Climate history of the principality of Transylvania during the Maunder Minimum (MM) years (1645 - 1715 CE)

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Abstract. This paper deals with the climate in the former Grand Duchy of Transylvania, now one of the three major geographical provinces of Romania, within the so-called Maunder Minimum (MM) (1645-1715), an astrophysically defined part of the Little Ice Age (LIA), which was characterized by reduced solar activity. The historical data from Transylvania are compared with that from Germany, Austria and Switzerland. This comparison for the period 1645-1715 shows good agreement but also reveals geographic characteristics of the region. For the first time, we present here a comparison between the four geographic areas in text and tabular form. Quotes from mostly German-language sources are reproduced in English translation. The results clearly help to identify regional climatic differences during the MM. Furthermore, we examine for a longer period (1500-1950) the extent to which the climate of Transylvania might have been affected by long-term fluctuations in solar activity, as deduced from isotopic reconstructions from ice cores. This comparison suggests a certain solar influence but the agreement is not very pronounced. Future investigation in a pan-European context is needed to reach reliable statements. Some results are unexpected – like an unusually small number of severe winters during the last decades of the MM, where extreme cold was restricted to a few years, like the extreme winters 1699/1700 and 1708/1709.

Keywords: Climate of Middle and Eastern Europe, Maunder Minimum, Little Ice Age, Solar Activity.

1. Introduction

The period 1645 - 1715 is called Maunder Minimum (MM) in solar physics and denotes an epoch of long-term reduced solar activity within the long-known eleven-year activity cycle. The modern discoverer of this seventy-year minimum period was the American astrophysicist John Eddy. He caused a sensation in a paper in Nature in 1976 (Eddy, 1976), especially because he postulated a causal connection with the Little Ice Age (LIA). Since then, the term MM has also been used by climatologists, but not always in its correct meaning. We take the MM strictly as the astrophysical definition of the calendar years from 1645 to 1715.

From the very beginning, when it was recognized, that our climate is not constant, climatic variations were attempted to be related to the Sun (e.g. Herschel, 1801), but the more precisely it became possible to measure solar irradiance, the more it became apparent, that the fluctuations of the solar constant registered so far are too small to directly justify climatic changes.

However, it is generally supposed that the Sun affects the climate indirectly. Usoskin and Kovaltsov (2006) suggested a possible process of ionization by cosmic rays, while Ney (1959), half a century before, suspected an increasing and decreasing frequency of cloudiness due to minor temperature differences.

Over the solar cycle, the irradiance changes mainly in the UV part of the spectrum, which could lead to a weakening and
5   widening of the tropical Hadley cells and to shifts of the subtropical jet streams, or to a shift of the intertropical convergence zone (Vita-Finzi, 2011). Theoretical considerations, however, assume that even in the case of a grand, i.e. long duration minimum, as it is assumed for the MM, no significantly reduced irradiance should have occurred (van Dorland et al., 2006). Therefore, indirect mechanisms, such as changes in air currents and pressure patterns in the troposphere due to different heating of the stratosphere, seem more plausible (e.g. Ineson et al., 2011). In any case, other factors such as volcanic eruptions or the
10 El Niño phenomenon also seem to have a much more drastic effect on cloud formation than fluctuations in solar irradiance.

Lockwood et al. (2010) supposed that low solar activity leads to cold winters on the British Isles and parts of continental Europe, while leaving most of continental Europe untouched. According to this study, European climate, lying below the polar jet stream, might be influenced by solar activity, in such a way that it "blocks" the jet stream and thus upholds the mild, humid westerly winds that otherwise characterize English winter. Such "blockings" might push them further north, replacing them
15 with cold, dry easterly winds over parts of Europe. However, it is open to discussion to what extent fluctuations in solar activity change stratospheric winds, given the small magnitude of the changes in irradiance between solar maximum and minimum, and presumably also the MM.

Mounting evidence shows, that the climate of the MM – and the LIA in general – was neither globally synchronous nor regionally coherent (e.g. Neukom et al., 2019), therefore it is necessary to study historical records (and proxy data) from
20 different regions. While several studies from western and central continental Europe as well as from the British Isles have been carried out on the climate of the grand minimum period (e.g. Owens et al., 2017), Eastern Europe has so far been rather neglected. We try to contribute to closing this gap (Stangl and Foelsche, 2020) by studying historical sources in Transylvania. Results on historical records of solar activity from the same region have just been published in Solar Physics (Stangl and Foelsche, 2021).

25 Extensive work in order to look Europe-wide into the problem has been done within the frame of the EU project ADVICE. (e.g. Luterbacher et al., 2001; Xoplaki et al., 2001) and important conclusions reached regarding the diversity of the climate of the MM over the different parts of Europe. While it is difficult to compare these results, which include instrumental data as well as sophisticated reconstructions of sea level pressures, with our findings, general patterns regarding the individual years can help to fill in the gaps in a region with sparse data, as it is the case with Transylvania.

30 In the present paper, we look at the situation in the former Grand Duchy of Transylvania, which was initially dependent from the Ottoman Empire and then (since 1699) incorporated into the Habsburg Empire. Today, Transylvania is only a geographical term. It describes one of the three major parts of the Republic of Romania, which consists of the major regions of Wallachia, Moldova and Transylvania. Individual authors have already dealt with issues of climate history of that region in the past, e.g. Cernovodeanu and Binder (1993), whose work is only available in Romanian, but a detailed annual compilation has so far

been lacking. To achieve this, we consulted original sources of the time and were therefore able to reconstruct the MM climatically for Transylvania on an annual basis. In section 3 we summarize historical records for the individual years, most often in the form of English translations from German originals, where we try to conserve the original ductus. Further we compare the material from Transylvania with that from Germany, Austria and Switzerland (section 4). And finally, we

5 investigate for a more extended period (1500-1950) whether the climatic conditions of the time in Transylvania actually indicate solar forcing or not.

2. Study area and historical sources

Transylvania is one of the three major geographical regions that constitute today's eastern European state of Romania and is of comparable geographical latitude with Austria and Switzerland, although the Carpathian Mountains do not reach the heights

10 of the Alps. Today's climate of Transylvania can predominantly be characterized with Dfb (warm summer continental or hemiboreal climate) and Cfb (oceanic climate) according to the Köppen scheme (Szabo et al., 2020).

Table 1: List of localities mentioned in the text, given with their names in the three major spoken languages of the country and their approximate coordinates and altitudes.

Romanian	Hungarian	German	approx. Coordinates	approx. Altitude
Biertan	Berethalom	Birthälm	46°08′N / 24°31′E	388 m
Bod	Botfalu	Brenndorf	45°46′N / 25°39′E	506 m
Brasov	Braso	Kronstadt	45°40′N / 25°37′E	600 m
Cluj-Napoca	Kolozsvar	Klausenburg	46°46′N / 23°35′E	340 m
Codlea	Feketehalom	Zeiden	45°41′N / 25°26′E	565 m
Halchiu	Höltöveny	Heldsdorf	45°46′N / 25°33′E	507 m
Harman	Szászhermány	Honigberg	45°43′N / 25°41′E	529 m
Medias	Medgyes	Mediasch	46°10′N / 24°21′E	330 m
Nasaud	Naszód	Nösen	47°17′N / 24°24′E	331 m
Rasnov	Barcarozsnyó	Rosenau	45°36′N / 25°28′E	635 m
Sebes	Szászsebes	Mühlbach	45°58′N / 23°34′E	248 m
Sibiu	Nagyszeben	Hermannstadt	45°48′N / 24°09′E	431 m
Sighisoara	Segesvar	Schäßburg	46°13′N / 24°47′E	380 m
Vulcan	Szászvolkány	Wolkendorf	45°38′N / 25°25′E	606 m
Zarnesti	Zernest	Zernescht	45°34′N / 25°20′E	716 m

30 All cities and villages mentioned in the text are given in Romanian language, but are listed in Table 1 in the three major languages spoken within the region, i.e. in Romanian, Hungarian and German. Mountains, rivers and other landmarks appear in their official designations in Romanian, but Hungarian or German names are given in many instances in brackets to ease their identification in historical sources.

The richest sources regarding our study period, i.e. the 17th and 18th centuries, can be found in the southern and eastern part

35 of Transylvania (Sienerth and Wittstock, 1997). Extensive chronicles like those written by Miles (1670) or Kraus (reprinted 1862) complement casual notes with relevance for climate history that have been found, among them in the so-called Turmknopfschrift ("poppyhead document") deposited in August 1794 in the poppy head of the Protestant church of Zeiden

(today Codlea) written by the former pastor of this place and afterwards recovered and published about a hundred years later (Draudt 1903). While Matthias Miles (1639-1686) describes events from the century preceding his lifetime, he is regarded a very reliable source by historians (Sienerth and Wittstock 1997, Stangl 2020). An eyewitness of the events, or at least a contemporary observer for the events he was writing about, was the city clerk of Sighisoara, Georg(ius) Kraus(s) (1607-1679).

5   In 1650 he started with working on his Siebenbürgische Chronik (Transylvanian Chronicle), which deals with local events between the years 1608 and 1665, although the events between 1650 and 1665 get the most intense treatment and occupy about 75% of the whole chronicle. While Kraus is regarded as the most important chronicler of his time, for our purpose of extracting clues with climatic relevance, the clumsy written chronicle of his contemporary Daniel Nekesch Schuller (born in 1606 - year of death unknown) is a somewhat richer source. An important source for our study have been diaries, most notably those by

10 Johannes Stamm, a linen weaver and Paul Benckner, a trader, both from Brasov.

The results from Transylvania are confronted with data from Austria, Germany and Switzerland (understood in their current borders). The climatological history of Germany and Switzerland has been extensively studied in monographs by Glaser (2008) and Pfister (1999), while for Austria only local compendia exist and for more limited time spans, most notably the studies of Jäger (2003) for the Tyrol region and Strömmer for the region of Lower Austria (2003). However, extensive older literature

15 and sources exist and many years in our study period are well documented by Pilgram (1788) and Peinlich (1878, 1882). As for Transylvania, the only extensive historical study is the one by Cernovodeanu and Binder (1993) which is available in Romanian language only.

Figure 1 shows the title page of a typical contemporary source, the "Siebenbürgischer Würg-Engel" by Matthias Miles.
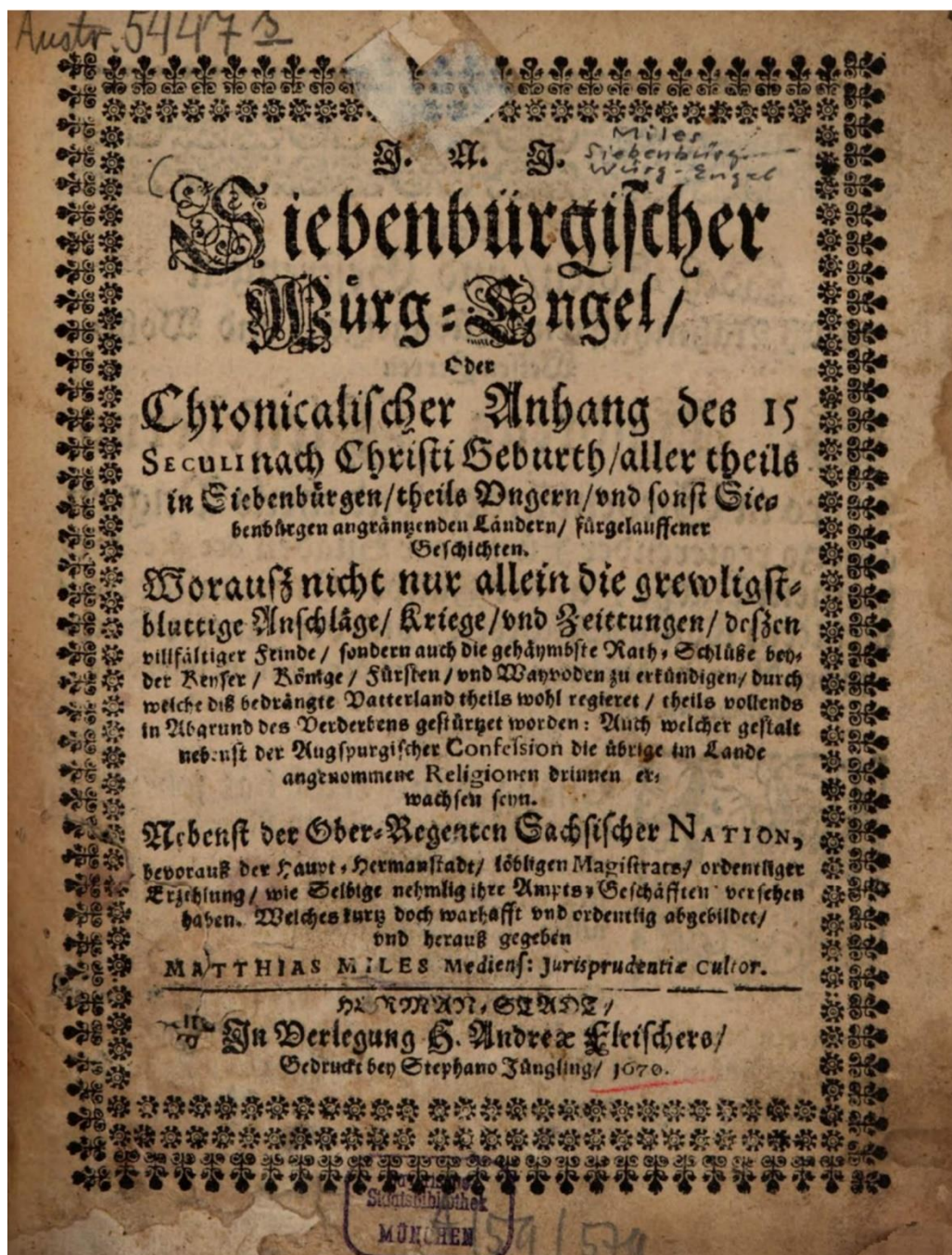
Figure 1: Title page of Matthias Miles' Siebenbürgischer Würg-Engel which reads "Transylvanian destroying angel or chronological appendix of the stories that occurred in Transylvania, partly in Hungary and in the other countries bordering on Transylvania in the 15th century AD, from which not only the horrific bloody attacks, wars, and news from various enemies of the country emerge, but also the most secret decisions of all emperors, kings, princes, and voyvods, through which its oppressed fatherland flourished in part, in part completely plunged into the abyss of ruin: in what manner besides the Augsburg confession the rest of the country's accepted religions have emerged." Courtesy Bayerische Staatsbibliothek München.

3. Annual characteristics of the MM in Transylvania

1645, the first year that solar physicists attribute to the MM, began with an extremely cold winter (Mild, 2010; 40). The summer
brought a plague of locusts (Armbruster, 1980; 394) and severe weather conditions: "On the day of St. John the Baptist (June
24) a large flood of water poured out and caused great damage. On the 11th day in July, the day of Eleneora, there was such a
5   big hail here in Cronen (Brasov) that one thought everything would get destroyed, the fruits of the earth destroyed in the whole
field; and then, after a short time there was such a big wind that one thought that everything would go to ruin; great damage
has occurred outside in the old town, in the barns and on the roofs. "(Nekesch-Schuller, 1903; 229). The winter of 1646 did
not seem unusually harsh to people, but on March 29, the cold returned for a short time: "On Maundy Thursday, a substantial
amount of snow fell." (Nekesch-Schuller, 1903; 230). The summer was very different from that of the previous year. According
10   to Georg Kraus, the city clerk of Sighisoara, there was not a single thunderstorm throughout the summer (Kraus, 1862; 165).
1647 was notable for inundations (Cernovodeanu and Binder, 1993; 123), 1648 by a harsh winter (Cernovodeanu and Binder,
1993; 123). In 1649, the winter was very long and severe. From December 6 of the previous year until April, the landscape
was continually snow-covered and people, as well as livestock, suffered from the great cold without interruption: "Anno 1649
is starting with a very cold and strong winter, because snow, which fell on December 6 the previous year, remained until April,
15   that is, for 4 months, during which the good grain was completely spoiled." (Kraus, 1862; 136). The autumn was characterized
by long-lasting rainfall: "Around November, as well as in the previous month, because of the constant rain and pouring water,
the soil is so soaked that everything, so to speak, has been swimming in the water; everywhere in Transylvania the roads have
become bad, and no one could travel without tying up many additional good horses and oxen, especially through villages and
swampy places, such as on the way to Nösen (Nasaud) (...); often, over 30 horses and oxen had to pull; (all of these) were signs
20   of ruin, just as many mountains and hills were broken and devasted in many places, according to the Psalm that the Earth is
tired of carrying such brood of hell (even longer); that is a sign of the Day of Judgement." (Kraus, 1862; 136).

1650 was apparently an unremarkable year. Only a strong storm in late winter seemed to be worth to report for the citizens of
Brasov: "On March 10, there was a terrible great wind at night that one thought everything was about to perish; (It) made a lot
25   of damage to the barns and buildings of the old town and trees were torn down and it also caused great damage to the roofs in
the city. " (Nekesch-Schuller, 1903; 233). In 1651, the Mures and other rivers caused inundations in January. A late frost at
the end of April damaged the fruits: "On April 26, heavy snow fell, which caused (such) a great and violent cold that the
vineyards and cherry orchards were completely ruined by frost, as was not often seen at the time, and the cost of a bucket of
grain was fl.[orin] 4.50 and fl.[orin] 3.30 at that time." (Nekesch-Schuller, 1903; 233). Strange weather conditions were noted
30   in Sighisoara: "Anno 1651. On May 3, it rained blood here in Segesvar (Sighisoara). In the current year, the time of ripeness
came very late, and the cherries and strawberries ripened only in August, and the roses bloomed in September." (Kraus, 1862;
183). In 1652, the winter was severe. Swarms of locusts bared the land in Moldova and then covered the ground in winter,
partly alive, partly dead. The plague was rampant in the country (Holban, 1968; 487). In the town of Medias a thunderstorm

in winter was interpreted as an omen by contemporaries: "Anno 1652. On February 16, in cold winter weather in Medias, very great wind and heavy weather with thunder and lightning hit the Church tower. This and the subsequent weather are once again signs of the ruin of Transylvania. "(Kraus, 1862; 188). For 1653, we lack climate-relevant information from the country. It can be assumed that the weather conditions met expectations, particularly that of farmers. In 1654, winter conditions prevailed for

5   more than half a year, namely until April, and beginning with September, the next winter started. "This year has been such a long, violent winter that in Holy Week (at the beginning of April) one could ride a sleigh." (Nekesch-Schuller, 1903; 238). "Nota. When the fruits in the country of Nösen (Nasaud) at the foot of the mountains ripened very late, a lot of snow falls in September and covers everything, so that the fruits have to be searched under the snow and it spoils a lot." (Kraus, 1862; 225). The short summer was characterized by floods: on July 12, the sun was grass-green when it rose; this was followed by

10 cloudbursts, which caused the streams and rivers to overflow their banks (Costin, 1976; 166); on August 23 there was another flood (Kraus, 1862; 175).

The severe winter that started early did not subside even after the turn of the year to 1655 (Cernovodeanu and Binder, 1993; 123). "April 19 brought a lot of snow due to God's punishment, so that in the gardens big fruit trees, grown 20 years ago, were

15 torn from the earth with roots by the hundreds." (Nekesch-Schuller, 1903; 239). Also in 1656 the winter is noted as severe (Cernovodeanu and Binder, 1993; 123), and the cold of the following winter of 1657 was also harsh, albeit with interruptions. In the middle of winter, the army of Prince George II Rakoczi could hardly cross the river Tisza. Due to a great inundation, the waters were swelled due to sudden snowmelt in the mountains of the Maramures, but then the cold fell again, and the Tisza froze (Szalardi, 1853; 298). In 1658 (Cernovodeanu and Binder, 1993; 123), and in the following years, there were many

20 complaints about bitter winter cold. "In October (1658) great snow fell, and did so much damage to the trees in the gardens and in the field, (and) to the fruit. One evil followed the other. Nulla calamitas sola." (Nekesch-Schuller, 1903; 239). In 1659, the winter was hard and long (Cernovodeanu and Binder, 1993; 123). "So, on May 31 in the night of Pentecost Sunday, it was snowing (so much) that in the morning the trees could hardly be seen; (the snow) melted the next day." (Stamm, 1915; 177).

25 In 1660 the winter was also very cold, but this time it was dry. There was a drought in summer, that was interrupted by sudden cloudbursts (Cernovodeanu and Binder, 1993; 90). In 1661, the winter was again severe and lacked snow. The summer was dry too, but the drought was repeatedly interrupted by heavy cloudbursts (Cernovodeanu and Binder, 1993; 91). In 1662, the weather was largely similar to that of the previous year (Cernovodeanu and Binder, 1993; 123). "An unusual snow fell on October 10, so you had to sow the grain in the snow." (Nekesch-Schuller, 1903; 263). Also in 1663, people complained about

30 a very cold winter and the drought of summer, which was very harmful to the harvest (Teleki, 1906 II; 528). "March begins, which should drive all evil vapors out of the earth and dry them out by the cleaning wind, but many harmful veils of mist are now emerging." (Nekesch-Schuller, 1903; 277). In 1664, winter was no less severe. For the fifth time in a row, there was a dry year, interrupted only by excessive downpours in summer, which also harmed the harvest. "On May 14, a very cold weather comes into (the time of) the flowering of the fruit, and there is also quite a bit of snow for two days; because we oppose God

with disobedience, God also sweeps us out of his annual order with the summer becoming winter, whereby the blessings of God are withdrawn from all fruit; but, O Lord, do not go to judgment with your servants, but be kind and gracious to us and promote the work of our hands. ... Bears, big and small, 21, come into the old town and the gardens, do great damage and also hurt a lot of people; and it is to be feared that these bears will become human bears and pull the skin over our ears with the

5   time ... On October 19, a heavy rainy weather mixed with snow develops for almost 8 days." (Nekesch-Schuller, 1903; 290).

In 1665, the winter was very cold again - "There was a lot of snow in all of Burzenland (Tara Barsei), which did a lot of damage to the fruits." (Konnerth, 2001; 112). The summer was plagued by heat and drought (Cernovodeanu and Binder, 1993; 123). The year 1666 has been described as a very fertile year (Mild, 2010; 46). "It was also a difficult winter this year because

10   the first snow that fell 14 days before Christmas Day (last year) remains very firm and heavy and persistent until March. Such an example (already) happened Anno 1608, and then there is a short and humid summer. Mense Aprili. At this time of spring, there comes a great dryness after the long winter." (Saeculum, 1915; 16). 1667 has gone down in history as a rainy year in Transylvania (Cernovodeanu and Binder, 1993; 123). "(On) July 22, the weather kills 3 Szeklers [people from Szekely district, Transylvania] in the field in front of Brasov." (Teutsch, 1903b; 107). An extremely early onset of winter in Brasov, at the foot

15   of the Carpathian mountains, shocked the people who got snow one day in late summer and their fruit trees suffered breakage; some trees are said to have been knocked down completely: "Anno 1667. Nota bene. On September 12, before dawn, there was so much snow, which fell at night, that many trees with fruit in the gardens were broken, and their roots were torn out." (Stamm, 1915; 191). 1668 was also a rainy year, and the warm part of the year was significantly shorter than the cold one. There was a major flood in Sighisoara at the end of January; the water came into the houses, and people had to flee to the attics

20   (Mild, 2010; 46). Between July 24 and August 5, there was constant rainy weather. The Tarnava Mare overflowed its banks and brought floods to Medias and Sighisoara (Toth, 1900; 146). "(On) April 1, Easter was with snow and strong wind (and) cold until the Sunday before Pentecost, and there was no sweet rain, but always snow mixed with cold winds. (...) from Easter to the day (Ascension Day; May 10) there is always snow and cold wind. July 26, (...) it started to rain until August 15, which resulted in a great flood of water, which you have never seen or heard before in the memory of men, with very great damage

25   to fruit, hay, and grass. Many buildings, houses, and mills are torn in several places, and the rainy weather lasted until August 15. Also, in Burzenland (Tara Barsei), 6 people died, and (sic!) drowned." (Teutsch 1915) "Anno 1668, October. After long rainy weather, there is a very nice, dry autumn without rain for a long time. However, quite a bit of snow fell early on October 20. And this year, the wine turned out well in Wallachia and there were all sorts of fruits in abundance." In contrast to the two previous years, drought dominated in 1669. Extreme heat and a wasp infestation prevailed in summer (Holban, 1968; 172).

30   "Anno 1669. From August 6 to November 6, there was no rain in Transylvania; after that, snow fell very early." (Saeculum, 1915; 19).

1670 was another rainy year; especially in March, April and June it rained continuously, and on August 13 a part of the city walls of Brasov collapsed due to flooding. In Moldova it is said to have rained constantly day and night in early summer. Fruit

and wine growing suffered from inundations in summer and frosts in autumn (Benckner, 1903; 187). Floods are also reported from the following year 1671 (Cernovodeanu and Binder, 1993; 123). 1672, however, was another year of drought; there was price increase and famine (Mild, 2010; 48). "Hoc anno is such a drought that you could not grind, but had to use the mortar and handmills." (Teutsch, 1903a; 345). In 1673 people groaned under a hot summer, which also brought hail; but there was "a

5   rich harvest of grain and wine". (Mild, 2010; 48). In 1674 there was a cold but dry winter; Water shortage everywhere, the mills stopped turning and there was an increase in prices (Mild, 2010; 48).

In 1675 the winter was severe and the summer was wet. Landslides and water damage have been reported from everywhere and the grapes did not ripen (Mild, 2010; 48). In 1676 a hot summer was recorded (Cernovodeanu and Binder, 1993; 123). In

10   1677 the winter was hard and the summer was rainy (Holban, 196; 352). 1678 had a very hot summer (Cernovodeanu and Binder, 1993; 123) and the Autumn was hot and dry too. "At this time of autumn it hadn't rained for several months and it was very dry weather, so that all you could do was sow in the dust; in the forests (with almost no exception) there were a lot of fires everywhere, which could not be extinguished, and so the most delicate forests burned with the many piles of wood in them, which resulted in no small damage." (Benckner, 1903; 199). 1679 was a humid year (Cernovodeanu and Binder, 1993;

15   123).

In 1680, as well as two years before, there was a hot summer (Cernovodeanu and Binder, 1993; 123), and a severe winter struck 1681 (Cernovodeanu and Binder, 1993; 123). 1682 was a year of famine. Furthermore, floods hit the country of Transylvania (Cernovodeanu and Binder, 1993; 123). A thunderstorm in late winter was reported in Tara Barsei: "On March

20   18 there was such a thunder and lightning as they are usually seen in the very highest of summer. This storm also hit a Vlach [Romanian] in Zernest [Zarnesti] together with his wife so that they both died. Afterward, a lot of snow fell. "(Benckner, 1903; 202). In 1683, one of the heavy winters was recorded (Cernovodeanu and Binder, 1993; 123), which occurred so frequently at that time. Also, in 1684 the winter was rough (Apor, 1863; 122). Even south of the Transylvanian Alps, people complained about a very harsh winter in Wallachia (Armbruster, 1980; 387). The year was also very rainy. In Moldova, it is said to have

25   rained continuously for four weeks in autumn. And finally, a cockchafer ("May beetle") infestation also occurred this year (Holban, 1968; 380f).

In 1685 there was another harsh winter (Cernovodeanu and Binder, 1993; 123). "The severe cold spoils the trees." (Teutsch, 1903d; 178). The warm season was severely shortened this year. "When people were on the hay-meadows on September 12,

30   it snowed an eighth of a snow (sic!) in the night." (Benckner, 1903; 215), In 1686, the winter was long. On April 15, it was snowing heavily at Thorenburg (Turda) (Szaniszlo, 1890; 503). The summer was very dry (Cernovodeanu and Binder, 1993; 99). 1687 was a rainy year (Cernovodeanu and Binder, 1993; 123), and in late spring, there was a bad cold snap: "May 26 (there) is such a cold that even sheep freeze to death." (Teutsch, 1903a; 99). In 1688 the winter was rough. (Cernovodeanu and Binder, 1993; 123). Rain and hailstones characterize the year 1689 (Cernovodeanu and Binder, 1993; 123). "In July such a

hail fell (in Tara Barsei) that the hailstones were as big as a walnut, as this had never been seen before; that spoiled the crops." (Konnerth 2001; 114).

In 1690, locusts invaded Moldova in such numbers that the sun was said not to have been seen for two months (Holban, 1968; 118f). Then they invaded Transylvania and darkened the sun over today's Cluj-Napoca. The summer was very hot (Toth, 1900; 327). "After a year of drought, there was again a terrible famine and price increase in Biertan." (Janesch, 1989; 138). In 1691, on May 24, a terrible storm struck Sibiu, Brasov, and Codlea, and on June 26, there was a devastating hailstorm; a little later, locusts invaded the country, and it was very hot and dry (Seyberger and Blasius, 1918; 441). "On the day of the Ascension of Christ (May 24) a fierce storm developed and moved over the Carpathian Mountains near Sibiu, where it divided. In Bucharest, it did great damage by striking the royal castle and lighting the powder in a tower, smashing nearby buildings. Still, the other (thunderstorm) approached our Burzenland (Tara Barsei) and threw a thick hail to the fields, which smashed all the grain in the field of Zeiden (Codlea) down to the roots, killing even crows, sparrows, and other small birds so violently that all the furrows and fields were full of skeletons; in some places, the earth was covered to the height of half a cubit. But the hailstones resembled a big chicken egg and could not melt in many days." (Annotata, 1903; 301). In 1692, there was drought. In August, a large number of locusts moved across the authorities of Hermannstadt (Sibiu) and Mühlbach (Sebes) (Draudt, 1903; 88f). 1693 was also a dry year. A cockchafer plague was followed by whole "clouds" of locusts that moved across the country. The summer was exceptionally dry (Apor, 1863; 130). Inundations are reported from 1694 (Cernovodeanu and Binder, 1993; 123).

1695 was also characterized by floodings (Cernovodeanu and Binder, 1993; 123). In autumn of that year, a cold spell damaged the wine cultures: "October 5, the cold spoils the wine." (Teutsch, 1903c; 408). Calamities have also been reported from 1696: on May 14 hoarfrost (Breitner, 2005; 146), later floods (Cernovodeanu and Binder, 1993; 123). "On August 21, great hail fell on the field of Zeiden [Codlea], Brenndorf (Bod), and Heldsdorf (Halchiu), which injured people and killed many birds and threshed the grain" (Teutsch, 1903b; 115). In 1697, there were inundations (Cernovodeanu and Binder, 1993; 123), while in 1698, the summer was particularly hot (Cernovodeanu and Binder, 1993; 123). In 1699, torrential rain fell over Transylvania between June 2nd and 5th. Particularly in the administrative district of Sibiu and in the mountains of the Siebenrichtergebirge (Muntii Lotrului) there were violent cloudbursts so that the river Cibin inundated the fields and flooded the swamps and ponds outside the city walls of Sibiu; the mountain streams of the so-called Transylvanian Alps south of the city swelled to torrents, which tore down mills and huts. In Sibiu itself, pouring streams flowed through the alleys, and water entered the houses through doors and windows (Fuchs and Lupinus, 1848; 284).

In 1700 there was a very severe and prolonged winter; only in April did the snow melt (Bielz, 1862; 57). Also the 18th century began with the grim winter of 1701 (Cernovodeanu and Binder, 1993; 205). In 1702 there was rainy weather all over the country and large, "never heard of" inundations (Rhethly II; 28). 1703 was a dry year (Cernovodeanu and Binder, 1993; 205) and even more 1704, where "terrible drought" is mentioned. (Rhethly II; 28).

1705 and 1706, however, were described as rainy years (Corfus, 1975; 171). From the year 1707, we have no climate-relevant testimony from Transylvania. Still, beyond the border, in Moldova, the air was so filled with flying locusts that they darkened the sunlight like clouds (Camarian, 1965; 23). In 1708, the weather was extremely dry (Cernovodeanu and Binder, 1993; 205), and the winter was so mild that it was practically non-existent at least at the beginning of the year: "Anno 1708. Just as we had

5   ended the past year with a lovely summer's day, we started this one with the most pleasant spring weather and brightest sunshine; the oldest people in this city testified, not without surprise, that during their lifetime they had no idea of such May weather in the winter months." (Christophori, 1915; 289). There was no rain in Honigberg (Harman) from August 21 to October 11 (Konnerth, 2001; 115). As extremely mild as the winter was that year, it showed itself from the grim side in the following of 1709: "It is so cold at the beginning of the year that many people, cattle and trees freeze to death, and the waters freeze to

10   the bottom (Teutsch, 1903d; 178). In June, locusts invaded Transylvania via the Bran pass (Armbruster, 1980; 395). "When Charles XII (of Sweden) fled to Bessarabia this year, there were swarms (of locusts) from the Black Sea that rose like a storm wind and fell like hailstorms that his infantry and cavalry could neither see, nor get away." (Pilgram, 1788; 314).

In 1710 there was a terrible drought accompanied with unbearable summer heat; in Moldova locusts filled the air, darkening

15   the sky and causing a terrible roar. They left the forests bare as if it were winter (Holban, 1968; 317f). When they came to Transylvania, they began to kill each other, so that people waded in their carcasses up to the ankles (Cserei, 1852; 441). "Again the strongest springs dried up and also many water-rich rivers in such a way that one had big problems with grinding." (Teutsch, 1903d; 178). The drought also had tragic consequences due to superstition: "(On) August 15, a weather maker from Wolkendorf (Vulcan), had put in the spring the dew from 3 meadows into a sack of leather so that it would not rain for a long

20   time. A prolonged heat followed this in Rosenau (Rasnov), so she was sentenced to death in prison ... On September 21, white and red roses bloomed, and in some places, the fruit trees also bloomed like in the spring." (Seyberger and Blasius, 1918; 458). 1711 was a year with another plague of locusts, probably because of the weather: In Moldova, people complained about unbearable heat and drought in summer (Holban, 1968; 559ff), while in Transylvania floods in the area of the so-called Drei Stuehle took many mills with them; The damp weather also caused the grapevines to rot, and only little and inferior wine was

25   made (Cserei, 1852; 475). In 1712, after inundations in spring, an exceptional drought occurred and led to a poor harvest (Acsady, 1896; 371). In autumn, locusts fell in again and hibernated in the Maramures region. In 1713 there was no sign of dry conditions. On the contrary: inundations were reported in summer (Rethly, 1970 II; 57f). In 1714, however, from February 28 to June 20, there was no rainfall in the whole country, causing the grain to spoil. (Teutsch, 1903a; 348). 1715, the last year of significantly reduced solar activity, was rainy in Transylvania (Acsady, 1896; 319).

30

We note that quite some years during this period had harsh winters – but also dry summers, which is compatible with a higher frequency of blockings (cf. Luterbacher et al., 2001), however, this was apparently not a continuous feature of the entire period – at least not in Transylvania (see also Table 2 below). Particularly interesting is the *small* number of severe winters during the last decades of the MM.

4. Annual comparison with data from Germany, Austria and Switzerland

In the following, the geographical regions Germany, Austria and Switzerland are understood in terms of their current borders, unless otherwise noted (the results are summarized in Table 2 at the end of this section).

While the winter of 1645 was described as exceptionally cold in Transylvania, Germany had average conditions (Glaser, 2008; 150). However, in Styria, in Austria, there was a freezing winter (Peinlich, 1882; 321), and in Switzerland, the lakes were mostly frozen in January and, there was snow in the lowlands (Pfister, 1999; 104). The winter of 1646, was described in Germany and Austria (Peinlich, 1877; I.515) severe like the one in Transylvania, while the dryness that was rather hinted than complained in Transylvania was lamented throughout Europe (Pilgram, 1788; 175). 1647 was a rather inconspicuous year in Germany. The inundations that occurred in Transylvania found their counterpart in Vienna, when the Danube flooded its banks in August after days of rainy weather (Pilgram, 1788; 150). 1648, the year in which the terrible Thirty Years' War ended with the Peace of Westphalia, brought an average winter to Germany (Glaser, 2008; 151), so the severity of the Transylvanian winter this year may be somewhat overstated due to the lack of quantification. The severeness of the Transylvanian winter of 1649, however, is supported by reports from Germany, where it also lasted until April and where wolves invaded the villages. And, just as in Transylvania, autumn was described as cold and wet (Glaser, 2008; 152). In Switzerland and Austria, however, no exceptional conditions were noted.

1650 was an average year in Germany with rather mild winter conditions (Glaser, 2008; 153). Even in Switzerland and Austria (Pilgram, 1788; 150), the year was not climatically noticeable, which is in good agreement with the reports from Transylvania. In 1651, there were no unusually cold winter conditions in Germany (Glaser, 2008 153), Austria (Pilgram, 1788; 252), and Switzerland. From late spring to mid-May, cold weather was also recorded in Germany, accompanied by rain, hail, and even snowfall (Glaser, 2008; 154), which corresponds to the above-quoted report by Nekesch-Schuller from Transylvania. The severe Transylvanian winter of 1652 cannot be confirmed in Germany, Switzerland, and Austria. On the contrary: in Germany, the winter was exceptionally mild that year (Glaser, 2008; 154). The year 1653, missing from our collection of Transylvanian sources, has not been noticed as unusual in Germany, Austria, and Switzerland either, which may explain the silence of the Transylvanian chroniclers about the weather this year. 1654 was either less cold in Germany than in Transylvania, or the chroniclers forgot to mention a few warm periods. Glaser (2008; 154) stated that the first half of winter was characterized by temperatures well above average. The river Main did not freeze until mid-February, and the winter cold continued through March. The following winter started in Germany at the end of November, two months later than in Transylvania.

The harsh winter of 1655 is confirmed by Austrian sources (Peinlich, 1877; I.535, Pilgram, 96), while Germany shows the differentiated picture of a changeable winter with alternating warm and cold periods (Glaser, 2008; 155). The situation is similar within the subsequent winter of 1656. Austria also reports it as strict (Peinlich, 1877; I.537), while Glaser for Germany has very different regional conditions. Only in southern Germany, according to the sources, does the winter seem to have been

severe (Glaser, 2008; 155). Even in 1657, winter conditions were quite different regionally. The winter in Germany was generally mild and rainy, but not in East Prussia, where a severe winter is reported. (Glaser, 2008; 156) Winter was also harsh in Austria, at least in the province of Styria (Peinlich, 1877; I.537). 1658 had an extreme winter, and in large parts, especially in Germany, it was long and snowy. The cold was so great that this year's winter is considered to have been one of the worst.

5   The Baltic Sea was frozen, wolves, and other wild animals invaded villages and towns. Even the great rivers and streams froze over. In this respect, it may come as a surprise that the Transylvanian winter was described as harsh, but not as outstanding compared to other contemporary winters or the following one in 1659, which was not particularly severe in Germany, but a lot more in Austria. Peinlich stated, "It was even colder (than the last) winter. The wine was freezing, that you had to split it with axes." (Peinlich, 1877; I.537).

In Germany (Glaser, 2008; 158) and Italy (Pilgram, 1788; 96), the year 1660 was counted among the harsh winters, and the so-called "Seegfrörne" (freezing of the lake) occurred at Lake Constance, meaning that it froze on the surface. As far as the drought of the year is concerned, there was no complaint about it in Central Europe, Glaser (2008) notes that the summer was characterized by good weather and little rainfall. 1661 was also a dry year in Transylvania, but in Germany this was only valid

15   for spring and the first half of summer. In winter, the conditions were felt to be exactly the opposite. While it was portrayed as strict and dry in Transylvania, Glaser considers the winter in Germany as very mild and humid. Even in 1662, the winter in Germany and Austria (Peinlich, 1877; I.541) was remarkably mild, while in Transylvania, it was counted as a harsh one. The lack of snow reported from Transylvania was also reported from Bohemia (Peinlich, 1877; I.320). In 1663, the winter in Germany was characterized by extremely low temperatures and an abundance of snow (Glaser, 2008; 158). The drought of the

20   Transylvanian summer found no counterpart in the German countries, on the contrary: June was rainy, stormy and cold there. At the beginning of July, there was warm summer weather for a few days, after which rainy and cool conditions set in. It was only in autumn that it became warm and dry. Also, in 1664 conditions were experienced rather differently in Germany than in Transylvania. Only the cold of the second half of winter was also felt in German countries. The year began mild in Germany, but severe winter cold set in in mid-January. Spring and summer were not uncommon, but autumn was characterized by cool

25   and rainy weather (Glaser, 2008; 159).

In 1665, the correspondence of the conditions in Germany, Austria, and Transylvania is evident. A freezing winter and a hot summer were noted in all three regions. (Glaser, 2008; 160, Pilgram, 96). However, the year 1666, was, compared to Transylvania, completely different in Germany, Austria, and Switzerland, where the striking feature was a summer

30   characterized by extraordinary heat and extreme drought (Glaser, 2008; 160, Pilgram, 175, Pfister, 131). There is no mention of a harsh winter there - on the contrary: Germany experienced an ordinary winter with a rather mild character (Glaser, 2008; 160). 1667 was also a rainy year in Austria (Pilgram, 1788; 151). Summer cold was reported in Switzerland, and in mid-June, there was knee-deep snow in the hilly country of Central Switzerland (Pfister, 1999; 144). The onset of winter in Germany was later than in Transylvania, but still early: In the middle of November, suddenly heavy snowfall set in (Glaser, 2008; 160).

1668 was a humid and mild winter in Germany. In March, there was a brief cold spell. The summer was cool and so rainy that the harvest had to be postponed to September. December was so mild in the east of the German Empire that the flowers came out. At Ulm, however, the Danube froze at the turn of the year (Glaser, 2008; 161). Overall, the conditions were not unlike those in Transylvania. The exceptional drought and summer heat of 1669 was confirmed in Germany (Glaser, 2008; 161) and

5   Switzerland (Pfister, 1999; 131). Despite inundations in Tyrol in July, the Austrian summer seems to have been similar; Pilgram particularly highlights the excellent wine of this year (Pilgram, 1788; 252).

The summer of 1670 was also rainy in Austria (Peinlich, 1878; II.440), but in Germany it was pleasantly warm (Glaser, 2008; 161). While the chroniclers in the Principality of Transylvania did not complain about winter cold this time, a hard winter was

10   reported from Germany (Glaser, 2008; 161) and Austria (Peinlich, 1878; II.440). The inundations that hit Transylvania in 1671 found their counterparts in Friuli (Pilgram, 1788; 151). In Germany this year attracted attention due to its mild weather all year round (Glaser, 2008; 162). 1672 was in Germany and Austria completely contrary to the conditions in Transylvania. From mid-July, rainy weather appeared in Germany and more or less characterized the rest of the year (Glaser, 2008; 162). It was a cold and wet summer in Austria (Peinlich, 1877; I.552). The situation was similar in the following year 1673, when the summer

15   was dry in Transylvania but wet in Austria, Switzerland, and Germany, where the summer was also cool (Glaser, 2008; 162). In Switzerland, rains at the beginning of summer led to inundations (Pfister, 1999; 161). As a result of constant rains in Austria, the Inn River flooded its banks, followed by the Danube in July, while in Germany the Elbe inundated in August (Pilgram, 1788; 151). In 1674, winter was hard in Germany. The three winter months were frigid, and the sea froze on the coasts (Glaser, 2008; 163). In western Central Europe, there was no trace of the drought prevailing in Transylvania, on the contrary, it was a

20   very wet year in particular in Bohemia (Peinlich, 1877; I.552) and the wine yields were few and poor (Pilgram, 1788; 252).

In June 1675, snow lay in Bern. In July, people went out with thick jackets, and in August, snow fell in the village of Einsiedeln at 880 m above sea level. Higher alpine pastures remained buried under the snow cover all summer (Pfister, 1999; 156). In southern Germany, winter was abnormally warm. Flowers are said to have grown in mid-January. Spring was rainy, and cool,

25   wet weather and inundations prevailed in summer, so the wine was bad and sour (Glaser, 2008; 164). The summer of 1676 brought beautiful, warm weather to large parts of Germany (Glaser, 2008; 164) and Switzerland (Pfister, 1999; 156). The vintage quality was praised in Austria (Pilgram, 1788; 252), which indicates a hot, dry summer as it was experienced in Transylvania. The winter of 1677 was not perceived as exceptionally cold in western Central Europe, although it varied widely from region to region in Germany (Glaser, 2008; 164). In Switzerland, the late summer was dry and yielded good wine (Pfister,

30   1999; 166), but in Germany, the summer was cool so that the wine was only mediocre (Glaser, 2008; 164). 1678 was also extremely hot and dry in Germany. The grape harvest started early, and the wine tasted excellent (Glaser, 2008; 165). In Austria, the summer was hot, but not dry (Peinlich, 1877; I.130). The wet annual characteristic of 1679 in Transylvania matches the reports from western Central Europe. According to Glaser (2008; 165), the summer in Germany was stormy and rainy, and Pilgram (1788; 151) notes for Austria: "The famous preacher in his day; Abraham [a Sancta Clara], an eyewitness, complains

about the unstable weather and frequent rain, which arose from the great plague that broke out here in mid-July. So the spring, and (at least) the first part of summer was damp."

In 1680, in Germany, people complained about the heat and drought starting in July (Glaser, 2008; 165). A very dry autumn, in which the temperatures were so high that the pear trees could be seen blooming again, was recorded in Switzerland (Pfister, 1999 166). Quantitatively good vintage is reported in Austria. (Pilgram, 1788; 252) In 1681, winter was extraordinarily cold in Germany, as was the spring. Increasing drought and heat, which then became extreme in summer, plagued Germany and Austria (Peinlich, 1878; II.131) and Switzerland (Pfister, 1999; 166). In the mild winter of 1682, inundations occurred in Germany (Glaser, 2008; 166). Austria experienced "unfortunate weather, its main character was wetness, even in summer; pestilence." (Peinlich, 1878; II.131). In 1683, winter in Germany was only of average cold, or even too mild regionally; only in East Prussia was it clearly severe (Glaser, 2008; 166). Lake Traunsee in Austria was frozen (Strömmer, 2003) and even the water near the coasts of the Adriatic is said to have frozen. (Pilgram, 1788; 97). In England, this winter was so cold that the Thames got 11 inches of ice (Peinlich, 1878; II.460). The subsequent winter of 1684 was extreme in all German-speaking countries. In Germany, it was "cruelly cold" and fairs were held on frozen rivers. At the end of March, there was ice on the streets in Königsberg (Kaliningrad) (Glaser, 2008; 168). In Switzerland, wine turned to ice in January and February, and trees split with a loud bang (Pfister, 1999; 92). Heavily loaded wagons moved across the frozen Rhine, and Lake Constance could be traversed from Hagenau to Münsterlingen on foot (Pfister, 1999; 93). Also in Austria, the cold was noted as "extraordinary" (Peinlich, 1878; II.137).

In 1685, the reports from Germany and Switzerland confirm the news from Transylvania again. Only in Austria, the winter cold seemed not worth mentioning to the chroniclers. In Germany, the winter was very severe, and Lake Constance froze as in the previous year. The sea at the coasts was covered with ice, and it was snowing on many days. Storms and snowfalls lasted into April, and there was still ice on the streets of East Prussia until the middle of the month (Glaser, 2008; 168). The cold winter of this year did not seem to end for people in Switzerland either. Rivers and lakes were covered in thick ice. Even in the middle of the summer, on July 26th and 27th, it was still snowing at lower altitudes, even in Zurich (400 m above sea level), snow is said to have fallen (Pfister, 1999; 102). In 1686, winter was only in Transylvania considered to be very long. In Germany, the winter was also very mild (Glaser, 2008; 169), and from Switzerland, we even find the opposite of what the Transylvanian chronicler reports. Vegetation started very early, at least in the eastern Alpine valleys. Austria only commemorates a good wine year (Pilgram, 1788; 253), which agrees well with the Transylvanian summer drought. he summer was also hot in Germany (Glaser, 2008; 169). The unusual cold that hit Transylvania at the end of May 1687 had its counterparts in Germany and Switzerland. In the first part of April, it snowed almost every day in Leipzig, but it suddenly became very hot in May. In summer, cool and rainy weather dominated, as in Transylvania (Glaser, 2008; 169). In Switzerland, there was snow throughout April in the village of Einsiedeln at 880 m (Pfister, 1999; 113). From Austria we learn about an "excellent summer with wine and fruit in such abundance that the branches broke under their load; afterward, rainy." (Peinlich, 1878; II.143). The

cold Transylvanian winter of 1688 did not have a counterpart in western Central Europe. There was an average winter in Germany (Glaser, 2008; 170), and it was not considered to be unusual in Austria and Switzerland either. In 1689 the spring was cold and wet in Germany, but summer was warm and dry (Glaser, 2008; 170). In Switzerland and Austria, the year was primarily characterized by many avalanches in winter (Pfister, 1999; Peinlich, 1878, II.461).

"Huge locust swarms in Hungary" (Peinlich, 1878; II.145), are mentioned in 1690 on the occasion of the description of that year's wet summer in Austria. The year was also marked by moisture in Germany, although the summer varied from region to region (Glaser, 2008; 170). The hot and dry summer in Transylvania and the generally wet weather conditions in western-Central Europe may have been responsible for the fact that locust swarms accumulated in extreme density in Eastern Europe.

10 While the summer of 1691 was rainy in Germany (Glaser, 2008; 171), it was rather dry and hot in Austria. Throughout the summer, there were violent thunderstorms without cooling the air (Peinlich, 1878; II.147). The conditions were not unlike those in Transylvania, but locusts again spared Europe's western parts. In 1692 they also haunted Transylvania but spared the Holy Roman Empire, where the summer was generally rainy and chilly (Glaser, 2008; 172, Pilgram, 152). In the following year, 1693, summer drought and heat also prevailed in western Central Europe (Glaser, 2008; 172; Jäger, 2003; 114), so that

15 locusts penetrated Austria (Peinlich, 1882). In 1694, Germany experienced a cool and rainy summer (Glaser, 2008; 173). From Austria, it is mentioned that the wine was not only sour but also very little (Pilgram, 1788; 253). In Tyrol, the year was wet and cold. In the Bolzano area, however, summer was said to be hot and dry (Jäger, 2003; 162).

The summer of 1695 was cool and rainy in Germany (Glaser, 2008; 173). Pilgram (1788; 253) notes "Miserable Wine" for

20 Austria. The conditions were similar to the Transylvanian. Poor conditions characterized the whole of June in 1696, but summer became warm and pleasant, at least in southern Germany (Glaser, 2008; 174). 1697 stood out in Western Europe due to an extremely cold and snowy winter (Glaser, 2008; 174, Pilgram, 97, PGPS, II.151). Spring was normal in Germany, summer unstable, and wet and stormy weather prevailed at harvest time (Glaser, 2008; 174). In 1698, conditions seem to have been contrary between the Holy Roman Empire and Transylvania. A long, heavy, and snowy winter was reported from Germany

25 and Switzerland. Wet and cold weather dominated the rest of the year, and the wine tasted terrible (Glaser, 2008; 175). In 1699, Transylvania was incorporated into the Habsburg Empire, but in terms of climate, the year was unremarkable.

Not only in Transylvania was the winter of 1700 extreme. In Austria, people and livestock froze to death, and even the fish in the ponds perished. "On March 15, it was still so cold that the spittle turned to ice before it fell to the ground." (Strömmer,

30 2003; 101). In Tyrol the temperatures likely dropped to below -30 °C, since some church bells cracked. In February there was also a lot of snow (Jäger, 265). It did not look any better in the north of the continent: "The Baltic Sea was covered with ice 10 miles from the coasts." (Strömmer, 2003; 101). A harsh winter did not open the new century in Central Europe like it did in Transylvania. In Germany, it frequently rained in the winter of 1701 (Pilgram, 1788; 207), while in Austria, high temperatures and exceptional drought dominated the year (Strömmer, 2003; 101). Only in Switzerland, especially at higher

altitudes, was there a lot of snow in April (Pfister, 1999; 114). The rainy year 1702 had its equivalent in Italy, where it rained almost continuously for four months, beginning at the end of February. On the other hand, great drought was reported from Austria as in the previous year (Strömmer, 2003; 102). Neither exceptionally dry nor exceptionally moist conditions were reported from Germany and Switzerland. In 1703 the wine became excellent in Austria "despite" an extreme drought
5 (Strömmer, 2003; 103). While the dry conditions in Transylvania continued in 1704, and Italy also suffered from July to October, summer in Switzerland was regarded as pleasant with sunny weather and not excessive warmth. In Austria, some witnesses considered the year to be even a rainy one, especially in Styria (Pilgram, 1788; 153).

1705 was rainy in Transylvania, and also Austria had wet conditions most of the year (Pilgram, 1788; 153). In Switzerland,
10 conditions have been more differentiated: July was hot, and August was also dry with pronounced summer heat, and there was very little snow in the high mountains. In October, Foehn storms swept across the Alps (Pfister, 1999; 169). 1706 was also a humid year in Transylvania. In Austria, however, at least winter and spring were very dry (Strömmer, 2003; 104). 1707 seems not to have been exceptional in Central Europe, while the strikingly mild Transylvanian winter of 1708 also prevailed in Germany (Glaser, 2008; 181) and Austria. However, there also occurred heavy snowfall there regionally (Strömmer, 2003;
15 105). Richard Peinlich clarifies: "It was so mild in the winter that the flowers bloomed around Ödenburg (Sopron) in February, but one day the cold in Styria was so strong that the wine froze in Pettau (Ptui)." (Peinlich, 1878; II.156). The severeness of the winter of 1709 prevailed in large parts of Europe, where it became known as "great frost" or "great winter". Glaser mentioned an extremely harsh winter for Germany (Glaser, 2008; 181), Peinlich in Austria called it the "coldest winter in a hundred years; the length and roughness of the same is said to be extraordinary everywhere; snow still fell in Ödenburg on
20 May 17". (Peinlich, 1878; II.157). In Switzerland, the cold in January was so great that the cattle were taken into the parlors in some places to save them from freezing to death. Birds are said to have fainted on the ground so that they could be caught by hand (Pfister, 1999; 102).

The year 1710 brought extreme drought to Germany, but only in autumn (Glaser, 2008; 182). In contrast, the following year,
25 1711, in western-central Europe was slightly humid in western Central Europe (Pilgram, 1788; 153; Strömmer, 2003; 108). 1712 was unremarkable in Germany and Switzerland. In Austria, the harvest failed as in Transylvania, but for a different reason. There were frequent storms in summer. The wine became delicious but was available only in very reduced quantities (Strömmer, 2003; 108). "Very changeable weather, so the harvest is bad", is reported from the province of Styria (Peinlich, 1878; II.178). The summer floods in Transylvania in 1713 had their equivalent in Austria. After a rainy May, there were
30 inundations in June, which destroyed mills (Strömmer, 2003; 109). The dry conditions of 1714 did not show up in western Central Europe. The weather in Germany, Austria, and Switzerland was very unstable and precipitation was rare (Glaser, 2008; 183). In 1715, the conditions were finally rainy, not only in Transylvania but also in Austria, at least in summer. Winter was temperate and dry in the province of Styria, but after that, the weather was even more changeable and unhealthy than last year's (Peinlich, 1878; II.230).

Table 2: Synoptic comparison of weather phenomena for Transylvania, Germany, Switzerland and Austria. All entries are discussed in the text and the respective references are given.

Year	Transylvania	Germany	Switzerland	Austria
1645	Harsh winter; Locusts; Storms	Normal winter	Long winter	Snowy winter
1646	Heavy snow on March 29	Harsh winter	–	Cold winter
	Summer without thunderstorms	Variable Summer	–	Dry summer
1647	floods	–	–	floods in August
1648	Harsh winter	Normal winter	–	–
1649	Long and Harsh winter with much snow	Long and Harsh winter	Normal winter	Normal winter
	cold and wet Fall	cold and wet Fall	–	–
1650	Harsh storm on March 10	Normal conditions	Normal conditions	Normal conditions
1651	floods in January	Normal winter	Normal winter	Normal winter
	Big snow and very cold at end of April	Cold April and May	–	–
1652	Harsh winter	Very mild winter	Normal winter	Normal winter
1653	–	Normal conditions	Normal conditions	Normal conditions
1654	Winter lasting until April	Only second half of winter cold	–	–
	New winter arrives in September	New winter arrives in November	–	–
1655	Harsh, long lasting winter with a lot of snow	Very changeable winter temperatures	–	Harsh winter
1656	Harsh winter	Harsh winter in the south of Germany	–	Harsh winter
1657	Harsh winter with interruptions	Mild winter in most parts of Germany	–	Harsh winter
1658	Harsh winter	Extremely cold and long winter	–	Cold winter with lots of snow
	New winter arrives in October	Cold September, warm November		
1659	Long and Harsh winter	variable winter	–	Extremely cold winter
1660	Harsh, but dry winter	Harsh winter	–	–
	Drought	Few rain in summer	–	–
1661	Harsh, but dry winter	Winter mild and dry	–	–
	Drought	Dry conditions in spring and summer	–	–
1662	Harsh, but dry winter	Mild winter	–	Mild winter, few snow in Bohemia
	Drought	–	–	–
	Snowfall on October 10	–	–	–
1663	Harsh, but dry winter	Extremely cold and long winter	–	–
	Drought	Summer wet and cold, dry autumn	–	–
1664	Harsh winter	Winter starting mild, but getting cold	–	–
	Drought interrupted due to heavy summer rains	Normal summer, rainy autumn	–	–
1665	Very cold, snowy winter	Very cold winter	Very cold winter	Very cold winter
	Summer hot and dry	Hot summer	Hot summer	Hot summer
1666	Harsh, long lasting winter with a lot of snow	Rather mild winter	–	–
	A year of great fertility	Summer very hot and dry	very hot and dry summer	very hot and dry summer
1667	Rainy year		Snow in June	Rainy year
	Big snowfall on September 12	Big snowfalls starting mid November	–	–
1668	Long winter	Winter mild, short cold phase in March	–	–
	Rainy summer	cold and rainy summer	–	–
	Snowfall on October 20	Warm December	–	–
1669	Very dry and hot summer	Very dry and hot summer	Very dry and hot summer	–
1670	Persistent rain from March to June	–	–	Rainy summer
	Cold autumn	–	–	–
1671	floods	Mild conditions during whole year	–	floods in Friuli
1672	Drought	Rainy during second half of year	–	cool and wet summer
1673	Hot summer, rich crops	Summer cool and rainy	Heavy rains in early summer	Rainy summer
1674	Harsh, but dry winter	Harsh winter	–	Wet and dry in Bohemia
1675	Harsh winter	Very mild winter in the south of Germany	Snow in summer	floods at Praha
	Wet summer	Summer cool and wet	Snow in summer	floods at Praha
1676	Hot summer	warm and pleasant summer	warm and pleasant summer	Good wine
1677	Harsh winter	Great regional differences in winter temperatures	–	–
	Rainy summer	Cool summer, wine mediocre	Summer dry, good wine	–
1678	Very hot summer and autumn	Summer very hot and dry	–	hot, but wet summer
1679	Wet year	Summer stormy and rainy	–	Wet year
1680	Very hot summer	July hot and dry	Autumn warm and dry	Wine in big quantity
1681	Harsh winter	Harsh and long winter	–	–
1682	floods	Inundations	–	Wet year
1683	Harsh winter	Harsh winter only in East Prussia	–	Harsh winter
1684	Very Harsh winter	Very Harsh winter	Very harsh winter	Very Harsh winter
1685	Harsh winter	Harsh and long winter	Severe and very long winter	–
1686	Long winter	Mild winter, not long	Short winter	–
	Drought in summer	Very warm summer	–	Good wine
1687	Great cold on May 26	Many snowfalls in April	Snow in April	–
	Rainy year	Summer cool and wet	–	Rainy autumn
1688	Harsh winter	Normal winter	Normal winter	Normal winter
1689	Strong hail shower in July	Summer warm and dry	–	–
1690	Very hot summer, drought, locusts	Summer rather wet	–	Wet summer
1691	Strong storms and hailshowers in May and June	–	–	Strong thunderstorms during summer
	Very hot and dry summer	Rainy summer	–	Summer dry and hot
1692	Drought, locusts	Cool and wet summer	–	Cool and wet summer
1693	Drought, extreme in summer; locusts	Hot and dry summer	–	Hot and dry summer; locusts
1694	floods	Cool and wet summer	–	Wine few and sour
1695	floods; Cold snap in autumn	Cool and wet summer	–	Very bad wine
1696	floods; Hail showers	Warm and pleasant summer	–	–
1697	floods	variable, wet and stormy summer	–	–
1698	Very hot summer	Cool and wet summer	Snowfalls in August	–
1699	Heavy rain at beginning of June	Normal conditions	–	Rather bad weather
1700	Harsh, long lasting winter	Extremely cold winter	–	Extremely cold winter
1701	Harsh winter	Mild winter	Snow in April	Very few snow in Tyrol
1702	Rainy year, Great floods	Normal conditions	Normal conditions	Very dry year
1703	Drought	–	–	Drought
1704	Drought	–	Pleasant summer	Rainy year in Styria
1705	Rainy year	–	Summer and autumn hot and dry	Wet year
1706	Rainy year	–	–	Winter and spring very dry
1707	–	Normal conditions	Normal conditions	Normal conditions
1708	Very mild winter	Very mild winter	–	Very mild winter
1709	Very cold winter	Very cold winter	Very cold winter	Very cold winter
1710	Very hot summer with extreme drought and locusts	Extreme drought in autumn	–	–
1711	Wet summer	Wet year	Wet year	Wet year
1712	Drought in summer	Normal conditions	Normal conditions	Rainy summer
1713	floods in summer	–	–	Floods in summer
1714	No rain between February 28 und June 20	Rainy spring	–	Wet spring
1715	Rainy year	–	–	Rainy summer

Table 2 shows the main weather characteristics for every year of the MM in Transylvania and the correspondences of the listed phenomena for Germany, Switzerland, and Austria. All entries were discussed here in the text, and the respective sources were given.

5. The decades before and after - comparison with the fluctuations in solar activity

5   As part of FWF project P 31088, we have created a still unpublished database that traces the climate of Transylvania down to the year 1500 CE in almost annual resolution (Stangl and Foelsche, 2020). From this data set, we counted the reported unusually cold or mild winters (Fig. 2) and particularly hot or cool summers per decade (Fig. 4) and compared these numbers with a graph of the reconstructed strength of the solar activity (Fig. 3), as published by Wu et al. (2018), which ends in 1889. For the later decades up to 1950, we used the annual SILSO sunspot numbers (Sunspot Index and Long-term Solar

10   Observations, source: Source: Royal Observatory of Belgium, Brussels; Clette, and Lefèvre, 2016). While decades are usually counted starting with the year "1", there is an alternative counting that defines decades from the 0 years to the years ending with 9. Since the reconstruction by Wu et al. (2018) uses the latter, we also adopted this scheme for better compatibility.

Two large and two small minima of solar activity fall within the investigation period. The two large ones are the Spörer Minimum (1450-1540) and the Maunder Minimum (1645-1715), the two small ones are known as the Dalton Minimum (1790-

15   1830) and the Gleissberg Minimum (1901-1912).

It is commonly believed that in years of high solar activity, temperatures on Earth will rise, and mild winters and hot summers will increase in frequency. In contrast, the number of severe winters and cool summers is expected to increase with decreasing solar activity. Although the historical data from Transylvania certainly do have specific gaps and are subject to a certain subjectivity of their reporters, a comparison can be risked after all. Only the decades around 1825, 1845, and 1855 contain

20   such sparse concrete information that the specified climate values are fraught with high uncertainty.

When comparing the top panel of Fig. 2 (number of hard winters) with Fig. 3 (solar activity), we can see an accumulation of severe winters in the time of the abating Spörer minimum (note that this minimum is only partly covered by our data) and also over long periods of the MM. In contrast, for the less pronounced Dalton and Gleissberg minima, no accumulation of cold winters is noticeable. However, it should be noted that there is no convincing correlation, since the number of exceptionally

25   cold winters has also high peaks in the middle and at the end of the eighteenth century and even after 1920 when the solar activity was high to very high.

Let us consider the bottom panel of Fig. 2, which shows those winters that the contemporaries considered exceptionally mild. A "negative picture" of the top panel of Fig. 2 would be expected this time: high numbers at times of high solar activity. The (moderate) peaks around 1555, 1585 and 1635-1645 somewhat match the moderate to strong solar activity between the two

30   grand Minima Spörer and Maunder between 1525 and 1645, as do the peaks from 1705-1715 with the renewal of solar activity at the end of the MM. However, the peak around 1795 would not have been expected because the sun's activity had subsided again due to the shallow Dalton minimum, while the peaks from 1885 still fit well with the high solar activity of that time.
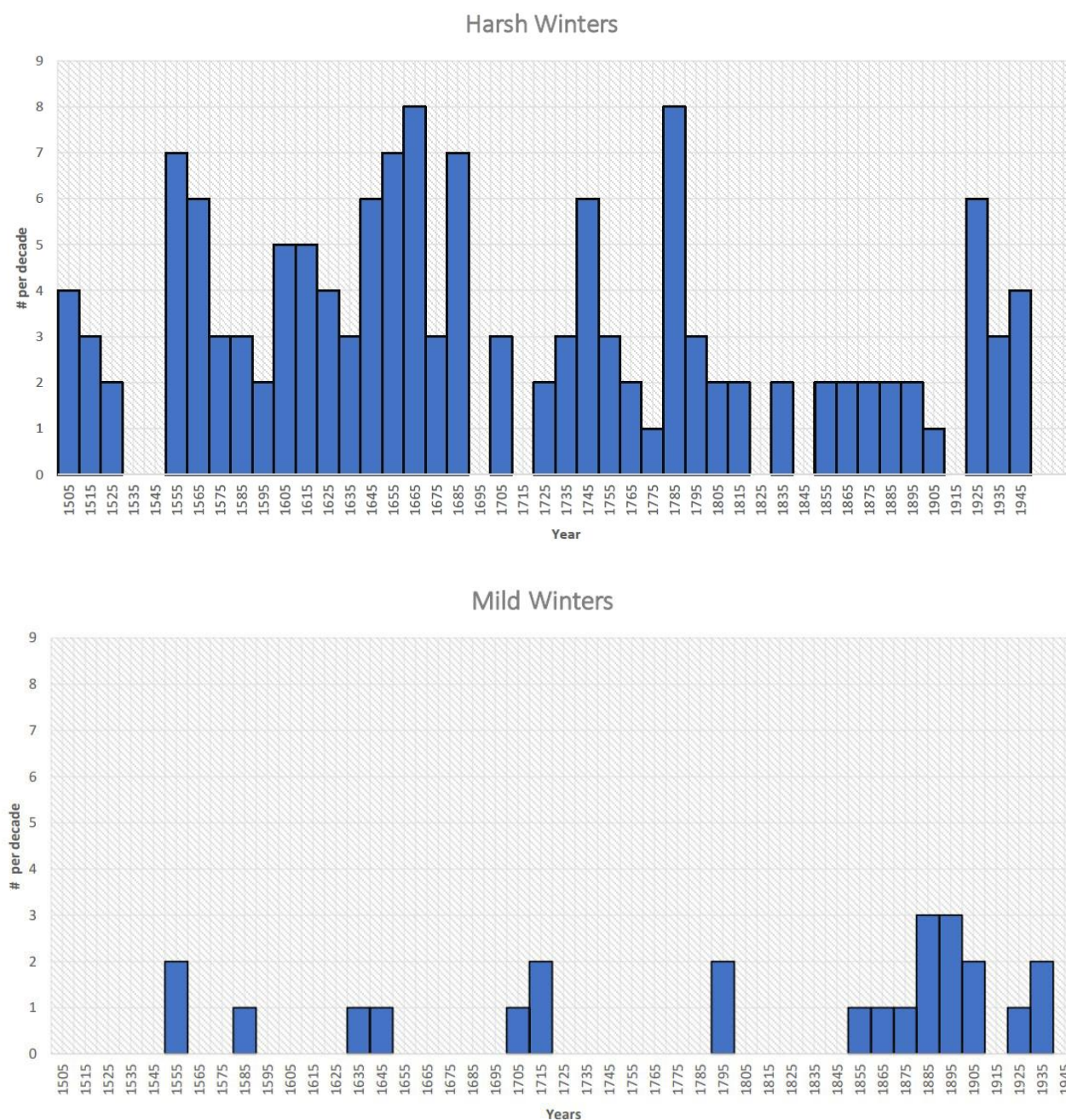
Figure 2: Decadal numbers of harsh winters (top) and mild winters (bottom) in Transylvania for the period 1500 to 1950.
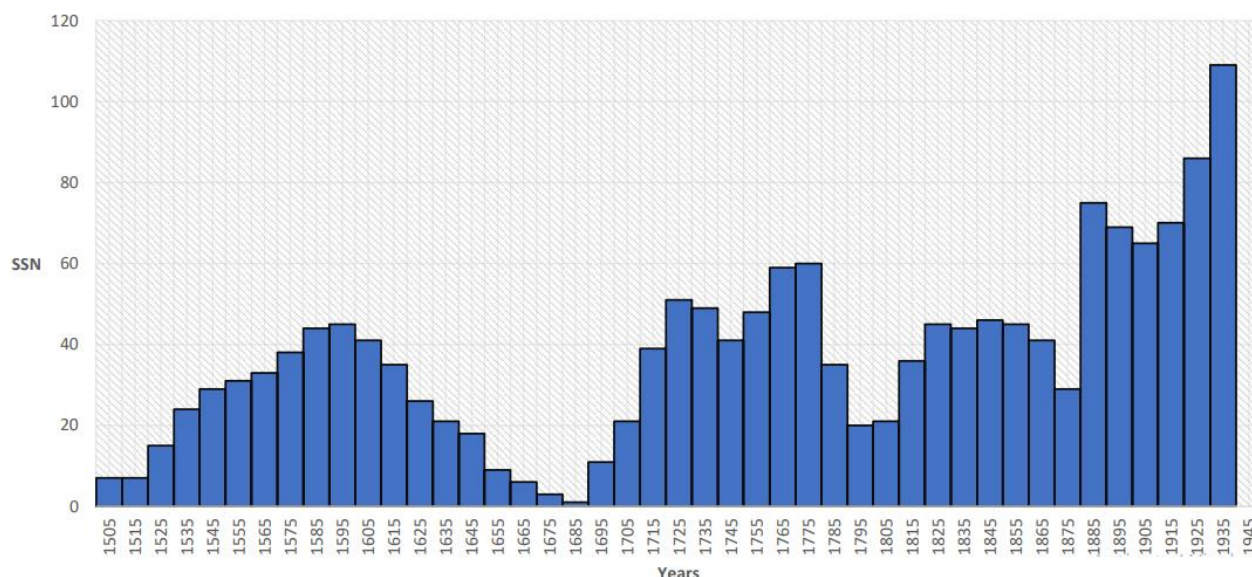
Figure 3: Solar activity in the years 1500 to 1950, given in decadal Sunspot Numbers (SNN). The time period 1500 to 1890 is based on the reconstruction by Wu et al. (2018), while actual sunspot numbers (directly observed or photographed) were used for the later decades (SILSO data, Royal Observatory of Belgium, Brussels).

The top panel of Fig. 4 shows the cool summers of the examination period. Their accumulation should again go hand in hand with low solar activity. In fact, the peaks from 1665-1675 fit well the most pronounced phase of the MM. Otherwise, the remaining peaks appear without exception at times of high solar activity.

The bottom panel of Fig. 4 finally shows the hot summers, the peaks of which should correspond to the peaks of solar activity.

10 While for the time between the Spörer and the Maunder Minimum the agreement is quite good and likewise for the time between Maunder and Dalton Minimum, it must be noted that distinct peaks fall in the very middle of the MM, where none were to be expected.

Although the data presented here for the Transylvanian climate suggest a certain degree of influence from long-term fluctuations in solar activity, one must remain extremely cautious in their interpretation. At best, one could see this as an

15 indication and wait for future evaluation of climate data from the entire German-speaking area. From a European perspective, Transylvania is only a small province, and the data are much sparser than for Germany, Austria, or Switzerland. Besides, we would like to emphasize that previous studies in this area, which had data on a much larger, and geographically broader basis, have not led to any convincing results regarding solar forcing (van Dorland, 2006). The sometimes seemingly striking agreement in parts of the curves presented here may, therefore, be purely coincidental.
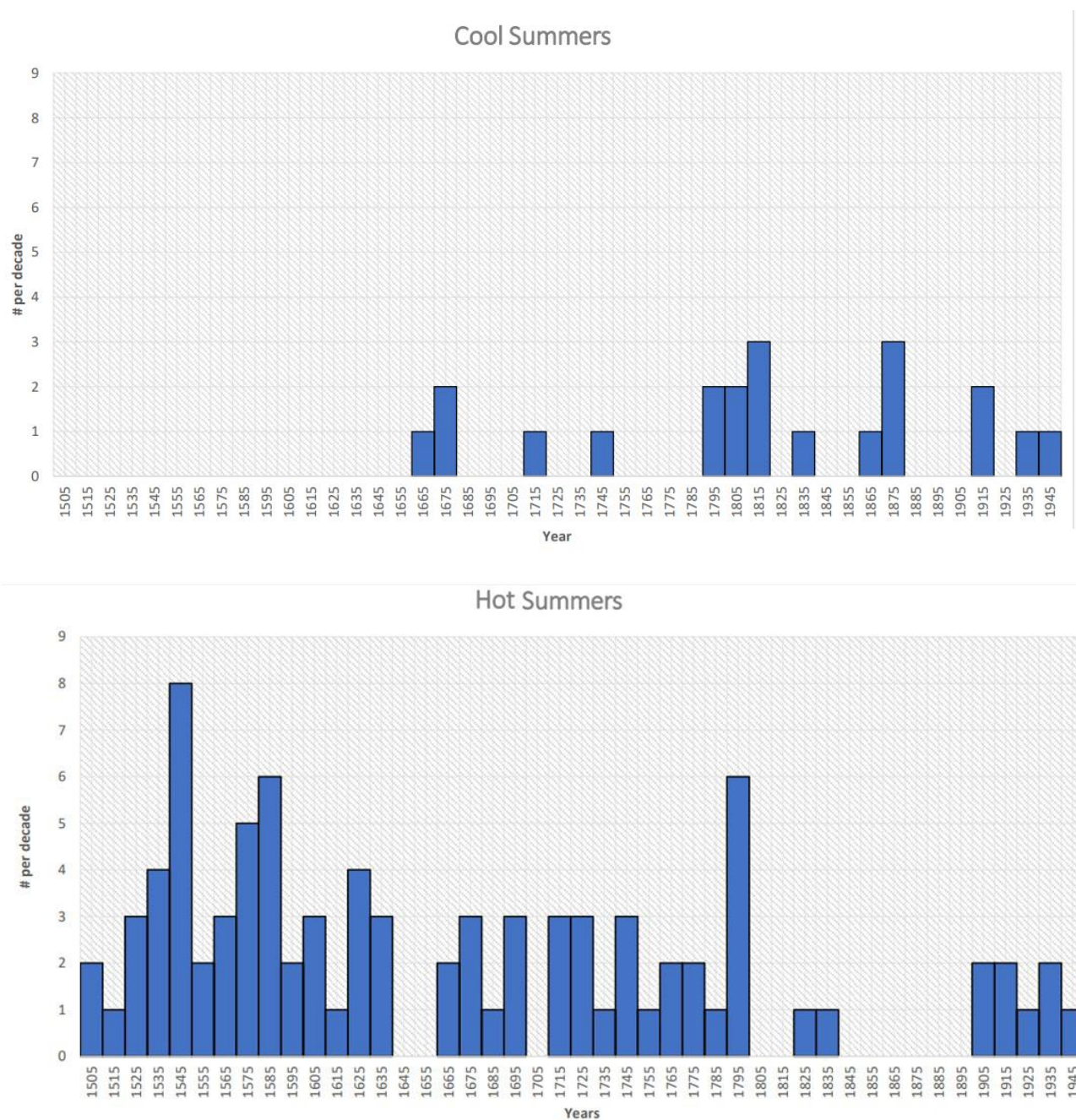
Figure 4: Decadal numbers of cool summers (top) and hot summers (bottom) in Transylvania for the period 1500 to 1950.

6. Summary and conclusions

For our work, we selected the period of the Maunder Minimum (MM, 1645-1715), an astrophysically defined section of the Little Ice Age (LIA), and compared the historical data from the Grand Duchy of Transylvania with those from Germany, Austria and Switzerland. For the first time, we present here a comparison between the four geographic areas in text and tabular form. Quotes from mostly German-language sources are reproduced in English translation. There are numerous similarities, but also geographic differences, so that a convincing picture emerges of the weather conditions prevailing in a region that until 1699 was somewhat outside and then just within the borders of the Habsburg Empire.

Furthermore, for a larger period (1500-1950), we examined on a decadal basis the extent to which an influence on the climate of Transylvania through long-term fluctuations in solar activity, as was inferred from isotope reconstructions from ice cores, can be seen. With the exception of the years 1820-1830 and 1840-1860, we had sufficient historical data to be able to count the frequencies of hot and cold anomalies in the respective summers and winters reliably, so that a picture emerges which decades were characterized by warmth above or below average in the respective seasons. Although this comparison shows some promising result, which suggests a certain solar influence, further studies in the pan-European context have to be awaited in order to arrive at reliable statements. Transylvania alone is an area that is too small and not sufficiently covered by data in terms of climate history, so far-reaching conclusions from this material alone cannot be drawn. However, the results clearly help to identify regional climatic differences during the MM. Some results are unexpected – like an unusually small number of severe winters during the last decades of the MM, where extreme cold was restricted to a few years, like the extreme winters 1699/1700 and 1708/1709.

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