

CASA0023 Remotely Sensing Cities and Environments

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Welcome

Hello and welcome to the Term 2 module Remotely Sensing Cities and Environments.

Similarly, to my Term 1 MSc module, CASA0005, this website holds all the practical instructions for the module. CASA0005 Geographic Information Systems and Science is a pre-requisite of the module so concepts taught there will mainly be assumed here.

Acknowledgement

Thanks to the following academics who inspired the creating of the module and various concepts within it:

- Dr Ellie Biggs
- Dr Gareth Roberts
- Dr Bryan Boruff
- Professor Ted Milton
- Dr Laurie Chisholm

Thanks again to the following people who have either contributed directly or provided code in repositories that have helped me style this book:

The R package and analysis artwork used within this book has been produced by `allison_horst`, whilst artwork used in information boxes has been produced by Desirée De Leon. You can find Allison's images on the stats

¹The Bartlett Centre for Advanced Spatial Analysis,
<https://twitter.com/andymaclachlan>

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R Studio	Others
<ul style="list-style-type: none">• STAT 545• rstudio4edu• Hadley Wickham• Alison Presmanes Hill• Desirée De Leon• Yihui Xie• Julia Silge• Jenny Bryan	<ul style="list-style-type: none">• Robin Lovelace• Twitter for R programmers• Matt Ng• StatQuest with Josh Starmer• Garrick Aden-Buie

illustration GitHub repository and Desirée's on the rstudio4edu GitHub repository.

I've certainly learnt a lot from their open code repositories!

1 Getting started with remote sensing

To start with we are going to spend some time exploring remotely sensed data ready for future analysis. We will first look at Sentinel and then move to Landsat data, which we have seen before in CASA0005.

You need to select **a city of your choice** and then use the image and explanation below...I will use Cape Town, South Africa for the rest of the practical.

1.1 Learning outcomes

By the end of this practical you should be able to:

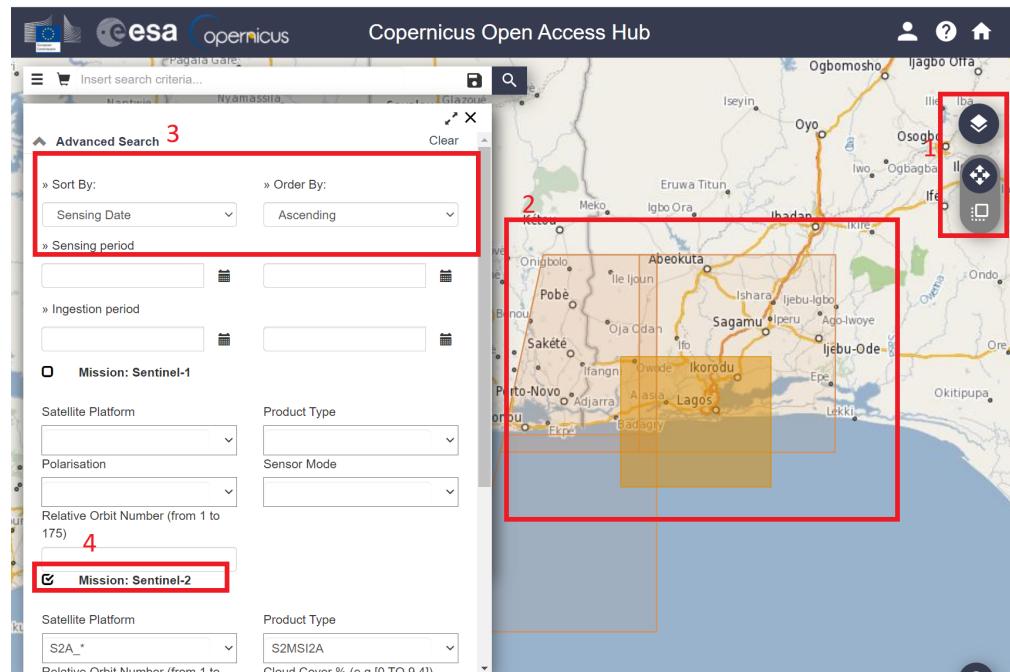
- Source, load and articulate the differences between Landsat and Sentinel data
- Undertake basic raster image statistics and processing
- Evaluate the (dis)advantages of each type of software you have used
- Pull out and statistically compare spectral signatures

1.1.1 Sentinel download

- Go to the Copernicus Open Access Hub
- You will need to make a free account

1 Getting started with remote sensing

- Draw around the study area
- Select image filter criteria
- Select search icon
- Download the S2MSI2A data



Within this image we have:

1. Allows you to either move around the global or draw a study area
2. An example of a study area
3. How to sort the image results
4. Sentinel mission selection :

1.1 Learning outcomes

- Sentinel product types refer to the amount of processing that has been undertaken on the multi-spectral imagery. S2MSI2A = Bottom of Atmosphere (BOA) or otherwise known as surface reflectance. Consult the product specification for more details.

You can also use the Sentinel 2 toolbox to replicate the conversation from TOA to BOA

- The platform refers to either sentinel 2A or 2B. These are the same sensors but they operate at 180 degrees from each other reducing the revisit time from 10 to 5 days. 2A was launched first in 2015 followed by 2B in 2017.
- Cloud cover e.g. [0 TO 5]

1.1.1.1 Open

Once downloaded and unzipped you'll be presented with a load of folders! Here we are interested in the 10m bands...which are:

You'll find then in the GRANULE > sensor number > IMG_DATA > R10.

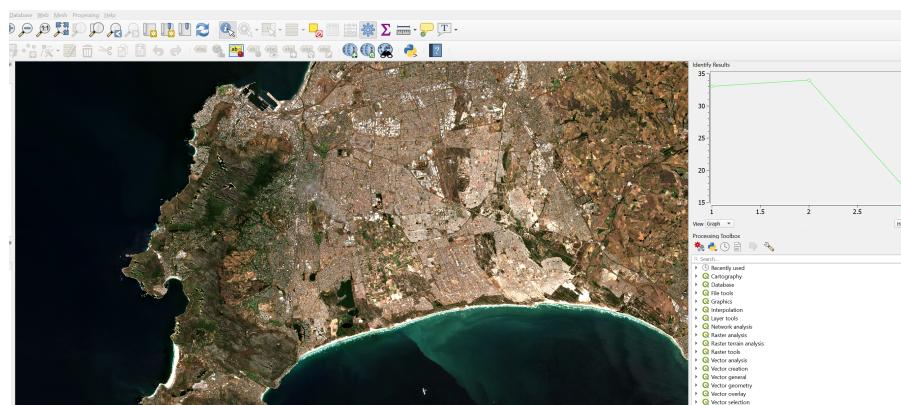
Next open them up in QGIS for some exploration, if there is a TCI image this is a True Colour Image of B02 (Blue), B03 (Green), and B04 (Red) Bands - open this first, it's just a single raster layer. See the Sentinel user guide definitions for any other acronyms you might need.

Using the Identify tool we can create a spectral signature by changing the view option to graph (look under the graph in the image above).

However the TCI values are coded between 0 and 255 which will limit what we can do with it. As the radiometric resolution of Sentinel-2 is 12-bit, meaning brightness levels from 0 - 4095 it's not clear how this product has been made.

1 Getting started with remote sensing

Band	Resolution	Central Wavelength	Description
B1	60 m	443 nm	Ultra blue (Coastal and Aerosol)
B2	10 m	490 nm	Blue
B3	10 m	560 nm	Green
B4	10 m	665 nm	Red
B5	20 m	705 nm	Visible and Near Infrared (VNIR)
B6	20 m	740 nm	Visible and Near Infrared (VNIR)
B7	20 m	783 nm	Visible and Near Infrared (VNIR)
B8	10 m	842 nm	Visible and Near Infrared (VNIR)
B8a	20 m	865 nm	Visible and Near Infrared (VNIR)
B9	60 m	940 nm	Short Wave Infrared (SWIR)
B10	60 m	1375 nm	Short Wave Infrared (SWIR)
B11	20 m	1610 nm	Short Wave Infrared (SWIR)
B12	20 m	2190 nm	Short Wave Infrared (SWIR)

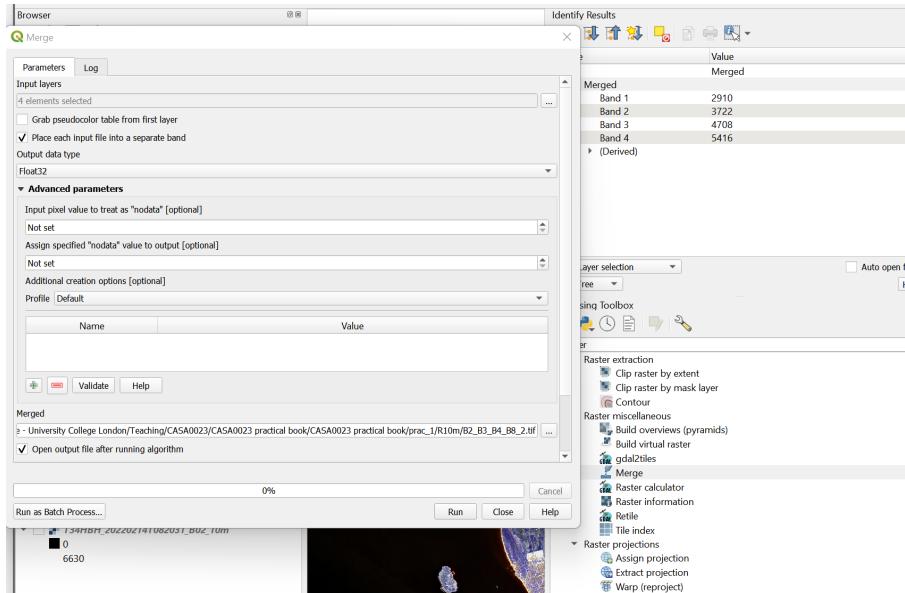


1.1 Learning outcomes

So we can make our own raster stack using the BOA bands, if you recall we did this in CASA0005 in R.

But in QGIS it's easier to visualise the output

Find the `merge` tool from the Raster miscellaneous tool box and select the following:



Note:

- The input layers are the four 10m bands that I loaded into QGIS
- The tick box selected meaning each raster file will be it's own layer
- The file being saved into a `.tiff` as opposed to memory

Once merged we can created a true colour composite using the BOA data...to do so:

- Right click on the merged layer in the attribute table

1 Getting started with remote sensing

- Symbology > Render type > select multiband color

In remote sensing the Red, Green, Blue display options are often called colour guns that are used to display images on the screen. For a true colour composite B1=Blue, B2=Green, B3=Red.

Try changing the contrast enhancement and see what happens, then consult GIS stack exchange to understand what is happening..

Of course we have only used the 10m bands so far...there are two options that we can take to use the full range of spectral data:

- Downscale the other bands to 10m forming a super-resolution
- Upscale the 10m to 20m

Down scaling is quite an intensive process and beyond the scope of this practical. However, it can be achieved using Sen2Res that is another plug in for the SNAP toolbox. Arguably SNAP is just a difference type of GIS software specific to Sentinel, but we will explore it later as it makes some of these concepts easier to understand.

Upscaling aggregates the images to a more coarse resolution (e.g. 10m to 20m). The Sentinel user guide states that bands will be resampled and provided (e.g. within the 20m folder there are 10 bands). However, it's not clear what method has been used, the documentation suggests nearest neighbour - <https://docs.sentinel-hub.com/api/latest/data/sentinel-2-l2a/>.

This can also be termed resampling, and nearest neighbour simply means taking the new raster resolution and then assiging the value from the closest value in the original data. Others approaches include bilinear or cubic convolution resampling.

1.1 Learning outcomes

1.1.1.2 SNAP

SNAP stands for Sentinels Application Platform it is a collection of tool-boxes specifically for pre-processing and analysing remotely sensed data.

SNAP allows us to easily do undertake many GIS raster type analysis that we've seen / discussed in other modules (like CASA0005) and that we will come across within this module including:

- re sampling raster data
- re projecting
- masking
- classifying data
- principal component analysis
- orthorectification
- many more methods!

Aside from these methods in a GUI the real benefit is that it's made to use remotely sensed data. Let's explore some features of SNAP.

1.1.1.2.1 Load data

- File > Open Product > select the .zip that was downloaded. Do not rename it or unzip it before hand!
- In the side bar under Product Explorer there will be a lot on data that you can load. The remotely sensed data is under Bands and then each band is listed (e.g. B1 443nm). What does 443nm mean?
- Double right click on a layer and it will appear in the viewer area

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1.1.1.2.2 SNAP layout

The layout of SNAP isn't too different to QGIS, we have:

- Products on the left side bar
- Map info in the bottom left
 - additional panes of info can be added through view >toolbar windows
 - note i have added pixel info (updates when moving the cursor) and world map
- Layer / mask managers in the right sidebar
- Processing tools in the top tool bars

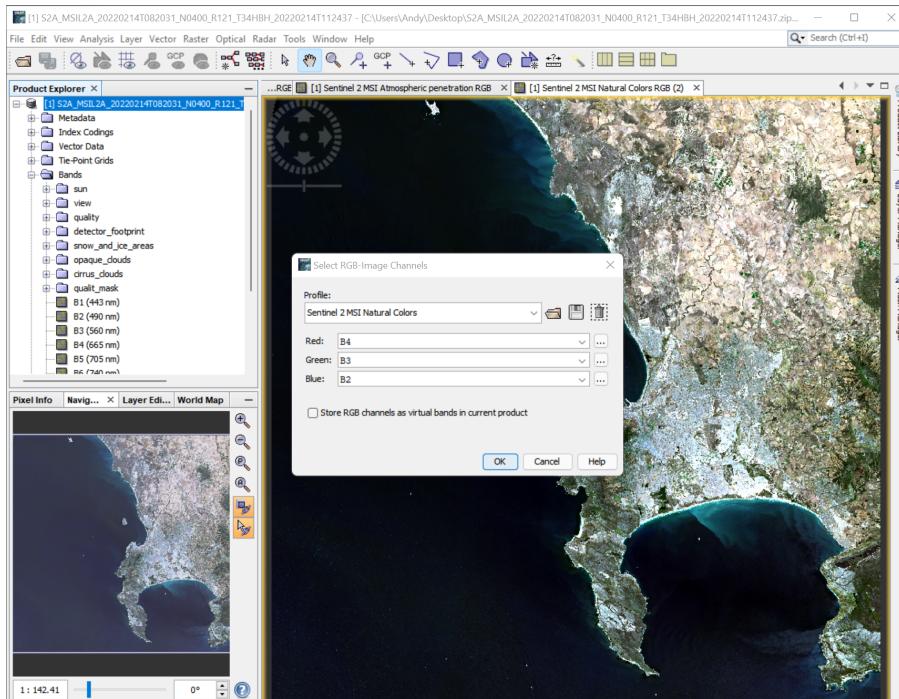


Here, i have also the two link buttons selected (bottom left window) these mean that if i move to another band i will still be in the same position on the image.

1.1.1.2.3 Colour composites

To re-created a true colour composite, right click on the data product and open RGB image

1.1 Learning outcomes



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There are a variety of other band combinations that we can use to show certain aspects of Earth's surface based on the absorption and reflection properties of the materials in the wavelengths of the bands we display "through the colour guns", for example:

- The false colour composite: B8, B4, B3. Plants reflect near-infrared and green light whilst absorbing red....
- Atmospheric penetration composite: B12, B11, B8A with no visible bands to penetrate atmospheric particles. Vegetation = blue, urban area = white, gray cyan or purple.
- The short-wave infrared composite: B12, B8A and B4 shows vegetation in green, the darker the greener the denser it is and brown shows built up or bare soil

For other band colour combinations consult gisgeogrpahy

1.1.1.2.4 Creating a project

Before we go any further we should create a project, that way all our processed outputs will be stored within the projected and loaded again when we open it in future - like projects in any other software such as QGIS or R. Go File > Project > Save project. A project tab next to the product explorer tab will appear, but not you can't access the bands from within the project that must be done through the product explorer.

1.1.1.2.5 Image statistics

1.1.1.2.6 Image histogram

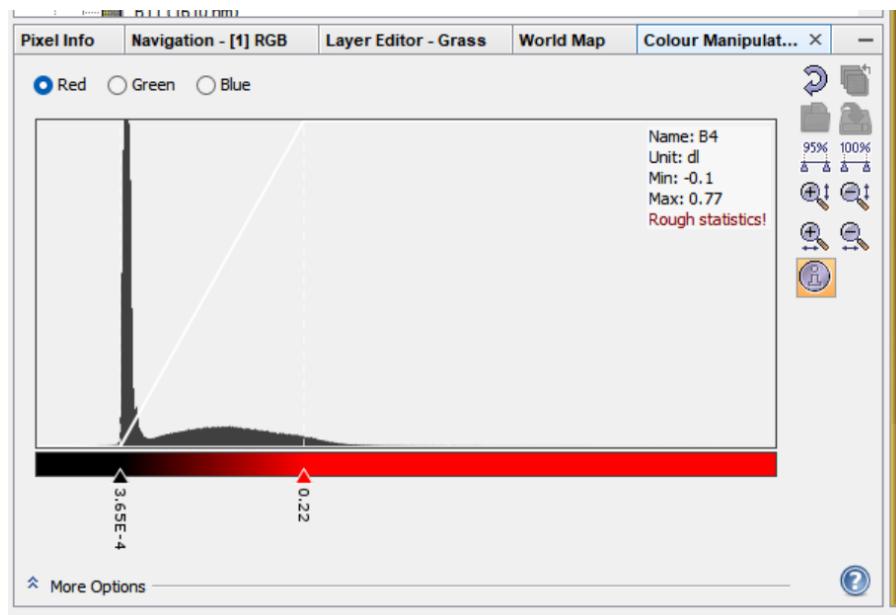
When we open an RGB image in SNAP the histogram is clipped by 1% at the lower end and 4% at the upper end and then mapped in bins between

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0 and 255 for display. A computer screen in full RGB displays colours between 0 and 255, hence why this is done.

This is similar to the contrast enhancement we saw in QGIS and we can manually change it here again through View > Tool Windows > Colour Manipulation.

Changing the distribution displayed will impact the colour of the image - try using the sliders or selecting 95% and 100% of all pixels to display. To reset click the back arrow button.

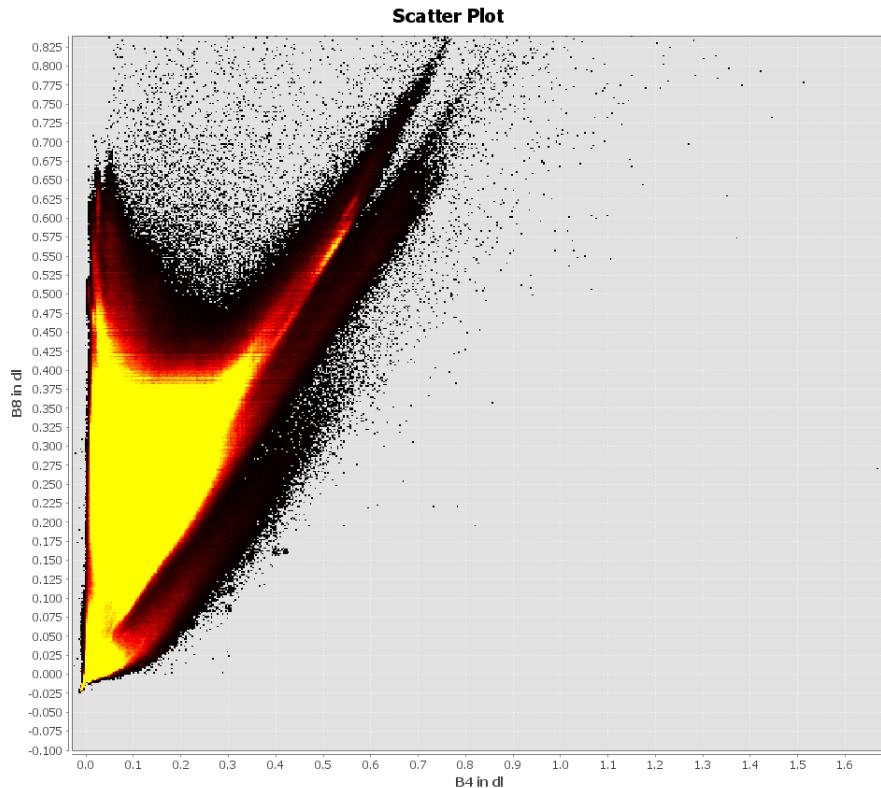


1.1.1.2.6.1 Scatterplots

Under the analysis button there are a variety of tools we can use to explore some image statistics....for example, here i have created a scatter plot of band 4 (x axis) and band 8 (y axis). These bands are the red

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(vegetation absorbs) and Near-infrared (NIR, that vegetation strongly reflects)...so where we have high values of NIR and low values of red the plot represents dense vegetation whilst low values of both red and NIR are usually wet bare soil:



In remote sensing this can be called “spectral feature space”, more on this later in the term. You might see the software ENVI in the source above - ENVI is propriety software that is similar to SNAP.

1.1.1.2.6.2 Tasseled Caps

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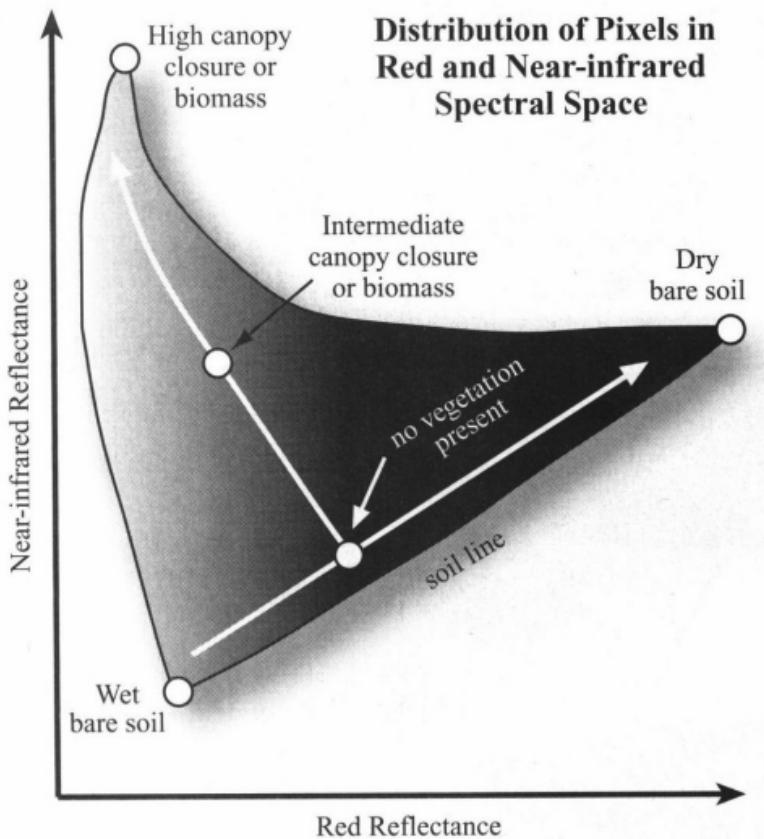


Figure 1.1: Source: Remote Sensing 4113

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The output should look somewhat like a “Tasseled Cap” (a wizards hat at an angle), although this is different to the tasseled cap *transformation* which was proposed by Kauth and Thomas (1976). The tasseled cap transformation was originally applied to Landsat data being composed of brightness, greenness, yellow stuff (yes!) and none-such. It was then modified in 1968 to brightness, greenness and wetness. This can be useful for identifying urban areas, they are **usually** bright (although Andy will have more to say on this), high biomass will show in the greenness and moisture in the wetness. The tasseled cap comes from the plot between brightness on the x axis and greenness on the y axis.

Traditionally this is usually only applied to Landsat data, however if our bands in other sensors (like Sentinel) cover the same wavelengths we can apply it...

$$\text{Brightness} = 0.3037(B2)+0.2793(B3)+0.4743(B4)+0.5585(B8)+0.5082(B11)+0.1863(B12)$$

$$\text{Greeness} = -0.2848(B2)-0.2435(B3)-0.5436(B4)+0.7243(B8)+0.0840(B11)-0.1800(B12)$$

$$\text{Wetness} = 0.1509(B2)+0.1973(B3)+0.3279(B4)+0.3406(B8)-0.7112(B11)-0.4572(B12)$$

Now, this is fairly straight forward to do in SNAP (or R) using Band Maths (Raster > Band Maths) and then clicking edit expression, before we can apply this we have two problems:

- B11 and B12 are at a 20 meter resolution whereas all the others are at a 10 meter resolution, to fix this we must re-sample to 20m
- Using the image provided will mean that the entire tile is computed when we really only care about our study area

Note, that there are many spatial indexes that can be applied to remotely sensed data, the Index DataBase holds them all or Chapter 8, pages 325 from Jensen is a good place to start.

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1.1.1.2.7 Masking and resampling

This is sometimes also called clipping in CASA0005 we saw cropping (to the extent of a polygon) and then masking. Here I am only interested in a study area of the City of Cape Town District Municipality, which is in the gadm40_ZAF_2 GADM data, it also appears in the gadm40_ZAF_3 data too!

Explore the GADM data in QGIS to work out what spatial aggregation you can use to mask your study area. For the sake of this example you might want to use the smallest spatial unit, GADM level 4, which for South Africa is wards.

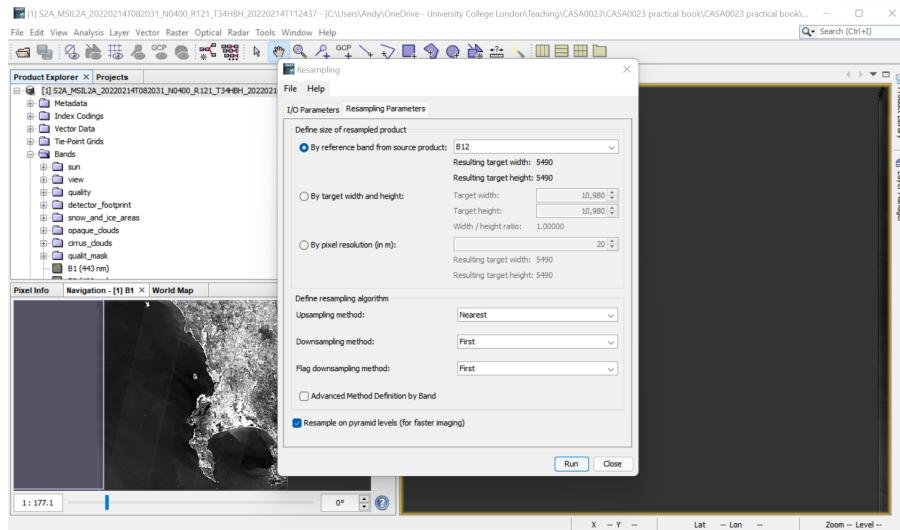
SNAP only permits ESRI shapefile to be loaded! To do so you must select the product on interest in the product explorer > Vector > Import > ESRI Shapefile

When you open a Shapefile in SNAP each polygon within your current extent will be made into an individual feature, opening the feature (from the Vector Data folder) will open the attribute table for the row of that polygon. You also might notice that the shapefile may have a larger extent than the image, this means we'd need to find another image and "mosaic" (merge or join together) them but we will see this later in the module, for now just accept that some area might be missing.

In my case the City of Capetown has been called ZAF_1 and now i will clip the raster to the polygon. However, the problem here is that we can only mask bands on the same spatial resolution, so we need to re sample bands 2,3,4 and 8 to 20m...here, we can use the Sentinel 2 resampling toolbox to resample the image and then move to masking it.

There are two options to resample within SNAP, a traditional resample which just considers the neighbouring pixels or the Sentinel 2 products resample to account for the particularities of the angle (satellite viewing) bands. For the sake of time we will use the traditional resample to generate a 20m raster dataset...Raster > Geometric > Resampling...

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Note that there will be both upsampling and downsampling here as i've selected a 20m output.

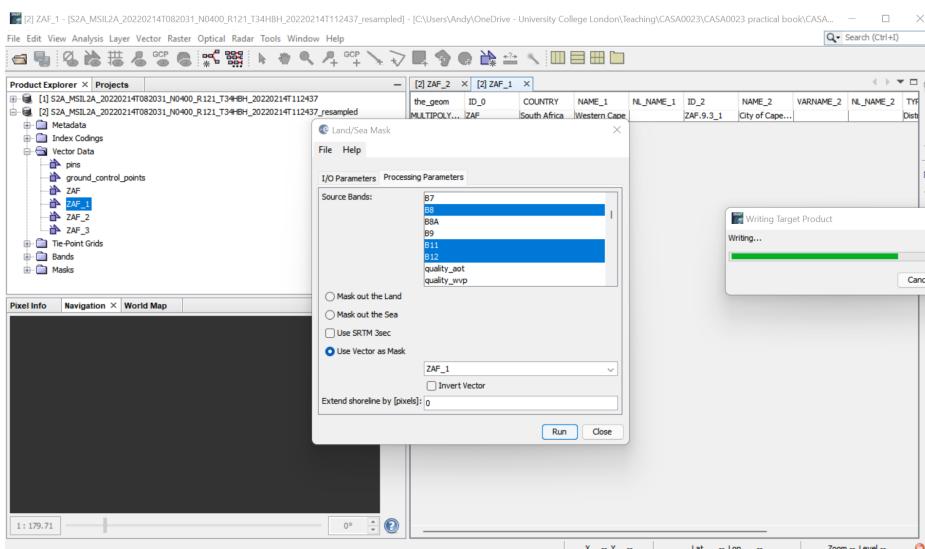
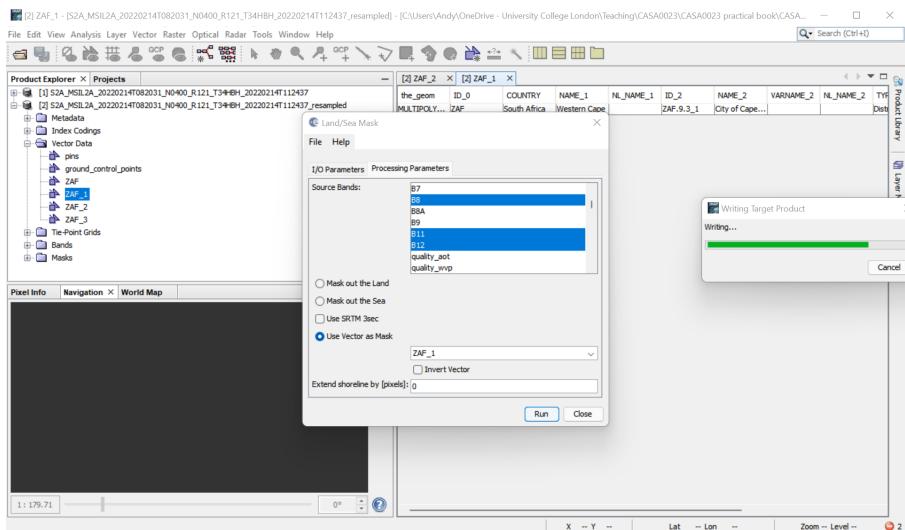
This will create a new product in the product explorer so make sure you use that from now we, next we can mask out the all the bands we need:

To mask out our study area use the Land/Sea mask (Raster > Masks > Land/Sea mask) and select the vector to use as the mask. Here, i only take forward the bands i need:

At this stage you may want to remove the shapefile that will still be within the new product created. Under the vector folder remove the relevant polygons.

Then compute the tasseled cap transformation (Raster > Band Maths) with the equations above. Note that when using a subtraction (-) you might get invalid expression so use the inbuilt subtraction within the edit expression button.

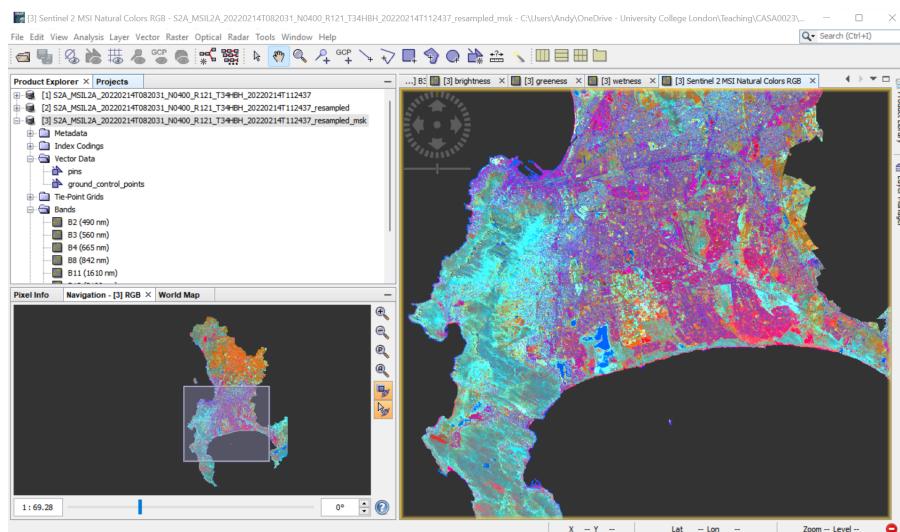
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We can now display the bands through the colour guns, R: Brightness, G: Greeness, B: Wetness and also create a scatter plot between Greeness (y) and Brightness (x) like we did earlier.

At this stage it is useful to also have open a true colour composite to compare to our tasseled cap transformation RGB image...what do the values and colours show? The [Tasseled Cap function]([https://pro.arcgis.com/en/pro-app/2.7/help/analysis/raster-functions/tasseled-cap-function.htm#:~:text=The%20Tasseled%20Cap%20\(Kauth%2DThor](https://pro.arcgis.com/en/pro-app/2.7/help/analysis/raster-functions/tasseled-cap-function.htm#:~:text=The%20Tasseled%20Cap%20(Kauth%2DThor)) from ArcPro will help explain this further.



1.1.2 Landsat

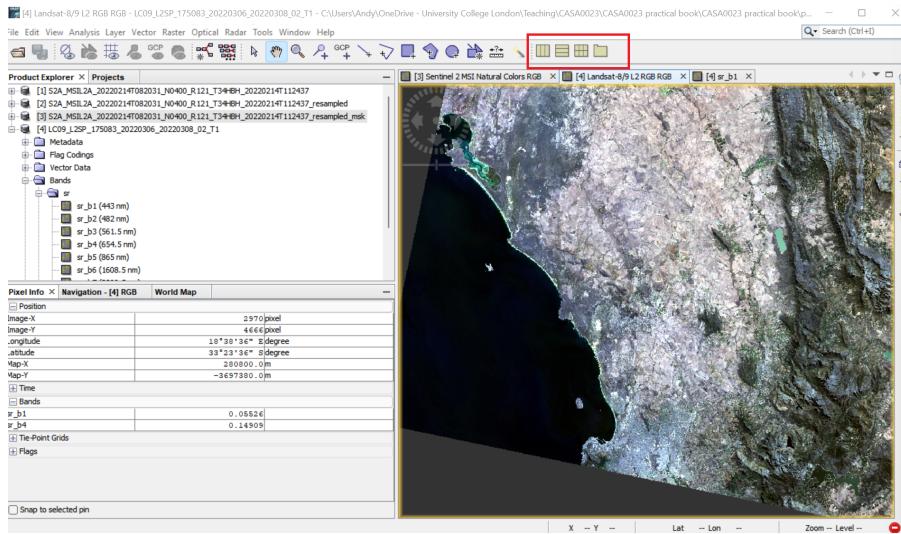
We have seen in CASA0005 how to access Landsat imagery. Now go and source some cloud free Landsat 8 Collection 2 level 2 imagery (surface reflectance data) for your city...and unzip it.

In SNAP go File > Open Product, navigate to the .MTL and open it. The

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product should appear. This is a real benefit of SNAP, having data from multiple sensors in the same software that can be explored together - when you move around on the Landsat image then the Sentinel image will also move to the same location.

To see the bands (or RGB images) side by side use the window dividers in the top right ...



For the next part of the practical we will compare the spectral signatures from both Sentinel and Landsat. To do so we need to generate a series of points of interest (called POIs) that are coincident in both images. First we need to do two things:

- Clip all the spectral data from the Sentinel image to the vector outline
 - we will need to resample the Sentinel data to the same pixel size so consider what you want to do here
 - * upscale or downscale ?

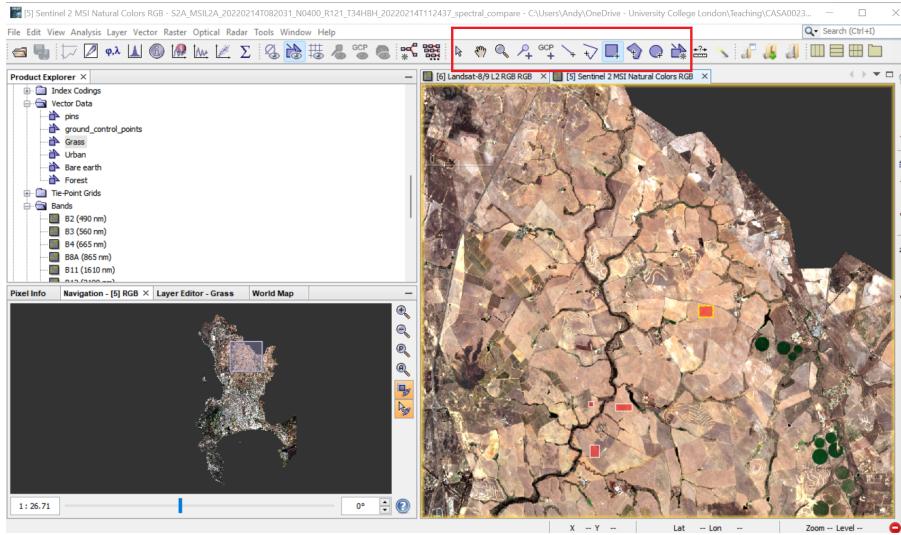
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- * What bands over Sentinel and Landsat actually overlap, do you need all of them
- * what resolution is useful
- Clip the Landsat image to the same vector outline as the Sentinel image, during the mask you can select the bands to mask and output

1.1.2.1 Select POIs

- To create points of interest we want select pixels representative of certain land cover types (e.g. Bare earth, water, grass, forest, urban) so we can compare them from both Landsat and Sentinel. Of course the pixels need to be present in both datasets.
- We can select pixels through QGIS, R or SNAP. I'll focus on the latter here.
- Make a new vector data container for a land cover type (icon on the right in the image below). Note that it will be created within the data product that is selected.
- Next use a drawing tool to draw around areas of land cover, when you select the drawing tool you will be asked which landcover the polygon is for, make sure the area is in both imagery - switch between them as we have done or display them side by side. Whilst doing this it is useful to have the spectrum view open (View > Tool Windows > Optical >Spectrum Viewer:
- Once done create another vector data container and repeat for the next land cover type.
- Consider have a separate class for highly reflective urban (e.g. industrial areas)

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1.1.3 Spectral signatures

To compare out spectral signatures we have a few options

- right click on the image in SNAP and then export mask pixels as a .txt, but you will need to do this for each land cover class and for each image (Sentinel and Landsat).

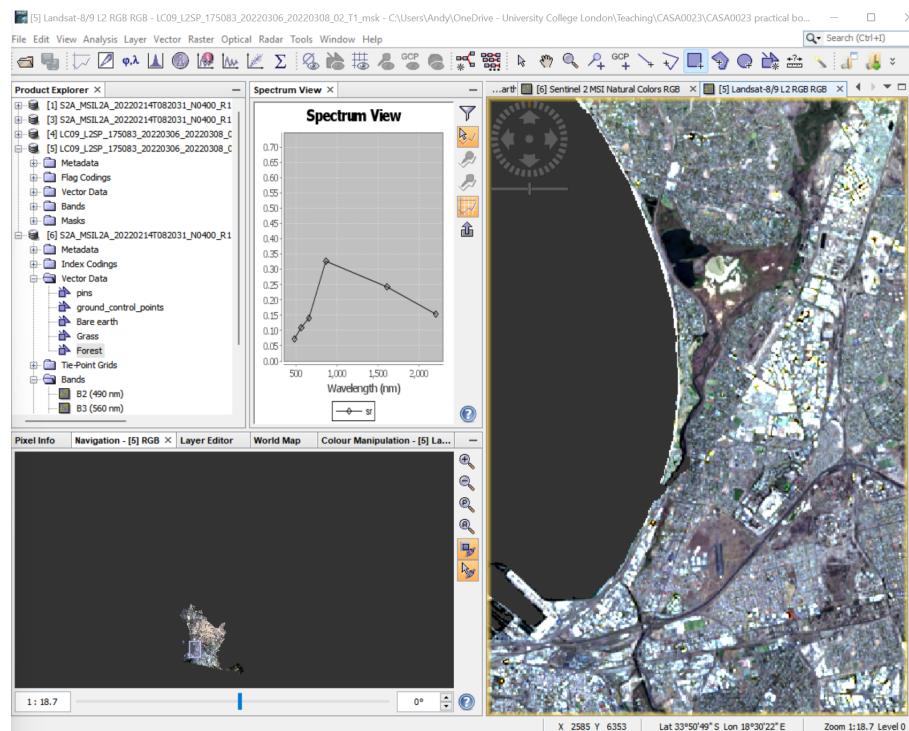
or

- export the imagery (to Geotiff) and vector files (to shapefiles) and then subset in R

I will do the second option here:

- Right clicking on the vector containers will allow export to shapefile
 - do this for all the land covers you have

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1.1 Learning outcomes

- To export the “product” which is what your image will be un SNAP. Select it (just click it) then go File > Export > GeoTIFF. When exporting the Landsat data click the subset button in the save box > band subset (select only spectral bands) and then metadata subset and remove all the selection.
- Open the GeoTIFFS and shapefiles in QGIS to check everything. This is another good opportunity to understand how contrast enhancement works - in QGIS > Symbology > expand min / max and then change the cumulative count cut the value for each band will change. For Landsat B3 is red, B2 is green and B1 is blue. This **does not change the values of the pixels**, just *how they are displayed on a colour screen*.

1.1.4 Using R

Remember that before we deal with large data sets in R, we **must** sort out the `.gitignore` file, if we intend to use Git and GitHub at any stage (hint: you will for the assessment). Go back to CASA0005 to remember how if you need to

Raster packages in R have and are still evolving rapidly, we have probably seen and used the `raster` package and may have seen the `terra` or `stars` packages. All can handle raster data and do the same analysis (pretty much).

In 2023 some key packages will retire like `maptools`, `rgdal` and `rgeos` as their maintainer, Roger Bivand will retire. `raster` uses `sp` objects for vector data and also the `rgdal` package - the Geospatial Data Abstraction Library (GDAL) for reading, writing and converting between spatial formats. `sp` (that we saw in CASA0005) also uses `rgdal` and suggests `rgeos`.

The `terra` package (2020) is somewhat mixed with `raster`, however the retiring packages are only needed by `raster`, with the `terra` package

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replacing **raster**. Terra is much faster than **raster** as datasets that can't be loaded into RAM are stored on disc and when loaded doesn't read the values. Then when computations occur they do so in chunks. Terra is very well documented and the functions are very similar to raster - <https://rspatial.org/terra/pkg/index.html>

The **stars** package (2018) works with **sf!!**, this means many of the functions we've seen and are familiar with will work - e.g. **st_transform()** which is much easier than doing it in raster. The real benefit of **stars** is its ability to handle large data (like satellite data) that can't fit into memory. It does this through not loading the pixel values but keeping a reference to them through a proxy and only loading / running computations when specifically needed (e.g. plotting, will only plot the pixels that can be seen)! The stars section from Spatial Data Science in Pebesma and Bivnud 2022 gives a good overview with examples

Stars is faster than terra, terra is faster than raster.

1.1.4.1 Data loading

```
library(sf)
library(stars)
library(terra)
library(raster)

bare_earth <- st_read("prac_1/Bare earth_Polygon.shp")
grass <- st_read("prac_1/Grass_Polygon.shp")
forest <- st_read("prac_1/Forest_Polygon.shp")
urban <- st_read("prac_1/Urban_Polygon.shp")
high_urban <- st_read("prac_1/high_albedo_urban_Polygon.shp")
```

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```
#Landsat equivalent  
bands <- c("2", "3", "4", "5", "6", "7")  
  
sentinel <- rast("prac_1/S2A_MSIL2A_20220214T082031_N0400_R121_T34HBH_20220214T112437_specified_bands.tif")  
  
names(sentinel) <- bands  
  
landsat<-rast("prac_1/subset_LC09_L2SP_175083_20220306_20220308_02_T1_msk2.tif")  
  
names(landsat) <- bands
```

Here i have chosen to use `terra`, this is because i want to extract the pixel values from within the polygons and at the moment `stars` will only permit aggregation - e.g. the mean of the pixels in the polygons. This is fine unless you want to explore the variation in signatures! then you will need the values.

To use a vector layer in `terra` it needs to be in a `SpatVector` (in `terra` the raster is a `SpatRaster`). Now there are two ways we can do this...the first is with the `vect()` function from `terra`:

```
urban <- vect(urban)
```

In the second we can actually convert the `SpatRaster` to a raster and then just use the `sf` object! I know, i know, how many formats do we need here! **But** this will mean we have a raster brick as we have all of our bands and a raster brick won't work here.

```
landsat <- as(landsat, "Raster")
```

Of course, we can just do this straight from loading the data with the pipe...

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```
bare_earth <- st_read("prac_1/Bare_earth_Polygon.shp") %>%
  vect()
grass <- st_read("prac_1/Grass_Polygon.shp") %>%
  vect()
forest <- st_read("prac_1/Forest_Polygon.shp") %>%
  vect()
urban <- st_read("prac_1/Urban_Polygon.shp") %>%
  vect()
high_urban <- st_read("prac_1/high_albedo_urban_Polygon.shp") %>%
  vect()
```

Before we can start the extraction you might have seen that my Landsat data is not in the same CRS as the rest of the data, it's close, but different. We can also just use the raster to get the CRS info, like

```
crs(landsat)
crs(sentinel)

# reproject landsat
landsat <- project(landsat, sentinel)
```

Now let's pull out those values, and get the mean and standard deviation, starting with urban from sentinel data...

```
library(tidyverse)
sen_urban<- terra::extract(sentinel, urban, progress = F) %>%
  as_tibble() %>%
  pivot_longer(cols = 2:7,
               names_to="bands",
               values_to="band_values") %>%
  add_column(sensor="sentinel") %>%
  add_column(land="urban")
```

1.1 Learning outcomes

Now, because this process will be the same for the other landcover types we can make a function...this is the **exact** same code as above but i've replaced two arguments with sensor and lancover that i can now change for each version (e.g. bare earth in Landsat or forest in Sentinel)

```
band_fun <- function(sensor, landcover) {  
  col_sensor <- deparse(substitute(sensor))  
  col_land <- deparse(substitute(landcover))  
  
  sen_urban<- terra::extract(sensor, landcover, progress = F)%>%  
    as_tibble()%>%  
    pivot_longer(cols = 2:7,  
                names_to="bands",  
                values_to="band_values")%>%  
    add_column(sensor=col_sensor)%>%  
    add_column(land=col_land)  
  
}
```

Later on we will also create a density plot, so let's write a function for all the values...it's very similar...we will call this one when we need it later...

```
band_fun_all_values <- function(sensor, landcover) {  
  col_sensor <- deparse(substitute(sensor))  
  col_land <- deparse(substitute(landcover))  
  
  sen_urban<- terra::extract(sensor, landcover, progress = F)%>%  
    as_tibble()%>%  
    pivot_longer(cols = 2:7,  
                names_to="bands",  
                values_to="band_values")  
  
}
```

1 Getting started with remote sensing

Then it's simply...

```
sen_bare <- band_fun(sentinel, bare_earth)
sen_grass<- band_fun(sentinel, grass)
sen_forest<- band_fun(sentinel, forest)
sen_high_urban <- band_fun(sentinel, high_urban)

lsat_urban<- band_fun(landsat, urban)
lsat_bare<- band_fun(landsat, bare_earth)
lsat_grass<- band_fun(landsat, grass)
lsat_forest<- band_fun(landsat, forest)
lsat_high_urban <- band_fun(landsat, high_urban)
```

Think about what this has given us?

The next stage is to put then into a tibble...

```
sen_lsat <- bind_rows(sen_urban, sen_bare, sen_grass,
                      sen_forest, sen_high_urban,
                      lsat_urban, lsat_bare, lsat_grass,
                      lsat_forest, lsat_high_urban)
```

The next stage is to get the mean (and standard deviation) values for each band per sensor and land cover type:

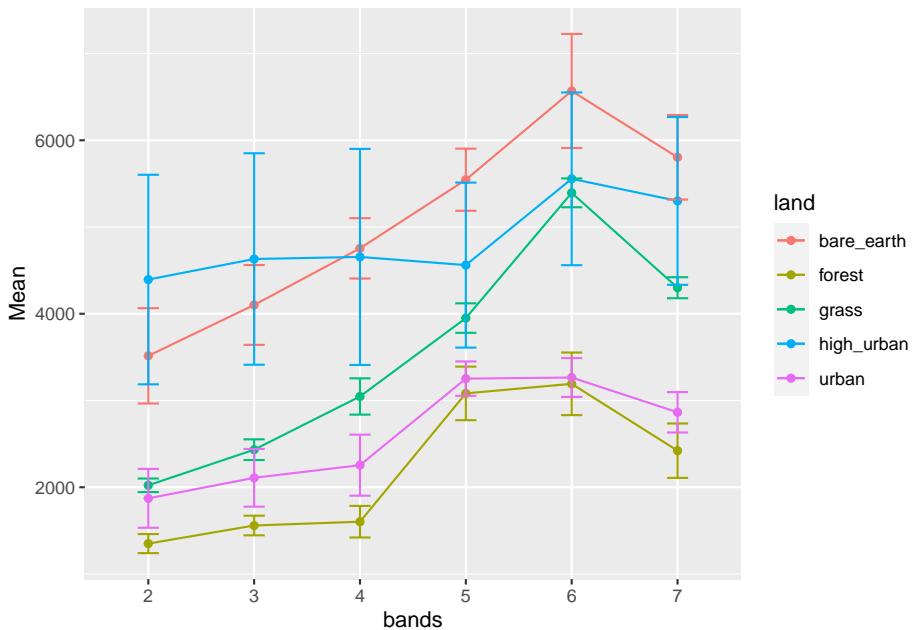
```
means<- sen_lsat%>%
  group_by(bands, sensor, land)%>%
  summarise(Mean=mean(band_values), Std=sd(band_values))
```

Plot some spectral profiles, first for Sentinel...

1.1 Learning outcomes

```
p1 <- means %>%
  filter(sensor=="sentinel") %>%
  ggplot(., aes(x = bands, y = Mean,
                col=land))+  
  geom_point()+
  geom_line(aes(group = land)) +
  geom_errorbar(aes(ymin = (Mean-Std), ymax = (Mean+Std), width = 0.2))
```

```
p1
```



We can also look at a density plot....ideally each land cover has a clear and separate histogram...

1 Getting started with remote sensing

```
p2 <- sen_lsat %>%
  filter(sensor=="sentinel") %>%
  ggplot(., aes(x=band_values, group=land, fill=land)) +
  geom_density(alpha = 0.6) +
#Add a mean vertical line
  geom_vline(data = . %>% group_by(land) %>% summarise(group_mean = mean(band_values), aes(xintercept=group_mean, color = land), linetype="dashed",
```

```
p2
```

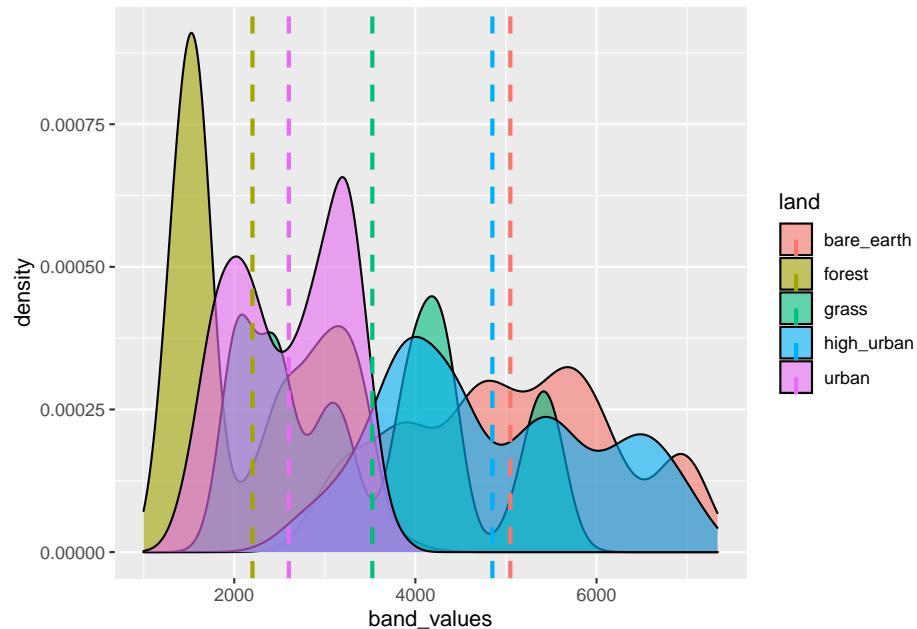


Figure 1.2: Thanks to Sydney Goldstein for some of this code

Remember this mean vertical line is for all values per land cover, it's not band specific.

1.1 Learning outcomes

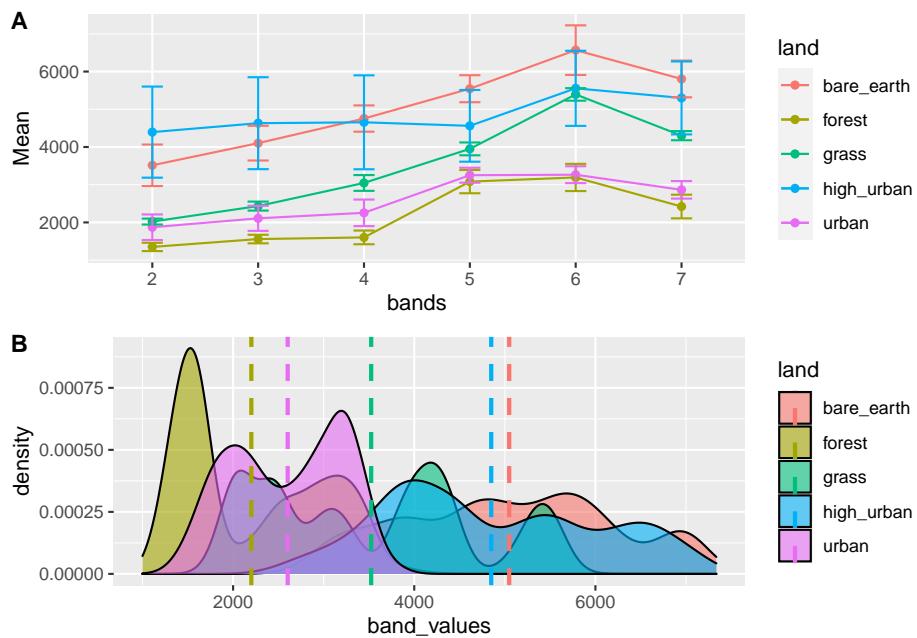
Andy will talk about these outputs.

We can arrange our grids nicely with the `cowplot` package...

```
library(cowplot)

output<-plot_grid(p1, p2, labels = c('A', 'B'), label_size = 12, ncol=1)

output
```



We can also export this if we wanted with `ggsave()` to, `ggsave` has a lot of options and can output to most formats, it also gives examples of not using `ggsave`

1 Getting started with remote sensing

```
ggsave("spectral_reflectance.pdf", width = 20, height = 20, units = "cm")
```

Here, i have just shown the process for Sentinel data. Your task is to respond to the review questions which will include doing a bit similar analysis of the Landsat data / some comparisons...perhaps even a statistical test (e.g. a t-test) to compare the difference between the reflectance of Landsat and Sentinel data e.g..

```
t1<- sen_lsat %>%
  filter(sensor=="sentinel" & land == "urban") %>%
  select(band_values) %>%
  pull()

t2<- sen_lsat %>%
  filter(sensor=="landsat" & land == "urban") %>%
  select(band_values) %>%
  pull()

t.test(t1, t2)
```

Welch Two Sample t-test

```
data: t1 and t2
t = -221.41, df = 2403.1, p-value < 2.2e-16
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
-9621.478 -9452.548
sample estimates:
mean of x mean of y
2602.833 12139.846
```

1.1 Learning outcomes

How do we interpret this?

1.1.5 Review questions

Write around 2-3 paragraphs on the following and support your responses with plots and literature:

- Briefly explain the process of sourcing, loading and manipulating remotely sensed datasets
- Consider the assumption made in comparing the spectral reflectance from Sentinel and Landsat
- Reflect on why differences in the reflectance might occur between sensors.

2 Portfolio

2.0.1 Review questions

3 Resources

<https://github.com/robmarkcole/satellite-image-deep-learning#techniques>

https://urbanspatial.github.io/classifying_satellite_imagery_in_R/#Supervised_Classification

<https://opengislab.com/blog/2018/5/14/flood-mapping-with-sentinel-1-data-using-snap-and-qgis>

4 Summary

In summary, this book has no content whatsoever.

1 + 1

[1] 2

References

