THE METEOROLOGICAL DIARIES OF JOHANN RUDOLF VON SALIS-MARSCHLINS, 1781-1800

Master's Thesis

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Abstract

The meteorological diaries of Johann Rudolf von Salis-Marschlins contain a rich collection of climatological data. Within the here studied years of 1781-1800, well over 10,000 pressure and temperature measurements, more than 4,000 observations of phenological phases, and close to 2,000 descriptions of precipitation events can be found. Despite their extraordinary wealth in data, however, the Marschlinian diaries played a minor role in historical climatology so far, which is mainly due to reported inaccuracies of the used instruments. With the construction and homogenisation of a monthly temperature and pressure series, this study was able to refute large parts of these reservations. Additionally, the precipitation observations have been quantified to obtain monthly precipitation depth totals. Furthermore, monthly snow cover duration and some selected phenological phases have been studied and their potential evaluated. Although not all systematic errors could be resolved for all series, measurements and observations generally are of high quality and, once homogenised, of high value to historical climatology. A continuation study of the entire Marschlinian record (1781-1823) is thus recommended. In addition to this analysis of the diaries' contents, this thesis also contains a complete transcription of the first twenty years of diary entries.

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I am especially grateful to my advisor, M.A. Lukas Heinzmann, and to M.A. Antoine Jover, who invested many hours in the adaptation of the software behind the *Dietrich-Edition* to the requirements of the transcription for the Marschlinian diaries. Lukas shared his experience on the use of *T-PEN* in multiple meetings and e-mail conversations and thus greatly eased my introduction to the program. Without his and Antoine's big effort, the here presented transcription would look substantially different.

Furthermore, I would like to thank Dr. Gabriela Schwarz-Zanetti, who suggested the use of an indices system for a more in-depth analysis of the qualitative precipitation data. Finally, thanks go to M.A. Lucas Pfister and Dr. Yuri Brugnara of the CHIMES project for the granted insights in their findings on pre-institutional Swiss measurement series, and the support on issues of homogenisation.

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1. Introduction

"Annus fructificat, non terra"[1]

Already within the first few lines of his diaries, Johann Rudolf von Salis-Marschlins gives a hint of what was motivating him in his undertaking of observing the weather. The citation from Theophrastus clearly displays his conviction: the annual climatology (and not the earth) is what decides between a fruitful year and one with bad harvests. Consequently, Salis-Marschlins started to spend large parts of his everyday-life in 1781, measuring and observing day-to-day weather and plant life in order to better understand the driving forces behind the annual phenological cycles, and thereby also the quality and quantity of agricultural yields. With that, Salis-Marschlins was far from alone. Over a hundred individual pre-1864[2] records can be found for the Grisons, more than for any other Swiss canton. The fact that Salis-Marschlins decided to start detailed meteorological observations and measurements in the late 18th century is thus not particularly remarkable. What is remarkable, however, is that he decided to continue these observations for decades to come, regardless of changes of residence or the threatening political situation during French occupation. Thanks to this high persistence, his *Ökonomische, botanische, meteorologische und physikalische Bemerkungen und Beobachtungen* contain meteorological data of more than four decades (1781-1823)[3]. This makes the Marschlinian diaries the longest and probably also most extensive source of pre-institutional climatological data for the Grisons accessible today.[4] In more than 10,000 pages, Salis-Marschlins noted his sub-daily measurements of pressure and temperature, described wind direction and strength, and commented on the state of weather. Furthermore, he recorded precipitation events and snow coverage, and made several thousand phenological observations, which "in their extent almost rival those of Sprüngli"[5]. It thus comes as a surprise that the Marschlinian diaries have almost entirely been overlooked in historical climatology so far.

[1] "The year makes the fruit, not the earth" (own translation).
[2] In 1864, institutional weather observations started in Switzerland.
[3] In fact, occasional observations from the time between 1828-1832 can also be found. Cf. Jenny 1974: 175-176.
[4] For more detail, see Section 1.3.
[5] "[...] umfangmässig mit denen [Johann Jakob] Sprünglis nahezu messen können." Pfister 1988: 40.

1.1. Aims and Structure of this Thesis

Having partially transcribed and evaluated the Marschlinian diaries for my bachelor's thesis,[6] my master's thesis now aims to finish what has been started and expand the field of research from just one year (1792) to the whole twenty-year period of 1781 to 1800. Unlike the rest of the Marschlinian series, this early period of Salis-Marschlins' observations cannot be found in convenient table form in the Swiss National Archive.[7] Thus, the first aim of this master's thesis was to improve the accessibility to the first twenty years of observation; not only of the climatologically interesting data that can be found within the records of Salis-Marschlins, but of all diary entries. This has been done by means of a transcription of the years of 1781-1800, which is available as a digital attachment to this thesis.[8] These first twenty years contain well over 10,000 pressure and temperature measurements, frequent and detailed descriptions of precipitation events and snow cover duration, and several thousand phenological observations. For the most part, these contents have not been included in historical climatological research up to date.[9]

Therefore, my second aim in this thesis is to demonstrate the high potential the Marschlinian diaries have, while also pinpointing the possible shortcomings and limitations within the data they provide. Having made the first twenty years of observation more easily accessible in the transcription, the data collected therein should now be used to reconstruct the local weather and climate of that time. The focus will thereby be set on pressure and temperature measurements, as those have been most critically viewed by literature. Additionally, Salis-Marschlins' phenological observations, as well as the gathered data regarding precipitation depth and snow cover data shall also be evaluated.

To reach these goals, the following structure was decided on. After this introduction in Chapter 1, the second chapter will elaborate on the nature of the Marschlinian diaries, as well as the author of the diaries himself. Only then will Chapter 3 present the air temperature and pressure measurements. In a first part, the three daily measurements recorded by Salis-

[6] Cf. Grimmer 2017.
[7] Cf. Marschlins Witterungsbeobachtungen 1800-1885, BAR, E3180-01#2005/90#242*; E3180-01#2005/90#232*; E3180-01#2005/90#229*; E3180-01#2005/90#235*; E3180-01#2005/90#243*; E3180-01#2005/90#241*. Furthermore, Salis-Marschlins himself published the years of 1802-1811 in the *Neuer Sammler*: Cf. Salis-Marschlins 1805-1812.
[8] Further details can be found in Section 1.5.
[9] The main reason for this is to be found in the said to be low accuracy of Salis-Marschlins' measurement devices, reported in some parts of the diaries themselves, and in Salis-Seewis 1811: 194-196. The analysis for the year of 1792, however, showed reasonably good results, once corrected for the expected systematic errors. For more detail, see Grimmer 2017: 26-30, 42-50.

Marschlins will be combined and corrected for their systematic errors to get an approximation for the daily average temperature and pressure values. After a homogenisation of the data, the result will be a twenty-year series of monthly averages for both temperature and pressure. Next, Chapter 4 will talk about the phenological observations that Salis-Marschlins made. Here, the focus will first be put on the blossoming of cherry trees and vines, as well as grape harvest dates. In a second step, series of other phenological phases of interest will be presented. The third results chapter, Chapter 5, contains the precipitation related diary entries. By combining both measurements and observations of precipitation events, an estimation for the monthly precipitation depths and the days with snow cover will be presented. Furthermore, this chapter holds a brief overview on flood and avalanche occurrences, as well as summer snowfall events. Finally, in Chapter 6, the conclusions to this thesis will be drawn.

1.2. State of Research

Modern historical climatology knows three main objectives: the investigation of vulnerability of past societies to (rapid) climatic change and extreme weather events; the study of past discourses and perceptions of the climate; as well as the reconstruction of past weather and climate.[10] While elements of climate perception and on instances also elements of the vulnerability to nature events can be found within the Marschlinian diaries, Salis-Marschlins clearly focused on the description of the current weather by means of observations and measurements. The state of research presented in the following will therefore concentrate on this third field of historical climatological research. Emphasis will be put on early instrumental measurement series in Central Europe. Also, some key publications of historical phenology shall be highlighted. In two final paragraphs, the research output that is directly connected to the Marschlinian diaries will be summarised. Apart from this last section, which aims at capturing all publications that included the Marschlinian records in their analysis, none of these brief overviews raises a claim for completeness by any means. The goal much rather is to point out a few key publications of these areas with a focus on Switzerland. A recent, far more in-depth literature review is offered by Chantal Camenisch, who not only presents a thorough summary for the field of historical climate reconstructions, but also gives a comprehensive overview of publications on climate change vulnerability analysis.[11]

[10] Cf. e.g. Mauelshagen 2010: 20; Pfister 2010: 25; Brázdil et al. 2005: 365-366.
[11] Cf. Camenisch 2015: 18-30.

Following Camenisch,[12] the onset of modern historical climatology is mainly owed to the work of Emmanuel Le Roy Ladurie, who in 1967 argued against the prevalent climate determinism of that time.[13] Another early milestone for historical climatology was the use of historical source material for the verification of the Medieval Warm Period (or Medieval Climate Anomaly) by Hubert Horace Lamb.[14] For Switzerland, the pioneering work on historical climatology is mainly to be ascribed to Christian Pfister. After focusing on early instrumental and descriptive data for the Swiss Plateau in his early studies,[15] Pfister enlarged his field of research to the climate history of the last 500 years for entire Switzerland in his two landmark publications *Klimageschichte der Schweiz*[16] and *Wetternachhersage*[17]. More recent publications in historical climatology, such as *Klimageschichte der Neuzeit* by Franz Mauelshagen or *Klimageschichte Mitteleuropas* by Rüdiger Glaser, encompass even wider areas and timespans.[18] A summary of the up-to-date methods and the current state of climate history can be found in the handbook edited by Sam White, Christian Pfister and Franz Mauelshagen.[19]

In the course of the 18th and early 19th century, continuous measurement series started in numerous places all over Europe.[20] In Switzerland, three such series that span over more than two centuries are currently accessible. In Basel (1755) and Geneva (1760), observations already started in the mid-18th century, while the series of the Great St. Bernard Pass only commences in 1819.[21] On the course of multiple centuries, measurement circumstances (e.g. instruments, station location, station environment, observing practise) usually change on multiple instances. Such artificial factors often introduce non-climatic shifts or gradual biases to these series. To obtain a meaningful series, such inhomogeneities thus need to be removed in the process of homogenisation as best as possible. A major homogenisation project under the coordination of Dario Camuffo and Phil Jones went by the name of IMPROVE. In the frame of this project, seven early instrumental series of temperature and/or pressure with daily resolution have been produced, analysed and homogenised.[22] In addition, several technical questions concerning

[12] Cf. ibid.: 18-20.
[13] Cf. Le Roy Ladurie 1967.
[14] Cf. Lamb 1965.
[15] Cf. Pfister 1975.
[16] Cf. Pfister 1988.
[17] Cf. Pfister 1999.
[18] Cf. Mauelshagen 2010; Glaser 2013.
[19] Cf. White, Pfister, Mauelshagen 2018.
[20] Cf. Dobrovolný et al. 2010: 79.
[21] Cf. Pfister et al. 2019: 1346. All three series were first evaluated by Bider, Schüepp and Rudloff. Cf. Schüepp 1957; Bider, Schüepp, Rudloff 1959; Bider, Schüepp 1961; Schüepp 1961. The series then were re-evaluated and are nowadays available on the data platform of MeteoSchweiz. Cf. Füllemann et al. 2012: 22; Bundesamt für Meteorologie und Klimatologie MeteoSchweiz 2019.
[22] Cf. Camuffo, Jones 2002.

common problems of early instruments and the effects of measuring times have been addressed.[23] One year later, in 2003, the WMO guidelines on climate metadata and homogenisation provided a concise theoretical framework and guidance for such homogenisation projects.[24] HISTALP, which launched in March 2009, plays a key role for the compilation and homogenisation of historical instrumental measurement series of the 'Greater Alpine Region'.[25] The website enables easy access to well over 500 homogenised monthly temperature, pressure, precipitation, sunshine and cloudiness series. Using a combination of such homogenised instrumental series and written historical sources, Dobrovolný et al. were able to construct monthly, seasonal and annual temperature series for Central Europe, starting in 1500.[26] Since 2016, the CHIMES project of the university of Bern is compiling, digitising and partly also homogenising pre-institutional documentary climate sources from Switzerland.[27] Amongst the more than 300 series are also the Marschlinian diaries. The current state of the project is described in an article by Lucas Pfister et al.[28] Compared to early instrumental temperature or pressure series, the availability of quantitative precipitation data is considerably lower, and reconstructions thus often need to be based around qualitative descriptions. Only a few climatologists have attempted such reconstructions of early instrumental precipitation anomalies for the region of Switzerland up to date.[29]

Since the onset of modern historical climatology, phenological observations have been an important source of proxy data for the reconstruction of past temperature variations. Unsurprisingly, it was the phenological phases of the two most important and thus best recorded economical plants, vine and crop, which were at the centre of the climatological interest first. Exponents of this early phase of historical phenology are once again Emmanuel Le Roy Ladurie and Christian Pfister.[30] Grape and vine phenology as a past climate indicator has been described and used in multiple articles and research projects since, as for example by Isabelle Chuine et al.[31] More recent is a publication by Oliver Wetter and Christian Pfister, who reconstructed Swiss summer temperatures in between 1444 and 2011 on the basis of vine phenology.[32] For the reconstruction of early spring temperatures, on the other hand, different phenological phases are needed.

[23] Cf. Camuffo 2002a; Camuffo 2002b.
[24] Cf. Aguilar et al. 2003.
[25] Cf. Auer et al. 2007 ; Böhm et al. 2009.
[26] Cf. Dobrovolný et al. 2010.
[27] Cf. University of Bern 2019.
[28] Cf. Pfister et al. 2019.
[29] Cf. e.g. Gimmi et al. 2007.
[30] Cf. Le Roy Ladurie 1967; Pfister 1975.
[31] Cf. Chuine et al. 2004.
[32] Cf. Wetter, Pfister 2013.

Rutishauser et al. suggest the flowering dates of cherry (*prunus avium*) and apple (*malus domestica*) trees as well as the bud burst of beeches (*fagus sylvatica*).[33] As institutional phenological observations in Switzerland are available only since 1951, long continuous series of phenological phases are rare and their construction highly labour-intensive. Nonetheless, This Rutishauser was able to reconstruct and homogenise a series of close to 300 years cherry blossom dates in his master's thesis.[34] A few years before, Claudio Defila and Bernard Clot had presented a 200 year series of the horse-chestnut (*aesculus hippocastanum*) bud burst in Geneva – a proxy for winter and spring temperatures – and a cherry blossom series for Liestal that starts in 1894.[35] A very recent evaluation of the data gathered by the Swiss Phenology Network since 1951 has been done by Auchmann et al.[36] A concise overview of the state of historical phenology is presented by Rutishauser in his dissertation,[37] as well as in his publication of 2009,[38] in which Rutishauser widened the frame of his studies to Central Europe. A slightly more recent summary of the 'state of the art' was published in collaboration with François Jeanneret and Robert Brügger.[39] A brief overview can also be gained from the article of Claudio Defila et al.[40]

The diaries of Salis-Marschlins themselves quite quickly attracted some scientific interest. For a long time, however, this interest was limited to those from inside the Salis family. First, Johann Rudolf von Salis-Marschlins himself got the results of several years of his observations (1802-1811) published in the journal *Neuer Sammler*.[41] These articles of around twenty pages contain monthly averages of all daily measured or observed quantities, as well as some remarks on phenology. The daily measurements themselves did not make it into these articles, however.[42] Apart from Salis-Marschlins himself, Johann Ulrich von Salis-Seewis[43] also published an article on the measurement series from Marschlins. In there, Salis-Seewis not only wrote a short summary of the years of 1794-1807 – with rather vague methods of calculating mean

[33] Cf. Rutishauser et al. 2007.
[34] Cf. Rutishauser 2003.
[35] Cf. Defila, Clot 2001.
[36] Cf. Auchmann et al. 2018.
[37] Cf. Rutishauser 2007.
[38] Cf. Rutishauser 2009.
[39] Cf. Jeanneret, Rutishauser, Brügger 2011.
[40] Cf. Defila et al. 2016.
[41] Cf. Salis-Marschlins 1805-1812.
[42] Furthermore, the monthly means were calculated by taking the average of the highest and lowest monthly value and are thus of very little use.
[43] Salis-Seewis was the brother-in-law of Johann Rudolf's brother, Karl Ulysses von Salis-Marschlins. For more details, see Marti-Weissenbach 2017.

values – but also briefly described the measurement devices and techniques used by Salis-Marschlins.[44] This latter part is of particular interest as the diaries mostly lack this information.

After the death of Johann Rudolf von Salis-Marschlins in 1835, his nephew Ulysses Adalbert[45] continued the tradition of meteorological observations in Marschlins for another 47 years (1839-1885).[46] Apart from his own results, Ulysses Adalbert also published some of his uncle's measurements and observations in his articles.[47] Since then, however, the meteorological measurements and observations of Johann Rudolf von Salis-Marschlins attracted very little attention. Although some later publications in historical climatology do mention the Marschlinian diaries,[48] their authors had reservations about them due to the inaccuracies of the measurement devices used by Salis-Marschlins. These limitations seem to have weighed too heavily in their judgments, and so hardly any of his observations or measurements were examined in more detail.[49] Nevertheless, Stefan Röllin did some first analyses of the Marschlinian diaries in the form of a proseminar thesis at the University of Bern. However, the scope of this thesis did not allow Röllin to study all contents of the diaries. He thus mainly concentrated on phenological observations, snow coverage, as well as cloudiness.[50] Since 2016, the diaries of Salis-Marschlins have returned to the centre of interest as they are part of the CHIMES project.[51]

1.3. State of Source Materials

Historical climatology works with a wide palette of historical sources, which can be divided into sources containing direct and sources containing indirect data. This second category of indirect or proxy data mainly encompasses phenological observations of the biotic (e.g. flowering of plants, harvest dates, yields), but also the abiotic (water levels of rivers and lakes, freezing of water bodies, duration of snow cover), environment. Direct data, on the other hand,

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[44] Cf. Salis-Seewis 1811.
[45] Ulysses Adalbert von Salis-Marschlins was the son of Karl Ulysses von Salis-Marschlins. More details on Ulysses Adalbert can be found in his biography, written by his daughter Meta von Salis-Marschlins. Cf. Salis-Marschlins 1921; Salis-Marschlins 1922a; Salis-Marschlins 1922b.
[46] Cf. Pfister et al. 2019: 1352, Table 2.
[47] Cf. e.g. Salis-Marschlins 1864-1865: 92-94.
[48] Cf. e.g. Pfister 1988: 39-40.
[49] Pfister, for example, only looked at summer snow coverage, parts of the precipitation records, and some phenological observations. He does include Salis-Marschlins in his list of ten extraordinary observers, however. Cf. Pfister 1975: 69-70, table 23; Pfister 1988: 39-40.
[50] Probably due to the mentioned reservations as well as time constraints, Röllin did not touch on the measurements of air pressure and temperature. Cf. Röllin 1974.
[51] Cf. University of Bern 2019.

includes both recorded observations of the weather, climate, and its anomalies, as well as measured values of temperature, air pressure, precipitation, and so on.[52]

However, since history is reliant on the presence of written records,[53] historical climatological research is mainly limited to the last few centuries. Source material certainly does exist for earlier times and has been put to use by many climatologists.[54] It was first and foremost the development of letterpress and the spirit of the reformation, however, which lead to a higher literacy of the population and which sparked a more widespread interest in nature.[55] As a consequence, the availability of climate- and weather-related narratives and records strongly increased around 1500. With the emergence of the first instruments to measure temperature, precipitation depth and air pressure in the late 16th and early 17th century, a new source for climatological research appeared. On their own initiative – later also coordinated by early meteorological networks – observers began to record their daily or even sub-daily measurements in meteorological diaries or measurement journals. Compared to other sources of historical climatology, meteorological diaries contain mostly direct data that generally have a high temporal resolution. The high degree of subjectivity, of which descriptive sources often are accused of, is close to non-existent for this type of source.[56] Thus, meteorological diaries are the go-to source for climatological and meteorological reconstructions, given that the recorded measurements were taken by a skilful observer with accurate instruments.[57] The value of such diaries is mainly determined by their length and completeness.[58]

Only three long measurement series that lead back to the period before the establishment of institutional observations in 1864 have been compiled for Switzerland up to date (Geneva, Basel, and Great St. Bernard Pass). However, a large number of early instrumental meteorological measurements can be found, which were recorded either by single observers or members of an early network. The CHIMES project is currently collecting and digitising this pre-institutional documentary evidence for Switzerland, pursuing the aim of producing a systematic survey of this data. For this, information is mainly drawn from the compilations by Wolf[59] and

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[52] Cf. Pfister 1999: 16.
[53] Historical climatology also makes use of pictorial and epigraphic sources. Cf. Rohr 2007: 89-91; 97-104.
[54] For the middle ages, climate-relevant data may be found in a variety of sources: chronicles, memoires, weather diaries, journals, annals, accounts or administrative documents. Cf. Glaser 2013: 14-17; Camenisch 2015: 41-47.
[55] Cf. Pfister 1988: 17; Glaser 2013: 13-14.
[56] Cf. Pfister 1988: 28. Of course, it may be argued that a small degree of subjectivity remains, as it was the observer who read the instruments and thereby decided whether to measure at the top, middle, or bottom of the meniscus.
[57] For the Marschlinian diaries, these two requirements will be discussed in extenso in Chapter 2.
[58] Cf. Pfister 1988: 26.
[59] Cf. Meteorologische Centralanstalt der Schweizerischen Naturforschenden Gesellschaft 1864.

Billwiller[60], which give hints to more than a hundred individual pre-1864 records for the Grisons. However, most of these series cover no more than a couple of months, or up to a few years. Only two of them span over more than twenty years. Firstly, the series that was conducted by an unknown observer in Fideris, which is said to span from 1759-1802, but could not be located yet.[61] And secondly, there are the meteorological diaries of Johann Rudolf von Salis-Marschlins, which cover the 43 year period of 1781-1823.[62] Together with the records of Salis Marschlins' nephew, Ulysses Adalbert, who took his own measurements in between 1839-1885,[63] an instrumental series of nearly a century exists for Marschlins.

In the late 18th and early 19th century, several other eager meteorologists recorded their long-time observations all over Switzerland.[64] Important contemporaries of Salis-Marschlins were, for example, Johann Jakob Sprüngli, who was living in Sutz by the time Salis-Marschlins had established his measurement practice, and is mostly known for his extensive phenological observations (1759-1802, of which the last seventeen years in Sutz);[65] Samuel Studer, who during more than fifty years measured in and around Bern (1777-1827);[66] Johann Christoph Schalch, whose observations from Schaffhausen also span over half a century (1794-1845);[67] and Hans Caspar Hirzel, thanks to whom data for Zurich is available (1767-1802).[68] Additionally, long measurement series have also been produced by Johann Jakob d'Annone and Guillaume Antoine Deluc, whose data have been included in the Basel and Geneva series.[69] For the early 19th century, the records of Johann Ulrich von Salis-Seewis, who took his measurements

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[60] Cf. Billwiller 1927.
[61] Cf. Billwiller 1927: 9. Judging from a comment by Gisler, these observations might never have existed in the first place. In his dissertation, Gisler states that records he found in the archive of the Schweizerische Meteorologische Anstalt (today MeteoSchweiz) were labelled "Fideris". However, they 'only' contained records by Hirzel, who made meteorological observations in Zurich in between 1767-1802. Cf. Gisler 1984: 74.
[62] The Marschlinian diaries can be found in the State's Archive of the canton of the Grisons under the signature B 335.
[63] Cf. Marschlins Witterungsbeobachtungen 1800-1885, BAR, E3180-01#2005/90#242*; E3180-01#2005/90#232*; E3180-01#2005/90#229*; E3180-01#2005/90#235*; E3180-01#2005/90#243*; E3180-01#2005/90#241*.
[64] An extensive overview can be found in Pfister et al. 2019: 1351-1353, Table 2.
[65] Cf. Tägliche meteorologische Beobachtungen: Witterung, Wind, Barometer, Thermometer, Pfarrer Johann Jakob Sprüngli (1717-1803), BBB, GA Oek.Ges.111, GA Oek.Ges.114-116.
[66] Cf. Samuel Studer (1757-1834), Meteorologische Betrachtungen, 1779-1827, BBB, MSS.h.h.XX.5.1-5.5.
[67] Cf. Schaffhausen Meteorologische Beobachtungen, BAR, E3180-01#2005/90#195*; E3180-01#2005/90#198*; E3180-01#2005/90#201*; E3180-01#2005/90#208*; E3180-01#2005/90#215*; E3180-01#2005/90#217*; E3180-01#2005/90#214*.
[68] The original records can be found in the state's archive of Zurich. Cf. Meteorologische Aufzeichnungen von Thermometer, Barometer, Wind und Witterung, von 1759-1802, von Hans Caspar Hirzel, StA ZH, B IX 278.1; B IX 278.2; B IX 278.4. The first two years have also been published as a supplement in Meteorologische Centralanstalt der Schweizerischen Naturforschenden Gesellschaft 1872: 358-361. The series of Schaffhausen and Zurich have been analysed and homogenised by Othmar Gisler. Cf. Gisler 1984.
[69] Cf. Bider, Schüepp 1961; Schüepp 1961.

in Chur, are of particular interest. Unfortunately, most of the original records appear to be lost for this series.[70] With respect to phenological observations, some additional sources can be found, which mainly come in the form of later compilations. Examples are the 136 years of vine phenological phases for Zollikon by J. M. Kohler;[71] the compilation by Simon Schwender, wherein he presents a variety of phenological data that was gathered in and around Zurich;[72] as well as the extensive publication about the canton of Glarus by Oswald Heer and Johann Jakob Blumer-Heer.[73]

As the diaries of Salis-Marschlins were not meant for publication, they lack most of what their author must have considered to be self-evident and thus not note-worthy to him; information on the exact location of measurements and the description of measurement devices can hardly be found. This lack of information on the circumstances of measurements can induce considerable errors into a climatological reconstruction. To reduce these sources of error, a variety of other contemporary sources have been consulted. Of particularly high interest are some undated, scribbled "remarks on the meteorological observations of Raoul[74] von Salis-Marschlins".[75] In this brief commentary, probably written by Ulysses Adalbert von Salis-Marschlins, the author notes the stages of Johann Rudolf's observations. In fact, these few lines by Salis-Marschlins' nephew are the most precise description of measuring environments we have. Stated therein are information on changes of measuring device as well as the actual room the measurements were taken in for most of the stages. Additionally, an article by Johann Ulrich von Salis-Seewis has been considered.[76] In there, Salis-Seewis provides information on the measurement devices and techniques used by Johann Rudolf von Salis-Marschlins, and thus adds to the descriptions of Ulysses Adalbert.

1.4. Methods

When trying to evaluate the Marschlinian diaries' potential for the reconstruction of past weather and climate, a large variety of data will have to be analysed, and thus several different

[70] In the scope of the CHIMES collection phase, only the records of 1816 were located. Cf. Pfister et al. 2019: 1351; personal correspondence with Lucas Pfister. However, the records have been published as a supplement. Cf. Meteorologische Centralanstalt der Schweizerischen Naturforschenden Gesellschaft 1871: 38-41, 90-91, 156.
[71] Cf. Kohler 1879.
[72] Cf. Schwender 1856.
[73] Cf. Heer, Blumer-Heer 1846.
[74] Amongst his relatives, Salis-Marschlins was mainly known under the name of Raoul instead of his birthname Johann Rudolf.
[75] Cf. Meteorologische Aufzeichnungen 1784-1862, Bemerkungen zu den meteorol. Beobb. Raoul's v. S. M., StA GR, D VI MA III VII.Z.1.
[76] Cf. Salis-Seewis 1811.

methods will have to be employed. Temperature and pressure measurements, for example, will require a quantitative approach. The multiple changes of instruments and relocations of the measuring station (see Chapter 2 for details) will likely have caused shifts within the series that are of non-climatic origin. Only by correcting the data for its systematic errors and adjusting it at its breakpoints during the process of homogenisation can a meaningful climatological series be achieved.[77] Multiple procedures have been suggested by the literature and applied to a variety of measurement series. However, there is no definitive approach. So, although the series will (hopefully) be more homogeneous after running such a procedure, room for improvement probably still exists. Thus, whenever a measurement series is homogenised, it is crucial to document the undertaken steps and to retain the original data.[78] The homogenisation process itself will be presented in extenso in Chapter 3.

When analysing phenological observations, on the other hand, it is rather the statistical link between the phenological phase and the individual climatological parameters that is of interest. To explore this link, the widely applied Pearson-correlation is going to be used, as a measure for the dependency of two datasets. The Pearson correlation coefficient is defined as the covariance of two datasets, divided by the product of their standard deviation. A positive correlation coefficient thus indicates a positive linear relation between the two datasets, and vice versa. If the correlation coefficient reads zero, on the other hand, no linear relationship exists. A variety of factors affect the growth and development of a single plant. It is not only dependent on climatic parameters such as temperature, precipitation, or insolation, but also determined by characteristics of the soil and the plant itself. Additionally, the weather during and between phenological phases also has an influence.[79] Thus, not all variability can be expected to be explained by the climatic drivers we are interest in here.

The descriptive nature of the precipitation depth data found in the Marschlinian diaries suggests the use of an indices-based approach. Such a quantification of qualitative data is a well-known method in historical climatology, which was largely made popular by Christian Pfister, who proposed the use of both weighted and unweighted temperature and precipitation

[77] This would also be required for the phenological series, as the shifts in location certainly will have changed the entry date of phenological phases. Due to the brevity of Salis-Marschlins' stay in Chur, no reliable correction can be found, however. Cf. Sections 4.2. and 4.3. As for the precipitation data, the observations taken in Chur were treated separately from those recorded in Marschlins, as the two precipitation regimes are too different from one another. For more details, see Section 5.1.
[78] Cf. Aguilar et al. 2003: 46-47. The original data for the Marschlinian series can be found in the digital annex of this thesis.
[79] Cf. Rutishauser 2007: 14.

indices ("Pfister-Indices").[80] With the help of these indices, Pfister was able to reconstruct temperature and pressure anomalies of the past 500 years on a monthly resolution,[81] and many other researchers have worked with a similar or identical indices system since.[82] As the Marschlinian diaries offer a sub-daily resolution for the precipitation data, a different approach will be required, however. The detailed and consistent descriptions of precipitation events in a high temporal resolution allow the construction of multiple categories to differentiate the intensity of individual precipitation events. As Salis-Marschlins aimed at describing the day-to-day weather, no bias towards extreme events is to be expected either. The availability of rain gauge measurements motivates a calibration of the built categories (cf. *Table 5.1.*, p. 117), on the basis of which individual precipitation events can be quantified, and can then be used to calculate daily and monthly totals. These categories should be built such that the totals of any month approximately follow a Gaussian normal distribution. The frequency distribution of daily totals, on the other hand, should exponentially decrease towards higher totals.[83] These two conditions may be used to test the built categories and their calibration.

Finally, we should not disregard the fact that we are dealing with a historical source: a meteorological diary that has been written by an author who, despite his best intentions, might tend towards exaggerations, who might have changed residence, or whose inexperience in the handling of instruments might have led to inaccurate measurements. A thorough source criticism that examines Salis-Marschlins' circumstances, whereabouts and the motivation behind his observational undertaking is thus indispensable. Additionally, the author's style of recording and dating should be studied. This will be done in Chapter 2.

1.5. Transcription

A major part of this master's thesis is the transcription of the approximately 5,200 diary pages that contain Salis-Marschlins' observations and measurements of the years 1781-1800. For any transcription, there is always a balance that needs to be struck between altering the original on behalf of facilitating the use of the edition, and the proximity of the transcription and the original. Often, this balance swung towards a lower fidelity to the original, as many editors valued an easily comprehensible transcription more.[84] However, this bears the

[80] Cf. Pfister 1988: 103-114.
[81] Cf. Pfister 1999.
[82] Cf. e.g. Camenisch 2015; Mauelshagen 2010.
[83] This at least is what the precipitation data for Landquart yield. Cf. *Figure A.1.* (p. 144).
[84] A detailed overview of this dispute over editorial methods is given in Sahle 2013: 39-59.

shortcoming that decisions of the editor are generally unverifiable for the end user. This problem can partly be mitigated by strictly following the editorial principles and establishing a highly labour-intensive text apparatus. At the same time, additional barriers can thereby be introduced, as an extensive apparatus also quickly becomes unwieldy.

While a perfect balance thus seems unattainable for a printed edition, digital methods offer a variety of new possibilities that can resolve many of these problems. While mouse-overs, links within the transcription and links to explanatory websites can strongly facilitate the use of an edition, the side-by-side comparison of transcription and original ensures the transparency of these editorial inferences. In the last few years, several research projects with the aim of creating such digital editions have thus been undertaken. The *Stapfer-Enquête*[85] and the *Sammlung Schweizerischer Rechtsquellen*[86] are only two examples that make use of at least parts of these digital features. Still in process at the time this thesis was submitted is the commented online edition of the diaries of Pater Joseph Dietrich.[87] Based around the transcription software *T-PEN*[88], the *Dietrich-Edition* can show for all the above-mentioned advantages of digital editions. Thanks to the support of Lukas Heinzmann and Antoine Jover, the general structure of the *Dietrich-Edition* could be transferred to the transcription of the Marschlinian diaries (as well as somewhat slimmed down at the same time), which allowed for the creation of a digital edition within the scope of a master's thesis.[89] This edition of the first twenty years of Salis-Marschlins' meteorological diaries can be found in the digital annex to this thesis, together with the editorial principles that were decided on.[90] The annex also contains the homogenised series of temperature and pressure, as well as the monthly precipitation totals. Finally, a file with the original climatologically relevant data obtained from the Marschlinian diaries, which will be analysed in the chapters to follow, can also be found in there.

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[85] Cf. Schmidt et al. 2015.
[86] Cf. Rechtsquellenstiftung des Schweizerischen Juristenvereins 2019.
[87] Cf. Dietrich 2018-.
[88] Cf. University of Saint Louis, Centre for Digital Theology 2019.
[89] Unfortunately, the workload still proved to be too large to tackle within the span of this thesis. While all 5,200 pages could be transcribed (excluding a few pages of low interest, i.e. the ones containing contents from other publications (mainly 'recipes' for miracle cures), and some of the observations performed while Salis-Marschlins was on a journey), mouse-overs and links were only added to the last five years 1796-1800, the first half of 1795, and the diaries of 1783. For more details, see the editorial principles in the digital annex.
[90] Whenever the Marschlinian diaries will be cited in this thesis, the page numbers refer to those decided on in the transcription.

2. The Diaries of Johann Rudolf von Salis-Marschlins – a General Survey

When assessing the value of an early instrumental measurement series, two qualities are crucial. First, the series should span over as long of a period as possible, with no, or few, gaps. Second, the individual measurements should be made at regular and preferably small intervals.[91] This high density of data points is generally what distinguishes historical sources from other climate proxy data (together with the high spatial resolution). It is rare that early instrumental series fulfil all these conditions, and neither does the part of the Marschlinian diaries that will be investigated in this study. Multiple gaps and location changes during the first and the last few years of the 1781-1800 period disrupt the series. All other requirements can be considered fulfilled, however: combined with the twenty-two years that are not being looked into in this study – and which contain considerably less gaps –, the series spans over more than forty years; the data points are evenly spread as Salis-Marschlins hardly ever left out on a measurement; and when he changed his previous daily or twice daily measurements to three times a day in 1783, the temporal resolution of the series improved even further.

There are other aspects of measurement required for a high-quality series, though. The first criteria when working with any historical sources is always the proximity of the recorded and the 'true' reality. In the context of meteorological observations, there are two main things to look out for. The first is the competence of the observer, and the second is the quality of the instruments. In the case of the Marschlinian diaries, the quality of instruments is reported to have been quite poor by the literature.[92] This will be investigated in further detail in Chapter 3. Furthermore, the competence of Salis-Marschlins might also be doubted – especially as he was described as "*geistig etwas beschränkt*"[93] – "mentally somewhat limited" – by his own grand-niece! Before dealing with the diaries and their contents in more detail in Sections 2.2. and 2.3, it will therefore be worthwhile to take a closer look at the author of these diaries, Johann Rudolf von Salis-Marschlins, as well as the historical context in which he wrote them.

2.1. Johann Rudolf von Salis-Marschlins

Despite more than 10,000 diary pages and several published articles, little is known about the life of Johann Rudolf von Salis-Marschlins. This might seem surprising for a member of

[91] Cf. Pfister 1988: 26.
[92] Cf. e.g. Pfister 1988: 40; Sprecher 1976: 418; Röllin 1974: 13.
[93] Salis-Marschlins 1921: 323.

what was probably the most powerful noble family of the *Drei Bünde*[94] at this time, and the son of the highly influential Ulysses von Salis-Marschlins. Many of his close relatives, such as his brother and celebrated naturalist Carl Ulysses, his nephew Ulysses Adalbert, or his grandniece Meta von Salis-Marschlins, best known for her advocacy of equal rights for women, also found their way in the history books.[95] In contrast, Johann Rudolf spent most of his time in or around Marschlins castle,[96] living a life in the shadows of his relatives. This is probably also the context in which Meta von Salis-Marschlins' comment on her granduncle's mental fitness should be read: compared to these 'giants' of the von Salis family, the politically inactive meteorologist simply could not keep up. When trying to describe some of the central stages in the life of Johann Rudolf von Salis Marschlins, we will mostly have to refer to the articles about his family members.

Johann Rudolf von Salis-Marschlins[97] was born in 1756 as the fifth of twelve children of Ulysses von Salis and his wife, Barbara Nicola von Rosenroll. Only three of his sisters, Ursula, Perpetua and Cornelia Adelaide, and his younger brother, Carl Ulysses, reached adulthood.[98] Johann Rudolf spent his early years at his birthplace, the family's castle of Marschlins (cf. *Figure 2.1.*). In 1767, he started his education with his brother Carl Ulysses at the seminar of Martin Planta, which at that time was located at Haldenstein Castle. Only four years later, in 1771, the seminar was moved to Marschlins castle, and the brothers returned home.[99] When the *Philanthropin* had to close down at the end of 1776 or early 1777,[100] their father decided to send his two sons to Dijon in May 1777, where they could continue their studies.[101] We then lose track of Johann Rudolf for some time. Carl Ulysses left the university of Dijon in the summer of 1778, travelling and then settling for a few years in the family's residence in

[94] *Drei Bünde* is the name of the union that was established between the *Graue Bund*, the *Zehngerichtenbund* and the *Gotteshausbund* around 1450. Part of the *Gotteshausbund* was also the *Hochgericht Vier Dörfer*, which consisted of the towns of Zizers, Untervaz, Trimmis and Igis, thereby also including Marschlins. Since 1512, the Valtellina was subject of the *Drei Bünde*. After its dissolution in 1798, the *Drei Bünde* (as well as Tarasp) was incorporated as *Kanton Rätien* into the Helvetian Republic and since 1803 has been the canton of the Grisons in the *Confoederatio Helvetica*. Cf. Collenberg 2017.
[95] Cf. e.g. Bener-Lorenz 1938: 28-32; Marti-Weissenbach 2017; Salis-Marschlins 1921; Salis-Marschlins 1922a; Salis-Marschlins 1922b; Sprecher 1976: 416-418; Wolf 1862: 293-304 for Carl Ulysses; Salis-Marschlins 1917 for Ulysses Adalbert; and Bollinger 2017 for Meta von Salis-Marschlins.
[96] Marschlins castle is located in the *Churer Rheintal*. Today, it is part of the municipality of Landquart.
[97] To avoid confusion, while maintaining some brevity, the family members will be called by their first names in this section. In the other sections, Johann Rudolf von Salis-Marschlins will only be referred to as Salis-Marschlins.
[98] Cf. Sprecher 1941: Tafel 11.
[99] Cf. Roedel 1941: 64-65.
[100] Cf. ibid.: 84.
[101] Cf. Salis-Marschlins 1921: 326.

Castione[102]. Whether Johann Rudolf joined his brother on these travels, whether he remained at Dijon,[103] or whether he returned directly to Marschlins remains unclear.

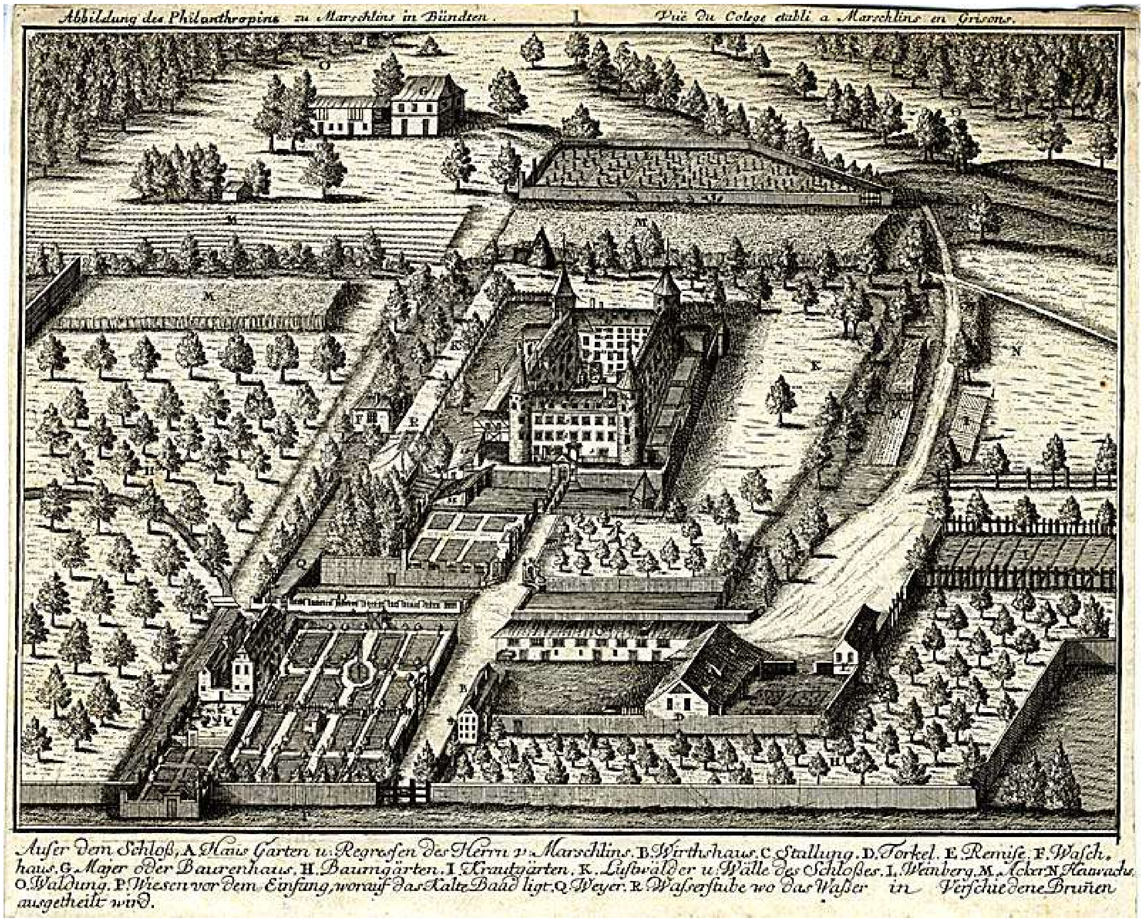

Figure 2.1.: Engraving of an oil painting by Wolfgang Johann Wanner, depicting Marschlins castle around 1776. The rectangular ponds in which Salis-Marschlins later used to measure the ice thickness during winter can be made out to the side and in front of the castle. Surrounding the castle are two arboreta, as well as several fields, vegetable patches and flowerbeds from which most of the phenological observations were made. The Schlössli, the residence of the von Salis, can be seen to the lower left. This is where Salis-Marschlins moved his instruments in 1802, abandoning the previous measuring rooms in the castle. Source: Fotos/Zeichnungen Schloss Marschlins, StAGR, D VI MA/Aa 018.

Although all three alternatives are possible, the return to his birthplace certainly is the likeliest option. Before he began recording his meteorological observations in 1781, Johann Rudolf was amongst the eight founding members of the *Gesellschaft landwirtschaftlicher Freunde in*

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[102] The short name of the small community of Castione Andevenno in the Valtellina.
[103] The last letter which Johann Rudolf wrote to his father from Dijon dates to the 24th of April 1778. Cf. Engste Familienbriefe, Band 1, StAGR, D VI BM 37.

Bünden in 1778, once again together with his brother.[104] The society's main purpose was the scientific examination of agriculture in the Grisons, with the aim of increasing its yield. This was to be achieved by first properly describing the state of local agriculture, second by evaluating possible improvements, and third by adopting techniques that were found to be successful elsewhere.[105] In later years, many diary entries can still clearly be placed in this context, whether it is the numerous detailed descriptions of tasks in the vineyard,[106] or the extensive and somewhat envious report of Zurich's viniculture and agriculture during his travels in late 1795.[107] It is thus most likely in this context that Johann Rudolf decided to start his weather observations in 1781. An important part of this society was also the *Sammler*, the weekly journal, in which the members of the society had the opportunity (and in fact the obligation) to publish their findings.[108] Although the last issue of the *Sammler* was printed in 1784,[109] less than six years after its launch, Johann Rudolf managed to publish four articles. Three of these deal with agricultural questions,[110] and the fourth already contains some meteorological observations.[111]

In the first few years of his observations, Johann Rudolf often left Marschlins for long periods.[112] Most notable is the temporary relocation of his place of residence between 1785 and 1790, when he moved to the *Oberer Spaniöl*, an old manor in the old city, close to the bishop's residence.[113] He also left the castle on other occasions, and travelled multiple times to the Valtellina to visit Carl Ulysses in *Castione*. After 1787, when his brother had left the Valtellina and gone on an extensive journey through Italy before returning to Marschlins in December 1789,[114] Johann Rudolf greatly reduced his travelling. He moved back to Marschlins in June

[104] Cf. Dolf 1943: 100-101, footnote 27.
[105] Cf. Erne 1988: 330.
[106] Cf. e.g. Meteorologische Beobachtungen, April 1st, 1791: IMG_6534-IMG_6536.
[107] Cf. Meteorologische Beobachtungen, October 7th-November 9th, 1795: IMG_7532-IMG_7545.
[108] Cf. Erne 1988: 330.
[109] This end to the *Sammler* was precedented by the quite rapid disintegration of the *Gesellschaft landwirtschaftlicher Freunde in Bünden*. Although the society appears to never have been formally dissolved, protocols stop in 1782 already. Cf. ibid.: 331.
[110] Cf. Salis-Marschlins 1779; Salis-Marschlins 1781a; Salis-Marschlins 1781b.
[111] Of higher interest than the not very detailed meteorological data is the accurate interpretation Salis-Marschlins gives in the same article for a phenomenon that the late 18th century scientific community largely failed to explain: the "fumes", which were noticed in large parts of Central Europe during that time. In said article, he assumes correctly that those were caused by the Laki eruption, which started on the 8th of June 1783. Cf. Salis-Marschlins 1783: 393.
[112] A more detailed overview of his whereabouts in the 1781-1800 period can be gained from *Figure 2.2.* (p. 32) and sub-section 2.2.4.
[113] Cf. Meteorologische Aufzeichnungen 1784-1862, Bemerkungen zu den meteorol. Beobb. Raoul's v. S. M., StA GR, D VI MA III VII.Z.1
[114] Cf. Salis-Marschlins 1921: 326.

1790, where he spent most of the rest of his life, and "served the economy"[115]. He only occasionally went on short trips to visit relatives around Lake Zurich.

Thus, Johann Rudolf was also in Marschlins at the time of the French occupation of the Grisons[116]. As the castle was located directly at the northern gate of the invaded region, Marschlins was amongst the first places to being seized and pillaged by the French army under the leadership of André Masséna[117] in early March 1799[118]. The castle then had to accommodate parts of the French army. According to a comment by Johann Rudolf, up to 54 soldiers had to be quartered in the castle at times.[119] Nonetheless, Johann Rudolf was in the lucky position of being allowed to stay in Marschlins, a fate that was not shared by Carl Ulysses, who was taken prisoner for almost two years. Johann Rudolf, on the other hand, was soon able to take up his observations again, although they were interrupted on multiple instances. The last of these breaks was after the morning measurement on the 13th of July 1800, when the castle was pillaged for the second time,[120] and he was forced to abandon his instruments. Taking Carl Ulysses' daughter with him, he was able to flee to his sister Ursula's house (the *Oberer Spaniöl*?) in Chur. Although it is not known when exactly he returned to Marschlins, he was probably back at the castle when his brother was released in early 1801.[121] With the castle partly in ruins, it is unlikely that Johann Rudolf took up his observations right away, but waited until the beginning of 1802.

The *Ökonomische Gesellschaft in Graubünden*, the successor to the *Gesellschaft landwirtschaftlicher Freunde in Bünden*, was founded on the 19th of December 1803, only shortly after the horrors of the French occupation were over. One year later, the first edition of the new society's journal appeared, appropriately titled *Neuer Sammler*. In the years to come, Johann Rudolf was able to concentrate on his meteorological work. There are few gaps known until the first missing year of 1817. As a part of the *Ökonomische Gesellschaft*, Johann Rudolf also had the opportunity to publish several annual summaries. Ten articles of his were printed in the

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115 Salis-Marschlins 1922a: 238.
116 Or rather of the area that was soon to become known as the Grisons.
117 For more details, see for example Rial 2014.
118 Since the diary entries of that time stop after the morning observation of March 6th, this was probably the day the castle was conquered.
119 Cf. Salis-Marschlins 1922b: 282.
120 Although the looting was supposedly even worse than that in March 1799 (cf. Salis-Marschlins 1922b: 281), at least the barometer appears to have survived the pillaging on both occasions, as it was in use until 1807. Cf. Meteorologische Aufzeichnungen 1784-1862, Bemerkungen zu den meteorol. Beobb. Raoul's v. S. M., StA GR, D VI MA III VII.Z.1.
121 Cf. Salis-Marschlins 1922b: 283.

Neuer Sammler in total, eight of which were based on his meteorological observations.[122] After his final article in one of the last editions of the *Neuer Sammler* in 1812, however, there are barely any traces of Johann Rudolf to be found any more. The tables in the Swiss National Archive prove that he continued his meteorological work at least until 1823, with another interruption in 1821, but the regular daily observations in the diaries have already stopped in 1820.[123] Only sporadic records can be found for 1828 to 1832.[124] Johann Rudolf von Salis-Marschlins died in May 1835.[125]

2.2. Source Criticism

2.2.1. Location, Extent and Condition of the Diaries

The diaries of Johann Rudolf von Salis-Marschlins are kept in the State's Archive of the Grisons under the listing B 335. The records for 1781-1800 are contained within 31 small volumes, each around 25x15 cm in size. The total records span over fifty volumes. While the loose sheets of the first few diaries are merely held together by a few strings, the diaries from 1785 onwards are almost always in the form of booklets in leather covers.[126] The length of these booklets varies greatly. While the unbound booklet of 1784 spans but 47 pages,[127] a thick leather binding of 358 pages contains observations for the entire period of 1798-1800. All in all, the observations of the first twenty-year period fill over 5,000 pages of these diaries; together with the second half of Salis-Marschlins' recordings, this number roughly doubles.[128] In general, the diaries are in excellent condition. Occasionally, there are pages with light damage, but their readability is barely affected. The most common problems concerning the readability of pages are due to the smearing of ink and ink stains, and were probably caused by the author himself. Double layers of text, caused by closing a booklet before the ink was fully dried, can also make reading more difficult and are attributed to Salis-Marschlins himself, too.

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[122] Cf. Salis-Marschlins 1805; Salis-Marschlins 1806a; Salis-Marschlins 1806b; Salis-Marschlins 1806c; Salis-Marschlins 1807a; Salis-Marschlins 1808; Salis-Marschlins 1809; Salis-Marschlins 1812. He also published two essays on garden work. Cf. Salis-Marschlins 1807b; Salis-Marschlins 1807c.

[123] Cf. Jenny 1974: 176; Röllin 1974: 5-6. For 1821 and 1822, only annual summaries can be found.

[124] Remarks can be found for 1828, 1829, 1831, and 1832. According to Röllin, they are of low quality, however. Cf. Röllin 1974: 5.

[125] A list including the costs of Salis-Marschlins' funeral only contains the month, but not the exact date. Cf. StAGR D VI MA VII.0: Beerdigungskosten für Onkel Joh. Rudolf.

[126] After 1785, the booklets not bound in leather mainly contain tables of monthly and yearly totals as well as written overviews of months and years.

[127] This booklet is of further interest as the observations that are contained therein might not have been conducted by Johann Rudolf von Salis-Marschlins himself. For more details, see sub-section 2.2.4.

[128] Cf. Röllin 1974: 12.

2.2.2. Language, Script and Navigation within the Diaries

Salis-Marschlins wrote most of his notes in the standard German of the time, but he quite frequently also uses Latin. Namely, for plant names he mostly uses their exact Latin denotation, often supplemented with the German and sometimes also a local name for the plant. Furthermore, he cites some short paragraphs and poems of other authors in Latin and French. Finally, French is often used for the description of different kinds of fruit. Salis-Marschlins mainly used *Kurrent*, the prevalent form of handwriting of his time, however, when noting something in a foreign language, as well as when using loanwords or words that were not well established in the German language at that time, he changed to write in the Latin handwritings.

Navigation within the diaries themselves is relatively difficult, as the author did not provide page numbers. The dates that are given within the diaries are also only helpful to a certain degree, as Salis-Marschlins only named the month at its beginning. Afterwards, he noted only the number of the day, omitting information about the month or the year. Dates are also only given for the first measurement of the day, but not with the other two. This can make orientation somewhat tedious during study, particularly for days in which the author elaborates on a topic, or lists several phenological observations, over several pages in between his measurements. The days where he contented himself with but a few lines in which he summarised his three daily measurements are far more frequent, however. The month, year, and sometimes also the exact date, were added in irregular intervals in the upper right-hand corner of a double page by an unknown hand later on, which helps to ease navigation.[129]

2.2.3. Dating

The canton of the Grisons has a tradition of being inhabited by people of both protestant and catholic persuasion. Thus, there was no uniform dating system for a long time, and the region was split between the Gregorian and the Julian calendar system. The last protestant municipality only accept the new form of dating in 1812.[130] For protestants of municipalities with split confessions, such as the *Vier Dörfer* (including Marschlins), the change happened somewhat earlier, but not before the second half of the 18th century.[131] As Salis-Marschlins, like most of his family members, was probably of protestant persuasion,[132] there is a possibility that at least some of the records are dated in Julian style. We can be sure that this is not so for the years

[129] While these corner entries were probably written by an archivist, the comments and corrections directly within the text of the diary are from a different feather.
[130] Cf. Gutzwiller 2018.
[131] Cf. ibid.
[132] Cf. Planta 2012.

from 1800 onwards, as there is no 29th of February in that year. However, the frequent gaps in observations leave room for an unnoticed calendar change at some point in the last two decades of the 18th century. Here, the saint's days as well as the dates of other religious feasts, which Salis-Marschlins noted on countless occasions throughout the diaries (but especially during the early years) come into play. In 1781, "Easter" was written in the diary entry for the 8th of April,[133] which corresponds to the date given by the Gregorian calendar. There are, however, other holiday date that confuse the reader for a moment. The Pentecost of 1793, for example, can be found on the 23rd of June,[134] a date that is in fact impossible in both calendar systems. The only reasonable explanation for these entries is that Salis-Marschlins still celebrated according to the Julian system, but had already taken over the Gregorian style for dating. In his diaries, he therefore noted down the dates that had been derived according to the Julian style, and then translated them into the Gregorian calendar system.[135] This can also be seen in his choice of words, as he calls them the "old feast days" at times.

2.2.4. Gaps and Changes of Location

As *Figure 2.2.* shows, Salis-Marschlins did not spend his entire life at Marschlins Castle, but changed his residence on a number of occasions. This was especially true during the second quarter of the series, when he moved back and forth between the *Oberer Spaniöl* in Chur and Marschlins Castle. He was able to continue conducting his observations and measurements during this time. Data is also available for Zizers, however, the observations from Marschlins partially overlap with the data that was gathered in Zizers at the beginning of April 1784. Furthermore, when the October 1784 data was being gathered in Zizers, Salis-Marschlins had already left for the Valtellina. The authorship of these observations thus remains somewhat unclear. The most probable observer is Johann Georg Amstein, a close friend to the family of Salis-Marschlins, as well as one of the founding members of the *Gesellschaft landwirtschaftlicher Freunde in Bünden*.[136] As Amstein commented on the pressure difference between Zizers and Marschlins,[137] he at the very least pursued his own meteorological research. It appears likely that he would have recorded some observations and passed these on to Salis-Marschlins.

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[133] Meteorologische Beobachtungen, April 8th, 1781: IMG_5312.
[134] Meteorologische Beobachtungen, June 23rd, 1793: IMG_6948.
[135] In the example of Pentecost 1793 given above, Salis-Marschlins added a correction of eleven days to the date of the Julian Pentecost, which was on the 12th of June in that year.
[136] Johann Georg Amstein was married to Hortensia von Salis-Marschlins, Johann Rudolf's sister. From 1779 to his death in 1794, he worked as a medical doctor in Zizers. Cf. Wieser 2001.
[137] Cf. Meteorologische Aufzeichnungen 1784-1862, Bemerkungen zu den meteorol. Beobb. Raoul's v. S. M., StA GR, D VI MA III VII.Z.1

Salis-Marschlins was not always able to maintain the entire spectrum of his observations. When residing in the Valtellina (mainly in Chiavenna and in *Castione*), for example, he did not have any measuring devices to hand, and he could therefore only make qualitative observations. During his 1786 stay, he at least maintained his rhythm of observing and recording three times a day. This was not the case when he went on shorter trips, such as his journeys to the Prättigau and Lake Zurich. During these journeys, he typically managed to note some observations once per day.

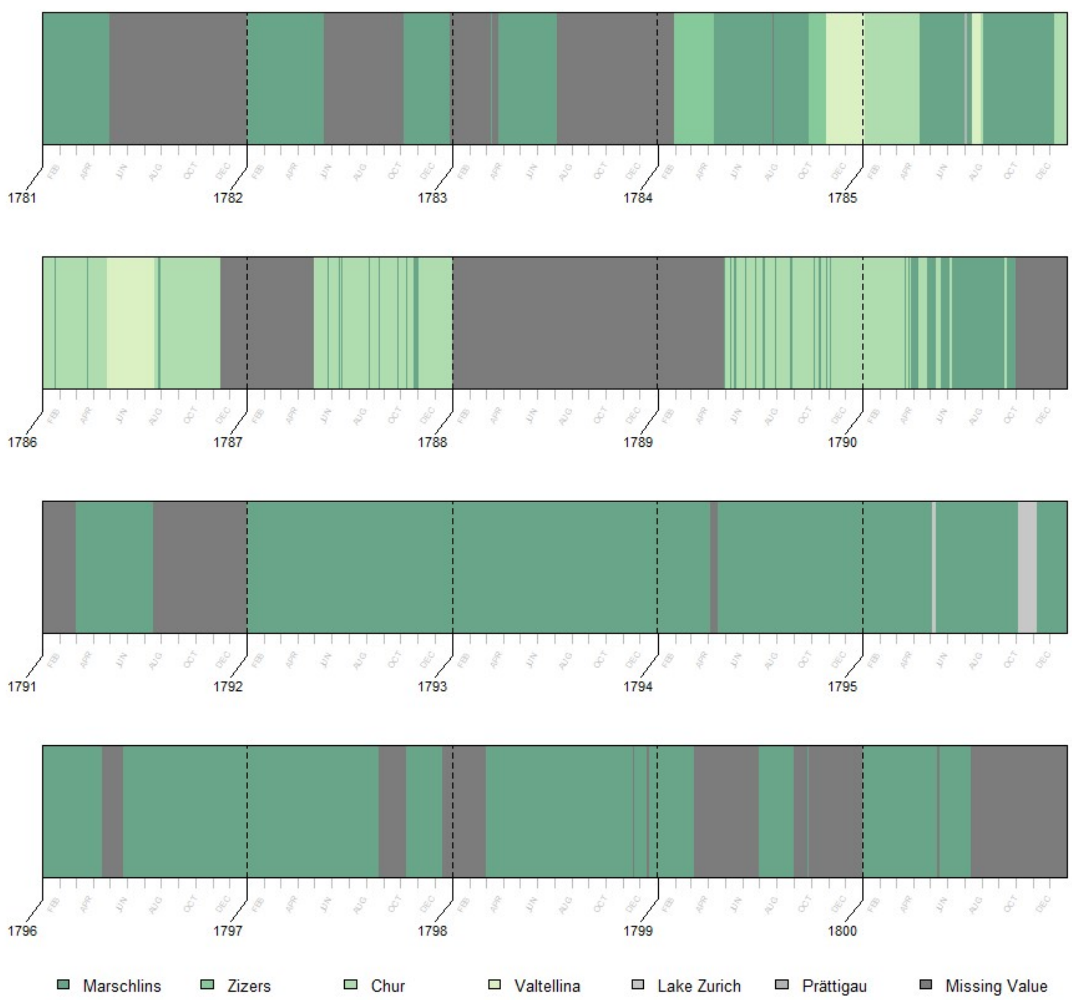

Figure 2.2.: Display of locations of measurement by Johann Rudolf of Salis-Marschlins on a daily resolution. Smaller changes of location (i.e. changing rooms, floors, etc.) are not captured by the graph, nor are changes of measuring devices.

Periods with missing observations are common at the beginning of the Marschlinian series, probably suggesting that its author had not established his later dedication and consistency in performing measurements and observations. In general, longer periods of missing values are mainly due to Salis-Marschlins interrupting his measuring activities (or at least his recording of them), for reasons we generally do not know. However, there are some gaps in the series which can be pinpointed to exact events. In 1796, for example, Salis-Marschlins had to interrupt his recordings due to a fluxion in the eye. The breaks in March 1799 and July 1800, on the other hand, were clearly caused by the circumstances of that time, when the castle was pillaged by French soldiers. Some of the periods marked as "Missing Value" in *Figure 2.2.* are also probably due to loss of the source material. This loss is almost certain for the measurements of summer 1783, as Salis-Marschlins did publish an article in the *Sammler* about the phenomenon of the hazy atmosphere after the Laki eruption earlier that year. In this article, he presented the reader with mean values for the June to August temperatures, which cannot be found in the diaries themselves.[138] The same is true for 1788, for which Johann Ulrich von Salis-Seewis was able to calculate an annual mean pressure and temperature value, as well as give some additional phenological data,[139] but for which a diary does not exist (any more). Finally, some abrupt starts to measurements (i.e. beginning a booklet without a proper title page) also suggest a potential loss of source material for the months prior to these volumes being started. The best example of this is again the booklet of 1783, which starts with a mid-March morning measurement directly on the cover.

2.3. Contents of the Diaries

As is the case for many other meteorological series, the custom of measuring and observing the weather multiple times a day first had to be established in Marschlins. During this 'orientation phase', Salis-Marschlins went from a single daily weather observation, paired with the occasional more elaborate comment, to three observations of four climatological parameters per day. Major shifts in what and how often was observed can thus be found from 1781 to 1786. For the remaining fourteen years of observation studied in this thesis (and probably also for the rest of the Marschlinian diaries), there were only minor changes in structure. This final section of Chapter 2 shall therefore provide a summary of what contents can be expected in which period, starting with the core of the Marschlinian diaries, that is the (multiple) daily measurements.

[138] Cf. Salis-Marschlins 1783.

[139] Cf. Salis-Seewis 1811: 195, 199, 208. Astoundingly, even Röllin does not label 1788 as 'entirely missing', but only as 'incomplete'. However, this was likely already a wrong statement at the time he wrote his proseminar thesis, at least if an older inventory of the Grisons State's Archive is to be trusted. Cf. Fiebig, Sprecher 1911: 247. In the same table, Röllin for example also checked the years of 1794, 1795 and 1796 as 'complete'.

2.3.1. The Core: Three Daily Measurements

Substantial differences can be seen when comparing the daily diary entries of the first *Ökonomische und Physikalische Bemerkungen* of 1781 to their appearance only a few years later. In 1781, Salis-Marschlins often only roughly characterised the daily weather in a single word. We search for pressure and temperature measurements in vain, and observations of the wind can only be found on rare occasions. In 1782, however, the number of observed parameters greatly increased. Although regular wind readings are still missing, daily pressure and temperature values can now be found. Salis-Marschlins also started measuring more than once per day. At times, he even exceeded the three daily measurements of later years. Unfortunately, he did not yet specify the measurement times. This changed in 1783 in a general wave of standardisation. In addition to noting the measurement times next to most entries, Salis-Marschlins also settled on three daily observations in this year. Moreover, the occasional note about the predominant wind direction was replaced by regular wind observations, which was also recorded three times a day. Finally, Salis-Marschlins also standardised his weather observations at this point. Instead of the rather unspecific one-word description of the daily weather, he started to group the cloud coverage into eight categories. After these two major changes in 1782 and 1783, Salis-Marschlins made only one more alteration to his observation pattern. After August 1786, he supplemented the observations of wind direction with an index system for the estimated wind speeds.[140]

From 1787 onwards, the diary entries for (almost) every day contain three measurements: one in the morning, at the time of sunrise; one in the afternoon, usually around 2 PM; and one in the evening, after the sun had set.[141] These measurements were all structured the same way. The first line of any recorded measurement contains the time it had been performed. If it was a morning measurement, the current date – or rather the day; the month and year were not repeated – was added in front. In the second line, Salis-Marschlins first noted the barometer reading. The mercury column was measured in units of Paris inches and lines, his unit of choice for any length measurement.[142] Judging from the precision of these pressure records, the barometer scale probably had a resolution of half or a quarter of a line. Next was the measurement of the current temperature in degrees Réaumur. A degree Réaumur can easily be translated into

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[140] The first index for wind speed can be found on August 25th. Cf. Meteorologische Beobachtungen, August 25th, 1786: IMG_6061.

[141] This meant that the time of the morning measurement was variable over the course of a year. The evening measurement, on the other hand, was shifted multiple times, but generally took place either at 8 PM or 9 PM. A summary of the usual measuring times can be found in *Table 3.1*.

[142] The Paris foot measures about 32.473 cm in the metric system. A foot consists of twelve inches, which can be split again into twelve lines. A Paris inch thus measures about 2.706 cm, a line about 2.25 mm.

degrees Celsius, as it scales linearly with a factor of 1.25. Similar to the barometer, the thermometer resolution appears to have been either a half or a quarter of a degree Réaumur, although it might have been different (lower) during the first years of observation. A more detailed discussion of the precision, and especially the accuracy, of Salis-Marschlins' measuring devices can be found in Sections 3.3.2. (for temperature) and 3.4.2. (pressure).

The third record in most measurement entries is the observation of wind direction and wind speed. This is certainly the most inaccurate of the four recorded parameters. The wind direction only has a resolution of 45 ° (SE, NW, etc.) and the entire spectrum of wind speed was described by indices 1 (calm or very light wind) to 4 (storm). It is not surprising that by far the most prominent index to be found is 2, which translates to a light wind "as can be spotted from the smoke of a chimney or from the movement of clouds"[143]. In average months, at least half, and often more than three quarters, of indices read "2". Thus, the windspeed observation is of rather low informative value, especially since higher windspeeds were generally also pointed out in an additional short description after the measurement.

The fourth and final part of a measurement entry consists of the weather observation. After giving mere one-word descriptions such as "fair", "changeable", "rain", and so on, until 1782, Salis-Marschlins standardised this observation in 1783 and increased the number of categories. Since then, cloud coverage was classified into eight different groups: from *trüb4* or *tr4* ("cloudy4") to *klar4* or *kl4* ("clear4"). Unfortunately, these categories cannot be translated into the number of octants covered by clouds. *Tr1* signifies a completely overcast sky, although the silhouette of the sun was still to be made out behind the clouds (i.e. thin high-layer clouds). Consequently, Salis-Marschlins would note down *tr4* if multiple layers of clouds covered both the sky and the mountaintops. *Kl4*, on the other hand, means that the sky was completely clear, whereas *kl1* was noted down if only a few blue spots could be made out.[144] In addition to these eight classes of sky cover, there were also categories for rain, snow and fog, which could once again be split into further groups. Salis-Marschlins not only distinguished between multiple intensities of rain,[145] but also noted a difference between 'normal' snowfall, *Schneeriesel* (trickles of snow grains), and *Schneeruten* (gushes of snow). Salis-Marschlins even had two different words for fog: *Nebel*, 'normal' fog, and *Brenthe*, dense fog. He often did not restrict those

[143] "[...] wann man den Rauch am Kamin sieht oder die Wolken sich bewegen." Meteorologische Beobachtungen, Vol. 1803/1804: second page.
[144] Cf. Meteorologische Beobachtungen, Vol. 1803/1804: second and second to last page.
[145] Cf. *Table 5.1.*

weather observations to the three measurement times, but also reported in between, when sudden changes in the weather situation occurred (e.g. a thunderstorm).

A particularity of these measurement entries is their probable time difference from the actual measurements. Multiple diary entries strongly suggest that Salis-Marschlins kept separate note sheets, from which he then later copied his measurements into the diaries. At times, he waited at least two days before transcribing those notes, as can be seen from the morning measurement of September 2nd, 1787, for example. On that entry, he had to overwrite the afternoon measurement of the following day, which he had accidentally copied instead.[146] Whether this was the case for all measurement entries or only small parts of them cannot be said with certitude. It is also unclear why Salis-Marschlins chose not to directly note measurements into the diaries. One explanation could be the physical distance between thermometer and barometer. If Salis-Marschlins wanted to close his diary after noting the pressure value, he would have had to wait for several minutes to let the ink dry. To avoid this, he might have chosen to write a diary entry only occasionally and to otherwise keep note of the measured and observed values on a separate sheet. Alternatively, he might simply not have had the time to write a proper diary entry on some occasions, in which case he would have only scribbled notes of the instrument readings.

2.3.2. Phenological Observations

Although the daily measurements are certainly the main element of the Marschlinian meteorological diaries, they are not the only thing that Salis-Marschlins deemed noteworthy. The largest share of these additional remarks, and certainly also those that are the most relevant from the perspective of historical climatology, are the phenological observations. Phenology has been involved in many different fields and has thus seen a variety of definitions over the years. While early definitions often focused on the phenology of plants, later terminologies expanded the spectrum, first to the entire biota, and then to abiotic occurrences as well.[147] The common element to all these definitions is the seasonality of a certain phenomenon, as well as the effect climate and weather had on the timing of this annual cycle. As studying the effects of weather and climate on plant growth and agricultural yields was the primary purpose of his diaries, Salis-Marschlins mainly focused on the different phenological phases of plants, but elements of the entire biotic as well as abiotic spectrum can be found in the diaries as well. For

[146] Cf. Meteorologische Beobachtungen, September 2nd, 1787: IMG_6183.
[147] A compilation of how the definition of phenology changed over time can be found in Jeanneret, Rutishauser, Brügger 2011: 12-13.

example, Salis-Marschlins commented on the date of the first hoarfrost and usually mentioned the days of the *Alpaufzug* and *Alpabzug*, when the cattle were driven up to or down from the alpine meadows, respectively. During the first years of his observations, Salis-Marschlins also recorded the arrival dates of several bird species. In later years, however, he mostly limited his remarks on animal life cycles to the swarming of bees.

These phenological observation were already a staple of Salis-Marschlins' observations in the first volume of his diaries, probably even more so than in later years.[148] Phenological remarks can be found throughout all diaries, although Salis-Marschlins had to reduce them somewhat during the time of French occupation. Naturally, the observations concentrate on the growing season, but some phenological indicators for the winter season can be found as well, such as the measurements of ice thickness in the castle's ponds. In contrast to the strictly timed and structured daily measurements, however, the records of the phenological observations do not follow any set rhythm and come in different shapes and forms. This lack of consistency is in large parts certainly owed to the great diversity of phenological observations that Salis-Marschlins noted down. Phenological observations often consist of the (plant) species combined with the phenological phases (e.g. blossoming). Just as common are lists of plant species that were all in the same phase. Less frequently, phenological observations are also 'hidden' within longer paragraphs or, conversely, plainly obvious, as they are the only word in a line (e.g. "hoarfrost"). In most of these different types of phenological observations, Salis-Marschlins was quite consistent in his recording and thus unequivocal about what phenological phases he described. The dates of the arrival of swallows, the first hoarfrost or the harvest day for grapes, for example, can easily be read from his diary entries. Unfortunately, this is not necessarily the case for his observations of plant phenological phases, however, which make up the vast majority of phenological data.

Within the twenty-year period involved in this study, there are observations for over 900 different species of flowers, shrubs, trees and crops. Salis-Marschlins commented on foliation, different stages of flowering, the maturity of fruit, and the colouring and fall of leaves. Due to his at times vague and ambiguous choices of words for these phases, however, some of these observations are difficult to assign to a specific phenological phase. This is most true for the different stages of flowering. Descriptions such as "*fängt an zu blühen*" ("starts to bloom"), "*in*

[148] At the end of many months in the first few of his diaries, Salis-Marschlins also commented on important agricultural tasks typically done in the respective month and gave an overview of what plants had been flowering. These summaries of phenological observations and phases are lacking in his later records.

völliger Blüte" ("full bloom"), or "*ist abgegangen*" ("has gone off, end of bloom") can be easily understood and accurately translated to a specific phenological phase. More frequent than these, however, are comments like "*blüht*" ("blooms"), "*blüht schön*" ("blooms nicely"), or "*blüht jetzt*" ("blooms now"). Although the latter two might be understood as "full flowering" and "start of flowering" by mere choice of words, they were also used to describe different phases. Similarly, the determination of the maturity of fruit can be complicated by the inconsistent use of terms like "*reift*" ("ripening"), "*reif*" ("ripe"), "*zeitigt sich*" ("in the process of 'being timely'"), and "*zeitig*" ("timely").

Salis-Marschlins was also unfortunately not very consistent in which plants or phenological phases he would observe throughout a year. Rarely were more than two observations recorded per species and year, usually only one, and while we might find comments on all the above-mentioned phases for some tree species in one year, it is very possible that no, or only a few of these, phenological stages are covered by the diaries for the very next year. As a consequence, many long series of phenological phases suffer from a considerable number of missing observations. This is of course not helped by the many gaps in the earlier years of the Marschlinian diaries themselves.

Apart from the inconsistency of the phenological phases observed, reservations can also be expressed concerning the precision of some observations. Particularly problematic are the lists of 'bulk observations', in which Salis-Marschlins summarised the plants he had found to be in the same phenological phase. Undoubtedly, such lists provide the summarised phenological data of many species, but for this data to be of value, an unequivocal description of the phenological phase would be necessary, and the list would have to be frequently updated. Instead, Salis-Marschlins compiled such phenological stages only irregularly, which strongly hints at him summing up the gathered observations of several days. The informative value of any of the recorded observations is thus strongly watered down, as the plants might have entered the stated stage at an earlier time. While this is somewhat less problematic for observations of plants in mid-blossom, observations in lists which summarise the start or end of flowering lose a great deal of their value.

When commenting on a plant species, Salis-Marschlins usually made sure to call a plant by its Latin name. He often added the German denomination as well as the names by which the plant was known colloquially. Thanks to this redundancy, the identification of plant species is normally quite easy, even if one or more of these names might no longer be in use today. Still, for a few species and particularly for kinds of fruit, problems can be caused by outdated or equivocal nomenclature. While in some cases, those ambiguities can be solved by cross-comparison within the diaries (i.e. checking whether other names have been used for the same species as well), others remain and thereby lead to a loss of data. This mainly affects the many kinds of apples and pears, for which Salis-Marschlins usually only knew the locally used name. In general, problems often occur when only the colloquial denomination of a species is given. Although they can usually easily be translated to the Latin name by a simple cross-comparison, there are a few local names that were used for multiple species. This can sometimes be dealt with by comparing the likely range for the observed phenological phase with the recorded date. However, since these identical nomenclatures can generally be found in similar species or species with similar phenological phases, this procedure is not usually possible.

In summary, a considerable share of phenological observations within the Marschlinian diaries are of rather poor quality. The low consistency regarding what phases would be observed, the frequent gaps, the reduced accuracy due to recordings in lists, as well as the occasional allocation problem due to outdated or equivocal nomenclature all lower the value of these phenological observations. Nevertheless, this phenological data certainly still deserves a closer look for the sheer quantity of observations. While reconstructing the phenological cycle of a whole year – for example, in the form of a phenological watch – will not be possible, some series of specific phenological phases can still be constructed. This will be attempted in Chapter 4.

2.3.3. From Lunar Phases to Earthquakes – Further Contents of the Diaries

In addition to the daily measurements and the phenological observations, a variety of other content can be found within the Marschlinian diaries. Certainly not all of the fairly diverse remarks would be considered related to meteorology or climatology in today's understanding. They range from regularly recorded diary entries, such as lunar phases or monthly summaries, to remarks on agricultural tasks as well as how to improve them, to rare observations of natural phenomena such as earthquakes and even aurora. Although this content will not be considered in the rest of this thesis, a short overview of what may be expected should nevertheless be given in the conclusion to this second chapter.

The most prominent place in these further diary entries involves the monthly reviews. Here, Salis-Marschlins summarised the past period in a few pages. These *Resultate* always start with an overview of the pressure and temperature measurements, in that Salis-Marschlins noted the maximum and minimum value of the past month and calculated the ‘monthly mean’ from these two values.[149] Next comes an enumeration of wind and weather observations, as well as any further weather-related observations, such as number of hoarfrosts, dews, thunderstorms, or *Höfe um den Mond*, coronae or halos around the moon.[150] Salis-Marschlins also created additional categories, such as “number of fair/partially fair/cloudy/rainy/etc. days”, “number of dry/wet days” and at times also “number of warm/cold days”[151]. During the winter months, the individual snow events as well as their measured snow depths were listed and summarised. In a second table, the number of days with snow cover were counted. Measured amounts of rain, on the other hand, can only rarely be found in the *Resultate*.[152]

Although these monthly reviews can be useful in order to gain a quick impression of a month’s general weather patterns, they should be used only with care. On closer inspection, many of the therein found totals and mean values turn out to be slightly inaccurate. This can easily be seen for the totals of wind and weather observations, since they are often not even in account with the number of observations performed during the past month. The maxima and minima for the summaries of pressure and temperature sometimes only correspond to the second or third highest or lowest value of the past month. The calculations of the ‘mean’ were also erroneous on multiple occasions. Finally, the summaries of snow depth and of days with snow cover often leave out smaller snowfall events, thereby providing a very conservative estimation of these monthly values. While omitting the smaller precipitation events was probably a deliberate choice by Salis-Marschlins, the other issues are clearly errors by the author. They may partly be due to him skipping a page of his diary when reviewing, however, the high occurrence of these often quite obvious mistakes is difficult to explain and strongly reduces the value of the first part of these results sections.

While some results sections stop after these lists of numbers, many continue with a written summary of the past weather. Such a weather review usually starts with two-line descriptions of the prevalent weather situation and wind direction during special lunar constellations: full

[149] Meaning that he simply took the average of maximum and minimum pressure and temperature, respectively.
[150] Additionally, Salis-Marschlins also took notes of when the sky reddened during dawn or dusk. These observations had a practical application, as Salis-Marschlins inferred the weather or wind of the upcoming day from it. Cf. Meteorologische Beobachtungen, October 26th, 1795: IMG_7542.
[151] Of course, this category had to be adapted from month to month.
[152] These are almost exclusive to 1787 and 1789, when the rain gauge was in close to regular use.

moon, new moon, crescent, as well as perigee and apogee.[153] Next, a similar portrayal of all days in the past month is given, regardless of whether they had already been described as a day of special lunar constellation. When the weather was constant, multiple days could be summarised in a combined entry. In a final paragraph, Salis-Marschlins would usually also add his impression of the month's weather. After a short sketch of the previous weather, he then proceeded by pointing out periods with outstanding measurements, as well as their effects on plant growth and phenological phases. While writing about whether he thought the past month had been warm, wet or average, he also liked to compare it to earlier months of the same or of prior years. He thus also allows us to gain some insight into his weather perception. In addition, these reviews can be helpful in gaining information about months that Salis-Marschlins had otherwise not recorded, or the recordings of which were lost.

Within the first few diaries, Salis-Marschlins would add yet another section to these monthly reviews. Here, he described the agricultural *Beschäftigungen* or *Verrichtungen* (activities) that were typical for the respective month. These were split into tasks in the fields, in the meadows, in the gardens, in the arboreta, in the orchard and in the vineyard. Salis-Marschlins also gave an overview of what plants were flowering during the month, which ones had withered away, which plants could be shifted into the open, and which ones were ready to be harvested. These descriptions can stretch over multiple pages, leaving some results sections longer than the month's observations themselves. After 1785, however, Salis-Marschlins contented himself with shorter monthly reviews that would only contain a summary of measured and observed values and a description of the past weather. In addition to the monthly reviews, Salis-Marschlins summed up the observations of some years in a similar fashion. As these summaries are structurally almost identical to the monthly results sections,[154] they will not be presented in further detail here.

Salis-Marschlins also often wrote diary entries describing current agricultural tasks, improved methods for completing said tasks, and other aspects of the daily (agricultural) life that were on his mind at that time. For example, a suggestion that is found multiple times throughout the diaries is the use of fertilisers other than manure. The fertilising effects of not only different

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[153] These lunar constellations play a quite important role within the diaries, as they also were always recorded at the day they occurred. Whether Salis-Marschlins hoped to find some correlation between lunar phases and meteorological or phenological patterns remains unclear. In his later articles in the *Neuer Sammler*, they are no longer mentioned.

[154] Instead of daily weather discussions, the characteristics of the individual months were summarised again.

types of manure and ash,[155] but also of human dung[156] had been tested by Salis-Marschlins and his relatives. This more widespread use of fertilisers was also considered an achievement of the *Gesellschaft landwirtschaftlicher Freunde*.[157] Salis-Marschlins occasionally also listed the food prices at local markets at the beginning and/or end of winter, when they were (already) particularly high. His recurrent complaints about cockchafer grubs and the measures enforced by the municipality of the *Vier Dörfer* against those insects are also of interest. Each household had to collect two *Viertel* per person and an additional half a *Quartane*[158] for each head of livestock owned.[159] By 1792, this had changed to one *Quartane* per household and one *Messlein*[160] for each hay-consuming animal.[161] Using the 40 *Quartanen* of grubs that had to be delivered by the Salis-Marschlins, their head count of cattle in 1792 can roughly be estimated as about 156 animals.[162] Unfortunately, this 'grub-to-cattle' ratio probably changed further over the years, so that later grub deliveries, for which no ratios are given, cannot be interpreted similarly.[163]

Finally, Salis-Marschlins also recorded rare occurrences, such as natural phenomena, fires, and diseases. Solar[164] and lunar[165] eclipses, meteorites burning up in the atmosphere[166] and even two aurorae borealis[167] can, for example, be found in the diaries. More common, however, are reports of more threatening natural events, predominantly floods. These will be treated in more detail – together with avalanches – in Section 5.3. On several instances, Salis-Marschlins also noted down earthquakes he had noticed, the strongest of which took place on April 26th, 1787. According to a later diary entry, it caused considerable damage to Haldenstein Castle.[168] One and a half years earlier, on December 30th, 1785, Salis-Marschlins had reported on the town fire of Igis, which consumed three houses and a stable.[169] On July 13th, 1790, he commented on a rock slide near Klosters, in which 32 head of livestock died.[170] Outbreaks of *Viehpresten*, a lung disease of cattle, which reached parts of the *Churer Rheintal* in 1795 were also of great concern

[155] Cf. Meteorologische Beobachtungen, March 8th, 1794: IMG_7255.
[156] Cf. Meteorologische Beobachtungen, February 17th, 1796: IMG_7609.
[157] Cf. Erne 1988: 332.
[158] A *Viertel* contains 4 *Quartanen* or about 30 l. Cf. Fümm 1948: 229
[159] Cf. Meteorologische Beobachtungen, Results of March 1786: IMG_5999.
[160] A *Quartane* contains 4 *Messlein*. Cf. Fümm 1948: 229
[161] Cf. Meteorologische Beobachtungen, April 30th, 1792: IMG_6681.
[162] Assuming that the 2 *Viertel* were owed by each household, and not as Salis-Marschlins wrote by each person.
[163] They can, for example, be found in 1795 (9 *Quartanen* grubs delivered) and in 1798 (once again 40 *Quartanen*). Cf. Meteorologische Beobachtungen, April 30th, 1795: IMG_7454; May 5th, 1798: IMG_7945.
[164] Cf. Meteorologische Beobachtungen, June 15th, 1787: IMG_6132.
[165] Cf. Meteorologische Beobachtungen, December 24th, 1787: IMG_6235; November 3rd, 1789: IMG_6354.
[166] Cf. Meteorologische Beobachtungen, September 11th, 1784: IMG_5702; May 26th, 1791: IMG_6578.
[167] Cf. Meteorologische Beobachtungen, May 13th and November 9th, 1787: IMG_6110, IMG_6217.
[168] Cf. Meteorologische Beobachtungen, April 26th and May 8th, 1787: IMG_6173, IMG_6184.
[169] Cf. Meteorologische Beobachtungen, Results of December 1785: IMG_5959.
[170] Cf. Meteorologische Beobachtungen, July 13th, 1790: IMG_6469.

to Salis-Marschlins.[171] One year later, in January 1797, a new outbreak was registered. As cattle from all around were infected, the livestock owned by the Salis-Marschlins had to be inspected as well. Although no signs of infection were found, the trade of livestock products was prohibited in the municipality for six weeks nevertheless, to stop the disease from spreading any further.[172] In December of the same year, however, Salis-Marschlins reported a new outbreak in Zizers and other towns of the region.[173]

[171] The disease was found in Chur and Maienfeld. Cf. Meteorologische Beobachtungen, December 5th, 1795: IMG_7559.
[172] Cf. Meteorologische Beobachtungen, January 16th-January 31st, 1797: IMG_7770-IMG_7776.
[173] Cf. Meteorologische Beobachtungen, November 22nd, 1797: IMG_7908.

3. Measurements of Temperature and Air Pressure

Having subjected the diaries to a critical source analysis in the previous chapter, it is time to focus our attention on the contents of the Marschlinian records and start evaluating their potential for historical climatology. In this first results chapter, the measurements of air pressure and temperature will be looked at in more detail. The aim is to provide the reader at the end of this chapter with a homogenised series of both daily and monthly averages that can be used for further climatological research. The Marschlinian pressure and temperature data in their original state are far from homogenous, however, as Sections 3.1. and 3.2. will show. In the first three sub-sections of Sections 3.3. (for the temperature series) and 3.4. (for the pressure series), multiple hurdles will therefore have to be overcome. These hurdles mainly involve the quality control of individual measurements, the evaluation of climatology for the region around Marschlins, and a test for break point detection. Only then will we be able to discuss the more homogeneous series obtained, in sub-sections 3.3.4. and 3.4.4., respectively. The final sub-sections, 3.3.5. and 3.4.5, will present some ideas about how to further improve the resulting temperature and pressure series. Before concentrating on the series themselves, however, we will first focus on some more general aspects. Section 3.1 will now briefly discuss the effect that Salis-Marschlins' frequent location changes had on the measurements of the twenty-year period 1781-1800. Section 3.2 will then discuss the different times of measurements.

3.1. Locations of Measurement

As seen in *Figure 2.2.* (p. 32), Salis-Marschlins changed his residence and thus the location of his instruments on several instances within the first few years of his observations. Such changes of location always also create sudden breaks (so-called 'break points') in measurement circumstances. Although the distances between Marschlins, Zizers and Chur may be small, the surroundings in which measurements took place might have been significantly different. Changes in altitude or the positioning of devices, for example, can introduce non-climatological bias into a series. Luckily, the diaries provide high quality metadata, with the exact date when Salis-Marschlins moved to a different place. This greatly narrows down the periods during which such a break point should be expected, but as the diaries contain numerous gaps, minor shifts in location, such as a change of floor or room, could easily go unnoticed during the missing periods. This is problematic, since break points do not always require large relocations, but may also be the product of minor alterations in measuring circumstances. Unfortunately, Salis-

Marschlins did not consider those small changes noteworthy.[174] He also had to exchange damaged instruments on multiple occasions, all of which could bring about additional break points. Considering these potential sources of inhomogeneity, multiple break points within the temperature and pressure series should certainly be expected. A break point detection test will be needed to determine which of these changes in measuring circumstances lead to a significant bias within the series. Such a test will be applied to the temperature data in sub-section 3.3.3, and to the pressure data in sub-section 3.4.3. Before starting with the preparations for such a test, however, we should turn our attention towards another problematic aspect of the daily data. For this, we must consider the times of day at which Salis-Marschlins took his measurements.

3.2. Three Daily Measurements

When working with recent daily averages of temperature or pressure, we can generally expect that they were attained by averaging 24 single measurements that have been taken at every full hour. Thanks to this high frequency, these daily averages are in almost every case very close to the 'true' value. The high accuracy of these artificial values was only made possible with the introduction of autonomous weather stations, as they allow for large amounts of data to be gathered with no real effort. Only a few decades ago, however, things were quite different, as daily (temperature) averages were still calculated using only three measurements.[175] Kämtz, who suggested this method all the way back in 1831, recommended using the weighted mean of the 7:00 AM, the 2:00 PM and twice the 9:00 PM measurements to obtain a reasonably good approximation for the daily average.[176] As a later analysis showed, this weighted mean overestimates the value obtained by the hourly measurements by around 0.1 K.[177]

Kämtz' suggestion indicates that the practice of taking three daily measurements – one in the early morning, one during the afternoon's heat, and one sometime after sunset – was already well established in his time. Many of the early instrumental series that started in the second half of the 18th century can offer three, or at least two, daily measurements at similar points of time

[174] From the note by Ulysses Adalbert von Salis-Marschlins, we know that Johann Rudolf changed the observation room in the castle at least twice until 1800. Cf. Meteorologische Aufzeichnungen 1784-1862, Bemerkungen zu den meteorol. Beobb. Raoul's v. S. M., StA GR, D VI MA III VII.Z.1. These moves are not reported in the diaries.
[175] The *Deutscher Wetterdienst* used this method until April of 2001, when it was replaced with the 24 points of measurement. Cf. Kaspar, Hannak, Schreiber 2016: 166.
[176] Cf. Kämtz 1831: 102.
[177] Cf. Augter 2013: 34. However, this study was performed only for German weather stations.

in the day.[178] Like many of his contemporaries, Salis-Marschlins also performed three measurements throughout the day, however, in contrast to Kämtz' proposition, Salis-Marschlins did not entirely fix the times at which he conducted his observations. Of his three daily measurements, those in the afternoon were the most consistent. It was only on rare occasions that they were not performed at 2:00 PM. Evening measurements also took place quite reliably at just one fixed time throughout a year. This fixed point[179] had changed by the end of 1787 from 9:00 PM to 8:00 PM, but then went back to 9:00 PM again in February 1796. The time of the morning measurements varied the most over the course of a year. Salis-Marschlins generally took his first measurement of the day at 5:00 AM during the summer months, but it gradually moved to a later time with the shorter days. During December and January, he usually measured at 8:00 AM, and then shifted to earlier times again as the days grew longer. As for the other two daily observations, there were some occasional outliers in the morning, with some measurements being taken at 3:00 AM, and others only being performed by 11:00 AM. A summary of the points in time Salis-Marschlins usually took his measurements can be found in *Table 3.1*. Where a measurement was missing a time mark in the calculations of daily averages later in this chapter, the respective time point presented in the table was used instead.

<table>
<tr><th>Jan, Dec</th><th>Nov</th><th>Feb, Oct</th><th>Mar</th><th>Apr, Sep</th><th>May-Aug</th></tr>
<tr><td>8:00 AM</td><td>7:30 AM</td><td>7:00 AM</td><td>6:30 AM</td><td>6:00 AM</td><td>5:00 AM</td></tr>
<tr><td colspan="6">2:00 PM</td></tr>
<tr><td colspan="3">08:00 PM (Mar-Jun 1786;
Jan 1789-Dec 1795)</td><td colspan="3">09:00 PM (Apr 1783-Feb 1786;
Jul 1786-Nov 1787; Jan 1796-Jul 1800)</td></tr>
</table>

Table 3.1.: Overview of the times that Salis-Marschlins generally took his three daily measurements. Salis-Marschlins rarely reported these times until the end of March 1783.

This adaptive morning observation was very probably motivated by the aim of capturing the daily minimum temperature. Together with the maximum temperature in the afternoon and the value closest to the daily average in the evening, all three characteristic temperatures of the day could thereby be measured. However, as measurements did not take place at the times suggested by Kämtz, his method is not a viable option for calculating Marschlinian daily means. As this method is only aimed at approximating the daily temperature mean, it would have been

[178] Cf. e.g. Cocheo, Camuffo 2002; Maugeri et al. 2002.
[179] During the first few years, stronger variations did occur, with measurements taking place as early as 7:00 PM and as late as 11:00 PM. However, those extremes rarely occurred and a fixed point for the evening measurements did establish by the end of 1784.

inappropriate for the calculation of daily pressure mean values regardless, and therefore, the alternative approach to establishing the local climatology (meaning the average daily temperature and pressure cycle), has been decided. With the help of these daily cycles, an optimal combination of the three available daily measurements and a correction factor will be determined. This will be done in sub-sections 3.3.2 and 3.4.2.

3.3. The Temperature Series

Direct measurements of climate variables can capture detailed information about the state of the atmosphere, and therefore, they are the basis of our most exact descriptions of current and past weather and climate. If such measurements are performed under sub-optimal circumstances, however, or with faulty measuring devices, the errors thereby caused can quickly become very difficult to correct for, and the series' worth greatly diminishes. Due to several remarks by Salis-Marschlins himself, wherein he complained about the imprecision of his thermometers,[180] the two directly measured climate variables in the Marschlinian diaries of air pressure and temperature were considered of minor interest by many later authors. Consequently, they have gained very little attention in climatological research so far.[181] Despite these assumed shortcomings of the gathered pressure and temperature data, however, a series of close to forty years in length should not be discarded without proper statistical testing. In the following two sections, we are therefore going to take a deeper look into these two series of climate variables and test their suitability for climatological reconstruction. As air temperature will be needed for the reconstruction of air pressure – to correct for the thermal expansion of the barometric substance – the thermometric measurements will be the focus first.

3.3.1. First Impression and Quality Control

A first impression of the recorded temperature measurements can be gained from the boxplots of monthly mean temperatures in *Figure 3.1*. The graph displays the expected sinusoidal shape of the temperature curve, and the anticipated temperature ranges, with afternoon temperatures being the highest and morning measurements the lowest values. The graph's outliers are interesting, as they give us the first hints about particularly cold or warm months. It should be noted that months with less than ten measurements were excluded from the boxplot in order to

[180] Cf. e.g. Meteorologische Beobachtungen, September 28th, 1786: IMG_6075; Results of January 1799: IMG_8020.
[181] These reservations are for example expressed in: Pfister 1988: 40; Sprecher 1976: 418; Röllin 1974: 13.

avoid artificial outliers. This mainly removed some evening measurements in the early years.[182] The same was also done for the graph of monthly mean temperatures in *Figure 3.2*.

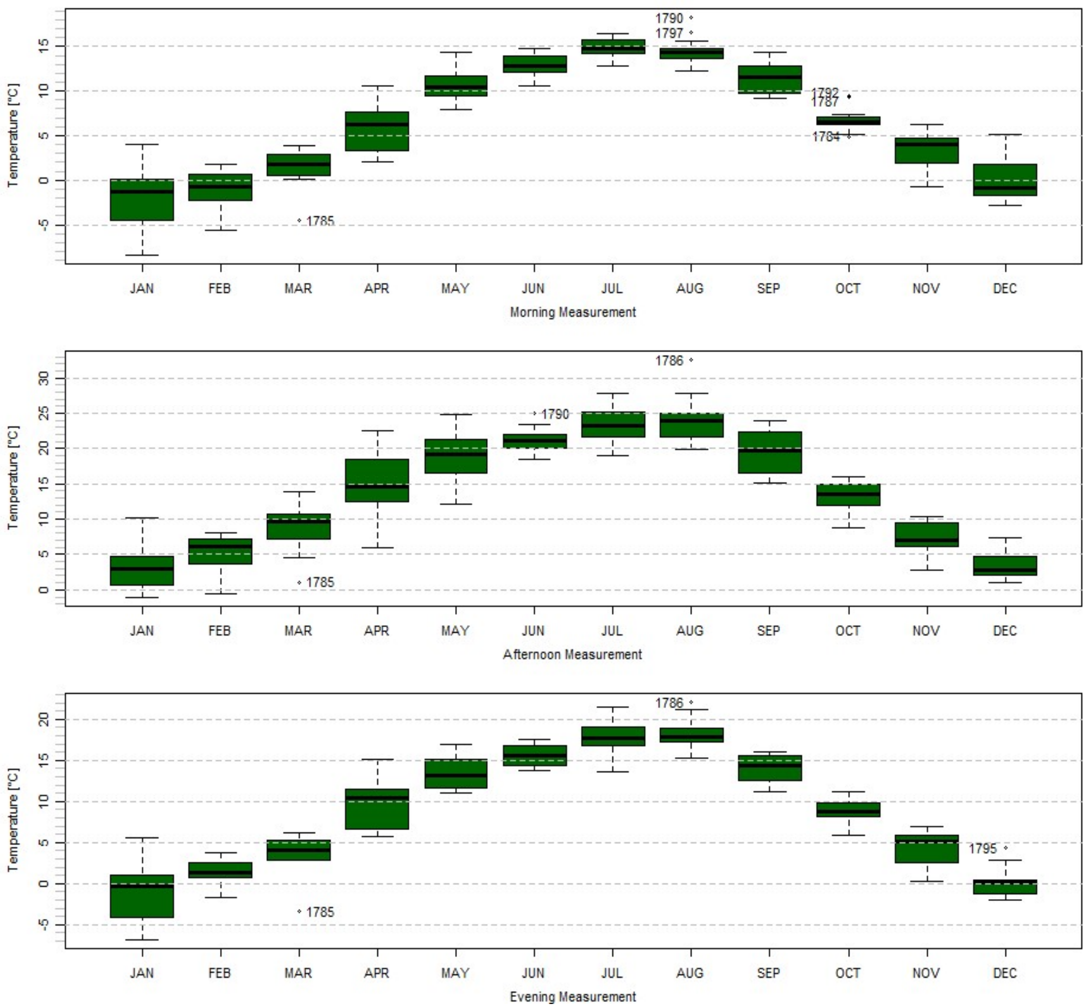

Figure 3.1.: Boxplot of the monthly mean values for morning (between 5:00 and 8:00 AM), afternoon (2:00 PM) and evening (generally between 8:00 and 9:00 PM) measurements of air temperature. The green shaded area includes the values in between the 1st and 3rd quantile, the thick black line the median of the respective month. Whiskers indicate the maximum and minimum of each month. Outliers are depicted as a dot with the year of the extreme value written next to it.

Four months appear to have been unusually warm: July 1797, October 1787, December 1792, and December 1795. In contrast, October 1784 seems to have been particularly cold.

[182] Evening measurements were excluded for the whole year of 1782; for March and July 1783; January, February and July 1785; July and October 1786; April, May and June 1790; April 1794; October 1795; May 1796; December 1797; March and September 1799 as well as July 1800. Additionally, afternoon measurements of March and July 1783; January and July 1785; October 1786; April 1790; October 1795; December 1797 as well as March and September of 1799 were omitted. Excluded morning measurements are identical to the afternoon data set, except for January of 1785 and December of 1797, which could be kept in the series.

Most of these extremes were only found in the morning means, however, so the respective months were not necessarily far from the norm when considering them in the context of the daily averages. The high variability in January and April temperatures is also apparent, with up to 15° C of difference between the warmest and coldest monthly averages. In fact, they cover such a large temperature range that some of these more extreme values will be discussed in more detail in Section 3.5.

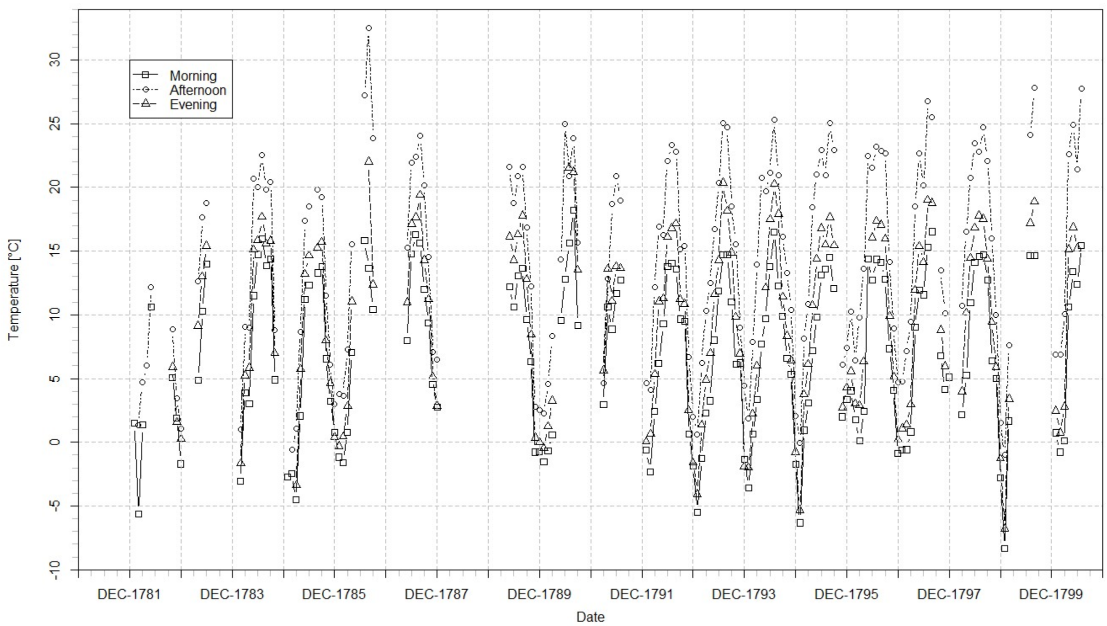

Figure 3.2.: Graph for the monthly mean values of morning (between 5:00 and 8:00 AM), afternoon (2:00 PM) and evening (generally between 8:00 and 9:00 PM) measurements of air temperature. No corrections whatsoever have been applied yet (e.g. elimination of faulty values due to corrupted thermometers, corrections for different thermometric substances etc.).

Additionally, the boxplots in *Figure 3.1.* may be indicative of periods with potentially faulty thermometers. Outliers, especially ones that are found several degrees Celsius beyond the whiskers, certainly should be reviewed very critically. The outlier of June 1790, for example, was caused by a faulty thermometer, as was confirmed by the author in the review of the respective month. Equally implausible appear to be the afternoon measurements of August 1786. A brief view of the plotted monthly mean temperature values in *Figure 3.2.* further strengthens the suspicion that a faulty measuring device might have been in use that time. In fact, Salis-Marschlins had complained by the end of September 1786 that his current thermometer was "of no use".[183]

A closer examination of the individual measurements during from July to October of 1786, shows that the thermometer in use at that time did in fact give values far from a plausible range. For example, in the afternoon of the 14th of September, a temperature of 36 °Ré (45 °C) had been noted. Even more worrying are the jumps of more than 20 °Ré (up to 30° C) within one day, meaning that it was not just the thermometer's scale that was offset, but that the device was truly defective. Unfortunately, no further information on the defect itself is available, nor any secondary measurements from nearby, which might help to correct the ones from Marschlins. For these reasons, the temperature measurements from that period – July to October 1786 – will be considered as missing values within our series for the rest of the analysis.

In 1790, the trouble started on the morning of April 19th, when the old thermometer broke.[184] It took Salis-Marschlins until the 14th of May to replace the device. Unfortunately, the new instrument seems to have been of very poor quality, as the mercury only ever rose to 14 °Ré (17.5 °C), even during very warm days. This was noted before long by Salis-Marschlins, who replaced the old device with a *Branderischer Universal Thermometer* on the 12th of June.[185] Once again, however, the new instrument did not measure temperature accurately. On a number of days, the thermometer suggested temperatures of more than 30 °Ré, with a record of 37 °Ré (46.25 °C) on June 21st. On the same day, a jump in temperature of more than 35 °C within nine hours was measured. Luckily, it appears that Salis-Marschlins was once again able to react quite quickly and replace the *Branderischer Universal Thermometer*, probably at the beginning of July. Although Salis-Marschlins did not mention a replacement around that time, the abbreviation *Br.* for *Branderischer Universal Thermometer* that Salis-Marschlins put beside most of his June temperature measurements, stops on the 1st of July. Most importantly, the temperature recordings that follow are once again within a plausible range (except perhaps for some warm evenings at the end of July). So, although the measurements for May and June cannot be used for the analysis, those from July onwards will remain part of the series for now.

In the boxplots of *Figure 3.1.*, all three mean values of March 1785 also look rather implausible. Whether these outliers were once again caused by low quality thermometers, whether

[183] Cf. Meteorologische Beobachtungen, September 28th, 1786: IMG_6075.
[184] Cf. Meteorologische Beobachtungen, April 19th, 1790: IMG_6422.
[185] Cf. Meteorologische Beobachtungen, May 14th, 1790: IMG_6451.

the change in measuring location had an impact – Salis-Marschlins had moved to Chur only in January of that year – or whether they are indeed part of a particularly cold and late winter of 1785 will need to be determined. On first sight, the values in fact do not appear to stem from a faulty device but are all within the expected temperature range. Furthermore, Salis-Marschlins never complained about the quality of his thermometer during this period. January 1799, on the other hand, does look like an extreme value in *Figure 3.2.*, but was not quite cold enough to qualify as an outlier in the boxplots. In general, the temperature amplitude between coldest and warmest months appears to be larger in the last two years of the series than in the rest of it. We do in fact know directly from the sources that Salis-Marschlins took his measurements at that time with a thermometer filled with *Weingeist* instead of mercury. According to Salis-Marschlins himself, *Weingeist* as a thermometric substance reproduces the actual temperature reasonably well around the zero-point. However, if temperatures do not stay within this moderate range, the thermometer suggests increased extremes.[186]

This behaviour can clearly be observed during the summer months of 1786 and 1790. In this period, afternoon temperatures reached implausible heights, whilst morning temperatures were quite underwhelming, only reaching around 10-15 °C. Although less extreme, this also holds true for the last two years of the Marschlinian series, when differences between morning and afternoon, as well as afternoon and evening temperatures were on average about 2 °C greater than for the period before (cf. *Figure 3.3.*). Somewhat worryingly, this can also be seen when comparing the 1791-1798 period with the first ten years of the series.[187] Finding the cause for this phenomenon is all but easy, as no *Weingeist* thermometer should have been in use in any of these years (except for the short periods discussed above). One possible explanation might be the new thermometer that came into use by the end of 1790, however, it is difficult to tell whether this new device indicated an overly large temperature spectrum, or whether the one in use beforehand was at fault. For now, neither a more detailed explanation nor a correction for this break can be given, and so those measurements will remain part of the series in their current state. In the later analysis, however, this phenomenon should once again be critically evaluated.

[186] Cf. Meteorologische Beobachtungen, Results of January 1799: IMG_8020. This is the opposite behaviour of alcohol thermometers, which show too high minima and too low maxima.
[187] Unfortunately, this difference series could not be statistically tested for break points as no reference series is available and as there are too many missing values. The inhomogeneity described above was therefore detected by eye.

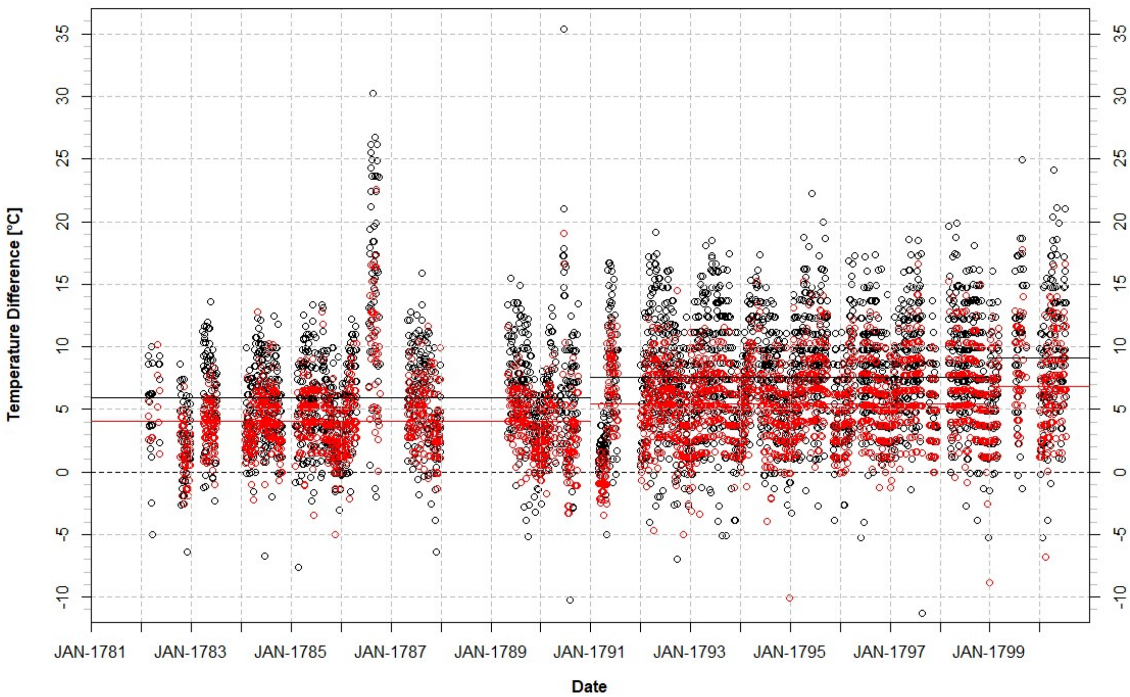

Figure 3.3.: Temperature difference between afternoon and morning measurement (black) as well as afternoon and evening measurement (red), respectively. The lines in black and red represent the average differences of the periods 1781-1790, 1791-1798 and 1799-1800. The periods of faulty instruments in the summers of 1786 and 1790 are also clearly visible.

Apart from this discussion of the broader trends of the temperature series, a detailed control of 'suspicious' individual data points should also be performed. Any temperature difference between afternoon and morning measurements of more than 20 °C or less than -5 °C has been examined. Only if the prevailing weather or wind situation could explain such an extraordinary difference were the respective measurements kept in the series. The same procedure was followed for differences between afternoon and evening measurements of more than 15 °C or less than -5 °C. Similarly, differences between evening and morning measurements greater than ±10 °C have been investigated. Particularly warm or cold temperatures for each individual month have also been inspected, however, only outliers that could clearly be assigned to a slip-up by the author (or the digitalisation) have been removed. Extreme values that were probably caused by the use of a *Weingeist* thermometer, on the other hand, have not been adjusted. As a result, quality control of the temperature series will be considered completed for now.

3.3.2. Constructing Daily Mean Values

After gaining a first impression of the temperature data and a first quality control, this section will focus on the construction of daily and monthly averages. The path from mere observations to solid approximations of daily means requires a good knowledge of measurement circumstances and of the representativeness of the measurements taken for the individual daily mean values. All available information on the thermometers used by Salis-Marschlins, and their likely positioning, will therefore be discussed in a first sub-section. In the second subsection, attention will be drawn towards the timing of the measurements. A sensible method of combining the three daily measurements and the required correction factors can be determined, with the help of today's temperature cycle for Chur. This will then enable us to make up a first draft of the series of daily and monthly temperature averages.

3.3.2.a. Thermometers and Thermometer Placement

Thermometers had been in existence for almost two centuries when Salis-Marschlins started recording his temperature measurements at the beginning of 1782. Within these two-hundred years, they had undergone substantial changes in design, from the first notoriously unstandardised thermometers by Galileo and his contemporaries in the early seventeenth century, to the increasingly widespread use of mercury as the thermometric substance of choice towards the beginning of the Marschlinian series. In the late 18th century, thermometers were still far from being able to describe the atmosphere's temperature with today's precision or accuracy, however. In fact, De Luc's *Recherches sur les modifications de l'atmosphère*, which was published in 1772,[188] marked only the beginning of several decades of intense research on the best thermometric substance, the calibration of thermometers, and further aspects of thermometry. Nevertheless, it can be assumed that at least within the group of people that cared for thermometers at that time, the research performed by De Luc and other members of the Royal Society of London was well-known. The same is also true for the introduction of the standards for thermometers suggested by the Royal Society of London.[189]

In his first major scientific work, De Luc had argued for the use of mercury instead of alcohol as the thermometric liquid of choice. Having a thermometric substance that behaves as close to linearly as possible was of great importance as thermometers were generally calibrated at the freezing point and at the boiling point of water. This meant that the precision of the device in between these two fixed points was entirely dependent on the thermometric substance (and the readings). By comparing the readings of thermometers with the calculated 'real' value of

[188] Cf. De Luc 1772.
[189] Cf. Chang 2004: 64.

the mixture,[190] De Luc was able to demonstrate that mercury's thermal expansion was in fact the closest to linear of any of the tested substances.[191] However, these experiments also showed that for calibration points at 0 and 100 °C, the mercury thermometer gave values that were too low. The greatest differences from the 'real' value amounted to almost 2 °C. Another difficulty of the device, which could introduce considerable inaccuracy, was the calibration of the thermometer itself. The Royal Society supported the use of the freezing and boiling points of water as fixed points, and in 1777, the Society also gave solutions to ensure a greater level of their fixity (i.e. correcting the boiling temperature for changes in air pressure and ensuring that the mercury was all at the same temperature).[192] The temperature at boiling will be different however, depending on the definition of when water is boiling. This left the upper calibration point far from being fixed, so yet another issue had to be tackled. In their 1777 report, the Royal Society therefore suggested the use of steam directly above the boiling water, which appeared to be relatively constant in temperature. Yet, they also approved two other methods that involved the use of boiling water.[193]

Salis-Marschlins himself hardly commented on the thermometers he used for his measurements. The few diary entries in which he mentions the measuring devices will therefore have to be complemented with the scarce information given in an article by Johann Ulrich von Salis-Seewis to evaluate the characteristics and quality of the thermometers used. From this article, it can be learnt that the instruments were of the "common kind": not particularly good, but still of reasonable quality.[194] Furthermore, the thermometers had generally been filled with mercury – except for the instances that Salis-Marschlins remarked on in the diaries, which were discussed in sub-section 3.3.1., for which further corrections will have to be applied. All in all, this supports our assumption that Salis-Marschlins knew about the 'state of the art' thermometry. However, it should be noted that no information is available regarding the calibration of the thermometers that were used. Perfect calibration at temperatures of 0 and 100 °C will therefore be assumed in the following.

The size of the effect that non-linearity in the thermal expansion of mercury had on the measurements is very hard to quantify, as this is also dependent on the instrument used. While

[190] To obtain the real temperature of his test water bodies, De Luc mixed two samples of liquids with previously known temperatures and volumes. Thereby, he could calculate the 'real' degree of heat of the mixture. Cf. De Luc 1772: 293.
[191] Cf. ibid.: 309, 311.
[192] Cf. Chang 2004: 11-12.
[193] Cf. ibid.: 27.
[194] Cf. Salis-Seewis 1811: 194.

differences to the ‘real’ degree of heat could be as much as 1.4 °Ré (1.75 °C) for temperatures around 40 °C, as stated by De Luc, they might also be as low as a few tenths of a degree according to more recent publications.[195] As no information on the instruments used by Salis-Marschlins is available, other than that they were of the “common kind”, a correction for this effect cannot reasonably be applied. The same is true when it comes to the period during which *Weingeist* was used instead of mercury as a thermometric substance. As we do not know exactly what Salis-Marschlins meant by “*Weingeist*”, a quantification of the effect that this liquid had on the temperature readings is not possible,[196] so, once again, no reasonable corrections can be applied right now. Nonetheless, the changes in thermometer substance should certainly be kept in mind during the break point analysis later in this chapter.

Apart from these concerns about the accuracy of the thermometers, their precision should also briefly be discussed. Judging from the fact that temperature was generally recorded in steps of quarters of a degree – at times probably also only at half a degree – it can be assumed that the thermometers in use scaled at best at intervals of a quarter of a degree Réaumur (which translates to 0.3125 °C). However, this limitation in the precision of individual measurements will be balanced out by the number of data points for the monthly averages. Finally, the human element is always a factor when reading a thermometer and noting down the temperature. Although mistakes can never be ruled out with absolute certainty, there do not appear to be any single values that are far off the plausible temperature range that haven’t been discussed already in sub-section 3.3.1., and which could clearly be attributed to this type of error. When Salis-Marschlins did misread the thermometer, therefore, the error committed was probably within the range of a few degrees at maximum, barely affecting monthly mean values.

The quality of the thermometer, however, is only half the battle on the path to an exact measurement of temperature. The other half involves the correct placement of the measuring device. It must be located so that radiation does not affect the temperature measured. While the thermometer naturally needs to be protected from direct sunlight, indirect or scattered radiation can have a substantial effect on the temperature reading and induce systematic errors of several degrees Celsius. The size of error introduced by this radiation depends on the time of day and year (i.e. the intensity of sunlight).[197] The great majority of the scientific community in the late

[195] Cf. Rivosecchi 1975, quoted from: Camuffo 2002a: 322.
[196] In fact, the behaviour of these *Weingeist* thermometers is opposite to what would be expected from an alcohol thermometer, i.e. the extremes get more pronounced during these periods in the Marschlinian series. It thus remains unclear, what exactly Salis-Marschlins meant by *Weingeist*.
[197] For more detail, see for example Böhm et al. 2010; Chenoweth 1993.

18th century appears to have been oblivious to this error, or at least did not know how to prevent it from occurring. Middleton dates the earliest records of a protective screen to 1835,[198] and although later publications suggest the use of thermometer screens as early as 1780,[199] they were certainly the exception rather than the norm at that time.

The diaries of Johann Rudolf von Salis-Marschlins offer no information about thermometer placement nor shielding, so a secondary source will have to be relied on. Luckily, there is an undated note of about half a page in length, presumably written by Ulysses Adalbert von Salis-Marschlins, who continued Johann Rudolf's measurements in 1835.[200] In these few scribbled lines, Ulysses Adalbert lists the different locations of the measurements taken by Johann Rudolf throughout the years. He also gives short explanations about the placements of the barometers. Only in one instance is information on the thermometer location also available, for the five-year period from December of 1785 to June of 1790, the period which Johann Rudolf von Salis-Marschlins spent in Chur. According to this note, the thermometer hung on the north-eastern wall of the *Oberer Spaniöl*, facing the "Buolian house"[201]. So, the thermometer was properly protected from any direct sunlight thanks to its position. On the other hand, the use of a screen to shield the thermometer from the indirect and scattered radiation seems unlikely. As mentioned above, such screens were almost unheard of in the late 18th century. Furthermore, if such a – for its time – unorthodox measuring device were indeed in use, it would very probably have been mentioned in the diaries or in the short note by Ulysses Adalbert in some way or form.

We unfortunately cannot learn anything about the placement of the thermometer for the measurements performed at Marschlins Castle from Ulysses Adalbert's note. A similar choice of thermometer position as that at the *Oberer Spaniöl* (north-northeast facing wall, protected from direct, but not from indirect, radiation) can almost certainly be assumed for Marschlins. There are some differences compared to the measurements taken in Chur, however, as Marschlins Castle is located right next to the *Parpikwald*, at the foot of the *Mittagsplatte*. Both forest and mountain obstruct the sun's rays from reaching the castle during the first hours of the day. The earliest the sun appears above these eastern ridges is at around 7:30 AM, several hours after

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[198] Cf. Middleton 1966, quoted from: Camuffo 2002c: 47.

[199] Early uses of screen are, for example, known for the series of Milan (since 1819) and Padua (probably as early as 1780). Cf. Camuffo 2002c: 47; Maugeri, Buffoni, Chlistovsky 2002: 103.

[200] Cf. Meteorologische Aufzeichnungen 1784-1862, Bemerkungen zu den meteorol. Beobb. Raoul's v. S. M., StA GR, D VI MA III VII.Z.1. As the note contains information for the years from 1783 onwards, yet Ulysses Adalbert was only born on the 6th of April 1795, he must have received this information directly from Johann Rudolf himself or by another member of his family.

[201] The house facing the *Oberer Spaniöl* had been constructed in the late 17th century who then used it as his residence. The Rhaetian Museum has been situated at this address since 1872. Cf. Rätisches Museum 2019.

the morning measurement was performed. Furthermore, the western mountain ridge blocked the sunlight in the evening as well. According to Salis-Marschlins, the sun set at 7:30 PM at the very latest, even during the summer solstice.[202]

The question now arises of how big an effect the indirect and scattered radiation had on these two main measuring sites. A quantification of this ‘early instrumental warm bias has only so far been attempted in detail by Böhm et al., for the series of Kremsmünster.[203] There, the authors had the opportunity to compare hourly values gathered with historical instruments, that are still in their original positions, with those obtained by modern and properly shielded automatic measuring devices that were located only a few meters away. Using this experimental setting, Böhm et al. were able to quantify the bias caused by both the insufficient shielding of thermometers and their placement right next to a wall. Their findings show that the strongest effects occur in the first few hours after sunrise during the summer months.[204] At those hours, measurements taken at the historical site gave up to 2.5 °C warmer temperatures than those found with a modern setup. The effect on the afternoon and evening measurements, on the other hand, appears to be far less pronounced. In general, afternoon measurements taken at the historical site seemed to underestimate the ‘true’ value, while evening measurements tended to overestimate the values gathered with up-to-date equipment by a few tenths of a degree.

Following Böhm et al., two main effects need to be considered when trying to transfer the Kremsmünster findings to a different location (apart from the time of day at which the measurements were taken); first, the shielding of the measuring device, and secondly, the orientation of the wall to which the instruments were attached or hung from.[205] As discussed above, Salis-Marschlins very probably shielded his instruments against direct sunlight, but not against indirect or scattered radiation.[206] Although the instruments in Kremsmünster are protected from scattered sky radiation by a metal plate, the shielding is far from perfect, so that the effect of indirect radiation should still be similar to that at Marschlins.

The orientation of the north-facing wall at Marschlins Castle and at the *Oberer Spaniöl* in Chur also is comparable to that at Kremsmünster, as all buildings are somewhat oriented towards the east. While the wall at Kremsmünster is rotated by about 30°, Marschlins is only turned about

[202] Cf. Meteorologische Beobachtungen, June 21st, 1795: IMG_7479.
[203] Cf. Böhm et al. 2010.
[204] Cf. ibid.: 49.
[205] Cf. ibid.: 54.
[206] Cf. ibid.: 49.

15° toward the east and the *Oberer Spaniöl* but a few degrees. So, while the curve presented by Böhm et al.[207] should still apply to the measurements of Marschlins, the effect of indirect and scattered radiation on the site in Chur was probably a little different. As the window from which Salis-Marschlins hung his thermometer faced almost exactly northwards, the peak in the morning would probably be less pronounced and the 'true' value would only be overestimated by a little more than one degree Celsius. It would, however, be accompanied by a second peak during the hours before sunset, around 4-7 PM, of similar amplitude.[208]

Despite these similarities of thermometer placement in Chur and Marschlins to that of Kremsmünster, there are two important differences that need to be considered. The most important difference to note is the variable observation times that Salis-Marschlins used throughout the year, which can be found in *Table 3.1*. As the morning measurement from May to August generally took place at 5 AM, the effect of the incoming direct solar radiation was substantially smaller. The same holds for the months of April and September, when measurements were usually taken at 6 AM. Even at Kremsmünster, the warm bias only amounts to a little more than 0.5 °C at this point of the day. Considering furthermore that the *Oberer Spaniöl* is facing almost perfectly north and that Marschlins Castle is hidden from the morning sun until 7:30 AM at the very least, the effect should even be smaller. What is left is basically only the heat stored within the building and potentially a tiny amount of scattered sunlight that could lead to a small warm bias of a few tenths of a degree Celsius. The same holds true for the evening measurements, as these were almost exclusively performed at or after 8 PM. At this time, the sun had set already during most of the year (there was no daylight-saving time yet), or it was blocked by the eastern mountain ridge in the case of Marschlins, or the neighbouring house in Chur. Compared to the morning measurement, the amount of energy stored within the walls is expected to be somewhat higher, so that a warm bias of up to about 0.5 °C during the longest days of the year seems to be a reasonable assumption for Chur. This value is probably somewhat smaller for Marschlins.

In summary, indirect and scattered radiation certainly did have an effect on the temperatures that were measured by Salis-Marschlins. However, his choice of observation hours and the surrounding mountain ridges and houses meant that the large peaks observed in Kremsmünster, which were caused by poorly blocked direct radiation, are not an issue for the Marschlinian

[207] Cf. ibid.
[208] Cf. ibid.: 52.

series. While morning and evening measurements probably suffer from a small warm bias of a few tenths of a degree Celsius due to heat storage and scattered sunlight, the values observed in the afternoon probably somewhat underestimated the 'true' temperature. All in all, the effect on the daily average should not have exceeded ~0.2 °C in any of the months. Consequently, no corrections will be applied.

3.3.2.b. Marschlinian Climatology

After investigating the effects that the thermometer and its placement had on the Marschlinian temperature series, the focus in this sub-section will be on the exact times the three daily measurements were taken. Once we have discussed and corrected for all the subtleties that play into this, we will then be able to reach our goal of constructing the daily average temperatures that will be needed in the following sections. Finally, some monthly corrections will be applied to these daily averages in order to get a better approximation of the 'true' daily average temperature.

When trying to obtain a good estimate of the daily average temperature with only one, two, or three daily measurements, instead of today's twenty-four (or even more), a smart choice of observation hours is needed. Reasonably good approximations were known to be the temperature at around 8 PM or the average between daily maximum and minimum temperature. By the end of the 18th century, the combination of these two methods had become ever more popular and the daily mean temperature could then be calculated by averaging these three measurements (see E*quation 3.1.*). Although Salis-Marschlins never noted daily averages himself, he still followed this trend and timed his measurements to capture these three specific temperatures. The variable time point of the morning measurement allowed him to capture the expected daily minimum throughout the year. But at what times were these observations truly performed?

$$T_{avg} = \frac{T_{max}+T_{min}+T_{20}}{3} \qquad \text{(Equation 3.1.)}$$

On first thought, this question appears to be trivial. Salis-Marschlins noted down most of his observation times as discussed in the beginning of this chapter. Of course, this neglects some minor discrepancies, as the time reported in the diaries was probably only an approximate value. Ultimately, however, the time marks noted down in the diaries will be reasonably accurate, as the few minutes by which the measurement would have been performed too early on one day would more or less balance out the somewhat late observation of one of the previous days.[209] Problems only start to occur when these measurements are compared to other series or to today's values. When the apparent solar time was abandoned for the average solar time in 1894,[210] Central Europe was given one single time zone. While this had many advantages in the everyday life of a society which could cover bigger distances in smaller amounts of time, it also meant that the time indicated on the bell tower no longer matched the apparent solar time. Consequently, if we want to describe the Marschlinian series in today's average solar time, the times noted down by Salis-Marschlins will have to be corrected accordingly.

Luckily, this correction is made quite easily. Using a longitude of 9 ° 55 min east, it is straightforward to show that the mean apparent solar time in Marschlins lags about 20 minutes and 20 seconds behind the average solar time of today. Somewhat more complex and uncertain is the correction that should be used for the second alteration brought by the introduction of mean solar time: the oscillations of true noon due to the 'Equation of Time'. While the length of a day is strictly set by our clocks to 24 hours nowadays, this was not the case two hundred years ago. As the Earth's axis is tilted by about 23.5 °, and as it does not orbit the sun in a perfect circle but in a slightly elliptic movement, the length of a solar day (meaning the time from noon of one day to noon of the following day) is not exactly 24 hours. Instead, depending of the time of the year, it can be somewhat either longer or shorter. Although it is only a few seconds in any day of the year, this difference in length adds up, setting apart apparent and average solar time by up to fifteen minutes in mid-February and early November.

Clocks in the late 18th century had to be synchronised every noon, as the apparent solar time was still the time in use. It is certainly questionable on how regular a basis and how accurately this was done in a relatively remote region like Chur. Although no definitive answer can be given, it can be argued that, since Salis-Marschlins was part of the scientific community of his time, he will most certainly have been aware of this phenomenon and thus probably also have corrected his clocks regularly. A correction for this time shift will therefore need to be applied. For simplicities sake, the equation of time that will be used for these corrections has been approximated by a linear interpolation in between points of maxima, minima, and zeroes (cf. *Figure 3.4.*).[211] Before getting to these calculations, it should briefly be noted that, as the

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[209] To be precise, this statement is not completely true, as the rate of temperature change is not constant throughout the day. Naturally, the measurements of minima and maxima are particularly susceptible to this (cf. *Figure 3.6.*, p. 63). Consequently, recorded minima temperatures are generally somewhat too high, while maxima temperatures are a bit too low.

[210] Cf. Camuffo 2002b: 337.

[211] Although rather crude, this approximation of the equation of time, suggested by Tad Dunne in the form of a poem, will be good enough for our requirements. The poem goes as follows: *"On September one, trust the sun /*

Equation of Time is a function of the obliquity of the ecliptic and the eccentricity of Earth, it also slightly varies with time. However, these variations are small enough that this inhomogeneity can and will be ignored, even on a timescale of two centuries.

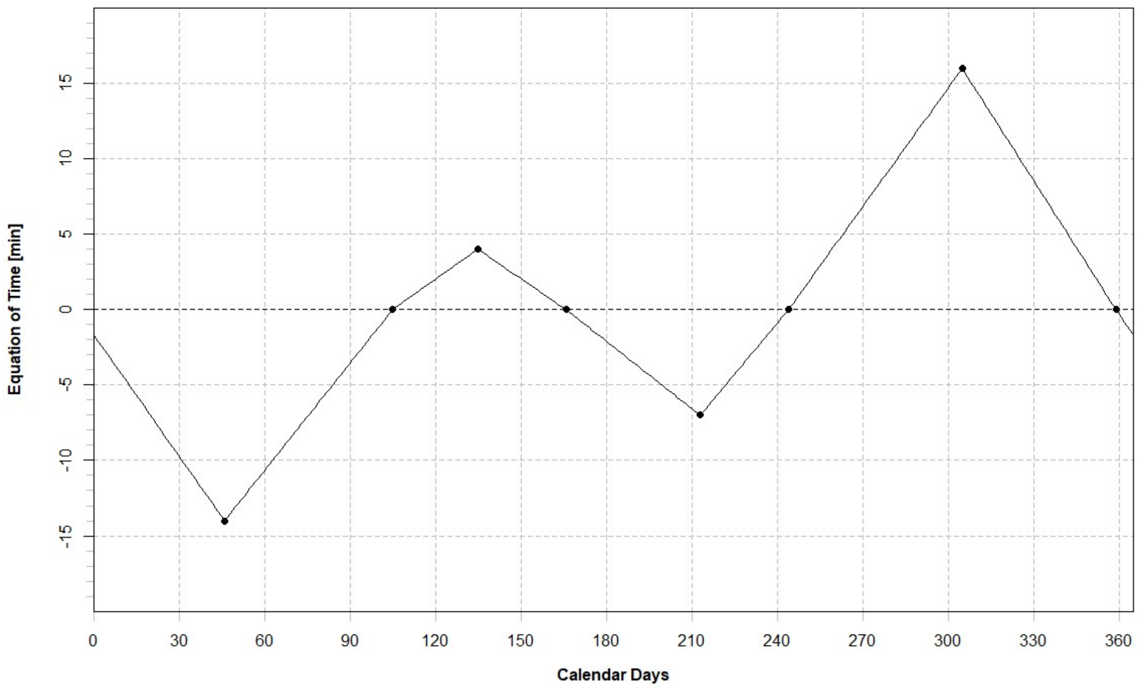

Figure 3.4.: Approximation of the Equation of Time as it will be used in this thesis. Fixed points are the minima at the 14th of February (-14 min) and the 1st of August (-7min), the zeros on the 15th of April, the 14th of June, the 1st of September and on the 25th of December, and the two maxima on the 15th of May (+4 min) and the 31st of October (+16 min). In between, the values have been linearly interpolated. The apparent minus the average solar time is plotted, so a negative value signifies that the apparent solar time leaps behind the average solar time (and vice versa for positive values).

Having identified the points in time at which Salis-Marschlins took his measurements in Central European (Winter!) Time, the last step will now be to create daily average temperatures. To get an idea of how well the observation times were chosen, we first need to know how the temperature in Marschlins behaved throughout a day and over the course of a year. This will then allow us to check the approximation of the daily average that *Equation 3.1.* yields. Unfortunately, Marschlins Castle is no longer used as a weather station. A direct translation of today's

Come Halloween, subtract sixteen / On Christmas Day, you're OK / For your Valentine true, add a dozen and two / When taxes are due, the dial is true / At the mid of May, take four away / On June fourteen, don't add a bean / When August begins, add seven little mins / The rest is easy: for any date / All you do is interpolate". Cf.: Dunne 1996.

temperature cycle to that of the past, as was done in Kremsmünster, is therefore out of reach.[212] Instead, close to forty years of hourly temperature data from the MeteoSchweiz station in Chur has been used to simulate a daily temperature cycle in the proximity of Marschlins. This will be our only reference for the Marschlinian temperature cycle, as there is little other temperature data available in this region.[213] This use of the Chur temperature cycle might introduce some small errors, as the alpine region is notorious for its microclimates. Apart from differences in sunshine duration due to the shape of the valley, winds will probably also play a role. Furthermore, a second assumption will be made, that the average temperature cycle in the *Churer Rheintal* has not changed over the course of the last two centuries. Although both assumptions are relatively important, and corrections applied with the help of the resulting climatology will not be perfect, they will still help us to obtain a better estimate of the daily, and thereby, monthly temperature averages.

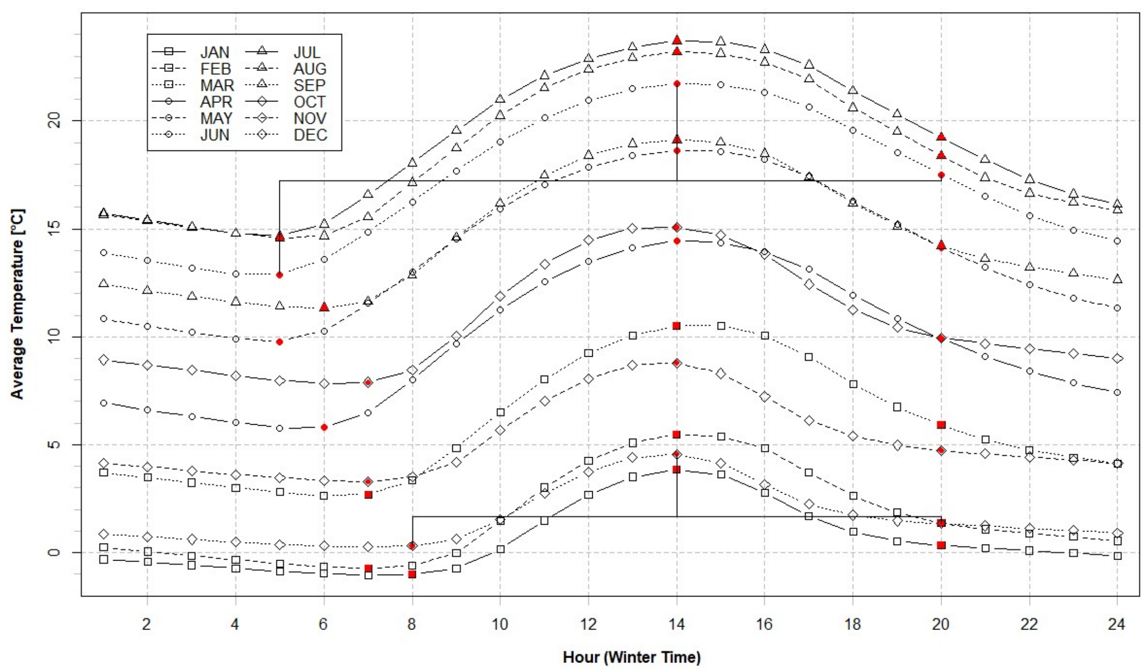

Figure 3.5.: Average daily temperature cycle in Chur between January 1981 and May 2019, split by months. The red dots mark the times at which Salis-Marschlins usually took his measurements. The two straight black lines indicate the mean daily averages of June (upper line) and December (lower line). The data for this graph is from the data platform of MeteoSchweiz.[214]

[212] Cf. Böhm et al. 2010.
[213] Although there is a weather station of MeteoSchweiz somewhat to the north-west of Marschlins in Bad Ragaz, it only started operation in early 2012, too late to create reliable climatology from that data. Still, a comparison of this brief period with the respective data from Chur showed reasonably good agreement.
[214] Cf. Bundesamt für Meteorologie und Klimatologie MeteoSchweiz 2019.

This monthly averaged daily temperature cycle can be found in *Figure 3.5.*, with the red dots indicating the hours at which Salis-Marschlins mostly took his measurements. At first sight, taking the average of the morning, afternoon, and evening measurements to obtain the daily mean, as suggested by *Equation 3.1.,* seems promising. To now apply corrections for the two biases introduced by the change from apparent to average solar time, the time-shift of each measurement is multiplied by the average rate of temperature change (cf. *Figure 3.6.*). Applying these corrections primarily affects the summer months, as the rate of change at the time of the evening measurement is still substantially negative. Overall, averaging the minimum, maximum, and 8 PM measurements (9 PM, respectively) generally overestimates the 'true' daily temperature mean by a few tenths of a degree Celsius, particularly during the winter months, as *Figure 3.7.* shows. Observing at 8 PM instead of 9 PM in the evening helps to contain the resulting averages within a closer error margin, although the 'true' value is thereby overestimated a little more.

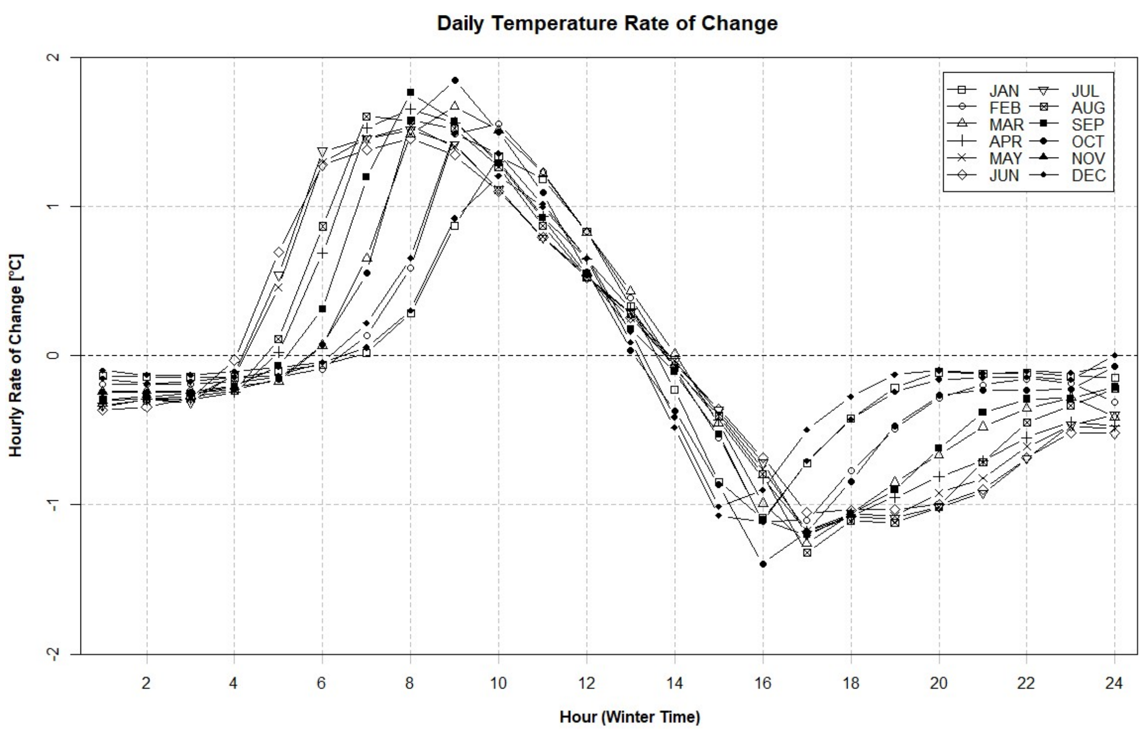

Figure 3.6.: Hourly rate of temperature change over the course of an average day in Chur between January 1981 and May 2019, for each individual month. The main differences occur during the morning and the evening measurements.

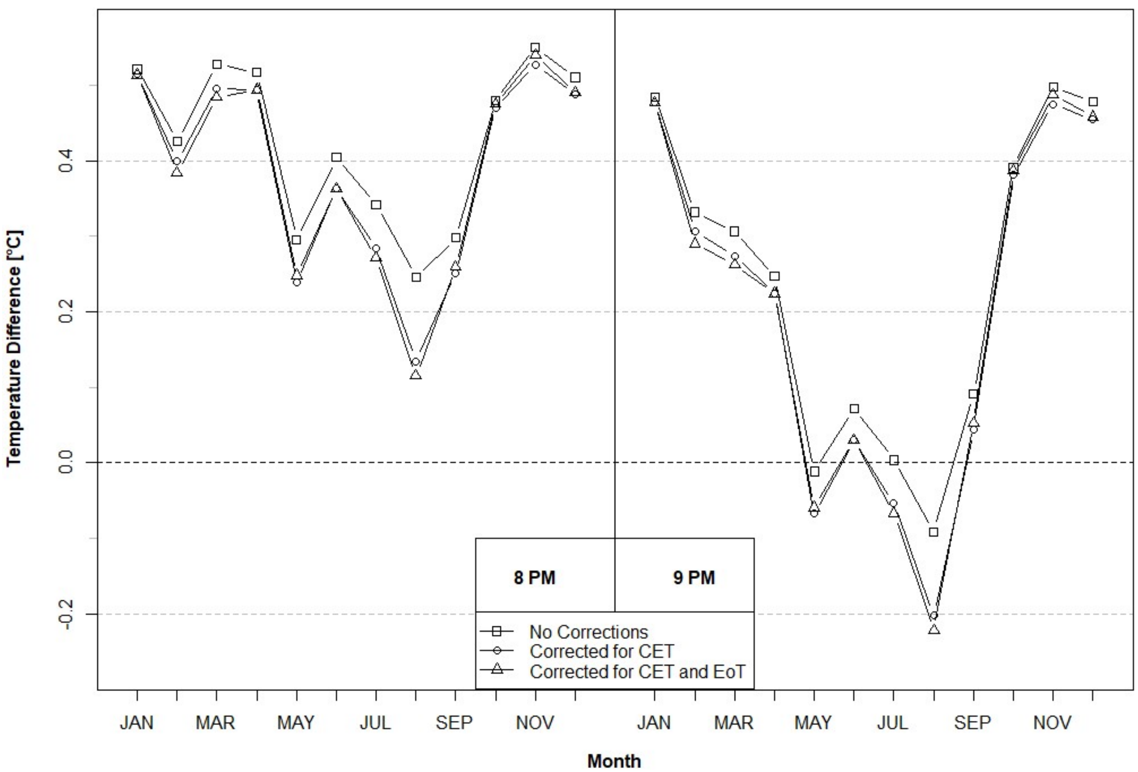

Figure 3.7.: Plotted temperature differences between daily means calculated with only three measurements (minimum and maximum temperature as well as the temperature at 8 PM (left) and 9 PM (right), respectively), and daily means calculated using all 24 observations. Introducing corrections for the change from apparent to average solar time (Central European Time (CET) and Equation of Time (EoT)) mainly affects the summer months.

So, averaging the morning, afternoon and evening measurements does yield a reasonable estimate for the daily average temperature, however, depending on the month, a considerable error of more than 0.5 °C (on a monthly average) will be introduced. The final step to take in this section is therefore to correct each individual daily average by its expected difference to the 'real' daily average. This difference is determined solely by the observation times of that respective day, once again by making use of the daily temperature cycle for Chur. *Figure 3.8.* gives an impression of these corrections, averaged by months. The shift of the evening measurement from 8 PM to 9 PM is clearly visible at the beginning of 1796. On second glance, the onset of a more standardised observation practice over the course of the first few years can also be retraced in this graph. As Salis-Marschlins started performing his measurements consistently at set points in time, the corrections of one year begin to strongly resemble those of the following. Conversely, the more widespread corrections of the first years reflect the frequent changes of observation hours in this early period. The applied daily corrections mirror this impression, as they closely follow the monthly mean corrections during the second half of the Marschlinian series. On the other hand, within the first few years, they can reach up to 1.5 °C on occasion.

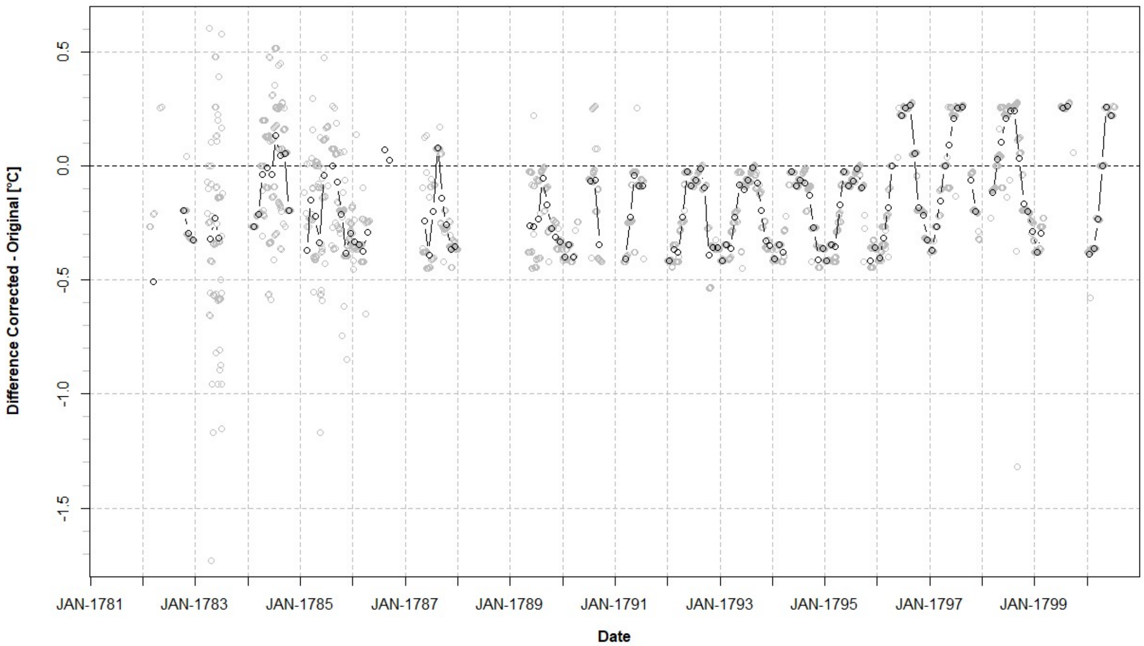

Figure 3.8.: Corrected differences between 'true' daily temperature averages and those calculated with the three (or two) daily observations at hand. The monthly averaged differences are plotted in black. Not depicted here are the effects that the removal of data points had on certain months. These could be quite drastic (e.g. almost 2 °C of difference in December 1798), as mainly extreme values had been removed. The daily correction factors actually applied are coloured in grey.

The resulting series of daily and monthly temperature averages can be found in *Figure 3.9*. Months that contain fewer than ten daily averages have not been included in this graph. Daily averages had to be calculated for March 1782 and February 1785 by averaging the daily minimum and maximum temperatures, as too many evening measurements were missing. Naturally, corrections for these daily averages had to be adapted accordingly. While most of the daily averages seem to lie within the expected range, a few outliers can still be detected. The most notable are to be found in the summer of 1790 and during December 1798, so, the chances are that the unreliable *Branderischer Universal Thermometer* was at least partially in use for somewhat longer than expected in Section 3.2. The extrema at the end of 1798, on the other hand, were probably caused by the *Weingeist* thermometer that was probably already in use in the end of 1798.[215] Before performing a break point detection test in the upcoming section, these extreme values and the two data points of August 1790 will be eliminated from the series.[216]

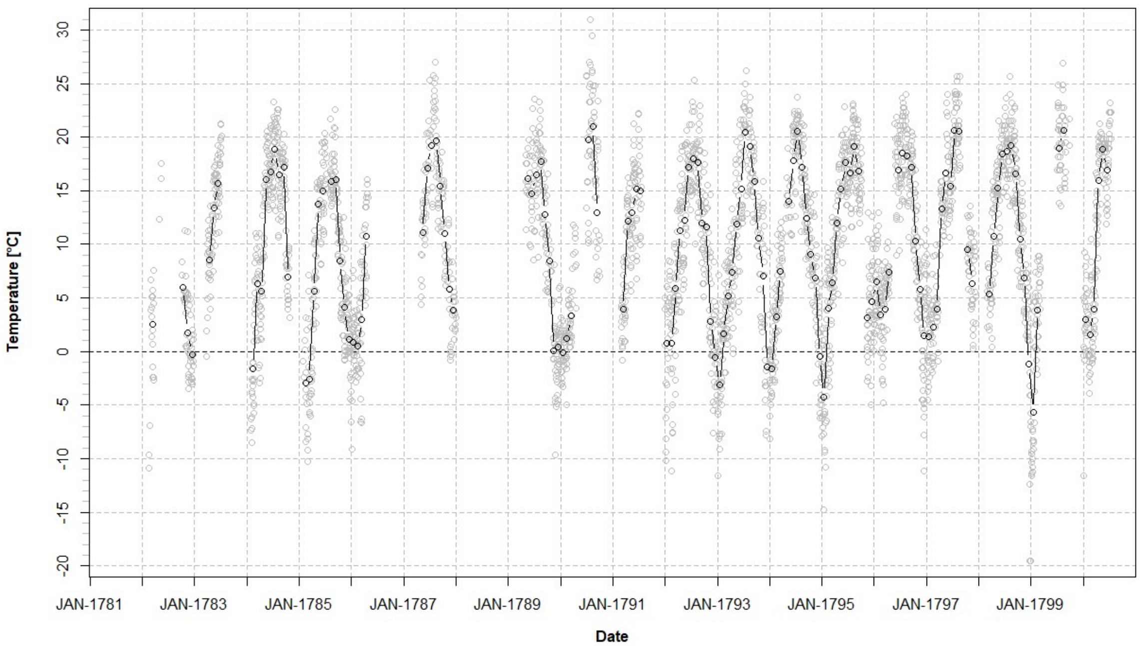

Figure 3.9.: Daily (grey) and monthly (black) average temperatures from the Marschlinian series with applied corrections for the changes in measurement time. Months with too few observations (less than ten daily averages) have not been plotted. The monthly values for March 1782 and February 1785 have partially been obtained by averaging only the maximum and minimum temperature (as the evening measurement was mostly not available).

3.3.3. Homogenisation

The meteorological observations of Salis-Marschlins are amongst the longest early instrumental measurement series of Switzerland. These observations hold valuable information on the climate variability over four decades, provided that the data is homogeneous, and the variations captured therein were only caused by variations in climate. Unfortunately, as the previous pages have shown, Salis-Marschlins adapted or was forced to adapt his measuring habits and surroundings multiple times throughout the twenty years examined in this thesis. Naturally, any

[215] Unfortunately, Salis-Marschlins did not note when exactly he had to change his thermometer to one that measured with *Weingeist*. It is first mentioned in the results section for January 1799. Salis-Marschlins probably switched thermometers during a gap in the recordings. Following this reasoning, either the break between the 17th and the 22nd of November or the one from the 13th to the 17th of December appear to be the most reasonable options.

[216] It should be noted that the monthly mean value of December 1798 is quite heavily altered by this measure (about 2 °C warmer on average!). As three very cold days of this month have been removed (although not as cold as indicated by the *Weingeist* thermometer), this new monthly average will be somewhat too high. This should be kept in mind when having a look at the results later in this chapter.

of these changes of location, measurement device, or observation technique might have introduced a bias to the temperature or pressure series, all of which would lead to a misinterpretation of the climate at that time. However, these non-climatic discontinuities are far from being unique to the Marschlinian series. In fact, homogenisation is a process that has to be undertaken when working with any long-term climatological time series, regardless of its age. Relocations of weather stations or gradual changes to the environment can occur today just as often as they did 200 years ago. In contrast to the homogenisation of a younger series, however, working with early instrumental data will usually add a few complications. For example, the replacement of an instrument was more likely to lead to a non-climatic shift in the data in the late 18th century, as the exact calibration of a device still posed a challenge and instruments were generally of a lower quality. Mainly for older series, metadata is not always available, meaning that smaller biases could go unnoticed. Luckily, the Marschlinian diaries and some additional sources hold some basic information on observation practice, although often falling short of detail. The homogeneity of the Marschlinian temperature series will be assessed in the following pages with the help of this metadata.

The homogenisation of a climate series generally involves four steps.[217] The first of these steps, metadata analysis and quality control, has already been addressed in the previous sections. The removal of outliers during the quality control is crucial before starting a homogenisation procedure, as additional break points can be avoided this way. This will also increase the quality of the correction factors, which will be added in the last step. The gathered metadata, on the other hand, can offer explanations for the breakpoints found, and enable the detection of further discontinuities in the 'candidate series' that is to be tested. Once all available metadata has been assembled and the data has been quality-controlled, it is then time to select an adequate statistical test and detect break points within the series. In preparation for this break point detection, a suitable reference series for the candidate series should be created first. Although having such a reference series is not a prerequisite for all statistical tests, it will strongly ease the detection of smaller inhomogeneities, or enable such a detection in the first place. Having a reference series with which to compare the candidate series that is to be homogenised is therefore advisable for any statistical breakpoint test.

Ideally, such a reference series should have experienced the same (major) climatic oscillations as the candidate series. Non-climatic discontinuities can easily be detected by differencing

[217] Cf. Aguilar et al. 2003: 31.

this way. In the case of Marschlins, creating such a reference series turns out to not be an easy endeavour. To begin with, as is the nature of early instrumental series, there are few other series for comparison. Additionally, both the geographical and climatological distance between the major European cities in which the usual nobles took their measurements, and the Rhine valley, whose climate is frequently affected by the *Fön*, are quite large. With a lack of other series to choose from, and in an attempt to capture the state of the atmosphere in as many directions of the Rhine valley as possible, the choice fell on the temperature series of Basel, Geneva, Milan, Innsbruck, Hohenpeissenberg (south-eastern Germany) and Karlsruhe. The stations in Milan, Innsbruck, Hohenpeissenberg and Karlsruhe are all part of the HISTALP project, during which a homogenisation of the data has been performed. The data from Basel and Geneva, on the other hand, was taken from the data archive of MeteoSchweiz,[218] as there are no other recent homogenisations of these series.[219]

The correlation of each series to the candidate series was calculated, month by month in order to weigh those stations according to their climatological proximity to the Marschlinian series. Somewhat surprisingly, the highest correlation was found for Hohenpeissenberg, followed by Basel, Geneva and Karlsruhe. All four stations show a yearly mean correlation coefficient of between 0.75 and 0.8. The largest climatological distance was found for Milan and Innsbruck, with a yearly mean correlation coefficient of a little more than 0.65 for Milan and close to 0.7 for Innsbruck. Looking at individual months, April was the most similar for all stations, as the averaged correlation coefficient read about 0.93. On the other side of the spectrum is December, which is only slightly over 0.4. The data of each of the six stations was then combined for the construction of the reference series, weighing each individual month according to its correlation coefficient.[220] In the following *Equation 3.2.*, T_i^{ref} is the i-th monthly average of the reference series, r_m stands for the correlation coefficient of the m-th month and the index j indicates the j-th station.

$$T_i^{ref} = \frac{\sum_j (T_i)_j \cdot (r_m)_j}{\sum_j (r_m)_j} \qquad \text{(\textit{Equation 3.2.})}$$

[218] Cf. Bundesamt für Meteorologie und Klimatologie MeteoSchweiz 2019.
[219] Schüepp 1961: 21, 25 is the only written publication that contains these two series up to date. His methods of homogenisation are somewhat outdated, though.
[220] The same or a similar approach has for example been suggested by Alexanderson, Moberg 1997: 26 or Aguilar et al. 2003: 34 and was followed by many homogenisation projects. Cf. e.g.: Cocheo, Camuffo 2002: 92; Maugeri et al. 2002: 130.

With the reference series built, we can proceed with the third step of the homogenisation process: the breakpoint detection for the difference between our candidate and reference series. The fifth version of RHtests has been used for this, as this software allows for the testing of both known and unknown changepoints within a temperature or pressure series.[221] The metadata from the diaries of Salis-Marschlins and the notes by his relatives can thus be used for the detection of additional inhomogeneities. At the same time, the metadata itself can be tested for its completeness by checking whether all statistically significant break points can be explained by the metadata.

Period	Adjustments in °C
Mar 1782 - Jun 1783	-0.2
Feb 1784 - Mar 1784	-2.3
Apr 1784 - Nov 1785	-0.5
Dec 1785 - Jun 1789	-1.0 + trend
Jul 1789 - Oct 1794	0 + trend
Nov 1794 - Nov 1798	-1.6 + trend
Dec 1798 - Jul 1800	-2.4

Table 3.2.: Adjustments made to the individual segments of the Marschlinian temperature series.

Depending on what should be regarded as a true inhomogeneity, three to seven change-points could be detected when using RHtests on the candidate series. After comparison with the metadata, six breakpoints were selected, as shown in *Table 3.2*. Two of these breakpoints were common in all runs performed; one when supported by metadata at the end of 1798 and one that is significant even without metadata support around October 1794. While breakpoint in 1798 of about 0.8 °C can probably be traced back to the change of thermometer around that time,[222] the metadata lacks any explanation for the second breakpoint. The only change in measurement circumstances that can be found in the available metadata for this period is a relocation of the measuring devices from the first to the second floor of the castle at the end of 1793. However, it seems unlikely that such a small change in location could have caused a shift of close to 1.6 °C, considering that moving the instruments to Chur went almost unnoticed by the

[221] Cf. Xiaolan, Yang 2013. For additional information on the methods implemented in these homogeneity tests, see: Wang 2008; Wang, Wen, Wu 2007.

[222] Another possibility might be the change of location (from second to first floor) that Salis-Marschlins undertook in July 1798, according to his nephew. Cf. Meteorologische Aufzeichnungen 1784-1862, Bemerkungen zu den meteorol. Beobb. Raoul's v. S. M., StA GR, D VI MA III VII.Z.1. However, as the RHtests detects January 1799 as a break point with no metadata added, the change of devices seems the more reasonable choice.

test. These doubts are further strengthened because there is no reverse break at the time the instruments were taken back to the first floor in July 1798.[223] Finally, it is not clear whether the thermometer was moved at all, or whether the newly acquired barometer was simply put in a different room than the one that broke in September 1793. In short, the metadata available cannot explain this shift in 1794.

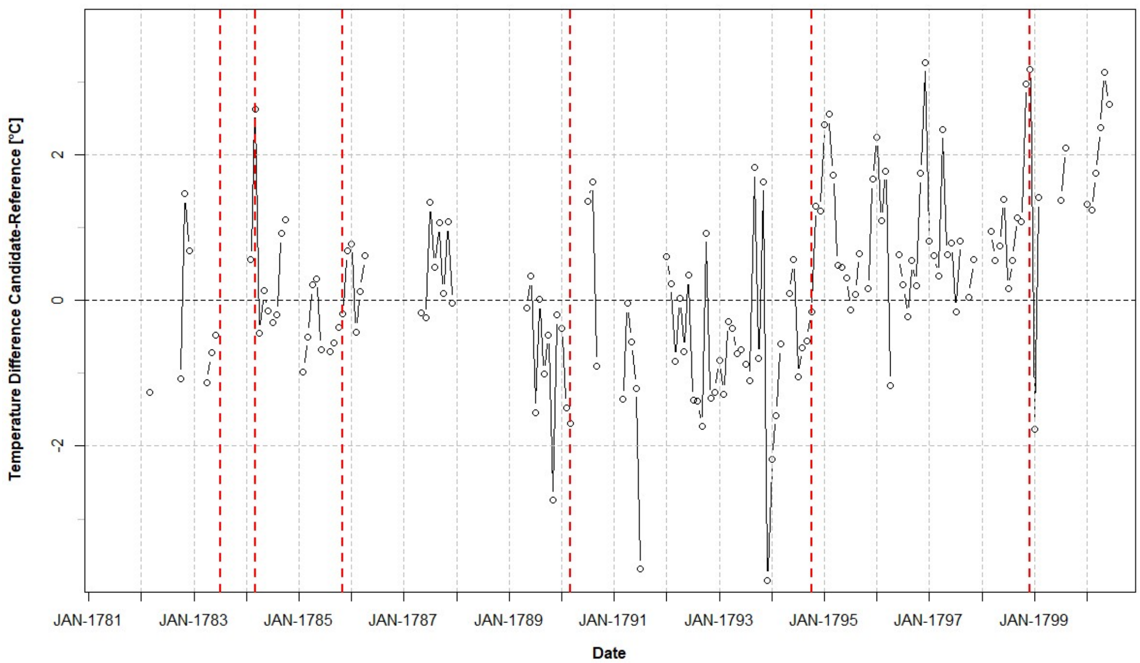

Figure 3.10.: Plot of the difference between the Marschlinian temperature series and the reference series. The dotted lines in red indicate the detected breakpoints.

Essentially, there are two possible explanations for such an inhomogeneity: a change in instrument that was not reported, or a – potentially unnoticed – modification of the thermometer's scale. A change of measuring device could certainly cause an inhomogeneity of this size, especially if it was accompanied by a change in thermometric liquid. In fact, when looking back at *Figure 3.3.* (p. 52), a slight increase in the temperature difference between afternoon and morning, as well as the afternoon and evening measurements can be found. This increase seems to be caused by generally slightly higher maximum temperatures for the years past 1794, which might hint at the use of *Weingeist* as the thermometric liquid. This shift in temperature differences is considerably smaller than the major breaks around 1791 and 1799, however, both of which can clearly be traced back to a change in thermometer. Thus, a change from mercury to

[223] See previous footnote.

Weingeist was far more likely at any of these two points in time than in October 1794.[224] Furthermore, it is questionable whether Salis-Marschlins would have kept quiet about this replacement of device. After all, he did mention the other changes in instrument and often even described the approximate effect the respective change had on the measurements.

The other option that might explain the 1794 inhomogeneity is a sudden shift between the scale and the glass thermometer attached to it.[225] Such a displacement of the scale could have been done on purpose, when trying to correct for a gradual drift in the observed temperatures. Although such a trend can clearly be observed in the Marschlinian series, the shift occurred in the wrong direction, thereby accentuating the offset to the reference series (cf. *Figure 3.10.*). Moreover, considering that the metadata remains silent on the cause of this shift, it is likely that both Salis-Marschlins and his relatives were ignorant of its occurrence. Thus, an accidental knock on the thermometer is the most probable explanation for this breakpoint. Regardless of which of the two options presented above is chosen, however, the correction applied to the Marschlinian temperature series will remain the same.

Apart from these clearly detectable breakpoints, four additional inhomogeneities were found by the software in combination with the metadata. Two of these breakpoints belong to the period in 1784, when measurements were taken in Zizers. As data had only been gathered in Zizers for a little more than two months, the step size of about 2 °C each contains considerable uncertainties and is probably somewhat too large. The remaining shifts can be associated with Salis-Marschlins moving to Chur and back to Marschlins again. It should be noted, however, that the breakpoint in March 1790 is barely significant. A breakpoint in June 1789 would have been preferred without metadata support.[226] Accordingly, the shifts of 0.5 °C in 1785 and a bit less than 1 °C in 1790 are rather small. The corrections for these six shifts have been applied so that the resulting series is homogenised around the fifth segment of the series from June 1790 to October 1794.[227] Although homogenised data is usually adjusted to the last

[224] In fact, this shift probably occurred in December 1798, as we know from the metadata. What exactly caused the first increase in temperature differences remains to be seen.
[225] Scales that were engraved directly on the glass thermometer itself were very rare in the 18th century. Considering that the instruments of Salis-Marschlins were said to be of "common kind", a glass thermometer attached to a wooden support on which the scale was drawn upon appears to be the most likely choice. Cf. Camuffo 2002a: 318.
[226] This significance of this breakpoint was also questionable, though.
[227] As this segment's average temperature before the homogenisation was about 0.6 °C lower than the one of the reference series, the average temperature of the whole series after homogenisation is close to that value at about 0.7 °C below the reference series. This is equivalent to an average yearly temperature of about 8.5 °C. It is difficult to say how close this gets to "reality". The average over the same months, retrieved at the grid point in the data grid mode of HISTALP that lies closest to Marschlins (close to Bad Ragaz), suggests a value of about 9 °C. So,

segment of a series, this did not seem reasonable in this case as temperatures were obtained with a *Weingeist* thermometer at that time. Thus, the latest segment for which trustworthy observations were made in Marschlins has been selected. The second period during which the data was taken at Zizers in October 1784 went unnoticed by the software. Similarly, the few months that Salis-Marschlins spent back at Marschlins in 1785 and both relocation of instruments within the castle at the end of 1793 and in July 1798 did not qualify for a breakpoint.

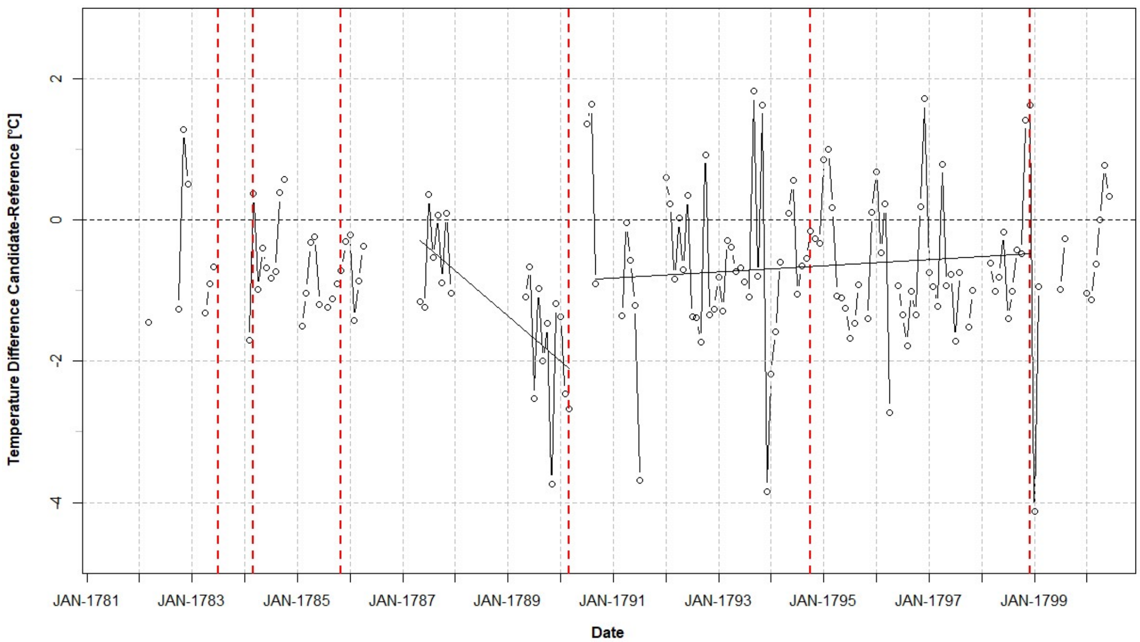

Figure 3.11.: Plot of the difference between the Marschlinian temperature series and the built reference series after applying the corrections for the detected break points (indicated by the dotted lines in red). The two prevalent trends have been indicated by black lines.

In addition to these break points, parts of the Marschlinian series also have a positive inherent trend. The RHtests software estimated the overall trend to about + 0.005 °C/month. Before applying such a correction to the entire series, though, a brief consideration of the possible causes of such a trend is worthwhile. While negative trends can have a multitude of causes, such as, alterations in the thermometric liquid, deformations in the scale due to the aging of the wood, or simply an increase in the surrounding vegetation, the choices for explaining a steadily rising trend are far more limited. In fact, Camuffo only gives one possible reason for a "slow rising of the zero, that often goes on for years [and] is particularly evident in certain mercury

considering that Bad Ragaz is only a few meters lower in altitude than Marschlins Castle, the chosen average might be a few tenths of a degree Celsius too low.

thermometers”[228]. At its origin is a gradual contraction of the glass thermometer within the first few years of its use, transferring more and more mercury into the capillary. This contraction is dependent on the composition of the glass. It could be somewhat mitigated by offsetting the calibration of the thermometer for some time after the construction of the instrument. As little of this effect was known in the end of the 18th century, however, no precautions appear to have been taken against it by Salis-Marschlins.

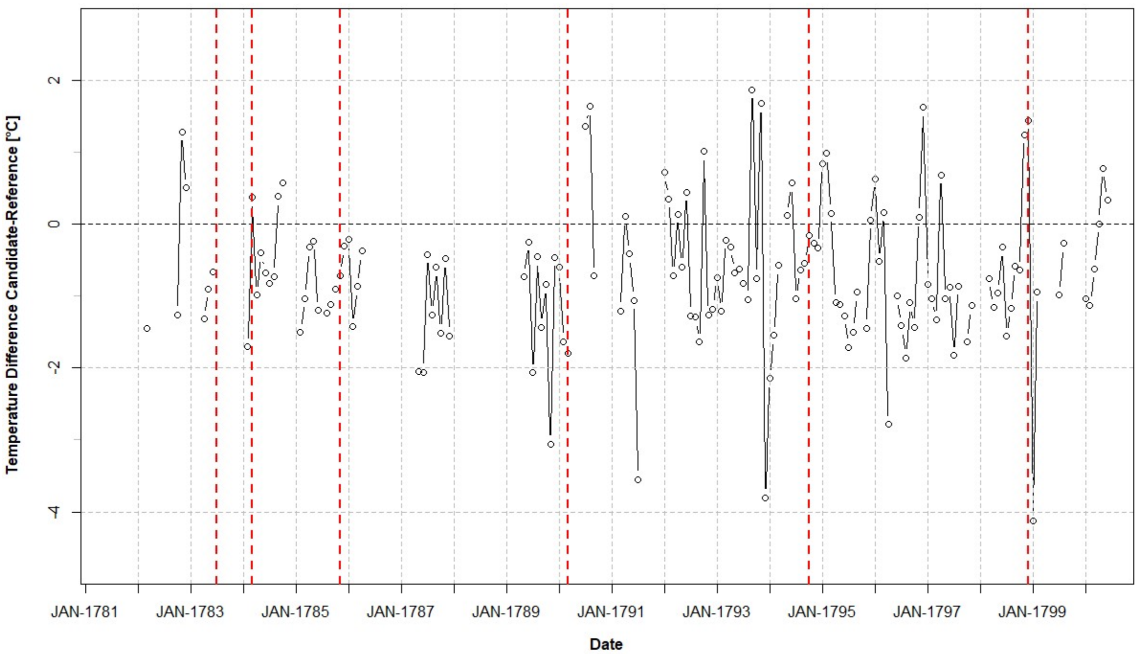

Figure 3.12.: Plot of the difference between the Marschlinian temperature series and the reference series after applying the corrections for the detected break points (indicated by the dotted lines in red) and the corrections for the negative trend from May 1787 to March 1790, and from September 1790 to December 1798.

As thermometers were far from being mass products in the 18th century, the composition and shape of the glass and the time of calibration is expected to be different from instrument to instrument. Since the gradual shift of the zero was caused by the contraction of the glass tube, this trend should also be somewhat different for each of the thermometers that Salis-Marschlins used. For that reason, a correction was only applied for the period of September 1790 to December 1798,[229] where a clear positive trend of approximately 0.0035 °C/month is found (cf. *Figure 3.11.*). The rest of the series was left unchanged, except for the period from May 1787

[228] Camuffo 2002a: 323.

[229] Here, July and August 1790 were excluded, as they were probably still partly affected by measurements taken with the *Branderischer Universal Thermometer*.

to March 1790, where a negative trend can be seen. As this negative trend corresponds exactly to the lifespan of the thermometer in use around that time, a non-climatic cause seems highly likely. As mentioned above, there are numerous potential causes for such a rise in the zero, and pinpointing a trend over such a short period to any specific reason is thus not possible. As Salis-Marschlins lived in Chur at that time, an increase in vegetation cover can at least be excluded. Despite not knowing the exact reason for this trend, a correction of 0.051 °C/month was applied to this part of the series.[230] After applying all corrections for breakpoints and trends, the corrected series of differences and the resulting Marschlinian temperature series can be found in *Figures 3.12.* and *3.13*.

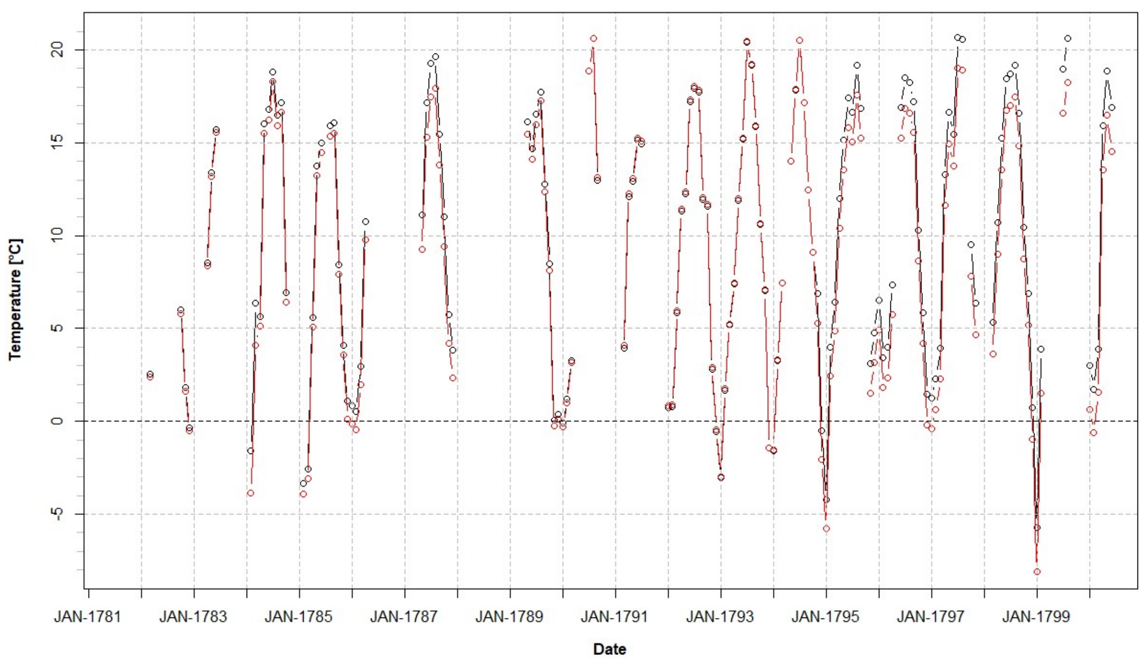

Figure 3.13.: The Marschlinian monthly mean temperature series before (black) and after (red) homogenisation.

Before continuing to the discussion of specific months in the next sub-section, a few words about the homogenisation process itself should be given at this point. As will have become evident, this homogenisation of the first twenty years of Marschlinian temperature observations contained quite a few difficulties. A major complication was added by the frequent changes of location and device. Unsurprisingly, not all breaks could be detected by the statistical test applied in the years of 1784 and 1785, when Salis-Marschlins moved between Marschlins, Zizers

[230] Both corrections have been applied so that the overall mean of the series remains unchanged.

and Chur once every few months. Considering the large gaps in observations that are frequently found during the first few years, the resulting homogenisation of this early period should be taken with at least a grain of salt. In the remaining fifteen years of the series, the main difficulty originated from the temporary use of different thermometric liquids and thermometers of poor quality. While the values that were obtained with faulty instruments had to be rejected altogether, the '*Weingeist* period' of December 1798 to July 1800 was kept as part of the series. The monthly averages of this period seem to match the reference series rather well (after homogenisation that is), however, their calculation using a morning measurement that was probably some degrees too cold and an afternoon and often also an evening measurement that are too warm, certainly is not satisfactory.[231] Some months during which faulty devices might still have been partly in use were also included (mainly July and August 1790).

The attentive reader will also note that only half of the initially set goal of producing a homogeneous monthly and daily temperature series has been achieved. However, considering that even the homogenisation of the monthly series posed serious problems, attempting the same for daily averages, whose variability is far higher, would add yet further difficulties. Although this might help define periods with low quality thermometers more exactly, similar problems as for the monthly series are still likely to occur. As this would involve yet further considerable effort, no homogenisation of daily averages will be undertaken in the scope of this study. The individual temperature measurements will thus be adjusted with the corrections for the monthly series instead for the temperature values on a sub-daily resolution, which will be required for the homogenisation of pressure data in Section 3.4.

3.3.4. The Marschlinian Temperature Series

As the homogenisation procedure of the monthly data has been completed, it is time to take a closer look at the resulting temperature series in *Figure 3.13*. While changes to the original series were rather small for most of the first fourteen years, corrections of about 2 °C were applied to the period of 1795-1800. Owing to these adjustments, the already cold Januaries of 1795 and 1799 came to have even colder temperatures. This led to January 1799 being more than 4 °C below what would be expected according to the reference series. In the following, months that show large differences from the reference series, and particularly warm or cold

[231] The 4 °C anomaly in January 1799 compared to the reference series can quite certainly be largely explained by this phenomenon, as the afternoon measurements were not able to compensate for the cold excess of the morning observation.

months, will therefore be discussed in more detail. Before that, however, we will consider the boxplot of the homogenised Marschlinian temperature series.

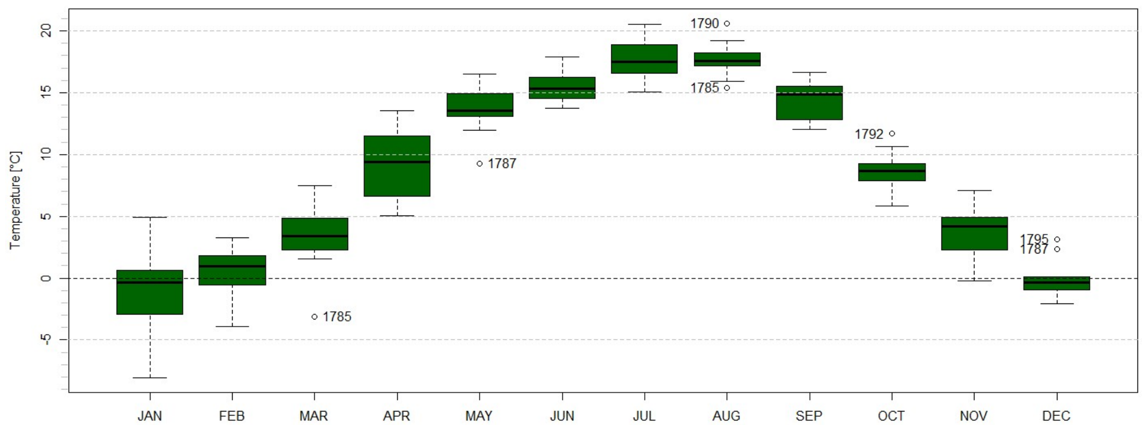

Figure 3.14.: Boxplot of the homogenised Marschlinian temperature series. In addition to the known extrema in March 1785 and August 1790, further outliers have appeared after homogenisation in comparison with Figure 3.1.

Next to the already known cold March (and February) in 1785 and the outlier in August 1790, *Figure 3.14.* shows some further temperature anomalies in May 1787, August 1785, October 1792, as well as December 1787 and 1795. Not all these outliers should be regarded as exceptionally anomalous months, however. December 1787 and 1795, for example, could only be compared to eight other December averages, so, although they were probably warmer than the average thanks to the predominantly prevalent southerly winds, they should not qualify as outliers in a climatological sense. This is confirmed by the results of December 1795, in which Salis-Marschlins described the respective month only as “nicht so wintermässig als wie der vorige Monat”[232] – not as wintery as the prior month. Similar arguments can be made for the October of 1792, which was compared to ten other months from this twenty-year period. Helped by the *Fön*, which reigned for more than two thirds of the month, it was described as “[...] very agreeable and warm and so to say the nicest month of that year”[233]. The outlier in August (and July) 1790, on the other hand, was probably not entirely of climatological origin, as the *Branderischer Universal Thermometer* might still have been in use for some of the measurements. Although this device was last mentioned in the diaries on the 1st of July 1790, some afternoon and evening measurements in late July and early August still seem suspiciously high,

[232] Meteorologische Beobachtungen, Results of December 1795: IMG_7568.
[233] “[...] sehr angenehm und warm und war so zu sagen [sic] der schönste monat [sic] von diesem Jare [sic]”. Meteorologische Beobachtungen, Results of October 1792: IMG_6804.

with temperatures reaching up to 35 °C at 8 PM. This suspicion is further strengthened as these two months are amongst those that differ the most from the reference series (cf. *Figure 3.12.*), while only being described as "rather warm" in the diaries.[234]

While the months discussed above were probably outside the norm but not exceptionally anomalous, May 1787 and the entire year of 1785 (and March 1785 in particular) are certainly more deserving of this title. In May 1787, the first few days set the tone for the rest of the month. The 1st and 2nd of this month came with gusts of snow, and temperatures throughout the first seven days were below 10 °C, except for the afternoon of the 4th. This trough of cold air was probably already present at the end of April, as Salis-Marschlins mentioned frostbitten trees on the first page of that year's diary, already calling it a sad May at this stage.[235] Although temperatures were then a little warmer and reached almost 25 °C by the 23rd, they remained below average for most of the month. Afternoon values only rarely exceeded the 20 °C threshold. These cold temperatures, probably paired with the damage dealt by the frost in April already, also had substantial effects on the phenological cycle. In this month's results section, Salis-Marschlins noticed that the vegetation was close to stagnant and was delayed by about four weeks compared to other years.[236] This probably only applied to the species that were harmed by the frost, as a small delay of only about five days can be found for the species portrayed in *Figure 4.4.* (p. 112). Nonetheless this remark clearly shows how May 1787 was perceived as an extraordinarily cold month.

Even more exceptional was the period from October 1784 to August 1785, one year after the Laki eruption. Although only March and August 1785 were cold enough to be considered outliers in the boxplot, this eleven-month time span contains many exceptionally cold months. The second coldest October; the coldest February, March and April; the third coldest June; and the coldest August of the entire twenty-year series can be found in this period. In addition, November 1784 to January 1785, for which unfortunately too few temperature records are available for the construction of monthly mean values, were very rich in snow[237] with temperatures probably also considerably below average. In January 1785, the noted (morning?) temperatures read sub-zero all but once, and in November 1784, rivers in *Castione* were frozen over by the

[234] Cf. Meteorologische Beobachtungen, Results of August 1790: IMG_6500.
[235] Cf. Meteorologische Beobachtungen, May 1st, 1787: IMG_6104. Unfortunately, no observations are available for the first four months of the year.
[236] Cf. Meteorologische Beobachtungen, Results of May 1787: IMG_6122.
[237] For more detail, see Section 5.2.

23rd.[238] It was only on March 21st that Salis-Marschlins experienced the first nice day of spring.[239] On that day, temperatures rose to 5 °C in the afternoon and the ground was still covered by more than 30 cm of snow. On the 5th of April, there was still enough snow to travel from Reichenau (Tamins) to Chur by sledge.[240] As a consequence of the long winter, hay was sparse by the middle of April and farmers had to feed their livestock with chaff and straw, and then had to put them to the slaughter.[241] This cold and snowy winter and early spring 1785 was far from exclusive to the Rhine valley. A stable high-pressure system over Greenland constantly pushed arctic air towards the Alps, leading to March temperatures of about 8 °C below the norm in large parts of Switzerland. This even caused the Vierwaldstättersee and parts of Lake Geneva to freeze over.[242]

In addition to these two extraordinarily cold periods, the two 'Siberian' Januaries in 1795 and 1799 should also be examined. At the beginning of January 1795, there was already more than one foot (~32.5 cm) of ice in the pond and by the 16th, water and milk started to freeze even in the warm chambers.[243] The wind blew constantly from the north-east and brought temperatures as low as -17 °C. The cold was only briefly broken between the 6th and the 9th as well as the 26th and the 29th. In total, Salis-Marschlins counted nineteen days during which temperatures did not surpass the freezing point.[244] January 1799 appears to have been even colder, as at this time the pond was frozen to a depth of more than two feet (~65 cm).[245] Nonetheless, a monthly average of -8 °C does seem implausible, especially as the reference series does not really reflect these icy temperatures. An explanation can be found, however, reading through the diary entries of that period. On the 5th of January, Salis-Marschlins writes that while the trees on the mountain slopes were free of snow and ice, the cold was residing on the valley bottom. A strong inversion appears to have built up, helped by a stable high-pressure system with only light wind.[246] This weather situation had lasted for twenty-four days (from the 29th of December 1798 to the 21st of January 1799), during which the thermometer did not once rise

[238] Cf. Meteorologische Beobachtungen, November 22nd, 1784: IMG_5742.
[239] Cf. Meteorologische Beobachtungen, March 21st, 1785: IMG_5758.
[240] Cf. Meteorologische Beobachtungen, April 9th, 1785: IMG_5767.
[241] Cf. Meteorologische Beobachtungen, April 12th and April 15th, 1785: IMG_5768, IMG_5770.
[242] Cf. Pfister 1999: 121.
[243] Cf. Meteorologische Beobachtungen, January 2nd and January 16th, 1799: IMG 7404, IMG_7409.
[244] Cf. Meteorologische Beobachtungen, Results of January 1795: IMG_7414.
[245] Cf. Meteorologische Beobachtungen, January 22nd, 1799: IMG_8018.
[246] Cf. Meteorologische Beobachtungen, January 5th, 1799: IMG_8014.

above 0 °C.[247] Of course, a slight exaggeration of the cold due to the *Weingeist* thermometer that was in use during that period cannot be ruled out.

Finally, the months in which the Marschlinian series strongly deviates from the built reference series should also briefly be addressed. Apart from the already discussed January 1799, it is mainly July 1791 and December 1793 that stick out (cf. *Figure 3.12.*). In December 1793, the monthly average was more than 3 °C lower than what could be expected from the reference series. Unfortunately, no long-lasting state of inversion can serve as an explanation this time. Instead, the cause is found in the unfortunate timing of an observation gap. During the first seven days, and in the last week of the month, Salis-Marschlins was almost always able to perform three measurements a day. With these temperature records, thirteen daily averages could be calculated. Consequently, December 1793 was not rejected during quality control. However, in the middle of December, when very few measurements were performed, temperatures were probably about 10 °C higher than they were during large parts of the days on record.[248] An error was thus introduced to the monthly average of several degrees Celsius, explaining the difference found in *Figure 3.12*. The discrepancy in July 1791, on the other hand, cannot be explained with certitude. As records stop on the 18th and considering the largely cold first half of the month, however, a similar cause as for December 1793 seems likely.

3.3.5. Improvements for Future Homogenisations

The Marschlinian temperature data has been analysed in quite some detail in these last four sub-sections. With the help of the temperature cycle for Chur and by adapting the recorded observation time marks to the average solar time, a reasonable approximation for daily temperature averages has been found. Furthermore, potential correction factors for indirect and scattered radiation have been discussed and then discarded, as they were of minor importance for the locations and times of day Salis-Marschlins took his measurements. Despite these efforts, however, the resulting temperature series is far from perfect. Indeed, a number of steps have been skipped over in the homogenisation process. This final segment of the section on temperature therefore presents a few of these additional corrections. We will also evaluate which of them might bring considerable improvements and would therefore be worthwhile undertaking.

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[247] Considering this strong inversion, which already occurred during parts of December 1798, the temperature extrema of -25 °C that had been measured during the Christmas days in 1798 and rejected as measurement errors earlier in this chapter might not have been so far from ‘reality’ after all.
[248] This is at least the case for the few afternoon measurements taken during this period.

In the end, some errors will be described, which, despite all this hard work will remain part of the series.

Probably the greatest potential for improving the quality of the monthly series lies in the inclusion of the remaining 22 years of temperature data gathered by Salis-Marschlins from 1802-1823. As Salis-Marschlins had reduced his mobility considerably in his later life, changes in measurement location but also gaps in observation are far fewer than for the period analysed in this study.[249] There are thus fewer breakpoints overall, and so probably better results can be expected from the homogenisation.[250] Although this does not directly affect the series of 1781-1800 studied here, having the homogenisation process run over forty instead of twenty years would still benefit the entire series. With twenty years of continuous observation in Marschlins, a better choice could be made for a 'normal state', around which the series is homogenised. In the twenty years studied here, this optimal situation of measurements taken in Marschlins, and with the help of a mercury thermometer, was only prevalent for slightly more than four years without a (major) break. The overall mean temperature could thus certainly be fixed more accurately. Having such a long series without breakpoints might also help to better quantify some of the (later) shifts.

The tables available in the Swiss National Archive could easily be used to obtain a first impression of the daily and monthly temperatures between 1802 and 1823.[251] However, if the goal is a detailed homogenisation of this second half of the Marschlinian series, studying the rest of the diaries is a necessity. Not only are the tables missing all the months of December and January, but the metadata, which greatly helps the homogenisation process, will without doubt also be more complete in the diaries. Furthermore, the tables lack the additional information the diaries can offer about the wind and weather situation, as well as the perception of the month in the results sections, which can be critical for months 'outside the usual'. Although completing the series with the remaining twenty-two years certainly is of great benefit to the temperature series, this step would also require an enormous effort.

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[249] Ulysses Adalbert von Salis-Marschlins only knows of one small relocation of instruments in August 1802. From this point onwards, measurements were exclusively taken in the *Schlössli*, the residence of the von Salis-Marschlins right in front of the castle (cf. *Figure 2.1.*, p. 26).
[250] This is of course assuming that no (frequent) changes in thermometer occurred during that period.
[251] Cf. Marschlins Witterungsbeobachtungen 1800-1885; BAR E3180-01#2005/90#242*; E3180-01#2005/90#232*; E3180-01#2005/90#229*; E3180-01#2005/90#235*; E3180-01#2005/90#243*; E3180-01#2005/90#241*.

Another, certainly less labour-intensive, improvement that may be made involves the inclusion of weather data, as was done for the Stockholm temperature and pressure series for example.[252] As it took Salis-Marschlins only an instant to observe and note down the current weather situation, almost every single temperature measurement is accompanied by an abbreviation of the state of the weather at that time. Often, Salis-Marschlins also made remarks on the sky becoming overcast or clearing up between the set measurement times. Knowing the weather at the points of measurement (and throughout the whole day) is crucial, as the daily temperature cycle, and thus also the representativeness of the three daily measurements, is strongly affected by it. This weather data could be used to build categories, distinguishing between sunny and cloudy days, and everything in between. Next, the expected temperature curve would be assigned to each of these categories. In a final step, the individual daily averages would be calculated accordingly. Although this would affect the monthly mean values only a little and was therefore omitted in the above analysis, a homogenisation of daily averages would greatly benefit from this additional correction.

Even if this correction and the extension in homogenisation length had been tackled, however, a handful of errors would remain. The error that is probably most commonly mentioned in this chapter is that caused by *Weingeist* thermometers. The use of a thermometric liquid that does not expand linearly when exposed to heat causes larger errors the further temperatures are from the calibration point(s). Severe errors can thus be introduced in both daily mean values and monthly averages. Unfortunately, this non-linearity is not unique to *Weingeist* and alcohol thermometers, but also occurs to a lesser extent in devices filled with mercury. As mentioned in sub-section 3.3.2.a., finding a correction for these errors is virtually impossible. The non-linearity is not only dependent on the composition of the liquid but also the shape of the glass, and the material of the scale and device itself. Finally, there is also the bias that is introduced by missing observations. Although these could be interpolated from other series, there will always remain a certain error which is expected to be bigger in the *Fön*-prone Rhine valley. In summary, there is plenty of room to improve the homogenisation of the Marschlinian temperature series presented in this section. However, any of these improvements would demand considerable effort while not being able to solve all problems inherent in the series. At this point, we will therefore end our discussion of temperature and focus on the pressure measurements instead.

[252] Cf. Moberg et al. 2002.

3.4. The Pressure Series

Only a few decades lie between the inventions of the thermometer and the barometer in the first half of the 17th century. However, measuring the pressure exerted by the atmosphere was by no means as straightforward as determining the air temperature in the late 18th century. Not only was it conceptually more challenging – getting hold of something that can neither be felt nor seen –[253] but it also required an arguably somewhat more elaborate instrument, which could not revolve around the banal concept of the thermal expansion of a liquid (or gas). Air pressure simply was not as 'useful' a climatological variable for observation, as for example was temperature. While the latter is often seen as characteristic of a time interval ("a warm month") and of great importance for agriculture, air pressure per se does not affect plant growth or the day that cattle can be sent to the Alps. Unsurprisingly, the number of early instrumental temperature series is considerably higher than that of pressure observations. Considering this scarcity of early instrumental pressure series, the data gathered by Salis-Marschlins is even the more valuable.

The steps that have to be taken to reach a homogeneous pressure series for the most part mirror those of the temperature series. During large parts of this section, we will therefore be able to proceed more quickly. There are, however, also a few additional rungs that will have to be climbed in order to build homogeneous daily and monthly averages. One of these originates from air pressure's dependence on altitude above sea level, the other from the thermal expansion of mercury, with which barometers at that time were filled. After taking a first look at the data in sub-section 3.4.1., these added difficulties will be treated individually in sub-section 3.4.2. The same sub-section will also contain the construction of daily averages. The homogenisation process can be found in sub-section 3.4.3. Sub-section 3.4.4. will be used to discuss some selected months in more detail. Finally, sub-section 3.4.5. contains potential improvements that might be considered in a future homogenisation of this pressure series.

3.4.1. First Impression and Quality Control

During the 1781-1800 period, Salis-Marschlins frequently changed locations and with that also altitudes, thereby causing multiple large breaks in the pressure series. Unlike for the temperature series, boxplots therefore cannot be used to obtain a first impression of the pressure data. Instead, the raw data should be looked at in the form of monthly mean values (cf. *Figure 3.15.*). As expected, the shifts due to moving the barometer to different locations are easy to

[253] Although the concept of temperature is also far from easy to grasp, one can 'get a feel' for the quantity itself.

spot. In the periods in which observations were taken in Zizers (early and late 1784), as well as in Chur (early 1785 and late 1785 to mid-1790), the barometers indicated values that were about 5-10 mm Hg lower than when Salis-Marschlins measured at the castle. However, there are undoubtedly some additional breakpoints to be found in this series. Most noticeably, there appears to be a major shift at the end of 1793, and an 'isolated' year of 1791. These breaks will certainly have to be further investigated in sub-section 3.4.3. It should also be pointed out that morning, afternoon and evening measurements appear to be very similar. This is not surprising, as the daily pressure cycle in the middle latitudes is only in the order of about 2 hPa (cf. *Figure 3.16.*).[254] As differences are on average this small, a daily pressure average has been accepted even where only one or two daily measurements were available.[255] More details on this can be found in sub-section 3.4.2.

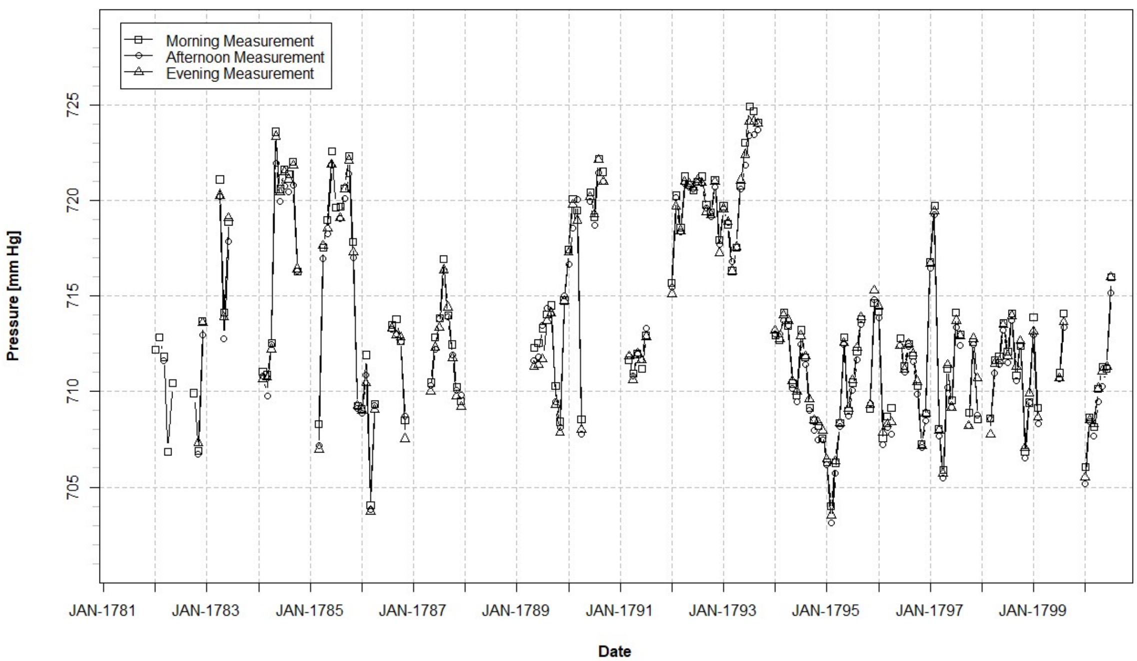

Figure 3.15.: Monthly mean values of morning, afternoon and evening pressure measurements in units of mm Hg. The measurements taken in Zizers (in 1784) and Chur (between 1785 and 1790) are clearly distinguishable, as they were performed at a different altitude. A few additional breaks are also visible.

As there are plenty of inhomogeneities during the whole series, finding outliers is rather difficult. There are certainly a few months with particularly high (e.g. February 1797) or low

[254] This of course does not mean that the pressure can only change by this amount within one day. This 'natural' daily cycle is superimposed and dominated by the dynamic variations of pressure in the atmosphere.
[255] This mainly affects 1782, as Salis-Marschlins generally only measured once or twice per day at that time.

(e.g. February 1795) values of pressure, that can be made out in the years between 1794 and 1800. For most of the other months, however, it is often unclear whether these extremes should qualify as outliers or whether they are just another inhomogeneity of the series. A discussion of extreme values will therefore only follow in sub-section 3.4.4, once the homogenisation has been completed. Nonetheless, the first few years appear to be somewhat noisier – regardless of the many breakpoints. Although a definitive answer will have to wait until after the homogenisation process, this impression is supported by a comment of Ulysses Adalbert von Salis-Marschlins, stating that the barometer in use between 1794-1807 was of good quality (compared to the others).[256]

As this many breaks and major shifts can even be seen by naked eye, quality control becomes somewhat more difficult as well. The defined maximum and minimum values as thresholds would need to be different for each segment of the series and are therefore impractical. Instead, pressure differences of more than 10 hPa between consecutive measurements have been examined. Explanations for most of these large differences could either be found in a change of observation station, or in the measurements simply being part of a general trend. Only on occasions where neither of these two situations were present – when the outlier went against the general pressure trend – have these measurements been corrected (if the transcription was wrong or an ambiguous reading in the source allowed it) or deleted. As was the case for temperature, monthly means that consist of less than ten daily averages will again not be included in the series.

3.4.2. Constructing Daily Mean Values and Eliminating Systematic Errors

The same considerations as for the temperature series come into play for the construction of daily mean values of pressure. As pressure varies by less than 2 hPa over the course of a day (not accounting for dynamic variations in the atmosphere), however, the adjustments that come with those considerations are of minor importance. Considering the other sources of error presented later in this sub-section, at least parts of these adjustments[257] could probably also be left out. Even so, as the procedure was elaborated during the homogenisation of the temperature series, only little effort is required to transfer it to the pressure series, and those corrections will be applied in the following.

[256] Cf. Meteorologische Aufzeichnungen 1784-1862, Bemerkungen zu den meteorol. Beobb. Raoul's v. S. M., StA GR, D VI MA III VII.Z.1.
[257] Namely the shift from apparent to average solar time.

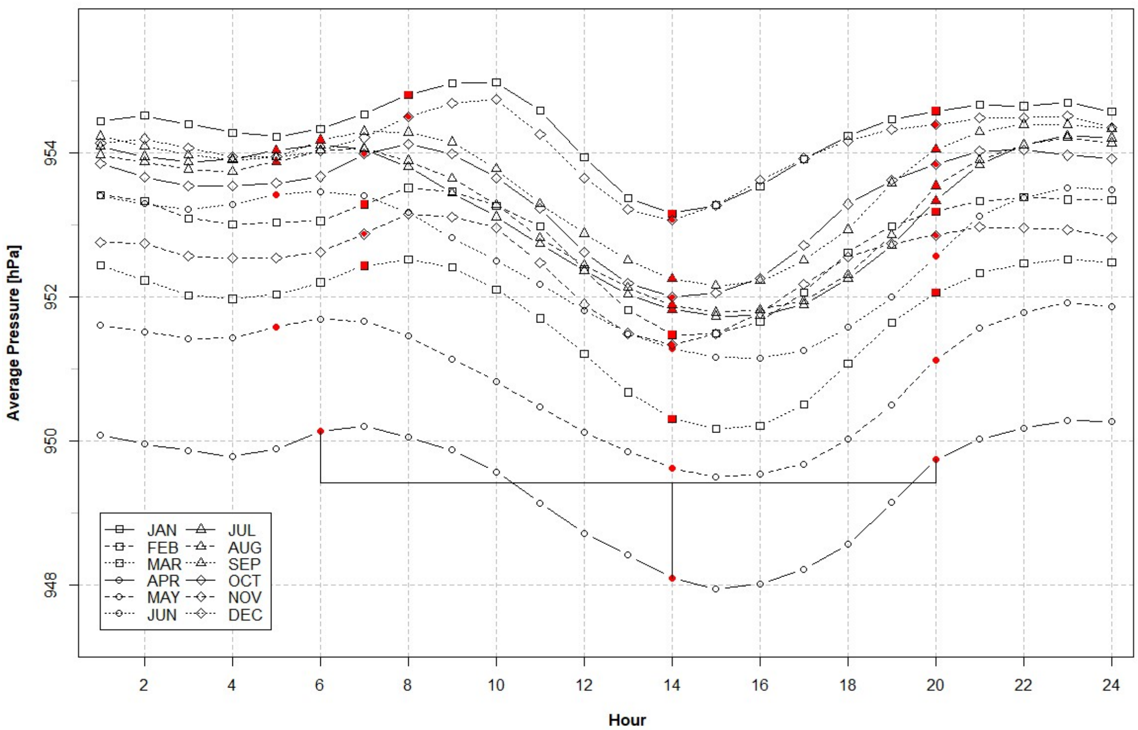

Figure 3.16.: Average daily temperature cycle in Chur (556 m a.s.l.) between January 1981 and May 2019, split by months. The red dots mark the times Salis-Marschlins usually took his measurements. The two straight black lines indicate the mean daily average for April. The data for this graph is from the data platform of MeteoSchweiz.[258]

First, the recorded times of measurement need to be corrected for the change from apparent to average solar time. As the hourly rates of change are about 0.5 hPa at maximum, this only involves minor adjustments. Next, the available three daily measurements are to be combined so that they best represent the daily average pressure. As the measurement times have been set with the goal of capturing three characteristic temperature values, they are not quite as optimally distributed throughout the day (cf. *Figure 3.16.*). By simply averaging over the three daily measurements, however, a reasonably good approximation of the daily average can be found. In a final step, the expected error that has thereby been committed can be accounted for by applying correction factors that take the time of the measurement and the month they were taken in into consideration.

So far, the pressure data appears to be far easier to handle than that for the temperature series. The exact timing of the measurements plays only a minor role, and the barometer

[258] Cf. Bundesamt für Meteorologie und Klimatologie MeteoSchweiz 2019.

placement is also not expected to be of major concern, but although temporal and spatial resolution are only of little importance to a pressure measurement, there are several other potential sources of error which can distort the reading of a mercury barometer. While some of these are relatively obvious, such as the altitude dependence of pressure, whose effect has already been noted in sub-section 3.4.1., others are peculiarities of mercury barometers or only certain types of mercury barometers. In the following four units, those sources of error will briefly be addressed individually, before combining the gained insights in the form of *Equation 3.4.*

3.4.2.a. Cistern Barometers

At the end of the 18th century, observers could choose from a large variety of barometers, all of which had their own advantages and shortcomings. Probably the most commonly used barometer at that time was the fixed-cistern barometer.[259] This type of barometer is based around the same principle as the original Torricelli experiment. The cistern houses the mercury, onto which the atmosphere exerts pressure. This pressure controls the mercury's level within a thin vertical glass capillary in which a vacuum has been created beforehand and which is immersed in the mercury at the bottom end. However, contrary to the newer design of Fortin,[260] the level of the mercury in the cistern could not be controlled. Consequently, an increase in atmospheric pressure, and thereby an increase in the level of mercury in the tube, always brought a decrease in the cistern's mercury level (and vice versa). This increases the hydrostatic pressure of the mercury in the tube while simultaneously lowering the opposing pressure by the mercury in the cistern. Clearly, this introduces a linear error[261] as atmospheric pressure changes in both directions are dampened. This error can be reduced by either increasing the diameter of the cistern or decreasing the diameter of the tube.[262] The scope of these improvements is limited, however, as a bigger cistern quickly adds to a barometer's size and weight, thereby lowering its portability. Moreover, a larger cistern also drastically increases the price of the instrument, as additional costly mercury will be required. The glass pipe, on the other hand, could only be fabricated so thinly.[263]

In addition to this strong dependence on the individual components and the calibration of the barometer, there is yet another difficulty involved in the correction for this effect. As the

[259] Cf. Brugnara et al. 2015: 1031-1032.
[260] Cf. Middleton 1964: 211.
[261] That is, when using a linear scale.
[262] The exact corrections for this error depend not only on the diameters of the tube and the cistern as well as the current air pressure, but also on the calibration of the instrument.
[263] Additionally, the smaller the bore, the higher the capillary depression will be, adding to another source of error. Furthermore, overly small diameters might cause a separation of the mercury column.

existence of this problem was well known by the end of the 18th century,[264] there is the possibility that the data or the device itself had already been adjusted by the observer. Although such adjustments were probably the exception rather than the rule, certain barometers did provide means of corrections that could be put to use by a skilled observer.[265] So, if we want to correct the data for compensating this dampening effect, not only do we need a detailed description of the barometer used, but also of the measurement process.[266] Unfortunately, the available sources are as indifferent about the type of barometer of Salis-Marschlins as they were for his thermometers – the instruments were of the "common kind" – meaning that correcting for this (potential) error is not possible.[267] However, estimations show that even in the worst case (i.e. extreme high- or low-pressure situations), errors are unlikely to be larger than 1 hPa.[268]

3.4.2.b. Correction for Height Differences

During the first decade of his meteorological observations, Salis-Marschlins gathered data from three different locations: Marschlins Castle, an unknown place in Zizers, and the *Oberer Spaniöl* in Chur. As the reading of a column of mercury is strongly dependent on the altitude at which the measurement was taken, the Marschlinian pressure series in its raw form contains several obvious breakpoints, as a brief glance at *Figure 3.15.* will confirm. One of the first steps towards a more homogenous pressure series therefore consists of correcting for these different station heights by reducing the data gathered in Zizers and Chur to the altitude of Marschlins. For this, *Equation 3.3.* was used:

$$p_h = p_{h+\Delta h} \cdot e^{\frac{M \cdot g_m}{R \cdot \bar{T}} \cdot \Delta h}. \qquad (\textit{Equation 3.3.})$$

Here, p_h is the atmospheric pressure at height h, which can be obtained by reducing the pressure measurement $p_{h+\Delta h}$, that was gathered at a height $h + \Delta h$. For that, the molecular mass of air $M = 0.02896\ {}^{kg}/_{mol}$, the local gravity $g_m = 9.80502\ {}^{m}/_{s^2}$,[269] the gas constant $R = 8.3145\ {}^{J}/_{K \cdot mol}$, the average temperature $\bar{T}$ of the fictious air column of height Δh, and the

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264 Cf. Middleton 1964: 203-210.
265 Possibilities ranged from pouring additional mercury to movable scales. Cf. ibid.: 203.
266 Or preferably direct access to the original instrument, as was possible for the reconstruction of the pressure series in Stockholm. Cf. Moberg et al. 2002: 194-195.
267 To be precise, Salis-Seewis does describe the barometers in somewhat more detail, as he states that they all had a narrow container. This might indicate that the cisterns were of rather small diameter and the caused error thus somewhat larger. Still, as the information is rather ambiguous and non-quantitative, adjustments cannot reasonably be drawn from it. Cf. Salis-Seewis 1811: 194.
268 Cf. Moberg et al. 2002: 194-195; Brugnara et al. 2015: 1033.
269 The value chosen for Marschlins has been measured in Igis, in about 800 meters distance to the castle. Cf. Klingele, Oliver, Kahle 1980: 89.

difference in altitude Δh itself, will be required. As all three locations are close together, the measured station temperature suffices as an approximation for $\bar{T}$.[270] So, all that is required are the station's altitudes. Unfortunately, as none of these buildings are used for meteorological observations anymore, their height above sea level will have to be estimated from hypsometric maps.

Using such a hypsometric map,[271] the courtyard of Marschlins Castle could be estimated as at about 534 m a.s.l., while the *Oberer Spaniöl* was found to be at about 606 m a.s.l. In addition to these measured ground altitudes, further metadata information is required about where exactly in the building the barometer was placed. We can once again rely on the note of Ulysses Adalbert von Salis-Marschlins for this, where the floor or the exact room his uncle used for measurements was recorded for each location. The first floor of the Marschlinian castle, located 18 Paris feet[272] above the courtyard, could be set to an altitude of 540 m a.s.l. This is the usual floor on which Salis-Marschlins measured when staying at the castle and will therefore be the altitude to which the other data will be reduced. The second floor of the castle, where the barometer was placed from January 1794 to July 1798, stands 30 to 32 Paris feet or about 10 m above the courtyard. An altitude of 544 m a.s.l. was therefore decided on for this location. When Salis-Marschlins did not reside in Marschlins, he mostly lived in the *Oberer Spaniöl* in Chur. Here, the barometer was placed on the first floor. Unfortunately, the metadata does not contain any information about the height of this floor, and it therefore had to be estimated from outdoor photographs to about 4 m above ground, leaving the barometer at an altitude of about 610 m a.s.l. for this location.

When trying to correct the remaining periods of February to early April and October 1784, during which measurements were performed in Zizers, we encounter a difficulty: the exact location of these measurements is unknown. Neither the diaries nor the additional sources give any detail about the house in which the observer stayed.[273] As Zizers is all but flat, the building in which observations took place was probably located anywhere between about 530-600 m a.s.l. This poses quite a severe problem, as pressure was only observed in Zizers for little more than three months. A comparison of means with the data gathered in Marschlins or Chur thus cannot be used to reliably narrow down the altitude. We therefore have to resort to a reported

[270] This also means that only pressure measurements for which simultaneous temperature values were recorded remain part of the series.
[271] Cf. Bundesamt für Landestopografie swisstopo 2019.
[272] One Paris foot measures about 32.47 cm. Cf. Trapp, Wallerus 2006: 249.
[273] As was stated in Chapter 2, we do not even know for sure who performed said observations.

comment of Johann Georg Amstein, according to whom the barometer indicated about a Paris inch less in Zizers than in Marschlins.[274] This corresponds to about 25 m. Assuming that measurements for this comparison in Marschlins were taken on the castle's first floor, this corresponds to an approximate height of 565 m a.s.l. As this roughly matches the altitude at which the house of Amstein is located, it appears very likely that the measurements during that period were indeed performed by him and not by Salis-Marschlins.

3.4.2.c. Correction for Temperature Dependence

When exposed to an increase in temperature, mercury – as almost every other material – will slightly expand, as the individual atoms move faster and thereby take up more space. While this behaviour is looked after in, and essentially enables, the liquid-in-glass-thermometer, it poses a major problem for mercury barometers. Although mercury has a rather small thermal expansion coefficient, errors can quite easily amount to 5 hPa. If possible, mercury barometers were therefore kept in a room with a constant temperature, especially if the barometer did not have a correction thermometer attached to it. Unfortunately, the diaries do not contain any information on the temperature of the barometer room (nor which room that actually was). We learn from Salis-Seewis, however, that at least the instrument in use between 1794 and 1807 had been placed in a room that was heated during winter.[275] During summer, the temperature was probably driven by the outdoor temperature, so that a constant temperature of 15 °Ré (18.75 °C), as assumed by Salis-Seewis, is certainly quite a drastic simplification. Nonetheless, temperature variations in this room can be expected to not over- or under-shoot that value by much, as outdoor temperatures should have been somewhat dampened.

When comparing the Marschlinian pressure data to the series of Vienna,[276] however, a seasonal pattern can be observed (cf. *Figure 3.17.*). While summer months generally show positive values (higher pressure in Marschlins than in Vienna), winter months are usually below zero. This clearly suggests that there is quite a strong temperature dependence inherent in this series, which cannot be explained by a few degrees of temperature variations that occur in a room with

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[274] Cf. Meteorologische Aufzeichnungen 1784-1862, Bemerkungen zu den meteorol. Beobb. Raoul's v. S. M., StA GR, D VI MA III VII.Z.1. As this comment was reportedly made by "Dr Amstein", it might also have originated from Johann Rudolf Amstein, the son of Johann Georg Amstein.

[275] Cf. Salis-Seewis 1811: 195.

[276] For this comparison, the Marschlinian pressure data had to be corrected for the discussed altitude dependence and then adjusted at its three major breakpoints in September 1790, July 1791 and September 1793. These breakpoints will be discussed in more detail in sub-section 3.4.3. Next, the Marschlinian series was reduced to the altitude of Vienna according to the procedure described in sub-section 3.4.2.e. and then increased by 7.6 hPa to adjust it to today's annual pressure average (see sub-section 3.4.3. for details).

virtually constant temperature. Instead, it seems far more likely that the barometer had been placed in an unheated room.[277] The bottom graph in *Figure 3.17.*, where the 'extreme situation' of the barometer being exposed to the outside temperature is assumed, further strengthens this impression. With this correction applied, no seasonal patterns can be found any more, from at least 1794 onwards, once measurements were performed with a barometer of good quality.[278]

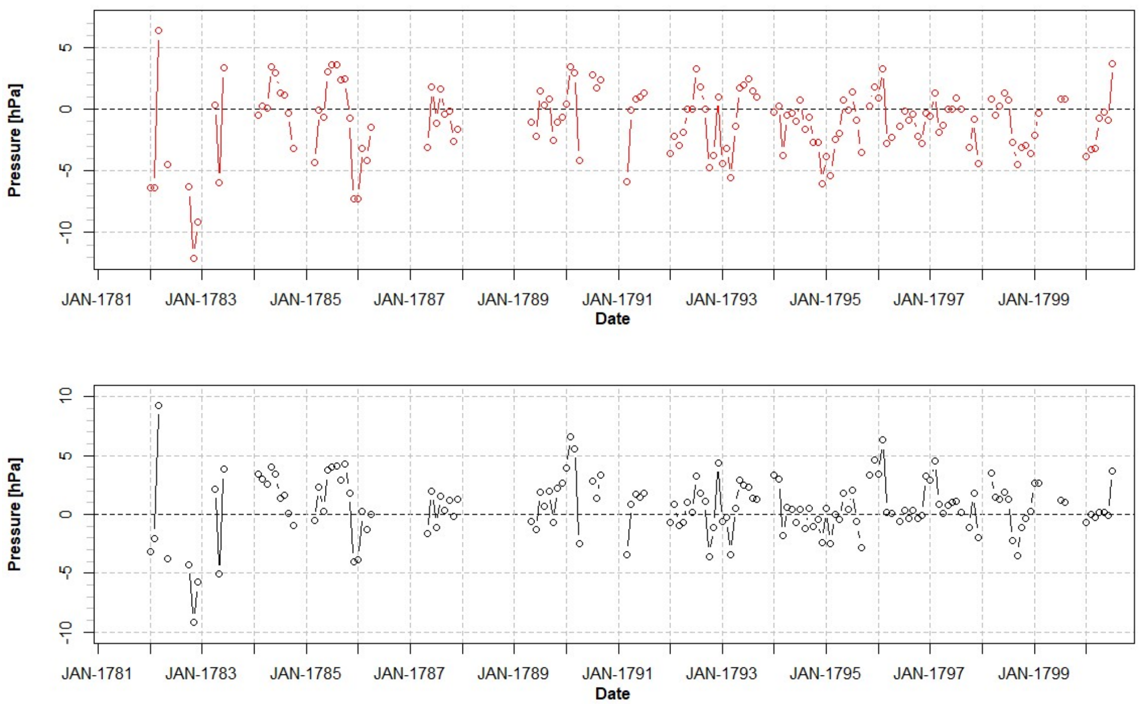

Figure 3.17.: Difference between the Marschlinian monthly pressure series (reduced to the altitude of Vienna) and the pressure series of Vienna. For the graph at the top (in red), the barometer temperature was assumed to be constant at 18.75 °C (as suggested by Salis-Seewis). In comparison, the graph at the bottom (in black) was plotted using Marschlinian outside temperatures.

Even after applying this highest possible correction factor, a clearly noticeable annual oscillation remains part of the series for most of the 1782-1793 period. There is no easy explanation for this behaviour of the pressure data (other than poor quality barometers), especially as no metadata can be consulted on this matter. Based on the nature of this temperature dependence, however, an educated guess can be made, which will be presented in the following. In the

[277] It is unclear how Salis-Seewis got the information about a heated room with a close to constant temperature of 15 °Ré. One explanation might be that this information is only valid for the years from 1802 onwards, when Salis-Marschlins moved all his instruments to the *Schlössli*, the family's residence right next to the castle.
[278] This barometer, which has been in use from 1794 to 1807, was probably the highest quality one. Cf. Meteorologische Aufzeichnungen 1784-1862, Bemerkungen zu den meteorol. Beobb. Raoul's v. S. M., StA GR, D VI MA III VII.Z.1.

late 18th century, multiple types of barometers using a secondary liquid (in combination with mercury) were known. This secondary liquid enabled considerably more precise pressure reading, as it allowed the introduction of multiple containers.[279] As this secondary liquid had to be of low density, coloured petroleum was preferably been used. However, since petroleum has a thermal expansion coefficient that is about five times higher than that of mercury, these devices were more susceptible to temperature changes than standard cistern barometers. Although this use of petroleum can explain an additional temperature dependence of barometer readings, it is clearly not a perfect solution for the behaviour found in the Marschlinian pressure series. First, it struggles to explain the apparent change in temperature dependence from year to year, and second, by adding a second liquid, we had to assume that Salis-Marschlins used a rather unusual barometer. This is in contradiction to the comment by Salis-Seewis, that Salis-Marschlins only used instruments of the "common kind". In summary, we unfortunately lack an altogether satisfactory explanation for the non-climatic pressure oscillations within the first thirteen years of the series.

3.4.2.d. Further Sources of Error

Apart from these major causes for inhomogeneities, a few additional (potential) sources of error should be mentioned at this point. The one that can be determined the most exactly is that induced by local differences in the gravitational acceleration. Depending on the latitude and some minor local effects,[280] the gravitational pull on the mercury can differ by about 0.5%. To make the data from Marschlins comparable to other pressure series, it should thus be reduced to standard gravity, which is defined at 9.80665 $m/_{s^2}$. As Marschlins is located close to the 45th degree of latitude, its local acceleration of gravity of about 9.80502 $m/_{s^2}$ is only slightly different from the defined value, and the applied correction only small.[281]

Far less clear than the effect gravity has on measurements performed with mercury barometers are the sizes of the errors that may have been caused by capillarity and friction. Both effects are stronger for thinner tubes and are therefore dependent on the components of the barometer, which are unknown for the Marschlinian instruments. Of these two potential sources of error, friction is less worrisome. The friction between the mercury and the tube, paired with

[279] For more details, see Holland, Stöhr 2012: 2.3.5.; 2.3.6.; 2.3.7.; 2.3.8.
[280] Mainly the local topography.
[281] To be exact, gravity in Zizers and Chur is expected to be different from that in Marschlins by the slightest amount. As errors caused by uncertainties regarding the altitude of the locations of observations outweigh those tiny shifts in gravity by orders of magnitude, this effect will not be corrected for.

the low rate of change of atmospheric pressure, causes the movement of the mercury column to remain incomplete. This dampening effect can easily be overcome by tapping on the tube. An experienced observer like Salis-Marschlins will have been aware of this with near certitude, so that the error caused by friction should be negligible.

The error brought about by capillarity, on the other hand, is of greater concern. As the surface tension of mercury (or rather its cohesion) is greater than the adhesive forces between the mercury and the glass tube, a capillary depression of the mercury within the glass tube will occur. For tubes with a diameter of less than 8 mm, the indicated pressure will be about 1 hPa too low.[282] As this error scales exponentially, it might have been considerably bigger or practically negligible, depending on the barometers that Salis-Marschlins was using for his measurements. As, once again, we do not have this information available, a systematic error, which is probably somewhat different for each individual instrument of the series, has to be accepted at this point.[283] In addition, the meniscus[284], as a secondary effect of capillarity, which makes determining the height of the mercury column somewhat ambiguous, might have either added to or reduced this systematic error. When adjusting the series for its breakpoints in sub-section 3.4.3., these errors will be addressed as best as they can be (without knowing their actual size).

3.4.2.e. Combining Corrections and Reduction to Sea Level

Having found the major sources of error in the previous units, the final step of this sub-section is to adjust the Marschlinian pressure data accordingly. The series should also be reduced to 0 °C and sea level, in order to allow comparison with other pressure series. To calculate the air pressure at station level p_{st} in units of hPa, include all the above discussed corrections and reduce the series to 0 °C, the following *Equation 3.4.* was used:

$$p_{st} = \rho_{Hg} \cdot g_m \cdot h_{mm\,Hg} \cdot (1 - \gamma T) \cdot 10^{-5}. \qquad (\textit{Equation 3.4.})$$

Here, $\rho_{Hg} = 13.5951 \cdot 10^3 \, {}^{kg}/_{m^3}$ is the density of mercury at 0 °C, $g_m = 9.80502 \, {}^{m}/_{s^2}$ the gravitational acceleration at Marschlins, $h_{mm\,Hg}$ the measured mercury column,

[282] Cf. Camuffo, Cocheo, Sturaro 2006: 497.
[283] Here, it is assumed that Salis-Marschlins did not adjust for this effect himself. Although correction tables existed since at least 1776 (cf. Brugnara et al. 2015: 1033), this assumption is reasonable and would explain at least parts of why the resulting Marschlinian pressure series is about 6 hPa lower than would be expected from today's climatology (cf. sub-section 3.4.3.).
[284] The surface of the mercury within the tube is curved upwards: it is the lowest where it touches the glass and reaches its highest point right in the centre of the tube.

$\gamma = 1.81 \cdot 10^{-4} K^{-1}$ the thermal expansion coefficient of mercury at 20 °C,[285] and T the temperature of the mercury in °C, which will be approximated by the measured outside temperature, as discussed above. To then reduce the resulting pressure series to sea level, a slight variation of the already discussed *Equation 3.3.* (p. 52) has been applied. As the series was reduced over a (fictional) air column of 540 m, $\overline{T}$ could no longer be approximated only by the outside temperature. A lapse rate of 0.65 °C per 100 m (as defined for the international standard atmosphere) also had to be assumed. The resulting series, which is now ready for homogenisation, can be found in *Figure 3.18.*

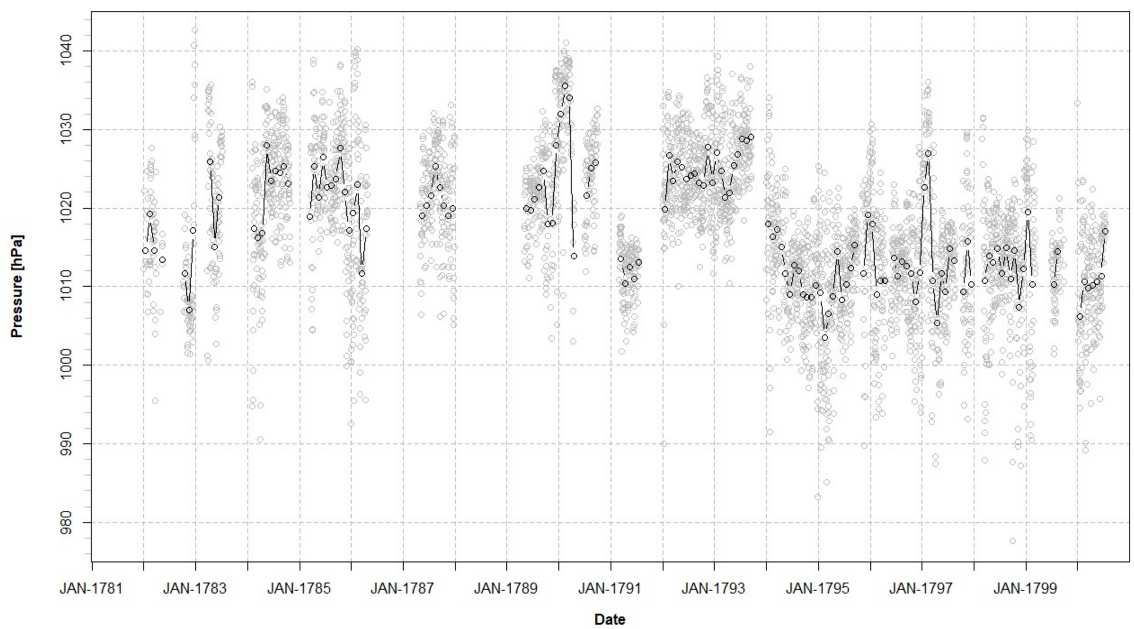

Figure 3.18.: Daily and monthly mean values of the reduced Marschlinian pressure series after adjusting the data for height differences between locations, the temperature dependence of the mercury, the local gravitational acceleration, and their time of measurement.

3.4.3. Homogenisation

Unlike temperature, air pressure is barely affected by orography and usually varies only a little on the scale of tens to a few hundreds of kilometres. A reference series may therefore also include pressure data from slightly more distant stations, but ideally should consider all

[285] Cf. Holland, Stöhr 2012: 2.5.0. As discussed above, we omit the non-linearity in the thermal expansion of mercury, as a constant factor is assumed here. Additionally, as no detailed information on the barometers is available, we also omit the thermal expansion of the instrument itself. We thereby probably overestimate the effect the temperature has on our data. However, as Bergström and Moberg show for the case of a brass scale, the thermal expansion is only slightly dampened by the extension of the barometer and its scale (the thermal expansion coefficient therein given is off by an order of magnitude). Bergström, Moberg 2002: 241.

geographic directions. The nearby pressure series of Basel, Geneva, Milan and Padua thus appears to be an obvious choice, which then needs to be complemented by a few stations from the north and east. Early instrumental pressure observations are limited, however, and while there are several pressure series from cities a few hundred kilometres to the west and south of Marschlins, the distances to the north and east are considerably longer. In fact, the closest pressure series to be found in the north of Marschlins are those from Stockholm and Uppsala. This distance proves to be too large, not only geographically, but also climatologically, as the slightly negative mean correlation coefficients show. Those two stations could therefore not be considered for the reference series. The closest station to the east, Vienna, on the other hand, has a mean correlation coefficient of a little more than 0.4 and was thus included.

The pressure series of Vienna is only slightly less correlated to Marschlins than those of Milan, Basel, and Geneva, whose mean correlation coefficients all are slightly lower than 0.5.[286] The series of Padua, as the fourth series from a nearby city, was surprisingly poorly correlated, with its mean correlation coefficient even being slightly negative. The Paduan series was therefore also excluded from our reference series, which thus only consists of the stations of Basel, Geneva, Milan, and Vienna. While winter months (excluding December) show relatively high correlation coefficients between 0.5 and 0.8 for all series, July and August are very poorly correlated to the Marschlinian series. The Vienna series even showed a negative monthly correlation coefficient for August.[287] With the help of these monthly correlation coefficients, the reference series was then calculated, using the same *Equation 3.2.* (p. 68) as for the temperature reference series.

With the reference series built, the Marschlinian candidate series can now be compared to it and thus be checked for breakpoints. Running the fifth version of the RHtests program again, four major breakpoints can be detected, all of which are significant even without metadata support (cf. *Figure 3.19.*). The first breakpoint of a little more than 6 hPa can be found around December 1782. Next, there are two shifts of about 10 hPa and 12.5 hPa in opposite directions, nearly cancelling each other out. One can be found after September 1790 and the second between July and December 1791. Finally, a large inhomogeneity of close to 12 hPa occurred between October and December 1793. In addition to these large shifts, two minor

[286] These low correlations are mainly due to the three large inhomogeneities (on the order of 10 hPa!) in the Marschlinian series in September 1790, July 1791 and September 1793. If the series is adjusted for these major shifts beforehand, the mean correlation coefficients increase drastically to about 0.8 each.
[287] When adjusting the series for its three major break points first, this turns into a positive monthly correlation coefficient of somewhat more than 0.6.

inhomogeneities can be found in May 1794 and September 1795 of about 2 hPa. The exact corrections can be found in *Table 3.3.*

Figure 3.19.: Plot of the difference between the Marschlinian pressure series and the built reference series. The breakpoints are indicated by the red dotted lines.

Out of these four major inhomogeneities, the breakpoint found after September 1793, is certainly the easiest to explain. After the barometer cracked on September 16th in 1793, Salis-Marschlins was not able to measure air pressure until the 1st of January 1794, when he obtained a replacement. On this occasion, he also decided to change rooms, and placed the new instrument on the second instead of the first floor. As the change in altitude was addressed to the best of our knowledge in sub-section 3.4.2.c., the change of instrument will have been the main cause for this breakpoint. There are multiple ways in which a change of barometer can introduce a systematic error, however, for it to bring about a shift of nearly 12 hPa, the new instrument must have been substantially different from the old one. The most likely explanation appears to be a narrowing of the barometer's capillary, causing a stronger capillary depression. As the old barometer broke three months before the new one arrived, a proper calibration of the new instrument seems not to have been possible. Apart from its poor calibration, this barometer most certainly was of considerably better quality than those in use before. When comparing the last seven years of the Marschlinian series to the reference series, significantly smaller oscillations can be found than in the period before. This observation strengthens our assumption of a more narrow capillary in the new barometer, as a smaller diameter of the glass tube also reduces the fluctuation of the zero.

Period	Adjustments for breakpoints in hPa
Jan 1782 - Dec 1782	+2.8
Mar 1783 - Sep 1790	+9.1
Mar 1791 - Jul 1791	-1.0
Jan 1792 - Sep 1793	+11.6
Jan 1794 - May 1794	-0.1
Jun 1794 - Sep 1795	-2.0
Nov 1795 - Jul 1800	0

Table 3.3.: Adjustments made to the individual segments of the Marschlinian pressure series.

The metadata unfortunately holds no explanations for the five other inhomogeneities. The two major shifts in September 1790 and July 1791 are of similar size to the one that occurred after September 1793, and thus, a change in barometer might once again be at the cause. However, breaking three barometers within such a short interval does seem rather unlikely (as well as costly). Some alternative explanations might therefore also be considered. Probably the easiest would be a change in location. As an inhomogeneity of more than 10 hPa corresponds to a change in altitude of close to 100 m, this does seem highly improbable, though. Additionally, this would be the only occasion on which Salis-Marschlins did not mention moving location. The more likely alternative is therefore an accidental displacement of the barometer scale, which was only noted several months later. While the initial displacement obviously would not have been reported in the diaries, its correction might have been made in the period of August and December 1791, for which no diaries are available. It should also be noted that the range of the pressure fluctuations in *Figure 3.19.* is similar to before and after the two inhomogeneities. Thus, a displacement of the scale might be favoured as an explanation over two consecutive changes of barometer.

The shift after December 1782 is somewhat smaller than those discussed so far. While any of the above presented options of a new device, new location, or a displacement of the scale, are also valid explanations in this case, a fourth possibility should be considered here as well. 1782 was the year Salis-Marschlins started recording both temperature and pressure. Although he might have practised the handling of the instruments beforehand, he was certainly lacking his later experience. Measuring errors might thus have occurred more frequently than in later periods. In addition, Salis-Marschlins usually only recorded one measurement per day at a non-specified point of the day and frequently also missed a measurement. Monthly means in 1782 therefore consist of significantly fewer data points than in later months. This of course increases the impact of any single, potentially faulty, measurement. Finally, the way Salis-Marschlins chose to note down large parts of his observations in January 1782 leaves considerable room for errors, as the difference between "missing value" and "same as above" remains unclear in most of the cases.[288]

Finally, there are the two minor opposite shifts in May 1794 and September 1795. Once again, no easy explanation can be found for them. It should be noted that they have a measurement gap of a few weeks in common, which took place around the time of the breakpoint: one in April 1794 and one in October 1795. However, it seems unclear how these brief interruptions could have caused inhomogeneities. A change in location and instrument can almost certainly both be ruled out, and while a minor adjustment of the scale always is a possibility, it seems odd that Salis-Marschlins would either forget to mention a deliberate correction of the scale to then undo it a year later, or that he would notice such a minor inhomogeneity if the shift has happened by accident. These two inhomogeneities will therefore have to remain unexplained.

After adjusting the data for these six breakpoints, a few additional characteristics of the Marschlinian pressure series may be noted (cf. *Figure 3.20.*). First, we can learn something about the quality of the individual barometers. For this, our attention should be drawn to the oscillations from about mid-1790 onwards; around the time Salis-Marschlins moved back to Marschlins and about three and a half years before the supposedly good barometer came into operation. These oscillations are substantially smaller than those earlier in the series. The relatively stable difference between the candidate and reference series is certainly an indication of an instrument of higher quality being in use in this period. At the same time, the range of daily averages was considerably greater from 1794 onwards than in the period between 1790 and 1793 (cf. *Figure 3.18.*, p. 93). While the daily values of the 1794-1800 period appear to be about in the expected range, those between 1790 and 1793 only varied by about 20 hPa at maximum. Such a dampening of individual measurements is a likely cause of a strong fluctuation of the zero, brought about by a cistern with too small a diameter.[289] So, in combination,

[288] Whenever this was the case, the respective measurement (which usually read the number of inches, followed by quotation marks instead of the amount of lines) was considered a missing value.
[289] The other cause of dampened measurements is friction. Since this can be overcome by simply tapping on the capillary, this option can be excluded here.

these two graphs clearly suggest that the device of 1790-1793 only captured a dampened signal of the atmospheric pressure, all the while giving a reasonably good approximation of the monthly mean value. The barometer that was in use between 1794 and 1807, on the other hand, indeed seems to have been the instrument of the highest quality.

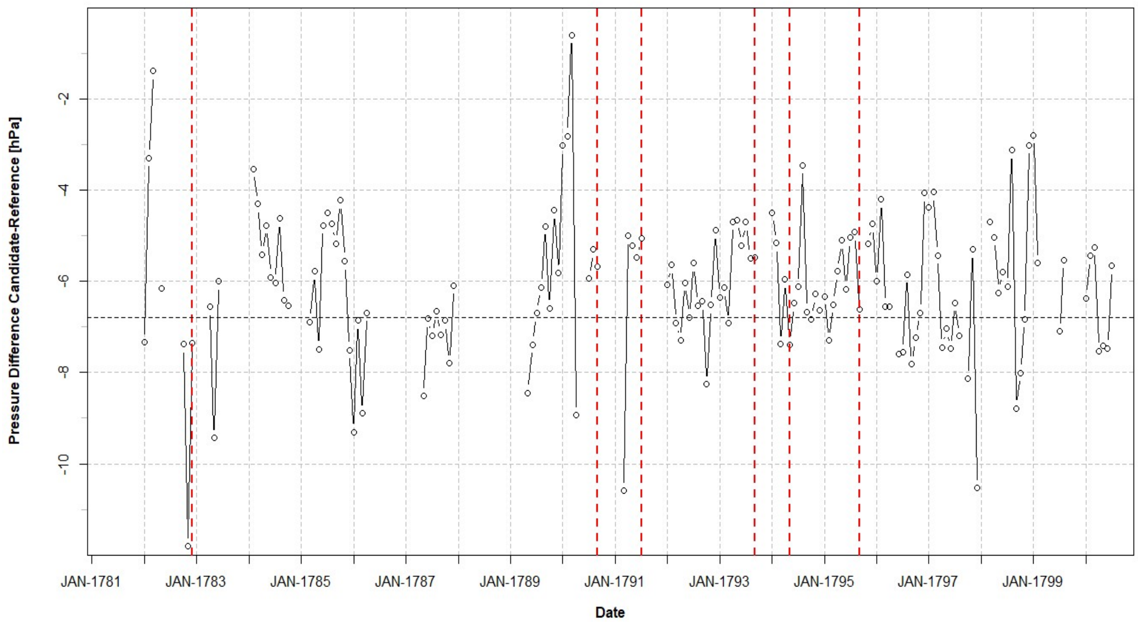

Figure 3.20.: Plot of the difference between the Marschlinian pressure series and the built reference series after applying the corrections in Table 3.3. for the detected break points (indicated by the dotted lines in red). The black dotted line represents the difference between the Marschlinian pressure series and the 1981-2018 series of Chur (both reduced to sea level).

Secondly, the trend of the resulting series should also briefly be mentioned. While the overall drift is negligible, there appears to be a negative trend within the period of 1784 to 1786. Just as for the thermometer, there are multiple potential causes for such a gradual reduction of recorded values. The evaporation of mercury[290] or a slow but unnoticed slipping of either the scale or the capillary are only two possibilities. Either of these effects certainly might have occurred in the 1784-1786 interval as well, and thereby have contributed to the negative trend. However, it is important to note that this is also the period of the most changes in measurement circumstances, and therefore also the most adjustments during the homogenisation process. These three years saw a total of five moves of observation location, and although no change of instrument has been noted in the metadata, it is anything but certain whether all measurements

[290] Cf. Maugeri et al. 2002: 144.

of this period have been recorded with the same barometer (or even by the same observer). It is therefore nearly impossible to decide whether the drift should be attributed to an actual deficiency of the barometer of that time, or whether it was brought about by the frequent inhomogeneities of this period 'by chance'. Consequently, this trend was not corrected for.

Finally, the difference between the means of the candidate and the reference series should also be addressed. As the Marschlinian series has been adjusted to its last segment, which is the period during which the barometer of highest quality was in use, its mean was also shifted accordingly. Due to these adjustments, the mean of the candidate series ended up close to 6 hPa below the mean of the reference series. When comparing this to the 1981-2018 pressure data for Chur, a similar difference of about 6.8 hPa can be found. This systematic error of the 1794-1807 barometer had already been noted by Salis-Seewis, who compared it to an "excellent London barometer" and found the Marschlinian instrument to be 1.5 Paris inches (ca. 4.5 hPa) too low.[291] As stated earlier, this error was probably caused by narrow capillary, paired with the poor calibration of an otherwise good barometer. To correct for this poor calibration, the entire Marschlinian pressure series has thus been increased by 6.8 hPa, and thereby adjusted to today's Chur series. The result of these applied corrections can be found in *Figure 3.21*.

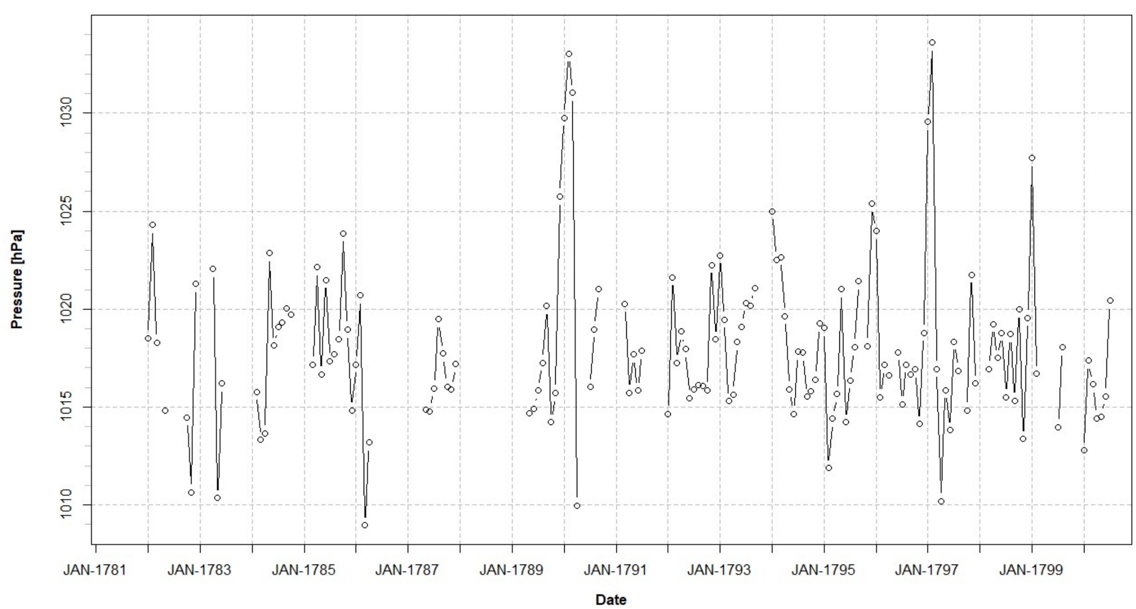

Figure 3.21.: The homogenised Marschlinian monthly mean pressure series, reduced to 0 °C and sea level.

[291] Cf. Salis-Seewis 1811: 194-195.

3.4.4. The Marschlinian Pressure Series

Having completed the homogenisation process for the Marschlinian pressure series, some of its characteristics and its outliers will be discussed in the following. Apart from the series itself (cf. *Figure 3.21.*), this will mainly be done on the basis of the boxplot of the monthly data, which can be found in *Figure 3.22*. The annual pressure cycle that can be observed in said boxplot looks fairly similar in its main features to what might be expected from today's pressure data for Chur. The Januaries are dominated by high-pressure situations, Aprils show low atmospheric pressure, thereby enabling the *Aprilwetter*, and high-pressure weather for the *Altweibersommer* can be found again during September. Undeniably, some surprising traits can also be found. The most noticeable of these are probably for January and February, surpassing the other months by several hPa. The pressure variability during the winter months, which is drastically higher than in the summer, is also striking. Even though these peculiarities can certainly be partly traced back to the low amount of data that this boxplot is based on, they may also suggest some faulty measurements.

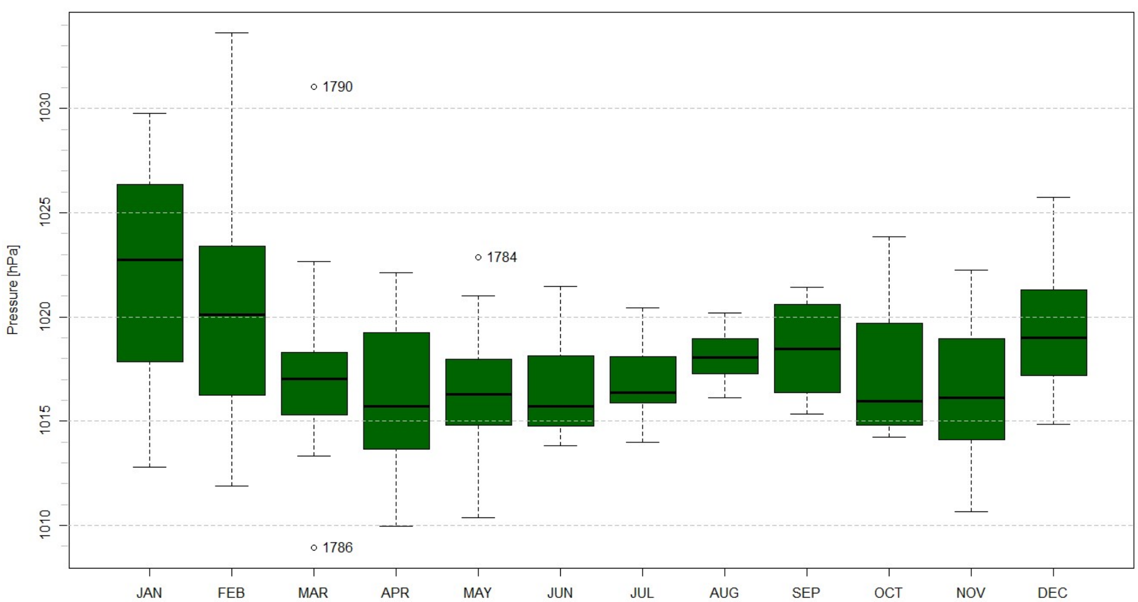

Figure 3.22: Boxplot of the homogenised Marschlinian pressure series.

When looking back at the comparison between candidate and reference series (cf. *Figure 3.20.*), this had to be expected to some degree. While the monthly mean values of about mid-1790 onwards appear quite truthful to the reference series, the large oscillations in the ten years before lead to considerable doubt about the trustworthiness of data for that period. Examination of some of the outliers in the boxplot mean that these doubts are further reinforced. For example, by far the largest outlier in March 1790 also coincides with the greatest pressure difference between the candidate and reference series of about 6 hPa. This certainly does not leave these earlier observations bare of any value – for the most part they still follow the general trends of the central European atmosphere of that time. However, when it comes to the face values of individual months, this comparison between candidate and reference series should certainly be kept in mind. In summary, the Marschlinian pressure series should only be considered reliable from mid-1790 onwards, in case of the monthly averages, and from 1794 onwards for the individual measurements.

Heeding this, some of the outliers found in the boxplot and in the graph of the homogenised pressure series itself should be looked at next. By far the biggest eye-catchers in *Figure 3.21.* are the peaks from January to March 1790 and January to February 1797, both of which are followed by a heavy drop in pressure in the month to follow. As mentioned above, the maximum in 1790 should be taken with a grain of salt, as it overshot the value suggested by the reference period by 4-6 hPa. Nonetheless, this was undeniably an anomalous period, with considerably higher atmospheric pressure than the mean. Helped by the dampening barometer that was in use at that time, no particularly high daily averages can be found. Instead, the period seemed to be characterised by stable, long-lasting high-pressure weather. As would be expected for such a situation, a surplus of sunny days was recorded during these three months. In contradiction to these statistics, however, both February and March were perceived as stormy and inconsistent by Salis-Marschlins in the respective results section.[292] The drop in pressure that followed in April 1790 cannot be pinpointed to a certain date, as no measurements were recorded for the first ten days of the month. The later days of April 1790 show constantly low atmospheric pressure, however, and the month was described overall by Salis-Marschlins as fairly inconsistent.[293]

The strong maximum in January and February 1797, on the other hand, was recorded when the high-quality barometer was in use. A first, weaker high-pressure system could be found at the end of December and persisted into the first week of January. After a brief period of comparatively low atmospheric pressure in mid-January, a strong high-pressure system was established by the 17th January and lasted nearly to the end of February. Only one brief intrusion can

[292] Cf. Meteorologische Beobachtungen, Results of February and March 1790: IMG_6401, IMG_6414.
[293] Cf. Meteorologische Beobachtungen, Results of April 1790: IMG_6428.

be found in mid-February. The highest daily averages of the entire series of more than 1040 hPa can be found during this period (except for a few not entirely trustworthy values from December 1782). Once again, a clear sky and rather low wind speeds are recorded for most of these first two months of 1797. Contrary to the pressure maximum in 1790, at least January 1797 was also perceived as an exceptionally sunny and dry period.[294] In contrast, April 1797 was dominated by low-pressures systems and thus unsurprisingly described as a month with very labile, capricious weather.[295]

3.4.5. Improvements for Future Homogenisations

The first thirteen years of the homogenised Marschlinian pressure series suffer from considerable uncertainties and probably also errors. As will have become evident by now, these problems mainly originated from the poor quality of the barometers that Salis-Marschlins used during this period. As the sources lack any exact description of the instruments in use, finding appropriate adjustments for the pressure data of these early years is very difficult. Whether the series should be considered representative of the 'reality' for the period of 1782-1793 is thus questionable. Regardless of this major weakness in the Marschlinian pressure series, however, several other improvements to the data could be made, as multiple minor causes of errors have been neglected during the homogenisation process. In conclusion to this section on the Marschlinian atmospheric pressure, some of these additional corrections will be presented and their potential for improving the series evaluated.

When removing the temperature dependence in sub-section 3.4.2.c., several simplifications had to be made. The neglect of the thermal expansion of the barometer and the scale itself, and the non-linearity of the dilatation of mercury have already briefly been addressed in the respective sub-section and found of minor importance. At this point of the homogenisation, yet another source of error was introduced, however. As the barometers were missing a correction thermometer, the mercury temperature was assumed to always correspond to the temperature simultaneously measured outside. As the barometer was kept inside a room, actual mercury temperatures were probably somewhat dampened in amplitude and delayed in time compared to the outside temperature. Thus, a low-pass filtered outdoor temperature cycle would quite certainly be a more accurate input for the temperature corrections than the outside temperatures used in this homogenisation. This has, for example, been demonstrated by Moberg et al. for the

[294] Cf. Meteorologische Beobachtungen, Results of January 1797: IMG_7779.
[295] Cf. Meteorologische Beobachtungen, Results of April 1797: IMG_7816.

Stockholm series.[296] Assuming that inside temperatures might have been dampened by about 5 °C at times compared to outside values, an error of ca. 1 hPa could be introduced by using outside temperatures instead. However, as no barometer temperatures nor any other temperature measurements within the barometer room are available at any time during the 1781-1800 period, the coefficients of such a low-pass filter cannot be determined exactly. An appropriate adaptation of the temperature correction factor is therefore not possible. This might change for later parts of the series, as observations may then include barometer temperatures. This can certainly be expected for the barometers used by Ulysses Adalbert von Salis-Marschlins towards the end of the 19th century. Even so, as the measurement chamber was moved from the castle to the *Schlössli* in 1802, exact coefficients remain unobtainable for the period from 1781 to 1800.

A final cause of error, which has so far been disregarded and should therefore briefly be mentioned here, are the alterations that the scale of an instrument – be it a barometer or thermometer – might undergo. These scales were generally made from wood, to which the glass tube was attached. This meant that the scale's length was slightly variable, not only depending on the temperature but mainly also on the wood's moisture content. The scale was therefore affected by the humidity content of the air. As relative humidity could not yet be measured in the late 18th century, approximations for corrections of this effect would have to be drawn from either the weather data of that period or from today's relative humidity measurements. Moreover, the correction factor is dependent on the length of the scale and the type and age of wood, all of which is unknown for the instruments of Salis-Marschlins. Luckily, these variations in scale length are usually only small and the error caused for a pressure or temperature reading thus mostly negligible.[297] In consideration of all these points, no corrections for this effect have been applied to the Marschlinian data.

[296] Cf. Moberg et al. 2002: 196.
[297] For example, Moberg et al. 2002: 193-194 found a maximum error of about 0.4 hPa for the Stockholm pressure series. On the other hand, when estimating the effects on a temperature scale of 1 m length, Camuffo 2002a: 318-320 calculated a potential error of 0.5 °C.

4. Phenological Observations

Between 1781 and 1800, Salis-Marschlins changed the title of his diaries quite frequently. Within the first 31 volumes, he went from 'economic and physical remarks' in 1781, to 'meteorological and economic remarks' in 1785, before settling on 'meteorological, physical and economical observations' in 1789 for the rest of this twenty-year period. Only later did he add the term 'botanical' to describe his records. This is clearly disproportional to what can actually be found within these diaries.[298] Over the course of this period, Salis-Marschlins described more than 900 different plant and animal species in well over 4,000 individual observations. To these, he had added a considerable number of observations on abiotic phenological phases. Admittedly, the frequent gaps in recording and the low consistency in observed phases mean that large parts of this 'multi-phases collection by a single observer' remain but 'fragmentary observations'.[299] On their own, most of the 1781-1800 observations thus cannot fulfil Pfister's requirements for a 'sufficiently long series'.[300] Nonetheless, the phenological observations of Salis-Marschlins are undoubtedly a central part of the Marschlinian diaries, which deserve a closer look.

4.1. Historical Phenology

In contrast to today's phenological data gathered by networks,[301] historical phenological observations are characterised by their high degree of subjectivity.[302] As these historical observations were not coordinated by an external institution, it was the observer themselves who defined which phenological phases they would observe and how exactly they should be defined. Over time and with more experience in observation, these definitions of phenological phases often changed. When working with early phenological data, we are therefore dependent on the

[298] On the other hand, it could be also somewhat telling of the purpose behind at least the first few diaries. It was the hope to gain insight into how weather and climate affected plant growth and yields, which then may be of use to improve certain agricultural tasks and to be more *economic*, which may have brought Salis-Marschlins to start his observations in the first place. Then again, the change in terminology of the word *ökonomisch* should also be kept in mind, which in the 18th century could also be used to describe agricultural activities. Cf. Adelung 1798: 604.
[299] Cf. Rutishauser 2007: 7, Figure 1.2.
[300] For that, Pfister suggests at least fifteen observations of the same phenological phase. Cf. Pfister 1988: 81, footnote 62. In combination with the later observations of Salis-Marschlins, this number can certainly be realised for a reasonable number of phenological phases.
[301] In Switzerland, for example, MeteoSchweiz operates a phenological observation network of 160 stations. In total, 69 phenological phases of 26 different species are being observed. The observation form as well as an observation guide ensure a relatively strict definition of phases. Cf. Bundesamt für Meteorologie und Klimatologie MeteoSchweiz 2018.
[302] Cf. Jeanneret, Rutishauser, Brügger 2011: 49.

observer to properly describe their definition of the observed phenological phases. Unfortunately, this was not always done by early phenologists, including Salis-Marschlins.[303] This lack of definitions raises another quality issue for the Marschlinian phenological records, although it might be somewhat less concerning than the reservations regarding the frequent use of undetailed lists and the at times equivocal nomenclature for phenological phases.[304] Nonetheless, these unclear characterisations of phenological phases may introduce a systematic error, that, if Salis-Marschlins adjusted his definitions of phenological phases, could furthermore be variable in time. Luckily, not all observed phenological phases lack such descriptions by far. For example, Salis-Marschlins differentiates between multiple stages of foliation ('buds visible', 'opening of buds', 'leaf sprouting', 'has leaves') or leaf fall ('starts to lose leaves', 'heavy leaf fall', 'bare of leaves'). Other phases, including the beginning and end of flowering and the start of full flowering and leaf colouring, are quite well defined, so that only small errors are to be expected. Finally, when comparing the Marschlinian data to other series, changes in the observed phase can at least partially also be noted and corrected for, as will be shown in the upcoming Section 4.2.

A few additional minor restrictions to the Marschlinian phenological records should also be mentioned here. These are mainly related to Salis-Marschlins not giving very detailed descriptions of the location at which he made his observations. Without doubt, most of the recorded data is from around the castle, where a pleasure garden, two arboreta, multiple vegetable patches and crop fields made for the perfect environment. However, the castle estate was quite large: one arboretum contained approximately 1,000 trees,[305] and the castle's vineyard measured 1942 *Quadratklafter,*[306] or about 1 ha[307]. Considering the surrounding topography, elevation and sunshine exposition probably varied considerably, depending on the exact whereabouts in the castle ground. While Salis-Marschlins did make a note whenever a phenological record concerned vegetation from outside the estate, the usual observation from within the castle grounds did not specify location. Similarly problematic is the time Salis-Marschlins spent in Chur, as the garden of the *Oberer Spaniöl* was probably rather small, leaving many observations with a somewhat uncertain location tag. Finally, for observations on tree species, there is

[303] Thus, as these descriptions are partly missing, the Marschlinian diaries do not perfectly fulfil Pfister's definition.
[304] Cf. Section 2.3.2.
[305] Cf. Meteorologische Beobachtungen, May 8th, 1797: IMG_7821.
[306] Cf. Meteorologische Beobachtungen, April 23rd, 1784: IMG_5572.
[307] Cf. Fümm 1948: 231.

uncertainty about whether it was always the same tree or even the same kind of tree[308] that was observed, which may potentially add yet another small error. No easy go-to solution can be given here for any of these reservations. Each series and each individual phenological phase is affected slightly differently and will thus require its own corrections. Therefore, a thorough metadata analysis is necessary for any use of phenological data, as will be shown in the following.

4.2. Cherry Blossom, Vine Blossom, and Grape Harvest Dates

The time of blossom for both *prunus avium* and *vitis vinifera*, and the grape harvest dates have already looked into by Röllin, who in his proseminar thesis furthermore presents plots for the blossom of *tilia* (*platyphyllos*?) and *cornus mas*.[309] As he used extracts from all fifty diaries, Röllin was able to build a series of close to forty years, twenty years more than can be produced by this study. Despite this setback in series length, the 1781-1800 observation of these three phenological phases have been examined again in this study and will be discussed in the following. This might seem redundant at first, however, a re-evaluation of even shorter versions of these series is indeed worthwhile; not only because of their key role in the historical phenology of Switzerland,[310] but also because such a revision can illustrate some of the above-mentioned problems of the Marschlinian phenological records.

Figure 4.1. shows the dates of full flowering for *prunus avium*, one of the most complete phenological records in the Marschlinian diaries. The observations of Salis-Marschlins are in relatively good accordance with the series of Zurich and Glarus, reassuring us that in fact the same phenological phase has been observed at all three places, at least for the most part. Nonetheless, there are a few years where the Marschlinian series diverges from the other two. This is most obvious in 1796, when the observation of full flowering is missing and had to be replaced by the beginning of flowering. A different cause underlies the offset in 1790. In this year, Salis-Marschlins noted three observations of the blossoming of cherry. A first note can be found in the diary entry of April 15th, stating that the cherry trees were blossoming.[311] On April 22nd, the entry reads that the cherry trees are flowering in Marschlins as well – Salis-Marschlins

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[308] This is mainly a problem for fruit and especially apple and pear trees, as a large variety were grown and observed in and around the castle.
[309] Cf. Röllin 1974: 14-16, Tables 1, 3-6, 15.
[310] For the blossom of prunus avium, a continuous series back to 1721 has been homogenised by Rutishauser (cf. Rutishauser 2007: 45-46). For the grape harvest, the series goes back even further, to 1480. Cf. Rutishauser 2007: 87-98. For the flowering of *vitis vinifera*, a wide spectrum of historical data is available. Cf. Pfister 1988: 85-86.
[311] Cf. Meteorologische Beobachtungen, April 15th, 1790: IMG_6421.

at that time was still moving between the *Oberer Spaniöl* and the castle.[312] Finally, on April 27th, Salis-Marschlins reported that the cherry trees were relatively fully flowering in Marschlins.[313] This is thus the date that has been plotted in *Figure 4.1.* Contrary to this study, however, Röllin used the 15th of April as the date of full flowering,[314] which is probably an observation that was made in Chur and should therefore be rejected. However, judging from the comparison with the series of Zurich and Glarus, the 27th of April chosen here also appears to be erroneous. Instead, the observation of the 22nd of April looks like the 'correct' data point. This clearly demonstrates one of the weaknesses of the Marschlinian phenological records, since only studying the text suggests that all three (or at least two) dates were valid options. Although such extensive insight cannot be provided for 1782 and 1786, the reason behind the offset of these two phenological observations can probably be traced back to a similar problem.

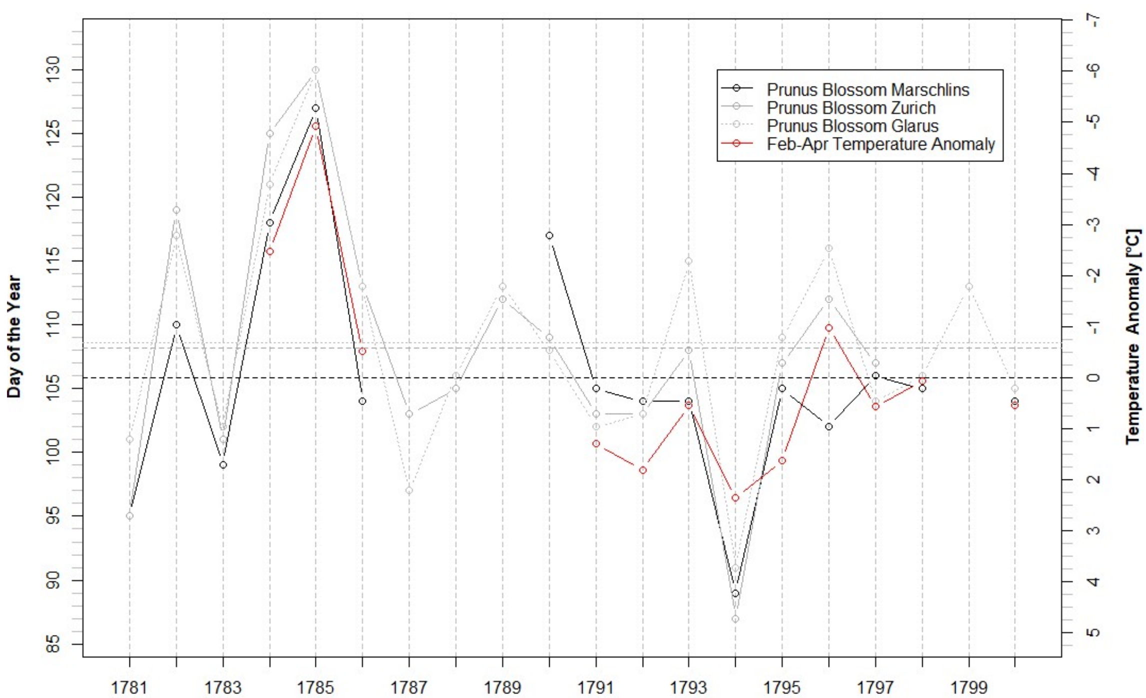

Figure 4.1.: Twenty-year series of full flowering of prunus avium in Marschlins, Zurich[315] *(*$r = 0.89$*) and Glarus*[316] *(*$r = 0.81$*). The dotted lines indicate the twenty-year average. On the other axis, the February to April temperature anomalies for Marschlins have been plotted (*$r = -0.87$ *with the flowering dates of Marschlins).*

[312] Cf. Meteorologische Beobachtungen, April 22nd, 1790: IMG_6422.
[313] Cf. Meteorologische Beobachtungen, April 27th, 1790: IMG_6423.
[314] Cf. Röllin 1974: Table 1.
[315] Cf. Schwender 1856: 41.
[316] Cf. Heer, Blumer-Heer 1846: 108.

Following Rutishauser,[317] the temperature of the period that proceeds the flowering of *prunus avium* is the most important driver for the timing of this phenological phase. *Figure 4.1.* nicely illustrates this close correlation ($r = -0.87$) of the date of flowering and the local February to April mean temperatures. The latter were only plotted when at least two out of three values were available from the reconstruction in Section 3.3. Where one monthly average was missing, the 1781-1800 mean was used for that month instead. As stated, the overall correlation is very high, such as the cold spell in 1785 that was transferred almost perfectly to this phenological phase. Two years somewhat disrupt the picture, however. The rather poor correlation in 1794, when vegetation was extremely early, can be traced back to the average April temperature of that year,[318] which did not play a role in the date of full flowering (as the phase had already been reached on March 30th), but which still affected the temperature curve. In 1796, on the other hand, the divergence can be explained by the already mentioned replacement of the date of full flowering with the somewhat earlier observation of the start of flowering.

The flowering of *vitis vinifera* and the grape harvest dates are two of the most important phenological phases in historical phenology, thanks to their long observation tradition.[319] Although they are not amongst the most frequently observed phenological phases in the case of the Marschlinian diaries, with only thirteen, and eleven, data points within the 1781-1800 period, respectively, they still deserve a brief examination. Before plotting the data, we should briefly spare a thought on the probable location of these observations. Being a family of power, the von Salis-Marschlins owned multiple vineyards, which were distributed all about Maienfeld, Malans, Igis, Zizers, and Chur. All in all, at least ten different vineyards were in possession of the family over the course of these twenty years.[320] While Salis-Marschlins clearly distinguished between these vineyards when noting the dates and yields of their grape harvests, he rarely named the location where he observed the vine blossom. The vineyard of the Marschlinian castle, as the closest vineyard to his domicile, will thus be the best guess, at least for the years he stayed in Marschlins. This vineyard was located on the slope right next to the castle (cf. *Figure 2.1.*, p. 26). As Salis-Marschlins on the other hand did state when a tree or vine was

[317] Cf. Rutishauser 2007: 46.
[318] As too few temperature measurements had been gathered to make a reasonable estimation on the monthly mean, the 1781-1800 April average temperature was assumed here.
[319] This is mainly thanks to the high lucrativeness of viticulture.
[320] Namely the *Schlossweingarten* in Marschlins, the *Bild*-, *Haag*-, *Rangs*- and *Rüfiweingarten* as well as the *Pfaffengut* in Igis and Zizers, as well as three unnamed vineyards, one of each in Maienfeld, Malans and Chur. Additionally, Salis-Marschlins also mentioned the *Bockweingarten*, which could not be allocated.

planted on an espalier, distortion due to such a favourable positioning of the grapevine can be ruled out in most cases.[321]

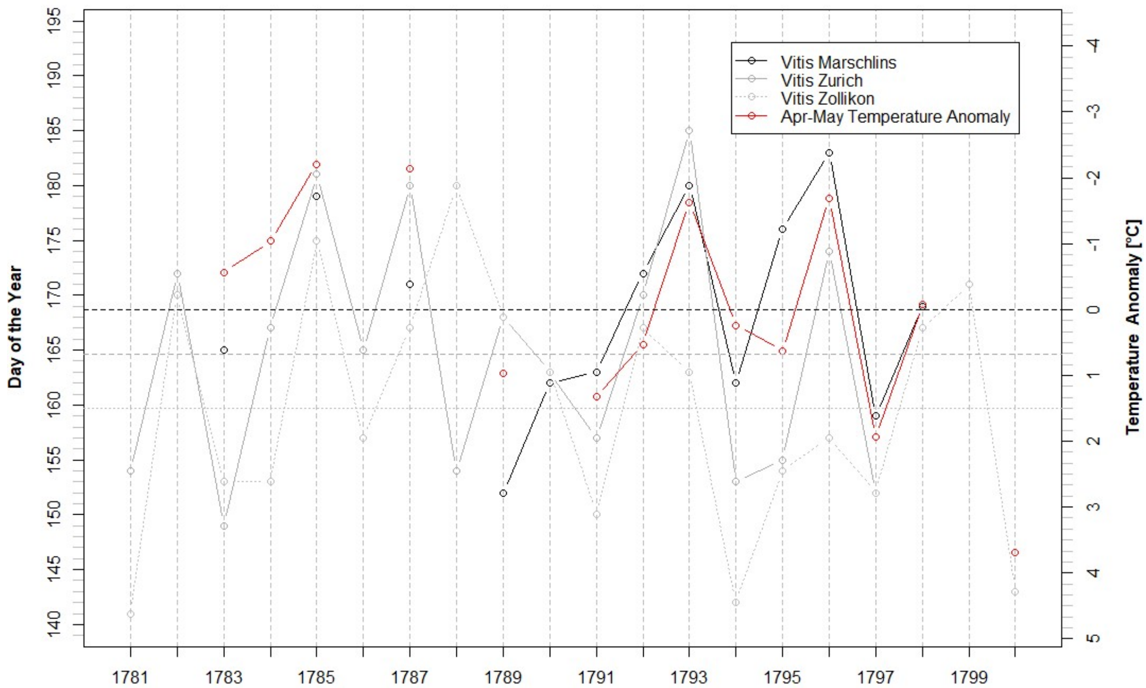

Figure 4.2.: Twenty-year series of the flowering of vitis vinifera in Marschlins, Zurich[322] *(*$r = 0.58$*), and Zollikon*[323] *(*$r = 0.26$*). The dotted lines indicate the twenty-year average. On the other axis, the April to May temperature anomalies for Marschlins have been plotted (*$r = -0.72$ *with the flowering dates of Marschlins).*

A plot of the recorded flowering dates of *vitis vinifera* can be found in *Figure 4.2.*, where they were put next to the series of Zurich and Zollikon. The correlations between the Marschlinian vine blossom series and these two stations are quite poor, especially in the case of Zollikon. The causes of some of these discrepancies can indeed be found in the Marschlinian series. The offset in 1789, for example, can quite certainly be explained by Salis-Marschlins only recording the flowering date of the 'early' vines. This appears to have been the case in 1786 to 1789, at least, during which Salis-Marschlins lived in Chur.[324] The seemingly late flowering in 1795, on the other hand, should probably be corrected by about ten days, as only the full

[321] There are years in which Salis-Marschlins also noted the flowering dates of espalier vines. In fact, this is the only available observation in 1785, leading to a data point that is probably about ten days too early.
[322] Cf. Schwender 1856: 41.
[323] Cf. Koller 1879.
[324] Since only two data points were recorded during this period, it is not possible to reasonably define a correction factor for the differences in elevation, sunshine duration, etc. of these two stations.

flowering had been noted down this year. Other divergences, like that of 1783, are difficult to explain. The reason behind the offset in this year and the generally low level of agreement between these three series is to be found in a combination of multiple factors. Apart from the already mentioned difference in the recorded phenological phase, a variety of environmental parameters such as soil fertility and differences in viniculture[325], the orientation and steepness of the slopes and the kind of vine might all have played a role in this. Of course, the difference in the climatology of these three locations may also be taken as a small part of the explanation. For *vitis vinifera*, it is mainly April and May temperatures that determine the date of flowering ($r = -0.72$).

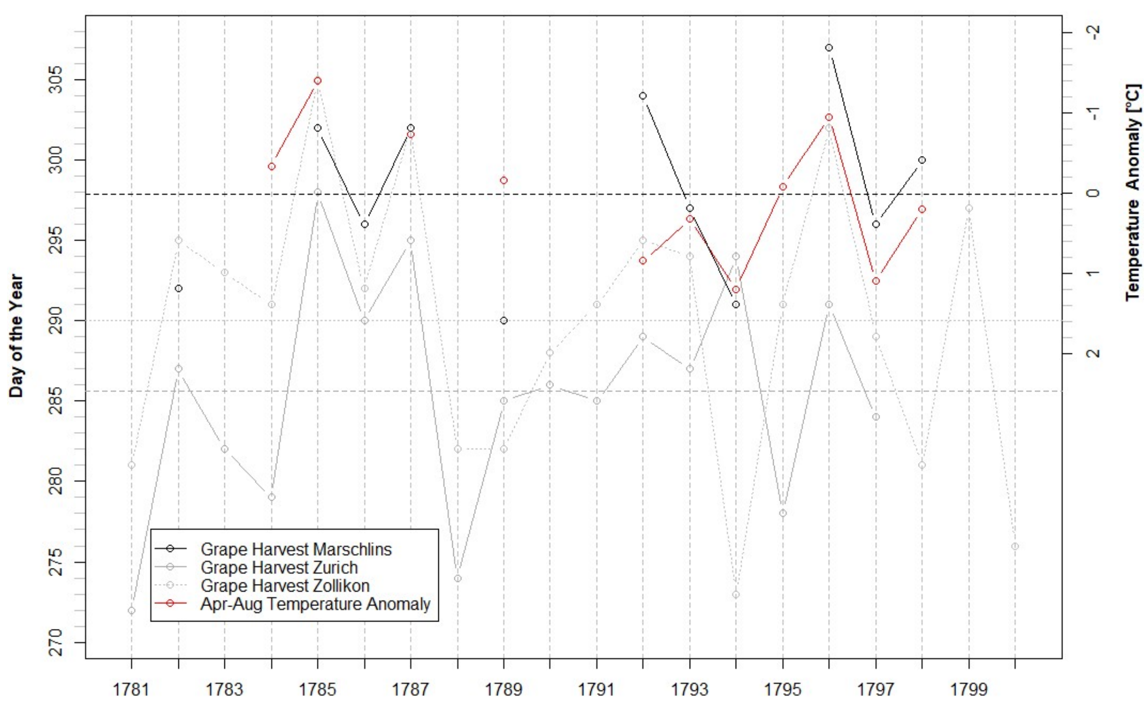

Figure 4.3.: Twenty-year series of grape harvest dates in Marschlins, Zurich[326] ($r = 0.42$) and Zollikon[327] ($r = 0.68$). The dotted lines indicate the twenty-year average. On the other axis, the April to August temperature anomalies for Marschlins have been plotted ($r = -0.50$ with the harvest dates of Marschlins).

The correlations of these three locations are slightly higher for the date of grape harvest (cf. *Figure 4.3.*). Surprisingly, Zollikon now shows a greater accordance with the

[325] On his trips along Lake Zurich, Salis-Marschlins pointed out the differences in viniculture of the two regions on multiple occasions. Cf. e.g. Meteorologische Beobachtungen, May 7th, 1795: IMG_7459-IMG_7460.
[326] Cf. Schwender 1856: 41.
[327] Cf. Koller 1879.

Schlossweingarten in Marschlins than Zurich. Once again, this probably cannot be reduced to a single cause. It is apparent, however, that the correlation of the harvest date with the temperatures of the preceding months of April to August is notably low ($r = -0.50$).[328] This indicates that other climatological, environmental, or administrative factors will have played a more prominent role this time. When reviewing the average date of blossom in *Figure 4.2.*, we can assert that the grapes in Marschlins hung for about four days longer on average than in either Zurich or Zollikon. This could confirm a comment by Pfister,[329] who uttered a suspicion that the vineyard in Marschlins was not subject to the *Weinlesebann*, enabling the von Salis-Marschlins to postpone the harvest by some days. Such a 'human element' could certainly explain parts of the shift in correlation. Additionally, it should be noted that a higher number of observations may also make these correlation coefficients look somewhat different.

4.3. Twelve Phenological Series

Despite the relatively harsh verdict regarding the Marschlinian phenological records in earlier paragraphs, due to the low consistency of the phases observed, the diaries of Salis-Marschlins still provide data for several interesting phenological series. For 11 out of 69 phases currently being collected by MeteoSchweiz,[330] at least ten observations have also been recorded by Salis-Marschlins in the 1781-1800 period. These observations have been plotted side by side in *Figure 4.4,* however, they have not been analysed in the same detail as the three series presented before, and so many of the previously mentioned quality issues prevail. Apart from the errors that can be caused when the specified phenological phases are not always clear,[331] it is mainly the phenological data related to fruit tree observations that is problematic. The flowering phases of *pyrus malus* and *pyrus communis,* for example, were clearly not observed on the same tree every year. Salis-Marschlins even switched between different kinds of apple and pear trees, which becomes evident in years where he recorded observations for multiple kinds. Unfortunately, the kind of tree was only partially noted down, leaving us to guess on many occasions. To best avoid the errors caused by such different kinds of trees, only observations without a

[328] The slightly higher correlation that was found for the February-August temperatures ($r = -0.57$) is probably only a consequence of the low amount of data, since vines are not usually active at temperatures below 12-15 °C. Cf. Pfister 1988: 87. At the same time, the September and October temperatures, which in a *Fön*-valley might also be expected to contribute in the determination of the date of grape harvest, even showed a positive correlation (meaning that in years with warm Septembers and Octobers, the grape harvest was later)!
[329] Cf. Pfister 1988: 83, footnote 66.
[330] Cf. Bundesamt für Meteorologie und Klimatologie MeteoSchweiz 2018.
[331] Those are mainly an issue for observations of flowering dates, for which the distinction between start of flowering and full flowering is not always clear.

kind specification have been used if available.[332] These generally appear to have been made for trees with 'average' flowering dates.[333]

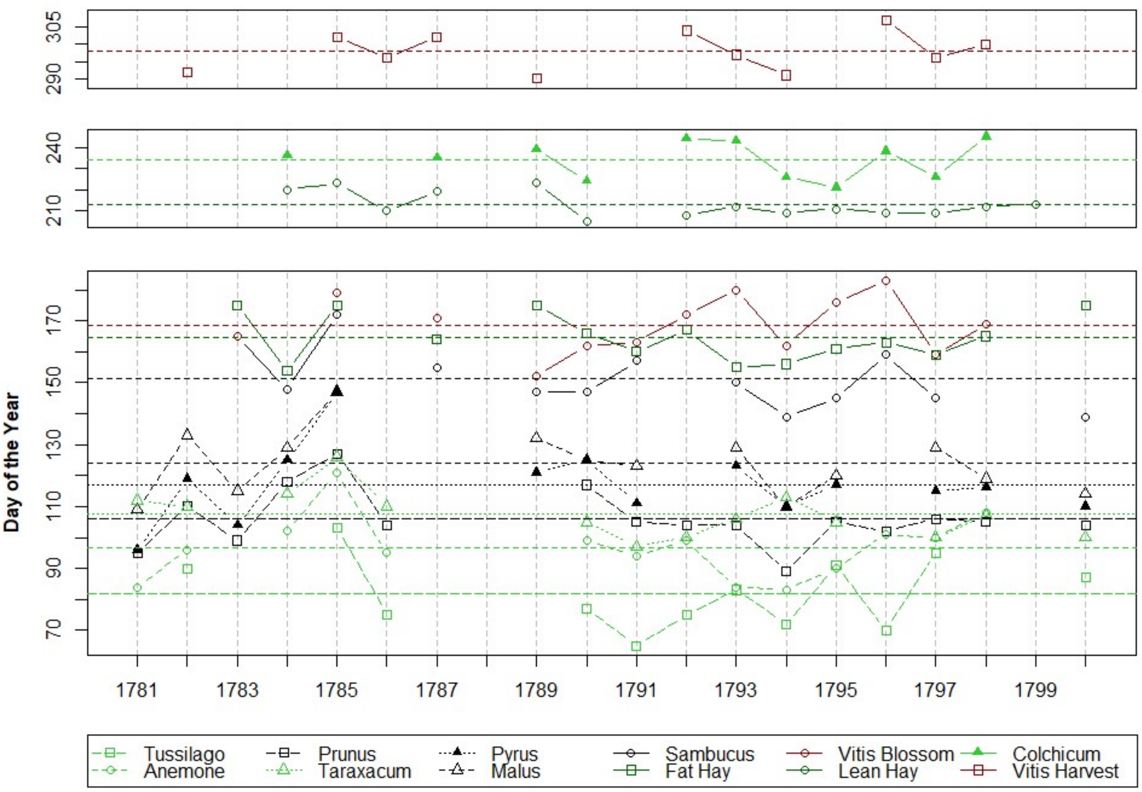

Figure 4.4.: Twenty-year series of selected phenological phases in days of the year, counted from the 1st of January. Those are (from earliest to latest in the year on average): blossom of tussilago farfara; blossom of anemone nemorosa; blossom of prunus avium; blossom of taraxacum officinale; blossom of pyrus communis; blossom of pyrus malus; blossom of sambucus nigra; beginning of fat hay harvest; blossom of vitis vinifera; beginning of lean hay harvest; blossom of colchicum autumnale; vine harvest. The dotted lines indicate the twenty-year average of the respective phase.

When looking at the twelve series in *Figure 4.4.* in combination, two years stand out. The first is 1785, where the effects of the long and cold winter that has already been discussed in sub-section 3.3.4. can also be seen in the phenology. All eleven phenological phases observed that year were delayed compared to the twenty-year average. These delays are especially accentuated in the first half of the year, where an extremely cold March (6.4 °C below the 1781-1800 average), followed by an only slightly less anomalous April (4 °C below average) held

[332] These observations generally read along the lines of 'the apple/pear trees are in blossom'.
[333] These 'average' flowering dates match those from Zurich (1781-1796), gathered by Schwender, quite well. The correlation coefficient is $r = 0.75$ for *pyrus communis* and $r = 0.92$ for *pyrus malus*. Cf. Schwender 1856: 41.

the vegetation back by about twenty days. The flowering of *pyrus communis* was as much as thirty days later than on average! Despite the cold August of that year (2.3 °C below average), the delay of the later phenological phases was only in the order of ten days. In 1794, the exact opposite can be found. After the two warm months of February (2.9 °C above average) and March (4.2 °C above average), all phenological phases portrayed in *Figure 4.4.* were earlier than in the 1781-1800 average, except for *taraxacum officinale*. Probably thanks to the warm summer, this advance of about ten to fifteen days was maintained over most of 1794.

4.4. The Potential of the Marschlinian Phenological Records

The image presented so far of the Marschlinian phenological records might seem somewhat two sided. On the one hand, there are reservations on multiple bases. Missing data points were not only caused by the frequent gaps, whose negative effects were noted during the construction of the temperature and pressure series, but also by the poor year-to-year consistency regarding the phenological phases observed. Additionally, parts of the data suffer from low accuracy, since Salis-Marschlins did not record phenology daily, but often summarised his observations from multiple days in the form of lists. The sometimes unclear or equivocal nomenclature he chose for some phenological phases and species adds to this low accuracy. On the other hand, this chapter has shown that construction of a relatively complete series is possible. Although Salis-Marschlins recorded only a handful of observations for most of the over 900 species that can be found in the diaries, the sheer number of more than 4,000 observations still offers enough data for several phenological phases. This will only improve when the years of 1802-1822 are added, for which gaps should be far less frequent.[334]

Furthermore, the three in-depth discussions of the flowering of *prunus avium* and *vitis vinifera* as well as the date of grape harvest could illustrate that, with some additional effort, faulty observations can be located and often also explained by the metadata. These data points can then be excluded from the series or, if a reference series is available, either adjusted or interpolated. Thus, the potential of the Marschlinian phenological records is far from exhausted. Considerable improvements are still possible even for the phenological series treated here. For example, if the diaries were re-evaluated with a stronger focus on phenological remarks, some of the above presented series could possibly be complemented with a few more data points.

[334] This can already be retraced in the graphs presented by Röllin. Cf. Röllin 1974: Tables 1, 3, 4.

Remarks like "*wann die Kirschenbäume im Blust sind, alsdann muss man Hanf säen*"[335] in particular may have potential for deducing such additional phenological data. A more in-depth analysis of the Marschlinian phenological observations should also consider climatological properties other than temperature for determining the driving factors behind the phenological phases. According to Pfister, sunshine duration and the amount of precipitation are the most promising.[336] A reconstruction of the latter will be attempted in the following Chapter 5.

[335] "As soon as the cherry trees blossom, it is time to sow hemp". Cf. Meteorlogische Aufzeichnungen, April 25th, 1792: IMG_6677.
[336] Cf. Pfister 1988: 81.

5. Precipitation

Together with temperature, the amount and intensity of precipitation plays a decisive role for any kind of agricultural activities. At the same time, it is a highly local phenomenon, as a few kilometres or a single mountain range can dramatically alter the amount of precipitation. As a consequence, even today's climate models struggle with high uncertainties in precipitation projections. For the same reason, the reconstruction of past precipitation depths requires a dense net of observations, as inferences from data from other sources can be a considerable distance from the 'truth', particularly in the micro-climate of the Alpine regions. Any early instrumental precipitation measurements or observations are thus of great interest.

Such observations and some attempts of measurements can also be found in the Marschlinian diaries. As Salis-Marschlins made a note of even the lightest of showers, they do show great promise for the reconstruction of precipitation. However, as precipitation events do not occur on a regular basis, Salis-Marschlins did not manage to quantify, nor always accurately describe, every rain shower. Instead, he could often only give qualitative descriptions of the intensity of precipitation which had fallen over a non-standardised and often non-specified duration. Nevertheless, this part of the Marschlinian diaries certainly also deserves attention. The following sections will therefore talk about the different kinds of precipitation observed by Salis-Marschlins, and some natural hazards brought about by them, starting with the observations and measurements of rainfall.

5.1. Rainfall Measurements and Observations

Precipitation measurements in Europe do not have a very long tradition. The first recorded measurements were conducted by Benedetto Castelli in 1639 – decades after the first uses of thermometers and only about four years before the "Toricelli-experiment".[337] Consequently, very few series of precipitation measurements date back to the 18th century. In Switzerland, continuous measurements started this early only in Geneva (in 1771).[338] At first sight, it might seem surprising that a supposedly easy to measure climatological parameter of this importance to everyday life was not monitored by more observers. However, to achieve an exact measurement of the amount of precipitation, an instrument of decent quality and a good amount of

[337] Cf. Strangeways 2010: 134.
[338] The series has not been homogenised so far, however. More details can be found on the Euro-Climhist website. Cf. Pfister, Rohr 2019.

expertise were required. In addition, the continuous monitoring of precipitation was a very tedious task, as the measurements could not be performed at a set point in the day but were dictated by the occurrence of precipitation itself. Thus, qualitative observations were often preferred over quantitative ones in the early instrumental period in the case of precipitation. Depending on their quality, this data merely allows for a distinction between particularly dry and wet periods, or for an approximation of the number of rainy days.[339] If the individual precipitation events are described in detail, however, an allocation into simple categories is possible, and an educated guess about the amount of precipitation can be made.

For large parts of his meteorological observations, Salis-Marschlins contented himself with descriptions of precipitation events. He did so in a rather detailed fashion, however, as in most cases he made a distinction between different intensities of rain as well as their duration. He also noted light drizzles, so that his observations are expected to be fairly complete.[340] On occasion, Salis-Marschlins also complemented his descriptions with measurements from a rain gauge. This instrument was first mentioned in 1784,[341] and had been in sporadic use at least until 1791, when the last measurement can be found.[342] We learn from his diary entries, that the device must have had a quadratic opening of a square foot (~0.1 m^2) in area.[343] Unfortunately, the sources do not provide any information about the exact shape nor the placement of the rain gauge. From the measured quantities, which have been noted down in both units of weight and length (depth), it can at least be concluded that the rain gauge was probably of box-shape and did not follow the later, more elaborate design of the Parisian academy.[344]

A rain gauge with such an open storage container has two main causes of error. First, snow, and to a lesser extent also water, can be blown off by heavy winds. As Salis-Marschlins never used his gauge in winter, this is not a big concern. Second, the large surface of the precipitate leads to more evaporation and therefore to measurements that are generally too low. The error caused thereby can be mitigated reasonably well if the depth is measured directly after a precipitation event. Unfortunately, Salis-Marschlins often did not read the gauge right away but waited for the water to accumulate a bit. While he might usually have aimed to capture the

[339] Such an estimation of days with precipitation must always apply as a minimum value, since there is a large likelihood the observer had missed some light precipitation events, especially when they took place during the night. Cf. Pfister 1988: 55-57.
[340] Still, the possibility of him missing some light precipitation event during the night is quite likely.
[341] Cf. Meteorologische Beobachtungen, July 18th, 1784: IMG_5653.
[342] Cf. Meteorologische Beobachtungen, April 30th, 1791: IMG_6558.
[343] Cf. Meteorologische Beobachtungen, May 30th, 1785: IMG_5804.
[344] These Parisian rain gauges had a cubic container with a shorter side length at the bottom of the collecting tray, which allowed for a more exact reading and reduced the error due to evaporation. Cf. Pfister 1988: 52.

precipitation for the whole day by doing so, there are also instances where he waited a sometimes also unspecified number of days before emptying the instrument. An additional problem arises due to the sources not specifying where the rain gauge was placed. Whether the instrument was positioned properly (in an open space, protected from the wind, and on flat ground) is questionable. Salis-Marschlins, at least, was not fully content with the measurements.[345] All in all, the trustworthiness of at least some of these measurements of precipitation depth can thus be questioned.

	One Hour	In the Morning, Afternoon, Evening, Night	Most/All of the Morning, Afternoon, Evening	The whole Night
Dribble	0.1	-	-	-
A Little Rain	0.3	-	-	-
Occasional Rain ("*bisweilen*")	0.5	1	1	1
Rain/Sun Interchanging ("*abwechselnd*")	1	2	2	2
Rain	2	4	8	12
Heavy Rain	4	6	12	18
Violent Rain	8	12	24	36
Downpour	12	-	-	-
Heavy Downpour	16	-	-	-

Table 5.1.: Categorisation and quantification of qualitative precipitation data in units of millimetre water column, based on the comparison with the available quantitative data. In cases of snowfall without simultaneous height measurement of the newly fallen snow, the values given here were halved (e.g. one observation of snowfall would contribute 2 mm to the monthly precipitation sum).

Nonetheless, in the attempt to get the most out of the qualitative data, those precipitation measurements that were deemed reliable have been used to quantify the mere descriptions, which make up the majority of the Marschlinian precipitation data. These 'reliable' precipitation depths are mainly from the later measurements (1789-1790), when Salis-Marschlins made more frequent use of the rain gauge and had returned to stating the measured quantities in units of length instead of weight.[346] As he was fairly detailed, and in addition very consistent in his

345 Cf. Meteorologische Beobachtungen, Results of July 1787: IMG_6161.
346 Although the weight measurements can easily be translated to units of Paris lines/millimetres, the measured amounts cannot always be trusted. This is probably due to Salis-Marschlins rounding the weighted amounts quite generously and possibly also incorrectly, as can be seen from measurements where he gives both units.

choice of words when noting down precipitation events,[347] a number of different categories could be built. The expected depth of precipitation was then assigned to all these categories. The resulting categorisation can be found in *Table 5.1.* It should be noted that the reconstruction presented here is a rather crude approximation, which for instance does not contain an accurate representation of intensity distributions.[348] The precipitation depth values found in *Table 5.1.* are thus merely estimations (based on the rain gauge measurements of Salis-Marschlins). A more thorough analysis, which may also extend the data basis by adding the second half of the Marschlinian records, may follow a more elaborate statistical approach, as for example the one demonstrated by Gimmi et al. for a precipitation series of Bern.[349]

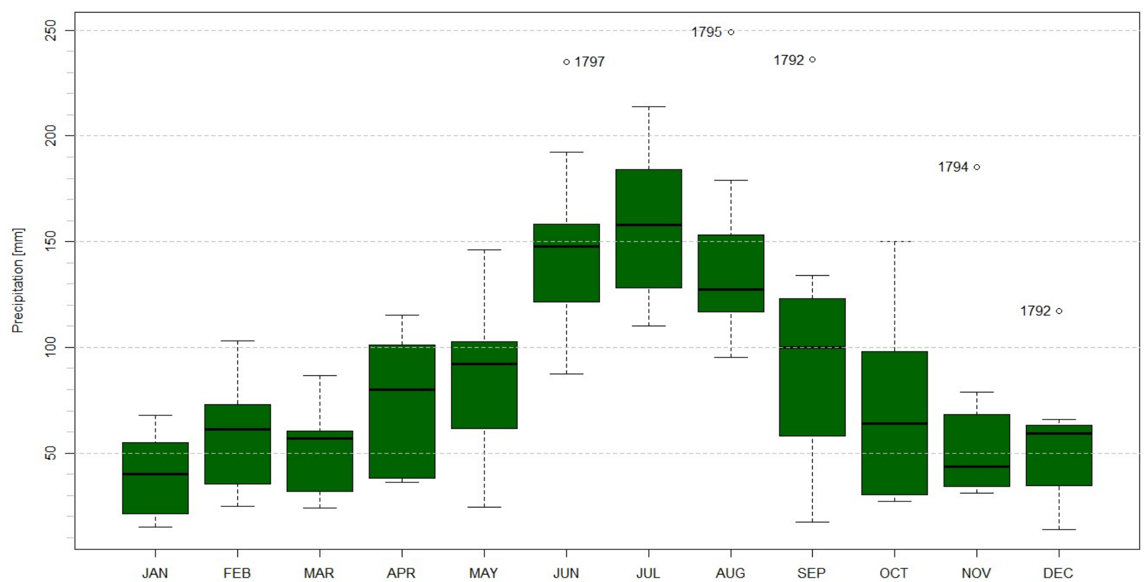

Figure 5.1.: Boxplot of the monthly precipitation in Marschlins for the years of 1783-1800 (excluding the period Salis-Marschlins spent in Chur). A clear amplification of summer rainfalls is visible.

Using these categories, the qualitative data could then be translated into a quantitative estimation of the rainfall depth. In addition, the measured snow depths had also to be converted into units of millimetres water column. As Salis-Marschlins usually took these measurements

[347] This is only true for the observations of 1783 onwards. During the first two years of the series, generally only one observation was made per day. Additionally, Salis-Marschlins did not yet distinguish between intensities of rain nor their duration during this period. The years of 1781 and 1782 had therefore to be excluded of the Marschlinian precipitation series.
[348] When comparing the frequency distribution for the reconstructed daily precipitation totals for the Marschlinian series with those for Landquart, a strong underrepresentation of low intensity rainfalls becomes apparent. While some of this may be explained by Salis-Marschlins missing the occasional light precipitation event, it also shows the chosen calibration is still far from perfect. Cf. *Figure A.1.* (p. 144).
[349] Cf. Gimmi et al. 2007: 189-190.

shortly after the snowfall had stopped, a rather low snow density of 0.1 kg/l has been assumed. Combining both rain and snow data, monthly precipitation totals could be calculated for the months with neither gaps nor larger changes of location. A boxplot of these precipitation totals can be found in *Figure 5.1*. Unlike for the temperature or pressure series, months that were lacking more data than the occasional skipped measurement could not be accepted here. Since the precipitation regime of Chur is quite different from that around Marschlins,[350] the years during which Salis-Marschlins stayed in the *Oberer Spaniöl* also had to be excluded for this boxplot.[351] On the other hand, the four months in 1784, during which observations were made in Zizers, were counted towards the Marschlinian precipitation series. As the distance between the house of Amstein (where the Zizers observations were probably made) and Marschlins Castle is little more than 1 km, and so the precipitation regimes of these two locations should not differ greatly from one another.

Unsurprisingly, some of the outliers found in *Figure 5.1* coincide with months during which floods occurred. This is the case for June 1797, when numerous meadows and fields were inundated. Rivers were also on the verge of flooding in mid-September 1792. Additionally, October 1787, during which Salis-Marschlins lived in Chur, should also be noted.[352] The calculated monthly sum of 244.3 mm (!) caused the Rhine to flood on the 12th and then again on the 15th of that month, together with some smaller torrents.[353] In contrast, no floods are mentioned during August 1795 (although there was one in late July). It seems that the fairly even distribution of rainfall during this month spared the region a second inundation that summer. On the other hand, the precipitation depths during the two anomalous winter months were simply not large nor concentrated enough to cause a flood. While the weather of November 1794 was described as "very wet" by Salis-Marschlins,[354] about half of the precipitation of December 1792 fell in the form of snow. Three quarters of this snowfall occurred between the 12th and the 14th, when Salis-Marschlins measured a total of 16 inches (~43 cm) of fresh snow.[355]

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[350] The *MeteoSchweiz* station for Landquart received about 200 mm more precipitation on a yearly average (for the period of 1909-2018) than the one for Chur. Cf. Bundesamt für Meteorologie und Klimatologie MeteoSchweiz 2019.
[351] Those are January-April 1785 as well as December 1785-May 1790. An overview with the estimated precipitation totals for all available months can be found in the annex, *Table A.2* (p. 145).
[352] The data point can thus not be found in *Figure 5.1*.
[353] Cf. Meteorologische Beobachtungen, October 12th and October 15th, 1787: IMG_6203.
[354] Cf. Meteorologische Beobachtungen, November 14th, 1794: IMG_7354.
[355] Cf. Meteorologische Beobachtungen, December 14th, 1792: IMG_6823.

Apart from the extreme values, the general shape of the boxplot curve is also noteworthy. While the annual sum of the Marschlinian series at 1070 mm is barely different from today's expected value, the monthly distribution does show hints of increased summer rainfall. This increase in June and July precipitation is mainly at the expense of winter precipitation. This tendency towards greater precipitation totals and more days with precipitation during the summer has already been noted by Pfister[356] for other series of the 18th and early 19th century.

5.2. Days with Snow Cover and Snow Layer Thickness

The timing, duration, and amount of snow were crucial factors in everyday life for late 18th century agricultural society. While the first frost and snow put a halt to many agricultural activities and marked the start of feeding the livestock in stables, the white layer also enabled the use of sledges. Snow thus allowed for the easier transport of heavy burdens. Consequently, winter months were often used for forestry work, the gathering of firewood and timber, work that is far more tedious if snow is lacking. The absence of snow in the cold months also threatens cold-sensitive plants, as they were then missing their insulating layer against winter temperatures. Too much snow, on the other hand, increased the likelihood of avalanches and could block important transalpine routes, and at the onset of spring, the late melting of snow could lead to hay shortage and, ultimately, to the loss of livestock, especially after a long winter and a poor harvest in the previous year.

Considering all the factors in which snow played an important role, it does not come as a surprise that Salis-Marschlins noted observations of snow fall events and snow melt quite regularly. Although he only occasionally recorded the amount of snow that lay on the ground in total, Salis-Marschlins wrote an entry whenever snowfall occurred, most often followed up by a height measurement of the newly fallen snow. As usual, he measured these heights in Paris feet, inches and lines. Salis-Marschlins generally also recorded days with heavy melting and marked the days when the ground became free of snow. Finally, the number of days with snow cover and the amount of fallen snow were often also mentioned in the month's results section. These summaries at the end of many months quite often provide additional information,

[356] Cf. Pfister 1988: 55.

especially for months for which only parts of the daily entries are found in the diaries, or months which are described in little detail.[357]

A fairly accurate estimation of the amount of days with snow cover can be achieved on the basis of these different measurements and descriptions. As some of the recorded notes leave room for interpretation, a set of rules must be established beforehand. First, a day should only be counted towards the total if at least half the ground was covered at the time of the morning measurement. Secondly, the ground on which observations should be performed needs to be flat and exposed to the sun; days where snow is still to be found on slopes oriented towards the north or in shadowy sites should not count. Finally, whenever the sources are ambiguous, the alternative with the least amount of days of snow cover should be chosen.

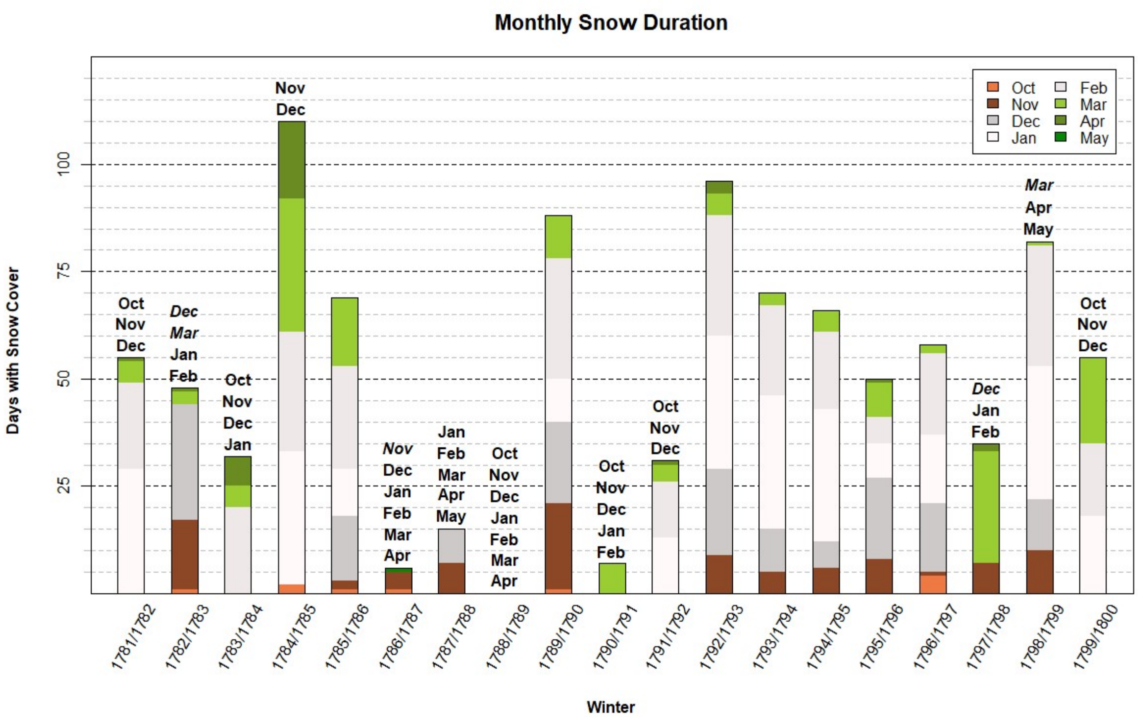

Figure 5.2.: Recorded days with snow cover during the winters of 1781/1782 to 1799/1800, split into months. Abbreviations of months printed in bold above the individual columns represent months with no observations; those printed in both bold and italic indicate months with partly missing data.

[357] The number of days with snow cover given therein were usually calculated very conservatively. Days during which the ground was only partly covered often were not counted towards that total. At times, individual days were also left out or forgotten. An extreme example of this can be found in February 1794. Even though six inches (~16 cm) of snow had already fallen on the 9th of this month, Salis-Marschlins only started counting from the 12th onward, when the ground was covered with an additional layer of fourteen inches (~38 cm). And although the last of the snow only melted on the 22nd, only ten days had been added to the sum of that month (instead of eleven if counted since the 12th or fourteen since the 9th, when the ground initially got covered). Cf. Meteorologische Beobachtungen, Results of February 1794: IMG_7250.

Unfortunately, the Marschlinian diaries often lack at least parts of the winter season, as can be seen in *Figure 2.2.* (p. 32). As the days grew shorter and the first frosts settled in, Salis-Marschlins' interest in observing nature must have declined as well. All in all, only seven out of nineteen winter periods have been described in their entirety within the 1781-1800 period. In addition, the descriptions were reduced to a minimum during many winter months, so that barely any entry outside the three daily measurements found its way into the diaries. This was especially true for the first years of observations, but also the politically unstable period of 1798-1800. Although snow fall events, and partly also intensities, were still recorded during these years, measurements of snow height and the melting of the last snow were rarely mentioned. Additional assumptions thus need to be made for these instances. The winter months of December, January and February were generally assumed to be covered in snow, unless stated differently (i.e. no snow fall had been observed so far or it was explicitly written that all snow had melted). For any other month, only one day of snow cover was counted towards the total per snow event recorded. Only if there was clear evidence of a longer duration of snow cover or of a continuous snow cover duration from the prior month were days added to the total. The resulting estimation can be found in *Figure 5.2.* As only seven winters are without gaps during the twenty-year period under investigation, a yearly average of days with snow cover is not very meaningful. In addition to the annual total, the sum of individual months and data gaps have thus been indicated.

Out of the nineteen winter seasons depicted, the snow cover during the winter of 1784/1785 stands out the most. Not only did it surpass any other season by at least thirteen days, but its total of 110 days with snow cover is also missing the data for the months of November and December 1784. During that time, Salis-Marschlins stayed in the Valtellina, where the rivers froze over on the 23rd of November and the ground probably remained covered by snow from the 9th of December until his return to the Grisons at the end of the year.[358] Some additional weeks with snow cover can thus also be expected for the Grisons. During most if not all of January and February, between one and two feet (about 32.5-65 cm) of snow lay on the ground. The masses of snow left the Alpine passes untraversable for most of the winter.[359] Following this cold and snowy winter was an even colder spring, with a March monthly mean of below -3 °C and an average April temperature of only a little more than +5 °C.[360] As a consequence, these snow layers were maintained far into spring. On March 23rd, more than a foot (~32.5 cm)

[358] Cf. Meteorologische Beobachtungen, November 22nd and December 9th, 1784: IMG_5742, IMG_5744.
[359] Cf. Meteorologische Beobachtungen, Results of April 1784: IMG_5548; February 28th, 1785: IMG_5754.
[360] For more details, cf. sub-section 3.3.4.

of snow still lay on the fields.[361] In the courtyard of the castle, more than two feet (~65 cm) could be found on the 6th of April, easily enough snow to travel by sledge.[362] From his brother Ulysses von Salis-Marschlins, who stayed in *Castione* during the winter, Johann Rudolf learned that there had been one foot of fresh snow on the 5th and 6th of April. On the day Ulysses had posted the letter, the snow in a valley next to Caiolo supposedly still reached higher than the roof tops.[363] In Marschlins, this extremely long winter also caused a severe shortage of hay and fodder in general, resulting in the cattle having to be fed with branches, leaves or dried fruit, and ultimately in the death of much livestock. According to Salis-Marschlins, even the oldest of people were not able to recall anything similar. Only on the 19th of April, after well over 110 days of constant snow cover, the ground was finally free of snow.

The information density within the diaries certainly allows for a reasonably good guess for the number of days with snow cover. As the above approximation only takes entries directly mentioning snow or snow cover into consideration, some of the monthly totals might very well be erroneous by a few days, especially when detailed descriptions are scarce. A more accurate result may be achieved with the help of a snow model, which might also take the given information on daily temperature, wind, and weather into consideration. Using a modelling approach, a reconstruction of the daily snow layer thickness might also be feasible – something the very sparse direct measurements cannot provide on their own. Nevertheless, the main limiting factor of the recurrent observation gaps during the winter season remains. As these gaps are far less frequent for the years after 1800,[364] a more in-depth analysis of snow cover and potentially also snow depth should be possible for these later twenty-two years of observations.

5.3. Avalanches, Floods, and Summer Snowfalls

Salis-Marschlins' primary focus was certainly not on extreme weather events or natural hazards when writing his diaries. After all, he specifically intended to get an understanding of the normal day-to-day weather, and not extraordinary, disastrous nature events. Anomalies are part of every series, however, and if observations continue for more than four decades, some of

[361] Cf. Meteorologische Beobachtungen, March 23rd, 1785: IMG_5759.
[362] Cf. Meteorologische Beobachtungen, April 6th and April 9th, 1785: IMG_5765, IMG_5767.
[363] Cf. Meteorologische Beobachtungen, April 11th, 1785: IMG_5767.
[364] Unfortunately, the tables from the National Archive, containing the temperature and pressure measurements from Marschlins, lack the months of December and January (and some others in instances as well). However, data for these months clearly exist in the original diaries, as Salis-Marschlins did include them in his publications in the *Neuer Sammler*: Cf. Salis-Marschlins 1805-1812. A first estimation of days with snow cover for this period can be found in Röllin 1974: 17-20, Tables 7-12.

the stronger anomalies will almost certainly have caused natural hazards, so, the Marschlinian records also hold information on multiple flood events and avalanches. When these occurred, Salis-Marschlins often dedicated somewhat more elaborate diary entries to these nature events, especially if they ended up being 'catastrophic'[365]. However, although such natural disasters were described in more detail, the event itself was rarely at the centre of interest. What was of importance to Salis-Marschlins was mainly the economic damage caused, be it by the destruction of yields and infrastructure, or by the ulterior demand for labourers for the prevention, or in the aftermath, of such an event.[366] Nonetheless, the diary entries usually allow an evaluation of the gravitas of such a natural disaster through a combined analysis of the reported damage and some short descriptions of the course of events.

The vast majority of precipitation-related natural disasters in the Rhine valley occur in the form of (summer) floods and avalanches. In all the diaries between 1781 to 1800, only one event outside of these two categories had been recorded: a landslide, which happened in August of 1787 close to Maienfeld and caused some property damage.[367] Far more frequent are the diary entries about flood events that took place in proximity to Marschlins Castle. While many of these entries describe only high tides or minor floods with no or very little actual damage, some mention larger inundations of cultivated land with damage to several buildings and bridges. Eight descriptions of local flood events can be found in the Marschlinian diaries: on the 22nd of August 1784; at the end of July 1785; at some point in August 1787; on the 12th of October 1787; the 28th of July 1795; the 23rd of June 1797; the 16th of July 1798; and on the 28th of January 1799.

Probably the most damaging event of this twenty-year period was the flooding of the Landquart and some smaller torrents in the night of the 16th to the 17th of July 1798. After about 100 mm water had fallen in the first two weeks of July,[368] heavy precipitation poured down on the 16th of that month during most of the day and throughout the entire night. These additional approximately 50 mm caused the Landquart and other streams to flood. Multiple bridges were caused to collapse, and large areas of farmable land were inundated. Furthermore, this flood

365 Following Rohr, some of the characteristics meaning that an event will be perceived as catastrophic are: the inability to explain its causes and/or meaning; the affectedness, be it direct or indirect; an accumulation of extreme events; the unexpectedness of the event. Cf. Rohr 2007: 55-62.

366 The relatively low interest Salis-Marschlins had in these events can also be seen in the length of the respective diary entries. Rarely do these reports on natural disasters take up more than one to two pages, less than for example descriptions of individual steps of an agricultural procedure. Salis-Marschlins also never forgot his 'duty' of three daily measurement over these incidents.

367 Cf. Meteorologische Beobachtungen, Results of August 1787: IMG_6176.

368 Calculated according to *Table 5.1.*

must also have affected at least parts of the Rhine shore, as Salis-Marschlins recorded that the "house at the upper toll bridge", which refers to a building next to the *Tardisbrücke* between Landquart and Mastrils, had been surrounded by water as well.[369] Another noteworthy event is the flood that had occurred on January 28th, 1799. On that day, large amounts of snow were melted by heavy rainfall and the *Fön* wind. The warm weather had also been able to crack the anchor ice that had formed in the Rhein after an extraordinarily cold January.[370] These blocks of ice were then swept away by the torrential river and destroyed a bridge next to Untervaz.[371]

As Salis-Marschlins resided on the valley ground during wintertime and the mountain slopes were at a safe distance, avalanches were of somewhat less concern to him. Only on rare occasions did Salis-Marschlins thus report on high frequencies of avalanches[372] or the dangers that the masses of snow could cause.[373] Nonetheless, at least two damage inflicting events came to his attention between 1781 and 1800, which he then also mentioned in his diaries. The first record of a minor avalanche incident can be found in March 1784. While Salis-Marschlins probably had been either in the Valtellina or on his way back to Marschlins,[374] there had been an avalanche at the *Splügen* pass, which had buried eight packhorses. What made this occurrence noteworthy to Salis-Marschlins was the *Rutner*[375], who supposedly was swept away as well, but managed to save himself and seven out of the eight horses from the snow.[376] Considerably more harm was caused by the numerous avalanches that occurred in the night between the 15th and 16th of February 1793. The large amounts of snow, which had accumulated during the winter, had become instable due to the warm temperatures of the previous days. That night, a *Fön* storm then caused many of these snow masses to collapse. Reportedly, thirty stables had been destroyed that night on the mountain slopes surrounding Seewis, and multiple houses in St. Anthönien were buried in snow.[377]

To conclude this chapter on the precipitation records of Marschlins, a last group of precipitation-related diary entries should briefly be addressed here as well. Summer snowfall events

[369] Cf. Meteorologische Beobachtungen, July 17th, 1798: IMG_7969.
[370] Cf. sub-section 3.3.4.
[371] Cf. Meteorologische Beobachtungen, January 28th, 1799: IMG_8019.
[372] Cf. Meteorologische Beobachtungen, February 13th, 1794: IMG_7244.
[373] Cf. Meteorologische Beobachtungen, January 7th, 1781: IMG_5275.
[374] As stated earlier, the meteorological observations of that time that were recorded in Zizers might have been made by Johann Georg Amstein. The fact that Salis-Marschlins heard of this "peculiar incident of an avalanche" is a strong hint that either he or his relatives were in the Valtellina at that time.
[375] Somebody who is responsible for keeping the pass traversable during wintertime. Cf. Schweizerisches Idiotikon 1881-: Vol. 2, Col. 1803.
[376] Cf. Meteorologische Beobachtungen, Results of April 1784: IMG_5547-IMG_5548.
[377] Cf. Meteorologische Beobachtungen, February 16th, 1793: IMG_6867.

could pose large problems for livestock that was being fed in the Alps during the winter. Depending on how far down these summer snowfalls reached, the cattle could not graze anymore, and had to be fed with fodder that might have been needed for the upcoming winter. In June 1796, the cattle that had left on the 19th even had to return to the *Maiensäss* on the 21st due to the extensive snowfall of that day.[378] Although the consequences of summer snow were not usually this drastic, Salis-Marschlins kept a book of its occurrences, nonetheless. These dates of summer snowfalls have partly been collected and analysed by Pfister.[379] Although Salis-Marschlins probably observed most of these snowfall events at the slopes of the Calanda ridge next to Chur, as stated by Pfister, other mountains and hills of the area have also been named in this context.[380] In *Table A.3.* (p. 146) in the annex, the five years analysed by Pfister have been corrected where necessary and completed by the other fifteen years of the 1781-1800 period.

[378] Cf. Meteorologische Beobachtungen, June 21st, 1796: IMG_7651.
[379] Cf. Pfister 1975: 68-69, Table 23.
[380] E.g. the Lerch as well as the Mittagsplatte to the (south-)west of Marschlins.

6. Conclusion and Outlook

The meteorological diaries of Johann Rudolf von Salis-Marschlins contain a rich collection of climatological data. Within the here studied first twenty years of observations, well over 10,000 pressure and temperature measurements, more than 4,000 observations of phenological phases, and close to 2,000 descriptions of precipitation events can be found. Additionally, Salis-Marschlins kept note of his three daily wind and weather observations and reported on the effects of local natural events such as floods and avalanches. Such an abundance of climate data is rarely seen in documentary sources of the late 18th and early 19th century and unrivalled for that time in the canton of the Grisons. Despite their extraordinary wealth in data, however, the Marschlinian diaries played a minor role in historical climatology so far. The relatively frequent gaps within the first few years of observations, as well as reservations due to reported inaccuracies of the used instruments and some of the applied measuring techniques, strongly dampened the scientific interest in these meteorological records. While meteorological and phenological observations received some attention by Pfister and Röllin, it is mainly the measured quantities, temperature, pressure, and precipitation, about which historical climatological research was most apprehensive.

With the construction and homogenisation of a monthly temperature and pressure series, this study was able to refute large parts of these reservations for at least half of the Marschlinian records. The resulting temperature series looks especially promising. During most months, differences to the built reference series are small, and where they get bigger, local weather phenomena or poor timing of measurement gaps can provide a plausible explanation. Both large-scale and small-scale temperature anomalies are captured by the homogenised monthly series. Examples for this are the eleven-month cold spell between October 1784 and August 1785 in reaction to the Laki eruption, or the extraordinarily cold January 1799, during which a strong temperature inversion was prevalent. Similarly, the homogenised monthly pressure series is in reasonably good agreement with the reference series from 1794 onwards. During that period, even large anomalies, such as the long-lasting high-pressure situation in early 1797, were accurately captured by the barometer of Salis-Marschlins.

Nonetheless, a number of reservations towards these instrumental measurements prevail. For the most part, these reservations are related to the first thirteen years of the pressure series, during which the quality of the used barometers was indeed poor. As not all systematic errors could be removed satisfactorily for this period, the absolute values of daily and for the first ten years also monthly averages cannot always be trusted. In general, these first ten years are the weak spot of Salis-Marschlins' meteorological and phenological observations. Changes of location and measuring devices caused several breakpoints and thus demanded considerable effort during homogenisation. Due to the high frequency of these changes, the applied corrections for that period suffer from considerable uncertainties. Problematic are also the last two years of temperature measurements, when a *Weingeist* thermometer was in use. This thermometric liquid led to somewhat enhanced extremes, for which no corrections could be found. There are also a handful of individual measurements that had to be rejected even before homogenisation. Most of these concern the temperature series, where, during two short periods, faulty thermometers had caused implausibly high extrema and temperature changes.

Among the main obstacles for both homogenisation procedures were the lacking descriptions of instruments, measurement circumstances, and measurement methods within the metadata. If this information was available, systematic errors and non-climatic trends could probably be explained and corrected more accurately. Similarly, the rain gauge measurements could have been put to better use, if the shape as well as the positioning of the device were known. Even so, in combination with the detailed qualitative precipitation observations, a quantitative estimation of monthly precipitation depth could be presented. Using this precipitation data, the majority of local floods recorded by Salis-Marschlins could be explained by a positive precipitation anomaly in the respective month. The other flood events could either be traced back to high-intensity rainfalls or extensive snow and ice melt. The estimated precipitation depths could also confirm a phenomenon found in other sources, in that it showed augmented values during the summer months compared to today's measurements. In addition, the Marschlinian diaries also allowed for a reconstruction of the monthly snow cover duration and summer snowfall events.

Apart from these three series of measurements, this study also examined the many phenological observations Salis-Marschlins had recorded. The expected high quantity of observations could be confirmed as records of well over 4,000 phenological phases distributed over more than 900 species were found in the diaries. However, several negative characteristics of these phenological records had been noticed under closer inspection. A poor year-to-year consistency in what phenological phases were observed, and the at times poor accuracy due to summarised observations in the form of lists and partly unclear or equivocal nomenclature tarnish the image. Nonetheless, this study could show that the construction of long series for multiple important phenological phases is still possible.

Finally, in the process of transcribing and analysing the diary's contents, a detailed overview of gaps in recording and of the whereabouts of Salis-Marschlins could be gained. It was also possible to correct some inaccuracies of older publications. Unfortunately, these corrections were mostly for the worse of the Marschlinian records. For any of the years in between 1794 and 1797, which so far had been considered complete, gaps of in between one to two months have been found. Also, considerable errors have been noticed in many of the monthly reviews provided by Salis-Marschlins. At the same time, other breaks and relocations of instruments could be defined more accurately, and thanks to some parallel measurements and hints from other sources, the data from Zizers could even be assigned to another observer. Furthermore, it was possible to reconstruct the causes leading to some of the gaps. Any interruptions in the last two years of the series, for instance, are likely to be traced back to the French occupation of Marschlins Castle, which started in March 1799.

Probably the most important outcome of this study is that the potential of the Marschlinian diaries is still far from fully tapped. Innumerable observations of phenological phases had to be left out during the analysis. Furthermore, weather and wind observations may be studied on their own or might also be included in the homogenisation process. Finally, there is the second half of Salis-Marschlins' meteorological diaries, which still awaits a proper analysis. Even though the tabulated temperature and pressure values of these later years can be found in the Swiss National Archive, these tables can probably only serve to get a first impression. They not only lack all months of December and January, but also most of the metadata support that the diaries can provide. Having supplementary information from the diaries and additional sources is crucial for the analysis of almost any of the here presented data, as this study clearly has shown. A thorough analysis of the entire Marschlinian temperature and pressure series – and of all other climatologically interesting data recorded in the Marschlinian diaries – will thus not get around the labour-intensive study of the diaries themselves. Although this demands a large effort, it certainly is a worthwhile undertaking.

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A. Annex

A.1. Precipitation Frequency Distribution

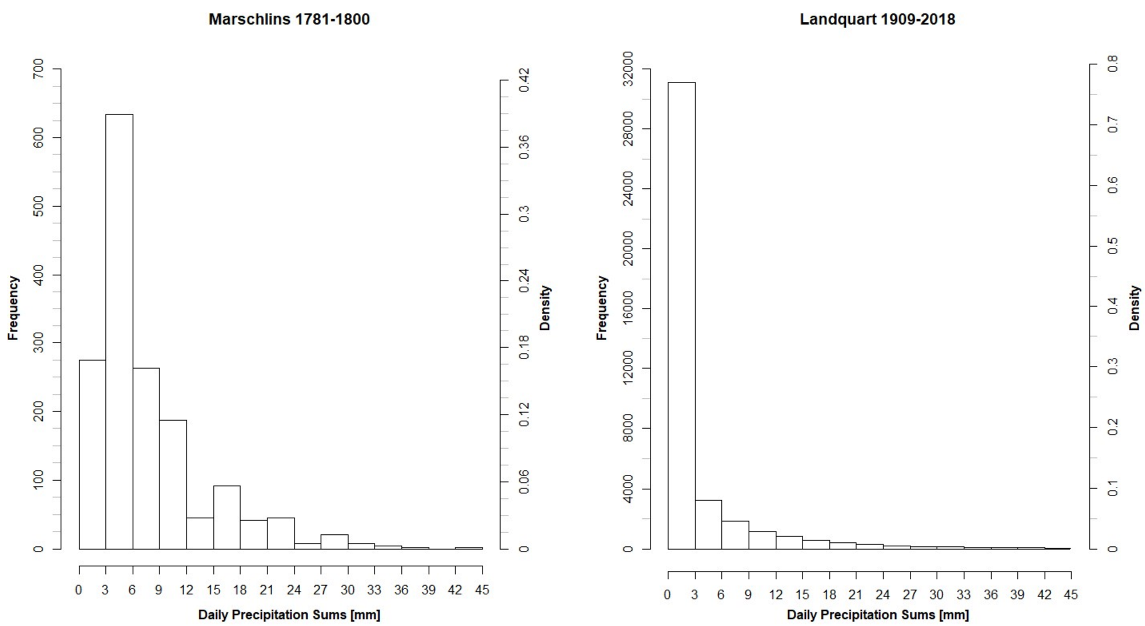

Figure A.1.: Comparison of frequency distribution of daily precipitation totals between the Marschlinian precipitation records and the 110 years measured daily precipitation depths from Landquart (Source: Bundesamt für Meteorologie und Klimatologie MeteoSchweiz 2019). With the chosen calibration, the light precipitation events are strongly underrepresented, while medium intensity events appear too frequently. Highest intensity precipitation events are difficult to capture with the method presented in Section 5.1. While the Marschlinian precipitation record has a daily maximum of 44.0 mm, values of up to 153.6 mm have been measured in Landquart.

A.2. Monthly Precipitation Totals

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1783	-	-	(10.0)	**38.0**	54.4	112.3	(4.0)	-	-	-	-	-
1784	-	*29.0*	*32.0*	*79.8*	24.3	148.0	(112.7)	153.1	***51.9***	*(30.0)*	-	-
1785	(6.0)	66.7	21.5	28.6	122.0	126.7	(48.0)	116.6	100.0	30.3	43.6	19.4
1786	21.7	27.7	40.4	(24.5)	-	-	(80.0)	182.3	78.4	27.7	(13.8)	-
1787	-	-	-	-	123.5	175.9	186.6	188.6	72.0	244.3	67.1	54.0
1788	-	-	-	-	-	-	-	-	-	-	-	-
1789	-	-	-	-	52.9	196.6	184.3	60.3	65.0	114.7	76.9	25.4
1790	29.4	53.0	42.5	44.9	154.9	87.6	202.3	123.6	118.0	-	-	-
1791	-	-	54.8	115.3	70.3	158.3	(194.3)	-	-	-	-	-
1792	21.8	103.3	60.5	101.3	146.3	147.9	110.0	131.0	236.0	81.0	32.5	117.2
1793	39.3	35.4	29.4	85.0	95.0	154.3	125.4	95.3	134.2	27.3	57.4	59.2
1794	15.0	98.9	64.1	(8.0)	89.3	145.4	141.1	179.0	100.0	98.0	185.4	60.2
1795	67.8	64.2	86.7	65.6	(95.1)	192.3	214.0	249.0	17.3	(21.4)	(39.9)	65.7
1796	44.0	61.3	24.1	(18.3)	(48.3)	182.0	158.0	140.0	58.0	150.1	35.7	33.5
1797	20.6	24.9	33.6	104.9	97.2	235.0	184.0	(108.9)	-	(85.0)	31.1	14.0
1798	-	-	59.0	36.1	102.7	121.6	181.0	110.4	123.0	47.0	79.0	36.0
1799	66.1	72.9	(4.0)	-	-	-	128.3	123.0	(14.0)	-	-	-
1800	40.9	46.8	59.5	37.4	61.7	112.0	(53.0)	-	-	-	-	-
Average	33.9	57.0	45.7	73.5	91.9	153.1	165.0	142.5	100.2	91.1	67.6	48.5

Yearly Average 1069.9

Table A.2.: Monthly precipitation depth in units of millimetres of water for Marschlins and Chur between 1783-1800. Values in brackets show months with considerable gaps, values printed in bold such with minor gaps. Values in italic typeface indicate months during which (some) of the observations were from Zizers. Finally, underlined values show months during which Salis-Marschlins (partially) took measurements in Chur.

A.3. Summer Snowfall

	May	June	July	August	September
1781	NA	NA	NA	NA	NA
1782	-	*NA*	NA	NA	NA
1783	-	21.	*NA*	NA	NA
1784	2. 13.	-	1. 23.	9. 10. 23. 26.	NA
1785	31.	1. 2.	5.[381] *NA*	14.	29.
1786	NA	NA	*NA*	18.	16. 25. 26. 27.
1787	11. 25. 30.	-	14. 21.	26.	19. 29. 30.
1788	NA	NA	NA	NA	NA
1789	-	4. 7. 12. 26. 27. 28. 29.	28.	24. 31.	15. 17.
1790	-	26. 27.	11. 14. 16.	-	7. 9. 11. 21. 24.
1791	18.	12. 13. 14. 15.	12. 14. *NA*	NA	NA
1792	4. 5. 9. 10. 23.		28.	19. 20.	7. 11. 17. 18. 23. 26.
1793	30. 31.	25.	20. 21.	16.	7. 17. 20. 21.
1794	12. 22. 23. 28. 29.	2.	-	3. 5. 23.	6. 7. 20. 24. 26. 27.
1795	27. 29. 30.	20.	1. 24. 26.	22. 30.	-
1796	-	3. 5. 6. 21.	4. 11. 12. 14.	28. 30.	-
1797	1. 3. 11. 30.	11. 15. 16. 17. 22. 27. 30.	7.	*NA*	NA
1798	13. 20.	21.	12. 16.	5. 7. 27.	13. 15. 28. 29.
1799	NA	NA	*NA* 17. 29.	25.	*NA*
1800	11. 13.	1. 15.	*NA*	NA	NA

Table A.3.: Summer (May-September) snowfall events in the mountains around Marschlins Castle. Observation gaps are indicated by "NA"*, partial gaps by "NA" (in italic). Snowfall during the night was counted towards the prior day.*

[381] At the time he made that observation, Salis-Marschlins was on a journey through the Prättigau.

Declaration of consent

on the basis of Article 30 of the RSL Phil.-nat. 18

Name/First Name: Grimmer Markus

Registration Number: 14-117-527

Study program: MSc in Climate Sciences

Bachelor ☐ Master ☑ Dissertation ☐

Title of the thesis: The Meteorological Diaries of Johann Rudolf von Salis-Marschlins, 1781-1800

Supervisor: Prof. Dr. Christian Rohr

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