Lab Assignment #4 – ESA SNAP and Sentinel-1 Radar Imagery: SLC, Topographic Corrections, Cross-Polarized Band Ratios for Land-Cover Analysis

1. Logistics

Date assigned:	Monday, November 18, 2024
Date due:	Monday, December 16, 2024 (via Moodle)
Points:	120 points

In this lab, we will work with C-band radar data from the Sentinel-1 mission. We rely on dual polarized data (VV and VH) and use them for classification, vegetation, and water-discrimination. We will focus on the areas of Berlin, Campus Golm and Neues Palais and will explore different radar properties, classification procedures, and differences in spatial resolution. In your homework, you will then compare these results to the analysis we performed on the Landsat-8 and Sentinel-2 images.

2. Initial setup and obtaining satellite data

Sentinel-1

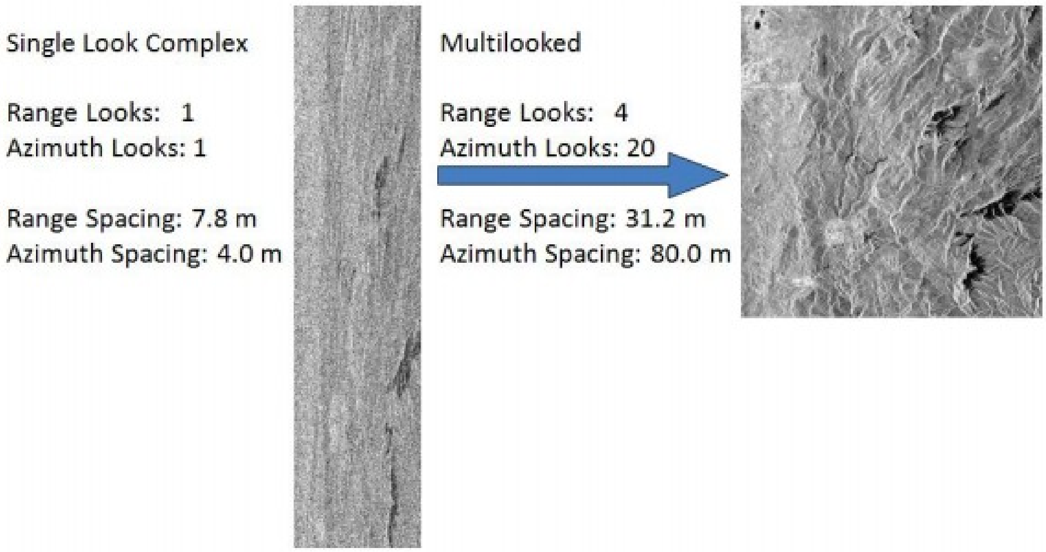
Sentinel-1 data are available through ESA's Scientific Data Open Hub (https://scihub.copernicus.eu/). Sentinel-1 radar data comes in either gridded (GRDH) or single-look complex (SLC) data. If you use SLC data, you will need to convert them to GRDH in SNAP. If you want to avoid taking that step, download GRDH data. Because of the lengthy processing time involved in working with SLC images, for this lab we will work only with the GRD data.

You can find here the data we work with in this lab (or on Moodle):
https://scihub.copernicus.eu/dhus/odata/v1/Products('8bdf7df9-d9ed-486b-8331-0211832a895c')/$value
Level-1 Ground Range Detected (GRD) products consist of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model. The ellipsoid projection of the GRD products is corrected using the terrain height specified in the product general annotation. The terrain height used varies in azimuth but is constant in range.

If you are curious about the original (non-gridded) data, you can find that here:
https://scihub.copernicus.eu/dhus/odata/v1/Products('5276b0ce-e516-45bf-8060-2b87cd0e306a')/$value
Level-1 Single Look Complex (SLC) products consist of focused SAR data, geo-referenced using orbit and attitude data from the satellite, and provided in slant-range geometry. Slant range is the natural radar range observation coordinate, defined as the line-of-sight from the radar to each reflecting object. However, we will not be working with the SLC data in this lab.

3. Multilooking and Terrain Correction (for SLC images)

Multilook processing can be used to produce a product with nominal image pixel size. Multiple looks may be generated by averaging over range and/or azimuth resolution cells improving radiometric resolution but degrading spatial resolution. As a result, the image will have less noise and approximate square pixel spacing after being converted from slant range to ground range.



Radar Data will need to be terrain corrected to account for several artefacts. Terrain Correction will geocode the image by correcting SAR geometric distortions using a digital elevation model (DEM) and producing a map projected product. Geocoding converts an image from Slant Range or Ground Range Geometry into a Map Coordinate System. Terrain Geocoding involves using a Digital Elevation Model (DEM) to correct for inherent SAR geometry effects such as foreshortening, layover and shadow.

Foreshortening

- The period of time a slope is illuminated by the transmitted pulse of the radar energy determines the length of the slope on radar imagery.
- This results in shortening of a terrain slope on radar imagery in all cases except when the local angle of incidence (⚠) is equal to 90˚.

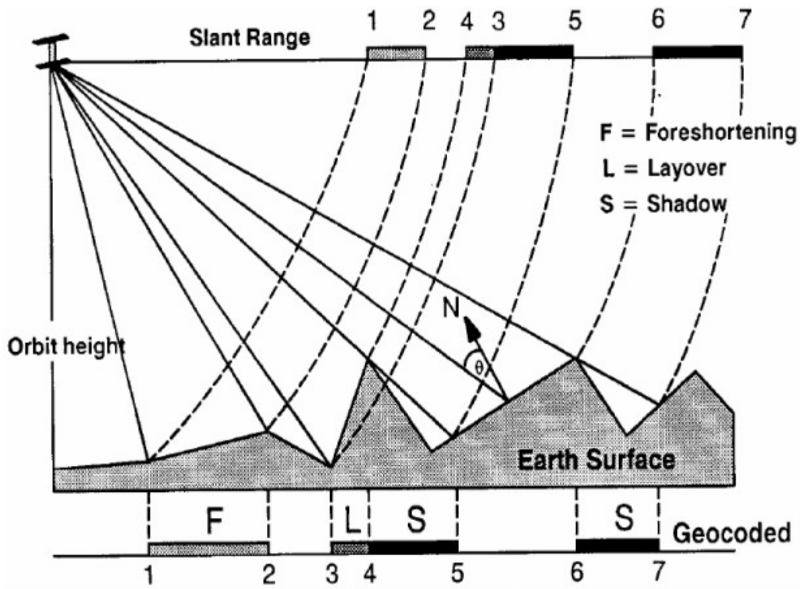
Layover

- When the top of the terrain slope is closer to the radar platform than the bottom the former will be recorded sooner than the latter.
- The sequence at which the points along the terrain are imaged produces an image that appears inverted.
- Radar layover is dependent on the difference in slant range distance between the top and bottom of the feature.

Shadow

- The back-slope is obscured from the imaging beam causing no return area or radar shadow.

The effects of these distortions can be seen below. The distance between 1 and 2 can appear shorter than it should and the return for 4 can occur before the return for 3 due to the elevation. Modern software packages perform these steps in a fast and efficient manner



SAR Geometric Effects

For more details on Radar geometry and correction, please see the paper linked in the course Moodle.

For simplicity (and time), we will only work with GRD data in this lab. However, if you would like to work with SLC data, there is an option for extra credit points for working through the whole process from SLC to final output.

4. Data Calibration

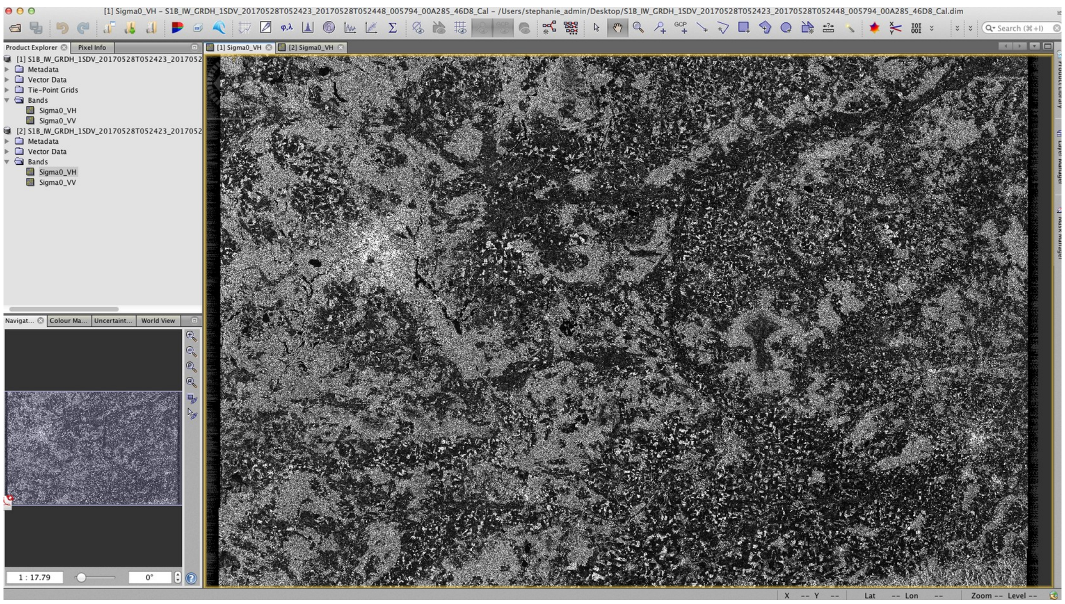
Before we perform the terrain correction, however, we should ***calibrate*** the data so that each pixel value represents the true radar backscatter of the reflecting surface. The calibration is based on the product's metadata, similar to the calibration we did for Landsat 8 data. We access this through the menu ***Radar > Radiometric > Calibrate.***

In the **Processing Parameters** window, if you don't select any source bands, then the calibration operator will automatically select all real and imaginary (i, q) bands (in SLC images). Uncheck 'Save in complex' so that the calibration operator will produce a single Sigma0 band per real and imaginary pair.

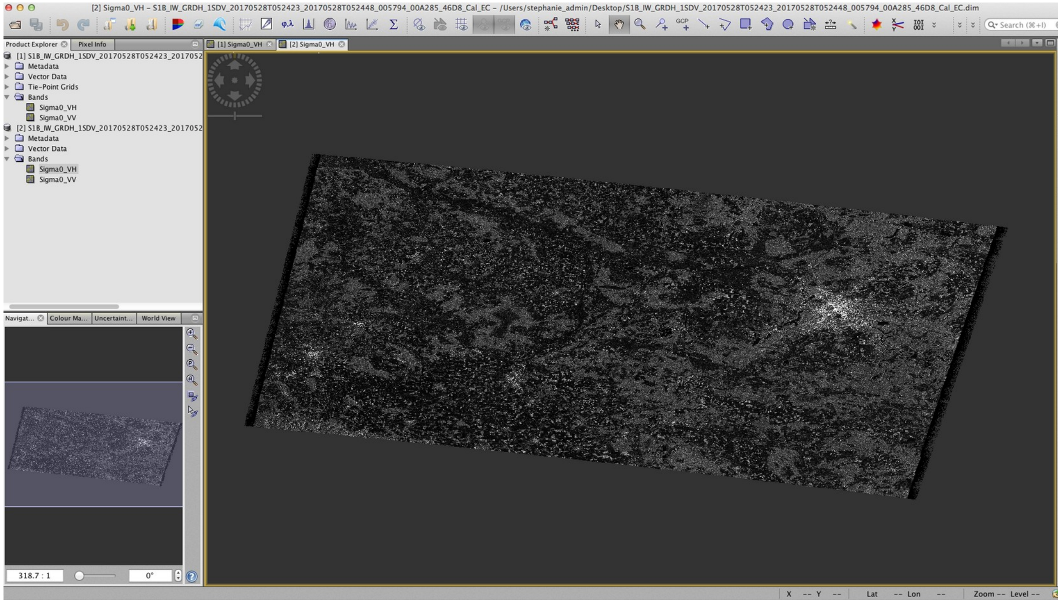
5. Geometric Correction

Before we perform the geographic corrections, we are going to create a **Subset** of the image for faster processing. This can be done in the ***Raster > Create Subset*** menu. Use your cursor to select the area around Berlin (middle of the image, if you cannot identify it). The smaller of a subset you create, the faster your processing will go.

In the **Product Explorer** menu on the left-hand panel, click on the ‘Bands’ folder and double click on either ‘Sigma0_VH’ or ‘Sigma0_VV’. This will open an image of the radar intensity (it takes a moment to load!). When you look at the image, you might notice that features you recognize are not oriented in correct geographic coordinates**. The GRDH image is still oriented with respect to data acquisition, resulting in an inverted image**. We can correct the image either with “terrain correction” or “ellipsoid correction” in the menu ***Radar > Geometric > Terrain Correction > Range-Doppler Terrain Correction*** or ***> Ellipsoid Correction > Geolocation Grid.*** This can take a while.



Inverted map as collected by instrument.



Corrected radar image, with proper geographic orientation.

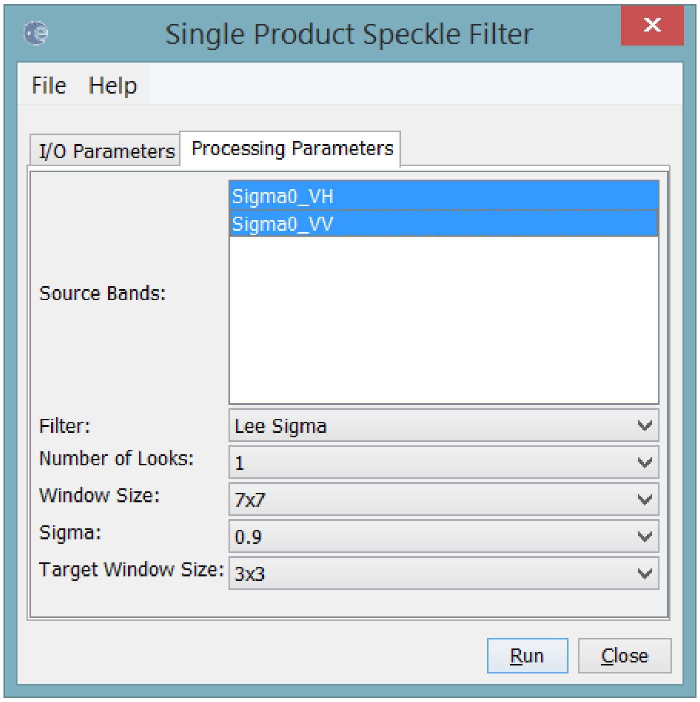
<u>Question 1:</u> Download your own GRDH data covering a different period over Berlin/Brandenburg (e.g., not the data that is available on Moodle) from ESA Scihub and perform calibration and geometric correction steps. Perform the calibration and geometric correction on your new subset using both the ***Ellipsoid Correction > Geolocation Grid*** the ***Range-Doppler Terrain Correction*** options. Export these images to QGIS and create maps (with standard scale, legend, etc) (25 points).

NOTE: If your SNAP hangs while trying to do the Range Dopplar Terrain Correction and SNAP hangs, try changing the *Elevation model* to 'SRTM HGT'. Some versions of SNAP cannot find the right file path for the SRTM 3s, and just wait to download a file that does not exist.

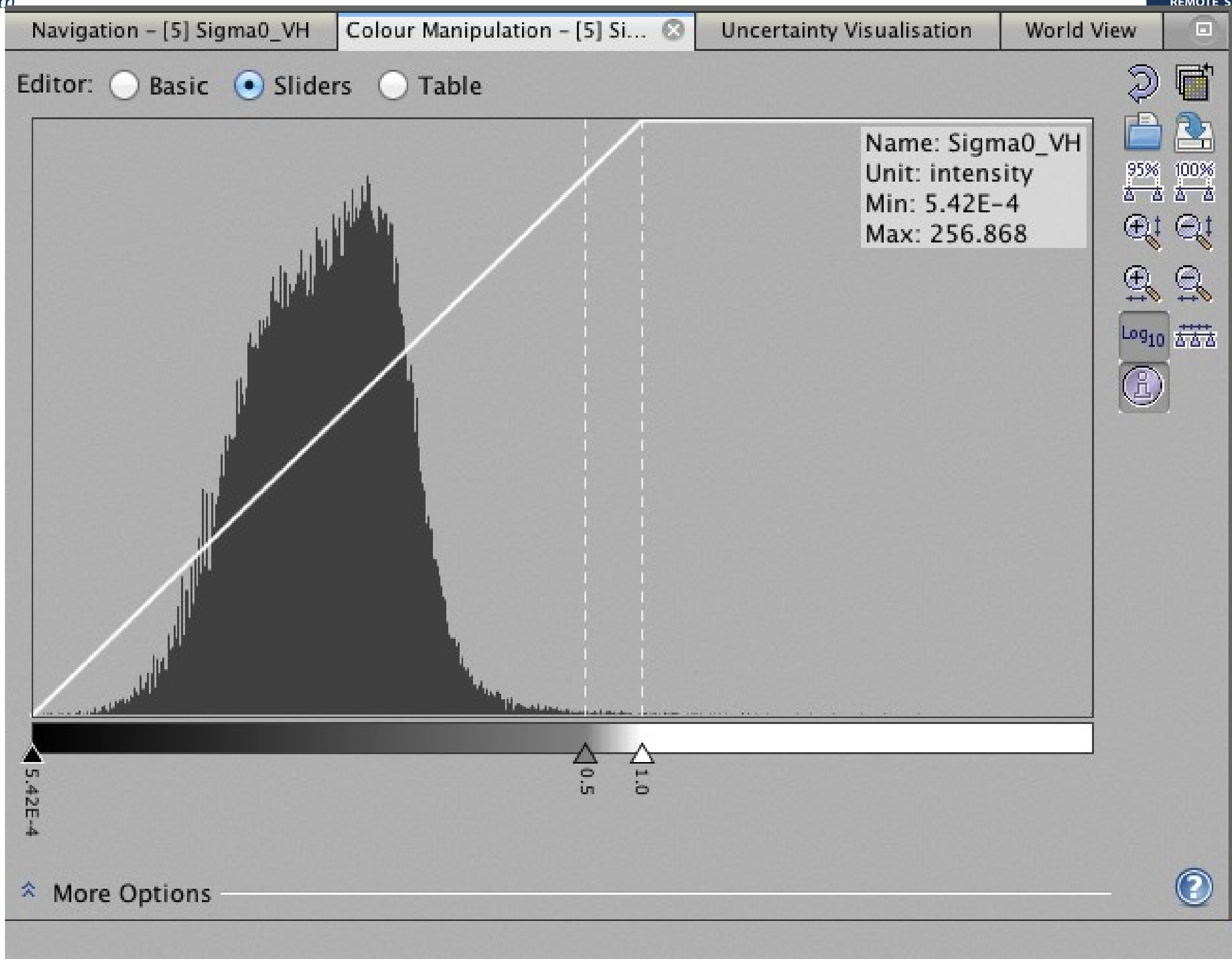
Extra Credit: Using a single IW swath of the SLC image, create a multi-looked and terrain-corrected raster similar to the GRDH. Please include which steps you have done (for example, by making a screenshot of your SNAP window showing the different processing steps). You can use this image for the solution to <u>Question 1</u>.

6. Application: Surface water detection

Because land and water have very different backscatter properties, radar can be effectively used to detect surface water. As a first step, we will reduce noise in the image by performing ***Speckle Filtering.*** Speckle is caused by random constructive and destructive interference resulting in salt and pepper noise throughout the image. Speckle filters can be applied to the data to reduce the amount of speckle at the cost of blurred features or reduced resolution. We will apply a 7x7 Lee sigma filter to reduce granular noise in the image. This can be found in the menu ***Radar > Speckle Filtering > Single Product Speckle Filter.***



To separate water from non-water, a threshold can be selected. For this, we will analyse the histogram of the filtered backscatter coefficient. On the left side panel select the **Colour Manipulation tab**, we can see the histogram of the image amplitude (may need logarithmic display). The histogram will show one or more peaks of different magnitude depending on the data**. Low values of the backscatter will correspond to the water**, and high values will correspond to the non-water class. We will select the value that will separate water from non-water. If there is not enough standing water in the scene to create a bimodal histogram, we may have to experiment with breakoff points between water and land.

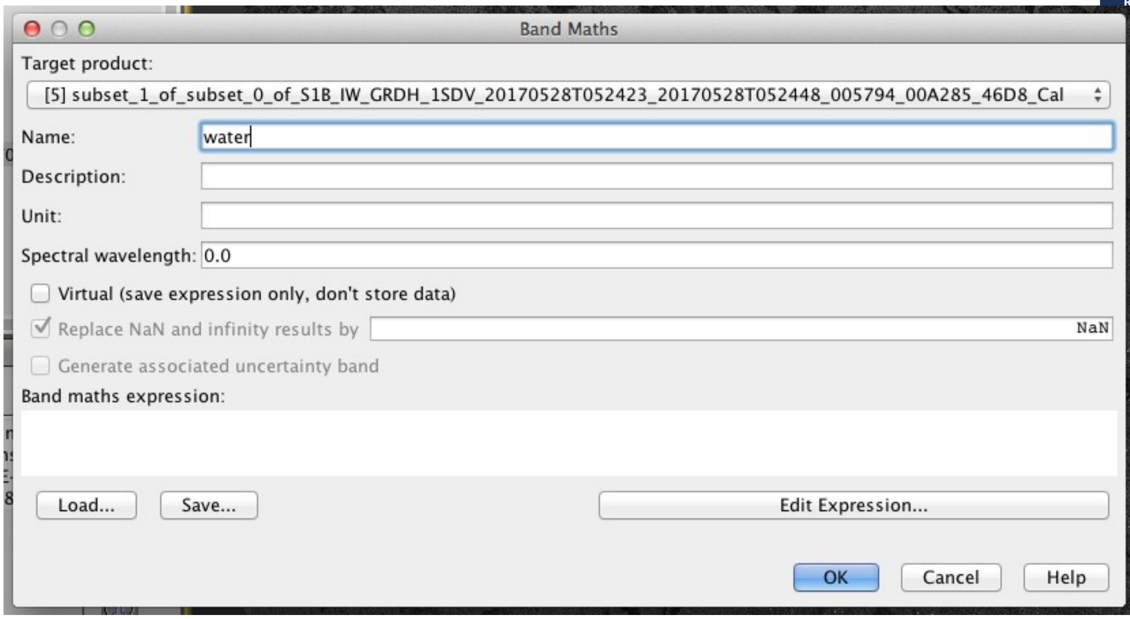


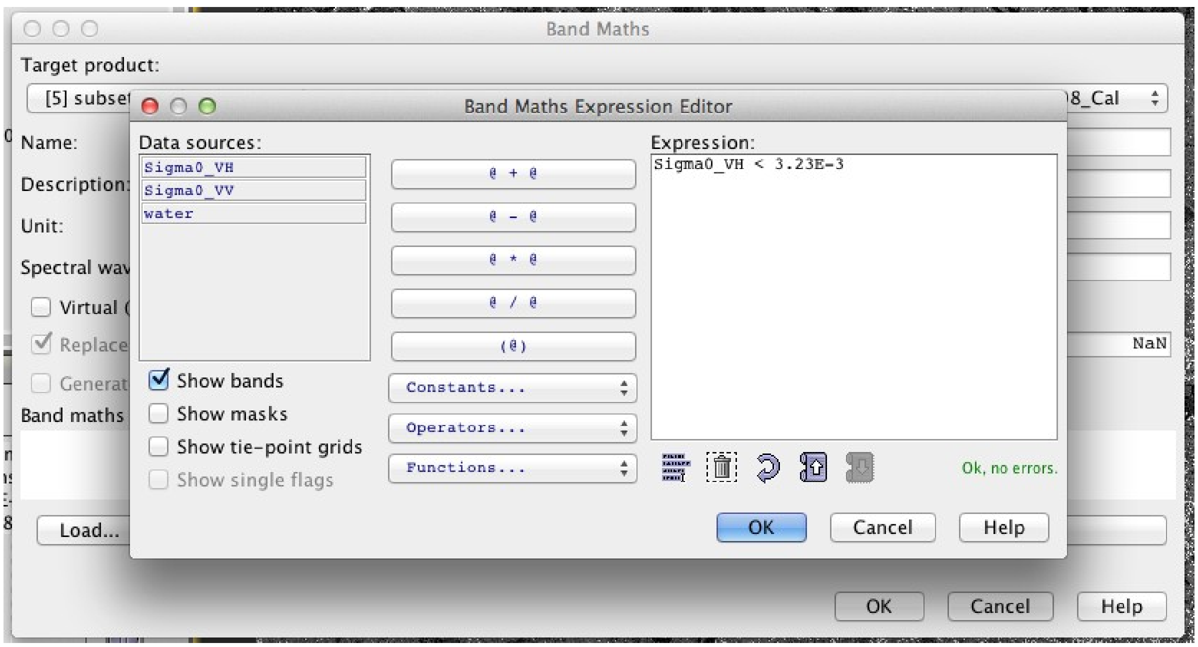
To create a map of water versus land, we will use the ***Band Maths*** option in the menu ***Raster > Band Maths***. A dialog will appear prompting you to choose a target product (our calibrated, georeferenced, and speckle-filtered subset of Berlin) and designate the new band (e.g., "Water"). Make sure to uncheck the box that says "Virtual", so you are able to save your output.

To set the threshold between water and non-water, we will now use the ***Edit Expression*** option. This will open a menu similar to the Raster Math menu in QGIS. Select the band you would like to use (e.g., Sigma0_VV) and make an expression designating a new raster as you would in QGIS, e.g.

Sigma0_VV < WATER_THRESHOLD

Again, if the histogram was not clear, you may have to experiment with different threshold values.





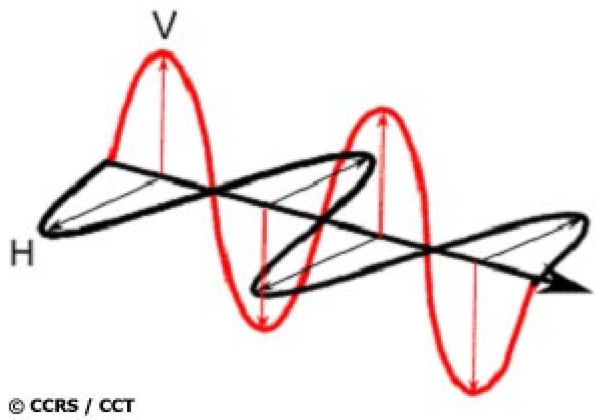
__Question 2:__ Export your new map of standing water as a GeoTIFF and import it into QGIS. How does it compare to the water map you made with the Landsat-8 and Sentinel-2 data (NDWI) in Lab 2? Where are the areas where all satellites find water? Where only one satellite finds water? You should explore this by calculating the difference between the three rasters to help you determine their relative strengths and weaknesses, and displaying the results as a **single raster image**. Please provide the answer to this question as a map (25 pts). **HINT: You might have to resample your datasets to the same spatial resolution to do the comparison! This can be done in either SNAP or QGIS. You also might want to re-classify your data to make comparing the datasets easier. HINT2: Try**

first classifying each image into water/not-water, and then combining them into a one final map.

7. Dual Polarized Radar Data

When discussing microwave energy propagation and scattering, the polarization of the radiation is an important property. For a plane electromagnetic (EM) wave, polarization refers to the locus of the electric field vector in the plane perpendicular to the direction of propagation. While the length of the vector represents the **amplitude** of the wave, and the rotation rate of the vector represents the **frequency** of the wave, polarization refers to the **orientation** and **shape** of the pattern traced by the tip of the vector.

The waveform of the electric field strength (voltage) of an EM wave can be predictable (the wave is polarized) or random (the wave is unpolarized), or a combination of both. In the latter case, the degree of polarization describes the ratio of polarized power to total power of the wave. An example of a fully polarized wave would be a **monochromatic** sine wave, with a single, constant frequency and stable amplitude.



Examples of horizontal (black) and vertical (red) polarizations of a plane electromagnetic wave (from the Canada Centre for Mapping and Earth Observation: http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9275)

Many radars are designed to transmit microwave radiation that is either horizontally polarized (H) or vertically polarized (V). A transmitted wave of either polarization can generate a backscattered wave with a variety of polarizations. It is the analysis of these transmit and receive polarization combinations that constitutes the science of radar polarimetry.

The Sentinel-1 SAR satellite is a dual polarized radar. It can transmit a signal and receive in both horizontal (H) and vertical (V) polarisation. Thus Sentinel-1 data is available in four polarisations (two single, two dual):

- HH – Horizontal transmitted, horizontal received
- VV – Vertical transmitted, vertical received
- HH + HV – HH and horizontal transmitted, vertical received
- VV + VH – VV and vertical transmitted, horizontal received

Dual polarisation SAR products containing complex value and inter-channel phase information allow for measurement of the polarisation properties of terrain in addition to the backscatter that can be measured from a single polarisation.

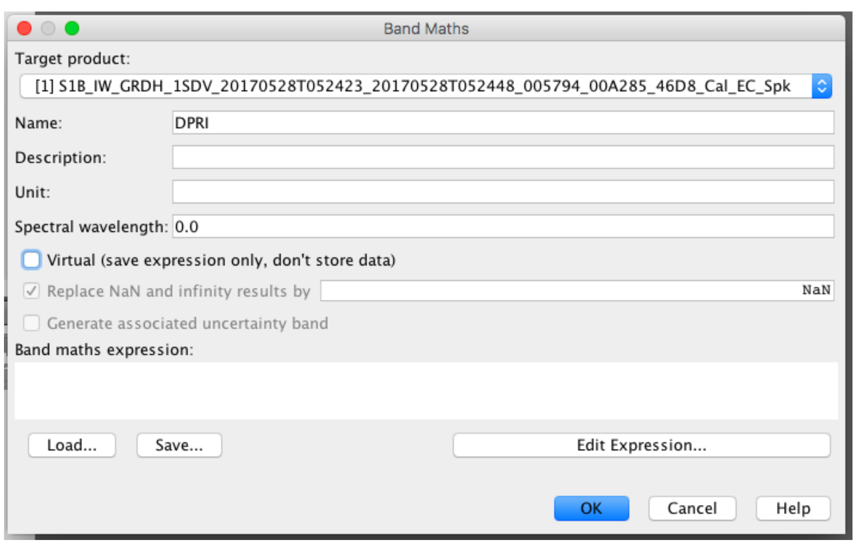
Targets on the ground have distinctive polarisation signatures reflecting different polarisations with different intensities and converting one polarisation into another. For example, volume scatterers (e.g., forest canopy) have different polarisation properties than surface scatterers (e.g., bare earth). Polarimetric decompositions allow the separation of different scattering contributions and can be used to extract information about the scattering process, providing improved classification of point targets and distributed target areas. For more information, please see here: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/product-overview/polarimetry

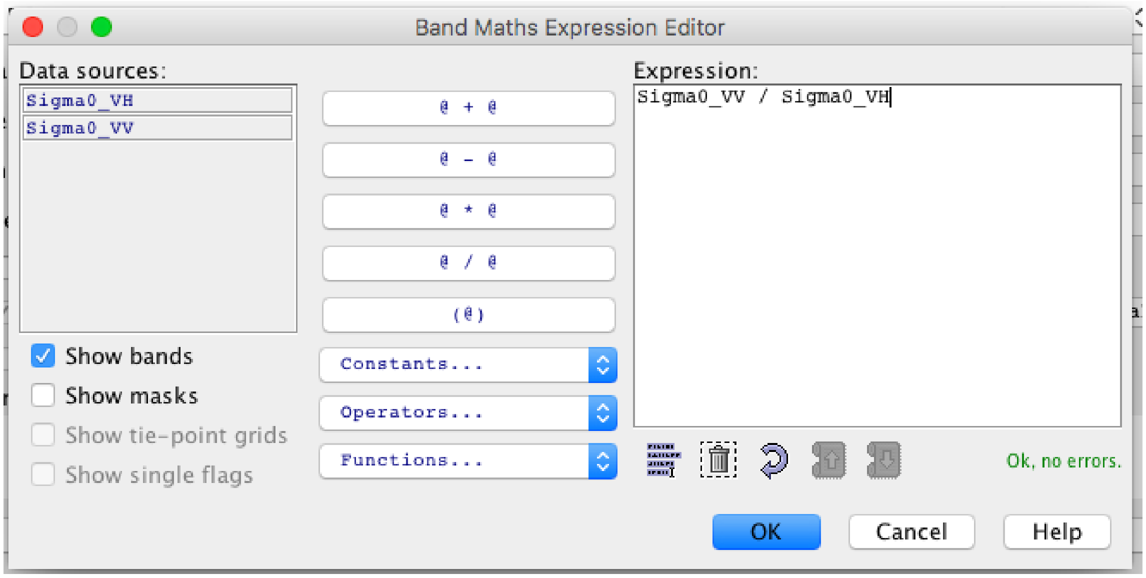
6. Generating products of VH and VV

As we generated ratios of visible light from the LANDSAT-8 data, we can also calculate useful ratios of polarized radar data. For example, using the VV and VH data of Berlin and Potsdam, we can calculate the:

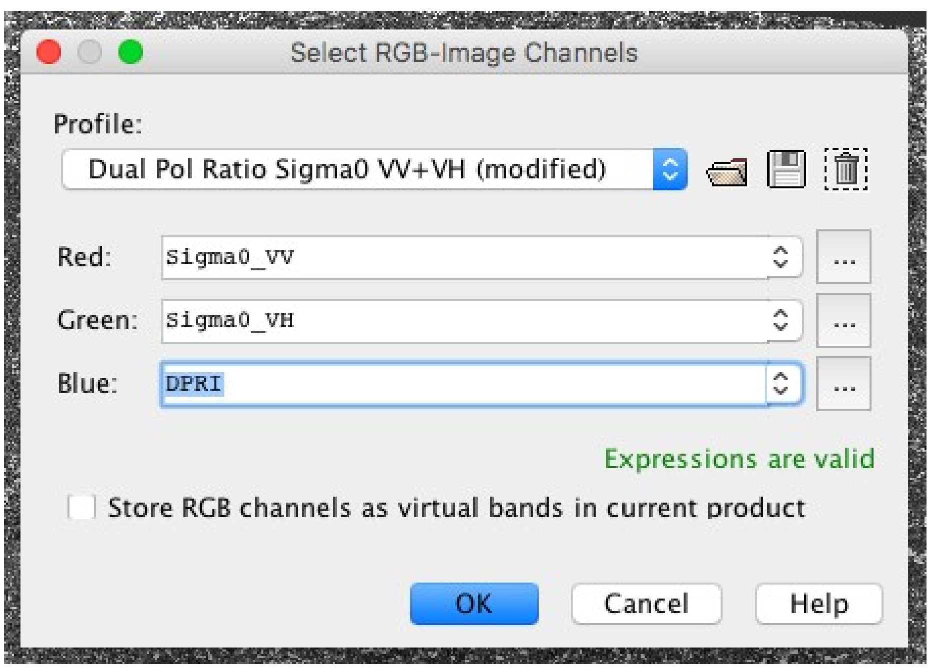
- DPRI (Dual Polarized Ratio Index) = VV/VH
- DPMI (Dual Polarized Multiplication Index) = VV*VH
- DPDI (Dual Polarized Differential Index) = VV - VH

We can use the two bands (VH and VV) to generate a third band and visualize this in colors. You can either multiple VH and VV to generate the third band, divide VV by VH, or subtract VH from VV. These indices can be easily calculated using the ***Raster > Band Maths*** tool.

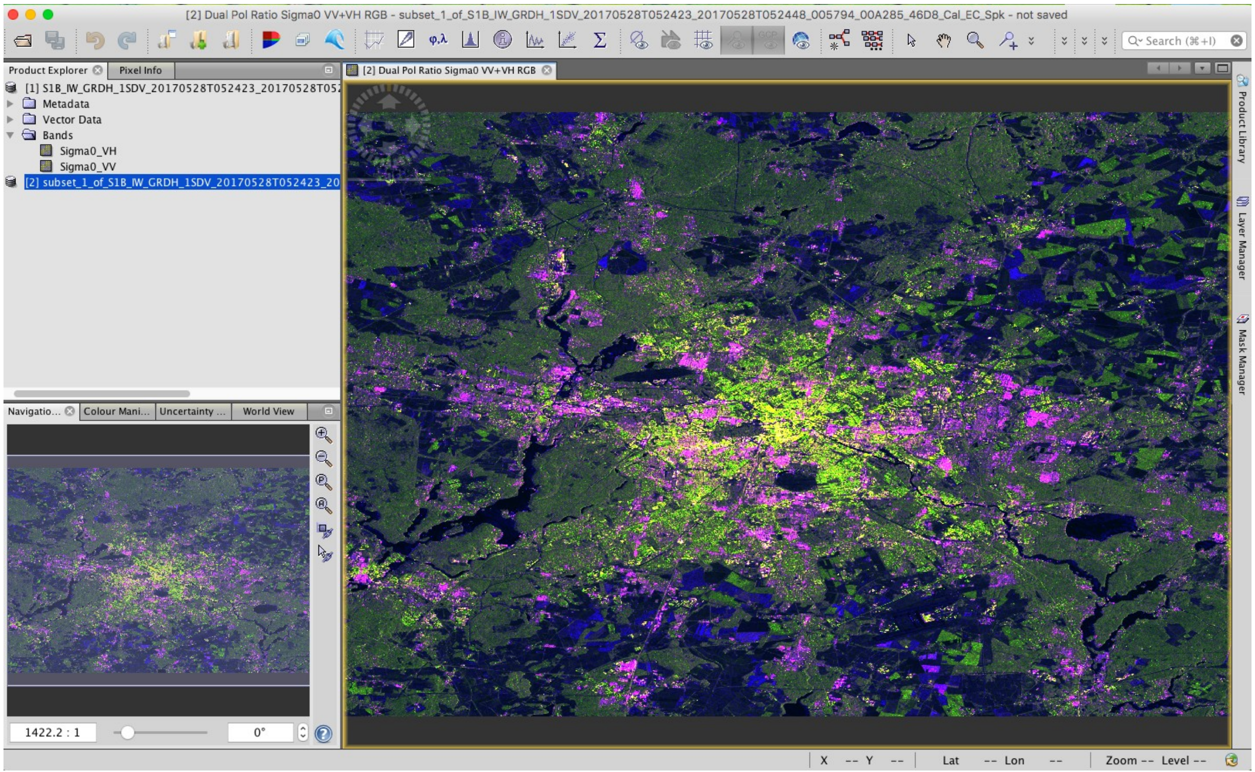




An RGB composite can be created to view the VV, VH, and VV/VH bands by right-clicking on the product in the ***Product Explorer*** menu on the left and selecting ***Open RGB Image Window.***



Here is the RGB composite with R = VV, G = VH, B = DPRI (VV/VH).



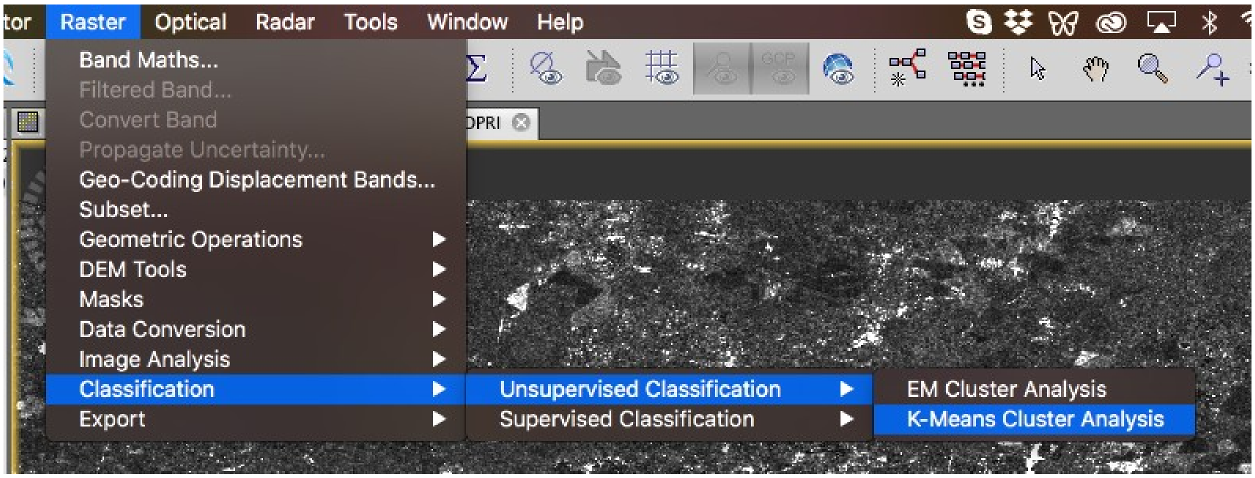
<u>Question 3:</u> Calculate the DPMI and DPDI and use these in combination with the VV and VH bands to create two more RGB images of Berlin and Potsdam. These should be submitted as maps, with a scale, useful title, and explanation of what each color (e.g., red, green, and blue) represents (e.g., VV, VH, DPMI, etc). You can use SNAP's built-in mapmaking tools, or export the images to QGIS first (20 points).

<u>Question 4:</u> What band combination is most useful for discriminating between forest and agricultural fields? (10 points).

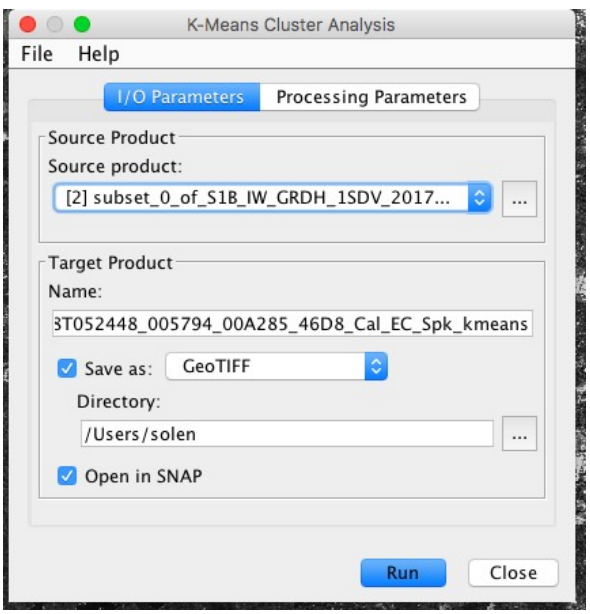
7. Land Cover Classification with SNAP

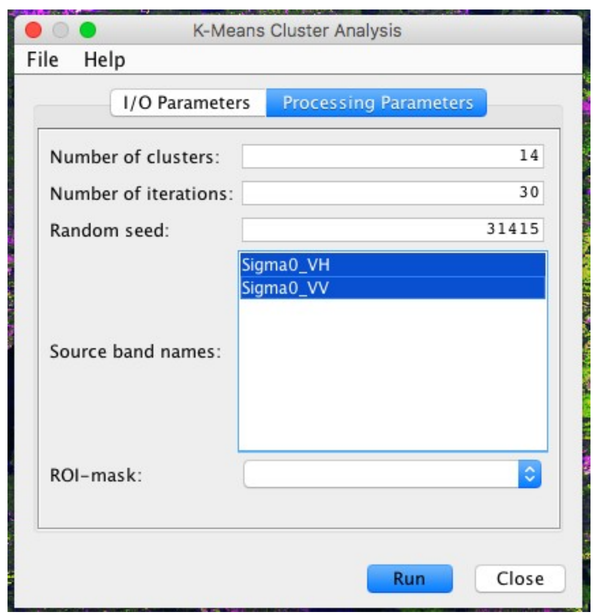
In the next lab, we will do an in-depth exploration of different methods of land cover classification techniques in QGIS. For the last part of this lab, we will take advantage of the inbuilt unsupervised classification in SNAP. Unsupervised classification means that SNAP will analyze the ratio of VV and VH bands and construct its own classes without user-input. This can generate interesting results, and we will compare them to the more careful classification we will do in a later lab.

From the ***Raster*** menu, navigate to ***Classification > Unsupervised Classification > K-Means Cluster Analysis.***



Make sure that the analysis is being done on the subset of the Berlin/Potsdam region. Select ***Sigma0_VV*** and ***Sigma0_VH*** as your source bands.

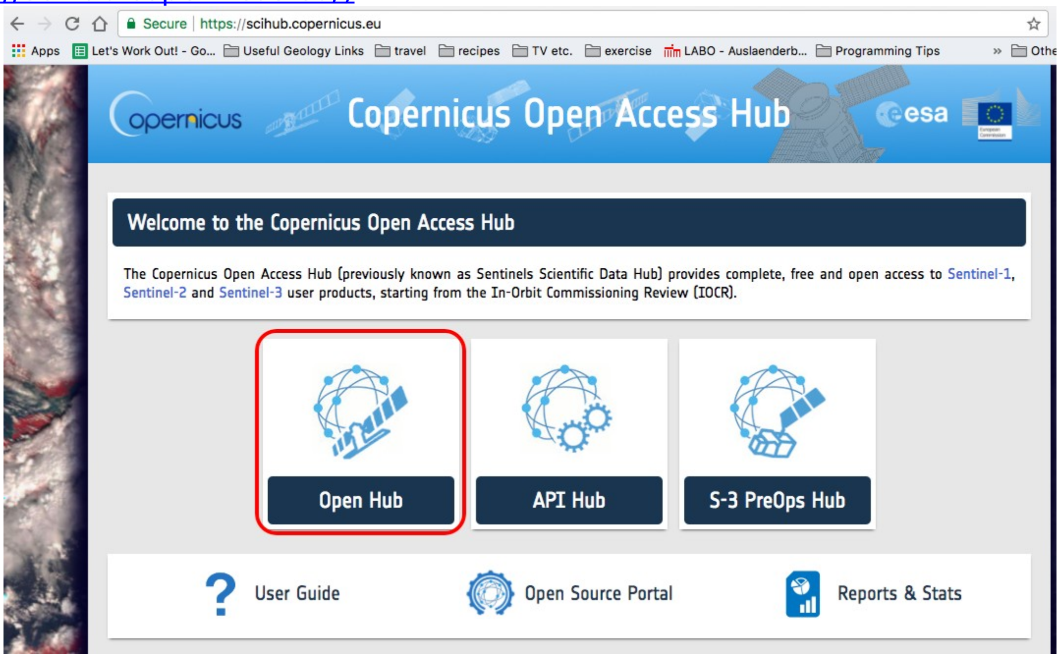




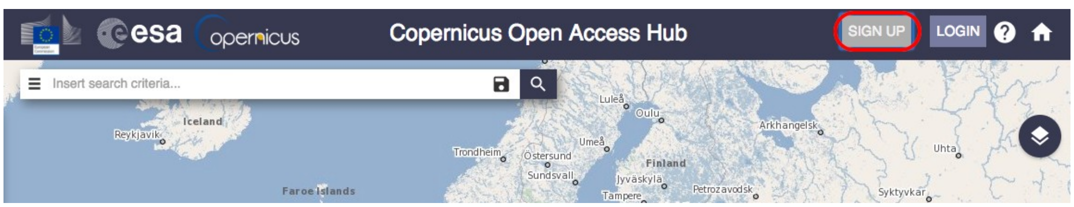
<u>EXTRA CREDIT</u>: How well does the SNAP classification perform for the Berlin/Brandenburg region? Do the land cover classifications seem realistic? Where does the classification perform the best? The worst? Using either the K-Means or EM Cluster tool, try using more or less clusters (e.g., 5, 10, 15, etc). How do the results look? Please turn in at least four maps showing different cluster algorithms and numbers of clusters, as well as text explaining why you chose the number of clusters, algorithm, etc. Maps should be made in QGIS, with a scale, legend, colorbar, and all other essential elements.

8. Working with your own data from ESA's Copernicus Open Science Hub

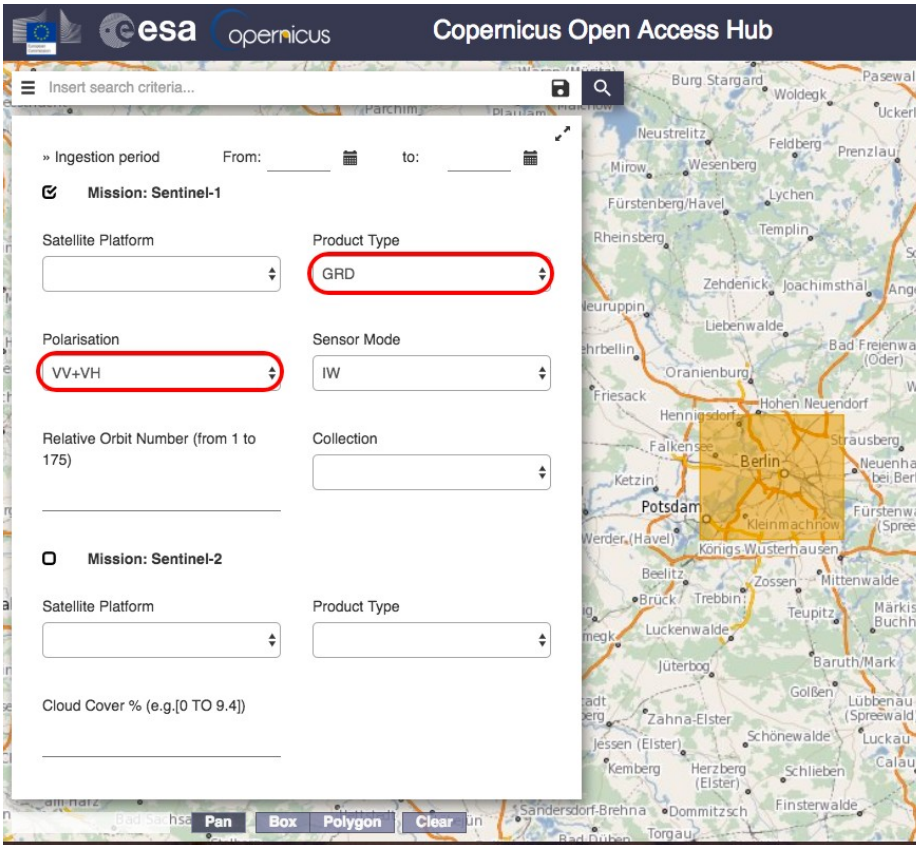
Sentinel-1 data can be accessed through the **ESA Copernicus Open Science Hub** ([https://scihub.copernicus.eu/)](https://scihub.copernicus.eu/).



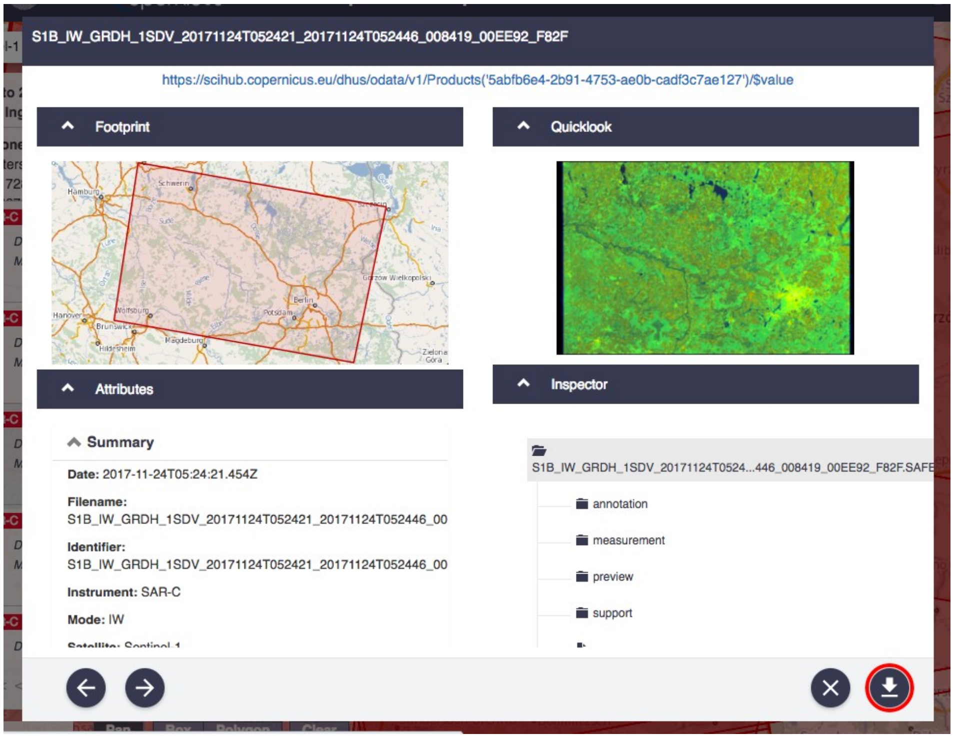
Sentinel-1 data is free, but you will need to create an account before you can download data.



Once you have a Copernicus SciHub account, you can search by panning the map to your area of interest (see options on bottom to Pan – Box – Polygon – Clear these allow you to navigate and select regions you're interested in. When you've navigated to your region of interest, use either the **Box** or the **Polygon** tool to highlight the specific area you want data for. Once you've done this, you can use the search criteria to specify what kind of data you want. For this exercise **please choose a dual-polarised GRD image.**



You can preview images using the “eye” icon next to each search result and download the data directly.



This works great for downloading a small number of images. If you want several images, you can add the images to your cart. When you download your cart, you will get a ".meta4" file that you will need to download from the command line using **aria2** (https://aria2.github.io/) or **sentinelsat** (https://sentinelsat.readthedocs.io/en/stable/).

```
aria2c --http-user='<your username>' --http-passwd='<your password>' --check-certificate=false --max-concurrent-downloads=2 -M products.meta4
```

Question 5: Download a new GRDH Sentinel-1 image from the Copernicus Open Science Hub. This can be from anywhere in the world that interests you. Using this data, perform the following tasks:

1) Subset the image to a specific region.
2) Perform a geographic correction on your subset, using either the ellipsoid or terrain correction. Try to choose the geographic correction more appropriate to your chosen area (e.g., terrain correction if you choose a mountainous region).
3) Perform speckle filtering.
4) Create **three** RBG images using R=VV, B=VH, and G = VV/VH, VV*VH, and VV-VH.

Please hand in the results of 4) as maps with a scale, north arrow, legend, title, and grid. Which of the three RBG maps best represents the land cover in your chosen area? How well does the unsupervised classification work in your chosen area? (40 points)