Climate of migration? How climate triggered migration from Southwest Germany into North America during the 19th century

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Abstract. This paper contributes to the ongoing debate to which extent climate and climatic change have a negative impact on societies by triggering migration, or even represent underlying causes for conflicts. It presents results from an in-depths analysis of the connection between climatic and selected socio-economic parameters and the major migration waves from Southwest Germany into North America during the 19th century. The aim was to assess to what extent climatic conditions

10   triggered these waves of migration. The observed century was in general characterized by the Little Ice Age Climate with three distinct cooling periods, causing major glacier advances in the alpine regions and quite a number of climatic extremes such as major floods, droughts and chilly winter times. Also, societal changes were tremendous, marked by the wartimes during the Napoleonic era (until 1815), the abolition of serfdom (1817), the bourgeois revolution from 1847/48, economic freedom (1862), the beginning of the industrialization process accompanied by large-scale rural-urban migration, resulting in

15   urban poverty, and finally by the foundation of the German Reich in 1870.

The presented study is based on a quantitative data and qualitative information based discourse analysis. It reflects climatic conditions as well as socio-economic and political issues, which lead to the hypothesis of a chain of effects, consisting of unfavorable climatic conditions – decrease of crop yields – rising cereal prices – emigration. For the identified emigration peak years of each wave of migration, the connections between emigration and the underlying climatic conditions, crop

20   yields and cereal prices were statistically evaluated by a sequence of linear models which proved to be significant with explanatory power between 22 % and 38 %.

1.   Introduction

Within the economically motivated migration theory, migration waves are often described as an interaction of so-called "push- and pull-" factors. This theoretical framework was initially conceptualized by Lee (1966), it has been developed

25   further (Hammar et al. 1997) and supplemented by further concepts such as "liquid migration" (e.g. Engbersen et al. 2010). The term "push-factor" in Lee´s concept subsumes all disadvantages and discriminations which a person feels and/or experiences in his or her home land. This comprises among other things political and/or religious discrimination or an economic situation which is perceived as unfavorable. This could be due to insufficient earning opportunities, permanent price increases for food or an agricultural rent system which is considered as unjust. "Pull"-factors on the other hand

30   describe all the different positive expectations potential emigrants have of their target countries. These include ideas of political and economic freedom as well as prospects of better economic opportunities, e.g. easier property acquisition, commercial freedom or the availability of fertile farmland as a free commodity. This push and pull-concept was complemented by the theory of "network-"or "chain-" migration. It describes how the so-called "pioneer-migrants" motivate their relatives and friends to migrate, supporting them with information and financial help.

35   Recently, increasing discussions emerged on the influence of climatic conditions and natural hazards, which are now considered as an independent group within the push-factors. Climate and climatic variability have been discussed and presented as crucial environmental factors influencing human migration in diverse scientific studies (e.g. Hugo, 1996; Lutz

et al., 2002; Hunter, 2005; McLeman, 2013). The effect of climatic conditions on population dynamics and societal success and/or failure at different scales during ancient and prehistoric times, including settlement patterns and migration processes, was described on a mesoscale level by Lamb (1982), Diamond (2005), Linden (2006) and Fagan (2008). Even though the decision processes leading to migration can also be governed by various other factors aside from climate-related

5 circumstances (McLeman & Smit, 2006), current discussions consider climate and climatic change to play a role within trends in population dynamics (McLeman, 2011). In this context, the investigation of interconnections during the recent past at a regional scale seems to be a valuable case study. In this study, the question of climatic influences on the waves of migration in Southwest Germany in the course of the 19th century was evaluated. While in most cases during the 18th and the beginning of the 19th century religious disputes (Tuchtenhagen, 1999) and direct recruitment of settlers (Scheuerbrandt,

10 1985) had led to emigration from Southwest Germany, it was hereinafter increasingly governed by lack of income and latent poverty, as well as by an overall lack of perspectives. Thereby, population pressure, harvest failure and subsequent price increases seem to have played an important role with climatic conditions predominantly affecting the harvest yields, the quality of the products and thus food prices.

2. Study area

15 The study area – the present German state of Baden-Württemberg – is situated in Southwest Germany. From the Napoleonic times on, this area comprised the sovereign states of the Grand Duchy of Baden, the Kingdom of Württemberg and the principality of Hohenzollern-Sigmaringen, which was a part of the Prussian Kingdom (see Fig. 1). In the western part, this area includes the Upper Rhine Plain, which in the eastern part is bounded by the mountain ranges of Odenwald and Black Forest. The Swabian Alb is located further east. Towards the south, the High Rhine (Hochrhein) and Lake Constance form

20 the borders to Switzerland and Austria.

Climatically the study area belongs to the so-called maritime influenced mid-latitudes with a temperate climate, expressed by a yearly temperature mean of +9 °C and 1000 mm annual precipitation with a slight maximum in summertime, but year-round precipitation (Cfb after Koeppen-Geiger – indicating a warm temperate climate, fully humid, with warm summers). The year-to-year variability is relatively high and various extremes occur, e.g. flood events, prolonged cold periods and

25 storms in winter as well as heat waves and droughts. Regional differences exist between the low-lying and somewhat warmer Upper Rhine Plain and the cooler mountainous areas of the Black Forest and the Swabian Alb reaching up to nearly 1500 m. Due to the topographic situation, the annual precipitation varies between 500 mm and 2000 mm. Soil conditions also change between rich Luvisols above Loess and poor podsolic Cambisols and Podsols above igneous rocks. These regional climatic and soil variations explain the differentiated ecological conditions, which have had a significant influence

30 onto harvest results and their regional variations.

Figure 1. Study area including the historical boundaries (Landeszentrale für Politische Bildung Baden-Württemberg, modified).

3. Working hypothesis and methodological concept

The aim of this study was the analysis and quantification of the effects of climatic conditions on migration. The underlying

35 hypothesis was that emigration in the 19th century was a function of climate and other environmental, as well as economic and socio-political factors. The main drivers were considered to be population development itself as well as changes in harvests yields and subsequent price developments; additional presumed push-factors were earning opportunities, latent poverty and religious and political discrimination, as well as a general lack of perspectives. Some of these factors, e.g.

harvest yields, quality and pricing, are more or less climate dependent. In addition, they are considered as crucial concerning the individual economic and social conditions.

Firstly, relevant numerical data on migration development and the assumed influencing factors were collected and compiled. Emigration data were used to identify periods with an above-average number of emigrants, which we referred to as "waves".

5   Focusing on the so-called "peak-years", the six resulting waves of migration were characterized by assessing appropriate available indicators. As temperature, precipitation, crop yields and cereal prices were considered as the main climatically influenced drivers of the effect variable *emigration*, these variables were used for an event-specific, statistical analysis. To evaluate more in depth the emergence of the specific waves of emigration, an additional analysis of qualitative, descriptive data with respect to social, economic and socio-political factors was carried out. Finally, statistical models were constructed

10 to test and quantify the assumed correlations and linkages between the identified drivers of emigration on a long-term basis. In Fig. 2 the conceptual framework is outlined.

Figure 2. Framework for the evaluation of climatic influences on migration.

4.   The long-term development of population, migration, harvest yields, pricing and climate

15 For the quantitative evaluation of the selected main variables, numerical data of population development, migration, harvest yields, cereal prices and climatic elements were acquired from different sources as described in detail below. The climate information available as measurement data could be compiled from the KNMI-explorer (Royal Netherlands Meteorological Institute, Dutch national weather service, http://www.knmi.nl/home), the CRU (Climatic Research Unit (England, University of East Anglia), http://www.cru.uea.ac.uk/) and the German Meteorological Service (DWD, http://www.dwd.de). The

20 historical data were retrieved from the collaborative research environment for climate and environmental history www.tambora.org.

4.1 Overall population development and migration in Southwest Germany during the 19th century

The consistent compilation of population data presented by the project HGIS-Germany (www.hgis-germany.de) shows a general population growth in Baden and Württemberg between 1815 and 1886 (Fig. 3); only for the periods 1817/1818,

25 1833/1834 and 1851–1855 (Württemberg) and 1817, 1833/1834, 1851–1855 (Baden) slight declines are recorded. In the emigration debate during the 19th century the keyword "overpopulation" played an important role. The Napoleonic era (Napoleon I, 1769–1821) brought Baden and Württemberg comparatively large territories and population growth: in 1806 Württemberg became a kingdom and Baden a Grand Duchy. Both doubled the surface of their dominions and thus also had twice as many inhabitants to feed. In 1815 this process was basically completed. Both countries gained areas with

30 completely different legal traditions and religious affiliations, taking the administrations a relatively long time to adapt to the new situation.

Figure 3. Population development in Baden and Württemberg (1815–1886).

The study is based on the official migration statistics for the Kingdom of Württemberg taken from Hippel (1984), Güll

35 (2013) and from the "Württembergischen Jahrbücher" (WJB), which were published as of 1818. For the Grand Duchy of Baden official migration statistics are available since 1850 (Statistische Mitteilungen über das Großherzogtum Baden, 1881), while for the period between 1840 and 1849 there is only a total number of 23966 emigrants (Großherzogtum Baden, 1857). Figure 4 shows the annual development of the official migration from Baden and Württemberg during the period from 1812

to 1886. The dashed line represents the average migration from Württemberg during this period of time (4339 persons). The underlying data were collected every year end of September, therefore the date refers to the period from October of the previous year to September of the current year.

5   **Figure 4.** Official numbers of emigrants from Württemberg and Baden (1812-1886).

The research focused on the six biggest waves of emigration (see Fig. 4), with three of them clearly standing out, namely the ones during the years 1815–1817, 1850–1855 and 1881–1883, which had their peak years in 1816/17, 1853/54 and 1881/82, respectively. Three secondary waves were identified for the years of 1830–1832, 1845–1847 and 1863–1869, with their respective peaks in 1831/32, 1846/47 and 1866/67. As the sources provided reliable data for Baden only from the 1840s

10   onward, the long-term analysis was carried out only for Württemberg. It can be assumed, though, that emigration from both countries correlated strongly during the second part of the 19th century.

4.2 Harvest yields and pricing

To first get an overview of whether and how the development of grain prices correlated with the waves of emigration, the development of emigration from Württemberg was compared qualitatively with the annual average grain prices (Fig. 5).

15   This comparison shows a clear correlation: while in phases of massive price increases high emigration occurred, emigration numbers were lower in periods of price decrease. However, pricing does not exclusively reflect crop yields, it also was a subject of speculative share trading. Therefore it was necessary to also refer to other contemporary sources (e.g. newspapers, local and city chronicles) to assess the relationship between crop yields and pricing.

The pre-modern agricultural crises of the 19th century in Baden and Württemberg are known as agricultural crises of the "old

20   type", characterized by an insufficient relationship between population and harvest yields. After the strong start of the industrialization in the second half of the 19th century and the following reduction of mass poverty, however, a "new type" of agricultural crises developed, representing supply and sales crises of the second and third sectors (Abel, 1972). Already in the 19th century, the pricing no longer just depended on the harvest of a product, but also on the possibilities of selling it profitably. With the emergence of intermediate trade and wholesale and the improvement of import and export capabilities

25   by faster transport routes and connections, local markets started losing more and more importance, resulting in an ever-increasing dependency on large-scale trade flows.

Thus, the direct relationship between crop yields and pricing decreased progressively. One of the main inflationary factors at this time was the so-called "Fürkauf", a speculation-sale of agricultural products purchased from the producers before the harvest, and thus removed from the local market. Although this development could have also favorable effects with regional

30   crop failures possibly being offset faster on the larger markets – if capacity was available there, harvest yield remained the most important indicator for the development of prices for food and feed.

For the assessment of long-term trends, this study used the annual average prices of grain in the Kingdom of Württemberg since 1766 and for Baden between 1833 and 1850 and from 1868 to 1886. Because of a lack of available data for Baden (Borcherdt et. al., 1989), the following evaluation only includes the time series for Württemberg. For the individual times of

35   crisis, the relevant price data were collected from different newspapers, archival sources and collections. Figure 5 gives an overview of the development of average prices of cereals and the waves of emigration. In the course of the research, a further weather-sensitive indicator, the so-called "potato disease", which started to occur in the southwest of Germany in 1845, was found (see section 5.4). It can be assumed that this disease repeatedly acted as a further pressure on grain prices during the subsequent decades.

Figure 5. Comparison of grain prices and the number of emigrants in the kingdom of Württemberg (1812–1886).

4.3 Climate development in the 19th century

The general climate development for Southwest Germany during the 19th century until the onset of the anthropogenic driven

5 greenhouse gas climate of the 20th century can be described with the term "Little Ice Age". In general, temperatures lay below the 20th century mean, precipitation was somewhat higher. Three major cooling periods and two major warming phases characterized the midterm trend, including a high year-to-year variability (see Glaser & Riemann, 2009; Glaser, 2013). Major glacier re-advances leading to pronounced lateral moraines in the alpine regions came along with these cooling periods (Grove, 1988; Pfister, 1985). Additionally, several climatic extremes can be identified, like the flood of 1824 in large

10 parts of the study area (Bürger et al., 2006), as well as floods in 1882 and 1896 (Glaser et al., 2010; Himmelsbach et al., 2015), each one resulting from different underlying climatic causes. Further extremes like winter storms, chilly winters like 1831/32 or the extreme droughts of 1834, 1842 and 1853, wet years like 1851 and 1878 and extreme frost events in 1854 and 1883 caused casualties and devastated the land.

While the establishment of the official weather recording started late this century (around the 1880s), there are quite a

15 number of homogeneous time series available (with some gaps) for the cities of Karlsruhe (Baden), Stuttgart (Württemberg), and partly also for Heilbronn (Württemberg) (KNMI, CRU, DWD). In addition, there is a broad variety of different further sources, like chronicles of grape harvests, early local chronicles, newspapers or administrative acts.

Figure 6. Development of the mean annual temperature in Germany (area average according to Baur and DWD).

20 The development of the yearly mean temperature in Germany shows on the one hand the high year-to-year variability including extreme years like the cold year of 1831 and on the other hand the medium-term decade trend (orange) and the long-term trend (red). The long-term trend clearly shows the last decadal fluctuations at the end of the little ice-age and the pass into the modern "greenhouse climate", especially pronounced since the 1970th (Glaser, 2013). For further analyses we derived the Standardized Precipitation Index (SPI) and the Standardized Temperature Index (STI) from the precipitation and

25 temperature time series.

5.   Emigration peaks 1812–1886 and their underlying climatological and socio-economic causes

To assess the climatic trigger of the identified main peaks of emigration (see Fig. 4), a first analysis focused on the single peak emigration years. Subsequently, the associated waves of emigration were described more in depth concerning their various climatic conditions as well as the socio-economic and political background during the particular time periods.

5.1 Event-specific analysis

To obtain an integrated view of the assumed relevant indicators for migration (see section 2), standardized values for the times of the migration peaks were evaluated. As the data base for the research area of Baden was too scarce, the analyses were only applied to the Württemberg area. The data set consists of the monthly mean temperatures and precipitation sums of the stations Stuttgart (DWD, KNMI) and Stuttgart-Echterdingen (CRU, Harris et al., 2014) which have been available

35 since 1800, resp. 1825. Annual data of crop yields for the cereal types rye, oat, barley, spelt and wheat between 1846 and 1886 were published yearly in the "Württembergischen Jahrbücher". The reference value for the crop yields was the so-

called "Mittelernte" (middle harvest). This term is not the same as average yield, it rather took into account the factors of cultivation areas, harvest per area and the quality of the crops (comparable to the specific weight of every crop), which was calculated yearly. The "Mittelernte" mean was given the value of 100 with better harvest getting a higher, smaller a lower value. The mean annual prices for the cereals rye, oat, barley and spelt, available since 1799, were also taken from the

5 "Württembergische Jahrbücher" (WJB 1896, 2). The sources for emigration data are the ones mentioned above.

The data were standardized to allow for direct comparisons (see Fig. 7). The calculations were made using the software environment R, version 3.1.3 (R Core Team, 2015), and particularly the R packages 'Hmisc' (Harrell, 2016), 'SPEI' (Beguería, S. & Vicente-Serrano, S. M., 2013; Vicente-Serrano et al., 2010) and 'STI' (Fasel, 2015). The underlying time interval for standardization was 1816–1886, unless otherwise noted. The annual data of crop yields and cereal prices were

10 standardized by z-transformation following Eq. (1) (Bortz et. al., 2010):

$$z = \frac{x - \bar{x}}{s} \tag{1}$$

A standardized value z, the z-score, is defined by the deviation of the initial value x from the mean $\bar{x}$ divided by the standard deviation s. To attain a standardized, temporal aggregation of the initially monthly data of temperatures and precipitation, the 3-monthly and 6-monthly SPI and STI were calculated. Hereby, the 3-monthly SPI or STI of May and August indicated

15 the degree of precipitation or temperature during the spring (March–May) and summer (June–August) season, while the 6-monthly SPI and STI of August were used to attain indicators for the spring and summer half-year (March–August). Figure 7 shows the standardized variables event-specifically for the peak years of the largest waves of emigration from Württemberg between 1816 and 1886. It illustrates the assumed influence of the observed indicators on emigration by displaying the z-scores (see Eq. (1)) of cereal prices during a year of high emigration as well as the seasonal STI and SPI for

20 spring and summer and the z-scores of crop yields one year before a high emigration year.

Figure 7. Standardized indicators before and during the largest waves of emigration from Württemberg between 1816 and 1886
25 illustrating the magnitude of possible influence factors on the individual emigration peaks.

As precipitation data of the station Stuttgart (KNMI) were not available until the year 1825, the SPI for the year 1816 was calculated using data of Stuttgart-Echterdingen (15 km south of Stuttgart); annual data of crop yields for Württemberg were available as of 1846. The positive z-scores in Fig. 7 indicate 'warmer temperatures', 'higher precipitation', 'higher crop yields' and 'higher prices' whereas negative values by analogy indicate 'lower temperatures', 'less precipitation', 'lower

30 crop yields' and 'lower prices'. The decision to display spring and summer values for temperature and precipitation was based on the necessity to consider both seasons separately as relevant growth periods of the observed cereal types. To prevent a possibly misleading impression, this should be kept in mind when comparing the values of the climate parameters of *two* seasons with the annual values for crops and prices.

The z-scores show how significantly each indicator deviates from the underlying time period´s mean by displaying each

35 deviation divided by this time period´s standard deviation. For example, in the case of August 1816, the average temperature (14.6 °C) was subtracted from the mean of the whole time period of 1804 to 1886 (18.5 °C) and divided through the standard deviation of this period, which was in this case 1.5 (see Fig. 8). The STI of summer 1816 was calculated using the moving average of the months June, July and August; it has a value of -2.83, meaning that the mean temperature of summer 1816 falls below the mean of 1804 to 1886 by 2.83-fold of the standard deviation.

40 By exposing the quantitative dimensions of the indicators presumed to be associated with the largest emigration waves, Fig. 7 clearly demonstrates that every peak of emigration was characterized by a particular set of preconditions and subsequent

effects. Focusing on the climatic parameters temperature and precipitation, these results suggest that there was no unidirectional impact of weather conditions. Specific similar tendencies may have had opposing effects depending on the different seasons. This could be observed for example in the case of the year 1846: while rather warm spring temperatures in combination with sufficient precipitation may have stimulated growth, the subsequent extraordinarily hot summer and a lack

5 of rainfall may have been the crucial factors for the far too poor harvest in 1846, and thus the rise in grain prices in the same and the following year.

Subsequently, the different waves of emigration including their single peak years and the assumed associated indicators, quantified by z-scores, are described within their economic and socio-political background.

5.2 The emigration peak of 1816/17 as a consequence of the "Year without a summer"

10 One of the most prominent natural disasters of the 19th century was the massive eruption of Mount Tambora, located on the Island of Sumbawa, Indonesia, between April 5th and April 10/11th, 1815, causing the death of approximately 71000 people. Volcanic ashes with an estimated volume of more than 150 km³ were expelled into the atmosphere, reaching heights of up to 50 km. The eruption ejected roughly 60 Mt of sulfur into the stratosphere forming a global aerosol veil and obscuring the sun for more than two years. This caused pronounced global climate perturbations. Temperature decreases were observed for

15 the Northeast of the USA, in East Canada and in Central Europe, resulting in the so-called "Year without summer" in 1816 (Stommel & Stommel, 1983). Crop failures were widespread and, as a consequence, subsistence crises and famine occurred (Oppenheimer, 2003; Behringer, 2016).

Temperature records from Southwest Germany confirm this specific situation: the year 1816 was one of the coldest years of the century (Stuttgart 1816: 8.10 °C, with only 1829: 7.83 °C and 1879: 8.09 °C being colder, Karlsruhe 1816: 8.92 °C, with

20 only 1805, 1864, 1871 and 1879 being colder at 8.31 °C, Bale 1816: 7.2 °C with 1805 and 1879 featuring the same lowest annual means in air temperature). The year 1816 is not only characterized by a below average annual mean temperature but, more importantly, by the unfavorable distribution of temperature and precipitation during the growth period and the harvest season (see Fig. 8).

25 **Figure 8.** Temperature and precipitation for Stuttgart for the year without summer (1816).

For both territories, harvest yields for 1816 were described as "bad failure" (Stieffel, 1842; Dürr, 1895). To assess and understand the general societal and environmental conditions during this year, the preceding years have to be taken into account. No one was prepared to deal with such an extreme year: the last full harvest dated back to 1812, since then granaries had not been filled completely due to the Napoleonic Wars and marauding troops. It seemed that, due to the

30 turmoil of war, large parts of the agrarian country were not cultivated in these times, which reduced the total harvest yields even more. As a consequence, large portions of the population were highly vulnerable with respect to food security. In addition, responsible politicians reacted with a substantial and disastrous time lag: it was not until November 1816 that tariff measures regulating import and export of grain were implemented, which was definitely too late.

In Württemberg, several thousand bushels of grain - worth 1.4 million guilders - had been exported instead of supplying

35 domestic population. In October it was already too late for a government-initiated additional purchase of grain on foreign markets. It was not possible to deliver the urgently required goods to Württemberg or Baden before wintertime. Transport was severely hindered and blocked by fast-freezing rivers with ice break-up taking place quite late in the following spring. Forage production also failed due to the wet and cold weather, leading to massive animal diseases. Hence, farmers sold their

livestock in large quantities before wintertime. Initially, this caused a substantial decline of prices in the meat market, which turned into the opposite in the following spring (Gehlinger, 1897). According to official statistics 22630 emigrants left the Kingdom of Württemberg between 1815/16 and 1817/18, with a peak of 17500 emigrants in 1816/17. The municipalities in charge of provisioning the poor were forced to buy large amounts of grain from the royal granaries, consequently

5 accumulating debts. This led to tax debts summing up to 8975783 guilders in the Kingdom of Württemberg alone. Between November 1816 and January 1817 the government of Württemberg imposed regulations to set up 'Wohltätigkeitsvereine' (benevolent societies). The Grand Duchy of Baden followed in March 1817 with the foundation of the 'Allgemeinen Wohltätigkeitsverein für das Großherzogtum Baden zur Bewältigung der Auswirkungen des Krieges und der Mißernte' (Benevolent Society for the Grand Duchy of Baden to Overcome the Impacts of War and Harvest Failures) under the

10 auspices of the Grand Duchess Stephanie (1789–1860). In April 1817 export tariffs were further increased (Regierungsblatt Württemberg).

In Baden, income from tariffs was re-allocated to the suffering municipalities in February 1817. In June 1817 both countries prohibited the speculative sale of the up-coming grain harvest 'auf dem Halm' (i.e. sale of growing crops before the harvest), and in Württemberg a census of all grain in stock took place, in the hope of triggering a decline in grain prices by

15 demonstrating that there were sufficient provisions until the coming harvest (Regierungsblatt Baden). The case of the year 1816 shows how subsequent unfavorable seasonal tendencies within one year may have an amplifying effect (see Fig. 7): while mean spring temperatures were unusually low, the summer can even be considered as extremely cold (z-score: -2.83) and quite wet (z-score: 1.30). These unfavorable conditions for crops ultimately contributed to a strong increase in cereal prices. In conclusion, the main reason for the crisis and famine of 1816 was the harvest failure in large parts of Europe due

20 to the adverse climate conditions. This clearly demonstrates that the 1816/17 migration peak was triggered by the climatic consequences of the Tambora eruption in 1815, enforced by a number of additional stressors (Heünisch, 1857; WJB 1818.1).

5.3 The emigration wave between 1829 and 1833 – unfavorable weather conditions, harvest failure and speculations

Between 1829 and 1833 the official number of emigrants from the Kingdom of Württemberg reached 18650, with a peak of

25 7066 emigrants in 1831/32 (see Fig. 4).

Regarding the climatic conditions, these years were not particularly anomalous, a notable exception being the chilly winter of 1829/30 which featured 112 ice days (today: frost days) in Stuttgart and 92 in Karlsruhe and was one of the longest and coldest winters since 1788. On February 2nd, the coldness in Stuttgart and Tübingen reached -32 °C and in Tuttlingen even -35 °C. Even in 1788 temperatures had not been as low (WJB 1830). The following year 1831 was characterized by just

30 slightly increased temperatures compared with the whole evaluation period (see Fig. 7, z-scores: 1.12 and 0.48), whereas precipitation rates during spring and summer were rather high (z-scores: 1.58 and 1.09). However, a possible influence on crop yields for this time period cannot be established quantitatively, as crop data were not available for years prior to 1846. The harvests of 1830 and 1831 in Baden were described as 'mangelhaft' (deficient), whereas in Württemberg the harvest yields were qualified as 'mittelmäßig' (fair) and 'noch ziemlich ergiebig' (still quite productive) (Stiefffel, 1842; Pfaff,

35 1846). Nevertheless the situation in Stuttgart got so bad that the soup kitchens for the poor had to be opened. In addition to the insufficient yield result, documentary sources point at another major reason for the soaring grain prices triggering the emigration, found in market speculations rather than in harvest failure. Even contemporaries could not see any connection to harvest yields in 1832. Instead, speculations of wholesale and intermediary vendors were considered to be responsible for the development of grain prices (Pfaff, 1846, p 351; Freiburger Zeitung, May 2nd 1832).

5.4 The emigration peak of 1846/1847 – a hot and dry summer, low crop yields, high prices and the specific situation of the potatoes disease

In the Kingdom of Württemberg, the number of emigrants had already been increasing since the year 1843/1844. Between 1845 and 1847, 16244 persons emigrated according to official statistics (see Fig. 4).

5   Regarding the climatic conditions of these years, the summer 1845 was generally wet with an extensive period of rain in June. In 1846 an exceptionally hot (see Fig. 7, z-score: 2.75) and dry summer (z-score: -0.93) occurred with abnormally low precipitation rates during May and June (see Fig. 9). This resulted in low crop yields (see Fig. 7, z-score: -1.97) and led to strikingly high cereal prices (z-score: 1.85) in the subsequent year 1847.

10   **Figure 9.** Temperature and precipitation for Stuttgart (1846).

Harvest yields for the years 1843 to 1845 in the Kingdom of Württemberg are described as „nicht so ergiebig" (not abundant) for winter wheat, but for spring wheat as „den Erwartungen entsprechend" (according to expectations) (WJB of the years 1843–1845). In the Grand Duchy of Baden, harvest yields 1843 are labeled as „mittlere Ernte" (average yield), in 1844 the harvest was „reich und gut" (rich and good) and in 1845 the weather was „sehr fruchtbar" (very fertile).

15   Nevertheless, according to other reports for 1845, the grain harvest yield was below average (Fleischmann, 1902). In 1846 the harvest yields in Baden were good only for oat and barley, the results for wheat and rye were considered poor, and for spelt (the most important bread grain) as average (Fleischmann, 1902). In Württemberg, both winter and spring wheat harvests resulted in only mediocre yields (WJB 1846.1). Insufficient yields were mainly recorded in areas characterized by unfavorable edaphic and climatic conditions, such as the Jura of Swabia, Odenwald, or the Black Forest.

20   While the grain yields seem to have been average to fair, another basic food product came under pressure: in 1845, a potato disease appeared in Württemberg and Baden for the first time. Recent research concerning the origin of this disease shows that it was first observed in Belgium in June 1845 and spread out from there throughout Central Europe and its southern parts until September. It is still unclear if it was brought to Europe from North or South America by seeds. In Ireland, this illness caused an extreme famine and in consequence an exceptionally high emigration peak because of the one-sided dependence on the potato plant and crop failures of up to 90 % While this fungal infection was completely specified in 1861, an operative fungicide was not developed before 1888 (Herrmann, 2011).

Figure 10. Potato harvest in Württemberg and the precipitation index for April-September (Stuttgart, 1848–1886).

Figure 10 shows the time series of the annual harvest of the main crop potato and the precipitation during their growth 30   period between April and September (6-monthly SPI of September for Stuttgart) after the first appearance of the potato disease in 1845. The inverse development of both time series indicates that during wetter years, i.e. years with a higher SPI, a higher percentage of potatoes fell victim to blight.

To understand the vast impact of the potato disease, especially for the Kingdom of Württemberg, one has to consider that an increasing number of factory workers also acted as part-time farmers at this time, favored by the partible inheritance system. 35   These subsistence economy activities in horticulture and agriculture on small inherited plots played a crucial role in ensuring food security. Especially potato cultivation was widespread because the plant was well suited for such activities due to the relatively small expenditure of work and its modest edaphic requirements. As a consequence, as from autumn 1845, the potato harvest failure resulted in a huge pressure on grain prices not only in the cities but also in the rural areas (Megerle, 1982). The potato disease of 1845 was not unique, but appeared again and again until the 20th century in varying degrees of 40   intensity, accordingly affecting crop prices.

Additionally, both Baden and Württemberg had completely lost freedom of action regarding tariffs on grain after joining the "Deutsche Zollverein" (German Customs Union), making it impossible to implement any measures to restrict the export of grain if the other members of the union denied such plans. Only a ban on the export of potatoes could be implemented (Landwirtschaftliches Wochenblatt für das Grh. Baden, Issue July/August 1845). In the following spring, potatoes started to

5 grow well and, as a consequence, the export ban was released. However, the dry summer of 1846 was again unfavorable to the growth of the crop. Additionally, the late blight spread into hitherto unaffected areas of Württemberg. In Baden, areas with unfavorable edaphic and climatic conditions suffered again from potato harvest failures. Collections of the benevolent societies dedicated to these regions were carried out as of 1847 (Freiburger Zeitung, May 14th 1847). In the municipalities, which were still responsible for the relief of the poor, soup kitchens were re-opened already in autumn 1846 (Freiburger

10 Zeitung, May 18th, 1847).

The increase of grain prices reached its peak between April and May 1847. As of the beginning of May, riots caused by hunger occurred in the cities of Ulm, Tübingen and Stuttgart (Kingdom of Württemberg) and also in Mannheim and Villingen (Grand Duchy of Baden) (Dürr, 1895; Brüning, 2007). At this point, the governments of both countries again initiated a census of existing food stocks to show that there were sufficient provisions and to calm down the markets in order

15 to level out prices, at least until the coming harvest (Freiburger Zeitung, May 7th 1847 and Regierungsblatt für das Königreich Württemberg, May 10th 1847). In both countries, these activities were successful along with further regulations. In summary, it can be said that although the rather warm spring temperatures in 1846 still may have been growth stimulating in combination with sufficient precipitation, the extraordinarily hot summer with a lack of rainfall seems to have been the crucial factor for the far too poor harvest. In consequence, prices for cereals increased strongly in the same and the following

20 year. The almost complete failure of the potato harvests between 1845 and 1847 additionally increased the pressure on grain markets. This shows that the emigration of those times was mainly triggered by climatic conditions via their effects on harvest yields and pricing.

5.5 The biggest emigration wave between 1850 and 1855 – low harvest yields, war and administrational support

During the biggest emigration wave from 1850 up to the end of 1855, a total of 61944 people from Württemberg and 60606

25 people from Baden left their countries. The main peak was reached 1853/54, when 21320 (Württemberg) and 21561 people from Baden emigrated. No other period within the 19th century reached this dimension (see Fig. 4).

In the summer of 1850, the weather tended to be damp and cool, reflected by the very small number of 25 summer days in Heilbronn and Stuttgart. The following summer of 1851 was also unusually humid, with only 32 summer days in Heilbronn and 23 in Stuttgart.

30 The winter 1851/52 led to famines in the climatically least favored areas of Odenwald and Black Forest (particularly in the counties Pforzheim, Waldshut, Säckingen, Schönau, Sankt Blasien and Wolfach). The support commissions again resumed their commitment: donations were collected and soup kitchens were re-opened (Fleischmann, 1902). In 1852 the months of August and September were wet again. In 1853, an unusually cold (see Fig. 7, z-score: -1.53) and wet (z-score: 1.26) spring was followed by a moderate summer (z-scores: 0.93 respectively 0.54); crop yields were below average (z-score: -2.27) and

35 cereal prices slightly increased (z-score: 1.25) during the following year.

With the outbreak of the Crimean War (1853–1856) France changed its customs regulations, banning the export of food and abolishing import tariffs. Hereafter, particularly Swiss buyers turned their attention to the Baden grain markets, putting a strong pressure on grain prices.

When in 1854 harvest yield was again only average, the effects of the protective customs regulations, which had been imposed by France, Russia and the other war-participating European states due to the Crimean War, became clearly apparent. Now the United States of America, which had always been a good alternative for grain purchases, was also involved in the Crimean War and did not have any transport ships available. Therefore, prices remained at a high level, even

5 after the rich harvest of 1855, as no stocks existed due to the difficult previous years (Fleischmann, 1902).

The specific feature of these years lies above all in the fact that the Grand Duchy of Baden – as the only country at this time – acted according to an 'emigration concept' to get rid of 'the poor' by paying for their emigration. This practice was pursued for years, thereby encouraging emigration (Hansen, 1976; Fies, 2010). Beside the state, communities and private people also financed this kind of emigration (see Table 1).

10 **Table 1.** Total financial support from the state, communities and private persons for the emigration from the Grand Duchy of Baden 1850–1855 (Fies, 2010).

The aim of getting control over the 'overpopu____' was apparently achieved, as a comparison of the censuses of 1852 and 1855 points out: in 1852, 1357208 people lived in Baden; until 1855, despite an excess of births of 14347 people, the population decreased by 3.12 %. Official agencies led this decline back to emigration alone, thus proving the success of this

15 policy. The support of emigrants in the Grand Duchy of Baden did not stop completely after 1855, but it was limited to isolated cases and single municipalities (Statistisches Jahrbuch für das Großherzogtum Baden, 1868 ff.).

All these facts indicate that this largest emigration wave was triggered by a number of forcing factors: on the one hand the unfavorable climatic conditions and a subsequent harvest failure again caused price increases, on the other hand the emigration policy of the Grand Duchy of Baden financially supported and thus triggered emigration. Additionally, the whole

20 situation was negatively influenced by the overall geo-political situation, with the Crimean War hindering the usual trading system.

5.6 The emigration wave between 1863 and 1869

During a smaller, but longer-lasting secondary emigration wave from 1863 to 1869, a total of 36770 people emigrated from Württemberg and 16033 people from Baden. For the years after 1866, this emigration can mainly be explained by a further

25 increase of the number of diseased potatoes in Württemberg (WJB 1866 ff.). Additionally, frost in lower altitudes is reported for Württemberg for the 23rd of May 1866, resulting in a significant loss of winter crops (WJB 1866).

Regarding temperatures, the year 1866 was on average (see Fig. 7, spring z-score: 0.31 and summer z-score: 0.36), however, spring was slightly dry (z-score: -0.66) and summer rather wet (z-score: 1.37), with especially the wet July being responsible for the frequent appearance of the potato blight (Dürr, 1895). Crop yields developed significantly below average (z-score: -

30 1.87). Also in the subsequent year 1867, the grain harvest in Württemberg remained behind the previous 10 years´ average, which is attributed mainly to the cool and rainy months of June and July (Dürr, 1895). In consequence, the cereal prices (z-score: 0.88) increased slightly. Despite these weather conditions, only 4 % of the potatoes in Württemberg were affected by the disease and the potato harvest was more yielding than in 1866 (WJB 1867).

In a climatologically broader context, the emigration between 1863 and 1869 fell into a phase of warmer temperatures (see

35), with quite inconsistent weather conditions during this whole period. In synopsis, the year 1863 was too dry and in parts too warm for effective crop production. Noteworthy is the six-week drought starting in July with rain not returning until September. Heat and drought also characterized the subsequent summer of 1864, while the winter 1864/65 was considered as long, lasting until the end of March. Then again, the weather became exceptionally warm, some periods even hot. Accordingly high was the number of summer days (103 days in Stuttgart and 57 days in Heilbronn). The following year

1866 can be classified as rather average with a hot, early summer, a wet August and a very dry October. The next winter, 1866/67 was mild, with May being very dry and warm, June and July, however, exceptionally chilly and humid, and August again unusually hot. In autumn, drought stroke again. The year 1868 generally was too warm and dry. In 1869, the weather was again very contradicting with respect to hygric as well as thermic conditions, with February being very warm, March

5 was rather cold, April and May again exceptionally warm, June, however, too cold; then it was very hot again until mid-August, while the second half of this month was rainy and chilly.

Interestingly, in this specific period of emigration, not one-directed adverse weather conditions, but rather the dichotomy of several subsequent seasons influenced harvest yields negatively. In combination with slightly increased market prices, these can be considered as a substantial cause of the emigration peak of 1866/67.

10 **5.7 The emigration wave between 1880 and 1886 – attraction of the 'New World' and family reunifications**

In the last striking emigration wave between 1880 and 1886, a total of 54776 people emigrated from Württemberg and 18822 people from Baden (see Fig. 4).

The year 1880 began with a severe winter and continued with a 'beautiful' spring. Noteworthy was the rainy period from late September on, which led to two smaller Neckar floods on the 20th and 28th of October. The year 1881 brought a good,

15 above-average harvest (see Fig. 7, z-score: 0.44) and was, apart from a cool January and October and hot July and August, marked by average temperatures (z-score spring: 0.05, z-score summer: 0.58). January, May, November and December were exceptionally dry (z-score spring: -0.66, z-score summer: -0.26). Even though climatic conditions and harvest yields have been quite good, cereal prices in 1882, the year with peak emigration, increased (z-score: 1.03).

The year 1882 began with snow and ice that lasted until mid-February. After a warm start of April, snowfall arose again.

20 June and July were too wet. However, this year was particularly characterized by two extreme flood events in November and at the end of December in Württemberg and Baden. 1883 was remarkable with regards to a cold spell since mid-March and high humidity in July. Although this did not diminish the abundant harvest of potatoes in this year, the entire harvest stayed somewhat behind the previous year´s. Climatically, 1884 was an almost average year which was a little warmer in spring and generally dryer than on average. 1885 brought a rich harvest of potatoes and, on the regional level, very differing crop

25 yields. One may highlight the chilly and quite humid months of May, August and October. In 1886, the harvest was a bit less than average and grain had to be imported. It was cold and wintry up to the 20th of March; summer was warm and nice and lasted until the middle of September and also autumn remained mild until the 20th of December. Subsequently, it came to a very strong snowfall, bringing everyday life to a standstill.

From the climate perspective, no special causes can be identified as strengthening moments for emigration. By then, world

30 food markets were better interconnected and more effective. As of the founding of the German Empire in 1871 consistent trade and customs measures existed, so there were enough and better buffering capacities to balance out short-term regional food shortages. The construction boom, which started shortly afterwards and the expansion of the public sector, brought more job opportunities for the people, e.g. in railway and post service, river training and road construction. Over all, a strong increase of the food sector´s resilience against climatic influences on regional crop yields can be noticed.

35 Looking for a major reason for this emigration wave, current research stemming from a more societal point of view concludes that the 'attraction of the New World' as a whole and the 'reunification' of successfully emigrated family members were the main drivers (Fies, 2010).

6. Quantitative analysis of the long-term influence of unfavorable climate, crop failure and increased prices on emigration

All major waves of emigration and single emigration peaks from Southwest Germany into North America revealed a chain of effects consisting of unfavorable climatic conditions – poor crop yields – rising cereal prices – emigration. For a

5   quantitative estimation of the climatic influence on the observed emigration, an assessment of the long-term relationships between the related variables was carried out. The method used was a statistical analysis of the joint indicators temperature, precipitation, cereal and potato yields and cereal prices, and their influence on the target value, emigration. This was explored by linear regression modelling of the particular connections within the assumed chain of effects. The analyses were performed on the data introduced in section 5.1 for the maximum time period, based on the availability of the individual data

10   sets. So, for example, the availability of crop yield data limited the time interval for observations including this variable to the period 1846–1886. Taking into account that every food plant needs different climatic conditions during the year for optimal growth, we separately modeled the climatic dependence of cereal crops and potatoes.

The assumption of normality was checked and verified by the Lilliefors test (Gross & Ligges, 2015), with normal distribution only rejected for total migration numbers: according to the likelihood and the data type (discrete), a negative

15   binomial distribution was chosen for this variable. Regression analyses on the relationships between the different variables were performed using R (R Core Team, 2015):

(1)   cereal crop yields ~ STI + SPI: a linear model of mean annual cereal crop yields (mean of wheat, barley, oat, spelt and rye) as a function of the 6-monthly STI and the 6-monthly SPI (considered as descriptors for weather

20   conditions during the course of the previous six months) was constructed for the time interval of 1846–1885. The strongest effect could be identified for the 6-monthly STI of February and the 6-monthly SPI of August as predictor variables. The model was significant ($F_{(2,37)} = 7.12$, $p < 0.01$, adjusted R^2: 0.24), with both predictors being significant ($p < 0.05$). Both predictors had a negative effect on the response variable.

This model explains about 24 % of the variance of cereal crop yields, with the SPI accounting for the major

25   proportion. This indicates a slightly positive effect of colder temperatures during preceding autumn and winter (September to February), especially for winter wheat and winter barley, and a stronger, negative effect of wet conditions during the growth period (in this case March to August) on the total crop yields.

(2)   potato crop yields ~ STI + SPI: a further linear model of potato crop yields as a function of the STI and the SPI was

30   constructed for the time interval of 1846–1885. The strongest effect could be identified for the 6-monthly STI of September and the 6-monthly SPI of August as predictor variables. This model was significant ($F_{(2,37)} = 6.35$, $p < 0.01$, adjusted R^2: 0.22) with the SPI as significant predictor ($p < 0.05$) and both predictors accounting for each about 10 % of the variance.

This model demonstrates a positive effect of the STI and a negative effect of the SPI on crop yields, which was

35   interpreted as a general increase of the potato harvest with warm and dry weather conditions during April to September. This may have been linked to the severe reduction of the potato harvest in years of high prevalence of the potato disease which seems to have been enhanced by wet conditions (see section 5.4).

(3)   cereal prices ~ cereal crop yields: a significant negative effect of mean cereal crop yields (1846–1885, mean of the

40   crops of barley, oat, spelt and rye) on mean cereal prices of the subsequent year (1847–1886, mean of the prices of barley, oat, spelt and rye) could be identified by a linear model ($F_{(1,38)} = 16.83$, $p < 0.001$, adjusted R^2: 0.29). This

was understood as a confirmation of the obvious link between price increases due to supply shortages. A temporal offset of one year emerged for the influence of crop yields on cereal prices, meaning that the effect on cereal prices in the same year was comparably smaller than in the following year.

5   (4) migration ~ cereal prices: finally, a generalized linear model was used to assess the effect of cereal prices (mean of the prices of barley, oat, spelt, rye and 'Kernen') on migration numbers within the time interval 1816–1886. A negative binomial regression model was chosen (Venables & Ripley, 2002) due to the distribution of the response variable 'migration'. This model was significant and shows that about 38 % of the variance of migration numbers between 1816 and 1886 can be explained by the cereal price trend (compare Fig 4, section 4.2). No considerable
10   overdispersion was found. The years 1818, 1819, 1849 and 1854 were identified as influential data points by Cook´s distance (Cook & Weisberg, 1982; Williams, 1987). Nevertheless, after excluding these points from the analysis, the model was still significant with $R^2 = 0.38$. Years with higher emigration rates were mostly accompanied by above-average cereal prices. The resulting pressure of food scarcity on individuals was considered as one important reason for emigration.

15 For all of the presented models, the residual plots were checked visually, without finding indications of violations of linearity, homoscedasticity or normality. The assumption of a normal distribution of the residuals was also not rejected by the Shapiro-Wilk normality test (Gross & Ligges, 2015).

Figure 11. Chain of effects on emigration in the kingdom of Württemberg with corresponding coefficients of determination.

20 The results of these models (Fig. 11) demonstrate weak to moderately strong effects and can be considered as a validation, albeit at different degrees, of the assumed influences of temperatures and precipitation on crop yields, of crop yields on the development of cereal prices and finally of the influence of cereal prices on emigration numbers of Southwest Germany during the 19th century.

7.   Discussion and conclusion

25 First of all, the quantitative and qualitative discourse analysis of the potential causes of emigration from South-West Germany shows that larger and smaller waves of emigration can be detected, with different underlying reasons. A closer look at the larger emigration waves indicates, particularly for the specific peak years, that a sufficient food supply of the population was not ensured, which increased the willingness for emigration. The influence of climatic conditions on emigration is an indirect one, as climate is a crucial factor for growth conditions and the ripening process of diverse crops,
30 subsequently influencing price developments on the food markets – depending on supply and demand. Regarding the evaluation period of 70 years, however, it turned out that the influence of the assumed chain of effects 'climate – harvest yields – prices' was not equally pronounced on the different peaks of emigration: while the peak years of 1816/17, 1846/47, 1853/54 and 1866/67 were primarily climatically induced, the major reasons for the emigration peak of 1831/32 and the last emigration peak of 1881/82 were seen in price speculation and various socio-political factors. Furthermore, this study
35 revealed that in some cases various factors came together to cause larger emigration waves: the already existing food shortage was aggravated by delayed political reactions, which in turn intensified the food supply crises, thereby triggering emigration (see section 5.2). Generally, the society had a positive attitude towards emigration during the considered decades, and administration even encouraged it financially, like in the 1850th in the Grand Duchy of Baden (see section 5.5). Towards

the end of the 19th century, the resilience against climatically adverse seasonal conditions was strengthened by more efficient trading routes and better access to food markets, finally reducing the climatic impact on migration (see section 5.7). Despite its detailed hermeneutic approach which also focused on the complex socio-political background of food shortages in the 19th century, this study highlights the existence of a long-term influence of climate on emigration. For the statistic

5   evaluation, linear modelling was applied (see section 6). The models show that the climatic variables temperature and precipitation explain 24 % of the total variation of grain harvests and 22 % of potato yields. Cereal crop yields, in turn, account for 29 % of the total variation of cereal prices, and these for 38 % of the variation of the variable emigration. The quantification of the relationships between these variables and their interlinked dependencies confirm the initial hypothesis of the considerable influence of weather conditions on harvest and the subsequent effects on emigration from Southwest

10 Germany during the second half of the nineteenth century.

8.   Data availability

Model results of this study are available from the corresponding author upon request (ruediger.glaser@geographie.uni-freiburg.de). For access to historical sources see www.tambora.org.

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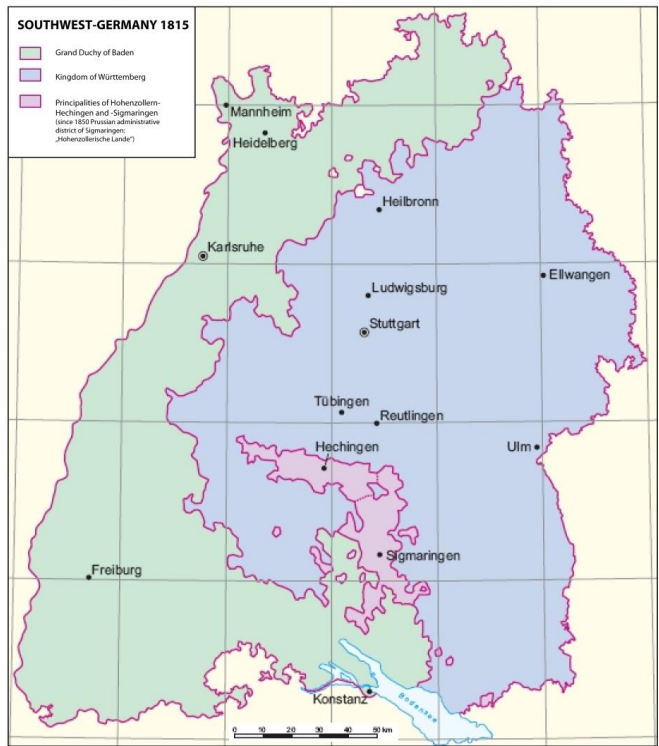
Table 1. Total financial support from the state, communities and private persons for the emigration from the Grand Duchy of Baden 1850–1855 (Fies, 2010).

Year	Number of Emigrants	Financial support [Florin]	Per person [Florin]
1850	2338	54090	23
1851	7913	264614	33
1852	14366	456706	32
1853	12932	224613	17
1854	21561	516688	24
1855	3334	85072	26
Total	**62444**	**1601783**	**ca. 26**

Figure 1. Study area including the historical boundaries (Landeszentrale für Politische Bildung Baden-Württemberg, modified).

5 **Figure 2.** Framework for the evaluation of climatic influences on migration.

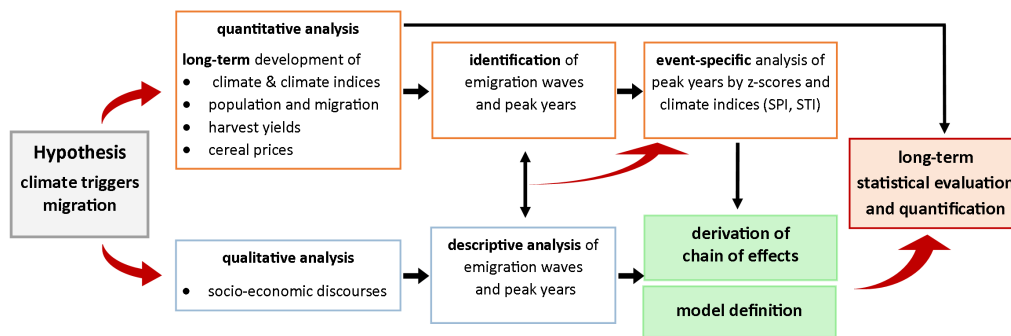



Figure 3. Population development in Baden and Württemberg (1815–1886).

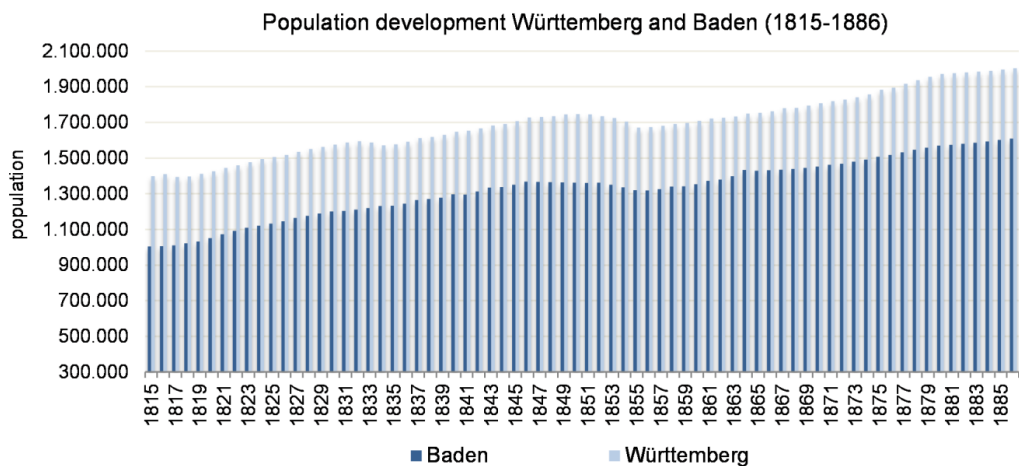



Figure 4. Official numbers of emigrants from Württemberg and Baden (1812-1886).

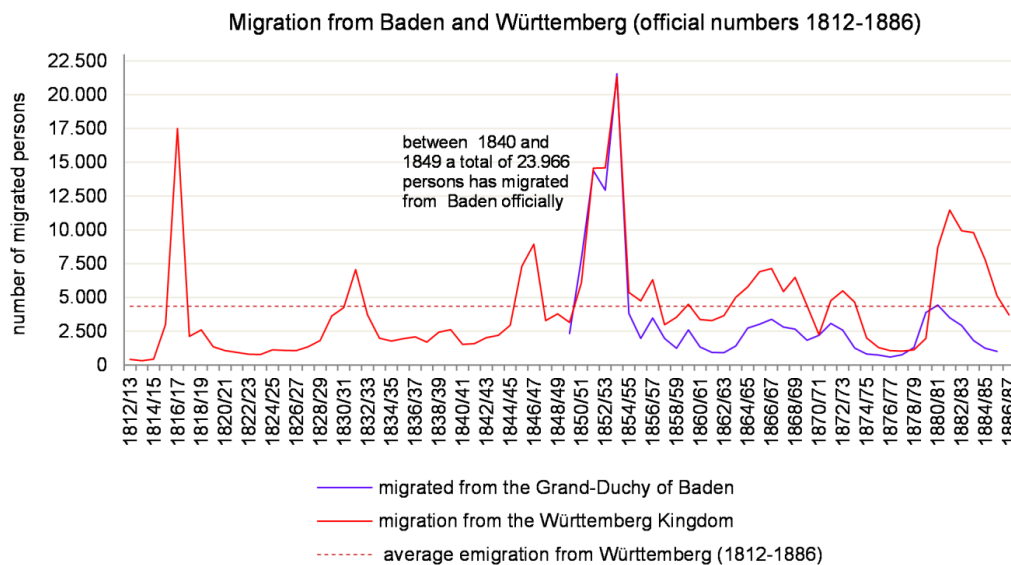



Figure 5. Comparison of grain prices and the number of emigrants in the kingdom of Württemberg (1812–1886).

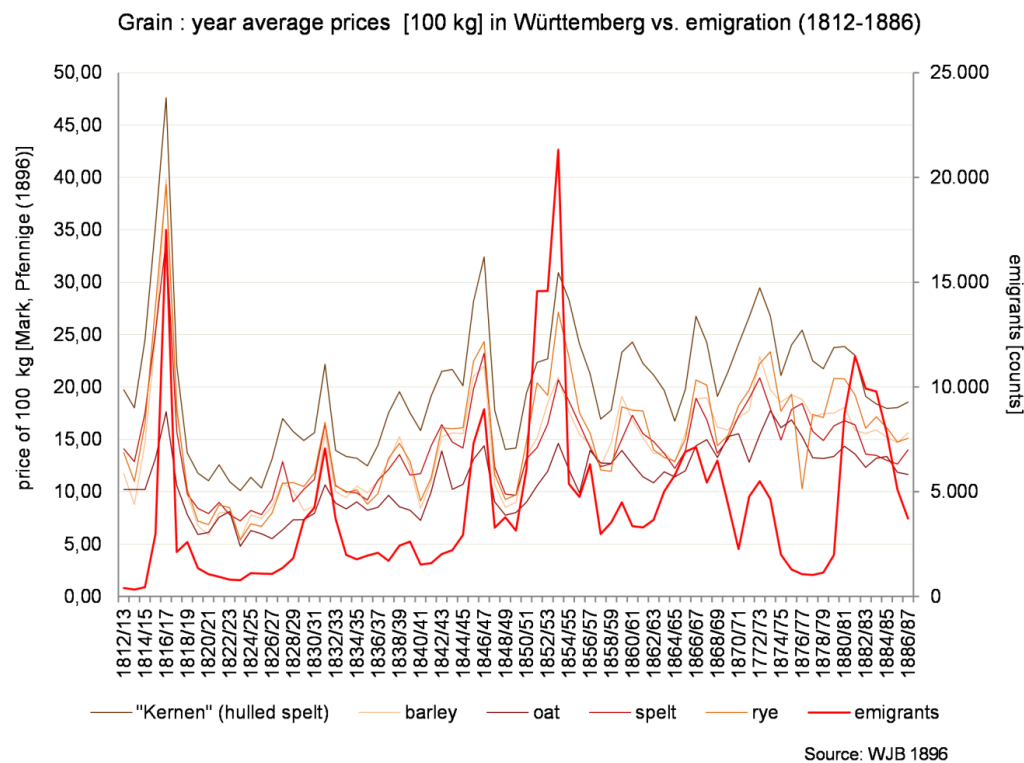



Figure 6. Development of the mean annual temperature in Germany (area average according to Baur and DWD).

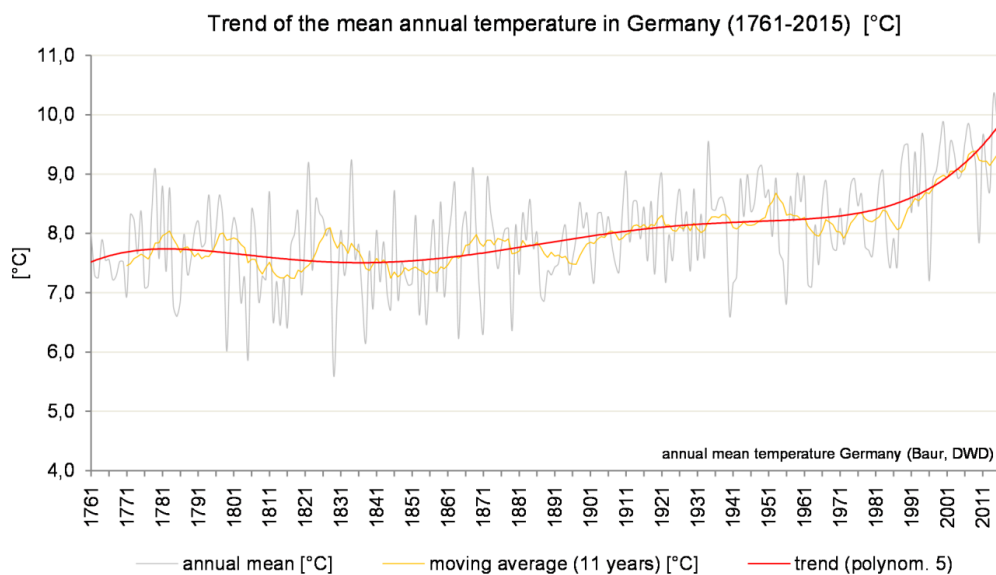



Figure 7. Standardized indicators before and during the largest waves of emigration from Württemberg between 1816 and 1886 illustrating the magnitude of possible influence factors on the individual emigration peaks.

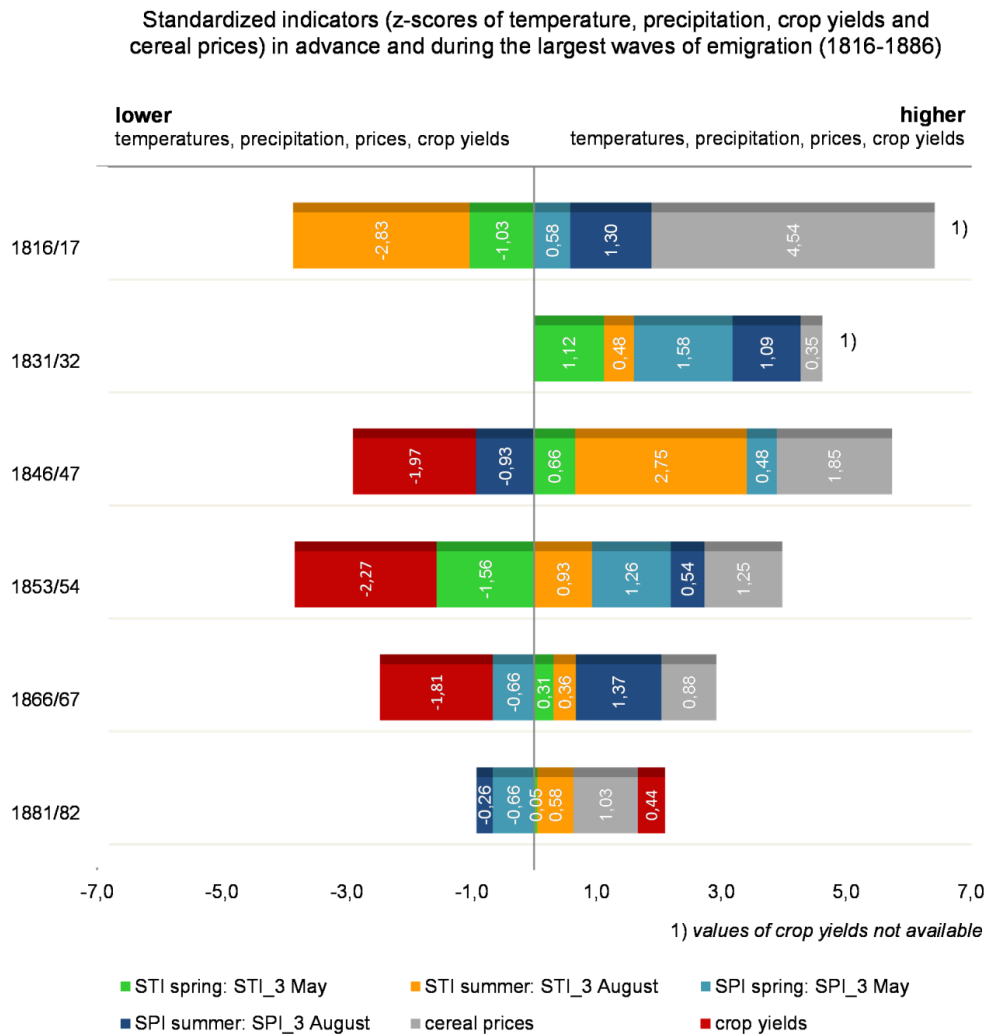



Figure 8. Temperature and precipitation for Stuttgart for the year without summer (1816).

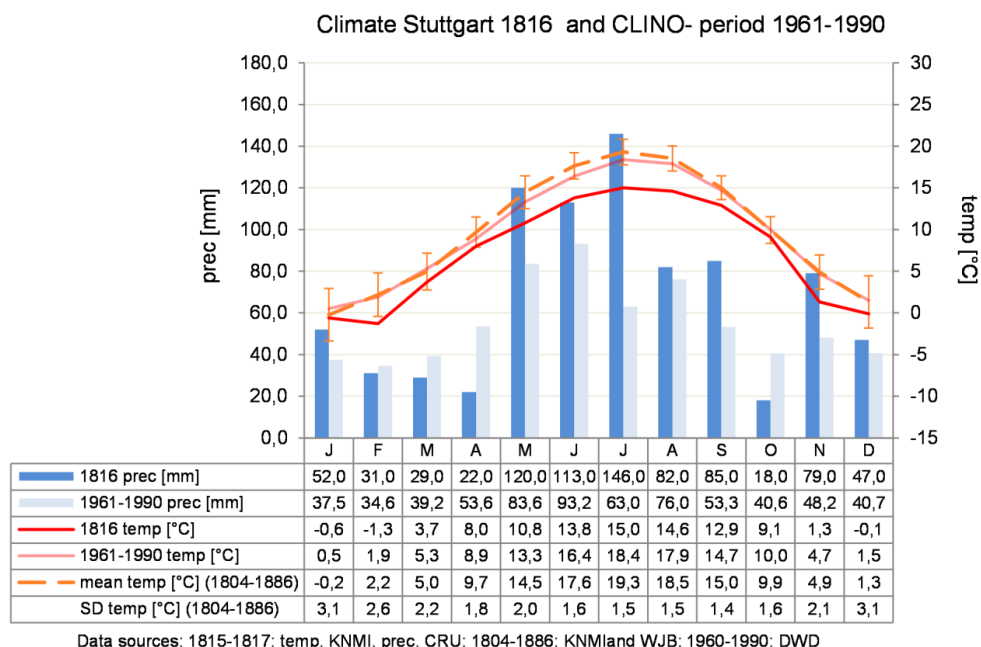



Figure 9. Temperature and precipitation for Stuttgart (1846).

Figure 10. Potato harvest in Württemberg and the precipitation index for April-September (Stuttgart, 1848–1886).

5   **Figure 11.** Chain of effects on emigration in the kingdom of Württemberg with corresponding coefficients of determination.