UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 3 – TUTORIAL

Key concepts of remote sensing data processing, converting DN values to radiance and reflectance, using SNAP software

esa

ÚSTAV GEOGRAFIE
Prírodovedecká fakulta UPJŠ v Košiciach

UNIVERZITA
PAVLA JOZEFA ŠAFÁRIKA
V KOŠICIACH

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Convert Landsat 8 radiance to reflectance
- Calculate Land Surface Temperature at the Top of the Atmosphere (TOA)
- Explore TOA temperatures within the area of interest

2 | Background

2.1 HOW TO CONVERT DNs TO PHYSICAL UNITS

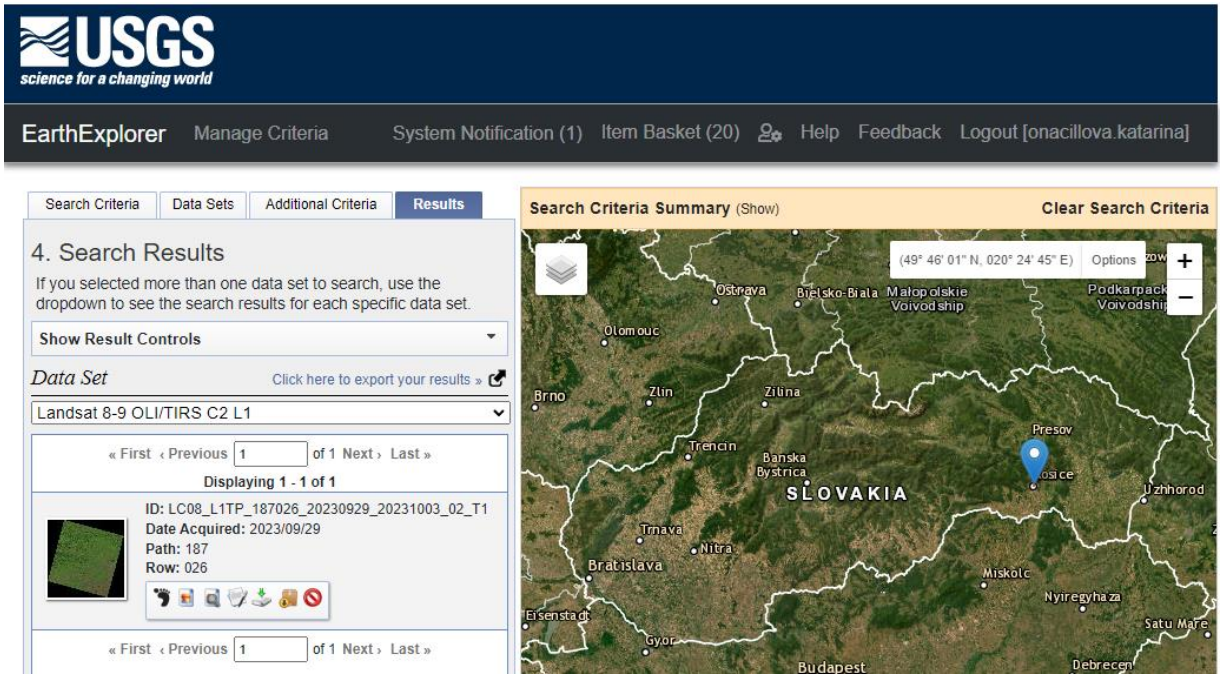
Multispectral sensors usually capture reflected solar energy and rescale this data into a digital number (DN) - a variable assigned to a pixel, usually in the form of a binary integer the range of which depends on the radiometric resolution; e.g. 0–255 (8-bit DNs) for Landsat ETM+. The Landsat 8 OLI sensor is more sensitive so these data are rescaled into 16-bit DNs with a range from 0 and 65536.

DNs can be used directly for spectral index calculation or land cover evaluation within a single scene. However, for comparing reflectance between two or more scenes, it is necessary to convert DNs to surface reflectance values. DNs do not directly express the values of a physical quantity. For radiance values, it is necessary to recalculate DN values.

There are a number of spaceborne multispectral sensors to date providing multispectral data in visible and thermal infrared spectrum simultaneously. For our purpose of this exercise, we opted for the Landsat-8 data that provide the highest possible spatial resolution of the thermal band among the deployed missions on the Earth's orbit. Also, there is a favorable temporal coincidence with Sentinel 2 acquisitions today that can be used for combined approach.

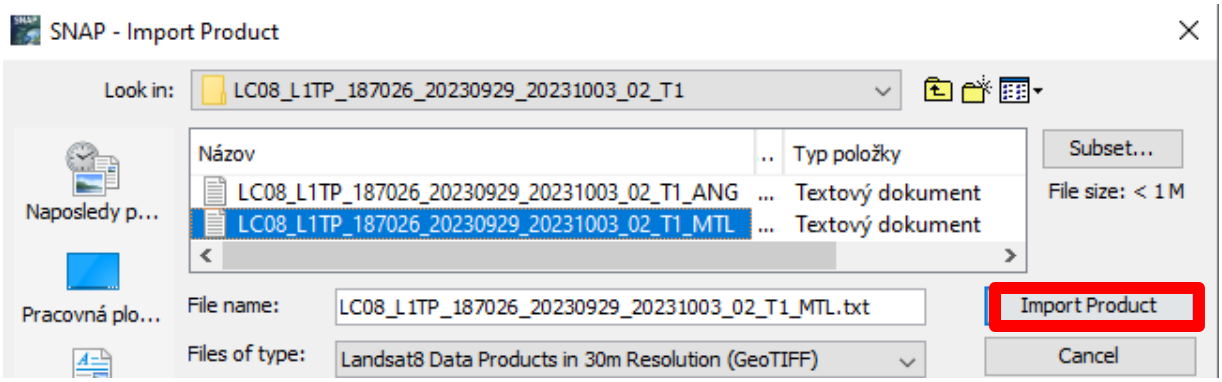
2.2 Study area and data used

For this exercise, we will use Landsat-8 L1 product (path 187, row 26, 29 September 2023, scene center time 9:26:47 GMT) for the study area of Košice City, Slovakia, which was downloaded from the USGS EarthExplorer website [@https://earthexplorer.usgs.gov/]. It contains data recorded by two instruments - the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) with a spatial resolution of 30 meters for visible, near infrared and short-wavelength infrared bands (bands 1-7, band 9), 15 meters for panchromatic band 8, and 100 by 30 meters for thermal bands 10 and 11. The data of thermal bands are resampled to 30 by 30 meter pixels in the L1T product.

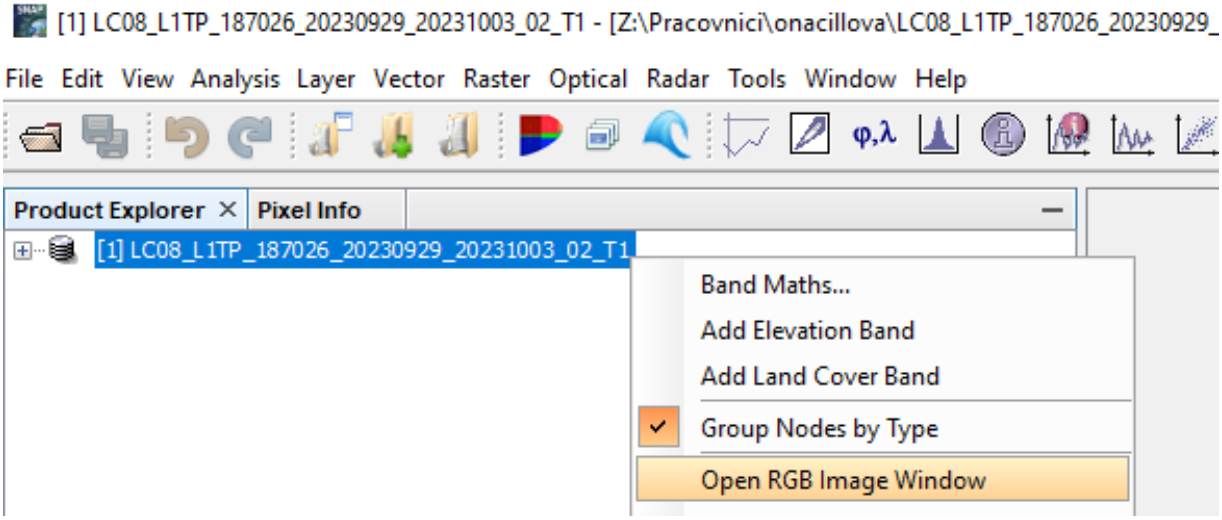


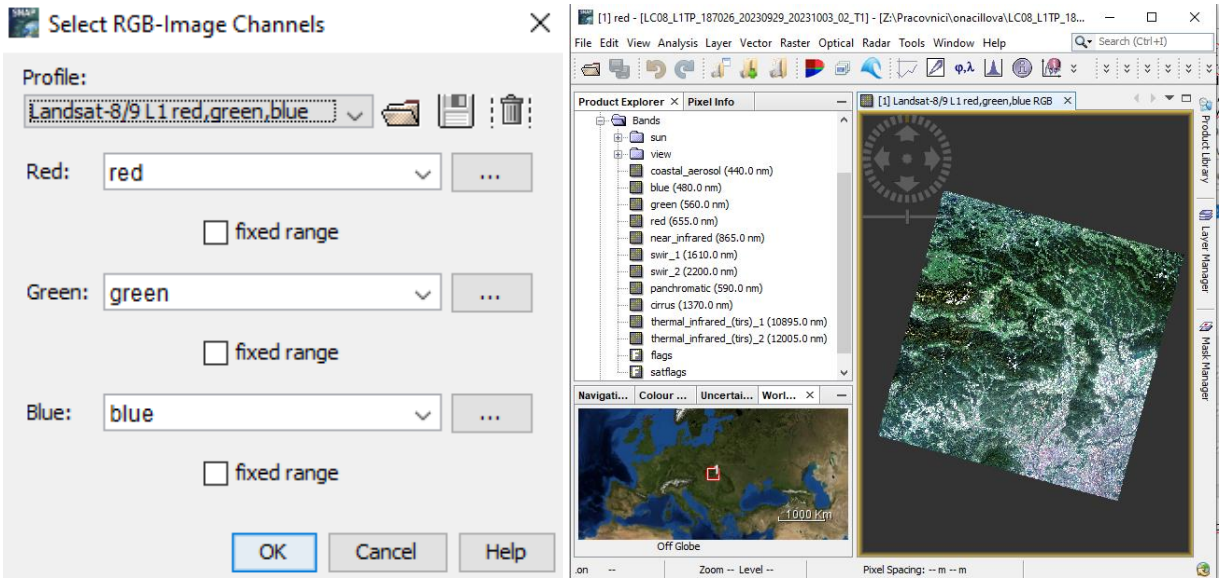
2.3 SNAP - Open and explore product

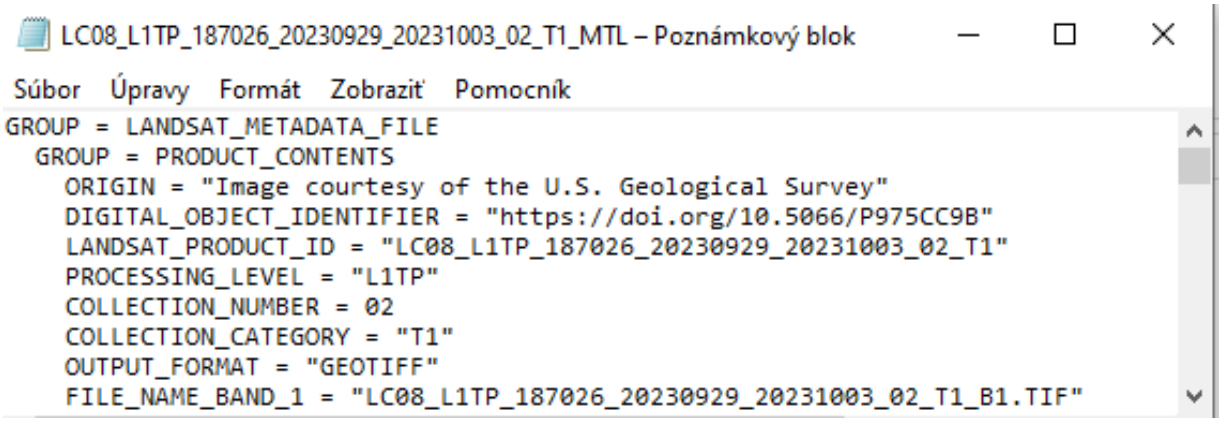
Open SNAP Desktop, click File – Import – Optical Sensors – Landsat – Landsat8 in 30m (GeoTIFF) and open downloaded product *„LC08_L1TP_187026_20230929_20231003_02_T1*" by double click on the metadata „LC08_L1TP_187026_20230929_20231003_02_T1_MTL .txt" inside the folder (or click on Import Product). The opened product will appear in Product Explorer window.



Display product using e.g. True color composition: Right click on the product – Open RGB Image Window – SNAP should automatically select Landsat-8/9 L1 red,green,blue profile (using Red, Green, Blue band in the corresponding red, green and blue color channels), resulting in a natural colored result, that is a good representation of the Earth as perceived by human eye. User can also explore Landsat-8 bands and metadata.



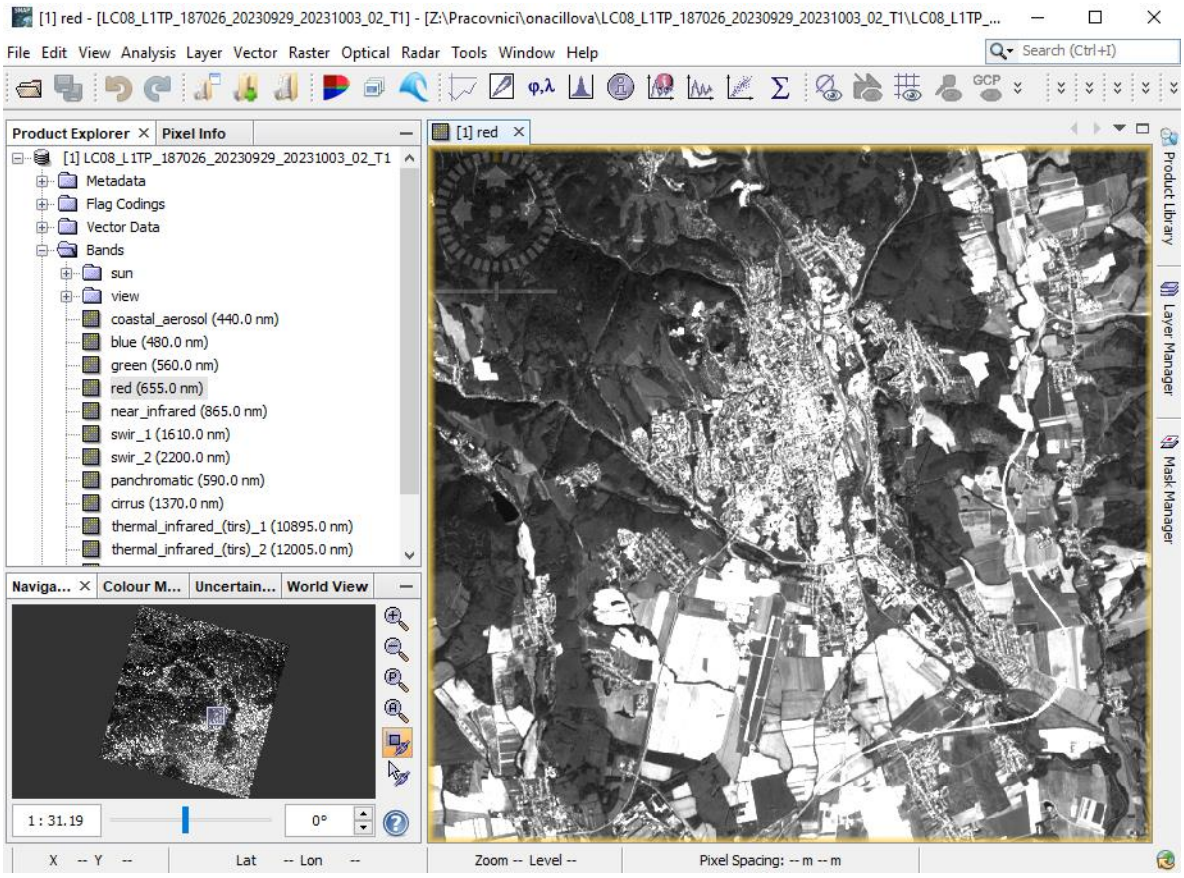


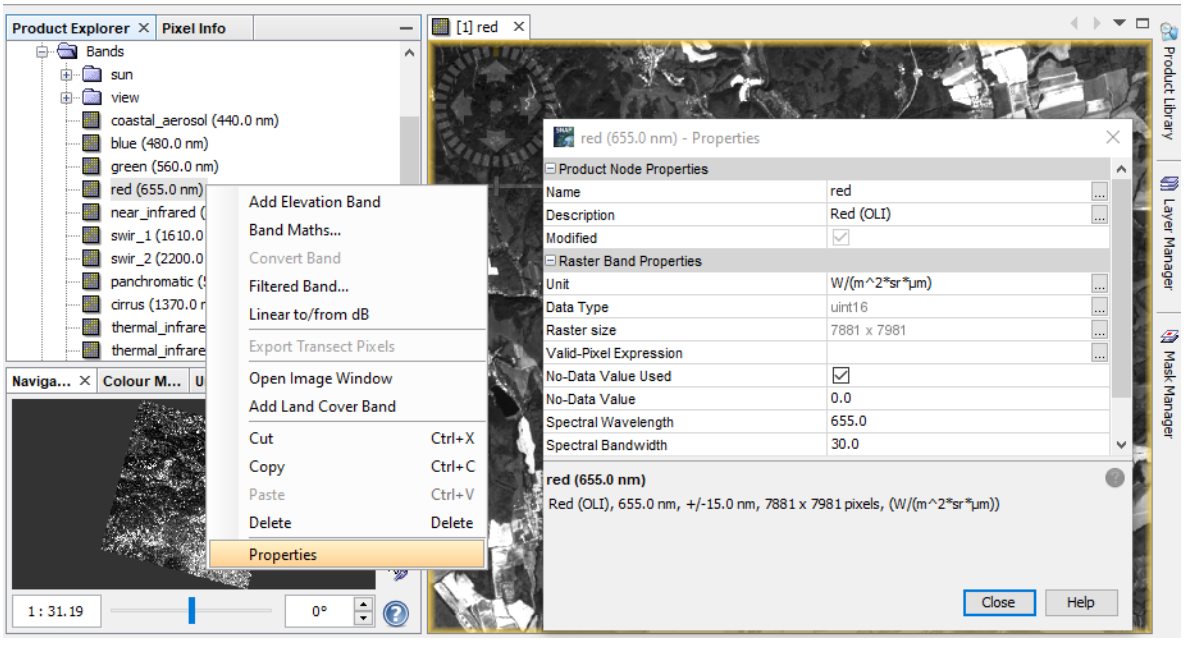


3 | Top of Atmosphere Reflectance

3.1 Conversion of DN values to TOA reflectance (without sun angle correction)

First, in SNAP we can display the Landsat-8 OLI band (raster) that we want to convert to physical units, e.g. Band 4 (Red) „LC08_L1TP_187026_20230929_20231003_02_T1_B4". In Product Explorer window expand Bands within your imported Landsat-8 product – double click on „red" (Band 4) to display selected band. We can have also a look at the raster properties (right click on the raster – Properties).



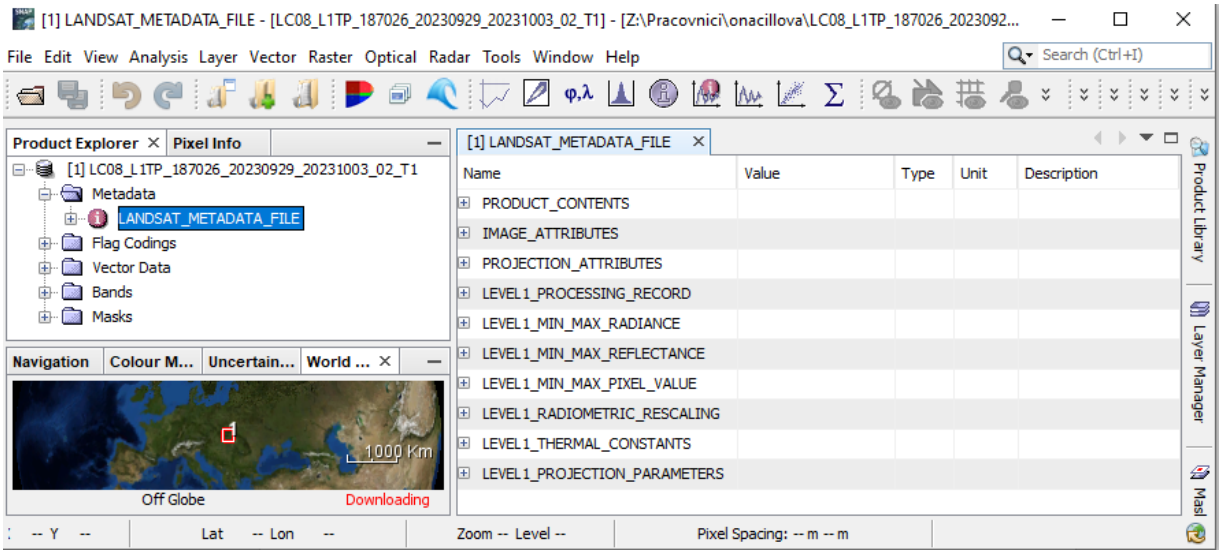


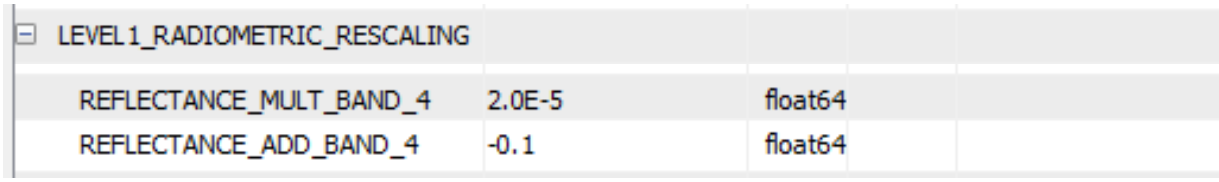
OLI sensor data (bands) can be converted to planetary reflectance at the TOA (Top Of Atmosphere = TOA) using reflectance scaling coefficients provided in the product metadata file (MTL file). The following equation is used to convert Level 1 DN values to TOA reflectance for OLI data without sun angle correction:

$$\rho\lambda' = M\rho * Qcal + A\rho$$

where:
ρλ' = TOA Planetary Spectral Reflectance, without correction for solar angle
Mρ = Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x from the metadata).
Aρ = Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x from the metadata).
Qcal = Quantized and calibrated standard product pixel value in DN

The needed values to perform the conversion can be found in the Landsat 8 metadata file (LC08_L1TP_187026_20230929_20231003_02_T1_MTL .txt) or by expanding and double click on Metadata information in SNAP.

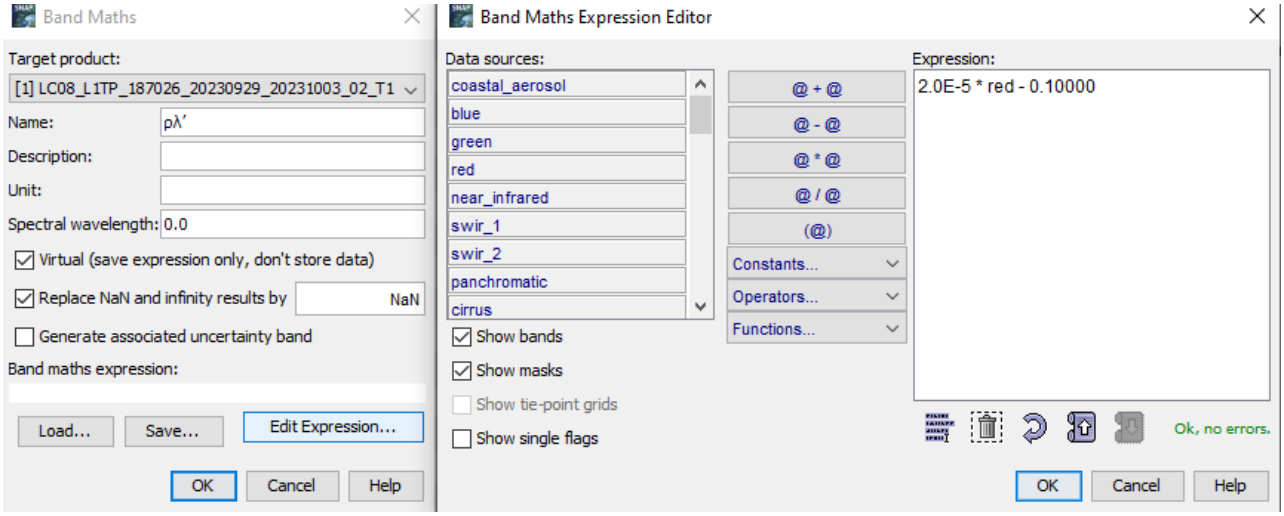


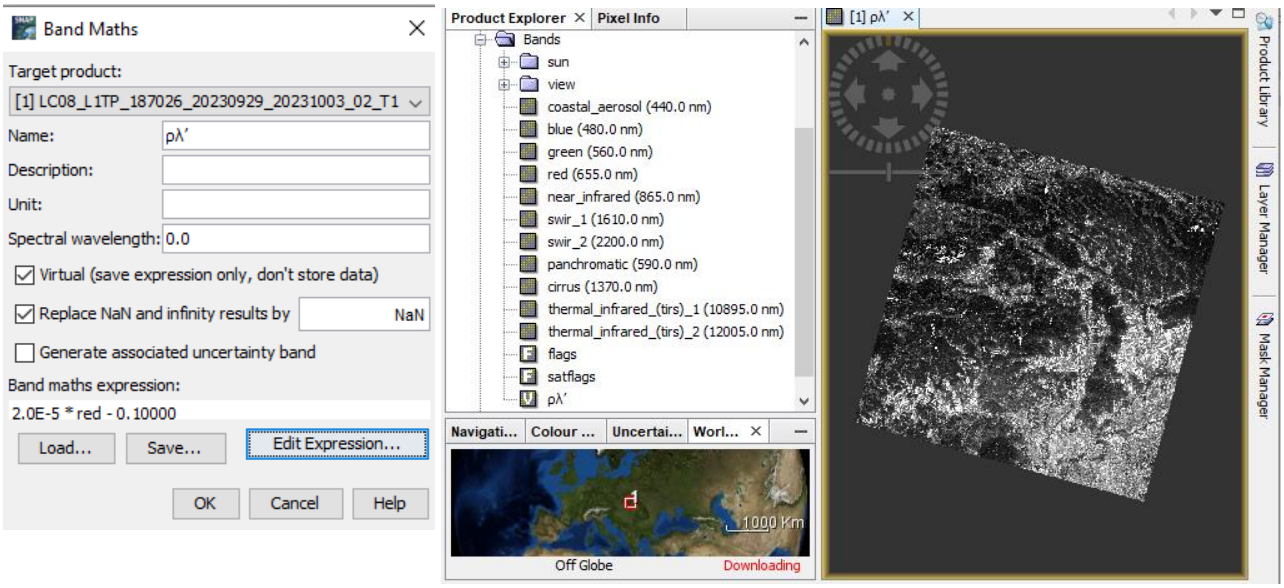


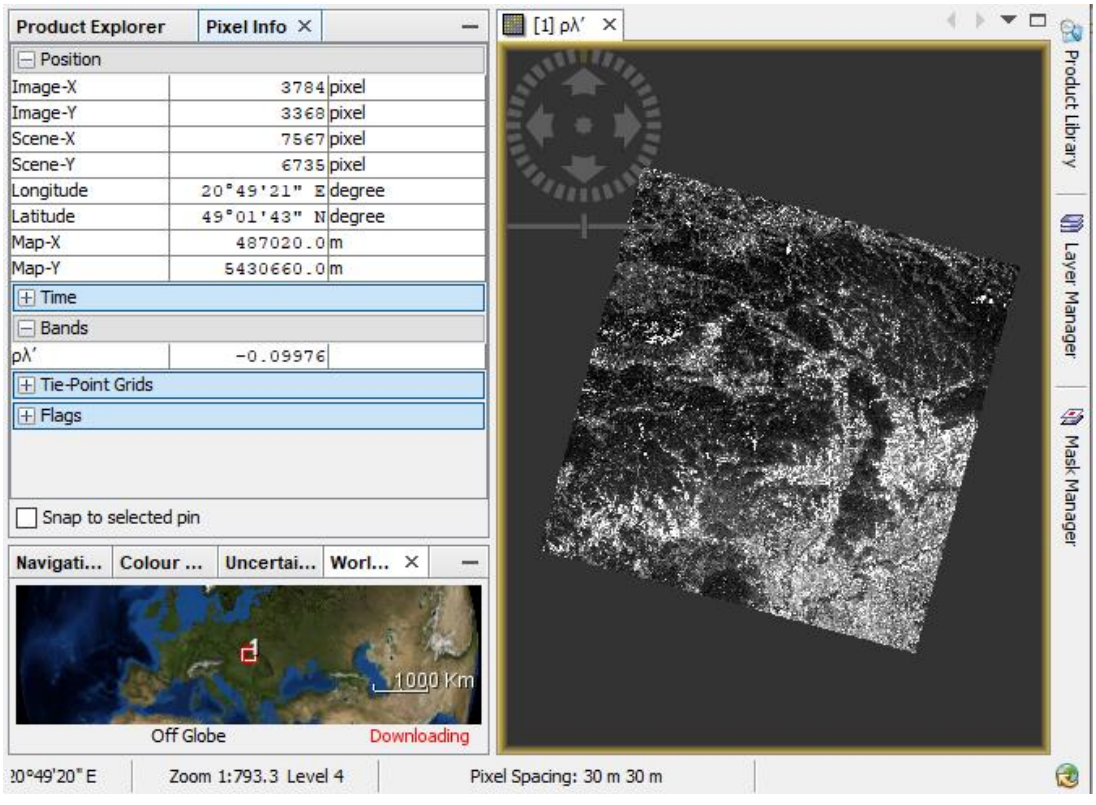
After substituting the reflectance scaling coefficients provided in the product metadata file, the equation to convert red band (Band 4) to planetary reflectance at the TOA will be as follows:

ρλ' = 2.0E-5 * red - 0.10000

Now go to Raster – Band Math and enter this expression to Band Maths Expression Editor.


Band Maths
Target product:
[1] LC08_L1TP_187026_20230929_20231003_02_T1
Name: ρλ'
Description:
Unit:
Spectral wavelength: 0.0
Virtual (save expression only, don't store data)
Replace NaN and infinity results by NaN
Generate associated uncertainty band
Band maths expression:
Load... Save... Edit Expression...
OK Cancel Help
Band Maths Expression Editor
Data sources:
coastal_aerosol
blue
green
red
near_infrared
swir_1
swir_2
panchromatic
cirrus
Show bands
Show masks
Show tie-point grids
Show single flags
@ + @
@ - @
@ * @
@ / @
(@)
Constants...
Operators...
Functions...
Expression:
2.0E-5 * red - 0.10000
Ok, no errors.
OK Cancel Help


Band Maths
Target product:
[1] LC08_L1TP_187026_20230929_20231003_02_T1
Name: ρλ'
Description:
Unit:
Spectral wavelength: 0.0
Virtual (save expression only, don't store data)
Replace NaN and infinity results by NaN
Generate associated uncertainty band
Band maths expression:
2.0E-5 * red - 0.10000
Load... Save... Edit Expression...
OK Cancel Help
Product Explorer
Pixel Info
Bands
sun
view
coastal_aerosol (440.0 nm)
blue (480.0 nm)
green (560.0 nm)
red (655.0 nm)
near_infrared (865.0 nm)
swir_1 (1610.0 nm)
swir_2 (2200.0 nm)
panchromatic (590.0 nm)
cirrus (1370.0 nm)
thermal_infrared_(tirs)_1 (10895.0 nm)
thermal_infrared_(tirs)_2 (12005.0 nm)
flags
satflags
ρλ'
Navigati...
Colour ...
Uncertai...
Worl...
1000 Km
Off Globe
Downloading
[1] ρλ'
Product Library
Layer Manager
Mask Manager


Product Explorer
Pixel Info
Position
Image-X 3784 pixel
Image-Y 3368 pixel
Scene-X 7567 pixel
Scene-Y 6735 pixel
Longitude 20°49'21" E degree
Latitude 49°01'43" N degree
Map-X 487020.0 m
Map-Y 5430660.0 m
Time
Bands
ρλ' -0.09976
Tie-Point Grids
Flags
Snap to selected pin
Navigati...
Colour ...
Uncertai...
Worl...
1000 Km
Off Globe
Downloading
[1] ρλ'
Product Library
Layer Manager
Mask Manager
20°49'20" E
Zoom 1:793.3 Level 4
Pixel Spacing: 30 m 30 m

Note that ρλ' is not true TOA Reflectance, because it does not contain a correction for the solar elevation angle that is left out of the Level 1 scaling at the users' request; some users are content with the scene-center solar elevation angle in the metadata, while others prefer to calculate their own per-pixel solar elevation angle across the entire scene.

Once a solar elevation angle is chosen, the conversion to true TOA Reflectance (with sun angle correction) is as follows:

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

where:
ρλ = TOA planetary reflectance
θSE = Local sun elevation angle; the scene center sun elevation angle in degrees is provided in the metadata
θSZ = Local solar zenith angle; θSZ = 90° - θSE

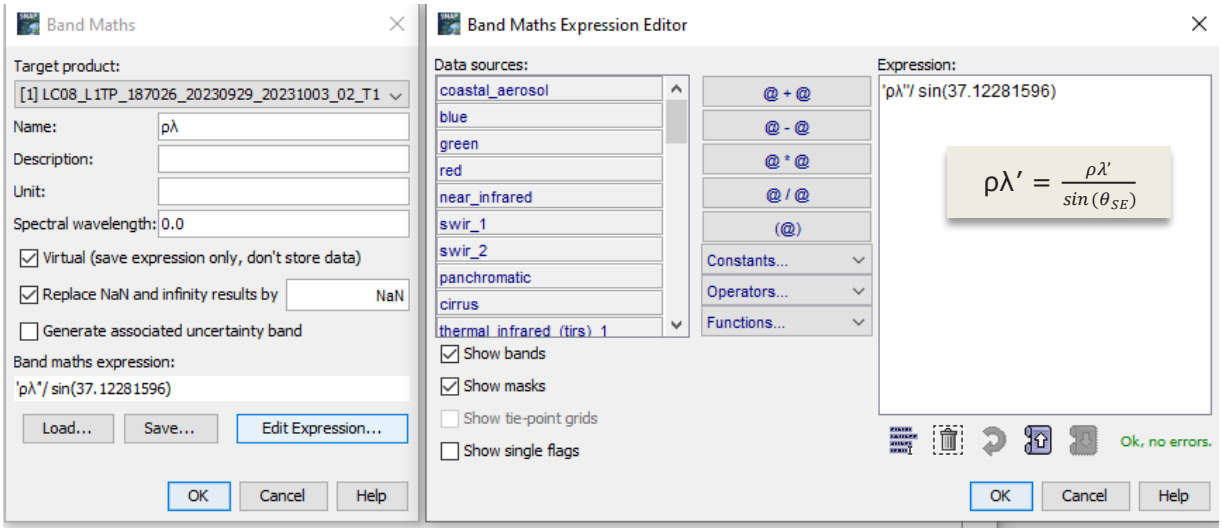
[1] LANDSAT_METADATA_FILE

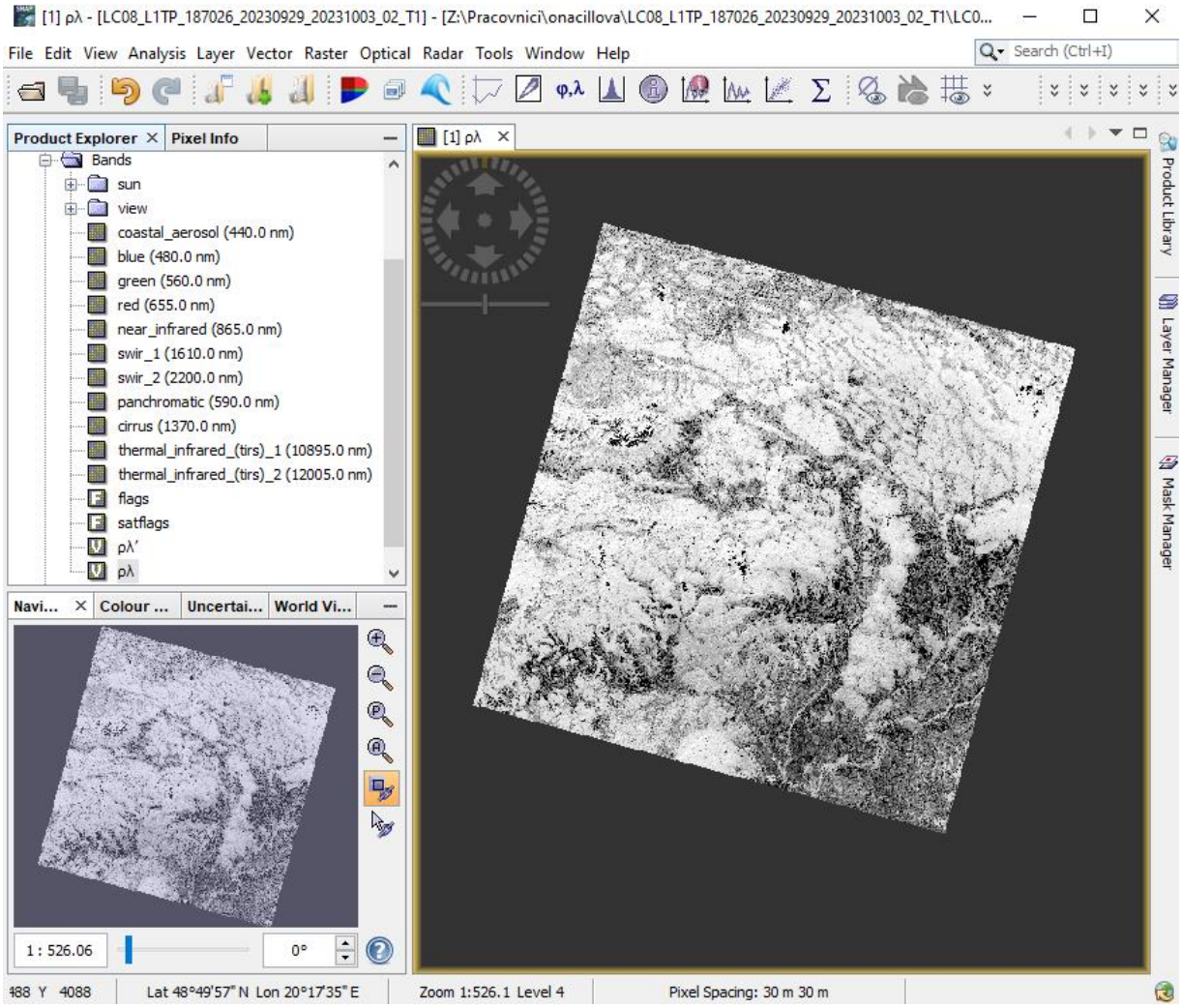
Name	Value	Type	Unit	Description
IMAGE_ATTRIBUTES				
SUN_ELEVATION	37.12281596	float64		

After substituting the local sun elevation angle provided in the product metadata file (or calculating local solar zenith angle), the equation to convert red band (Band 4) to true planetary reflectance at the TOA will be as follows:

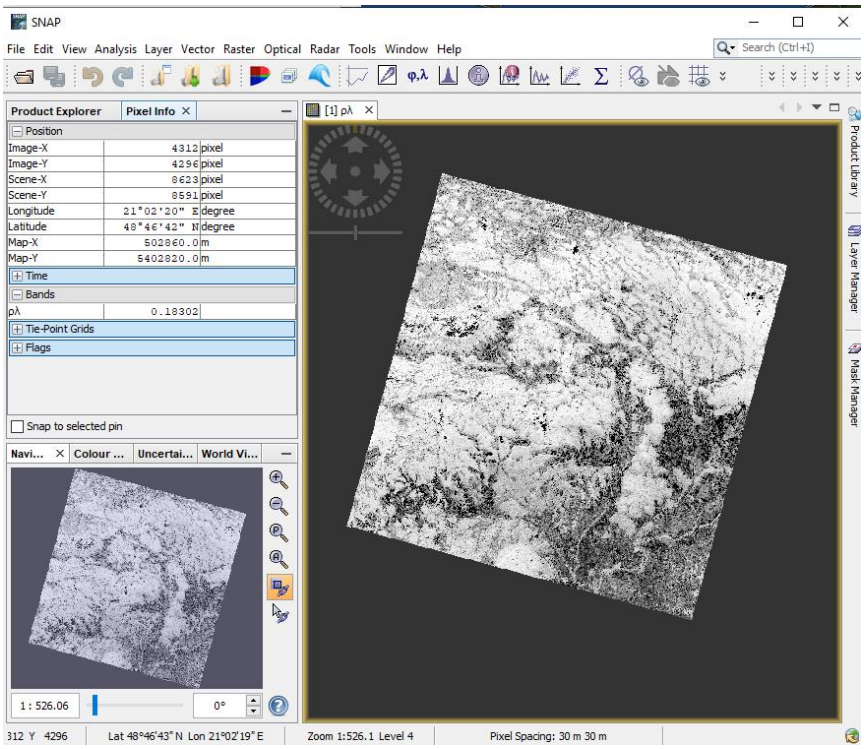
ρλ = ρλ'/sin(37.12281596)

Now go to Raster – Band Math and enter this expression to Band Maths Expression Editor.





True planetary reflectance at the TOA



4| Top of Atmosphere Radiance

4.1 Conversion of DN values to TOA radiance

Images are processed in units of absolute radiance using 32-bit floating-point calculations. These values are converted to 16-bit integer values in the finished Level 1 product. They can then be converted to spectral radiance using the radiance scaling factors provided in the metadata file. The equation below is used to estimate TOA radiance:

$$L\lambda = ML * Qcal + AL$$

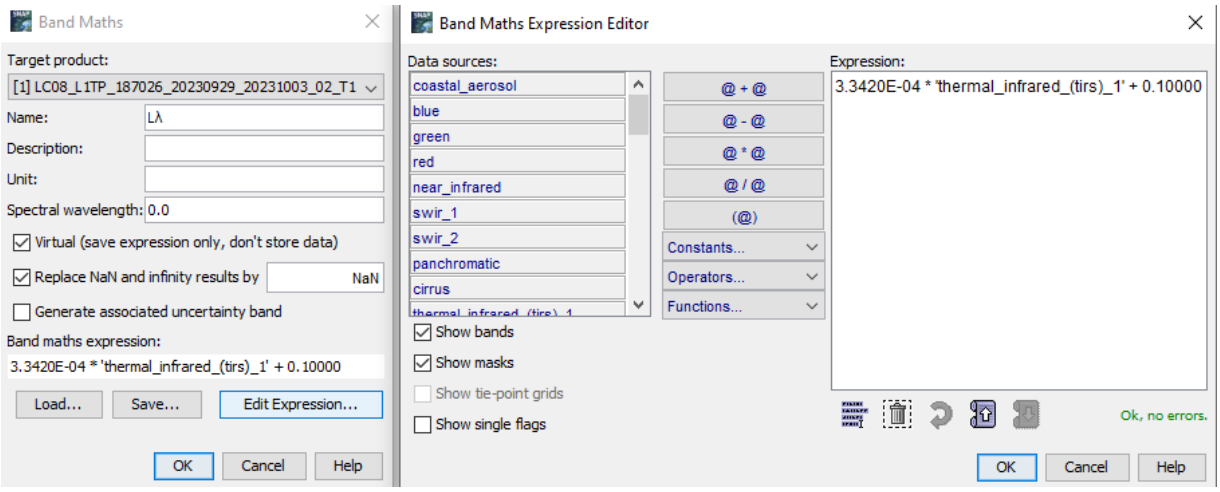
where:
Lλ = TOA Spectral radiance (Watts/(m2 * srad * μm))
ML = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x from the metadata, where x is the band number)
AL = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x from the metadata, where x is the band number)
Qcal = Quantized and calibrated standard product pixel value in DN

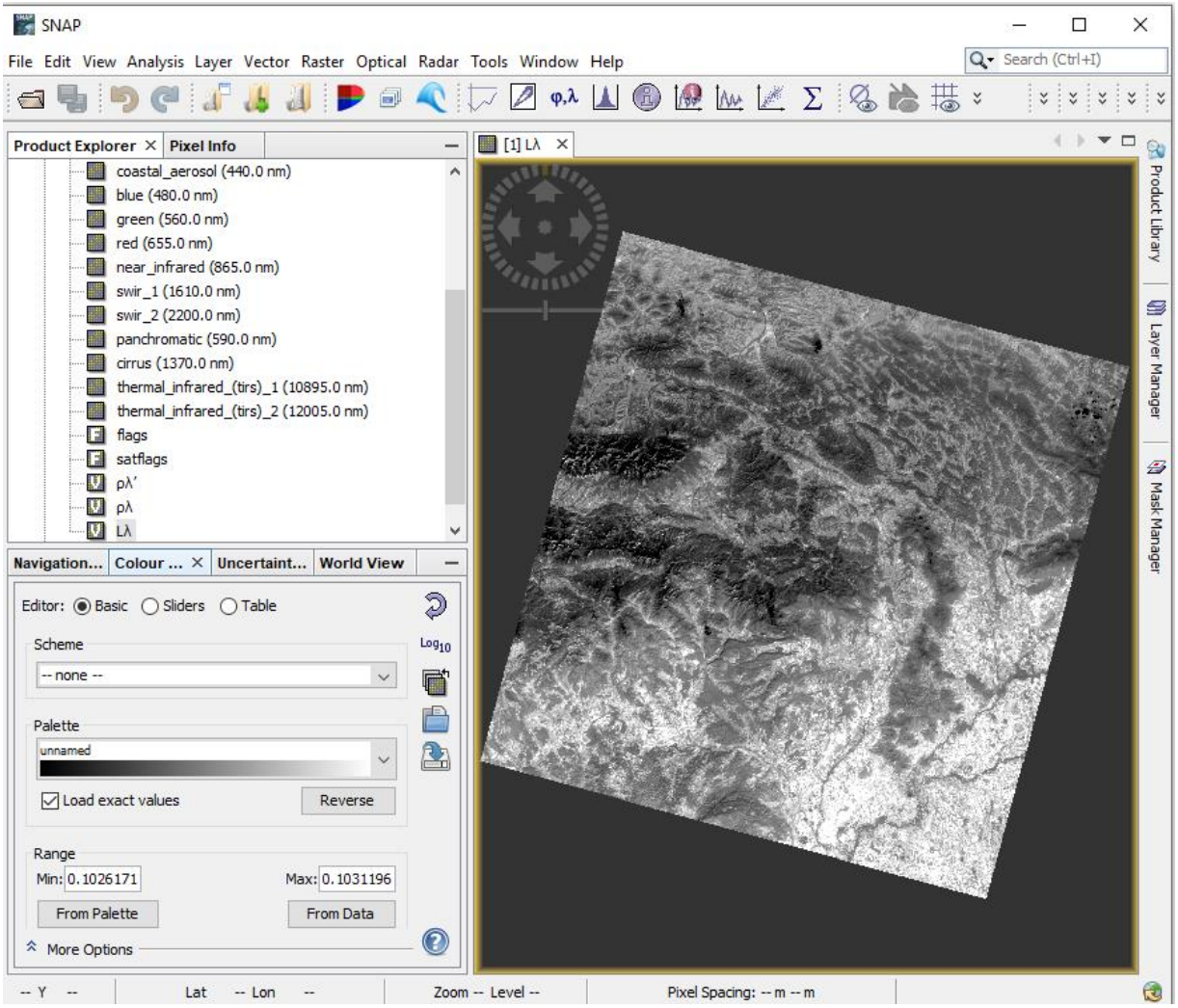
After substituting the variables in equation using provided metadata file, the equation to convert red band (Band 4) to radiance at the TOA will be as follows:

Lλ = 3.3420E-04 * thermal_infrared_tirs_(1) + 0.10000

By default, the S3TBX provides the TOA radiance of Landsat L1 data, but you can switch to TOA reflectance by specifying a property.

Now go to Raster – Band Math and enter this expression to Band Maths Expression Editor.





TOA spectral radiance (Watts/(m2 * srad * μm))

4.2 TIRS Top of Atmosphere Brightness Temperature

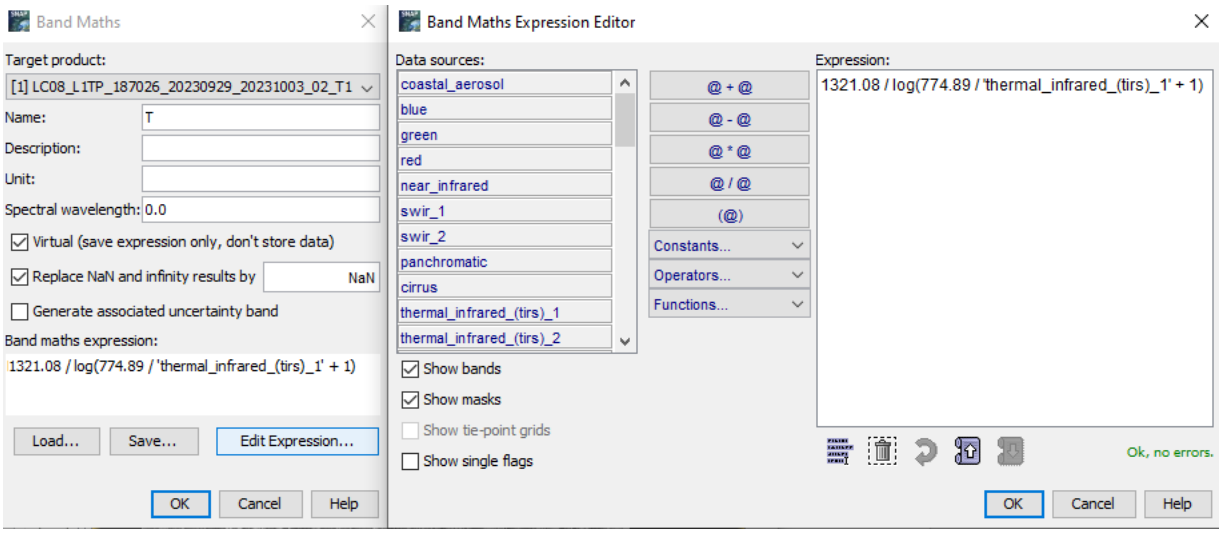
TIRS data can also be converted from spectral radiance (as described above) to brightness temperature, which is the effective temperature viewed by the satellite under an assumption of unity emissivity. The following conversion formula is used to convert TOA radiance to TOA brightness temperature:

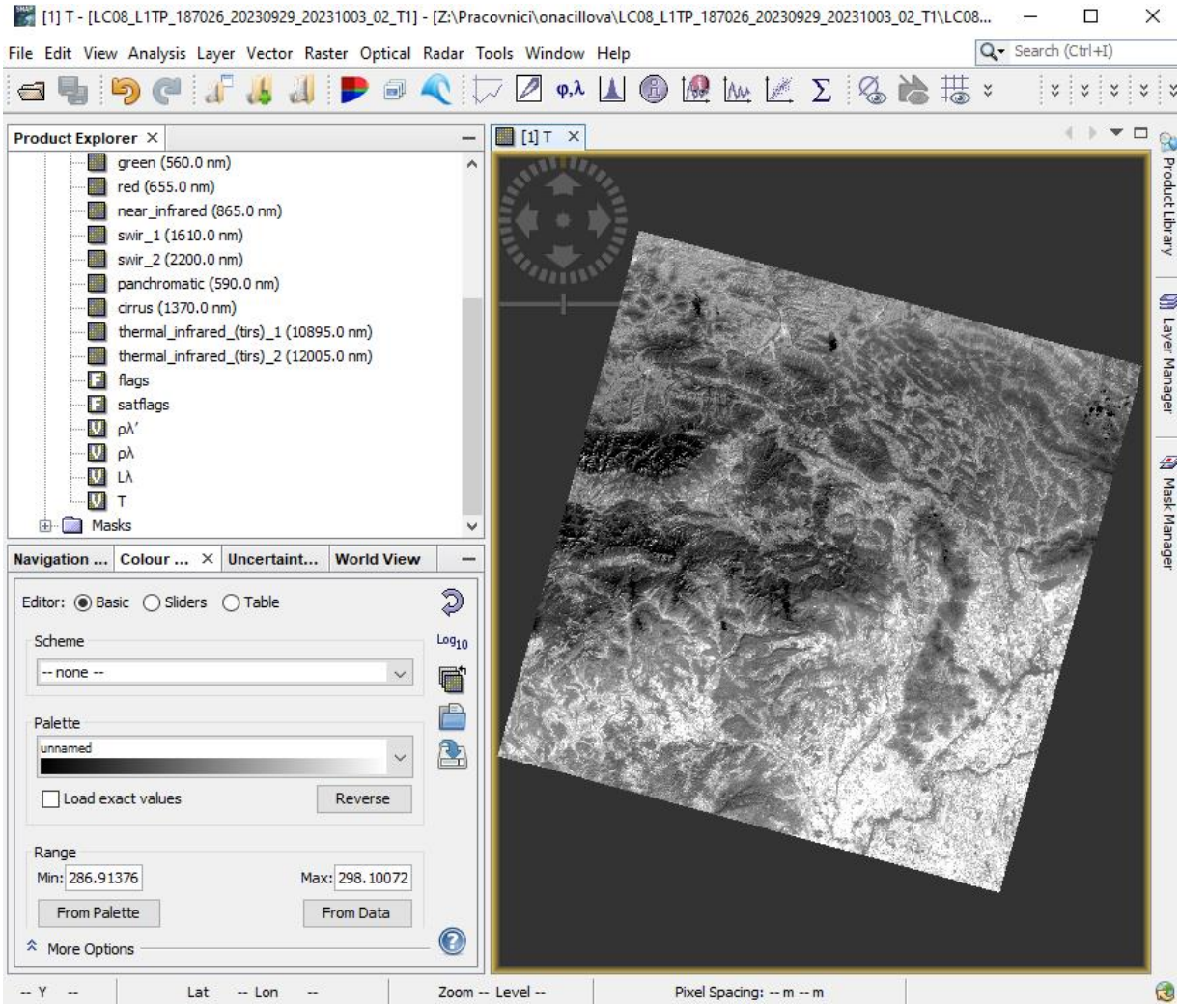
$$T = \frac{K_2}{ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

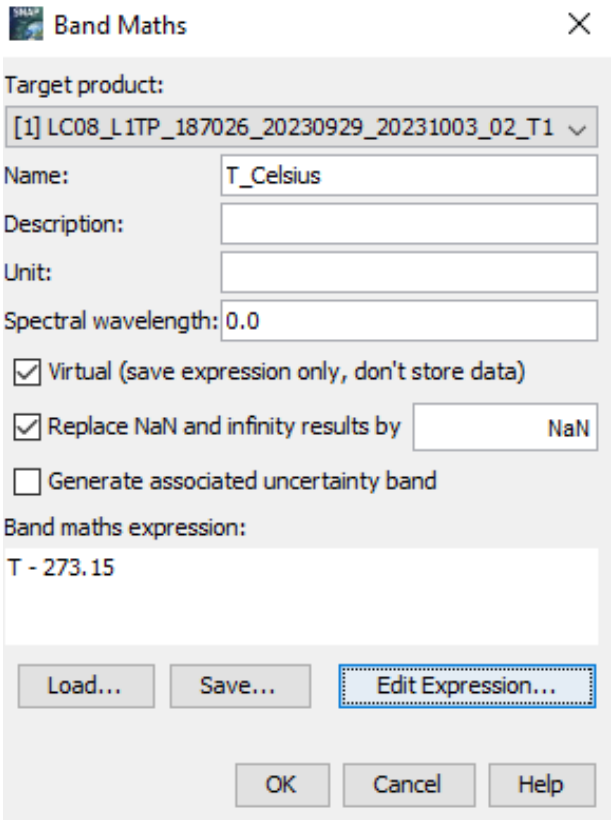
where:
T = Top of atmosphere brightness temperature (K)
Lλ = TOA spectral radiance (Watts/(m2 * srad * μm))
K1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)
K2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

After substituting the variables in equation using provided metadata file, the equation to convert thermal band no. 10 (Band 10) to radiance at the TOA will be as follows:

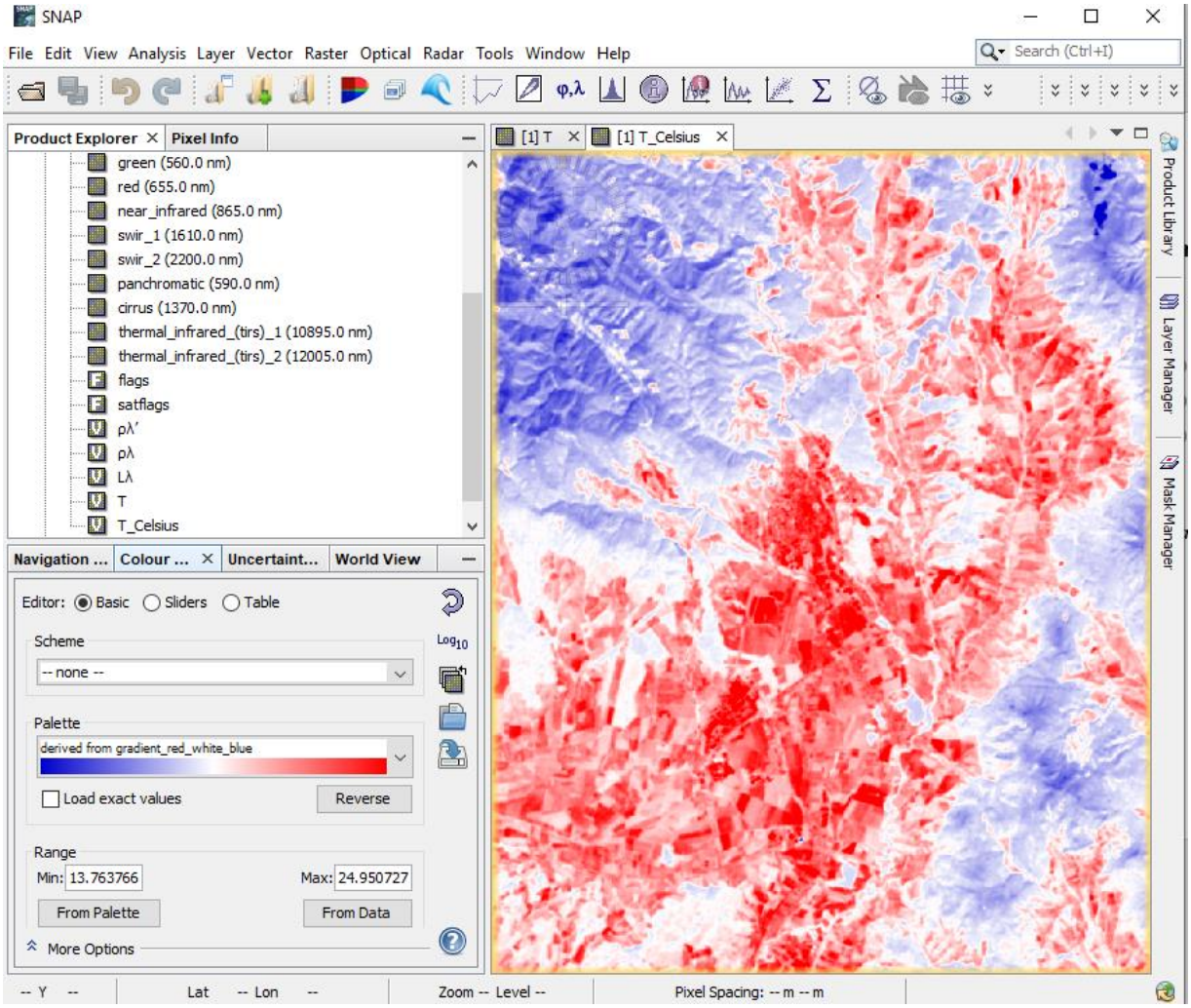
$$T = \frac{1321.08}{\ln\left(\frac{774.89}{L_\lambda} + 1\right)}$$







Now you have converted the T into degrees Kelvin. If you want to convert this into Celsius, you need to subtract 273.15 from the degrees kelvin. For Fahrenheit, multiply the degrees Celsius by 1.8 and then add 32. You can do this as one step within the Band Math function.



Visualize by double click the final Top of Atmosphere Brightness Temperature raster converted into Kelvin degrees. Change the colour ramp to see diferrences better.

Explore the distribution of TOA temperatures within the city of Košice. Compare it with, e.g. land cvoer map to see how different land cover/land use correlate with these temperatures.

For more information, see the lecture: 3. Key concepts and physical principles of remote sensing methods: electromagnetic energy, its properties, spectral behaviour and interaction with the environment

THANK YOU FOR FOLLOWING THE EXERCISE!