Observation and Forecast of Glacier Shrinkage at the Hintertux Glacier

Abstract

The global warming is changing earth's environmental situation. Humanity observes temperature rises, weather changes and glacial shrinkage. In this context glaciers play a tremendous role since they are an important freshwater reservoir and habitat for many species. These aspects also concern the Hintertux glacier, both as a natural habitat for a variety of creatures and as a tourist attraction in the form of a year-round ski area. Accordingly, it is a decisive question whether and how long the Hintertux glacier will still exist.

The recent development on the glacier was analyzed, using Landsat satellite data from 2013 to 2019. For this purpose, the data was first topographically corrected, which meant reprojecting the data, cropping the data to the area of interest, removing disturbing shadows and calculating the NDVI. Subsequently, a supervised classification was carried out with the prepared data, whereby the training sites were created manually, and the random forest model served as a basis. The size of the glacier was then derived from the classification and the corresponding classes for snow and ice.

From 2013 to 2019 the area of the Hintertux glacier decreased about 105.3 ha from 828.45 ha to 723.42 ha. This corresponds to a reduction of the area by 12.68 %, on average this results in 17.51 ha per year. For a forecast, the calculated values were applied to a linear and a logarithmic model, as the values for both showed useful approaches. The disappearance of the glacier is predicted by the linear model for 2061 and by the logarithmic model for 2034.

Finally, it becomes clear that the Hintertux glacier is melting and that the time of its disappearance will be roughly in the period of the years calculated by the models.

1. Introduction

About one third of the ice mass in the Alps disappeared over the last 150 years (Greenpeace n. d., p. 5). In 1995 Haeberli and Hoelzle published a paper including a pilot study about the European Alps. According to this research, the total glacier volume in the Alps was estimated at about 130 km^3 in the 1970s. In the following 20 years 10–20 % of the total volume disappeared. Furthermore, 50 % of the Alpine ice mass has melted since the 1950s (Haeberli and Hoelzle 1995).

As huge freshwater reservoirs and habitat of a variety of animals, glaciers play a very important role in the global system. Furthermore, the Alps are an economic resource. Our research area, the Hintertuxer glacier is a touristic ski resort for example. It has an allover slope length of 26 km. The eight lift system can transport a maximum of 12.410 people/h. With around 8.000 guest beds the region is a booming tourism resort (Zillertaler Gletscherbahn GmbH & Co KG 2014, p. 14). However, the resort is at risk. Either tourists are going to dispense with skiing or operators will be depend on artificially generated snow. This in return would cause an impairment of the natural habitat. One way or another, there will be a two-tier society that separates higher situated skiing areas from lower resorts that are going to run out of natural snow and ice (Österreichischer Alpenverein 2005, p. 16). The disappearance of natural ice and snow would cause tremendous floods followed by a lack of freshwater and a loss of biodiversity. Resulting from this, a rise of the sea level would cause global changes. The fast melting would uncover rock walls that could initiate in landslides and would threat civilization and nature (Greenpeace n. d., p. 14).

Due to the massive and meaningful consequences of glacial melting and also the general interest in skiing at the Hintertux region, we set the aim of the study. With this research we wanted to find out how the Hintertux glacier has changed in the recent past regarding its size. In addition, we wanted to venture a forecast of how the size of the glacier will change in the future. Despite that, the use of our methods is neither limited to the area of the examined glacier nor the chosen time period. They could be used for different regions, different times as well as different data sources. Therefore, it is also possible to expand this model of the Hintertux glacier in the future with more recent data and specify the forecast or compare it to other glaciers. Our work could be used to analyze glaciers automatically with aerial photos rather than collecting complex data manually over a long time period. Besides, the data used is open source, so this work can be rebuilt and expanded by researches based on it.

Following up on the study of Haeberli and Hoelzle in 1995, which based on data from regional glacier inventories collected by Haeberli and others, the European Geoscience Union (EGU) constructed a model of the Alps based on the Open Global Glacier Model (OGGM). The OGGM "can simulate past and future mass-balance, volume and geometry of (almost) any glacier in the world in a fully automated and extensible workflow" (Maussion et. al. 2019, p. 1). With this model the EGU foretold the loss of volume and area of glacial ice in the whole Alps region in the upcoming 80 years as shown in illustration 1.

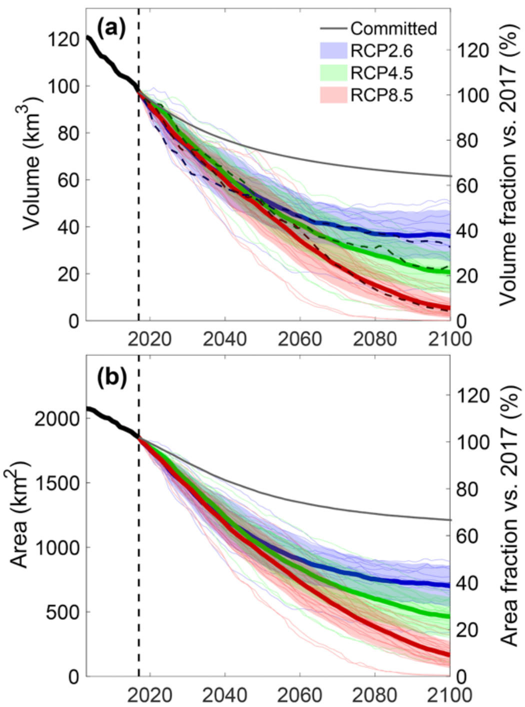

Illustration 1: showing a forecast for the (a) volume and (b) area of the glaciers in the European Alps (Zekollari, H. et. al. 2019)

None of the previous elaborations use aerial photos for analysing glacial areas and none show a result for only a single glacier. Even if the single display would theoretically be possible with the OGGM we wanted to work out a transparent way to analyze aerial photos. We came to our research issue: "Is the Hintertux Glacier shrinking?". By the current state of the art it is nearly obvious, that Alpine glaciers are shrinking. We wanted to determine the development of the glacier regarding its area, concerning the past as well as the future based on the hypothesis that the area of the Hintertux glacier will decrease in the future. This overarching question gave rise to further questions which we also wanted to answer with our study which is why our research refers to both the assumption above and the questions: "How fast is the glacier decreasing?", "When might there be no more ice and snow on the Hintertux glacier?" and "When is the glacier going to be melted away?".

In order to be able to make statements about the development of the glacier, the area has to be calculated using a classification based on the random forest model. Before starting the classification, a topographical correction had to take place in order to achieve valid results. In this context the data had to be cropped to the area of interest, the NDVI calculated, shadows had to be removed and projections adjusted.

Research was conducted in R, except for the training sites and a shapefile for cropping on the area of interest, which were created in QGIS. The main workflow can be done using a single script, the "analysis.R" script, which uses methods from several other scripts. The corresponding repository and README.md are available on github.

2. Methods

Initially, we looked for data that might be suitable for our study. Therefore, we tested Landsat-, Sentinel- and Aster-data. Our need was to have datasets which include the visible infrared and thermal bands to be able to make statements on the condition of the ice on the glacier. That's why we decided to use Landsat data because all the above mentioned bands and more are available via the earthexplorer. We decided on using “Landsat 8 OLI/TIRS C1 Level-1”-data which is available with suitable data for our area from 2013 to now (USGS 2017).

The next step was to find cloud-free datasets. Therefore, we searched the Landsat data and decided for datasets in 2013, 2016 and 2019 so that a regular time step between the data is given. Currently this is currently the highest possible range for the Landsat-data. We focused on the months August and September because at this time of the year the snow level is the lowest and the observation can be focused on the ice.

In addition we used a digital elevation model (DEM) with a precision of 10 m for our calculations, which we cropped on our observation area by the “prepareDEM.R”-script.

Our workflow started with the need that the data had to be locally available. Therefore we downloaded the data by the “downloadLandsatData.R”-script using the getSpatialData-package, but after several attempts, we determined that we could not get the data the way we needed. We have not found a way to formulate the request, so that our required data will be exactly delivered as described above. That is why we decided to download the data independently from the earthexplorer. A detailed description for this process can be found in the repositories README.md.

The next step was a topographic correction of the data. This was implemented by the “preparation.R”-script. First the three visible bands (red, green and blue), the infrared band and the thermal band got extracted. Then they got reprojected on the same projection “WGS84 / UTM zone 33N” with the help of the raster-package, followed by a crop on our area of interest, the Hintertux glacier. This was a rough cut, as there should still be sufficient areas and corresponding classes for a valid classification. We noticed that in mountainous areas the shadows on the satellite pictures distorted the actual image and thus also our investigation. To solve this problem we decided to remove the shadow by using functions of the raster- and satellite-package. For this process we needed the DEM which was mentioned before. The preparation was finished by bringing the different bands together in one stack. In addition to the bands mentioned above, the NDVI, which we calculated before, was also included in the stack.

The next decisive step was the classification. Therefore, training sites were needed, which we created in QGIS 3.10. A detailed description on our process of how we created the training sites can be found in the README.md on github. We decided to train a model for only one dataset and reuse it for the classification of the others. Because we used the same type of data for every year the pixel values should stay the same for the classification of each dataset. On basis of the training sites created with a dataset dated 27.08.2019 in QGIS we trained a model by the “trainModel.R”-script. For the training which is based on Geostat2018 practice the packages raster, sf and caret were used. During this step the random forest model was applied, as this fits in well with our area of investigation. The resulting model is available in our repository on github. Finally the model was used to classify the whole area of each dataset (“classification.R”-script).

After the classification the next task was to calculate the area of the glacier. Therefore the section to be considered was cropped by a shape-file which was created in QGIS, exactly adapted on the area of the Hintertux glacier. It was assumed that at the time of year when the satellite images were taken, the glacier consists of the area where ice is visible and the area where snow is visible. The assumption was that wherever there is snow, there is also glacier under the snow. So, the area of the glacier is composed of the ice and snow surface. We added up the pixels classified as ice and snow and multiplied them by the number 900, because one pixel is sufficient for an area of 30 m × 30 m . This gave us the first result, as the area of the Hintertux glacier in the respective year was calculated.

In order to make valid statements about the development, the results of the different years have been put into context and output with different plots (“prediction.R”-script). In addition, past data was used for a forecast and applied to two different models. Therefore, on the one hand a linear model was used and on the other side a logarithmic model. Various models were used to forecast the various possible courses for the future. The results were plotted and calculated to detect how the Hintertux glacier will develop in the future.

3. Results

As results we got the area of ice and snow at the Hintertux Glacier from every considered year.

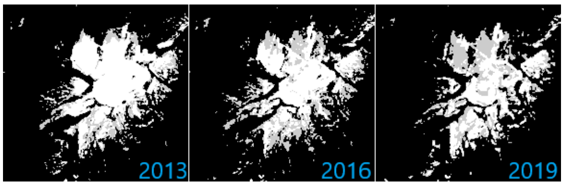

Illustration 2: classification and development of the snow (white), ice (gray), other (black) area in the regarded years (own illustration)

In 2013 we calculated an area of 828.45 ha ice and snow at the Hintertux Glacier. 2016 there were 799.02 ha and in 2019 723.42 ha. That’s a decrease of 29.43 ha from 2013 to 2016 which conforms 3.55 %. With 75.6 ha from 2016 to 2019 the decrease amounts 9.46 %. In total this is a decrease of 105.3 ha or 12.68 % in the six years from 2013 to 2019.

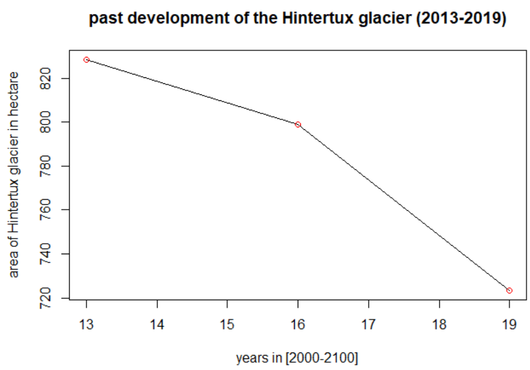

Illustration 3: ice and snow areas at the Hintertux glacier - red dots were calculated within the research (own illustration)

In average a decrease of 17.51 ha per year took place. With this value we got a linear function

$$f(x) = -17.51 \times x + 1063.71$$

which is illustrated in the following figure. In this function the x-axial-intersection-point is at x = 60.766.

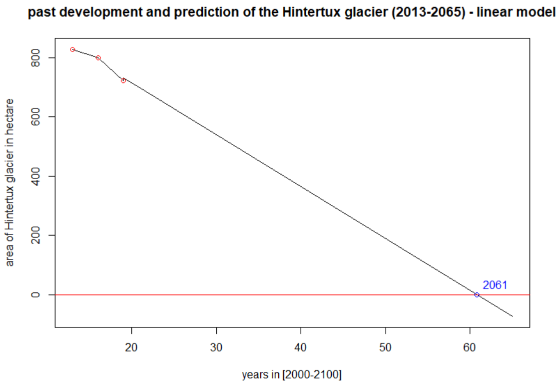

Illustration 4: predicted linear model of the Hintertux glacier development until 2065 (own illustration)

Additionally, a logarithmic model was generated

$$f(x) = -1192.2 - 99.1 \times x - 1290.1 \times (-\ln(x))$$

In this model the x-axial-intersection-point is at x = 33.8.

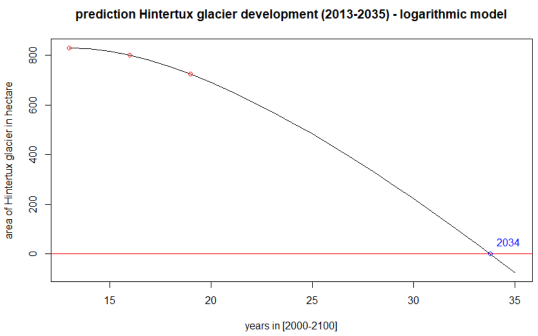

Illustration 5: predicted logarithmic model of the Hintertux glacier development until 2035 (own illustration)

4. Discussion

With the results obtained, the fundamental research question can be clearly answered. The Hintertux Glacier is shrinking and lost about 12.68 % of its area from 2013 to 2019. This result in an averaged loss of area of about 17.51 ha per year. Using this average, one assumes a linear shrinkage of the glacier. However, a logarithmic trend can also be seen from the data collected from 2013 to 2019. With this aspect in mind, we have decided to calculate a linear as well as a logarithmic model to answer the research question of when the glacier may no longer exist. As expected, the results show, that the glacier is going to melt faster according to the logarithmic than to the linear model. Corresponding to the linear model, there is going to be no ice and snow from about August, September of 2061. Using the logarithmic model, however, there is going to be no ice and snow in the late summer of 2034. This suggests that the glacier will have melted in the corresponding year. It should be noted that these are forecasts. It is not possible to commit to either model, but it can be stated that the development will roughly be within this range.

To optimize our model, we could add some more detailed information about climate change over the examined decades. Some researches already built this connection (for example Oerlemans, J. 2005 or Cannone, N., Diolaiuti, G., Guglielmin, M., Smiraglia, C. 2008). Because “in the European Alps the increase in air temperature was more than twice the increase in global mean temperature over the last 50 years” (Cannone, N. et. al. 2008) we could say that the climate change plays a main part in the interaction with glacial shrinkage.

We have to emphasize that other parameters could also have been included in the investigations. For this purpose, the elevation models of the different years could have been included in order to calculate not only the area but also the shrinkage in height of the glacier. This would allow statements to be made about the volume and not only about the area. With knowledge about the thickness of the ice, predictions about when it will melt would be even more precise.

In addition, one has to consider that the forecast had a data basis of only 6 years, since Landsat data is only available from 2013 onwards and is only suitable for our research within this framework with regard to its quality.

Furthermore, the use of smaller training areas within the classification can lead to even more accurate results.

In view of the comparable studies mentioned above, it is shown that our research fits into this category. Our models cannot be transferred directly to other glaciers, as the development depends on different parameters, but they still give a rough course for glaciers in similar positions and with similar parameters.

The forecast of the EGU (Illustration 1) compared to our forecasts (Illustration 4 and 5) shows that they are different but still a similarity can be seen. With more data and information, the two models may move closer together and our model would become more precise. Still it shows a possible progress of melting ice at the Hintertux glacier.

5. Conclusion

With the previously presented methods, which are mainly based on topographic preparation of the data and a classification of Landsat satellite images, it was clearly established that the Hintertux glacier is melting. It has been calculated that between 2013 and 2019 the average melting rate was a loss of area about 17.51 ha per year. Further, a disappearance of the glacier was predicted for 2061 by the linear model and for 2034 by the logarithmic model.

In Hintertux the glacier takes over important functions. On the one hand, it stands out as an attraction for tourism, as the glacier enables a skiing area with year-round operations and on the other side, the glacier is a natural habitat for a variety of species. If the glacier is going to melt like it was predicted, these functions would be lost without an intermediate-term detectable replacement.

However, certain limitations of the study must be taken into account. With regard to the forecasts, there may well be certain deviations, as these are only based on a database of three Landsat satellite images from three years over a period of six years. Nevertheless it is possible to carry out the calculations of the study again without any major effort as soon as a higher number of usable satellite images is available, to verify the results with a larger data basis. The repository with a corresponding readme offers a pleasant and ready to use possibility.

With the completion of the study, the questions of whether the Hintertux glacier is going to melt, how fast it will melt and when it will be gone, have been answered, even if this answer contains a certain inaccuracy. Subsequently, a follow-up study would make sense to reduce this imprecision by further calculations. Suitable examples for these calculations are the use of additional satellite images, the influence of elevation data and other data as described above.

Furthermore, another field of research opens up to find the reasons for glacier retreat, not only at the Hintertux glacier but in the Alps and the whole world in general.

Individual Contribution

The research work was part of the Study project "Remote sensing based analysis of environmental change" in the winter term 2019/2020 at the Institute for Geoinformatics at the university of Muenster.

The three people involved in the work were Lukas, Tom and Jan. Research was done in two meetings per week.

The focus of Jan and Tom was more on implementation. Jan first searched for possible useful methods in QGIS, while Tom was looking for a way to easily integrate the satellite data into R. Once a basic approach was decided upon, the team members were almost entirely working together as they complemented each other in terms of knowledge. After implementation, the applied methods, results and interpretation were transferred by the two group members to the paper.

Lukas mainly provided background information on the research topic, such as possible approaches and data sources, throughout the entire period, as well as he did the connection of our paper to other papers including the investigations.

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