Atlas of our Changing Environment - Potential for Update and Upgrade

Comparitive analysis of potential candidates: SEPAL and DCoD

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1. Summary

With the use of satellite imagery, remote sensing has been able to visually show in an impactful way the changes that have occurred over the last several decades on our precious and unique Planet Earth. The Atlas of Our Changing Environment illustrates some of the changes that humans have made to the environment in the last decades of the 20th century in all ecosystems, such as in coastal areas, forests and grasslands, and also in urban settings. Since 2005, the year of publication of the first Atlas, changes have continued to occur. The purpose of my internship at UNEP-GRID was to use two technologies able to analyse Earth observations, SEPAL and the Data Cube on Demand (DCoD), and see their potentialities to update and upgrade the Atlas. Although both technologies generate RGB mosaics from satellite imagery the experience when using them are very different from each other. By using SEPAL and DCoD in two same locations in Switzerland I was able to appreciate the positives and negatives of both platforms to be able to suggest my opinion on the way forward for the Atlas project. With the aim of exploring a first possibility of such updates, this work was carried out with the help of the geographic information system software QGIS.

2. Introduction

Over the centuries human beings have been very successful in exploiting the Earth's resources and have become the most dominant species on Planet Earth, conquering all corners of the globe. In just a few generations the world population has exponentially grown, and the standard of living has risen. All this has not gone unnoticed, as with each new person added to our growing population, the amount of our living space decreases (Atlas, 2005). Our activities have brought about climate change and other environmental problems such as air pollution, degraded waters, and damaged ecosystems. Humans are particularly adept at modifying their environments, and began transforming their environment a long time ago, by altering grasslands and cutting down forests for tools, fire, and settlements and eventually agriculture (Atlas, 2005). But the scale at which our activities have altered the surrounding environment have increased since the industrial revolution and with the use of satellites we have been able to see and detect the changes done on the landscape over the last decades. Our impacts are visible from space (Atlas, 2005).

The Atlas of our Changing Environment was first released to illustrate visually the changes we have made to the environment that have occurred over the years in different sites around the world (Atlas, 2005). The first Atlas covered the whole world, and several Atlases area-specific followed (for continents and large areas such as for Africa, Latin America and the Caribbean, and for individual countries like for Kenya, Uganda, Rwanda). Issued in 2005, the first Atlas illustrated the changes occurred over the 30 years prior the publication date. The Atlas was first of its kind and it was intended to serve as an early warning for things to come and as a basis for developing policy decisions that could help sustain the well-being of Earth as well as our own (Atlas, 2005), as to continue to prosper as a species we need and depend on a healthy planet.

As almost 20 years have gone by since its original publication, there is an idea to update the Atlas of our Changing Environment. The purpose of this internship at UNEP-GRID is to evaluate two possible platforms that can be used to access and analyse satellite imagery in order to update and potentially upgrade the Atlas: the first platform being SEPAL and the second one being the Data Cube on Demand (DCoD). Both technologies generate RGB mosaics, and with the help of the geographic information system software QGIS their outputs can be compared. As SEPAL and DCoD are very different form one another, the way you get the RGB mosaics and the overall experience using the platforms varies greatly.

The DCoD is one example of an Open Data Cube (ODC) where Analysis Ready Data (ARD) are generated from Earth observation satellite images. The Swiss data Cube, and other ODC such as the Australian Data Cube and the African Regional Data Cube, have three or more dimensions that include space, time and spectral derived properties, and are usually used for image time series analysis (Giuliani, Chatenoux, De Bono, *et al.*, 2017; Gomes, Queiroz, & Ferreira, 2020). SEPAL (the System for Earth observation, data access, Processing, Analysis for Land monitoring) is a free and open source cloud computing platform for geo-spatial data access and processing (FAO, 2020). Data can be created and analysed for any place on Earth using SEPAL. Whereas for DCoD, as it is part of the Swiss Data Cube, only sites in Switzerland can be retrieved. By using these technologies in two identical locations in Switzerland it was possible to compare the platforms and evaluate the positive and negative aspects of them, in order to revive the Atlas project and continue portraying the nature and extent of our impact on the planet.

3. Theoretical Concepts

Most changes on Earth can be observed through remotely sensed Earth Observations (EO) (Atlas, 2005; Giuliani, Chatenoux, De Bono, *et al.*, 2017). Remote sensing is the collection of information about an object without being in physical contact with the object (Atlas, 2005). Aircraft photography and satellite imagery are the most common platforms from which remote sensing observations are made (Atlas, 2005). Satellite imagery is especially useful for studying the changes on Earth, as satellites have stable orbits that record with the same resolution and the same data characteristics at periodical time intervals. Because of this, satellite imagery is ideally suited to detect changes on large scales, regarding agriculture and forests monitoring, resource extraction, as well as urban expansion and polar ice extension. In fact, satellite images reveal in startling detail the sign of human impact on the landscape, from disturbing unnatural patterns of deforestation etched into a once-undisturbed forest to the anthropocentric symmetry of patterns of agriculture fields and concrete arrangements of urban sprawl (Atlas, 2005).

Figure 1: Example from UNEP's Atlas of Our Changing Environment, illustrating the oil sands of Fort McMurray, in Alberta, Calgary (Atlas, 2005).

Figure 2: Example of land use change visible from space from the Atlas of Our Changing Environment. The unnatural "fishbone" pattern of logging is clearly noticeable (Atlas, 2005).

The application of remote sensing sensors and methods relies on the existence of electromagnetic (EM) radiation, which travels in waves and spans a broad spectrum from very long radio waves to very short gamma rays (Canada Centre for Remote Sensing, 2019).

Satellite imagery is collected using multispectral sensors, which collect data covering different parts of the light (electromagnetic) spectrum, including the visible light and also ranges not visible to the human eye, such as the infrared and ultraviolet light (Atlas, 2005). By analysing the electromagnetic radiation (reflected or emitted energy) coming from an object we can use remote sensing instruments to characterize land areas (Canada Centre for Remote Sensing, 2019).

The range of wavelengths measured by a sensor is known as a band, and we can combine three image bands into one picture by displaying each band as either Red, Green or Blue (RGB). To produce a picture displaying the Earth in colours similar to what our own eyes might see, it is necessary to create a Natural or True Colour composite. To create a Natural or True Colour composite it is necessary to display the combination of visible red, green and blue bands to the corresponding red, green, and blue channels (Canada Centre for Remote Sensing, 2019).

The Atlas of Our Changing Environment uses extensively satellite imagery, together with and aerial and ground photography, to show the changes that have occurred over the years (Atlas, 2005). By comparing recent satellite images of the Earth's surface with those taken one or several decades ago, the impact people have had on the planet is striking and often shocking (Atlas, 2005). Many texts and articles have been written explaining the consequences humans are having on the environment, but the first Atlas Our Changing Environment was unique as it used remote sensing techniques to provide an exceptional view of how people have been impacting the terrestrial environment (Atlas, 2005). As the expression says well, "a picture is worth a thousand words", and illustrates impactfully and immediately the changes occurred from on year to another. Remotely sensed Earth Observations, thus, enable decision makers around the world to better understand the issues they face, in order to shape more effectively policies (GEO, 2020).

The Atlas of Our Changing Environment compared images of the 70s and 80s to images dating in the yearly 2000s. The pairs of satellite images illustrated both negative and positive changes, but the negative examples greatly outweighed the positive ones (Atlas, 2005). The first Atlas used satellite images from the Landsat program, the longest continuous space-based record of Earth's surface provided jointly by NASA and USGS. With the archives from Landsat satellite sensors, the evolution of land use change can be monitored all the way back to 1972 with images every 15 days at 30 m spatial resolution. Now both the spatial and temporal resolutions have increased with the introduction of new satellite sensors such as Sentinel-2 from the Copernicus Space Programme (the European Union's Earth Observation programme) (Giuliani, Chatenoux, De Bono, *et al.*, 2017). In order to see the changes occurred since 2005, the year of publication of the first Atlas of Our Changing Environment, it is necessary to update the images for all the worldwide UNEP case studies and see how things have evolved with time over the last two decades.

Remotely sensed Earth Observation satellites have generated big amounts of geospatial data and has been increasingly available from a number of freely and openly accessible repositories for society and researchers (Giuliani, Chatenoux, De Bono, *et al.*, 2017; Gomes, Queiroz, & Ferreira, 2020). There are several platforms for big Earth observation data management and analysis, such as Google Earth Engine (GEE), Sentinel Hub, Open Data Cube (ODC), System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL), openEO, JEODPP, and pipsCloud (Gomes, Queiroz, & Ferreira, 2020). In the interest of my internship at UNEP-GRID, I used SEPAL and the Data Cube on Demand (DCoD), which is part of the Swiss Data Cube. With SEPAL and the DCoD you can access both Landsat and Sentinel satellite imagery and you can get RGB True colour mosaics (or composite), and get pictures resembling what would be observed naturally by the human eye and see how land use has changed over the last decades.

4. Data and Methodology

4.1 Data and location

The data used was retrieved using two different platforms able to analyse Earth observations: **SEPAL** and the Data Cube on Demand (**DCoD**). With both technologies you are able to access Landsat and Sentinel satellite imagery and retrieve RGB true colour mosaics, and with the help of QGIS the outputs can be compared. As with the DCoD you can access imagery only in Switzerland, in order to compare the two technologies, it was necessary to select areas in Switzerland. For a better evaluation of the potentials of SEPAL and the DCoD two different locations in distinctive geographical areas were chosen, one in an urban setting and the other in a mountainous area. The first location selected was in the proximities of the city of Basel and surrounding area (**Basel location**). Basel is one of the major cities in Switzerland, third in terms of population numbers, and it has continued to expand over the last decades. Basel's lowest elevation is the lowermost point North of the Alps in Switzerland. In contrast, the second location chosen was at higher elevations in an Alpine area in the northernmost part of the canton of Valais depicting the Rhone Glacier and nearby valleys (**Rhone Glacier area**). As the glacier is located close to the Furka Pass road it is easily accessible and the retreating glacier has been well documented through historical pictures as well as paintings dating back as far as the end of the 19th century. The time period chosen was a four months period, starting on the 1st of July and ending the 31st of October. Data was retrieved every 5 years for both SEPAL and the DCoD, starting in 1985 and ending in 2020. Data was collected using all scenes in the four months period as well as for selected scenes to try to optimize the images.

4.2 Data Cube on Demand (DCoD)

The DCoD is part of the Swiss Data Cube (SDC), which is powered by CEOS (Committee on Earth Observation Satellites) and GRID-Geneva and is a new collaborative approach for storing, organising and analysing the vast quantities of satellite imagery, and other Earth Observations, making it quicker and easier to provide information on issues that can affect Switzerland (Swiss Data Cube, 2016). The SDC is built on the Open Data Cube (ODC) software suite which is an open source project initiated by Geoscience Australia, the Commonwealth Scientific and Industrial Research Organization (CSIRO), the USGS, NASA and CEOS (Chatenoux, Richard, Small, *et al.*, 2021). The SDC uses the power of the Open Data Cube (ODC) to help address the needs satellite data users have, giving them new insights of their land resources and land change, providing access to large spatio-temporal data in an analysis ready form (Swiss Data Cube, 2016). The SDC, and thus the DCoD, contain the complete Landsat 5, 7, 8 and Sentinel 2 collection in an Analysis Ready Data form for the entire territory of Switzerland since 1984 (Swiss Data Cube, 2016; Chatenoux, Richard, Small, *et al.*, 2021). New data is automatically updated daily as new scenes become available. The products of interest of the SDC are urbanization, cloud free mosaics, and snow cover (Open Data Cube, 2021). Within the DCoD, which uses a chain of orchestrated scripts to enable the automatic generation of a data cube, it is simply necessary to provide the Area of Interest (AOI), the time frame and the desired satellites to retrieve the scenes and run the scripts (Giuliani, Chatenoux, Piller, *et al.*, 2019).

In order to get products from the DCoD it is necessary to have access to a Jupyter Notebook and thanks to the help of Mr. Bruno Chatenoux scripts were made enabling me to retrieve satellite imagery of both the Landsat and Sentinel programs. Jupyter Notebook is used as a processing interface to interactively interact with the created Data Cube and the data is analysed using Python programming language (Giuliani, Chatenoux, Piller, *et al.*, 2019). Within the DCoD a folder was created to retrieve optical mosaics, and the chain of orchestrated scripts had four main sections. Before going through the sections each generating distinctive tiff files, it is necessary to provide a spatial extent of the Area of Interest (AOI), give the temporal extent, and select the satellites between Landsat 5, 7, 8 and Sentinel-2. The first part of the script enabled me to access all of the scenes of the selected time period and the mosaic generated was an image composed of the full extent of the scenes, called the ***All Scenes* image**. The second part gives an Optimized mosaic, using the fewest number of scenes to reach a threshold of completeness. The **threshold of completeness** enables you to have the best images with the highest quality and it takes all the images necessary to reach the set limit of threshold completeness. Usually the completeness threshold was set at 0.9999, meaning that the image generated uses all the scenes necessary to reach a 0.9999 quality of image (or 99.99% completeness). The ***Optimized image***, thus, was composed of the scenes with the highest quality (i.e. the least amount of cloud cover), starting from the highest quality image, and using all the scenes necessary to reach the set threshold completeness. The third part of the script gives a ***Centred optimized mosaic***, using first the scenes in the middle of the time period selected and uses the fewest number of scenes to reach a set threshold of completeness (even for this part the threshold was set at 0.9999 completeness). The output gives an image using scenes with a similar time period as it uses the least number of scenes close to each other in the middle of the time period. The fourth and final part of the script generates a mosaic with scenes manually selected, called the ***Indexes image***, as you manually select the indexes. In this section you can visually see all the scenes and just choose the best and most complete ones and see how many are needed to reach the threshold of completeness.

Theoretically, in the years that there are several scenes with clouds, and you don't reach the 0.9999 threshold completeness, you can lower the threshold for the optimized as well as centred image. There can be some situations where you don't have enough high-quality scenes for a given year or place, and so even by lowering the threshold the optimized image is very similar if not identical to the full-scene image as the threshold isn't reached. As the order of the scenes selected is important, the centred image is always different compared to the full and optimized images, even when all the scenes are selected. For the indexes image, as you are manually choosing the scenes, the image can be similar to the optimized image as you take the highest quality scenes. The only exception is in the years where the threshold completeness is not reached (so both full and optimized image are similar or identical depending on where you set the lowered threshold). In this case, to ensure that the indexes image is not identical to both the full and optimized images, only a few scenes are selected.

4.3 SEPAL

The System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL) is a free, open-source cloud-based computing software for geo-spatial data access and processing designed by the Open Foris team in Forestry Department of the United Nation's Food and Agricultural Organization (FAO), funded by the government of Norway (Dyson & Tenneson, 2021; FAO, 2020; Gomes, Queiroz, & Ferreira, 2020). The system provides a platform for users to access satellite imagery (Landsat and Sentinel-2 programs) and quickly process large amounts of data to perform change detection and land cover classifications using a set of easy-to-use tools. SEPAL was designed to be used in developing countries where internet access is limited and computers are often outdated and, thus, inefficient for processing satellite imagery (Dyson & Tenneson, 2021). It achieves this by drawing on a cloud-based supercomputer, which enables users to process, store, and interpret large amounts of data on their own computers or mobile devices. Data can be created and analyzed for any place on Earth using SEPAL (FAO, 2020).

SEPAL combines cloud services, such as Google Earth Engine, Amazon Web Services Cloud (AWS), with free software, such as Orfeo Toolbox, GDAL, RStudio, R Shiny Server, SNAP Toolkit and OpenForis Geospatial. It thus works as an interface that facilitates access and integration of other services complimenting the functionalities of SEPAL (Gomes, Queiroz, & Ferreira, 2020). This being said, SEPAL can be used without these complimentary tools and it provides the user access to complex workflows without requiring knowledge of digital programming and is composed of nice user interfaces to ensure the best possible user experience (Dyson & Tenneson, 2021). The SEPAL platform can be accessed through a web portal (https://sepal.io) and you can request an account which will take up to a day or so to get confirmation (Dyson & Tenneson, 2021) (it took me less than an hour). It is possible, and recommended, to connect your SEPAL account to a Google account, and in order to do so you need a Google Earth Engine (GEE) account. If the GEE and SEPAL accounts are connected, SEPAL uses the Google Drive as a temporary storage space for data downloaded (Dyson & Tenneson, 2021). It is recommended to connect to a GEE account even because SEPAL is not intended to be used for long-term data storage. Once a product has been processed and produced, the data should be downloaded to a personal computer, or drive, and deleted from SEPAL (Dyson & Tenneson, 2021).

In the SEPAL web portal, the functionalities are divided into 4 areas – *Process*, *Files*, *Terminal*, and *Apps* and you manually select the desired object by pressing the designated button (Gomes, Queiroz, & Ferreira, 2020). In *Process*, I only selected the *optical mosaic* function to create a mosaic using Landsat or Sentinel 2. It is then necessary to select the Area of Interest (AOI), a year or a specific time period, and then the source of the scenes (Landsat 4-5, 7, 8, 9, and Sentinel 2). After it is possible to use all of the scenes of the time period or select the scenes by prioritizing cloud free scenes or scenes closer to the target date (or balance both target date and cloud free scenes). If you choose to select the scenes you then have to manually select the scenes or use the auto-select scenes function which chooses the scenes for you. If you manually select the scenes you can visually see each scenes by clicking the preview button and you can see each of the scene’s cloud cover as well as how close the scenes are to the target date (which usually is in the middle of the year or in this project case in the middle of the four months period unless you define it either wise). On SEPAL, I thus generated an image using all of the scenes possible within the time period chosen (***All Scenes image***), and also a mosaic called ***Scene Selection***, which I manually chose using the images with the highest quality (i.e. least amount of cloud cover), and used the fewest amount of scenes to have a good quality image.

On SEPAL, when you manually select the scenes and you have the scenes desired, you can then use the *default composing method* or decide to change it, by changing one or multiple of the options proposed: shadow tolerance, haze tolerance, NDVI importance, type of correction, cloud masking and cloud buffering, snow masking and composing method. Finally, the mosaic recipe desired can be saved and also retrieved if desired. Each user has a certain amount of budget per month: $US 1.00 instance spending and storage spending and 20.0 GB storage space. Each time you retrieve an image the instance spending usually increases by 2% and you can decide to retrieve it in the personal SEPAL workspace or the Google Drive of the GEE (if connected to the personal GEE account). When retrieving the mosaic in SEPAL it goes in the *Files* folder where you can download the files created (the TIF and VRT files) to store ton a personal computer or drive. Once you download it is suggested to delete the retrieved mosaics on the *Files* folder, if not the storage spending and storage space increase. At the end of a month, the resources go back to zero, and if you exceed the instance spending within a month and need more you can ask for additional spending in the Sepal Users Google Group

(SEPAL Users Google Groups, 2022). It should be noted that when creating an optical mosaic it gets saved on SEPAL and it does not count towards the monthly user budget, so in case the spending exceeds the limit, and the user is not on a time constraint, the mosaic can be download at the start of a new month when the resources go back to zero.

Playing around with the different composing method, it was noticed that the default option works very well for urban areas. On the other hand, for mountainous areas it is necessary to change the composing method and change a few options. This is because when you are at higher elevations and there is snow present it is hard to tell the difference between snow and clouds. The optimal options depend on if the scenes are from a Landsat or Sentinel satellites. In order to get a high-quality image in an alpine area with a Landsat source it is necessary to set the *Cloud Detection* to **Cloud Score**, *Snow Masking* to **Off,** and *Composing Method* to ***Median***. For a mosaic with a Sentinel-2 source, it is optimal to also have the *Snow Masking* ***Off*** and have a ***Median*** *Composing Method*, but with a ***QA Bands*** *Cloud Detection*. This procedure of optimizing the image is illustrated from the below figures:

Figure 3: showing a map of Switzerland and how by changing the default options you can get a much better-quality image for the SEPAL images in alpine areas. Top left is default option; top right is by just changing the Cloud Score; bottom left by selecting cloud score and Snow Masking Off; and the last one in bottom right is the optimized image by also selecting Median Composing Method

It has to be mentioned that SEPAL stopped working for me for two months. I could continue creating mosaic receipts, but not retrieve and download them. The problem was related to a policy change from GEE side (SEPAL Users Google Groups, 2022). There was a bug for users not using their own Google account, and relied on SEPAL to retrieve imagery to their own workspace (Geographic Information Systems Stack Exchange, 2022; Open Foris Support, 2022; SEPAL Users Google Groups, 2022). This was due to an error in the Google Cloud Storage configuration, and users not connected to their Google account couldn't do anything about it (Geographic Information Systems Stack Exchange, 2022). Researching for help, I found that I was not the only one with this issue. In theory if connected to a personal GEE account then the problem would disappear. The only thing was that I had asked already in January for a GEE account, and I never got a confirmation. I registered my interest for an account several times and did as they suggest on the interest form (putting full name, no abbreviations, and detailed description of what I would want to accomplish with GEE), with no success. Only when creating a new gmail account did I manage to get access a week later (the gmail included "gee", i.e. *"name".gee@gmail.com*, so I guess it seemed more professional). This though happened after SEPAL had fixed the bug, so I was able to retrieve mosaics even without having connected my GEE account. In theory I was also supposed to use GEE to retrieve and analyse satellite imagery, but because of this issue I wasn't able to do so, as I got access to a GEE account only when finishing my internship.

For SEPAL (once the issue was solved by SEPAL), just like for the DCoD, for both the Basel location and the Rhone glacier area data was collected each 5 years starting from 1985 till 2020. Data was retrieved for all the scenes of the time period and also selecting manually the scenes based on the quality of the scenes. On SEPAL, additionally, as the whole world is accessible, mosaics were generated for locations around the globe to see if changes have occurred in some of the UNEP sites of the original Atlas of Our Changing Environment.

5. Presentation and Commentary of Results

5.1 Images used and Presentation of Results

After having downloaded and retrieved the files for both the DCoD and the SEPAL images they could be analysed and compared using QGIS. The images using all of the scenes possible in the four months period could be compared straightforwardly. To be able to better compare the two platforms for the images that were using selected scenes, it was necessary to have the data selected in a similar manner. For the DCoD in the Basel location, as all of the years (except two) reached the threshold completeness, the images used were the optimized ones, as it used the higher quality scenes and it was easier to compare with the SEPAL images, which were also selected based on the completeness of the image (i.e. lower cloud cover). The only exceptions were for 1990 and 2000, where the threshold was slightly lowered, but still high, at 0.9998 and 0.9997 respectively, to have the image different than the image with all the scenes (all the scenes reached 0.99982 completeness in 1990, and 0.99975 in 2000). For the optimized images, often only a few images were automatically selected, ranging from 2 to 6 images to reach the 0.9999 completeness threshold, and were very similar if not identical to the indexes images as I manually selected the higher quality images. The mosaics used for the DCoD in the Rhone area were always the indexes images (manually selecting the higher quality images) to better compare with the SEPAL images. This because the 0.9999 threshold of completeness was never reached, meaning that the optimized and full images were the same. The full images completeness ranged from 0.789 quality (in 1995) and 0.968 (in 2020). The threshold could have been lowered to use the optimized images, but often it was necessary to just select a few scenes to reach a respectable quality image, ranging from 2 to 10 images. The quality completeness was lower in the Rhone area as there were more clouds present in the scenes. In general, it was necessary to select more scenes for the mountainous area compared to the urban location as there is a higher cloud cover in alpine regions. In brief, for better comparison between platforms took the images with all the scenes for both SEPAL and the DCoD in the two locations and optimized images for Basel site and indexes images for the Rhone area as they were more similar to the manually selected scenes on SEPAL.

Table 1: Showing which images where chosen for SEPAL and DCoD for the two locations, to have the most similar images to compare between the platforms

	Basel	Rhone Glacier
DCoD	All Scenes	All Scenes
	Optimized	Indexes images
SEPAL	All Scenes	All Scenes
	Manually Selected Scenes	Manually Selected Scenes

Below the images retrieved from the DCoD and SEPAL and analysed with QGIS can be seen and compared for each year. It has to be noted that the images were quite dark or with saturated vibrant colours. For the SEPAL images I always had to set the correct order for the RGB bands, and I had to copy and paste the *Style* from an image with good colours. It took a while to find images that weren't saturated or too dark by just uploading them on QGIS. Eventually used the 2020 scene selected image for SEPAL and the 2015 index image for DCoD images. By using these good quality images, it was possible to copy and paste the style and get appropriate colours for every image, allowing comparison between mosaics. This was necessary as at what point I thought I was never going to be able to compare the images retrieved and downloaded. Each set of four images for each year can be seen below (DCoD images on top and SEPAL's bottom; images with all scenes on the left, and selected scenes images on right). To visualize the images in a bigger format they can be found in the Annex at the end of this report.

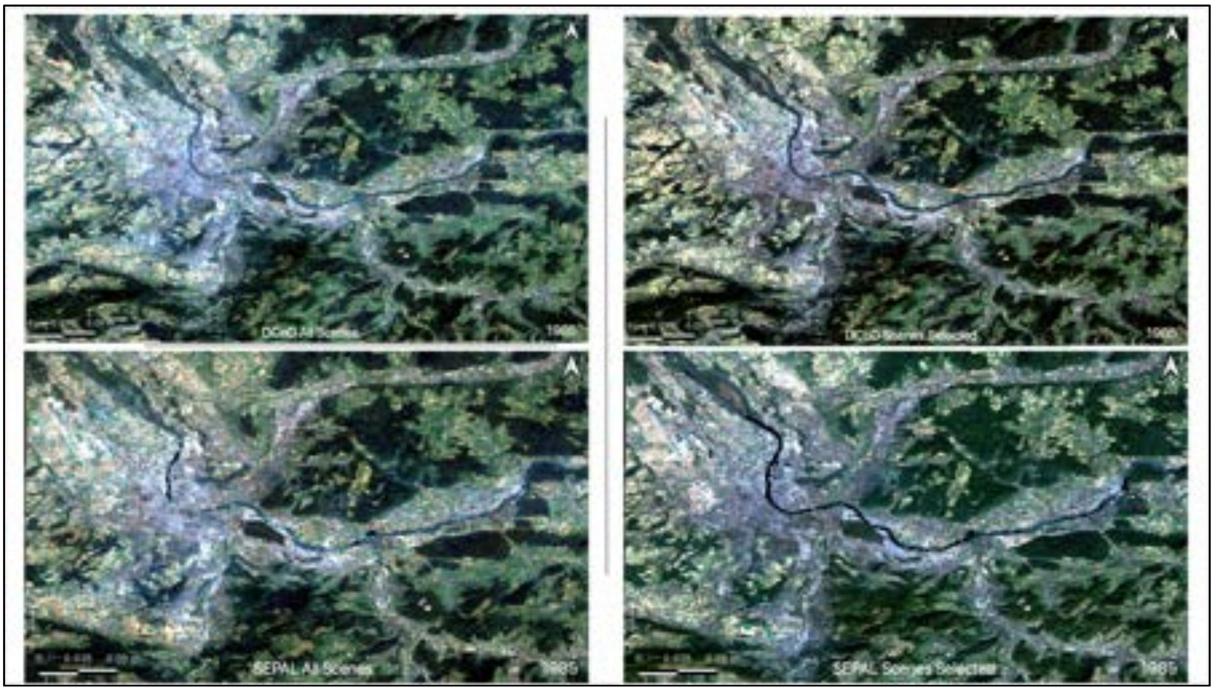

Figure 4: illustrating the four scenes for 1985 for the Basel urban area

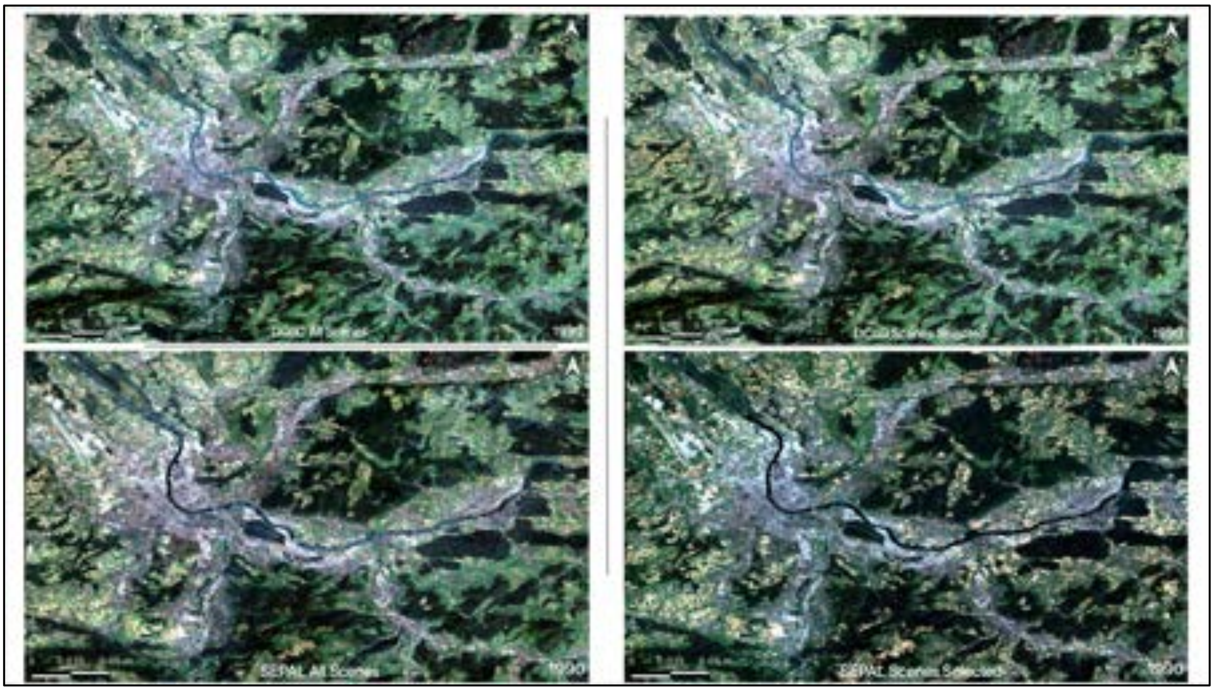

Figure 5: illustrating the four scenes for 1990 for the Basel urban area

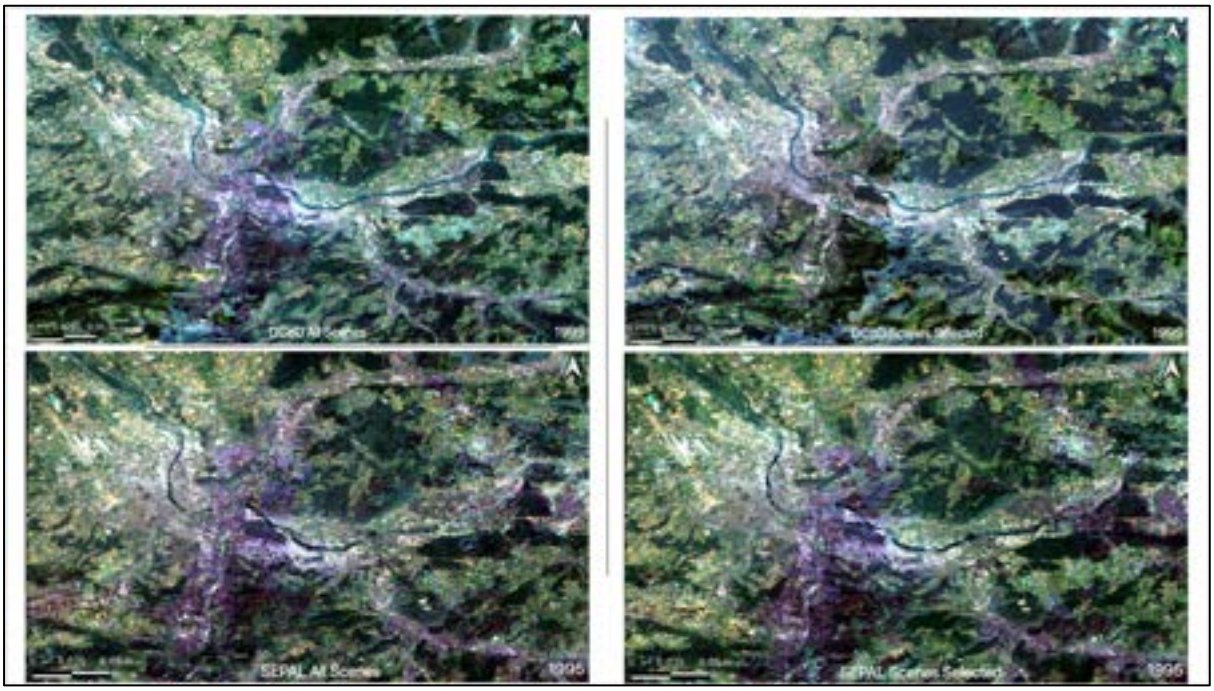

Figure 6: illustrating the four scenes for 1995 for the Basel urban area

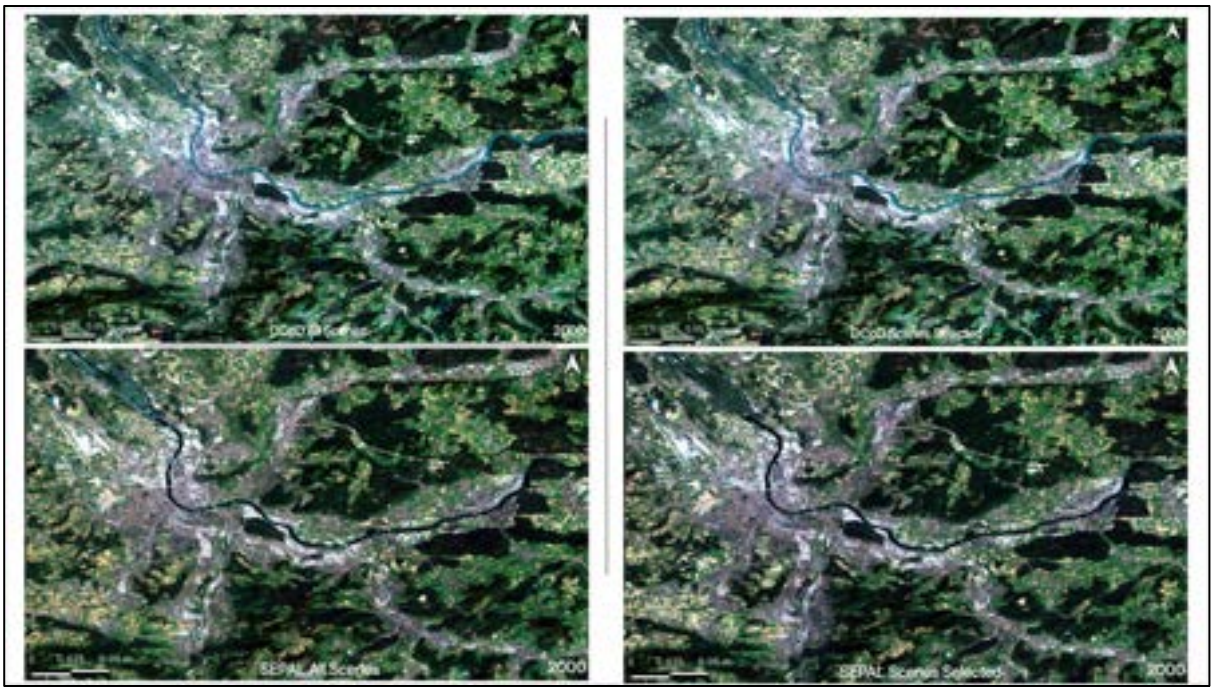

Figure 7: illustrating the four scenes for 2000 for the Basel urban area

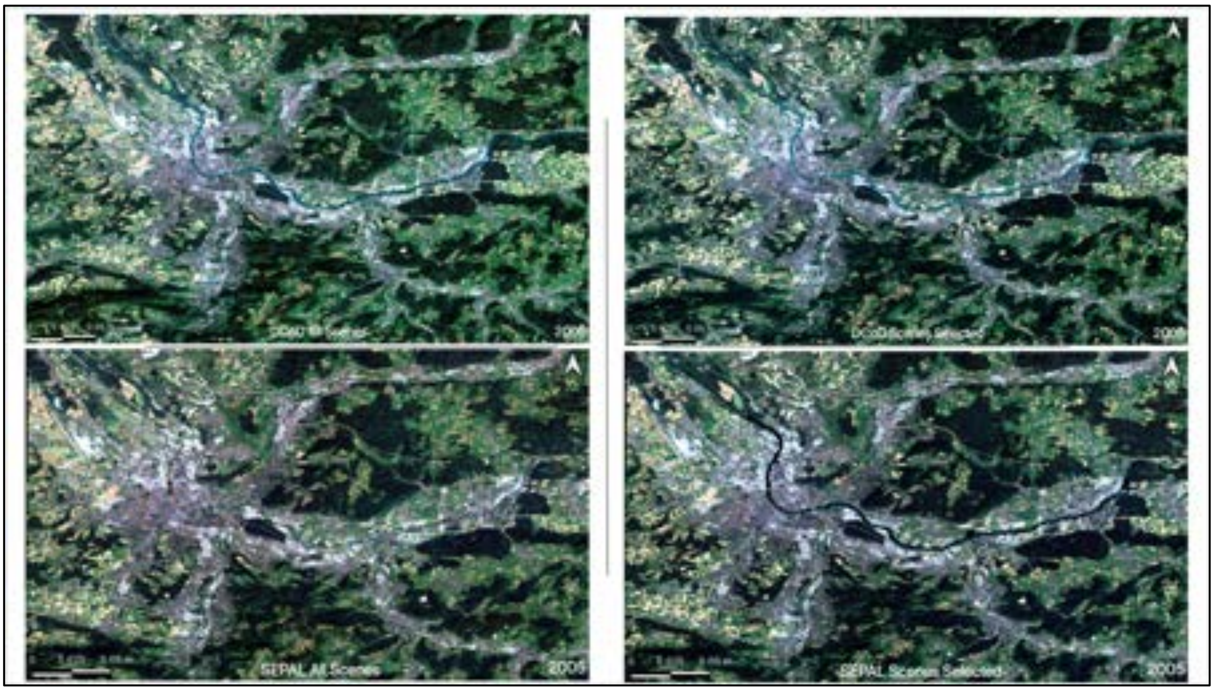

Figure 8: illustrating the four scenes for 2005 for the Basel urban area

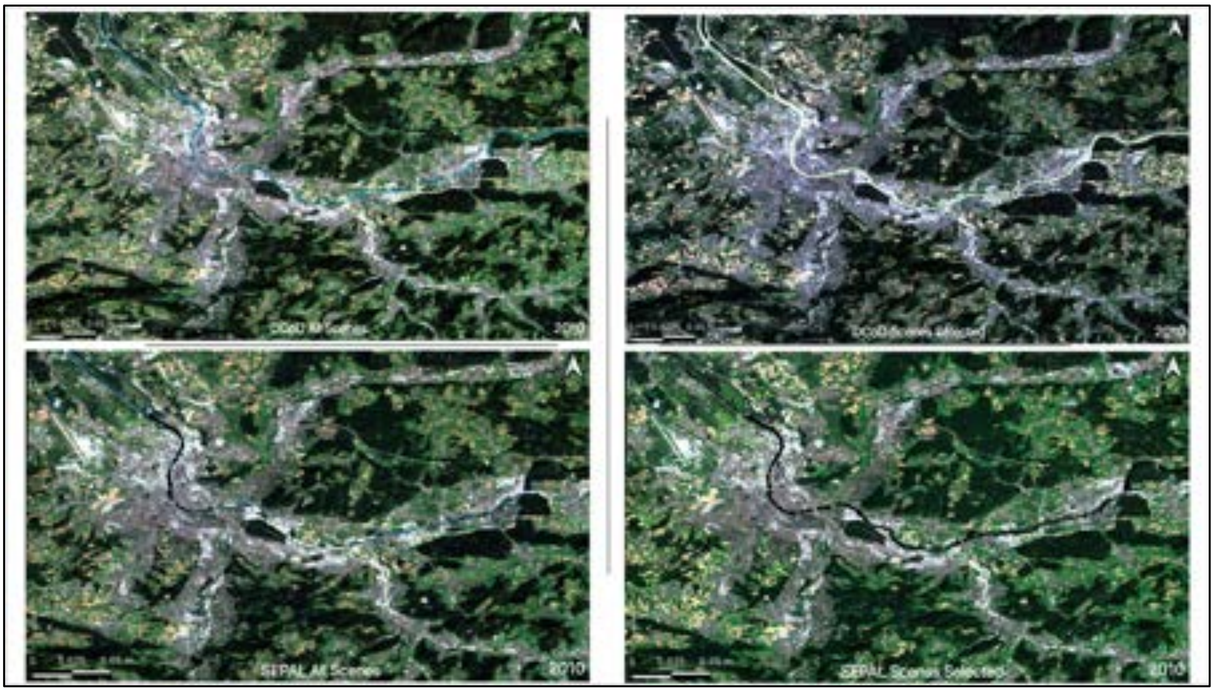

Figure 9: illustrating the four scenes for 2010 for the Basel urban area

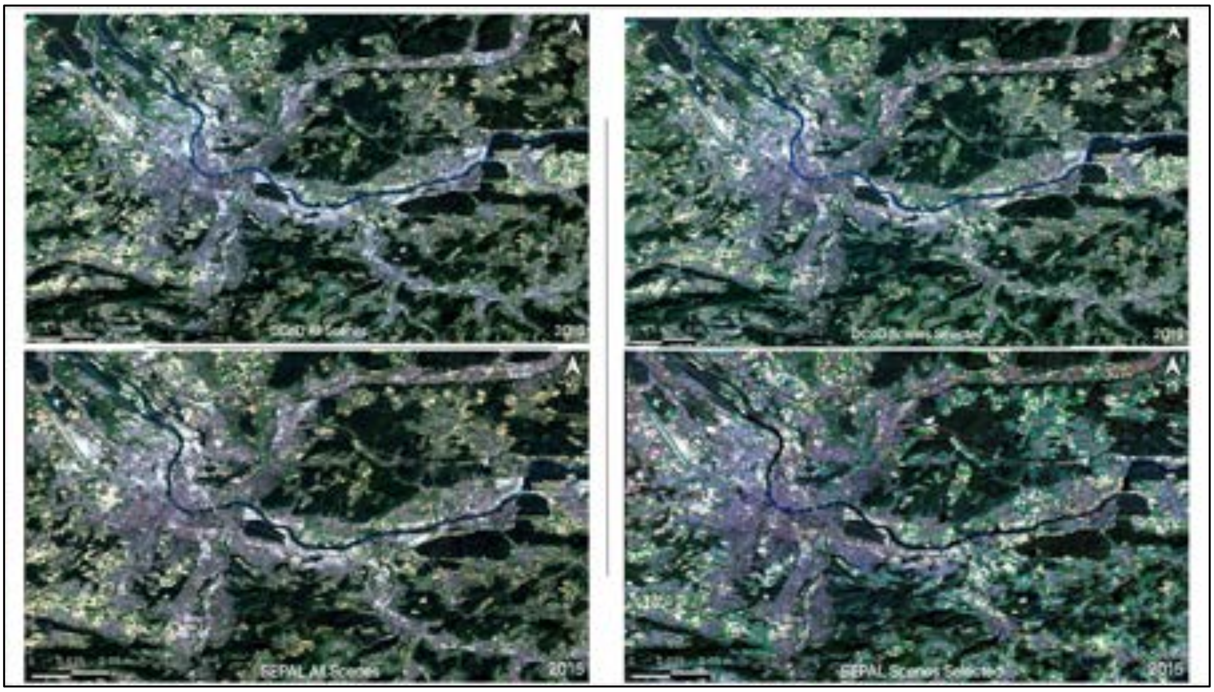

Figure 10: illustrating the four scenes for 2015 for the Basel urban area

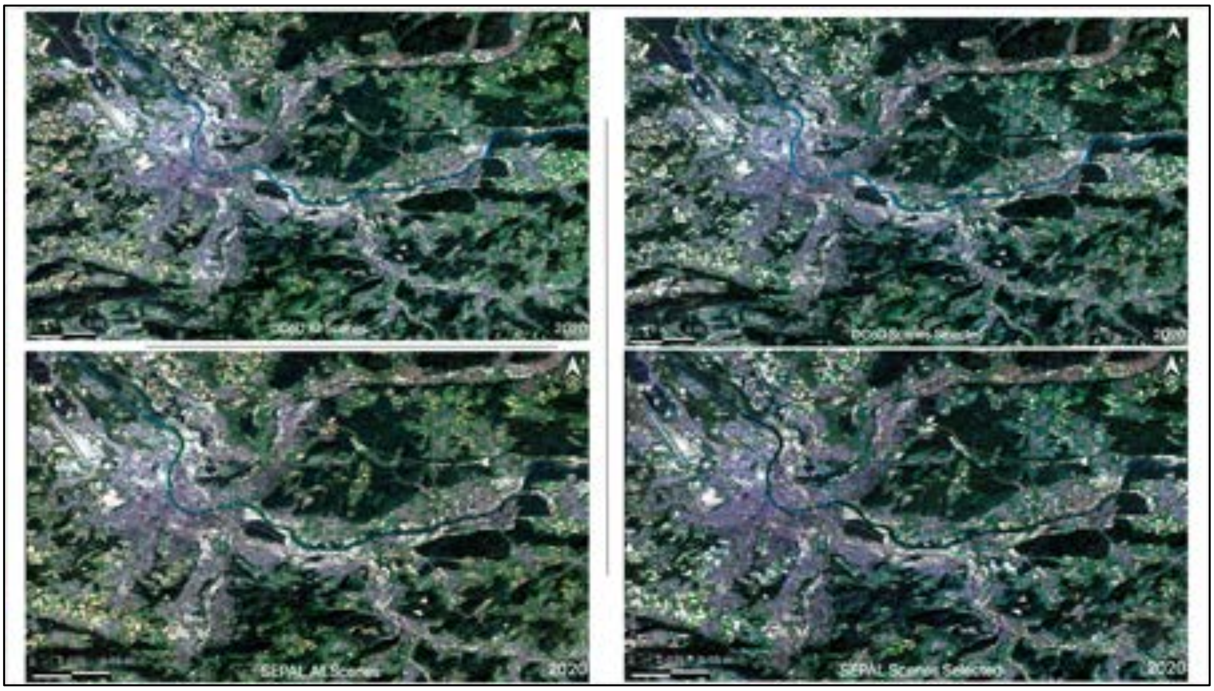

Figure 11: illustrating the four scenes for 2020 for the Basel urban area

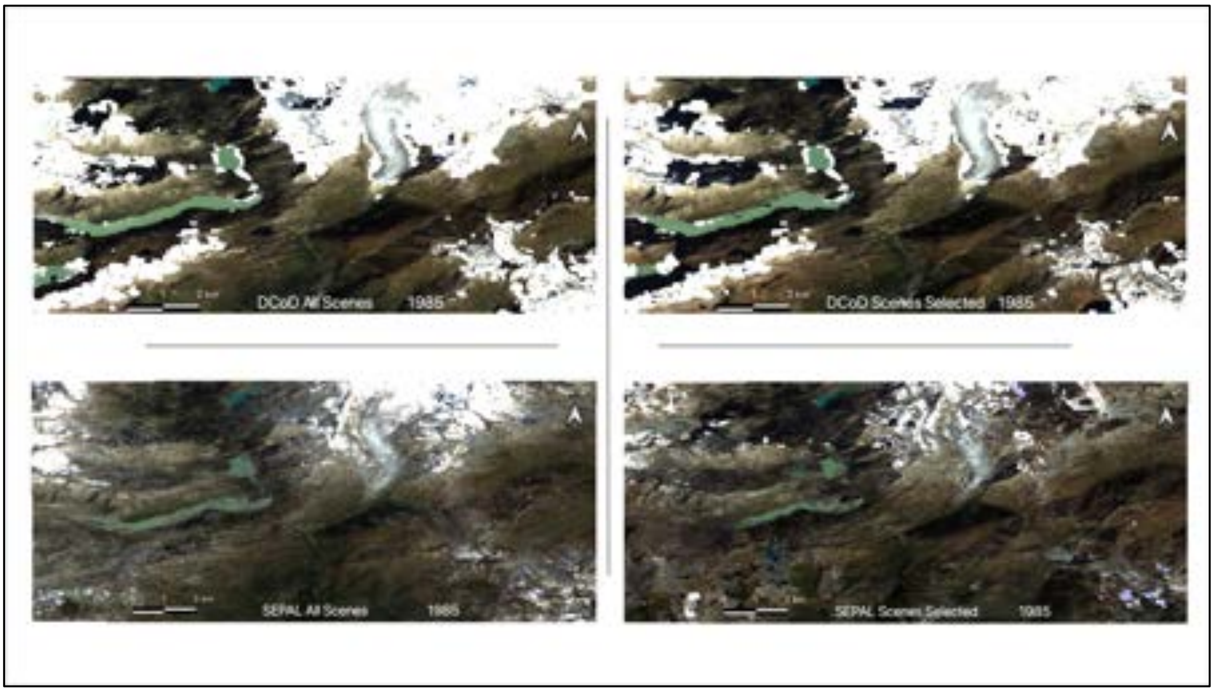

Figure 12: illustrating the four scenes for 1985 for the Rhone Glacier alpine area

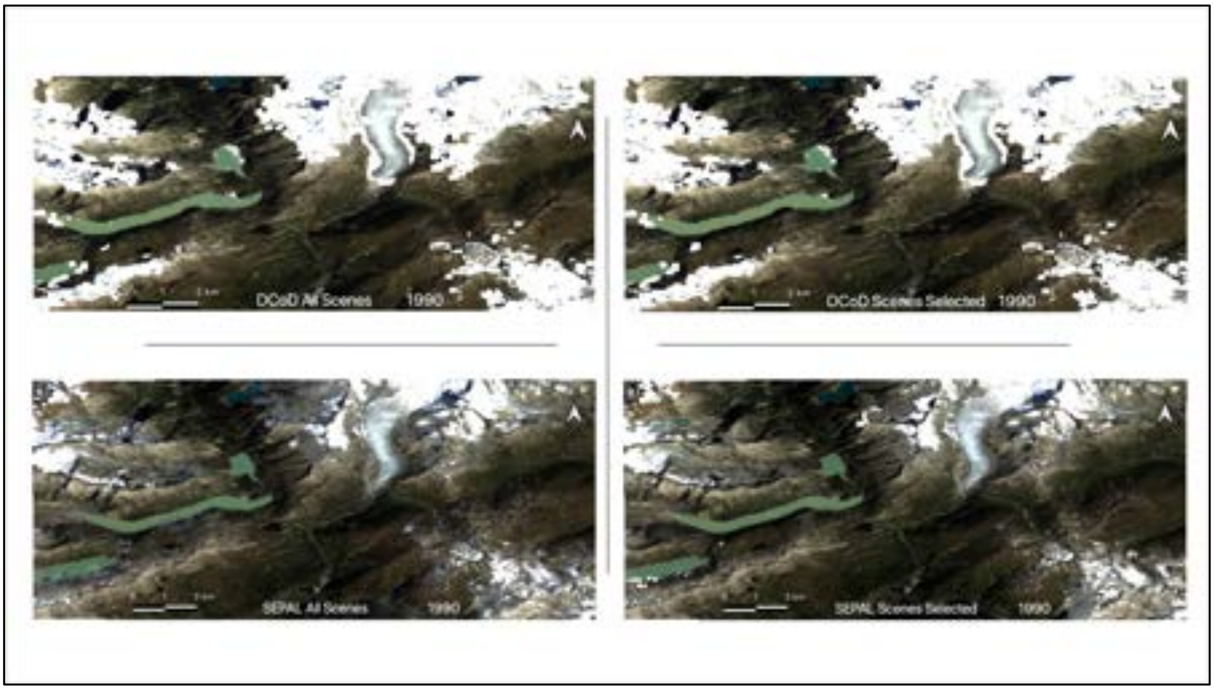

Figure 13: illustrating the four scenes for 1990 for the Rhone Glacier alpine area

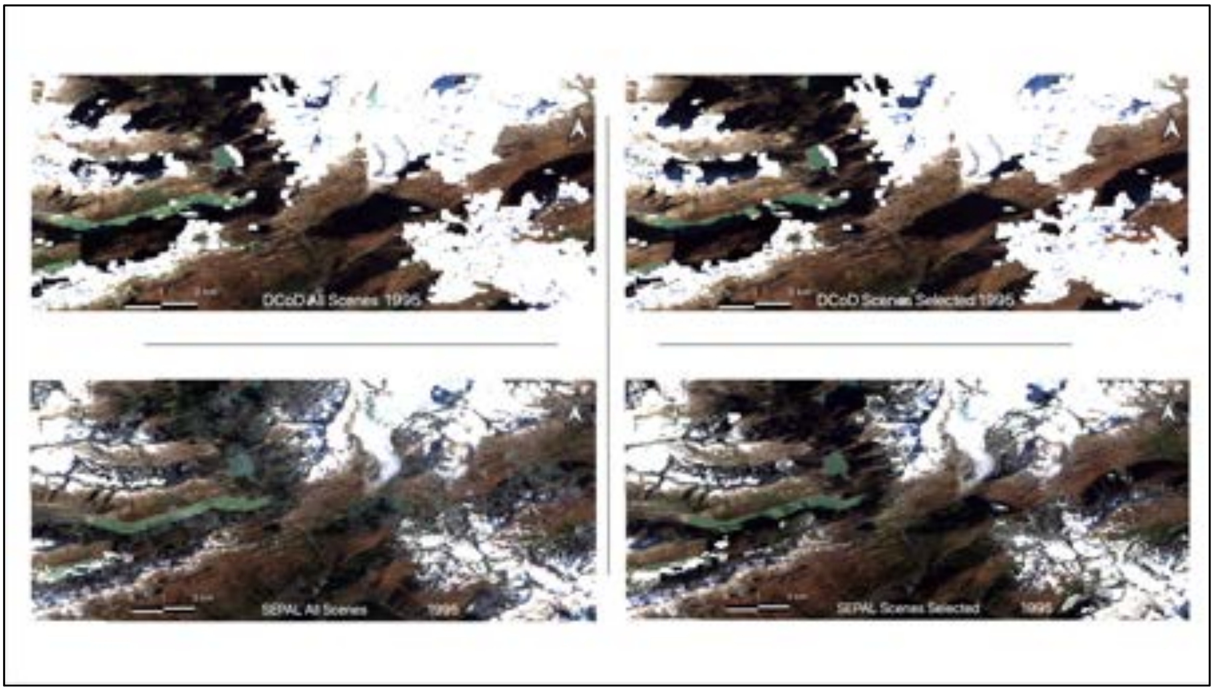

Figure 14: illustrating the four scenes for 1995 for the Rhone Glacier alpine area

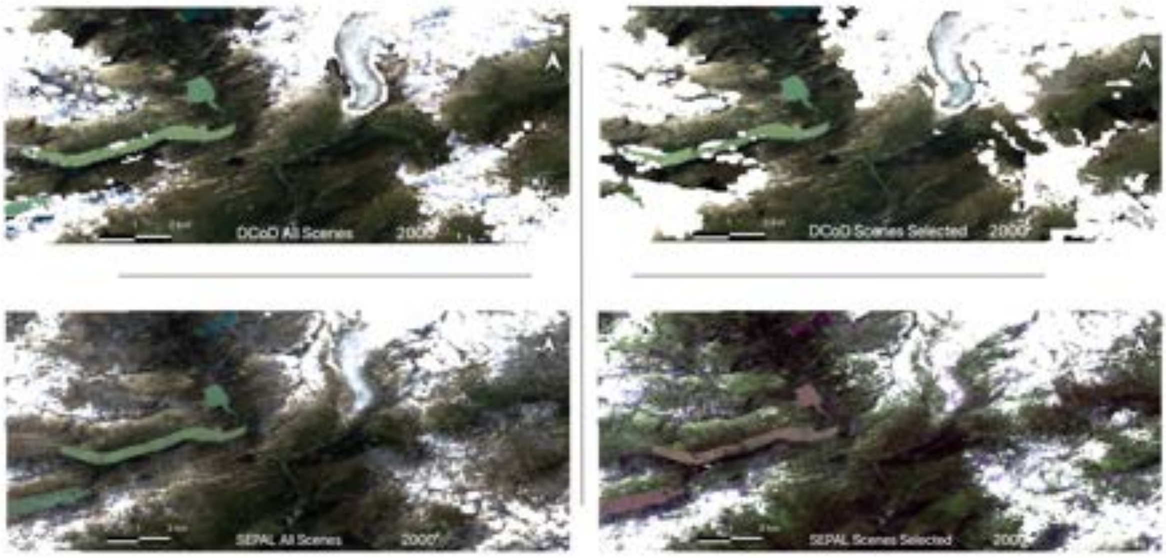

Figure 15: illustrating the four scenes for 2000 for the Rhone Glacier alpine area

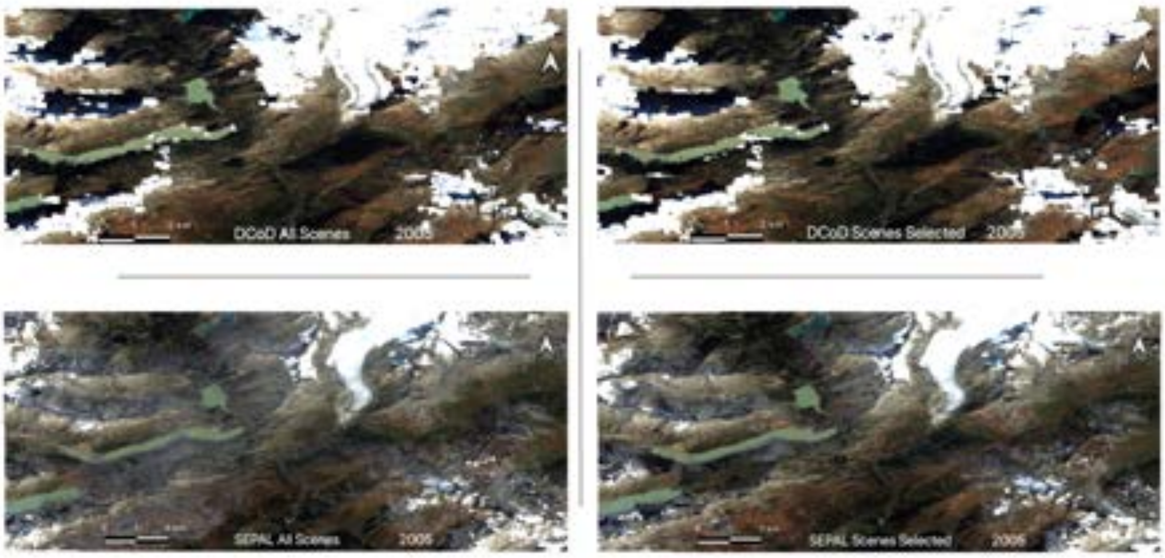

Figure 16: illustrating the four scenes for 2005 for the Rhone Glacier alpine area

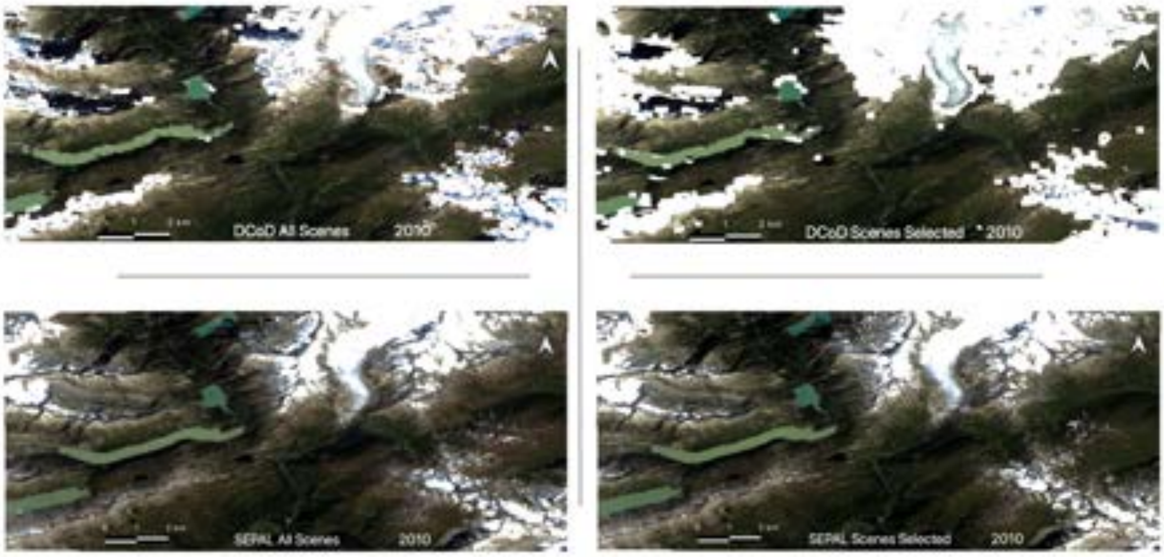

Figure 17: illustrating the four scenes for 2010 for the Rhone Glacier alpine area

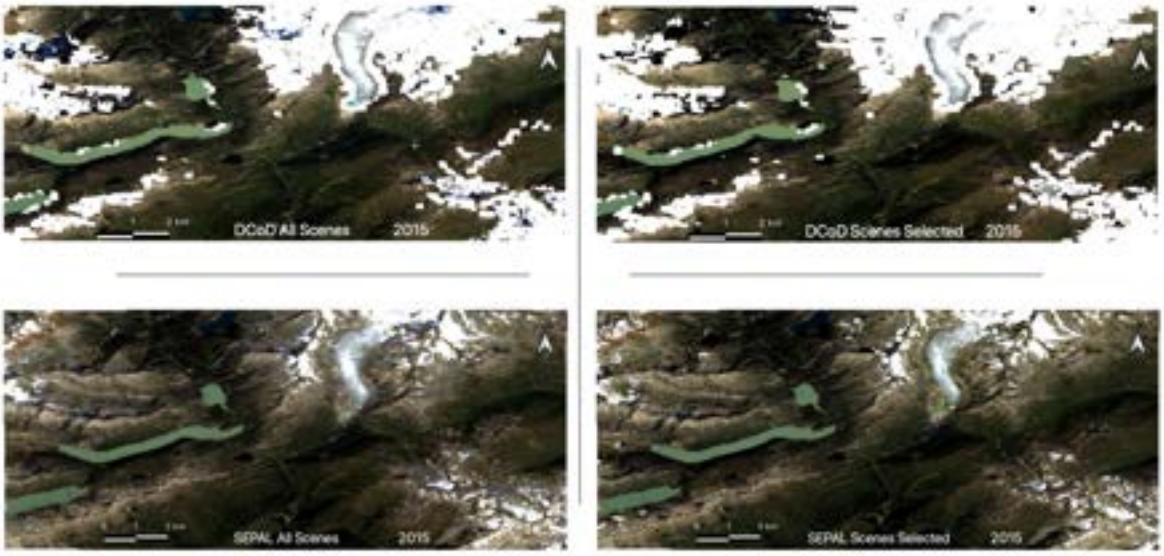

Figure 18: illustrating the four scenes for 2015 for the Rhone Glacier alpine area

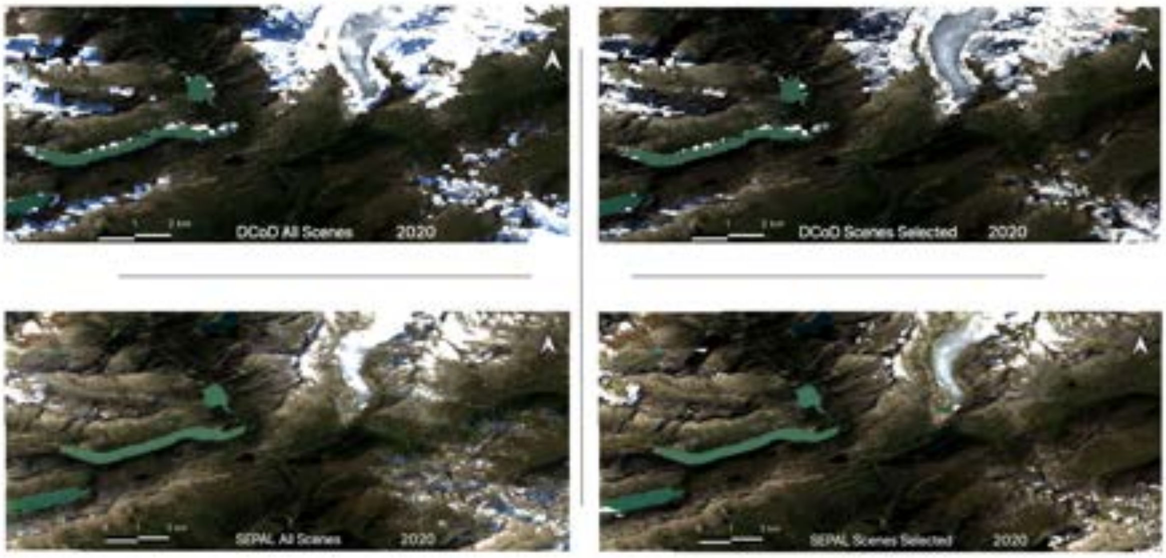

Figure 19: illustrating the four scenes for 2020 for the Rhone Glacier alpine area

5.2 Comparison of Results

By viewing each image one year at a time, it can be possible to evaluate which one is better. For the Basel urban location, the results are very similar and comparable. This being said, overall the DCoD images were preferred, this because it had better quality colours (both for all of the scenes and the selected scenes images). On the other hand, for the Rhone Glacier, all the images were better with SEPAL. Between the two DCoD images, for both Basel and Rhone Glacier locations, selecting all of the scenes was preferred compared to the selected scenes (optimized images), because get more quality completeness. Nevertheless, three out of eight (3/8) images for the Basel location were preferred by selecting the scenes, meaning that it still is worth downloading the optimized images. For the two SEPAL images, for the Basel location, the selected images were generally better than the full images, illustrating that it is worth taking the time to select the scenes manually on SEPAL. Even if there were closer similarities, this was also true for the Rhone Glacier location. Therefore, overall it seems that usually for the DCoD is better to get the images with all of the scenes, whereas for SEPAL it is beneficial to manually select the scenes. The reason why SEPAL worked better for the alpine location, is that the default options were changed on SEPAL, to take into account for the higher quality of cloud cover (for example by changing the Snow Masking to *Off* and the Cloud Detection to *Cloud Score*). These results can be observed and appreciated in the below synthetic table of results.

Table 2: Showing which image was best for each platform for each year for the Basel location, and illustrating with an X which one was the best image within the platform for that particular year, and also comparing it with the other platform. Within SEPAL the *Scene Selection* images are most often the better option. Overall the best option for the Basel location is the ***All Scenes*** image retrieved with **DCoD**.

Basel	**DCoD**				**SEPAL**		**Overall Best Platform**
Year	All Scenes	Optimized	Centred	Index	All Scenes	Scene Selection	
1985		**X**				x	DCoD

1990	**X**				x		DCoD
1995		**X**				x	DCoD
2000	**X**					x	DCoD
2005	**X**					x	DCoD
2010	**X**					x	DCoD
2015		**X**			x		DCoD
2020	**X**				x		DCoD
Total (within platform)	5/8	3/8	0	0	3/8	5/8	**DCoD**
Overall Best per Year compared to the other platform	**5/8**	3/8	0	0	0	0	**DCoD (All Scenes)**

Table 3: Showing which image was best for each platform for each year for the Rhone Glacier location, and illustrating with an X which one was the best image within the platform for that particular year, and also comparing it with the other platform. Within DCoD, most often the better option is the *All Scenes* images. Although both *All Scenes* and *Scene Selection* scored 4/8 within SEPAL, the times the *All Scenes* image was best was only slightly better compared to the *Scene Selection*. Instead when the *Scene Selection* was best it was quite a bit better. This is way overall the best option for the Rhone Glacier location is the ***Scene Selection*** image retrieved with **SEPAL.**

Rhone Glacier	**DCoD**				**SEPAL**		**Overall Best Platform**
Year	All Scenes	Optimized	Centred	Index	All Scenes	Scene Selection	
1985	x				**X**		SEPAL
1990	x					**X**	SEPAL
1995				x		**X**	SEPAL
2000	x				**X**		SEPAL
2005	x					**X**	SEPAL
2010	x				**X**		SEPAL
2015	x				**X**		SEPAL
2020				x		**X**	SEPAL
Total (within platform)	6/8	0	0	2/8	4/8	4/8	**SEPAL**
Overall Best per Year compared to the other platform	0	0	0	0	4/8	**4/8**	**SEPAL (Scene Selection)**

5.3 Evaluation of other Criteria

-Image availability over time (Landsat 5, 7, 8, Sentinel 2)
Both DCoD and SEPAL can access and use Landsat 5, 7, 8 and Sentinel-2 satellite imagery, starting from 1984.

- Image processing level
For both DCoD and SEPAL uses L2 level, with already the atmospheric and topographic correction. With SEPAL can calibrated a bit to be able to see better snow and glacier.

- Processing time
With SEPAL it is hard to say exactly how much time it took to process everything. When using all of the images it is very fast. When selecting manually the scenes, playing around with the multiple options available on SEPAL, and finding the best option for each scene it can take a bit of time to have the image ready to be retrieved. Once the image is set to be downloaded, it took about 5-15 minutes to download the optical mosaic. It takes more time to retrieve Sentinel 2 images, less time for full images with Landsat, and even less time selecting the scenes with Landsat (the fewer the images for SCN the fastest, but wouldn't change much, usually only 2-3 minutes difference between full scene image and selected scene image). When the area of interest is greater, it does take more time. For example, in one instance, when retrieving a Sentinel-2 image on SEPAL that had a big area of interest it took about 20 minutes to retrieve. For DCoD, once the coordinates were set for one site and the satellites chosen, it was just necessary to basically change the file names and change the year and run the script. Just had to wait for each section to finish running and go through all the script, and including the time needed to select the scenes for the index images took about 15 minutes per year to retrieve all images. And always less time required once understood how it fully worked.
In general, though, the processing time itself wasn't what made the difference. It was more the preparation of the images (area of interest, seeing if there was change, selecting satellite, year, on sepal seeing if image was good, looking at satellite images, quality of the overall image). Once image was ready the processing time to download wasn't too bad. Overall though, once you are familiar with the DCoD, it is definitely faster than SEPAL.

- Cost
Both DCoD and SEPAL are free to use. The only thing is that SEPAL has a certain amount of instance spending ($1.00/month), storage spending ($1.00/month) and storage space (20.00 GB) per month. Every mosaic retrieved usually increases the instance spending by 2% (sometimes, but rarely 3%), meaning that you can retrieve about 50 mosaics per month. If you don't leave mosaics retrieved on SEPAL and eliminate them on the *Files* tab once the downloaded images are put on personal computer or cloud, the storage doesn't go up. If not, though, the storage goes up by 0-1% for Landsat images, and for Sentinel by 8%, and the more time you keep files stored on SEPAL the higher it goes up. So better to always eliminate the downloaded images from the *Files* tab as well as the *Task* tab once retrieve and download images on a computer or cloud. If reach the limit of instance spending, you can ask for more on the SEPAL Users Google Group (SEPAL Users Google Groups, 2022). I never did reach the limit of spending, and at the end of the month the values go to zero.
The only hidden costs of both SEPAL and DCoD is the running cost in energy required to keep the systems working.

- License on products
Both DCoD and SEPAL are open source, meaning that you can use the platforms as you want as they are made freely available and the original source code may be redistributed and modified. When using these platforms, though, it is always better to mention that the images were generated through these platforms and reference it appropriately.

- User friendliness
SEPAL very user friendly. Straight forward and doesn't require too much prior knowledge about GIS. The DCoD is a bit different. Depends if you like coding and are familiar with it. For me coding isn't too straight forward (yet), but thanks to the help of Mr. Bruno Chatenoux I understood better how it works and understood its very useful usage (i.e. just change date and can run everything with same coding script).

- Comparison of results
See above section and its Table 2, but overall DCoD and SEAL are very similar for an urban area such as Basel, but I would say the images generated with DCoD were better (and for me it was better to get the image with the all the scenes as get higher completeness). On the other hand, in an alpine region like for the Rhone Glacier area, SEPAL was definitely better as it can account for the higher amount of cloud cover (and from my experience it was usually better to use the selected scenes images as I took the time to get the best high-quality scenes).

- Specific advantages and limitations
What I enjoyed about SEPAL is that you can see and visualize what is going on, see right away what the full or scene selected image looks like. Can play around with it easily for example by changing satellite sensors, years and specific time period, changing parameters (cloud score, cloud buffering, snow masking). It would definitely be useful to be able to create an exact square/rectangle as area of interest, or to be able to set the coordinates like on the DCoD. The user friendliness of SEPAL is a favourable positive advantage, as it is straight forward and quite easy to use, and non-GIS and remote sensing experts can access satellite imagery quite straightforwardly. Anyone with a little bit of time I believe can use and understand SEPAL. DCoD needs more time and maybe a little more background knowledge about programming and remote sensing. Mr. Bruno Chatenoux definitely help me very much and made what at first seemed something very complicated to my own eyes something more understandable. I really enjoyed the efficiency of retrieving imagery with DCoD. I think for anyone that is starting with the DCoD it would be useful to go through the Jupyter Notebook and the scripts a bit with somebody familiar with it. With a quick helping hand you can understand how it works. And once you know how the DCoD works, you can play around with the code lines and scripts to get the output desired, and quickly retrieve them. So even someone not familiar with coding (like me), can process imagery quite fast and efficient, by just selecting the area of interest, satellites, and time period. So, it is very easy and faster than SEPAL. The only thing is that to fully see better the image it is necessary to put the downloaded file on QGIS, whereas on SEPAL you see right away what the image looks like without having to put it on QGIS (or another geographic information system application).

SEPAL's limitation is that if you need to generate a lot of mosaics in a short amount of time you might exceed the amount of free monthly spending. I haven't found any place where you can pay for more instances, but you can just ask for more instances. If you are not on a time constraint you can still create and save mosaic scripts, to be retrieved and downloaded at the start of a new month. The main problem with SEPAL is that for me it stopped working for two months (from mid-March to mid-May 2022), and I couldn't do anything about. The problem was because of a technical issue with a policy change between Google and SEPAL.

DCoD limitation is that it can analyse areas only in Switzerland for the moment, and for the Atlas of Our Changing Environment need to update for sites all over the Earth. SEPAL, instead, can access and analyse sites in the whole world. Because of this, for the time being, I think SEPAL is the better suggestion to update UNEP Atlas project. This even because when the images from DCoD were better from the Basel location the difference wasn't too pronounced. And for mountainous areas, which Switzerland has a lot of, it is significantly better SEPAL compared to the DCoD.

5.4 Changes in land use between 1985 and 2020

By analysing the images through time for both scenes, from 1985 to 2020, you would imagine some changes have occurred. For the Basel location, urban expansion seems to have continued, and the city's population has increased. Although changes have occurred, as it was already quite a densely populated city, Basel has not expanded too much in the last decades. For the Rhone Glacier location, between 1985 and 2020, the glacier has retreated and a lake at the base of the glacier has developed. This often happens with mountain glaciers as they melt and are forced to retreat up the mountain's valleys. The lake was first noticeable in 2005 and has since gotten bigger. Although the lake is also noticeable with the DCoD images, it significantly has a better quality in the SEPAL images.

5.5 Connecting back to the UNEP Atlas Project

The scope of the internship was to compare images generated with the DCoD and SEPAL, to see which one generates the best images to potentially update the Atlas. As with the DCoD sites outside of Switzerland can't be accessed, I tried with SEPAL to see the potential changes that have occurred in different locations since the initial date of publication of the UNEP Atlas. Below are two examples of how the land-use change has continued to progress negatively since 2005. By using the same years used by the Atlas of Our Changing Environment, and adding the latest changes, we can see how these two examples illustrate the potential of SEPAL in updating the Atlas. The first example is in Fort McMurray, in Alberta, Canada, where there are the biggest oil sand deposits of the world. The second example is in the north-easter State of Rondônia, in Brazil, where forest deforestation has continued to progress extensively in these last two decades. In order to see the full extent of the changes occurred since the early 2000s it was necessary for both locations two zoom out and increase the area of interest. Only by doing this could the change be truly appreciated, showcasing how unfortunately there is still a lot to do to halt the environmental problems we are faced with. May these two examples illustrate that it might just be time to update the Atlas of Our Changing Environment to try to have an impact on policy makers.

Figure 20: illustrating the changes in land use over the years and since the initial Atlas report the oil sands have continued to expand north of Fort McMurray, Canada, even when we know that we must try to reduce and stop burning fossil fuels

Figure 21: showing the horrific expansion of deforestation in the north-west of the Brazilian State of Rondônia, which is one of the most deforested regions of the Amazon rainforest. Hundreds of km of trees have been cut down for agriculture and livestock.

6. Conclusion

As mentioned, for the time being, my personal view is that SEPAL would be a good option to potentially update the UNEP Atlas Project as all places on our planet can be access with SEPAL. The two above examples of oil sand enlargement in Fort McMurray, in Canada, and of the deforestation expansion North Western State of Rondônia, in Brazil, illustrate well how SEPAL could be used to update the UNEP Atlas. Both DCoD and SEPAL have benefits and negatives, and it is hard to compare between two very different platforms. It depends from the user, if they prefer coding or visualization. As seen, it depends on the type of terrain (SEPAL for the moment is better for mountainous regions, and DCoD potentially better for urban areas). It depends on the time constraint, as if somebody that has to process and retrieve many images it might be better to use DCoD as you can process images faster and there is not instance spending constraint. When more time is available, I believe it is worth using SEPAL and manually selecting the scenes as it generally results in advantages later on with better quality images. And with SEPAL, when working properly, can access the whole globe and can potentially update better the UNEP Atlas sites. There have been two examples, in Bolivia and the Democratic Republic of the Congo (DRC), where the DCoD was successful outside of Switzerland, showing its potentiality also worldwide (Giuliani, Chatenoux, Piller, *et al.*, 2019). Ideally you could get the best of both worlds, the efficiency and ease of coding and running scripts, and the smoothness and visualization and user-friendliness of SEPAL. I appreciate learning some coding and see its benefits, but as I don't have a coding background, I did feel more comfortable with SEPAL at first. I thought it was interesting to have two different ways to access and retrieve satellite imagery, which allowed me to learn even more as the overall experiences were different. Ideally it would be interesting to use GEE and see the output and experiences that come with using this platform and see its potentials to be a candidate in updating, and potentially upgrading, the Atlas of Our Changing Environment.

7. Acknowledgments

I would like to thank the UNEP-GRID Geneva for allowing me to have had this opportunity and this enriching experience in order to complete my Certificat Complémentaire en Géomatique. I would like to acknowledge Dr. Gregory Giuliani that advised me to contact Ms. Karin Allenbach, who in turn put me in contact with my supervisor Mr. Bruno Chatenoux, who was very helpful, supportive, and understanding along all of the course of the internship. Everybody at the UNEP-GRID was very welcoming, kind and interested in hearing what I was doing.

8. Presentation of the host organization

The Global Resource Information Database – Geneva (GRID-Geneva) is a partnership between the United Nations Environmental Programme (UNEP), the Swiss Federal Office for the Environment (FOEN) and the University of Geneva (UniGe). The team is composed of 20 Environment Data Scientist. GRID-Geneva's main role is to transform data into information and knowledge to support the decision making process related to environmental issues.

9. Reflections on the course of the internship

The internship at the GRID-Geneva was a very nice experience and I enjoyed it very much. I was able to get exposed to real life GIS techniques that in a classroom I would have never encountered. It was a great experience to be able to meet people that work in GIS and to get a hands-on experience doing a project for my internship that could actually be useful, as the idea is to update the images of the UNEP Atlas of Our Changing Environment. A project born in 2005, and unfortunately many negative land use changes have occurred since then so need to update images to show the continuous impacts we have done on our environment over the last couple of decades.

Because of Covid-19 the internship was mainly done remotely. During the first two months, for all of February and March, I was not able to go to GRID-Geneva because of the Covid-19 rules set by the Swiss government but also by the UN. From April I was able to go and I would go once a week to the offices in Geneva, and from May, when the rule of warring the masks in the building while walking dropped, more people came to the office and I generally would go 1 or 2 times per week. Once it was possible to go to the offices, I have to say that it was much better, as the first two months, even if my supervisor was always available if necessary, I wasn't always as productive working from home. Being in the offices was much better as I first of all could meet in person my supervisor and could asked more easily questions if had any. Additionally, I was able to meet the people working at the UNEP-GRID which was motivating and always interesting to interact with and to hear what they are doing.

For my internship I needed some basis in remote sensing which I had, and ideally even a bit of coding, which wasn't really the case, but my supervisor was very helpful and explained to me clearly what was needed in order to complete the internship. Overall, I probably could have finished the internship sooner, but I had a few technical problems which I couldn't do anything about, and a few personal things going on which made me finish the internship a bit later than expected. This wasn't a problem as it actually allowed me to go more times to the offices and get a better feel for what people do at UNEP-GRID and the projects that are going on.

I would definitely suggest an internship at UNEP-GRID to anyone that is interested in GIS. There are all kind of interesting projects and you have only things to gain.

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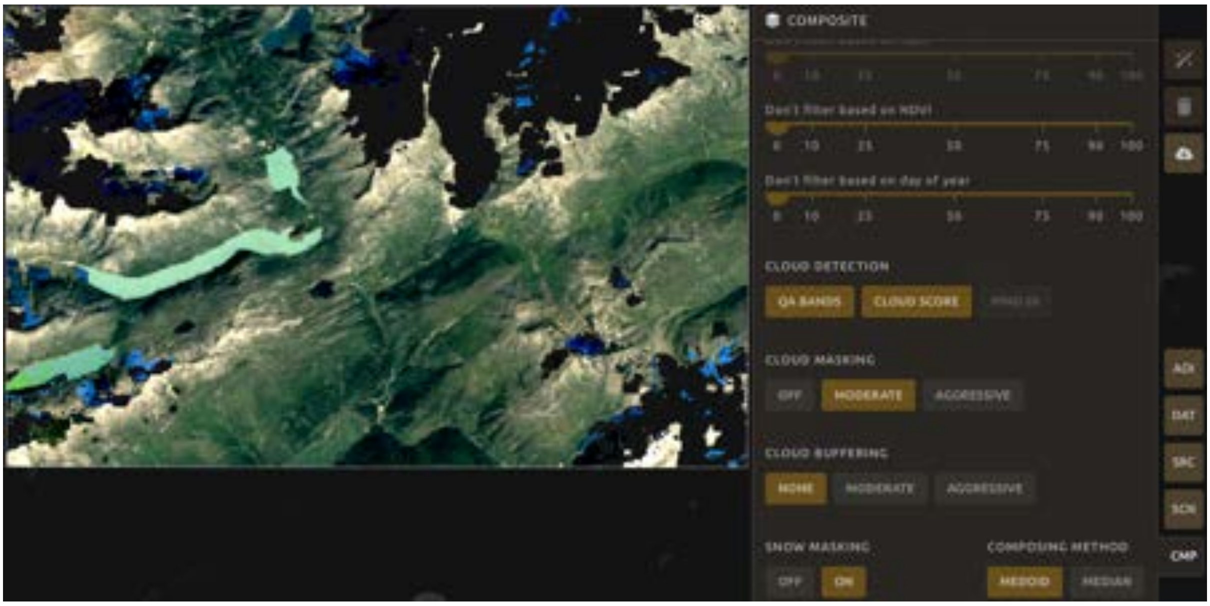
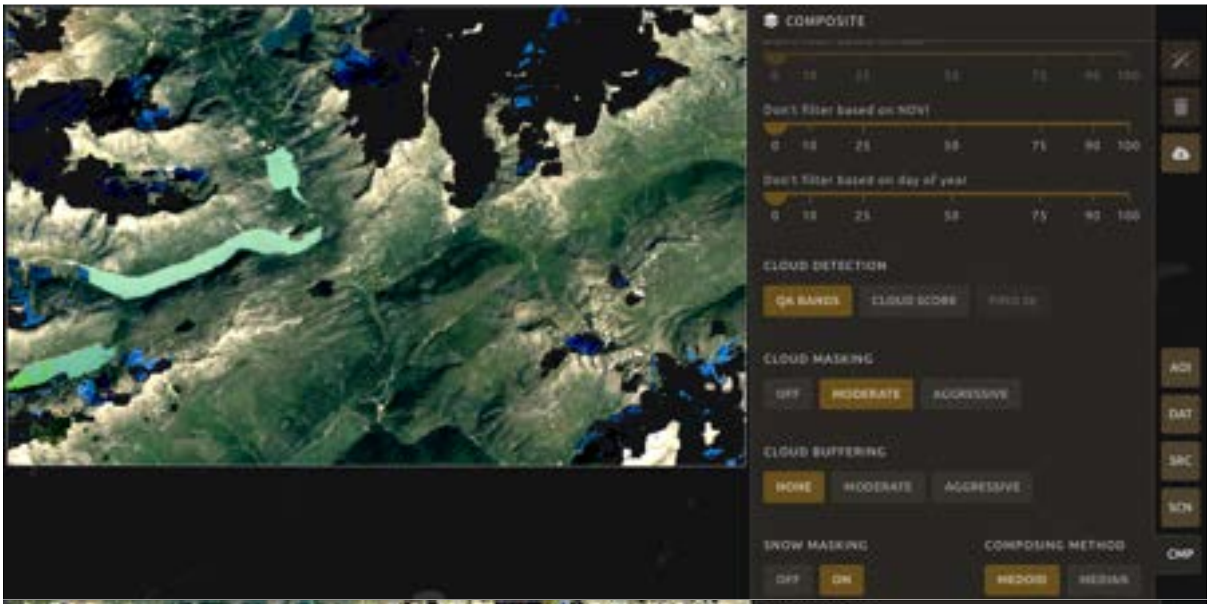
11. Annex

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Don't filter based on day of year
CLOUD DETECTION
QA BANDS
CLOUD SCORE
CLOUD MASKING
OFF
MODERATE
AGGRESSIVE
CLOUD BUFFERING
NONE
MODERATE
AGGRESSIVE
SNOW MASKING
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ON
COMPOSING METHOD
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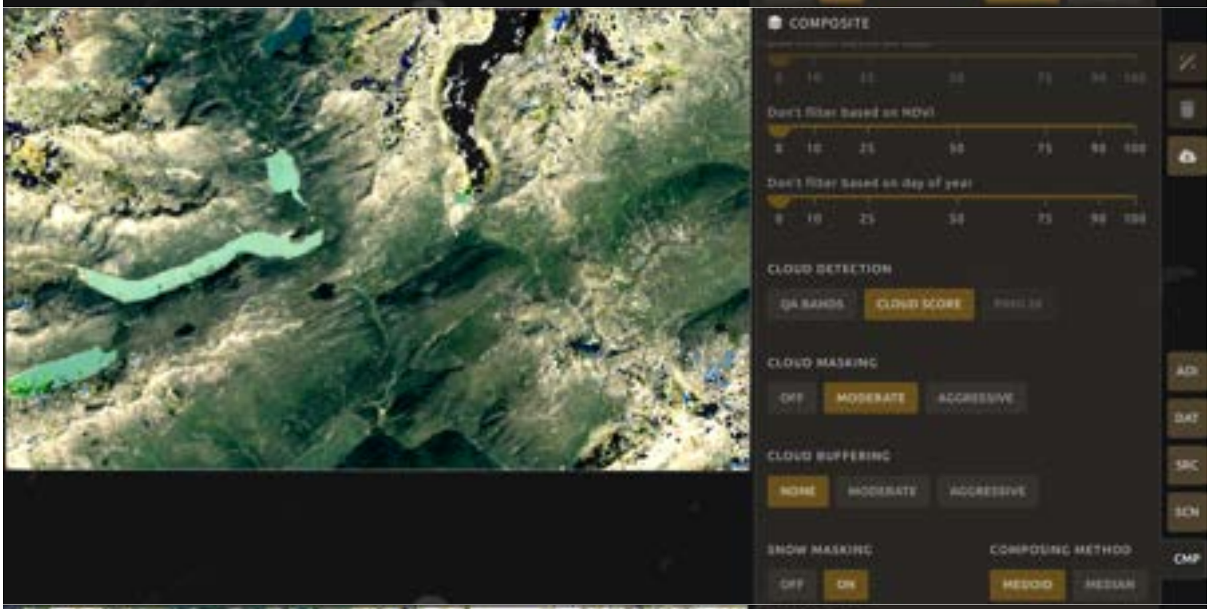
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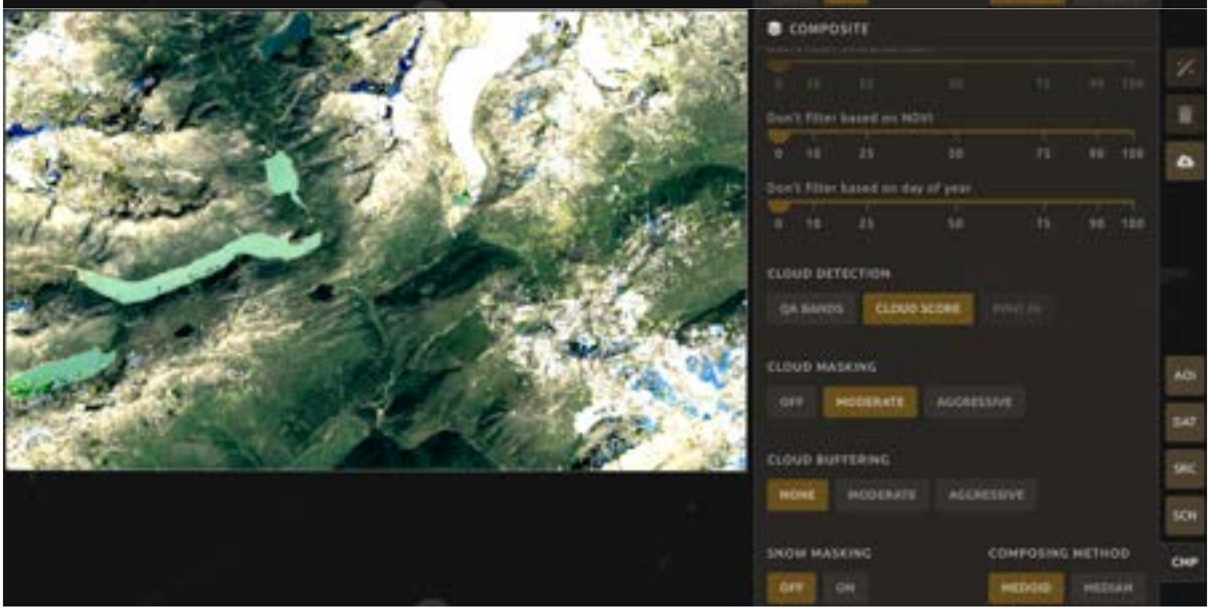
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COMPOSITE
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Don't filter based on day of year
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COMPOSITE
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OFF
MODERATE
AGGRESSIVE
CLOUD BUFFERING
NONE
MODERATE
AGGRESSIVE
SNOW MASKING
OFF
ON
COMPOSING METHOD
MEDOID
MEDIAN

0 0.025 0.05 m
DCoD All Scenes
1985

0 0.025 0.05 m
SEPAL All Scenes
1985


0 0.025 0.05 m
DCoD Scenes Selected
1985


0 0.025 0.05 m
SEPAL Scenes Selected
1985


0 0.025 0.05 m
DCoD All Scenes
1990


0 0.025 0.05 m
SEPAL All Scenes
1990

0 0.025 0.05
DCoD Scenes Selected
1990

0 0.025 0.05 m
SEPAL Scenes Selected
1990


0 0.025 0.05 m
DCoD All Scenes
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0 0.025 0.05 m
SEPAL All Scenes
1995


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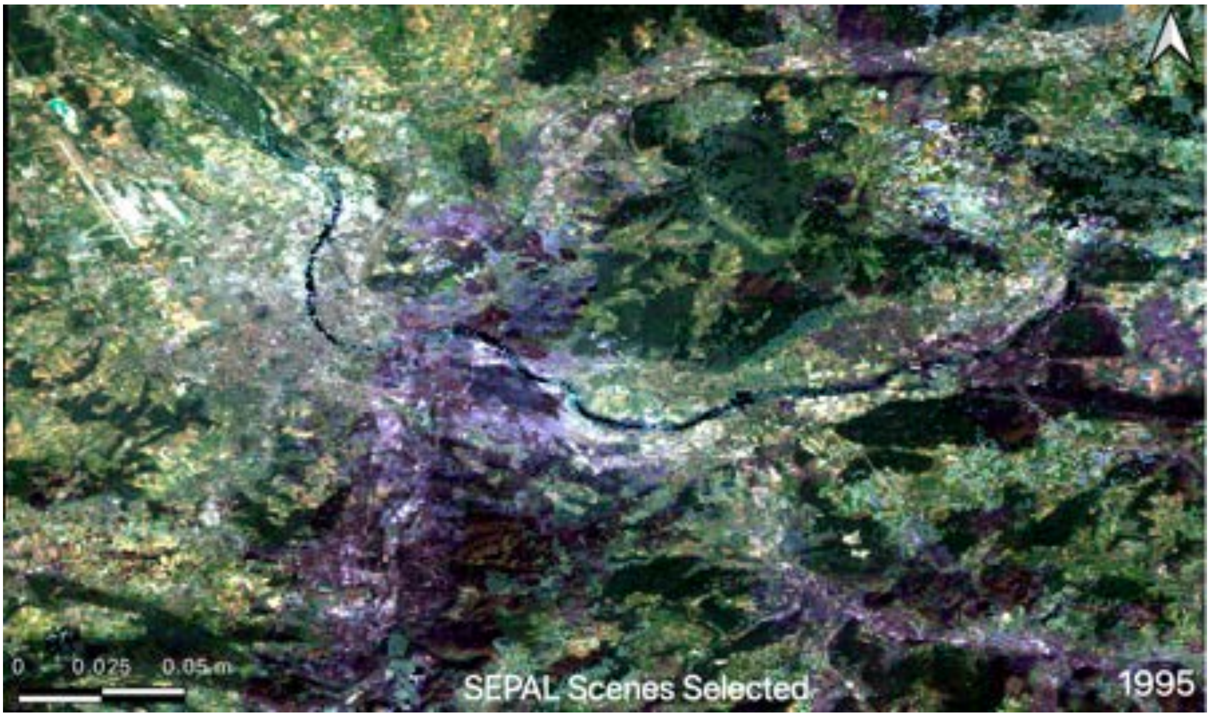
DCoD Scenes Selected
1995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SEPAL Scenes Selected
1995


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0.05 m
DCoD All Scenes
2000


0
0.025
0.05 m
SEPAL All Scenes
2000


0 0.025 0.05 m
DCoD Scenes Selected
2000


0 0.025 0.05 m
SEPAL Scenes Selected
2000


0
0.05 m
DCoD All Scenes
2005


0
0.025
0.05 m
SEPAL All Scenes
2005


0 0.025 0.05 m
DCoD Scenes Selected
2005


0 0.025 0.05 m
DCoD Scenes Selected
2005


0 0.025 0.05 m
DCoD All Scenes
2010

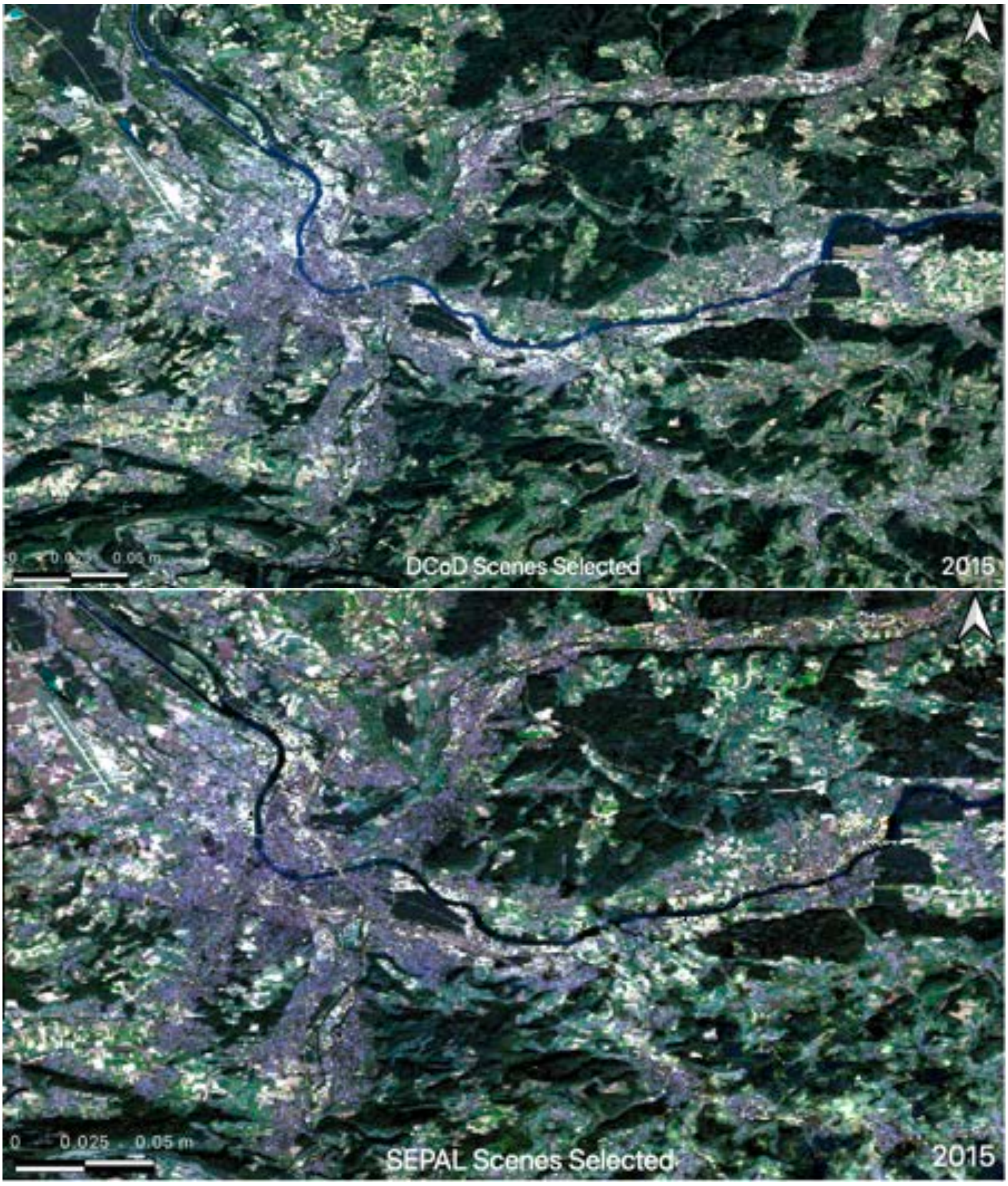

0 0.025 0.05 m
SEPAL All Scenes
2010


0
0.025
0.05 m
DCoD Scenes Selected
2010


0
0.025
0.05 m
SEPAL Scenes Selected
2010


0 0.025 0.05 m
DCoD All Scenes
2015


0 0.025 0.05 m
SEPAL All Scenes
2015

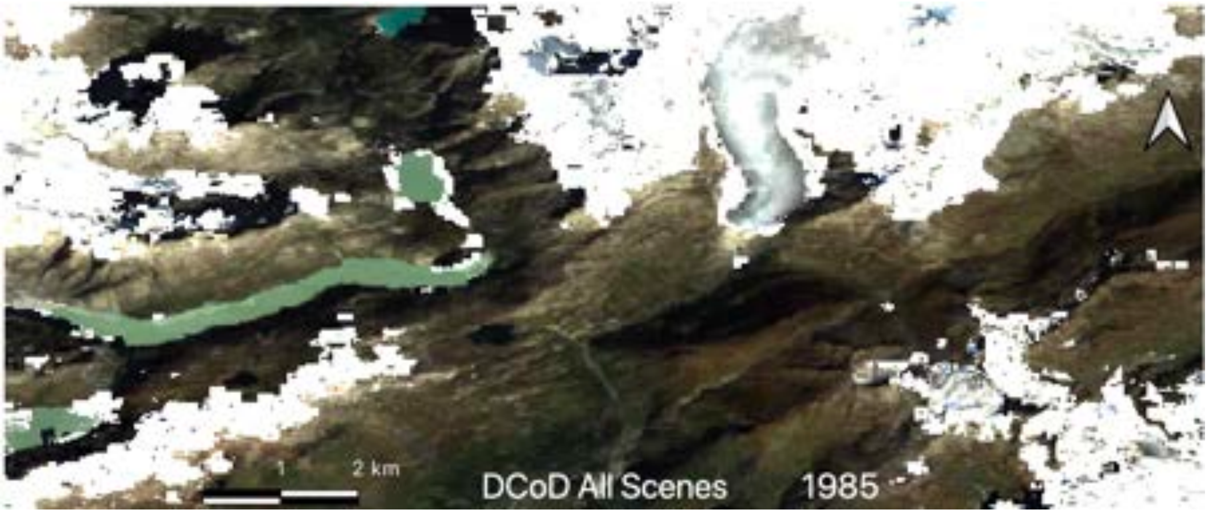

0
0.025
0.05 m
DCoD Scenes Selected
2015
0
0.025
0.05 m
SEPAL Scenes Selected
2015

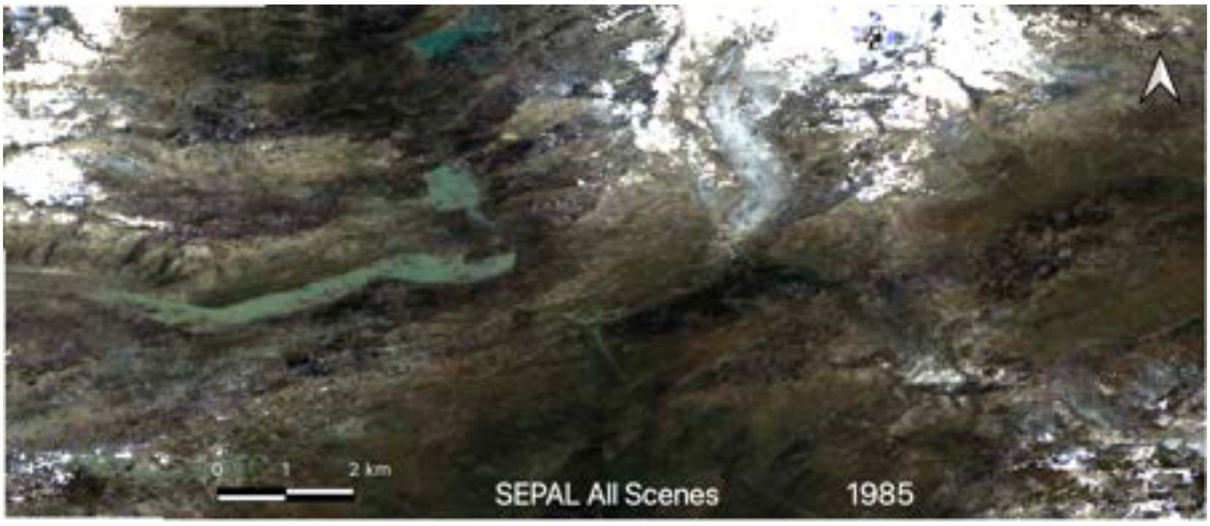

0 0.025 0.05 m
DCoD All Scenes
2020


0 0.025 0.05 m
SEPAL All Scenes
2020


0 0.025 0.05 m
DCoD Scenes Selected
2020

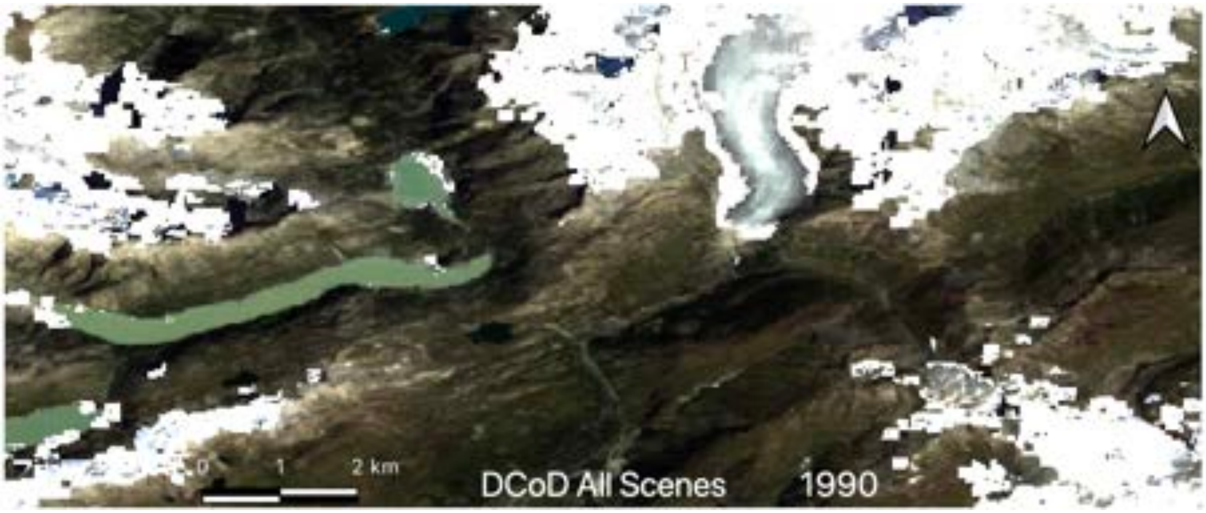

0 0.025 0.05 m
SEPAL Scenes Selected
2020


1
2 km
DCoD All Scenes
1985


0
1
2 km
SEPAL All Scenes
1985


0
1
2 km
DCoD Scenes Selected
1985


0 1 2 km
SEPAL Scenes Selected
1985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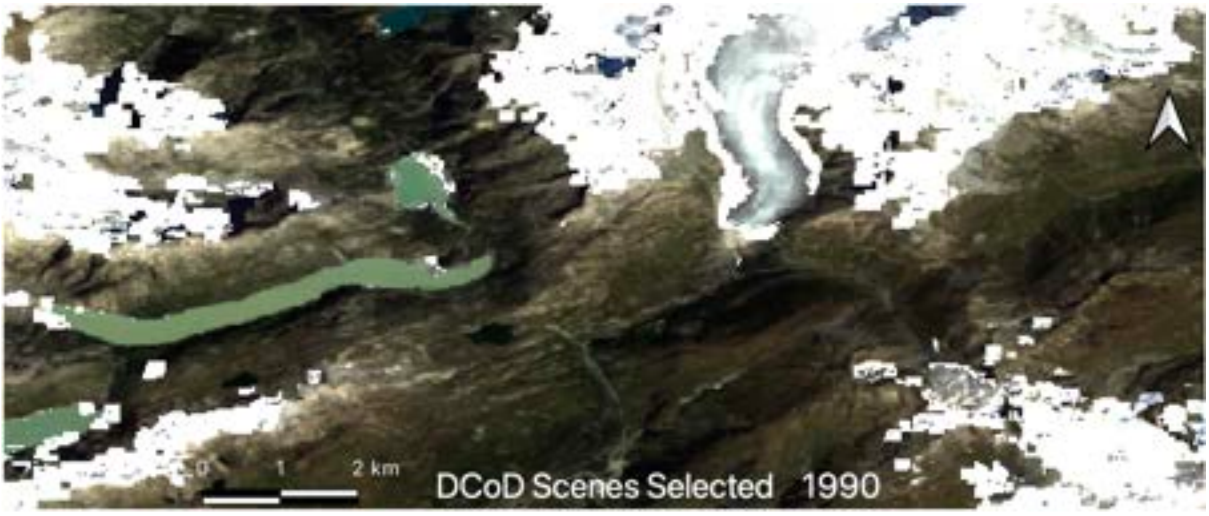
DCoD All Scenes
1990


0 1 2 km
SEPAL All Scenes
1990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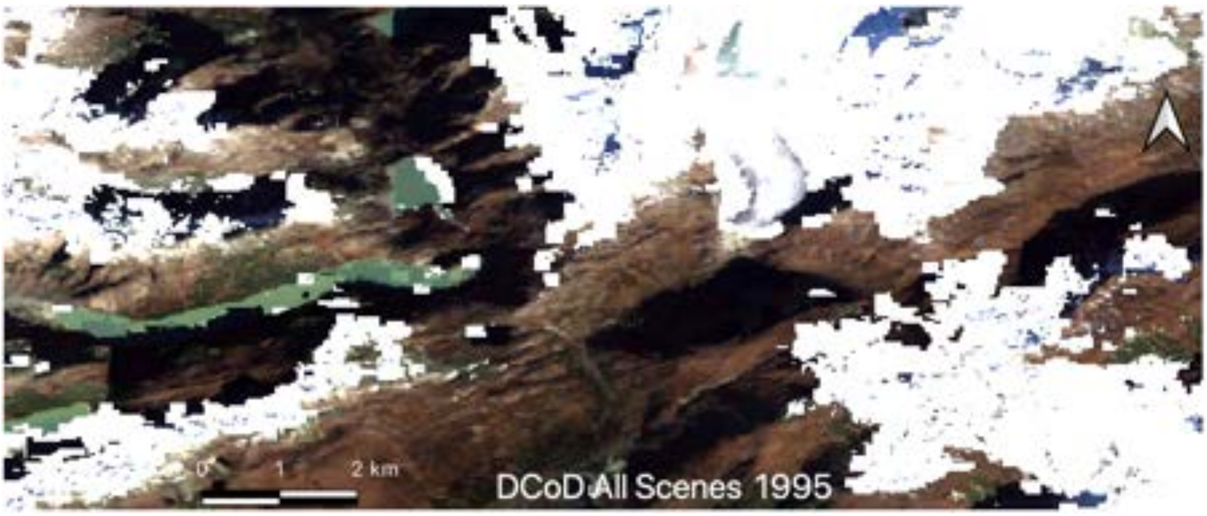
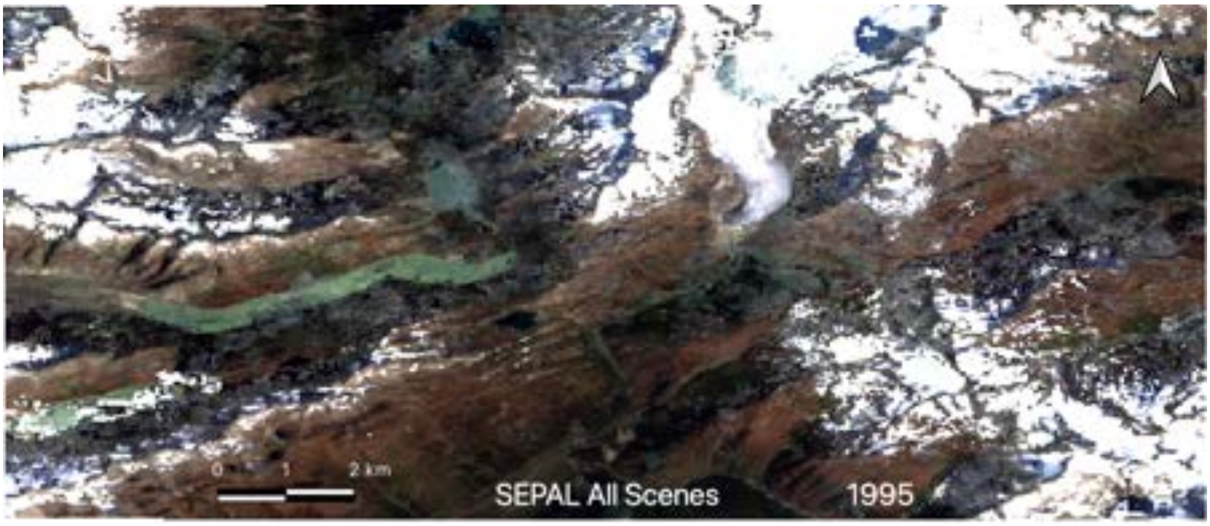
DCoD Scenes Selected 1990


0 1 2 km
SEPAL Scenes Selected 1990


0 1 2 km
DCoD All Scenes 1995


0
1
2 km
DCoD Scenes Selected 1995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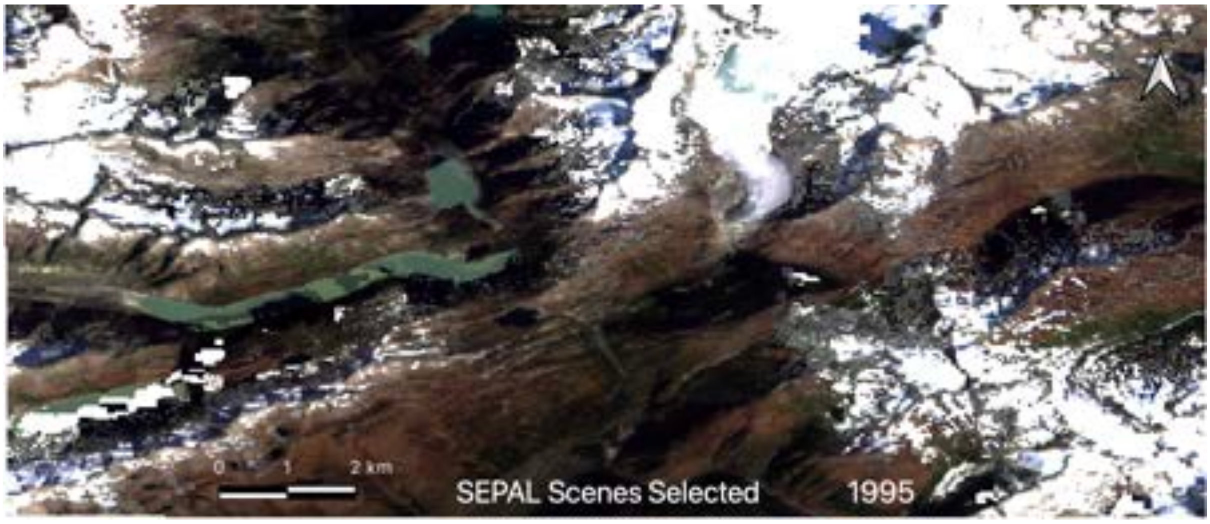
1
2 km
SEPAL All Scenes
1995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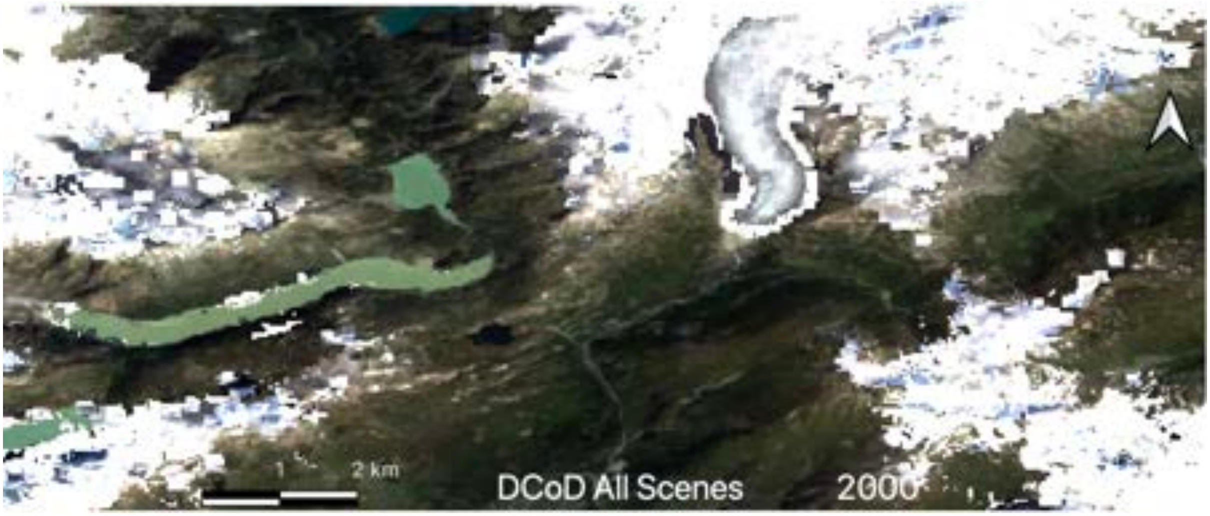
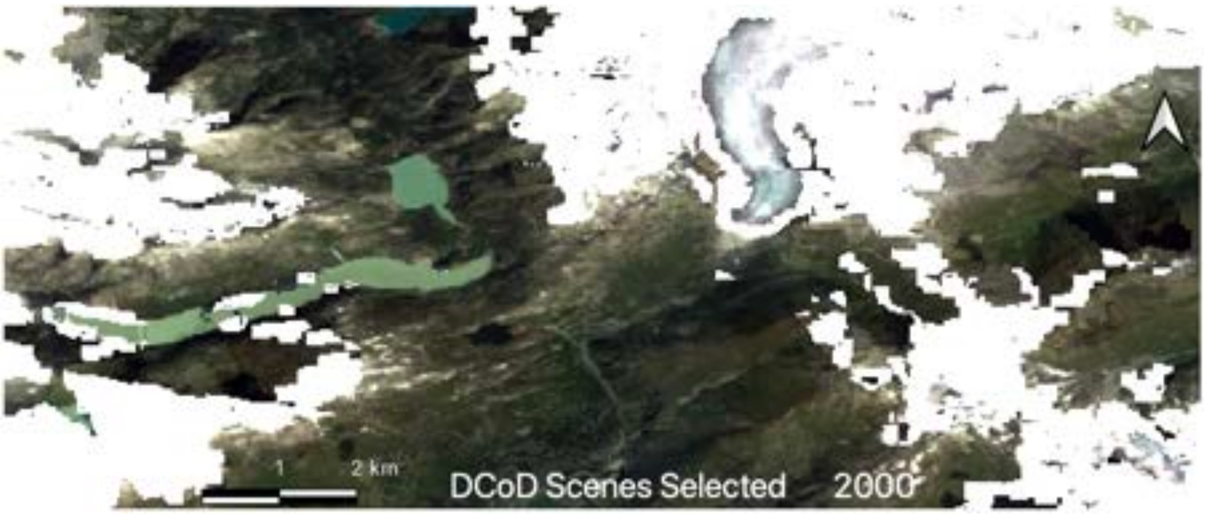
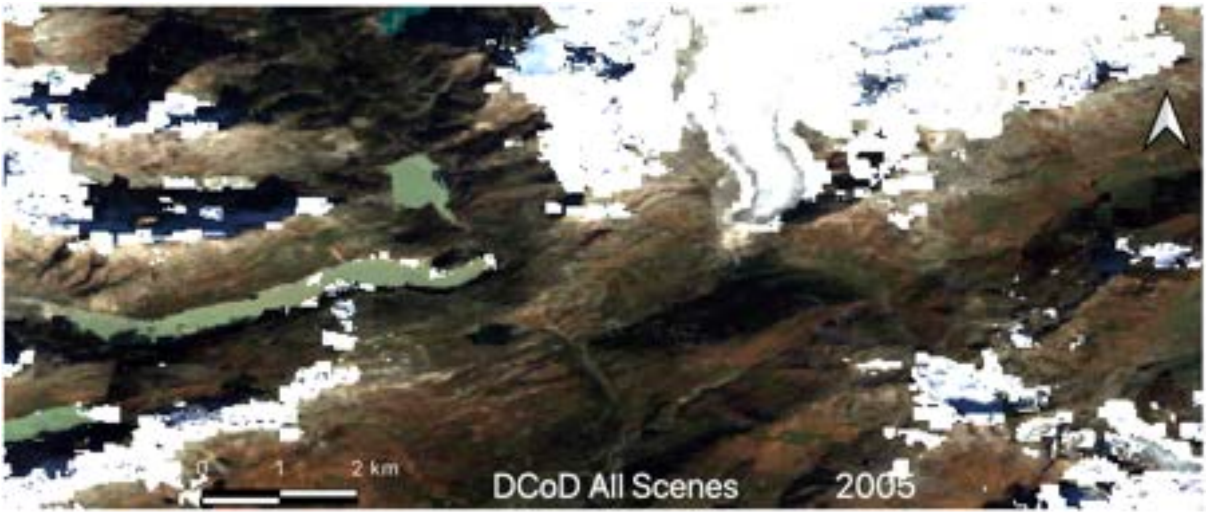
1
2 km
SEPAL Scenes Selected
1995

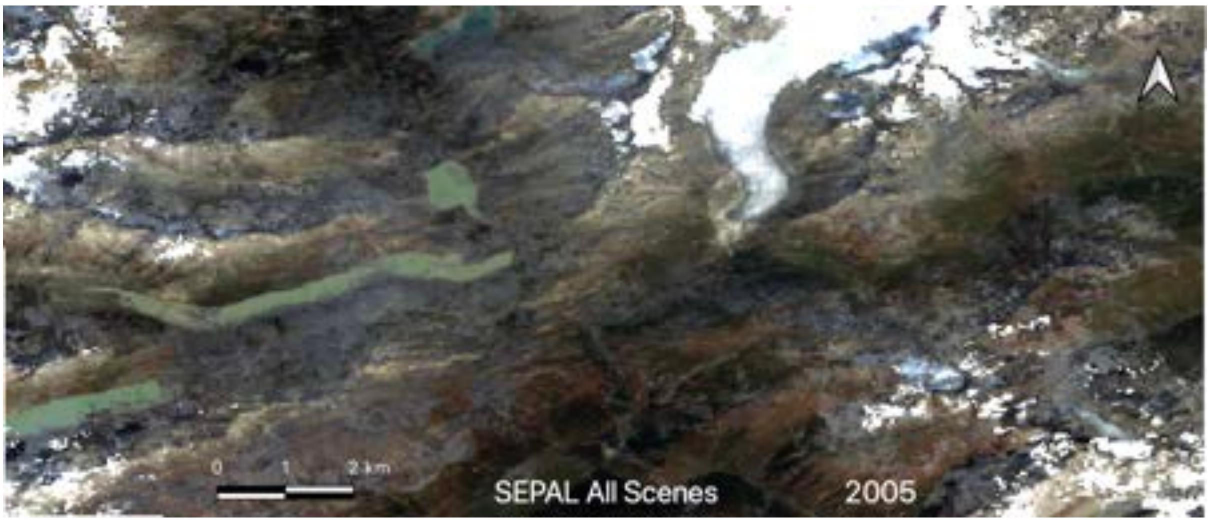

1
2 km
DCoD All Scenes
2000

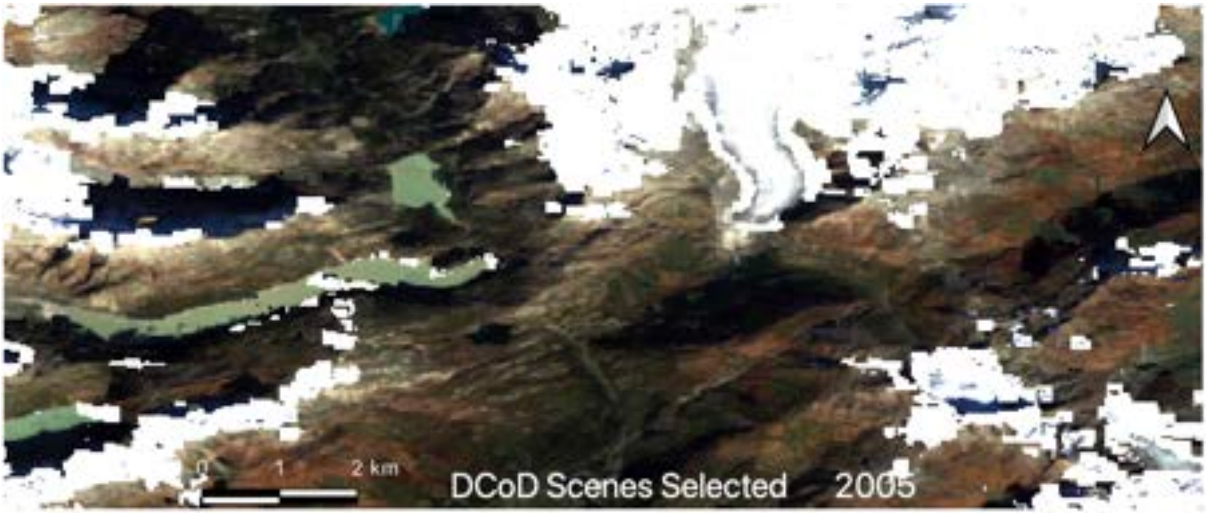

0
1
2 km
SEPAL All Scenes
2000

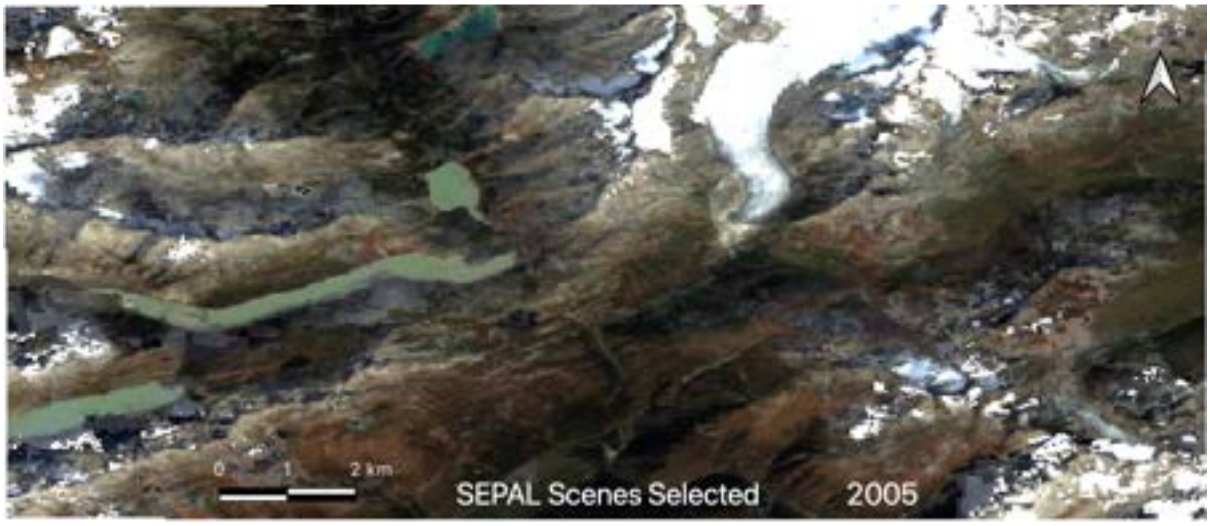

1
2 km
DCoD Scenes Selected
2000

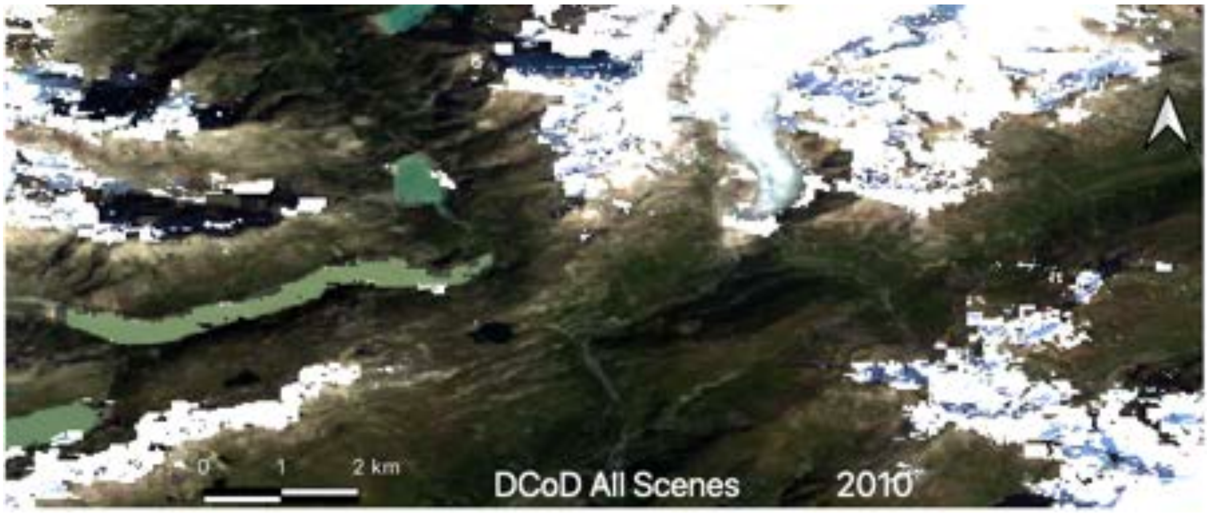

1 2 km
SEPAL Scenes Selected
2000


0 1 2 km
DCoD All Scenes
2005

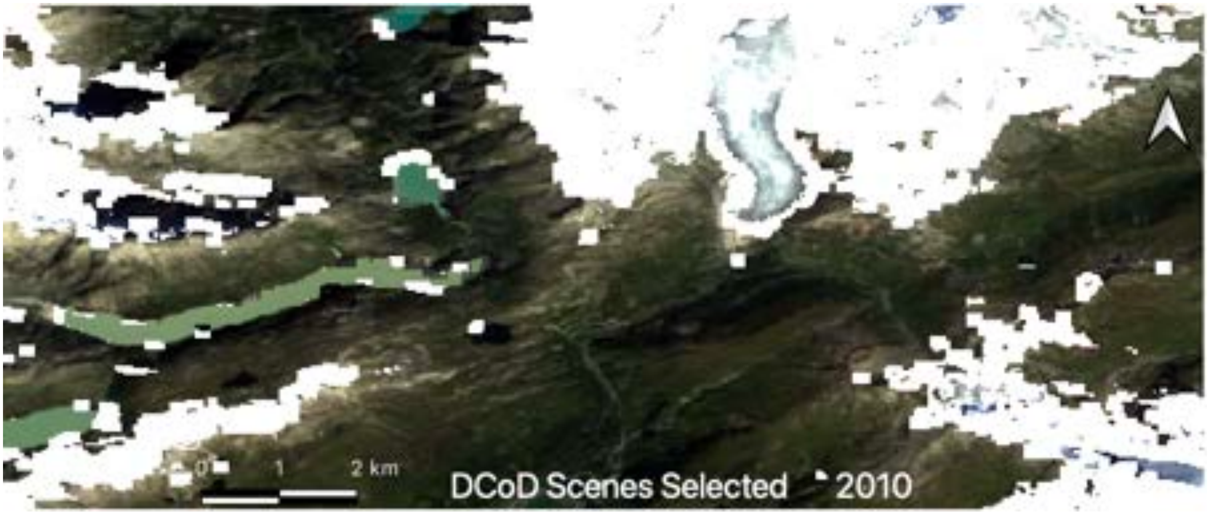

0 1 2 km
SEPAL All Scenes
2005


0 1 2 km
DCoD Scenes Selected
2005

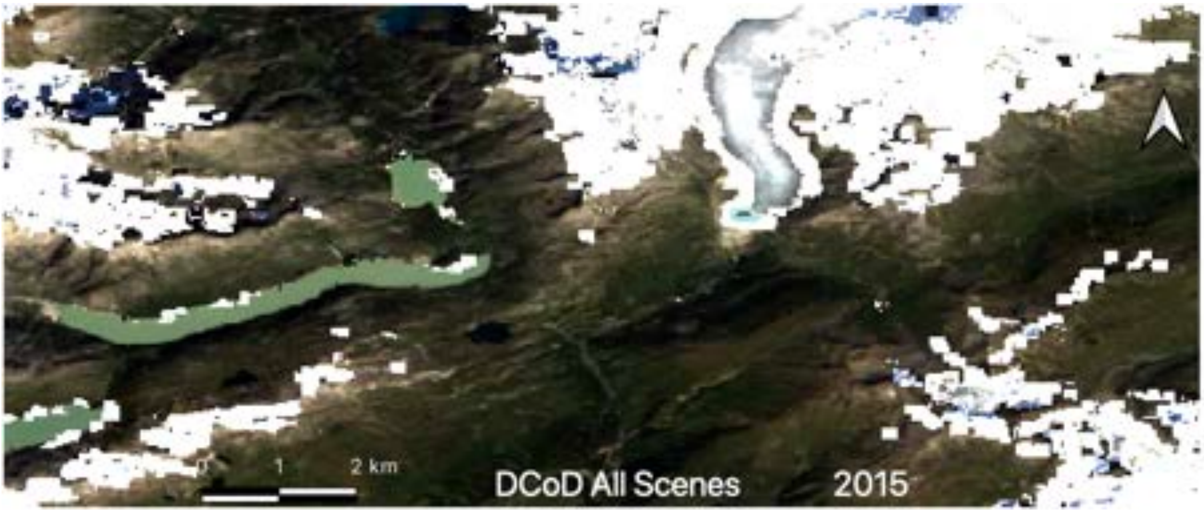

0 1 2 km
SEPAL Scenes Selected
2005


0 1 2 km
DCoD All Scenes
2010

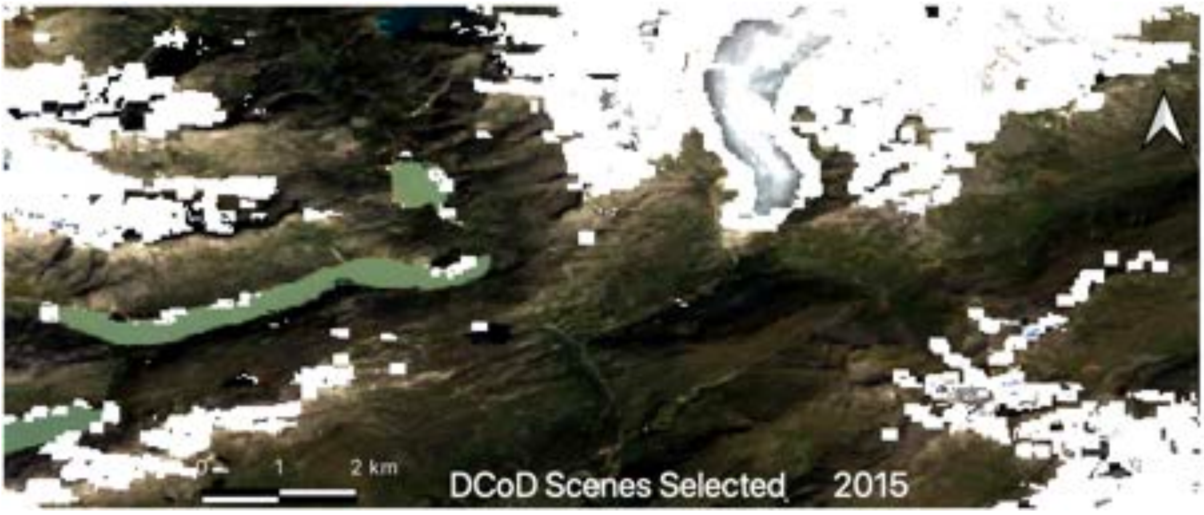

0 1 2 km
SEPAL All Scenes
2010


0 1 2 km
DCoD Scenes Selected
2010

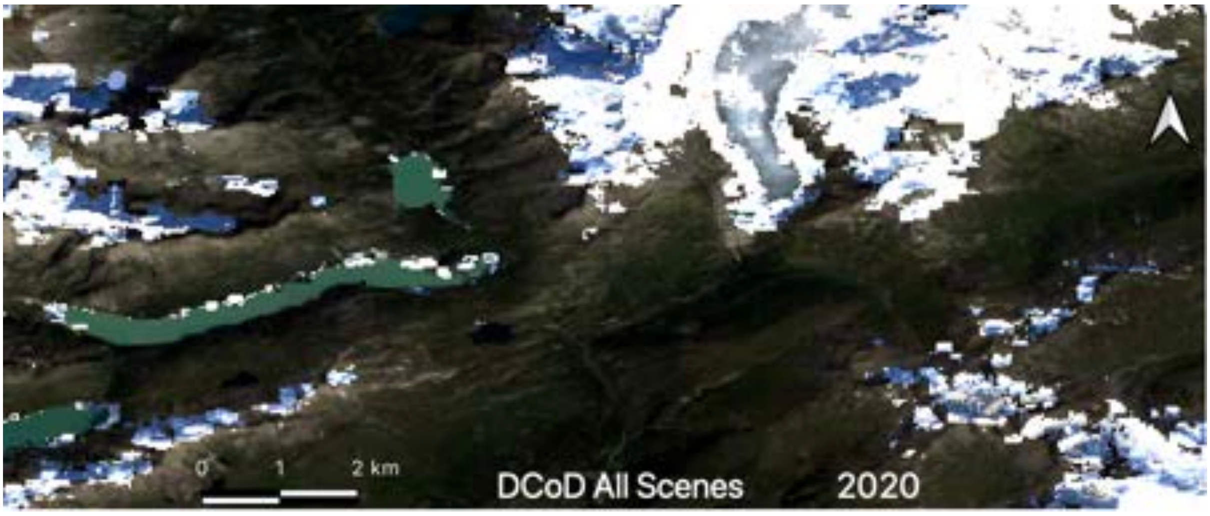

0 1 2 km
SEPAL Scenes Selected
2010

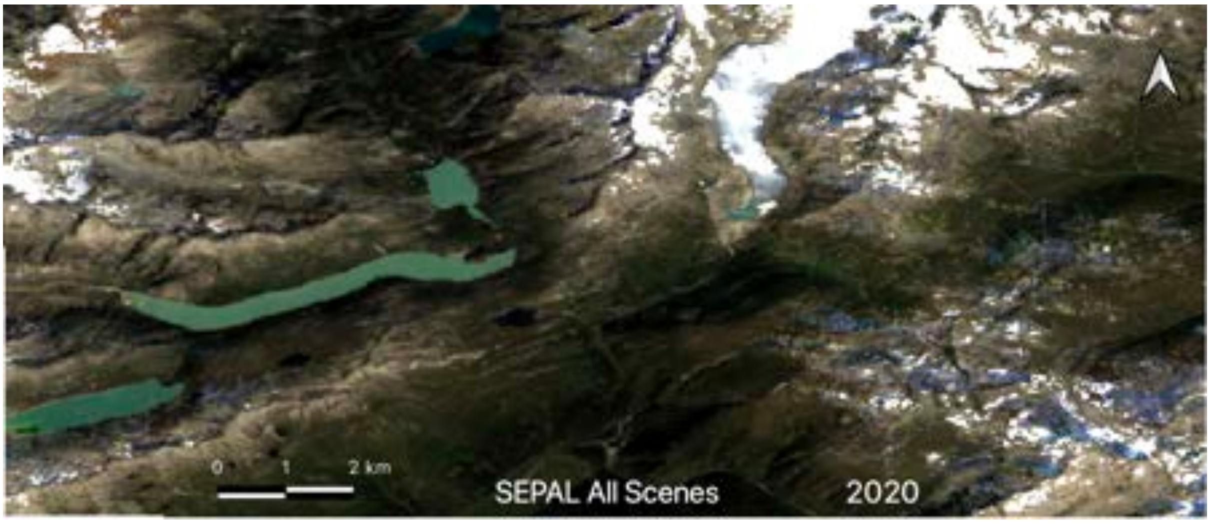

0 1 2 km
DCoD All Scenes
2015

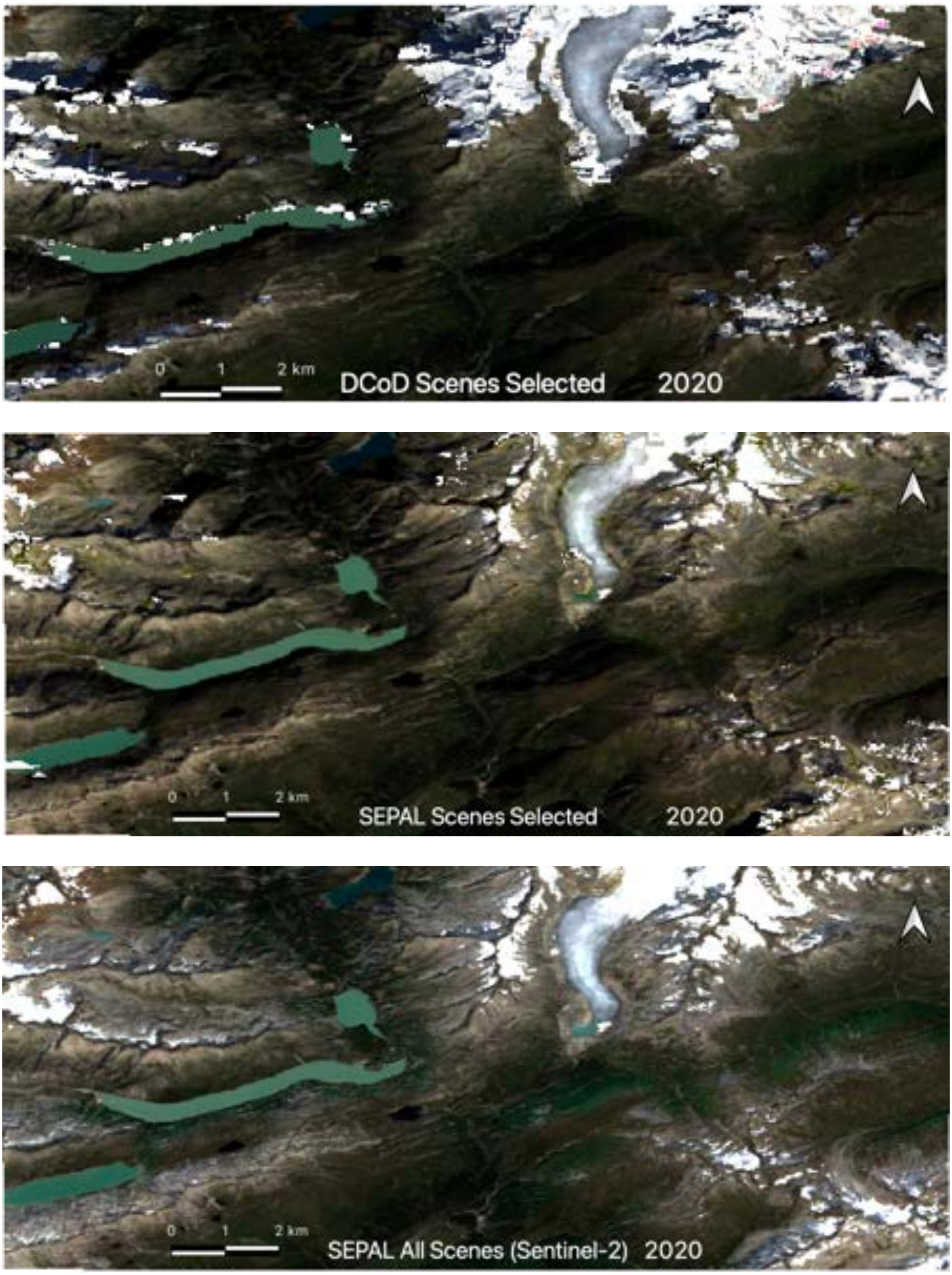

0 1 2 km
SEPAL All Scenes
2015


0 1 2 km
DCoD Scenes Selected
2015


0 1 2 km
SEPAL Scenes Selected
2015


0 1 2 km
DCoD All Scenes
2020


0 1 2 km
SEPAL All Scenes
2020


0 1 2 km
DCoD Scenes Selected 2020
0 1 2 km
SEPAL Scenes Selected 2020
0 1 2 km
SEPAL All Scenes (Sentinel-2) 2020


0
1
2 km
SEPAL Scenes Selected (Sentinel-2) 2020