<u>**User guide for the Remote Sensing Tool**</u>

The Remote sensing Tool of the PULCHRA City Challenges Platform is a special feature of the Visualization Tools offered to the users of the Platform to enhance their urban ecosystems knowledge. The Remote Sensing Tool can be used for the discovery and exploration of full-resolution Sentinel-2, Landsat 8, and MODIS imagery. It is a graphical interface to a complete and daily updated Sentinel-2 archive, a massive resource for anyone interested in cities' changing surface, natural or manmade.

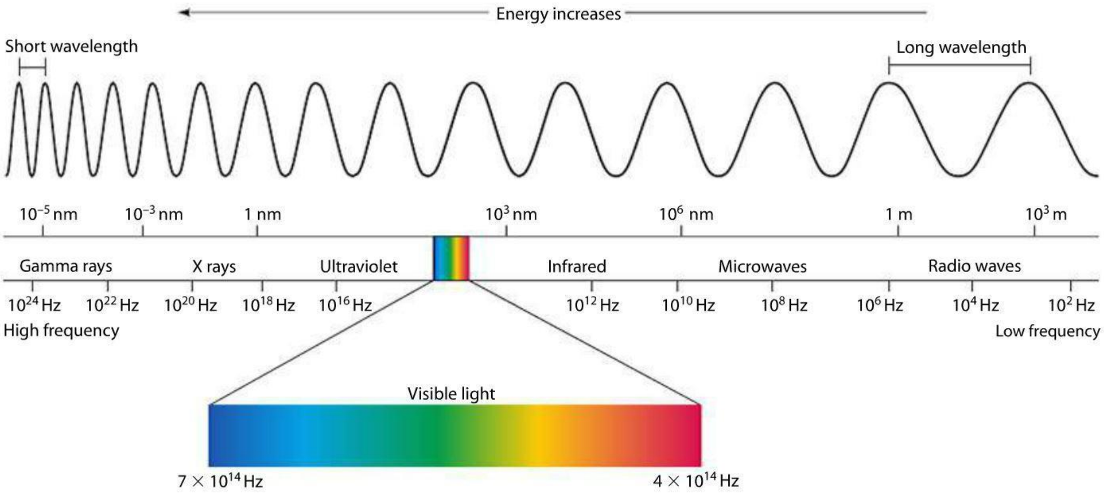
The application is perfect for someone, who wants to explore the urban characteristics of cities, work with the latest available images of current events (fires, droughts, etc) download a nice looking image, or simply understand how Earth observation products are built.

For anyone not confident in understanding the basic remote sensing concepts, we provide you with a short theory introduction that should prepare you for the exploration of the Remote Sensing Tool.

1. A simplified theoretical introduction

1.1 Optical satellites

To start creating beautiful and useful images, the first thing we need to understand is the electromagnetic spectrum. You can see the representation of it on the image below. Electromagnetic energy travels in the form of waves with different frequencies. The frequency of a wave is related to its wavelength; the shorter the wavelength, the higher the frequency and also the energy of a wave. Frequency is the main characteristic of waves and thus determines how the wave is going to interact with matter.



The electromagnetic spectrum (Miniphisycs.com)

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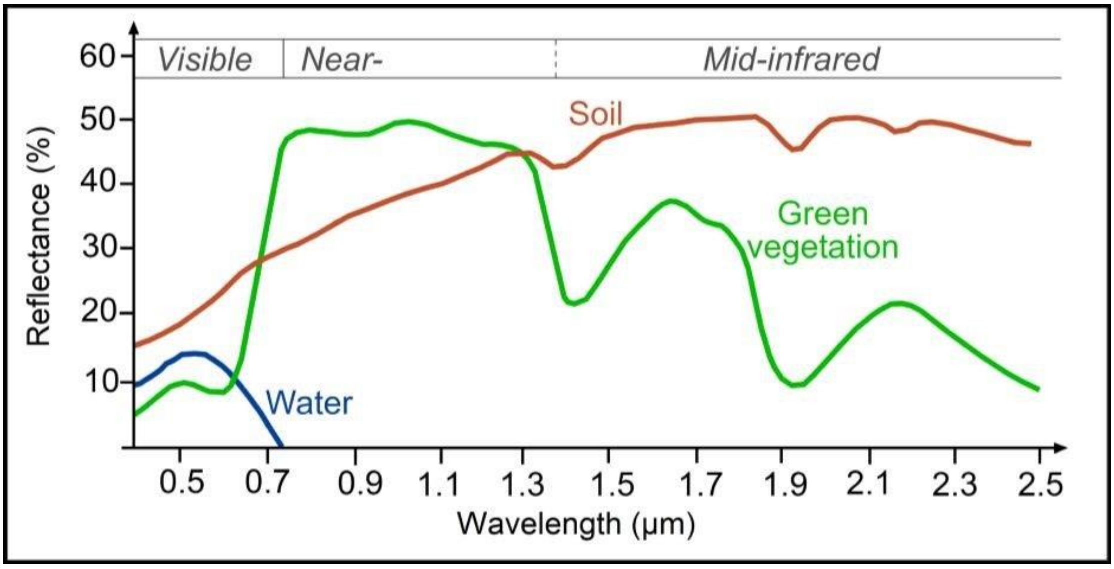
Objects absorb specific wavelengths of light and reflect others, based on the material. For example, plants absorb blue and red light, while they reflect green light. That is why they appear green to the naked eye. However, they also strongly reflect some parts of the infrared spectrum. If we were to look at an infrared image, we would clearly see vegetation.

Satellites orbit the Earth and capture images of it, similar to cameras. They carry light sensors, each sensitive to a specific electromagnetic wavelength range. Optical satellites have sensors sensitive to visible (red, green, blue) light, infrared light and sometimes UV light. Radar satellites work in the microwave part of the spectrum. Images captured by satellite sensors are called **bands**.

Each object has its own **spectral signature**, as is depicted on an image below. Here we can see spectral signatures for water, soil and green vegetation. It shows which wavelengths are absorbed (low reflectance values) and which are reflected.



Soil, water and green vegetation spectral signatures (GrindGIS.com)

For example, if we look at the image above, we can see, that at wavelength around 2.1 μm, both soil and green vegetation are reflective, while water is not. If we look at a satellite band, that captures 2.1 μm wavelength, we will see soil as bright, since its reflectance is high (around 50 %), green vegetation as darker grey, since its reflectance is lower (around 20 %) , and water as black, since its reflectance is 0 %. At other wavelengths the image would be different, since soil, vegetation and water reflect different amounts at different wavelengths, as is evident from spectral signatures. For example, if we were to look at a satellite band displaying reflectance at around 0.5 μm, differences between water, soil and vegetation would be barely noticeable, since they all have low and similar reflectance. If we wish to see the differences between them, it would thus be best to choose the wavelength (satellite band), where differences are higher. In general, every material type has its own spectral signature, meaning its reflectance at different wavelengths is variable. It is thus possible to see the

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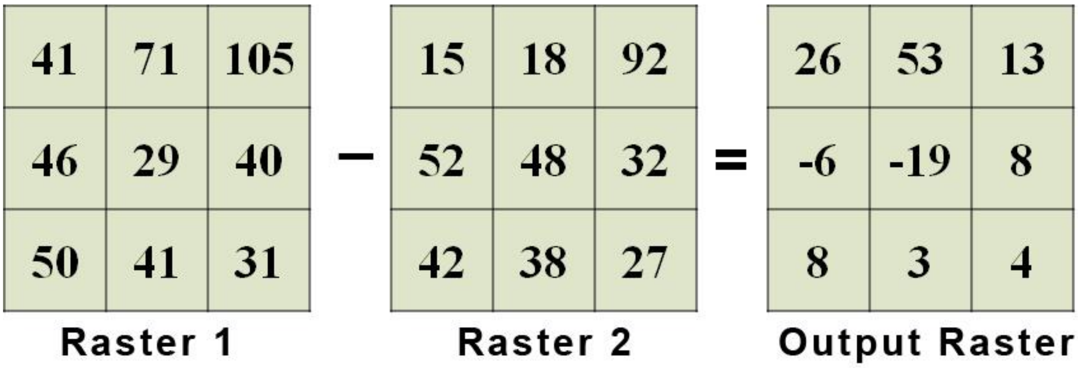
differences between different types of land use and land cover, if we choose to observe the Earth using suitable bands.

To learn more about remote sensing basics, visit this remote sensing tutorial.

1.2 Band calculations using map algebra

Each satellite band is an image. An image is represented as a grid of values in computers (also called a raster). Every grid cell is called a pixel and is square shaped.

We can use map algebra to perform calculations between satellite bands. The way we do that is by calculating between the corresponding pixels. For example, on the graphics below, we can see how we would subtract one band from another. The value of a pixel in row 1 and column 1 of the first raster will be subtracted from the value of a pixel in row 1, column 1 of the second raster and so on.



Map algebra (Humboldt State University)

We can add, subtract, multiply and divide bands with other bands or with scalar values. As you will see later, we can use map algebra to calculate remote sensing indices, such as NDVI. In the tables below you can see bands for the three satellites of the Tool (only the bands that are included in the Tool), along with the corresponding wavelengths and spatial resolutions.

Landsat 8 bands

Band	Wavelength (μm)	Spatial Resolution (m)
1	0.433–0.453	30 m
2	0.450–0.515	30 m
3	0.525–0.600	30 m
4	0.630–0.680	30 m
5	0.845–0.885	30 m
6	1.560–1.660	30 m
7	2.100–2.300	30 m
8	0.500–0.680	15 m
9	1.360–1.390	30 m

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Sentinel 2 bands

Band	Central wavelength (nm)	Bandwidth (nm)	Spatial resolution (m)
1	443	20	60
2	490	65	10
3	560	35	10
4	665	30	10
5	705	15	20
6	740	15	20
7	783	20	20
8	842	115	10
8a	865	20	20
9	945	20	60
10	1375	30	60
11	1610	90	20
12	2190	180	20

MODIS bands

Band	Wavelength (µm)	Spatial Resolution (m)
1	620 - 670	250 m
2	841 - 876	250 m
3	459 - 479	500 m
4	545 - 565	500 m
5	1230 - 1250	500 m
6	1628 - 1652	500 m
7	2105 - 2155	500 m

2.3 Color

Next, we need to understand color. The human eye has 3 types of color receptors: red, blue and green. Computers use the RGB color model to represent colors. R in RGB stands for red, G for green and B for blue. We also call those color channels. Every color a computer can display, contains certain amounts of red, blue or green light. Values range from 0 to 255 for every channel, adding up to 16,7 million different colors for most modern computer screens.

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For example, a “pure red” color will have a value 255 in the red channel, and 0 in both green and blue channels. If we add 255 into the blue channel instead of 0, red and blue colors will mix and we will get purple. The higher the channel value, the more of the color will be mixed in. If all three channels have equal values, we get a color in black and white range; white, if all three values are 255 and black, if they are all 0.

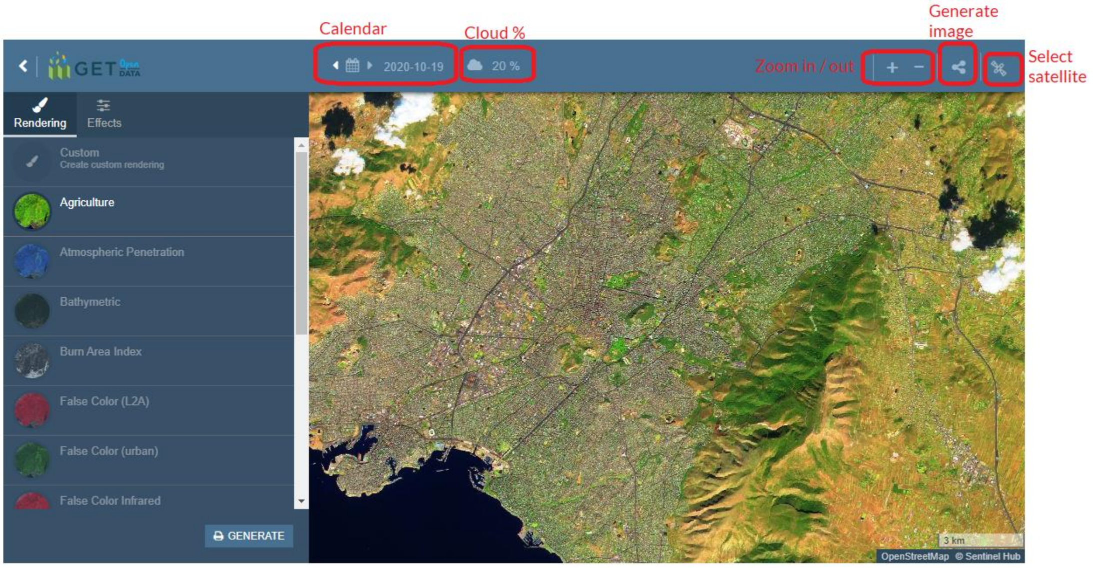
Visit [this page]() and try to input different RGB values, to get a sense of how the colors mix.

2. Working with the Remote Sensing Tool

The two main features of the tool are:

-the search feature

-the results feature



2.1 Search

The search feature gives as the ability to search for available satellite images.

-Search for the location of your interest by scrolling the map with mouse

-Choose the satellite you want (top right corner).

-Select maximum Cloud coverage percentage.

-Select the date from calendar.

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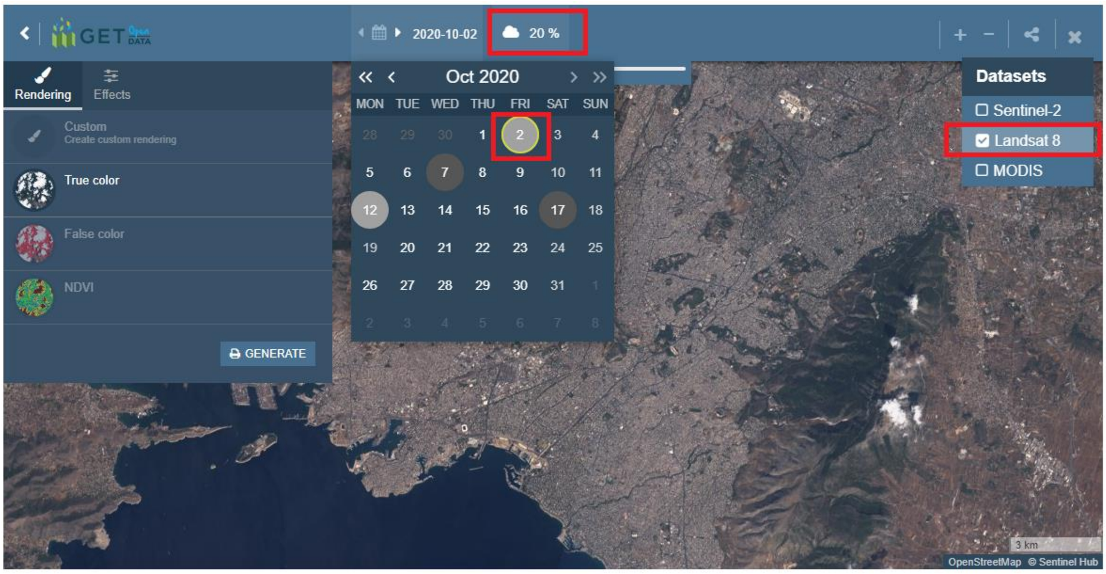

In the above example we search for an image on October 2020 with maximum 20% cloudiness from the Landsat 8 satellite.

2.2 Results

After the search the results appear in the left side panel. For the current example three options are available:

-True color,

-False color and

-NDVI.

By default the True color option is selected. The default options for each satellite are:

Sentinel 2 Composites

Agriculture RGB (11,8,2)	**This composite, often called the Agriculture RGB composite, uses bands SWIR-1 (B11), near-infrared (B08) and blue (B02). It's mostly used to monitor crop health, as both short-wave and near infrared bands are particularly good at highlighting dense vegetation, which appears dark green in the composite. SWIR measurements can help scientists estimate how much water is present in plants and soil, as water reflects SWIR light. Shortwave-infrared bands are also useful for distinguishing between snow, and ice, all of which appear white in visible light. Newly burned land reflects strongly in SWIR bands, making them valuable for mapping fire damage.**
Atmospheric penetration RGB(12,11,8a)	This band combination shows results similar to that of a traditional false color infrared photography but has an excellent clarity. It involves no visible bands while

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	penetrating atmospheric particles, smoke and haze reducing the atmospheric influence in the image. Water attenuates the NIR and the short-wave infrared (SWIR) wavelengths, ice and snow giving well-defined shores, coastlines and highlighted sources of water within the image. Vegetation in the band combination appears blue, displaying details related to the vegetation vigor, the healthy vegetation is shown in light blue while the stressed, sparse or/and arid vegetation appears in dull blue. Urban features are white, gray, cyan or purple. The band combination can be used to find soils moisture, textural and characteristics each band in the combination plays a major in indicating different features giving them different characteristic in the appearance of the image.
True Color L2A RGB (4, 3, 2)	True color composite uses visible light bands red (B04), green (B03) and blue (B02) in the corresponding red, green and blue color channels, resulting in a natural colored result, that is a good representation of the Earth as humans would see it naturally.
False Color L2A RGB (8,4,3) **Or** **False Color Infrared**	False color imagery is displayed in a combination of standard near infra-red, red and green band. False color composite using near infrared, red and green bands is very popular. It is most commonly used to assess plant density and health, as plants reflect near infrared and green light, while absorbing red. Since they reflect more near infrared than green, plant-covered land appears deep red. Denser plant growth is darker red. Cities and exposed ground are gray or tan, and water appears blue or black.
SWIR RGB (12,8,4)	Short wave infrared (SWIR) bands 11 and 12 can help scientists estimate how much water is present in plants and soil, as water reflects SWIR wavelengths. Shortwave-infrared bands are also useful for distinguishing between cloud types (water clouds versus ice clouds), snow and ice, all of which appear white in visible light. Newly burned land reflects strongly in SWIR bands, making them valuable for mapping fire damage. Each rock type reflects shortwave infrared light differently, making it possible to map out geology by comparing reflected SWIR light. In this composite, B8A is reflected by vegetation and shown in the green channel, while the reflected red band, highlighting bare soil and built up areas, is shown in the blue channel.
Geology RGB (12,11,2)	The geology band combination is a neat application for finding geological features. This includes faults, lithology, and geological formations. By leveraging the SWIR-2 (B12), SWIR-1 (B11), and blue (B2) bands, geologists tend to use this Sentinel band combination for their analysis.
Normalized Burn Ratio	To detect burned areas, the Normalized Burn ratio is the most appropriate choice. Using bands 8 and 12 it highlights burnt areas in large fire zones greater than 500 acres. To observe burn severity, you may subtract the post-fire NBR image from the pre-fire NBR image. Values description: Darker pixels indicate burned areas.

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False Color (Urban) RGB (12,11,4)	This combination is used to obtain pseudo-natural colors under certain conditions when the image is visualized similar to the natural one and allows you to analyze the atmospheric haze, the state of suspensions in the atmosphere, its smoke. Vegetation is visible in shades of green, urbanized areas are represented by white, gray, or purple, and soils, sand, and minerals are shown in a variety of colors. Due to the almost complete absorption of solar radiation in the middle IR range by water, snow, and ice, coastlines and water objects are well distinguished. Snow and ice appear as dark blue, and water as black or blue. Flooded areas are a very dark blue and almost black, whereas in composition 3-2-1, shallow flooded areas are gray and difficult to distinguish.
Moisture Index (B08 - B11) / (B08 + B11)	The NDMI is a normalized difference moisture index, that uses NIR and SWIR bands to display moisture. The SWIR band reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content. The amount of water available in the internal leaf structure largely controls the spectral reflectance in the SWIR interval of the electromagnetic spectrum. SWIR reflectance is therefore negatively related to leaf water content. In short, NDMI is used to monitor changes in water content of leaves. NDWI is computed using the near infrared (NIR) and the short wave infrared (SWIR) reflectance's:
Vegetation Index (B08 - B04) / (B08 + B04)	NDVI< -0.2 NDVI< -0.1 NDVI< 0 NDVI< 0.1 NDVI< 0.2 NDVI< 0.3 NDVI< 0.4 NDVI< 0.5 NDVI< 0.6 NDVI< 0.7 NDVI< 0.8 NDVI< 0.9 NDVI< 1

Landsat 8 Composites

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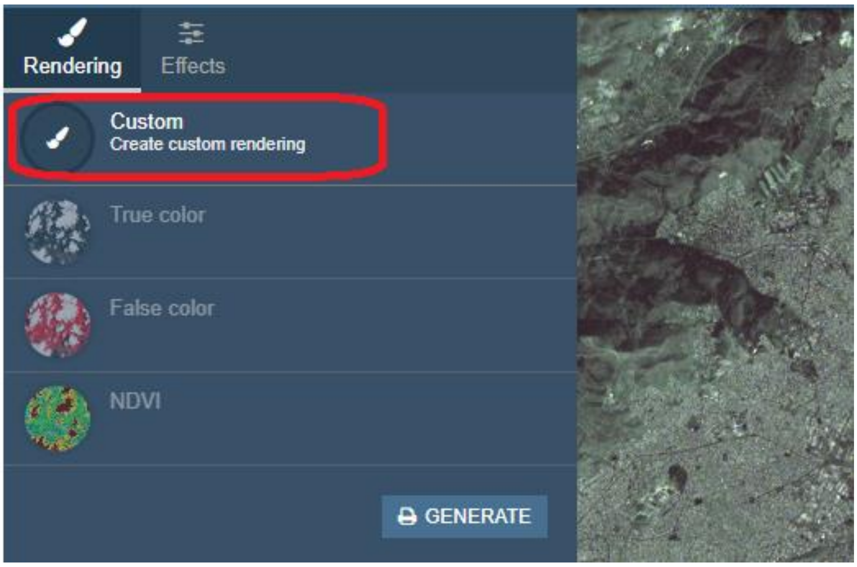
True Color **RGB(4,3,2)**	**This band combination is as close to "true color" as you can get with a Landsat OLI image. One unfortunate drawback with this band combination is that these bands tend to be susceptible to atmospheric interference, so they sometimes appear hazy.**
False Color **RGB(5,4,3)**	This band combination is used to assess plant density and health. Vegetation really pops in red, with healthier vegetation being more vibrant. It's also easier to tell different types of vegetation apart than it is with a natural color image. This is a very commonly used band combination in remote sensing when looking at vegetation, crops and wetlands.
NDVI **(B08 - B04) / (B08 + B04)**	NDVI< -0.2 NDVI< -0.1 NDVI< 0 NDVI< 0.1 NDVI< 0.2 NDVI< 0.3 NDVI< 0.4 NDVI< 0.5 NDVI< 0.6 NDVI< 0.7 NDVI< 0.8 NDVI< 0.9 NDVI< 1

If we are interested in creating custom composite images ourselves, we must choose the "Custom" option on top.



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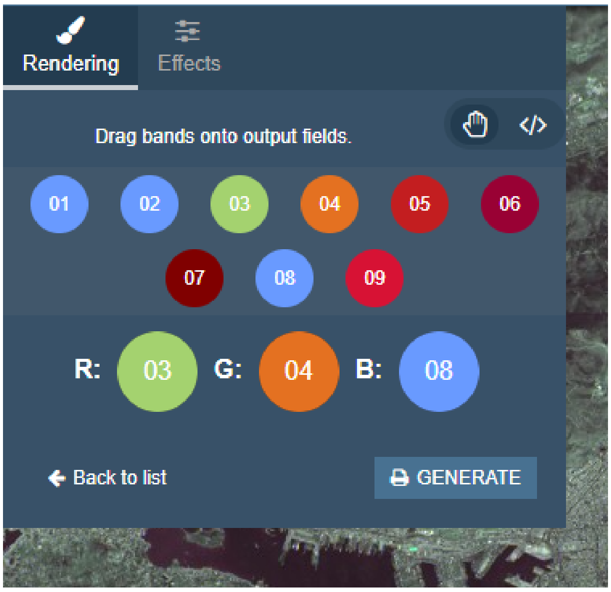
The custom visualization panel opens, where you can manually drag and drop satellite bands into the RGB channels. As you do that, the satellite image is updated automatically.



Satellite bands are named with a number, e.g. 01, 08, etc. If we look at a single satellite band, it will appear in the black and white color range, called grayscale. Lighter values represent higher reflectance values of objects on the ground, while darker values represent lower radiance (the light sensed by the sensor) values.

To get a color image, we must create it by combining 3 bands by inputting them into the red (R), green (G) and blue (B) channels. This means, that the band we choose to input into the red channel will appear red on the image, the one in the green channel will appear green and the one in the blue channel will appear blue. The resulting image is called a composite.

If we input a band, that displays reflectance of red wavelength (called a red band) into the red channel, green band into the green channel and blue band into the blue channel, we get an image, that corresponds to colors, as humans see naturally. In Sentinel-2, bands that correspond to red, green and blue light are B04, B03 and B02 respectively. Such composites are called true color composites.

True color band combinations for the three satellites of the Tool

	RED	GREEN	BLUE
Sentinel-2	04	03	02
Landsat 8	04	03	02
MODIS	01	04	03

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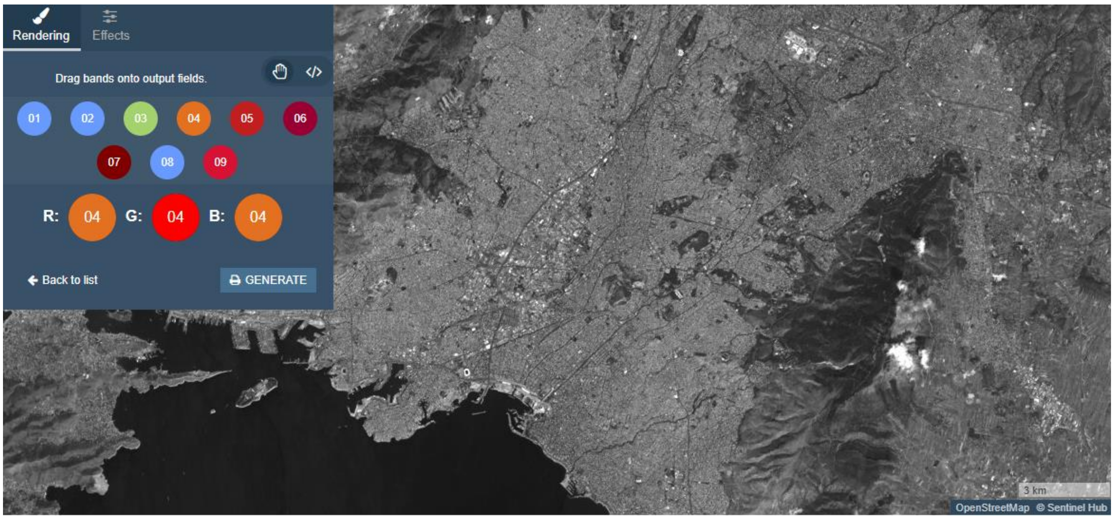
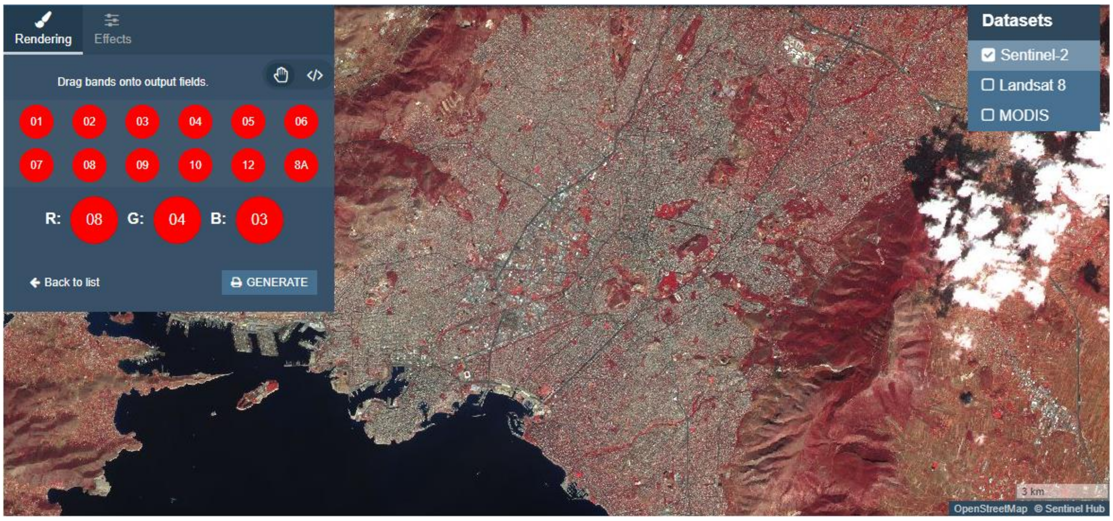
We can input the same band into multiple channels; in case we put the same band into all 3 color channels, we lose the RGB properties and get a grayscale image of the band, as is shown on the image below.



We can put any band in any one of the 3 channels. A composite, that is not a true color composite, is called a false color composite. For example, to create a composite, that highlights vegetation in Sentinel 2, we could input band 8 (near infrared) into the red channel, band 4 (red) into the green and band 3 (green) into the blue channel, as shown on the image below. Since the image is mostly red, it means, that the values in band 8 are higher than values in bands 4 and 3.



The reasons some bands are brighter than others are that bands have different bandwidths (band wavelength range from min to max), different spatial resolutions and that the amount of electromagnetic energy reflected from the Earth's surface and absorbed through the atmosphere varies with wavelength. If we wanted to make one of the less dominant bands stronger, we could use custom scripts to multiply them.

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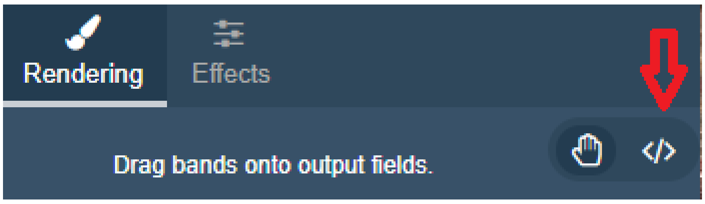
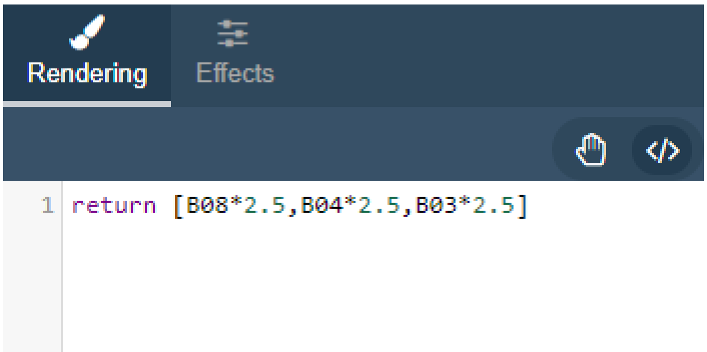
To access custom scripts, click on the green hand symbol under custom, to toggle between draggable bands and custom scripts </>.



As the white javascript window opens, you can start changing the code. When you're done, scroll down and click refresh, since the image won't update automatically.



To make a simple true color composite, write the following code:

```
return [ B04, B03, B02 ]
```

The array of values in a return statement defines the colors for visualization. An array in javascript is a collection of elements, separated by a comma and contained within square brackets. The first number in the array will be used to visualize red color, the second number in the array to visualize green color and the third number to visualize blue color. We can define either one or three elements in the array.

If we use a single band 3 times, the result is the same, as if we only call it once – we get a grayscale image.

```
return [ B04, B04, B04 ] // One band in all 3 RGB channels – grayscale image of the band
return [ B04 ] // Same as above
```

Note, that we can use // to comment in javascript. Comments will not be executed. To create a multiline comment, we use /* to start, and */ to end a comment.

To manipulate the result, we can multiply the bands by numerical values. Multiplying each band by 2.5 proved to be useful for Sentinel-2 true color composites, as it improves the appearance of images. The true color composite we get by dragging and dropping bands is also multiplied, which you can check by looking at the script.

```
return [ B04 * 2.5, B03 * 2.5, B02 * 2.5 ]
```

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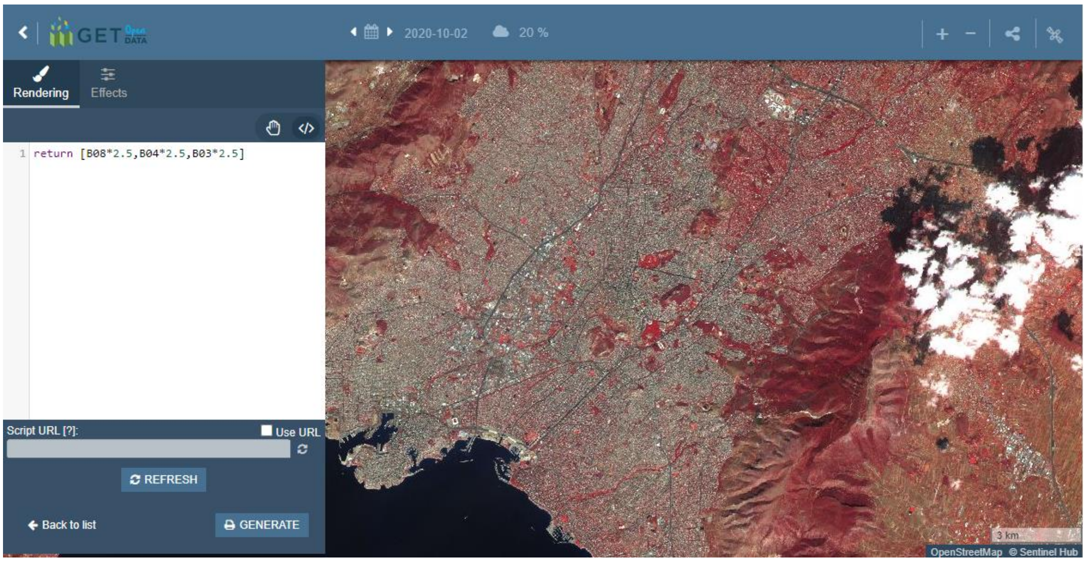
Let's create two simple false color composites, where vegetation appears either red or green. The common false color composite inputs the band 8, which displays vegetation, into the red (first) channel and bands 4 and 3, which have high values for non-vegetated areas, into the other two channels. The result is shown below. Vegetation is displayed in red, color darkness indicating depth of vegetation; deep red for forests and light red for grasslands. In white, brown and sandy colors we see non-vegetated areas, such as rock, bare soil or snow.

```
return [B08 * 2.5, B04 * 2.5, B03 * 2.5] // Vegetation in red
```



To instead show vegetation in green, we should input band 8 into the green (second) channel.

However, the result (first image) is not as clear as before, since non-vegetated areas appear bright green. We should tweak the values to show bare ground more clearly.

We can choose to multiply each channel differently, to manipulate the brightness of each color. We will multiply bands 3 and 4, to make them brighter. Bare ground areas now appear bluish-purple, since we input higher values to red and blue channels, and the image is clearer (second).

```
return [B03 * 2.5, B08 * 2.5, B04* 2.5] // Vegetation in green

return [B03 * 3.5, B08 * 2.5, B04* 4.5] // Vegetation in green, tweaked values
```

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3. Creating a remote sensing index

We will use map algebra to calculate the NDVI index based on two bands. First, we assign our calculation to the variable, using **let**, which literally means, *let something be…* The variable we are assigning our index to can have any name we want, but can only be a single word (excluding numbers, spaces and signs). Here, we name it **value**. Then we set it equal to (=) and write our calculation.

Next, we simply call our variable **value** inside a **return** array. This way we get a grayscale result.

*Note that in Javascript the equal sign (=) implies, that we are assigning a value. It does not imply that the two are identical. If we want to check if **val** is identical to, let say 2, we would use double equal sign (==).*

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The simple example of a band combination would be to add two bands:

```
let value = B11 + B02;

return [value]
```

We can input any calculation we like. For example, we will calculate the NDVI index, which shows vegetation health:

NDVI = (NIR−RED)/(NIR+RED)

NIR stands for "near infrared" and for Sentinel-2 it corresponds to band 8, which shows vegetation best and "RED" corresponds to band 4.

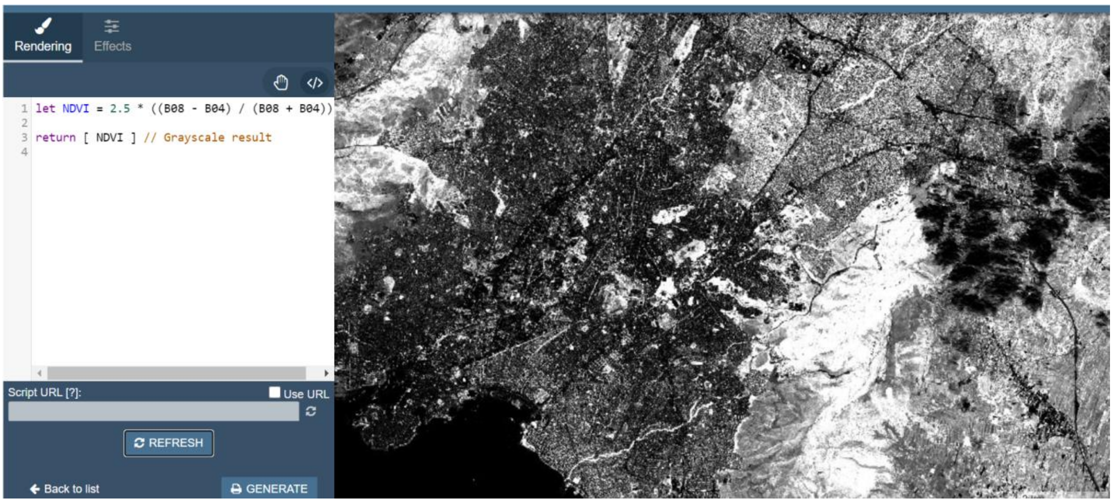
An NDVI index would thus look like this:

NDVI = (B08−B04)/(B08+B04)

We can simply input the calculation into our script (we multiply it by 2.5 to increase the brightness) as follows:

```
let NDVI = 2.5 * ((B08 - B04) / (B08 + B04));

return [ NDVI ] // Grayscale result
```



We can visualize most indices this way. Check out **the following webpages** for a list of indices, you could use.

[Sentinel-2]

[Landsat 8]

[MODIS]

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For now, we returned the result in grayscale. When we calculate an index, we have to consider how to best visualize it.

We need to use a color scale, which will help us correctly interpret NDVI (or any other data). It will help us distinguish between low and high values, understand how the values of NDVI change spatially and through time, and emphasize values of special importance. For this, we need to learn new methods for displaying color.

4. Custom color scales

The easiest way to create custom color classes is by using if **statements**.

In Javascript, we can use an if statement to specify the conditions for something to happen. In our case, we want to decide which value ranges will get which colors. This way we create discrete classes, each of its own color. For example, if we know that certain values represent forest and others urban areas, we can create classes, to display each of them in a separate color.

An if statement has the following structure:

```
If (this is true) {
that should happen
}
```

In the brackets after an if, we specify the condition. Then we wrap our command into **curly brackets**.

For example:

```
if ( NDVI < 0.2 ) {
return [ 0, 1, 0 ]
}
```

The range of RGB color values here is 0 – 1, where the [0, 0, 0] array represents black color and the [1, 1, 1] array represents white color.

The above if statement will use green color ([0, 1, 0]) to visualize pixels with NDVI values less than 0.2.

Instead of smaller (<), we can use any other **JavaScript logical operator**.

We can specify multiple if conditions. If we want to specify a command in case if is not true, for example for all the values that do not equal 0.2, we could follow the if statement with an else statement. It is important, that the classes do not overlap.

```
if (NDVI < 0.2) {
return [0.3, 0.3, 0.3]
}
```

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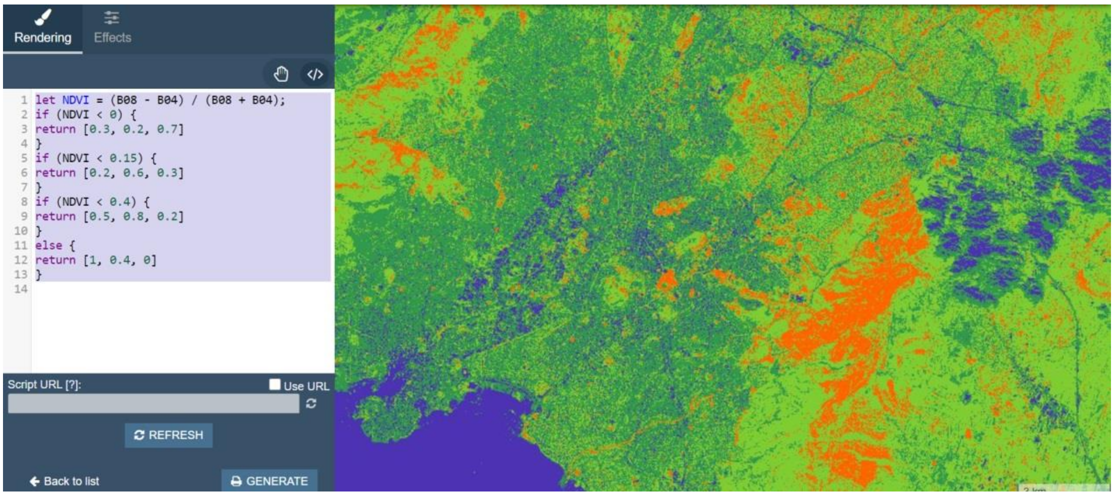
```
else {
return [0.9, 0.2, 0.2]
}
```

For example, here is an NDVI visualization, using if statements:

```
let NDVI = (B08 - B04) / (B08 + B04);
if (NDVI < 0) {
return [0.3, 0.2, 0.7]
}
if (NDVI < 0.15) {
return [0.2, 0.6, 0.3]
}
if (NDVI < 0.4) {
return [0.5, 0.8, 0.2]
}
else {
return [1, 0.4, 0]
}
```



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