CLIMATE CHANGE IN THE FRIBOURG PREALPS

A CASE STUDY IN THE TISSINIVA REGION

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1 Acknowledgements

I would like to express my gratitude to Mr Jacques Ruffieux, the mountain farmer of the Tissiniva mountain pasture, for allowing me to install my equipment on his land, for welcoming me, and for taking the time to answer my questions. I would also like to sincerely thank my teacher, Mr Sébastien Morard, for his invaluable assistance in setting up the weather station and for his help in collecting data. I am also deeply grateful to my expert, Mr Léonard Schneider, for his support throughout the Swiss Youth in Science competition and for his insightful advice. Finally, I would like to express my heartfelt thanks to my dad, who accompanied and assisted me in the field on numerous occasions.

2 Abstract

Observations indicate that the Swiss Alps are experiencing significant changes due to global warming, such as reduced snowfall, rising temperatures, and altered precipitation patterns. This research project looks at climate change in the Fribourg Prealps, focusing on the specific case of

the Tissiniva mountain pasture. The aim is to gain a better understanding of the environmental, economic and human consequences of climate change at a local level. To this end, a methodology combining three approaches has been used: analysis of long-term meteorological data from MétéoSwiss (Moléson and Château-d'Oex stations), the installation of measuring instruments in the field (weather station and snow pole), and an interview with a local stakeholder, Mr Jacques Ruffieux, who runs the Tissiniva mountain pasture. The results indicate an increase of 2°C of the annual mean temperature between 1983 and 2023, a decrease in snow cover of around 60 cm over the same period, and earlier snow melt. In addition, water scarcity on the mountain pastures was observed, requiring deliveries by helicopter in 2022. The analysis also shows that Temperatures have risen more in summer than in other seasons, and that climate change at medium altitudes is more pronounced than the national average. These observations confirm the initial assumptions, such as a decrease in snow cover and an increase in temperatures, although some results differ from the expected models, notably an increase in summer precipitation where a decrease was predicted. One way to further the study would be to analyse how reduced snow cover and changes in precipitation distribution affect access to water. Finally, this study highlights the vulnerability of traditional agricultural practices to climate change and underscores the need for local adaptations.

Figure 1:Map showing the location of Tissiniva

3 Introduction

Global warming is one of the major challenges of the 21st[e] century, with major effects on natural and human systems: rising sea levels, extreme weather events, reduced biodiversity and changes to water regimes (IPCC 2022). These impacts manifest themselves on a global scale but understanding them on a local scale is essential if we are to develop targeted and effective adaptation strategies (UNPD 2024). Switzerland's mountain regions are particularly sensitive to climate change. In the Alps, melting glaciers, more unstable slopes, more wet avalanches and shorter snow cover are affecting ecosystems and human activities, particularly winter tourism, which represents a key aspect of the Swiss culture and provides thousands of jobs. These effects can also be seen in the Prealps, a mid-range mountain range stretching from Lake Geneva to the canton of St. Gallen. This region has been warming markedly since the 19th century, and climate projections indicate that this trend will continue and even intensify (NCCS 2021). Among these areas, the Fribourg Prealps, and more specifically the Vanil Noir and Motélon Valley region, offer a relevant terrain for studying climate change. The Tissiniva mountain pasture, located at an altitude of 1632 m, is typical of this region (fig.1 and 2). Mountain farming is a traditional and important part of the Swiss economy. It relies on cows grazing high-altitude pastures during summer, with the quality of milk and cheese closely linked to the richness of these meadows. This practice supports regional economies, preserves biodiversity, and is deeply rooted in Swiss culture and identity. Snow cover is already declining, calling into question the viability of certain ski resorts such as Les Paccots. The region would suffer adverse consequences, as the economic benefits generated by the resort are estimated at 6.6 million Swiss francs by the Fribourg Tourism Association. A decrease in snow cover also leads to a decline in grass quality, reducing the carrying capacity of herds and altering the length of the summer grazing period. Water resources in the mountain pastures are scarcer during the summer due to low snowfall, high temperatures and long periods of drought. In an extreme case during the summer of 2022, water had to be supplied to the mountain pasture by helicopter.

Figure 2:Tissiniva mountain pasture

4 Hypotheses

This case study will enable us to answer the following research question: **How has the climate been changing in the Fribourg Prealps over the past 50 years?** The 50-year period was chosen because it was around 1975 that the shepherd, Mr Ruffieux, began visiting the mountain pasture as a child, and because weather data from nearby stations is available for this period. This question is relevant because observing changes over a medium-term period allows us to identify local trends in temperature, precipitation and snowfall. To answer this question, the following hypotheses will be verified:

1. Snowfall is becoming increasingly scarce in winter, and the snow season is shorter than it used to be.
2. Average annual temperatures have been rising over the last 50 years (the period studied), with a more pronounced increase in mountainous regions than the global average.
3. Water resources are scarcer in summer due to poor snow cover, high temperatures and long periods of drought.

5 Methods

5.1 Interview with Jacques Ruffieux

Among the methods used in this work, the testimony of Mr. Jacques Ruffieux, mountain keeper of the Tissiniva alpine pasture, was employed. He is a farmer with around 70 cows, and his activity is representative of traditional mountain farming in the Fribourg Prealps. This alpine pasture has belonged to his family since 1976, when his parents began managing it. In 1992, Mr. Ruffieux took over its management and has been responsible for it since then. Residing on-site throughout the summer and occasionally visiting in winter, he has developed detailed and empirical knowledge of the area over several decades. His local expertise, based on continuous environmental observation, represents a valuable form of empirical data. It contributed a complementary qualitative approach to the scientific analysis. His involvement included providing advice for the installation of measuring instruments, notably the snow pole due to his experience understanding the local winter conditions. He also agreed to the installation of meteorological equipment on the site. His statements were later compared with meteorological data to support conclusions. Finally, his testimony helped clarify some results and offered a fieldworker's perspective on climate changes in the prealpine regions.

5.2 Method for estimating precipitation in the form of snow in Tissiniva.

To monitor changes in the climate at Tissiniva, measuring devices (camera, snow pole, weather station) have been installed, but their data will only relate to the winter of 2023-2024. To obtain climate data from previous decades, datasets from nearby meteorological stations in Château-d'Oex and Le Moléson, covering the period 1983 to 2023, have been collected. A reconstruction method has been established: it combines precipitation measured at a neighbouring station and temperatures reconstructed using the average temperature gradient (0.65°C/100m). The temperature is therefore adjusted according to the difference in altitude between a neighbouring station and Tissiniva. The precipitation from the neighbouring station is then taken and snowfall is assumed when the reconstructed temperature at Tissiniva is below 1°C (fig.3). A ratio of 1 mm of rain to 1 cm of snow is then applied due to the difference in density.

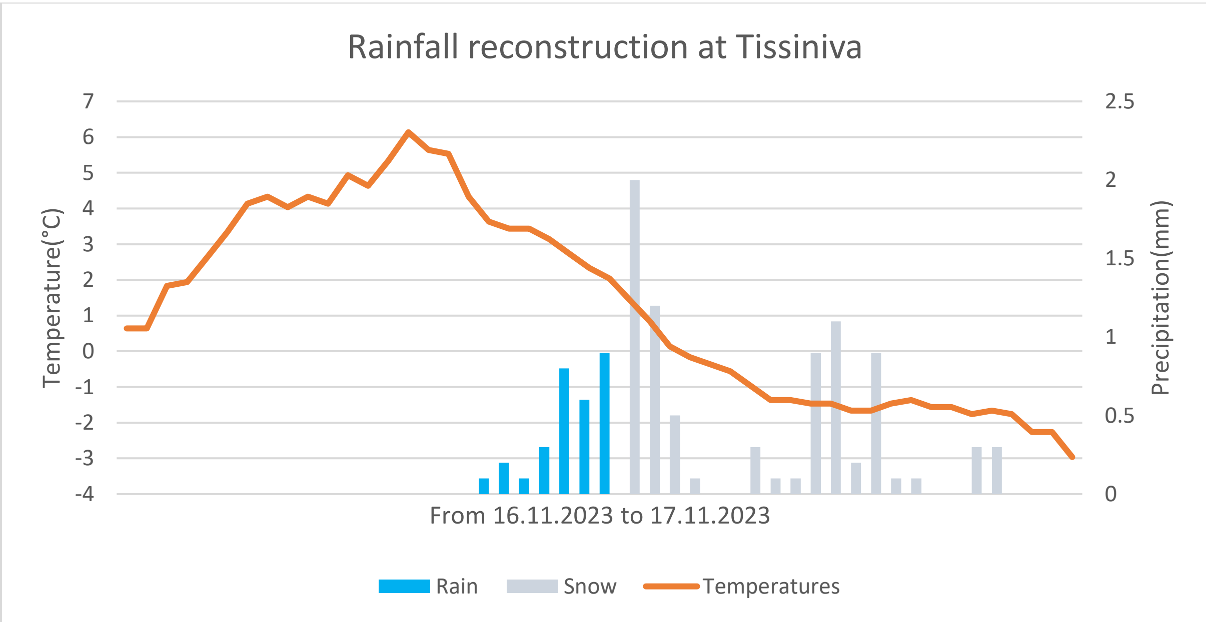

Figure 3:Illustration of the rainfall reconstruction method at Tissiniva

5.3 Method for analyzing interannual trends in temperature and precipitation

For analyzing interannual trends in temperature and precipitation, the aim is to combine the use of two different sources monthly or annual data from MeteoSwiss and the results of discussions with Mr Ruffieux. In this way, it will be possible to observe changes in the local climate over the years. However, the period of analysis will be between 1983 and 2023, as no data is available before then from the Moléson station. The latter was chosen over the Château-d'Oex station because, although although the station in Château d'Oex is located 100 metres above the valley floor, it could still be affected by the cold air pool phenomenon and its temperature would therefore be less relevant to use than that of the Moléson. The evolution of various meteorological parameters will be represented on a graph with its linear regression, a mathematical method that consists of drawing the straight line closest to a scatter plot to show a trend. Each linear regression has a coefficient of determination R^2 that measures the quality of the linear regression, i.e. how close the line is to the data. The value of the coefficient is between 0 and 1, with 0 indicating that the model has no explanatory power and 1 indicating that the regression perfectly explains the variance in the data.

5.4 Snow pole

The aim is to monitor the development of the snowpack at a given location over a winter. This involves measuring the temperature at different heights above ground level, at which sensors are installed (fig.4). This is because the temperature of the snowpack does not vary in the same way as that of the air, except during periods of very strong atmospheric disturbances. The variations will be much smaller if the sensor is under the snow than if it is outside. Furthermore, these variations decrease very rapidly with depth (Delaloye 2004). In this way, it is possible to identify which sensor is under the snow at which time.

5.5 Weather station

The most important tool for gathering data on the weather and climate of Tissiniva is the weather station (fig.5). It measures pressure, rainfall, temperature, solar irradiation and humidity levels. It operates via 4G radio, and the data can be accessed online.

Figure 4:Snow pole (with sensors at heights of 0, 30, 60, 90, 120, 150 and 170 cm)

Figure 5:Weather station mounted on a stake

6 Results

6.1 Snow conditions at Tissiniva in winter 2023-2024

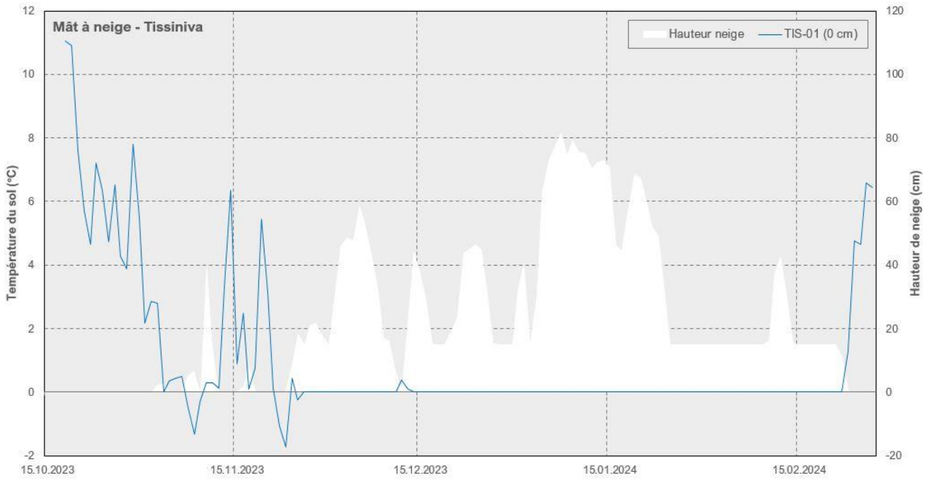

Figure 6: Evolution of snow cover during the winter of 2023-2024 at Tissiniva

By collecting the data from the snow pole, the following graph showing the evolution of the snow cover over the winter of 2023-2024 is obtained (fig.6). As described in chapter 4, another way of measuring snow cover is to extrapolate available data from nearby stations. We therefore take precipitation in the form of snow during the period from 15 October 2023 to 29 February 2024 (fig.7). This period was chosen because it is the same period for which data was measured by the snow pole. In this way, it should be possible to superimpose the two graphs and look for any similarities (which should be present if both methods work). However, it is important to note that two different parameters are being analysed. With the snow pole, we are measuring the evolution of the snowpack over the winter of 2023-2024, whereas with the reconstruction method, we are measuring the amount of precipitation in the form of snow.

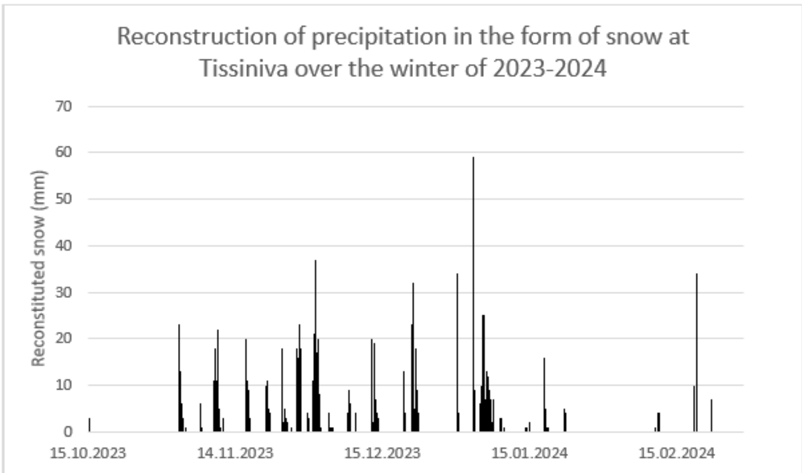

Figure 7: Precipitation in the form of snow at Tissiniva reconstructed using data from the Moléson station

If we now compare these two variables, we can see that at the beginning of each increase in snow cover height, there is systematically relatively heavy precipitation in the form of snow (fig. 8). The two peaks in snow cover and snow precipitation also coincide. Heavy snowfalls occurred from 03/01/2024 to 07/01/2024, which significantly increased the height of the snowpack. Then, from 22.01 to 11.02, no more snow fell, and the snowpack melted. One is not necessarily a consequence of the other, but it is consistent, nonetheless. Furthermore, it is also possible that during this period, precipitation took the form of rain due to warmer temperatures. This has been confirmed by the weather station. Having compared these two graphs and noted their relevance, the results suggest that these two methods have produced plausible results, since they are consistent with each other. If we add up the precipitation in the form of snow from 03.01 to 07.01, we arrive at 66.7 cm of snow. If we add this to the 15 centimetres of snow already present, we get 81.7cm. If we allow for the snowpack to settle by a few centimetres, we arrive at a very close result of around 78cm of snow, which appears on the graph showing the height of the snowpack. This demonstrates the accuracy and reliability of the snow cover reconstruction method.

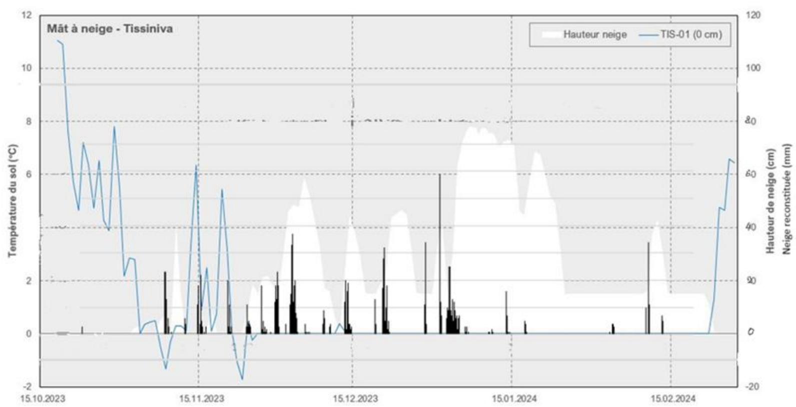

Figure 8: Relating the graph of the snow pole to that of the reconstruction of snow precipitation at Tissiniva during the winter of 2023-2024

Figure 9: Photograph of the Tissiniva mountain pasture taken on 23 February 2024

However, it is important to point out that the height of the snowpack is very heterogeneous mountain regions, as can be seen in the image above (fig.9). The height of the snow cover measured in the valley below the mountain pasture does not therefore reflect the height of the snow cover as a whole.

6.2 Interannual trends in temperature and precipitation

For the analysis of trends in snow cover, the statements of Mr Ruffieux were taken into consideration. When comparing the snow cover at Tissiniva today with that of 50 years ago, he notes a significant decrease over the years. He also notes that periods of thaw last longer than in the past. According to him, several decades ago they lasted just a few days, whereas today they can last several weeks or even a whole month. One problem he sees is that the snow is melting more quickly in the mountains, also due to rarer snowfalls. The snow should stay on until at least late April or early May, protecting the layer of grass underneath. But in so-called 'early years', when the snow melts too early at the end of winter, which he believes is happening more and more often, the quality of the grass is poorer. Indeed, the first layer comes out looking like hay, and the good grass underneath doesn't come out because of a lack of moisture. The result is a chain reaction. The poor quality of the grass that the cows eat adversely affects the quality of the milk they produce, which in turn negatively impacts the quality of the cheese, making it tend to be a little 'sandier' to the bite (Ruffieux 2024). In order to contextualise Mr Ruffieux's assertions, reconstruction of snow precipitation at Tissiniva were used (fig.10). Looking at the graph, we can see that there is a great deal of heterogeneity between the different years. The coefficient of determination (R^2) is very low (0.0337), which means that the linear regression model does not fit the data well and it is difficult to see a clear trend. There has been an average fall in the annual sum of precipitation in the form of snow of more than 60 cm between 1983 and 2023. There was an initial phase up to 1997, when the total amount of precipitation in the form of snow was rather higher than average. This is followed by a phase in which the sum is lower until 2010. The sum rises again in the last phase, with sums similar to those in the first phase. Although the trend is not marked, it is nevertheless downward, which is in line with Mr Ruffieux's observations.

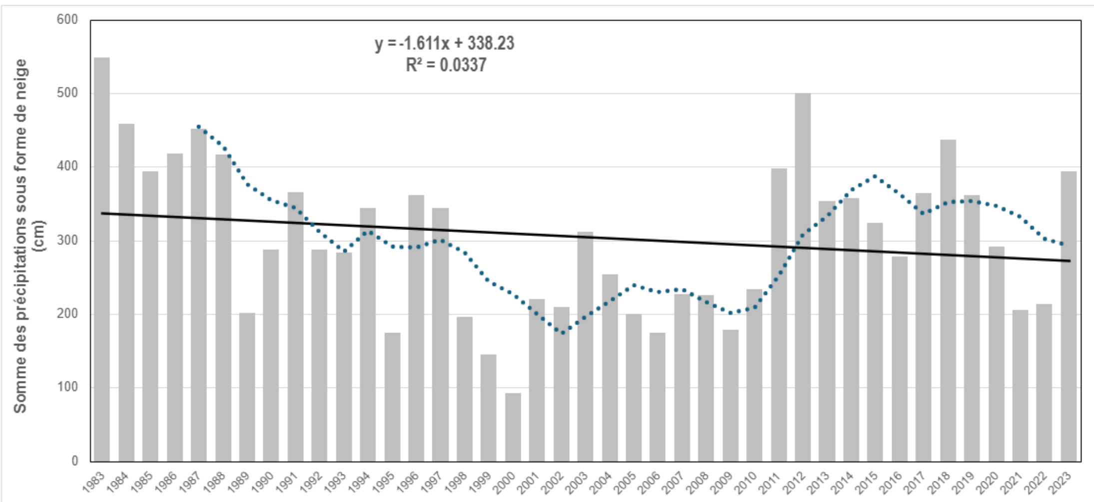

Figure 10: Change in total reconstructed precipitation in the form of snow at Tissiniva between 1983 and 2023

Mr Ruffieux's observations don't stop at snow cover. He has also noticed changes in temperatures, which he finds to be warmer today, particularly in summer, and with greater variations over short periods. The average annual temperatures at Tissiniva will be compared between 1983 and 2023 (fig.11). In contrast to precipitation in the form of snow, there is a clear trend here, with a much higher coefficient of determination. Average annual temperatures have risen by 2°C in 40 years. The results shown in the graph are consistent with Mr Ruffieux's observations.

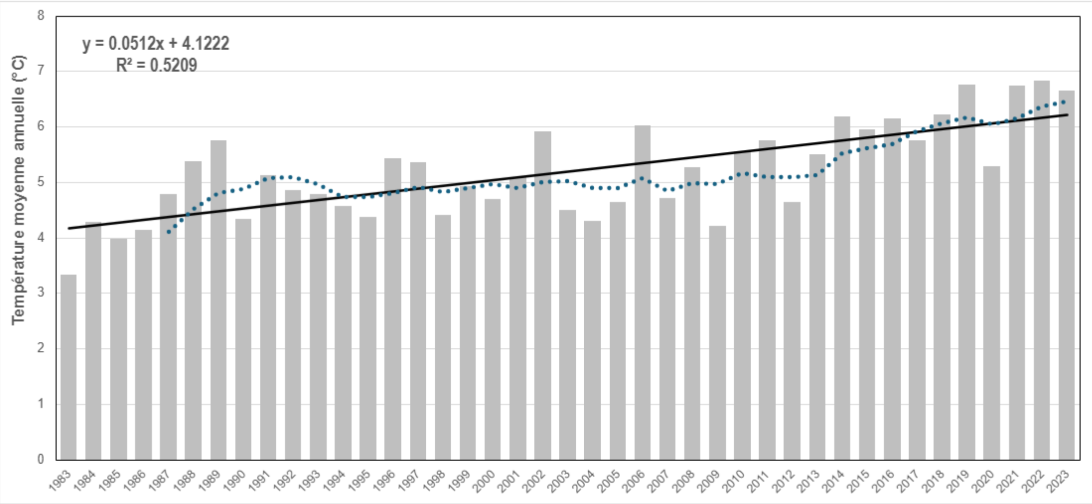

Figure 11: Trend in reconstructed mean annual temperatures between 1983 and 2023

However, it is possible to go further. Mr Ruffieux points out that temperatures increased more in summer. This can be verified by analysing changes in average annual temperatures by meteorological season (Swiss Meteorology 2024), namely: winter (December, January, February - DJF), spring (March, April, May - MAM), summer (June, July, August - JJA) and autumn (September, October, November - SON). First, we look at changes in average winter temperatures (fig.12). A very low R^2 coefficient can be seen, which indicates very heterogenous mean temperatures. This could be due to various winter phenomena such as the influence of different air masses or the albedo effect, which are not found to the same extent in other seasons. Temperatures are nevertheless rising, but less than annual temperatures (annual temperatures are increasing by approximately +0.512°C per decade, compared to +0.288°C per decade for average winter temperatures).

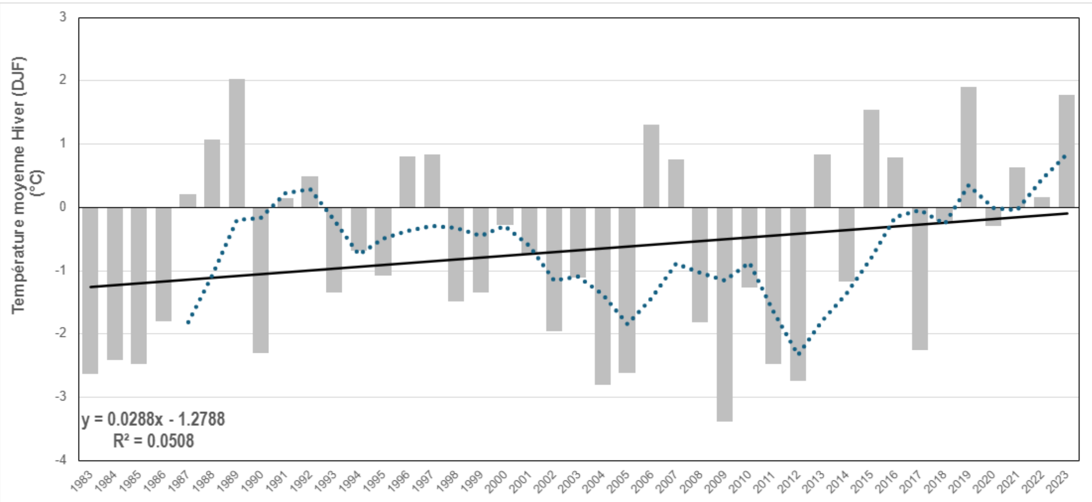

Figure 12: Trend in reconstructed average winter temperatures between 1983 and 2023

Mean spring temperatures, on the other hand, increase more than mean annual temperatures (+0.625 °C per decade) (fig.13). The R^2 is higher. This is consistent with Mr. Ruffieux's observations that snow season ends earlier than before in spring. In addition, warmer temperatures lead to earlier snowmelt, as he also explained.

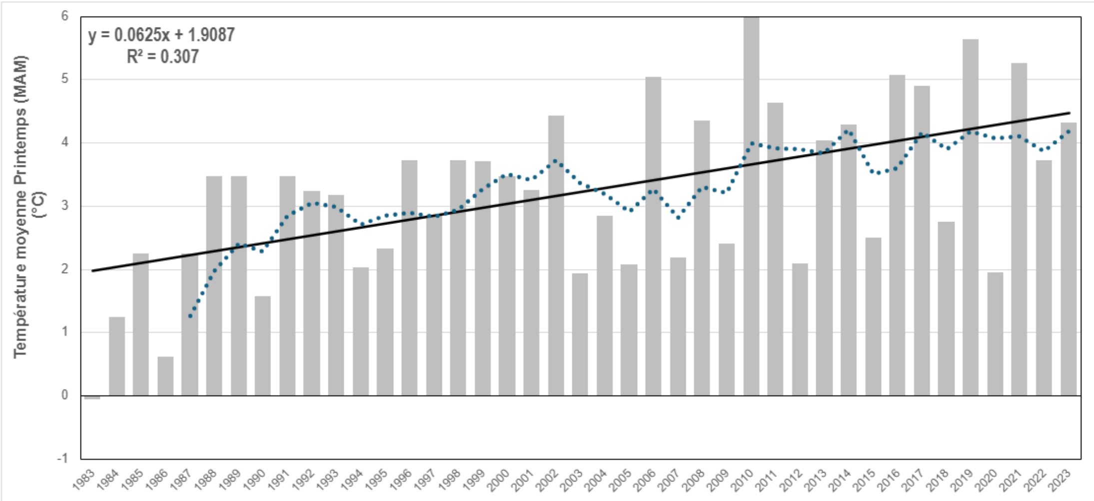

Figure 13: Trend in reconstructed average spring temperatures between 1983 and 2023

The change in average summer temperatures is undoubtedly the graph most relevant to Mr Ruffieux's comments on temperatures at Tissiniva (fig.14). He notices that temperatures had particularly risen in summer. If we analyse the slope of the linear regression, we see that it is the highest of the four seasons (+0.767 °C per decade) and therefore the one with the greatest increase. With an increase of over 3°C in 40 years, i.e. one degree above average temperatures, the graph confirms Mr Ruffieux's statements. With an R^2coefficient of 0.4763, the linear regression is of fairly good quality. It shows a fairly regular increase in summer temperatures since 1983.

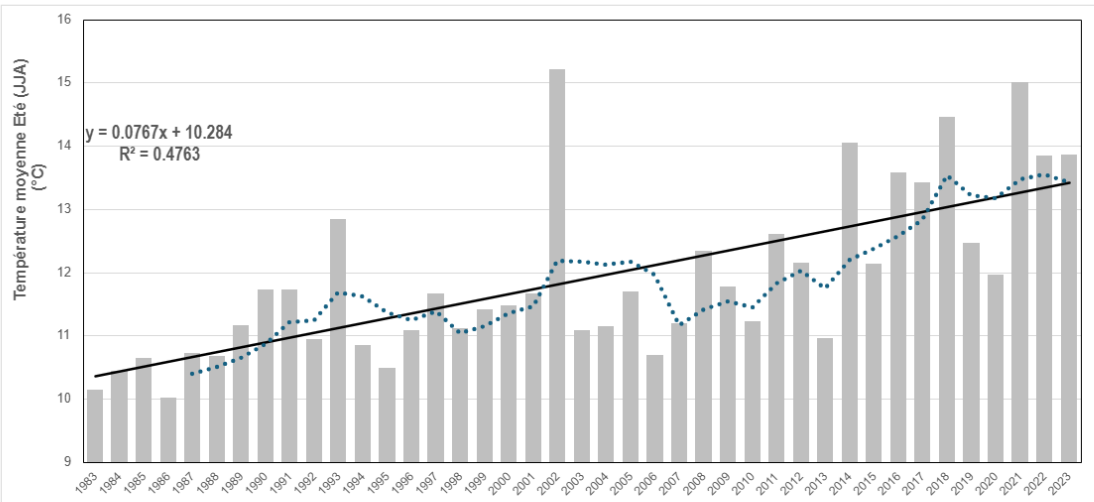

Figure 14: Trend in reconstructed average summer temperatures between 1983 and 2023

The last graph shows the trend in average temperatures in autumn (fig.15). The trend is not very regular and the R^2 coefficient is 0.1493. Temperatures rise as in all the other seasons, but the autumn warming is less pronounced than the average warming. To sum up, there has been an increase in mean annual temperatures, particularly in spring and summer. This would mean a greater thermal amplitude over the year. If we compare average annual temperatures in 2023 with those of 40 years ago, we can estimate that mid-mountain areas now have temperatures equivalent to those observed 200 to 300 metres lower four decades ago. Global temperatures have risen by an average of 1.2°C since industrialisation (MeteoSwiss 2021). However, according to the graph showing average annual temperatures between 1983 and 2023 (fig.15), they have risen by 2°C in 40 years in Tissiniva. Although the data are only representative of a limited region, we clearly see that temperature increases faster in Tissiniva than at global scale – almost twice faster. These changes also have an impact on the length of the seasons. Higher spring and autumn temperatures mean shorter winters and longer summers. These results are also consistent with Mr Ruffieux's observations.

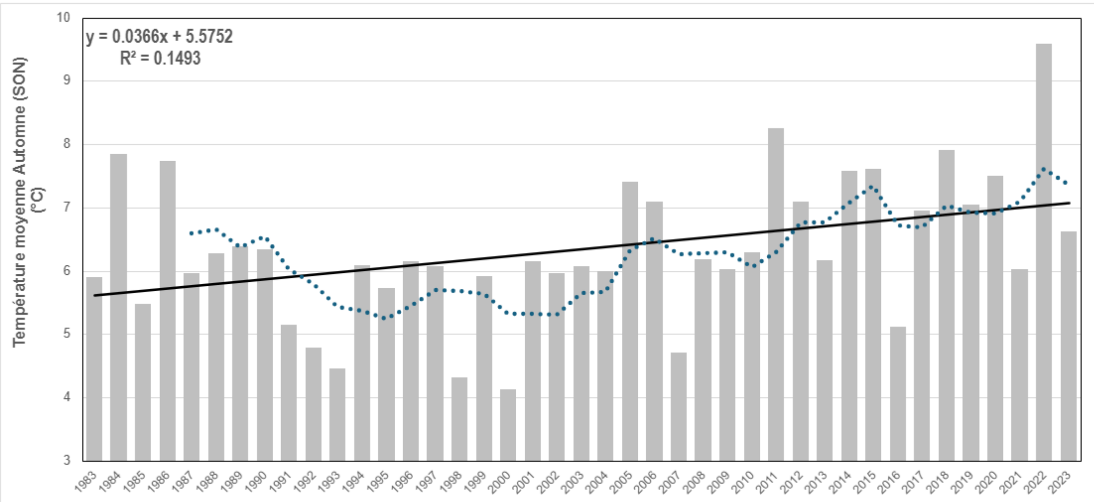

Figure 15: Trend in reconstructed average autumn temperatures between 1983 and 2023

Mr Ruffieux points out that high temperatures are not the only problem in summer. The level of drought is also a problem. In his opinion, summers have been drier than in the past 10 years. It is therefore possible to use the graph showing changes in the annual sums of precipitation between 1983 and 2023 in Moléson (fig.16). If we look at this trend, we see that the linear regression stays constant, which means that the annual sum of precipitation remains stable. There is indeed a drop in the sum of precipitation from 1997 to 2010, but the curve will then rise again and return to values equivalent to those for the first 15 years. It is therefore not possible to confirm from this graph that there is less rainfall than 40 years ago.

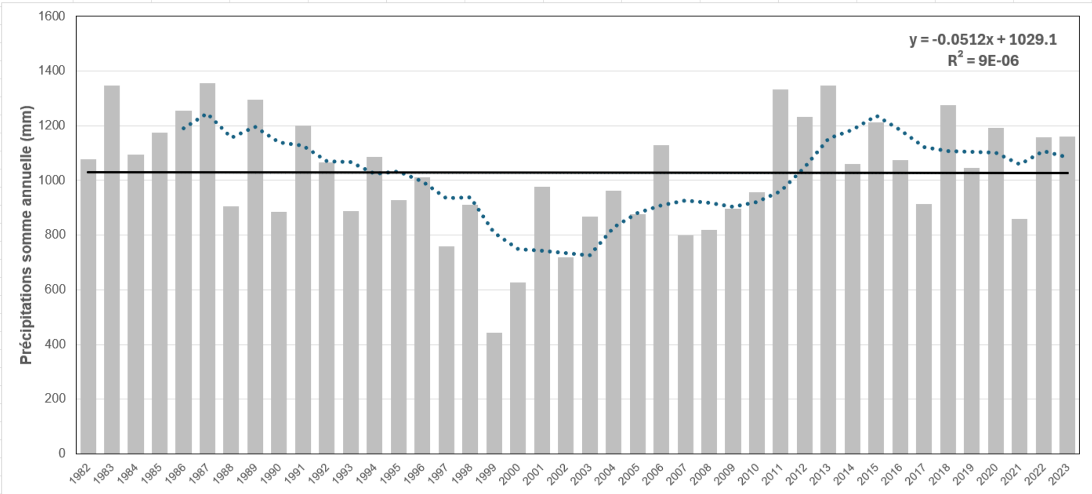

Figure 16: Change in annual sum of precipitation between 1983 and 2023 at Moléson

However, Mr Ruffieux explained that he found that rainfall was rarer, especially during the summer period, resulting in drier summers. To verify this, we need to look at the graph showing the sum of rainfall in the summer period only (fig.17). This shows results that differ from what Mr Ruffieux says. The sum of summer rainfall tends to increase rather than decrease. However, if we look at the last few years, from 2021 onwards, we see that the sum of precipitation shows a downward trend. Nevertheless, the sums are not really low compared with the entire 40-year period. In 2022, for example, when a helicopter was needed to supply water to the mountain pastures, a very low rather than average rainfall total would have been expected. One explanation for this could be there were less rainfall episodes but with higher amount of precipitations over the summer led to a period of drought. A second possible explanation could be that with higher temperatures, the level of drought increases, because more humidity is evaporated from the soils and from the vegetation.

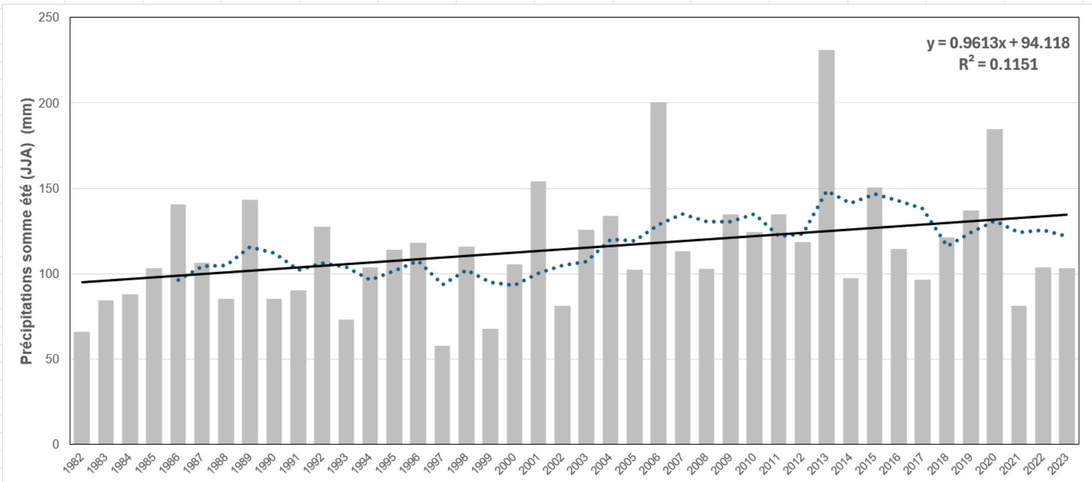

Figure 17: Change in the summer sum of precipitation between 1983 and 2023 at Moléson

7 Discussion

The results highlight the challenges of taking field measurements, particularly given the complexity of the pre-Alpine climate. In terms of measuring equipment, the snow pole proved to be a success. Thanks to it, it was possible to trace the evolution of the snow cover at Tissiniva over the winter of 2023-2024. However, an anomaly has been observed. The height of the snowpack observed on site when the pole was retrieved was not the same as on the graph obtained (difference of 25cm). This shows that even if the data on the evolution of the snowpack over the winter makes sense, there may be inaccuracies. The weather station also worked. The data available on the online platform is quality-checked by MeteoSwiss. As far as the climate in the Prealps is concerned, it has been noted that describing climate evolution in details is a complex task, especially when there is no measuring station on site. For example, it was only when we were on site that we realised that the height of the snow cover was very heterogeneous at local level. As illustrated above, the snow pole was in a hollow. This choice had been made in order to obtain a certain height of snow. However, this means that the height of the snowpack measured at this point does not reflect the general state of snow cover in the area surrounding the mountain pasture, let alone that of the entire Prealps. Another important aspect to consider is the timeline of the work. The initial goal was to install measuring devices in the field. However, it was later determined that it would be more useful to analyse changes over a longer period. The measurements taken are therefore mainly used to observe short-term trends, such as heat waves or cold spells, to illustrate some of Mr Ruffieux's observations on current winters, to identify certain local specificities or to compare the meteorological parameters of the Tissiniva station with neighbouring stations. These data were also used in an earlier version of the work to compare the winter of 2023-2024 with a winter that occurred fifty years earlier. However, this comparison has been replaced by an analysis of interannual trends using linear regression, which is considered more relevant. For this reason, most of the results, as well as the most interesting aspect of the work, focus on these interannual trends. This work was compared with two other studies on climate change. The report "Préalpes Vision 2030" analyses the impact of climate change on tourism in the canton of Fribourg. The analysis shows that days with at least 30 cm of natural snow will become extremely rare by 2035 (State of Fribourg 2019). This study also shows a decrease in snow cover. The analysis highlights an increase in average temperatures of 2.1°C between 1960 and 2018 (State of Fribourg 2019). This study on Tissiniva showed a temperature increase of 2°C between 1983 and 2023. In both cases, the measured temperature increase is greater than the 1.2°C increase in global temperatures since industrialisation. It is worth noting that these two trends are roughly double the global average. In a less targeted manner, a study by Schoeneich and de Jong on changes in the Alpine environment analyses the impacts of climate change on the Alps. That study also shows that warming in the Alps has been more pronounced than the global average, with a temperature increase of 0.9 to 1.5°C since 1850, compared to 0.7 to 0.8°C globally (Schoeneich & de Jong 2008). That study suggests that this change is not linear or uniform, as winter and spring have generally warmed more than summer (Schoeneich & de Jong 2008). On this point, the results are not consistent with those obtained in this research. In fact, it was observed that it was the summer that had warmed the most, and the winter the least. That study refers to a change in precipitation patterns. Models predict a decrease in summer precipitation and an increase in winter precipitation. By tracing the evolution of summer precipitation between 1983 and 2023 in this study, it was found that the total tended to increase rather than decrease, which differs from the results of the models. However, that study explains that summer precipitation could have a different rhythm and occur less frequently and in the form of more intense storms. These factors were noted by Mr Ruffieux, who also mentions lower frequency but more thunderstorms. Summarising the comparison of these two studies of different scope, it can be seen that the results are generally consistent. However, while the results obtained by the study on ski resorts in the canton of Fribourg were consistent in all respects with those of this study, some results of the study on changes in the alpine environment differed. It is important to note that that second study was more comprehensive and precise, with more parameters, and it is therefore possible that more parameters differ. Furthermore, the study was conducted some time ago and may no longer reflect current conditions. Since 2008, warming has continued. It is also conducted at larger scale. Concerning precipitations, there can be variations at local scale. Another conclusion could also be drawn. Since the Fribourg study was conducted on a more local scale in areas surrounding Tissiniva, it is possible that the results are more similar because the climate does not change in the same way across different regions and some of the consequences of global warming vary from one region or country to another.

8 Conclusion

In this conclusion, answers are provided to the hypotheses set out above in order to determine the extent to which they have been verified during this work.

The first hypothesis, **Snowfall is becoming increasingly scarce in winter, and the snow season is shorter than it used to be**, has been confirmed by this work. The two tools used to confirm it are the interview with Mr Ruffieux and the use of MeteoSwiss data. Mr Ruffieux notes a drop in snow cover compared with 50 years ago and a gradual advance in the melting of the snow at the end of winter. A comparison of the MeteoSwiss data showing changes in the amount of precipitation in the form of snow between 1983 and 2023 shows that there has indeed been a decline. The most significant changes appear to be the duration of snow cover and the period of snowmelt at the end of winter, which seems to occur earlier than it did forty years ago. It should also be noted that it is difficult to study the evolution of the snowpack at Tissiniva due to the absence of measuring equipment on site in recent years. It is possible to estimate this evolution by taking data from other stations, but these would not be precise enough for Tissiniva due to different parameters such as altitude and topography.

The second hypothesis, postulating that **Average annual temperatures have been rising over the last 50 years (the period studied), with a more pronounced increase in mountainous regions than the global average**, is partially confirmed using MeteoSwiss data. Temperature trends at Tissiniva between 1983 and 2023 show an average increase of 2°C over 40 years. Global temperatures have risen by an average of 1.2°C since industrialisation (MeteoSwiss 2021). Mr Ruffieux also points out that temperatures in the mountains seem warmer than before, especially in summer. In fact, it has been confirmed in this work that summer temperatures have risen the most. Based on the results of the two comparative studies and the MeteoSwiss data, it was confirmed that temperatures in mid-mountain regions have risen more than global temperatures since industrialisation. However, we should not go too far in our interpretation. Warming is more pronounced over land than over the oceans (Sutton & Dong & Gregory 2007). In Switzerland, a linear temperature increase of 2.9°C since 1864 has been measured (Begert & Stöckli & Croci-Maspoli 2019). The increase is therefore greater than that of Tissiniva, but over a much longer period. To make an accurate comparison between mountains and plains, we would need to look at the overall trend in Switzerland over the same period (1983–2023) but no such trend could be found.

The third hypothesis, **Water resources are scarcer in summer due to poor snow cover, high temperatures and long periods of drought**, was only partially confirmed. Mr Ruffieux states that water resources are scarcer in summer. He will be installing a new cistern next year to remedy this problem. During the particularly dry summer of 2022, more drastic solutions had to be employed with water being supplied by helicopter. However, according to Mr Ruffieux, this was only a temporary solution. In the second hypothesis, it was established that snow cover had declined, but a systematic trend towards long periods of drought could not be established. However, the existence of certain periods with these characteristics, such as the summer of 2022, which was particularly dry, was nevertheless noted. It was also noted that summer temperatures had risen the most. Analysis of the precipitation data showed that the annual sum had been stable for 40 years and that the summer sum was even tending to increase. This analysis contradicts the hypothesis. However, this does not imply that there are no drought issues, as soils can become dryer in a warming climate. It would be interesting to conduct more studies at local scale to understand the links between temperatures, precipitations and hydric stress during summers in the Prealps.

These changes have a direct impact on Mr Ruffieux's job, and therefore on his day-to-day life. Reduced snow cover, hotter, drier summers and wide variations in temperature have a direct impact on the quality of the grass and the well-being of the cows, which in turn affects the quality of his cheese, one of his main sources of income. A typical change resulting from global warming is the appearance of new animal and plant species. At Tissiniva, Mr Ruffieux has noticed the appearance of ticks, a species he never encountered 10 years ago. This is affecting the health of his cows, which are infected and stressed. To adapt to the earlier start to the alpine pasture season, Mr Ruffieux has adopted the strategy of going up earlier and with fewer animals. Despite the presence of a generator on the mountain pasture, he believes that the carbon footprint of cheese-making on the mountain pasture is better than on the plains. In fact, there are fewer journeys between the mountain pastures and the villages to transport the milk, as the cheese-making stages take place on site. For the time being, Mr Ruffieux is more concerned about the reduction in the number of staff on the mountain pastures: the less arduous working conditions on the plains are more attractive to chalet staff. Regardless, in the future, the mountain pastures will have to face up to the new problems imposed by global warming. Sustainable solutions will have to be found, just like the measures already taken by the herdsman. He is also in favour of exploring new sources of renewable energy on the mountain pasture, such as solar panels. As a state-owned property, the chalet could serve as a model for the adoption of this form of energy.

This local testimony is part of a much broader issue. The challenges faced in Tissiniva are representative of those affecting all mountain regions in Switzerland and beyond. Among these challenges, water management is becoming a major concern. Reduced winter snowfall and earlier snowmelt compromise water availability in summer, when the need for water for livestock is greatest. The increasing scarcity of water resources is forcing local stakeholders to adapt. Rising temperatures are reducing animal welfare, drying out the soil more quickly and reducing grass quality. At the national level, this raises questions about the sustainability of the mountain farming model and equitable access to water resources in a context of scarcity. Through the observation of a specific case, this study contributes to a better understanding of how mountain regions are responding and will need to adapt to a changing climate.

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10 Iconography

Cover: Tissiniva mountain pasture with the Dents de Brenleire and Folliéran in the background. Photograph taken on 23 February 2024. Loris Affolter.

Fig.1 *Map showing the location of Tissiniva.* Map. Swisstopo. SWISSTOPO, 2024. map.geo.admin.ch [online]. [Accessed 24.05.2025]. Available at: https://map.geo.admin.ch

Fig.2 *Tissiniva mountain pasture.* Photograph. Alpine pastures and chalets. TISSINIVA, 2024. alpagesetchalets.ch [online]. [Accessed 01.03.2024]. Available at: http://www.alpagesetchalets.ch/fr/les-chalets/tissiniva/

Fig.3 *Illustration of the rainfall reconstruction method at Tissiniva.* Graph. Loris Affolter.

Fig.4 *Snow pole (with sensors at heights of 0, 30, 60, 90, 120, 150 and 170 cm).* Photograph taken on 19 October 2023. Loris Affolter.

Fig.5 *Weather station mounted on a stake.* Photograph taken on 19 November 2023. Loris Affolter.

Fig.6 *Evolution of snow cover during the winter of 2023-2024 at Tissiniva.* Graph. Sébastien Morard.

Fig.7 *Precipitation in the form of snow at Tissiniva reconstructed using data from the Moléson station*. Graph. Loris Affolter.

Fig.8 *Relating the graph of the snow pole to that of the reconstruction of snow precipitation at Tissiniva during the winter of 2023-2024.* Graph. Sébastien Morard, Loris Affolter.

Fig.9 *Photograph of the Tissiniva mountain pasture taken on 23 February 2024*. Photograph by Alexandre Affolter.

Fig.10 *Change in total reconstructed precipitation in the form of snow at Tissiniva between 1983 and 2023*. Graph. Sébastien Morard, Loris Affolter.

Fig.11 *Trend in reconstructed mean annual temperatures between 1983 and 2023*. Graph. Sébastien Morard, Loris Affolter.

Fig.12 *Trend in reconstructed average winter temperatures between 1983 and 2023*. Graph. Sébastien Morard, Loris Affolter.

Fig.13 *Trend in reconstructed average spring temperatures between 1983 and 2023*. Graph. Sébastien Morard, Loris Affolter.

Fig.14 *Trend in reconstructed average summer temperatures between 1983 and 2023*. Graph. Sébastien Morard, Loris Affolter.

Fig.15 *Trend in reconstructed average autumn temperatures between 1983 and 2023*. Graph. Sébastien Morard, Loris Affolter.

Fig.16 *Change in annual sum of precipitation between 1983 and 2023 at Moléson*. Graph. Sébastien Morard, Loris Affolter.

Fig.17 *Change in the summer sum of precipitation between 1983 and 2023 at Moléson.* Graph. Sébastien Morard, Loris Affolter.