QGIS CONVERSION TO SURFACE REFLECTANCE

Please note, there is the option of automatic conversion to surface reflection using Semi-Automatic Classification Plugin (SCP). Try to compare both approaches.

The manual was created with the help of GIS Ag Maps - http://www.gisagmaps.com/.

Content

BACKGROUND OF ATMOSPHERIC SCATTER REFLECTANCE

The path of solar radiation to Earth than to a satellite sensor involves many interactions. The following graphic (Jenson, 2007) shows various paths of incoming solar radiation (see descriptions below graphic). Overall, the result of the incoming solar radiation interactions is to erroneously add to Top of Atmosphere (TOA) reflectance, predominantly due to Path 2 radiance (as shown in the simplified diagram below; **TOA reflectance is the ratio of total radiance at the sensor [Ls] to total incoming irradiance at the top of the atmosphere** where a satellite sensor is located). Path 2 radiance is the predominant path radiance, and it erroneously increases visible and near-infrared (NIR) reflectance (though it increases NIR much less than visible reflectance). Image-based atmospheric correction deducts path 2 radiance (which is the predominant path radiance and is a type of atmospheric scatter) to derive surface reflectance.
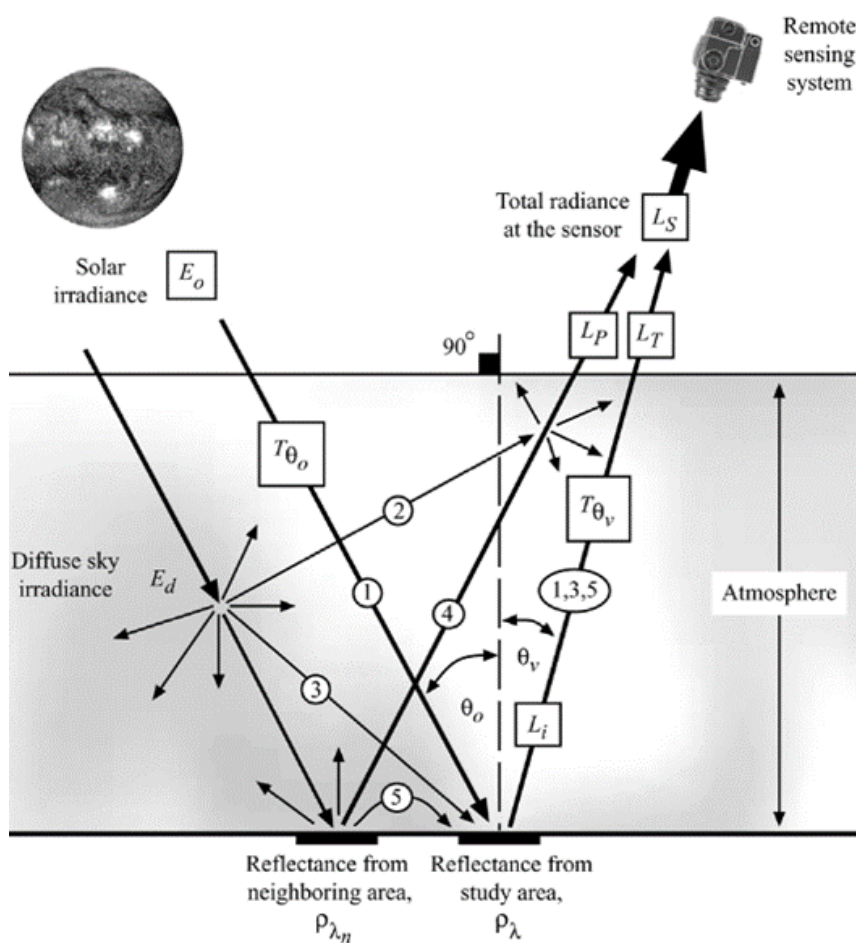

Figure 1. Paths of incoming radiance to the sensor.

As above (Figure 1), *Ls* is the total radiance at the sensor, which includes erroneous additive path radiance, *Lp*, of Path 2 and Path 4. Path 2 is diffuse irradiance that can include Rayleigh scattering and Mie scattering. Path 4 is reflectance from neighbouring areas which is adjacency radiation. *Lt* is the total radiance from the actual surface/target of interest. Path 1 is irradiance that reduced very little before striking the surface. Path 3 is irradiance that has been scattered downward onto the study area. Path 5 is radiation that has been reflected from a neighbouring area, then scattered down onto the study area.

Path 2 can include Rayleigh scatter which is the scattering of light by molecules (much smaller than wavelengths of light) and results in smaller wavelengths scattering much more than larger wavelengths, which is why the sky is blue on a clear day (blue light has smaller wavelengths than green or red). Path 2 can also include Mie scatter (which can include haze) and is the scattering of light by particles with a similar size to the light wavelengths; Mie results in larger wavelength scatter than Rayleigh. Clearer days have less overall scatter but a higher ratio of blue light to red light scatter because clearer days have more Rayleigh scattering; while, conversely, hazier days have more overall scatter but a smaller ratio of blue light to red light scatter because hazier days have more Mie scatter. *Near-infrared radiation (not shown below) scatters a very small amount, though it should still be deducted (it is the longest wavelengths that should be deducted; see Relative Scatter Calculator page for specific values).*

Fortunately, even with all the atmospheric radiation paths and interactions, a relatively simple image-based method to calculate surface reflectance quite accurately was developed, the **Dark Object Subtraction** – DOS (Chavez, 1996). The theory behind DOS atmospheric correction is that in a satellite image scene with tens of millions of pixels, there should be some pixels that have zero reflectance (in visible and NIR bands); the reason there is not, is due to atmospheric scattering erroneously increasing reflectance values (mainly caused Path 2 radiance above). Chavez (1988) calculated the scatter amount by establishing a base of the Landsat TM histogram (which is considered the Dark Object and is not necessarily the lowest value); the reflectance corresponding to the base was established as the scatter reflectance amount that should be subtracted. Chavez (1996) then deducted .01 from the established scatter reflectance value (so that the established dark object had a surface reflectance of .01) because of "the fact **that very few targets on the Earth's surface are absolutely black**, so an **assumed one-per cent minimum reflectance is better than zero per cent**" (Chavez, 1996).

Chavez (1988) suggested that continual relative scatter could be applied. *GISAgMaps.com* followed that suggestion and developed custom continual relative scatter calculators and lookup tables for Landsat 8 and Sentinel-2 based on principles in Chavez (1988). Per Chavez (1988), scatter values should have a power relationship (shown below) between band centre wavelength and amount of scattering (as the calculators and lookup tables on this website do). The point of applying relative scatter is to establish scatter for one band (Red band is recommended), then using the relative scatter for the other bands.

BACKGROUND OF SCATTERING METHOD

The hybrid method of the Chavez (1996) *Base of the Histogram Reflectance - .01* and GISAgMaps.com ***Bin 5 - .008***. For Sentinel-2, the *Base of the Histogram*, ***Bin 5****,* and *Lowest Connected Value Methods* (all described below) can all correspond to the same value but are usually not the same values. The **.008 deduction value is based on research**. The starting scatter should be less than the Bin 5 value. This is similar to the Base of Histogram -.008 method. Chavez (1988 and 1996) established reflectance scatter value at the base of Landsat TM histograms and then deducted .01 from that value because "very few targets on Earth's surface are absolutely black, so an assumed one-per cent minimum reflectance is better than zero" (Chavez, 1996; known as 1% dark object reflectance).

It is important to emphasize that the QGIS histogram does not include all values; it generalizes in a way that the very lowest values are commonly not represented, but very low values are represented. The frequency 1 values comprise a very small statistical tail (and they start to break apart) and should mostly not used as the base. It is worth noting that the Sentinel-2 (which is based on 12-bit pixel depth, then converted to 4-digit Integer raster) histogram does not have the long low-end statistical tail that Landsat 8 (16-bit pixel depth) has, it is more similar to the Landsat TM (8-bit pixel depth) histograms.

References:

Chavez, P.S., Jr. 1996. Image-based atmospheric corrections–revisited and improved. Photogrammetric Engineering and Remote Sensing 62(9): pp.1025-1036.

Chavez, P.S., Jr. 1988. An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. Remote Sensing of Environment 24: pp.459-479.

SENTINEL-2 Image processing

1) Download the Sentinel-2 L1C. An important aspect to realize about Sentinel-2 imagery is that they are downloaded in 110 x 110-kilometre tiles, that may or may not have NoData (zero) values (tile may be complete with imagery or have a sliver of imagery). A complete tile of 10-meter resolution imagery has 121,000,000 pixels, which is about 3 times more pixels than a Landsat scene (which has a much larger extent, but 30-meter pixel resolution). The tile downloaded from this website is full imagery (110 x 110 km; N↑).

2) Extract the compressed download by right-clicking on it, and open QGIS.

3) Add the Sentinel-2 band 4 image to QGIS (Layer > Add Layer > Add Raster Layer). Change the Contrast Enhancement, if necessary (Layer Properties – Symbology).

4) Click *Processing* (in top menu), then *Toolbox* to add the *Processing Toolbox* if necessary. Then open *GDAL > Raster Conversion > Translate (convert format)*.

5) The NoData values are necessary to eliminate; do this step even if you do not think there are any NoData value in the image. The *Translate* tool window will eliminate zero pixels if there are any. Enter 0 in the NoData window and select Int16 in *Advanced parameters* as an Output data type, then click *Run*. A new layer appears at the Layers panel on the left (Figure 2).
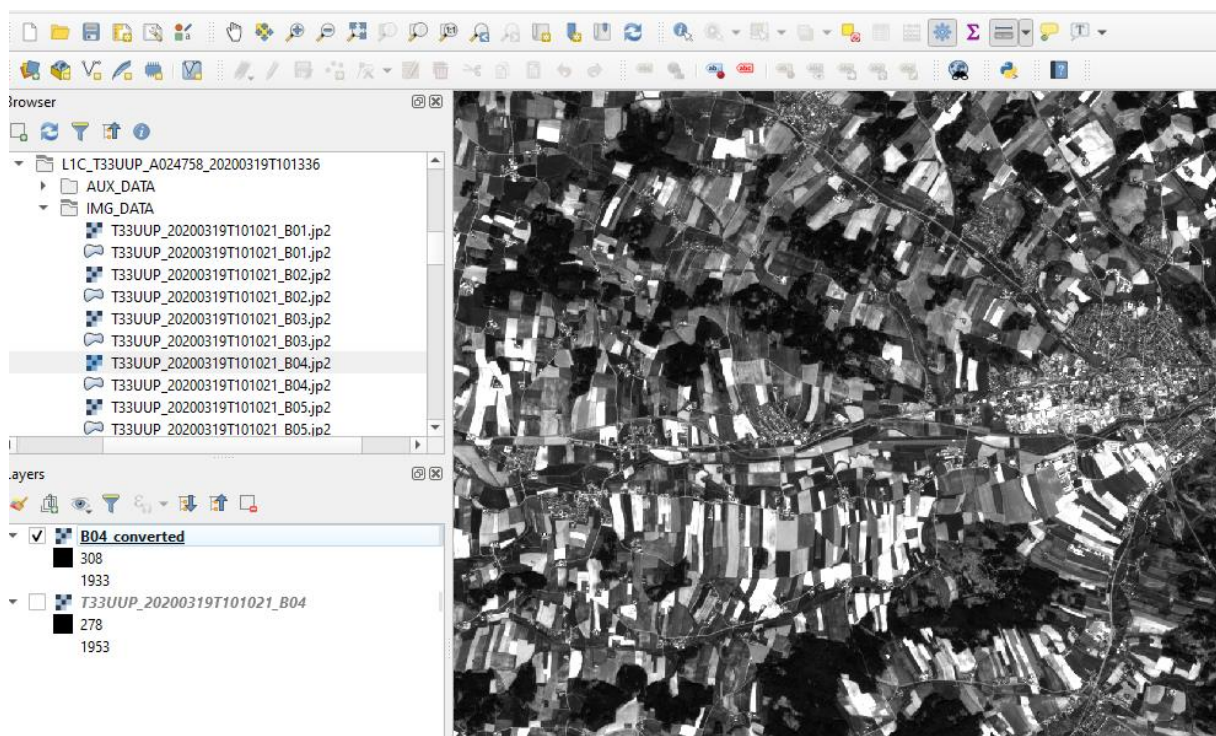

Figure 2. The output of the Translate tool.

6) You need to determine the scatter amount in the process of converting to surface reflectance. Scatter is based on the low end of the histogram. Open *Raster layer statistics* tool in the Toolbox (*Raster Analysis*) and Run the tool. You may save the output as a temporary file. When the tool has run, the minimum value in the raster will appear along with other values; only concern yourself with the minimum value.

7) Right-click the *Converted* layer, then click *Properties*. Click *Histogram* on the left to view the image histogram. You are accessing the histogram to establish the scatter amount. The histogram may appear in a line or bar format (you may change it in *Prefs/Actions* option). Enter the minimum value from the previous step in the *Min* box, and click the cursor on the *Max* box to set the value. *The QGIS histogram does not represent/show every value, but it does displays values well enough to establish a scatter value as described in the steps that follow.*

8) Hover the cursor over the histogram and it will turn to a magnifying glass. Drag the magnifying glass over the low end of the histogram to start zoom to the scatter value at the low end of the histogram (Figure 3). If you zoom too much or want to start over for any reason, click *Prefs/Action* and *Recompute Histogram*. Keep zooming to find the base of the histogram.
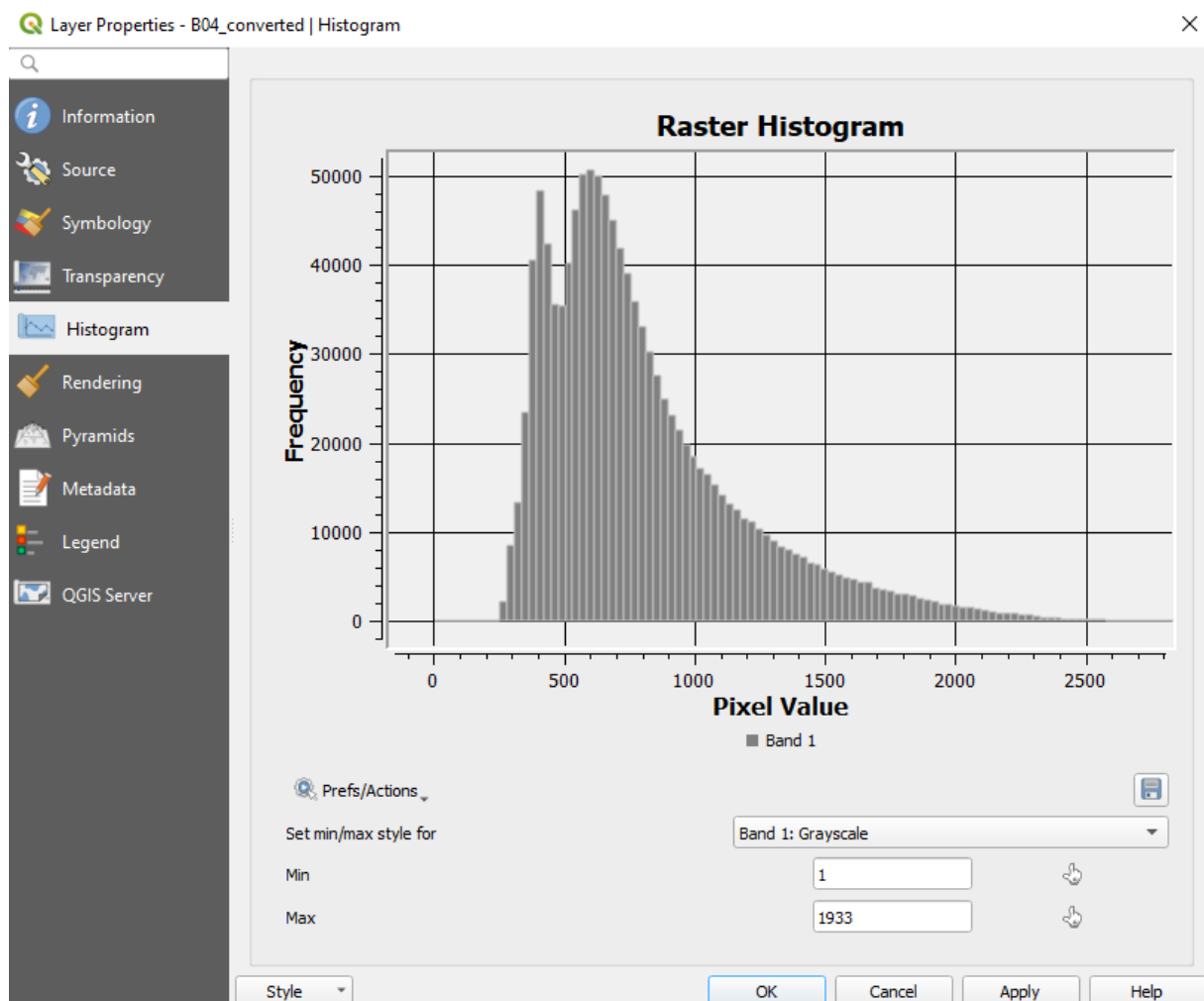

Figure 3. A magnified bar histogram of one band.

9) The *Base of the Histogram - .008*. The left edge of the lowest connected bin (there is no sub-5 frequency bin) corresponds to the value of 225 (Figure 4), i.e. .0225 reflectance (divide Sentinel-2 values by 10,000 to convert to Top of Atmosphere reflectance). As described above, I consider the frequency 1 values as erroneous (the frequency 1 values comprise a very small statistical tail and they start to break apart). See the Sentinel-2 QGIS Base of Histogram Method Rules & Examples for a better understanding of how to find your values.
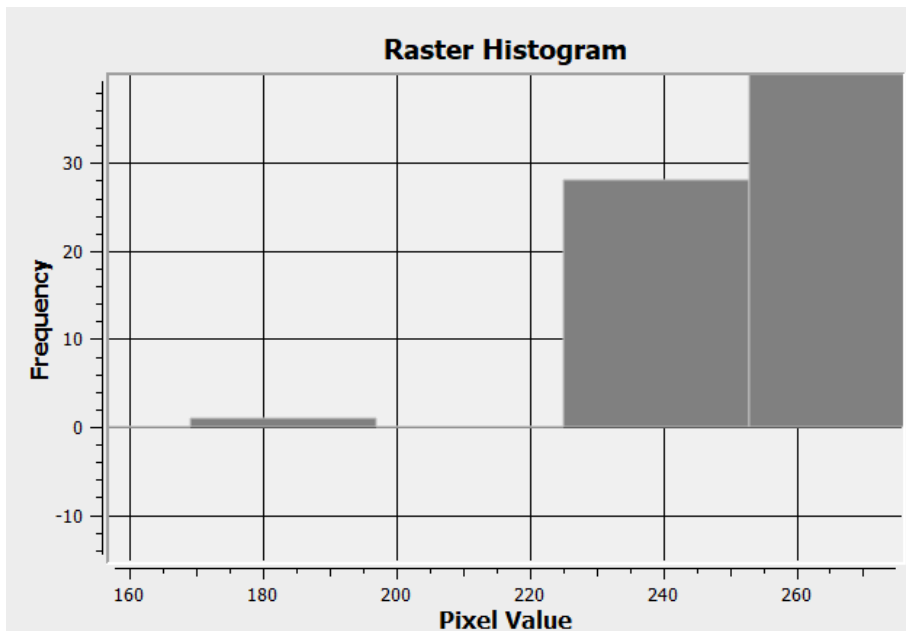

Figure 4. The base of the image histogram.

10) Access the **Sentinel-2 Relative Scatter Calculator** and enter the scatter amount of .0145 (i.e. subtracted .008 from 0.225). After entering the starting band 4 scatter value (may need to press enter), the relative values will appear (Figure 5). If the Calculator is not working for any reason, use the Relative Scatter Lookup Table below it. Scatter does not need to be deducted for bands larger than 8 (scatter amounts are irrelevant and negligible at best).

S2 Band	Enter Red Band Scatter 4	Sentinel-2 Relative Scatter 2	3	5	6	7	8	8a
BCW	0.665	0.494	0.560	0.704	0.740	0.781	0.834	0.864
Scatter	0.01450	0.05362	0.03024	0.01128	0.00917	0.00720	0.00527	0.00469

Figure 5. Relative Scatter Calculator.

11) After establishing starting scatter reflectance, convert the TOA raster to reflectance units by dividing it by 10,000 with the raster calculator. Click *Raster*, the *Raster Calculator* (Figure 6).
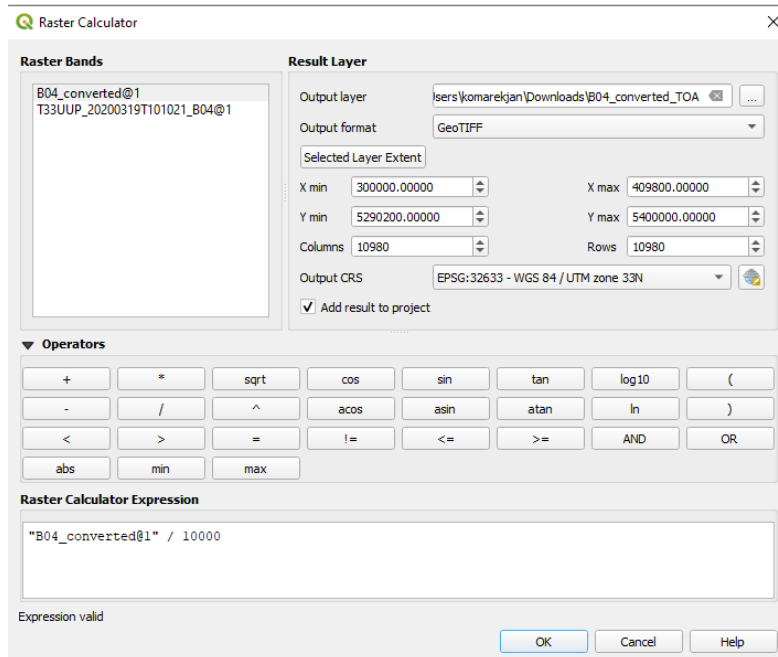

Figure 6. Raster calculator – calculation of TOA values.

12) The TOA layer in reflectance units will appear in the window. Repeat the same steps to calculate TOA values for a different band.

23) To calculate surface reflectance, **deduct the scatter reflectance from the band TOA** raster using the *Raster Calculator* to receive the BOA – Bottom of Atmosphere values (Figure 7). You should do the calculation for all possible bands, i.e. bands 2-8 of Sentinel-2.
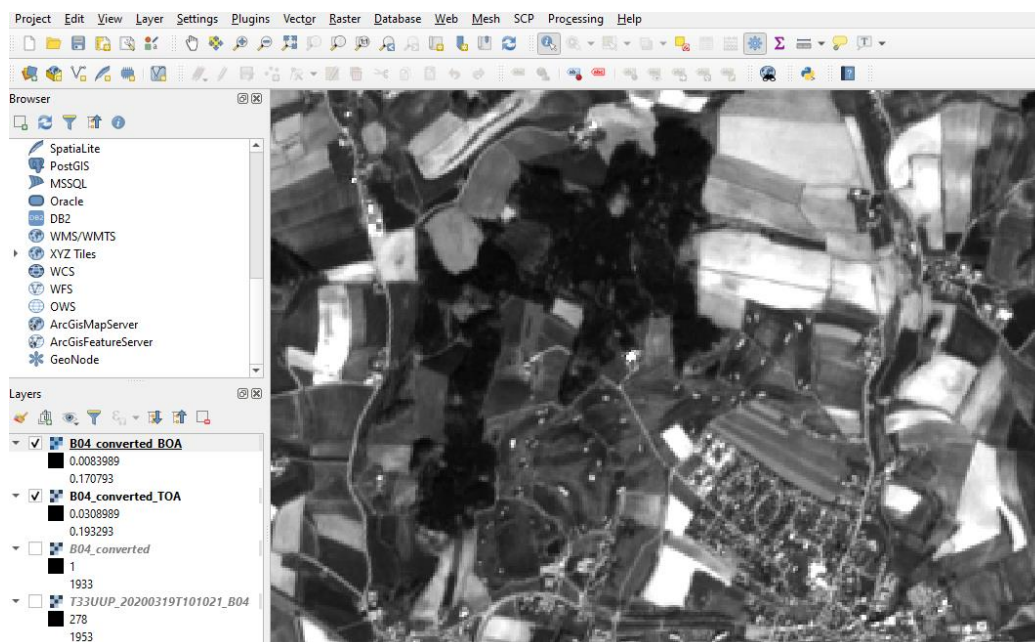

Figure 7. TOA and BOA values of atmospherically corrected Band 4 of Sentinel 2 image.

LANDSAT 8 Image processing

1) Download the Landsat-8 Level 1 image. Landsat 8 scenes are about 185 x 180 kilometres (slightly more in the northerly direction; N↑), but scene sizes can vary somewhat.

2) Extract TWICE the compressed download by right-clicking on it, and open QGIS.

3) Add the Landsat-8 band 4 image to QGIS (Layer > Add Layer > Add Raster Layer). Change the Contrast Enhancement, if necessary (Layer Properties – Symbology).

4) Click *Processing* (in top menu), then *Toolbox* to add the *Processing Toolbox* if necessary. Then open *GDAL > Raster Conversion > Translate (convert format)*.

5) The NoData values are necessary to eliminate; do this step even if you do not think there are any NoData value in the image. The *Translate* tool window will eliminate zero pixels if there are any. Enter 0 in the NoData window and select Int16 in *Advanced parameters* as an Output data type, then click *Run*. A new layer appears at the Layers panel on the left (Figure 8).
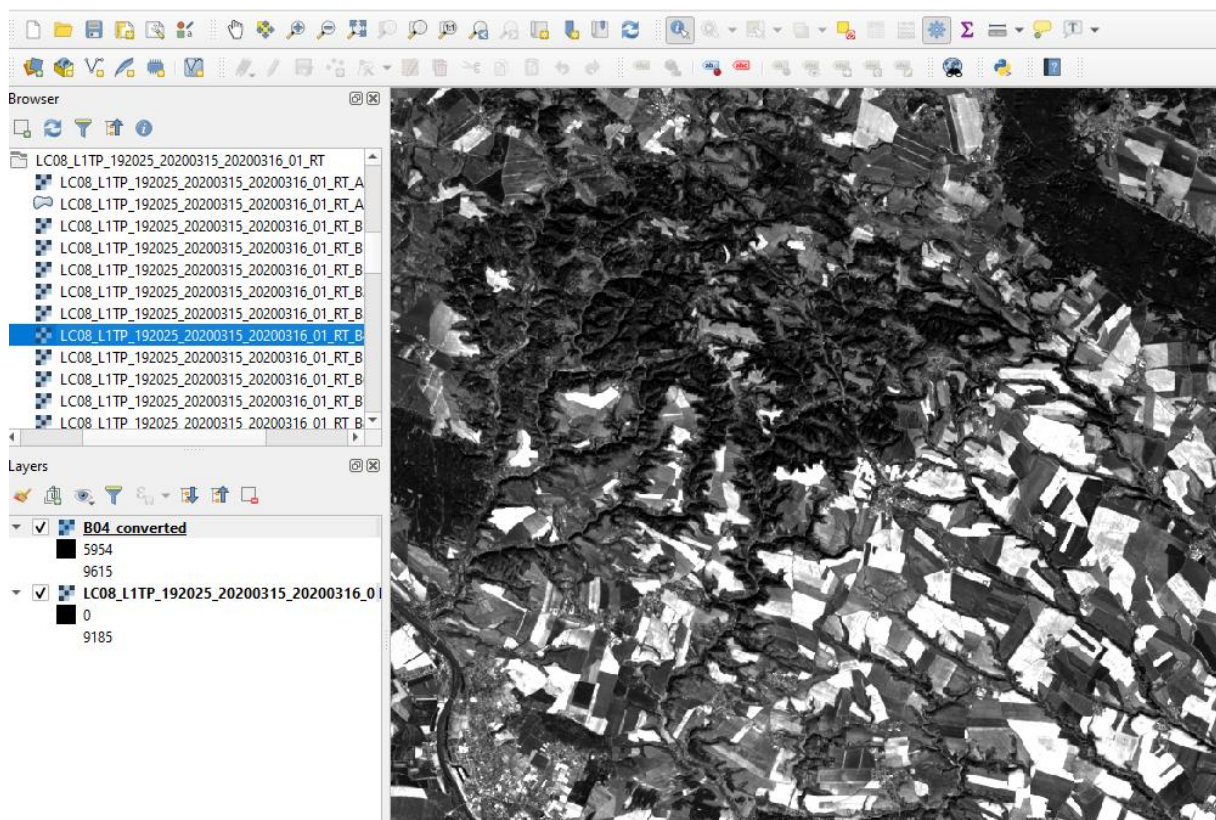

Figure 8. The output of the Translate tool for Landsat-8.

6) You need to determine the scatter amount in the process of converting to surface reflectance. Scatter is based on the low end of the histogram. Open *Raster layer statistics* tool in the Toolbox (*Raster Analysis*) and Run the tool. You may save the output as a temporary file. When the tool has run, the minimum value in the raster will appear along with other values; only concern yourself with the minimum value.

7) Right-click the *Converted* layer, then click *Properties*. Click *Histogram* on the left to view the image histogram. You are accessing the histogram to establish the scatter amount. The histogram may appear in a line or bar format (you may change it in *Prefs/Actions* option). Enter the minimum value from the previous step in the *Min* box, and click the cursor on the *Max* box to set the value. *The QGIS histogram does not represent/show every value, but it does displays values well enough to establish a scatter value as described in the steps that follow.*

8) Hover the cursor over the histogram and it will turn to a magnifying glass. Drag the magnifying glass over the low end of the histogram to start zoom to the scatter value at the low end of the histogram (Figure 9). If you zoom too much or want to start over for any reason, click *Prefs/Action* and *Recompute Histogram*. Keep zooming to find the base of the histogram.

9) The *Base of the Histogram - .008*. The left edge of the lowest connected bin corresponds to the value of 5700 (Figure 9), i.e. .00917 reflectance. For Landsat-8 follow the formula **([DN x .00002] - .1) / cosine of the solar zenith** to calculate Top of Atmosphere reflectance. As described above, I consider the frequency 1 values as erroneous (the frequency 1 values comprise a very small statistical tail and they start to break apart). See the Sentinel-2 QGIS Base of Histogram Method Rules & Examples for a better understanding of how to find your values.
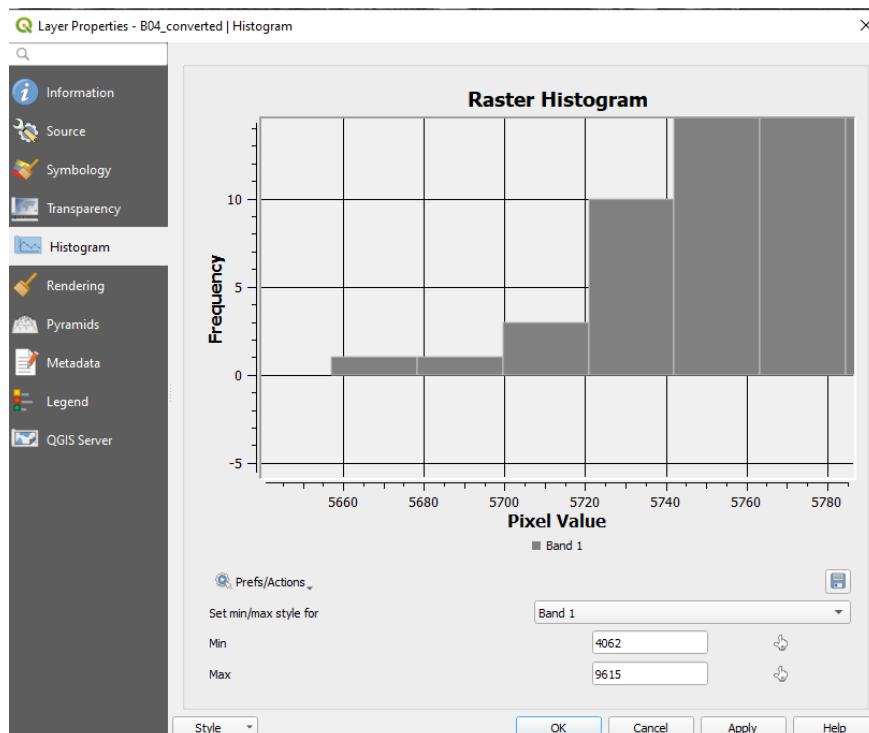

Figure 9. A magnified bar histogram of one band of Landsat-8.

Note: The solar zenith = (90 - solar elevation [in degrees]). The cosine of the solar zenith is the same as the sine of the solar elevation. To find the solar (sun) elevation, open the uncompressed downloaded folder, then open the text .mtl file, locate the Sun Elevation, then copy it (Figure 10). Visit Embedded Excel calculator here and paste the copied values there (Figure 11).

```
TIRS_SSM_POSITION_STATUS = "ESTIMATED"
TIRS_STRAY_LIGHT_CORRECTION_SOURCE = "T
ROLL_ANGLE = -0.001
SUN_AZIMUTH = 156.23137098
SUN_ELEVATION = 35.30228266
EARTH_SUN_DISTANCE = 0.9945725
SATURATION_BAND_1 = "Y"
SATURATION_BAND_2 = "Y"
SATURATION_BAND_3 = "Y"
```

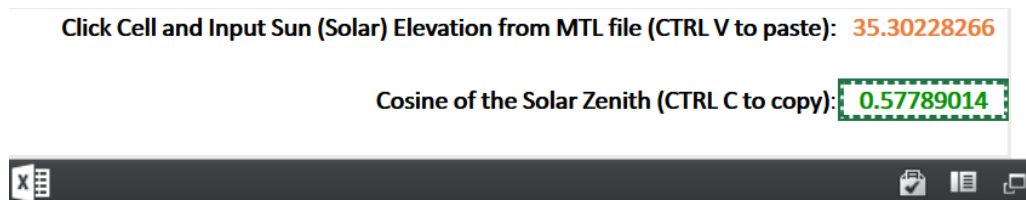*Figure 10. Details of TML file download together with the Landsat-8 images.*

Click Cell and Input Sun (Solar) Elevation from MTL file (CTRL V to paste): 35.30228266

Cosine of the Solar Zenith (CTRL C to copy): 0.57789014

Figure 11. Calculation of Cosine of Solar Zenith.

10) If using the Bin 5 Scatter Method where .008 is deducted from the Bin5 reflectance value, the Bin5 5700 value is calculated to a starting red band scatter reflectance of .00917, as follows: 5700 x .00002 - .1 = .014; then after inputting the sun elevation of 35.30228266 into the Cosine of the Solar Zenith Calculator above, the value .57789014 is computed and .014 is divided by .81515163 to calculate a reflectance of .01717; (3) .008 is subtracting from .01717 to calculate the starting scatter from band 4 (red band) of .00917.

11) Access the **Landsat-8 Relative Scatter Calculator** and enter the scatter amount of .00917 (to the box with the red values, Figure 12). After entering the starting band 4 scatter value (may need to press enter), the relative values will appear. If the Calculator is not working for any reason, use the Relative Scatter Lookup Table below it. The red band is recommended as a starting scatter band here. Scatter does not need to be deducted for bands larger than 8a (scatter amounts are irrelevant and negligible at best).

	Enter Red Band Scatter	Landsat 8 Relative Scatter		
L8 Band	4	2	3	5
BCW	0.655	0.482	0.561	0.865
Scatter	0.00917	0.04891	0.02160	0.00200

Figure 12. Relative Scatter Calculator for Landsat-8 bands.

12) After you have determined scatter amounts, the imagery can be converted to surface reflectance quite easily. Open the Raster Calculator in QGIS by clicking *Raster* then *Raster Calculator*. Enter the equation (i.e. DN x .00002 - .1) and calculate new values for bands. Then you have to divide the calculated raster by the *Cosines of the Solar Zenith* value (you may merge those steps and calculate TOA values at one step, Figure 13).
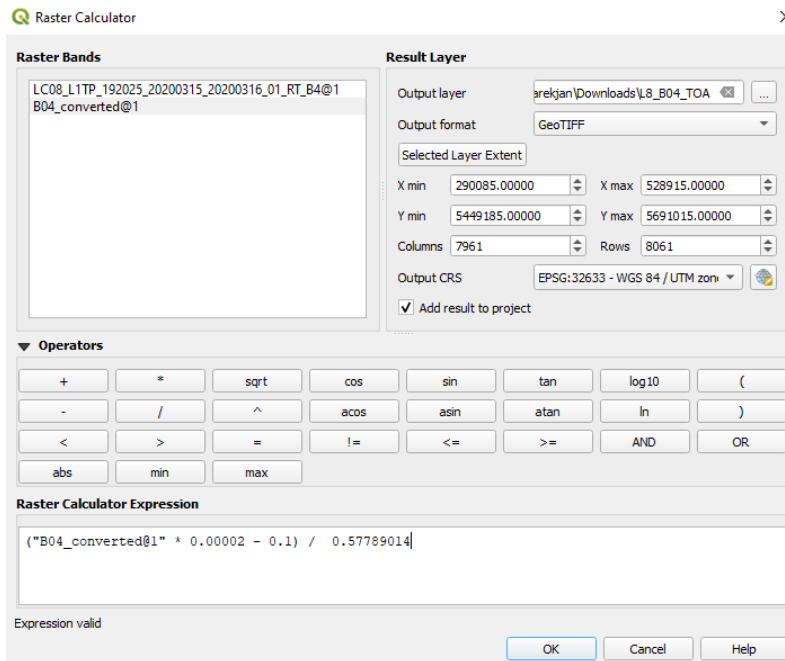

Figure 13. Calculation of TOA for Landsat-8 bands.

13) The TOA layer in reflectance units will appear in the window. Repeat the same steps to calculate TOA values for a different band.

24) To calculate surface reflectance, **deduct the relative scatter reflectance from the band TOA** raster using the *Raster Calculator* to receive the BOA – Bottom of Atmosphere values (Figure 14). You should do the calculation for all possible bands, i.e. bands 2-5 of Landsat-8.
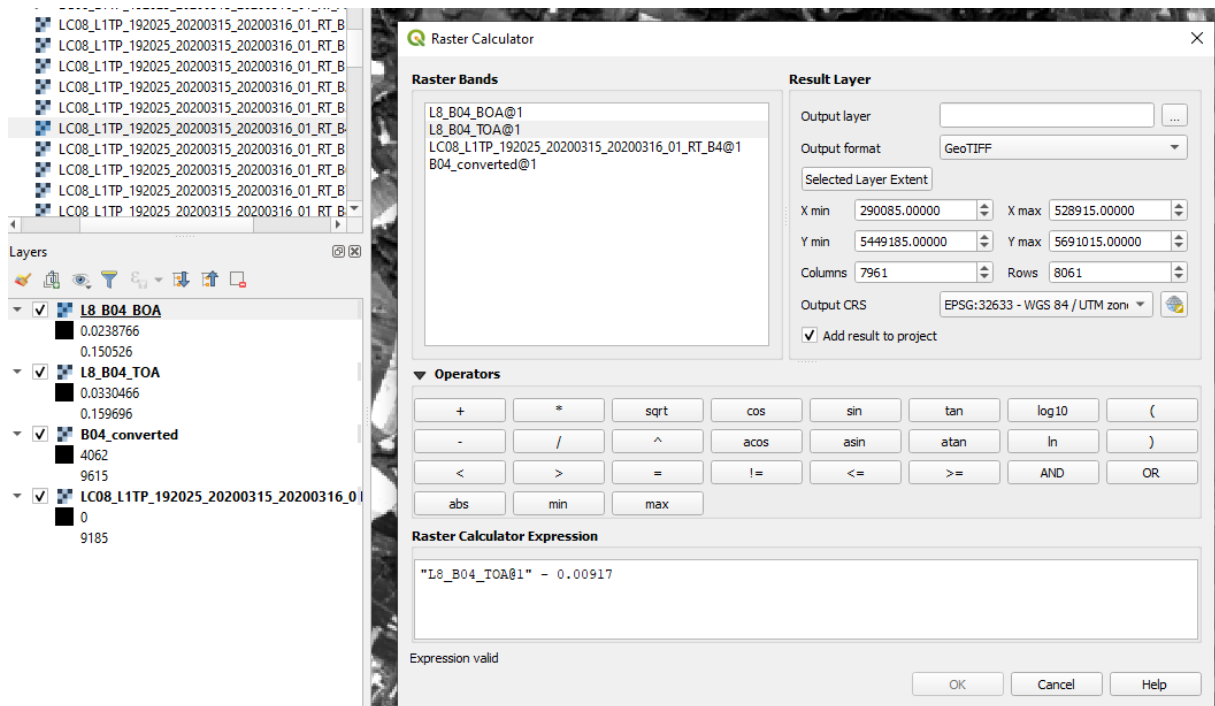
Figure 14. Calculation of BOA values for Landsat-8 band.