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Wine, victuals and volcanoes – potential impacts of the 1640/1641 double volcanic eruption on climate and society in early modern Switzerland

Niklaus E. Bartlome[1,2]

[1]Institute of History, University of Bern, Bern, CH-3012, Switzerland
[2]Oeschger Centre for Climate Change Research, University of Bern, Bern, CH-3012, Switzerland

Correspondence to: Niklaus E. Bartlome (niklaus.bartlome@unibe.ch)

Abstract. This study examines how three municipal hospitals on the Swiss Plateau - in Fribourg, Bern and St. Gallen - coped with climate anomalies in the early 1640s that coincided with the Komagatake/Parker double volcanic eruption. The eruption led to catastrophic consequences in regions such as China, Japan and northern Europe. Unlike these regions, Switzerland did not experience a comparable famine. Rather than focusing on a narrative of disaster, the study analyses how local authorities coped with climate anomalies. The focus is on the cities of Fribourg, Bern and St. Gallen and their respective municipal hospitals (care institutions), whose economies and agrarian sectors (viticulture, husbandry, dairy production and crop cultivation) are analysed. Between 1639 and 1643, the study region experienced cold springs and summers, likely resulting from a combination of internal stochastic variability and volcanic forcing from the double eruption. All sectors of the hospitals' agricultural production were affected simultaneously, due to their interconnectedness. The hospitals' greatest vulnerability was the extent of their involvement in direct cultivation. Staple food shortages and high prices caused by multi-annual climate anomalies and the impacts of the neighbouring war between France and the Franche-Comté led to a subsistence crisis across the Swiss Plateau. Coping strategies were implemented on two levels. Hospitals adopted internal measures, such as switching from exporting to importing foodstuffs or reducing unnecessary expenditure, to increase the availability of staple food products. They also benefited from external measures ordered by the city authorities, who issued mandates to ensure food security for their populations. Although the available hospital records do not show an obvious increase in recorded deaths among residents and the authorities' economic policy coincided with a peasant revolt in Bern in 1641, the subsistence crisis nonetheless placed the hospitals under considerable pressure. While the study primarily focuses on urban populations, further research on rural populations would be useful to examine how they coped with the subsistence crisis.

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1 Introduction

In 1641, the Hospital of the Holy Spirit in St. Gallen in eastern Switzerland recorded that "*the majority of grapes could not ripen due to early frosts and other harsh weather, [so this year] wine is excessively overpriced and will cause the hospital a loss of many thousand florins*" (Historical Source (HS) 1, see appendix C). This was not an isolated incident. Poor harvests following extreme weather conditions occurred throughout Europe in the early 1640s (Brázdil et al., 2023) threatening the availability of staple food or, as they are called in historical sources, victuals (*Victualien*). These temperature anomalies happened in the wake of back-to-back eruptions of two volcanoes – Komagatake (31 July 1640) and Mount Parker (26 December 1640 – 4 January 1641) (Stoffel et al., 2022). Research on global impacts of such large eruptions within the nexus of volcano-climate-society (VCS) has flourished over the past two decades, as comprehensively reviewed by Büntgen et al. (2025).

1.1 The shocks of volcanic eruptions to the climate system

Large tropical volcanic eruptions act like a "whiplash" (Wanner, 2020, p. 140) i.e. a short-term disruption on the climate system. This impacts large-scale climatology and mesoscale meteorology as described by Büntgen et al. (2025). A crucial process is the ascent of volcanically emitted sulphur compounds into the stratosphere, where they are converted into sulphate aerosols. Atmospheric circulation transports them to both hemispheres within a year. As this aerosol mass reduces the amount of solar radiative forcing reaching the Earth's surface, it can lead to cooling of the troposphere especially during the summer months (June–July, JJA), lasting up to three years (Fischer et al., 2007; Pfister and Wanner, 2021). In contrast to this summer cooling, tropical eruptions can trigger a positive NAO by strengthening the stratospheric polar vortex, leading to a so-called winter warming across Northern Eurasia, whereas large extratropical eruptions are proposed to have the opposite effect (Tao et al., 2025). Also, the hydroclimate can be influenced by large tropical eruptions. Aerosol-induced cooling reduces the land–sea temperature contrast, which weakens the African and Asian monsoon circulations. Through changes in the Hadley cell this can impact European summer precipitation (Wegmann et al., 2014). As a result in the years following such eruptions, the western Mediterranean experiences increased precipitation, while north-western Europe and the British Isles become drier (Rao et al., 2017). Larger tropical eruptions generally produce stronger hydroclimate signals (Gao and Gao, 2017). This spatial and temporal heterogeneity is particularly relevant for a study region situated in the transition zone between the southerly wetting and north-westerly drying response.

VCS research uses terms such as *whiplash to the climate system* or *climatic shock* to describe the multiannual impacts on climate and agriculture, where they can be attributed to volcanic forcing (e.g. Wanner et al., 2000; Ljungqvist et al., 2025). However, this study prefers the term *climate anomalies* to describe the European temperature and precipitation anomalies during the 1640s as direct causal attribution to the eruptions remains difficult at the regional scale (see Sect. 5.1).

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At the ecological level, this affects vegetation, wild animals and domesticated livestock. Specifically, cold temperatures during the growing season severely affect crop cultivation. A substantial temperature deficit in the spring months can have a devastating impact on grain price development. Similarly, cold spells in late winter and spring reduce harvests and deplete hay stocks, leaving livestock starving and unable to produce milk, which negatively affects caseiculture (dairy production) (Pfister et al., 2021). Viticulture exhibits similar vulnerabilities, being highly susceptible to climate and weather variability; cold conditions negatively affect grape cultivation almost throughout the year, with late spring and early summer temperatures (April–July, AMJJ) being particularly critical (Pfister, 2007, 2024). Initial case studies have begun to establish links between volcanic eruptions and their impact on viticulture (Ljungqvist et al., 2025), providing a foundation for the analysis presented here.

For early modern society, these climate anomalies could threaten food security, leading from poor harvests to high food prices, which could result in a subsistence crises or even famine and notably increased mortality and force migration, to name but a few impacts (Büntgen et al., 2026; Ljungqvist et al., 2020). At the regional level, the main staple food production – such as crop cultivation, animal husbandry, caseiculture and viticulture – was highly interconnected. The example of eastern Switzerland illustrates how closely the individual agricultural sectors were linked and how specific regions specialised in one sector of agriculture (Sonderegger, 2019). Hence, climate anomalies from a volcanic eruption could affect the entire food security system at the same time (Huhtamaa, 2015; Ljungqvist et al., 2020; Pfister, 2007).

The extent to which a region was affected by the aftermath of a large volcanic eruption depended on a combination of climatic, agricultural and societal factors. Crucial among these were the magnitude of the resulting climatic anomaly for the region and the capacity of the affected society to cope with its consequences. The two key factors defining the coping capacity of social systems were their resilience and vulnerability (White et al., 2018), as conceptualised in various studies concerning climatic impacts on early modern societies (Athimon and Maanan, 2018; Degroot et al., 2021; Pfister and Brázdil, 2006; Soens, 2018). This study follows the definitions of vulnerability and resilience by Soens (2018), where a socio-environmental system is considered vulnerable if climate-induced disruption cannot be counteracted through absorption, adaptation, or transformation. If a society can recover swiftly after an extreme climate event without major structural changes, or by implementing changes to increase its coping capacity, such a society can be considered resilient.

Even a resilient society can still experience a subsistence crisis, defined in this study as "temporally limited periods of stable food scarcity" (Camenisch, 2019, p. 41). Such a crisis affects large parts of the population, particularly poor people and those in need. The magnitude of these crises ranges from short-term shortages of staple food products on the market to outright famines. They are defined here as the final and gravest stage of a subsistence crisis, when people can no longer obtain sufficient staple foods and their health is so severely affected that the mortality rate rises sharply. (Camenisch, 2019).

1.2 Komagatake-Mount Parker double eruption 1640–1641

The period shortly before the middle of the seventeenth century marks an important phase of the Little Ice Age (LIA). Climatic conditions deteriorated from the beginning of the Maunder Grand Solar Minimum (1621–1718), a period of greatly reduced

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solar forcing. Hence, the period of abrupt cold spells following the cluster of eruptions are also referred to as a Little Ice Age Type Event (LIATE) (Wanner et al., 2000). The 1640 double eruption of Komagatake (Japan) and Mount Parker (Philippines), locally known as Mélébingóy, is one of three major eruption clusters of the seventeenth century, with Europe – in particular Northern and Central Europe – experiencing a distinct summer cooling for the year of the eruption 1641 (Y0) and the following two years (Y1 and Y2) (Luterbacher et al., 2016). The summer cooling of 1641 (-1.19°C) is comparable to the cooling in 1816 observed after the infamous Tambora eruption (-1.23°C) (Stoffel et al., 2022). Wegmann et al. (2014) show for the first summer (JJA) after the eruption (1641) an increase in precipitation (0.327 mm/day) for southern Europe over land area (36°–46°N, 10°W–40°E). For an overview of temperature and precipitation anomalies for Europe (16°E–30°W, 34°–60°N) in the years before and after the double eruption (1635–1646), see Appendix A.

Back-to-back eruptions that occur in close succession, as in the 1640s, often have cumulative impacts on the climate and society. The other two volcanic events in the seventeenth century are the eruption of Huaynaputina (Peru) in 1600 and the as yet unidentified eruption cluster of the 1690s (Gabriel et al., 2025). In recent years, the mid-seventeenth century double eruption has received increasing attention in research, looking at its local impacts (Sugimori and Maeno, 2023) and its teleconnections and pronounced climatic, agricultural and societal impacts on the most affected regions: China and Japan (Chen et al., 2020; Gao et al., 2021; Stoffel et al., 2022), western and Central Europe (Brázdil et al., 2023; Stoffel et al., 2022) and northern Europe (Huhtamaa et al., 2022; Stoffel et al., 2022). However, less is known about regions that experienced climatic anomalies but did not suffer severe societal consequences. The area of present-day Switzerland appears to have undergone climate anomalies – cold summers and long winters – in the 1640s following the eruption (Stoffel et al., 2022).

While Switzerland had to combat its last famine after the eruption of Tambora and the so-called Year Without a Summer (Brönnimann and Krämer, 2016; Krämer, 2015), there was no outright famine in the 1640s (Camenisch, 2021; Collet and Krämer, 2017). This paper examines the climatic, agricultural and societal conditions of various localities within present-day Switzerland, particularly Fribourg, Bern and St. Gallen, for the eruption cluster of the mid-seventeenth century (1635–1647). Rather than focusing on a narrative of disaster, this study analyses how local authorities coped with climate anomalies and mitigated their potential agricultural and societal consequences. To answer these questions, this study analyses three urban hospitals in the Swiss Plateau – institutions that provided care and accommodation for a broad spectrum of vulnerable groups. These are the Burghers' Hospital (*Hôpital des Bourgeois*) in Fribourg, the Lower Hospital (*Unteres Spital*) in Bern and the Hospital of the Holy Spirit (*Heiliggeistspital*) in St. Gallen. They are ideal candidates for such a study because, taken together, their properties and thus information on potential climate impacts on agriculture, cover a large area across the Swiss Plateau (see Fig. 1). Furthermore, because of the nature of such institutions, their mission, economy, accounting and record keeping are very similar and therefore highly comparable. Finally, as a municipal entity, their records had to be well archived, meaning there are almost no data gaps in the current study. As it focuses on urban centres, its relevance to the situation of the rural population is limited.

The introduction is followed by a concise historical overview of Switzerland in the mid-seventeenth century relevant to the present study, as well as of hospitals as institutions and then a presentation of the three selected objects of study. The

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methodology, sources and data basis are then presented. The results section analyses the climatological impact of the double eruption and examines its impacts on the respective hospital agrarian production and economy. The discussion section places the results in a broader agricultural and societal context and considers how the authorities responded to this climatic anomaly. Finally, the conclusion summarises the key findings of the article.

2 Switzerland in the 1640s "*in the eye of the hurricane*"

To understand the regional context of these findings, a brief historic overview of Switzerland is necessary. In the seventeenth century, the territory now known as Switzerland was often referred to as the *Corpus Helveticum* (Helvetic Body Politic). It was a complex confederation comprising numerous different territories (see Fig. 1), including partly sovereign republics or dominions such as the 13 old cantons (*Dreizehn Alten Orte*) and their associates (*Zugewandte Orte*), as well as subject territories (*Untertanengebiete*) and condominiums (*Gemeine Herrschaften*) (Walter, 2010). Most of the population lived on the Swiss Plateau (*Schweizer Mittelland*), which stretches from Genf to St. Gallen. The cities selected for the study – Fribourg (FR), Bern (BE) and St. Gallen (SG) – are located in this area (see Fig. 1). They were sovereign entities with decision-making power over their own territories and people. Based on a paternalistic ideology, the authorities of these cities felt obliged to care for their populations and maintain order during times of crisis through laws and mandates (Camenisch, 2019).

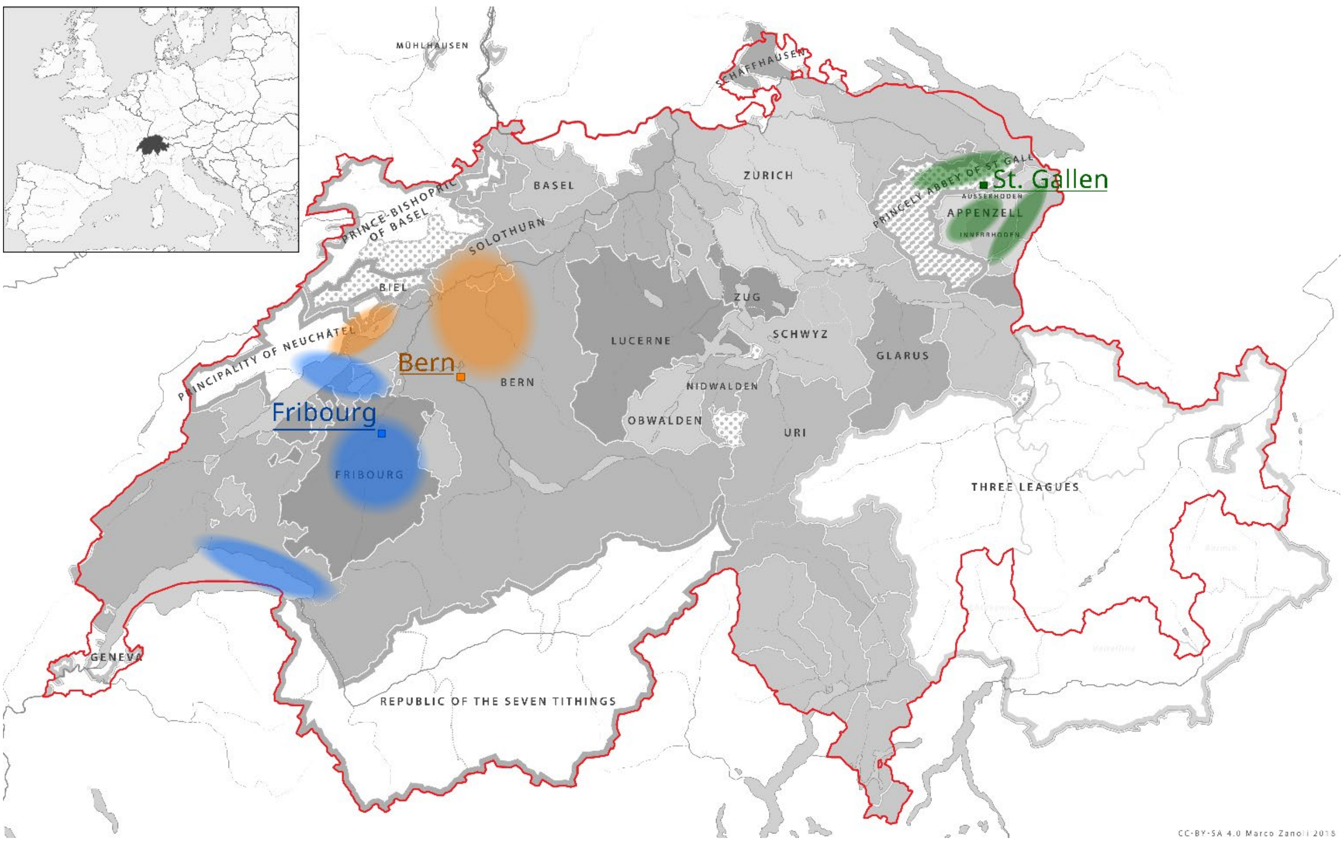

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Figure 1: The *Corpus Helveticum* of the 13 cantons in the mid-seventeenth century and Switzerland's current border in red with a map of Central Europe as reference. The locations of the three hospitals and their properties are coloured: Burghers' Hospital in Fribourg (blue), Lower Hospital in Bern (orange), Hospital of the Holy Spirit in St. Gallen (green), modified after Marco Zanoli (2018) (CC-BY-SA 4.0).

To discuss broader affairs with other cantons, they participated in the federal diets (*Tagsatzung*). There, joint, current and important political matters were discussed in the spirit of a federal congress of envoys. The decisions were recorded in so-called resolutions (*Abschiede*), which, however, had neither legal force nor coercive power (Würgler, 2014). One of the greatest challenges facing the Diet in the first half of the seventeenth century was the Thirty Years' War (1618–1648), which, along with extreme climate and weather conditions, devastated much of Europe (Brázdil et al., 2023). Switzerland remained neutral in this pan-European conflict, did not participate actively in the war and was largely spared direct military impacts, which Swiss historian André Holenstein compared to being "in the eye of the hurricane" (Holenstein, 2021, p. 112). Nevertheless, the years after 1630, marked by internal tensions and the indirect impacts of the war, were the most difficult phase of the conflict for the Swiss cantons (Walter, 2010).

One of these indirect impacts, which is vital for this case study, was partially caused by the Ten Years' War (1634–1644), a regional phase of the Thirty Years' War between the Franche-Comté (the county of Burgundy) under Spanish Habsburg rule and the Kingdom of France. The Franche-Comté was not only a direct neighbour of the western Swiss cantons but also an important economic trading partner, particularly due to its salt mines in Salins-les-Bains. Between 1638 and 1640, the region was completely devastated by French troops. A fatal famine broke out and many Burgundians fled to neighbouring Swiss cantons, like Bern and Fribourg (Gérard, 1998). In 1641, the Franche-Comté was severely affected by bad weather and as a result, in 1642, food prices rose to levels that surpassed all previous increases (Gérard, 1998).

3 Hospitals: institutions of care and wealthy taxpayers

During these times of crisis, help for people in need often came from authorities or institutions. The main source material for this study comes from municipal hospitals. Most were founded in the Middle Ages, including the Burghers' Hospital in Fribourg (before 1249), the Lower Hospital in Bern (1307) and the Hospital of the Holy Spirit in St. Gallen (1228) (Morgenthaler, 1945; Sonderegger, 1996; Utz Tremp and Blanck, 2003). In the late Middle Ages and Early Modern period, hospitals were welfare institutions that cared for and housed people in need of various kinds (Gilomen-Schenkel et al., 2012). The civic hospital in Fribourg exemplifies the heterogeneity of permanent and ambulant hospital residents. It distinguished between five categories of people who received support: the sick and wounded, the elderly and those in need of support, orphaned and abandoned children, women after childbirth and poor travellers and pilgrims (Niquille, 1921; Raemy, 1889). In the first half of the seventeenth century, charitable measures were strongly restricted to fellow citizens. From 1625 onwards, foreign beggars had to work in the hospital to receive support (Utz Tremp and Blanck, 2003).

On the one hand, hospitals were responsible for their permanent elderly residents, similar to today's retirement homes and had to provide them with medical care in their sickrooms (*Siechstuben*). At the same time, they provided ambulant care, including meals for non-permanent residents in need, such as beggars from outside the area (Ohngemach, 2008). Based on the

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expenditure recorded in the accounts of the hospitals examined and the prebends' registers, it was possible to reconstruct the exact number of permanent hospital residents during the period under examination (1635–1647). In Fribourg, the number fluctuated between 33 and 55 internal and external prebends. In Bern, between 51 and 60 prebends lived in the hospital and in St. Gallen there were between 85 and 128 prebends.

During the municipalisation and centralisation of hospital institutions since the sixteenth century, most hospitals came under the control of urban governing elites, making them important municipal institutions (Gilomen-Schenkel et al., 2012; Ohngemach, 2008). The three selected hospitals in Fribourg, Bern and St. Gallen had been so since their foundation. As instruments of authority serving the interests of the cities, they were relevant to the political careers of the cities' aristocracy. This is evident, among other things, in the importance of the office of hospital master (*Spitalmeister*). In Fribourg, they usually held office for five years in the seventeenth century (Utz Tremp and Blanck, 2003). The office was prestigious and formed part of the *cursus honorum* of the Fribourg patriciate. In the seventeenth century, it was held towards the end of one's career. Many Fribourg hospital masters later held important leadership positions in the government (Donzé, 2003). Additionally, municipal hospitals also served the authorities as a means of social control (Walter, 2010). For example, so-called beggar bailiffs (*Bettlervogt*) took beggars who had fled to the city from the city gate to the alms distribution point at the hospital, then led them out of the city again (Ohngemach, 2008).

However, the largest and most important group of hospital residents were the prebends (*Pfründner*): elderly citizens who paid for a place in the hospital, including meals, for the rest of their lives. Most hospitals distinguished between different classes of prebends – such as gentlemen's prebends (*Herrenpfründ*), middle-class prebends (*Mittelpfründ*) and poor prebends (*Armenpfründ*) – depending on the amount paid. Contracts specified exactly how much food one prebend was to receive each day. In St. Gallen, the holder of a gentlemen's prebend position received about two litres of quality wine per day, bread, vegetables, fruit and meat or fish on fasting days, while holders of the lowest prebend category received only grain porridge and half a litre of wine per day (Sonderegger, 1996). In addition to products made from grain, meat and dairy, wine was also a staple food for people in the early modern period, as water could be heavily contaminated depending on the source and wine contained more nutrients (Flutsch and Lüdi, 2014). Additionally to food and accommodation, the hospitals also had to pay for clothing and ultimately, funeral costs (Ohngemach, 2008).

To fulfil this wide range of tasks and provide daily meals for the prebends, hospitals required income in the form of money and goods in kind, which they secured through donations and the purchase of various tithes, rent and property. At the beginning of the seventeenth century, most hospitals ran themselves their owned estates. By the late Middle Ages, many hospitals were well endowed, such as the hospital in Fribourg, which by then was already the richest taxpayer in the city (Utz Tremp and Blanck, 2003). Many hospitals were important economic actors in urban areas (Donzé, 2003; Gilomen-Schenkel et al., 2012; Ohngemach, 2008).

The properties belonging to the three hospitals stretch from Lake Genf in western Switzerland to the Rheintal in eastern Switzerland. They are marked in colour on the map (see Fig. 1). In the 1640s, the hospital in Fribourg owned property for crop cultivation in Bertigny, Gambach and Planafaye. Its vineyards were located near Riex and Epesses (Lavaux), near Chailly and

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La Tour-de-Peilz (Vevey) on Lake Genf, near Auvernier on Lake Neuchâtel and in Vully on Lake Murten (Niquille, 1921). In total, the hospital owned 40.03 *poses* (approximately 17 hectares) of vineyards during the period under review. In Bern, after the Reformation, many of its properties were granted to the Lower Hospital. In the seventeenth century, the hospital obtained most of its grain from Stettlen, Biglen, Büren, Jegenstorf, Lüsslingen and Vechigen. It sourced its wine from St. Petersinsel, which it owned, as well as from Ligerz, Twann, Neuenstadt and Le Landeron (Morgenthaler, 1945). In the 1640s, the hospital owned a total of 324 *Mannwerk* of vineyards (approximately 14.5 hectares). The Hospital of the Holy Spirit in St. Gallen had the largest vineyard holdings among the three hospitals. Its vineyards were in the Rheintal (Altstätten, Marbach, Berneck, St. Margrethen), in Buchberg and in Roggwil and covered a calculated 80 hectares. It also had additional holdings for agriculture or husbandry in the surrounding area, in the St. Gallen Fürstenland, in the Appenzellerland and in Thurgau (Krauer and Sonderegger, 2010).

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4 Method and data

4.1 Climate data

Thanks to research on ice cores from Greenland and Antarctica, the size and timing of global volcanic activity in the mid-seventeenth century and its impact on the Northern Hemisphere (NH) can be determined (Gabriel et al., 2025; Toohey and Sigl, 2017). To achieve this, data from monthly reconstructed volcanic stratospheric sulphur injections (VSSI) is used to calculate the stratospheric aerosol optical depth (SAOD). The higher the SAOD, the more strongly solar radiation is reduced. To constrain the potential impacts of the volcanic forcing to the midlatitudes (30°–60°N), this study uses a recalibrated version of the 2017 dataset with annual resolution.

To assess potential volcanic-induced impacts on climate, reconstruction data are needed. Temperature and precipitation reconstructions for Central Europe and specifically for the Alpine region, have existed for several decades (e.g. Casty et al., 2005; Pauling et al., 2006; Luterbacher et al., 2016). This study uses three datasets from the global monthly Modern Era reanalysis project (ModE-RA) to evaluate past growing-season (AMJJ) temperature and precipitation conditions in Switzerland (6.56°–10.31°E, 46.63°–48.49°N) in the mid-seventeenth century (Valler et al., 2024). ModE-RA has a 2° grid resolution (1.875° longitude x 1.865° latitude) and combines atmospheric model simulations and observations with offline data assimilation. The observational data are derived from natural proxy records (tree rings, ice cores, speleothems, corals, lake sediments, etc.), as well as documentary and instrumental data. For Switzerland in 1641 climate reconstructions in ModE-RA rely not only on tree-ring data (Büntgen et al., 2006) and weather diary information but also on harvest dates from crop cultivation (Wetter and Pfister, 2011) and viticulture (Meier et al., 2007). To assess whether potential climate anomalies in ModE-RA are driven more by the simulation or by the observations, the two underlying datasets – the model simulation ModE-Sim (Hand et al., 2023) and the proxy-driven sensitivity experiment ModE-RAclim (Valler et al., 2024) – are examined separately. The ModE-datasets are further analysed using the data processing tool ClimeApp (Warren et al., 2024) and compared with descriptive historical sources used in the study.

4.2 Historical sources

The main historical source complex – annually maintained accounting books – comes from four archives (see Table 1): the State Archives of the Canton of Fribourg (AEF), the Burgerbibliothek Bern (BBB), the State Archives of the Canton of Bern (StaBE) and the City Archives of the Municipality of St. Gallen (SASG). The three urban hospitals were accountable to their respective city councils. Their accounting books contain serial information on the annual quantities of harvested crops and produced victuals from the second half of the sixteenth century onwards.

As the hospitals often engaged in the same agricultural activities (Ohngemach, 2008), the sources from the three hospitals contain comparable information on the four areas examined here: viticulture, caseiculture, husbandry and crop cultivation. The fact that the cities of Bern and St. Gallen were Protestant and Fribourg was Catholic makes no discernible difference in this case. The layout and structure of the hospitals' accounts are very similar across all three institutions. Their financial accounts

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are divided into income and expenditure, followed by the accounting for rents in kind. Income has been categorised in such a manner that, for example, a distinction can be made between purchased and harvested grain. Differences in cultivation methods or type of yield primarily affected crop cultivation (see Sect. 5.5). The greatest difference in property location lay in whether a hospital held estates in the Prealps, which was particularly relevant for husbandry (see Sect. 5.3). When reconstructing harvest and production quantities of the three hospitals, the fact that the fiscal year began at different days of the year in each hospital (see below) was not important for this study, as thanks to the detailed accounting records of all three hospitals, the income could be correctly allocated to the corresponding harvest years (For the processing, normalization and homogenization of the used historical sources see appendix B).

Table 1: List of the principal archival sources and their provenance.

Hospital	Source title	Source type	Archive	Code
FR	*Comptes de l'Hôpital*	Accounting book	AEF	HB A 3.207–3.219
FR	*Brodard Memorabilia*	Memorial book	AEF	HB A 1.1
FR	*Livre des Sentences*	Minutes	AEF	HB A 2.7
FR	*Grosses de l'hôpital*	Rental	AEF	Grosses Hôpital 133
FR	*Ratsmanual*	Minutes	AEF	RM 191–192
FR	*Mandatenbuch*	Mandates	AEF	Mandatenbuch 4
BE	*Rechnungen des Spitalmeisters des unteren Spitals*	Accounting book	BBB	VA BSB 190–191
BE	*Pfründer Fronfasten-Rodel des unteren Spitals*	Memorial book	BBB	VA BSB 1366
BE	*Reb-Urbar*	Rental	BBB	VA BSB 1255
BE	*Ratsmanual*	Minutes	StaBE	A II 393–395
BE	*Mandatenbuch*	Mandates	StaBE	A I 484
SG	*Jahrrechnungen*	Accounting book	SASG	Spitalarchiv B 156–168
SG	*Jahresrechnungen des Heiliggeist-Spitals gegen die Stadt*	Accounting book	SASG	Stadtarchiv Bd. 27
SG	*Denkbuch: Weinlaufbuch*	Memorial book	SASG	Spitalarchiv I 6
SG	*Rheintaler Güterbeschreibungen*	Rental	SASG	Spitalarchiv Q 15
SG	*Protokolle der Ausser- und Inntermeister*	Minutes	SASG	Spitalarchiv W 12

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SG	*Ratsprotokolle*	Minutes	SASG	Stadtarchiv Ratsprotokoll 1641
SG	*Mandatenbuch*	Mandates	SASG	Stadtarchiv Bd. 547

To analyse this corpus of sources and compare them, the data must be processed first. Where appropriate, data has been aggregated, for instance by grouping areas located near each other. To enable comparison of income and expenditure of individual victuals across regions, they were normalised, i.e. converted into units of the international system of units (SI), for example, 1 barrel (*Fass*) of wine into hectolitres or 1 bushel (*Mütt*) of grain into hectolitres. Price data was, as is standard practice (Allen, 2001), converted into its theoretical silver content as grams of silver per quantity in SI (e.g. g Ag / l). However, to identify climate-related anomalies in agricultural production, such as in viticulture, yields must be homogenized and converted into area yields and expressed in SI units (e.g. hl / ha). For this, the cultivation type (e.g. sharecropping), the size of the cultivated area and possible fixed revenues such as ground rent must be calculated. The size of the hospital vineyards could be reconstructed thanks to vine rentals from all three hospitals, with the Lower Hospital in Bern having the most reliable records, which could be used as a standard and reference for the other two (see Table 1).

This lays the groundwork for a quantitative analysis of hospital economy, supplemented by descriptive information on the weather, the harvest and the authorities' responses. The city councils themselves explicitly recorded their proceedings and issued mandates. Thus, there is both novel continuous quantitative and detailed descriptive information for the 1640s.

In the seventeenth century, these records were maintained by the hospital master (*Spitalmeister*). In Fribourg, the fiscal year usually began on St John's Day (24 June, Gregorian calendar). The account books from the 1640s are divided into income and expenditure, each organised by topic. Since 1594, a grain account (*Kornrechnung*) had to be kept, recording the hospital's economy in kind (grain, dairy products, wine and meat) (Niquille, 1921). Already in the seventeenth century, the hospital itself recorded memorable events (see Table 1). However, equally important for this study are the discussions about hospital matters held by the city council and its decisions, which were implemented by means of mandates, to determine how the local authorities in Fribourg responded to this climatic anomaly.

A similar situation is found in Bern (Morgenthaler, 1945). The accounts of the Lower Hospital have been preserved with few gaps since 1550. They provide details not only of the hospital's income and expenditure, but also valuable information about its activities. Its accounting period began on St James's Day (25 July, Julian calendar / 4 August, Gregorian calendar). Based on a register of quarterly fixed payments to all prebends (see Table 1), it is possible to reconstruct both the number of prebends and the number of deaths of hospital residents in the 1640s. As in Fribourg, the reactions of the authorities as the hospital's governing body can be found in the council manuals and the mandate book.

Similarly, in eastern Switzerland, the Hospital of the Holy Spirit sent copies of its annual accounts to the city. Of the three hospitals, its accounting system was the most detailed and structured with information on income and expenses, even providing clear details on the number of residents. In the mid-seventeenth century, its financial year began in March on *Laetare* (the fourth Sunday in Lent). The hospital recorded relevant information and its decisions. Uniquely, as their wine economy was so

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important, they recorded valuable information on the wine harvest, wine prices and the harvest season in a small booklet covering 175 years of viticulture. Likewise, as in the other cities, the mandates implemented by the city council can be examined.

A list of all analysed victuals demonstrates the heterogeneity of the novel archival material used (see Table 2). This source complex of the three municipal institutions, due to their similarity, offers a unique opportunity to analyse three important regions of early modern Switzerland, how they were affected by such an extreme climate event and how local authorities responded and potentially mitigated its impacts.

Table 2: List of analysed material concerning victuals from hospital accounting books and vine rentals.

Hospitals	Category	Type	Unit	Data
FR, BE, SG	Viticulture	Wine harvest yield and expenses	hl	normalized
FR, BE, SG	Viticulture	Wine harvest yield per area	hl / ha	homogenized
FR, BE, SG	Viticulture	Income from sold wine and expenses for purchased wine	g Ag	normalized
FR, BE, SG	Viticulture	Wine price	g Ag / l	normalized, calculated
FR, BE	Caseiculture	Butter yield	kg	normalized
FR, BE, SG	Caseiculture	Income from sold dairy products and expenses for purchased dairy products	g Ag	normalized
FR	Caseiculture	Cheese loaf yield	number	aggregated
BE	Caseiculture	Butter and cheese price	g Ag / kg	normalized, calculated
FR, SG	Husbandry	Slaughtered livestock (heifers, calves, pigs)	number	aggregated
FR, SG	Husbandry	Livestock (milk cows, heifers, calves, oxen, horses)	number	aggregated
FR, BE, SG	Crop cultivation	Crop yields from hospital owned pastures and total crop income (spelt, oat, hard grain)	hl	normalized, aggregated
FR, BE, SG	Crop cultivation	Income from sold grain or expenses for purchased grain (general)	g Ag	normalized, aggregated
FR, BE	Crop cultivation	Grain price	g Ag / l	normalized, calculated

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FR, BE, SG	General victuals	Income from total victuals (wine, dairy products, meat/livestock and grain) sold and expenses for total victuals purchased vicutals (wine, dairy products, meat/livestock and grain)	g Ag	normalized, aggregated

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5 Results

5.1 Climate "*This year, such an early and consistently warm summer*"

With these words (HS2), the hospital of St. Gallen described the summer of 1638, a season that produced a vintage of exceptional quality and quantity, referred to as a true "*sublime wine*" (HS3).

This description of the summer of 1638 corresponds with the increased AMJJ temperature anomaly (+2.2 °C) from ModE-RA (see Fig. 2b) for Switzerland (6.56°–10.31° E, 46.63°–48.49° N). Looking at the volcanic signal (averaged SAOD for AMJJ) for the NH mid-latitudes (30°–60° N) following the double eruption, SAOD values peak (0.1950) in 1641, remain elevated in 1642 (0.1841) and start dropping from 1642 onwards (see Fig. 2a). Based on the mechanisms outlined in Sect. 1.1, a drop in mean summer temperatures could be expected for the years 1641–1643. ModE-RA shows negative temperature anomalies for the eruption year and the two following years, reaching a negative peak value (–1.16 °C) in 1642 (see Fig. 2b). However, attributing these anomalies solely to volcanic forcing would be an oversimplification. Two points deserve closer attention.

First, the model component of the reanalysis (ModE-Sim), which is driven by prescribed external forcings including volcanic aerosol (Hand et al., 2023), shows only a modest temperature response to the eruption. The volcanic cooling signal expected from the elevated SAOD values is clearly not discernible in the model output alone for the AMJJ season. Adding to this, Marshall et al.(2025) showed that the climate response to the 1640/41 Parker eruption can vary strongly across model ensemble members because of differences in the hemispheric distribution of aerosol driven by internal variability. Their simulations for the Parker eruption produced a disproportionately strong NH summer cooling relative to its SO_2 emission. They propose that internal variability can both amplify and dampen the forced response, which is not solely linked to the volcanic signal.

Second, ModE-RA and the proxy-driven sensitivity experiment ModE-RAclim show both that negative temperature anomalies already appear in 1639, long before the double eruption (see Fig. 2b). As ModE-RAclim reflects the climate signal reconstructed from assimilated proxy observations rather than the model's response to prescribed forcing, this pre-eruption cooling should have different origins. The decline in TSI towards the Maunder Minimum did not begin until the 1640s (Penza et al., 2024). The previous eruptions of the Hekla volcano in Iceland (1636) were too small to cause major climate disturbances (Stoffel et al., 2022). Therefore, the cause of these temperature fluctuations is likely to be internal stochastic climate variability.

For precipitation, because of its complex response to volcanic eruptions in Central Europe, as discussed in Sect. 1.1, a potential link between precipitation anomalies and the 1640/41 double eruption should not be attempted given the focus of this study and the material used. It should nonetheless be noted for context that ModE-RA and ModE-RAclim indicate increased AMJJ precipitation anomalies for the years 1639 to 1643 (Fig. 2c), while ModE-Sim shows much weaker fluctuations.

Because of these factors it is not possible to statistically separate or attribute the relative contributions to internal variability or volcanic forcing to the temperature and precipitation fluctuations discussed here. This study therefore uses the term *climate anomalies* rather than *climatic shocks* to signal that a volcanic impact on the regional climate, while plausible, cannot be statistically confirmed with the sources employed here.

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Importantly, the temperature and precipitation anomalies derived from the reanalysis are broadly consistent with the descriptive evidence of climatic conditions in Switzerland used in this study, none of which was used as documentary data in the ModE data sets. 1638 “*This year, such an early and consistently warm summer*.” (HS2), 1640 “*It remained lying in the field due to the persistent rain and came to ruin*” (HS8), 1641: “*the majority of grapes could not ripen due to early frosts and other harsh weather,*” (HS1), to mention a few. On the basis of this agreement between the reanalysis and the narrative sources, a period of potential crisis can be defined (1639–1643) that is distinct from the preceding years (1635–1638) and the subsequent recovery (1644–1647).

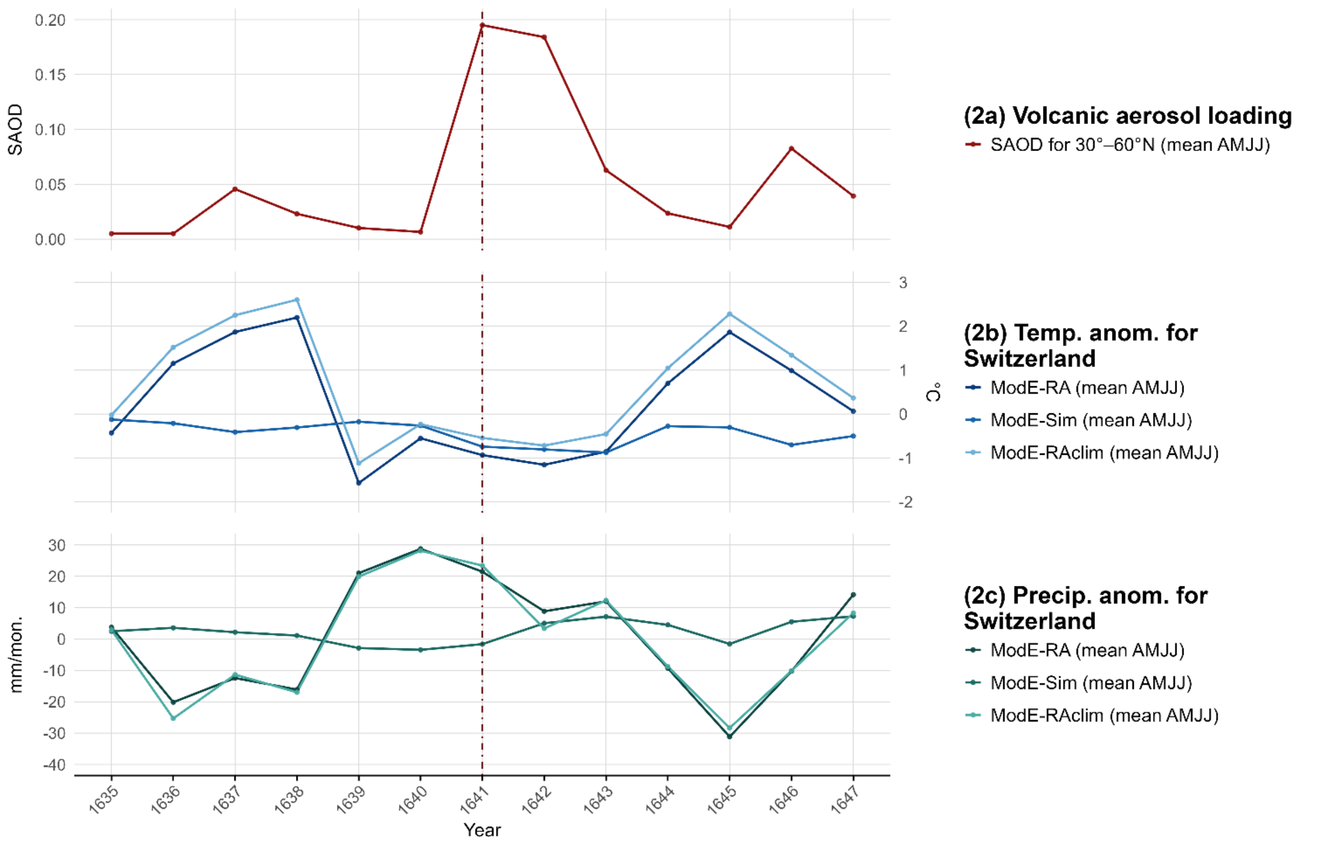

Figure 2: Volcanic signal and climate anomalies. (2a) Mean AMJJ SAOD for NH midlatitudes (30°–60°N) (Toohey and Sigl, 2017). (2b) Mean AMJJ temperature (temp.) anomalies (anom.) for Switzerland (6.56°–10.31°E, 46.63°–48.49°N) from ModE-RA, ModE-Sim and ModE-RAclim in °C, wrt. 1961–1990 (Hand et al., 2023; Valler et al., 2024). (2c) Mean AMJJ precipitation (precip.) anomalies (anom.) for Switzerland (6.56°–10.31°E, 46.63°–48.49°N) from ModE-RA, ModE-Sim and ModE-RAclim in mm/mon., wrt. 1961–1990 (Hand et al., 2023; Valler et al., 2024).

5.2 Viticulture “*Item anno 1641 when the wine turned out ill […]*”

When the Hospital of the Holy Spirit in St. Gallen described the exceptionally fine wine of 1638, it also noted that never before in its history had a larger grape harvest been recorded than during that warm summer. The cold spells in the springs of 1639

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to 1643 had disastrous consequences for the hospital's viticulture. A late frost at Easter 1639 damaged the vines in the St. Gallen Rheintal so severely that only "*little and sour wine*" (HS4) could be harvested. Late frosts recurred in the springs of 1641 and 1643, as recorded in the St. Gallen Wine Booklet. In western Switzerland, the hospital records also describe how the harsh weather in 1641 destroyed parts of the harvest and led to poor-quality wine, as evidenced by the chapter's opening quotation (HS5) from the accounts of the hospital in Fribourg. This is consistent with the findings of Pfister et al. (2024), who demonstrated a strong correlation (75% of the variance) between fluctuations in temperature and precipitation in spring and summer and the quality of the grape harvest.

All the areas, where the three hospitals in Fribourg (FR), Bern (BE) and St. Gallen (SG) owned vineyards, recorded a considerable decline in their harvests between 1639 and 1643 (see Fig. 3a). This applies not only to the absolute volume of must harvested, but also to the calculated yield per hectare (hl / ha) of the vineyards of the three hospitals (see Fig. 3b). It is noteworthy, however, that although the quality of the 1641 harvest suffered greatly from the temperature anomalies, as described, the harvest volume increased again in the year with the highest SAOD in all regions except the Seeland. The following two years were again poor harvest years. Thanks to the warmer growing seasons from 1644 onwards, viticulture on Lake Genf and in the Seeland also recovered. In the St. Gallen Rheintal, it took a year longer for the yield per hectare to reach the level seen before the crisis years (see Fig. 3b).

This sharp decline in wine production during the crisis years of 1639–1643 had economic and societal repercussions for the hospital's operating. Although obliged to serve the wine owed to their prebends, sources indicate that, in Fribourg for example, substantial cuts were made to the wine served to the sick and needy from 1640 onwards. All three hospitals recorded a decline in their own wine consumption during the crisis (see Fig. 3c). Only in Bern did consumption continue to fall after 1643. Compared with the years before and after the crisis, consumption fell by 33% in Fribourg, by around 10% in Bern and by 13% in St. Gallen.

The hospitals employed three strategies – internal mechanisms – to secure their wine supply and mitigate the impacts of crop failures. Firstly, they drew on their stocks. In Fribourg, these stocks fell by 36% during the crisis years; in Bern, by as much as 81%; in St. Gallen, however, by only 16%. Secondly, they reduced the sale of hospital wine. The hospitals in Fribourg and Bern almost completely halted their sales (see Fig. 3d). The hospital in St. Gallen sold around 40% less wine between 1639 and 1644. Thirdly, if this proved insufficient, they still had the option of purchasing the missing wine on the market. Both Fribourg and Bern had to buy wine from outside between 1640 and 1642, which was all the more costly due to the rise in wine prices in western Switzerland (see Fig. 3e).

In Fribourg, the price of wine more than tripled during the crisis. In eastern Switzerland, the price of wine did not rise as sharply, owing to a more reliable supply. All of this indicates that the wine economy in eastern Switzerland was not hit as hard as the economy in western Switzerland. The hospital in St. Gallen did not need to purchase any wine, as it held much larger stocks than the other two municipal hospitals. In 1640/41, the hospital transported 280 hl of wine from its cellar in Altstätten in the Rheintal to their buildings in St. Gallen. Furthermore, the hospital in St. Gallen produced on average about four times as much wine as it required for its own consumption, whereas Fribourg, for example, produced only just over one and a half

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times as much. However, the severity of crop failures in viticulture for the hospital economy in general is illustrated by the proportion of annual revenue from wine sales compared to total revenue (see Fig. 3f). In normal years, this proportion was around 10% in Fribourg and 11% in Bern. In St. Gallen, almost a third (31%) of the hospital's revenue came from viticulture. Poor harvests in viticulture, due to cold springs and summers, not only disrupted the hospitals' operating but also placed a considerable direct strain on the hospital's finances.

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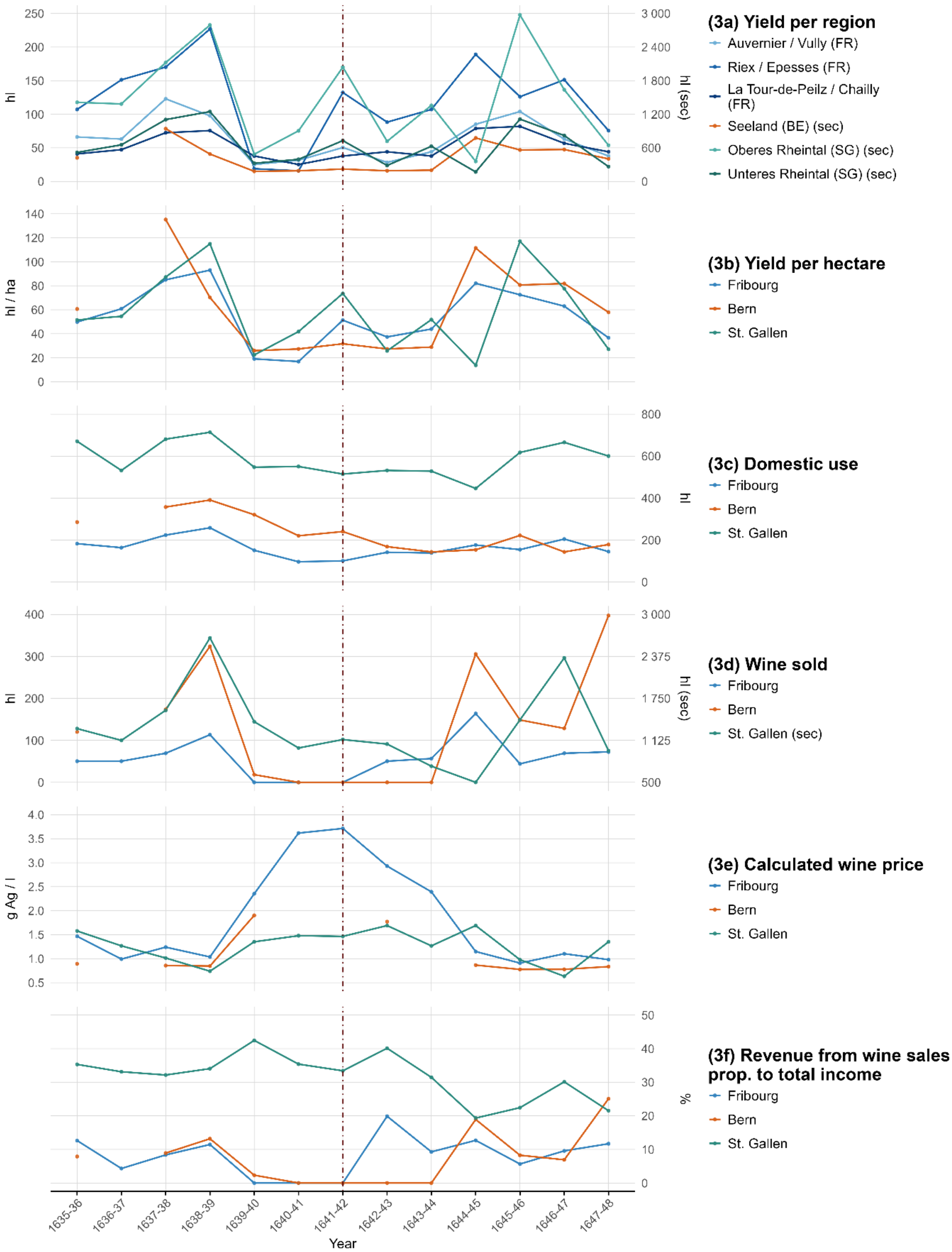

390 **Figure 3:** Viticulture. (3a) Annual yields from hospital vineyards in hectolitre (hl), aggregated by area. (3b) Homogenized yield from hospital vineyards in hectolitre per hectare (hl / ha), aggregated by hospital. (3c) Annual in-house wine consumption in hl. (3d) Annual wine sales in hl. (3e) Calculated wine price in grams of silver per litre (g Ag / l). (3f) Revenue from wine sales proportional to total income in %.

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5.3 Husbandry "*And then two cows were so sick […]*"

An analysis of the accounting records shows that the hospitals in Fribourg and St. Gallen were actively engaged in livestock farming in the mid-seventeenth century. They maintained records of their livestock (dairy cows, heifers, calves, draught animals, swine, etc.) and the animals slaughtered each year. As part of the alpine economy, the livestock was kept in the Fribourg Prealps respectively the Appenzell Prealps during the summer and spent the winter in the valleys, where it was fed hay or slaughtered (Niquille, 1921; Sonderegger, 2019). The Lower Hospital in Bern, however, did not practise husbandry to the same extent. It mainly purchased animals ready for slaughter or meat at the local market to meet its meat requirements, which is why Bern is not suitable for quantitative analysis.

Overall, the number of heifers and swine slaughtered in Fribourg and St. Gallen remained almost unchanged between 1635 and 1647. While the total number of animals slaughtered in St. Gallen increased slightly, slaughtering in Fribourg declined slightly from 1639 onwards (see Fig. 4a). On average, the hospital in St. Gallen slaughtered nearly 80% more animals than the hospital in Fribourg. The total livestock population at both hospitals also showed a general upward trend during the period under review (see Fig. 4b). The fact that the hospitals did not experience a general loss of livestock is a key indicator for assessing later the extent of the subsistence crisis. Catastrophic, widespread famines typically result only from a combination of high livestock loss and crop failures over several years, as occurred in Japan during the Great Kan'ei Famine of 1640–1643 (Stoffel et al., 2022).

Nevertheless, the negative temperature anomalies of the 1640s also affected livestock farming in the Swiss Plateau. The hospital in St. Gallen responded to the cold summers by sending notably fewer cattle to the Alpine pastures between 1639 and 1643. In years with warm summers (1637–1638 and after 1643), however, it sent most of its livestock to the Alpine pastures (see Fig. 4b). The cold periods not only negatively impacted winter fodder supplies, as the hospital in Fribourg noted in its accounts in 1640 but may also have contributed to the spread of a livestock epidemic that had been ongoing independently since 1637. From 1637 onwards, western Switzerland suffered from a spreading cattle epidemic, which intensified between 1640 and 1641 (Bühlmann, 1916). As the opening quotation describes (HS6), the hospital in Fribourg had to slaughter two of its 25 cattle due to the epidemic. The rampant cattle epidemic is most clear in the decline in calf slaughtering (see Fig. 4c–d). Between 1639 and 1643, the hospital in Fribourg slaughtered about 24% fewer calves and the hospital in St. Gallen about 16% fewer calves than in the periods before and after. This enabled the hospitals to cushion potential losses of livestock due to the epidemic and after a few years, to increase their cattle herds (see Fig. 4c).

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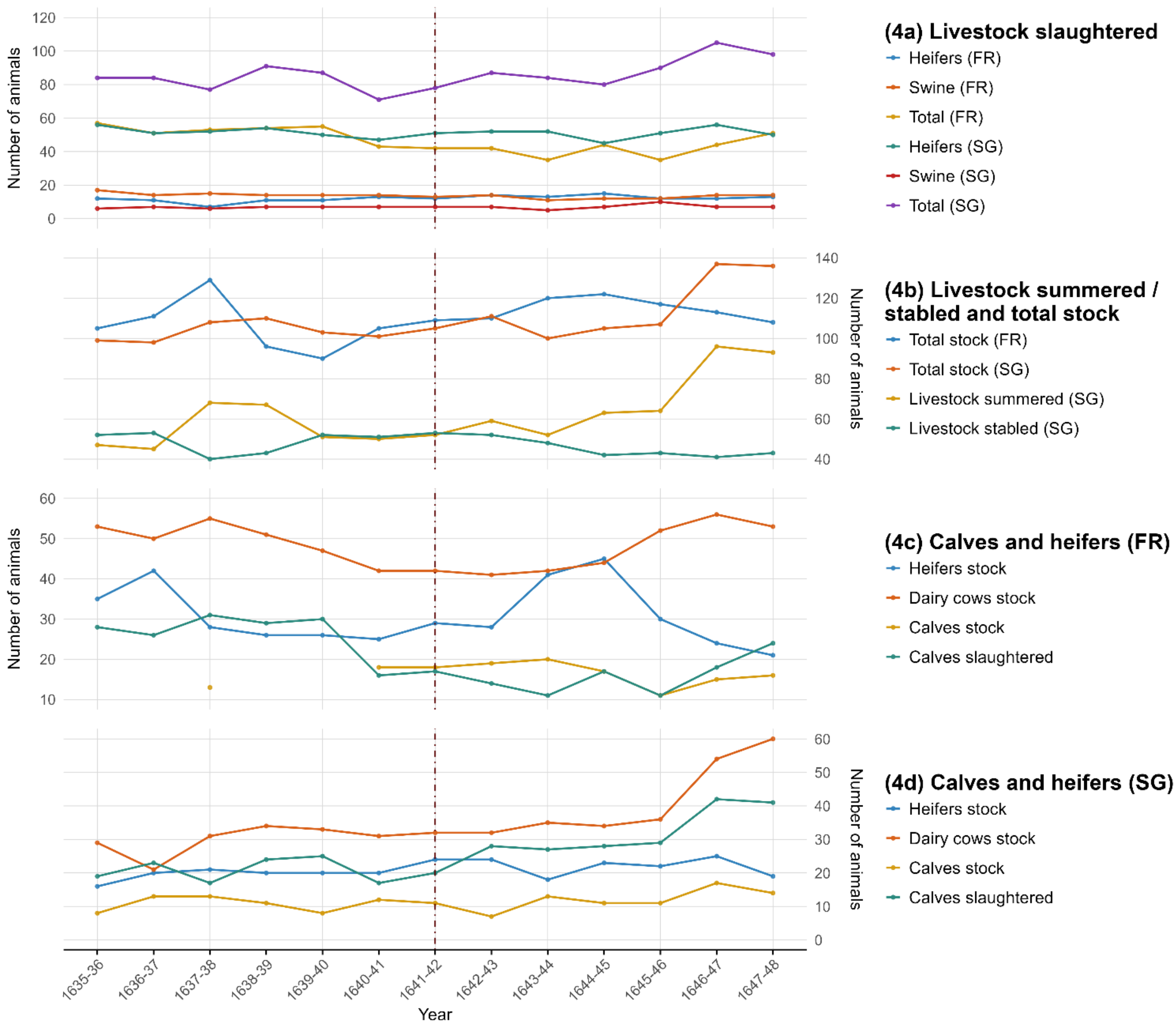

Figure 4: Husbandry. (4a) Total slaughtered livestock and slaughtered heifers and swine for Fribourg and St. Gallen. (4b) Total livestock for Fribourg and St. Gallen and total livestock summered and stabled for St. Gallen. (4c) Calves and heifers for Fribourg. (4d) Calves and heifers for St. Gallen.

5.4 Caseiculture "*Winter cheeses […] up to now, not much owing to the poor fodder*"

Caseiculture is closely connected to husbandry. The hospital in Fribourg was the only one of the three institutions studied to document the annual yield of dairy products in kind (milk, butter and cheese). The decline in the number of dairy cows in Fribourg (see Fig. 4c) led to a simultaneous decrease in cheese production (see Fig. 5a). The hospital recorded for 1640 that, due to the poor quality of fodder harvested that year, it was almost unable to produce any winter cheese (HS7). To meet its own needs, the hospital had to purchase cheese at the market in 1641 and 1642 (see Fig. 5c). Revenue from butter was almost

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entirely lost in 1637 and 1640. As a result, the hospital used up its entire butter supply in 1641, had nothing left for its own needs and was unable to sell any.

This is also evident from the revenue generated by dairy product sales. While the hospital in Fribourg was usually able to sell its surplus on the local market due to intensive livestock farming and resulting cheese production, it had to cease sales entirely between 1640 and 1642 because of dwindling stocks. The hospital in eastern Switzerland also experienced a decline in sales of dairy products (see Fig. 5b). For both hospitals, these financial losses – unlike those from viticulture – were not considerable, as average revenue from dairy product sales accounted for only 1% of total revenue in Fribourg and 3% in St. Gallen.

Although the hospital in Bern had to purchase all the dairy products it required for its own use, as it did not keep livestock, expenditure on these items did not increase (see Fig. 5c). This is explained by the Bernese government's heavy regulation of the dairy industry in the seventeenth century, including setting maximum prices for dairy products (Zangger et al., 2009). Consequently, prices for dairy products in Bern did not rise sharply even during crises (see Fig. 5d). Expenditure on dairy products by the hospital in St. Gallen rose slightly between 1640 and 1642 but declined when considered over the entire period under study.

It is evident that, from 1637 onwards, the production of dairy products was adversely affected by the cattle disease mentioned above. The situation worsened in the early 1640s due to cold spring and summer temperatures, which may have encouraged the spread of the disease and impaired both the quantity and quality of fodder available for dairy cows. The situation for caseiculture is as good as any for highlighting the interconnectedness between different agricultural sectors, such as husbandry, crop cultivation and dairy production.

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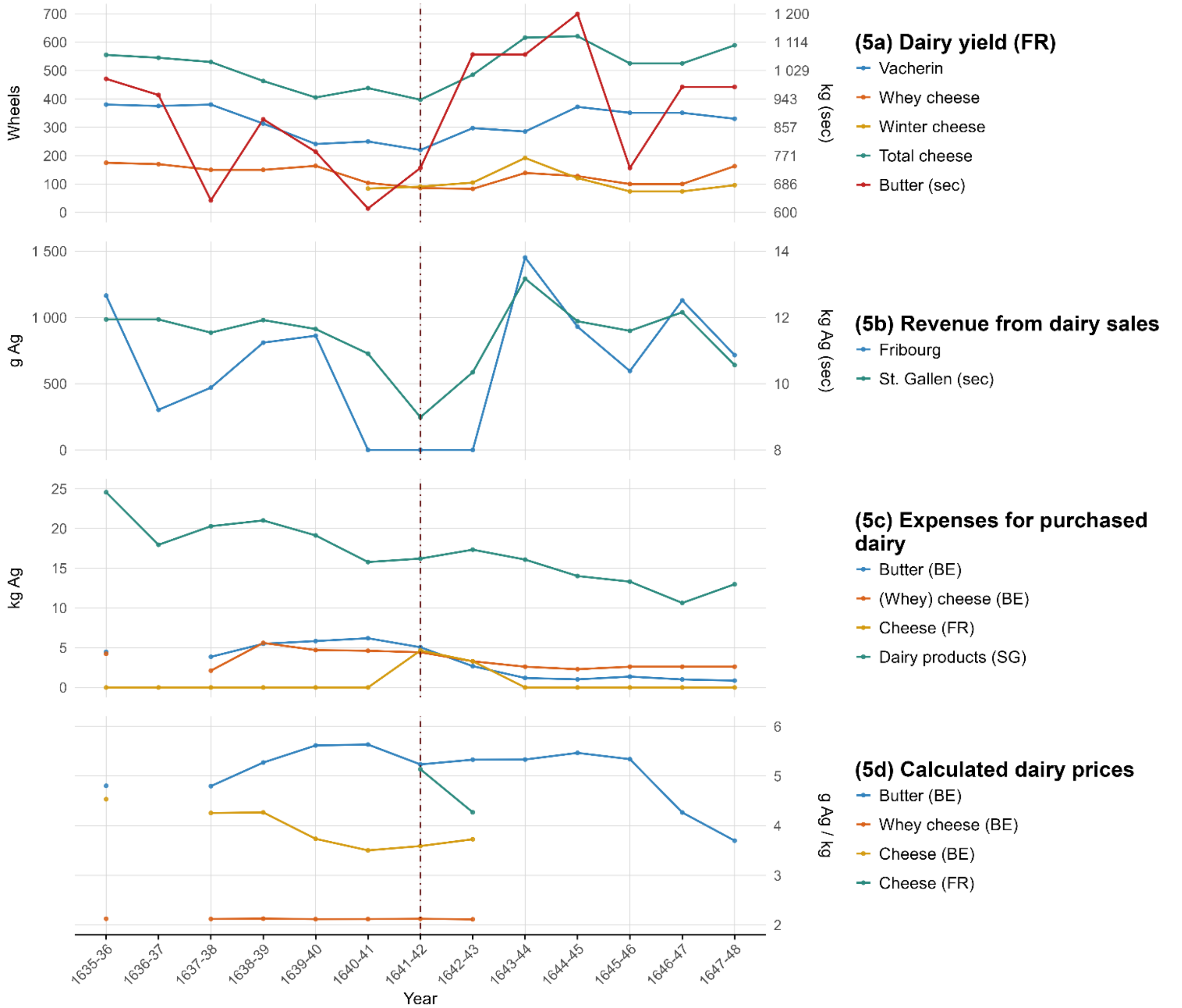

Figure 5: Caseiculture. (5a) Annual yield of dairy products by the hospital in FR in number of wheels or kilogram (kg). (5b) Annual income from sold dairy products by the hospitals in Fribourg and St. Gallen in kilograms of silver (kg Ag). (5c) Expenses for dairy products for the three hospital's own use in kg Ag. (5d) Calculated dairy product prices in grams of silver per kg (g Ag / kg).

5.5 Crop cultivation "*It remained lying in the field due to the persistent rain and came to ruin*"

As grain – whether as bread or porridge – was the most important staple food of the Swiss Plateau's population, it is crucial to trace the impact of the climate anomalies of the 1640s on crop cultivation as well. The accounts of the three hospitals record the annual harvest yields of the hospital crops (*Spitalgwächs*), that is, the grain cultivated by the hospital itself on its own land. Between 1641 and 1644 the harvest of hospital crops in Fribourg fell by 28%. As the opening quotation describes (HS8), in 1640 part of the harvest was left in the fields and rotted due to persistent heavy rain. In 1641, the maslin (mixed grain) froze

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in the field, so that in response more barley – a temperature-resistant grain with a shorter growing season – had to be cultivated. Also, for 1643, sources from Fribourg mention a poor harvest of spelt and maslin due to bad weather. In eastern Switzerland, the hospital in St. Gallen suffered a 22% decline in income from hospital crops at the same time. The hospital in Bern experienced crop failures in 1640, 1641 and 1643. Figure 6a shows both the general variability of the yields of hospital crops and the slumps in 1641 and 1643.

For Fribourg and St. Gallen, however, this did not mean there was a sharp decline in total grain income during the crisis years (see Fig. 6b), a fact linked to the diversity of their various sources of grain income (see Fig. 6c). In addition to income from hospital crops, the three hospitals also received grain from fixed grain rents, grain tithes and purchases from the market. In St. Gallen, income from hospital crops accounted for only 7% of total grain income. In Bern, income from their hospital crops amounted to only 6% between 1635 and 1642. To free themselves almost entirely from this dependence, the amount of grain they grew themselves was reduced through a reform of the hospital's operation from 1642 onwards, so that its share of total grain income fell to an average of 3%.

The Burghers' Hospital in Fribourg, on the other hand, derived 47% of its grain income from its own crops in normal harvest years. However, this proportion fell drastically during the harvest crises. In 1641, income from the hospital's own crops accounted for just 32% and in 1643 as little as 5% of total grain income (see Fig. 6c). While the hospital in Fribourg normally sourced just under half of its grain from its own crops, the hospitals in St. Gallen and Bern relied primarily on more stable income from grain rents and tithes. This made them far less vulnerable to crop failures due to climatic anomalies, as the risk of a poor harvest was borne by third parties and debts could be recovered.

The internal demand for grain did not decrease in either Fribourg or St. Gallen. Only in Bern did internal consumption decline after 1641 because of the hospital reform mentioned above (see Fig. 6d). To ensure food security for its residents, the hospital in Fribourg had to purchase additional grain on the market. In normal times, grain purchases accounted for about 6% of total expenditure. During the crisis years of 1641–1644, this proportion rose to 28%. In 1641, when grain prices in Fribourg peaked (see Fig. 6e), grain purchases accounted for as much as 42% of the hospital's total expenditure. In 1643, the authorities assisted the hospital by allocating it 5,000 pounds from a donation, with the government summarily disregarding the intentions of the donor, who had outspokenly bequeathed the money to another institution (Niquille, 1921).

The situation was the reverse for Bern and St. Gallen. Thanks to their annual grain revenues, they were able to meet their own needs even in times of crisis, so they could sell the surplus on the local market. Between 1639 and 1643, they sold about 170% more grain than in the years before and after. In St. Gallen, the municipal institution sold almost 1400% more grain "*to the city's burghers as porridge meal*" (HS9) to ensure food security for the town's population, including those outside the hospital and to bolster its own finances.

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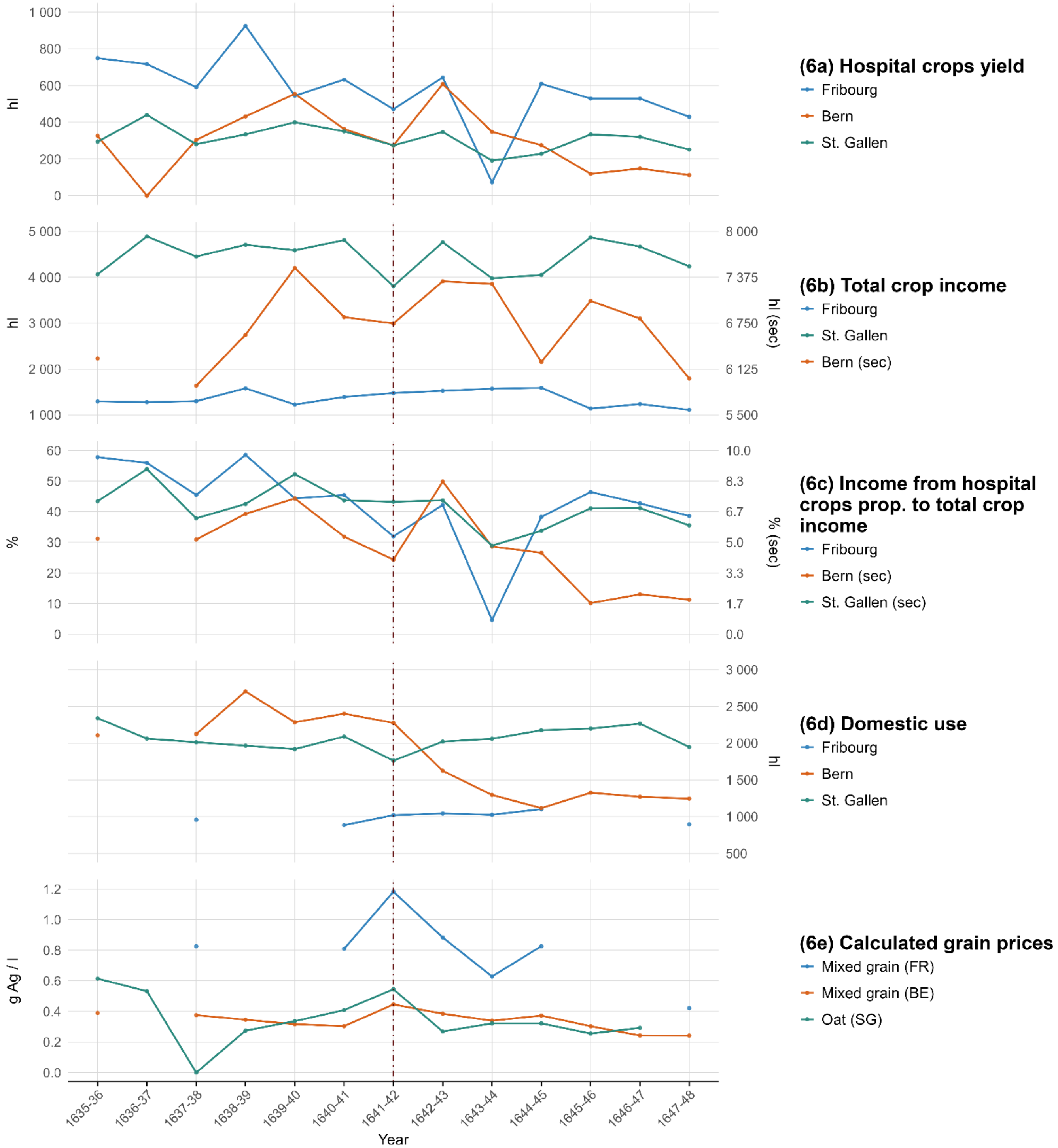

490 **Figure 6:** Crop cultivation. (6a) Annual yields from hospital owned crops in hl. (6b) Annual total crop income in hl. (6c) Income from hospital crops proportional to total crop income in %. (6d) Annual in-house grain usage in hl. (6e) Calculated grain prices g Ag / l.

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5.6 General hospital operations (*Spitalbetrieb*): "*[…] so expensive that it will cause the hospital a loss of many thousands of florins*"

To identify general trends and changes in hospital operations and economy, the annual total income and expenditure of the three hospitals were compared (see Fig. 7a). Fribourg generally reported a balanced income statement during the period under review, with the main exception being the annual accounts for 1641, which finished with a substantial loss. The Lower Hospital in Bern recorded big losses for 1635, 1639, 1641 and 1643. The accounts of the Hospital of the Holy Spirit in St. Gallen were predominantly positive up to 1642; after 1642, however, the hospital in eastern Switzerland recorded losses. The two major peaks in expenditure in 1637 and 1645/46 resulted from investments made when the hospital purchased new properties.

The extent to which the climatic anomalies between 1639 and 1643 affected hospital finances is best illustrated by income from the sale of and expenditure on victuals. The victuals discussed above – wine, dairy products, meat/livestock and grain – were grouped together to form a staple food basket. In the periods before and after the crisis years, revenue from the sale of victuals as a proportion of total revenue was 11% in Fribourg, 42% in Bern and 38% in St. Gallen. While Bern (49%) and St. Gallen (49%) were even able to increase their revenue thanks to the sale of victuals, revenue in Fribourg fell to an average of 7%. At its lowest point in 1641, only 1% of the hospital's total revenue in Fribourg came from the sale of victuals (see Fig. 7b).

The situation is reversed regarding expenditure on the purchase of victuals (see Fig. 7c). In normal years, the Burghers' Hospital in Fribourg spent an average of 9% of its total expenditure on this, the Lower Hospital in Bern 40% and the Hospital of the Holy Spirit in St. Gallen 28%. During the crisis years, the hospital in Fribourg had to spend 33% of its expenditure on victuals, rising to as much as 60% in the extreme year of 1641. In relative terms, Bern spent the most (54%) on purchased victuals in 1639 and St. Gallen in 1641 (43%), as indicated in the chapter's opening quotation (HS10). On average, however, the proportion that these two hospitals – Bern (39%) and St. Gallen (28%) – spent on victuals remained roughly the same as during normal years. This shows not only that the hospital in Fribourg was much more severely affected by the climatic anomalies of the 1640s, but also that its hospital economy was generally much more dependent on produce from its own estates. The hospitals in Bern and St. Gallen had diversified their hospital economies in terms of rents and tithes much more broadly and therefore suffered less from the climatic impacts of the cold years.

Finally, a few comments can be made regarding the number of deaths in the hospital. Using records from the hospital archives, it was possible not only to reconstruct the number of benefactors but also to estimate approximately how many people died in the hospitals each year (see Fig. 7d). Hospitals were required to cover the funeral costs of benefactors and of poor people who died in the hospital (Ohngemach, 2008). In some cases, the number of deaths for the three hospitals is stated directly in the sources; in others, it could be calculated from information in the prebends' registers or from data on annual expenditure. Although the calculated figures should be regarded as estimates, it is evident that the number of deaths in the hospital did not rise substantially during or after the crisis years of the 1640s.

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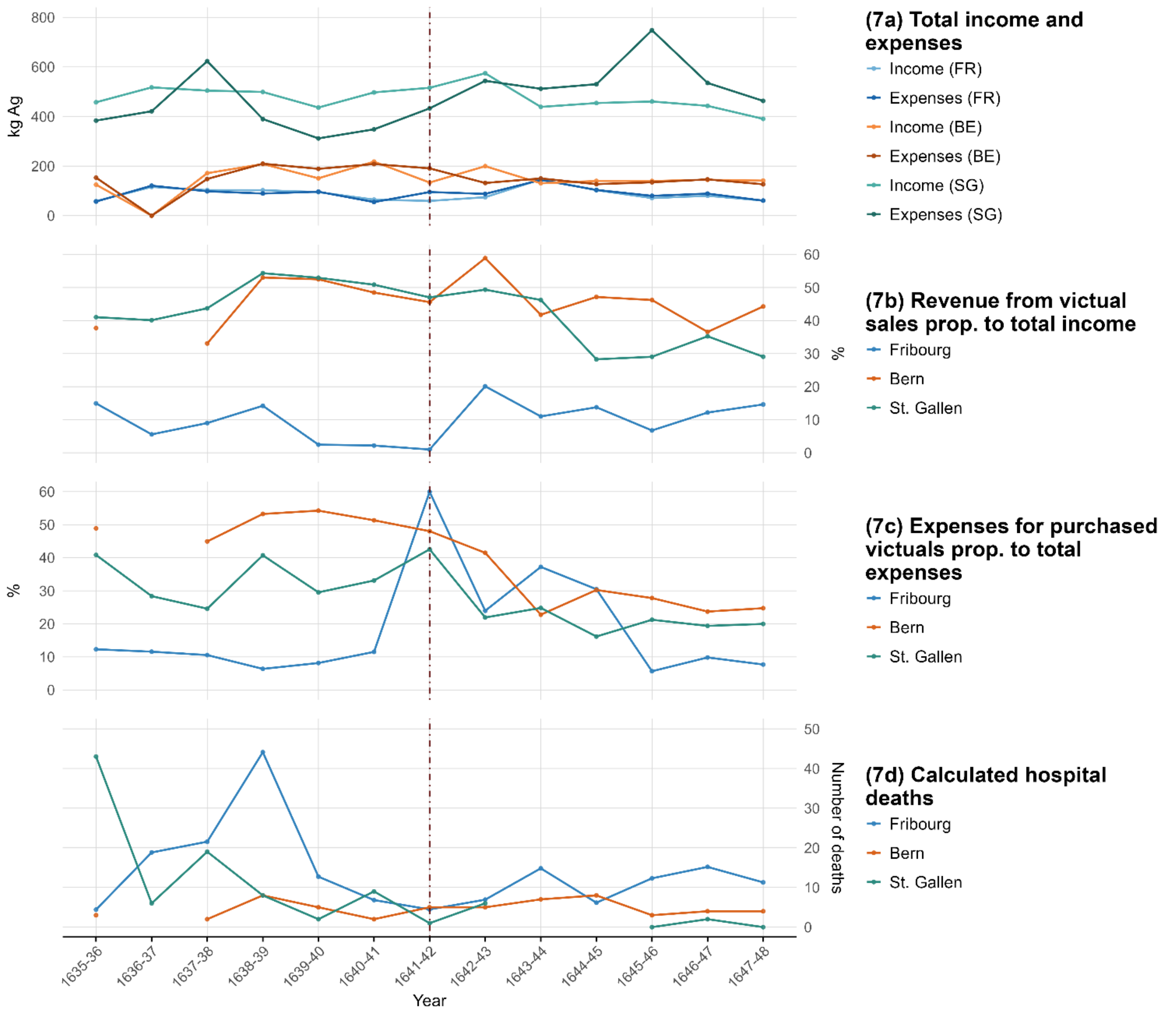

525 **Figure 7:** General hospital operations (*Spitalbetrieb*). (7a) Annual total income and expenses in kg Ag. (7b) Annual revenue from victual sales (wine, dairy products, meat/livestock and grain) as a proportion to the total income in %. (7c) Annual expenses for purchased victuals (wine, dairy products, meat/livestock and grain) as a proportion to total expenses in %. (7d) Calculated annual hospital deaths.

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6 Discussion

While the previous chapter showed how Switzerland experienced climatic anomalies in the early 1640s and the impact this had on the relevant agricultural sectors, the following section focuses on the social consequences of those cold springs and summers for Fribourg, Bern and St. Gallen. To cope with a famine such as the one in Franche-Comté in the early 1640s, early modern authorities had three basic strategies at their disposal to manage a subsistence crisis and ensure the food security of the population. Firstly, the availability of victuals could be increased; secondly, their prices could be fixed; and thirdly, attempts could be made to reduce the demand for victuals (Camenisch, 2019). In addition to such external sanctions ordered by the city authorities, the hospitals themselves could take internal measures to respond to a subsistence crisis.

As demonstrated earlier, one of these internal measures undertaken by all three hospitals was to switch their economic focus from export to import, or vice versa. Another measure is attempting to stabilise prices. Following the poor wine harvest of 1641, the St. Gallen hospital, together with the winegrowers in the Rheintal, attempted to set the annually fixed wine price as low as possible. This attempt failed, leading to an open dispute that could only be resolved through external arbitration. The fixed price, as already indicated above, caused the hospital a substantial financial loss. The hospital in Fribourg attempted to reduce its consumption of provisions. As early as 1640, with explicit reference to the crop failures and high prices, the meals provided during the annual hospital fair (*Spitalkilbi*) had been abolished. Furthermore, the meal that the town doctor and his assistants received as remuneration after every treatment carried out in the hospital, the so-called incision meal (*Schnittmahl*), was also abolished from 1640 onwards due to the generally high food prices.

The decrees issued by the authorities of the three towns (see Table 1 for used sources) illustrate the scale and duration of the subsistence crisis. This is presented for each victual examined. The wine trade in Bern and Fribourg was heavily regulated from October 1639. Prohibitions on the forestalling of wine and its price speculation (*Fürkaufsverbote*) were imposed and regularly reiterated. From September 1641, Fribourg attempted to enforce a fixed price for wine sold; however, prices calculated from hospital records show that this attempt achieved only moderate success (see Fig. 3e). It was not until 1643 that the Bernese authorities decided to lift the import and export regulations for the wine trade again.

The authorities also responded to the cattle plague that broke out in 1637 and was worsened by the poor weather, by issuing decrees and attempting to contain the risk of infection through various strategies. From July 1637, import and export bans on livestock were imposed. Between 1640 and 1643, Bern and Fribourg further restricted movement by prohibiting the driving of sick cattle from one market to another within their territories and ordering them to be isolated. Although the city of Basel had already required health certificates for alpine cattle as early as 1637 (Bühlmann, 1916), Bern did not introduce this until 1640 and Fribourg until 1641. To prevent the livestock population from being completely decimated, a ban on the sale and slaughter of calves that were too young was introduced in 1641. As already mentioned, this measure was implemented by the hospitals in Fribourg and St. Gallen (see Fig. 4c–d). The available records suggest that these measures may have helped limit livestock losses, as the livestock numbers of the hospitals, while declining, were never completely decimated. From July 1639, the authorities in Bern and Fribourg also sought to increase the availability of dairy products by imposing bans on exports and

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purchases. To further reduce demand, Fribourg issued a decree in April 1641 calling for moderate consumption of victuals, particularly dairy products.

No other foodstuff better illustrates how closely the impacts of climate anomalies, crop failures, war-induced migration and social unrest are intertwined than grain. While war refugees from neighbouring Franche-Comté were still welcomed by the towns of western Switzerland in 1637 (Gérard, 1998), the situation changed abruptly with the onset of years of poor weather and subsequent bad harvests. As early as February 1639, Bern prohibited private individuals from taking in Burgundian refugees. Orders mandating the expulsion of Burgundian war refugees were repeatedly issued by the cities of Fribourg, Bern and St. Gallen between 1639 and 1646. A major concern for the cities was the purchase of grain either by outsiders or for speculative purposes, which – as with other victual – was to be prevented by export bans and forestalling prohibitions issued between 1640 and 1642. Fribourg, for example, justified such decrees in April 1641 on the grounds that "*this year's grain crop is not proving to be the most fruitful and our country is being greatly burdened by many strangers from the neighbouring lands ravaged by war*" (HS11). During the height of the crisis in 1641/42, the three cities issued ordinances to regulate the market even more directly. Whereas regulations had previously been general, specific groups were now addressed directly. Millers and bakers were explicitly forbidden to sell grain and flour to outsiders and the gatekeepers were instructed to inspect all passing carts for grain. In addition to these interventions, all aimed at increasing the general availability of grain, regulations were also enacted in Fribourg urging the population to exercise moderation to reduce consumption of bread, grain and flour. The measures listed here are drawn from a catalogue of proved actions regularly employed by the early modern cantons of the Swiss Confederation to combat subsistence crises (Camenisch, 2019). The situation on the grain market appeared to improve again from 1643 onwards. Bern lifted the imposed restrictions in August. The year 1643 was followed by warmer growing seasons, which resulted in fruitful harvests. Consequently, in the summer of 1644, as during the last good harvest in 1638, Bern ordered all its districts to fill the granaries to be prepared for a potential future crisis.

As the measures described above were primarily intended to ensure food security for the local population rather than for the Burgundians who had fled the war, the number of itinerant foreign beggars increased dramatically. The three cities revised their begging regulations several times between 1640 and 1643. However, as this proved insufficient, from 1641 onwards Fribourg and Bern repeatedly called for nationwide beggar hunts to drive out the foreign beggars. Despite these measures, many Burgundian refugees remained in the Swiss cantons even after the end of the war in 1644 (Gérard, 1998).

In the territory of Bern, social unrest broke out during the crisis years of the 1640s. The introduction of a military tax in January 1641 to finance mercenaries intended to protect the threatened borders led to a peasant revolt in 1641, known as the Thun Affair (*Thunerhandel*) (Landolt, 1990). The Berner Oberland and the Emmental were particularly affected. The revolt was rooted in long-standing dissatisfaction among the peasants with the authorities' increasingly absolutist economic and fiscal policy, which had been building for decades (Landolt, 1990). While the immediate trigger was the military tax, the economic measures implemented to address the subsistence crisis – including export bans, market regulations (*Marktzwang*) and forestalling prohibitions (*Fürkauf*) – formed part of the wider set of grievances, as the peasants perceived them as parallel restrictions on their economic freedoms (Landolt, 1990, p. 145). The poor harvests of 1640–42 may have further heightened

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tensions by reducing peasant incomes at a time of increasing regulatory pressure. This persistent discontent among the peasants also erupted during the 1640s in further revolts: refusals to pay tribute in 1641/42 and riots in Sigriswil (1642), Bipp (1643) and Aarwangen (1644) (Landolt, 1990).

Although this study focuses primarily on the cantons of Fribourg, Bern and St. Gallen, a review of the resolutions (*Abschiede*) of the federal Diet shows that the Old Swiss Confederation was generally affected by the crisis of the 1640s (for the individual resolutions see Vogel and Fechter (1875)). At the Diet of the Swiss Confederation in August and September 1641, discussions were held on how to prevent inflation caused by the poor grain harvest. The cantons were advised to reinstate measures that they thought had proved effective in earlier crises, such as the mentioned export bans and the prohibition of forestalling.

Two years later, at the Diet held from July to August 1643, the cantons noted that the nationwide rise in prices of victuals was attributable to the Burgundian and French troops stationed near the Swiss border. In 1645, the tense situation in the hospitals, caused by the general increase in foreign beggars, was also discussed at the Diet. It was emphasised that hospitals should provide food assistance only to the local poor and to those unable to support themselves through manual labour. The actual efficiency of these kinds of measures is quite difficult to prove (Camenisch, 2019).

Returning to the situation of the three hospitals examined, the most meaningful long-term impacts of the subsistence crisis of the 1640s on hospital operations are outlined. The hospitals weathered the subsistence crisis of the mid-seventeenth century without a distinct increase in the number of recorded deaths or a decline in the number of residents. Although all three institutions were well-endowed and largely self-financing during the period under review (see Fig. 7a), they came under enormous pressure as care institutions and the first point of contact for those in need during the height of the crisis, due to the many people fleeing war and famine. To counter this in future, the Burghers' Hospital in Fribourg introduced stricter controls from 1646 onwards to ensure that only the sick in need were provided with food free of charge.

It also became clear what major vulnerability it was for the hospital in Fribourg, compared to the other two hospitals examined, to derive almost half its grain income from its own crops. As demonstrated above, this resulted in exorbitant additional expenditure in 1641 and 1643. In response and to increase its resilience to future subsistence crises, it sold a large proportion of its estates used for crop cultivation in 1655 and – like the hospitals in Bern and St. Gallen – ceased growing almost all its own grain (Niquille, 1921). Overall, consistent with the resilience theory outlined at the beginning, the hospitals were largely able to mitigate the impacts of climate anomalies likely resulting from internal stochastic climate variability and external volcanic forcing through absorption (drawing down reserves), adaptation (internal and external measures) and transformation (longer-term adjustments to hospital operations).

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7 Conclusion

This paper examined the climatic, agricultural and societal impacts of the Komagatake/Parker double volcanic eruption of 1640/41 on the Switzerland. Unlike regions such as China, Japan and northern Europe, Switzerland did not experience a comparable famine. To research this, the study focused on three municipal hospitals in the Swiss Plateau (Fribourg, Bern and St. Gallen) and analysed to what extent viticulture, husbandry, caseiculture and crop cultivation – on which their operations heavily depended – were impacted between 1635 and 1647.

Switzerland experienced cold springs and summers between 1639 and 1643, likely resulting from a combination of internal stochastic variability and volcanic forcing from the double eruption. This severely affected all key sectors of the hospitals' agricultural production simultaneously, due to their interconnectedness and interdependence. Repeated grain harvest failures during the crisis period, along with hospitals suffering around 25% loss of revenue from home-grown crops, also affected husbandry, as the lack of high-quality fodder possibly intensified a livestock epidemic that had been ongoing independently since 1637. This, in turn, led to a decline in vital dairy production. In addition, yields in viticulture fell extensively, particularly affecting the hospital economies of Bern and Fribourg, as the loss of revenue from wine sales caused their total income to fall by about 10%. To meet domestic demand, the hospitals were forced to deplete their stocks. When this proved insufficient, the missing victuals had to be purchased at high prices from the local market. The greatest vulnerability in the subsistence crises was the extent to which the hospitals engaged in direct crop cultivation. While Bern and St. Gallen were able to sell their surplus grain, obtained from rents and tithes, at a profit – thus alleviating the suffering of the urban population – the hospital in Fribourg had to spend almost half of its total expenses on purchasing grain from the market, because about half of its grain requirements were met through direct crop cultivation.

To mitigate this subsistence crisis, hospitals and the authorities implemented various coping strategies. Hospitals took initial steps through internal measures such as switching from exporting to importing victuals or reducing unnecessary expenditure. In addition, they benefited from external measures ordered by the cities' authorities through mandates to ensure food security for their populations. The city councils sought to stabilise food prices by introducing fixed prices, increase the availability of goods through purchase and export bans, market regulations and health certificates for livestock and reduce food consumption by propagating moderation. The subsistence crisis was worsened by the effects of the Ten Years' War between France and the Franche-Comté. Burgundian war refugees bought up victuals, causing their prices to rise further and wandered the country as beggars. The authorities' response to the subsistence crisis coincided with a peasant revolt in Bern in 1641, whose grievances included the military tax and the trade restrictions that formed part of the authorities' crisis management. Although the food crisis was discussed at the federal level and many cantons were affected, a nationwide famine comparable to those in neighbouring regions was not recorded. Nevertheless, the urban hospitals studied were directly affected by the climate anomalies yet showed sufficient resilience to manage the crisis by adapting their operations and thus did not experience an increased number of deaths among hospital residents.

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Unlike the typical portrayals of disasters in VCS research, this study focused on a region that was spared from famine. It not only demonstrated how local institutions and authorities responded to climate anomalies and mitigated their potential agricultural and societal consequences but also highlighted their multi-causal origins. The comparative analysis of three hospital economies demonstrates that the degree of vulnerability depended primarily on the extent of direct cultivation and that institutional diversification through rents and tithes provided greater resilience to climatic shocks. As this study deliberately focused on urban populations, it would be useful to conduct further research on rural populations to examine how they coped with the subsistence crisis. Given the reliable and comparable archival records of the hospitals, it would also be worthwhile to analyse one of the victuals – such as wine – diachronically across the centuries, or to conduct a comparative study of another eruption – such as the Laki eruption of 1783, which occurred 140 years later on the eve of the French Revolution – for the same region and the same actors to see whether the prebends of the hospital of the Holy Spirit in St. Gallen had to drink sour wine also in 1784.

Appendix A: European temperature and precipitation anomalies (1635–1646)

Since the present study focuses on early modern Switzerland (6.56°–10.31°E, 46.63°–48.49°N), the European (16°E–30°W, 34°–60°N) climate conditions surrounding the double eruption of 1640/41 (1635–1646), in terms of mean growing-season (AMJJ) temperature (see Fig. A1) and precipitation (see Fig. A2) anomalies, are shown here for context (see Fig. A1 and A2), using reanalysis data from ModE-RA (Valler et al., 2024). Between 1636 and 1638, warm growing seasons (up to +2.57°C in 1636) dominated Central Europe (see Fig. A1b–d). Figure A1e shows, that the situation changed in 1639 with a drop in average AMJJ temperatures anomalies (down to -1.6°C). Several consecutive years of cool late springs and early summers followed, particularly between 1641 and 1643, with local negative anomalies reaching -2.76°C in 1643 (see Fig. A1g–i). Growing season temperatures improved only from 1644 onwards (see Fig. A1j).

In contrast, the pattern of European late-spring to early-summer (AMJJ) precipitation is more heterogeneous in both time and space, with four distinct types of periods identifiable. For the period 1636 to 1638, ModE-RA shows negative precipitation anomalies for Central Europe, with local negative anomalies reaching −32.77 mm/month in 1637 (see Fig. A2b–d), while Southern Europe exhibits increased precipitation anomalies. This pattern reverses in 1639 and 1640, when Central Europe experiences increased anomalies (up to +34.36 mm/month in 1640) and Southern Europe shows slightly decreased precipitation anomalies (see Fig. A2e and A2f). From 1641 onwards, Southern Europe generally experiences an increase in precipitation (up to +31.45 mm/month in 1642), while Central Europe shows a decrease (down to -36.87 mm/month in 1645), with the apparent transition zone located in the Alps between 1644 and 1646.

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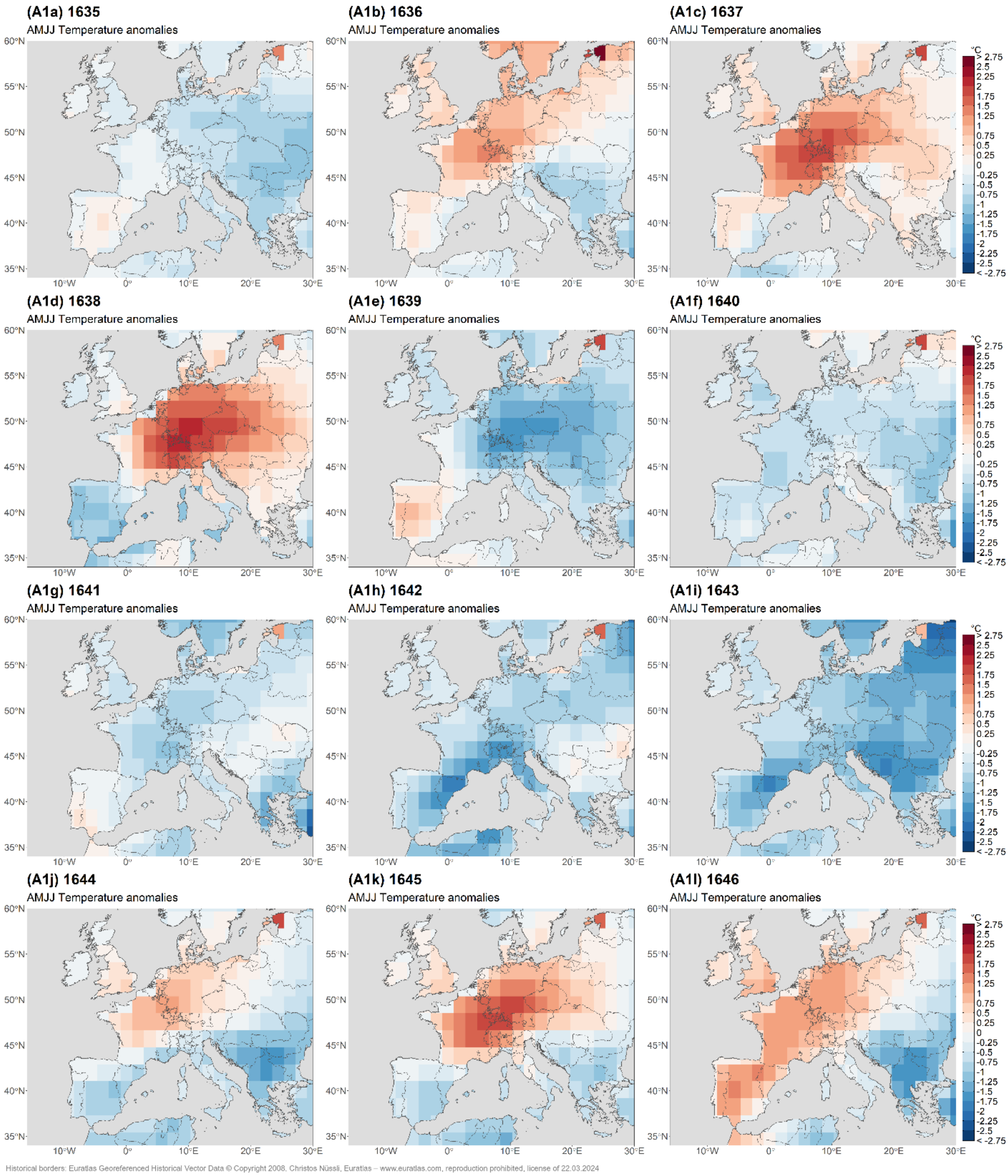

Figure A1: European growing season temperature anomalies. (A1a-l) Mean AMJJ temperature anomalies over Europe (16°E–30°W, 34°–60°N) from 1635 to 1646, wrt. 1961–1990, from ModE-RA (Valler et al., 2024), analysed with ClimeApp (Warren et al., 2024); with historical borders for the late-seventeenth century (Euratlas Georeferenced Historical Vector Data © Copyright 2008, Christos Nüssli, Euratlas – www.euratlas.com, reproduction prohibited, license of 22.03.2024).

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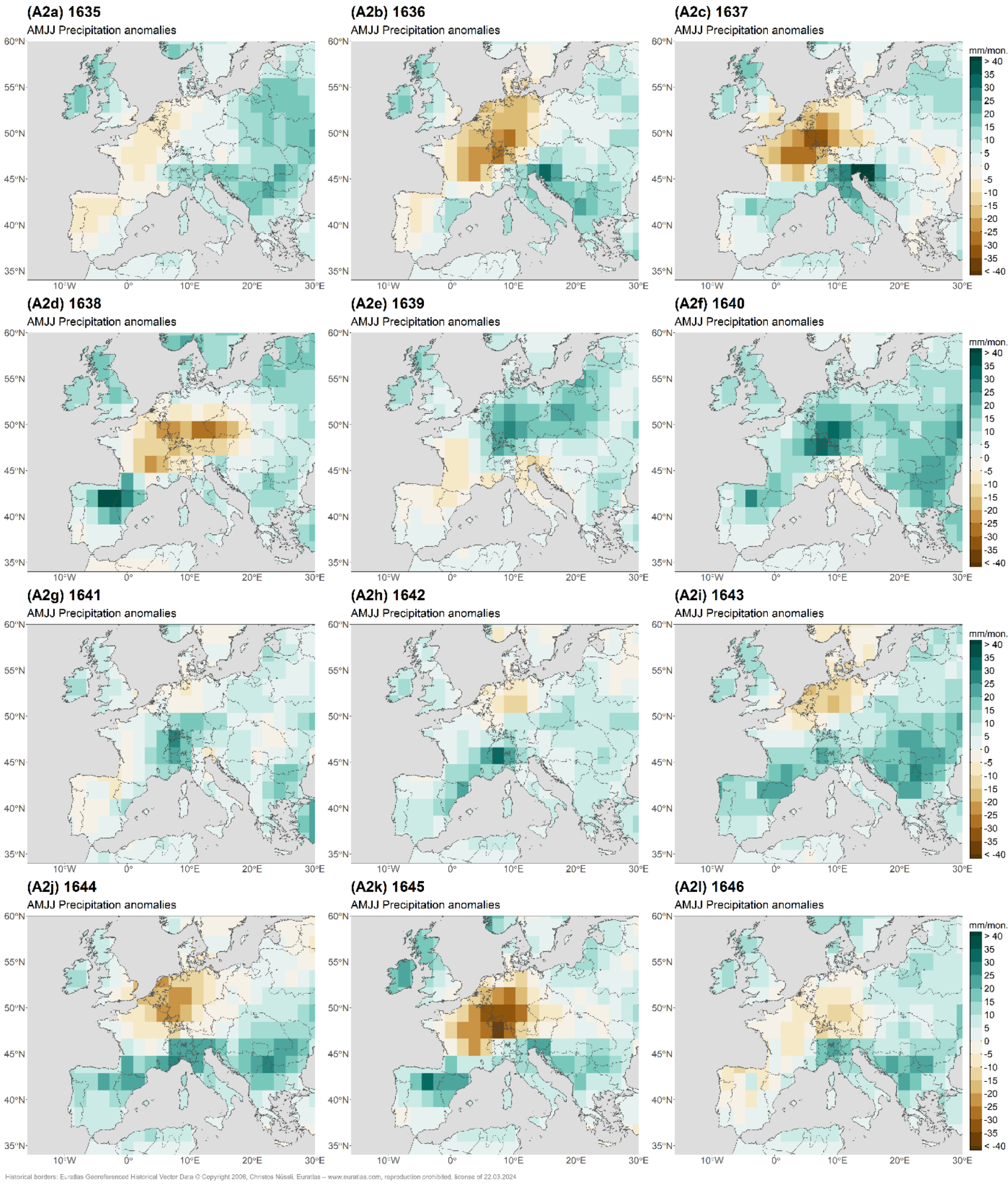

Figure A2: European growing season precipitation anomalies. (A2a-l) Mean AMJJ precipitation anomalies over Europe (16°E–30°W, 34°–60°N) from 1635 to 1646, wrt. 1961–1990, from ModE-RA (Valler et al., 2024), analysed with ClimeApp (Warren et al., 2024); with historical borders for the late-seventeenth century (Euratlas Georeferenced Historical Vector Data © Copyright 2008, Christos Nüssli, Euratlas – www.euratlas.com, reproduction prohibited, license of 22.03.2024).

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Appendix B: Processing, normalization and homogenization of historical sources

To quantify the impacts of the climate anomalies on hospital economies, percentage changes were calculated by comparing the mean of the crisis period (1639–1643) with the mean of the surrounding years (1635–1638 and 1644–1647), which serves as the baseline (100%). The underlying annual data are deposited in the BORIS repository (Bartlome, 2026). Thanks to the exceptionally good source transmission (*Quellenüberlieferung*) for all three hospitals, the dataset is nearly complete. Where there were small data gaps, they were omitted and not interpolated. The same applies to the only notable gap: the missing annual accounts for 1636 for the Lower Hospital in Bern, which fall outside the crisis period.

To calculate the yield per hectare (hl / ha) of the three hospitals' vineyards, the extent of their property had to be reconstructed from vine rentals or information given in the accounting books (see Table 1). The Lower Hospital in Bern provides the most reliable basis, as its size was recorded for six of the thirteen years of the study period. For Fribourg, the vineyard extent was taken from a rental compiled between 1629 and 1636 (AEF, Grosses Hôpital 133); for St. Gallen, from a property description (*Güterbeschreibungen*) dating to 1641 (SASG, Spitalarchiv Q 15). In both cases, a review of the surviving purchase and sale deeds for the years of the study period revealed no transactions, supporting the assumption that their property remained stable. Because the Bernese property documentation is continuous – with the exception of year 1636 – and particularly thorough, its reconstructed yield per area was used as a reference standard for the other two hospitals. Vineyards in Bern and St. Gallen were cultivated under sharecropping contracts (*Halbrebenverträge*), so the recorded volumes represent only the hospital's portion; a factor of 2 was applied to obtain total yields. For Fribourg, a factor of 4 was used instead, as a portion of its property was leased under fixed rents (*Fixzinsen*), meaning the accounts substantially understate the actual harvest (Niquille, 1921).

The biggest uncertainty however concerns the size of St. Gallen's vineyard property. The 1641 property description records vineyard size not as a measured area but as the expected annual yield of individual units (*Stück Reben*) in Saum. A minimum of approximately 65 ha and a maximum of 115 ha can be calculated; the most plausible estimate, used for this study, is 80 ha (for the calculations see Bartlome, 2026)

For historical economic data – such as harvest yields, prices, income and expenditure – from different regions to be compared or used in historical climatological research, it must first be normalized using SI units. To achieve this, a conversion metric was developed for each victual examined at each hospital. Dubler (1975) provides regionally specific conversion values for weights and measures in historical Switzerland that reduce local metrological uncertainty to a negligible level. Using systematically reconstructed exchange rates (Körner et al., 2001) for Swiss currencies (1600–1799), monetary and price data were normalized into kilograms or grams of silver (or grams of silver per victual, in SI units) to be compared across regions. It is based on the homogenized silver content of the German *Reichstaler* (Elsas, 1940). This results in the following conversion metrics for all used variables for the three examined hospitals (see Table B1–B3):

Fribourg

Table B1: List of used and normalized weights and measures for Fribourg.

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Type	Original measuring unit	Normalized SI unit
Area measure	1 Pose (juchart)	0.43 ha
Liquid measure (wine)	1 Fass (barrel)	6.304 hl
Grain measure	1 Mütt (bushel)	3.8328 hl
Weight measure	1 Pfund (pound)	0.4895 kg
Money of account	1 Pfund Lb (pound Lb)	5.2269 g Ag

Bern

Table B2: List of used and normalized weights and measures for Bern.

Type	Original measuring unit	Normalized SI unit
Area measure	1 Mannwerk (daywork)	0.043 ha
Liquid measure (wine)	1 Saum (load)	1.67 hl
Grain measure	1 Mütt (bushel)	1.68 hl
Weight measure	1 Pfund (pound)	0.4895 kg
Money of account	1 Pfund Lb (pound Lb)	7.840 g Ag

St. Gallen

Table B3: List of used and normalized weights and measures for St. Gallen.

Type	Original measuring unit	Normalized SI unit
Area measure	1 Stück Reben (piece of vineyard)	0.4524 ha
Liquid measure (wine)	1 Saum (load)	1.7152 hl
Grain measure	1 Malter (quarter)	3.304 hl
Grain measure	1 Mütt (bushel)	0.826 hl
Weight measure	1 Pfund (pound)	0.465 kg
Money of account	1 Gulden Fl (florin Fl)	18.12 g Ag

Appendix C: Historical sources (HS)

Listed below is the original, untranslated wording of the direct quotations used in the text and their archival code.

HS1: "der mehrtheil trauben, haben weg[en], früen Reyffen, und anderen ungeschlachten gwiter nit mögen Reiff werd[en], [in diesem Jahr:] wein ist über alle massen übersetz, so dem spital vil 1000 fl. verlust [ver]ursachen wirt" (SASG Spitalarchiv I 6, 1641)

HS2: "In disem obstendtem Jar ist ein solchen früern und on underlass warmen Som[m]er" (SASG Spitalarchiv I 6, 1638)

HS3: "einen solchen Stattlichen gut[en] wein" (SASG Spitalarchiv I 6, 1638)

HS4: "wenig und zimblich Sauren wein" (SASG Spitalarchiv I 6, 1639)

HS5: "Item als A[nn]o 1641 der Weyn übel gerathen […]" (AEF HB A3.216b, 5v)

HS6: "und dann 2 [Vieh] So Siech waren […]" (AEF HB A3.212, 24r)

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HS7: "Winterkäsen […] bis dato uberal mer nit von wegen des schlechten fuotters" (AEF HB A3.212, 23v)

HS8: "ist auch by dem Steten Regenwetter uffem Veldt geblib[en] und Zu schad[en] kommen" (AEF HB A3.212, 23v)

HS9: "denen bürgeren als muesmell" (SASG Spitalarchiv B 162, 26r)

HS10: "über alle massen übersetz, so dem spital vil 1000 fl. verlust [ver]ursachen wirt" (SASG Spitalarchiv I 6, 1641)

HS11: "Wie leider diss Jahres das khorngewächs nit Zum fruchtbarlichsten sich erzeigt, und unser Landt mit vihlen frembden lüthen beladen, auch der benachtbarten mit kriegsverderbten Landen wegen" (AEF, Mandatenbuch 4, 178v)

Data availability

The used ModE-RA, ModE-Sim, ModE-RAclim and SAOD data are available through the World Data Center for Climate (WDCC) (Toohey and Sigl, 2019; Valler et al., 2023). The data underlying the plots are published in the Bern Open Repository and Information System (BORIS) of the University of Bern (Bartlome, 2026).

Author contributions

This is a single author submission. The author was responsible for all aspects of the study, including conceptualization, data gathering, analysis, visualization and writing.

Competing interests

The author declares that he has no conflict of interest.

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