Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 36, 2024, Sofia

DOI: https://doi.org/10.3897/arb.v36.e09

APPLICATION OF SATELLITE DATA FOR MONITORING THE RETREAT OF MOUNTAIN GLACIER *MORTERATSCH*, SWISS ALPS, OVER A PERIOD OF 51 YEARS

Andrey Stoyanov

Space Research and Technology Institute – Bulgarian Academy of Sciences
e-mail: andreiikit@space.bas.bg

Keywords: *Glacier monitoring, Satellite data, Landsat, Sentinel-2, Global Warming*

Abstract

The presented study aims to apply a method for monitoring the retreat of mountain glaciers in the Alpine region of the Swiss Alps, which consists of using optical satellite imagery and their spectral capabilities to observe snow and ice objects on the earth's surface. Satellite imagery with its big legacy archive dating back to 1972 for Landsat imagery, can be of big help to track and monitor the alpine glaciers retreat for long periods and serve as a database for modelling and predicting the glaciers retreat in the future. By combining different satellite data processing approaches, results have been obtained on the spatial distribution and dynamics of the Morteratsch Glacier over a period of 51 years. The focus of the study is to track the changes that have occurred along the positions of the ice front (terminus) in the glacier's ablation zone to obtain information about the glacier's dynamics during the study period.

Introduction

The negative effects of climate change and global warming are rapidly increasing every year worldwide, including natural phenomena such as heat waves, droughts, extreme rainfalls, floods, rockfalls, etc. These consequences of Climate Change are happening twice as fast, especially in the Alpine region [1], where events such as glacier recession, reduction of snow cover, and rockfalls (driven by the permafrost thaw) are observed.

The retreat of glaciers is well documented and is one of the major negative effects of climate change. It provides evidence for the rise in global temperatures since the late 19th century. Glacier retreat impacts the availability of freshwater supplies for irrigation and domestic use, river runoffs, mountain recreation, and animals and plants depending on glacier melt [2].

Because of the long history of optical satellite imagery of the Earth, satellite remote sensing offers a wide variety of opportunities for mapping glacier recession. With repeated images over time satellite remote sensing allows for the regular monitoring of glacier surface elevation, velocity, area, length, equilibrium line altitude, terminus position, and more [3].

Area of interest

The Morteratsch Glacier [Fig. 1] is the largest glacier by area situated in the Bernina Range of the Bündner Alps, Switzerland, at an altitude starting from 2040 m and reaching up to 4048 m of Piz Bernina peak. It is located in the strongly glaciated Bernina Range on the border with Italy [4]. Morteratsch is a typical valley glacier with a distinct *terminus* and its *accumulation zone* lies between the peaks of Morteratsch, Bernina, Zupò, and Bellavista. Yearly length change measurements have been recorded since 1878, when its maximum length was 8,63 km, while in 2023, it was 5,59 km [5, 6].

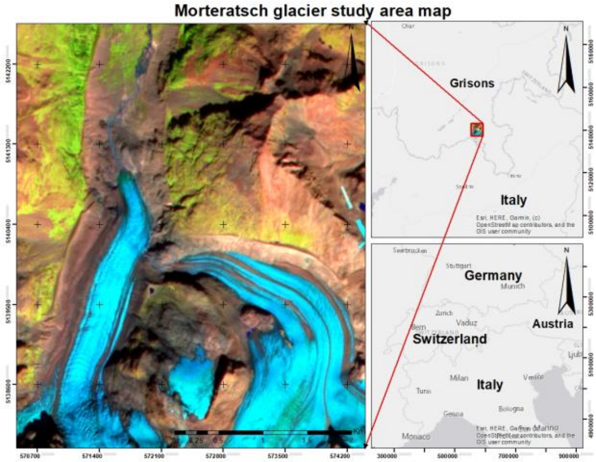

Fig. 1. Area of interest

Method and processing steps

The proposed approach in the present study involves processing of collected optical cloudless satellite datasets within the selected time frame of several missions: Landsat 1-2 MSS [8], Landsat 5 TM[8], Landsat 8 OLI [8] and Sentinel-2 MSI [9]; creating RGB pseudo-composites [10] by using the Green, NIR and MIR bands of each satellite image (except Landsat 1-2); applying of Normalized Differential Snow Index (NDSI) as reference and measurements, through GIS techniques, focused on the changes that occurred in the *terminus* position of Morteratsch glacier over the period of 51 years. Additionally, the changes that occurred in the size, length, and width of its *ablation zone* are calculated using GIS tools. Tracking the change in the location of a glacier *terminus* is a proof method of monitoring a glacier's movement based on the differences in positions of the terminus measured from fixed positions at different time intervals [7].

Data use

All the temporal points of the chosen temporal period are collected during the late-summer time around the last decade of August and the first two decades of September, with the exception of the year 1972. The criteria for this selection of the year are due to the past maximum solar radiation and new and fresh snowfall typical of this altitude, which is yet to come. All the collected satellite images within the timeframe (Table 1) are processed in a GIS environment.

Table 1. Satellite datasets for the time frame of the study

Satellite, sensor	**Acquisition date**	**Spectral bands**	**Resolution** (m)
Landsat 1-2 MSS	07.10.1972 13.09.1975 04.09.1980	visible, NIR	60x60
Landsat 5 TM	20.08.1985 12.09.1990 16.08.1995 22.08.2000 05.09.2005 25.08.2010	NIR, SWIR, Green	30x30
Landsat 8 OLI	10.08.2013	NIR, SWIR, Green	30x30
Sentinel-2 MSI	26.08.2015 09.09.2016 30.08.2017 09.09.2018 04.09.2019 08.09.2020 13.09.2021 24.09.2022 08.09.2023	NIR, SWIR, Green	10x10 20x20

Results

Landsat 1-2 MSS RGB pseudo-composite 3D maps with a combination of NIR-NIR-Green bands delineating the glacier territory are shown in Fig. 2, where the temporal point of 1972 year serves as a starting point (and as fixed position of subsequent measurements) on the selected study period. The retreat of the glacier ice terminus for the 1972–1980 period is estimated at about 258 m.

Fig. 2. Landsat 1-2 MSS RGB composites from 1972, 1975 and 1980 year

Landsat 5 TM RGB pseudo-composites 3D maps with band combination SWIR-NIR-Green for the 1990–2000 period are shown in Fig.3. The change of the glacier terminus of the period 1980–1990 is estimated approximately at 128 m and for the 1990-2000 period at 146 m, respectively.

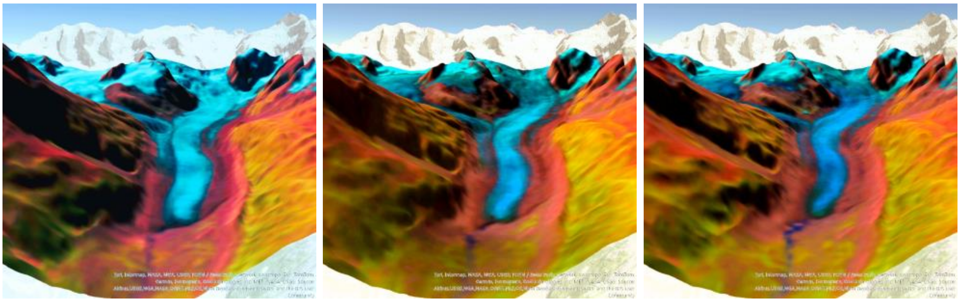

Fig. 3. Landsat 5 TM RGB composites from 1990, 1995 and 2000 year

Landsat 5 TM and Landsat 8 OLI RGB pseudo-composites 3D maps with band combination SWIR-NIR-Green (2005–2013) are shown in Fig. 4. The change of the glacier terminus for the decade 2000–2010 is estimated at 459 m, with a maximum loss of 260 m for the period 2005–2010.

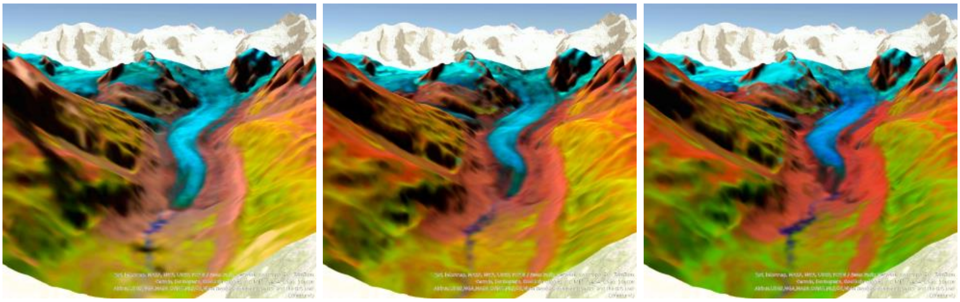

Fig. 4. Landsat 5 TM RGB composites from 2005, 2010 and Landsat 8 OLI - 2013 year

Sentinel-2 MSI RGB pseudo-composites 3D maps with band combination SWIR-NIR-Green for the years 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, and 2023 are shown in Fig. 5, 6, 7.

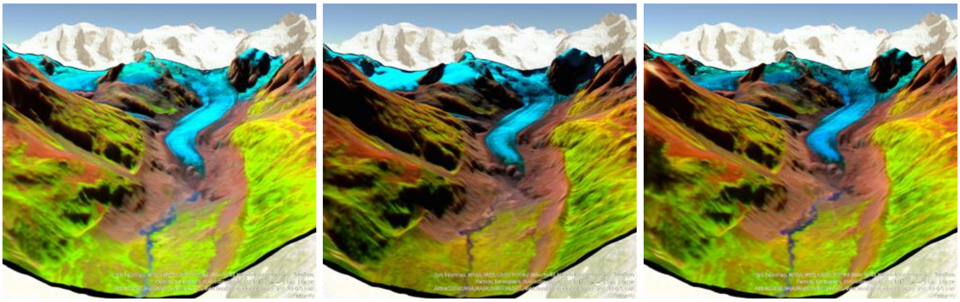

Fig. 5. Sentinel 2 MSI RGB composites from 2015, 2016 and 2017 year

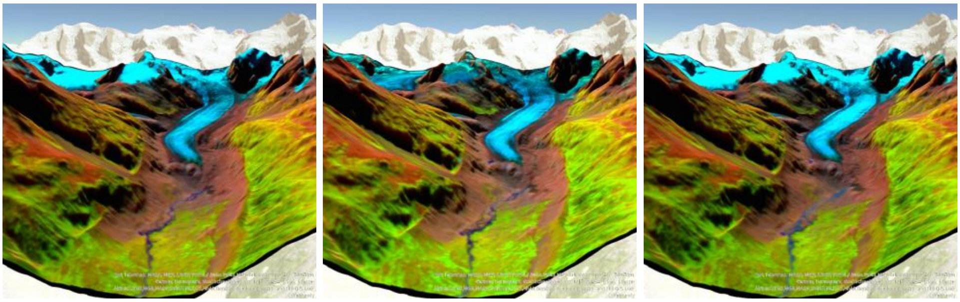

Fig. 6. Sentinel 2 MSI RGB composites from 2018, 2019 and 2020 year

The retreat of the glacier ice front for the period 2010–2015 is estimated at 385 m, for the period 2015–2019 is 240 m, and for the period 2019–2023 is 109 m.

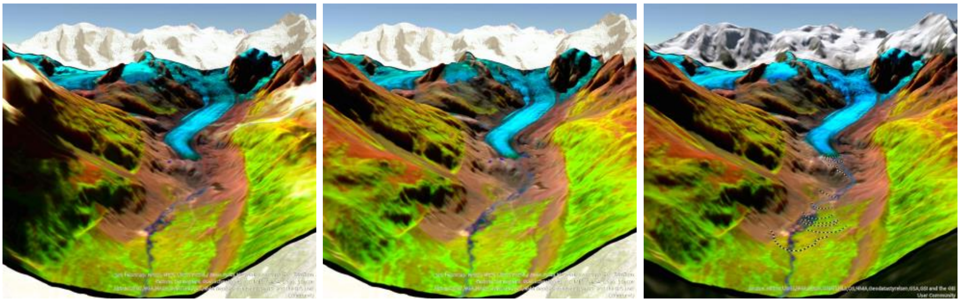

Fig. 7. Sentinel 2 MSI RGB composites from 2021, 2022 and 2023 year

Fig. 8 marks and graphically presents the positions of the glacier terminus and the changes that occurred in the length of Morteratsch from 1972 to 2023. The major retreat at a distance of about 844 m between 2000 and 2015 is easily visible.

The total change length of the Morteratsch terminus during the study period was approximately 1704 m. In addition, the width of the glacier measured in conjunction with Pers glacier has decreased by 582 m, and the area of the ablation zone (measured below the altitude line of 2600 m near the equilibrium line) of the glacier has seized approximately 2,37 km^2.

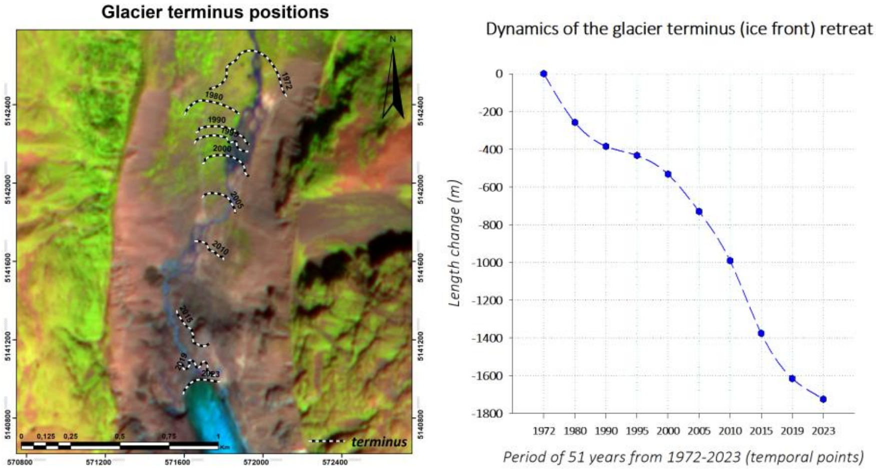

Fig. 8. Glacier terminus positions during the period 1972-2023 and graphic of its length change in m

The area size of the glacier ablation zone that decreased throughout the study period according to the processed data is presented as follows in Table 2.

Table 2. Changes in the area of the Morteratsch ablation zone during the study period

Year of the study period	Area in km^2
1972	3,41
1990	2,16
2000	1,62
2010	1,11
2020	1,06
2023	1,04

Conclusion

During the entire study, the temporal trend of the glacier dynamics was negative, with a change length of -1704 m. Until the year 1980, the retreat of the terminus was 258 m, showing a high melting rate, while for 1980–1990, the rate was slowing to 128 m per decade. For the period 1990–2000, the dynamics of the retreat were still keeping a slow movement of 146 m per decade. During the decade 2000-2010, the dynamics had a huge movement of 459 m, and the negative trend increased to nearly 630 m for the decade 2010–2020. Of the total length of 1704 m of the Morteratsch terminus retreat in a period of 51 years, nearly 1200 m of it has melted in the last 23 years, showing a trend of 52 m per year on average and around 550 m per decade.

Acknowledgments

This work was partially supported by the Bulgarian Ministry of Education and Science under the National Research Programme "Young scientists and postdoctoral students-2" approved by DCM 206 / 07.04.2022.

References

1. https://creamontblanc.org/en/climate-change-and-its-impacts-alps/
2. Lee, E., Carrivick, J.L., Quincey, D.J. *et al.* (2021), Accelerated mass loss of Himalayan glaciers since the Little Ice Age. *Sci Rep* 11, 24284. https://doi.org/10.1038/s41598-021-03805-8
3. https://www.antarcticglaciers.org/
4. https://www.glamos.ch/en/factsheet#/E22-03
5. GLAMOS 1881-2023, The Swiss Glaciers 1880-2022/23, Glaciological Reports No 1-142, Yearbooks of the Cryospheric Commission of the Swiss Academy of Sciences (SCNAT), published since 1964 by VAW / ETH Zurich, doi:10.18752/glrep_series.
6. https://www.swisseduc.ch/glaciers/morteratsch/2005-2006/index-en.html
7.https://web.archive.org/web/20060903035209/http://www.glaciers.pdx.edu/MRNP/Res00.html5. http://www.codeblocks.org/

8. https://earthexplorer.usgs.gov/
9. https://dataspace.copernicus.eu/
10. https://eos.com/

ПРИЛОЖЕНИЕ НА САТЕЛИТНИ ДАННИ ЗА МОНИТОРИНГ НА ПЛАНИНСКИЯ ЛЕДНИК MORTERATSCH, ШВЕЙЦАРСКИ АЛПИ, ЗА ПЕРИОД ОТ 51 ГОДИНИ

А. Стоянов

Резюме

Представеното изследване има за цел да приложи метод за наблюдение на намаляване територията на планински ледник в алпийския регион на Швейцарските Алпи, който се състои в използване на оптични сателитни изображения и техните спектрални възможности за наблюдение на снежни и ледени обекти на земната повърхност. Сателитните изображения със своя голям натрупан архив, датиращ от 1972 г. за изображенията от Landsat, могат да бъдат от голяма помощ за проследяване и наблюдение на намаляването на алпийските ледници за дълги периоди и да служат като база данни за моделиране и прогнозиране на динамиката на ледниците в бъдеще. Чрез комбиниране на различни подходи за обработка на сателитни данни са получени резултати за пространственото разпределение и динамиката на ледника Morteratsch за период от 51 години. Фокусът на изследването е да се проследят промените, които са настъпили по протежение на ледниковия език в зоната на *топене* на ледника, за да се придобие информация относно динамиката на ледника за изследвания период.