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Climate, Wine and Crisis

Assessment of Grape Harvest Fluctuations in Swiss Viticulture in the 19th Century and Alpine Summer Temperature Reconstruction back to 1529

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Abstract

This study deals with the relationship between viticulture and climate in the Swiss *Mittelland* in the 19th century. A Climate Impact Models helps conceptualise this relationship by distinguishing first-order impacts of climate on the biophysical sphere from higher-order impacts in economic, social, political, and cultural areas.

In order to contribute to better understanding of past climate, a time-series on grape harvest volumes for the *Mittelland* is used to reconstruct mid-summer temperature (June and July) from 1529 to 1966 for the Northwestern Alpine region. The 1780-1819 period served for calibration to homogenised temperature data from the HISTALP database. The model for reconstruction proved useful in verification (1820-1859) with a significant correlation (0.70) and good skill ($RE = 0.45$). The reconstruction continues a previous examination of climate-viticulture relationship for the *Mittelland* (Pfister 1981).

Problems arise with calibration and verification periods in the later part of the 19th century. The period from roughly 1825 to 1880, and particularly from the 1850s on, is marked by a sequence of large grape harvests. Climate does not provide an explanation as temperatures were generally below the long-term average in this period. It is assumed that production improvements and the expansion of the wine-growing sector contributed to this situation.

The relationship between grape harvests and climate is also reviewed with respect to the significance of viticulture to society. Climate exerts considerable effects on viticulture, particularly on small-scale wine-growers who rely on the revenue from vineyards to buy food. This is especially visible in devastating years such as 1816, when yields almost completely failed. However, only looking at climatic fluctuations would be misleading.

The crisis in viticulture in the 1880s is reviewed in more detail. Structural changes contributed extensively to the decline to about one third of the grape area in 50 years, but climate assumed a role as well. A series of cold summers in the 1880s initiated the crisis in viticulture. The continued below average summer temperature can be viewed as a "background" variable to other developments. In particular, the economic situation must be taken into account. The most important cause for the decline of viticulture was shrinking profitability. While production costs increased, wine prices decreased. This was mainly due to the import of cheap wine. Particularly important for this development was the opening of the various railway tunnels (Gotthard in 1882), which lowered costs of transportation.

Contents

List of Figures

List of Tables

1 Introduction

For wine-growers in a country like Switzerland, which is not best suited for viticulture, weather conditions are even more crucial than elsewhere. Adverse weather conditions such as a never-ending cold summer are felt heavily in harvest sizes. Besides the troubles of the wine-maker, such conditions also impact other aspects of society. For example, taxes on wine trade and consumption financed a large share of states' public spending, even in the 19th century. These revenues tended to decline considerably in such adverse weather conditions.[1] Therefore, the significance of up- and downturns in wine production – climate-imposed or not – is great.

Historians view relationships between climate and viticulture from two angles. The first angle focuses on the significance of viticulture in societies. For centuries, wine not only was a beverage with a rich cultural history but it was also a very lucrative commodity.[2] It improved the living of those who were entitled to the revenues from vineyards. This is the reason why not only specialised wine-growers cultivated grapes. Up to the 19th century, mid- and small-scale farmers often grew some grapes in addition to grain or dairy farming as a "cash-crop".[3] The term "cash-crop" describes the role of grapes to provide cash with which farmers bought grain. In addition, many social institutions such as poor houses were financed with the returns of vineyards.[4] It is clear that wine production from this social perspective gains socioeconomic significance. It is therefore essential that climate, as the most important factor affecting wine crops, is investigated as a circumstantial variable in the investigation of socioeconomic conditions of agrarian societies.

The second angle approaches climate and viticulture in contrast to the first angle outlined above. Information about wine crops can be used to understand climate conditions. Production figures of climate-sensitive crops provide important data on climate conditions of the time, especially for earlier periods.[5] As climate helps to explain the

[1] Erich Landsteiner. "The crisis of wine production in the late sixteenth-century Central Europe: Climate causes and economic consequences". In: *Climatic Change* 43 (1999), pp. 323–334.

[2] Marcel Lachiver. *Vins, vignes et vignerons: Histoire du vignoble Français.* Paris: Fayard, 1988; Jacques Dubois. *Les vignobles vaudois. Etude de géographie viticole.* Yens sur Morges: Cabédita, 2008.

[3] Christian Pfister. "Die Fluktuationen der Weinmosterträge im schweizerischen Weinland vom 16. bis ins frühe 19. Jahrhundert. Klimatische Ursachen und sozioökonomische Bedeutung". In: *Schweizerische Zeitschrift für Geschichte* 31 (1981), pp. 445–491, p. 446; Walter Schlegel. *Der Weinbau in der Schweiz.* Wiesbaden 1973, p. 25.

[4] Hans Markwalder. *Das Rebgut der Stadt Bern am Bielersee.* Bern 1946.

[5] Christian Pfister. *Klimageschichte der Schweiz 1525–1860: das Klima der Schweiz von 1525–1860 und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft.* 3rd ed. Bern, Stuttgart: Haupt, 1988; Christian Pfister. *Wetternachhersage: 500 Jahre Klimavariationen und Naturkatastrophen.* Bern: Paul Haupt, 1999.

size and quality of vintages to a relatively good degree, it is possible to infer climate characteristics of a year by examining wine harvests in the same period. This is the domain of the climate historian. Such approaches have proved helpful in geography to reconstruct past climate conditions. Wine is just one crop used to this end. A great deal of our knowledge about past climate is based on approaches inferring from indirect data on climate conditions.

In fact, in the absence of direct – instrumental – data on climate, researchers are forced to look for indirect or proxy data.[6] Often such information is found in documentary data where "the impact of weather on elements in the hydrosphere, the cyrosphere or the biosphere" is reflected.[7] As illustrated in Figure 1, grape yields constitute a typical case for man-made proxy data. The concept of proxy data is well established. By examining the up- and downturns of wine production, this study deals with typical proxy evidence for climate.

In recent years there have been heated discussions on global warming. For vineyards, global warming is frequently viewed positively as higher temperatures promise higher quality of vintages.[8] The ongoing debate about global warming, its causes and consequences, shows how valuable knowledge about climate variability is.[9] Following the scientific consensus, public debate increasingly accepts global warming as a fact as well. Hence, discussions focus more and more to questions about how to deal with the changing climate.[10] History provides insights about how past societies dealt with climate variability or even climate change. The following questions can be addressed in such historical studies: What problems did societies face? How did they respond? Answers to such queries require understanding of past climatic changes, their impact on society, and the reactions they caused – in other words: it requires examination of both angles outlined above. This study employs such a bidirectional view on the wine-climate relationship.

Objective

The objective of this research is to investigate the societal significance of viticulture in the Swiss *Mittelland* in the course of the 19th century. At the same time, this view shall

[6]Rudolf Brazdil et al. "Historical Climatology in Europe - The State of the Art". In: *Climatic Change* 70 (2005), pp. 363–430; Pfister, *Wetternachhersage*.

[7]Brazdil et al., "Historical Climatology", p. 370.

[8]Karl Storchmann. "English Weather and Rhine Wine Quality: An Ordered Probit Model". In: *Journal of Wine Research* 16.2 (2005), pp. 105–119, p. 117; Gregory V. Jones et al. "Climate Change and Global Wine Quality". In: *Climatic Change* 73.3 (2005), pp. 319–343.

[9]IPCC. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva 2007.

[10]Stefan Rahmstorf and Hans Joachim Schellnhuber. *Der Klimawandel.* München 2007, p. 7.

Information \ **Archives**	**Natural**		**Man-made**		
direct observation of weather and climate or **instrumental measurement** of meteorological parameters			**Documentary**	**observed** • anomalies • natural hazards • weather situations • daily weather	**measured** • barometric pressure • temperature • precipitation • water-gauge, etc.
indirect references: **(Proxy data)** indication of controlled or affected processes through meteorological parameters	**organic** • tree rings • fossil pollen • animal and plant remains • fossil wood (trees), etc.	**non-organic** • ice-cores • varves • terrestrial sediments • temperature of boreholes • moraines, etc.		**organic** • plant phenology • yield of vine • time of grain and vine harvest • sugar content of wine, etc.	**non-organic** • water levels • snow fall • freezing of water bodies • snow cover, etc.
				• **cultural:** • **pictorial**	rogations • **epigraphical**
			material:		• archeological remains

Figure 1: Overview of proxy data in historical climatology. From Brazdil et al. 2005, Pfister 1999.

also gather proxy evidence for temperature reconstruction. Climate historian Christian Pfister demonstrated in a seminal article published in 1981 that grape harvest data is very skilful as proxy evidence.[11] Very rarely did other researchers take up the approach and used grape yield data to reconstruct temperature.[12] This study aims to continue Pfister's work. In particular, this study aims to extend Pfister's time-series further into the 19th century applying the latest methodology of temperature reconstruction.

The 19th century represents an important era for research for two reasons. First, it is a crucial period for temperature reconstructions as it offers a sufficient period of time in which instrumental temperature data and proxy data on climate overlap. This is due to the establishment of meteorological networks in Middle Europe in that time. For the reconstruction, production data and a given climate variable (temperature, precipitation) can be compared to establish the quantitative relationship between the two. This is done through statistical analysis (calibration). The statistical model that this procedure returns is then controlled for goodness (verification) and may then be applied to historical data. As a result, this approach estimates climate data for times in which no instrumental data exists.[13]

Secondly, the 19th century is a period of transformation, particularly the last third. Modernisation in agriculture in Europe enabled higher outputs.[14] Furthermore, newly constructed train lines provided better greater transport possibilities. Supply of agricultural products such as wine were less dependent on weather as imports could make up for local failures. Also, the organisation of production adapted. While this second of three "agricultural revolutions" is well researched for goods such as grain and dairy farming, few modern studies deal with viticulture specifically. Furthermore, findings in other areas do not necessarily apply to wine-production. For example increasing grape production demands a unique approach due to its low geographical spread, the high value of the crop, and the labour-intensive production process. By investigating aspects specific to viticulture this research hopes to contribute to knowledge about the 19th century.

[11] Pfister, "Fluktuationen der Weinmosterträge".

[12] Two examples which will be further discussed: André de Montmollin. "Le rendement viticole de la région neuchâteloise de 1750 à 1900 dans ses relations aves les conditions atmosphérique et estivales". MA thesis. Geographisches Institut der Universität Zürich, 1986; Wilhelm Lauer and Peter Frankenberg. *Zur Rekonstruktion des Klimas im Bereich der Rheinpfalz seit Mitte des 16. Jahrhunderts mit Hilfe von Zeitreihen der Weinquantität und Weinqualität.* Mainz: Gustav Fischer Verlag, 1986.

[13] The method is explained in more detail in section 2.

[14] Paul Bairoch. "Les trois révolutions agricoles du monde développé: rendements et productivité de 1800 à 1985". In: *Annales. Economies, Sociétés, Civilisations* 44.2 (1989), pp. 317–353; Pfister, *Klimageschichte*; Rolf Peter Sieferle et al. *Das Ende der Fläche. Zum gesellschaftlichen Stoffwechsel der Industrialisierung.* Böhlau Verlag. Köln, Weiman, Wien 2006. The most important factor contributing to this increase in production was the usage of more dung as more cattle was available.

Great changes marked wine-growth in the 19th century, more so than in the centuries before. Brugger estimates the area planted with grapes to be 19'000 hectares at the time of the Helvetic Republic (1798-1803).[15] A great expansion began around 1850 and reached its peak in the 1880s with an acreage of between 29'600 and 34'380 ha, depending on the sources.[16] Subsequently, viticulture declined steadily and at times dramatically until the 1930s. This "shock" will be addressed in more detail in the course of this study.

Reasons for the fluctuations in viticulture are manifold. In the beginning of the century, increases and decreases in acreage were often caused by export possibilities that appeared and vanished – especially with the german Länder adjacent to the Eastern part of Switzerland (introduction and abolition of duties on wine occurred regularly).[17] The decline in the latter part of the century must be placed in a more general structural transformation. The construction of networks of communication, especially the railway lines, meant increased competition for Swiss wine from Italy and France. Imports rose dramatically.[18] Furthermore, the grape pest Phylloxera – and other diseases – hit Switzerland causing losses in some regions.[19] This outline serves as an overview which will be complemented in the remainder of this study.

Viticulture in Switzerland is a wide field of study and this research only covers certain aspects. The scope of the research is as follows: The 19th century is identified above as a period which promises helpful contributions to temperature reconstructions and insights in a phase of transformation. Therefore, evolution of viticulture in the time between 1800 and 1914 will be studied. Special attention is paid to the 1880s when Swiss viticulture began to decline. The beginning of the First World War (1914-1918) is chosen as an endpoint as it constitutes a sharp rupture to economic continuity. In some instances, particularly in reconstruction, data outside this period is also used (1750-1966).

Geographically, this study is limited to the Swiss *Mittelland*. The region contains the plateau plains of present-day Switzerland. Roughly, the *Mittelland's* borders constitute the Alps in the east, the Jurassian mountain chain in the west and the Bodensee and Lake of Geneva in the north and south, respectively. The main wine-growing regions were

[15] Hans Brugger. *Die schweizerische Landwirtschaft in der ersten Hälfte des 19. Jahrhunderts.* Frauenfeld 1956, p. 48.

[16] The official acreage by the federal bureau of statistics was considerably lower than the figure indicated by Brugger form the farmer's secretariat (*Bauernsekretariat*). Bundesamt für Statistik BFS. *Rebfläche nach Kantonen 1855-2002 (Anbaustatistiken, T. 7.3.1.5).* url: http://www.bfs.admin.ch (12.3.2009); Brugger, *Landwirtschaft erste Hälfte 19. Jahrhundert*, pp. 162-163.

[17] Brugger, *Landwirtschaft erste Hälfte 19. Jahrhundert*, pp. 49;107.

[18] Heiner Ritzmann-Blickenstorfer. *Historische Statistik der Schweiz – Statistique historique de la Suisse – Historical statistics of Switzerland.* Zürich 1996, p. 660.

[19] Schlegel, *Weinbau in der Schweiz*, pp. 60–61.

situated in the cantons of Vaud, Zürich, and Argovia. Minor plantations also existed in Bern, Thurgau, Schaffhausen, and Neuchâtel. Due to different climatological conditions (southerly), wine plantations in Ticino, Valais and Graubünden are not considered even though the regions Ticino and Valais are very important nowadays.

1.1 Theoretical considerations

The nature of this research also requires integrated investigation of non-human factors, such as the biophysical impact of climate variability on grapes and human factors, such as social reaction to climate variability and other developments independent of climate (e.g. modernisation processes). By making use of both the so called "hard" and "soft" sciences in an interdisciplinary way, it is advisable to reflect on how to reconcile varying methodologies. This union rests on a shared conviction that "assessments of climatic impact assume, explicitly or implicitly, certain underlying relationships among climatic events and impacted people and places"[20] Some theoretical thoughts about the relationship between viticulture and climate are therefore warranted.

As soon as climate impacts on society are mentioned, it is dangerous to argue with a deterministic view. Climate determinism states that climate explains societal phenomena directly. Such an argument is untenable; climate does not exert an immediate effect on societies.[21] However, it is not justified to neglect climate in history altogether. Moreover, including climate factors in historical research leads to an expanded view.[22] While a generalisable relationship between "history" and "climate" might be out of reach for research due to the abstract nature of both terms, an alternative is to resort to "lower scales of analysis".[23] Most importantly, this means restricting research to a defined area of human activity and its relation to a set of climate variables. A general rule characterises this relationship: "beneficial climatic effects tend to enlarge the scope of human action, whereas climatic shocks tend to restrict it."[24] Such developments based on this relationship are, of course, contingent on other developments in historical context which must be considered as well.

[20] Robert W. Kates. "The Interaction of Climate and Society". In: *Climate Impact Assessment.* Ed. by Robert W. Kates. Chichester: John Wiley & Sons, 1985, pp. 3–37, pp. 4-6.

[21] Brazdil et al., "Historical Climatology", pp. 369-370.

[22] Jan de Vries. "Analysis of Historical Climate-Society Interaction". In: *Climate Impact Assessment.* Ed. by Robert W. Kates. Chichester: John Wiley & Sons, 1985, pp. 273–292, pp. 273-276.

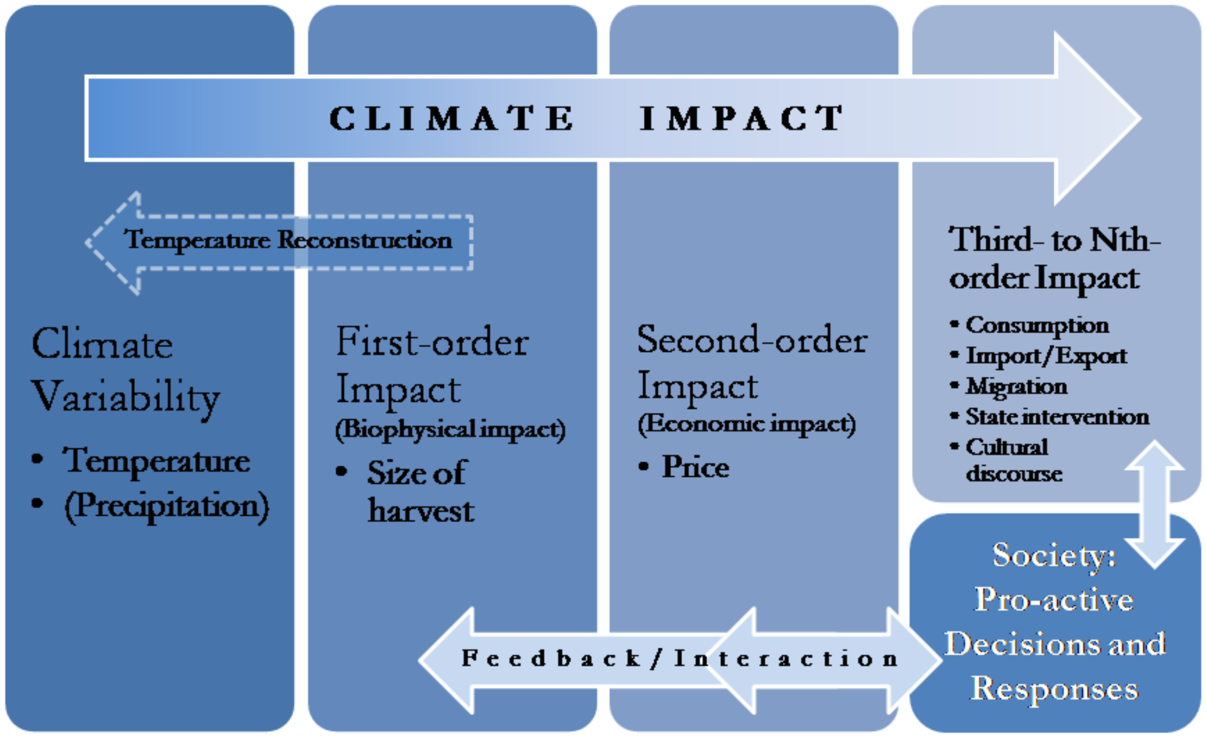
[23] Brazdil et al., "Historical Climatology", p. 403; Christian Pfister. "Weeping in the Snow. The Second Period of Little Ice Age-type Impacts". In: *Kulturelle Konsequenzen der Kleinen Eiszeit – Cultural consequences of the Little Ice Age.* Ed. by Wolfgang Behringer, Hartmut Lehmann, and Christian Pfister. Göttingen 2005, pp. 31–85, p. 59.

[24] Pfister, "Weeping in the Snow", pp. 58-59.

A great range of potential impact areas exists. In pre-industrial societies, which depended heavily on weather conditions, climate variability could result in famine or prosperity. In both cases these outcomes affected the economic, political, social, or cultural characteristics of societies. Generally, such impacts are thought of as chains of causation.[25] This chain is best depicted in a cascade model. Figure 2 depicts such a model for the wine-climate relationship following Kates' consideration and several extensions to it.[26] Climate variability stands at the beginning with several higher-order climate impacts following (top arrow from left to right). Interacting relationships are illustrated as well (bidirectional arrow on the bottom). This model reflects potential impacts and provides a conceptual framework for this research.

[25] Kates, "Interaction".

[26] Pfister, "Weeping in the Snow", p. 61; Christian Pfister and Rudolf Brazdil. "Social vulnerability to climate in the "Little Ice Age": an example from Central Europe in the early 1770s". In: *Climate of the Past* 2 (2006), pp. 115–129, p. 118; Stefan Trachsel. "Climatic Influences on Australia's Wheat Production during the First World War". Bachelor thesis at the Institute of History, University of Bern, 2007 (unpublished). P. 9



Model after Kates 1985.

Figure 2: Climate Impact Model for viticulture in Switzerland – The model illustrates the assumed relationship of various factor related to viticulture in Switzerland. Special focus is given to the impact of climate which stands at the beginning of the chain of causation.

First-order impacts

Climate variability exerts its most direct impact in biophysical processes (first-order impact). Adverse weather conditions during the growth period mean a smaller grape harvest, whereas favourable conditions lead to sizeable harvests. For wine, temperature is a major climate element influencing harvest quantity. Generally, cold temperatures during the midsummer months are associated with poor harvests in autumn. June, July, and to some extent also August constitute the deciding months for the Swiss *Mittelland* harvest size.[27] Depending on the magnitude of the variability, the harvest quantity deviates more or less from the average.[28] The biophysical impact of temperature is the first and the clearest impact of climate on viticulture.

Due to its direct nature, the biophysical reaction of grapes to climate variability is also used for the reconstruction of past temperature. The reverse arrow termed "Temperature Reconstruction" in the model depicts this. It should be noted that the arrow merely illustrates how the impact chain may be used to study past climate. Strictly speaking, it is not part of the model.

Second-order impacts

Following climate's impact on the size of grape harvests, variability in production affects several areas of societies. It is important to note that climate impact tends to be increasingly more difficult to determine in second- and higher-order impacts.[29] Also, the order of the impacts may not always be clear. Nevertheless, price is here assumed to be the impact of the second order. Price is the economic area most directly affected by fluctuations in production, which in turn is most directly affected by climate. Prices fluctuate according to the economic law of offer and demand. This holds true for a product like wine which is often traded on markets. Therefore, variability in harvests should be clearly visible in the price movements.

Third- and higher-order impacts

Progressing further, impacts are felt in the political, social, and cultural sphere of societies. Consumption may indirectly change through the price of wine. It may prevent or encourage consumers from drinking wine. The price-consumption relationship is clearly

[27] Pfister, "Weeping in the Snow", p. 63; Pfister, "Fluktuationen der Weinmosterträge".
[28] In addition to quantity, quality of harvest is affected by temperature as well. For instance, quality is measured by the sugar content of wine. September and October temperatures are most influential for quality.
[29] Kates, "Interaction", p. 4; Pfister, "Weeping in the Snow", p. 61.

a reality. Impacts may further be visible in the quantities of wine being imported and exported. Since a greater yield requires more workforce, migration may also be a further impact area. State intervention can be thought of as enhancing a sector or restricting it. Furthermore, such impacts are often accompanied by cultural discourses.

It is important to stress that climate is not the only influence for such higher-order impacts. Indeed, price already depends on a range of other factors that are not related to climate conditions such as demographic developments or shifts in demand. This reinforces that such impacts are considerably harder to relate back to climate events.[30]

Interaction, Response, and Feedback

When examining a long period of time such as a century, climate impact cannot be considered as a single factor for development. Instead, a multitude of influential factors on viticulture warrant attention. Often such factors can be traced back to earlier events or developments in the sector itself. Sometimes, factors originate exterior to the sector. The model pays special attention to feedback effects and associated factors. Such actions are understood as "pro-active decisions and responses" by society in Figure 2. While the exact impact of these effects is often hard to predict, an example illustrates how important it is to integrate them in the model: Imports always played a significant role for Swiss wine growers. In the second half of the 19th century railway lines were built connecting Switzerland with its neighbours. As a result, the amount of imported wine grew dramatically. Consequently, wine had to be sold cheaper which meant the entrepreneurial end for many wine growers. However, others avoided this fate by adapting production to produce premium high-quality wine.[31] Here we see societal adaptations in order to survive changing conditions. Feedback developments are crucial in evaluating the long-term evolution of a sector such as wine-growth, particularly when the interest lies on climate impact.

Such shifts in the production scheme may also have an influence on vulnerability to climatic events. The feedback/interaction arrows in Figure 2 account for such adaptational adjustments. The bidirectional arrow further illustrates that impacts can emerge form societal action as well. Society may exert influence on a agricultural area to the point that the area fundamentally changes. Indeed, the wine-growing area in Switzerland declined dramatically after the 1880s.[32] Despite the name "climate impact model",

[30] Kates, "Interaction", p. 4; Pfister, "Weeping in the Snow", p. 61.

[31] Schlegel, *Weinbau in der Schweiz*; Hans Brugger. *Die schweizerische Landwirtschaft 1850-1914*. Frauenfeld 1978.

[32] Hans Brugger. *Statistisches Handbuch der schweizerischen Landwirtschaft.* Bern 1968, pp. 152–161.

society is in fact an equally important focal point of the model. The bidirectional view on climate-wine relationship as outlined above assigns importance to both aspects.

Finally, it must be noted that the model was developed to provide a conceptual framework. This model should help to view interrelated processes in a simplified manner. In reality, climate impact cannot be evaluated so straightforwardly but by using the model as a guideline it should be possible to estimate the effect climate and other factors had on 19th century viticulture in Swiss *Mittelland*. The *Mittelland* also constitutes the scale on which these events are traced. In some instances, focus will also shift to region.

1.2 Research questions

In many ways, this study continues existing work. The main objective is to investigate 19th century wine production in the Swiss *Mittelland* in order to use the information for a reconstruction of summer temperatures from the 16th to the 20th century. The impact model presented in the previous section conceptualises the relationship between climate, viticulture and aspects of society. It serves as a guiding principle to this research. Therefore, research questions are closely linked to the model. In the logical order of the impacts, the research first looks at the climate variability. This part also entails the alignment of the wine and temperature data (calibration and verification) as a basis for a temperature reconstruction. Afterwards, the study focuses to the various impacts. Generally, this research is interested in how the wine-growing industry dealt with up- and downturns in production. This covers fluctuations which are related to climatic conditions, non-climate factors or an interaction of both.

The questions primarily related to the temperature reconstruction aim to enhance the quality of the statistical model that states the relationship between wine production and climate. This goal can be achieved if the circumstances of the data are known and duly considered, especially the changing context in the 1880s. The following research questions provide the input for this part of the study:

1. Which climate signal (month, set of months) is stored in wine production data?
2. What obstacles complicate temperature reconstruction in the 19th century?
3. What are the strengths and limitations of the temperature reconstruction in 19th century Swiss *Mittelland*?

Production in agrarian societies was at the mercy of the weather. This holds true late into the 19th century and viticulture was no exception. However, temperature reconstruction alone does not show what fluctuations in wine production meant to those affected. An historical approach is needed to establish the significance of a given event or process in a larger context. This study will use this approach to do this .

Therefore, the second set of research questions aims to define the societal significance of viticulture in the Swiss *Mittelland* in the 19th century and how viticulture evolved during this time. The second- and higher-order impacts stated in the above outlined model provide the framework for these questions.

A number of factors changed the Swiss economy throughout the 19th century, which may have influenced wine growth. Some of these factors include for example, the modernisation of agricultural processes which provided farmers with greater possibilities for production. Land use also changed with the abolition of tithes ("Zehnte") and ground rents. New train lines, especially the opening of the Gotthard tunnel in 1882, reduced the distance between markets fuelling competition from foreign producers. Viticulture was also specifically affected by the spread of the parasite phylloxera (vine fretter, *Phylloxera vastatrix*).[33] All these factors influenced the wine-growing parts of the Swiss *Mittelland*. But to what extent did things change and what were the reasons for it? Some areas worthy of investigation have been identified with the help of the conceptual model. The research questions addressing the societal significance of viticulture are presented below.

1. How did the Swiss *Mittelland* wine-growing industry change in the course of the 19th century?

2. What was the impact of climate in this process?

3. How is the interrelation between factors such as production size, price, consumption, import, migration, or state intervention to be understood? What were dominating topics in the public debate?

4. The 1880s were the beginning of a steady decline of viticulture in Switzerland. Which factors led or contributed to these changes? Did climate play a role?

It should be noted that while both sets of question will be addressed, it will not necessarily be separate of each other. The distinction in two sets mainly serves clarity and is based on conceptual reasons. It makes sense though to regard the relationship as one entity despite its two angles. As was outlined above, there are interactions and feedback loops between climate and viticulture, which entangle climatic and non-climatic elements.

[33]Schlegel, *Weinbau in der Schweiz*, p. 67.

1.3 Literature review

A vast body of literature on past climate variations exists. Literature has grown increasingly in the last few years with climate change becoming more and more popular as discussions about global warming emerged. In the Swiss area, historical climatology is closely linked to Pfister's work which dates back to the 1970s. A selective overview is given here on important aspects with respect to the topic of this study.

1.3.1 Documentary data and temperature reconstruction

Contrary to temperature reconstructions from tree-rings or ice cores, this study uses anthropogenic sources. The cultivation of wine and the collection of data about it are a consequence of human activity. The documentary sources that emerge from these activities contribute precious information about past climate. The approach is referred to as "historical climatology" and is distinguished from paleo-climatology (using proxies such as tree-rings, ice cores etc.) and modern instrumental measurement.[34] Informations from documentary data is particularly important for the pre-instrumental period, as they are "the only evidence from which the timing and severity of natural hazards can be assessed".[35] Often such documentary sources are outright ignored by the so called natural or "hard" sciences. This may be visible, when studies based on documentary sources are overlooked.

The "state of the art" in historical climatology is presented by Brazdil et al.[36] Among other things, the calibration-verification approach is explained there as the centrepiece of climate reconstructions. A large number of publications apply such an approach to reconstruct past temperature using proxy data. Reconstructions using yearly tree-ring width gathered from ancient trees reach back as much as thousand years.[37] Such studies in dendroclimatology use instrumental data to calibrate the tree-ring data and derive past temperature anomalies from it. Further studies combine several indicators (multiple proxies) to reconstruct past climate indicators.[38]

[34] Christian Pfister et al. *Documentary evidence as climate proxies. White paper on Documentary Data.* Trieste 2008, p. 1

[35] Pfister et al., *Documentary evidence*, p. 2.

[36] Brazdil et al., "Historical Climatology".

[37] For instance: Keith Briffa et al. "Treering width and density data around the Northern Hemisphere". In: *The Holocene* 12 (2002), pp. 737–758.

[38] For instance: Carlo Casty et al. "Temperature and Precipitation Variability in the European Alps since 1500". In: *International Journal of Climatology* 25 (2005), pp. 1855–1880; Jürg Luterbacher et al. "European Seasonal and Annual Temperature Variability, Trends and Extremes Since 1500". In: *Science* 303 (2004), pp. 1499–1503; Michael E. Mann. "The Value of Multiple Proxies". In: *Science* 297 (2002), pp. 1481–1482. Further references in Brazdil et al., "Historical Climatology".

1.3.2 Research on using grape data to reconstruct temperature

Wine often figures in temperature reconstruction studies due to its reaction to summer temperature. Typically, such studies look at one of three elements of viticulture: grape phenology, quantity of grape production, or quality of grape production. Various such studies have been published in the last 30 years specifically concentrating on the Swiss *Mittelland*. Production data was notably used by Pfister, De Montmollin and Ritzmann.[39]

Pfister's study provides a reconstruction back to 1529. However, his reconstruction ends in 1825 and his methodology did not include a verification of the model that emerged from the climate-wine relationship. Nevertheless, indicators tell of a highly successful attempt: Pfister indicates that the temperature model explains 65 per cent of the variation in grape yield (1755 to 1825). According to Pfister, the individual summer months (June, July, and August) of the harvest year and the same months in the year preceding the harvest year prove to be the most influential for the grape harvest.[40] Furthermore, this study also elaborated on the significance of the fluctuations in wine production. Since the present study relies heavily on Pfister's works, it will be discussed in more detail. Pfister also referred to his studies on grape harvest in countless other works.[41]

De Montmollin reconstructed a temperature time-series much in the same way as Pfister but he restricted it to the Neuchâtel area.[42] By compiling 14 local time-series from 1750 to 1914, his work differs a great deal from Pfister's. It was possible to attain similarly strong correlations as Pfister did after the elimination of several problematic years (hail and frost). The relationship between the harvest size and the summer temperature was clearly evident. In the case of De Montmollin the most influential months were: June and July of the year preceding the harvest and July of the harvest year. These months explained 63 per cent of the harvest size. However, one limitation of De Montmollin's research is that he did not apply the "state of the art" methodology.[43]

Ritzman examined the economic contribution of viticulture to the Swiss economy in 19th century.[44] He collected local wine-production time-series and used them to estimate national figures. A model based on five climatological variables helped him to do so.

[39]Pfister, "Fluktuationen der Weinmosterträge"; Montmollin, "Rendement viticole"; Heiner Ritzmann. *Die Wertschöpfung im Ersten Sektor, 1837-1945.* Beitrag zum Nationalfonds-Projekt "Geldmenge und Wirtschaftswachstum in der Schweiz, 1851-1931". Zürich 1990.
[40]Pfister, "Fluktuationen der Weinmosterträge", p. 476.
[41]For instance: Pfister, *Klimageschichte*; Pfister, *Wetternachhersage*
[42]Montmollin, "Rendement viticole".
[43]Brazdil et al., "Historical Climatology".
[44]Ritzmann, *Die Wertschöpfung im Ersten Sektor, 1837-1945.*

These five climatological variables were: average number of days with rain in May, June, July; average temperature in September; average temperature in September in the year prior to harvest; average temperature of April; dummy variable for strong winters. These variables are somewhat different from other studies on viticulture. However, this is Ritzmann's overall intention. The model should apply to all agricultural production, not just specific to wine . Nevertheless using these five variables and neglecting detrending, the model corresponded considerably well with wine-production data ($R2 = 0.65$, for the period of 1855 to 1920).[45] While also establishing the relationship between climate and grape production quantity, Ritzmann's objective was also to find the value added (Wertschoepfung) of the agricultural sector in 19th century Switzerland. Therefore, Ritzmann used climate as a predictor for grape harvest whereas this study does the contrary.

Researchers outside the Swiss *Mittelland* have also successfully reproduced the approach although they have applied different statistical methods. Wine production data from 1691 to 1984 from german region Rheinland-Pfalz was the subject of another temperature reconstruction.[46] This area is roughly 300 to 400 kilometres away from the Swiss *Mittelland*. The result of their approach is not comparable to the studies dealt with above.[47] Particularly, the authors point to potential problems with the detrending approach that Pfister and De Montmollin employed. They fear that it eliminates important climate information as well.

Furthermore, they use Principal Component Analysis (PCA) to find the relationship. However, PCA requires such a large number of climatological indicators that it renders the approach impossible for historical periods. Consequently, Lauer and Frankenberg fit the wine production series to temperature in the (short) time between 1948 and 1980. In this time, the yield per hectare grew dramatically which poses questions to the homogeneity of the data source. Another study using PCA was carried out by Jones and Davis who conducted highly detailed research on the wine-climate relationship by testing daily weather patterns to wine quantity and quality in the famous French viticulture region of Bordeaux.[48]

Finally, earlier studies also discuss the relationship between climate and wine production in Switzerland. Guyot/Godet and Guyot, for instance, examine the relationship

[45]Ritzmann, *Die Wertschöpfung im Ersten Sektor, 1837-1945*, p. 117.
[46]Lauer and Frankenberg, *Rekonstruktion des Klimas*.
[47]Lauer and Frankenberg, *Rekonstruktion des Klimas*, p. 43.
[48]Gregory V. Jones and Karl Storchmann. "Wine market prices and investment under uncertainty: An econometric model for Bordeaux Crus Classés". In: *Agr. Econ.* 26.2 (2001), pp. 115–133.

between climate and wine production in the Neuchâtel canton.[49] They also investigated production figures.

Literature also places great emphasis on the date of the grape harvest in addition to the size of grapes. This is because plant growth stages (phenology) are primarily dictated by climatic conditions. Le Roy Ladurie (with Baulant) used these indications already in the 1980s, but re-published them using more modern methods later.[50] Grape harvest dates prove highly successful in predicting early summer temperatures, which is why a large number of studies was published on them.[51] One finding of such studies is that the 2003 heat summer is likely one of the most extreme summer anomalies in the past 500 years. However, it is problematic that the date of grape harvest was often set and controlled by authorities.[52]

Recently, Meier used phenological data from the Swiss Mittelland to create a summer temperature reconstruction reaching from the 16th century to the present.[53] Her research demonstrates the skill of reconstruction periods throughout the 19th and 20th century. Meier's results regarding the choice of calibration and verification periods suggests that earlier periods return better results and should therefore be preferred. Combined use of phenological data for the Swiss *Mittelland* proved very successful for temperature reconstruction.

More often than the size of the production figures the phenology of the grapes in the literature. Phenology indicates the growth stages of a plant. This is mostly dictated by climatic conditions. Similarly well documented as the grape size is the date of the grape

[49] Edmond Guyot and Charles Godet. "Influence du climate sur le rendement de la vigne". In: *Bulletin de la Société des Sciences Naturelles de Neuchâtel* 58 (1933), pp. 77–96; Edmond Guyot. "Calcul du coefficient de corrélation entre le rendement du vignoble neuchâteloise, la temperature et la durée d'insolation". In: *Bulletin de la Société des Sciences Naturelles de Neuchâtel* 65 (1940), pp. 5–15.

[50] Emmanuel Le Roy Ladurie and M. Baulant. "Grape harvests from the Fifeteenth through the Nineteenth Centuries". In: *Journal of Interdisciplinary History* 10.3 (1980). History and Climate: Interdisciplinary Explorations, pp. 839–849; Emmanuel Le Roy Ladurie, Valérie Daux, and Jürg Luterbacher. "Le climat de Bourgogne et d'ailleurs". In: *Histoire, Économie et Société* 3 (2006), pp. 421–436.

[51] For instance: N. Etien et al. "Summer maximum temperature in northern France over the past century: instrumental data versus multiple proxies (tree-ring isotopes, grape harvest dates and forest fires)". In: *Climatic Change* 94 (2009), pp. 429–456; Annette Menzel. "A 500 year pheno-climatological view on the 2003 heatwave in Europe assesed by grape harvest dates". In: *Meteorologische Zeitschrift* 14 (2005), pp. 75–77; Valérie Daux et al. "Oxygen Isotope Composition of Human Teeth and the Record of Climate Change in France (Lorraine) during the last 1700 Years". In: *Climatic Change* 70 (2005), pp. 445–464; Nicole Meier et al. "Grape Harvest Dates as a proxy for Swiss April to August Temperature Reconstructions back to AD 1480". In: *Geophysical Research Letters* 34 (2007), p. L20705

[52] Pfister, *Wetternachhersage*, pp. 39–40.

[53] Meier et al., "Grape Harvest Dates" which is based on Nicole Meier. "Grape Harvest Records as a Proxy for Swiss April to August Temperature Reconstructions". MA thesis. Philosophisch-naturwissenschaftliche Fakultät der Universität Bern, 2007

harvest. Often, this date was set and controlled by authorities.[54] Le Roy Ladurie (with Baulant) used these indications already in the 1980s, but re-published them using more modern methods later.[55] Grape harvest days prove highly successful in predicting early summer temperature, which is why a large number of studies was published on them.[56] For instance, it could be shown with grape harvest dates that the heat summer of 2003 is likely to be one of the most extreme summer anomalies in the past 500 years.

1.3.3 Interpretation of production fluctuations

Research that considered grape characteristics and grape development was also extended to include consideration of societal effects. This is not surprising since documentary sources often not only indicate levels of production but also the social dimension associated with such fluctuations. Due to the great importance of wine production in past societies, there is ample necessity to also interpret the societal effects.

Literature on climate impact has hugely expanded over the last years. The concept of vulnerability is of special value in this respect.[57] However, although the majority of studies deals with scenarios for future climate conditions and societies' potential and necessity to adapt to them, historians increasingly begin to use the concept as well.[58] Concentration on the present or future might be understandable in view that future societies will most likely face fairly different climatic conditions. Nevertheless, experiences of past societies are worthwhile to study. There might not be lessons to be learned, but understanding past climate impact helps contextualise present problems. For example, such studies shed light on the adaptational potential of past societies.

An interesting point regarding climate impact was during the 16th century. Throughout Europe, a remarkable drop in wine production level was observed in the later part of this century. This corresponds to the time of the Little Ice Age (LIA). For instance, in Lower Austria, the state experienced great financial problems because taxes on wine

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[54] Pfister, *Wetternachhersage*, pp. 39–40.

[55] Le Roy Ladurie and Baulant, "Grape harvest"; Le Roy Ladurie, Daux, and Luterbacher, "Climat de Bourgogne".

[56] For instance: Etien et al., "Summer maximum temperature in northern France"; Menzel, "500 year pheno-climatological view"; Daux et al., "Record of Climate Change"; Meier et al., "Grape Harvest Dates".

[57] Hans-Martin Füssel. "Vulnerability: A generally applicable conceptual framwork for climate change research". In: *Global Environmental Change* 17 (2007), pp. 155–167.

[58] Pfister and Brazdil, "Social vulnerability".

were absent for a prolonged period of time. [59] These and other consequences are well researched.[60]

An interesting point in case for the investigation of climate impacts represents the 16th century. All over Europe, a remarkable drop in wine production level can be observed in the later part. This corresponds to the time of the Little Ice Age (LIA). Contributions point to causes of this drop in wine production, which underlines the importance of the good. For instance, in Lower Austria, the state experienced great financial problems because taxes on wine misses for a prolonged period of time. [61] Also, consequences for other places as well as cultural consequences are well researched for the LIA.[62]

Finally, the history of viticulture in Switzerland is considered. An old but still relevant work on the history of viticulture in Switzerland was written by Schlegel in 1973.[63] Being a geographer, Schlegel concentrated much of his study on natural conditions affecting viticulture in the 1960s. Nevertheless, his historical portrayal goes back to Roman times. Knowledge on viticulture in the Swiss *Mittelland* was already fairly well researched 30 years ago. Regional studies – partly or entirely dedicated to viticulture – extended the knowledge on specific aspects.[64]

1.4 Material, sources, and source critique

This section elaborates on the availability of historical sources. The characteristics of the wine-production data, related problems and a comparison of them are provided in the data section below (section 4). Temperature data will also be examined in the same section.

1.4.1 Instrumental Temperature data

In the second half of the 18th century individuals in various locations throughout the Swiss *Mittelland* area began collecting temperature data. The earliest temperature time-

[59] Landsteiner, "Crisis of wine production".

[60] Wolfgang Behringer, Hartmut Lehmann, and Christian Pfister. *Kulturelle Konsequenzen der Kleinen Eiszeit – Cultural consequences of the Little Ice Age*. Göttingen 2005; Pfister and Brazdil, "Social vulnerability"; Christian Pfister. "Climatic Extremes, Recurrent Crises and Witch Huntes: Strategies of European Societies in Coping with Exogenous Shock in the Late Sixteenth and Early Seventeenth Centuries". In: *The Medieval History Journal* 10 (2007), pp. 1–41.

[61] Landsteiner, "Crisis of wine production".

[62] Behringer, Lehmann, and Pfister, *Cultural consequences*; Pfister and Brazdil, "Social vulnerability"; Pfister, "Witch Hunts"; Pfister, "Weeping in the Snow".

[63] Schlegel, *Weinbau in der Schweiz*.

[64] For Vaud: Dubois, *Les vignobles vaudois*, for Bern (some aspects): Christian Pfister. *Im Strom der Modernisierung*. Bern 1995, for the Lake of Zürich area: Andres M. Altwegg. *Vom Weinbau am Zürichsee. Struktur und Wandlungen eines Rebgebiets seit 1850*. Stäfa 1980.

series exists for Geneva and begins in 1753.[65] Another early temperature series exists for Basel and starts in 1755.[66] However, the Basel series has often been criticised for having systematic errors around the turn of the 18th century as it indicates summer temperatures much higher compared with other such early time-series.[67] Furthermore, Auer et al. provide a time-series for the Greater Alpine Region. The so called HISTALP time-series is homogenised, quality-controlled and corrected back to 1760.[68] A homogeneous time-series for all parts of Switzerland only exists for 1864 onwards.[69]

An abundant number of temperature time-series beginning in the late 18th century exists and will be used in this research. As data quality for such early instrumental series remain at times problematic, this will be addressed in detail in order to use the most suitable available data. Nevertheless, the increasing density of meteorological networks in the course of the 19th century is crucial for temperature reconstruction with proxy-data.

1.4.2 Wine production data

It can be said that viticulture is a very well documented area of past societies. The reason for this is simple. There was a great deal of money to be earned from viticulture. Individuals or institutions who were receiving money from wineries took an interest in collecting data regarding production and revenue. Detailed book-keeping provided both control and accountability. Pfister made use of this effort to create his time-series back to 1525. In most cases he calculated production figures by referring to tithe contributions from grapeyards. The circumstances of these sources varied across the Swiss *Mittelland* which needed to be observed. Pfister also managed to calculate figures for yield by unit area.[70]

[65] Max Schüepp. "Der Temperaturverlauf in der Schweiz seit dem Beginn der meteorologischen Beobachtungen". In: *Annalen der Schweizerischen Meteorologischen Zentralanstalt* Anhang II (1957).

[66] Max Bider, Max Schüepp, and Hans von Rudloff. "Die Reduktion der 200-jährigen Basler Temperaturreihe". In: *Archiv für Meteorologie, Geophysik und Bioklimatologie* B9 (1959), pp. 360–412. The Geneva and Basel time-series were obtained from the Institute of History, Section of Economic, Social, and Environmental History (WSU) of the University of Berne.

[67] The latest contribution dealing with this problem is Max Burri. "Pflanzen- und Schneebeobachtungen aus den Kantonen Bern und Wallis 1755-1804 und ihre Bedeutung für die Temperatur-Rekonstruktion". MA thesis. Institute of History, University of Berne, 2009. In general: David Frank et al. "Warmer early instrumental measurements versus colder reconstructed temperatures: shooting at a moving target". In: *Quartenary Science Reviews* 26 (2007), pp. 3298–3310.

[68] Ingeborg Auer et al. "HISTALP - historical instrumental climatological surface time series of the Greater Alpine Region". In: *International Journal of Climatology* 27 (2007), pp. 17–46. DOI: 10.1002/joc.1377.

[69] Michael Begert, Thomas Schlegel, and Werner Kirchhofer. "Homogenous Temperature and Precipitation Series of Switzerland from 1864 to 2000". In: *International Journal of Climatology* 25 (2005), pp. 65–80. DOI: 10.1002/joc.1118.

[70] Pfister, "Fluktuationen der Weinmosterträge".

However, while viticulture is well documented in the *ancien régime* severe problems arise in the 19th century. Viticulture shares this fate with other agricultural goods. Political and societal changes associated with the Helvetic Revolution (1798) and the notoriously unstable Helvetic Republic (1798-1802) often caused gaps in collections. Many time-series end in 1798 or in the first decades of the 19th century when tithe contributions were abandoned. Nevertheless, some data on viticulture has been collected and was also published.[71] In some areas, notably Zurich, detailed sources can be found up until the 1830s and in one case up until the 1870s.[72] However, for two to three decades after the 1830s data is rare.

Data availability improves for the last quarter of the 19th century when the cantonal federal bureaus of statistics began collecting data nationwide. Some cantons already provide data from the 1850s on.[73] Statistics on viticulture were among the first to be collected.

The data used in this study for the period prior to 1800 stems from Pfister's work.[74] De Montmollin also used Pfister's data but complemented it with further data collected in the Neuchâtel and Vaud regions.[75] His data is also included in this study. Further data can be found in a variety of publications. Some are sources[76], others – above all Brugger's contributions – reproduce data taken from original sources, which were not always clearly labelled.[77] In some instances existing data was extended with further data from additional sources. For example, Pfister stopped collecting data for periods later than 1825 but some time-series could be extended into the 1870s. Furthermore, with the beginning of more sophisticated statistics in the 1870s cantonal and federal statistical yearbooks provide a good account of the Swiss "'Mittelland"' wine-growing industry.[78]

Despite the relatively high number of individual time-series (more than 40) in this study, the quality of this data requires careful evaluation. For instance, cantonal officials estimated the area planted with grapes applying a rule-of-thumb approach in the late 19th century.[79] To illustrate this, there is a significant difference between the area indicated in

[71] Brugger, *Landwirtschaft erste Hälfte 19. Jahrhundert* and other works by the same author.
[72] J.M. Kohler. "Weinerträge am rechten unteren Ufer des Zürichsees von 1731-1866". In: *Schweizerische Landwirthschaftliche Zeitschrift* 7 (1879), pp. 193–210.
[73] See for example Brugger, *Landwirtschaft 1850-1914*.
[74] Pfister, *Klimageschichte*, Tabelle 1/34.3.
[75] Montmollin, "Rendement viticole".
[76] Kohler, "Weinerträge Zürichsee"; Dr. Zweifel. "Einige Bemerkungen über die Pflanzungen der Rebe im Limmathale". In: *Schweiz. Zeitschrift für Landwirtschaft* 3 (1848), pp. 81–88.
[77] Brugger, *Landwirtschaft erste Hälfte 19. Jahrhundert*; Brugger, *Statistisches Handbuch*; Brugger, *Landwirtschaft 1850-1914*.
[78] *Statistisches Jahrbuch der Schweiz.* Bern/Neuenburg 1891ff.
[79] Ritzmann, *Die Wertschöpfung im Ersten Sektor, 1837-1945*, p. 109.

the Zurich statistical yearbooks and in a land register (*Kataster*) for the years 1876 - 1920. Brugger corrected some of the statistics using data he obtained from the farmer's bureau, where he worked.[80] The farmer's secretary's report are based on data gathered in its own surveys of individual farms. These uncertainties on data warrant a cautious review of the data used in this study. Furthermore, it should also be mentioned that surfaces of grapeyards were often estimated. Additionally, measures of surfaces and volumes varied regionally.[81] Several tests are therefore required in order to ensure comparability of the data obtained.

1.4.3 Sources regarding higher-order impacts

A great range of areas relevant for the development of the wine-growing industry in the 19th century have been identified above. Literature has dealt with these aspects relatively extensively, since they constitute important topics for the history of 19th century Switzerland. Therefore, this study takes advantage of these contributions in concluding on potential higher-order impacts of climate on viticulture.

To examine such a long time, it is important to find a balance between quantitative and qualitative approaches. The relationship as stated in the model above, tempts to rely on purely quantitative research. This will receive due consideration here since it can best represent how changes in viticulture were interrelated to each other. Therefore, such relationships will mostly be examined using existing time-series on aspects such as consumption, price and import data. This data can be identified from literature. However, the same literature also provides also qualitative accounts which will also be considered.

1.5 Structure

The interdisciplinary approach to this research influences the structure of this study. The first part is dedicated to an in depth discussion of the data used for the reconstruction and the reconstruction itself. The second part addresses the impacts of the fluctuations.

Following this introduction, the methodology outlines the research process for this study (section 2). Afterwards, some biological aspects of the grape plant, especially its reaction to climate, are explained (section 3) The main goal of this study is to create a homogenous time-series of wine-production data. This is presented in the data section (section 4). The data section also incorporates an overview and critical evaluation of

[80]Brugger, *Statistisches Handbuch.*
[81]Pfister, *Klimageschichte*, Tabelle 1/34.1.

both the temperature and the wine-production data. Then, the section 5 presents the results of the reconstruction. Foremost, this includes the calibration and verification and how this approach is best applied to the existing data. This includes both the alignment of the raw wine-production data to instrumental data and the actual reconstruction that extends back to 1529 using Pfister's data.

The study concludes with a synthesis of the findings of the previous sections. The synthesis aims to summarise the development of viticulture in the 19th century with special respect of the role climate played in this process. As previously mentioned, such an endeavour requires extensive consideration of variables that have little to do with climate at first appearance. This study aims to show how such climatic and non-climatic factors are interrelated by addressing the specific research questions.

2 Methodology

This study applies an interdisciplinary approach, which is reflected in its methodology. The model outlined in Figure 2 in the introduction guides the research questions and dictates the order of the research process and the structure of the thesis. Furthermore, the model allows the combination of approaches from both ‘soft’ and ‘hard’ sciences to the subject.

While the methods for reconstruction are borrowed from climatology or geography, the examination of higher-order impacts uses historical techniques. As outlined above, the temperature reconstruction will apply the ‘state of the art’ calibration-verification procedures[82] which were not yet available when Pfister published his article some 30 years ago. This procedure entails a statistical approach to reconstruct climate.

2.1 Data preparation and reconstruction

Before reconstruction, the relavant data needs to be collected and prepared in order to be used for the calibration and verification. The goal is the creation of a homogenous time-series from 1750 to 1966 which expresses the level of the grape harvests in the Swiss *Mittelland*. Such a series is required in order to derive information about the wine-climate relationship.

The content of this series – information on local levels of grape harvests – must be collected from published literature and primary sources. No data will be collected for times before 1750. However, the local time-series from Pfister are used to extend the *Mittelland* time-series back to 1525.[83] This is crucial for the reconstruction of temperature for the whole period. The relevant indicator for the yield is the quantity per area, i.e. hectolitres per hectare. This indicates how successful a harvest was regardless of changes in the area planted with grapes. The exact procedure to construct the composite series will be outlined in the section on data (section 4).

In a next step, the relationship between climate and wine production will be examined in detail. The goal of this part is to find the set of months that is most promising for reconstruction. The correlation of monthly average temperature and wine production level serves as an indicator.

The procedure to reconstruct the temperature entails three steps.[84] The first two steps (calibration-verification) take place in the period of time when instrumental tem-

[82] Brazdil et al., “Historical Climatology”, pp. 380-383.
[83] Pfister, “Fluktuationen der Weinmosterträge”, pp. 470–474; Pfister, *Klimageschichte*, Tabelle 1.34/3.
[84] Brazdil et al., “Historical Climatology”, p. 378.

perature data and quantiative production data overlap. The calibration aims at finding a quantitative relationship between a climate-sensitive agricultural good such as wine and climate. This is done with linear regression which returns a function. This function is called "transfer function", because it will be used to "transfer" the relationship between wine and climate to past times, when climate is not known.[85]

Verification adheres to scientific standard since "the validity of any kind of data needs to be verified by applying suitable statistical methods and using independent data."[86] In other words: the reconstruction is tested in a different period of time in which climate and wine production data also overlap. In order to do this, the transfer function is applied to the wine production data. Statistics such as the correlation coefficient and more sophisticated indicators show whether the calibration returned a valid model. The statistical procedures used to perform calibration and verification will be presented in the respective sections.

Various calibrations and verifications will be tested in order to find the suitable combination. The third step – reconstruction – entails the application of the most suitable transfer function(s) calculated in calibration and controlled in verification to the early part of the series. In doing so, temperature is reconstructed with the help of a proxy indicator.

2.2 Higher-order impacts

Historical examination is required to establish the significance of changes in the wine-growing industry in the course of the 19th century. The historical method is not as clearcut as that of other scientific disciplines. What historians deal with is information about the past taken from primary sources. They situate such sources in a larger context and discuss their significance or role through interpretive techniques. Often, questions from the present guide the research into such remainders of past societies. Broadly speaking, this is also done in this study.

Several data sets will be used to address higher-order impacts. This data needs to be prepared as well. However, these procedures will be outlined in the respective sections. It is important to acknowledge that in this second part of the study, the qualitative aspects dominate. Furthermore, it is important to note that for this second part, the study relies heavily on conclusions and resources from literature.

[85] Brazdil et al., "Historical Climatology", p. 380.
[86] Brazdil et al., "Historical Climatology", p. 380.

3 The biology of the grape vine

This section reviews the growth period of grapevines. It outlines various growth stages and factors affecting grapevine growth. By doing so, it also discusses how climatic factors may be or may not be responsible for fluctuations in grapevine production. The aim is to identify to what extent climate is responsible for grape growth. In line with the objectives of this study, this section provides information on the limitations associated with the use of wine production in reconstructing past climate effects.

3.1 Growth stages

Viticulturers distinguish between several growth stages for grapes. Such compilations may be highly detailed and contain nearly 50 different stages and sub-stages. For the purpose of this study, five stages of grape growth are briefly outlined below. The dates given relate to the Northern Hemisphere and therefore are accurate for the Swiss *Mittelland*. The outline follows a number of works investigating grapevine growth.[87]

1. Bud break: March marks the beginning of the growth cycle. Shoots are developed from buds and begin inflorescence development. Leaves begin to separate. The grapevine starts turning green with the first shoots appearing. Regular temperatures of around 10°C is necessary for this stage of development.

2. Flowering: Around May, flowers begin to appear on the shoots. Most grapevines do not need insects for pollination as grapes can self-pollinate. At this time, flowers start to grow and seeds develop as a result of germination. These seeds are then protected by the berry which later grows into the grape. This process starts shortly after flowering. Average daily temperatures must exceed 15 degrees for flowering to occur. In a previous study that concentrated on grape-growing in Switzerland, a relationship was found between the beginning of flowering and the number of days with midday temperature higher than 15 degrees.[88]

   The flowering phase is highly sensitive to adverse weather conditions. Cold temperatures in March and April may delay the onset of flowering. Cold, wet, and windy weather in this period may mean significantly lower production. However, overly

[87] Michael G. Mullins, Alain Bouquet, and Larry E. Williams. *Biology of the grapevine*. WSU: GE: Conservatoire Botanique: 663 MUL; A5439 / A5125. Cambridge 1992; B. Coombe. “Adoption of a system for identifying grapevine growth stages”. In: *Australian Journal of Grape and Wine Research* 1 (1995), pp. 104–110; Werner Koblet. *Physiologie der Weinrebe*. Wädenswil 1975.

[88] Koblet, *Physiologie der Weinrebe*, p. 13.

high temperatures and dryness may also mean that a smaller number of flowers develop into grapes.

3. Berry development (growing): In the weeks following flowering, the green and hard grape berries grow to about half their size, before they change color. This growing period occurs between May and July depending on the earlier development of the grape. There are three weather factors which can affect production: High temperatures (20°C or more), great sun-light exposure, and sufficient water supply (through precipitation at night, preferably).[89] Light is important because it is an essential element of photosynthesis.

4. Veraison: The stage when berries take on the colour characteristic of each grape variety (red or white) is called veraison. The change in color is due to chemical processes inside the grape. Veraison takes place around the end of July, beginning of August, after flowering. Once the grapes start taking on colour, they begin to ripen rapidly. The simultaneous softening of the berry happens due to the rising sugar level in the berry. Warm weather is crucial in this phase: The more a grape berry is exposed to warmth, the earlier veraison begins. For instance, grapes covered by leaves take on colour later than those being exposed to the sun. After floraison, some energy is stored inside the plant as reserve for growth in the next cycle.

5. Harvest: In September, October, or at times as late as November, harvesting takes place. The growing process is over and the winemaking process begins. In recent times, literature cites subjective evaluation of ripeness by the winegrower as decisive for when grapes are harvested. In agrarian societies, however, harvest dates were often set randomly by authorities. Therefore, historical documents referring to this act prove very helpful for temperature reconstruction based on that phenological indicator. After harvest, the grape continues to store energy for the next growing cycle. When temperatures fall, the grapevine begins its dormancy period until the next bud break.

It should be noted that phenological dates referring to growth stages are highly correlated with each other.[90] This means that delays in the early development of the grape are still felt in the remainder of the growth process. Nevertheless, climate reconstructions using phenological data of wine production have proved highly skilfull. The date of

[89] Cited after Montmollin, "Rendement viticole", p. 15.

[90] Gregory V. Jones and Robert E. Davis. "Using A Synoptic Climatological Approach To Understand Climate-Viticulture Relationships". In: *International Journal of Climatology* 20 (2000), pp. 813–837, p. 829.

harvest, the well documented last stage in the grape growing cycle, was used for climate studies as early as in the 19th century, as De Montmollin notes.[91] More recently, Meier et al. used harvesting dates in combination with other indicators such as bud break and veraison. Their reconstruction model had a great skill predicting April to August temperatures.[92]

The relationship between climate and quality, quantity, and phenological stages of wine production is well established. Jones and Davis detected all these relationships in one single study.[93] As opposed to former studies, they did not compare viticulture to monthly average data, but to the frequency of daily weather patterns. Therefore, they were able to use higher-resolution climate data. Such an approach was made possible by the fact that they examined 20th century vintages in the French wine region of Bordeaux. Such detailed climate information does not exist for earlier periods. Their results may serve as empirical proof for the influences of climate mentioned in the above scheme. For phenological stages, Jones and Davis conclude: "In general, events that bring about cooler and moister conditions (...) during the preceding stage control to a large degree when the phenological event occurs."[94] Regarding production, higher temperatures during the growing period up to July tend to increase the size of production, whereas cold conditions do not guarantee full berry development.

Jones and Davis also explained half of the variation in quality ratings for Bordeaux vintages with climate. According to their statistical tests, wet weather during flowering and berry set (May to July) exhibited a negative influence. Conversely, when warm and stable weather allows for full maturation of the berries, (during veraison at the end of July), quality ratings tend to be higher.[95]

Despite the conclusive results, it is important to be aware that the above scheme constitutes a very basic outline of grape growth. A range of further factors or events may influence grape growth. Among those are: the characteristics of soil and grape variety; occurrence of pests and diseases; water supply in the vineyard; age and health of the grapevine; different ways of cultivating grapes. Some, such as diseases or funguses, may even be influenced by temperature and precipitation or moisture as well. Such phenomena cannot be neglected. Systematic changes in production levels or negative outliers might well be attributable to such factors. What comes especially to mind is

[91] Montmollin, "Rendement viticole", p. 8.

[92] Meier et al., "Grape Harvest Dates". Further studies showing similarly good results: Isabelle Chuine et al. "Historical Phenology. Grape Ripening as a Past Climate Indicator". In: *Nature* 432 (2004), pp. 289–290. DOI: 10.1038/432289a; Le Roy Ladurie, Daux, and Luterbacher, "Climat de Bourgogne".

[93] Jones and Davis, "Climate-Viticulture Relationships".

[94] Jones and Davis, "Climate-Viticulture Relationships", p. 833.

[95] Jones and Davis, "Climate-Viticulture Relationships", pp. 833-834.

the occurrence of the grape disease phylloxera in the third quarter of the 19th century in Switzerland.

While the stages above constitute the main steps in the cycle of wine growing, it was implicitly mentioned that the growth of the buds actually begins in year before the harvest. The buds begin to grow as early as during flowering of the preceding year. In that time, high temperatures do not only benefit the development of the grape, but also the buds for the next cycle. These buds are green and individual buds are covered in bud scales at that time. The positive influence of warm climate is due to the fact that nutrients and energy are stored in the plant. Given this biological process, it is not surprising that both De Montmollin and Pfister found significant relationships between yields and temperatures in the summer one year before harvest.[96] This fact cannot be overlooked.

3.2 Summary

From the above scheme and empirical results it is evident that climate is a major factor in the fate of a year's grape yield and thus wine production. Nowadays as well as in the past, the quantity and quality of yields is often explained with the prevailing weather conditions during the growing season. Consequently, it is legitimate to use wine production data in climate reconstruction. The biological stages of grape growth show that moderate to high temperatures between March and September are crucial for the development of grapes, despite other factors playing significant roles as well.

In summary, temperature exhibits a tremendous effect on wine growing. However, alone from looking at the biological side of the grape growing season, a range of limits to the use of wine production must be noted. Firstly, from a biological perspective the growth of a year's yield begins in the preceding year with buds being developed during flowering and the plant storing reserve energy later in the growth process. This means that there will never be a perfect correlation between the yield of a certain year with the summer temperature of that year. Statistical analysis of the available data on wine production will need to show to what extent temperature in a certain month explains yields.

Secondly, while temperature is important, it clearly is not the only factor affecting yield quantity. Other factors such as characteristics of the grape and its surroundings, (extreme) short-term weather patterns, or pests and diseases exhibit a considerable influence on the growth of the grape as well. These events have to be controlled as they

[96] Pfister, "Fluktuationen der Weinmosterträge", p. 476; Montmollin, "Rendement viticole", pp. 54;57.

might bias the temperature signal in grapes. For the following climate reconstruction, the main characteristics of grape growth must guide the research, while at the same time the limits must be kept in mind.

4 Data

This study uses several time-series to illustrate the yearly condition of temperature and wine productions. Such data, whether relating to a distant or not-so distant past, often raises questions about reliability, uncertainties, context changes, and further conflictual issues. A careful discussion of the characteristics and origins of the data used in this study is therefore necessary. This section discusses the most important data of this study: the temperature and grape harvest time-series and their relationship.

4.1 Instrumental temperature data

Temperature measured with thermometers constitutes the backbone of the temperature reconstruction. For the Alpine region, such instrumental data is available from around 1750, even though its quality is sometimes problematic.[97] It is common to use average temperatures. This study uses monthly average data and accordingly draws indications for longer periods such as seasons from it. Temperature data is generally expressed in respect to the mean of a fixed period. Here, this period is set at 1901 to 2000.

While the interest of this study is to reconstruct temperature for times in which no direct records exist, the characteristics of the instrumental data that is used as a target should not be ignored. Climate variation is natural and so is the environmental reaction to these fluctuations. Long-term tendencies in temperature may affect plants (e.g. harvest level) which can affect their validity as climate indicators. Therefore, it is crucial to not only discuss the origin but also the content of the temperature time-series.

4.1.1 HISTALP temperature time-series

The HISTALP data set provides a homogenised time-series for temperature in the Greater Alpine Region (GAR, 4-19° E, 43-49° N) reaching back to 1760 for temperature.[98] More than a dozen meteorological offices in European countries contributed instrumental data to the database which is described in Auer et al.[99] The database contains more than 500 time-series for 200 locations.

[97] Brazdil et al., "Historical Climatology".

[98] HISTALP is short for: Historical Instrumental Climatological Surface Time Series Of The Greater Alpine Region.

[99] Auer et al., "HISTALP". The dataset is available for download on the internet: `http://www.zamg.ac.at/histalp/`: Reinhard Böhm et al. "Eine neue Website mit instrumentellen Qualitätsklimadaten für den Grossraum Alpen zurück bis 1760". In: *Wiener Mitteilungen* 216 (2009), pp. 1–14.

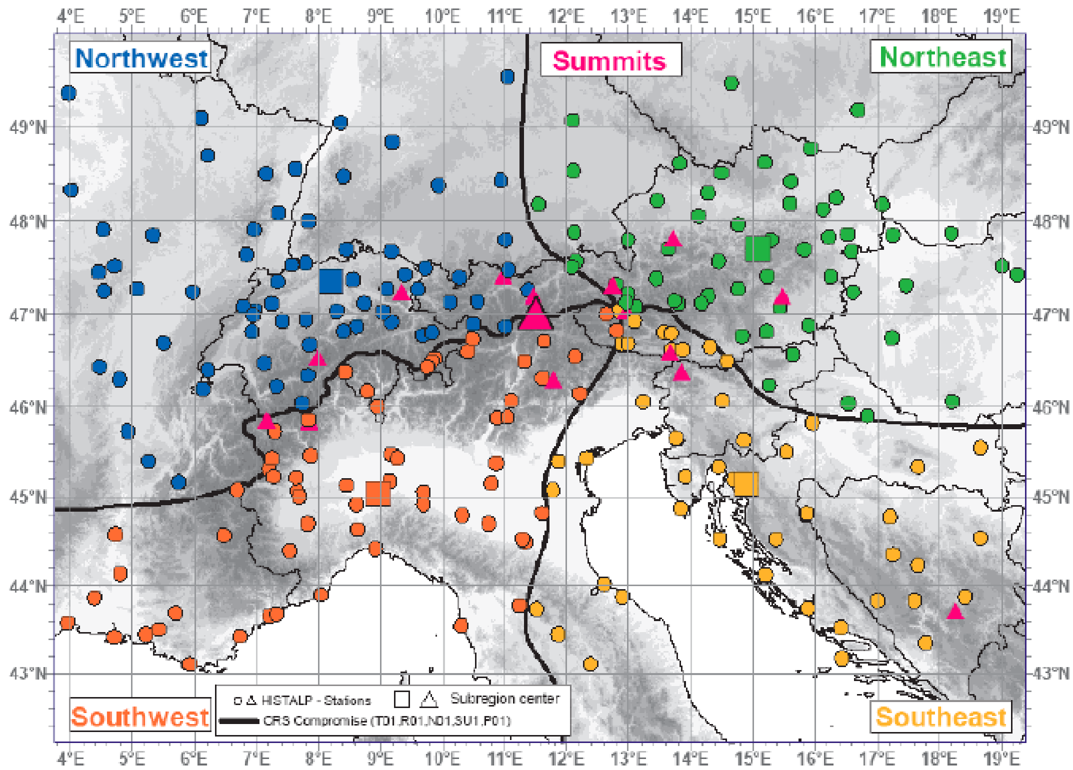

Figure 3: HISTALP: stations and subregions (CRSM) – The Northwestern (NW) subregion (stations in blue) is used in this study. Source: Böhm et al. 2009, p. 12.

HISTALP divides the GAR in four subregions (Coarse Resolution Subregional Means CRSM) which were identified for their similarity with statistical procedures (PCA over all available climate elements). The most appropriate subset for the *Mittelland* is the Northwestern (NW) region. Figure 3 illustrates that the NW region covers the northern part of Switzerland and thus the area that is also represented by the *Mittelland* wine production data. Stations with early data from Switzerland include Basel (temperature data from 1760 onwards), Geneva (1760), Bern (1777), and Zürich (1830). However, the NW subregion also contains stations outside Switzerland such as Innsbruck (A, 1777), Karlsruhe (D, 1779), Stuttgart (D, 1792), and Strasbourg (F, 1801).[100] The geographical centre of the HISTALP-NW subregion lies approximately 30 kilometres West of Zürich. The data set is referred to simply as HISTALP.

The great advantage of the HISTALP time-series is its homogenisation. In that process, the data was systematically quality-controlled with outliers and inhomogenities being detected and removed and gaps filled.[101] Therefore, HISTALP temperature data can be compared over time.

Due to this advantage this study generally uses the HISTALP time-series. There are other reasons for this decision: As was mentioned before, the early Basel time-series is often criticised for its warmth bias in the turn of the 18th century.[102] Using the Geneva time-series alone is problematic due to its peripheral position with respect to the wine-growing regions in the Swiss *Mittelland* – tests showed that the Geneva time-series returns weak results for climate-wine relationships even with the relatively close region of Vaud. Furthermore, both the Basel and the Geneva time-series have a break in 1864. After that date, homogenised data is available, but not before.[103]

Nevertheless, the two time-series of Basel and Geneva only differ to a minor degree with HISTALP. The correlation for summer temperature between all three series is relatively high, even for the time before 1914 when differences are more likely to occur due to measurement problems. Table 1 shows these correlations.

The graph in Figure 4 illustrates the summer temperatures as returned by the three series. In some stretches, especially in the early 19th century some differences are visible.

[100] Auer et al., "HISTALP", pp. 26–27.

[101] This is described in Ingeborg Auer et al. "Metadata and their role in homogenising". In: *Proceesdings of the Fourth Seminar for Homogenization and Quality Control in Climatological Databases, WMO-TD No. 1236*. 2003. It should be noted that the Swiss Meteorological Office "MeteoSchweiz" uses a different homogenisation process.

[102] Burri, "Pflanzen- und Schneebeobachtungen".

[103] Begert, Schlegel, and Kirchhofer, "Homogenous Temperature". The Basel and Geneva temperature time-series are described in Bider, Schüepp, and Rudloff, "Basler Temperaturreihe" and Schüepp, "Temperaturverlauf", respectively.

	HISTALP	Basel
Basel	0.947	–
Geneva	0.888	0.887

Table 1: Comparison of summer temperature between the HISTALP, Basel, and Geneva time-series (Correlations for 1753 to 1914) – All values significant with $p < 0.001$.

HISTALP temperatures tend to overshoot the other two series in some years, especially in hot summers, but also in some cases with below average temperature. In fact, on average HISTALP shows temperatures 0.2 °C higher than the Basel time-series. This is not irrelevant considering the assumed warm bias for early Basel temperatures. It is nevertheless justified to use the HISTALP time-series to fit wine production data to it because it guarantees homogenity for the whole period. Furthermore, it represents the average of a larger area for the reconstruction. This is probably also the reason for the higher temperatures.

4.1.2 Summer temperature in the 19th and 20th century

In the following section, summer temperature as described by the HISTALP time-series is discussed. The graph in Figure 4 (on page 34) shows again the summer temperatures as returned by the HISTALP time-series. Summer temperature (June, July, August mean) is used as grapevine growth relies heavily on warm weather during these months. The curve clearly shows the warming trend in the last decades of the 20th century. What is of greater interest for this study, however, is the development in the 19th century.

Temperature fluctuations require great scrutiny as grapevine development reacts sensitively to temperature, as previously explained with theoretical and empirical references. The 11-year moving average (red in Figure 5) indicates the long-term tendencies of summer temperatures. After temperatures fluctuated around the average in the beginning of the time-series in 1760, they reach above average levels in the end of the 18th century. This short warm period is followed by a sharp decline to average and below average temperature to the 1820s. This drop is mainly caused by volcanic eruptions. The most (in)famous of them, the Tambora eruption in nowadays Indonesia, caused the 1816 "year without a summer".[104] After this break, temperatures stayed at below average

[104] Charles R. Harington. *The year without a summer? World climate in 1816.* Ottawa 1992; John D. Post. *The last great subsistence crisis in the Western world.* Baltimore, London: John Hopkins University Press, 1977.

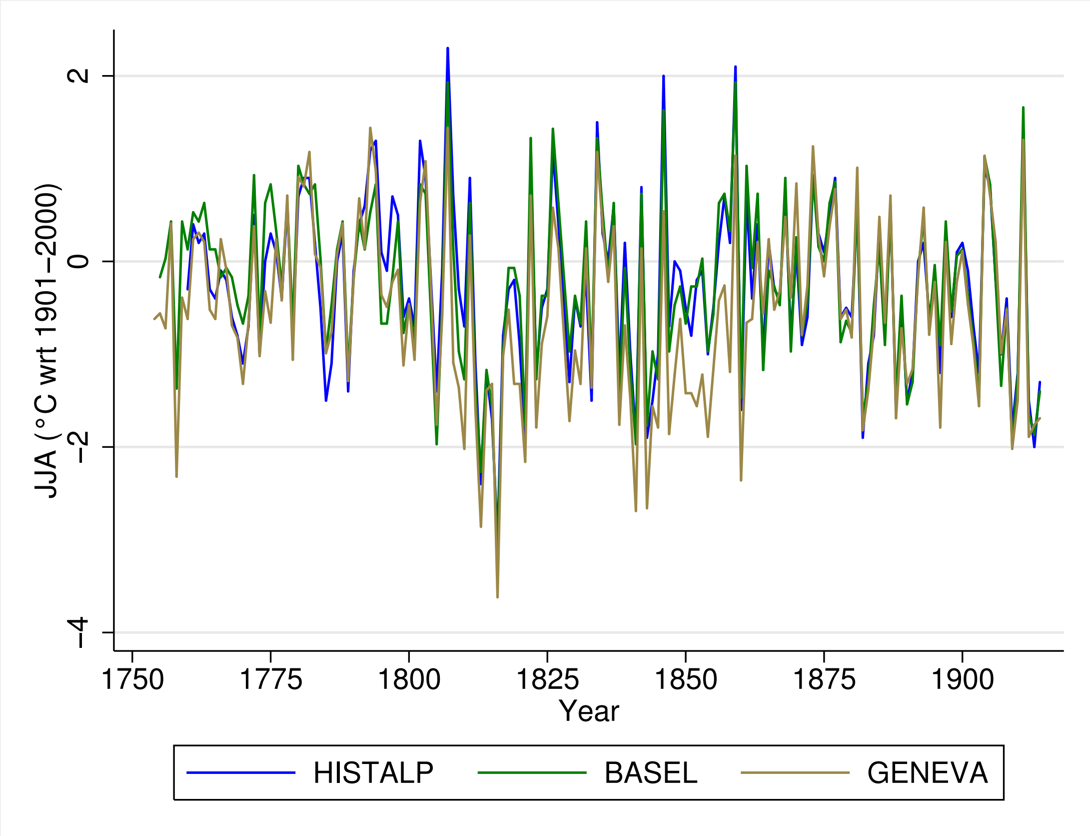

Figure 4: Comparison of summer temperature between the HISTALP, Basel, and Geneva time-series (Graph for 1753 to 1914)

level for most of the 19th century and also the beginning of the 20th century. This cold summer period is often referred to as the Little Ice Age. However, extreme negative values are rarer in this time as opposed to the 1810s and the first quarter of the 20th century. Several positive outliers can be detected, almost all of them before 1860.

4.2 Wine-production data

A total of 43 time-series were available for the reconstruction. They were extracted from various primary and secondary sources. The goal of this section is to create a time-series that expresses the average *Mittelland* grape yield for each year as a percentage of a "norma" yield in that year. The following section explains the procedure how the local time-series are integrated in a *Mittelland* series.

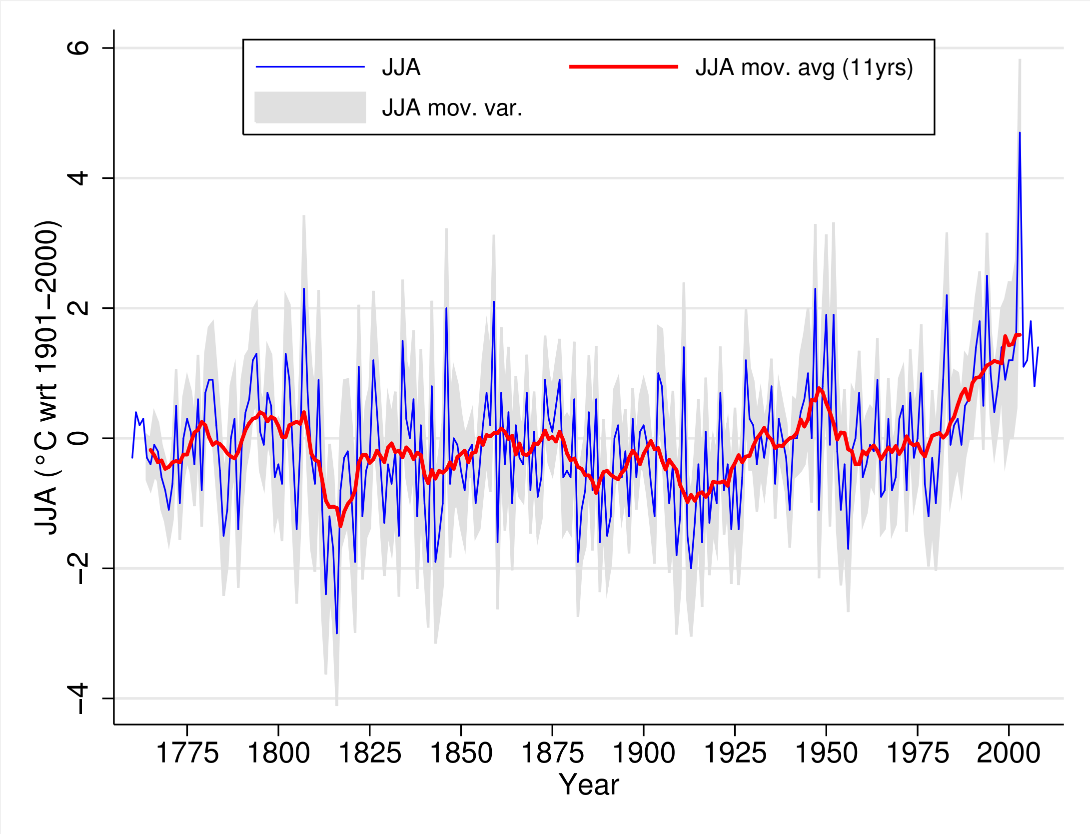

Figure 5: Summer temperature in HISTALP time-series (1760-2005). Average temperature for June, July, and August (JJA, blue) is shown along with its 11-year moving average (red). The shaded area shows the 11-year moving standard deviation.

4.2.1 Origins and characteristics of local time-series

The table below summarises the main information about the local time-series (Table 2). Besides illustrating the location, start and end year, and the number of observations (N) the table also shows to which the local time-series belongs. The last column in Table 2 reveals the source for the series. Besides the time-series taken from Pfister and De Montmollin who undertook similar works, Brugger's various contributions on agriculture proved a rich source.[105] The specialist for agricultural statistics in the 19th century collected various grape harvest time-series from all parts of Switzerland. The majority of them comprised yield-per-acre figures which facilitated the integration of these series.

[105] Brugger, *Landwirtschaft erste Hälfte 19. Jahrhundert*; Brugger, *Statistisches Handbuch*; Brugger, *Landwirtschaft 1850-1914*.

These works and also others[106] provided further hints on available grape harvest data, such as the long times-series for Zollikon by Kohler.[107] All series had to be transformed to machine-readable form before processing.

Further data was collected using primary sources from archives. This made it possible to fill the gap that opens after 1825 in data availability. However, these series only cover a little more than a decade. Yield and grapeyard acreage was recorded in accounting books of various institutions, such as the Spital Zürich and the Amt Fraumünster (district authority).[108] Those were collected and partly averaged (cf. Table 2). Figure 6 shows a drawing of the grapeyard in Höngg in the Zürich region from which data is included in this research.[109] However, exact data after the abolition of the tithe[110] misses from state archives, thus rendering data collection for the time between roughly 1835 and 1870 more difficult.

In addition to historical time-series, information was also taken from the federal statistical yearbooks up to 1966.[111] Brugger reviewed the yearbook data and heavily criticised grape harvest data before the 1920s. He also tried to correct it. Corrected data provided by Brugger is preferred over the yearbook data.[112] Yield data for periods after 1966 was not collected. It is assumed that with the great modernisation in agriculture after the Second World War, it would hardly be possible to use the data for climate reconstruction.[113] This does not mean that climate were a negligible factor for winegrowers, but its influence might be sufficiently different so that the relationship is not comparable to the 19th century and earlier.

[106]Most importantly: Ritzmann, *Die Wertschöpfung im Ersten Sektor, 1837-1945*; Ritzmann-Blickenstorfer, *Historical statistics.*

[107]J. M. Kohler. *Der Weinbau und die Weinbehandlung. Mit besonderer Berücksichtigung der schweizerischen Verhältnisse.* Aarau 1878.

[108]*Rechnung über die Verwaltung des Spitalamtes 1825-1838.* Staatsarchiv Zürich, RRII 120b.1; *Rechnung um die Verwaltung des Amts Cappel 1798–1834.* Staatsarchiv Zürich, Signatur: RRII 48; *Amtsrechnungen Fraumünsteramt 1824-1840.* Stadtarchiv Zürich, IV A.1.

[109]The picture is taken from Samuel Wyder. "Lehenshöfe des Spitals Zürich. I. Weinbau und Lehensverträge im 18. Jahrhundert". In: *Schweizerische Zeitschrift für Obst- und Weinbau* 9 (1999), pp. 241–244, p. 265.

[110]Brugger, *Landwirtschaft erste Hälfte 19. Jahrhundert*, p. 209.

[111]*Statistisches Jahrbuch.*

[112]Brugger, *Statistisches Handbuch*, pp. 152-162.

[113]The dramatic increase of the average yield per unit area in Switzerland from 76 hl/ha in 1961/65 to 107 hl/ha in 1996/2000 illustrates the changes in cultivation. Bundesamt für Statistik BFS. *Hektarerträge im Getreide-, Kartoffel- und Weinbau 1841-2000 (T 7.3.3.1.3).* url: http://www.bfs.admin.ch (12.3.2009).

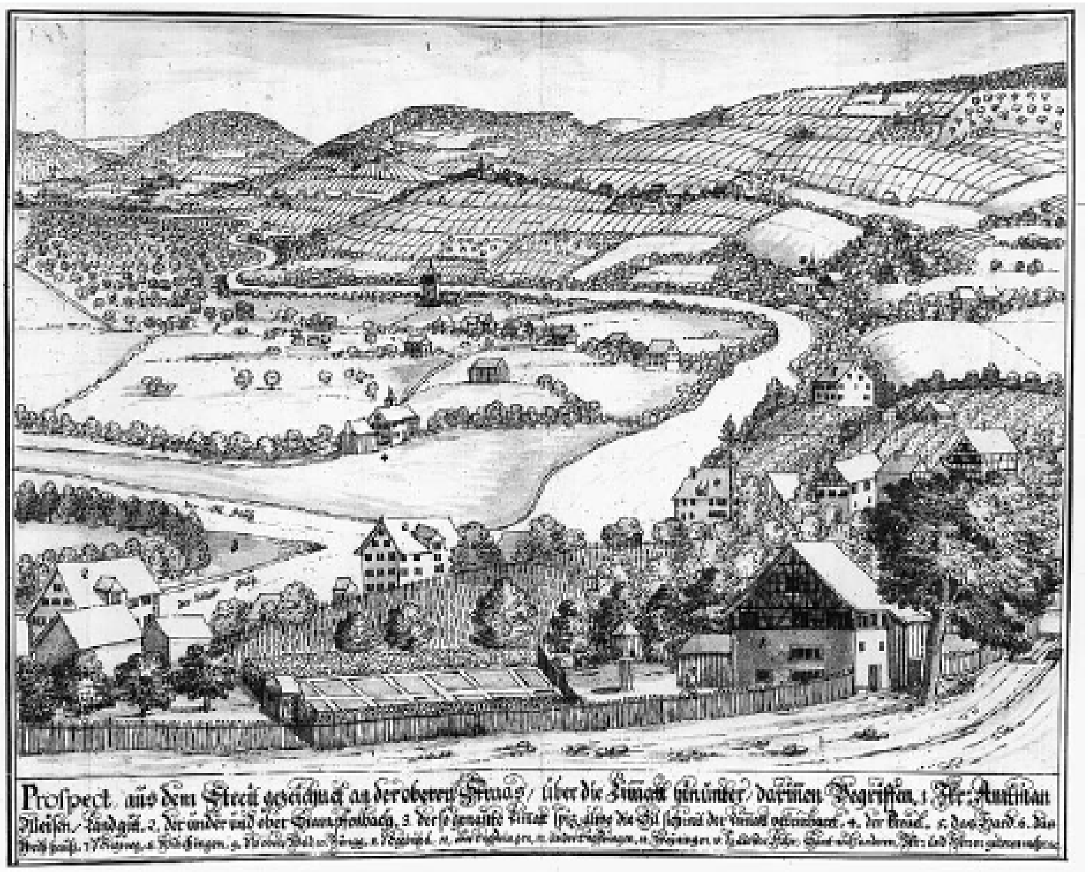

Figure 6: Vineyard of Höngg in Zürich. – Source: Wyder 1999, p. 265.

StartYear	EndYear	Place	Region	N	Source
1750	1819	Tschugg BE	NE/Biel	70	Pfister 1981 (De Montmollin 1986)
1750	1772	Malessert FR	NE/Biel	22	Pfister 1981
1750	1825	Lower Lake of Zürich	ZH	76	Pfister 1981
1750	1796	Wipkingen/Höngg ZH	ZH	47	Pfister 1981
1750	1774	La Neuveville BE (3)	NE/Biel	25	De Montmollin 1986
1750	1900	Ile St.-Pierre BE	NE/Biel	151	De Montmollin 1986
1753	1877	Zollikon ZH	ZH	125	Kohler 1878 (Pfister 1981)
1760	1810	Obererlinsbach AG	AG	51	Pfister 1981 (Brugger 1956)
1760	1819	St-Blaise NE	NE/Biel	60	De Montmollin 1986
1773	1796	Lutry VD	VD	24	Pfister 1981
1774	1791	Le Landeron NE	NE/Biel	18	De Montmollin 1986
1775	1796	Bursins VD	VD	22	Pfister 1981
1775	1812	Neuchatel	NE/Biel	38	De Montmollin 1986
1799	1823	Bonvillars VD	VD	25	Pfister 1981 (De Montmollin 1986)
1800	1850	Canton ZH - Notes	ZH	51	Brugger 1956 (Müller 1878)
1802	1821	Rheinthal (SG)	SG	20	Pfister 1981
1805	1832	Weiningen/Höngg ZH	ZH	28	Zweifel 1848 (Pfister 1981, Brugger 1956)
1814	1866	Lavaux VD	VD	53	De Montmollin 1986
1820	1886	La Neuveville BE (2)	NE/Biel	67	De Montmollin 1986
1820	1839	Auvernier NE	NE/Biel	20	De Montmollin 1986
1824	1837	Enge (ZH, Fraum.)	ZH	14	Stadtarchiv Zürich
1824	1831	Horgen ZH (Fraum.)	ZH	8	Stadtarchiv Zürich
1824	1837	Rümlang ZH (Fraum.)	ZH	14	Stadtarchiv Zürich

Continued on next page

StartYear	EndYear	Place	Region	N	Source
1825	1833	Cappelhofen (ZH, 5 viney.)	ZH	8	Staatsarchiv Zürich
1826	1833	Spital Zürich	ZH	8	Staatsarchiv Zürich
1829	1880	Canton Aargau (1)	AG	51	Brugger 1956, 1978
1830	1893	Vevey VD	VD	64	De Montmollin 1986
1833	1860	Villette GE	-	28	Brugger 1956, 1978
1846	1890	Corcelles VD	NE/Biel	45	De Montmollin 1986
1850	1914	La Neuveville BE (6)	NE/Biel	65	De Montmollin 1986
1850	1880	Canton VD (1)	VD	30	Brugger 1978
1850	1880	Canton NE (1)	NB/Biel	31	Brugger 1978
1858	1966	Canton SH	SH	108	Brugger 1968
1861	1880	Canton GE	-	21	Brugger 1978
1871	1966	Canton NE (2)	NE/Biel	96	De Montmollin 1986, Brugger 1968
1880	1966	Canton VD (2)	VD	87	Brugger 1968
1881	1966	Canton ZH		86	Brugger 1968
1881	1966	Canton BE	ZH	86	Brugger 1968
1887	1966	Canton AG (2)	AG	80	Brugger 1968
1893	1966	Canton GE	-	74	Brugger 1968
1893	1954	Canton SG	SG	62	Brugger 1968
1901	1966	Canton TG	-	66	Brugger 1968
1901	1966	CH	-	66	Brugger 1968

Table 2: Time-series: general information, sources, and trends

Grape harvests exhibit a tremendous year-to-year variability. Some general remarks on this characteristic are necessary as this is important to understand the creation of the time-series. Contemporary sources tell of this phenomenon by saying that a failure year strips the wine-grower off his clothes, "but a good yield can also put them back on at once".[114] Looking at all time-series from 1750 to 1966, yields up to 50 per cent above or under the average can still be considered within "normal" variation. The minima and maxima of yields exemplify the great spread further. In bad years yields may fail almost completely, a yields of next to nil is not unheard of. Events such as hail or frost may limit such catastrophic years to a certain location, whereas cold and overly wet summers, e.g. the 1816 "year without a summer", affect the whole *Mittelland*, resulting in devastating yields everywhere. Good conditions on the other hand, may lead to yields two or more times larger than the average. The great variation between regions and in time has consequences for the creation of wine-production series. As mean values of several regional series will be calculated, it is possible that one or more regional series contrasts starkly to the mean of all series.

Weather events such as local hails or late frosts may be reasons for these negative outliers. This may distort the temperature signal stored in the grape harvest. The question arises whether such outliers should be eliminated, and how. While Pfister acknowledged this problem, he did not exclude years in the creation of the series.[115] De Montmollin eliminated five hail-torn years in the creation and further years in the reconstruction.[116] This approach was especially justified as his study dealt with one region which means such events would impact most local time-series.

This study generally abstains from eliminating outlier years in the creation of the series. Since a great number of local series is computed, it is believed that the effect of such events on the averaged yield figure is minor. Hail for instance, could affect a wine region very differently, from complete destruction of grapes to no impact at all. In case of destruction, some harvest was still possible as grapes regrew.[117] The large number of series from different locations justifies this decision as well. With more than 2000 data points, complete examination of distorting events for all locations was unrealistic. An exception was made with the already known years of hail from De Montmollin. These years were eliminated prior to the creation of the *Mittelland* series.[118]

[114]Saying from Zürich, cited after Pfister, "Fluktuationen der Weinmosterträge", p. 487.
[115]Pfister, "Fluktuationen der Weinmosterträge", p. 475.
[116]Montmollin, "Rendement viticole", pp. 42, 51–54.
[117]Pfister, "Fluktuationen der Weinmosterträge", p. 475.
[118]The following years were eliminated from all time-series in the Neuchâtel and Vaud region: 1762, 1769, 1784, 1789, 1793, 1795. Montmollin, "Rendement viticole", pp. 51–54.

Attempts to calculate series with years eliminated due to hail and frost were made, but did not prove successful. The effort to systematically identify the correct outlier years from sources exceeds the impact of this procedure on the overall series by far. It will be evident that exceptionally good years distort the time-series to a greater extent. Therefore, elimination of years at the *Mittelland* level will be reconsidered in the reconstruction.

4.3 Preparation and creation of the *Mittelland* wine-production time-series

The various local series must be integrated into aggregate time-series. Pfister employed a six-step procedure to create aggregate and homogenised time-series.[119] De Montmollin adapted this method to his requirements – he reduced it to four steps because of the restricted scope of the study – and reproduced it.[120] Lending from these approaches, the procedure applied here includes the following operations:

1. Preparation of local time-series (unifying of units of measurement, quality control)
2. Calculation of trends and residuals for each local time-series in order to detrend the data material
3. Homogenisation of residuals
4. Integration of homogenised residuals into regional time-series
5. Integration of regional time-series into a Swiss *Mittelland* time-series

4.3.1 Preparation of local time-series

Local time-series for this study were presented in Table 2 (on page 39). Most of these time-series have been used in studies before; quantities are therefore already expressed as hectoliters and hectares.

The researchers who undertook these transformations added some important information regarding this process. This information must be repeated here as it is relevant to the quality of the data. Firstly, two different units of measurements existed for grapes in some parts of Switzerland. Either the quantity is given directly after grapes were harvested, or a certain time later. In the first case, solid matters from the grapes such

[119] Pfister, "Fluktuationen der Weinmosterträge", pp. 457-467.
[120] Montmollin, "Rendement viticole", pp. 34-44.

as pulp, was included in the pots. Later, however, pulp was removed. This results in the quantities differing by approximately 7 per cent.[121] Which unit was used is not obvious in every case and this may lead to a minor inaccuracy in a small number of cases. Secondly, original data was expressed in a variety of regional or even local units. Some of these units of measurements were difficult to transform into hectolitres or hectares. Often sources may indicate different relationships to known units. Techniques to measure grapeyard areas or volumes cannot be considered as precise to today's standards. Therefore, because of these reasons some time-series have a higher degree of accuracy than others. Generally, time-series from the Eastern part of Switzerland (e.g. Zürich) are considered more accurate than those the Western parts.[122]

For these reasons, it must be noted that early wine-production time-series are approximate values.[123] Nevertheless, statistical comparison with temperature data have shown an astonishing quality of such time-series, despite all reliability issues – the same is true for the time-series used here.

4.3.2 Detrending and Homogenisation

Factors affecting viticulture may change over time. To account for the long-term variation, data must be detrended. The procedure applied here involved two steps. Firstly, trends are calculated over time and secondly, the difference between the yield of a given year and the trend is calculated (residuals).

The trend of each local series is calculated using linear regression. Time, in this case years, are used as a predictor of yearly grape yield. As is expressed in the term "trend", the regression returns a tendency showing gradual and long-term effects on viticulture.[124] This may include changes in productivity, in climate conditions, or in the cultivation of vines.[125] In cultivation, grape variety may change, the level of dung usage or the quality of care to the vineyard. The trend is an alternative to the arithmetic mean of a long time-series. Contrary to the mean, which is stationary, the trend accounts for long-term tendencies.

As opposed to linear regression, it is sometimes advisable to use a polynomial function to account for a non-linear trend in harvests.[126] This suggests an increased progress in the yield data over time. However, such approaches are more suitable for absolute

[121] Pfister, "Fluktuationen der Weinmosterträge", pp. 457-458; Montmollin, "Rendement viticole", p. 35.
[122] Pfister, "Fluktuationen der Weinmosterträge", pp. 458-459.
[123] Pfister, "Fluktuationen der Weinmosterträge", p. 467.
[124] Pfister, "Fluktuationen der Weinmosterträge", p. 464.
[125] Pfister, "Fluktuationen der Weinmosterträge", p. 464; Montmollin, "Rendement viticole", p. 36.
[126] Jones and Davis, "Climate-Viticulture Relationships", p. 829.

production levels that are not expressed in relation to the area planted with grapevines. If the acreage increases along with the harvest, a non-linear trend represents this more accurately than linear regression. Also, in times of dramatic progress – as can be seen in agriculture after the Second World War – a polynomial function may account for an exponential growth due to more intensive fertilizer use. However, non-linear trend models did not prove more significant than the linear models that were finally applied.

Successfully calculating trend equations requires a sufficient length of time-series data. Where this is not the case or where the regression did not return a significant result, the arithmetic mean is instead used as a trend value to generate residuals. Generally data length is deemed insufficient when fewer than 15 years are included. To calculate the trend equation all available data was used. This meant that for the Zürich series taken from Pfister, trends were not only calculated for the 1750 to 1825 period, but rather back to the 16th century. Trends calculated by De Montmollin were kept for the series taken from his study.[127]

In a second step, residuals were calculated. This was done by subtracting the original data of a given year from the values that the trend equation (or mean) returns for that year. This operation finalises the detrending. The values obtained show wine-production data as it was affected by short-term influences only. Such influences are "almost entirely" made up of short-term climatic conditions, i.e. yearly weather conditions.[128] Therefore, detrended values illustrate what is relevant for this study: the yearly climate signal stored in wine-production data.

After detrending, the long-term effects are removed from the data but one more factor remains. Areas several hundred kilometres apart show great differences in suitability for viticulture. However, great differences may also exist within shorter distances. Yearly yields in one grapeyard may be considerably larger due to superior sun exposure or higher soil quality compared to another grapeyard just kilometres away. To account for this bias, data must be homogenised. In accordance to Pfister, this is done as follows. The detrended data (residual) is expressed as a percentage of the trend equation.[129] After this operation the data is expressed as a percentage of the yield that would be expected, if the year had turned out "normal".

[127] Trend equations are enclosed in the Appendix.
[128] Pfister, "Fluktuationen der Weinmosterträge", p. 464.
[129] Pfister, "Fluktuationen der Weinmosterträge", p. 466.

4.3.3 Creation of regional time-series

Viticulture depended on a variety of local factors. Although the Swiss *Mittelland* covers a relatively small area, the suitability for viticulture is considerably different within the region. This is exemplified for instance, by the shift of wine growing to the Western parts of Switzerland, along the Lake Geneva, during the later part of the 19th century. Conditions for viticulture were better there than in the rest of the *Mittelland*.

As the areas around the Lakes of Geneva, Neuchâtel and Biel, and also the german-speaking parts in the north-east (*Deutschschweiz*) each exhibit a distinct nature, several time-series were at first created in order to account for these differences. In accordance with Pfister, these regions were: Zürich, Neuchatel/Biel (NE/Biel), Vaud, Aargau, St. Gallen (SG), and Schaffhausen (SH).[130] The column "Region" in Table 2 depicts which local time-series belongs to which regional time-series.

It was not possible to allocate the Genevan series to a region. Tests showed that correlations with both the Vaud and NE/Biel regions are weak. This suggests that viticulture in the Geneva region exhibits different characteristics than in the neighboring regions. There was no point in creating a new regional series for Geneva since no historical time-series for this region are available. Also, the composite Swiss series was not used. However, it showed relatively high correlations with the regional series which serves as a validation for the data quality of the approach.

The correspondence of yields between different regions is of a varying degree. Tables 3 (1750 to 1914) and 4 (1750 to 1833) below show the correlations between the homogenised time-series of the different regions. It must be noted that the correlations improve when earlier periods are used; correlations for data prior to 1833 show better results than the same correlations up to 1914.

In both periods, all correlations are highly significant with one single exception each. This illustrates that the *Mittelland* shows a fairly uniform reaction to external influences on viticulture. High correlations exist between the Zurich and St. Gallen series as well as between the Vaud and NE/Biel series. Also, the series for Aargau and Schaffhausen correlate higher in the longer period. The correlation between the regions in the West and in the East is generally weaker than within those parts. Furthermore, for both periods of time, the correlation between the *Mittelland* series and the regional series is high which means that the combined series is valid for the climate reconstruction.

[130] Pfister also used data from Thurgau, but not for the yield-per-area data.

	Zürich	Vaud	Aargau	NE/Biel	SG	SH
Vaud	0.52	–				
Aargau	0.61	0.50	–			
NE/Biel	0.58	0.76	0.62	–		
SG	0.73	0.62	0.66	0.62	–	
SH	0.62	0.67	0.78	0.65	(0.37)	–
Mittelland	0.91	0.76	0.82	0.87	0.84	0.85

Table 3: Correlation of regional time-series of grape yield (1750-1914) – Values in parentheses are not significant. All other values are significant with $p < 0.001$.

	Zurich	Vaud	Aargau	NE/Biel	SG	SH
Vaud	0.53	–				
Aargau	0.54	0.54	–			
NE/Biel	0.64	0.72	0.62	–		
SG	0.80	0.71	(0.60)	0.73	–	
SH	n/a	n/a	n/a	n/a	n/a	–
Mittelland	0.92	0.76	0.85	0.82	0.91	n/a

Table 4: Correlation of regional time-series of grape yield (1750-1833) – Values in parentheses are not significant. All other values are significant with $p < 0.001$.

4.3.4 Creation of the *Mittelland* time-series

So far, the local time-series were quality controlled, detrended, homogenised and sampled in regional time-series. The next and most important step, is to integrate all the series into one time-series for the whole *Mittelland*.

There are different ways to integrate regional time-series into aggregate time-series. Pfister and De Montmollin average the regional series using the arithmetic mean. In other studies, the median is used to integrate several local time-series into aggregate time-series.[131] The advantage of using the median is that it is more robust compared to the arithmetic mean: Positive or negative outliers influence the average to a lesser extent, e.g. the complete failure of a yield in a certain area because of a local hail storm. Both variants have been computed, but the median proved less skilful. Therefore, the approach of using the arithmetic mean is kept.

In averaging the regional series, the Zürich series was attributed a larger weight than the other series. Compared to all other regional series, the Zürich series was counted with the factor 3. Several reasons justify this step: The original series by Pfister rely heavily

[131] An example for such an approach is provided by Meier, "Grape Harvest Records".

on local series from this region. This constitutes a situation similar to a weighting. Furthermore, for the earliest part of the composite series by Pfister, the only series for the *Mittelland* is from Zürich. This is especially important since the emerging transfer function will be applied to this data. Therefore, weighting ensures that the transfer function may be applied to the early time-series.

As the previous operations were done for each local time-series separately, strictly speaking, these series are not homogenised between each other.[132] Many time-series do not overlap in time sufficiently (or not at all) which renders homogenisation between them impossible. The individual homogenisation must be accepted. It should not weigh too heavy. The goal of this part of the study is to create a time-series indicating the quantity of wine-production for the Swiss *Mittelland*. Given the great area that such an indication must account for, the aggregate time-series must not be confused with an exact information on the wine-production. Furthermore, the time-series should also represent the actual situation fairly correctly since a large number of series were computed. In any case these are approximate values.

Evaluation of the *Mittelland* series

Figure 7 (on page 47) displays the grape harvests between 1750 and 1966 with both the homogenised and absolute yield plotted in a graph. The homogenised time-series is the result of the procedures outlined above. While the year-to-year curve shows the high variability of yearly yields (blue), the moving average (red) illustrates the long-term fluctuations. The use of homogenised production figures allows for a direct comparison of the wine production development over time, although keeping in mind the approximate nature of the figures. This data will be used for the temperature reconstruction as it should represent the temperature signal stored in a year's yield.

After the data was detrended, it should not come as a surprise that the graph lacks a long-term tendency. The catastrophic years in the 1810s (with the 1816 "year without a summer"), and in the war-inflicted 1910s are clearly visible in the graph. Prolonged periods of clearly above average grape harvests do not occur between 1750 and 1966. Harvests around the turn of the 19th century with the year 1900 as a peak come closest to such a favourable period. The peak in the first decade of the 19th century, however, is rather caused by the extremely good harvest of 1804. It is the best harvest in the record.

Not only does the homogenised data fail to show a sustained increase or decline in time, but also the yield in hectolitres per hectare does not do so. Instead, the 11-year

[132] Pfister, "Fluktuationen der Weinmosterträge", p. 464.

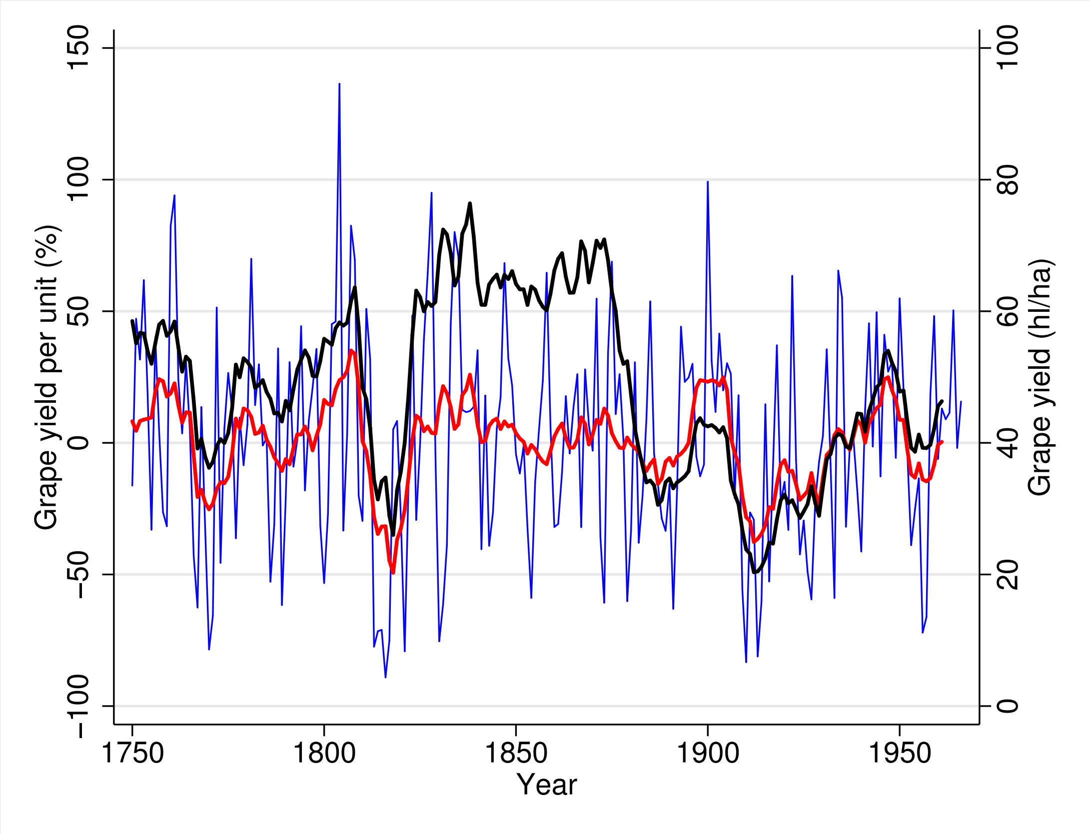

Figure 7: Wine production (yield per are) in the Swiss *Mittelland* between 1750 and 1966 depicted as homogenised values (blue), 11-year moving average of homogenised values (red), and 11-year moving average of absolute values (black, hl/ha). The scale on the left y-axis refers to the homogenised values, the scale on the right y-axis to the absolute values. Only the fluctuations, but not the levels of the two scales are comparable.

moving average (gray) reveals the astonishing situation of a period of very high yields per area with a clear-cut beginning (1822) and a fairly precise end (around 1880). At the same time, the high variability of the homogenised data catches the eye (blue). The effect is overstated in the graph as the two scales are not directly comparable. Nevertheless, this picture of substantially higher yields requires an explanation.

Looking at the individual years more closely a few things attract attention. Foremost, a range of exceptional grape harvests fall within the period in question: In the whole time-series from 1750 to 1966 (217 years), the yield per acre equalled 90 hl/ha or more in 9 years – 8 of those years belong to the 1822-1876 subperiod (54 years).[133] Several other years fall just short of this 90 hl/ha-threshold, which represents the double standard deviation from the mean. Values over 90 hl/ha can thus be considered outliers by statistical measures. Furthermore, only a single year (1830) within the period returned an extremely low yield of less than 20 hl/ha. All local time-series show a substantially higher average for the same periods. This exceptional series of productive years (at least one per decade with more than 80 hl/ha) drives the moving average to a sustained height and partly explains the effect visible in the graph.

Climate, however, does not provide an explanation for this viticultural thriving. As was seen in the previous section, the HISTALP data does not suggest especially warm summers between 1822 and 1876. On the contrary, temperature fluctuated below the average for most of the time. This situation complicates the reconstruction. It challenges the notion that warm summer temperature accounts for high yields per area. Therefore, the period in question will be closely reviewed in the following section which evaluates the relationship between wine production and climate.

The homogenised data (blue line) reflects the high variability of grape yields. In anticipation of potential obstacles to the reconstruction process, it was tried to account for these exceptional characteristics in the detrending process. To find the most suitable trend equations for the raw data, various attempts were made to deal specifically with this series of exceptional years, among other things by experimenting with a trend equation reaching from 1822 and 1876. However, no significant model could be calculated.[134] It is an option to eliminate the peak years from the data set prior to reconstruction since 90 hl/ha clearly cannot be considered within normal variation.[135]

4.4 Grape harvests as a predictor of temperature data

With the temperature data discussed and the *Mittelland* wine production series created, the next step is to compare temperature and wine production on a long-term basis. This step should show that growth of the grapes – and thus the yield per area – reacts strongly to summer temperatures. In the previous section, such a relationship was postulated by outlining growth stages of the grapevine and the influence of temperature in this process. Depending on the strength of this influence, it can be decided which month or

[133] Those are the following years: 1827-28, 1834-35, 1847, 1858, 1871, 1875. The only other year with a yield greater than 90 hl/ha occurred before the devastating 1810s: 1804.

[134] For instance, detrending using the mean value for each local time-series and, alternatively, for the yield-per-acre time series as a whole, did not improve the correspondence to the climate data.

[135] In a normal distribution roughly 96 per cent of the observations are expected within the double standard deviation.

group of months promise the best results for temperature reconstruction. The (Pearson) correlation coefficient serves as an indicator to test these relationships.

4.4.1 Correlations with monthly data

As seen with correlations between regional series above, correlation levels differ considerably between earlier (up to the 1840s/50s) and the whole period for which data is available. This suggest changes in cultivation over time which affected the climate-sensitivity of grapes. Therefore, the correlation between grape harvests and monthly temperature is computed for several periods within the time covered by this study. Table 5 illustrates correlations for individual months and groups of months with the *Mittelland* series. All correlations were calculated for individual months or sets of months only; the influence of the other months was not held constant in this method (no partial correlation).

Month(s)	1760-1825	1780-1850	1820-1880	1880-1966
June	0.47	0.49	(0.32)	0.35
July	0.58	0.53	(0.31)	0.38
August	((0.36))	(0.31)	n.s.	n.s.
JJ	0.67	0.65	0.42	0.48
JJA	0.68	0.63	0.37	0.46
JJA_{y-1}	0.54	0.34	0.39	0.35
$JJ_{y,\ y-1}$	0.77	0.79	0.62	0.55
$JJA_{y,\ y-1}$	0.75	0.75	0.55	0.56

Table 5: Correlation between wine production and average temperature of months or group of months – Note: JJ = June, July; JJA = June, July, August; JJA_{y-1} = JJA average of the preceding year; $JJ_{y,\ y-1}$ = JJ average of two years; $JJA_{y,\ y-1}$ = JJA average of two years. All values are significant with $p < 0.001$; except for values in parentheses: $p < 0.025$; and double parentheses: $p < 0.05$.

Generally, the results of the correlation analysis show that wine production is significantly correlated with summer temperature. Even for the time-series of the entire length (206 years), correlations are highly significant (not shown). However, it is striking how the magnitude of the correlation coefficients decreases in the course of the 19th century. Separate correlation for the four periods 1760-1825, 1780-1850, 1820-1880, and 1880-1966 allows to discuss for parts of the whole period. There is no great difference between the two early periods. However, the 1820-1880 period shows remarkably worse results, while the last part indicates better correlation again.

For an individual month, July seems to be the most influential to harvests with a correlation coefficient of up to $r = 0.58$. Other months than the summer months did not return significant results. August temperatures exhibit a minor influence. Groups of months show stronger correlations than individual months. Generally, any combination involving June and July temperatures returns the highest correlations. The averages of June and July (JJ) and June, July, and August (JJA) temperatures correlate better with grape harvest than the individual months alone. Therefore, the high correlation of mid-summer temperatures with grape harvests as suggested by the literature on Swiss viticulture is confirmed here.[136]

The relevance of the two years preceding the harvest, as suggested by the grape biology outline, can indeed be found in the correlations: the average summer temperature of the year before a harvest ($JJA_{y\text{-}1}$) returns a correlation (up to $r = 0.54$) only slightly weaker than the individual summer months of the harvesting year. The basis for a year's harvest is laid in the summer before.

Consequently, the best correlation is attained when wine production is compared to the average of summer temperatures in the harvest year and the year before. The correlation coefficients reach up to $r = 0.79$ in the 1780-1850 period for $JJ_{y,\ y\text{-}1}$ and correlations remain strong in other periods. Furthermore, correlations for $JJA_{y,\ y\text{-}1}$ show a similar picture. The reason for $JJA_{y,\ y\text{-}1}$ correlations being slightly weaker is probably due to the weaker relevance of August temperatures. These results are in line with studies by Pfister and De Montmollin who both used average temperatures of two years as a target for their reconstruction.[137]

Various other calculations did not return significant values for correlation between temperature and wine production. Among those are all other months and also the set of April to August temperatures commonly used to fit grape phenology to.[138] However, weak correlations were also calculated for the individual months of June, July and August of the year preceding the harvest. Those correlations show the same tendency to stronger correlations in the earlier periods, especially prior to 1825. These results further explain why the averaged (mid-)summer temperature for two years returns such strong correlations.

This analysis showed that summer temperatures are the most influential to harvests. Single months will therefore not be considered in the reconstruction. Apart from the summer temperatures averaged over two years, various groups of months show high

[136]Pfister, "Fluktuationen der Weinmosterträge"; Montmollin, "Rendement viticole".
[137]Pfister, "Fluktuationen der Weinmosterträge"; Montmollin, "Rendement viticole".
[138]Meier et al., "Grape Harvest Dates".

correlations. Therefore, the reconstruction will have to be carried out with several combinations of the summer months temperature averages.

However, the decreasing correlation in time requires an explanation. Looking at factors other than statistics, it must be stressed that agriculture underwent a great modernisation within the 19th century.[139] Production levels should reflect this process. Furthermore, wine production data may replicate these changes as well. From the 1850s on, wine production in Switzerland was in great motion, read: it expanded considerably. This can both mean that not as much attention was paid to accurate measurement as in the time of tithes collection. Furthermore, it is certain that the composition of the wine-growing area changed; increasingly, grapes were planted on marginal land.[140] This influenced the yield-per-area figure. Curiously, exactly in this time, the series computed here shows a sustained height of hectolitre per hectare yields. The climate impact for this period could not be extracted from the wine production data even with various detrending procedures, as seen above.

Nevertheless, the effect of decreasing correlation is not limited to the data used in this study. De Montmollin also acknowledged a decreasing correlation after 1825.[141] Since many other series in addition to De Montmollin's are used here, this refers to a genuine decline of climate-wine relationship for the later part of the 19th century.

4.4.2 The effect of very hot summer temperature

The correlation between grape-growing data and temperature is considerable but falls somewhat short of expectations for a plant that is said to thrive so much from warm weather. One reason for this is that rainfall was not considered in these calculations. The hottest summer does not help plants if they lack moisture. However, weak relationships might also point to a not purely linear relationship between temperature and yield per area. This leads to the question which will be addressed on the following pages. Namely, what relationship does exactly exist between grape growth and climate?

The comparison of a year's yield per area and the corresponding summer temperature points to a spurious effect of very hot summers. Figure 8 depicts this comparison. The scatter plot shows the summer temperature on the x-axis and the coresponding harvest (hl/ha) on the y-axis. Two discoveries can be made. First, in the best harvest years summer temperatures were within 0.5°C the average. Second, very hot summers sometimes recorded harvests only close to the average. This is the case in two of the

[139] Bairoch, "Trois révolutions agricoles".
[140] Schlegel, *Weinbau in der Schweiz*, p. 65.
[141] Montmollin, "Rendement viticole", p. 57.

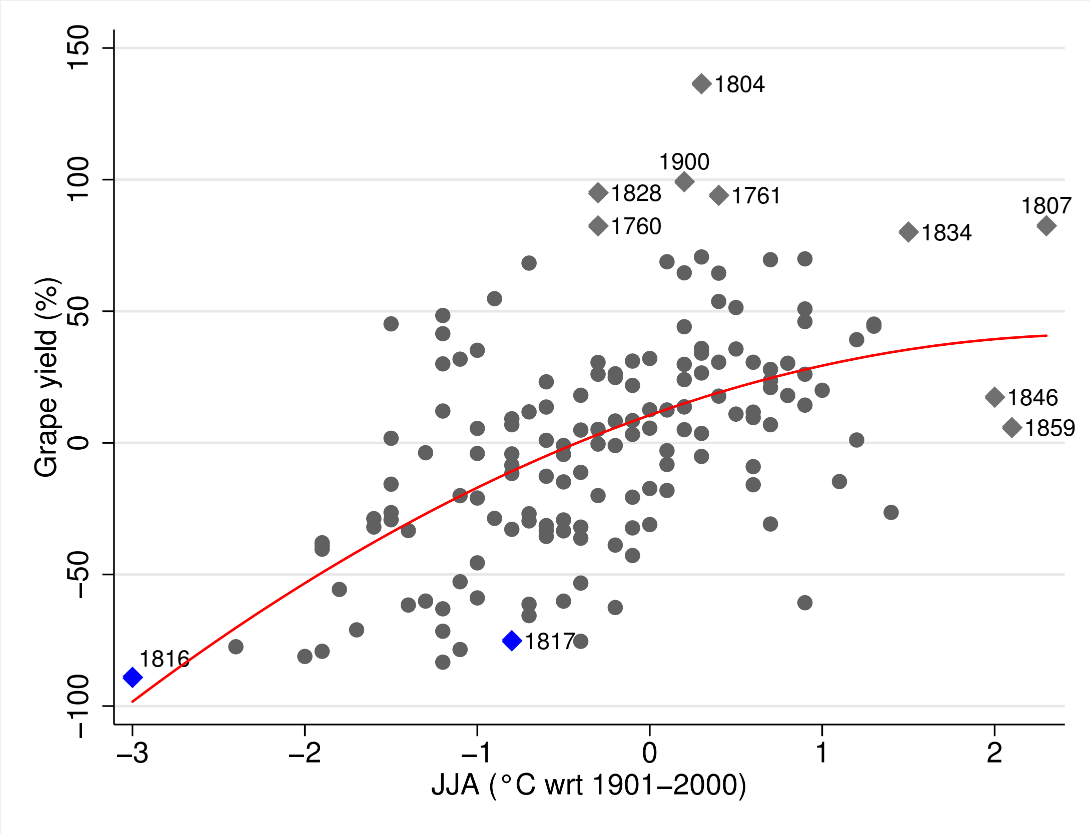

Figure 8: Scatter plot of grape harvests (yield per area) and summer temperature (JJA) from 1760 to 1914 – The red line illustrates the quadratic fit for the relationship between grape harvests and JJA temperatures. Labeled years are referred to in the text.

five hottest years. Indeed hot temperatures in June, July, and August do not necessarily mean great harvests.

A closer look at those years in question reveal some differences in the pattern of summer weather which may explain the individual outcome in terms of grape harvests (those years are labeled in Figure 8). In fact, all of the hot years are explained in greater detail in a compilation on past weather.[142] According to these monthly outlines, 1846 had one specific characteristic: a very hot June.[143] In 1846, temperatures in Basel were 2.6°C above the average. Rainfall was on average. The story of 1859 is similar: July and August were exceptionally hot – in Basel they were 3.1 and 2.6° C above the average,

[142] Pfister, *Wetternachhersage*.
[143] Pfister, *Wetternachhersage*, p. 132.

respectively.[144] Furthermore, 1859 was also very dry in most parts of the country. High temperatures in these months are generally presumed to be beneficial to grapes, yet statistical analysis suggests that there are limits to this relationship.

However, with 1834 and 1807 there are also some very hot summers that recorded considerable yields, even with 1807 being considered a "heat summer" (*Hitzesommer*).[145] This heat wave only began in July though with temperatures being 2.7° C above average. It worsened in August when thermometres reached 3.9° C above average. June was not as hot and reasonably wet too. In 1834, May was the anomalous month with 2.3° C above the average in Basel. Rainfalls were around the average in this year. The 1834 situation led to grapes beginning to bloom three weeks earlier than usual.[146]

Thus, all of these years with hot temperatures, but various levels of grape harvests have their weather "story". This is different for the exceptional harvests in 1760/61, 1804, 1900, and 1828. None of these years figures in the list of anomalous years.[147] With good reason: their average temperature was not exceptionally high. In fact it was within 0.5°C of the long-term average. It can be assumed that the pattern and level of rainfalls would have been favourable in these years.

This look at the history of individual harvests revealed that the best years were basically "normal years" in terms of weather. Very hot summers, on the other hand may or may not be successful for wine-growers. The outcome of the harvest depends heavily on the characteristics of an individual summer. Especially, the onset of heat and the pattern of rainfall seems to be crucial. The seasonal development of the grapevine is expected to also plays a further role as to what weather condition is beneficial. Therefore, it should also be mentioned that for all the these anomalously hot years, the phenology of grapes was exceptionally early.

A further effect must be acknowledged. With the biannual influence of climate well-established (cf. section 4.4) some of the outliers in the scatter plot of figure 8 appear in a different light. For instance, the devastating 1817 harvest occurred despite summer temperatures not much below the average. The preceding "year without a summer" could explain this since the development of the buds was affected during that summer. The same effect can also be observed for relatively hot summers after a year with low summer temperature.

Running a linear regression on the relationship between climate and wine production for a long period of time (1760-1914), summer temperatures (JJA) explains merely around

[144] Pfister, *Wetternachhersage*, p. 137.
[145] Pfister, *Wetternachhersage*, p. 140.
[146] Pfister, *Wetternachhersage*, pp. 116-117.
[147] Pfister, *Wetternachhersage*, pp. 294–298.

25 per cent of the variation in grape production (R^2).[148] Models over such a long time are not significant. Figure 8 also illustrates the look of a non-linear relationship between grape harvests and summer temperatures (red line). By visual examination, the quadratic fit may seem plausible. However, its explanatory power only lies within 1 or 2 per cent points of the linear fit's explanatory power, depending on the period chosen.

This analysis and the spurious effect of hot summers reveal the complicated relationship between viticulture and climate. Taking into account the highly significant correlations between the two time-series, it is possible to infer temperature from grape harvest but this pertains some specific limits. Besides adverse local events, these are the extreme values in both time-series. An extremely good yield does not necessarily point to an exceptionally warm summer. Instead, it might be the consequence of an ordinary year with an exceptionally good timing of weather conditions. Similarly, the climate signal of a hot summer may be ambiguous. Under favourable circumstances, it caused a good yield which means the reconstruction estimates the temperature correctly. But it could also have been too hot for the grapevine, which returned "only" average yields. In other words: One grape yield indication may point to two very different temperature situations. Unfortunately, statistical procedures are unable to solve this problem.

This situation of high yield due to favourable weather pattern (and not high summer temperature) causes problems for the reconstruction. Foremost, the inability of statistical models used here to correctly account for very good yields warrants adjustments. With these outliers years (good yield despite average temperature) identified, it is recommendable to eliminate these years for calibration. The consequence of including them would be that the transfer function contained the spurious effect of these yields and thus returns less reliable results. However, such a adjustment must also be considered for the reconstruction period. It is possible that high yields pertain to exactly this spurious effect and thus should be verified with other sources.

4.5 Summary

This section dealt with various aspects regarding the data used for the temperature reconstruction in this study. On the one hand, the long-term temperature time-series from the HISTALP database and its role as a target for the calibration was discussed. On the other hand, the data on *Mittelland* wine production had to be prepared so it can be used as a predictor for temperature.

[148] This corresponds to the results of the correlation analysis since R^2 is the square of the correlation coefficient r. Accordingly, summer temperature explains roughly half of the grape harvest variation in the earliest period from 1774 to 1825.

The data discussed here covers the climate variation and its first impact as outlined in the theoretical model from the introductionary section. The two time-series each serve as quantitative indicators for the two first elements of this model. Most importantly, tests demonstrated the strong and highly significant relationship between (summer) weather and wine production. This relationship is also well founded in the grape growth stages.

Statistically, various averages of summer months temperatures returned significant correlations with the wine production. The strongest relationship was established to the average of the mid-summer temperatures in the harvesting year and the year preceding it ($JJ_{y,y\text{-}1}$). This is in line with previous studies that already illustrated this biannual influence of climate.

However, a range of limits, both regarding the creation of the wine production time-series and the relationship of the time-series to summer temperature need be acknowledged. An important finding was that correlations between temperature and wine production decrease with time. Especially the period from roughly 1825 to 1880 showed very weak correlations.

While the relationship between climate and grape harvests is strong, there is one reservation. Hot summers do not consistently mean great harvests. Anomalously hot summers such as 1846 or 1859 did not result in similarly great harvests, but comparably hot summers (1807) could do so, particularly when rainfall levels were sufficient. This explains why yield-per-area harvest size does not correspond perfectly to temperature.

5 Temperature Reconstruction

This section entails the reconstruction of summer temperatures with calibration and verification. As no period for calibration emerged as superior to others, the skill of wine production data to predict summer temperature will be tested for various periods. The methodology of this procedure was presented in section 2.[149]

The grape harvests of several years contain a spurious effect. Some years return exceptionally good harvests, despite "only" average temperature in summer. The reason for this is assumed to be the favourable weather pattern in these years. Therefore, such years would distort calibration. Consequently, these years will not be included in the calibration and verification. The following five years have been identified in the previous section and are thus eliminated: 1760/61, 1804, 1828, 1900.

5.1 Choice of calibration/verification periods and target temperature

Various periods were chosen for the calibration. The HISTALP data set provides temperature indications from 1760 onwards. Since 1760 and 1761 were eliminated, 1762 is the earliest year used for the reconstruction. Earlier periods roughly to 1850 (see section 4.4.1) show a positive bias for reconstruction due to the higher correlations between climate and wine production. Therefore, only these periods are considered for calibration.[150]

The process of calibration is carried out over several periods covering various sections of the earlier data part. Table 6 summarises the calibration and verification periods. Generally, the calibration and verification periods run for a similar length. The number of observations accounts for eliminated years. In two cases (1762-1843, 1780-1859), the calibration-verification runs for approximately 80 years, in a short version it runs for 60 years (1800-1862). It was also tried to include as many years as possible in one calibration-verification with a further verification lasting from 1842 to 1966 (125 years).

Additional calibrations are carried out using Pfister's standard series as predictor.[151] The shorter length of the time-series reduces the number of calibrations. Two are carried out: One running from 1762 to 1799. This allows for verification from 1800 to 1825. Another calibration is calculated for the entire overlap of Pfister's series with temperature data (1762-1825).

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[149] Brazdil et al., "Historical Climatology".
[150] Calibration with later periods (and verification with earlier periods) did not prove successful in tests.
[151] Pfister, "Fluktuationen der Weinmosterträge"; Pfister, *Klimageschichte*, Tabelle 1.34/3.

Predictor	Calibration	Verification	N
Mittelland	1762-1801	1802-1843	80
Mittelland	1780-1819	1820-1859	78
Mittelland	1780-1841	1842-1966	125
Mittelland	1800-1831	1832-1862	60
Pfister 1981	1762-1793	1800-1825	63
Pfister 1981	1762-1825	–	63

Table 6: Reconstruction (calibration/verification) periods – Note: *"Mittelland"* refers to the time-series calculated in this study. "Pfister 1981" refers to the original time-series. "N" indicates the number of years included in the reconstruction.

For the reconstruction, a set of months need be specified. The tests to find the month or months most promising for reconstruction were similarly inconclusive as the tests regarding the calibration period. Various combinations attained promising results. In any case, these combinations included some of the mid-summer months June and July. Four combinations of temperature averages will be included in the calibration process. Two of them take temperatures of one year into account, the other two constitute an average of two years, because of the often biannual relationship between climate and viticulture. The following months are considered:

1. June, July, and August (JJA)
2. June and July (JJ)
3. June and July of the harvesting year and June and July of the year preceding the harvest ($JJ_{y,\ y\text{-}1}$)
4. June, July, and August of the harvesting year and June, July, and August of the year preceding the harvesting year ($JJA_{y,\ y\text{-}1}$)

5.2 Calibration

The result of each calibration is a function that estimates the relationship between grape harvest size and climate within the calibration period. This is done with linear regression which returns an equation of the following form:

$$y = \alpha + \beta \cdot x \tag{1}$$

where y is the target temperature, x stands for the wine production time-series, α is the constant, and β the slope for the predictor (grape harvest).

Two indicators determine the goodness of the model: Firstly, the statistical significance of the regression coefficients β. Secondly, the coefficient of determination (R^2) indicates how much variation in the dependent variable can be explained by the independent variable. All computed regressions for the *Mittelland* series returned coefficients significant on the 95-per-cent confidence level. The values for R^2 vary. Generally, higher values indicate a better model. Table 7 displays these information regarding the goodness for each calibration period.

Months	1762-1801 R^2	1780-1819 R^2	1780-1841 R^2	1800-1831 R^2
JJA	0.45	0.66	0.46	0.55
JJ	0.57	0.63	0.45	0.47
$JJ_{y,\ y\text{-}1}$	0.45	0.66	0.64	0.67
$JJA_{y,\ y\text{-}1}$	0.42	0.69	0.61	0.69

Table 7: Goodness of calibration periods – Coefficient of determination (R^2) as a skill indicator of the models calibrated for the periods 1762-1801, 1780-1819, 1780-1841, and 1800-1831. All models are significant.

For the *Mittelland* series, the calibration models return highly significant fits in all of the four periods. This confirms that wine production possesses explanatory power for summer temperature. The magnitude of this explanatory power lies roughly between 45 and 70 per cent as the coefficients of determination (R^2) in Table 7 reveal. Such values indicate that wine production levels explain up to seven tenths of the variation in temperature.

These results may be compared with results from other studies. First of all, it is in line with the studies of Pfister and De Montmollin. Pfister calculated a R^2 of 0.65 for his model; De Montmollin calculated 0.63.[152] The similar scope is not astonishing since the data basis is very similar to this study. Also, Ritzmann's model shows a very similar explanatory power (0.65) even though he integrated also rainfall and frost data into it.[153]

Furthermore, the results of the calibration of harvest size data also corresponds well to the reconstruction skill of grape phenology. Meier calculated $R^2 = 0.66$ using the date of the grape harvest and veraison to reconstruct April to August temperature. The

[152] Pfister, "Fluktuationen der Weinmosterträge", p. 475; Montmollin, "Rendement viticole", p. 54.
[153] Ritzmann, *Die Wertschöpfung im Ersten Sektor, 1837-1945*, pp. 116-117.

grape harvest date alone reached an R^2 of 0.55.[154] Therefore, it can be concluded that the various indicators from wine production show very similar skills for reconstruction. This is especially beneficial for reconstruction as production level and phenology react to different monthly temperatures.

The relevance of two consecutive years to viticulture characterises some calibrations. Especially, the late period from 1780 to 1841 and the short period from 1800 to 1831 show the best results for summer averages over the harvest year and the year preceding it ($\mathrm{JJ/JJA}_{\mathrm{y,\ y\text{-}1}}$) with R^2 up to 69 per cent. However, the difference to other monthly averages remains minor with a few exceptions. Despite the great difference in lengths of calibration, results are within a remarkably tight interval.

The length of the calibration seems to be irrelevant to the explanatory power of the calibration. The reason that the shortest period (1800-1831) shows some of the highest R^2 values might lie in the devastating 1810s. The series of cold summers affected viticulture heavily; thanks to these negative outlier years the wine-production figures correspond very well to temperature. The same effect might be the reason for the "best" calibration period (1780-1819). Besides the 1810s, this period also includes the 1780/90s which showed also some outliers in temperature. That they were not as strong as the 1810s can be seen from the fact that the 1762-1801 calibration – without the beneficial effect of the 1810s – returns the lowest R^2s.

It should be kept in mind that the explanatory power of the calibration only indicates how well the function received through linear regression fits the temperature. In other words: it shows whether wine production data explains temperature in the calibration period. The skill of the calibration will only be examined when an independent span of time is tested with the function. This will be done in the next section.

Calibration with Pfister's original series

After goodness indicators of calibrations revealed acceptable levels for both short and long periods of time, an attempt was made to use Pfister's original *Mittelland* series as a predictor for summer temperatures. Due to data availability, only two periods can be considered. The results are displayed in Table 8.

The models for Pfister's original series reach an explanatory power of the same magnitude as the models for the new *Mittelland* series compiled for this study. A direct comparison is not possible because the periods differ. The calibration running over the entire length for which data is available (1762-1825) shows remarkable results. Unfor-

[154] Meier, "Grape Harvest Records", p. 40.

Months	1762-1793 R^2	1762-1825 R^2
JJA	0.43	0.57
JJ	0.48	0.56
$JJ_{y, y-1}$	0.44	0.68
$JJA_{y, y-1}$	0.47	0.63

Table 8: Goodness of Calibration period for Pfister's original series – Coefficient of determination (R^2) are shown as a skill indicator of the models calibrated using the original series calculated by Pfister as predictor. Two periods are displayed: 1762-1793, 1762-1825. All models are significant.

tunately, this promising calibration cannot be verified due to lack of data. The second model will allow verification. It shows similar results as the earliest model of the *Mittelland* series.

5.3 Verification

The result of each calibration was a function that expresses the relationship between temperature and wine production for various periods of time. While the coefficient of determination already serves as an indicator of the goodness of the individual models, it is necessary to verify the calibration's skill in an independent period.[155]

Various indicators show the skill of the calibration. Two are used here. First of all, the (Pearson) correlation coefficient shows to what extent two variables are related to each other. In this case, the temperature value predicted by the model is compared to the measured temperature in the verification period.[156] The square of the correlation represents the coefficient of determination (R^2), which shows the explanatory power of the predictor.

The second indicator is the Reduction of Error (RE) coefficient which is often used in climatological reconstructions.[157] It shows the skill of a model by comparing the model to climatology. The RE indicates whether the model has a better skill than if the long-term average would be used as a predictor. In this reconstruction, the temperature

[155] Brazdil et al., "Historical Climatology", p. 380.

[156] Examples with temperature reconstruction include: Chuine et al., "Historical Phenology".

[157] E Cook., K. Briffa, and P. Jones. "Spatial regression methods in Dendroclimatology. A review and comparison of two techniques". In: *International Journal of Climatology* 14 (1994), pp. 379–402; Carlo Casty. "Climate variability over the North Atlantic/European and Alpine regions since 1500". PhD thesis. Geographisches Institut der Universität Bern, 2005; Casty et al., "Temperature Variability in the European Alps".

mean during the calibration periods serves as this climatological value. Therefore, the measured temperature for each year in verification is compared to the value that the calibration model predicts for this year. The comparison is done following the formula below.

$$RE = 1 - \left[\frac{\sum (x_t - \hat{x}_t)^2}{\sum (x_t - \bar{x}_t)^2} \right] \tag{2}$$

where x_{t} is the measured temperature in year t of the verification period, $\hat{x}_{\mathrm{t}}$ is the value predicted by the model for that same year, and $\bar{x}_{\mathrm{c}}$ is the mean of the measured temperature during the calibration period. The RE coefficient takes on a maximal value of 1. A value between 0 and 1 indicates that the model possesses good skill; 1 would be a perfect reconstruction. A value between -1 and 0 means that the model has still more skill than a random model. Values smaller than -1 indicate that the model has no skill.[158]

The R^2 and RE are depicted in the tables below as values indicating the skill of the calibrations as established through verification. The values are presented for each calibration-verification pair. In Table 9 below, the *Mittelland* wine production series calculated for this study is used as a predictor. Further below, the same is done with the original series by Pfister.

Calibration	1762-1801		1780-1819		1780-1841		1800-1831	
Verifiaction	1802-1843		1820-1859		1842-1966		1832-1862	
Months	r	RE	r	RE	r	RE	r	RE
JJA	0.69	0.41	0.42***	0.00	0.44	0.16	0.44*	0.19
JJ	0.66	0.40	0.48***	0.19	0.48	0.21	0.57***	0.42
$\mathrm{JJ}_{\mathrm{y,\ y\text{-}1}}$	0.86	0.62	0.70	0.45	0.54	0.23	0.57	0.45
$\mathrm{JJA}_{\mathrm{y,\ y\text{-}1}}$	0.83	0.53	0.64	0.13	0.53	0.19	0.43***	0.00

Table 9: Skill of verification – Correlation coefficient (r) and Reduction of Error (RE) illustrate the skill of the reconstruction model with various calibration and verification periods. All values r are significant: no sign: p< 0.001; ***: p< 0.01; **: p< 0.025; *: p< 0.05

The verification of the calibration models shows that all "pass" the test with significant correlation coefficients and REs greater than zero. However, the differences are considerable. Some models stick out as clearly superior.

[158] Casty, "Climate variability", p. 27; Cook. Briffa, and Jones, "Spatial regression".

The double year averages generally show better skill indicators than the corresponding single year models. The best results are shown for the first two calibration-verification periods. $JJ_{y,\ y\text{-}1}$ reconstruction from 1762 to 1843 returns the highest RE with 0.62. Admittedly, this is still considerably below the same indicator for grape phenology. Meier calculated up to $RE = 0.93$.[159] In general, $JJ_{y,\ y\text{-}1}$ shows the best skill with the highest RE. Also, $JJA_{y,\ y\text{-}1}$ temperature shows good results in the first period (1762-1843). The single year reconstructions show good results for this same period.

What is promising is that even the longest verification period from 1842 to 1966 shows acceptable results. This shows that grape harvest production still relies fairly considerable on summer temperatures – despite all changes. And it also confirms that various verification periods may be chosen and they arrive all at the result that wine production is valid to reconstruct summer temperature. However, as was seen many times before in this study, values for the later periods decrease in correlation.

Verification with Pfister's original series

Calibration	1762-1793	
Verification	1794-1825	
Months	r	RE
JJA	0.80	0.58
JJ	0.77	0.58
$JJ_{y,\ y\text{-}1}$	0.91	0.72
$JJA_{y,\ y\text{-}1}$	0.85	0.63

Table 10: Skill of verification (original *Mittelland* series – Correlation coefficient (r) and Reduction of Error (RE) show the skill of the calibrations with the original *Mitelland* series as predictor. All values of r are significant with $p < 0.001$

Since Pfister's grape harvest record ends in 1825, only the earlier of the two calculated calibrations can be verified. This calibration shows convincing results with correlation coefficients at least at $r = 0.77$. All models return clearly positive REs above 0.58. The $JJ_{y,\ y\text{-}1}$ reconstruction with Pfister's series shows the best result among all calibration models. No calibration-verification with the new *Mittelland* series surpasses this skill indicator. A direct comparison between Pfister's series and the new ones is not possible though.

[159] Meier, "Grape Harvest Records", p. 40.

Although only one verification is available for the original series, this data can also be used for reconstruction. It shows good skill, despite containing a smaller number of local series and also entailing series based on yield size as opposed to yield per area figures.

Evaluation of the verifications

In a next step, the calibration and verification are viewed graphically which should depict where the prediction misses the measured temperature. Figure 9 plots the reconstructed and measured mid-summer temperatures ($JJ_{y,\ y\text{-}1}$) for the period from 1780 to 1819 (calibration) and 1820 to 1859 (verification). It constitutes one of the best calibrations-verifications (see table 9).

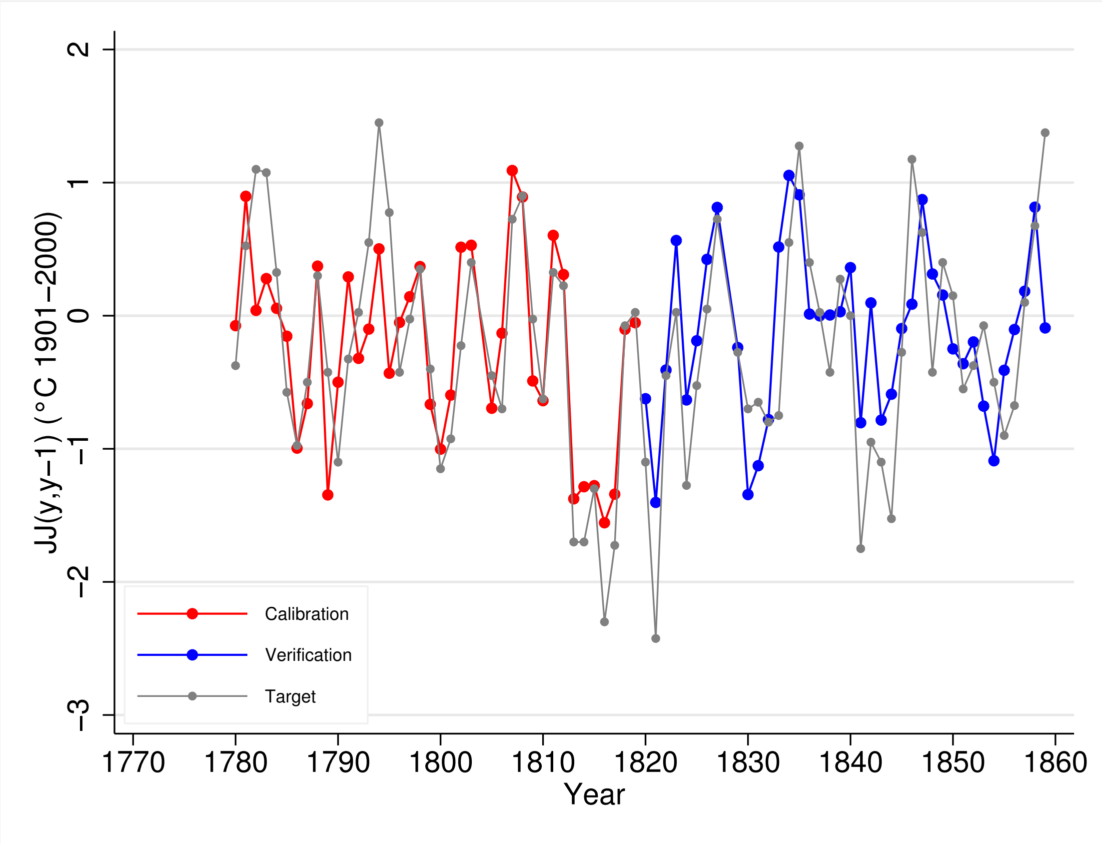

Figure 9: Plot of the calibration/verification from 1780 to 1859 – Calibration (1780-1819) is shown in red, verification (1820-1859) in blue. Target is the mid-summer temperature ($JJ_{y,\ y\text{-}1}$) from HISTALP (gray).

The graph shows that the prediction recreates the temperature pattern fairly correctly. In the calibration period (red) it can already be seen that extreme years are not always predicted correctly. The devastating years around 1815 – several volcanic eruptions, including Tambora 1816 – are predicted as cold years, however, the reconstruction does not predict the full scale of these years. Generally, it can be said that extreme years are not presented in their full scale. Very cold summers are predicted not as extremely cold, very hot summers turn out rather mild. This effect was already acknowledged by Pfister.[160]

Another spurious element in the single-year reconstructions is the sporadic lags that are shown by the reconstruction (not shown). This is due to the biannual nature of the wine-climate relationship: a warm year can influence the next year so that the harvest might still be remarkably good even if the summer turns out to be rather cold – or vice versa. In such cases, the prediction is "misled" and fails to show the correct tendency. Consideration of the average of two years solves this problem to a certain extent, but it must be accepted that it shows an aggregate figure.

To conclude, a few points can be summarised from the quantitative results of the calibration-verification process outlined on the last pages.

- The calibration-verification for grape harvest data (yield per unit area) was successful since highly correlated predictors emerged and models showed positive REs.
- The reconstruction is more successful, however, when early periods are considered. Due to the lack of homogenised temperature, calibration begins after 1760.
- Mid-summer temperature of the harvest year ($JJ_{y,\ y\text{-}1}$), and also the average of the mid-summer temperature of the harvest year and the year before ($JJA_{y,\ y\text{-}1}$) can be reconstructed using the series discussed in this study.
- The original *Mittelland* series also proves successful in calibration-verification. It can also be used for the reconstruction.

5.4 Discussion of the calibration-verification

The calibration-verification in the last section and also the remarks to the preparation raised an interesting – and recurring – question which could not be entirely answered: Why does the reconstruction perform so poorly in times after roughly 1850? This question shall be addressed in this section with the help of some statistical considerations.

[160]Pfister, "Fluktuationen der Weinmosterträge", p. 475.

It is important to recall several characteristics of the temperature and grape harvest time-series which were noted in the previous section on data. Firstly, the average summer temperature stayed at levels below the long-term average in the course of the 19th century. Secondly, the variability of this temperature was low after the devastating 1810s and again from the 1850s on. Thirdly, the period of 1822 to around 1880 showed substantially higher yields for the *Mittelland* in both the aggregate and the local time-series. This was chiefly caused by exceptional harvest years that occurred regularly. Finally, the statistical examination of climate-wine relationship pointed to a paradoxical effect: The best years for grape harvests were "normal" years in terms of their weather pattern, i.e. summer temperature was close to the average. It will be examined in greater detail how these developments proceeded and to what extent the temperature characteristics may have influenced grape growing.

Figure 10 (on page 66) illustrates these characteristics that were just described. The blue line depicts the long-term variability with the standard deviation averaged over 11 years. The peak in the 1810s with values up to 1.6 is hardly representative since volcanic eruptions caused climatic havoc all over Europe.[161] A peak was also reached in the 1840s. After 1850 variability remained generally modest up to the turn of the century – below 1 for most of the time. This period of low variability was coupled with relatively low summer temperatures.

It must be evaluated what this climatic situation means for the grapes. It can be assumed that grapes reacted to this situation of low variability in the middle of the 19th century with higher yields. Furthermore, many years between 1850 and 1880 had summer temperatures close to the "optimal" range between -0.5 and 0.5°C within the average. The same assumption might apply to the phase after 1820 before the series of cold summer in the middle of the 1840s.

A further issue to consider is the problem of temperature thresholds that grapes tend to react to. In the 1970s and 1980s, researcher demonstrated another relationship between temperature and grape growing levels apart from the average monthly temperature.[162] Namely, during flowering grapes require daily temperatures exceeding a certain threshold in order to grow favourably (see section 3). A close relationship was found between the flowering date and the number of days in a month with temperatures above 15°C before flowering. This also influences the size of the harvest. Temperatures substantially below this threshold result in lower amounts of grapes being developed and thus a smaller yield.

[161] Post, *Last great subsistence crisis*; Harington, *Year without a summer.*

[162] Koblet, *Physiologie der Weinrebe*, p. 13; P. Basler. "Beeinflussung von Leistungsmerkmalen der Weinrebe (Vitis vinifera L.) in der Ostschweiz durch Klimafaktoren und Erträge sowie Versuch einer Qualitätsprognose". In: *Die Weinwissenschaft* 1-4 (1980).

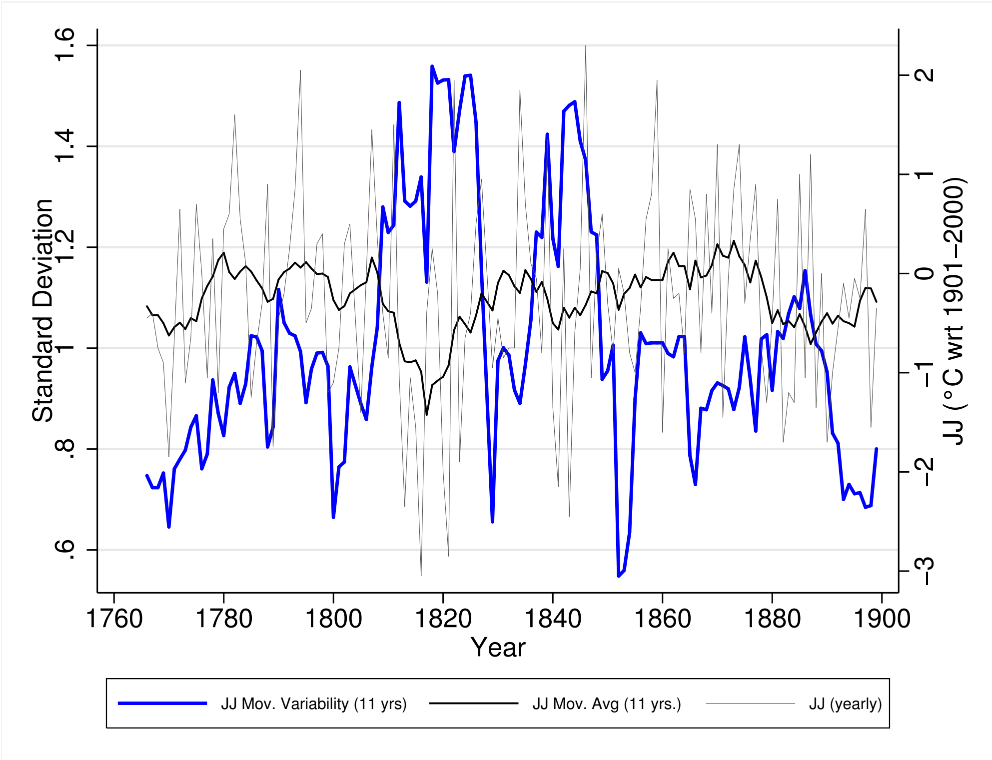

Figure 10: Comparison of moving average and moving variability of the HISTALP time-series (1765-1900) – The moving average (over 11 years) of the mid-summer temperature (JJ) is plotted in black, the moving variability (over 11 years) is plotted in blue. The light gray line shows the JJ temperature for each year.

From monthly averages it cannot be seen whether such a situation persisted between 1850 and 1880. But the existence of such a relationship emphasises that not only monthly averages are relevant for the growth of grapes.

Another factor cannot be neglected: agricultural improvements. Such are well known for Switzerland in this period.[163] The development did not take place uniformly: the Vaud region is considered to be the most advanced.[164] Improvements are characterised by a greater yield per unit area unit when all other factors are held constant. Between 1825 and 1880 yields undoubtably show a greater magnitude than before, which can be attributed to potential improvements in cultivation. However, it declined again after 1880: Looking at climate, the average temperature from 1880 dropped more pronouncedly than in the decades before. This might explain the drop in production levels (yield per unit area). But there are also two circumstantial reasons for this effect after 1880: On the one hand, it is the spread of the grape pest phylloxera which diminished harvests. On the other hand, with improved transportation means (railway tunnels), imports increased dramatically which lowered the Swiss viticultural area significantly. Both these effects will be further addressed in the last section on higher-order impacts.

In reviewing results of the reconstruction, one is tempted to point to the original times-series by Pfister. It shows very good results when compared to climate indicators. The series constructed in this study and Pfister's series share many similarities: Pfister constructed his series with the same method as this study. Furthermore, the data used by Pfister was also part of this study. The difference lies in the number of series considered. While this study uses the same series as Pfister, it complements those series with a further from De Montmollin and elsewhere. Since these time-series stem from various places, especially from the Neuchâtel and Vaud region, the basis of the newly calculated *Mittelland* is more to the West of Switzerland, whereas the original time-series relies heavily on data from the Zürich region.

It turns out that the data from Zürich systematically shows greater correlation with the HISTALP summer temperature data as opposed to other series. The reason for this might lie in the relative certainty about grape measurements which led to more precise series compared to those from the Western part of Switzerland. Therefore, the success of Pfister's series can mostly be attributed to the dominance of series from Zürich. If the Zürich regional series of this study is tested against summer temperature, the coefficient of determination is even higher than for the *Mittelland* series. With this finding, it is fair to raise the question whether it would be worthwhile to attempt a temperature

[163] Montmollin, "Rendement viticole", p. 45; Dubois, *Les vignobles vaudois.*

[164] Brugger, *Landwirtschaft erste Hälfte 19. Jahrhundert*, p. 53; Dubois, *Les vignobles vaudois.*

reconstruction restricted to the Zurich area. However, the relatively higher correlations for wine production from Zürich end little later than 1830. Thereafter, the often observed decreasing correlation cannot be eliminated even for the Zurich series.

5.5 Reconstruction

Calibration and verification set the basis for the main objective of this study: the reconstruction of temperature form 1529 to 1966. Methodically, this is done by applying the transfer function established in the last sections to wine-production figures from earlier times. The verification of the transfer function allows to indicate the certainty of the reconstructed temperature time-series. In addition, the standard error (SE) established through linear regression in calibration serves as a further indication of statistical certainty.

5.5.1 Preparation of the time-series

Several preparatory steps needed to be executed before the reconstruction could be done. One problem was the usage of data for the earlier parts of the reconstruction time (prior to 1750). The only data available is the composite series by Pfister and the various local time-series he used to calculate it. The non-uniform nature of this "standard series" is a problem. Two series were merged: From 1798 to 1825, a yield-per-area time-series (hl/ha as a basis) was used. For times before 1798, the series consists of several regional series showing the (detrended and homogenised) size of the yield (hl as a basis).[165] Therefore, the time-series has a break in 1798. This is less problematic for the original series as it was already calibrated and verified with this break.

More serious problems emerge for the new *Mittelland* series, which reaches from 1750 to 1966. The transfer function calculated from this new and longer series cannot be applied to the early data from Pfister's series, because the series differ – data prior to 1798 is based on yield size only and not yield per unit area. Therefore, data needs to be created that extends further back and shares the same technical characteristics with the 1750-1966 series used for calibration and verification. This was ensured by calculating a new series with Pfister's raw data. These local series are retrievable.[166] The same procedure with regard to detrending and homogenising as outlined in section 4.3 informed this process. This resulted in a seamless extension of the 1750-1966 time-series

[165] Pfister, "Fluktuationen der Weinmosterträge", p. 467.
[166] Pfister, *Klimageschichte*, Table 1/34.3.

back to 1529. Therefore, the transfer function could be applied to the newly calculated earlier time-series for the *Mittelland*.

This new series is very similar to Pfister's original series. It merely differs in the level of the percentages. Generally, they are lower compared to the original time-series. This difference is probably caused by the combination of yield-size and yield-per-area figures in Pfister's "standard series". Furthermore, the fluctuation in the newly calculated time-series is more pronounced since it consists of less data.

It should be noted that the earliest part of Pfister's series (to 1630) and thus also the newly calculated *Mittelland* series chiefly consist of data from Zürich. This further justifies the heavier weight attributed to the Zürich regional series in the *Mittelland* time-series for calibration-verification (see section 4.3). This weighting ensures that the time-series for calibration-verification and the one for reconstruction correspond.

5.5.2 Discussion of reconstructions

All reconstructions calculated in this study show a very similar pattern, regardless of calibration-verification periods and reconstructed set of months. They differ in the maxima and minima. Some show larger peaks than others due to the different transfer functions emerging from calibration. This is mainly due to the different values for the slope (β). Furthermore, they also show different levels of statistical certainty with standard errors of various magnitudes. Therefore, only a selection of the reconstructions is presented here. Some general characteristics of the reconstruction are outlined. However, the study refrains from a detailed discussion since the topic of wine-production fluctuation in these early times is not covered by the research interest.

Figure 11 (on page 70) shows the reconstruction for mid-summer temperature ($JJ_{y,\ y\text{-}1}$) in the Northwest Alpine region back to 1529. The graph includes both the reconstructed temperature for individual years and a 11-year moving average to depict long-term tendencies. Furthermore, the calibration-verification approach allows to illustrate the statistical certainty of the reconstruction (95% confidence interval, 2 standard errors SE). It should be noted that the reconstructed temperature values show the average for two years.

In general, large parts of the curve stay below the long-term average. Some peaks struck the eye. Firstly, a series of low summer temperatures can be identified in the in of the 16th century. This result is well discussed in other research. The consequences of these cold summers was particularly felt on wine harvests.[167] The climate-imposed low

[167]Landsteiner, "Crisis of wine production".

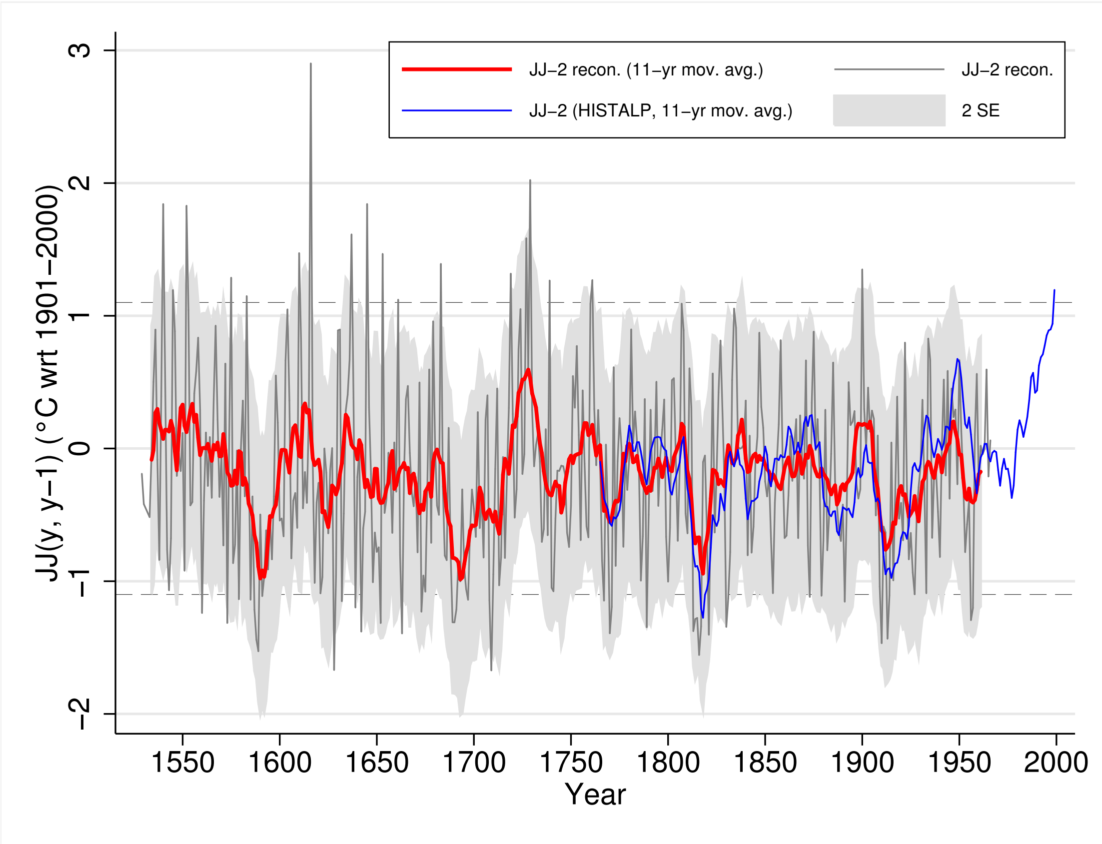

Figure 11: Reconstruction of $JJ_{y,\ y\text{-}1}$ temperature 1529 to 1966 with calibration-verification from 1780 to 1859. The *Mittelland* time-series constructed for this study was used as a predictor. The 11-year moving average of the reconstructed temperature is plotted in red. The shaded area indicates 2 standard errors representing a 95 per cent confidence interval. HISTALP temperature is shown in blue for the later periods. The dashed lines display 2 standard deviations of the mean 1901-2000 temperature.

level of grape yields and thus wine-production caused far-reaching problems for societies in Europe. The late 17th century sticks out as a further low point. Temperatures reached similarly low values as in the end of the 16th century. A minor low point also occurs around 1630 which still belongs to the series of cold summers in the end of the 16th century.

Periods of especially warm summers occur less frequently. However, a positive peak can be detected in the first half of the 18th century with 1729 showing the largest harvest. It should be noted that this value might be spurious as great yields do not necessarily mean very hot summer temperature. This peak may just as likely be the consequence of a very favourable timing of the weather pattern which benefited the grapevines.

Furthermore, it can be seen from the graph that the reconstruction still depicts correct tendencies for the first half of the 20th century. However, the period in the later part of the 19th century reveals the correlational problems referred to before. While the tendencies of the reconstructed temperature correspond well to the instrumental measurements, the fit is slightly worse compared to the calibration period before.

In climatological studies, the long-term temperature is usually illustrated using a 30-year or longer filter. Here, a 11-year moving average is applied. The reason for this lies in the higher relevance of outliers of a length shorter than 30 years. To assess the impact of climate on society, a shorter period of time is more realistic.

Comparing the present reconstruction with established reconstructions from literature allows for a validation of the result.[168] Casty et al. reconstructed summer temperatures for the Alpine region using both instrumental data and documentary evidence.[169] Luterbacher et al. used similar evidence to reconstruct European summer temperatures back to 1500.[170] Both studies show cold summers at turn of the 16th century and the end of the 17th. However, the warm peak around 1740 does not show up. Yet, the reconstruction by Casty, for instance, shows a low variability in temperature for approximately the same period as the reconstruction of this study displays a (potentially spurious) peak in temperature. This low variability may have caused grape harvests to react with a sustained high yield level – it would be the same effect as between roughly 1850 to 1880.

Furthermore, both studies show relatively warm temperatures for the second half of the 19th century (more so for the European than for the Alpine region). This is not replicated by the temperature reconstruction done here.

[168]The graphs that are used as a comparison in this paragraph can be found in the Appendix.
[169]Casty, "Climate variability", p. 1860.
[170]Luterbacher et al., "European Temperature Variability", p. 1500.

Reconstruction with Pfister's "standard series"

Additionally, the calibration-verification was carried out with the original series from Pfister. The so called "standard series" *Mittelland* is somewhat problematic since it consists of yield-per-unit-area figures for the later part and yield-size figures for the earlier part (before 1798).[171] Nevertheless, the calibration (with yield-size figures) and the verification (mostly yield-per-unit-area figures) showed very convincing results. Therefore, the reconstruction is also done using this "standard series". Figure 12 (on page 73) depicts this reconstruction.

Contrary to the above reconstructions with the newly calculated *Mittelland* series, temperatures from the 16th to the 19th century remain below the 20th century average for almost the whole time. However, positive mean values only occur very rarely. The phases of relative cold at the turn of the 16th and before the end of the 17th century are included as well. This is not surprising since the data basis for this reconstruction and the one for the newly calculated series are largely the same. The same holds true for the positive peak in the first half of the 18th century.

It should further be noted that the larger number of data series in the early parts leads to a smoother curve compared to the above reconstructions with the newly calculated series. This is also depicted with the gray line being smoother.

The last example of the reconstruction with the original wine production data points to a general problem of temperature reconstruction with wine production data. When the grape harvest data is fit to temperature during a period of relatively low variability, the resulting transfer function produces slope coefficients of a small magnitude. This can be spurious; viticulture seems to react to a lesser degree to temperature levels when there is little variation over a a longer period of time.

Therefore, this phenomena needs be taken into account when doing a reconstruction. It results in the transfer function not representing extreme years correctly. In other words: the transfer function will only reconstruct cold summer fairly correctly, if such summer with typically bad harvest are represented in the calibration. For instance, the reconstruction in figure 12 (on page 73) with calibration from 1762 to 1796 predicts higher temperatures for the "year without a summer" period around 1816 as they were measured. Therefore, calibration should include such years.

Periods with little variation were identified notably in two periods also used for calibration in this study. On the one hand this is the period prior to 1780 and in the middle of the 19th century roughly between 1825 and 1880 (with the exception of a short

[171] Pfister, "Fluktuationen der Weinmosterträge", p. 467.

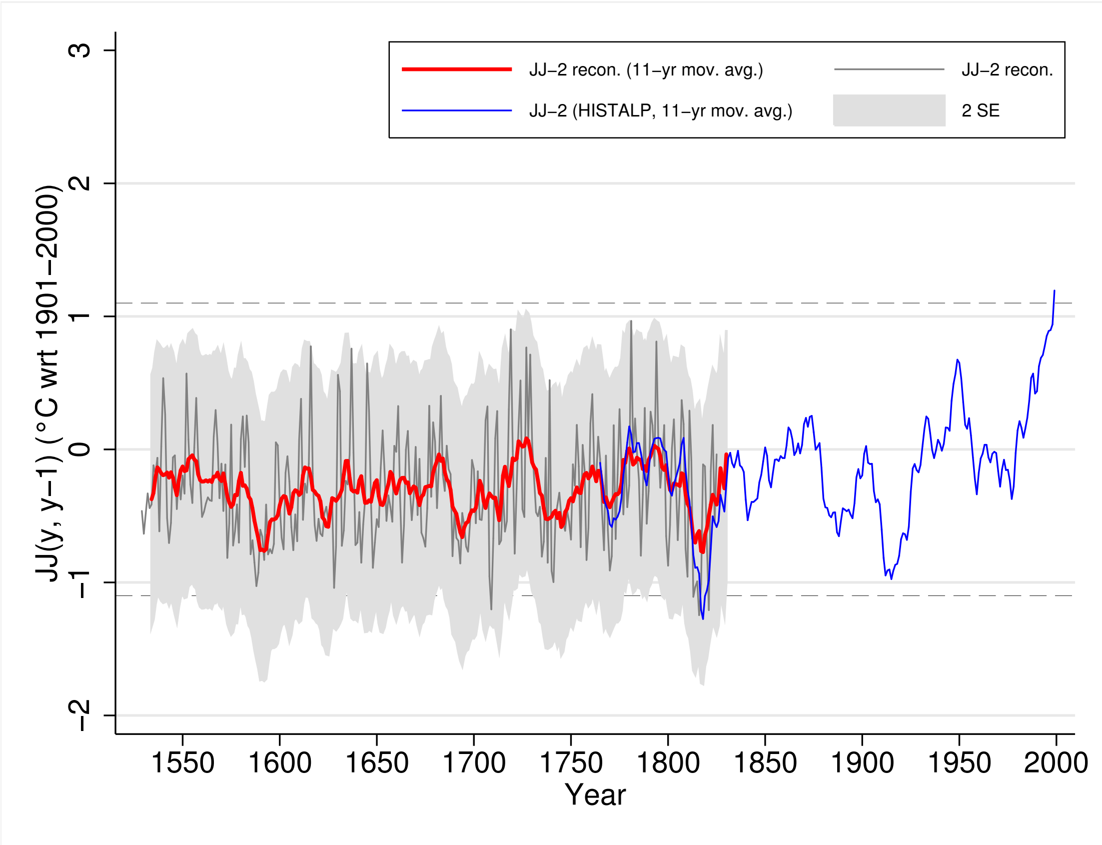

Figure 12: Reconstruction of $JJ_{y,\ y\text{-}1}$ temperature 1525 to 1966 with calibration-verification from 1762 to 1825. The original grape harvest time-series from Pfister (1981) was for calibration-verification. The 11-year moving average of the reconstructed temperature is plotted in red. The shaded area indicates 2 standard errors representing a 95 per cent confidence interval. The dashed lines display 2 standard deviations. HISTALP temperature is shown in blue for the later periods. The dashed lines display 2 standard deviations of the mean 1901-2000 temperature.

intermezzo in the 1840s). Consequently, these reconstructions reveal the same effect as outlined above.[172]

5.6 Summary

The strong reaction of grape harvests to temperature fluctuations may be used to reconstruct temperature for times before instrumental measurements are available. This section carried out such a reconstruction. The target temperature from HISTALP covering the Northwestern Alpine (NW) subregion, the reconstruction also applies to this area. Due to the biannual nature of the climate-wine relationship, averages of summer months from two years were used: the harvest year and the year preceding it. The June and July double year average proved the most successful.

Four pairs of calibration and verification covering various parts of the available data were tested for their skill in reconstructing temperature. Calibration showed good and significant results for all periods with up to 70 per cent explained variance in some cases. The majority of models proved to have better skill as a neutral indicator for reconstruction. In one case, the skill of the calibration was tested in a 120-years period up to 1966 – and it passed.

Generally, reconstructed temperatures fail to account for the full scale of extreme years. It was again noted that very high summer temperatures in reconstruction may be the result of a spurious effect and should therefore be assessed carefully. Furthermore, a period in the second half of the 19th century was identified as problematic for reconstruction. The low variability in temperature is assumed to have a detrimental effect on the usually strong relationship between climate and wine-production. A similar case in point may be the 1760s.

Temperature reconstruction was possible back to 1529 using the raw data from Pfister's study from 1981. The resulting temperatures show similar results as studies in climatology relating to the same region. However, some differences were also noted.

Reconstruction was also carried out for the original "standard series" used by Pfister in 1981. These series proved highly successful in calibration and verification although the lengths of these tests were limited due to the end of the series in 1825. In reconstruction, this time-series shows markedly lower temperature values, but the same pattern of fluctuation.

[172] An example is given in the Appendix for the reconstruction period 1762 to 1801 with the newly calculated *Mittelland* series.

6 Viticulture in 19th century Swiss *Mittelland*

After having extensively examined the relationship between temperature and viticulture, this last part of the study takes a different perspective. Climate exhibits a great influence on the outcome of grape harvests although the temperature reconstruction demonstrated that the relationship is far from perfect. This suggests other factors play significant roles as well. Therefore, when examining the significance of viticulture on a society, a range of influences must be investigated.

Structural changes may completely alter the face of the wine-growing sector. Late 19th century Switzerland experienced such changes which led to a decline of viticulture to one third of its peak extension in only a few decades.[173] This study trails these changes by entangling the various factors which contributed to it, and, by assessing the influence of climate in this process. The model guiding this research (section 1.1) provides a framework showing how such an assessment may combine the different factors.

In this view climate takes on the role of a "background" variable. Climate is not usually the primary area of focus but it also cannot be neglected when examining changes. In the first part, research interests purely focused on the role of climate in viticulture. In this part, the second half of the impact model is the centre of interest. That is for instance, the relationship between the volume of wine production and its price, the level of consumption and the role of imports. Investigation of societal activity promises interesting insights in part of 19th century economic history.

In the first half of the 19th century, viticulture played a significant role in economy. A short detour to the 16th century exemplifies the relevance of viticulture in pre-modern societies. The importance of certain sectors often becomes most visible, when abrupt events alter the "normal" course. This can be observed in the last decade of the 1500s, when cold weather (especially in winter) prevailed for a prolonged period (1587-1593). Viticulture and thus the wine trade were especially affected by these adverse conditions. Landsteiner outlined what this meant for Lower Austria in his study. He shows that prices for wine "skyrocketed" which led people to change their habits and drink substantially more beer and less wine.[174] Wealthy landowners were most likely able to adapt to this change in demand. Small-scale wine-growers suffered most from the harvest losses. Furthermore, the Habsburg state ran into huge problems since it relied heavily on the taxes generated from the consumption and trade of wine.[175] To avoid decreasing revenues,

[173]Schlegel, *Weinbau in der Schweiz*; Brugger, *Statistisches Handbuch*, pp. 162–163.
[174]Landsteiner, "Crisis of wine production", pp. 328–329. Another study on the impacts of climate in this time: Pfister, "Weeping in the Snow".
[175]Landsteiner, "Crisis of wine production", p. 331.

authorities resorted to a number of measures such as restriction on the sale of wine and higher duties on exports or fixed prices. In short: Actors needed to adapt to this situation. These examples underline the logic with which changes in viticulture – climate-imposed in the case of Lower Austria – affect various players.

There is ample evidence to suggest that the importance of viticulture continued well into the 19th century. For instance, the canton of Berne, although not among the chief wine-growing areas in Switzerland, met its expenses entirely with taxes on wine consumption and stamp duties as late as 1804.[176] The revenue from the consumption tax continued to be substantial for most of the century (see section 6.3.2). Therefore, studying how changes in the wine economy affected a society is worthwhile.

In the 19th century there was no single shock which hit the wine-growing industry in Switzerland. Societies did therefore not have to adjust to a completely different situation in a short time span. More to the point, 19th century viticulture is characterised by a marked expansion in the middle of the century and an more pronounced decline from the 1880s onwards. This decline lasted about 50 years until viticulture reached a stable position again. The focus of the assessment in this study lies on the beginning of this period of decline around 1880.

The remainder of this section is ordered as follows: Firstly, a brief summary of the development of wine production in light of the temperature is given (First-order impact). This draws heavily from the temperature reconstruction. Before considering higher-order impacts, the contextual situation is presented. This includes a discussion of the economic situation in the 19th century, the role of diseases such as Phylloxera and the role the state played in relation to the wine-growing sector. It is important to note that only the general aspects are mentioned. These contextual issues are addressed first in order to refer back to them when the higher-order impacts are discussed in the following section.

Price, consumption, exterior trade, and migration constitute the higher-order impacts identified to potentially have a relationship to the fluctuations in viticulture in Switzerland. These "hypotheses" are discussed in the respective section.

[176] Hermann Rennefahrt. *Grundzüge der bernischen Rechtsgeschichte.* Bern: Verlag von Stämpfli & Cie., 1928, p. 148. The tax on wine consumption also accounted for 40 per cent of the state revenues up to the end of the 18th century in Basel. Arthur Vettori. *Finanzhaushalt und Wirtschaftsverwaltung Basels (1689-1798).* Basel / Frankfurt a. M.: Verlag Helbing & Lichtenhahn, 1984.

6.1 First-order impact: Temperature influence on wine-production

In light of the findings of the above section and the insights gained from the temperature reconstruction, it is possible to conclude on the first-order impact (see section 1.1) of climate on viticulture for the later part of the 19th century.

6.1.1 Fluctuation of production volume

Figure 13 illustrates the up- and downturns in wine production in the second half of the 19th century. In this graph, the production level of wine is depicted as the value added (adjusted for inflation) of the wine-growing industry (black).[177] The decision to resort to this data is open to criticism. It is true that the value added does not indicate the exact production level since it is a more encompassing concept and thus subject to changes in the economic situation (e.g. profitability). However, the time-series provided by the value added time-series from the *Historical statistics* might be the most homogenised time-series related to production size. Time-series published elsewhere (Brugger) often include only a selection of vineyards or regions. The official production data from the federal Bureau of Statistics only begins in 1893.

In order to ensure comparability over time, the value added time-series is adjusted for inflation.[178] In addition to the value added as a proxy for production size, the summer temperature from HISTALP is plotted (red). Both series are smoothed using a 5-year moving average.

In general, production and temperature follow a similar trend. However, a gap opens between the late 1850s and the mid 1870s. While temperatures fell to below average levels in comparison with the 1901-2000 period, wine production maintained a sustained high level. This effect was elaborated on before (see section 4.4). It is assumed that the conditions in these years were optimal, not particularly in terms of temperature, but in terms of the weather patterns. The period is also termed a "long series of golden autumns" referring to the beneficial effect of warm weather before harvest.[179] Indeed, remarkably cold autumns are absent from records. Consequently, grape yields developed nicely. The gap between wine harvests and summer temperature is therefore due to the

[177]Ritzmann-Blickenstorfer, *Historical statistics*, pp. 554–555; Ritzmann, *Die Wertschöpfung im Ersten Sektor, 1837-1945*.

[178]Christian Pfister kindly made the swistoval tool available. It was developed by the Institute of History at the University of Berne. A description is in preparation. The converter uses a historic wage index and a historic consumer price index to adjust for inflation. The price index was used in this case.

[179]Pfister, "Fluktuationen der Weinmosterträge", p. 451.

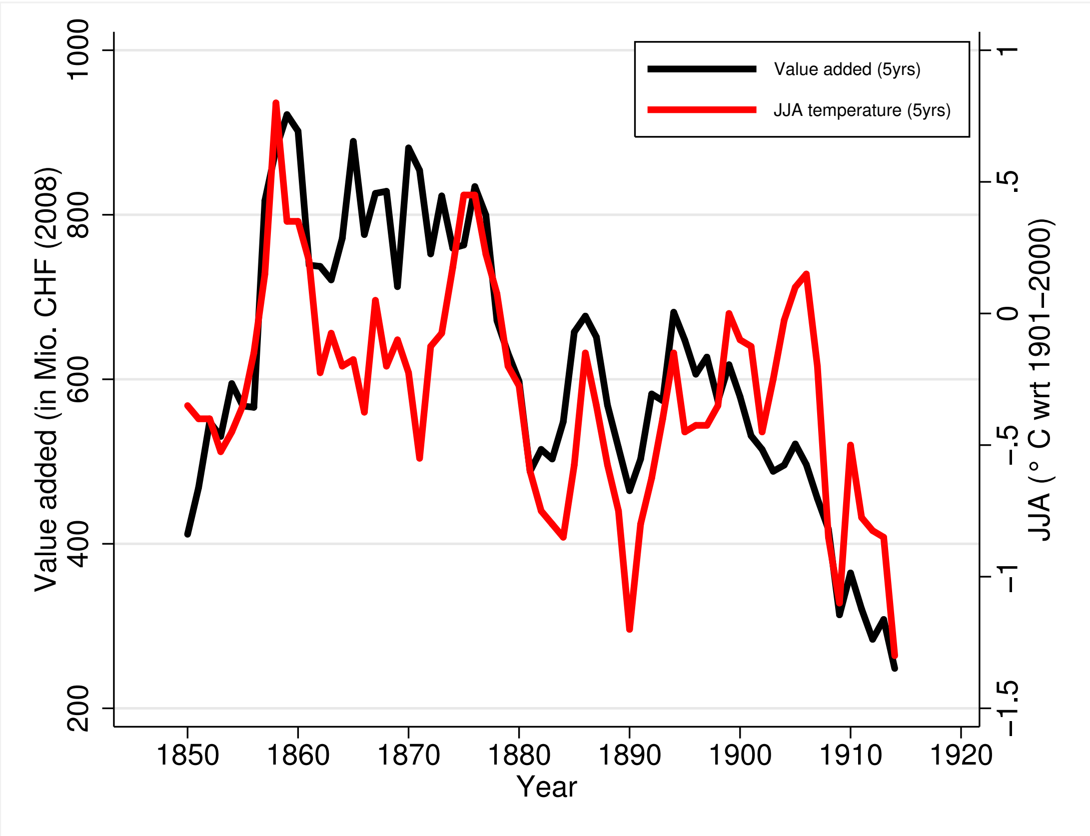

Figure 13: Comparison of production level (value added) and summer temperature (1850-1914) – The graph compares the production level as depicted by the value added adjusted for inflation (black) and the summer temperature (JJA, red). Both time-series are shown as 5-year moving averages. Sources: Ritzmann 1996 (value added), HISTALP (temp.).

well-established effect that the best harvests occur in "normal years" with favourable weather patterns (enough rain and sun) and absence of prolonged cold spells.

Furthermore, the value added does not reproduce the fluctuations of the temperature curve. In light of the problems experienced with that period in temperature reconstruction, this is no surprise. It seems that the effect that caused sustained higher yields also distorted the usually close relationship between climate and wine-production.

The pattern of temperature and wine production corresponds to a higher degree again from the late 1870s to the turn of the century. Startlingly, the minor decline in average summer temperature resulted in a dramatic drop of wine production. This may suggest that viticulture has a temperature threshold after which it reacts. In other words, when summer temperatures fall to a certain level, grape yields are more affected.

As examined in the first part of the study, extremely cold years exert the most notable effect on viticulture. Such years did not occur in great numbers until after the 1816 "accident". As a result, grape yields were substantially higher than in the periods before and after. In fact, similar yields per unit area occurred only after the middle of the 20th century.[180] Therefore, the most important effect of temperature on viticulture was the absence of cold summers.

It is probably inappropriate to term this a favourable effect since it caused an expansion that was unhealthy for the sector and ultimately led to its demise. However, the effect points to the fact that not only adverse climate conditions – such as 1816 – can have a lasting effect, but also conditions that can cause larger harvests.

Furthermore, the onset of the viticulture crisis coincided with a drop in summer temperatures in the beginning of the 1880. Consequently, literature often cites this as a contributing factor to the demise.[181] There is no evidence in this study that contradicts this interpretation. The summers of 1881 to 1883 were remarkably cold with average temperatures at least 1°C below the long-term average.

In the middle of the 19th century, viticulture did not "feel" much from climate conditions. Usually, conditions were good for the grapes. Nevertheless, it should be noted that harvest failures could have a devastating effect on wine-growers. Pfister vividly outlines what harvest failures meant to wine producers.[182] The most negatively affected were the small producers. They had to sell their harvest in the year it was grown in order to meet expenses for foodstuffs. In bad years, they ran the risk of not being able to sell enough wine, despite high prices. Their situation aggravated since

[180]BFS, *Hektarerträge im Getreide-, Kartoffel- und Weinbau 1841-2000 (T 7.3.3.1.3).*
[181]Schlegel, *Weinbau in der Schweiz*, p. 64.
[182]Pfister, "Fluktuationen der Weinmosterträge", pp. 487–489.

climate-imposed failures also affected grain harvests, which resulted in higher prices for grain. Quite contrarily, large-scale producers were more likely to absorb the negative consequences of harvest failure. They had the capacities and financial reserves to store wine and sell it when prices picked up again. At times, such producers also engaged in speculation when they bought harvests of small scale wine-growers. However, consecutive years of failure also caused harm for this category of wine-growers.

While this mainly accounts for pre-modern agricultural society, one needs to be aware of the fact that Swiss agriculture in the 19th century still was in the course of transition to a post-agricultural society.

6.2 Economic situation

In the second half of the 19th century, Switzerland developed to what it is still known for today: a (small) export economy. The importance of the exterior trade can be clearly observed at the turn of the century when the trade ratio – the exterior trade volume expressed as a percentage of the Gross Domestic Product (GDP) – amounted to 67 per cent.[183] The shift from the agrarian society of the beginning of the 19th century to an increasingly industrialised society at the end of the century was not without friction. Agriculture and the wine-growing sector are telling examples.

A special characteristic of the late 19th century was an economic crisis starting around 1875 and lasting for roughly two centuries. During this time, production levels and prices declined; the GDP shrank.[184] This was mainly caused by the adverse developments in industry and construction. Despite the often applied term "Great Depression" for that period, the downturn did not in fact affect all parts of the economy and there were times that even showed thriving. For instance, in the early 1880s, the situation improved for a short period of time for the industrial and construction sectors.[185]

However, one area that was clearly and sustainably affected by the crisis was agriculture. The first sector underwent great changes during the entire 19th century. The abandonment of traditional production schemes such as the three-field crop rotation by the middle of the century led to an increase in productivity. While this improved the situation, other developments made it more difficult: The exposition to the global grain market due to better and cheaper transportation means put the grain production in

183 Heiner Ritzmann-Blickenstorfer. "Konjunktur". In: *Historical Dictionary of Switzerland (HDS)* (1996–2009). url: http://www.hls-dhs-dss.ch/textes/d/D13918.php (25.6.2009).

184 Ritzmann-Blickenstorfer, "Konjunktur".

185 Thomas Widmer. *Die Schweiz in der Wachstumskrise der 1880er Jahre*. Zürich: Chronos, 1992, pp. 117–119.

Switzerland under pressure.[186] This led to a sustained re-orientation of Swiss agriculture: farmers in the *Mittelland* switched to dairy farming (to produce for export) instead of the wide-spread crop plantations. The contraction comprised viticulture as well. It was particularly visible in the distribution of vineyards. In the Eastern parts of Switzerland their number declined, while it was maintained in the Western part. The main period of decline was the crisis in agriculture around the 1880s.[187]

6.2.1 Expansion and contraction of viticulture

The most remarkable characteristic of the 1880s crisis in viticulture was the contraction of the area planted with grapevines. It began at the onset of the crisis and continued to the end of the First World War. In this time, two thirds of wine-growing acreage disappeared.[188] The districts where grapes were grown for a long time were not affected as much as places where wine-growers started to cultivate the crop only in the 1850s. Therefore, the decrease in the acreage led to a concentration on favourable areas.[189]

The reasons for this decrease are manifold. Apart from external factors such as the consequences of increased global trade, the decline "corrected" an excessive expansion that began in the 1850s with an increase of viticulture in Switzerland to unprecedented heights.[190] No exact figures display the situation for the whole country.[191] Sporadic cantonal surveys in 1858 and 1884 suggest that the cantons of Zürich and Vaud were mainly responsible for the expansion. However, the increase was not as pronounced as the following decline. According to the cantonal survey, the acreage in Zürich increased from 4,151 to 5,580 ha (+ 34 per cent), in Vaud from 5,562 to 6,430 ha (+ 16 per cent) in the span of 26 years. Increases in the other cantons – all with less acreage – was minor.[192] Nevertheless, viticulture in general experienced a "boom" phase from 1850 onwards.[193]

The euphoria which led to expansion was mainly fuelled by very favourable conditions in the wine economy. Not only did yields turn out sizeable, the market offered

[186] Peter Moser and Werner Baumann. "Landwirtschaft". In: *Historical Dictionary of Switzerland (HDS)* (1998–2009). url: http://www.hls-dhs-dss.ch/textes/d/D13933.php (25.6.2009).
[187] Schlegel, *Weinbau in der Schweiz*, pp. 46–61.
[188] Brugger, *Statistisches Handbuch*, pp. 152-163; BFS, *Rebfläche nach Kantonen 1855-2002 (Anbaustatistiken, T. 7.3.1.5).*
[189] Brugger, *Landwirtschaft 1850-1914*, pp. 145–146; Schlegel, *Weinbau in der Schweiz*, pp. 56–57.
[190] Schlegel, *Weinbau in der Schweiz*, p. 57.
[191] Brugger indicates the grape acreage in the whole country at 34,380 ha for the whole country in 1884. Brugger, *Statistisches Handbuch*, pp. 152-163. Schlegel believes this figure is 5 per cent too low. Schlegel, *Weinbau in der Schweiz*, p. 46. The official figure is even lower: 29,600 in BFS, *Rebfläche nach Kantonen 1855-2002 (Anbaustatistiken, T. 7.3.1.5).*
[192] Brugger, *Statistisches Handbuch*, pp. 152-163.
[193] Pfister, "Fluktuationen der Weinmosterträge", p. 450.

good prices for wine as well. In the middle of the 19th century, high prices for foodstuffs persisted in general.[194] Higher employment thanks to industrialisation meant more people could afford to buy wine. Transportation did not allow for imports. Therefore, the demand was largely met with domestic wine.[195] In the course of the 19th century, the prosperous core zones of the industrialisation were expanding markets for wine-growers. This was especially felt in the Eastern part of Switzerland, but even in far-away Romandie. Zurich, Schaffhausen and Aargau increased their grape acreage considerably.[196]

At the same time as high prices persisted, cost of production did not change a great deal. This resulted in higher earnings from wine returns which encouraged the sale of vineyards. Consequently, prices of vineyards soared to heights far above the actual value – also owing to speculation.[197] However, this situation led to what is termed a "bubble" in economics.[198] More and more farmers took on debts too heavy to carry. This situation called for a "correction".

Profitability problems are most often cited as the cause for the decline of viticulture in the *Mittelland* in the 1880s, when the bubble burst.[199] With rising production costs, wine-growers were unable to do business profitably. A distinct characteristic of viticulture is responsible for this. On the one hand, production costs were stable, but on the other hand returns form yield varied to a large degree due to the fluctuation of harvests. Prices did not adjust sufficiently to compensate for a bad harvest.[200] Therefore, in the 1880s, the interest on the mortgages to buy vineyards proved too heavy a burden in a time with consecutive yield failures. Several other factors contributed further.

Initially, small wine-growers could better cope with this development since they relied mainly on family members for work. As long as wine prices and demand remained high they could maintain their holdings. However, larger wineries, mainly in the canton of Zürich and along the Lake of Geneva, struggled. Many wineries were sold to farmer families in this time.[201]

This situation however, did not last long. Once prices fell (shortly after 1880), particularly small-scale farmer faced a "debt problem". In the end of the 1880s, supporters

[194] Peter Moser. *Der Stand der Bauern. Bäuerliche Politik, Wirtschaft und Kultur gestern und heute.* Frauenfeld: Huber, 1994, pp. 14–15.
[195] Schlegel, *Weinbau in der Schweiz*, p. 46.
[196] Schlegel, *Weinbau in der Schweiz*, pp. 69-70.
[197] Pfister, "Fluktuationen der Weinmosterträge", p. 451.
[198] Moser, *Stand der Bauern*, pp. 14–15 The similarity of recent developments (in the U.S. housing market) is all too obvious.
[199] Schlegel, *Weinbau in der Schweiz*, p. 51.
[200] Pfister, "Fluktuationen der Weinmosterträge", p. 450.
[201] Schlegel, *Weinbau in der Schweiz*, p. 67.

of a “Farmer’s Association” (“Bauernbund”) demanded to reform the mortgage system[202], even though devaluation of ground and sinking prices for raw material seems to have stopped by the end of 1885.[203] Many farmers faced a great deal of debt and seemed unable to escape the spiral of debt. The propositions included a fixed maximum interest rate or the creation of a federal bank for agricultural credits. However, farmers were divided on the subject. Small farmers with a load of debt criticised large-scale farmers for their reluctant position on the subject. Often wealthy farmer’s were also money lenders which explains their stance to mortgage reform. Consequently, no action was taken.[204]

Therefore, the notion of the crisis as a “correction” is accurate. Vineyards close to cities and in unsuitably high altitudes were cleared. “To be sure, the agrarian crisis [in the 1870/80s] was more than an economic crisis.”[205] It was accompanied by structural change which led to much needed increase of productivity. For viticulture this meant – among other things – the concentration on the climatically favoured parts, i.e. in the french-speaking part of Switzerland, especially on the shores of the Lake Geneva.

6.2.2 The lack of workers

Shortage of labour is another factor often considered responsible for the decline of viticulture during the 19th century. Especially during harvest, wine-growers were in desperate need of workers and often they were acquired from far away. This proved more difficult when the expanding industrial sector absorbed an ever-larger number of workers. This development affected viticulture particularly in the second half of the 19th century. Thus, wine-growers had to increase wages.[206]

A comparison of different agricultural subsectors shows that labour costs make up roughly half of the production costs in viticulture in the beginning of the 20th century – 1.5 times more than in grain cultivation.[207] Therefore, higher wages affected the labour intensive wine-growing sector disproportionately. Higher wages are indeed postulated for

[202] Moser, *Stand der Bauern*, pp. 14–15.
[203] Widmer, *Wachstumskrise 1880er Jahre*, p. 121.
[204] Moser, *Stand der Bauern*, pp. 14–15.
[205] Moser, *Stand der Bauern*, p. 20.
[206] Dino Renato Panosetti. *Die staatlichen Massnahmen zur Regelung und wirtschaftlichen Sicherung von Weinproduktion und Weinabsatz.* Varese 1948, pp. 32–33; Hans Hasler. *Der schweizerische Weinbau mit besonderer Berücksichtigung der zürcherischen Verhältnisse. Eine volkswirtschaftliche Studie.* Zürich: Academia, 1907.
[207] Panosetti, *Die staatlichen Massnahmen*, p. 33. The only agricultural sector with a larger share of wages in production cost was the vegetable cultivation.

the second half of the 19th century. In Zürich, according to Kohler, wages rose by 30 to 50 per cent in the 1860s alone.[208]

Production cost in viticulture (CHF/ha)			
Year	CHF	CHF-2008 (W)	CHF-2008 (P)
1850	1,040	120,400	19,773
1880	1,380	73,795	15,305
1906	1,630	61,424	19,532
Cost of wages in viticulture (CHF/ha)			
Year	CHF	CHF-2008 (W)	CHF-2008 (P)
1850	300	34,731	5,704
1880	600	32,085	6,654
1906	700	26,378	8,388

Table 11: Production cost and wages in viticulture (CHF/ha) – Values are indicated as nominal (CHF), adjusted to inflation with wage index [CHF-2008 (W)] and with price index [CHF-2008 (P)]. Source: Hasler 1907, pp. 123–124.

Hasler provides absolute levels of the wage development.[209] Table 11 shows these indications. The upper table presents the total production cost in viticulture expressed in Swiss Franks per hectare (CHF/ha) for years before (1850), at the onset (1880), and during the crisis (1906). The lower table depicts the wages alone. They make up a large part of the total production cost (up to 50 per cent). The rest of the production cost comprises: interests; fertiliser; combat of diseases, pests and weeds; maintenance; and the control cost for harvest and winery.[210] In both tables, the column of interest is the second which indicates the nominal figures as stated by Hasler. These numbers illustrate the increase in the cost of production. Indeed, between 1850 and 1880, wages doubled.

The two columns to the right show the same values adjusted for inflation in 2008 CHF.[211] While the nominal levels of the wages show a steady increase, it is interesting to see that this increase disappears if the values are inflation adjusted. Instead of an increase, the inflation adjusted values reveal a dramatic decrease of wages and therefore production costs – at least when the wage index is used for the adjustment (CHF-2008 (W)).[212]

[208] Kohler, *Weinbau Schweiz*, pp. 98–101.
[209] Hasler, *Schweizerischer Weinbau*, pp. 123–124.
[210] Panosetti, *Die staatlichen Massnahmen*, p. 38.
[211] See note 178.
[212] The usage of a wage index as basis for the inflation adjustment seems justifiable since wages account for half of the production cost. However, it would also be possible to use the price index. Therefore,

It is important to note that the results of this exercise do not contradict the interpretation that higher wages were the cause of the viticulture decline. The inflation-adjusted values suggest that wages for workers in vineyards declined between 1850 and 1880 by 8 per cent and in the 1850-1906 period by 25 per cent. However, what was important for wine-growers at the time was the benefit that they made. Profit was determined as the difference between production cost and return. It will be interesting to see how the prices developed – not only in absolute terms, but also as inflation-adjusted values.

Wage development alone does not allow a conclusion on whether workers were scarce or not in the wine-growing industry. However, the agricultural sector often suffered from lack of workers during the industrialisation, when workers abandoned rural areas in favour of cities and places where industrial jobs were available.[213] While industrialisation helped create a new market as people earned more money to buy wine, this development struck back as ever more people were attracted by the opportunities of work in factories.

Therefore, it can be stated that the nominal wages indeed increased in the course of the crisis in viticulture. The reason for this is likely to be the lack of workers. It should be noted though that in real terms, the increase disappears and gives way to a decrease of wages and production cost. This suggests that inflation ate up the increase in wages making the situation for vineyard workers generally more difficult.

6.2.3 Phylloxera and other diseases

The increased trade in the late 19th century brought not only goods but also diseases. The grape pest phylloxera and the disease downy mildew (dt. *Falscher Mehltau*) were the two biological problems affecting viticulture the most at the turn of the 19th century. Both phylloxera and mildew originate from North America and reached Europe from there. While both exerted considerably worse effects in the beginning of the 20th century, they were already felt in the last part of the 19th century. Phylloxera, an insect that particularly harms the roots of the (European) grape (*Vitis vinifera*), reached Europe through import of American grapevines. Phylloxera "can cause significant economic damage to the root system of [the grapevine], resulting eventually in yield decline or even death of the host."[214] American grapevines can be infected, but they are not harmed by phylloxera.

values adjusted using the price index are shown as well. They indicate an inflation-adjusted increase in production in 1880 by about one third compared to 1850, but an equal level in 1906.

[213] François Höpflinger. *Bevölkerungswandel in der Schweiz.* Grüsch: Verlag Rüegger, 1986.

[214] Kevin Powell. "Grape phylloxera: An Overview". In: *Root Feeders.* Ed. by Scott N. Johnson and Philip J. Murray. North Wyke: CAB International, 2008, pp. 96–114, pp. 96–97.

Phylloxera somewhat later infected the first Swiss vineyards than the neighbouring vineyards of France, where the first harmful outbreak took place in 1863. In 1874, phylloxera was first discovered in Switzerland in a Genevan vineyard.[215] Due to the dispersed Swiss viticulture landscape it took several years for the insect to spread. It was not until 1900 when most cantons reported some cases. However, losses in Switzerland did not reach the catastrophic proportion of the closed-space vineyards of France and Austria.

One reason for the relatively light damage of phylloxera was the early reaction of the federal state which took measures to prevent the spread. These measures were in line with the international convention to fight phylloxera adopted in 1878. In the first years of the outbreak, infected vineyards were usually "cleared" using 2,500 to 3,000 kg carbon disulphide per hectare to kill phylloxera – but also grapevines.[216] Wine-growers were compensated for their loss in grapevines. The amount dedicated to these compensations increased particularly in the first decade of the 20th century. In 1880, it amounted to "only" 9,125 CHF. Only fifteen years later (1895), it reached 131,043 CHF.[217] Furthermore, a fund was adopted to help wine-growers overcome losses (*Rebbaufonds*).

Neuchâtel and Vaud in the Western part of Switzerland had the largest share of grapevines cleared due to phylloxera infection. Between 1886 and 1922 a total of 434 hectares were cleared in the canton of Vaud. In Neuchâtel it was 239 hectares between 1877 and 1921. Zürich was most affected in the rest of Switzerland with 66 hectares cleared between 1886 and 1922.[218] In Neuchâtel, the toll was heavy: compared to the total acreage of vineyards in 1884, more than one third was cleared by 1921. However, in Vaud and Zurich, the share of cleared vineyards accounted to 4 per cent (Vaud) and 1 per cent (Zürich).[219] Devastating effects experienced Ticino where entire vineyards were abandoned due to phylloxera infection.[220]

Despite these rather modest indications on the consequences of phylloxera in the german-speaking part of Switzerland, the effect of phylloxera cannot be underestimated. The wine-growing industry was in a state of transformation at that time. A disease with the potential of severe damages caused great anxiety. It was not primarily the amount of cleared grapevine acreage that harmed Swiss viticulture, but the discouragement that

[215] Schlegel, *Weinbau in der Schweiz*, pp. 60–61.
[216] Schlegel, *Weinbau in der Schweiz*, p. 61.
[217] Panosetti, *Die staatlichen Massnahmen*, p. 38. By 2008 standards, these compensations amount to 101,202 CHF-2008 (for 1880) and 1,644,414 CHF-2008 (1895). The tool swistoval was used for the adjustment (price index), see note 178.
[218] Brugger, *Statistisches Handbuch*, pp. 152-169.
[219] Brugger, *Statistisches Handbuch*, pp. 152-169.
[220] Schlegel, *Weinbau in der Schweiz*, p. 70.

wine-growers felt and the logistic obstacles associated with some vineyards being cleared in the midst of others.[221]

The drastic practice of killing phylloxera and grapevines was later relaxed in some places of Switzerland. Prevention also became more eminent. Most importantly, wine-growers began to create and plant grapevines resistant to phylloxera using American grapevines. The state encouraged this with subsidies.

The devastating (fungicidal) disease downy mildew (*Peronospora*) struck Switzerland at the turn of the century and especially around 1910. Downy mildew had the potential to cause huge damage, but its onset was not as feared as the onset of phylloxera, mainly because there was a way to prevent infection. Spraying the grapevines turned out to be an effective, yet costly, solution to avoid downy mildew. Therefore, it took some time until the practice won over wine-growers.[222]

6.2.4 State intervention

In general, state intervention with regard to agriculture increased "slowly and gradually" in the 1880s which constituted a change of course in the still young, and free-trade loving federation.[223] A regulation on subsidies was put in place in 1884 (*Bundesbeschluss betreffend die Förderung der Landwirtschaft durch den Bund*). Before, subsidies were handed out sporadically without legal basis. The institutionalisation during the agrarian crisis was further manifested in the creation of a section on agriculture in the federal Economic Department. Encouragement of rational production is assumed to be the driving force behind the activities of the agricultural authorities.[224]

The question of protective measures during the crisis of the 1880s arose quickly. Wine-growers, together with grain farmers, endorsed the idea of protective duties on agricultural imports most markedly during the crisis.[225] The two subsectors suffered most from foreign competition. However, duties on grain were particularly controversial as they would affect a large part of the population including dairy farmers who relied on cheap foreign grain for their cattle. Duties on wine were more favoured by the public as they were seen as a tactical advance in tariff negotiations with foreign countries. Indeed, for decades low duties were maintained for economic reasons: Low duties on wine were

[221]Schlegel, *Weinbau in der Schweiz*, p. 62.
[222]Schlegel, *Weinbau in der Schweiz*, p. 60.
[223]Moser, *Stand der Bauern*, p. 20.
[224]Moser, *Stand der Bauern*, p. 23.
[225]Moser, *Stand der Bauern*, p. 34.

the price to pay to be able to export industrial commodities and excess dairy products.[226] Large wine producers such as France and Italy fought heavily for the Swiss wine market.

Consequently, no protective duties for wine were integrated in the tariff of 1884. However, the tariff of 1887 brought minor duties. For wine, this meant that the existing duty of 3 CHF for a 100 kg barrel increased to 3.50 CHF. This amount remained unchanged in the next tariff in 1890.[227] By this, it can be seen that the main goal of the tariff was to protect industry and trade and not agriculture.[228] However, opposition to protective measures increasingly vanished when neighbouring countries resorted to the same means in the 1890s. Also, the initial opposition in the bourgeoisie diminished as well by the turn of the century. Social democrats and consumer organisations remained the sole opposition, which caused frictions with the farmer's organisation.[229]

A substantial increase in the tariff on wine to 8 CHF per 100 kg barrel was only introduced in 1906.[230] The reason for this shift in the tariff policy is primarily attributable to a re-evaluation of priorities. While the coalition of the export industry and wine importers had managed to maintain low tariffs, the domestic wine-growing industry suffered more and more from this situation. Therefore, the situation was deemed "unhealthy for the national economy."[231] Furthermore, other European states extensively resorted to protective duties during the crisis. Finally, two main reasons led to the decision to introduce protective duties on wine and therefore to state intervention in favour of the wine-growing industry: Firstly, the interest in fiscal revenue from tariffs. Secondly, it turned out that the neighbouring states were unwilling to accept concessions in exchange for the low tariffs on wine. Thus, the greatest argument against protective duties became futile.[232] It should be noted that this increase in the tariff happened reasonably late, it was some 25 years after the crisis began.

Protective duties at a late stage of the crisis were one way of state intervention. A further measures that the state assumed was the aid to combat phylloxera which was outlined in the previous section.

[226]Schlegel, *Weinbau in der Schweiz*, p. 69.
[227]Moser, *Stand der Bauern*, p. 35; Panosetti, *Die staatlichen Massnahmen*, pp. 108–109.
[228]Widmer, *Wachstumskrise 1880er Jahre*, pp. 104–106.
[229]Moser, *Stand der Bauern*, pp. 49–52.
[230]Panosetti, *Die staatlichen Massnahmen*, p. 109; Brugger, *Landwirtschaft 1850-1914*, p. 157.
[231]Panosetti, *Die staatlichen Massnahmen*, p. 108.
[232]Panosetti, *Die staatlichen Massnahmen*, p. 108.

6.3 Second- and higher-order impacts

The developments characterising the expansion and contraction of Swiss viticulture in the second half of the 19th century are interrelated in a complicated way. While the main events and issues have been outlined in the previous section some more details are provided in this section, which aims at discussing the second-order impacts according to the model guiding this research (see section 1.1). A vast body of variables have been mentioned so far. Therefore, this last part aims at entangling these different issues in order to grasp the logic of their relation. Furthermore, the influence of climate will be evaluated.

6.3.1 Price

Besides harvest size, price is the other component determining the financial outcome for a winery in a given year. In years with large harvests, prices tend to fall because there is plenty of supply to satisfy the demand for wine. However, in bad years, price increases cannot compensate for loss of quantity. This is due to the possibility of consumers to resort to other drinks – while wine is popular, it cannot be considered a basic nutritional good. For instance, in the later 16th century, consumers reacted to the high prices due to harvest failure by drinking beer instead of wine.[233]

Price fluctuations are well documented. Several time-series exist to examine how prices evolved in the 19th century. A time-series on Swiss wine prices from the federal bureau of statistics (BFS) is used for the investigation here as it covers the whole of Switzerland and thus the largest possible area.[234] The data begins in 1800 and continues for the entire 19th century. It shows wholesale prices. Two issues are of particular interest. Firstly, the short- to mid-term reaction of prices to the fluctuations in harvest quantity. Secondly, the long-term development of prices in light of the transformation in viticulture in the late 19th century. Falling prices (due to import of cheaper foreign wine) are considered to be among the factors which contributed to the sharp decline of the Swiss wine-growing sector at the turn of the 19th century. This will also be addressed below in the section on imports.

Figure 14 displays the price development along with the grape yield measured as yield per unit area (hl/ha). The price time-series was adjusted for inflation.[235] Adjusted values allow a comparison of the prices over time. Furthermore, this approach corre-

[233]Landsteiner, "Crisis of wine production", p. 328.

[234]Bundesamt für Statistik BFS. *Produzentenpreisindizes und Produzentenpreise pflanzlicher Erzeugnisse 1784-1983 (T 7.3.4.1)*. url: http://www.bfs.admin.ch (12.3.2009).

[235]See note 178. The price index was used for the adjustment.

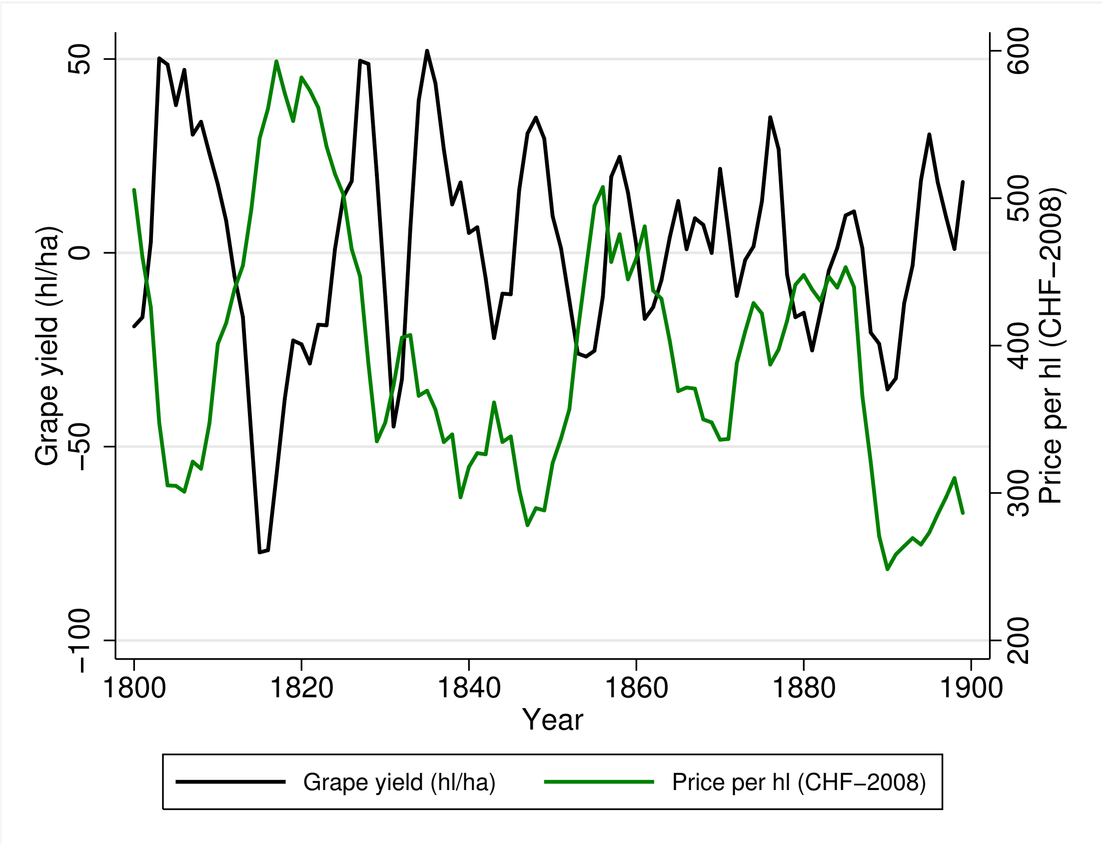

Figure 14: Comparison of price level and grape yield (1800-1899)

sponds to the detrending of the grape yield data which was used for the temperature reconstruction. Thus, two "detrended" indicators are shown in Figure 14. It is justified to use the grape yield per hectare indicator as it is of interest how prices reacted to up- and downturns in harvests. Furthermore, the value added indicator cannot be used as it includes price information already.

Two unsurprising detection may be drawn from Figure 14. Firstly, prices show a strong negative relationship to grape yield. The above considerations explained this: sizeable harvests cause an oversupply on the market and thus prices fall. A further detection is the lag in the reaction of prices to the harvest outcome. In the great majority of cases, the outcome of the harvest is only felt in the next year. Also, this is justified by the cycle of the wine economy: wine grown in autumn will only be on sale during the following year.

Comparison of the two time-series supports these two characteristics. The correlation coefficient between wine price and grape yield of the preceding autumn amounts to -0.50 for the whole 19th century.[236] Prices react to grape harvest levels conversely and with a one year delay. However, this relationship is clearer in the first part of the 19th century.

Since grape yields react sensitively to temperature levels a further conclusion states that prices are therefore also considerably influenced by climate characteristics. However, this chain of causation is far from perfect. Therefore, the relationship proves to be very weak by statistical terms, i.e. not significant. A range of other factors contribute to the price building which is a well established fact.[237] It should also be noted that due to the biannual climate-wine relationship, prices may actually be affected by up to three prior years. Therefore, the climate historian stresses that prospering and striving of wine-growers relies to a considerable extent on climate conditions. Little is known about how exactly climate influenced viticulture in the first half of the 19th century as studies on this topic are rare. What is well researched is the crisis during the devastating 1816 with near-zero harvests.[238] Prices soared which is also visible in the graph in Figure 14. Furthermore, the fall of the Swiss viticulture sector during a period of cold summers (1880s) further illustrates the relevance of climate.

The long-term development of prices should also be considered after this discussion of short-term reactions. It was evident that these short-term effects mainly apply to the early decades of the 19th century. In the later part of the century these short-term

[236] The correlation coefficient is significant with $p < 0.025$.
[237] Pfister and Brazdil, "Social vulnerability".
[238] Pfister, "Fluktuationen der Weinmosterträge", p. 457.

effects weaken. Statistically, this can be exemplified by a decreasing correlation between price and grape yield after 1850. For the 1801 to 1850 period, the correlation coefficient between wine prices and wine harvests actually reached $r = -0.70$, while it amounted to -0.50 for the whole 19th century. Therefore, the second half from 1851 on is responsible for the lower correlation.

Indeed, the negative relationship between the two indicators is maintained with almost no exception up to roughly 1850. Shortly after, however, a period can be detected with prices almost as high as during the 1810s when the 1816 harvest failed almost completely. The harvest situation in the 1850s shows quite the opposite picture to the 1810s with yields being very favourable. Literature stresses that increasing demand contributed to the boom phase in viticulture, with respect to the 1850s.[239] As industrialisation created plenty of jobs more people were able to buy wine. This meant that good harvest could be sold for good prices. This is assumed to be the reason for this short period of high prices despite relatively high yields. However, only few years later (1870s) a price drop occurs. It is interesting to note that the (minor) ups and down are not reproduced by price development.

In the middle of the 1880s prices for wine fall dramatically. The interaction of various factors can be blamed for this. First of all, it is the time when phylloxera (see section 6.2.3) reached Switzerland and caused – besides substantial grape acreage loss in Neuchâtel – great uncertainty among wine-growers. Increasing imports are supposed to be the second reason for this drop. With new railway tunnels allowing transportation of cheap wine into Switzerland prices came under pressure. Furthermore, the general crisis in Swiss economy contributed as well to the price decline. Estimates indicate that there was a substantial oversupply of wine in the 1880s, which caused prices to fall further.[240] Finally in 1887, the federal government prohibited the *Ohmgeld*, a tax on consumption of wine and spirits. By that time only some cantons still applied this tax. But the omission of this tax let prices fall further. However, this drop did not affect producers directly.

6.3.2 Consumption

After evaluating the price of wine the next step is to discuss wine consumption. Indications of consumption are closely related to price. However, direct indications of consumption for longer periods in the 19th century do not exist in literature. One way to examine consumption levels is resorting to taxes levied on alcoholic beverages. The *Ohmgeld* was such tax. It existed in several cantons up to 1887 when the federal state

[239] Schlegel, *Weinbau in der Schweiz*, p. 46.
[240] Brugger, *Landwirtschaft 1850-1914*, p. 157.

prohibited it. Tellingly, among the states that had such taxes at one time, most did not have a large number of vineyards in their territory. These states were: Bern, Luzern, Uri, Obwalden, Nidwalden, Glarus, Zug, Freiburg, Solothurn, Basel-Land, Graubünden, Aargau und Genf.[241]

The *Ohmgeld* is a tax on wine and spirits. It was applied to wine that was offered in public spaces such as taverns. In the 19th century it covered imported and publicly offered wine and spirits but was exempt on wine for private use.[242] It has its roots as a import duty which turned into a consumption tax. In the canton of Bern, certain locations had the *Ohmgeld* in place already in the second half of the 14th century – over the time, various goods were subject to the tax. From 1803 on, it came into cantonal authority.[243] In Bern it amounted to 5 Rappen per "Mass" from 1815 on.[244] In a time with no direct taxes (canton Bern: up to the 18th century), the *Ohmgeld* contributed a large share to the state finances. Around 1804, according to Rennefahrt, the *Ohmgeld* made up for the whole expenses of the state together with stamp taxes.[245] In addition to wine, spirits made up a large part of the *Ohmgeld* as well.

Consumption time-series could not be found in the literature. *Ohmgeld* time-series seem to be also missing. However, documents related to taxes generally found their way into archives. Therefore, the *Ohmgeld* accounts for the canton of Bern – as an example – were consulted and the amounts compiled to a time-series which covers the 1815 to 1887 period.[246] In this way, it is hoped to reconstruct the consumption level in the 19th century.

Over the years several people were responsible for accounts. Their approaches to keeping the accounts vary in terms of what details they outlined or not. As far as possible, the indications were made consistent. This was not always possible. Despite *Ohmgeld* indications for earlier periods, the time-series only shows reliable results for 1815 onwards. In the last decade of the record – just before the *Ohmgeld* abolition – it is not certain whether the basis for the *Ohmgeld* collection changed substantially. Therefore, values later than 1875 must be assessed carefully.

[241]Brugger, *Landwirtschaft 1850-1914*, pp. 156–158.

[242]Rennefahrt, *Bernische Rechtsgeschichte*, pp. 137–139.

[243]Anne-Marie Dubler. "Ungeld". In: *Historical Dictionary of Switzerland (HDS)* (1996–2009). url: http://www.hls-dhs-dss.ch/textes/d/D26199.php (15.6.2009).

[244]Rennefahrt, *Bernische Rechtsgeschichte*, pp. 20–21. The amount was only tentatively increased by the middle of the century. There were separate taxes for wine imported in barrels or bottles.

[245]Rennefahrt, *Bernische Rechtsgeschichte*, p. 148.

[246]*Rechnungen der Zoll- und Ohmgeld-Verwaltung 1803–1887*. Staatsarchiv Bern, Signatur B VIII 702-777.

Finally, the time-series indicated the total value of the *Ohmgeld* contributions to the canton of Bern. This value is not suitable for tests because the total tends to increase with growing population. Therefore, the total value for each year was divided by the number of inhabitants, which results in a per capita (p.c.) indication of the consumption. Various censuses were carried out during the 19th century in the canton of Bern. The results of these censuses could be found in the BERNHIST database.[247] The gaps between the surveys were interpolated assuming a linear trend between each census.

It should be noted that the *Ohmgeld* values per capita are only approximate indications of wine consumption. Several uncertainties arise. Sometimes it was not clear whether expenses for the collection of the tax was already subtracted from the amount indicated to the cantonal authority. Furthermore, files indicate that certain vineyards did not have to pay *Ohmgeld* on their grapevines. The documents in the archive do not exactly state how many such *Ohmgeld*-free estates existed and how this number changed over time. It is believed that this was not a large number. However, even though the amount of *Ohmgeld* on wine changed several times, there was no doubt about it since it was always stated. Furthermore, the distinction between the *Ohmgeld* paid on wine and on spirits was made sufficiently clear. These two potential sources for errors are therefore obsolete.

In order to assess the reliability of this reconstruction of the consumer level it is possible to resort to an indication from literature. Hasler indicates some figures on the consumption in the course of the 19th century. By citing the following figures, Hasler exemplifies the increase in consumption. In the 1840s, consumption per capita amounted to 47.3 litre; in the 1870s it reached 58 litre; and in the 1890s consumption amounted to 70 litre.[248] The Bern series shows 32 litres p.c. in the 1840s (with three years missing) and 44 litres p.c. in the 1870s; no indication is possible for the 1890s since the *Ohmgeld* was abolished. Therefore, the series from Bern returns considerably lower values.[249] Currently, the wine consumption in Switzerland amounts to 38.6 litres p.c. in 2008.[250] It would be realistic, if consumption levels were higher in the 19th century than nowadays. A further possibility to explain the difference is that the *Ohmgeld* covered not all wine,

[247] Christian Pfister. *BERNHIST, Historisch-Statistische Datenbank des Kantons Bern.* Internet-based database. url: www.bernhist.ch (15.6.2009). 1994–2006.

[248] Ernst Lauer, Enquête zur Vorbereitung der künftigen Handelsverträge, cited in Hasler, *Schweizerischer Weinbau*, p. 107.

[249] It is possible that Lauer (whom Hasler cites) only considered adults in his calculation of the per capita consumption. In this study the entire population is included. This could explain the difference. However, this is only an assumption.

[250] Eidgenössische Alkoholverwaltung EAV. *Alkohol in Zahlen 2009.* url: http://www.eav.admin.ch/aktuell/neues/index.html?lang=de (28.7.2009), p. 22.

e.g. no *Ohmgeld* was due on privately used wine. In any case, the level of the consumption series reconstructed from the Bernese *Ohmgeld* is likely to underestimate the actual level. However, it is assumed that the fluctuations are depicted with a high degree of certainty.

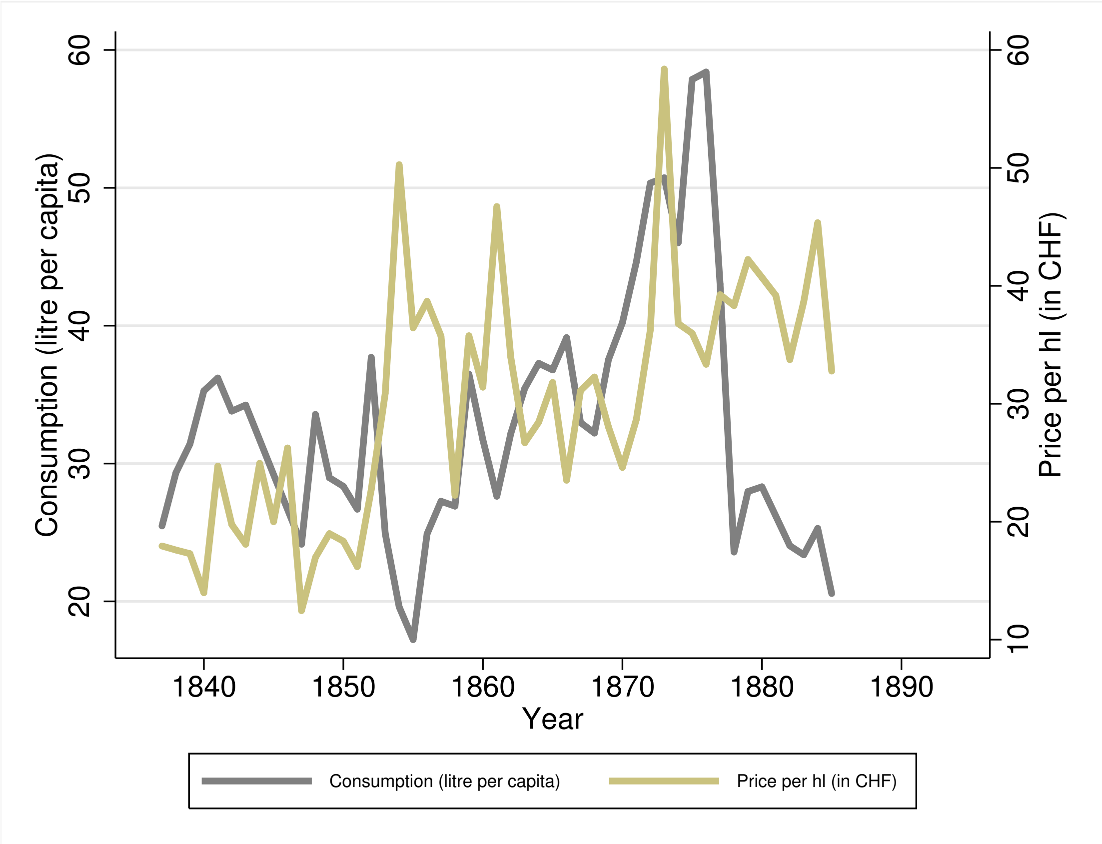

Figure 15: Level of consumption (1837-1885)

In Figure 15, the consumption level is shown along with the price of wine. Similar to the grape yield/price illustration, the relationship between the two has a negative relationship. High prices correspond to lower consumption and vice versa. The graph demonstrates this at times quite clearly. This relationship may also be described in terms of the relationship to the harvest size per unit area. The better the yield (of the preceding year), the greater the consumption of wine. In this case the relationship is positive. Both relationships prove significant – and almost of the same magnitude – in a statistical test.[251]

[251] The correlation between price and consumption amounts to $r = -0.41$ for the 1822 to 1886 period. For consumption and grape yield (hl/ha) it is $r = 0.45$.

A further characteristic of the graph in Figure 15 is the increase in the level of consumption from the (very weak) value at the middle of the century to 1875. This supports the thesis that during this time sustained high demand for wine fuelled the expansion of viticulture in Switzerland. The dramatic decline after 1875 may be spurious, as was explained above.

Regarding its relationship to temperature, consumption levels do not show dramatic reactions in every case. The 1816 failure is clearly depicted in the consumption series (despite some doubts about reliability). Consumption levels in the following year fell to 6 litres per capita. A similar, yet not as dramatic situation occurs following the bad yield in 1854. The high prices, which are due to an exceptionally cold year, cause the consumption level to drop to the lowest value since the 1810s. Consumption amounted to below 20 litres per person. Such sharp reactions do not occur anymore in the second half of the century. Consumption generally stays at a high level.

This situation is reflected in the cultural and political sphere. A marked debate about alcoholism characterised the 1870s and 1880s. Most importantly, sprits consumption was criticised, but wine was also deemed to be part of the problem.[252] This discussion culminated in the adoption of a constitutional article establishing the alcohol monopoly for the federation. Instead of the *Ohmgeld*, a federal tax was raised on spirits. The cantons shared the revenue.

Examination of the *Ohmgeld* also highlights the fiscal importance of wine production. As previously outlined, the *Ohmgeld* contributed heavily to state finances. From the 1860s onwards the yearly contribution to the cash box of the canton of Bern amounted to at least 1 million CHF. The maximum of 1876 reached 1.88 million CHF. On average 1.2 million CHF was paid to the canton from *Ohmgeld*. Given the large spread of the contributions and the uncertainty about the yield size, financial planners of the canton did not have an easy job.

At the federal level debates prior to the vote on the alcohol article (1885) often dealt with the tax issue of consumption taxes on alcohol.[253] Wine-growers associated the new article with the abolition of the *Ohmgeld* which promised increasing wine sales. With this in mind, wine-growers particularly in the Western part of Switzerland favoured the act.[254] Consumption figures for the last decade of the century confirm this logic. According to Widmer, the consumption of wine increased from 70 litres per capita in 1880/84 to 88.8 litres in the 1890s.[255]

[252] Widmer, *Wachstumskrise 1880er Jahre*, p. 524.
[253] Widmer, *Wachstumskrise 1880er Jahre*, p. 533.
[254] Widmer, *Wachstumskrise 1880er Jahre*, p. 535.
[255] Widmer, *Wachstumskrise 1880er Jahre*, p. 541.

6.3.3 Import

The increasing imports due to the emergence of global trade to the end of the 19th century was one of the main external factors that contributed to the decline of viticulture in Switzerland. The main reason for the detrimental effect will be outlined here.

Two crucial moments in railway history are often cited as particularly influential to the wine economy. On the one hand, it was the opening of the Gotthard tunnel in 1882. The tunnel established a fast connection to Italy. On the other hand, the construction of the Arlberg tunnel in 1884 facilitated imports from Tyrol. Consequently, imports of wine from these two locations increased tenfold between 1851 and 1905, according to Schlegel.[256] Together with the domestic production this led to an oversupply of wine in the 1880s and thus lower prices.

While the opening of these two tunnels led to a decline of viticulture in the "centres" of the sector, some peripheral regions already faced foreign competition. Graubünden and the St. Gallen Rheinthal in the Southeast of Switzerland experienced a decline starting after 1865 when the Bernina pass got an improved street. Prior to that, in 1858, the opening of the train line form Lyon (F) to Geneva led to an increased competition with wines from France. Generally, the influence of the imported wine affected the german-speaking part of Switzerland first. In the Western parts (and also Schaffhausen), the onset of the "real" crisis only occurred at the turn of the 19th century.[257]

Switzerland was an important market for wine exporting countries. This was exemplified in the discussion on duties (see section 6.2.4). The largest share of imported wine between 1885 and 1890 came from the neighbouring countries. Italy and France accounted for almost two thirds of the imports to Switzerland. A substantial amount also came from Greece. In the 1890s, the share of Spanish and Portuguese wine increased dramatically from 7 to 39 per cent compared to the 1885-1890 period, at the expense of French and Greek wine.[258]

Overall, the combined contribution of the various factors – and especially the role of imports – reveals an astonishingly clearcut picture of the interdependence that led to the decline of viticulture in Switzerland. Figure 16 shows those parts of this interdependence that can be displayed graphically. The three graphs represent the value added (adjusted for inflation, black), the price of wine (adj. for inflation, green), and the quantity of imported wine (in 1000 barrels, blue).

[256] Schlegel, *Weinbau in der Schweiz*, p. 65.
[257] Schlegel, *Weinbau in der Schweiz*, p. 70.
[258] Panosetti, *Die staatlichen Massnahmen*, p. 88.

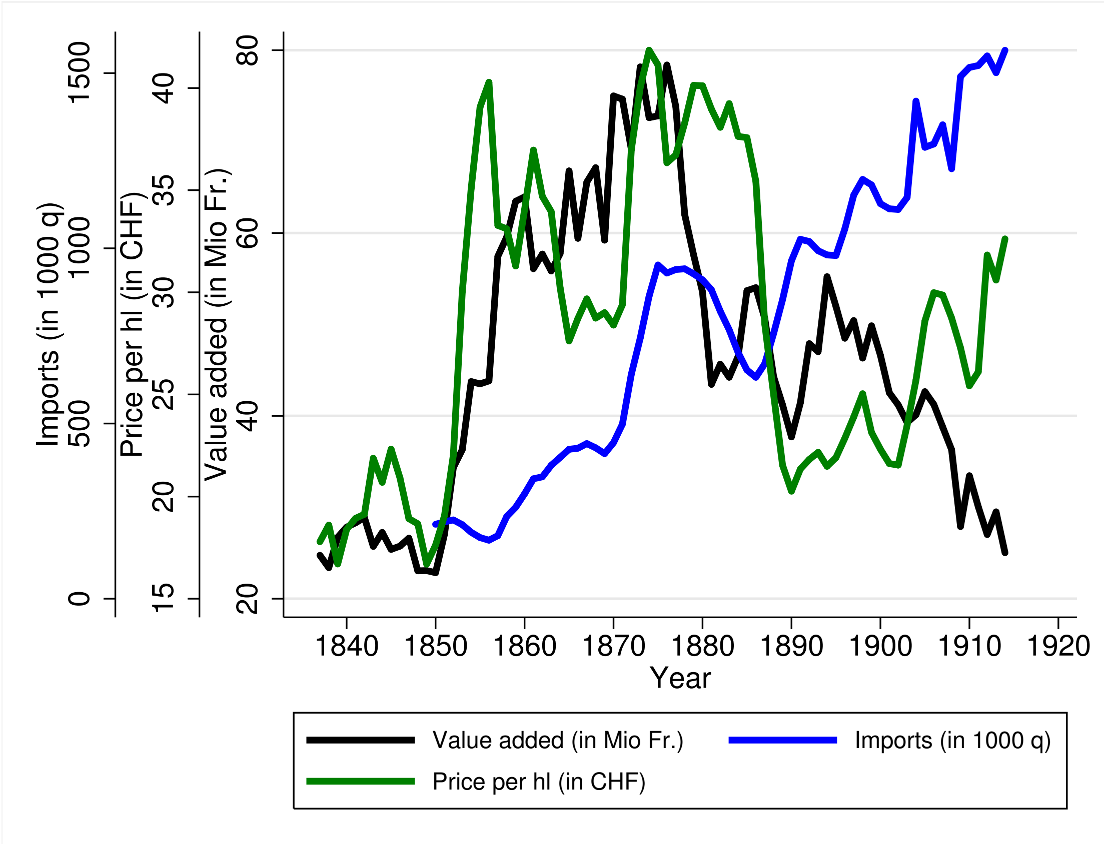

Figure 16: Import, Price, and Production level (1837–1914) – The values shown are 5-year moving averages.

The figures on the imports were taken from the *Historical Statistics*.[259] As to the imports, which were not discussed in quantitative terms so far, it can be seen from this graph that there is a steady increase starting from 1860 to the end of the century (and further). The rise breaks only once in the middle of the 1870s for about 13 years. The reason for this is the phylloxera infections of vineyards in export countries such as France or Italy. The amount of imported wine increased from a negligible quantity in 1850 to 1.5 million barrels in 1914.

The import quantities play a crucial role in the development of Swiss viticulture. The curve of the imports crosses both the line for value added and price in 1888 when both these indicators were in a sharp fall. For imports, this marks the period in which imports equalled inland production for the first time.[260] This events signifies that domestic wine was increasingly replaced by imported wine. This development went synchronous with a decline of the price. On the one hand, the fall of the prices is directly caused by the increasing imports. Foreign wines were cheaper because production costs in countries such as France were lower. On the other hand, the decline in prices also contributed to a further decline in viticulture. With such low prices wine-makers were unable to do business for profits. In fact, Swiss wine-makers found themselves in a spiral to the bottom.

From the 1890s onwards, price does not react directly to value added anymore but to the level of the imports. However, the lag amounts to two to three years instead of the one year lag from earlier in the 19th century. The reason for the increasing prices can be found in the "correction" of the expansion that took place from the 1850s onwards. After the onset of the crisis, when the structure of viticulture was already partly adjusted, prices started to increase again slowly.

6.3.4 Migration

Migration as a further higher-order impact marks a trip into uncharted waters. It seems no research was conducted specifically on this presumed relationship. Therefore, this section assumes an exploratory position. An excellent study on overseas migration from Switzerland in the 19th century allows testing the relationship.[261] The following question guides the discussion in this section. Did the decline in viticulture in the 1880s lead to higher outward migration from districts with receding viticulture?

[259] Ritzmann-Blickenstorfer, *Historical statistics*, p. 660.
[260] Brugger, *Landwirtschaft 1850-1914*, pp. 156–157.
[261] Heiner Ritzmann-Blickenstorfer. *Alternative Neue Welt. Die Ursachen der schweizerischen Überseewanderung im 19. und frühen 20. Jahrhundert.* Zürich: Chronos, 1997.

Generally, the wage level (of the preceding year) was one of the most important factors influencing overseas emigration.[262] Climatic accidents such as the 1816 (and 1817) cold spell with devastating harvests made people leave Switzerland in great numbers. Ritzmann estimates that 10,000 travelled to North America in these two years.[263] However, in general, grain and potato harvest were decisive for migration waves but not the fluctuation of the grape harvest. This is exemplified that Ritzmann attributes wine production a lower weight than grain and potato cultivation. It seems the grape size did not influence emigration strongly.[264] The more interesting factor to examine is whether the contraction of the wine-growing sector from the 1880s was felt in emigration numbers.

The most important area for emigration in the early 1880s, the Bernese Oberland, did not have much wine-growing area.[265] However, large numbers of people emigrated from Schaffhausen and the Bernese Seeland where wine was grown. The Schaffhausen region Klettgau figures in the group of districts with the second strongest emigration rate in the 1885-1893 period. In every year, between 0.7 and 0.8 per cent of the inhabitants left their home for a new life overseas.[266]

Emigration from Klettgau in the 1885-1893 period was not primarily the consequence of the contraction of viticulture. However, an earlier example from that region provides an interesting case of how viticulture could contribute to emigration.[267] The main problem of viticulture in Klettgau was its dependence on exports to neighbouring Germany. Therefore, when wine from Klettgau was burdened with heavy duties by the German *Zollverein* from 1838 onwards, this was immediately felt in the region. Ritzmann names this as one of the causes for the significant overseas emigration away from Klettgau. This situation – in conjunction with other developments - led to a re-agrarisation of Schaffhausen. However, in the time of the viticulture crisis the Klettgau suffered from structural problems rather than from a further decline in viticulture.

The decline of viticulture in the canton of Zürich from the 1880s on did not cause a great deal of emigration. It is assumed that the industry absorbed workers in large numbers and thus contributed to the decline. Therefore, the wine-growing districts showed a

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[262] Ritzmann-Blickenstorfer, *Alternative Neue Welt*, pp. 54–55.

[263] Ritzmann-Blickenstorfer, *Alternative Neue Welt*, p. 66.

[264] It should be noted that the exact effect of grape harvest levels on migration is hard to estimate from the available data. Usually, grape harvests showed the same tendency as grain and potato harvests. Yet, due to the greater importance of grain and potato more workers were employed in these sectors than in viticulture. Emigration after harvest failures are mostly attributed to the more important sectors.

[265] Ritzmann-Blickenstorfer, *Alternative Neue Welt*, p. 194.

[266] Ritzmann-Blickenstorfer, *Alternative Neue Welt*, p. 197.

[267] Ritzmann-Blickenstorfer, *Alternative Neue Welt*, pp. 222–227.

rather low share of emigration.[268] Furthermore, the largest contraction in viticulture in Zürich only took place in the beginning of the 20th century. Therefore, evaluation of the 1880s situation is too early to conclude on the effects of wine-growing developments on migration.

Particularly low was also the emigration from the Western part of Switzerland. There is no big difference between the wine-growing districts and other districts in the cantons of Vaud and Neuchâtel, for instance.[269] This is consistent with the concentration of viticulture in the Western part of Switzerland. Instead of a decrease of demand, this situation would create jobs.

There is some evidence that an assumed migration away from wine-growing districts due to the decline of the sector may not be tenable. Factories absorbed more and more people during industrialisation. As a consequence the labour-intensive wine-growing sector suffered a lack of workforce. Therefore, it could be assumed that this lack of workers led to the decline as opposed to the contrary, that people left wine-growing districts because of the decline. In other words people would have left even without a crisis in viticulture. However, this hypothesis would require more research for verification.

In summary, agricultural up- and downturns did indeed contribute to migration in the 19th century. However, evidence suggests that grain and potato harvests, which accounted for a much larger share of agriculture than viticulture were the decisive factors. Nevertheless, the example of the Klettgau district in Schaffhausen showed that a dramatic decline in viticulture may result in emigration. Unfortunately, the data availability does not allow concluding on the year-to-year effects of harvest sizes on migration. Therefore, the intuitive assumption that harvest failures might have led to population movement cannot be tested.

6.4 Summary

Factors related to the decline of viticulture in Switzerland were discussed individually in this section. However, it became clear that these factors are strongly interrelated. The aim of this closing section is to sum up these interrelationships with regard to the impact model that guides this research.

The largest part of the 19th century was characterised by an above average harvest situation (roughly 1825 to 1880). Favourable weather conditions contributed to this "boom" phase. Normally, periods with large harvests lead to modest prices because of an oversupply. However, this was not the case in the 1850s. As the emerging industrialisation

[268] Ritzmann-Blickenstorfer, *Alternative Neue Welt*, p. 631.
[269] Ritzmann-Blickenstorfer, *Alternative Neue Welt*, pp. 636–637.

created new jobs, demand for wine increased and thus prices soared. This opportunity attracted buyers for vineyards as they promised even higher profits than normal.

With that a turning point was reached. Industrialisation had another impact on viticulture, it absorbed ever more people. Consequently, the labour-intensive wine-growing sector experienced more and more troubles recruiting workers at reasonable prices. Wages doubled within 30 years by nominal values. Furthermore, the opening of new railway lines (Gotthard tunnel) in the beginning of the 1880s facilitated imports of cheap foreign wine. As a result prices began to drop. At the same time, phylloxera hit and the low prices did not allow to make enough profit to meet interests on the high investments made during the boom phase. At least three consecutive years of low summer temperature, which caused modest yields, completed the crisis of the 1880s. The federal state reacted late with protective duties on wine (1906) – too late to change the course for viticulture. The result was a demise of Swiss wine-growing industry to roughly one third of its spread in just 50 years.

The model outlined in the beginning of this study suggests a relationship between climate, biophysical, economic, and other additional factors. This relevance of this concept became obvious as these relationships could be detected. It was possible to explain general phenomena such as the yield-price relationship, but the model could also help to conceptualise the interplay of various contributing factors in a probably unique crisis.

Interaction effects could also be found with the feedback of society to the favourable (climatic and non-climatic) conditions for viticulture. Indirectly, the behaviour in this phase led to the later contraction on as conditions were no longer favourable. The role of climate can generally be seen as a “background” variable in such processes.

7 Synthesis

Viticulture in the Swiss *Mittelland* went through a time of transformation in the 19th century. Climatic ups and downs, increasing competition from foreign products due to new systems of communications and a changing domestic economy were the most important changes that the sector had to adapt to in the later part of the century. These changes led to a crisis in the 1880s and a dramatic decline of viticulture. This study examined the viticulture in this time from two different perspectives. The relationship between viticulture and climate is the primary focus of this study.

There is a great potential for data on wine production to reconstruct climate for past times. This data can be used to improve understanding of past climate. Better understanding of climate changes and knowledge about strategies to adapt to climate changes is beneficial to our society, as climate is bound to change in the future. Viticulture can provide insight to such queries not just because of its strong relationship with climate, but also because the viticulture industry has been in the past, and continues to be, well documented. There was abundant data available to estimate the harvest sizes for the 19th century. For times as early as the 16th century, time-series on wine production could also be found in literature.

Results from this study show summer temperatures most influence the outcome of the grape harvest. The mid-summer months June and July were best represented in the wine production data. However, it became obvious that not only the weather conditions for the harvest year need to be considered, but equal consideration also needs to be given to weather conditions from the previous year. Previous summer temperatures are still highly correlated with the harvest outcome since these conditions set the basis for the harvest outcome. This emulates previous studies on viticulture in Switzerland. These findings suggest that the June and July temperatures of two years are best suited for reconstruction as their signal is stored in wine production data.

Temperature reconstruction faces a considerable obstacle in the middle of the 19th century. From the 1820s on, the correlation between summer temperatures and the grape harvest size decreases to a significantly lower level. The period is marked by sustained large outputs in viticulture. Several years returned harvests greater than 90 hl/ha, which was only regularly surpassed again in the second half of the 20th century. Owing to the bidirectional view on the wine-climate relationship, reasons for this were sought both in the climate and in the wine production conditions.

Climate conditions do not correspond to these great yields. In fact, average temperatures in the 19th century are well known for being considerably lower than the long-term average. It is possible that the relatively low variability of summer temperatures from the 1850s to the 1880s – despite below average temperatures – contributed to the prosperous situation in viticulture. At the same time, low variability in temperature causes calibration and verification to perform rather poorly. Furthermore, as the whole agricultural sector was in motion this also applied to viticulture. Technological improvements are known for the major wine-growing regions, particularly Vaud and Neuchâtel. These developments in the 1820s coincide with the beginning of the phase with large output.

Therefore, the explanation for weak correlation between wine and temperature remains somewhat inconclusive. Finally, despite independent data showing the same decrease, problems with data reliability cannot completely be ruled out. Whatever the reason for this situation is, the consequence for the reconstruction was that calibration and verification need be placed preferably before the 1850s. The decreasing skill of the climate-wine relationship in production size contrasts the situation for grape phenology. Both in the past and in the present changes in the onset of the grape growth stages are rather contributed to climate change than to the technological progress in viticulture.

A further problem with temperature reconstruction with wine production data constitutes the spurious effect of very hot summers. For calibration of the wine production data to temperature, it is assumed the warmer the summer the larger the harvest. Such a linear relationship does not entirely represent reality of viticulture. The best harvests were found in years with summer temperatures close to the average. Other aspects, such as timely rain or two consecutive stable and warm summers, make for great harvests. Such years should be eliminated for calibration and in reconstruction exceptional harvests must be double checked with further sources.

Despite all caveats, the result of the reconstruction from 1529 to 1966 was remarkably skilful. The wine production data was calibrated to temperature in the period from 1780 to 1819. In verification from 1820 to 1859 the reconstructed temperature corresponded well to the measured temperature with $r = 0.70$ and $RE = 0.45$. This transfer function for June and July temperature for the harvest year and the year preceding it was applied to wine production data back to 1529. The temperature that was thus reconstructed applies to the Northwestern Alpine region, including most of Switzerland.

It was hoped to use wine production data of the entire 19th century to successfully conduct a calibration-verification procedure and apply the results to grape harvest data back to 1529. This proved unrealistic. Even a large number of local time-series did not show a continued strong relationship between summer temperature and harvest size. This allows an important conclusion for future temperature reconstructions with wine harvest volumes. The period between the 1850s and the 1880s (and to a lesser degree the 30 years before) is “toxic” and is therefore of limited use for calibration and verification.

Nevertheless, it is possible this was not the last word on this relationship. Future research might resort to higher-resolution time-series and then find a continued relationship. Furthermore, the shift to quality wine meant that different grape varieties were used. This study did not consider this shift due to lack of suitable data. If considered, it may be possible to draw new conclusions.

The decline of Swiss viticulture in the 1880s is often viewed as an adjustment of the great expansion of the sector in the 30 years before. Demand for wine was high from the 1850s onwards because a large number of people found work in the emerging industrial sector and could therefore buy more wine. As a result, areas of viticulture spread greater than ever. In fact, the increase in the total area began in the first decades of the 19th century when the ground rent and tithes were abandoned. In the first half of the century, changes in the area were often due to regional factors. For example, the Schaffhausen wine-growing area relied heavily on exports to neighbouring german *Länder* such Baden. Therefore, when the duty regime tightened, viticulture receded.

Climate exerted a considerable effect on viticulture, but mainly in the short term. For example the 1816 “year without a summer” led to a devastating yield. In this time, maintaining resilience among small-scale wine growers was problematic as they relied on the sale of their grapes for food. Higher prices for grapes due to bad harvests did not compensate for the loss in quantity. The production time-series compiled for this study also shows that harvests were very sizeable in the 1820 to 1880s. As previously mentioned, the role of climate is assumed to be only minor.

The Climate Impact Model that guided this research helped to evaluate the evolution of viticulture in the second half of the 19th century. Resorting to such a conceptual framework proved useful. Only looking at climatic fluctuations would be misleading. Structural changes contributed extensively to the decline to about one third of the grape area in 50 years. The model served to disentangle these various structural factors. Therefore, the Climate Impact Model was used for more than just assessing climate impact. In fact, it did not matter that non-climatic factors played at least an equally important role as climate.

However, it is striking that a series of cold summers stood at the onset of the crisis in the 1880s. This phase of below average summer temperature continued for the whole decade. This situation must be seen as a “background” variable to the other developments. Climate might be viewed as a starting point for the evaluation, as the impact model suggests. However, to evaluate the course and also the extent of the crisis it is necessary to resort to other aspects.

The various higher-order impacts relating to wine-growing and its development could not be disentangled easily. This did not come by surprise. Prior literature pointed to the great extent of the transformation in the late 19th century and the complexities of the interdependency between factors such as price, consumption, imports, and overall economy. The economic situation needs to be taken into account to understand the decline in viticulture. While industrialisation originally contributed to the spread of viticulture, it absorbed more and more workers later on and therefore industrialisation also played a crucial role in viticulture's decline. This meant higher production costs for vineyards as wages rose. Up to half of the production cost was comprised by wages in the labour-intensive wine-growing sector. Furthermore, the crisis in Swiss economy in the 1880 also led to a decline in price of wine.

However, the most important cause for the decline of viticulture was shrinking profitability. While production costs increased, prices of wine decreased. This was mainly due to the import of cheap wine from France and Italy. Particularly important for this development was the opening of the various railway tunnels (Gotthard in 1882), which lowered costs of transportation. The introduction of protective duties on foreign wine was therefore a recurrent topic of the public debate. However, duties were only increased in 1906 when the opposition of the export industry and the wine importers vanished. By then it was too late.

The significance of viticulture rests strongly on climate, particularly in the year-to-year development. This relationship proves very helpful for climate reconstruction. But also for the evaluation of the relevance of the viticulture sector on society, climate cannot be neglected.

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8 References

8.1 Primary Sources

Amtsrechnungen Fraumünsteramt 1824-1840. Stadtarchiv Zürich, IV A.1.

Hasler, Hans. *Der schweizerische Weinbau mit besonderer Berücksichtigung der zürcherischen Verhältnisse. Eine volkswirtschaftliche Studie.* Zürich: Academia, 1907.

Kohler, J.M. "Weinerträge am rechten unteren Ufer des Zürichsees von 1731-1866". In: *Schweizerische Landwirthschaftliche Zeitschrift* 7 (1879), pp. 193–210.

Müller, C.K. *Joh. Heinrich Waser, der zürcherische Volkswirtschafter*. Zürich 1878.

Rechnung um die Verwaltung des Amts Cappel 1798–1834. Staatsarchiv Zürich, Signatur: RRII 48.

Rechnung über die Verwaltung des Spitalamtes 1825-1838. Staatsarchiv Zürich, RRII 120b.1.

Rechnungen der Zoll- und Ohmgeld-Verwaltung 1803–1887. Staatsarchiv Bern, Signatur B VIII 702-777.

8.2 Literature

Altwegg, Andres M. *Vom Weinbau am Zürichsee. Struktur und Wandlungen eines Rebgebiets seit 1850*. Stäfa 1980.

Auer, Ingeborg et al. "HISTALP - historical instrumental climatological surface time series of the Greater Alpine Region". In: *International Journal of Climatology* 27 (2007), pp. 17–46. DOI: 10.1002/joc.1377.

Auer, Ingeborg et al. "Metadata and their role in homogenising". In: *Proceesdings of the Fourth Seminar for Homogenization and Quality Control in Climatological Databases, WMO-TD No. 1236*. 2003.

BFS, Bundesamt für Statistik. *Hektarerträge im Getreide-, Kartoffel- und Weinbau 1841-2000 (T 7.3.3.1.3)*. url: http://www.bfs.admin.ch (12.3.2009).

— *Produzentenpreisindizes und Produzentenpreise pflanzlicher Erzeugnisse 1784-1983 (T 7.3.4.1)*. url: http://www.bfs.admin.ch (12.3.2009).

— *Rebfläche nach Kantonen 1855-2002 (Anbaustatistiken, T. 7.3.1.5)*. url: http://www.bfs.admin.ch (12.3.2009).

Backhaus, Klaus et al. *Multivariate Analysemethoden. Eine anwendungsorientierte Einführung*. 11th ed. Berlin, Heidelberg, New York: Springer, 2006.

Bairoch, Paul. "Les trois révolutions agricoles du monde développé: rendements et productivité de 1800 à 1985". In: *Annales. Economies, Sociétés, Civilisations* 44.2 (1989), pp. 317–353.

Basler, P. "Beeinflussung von Leistungsmerkmalen der Weinrebe (Vitis vinifera L.) in der Ostschweiz durch Klimafaktoren und Erträge sowie Versuch einer Qualitätsprognose". In: *Die Weinwissenschaft* 1-4 (1980).

Begert, Michael, Thomas Schlegel, and Werner Kirchhofer. "Homogenous Temperature and Precipitation Series of Switzerland from 1864 to 2000". In: *International Journal of Climatology* 25 (2005), pp. 65–80. DOI: 10.1002/joc.1118.

Behringer, Wolfgang, Hartmut Lehmann, and Christian Pfister. *Kulturelle Konsequenzen der Kleinen Eiszeit – Cultural consequences of the Little Ice Age*. Göttingen 2005.

Bider, Max, Max Schüepp, and Hans von Rudloff. "Die Reduktion der 200-jährigen Basler Temperaturreihe". In: *Archiv für Meteorologie, Geophysik und Bioklimatologie* B9 (1959), pp. 360–412.

Brazdil, Rudolf et al. "Historical Climatology in Europe - The State of the Art". In: *Climatic Change* 70 (2005), pp. 363–430.

Briffa, Keith et al. "Treering width and density data around the Northern Hemisphere". In: *The Holocene* 12 (2002), pp. 737–758.

Brugger, Hans. *Die schweizerische Landwirtschaft 1850-1914*. Frauenfeld 1978.

— *Die schweizerische Landwirtschaft in der ersten Hälfte des 19. Jahrhunderts*. Frauenfeld 1956.

— *Statistisches Handbuch der schweizerischen Landwirtschaft*. Bern 1968.

Burri, Max. "Pflanzen- und Schneebeobachtungen aus den Kantonen Bern und Wallis 1755-1804 und ihre Bedeutung für die Temperatur-Rekonstruktion". MA thesis. Institute of History, University of Berne, 2009.

Böhm, Reinhard et al. "Eine neue Website mit instrumentellen Qualitätsklimadaten für den Grossraum Alpen zurück bis 1760". In: *Wiener Mitteilungen* 216 (2009), pp. 1–14.

Casty, Carlo. "Climate variability over the North Atlantic/European and Alpine regions since 1500". PhD thesis. Geographisches Institut der Universität Bern, 2005.

Casty, Carlo et al. "Temperature and Precipitation Variability in the European Alps since 1500". In: *International Journal of Climatology* 25 (2005), pp. 1855–1880.

Chuine, Isabelle et al. "Historical Phenology. Grape Ripening as a Past Climate Indicator". In: *Nature* 432 (2004), pp. 289–290. DOI: 10.1038/432289a.

Cook., E, K. Briffa, and P. Jones. “Spatial regression methods in Dendroclimatology. A review and comparison of two techniques”. In: *International Journal of Climatology* 14 (1994), pp. 379–402.

Coombe, B. “Adoption of a system for identifying grapevine growth stages”. In: *Australian Journal of Grape and Wine Research* 1 (1995), pp. 104–110.

Daux, Valérie et al. “Oxygen Isotope Composition of Human Teeth and the Record of Climate Change in France (Lorraine) during the last 1700 Years”. In: *Climatic Change* 70 (2005), pp. 445–464.

Dubler, Anne-Marie. “Ungeld”. In: *Historical Dictionary of Switzerland (HDS)* (1996–2009). url: http://www.hls-dhs-dss.ch/textes/d/D26199.php (15.6.2009).

Dubois, Jacques. *Les vignobles vaudois. Etude de géographie viticole*. Yens sur Morges: Cabédita, 2008.

EAV, Eidgenössische Alkoholverwaltung. *Alkohol in Zahlen 2009*. url: http://www.eav.admin.ch/aktuell/neues/index.html?lang=de (28.7.2009).

Etien, N. et al. “Summer maximum temperature in northern France over the past century: instrumental data versus multiple proxies (tree-ring isotopes, grape harvest dates and forest fires)”. In: *Climatic Change* 94 (2009), pp. 429–456.

Frank, David et al. “Warmer early instrumental measurements versus colder reconstructed temperatures: shooting at a moving target”. In: *Quartenary Science Reviews* 26 (2007), pp. 3298–3310.

Füssel, Hans-Martin. “Vulnerability: A generally applicable conceptual framwork for climate change research”. In: *Global Environmental Change* 17 (2007), pp. 155–167.

Guyot, Edmond. “Calcul du coefficient de corrélation entre le rendement du vignoble neuchâteloise, la temperature et la durée d’insolation”. In: *Bulletin de la Société des Sciences Naturelles de Neuchâtel* 65 (1940), pp. 5–15.

Guyot, Edmond and Charles Godet. “Influence du climate sur le rendement de la vigne”. In: *Bulletin de la Société des Sciences Naturelles de Neuchâtel* 58 (1933), pp. 77–96.

Harington, Charles R. *The year without a summer? World climate in 1816*. Ottawa 1992.

Höpflinger, François. *Bevölkerungswandel in der Schweiz*. Grüsch: Verlag Rüegger, 1986.

IPCC. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva 2007.

Jann, Ben. *Einführung in die Statistik*. 2nd ed. München, Wien: R. Oldenbourg, 2005.

Jones, Gregory V. and Robert E. Davis. “Using A Synoptic Climatological Approach To Understand Climate-Viticulture Relationships”. In: *International Journal of Climatology* 20 (2000), pp. 813–837.

Jones, Gregory V. and Karl Storchmann. “Wine market prices and investment under uncertainty: An econometric model for Bordeaux Crus Classés”. In: *Agr. Econ.* 26.2 (2001), pp. 115–133.

Jones, Gregory V. et al. “Climate Change and Global Wine Quality”. In: *Climatic Change* 73.3 (2005), pp. 319–343.

Kates, Robert W. “The Interaction of Climate and Society”. In: *Climate Impact Assessment.* Ed. by Robert W. Kates. Chichester: John Wiley & Sons, 1985, pp. 3–37.

Koblet, Werner. *Physiologie der Weinrebe.* Wädenswil 1975.

Kohler, J. M. *Der Weinbau und die Weinbehandlung. Mit besonderer Berücksichtigung der schweizerischen Verhältnisse.* Aarau 1878.

Kohler, Ulrich and Frauke Kreuter. *Datenanalyse mit Stata.* München, Wien: R. Oldenbourg, 2006.

Lachiver, Marcel. *Vins, vignes et vignerons: Histoire du vignoble Français.* Paris: Fayard, 1988.

Landsteiner, Erich. “The crisis of wine production in the late sixteenth-century Central Europe: Climate causes and economic consequences”. In: *Climatic Change* 43 (1999), pp. 323–334.

Lauer, Wilhelm and Peter Frankenberg. *Zur Rekonstruktion des Klimas im Bereich der Rheinpfalz seit Mitte des 16. Jahrhunderts mit Hilfe von Zeitreihen der Weinquantität und Weinqualität.* Mainz: Gustav Fischer Verlag, 1986.

Le Roy Ladurie, Emmanuel and M. Baulant. “Grape harvests from the Fifeteenth through the Nineteenth Centuries”. In: *Journal of Interdisciplinary History* 10.3 (1980). History and Climate: Interdisciplinary Explorations, pp. 839–849.

Le Roy Ladurie, Emmanuel, Valérie Daux, and Jürg Luterbacher. “Le climat de Bourgogne et d’ailleurs”. In: *Histoire, Économie et Société* 3 (2006), pp. 421–436.

Luterbacher, Jürg et al. “European Seasonal and Annual Temperature Variability, Trends and Extremes Since 1500”. In: *Science* 303 (2004), pp. 1499–1503.

Mann, Michael E. “The Value of Multiple Proxies”. In: *Science* 297 (2002), pp. 1481–1482.

Markwalder, Hans. *Das Rebgut der Stadt Bern am Bielersee.* Bern 1946.

Meier, Nicole. “Grape Harvest Records as a Proxy for Swiss April to August Temperature Reconstructions”. MA thesis. Philosophisch-naturwissenschaftliche Fakultät der Universität Bern, 2007.

Meier, Nicole et al. “Grape Harvest Dates as a proxy for Swiss April to August Temperature Reconstructions back to AD 1480”. In: *Geophysical Research Letters* 34 (2007), p. L20705.

Menzel, Annette. “A 500 year pheno-climatological view on the 2003 heatwave in Europe assesed by grape harvest dates”. In: *Meteorologische Zeitschrift* 14 (2005), pp. 75–77.

Montmollin, André de. “Le rendement viticole de la région neuchâteloise de 1750 à 1900 dans ses relations aves les conditions atmosphérique et estivales”. MA thesis. Geographisches Institut der Universität Zürich, 1986.

Moser, Peter. *Der Stand der Bauern. Bäuerliche Politik, Wirtschaft und Kultur gestern und heute*. Frauenfeld: Huber, 1994.

Moser, Peter and Werner Baumann. “Landwirtschaft”. In: *Historical Dictionary of Switzerland (HDS)* (1998–2009). url: http://www.hls-dhs-dss.ch/textes/d/D13933.php (25.6.2009).

Mullins, Michael G., Alain Bouquet, and Larry E. Williams. *Biology of the grapevine.* WSU: GE: Conservatoire Botanique: 663 MUL; A5439 / A5125. Cambridge 1992.

Panosetti, Dino Renato. *Die staatlichen Massnahmen zur Regelung und wirtschaftlichen Sicherung von Weinproduktion und Weinabsatz*. Varese 1948.

Pfister, Christian. *BERNHIST, Historisch-Statistische Datenbank des Kantons Bern.* Internet-based database. url: www.bernhist.ch (15.6.2009). 1994–2006.

— “Climatic Extremes, Recurrent Crises and Witch Huntes: Strategies of European Societies in Coping with Exogenous Shock in the Late Sixteenth and Early Seventeenth Centuries”. In: *The Medieval History Journal* 10 (2007), pp. 1–41.

— “Die Fluktuationen der Weinmosterträge im schweizerischen Weinland vom 16. bis ins frühe 19. Jahrhundert. Klimatische Ursachen und sozioökonomische Bedeutung”. In: *Schweizerische Zeitschrift für Geschichte* 31 (1981), pp. 445–491.

— *Im Strom der Modernisierung*. Bern 1995.

— *Klimageschichte der Schweiz 1525–1860: das Klima der Schweiz von 1525–1860 und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft*. 3rd ed. Bern, Stuttgart: Haupt, 1988.

— “Weeping in the Snow. The Second Period of Little Ice Age-type Impacts”. In: *Kulturelle Konsequenzen der Kleinen Eiszeit – Cultural consequences of the Little Ice Age*. Ed. by Wolfgang Behringer, Hartmut Lehmann, and Christian Pfister. Göttingen 2005, pp. 31–85.

— *Wetternachhersage: 500 Jahre Klimavariationen und Naturkatastrophen*. Bern: Paul Haupt, 1999.

Pfister, Christian and Rudolf Brazdil. “Social vulnerability to climate in the "Little Ice Age": an example from Central Europe in the early 1770s”. In: *Climate of the Past* 2 (2006), pp. 115–129.

Pfister, Christian et al. *Documentary evidence as climate proxies. White paper on Documentary Data.* Trieste 2008.

Post, John D. *The last great subsistence crisis in the Western world.* Baltimore, London: John Hopkins University Press, 1977.

Powell, Kevin. “Grape phylloxera: An Overview”. In: *Root Feeders.* Ed. by Scott N. Johnson and Philip J. Murray. North Wyke: CAB International, 2008, pp. 96–114.

Rahmstorf, Stefan and Hans Joachim Schellnhuber. *Der Klimawandel.* München 2007.

Rennefahrt, Hermann. *Grundzüge der bernischen Rechtsgeschichte.* Bern: Verlag von Stämpfli & Cie., 1928.

Ritzmann-Blickenstorfer, Heiner. *Alternative Neue Welt. Die Ursachen der schweizerischen Überseewanderung im 19. und frühen 20. Jahrhundert.* Zürich: Chronos, 1997.

— *Historische Statistik der Schweiz – Statistique historique de la Suisse – Historical statistics of Switzerland.* Zürich 1996.

— “Konjunktur”. In: *Historical Dictionary of Switzerland (HDS)* (1996–2009). url: http://www.hls-dhs-dss.ch/textes/d/D13918.php (25.6.2009).

Ritzmann, Heiner. *Die Wertschöpfung im Ersten Sektor, 1837-1945.* Beitrag zum Nationalfonds-Projekt "Geldmenge und Wirtschaftswachstum in der Schweiz, 1851-1931". Zürich 1990.

Schlegel, Walter. *Der Weinbau in der Schweiz.* Wiesbaden 1973.

Schüepp, Max. “Der Temperaturverlauf in der Schweiz seit dem Beginn der meteorologischen Beobachtungen”. In: *Annalen der Schweizerischen Meteorologischen Zentralanstalt* Anhang II (1957).

Sieferle, Rolf Peter et al. *Das Ende der Fläche. Zum gesellschaftlichen Stoffwechsel der Industrialisierung.* Böhlau Verlag. Köln, Weiman, Wien 2006.

Statistisches Jahrbuch der Schweiz. Bern/Neuenburg 1891ff.

Storchmann, Karl. “English Weather and Rhine Wine Quality: An Ordered Probit Model”. In: *Journal of Wine Research* 16.2 (2005), pp. 105–119.

Trachsel, Stefan. “Climatic Influences on Australia’s Wheat Production during the First World War”. Bachelor thesis at the Institute of History, University of Bern, 2007 (unpublished).

Vettori, Arthur. *Finanzhaushalt und Wirtschaftsverwaltung Basels (1689-1798).* Basel / Frankfurt a. M.: Verlag Helbing & Lichtenhahn, 1984.

Vries, Jan de. “Analysis of Historical Climate-Society Interaction”. In: *Climate Impact Assessment.* Ed. by Robert W. Kates. Chichester: John Wiley & Sons, 1985, pp. 273–292.

Widmer, Thomas. *Die Schweiz in der Wachstumskrise der 1880er Jahre.* Zürich: Chronos, 1992.

Wyder, Samuel. “Lehenshöfe des Spitals Zürich. I. Weinbau und Lehensverträge im 18. Jahrhundert”. In: *Schweizerische Zeitschrift für Obst- und Weinbau* 9 (1999), pp. 241–244.

Zweifel, Dr. “Einige Bemerkungen über die Pflanzungen der Rebe im Limmathale”. In: *Schweiz. Zeitschrift für Landwirtschaft* 3 (1848), pp. 81–88.

A Appendix

A.1 Original Sources

Place	Original Source
Tschugg BE	Christoph und Friedrich Steiger, Verwaltungsbuch des Gutes zu Tschugg. Burgerbibliothek Bern. Mss. h. h. L. 62 a.
Malessert FR	(Johann David von Wattenwyl), Extract aus dem Journal von Malessert in La Côte seit 1694 bis 1770, die Ertragenheit dieses Rebguts von 18 Jucharten betreffend, mit landwirtschaftlichen Beobachtungen begleitet. Abhandlungen und Beobachtungen der Ök. Gesellschaft Bern, 13. Jg., 1772, 2 Stück. Tabellenanhang.
Lower Lake of Zürich	Amtsrechnungen Cappelerhof. Staatsarchiv Zürich, F III 7 (1584-1797).
Wipkingen/Höngg ZH	Amtsrechnungen Fraumünsteramt. Stadtarchiv Zürich, IIIB 310-736; IV A 1-45.
La Neuveville BE (3)	Carnet pour M. Theobald Petitmaitre, JV, 2, Archiv der Burgergemeinde Solothurn. / Carnet pour le Receveur, JV, 3, Archiv der Burgergemeinde Solothurn.
Ile St.-Pierre BE	Beglinger, Bendicht, Die Weinmostertragsreihe St. Peterinsel 1715-1900, Proseminararbeit, Universität Bern.
Zollikon ZH	J.M. Kohler. “Weinerträge am rechten unteren Ufer des Zürichsees von 1731-1866”. In: *Schweizerische Landwirthschaftliche Zeitschrift* 7 (1879), pp. 193–210
Obererlinsbach AG	Rudolf Meyer, Notizen Nr. 14: (Ertrag der Reben im Weingärtlein und in der Egg in Obererlinsbach). Verhandlungsblätter der Ges. f. vaterländ. Kultur im Kt. Aargau, Jg. 1817. Aarau. S. 41f.
St-Blaise NE	Kopp, Ch. Statistique des vignes de Neuchâtel de 1780 à 1819. Bull. de la Soc. neuc. des Sci. Nat. V, 1867, p. 219-235.
Lutry VD	Amtsrechnungen Lausanne. Archives Cantonales Vaudoises, Serie Bp 32 (1557-1796).
Le Landeron NE	Remarque du produit de chacune de mes vignes et prés, Série vigne et vin, Vignes de particuliers, dossier 2/XIII, Archives de l’Etat de Neuchâtel.
Bursins VD	Amtsrechnungen Romainmôtier. Archives Cantonales Vaudoises, Serie Bp 40 (1537-1796).

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Place	Original Source
Neuchatel	Produit des vignes, Fonds Marval/Immeuble, G28, Archives de l'Etat de Neuchâtel. / Compte des vignes, Fonds Marval/Dossiers particuliers, F24, Archives de l'Etat de Neuchâtel.
Bonvillars VD	Dominicé, Résumé de la production des vignes de Bonvillars près Grandson (Vaud) de 1799 à 1872. Bull. de la classe d'agric., Serie 2, Bd. 5, Nr. 55/56. Genève 1873. S. 543-544.
Canton ZH - Notes	C.K. Müller. *Joh. Heinrich Waser, der zürcherische Volkswirtschafter*. Zürich 1878
Rheinthal (SG)	Rechnung über den Ertrag von ca. 180 Burden Stickel mit Reben, im unteren Rheintal, während den Jahren 1802 bis und mit 1821. Schweiz. Zeitschr. f. Landw. und Gewerbe, Bd. 2, Nr. 6. St. Gallen 1832. S. 23-24.
Weiningen/Höngg ZH	Dr. Zweifel. "Einige Bemerkungen über die Pflanzungen der Rebe im Limmathale". In: *Schweiz. Zeitschrift für Landwirtschaft* 3 (1848), pp. 81–88
Lavaux VD	Manuscrit de Lavaux, Musée de la vigne et du vin, Boudry.
La Neuveville BE (2)	Produit des vignes, Domaine de Neuveville, Domaine de Landeron, JIII, 104, Archiv der Burgergemeinde Solothurn.
Auvernier NE	Berichte über die Rebgüter der Burgerspital, JII, 37 Archiv der Burgergemeinde Solothurn. / Bericht über die Rebgüter des Burgerspital der Stadtgemeinde Solothurn, JII, 45, Archiv der Burgergemeinde Solothurn.
Enge (ZH, Fraum.)	*Amtsrechnungen Fraumünsteramt 1824-1840*. Stadtarchiv Zürich, IV A.1
Horgen ZH (Fraum.)	*Amtsrechnungen Fraumünsteramt 1824-1840*
Rümlang ZH (Fraum.)	*Amtsrechnungen Fraumünsteramt 1824-1840*
Cappelhofen (ZH, 5 viney.)	*Rechnung um die Verwaltung des Amts Cappel 1798–1834*. Staatsarchiv Zürich, Signatur: RRII 48
Spital Zürich	*Rechnung über die Verwaltung des Spitalamtes 1825-1838*. Staatsarchiv Zürich, RRII 120b.1
Vevey VD	Taxe des vins nouveaux, leur qualité et leur rendement pour les récoltes de la ville et de l'hôpital de Vevey pendant les années 1830 à 1893, Annuaire Statistique de la Suisse, 1893, p. 256.

Continued on next page

Place	Original Source
Corcelles VD	Charles Godet et Edmond Guyot, Influence du climat sur le rendement de la vigne. Bull. de la Soc. neuc. des Sci. Nat. 58, 1933, p. 77-96.
La Neuveville BE (6)	Markwalder, Hans, Das Rebgut der Stadt Bern am Bielersee, Bern, 1946.
Canton NE (2)	Charles Godet et Edmond Guyot, Influence du climat sur le rendement de la vigne. Bull. de la Soc. neuc. des Sci. Nat. 58, 1933, p. 77-96.

Table 12: Original sources of the local time-series used for temperature reconstruction. Data from Brugger does not contain full source information.

A.2 Trend equations

Place	Subperiod	α	β	Mean
Tschugg BE				54.7
Malessert FR				44.9
Lower Lake of Zürich		-82.4	0.07	
Wipkingen/Höngg ZH		-112.5	0.09	
La Neuveville BE (3)				21
Ile St.-Pierre BE	1745-1818			56
	1819-1875	-272.0	0.19	
	1876-1900			40
Zollikon ZH	1755-1877	-288.0	0.19	
Obererlinsbach AG				34.4
St-Blaise NE				53
Lutry VD		-1818.7	1.05	
Le Landeron NE				60
Bursins VD				35.14
Neuchatel	1775-1817			42
	1818-1838	-2608.0	1.46	
Bonvillars VD				44.8
Canton ZH - Notes				
Rheinthal (SG)				22.47
Weiningen/Höngg ZH		2168.0	-1.16	
Lavaux VD		-1244.0	0.70	
La Neuveville BE (2)	1820-1876	-428.0	0.26	
	1877-1900			42
Auvernier NE	1820-1839	-4890.0	0.70	
	1860-1908	-766.0	0.29	
Enge (ZH, Fraum.)				140.3
Horgen ZH (Fraum.)				76.7
Rümlang ZH (Fraum.)				43.7
Cappelhofen (ZH, 5 viney.)				53.9
Spital Zürich				46.9
Canton Aargau (1)		-307.8	0.19	
Vevey VD	1830-1875			91
	1876-1893			55
Villette GE		217.3	-0.08	
Corcelles VD				52
La Neuveville BE (6)	1850-1876	-2186.0	1.20	
	1877-1914			30
Canton VD (1)		395.6	-0.17	
Canton NE (1)		-464.9	0.30	

Continued on next page

Place	Subperiod	α	β	Mean
Canton SH	1858-1918	1142.8	-0.58	
	1919-1966			
Canton GE		5547.8	-2.93	
Canton NE (2)				49
Canton VD (2)	1880-1917	1285.6	-0.65	
	1918-1966	-1212.6	0.66	
Canton ZH				
Canton BE		-301.7	0.18	
Canton AG (2)		-410.0	0.23	
Canton GE		-977.7	0.54	
Canton SG	1893-1918	1732.1	-0.89	
	1919-1954	-998.8	0.53	
Canton TG		-877.2	0.47	
CH		-1295.8	0.69	

Table 13: Trend equations for the local time-series used for reconstruction. Several time-series have different trends for subperiods. α denotes the constant of the trend equation, β the slope. Where no significant trend could be found, the arithmetic mean was used for detrending.

A.3 Time series

Year	Vaud	NB/Biel	Aargau	Zurich	SG	SH	Mittelland
1750		-25.51		-13.15			-16.24
1751		-14.49		67.69			47.14
1752		-37.61		54.80			31.70
1753		82.14		55.05			61.82
1754		10.87		20.87			18.37
1755		-9.13		-40.94			-32.99
1756		18.60		47.29			40.12
1757		48.67		-10.44			4.34
1758		-64.63		-13.56			-26.33
1759		-32.84		-31.26			-31.65
1760		133.37	108.09	56.90			82.43
1761		100.40	96.53	91.05			94.02
1762		-4.07	4.05	40.06			31.06
1763		84.56	-59.54	-2.33			3.60
1764		72.70	-1.73	27.30			30.57
1765		30.62	-30.64	8.12			4.87
1766		-66.58	-47.98	-33.14			-42.80
1767		-41.46	-79.77	-63.83			-62.55
1768		31.65	24.28	4.06			13.62
1769		-78.10	-7.51	-26.19			-21.52
1770		-66.99	-88.44	-79.03			-78.50
1771		-44.74	-76.88	-68.85			-65.63
1772		66.25	-1.73	64.20			51.42
1773	6.97	-2.25	-71.10	-69.04			-45.58
1774	-26.35	-0.22	4.05	18.67			5.58
1775	43.31	54.35	-36.42	32.68			26.55
1776	1.64	26.19	1.16	15.33			12.50
1777	-21.54	-44.21	-79.77	-23.95			-36.23
1778	-47.90	31.98	47.40	8.73			9.61
1779	-8.82	-4.67	-82.66	15.10			-8.48
1780	-8.69	-7.54	-27.75	28.47			6.91
1781	72.75	117.79	50.29	59.54			69.91
1782	-11.92	55.64	-13.29	18.54			14.34
1783	2.05	36.06	110.98	9.98			29.84
1784	-33.52	-33.74	30.06	10.44			15.34
1785	45.26	36.08	-45.09	-8.58			1.75
1786	-62.80	-45.46	-94.22	-38.03			-52.76
1787	-9.12	-30.44	-62.43	-28.11			-31.05
1788	-14.40	-2.20	58.96	57.67			35.89

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Year	Vaud	NB/Biel	Aargau	Zurich	SG	SH	Mittelland
1789	-25.28	-42.17	-42.20	-86.65			-75.54
1790	-25.05	-39.40	-21.97	-12.48			-20.64
1791	-12.72	22.03	35.84	46.28			30.66
1792	42.34	45.06	-1.73	-46.62			-9.03
1793	10.47	-24.86	-27.75	16.21			5.22
1794	33.78	57.34	131.21	14.55			44.33
1795	4.99	-48.42	-100.00	11.64			-16.27
1796	36.47	-25.17	-73.99	37.83			8.47
1797		-26.50	-24.86	52.15			21.02
1798		15.81	38.73	41.29			35.68
1799	29.46	3.27	-91.33	-43.31			-31.42
1800	-41.96	-27.35	-33.53	-72.23			-53.26
1801	-48.66	-36.74	12.72	-29.61			-26.92
1802	-66.52	7.31	-13.29	88.62	122.52		45.12
1803	78.57	90.62	-53.76	41.53	82.47		46.07
1804	158.93	91.94	264.16	62.81	251.58		136.43
1805	7.14	-19.83	-7.51	-55.47	-46.60		-33.32
1806	-19.64	-20.00	21.39	26.19	-37.69		3.23
1807	74.11	75.17	148.55	83.49	29.06		82.48
1808	94.20	74.98	206.36	9.69	82.47		69.58
1809	-15.18	-38.25	-13.29	-25.25	2.36		-20.02
1810	-39.73	0.39	15.61	-60.57	-2.09		-29.65
1811	-17.41	11.32		71.88	95.82		50.89
1812	105.36	15.36		12.77			31.81
1813	-82.14	-71.62		-76.24	-82.20		-77.45
1814	-65.82	-63.83		-76.94	-68.85		-71.56
1815	-61.39	-42.83		-79.95	-82.20		-71.04
1816	-81.95	-95.29		-88.76	-91.10		-89.10
1817	-82.99	-94.10		-63.94	-82.20		-75.18
1818	16.36	-1.58		17.88	-37.69		5.12
1819	56.57	96.78		-27.86	-19.89		8.31
1820	-18.66	-3.30		-35.98	-42.15		-28.68
1821	-66.46	-76.55		-86.28	-73.30		-79.19
1822	-64.30	-43.05		11.29			-14.70
1823	80.30	52.69		36.32			48.39
1824	-23.78	-32.37		-30.08			-29.28
1825	-10.45	-25.46		11.22			-0.45
1826	113.45	4.17		26.12			39.19
1827	8.88	160.40		51.05			64.49
1828	48.88	61.90		121.45			95.02
1829	26.72	-21.16	-26.44	-0.51			-3.74

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Year	Vaud	NB/Biel	Aargau	Zurich	SG	SH	Mittelland
1830	-62.61	-79.89	-82.63	-75.72			-75.38
1831	-47.56	-72.53	-66.95	-60.27			-61.31
1832	2.41	-40.48	-63.23	-43.90			-38.83
1833	66.44	37.15	41.92	41.93			45.21
1834	92.96	133.61	101.67	50.79			80.10
1835	15.16	58.69	132.54	72.48			70.64
1836	22.06	7.26	27.98	6.00			12.55
1837	22.60	3.22	-21.23	21.84			11.68
1838	58.58	32.27	-38.08	6.60			12.10
1839	-8.92	-7.41	37.95	20.12			13.66
1840	35.14	16.92	58.53	33.47			35.17
1841	8.99	-26.50	-66.43	-52.76			-40.37
1842	53.47	-28.52	13.21	23.26			17.99
1843	-43.92	-15.00	-17.96	-52.58			-39.10
1844	-38.13	-56.56	-24.19	-13.35			-26.49
1845	40.85	21.17	-38.38	3.10			5.49
1846	-31.64	-39.26	4.60	56.81			17.35
1847	85.05	173.05	13.62	46.03			68.30
1848	12.14	30.65	53.56	32.03			32.07
1849	-53.54	-11.30	32.32	54.49			21.83
1850	5.11	0.71	-50.67	6.14			-4.40
1851	35.27	16.27	-39.58	-27.26			-11.64
1852	-20.75	12.64	-2.70	1.56			-1.02
1853	-70.96	-44.61	-62.99	-5.08			-32.30
1854	-52.33	-64.27	-32.04	-68.25			-58.90
1855	1.34	-28.36	-52.11	-3.29			-14.83
1856	-29.36	-18.45	-35.54	37.80			5.01
1857	2.47	31.86	58.92	16.24			23.66
1858	41.59	68.33	88.61	71.33		39.85	64.62
1859	-21.41	15.19	26.94	8.22		-4.78	5.80
1860	-13.15	-30.19	-31.36	-33.53		-48.52	-31.97
1861	-1.57	-16.86	-61.76	-17.84		-81.92	-30.81
1862	-17.22	-46.08	-13.03	-5.06		13.12	-11.20
1863	18.95	58.55	75.78	-19.96		30.92	17.76
1864	-13.27	-13.28	4.94	7.37		-28.66	-4.02
1865	-4.31	-4.45	-3.61	40.18		-12.23	13.70
1866	67.93	80.24	54.53	-22.26		46.55	26.07
1867	-56.15	-43.44	0.75	-44.22		7.53	-32.00
1868	10.94	40.42	60.94	15.72		35.91	27.91
1869	21.76	56.44	44.40	-28.97		12.61	6.90
1870	17.29	-19.16	-26.84	8.49		-17.41	-2.95

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Year	Vaud	NB/Biel	Aargau	Zurich	SG	SH	Mittelland
1871	74.64	77.43	58.61	49.61		23.92	54.78
1872	-44.43	-51.58	-58.60	-22.91		-25.38	-35.53
1873	-60.95	-72.50	-33.04	-78.03		-24.43	-60.72
1874	41.85	69.46	10.22	26.01		39.04	34.09
1875	34.45	4.63	111.74	74.87		106.23	68.81
1876	-23.81	9.58	29.50	14.47		17.81	10.93
1877	16.59	1.63	13.00	49.71		2.25	26.08
1878	-23.50	17.52	-9.44			19.25	0.96
1879	-69.18	-62.21	-69.95			-39.16	-60.13
1880	15.87	-21.44	-82.55			-45.05	-33.29
1881	-18.05	23.06	42.89	61.54		-18.09	30.63
1882	-38.56	7.54		-47.65		-53.73	-37.95
1883	-35.48	-29.24		-11.85			-20.05
1884	29.67	52.41	30.41	-6.50		-28.95	9.15
1885	20.91	47.26		64.70		60.11	53.73
1886	31.78	32.15		-19.31		-31.17	-4.20
1887	-23.11	-56.80	-17.05	-2.44		-7.04	-15.90
1888	-27.74	-55.88	-28.39	-19.05		-32.35	-28.79
1889	-39.39	-50.62	-29.68	-30.69		-22.28	-33.44
1890	-18.26	-19.44	-21.01	-18.99		5.82	-15.69
1891	-61.06	-81.22	-72.34	-47.91		-83.02	-63.05
1892	18.23	-32.24	-56.09	-10.27		-20.48	-17.34
1893	120.51	100.87	-22.20	30.50	41.97	20.35	44.13
1894	65.08	33.15	16.97	18.13	-20.95	36.93	23.20
1895	-15.89	-23.02	1.46	67.89	20.34	12.09	24.83
1896	32.74	-20.02		53.26	1.61	36.02	30.02
1897	15.72	-20.37	-37.55	-3.22	3.34	7.36	-5.15
1898	-17.38	8.51	-34.08	1.90	-28.65	-35.59	-12.69
1899	-18.14	-18.37	3.64	-0.26	-16.79	-15.33	-8.22
1900	144.96	154.74	130.88	45.82	50.83	174.79	99.21
1901	46.01	-16.49	40.05	45.28	28.28	14.98	31.08
1902	49.08	11.28	-3.38	-5.11	61.69	-9.15	11.77
1903	-43.07	-16.21	94.61	68.20	89.11	2.82	41.48
1904	58.80	50.93	-34.32	17.97	51.30	-20.76	19.98
1905	49.62	-27.92	22.89	45.67	-7.78	68.28	30.26
1906	57.16	84.20	20.21	21.08	-50.16	35.29	26.24
1907	-35.97	-36.92	-43.59	-19.27	-7.18	13.86	-20.95
1908	47.43	40.53	-3.95	-9.62	73.90	15.62	18.08
1909	-62.25	-51.34	-73.15	-58.12	-13.67	-70.71	-55.68
1910	-93.34	-99.25	-92.19	-74.76	-75.61	-81.85	-83.32
1911	28.21	-42.24	-66.13	-29.20	-12.59	-31.13	-26.43

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Year	Vaud	NB/Biel	Aargau	Zurich	SG	SH	Mittelland
1912	6.43	-9.87	-51.55	-44.38	-65.75	20.18	-29.21
1913	-90.59	-87.96	-84.84	-81.06	-96.84	-45.69	-81.14
1914	-56.13	-74.37	-83.56	-65.36	-26.43	-44.28	-60.10
1915	-22.63	-22.80	15.02	46.90	-87.06	93.98	14.65
1916	-41.40	-58.89	-61.47	-53.07	-45.28	-55.01	-52.66
1917	-21.30	-47.14	-38.13	-0.56	55.43	-18.64	-8.93
1918	28.64	42.17	18.56	38.76	57.38	33.48	37.07
1919	-8.28	-19.05	-28.60	-22.79	-39.96	-15.73	-22.50
1920	-18.71	-0.02	-59.21	-40.73	46.15	35.48	-14.81
1921	-62.04	-36.64	-68.27	-18.39	-7.05	-35.34	-33.07
1922	71.38	99.24	43.00	81.50	-28.56	77.87	63.43
1923	33.62	62.22	-25.85	-13.51	-26.52	-55.69	-6.59
1924	-63.67	-30.21	-57.36	-56.60	-61.65	43.58	-42.39
1925	-56.57	-76.15	-68.82	-8.12	12.75	-22.89	-29.50
1926	-5.61	-16.67	-81.44	-68.93	-10.71	-69.74	-48.87
1927	-49.52	-75.09	-70.69	-65.98	-25.58	-56.98	-59.47
1928	9.27	35.25	-64.59	-45.34	-25.15	3.37	-22.23
1929	63.77	47.79	-23.75	-56.17	5.55	17.55	-7.20
1930	12.87	34.53	-58.63	-15.01	48.65	28.61	2.63
1931	-15.68	-7.89	-23.14	65.46	78.35	56.18	35.53
1932	-27.87	-46.64	-15.73	2.58	-15.28	34.52	-7.91
1933	-60.98	-57.37	-79.65	-68.19	-19.54	-49.40	-58.94
1934	66.11	95.14	63.38	54.74	44.58	90.06	65.44
1935	161.71	93.16	-2.06	30.66	67.73	27.95	55.06
1936	-30.83	1.56	-41.15	-39.88	-51.24	-13.69	-31.87
1937	-51.43	-39.25	13.24	18.21	0.42	12.17	-1.28
1938	-67.37	-66.90	1.61	27.28	40.21	17.75	0.89
1939	14.44	-2.78	-22.96	-31.49	-37.47	-10.29	-19.19
1940	-56.32	-45.83	-32.40	-42.77	-9.37	-57.85	-41.26
1941	31.84	31.37	6.90	25.80	-22.52	-23.85	12.64
1942	4.18	107.34	31.03	64.06	44.68	-16.02	45.42
1943	10.44	27.64	-10.96	-1.01	-30.56	-4.82	-1.41
1944	64.43	123.34	97.56	22.98	-3.50	46.27	49.63
1945	5.52	11.75	-57.60	-6.51	19.70	-61.72	-12.74
1946	5.04	-17.22	89.82	62.59	-8.68	71.65	41.05
1947	26.30	66.65	37.72	25.05	30.11	-19.21	27.09
1948	3.99	52.54	54.94	21.98	47.81	20.84	30.76
1949	-30.96	-32.14	-9.98	4.17	16.40	-1.37	-5.69
1950	7.49	34.65	154.35	70.54	-12.56	43.56	54.89
1951	20.63	32.18	49.53	7.00	29.50	9.85	20.34
1952	-23.77	-12.70	14.52	6.74	-11.95	-17.18	-3.86

Continued on next page

Year	Vaud	NB/Biel	Aargau	Zurich	SG	SH	Mittelland
1953	-3.92	16.91	-37.98	-62.67	-35.04	-62.90	-38.86
1954	-14.94	-13.29	-1.23	-25.11	-60.12	-37.16	-25.26
1955	3.08	12.07	-8.46	-26.34		-21.94	-13.47
1956	-63.19	-49.03	-69.91	-84.74		-68.23	-72.08
1957	-47.01	-60.84	-86.72	-61.49		-84.07	-66.16
1958	-42.24	-54.74	63.64	40.03		40.79	18.22
1959	26.18	28.00	70.44	56.18		44.14	48.19
1960	62.39	8.48	40.88	-28.73		-68.46	-6.13
1961	6.90	-8.47	14.30	12.90		39.99	13.06
1962	-35.65	-18.08	42.57	17.34		22.02	8.99
1963	35.90	-1.15	20.82	-7.64		47.73	11.48
1964	3.46	2.08	68.66	78.68		42.12	50.34
1965	3.12	-35.27	3.77	6.99		-6.05	-1.92
1966	-3.17	-18.35	39.47	27.24		10.42	15.73

Table 14: Detrended and homogenised time-series for grape harvests in the various regions and the Mittelland. Values are indicated as deviations from the trend/mean in per cent. Refer to the section on data for information about how they were created.

A.4 Reconstruction material

Example: Calibration in a period with low variability

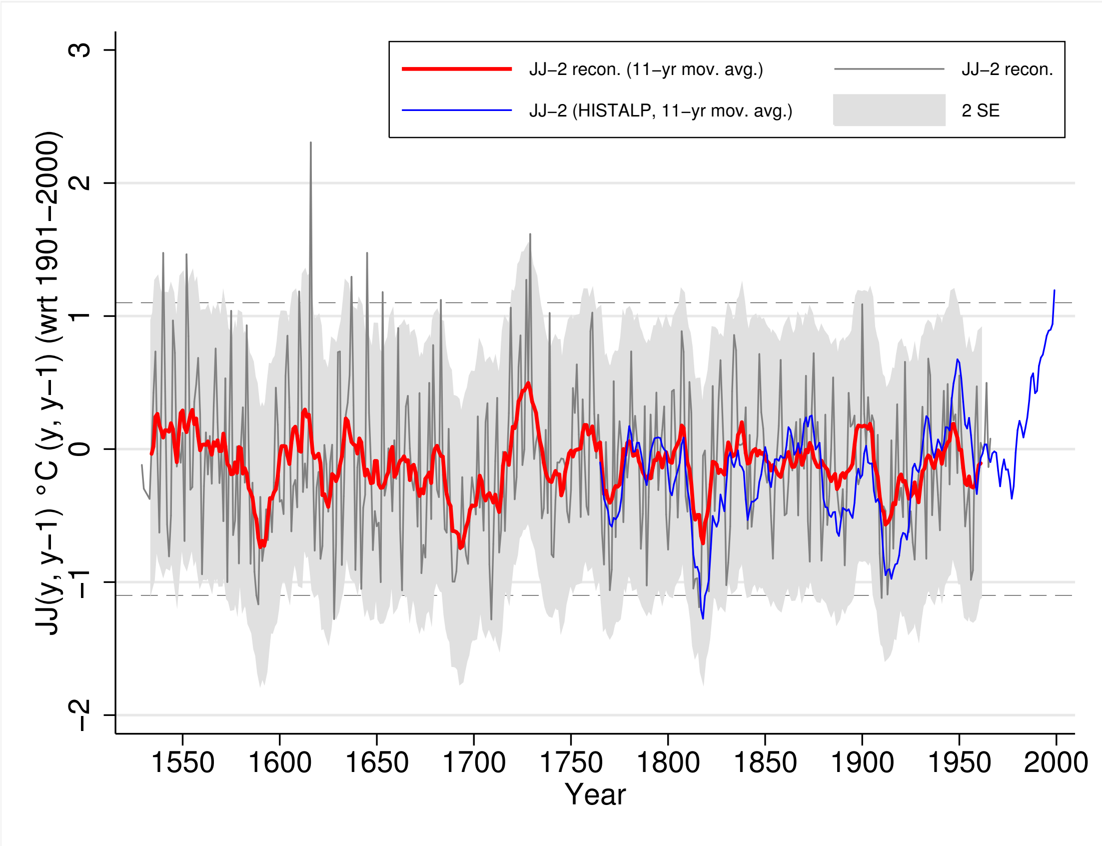

Figure 17: Reconstruction of $JJ_{y,\ y\text{-}1}$ temperature 1525 to 1966 with calibration-verification from 1762 to 1801. The *Mittelland* time-series constructed for this study was used as a predictor. The 11-year moving average of the reconstructed temperature is plotted in red. The shaded area indicates 2 standard errors representing a 95 per cent confidence interval. The dashed lines display 2 standard deviations. HISTALP temperature is shown in blue for the later periods. – This reconstruction exemplifies that calibration periods with low variability return problematic reconstructions.

Example: Reconstruction of single year monthly average

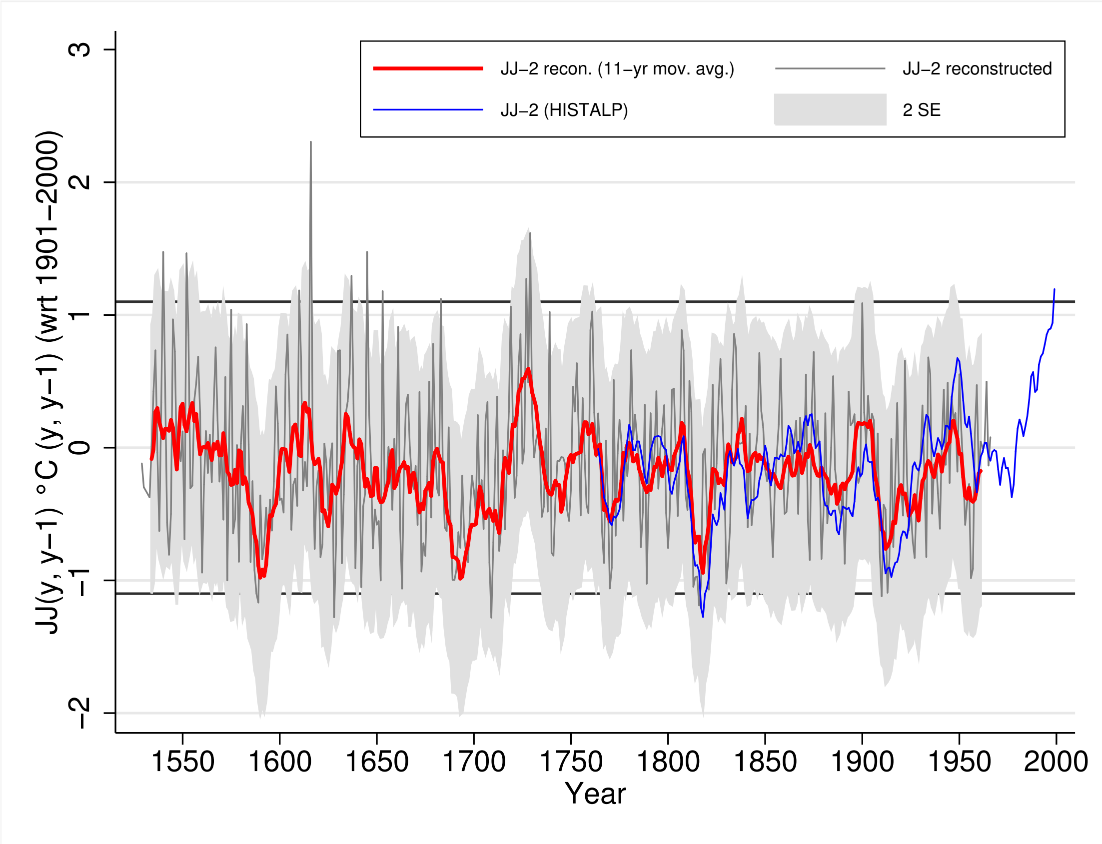

Figure 18: Reconstruction of JJ temperature 1525 to 1966 with calibration-verification from 1780 to 1819. The *Mittelland* time-series constructed for this study was used as a predictor. The 11-year moving average of the reconstructed temperature is plotted in red. The shaded area indicates 2 standard errors representing a 95 per cent confidence interval. The dashed lines display 2 standard deviations. HISTALP temperature is shown in blue for the later periods. – This reconstruction includes only one year as opposed to the two-year averages of the other reconstructions shown.

Temperature reconstruction from Jürg Luterbacher et al. "European Seasonal and Annual Temperature Variability, Trends and Extremes Since 1500". In: *Science* 303 (2004), pp. 1499–1503, p. 1500

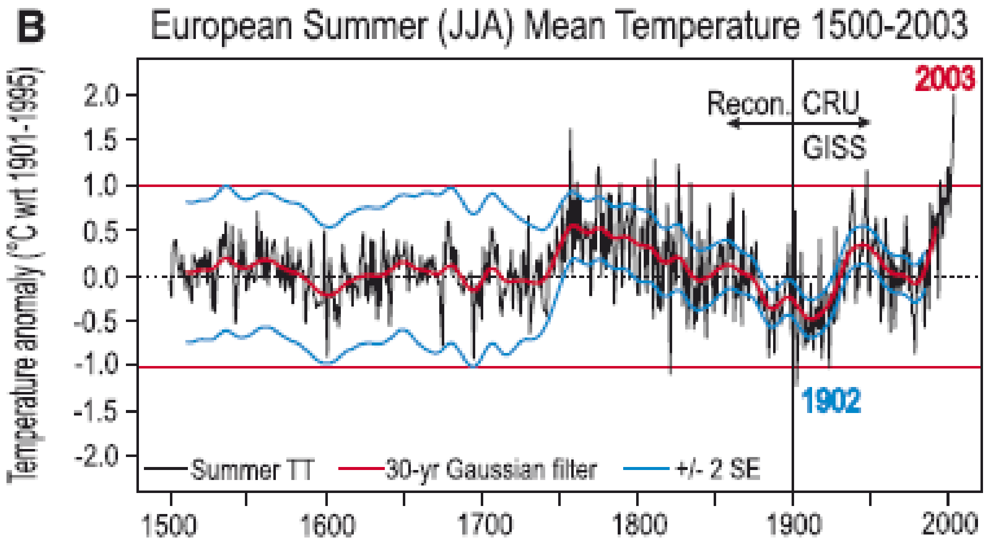

Figure 19: Summer temperature reconstruction for Europe by Luterbacher et al. 2004

Temperature reconstruction from Carlo Casty et al. "Temperature and Precipitation Variability in the European Alps since 1500". In: *International Journal of Climatology* 25 (2005), pp. 1855–1880, p. 1860

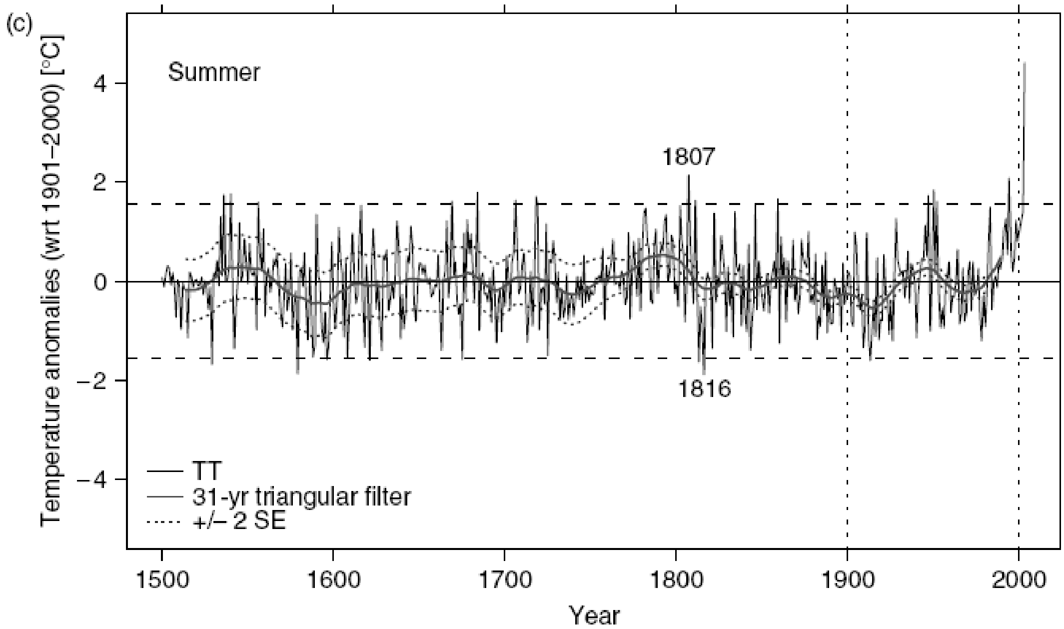

Figure 20: Summer temperature reconstruction for Alpine region by Casty et al. 2005