- **Normalized Difference Water Index:**

$$\mathrm{NDWI} = \frac{\mathrm{Green} - \mathrm{NIR}}{\mathrm{Green} + \mathrm{NIR}} \tag{1}$$

The Normalized Difference Water Index (NDWI) is used to monitor changes related to water content in water bodies. As water bodies strongly absorb light in the visible-to-infrared range of the electromagnetic spectrum, NDWI uses green and near-infrared (NIR) bands to highlight water bodies. It can also be used for snow and ice coverage monitoring.(Sentinelhub, n.d.)

- **Normalized Difference Snow Index:**

$$\mathrm{NDSI} = \frac{\mathrm{Green} - \mathrm{SWIR}}{\mathrm{Green} + \mathrm{SWIR}} \tag{2}$$

The Normalized Difference Snow Index (NDSI) is a measure of the relative magnitude of the difference in reflectivity between visible (green) and shortwave infrared (SWIR) used to detect snow covered areas. (Sentinelhub, n.d.)

- **Normalized Difference Vegetation Index:**

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \tag{3}$$

The Normalized Difference Vegetation Index (NDVI) is a simple, yet effective index for quantifying green vegetation. It normalizes green leaf scattering in near-infrared wavelengths with chlorophyll absorption in red wavelengths. (Sentinelhub, n.d.)

- **Modified soil adjusted vegetation index:**

$$\mathrm{MSAVI} = \frac{2\cdot\mathrm{NIR}+1-\sqrt{(2\cdot\mathrm{NIR}+1)^2-8\cdot(\mathrm{NIR}-\mathrm{Red})}}{2} \tag{4}$$

The Modified Soil Adjusted Vegetation Index (MSAVI) works where other vegetation indices do not, for example during seed germination and leaf development stages. In this analysis, it was used to quantify the growth of vegetation where the glacier retreated.

2.3 Classification Methods

Techniques, such as unsupervised and supervised classification are useful for analysing the extend of glaciers and how it changes over time. Both methods have distinct advantages and limitations. Both the analysis with unsupervised and supervised have been performed using Python Notebooks on Google Colab.

- **Unsupervised Classification** Unsupervised classification involves the automatic grouping of pixels in a remote sensing image into clusters based on their spectral properties without prior knowledge or training data. The method used in this analysis is the k-means clustering algorithm. The strength of the unsupervised method is that there is no need of labeled training data and often it requires fewer computational resources compared to supervised methods. Drawbacks are usually a lower accuracy due to the lack of training samples and that the clusters are unlabelled, leading to difficulties in interpreting their meaning.
- **Supervised Classification** Supervised classification involves training a model using labelled training data. The Random Forest algorithm builds multiple decision trees using bootstrapped samples of the training data and averages their predictions to improve accuracy and robustness. Supervised methods usually have a higher accuracy due to the use of labeled training data that guides the algorithm. This also allows for higher control on the class definition, which is particularly useful when looking for some specific feature. However, the drawbacks are: the need of the labelled training data and higher computational complexity.(L. Biagi and Oxoli, 2024)

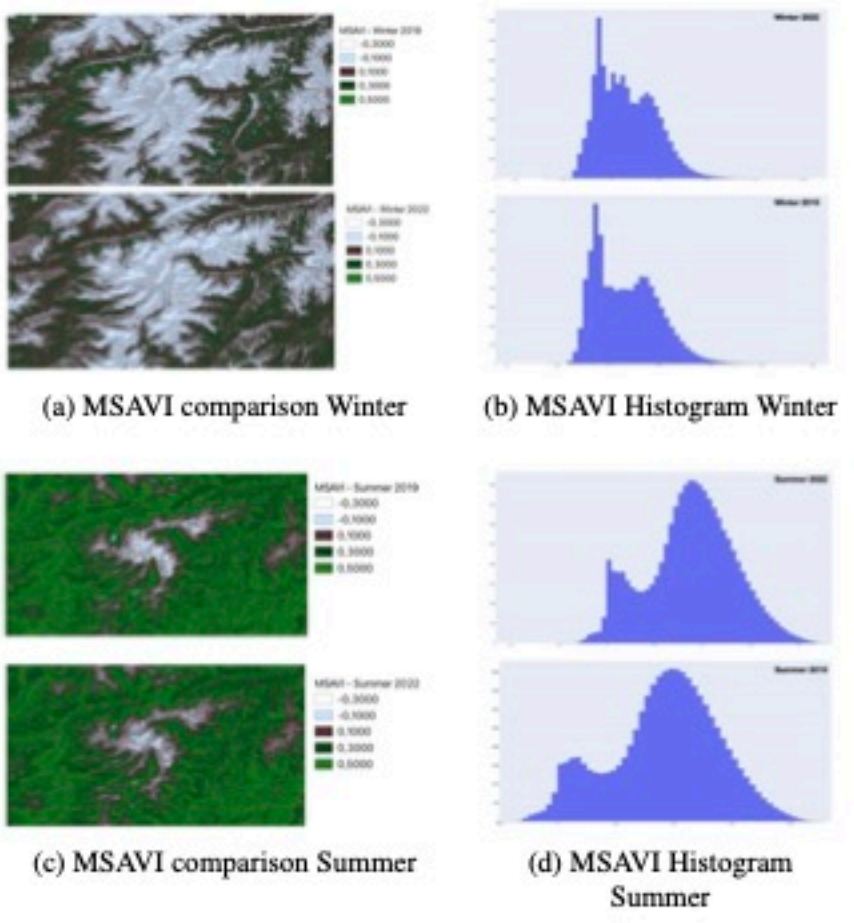
3. Results discussions

From the computation of the indices defined in 2.2 it is possible to gain insights into the changes in snow and ice cover (NDWI and NDSI), and changes in vegetation growth and healthiness (MSAVI and NDVI) over the considered time interval.

3.1 Spectral Indices

For vegetation monitoring:

- **Modified soil adjusted vegetation index:**



(a) MSAVI comparison Winter

(b) MSAVI Histogram Winter

(c) MSAVI comparison Summer

(d) MSAVI Histogram Summer

Figure 2. *Comparison MSAVI spectral index*

The MSAVI analysis, showed in Figure 2, have been carried out both in summer and in winter. The histograms suggest that while the overall vegetation health in the area remained relatively stable from 2019 to 2022, there are signs of increased variability and potential degradation in certain areas. The 2022 histogram shows more lower MSAVI values, indicating regions with reduced vegetation health or increased soil exposure. This could be due to the areas where the glacier retreated and the vegetation still didn't grow or area with rocks and with a low MSAVI values. From the images of the MSAVI we can also notice a retreat of the glacier, with a reduction of the ice coverage.

Assessing Change Detection of Adamello Glacier Using Sentinel-2 Images

Ellen Poli, 10728490

Politecnico di Milano, Geoinformatics Engineering

Abstract

This study focuses on monitoring glacier changes using multispectral satellite data from Sentinel-2. The Adamello Glacier is the largest glacierized area in the Italian Alps and is analyzed to assess glacier retreat and vegetative growth in areas where the glacier has receded. Various spectral indices, including NDWI, NDSI, NDVI, and MSAVI, were computed with GEE to enhance the features of the area. Two classification methods have been performed: one unsupervised, Kmeans, and one supervised, Random Forest using Python notebook. Both methods faces some challenges in divide in clusters the area and distinguishing melting snow from rocks, vegetation and urban areas. To improve classification results, different numbers of clusters were tested. The Random Forest classifier, benefiting from labeled training data, demonstrated higher accuracy and robustness in distinguishing different land cover types. Results indicated a decrease in glacier extent, with a difference in snow and ice coverage of $1,12\,\mathrm{km}^2$ *from 2019 to 2022. The spectral indices showed changes in snow and ice cover, with indices values indicating increased melting. These results underscore the importance of using both classification methods and spectral indices to monitor glacier dynamics and highlight the impact of climate change on glacial environments.*

1. Introduction

The Adamello massif, with a maximum altitude of 3539 m a.s.l., is located in the eastern part of the Central Italian Alps. It includes the Adamello Glacier, that belongs to two different regions: the Lombardia region and the Trentino-Alto Adige region. The Glacier surface had an extension of $16.30\,\mathrm{km}^2$ in 2007 that is retreating fast in the last years. (wikipedia, 06.2024) Figure 1 shows the location and boundaries of the study area. The Adamello Glacier is the largest glacierised area in the Italian Alps and consists of five hydrographic units, the major in size being the Mandrone Glacier. (Roberto Ranzi, 2010) European Union studies have proven that glaciers have retreated by about 200 meters from 2016 to 2023 due to the effects of global warming.(UE, 08/09/2023)

Figure 1. *Study area*

The primary objective of this analysis is to determine the extent of the glacier's retreat from 2019 to 2022. The secondary objective is to assess the vegetative growth in areas where the glacier has receded.

2. Materials and method

2.1 Data

For this analysis, Sentinel-2A satellite data for the years 2019, 2022 were directly downloaded from Google Earth Engine (GEE). Sentinel-2 is an ESA mission and part of Copernicus program. It constitutes two satellites launched into orbit in June 2015 (Sentinel-2A) and March 2017 (Sentinel-2B). A new mission is planned for September 2024 (Sentinel-2CC). Sentinel-2 missions are aimed at acquiring Multi-spectrum images in 13 bands and with a resolution of 10, 20 and 60 m. It collects passive sensor imagery and the revisit time is of 5 days.

Data from both summer and winter seasons were selected to provide an overview of seasonal variations. The selected images are characterised by less than 5% of cloud coverage to ensure minimal interference from clouds. Most of the data does not contain clouds therefore, in most cases, cloud masking has a low impact on the images. Therefore the cloud coverage processing haven't been applied.

2.2 Spectral Indices

All spectral indices presented in the following were computed with GEE. A spectral index is a mathematical combination of wavelengths designed to enhance the information content of imagery data. These indices are useful for extracting specific features or properties of the Earth's surface, such as vegetation density, soil moisture, or water quality (Adisa, 23/04/2023) (L. Biagi and Oxoli, 2024). For the aim of the analysis, evaluating snow surface and vegetation growth, the following spectra indices have been selected: