Climate and climate change in the Austrian–Swiss region of the European Alps during the twentieth century according to Feddema

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Abstract

Feddema's (Physical Geography 26: 442–466, 2005) generic climate classification method is applied to study climate and climate change in the Austrian–Swiss region of the European Alps during the course of the twentieth century. A fine-tuned version of it is also tested in addition to the original scheme. Monthly precipitation (P) and air temperature (T) data at a spatial resolution of 10'x10' are taken from the Climatic Research Unit (CRU) TS 1.2 database to construct 30-year and 50-year period averages. It is shown that the alpine climate is sufficiently heterogeneous to make it unnecessary to perform fine-tuning of the original scheme for its characterization on the meso-β scale. It is also demonstrated that data organizational effects are much less intense than the effects caused by the fine-tuning. The area heterogeneity of climate and climate change types is the highest in the vicinity of lakes (Austria: Lake Constance; Switzerland: Lakes Geneva, Neuchâtel, Biel, Zurich and Constance) and along river valleys (Austria: the Danube, Drava, and Mur; Switzerland: the Aare and Ticino). The dominant climate change process was drying in Austria and warming in Switzerland. Large areas characterized by cold and saturated climate in the Central Eastern Alps did not experience climate change during the twentieth century.

1 Introduction

Generic climate classification methods serve the best characterization of climate in the given region. Among other climate classification methods, for instance, genetic methods or mostly mathematically established methods, these generic methods use as little data as possible and are the simplest, which enables their classroom applications while also being biophysically based. According to Essenwanger (2001) all these features are of crucial importance from the viewpoint of well-established climate classification.

Among generic methods the two most commonly used methods in the scientific community are the Köppen-Geiger (Geiger 1961) scheme and the Thornthwaite-based methods (Thornthwaite 1948; Feddema 2005). The main difference between them is in estimating the available heat. Köppen (1900, 1923, 1936) solved this problem as simply as possible using temperature data only. Thornthwaite (1948) recognized that potential evapotranspiration (PET) is a better indicator for this, so his method is PET-based not only in estimating thermal but moisture characteristics also. This PET-based method increases both the complexity and the applicability. Its applicability is increased since PET is a more suitable quantity for fine-tuning than temperature. Both methods are constructed for global scale analysis. There is an abundance of studies where the Köppen-Geiger (Geiger 1961) scheme was used for climate (Kottek et al. 2006; Peel et al. 2007) or climate change (Rubel and Kottek 2010) analyses. Thornthwaite's original method (Thornthwaite 1948) was never applied on the global scale, only its very simplified version constructed by Feddema (2005). There are also regional-scale analyses in which Köppen's (1936) scheme was also in the majority (e.g. Alvares et al. 2014; Engelbrecht and Engelbrecht 2016; Baker et al. 2010; Stern et al. 2000). Note that such analyses refer to countries or regions where the climate is fairly heterogeneous. Applications at even smaller scales are not common, but recently there have been such attempts (e.g. Ács et al. 2015; Breuer et al. 2016). These studies refer to a continental climate where the relief is quite uniform. To the best of our knowledge, there are no similar treatments referring to upland regions though the climate of upland regions is strongly heterogeneous even at local scales.

In this work, Feddema's (2005) method is used to characterize an upland climate, specifically, the climate of the European Alps, in its Austrian–Swiss region during the course of the twentieth century. We chose this region since it is located at about the same geographical latitude as Hungary. So, the climate differences between the lowland and the upland can be attributed mainly to differences in relief. The data needed are monthly precipitation (P) and temperature (T). They are taken from the Climatic Research Unit (CRU) TS 1.2 database (Mitchell et al. 2004). The analysis is performed using data of three 30-year periods (1901–1931; 1936–1965; 1971–2000) and two 50-year periods (1901–1950; 1951–2000).

We wish to answer the following questions: 1) Is it necessary to fine-tune Feddema's (2005) original scheme to be able to characterize the structure of climate on the mezo-β scale (20–200 km)? 2) What are the main features of the alpine climate in the Austrian–Swiss region according to Feddema? 3) What are the main features of climate change in this region during the twentieth century? Finally 4) to what extent are the results sensitive to data organizational effects?

2 Method and data

2.1 Feddema's original scheme

The original scheme is well presented in Feddema (2005). It is also discussed in Ács et al. (2015), therefore only the most important features will be presented. Feddema's (2005) climate classification is based on calculation of PET and a moisture index I_m, which is defined as follows:

$$I_m = \begin{cases} 1 - \frac{PET}{P}, if \;\; P > PET, \\ 0, \qquad\quad if \;\; P = PET, \\ \frac{P}{PET} - 1, if \; P < PET. \end{cases}$$

PET is calculated after McKenney and Rosenberg (1993) since we did not find a special PET-formula for alpine climate regions. The same parametrization works well (Ács et al. 2015) in the Pannonian Plain, where the climate is continental. The method uses T and monthly mean of potential sunshine duration as input.

2.2 Feddema's fine-tuned scheme

The basic characteristics of Feddema's fine-tuned scheme referring to the European Alps are presented in Tables 1, 2 and 3.

Table 1 Thermal types used in Feddema's fine-tuned scheme version

Thermal type	Annual PET ($mm \cdot year^{-1}$)
cool	600–800
moderately cold	545–600
cold	300–545

Table 2 Moisture types used in Feddema's fine-tuned scheme version

Moisture type	Moisture index (I_m)
saturated	0.66–1.00
wet	0.47–0.66
moderately wet	0.33–0.47
moist	0.00–0.33
dry	-0.33–0.00

Table 3 The magnitude of seasonal variability according to Feddema's fine-tuned scheme version

Magnitude of seasonal variability	Annual range of I_m
low	0.00–0.50
medium	0.50–1.00
high	1.00–1.25
very high	1.25–1.50
extreme	1.50–2.00

Concerning thermal types, we introduced the “moderately cold” type in addition to the “cool” and “cold” categories. Concerning moisture types, the procedure was similar: the “moderately wet” category is used beside the categories “dry”, “moist”, “wet” and “saturated”. The criteria for deciding which climatic variable possesses seasonality remained unchanged. Nevertheless, the criteria for characterizing the magnitude of seasonal variability (Table 3) were slightly modified. We introduced the new category “very high” besides the categories “low”, “medium”, “high” and “extreme”.

2.3 Data

Monthly temperature and precipitation data are taken from the Climatic Research Unit (CRU) data center of the University of East Anglia. Data are part of the CRU TS 1.2 database (Mitchell et al. 2004), refer to the period 1901–2000 and possess a spatial resolution of 10’x10’ (approximately 18x18 km^2). The studied region is presented in Fig. 1 together with the most important geographical designations used in the study. The area contains 1536 pixels located between the 5.83°–17.33°/45.67°–49.17° longitude/latitude lines. In the analysis, we focused only on the Austrian–Swiss region using thirty-year (in total 71 fields) and fifty-year (51 fields in total) means of temperature and precipitation.

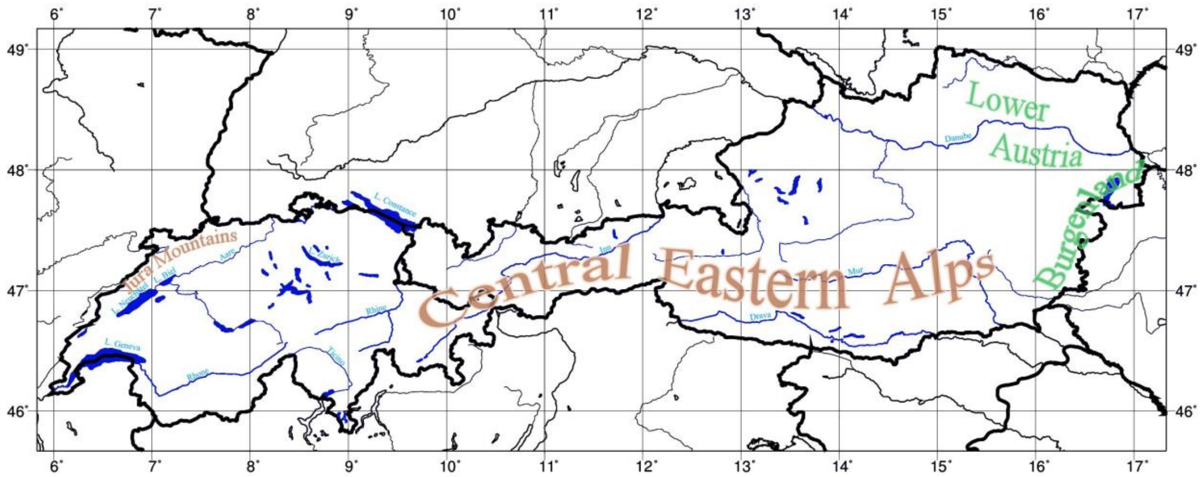

Fig. 1 Austria and Switzerland in the studied region together with the major geographical designations used in the study

3 Results

The climate and the change of the climate in the Austrian–Swiss region of the European Alps during the course of the twentieth century will be discussed separately for 30-year and 50-year datasets. In the analysis, we mainly used Feddema’s (2005) original scheme. The fine-tuned model version applications based on 30-year datasets are used only for climate characterization purposes.

3.1 The climate of the Austrian–Swiss alpine region – original scheme

3.1.1 Thirty-year periods

Climate maps obtained from the original scheme at the beginning, in the middle and at the end of the twentieth century based on 30-year datasets are presented in Figs. 2, 3 and 4, respectively.

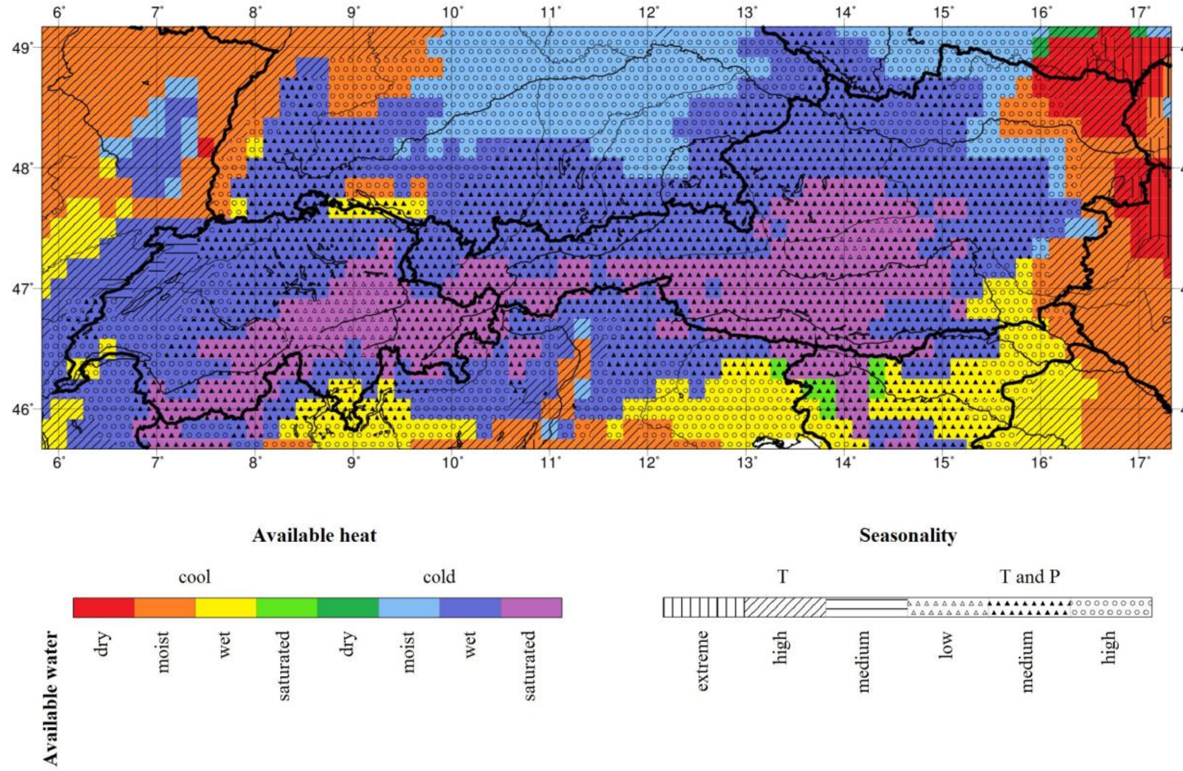

Fig. 2 The climate of the Austrian–Swiss alpine region in the period 1901–1930 according to Feddema's (2005) original scheme

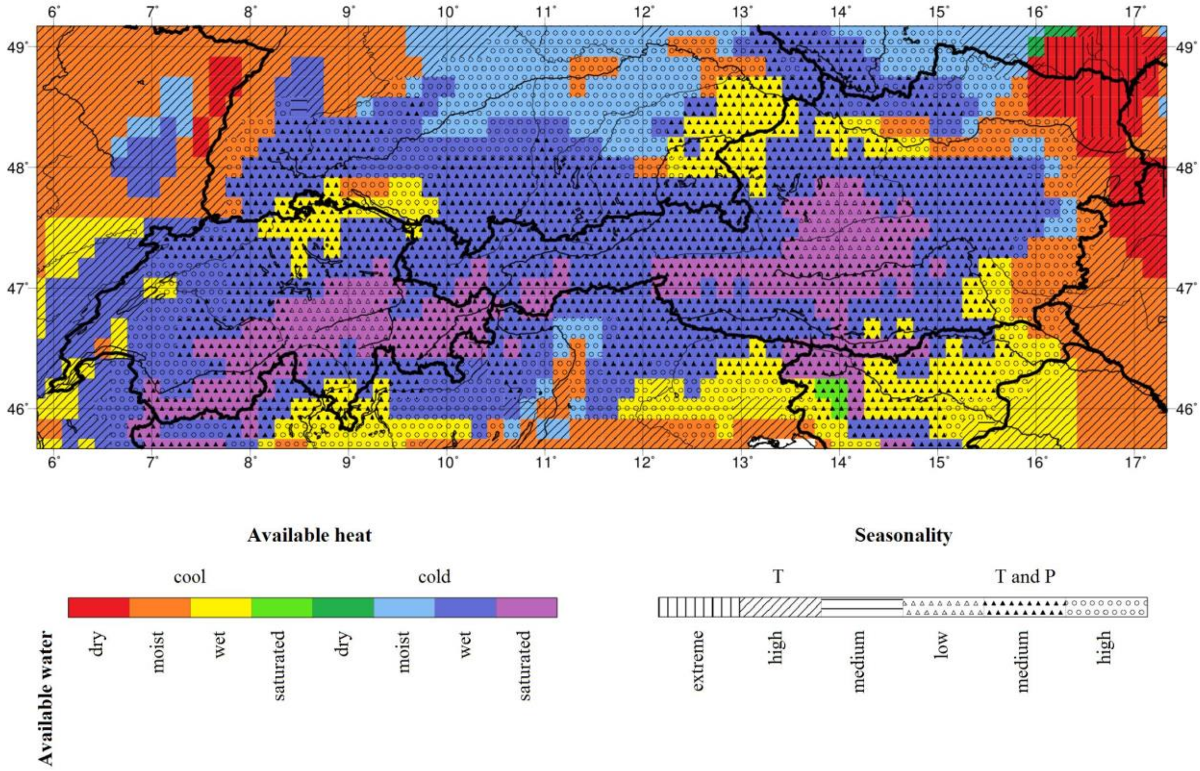

Fig. 3 The climate of the Austrian–Swiss alpine region in the period 1936–1965 according to Feddema's original scheme

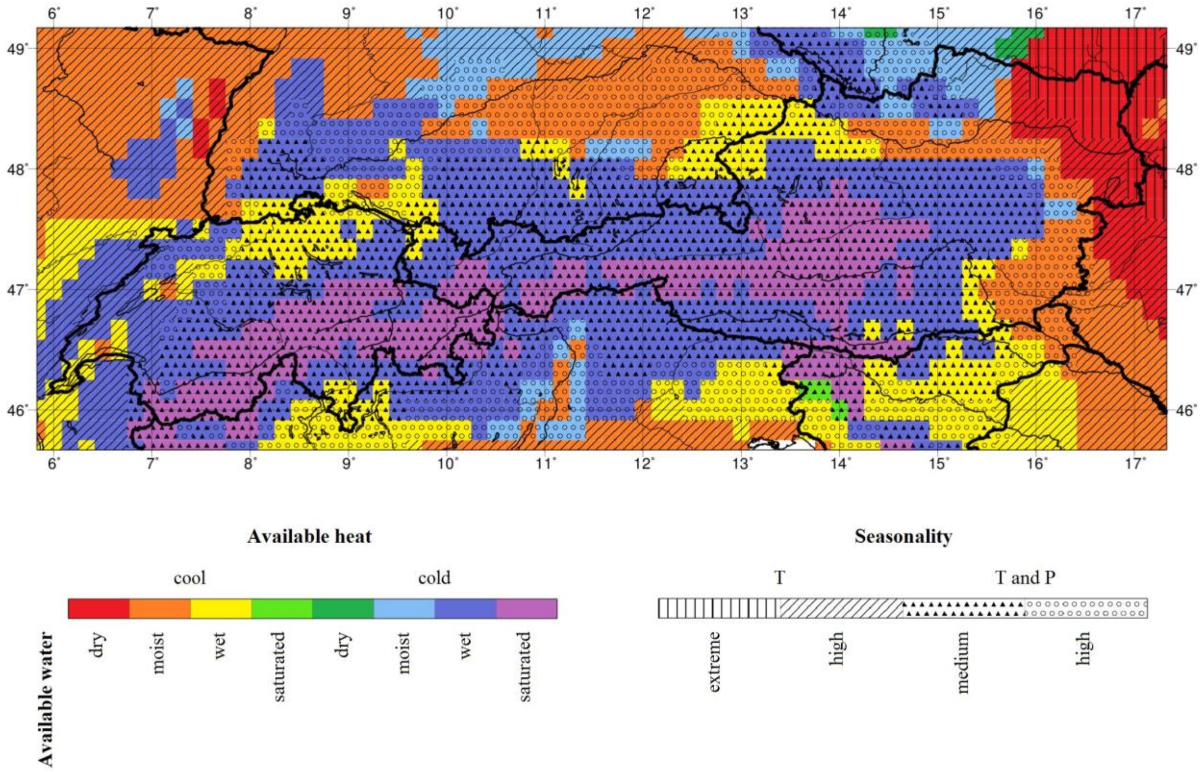

Fig. 4 The climate of the Austrian–Swiss alpine region in the period 1971–2000 according to Feddema's original scheme

The climate is the most heterogeneous in the north-eastern part of Austria. The greatest climate gradient is on the line that connects the eastern parts of Lower Austria and the Central Eastern Alps. The warmest and driest parts of the region are located in the Pannonian Plain (Lower Austria) and in the river and lake valleys. In these areas, 1) cool and dry, 2) cool and moist and 3) cool and wet climate types can be found with different seasonal characteristics. Extreme and high seasonality of T is a mainly Lower Austrian characteristic, but it can also be found on the shores of Lake Geneva, Lake Biel and along the Danube valley. Switzerland is cooler and wetter than Austria. In Switzerland, the climate type "cool and dry" does not exist. Areas with climate type "cool and moist" are rare, and can be found at Lake Geneva, Lake Biel and in the very small area of the Upper Rhine Plain. The climate type "cool and wet" covers larger areas than the climate type "cool and moist". This can be found in the valleys of the Mur, Drava, Danube and Inn, on the shores of Lake Geneva, Lake Constance, in the region of the Swiss Plateau and in the Canton of Ticino, which is the most southern part of Switzerland. In these areas, seasonality is characterized by medium or high seasonality of both P and T. Note that this seasonal change characteristic is typical of alpine areas.

In the Central Eastern Alps, the "cold and wet" and "cold and saturated" climate types are prevailing with low or medium seasonality of both P and T. So, in total fifteen different climate types (different annual and seasonal characteristics) are registered by Feddema's (2005) original scheme in the Austrian–Swiss region of the European Alps during the twentieth century.

3.1.2 Fifty-year periods

The climate maps obtained using the original scheme referring to the 1st and 2nd part of the twentieth century based on 50-year datasets are presented in Figs. 5 and 6, respectively.

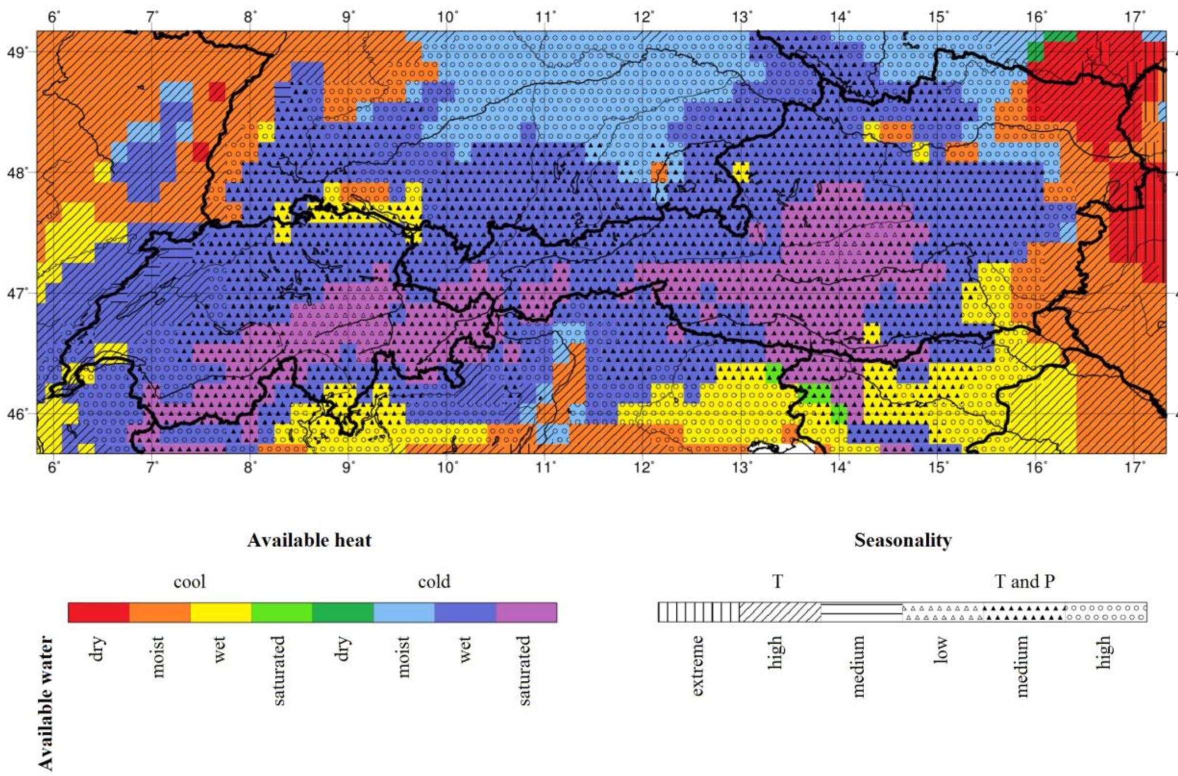

Fig. 5 The climate of the Austrian–Swiss alpine region in the period 1901–1950 according to Feddema's original scheme

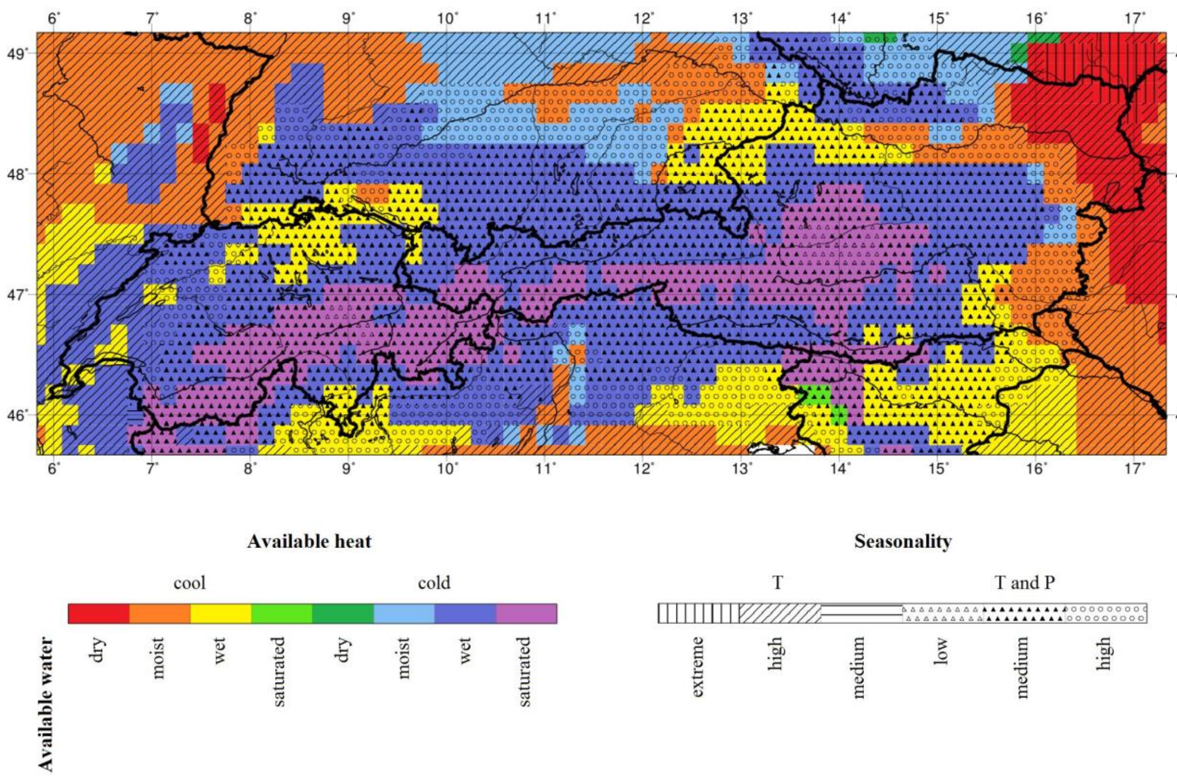

Fig. 6 The climate of the Austrian–Swiss alpine region in the period 1951–2000 according to Feddema's original scheme

Inspecting Fig. 5, we see that it is very similar to Fig. 2. There are only minor differences between them, that is, the spatial distribution of climate types is almost unaltered. Inspecting Fig. 6, we easily detect that it is really very similar to Fig. 4. The climate types "cool and moist" and "cool and wet" are also located in river valleys, on the shores of Lakes Geneva, Neuchâtel, Biel and Zurich and in the Canton of Ticino. The climate types "cold and wet" and "cold and saturated" are also typical only of alpine areas. As for 30-year periods, there are fifteen climate types in total.

3.2 The climate of the Austrian–Swiss alpine region – fine tuned scheme

3.2.1 Thirty-year periods

The climate maps obtained from the fine-tuned scheme at the beginning, in the middle and at the end of the twentieth century based on 30-year datasets are presented in Figs. 7, 8 and 9, respectively.

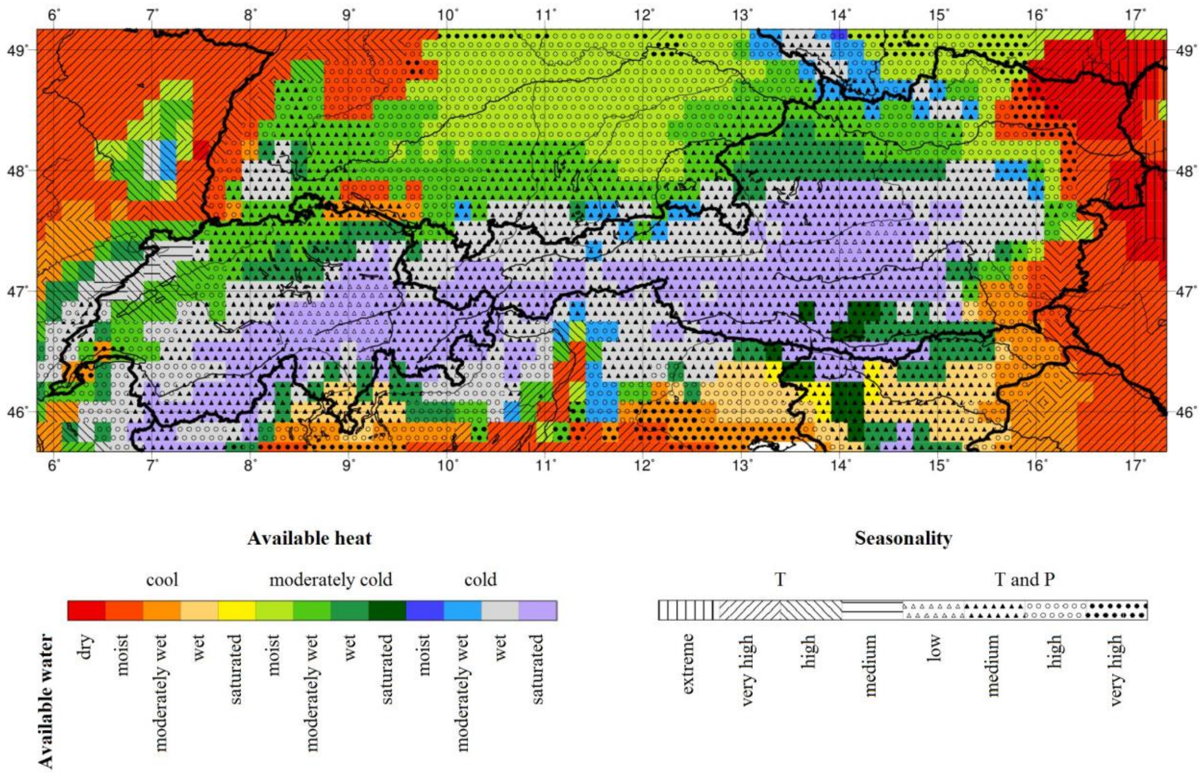

Fig. 7 The climate of the Austrian–Swiss alpine region in the period 1901–1930 according to Feddema's fine-tuned scheme

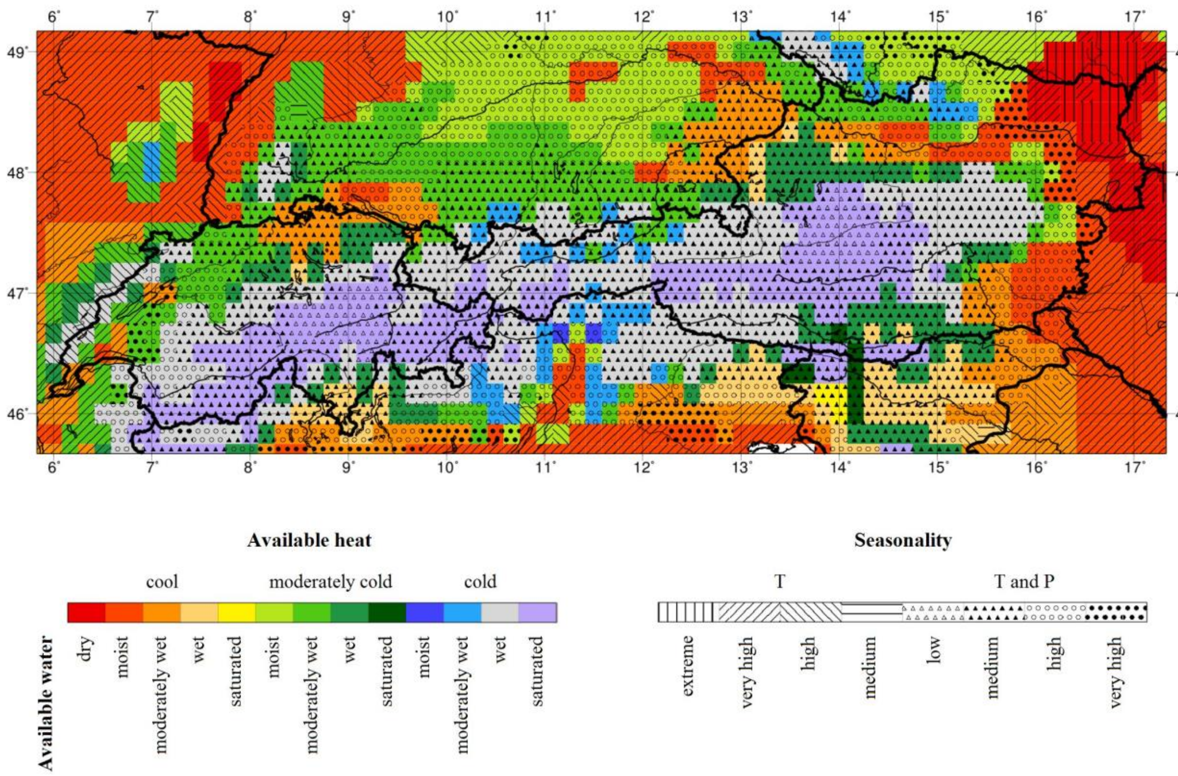

Fig. 8 The climate of the Austrian–Swiss alpine region in the period 1936–1965 according to Feddema's fine-tuned scheme

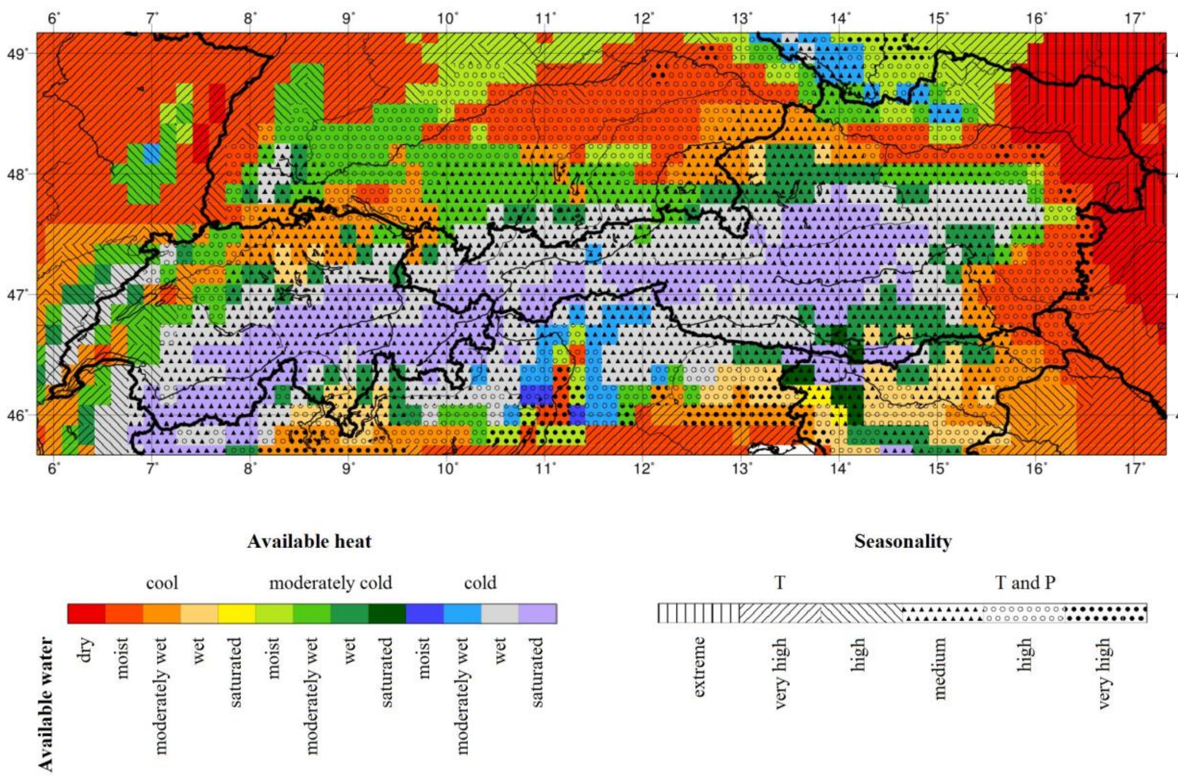

Fig. 9 The climate of the Austrian–Swiss alpine region in the period 1971–2000 according to Feddema's fine-tuned scheme

It is obvious that the number of climate types is much higher than in the cases (Figs. 2, 3 and 4) when the original scheme was applied. Fine-tuning does not influence the area heterogeneity of climates in high mountainous regions, rather in river valleys and in the vicinity of large lakes. This is especially valid for the Mur and Danube in Austria, for Lake Geneva, the river Aare and the river Ticino in the most southern part of Switzerland. The change in climate types along the Mur valley is really pronounced (see Fig. 7). At the beginning of the twentieth century there were six climate types within a distance of about one hundred kilometers,:

- 1) cool and moderately wet with high variability of T and P,
- 2) moderately cold and moderately wet with high variability of T and P,
- 3) moderately cold and moderately wet with medium variability of T and P,
- 4) moderately cold and wet with medium variability of T and P,
- 5) cold and wet with medium variability of T and P and
- 6) cold and saturated with medium variability of T and P.

In the Danube valley the situation is similar. There were also six climate types within the distance of about two hundred kilometers at the beginning of the twentieth century (Fig. 7). In the Pannonian Plain region the climate is “cool and moist with very high variability of T”, while in the German–Austrian border region the climate type is “moderately cold, moderately wet with medium variability of T and P”. In the vicinity of Lake Geneva, the area heterogeneity of climate is also high. There are in total six climate types at the beginning of the twentieth century (Fig. 7). In the western parts of the lake the climate is “cool and moderately wet with high variability of T and P”, while in its eastern parts the climate is cooler and wetter. The greatest area heterogeneity of climates (high number of climate types in a small area) in Switzerland is in the Ticino valley. Four climate types can be found in this small region (Figs. 7, 8 and 9): “cool and wet”, “moderately cold and wet”, “cold and wet” and “cold and saturated”, while the magnitude of T and P variability is medium. Lastly: at the beginning of the twentieth century (Fig. 7) there were eighteen climate types in Austria and sixteen climate types in Switzerland. The total number of climate types in the Austrian–Swiss region is twenty-nine.

3.3 Climate change in the region

The climate change process is investigated only by using Feddema's (2005) original scheme using both 30-year and 50-year datasets. In the first case, we compared climate maps referring to the beginning (Fig. 2) and to the end of the century (Fig. 4), while in the second case Figs. 5 and 6 were compared. These comparisons were made as exactly as possible according to the procedure presented in the work of Breuer et al. (2016). The fine-tuned scheme is not applied for climate change analysis. It gave twenty-nine climate types, consequently there would also be an abundance of possible climate change types, which would enormously increase the complexity of analysis.

3.3.1 Original scheme: thirty-year periods

The spatial distribution of climate change types in the Austrian–Swiss alpine region during the twentieth century obtained by Feddema's (2005) original scheme and 30-year datasets is presented in Fig. 10.

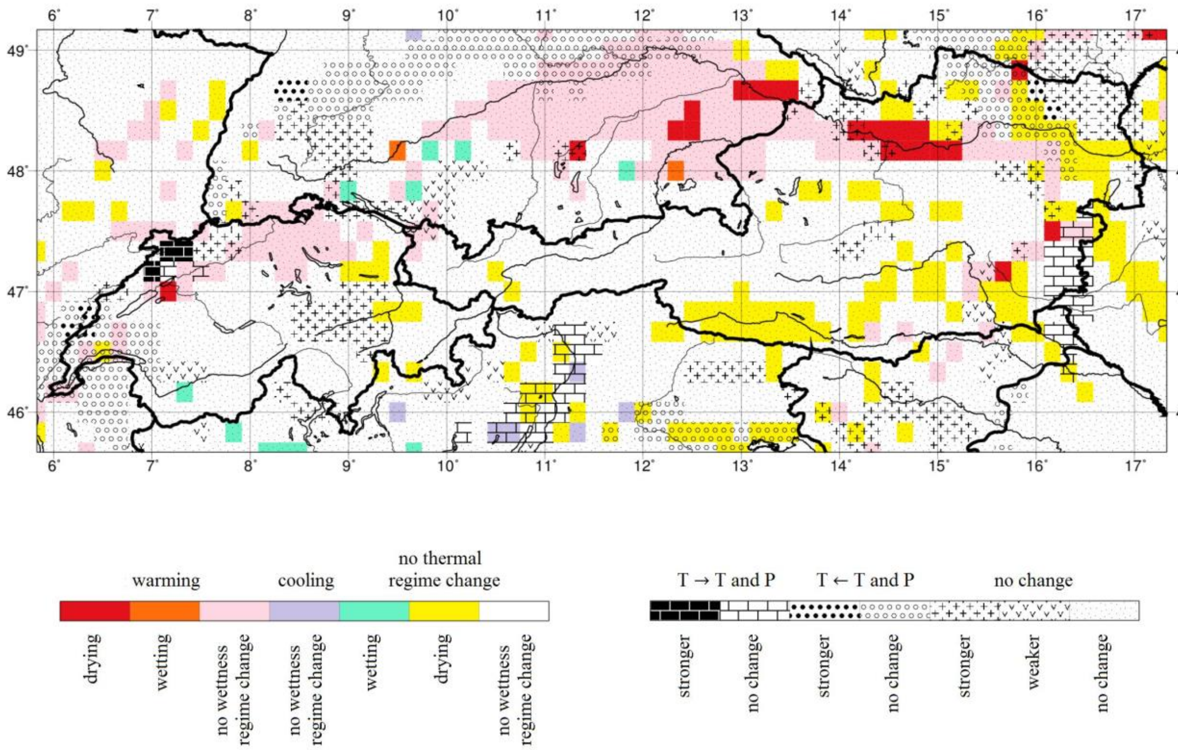

Fig. 10 The climate change types in the Austrian–Swiss alpine region during the twentieth century based on 30-year datasets according to Feddema's original scheme

The climate change process was most pronounced along river valleys and around large lakes. In Austria, the dominant process was drying. The most sensitive areas in Austria were the valleys of the Danube, Drava and Mur and the shores of Lake Constance with the process of drying even being observable in the Drava valley. The climate change process is more complex along the Danube valley. Beside "single" changes of warming or drying, the "double" change of warming and drying (in brief warming/drying) has also occurred. Only "single" changes of warming or drying can be found in the Mur valley. Warming was registered around Lake Constance. Changes in seasonal characteristics can be observed in Burgenland and in northern parts of Lower Austria. In some areas, seasonal type changes occurred: seasonality of T and P transformed into seasonality of T (T and P → T) and, vice versa, seasonality of T transformed into seasonality of T and P (T → T and P). There are also areas (for instance, in the vicinity of Vienna) where the magnitude of variability increased.

The dominant climate change process in Switzerland is warming. The "single" change process of warming can be observed on the shores of Lake Geneva, in the river Aare valley and in the region between the river Aare and Lake Zurich. The "double" change process of warming and drying is not typical for Switzerland, only one such pixel can be found around

Lake Biel. The “single” change process of drying can also be observed, for instance, at Lake Geneva, or in the Rhine valley. Interestingly, there is also one pixel where the process of wetting occurred. This can be found in the Rhône valley. Changes in seasonality can also be observed. Such changes are typical for Lake Geneva and the Jura Mountains, but some such areas are also located in the Central Eastern Alps. Note that there is no climate change in the area of the Canton of Ticino.

3.3.2 Original scheme: fifty-year periods

The spatial distribution of climate change types in the Austrian–Swiss alpine region during the twentieth century obtained by Feddema’s (2005) original scheme and 50-year datasets is presented in Fig. 11.

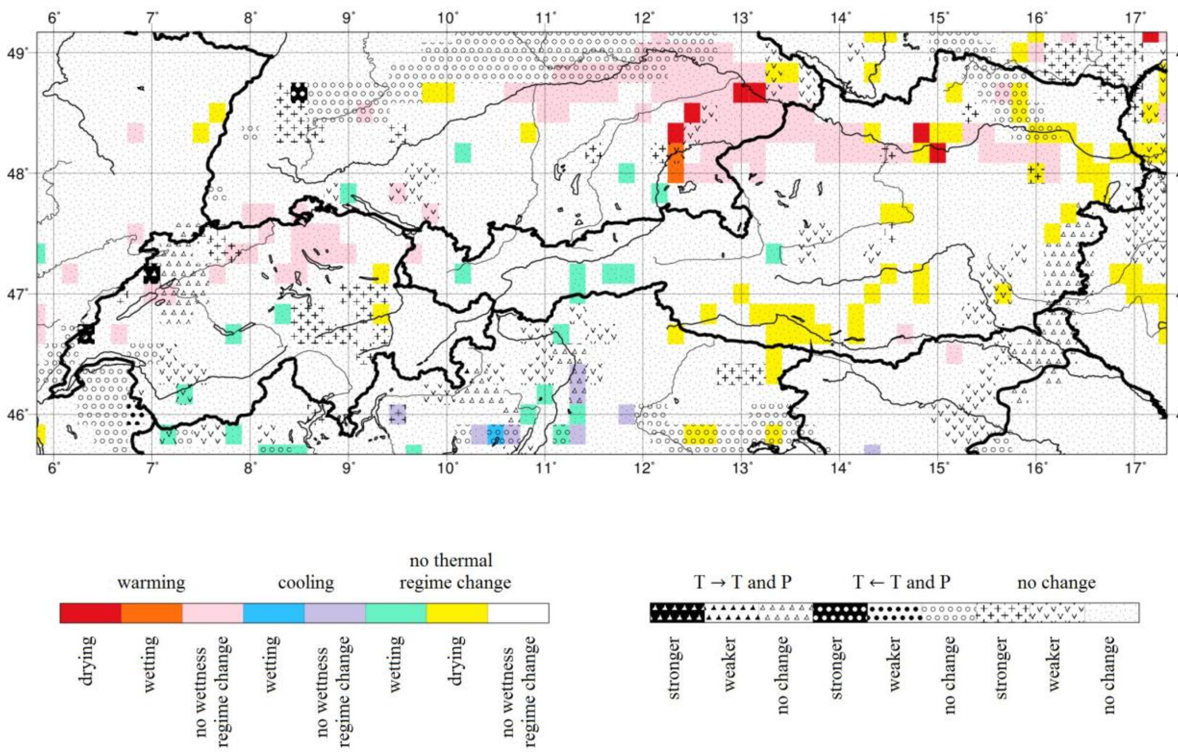

Fig. 11 The climate change types in the Austrian–Swiss alpine region during the twentieth century based on 50-year datasets according to Feddema’s original scheme

This climate change map is similar to the map presented in Fig. 10 but there are also significant differences. Beside the “single” climate change processes of warming or drying, the process of wetting is also represented not only in Switzerland but also in Austria. In Austria, the processes of warming and drying are approximately equally represented and the areas where the “double” climate change process of warming and drying is represented are considerably reduced. There are only two such pixels in the Danube valley. Otherwise, the Danube valley is the area where climate change is the most pronounced. In the Drava valley, the process of drying is typical as in the former case. There is also a drying process in the Mur valley but not so pronounced. There, changes in seasonality could also be observed.

In Switzerland, warming is the dominant “single” climate change process. Areas characterized by warming can be found around Lakes Zurich, Neuchâtel and Biel and in the river Aare valley. Changes in seasonality can be observed approximately equally around Lake Geneva, in the Jura Mountains and in the Central Eastern Alps. These changes are various, not only the type but also the magnitude of variability changed. Concerning magnitude of variability, both the increase (around the Rhine) and decrease (around the Rhône) can be observed. As in the former case, no climate change was registered in the area of Canton of Ticino.

4 Conclusion

Concluding remarks will be organized according to the questions given in the last paragraph of section 1. 1) The fine-tuning of Feddema’s (2005) scheme has larger effect on the appearance of climate maps than the organization of data. The fine-tuning increased the number of climate types from fifteen to twenty-nine, but with this the crowding of the map increased and transparency decreased. Based on this, we do not suggest that a fine-tuned version of Feddema’s (2005) scheme be used in upland regions, like the European Alps, for climate classification purposes on the mezo-β scale. 2) The area heterogeneity of climate and climate change types is higher around lakes, along river valleys and lower in upland regions. These high heterogeneity regions are located in the valleys of the Danube, Mur and Drava in Austria, and in the valleys of the Aare and Ticino as well as around Lakes Geneva, Neuchâtel, Biel, Zurich and Constance in Switzerland. In Austria, the dominant climate change process was drying, while in Switzerland it was warming. The highest climate type heterogeneity area can be found in the Canton of Ticino, at the same time there was no climate change registered during the course of the twentieth century. It is to be noted that there are extended areas of cold and saturated climate in the Central Eastern Alps. In these areas no climate change occurred during the twentieth century.

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