EPFL

Exercise 3 - Visible/InfraRed Earth Observations

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1 Earth Observations using low-orbit (LEO) satellites

In this exercise, you will be working with data from the Landsat Satellite Mission. The Landsat Mission launched the first civilian Earth-observing satellite in 1972. Since then, nine satellites have been sent to orbit. The acquisition of millions of images has allowed changes to the Earth's surface to be monitored over the past 50 years.

Landsat satellites follow a sun-synchronized near polar-orbit, which enables them to pass over any given point of the planet's surface at the same local mean solar time. Each satellite makes a complete orbit every 99 minutes, completes about 14 full orbits each day, and crosses every point on Earth once every 16 days.

The passive multi-spectral imaging sensors carried by these satellites measure the reflectance and emission from the Earth in specific wavelengths ranges. The data used for the Glacier Monitoring exercise (see Section 3) stems from Landsat 5 and Landsat 8.

1. Describe the sensors onboard Landsat 5 and explain the interest in having detectors observing in different spectral bands. Explain the purpose of observing the radiances within the 8-14 μm infrared range.

2 Normalized Difference Indices

A Normalized Difference Index (NDI) combines the information at two spectral bands to derive an univariate index enabling the discrimination of different physical surface properties. Three commons NDIs are the Normalized Difference Water Index (NDWI), the Normalized Difference Vegetation Index (NDVI), and the Normalized Difference Snow Index (NDSI). Additional information can be found here and here.

2. Describe the interpretation, shortcomings and possible applications of three NDIs of your choice. Feel free to search additional information outside of the provided resources.

To familiarize yourself with these indices, you can visualize them on this online platform (Fig. 1). The link provides a true colour satellite image of the Marmolada Glacier in late summer 2017. Under *Layers, Custom, Index*, you can create your own NDI. Drag and drop the band numbers into the index formula and see how the image changes. Press on *Back* to find some of the pre-programmed options, such as the NDVI. Try to recreate the indices you described in Question 2 and also evaluate how the indices designed behave on other dates.

Note that the data on the online platform are from Sentinel-2. Sentinel-2 is a satellite managed by the European Space Agency (ESA) which can be seen as a European "counterpart" of the American satellite program Landsat. More information on the Sentinel-2 mission can be found here.

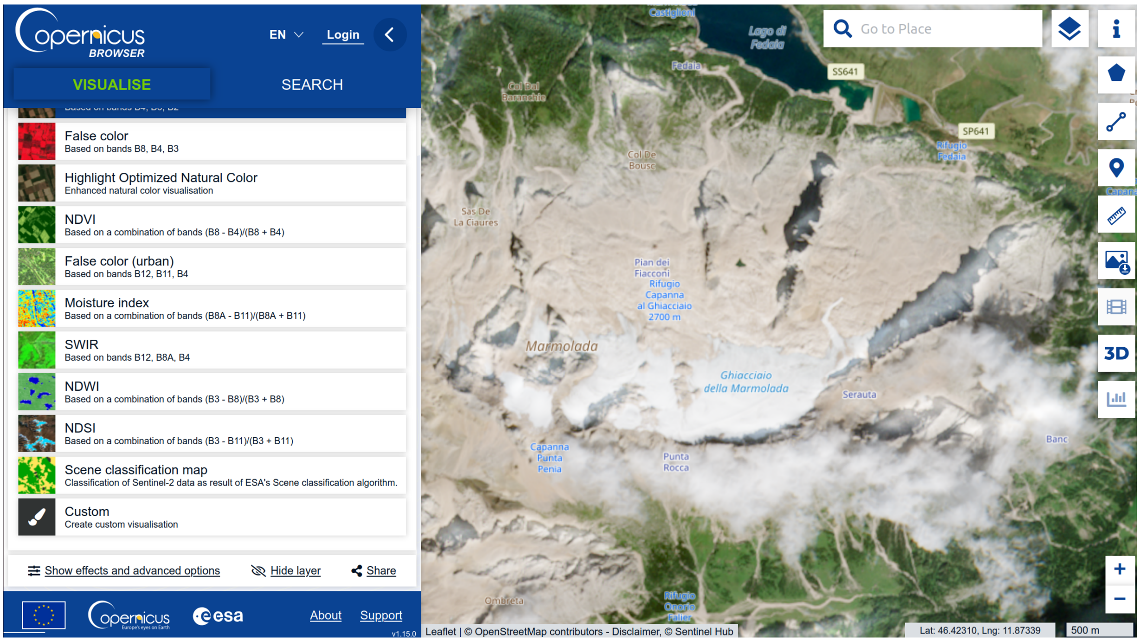

Figure 1: Copernicus Browser for interactive NDIs visualization.

3. Based on the information in the sources above, propose (without implementing it yet) an approach to estimate the surface area covered by snow and ice. Please detail which NDI(s) you would use, and explain why using a single spectral band is not a recommended solution.

3 Glacier Monitoring

In this part of the exercise, we aim to estimate the temporal evolution of the Marmolada Glacier in the Dolomites region of the Alps in Italy. In order to start the exercise, download all data on Moodle and import the *True Color* images available for the years 1994 and 2005 taken by Landsat 5 into QGIS, and the one in 2018 by Landsat 8.

To facilitate the estimation of the glacier area in this exercise, start by delineating the area of interest (AOI) around the glacier, as shown in figure 2. Your area does not need to be exactly the one of this figure, but you should make sure that it comprises all the glaciated areas observed in late summer 1994.

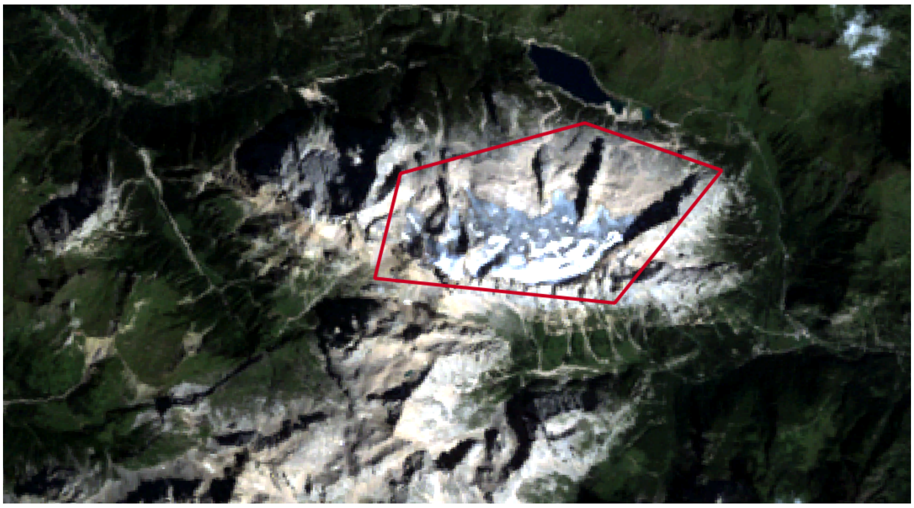

Figure 2: The area of interest around the Marmolada Glacier (over Landsat 5 data from 15th Aug. 1994), enclosed by the red polygon.

To define the AOI proceed as follow:

- In the QGIS menubar, select *Layer*, navigate through *Create Layer* and click on *New shapefile layer*.
- Put the layer name (i.e. *AOI_polygon*) in the file name field and select the geometry type *Polygon*.
- Click *OK* to initialize the layer. The layer now will appear in your layers panel.
- Click on the layer to select it and press the *Toggle editing* button in the toolbar. This unlocks the *Add polygon feature* button on the top.
- Select it and shape your area by right-clicking in every corner of your desired area.
- To finalize the polygon, click the mouse left button and press *OK* on the dialogue that appears[1].
- Click again on the *Toggle editing* button and save the changes to the layer.

[1]Depending on your QGIS version or operating system, you might have to double click instead of left clicking.

- Now go into the *Attribute Table* of the *AOI_polygon* and compute its total area using the *$area* in the *Field calculator - Geometry*.,

4. Look at the variability of glacier extent with the True Color images between 1994 and 2018 and describe what you observe. What can you say about the timescales of the changes you observe? Let's say we aim to investigate the glacier dynamics. What would be a relevant revisit-time for such scientific application? Would the Landsat mission meet such a requirement?

Now, we will try to estimate the glacier area evolution more quantitatively.

An interesting feature of the NDIs is that they offer the possibility to discriminate features when specifying appropriate thresholds. Since we aim to identify the glacier area, we will employ the NDI that, based on your previous answer to Question 3, facilitates the identification of surfaces covered with snow and ice.

Start by importing all bands from the Landsat acquisitions taken in 1994, 2005 and 2018 into QGIS. We then suggest performing the following processing steps for one Landsat acquisition, and then repeating the tasks for the other two:

- Compute the NDI that facilitates snow/ice identification. To compute the index, use the *Raster Calculator*, which you can find under the *Raster* menubar. The *Raster Calculator* enables you to compute new raster layers by performing mathematical and logical operations on existing raster layers.
- Adjust the limits of the colormap to the expected range of values of the NDI.
- Using the *Identify Features* option of QGIS and/or playing with the transparency of a layer (available in the *Transparency* tab of the *Layer Properties*) try to identify the range of NDI values corresponding to snow/ice areas.
- Once you have identified plausible lower and/or upper threshold values, you can use the *Raster Calculator* in combination with logical operators, to obtain a binary raster layer that classifies the surfaces covered by snow/ice.

Begin by identifying the thresholds for one Landsat acquisition, and then refine your thresholds by analyzing the other images to ensure you are effectively isolating the glacier snow/ice signatures.

When you have identified the appropriate NDI thresholds and computed the snow/ice binary layers for the three Landsat acquisitions, we recommend clipping all binary layers using the *AOI_polygon* defined above:

- Click on *Raster* in the menubar, navigate to *Extraction* and select *Clip Raster by Mask Layer*.
- Select one of the binary layers as the *Raster Layer* and your *AOI_polygon* as the *Mask Polygon*.

- Select a destination file to save your output clipped binary layer and press *Run*.

Now, you can start estimating the total glacier area following either a raster-based or a vector-based approach.

- The raster-based approach consists in using the *Zonal histogram* tool. The *Zonal histogram* can be found by searching for its name in the *Processing Toolbox*, which should be attached to the right-hand side of your QGIS workspace. This tool can be used to count the pixel values occurrence of a Raster layer. If applied to the snow/ice binary layer, it allows the number of pixels assumed to be snow or ice to be counted. We suggest applying the *Zonal histogram* to the binary layers clipped by the *AOI_polygon* (see above), so that you can infer the fraction of snow/ice pixels within the *AOI_polygon*. At this point, based on the area of the *AOI_polygon*, you are able to calculate an estimate of the glacier area.
- Alternatively, to estimate the glacier area using a vector-based approach, you should start by vectorizing your binary layers using the *Polygonize (Raster to Vector)* tool that you can find under *Raster* → *Conversion* in the menu bar. Using your binary layers as input, *Polygonize (Raster to Vector)* will create polygons for every isolated zone of your input raster layer and will associate to them the corresponding raster value. Successively, you can then filter your polygons in the *Attribute Table* and delete those not associated to snow/ice areas. Finally, using the *Field calculator* > *Geometry* in the *Attribute Table*, you can compute the area of each of the remaining polygons. By summing up the area of the polygons identifying snow/ice surfaces, you can retrieve the total glacier area.

Remember to clip the binary layers with the AOI polygon before performing the area computations in order to speed up the computations!

Please keep in mind that the Landsat-5 and Landsat-8 band numbers do not correspond to the same sensor spectral bands! Therefore pay attention to which band number you choose when computing the NDI !!!

5. Using the NDI detailed in Question 3, derive an estimate of the glacier area in late summer 1994, 2005 and 2018.

4 Cloud vs Snow Discrimination

The data provided for the first part of the exercise and used for glacier monitoring have been mostly selected over cloud-free days (at least over the region used for the analysis). When clouds are present in the atmosphere, the visual distinction between clouds and snow/ice is much harder - especially in the visible part of the electromagnetic spectrum where both features share similar reflective properties. However, distinguishing snow and clouds is important for monitoring snow area over time. Hence, image analysis techniques enabling such a distinction are needed.

While NDIs provide a first possible solution to separate clouds from snow, false color image composites are also an interesting solution to help in this task. False color images are defined by assigning a specific band (or NDI) to each of the 3 (RGB) image channels. By preserving the information from each band in the different color channels, specific band combinations help visualize and isolate specific patterns or objects. In this part of the exercise, we will use both NDIs and false color image composites to visually discriminate clouds and snow.

We will be focusing on a region covering a large portion of the Swiss Alps, the Jura mountains and the Swiss Plateau. The images were taken by Sentinel-2 on the 19th January 2023-19 and 8th February 2023.

To start the exercise, download and unzip the *SnowCloud_Discrimination.zip* folder. Then import all the provided Sentinel-2 data into QGIS and use the *Raster Calculator* tool available from the *Processing toolbox* to compute, for both Sentinel-2 acquisitions, the following three NDIs layers: NDWI, NDSI and NDVI.

Please keep in mind that the Landsat and Sentinel-2 band numbers do not correspond to the same sensor spectral wavelengths! Therefore pay attention to which band number you choose when computing the indices!

6. Using the visual information you can get from the different images, which one among the NDVI, NDWI and NDSI seems to be the most appropriate index to visually identify clouds? Considering the bands used to compute this indicator and the spectral properties of snow and clouds, why is this index more appropriate than the other two to separate snow from clouds?

7. With the NDI you chose in the previous question, what is the approximate range of values (lower and upper bounds) of clouds? What limitation(s) do you see with this segmentation approach for cloud vs snow discrimination?

Relying on only 2 bands is often too limiting for a satisfying separation of different features present in an image. The use of some more advanced image processing algorithms can help for a more precise segmentation of an image, but this will be the subject of a later lab. On the other hand, false color image composites – combining the information from three different bands (or NDIs) – can bring additional information and help in the discrimination of multiple image features. In this section, we will create a virtual raster of a false color image composite where the R-G-B channels of the color layer each correspond to a specific sensor spectral band.

To start, remove all layers from the Layers panel and re-import the NDSI layer you created above. Then load in the layer panel only the bands #2 (Blue band), #11 (SWIR 1 band) and #12 (SWIR 2 band) of the two Sentinel-2 acquisitions. To create a false color image composite, we will use the Build Virtual Raster function from QGIS.

To do so, open the *Raster* menu then select *Miscellaneous* and then click on *Build Virtual Raster*. Select the bands #2, #11 and #12 of a specific Sentinel-2 acquisition in the *Input layers* field and tick the option *Place each input file into a separate band*. Mind that the order in which the layers are added is important. The following should be applied to the RGB composite: R = band #2, G = band #11, B = band #12.

Figure 3 illustrates how one of the two images should look like.

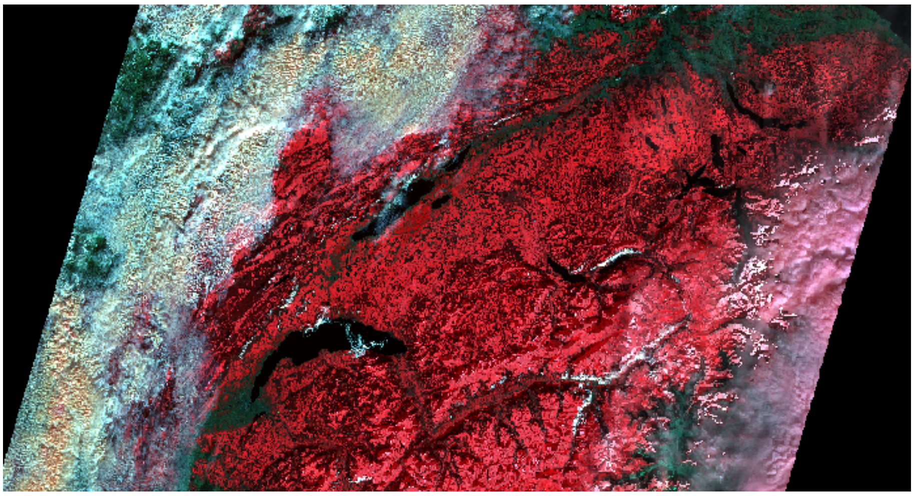

Figure 3: Image composite combining Sentinel-2 spectral bands #2, #11 and #12.

8. How do the composite images visually improve the snow/cloud discrimination in comparison to the NDSI images? Describe the main surface and meteorological features as well as the differences you observe between the two Sentinel-2 acquisitions.

9. Based on the spectral properties of the snow, clouds and water bodies, explain their visual signatures in the false color image composites.