HISTORICAL WEATHER DATA FROM *CHRONICON CONVENTUS FRANCISCANI BRODII IN SAVO* (1706–1932): AN ATTEMPT TO RECONSTRUCT MICROREGIONAL WEATHER PATTERNS AND THEIR INFLUENCE ON DAILY LIFE

POVIJESNI VREMENSKI PODACI IZ IZVORA *CHRONICON CONVENTUS FRANCISCANI BRODII IN SAVO (1706–1932):* POKUŠAJ REKONSTRUKCIJE MIKROREGIONALNIH VREMENSKIH OBRAZACA I NJIHOVOG UTJECAJA NA SVAKODNEVNI ŽIVOT

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Summary

Historical weather data from Chronicon Conventus Franciscani Brodii in Savo (1706–1932) *consists of numerous entries regarding weather patterns, such as storms, hail, extreme pluvial episodes, drought and cold periods, flooding and periods of Sava river freezing, grape harvests etc. Franciscan monastery in question is situated on the left bank of the Sava river, in a region specific for its microclimate conditions while in the wider region, it is situated at a very sensitive spot between hydrologically active regions of northern Balkan Peninsula and the Alps. The data is analysed and compared to reconstructed Old World Drought Atlas (OWDA) and other available climate data such as temperature, precipitation and consequently flooding episodes. Influence on daily life is considered. Regardless of strong bias in quality of entries* Chronicon *is a highly valuable source of information.*

Keywords: Sava river valley, Slavonski Brod, Franciscan Chronicles 18th – 20th century, Early Modern Period, Contemporary History, historical weather data, historical climatology

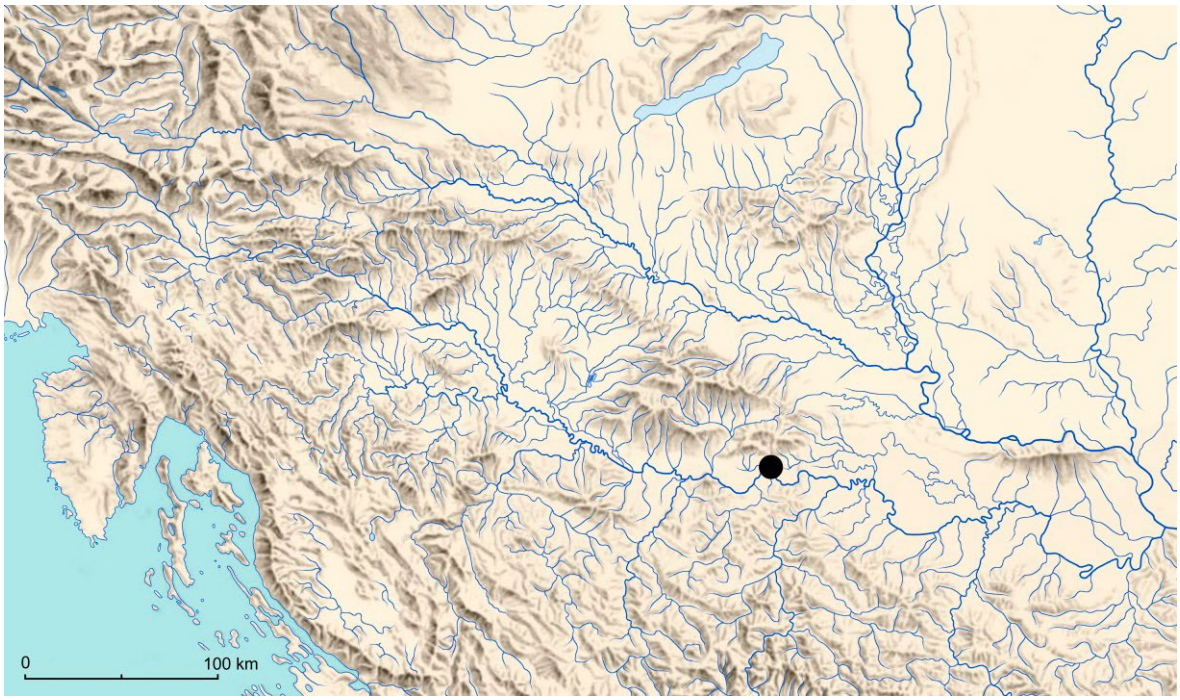
Ključne riječi: Dolina rijeke Save**,** Slavonski Brod, franjevačke kronike 18. – 20. stoljeća, rani novi vijek, suvremena povijest, povijesni vremenski podaci, povijesna klimatologija

INTRODUCTION

Study area

Geographical area studied in this paper is the contact zone between the northern Balkan Peninsula[1] and the southern Carpathian Basin (Map 1). Microregionally, it is the area between the Sava river valley and the Požega Valley mountain range in the central Slavonia (Croatia), i.e. its southern Dilj mountain range (Vrbanus 2012: 21).

[1] This region is referred to as Dinaric Alps by some authors.



Map 1 *Position of the town of Slavonski Brod (made by: K. Botić; map source: Institute of Archaeology, Zagreb).*

The studied area is situated in a hydrologically very active region. The Sava river and its main tributaries (Kupa, Una, Vrbas, Bosna rivers being the largest) bring seasonal floods to vast areas along its course from its spring in Slovenian Alps to its mouth.[2] The last devastated flooding occurred in May 2014 when central Bosnian rivers, due to the extreme amount of precipitation (almost three months' amount of rain in a few days), flooded large areas along the Sava river destroying settlements and infrastructure (Kuspilić et al. 2014; Strelec Mahović et al. 2015; Stadtherr et al. 2016).[3] Spring floods can also be caused by snow melting in the Alps and central Balkan mountains.

The average annual water levels of Sava river in Slavonski Brod changed over time: from about 340 cm (1878-1941) and 300 cm (1942-1980) to 231 cm in the most recent period (1981-2013) (Bonacci 2014: 269, figure 4). The average monthly water levels vary, usually reaching maximum in April and November (Bonacci 2014: 269, figure 5); the highest reconstructed normal water levels in the period between 1878 and 1941 reached about 470 cm in April. On 18th May 2014 the maximum water level was over 939 cm (Kuspilić et al. 2014: 656, Tab. 2; Bonacci 2014: 272, figures 12-13), i.e. over the maximum level of the measure station.

Climatologically, this region is influenced by the sub-Mediterranean and temperate continental climate as the principal modifier, followed by the Dinarides' orography with their position relative to the prevailing air flow and open space towards the northeast, i.e. the Carpathian Basin etc. The maritime influence of the Mediterranean is stronger in the area south of the Sava river and weakens towards the east. Mountains forming the Požega Valley are a local climate modifier which facilitates short-term heavy precipitation on the windward side and formation of dry area (rain shadow) on the leeward side. During the whole year the state of the atmosphere is highly variable and characterised by a diversity of weather conditions with frequent and intense exchanges (Zaninović 2008: 15).

[2] For a full view of Sava river catchment see Kuspilić et al. 2014: 653, figure 1.

[3] NASA Earth Observatory - https://earthobservatory.nasa.gov/images/83697/severe-flooding-in-the-balkans (last accessed 10th August 2020).

The town of Slavonski Brod (Map 1) is situated on the left bank of the Sava river near the natural crossing which was used from prehistoric, Roman, mediaeval to early modern times. Franciscan monastery in Slavonski Brod (45° 9'7.61"N; 18° 1'2.13"E) is situated near the river; today it is a part of the historical centre while in the past it was situated in the easternmost part of the town.

The monastery and its meadow and a farm[4] were situated on poorly drained soil with natural vegetation consisting of lowland and alluvial forests, in a humid environment, but with the mean annual precipitation of less than 740 mm (Tab. 1). Vineyards were situated in Podvinje hilly region north of the town on well-drained soil. Although modern mean monthly temperatures (Tab. 2) are moderate, records show that the first half of the 19th century was not so moderate, especially regarding the Sava winter ice and snow in early spring (April-May) (Fig. 1).

Table 1 *Current environmental parameters: elevation data (Geoportal), soil data (Bogunović et al. 1996; 1997; Soil Atlas of Europe 2005), precipitation and temperature data (International Water Management Institute World Water and Climate Atlas) and European vegetation maps (Bohn et al. 2004). Vegetation: F1a Lowland to submontane types; U3.1 Hardwood alluvial forests in combination with willow and poplar alluvial and wet lowland forests of large river valleys.*

Elevation (m a.s.l.)	EuroVegMap vegetation	Distance to major rivers (km)	Soil drainage	Soil type	Mean annual precipitation (mm)	Mean temp. of the coldest months (°C) (Dec – Jan)	Mean temp. of the warmest months (°C) (Jul – Aug)	Humidity (%) (lowest – highest)
91–92 m	F1a, U3.1	0 km (Sava's bank)	poorly drained	Redzina on marl and soft limestone (vineyard); Fluvisol notflooded (monastery and farm)	739.75	1.7 – -0.1	21 – 20.8	68 (Apr, Jul) – 86 (Dec)

Table 2 *Current precipitation, temperature, air humidity and sushine hours data for Slavonski Brod; P50 = 50% probability of assured rainfall (International Water Management Institute World Water and Climate Atlas).*

	P50 (mm/ month)	Days with rain (days/month)	Mean temp. (°C)	Days with frost (days/month)	Relative humidity (%)	Sunshine (% of hrs)
Jan	49.85	11.8	-0.1	24.6	85	23
Feb	44.57	11.3	2.6	19.6	79	31
Mar	45.03	11.8	6.9	14.9	72	39
Apr	66.12	13.1	11.6	5.3	68	44
May	72.74	12.9	16.2	0.5	69	48
Jun	87.54	13.7	19.3	0	70	52
Jul	74.95	11.4	21	0	68	60
Aug	66	10.8	20.8	0	69	60
Sep	55.69	10.2	17.4	0.2	73	54
Oct	45.92	10.2	12.2	5.6	76	46
Nov	68.91	12.8	6.2	12	83	28
Dec	62.43	12.9	1.7	20.9	86	20

[4] Meadow Aleksinka and the field/farm Viju$ were situated about 1.5 km to the east, next to the new course of Glogovica stream dug out by the military in 1810 (II, 112-113).

Sources

Main sources of records used in this paper are four volumes of *Protocollum seu liber annotationum conventus Sanctissimae Trinitatis* entitled *Chronicon conventus franciscani Brodii in Savo,* edited by Dr Josip Barbarić and pater Egidije Stjepan Biber, published between 1995 and 2003 (*Protocollum* further on in this text).[5] The principal historical sources for these four volumes are two handwritten volumes entitled Chronicles of the Franciscan monastery in Slavonski Brod (Kronike Franjevačkog samostana u Slavonskom Brodu) kept in the monastery's archive under the signatures B-I-1 (vol. I, 1737-1812) and B-I-3 (vol. II, 1814-1878). These two original volumes were published in the first three volumes: Book I (1706-1787), Book II (1806-1833) and Book III (1834-1878) (Barbarić, Biber 1995: XXV). Book IV (1879-1932) contains chronicles from the third archive volume kept under the signature B-I-4 (Balen, Jandrić-Balen 2015: 124).

Historical background

During the Great Turkish War, in the autumn of 1691 the town of Brod and its surroundings were freed from the Ottoman governance entering thusly the Habsburg Slavonian border zone between the Habsburg and Ottoman Empires and the obligation of military service; the town also had a military outpost. In 1702 there were 360 houses in Brod (Vrbanus 2012: 14-15) while in 1730 there were 964 inhabitants of the town in 235 inhabited houses with a very short life expectancy of about 30 years (Živaković-Kerže 2012: 84). On 30th January 1753 town was awarded the status of a free military municipality and it prospered reaching 1487 inhabitants in 384 houses in 1758. As the new construction rules around the military fortress situated in the western part of the town demanded open space around it for cannon range, some of the houses were taken down and only wooden architecture was allowed between the fortress (in the west) and the monastery (in the east). Because of that, in 1775 only 1403 inhabitants in 338 houses were recorded. In 1784 there were 130 people with the status of citizens in Brod. On 26th June 1787 until the end of the 18th century, the town lost its status of a free military municipality and once again become the centre of the Brod military regiment (Živaković-Kerže 2012: 85, 86, 88).[6]

The presence of Franciscan friars (*Ordo Fratrum Minorum*) in the town of Brod and its surroundings predated the Ottoman occupation; they were part of the Province of Bosna Srebrena (I, 16-17). Under the Ottoman rule they were the only ones caring for the spiritual needs of the Catholic population. After the defeat of the Ottoman Empire and its retreat from the town, on 16th June 1694 parish got a status of a residence and on 30th October 1708 monastery status (I, 18-19).[7] In 1727 the building of a new stone church and the first western wing of the monastery started (I, 30-31) but the building of the church only continued in 1743 and it was finished in 1753 (I, 100-101; 122-123). Between 1729 and 1732 the southern wing of the monastery was built (I, 100-101). The north wing of the monastery was built in 1758 (I, 140-141) and the eastern wing was built between 1768 and 1769 (I, 184-185).

In 1754 friars lost the Brod parish and with it a great deal of income (I, 124-125). The same year and in 1756 they lost most of the parishes around the town of Brod (I, 124-125; 128-129). In 1757 the Province of Bosna Srebrena was transformed and a new Province of St Ivan Kapistran (Giovanni da Capistrano) was established which the monastery in Brod belonged to (I, 138 etc.). In 1900 another change occurred: the forming of the Province of St Cyril and Methodius and introduction of some new rules (IV, 208-209).

In 1787, during the reign of Joseph II, the monastery was dissolved (I, 286-287); in 1806 the monastery was once again inhabited by the Franciscan friars (II, 4-5 etc.).

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5 *Protocollum* is a more adequate term but the editors of these volumes preferred the title *Chronicon* (…). We are using both.

6 Napoleonic wars, 1848 revolution, strengthening of the nationalist thought from the second part of the 19th century, First World War etc. are all mentioned in the monastery records.

7 "*… die 30. Octobris 1708. residentia Brodiensis Fratrum minorum de observantia provinciae Bosnae Argentinae crevit in conventum.*" (I, 18).

Apart from the ownership of a garden adjacent to the monastery, a meadow and a farm close by,[8] in 1818 friars bought a vineyard from a town's painter (II, 238-239), in 1840 the adjacent vineyard (III, 102-103) and in 1883 another vineyard (IV, 58-61). These were the main sources of their livelihood.

Sava river was of great importance in the 18th and 19th century as the principal and cheap way of transporting people and goods to and from the Austro-Hungarian Empire. However, only in the mid- 19th century large infrastructure works on its banks and the bed were conducted in order to enable the flow of large quantities of water, ice and sediments, and safe navigation of the boats. Frequent floods and heavy precipitation prevented the use of the roads in and around the town of Brod as well because most of them were not paved; it was impossible to get the flour from the mills, wood for heating and cooking etc. (Živaković-Kerže 2012: 90).

METHODOLOGY

In this paper, data available from the historical records are organized in 50 year's periods except for the last period of 32.5 years. Availability of records in each period varies from almost none in the first half of the 18th century to several dozen in the later periods. From all available records only a certain percentage refers to each group of weather-related records in each period (Tab. 3).

For easier data organization, seasons were grouped in three months as follows: spring – March, April, May; summer – June, July, August; autumn – September, October, November; winter – December, January, February.

Event	Period	Available information (number of years)	%
Grape harvest	1700-1749	0	0
	1750-1799	0	0
	1800-1849	30	68
	1850-1899	46	92
	1900-1933	27	92
Floods	1700-1749	0	0
	1750-1799	3	30
	1800-1849	22	50
	1850-1899	12	24
	1900-1933	7	24
Sava winter ice, spring frost, APR-MAY snow, A-M-J cold	1700-1749	0	0
	1750-1799	2	20
	1800-1849	25	57
	1850-1899	20	40
	1900-1933	12	41
Hail	1700-1749	0	0
	1750-1799	4	40
	1800-1849	14	32
	1850-1899	7	14
	1900-1933	5	17
Storm	1700-1749	1	33
	1750-1799	1	10
	1800-1849	9	21
	1850-1899	6	12
	1900-1933	3	10

Table 3 *Availability of information on certain events in the overall available records (number of years) for periods 1700-1749 (3 years), 1750-1799 (10 years), 1800-1849 (44 years), 1850-1899 (50 years) and 1900-1933 (29.5 years). Calculated percentage (%) of available data for certain events in overall available records is given in the last column. Number of records for certain periods and events vary and may be a cause of bias in the interpretation charts. Results are presented in charts in which data are mostly organized by the number of years in which certain events occur and sometimes by the number of months or single episodes/events.*

[8] See note 4.

Bias

The quality and quantity of available records vary and depends on the interests and inclination of each chronicler and historical circumstances. As a result, some of the graphs presented in this paper may show biased results. This is particularly visible during the course of the 19th century in which the recorded data are more numerous in the first half of the century. The only constant is the record of grape harvest dates and the quantity/quality of wine, although by the First World War and beyond this record is less accurate.

RESULTS

Sava winter ice, spring frost, cold episodes and snow

Strong winter ice completely covering or floating down the Sava river was frequent in the first half of the 19th century with its frequency dropping by the beginning of the 20th century (Fig. 1). From a very few records altogether available for the second half of the 18th century, two episodes are mentioned: in January 1755 (I, 126-127) and January 1775 (I, 236-237). Ice on the river in March was reported only in 1808 (II, 56-57), 1839 (III, 90-91) and 1858 (III, 226-227). March 1839 was the coldest of three with ice appearing between the 15th and the 19th (III, 90-91).

Spring cold and snow were recorded in various years; snow in April was recorded in 1807 (II, 32-33), 1808 (II, 58-59), 1809 (II, 82-83), 1835 (III, 20-21), 1838 (III, 70-71), 1852 (III, 184-185), 1861 (III, 254-255), 1862 (III, 262-263), 1864 (III, 280-281), 1903 (IV, 232-233) and 1929 (IV, 342) while only in 1836 snow was recorded in May (III, 38-39). Especially cold was 1864 when on 8th August snow in Zagreb and the surroundings was reported, but not in Slavonski Brod (III, 282-283).[9] In 1837 cold weather was recorded during the whole spring and in August (there was a need to heat the rooms; III, 68-69). During several years in April (1808, 1810, and 1877 – II, 54-55, 106-107; III, 396-397) and May (1812, 1864 – II, 146-147; III, 280-281) heating of the rooms was recorded. Interestingly, in only two years heating of the rooms in October was recorded (1861 and 1912 – III, 260-261; IV, 263) which was probably extraor-

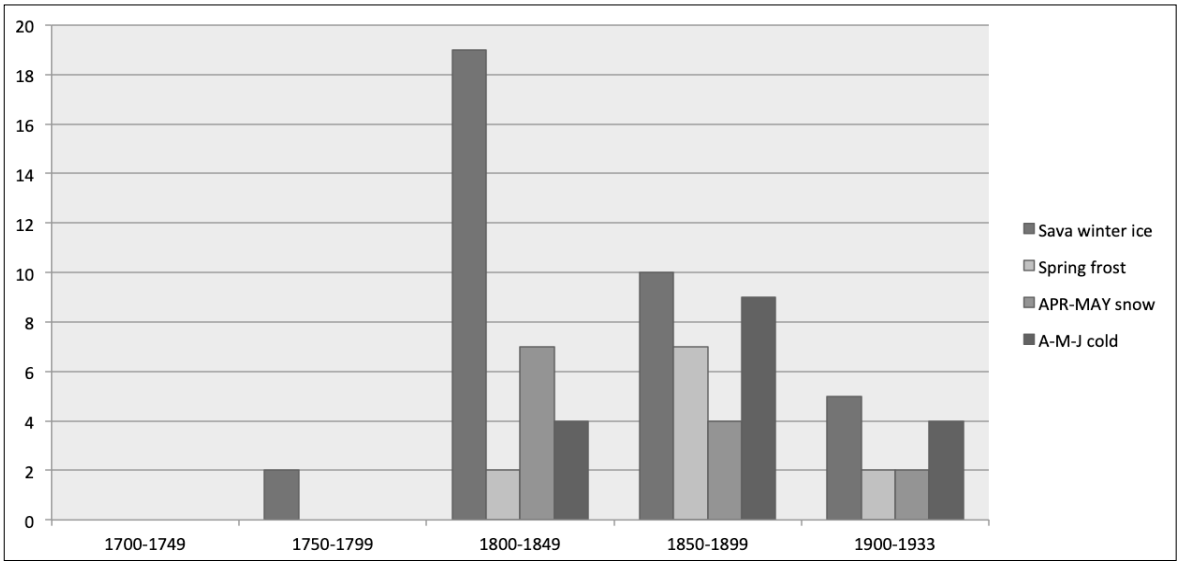

Figure 1 *The chart shows correlation between Sava winter ice and April-May snow and also between spring frost and April-May-June cold events (number of years of specific events and not the number of individual events was used). Despite possible bias regarding the quantity and quality of available written records, shift in winter/spring intensity of cold weather can be observed over time.*

[9] Earlier that year, in January, the temperature dropped to –25,5°C (–20°R – Réaumur scale) (III, 276-277).

dinary. Bearing in mind that the monastery did not own woods and depended on donations of wood or purchase, heating of the rooms so late in the spring or early in the autumn must have been quite a financial strain.

Spring frost was recorded in April – 1857 (III, 214-215), 1861 (III, 254-255), 1864 (III, 280-281), 1874 (III, 378-379), 1913 (IV, 265), or May – 1836 (III, 38-39), 1838 (III, 72-73), 1876 (III, 390-391), 1893 (IV, 164-165), 1902 (IV, 224-227); only in 1866 both in April and in May (III, 298-299, 300-301).[10]

In 1932 (IV, 356) and 1933 (IV, 359) lack of lilies on St. Anthony's day (13th June) was recorded, due to the previous cold weather and their late blooming.

Floods

Floods were a frequent problem for the town and the monastery (Vrbanus 2012: 23 – in the lowland surrounding the town almost 83% of arable land and meadows were frequently flooded or marshy). Fluctuations in the water levels in the 18th century were not high as there were no embankments and thicker vegetation was covering the areas close to the river. Several great floods in the 18th century appear in other records: 1707, 1708, 1709, 1775, 1777 and 1780 (Živaković-Kerže 2012: 91).

From a very few records altogether available for the second half of the 18th century four floods were recorded in the monastery's *Protocollum* of which two were extreme (Fig. 2a-b). In 1775 the flood was so severe that the monastery's basement was flooded with all of the auxiliary facilities and the water reached the middle of the town square; all the villages in the surroundings were flooded and people moved with their cattle to the hills (I, 238-239). It lasted from 30th May until the end of June. The second time basement and auxiliary facilities were flooded was in November 1780 (I, 268-269). In the 19th and the beginning of the 20th century, only two floods were so extreme: in 1878 and 1932. Flood in November 1878[11] devastated large area around the town of Brod with many villages completely cut off the world (III, 132-433). During the flood in April of 1932 which lasted for three weeks, basement of the monastery was also flooded (IV, 355).[12]

The maximum number of months or flood episodes in a year was recorded in 1809, 1838 and 1914. In 1807, 1895 and 1917 single floods lasted for several months. The worst was 1809 with three floods that lasted almost seven months; the first lasted three full months starting in January (II, 78-79). The second flood occurred in September and the beginning of October which prevented corn harvest or the harvest was done by boats (II, 94-95).[13] The third flood started in November and in December provoked lack of firewood (some people burned their fences) and food in general (II, 96-99). In 1838 Sava flooded from the end of January but the worst was in March (III, 70-71); Danube flood was also recorded especially because it brought severe damage to the Budim and Pest in Hungary that year.[14] In 1914 the first flood occurred in March; both sides of the Sava river were flooded and dead could not be buried around Brod, but had to be transported by boats to the Bosnian side (IV, 270). Two consequent floods occurred in May and June of the same year (IV, 271, 272).

In 1807 flood lasted from February until the end of April (II, 28-29, 32-33); in 1895 flood lasted from March until the end of May (IV, 172-173) flooding parts of the town close to the river and the whole monastery's meadow. In 1917 extensive flooding was recorded "from autumn until spring" (IV, 284).

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[10] The same is recorded in the *Protocollum* of Šarengrad Franciscan monastery (ŠP II, 124-125). This monastery is situated in the easternmost part of Croatia, in Syrmia province outskirts and on the right bank of the Danube. Geological, geographical and climate circumstances differ from those around the town of Slavonski Brod.

[11] Flooding of Bosut and Danube in December of 1878 was recorded in Šarengrad *Protocollum* (ŠP II, 264-265).

[12] These extreme episodes of flooding can probably be compared to the extreme event of May 2014 during which extreme pluvial episodes, especially in the southern part of the Sava river catchment, combined with already high soil humidity lead to devastating flooding of the middle and lower course of the Sava river.

[13] *…Insuper, exundatio Savi tam vehemens, ut coacti fuerint Savani fagopyrum immaturum colligere, in nonnullis locis etiam cimbis*…. (II, 94-95)

[14] In Šarengrad *Protocollum* there's no mention of Danube floods in March that year.

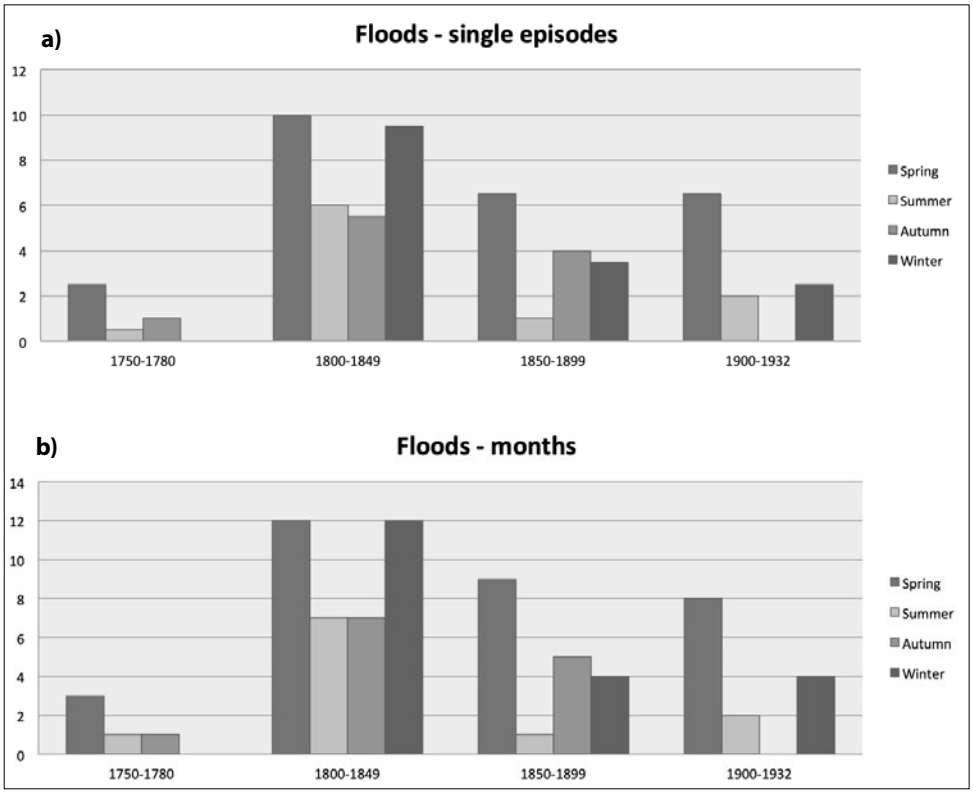

Figure 2 *The chart shows occurrences of floods by single episodes (a) and duration in months (b). Despite possible bias regarding the quantity and quality of available written records, decrease in number of events can be observed, although prevalence of spring and winter flooding is mostly consistent.*

The number of years with two shorter annual floods decreases over time: in the 1750-1800 period only one (1777), in the 1800-1850 period four (1815, 1824, 1825, 1828), in the 1850-1900 period three (1878, 1879, 1896) and in the 1900-1932 two (1901, 1902) were recorded.[15]

Storms and hail

Another limiting factor for agriculture and grape production was severe storms and hail. Hail was recorded between April and September while the only month without any storm records is February; most of the storms were recorded in the summer months as were the hail episodes (Fig. 3). Interestingly, in the second half of the 19th century more autumn than summer storms was recorded while at the beginning of the 20th century only spring and summer storms were recorded.

Damages to the church and/or monastery were recorded in 1739 (I, 88-89), 1757 (I, 132-133), 1775 (I, 240-241), 1816 (II, 218-219), 1817 (II, 228-229), 1828 (II, 312-313), 1850 (III, 176-179), 1883 (IV, 56-57) and 1903 (IV, 234-235). Hail with large hailstones was recorded in 1756 (when it weighed more than 1 libra = 0.56 kg – I, 128-129); hail the size of a chicken egg was recorded in 1775 (I, 240-241) and 1828 (II, 312-313), while the size of a walnut in 1814 (II, 162-163), 1816 (II, 218-219) and 1820 (II, 246-247), and hazelnut in 1817 (II, 228-229). In all the available records damage to the vineyards was mentioned in 20 years.

Grape harvest

At the end of the 17th century viticulture was a less important economic branch than agriculture and cattle breeding (Vrbanus 2012: 45) probably due to the need to produce enough food, although this is consistent with the change provoked by the Little Ice Age (LIA) climate anomaly (Mrgić 2018: 140).

The limiting factors for the cultivation of vines in the continental climate are the low winter temperatures and/or low temperatures (i.e. frost) at the start (late spring) or the end of the vegetation season

[15] However, the quantity of years in which available records appear vary between these arbitrary periods: 1750-1800 three years; 1800-1850 22 years; 1850-1900 12 years; 1900-1932 seven years.

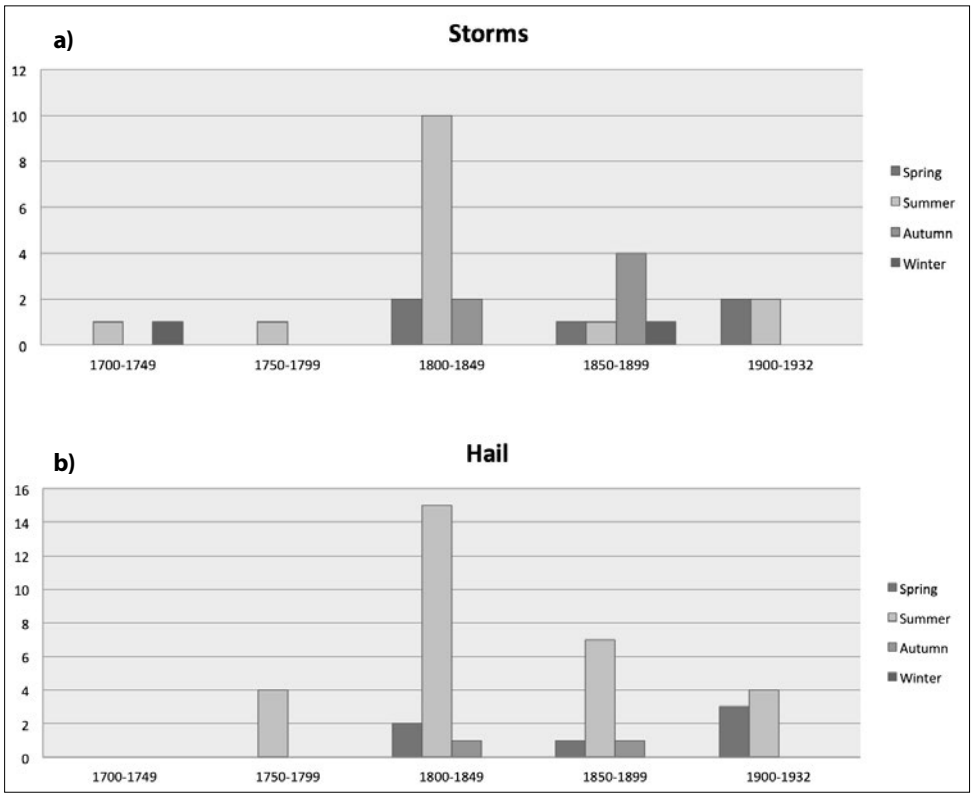

Figure 3 *The charts show occurrences of storms (a) and hail (b) over the seasons (number of years of specific events and not the number of individual events was used). Despite possible bias regarding the quantity and quality of available written records, decrease in number of events and shift to the first half of the year can be observed.*

(early autumn) resulting in the freezing of vital parts of the plants or entire plants. Vegetation season for the vine lasts from early April to the end of October. Very important factors are also annual quantity of precipitation, quantity of precipitation during the vegetation period, hours of sunlight, elevation and exposition (Maletić et al. 2015: 27, 29). Grape harvest dates also correlate to the spring-summer temperature anomalies and can be used as a past climate indicator (Chuine et al. 2004; Kiss et al. 2011). As mentioned before, storms and hail were also limiting factors for vine production.

Grape harvest records are the most numerous in the Brod *Protocollum* – for the period of 132 years (1800-1932) the records exist for 104.[16] The first records appear in 1807 and are general because the monastery at that time did not own a vineyard. The first vineyard was purchased in 1818, the second in 1840 and the third in 1883. Only two times no grape yield was recorded: in 1866 (III, 304-305)[17] and 1912 (IV, 263).[18] The best yield was also recorded twice: in 1862 (III, 264-265) and 1903 (IV, 242-243).[19] In 1889 an infestation of downy mildew (*Plasmopara viticola*) was recorded (IV, 152-153).

In the period between 1800 and 1932 grape harvests occurred more frequently in September (Fig. 4a-b) and mostly in the second half of that month. During the first half of the 19th century grape harvests in the first half of October were more frequent than in the later periods while only one grape harvest in the second half of October is recorded in 1825 (II, 282-283) with a very poor yield. At the beginning of the 20th century the quality of records diminishes with more than a half of records without specific date or even month of the grape harvest.

[16] Before wine production, monastery occasionally produced plum brandy (for example, more than 40 barrels were produced in 1772 – I, 206-207). Plum brandy substituted wine production during the Little Ice Age period (LIA) in the Ottoman Balkans (Mrgić 2018: 140), although reason for plum brandy production and not wine in Brod monastery before 1800s was most probably related to its economic status, i.e. lack of vineyards, rather than LIA climate crisis.

[17] Frost in May (III, 300-301) and heat in June (+41°C = +33°R "many days") (III, 302-303).

[18] Six times hail was recorded for that year (IV, 263).

[19] This year's yield and consequent wine production was so great that the head of the monastery had to go to Zagreb to buy more barrels.

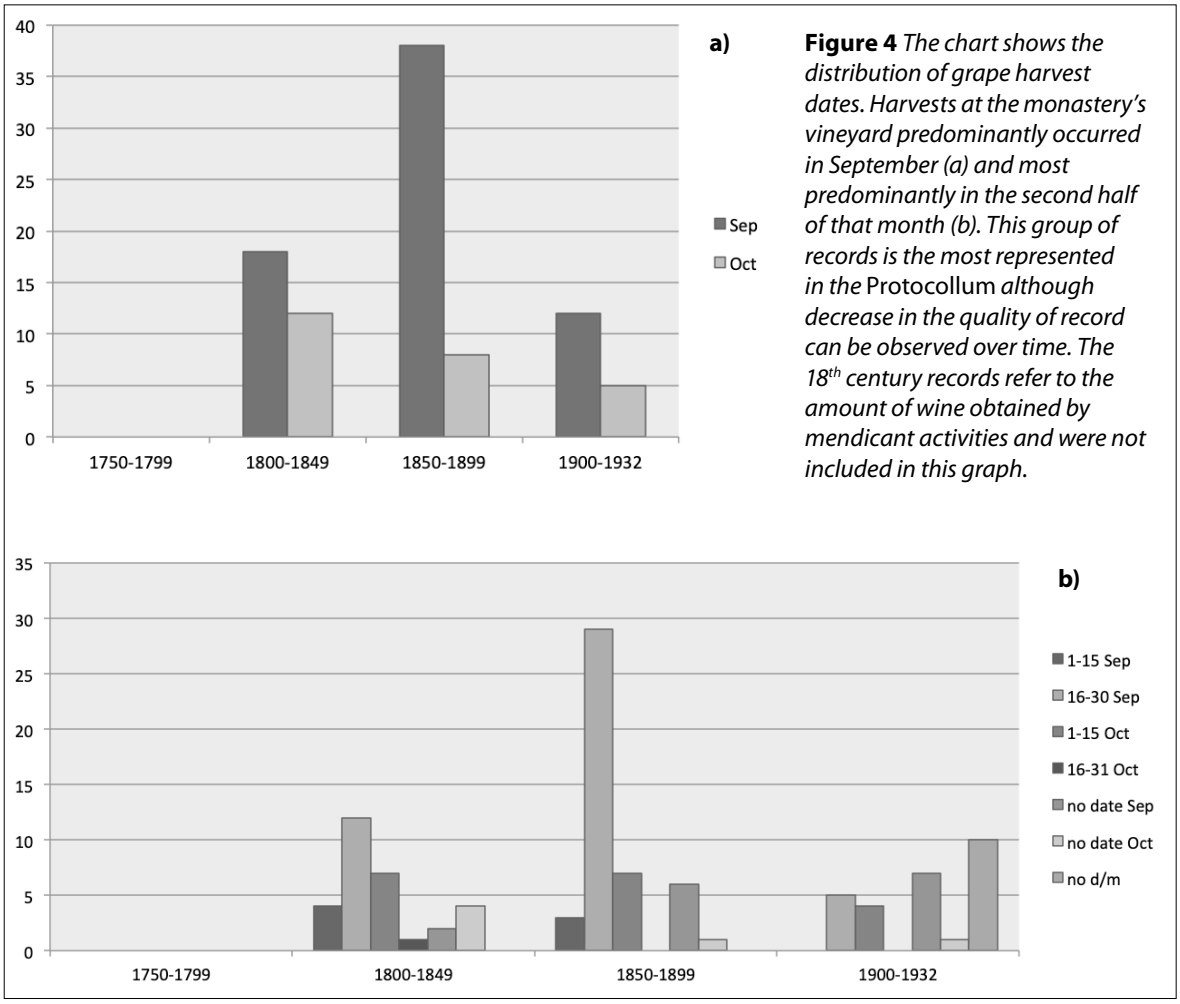

Figure 4 *The chart shows the distribution of grape harvest dates. Harvests at the monastery's vineyard predominantly occurred in September (a) and most predominantly in the second half of that month (b). This group of records is the most represented in the* Protocollum *although decrease in the quality of record can be observed over time. The 18th century records refer to the amount of wine obtained by mendicant activities and were not included in this graph.*

DISCUSSION

A few relatively new studies deal with reconstruction of past environmental conditions in Europe. The 2000 years long Old World Drought Atlas (OWDA) (Cook et al. 2015) uses extended record of natural hydroclimate variability from tree-rings. The limiting factor in using OWDA is the fact that it represents only the reconstructed summer season (June-July-August, JJA) reflecting Spring-Summer soil moisture conditions (Cook et al. 2015: 2) and it is composed of different chronologies of a variety of tree species. For mayor climate events this might not pose a problem as the global conditions would have been pronounced, but it might pose a problem with local indicators. The second study based on the tree-ring series of *Pinus nigra* in Bosnia and Herzegovina (Poljanšek et al. 2013) brings interesting points regarding the possible influence of volcanic eruptions on mean June-July sunshine hours. However, it is in itself limiting as it deals with only one tree species which is not present in the lowlands of major rivers north of the study area. The third study of 500 years long history of floods compared to the current European flood-rich period (Blöschl et al. 2020) is possibly the best in comparison with mayor similar events that occurred in the Sava valley over the observed period in this paper (1750-1932).

Reconstruction of temperature and precipitation changes in the Carpathian Basin and central Europe, deriving both from historical and tree-ring records, can be found in several papers (Dobrovolný et al. 2010; Rácz 2010; Kiss et al. 2011).

Comparing data to the Old World Draught Atlas maps (OWDA) and other records

Extended record of natural hydroclimate variability from tree-rings was used by Cook at al. (2015) to create the Old World Drought Atlas (OWDA). Paper is accompanied by detailed year-by-year maps of Europe during the Common Era freely available on-line. These reconstructed drought and pluvial periods are compared to the records available from the *Protocollum*, a selection of which can be found in Tab. 4. A limiting factor for this kind of comparison is the lack of data in *Protocollum* regarding the months of July and especially August. However, some of the available records show different results. For wet spring-summer conditions of 1809, 1816, 1820, 1826, 1857, 1899 and 1913 in OWDA records, *Protocollum* records show dry summers while 1828, 1836, 1887 and 1902 average seasons in OWDA appear dry/very dry/extremely dry in the *Protocollum* records.

The same wet conditions for 1815, 1837, 1838, 1885 and 1914 summers in both datasets are recorded as well as average/dry conditions in 1839, 1852, 1866, 1879, 1898, 1917 and 1928. Further detailed analysis is needed to fine tune both sets of data, using methodology proposed by Kiss (2018) for the late mediaeval Hungary. However, the limiting factor is the lack of tree-ring records for north-eastern Croatia.

Table 4 *Comparison of data from the* Protocollum *for the years mentioned in the results and discussion with Old World Drought Atlas (OWDA) maps (Cook et al. 2015; National Centers for Environmental Information, NESDIS, NOAA, U.S. Department of Commerce). Some extraordinary events, local and non-local, are marked in bold letters.*

Year	OWDA (Cook et al. 2015): pronounced droughts (-) and pluvials (+)	OWDA (Cook et al. 2015): only Slavonski Brod region	*Protocollum* summer	*Protocollum* whole year	*Protocollum* events
1739		average/dry	x	x	25th July extreme storm with strong winds, half of the church tower torn down (I, 88–89); 5th December storm similar to the summer storms (idem)
1756	-	extremely dry	x	x	7th August large hail (over 1 libra = 0.56 kg) (I, 128–129)
1757		average/dry	x	x	1st July heavy storm and hail, all the windows on the monastery and the church damaged by hail, part of the church's roof destroyed (I, 132-133)
1775		average	x	x	30th May – 30th June extreme flooding of Sava, up and down stream villages flooded; middle of the town square flooded (I, 238–239); church windows broken by hail the size of chicken eggs in August (I, 240-241)
1777		average	x	x	floods in March and May (I, 254–257)
1780		average/dry	x	x	extreme flood in November (I, 268–269), basement and the auxiliary facilities flooded
1807	-	extremely dry	x	x	very wet and cold spring (II, 28–33), snow in April; single flood from February till the end of April (II, 28–29, 32–33)
1808	-	average/dry	x	x	very cold spring with snow (II, 54–59); river ice in March (II, 56-57); heating of the rooms in April (II, 54-55)
1809	+	wet	dry	extremely wet	3 floods: 1) 3 months extreme floods from January until March (II, 78-79), 2) in September/1st half October (II, 94-95), 3) November and December (II, 96-99); snow in April (II, 82-83) and rain in spring, rain in autumn and winter (II, 76–101)
1810	+	wet/very wet	x	x	wet and cold spring (II, 100–107), heating of the rooms in April (II, 106-107); floods from February to the end of March (II, 102–103)

Year	OWDA (Cook et al. 2015): pronounced droughts (-) and pluvials (+)	OWDA (Cook et al. 2015): only Slavonski Brod region	*Protocollum* summer	*Protocollum* whole year	*Protocollum* events
1812		wet	x	x	cold spring (?) – heating of rooms at the beginning of May (II, 146–147)
1813	+	average/wet	x	x	flood in November (II, 156–157)
1814	+	wet/very wet	x	x	flood in September (II, 204–205); hail the size of a walnut (II, 162-163)
1815	+	wet	extremely wet	x	2 floods in July due to extreme rain (II, 210–211); rain from the 2nd half of August onwards, grave damage to the vineyards (II, 210-211); extremely wet in November (II, 214–215)
1816	+	wet/very wet	dry	1st half wet, 2nd half dry	wet January, March, April and May (II, 214-217); extreme flooding in June – beginning of July (II, 218–219); August warm and dry (II, 218-219); cold end of November and December (II, 222-223); hail the size of a walnut, damage to the church windows (II, 218-219)
1817		average/wet	mostly dry	1st half mostly dry	hail the size of hazelnuts (II, 228-229); damage to the church and the monastery's roof (II, 228-229)
1819	+	extremely wet	x	x	extreme floods in October and November, very wet October – December (II, 242–243)
1820		wet	very dry	x	flood in March (II, 244–245); hail the size of walnut (II, 246-247)
1825		wet	x	x	floods in April and end of August but dry summer and winter (II, 272–279)
1826		wet	extremely dry	2nd half wet	floods in February and October (II, 278–279, 282–283); **the only grape harvest in the 2nd half of October recorded** (II, 282-283)
1828		average	extremely dry	1st half mostly wet	floods at the end of February and the end of March (II, 310–311); hail the size of a chicken egg damaging monastery's windows (II, 312-313)
1835		average/wet	x	average	snow in April (III, 20-21); flood in May (III, 22–23); very wet end summer/beginning of autumn (III, 34–35), cold December: –13°C (III, 32–33)
1836	-	average	extremely dry	average	snow and frost in May (III, 38–39): *Hic mensis totus erat frigidus at pluviosus, adeo ut potius Novembrem quam Maium dicere possimus*.
1837		wet	wet	very wet	mild winter, cold summer/heated rooms in August (III, 68–69): … *nam adeo erant dies etiam caniculares, frigidi, quod delicatiores sibi calefieri curare debuerint;*…
1838		wet	wet?	extremely wet	floods in January, February (III, 68–71), **floods in March** (III, 70–71) **also of Danube** which destroyed Buda and Pest, felt in other provinces too (III, 88–91); snow in April (III, 70–71); frost in May (III, 72-73)
1839	-	average/dry	dry	1st half cold and wet, 2nd half dry	river ice in the 2nd half of March (III, 90-91); very cold and wet 1st half of the year (III, 90–93); flood in May (III, 92–93)
1850		wet	x	x	8th July storm with hail, total damage of the crops, very strong vortexes pulling out trees, damage to the monastery's eastern windows and roof and the front of the church (III, 176–177)
1852		average	average	x	very cold April: 11th April –6,5°C, snow (III, 184–185)

Year	OWDA (Cook et al. 2015): pronounced droughts (-) and pluvials (+)	OWDA (Cook et al. 2015): only Slavonski Brod region	*Protocollum* summer	*Protocollum* whole year	*Protocollum* events
1857		average/wet	dry?	mostly dry	February temperatures between –15°C and + 15,5°C (III, 208–2011); **Danube frozen but not Sava** (III, 210–211); flood in March (idem); frost in April (III, 214-215)
1861	-	extremely dry	x	average?	20th April snow, whole month cold, frost (III, 254–255); heating of the rooms in October (III, 260-261)
1862	-	extremely dry	x	average?	very cold January, temp. –21,5°C and –24°C (III, 260–261); 16th April snow (III, 262–263); **the best wine harvest since the beginning of the monastery's vineyard** (III, 264–265)
1864	-	average	cold and wet	mostly cold and wet	January temp. –25,5°C (III, 276–277); flood in February and March (III, 276–277, 280–281); 8th–12th April snow and frost (III, 280–281); heating of the rooms in May (III, 280-281); **8th August snow in Zagreb and surroundings** (III, 282–283)
1866	-	dry	extremely dry	extremely dry	13th May snow in Našice and surroundings, frost in May (III, 300–301); June temp. +41°C (III, 302–303); **no grape harvest this year** (III, 304–305)
1874	-	extremely dry	x	x	April frost (III, 378-379); very cold May (III, 378–379)
1876		average/dry	wet?	wet?	flood in May (III, 390–391); May frost (III, 390-391)
1877	-	dry	x	x	heating of the rooms in April (III, 396-397)
1878	-	dry	x	x	floods in September (III, 430–431) and December (III, 432–433): extreme flooding of Kobaš, Bebrina, Kaniža, Zbijeg, Šumeće, Slobodnica, Varoš and Brod, monastery's basement flooded
1879	-	dry	dry?	x	floods in January and April (IV, 16–19)
1883		average	x	x	wind damaged roofs of the monastery and the church in March (IV, 56-57)
1884	+	wet	x	x	June rainy (IV, 70-71)
1885		wet	wet	x	August rainy in the 2nd half, damage to the vines (IV, 84-85)
1886		wet	x	x	warm and pleasant days half of autumn with occasional warm rain, the end of autumn and beginning of winter wet and abundant snow (IV, 114-117)
1887	-	average	very dry	x	very wet autumn (IV, 124–125)
1889		average	x	x	infestation of downy mildew (*Plasmopara viticola*) (IV, 152-153)
1893	-	average/dry	x	x	very cold January temp. –15,5°C/–29°C (IV, 164–165); frost in May (IV, 164-165)
1895		average	x	x	flood from March until the end of May (IV, 172–173), the whole marginal part of the town and the fields flooded – **the max. number of months of flood**
1896		average	wet?	wet	floods in March (IV, 176–177) and September – October (IV, 182–183)
1897		average/wet	x	very wet	January rainy (IV, 184-185); flood in February (IV, 184–185); May mostly cold and rainy (IV, 186-187); September and October rainy (IV, 188-189)
1898		average	average?	x	December dry and warm (IV, 198-199)

Year	OWDA (Cook et al. 2015): pronounced droughts (-) and pluvials (+)	OWDA (Cook et al. 2015): only Slavonski Brod region	*Protocollum* summer	*Protocollum* whole year	*Protocollum* events
1899		wet	dry?	dry	extremely warm January temp. up to + 30°C (IV, 198–199); rain and snow in the 2nd half of March (IV, 200–201); flood in June (IV, idem); July rainy in the beginning, extremely dry later (IV, 202-203)
1900		wet	x	x	NO DATA
1901		wet	x	wet?	January very cold, river ice (IV, 216-217); February nice spring days in the 2nd half (IV, 216-217); floods in March and June (IV, 216–217); April and May cold and rainy (IV, 216-217)
1902		average	dry?	1st half very wet	January and February warm (IV, 222-223); floods in March and April due to rain (IV, 224–225); frost in May damaging vineyards (IV, 224-227); June rainy (IV, 224-229); 3 months after without rain (IV, 230-231); 2nd half of November and December snow (IV, 230-231)
1903		dry	x	x	14th April snow with hail (IV, 232–233); flood in December (IV, 236–237); **the best wine harvest, need to buy more barrels** (IV, 242-243); damage to the roofs of the monastery, church and auxiliary facilities by storm and hail (IV, 234-235)
1912		average	x	wet?	**no grape harvest this year** (IV, 263) because six times hail was recorded (IV, 263); heating of the rooms in October (IV, 263)
1913	+	wet	dry?	average/dry	frost in April (IV, 265)
1914	+	wet	wet	extremely wet	very cold in January – February, temp. –20°C (IV, 269); flood in March (IV, 270), all of the villages along Sava on both sides, flood of Glogovica as well north of Brod – Varoš, Slobodnica, Lužani flooded, dead transported by boats to be buried on Bosnian side (IV, 270); floods in May (IV, 271) and June (IV, 272)
1915		average	x	wet?	wet spring (IV, 277) and autumn (IV,280); vineyards destroyed by hail and downy mildew; rainy winter (IV, 280)
1916		average/dry	x	x	reduced wine harvest but excellent quality vine, very high prices of vine (IV, 283); **famine in Dalmatia, Lika, Istria, Primorje, Zagorje** (IV, 286)
1917		dry	extremely dry?	extremely wet spring, after that drought for several months	very cold February and March, temp. –20°C/–24°C (IV, 283–284); from autumn 1916 until spring 1917 Posavina flooded (IV, 284); also shortage of food in Slavonia (IV, 286); **excellent wine harvest** (IV, 290)
1928	-	dry/very dry	very dry?	x	very hard and long winter (IV, 338)
1929	-	dry/very dry	x	x	7th and 17th April snow and very cold (IV, 342); last winter very cold, damage to the vineyard (IV, 343)
1932		average/wet	x	wet?	flood for 3 weeks in April (IV, 355), monastery's basement flooded; cold and wet spring(?) – no lilies for St Anthony's day (13th June) (IV, 356)
1933		average	x	1st half wet?	cold and wet spring(?) – no lilies for St Anthony's day (13th June) (IV, 359)

Summer sunshine is another factor to be considered regarding the moisture stress in trees, especially June-July sunshine hours (Poljanšek et al. 2013: 30, 32). Poljanšek et al. (2013: 34-35) concluded that in general summers with low values of sunshine hours can be linked to oscillation patterns from continental Europe and regions north of the northern Balkans while sunny summers can be linked to the oscillations from the south-eastern and the continental part of the Balkans or south-eastern/eastern Mediterranean (Poljanšek et al. 2013: 35, Tab. 5). Less sunny summers may match well with years of major volcanic eruptions and can be seen in the abrupt change in the same growth year, change in the following year or as a prolonged effect (Poljanšek et al. 2013: 35, Fig. 5). In this regard, influence of eruptions of Vesuvius (May 1771; July 1895 until September 1899 – more than 1500 days), unknown (1810), Tambora (1815) and Raung/Ijen (1817) in Indonesia, Etna (1843), Krakatoa (1883), Taal in Philippines (1911) among others were recognized in the Bosnia and Herzegovina (Poljanšek et al. 2013: 36). For 1771 eruption no data exist in *Protocollum*. For eruptions of 1810, 1815 and 1817 Poljanšek et al. (2013: 36) reconstructed a period of 1813-1821 (excluding 1817) with a low number of summer sunshine hours. In *Protocollum* records for most of the summers in that period are not available but the rest is consistent with Poljanšek et al. reconstruction (including 1815 and 1817). For Vesuvius eruption of 1895-1899 Poljanšek et al. found 1897-1900 and 1902 less sunny (2013: 36) but *Protocollum* records show that 1895 was the year with the maximum months of a single flood in the whole available record and less sunny. Until the end of 1898 the weather conditions were wet; December of that year was dry and warm, while in January of 1899 temperatures reached + 30°C[20] and the summer was dry. Data is missing for 1900 and the summer of 1902 is described as 3 months without rain. Eruption of 1911 affected tree growth in Bosnia and Herzegovina in the following years 1912-1915 (Poljanšek et al. 2013: 36) and the records from the *Protocollum* are consistent with this: for 1911 records are missing, but 1912 was only the second time that there was no grape harvest due to very frequent hail, in 1914 a massive flood in March occurred and the temperatures in January and February dropped to –20°C while 1915 had a wet spring and autumn. Not enough *Protocollum* records exist for the years when eruptions of Etna (1843) and Krakatoa (1883) were recorded.

On the other hand, flood-rich periods in central Europe were identified as 1540–1600, 1640–1700, 1730–1790 and 1790–1840 periods (Glaser et al. 2010; Blöschl et al. 2020: 560) with a tendency to occur more often in the central and western Europe (Blöschl et al. 2020: 560-562, Fig. 1 and 3). According to data collected by Blöschl et al., the most pronounced periods were 1560–1580 (period II, in western and central Europe), 1760–1800 (period V, in most of Europe), 1840–1870 (period VI, in western and southern Europe) (Blöschl et al. 2020: 561, Fig. 1). Their conclusion is that in central Europe floods mainly occur in summer (41% flood-rich period and 42% inerflood period, i.e. period without major floods recorded), in southern Europe in autumn (43% flood-rich, 41% inerflood) while in western Europe in winter (49% flood-rich, 46% inerflood). *Protocollum* records, however, show that there is a prevalence of spring floods in all periods (Fig. 5) in the Sava river valley around the town of Brod: 62% in 1750-1780, 32% in 1800-1850, 43% in 1850-1900 and 59% in 1900-1932. Summer floods appear less frequently, but this might be the result of a bias as the summer records are less frequent in *Protocollum* than spring or autumn. The same is true for the first period (Fig. 5a) as there are altogether very few records available. Autumn floods appear less frequently and are altogether absent from the records in the period of 1900-1932. Winter floods are usually more frequent than autumn ones. As mentioned before, the majority of floods were recorded in the first half of the 19th century. This is also a period in which lowest winter temperatures were recorded (Tab. 4), most of the years with winter river ice and spring snow and frost (Fig. 1), more evenly distributed dates of grape harvests (Fig. 4b) and predominant occurrences of storms and hail in the summer (Fig. 3). In the second half of the 19th century floods, winter river ice, cold and frost in spring (Fig. 1) is less frequent while grape harvests predominantly occurred in the second half of September (Fig. 4a); storms are more frequent in autumn and summer hail is less frequent (Fig. 3).

[20] *Ianuarius. (…) Ast unum hoc factum pro futuris temporibus adnotamus: quod per totum decurrentem mensem optimum, calidum, vereque aestivum tempus, juxta Celsium etiam ad 30 gradus caloris habuerimus.* (IV, 198).

One of the factors for altogether more frequent flood episodes in the colder period of the first half of the 19th century[21] is soil moisture; lower temperatures lead to less evaporation, leaving higher soil moisture, which results in more pronounced floods for the same rainfall (Blöschl et al. 2020: 564). Frequency of floods coinciding with cooler periods was noticed in the other regions too (Büntgen et al. 2011; Glur et al. 2013; Wirth et al. 2013). Flood records for Drava river valley presented in Blöschl et al. (2020: 562, Fig. 2) partly correspond to Sava river valley floods as registered in *Protocollum* especially regarding the first half of the 19th century.[22] Both Drava and Sava rivers have their springs in the Alpine region which can partly explain simultaneous occurrence of some past flood episodes in both river valleys.

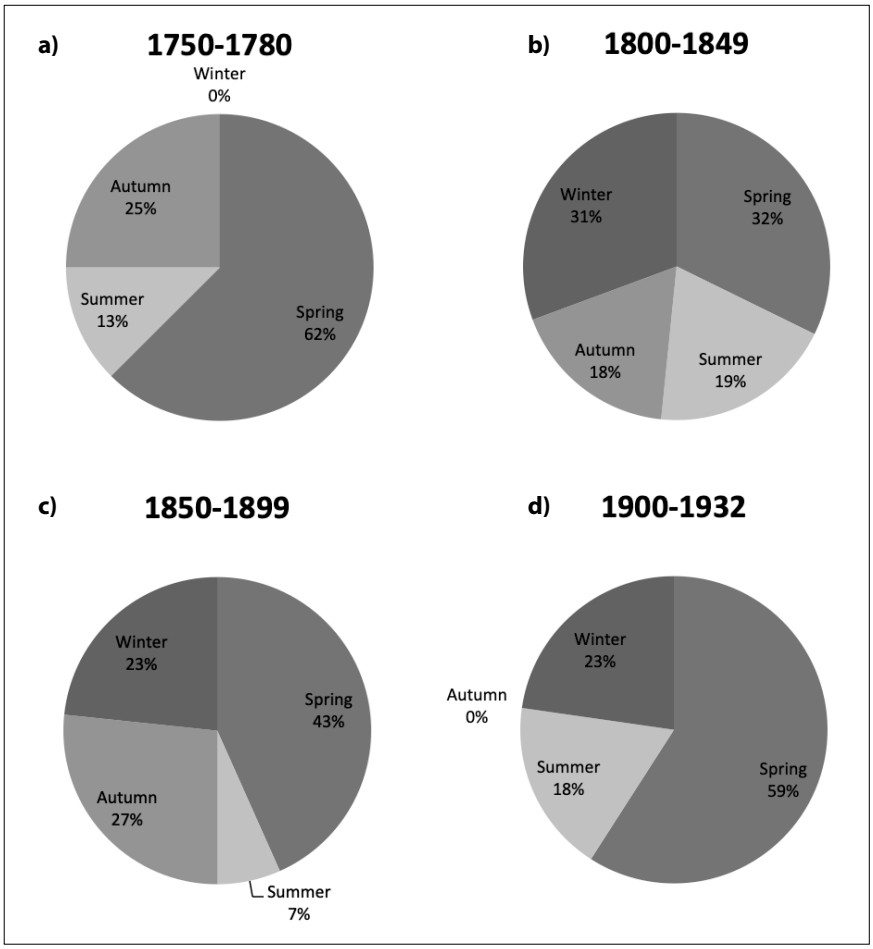

Figure 5 *The chart shows occurrences of floods in observed periods by seasons. The results are based on the data from Fig. 2a. There is a possible bias regarding the quantity and quality of available written records which especially apply to the first period. Prevalence of spring floods is visible in all of the periods.*

CONCLUSION

In the records of the Franciscan monastery in Slavonski Brod there are many entries mentioning weather and environmental conditions mostly from the period between 1750 and 1932. These records, compared to other published datasets and studies (Dobrovolný et al. 2010; Rácz 2010; Kiss et al. 2011; Kiss 2018; Poljanšek et al. 2013; Cook et al. 2015; Blöschl et al. 2020) show some specific occurrences

[21] For temperature reconstruction see Dobrovolný et al. 2010; Rácz 2010; Kiss et al. 2011.

[22] Flood of September 1814 (Petrić 2014: 270, 283) corresponds to Sava flood of the same month (II, 204-205); in 1827 devastating Drava floods were recorded on 11th June (Petrić 2014: 271, 284-285) while Sava flooded from 18th June until 8th July with heavy rain preceding it (II, 300-301, 304-305). Earlier 1775 flood was both recorded for Drava (Petrić 2014: 279, 281) and Sava rivers (I, 238-239) in June. Overlaping records for several other years in both river valleys in the late 18th and early 19th century also appear: 1777, 1780, 1810, 1815, 1820, 1821, 1822, 1826, 1828, 1830, 1838, 1839.

such as the most frequent spring floods or some years in which spring-summer moisture records show bad agreement. They also show some correlation with the Drava river valley occurrences, especially in the first half of the 19th century. Specific geographical position on the borderline of two major climate zones (continental and sub-Mediterranean) with possible stronger influence of the North Atlantic oscillations at certain periods make area around Slavonski Brod very sensitive to changes in the atmosphere in a much wider region especially regarding the hydrological conditions. Frequent floods recorded had their origin partly in precipitation (rain) in the area around Slavonski Brod, but greatly in precipitation (rain and snow) in the wider region, including pre-Alpine region and northern Bosnian mountains. Records show that the first half of the 19th century was colder with more frequent floods, river ice, cold springs and altogether more frequent moist (wet) summers or wet conditions during the whole years. The grape harvests occurred more evenly distributed between September and October and storms and hail appeared predominantly in the summer. The second half of the 19th century and the beginning of the 20th century see less frequent floods, river ice, cold springs, storms and hail. In the second half of the 19th century the predominant period of grape harvest was the second half of September. In all mentioned periods floods predominantly occurred in the spring, which differs from the results of Blöschl et al. (2020). Data collected from the *Protocollum* may further be analysed and used for the reconstruction of seasonal/annual temperatures and their change over time, possibly complementing other published datasets (for example Dobrovolný et al. 2010; Battipaglia et al. 2010; Kiss et al. 2011; Kiss 2018) of monthly, seasonal and annual temperature reconstructions for Central Europe.

Frequent frost, cold, hail and storms influenced the food production and the quality of life in the monastery, the town and its surroundings, especially in the 18th and the first half of the 19th century. The beginning of the 20th century saw milder weather conditions, but the economic consequences of the First World War were heavily felt in this region too.

Historical records, such as this *Protocollum*, are of extreme importance as a source for the reconstruction of environmental changes over time on a microregional scale. Comparison with other similar records in the somewhat wider region is needed to complete this dataset and enable fuller interpretation. We consider this paper an introduction to the future study.

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