Lab Assignment #2 – Earth Remote-sensing with Landsat-8 Imagery

1. Logistics

Date assigned:	Monday, October 21, 2024
Date due:	Monday, November 18, 2024 (via Moodle)
Points:	100 points

Please submit all homework as a single PDF file via Moodle.

In this lab, you will work with multispectral remote sensing data from the Landsat-8 (OLI) satellite. We will focus on the Berlin region and will explore different multispectral properties, vegetation classification, and differences in spatial resolution. We will also show you how to download your own data for an area of your choice.

2. Initial Setup and Data Sources

Landsat

Landsat data are provided free of charge from the USGS. The data are free, but you will eventually need to register/create an account to obtain data for this and future labs. See here: https://landsat.usgs.gov/landsat-data-access. We suggest you create an EarthExplorer account at https://earthexplorer.usgs.gov/. The data for the first part of the lab is available on Moodle.

Information about the Landsat 8 OLI (Operational Land Imager) and the TIRS (Thermal Infrared Sensor)
sensor can be obtained from the lecture and other documents online. A general introduction to the
Landsat 8 sensor is available at https://landsat.usgs.gov/landsat-8 (with additional links on that webpage). Landsat-8 data is provided as a suite of GeoTIFFs for a given tile. Each GeoTIFF/band represents a different wavelength (e.g., ‘visible red’, ‘visible green’, ‘near infrared’, etc.). For reference for this lab, the bands for Landsat-8 are:

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Ultra Blue (coastal/aerosol)	0.435 - 0.451	30
	Band 2 - Blue	0.452 - 0.512	30
	Band 3 - Green	0.533 - 0.590	30
	Band 4 - Red	0.636 - 0.673	30
	Band 5 - Near Infrared (NIR)	0.851 - 0.879	30
	Band 6 - Shortwave Infrared (SWIR) 1	1.566 - 1.651	30
	Band 7 - Shortwave Infrared (SWIR) 2	2.107 - 2.294	30
	Band 8 - Panchromatic	0.503 - 0.676	15
	Band 9 - Cirrus	1.363 - 1.384	30
	Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100 * (30)
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 * (30)

* TIRS bands are acquired at 100 meter resolution, but are resampled to 30 meter in delivered data product.

Caution is needed when using older Landsat products, however, as band designations change between generations (https://landsat.usgs.gov/what-are-band-designations-landsat-satellites).

3. Pre-processing and Correcting Landsat-8 (OLI) data

Uncompress the Landsat Archive (LC08_L1TP_193023_20151003_20170403_01_T1.tar.gz). *Note that this file is compressed twice.* You can use 7zip or a similar package to uncompress the gzip file (.gz), then
you uncompress the tar file (again with 7zip or a similar tool). Each file is a Landsat band (cf. Figure 6).
You can view the Landsat 8 file by opening it in QGIS.

Before working with the Landsat data for most applications, it is essential to convert the digital numbers (16-bit) stored in the file to TOA (top-of-atmosphere) radiances and reflectances. This will allow to compare various Landsat scenes from different dates, atmospheric conditions, and seasons more easily. It also will allow you to compare images from different satellites (e.g., Landsat 8 vs. Sentinel-2) Detailed information about this process can be found here: https://landsat.usgs.gov/using-usgs-landsat-8-product.
There are several different ways to do the conversion to radiances, including both desktop (e.g., QGIS) and scripting (e.g., Python, R, Matlab) approaches. In general, the calculation for radiance is:

$$\boldsymbol{L_\lambda = M_L\, Q_{cal} + A_L}$$

with parameters for each band taken from the *_MTL.txt file provided with each Landsat file (in the same folder). These are:

- L_λ = TOA spectral radiance (Watts/(m2 * srad * µm))
- M_L = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)
- A_L = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)
- Q_{cal} = Quantized and calibrated standard product pixel values (digital number, DN, provided in the tif file).

The calculation for reflectance is:

$$\rho\lambda' = M_\rho Q_{cal} + A_\rho$$

again with parameters taken from the *_MTL.txt file. These are:

- $\rho\lambda'$ = TOA planetary reflectance, without correction for solar angle. Note that $\rho\lambda'$ does not contain a correction for the sun angle.
- M_ρ = Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number)
- A_ρ = Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number)
- Q_{cal} = Quantized and calibrated standard product pixel values (DN)

Finally, to correct for sun angle, we use:

$$\rho\lambda = \frac{\rho\lambda'}{\cos(\theta_{SZ})} = \frac{\rho\lambda'}{\sin(\theta_{SE})}$$

Where:

- $\rho\lambda$ = TOA planetary reflectance
- θ_{SE} = Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION).
- θ_{SZ} = Local solar zenith angle; $\theta_{SZ} = 90° - \theta_{SE}$

4. Processing Landsat-8 (OLI) data with QGIS

The Landsat directory contains a file with information about the senor, bands, and correction factors in LC08_L1TP_193023_20151003_20170403_01_T1_MTL.txt. Let’s first take a look at that metadata file:

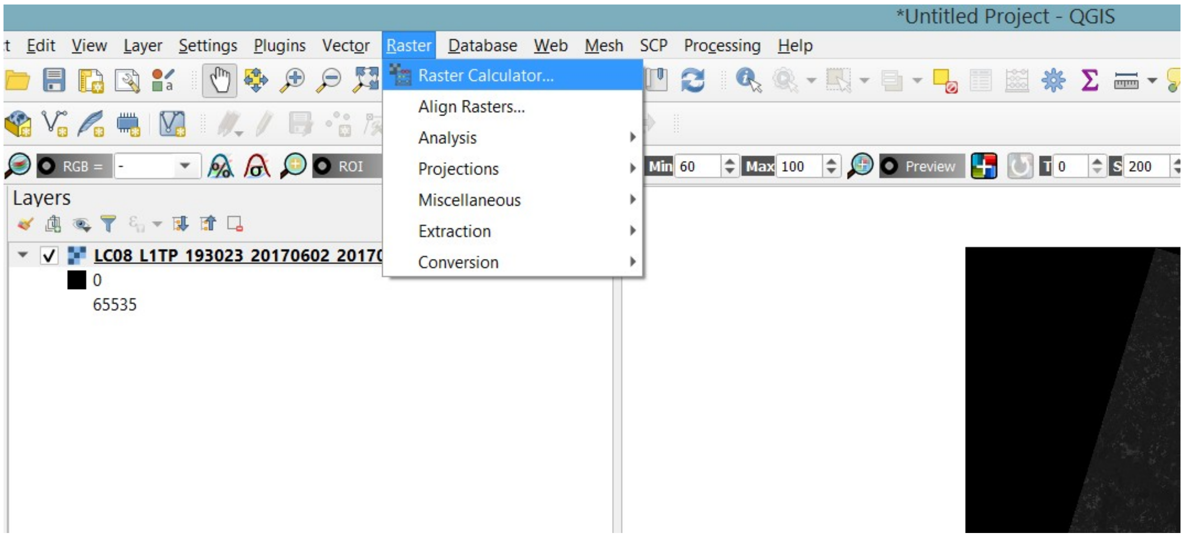
```
GROUP = L1_METADATA_FILE
  GROUP = METADATA_FILE_INFO
    ORIGIN = "Image courtesy of the U.S. Geological Survey"
    REQUEST_ID = "0701706146367_00014"
    LANDSAT_SCENE_ID = "LC81930232017153LGN00"
    LANDSAT_PRODUCT_ID = "LC08_L1TP_193023_20170602_20170615_01_T1"
    COLLECTION_NUMBER = 01
    FILE_DATE = 2017-06-15T22:27:06Z
    STATION_ID = "LGN"
    PROCESSING_SOFTWARE_VERSION = "LPGS_2.7.0"
  END_GROUP = METADATA_FILE_INFO
  GROUP = PRODUCT_METADATA
    DATA_TYPE = "L1TP"
    COLLECTION_CATEGORY = "T1"
    ELEVATION_SOURCE = "GLS2000"
    OUTPUT_FORMAT = "GEOTIFF"
    SPACECRAFT_ID = "LANDSAT_8"
    SENSOR_ID = "OLI_TIRS"
    WRS_PATH = 193
    WRS_ROW = 23
    NADIR_OFFNADIR = "NADIR"
    TARGET_WRS_PATH = 193
    TARGET_WRS_ROW = 23
    DATE_ACQUIRED = 2017-06-02
    SCENE_CENTER_TIME = "10:02:10.2054180Z"
    CORNER_UL_LAT_PRODUCT = 54.15675
    CORNER_UL_LON_PRODUCT = 11.60137
    CORNER_UR_LAT_PRODUCT = 54.20435
    CORNER_UR_LON_PRODUCT = 15.30048
    CORNER_LL_LAT_PRODUCT = 51.96523
    CORNER_LL_LON_PRODUCT = 11.76978
    CORNER_LR_LAT_PRODUCT = 52.00920
    CORNER_LR_LON_PRODUCT = 15.28556
    CORNER_UL_PROJECTION_X_PRODUCT = 278100.000
    CORNER_UL_PROJECTION_Y_PRODUCT = 6006300.000
    CORNER_UR_PROJECTION_X_PRODUCT = 519600.000
    CORNER_UR_PROJECTION_Y_PRODUCT = 6006300.000
    CORNER_LL_PROJECTION_X_PRODUCT = 278100.000
```

As you can see, there is A LOT of data stored in there about timing, satellite angles, geographic location, etc. Further down, there are a set of correction factors that we will need to use to turn the raw Landsat pixel values into radiances (how much light the satellite collects) and reflectances (a unitless ratio measure).

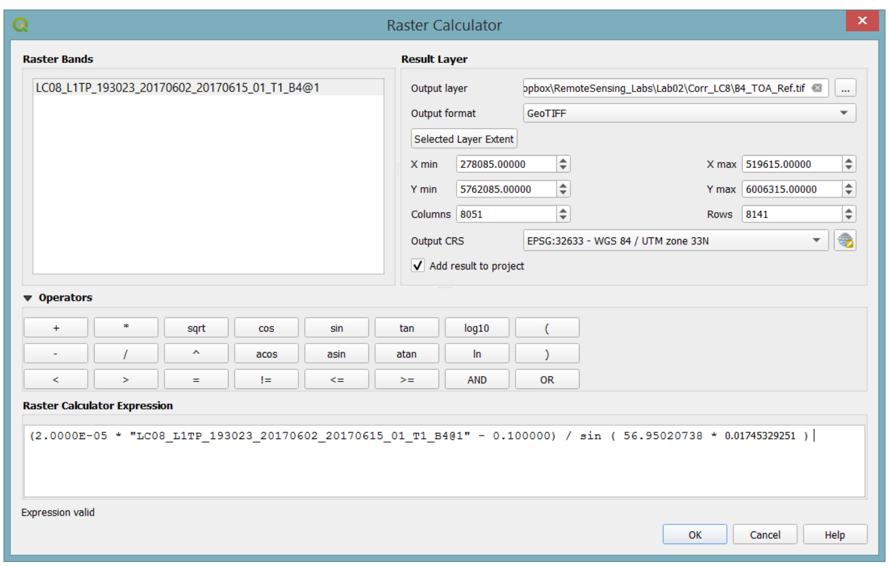
```
GROUP = MIN_MAX_RADIANCE
  RADIANCE_MAXIMUM_BAND_1 = 738.90698
  RADIANCE_MINIMUM_BAND_1 = -61.01918
  RADIANCE_MAXIMUM_BAND_2 = 756.64978
  RADIANCE_MINIMUM_BAND_2 = -62.48438
  RADIANCE_MAXIMUM_BAND_3 = 697.24628
  RADIANCE_MINIMUM_BAND_3 = -57.57883
  RADIANCE_MAXIMUM_BAND_4 = 587.95734
  RADIANCE_MINIMUM_BAND_4 = -48.55371
  RADIANCE_MAXIMUM_BAND_5 = 359.80057
  RADIANCE_MINIMUM_BAND_5 = -29.71245
  RADIANCE_MAXIMUM_BAND_6 = 89.47913
  RADIANCE_MINIMUM_BAND_6 = -7.38922
  RADIANCE_MAXIMUM_BAND_7 = 30.15926
  RADIANCE_MINIMUM_BAND_7 = -2.49056
  RADIANCE_MAXIMUM_BAND_8 = 665.40588
  RADIANCE_MINIMUM_BAND_8 = -54.94944
  RADIANCE_MAXIMUM_BAND_9 = 140.61823
  RADIANCE_MINIMUM_BAND_9 = -11.61230
  RADIANCE_MAXIMUM_BAND_10 = 22.00180
  RADIANCE_MINIMUM_BAND_10 = 0.10033
  RADIANCE_MAXIMUM_BAND_11 = 22.00180
  RADIANCE_MINIMUM_BAND_11 = 0.10033
END_GROUP = MIN_MAX_RADIANCE
GROUP = MIN_MAX_REFLECTANCE
  REFLECTANCE_MAXIMUM_BAND_1 = 1.210700
  REFLECTANCE_MINIMUM_BAND_1 = -0.099980
  REFLECTANCE_MAXIMUM_BAND_2 = 1.210700
  REFLECTANCE_MINIMUM_BAND_2 = -0.099980
  REFLECTANCE_MAXIMUM_BAND_3 = 1.210700
  REFLECTANCE_MINIMUM_BAND_3 = -0.099980
  REFLECTANCE_MAXIMUM_BAND_4 = 1.210700
  REFLECTANCE_MINIMUM_BAND_4 = -0.099980
  REFLECTANCE_MAXIMUM_BAND_5 = 1.210700
  REFLECTANCE_MINIMUM_BAND_5 = -0.099980
```

As a first step, we will use these correction factors to produce TOA (top of atmosphere) reflectance values from our Landsat data. Then, we will calculate the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI) for the Berlin area using the corrected Landsat data.

Let’s start with Band 4 – eventually we will want to correct Bands 3, 4, and 5 for the first part of the lab.
We can use the ‘Raster Calculator’ tool to add the correction factors to each band to reflectance:



Taking the correction factors from the metadata file and using the equations above for reflectance, we should have something like this:



Note that we have to change the units of the sun angle from DEGREES TO RADIANS! This is very important.

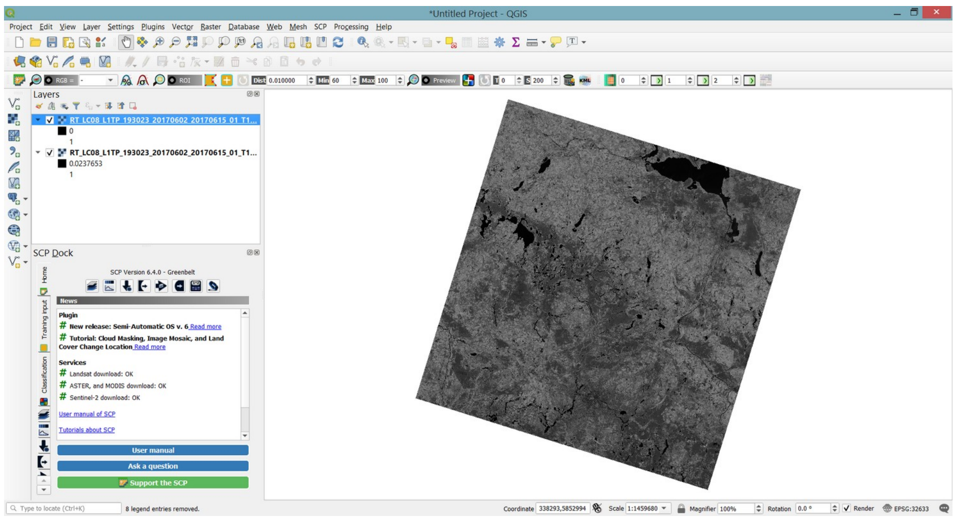
Go ahead and do this for Bands 3 and 5 as well – the correction factors are all the same. We will then use the corrected data for the next part of the lab.

5. Calculating Band Ratios (NDVI and NDWI)

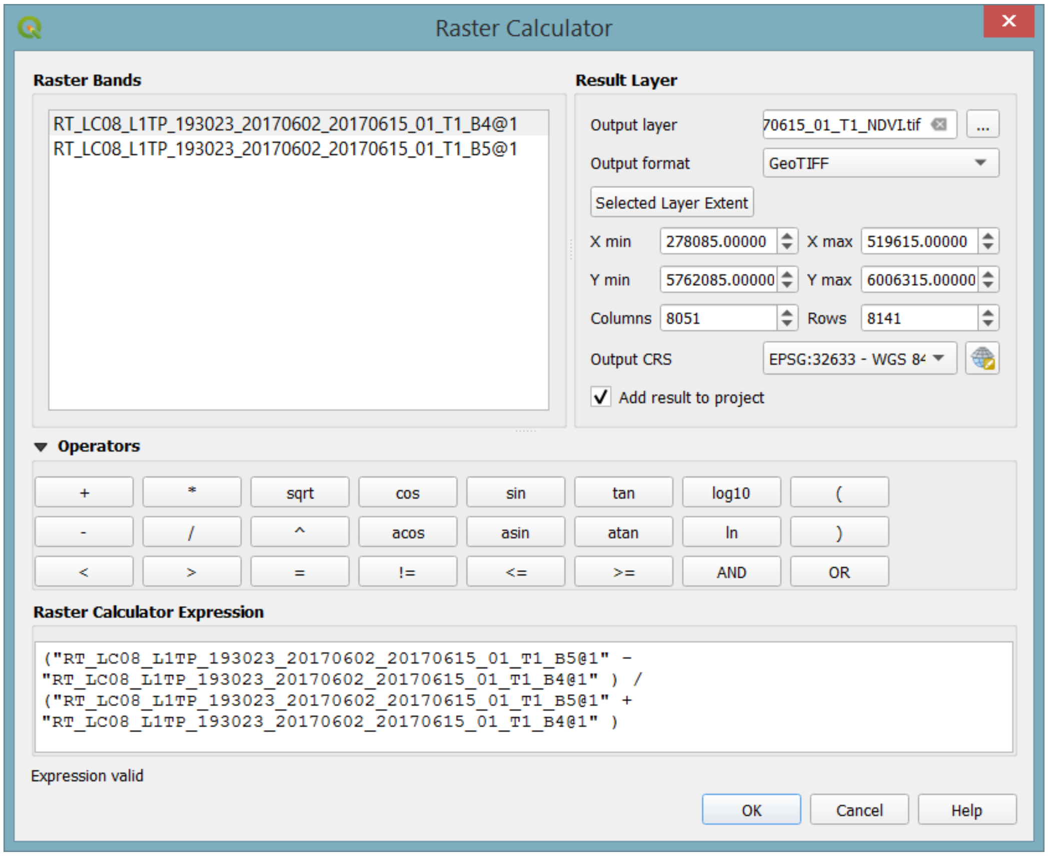
NDVI is a measure of vegetation density based on the ***visible red*** and ***near infrared (NIR)*** bands, such that:

NDVI = (NIR – RED) / (NIR + RED)

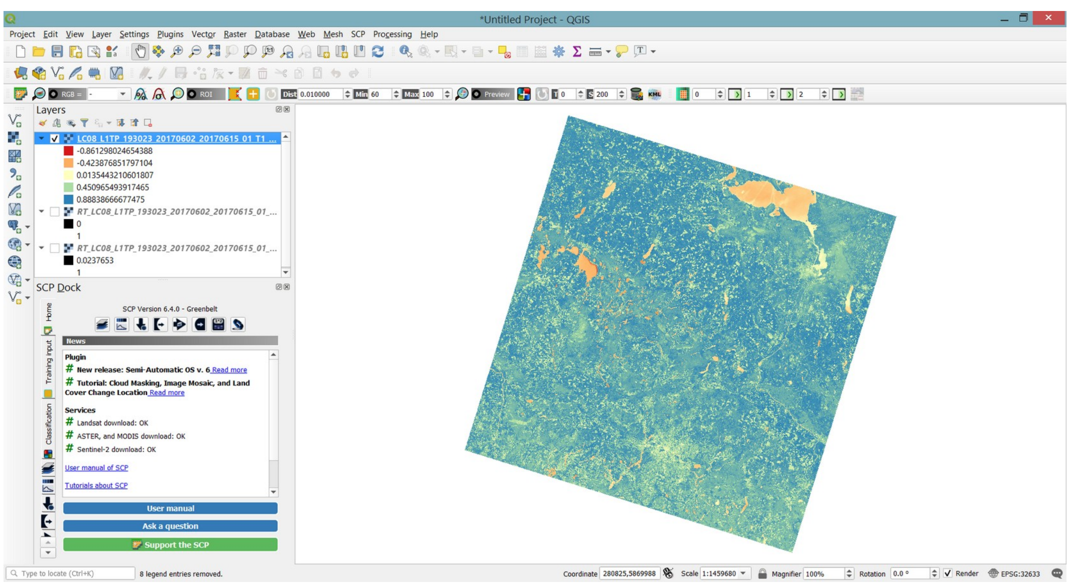
Begin by loading the red band (Band 4) and near infrared band (Band 5) into QGIS. **IMPORTANT: Make sure that you are using the corrected data!** Your window should look something like this:



We will use these bands to create a new GeoTIFF of NDVI using the ***Raster Calculator.*** Open the Raster Calculator from the "Raster" menu. You will see the two bands already loaded into the project in the 'Raster bands' menu. Use the calculator buttons and the bands from this menu to enter the NDVI equation. (Note: You can save yourself a lot of time by double-clicking the raster band name in the menu rather than trying to write it in yourself.) Designate the output file name in the 'Output layer' option.



NDVI values theoretically range from -1 to 1, with negative values generally representing water, values close to zero (-0.1 to 0.1) corresponding to barren regions, and positive values representing increasingly dense vegetation cover.

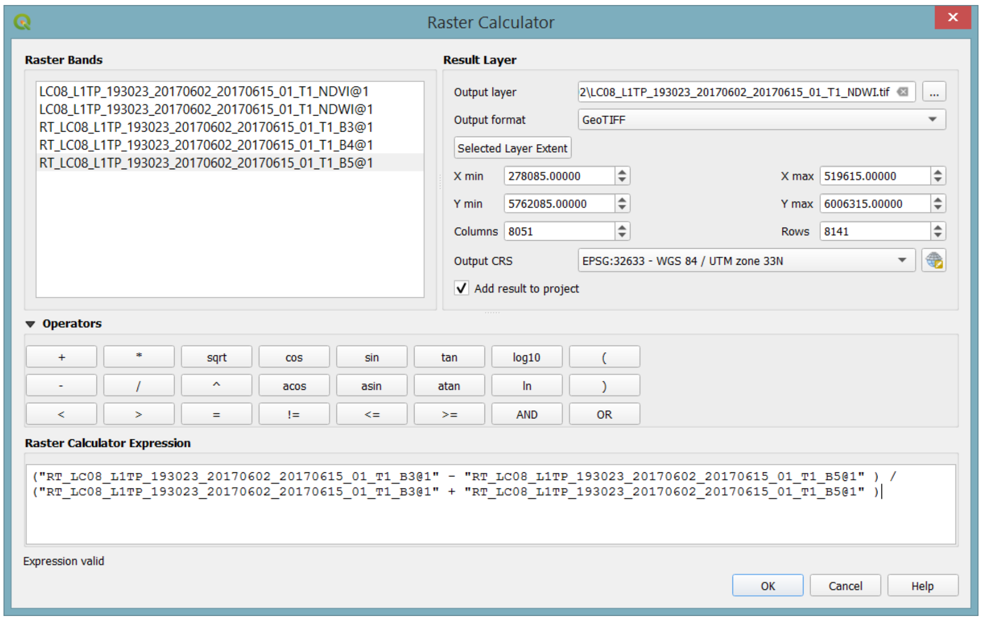


(2) If you’re familiar with the region, you may notice that water bodies appear on this map as bright red/orange (negative NDVI values). We can also calculate surface

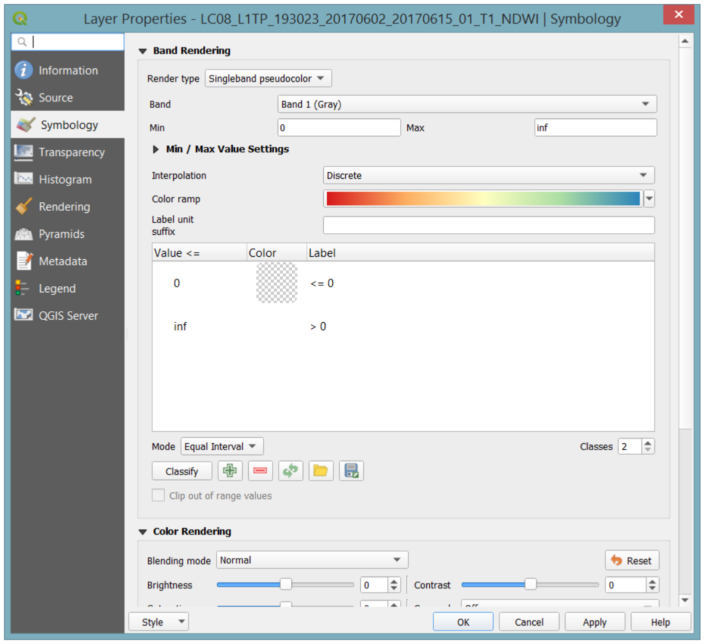
water bodies using the Normalized Difference Water Index (NDWI) using the NIR and green bands, such that:

NDWI = (Green – NIR) / (Green + NIR)

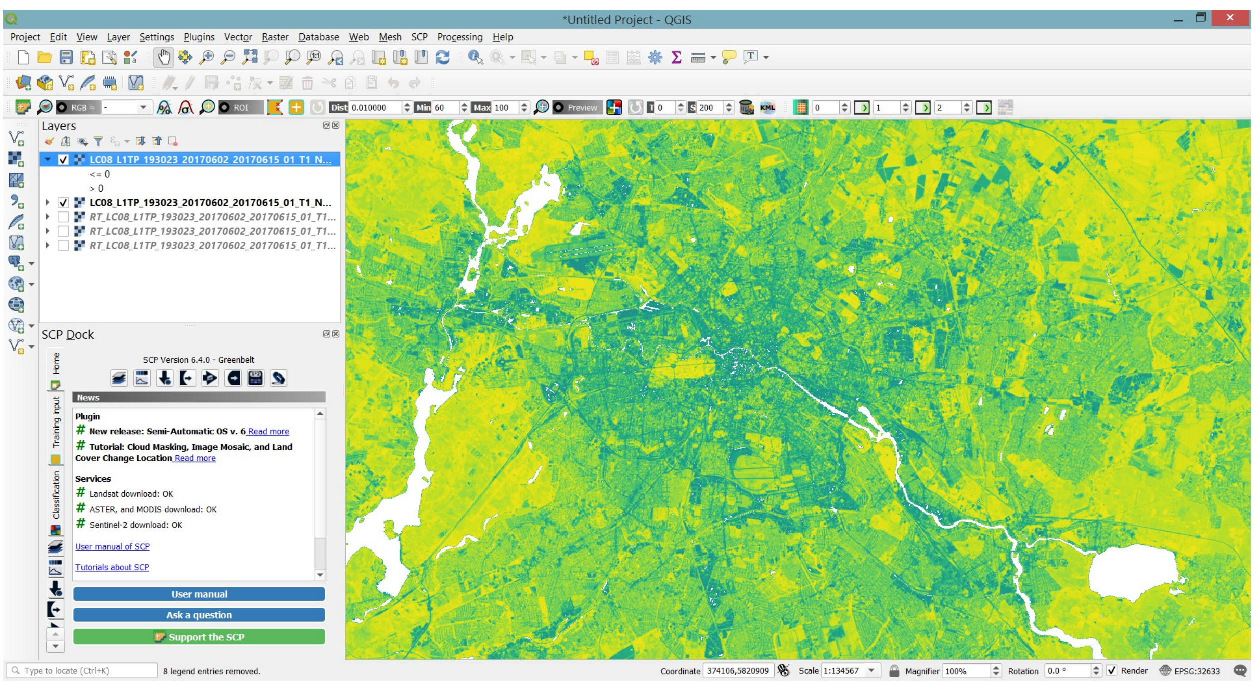
Positive values will generally correspond to water bodies, while negative values generally correspond to land surface. Note that some anthropogenic features may also display negative values. To calculate the NDWI, load the green band (Band 3) and use the raster calculator to input the NDWI equation.



Once you’ve calculated NDWI, use the layer properties to set all values below zero (land surface) to be transparent and all values above zero to be a color not on your NDVI color scheme (e.g., white, black). **Note:** You can set color opacity by double clicking on the icon in the ‘Color’ column and reducing the opacity tab.



Zoom into a region you know. You should now see something like this:



<u>Question 1:</u> Create a map of the Landsat data showing the NDVI band ratio masked with the NDWI. Include a coordinate grid, color legend, scale, and north arrow. (10 points).

6. Using Landsat Thermal Bands to Derive Surface Temperature

The thermal bands of the Landsat 8 TIRS instrument (also from earlier Landsat missions) allows converting radiances to surface temperatures. This is extremely useful and is often applied to derive surface temperatures. It relies on some constants and the TIRS band 1. The reflectance of that band is proportional to surface temperature following the relation:

$$\mathbf{T = K_2 \,/\, \textit{ln}\,(K_1/L_\lambda + 1)}$$

where:

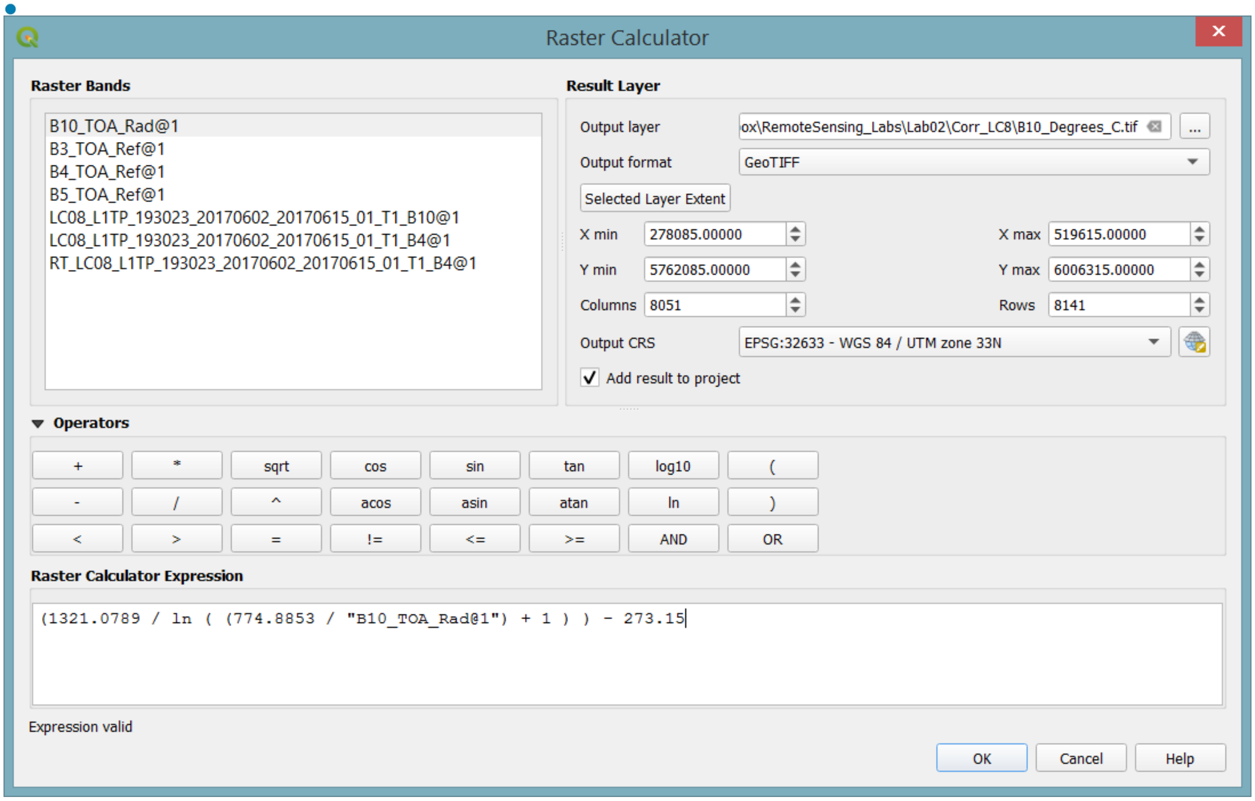
- T = at-satellite brightness temperature in degrees Kelvin
- K_2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x where x is band number 10 or 11)
- K_1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x where x is band number 10 or 11)
- L_λ = product of the Radiance formula

This is fairly straightforward in QGIS – we simply need to use the thermal correction parameters found in the MTL metadata file for each band, similar to how we did it for Bands 3/4/5. First we need to correct the Band 10/11 data to TOA Radiance, and then use the thermal correction parameters. Look in the _MTL.txt file and find the K1/2 values near the end of the file:

```
    REFLECTANCE_MULT_BAND_4 = 2.0000E-05
    REFLECTANCE_MULT_BAND_5 = 2.0000E-05
    REFLECTANCE_MULT_BAND_6 = 2.0000E-05
    REFLECTANCE_MULT_BAND_7 = 2.0000E-05
    REFLECTANCE_MULT_BAND_8 = 2.0000E-05
    REFLECTANCE_MULT_BAND_9 = 2.0000E-05
    REFLECTANCE_ADD_BAND_1 = -0.100000
    REFLECTANCE_ADD_BAND_2 = -0.100000
    REFLECTANCE_ADD_BAND_3 = -0.100000
    REFLECTANCE_ADD_BAND_4 = -0.100000
    REFLECTANCE_ADD_BAND_5 = -0.100000
    REFLECTANCE_ADD_BAND_6 = -0.100000
    REFLECTANCE_ADD_BAND_7 = -0.100000
    REFLECTANCE_ADD_BAND_8 = -0.100000
    REFLECTANCE_ADD_BAND_9 = -0.100000
  END_GROUP = RADIOMETRIC_RESCALING
  GROUP = TIRS_THERMAL_CONSTANTS
    K1_CONSTANT_BAND_10 = 774.8853
    K2_CONSTANT_BAND_10 = 1321.0789
    K1_CONSTANT_BAND_11 = 480.8883
    K2_CONSTANT_BAND_11 = 1201.1442
  END_GROUP = TIRS_THERMAL_CONSTANTS
  GROUP = PROJECTION_PARAMETERS
    MAP_PROJECTION = "UTM"
    DATUM = "WGS84"
    ELLIPSOID = "WGS84"
    UTM_ZONE = 33
    GRID_CELL_SIZE_PANCHROMATIC = 15.00
    GRID_CELL_SIZE_REFLECTIVE = 30.00
    GRID_CELL_SIZE_THERMAL = 30.00
    ORIENTATION = "NORTH_UP"
    RESAMPLING_OPTION = "CUBIC_CONVOLUTION"
  END_GROUP = PROJECTION_PARAMETERS
END_GROUP = L1_METADATA_FILE
END
```

Normal text file

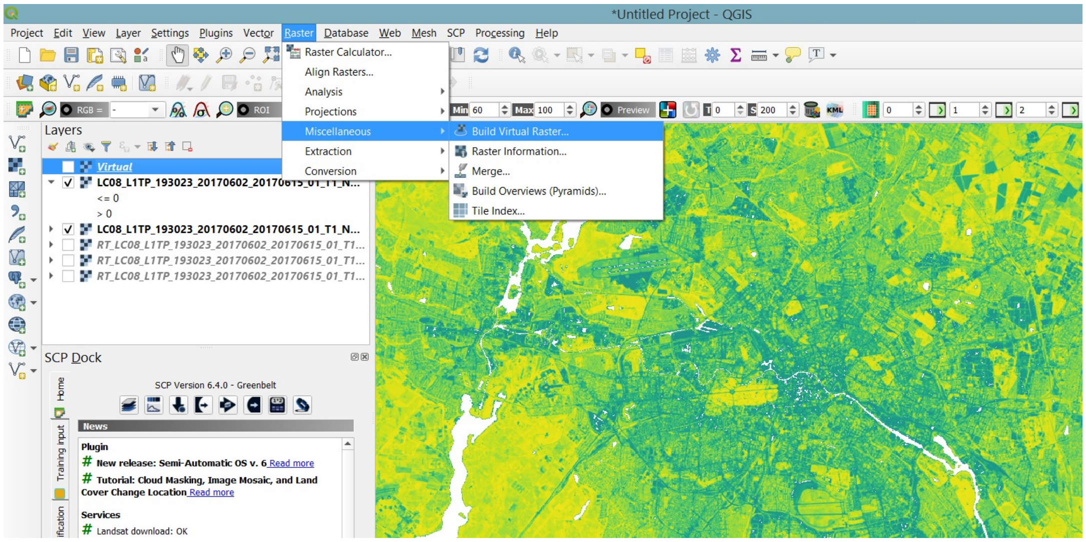
The surface temperatures we derive here are in KELVIN. To convert them to degrees Celsius, subtract 273.15. We can incorporate this directly in the band math step:



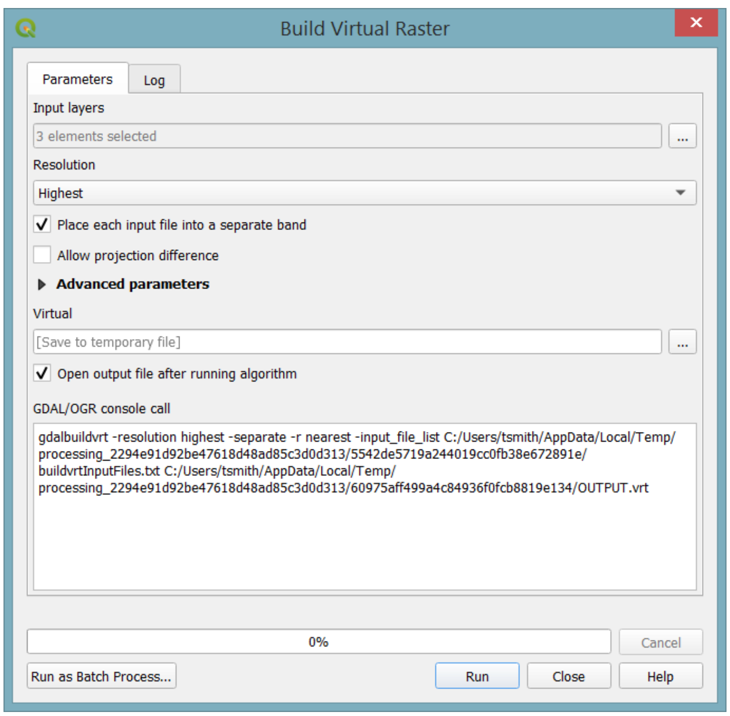
<u>Question 2:</u> Convert the Landsat 8 bands 10 and 11 to degrees Celsius. Show two maps for the greater Potsdam area – these should include the Neues Palais, Golm, but also areas of Berlin. Color scaling should be appropriate for surface temperatures in degree C. Are these temperatures realistic? Between what objects exists the largest temperature difference? Please show two maps with the same color scaling. The map should include the standard north arrow, scale bar, color scale, and grid. (20 points).

7. Band Ratios and Combinations

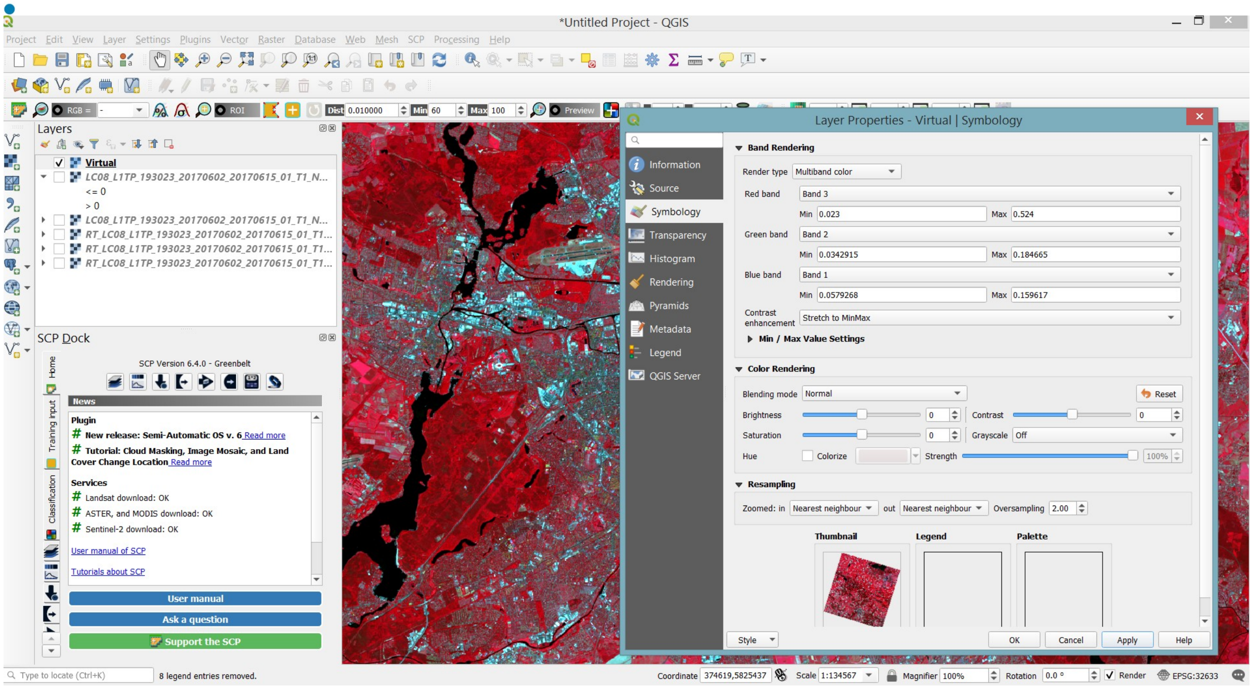
One common approach to using Landsat data is to use ***false-color images***. ‘True-color’ combines bands red-green-blue. A common false-color combination for monitoring vegetated versus non-vegetated surfaces is NIR-red-green. To create a false-color image in QGIS, we will first need to create a Virtual Raster Catalog. You can select this from the ‘Raster>Miscellaneous’ menu.



Choose bands 5, 4, and 3 to add to the Virtual Raster Catalog. Opt to have the bands separated, and loaded into the current project. **NOTE: Remember the order that you saved your bands in! This will be important for the next steps.**



When the Virtual Raster Catalog is loaded, you should have a false-color image where vegetated regions are generally red and urban areas are generally light blue.



If the bands did not automatically load in the correct order, you can reset this in the 'catalog' layer properties by choosing in the Style menu "Multiband Color" as the render type and setting the following: Band 1 = NIR, Band 2 = Red, Band 3 = Green.

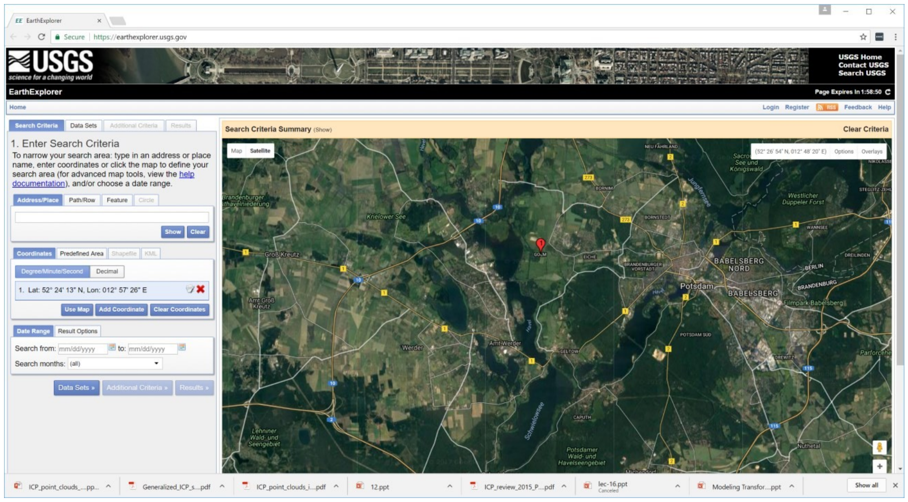
Question 3: Create two maps of the Landsat data (1) the 5-4-3 false color ratio and (2) another Landsat band set (e.g., see here: https://gisgeography.com/landsat-8-bands-combinations/ for ideas). Include a coordinate grid, color legend, scale, and north arrow. What are the main differences between the maps? **NOTE: You need to correct every band that you use for your band ratios! Otherwise the values/colors won't make sense.** (20 points).

8. Choosing your own data

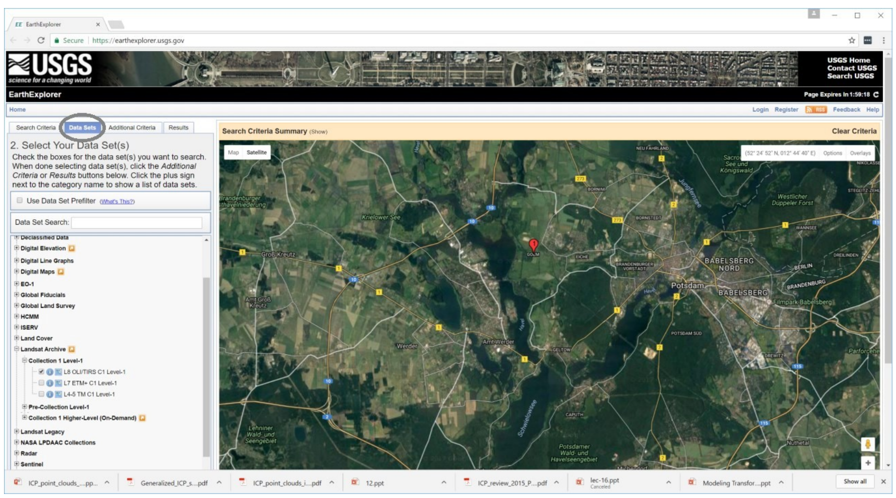
In this section we will show you how to get your own data, which you then can use to generate similar images at different times of the year, or across different years. Feel free to choose the kind of land cover that interests you (mountains, rivers, glaciers, cities, etc), and for whichever region of the world you prefer.

(1) *Downloading Data*

Once again, the location to download Landsat data from is here:
https://earthexplorer.usgs.gov/
You will have to register for an account to download data.



You can choose any location you would like by zooming around the map.

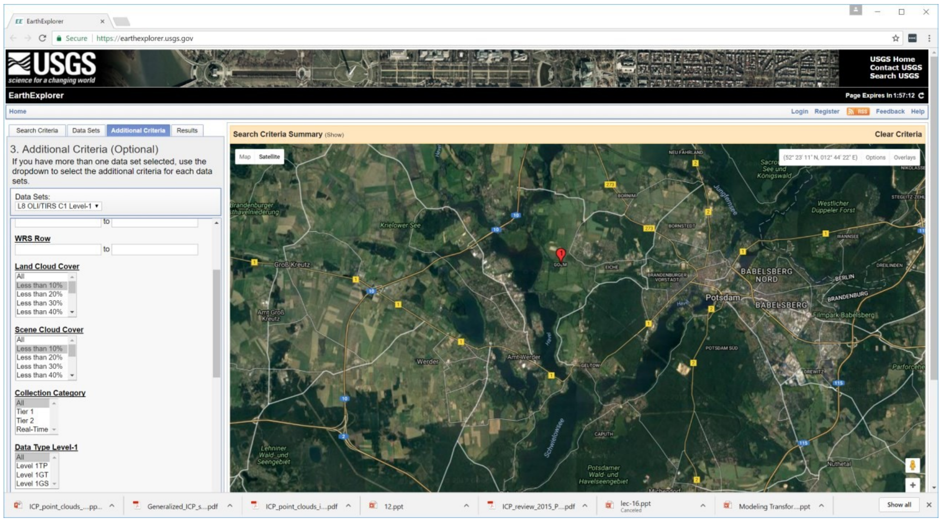


There are a wide range of datasets available from USGS. We are interested here in the Landsat data, which runs from Landsat 5-8. For more information on the Landsat missions, see here: https://landsat.usgs.gov/landsat-missions-timeline

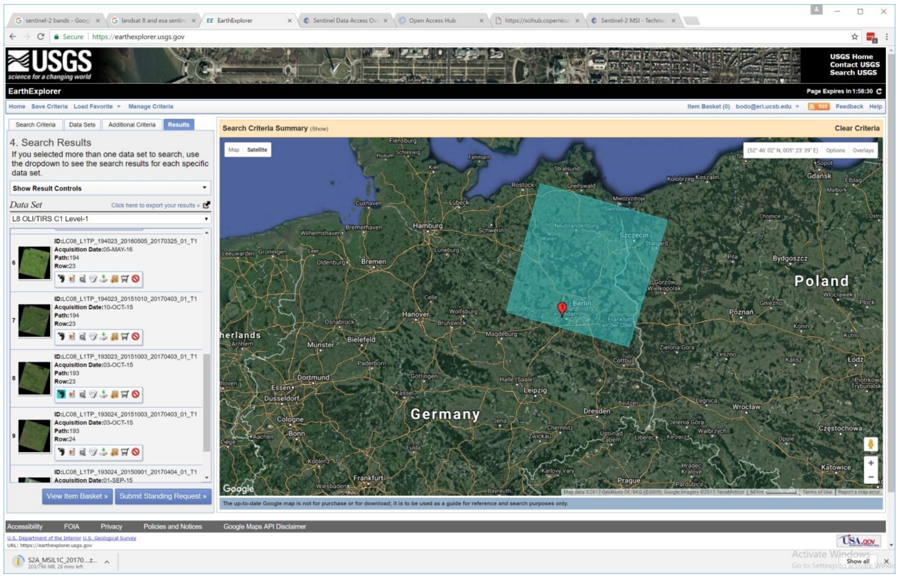
It is up to you whether you would like to examine two different seasons (e.g., look at one image from the Winter and one from the Summer), or from different times (e.g., one from the 1990s and one from today). Choose two different times that will be interesting for your region. Some possibilities would be to look at two different growing seasons in an agricultural area, changes in the length of a glacier over a long period of time, or the conversion of forested regions to agriculture.

NOTE: Please use the Landsat Level-1 Data – the on-demand processing to Level-2 takes a while to be available. If you decide to wait for Level-2 Data, you can skip the pre-processing step in QGIS.

Once you have selected which datasets (Landsat 5/7/8) you would like to use, you can provide additional search criteria.

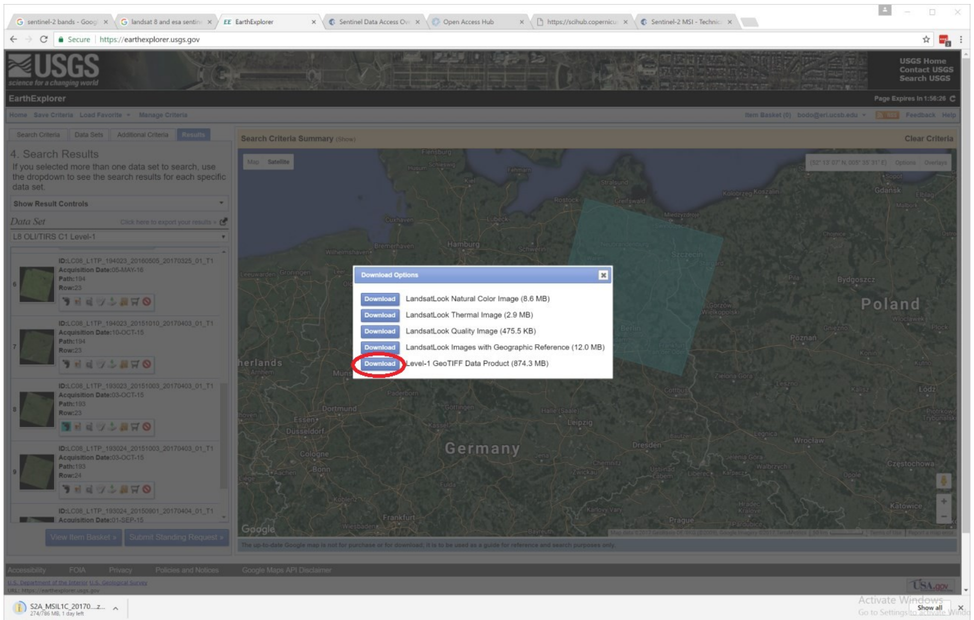


Here you can specify specific cloud cover percentages, as well as choose specific geographic coverage (Path/Row combinations). The Path/Row combination is how Landsat identifies the 'grid' that the Landsat satellite flies over. The grid is semi-overlapping, so depending on where you chose to look for data from, you may have multiple different Path/Row combinations available. When comparing data between times or seasons, it is generally better to use only one Path/Row combination.



On the last tab (Results), you can examine the different data that satisfied your search criteria. By clicking on the 'footprint' button (the little black foot), you can examine the geographic coverage of your image. The small 'picture' icon will let you preview what a natural color composite of your dataset will look like.

Once you have decided on an image that works for you, download the highest-level data (Level-1 GoeTIFF Data product). This will be around ~900MB for Landsat 8, but will be a bit smaller for Landsat 5/7.



(2) <u>Calculating NDVI/NDWI and Making Maps</u>

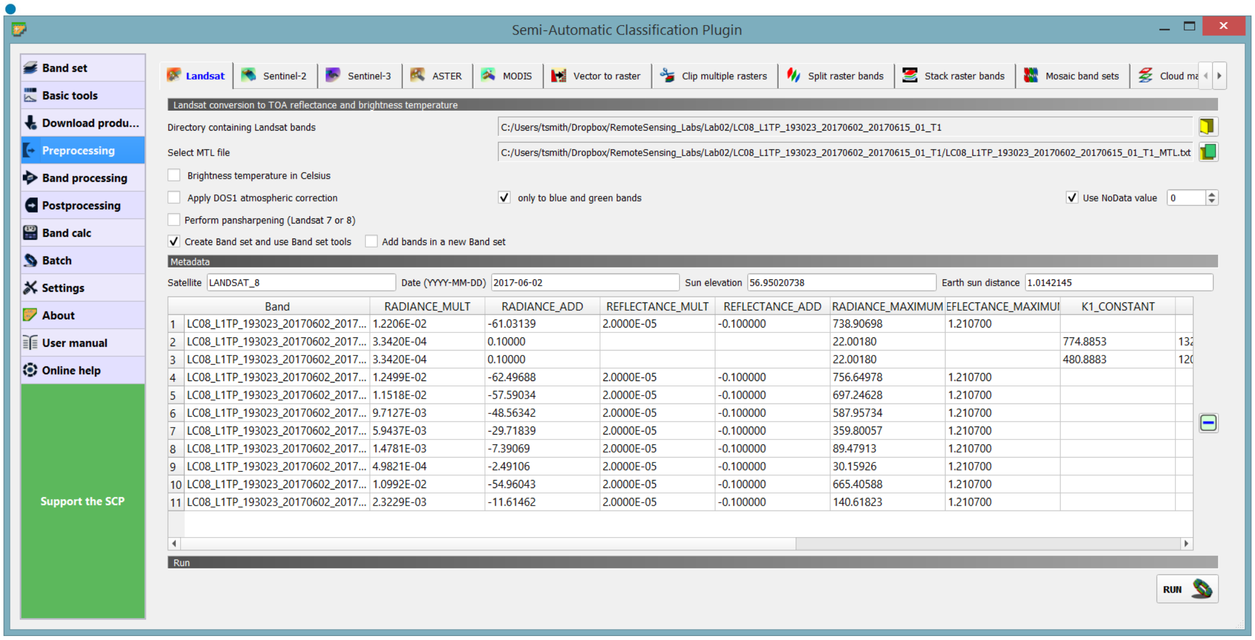
Using the same techniques as in the previous section of the lab, make maps of NDVI, NDWI, or some other useful band ratio (such as the Normalized Burn Ratio, Normalized Difference Snow Index, or others) for two different time periods. Make sure that you correct the data before using it!

> <u>**Question 4:**</u> Following the same steps, generate at least two maps showing a band ratio approach over a seasonal or inter-year time scale. Include a coordinate grid, color legend, scale, and north arrow. Explain why you chose your study area, what the two images show, and why you chose to show those particular ratios for that location. **NOTE: You need to use corrected (TOA Reflectance) data for both scenes! Otherwise the values are not comparable between your two time periods.** (50 points).

9. Hint – Faster Bulk Processing of Landsat Corrections

There are python scripts that allow you to process an entire directory into TOA reflectances and radiances (e.g., https://pypi.python.org/pypi/landsat-util/ and https://github.com/apburnes/landsat8). For the Python-savvy user, there exist GDAL-based scripts that perform the conversion and calibration in a Python or command-line environment (https://pypi.python.org/pypi/landsat-util/ or http://www.spectralpython.net/).

Landsat correction can also be run in QGIS via the Semi-Automated Classification Plugin:



This will export corrected versions of all of the Landsat bands into a new folder with a ‘RT_’ flag at the front of them.