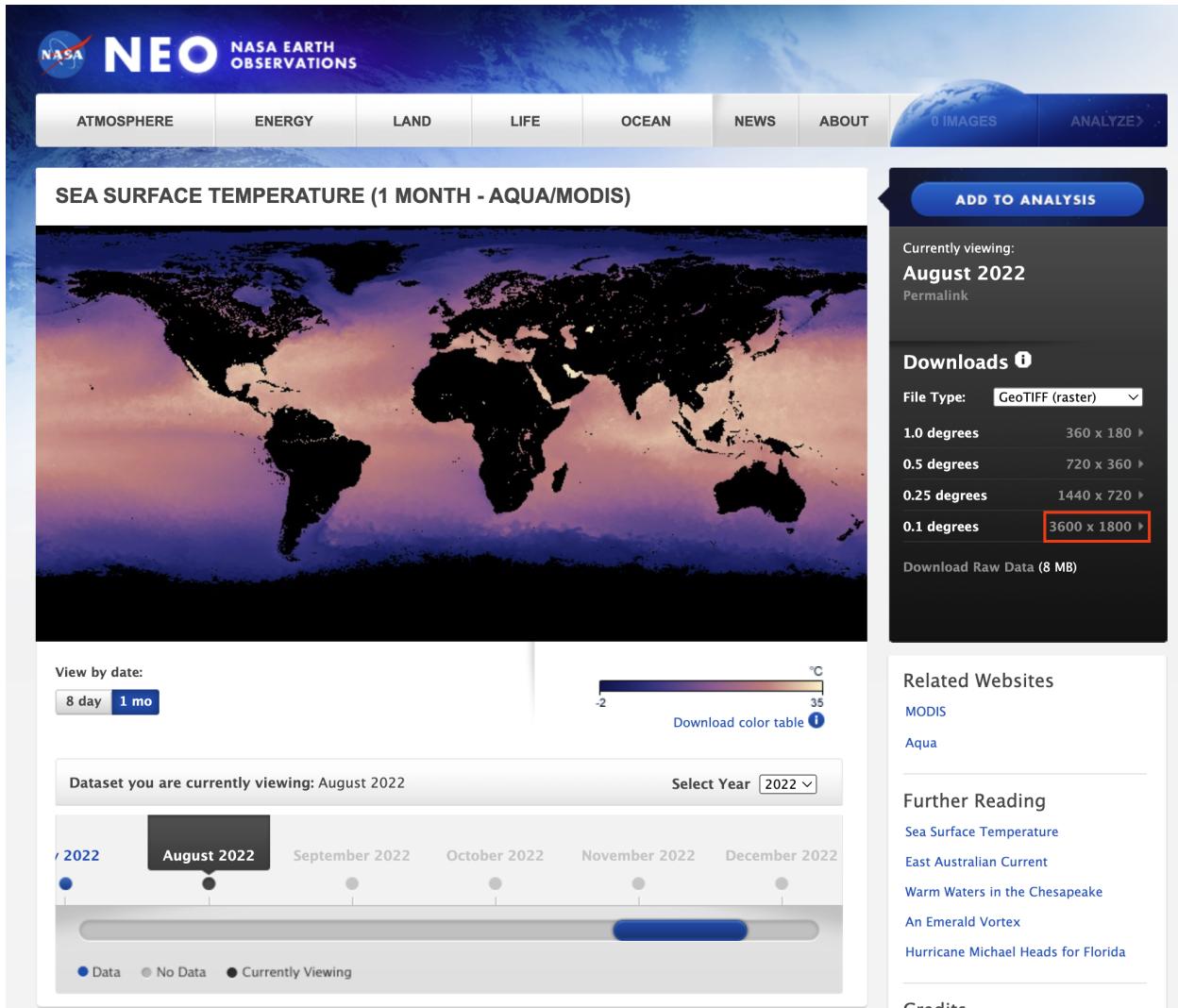
## class      : SpatRaster
## dimensions : 2160, 4320, 2  (nrow, ncol, nlyr)
## resolution : 0.0002314815, 0.000462963  (x, y)
## extent     : 0, 1, 0, 1  (xmin, xmax, ymin, ymax)
## coord. ref. :
## sources    : AQUA_MODIS.20220801_20220831.L3m.MO.SST.sst.9km.nc://qual_sst
##               AQUA_MODIS.20220801_20220831.L3m.MO.SST.sst.9km.nc://sst
## varnames   : qual_sst
##             sst
## names     : qual_sst, sst

# And plot
plot(sst)
```



Immediately we got a warning that the raster had an unknown extent. When we print `sst` we see that the extent is indeed unexpected (try `ext(sst)`): 0, 1, 0, 1. We expect that to be in degrees (longitude and latitude). Also, we see that the coordinate reference system is missing (try `crs(sst)`). When we plot it it looks okay, but notice the values of the axes.

You could look at some tutorials on how to read these NetCDF files into a sensible format (for example [this one](#)), but let's again keep it simple and download a GeoTIFF from the site. I go back and click on the image dimensions next to the highest resolution download (0.1 degrees). Highlighted in red in the screenshot below:



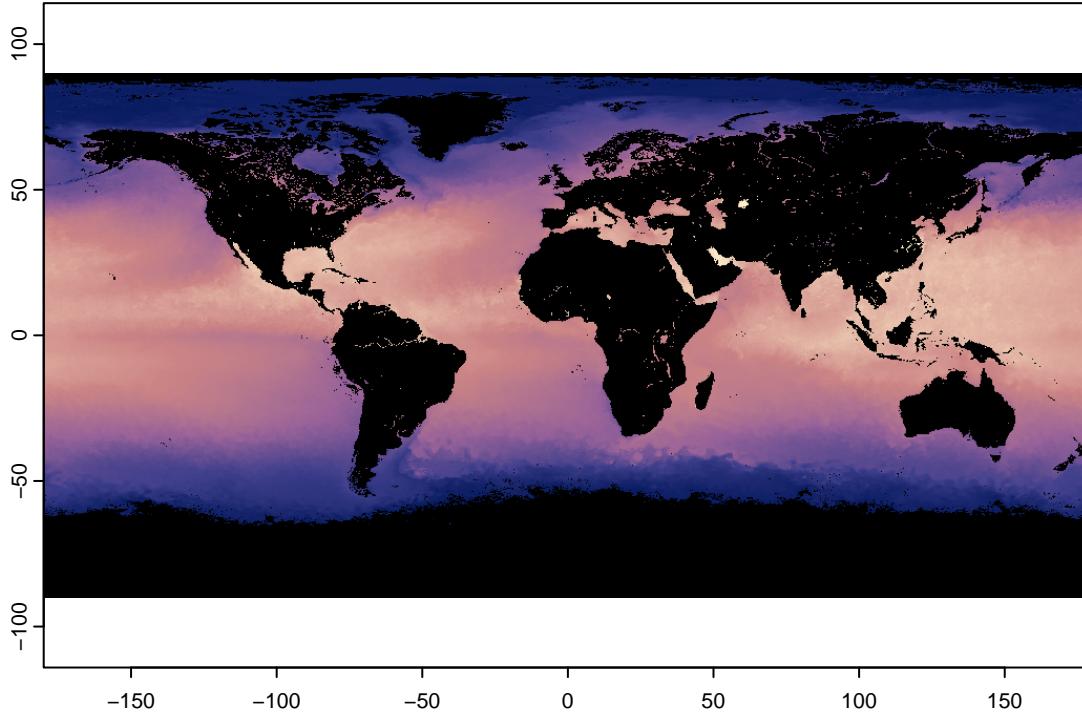
That allows us to save a file called `MYD28M_2022-08-01_rgb_3600x1800.tiff`, which I also put on Blackboard. This is a raster file; let's read it in.

```
# Read in the SST raster
sst_raster <- rast("data/MYD28M_2022-08-01_rgb_3600x1800.tiff")

# Check it's properties
sst_raster # seems much better

## class      : SpatRaster
## dimensions : 1800, 3600, 1 (nrow, ncol, nlyr)
## resolution : 0.1, 0.1 (x, y)
## extent     : -180, 180, -90, 90 (xmin, xmax, ymin, ymax)
## coord. ref. : lon/lat WGS 84 (EPSG:4326)
## source     : MYD28M_2022-08-01_rgb_3600x1800.tiff
## color table : 1
## name       : MYD28M_2022-08-01_rgb_3600x1800
```

```
# And plot it
plot(sst_raster, legend = TRUE) # looks better
```



```
# But...
# No SST values, because this is a GeoTIFF image!
# The value in each grid cell represents a colour instead of an SST value.
values(sst_raster)[1:10] # Look at the first ten values, for example
```

```
## [1] 255 255 255 255 255 255 255 255 255 255
```

The website says:

In addition to the standard file formats—JPEG, PNG, GeoTIFF, or GoogleEarth (KMZ)—many (not all) datasets support these “data value” formats. (**Note:** These data values are only approximations based upon the scaled range of the imagery. These values should not be used as scientific absolutes but only for simple analysis.

So, we should use the raw data in the NetCDF file, or find another source for data. This is why it’s important to carefully explore our data before we start working with it. It’s also an example of some of the frustrating steps we have to work through when finding data to use.

Let’s remove the rasters from our workspace before we carry on. They can take up a lot of memory. We take two steps. First, we remove the objects with `rm()`, then we also remove any temporary rasters that we can’t see, with `tmpFiles()`.

```
# Remove the raster objects
rm(sst, sst_raster)

# Remove any temporary raster files.
tmpFiles(remove = TRUE)
```

We’ll discuss getting data (including working with NetCDF) in more detail in a later lab, for the moment, let’s read in some SST files that I have downloaded and converted raster for this lab.

There are seven files (all with a .tif extension. Save these inside a folder called `sst_files` in your data directory.

Once you've done that, verify the files are in the right place using the `list.files()` function. This is a handy function for when you start programmatically accessing lots of files.

```
# Check that you downloaded the files in the right place.  
list.files("./data/sst_files")
```

```
## [1] "sst_2020-01-01.tif" "sst_2020-01-02.tif" "sst_2020-01-03.tif"  
## [4] "sst_2020-01-04.tif" "sst_2020-01-05.tif" "sst_2020-01-06.tif"  
## [7] "sst_2020-01-07.tif"
```

There are seven SST files. Each file is the daily sea surface temperature for an area in the North Sea, north-east of the Scottish mainland (I want to reproduce the same area as Figure 3.3 in the Scales et al. chapter).

Let's look at one of these:

```
sst_01 <- rast("./data/sst_files/sst_2020-01-01.tif")  
  
# Check out the resolution, extent and coordinate reference system.  
sst_01
```

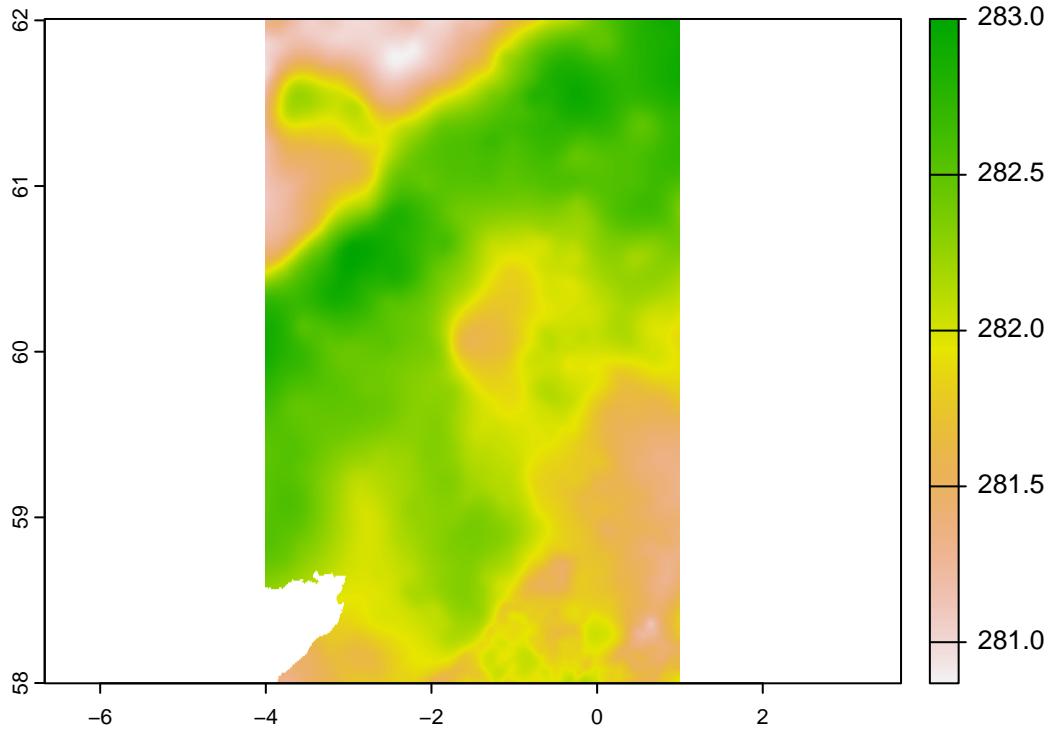
```
## class       : SpatRaster  
## dimensions : 401, 500, 1  (nrow, ncol, nlyr)  
## resolution : 0.01, 0.01000056  (x, y)  
## extent     : -4, 1, 57.99822, 62.00844  (xmin, xmax, ymin, ymax)  
## coord. ref. : lon/lat WGS 84 (EPSG:4326)  
## source     : sst_2020-01-01.tif  
## name       : sst_2020-01-01  
## min value  :         280.868  
## max value  :         283.000
```

Note: The coordinate reference system we get by calling `crs(sst_01)` is  
lon/lat WGS 84 (EPSG:4326)

This is the WGS 84 system, a common one used, for example, for GPS. We can look up the coordinate reference system using the EPSG code (4326) on the [epsg.io](https://epsg.io/4326) website: <https://epsg.io/4326>.

Let's plot our raster

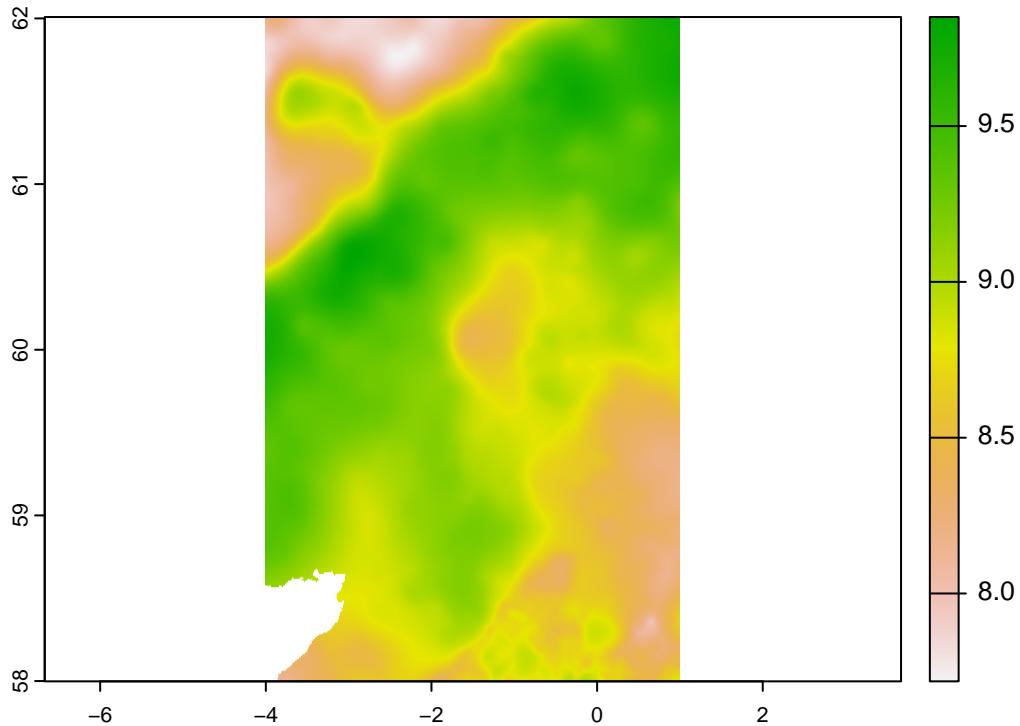
```
plot(sst_01)
```



Notice the values. The temperature is measured in Kelvin, so we need to correct it.

We can use *raster algebra* in various ways. In this case, we can subtract a single value from the whole raster to make the correction.

```
sst_01 <- sst_01 - 273.15 # We simply subtract the correction value
plot(sst_01)
```



```
minmax(sst_01)
```

```
##      sst_2020-01-01
## min      7.718011
## max     9.850000
```

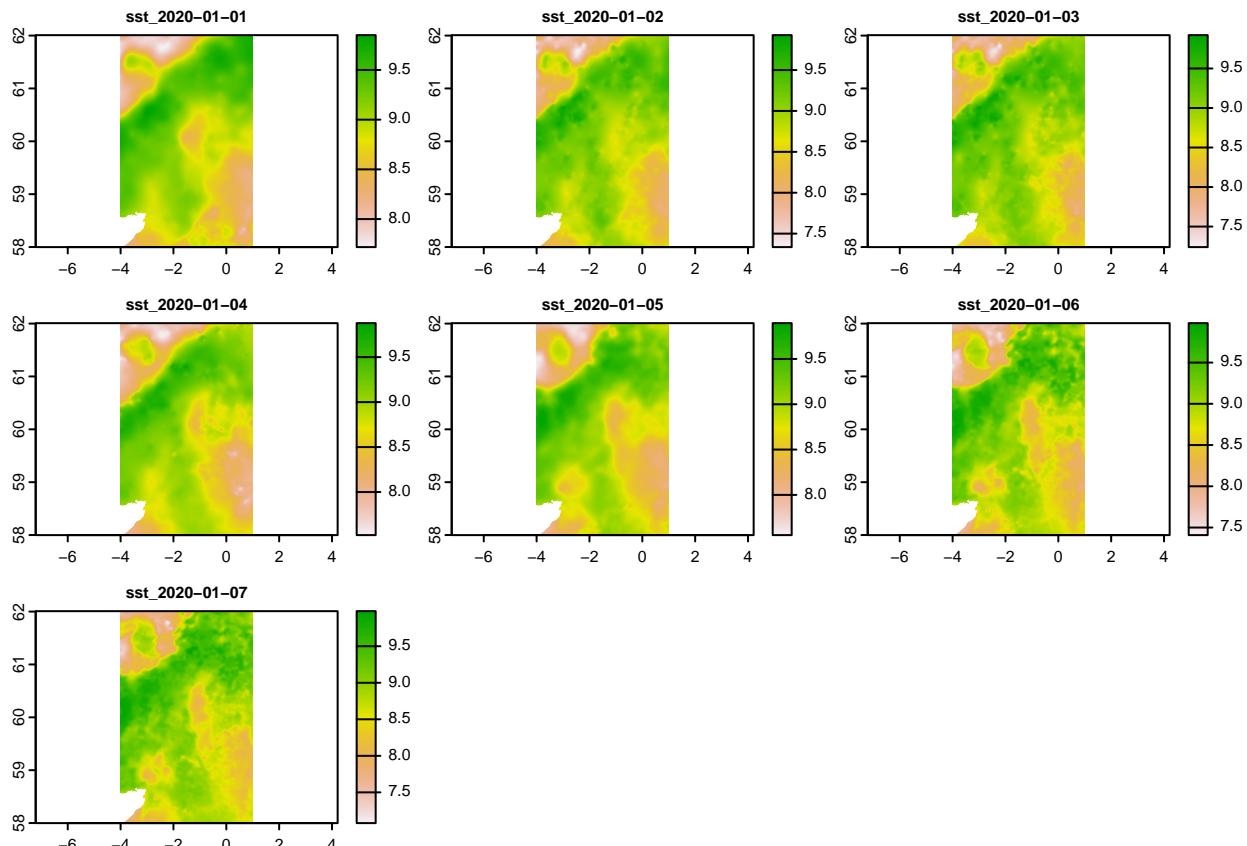
Let's read in the files for all seven days, and correct them as we read them in.

```
sst_01 <- rast("./data/sst_files/sst_2020-01-01.tif") - 273.15
sst_02 <- rast("./data/sst_files/sst_2020-01-02.tif") - 273.15
sst_03 <- rast("./data/sst_files/sst_2020-01-03.tif") - 273.15
sst_04 <- rast("./data/sst_files/sst_2020-01-04.tif") - 273.15
sst_05 <- rast("./data/sst_files/sst_2020-01-05.tif") - 273.15
sst_06 <- rast("./data/sst_files/sst_2020-01-06.tif") - 273.15
sst_07 <- rast("./data/sst_files/sst_2020-01-07.tif") - 273.15
```

## Raster stacks

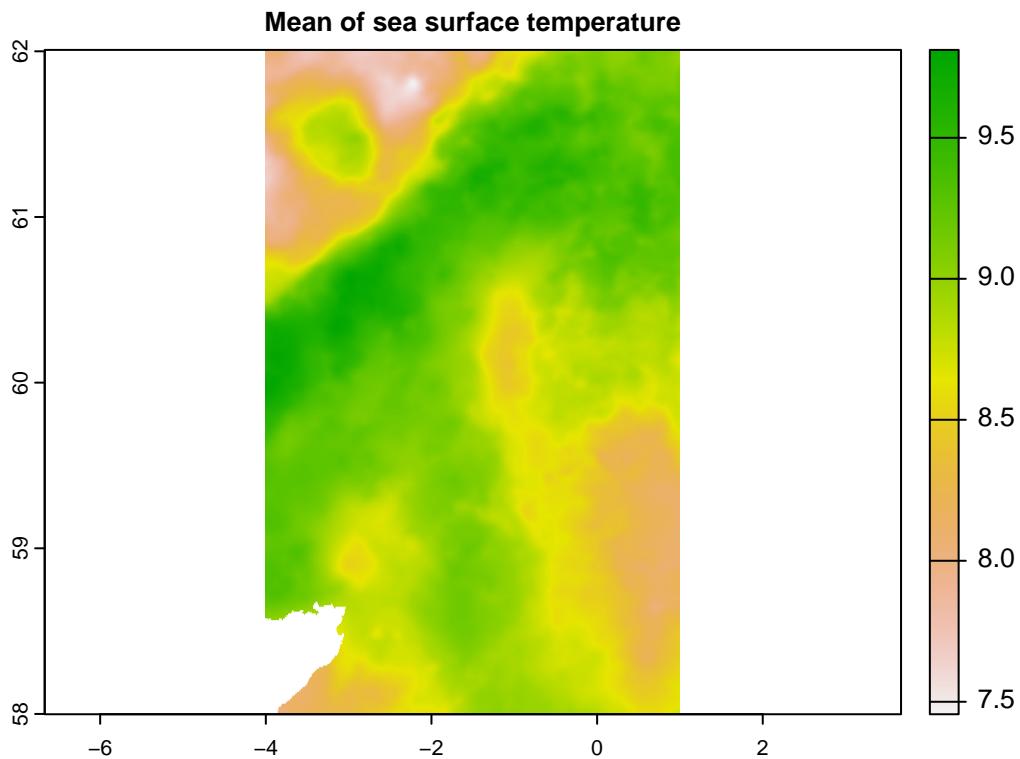
We can have many layers in a raster, representing different times or different bands in the case of multispectral imagery. This means we can 'stack' each daily file into a single 'raster stack' with 7 layers.

```
# We simply use the c() function
sst_all <- c(sst_01, sst_02, sst_03, sst_04, sst_05, sst_06, sst_07)
plot(sst_all)
```



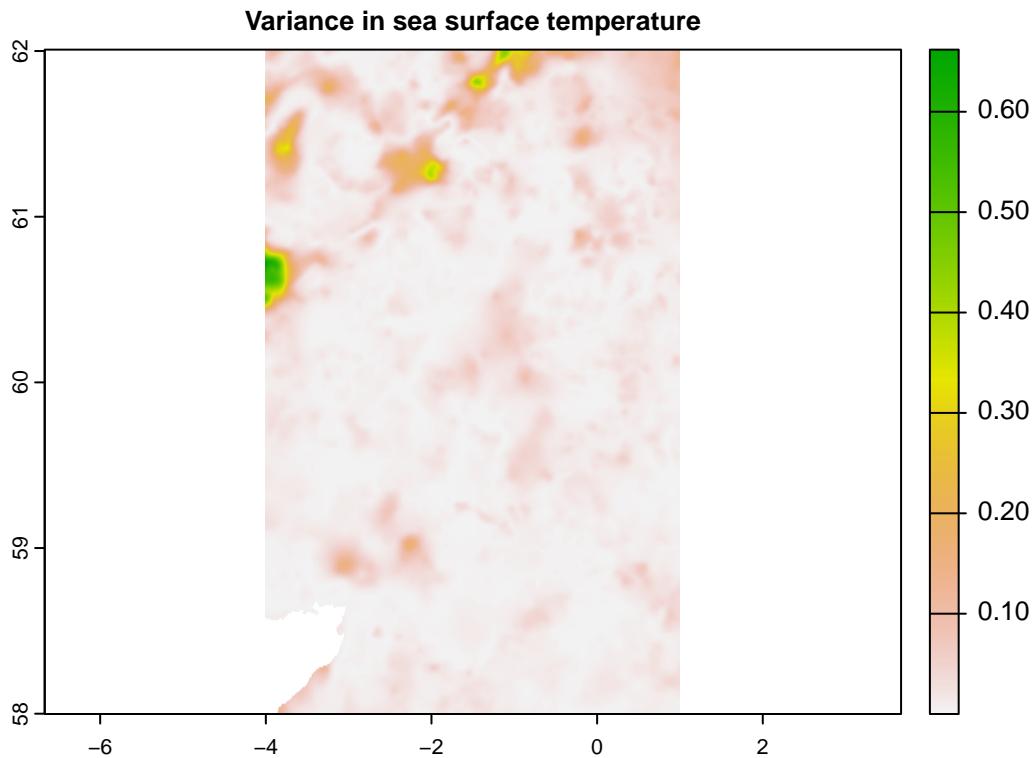
Again, we can use mathematical functions to work with rasters. For example, we could calculate the average value in each grid cell (pixel) across the whole week. Notice that this will produce a single raster, because we have calculated a single mean for each cell.

```
sst_mean <- mean(sst_all)
plot(sst_mean,
     main = "Mean of sea surface temperature")
```



Or we could have looked at the variance to see how variable SST was in each grid cell across the week. In this case we use the `app` function, which applies a function to a raster stack.

```
# we tell the app function we want to use the variance function - var() - with fun = "var"
sst_variance <- terra::app(sst_all, fun = "var")
plot(sst_variance,
     main = "Variance in sea surface temperature")
```

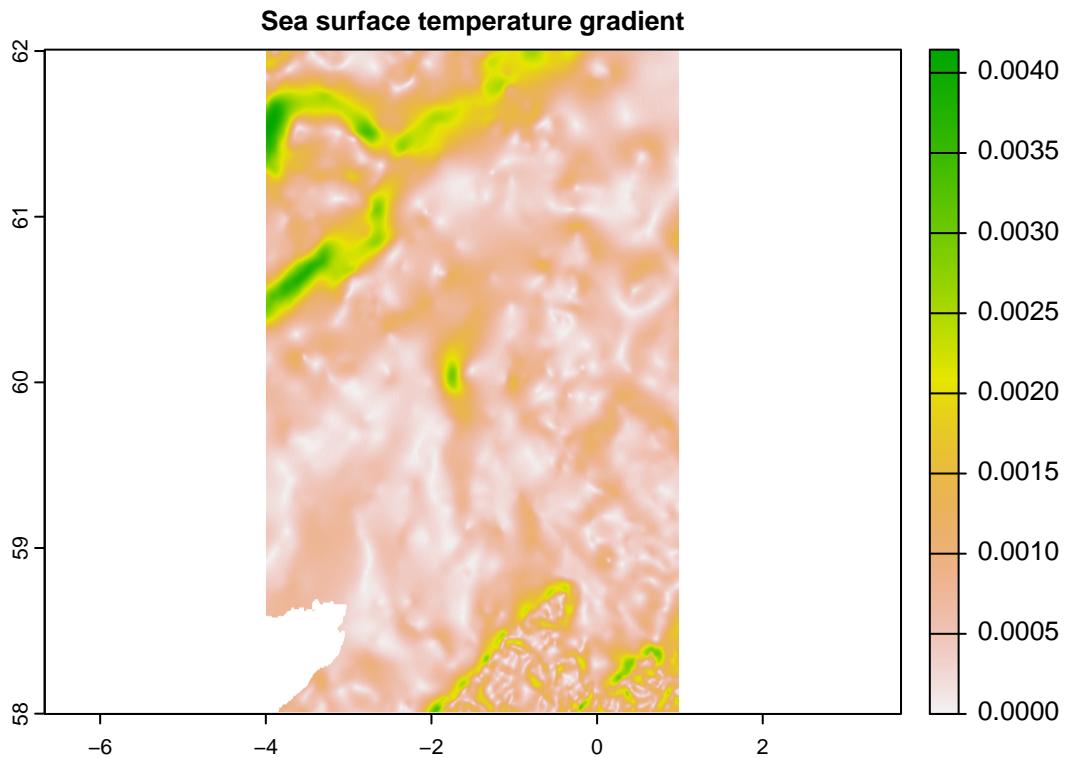


Look at the `terra` tutorial for more examples: <https://rspatial.org/terra/rs/3-basicmath.html>.

### Finding spatial gradients

Let's find a spatial gradient in one of the sst rasters. We can use the `terrain()` function that we used earlier, since this is also a kind of gradient (although the output units in this case don't quite make sense).

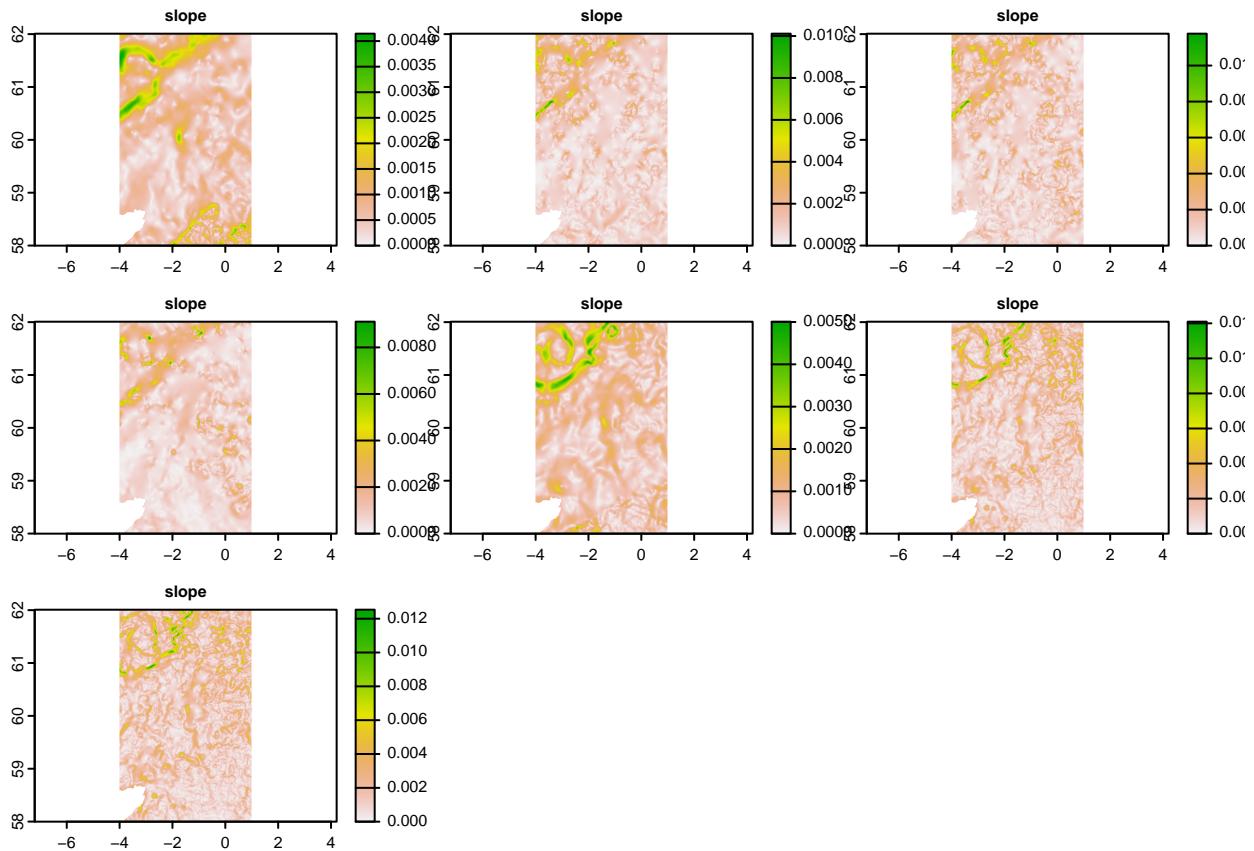
```
sst_gradient <- terrain(sst_01, v = "slope")
plot(sst_gradient,
     main = "Sea surface temperature gradient")
```



That's starting to look a bit like Figure 3.3 in the Seascape Ecology textbook, right? The green areas are regions with high sst gradient - they are places where SST is changing quickly across space. Ecotones?

We can also apply this kind of function to the whole stack using the `sapp()` function and in this case the function works layer by layer instead of calculating a value in each cell *across* all the layers.

```
sst_all_gradient <- sapp(sst_all, terrain, v = "slope")
plot(sst_all_gradient)
```



But let's calculate sea surface temperature fronts (also a kind of gradient) using a proper algorithm - Belkin & O'Reilly's (2009) front detection algorithm (<https://doi.org/10.1016/j.jmarsys.2008.11.018>).

For that we'll need the `grec` package.

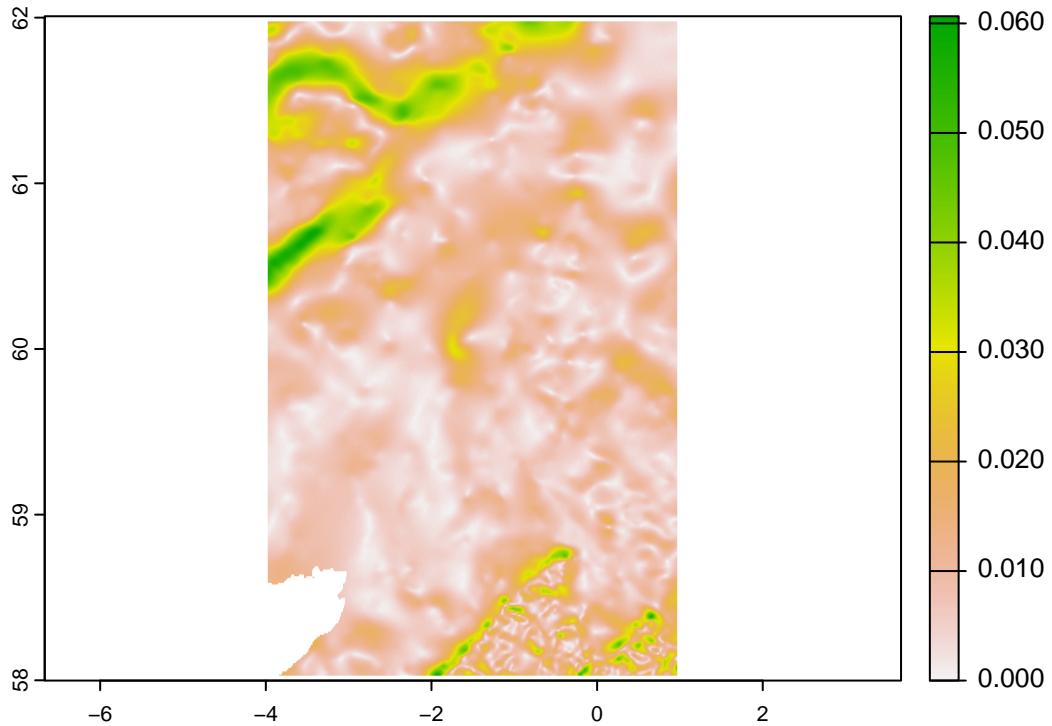
```
# If necessary, install grec
install.packages("grec",
  repos = "https://cran.rstudio.com/",
  dependencies = TRUE)

##
## The downloaded binary packages are in
## /var/folders/yy/g9_xx9fn2dj3b58c1_cxqcrw0000gq/T//RtmpxNIn6B downloaded_packages

# The attach the library
library(grec)

## Loading required package: imagine
## Loading required package: raster
## Loading required package: sp
# And run the function
# grec doesn't yet accept terra rasters, so we first convert our raster to the old raster package raster
sst_01_oldstyle <- raster(sst_01)
# Then we run the function
sst_fronts <- detectFronts(sst_01_oldstyle)
# And convert back to terra
sst_fronts <- rast(sst_fronts)
```

```
plot(sst_fronts)
```



So, it looks about the same as the raster we calculated with the `terrain` function, but notice that the units are different. They are now in degrees Celsius per km.

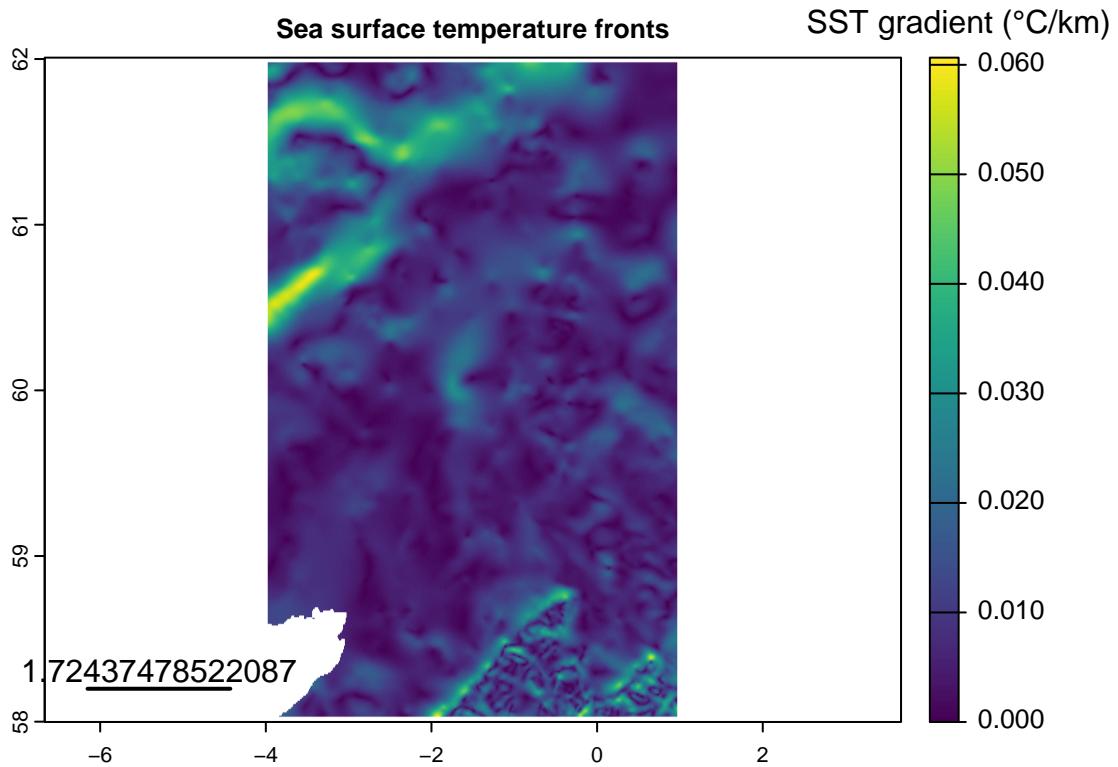
Let's make the map a bit better.

```
# Install the viridis package for some more colour palettes
install.packages("viridis",
  repos = "https://cran.rstudio.com/",
  dependencies = TRUE)

##
## The downloaded binary packages are in
## /var/folders/yy/g9_xx9fn2dj3b58c1_cxqcrw0000gq/T//RtmpxNIn6B/downloaded_packages
library(viridis)

## Loading required package: viridisLite
# And plot
terra::plot(sst_fronts,
  main = "Sea surface temperature fronts", # main title
  plg = list(title = "SST gradient (°C/km)", # a title for the legend
  col = viridis(125)) # use the viridis colour scale

# Add a scale bar
terra::sbar()
```



## More reading and practice

For more, continue working on the tutorials from

- Geocomputation with R  
<https://geocompr.robinlovelace.net/>
- Spatial Data Science with R and “terra”  
<https://rspatial.org/terra/index.html>